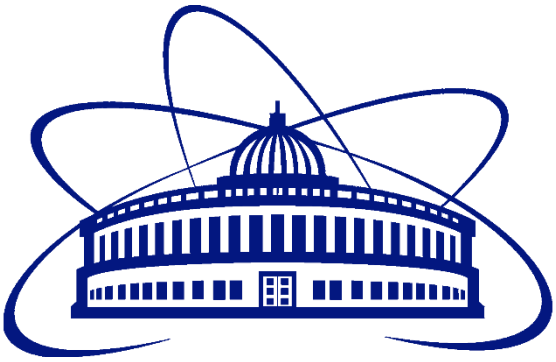

JOINT INSTITUTE FOR NUCLEAR RESEARCH

TOPICAL PLAN
FOR JINR RESEARCH
AND INTERNATIONAL COOPERATION
2025

Dubna 2024

All the Themes in the Plan are listed by fields of research. Each Theme is coded according to the JINR system of classification and contains the following information:

the first number*	-	the field of research;
the second number **	-	the conventional number of Laboratory;
the third number	-	the theme's ordinal number;
the fourth and the fifth numbers	-	the years of the theme's activity's beginning and completion.

All the Projects (Subprojects) in the Plan are listed by Themes. Each Project (Subproject) is coded according to the JINR system of classification and contains the following information:

the first number*	-	the field of research;
the second number **	-	the conventional number of Laboratory;
the third number	-	the theme's ordinal number;
the fourth number	-	the project's (and subroject's) ordinal number;
the fifth and the sixth numbers	-	the years of the project's (subroject's) beginning and completion.

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* 01 - Theoretical Physics
02 - Elementary Particle Physics and High-Enegry Heavy-Ion Physics
03 - Nuclear Physics
04 - Condensed Matter Physics
05 - Radiation Research in Life Sciences
06 - Information Technology
07 - Applied Innovation Activities
08 - Physics and Technology of Charged Particle Accelerators
09 - Organization of Scientific Activity and International Cooperation. Strengthening Human Resources. Educational Programme

** 1 - VBLHEP
Veksler and Baldin Laboratory of High Energy Physics
2 - DLNP
Dzhelepov Laboratory of Nuclear Problems
3 - BLTP
Bogoliubov Laboratory of Theoretical Physics
4 - FLNP
Frank Laboratory of Neutron Physics
5 - FLNR
Flerov Laboratory of Nuclear Reactions
6 - MLIT
Meshcheryakov Laboratory of Information Technologies
7 - LRB
Laboratory of Radiation Biology
8 - DSOA
Department of Science Organization Activities
9 - UC
University Centre

Prepared by
N.A. Boklagova
D.S. Korobov

Contents

List of projects and subprojects of the JINR Topical Plan for 2025

[1] Participation in the DUNE experiment is temporarily suspended until further notice.

JINR Large Research Infrastructure

02-1-1065-2007/2026

NICA Complex
Design and Construction of the Complex of Accelerators, Collider and Physics Experimental Facilities at Extracted and Colliding Ion Beams Aimed at Studying Dense Baryonic Matter and the Spin Structure of Nucleons and Light Ions, and at Carrying out Applied and Innovation Projects

Leaders: V.D. Kekelidze
A.S. Sorin
G.V. Trubnikov

Deputies: A.V. Butenko
V.M. Golovatyuk
M.N. Kapishin

Participating countries and international organizations:
Armenia, Azerbaijan, Belarus, Bulgaria, China, Cuba, Czech Republic, Egypt, Germany, Georgia, Kazakhstan, Mexico, Moldova, Mongolia, Russia, Serbia, Slovakia, Uzbekistan, Chile, South Africa, Japan.

The problem under study and the main purpose of the research:
Search and investigation of phase transitions in strongly interacting nuclear matter at extremely high baryon densities, study of the nucleon spin structure, of light nuclei and polarization phenomena in few nucleon systems. Development of theoretical models of the studied processes and theoretical support of the experiments. Development of the Nuclotron accelerator complex as a basic facility for studying relativistic nuclear collisions in the range of atomic masses A = 1÷197. Investigation of reaction dynamics and studing modifications of hadron properties in nuclear matter, near-threshold strange hyperons production and search for hyper nuclei in interactions of the Nuclotron extracted ion beams with fixed targets at the BM@N detector. Development and stage-by-stage creation of the NICA heavy ion collider accelerator complex, the multi-purpose detector (MPD/NICA) and spin physics detector (SPD/NICA) for experiments with colliding heavy ions beams. Modernization of extraction beam lines and Nuclotron magnetic system. Carrying out of experiments with ion beams and polarized proton and deuteron beams at the Nuclotron. Development of the infrastructure for applied research at NICA heavy ion beams.

Projects:

	Name of the projects	Project Leaders	Project code
1.	Nuclotron-NICA	A.V. Butenko H.G. Khodzhibagiyan *Scientific leader:* I.N. Meshkov	02-1-1065-1-2011/2027
2.	BM@N	M.N. Kapishin	02-1-1065-2-2012/2026
3.	MPD	V.M. Golovatyuk V.D. Kekelidze *Deputy:* V.G. Riabov	02-1-1065-3-2011/2025
4.	SPD	A.V. Guskov *Deputy:* V.P. Ladygin	02-1-1065-4-2020/2029

Projects:

	Name of the project	Project Leaders	Status
Laboratory (Subdivision)	Responsible from laboratories		
1.	**Nuclotron-NICA**	**A.V. Butenko** **H.G. Khodzhibagiyan** *Scientific leader:* **I.N. Meshkov**	Realization
1.1.	**NICA injection complex: technical design preparation and construction of the NICA injection complex:(sources of heavy ions and polarized light nuclei, HILAC linear accelerators of heavy ions and light nuclei of beam transporting to the Nuclotron)**	**V.A. Lebedev** **V.A. Monchinsky** **E.M. Syresin** **A.V. Tuzikov**	Realization
1.1.a.	**Commissioning of the heavy ion source (KRION)**	**E.E. Donets**	Realization
1.1.b.	**Upgrade the polarized proton and deuteron source (SPI)**	**V.V. Fimushkin** **R.A. Kuzyakin**	Realization
1.1.c.	**Development and construction of the beam injection systems and beam transportation channels. Development of the beam control and diagnostics systems**	**D.E. Donets** **E.V. Gorbachev** **A.V. Tuzikov**	Realization
1.1.d.	**Design and start of construction the new proton and light ion injector LILAC**	**A.V. Butenko** **K.A. Levterov** **B.V. Golovensky** **E.M. Syresin**	Realization
VBLHEP	V.P. Akimov, M.Yu. Averyanov, A.M. Bazanov, S.A. Besfamilniy, A.S. Bogatov, A.Yu. Boytsov, S.A. Burashnikov, A.M. Butenko, V.V. Chumakov, V.V. Fimushkin, A.R. Galimov, N.I. Garanzha, S.V. Gudkov, J. Guran, I.L. Guryleva, E.E. Donets, A.M. Ivanov, K.A. Ivshin, V.N. Karpinsky, A.E. Kirichenko, S.S. Kiselev, V.V. Kobets, S.Yu. Kolesnikov, A.B. Kolesov, O.S. Kozlov, A.A. Kozlovsky, M.V. Kulikov, N.A. Kulikov, V.N. Kulikov, O.A. Kunchenko, R.A. Kuziakin, S.M. Kuznetsov, D.Yu. Legontsev, D.S. Letkin, D.O. Leushin, D.A. Luosev, A.V. Lushin, N.A. Malyshev, A.A. Martynov, S.V. Mikhailov, V.V. Myalkovsky, A.V. Nesterov, O.A. Parfenov, A.V. Peltikhin, V.V. Peshkov, A.A. Pogodin, D.O. Ponkin, R.G. Pushkar, A.Yu. Ramzdorf, D.N. Rassadov, Yu.V. Riazantsev, S.S. Romanenko, V.V. Salnikov, V.O. Shapovalov, I.V. Shirikov, A.M. Shumkov, V.B. Shutov, P.V. Sinuygin, A.A. Slivin, A.N. Soloviev, P.N. Sotnikov, A.S. Spiridonov, A.N. Svidetelev, S.B. Timofeev, A.M. Tikhomirov, E.V. Tikhonov, V.I. Tiulkin, A.V. Tsvetkov, E.D. Tsyplakov, A.V. Vadeev, A.A. Voronin, A.Yu. Zakharov, I.N. Zhabin, L.V. Zinoviev		
1.2.	**Development of the NICA Booster and its technological systems**	**A.V. Butenko** **V.A. Lebedev** **I.N. Meshkov** **E.M. Syresin** **A.O. Sidorin**	Realization
1.2.a.	**Magnet cryostat system, vacuum system, system of electron cooling**	**A.R. Galimov** **V.S. Shpakov**	Realization
1.2.b.	**Power supply and energy evacuation system**	**E.V. Ivanov** **V.N. Karpinsky**	Realization
1.2.c.	**RF accelerating system of the Booster**	**O.I. Brovko**	Realization

1.2.d.	**Diagnostics, injection, correction of optics, beam extraction and transport systems**	**A.V. Tuzikov** **E.V. Gorbachev**	Realization

VBLHEP N.N. Agapov, A.V. Alfeev, V.A. Andreev, A.S. Averichev, M.Yu. Averyanov, A.A. Baldin, A.M. Bazanov, A.V. Beloborodov, D. N. Bogoslovsky, V.P. Chernyaev, D.E. Donets, V.M. Drobin, A.A. Fateev, S.A. Goncharov, A.Yu. Grebentsov, I.L. Guryleva, G.E. Ivanov, O. Kazinova, P.R. Kharyuzov, A.E. Kirichenko, S.Yu. Kolesnikov, A.V. Konstantinov, A. I. Korobkov, D.S. Korovkin, S.A. Korovkin, V.V. Kosachev, S.A. Kostromin, E.V. Kostyukhov, O.S. Kozlov, A.V. Kudashkin, E.A. Kulikov, O.A. Kunchenko, G.L. Kuznetsov, N.I. Lebedev, A.V. Lushin, S.V. Mikhailov, V.A. Mikhailov, V.V. Myalkovsky, A.V. Nesterov, D.N. Nikiforov, A.L. Osipenkov, K.G. Osipov, A.V. Pel'tikhin, M.V. Petrov, G.A. Petrovsky, A.V. Philippov, N.V. Pilyar, R.V. Pivin, O.V. Prozorov, S.V. Romanov, P.A. Rukoyatkin, T.V. Rukoyatkina, G.S. Sedykh, N.V. Semin, A.S. Sergeev, A.V. Shabunov, M.M. Shandov, A.A. Shurygin, V.S. Shvetsov, A.I. Sidorov, Z.I. Smirnova, A.N. Svidetelev, V.V. Tarasov, A.M. Tikhomirov, N.D. Topilin, Yu.A. Tumanova, V.I. Tyulkin, B.V. Vasilishin, A.I. Zagray, A.Yu. Zakharov

DLNP E.V. Akhmanova, V.I. Khilinov, O.S. Orlov, A.Yu. Rudakov, N.A. Rybakov, A.A. Sidorin, S.L. Yakovenko

1.3.	**Development and renovation of the Nuclotron**	**A.V. Butenko** **A.O. Sidorin** **E.M. Syresin** **H.G. Khodzhibagiyan**	Projecting Realization
1.3.a.	**Magnet cryostat system, vacuum system**	**A.R. Galimov**	Projecting Realization
1.3.b.	**Power supply and energy evacuation system**	**E.V. Ivanov** **V.N. Karpinsky**	Projecting Realization
1.3.c.	**RF accelerating system of the Nuclotron**	**O.I. Brovko**	Projecting Realization
1.3.d.	**Diagnostics, injection, correction of optics, beam extraction and transportation systems**	**E.V. Gorbachev** **P.A. Rukoyatkin**	Projecting Realization

VBLHEP R.M. Akhmadrizyalov, A.S. Aksenov, A.V. Alfeev, V.S. Alexandrov, V.A. Andreev, S.A. Arefiev, A.S. Averichev, A.M. Bazanov, E.S. Belyakov, S.A. Besfamilny, Yu.G. Bespalov, N.A. Blinov, A.S. Bogatov, L.G. Bogdan, V.V. Borisov, A.Yu. Boytsov, A.P. Bulakh, A.M. Butenko, E.A. Butenko, P.S. Cherkasov, A.Yu. Chmyrev, V.V. Chudakov, V.V. Chumakov, S.A. Dolgiy, D.E. Donets, E.E. Donets, I.I. Donguzov, A.M. Donyagin, G.L. Dorofeev, V.M. Drobin, A.V. Eliseev, V.G. Elkin, A.E. Emelianov, R.O. Esaulkov, A.A. Fateev, A.A. Feoktistov, G.A. Filatov, V.V. Fimushkin, A.V. Gaevsky, V.E. Galkin, F.N. Ganyushkin, N.I. Garanzha, A.A. Garkin, B.V. Golovensky, I.I. Golubev, O.M. Golubitsky, S.A. Goncharov, S.P. Gorelikov, A.V. Grebennikov, A.Yu. Grebentsov, D.M. Gribov, S.V. Gudkov, S.V. Gudkov, M.V. Gulina, K.N. Gurylev, I.L. Guryleva, S.A. Gusev, G.E. Ivanov, A.N. Karpuk, V.A. Kashirin, A.E. Kirichenko, S.V. Kirov, D.I. Klimansky, A.S. Klyagin, V.V. Kobets, A.B. Kolesov, A.V. Konstantinov, A.V. Kopchenov, M.Yu. Korobitsyna, S.A. Korovkin, V.S. Korolev, G.E. Koroleva, V.V. Kosachev, V.A. Kosinov, A.A. Kotova, I.K. Kovrizhina, A.P. Kozlov, O.S. Kozlov, A.V. Kudashkin, T.G. Kudinova, P.I. Kudryashov, T.A. Kulaeva, E.A. Kulikov, M.V. Kulikov, N.A. Kulikov, O.A. Kunchenko, V.V. Kuptsov, L.V. Kutuzova, A.A. Kuznetsov, A.A. Kuznetsov, G.L. Kuznetsov, D.Yu. Kuznetsov, M.I. Kuznetsov, R.A. Kuzyakin, R.V. Lapin, I.N. Lebedev, N.I. Lebedev, V.A. Lebedev, I.G. Lebedeva, M.P. Lepkin, D.S. Letkin, D.O. Leushin, K.A. Levterov, D.V. Lobanov, N.A. Lopatin, K.V. Loshmanova, V.O. Luchentsov, D.A. Luosev, A.V. Lushin, V.M. Lutsenko, A.M. Malyshev, A.A. Martynov, R.N. Masalov, E.S. Matyukhanov, A.A. Merkuriev, M.Yu. Meshenkov, E.A. Mikhailov, S.V. Mikhailov, V.A. Mikhailov, Yu.A. Mitrofanova, D.V. Monakhov, V.A. Monchinsky, D.M. Morozov, V.V. Morozova, V.A. Mosalov, V.V. Myalkovsky, O.E. Naumov, S.I. Nefediev, O.A. Nefedov, E.A. Negey, A.V. Nesterov, N.A. Newgate, D.N. Nikiforov, A.M. Nikitin, I. Yu. Nikolaichuk, K.A. Nosov, M.S. Novikov, S.Yu. Novozhilov, Yu.M. Nozhenko, M.N. Omelianenko, A.L. Osipenkov, O.A. Parfenov, V.V. Pashinsky, A.V. Peltikhin, V.V. Peshkov, L.A. Peshkova, I.M. Petrov, M.V. Petrov, V.D. Petrov, A.S. Petukhov, A.V. Philippov, M.N. Philippov, N.A. Philippov, E.Yu. Philippova, N.V. Pilyar, R.V. Pivin, A.A. Pogodin, V.K. Polyakova, D.O. Ponkin, A.A. Ponomarev, O.V. Prozorov, R.G. Pushkar, A.Yu. Ramsdorf, D.N. Rassadov, I.N. Repkin, S.V. Romanov, T.V. Rukoyatkina, S.A. Rumyantsev, D.V. Ryzhov, D.Yu. Saveliev, M.K. Savenkova, A.N. Scherbakov, G.S. Sedykh, A.V. Sergeev, E.V. Sergeeva, V.G. Shabratov, M.M. Shandov, A.V. Shemchuk, I.V. Shirikov, E.E. Shirkova, A.M. Shumkov, V.M. Shumkov, V.B. Shutov, A.A. Shurygin,

D.S. Shvidky, T.V. Sidorenkov, A.I. Sidorov, P.A. Sidorov, V.O. Sidorova, A.V. Skrypnik, A.A. Slivin, S.A. Smirnov, V.L. Smirnov, Z.I. Smirnova, R.A. Smolkov, A.G. Sorokin, O.Yu. Stankov, L.E. Sveshnikova, A.L. Svetov, A.N. Svidetelev, M.I. Svideteleva, R.V. Talysin, V.V. Tarasov, A.M. Tihomirov, E.V. Tikhonov, A.B. Tischenko, N.V. Travin, A.A. Troitsky, A.V. Tsvetkov, Yu.A. Tsvetkova. V.I. Tyulkin, A.V. Vadeev, B.V. Vasilishin, A.A. Volodin, A.A. Voronin, N.A. Voroshilov, M.I. Yablochkin, M.V. Yurkov, A.Yu. Zakharov, A.I. Zagray, L.V. Zinoviev, D.A. Zolotykh, A.G. Zorin, I.N. Zhabin, V.M. Zhabitsky, A.S. Zhbankov

1.4.	**Technical design, R&D of technological systems and construction of the NICA heavy ion collider with an energy of E_{CM}= 4-11 GeV and an average luminosity of $1\cdot 10^{27}$ см $^{-2}$с $^{-1}$ and light polarised nuclei with a luminosity of $1\cdot 10^{32}$ см $^{-2}$с $^{-1}$ (by protons, at E_{CM}=27 GeV)**	**S.A. Kostromin V.A. Lebedev I.N. Meshkov A.O. Sidorin E.M. Syresin**	Projecting Realization
1.4.a.	**Magnet cryostat and vacuum systems**	**A.R. Galimov H.G. Khodzhibagiyan**	Realization
1.4.b.	**Power supply and energy evacuation system**	**E.V. Ivanov V.N. Karpinsky**	Realization
1.4.c.	**RF system of the Collider**	**O.I. Brovko A.Yu. Grebentsov**	Realization
1.4.d.	**Beam diagnostics, injection and transportation systems**	**A.V. Tuzikov E.V. Gorbachev**	Projecting Realization
1.4.e.	**Cooling and feedback systems for charged particle beams**	**I.N. Meshkov A.O. Sidorin V.A. Lebedev**	Projecting Realization
1.4.f.	**Systems of proton and deuteron polarization monitoring and control**	**S.A. Kostromin V.V. Fimushkin**	Projecting Realization

VBLHEP R.M. Akhmadrizyalov, A.S. Aksenov, A.V. Alfeev, V.S. Alexandrov, V.A. Andreev, S.A. Arefiev, A.S. Averichev, A.M. Bazanov, E.S. Belyakov, S.A. Besfamilny, Yu.G. Bespalov, N.A. Blinov, A.S. Bogatov, L.G. Bogdan, V.V. Borisov, A.Yu. Boytsov, O.I. Brovko, A.P. Bulakh, A.M. Butenko, E.A. Butenko, P.S. Cherkasov, A.A. Chernova, A.Yu. Chmyrev, V.V. Chudakov, V.V. Chumakov, S.A. Dolgiy, D.E. Donets, E.E. Donets, I.I. Donguzov, A.M. Donyagin, G.L. Dorofeev, V.M. Drobin, A.V. Eliseev, V.G. Elkin, A.E. Emelianov, R.O. Esaulkov, A.A. Fateev, A.A. Feoktistov, G.A. Filatov, A.V. Gaevsky, V.E. Galkin, F.N. Ganyushkin, N.I. Garanzha, A.A. Garkin, B.V. Golovensky, I.I. Golubev, O.M. Golubitsky, S.A. Goncharov, E.V. Gorbachev, S.P. Gorelikov, A.V. Grebennikov, A.Yu. Grebentsov, D.M. Gribov, S.V. Gudkov, S.V. Gudkov, M.V. Gulina, K.N. Gurylev, I.L. Guryleva, S.A. Gusev, E.V. Ivanov, G.E. Ivanov, A.N. Karpuk, V.A. Kashirin, A.E. Kirichenko, S.V. Kirov, D.I. Klimansky, A.S. Klyagin, V.V. Kobets, A.B. Kolesov, A.V. Konstantinov, A.V. Kopchenov, M.Yu. Korobitsyna, S.A. Korovkin, V.S. Korolev, G.E. Koroleva, V.V. Kosachev, V.A. Kosinov, A.A. Kotova, I.K. Kovrizhina, A.P. Kozlov, O.S. Kozlov, A.V. Kudashkin, T.G. Kudinova, P.I. Kudryashov, R.I. Kukushkina, T.A. Kulaeva, E.A. Kulikov, M.V. Kulikov, N.A. Kulikov, O.A. Kunchenko, V.V. Kuptsov, L.V. Kutuzova, A.A. Kuznetsov, A.A. Kuznetsov, G.L. Kuznetsov, D.Yu. Kuznetsov, M.I. Kuznetsov, R.A. Kuzyakin, R.V. Lapin, I.N. Lebedev, N.I. Lebedev, I.G. Lebedeva, M.P. Lepkin, D.S. Letkin, D.O. Leushin, K.A. Levterov, D.V. Lobanov, N.A. Lopatin, K.V. Loshmanova, V.O. Luchentsov, D.A. Luosev, A.V. Lushin, V.M. Lutsenko, A.M. Malyshev, A.A. Martynov, R.N. Masalov, E.S. Matyukhanov, A.A. Merkuriev, M.Yu. Meshenkov, E.A. Mikhailov, S.V. Mikhailov, V.A. Mikhailov, Yu.A. Mitrofanova, D.V. Monakhov, V.A. Monchinsky, D.M. Morozov, V.V. Morozova, V.A. Mosalov, V.V. Myalkovsky, O.E. Naumov, D.V. Neapolitansky, S.I. Nefediev, O.A. Nefedov, E.A. Negey, A.V. Nesterov, N.A. Newgate, D.N. Nikiforov, A.M. Nikitin, I. Yu. Nikolaichuk, K.A. Nosov, M.S. Novikov, S.Yu. Novozhilov, Yu.M. Nozhenko, M.N. Omelianenko, A.L. Osipenkov, O.A. Parfenov, V.V. Pashinsky, A.V. Peltikhin, V.V. Peshkov, L.A. Peshkova, I.M. Petrov, M.V. Petrov, V.D. Petrov, A.S. Petukhov, A.V. Philippov, M.N. Philippov, N.A. Philippov, E.Yu. Philippova, N.V. Pilyar, R.V. Pivin, A.A. Pogodin, V.K. Polyakova, D.O. Ponkin, A.A. Ponomarev, O.V. Prozorov, R.G. Pushkar, A.Yu. Ramsdorf, D.N. Rassadov, I.N. Repkin, S.V. Romanov, P.A. Rukoyatkin, T.V. Rukoyatkina, S.A. Rumyantsev, D.V. Ryzhov, D.Yu. Saveliev, M.K. Savenkova, A.N. Scherbakov, G.S. Sedykh, A.V. Sergeev, E.V. Sergeeva, V.G. Shabratov, M.M. Shandov, A.V. Shemchuk, I.V. Shirikov, E.E. Shirkova, A.M. Shumkov,

V.M. Shumkov, V.B. Shutov, A.A. Shurygin, D.S. Shvidky, T.V. Sidorenkov, A.I. Sidorov, P.A. Sidorov, V.O. Sidorova, A.V. Skrypnik, A.A. Slivin, S.A. Smirnov, V.L. Smirnov, Z.I. Smirnova, R.A. Smolkov, A.G. Sorokin, O.Yu. Stankov, L.E. Sveshnikova, A.L. Svetov, A.N. Svidetelev, M.I. Svideteleva, E.M. Syresin, R.V. Talysin, V.V. Tarasov, A.M. Tihomirov, E.V. Tikhonov, A.B. Tischenko, N.V. Travin, A.A. Troitsky, A.V. Tsvetkov, Yu.A. Tsvetkova. V.I. Tyulkin, A.V. Vadeev, B.V. Vasilishin, A.A. Volodin, A.A. Voronin, M.I. Yablochkin, M.V. Yurkov, A.Yu. Zakharov, A.I. Zagray, L.V. Zinoviev, D.A. Zolotykh, A.G. Zorin, I.N. Zhabin, V.M. Zhabitsky, A.S. Zhbankov

DLNP E.V. Akhmanova, V.I. Khilinov, O.S. Orlov, A.Yu. Rudakov, A.A. Sidorin, S.L. Yakovenko

DRB V.N. Buchnev, V.Yu. Schegolev

1.5.	**R&D, construction and development of cryogenic systems**	**N.N. Agapov** **H.G. Khodzhibagiyan**	Projecting Realization

VBLHEP S.A. Arefiev, M.B. Basheva, D.B. Belov, V.D. Drobin, L.E. Egorova, A.E. Emelyanov, E.F. Filippova, S.G. Gorelikov, S.G. Gudkov, E.I. Ivanov, M.K. Kondratiev, A.K. Konstantinov, V.K. Kosinov, E.K. Kulikov, D.L. Lobanov, Y.M. Mitrofanova, I.P. Petrov, L.P. Peshkov, S.S. Smirnov, O.Y. Yarovikova

Brief annotation and scientific rationale:
The development and carryout works on of the existing infrastructure of the VBLHEP accelerator complex: HILAC, Booster, Nuclotron, beam transport channels in bldg. 1, bldg. 205 and new building 17 and other systems and new equipment required for the NICA collider commissioning at project equipment configuration in 2027.

Expected results upon completion of the project:
Commissioning of the NICA complex objects at basic configuration of the collider equipment, prolongation of the experiments at fixed targets with heavy ion and light nuclei polarized beams, start the experiments at colliding beams, R&D, prototyping, testing, pre-serial magnet production for the "new" Nuclotron ring.

Expected results of the project in the current year:
Experiments with circulating in collider heavy ion beams at the kinetic energy up to 2 GeV/n with internal target and colliding beams.

2.	**BM@N**	**M.N. Kapishin**	Realization
2.1.	**Development of the operational area of the setup: increasing the radiation protection, improving detector subsystems and engineering infrastructure**	**S.Yu. Anisimov** **M.N. Kapishin** **S.M. Piyadin**	Realization
2.2.	**Construction of the basic detector complex of the BM@N setup**	**M.N. Kapishin** **S.M. Piyadin**	Realization
2.3.	**Development of the technological and engineering systems, control systems and test areas of the setup**	**S.Yu. Anisimov** **S.M. Piyadin** **N.D. Topilin**	Realization

VBLHEP G.N. Agakishiev, S.V. Afanasiev, K.A. Alishina, V.I. Astakhov, V.N. Azorskiy, V.A. Babkin, R.Barak, S.N. Bazylev, M.G. Buryakov, S.G. Buzin, A.I. Chebotov, D.D. Chemezov, D.V. Dementiev, A.V. Dmitriev, J.R. Drnoyan, D.K. Dryablov, B.V. Dubinchik, P.O. Dulov, A.S. Egorov, D.S. Egorov, V.V. Elsha, A.A. Fedyunin, I.A. Filippov, I.R. Gabdrakhmanov, O.P. Gavrischuk, K.V. Gertsenberger, V.M. Golovatyuk, P.N. Grigoriev, I.Yu. Kapitonov, V.Yu. Karzhavin, R.R. Kattabekov, S.V. Khabarov, V.D. Kekelidze, A.Yu. Khukhaeva, A.S. Khvorostukhin, Yu.T. Kiryushin, V.I. Kolesnikov, A.A.Kolozhvari, Yu.A. Kopylov, L.D. Kovachev, Yu.S. Kovalev, I.V. Kruglova, S.N. Kuklin, E.M. Kulish, V.V. Kutergina, A.S. Kuznetsov, E.A. Ladygin, N.A. Lashmanov, R. Lednický, V.V. Lenivenko, A.M. Makan'kin, A.I. Malakhov, E.V. Martovitsky, S.P. Merts, Yu.A. Murin, R.V. Nagdasev, D.N. Nikitin, S.V. Novozhilov, V.A. Plotnikov, N.E. Pukhaeva, S.V. Reshetova, V.Yu. Rogov, I.A. Romanov, P.A. Rukoyatkin, M.M. Rumyantsev, I.A. Rufanov, D.G. Sakulin, S.A.Sedykh, S.V. Sergeev, A.D. Sheremetiev, A.I. Sheremetieva, A.V. Shchipunov, M.O. Shitenkov, A.V. Shutov, V.B. Shutov, I.V. Slepnev, V.M. Slepnev, I.P. Slepov, A.V. Smirnov, T. Smolyanin, A.S. Sorin, V.N. Spaskov, Yu.Yu. Stepanenko, E.A. Streletskaya, B.V. Sukhov, D.A. Suvarieva, N.A. Tarasov, O.G. Tarasov, A.V. Terletsky,

V.V. Teryaev, V.V. Tikhomirov, A.A. Timoshenko, I.A. Tyapkin, V.V. Ustinov, V.A. Vasendina, V.K.Velichkov, A.A.Voronin, V.I. Yurevich, N.I. Zamyatin, I.A. Zhavoronkova, A.I. Zinchenko, R.A. Zinchenko, E.V. Zubarev

MLIT E.I. Alexandrov, I.N. Alexandrov, N.A. Balashov, D.A. Baranov, I.A. Filozova, Zh.Zh. Musulmanbekov, V.V. Palichik, I.S. Pelevaniuk, D.V. Podgainy, O.I. Streltsova, N.N. Voytishin, M.I. Zuev

FLNP E.I. Litvinenko, I.S. Zhironkin

2.4. Analysis of BM@N experimental data and feasibility studies for BM@N program in heavy ion beams — **M.N. Kapishin, A.I. Zinchenko** — Realization

Brief annotation and scientific rationale:
Investigation of reaction dynamics and studingmodifications of hadron properties in nuclear matter, near-threshold strange hyperons production and search for hyper nuclei in interactions of the Nuclotron extracted ion beams with fixed targets at the BM@N detector.

Expected results upon completion of the project:
Commissioning of BM@N and obtaining physics results on interactions of Nuclotron extracted ion beams with fixed targets to study reaction dynamics and the equation-of-state of nuclear matter, modifications of hadron properties in nuclear matter, near-threshold strange hyperons production and to search for hyper nuclei.

Expected results in the current year:
Preparing the BM@N set-up for the physics run with a heavy ion beam extracted from the Nuclotron. New data collection with a heavy ion beam at BM@N. Analysis of new experimental data collected at BM@N.

3. MPD — **V.M. Golovatyuk, V.D. Kekelidze** *Deputy:* **V.G. Ryabov** — Realization

VBLHEP S.V. Afanasev, G.N. Agakishiev, N.V. Anfimov, A.E. Antonova, A.A. Aparin, V.I. Astakhov, S.V. Andreeva, T.V. Andreeva, S.P. Avdeev, G.S. Averichev, A.V. Averiyanov, V.A. Babkin, I.A. Balashov, V.M. Baryshnikov, A.E. Baskakov, A.G. Bazhazhin, S.N. Bazylev, A.V. Belyaev, E.V. Belyaeva, S.E. Belyaev, D.N. Bogoslovsky, I.V. Boguslavsky, M.G. Buryakov, A.V. Butenko, A.V. Butorin, A.V. Bychkov, S.G. Buzin, V.V. Chalyshev, V.A. Cheplakova, V.V. Chepurnov, V.F. Chepurnov, A.E. Cheremukhin, G.A. Cheremukhina, P.V. Chumakov, D.V. Dementiev, A.V. Dmitriev, V.Kh. Dodokhov, E.V. Dolbilina, A.G. Dolbilov, D.E. Donets, V.I. Dronik, A.Yu. Dubrovin, P.O. Dulov, V.B. Dunin, V. Dyatlov, D.S. Egorov, V.V. Elsha, A.E. Emelianov, N.E. Emelianov, O.V. Fateev, A.E. Fedotov, Yu.I. Fedotov, A.A. Fedyunin, I.A. Filippov, M.A.Gaganova, T.T. Gandzhelashvili, O.P. Gavrischuk, K.V. Gertsenberger, S. Ghoneim Umna, N.V.Gorbunov, Z.A. Igamkulov, A.V. Ivanov, A.Yu. Isupov, S.I. Kakurin, M.N. Kapishin, G.D. Kekelidze, A.O. Kechechan, V.A. Kireev, Yu.T. Kiryushin, I.S. Kiryutin, H.G. Khodzhibagiyan, V.I. Kolesnikov, A. Kolozhvari, N. Kolomoyets, V.G. Komarov, V.A. Kramarenko, L.M. Krasnova, Yu.F. Krechetov, I.V. Kruglova, A.V.Krylov, V.A. Krylov, S.I. Kukarnikov, S.N. Kuklin, E.A. Kulikov, V.S. Kuz'min, N.A. Lashmanov, R. Lednicky, A.N. Livanov, V.I. Lobanov, Yu.Yu. Lobanov, S.N. Lobastov, Yu. Lukstin'sh, D.T. Madigozhin, A.A. Makarov, V.I. Maksimenkova, A.I. Malakhov, I.V. Malikov, D.G. Melnikov, S.P. Merts, I.N. Meshkov, G.V. Meshcheryakov, I.I. Migulina, K.V. Mikhailov, G.D. Milnov, Yu.I. Minaev, S.A. Movchan, N.A. Molokanova, A.E. Moskovsky, A.A. Moshkin, Yu.A. Murin, K.A. Mukhin, D. Myktybekov, V.A. Nikitin, I.A. Oleks, O.E. Orlov, V.A. Pavlyukevich, V.A. Penkin, V.A. Petrov, D.V. Peshekhonov, A.V. Pilyar, N.V. Pilyar, S.M. Piyadin, D.S. Potapov, N.O. Ridinger, O.V. Rogachevsky, V.Yu. Rogov, M.M. Rumyantsev, I.A. Rufanov A.A. Rybakov, A.A. Rymshina, Z.Ya-O. Sadygov, A.A. Savenkov, S, Sebalos Sanches, S.A.Sedykh, A.Yu. Semenov, I.A. Semenova, V.Z. Serdyuk, S.V. Sergeev, N.A. Sergeeva, E.V. Serochkin, A.O. Sidorin, I.P. Slepov, V.M. Slepnev, I.V. Slepnev, Yu.A. Solnyshkin, A.S. Sorin, E.A. Streletskaya, G.G. Stiforov, S.I. Sukhovarov, V.L. Svalov, A.V. Shabunov, A.D. Sheremetiev, A.I. Sheremeteva, R.A. Shindin, M.O. Shitenkov, I.A. Shmyrev, A.A. Shunko, A.B. Shutov, V.B. Shutov, D.V. Schegolev, A.N.Scherbakov, A.V. Schipunov, N.A. Tarasov, A.V. Terletsky, O.V. Teryaev, S.V. Timofeev, A.E. Timofeeva, A.A. Timoshenko, V.V. Tikhomirov, G.P. Tkachev, N.D. Topilin, A.V. Trubnikov, G.V. Trubnikov, I.A. Tyapkin, S.Yu. Udovenko, V.A. Vasendina, I.N. Vasilev, S.V. Vereschagin, A.S. Vodopiyanov, O.A. Volodina, A.A. Voronin, V. Voronyuk, G.A. Yarygin, V.I. Yurevich, M.V. Zaitseva, N.I. Zamyatin, S.A. Zaporozhets, A.I. Zinchenko, D.A. Zinchenko, V.N. Zryuev

DLNP K.G. Afanaviev, A.V. Guskov, N.V. Khomutov, N.P. Kravchuk, N.A. Kuchinski, V.L. Malyshev, A.G. Olshevsky

MLIT A. Abgaryan, A.S. Airyan, E.I. Aleksandrov, I.N. Aleksandrov, A.I. Balandin, N.A. Balashov, D.A. Baranov, D.V. Belyakov, Ya. Busha, O. Grigoryan, A.O. Golunov, S. Hnatic, V.V. Ivanov, I.A. Kashunin, A.A. Kokorev, V.V. Korenkov, V.V. Mitsyn, A.N. Moibenko, Zh.Zh. Musulmanbekov, A.V. Nechaevskiy, V.V. Papoyan, S.S. Parzhitskiy, I.S. Pelevanyuk, D.V. Podgainyi, D.I. Pryakhina, R.N. Semenov, S.V. Shmatov, O.I. Streltsova, T.A. Strizh, V.V. Trofimov, N.N. Voitishin, A.S. Vorontsov, M.I. Zuev

LTP V.D. Toneev

FLNP E.I. Litvinenko

3.1.	**Design and construction of the superconducting solenoid and magnet yoke**	**K.A. Mukhin** **N.D. Topilin**	Realization

VBLHEP S.E. Belyaev, E.V. Belyaeva, R.V. Baratov, S.E. Gerasimov, Yu.Yu. Lobanov, V.A. Novoselov, I.A. Smelyansky, T. Smolyanin, D.A. Tereshin, G.P. Tkachev

3.2.	**Construction of the detector complex of the start configuration of the MPD setup**	**V.M. Golovatyuk** **V.D. Kekelidze**	Realization

VBLHEP V.A. Babkin, C.N. Bazylev, A. Ivashkin, S.A. Movchan, Yu.A. Myrin, I.A. Tyapkin, N.D. Topilin, V.I. Yurevich

3.3.	**Design and creation of the data acquisition and control systems**	**S.N. Bazylev** **I.V. Slepnev**	Realization

VBLHEP A.E. Baskakov, A.A. Fedyunin, I.A. Filippov, S.N. Kuklin, A.V. Schipunov, A.B. Shutov, V.M. Slepnev, N.A. Tarasov, A.V. Terletsky

3.4	**Development of MPD physical program**	**V.G. Ryabov** **V.I. Kolesnikov** **A.I. Zinchenko**	Realization

3.5.	**Development of MPD data processing and physics analysis system**	**O.V. Rogachevsky** **A.G. Dolbilov** **S.V. Shmatov**	Realization

VBLHEP A.A. Moshkin, I.P. Slepov

MLIT E.I. Aleksandrov, I.N. Aleksandrov, A.I. Balandin, N.A. Balashov, D.A. Baranov, D.V. Belyakov, A.O. Golunov, A.G. Dolbilov, S.Hnatic, I.A. Kashunin, V.V. Korenkov, V.V. Mitsyn, A.N. Moibenko, Zh.Zh. Musulmanbekov, S.S. Parzhitskiy, I.S. Pelevanyuk, D.V. Podgainy, D.I. Pryakhina, R.N. Semenov, O.I. Streltsova, T.A. Strizh, V.V. Trofimov, N.N. Voitishin, A.S. Vorontsov, M.I. Zuev

Brief annotation and scientific rationale:
The physical launch of the NICA collider with the beam is planned for 2025. By the middle of 2025, the collider should provide collisions of the Xe beam with the fixed wire target installed in the collision area of the MPD experiment. Tungsten will be used as the wire material. In the second and third stages of the launch, interactions of Xe colliding beams should be implemented. The timing of the construction and launch of the experimental facility is tightly linked to the collider launch schedule. By mid-summer 2025, the MPD experimental facility should be fully assembled and installed in its operation position with the beam. The detector subsystems should be integrated into a common data control and readout system. The first data collected by the MPD facility with the beam will be used to study the operation and characteristics of the detector subsystems, to tune the signal recovery algorithms in the detector subsystems, and to reconstruct charged particle tracks and their association with signals in external detectors.

Expected results upon completion of the project:
Creating and launching the first stage of the MPD experimental.
The configuration of the first stage includes: a magnet that creates a uniform field up to 0.57T, a track system based on the time projection chamber TPC, a time-of-flight detector FFD-TOF, an electromagnetic calorimeter ECal and a forward hadron calorimeter FHCal. Holding a technical run on the beams of the NICA collider to configure all subsystems of the MPD experimental setup, holding a physical run on the beam for a set of events corresponding to collisions of heavy ions in the required beam configuration in order to study the properties of baryonic matter.

Creation and commissioning of a centralized monitoring, control and operation system for detectors, magnets, gas system (DCS), as well as an emergency indication and emergency response system.
Development of the DAQ system for the detector subsystems.

Development of a system for continuous monitoring of the quality of data recorded from detectors (QA), calibration of detectors and primary processing of data obtained from the experimental facility to switch from the raw data format to tables of recovered tracks and hits in detector subsystems, processing of the tables of tracks and hits obtained at the previous stage in order to determine the operational characteristics of detectors and the entire facility, as well as obtaining the first physical results.

Expected results of the project in the current year:
Cooling of the Solenoid to the temperature of liquid nitrogen, start of the first collaboration shifts.

Current supply to superconducting and correction magnet windings, testing of magnet operation modes and energy evacuation systems.

Carrying out measurements of the magnetic field at different current values.

Completion of the construction of TOF, FHCal, FFD subsystems, assembly of the TPC housing, and first 40 half-sectors of the ECal.

Determination of optimal parameters and algorithms for the operation of the MPD trigger system, built on the basis of FFD, FHCal and TOF, for effective selection of events corresponding to collisions of nuclei with the fixed target and in the collision mode of colliding beams, determination of the coordinates of the primary vertex and the starting time T0. Implementation of the developed algorithms in hardware.

Simulation of the operation of the MPD experimental facility in Xe+W collisions using various event generators in order to study the possibilities of its use for studying collisions of an ion beam with a fixed target. Such a beam configuration is likely to provide the largest amount of experimental data available for study.

4.	**Construction of the SPD facility for studying spin effects in nuclear interactions**	**A.V. Guskov** *Deputy:* **V.P. Ladygin**	Project preparation

VBLHEP R.R. Akhunzyanov, V.Yu. Alexakhin, V.A. Anosov, V.I. Astakhov, N.I. Azorskiy, D. Baigarashev, A.A. Baldin, E.G. Baldina, K.D. Basharina, V.V. Bautin, E.V. Belyaeva, Yu.G. Bespalov, Ver.V. Bleko, V.V. Bleko, D.N. Bogoslovskii, V.V. Borisov, D.V. Budkouski, E.A. Bushmina, D.D. Chemezov, S.A. Chetverikov, V.B. Chmill, V.B. Dunin, T.L. Enik, A.S. Galoyan, O.P. Gavrishchuk, S.E. Gerasimov, S.M. Golubykh, N.V. Gorbunov, Yu.V. Gurchin, A.Yu. Isupov, A.V. Ivanov, N.Y. Ivanov, S.I. Kakurin, Y. Kambar, I.Yu. Kapitonov, V.Yu. Karjavin, G.D. Kekelidze, D. Kereibay, S.V. Khabarov, P.R. Kharyuzov, E.A. Klevtsova, E.S. Kokoulina, Yu.A. Kopylov, V.A. Kukharev, D.S. Korovkin, A. Korzenev, E.V. Kostyukhov, A.A. Kotova, M.A. Kozhin, V.A. Kramarenko, E.A. Ladygin, R. Lednicki, A.N. Livanov, K.V. Loshmanova, V.M. Lysan, D.T. Madigozhin, S.A. Movchan, K.V. Mikhailov, O. Minko, Y. Mukhamejanov, A. Mukhamejanova, D. Myktybekov, S.N. Nagorniy, D.N. Nikiforov, V.A. Nikitin, V.V. Pavlov, V.V. Perelygin, M.V. Petrov, V.V. Popov, S.I. Pudin, S.G. Reznikov, N.S. Rogacheva, S. Romakhov, K.M. Salamatin, A.B. Safonov, N. Sagimbaeva, A.A. Savenkov, V.V. Shalaev, A.I. Sheremeteva, S.S. Shimansky, S.N. Shkarovskiy, A.A. Shunko, S.E. Sinelshchikova, S.Yu. Starikova, E.A. Streletskaya, S.I. Sukhovarov, O.G. Tarasov, A.A. Terekhin, A.V. Tishevsky, N.D. Topilin, Yu.A. Troyan, E.A. Usenko, E.V. Vasilieva, I.S. Volkov, P.V. Volkov, Yu.V. Yershov, N.I. Zamiatin, E.V. Zemlyanichkina, I.A. Zhizhin, I.A. Zhukov, A.V. Zinin, D.A. Zolotykh, E.V. Zubarev

DLNP V.M. Abazov, L.G. Afanasyev, G.D. Alexeev, A.Eh. Allakhverdieva, N.B. Anfimov, A.M. Artikov, N.V. Atanov, A.V. Baranov, A.V. Boikov, A.E. Bolshakova, V.V. Chalyshev, A.V. Chetverikov, D. Choheli, A.V. Chukanov, A. Datta, Yu.I. Davydov, D.V. Dedovich, M.A. Demichev, I.I. Denisenko, M. Dima, M.-T. Dima, M.-O. Dima, D.V. Fedoseev, V.N. Frolov, A.-B.V. Gazzaev, L.K. Gladilin, A. Gongadze, A.O. Gridin, K.I. Gritsay, A.V. Guskov, N. Huseynov, A.V. Karpishkov, N.A. Kovyazina, V.A. Kozhukalov, V.G. Kruchonak, Yu.A. Kulchitsky, A.V. Kulikov, V.S. Kurbatov, Zh. Kurmanaliev, S.A. Kutuzov, K.I. Kuznetsova, P.I. Lensky, I. Lyashko, A. Maltsev, A.G. Olshevsky, A.A. Piskun, F.V. Prokoshin, D.I. Rusov, A.V. Rybnikov, A.G. Samartsev, O.B. Samoylov, A.S. Selyunin, S.S. Seryubin, V.I. Sharov, A.V. Shipilova, K. Shtejer, A.V. Simonenko, A.N. Skachkova, S.A. Sokolov, V.V. Tereshchenko, A.I. Tropina, Yu.N. Uzikov, A.O. Vasyukov, A.Yu. Verkheev, Yu.L. Vertogradova, L.S. Vertogradov, I.V. Yeletskikh, A.S. Zhemchugov, N.I. Zhuravlev, I.Yu. Zimin

MLIT E.I. Alexandrov, I.N. Alexandrov, M. Bures, A.V. Didorenko, N.V. Greben, Z.K. Khabaev, A.S. Konak, B.F. Kostenko, M.A. Mineev, D.A. Oleynik, G.A. Ososkov, A.Sh. Petrosyan, S.V. Shmatov, V.V. Uzhinsky, N.N. Voitishin

BLTP O.V. Teryaev, A.S. Zhevlakov, V.A. Saleev

Brief annotation and scientific rationale:
The Spin Physics Detector is a planned experimental setup at the NICA collider is intended to study the spin structure of the proton and deuteron and the other spin-related phenomena with polarized proton and deuteron beams at a collision energy up to 27 GeV and a luminosity up to 10^{32} cm^{-2} s^{-1}. In the polarized proton-proton collisions, the SPD experiment will cover the kinematic gap between the low-energy measurements at ANKE-COSY and SATURNE and the high-energy measurements at the Relativistic Heavy Ion Collider, as well as the planned fixed-target experiments at the LHC. As for the possibility for NICA to operate with polarized deuteron beams at such energies, it is unique. SPD is planned to operate as a universal facility for comprehensive study of the unpolarized and polarized gluon content of the nucleon at large and moderate *x*, using different complementary probes such as: charmonia, open charm, and prompt photon production processes. A priority of the experiment is the measurement of parton distributions depending on the transverse momentum of partons in the nucleon (TMD PDFs). The study of spin effects in the elastic scattering of protons and deuterons, and in the production of lambda-hyperons, search for dibaryon resonances, study of the charmed particles production near threshold, study of multiquark correlations, and other polarized and unpolarized physics will be available at the first stage of the collider operation with reduced luminosity and collision energy of proton and ion beams.

Expected results upon completion of the project:
The main result of the experiment should be new information on the gluon helicity, gluon Sivers, Boer-Mulders and other Transverse Momentum Dependent PDFs in the nucleon, as well as the gluon transversity distribution and tensor PDFs in the deuteron, via the measurement of specific single and double spin asymmetries. The results expected to be obtained by SPD will play an important role in the general understanding of the properties of strong interaction, specifically, of the nucleon gluon content and will serve as a complementary input to the ongoing and planned studies at RHIC, and future measurements at the EIC (BNL) and fixed-target facilities at the LHC (CERN). Simultaneous measurement of the same quantities using different processes at the same experimental setup is of key importance for minimization of possible systematic effects.

Expected results of the project in the current year:
Design, development, testing and optimization of prototypes of the detectors and other subsystems of the SPD setup.

Creation and development of infrastructure for testing prototypes of the SPD subsystems at the Nuclotron beams.

Finalization of the SPD technical design report. Approval of the technical design by the SPD International Advisory Committee.

Activities of the infrastructure:

	Name of the activity	**Leaders**	**Implementation period**
Laboratory	Responsible from laboratories		**Status**
1.	**Theoretical investigations, calculations and development of models describing nuclear matter properties at high temperatures and compressions, dynamics of high energy nuclear interactions at extremely high baryonic densities, spin and P-odd effects**	**D. Blaschke** **A.S. Sorin** **O.V. Teryaev**	2024-2026 Realization
BLTP	V.V. Braguta, A. Frizen, Yu.B. Ivanov, A.S. Khvoroctukhin, Ya.N. Klopot, A.G. Oganesyan, A. Parvan, A.A. Roenko		
MLIT	Yu.L. Kalinovsky, Zh.Zh. Musulmanbekov, E.G. Nikonov		
DLNP	G.I. Lykasov		
VBLHEP	Kh.U. Abraamyan, D.A. Artemenkov, P.N. Batyuk, D.K. Dryablov, V.D. Kekelidze, M.A. Kozhin, R. Lednicky, A.I. Malakhov, S.G. Reznikov, O.V. Rogachevsky, V. Voronyuk		
2.	**Computer infrastructure: online and offline clusters of the distributed computer complex, system of simulation, data transfer and analysis, information and technological computer systems**	**A.G. Dolbilov** **O.V. Rogachevsky**	2024-2026 Realization
VBLHEP	O.S. Fedoseev, D.G. Mel'nikov, Yu.I.Minaev, S.A. Mityukhin, D.V. Peshekhonov, I.P. Slepov, B.G. Schinov, I.V. Slepnev, S.N. Shkarovsky, V.L. Svalov		
MLIT	I.A. Kashunin, D.V. Kekelidze, V.V. Korenkov, V.V. Mitsyn, D.A. Oleynik, I.S. Pelevanyuk, A.Sh. Petrosayn, M.S. Plyashkevich, D.V. Podgainy, T.A. Strizh, V.V. Trofimov, P.V. Zrelov		

3.	**Construction and development of the test zone for detector R&D at the linear electron accelerator at DLNP**	**A.S. Zhemchugov**	2024-2026 Projecting Realization

VBLHEP A.A. Baldin, T. L. Enik, O. Gavrishchuk, V.V. Kobets, Yu.A. Murin, V.G. Shabratov

DLNP A.E. Brukva, D.L. Demin, M.I. Gostkin, V.G. Kruchonok, S.Yu. Porokhovoy, Ya.A. Samofalova, A.N. Trifonov, K.E. Yunenko

4.	**Construction and development of infrastructure for applied and innovation research at the NICA complex**	**A.V. Butenko** **A.S. Sorin**	2024-2026 Projecting Realization
4.1	**Construction of beamlines for applied research, of stations for irradiation of electronic components and biological objects with long-range ions and stations for irradiation of electronic components with low-energy ions**	**A.V. Butenko** **E.M. Syresin**	Realization
4.2	**R&D for the development and exploitation of irradiation stations for applied research at the NICA complex; organization of international collaboration**	**O.V. Belov** **S.I. Tyutyunnikov**	Projecting Realization

VBLHEP A.A. Baldin, E.A. Levterova, A.V. Rogachev, V.N. Shalyapin, 3 pers.

DLNP K.V. Belokopytova

FLNP M.V. Bulavin

5.	**Construction of the complex of buildings with engineering infrastructure for object placement, engineering systems and carrying out R&D for the NICA complex**	**N.N. Agapov** **V.D. Kekelidze** **N.D. Topilin**	2024-2026 Projecting Realization
5.1.	**Technical designing, coordination of the construction of the building complex and engineering infrastructure development**	**A.V. Dudarev** **I.N. Meshkov**	Projecting Realization
5.2.	**R&D, production of prototypes and full-scale superconducting magnets for the NICA booster and collider, renovated Nuclotron**	**H.G. Khodzhibagiyan**	Projecting Realization

VBLHEP V.V. Agapova, A.S. Averichev, A.M. Bazanov, N.P. Bazylev, V.I. Batin, N.A. Blinov, Yu.T. Borzunov, V.V. Borisov, A.A. Bortsova, A.V. Butenko, A.V. Bychkov, S.A. Dolgy, A.M. Donyagin, V.M. Drobin, N.A. Filippov, E.Yu. Filippova, E. Fischer, A.R. Galimov, O.M. Golubitsky, Yu.V. Gusakov, E.Yu. Ivanenko, V.N. Karpinsky, R.A. Karpunin, I.E. Karpunina, S.Yu. Kolesnikov, A.V. Konstantinov, V.S. Korolev, S.A. Kostromin, A.V. Kudashkin, G.L. Kuznetsov, E.A. Kulikov, O.A. Kunchenko, V.I. Lipchenko, D.V. Lobanov, A.A. Makarov, Yu.A. Mitrofanova, A.Yu. Merkur'ev, A.V. Nesterov, D.N.Nikiforov, M.S. Novikov, A.L. Osipenkov, R.V. Pivin, D.O. Ponkin, T.F. Prakhova, A.S. Sergeev, S.A. Smirnov, A.V. Shabunov, M.M.Shandov, A.V.Shemchuk, E.V. Shevtchenko, Yu.A. Tumanova, N.A. Zhil'tsova

MLIT P.G. Akishin

5.3.	**Upgrade and development of electric power and technological nets aimed at the increasing of economics and technical efficiency**	**N.N. Agapov** **N.V. Semin**	Projecting Realization

VBLHEP A.V. Alfeev, E. Fischer, A.M. Karetnik, H.G. Khodzhibagiyan, A.A. Makarov, M.I. Migulin, M.S. Novikov, E.V. Serochkin, V.M. Stepanov, A.N. Sotnikov, A.V. Shabunov, V.Yu. Shilov, O.M. Timoshenko, N.D. Topilin, V.P. Tchernyaev

CCD Yu.N. Balandin, I.S. Frolov, L.I. Tikhomirov

OCE V.N. Buchnev, 2 pers.

LRB G.N. Timoshenko, 3 pers.

Brief annotation and scientific rationale (p.5):
The activity is related to the production of a superconducting inductive energy storage device for the power system of the Booster and the Nuclotron, as well as the superconducting magnetic system of the New Nuclotron based on HTS magnets.

Expected results upon completion of the activity:
Development of a superconducting magnetic energy storage (SMES) in the power system of the Booster and Nuclotron with a stored energy of about 3 MJ.

Production of a model dipole magnet for the New Nuclotron made of HTS material.

Expected results of the activity this year:
Construction of a machine to produce HTS cable for SMES magnet.

Studies of the characteristics of HTS tapes under irradiation with heavy ions.

Development of a model dipole magnet for the New Nuclotron.

Collaboration

Country or International Organization	**City**	**Institute**
Armenia	Yerevan	Foundation ANSL
Azerbaijan	Baku	NNRC
Belarus	Minsk	BSU
		INP BSU
		IP NASB
		JIPNR-Sosny NASB
		PTI NASB
Bulgaria	Plovdiv	PU
Chile	Valparaiso	UTFSM
China	Beijing	"Tsinghua"
		CIAE
		IHEP CAS
		UCAS
	Hefei	ASIPP
		USTC
	Hengyang	USC
	Huzhou	HU
	Jinan	SDU
	Lanzhou	IMP CAS
	Shanghai	Fudan
		SINAP CAS
	Wuhan	CCNU
	Yichang	CTGU
Cuba	Havana	InSTEC

Czech Republic	Olomouc	UP
	Rez	NPI CAS
Egypt	Cairo	ECTP MTI
Georgia	Tbilisi	GTU
Germany	Darmstadt	GSI
	Julich	FZJ
Japan	Tokyo	Nihon Univ.
Kazakhstan	Almaty	INP
		PhysTI
Mexico	Mexico City	UNAM
	Puebla	BUAP
Moldova	Chisinau	IAP
Mongolia	Ulaanbaatar	IPT MAS
Russia	Belgorod	BelSU
	Dolgoprudny	MIPT
	Fryazino	ISTOK
	Gatchina	NRC KI PNPI
	Kazan	Compressormash
		Spetshmash
	Moscow	Cryogenmash
		Geliymash
		IBMP RAS
		ITEP
		LPI RAS
		MIREA
		MSU
		NNRU "MEPhI"
		NRC KI
		NRU HSE
		PRUE
		SINP MSU
		VEI
	Moscow, Troitsk	INR RAS
	Novocherkassk	SRSPU NPI
	Novosibirsk	BINP SB RAS
		STL "Zaryad"
	Protvino	IHEP
	Saint Petersburg	SPbSPU
		SPbSU
	Samara	SU
	Syktyvkar	DM Komi SC UrB RAS
	Tomsk	TSU
	Vladikavkaz	NOSU
	Zhukovsky	TECHNOLOGY
Serbia	Belgrade	INS "VINCA"
Slovakia	Kosice	UPJS
	Nova Dubnica	EVPU
South Africa	Somerset West	iThemba LABS
	Stellenbosch	SU
Uzbekistan	Tashkent	Assoc. P.-S. PTI

02-2-1148-2010/2028

Baikal-GVD
Baikal Deep Underwater Gigaton Volume Neutrino Telescope

Leaders: I.A. Belolaptikov

Deputy: S.V. Rozov

Participating countries and international organizations:
Czech Republic, Kazakhstan, Russia, Slovakia.

The problem under study and the main purpose of the research:
Implementation of the project that includes modernization and development of the Baikal deepwater detector up to the detection volume of 1 km^3 in studies of high-energy neutrino fluxes of astrophysical origin.

Project:

Name of the project	Project Leaders	Project code
Laboratory Responsible from laboratories		**Status**
1. Baikal-GVD	**I.A. Belolaptikov** *Deputy*: **S.V. Rozov**	02-2-1148-1-2010/2028 Realization

DLNP V.F. Allakhverdyan, P.I. Antonov, I.V. Borina, V. Dik, I.S. Dotsenko, A.A. Doroshenko, T.V. Elzhov, A.N. Emelianov, A.Golubev, K.V. Golubkov, N.A. Gorshkov, B. Kalinova, I. Kamnev, S.A. Katulin, S.L. Katyulina, E.V. Khramov, M.M. Kolbin, K.V. Konischev, A.V. Korobchenko, M.V. Kruglov, E. Kulkova, T. Lednitska, N.V. Mazarskaya, M.L. Minaev, T.A. Morozova, D.V. Naumov, D.A. Orlov, D.P. Petukhov, E.N. Pliskovski, V.G. Sandukovsky, G.B. Safronov, I. Scherbakova ,A.E. Sirenko, M.N. Sorokovikov, N.I. Sosunov, I.A. Stepkin, A.P. Stromakov, B.A. Shaybonov, K.I. Shevchenro, M. Shevchenko, B.B. Ulzutuev, V. Volnykh, Yu.V. Yablokova, E.Yakushev, D.V. Zvezdov, S. Zavialov, A. Zaikin

MLIT M.S. Katulin, A. Soloviev

Brief annotation and scientific rationale:
The Baikal-GVD project is aimed at the further development of the gigaton-scale neutrino telescope for conducting research in multimessenger astronomy, study of fundamental properties of the most energetic cosmic neutrinos, indirect search for galactic dark matter and applied research. The international collaboration of the Baikal-GVD project is constructing a neutrino telescope in Lake Baikal. The arrays of light-sensitive elements, housed in optical modules, detect Cherenkov light produced by charged particles in the water of the lake while travelling with the speed exceeding the speed of light in water. These particles could originate from interactions of neutrinos in water or in the rock of the lake bed. The energy and direction of original neutrinos are reconstructed from the amount of Cherenkov photons and time of their detection by light-sensitive elements. The telescope is capable of investigating cosmic neutrinos and identifying their sources, searching for neutrinos from dark matter annihilation and other rare phenomena. The scientific programme of the project is focused on solving fundamental problems of astrophysics and elementary particle physics: identification of astrophysical sources of ultrahigh-energy neutrinos, revealation of mechanisms of formation and evolution of galaxies, etc. In particular, one of the short-range goals is mapping the high-energy neutrino sky in the Southern Hemisphere, including the region of the Galactic Centre. Other topics include the indirect search for dark matter by detecting neutrinos produced in WIMP annihilations in the Sun or in the Earth's interior. Baikal-GVD will also search for exotic particles, such as magnetic monopoles, supersymmetric Q-balls or nuclearities. Baikal-GVD, the unique neutrino telescope, is one of the basic facilities at JINR.

Expected results upon completion of the project:
Construction of a deep-underwater neutrino telescope on a scale of 1 km^3 in Lake Baikal. Study of high-energy neutrino fluxes from space, search for hypothetical particles – magnetic monopoles, as well as particles – candidates for dark matter. A large detection volume, in combination with a high angular and energy resolution and also with moderate background conditions typical of fresh water, makes it possible to effectively study the diffusive neutrino flux and fluxes from individual astrophysical objects with constant and variable luminosity.

Expected results for the project in the current year:
Data taking by 13 already installed clusters of the Baikal-GVD neutrino telescope. Search for and study of events from high-energy neutrinos of astrophysical origin. Preparation for and deployment of the following detector clusters. Testing of a new system of data acquisition and transmission which ensures the reduction of the threshold of detectable energies.

Collaboration

Country or International Organization	City	Institute
Czech Republic	Prague	CTU
Kazakhstan	Almaty	INP
Russia	Irkutsk	ISU
	Moscow	SINP MSU
	Moscow, Troitsk	INR RAS
	Nizhny Novgorod	NNSTU
	Saint Petersburg	SMTU
Slovakia	Bratislava	CU

06-6-1118-2014/2030

MICC
Multifunctional Information and Computing Complex

Leaders: V.V. Korenkov
S.V. Shmatov

Deputies: A.G. Dolbilov
D.V. Podgainy
T.A. Strizh

Participating Countries and International organizations:
Armenia, Azerbaijan, Belarus, Bulgaria, CERN, China, Egypt, France, Georgia, Kazakhstan, Mexico, Mongolia, Russia, Slovakia, South Africa, Taiwan, USA, Uzbekistan.

The problem under study and the main purpose of the research:
The main objective of the MICC is to meet the needs of the JINR scientific community to the maximum extent possible in order to solve urgent tasks, from theoretical research and experimental data processing, storage and analysis to the solution of applied tasks in the field of life sciences. The tasks of the NICA project, the neutrino programme, the tasks of processing data from the experiments at the LHC and other large-scale experiments, as well as support for users of the JINR Laboratories and its Member States will be the priorities.

The project presupposes the inclusion of two activities, which, like the project, are aimed at meeting the requirements of a large number of research and administrative personnel:

– development of the digital platform "JINR Digital EcoSystem", which integrates existing and future services to support scientific, administrative and social activities, as well as to maintain the engineering and IT infrastructures of the Institute, which in turn will provide reliable and secure access to different types of data and enable a comprehensive analysis of information using modern technologies of Big Data and artificial intelligence;

– creation of a multi-purpose hardware and software platform for Big Data analytics based on hybrid hardware accelerators; machine learning algorithms; tools for analytics, reports and visualization; support of user interfaces and tasks.

Project:

Laboratory	**Name of the Project** Responsible from laboratories	**Project Leaders**	**Project code** **Status**
1.	**MICC** **Multifunctional Information and Computing Complex**	**V.V. Korenkov** **S.V. Shmatov** *Deputies:* **A.G. Dolbilov** **D.V. Podgainy** **T.A. Strizh**	06-6-1118-1-2014/2030 Realization

MLIT K.N. Angelov, A.I. Anikina, O.A. Antonova, A.I. Balandin, N.A. Balashov, A.V. Baranov, D.V. Belyakov, T. Zh. Bezhanyan, S.V. Chashchin, A.I. Churin, O.Yu. Derenovskaia, V.P. Dergunov, A.T. Dzakhoev, A.V. Evlanov, V.Ya. Fariseev, M.Yu. Fetisov, S.V. Gavrilov, A.P. Gavrish, T.M. Goloskokova, A.O. Golunov, L.I. Gorodnicheva, E.A. Grafov, E.N. Grafova, N.I. Gromova, A.E. Gushchin, A.V. Ilyina, N.N. Karpenko, I.I. Kalagin, A.S. Kamensky, I.A. Kashunin, M.Kh. Kirakosyan, A.A. Kokorev, G.A. Korobova, S.A. Kretova, N.A. Kutovsky, I.V. Kudasova, O.N. Kudryashova, E.Yu. Kulpin, A.E. Klochiev, A.V. Komkov, V.I. Kulakov, A.A. Lavrentiev, A.M. Levitin, Yu.M. Legashchev, M.A. Lyubimova, M.A. Maksimov, V.N. Markov, S.V. Marchenko, M. A. Matveev, A.N. Makhalkin, Ye. Mazhitova, A.A. Medyantsev, V.V. Mitsyn, N.N. Mishchenko, A.N. Mityukhin, A.N. Moibenko, I.K. Nekrasova, V.N. Nekrasov, D.A. Oleinik, V.V. Ovechkin, S.S. Parzhitsky, I.S. Pelevanyuk, D.I. Pryakhina, A.Sh. Petrosyan, D.S. Polezhaev, L.A. Popov, T.V. Rozhkova, Ya.I. Rozenberg, D.V. Rogozin, R.N. Semenov, A.S. Smolnikova, E. V. Solovieva, I.G. Sorokin, I.N. Stamat, V.P. Sheiko, D.A. Shpotya, B.B. Stepanov, A.M. Shvalev, M.L. Shishmakov, O.I. Streltsova, I.A. Sokolov, Sh.G. Torosyan, V.V. Trofimov, N.V. Trubchaninov, E.O. Tsamtsurov, V.Yu. Usachev, S.I. Vedrov, A.S. Vorontsov, N.N. Voytishin, A.Yu. Zakomoldin, S.E. Zhabkova, M.I. Zuev

VBLHEP K.V. Gertsenberger, A.O. Golunov, Yu.I. Minaev, A.N. Moshkin, O.V. Rogachevsky, I.V. Slepnev, I.P. Slepov

BLTP	A.A. Sazonov
FLNP	G.A. Sukhomlinov
FLNR	A.S. Baginyan, A.G. Polyakov, V.V. Sorokoumov
DLNP	Yu.P. Ivanov, V.A. Kapitonov, A.S. Zhemchugov
LRB	V.N. Chausov
UC	I.N. Semenyushkin
Assosiated Personnel MICC	A.V. Anisenkov, A.K. Kiryanov

Brief annotation and scientific rationale:
To attain the major goals of JINR's flagship projects, it will be required to process a huge amount of experimental data. According to a very rough estimate, these are tens of thousands of processor cores and hundreds of petabytes of experimental data. The experiments of the NICA project and the JINR neutrino programme (Baikal-GVD, JUNO, etc.) entail Tier0, Tier1 and Tier2 grid infrastructures. To achieve these goals, it is essential to develop distributed multi-layer heterogeneous computing environments, including on top of the resources of the participants of other projects and collaborations.

The concept of the development of information technology, scientific computing and Data Science in the JINR Seven-Year Plan provides for the creation of a scientific IT infrastructure that combines a multitude of various technological solutions, trends and methods. The IT infrastructure implies the coordinated development of interconnected IT technologies and computational methods aimed at maximizing the number of JINR strategic tasks to be solved that require intensive data computing. The large research infrastructure project "Multifunctional Information and Computing Complex" holds a special place in this concept.

The MICC LRIP main objective for 2024-2030 is to perform a set of actions aimed at the modernization and development of the major hardware and software components of the computing complex, the creation of a state-of-the-art software platform enabling the solution of a wide range of research and applied tasks in accordance with the JINR Seven-Year Plan. The rapid development of information technology and new user requirements stimulate the development of all MICC components and platforms. The MICC computing infrastructure encompasses four advanced software and hardware components, namely, the Tier1 and Tier2 grid sites, the hyperconverged "Govorun" supercomputer, the cloud infrastructure and the distributed multi-layer data storage system. This set of components ensures the uniqueness of the MICC on the world landscape and allows the scientific community of JINR and its Member States to use all progressive computing technologies within one computing complex that provides multifunctionality, scalability, high performance, reliability and availability in 24x7x365 mode with the multi-layer data storage system for different user groups.

Within the MICC LRIP, it is provided to support the operation of all MICC hardware and software components, i.e., the Tier1 and Tier2 grid sites, the cloud infrastructure, the hyperconverged "Govorun" supercomputer, the multi-layer data storage system, the network infrastructure, the power supply and climate control systems, as well as to modernize/reconstruct the above components in accordance with new trends in the development of IT technologies and user requirements. In addition, it is required to ensure high-speed telecommunications, a modern local area network infrastructure and a reliable engineering infrastructure that provides guaranteed power supply and air conditioning for the server equipment.

Expected results upon completion of the project:
Modernization of the JINR MICC engineering infrastructure (reconstruction in accordance with modern requirements of the machine hall of the 4th floor of MLIT).

Modernization and development of the distributed computing platform for the NICA project with the involvement of the computing centres of the NICA collaboration.

Creation of a Tier0 grid cluster for the experiments of the NICA megaproject to store experimental and simulated data. Expansion of the performance and storage capacity of the Tier1 and Tier2 grid clusters as data centres for the experiments of the NICA megaproject, the JINR neutrino programme and the experiments at the LHC.

Enlargement of the JINR cloud infrastructure to broaden the range of services provided to users on the basis of containerization technologies. Automation of the deployment of cloud technologies in the JINR Member States' organizations.

Expansion of the HybriLIT heterogeneous platform, including the "Govorun" supercomputer, as a hyperconverged software-defined environment with a hierarchical data storage and processing system.
Design and elaboration of a distributed software-defined high-performance computing platform that combines supercomputer (heterogeneous), grid and cloud technologies for the effective use of novel computing architectures.

Development of a computer infrastructure protection system based on fundamentally new paradigms, including quantum cryptography, neurocognitive principles of data organization and data object interaction, global integration of information systems, universal access to applications, new Internet protocols, virtualization, social networks, mobile device data and geolocation.

Expected results for the project in the current year:
Provision of the stable, safe and integral functioning of the JINR information and telecommunication network (backbone network (2x100 Gbps); the transport network of the NICA megaproject (4x100 Gbps); the MLIT mesh network (100 Gbps); backbone external telecommunication channels (3x100 Gbps); the Wi-Fi network at the Institute's sites in 24x7x365 mode. Support of standard network services: email, file sharing, security, user database support and maintenance, IPDB network element database support, etc. Elaboration of a methodology and technology for dual authorization and certification authorities. Development of a project for alternative routes of the external network infrastructure. Elaboration of a project of a dedicated optical network for NICA collaborations.

Operation of the guaranteed power supply (diesel generators, uninterruptible power supplies) and climate control systems (chillers, dry coolers, inter-row air conditioners, etc.), as well as the fire safety system, of the MICC computing infrastructure in 24x7x365 mode. Maintenance of the full-scale and optimal functioning of the MICC engineering equipment. Modernization of Modules 1 and 2 of the machine hall on the 2nd floor. Design and implementation of the first stage of modernization of the server room in the hall of the 4th floor of the MLIT building.

Expansion of the performance and storage system of the MICC basic components, namely, the Tier1 center up to 23,000 CPU cores and 16,000 TB, Tier2/CICC up to 12,000 CPU cores, the EOS system up to 35 PB. Modernization of the EOS-based data lake. Enlargement and maintenance of the unified storage and access system for common software (CVMFS). Support of the software system for working with tape robots (CTA). Support and maintenance of the operation of WLCG virtual organizations, the NICA, COMPASS, NOvA, ILC and other experiments, local user groups on the MICC Tier1 and Tier2 resources. Implementation of a regional center for the JUNO experiment on top of the MICC resources.

Development of prototypes of fully functional Tier0, Tier1 centers for the experiments at the NICA accelerator complex. Creation of basic services for Tier0, Tier1 and third-party Tier2 centers: registration of users and resources; authorization and support for the security of resource use and user work in the distributed system; problem fixing and notification of resource users and administrators; systems for combining distributed computing resources; systems for combining distributed data storage resources.

Extension of the number of users and participants of the distributed information and computing environment (DICE) on the basis of the cloud resources of the JINR Member States' organizations. Enlargement of the computing resources of the MICC cloud (if technically possible), including at the expense of resources acquired by the Baikal-GVD, JUNO, NOvA/DUNE experiments, and their maintenance. Update of all software components of the JINR cloud infrastructure and services to the latest versions. Implementation of a system for the automated testing of servers before putting them into operation. Enhancement of the HTCondor cluster monitoring system to monitor the status of multi-core jobs. Transfer of the system for alerting and monitoring the current state of cloud infrastructure components from Icinga to the Grafana/Prometheus stack.

Enhancement of the efficiency of using the distributed heterogeneous computing environment built on top of the DIRAC software by developing and introducing into the system a methodology for analyzing the performance of jobs running in the distributed environment. Optimization of the job launch mechanism via the use of the DIRAC software environment preinstalled in CVMFS. Conducting mass data production sessions within the BM@N experiment, technical support for launching jobs of the MPD and SPD experiments.

Development of a system for automating the jobs of deploying and configuring the system software of the HybriLIT platform. Development of a system for analyzing the load on computing resources to solve the tasks of modernizing and optimizing the configuration of the "Govorun" supercomputer. Testing and implementation of parallel and distributed data storage and processing systems such as MinIO, Apache Ignite, etc. to enhance the efficiency of working with model and experimental data on the HybriLIT platform. Development and integration of a system for collecting and analyzing statistics on the usage of application software by HybriLIT heterogeneous platform users via the Modules system. Enhancement of the GPU components of the "Govorun" supercomputer to provide advanced computing architectures for the current needs of users and planned research within the NICA experiments, as well as for the development of the ML/DL/HPC ecosystem, including the quantum computing polygon.

Trial operation of the prototype of a data storage and processing system for the SPD experiment using the MICC resources (cloud infrastructure for hosting middleware services, CICC computing infrastructure for performing jobs, EOS for data storage). Testing of work with the MICC tape storage.

Enlargement of the LITmon monitoring system through the integration of local systems for monitoring electrical equipment (diesel generators, transformers and uninterruptible power supplies) and refrigeration systems (cooling towers, pumps, water circuits, heat exchangers, chillers). Introduction of new MICC equipment in the monitoring system. Creation of a prototype of a control room for the MICC engineering infrastructure with a single access point. Elaboration of a prototype of a unified MICC accounting system based on the accounting systems of the complex components and a system for monitoring logs of serial consoles of MICC servers.

Activities of the infrastructure:

Name of the activity	Leaders	Implementation period
Laboratory Responsible from laboratories		Status
1. The digital ecosystem (Digital JINR)	**V.V. Korenkov** **S.D. Belov**	2024-2026 Realization

MLIT E.V. Antonov, A.A. Artamonov, N.A. Balashov, N.E. Belyakova, O.V. Belyakova, A.S. Bondyakov, N.A. Davydova, I.A. Filozova, L.A. Kalmykova, E.N. Kapitonova, A.O. Kondratiev, E.S. Kuznetsova, E.K. Kuzmina, S.V. Kunyaev, L.D. Kuchugurnaya, D.V. Neapolitanskiy, I.K. Nekrasova, M.M. Pashkova, L.V. Popkova, Ya.I. Popova, A.V. Prikhodko, T.F. Sapozhnikova, V.S. Semashko, S.V. Semashko, I.A. Sokolov, E.V. Sheiko, G.V. Shestakova, T.S. Syresina, D.Yu. Usov, P.V. Ustenko, T.N. Zaikina

VBLHEP V.V. Morozov, I.V. Slepnev, A.V. Trubnikov

DSDD A.V. Sheiko, M.P. Vasiliev

Brief annotation and scientific rationale:
The activity is related to the creation of an Institute-wide digital platform "JINR Digital EcoSystem". The main objective is the organization of a digital space with a single access and data exchange between electronic systems, as well as the transition of actions that previously required a personal or written request to a digital form. The platform is designed to ensure the integration of existing and future services to support scientific, administrative and social activities, as well as to maintain the engineering and IT infrastructures of the Institute.

Within the activity, two main directions of work are planned: the creation of the basic infrastructure of the digital platform (including the software-hardware and methodological support of its functioning) and different digital services. In addition to service support, digital services for scientific collaborations, whose activity is related to JINR's basic facilities, will be developed and maintained for use by the Institute's staff members.

Expected results upon completion of the activity:
Creation of a hardware-software and methodological basis for the functioning of the Institute-wide digital platform.

Development and implementation of digital services for distributed access to resources (information, computing, administrative, organizational ones) in a unified environment.

Transition of the processes of getting permits, approvals and applications of different types into a digital form.

Creation of a catalogue and a distributed storage of data related to the scientific and technical aspects of the Institute's activity, as well as of tools for their analysis, presentation and the construction of predictive models.

Expected results in the activity in the current year:
Creation of a unified environment for the data storage and management of basic and applied DES services, integration with the Big Data infrastructure to analyze the specified data.

Commissioning of a deeply redesigned version of the PIN system integrated with the DES and the repository of JINR publications.

Integration of the JINR institutional repository of publications with other DES services, provision of publication data for automated processing and analysis.

Automation of the deployment, monitoring and support of reliable and safe operation of basic DES services.

Organization of a user support system, including various means of interaction with users and service administrators, electronic application services, knowledge bases and documentation organization tools.

Ongoing support and development of the "Dubna" EDMS. Preparation for the transfer of procurement processes to the document management system created by the Development of Digital Services Department.

Implementation of additional capabilities in the geoinformation system to support the activities of JINR technology services and departments upon their request. Integration of the geoinformation system with other DES services.

Implementation of the system "Management of buildings, premises and workplaces": organization of the workspace based on the digital twin of the building. Map of workplaces, their assignment to departments, status and usage calendar. Labor Code compliance monitoring of working conditions.

Creation and development of digital collaboration services (scientific documentation database, calendars, project management, etc.).

2. The multi-purpose hardware and software platform for Big Data analytics **P.V. Zrelov** 2024-2026

Realization

MLIT A.A. Artamonov, D.A. Baranov, S.D. Belov, I.A. Filozova, Yu.E. Gavrilenko, A.V. Ilyina, I.A. Kashunin, M.A. Matveev, D.V. Neapolitanskiy, I.S. Pelevanyuk, R.N. Semenov, T.M. Solovieva, E.V. Sheiko, V.A. Tarabrin, T.N. Zaikina, D.P. Zrelova

Bref annotation and scientific rationale:
The activity provides for the creation of a multi-purpose hardware and software platform for Big Data analytics, which implements a full cycle of continuous processing, from data acquisition to the visualization of processing and analysis results, forecasts, recommendations and instructions, within the JINR MICC. One of the tasks planned to be solved using the platform is the elaboration of an analytical system for managing the MICC resources and data flows to enhance the efficiency of using computing and storage resources and optimize experimental data processing, as well as the development of the intelligent monitoring of distributed computing systems and data centres. Another essential task is the creation and development of analytics tools for the services of the JINR Digital EcoSystem.

Expected results upon completion of the activity:
Creation of a universal core of a Big Data mining platform.

Development and implementation of a number of standard software solutions for different classes of tasks within the platform.

Elaboration and development of analytics tools for the JINR Digital EcoSystem.

Development of methods and creation of complex solutions for analysing the security of data and computer systems.

Development of artificial intelligence methods within the analytical platform and creation of a software environment for work with technical and scientific information.

Elaboration of common solutions based on Big Data analytics for expert and recommendation systems, including for the optimization of the processes of functioning of the MICC components.

Expected results of the activity in the current year:
Creation of a custom Big Data infrastructure based on CPU and GPU computing resources using software for organizing computing, libraries of analysis, modeling and visualization tools with open source code.

Methodology and software tools for the intellectual processing of scientific and technical information on the Institute's topics (scientific publications, patents, materials for registering programs and databases, digital traces of projects, materials for the development of human resources).

Software tools and infrastructure for the intelligent monitoring of distributed computing systems based on the analysis of information about the system functioning (logs, state metrics, structure information, etc.) using large language models (LLMs).

Elaboration of a mechanism for monitoring and analyzing the security of network connections to resources hosted in the JINR MLIT cloud environment.

Acceleration of data processing by the ROOT framework using distributed computing on the Spark cluster.

Analytical tools, hardware and software infrastructure, methods for integrating and analyzing data from Digital EcoSystem services.

Collaboration

Country or International Organization	City	Institute
Armenia	Yerevan	IIAP NAS RA
Azerbaijan	Baku	ADA
		IP ANAS
Belarus	Minsk	INP BSU
		JIPNR-Sosny NASB
		UIIP NASB
Bulgaria	Sofia	INRNE BAS
		SU
CERN	Geneva	CERN

China	Beijing	IHEP CAS
Egypt	Cairo	ASRT
	Giza	CU
France	Marseille	CPPM
Georgia	Tbilisi	GRENA
		GTU
		TSU
		UG
Kazakhstan	Almaty	INP
	Astana	BA INP
Mexico	Mexico City	UNAM
Mongolia	Ulaanbaatar	IMDT MAS
Russia	Chernogolovka	SCC IPCP RAS
	Dubna	Dubna State Univ.
		SCC "Dubna"
		SEZ "Dubna"
	Gatchina	NRC KI PNPI
	Moscow	BMSTU
		FRC IM RAS
		IITP RAS
		ISP RAS
		ITEP
		JSCC RAS
		KIAM RAS
		MPEI
		MSK-IX
		MSU
		NNRU "MEPhI"
		NRC KI
		NRU HSE
		PRUE
		RCC MSU
		RSCC
		SINP MSU
	Moscow, Troitsk	INR RAS
	Novosibirsk	BINP SB RAS
		ICMMG SB RAS
		SKIF
	Protvino	IHEP
	Puschino	IMPB RAS
	Saint Petersburg	FIP
		ITMO
		SPbSPU
		SPbSU
	Samara	SU
	Vladikavkaz	NOSU
	Vladivostok	IACP FEB RAS
Slovakia	Kosice	IEP SAS
South Africa	Cape Town	UCT
Taiwan	Taipei	ASGCCA
USA	Arlington, TX	UTA
	Batavia, IL	Fermilab
	Upton, NY	BNL
Uzbekistan	Tashkent	AS RUz
		INP AS RUz

03-5-1129-2017/2028

DRIBs-III
Development of the FLNR Accelerator Complex and Experimental Setups

Leaders: I.V. Kalagin
S.I. Sidorchuk

Deputy: V. A. Semin

Scientific leader: Yu.Ts. Oganessian

Participating countries and international organizations:
Armenia, China, Egypt, Kazakhstan, Russia, Serbia, South Africa.

The problem under study and the main purpose of the research:
The implementation of the DRIBs-III project that includes the upgrade and development of the FLNR cyclotron complex, expansion of the experimental infrastructure of the Laboratory (construction of new physics set-ups), and the development of accelerator systems. The project is aimed at improving the operation stability of accelerators and at increasing the intensity and improving the quality of ion beams of both stable and radioactive nuclides, while at the same time reducing power consumption. The goal of the project is to significantly improve the efficiency of experiments on the synthesis of superheavy elements and study of their properties.

In addition, the construction of the DC-140 accelerator complex for applied research has continued. The work is carried out under "The project for the creation of the JINR Innovation Research Center" as a part of "The FLNR research complex for materials science" project.

Within the theme quite as important are the support of physics experiments and the development of existing accelerators and experimental setups.

Projects:

	Name of the project	Project leaders	Project code
1.	Construction of the U-400R accelerator complex	I.V. Kalagin A.G. Popeko *Deputy:* V. A. Semin	03-5-1129-1-2024/2028
2.	Development of the experimental setups to study the chemical and physical properties of superheavy elements	S.I. Sidorchuk *Deputy:* A.M. Rodin	03-5-1129-2-2024/2028

Projects:

Laboratory	Name of the project Responsible from laboratories	Project leaders	Status
1.	**Construction of the U-400R accelerator complex**	**I.V. Kalagin** **A.G. Popeko** *Deputy:* **V.A. Semin**	Manufacture

FLNR M.B. Barbashev, V. Bass, E. Batchuluun E., A.A. Bogachev, A.N. Bykov, O.A. Chernyshev, A. Dey, I. Franko, K.B. Gikal, Yu.M. Itkis, I.A. Ivanenko, G.N. Ivanov, N.Yu. Kazarinov, S.A. Klygin, E.A. Klenov. G.N. Knyazheva, E.M. Kozulin, N.I. Kozulina, G.A. Kononenko, A.V. Kulikov, K.A. Kulkov, V.I. Lisov, M.I. Makarov, K.V. Novikov, N.F. Osipov, S.V. Pashchenko, I.V. Pchelintsev, N.N. Pchelkin, E.O. Savelieva, S. Satian, Yu. M. Sereda, A.A. Sidorov, A.A. Suslov, A.V. Tikhomirov, R.S. Tikhomirov, R.E. Vaganov, V.A. Veryovochkin, V.A. Vorobyov, A.N. Vorontsov, A.S. Zabanov, S.I. Zagrebayeva, A.O. Zhukova, S.Yu. Zinchenko

Brief annotation and scientific rationale:
The goal of the project is the construction of the U-400R accelerator complex for the detailed study of the mechanisms of nuclear reactions with stable heavy-ion beams (fusion–fission, quasifission, multinucleon transfer, etc.), synthesis of new nuclides in these reactions, and decay spectroscopy of nuclei under investigation.

The project encompasses such tasks as the construction of a new experimental hall, the upgrade of the U-400 cyclotron (U-400R following the modernization), and the construction of new separators and ion-guide systems for beam transport.

The accelerator complex will be used for the detailed study of the properties of the isotopes of heavy and superheavy elements and in searches for novel methods of synthesizing heavy nuclides. The studies do not imply the use of radiactive target material in amounts exceeding 10^5Bq.

Expected results upon completion of the project:
Upgrade of the U-400 cyclotron → U-400R.

Construction of a new experimental hall of U-400R.

Construction of new experimental set-ups and beam transport channels from U-400R.

Commissioning of the DC-140 accelerator complex for complex applied research.

Expected results of the project in the current year:
Implementation of the experimental programme at the U-400 cyclotron.

Construction of the U-400R experimental hall.

Start of the reconstruction of the U-400 (U-400R) cyclotron.

Construction of a beamline transport system following from building No. 131 to the U-400R experimental hall.

Development of a design of the STAR kinematic separator of multinucleon transfer reaction products.

Development of the design concepts of the SCIF-D set-up for studying nuclear reaction mechanisms and work on the project.

Construction of the DC-140 cyclotron.

Development of methods for beam diagnostics of stable and radioactive nuclides.

2. Development of the experimental setups to study the chemical and physical properties of superheavy elements

S.I. Sidorchuk
Deputy:
A.M. Rodin

Manufacture

FLNR N.V. Aksenov, A.A. Astakhov, A.Yu. Bodrov, G.A. Bozhikov, E.V. Chernysheva, I. Chuprakov, A.I. Holtzman, A.V. Guljaev, A.V. Guljaeva, D. Ibadullayev, P. Kohout, A. Kohoutova, A.B. Komarov, N.D. Kovrizhnykh, I. Krupa, V.D. Kulik, D.A. Kuznetsov, A.Sh. Madumarov, I.V. Muravyov, A.S. Novoselov, A. Opihal, O.V. Petrushkin, A.V. Podshibyakin, V.S. Salamatin, V.D. Shubin, M.V. Shumeiko, D.I. Soloviev, V.Yu. Vedeneev, S.A. Yuhkimchuk

Brief annotation and scientific rationale:
Nowadays acceleration of high-intensity beams at the DC-280 cyclotron (SHE Factory) provides sufficient statistics in experiments on the synthesis of superheavy nuclei in the vicinity of the island of stability (Z=114, N=184), thereby opening up new avenues for research. Among the new opportunities the SHE Factory offers are first and foremost studies of the chemical properties of short-lived ($T_{1/2}$<0.5 s) isotopes of superheavy elements and precise measurements of their masses.

The project aims to create novel state-of-the-art experimental instruments. Experimental set-ups to be installed at the DC-280 cyclotron will be used for synthesizing and studying the physical and chemical properties of the isotopes of heavy and superheavy elements as well as in studies of nuclear reaction mechanisms, in nuclear spectrometry and mass spectrometry. To attain these goals, we are planning to construct a new gas-filled GASSOL separator whose key elements are a superconducting solenoid and a multi-reflection time-of-flight mass spectrometer.

Based on a superconducting solenoid magnet, the magnetic gas-filled separator (GASSOL) is intended for studying the physical and chemical properties of superheavy elements, including their short-lived ($T_{1/2}$< 0.5 s) isotopes, thereby establishing a pathway to elements heavier than Fl. In addition to the efficient separation of reaction products, the separator will focus nuclei of interest into a spot not exceeding 1 cm in diameter.

The specialized high-resolution mass spectrometer is designed for measuring the masses of superheavy elements with Z=104–118 and A=266–294 and their radioactive decay products with an accuracy of <100 keV. Its principle of operation is based on the multi-reflection time-of-flight (MR TOF) technique.

Expected results upon completion of the project:
Development of methods for producing intensive beams of ^{48}Ca, ^{50}Ti, ^{54}Cr, etc.

Assembly of the solenoid magnet of the superconducting gas-filled GASSOL separator.

Construction of a multi-reflection time-of-flight mass spectrometer.

Expected results of the project in the current year:
Enabling experiments on the synthesis of superheavy elements and study of their properties at the Superheavy Element Factory.

Assembly and commissioning of the superconducting gas-filled GASSOL separator. Installation of the GASSOL engineering systems and a beamline transport system from DC-280 to the separator.

Design of a multi-reflection time-of-flight mass spectrometer. Test run of the cryogenic gas ion catcher.

Collaboration

Country or International Organization	City	Institute
Armenia	Yerevan	Foundation ANSL
China	Lanzhou	IMP CAS
Egypt	Cairo	EAEA
Kazakhstan	Astana	BA INP
Russia	Nizhny Novgorod	IAP RAS
	Saint Petersburg	IAI RAS
		NIIEFA
	Tomsk	TSU
Serbia	Belgrade	INS "VINCA"
	Novi Sad	UNS
South Africa	Port Elizabeth	NMU
	Somerset West	iThemba LABS
	Stellenbosch	SU
	Vanderbijlpark	VUT

04-4-1149-2024/2028

Pulsed Neutron Source and Complex of Spectrometers

Leader: E.V. Lychagin

Participating countries and international organizations:
Argentina, Armenia, Azerbaijan, Belarus, Bulgaria, China, Cuba, Czech Republic, Egypt, France, Germany, Hungary, IAEA, India, Italy, Japan, Kazakhstan, Latvia, Mongolia, Poland, Romania, Russia, Serbia, Slovakia, South Africa, Spain, Sweden, Switzerland, Tajikistan, USA, Uzbekistan, Vietnam.

The problem under study and the main purpose of the research:
Revealing the relationships between the structural features of materials and their physical properties at the microscopic level is one of the fundamental tasks that determine the development of modern concepts in the field of condensed matter physics, materials science, chemistry, geophysics, engineering, biology and pharmacology. The unique advantages of using neutron research methods make their application the most optimal, and in some cases the only approach for solving a wide range of topical fundamental and applied problems. For the successful implementation of the neutron research program, it is of utmost importance to support and develop large infrastructures, encompassing the neutron source and the suite of spectrometers.

The main task of the project for the development of the existing neutron source is to increase the efficiency in the use of the IBR- 2 research nuclear facility for implementation of the program of experimental investigations, to ensure operational reliability and safety of the reactor. Regular operation of the IBR-2 research nuclear facility is carried out in accordance with the Rostekhnadzor license with an average power of up to 2 MW. The IBR-2 facility is equipped with modern safety control systems, systems of analysis and diagnostics of the reactor state, systems for radiation monitoring and control of radiation situation.

The main objective of the project for the development of the complex of spectrometers is the continuous improvement of experimental techniques available to the scientists. It is achieved mostly through increasing the number of controlled parameters, number of detectors, and sample environment systems used in the experiment. The quality is enhanced also by their sophistication, heightened requirements for accuracy and operation speed of data acquisition equipment, necessity to provide remote control over spectrometer subsystems and the experiment. The user policy carried out at the IBR-2 spectrometers imposes additional requirements for the equipment of the spectrometers, control systems, and data acquisition systems, which should be easy to master and easy to use, should have convenient graphic interface and provide access to measurement results via the Internet.

The development of the concept of the new advanced neutron source at JINR is an important task, the successful solution of which is of key importance for the continuation of the neutron research program after the expiration of the IBR-2 service life. As part of this task, work on the development and construction of the new pulsed fast neutron reactor was included in the Seven-Year Plan for the Development of JINR for 2017-2023 and will be continued in the current seven-year period. The main stages of developing the concept of the new source include: development of a preliminary scientific program and determination of the composition of the suite of scientific instruments for conducting neutron research, development of technical specifications for the draft and infrastructure projects, justification of the design of the new neutron source, and the implementation of the research and development program. Work on the reactor design also includes computational and experimental research into the dynamics of pulsed reactors, optimization of the design of the main reactor systems, development of fuel and fuel elements based on it, optimization of the configuration of the complex of moderators, and development of prototypes or special test stands.

Projects and Subprojects:

	Name of the project / subproject	Project / subproject leader	Project / subproject code
1.	Development of the IBR-2 nuclear facility with a complex of cryogenic moderators	A.V. Vinogradov A.V. Dolgikh	04-4-1149-1-2011/2028
1.1.	Construction of a complex of cryogenic moderators at the IBR-2 facility	A.A. Belyakov M.V. Bulavin	04-4-1149-1-1-2014/2025
2.	Investigations of functional materials and nanosystems using neutron scattering	D.P. Kozlenko V.L. Aksenov A.M. Balagurov	04-4-1149-2-2021/2028
2.1.	Study of structure and dynamics of functional materials and nanosystems at the IBR-2 spectrometer complex	D.P. Kozlenko *Deputies:* M.V. Avdeev G.D. Bokuchava	04-4-1149-2-1-2024/2028
2.2.	Development of an inelastic neutron scattering spectrometer in inverse geometry	D.M. Chudoba	04-4-1149-2-2-2021/2028

	BJN (Bajorek-Janik-Natkaniec) at the IBR 2 reactor		
3.	Scientific and methodological research and developments for condensed matter investigations with IBR-2 neutron beams	V.I. Bodnarchuk V.I. Prikhodko	04-4-1149-3-2021/2028
3.1.	Construction of a wide-aperture backscattering detector (BSD-A) for the HRFD diffractometer	V.M. Milkov	04-4-1149-3-1-2021/2028
3.2.	Vector magnet for investigations with polarized neutrons	A.N. Chernikov	04-4-1149-3-2-2024/2028
3.3.	Design and development of infrastructure elements for spectrometers at the IBR-2 reactor	V.I. Bodnarchuk V.I. Prikhodko M.V. Bulavin	04-4-1149-3-3-2024/2028
4.	New advanced neutron source at JINR	E.V. Lychagin V.N. Shvetsov M.V. Bulavin	04-4-1149-4-2021/2028
4.1.	Research and development for the justification of the draft design of the new advanced neutron source at JINR – NEPTUN pulsed fast reactor	E.V. Lychagin V.N. Shvetsov M.V. Bulavin	04-4-1149-4-1-2024/2028

Projects/Subprojects:

	Name of the project	**Project leaders**	**Status**
Laboratory	Responsible from laboratories		
1.	**Development of the IBR-2 nuclear facility with a complex of cryogenic moderators**	**A.V. Vinogradov** **A.V. Dolgikh**	Realization

FLNP A.A. Belyakov, D.Yu. Denisenko, V.A. Krivov, Yu.N. Pepelyshev, Yu.M. Slotvitsky, 60 engineers, 65 workers

Brief annotation and scientific rationale:
The main objective of the theme is to ensure the operational reliability and safety of the reactor, to provide for the maximum possible service life of the reactor and its uninterrupted operation, as well as to increase the efficiency of using the IBR-2 research nuclear facility during the implementation of the experimental research program.

Regular operation of the IBR-2 research nuclear facility is carried out in accordance with the Rostekhnadzor license with an average power of up to 2 MW to provide neutron beams for conducting physics experiments. The IBR-2 facility is equipped with modern safety control systems, systems of analysis and diagnostics of the reactor state, systems for radiation monitoring and control of radiation situation.

Expected results upon completion of the project:
After completion of work on the subproject, JINR will continue to operate a world-class high-flux neutron source for research in the field of condensed matter physics and nuclear physics — the IBR-2 research nuclear facility of advanced safety and reliability. The suite of equipment of the IBR-2 will comprise:

– cryogenic moderators that ensure the implementation of a cutting-edge and competitive program of physics research;

– advanced equipment for safety-related systems of the IBR-2.

Reserve movable reflector MR-3R, which will be fully prepared for operation to ensure guaranteed functioning of the IBR-2 nuclear facility.

Expected results of the project in the current year:
Check assembly, adjustment and trials of the MR-3R reserve movable reflector at the FLNP test stand.

Phased replacement and upgrading of the IBR-2 basic technological and electrical equipment, which is important for the safe operation of the IBR-2 nuclear facility.

In cooperation with the Rosatom State Corporation, working out and consideration of the possibility of manufacturing and supplying an additional batch of fresh fuel for the IBR-2 core in order to extend the service life of the reactor for physics experiments until 2040-2042.

Name of the subproject		Status
1.1. Construction of a complex of cryogenic moderators	**A.A. Belyakov** **M.V. Bulavin**	Realization
FLNP	A.V. Dolgikh, 16 engineers, 40 workers	

Brief annotation and scientific rationale:
In the framework of the theme "Development of the IBR-2 Facility with a Complex of Cryogenic Neutron Moderators", phased realization of the project "Construction of a complex of cryogenic moderators at the IBR-2 facility" continues. The unique complex of cryogenic moderators being constructed (using a mixture of aromatic hydrocarbons of mesitylene and metaxylene in a ratio of 3 to 1, in a solid frozen phase, in the form of beads with a diameter of 3.5-3.9 mm) makes it possible to significantly increase the cold neutron flux for experimental condensed matter research.

The complex of cryogenic moderators includes three moderators surrounding the reactor core. Cold neutrons for physics experiments are produced with the CM-202 cryogenic neutron moderator (in the direction of neutron beamlines № 7, 8, 10, 11) and the CM-201 cryogenic moderator (in the direction of beamlines № 1, 4, 5, 6, 9). These moderators are currently operating in trial operation mode. The CM-203 neutron moderator is at the stage of development of the technical design specification.

The operation of the complex of cryogenic moderators at the IBR-2 nuclear facility greatly increases the intensity of cold neutrons compared to the thermal moderator and can significantly shorten the time of experiments and improve the accuracy of the data obtained.

Expected results upon completion of the subproject:
Operation of the complex of cryogenic moderators at the IBR-2 nuclear facility, comprising three moderators CM-201, CM-202, covering most of the neutron experimental beamlines of the IBR-2 facility. Reliable and trouble-free operation of the complex will allow maintaining and strengthening the leading position of the IBR-2 reactor among the world's most high-intensity research neutron sources used for condensed matter investigations by neutron scattering methods.

Expected results of the subproject in the current year:
Continuation of work on the optimization of the system of automatic control and regulation of parameters, system of charging/discharging and transportation of the moderator material (frozen mesitylene pellets) in the working chambers and pipelines of the cryogenic complex with the simultaneous use of two cryogenic moderators CM-201 and CM-202 for physics experiments.

In order to ensure the most efficient use of the suite of IBR-2 instruments in working with cold neutrons, it is planned to put into operation the second Linde AG cryogenic refrigerator with a cooling power of 1800 W at 10 K (KGU 1800/10). Until the end of 2025, it is planned to carry out the optimization of the operation of the cryogenic complex, develop requirements specification and project documentation for the moderator for beamlines 2 and 3.

Collaboration

Country or International Organization	City	Institute
Azerbaijan	Baku	IRP ANAS
		NNRC
Belarus	Minsk	JIPNR-Sosny NASB
Mongolia	Ulaanbaatar	IPT MAS
Romania	Bucharest	IFIN-HH
Russia	Moscow	INEUM
		NIKIET
		SSDI
		SYSTEMATOM
		VNIINM

Name of the project	Project leaders	Status
2. Investigations of functional materials and nanosystems using neutron scattering	**D.P. Kozlenko** **V.L. Aksenov** **A.M. Balagurov**	Realization
FLNP, LIT, BLTP, VBLHEP, FLNR	see subproject participants	

Within the framework of the project, it is planned to study the structural features, magnetic ordering, dynamics, physicochemical properties of new promising materials and nanosystems that demonstrate important functional properties, the microscopic mechanisms of which are poorly understood. The list of objects of study includes multiferroic materials, alloys with giant magnetostriction and shape memory effects, low-dimensional and geometrically frustrated magnets exhibiting unusual magnetic states and properties, materials promising for use in compact electric current sources, magnetic layered nanostructures demonstrating various proximity effects, for example, the coexistence of superconducting and magnetically ordered states, organic functional materials with hydrogen bonds, complex fluids and polymers with a wide range of potential technological applications, the structural organization and properties of which can change significantly with changes in concentration and chemical composition, biological nanosystems, including lipid membranes, proteins and their complexes, the study of which makes it possible to understand the biophysical processes occurring in living organisms, the mechanisms of action and transfer of drugs, the causes of various diseases, biohybrid materials, structural materials that are widely used or planned to be used in various industrial and manufacturing sectors. In addition, it is planned to conduct applied studies of texture, residual stresses and internal organization of rocks and minerals, structural materials, objects of natural and cultural heritage, aimed at establishing mechanisms of geophysical processes, formation of defects and stressed areas in industrial products, reconstruction and analysis of ancient technologies, evolution and development of classification of fossil organisms.

Expected results upon completion of the project:
In the process of realization of the scientific program, new experimental results will be obtained in the study of the relationship between the structural features and dynamics of new functional materials and nanosystems and their physical properties at the microscopic level, which are of great importance for the development of modern concepts in the field of condensed matter physics, chemistry, materials science, biophysics, geophysics and the development of advanced technologies in the field of electronics, compact power sources, pharmacology and medicine. During the implementation of the scientific program, theoretical predictions and models will be experimentally tested, and new phenomena and regularities will be revealed.

The implementation of the methodological program will result in the modernization of the available spectrometers and the development and construction of new instruments at IBR-2, which will expand the scope of their application for interdisciplinary scientific research of new functional materials and nanosystems.

Development and construction of basic elements of the BJN spectrometer will be performed.

Expected results of the project in the current year:

Realization of scientific program

Determination of characteristics of the atomic structure and phase states of magnetostrictive alloys, shape memory alloys and other intermetallic functional materials.

Determination of parameters of the atomic and magnetic structure of low-dimensional magnetic materials in a wide range of thermodynamic parameters (temperature, pressure).

Analysis of high-pressure effects on the structural and magnetic properties of functional materials.

Analysis of complex structural and microstructural states of solid electrolytes and electrodes for metal-ionic accumulators.

Determination of the crystal structure and analysis of the dynamics of functional materials with molecular complexes and ionic liquids.

Establishing of phenomena and effects, related to coexistence of magnetism and superconductivity in layered nanostructures composed of transition, rare-earth and other metals.

Determination of structural characteristics of carbon nanomaterials, single wall carbon nanotubes on substrates.

Determination of structural characteristics and aggregation kinetics in fullerene solutions with different polarity, and in fullerene solutions with various amino adducts.

Analysis of structural properties of magnetic nanosystems, including colloids, composites with magnetic nanoparticles, aggregation effects in magnetic fluids and core-shell nanostructures.

Determination of structural characteristics of polymer systems on substrates, surfactant micelles in bulk and on the surface, surfactant-micelle complexes.

Analysis of structural organization of polymer nanomaterials, glass transition of polymers and polymer thin films.

Analysis of physical and biological properties of lipid and native membranes, protein interactions, structure and properties of protein and membrane-protein complexes, crystallization of proteins.

Determination of structural characteristics and study of properties of biohybrid complexes.

Determination of residual stresses and microstrains in constructional materials and bulk products, geological objects.

Texture analysis of biological and paleontological objects, construction materials and earth rocks.

Analysis of internal organization and construction of 3D models of cultural and natural heritage objects, industrial materials and products using neutron radiography and tomography.

Realization of instrument development program for the IBR-2 spectrometers

Installation of elements of the neutron guide system of the small-angle scattering and imaging spectrometer on beamline 10.

Development of the detector system for the new DN-6 diffractometer for studies of microsamples, aimed at improving its technical parameters and expanding the available range of high pressures.

Improvement of technical parameters and expansion of experimental capabilities of the GRAINS multifunctional reflectometer (development of liquid cells for experiments).

Modernization of the available IBR-2 spectrometers aimed at improving their technical characteristics, replacing obsolete and failed units.

Upgrade of the FSS correlation spectrometer on beamline 13 and improvement of its technical parameters. Further development of the RTOF correlation method.

Purchase and testing of pyrolytic graphite crystals to develop a focusing analyzer of the BJN spectrometer, assembly of a model prototype of the analyzer and test measurements with prototype at the IBR-2 reactor.

Name of the subproject		
2.1. Study of structure and dynamics of functional materials and nanosystems at the IBR-2 spectrometer complex	**D.P. Kozlenko** *Deputies:* **M.V. Avdeev** **G.D. Bokuchava**	Realization

FLNP	M.V. Avdeev, G.D. Bokuchava, D.M. Chudoba, S.E. Kichanov, A.I. Kuklin, V.A. Turchenko
LIT	A.G. Soloviev, E.V. Zemlyanaya
BLTP	V.Yu. Yushankhai
VBLHEP	S.I. Tyutyunnikov, M.Yu. Barabanov
FLNR	P.Yu. Apel, V.A. Skuratov

Brief annotation and scientific rationale:

The subproject is aimed at studying the features of the structure, magnetic ordering, dynamics, physical and chemical properties of novel promising functional and structural materials, complex liquids and polymers, nanosystems, geophysical objects. The explanation of microscopic mechanisms of the formation of their properties is important both for the development of modern concepts in the field of condensed matter physics, materials science, biophysics, chemistry, geophysics, pharmacology, engineering sciences, and new technological applications in energy production, electronics, biology and medicine.

Neutron methods for studying matter (diffraction, small-angle scattering, reflectometry, inelastic scattering, radiography and tomography) provide detailed information about the atomic and magnetic structure and dynamics of materials at the atomic and nanoscale levels. Due to the peculiarities of the interaction of slow neutrons with matter, neutron scattering methods are highly effective in determining the positions of light atoms surrounded by heavy ones, studying the distribution of elements with close atomic numbers, studying isotopic substitution processes and magnetic structures. This provides great advantages when using neutron scattering methods in the study of a wide range of promising functional materials and nanosystems compared to other approaches.

To ensure the solution of the scientific tasks of the project, it is planned to carry out work to ensure the uninterrupted operation, modernization and reconstruction of the existing spectrometers of the IBR-2 reactor, as well as to complete the work on the creation of a new small-angle scattering and imaging spectrometer. Along with neutron methods, complementary methods of X-ray scattering, Raman, atomic force spectroscopy, etc. with the application of additional laboratory equipment, will be used to improve the efficiency of solving the tasks.

Expected results upon completion of the subproject:

The realization of the scientific program is expected to result in obtaining new experimental information, which will be of importance for studying the relationship between the structural features and dynamics of new functional materials and nanosystems and their physical properties at the microscopic level, as well as for developing modern concepts in the field of condensed matter physics, chemistry, materials science, biophysics and geophysics. The obtained results can later be used to

develop scientific foundations for the development of advanced technologies in the field of electronics, compact current sources, pharmacology and medicine. During the implementation of the scientific program, theoretical predictions and models will be experimentally tested, and new phenomena and regularities will be revealed.

The implementation of the methodological program will result in the modernization of the available spectrometers and the development and construction of new instruments at IBR-2, which will expand the scope of their application for interdisciplinary scientific research of new functional materials and nanosystems.

Expected results of the subproject in the current year:

Realization of scientific program

Determination of the structural parameters and phase composition of magnetostriction alloys, shape memory alloys and other intermetallic functional materials.

Determination of parameters of the atomic and magnetic structure of low-dimensional magnetic materials in a wide range of thermodynamic parameters (temperature, pressure).

Analysis of high-pressure effects on the structural and magnetic properties of functional materials.

Analysis of complex structural and microstructural states of solid electrolytes and electrodes for metal-ionic accumulators.

Determination of the crystal structure and analysis of the dynamics of functional materials with molecular complexes and ionic liquids.

Establishing of phenomena and effects, related to coexistence of magnetism and superconductivity in layered nanostructures composed of transition, rare-earth and other metals.

Determination of structural characteristics of carbon nanomaterials, single wall carbon nanotubes on substrates.

Determination of structural characteristics and aggregation kinetics in fullerene solutions with different polarity, and in fullerene solutions with various amino adducts.

Analysis of structural properties of magnetic nanosystems, including colloids, composites with magnetic nanoparticles, aggregation effects in magnetic fluids and core-shell nanostructures.

Determination of structural characteristics of polymer systems on substrates, surfactant micelles in bulk and on the surface, surfactant-micelle complexes.

Analysis of structural organization of polymer nanomaterials, glass transition of polymers and polymer thin films.

Analysis of physical and biological properties of lipid and native membranes, protein interactions, structure and properties of protein and membrane-protein complexes, crystallization of proteins.

Determination of structural characteristics and study of properties of biohybrid complexes.

Determination of residual stresses and microstrains in constructional materials and bulk products, geological objects.

Texture analysis of biological and paleontological objects, construction materials and earth rocks.

Analysis of internal organization and construction of 3D models of cultural and natural heritage objects, industrial materials and products using neutron radiography and tomography.

Realization of instrument development program for the IBR-2 spectrometers

Installation of elements of the neutron guide system of the small-angle scattering and imaging spectrometer on beamline 10.

Development of the detector system for the new DN-6 diffractometer for studies of microsamples, aimed at improving its technical parameters and expanding the available range of high pressures.

Improvement of technical parameters and expansion of experimental capabilities of the GRAINS multifunctional reflectometer (development of liquid cells for experiments).

Modernization of the available IBR-2 spectrometers aimed at improving their technical characteristics, replacing obsolete and failed units.

Upgrade of the FSS correlation spectrometer on beamline 13 and improvement of its technical parameters. Further development of the RTOF correlation method.

Name of the subproject

2.2. Development of an inelastic neutron scattering spectrometer in inverse geometry BJN (Bajorek-Janik-Natkaniec) at the IBR 2 reactor **D.M. Chudoba**

Realization

FLNP A.B. Eresko, E.A. Goremychkin, A.A. Kruglov

Brief annotation and scientific rationale:
An analysis of the state of research in the field of condensed matter dynamics using inelastic neutron scattering (INS) at FLNP has shown that the existing NERA inelastic neutron scattering spectrometer, which some time ago successfully competed with similar facilities in European neutron centers, is now significantly outdated and no longer meets the needs of the user community in the Eastern European region. Therefore, an extremely important task is to upgrade the INS spectrometer in the historically established research area in order to maintain the competitive position of the FLNP JINR in the field of neutron spectroscopy among other world neutron centers.

A promising approach is the creation of a new high-luminosity INS spectrometer that will use modern neutron optics and new design solutions to obtain high-resolution results with a good signal-to-background ratio over a wide range of energy transfer and using the smallest possible mass of the sample under study. This approach is proposed to be used to develop and construct a universal inverse geometry INS spectrometer BJN (**B**ajorek-**J**anik-**N**atkaniec). The combination of the high flux of the IBR-2 pulsed neutron source, modern focusing neutron optics, energy analyzers with a very large surface (two analyzers with an area of ~3.3 m^2) will ensure the maximum possible luminosity of the spectrometer being developed, while the gain factor compared to the NERA spectrometer can be up to a factor of 400.

The main range of scientific problems for which the BJN spectrometer will be used, includes:
– investigations of structural phase transitions at the microscopic level;

– study of proton diffusion processes in systems with different types of hydrogen bonds;

– study of the dynamics of protons in molecular crystals in a wide energy-transfer range;

– investigations of associative interactions of chemical particles, including systems with the formation of hydrogen bonds of various types;

– investigations of magnetic dynamics in compounds with 4*f* and 3*d* transition metals.

List of research objects:

– molecular crystals and their phase derivatives;

– pharmaceutical preparations in the bulk form and in the form of "micronized" or "amorphous" powders;

– new biologically active compounds, including nanostructured ones;

– energy storage materials;

– intermetallic compounds of 4*f* and 3*d* transition metals;

– catalysts;

– photonic materials for industrial applications;

– nanocomposite materials.

Expected results upon completion of the subproject:
Development and construction of basic elements of the BJN spectrometer.

Expected results of the subproject in the current year:
Purchase of pyrolytic graphite crystals to develop a focusing analyzer.

Assembly of a model prototype of the focusing analyzer of the BJN spectrometer.

Test measurements with the model prototype of the focusing analyzer of the BJN spectrometer at the IBR-2 reactor.

Collaboration

Country or International Organization	City	Institute
Armenia	Yerevan	Foundation ANSL
		SRCHCH
Azerbaijan	Baku	AzTU
		IP ANAS
Belarus	Minsk	JIPNR-Sosny NASB
		RI PCP BSU
Bulgaria	Sofia	IE BAS
		IEES BAS
		INRNE BAS
		ISSP BAS
		UCTM
China	Harbin	HEU
Cuba	Havana	InSTEC
Czech Republic	Prague	BC CAS
		CTU
		CU
		IG CAS
		IP CAS
Egypt	Alexandria	Univ.
	Cairo	ASU
		EAEA
	Giza	CU
France	Grenoble	IBS
		ILL
	Saclay	LLB
Germany	Darmstadt	TU Darmstadt
Hungary	Budapest	HUN-REN
		Wigner RCP
India	Patna	NIT Patna
Italy	Messina	UniMe
Japan	Minato	Keio Univ.
	Tokyo	Waseda Univ.
Kazakhstan	Almaty	INP
		KazNU
Latvia	Riga	ISSP UL
Mongolia	Ulaanbaatar	IPT MAS
Poland	Bialystok	UwB
Romania	Baia Mare	TUCN-NUCBM
	Bucharest	INCDIE ICPE-CA
		UB
	Cluj-Napoca	INCDTIM
		RA BC-N
		UBB
	Constanta	MINAC
	Craiova	UC
	Iasi	IULS
		NIRDTP
		TUIASI
		UAI
		UAIC
	Magurele	NIMP
	Pitesti	UPIT
	Targoviste	VUT

	Timisoara	ICT
		ISIM
		UVT
	Tulcea	DDNI
Russia	Chelyabinsk	SUSU
	Chernogolovka	ISSP RAS
	Dolgoprudny	MIPT
	Dubna	Dubna State Univ.
	Gatchina	NRC KI PNPI
	Kaliningrad	IKBFU
	Kazan	FRC KazSC RAS
		KFU
	Krasnoyarsk	FRC KSC SB RAS
		KIP SB RAS
		SibFU
	Moscow	IA RAS
		IC RAS
		ICP RAS
		IEPT RAS
		IGEM RAS
		IGIC RAS
		IMET RAS
		INMI RAS
		Inst. Immunology
		IPE RAS
		MIET
		MISIS
		MSU
		NNRU "MEPhI"
		NRC KI
		PIN RAS
		SINP MSU
	Moscow, Troitsk	HPPI RAS
		INR RAS
	Nizhny Novgorod	IPM RAS
		UNN
	Omsk	OSTU
	Perm	ICMM UrB RAS
		ITCh UrB RAS
	Rostov-on-Don	RIP SFU
		SFedU
	Saint Petersburg	CRISM "Prometey"
		IMC RAS
		Ioffe Institute
	Stavropol	NCFU
	Sterlitamak	SB BSU
	Tomsk	TPU
	Tula	TSU
	Tyumen	UTMN
	Yekaterinburg	IMP UB RAS
		UrFU
Serbia	Belgrade	INS "VINCA"
	Novi Sad	UNS
Slovakia	Kosice	IEP SAS
South Africa	Pretoria	Necsa

		UP
Spain	Barcelona	ICMAB-CSIC
	Leioa	BCMaterials
	Madrid	CENIM-CSIC
Switzerland	Villigen	PSI
Tajikistan	Dushanbe	NAST
		PHTI NAST
		TTU
USA	Berkeley, CA	UC
Uzbekistan	Tashkent	INP AS RUz
Vietnam	Da Nang	DTU
	Hanoi	IOP VAST

Name of the project	Project leaders	Status
3. Scientific and methodological research and developments for condensed matter investigations with IBR-2 neutron beams	**V.I. Bodnarchuk** **V.I. Prikhodko**	Realization

FLNP — see subprojects participants

Brief annotation and scientific rationale:
The conduction of condensed matter investigations at a state-of-the-art level is characterized by continuous improvement of experimental techniques, increase in the number of controlled parameters as well as in the number of detectors and sample environment systems used in the experiment and their sophistication, heightened requirements for accuracy and operation speed of data acquisition equipment, necessity to provide remote control over spectrometer subsystems and the experiment as a whole, and requires constant development of both the spectrometers and IBR-2 research nuclear facility, including in particular, the complex of cold moderators. The user policy carried out at the IBR-2 spectrometers imposes additional requirements for the equipment of the spectrometers, control systems, and data acquisition systems, which should be easy to master and easy to use, should have convenient graphic interface and provide access to measurement results via the Internet, etc.

Expected results upon completion of the project:
Commissioning of BSD-A detector at HRFD on beamline 5 of the IBR-2 reactor and obtaining the first experimental results.

Development of a vector magnet based on asymmetric Helmholtz coils, with a temperature control device for low (1.5 K) and ultra-low (down to 0.5 K) temperatures for the REMUR reflectometer.

Development of technical documentation for the equipment of control systems of the complex of cryogenic moderators of the IBR-2 reactor; commissioning of control systems for the collector unit and cooling pipelines, and cryogenic moderators CM-201, CM-202 and CM-203; installation of a dispatching system with a server that integrates control over the entire complex of cryogenic moderators, commissioning of the dispatching system.

Installation of a new chopper on beamline 8 of the IBR-2 reactor.

Introduction of automatic PLC-based control systems to control the vacuum integrity in the channels.

Development and manufacture of PSC with a cathode of different diameters.

Development of a test stand to test the characteristics of PSD.

Optimization of data acquisition system based on multichannel digitizers.

Development of a standard module of a PSD system based on resistive-wire tubes with a cathode diameter of 6 mm.

Development and commissioning of a new detector system for the REMUR spectrometer.

Development and fabrication of direct-beam monitor at the YuMO spectrometer.

Development of the architecture of a multi-gap ^{10}B-PPRC, manufacture of the prototype and study of its characteristics.

Development of a multi-counter system for the inelastic scattering instrument being designed on beamline 2 of IBR-2.

Adjustment and testing of the ASTRA-M detector at the FSD spectrometer.

Development of a technical design for the BSD-FSD backscattering detector for the FSD spectrometer.

Development of a new ±90°-detector with combined electronic and time focusing, similar to the ASTRA-M detector on the FSD spectrometer.

Development of detector electronics and data acquisition, pre-processing and accumulation systems for new detector systems. Introduction of multichannel digitizers into the measuring systems of IBR-2 spectrometers.

Introduction of PLCs into control systems of spectrometers. Equipping spectrometers with video surveillance systems. Introduction of new measuring devices and controllers at the request of instrument responsible persons. Automation of the vacuum control system on spectrometers NERA, SKAT, FSD, FSS. Automation of the control system of the magnet current source for the DN-12 cryostat. Unification of temperature control and regulation systems used on IBR-2 spectrometers.

Development of a new cryostat for cooling high-pressure chambers at the DN-12 diffractometer.

Development and implementation on the IBR-2 spectrometers of a new version of the Sonix+ software package and related systems adapted to work with the event list data format.

Continuous modernization (in cooperation with LIT) of the FLNP local area network segment.

Simulation of spectrometers or its elements for the purpose of modernization of operating spectrometers and for the development of the new one.

Commissioning of an automated storage of containers with irradiated samples and an automated sample positioning system at the irradiation facility.

Providing of uninterrupted operation of all spectrometers on IBR-2 beamlines.

Expected results of the project in the current year:
Commissioning of BSD-A detector at HRFD on beamline 5 of the IBR-2 reactor and obtaining the first experimental results.

Development and manufacture of PSC with a cathode of different diameters.

Development of a standard module of a PSD system based on resistive-wire tubes with a cathode diameter of 6 mm.

Development of a test stand to test the characteristics of PSD.

Development and fabrication of direct-beam monitor at the YuMO spectrometer.

Development of a multi-counter system for the inelastic scattering instrument being designed on beamline 2 of IBR-2.

Installation and commissioning of an industrial control system for the CM-201 cryogenic moderator in the direction of IBR-2 beamlines 1, 4, 5, 6, 9. Development of a control system for the CM-202 moderator in the direction of IBR-2 beamlines 7, 8, 10, 11.

Adjustment and testing of the ASTRA-M detector at the FSD spectrometer.

Development of a new ±90°-detector with combined electronic and time focusing, similar to the ASTRA-M detector on the FSD spectrometer.

Development of a project of a detecting module and data acquisition system for the multi-detector system of the DN-12 spectrometer; testing of elements of the data acquisition system on a neutron beam.

Development of infrastructure for constructing neutron detectors.

Introduction of digitizers into the measuring systems of IBR-2 spectrometers (FSD, FSS and HRFD).

Assembly of a cryostat of the REMUR reflectometer.

Assembly of a test cryostat for studying current leads and magnet coils.

Production of sections of HTSC tape necessary for winding magnet coils by soldering its pieces.

Development of a system for high-precision movement of facility equipment towards the IBR-2 reactor; manufacturing of an automated storage facility for radioactive samples in accordance with the developed design documentation. Study of radiation resistance of materials at the radiation research facility of the IBR-2 reactor.

Development and implementation on the IBR-2 spectrometers of a new version of the Sonix+ software package and related systems adapted to work with the event list data format.

Development of the Sonix+ software package for connecting new systems, DAQ controllers and sample environment devices according to user requests.

Ongoing and timely support of the FLNP local area network segment and its modernization in accordance with LIT plans, as well as maintenance of the FLNP Central Computing Complex.

Name of the subproject

3.1. Construction of a wide-aperture backscattering detector (BSD-A) for the HRFD diffractometer — **V.M. Milkov** — Realization

FLNP A.M. Balagurov, A.A. Bogdzel, N.N. Bogobmolova, O.N. Bogomolova, O. Daulbaev, V.A. Drozdov, Hai Van, P.A. Kislitsyn, A.A. Kozlyakovskaya, A.K. Kurilkin E.I. Litvinenko, G.E. Malkova, S.M. Murashkevich, M.M. Podlesny, A.V. Semechkin, V.V. Shvetsov, O.V. Volodin

Brief annotation and scientific rationale:
At present, the HRFD detector system consists of three detectors, two of which are located at scattering angles of ±152°, and the third one at 90°. The first two detectors are mainly used to study the structure of polycrystals, and the third one is employed to measure internal stresses. The detecting element is Li-glass-based scintillators. From the present-day viewpoint, these detectors have two disadvantages: high sensitivity to γ-background and insufficiently large solid angle (~0.16 sr). Due to this, the resulting diffraction spectra have a rather high background and a low (by modern criteria) data acquisition rate, despite the fact that the neutron flux at the sample position is sufficiently high (10^7n/cm^2/s).

To eliminate these shortcomings, in 2017 it was proposed to replace the existing backscattering detectors shown in Fig. 1 with a new wide-aperture scintillation detector based on the ZnS(Ag)/^{6}LiF scintillator using combined electronic-geometric focusing. Its implementation will make it possible to radically improve the parameters of the HRFD diffractometer and bring it to the leading positions in the world. Estimates show that the use of the new wide-aperture detector will allow an approximately two- to three-fold increase in the number of experiments, along with a significant improvement in the accuracy of the obtained structural information, and the expansion of the capabilities of the diffractometer for performing experiments under various external conditions at the sample position.

Expected results upon completion of the subproject:
Commissioning of BSD-A detector at HRFD on beamline 5 of the IBR-2 reactor and obtaining the first experimental results.

Expected results of the subproject in the current year:
Commissioning of BSD-A detector at HRFD on beamline 5 of the IBR-2 reactor and obtaining the first experimental results.

Name of the subproject

3.2. Vector magnet for investigations with polarized neutrons — **A.N. Chernikov** — Realization

FLNP A.V. Altynov, V.I. Bodnarchuk, A.P. Buzdavin, F.A. Chervyakov, U.D. Lusina, I.A. Morkovnikov., T.B. Petukhova, V.V. Sadilov, N.D. Zernin, V.D. Zhaketov

Brief annotation and scientific rationale:
Reflectometry of polarized neutrons is an experimental method for studying low-dimensional metal heterostructures, polymer films, biological systems, the free surface of liquids, magnetic fluids, and requires experimental equipment that includes a special magnetic system. The developed magnetic system—a vector magnet—will allow changing the direction of the magnetic field in two directions and will have an aperture that allows placing a temperature control device at low and ultra-low temperatures, as well as a neutron and gamma-ray detection system. The vector magnet will be installed on the REMUR reflectometer on beamline 8 of the IBR-2 reactor.

Expected results upon completion of the subproject:
Development of a vector magnet based on asymmetric Helmholtz coils, with a temperature control device for low (1.5 K) and ultra-low (down to 0.5 K) temperatures for the REMUR reflectometer.

Expected results of the subproject in the current year:
Assembly of a cryostat of the REMUR reflectometer.

Assembly of a test cryostat for studying current leads and magnet coils.

Production of sections of HTSC tape necessary for winding magnet coils by soldering its pieces.

Name of the subproject

3.3. Design and development of infrastructure elements for spectrometers at the IBR-2 reactor — **V.I. Bodnarchuk, V.I. Prikhodko, M.V. Bulavin** — Realization

FLNP Yu.A. Astakhov, V.V. Bulavina, A.V. Churakov, T.N. Dydyshko, A.A. Evseev, V.Yu. Egorov, O.V. Ermolaeva, A.I. Ioffe, I.V. Kovalev, A.G. Kolesnikov, T.V. Milkova, A.S. Ovodov, M.O. Petrova, G.A. Sukhomlinov, N.V. Shvetsov, V.K. Shirokov, E.Yu. Voskanyan, K.B. Yakovlev, V.V. Zhuravlev

Brief annotation and scientific rationale:
The IBR-2 reactor is a unique neutron source, which is used to study the structure and physical properties of condensed matter. Information about objects under study is obtained using specialized neutron scattering instruments (spectrometers) by applying various research techniques. The quality of the obtained information is largely determined by the characteristics of the neutron source and the quality of experimental equipment. The IBR-2 pulsed reactor is a high-flux neutron source with a power of over 1 MW. The key requirements for the equipment of scientific instruments are the most efficient use of the thermal neutron flux within the framework of the implemented methodology. The equipment of any spectrometer is quite diverse and includes elements that form a neutron beam, systems for detecting neutron and other types of radiation, various systems for monitoring and controlling experiments, special equipment for creating the required conditions at the sample position during measurements, etc. At the same time, all elements and mechanisms must perform their functions under conditions of increased radiation load and ensure uninterrupted operation for long periods of time. Each spectrometer is a unique object even within the framework of the implementation of one and the same technique at the same source. Despite the fact that the equipment of IBR-2 instruments includes a number of standard elements, their configuration is always unique and requires special attention.

This sub-subproject is aimed at fulfilling the tasks of designing and developing reliable and efficient elements of spectrometers for comprehensive support of experimental work and obtaining high-level scientific results.

The high qualification of the personnel of the Department of the IBR-2 spectrometers' complex (SC) and their extensive experience in the development and operation of equipment and control systems for the IBR-2 spectrometers will undoubtedly make it possible to implement this sub-subproject aimed at further improving the experimental infrastructure of the IBR-2 reactor. The sub-subproject consists of 7 sections, each representing a separate element of the experimental infrastructure.

Expected results upon completion of the subproject:
Development of technical documentation for the equipment of control systems of the complex of cryogenic moderators of the IBR-2 reactor; commissioning of control systems for the collector unit and cooling pipelines, and cryogenic moderators CM-201, CM-202 and CM-203; installation of a dispatching system with a server that integrates control over the entire complex of cryogenic moderators, commissioning of the dispatching system.

Installation of a new chopper on beamline 8 of the IBR-2 reactor.

Introduction of automatic PLC-based control systems to control the vacuum integrity in the channels.

Development and manufacture of PSC with a cathode of different diameters.

Development of a test stand to test the characteristics of PSD.

Optimization of data acquisition system based on multichannel digitizers.

Development of a standard module of a PSD system based on counters with resistive anodes and a cathode diameter of 6 mm.

Development and putting into operation of a new detector system for the REMUR spectrometer.

Development and fabrication of direct-beam monitor at the YuMO spectrometer.

Development of the architecture of a multi-gap ^{10}B-PPRC, manufacture of the prototype and study of its characteristics.

Development of a multi-counter system for the inelastic scattering instrument being designed on beamline 2 of IBR-2.

Adjustment and testing of the ASTRA-M detector at the FSD spectrometer.

Development of a technical design for the BSD-FSD backscattering detector for the FSD spectrometer.

Development of a new ±90°-detector with combined electronic and time focusing, similar to the ASTRA-M detector on the FSD spectrometer.

Introduction of multichannel digitizers into the measuring systems of IBR-2 spectrometers.

Introduction of PLCs into control systems of spectrometers. Equipping spectrometers with video surveillance systems. Introduction of new measuring devices and controllers at the request of instrument responsibles. Automation of the vacuum control system on spectrometers NERA, SKAT, FSD, FSS. Automation of the control system of the magnet current source for the DN-12 cryostat. Unification of temperature control and regulation systems used on IBR-2 spectrometers.

Development of a new cryostat for cooling high-pressure chambers at the DN-12 diffractometer.

Development and implementation on the IBR-2 spectrometers of a new version of the Sonix+ sotware package and related systems adapted to work with the event list data format.

Continuous modernization (in cooperation with LIT) of the FLNP local area network segment.

Simulation of spectrometers or its elements for the purpose of modernization of operating spectrometers and for the development of the new one.

Study of radiation resistance of materials at the radiation research facility of the IBR-2 reactor. Regular operation of a system for high-precision movement of facility equipment towards the IBR-2 reactor; manufacturing of an automated storage facility for radioactive samples in accordance with the developed design documentation.

Providing of uninterrupted operation of all spectrometers on IBR-2 beamlines.

Expected results of the subproject in the current year:
Installation and commissioning of an industrial control system for the CM-201 cryogenic moderator in the direction of IBR-2 beamlines 1, 4, 5, 6, 9. Development of a control system for the CM-202 moderator in the direction of IBR-2 beamlines 7, 8, 10, 11. Development of an automated high-performance device for the production of working material for the complex of IBR-2 cryogenic moderators.

Development and manufacture of PSC with a cathode of different diameters.

Development of a standard module of a PSD system based on counters with resistive anodes and a cathode diameter of 6 mm.

Development of a test stand to test the characteristics of PSD.

Development and fabrication of direct-beam monitor at the YuMO spectrometer.

Development of a multi-counter system for the inelastic scattering instrument being designed on beamline 2 of IBR-2.

Adjustment and testing of the ASTRA-M detector at the FSD spectrometer.

Development of a new ±90°-detector with combined electronic and time focusing, similar to the ASTRA-M detector on the FSD spectrometer.

Development of a project of a detecting module and data acquisition system for the multi-detector system of the DN-12 spectrometer; testing of elements of the data acquisition system on a neutron beam.

Introduction of multichannel digitizers into the measuring systems of IBR-2 spectrometers.

Development and implementation on the IBR-2 spectrometers of a new version of the Sonix+ sotware package and related systems adapted to work with the event list data format.

Support and development of the SONIX+ software on requests of responsibles, based on USB-3 adaptation of SONIX+ software for the operation with DAQ controllers. Development of the new version of SONIX+ software adjusted for the operation in the list mode.

Ongoing and timely support of the FLNP local area network segment and its modernization in accordance with LIT plans, as well as maintenance of the FLNP Central Computing Complex.

Study of radiation resistance of different materials at the radiation research facility. Development of a system for high-precision movement of the radiation research facility as part of a robotic system for handling radioactive samples with a visual and dose monitoring system; manufacturing of an automated storage facility for radioactive samples in accordance with the developed design documentation.

Putting into operation of new measuring devices and controllers at the request of instrument-responsible scientists.

Collaboration

Country or International Organization	**City**	**Institute**
Belarus	Minsk	INP BSU
Czech Republic	Husinec	UJV
Egypt	Cairo	EAEA
Hungary	Budapest	Wigner RCP
Kazakhstan	Almaty	INP
Romania	Bucharest	IFIN-HH
	Cluj-Napoca	INCDTIM
		UBB
		UTC-N
	Targoviste	VUT
Russia	Dolgoprudny	MIPT
	Dubna	Dubna State Univ.
	Gatchina	NRC KI PNPI
	Kazan	KFU
	Moscow	NRC KI

	Moscow, Troitsk	INR RAS
	Yekaterinburg	IMP UB RAS
Sweden	Lund	ESS ERIC
Uzbekistan	Tashkent	INP AS RUz

	Name of the project	Project leaders	Status
4.	**New advanced neutron source at JINR**	**E.V. Lychagin** **V.N. Shvetsov** **M.V. Bulavin**	Realization

FLNP see subproject participants

Brief annotation and scientific rationale:
Since 2016, the development of a project for a new advanced neutron source has been underway at FLNP JINR. Within the framework of the seven-year plan for the long-term development of JINR for 2024-2030, a list of works under the subproject for the development and construction of the new NEPTUN pulsed reactor has been defined. The concept of the NEPTUN pulsed fast reactor with neptunium nitride fuel was selected based on the results of work carried out in the previous seven-year period, and supported and approved at the 51st meeting of the PAC for CMR in January 2020 for further elaboration.

The main stages of work on the development and construction of the new NEPTUN reactor include: development of a preliminary scientific program and determination of the composition of a suite of scientific instruments for conducting neutron research, development of technical specifications for preliminary design and infrastructure projects, scientific and technical rationale for the design of the new neutron source, as well as the implementation of the research and development program, which includes the study of the dynamics of pulsed reactors, optimization of the design of the main reactor systems, development of neptunium-nitride fuel and neptunium-nitride-based fuel rods, optimization of the configuration of the complex of moderators, development of prototypes or special test stands (for example, an experimental test stand or a prototype of a reactivity modulator, a prototype of experimental fuel elements, test stand for a mesitylene-based cryogenic moderator with a system for fast change of the working material, etc.).

The work performed is a serious R&D groundwork laid down in the period from 2020 to 2023, requiring the continuation and development of the above stages to move from the concept development stage to the stage of the draft design of the new NEPTUN reactor.

At the same time, the results of recent (2021-2024) computational studies of non-stationary processes in the NEPTUN reactor and the practice of operating the IBR-2 and IBR-2M reactors have shown that the configuration of the core has a greater impact on the threshold of the reactor power stability than previously thought. In this regard, in 2025, within the framework of the current seven-year plan, it is planned to focus efforts on studying the mechanisms of the formation of power feedback of pulsed reactors, developing mathematical models that describe processes leading to pulse energy fluctuations, including those based on the experience of IBR-2 operation, performing calculations for the complex of moderators, developing the concept of the suite of research instruments, and conducting preparatory work on the certification and verification of software for performing calculations to justify the safety of pulsed research reactors.

Expected results upon completion of the project:
Development of the scientific program and the concept of the suite of instruments for conducting scientific and applied research at the new neutron source.

Model of dynamics of pulsed fast reactors.

Selection and justification of the maximum power of the NEPTUN reactor.

Analysis of options for using advanced nuclear fuel and fuel rods based on it for the new neutron source.

Selection of optimal materials for use as cryogenic moderators at the new neutron source.

Determination of the list of software for performing calculations to justify the safety of research pulsed reactors. Preparation for the procedure of justifying the choice of software (validation) for performing calculations of pulsed reactors.

Expected results of the project in the current year:
Formulation and justification of the relevance and prospects of the main areas of research on the new neutron source.

Development of a model of dynamics of pulsed fast neutron reactors using experimental data obtained during the operation of the IBR-2 reactor.

Analysis of options of using advanced nuclear fuel and fuel elements based on it for the new neutron source in cooperation with JSC VNIINM, Rosatom State Corporation.

Analysis of the efficiency of using hydrogen-containing materials (methane, triphenylmethane, liquid hydrogen, deuterium, etc.) as cryogenic moderators at the new neutron source and their comparison with mesitylene. Development of draft working design documentation for a chamber-simulator of a cryogenic mesitylene-based moderator with a system for fast change of working material. Development of facilities for the production of frozen pellets from hydrocarbons for cryogenic moderators.

Analysis of alternative concepts for the new neutron source.

Analysis of the scope of work on certification and verification of software for performing calculations to substantiate the safety of the pulsed reactor. Development of a scheme for verifying the software for the pulsed reactor.

Development of advanced industrial-level control electronics systems for cryogenic moderators of high-flux neutron sources.

	Name of the subproject		
4.1.	**Research and development for the justification of the draft design of the new advanced neutron source at JINR — NEPTUN pulsed fast reactor**	**E.V. Lychagin V.N. Shvetsov M.V. Bulavin**	Realization

FLNP M.V. Avdeev, A.M. Balagurov, V.I. Bodnarchuk, G.D. Bokuchava, K.V. Bulatov, O.E. Chepurchenko, D.M. ChudobaP.A. Dorofeev, V.V. Ermolaev, T.Yu. Fedorova, A.I. Frank, A.V. Galushko, E.A. Goremychkin, D.S. Grozdov, A.A. Khassan, K. Khramko, S.E. Kichanov, Yu.N. Kopach, D.P. Kozlenko, N. Kučerka, A.I. Kuklin, I.V. Kushnir, E.E. Perepelkin, M.M. Podlesnyy, M.V. Rzyanin, E.P. Shabalin, A.E. Verkhoglyadov, I. Zinicovscaia, 3 engineers, 3 researchers

VNIITF S.A. Andreev, D.V. Khmelnickii, 3 researchers

VNIINM A.V. Davydov, Yu.A. Ivanov, 7 engineers, 4 researchers

NIKIET A.B. Goryachikh, A.V. Lopatkin, I.T. Tretyakov, 4 engineers, 3 researchers

Brief annotation and scientific rationale:
In accordance with the roadmap of the NEPTUN project, the next major stage after the completion of the stages of preliminary design and development of a technical proposal is a draft design. A draft design is developed to determine the principal (constructive, schematic, etc.) solutions for the product, giving a general idea of the working principle and (or) the design of the product. On the basis of the draft design, a justification for investments is developed, which is an obligatory document in the development of such a complex facility as a research reactor (Decree of the Government of the Russian Federation №306 of 14.03.1997).

At the draft design stage, the development and selection of basic technical solutions, the study of structural and functional schemes of the product, the selection of basic structural elements, etc. are carried out. As a rule, at this stage, one or two variants of the reactor are considered from among those recognized as feasible at the conceptual design stage.

The choice of a specific core configuration option is the most important moment and the key point of the entire project of construction of the NEPTUN reactor. This is due to the fact that the technical solutions fixed in the draft design, further at the next stages (technical design, working design documentation), being included in the voluminous design documentation, can only be changed with great difficulty. Therefore, already before the draft design stage, a thorough study of all controversial and ambiguous points is required, as well as R&D and calculations (kinematic, electrical, thermal, etc.) that confirm the operability and reliability of the product in all specified operating conditions.

The main goal of the subproject is to conduct research and development work to justify the development of a draft design of the NEPTUN reactor. These R&D include: development of neptunium nitride fuel and neptunium-nitride-based fuel rods; study of dynamics of the pulsed reactor; optimization of the design of the reactivity modulator and the reactor vessel in terms of reducing thermal loads and shape changing; development and implementation of a list of R&D to justify the development of the draft design.

Expected results upon completion of the subproject:
Development of a computer model describing the phenomenon of vibrational instability of a pulsed reactor, including neutron-physical, thermohydraulic and thermomechanical calculation modules.

Determination of the reactor core configuration.

Search for technical solutions for the design of the vessel and reactivity modulator with permissible thermal loading and temperature deformations. Development of a list of R&D necessary to justify the design of the reactivity modulator, its components and the reactor vessel. Working design documentation for a full-scale test stand (model) of the reactivity modulator.

Justification of the maximum power of the NEPTUN reactor, taking into account the permissible fluctuations and temperature deformations of its components of the core, vessel and modulator.

Expected results of the subproject in the current year:
Development of a simplified computer model describing the phenomenon of vibrational instability of a pulsed reactor, including neutron-physical, thermohydraulic and thermomechanical calculation modules. Verification of the model on the basis of experimental data obtained during the operation of IBR-2.

Determination of the reactor core configuration.

Development of technical specifications for conducting R&D work to study the release of radiolytic hydrogen in titanium hydride under conditions of a real reactor experiment with close values of operating temperatures of the reactivity modulator of the NEPTUN reactor.

Development of advanced industrial-level control electronics systems for cryogenic moderators of the new high-flux neutron source on the basis of the complex of moderators of the IBR-2 reactor.

Collaboration

Country or International Organization	**City**	**Institute**
Argentina	Bariloche	CAB
Belarus	Minsk	BSTU
Czech Republic	Rez	NPI CAS
France	Grenoble	ILL
Germany	Berlin	HZB
	Julich	FZJ
Hungary	Budapest	Wigner RCP
IAEA	Vienna	IAEA
Romania	Bucharest	INCDIE ICPE-CA
Russia	Gatchina	NRC KI PNPI
	Moscow	NIKIET
		NRC KI
		VNIINM
	Moscow, Troitsk	INR RAS
	Obninsk	IPPE
	Snezhinsk	RFNC-VNIITF
South Africa	Pretoria	UP
Sweden	Lund	ESS ERIC
Uzbekistan	Tashkent	INP AS RUz

Theoretical Physics (01)

01-3-1135-2019

Fundamental Interactions of Fields and Particles

Theme leaders: D.I. Kazakov
O.V. Teryaev

Participating Countries and International organizations:
Belarus, Bulgaria, Canada, Chile, China, Croatia, Finland, France, Germany, Greece, Hungary, India, Iran, Italy, Poland, Portugal, Russia, Serbia, Slovakia, Spain, Sweden, United Kingdom, USA, Vietnam.

The problem under study and the main purpose of the research:
The main current problems of the modern theory of fundamental interactions are the development of methods of quantum field theory, their application to the description of elementary particle physics within the Standard Model and beyond, theoretical support for existing and planned experiments. Within the framework of the Standard Model, efforts will be focused on the development of multiloop computing methods and their applications to processes at the Large Hadron Collider, the development of new approaches to hadron physics, including heavy quark physics. In physics beyond the Standard Model, the search for Dark matter, manifestations of supersymmetry and other possible new physical phenomena are of particular interest. Theoretical support for the search for new physics in accelerator experiments will be combined with research and analysis of astrophysical data.

Developments in neutrino physics, including the field-theoretic description of neutrino oscillations and the processes of neutrino-nucleon interactions with nuclear matter, in particular in connection with the Baikal-GVD experiment, will remain under constant concern. Special attention will be paid to the theoretical support of the key elements of the JINR experimental program. By studying QCD methods, various approaches to the description of the structure of hadrons and quark-gluon matter under the specific conditions of the NICA complex will be developed and applied.

Projects in the theme:

	Name of the project	Project Leaders	Project code
1.	Quantum field theory and physics beyond the standard model	D.I. Kazakov A.V. Bednyakov	01-3-1135-1-2024/2028
2.	QCD and hadron structure	I.V. Anikin S.V. Mikhailov O.V. Teryaev	01-3-1135-2-2024/2028
3.	Phenomenology of strong interactions and precision physics	V.I. Korobov M.A. Ivanov	01-3-1135-3-2024/2028
4.	Theory of hadronic matter under extreme conditions	V.V. Braguta E.E. Kolomeitsev S.N. Nedelko	01-3-1135-4-2024/2028
5.	Theory of electroweak interactions and neutrino physics	A.B. Arbuzov V.A. Naumov	01-3-1135-5-2024/2028

Projects:

	Name of the project	Project Leaders
Laboratory	Responsible from laboratories	
1.	**Quantum Field Theory and physics beyond the Standard Model**	**D.I. Kazakov** **A.V. Bednyakov**

BLTP A.N. Baushev, A.T. Borlakov, Ch. R. Das, N.A. Gramotkov, V.A. Filippov, R.M. Iakhibbaev, A.V. Kotikov, G.A. Kozlov, A.I. Mukhaeva, A.V. Nesterenko, A.I. Onishchenko, M.V. Savina, O.P. Solovtsova, D.M. Tolkachev, D.A.Volkova

MLIT S.V. Shmatov

VBLHEP B.Yu. Alexakhin, B.G. Shaikhatdenov

Brief annotation and scientific rationale:
Quantum Field Theory (QFT) is a widely recognized "language" used to describe the properties of elementary particles and their interactions. It is well known that the triumph of the Standard Model (SM) of particle physics would have been impossible without comparing experimental data obtained from accelerators such as LEP (CERN), HERA (DESY), Tevatron (Fermilab), and LHC (CERN) with high-precision calculations performed using QFT methods. Many years have passed since the construction of the SM, and all these years scientists were searching for New Physics. The problem of dark matter in the Universe is an obvious argument for such searches. The main aim of the Project is to develop the quantum field formalism of gauge and supersymmetric theories, as well as to construct and study particle physics models beyond the Standard Model. In the context of the Project, it is planned to use existing experience and new ideas to investigate a wide range of problems related to high-precision calculations within and beyond perturbation theory as well as to the nature of possible New Physics. Special attention will also be paid to issues that arise at the intersection of particle physics, astrophysics, and cosmology.

Expected results upon completion of the project:
Improved estimate of the contribution from hadronic vacuum polarization to the anomalous magnetic moment of the muon.

Investigation of the shapes of higher twist contributions in deep inelastic scattering with the resummation of large threshold logarithms.

Calculation of two-loop diagrams that arise in non-relativistic QED using the effective mass method and investigation of the completeness of basis functions for elliptic polylogarithms.

Development of a new specialized computer package for the epsilon expansion of generalized hypergeometric functions with one or more variables, whose indices depend on the dimensional regularization parameter, as well as for the numerical calculation of the resulting functions.

Explicit analytical calculation of multi-point master integrals using differential equations.

Calculation of two-loop contributions to electron-muon scattering and quarkonia production.

Calculation of the double spectral density in the problem of sum rules for B-anti-B mixing, which is an important experimental quantity that imposes strict constraints on possible new physics.

Calculation of three-loop massive form factors and polarization operators in QCD.

Calculation of multi-loop amplitudes and form factors with a large number of kinematic invariants in theories with extended supersymmetry.

Derivation of systematic solutions to quantum spectral curve equations in the case of maximally supersymmetric Yang-Mills theory in four dimensions and ABJM theory in three dimensions, both in the weak and strong coupling limits.

Calculation of spectra, correlation functions, and amplitudes in a number of six-dimensional "fishnet" models.

Application of the large charge expansion method to gauge theories and analysis of the resulting implications in both particle physics and condensed matter theory.

Investigation of the scheme dependence of a previously proposed self-consistent subtraction procedure for non-renormalizable theories.

Calculation of effective potentials for a range of theories of modified gravity and their application to analyze various inflationary models.

Investigation of the theory and phenomenology of scalar and vector bosonic stars.

Detailed cosmological and astrophysical analysis of the properties of primary black holes and their connection to the dark matter problem and observable supermassive black holes.

Analysis of the prospects for experimental detection of additional Abelian gauge symmetries and an extended Higgs sector in a range of new physics models. Investigation of the so-called supersymmetric extensions of the Standard Model.

Physical analysis of LHC data aimed at detecting manifestations of the "dark sector" in events where either a Higgs boson or a Z boson is produced, accompanied by a significant fraction missing "transverse" energy (MET), presumably carried away by a messenger particle that ultimately decays into DM particles. The expected outcome is new anomalies in the experimental data (in the fortunate event – the discovery of New Physics), or, in the absence of such signals, new unique constraints on the model parameter space for the considered scenarios of dark matter and Higgs sector.

Development of new (using neural networks for global scanning) as well as optimization and improvement of existing software for modeling physical processes beyond the Standard Model.

Expected results of the project in the current year:
Detailed analysis of the properties of cosmological perturbations and their possible connection with the problem of rapid formation of supermassive black holes.

Theoretical study of the formation of galaxies and the velocity field of galaxies at the void center, comparison of the obtained results with observations.

Study of the diffuse supernova neutrino background (DSNB) within New Physics core-collapse models.

Phenomenological analysis of rare B-meson decays in New Physics 3-3-1 models with an extended gauge group.

Analysis of thermodynamics of scalar degrees of freedom in scalar boson stars within Higgs-like models with gravity.

Study of the hadronic vacuum polarization contributions to the muon anomalous magnetic moment at a new level of accuracy.

Derivation of an explicit form of electromagnetic corrections to the anomalous magnetic moments of leptons from diagrams with insertions of the polarization operator with five leptonic loops.

Multi-loop analysis of the asymptotically-safe quantum field model taking into account all possible scalar operators of dimension from two to four, investigation of the vacuum-stability constraint on model parameters.

Construction and study of large-charge expansion in a number of non-Abelian theories with global/local symmetries in strong and weak coupling regimes.

Calculation and analysis of the structure of multi-loop renormalization group equations for basis invariants of the scalar sector of a two higgs-doublet extension of the Standard Model.

Calculation of high-order corrections in a non-renormalizable model with 4 fermion interactions up to three-loop order. Derivation of recurrence relations and a generalized renormalization group equation. Numerical analysis of the latter and the study of the high-energy asymptotics of the solution.

Computation and study of the leading corrections to the effective potential in the Wess-Zumino model for the chiral potential of an arbitrary type.

Derivation and analysis of generalized renormalization group equations in scalar-tensor models of general type.

Analysis of the subtraction-scheme dependence of amplitudes and effective actions within non-renormalizable theories.

Development of a method for calculating universal anomalous dimensions of operators of various twists in the N=4 SYM and ABJM models using modular arithmetic.

Fitting of experimental data on deep inelastic scattering in schemes with effective resummation of large threshold logarithms.

Analysis of deep-inelastic-scattering sum rules in the framework of the analytical coupling at small values of the squared momentum transfer.

2. QCD and hadron structure — **I.V. Anikin, S.V. Mikhailov, O.V. Teryaev**

BLTP V.V. Bytiev, S.V. Goloskokov, R.V. Khakimov, N.V. Krasnikov, A.G. Oganesian, A.V. Pimikov, A.A. Pivovarov, G.Yu. Prokhorov, V.A. Saleev, A.A. Sazonov, O.V. Selyugin, D.A. Shohonov, A.Ya. Silenko, D. Strozik-Kotlorz, N.I. Volchanskiy, V.I. Zakharov, A.S. Zhevlakov

Brief annotation and scientific rationale:
Lacking a complete theoretical understanding of the color confinement, the only method of applying QCD is based on the factorization of the short-distance (perturbative) and long-distance (nonperturbative) dynamics. The conventional systematic way of dealing with the long-distance part is to parametrize it in terms of matrix elements of quark and gluonoperators between hadronic states generating GPDs, DAs, TMDs, etc. These matrix elements have to be either extracted from experiment or determined on the lattice. In many phenomenological applications they are usually modeled in terms of various nonperturbative methods or models. The main objective of the project is to develop comprehensive theoretical frameworks to study the multi-dimensional partonic content of hadrons by combining various approaches based on the factorization theorem and starting from the first principles of QCD.

For many years, theoretical and experimental studies of the nucleon structure have been restricted to a one-dimensional picture along a light-cone direction. Within this one-dimensional picture, quark and gluon contents of the nucleus are described by the parton distribution functions (PDFs) which depend on the longitiudinal momentum of the parton inside the hadron.

The last decade has witnessed a tremendous effort to go beyond this one-dimensional description of the nucleon. Recent improvements in experimental facilities such as increased electron beam luminosities and polarization degrees, detector resolution

and coverage, and advanced theoretical computation frameworks, such as calculating radiative and power corrections to complementary sets of observables, provide a breakthrough for investigating the multi-dimensional partonic content of the nucleon, which is also referred to as hadron tomography. In this respect, the multi-dimensional parton distribution functions such as transverse-momentum-dependent distribution functions (TMDs) or generalized parton distribution functions (GPDs) have been the key subjects of both experimental and theoretical studies.

With the advent of new generation colliders such as the Electron Ion Collider (EIC) in the USA and the Large Hadron electron Collider (LHeC) at CERN, theoretical improvements of these distribution functions are mandatory for a precise comparison with experimental data. Motivated from this need, the main objective of the proposed project is to develop a comprehensive theoretical framework to study the multi-dimensional partonic content of the hadrons by combining various approaches starting from the first principles of QCD.

Expected results upon completion of the project:
Analytic evaluation of 3-loop 2-point Feynman master-integrals with composite external vertices for arbitrary indices of propagators.

Calculation of $\alpha^2_s(\alpha_s\beta_0)^{n-1}$ and $\alpha^3_s\beta_1(\alpha_s\beta_0)^{n-2}$ contributions in the nonsinglet ERBL evolution kernel and correlator of two vector composite quark currents in QCD.

Calculation of pion electromagnetic form factors in the framework of light-cone sum rules in the low and (or) moderate energy regime.

Revision of distribution amplitudes (leading twist) of (pseudo)scalar and (longitudinal and transverse) vector mesons within QCD sum rules taking into account new QCD corrections $O(\alpha^2_s)$ obtained by us for all of their components.

Derivation and analysis of the full differential equation system for Feynman integrals with multiple parameters of masses and impulses.

Study of tau lepton decays and processes of electron-positron annihilation into mesons including the processes with three pseudoscalar mesons in the final state.

Investigation of the inner structure and nature of the meson interaction at low energies by using the Nambu–Jona-Lasinio model.

Study of the Drell-Yan hadronic structure function within the perturbative QCD in α^2_s order of the coupling constant. Check of the Lam-Tung identity in α^2_s order of the strong coupling constant.

Study of dark axion portal and obtaining bounds for the model in fixed target experiments. The analysis of new physics for NA64 experiment. Study of visible mode of axion or dark photon.

Study of the sum rules for hadron fragmentation functions in QCD with the use of the generalized truncated Mellin moments approach.

Investigation of analytical and numerical optimizations of perturbative series for observables using the renormalization group in QCD.

Study of anomalous transport phenomena in a relativistic quantum medium associated with the curvature of space-time.

Study of the influence of the hadron potential at large distances on the total cross sections, which determines the peculiarity of the scattering amplitude at small momentum transfer. Investigation of the energy dependence and crossing properties of the new anomalous terms of the elastic amplitude of proton-proton and proton-antiproton scattering at NICA energies.

Study of the new-found types of transverse momentum dependent parton distributions within the original frame that involves the newly-found additional contribution in the inverse Radon transforms.

Study of the phase diagram of the SU(2)-Higgs Electroweak theory. Study of Z(N) symmetry and thermodynamic properties of meta-stable states at very high temperature in the context of QCD and Electroweak theory.

The creation of a computational framework to analyze CMS Open Data.

Expected results of the project in the current year:
Study of tau lepton decays and processes of electron-positron annihilation with three mesons in the final state.

Analytical and numerical optimizations of perturbation series for observables using beta-expansion and renormalization group in QCD.

Calculation of the correlator of two vector composite quark currents and the nonsinglet ERBL evolution kernel of the orders $\alpha^2_s(\alpha_s\beta_0)^{n-1}$ and $\alpha^3_s\beta_1(\alpha_s\beta_0)^{n-2}$ in QCD.

Analysis of polarization effects in the elastic e + p to e + p processes in the one-photon exchange approximation in the case when the spin quantization axes of the target proton at rest and the incident or scattered electron are parallel.

Study of heavy meson leptoproduction in the Generalized Parton Distributions approach.

Study of the charge sum rules for hadron fragmentation functions in QCD.

Study of inclusive hadron production in proton-proton and heavy-ion collisions at the NICA collider kinematics.

Analytical and numerical optimization of perturbative series for observables using the renormalization group in QCD. Applications to the DIS sum rules.

Analytic evaluation of 3-loop 2-point Feynman master-integrals with composite external vertices for arbitrary indices of propagators.

Development of a method to directly obtain higher orders of ε-expansion of multivariate hypergeometric functions which are important for QCD applications.

Evaluation (making use of resurgent-analysis methods) of currently unavailable nonperturbative contributions to the QCD Adler function of the subleading order in large-n_f expansion (n_f indicates the number of quark flavors).

Study of T-even hadronic structure functions of the Drell-Yan process.

Study of the axion and vector portal between the Standard Model and dark matter, implementation to fixed target experiments to obtain bounds for the model.

Study of dark matter from rare meson decays.

Calculation of the electromagnetic pion form factor for moderate momentum transfers in the framework of the analytical perturbation theory of QCD and comparison with the latest JLab experimental data.

Investigation of the possibility of existence of previously unknown phase transitions in relativistic fluid of elementary particles in the region of ultralow temperatures and extremely high accelerations and vorticities.

Analysis of manifestation of dark matter axions in their interaction with leptons proportional to the axion-photon coupling constant.

Investigation of the dissipative properties of the relativistic quantum medium in curved spaces with a horizon and search for dissipative transport coefficients for theories with different spins, and analysis of the connection with predictions based on string theory.

Derivation of the energy dependence of the contribution estimates of tenzor pomeron to spin-dependent amplitudes of nuclon-nuclon elastic scattering. Obtaining quantitative description of all available experimental data on differential cross sections and spin-correllation parameters in elastic NN-scattering from sqrt(s)= 5 GeV up to sqrt(s)= 14 TeV.

Study of the contribution of the effects induced by the effective one-loop action of Heisenberg-Euler QED and its generalization to QCD to the transport coefficients of transport effects (CME, CSE, CESE, CMW, CEW, CVE) in heavy ion collisions.

Study of particle production with orbital angular moments in strong interactions in heavy-ion collisions. Analysis of manifestation of dark matter axions in spin effects.

3. Phenomenology of strong interactions and precision physics — **V.I. Korobov, M.A. Ivanov**

BLTP D. Aznabayev, G. Gurjav, A.N. Issadykov, D.I. Melikhov, Yu.S. Surovtsev, J. Tyulemissov, A. Tyulemissova

Brief annotation and scientific rationale:
The project is expected to develop low-energy effective field theories: non-relativistic quantum electrodynamics (NRQED) and covariant quark model of hadrons (Covariant Confined Quark Model, CCQM).

The Standard Model of particle physics, formulated about 50 years ago, forms the basis of our understanding of fundamental interactions. During this time, significant theoretical work has been carried out to improve the calculation technique and increase the accuracy of predictions in the SM. An effective field theory (EFT) is a quantum field theory which is not fundamental but is valid over a limited range of energies or distances. This makes it possible to successfully use EFT and renormalization group methods to calculate real physical quantities and processes observed in the experiment with high accuracy. The EFT approach provides not only a systematic approach to the analysis of experimental results, but is also a valuable tool for determining the correlation of various observables, which gives a deeper understanding of where to look for possible indicators of new physics beyond the SM.

Expected results upon completion of the project:
Exploration of the possibilities of using the combined approach in NRQED, when part of the contributions to the energy of the bound system is considered in the framework of QED, as the total sum over all terms in the powers of the electron binding parameter $v/c \sim Z\alpha$.

Introduction of new terms in the general NRQED scheme, which will make it possible to take into account the contributions of light scattering on light, nontrivial centipede diagrams for one- and two-loop self-energy diagrams, necessary for calculating corrections of the order $m\alpha^7$-$m\alpha^8$ and higher.

It is planned to study the spectra of pionic (π^-−He+) and kaonic (K^-−He+) helium atoms in order to refine the pion and kaon masses. The expected relative accuracy in mass measurements is $\sim 10^{-8}$.

Within the framework of CCQM, investigate the possibility of violation of lepton universality in lepton decays of charmonium and bottomonium and their radial excitations.

Obtain bounds on the values of the Wilson coefficients of the Standard Model Effective Theory (SMEFT) operators responsible for the violation of lepton universality in the tauon sector.

Calculate the partial widths of strong and electromagnetic decays of vector D-mesons with an open charm.

Calculate matrix elements and widths of nonleptonic two-particle decays of charmed baryons without changing the charm.

Perform an analysis of strong decays of the charmonium-like state Y(4230) in order to study the nature of its structure.

Perform a theoretical analysis of lepton decays of the B-meson with four leptons in the final state.

Expected results of the project in the current year:
Obtaining the Wilson coefficients in the NRQED Lagrangian with the precision required to calculate corrections for bound states in quantum electrodynamics up to the order of $m\alpha^8$ inclusive.

Calculation of relativistic corrections of order $m\alpha^6$ for bound states of molecular hydrogen ions H_2^+ and HD^+ within the *ab initio* three-body formalism. At present, this term in the interaction Hamiltonian has been calculated only in the adiabatic approximation and has made the largest contribution to the theoretical error in the energies of rho-vibrational and spin transitions.

Analysis of leptonic decays of heavy quarkoniums within the framework of the covariant quark model based on a new approach to treat radial excitations.

Obtaining restrictions on the parameter characterizing the inverse moment of the amplitude of the B_s meson distribution using the available data for the form factors of weak transitions of the B_s meson to a photon and φ meson.

Calculation of the widths of single-photon radiative decays of S- and P-wave excitations of charmonium within the framework of the covariant quark model and study of the dependence of the results on the model parameters.

4. Theory of hadronic matter under extreme conditions

V.V. Braguta
E.E. Kolomeitsev
S.N. Nedelko

BLTP M. Bordag, M. Hasegawa, Y. Heo, Yu.B. Ivanov, A.S. Khvorostukhin, K.D. Montenegro, Nguyen Hoang Wu, A.V. Nikolsky, A.A. Roenko, A.M. Snigirev, D.A. Sychev, N.S. Tsegelnik, V.E. Voronin, D. Voskresensky

Brief annotation and scientific rationale:
Modern heavy ion accelerators make it possible to study the properties of strong interactions of elementary particles, which are described by quantum chromodynamics (QCD) under the influence of extreme external conditions. In particular, the quark-gluon matter that is created in such experiments is expected to have a temperature of several hundred MeV, the baryon chemical potential of about 100 MeV, external magnetic field eB ~ 1 GeV^2 and relativistic rotation with an angular velocity of ~ 10 MeV. Such conditions significantly change the properties of QCD. In the presented project, it is planned to study the properties of QCD at nonzero baryon density, high temperature, large external magnetic field and relativistic rotation using lattice simulation and other approaches.

Expected results upon completion of the project:
In the presented project, it is planned to study the properties of QCD at non-zero baryon density, non-zero temperature and non-zero magnetic field using lattice simulation with an imaginary chemical potential, dynamic u-, d-, and s- quarks and the physical mass of the pi-meson. To conduct such a study, a program written by our group will be used that implements advanced supercomputer technologies and algorithms.

It is expected that quark-gluon matter, which is produced in the process of collision of heavy ions, is not only highly heated and affected by a strong magnetic field but also has a non-zero angular velocity of rotation. Therefore, to interpret the results of heavy ion collision experiments, an important theoretical problem is the study of the properties of rotating quark-gluon matter. In the presented project, we are planning for the first time to study the properties of rotating quark-gluon matter in the framework of lattice simulation.

One of the aims of the project is to impose new constraints on the equation of state of the nuclear and hadronic matter under extreme conditions existing in heavy-ion collisions and the centers of compact stars. For this, the description of strongly interacting systems in and out of equilibrium will be developed. Such observables as the strange and charmed particle production, the directed and elliptic flows of particles, the global spin polarization of hyperons and their intercorrelations will be analyzed within transport and hydrodynamic approaches and compared with existing and future experimental data. Various sources of the spin polarization such as local vorticity of the medium, axial vortex effect, and electromagnetic field will be quantitatively compared and their role in the formation of the observable polarization signal will be clarified.

The possibility of the thermodynamic description of light nuclei and hypernuclei production in heavy-ion collisions within the hydrodynamic approach will be theoretically explored. Formulation of the equations of the viscous hydrodynamics with the internal spin and rotation degrees of freedom as an effective field theory will be achieved. Possible phase transformation in nonequilibrium and equilibrium nuclear matter under the influence of compression, heating, magnetic field, and rotation will be classified and studied. New constraints on the equation of state from the description of the neutron star masses, radii, and the neutron star cooling should be obtained.

Elementary hadronic scattering amplitudes and the corresponding differential cross sections are important ingredients of transport models. The multichannel description of the meson-baryon scattering within the generalized potential approach based on the chiral SU(3) Lagrangian with the parameters tuned to the lattice QCD data and available experimental data on the hadron scattering will be developed.

Expected results of the project in the current year:
Study of the mass-radius relationship for neutron and hybrid stars. Analysis of the equations of state both in the absence of hyperons and quarks and taking into account hyperonization and the possibility of the presence of a quark core. Comparison of the results with the results for the equations of state with sigma-scaled masses.

Study of charged pion condensation under the simultaneous action of rotation and magnetic field in the presence of electric and scalar potential wells and nuclear matter. Allowance for London moment and the Meissner effect. Carrying out analogies and study of differences with behavior of metallic superconductors.

Kaon interaction with other hadrons is noticeably weaker than the interaction of non-strange hadrons with each other. Therefore, one may expect that the kaon distribution in heavy-ion collisions gets frozen out earlier than those of non-strange hadrons. The impact of such early freezing on various observables will be studied.

As is well known, the chiral symmetry restoration results in modifications of kaons in dense baryonic matter. At the same time, the matter formed in relativistic heavy-ion collisions is not only (and not always) baryon dense but also consists of dense pion medium, the effect of which has not yet been studied. The effect of dense pion environment on the in-medium modifications of kaons in the relativistic heavy-ion collisions will be studied.

Gravitational form factors of hadrons are related to generalized parton distributions which are an important ingredient of the parton model. The parton model is applied to hard processes involving hadrons. On the other hand, the domain model of QCD vacuum describes low-energy physics of mesons. The latter will be applied to gravitational form factors, which will make it possible to find its connection with the parton model.

Various phenomenological relativistic generalizations of the Breit–Wigner formula are employed while analysing experimentally observed hadronic resonances. The line shape of light vector mesons is to be investigated in the domain model of QCD vacuum.

The relation between the observed alignment of spots in the X-ray films in cosmic ray emulsion experiments and the selection procedure of the highest-energy particles itself together with the transverse momentum conservation will be analyzed in the framework of the HYDJET++ model. The possible influence of transverse momentum conservation in every event in the statistical model approach will be taken into account in the form of missing transverse momentum.

The phenomenological analysis of Pb+Pb data for net-charge fluctuations at the LHC ene tgies will be made within the HYDJET++ model. It is expected that the modification of this model through the explicit inclusion of charge conservation in a statistical approach allows one to reproduce experimental data.

In the framework of the lattice simulations, the properties of rotating QCD with dynamic fermions will be studied. In particular, spatially inhomogeneous phase transitions in rotating QCD will be considered.

5. Theory of electroweak interactions and neutrino physics — **A.B. Arbuzov, V.A. Naumov**

BLTP A. Ahmedov, Yu.M. Bystritskii, M. Deka, A.D. Dolgov, M.S. Dvornikov, S.B. Gerasimov, N.L. Haong, I.D. Kakorin, S.G. Kovalenko, K.S. Kuzmin, D.A. Kuznetsov, A.A. Nikitenko, N.N. Nikolaev, K. Nurlan, A.A. Osipov, V. Shmidt, M.K. Volkov, U.E.Voznaya, A.F. Zakharov, V.A. Zykunov

DLNP D.S. Shkirmanov

Brief annotation and scientific rationale:
The Standard Model of particle physics is the most successful theory of fundamental interactions. Despite numerous experiments on its verification and a deep theoretical study of its properties, there are still many problems in this model that need to be solved. The presence of such problems leads us to believe that the Standard Model is only an effective theory, i.e., a low-energy approximation of a more fundamental physical theory. To search for new physical phenomena, it is necessary to have high-precision predictions obtained within the framework of the Standard Model. Within this project, it is planned to obtain such predictions for the conditions of existing and future experiments at colliders, including LHC, FCCee, CEPC, ILC. Calculations will be carried out in order to carry out precise verification of the Standard Model (SM) and search for the limits of applicability of the latter.

Neutrinos are a unique source of information on physics beyond the Standard Model. In particular, reliably observed transitions between different types of neutrinos (neutrino flavors) indicate a violation of the conservation of the electron, muon and taon quantum numbers, which is present in the SM with massless neutrinos. The project is devoted to the study of physical processes involving neutrinos, including elementary exclusive interactions of neutrinos with nucleons and nuclei, neutrino transport in matter, taking into account coherent and inelastic interactions, study of astrophysical and cosmological effects, superhigh-energy neutrinos in cosmic rays, manifestation of neutrino oscillations in primary nucleosynthesis under extreme astrophysical conditions (in particular, in the vicinity of astrophysical black holes), as well as in accelerator and reactor experiments. In particular, the hypothesis about the possible existence of a sterile neutrino, its role in nucleosynthesis and the formation of the large-scale structure of the Universe will be considered. It is also planned to study a new mechanism for the production of ultrahigh-energy neutrinos, up to 10^{21} eV (UHECR) in models of modified gravity in higher-dimensional space. Research carried out within the framework of this project will allow obtaining restrictions on models of compact objects, on the properties of particles (for example, on the mass of a graviton), as well as on alternative theories of gravity, which have been proposed recently. In recent years, reliable evidence has been obtained for the association of high-energy neutrinos with blazars, which are most likely supermassive black holes, and the construction of consistent models of these phenomena is also extremely important and timely. Cosmological and astrophysical phenomena predicted in modified gravity models will be investigated. First of all, scalar-tensor models of gravity will be considered and the manifestations of quantum field effects in them will be studied.

Expected results upon completion of the project:
Improvement of basic phenomenological models of electromagnetic nucleon forms-factors in the space-like and time-like domains of q^2 based on the global statistical analysis of elastic electron scattering data on hydrogen and deuterium. Implementation of the models in the form of software modules of the GENIE neutrino generator. Application of the results to calculations of the cross sections of neutrino-nucleon interactions in the models of the running axial mass (M_A^{run}) and SuSAM*.

Improvement of the superscaling model SuSAM* with a modified scaling function based on a global statistical analysis of quasielastic electron scattering data on various nuclear targets (from hydrogen to uranium). Model implementation in the GENIE generator. Predictions of the momentum distribution of nucleons in the nucleus within the superscaling approach.

Improvement of the RK model of resonance neutrinoproduction of pions with corrected contributions to the full amplitude based on the global statistical analysis of single pion production data in (anti)neutrino interactions with hydrogen and deuterium. Implementation of the model in the GENIE generator.

Development of a method for solving the quantum kinetic equations describing the transport of massive high-energy neutrinos in heterogeneous (astrophysical) media taking into account the neutrino mixing (including mixing with hypothetical sterile states) and their coherent and inelastic interactions with matter. Application of the theory to the calculation of the passage through the Sun of neutrinos generated by cosmic rays in the solar atmosphere (prediction of the flavor composition, energy and angular distributions). Evaluation of the corresponding background in the experiments on the detection of neutrinos generated by the annihilation of dark matter particles gravitationally bound in the Sun.

Study of the contribution of ultra-high energy neutrinos arising in a multidimensional modification of gravity and comparison of theoretical expectations with observations with the Baikal GVD and IceCube detectors.

Calculation of electroweak radiative corrections to electron-positron annihilation processes, which are planned to be studied at future colliders, including FCCee, CEPC and Super Charm-Tau Factory. Creation of computer programs that can be directly used to simulate and analyze data from experiments at these colliders.

Application of the method of parton distributions developed in QCD to describe electrodynamic corrections to processes studied in current and future experiments in the field of high energy physics.

Construction of high-precision theoretical predictions for Bhabha scattering processes at small and large angles used for luminosity monitoring at electron-positron colliders.

Analysis of semileptonic many-particle decay modes of tau leptons taking into account the excited states of mesons in intermediate states. Construction of a consistent scheme for describing such decays and creation of a computer program for simulating such processes.

Expected results of the project in the current year:
Precision calculation and systematization of the effects of radiative corrections in the forward-backward asymmetry of the dilepton production process in hadronic collisions in the CMS LHC experiment in the Run3/HL mode.

Study of spin asymmetry in the processes of production of pseudoscalar mesons in proton-proton collisions under the conditions of the STAR experiment.

Calculation of the bremsstrahlung and pair production cross sections at low energies under the conditions that will be used to obtain a polarized positron beam.

Description of tau lepton decays and processes of meson production in colliding electron-positron beams in the energy range up to 2 GeV within the framework of the U(3)xU(3) Nambu-Jona-Lasinio model.

High-precision calculation of the light quark masses by fitting the squares of the masses of π^+, K^+, and K^0 mesons to their analytical expressions obtained in the NNLO approximation of 1/Nc expansion.

Study of the impact of NNLO corrections to the Wess-Zumino-Witten anomaly, due to the explicit violation of chiral SU(3)xSU(3) symmetry on the widths of two-photon decays of pions and eta mesons.

Analytical calculations and numerical analysis of higher-order radiative corrections to the processes of electron-positron annihilation and muon-electron scattering under the conditions of modern and future experiments.

Calculation of the contribution of the Casimir energy of the Standard Model fields to the energy density of the Universe within the conformal cosmological model.

Study of scattering of ultrarelativistic neutrinos by a black hole surrounded by a magnetized accretion disk.

Investigation of the problem of non-Abelian gauge symmetry breaking for the solution of the Yang-Mills equation in an expanding space with a negative scalar curvature parameter.

Calculations of baryon and lepton asymmetry of the Universe in the process of capturing heavy neutrinos by primary black holes.

Estimation of the ultrahigh energy neutrino flux in the process of cosmic-ray generation during decay or annihilation of superheavy dark matter particles.

Possible birth of relic neutrinos by photons in the transformation of gravitons into photons in cosmic magnetic fields.

Resonant evolution of transitions between active and sterile neutrinos.

Optimization of the MC model of resonant single pion neutrinoproduction on nucleons and implementation of the model in the GENIE neutrino generator.

Optimization of the running axial mass model for description of quasielastic neutrino scattering on nuclei.

Obtaining constraints on the parameters of alternative theories of gravitation from observations of trajectories of bright stars in the neighborhood of the Galactic Center.

Study of gravitational lensing for the dark matter model of the Galactic Center.

Study of shadows in the neighborhood of the Galactic Center.

Collaboration

Country or International Organization	**City**	**Institute**
Belarus	Gomel	GSTU
		GSU
	Minsk	INP BSU
		IP NASB
		JIPNR-Sosny NASB
Bulgaria	Sofia	INRNE BAS
Canada	Corner Brook	MUN
Chile	Arica	UTA
	Santiago	UNAB CTEPP
China	Beijing	IHEP CAS
	Guangzhou	SYSU
	Haikou	HNU
	Lanzhou	IMP CAS
Croatia	Zagreb	RBI
Finland	Helsinki	HIP
France	Paris	ENS
		UPMC
	Saclay	IRFU
Germany	Dusseldorf	HHU
	Hamburg	Univ.
	Karlsruhe	KIT
	Regensburg	UR
	Tubingen	Univ.
	Zeuthen	DESY
Greece	Rethymno	UoC
Hungary	Budapest	ELTE
India	Ettimadai	Amrita
	Kolkata	IACS
	Sunabeda	CUO
Iran	Tehran	IPM
		Univ.
Italy	Naples	INFN
	Pisa	INFN
Poland	Katowice	US
	Krakow	INP PAS
	Otwock (Swierk)	NCBJ
Portugal	Coimbra	UC
Russia	Chernogolovka	LITP RAS
	Dubna	Dubna State Univ.
	Irkutsk	ISDCT SB RAS
		ISU
	Moscow	ITEP
		SINP MSU

	Moscow, Troitsk	INR RAS
	Novosibirsk	BINP SB RAS
		NSU
	Protvino	IHEP
	Vladivostok	FEFU
Serbia	Belgrade	AOB
		INS "VINCA"
Slovakia	Bratislava	CU
		IP SAS
Spain	Granada	UGR
Sweden	Stockholm	KTH
United Kingdom	Liverpool	Univ.
	London	Imperial College
USA	Wako, TX	BU
Vietnam	Hanoi	IOP VAST
	Ho Chi Minh City	VNUHCM

01-3-1136-2019

Theory of Nuclear Systems

Theme leaders: N.V. Antonenko
A.A. Dzhioev
S.N. Ershov

Participating Countries and International organizations:
Algeria, Armenia, Belarus, Belgium, Brazil, Bulgaria, China, Czech Republic, Egypt, France, Germany, Greece, Hungary, India, Iran, Italy, Japan, Kazakhstan, Lithuania, Mexico, Norway, Poland, Republic of Korea, Romania, Russia, Serbia, Slovakia, South Africa, Spain, Sweden, United Kingdom, USA, Uzbekistan.

The problem under study and the main purpose of the research:
The theme proposes to research and develop ways to solve current problems in nuclear physics, relativistic nuclear physics, nuclear astrophysics, in the field of quantum few-body systems, and nonlinear quantum processes. Researches will be closely coordinated with experimental programs at facilities that exploit high-intensity beams of stable and/or radioactive ions at JINR (SHE-factory, ACCULINA-2) and worldwide (FAIR, ISOL facilities, SPES, SPIRAL2, FRIB, RAON, HIAF, iThemba LABS, ELI-NP). Studies of collisions of high-energy heavy ions and the phenomenon of color transparency will be associated with the NICA project at JINR. Large-scale studies of the structure of exotic nuclei, the dynamics of nuclear reactions, properties and methods of obtaining superheavy nuclei are planned. The task is to include dissipation and diffusion in the dynamics of the nucleus-nuclear interaction and preserve the essence of the quantum multiparticle nature of colliding nuclei. The study of systems with a small number of particles is also necessary in order to describe resonant processes in nuclear physics and high-energy physics. Studies of nonlinear quantum processes in very strong polarized electromagnetic fields, which are achieved in short high-frequency laser pulses, are of interest.

Projects in the theme:

	Name of the project	Project Leaders	Project code
1.	Microscopic models for exotic nuclei and nuclear astrophysics	A.A. Dzhioev	01-3-1136-1-2024/2028
2.	Low-energy nuclear dynamics and properties of nuclear systems	S.N. Ershov G.G. Adamian	01-3-1136-2-2024/2028
3.	Quantum few-body systems	A.K. Motovilov V.S. Melezhik	01-3-1136-3-2024/2028
4.	Relativistic nuclear dynamics and nonlinear quantum processes	S.G. Bondarenko A.B. Larionov	01-3-1136-4-2024/2028

Projects:

	Name of the project	Project Leaders
Laboratory	Responsible from laboratories	
1.	**Microscopic models for exotic nuclei and nuclear astrophysics**	**A.A. Dzhioev**

BLTP N.N. Arsenyev, E.B. Balbutsev, I.N. Borzov, H.G. Ganev, V.A. Kuzmin, L.A. Malov, M.A. Mardyban, I.V. Molodtsova, V.O. Nesterenko, A.P. Severyukhin, G. Stratan, A.I. Vdovin, P.I. Vishnevskiy

Brief annotation and scientific rationale:
The scientific Project aims to solve a fundamental task of contemporary nuclear physics - development and improvement of a self-consistent microscopic approach to describe the structure of ground and excited states of exotic and superheavy atomic nuclei, as well as to predict their decay properties. On the one hand, such an approach is necessary for planning the research program of modern heavy ion accelerator facilities (SHE-Factory at JINR, SPIRAL2 at GANIL, FAIR at GSI, RIBF at RIKEN) and for interpretation of their results. On the other hand, the need for reliable theoretical nuclear data is also relevant for modeling various astrophysical processes.

The self-consistent microscopic approach used in the Project to describe ground and excited nuclear states is based on the combination of the energy density functional (EDF) method and the quasiparticle-phonon nuclear model (QPM). The EDF has proven itself in global calculations of nuclear characteristics and in astrophysics. The use of the coupling of simple and complex

configurations in the framework of QPM is nowadays practically the only way allowing one to go beyond the harmonic approximation using large configuration space without violating the Pauli principle.

Expected results upon completion of the project:
The form and parameters of the EDF will be extrapolated far beyond the stability valley. Special attention will be paid to isovector properties, which play a crucial role in nuclei with large neutron-proton asymmetry.

Using a unified set of EDF parameters, the effect of interaction between simple and complex configurations on the properties of charge-neutral and charge-exchange nuclear excitations will be investigated with respect to their resonance structure as well as on the decay characteristics of nuclei at the driplines.

The developed self-consistent EDF+QPM framework will be applied to study β-decay in the context of astrophysical r-process and weak nuclear reactions with hot nuclei in various astrophysical scenarios (supernova explosions, stellar nucleosynthesis, neutrino emission).

Prediction of α spectra of superheavy nuclei for planning future experiments. α-decays from isomeric states as well as fission from these states will be considered.

In order to determine the competition between different modes of radioactive decay of superheavy nuclei, lifetime calculations concerning orbital electron capture and β^+-decay will be carried out.

Analysis of the evolution of magic numbers as a function of the ratio of neutron to proton numbers in the nucleus and prediction of new nuclei with closed (sub)shells near the proton and neutron driplines.

Study of the role of tensor interaction in the fragmentation of the Gamow-Teller resonance and beta-decay of exotic nuclei.

Investigation of neutrino interaction with matter that is important in various astrophysical phenomena, e.g., supernovae, neutron star mergers, etc. The role of inelastic neutrino scattering on nuclei and the magnetic field in the neutrino thermalization process must be elucidated.

Calculations of charge and matter distribution radii for long isotopic chains, including deformed nuclei. Theoretical analysis of isotopic behavior of radii and observed anomalies.

Expected results of the project in the current year:
Analysis of the interplay between the pygmy and toroidal E1 excitations in the framework of the random-phase-approximation with Skyrme forces.

Search for signatures of the toroidal E1 mode in the (e,e'g) reaction.

Prediction of pairing vibrations in nobelium isotopes.

Study of the Giant Dipole Resonance and accompanying collective spin-M2 ($K^\pi = 0^-, 1^-$) states in deformed nuclei within the Wigner function moments method: calculation of energies and excitation probabilities.

Analysis of the contribution of the two-phonon configurations in the formation of the spin-dipole resonance.

Calculation of the rates of ordinary muon capture by even isotopes of selenium and barium in connection with the experiments carried out at the LNP JINR.

Investigation of the low-lying collective states in the neutron-rich Ge isotopes.

Study of low-lying collective excitations in the actinide mass region within the microscopic shell-model version of the Bohr-Mottelson model.

Study of the EC/β^+ decay of superheavy nuclei taking into account the contribution of forbidden transitions.

2. Low-energy nuclear dynamics and properties of nuclear systems — **S.N. Ershov, G.G. Adamian**

BLTP	E.Kh. Alpomishev, A.V. Andreev, N.V. Antonenko, A.N. Bezbakh, R.V. Jolos, Sh.A. Kalandarov, E.V. Mardyban, R.G. Nazmitdinov, A.K. Nasirov, H. Pasca, A. Rahmatinejad, I.S. Rogov, V.V. Sargsyan, T.M. Shneidman, N.B. Shulgina
MLIT	J. Busa, E.G. Nikonov
FLNR	Y.V. Pyatkov

Brief annotation and scientific rationale:
The purpose of the project is to study the important dynamical nuclear processes such as fusion, quasifission, multinucleon transfers, capture and breakup. Investigations of the near threshold effects demand uniform description of the nuclear structure and reactions. Priority will be a development of cluster models that allow us to reveal peculiarities of the nuclear structure at extreme excitatios. A further development of the completely quantum models for decays of weakly bound nuclei is planned. The transport coefficients and nucleus-nucleus potentials calculated microscopically would be used in the double-folding model for a description of the fusion dynamics.

It is necessary to study in detail the influence of the environment on the rate of astrophysical reactions. This demands further development of the theory of the quantum systems. Thus, it is necessary to consider low-energy dipole excitations that play presumably a noticeable role in stellar nucleosynthesis.

Study of the nuclear properties depending on an energy is necessary to reveal effects outside the mean field description. In heated nuclei, the potential energy surface changes in such a way that the height of the fission barrier for superheavy nuclei decreases. Therefore, investigations of the shell effects damping with increasing energy are important for estimation of the stability of excited heavy nuclei.

Exploring the formation of superheavies with Z=119 and 120 in fusion reactions must be continued within a microscopic approach. Also, the peculiarities of the quasifission competing with the complete fusion will be considered. There are plans to compare the calculated mass distributions and TKE of the quasi-fission products with distributions of the fission products. New heavy ion isotopes, which cannot be obtained in the complete fusion reactions, can be formed by transfer reactions. Therefore, further theoretical analysis of these reactions by including a cluster transfer into the description is required. Investigations of the synthesis of new isotopes of superheavy nuclei must be continued in the evaporation channels of charged particles in order to search for the most suitable reactions for future experiments.

The advantage of the cluster approach is the simultaneous description of α-decay and spontaneous fission from the ground state of both even-even and even-odd nuclei with the same set of parameters. The main model assumption is that charge asymmetry as a collective coordinate is responsible for these processes. In the same approach, it is necessary to investigate fission from isomeric states and induced fission. Success in describing experimental data will lead to a new insight into fission process.

Expected results upon completion of the project:
Creation of new theoretical approaches and models for description and prediction of the properties of unstable nuclei and exotic nuclear systems and their application to astrophysical problems.

Explanation of the reaction mechanism with particles and nuclei within the broad energy interval.

Exploring the limits of nuclear stability, positions of proton and neutron drip-lines, detection of proton shell closure beyond Pb, and the best way to produce a certain isotope.

Study of fusion and fission dynamics providing benchmarks for confirming certain ways of fusion and fission.

Investigation of the influence of the environment on astrophysical reactions.

Study of the nuclear structure change with temperature and angular momentum, the role of cluster degrees of freedom in nuclear excitations, and the properties of superheavies.

Exploration of the properties of nuclear systems beyond the nucleon stability, the multineutron radioactive decay existence.

Expected results of the project in the current year:
Investigation of the structure of superheavy nuclei belonging to the alpha-decay chain of ^{288}Mc.

Study of the potential surface of superheavy nuclei (Th, Fm, Hs) depending on temperature at various deformations of the systems.

Study of the level density parameters of superheavy nuclei (Th, Fm, Hs).

Estimation of the probability of neutron emission from superheavy nuclei (Th, Fm, Hs).

Development of the method for describing spin distributions extracted from the measured gamma-multiplicity associated with the evaporation residues formation in the ^{16}O+^{208}Pb, ^{18}O+^{206}Sm, ^{16}O+^{154}Sm and ^{32}S+^{154}Sm reactions.

Study of the physical reasons for the absence of the quasifission products yield in heavy ion collisions at the energies above the Coulomb barrier.

Investigation of the evidences of the multinucleon transfer mechanism of the complete fusion of nuclei in heavy ion collisions.

Predictions of the fine structure of alpha-decay of superheavy nuclei, which will provide information about their lowest excited states.

Explanation of the experimental observation of the absence of correlations in fission fragments angular momenta within the quantum-mechanical treatment of angular vibrations at the scission point.

Study of the isospin dependence of level density parameter ratios corresponding to various decay channels for superheavy nuclei.

Calculation of the properties of fission products in spontaneous fission of transfermium nuclei taking into account the evolution of a dinuclear system towards the scission point.

Calculation of the yields of ^{209}Bi(γ, xn) and ^{209}Bi(γ, pxn) photonuclear reactions and the analysis of the role of pre-equilibrium nucleon emissions in these reactions.

Description of the cluster emission in the polar and perpendicular directions in ternary decay processes.

Application of the "formation-decay" approach to calculate cross sections in the synthesis of superheavy elements in the framework of the DNS model.

Study of the dependence of the fine structure of alpha decay of even-even actinide nuclei.

Calculation of spectroscopic factors of alpha decay based on the model of a dinuclear system taking into account the relative motion of the alpha particle and the daughter nucleus.

Analysis of the properties of low-lying 2^+ excitations in $^{70-88}$Ge isotopes.

Calculation of potential energy surfaces and mass parameters within the framework of a relativistic mean field model with different parameterizations of the energy density functiona.

Calculation of the realistic profile functions and emission spectra of four neutrons in the ^{2}H(^{8}He, ^{3}He)^{7}H --> ^{3}H+4n reaction.

3. Quantum few-body systems

A.K. Motovilov
V.S. Melezhik

BLTP M.V. Egorov, D. Janseitov, E.A. Kolganova, V.N. Kondratyev, E.A. Koval, A.V. Malykh, Yu.V. Popov, S.A. Rakityansky, S.A. Shadmehri, E.A. Solov'ev, D. Valiolda, S.I. Vinitsky, 3 pers.

DLNP O.I. Kartavtsev

MLIT O. Chulunbaatar, A.A. Gusev

VBLHEP A.A. Korobitsin

Brief annotation and scientific rationale:
The project is aimed at studying systems formed by a small set of constituents of nuclear, subnuclear or atomic-molecular origin. The smallness of the number of constituents in a system allows one to develop and use mathematically rigorous, precise and consistent approaches to its investigation, the approaches that do not require further simplifying physical assumptions and approximations. The goal of the project consists in developing and improving the methods of numerical solving of few-body problems in nuclear, atomic and molecular physics, and astrophysics. The developed approaches and methods will be employed in the numerical study of various concrete few-body quantum systems.

Expected results upon completion of the project:
Development of methods and approaches of the theory of few-body systems, settling some still remaining mathematical questions and issues. A contribution to Efimov physics with establishing new universal features in the behavior of ultra-cold few-body systems including the lattice few-body systems. Numerical calculations of ultracold three-atom systems in Efimov or pre-Efimov states by employing Faddeev equations. Theoretical study of non-stationary systems, in particular, the study of few-particle systems in varying external fields. Analysis of bound-state problems and scattering processes in low-dimensional few-particle systems. Development of the dynamical adiabatic theory and theory of hidden crossings of the potential-energy levels. Application of these theories to inelastic transitions in atom-atom collisions.

Expected results of the project in the current year:
Investigation of the halo structure in breakup reactions within the quantum-quasiclassical approach.

Development of the calculation methods of the rotation-vibration spectrum of the collective model of atomic nuclei.

Studies of structural features of light weakly bound nuclei in direct nuclear reactions.

Study of adsorption enthalpies of selected superheavy elements and their compounds on selenium surfaces from first principles.

Study of neutrino flux properties of magnetorotational supernovae with allowance for resonant flavor mixing and the perspectives of observation.

Search for diffractionless solutions for bound states of the model 1D three-body problem.

Development of a theoretical model of threshold resonant amplification.

Investigation of spectral properties of a two-boson lattice Hamiltonian with interactions up to next-neighboring sites.

Study of quasi-elastic scattering of fast (several keV) electrons on atoms at large momentum transfer: the role of nuclear motion.

Development of a phenomenological method for constructing wave functions of bound and resonant states of quantum few-body systems based on their experimental parameters.

Investigation of classical representation for a rectangular potential well.

4. Relativistic nuclear dynamics and nonlinear quantum processes — **S.G. Bondarenko, A.B. Larionov**

BLTP A.V. Frizen, L.P. Kaptar, V.K. Lukyanov, A. Parvan, A.I. Titov, V.D. Toneev, S.A. Yuriev

Brief annotation and scientific rationale:
The aim of the project is to study the universal laws in relativistic collisions of heavy ions accompanied by various particles production; determination of the most important observables to test the equation of state of the nucleus; theoretical support for experiments at the NICA complex. The large nuclear transparency compared to the predictions of Glauber-like models may indicate the presence of color transparency and should be carefully considered. Based on the generalized eikonal approximation, nuclear transparencies in *dd* collisions will be calculated, which are available at NICA SPD. It is planned to study three/four-nucleon bound (^{3}He,T,^{4}He) and scattering systems (elastic proton-deuteron) in the Bethe-Salpeter-Faddeev relativistic formalism. Study the properties of heated and compressed nuclear matter in the collision of heavy ions is based on the Nambu-Iona-Lasinio Polyakov loop model.

Our theoretical efforts are aimed at solving the following problems:

– improving transport approaches for describing the dynamics of relativistic collisions of heavy ions;

– identification of the most important observables in relativistic collisions of heavy ions to test the equation of state of the nucleus;

– study of the time of evolution of rapidly colliding systems to a local isotropic state in momentum space;

– study of the features of the interaction of high-energy gamma quanta with a strong laser field

– consideration of relativistic effects in low-nucleon systems.

Expected results upon completion of the project:
Development of theoretical models and methods in the theory of nonlinear quantum processes of interaction of charged particles with intense electromagnetic fields. In this case, in addition to the dependence of observables on the field intensity, it is planned to study the polarization effects and the role of the shape and the carrier phase of the pulse.

Extension of the relativistic consideration of three-nucleon (^{3}He,T) systems in the formalism of the Bethe-Salpeter-Faddeev equation with separable interaction to four-nucleon systems in the Yakubovsky formalism (calculation of the ^{4}He binding energy, electromagnetic form factor of the system). Investigation of elastic proton-deuteron backscattering using the relativistic three-nucleon Bethe-Salpeter-Faddeev equation with a separable interaction kernel (taking into account nucleon rescattering diagrams). Consideration of the elastic electromagnetic form factor of the pion taking into account the anomalous magnetic moment of the quark in the framework of the covariant separable quark-quark interaction.

Study of the properties of heated and compressed nuclear matter in the collision of heavy ions. Of particular interest is the study of possible phase transitions that occur during the cooling of the system, as well as the problem of violation of CP invariance in strong interactions, which may be a consequence of the influence of the chiral anomaly on the topological structure of QCD vacuum in strong magnetic fields arising during the collision of heavy ions. The purpose of the study is to consider how the scattering cross section changes depending on the properties of the medium. Study of two-photon and Dalitz decays of light mesons within the NJL model at finite temperature and density. The production spectrum of dilepton pairs is directly related to various intermediate states of quark-hadron matter, and its study can provide information on phase transitions.

Investigations of the phenomenon of color transparency (CT), short-range nucleon-nucleon correlations and cumulative effect. Predictions for planned CPU search experiments at FAIR PANDA and NICA SPD. Based on the generalized eikonal approximation, taking into account the CT effects, we will calculate the nuclear transparency in the hard processes $d(d,2p)nn$ and $A(p,2p)$ with heavier nuclear targets (A >2) , for which the CT effects should be stronger.

Development of a solid theoretical basis for describing the interaction of a proton with a SRC pair in the nucleus, taking into account the NLS/VKD. Nucleon-nucleon short-range correlations (SRC) manifest themselves in interactions of high-energy particles with nuclei with sufficiently large momentum transfers (Q > 1 GeV).

Investigation of the influence of the nuclear medium on such fundamental characteristics of the elementary NN amplitude as the total cross section for scattering of a nucleon by a bound nucleon of the nuclear medium, the energy dependence of the ratio of its real part to the imaginary part, as well as its slope parameter depending on the momentum transferred to the nucleon bound in the nucleus.

Calculation of exact hadronic distributions in transverse momentum and rapidity by new methods within the framework of Tsallis- 1, Tsallis-3 and *q*-dual statistics and their application to describe experimental data for hadrons produced in collisions of heavy ions and protons with protons at LHC, RHIC, NICA and FAIR energies. Generalization of the quantum-statistical hadron model with exactly conserved strangeness of the system to the case of exact conservation of the baryon and electric charges of the system and finding recursive equations for the exact solution of the partition function and ensemble averages. The use of this model to calculate the multiplicity of identified hadrons produced in heavy ion collisions at LHC, RHIC, NICA and FAIR energies.

Investigations of the behavior of ghost and gluon propagators at finite temperature in an approach based on the Dyson-Schwinger equation in the Landau gauge in the truncated rainbow approximation. It is planned to investigate possible phase transitions from a bound state of a glueball to a free gluon plasma for the problem of phase transitions to a quark-gluon plasma in a hot nuclear medium (in processes in experiments at the NICA facility).

Expected results of the project in the current year:
Study of the medium-dependent cross sections of the Y-meson in BB collisions in the framework of the model with non-local separable universal interaction kernel.

Calculation of the binding energy of the helium-4 nucleus and amplitudes of states within the framework of the relativistic generalization of the Faddeev-Yakubovsky equation using a separable multi-rank potential of nucleon-nucleon interaction; calculation of the charge form factor of the helium-4 nucleus in the relativistic case.

Refinement of the method of general eikonal approximation taking into account diagrams up to triple soft rescattering and its application to the reactions d(p,2p)n and d(d,2p)nn induced by hard elastic pp scattering.

Development of theoretical models and methods for studying nonlinear quantum processes during the interaction of photons and charged particles with intense laser fields with particular attention to the most relevant nonlinear processes of electron-positron pairs production.

Formulation of the nonextensive quantum-statistical hadron model for a mixture of hadron species within the framework of the Tsallis statistical mechanics and calculation of the exact transverse momentum distributions of hadrons. Application of these distributions to describe experimental data for hadrons produced in heavy ion and proton-proton collisions at LHC and RHIC energies.

Analysis of the data on proton scattering cross sections by carbon, calcium, nickel and lead nuclei at energies of 200-1000 MeV using the constructed microscopic potential; calculation on this basis of the parameters of the elementary amplitude of NN scattering on bound nucleons of the nucleus and their comparison with the corresponding parameters of proton scattering on free nucleons.

Investigation of the finite-temperature behaviour of scalar glueballs within an approach based on the rainbow truncated Dyson-Schwinger equations in the Landau gauge. Numerical solution of the system of coupled equations for the ghost and gluon propagators as a function of temperature T, Matsubara frequency Omega_n and three-momentum squared k^2 in a large range of T. Calculations of the temperature-dependent Bethe-Salpeter equation for scalar glueballs with the use of this solution. Investigation of possible phase transitions from the glueball bound state to free gluon plasma. This study is directly related to problems of phase transitions into quark-gluon plasma in a hot nuclear environment (e.g., in processes planned for researches at the NICA).

Analytical calculations of the lepton anomaly g-2 due to bubble-like Feynman diagrams up to the 10th order in QED within the combined Mellin-Barnes and dispersion-relations approach to the x parametrization of the corresponding diagrams.

Investigation of the pion properties in the Bethe-Salpeter formalism and study of the off-mass behavior of the pion form factors.

Collaboration

Country or International Organization	**City**	**Institute**
Algeria	Setif	UFAS
Armenia	Yerevan	RAU
		YSU
Belarus	Gomel	GSTU
	Minsk	IP NASB
Belgium	Brussels	ULB
	Louvain-la-Neuve	UCL

Brazil	Florianopolis, SC	UFSC
	Niteroi, RJ	UFF
	Sao Jose dos Campos, SP	ITA
	Sao Paulo, SP	UEP
Bulgaria	Sofia	INRNE BAS
		NBU
China	Beijing	CIAE
		ITP CAS
		PKU
	Lanzhou	IMP CAS
	Shanghai	Univ.
Czech Republic	Prague	CU
Egypt	Cairo	FUE
	Giza	CU
France	Caen	GANIL
	Orsay	IJCLab
Germany	Berlin	HZB
	Bielefeld	Univ.
	Bonn	UniBonn
	Cologne	Univ.
	Darmstadt	GSI
		TU Darmstadt
	Dresden	HZDR
		TU Dresden
	Erlangen	FAU
	Frankfurt/Main	Univ.
	Giessen	JLU
	Hamburg	Univ.
	Leipzig	UoC
	Mainz	JGU
	Rostock	Univ.
	Siegen	Univ.
Greece	Athens	INP NCSR "Demokritos"
Hungary	Budapest	Wigner RCP
	Debrecen	Atomki
India	Chandigarh	PU
	Kasaragod	CUK
	New Delhi	IUAC
Iran	Zanjan	IASBS
Italy	Catania	INFN LNS
	Messina	UniMe
	Naples	INFN
	Turin	UniTo
Japan	Kobe	Kobe Univ.
	Morioka	Iwate Univ.
	Osaka	Osaka Univ.
		RCNP
Kazakhstan	Almaty	INP
		KazNU
Lithuania	Kaunas	VMU
Mexico	Mexico City	UNAM
Norway	Bergen	UiB
	Oslo	UiO
Poland	Krakow	INP PAS
	Lublin	UMCS

	Otwock (Swierk)	NCBJ
	Warsaw	UW
Republic of Korea	Daejeon	IBS
	Jeonju	JBNU
	Seoul	SNU
Romania	Bucharest	IFIN-HH
		UB
	Cluj-Napoca	UBB
Russia	Dolgoprudny	MIPT
	Gatchina	NRC KI PNPI
	Khabarovsk	PNU
	Moscow	MSU
		NNRU "MEPhI"
		NRC KI
		SINP MSU
	Moscow, Troitsk	INR RAS
	Omsk	OmSU
	Saint Petersburg	SPbSU
		VNIIM
	Saratov	SSU
	Tomsk	TPU
	Vladivostok	FEFU
Serbia	Belgrade	IPB
Slovakia	Bratislava	CU
		IP SAS
South Africa	Johannesburg	WITS
	Pretoria	UP
	Somerset West	iThemba LABS
	Stellenbosch	SU
Spain	Palma	UiB
Sweden	Goteborg	Chalmers
	Lund	LU
United Kingdom	Guildford	Univ.
USA	Notre Dame, IN	ND
	University Park, PA	Penn State
Uzbekistan	Namangan	NamMTI
	Samarkand	SamSU
	Tashkent	Assoc. P.-S. PTI
		IAP NUU
		INP AS RUz

01-3-1137-2019

Theory of Complex Systems and Advanced Materials

Theme leaders: V.A. Osipov
A.M. Povolotsky

Participating Countries and International organizations:
Armenia, Australia, Belarus, Brazil, Bulgaria, Canada, China, Egypt, Finland, France, Germany, India, Iran, Japan, Mongolia, Poland, Romania, Russia, Serbia, Slovakia, South Africa, United Kingdom, USA.

The problem under study and the main purpose of the research:
The most important directions of fundamental research will be theoretical studies of physical phenomena and processes in condensed matter, studies of the properties of new advanced materials, constructing and analysis of theoretical models and the development of analytical and computational methods for their solution. Complex materials such as high-temperature superconductors, magnetic materials, smart composite materials, fractal and layered structures are supposed to be studied and a wide class of systems with strong electronic correlations will be analyzed. Theoretical research in this area will be aimed at supporting the experimental study of these materials carried out at the Frank Laboratory of Neutron Physics, JINR. It is planned to conduct research in the field of physics of nanostructures and nanomaterials, in particular, using the software packages for modeling physical and chemical processes and for analysis of physical characteristics. First of all, these are modern two-dimensional materials such as graphene, transition metal dichalcogenides, etc., including their modification and chemical functionalization for a subsequent use in the design of new devices for nanoelectronics, spintronics, etc. Partly, these studies are focused on experiments held at the FLNR Center for Applied Physics JINR, Centre "Nanobiophotonics" at FLNP JINR, the Institute of Semiconductor Physics SB RAS and a number of other laboratories of the JINR Member States. The physical properties of stacks of Josephson junctions and various Josephson nanostructures will be studied in detail. Much attention will be paid to the analysis of both lattice and field models of equilibrium and nonequilibrium systems of statistical mechanics. The concepts of scaling and universality allow one to go beyond the model approach and apply the results obtained to broad classes of phenomena studied in the physics of condensed matter. Studies of a wide range of universal phenomena in complex systems - phase transitions in condensed matter and high-energy physics, scaling in (magneto)hydrodynamic turbulence, chemical reactions, percolation, etc. by the methods of quantum field theory including the functional renormalization group are supposed to be carried out.

Projects in the theme:

	Name of the project	Project Leaders	Project code
1.	Complex materials	E.M. Anitas	01-3-1137-1-2024/2028
2.	Mathematical models of statistical physics of complex systems	A.M. Povolotsky	01-3-1137-2-2024/2028
3.	Nanostructures and nanomaterials	V.A. Osipov V.L. Katkov	01-3-1137-3-2024/2028
4.	Quantum field theory methods in complex systems	M. Hnatič	01-3-1137-4-2024/2028

Projects:

	Name of the project	Project Leaders
Laboratory	Responsible from laboratories	
1.	**Complex materials**	**E.M. Anitas**
BLTP	N.N. Bogoliubov, A.Yu. Cherny, A.A. Donkov, N.K. Hoang, A.L. Kuzemsky, P.A. Maksimov, Tung Nguen Dan, A.A. Vladimirov, V.I. Yukalov,V.Yu. Yushankhai	
FLNP	V.L. Aksenov, A.M. Balagurov, A.S. Doroshkevich, A. Islamov, D.P. Kozlenko, A.I. Kuklin, E.P. Popov	
MLIT	L.A. Syurakshina, E.P. Yukalova	
FLNR	M. Mirzaev	
DLNP	D.V. Karaivanov, Nguyen Trung, A.I. Velichkov	

Brief annotation and scientific rationale:
Enormous recent progress in both the art of sample preparation and the measurement techniques has produced a wealth of high-quality data on thermodynamic, transport, structural and spectroscopic properties for new complex materials that exhibit unconventional forms of magnetism, showing evidence for strong electronic and magnetic correlations, or having fractal properties at nano and microscales. These materials attract now considerable attention for various applications, e.g., in quantum computing or in describing the physical and chemical properties of colloids, biological systems, granular materials etc.

Expected results upon completion of the project:
Estimation of the exchange parameters of Kitaev materials based on transition and rare-earth metals and calculation of their spin-wave spectrum.

Magnetic phase diagrams in strongly-correlated electronic systems within the t-J model for electron doping.

Explaining the structure of systems of dense random packings in nano- and micro-materials.

Development and application of quantum algorithms for computational problems in condensed matter physics and quantum chemistry.

Development of a theory of stability for mixtures of quantum fluids.

Understanding the irradiation resistance of various compounds.

Expected results of the project in the current year:
Calculation of the magnetic spectrum of the Kitaev triangular lattice ferromagnet with quantum corrections.

Extraction of the magnetic Hamiltonian of the Kitaev antiferromagnet $BaCo_2(AsO_4)_2$ from inelastic neutron scattering data.

Investigation of defect formation in titanium alloys for the purposes of machine tool engineering.

Numerical studies of the electronic properties of bismuth vanadate for use as semicondustor devices.

Computational description of chemical reactions on crystalline surfaces.

Investigation of scaling relations in the theory of strongly nonequilibrium and turbulent Bose-atoms in traps.

Development of the approach for describing the arising ordering in complex statistical systems by introducing order indices.

Development and study of the model of a complex network with colored intrinsic noise.

Investigation of the correlation properties of dense random packing systems with a power-law distribution of their sizes in the thermodynamic limit: criteria of spatial randomness and the influence of its non-randomness on the correlation properties.

2. Mathematical models of statistical physics of complex systems **A.M. Povolotsky**

BLTP G.Y. Chitov, V.I. Inozemtsev, V.V. Papoyan, P.N. Pyatov, V.P. Spiridonov

Brief annotation and scientific rationale:
Non-perturbative studies of large-scale systems with many interacting degrees of freedom constitute an important part of modern theoretical physics that has been experiencing a growing interest of researchers during the last decade. Recent advances in this direction are based on the construction and investigation of exactly solvable models of equilibrium and non-equilibrium statistical physics, quantum mechanics and related quantum field theories. Then, with the use of the concepts of scaling and universality the results obtained from the exact solutions can be extended to vast classes of physical phenomena far beyond the realm of such systems. The exact solvability of models of physical systems is provided by their special mathematical structure coined by the term integrability. The models with such a structure is the major subject of studies within the current project.

The project is aimed at further exploration of the field of exactly solvable models of statistical physics, quantum mechanics and quantum field theories, which requires a development of new theoretical tools based on the theory of integrable systems and discovery of new mathematical structures standing behind the exact solvability. The main objectives of the project consist in obtaining exact results about universal laws in interacting particle systems with stochastic dynamics and models of random interface growth, models of equilibrium statistical physics including percolation, polymers and other two-dimensional lattice models and quantum spin chains, studies of known and construction of new types of special functions playing the role of building

blocks in the theory of integrable systems and computations of partition functions (superconformal indices), studies of known and construction of new algebraic structures standing behind the integrability concept.

Expected results upon completion of the project:
Construction and complete classification of one-dimensional stochastic models of interacting particles based on representations of Hecke algebras and related two-dimensional lattice models of interacting paths, as well as obtaining their exact solutions using the Markov duality methods.

Calculation of exact cluster densities and their asymptotic expansions in percolation models, as well as loop densities in associated densely packed loop models on lattices with different boundary conditions, construction of asymptotic expansions of thermodynamic quantities characterizing the behavior of free-fermionic models on lattices of finite size, such as dimers, Ising model and spanning tree models with different geometry under various boundary conditions. It is also planned to study the boundary behavior of nonlocal correlation functions in models of dense polymers and spanning trees, as well as to describe the limiting forms and universal fluctuations of polymer configurations in these models.

Application of the studied models of polymers and quantum spin chains to problems from related fields of quantum mechanics and biophysics. Among them are the studies of "entangled states" and magnetic properties of complex quantum spin systems related to the problems of quantum computing, the use of a rotor-router model (Eulerian walks) to study the dynamics of double-stranded DNA breaks.

Development of mathematical structures behind the integrability. In particular, further study of the properties of elliptic beta integrals and elliptic hypergeometric functions and their various limiting forms, new applications of these functions to quantum field theory, quantum and statistical mechanics and soliton theory, construction of complex hypergeometric functions on root systems in the Mellin-Barnes representation and study of their connections to the two-dimensional conformal field theories. Finding generalized modular transformations for elliptic hypergeometric integrals and description of their consequences for superconformal indices (statistical sums) of four-dimensional supersymmetric field theories. It is also planned to generalize the obtained results to the cases of rarefied hypergeometric functions of various types and describe the relevant physical systems, as well as to investigate connections between soliton solutions of integrable equations, lattice Coulomb gases, non-local Ising chains and ensembles of random matrices.

Construction and study of new algebraic structures underlying integrability and their use for constructing new integrable systems that could be useful in various applications. Generalization of the Hamilton-Cayley theorem to the case of orthogonal type quantum matrix algebras and study of the subalgebra of spectral values of orthogonal quantum matrices. Construction of an analogue of the Gauss expansion in the reflection equation algebras, and development of the representation theory of these algebras.

It is also planned to study a series of R-matrix solutions of the braid relation, which make it possible to model stochastic reaction-diffusion processes and study the possibility of constructing new link/knot invariants using new series of R-matrices.

Expected results of the project in the current year:
Construction and exact solution of lattice models of interacting particles with chemical reactions.

Exact solution of models of interacting particles with annihilation and coagulation on a periodic one-dimensional lattice.

Description of the anomalous behavior of finite-size correction coefficients in a dimer model with different boundary conditions on a lattice.

Studies of "entangled states" and magnetic properties of clusters containing Copper, Nickel and Cobalt with spins of 1/2, 1, and 3/2, respectively.

Description of the dynamics of recovery of double-stranded polymer breaks using the rotor-router model also known as the Eulerian walk.

Construction of the ground-state phase diagram of the dimerized XXZ chain in the presence of uniform and alternating transverse magnetic fields within the RG approach.

Explanation of the cascades of percolation transitions in models of the type of cellular automata from the analysis of Lee-Yang zeros of the generalized partition functions of stationary (non-equilibrium) states. Development of the RG approach for analysing these transitions.
Computation of the rarefied elliptic beta integral proving the equality of superconformal indices for the Seiberg duality of the simplest supersymmetric gauge field theories on the special lens space.

Investigation of a new rational version of the integrable Ruijsenaars model connected with the complex hypergeometric functions.

Constructions of a complete set of eigenfunctions of the corresponding many-body Hamiltonian by means of a special degeneration limit of known wave functions of the hyperbolic Ruijsenaars mode.

Construction of a series of constant gl(2|1) type R-matrices associated with symmetric powers of the vector representation, their Baxterization and investigation of their applications.

3. Nanostructures and nanomaterials **V.A. Osipov**
V.L. Katkov

BLTP M. Abdelghani, D. Anghel, T. Belgibaev, K.K. Kesharpu, E.A. Kochetov S.E. Krasavin, K.V. Kulikov, N.L. Matsko, I.R. Rahmonov, I.K. Sobolev, Yu.M. Shukrinov

MLIT I. Sarhadov, E.B. Zemlianaya

FLNP G.M. Arzumanyan

FLNR V.A. Skuratov

LRB A.N. Bugay

Brief annotation and scientific rationale:
It is planned to conduct research in the field of physics of nanostructures and nanomaterials, in particular, using the software packages for modeling physical and chemical processes and for analysis of physical characteristics. First of all, these are modern two-dimensional materials such as graphene, transition metal dichalcogenides, etc., including their modification and chemical functionalization for a subsequent use in the design of new devices for nanoelectronics, spintronics, etc. Partly, these studies are focused on experiments held at the FLNR Center for Applied Physics JINR, Centre "Nanobiophotonics" at FLNP JINR, the Institute of Semiconductor Physics SB RAS and a number of other laboratories of the JINR Member States. It is planned to analyze topological superconductivity in strongly correlated electronic systems in order to find possible applications for the transmission and storage of quantum information. The physical properties of stacks of Josephson junctions and various Josephson nanostructures will be studied in detail.

The main goal of the project is a theoretical study of the properties of new promising materials, primarily nanostructures and nanomaterials. This is explained not only by the fundamental nature of the physical properties of these materials but also by their practical importance for designing new electronic devices, as well as devices for storing, processing and transmitting information, sensors and biosensors, and others.

Expected results upon completion of the project:
The project is aimed at solving tasks in the following areas:
– in order to identify materials with promising properties for use as a component base for a new generation of electronics, it is planned to study thermal and electron transport in low-dimensional materials of various configurations and chemical composition. An analysis will be made of the role of functionalization, structural modification, the influence of thin layers, polycrystalline, structural defects, and other factors. Experimental studies are carried out in cooperation with the Educational and Scientific Technological Laboratory "Graphene Nanotechnologies" NEFU in Yakutsk (synthesis), the Institute of Semiconductor Physics SB RAS (synthesis, characterization, functionalization), FLNP JINR (chracterization, functionalization, irradiation) and FLNR JINR (ion irradiation to create nanopores);

– analysis of topological superconductivity in strongly correlated electronic systems in order to search for possible applications for the transmission and storage of quantum information and for the study of non-standard quantum transport that is insensitive to local noise sources;

– study of dynamic, transport and chaotic phenomena in hybrid Josephson nanostructures with magnetic materials for the purposes of superconducting spintronics. Modeling of quantum phenomena in Josephson qubits (memory elements);

– study of the properties of polarons in low-dimensional materials and nanostructured objects. Analysis of plasmon-phonon interaction and plasmons in nanoscale and massive objects.

Expected results of the project in the current year:
Investigation of the influence of resonance impurities on electrical resistivity of polycrystalline graphene.

Investigation of the effects of Rashba spin orbit coupling and magnetic field on the topological properties of the strongly correlated superconducting nanowire.

Study of topological superconductivity induced by strong electron (e-e) correlation.

Analysis of the influence of phonon modes on band and transport characteristics in various nanostructures.

First-principles calculations of photoluminescence of rare earth metal atoms placed on a graphene/transition metal dichalcogenide (TMD) substrate and placed between graphene/TMD layers.

Study of the role of ferromagnetic resonances in a Josephson junction with a ferromagnet.

Development of a method to flip the magnetization of individual elements of an array of coupled nanomagnets using superconducting current pulses through Josephson elements.

Analysis of magnetization in a shunted anomalous Josephson junction.

Study of quantum effects in nanostructures with a toroidal configuration in the presence of external currents.

4. Quantum field theory methods in complex systems **Hnatič M.**

BLTP L.Ts. Adzemyan, N.V. Antonov, N.M. Gulitskiy, G.A. Kalagov, M.V. Kompaniets, N.M. Lebedev, L. Mižišin, Yu.M. Molotkov, M.Yu. Nalimov, L.A. Sevastyanov

MLIT J. Buša

Brief annotation and scientific rationale:
Complex physical phenomena such as developed turbulence, transport phenomena, non-equilibrium phase transitions, percolation, chemical reactions and surface growth in random media are difficult to study theoretically and experimentally; however, in the light of their wide distribution in nature such studies prove themselves to be very valuable.

The main task of the project will be the formulation of the corresponding theoretical models, which can be investigated using the methods of quantum field theory and non-equilibrium statistical physics. The main goal is to study the statistical characteristics of fluctuating fields in the region of large spatial scales, identify phase transitions and to calculate universal critical exponents and non-universal amplitudes.

Dynamic nonlinear systems in which non-equilibrium (stochastic) fluctuations of physical quantities play a decisive role, is one of the most important research topics by leading scientific teams in the world. They cover a wide range phenomenon, which we observe in the world around us.

Notable examples of stochastic processes include: hydrodynamic and magneto-hydrodynamic turbulence, describing, in particular, turbulent movements in the Earth's atmosphere and oceans, the spread of pollutants in them (including chemically active), as well as chaotic motions of plasma on the surface of the sun and in space. One of the important consequences of the existence of mechanical instabilities in electrically conducting turbulent media is an exponential growth of magnetic fluctuations leading to the formation of observed nonzero averaged magnetic fields only due to the kinetic energy of the turbulent medium.

Another important example of stochastic systems is percolation processes. They describe phenomena such as seepage in porous media, filtration, spread of infectious diseases, forest fires and others. Their universal feature is the existence of a non-equilibrium phase transition to an inactive (absorbing) state that extinguishes all activity of the observed system. Obviously, the study of transitions between a stationary active and the inactive phase is of great practical importance.

The main object of the study is physical quantities that depend on space-time coordinates and therefore are fluctuating fields, and the measured quantities are their statistical averages. The most important of them are non-zero average field values, response functions, multipoint correlation functions, two-point simultaneous correlations (structural functions), including composite fields (operators). In the region of large spatial and temporal scales, their scaling behavior with universal critical exponents is observed. The analysis of stability regions of scaling regimes and the calculation of indices is a priority goal in the study of stochastic nonlinear systems.

The main goal of the project is to study stochastic nonlinear dynamic systems such as developed (magneto)hydrodynamic turbulence, non-equilibrium phase transitions, phase transitions in systems with high spins, kinetics of chemical reactions, percolation processes, surface growth in random media and self-organized criticality.

Expected results upon completion of the project:
Investigation of the crossover in systems of multicomponent fermions within the BEC-BCS functional renormalization group: analysis of phase diagrams and calculation of transition temperatures to the ordered state. Approbation and adaptation of computational methods for solving non-perturbative equations of the functional renormalization group.

Development of computational methods for calculating the contributions of multi-loop diagrams to the renormalization group functions of dynamical models. Investigation of the dynamics of the superconducting phase transition in low-temperature superconductors.

Study of the effects associated with the violation of mirror symmetry in magneto-hydrodynamic developed turbulence. Calculation of two-loop Feynman diagrams generated by the Lorentz force and two-loop diagrams of the response function leading to an exponential growth of magnetic field fluctuations in the region of large scales. Study of the phenomenon of turbulent dynamo.

Construction of effective field-theoretical models of chemical reactions of various types of particles occurring in random media. Study of the infrared scaling behavior of statistical correlations of particle densities by renormalization group methods.

Study of isotropic and directed percolation. Calculation of multi-loop Feynman diagrams generating ultraviolet divergences. Finding fixed points of the renormalization group equations and calculating critical exponents for physically significant and experimentally observable quantities - response functions, density of active nodes (agents), effective radius and mass of active zones.

Study of the effect of isotropic motion of a medium with different statistical characteristics on the possibility of anisotropic scaling in the Hua-Kardar self-organized criticality model. Investigation by the functional renormalization group method of possible asymptotic regimes corresponding to the non-universal scaling behavior of a surface growing in a random environment and described by a model that includes an infinite number of types of interactions.

Expected results of the project in the current year:
Evaluation of thermodynamic characteristics of a multi-component Fermi gas in the unitary regime within the non-perturbative renormalization group in the entire temperature range including the superfluid phase transition point.

Investigation of a field theoretical model of stochastic magnetic hydrodynamics with broken mirror symmetry: calculation of ultraviolet Λ-divergences of the magnetic field response function in the two-loop approximation and their elimination by the mechanism of spontaneous symmetry breaking. Calculation of the parameters of the α-effect associated with the emerging electromotive force.

Two-loop calculations in a model of turbulent transport of a vector admixture with nonlinearity of the most general form in an incompressible medium modeled by the stochastic Navier-Stokes equation.

Investigation of isotropic percolation: three-loop calculations of renormalization constants of the field-theoretical model and the dynamical critical index.

Calculations of the A-model of critical dynamics by the hyperlogarithm method. Six-loop calculation of RG-functions in the φ^6 model.

Calculation of non-universal critical exponents in the model of a randomly growing surface including an infinite number of coupling constants by the method of functional renormalization group. Study of the dependence of the calculated exponents on the model parameters.

Calculation of critical dimensions of velocity and density fields in the vicinity of the λ-point. Derivation of a quantum analog of the Navier-Stokes equation based on the formalism of time-dependent Green's functions at finite temperature.

Description of stochastic kinetic systems based on Finsler geometry, solving kinetic equations for stochastic models using physics-based neural networks (PINNs).

Collaboration

Country or International Organization	**City**	**Institute**
Armenia	Yerevan	Foundation ANSL
		YSU
Australia	Canberra, ACT	ANU
	Sydney, NSW	Univ.
Belarus	Minsk	IM NASB
		IP NASB
		SPMRC NASB
Brazil	Natal, RN	IIP UFRN
	Sao Paulo, SP	USP
Bulgaria	Sofia	IMech BAS
		ISSP BAS
Canada	Montreal	UdeM
	Sherbrooke	UdeS
China	Beijing	"Tsinghua"
Egypt	Giza	CU
Finland	Helsinki	UH

France	Angers	UA
	Marseille	CPT
Germany	Leipzig	UoC
	Wuppertal	UW
India	Kolkata	IACS
Iran	Zanjan	IASBS
Japan	Utsunomiya	UU
Mongolia	Ulaanbaatar	IPT MAS
Poland	Wroclaw	WUT
Romania	Bucharest	UB
	Timisoara	UVT
Russia	Moscow	NRU HSE
		PFUR
	Novosibirsk	ISP SB RAS
		NIIC SB RAS
	Protvino	IHEP
	Saint Petersburg	PDMI RAS
		SPbSU
	Saratov	SSU
	Tomsk	TPU
	Vladivostok	FEFU
Serbia	Belgrade	INS "VINCA"
Slovakia	Bratislava	CU
	Kosice	IEP SAS
		UPJS
South Africa	Pretoria	UNISA
United Kingdom	Coventry	Warwick
USA	Pasadena, CA	Caltech

01-3-1138-2019

Modern Mathematical Physics: Integrability, Gravity and Supersymmetry

Theme leaders: A.P. Isaev
S.O. Krivonos

Participating Countries and International organizations:
Armenia, Australia, Brazil, Bulgaria, CERN, China, Czech Republic, France, Germany, Greece, Iran, Ireland, Israel, Italy, Japan, Kazakhstan, Kyrgyzstan, Poland, Portugal, Russia, Serbia, Spain, United Kingdom, USA.

The problem under study and the main purpose of the research:
The main task of the Theme is the development of mathematical methods for solving the most important problems of modern theoretical physics, namely: development of new mathematical methods for studying and describing a wide class of classical and quantum integrable systems and their exact solutions; analyzing and searching for solutions to a wide range of problems of supersymmetric theories, including models of strings and other extended objects; study of nonperturbative regimes in supersymmetric gauge theories; development of cosmological models of the early Universe, gravitational waves and black holes.

Projects in the theme:

	Name of the project	Project Leaders	Project code
1.	Integrable systems and symmetries	A.P. Isaev S.O. Krivonos N.A. Tyurin	01-3-1138-1-2024/2028
2.	Supersymmetry, higher spins, gravity	E.A. Ivanov S.A. Fedoruk	01-3-1138-2-2024/2028
3.	Quantum gravity, cosmology and strings	I.G. Pirozhenko D.V. Fursaev	01-3-1138-3-2024/2028

Projects:

	Name of the project	Project Leaders
Laboratory	Responsible from laboratories	
1.	**Integrable systems and symmetries**	**A.P. Isaev** **S.O. Krivonos** **N.A. Tyurin**
BLTP	H.D. Dimov, A.A. Golubtsova, N.Yu. Kozyrev, M.A. Podoinicin, A.A. Provorov	

Brief annotation and scientific rationale:
Our project is devoted to important problems of modern mathematical physics. The three most important investigation directions of the project are the study of holographic duality, construction of supersymmetric theories and description of unitary irreducible representations of Poincare groups in higher dimensions. Each of these directions can be regarded separately but, in our project, we concentrate our attention on the problems which lie on the borders of these major directions. As byproducts, we study certain applied problems, including those that arise in connection with booster thematic.

Expected results upon completion of the project:
The first problem of the project is the study of algebraic and differential structures in holographical systems, which belongs to the subject of modern mathematical physics considered in the context of holographic duality. This part of the project is focused on the study of properties of integrable systems appearing in holographical models.

The second problem is devoted to the construction of an action of the non-Abelian N=(1,0), d=6 tensor multiplet possessing as many as possible numbers of properties of six dimensional superconformal theories. This problem is related to the first one since it is devoted to field theories with extended supersymmetry which are very important in the mathematical physics studies since they help to describe common properties of quantum fields theories and many aspects of the string theory.

The third problem of our project arises in the context of studies of the models with higher spin fields requiring a certain description of unitary irreducible representations of Poincare groups and symmetry groups of AdS spaces. According to Wigner, each irreducible representation of the four-dimensional Poincare group is assotiated with an elementary particle (field). This conception

is generalized to the case of arbitrary dimension and to the case of other groups including supergroups. Therefore, when studying different field models, one first of all asks the question of classification and explicit construction of unitary irreducible representations of the symmetry group of the studied theory.

Expected results of the project in the current year:
Calculation of color factors in infinite series of Feynman diagrams arising in non-Abelian gauge theories based on the properties of the split Casimir operator. Search for new series of representations of all simple Lie algebras (not known within the framework of Vogel universality) that admit a universal description. In particular, search for universal formulas for all dimensions of these representations.

Construction and analysis of analytica black hole solutions with AdS asymptotics in 3d N=(2,0) gauge supergravity coupled to a sigma model with hyperbolic target space; study of the thermodynamic properties of the constructed holographic RG flows at finite temperature.

Search for a formulation of pure N=(1,0), d=6 supergravity where anti-self-dual equation of motion of the tensor field is induced by a superfield version of the Pasti-Sorokin-Tonin mechanism.

Study of the continuous spin representation for the symmetry groups of the AdS and dS spaces. In particular, calculation of the Casimir operators of the corresponding algebra in dimension D=4 in a fairly general representation. Analysis of their spectrum within the framework of already proposed models for particles with continuous spin in spaces of constant curvature.

2. Supersymmetry, higher spins, gravity **E.A. Ivanov**
S.A. Fedoruk

BLTP I.L. Buchbinder, A.S.Budekhina, A.P. Nersessian, E.D. Petukhov, G.A. Sarkissian, Ya.M. Shnir, S.S. Sidorov, A.O. Sutulin, N.M. Zaigraev

Brief annotation and scientific rationale:
The project is aimed at solving fundamental problems of modern theoretical physics associated with the development of superfield methods in gauge theories with extended supersymmetry in various dimensions, including extended supersymmetric mechanics. The implementation of the project includes the construction of new field and quantum-mechanical models with global and gauge symmetries, the development of new, including geometric, methods for studying the structure of these models at the classical and quantum levels, the study of the structure of the corresponding quantum effective actions and classical solutions of these models, including black holes. All tasks of the project are set by the modern development of theoretical physics and are organically joined by the unity of methods and approaches.

Expected results upon completion of the project:
Calculating all leading and subleading in the dimensional regularization parameter two-loop counterterms in 6D, N=(1,0) and N=(1,1) supersymmetric gauge theories.

Constructing a one-loop induced effective action in the theory of hypermultiplet interacting with N=2 supergravity in the harmonic superspace approach.

Development of the methods of calculation of the one-loop induced effective action in the theory of hypermultiplet coupled to external fields of N=2 harmonic gauge superfields.

Derivation of 4D, N=2 harmonic superfield formulation for N=2 supersymmetric gauge fermionic higher spin fields.

Working out 4D, N=2 superfield gauge theory of higher spin fields in the AdS space.

Development of effective methods for describing gauge fields and superfields of an infinite spin in an arbitrary space-time dimension.

Finding Lagrangians describing the interactions of infinite spin fields and higher spin fields with fields of a fixed spin.

Finding out superfield harmonic Lagrangians of sigma models obtained by T-duality from 2D, N=(4,4) supersymmetric hyperkahler and quaternion-kahler sigma models.

Building a superfield matrix formulation of new N=4 and N=8 supersymmetric extensions of integrable many-particle systems and their quantization.

Construction of new models of N-extended supersymmetric quantum mechanics by using the superfield gauging method, which describe the interaction of dynamic and semidynamic multiplets of various types.

Construction and study of N=4 models of supersymmetric mechanics based on the interaction of linear and nonlinear supermultiplets with the component content (4,4,0), (3,4,1) and (2,4,2).

Constructing the Hamiltonian formulation and performing quantization of the generalizations of systems with the nonlinear (2,4,2) supermultiplet.

Constructing an extension of N=4 supersymmetric mechanics with (3,4,1) supermultiplet to the class of systems parametrized by an arbitrary holomorphic function.

Construction and study of many-particle systems with nonlinear supermultiplets.

Construction of a superfield description of Calogero-type models with extended N≥4 supersymmetries.

Analysis of the integrability of N-extended supersymmetric systems of the Euler–Calogero–Moser and Calogero–Moser–Sutherland types for the A(n-1) series of the Coxeter group.

Finding an explicit form of the functionally independent conserved Liouville currents in N=2 supersymmetric Calogero models for all root systems of Coxeter groups.

Construction of two new exactly calculated rarefied elliptic beta integrals associated with special lens spaces and a special subgroup of the modular transformations group SL(2,Z).

Computation of a matrix of modular transformations of one-point conformal blocks on a torus in the Neveu-Schwarz sector of the N=1 superconformal Liouville field theory, based on the expression of this matrix as an integral of the product of certain elements of the fusion matrix.

Obtaining the difference equations for the fusion matrix in the Neveu-Schwarz sector of the N=1 superconformal Liouville field theory.

Finding a new class of solutions of GR with gauge multicomponent matter fields in models with spontaneous symmetry breaking.

Constructing and exploring a new class of solutions of extenged Einstein gravity with the Chern-Simons term that represents stationary rotating black holes.

Expected results of the project in the current year:
Calculation of two-loop counterterms in 6D, N=(1,0) and N=(1,1) supersymmetric gauge theories, subleading in the dimensional regularization parameter.

Construction of the one-loop induced effective action in the hypermultiplet theory coupled to N=2 supergravity in the harmonic superspace approach.

Construction of the Lagrangian formulation for supersymmetric infinite spin field theory in external field of N=1 supergravity.

Construction of minimal interaction of infinite spin fields and higher spin fields with fixed spin fields.

Construction and study of the N=4 supersymmetric extension of the Pöschl-Teller model at the classical and quantum levels.

Construction of models of the N=4 supersymmetric mechanics with spin degrees of freedom based on the interaction of linear and nonlinear supermultiplets. Study of nonlinear multiplets as semi-dynamical (spin) multiplets.

Search for a superfield description of long reducible multiplets of the N=4 supersymmetric mechanics and building models with their interaction. Quantization of the constructed models.

Construction and study of the Hamiltonian formulation of relativistic particle systems with the Lagrangians depending on extrinsic curvatures of isotropic and non-isotropic curves in three- and four-dimensional Minkowski spaces.

Construction, based on the Olshanetsky-Perelomov method, of a set of Liouville currents and additional conserved charges for Calogero-Moser models with N=2 supersymmetry associated with root systems of groups of B_n, C_n and D_n series.

Study of the integrability of the Calogero-Moser-Sutherland models with N=2 and N=4 supersymmetry by finding the corresponding Lax pair and conserved currents. Construction of Lax pairs for the N-extended supersymmetric Euler-Calogero-Moser model.

Search for eigenfunctions of the two-particle Hamiltonian of the complex rational Ruijsenaars-Sutherland model.

Search for explicit construction of hairy black holes in the U(1) gauged Einstein-Skyrme-Maxwell theory and exploration of localized configurations representing multipolar pion stars stabilized by gravitational interaction.

Study of the Regge symmetry for 6j-symbols of unitary principal series representations of the SL(2,C) group. Study of the properties of 6j-symbols of unitary principal series representations of the SL(2,C) group in the large spin.

3. Quantum gravity, cosmology and strings **I.G. Pirozhenko**
D.V. Fursaev

BLTP E.A. Davydov, A.B. Pestov, A.S. Sorin, V.A. Tainov, P.V. Tretyakov

Brief annotation and scientific rationale:
The project is aimed at solving the fundamental problems of classical and quantum gravity and conducting advanced theoretical research at the national and world level in this area at BLTP JINR. In classical gravity, the project is focused on studying all kinds of gravitational wave phenomena, including shock waves in General Relativity, as well as various sources of gravitational wave background such as cosmic strings. One of the directions of the project is the elaboration of cosmological models that explain the properties of the observable Universe based on field theory methods and modified gravity. In the field of quantum gravity, it is planned to develop an apparatus of quantum field theory in an external classical gravitational background and new methods for an approximate estimation of the effective gravitational action in various regimes. Asymptotic symmetries in gravity, the relationship between gravity, thermodynamics and quantum entanglement, the holographic properties of gravity, and the AdS/CFT correspondence will also be explored.

Expected results upon completion of the project:
Development of field theory methods against the background of shock gravitational waves using the method of supertranslations at the wave front; study of classical field effects induced by shock waves, including the astrophysical applications.

Study of classical effects in the gravitational field of shock gravitational waves, including the case of the gravitational field induced by null cosmic strings (cosmic strings moving at the speed of light); study of gravitational (electromagnetic) radiation induced by the motion of null cosmic strings near massive (charged) sources, estimation of the parameters of these objects corresponding to the observed characteristics of induced radiation.

Study of physical effects associated with the formation of caustics and other defects on the world sheet of the null cosmic string as possible sources of gravitational bursts; development of the holonomy method proposed for describing free classical fields against the background of a gravitational shock wave.

Quantization and study of quantum effects in the gravitational field of shock gravitational waves, calculation of the expectation value of the renormalized energy-momentum tensor.

Derivation and study of the properties of exact solutions of the Einstein equations related to the subject of this project, for example, the search for non-trivial solutions that have global hyperbolic isometry and allow the introduction of holonomy associated with these transformations.

Study of the gravitational entropy associated with various surfaces in Riemannian geometry, in particular, study of the entropy formed when the light cones of the past and future (causal diamonds) intersect, as well as study of quantum corrections and renormalization of this quantity.

Further development of spectral geometry methods applied to nonlinear spectral problems; using these methods to study the finite-temperature QFT on stationary manifolds of a general form, as well as the application of this theory to calculate the effects of quark-gluon matter taking into account rotation and acceleration.

Study of cosmological models of modified gravity, an attempt to explain on their basis the key characteristics of the observed cosmology such as the accelerated expansion of the Universe; the study of cosmological perturbations in a teleparallel theory with a non-minimal scalar-tensor coupling, where the main object is the torsion scalar, in contrast to general relativity, where the main object is the Ricci scalar.

Construction of integrable cosmological potentials for spatially flat cosmologies with one scalar field for searching and constructing realistic completely integrable inflationary models with a phase transition; study of phase transitions in quantum theory, including gravity, and the formation dynamics of walls separating regions with different field values, the development of the thick-wall approximation method taking into account gravity, as well as the construction and study of exactly solvable inflationary models with phase transitions.

Development of methods in the framework of the Picard-Lefschetz theory and their application for calculating Lorentz path integrals in problems of quantum field theory, gravity and cosmology, and, in particular, in problems of describing the lensing of gravitational waves.

Expected results of the project in the current year:
Study of dynamic compactification and obtaining the effective Higgs potential in multidimensional cosmological models with a scalar field and a Gauss-Bonet type term.

Study of the impact of plane shock gravitational waves on classical and quantum field systems. Consideration of shock gravitational waves from different sources (massless particle, null string, null brane), including shock gravitational waves with a time-dependent profile function.

Investigation of gravitational wave scattering by gravitating sources. Study of secondary shock waves in various field systems caused by primary shock gravitational waves.

Study of jumps in the energy-momentum tensor of fields on null surfaces, their geometric interpretation in Einstein's theory of gravity. Comparison of non-analyticities of Lorentzian manifolds on null hypersurfaces (non-analyticity of curvature such as the delta function and theta function).

Study of the physical effects of flat shock gravitational waves with a surface energy density distributed along the wave front sourced by ultrarelativistic heavy ions (in the limiting case). Study of the effect of quantum particle production by shock gravitational waves with a time-dependent profile function.

Collaboration

Country or International Organization	**City**	**Institute**
Armenia	Ashtarak	IPR NAS RA
		IRE NAS RA
	Yerevan	Foundation ANSL
Australia	Perth, WA	UWA
	Sydney, NSW	Univ.
Brazil	Juiz de Fora, MG	UFJF
	Santo Andre, SP	UFABC
	Sao Paulo, SP	USP
Bulgaria	Sofia	INRNE BAS
		SU
CERN	Geneva	CERN
China	Beijing	UCAS
	Guangzhou	SYSU
	Hengyang	USC
	Nanchang	NCU
	Shanghai	Univ.
Czech Republic	Prague	CTU
France	Annecy-le-Vieux	LAPP
	Lyon	ENS Lyon
	Marseille	CPT
	Nantes	SUBATECH
	Paris	ENS
		LUTH
	Tours	Univ.
Germany	Bonn	UniBonn
	Hannover	LUH
	Leipzig	UoC
	Munich	LMU
	Oldenburg	IPO
	Potsdam	AEI
Greece	Athens	UoA
Iran	Isfahan	Univ.
	Tehran	FU
		IPM
Ireland	Dublin	DIAS
Israel	Jerusalem	HUJI
	Tel Aviv	TAU
Italy	Frascati	INFN LNF
	Padua	UniPd

	Trieste	SISSA/ISAS
	Turin	UniTo
Japan	Okinawa	OIST
	Tokyo	Keio Univ.
		UT
Kazakhstan	Almaty	KazNU
Kyrgyzstan	Bishkek	BSU
Poland	Bialystok	UwB
	Krakow	JU
	Wroclaw	UW
Portugal	Aveiro	UA
Russia	Chernogolovka	LITP RAS
	Dolgoprudny	MIPT
	Kazan	KFU
	Moscow	IPMech RAS
		ITEP
		LPI RAS
		MI RAS
		MSU
		NRU HSE
		SAI MSU
		Skoltech
	Moscow, Troitsk	INR RAS
	Novosibirsk	NSU
	Protvino	IHEP
	Saint Petersburg	PDMI RAS
	Tomsk	TPU
		TSPU
	Voronezh	VSU
Serbia	Nis	Univ.
Spain	Barcelona	IEEC-CSIC
	Bilbao	UPV/EHU
	Santiago de Compostela	USC
	Valencia	IFIC
	Valladolid	UVa
United Kingdom	Cambridge	Univ.
	Canterbury	Univ.
	Durham	Univ.
	Glasgow	U of G
	London	Imperial College
USA	College Park, MD	UMD
	Coral Gables, FL	UM
	New York, NY	CUNY
		SUNY
	Philadelphia, PA	Penn

Elementary Particle Physics and High-Energy Heavy-Ion Physics (02)

Participation in international experiments

02-1-1066-2007

Investigation of the Properties of Nuclear Matter and Particle Structure at the Collider of Relativistic Nuclei and Polarized Protons

Theme leaders: R. Lednicky
Yu.A. Panebrattsev

Participating countries and international organizations:
Armenia, Azerbaijan, Bulgaria, China, Cuba, Czech Republic, Egypt, France, India, Kazakhstan, Mexico, Mongolia, Russia, Serbia, Slovakia, USA, Vietnam.

The problem under study and the main purpose of the research:
Investigation of the properties of nuclear matter with extremely high density and temperature, search for the signatures of the quark deconfinement and possible phase transitions at the collisions of heavy nuclei at the energies of the Relativistic Heavy Ion Collider (RHIC). Measurement of spin dependent structure functions of nucleons and nuclei using polarized proton beams at RHIC.

Project in the theme:

Name of the project	**Project Leaders**	**Project code**
Laboratory	Responsible from laboratories	**Status**
1. STAR	**Yu.A. Panebrattsev** **R. Lednicky**	02-1-1066-1-2010/2026 Realization
VBLHEP, MLIT, BLTP, UC	the list of participants is given in Activities	

Brief annotation and scientific rationale:
The goal of the STAR project (JINR participation) is to study the properties of nuclear matter at extreme densities and temperatures, to search for signatures of quark deconfinement and possible phase transitions in heavy ion collisions over a wide energy range at the Relativistic Heavy Ion Collider (RHIC). The research program also includes the study of the structure functions of quarks and gluons in collisions of transversely and longitudinally polarized protons.

Expected results upon completion of the project:
Obtaining information about the properties of excited nuclear matter. Participation in experiments with nuclei and polarized protons at the STAR facility at the RHIC nuclear collider at BNL.

Measurement at the STAR facility of spin effects in experiments with polarized protons. Obtaining new information about the spin – dependent distribution functions of quarks and gluons in the proton.

Research of femtoscopic correlations, structure of events and scaling properties of nuclear interactions, global polarization, events with wide transverse momenta.

Conducting experiments on the Beam Energy Scan program BESII in the collider mode and in the fixed target mode. Search for signatures of phase transitions and critical points of QCD.

Development of the STAR detector software and creation of corresponding infrastructure at JINR for processing and analysis of experimental data of the STAR facility at JINR.

Creation of the joint educational programs in relativistic nuclear physics and physics of the microworld together with BNL and JINR member states universities.

Expected results of the project this year:
Analysis of experimental data using the BES II energy scann program in collider experiments in the energy range 7.7–200 GeV and experiments with a fixed target in the energy range 3.0–7.7 GeV. Search for signatures of phase transitions and the QCD critical point.

Collection of statistics in experiments with gold nuclei and proton-nucleus collisions with epy energy of 200 GeV and the maximum luminosity of the collider in the central region ($-1.5 < \eta < 1.5$) and in the region of small angles ($2.5 < \eta < 4.2$).

Study of event structure, collective variables, correlation characteristics, femtosopic correlation functions and high-p_T processes. Study of femtoscopic correlations in the energy range from 3 to 7.7 GeV. Study of the nuclear modification factor in collisions of gold nuclei at energies of 14.6, 19.6 and 27 GeV.

Software development and creation of infrastructure for processing STAR data at JINR using GRID technologies. Using machine learning methods for data processing.

Creation of media resources and laboratory works with the BNL and universities of the participating countries for training personnel to work at colliders of relativistic nuclei and polarized protons.

Study the possibility of future expansion of the investigation of nuclear structure and proton spin structure in *e-p* and *e*-A collisions at the NICA complex, as well as study the possibility of participating in the development of the Electron-Ion Collider (EIC) project.

Development of proposals for the creation of detectors for studying polarization phenomena at colliders, including the NICA collider.

Activities of the theme:

	Name of the activity	**Leaders**	**Implementation period**
Laboratory	Responsible from laboratories		**Status**
1.	**Participation in experiments and data analysis according to the BESII energy scan program. Search for signatures of phase transitions and the QCD critical point**	**Yu.A. Panebrattsev**	2024-2026 Data taking Data analysis
VBLHEP	A. Aitbayev, A.A. Aparin, G.S. Averichev, T.G. Dedovich, V.B. Dunin, A.O. Kechechyan, A.A. Korobitsyn, S.S. Panyushkina, V.V. Tikhomirov, M.V. Tokarev, Vinh Ba Luong, G.A. Yarygin		

Brief annotation and scientific rationale:
Data processing using the BESII energy scan program in collider mode and in fixed-target mode.

Expected results upon completion of the activity:
Drawing conclusions about phase transition signatures and the QCD critical point based on data analysis of the BESII program.

Expected results of the activity this year:
Study of event structure, collective variables, correlation characteristics, femtosopic correlation functions and high-p_T processes. Study of femtoscopic correlations in the energy range from 3 to 7.7 GeV. Study of the nuclear modification factor in collisions of gold nuclei at energies of 14.6, 19.6 and 27 GeV.

2.	**Study of spin effects in collisions of transversely polarized protons with protons and nuclei. Measurement of inclusive transverse spin asymmetries and fragmentation functions**	**M.V. Tokarev**	2024-2026 Realization
VBLHEP	A.A. Aparin, T.G. Dedovich, V.V. Lyuboshits, E.I. Schakhaliev, O.V. Teryaev		
MLIT	Zh.Zh. Musulmanbekov		
BLTP	S.V. Goloskokov		

Brief annotation and scientific rationale:
Study of the structure functions of quarks and gluons in collisions of transversely and longitudinally polarized protons at an energy of 510 GeV and in collisions of polarized protons with nuclei at an energy of 200 GeV. Analysis of experimental data using the Cold QCD program.

Expected results upon completion of the activity:
Conducting experiments with longitudinally and transversely polarized protons at a maximum energy of 510 GeV.

Analysis of experimental data using the Cold QCD program. This allowed us to study the distributions of Sievers, transversity, Collins fragmentation functions in previously inaccessible regions and expand the program for the analysis of asymmetries of the production of $W^{\pm}$ and Z^0 bosons.

Expected results of the activity this year:
Execution of an experimental program with transversely polarized protons at an energy of 200 GeV.

Performing measurements in a wide range of pseudo-rapidities of $-1.5 < \eta < 1.5$ (central region) and $2.8 < \eta < 4.2$ (forward rapidity), corresponding to the range of Bjorken variable $0.005 < x < 0.5$.

3.	**The study of event structure, collective effects, femtoscopic correlations and high-p_T processes**	**R. Lednicky** **Yu.A. Panebrattsev**	2024-2026 Realization

VBLHEP G.N. Agakishiev, A.A. Aparin, T.G. Dedovich, A.O. Kechechyan, A.A. Korobitsyn, Vinh Ba Luong, G.A. Nigmatkulov, S.S. Panyushkina, E.I. Schakhaliev, M.V. Tokarev

MLIT G.A. Ososkov

Brief annotation and scientific rationale:
Further development and application of correlation femtoscopy methods developed at JINR for the analysis of experimental data.

Expected results upon completion of the activity:
Study of the space-temporal parameters of the production processes, using correlations of identical and non-identical particles, including hyperons, considering the interaction in the final state and spin correlations, to clarify the equation of state of dense and super dense nuclear matter similar to that in neutron stars.

Expected results of the activity this year:
Study of the fractal structure of events depending on the transverse momentum.

Determination of the fractal structure of interactions in events with high multiplicity. Determination of spatiotemporal parameters in the fixed-target mode.

Study of the production of neutral kaons in the region of small transverse momenta.

4.	**Modernization of the STAR facility for measurements in the rapidity region of $2.5 < \eta < 4.2$. Collection of statistics on collisions of gold nuclei at an energy of 200 GeV and the maximum luminosity of the RHIC collider**	**Yu.A. Panebrattsev**	2024-2026 Data taking Data processing Data analysis

VBLHEP A.A. Aitbaev, G.N. Agakishiev, A.A. Aparin, G.S. Averichev, T.G. Dedovich, A.O. Kechechyan, G.A. Nigmatkulov, Vinh Ba Luong, O.V. Rogachevsky, E.I. Schakhaliev, M.V. Tokarev

MLIT N.I. Gromova, V.V. Mitsyn

Brief annotation and scientific rationale:
Implementation of an experimental program with heavy nuclei using the Hot QCD Physics program in the extended acceptance of the STAR facility in the region of high rapidity and increased luminosity of the RHIC collider.

Expected results upon completion of the activity:
Investigation, within the framework of the Hot QCD Physics program, the microstructure of QGP in gold-gold collisions at the energy of 200 GeV to refine the QCD phase diagram and determine the properties of QGP at small scales.

Expected results of the activity this year:
Obtaining an experimental data of the Hot QCD program for collisions of gold nuclei at a maximum energy of 200 GeV and maximum luminosity of the collider.

5.	**Development of the software and formation of the infrastructure for the STAR data processing at JINR. Application of machine learning methods for data processing**	**Yu.A. Panebrattsev** **V.V. Korenkov** (MLIT)	2024-2026 Realization

VBLHEP A.A. Aparin, G.N. Agakishiev, A.A. Korobitsyn, P.D. Semchukov

MLIT N. Balashov, V.V. Mitsyn, G.A. Ososkov, T.A. Strizh

Brief annotation and scientific rationale:
Using distributed computing capabilities (JINR GRID structure) to process data from the STAR experiment. Development of machine learning methods for analyzing experimental data from the STAR facility.

Expected results upon completion of the activity:
Preparation of experimental data from runs 2022–2024 in the formats for data processing at JINR.

Development of new data processing methods.

Expected results of the activity this year:
Development of machine learning methods for analyzing experimental data from the STAR facility.

6. **Creation of media resources and laboratory works with the BNL and universities of the participating countries for training personnel to work at colliders of relativistic nuclei and polarized protons** — **N.E. Sidorov, K.V. Klygina** — 2024-2026 — Realization

VBLHEP E.I. Golubeva, M.P. Osmachko, P.D. Semchukov, N.I. Vorontsova

UC S.N. Balalykin, Hoang Bao Han Nguyen, L.V. Platonova, O.A. Smirnov, T.G. Stroganova

Brief annotation and scientific rationale:
Development of media resources and laboratory workы for training personnel to work at colliders of relativistic nuclei and polarized protons.

Expected results upon completion of the activity:
Preparation of educational and presentation materials on studying the structure of matter and nucleus-nucleus interactions in experiments at colliders (RHIC, NICA).

Expected results of the activity this year:
Preparation of a VR excursion to the NICA accelerator complex, preparation of a textbook "Experimental Nuclear Physics and Nuclear Electronics", development of an exhibition in the NICA/MPD hall.

7. **Development of proposals on creating detectors for study of polarization phenomena at colliders** — **V.B. Dunin** — 2024-2026 — Project development

VBLHEP V.V. Fimushkin

Brief annotation and scientific rationale:
Development of proposals for the creation of detectors for polarimetry at the NICA collider.

Expected results upon completion of the activity:
Creation of a polarimeter that will provide an accuracy of about 2 % in 300 seconds at a current of 10 mA.

Expected results of the activity this year:
Production of a prototype of a universal proton polarimeter, where it is planned to place 4 clusters of silicon detectors placed at angles of 110 and 130 degrees, allowing to measure the asymmetry in the ^{6}Li(p, ^{3}He)^{4}He reaction.

8. **Study the possibility of future expansion of the investigation of nuclear structure and proton spin structure in *e-p* and *e*-A collisions at the NICA complex, as well as study the possibility of participating in the development of the Electron-Ion Collider (EIC) project** — **A.A. Aparin** — 2024-2026 — Project development

VBLHEP V.B. Dunin, A.A. Korobitsyn, N.A. Lashmanov, S.S. Panyushkina, V.Yu. Rogov

DLNP A.S. Zhemchugov

Brief annotation and scientific rationale:
Further prospects for research in the field of relativistic nuclear physics are associated with the creating and conducting experiments at electron-ion colliders. Studies of spin effects at the EIC appear to complement the physics program of the SPD experiment at the NICA collider.

Expected results upon completion of the activity:
Together with JINR Member States, participation in the preparation of the EIC physics program. Preparation of proposals for the participation of the JINR group in the development of the technical design of one of the detectors for studying electron-ion collisions.

Expected results of the activity this year:
Creation of a stand based on a scintillation hodoscope with the collection of data from silicone photomultipliers for work on creating a prototype of a DIRC Cherenkov detector.

Collaboration

Country or International Organization	City	Institute
Armenia	Yerevan	Foundation ANSL
Azerbaijan	Baku	IRP ANAS
Bulgaria	Sofia	INRNE BAS
		SU
China	Lanzhou	IMP CAS
	Wuhan	CCNU
Cuba	Havana	InSTEC
Czech Republic	Rez	NPI CAS
Egypt	Cairo	AUC
	Giza	NILES CU
France	Nantes	SUBATECH
India	Chandigarh	PU
	Jammu	Univ.
	Tirupati	IISER
Kazakhstan	Almaty	INP
Mexico	Mexico City	UNAM
Mongolia	Ulaanbaatar	MNUE
Russia	Dolgoprudny	MIPT
	Moscow	ITEP
		NNRU "MEPhI"
	Protvino	IHEP
	Saint Petersburg	SPbSU
Serbia	Belgrade	INS "VINCA"
	Novi Sad	UNS
Slovakia	Bratislava	IP SAS
	Kosice	UPJS
USA	Berkeley, CA	Berkeley Lab
	Bloomington, IN	IU
	Chicago, IL	UIC
	Lemont, IL	ANL
	New Haven, CT	Yale Univ.
	Stony Brook, NY	SUNY
	University Park, PA	Penn State
	Upton, NY	BNL
Vietnam	Da Lat	DNRI

02-2-1081-2009

ATLAS
Upgrade of the ATLAS Detector and Physics Research at the LHC

Theme leader: V.A. Bednyakov
I.V. Yeletskikh

Participating countries and international organizations:
Armenia, Azerbaijan, Belarus, Bulgaria, Canada, CERN, Czech Republic, France, Georgia, Germany, Israel, Italy, Netherlands, Russia, Slovakia, Spain, USA.

The problem under study and the main purpose of the research:
Studies of the proton-proton interactions at unprecedented collision energies (up to 14 TeV), in particular, investigation of the nucleon structure, measurements of the Higgs-boson properties, searches for new phenomena beyond the Standard Model, studies of the heavy quarks and multiquark states, precision Standard Model tests, participation in software support of the ATLAS experiment, modelling of the physical processes and upgrade of the detector systems.

Projects in the theme:

	Name of the project	Project Leaders	Project code
1.	ATLAS Physical researches at the LHC	V.A. Bednyakov I.V. Yeletskikh	02-2-1081-1-2010/2025
2.	Upgrade of the ATLAS detector	A.P. Cheplakov I.V. Yeletskikh	02-1-1081-2-2013/2025

Projects:

	Name of the project	Project Leaders	Status
Laboratory	Responsible from laboratories		
1.	**ATLAS** **Physical researches at the LHC**	**V.A. Bednyakov** **I.V. Yeletskikh**	Technical Proposal

DLNP A.M. Artikov, N.V. Atanov, V.Yu. Baranov, V.Yu. Batusov, I.R. Boyko, M.V. Chizhov, Yu.I. Davydov, D.V. Dedovich, M.A. Demichev, A.R. Didenko, A.V. Ershova, L.R. Gladilin, V.V. Glagolev, A. Gongadze, I. Gongadze, L. Gongadze, M.I. Gostkin, K.I. Gritsay, A.V. Guskov, N. Huseinov, Yu.P. Ivanov, L.V. Kalinovskaja, S.N. Karpov, Z.M. Karpova, N.N. Kaurtsev, N.V. Kirichkov, T.V. Khramov, D.V. Kharchenko, O.A. Koval, N.A. Kovyazina, D.A. Kozhevnikov, V.G. Kruchonok, Yu.A. Kultchitsky, M.V. Lyablin, A.V. Lapkin, G.I. Lykasov, I. Lyashko, V.V. Lyubushkin, T.V. Lyubushkina, S.N. Malyukov, I. Minashvili, I. Minashvili I., Yu.A. Nefedov, A.A. Nozdrin, E.M. Plontikova, S.Yu. Porokhovoy, I.N. Potrap, T.O. Rudenko, A.A. Sapronov, A.V. Shaikovskii, A.V. Simonenko, R.V. Sotenskii, M.M. Shiyakova, A.N. Shalyugin, V.V. Tereschenko, I.N. Troeglazov, P.V. Tereshko, Yu.A. Usov, A.O. Vasyukov, V.I. Yermolchik, Yu.V. Yermolchik, A.S. Zhemchugov

VBLHEP F.N. Ahmadov, A.P. Cheplakov, Yu.A. Fillipov, A.V. Ivanov, V.V. Kukhtin, E.A. Ladygin, M. Manashova, S.N. Nagorny, B.G. Shaykhatdenov, A.A. Soloshenko, T. Turtuvshin, N.I. Zimin

MLIT E.I. Alexandrov, I.N. Aleksandrov, N.I. Gromova, , A.V. Iakovlev, V.V. Korenkov, M.A. Mineev

BLTP A.B. Arbuzov, A.V Bednyakov, S.G. Bondarenko, D.I. Kazakov, O.V. Teryaev

Associated Personnel ATLAS A.N. Amirkhanov, V. Bobrovnikov, A. Buzykaev , S.N. Filimonov, O.I. Kuchinskaya, A. Maslennikov, O. Rezanova, , I.V. Shreiber , A.A. Snesarev, E.Yu. Soldatov, Yu. Tikhonov

Brief annotation and scientific rationale:
The main purpose of the international ATLAS experiment is investigation of proton-proton interactions at unprecedented energies at the LHC collider (from 7 to 14 TeV center-of-mass energy). These interactions are the source of different (including unknown)

physical processes between elementary particles. Study of such processes and their description within a common framework represent the main problem of the modern physical science.

The ATLAS experiment is performing a number of precision tests of the Standard Model, probing the limits of its validity and searching for the answers to the key questions of the modern physics like the nature of the dark matter, existence of additional spacial dimensions, etc.

The ATLAS multipurpose facility is unique and unprecedented w.r.t. its performance and complexity. It combines the most up-to-date advances of science, technology and communication. Participation in such large-scale international project gives access to the cutting-edge technologies of the physical experiment, gaining experience in real data analysis, precision modelling of the physical processes, software and theoretical support of experiment and looks absolutely necessary for such international organisation as JINR.

Expected results upon completion of the project:
Analysis of pp-collisions data at 13.6 TeV as well as High-Luminosity LHC (HL-LHC) data are going to provide the new and unique experimental results. The most important among them are -- investigation of the proton structure, in particular, the transverse momentum density of gluons in proton; studies of the heavy hadron spectra, including beauty mesons and exotic tetraquark and pentaquark states; precision SM tests at LHC energies and searches beyond the SM. High Luminosity regime of LHC will allow studies of the rare processes, e.g., Higgs-boson production in association with single top-quark.

Achieving these goals is impossible without developing new methods of data processing analysis. The active participation of JINR physicists is planned in the trigger software support, developing new methods of detector simulation, application of the machine learning techniques in physics analysis.

The implementation of this Project aimed at solving highly significant scientific problems will yield unique applied results. Among these 'byproduct' results are the experience in operation of remote monitoring systems for technically complicated devices, big data processing and development and practical use of distributed comtputing systems (GRID) and database monitoring applications in long-term large-scale experiments. Applications of this experience if possible, in other JINR projects.

Expected results of the project this year:
Study of the resonant Jpsi pairs production, probing of the fully-charmed tetraquark models describing these processes.

Studies of the hidden-charm tatraquark states in B-hardron decays to Jpsi + light hardon tracks.

Analysis of the Higgs boson production in association with single top quark.

Measurements of the heavy beauty meson properties, in particular, Bc-meson excited states.

Predictions and measurements of the gluon transverse momentum density in proton.

Search for quantum black holes in the lepton+jet channel at 13 TeV.

Higgs boson production in association with vector W, Z bozons studies.

Development and support of the ATLAS software.

Development of database monitoring applications.

Simulation studies of the ATLAS colorimeter response.

Participation in the Phase-2 ATLAS Upgrade Project of the muon spectrometer and calorimeters.

2.	**Upgrade of the ATLAS detector**	**A.P. Cheplakov** (VBLHEP) **I.V. Yeletskikh**	Implementation

DLNP	N.V. Atanov, V.Yu. Baranov, A.V. Boikov, Yu. I. Davydov, S.N. Malyukov, K.I. Gritsaj, A. Gongadze, I. Minashvili., V.A. Rogozin , A.V. Shaikovsky
VBLHEP	F.N. Ahmadov, V.V. Kukhtin, E.A. Ladygin, M. Manashova, T. Turtuvshin
FLNP	M. Bulavin

Brief annotation and scientific rationale:
The second phase of the ATLAS detector upgrade is aimed at preparing the facility for operation in the conditions of high luminosity of the LHC. During the first phase, which was successfully completed in 2022, the main contribution of the JINR group was participation in the implementation of the project to create a new muon wheel, an important element of the muon spectrometer. The modernization of the muon spectrometer continues in terms of creating RPC cameras. The development, testing and manufacturing of a system for reading signals from a liquid-argon calorimeter (LAr) based on fiber optic technology is underway. With the participation of JINR, a new high-granularity timing detector (HGTD) is being developed.

Expected results upon completion of the project:
Completion of the modernization of the detector systems will ensure stable and efficient operation of the ATLAS facility with the LHC luminosity at a level 5-7 times higher than the design value of about 10^{34} cm^{-2} s^{-1}, and collecting full statistics at the level of 3000 fb^{-1}.

Expected results of the project this year:
Development and prototyping of the RPC cameras. Creation of fiber optic cables for the LAr test bench. Creation of a tooling prototype for HGTD assembly.

Collaboration

Country or International Organization	City	Institute
Armenia	Yerevan	Foundation ANSL
Azerbaijan	Baku	IP ANAS
Belarus	Gomel	GSTU
		GSU
	Minsk	IAP NASB
		INP BSU
		IP NASB
Bulgaria	Sofia	SU
Canada	Vancouver	TRIUMF
CERN	Geneva	CERN
Czech Republic	Prague	CU
France	Clermont-Ferrand	LPC
	Orsay	LAL
Georgia	Tbilisi	HEPI-TSU
Germany	Zeuthen	DESY
Israel	Rehovot	WIS
Italy	Pisa	INFN
Netherlands	Amsterdam	NIKHEF
Russia	Moscow	ITEP
		LPI RAS
		MSU
	Protvino	IHEP
	Vladikavkaz	NOSU
Slovakia	Bratislava	CU
		IP SAS
Spain	Barcelona	IFAE
USA	Lemont, IL	ANL

02-1-1083-2009

CMS
Compact Muon Solenoid at the LHC

Theme leader: V.Yu. Karjavin

Scientific leader: V.A. Matveev

Participating countries and international organizations:
Armenia, Austria, Belarus, Belgium, Brazil, Bulgaria, CERN, China, Croatia, Cyprus, Czech Republic, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, India, Iran, Ireland, Italy, Lithuania, Mexico, Montenegro, Netherlands, New Zealand, Pakistan, Poland, Republic of Korea, Russia, Serbia, Spain, Switzerland, Taiwan, Turkey, United Kingdom, USA, Uzbekistan.

The problem under study and the main purpose of the research:
Development and realization of a research program at the LHC accelerator complex to study phenomena within the standard model and beyond; modernization, commissioning and operation of the CMS experimental complex.

Projects in the theme:

	Name of the Project	Project Leader	Project code
1.	CMS Physical researches at the LHC	V.Yu. Karjavin	02-1-1083-1-2010/2025
2.	Upgrade of the CMS Detector	V.Yu. Karjavin	02-1-1083-2-2010/2026

Projects:

Laboratory	Name of the Project Responsible from laboratories	Project Leader	Status
1.	**CMS** **Physical researches at the LHC**	**V.Yu. Karjavin**	Realization
1.1.	**Research physics programme with the CMS detector**	**S.V. Shmatov** (MLIT)	Realization
VBLHEP	V.Yu. Alexakhin, S.V. Afanasiev, P.D. Budkovsky, M.G. Gavrilenko, I.N. Gorbunov, A.Yu. Kamenev, L.G. Kobylets, A.V. Lanev, A.I. Malakhov, V.V. Shalaev, S.G. Shulga, I.A. Zhizhin, A.V. Zarubin		
BLTP	M. Deka, G.A. Kozlov, M.V. Savina, O.V. Teryaev, V.A. Zykunov		
MLIT	O.L. Kodolova, V.Yu. Korsakov, A.N. Nikitenko, G.A. Ososkov, V.V. Palchik, K.V. Slizhevsky, N.N. Voytishin		
1.2.	**Hadron calorimetry**	**A.V. Zarubin**	Maintenance Data taking
VBLHEP	P.D. Bunin, Yu.V. Ershov, N.S. Golova, A.M. Kurenkov		
1.3.	**Forward muon station ME1/1**	**V.Yu. Karjavin**	Maintenance Data taking
VBLHEP	Yu.V. Ershov, A.O. Golunov, N.V. Gorbunov, A.Yu. Kamenev, S.V. Kilchakovskaya, A.M. Kurenkov, A.M. Makan'kin, V.V. Perelygin, A.V. Zarubin		
MLIT	V.V. Palchik, N.N. Voytishin		
UC	B.S. Yuldashev		

1.4.	**Development of software for distributed computation, data processing and analysis based on GRID-technology**	**V.V. Korenkov** (MLIT) **S.V. Shmatov** (MLIT)	Realization

MLIT A.G. Dolbilov, I.A. Filozova, A.O. Golunov, I.A. Kashunin, V.V. Mitsyn, A.N. Moybenko, D.A. Oleynik, G.A. Ososkov, V.V. Palichik, A.Sh. Petrosyan, R.N. Semenov, T.A. Strizh, V.V. Trofimov, N.N. Voytishin

VBLHEP N.V. Gorbunov, A.O. Golunov

Associated Personnel CMS Yu.M. Andreev, T. Aushev, M.V. Chadeeva, R.N. Chistov, M.V. Danilov, T. Dimova, A.A. Erchov, A.M. Gribushin, L. Hein, V.N. Ivanchenko, M.M. Kirsanov, V.I. Klyukhin, A.N. Kozyrev, S.V. Petrushenko, S.N. Polikarpov, O. Radchenko, Yu.I. Skovpen, I.V. Tlisova, A.N. Toropin

Brief annotation and scientific rationale:
The goal of research is to study the physics of pp collisions at the Large Hadron Collider (LHC) using data collected with the CMS detector, corresponding to an integrated luminosity of up to 450 fb^{-1}; data taking, data processing and analysis to obtain new physics results in the following fields:

– searches for new physics with the dimuon in final states, based on extended gauge models and scenarios with TeV-scale gravity (extra dimension models);

– searches for dark matter candidates with the dimuon/b-quarks in final states and missing transverse energy;

– studies of Higgs boson properties and searches for new scalar bosons in lepton decays, predicted by extended Higgs sector;

– studies of muon pair production in Drell-Yan process to test SM at new energy scale, measurement of weak mixing angle and parton distribution functions (PDF);

– jet measurements for studies of hadronization, improvement of PDF and QCD coupling precision.

The project is also focused on the operation and study of performance of the CMS endcap detectors – hadron calorimeters (Hadron Endcap, HE) and forward muon stations (Muon Endcap, ME1/1).

Expected results upon completion of the project:
Experiments with the CMS Detector at the LHC, commissioning and ensuring operation of CMS hadron calorimetry and the forward muon stations during data taking at high luminosity and nominal energy.

Development and realization of physics program to test the Standard Model and searches for physics beyond the Standard Model using data collected with the CMS detector facility at the LHC corresponding to an integrated luminosity of 450 fb^{-1} at a nominal center-of-mass energy.

Expected results of the project this year:
Tests of the Standard Model and searches for new physics with high energy muons and missing transverse energy in the final state based on processing and analysis of proton-proton collision data collected with the CMS detector at the LHC at a center-of-mass energy of 13 and 13.6 TeV, corresponding to an integrated luminosity of up to 350 fb^{-1}; development and improvement of algorithms for reconstruction of high energy muons and jets.

Maintance and operation of the CMS detectors, participation in data taking, data quality monitoring, and shifts.

Development of software for GRID-based distributed system for data processing and analysis. Data transmission between the Tier-1/Tier-2 centers of CMS and JINR.

2. Upgrade of the CMS Detector		**V.Yu. Karjavin**	Realization
2.1.	**Upgrade of the forward muon station ME1/1**	**V.Yu. Karjavin**	Upgrade

VBLHEP Yu.V. Ershov, A.O. Golunov, N.V. Gorbunov, A.Yu. Kamenev, S.V. Kilchakovskaya, A.M. Kurenkov, A.M. Makan'kin, V.V. Perelygin

MLIT V.V. Palchik, N.N. Voytishin

2.2.	**Construction of the high granularity calorimeter**	**S.V. Afanasyev**	Realization

2.2.1.	**Experemental facility for complex tests of HGCal Cassettes**	**S.V. Afanasiev A.I. Malakhov**	Realization
2.2.2.	**Cooling plates and sensors for the High Granularity Calorimeter**	**A.V. Zarubin**	Realization

VBLHEP V.Yu. Alexakhin, P.D. Bunin, B.V. Dubinchik, Yu.V. Ershov, A.O. Golunov, N.V. Gorbunov, A.M. Kurenkov, V.A. Smirnov, E.V. Sukhov, V.V. Ustinov, N.I. Zamyatin

MLIT A. Khvedelidze, V.V. Korenkov, V.V. Palchik, I. Satyshev, S.V. Shmatov, N.N. Voytishin

UC B.S. Yuldashev

Brief annotation and scientific rationale:
Starting from 2029 the LHC will be running at luminosity of 7.5×10^{34} $cm^{-2}c^{-1}$ (High Luminosity LHC, HL−LHC) that will allow increasing statistics by more than one order of magnitude ($L_{int} \sim 3000$ fb^{-1}). The LS 3 for the LHC upgrade to HL−LHC is planned from 2026 to 2029. The main goal of the CMS upgrade in LS3 is to ensure effective work of all subsystems in HL−LHC era.

The main goal of this project is contribution to construction of the Highly Granularity Calorimeter (HGCal) and an upgrade of the CMS ME1/1 Cathode Strip Chambers.

Expected results upon completion of the project:
Upgrade of the CMS Detectors with JINR responsibilities to ensure effective operation at high luminosity in pp−collisions at the nominal LHC energy.

Expected results of the project this year:
Upgrade of the forward muon station ME1/1 and study of degradation in performance of the CSC chambers at the HL−LHC conditions.

Construction of the experimental facility and participation in complex tests of HGCal active elements.

Applictaion of the technology for manufacturing the HGCal cooling plates for the mass production.

Collaboration

Country or International Organization	**City**	**Institute**
Armenia	Yerevan	Foundation ANSL
Austria	Vienna	HEPHY
Belarus	Gomel	GSU
	Minsk	INP BSU
Belgium	Antwerp	UAntwerp
	Brussels	ULB
		VUB
	Ghent	Ugent
	Leuven	KU Leuven
	Louvain-la-Neuve	UCL
	Mons	UMONS
Brazil	Rio de Janeiro, RJ	CBPF
		UERJ
	Sao Paulo, SP	Unesp
Bulgaria	Sofia	INRNE BAS
		SU
CERN	Geneva	CERN
China	Beijing	"Tsinghua"
		IHEP CAS
		PKU
	Hangzhou	ZJU
Croatia	Split	Univ.
	Zagreb	RBI
Cyprus	Nicosia	UCY

Czech Republic	Prague	CU
Estonia	Tallinn	NICPB
Finland	Helsinki	HIP
		UH
	Lappeenranta	LUT
France	Lyon	UL
	Paris	IN2P3
	Saclay	IRFU
	Strasbourg	IPHC
Georgia	Tbilisi	GTU
		HEPI-TSU
Germany	Aachen	RWTH
	Hamburg	DESY
		Univ.
	Karlsruhe	KIT
Greece	Athens	INP NCSR "Demokritos"
		NTU
		UoA
	Ioannina	UI
Hungary	Budapest	Wigner RCP
	Debrecen	Atomki
		UD
India	Chandigarh	PU
	Jatani	NISER
	Kolkata	SINP
	Mumbai	BARC
		TIFR
Iran	Tehran	IPM
Ireland	Dublin	UCD
Italy	Bari	INFN
	Bologna	INFN
	Catania	INFN LNS
	Florence	INFN
	Frascati	INFN LNF
	Genoa	INFN
	Milan	INFN
	Naples	INFN
	Padua	INFN
	Pavia	INFN
	Perugia	INFN
	Pisa	INFN
	Rome	INFN
	Trieste	INFN
	Turin	INFN
Lithuania	Vilnius	VU
Mexico	Mexico City	Cinvestav
	Puebla	BUAP
Montenegro	Podgorica	Univ.
Netherlands	Eindhoven	TU/e
New Zealand	Auckland	Univ.
	Christchurch	UC
Pakistan	Islamabad	QAU
Poland	Krakow	AGH
		AGH-UST
	Otwock (Swierk)	NCBJ

	Warsaw	UW
Republic of Korea	Daejeon	KIST
	Gwangju	CNU
	Seoul	KU
		SJU
		SKKU
		SNU
		Yonsei Univ.
Russia	Gatchina	NRC KI PNPI
	Moscow	ITEP
		LPI RAS
		NIKIET
		SINP MSU
	Moscow, Troitsk	INR RAS
	Protvino	IHEP
	Saint Petersburg	Electron
	Snezhinsk	RFNC-VNIITF
	Tomsk	TPU
	Zhukovsky	MDB
Serbia	Belgrade	INS "VINCA"
Spain	Madrid	CIEMAT
		UAM
	Oviedo	UO
	Santander	IFCA
Switzerland	Villigen	PSI
	Zurich	ETH
		UZH
Taiwan	Taipei	NTU
	Taoyuan City	NCU
Turkey	Adana	CU
	Ankara	METU
	Istanbul	BU
		YTU
United Kingdom	Bristol	Univ.
	Didcot	RAL
	London	Imperial College
USA	Baltimore, MD	JHU
	Batavia, IL	Fermilab
	Boston, MA	BU
		NU
	Boulder, CO	CU
	Buffalo, NY	UB
	Cambridge, MA	MIT
	Charlottesville, VA	UVa
	Chicago, IL	UIC
	College Park, MD	UMD
	College Station, TX	Texas A&M
	Columbus, OH	OSU
	Davis, CA	UCDavis
	Detroit, MI	WSU
	Evanston, IL	NU
	Gainesville, FL	UF
	Houston, TX	Rice Univ.
	Iowa City, IA	UIowa
	Ithaca, NY	Cornell Univ.

Knoxville, TN	UTK
Lawrence, KS	KU
Lincoln, NE	UNL
Livermore, CA	LLNL
Los Angeles, CA	UCLA
Lubbock, TX	TTU
Madison, WI	UW-Madison
Manhattan, KS	KSU
Minneapolis, MN	U of M
Nashville, TN	VU
New Brunswick, NJ	RU NB
New York, NY	RU
Notre Dame, IN	ND
Oxford, MS	UM
Pasadena, CA	Caltech
Pittsburgh, PA	CMU
Princeton, NJ	PU
Providence, RI	Brown
Riverside, CA	UCR
Rochester, NY	UR
San Diego, CA	SDSU
Santa Barbara, CA	UCSB
Tallahassee, FL	FSU
Tuscaloosa, AL	UA
Wako, TX	BU
West Lafayette, IN	Purdue Univ.

02-2-1085-2009

Experimental Tests of the Fundamentals of QCD

Theme leader: A.V. Guskov

Deputy: A.S. Zhemchugov

Participating countries and international organizations:
Belarus, CERN, China, Czech Republic, Germany, Israel, Italy, Japan, Poland, Portugal, Russia, United Kingdom, USA.

The problem under study and the main purpose of the research:
Quantum chromodynamics is a true theory of strong interaction. However, despite its considerable success in describing the interaction of quarks and gluons within the perturbative approach, the question of why hadrons and nuclei are as we see them remains open. Description of fundamental properties of hadrons, such as their masses, spins, parton distributions, form factors, spectra, etc., on the basis of fundamental principles of QCD is one of the main unsolved problems of quantum chromodynamics. Confinement of quarks and gluons in hadrons, as well as the growth of the running constant of strong interaction with decreasing characteristic scale of interaction energy does not allow direct use of the perturbative approach, which has proved itself at high energies. At present, various phenomenological models are used to quantitatively describe the hadron spectrum, static properties of hadrons, and their interactions at low energies. Certain success has been achieved in lattice calculations. A comparison of model predictions and theoretical calculations for observables with measurement results is an important test of the consistency and applicability limits of the approaches used. The ultimate goal of the research in this direction, both theoretical and experimental, is to obtain a description of the spectra, structure, and properties of hadrons from first principles of QCD.

Projects in the theme:

	Name of the project	Project Leaders	Project code
1.	BESIII	I.I. Denisenko *Deputy:* A.S. Zhemchugov	02-2-1085-1-2007/2028
2.	NA66 / AMBER	A.V. Guskov	02-2-1085-2-2024/2026

Projects:

	Name of the project	Project Leaders	Status
Laboratory	Responsible from laboratories		
1.	**BESIII**	**I.I. Denisenko** *Deputy:* **A.S. Zhemchugov**	Implementation

DLNP	O.V. Bakina, I. P. Boyko, D.V. Dedovich, P.A. Egorov, A.V. Guskov, Y.A. Nefedov
BLTP	V.V. Bytyev
MLIT	G. A. Ososkov, I.P. Pelevanyak, V.V. Rorenkov

Brief annotation and scientific rationale:
The goals of the JINR group in the BESIII project are to study hadronic QCD spectra and search for exotic states, study the production and decays of Charmonium states, search for exotic Charmonium states and charmonium-like structures, and determine c-quark fragmentation functions. The JINR group's participation in the project involves data analysis and development of algorithms for event reconstruction in the BESIII detector using machine learning methods.

Expected results upon completion of the project:
The project will produce new knowledge about the properties of strong interactions on the $Q^2 \sim M^2_{Jpsi}$ scale. In particular, information will be obtained on the spectrum of exotic light and charmonium-like states and their properties, as well as on the details of inclusive c-quark production.

Expected results of the project this year:
BESIII data analysis. Development of offline software and analysis tools. Participation in the data taking.

2. NA66 / AMBER **A.V. Guskov**

Implementation

DLNP V.M. Abazov, G.D. Alexeev, N.V. Anfimov, I.I. Denisenko, V.N. Frolov, A. Gongadze, A.O. Gridin, N.A. Koviazina, A. Maltsev, A.A. Piskun, A.G. Samartsev, A.S. Selyunin, S.S. Seryubin, N.I. Zhuravlev

VBLHEP V.A. Anosov, O.P. Gavrischuk, R. Gushterski, A.Yu. Korzenev, O.M. Kuznetsov, D.V. Peshekhonov, A.A. Shunko, E.V. Zemlyanichkina

MLIT A.Sh. Petrosyan

Brief annotation and scientific rationale:
AMBER (Apparatus for Meson and Baryon Experimental Research) is a new experimental facility with a fixed target on the M2 beam line of the CERN SPS. The facility is designed to perform a variety of measurements aimed at addressing fundamental questions of quantum chromodynamics, which are expected to lead to a significant improvement in the understanding of QCD as a modern theory of strong interactions. The proposed measurements cover physics ranging from the smallest Q^2 values, such as determining the charge radius of a proton in elastic muon-proton scattering, reactions with moderate Q^2 values for hadronic spectroscopy, and studies of hadronic structure with high Q^2 using rigid Drell-Yan, Charmonium, and fast photon production processes. The JINR group is responsible for the modernization and operation of the HCAL1 hadron calorimeter and MW1 (Muon Wall 1) high-angle muon identification system. It is also involved, along with a group from the University of Turin, in the production and support of the Bulk Micromegas track detectors that will replace the obsolete multi-wire chambers (MWPCs) in the SAS behind the SM2 magnet.

Expected results upon completion of the project:
Solving the proton radius puzzle. New knowledge of the quark and gluon structure of mesons. Accurate knowledge of the yield of antiprotons in p-p and p-He processes, essential for the search for dark matter in astrophysical experiments.

Expected results of the project this year:
Participation in the data taking for the Proton Radius Measurement program.

Participation in R&D for Micromegas detectors.

Data analysis on the antiproton production in p-He interaction.

Preparation of the front-end electronics upgrade to be able to operate in the triggerless mode.

Upgrade of the MW1 muon system.

Activities of the theme:

Laboratory	Name of the activity Responsible from laboratories	Leaders	Implementation period Status
1.	**PANDA**	**G.D. Alexeev**	2024-2026

Technical proposal

DLNP V.M. Abazov, S.A. Kutuzov, A.A. Piskun, I.K. Prokhorov, A.M. Rozhdestvensky, A.G. Samartsev, A.N. Skachkova, A.Yu.Verheev, L.S.Vertogradov, Yu.L.Vertogradova, V.P. Volnykh, N.I. Zhuravlev

Brief annotation and scientific rationale:
The PANDA project plans to conduct fundamental research on various topics related to the properties of weak and strong interactions, exotic states of matter, and the structure of hadrons. To collect all the necessary information in antiproton-proton collisions, a universal detector will be built that can provide accurate track reconstruction, energy and momentum measurements, and very efficient identification of charged particles.

Expected results upon completion of the activity:
Constructing the PANDA muon system.

Expected results on the activity this year:
Preparation to construct the PANDA muon system.

2. ARIeL **L.V. Kalinovskaya** 2024-2026

Theoretical support of collider experiments

Implementation

DLNP R. Boyko, E.V. Dydyshko, V.L. Ermolchik, Yu.V. Ermolchik, A.A. Kampf, V.V. Kornienko, Yu.A. Nefedov, L.A. Rumyantsev, R.R. Sadykov, A.A. Sapronov, A.S. Zhemchugov

BLTP A.B. Arbuzov, S.G. Bondarenko, V.V. Bytiev

Brief annotation and scientific rationale:
Currently there are 4 electron-positron collider projects under consideration: FCC, CEPC, ILC and CLIC. The measurements on refinement of parameters of the Standard Model will be carried out, and also various searches for effects beyond its limits will be performed. This requires highly accurate theoretical predictions for all SM processes to be studied at future colliders. Within the framework of this activity, it is planned to make theoretical predictions for most of the important observables. The required accuracy will be achieved by taking into account high-order radiative corrections and polarization effects.

Expected results upon completion of the activity:
High-precision theoretical predictions for effects in the Standard Model and beyond.

Expected results of the activity this year:
Precision theoretical calculations of radiation corrections for experiments at the future CLIC, ILC, FCC-ee and CEPC colliders.

Collaboration

Country or International Organization	**City**	**Institute**
Belarus	Minsk	INP BSU
CERN	Geneva	CERN
China	Beijing	IHEP CAS
Czech Republic	Prague	CTU
		CU
Germany	Bonn	UniBonn
	Darmstadt	GSI
	Freiberg	TUBAF
	Munich	TUM
Israel	Tel Aviv	TAU
Italy	Trento	UniTn
	Trieste	INFN
	Turin	INFN
Japan	Yamagata	Yamagata Univ.
Poland	Otwock (Swierk)	NCBJ
	Warsaw	IEP WU
		WUT
Portugal	Aveiro	UA
	Lisbon	LIP
Russia	Gatchina	NRC KI PNPI
	Novosibirsk	BINP SB RAS
	Protvino	IHEP
United Kingdom	Glasgow	U of G
USA	Los Alamos, NM	LANL

02-1-1087-2009

Research on Relativistic Heavy and Light Ion Physics. Experiments at the Accelerator Complex Nuclotron-M/NICA at JINR and CERN SPS

Theme leaders: A.I. Malakhov
S.V. Afanasiev

Participating countries and international organizations:
Armenia, Belarus, Bulgaria, CERN, China, India, Mongolia, Romania, Russia, Slovakia, Uzbekistan.

The problem under study and the main purpose of the research:
Study of new phenomena in multiple particle productions associated with the manifestation of the quark and gluon degrees of freedom in the interaction of relativistic nuclei. Study of nucleon and nuclear interactions at the VBLHEP accelerator complex, CERN SPS. Energy scan of interactions of nuclei at 20-158 GeV/nucleon energies and the study of their dependence on the atomic number of nuclei. To search for the critical point on the phase diagram of nuclear matter at the NA61 / SHINE (SPS, CERN). Study of hadron production in hadron-nucleus interactions. Use of the obtained data for the precision calculations of neutrino spectra and fluxes in the accelerator experiments to study the neutrino oscillations. Investigation of nucleon clustering and the contribution of unstable nuclear-molecular States to the dissociation of light stable and radioactive isotopes, as well as the properties of rarefied baryonic matter in the dissociation of heavy nuclei. Experimental and theoretical study of deep subthreshold, cumulative processes, the formation of hadrons and antimatter in the transition energy region. Investigation of processes in the region of large P_T ($P_T \geq 1$ GeV/c) in non-cumulative and cumulative kinematic regions at SPIN and FODS setups. Study of the behavior of elementary particles, nucleon resonances and nucleon fluctuations in nuclear matter on the SCAN spectrometer. Preparation of proposals of the experiments at the VBLHEP accelerator complex on the Nuclotron extracted beams and NICA Collider. Study of the short-range nucleon-nucleon correlations and the cluster structure of the nuclei using the beams of ions, polarized protons and deuterons at the internal target of the Nuclotron.

Projects in the theme:

	Name of the project	Project Leaders	Project code
1.	NA61 / SHINE	A.I. Malakhov *Deputies:* A.V. Dmitriev A.A. Zajtsev	02-1-1087-1-2012/2026
2.	SCAN-3	S.V. Afanasiev *Deputy:* D.K. Dryablov	02-1-1087-2-2017/2027

Projects:

	Name of the project	Project Leaders	Status
Laboratory	Responsible from laboratories		
1.	**NA61 / SHINE**	**A.I. Malakhov** *Deputies:* **A.V. Dmitriev** **A.A. Zajtsev**	Upgrade Preparation Data analysis
VBLHEP	V.A. Babkin, M.G. Buryakov, V.M. Golovatyuk, R.Yu. Kolesnikov, V.A. Kireev, V.A. Matveev, G.L. Melkumov, M.M. Rumyantsev		
DLNP	V.V. Lyubushkin, G.I. Lykasov, B.A. Popov, V.V. Tereschenko		
Associated Personnel NA61 / SHINE	I.V. Azhinenko, N. Karpushkin, S. Morozov		

Brief annotation and scientific rationale:
The main physics goals include: search for the second-order critical end-point in the temperature versus baryon-chemical potential phase diagram (looking for nonmonotonic behavior of critical point signatures, such as transverse momentum and multiplicity

fluctuations, intermittency signal, etc., when system freezes out close to the critical point), study the properties of the onset of deconfinement (search for the onset of the horn, kink, step, and dale structures in collisions of light nuclei). In recent years, the program has been extended by Pb+Pb collisions where the open charm production, as well as collective effects are studied. Based on the obtained results, few years ago NA61/SHINE introduced a concept of two onsets in nucleus-nucleus collisions at the CERN SPS energies: onset of deconfinement (beginning of QGP formation – collision energy threshold for deconfinement) and onset of fireball (beginning of formation of a large cluster which decays statistically – system-size threshold for creation of statistical system). The strong interactions program is based on beam momentum scans (13A-158A·GeV/c) with light and intermediate mass nuclei (from p+p to Xe+La).

Expected results upon completion of the project:
Data analysis of the NA61/SHINE experiment (SPS, CERN).

Studies of the birth of hadrons in hadron-nuclear interactions.

The study of the formation of charmed hadrons (mainly D-mesons) during the interaction of heavy ions in order to obtain new data on the average number of charmed quark-antiquark pairs and to understand the mechanism of the birth of open charm.

Obtaining data for precision calculation of neutrino spectra and fluxes in accelerator experiments for the study of neutrino oscillations.

Completion of the modernization of the TOF system.

Expected results of the project this year:
Processing and analysis of experimental data obtained at the NA61/SHINE installation on p+p, Be+Be, Ar+Sc, O+O, Pb+Pb collisions.

Conducting experimental studies on a beam of relativistic lead nuclei.

Investigation of anti-core formation in Ar+Ca and Xe+La collisions.

The study of the formation of enchanted hadrons in the interaction of heavy ions in order to understand the mechanism of the birth of an open charm.

2. **SCAN-3** **S.V. Afanasiev**
Deputy:
D.K. Dryablov

Upgrade
Preparation
Data analysis

VBLHEP Yu.S. Anisimov, A.A. Baldin, B.V. Dubinchik, P.R. Kharyuzov, S.V. Kilchakovskaia, Yu.F. Krechetov, O.V. Kutinova, M. Paraypan, D.G. Sakulin, V.A. Smirnov, E.V. Sukhov, V.V. Ustinov, D.V. Ustinov, V. Vartik

Brief annotation and scientific rationale:
The project is aimed at studying highly excited nuclear matter formed in dA interactions. This state of matter is studied by observing the decay of the excited nucleus into a pair of energetic particles emitted at an angle close to 180^0 and with an energy resolution of 4–5 MeV. The physics programme includes the study of the η- and Δ–nuclei formation and the determination of binding energies and widths of quasi-bound states.

Expected results upon completion of the project:
Upgrade of the SCAN setup.

Analysis of the experimental data on the behavior of nucleon resonances and nucleon fluctuations in nuclei, on the search and study of properties of the bound state-meson in nuclear matter.

Expected results of the project this year:

Testing of a three-beam magnetic spectrometer SCAN.

Conducting a technical session on the internal beam of the nuclotron to adjust the detectors and debug the data collection program.

Analysis of experimental data.

Activities of the theme:

	Name of the activity	Leader	Implementation period
Laboratory	Responsible from laboratories		Status
1.	**BECQUEREL2023**	**P.I. Zarubin** *Deputy:* **A.A. Zaytsev**	2024-2026 Upgrade Preparation Data analysis

VBLHEP D.A. Artemenkov, N.K. Kornegrutsa, M. Natarjan, V.V. Rusakova, P.A. Rukoyatkin

Brief annotation and scientific rationale:
The BECQUEREL experiment is aimed at solving topical problems in nuclear clustering physics. The used method of nuclear track emulsion (NTE) makes it possible, due to its unique sensitivity and spatial resolution, to study in a unified approach multiple final states arising in dissociation of relativistic nuclei. Progress in this direction relies on computerized microscopy.

Expected results upon completion of the activity:
Search and study of the Hoyle state and more complex nuclear-molecular States in the dissociation of light nuclei.

Analysis of the isotopic composition of the fragmentation of heavy nuclei.

Use of automated microscopes, as well as improvement of the NE technology.

Expected results of the activity this year:
Analysis of exposures to Xe (NICA/Nuclotron) and Kr (GSI) nuclei to study ^{8}Be decays and the Hoyle state and accompanying α-ensembles and search for the 4α-condensate.

Estimation of the parameters of accompanying neutrons.

Mastering identification by multiple scattering of *He* and *H* isotopes on a motorized microscope.

Search for ^{8}Be and ^{9}B isobar-analogue states in the ^{9}Be and ^{10}C exposures.

Mastering the identification of ensembles of stopped α-particles in the fragmentation of nuclei from the composition of the emulsion under the action of relativistic particles.

2.	**Experiment FASA-3 for registration of nuclear fragments**	**S.P. Avdeev**	2024-2026 Upgrade Preparation Data analysis

DLNP V.I. Stegaylov

FLNR V.V. Kirakosyan, E.M. Kozulin, G.V. Mushinsky, O.V. Strekalovsky

VBLHEP H.U. Abraamian, Z.A. Igamkulov, V. Karach, L.V. Kornyushina, P.A. Rukoyatkin, Z.A. Sadygov

Expected results upon completion of the activity:
Analysis of the experimental data on the processes of the multiple emission of intermediate mass fragments on the beams of relativistic light ions using a 4-π PHASE-3 setup for the registration of nuclear fragments.

Performing data analysis to determine the mechanism of multifragmentation and to obtain new information about the nuclear phase transitions "liquid-fog" and "liquid-gas".

Investigation of properties of hot nuclei formed in the collisions of light relativistic ions with heavy targets.

Production of the detector system for the registration of the decay of hypernuclei.

Expected results of the activity this year:
Debugging of the QUARTUS CAEN program at the PHASE spectrometer for registration of nuclear fragments.

Analysis of experimental data in the framework of statistical and dynamic models.

Preparation of a new project.

3. Investigation with light and heavy ions for applied research — **A.I. Malakhov** — 2024-2026

Realization
Preparation
Data taking

VBLHEP N.N. Agapov, Yu.S. Anisimov, A.A. Baldin, E.G. Baldina, D.K. Dryablov, M. Paraypan

Expected results upon completion of the activity:
Use of heavy and light ions for applied research.

Expected results of the activity this year:
Analysis of the results of irradiation of biological objects in accordance with Agreement of the JINR-BAS cooperation.

4. Upgrade of equipment the station of internal target of the Nuclotron — **S.V. Afanasiev, R.Yu.Kolesnikov** — 2024-2026

Upgrade
Data taking

VBLHEP Yu.S. Anisimov, D.K. Dryablov, B.V. Dubinchik, V. Vartik, A.S. Kuznetsov, S.N. Kuznetsov, D.G. Sakulin

Expected results upon completion of the activity:
Replacement of target operation control electronics from the KAMAK system to modern industrial standards.

Creating software for new electronics. Production of a target based on the carbon isotope ^{13}C.

Expected results of the activity this year:
Preparing the station for operation in the spring Nuclotron Run.

5. Test of the detectors for measurements and control the luminosity at the collider NICA — **G.D. Milnov** — 2024-2026

R&D
Technical Proposal

VBLHEP R.A. Akbarov, K.U. Abraamyan, T.Y. Bokova, Z.A. Igamkulov, L.V. Kornyushina, I.I. Migulina, A.Z. Sadygov, Z.Y. Sadygov, V.I. Shokin

FLNP E.I. Litvinenko

Expected results upon completion of the activity:
Creation of a detector and development of algorithms for configuring beam reduction in the NICA collider.

Expected results of the activity this year:
Preparation of a technical project for luminosity measurement at the NICA collider.

Production of two planes for the luminosity measurement detector.

6. Study of the multiparticle correlations at modernized internal targetstation at Nuclotron — **V.P. Ladygin** — 2024-2026

Preparation
Data taking

VBLHEP I.S. Volkov, Yu.V. Gurchin, A.Yu. Isupov, V.A.Kireev, N.B. Ladygina, K.S.Legostaeva, A.I. Malakhov, S.G. Reznikov, A.A. Terekhin, A.V. Tishevsky

Brief annotation and scientific rationale:
The study of multiparticle correlations is one of the ways to study the dynamics of nuclear-nuclear collisions. One of the goals of research on the internal target of the Nuclotron is to evaluate the contribution of short-range 2-nucleon correlations for C+A and Xe+A collisions.

Expected results upon completion of the project:
Experimental and theoretical research on the project program.

Expected results of the project this year:
Processing of experimental data obtained on a ^{124}Xe beam with an energy of 3 GeV/nucleon 3.8 GeV/nucleon.

7. Search and investigation of a new charged particle in the 2-120 MeV mass range — **V.A. Nikitin** — 2024-2026

Data analysis

VBLHEP M.Kh. Anikina, A.V. Beloborodov, V.S. Rikhvitsky, A.Yu. Troyan, A.A. Zaicev

Expected results upon completion of the activity:
Search and investigation of a charged particle in the 2-120 MeV mass range.

Expected results of the activity this year:
Addition of existing results with new data.

8. Acquisition, processing and digitation of information from bubble chamber and other fixed target experiments in the conditions of registration of multiple particle production in an energy range of 1-300 GeV — **A.A. Baldin**, **V.V. Glagolev** — 2024-2026

Data analysis

VBLHEP S.G. Arakelyan, E.G. Baldina, A.V. Belyaev, A.V. Beloborodov, Ver.V. Bleko, Vit. V. Bleko, D.N. Bogoslovsky, S.A. Chetverikov, A.P. Ierusalimov, V.V. Ilyushchenko, P.R. Kharyuzov, E.A. Klevcov, D.S. Korovkin, N.E. Kukharev, V.A. Pukhaeva, O.V. Rogachevsky, A.B. Safonov, A.Yu. Troyan, Yu.A. Troyan

Expected results upon completion of the activity:
Collection, processing and digitization of the film information obtained using bubble chambers and in electronic experiments with fixed targets under the conditions of registration of multiple birth of particles in the energy range of 1-300 GeV.

Preparation of an education programme for highly qualified students for the NICA project.

Expected results of the activity this year:
Analysis of bubble chamber data, search and research of new phenomena based on the JINR LIT supercomputer.

Replenishment of the experimental data base in the field of relativistic nuclear physics.

Refinement of the results obtained on a propane two-meter chamber, and analysis of data on the results of the NA61/SHINE experiment.

Collaboration

Country or International Organization	City	Institute or laboratory
Armenia	Yerevan	Foundation ANSL
		YSU
Belarus	Minsk	INP BSU
Bulgaria	Blagoevgrad	AUBG
	Sofia	INRNE BAS
		Inst. Microbiology BAS
		SU
CERN	Geneva	CERN
China	Beijing	CIAE
		IHEP CAS
	Wuhan	CCNU
India	Jaipur	Univ.
	Mumbai	BARC
Mongolia	Ulaanbaatar	IPT MAS

Romania	Bucharest	IFIN-HH
		UB
	Magurele	ISS
Russia	Belgorod	BelSU
	Chernogolovka	ISMAN RAS
	Moscow	ITEP
		LPI RAS
		MSU
		NRC KI
	Moscow, Troitsk	INR RAS
	Protvino	IHEP
	Saint Petersburg	FIP
	Smolensk	SSU
	Tomsk	TPU
	Vladikavkaz	NOSU
		VTC "Baspik"
Slovakia	Bratislava	IP SAS
	Kosice	UPJS
Uzbekistan	Jizzakh	JDPU
	Samarkand	SamSU
	Tashkent	Assoc. P.-S. PTI

02-1-1088-2009

ALICE
Study of Interactions of Heavy Ion and Proton Beams at the LHC

Theme leader: A.S. Vodopyanov

Participating countries and international organizations:
Armenia, Austria, Azerbaijan, Bangladesh, Brazil, Bulgaria, CERN, China, Croatia, Cuba, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, India, Indonesia, Italy, Japan, Malta, Mexico, Netherlands, Norway, Pakistan, Peru, Poland, Republic of Korea, Romania, Russia, Slovakia, South Africa, Sri Lanka, Sweden, Thailand, Turkey, Ukraine, United Kingdom, USA.

The problem under study and the main purpose of the research:
Experimental study of heavy ion interactions at relativistic and ultra-relativistic energies.

Project in the theme:

Laboratory	Name of the Project Responsible from laboratories	Project Leader	Project code Status
1.	**ALICE**	**A.S. Vodopyanov**	02-1-1088-1-2010/2025 Realization
VBLHEP	V.I. Astakhov, V.A. Arefiev, S.C. Ceballos, R.A. Diaz, V.H. Dodokhov, E.M. Klass, V.I. Lobanov, P.V. Nomokonov, I.A. Rufanov		
Associated Personnel ALICE	A. Borisov, D.A. Finogeev, A.A. Furs, O.V. Karavichev, T.L. Karavicheva, N.V. Kondratieva, E.L. Kryshen, M.A. Sukhanov, N.O. Voznyuk		

Brief annotation and scientific rationale:
Participation in the preparation of proposals for the modernization of the ALICE detector: a magnetic system and forward detectors.

Expected results upon completion of the project:
Participation in the maintenance and operation of the ALICE detector.

Participation in the preparation of the modernization of the ALICE detector: a superconducting magnet, an outer tracker based on silicon sensors.

Expected results of the project this year:
Participation in the maintenance and operation of the ALICE detector.

Elaboration of the technical project of an electromagnetic calorimeter and an outer tracker.

Activities of the theme:

Laboratory	Name of the activity Responsible from laboratories	Leader	Implementation period Status
1.	**Physical process simulation and data analysis**	**B.V. Batyunya**	2024-2025 Realization
VBLHEP	M.Yu. Barabanov, S.S. Grigoryan, A.V. Kuznetsov, K.P. Mikhaylov, E.P. Rogochaya, Yu.L. Vertogradova, A.S. Vodopyanov		
DLNP	G.I. Lykasov		
BLTP	D. Blaschke, S.N. Nedelko		

Brief annotation and scientific rationale:
Participation in the development of the ALICE scientific program and the processing and analysis of experimental data.

Expected results upon completion of the project:
Processing and analysis of experimental data on femtoscopy of charged kaons and ultraperipheral interactions in collisions of protons, nuclei and nuclei with protons.

Preparation of publications, reports at international conferences.

Expected results of the project this year:
Processing and analysis of experimental data on femtoscopy of charged kaons and ultraperipheral interactions in collisions of protons, nuclei and nuclei with protons.

Preparation of publications, reports at international conferences.

2.	**ALICE Computing in the distributed environment-GRID**	**A.S. Vodopyanov**	2024-2025
			Realization
VBLHEP	B.V. Batyunya, E.P. Rogochaya, G.G. Stiforov		
MLIT	A.O. Kondratiev, V.V. Mitsyn		

Brief annotation and scientific rationale:
Processing and analysis of experimental data are carried out within the framework of the distributed computer network GRID of the ALICE collaboration. Modernization of equipment and software is carried out on a permanent basis. The MLIT JINR Complex is part of the ALICE GRID.

Expected results upon completion of the project:
Maintaining the working state of the ALICE GRID part at JINR.

Expected results of the project this year:
Maintaining the working state of the ALICE GRID part at JINR.

3.	**Forward detectors (FIT)**	**A.S. Vodopyanov** **P.V. Nomokonov**	2024-2025
			Realization
VBLHEP	M.G. Buryakov, S.G. Buzin, N.V. Gorbunov, A.V. Kuznetsov, S.A. Rufanov		

Brief annotation and scientific rationale:
In connection with the need to improve forward detectors it is necessary to upgrade a system for reading signals from scintillating and quartz units of the forward subdetectors.

Expected results upon completion of the project:
An upgrade of the system for reading signals from scintillators and quartz units based on new recording electronics to be developed.

Expected results of the project this year:
Testing of prototypes in CERN beams.

4.	**Superconducting magnet**	**A.S. Vodopyanov**	2024-2025
			Projection
VBLHEP	N.A. Baldin, V.Kh. Dodokhov, A.A. Efremov, V.I. Lobanov, Yu.Yu. Lobanov, I.A. Oleks		

Brief annotation and scientific rationale:
As the part of the modernization of the ALICE detector (PHASE2), it is planned to create a superconducting magnet.

Expected results upon completion of the project:
Participation in the design of a superconducting magnet.

Expected results of the project this year:
Elaboration of the stages of the design and manufacturing the superconducting cable.

Collaboration

Country or International Organization	City	Institute
Armenia	Yerevan	Foundation ANSL
Austria	Vienna	SMI
Azerbaijan	Baku	NNRC
Bangladesh	Dhaka	DU
Brazil	Campinas, SP	UNICAMP
	Porto Alegre, RS	UFRGS
	Santo Andre, SP	UFABC
	Sao Paulo, SP	USP
Bulgaria	Sofia	IAPS
		SU
CERN	Geneva	CERN
China	Beijing	CIAE
	Hefei	USTC
	Shanghai	SINAP CAS
	Wuhan	CCNU
		HBUT
Croatia	Split	Univ.
	Zagreb	RBI
		UZ
Cuba	Havana	CEADEN
Czech Republic	Prague	CTU
		IP CAS
	Rez	UJV
Denmark	Copenhagen	NBI
Finland	Helsinki	HIP
	Jyvaskyla	UJ
France	Clermont-Ferrand	LPC
	Grenoble	LPSC
	Lyon	UL
	Nantes	SUBATECH
	Orsay	IJCLab
	Saclay	IRFU
	Strasbourg	IPHC
	Villeurbanne	CC IN2P3
Germany	Bonn	UniBonn
	Darmstadt	GSI
		TU Darmstadt
	Frankfurt/Main	FIAS
		Univ.
	Heidelberg	Univ.
	Munich	TUM
	Munster	WWU
	Tubingen	Univ.
	Worms	ZTT
Greece	Athens	UoA
Hungary	Budapest	Wigner RCP
India	Aligarh	AMU
	Bhubaneswar	IOP
	Chandigarh	PU
	Guwahati	GU
	Indore	IIT Indore
	Jaipur	Univ.
	Jammu	Univ.

	Jatani	NISER
	Kolkata	BNC
		SINP
		UC
		VECC
	Mumbai	BARC
		IIT Bombay
Indonesia	Jakarta	LIPI
Italy	Alessandria	DiSIT UPO
	Bari	DIF
		INFN
		Poliba
	Bologna	INFN
		UniBo
	Brescia	UNIBS
	Cagliari	INFN
		UniCa
	Catania	INFN
		UniCT
	Erice	EMFCSC
	Foggia	Unifg
	Frascati	INFN LNF
	Legnaro	INFN LNL
	Messina	UniMe
	Padua	INFN
		UniPd
	Pavia	UniPv
	Rome	CREF
		INFN
		Univ. "La Sapienza"
	Salerno	INFN
	Trieste	INFN
		UNITR
	Turin	INFN
		Polito
		UniTo
	Vercelli	UPO
Japan	Hiroshima	Hiroshima Univ.
	Nagasaki	NiAS
	Nara	NWU
	Osaka	RCNP
	Saga	Saga Univ.
	Tokai	JAEA
	Tokyo	UT
	Tsukuba	Univ.
	Wako	RIKEN
Malta	Msida	UM
Mexico	Culiacan	UAS
	Mexico City	Cinvestav
		UNAM
	Puebla	BUAP
Netherlands	Amsterdam	AUAS
		NIKHEF
	Utrecht	UU

Norway	Bergen	HVL
		UiB
	Oslo	UiO
	Tonsberg	USN
Pakistan	Islamabad	COMSATS
		PINSTECH
Peru	Lima	PUCP
Poland	Krakow	AGH
		INP PAS
	Otwock (Swierk)	NCBJ
	Warsaw	WUT
Republic of Korea	Cheongju	CBNU
	Daejeon	KIST
	Gangneung	GWNU
	Incheon	Inha
	Jeonju	JBNU
	Pusan	PNU
	Seoul	Konkuk Univ.
		SJU
		Yonsei Univ.
Romania	Bucharest	IFIN-HH
		UPB
	Magurele	ISS
Russia	Gatchina	NRC KI PNPI
	Moscow	ITEP
		NNRU "MEPhI"
		NRC KI
		SINP MSU
	Moscow, Troitsk	INR RAS
	Novosibirsk	BINP SB RAS
	Protvino	IHEP
	Saint Petersburg	FIP
	Sarov	RFNC-VNIIEF
Slovakia	Bratislava	CU
	Kosice	IEP SAS
		TUKE
		UPJS
South Africa	Cape Town	UCT
	Johannesburg	WITS
	Somerset West	iThemba LABS
Sri Lanka	Moratuwa	Univ.
Sweden	Lund	LU
Thailand	Bangkok	KMUTT
	Chachoengsao	TMEC
	Nakhon Ratchasima	SLRI
		SUT
Turkey	Istanbul	Univ.
		YTU
	Konya	Karatay Univ.
Ukraine	Kharkov	NSC KIPT
	Kiev	BITP NASU
United Kingdom	Birmingham	Univ.
	Daresbury	DL
	Derby	Univ.
	Liverpool	Univ.

USA	Austin, TX	UT
	Berkeley, CA	Berkeley Lab
		UC
	Chicago, IL	CSU
	Columbus, OH	OSU
	Detroit, MI	WSU
	Houston, TX	UH
	Knoxville, TN	UTK
	Los Alamos, NM	LANL
	New Haven, CT	Yale Univ.
	Oak Ridge, TN	ORNL
	Omaha, NE	Creighton Univ.
	San Luis Obispo, CA	Cal Poly
	West Lafayette, IN	Purdue Univ.

02-1-1096-2010

Study of Rare Charged Kaon Decays and Search for Dark Sector in Experiments at the CERN SPS

Theme leaders: V.D. Kekelidze

Deputy: D.V. Peshekhonov
D.T. Madigozhin

Participating countries and international organizations:
Belarus, Belgium, Bulgaria, Canada, CERN, Chile, Czech Republic, France, Germany, Italy, Kazakhstan, Mexico, Romania, Russia, Slovakia, Spain, Switzerland, United Kingdom, USA.

The problem under study and the main purpose of the research:
Search for and study of rare kaon decays and CP violation processes. Search for rare events using beam-dump and missing energy techniques with CERN SPS secondary beams. Search for phenomena beyond the Standard Model. Construction and maintenance of detectors.

Projects in the theme:

	Name of the project	Project Leaders	Project code
1	NA62	V.D. Kekelidze *Deputy:* D.T. Madigozhin	02-1-1096-1-2010/2027
2.	NA64	V.A. Matveev D.V. Peshekhonov	02-1-1096-2-2017/2026

Projects:

	Name of the project	Project Leaders	Status
Laboratory	Responsible from laboratories		
1.	**NA62**	**V.D. Kekelidze** *Deputy:* **D.T. Madigozhin**	Data taking Data analysis

VBLHEP A.N. Baeva, V.V. Bautin, D. Baigarashev, T.L. Enik, D.D. Emelyanov, V.P. Falaleev, S.R. Gevorgyan, V.N. Gorbunova, E.A. Gudzovsky, I. Kambar, D. Kereibay, A.M. Korotkova, N.A. Molokanova, I.A. Polenkevich, K.M. Salamatin, S.N. Shkarovsky

Brief annotation and scientific rationale:
Realization of the NA62 Project allows to clarify the CP-violation problem, to measure precisely very rare charged kaon decay to charged pions and two neutrinos, to carry out a search for supersymmetric particles and their partners to observe physics beyond the Standard Model. In addition, the characteristics of rare kaon and hyperon decays will be improved. Straw-detectors of the NA62 high resolution magnetic spectrometer working in vacuum will be supported during experimental runs. Development of a new detector prototype based on straws with a smaller diameter will be started to use it at higher intensity of the beams. Software for simulation, data analysis and processing will be developed.

Expected results upon completion of the project:
Measurement of the rare decay of a charged kaon into a pion and two neutrinos with an accuracy of about 10%, which will make it possible to refine the parameters of the Cabibbo-Kobayashi-Maskawa matrix and will be a decisive test of the Standard Model.

In addition, the probabilities and other parameters of a number of rare decays of charged kaons will be measured, which will make it possible to refine the parameters of the Chiral Perturbation Theory, which describes strong interactions at low energies.

Expected results of the project this year:
NA62 and NA48/2 data analysis will be carried out. Two articles will be published in peer-reviewed journals with decisive participation of JINR staff in data analysis.

Software for the simulation of the magnetic spectrometer and full set-up will be developed; system for detector calibration and event reconstruction will be upgraded; general software of the experiment will be developed.

Participation in the maintenance of the NA62 spectrometer, as well as in the development and maintenance of the control system for all detectors of the experiment.

Participation in the development of a straw detector for high intensity beams.

Participation in the NA62 experimental run at the CERN SPS.

2.	**NA64**	**V.A. Matveev** **D.V. Peshekhonov**	Preparation Data taking Data analysis

VBLHEP	T.L. Enik, S.V. Gertsenberger, A.V. Ivanov, I. Kambar, G.D. Kekelidze, V.A. Kramarenko, K.M. Salamatin, E.V. Vasilieva, P.V. Volkov, I.A. Zhukov
DLNP	V.N. Frolov
BLTP	N.V. Krasnikov, A.S. Zhevlakov
Associated Personnel NA64	A.V. Dermenev, S.M. Gninenko, D.V. Kirpichnikov, V. Polyakov, D. Shchukin

Brief annotation and scientific rationale:
The main objective of the NA64 experiment is to search for new physics beyond the SM, namely the search for the dark photon (A'), hypotetical boson with 16.7 MeV mass and other manifestations of the dark sector in the experiments on the CERN SPS electron and muon secondary beams. Tracking detectores based on the straw tube technology support. Software for data MC simulation and analysis will be developed. Data analysis will be provided.

Expected results upon completion of the project:
The main aim of the NA64 project is s search of the new physics beyond the SM, namely the search on the secondary CERN SPS electron and muon beams of the dark photon (A') and hypotetical 16,7 GeV boson as well as other dark sector manifestations.

Expected results of the project this year:
NA64, analysis of the experimental data.

Operation and support of the detectors.

Participation in NA64 experimental runs in the experimental zone on the H4 and muon SPS channels, CERN.

On-line and off-line software development, for the straw chambers analysis and for the DAQ experiment in particular.

Collaboration

Country or International Organization	**City**	**Institute**
Belarus	Minsk	INP BSU
Belgium	Louvain-la-Neuve	UCL
Bulgaria	Blagoevgrad	SWU
	Plovdiv	PU
	Sofia	SU
Canada	Toronto	YU
	Vancouver	TRIUMF
		UBC
CERN	Geneva	CERN
Chile	Valparaiso	UTFSM
Czech Republic	Prague	CU
France	Marseille	CPPM
Germany	Bonn	UniBonn

	Mainz	JGU
Italy	Ferrara	INFN
	Florence	INFN
	Frascati	INFN LNF
	Genoa	INFN
	Naples	INFN
	Perugia	INFN
	Pisa	INFN
	Rome	INFN
		Univ. “Tor Vergata”
	Turin	INFN
Kazakhstan	Almaty	INP
Mexico	San Luis Potosi	UASLP
Romania	Bucharest	IFIN-HH
Russia	Moscow	LPI RAS
		SINP MSU
	Moscow, Troitsk	HPPI RAS
		INR RAS
	Protvino	IHEP
	Tomsk	TPU
Slovakia	Bratislava	CU
Spain	Valencia	IFIC
Switzerland	Lausanne	EPFL
	Zurich	ETH
United Kingdom	Birmingham	Univ.
	Bristol	Univ.
	Glasgow	U of G
	Lancaster	LU
USA	Boston, MA	BU
	Fairfax, VA	GMU
	Menlo Park, CA	SLAC
	Merced, CA	UCMerced
	Upton, NY	BNL

02-2-1151-2025

Development of Advanced Detectors and Analysis Methods, Hadronic and Rare Leptonic Processes

Theme Leader: Yu.I. Davydov

Participating countries and international organizations:
Azerbaijan, Belarus, France, Italy, Japan, Russia, Switzerland, Uzbekistan.

The problem under study and the main purpose of the research:
Development of experimental elementary particle physics proceeds in two main directions - increasing the energy of particle beams and their intensity. This requires the use of new materials, development of promising detectors and methods for registering particles, and development of new methods for data analysis. The theme joins efforts aimed at developing new detectors and new approaches for registering and identifying particles in future experiments, as well as activities aimed at studying leptonic and hadronic processes.

Project in the theme:

	Name of the project	**Project Leader**	**Project code**
Laboratory	Responsible from laboratories		**Status**
1.	**Development of a particle registration technique in future experiments with the participation of JINR**	**Yu.I. Davydov** *Deputy:* **Yu. A. Kulchitsky**	02-2-1151-1-2025/2025 R&D Realization
DLNP	K.G. Afanasiev, A.M. Artikov, N.V. Atanov, O.S. Atanova, V.Yu. Baranov, V. Boikov, D. Chokheli, K.I. Gritsay, N.A. Guseinov, V.I. Kiseeva, N.V. Khomutov, N.P. Kravchuk, V.A. Krylov, N.A. Kuchinsky, E.S. Kuzmin, V.L. Malyshev, V.D. Moskalenko, E.M. Plotnikova, V.A. Rogozin, A.V. Simonenko, A.N. Shalyugin, I.A. Suslov, P.V. Tereshko, A.D. Tropina, I.I. Vasilyev, I.Yu. Zimin		
VBLHEP	T.L. Enik, A.O. Kolesnikov, C.A. Movchan		
FLNP	M.V. Bulavin		

Brief annotation and scientific rationale:
The development of experimental elementary particle physics requires the use of new materials, development of advanced detectors and particle registration techniques, and development of new data analysis methods.

The aim of the project is to develop detector systems for accelerator experiments and new approaches to registering and identifying particles. The project envisages development of a methodology for creating and studying promising detectors. Work will be carried out to develop new gas detectors and study their parameters, and create and study prototypes of calorimeters using both organic scintillators and crystals.

The goals set in the project are aimed at solving problems arising in future collider experiments at the Super c-tau factory (SCT) in Russia, the Super τ-Charm facility (STCF) and the Circular Electron Positron Collider (CEPC) in China, as well as at fixed-target accelerators at intermediate and high energies, and in the Mu2e-II and Comet search experiments. Special requirements are imposed on detectors planned for use in high-load conditions (intensity frontier) and/or high-energy conditions (energy frontier). Both require radiation-hard, high-speed detectors capable of operating effectively in harsh radiation environments.

Expected results upon completion of the project:
Microstructured gas detectors of the Micromegas and well types (RWELL) with a resistive anode made of DLC coating (diamond-like carbon) will be developed and investigated; prototypes of a sectioned electromagnetic calorimeter using LYSO and other types of crystals will be modelled, built and tested; new data on the radiation resistance of crystals used in electromagnetic calorimeters will be obtained; circuits will be developed, low-noise radiation-resistant preamplifiers on discrete GaN (GaAs) elements for SiPMs will be modelled and manufactured and their radiation resistance will be studied; new heterogeneous detectors for recording thermal neutrons with the sensitivity to gamma quanta suppressed by 2-3 orders of magnitude will be developed.

The design of the structures will be developed, prototypes of electromagnetic and hadronic calorimeter modules will be created, their studies will be conducted on cosmic muons and in accelerator beams, and the test results will be compared with the predictions of Monte Carlo models for prototypes and full-scale calorimeter modules.

Expected results of the project this year:
Creation of prototypes of microstructure detectors of the Micromegas type and the well-type electron multiplier (RWELL) with a resistive anode made of DLC coating and conducting studies on resistance to multiple electrical discharges. Development and creation of a prototype of a coordinate detector using bulk micromegas technology with a DLC coating with a small amount of substance for an ion beam monitoring system.

Creation of two-coordinate straw detectors with a resistive high-voltage internal cathode and study of their parameters.

Study of the properties of BaF_2 and LYSO crystal samples before and after irradiation with a gamma radiation source. Study of the optical properties of crystal samples before and after irradiation with a Linac-800 electron beam. Irradiation of GaN transistors with a gamma radiation source, study of the properties of transistors before and after irradiation.

Development of a preamplifier for signal pickup from SiPMs and study of the properties of individual LYSO crystals (1x1x4 cm^3) using it on the Linac-800 electron beam. Development of radiation-resistant electronic units for connecting SiPMs to obtain a time resolution better than 100 ps and their electron beam testing.

Creation of new scintillation heterogeneous materials based on zinc sulfide, lithium fluoride and boron oxide crystals for recording thermal neutrons, modelling and studying their properties in neutron beams.

Development of software and mathematical support for Monte Carlo modelling and analysis of experimental data for prototypes and full-scale modules of electromagnetic calorimeters for planned experiments at future accelerators. Modelling of calorimeter prototypes for geometry optimization, and determining the influence of optical properties of scintillators and wavelength-shifting fibers, and dead matter on the resolution of calorimeters.

Activities of the theme:

Name of the activity	Leaders	Implementation period
Laboratory Responsible from laboratories		Status
1. T2K-II	**Yu.I. Davydov**	2025-2025
		R&D Realization

DLNP A.M. Artikov, O.S. Atanova, V.Yu. Baranov, A.V. Boikov, N.V. Khomutov, V.I. Kiseeva, A.V. Krasnoperov, V.L. Malyshev, B.A. Popov, I.A. Suslov, V.V. Tereschenko, S.V. Tereschenko, I.I. Vasilyev

BLTP G.A.Kozlov

VBLHEP A.O. Kolesnikov

Brief annotation and scientific rationale:
Investigation of CP violation in the lepton sector with a significance of 3σ or higher for the case of large CP violation with more accurate measurement of neutrino oscillation parameters.

Expected results upon completion of the activity:
Use of the upgraded near detector of the T2K experiment for detailed study of neutrino interaction properties and more accurate measurement of neutrino oscillation parameters. The T2K-II experimental program will eventually allow statistics up to $10x10^{21}$ protons on target to be collected, in order to measure the neutrino mixing parameters, Θ_{23} and Δm^2_{32}, with an accuracy of 1.7º or better and 1%, respectively.

Expected results of the activity this year:
Participation in data collection runs at the J-PARC accelerator using the upgraded near detector of the T2K experiment.

Analysis of experimental data for more accurate measurement of neutrino oscillation parameters.

Search for light dark matter using near detector data.

2. Mu2e **Yu.I. Davydov** 2025-2025

R&D Realization

DLNP A.M. Artikov, N.V. Atanov, O.S. Atanova, V.Yu. Baranov, A.V. Boikov, V.V. Glagolev, V.I. Kiseeva, V.L. Malyshev, A.N. Shalyugin, I.A. Suslov, I.I. Vasilyev, I.Yu. Zimin

BLTP G.A. Kozlov

VBLHEP A.O. Kolesnikov

Brief annotation and scientific rationale:
The Mu2e experiment is aimed at searching for a process with lepton number violation for charged leptons μ-N→e-N, which is a coherent conversion of a muon into an electron in the field of a nucleus. At the non-zero neutrino mass this process is possible, but remains unobservable, since the probability is proportional to $(\Delta m^2_{ij}/M^2_W)^2$, where Δm^2_{ij} is the difference between the squares of the masses of the eigenstates of the *i*th and *j*th neutrinos, and M_W is the mass of the W boson. The predicted probability for the process $\mu^- N \rightarrow e^- N$ is ~ 10^{-50}. This process is a theoretically perfect target for new physics searches. In many new physics models that include massive neutrinos, the probabilities of these processes increase significantly and become observable.

Expected results upon completion of the activity:
The data collection will be carried out in two runs, with a two-year interval. In the first run it is planned to collect 6×10^{16} stopped muons. In the absence of $\mu^- \rightarrow e^-$ conversion events, a new limit on this process will be set at $R_{\mu e} < 6.2\times10^{-16}$ (90% CL), which is three orders of magnitude lower than the current limit $R_{\mu e} < 7\times10^{-13}$ (90% CL) set by the SINDRUM II experiment.

In the second stage of the data collection, it is planned to lower the limit on $\mu^- \rightarrow e^-$ conversion by another order of magnitude.

Expected results of the activity this year:
Participation in the preparation of a research program on a muon beam.

Participation in the preparation of software for data analysis.

3. MEG-II **N.V. Khomutov** 2025-2025

Realization Data taking Data processing

DLNP K. Afanasiev, N.P. Kravchuk, V.A. Krylov, N.A. Kuchinsky, V.L. Malyshev, A.M. Rozhdestvensky

VBLHEP A.O. Kolesnikov

Brief annotation and scientific rationale:
The Standard Model (SM) of particle physics predicts a vanishingly small probability (< 10^{-50}) of processes violating the conservation of lepton number for charged leptons. Therefore, the detection of such processes is an absolute indication of the presence of new physics beyond the SM, and their absence imposes a limitation on theories beyond the SM. The decay $\mu^+ \rightarrow e^+\gamma$ is especially sensitive to such new physics. The MEG II experiment is the second phase of the MEG experiment to search for the decay $\mu^+ \rightarrow e^+\gamma$ on the high-intensity (7×10^7 muons/s) beam of the HIPA accelerator at PSI (Switzerland). Thanks to a deep modernization of the facility, it is planned to improve the record upper bound for the decay probability obtained earlier in the first phase of the experiment by approximately an order of magnitude.

Expected results upon completion of the activity:
Processing of the full data set collected in 2021-2026. If the $\mu^+ \rightarrow e^+\gamma$ decay is not detected, the existing constraint on the decay probability $B(\mu^+ \rightarrow e^+\gamma) < 4{,}2 \times 10^{-13}$ (90% C. L.) will be improved to a level of ~ 6.0×10^{-14}.

Expected results of the activity this year:
Continuation of data collection.

Commissioning of the new drift chamber.

Completion of processing of experimental data collected in 2022-2023 and publication of intermediate results.

4. "CERN Neutrino platform" **B.A. Popov** 2025-2025

Data taking Data processing

DLNP N.V. Atanov, A.V. Krasnoperov, V.L. Malyshev, V.V. Tereschenko, S.V. Tereschenko

VBLHEP A.O. Kolesnikov

Brief annotation and scientific rationale:
To predict spectra and fluxes of neutrinos and antineutrinos in new-generation accelerator experiments (Hyper-Kamiokande, DUNE, etc.) with an accuracy of better than 5%, it is necessary to conduct studies using CERN hadron beams to measure yields of hadrons in proton-nucleus and pion-nucleus interactions.

Expected results upon completion of the activity:
Participation in the creation and testing of prototype detectors for new-generation neutrino experiments.

Research on measuring hadron yields in proton-nucleus and pion-nucleus interactions to predict neutrino and antineutrino spectra and fluxes in accelerator experiments.

Expected results of the activity this year:
Participation in the collection and analysis of experimental data at CERN beams.

Development of software for data processing and analysis.

Collaboration

Country or International Organization	**City**	**Institute**
Azerbaijan	Baku	IP ANAS
		IRP ANAS
Belarus	Minsk	INP BSU
		IP NASB
		IPE NASB
France	Paris	LPTHE
Italy	Frascati	INFN LNF
	Pisa	INFN
Japan	Tokai	JAEA
	Tokyo	UT
Russia	Moscow, Troitsk	INR RAS
Switzerland	Villigen	PSI
Uzbekistan	Samarkand	SamSU

Experiments at the NICA accelerator complex

02-1-1086-2009

Strangeness in Hadronic Matter and Study of Inelastic Reactions Near Kinematical Borders

Theme leaders: E.A. Strokovsky
E.S. Kokoulina
D.O. Krivenkov

Participating countries and international organizations:
Belarus, Cuba, Czech Republic, Egypt, India, Israel, Russia, Slovakia, Ukraine, USA.

The problem under study and the main purpose of the research:
Strangeness in hadronic matter and study of boundary effects:
study of stabilizing effects of strangeness in nuclear matter and properties of the lightest hypernuclei; study of multi-particle dynamics in the inelastic proton-proton and proton-nucleus interactions with extremally high multiplicity; study of spectra and yields of soft photons in the deuteron-nucleus and nucleus-nucleus interactions; determination of hadronization parameters at NICA energy at the SPD facility; study of Short-Range Correlated (SRC) pairs of nucleons.

Project in the theme:

Laboratory	**Name of the project** Responsible from laboratories	**Project Leaders**	**Project code** **Status**
1.	**HyperNIS-SRC** **HyperNuclear intrinsic strangeness and short-range correlations**	**D.O. Krivenkov** **J. Lukstins** *Deputy:* **M.A. Patsyuk**	02-1-1086-1-2025/2029 Realization Data taking
1.1.	**HyperNIS experiment**	**D.O. Krivenkov** **J. Lukstins**	

VBLHEP V.D. Aksinenko, M.H. Anikina, T. Atovullaev, A. Atovullaeva, A.V. Averyanov, S.N. Bazylev, A.E. Baskakov, D.V. Dementiev, A.A. Feschenko, A.A. Fedyunin, A.I. Filippov, S.V. Gertsenberger, A.S. Khvorostukhin, A.M. Korotkova, Yu.A. Murin, O.V. Okhrimenko, S.N. Plyashkevich, N.G. Parfenova, P.A. Rukoyatkin, A.V. Salamatin, A.V. Shipunov, M.O. Shitenkov, A.D. Sheremetiev, I.V. Slepnev, V.M. Slepnev, N.A. Tarasov, A.V. Terleskiy, A.L. Voronin

DLNP B.A. Popov, V.V. Tereschenko, S.V. Tereschenko

OCE A.N. Parfenov

Brief annotation and scientific rationale:
The study of properties of the lightest hypernuclei is actual, has high significance and the Nuclotron beam is suitable place to investigate these tasks. The study of properties of light neutron-rich hypernuclei is of great interest, first of all, to clarify the theory of the intranuclear nucleon-nucleon interactions: the neutron halo, ΛN interaction including ΛN – ΣN conversion and the spin-dependent ΛN interaction etc. The special interest to this investigation is because of absence of reliable data on ${}^{6}_{\Lambda}$H properties and theoretical predictions that are strongly depend on model and controversial. Simultaneously, the lifetimes and production cross sections of ${}^{4}_{\Lambda}$H and ${}^{3}_{\Lambda}$H will be studied in the same experiment. The end measurement scan be used as “reference points” to confirm the production and decay of ${}^{6}_{\Lambda}$H**.**

Expected results upon completion of the project:
Experimental conclusion about the existence of the hypernucleus ${}^{6}_{\Lambda}$H.

New experimental data on the properties of the lightest hypernuclei and experimental verification of corresponding theoretical models for these hypernuclei.

New experimental data on the drip-line location for loosely bound light hypernuclei with high neutron excess, necessary for the development of the theory of neutron-rich hypernuclei and models of their production in non-central nucleus-nucleus interactions.

New experimental data on the production of strangeness and vector mesons (including those, containing strange quarks) by polarized photons (close to the relevant thresholds).

Universal spectrometer for users of the Nuclotron beams.

Expected results of the project this year:
Data taking for $^{6}_{\Lambda}$H search using beam of ^{7}Li nuclei. Analysis of the first experimental data for the $^{6}_{\Lambda}$H search and for the measurements of hyperhydrogen isotopes $^{6}_{\Lambda}$H and $^{4}_{\Lambda}$H lifetimes.

Upgrade of the HyperNIS magnetic spectrometer (tracking system) by adding the planes of GEM detectors. These detectors, which have already been (partially) purchased and are being tested at the HyperNIS setup by staff, will be integrated into this setup to improve accuracy of the hypernucleus decay vertex determination. Preparation of a project for joint experiments with SRC, integration of detectors, development of a technical design for a spectrometer with two magnets (installations of a second magnet, supply of communications, supports for detectors), common data acquisition systems (design and tests), MC for the optimal geometry of joint detectors.

Within the collaboration with Japan: data taking at LEPS/LEPS2 setups on the production of strangeness and vector mesons (including those, containing strange quarks) by polarized photons (close to the relevant thresholds); analysis of data on such reactions, taken before.

1.2. SRC experiment **M. Patsyuk**

Realization
Data taking

VBLHEP	V.D. Aksinenko, M.H. Anikina, T. Atovullaev, A. Atovullaeva, A.V. Averyanov, A.G. Bochkova, A.A. Feschenko, S.V. Gertsenberger, A.M. Korotkova, O.V. Okhrimenko, S.N. Plyashkevich, N.G. Parfenova, P.A. Rukoyatkin, A.V. Salamatin
DLNP	V.V. Tereschenko, Y.N. Usikov
BLTP	A.B. Larionov

Brief annotation and scientific rationale:
The properties of nuclei are defined by interaction of their constituents: nucleons on the level of lower resolution and quarks and gluons at high resolution. The relation between these two descriptions remains a challenge. Short-Range Correlated (SRC) pairs of nucleons, which are temporary fluctuations of strongly interacting nucleons at a distance of around nucleon radius and individual momenta larger than that of mean-field nucleons, are coupled to both nuclear scales. Electron scattering experiments have shown the far-reaching impacts SRCs have on the many-body systems, the nucleon-nucleon interaction, and nucleon substructure.

Expected results upon completion of the project:
The next experiment being planned right now will involve the use of a tensor polarized deuteron beam from Nuclotron and existing detection equipment at LHEP JINR. Specifically, we will explore polarized deuteron hard scattering off a liquid hydrogen target, with a focus on SRC kinematics. With a polarized deuteron beam of 6 GeV/c/nucleon momentum we will select interactions with $|t, u| > 1$ (GeV/c)², and a center-of-mass scattering angle around 90 degrees. A coincidence between the two arms of a dedicated spectrometer will identify two protons resulting from the p(d,2p)n reaction. Simultaneous detection of the recoil partner neutron arising from the deuteron's hard breakup will also be possible. The two-arm spectrometer will be akin to the one used in the 2022 SRC/BM@N measurement. Detection of the recoil neutron will necessitate the incorporation of a neutron detector along the beam. It is important to note that the installation of the required detection systems for planned measurements in the HyperNIS experimental area will not disrupt the existing HyperNIS experimental setup. However, a larger band by the magnetic field is needed to obtain the required resolution. For that a second magnet needs to be installed. Another solution is creating a new analyzing magnet instead of the installed one.

Expected results of the project this year:
SRC at BM@N data analysis.

Estimation of the momentum resolution of the HyperNIS magnetic spectrometer in the perspective of solving the problems of the SRC experiment.

Estimation of the momentum resolution of the HyperNIS magnetic spectrometer for solving tasks of the SRC experiment.

Activities of the theme:

	Name of the activity	Leaders	Implementation period
Laboratory	Responsible from laboratories		Status
1.	**NEMAN**	**E.S. Kokoulina** **V.A. Nikitin**	2025-2025 Project preparation Data taking
VBLHEP	V.B. Dunin, O.P. Gavrischuk, V.V. Popov, S. Y. Sinelcshikova, M.V. Tokarev		
BLTP	A.B. Arbuzov, Yu.A. Bystritsky, V.F. Zykunov		

Brief annotation and scientific rationale:
In high energy physics, events are usually analyzed for which the deviation from the average multiplicity does not exceed two average values. Events with a higher multiplicity occur extremely rarely, so it is difficult to collect large statistics for them, in addition, there are difficulties in processing them. When planning any experiment, simulations are performed, but despite the fact that the number of Monte Carlo generators increases every year, their predictions deviate significantly in the region of high multiplicity. Setting their parameters at the given energy stops working when moving to a higher energy. All this indicates a significant misunderstanding of the mechanism of multiple production. The study of events with the production of a large number of secondary particles will allow a deeper understanding of strong interactions, including the hadronization stage.

In the region of high multiplicity, a series of collective phenomena with a quantum nature are predicted, such as the formation of a pion (Bose- Einstein) condensate, an excess soft photon (less than 50 MeV) yield, Cherenkov radiation of gluons by quarks, and others. In this region, the longitudinal component of the momentum approaches the transverse component, reaching it. This indicates the disappearance of the leading effect, and in the same region, apparently, the formation of a condensate begins. These and other collective manifestations in the behavior of secondary particles can be studied at the future NICA collider in the SPD project, since it is planned to register events in the absence of any trigger. This project is aimed at studying the gluon component of the nucleon. The study of processes with high multiplicity in the model of gluon dominance developed at JINR will provide additional knowledge about the gluon component of the nucleon and its contribution to hadronization.

Expected results upon completion of the activity:
Preparation of a physics program for the study of collective phenomena in the region of high multiplicity in proton and deuterium interactions at the SPD facility at the NICA collider.

Development of the gluon dominance model for the collective behavior study of secondary particles in high multiplicity events at the energies of the future NICA collider at the SPD facility. Estimates of the contribution of gluon bremsstrahlung by quarks and gluon fission as dominant elementary QCD processes in this region. Estimatesof hadronization parameters for different kinds of hadrons.

Designing of a stand-alone multichannel spectrometer-calorimeter for detecting soft photons and using it to measure the polarization by the SPILER polarimeter at the output of a spin polarization source (SPI).

Determination of the critical region of multiplicity, at which the longitudinal and transverse components of the momentum become the same (the disappearance of the leading particle) and the establishment of its connection with the region of the pionic condensate formation.

Optimization of the SpdRoot simulation program.

Expected results of the activity this year:
Designing of electronics for reading and controlling silicon photomultipliers (SiPM) of a stand-alone multichannel spectrometer-calorimeter for detecting soft photons and using it to measure the polarization of the SPILER polarimeter at the output of a spin polarization source (SPI).
Manufacture of a spectrometer-calorimeter prototype together with colleagues from Belarus.

The detailed simulation of the deuteron-deuteron interaction at the planing beam energy.

Manufacture of scintillation counters based on vacuum PMTs, and, further, as a development of the workable concept, based on solid-state PMTs (SiPM). Reading control and presentation of the received information will be carried out directly at the source control panel workstation. Testing the prototype on the PNPI beam.

Participation in the development of a physics program at the future SPD facility with unpolarized and polarized beams of light nuclei and protons to study the behavior of multiplicity. Simulation of pp (dd, pd) interactions at energies up to 27 GeV.

Preparation of a physics program aimed at searching for collective phenomena in events with a large (exceeding average) multiplicity, in particular, the pion (Bose-Einstein) condensate discovered at the U-70 accelerator, excess soft photon yield, Cherenkov radiation of gluons by quarks, disappearance of the leading particle effect.

Using the data from the Thermalization project, obtain multiplicity distributions of neutral pions as a function of total multiplicity and confirm their approximation to the Poisson distribution predicted in the works of R. Lednitsky and colleagues. Construct a scheme for hadron annihilation in the gluon dominance model, explain the discovered feature of multiplicity behavior at the Novosibirsk collider experiment in e^+e^--annihilation in the threshold region of proton-antiproton pair production.

Develop a physics program on a future SPD facility with unpolarized and polarized proton beams and light nuclei to study multiplicity behavior. Simulation of pp (dd, pp) interactions at energies up to 27 GeV and preparation for a detailed study of the parameters of the hadronization stage of charged and neutral particles (mesons and baryons) in the gluon dominance model.

Development and modernization of an algorithm for setting the initial parameters of tracks in the Kalman filter to increase the efficiency of track reconstruction, the accuracy of pulse reconstruction, and finding interaction vertices in the SpdRoot software.

Investigate the influence of the substance in the endcap of the SPD installation on the reconstruction of tracks and the selection of optimal parameters for the reconstruction of tracks.

Develop a software package SpdRoot for working on simulated events close to experimental ones. Preparation of the NEMAN project.

Collaboration

Country or International Organization	**City**	**Institute**
Belarus	Gomel	GSTU
		GSU
	Minsk	BSUIR
		IAP NASB
		IP NASB
Cuba	Havana	InSTEC
Czech Republic	Prague	CTU
Egypt	Alexandria	Univ.
India	Kolkata	UC
Israel	Tel Aviv	TAU
Russia	Chernogolovka	ISSP RAS
	Moscow	"Azimuth-Photonics"
		"FOMOS-MATERIALS"
		SINP MSU
	Moscow, Zelenograd	RIMST
	Protvino	IHEP
	Saint Petersburg	SPbSPU
Slovakia	Banska Bistrica	UMB
Ukraine	Kiev	BITP NASU
USA	Cambridge, MA	MIT

02-1-1097-2010

Study of Polarization Phenomena and Spin Effects at the JINR Nuclotron-M/NICA Facility

Theme leaders: E.A. Strokovsky
V.P. Ladygin
Deputies: N.M. Piskunov
R.A. Shindin

Participating countries and international organizations:
Bulgaria, France, Japan, Romania, Russia, Slovakia, Sweden, United Kingdom, USA, Uzbekistan.

The problem under study and the main purpose of the research:
Polarization studies are undoubtedly relevant now. They combine the efforts of the JINR Laboratories and many foreign laboratories, both participating and non-participating countries, in the design and conduct of experiments using unique beams of polarized deuterons with energies ranging from 5 MeV per nucleon to 5.6 GeV/n, secondary beams of polarized protons and neutrons, as well as beams of polarized protons directly accelerated in the Nuclotron. The possibility of obtaining beams of accelerated polarized protons in the Nuclotron without significant investment, demonstrated in 2017, became the basis for intensifying work on the spin program of the NICA project and, in particular, for the development of polarimetry techniques, the creation of new methods for precise control of the direction of the spin of protons, deuterons and other particles. This part of the work on the topic is directly related to the creation of the NICA complex and the testing of a new approach to controlling the polarization in the spin transparency mode. Of undoubted interest is also the study of the possibility of setting up experiments at the upgraded Nuclotron and the collider to measure EDM and parity violation. Within the framework of the theme, two projects are being carried out: ALPOM-2 and DSS. Preparation of the project on spin effects measurements in nucleon-nuclear scattering with using Movable Polarized Target and modernized Delta-Sigma spectrometer is under consideration. A new project is a systematic study of spin effects in the processes of production of strange baryons and vector mesons in elementary reactions and in cold dense nuclear matter at Nuclotron energies using beams of polarized and unpolarized particles on a fixed target and a wide-aperture magnetic spectrometer. Taking into account the presence of polarized beams, new experimental data will be obtained on the study of charge-exchange processes, on the study of the structure of 2- and 3-nucleon correlations in the reactions of deuteron-proton elastic scattering and deuteron breakup, by measuring of the vector and tensor analyzing powers in the deuteron core region, as well as other processes that are important for the development of the theoretical models describing the interactions of the simplest nuclear systems with allowance for relativism and the contribution of the meson and quark-gluon components of the internal motion of constituents in nucleons.

Projects in the theme:

	Name of the Project	Project Leaders	Project code
1.	ALPOM-2	N.M. Piskunov *Deputies:* E. Tomasi-Gustafsson V. Punjabi R.A. Shindin	02-1-1097-1-2010/2027
2.	DSS	V.P. Ladygin	02-1-1097-2-2010/2027

Projects:

Name of the project	Project Leaders	Status
Laboratory Responsible from laboratories		
1. ALPOM-2	**N.M. Piskunov** *Deputies:* **E. Tomasi-Gustafsson** **V. Punjabi** **R.A. Shindin**	Preparation Data taking

VBLHEP S.N. Bazylev, A.A. Druzhinin, O.P. Gavrishchuk, D.A. Kirillov, K.S. Legostaeva, A.N. Livanov, P.A. Rukoyatkin, I.M. Sitnik

Brief annotation and scientific rationale:
At present, it is necessary to measure the analyzing powers of protons and neutrons in scattering on CH2, CH and other targets. Such data are necessary for experiments requiring measurements of the polarization of protons and neutrons in nuclear reactions. It also needs optimization hadronic polarimetry and expanding the database on analyzing powers both for protons, the same for neutrons. This is possible only in Dubna, where polarized proton beams and neutrons obtained by fragmentation of accelerated polarized deuterons.

Expected results upon completion of the project:
Investigation of the analyzing powers in the scattering of polarized protons (at momenta up to 7.5 GeV) and neutrons (at momenta up to 6 GeV) on polyethylene, at the ALPOM-2 setup.

Expected results of the project this year:
Completion of the modernization of the setup (new drift chambers and a new wide-aperture hadron calorimeter), the beginning of measurements on beams of polarized nucleons.

2. DSS **V.P. Ladygin**

Preparation
Data taking

VBLHEP E.V. Chernykh, Yu.V. Gurchin, A.Yu. Isupov, N.B. Ladygina, K.S. Legostaeva, A.N. Livanov, S.G. Reznikov, A.A. Terekhin,A.V. Tishevsky, I.S. Volkov

DLNP G.I. Lykasov

Brief annotation and scientific rationale:
Study of the structure of 2- and 3-nucleon correlations in the reactions of deuteron-proton elastic scattering and deuteron breakup by measuring of the vector and tensor analyzing powers in the region of the deuteron core, as well as other processes important for the development theoretical models describing the interactions of the simplest nuclear systems, taking into account relativism and the contribution of the meson and quark-gluon components of the internal motion of constituents in nucleons.

Expected results upon completion of the project:
Measurement of the structure of 2- and 3-nucleon correlations in deuteron-proton elastic scattering and nonmeson deuteron breakup in the experiments at the Nuclotron internal target.

Measurement of cross sections and analyzing powers of these reactions. Performing experiments on the deuteron and proton spins manipulation, development of the polarimetry at the Nuclotron internal target.

Obtaining of the experimental data on many-particle correlations in nucleus-nucleus interactions.

Expected results of the project this year:
Completion of the analysis of data on the analyzing powers A_y, A_{yy} and A_{xx} of the deuteron-proton scattering up to 1800 MeV.

Upgrade of the deuteron and proton polarimeter at the Nuclotron internal target.

Publication of the results obtained on the polarimetry, on the deuteron analyzing powers in deuteron-proton elastic scattering and many-particle correlations in nucleus-nucleus interactions.

Activities of the theme:

Laboratory	**Name of the activity** Responsible from laboratories	**Leader**	**Implementation period** **Status**
1.	**Development of spin physics research infrastructure and technologies at the Nuclotron and other facilities. Design, construction and development of the spin control and polarimetry systems. Consideration of new experiments with polarized beams at the NICA complex**	**A.V. Butenko**	2025-2027 Realization

VBLHEP A.V. Averyanov, Yu.N. Filatov, V.V. Fimushkin, A.S. Galoyan, D.O. Krivenkov, R.A. Kuzyakin, M.V. Kulikov, V.P. Ladygin, K.S. Legostaeva, A.N. Livanov, N.M. Piskunov, S.G. Reznikov, R.A. Shindin, E.A. Strokovsky

DLNP Yu.N. Uzikov

MLIT V.V. Uzhinsky

Brief annotation and scientific rationale:
The possibility of obtaining beams of accelerated polarized protons in the Nuclotron without significant investment, demonstrated in 2017, became the basis for the intensification of work on the spin program of the NICA project and, in particular, for the development of polarimetry methods, the creation of new methods of precise control of the direction of the rotation of protons, deuterons and other particles. This part of the work topic is directly related to the creation of the NICA complex and the development of a new approach to operate the polarization in the spin transparency regime. Of undoubted interest is also the study the possibility of setting up the experiments at the upgraded Nuclotron and collider to measure the EDM and parity violation.

Expected results upon completion of the activity:
Development of infrastructure for spin research at the Nuclotron-M/NICA complex and other installations. Preparation of technical projects for spin control systems and polarimetry. Analysis of the possibility of setting up new experiments with polarized proton beams and deuterons at the NICA complex, in particular on the search for EDM.

Expected results of the activity this year:
Creation of a project for the placement of elements of polarimetry for beam diagnostics and polarization control in the SPD section of the NICA collider ring. Completion of the upgrade of the polarimeter at the F3 focus.

2.	**Preparation a project of measurement spin effects in the nucleon-nuclear scattering using modernized movable polarized target and upgraded Delta-Sigma spectrometer**	**R.A. Shindin** **Yu. A. Usov** (DNLP)	2025-2025 Proposal preparation

VBLHEP A.N. Livanov

DLNP N.A. Bazhanov, N.S. Borisov

FLNP A.N. Chernikov

Brief annotation and scientific rationale:
Preparation of a project to ьуфыгку spin effects using a proton polarized target and a Delta-Sigma spectrometer. For this purpose, it is necessary to modernize the polarized target in order to create transverse polarization, as well as to carry out design work to create a target environment detector.

Expected results upon completion of the activity:
Carrying out work on creating transverse polarization coils for a polarized proton target.

Expected results of the activity this year:
Preparation of a proposal for an experiment to measure polarization observables in neutron-proton elastic scattering.

3.	**Preparation of a project to study the spin properties of strange baryons and mesons in a cold dense nuclear medium**	**V.P. Ladygin**	2025-2027 Proposal Preparation

VBLHEP A.A. Aparin, D.I. Klimansky, B.V. Lyong, E.V. Nedorezov, S.S. Panyushkina, M.M. Shandov

LIT O.V. Derenovskaya, N.N. Voytishin

BLTP A.N. Isadykov, G.Yu. Prokhorov, O.V. Teryaev, A.S. Zhevlakov

Brief annotation and scientific rationale:
Data on the production of vector mesons obtained in different reactions at BNL, KEK and GSI show strong absorption of mesons in the nuclear medium, as well as changes in their masses and widths. A new important observable is the spin alignment of vector mesons and the dependence of its magnitude on the properties of dense matter. The increase in global polarization values of hyperons measured at BNL with decreasing energy of colliding nuclei also requires further experiments at Nuclotron energies. The goal of the new project is the systematic study of the spin effects in the processes of production of strange baryons and vector mesons in elementary reactions and in cold dense nuclear matter at Nuclotron energies using beams of polarized and unpolarized particles at a fixed target and a wide-aperture magnetic spectrometer.

Expected results upon completion of the activity:
Monte Carlo simulations will be performed using different event generators for the main physical processes in the Nuclotron energy range in fixed target kinematics for various colliding systems.

A plan for setting up the experiment with detector systems will be prepared, the required accuracy of signal recording and the possibility of the physical signal selection from the background will be assessed.

Test work will be carried out to develop and to manufacture promising detectors and readout electronics systems for them.

A letter of intent, conceptual and technical designs for a fixed target experiment with extracted and secondary beams of the Nuclotron, aimed at studying the properties of cold baryonic matter, including spin and polarization effects, will be prepared.

Expected results of the activity this year:
Monte Carlo simulation of nucleon-nucleon and nucleon-nucleus collisions at Nuclotron energies, comparison with existing experimental results obtained previously at BNL, CERN and GSI.

Development of the detector concept for the implementation of the proposed experimental program. Preparing a letter of intent.

4.	**Experiments on the program STRELA at polarized deuteron beam**	**N.M. Piskunov**	2025-2027 Data taking

VBLHEP S.N. Bazylev, A.A. Druzhinin, D.A. Kirillov, R.A. Shindin, I.M. Sitnik

Brief annotation and scientific rationale:
Performance of the experimental works on the charge exchange reaction measurements using polarized deuteron beam in the Nuclotron energy range.

Expected results upon completion of the activity:
Carrying out measurements on beams of polarized and unpolarized deuterons in the range from 3 to 6 GeV/c.

Expected results of the activity this year:
Preparation of the experimental zone in the focus of F5 of the VP-1 beamline of building 205.

5.	**Theoretical calculations of polarized processes**	**V.K. Lukyanov** (BLTP)	2025-2027 Data analysis

VBLHEP A.P. Ierusalimov, N.B. Ladygina

Brief annotation and scientific rationale:
Development of theoretical models describing the structure of light nuclei and the interactions of the simplest nuclear systems, taking into account relativism and the contribution of the nucleon-meson and quark-gluon components to the internal motion of constituents in nucleons.

Expected results upon completion of the activity:
Description of experimental data on cross sections and polarization observables in reactions involving light nuclei, including those obtained at the Nuclotron/NICA accelerator complex.

Expected results of the activity this year:
Description of experimental data on deuteron analyzing powers of deuteron-proton elastic scattering at intermediate energies. Analysis of the energy behavior of the cross section, tensor analyzing power and vector polarization transfer coefficient from deuteron to proton in deuteron-proton backward scattering at Nuclotron energies.

Collaboration

Country or International Organization	**City**	**Institute**
Bulgaria	Sofia	UCTM
France	Orsay	IPN Orsay
	Saclay	IRFU
Japan	Hiroshima	Hiroshima Univ.
	Wako	RIKEN
Romania	Bucharest	INCDIE ICPE-CA
Russia	Belgorod	BelSU
	Moscow	LPI RAS
		NRC KI
	Moscow, Troitsk	INR RAS

		LPP LPI RAS
Slovakia	Bratislava	IP SAS
	Kosice	IEP SAS
		UPJS
	Zilina	UNIZA
Sweden	Uppsala	TSL
United Kingdom	Glasgow	U of G
USA	Newport News, VA	JLab
	Norfolk, VA	NSU
	Upton, NY	BNL
	Williamsburg, VA	W&M
Uzbekistan	Tashkent	Assoc. P.-S. PTI
		INP AS RUz

02-1-1150-2025

Fundamental and Applied Physics Research with Relativistic Particle Beams

Theme leader: A.A. Baldin

Participating countries and international organizations:
Armenia, Belarus, Chile, Russia, United Kingdom.

The problem under study and the main purpose of the research:
It is planned to develop fundamental and applied fields of experimental research with beams of relativistic particles, including the acceleration complex NICA at the Test Zone of the SPD experiment (experimental facility "MARUSYA"), experiments at the front part of the extraction channel of Nuclotron to the F3 focus, as well as with beams LINAC-200 (800) electron accelerator in the framework of the new collaboration FLAP (Fundamental&applied Linear Accelerator Physics collaboration), namely, investigation of the mechanisms of electromagnetic interactions and new applications involving the creation of neutron sources, controllable generation of various types of electromagnetic radiation using relativistic electrons, development of new methods of charged particle beam diagnostics, testing and calibration of detectors of particles and radiations for collider and other accelerator experiments.

Project in the theme:

Name of the project	Project Leaders	Project code
Laboratory Responsible from laboratories		Status
1. FLAP	**A.A. Baldin**	02-1-1150-1-2025/2029
Fundamental&applied research with beams of relativistic accelerated electrons	*Deputy:* **Vit.V. Bleko**	Development and testing of diagnostic systems Data acquisition and analysis

VBLHEP V.A. Alexandrov, V.I. Astakhov, E.G. Baldina, A.V. Beloborodov, Ver.V. Bleko, D.N. Bogoslovskiy, E.A. Bushmina, A.V. Butenko, S.A. Chetverikov, P.R. Khar'yuzov, E.A. Klevtsova, V.V. Kobets, D.S. Korovkin, V.A. Kukharev, A.B. Safonov, V.G. Shabratov, A.V. Skrypnik, S.Yu. Starikova, A.P. Sumbaev, Yu.A. Troyan

DLNP D.L. Demin, A.N. Fedorov, V.V. Glagolev, M.I. Gostkin, M.A. Nozdrin, A.S. Zhemchugov

MLIT E.K. Kuz'mina, M.M. Pashkova, V.S. Semashko, S.V. Semashko

Brief annotation and scientific rationale:
It is planned to develop the fields of research at which the new collaboration FLAP (Fundamental & applied Linear Accelerator Physics collaboration) is focused, namely, investigation of the mechanisms of electromagnetic interactions and new applications, including the creation of neutron sources, controllable generation of various types of electromagnetic radiation, such as diffraction Cherenkov and THz radiation in a range from 1 to 10 THz by relativistic electrons. Development of the new methods of charged particle beam diagnostics, testing and calibration of particle and radiation detectors for collider and other accelerator experiments, including the creation of time-of-flight calibrated beams of secondary neutrons with energies from thermal to 20 MeV.

Expected results upon completion of the project:
The main global results of the project will be:
– creation of a unique scientific-research installation for investigation of the mechanisms of generation of electromagnetic radiation in a wavelength range from 1 mm (microwave range) to 1 pm (g radiation) at interaction of relativistic electron beams wtih matter and external electromagnetic fields;

– development of fundamentally novel approaches to generation of electromagnetic radiation with controllable parameters based on the application of targets from functional materials;

– development of new nondestructive methods of charged particle beam diagnostics;

– development, testing and calibration of charged particle detectors and radiations for NICA SPD and MPD experiments:

– radiobiological studies with accelerated electron beams and secondary g quanta and neutrons:

– development of a pulsed neutron source with known parameters for investigations in the field of extreme states of matter:

– experiments on the search of hypothetic particles beyond the Standard Model.

Expected results of the project this year:
Creation and beam testing of particle detectors based on fast scintillator.

Registration of GHz and THz radiation from active targets irradiated by relativistic electron beams.

Creation of the time of flight test bench for registration of secondary neutrons.

Testing of stilbene-based scintillators for n - g separation.

Activities of the theme:

	Name of the activity	**Leaders**	**Implementation period**
Laboratory	Responsible from laboratories		**Status**
1.	**Processing, digitizing, and analysis of primary experimental information (films) obtained using bubble chambers**	**A.A. Baldin** **E.A. Klevtsova**	2025-2027 Data analysis

VBLHEP S.G. Arakelyan, E.G. Baldina, A.V. Belyaev, A.V. Beloborodov, Ver.V. Bleko, Vit.V. Bleko, D.N. Bogoslovsky, E.A. Bushmina, S.A. Chetverikov, D.S. Korovkin, N.E. Kukharev, V.A. Pukhaeva, O.V. Rogachevsky, A.B. Safonov, A.Yu. Troyan, Yu.A. Troyan

MLIT E.K. Kuz'mina, M.M. Pashkova, V.S. Rikhvitsky, V.S. Semashko, S.V. Semashko

Brief annotation and scientific rationale:
Continuation of filling in the experimental data base on multiple particle production in an energy range from 1 to 300 GeV obtained in experiments with bubble chambers.

Analysis of experimental data in the internediate energy range in relativistic physics based on the self-similarity approach and application of the properties of Lobachevsky geometry for description of multiple particle production.

Search and study of new phenomena in the conditions of registration of «soft processes» of particle production with high spatial and momentum resolution which is inavailable in modern electronic experiments.

Expected results at the end of the activity:
Creation of the required equipment for digitizing of experimental film information obtained using bubble chambers and in fixed-target electronic experiments in the conditions of registration of multiple particle production in an energy range of 1- 300 GeV.

Preparation of the educational program for students qualifying for the NICA project.

Comparison of the results obtained using the bubble chambers and the simulations with modern models. Development of recommendations for the strategy of experimental research at the accelerator complex NICA.

Publication of the results of analysis of bubble chamber data.

Expected major results in the current year:
Creation of the electronic data base from scanned photofilms and processes stereo images.

Organization of the procedure of storage and processing of the obtained images using the JINR LIT capacities.

More precise determination of the results obtained using the 2 m and 1 m hydrogen bubble chambers.

2.	**Investigation of deep subthreshold processes, applied and educational programs at MARUSYA setup**	**A.A. Baldin** **D.S. Korovkin**	2025-2027 Preparation Data taking

VBLHEP V.A. Arefiev, S.V. Afanasiev, V.I.Astakhov, E.G. Baldina, S.N. Bazylev, A.I. Berlev, A.V. Beloborodov, Ver.V. Bleko, Vit.V. Bleko, D.N. Bogoslavsky, E.A. Bushmina, S.A. Chetverikov, P.R. Kharyuzov, E.A. Klevtsova, V.A. Kukharev, A.B. Safonov, S.Yu. Starikova, A.P. Sumbaev, A.Yu. Troyan, Yu.A. Troyan

BLTP S.G. Bondarenko

MLIT V.V. Korenkov, E.K. Kuz'mina, M.M. Pashkova, V.S. Semashko, S.V. Semashko

DLNP A.N. Fedorov

Brief annotation and scientific rationale:
Experimental studies of deep subthreshold and cumulative reations at extracted beams of Nucltron-N (SPD Test Zone, MARUSYA facility).

Performing correlation experiments with registration of groups of particles in the final state with one cumulative particle. Studies in the pre-cumulative and cumulative regtions with extracted polarized beams.

Expected results at the end of the activity:
New experimental data on A-dependences of rare subthreshold and cumulative processes of pion, kaon, and light nuclei production depending on the type and energy of projectile nuclei, momentum and angle of registered particles.

New upgraded facility supplemented with detectors for correlation experiments: multichannel gamma spectrometer, multiplicity detector, neutron detector.

Expected major results in the current year:
Putting in operation of the upgraded magnetooptical channel of MARUSYA facility.

Reconstruction of the experimental zone of the spectrometer channel at F4. Creation of the new data acquisition system of the facility. Putting in operation of track detectors. Development and creation of the neutron detector. Testing of the Cherenkov detector.

Testing of the prototype detectors for the SPD experiment. Continuation of experiments at extracted beams of Nuclotron-N wtih maximum available intensity. Development of the software for simulation and processing of experimental data.

3.	**Neutron resonance spectroscopy**	**A.A. Baldin** **V.N. Shvetsov**	2025-2027 Preparation Data taking

VBLHEP V.I. Astakhov, E.G. Baldina, A.V. Beloborodov, Ver.V. Bleko, Vit.V. Bleko, D.N. Bogoslavskiy, E.A. Bushmina, S.A. Chetverikov, P.R. Kharyuzov, E.A. Klevtsova, V.A. Kukharev, A.B. Safonov, S.Yu. Starikova, A.P. Sumbaev, Yu.A. Troyan

MLIT S.V. Semashko

FLNP N.V. Rebrova

Brief annotation and scientific rationale:
Experimental study of the methods for registration and measurement of neutron resonances upon passage of radiation generated by a neutron source through various materials. Neutron resonance spectroscopy and radiography for investigation of the properties of materials in extreme states.

Development and study of the methods of nondestructive inspection of samples and materials using thermal and epithermal neutrons.

A neutron image detector with high spatial (20-50 mkm) and time (50-100 ns) resolution will be developed in the framework of development of methods of real-time neutron tomography with thermal and resonance neutrons. This study is aimed at a broad range of fast processes in the field of the physics of extreme states of matter and material research. This method will allow one to study the physical and chemical composition of machine-building materials, gaseous cavities inside structural materials with high atomic mass. Another important advantage of neutron radiography is the possibility of visualization of hydrogen-containing substances in a metal matrix.

Expected results at the end of the activity:
Practical implementation of the method of nondestructive measurement of parameters of materials in extreme states. Practical implementation of the method of nondestructive study of composite materials.

Study of the feasibility of development of low-current power supply elements based on decay of unstable isotopes produced using a neutron source.

Expected major results in the current year:
Numerical and experimental determination of optimal characteristics of the neutron source.

Experimental determination of an optimal configuration of the experiment design to achieve the required measurement precision.

Improvement of methods for registration of parameters of neutron resonances.

Measurement of experimental spectra of neutrons from various materials irradiated by accelerated electron beams.

Collaboration

Country or International Organization	City	Institute
Armenia	Yerevan	IAPP NAS RA
		YSU
Belarus	Minsk	INP BSU
Chile	Santiago	UNAB CTEPP
Russia	Belgorod	BelSU
		Erendi Vakuum
	Dubna	IAS "Omega"
		IPTP
	Gatchina	NRC KI PNPI
	Moscow	LPI RAS
		Marafon
		MIREA
	Saint Petersburg	SPbSPU
	Sarov	RFNC-VNIIEF
	Tomsk	TPU
	Vladikavkaz	VTC "Baspik"
United Kingdom	London	JAI@RHUL

Neutrino physics and astrophysics

02-2-1099-2010

Study of Neutrino Oscillations and Astrophysical Research

Theme leaders: D.V. Naumov
A.G. Olshevskiy

Participating countries and international organizations:
China, Czech Republic, France, Germany, Italy, Japan, Romania, Russia, Slovakia, Switzerland, Turkey, USA.

The problem under study and the main purpose of the research:
Measurement of the parameters of neutrino oscillations and other properties of neutrinos in experiments of various types, as well as astrophysical research in ground-based and space experiments. Global analysis of data from neutrino experiments, development of experiments and creation of new-type facilities.

Projects in the theme:

	Name of the project	Project Leaders	Project code
1.	JUNO	D.V. Naumov *Deputies:* N.V. Anfimov M.O. Gonchar	02-2-1099-1-2009/2026
2.	NOvA/DUNE	A.G. Olshevskiy *Deputies:* N.V. Anfimov O.B. Samoylov	02-2-1099-2-2015/2026
3.	TAIGA	A.N. Borodin	02-2-1099-3-2015/2026

Projects:

Laboratory	Name of the project	Project Leaders	Status
Responsible from laboratories			
1.	**JUNO**	**D.V. Naumov** *Deputies:* **N.V. Anfimov** **M.O. Gonchar**	Implementation
DLNP	A.I. Antoshkin, T.A. Antoshkina, N.S. Bessonov, S.V. Biktemerova, A.E. Bolshakova, V.V. Chalyshev, A.V. Chetverikov, A.V. Chukanov, S.G. Dmitrievskiy, D.A. Dolzhikov, D.V. Fedoseev, Yu.A. Gornushkin, V.O. Gromov, M.B. Gromov, D.E. Korablev, A.V. Krasnoperov, K.I. Kuznetsova, E.A. Naumova, I.B. Nemchenok, A.G. Olshevskiy, A.V. Rybnikov, A.B. Sadovskiy, A.S. Selyunin, O.Yu. Smirnov, S.A. Sokolov, A.P. Sotnikov, V.I. Sharov, V. Zavadskiy,		
MLIT	N.A. Balashov, N.A. Kutovskiy		
BLTP	N.S. Tsegelnik		
VBLHEP	V.I. Astakhov, V.B. Shutov		

Brief annotation and scientific rationale:
Measurement of the neutrino mass hierarchy in the long-baseline reactor experiment. Precise determination of the parameters of neutrino oscillations. Study of neutrino fluxes from various sources: the Sun, the Earth and others.

Expected results upon completion of the project:
Determination of the ordering of neutrino masses with an accuracy of > ~3 sigma, precision measurement of the spectrum of reactor antineutrinos, search for sterile neutrino states, measurement of solar and geoneutrino fluxes.

Expected results of the project his year:
Completion of installation and launch of the JUNO setup, calibration of detectors. Obtaining the first data and testing the developed analysis algorithms. Launching the detector systems of the TAO setup, setting up the detector calibration system and data acquisition.

2. **NOvA/DUNE**[2] **A.G. Olshevskiy** Implementation

Deputies:
N.A. Anfimov
O.B. Samoylov

DLNP A.I. Antoshkin, A.E. Bolshakova, V.V. Chalyshev, A.V Chetverikov, A.V. Chukanov, D.V. Fedoseev, V.O. Gromov, A.D. Ivanova, A.I. Kalitkina, O.L. Klimov, V.A. Kozhukalov, L.D. Kolupaeva, I.E. Kreslo, K.I. Kuznetsova, P.I. Lenskiy, A.D. Morozova, A.V. Pavlov, A.V. Rybnikov, A.S. Selyunin, S.A. Sokolov, A.P. Sotnikov, A.V. Stepanova, V.I. Sharov, A.S. Sheshukov, D.S. Shkirmanov, S.G. Vasina

BLTP I.D. Kakorin, K.S. Kuzmin, V.A. Matveev, V.A. Naumov

MLIT N.A. Balashov, A.V. Baranov, A.G. Dolbilov, E.A. Kuznetsov, N.A. Kutovskiy

VBLHEP N.I. Azorskiy, V.V. Bautin, D. Baygarashev, T.L. Enik, Y. Kambar, G.D. Kekelidze, A.O. Kolesnikov, Yu.S. Kovalev, S.A. Movchan, E. Mukhamedzhanov, K.R. Salamatin, E.V. Vasileva

Brief annotation and scientific rationale:
Measurement of the neutrino mass hierarchy, CP-parity violation, and other parameters of neutrino oscillations in long-baseline accelerator experiments. Search for new particles and exotic reactions.

Expected results upon completion of the project:
Determination of the neutrino mass ordering and the lepton CP-parity violation parameter in long-baseline accelerator experiments. Global analysis of data from neutrino experiments, development of experiments and creation of new-type facilities. Search for new particles and exotic reactions.

Expected results of the project this year:
Analysis of the NOvA experiment data, including exotic reactions and measurements of the mass hierarchy and CP (and also a collaborative analysis of different experiments). Detector methodology research and development of the readout electronics.

3. **TAIGA** **A.N. Borodin** Implementation

DLNP P.A. Bezyazykov, A.V. Blinov, V.M. Grebenyuk, A.A. Grinyuk, H. Karatash, M.V. Lavrova, S.Yu. Porokhovoy, A. Pan, A.B. Sadovsky, A.V. Shaikovsky, E. Sholtan

FLNP A.D. Rogov

MLIT I. Satyshev

VBLHEP N.V. Gorbunov

Brief annotation and scientific rationale:
Investigation of gamma radiation and charged cosmic rays (CRs) in the energy range of $10^{13}-10^{18}$ eV by detecting Cherenkov radiation from extensive air showers (EAS): studying the high-energy edge of the spectrum of the brightest galactic and extragalactic sources of gamma radiation, searching for galactic PeVatrons, applying a new hybrid approach to study mass composition of CRs in the range of 10^{14} -10^{17} eV, studying of CR anisotropy in the energy range of 100 - 3000 TeV.

Expected results upon completion of the project:
Investigation of the energy spectrum of gamma quanta from galactic sources and the search for new sources of gamma quanta. Monitoring of the flux of gamma rays from nearby extragalactic sources. Search for TeV gamma rays from gamma-ray bursts and gamma rays correlated with high-energy neutrinos. Search for cosmic accelerators in which protons are accelerated to energies of 100 - 3000 TeV. Investigation of the mass composition of cosmic rays in the region of transition from galactic to extragalactic rays.

Expected results of the project this year:
Further collection and analysis of data to reconstruct the spectrum of gamma rays from galactic sources. Commissioning of the 5th Cherenkov telescope, development and preparation for operation of new Cherenkov detectors.

[2] Participation in the DUNE experiment is temporarily suspended until further notice.

Activities of the theme:

	Name of the activity	Leaders	Implementation period Status
Laboratory	Responsible from laboratories		
1.	**Experiments NA65 / DsTau and FASER**	**Yu.A. Gornushkin**	2024-2026 Data taking Data processing

DLNP S.G. Dmitrievsky, M. Miloi, A.B. Sadovsky, A.P. Sotnikov, S.G. Vasina

Brief annotation and scientific rationale:
Study of neutrino properties at the LHC. A search for new long-lived particles - dark photons and axions. Study of the tau-neutrino production in proton-nuclear interactions.

Expected results upon completion of the activity:
Measurement of the interaction cross-section of all types of neutrinos in the LHC energy range. Limits on production of exotic particles at LHC. Measurement of the tau-neutrino production cross-section in p-W interactions at CERN SPS.

Expected results of the activity this year:
Detection of electron neutrinos produced at LHC. First estimation of cross-section of electron and muon neutrino interactions in the TeV-energy range. Limits on production of dark photons and axions at LHC. Results of the study of proton-nuclear interactions in NA65.

2.	**Experiment Borexino/DarkSide**	**O.Yu. Smirnov**	2024-2026 Data analysis

DLNP M.V. Gromov, D.V. Korablev, O.E. Lychagina, O.B. Samoylov, A.P. Sotnikov, A.S. Sheshukov, A.V. Vishneva

Brief annotation and scientific rationale:
Completion of the analysis of unique data from the Borexino detector. Search for dark matter particles in the DarkSide-20k experiment.

Expected results upon completion of the activity:
New restrictions on rare processes and non-standard neutrino interactions using Borexino data. Search for WIMP particles with a sensitivity of two orders of magnitude greater than current limits.

Expected results of the activity this year:
New restrictions on the effective magnetic moment of solar neutrinos and on the contribution of non-standard neutrino interactions using Borexino data. New limits on the lifetime of argon-36 in relation to double K-capture.

Collaboration

Country or International Organization	City	Institute
China	Beijing	IHEP CAS
Czech Republic	Prague	CU
France	Strasbourg	CRN
Germany	Aachen	RWTH
	Hamburg	Univ.
Italy	Milan	UNIMI
	Salerno	INFN
Japan	Fukuoka	Kyushu Univ.
	Nagoya	Nagoya Univ.
	Tokyo	Toho Univ.
Romania	Magurele	ISS
Russia	Irkutsk	ISU
	Moscow	SINP MSU
Slovakia	Bratislava	CU
Switzerland	Bern	Uni Bern
Turkey	Ankara	METU
USA	Batavia, IL	Fermilab
	Cambridge, MA	Harvard Univ.
	Columbia, SC	UofSC
	Indianapolis, IN	IUPUI

02-2-1144-2021

Search for New Physics in the Lepton Sector

Theme Leader: Z. Tsamalaidze

Participating countries and international organizations:
Belarus, Czech Republic, France, Georgia, Germany, Japan, Kazakhstan, Russia, United Kingdom.

The problem under study and the main purpose of the research:
Search for evidence of new physics beyond the Standard Model by measuring the neutrinoless coherent transition of a muon to an electron (μ → e conversion) in the field of an aluminium nucleus.

Project in the theme:

Laboratory	Name of the project Responsible from laboratories	Project Leader	Project code Status
1.	**COMET**	**Z. Tsamalaidze**	02-2-1144-1-2025/2029 R&D Realization

DLNP	D.Sh. Chokheli, P.G. Evtukhovich, I.L. Evtukhovich, V.A. Kalinnikov, E.S. Kaneva, Kh. Khubashvili, A.V. Pavlov, B.M. Sabirov, A.G. Samartsev, A.V. Simonenko, V.V. Tereschenko, N. Tsverava, I.I. Vasilyev, E.P. Velicheva, A.D. Volkov
BLTP	D. Aznabaev, A. Issadykov, G.A. Kozlov
MLIT	D. Goderidze, A. Khvedelidze
VBLHEP	D. Baigarashev, T.L. Enik

Brief annotation and scientific rationale:
Charged-lepton flavour-violating (CLFV) processes offer deep probes for new physics with discovery sensitivity to a wide range of new physics models — SUSY, Higgs Doublets, Extra Dimensions, and, particularly, models explaining the neutrino mass hierarchy. The most sensitive exploration of CLFV processes is ensured by experiments that utilize high intensity muon beams to search for CLFV μ→e transitions, such as: $\mu^+ \to e^+\gamma$ (MEG at PSI, Switzerland); $\mu^+ \to e^+e^-e^+$ (Mu3e at PSI, Switzerland) and the coherent neutrinoless conversion of a muon into an electron in the field of a nucleus $\mu^-N \to e^-N$ (COMET at J-PARC, Japan; Mu2e at Fermilab, USA).

The COMET experiment seeks to measure the neutrinoless coherent transition of a muon to an electron in the field of an aluminium nucleus. The event signature of coherent neutrinoless $\mu^- \to e^-$ conversion in a muonic atom is the emission of a monoenergetic single electron in a certain time interval. The energy of the signal electron for aluminium is 104.97 MeV, and the lifetime of the muonic atom is 864 ns.

This makes neutrinoless $\mu^- \to e^-$ conversion very attractive experimentally. Firstly, the e^- energy of about 105 MeV is well above the end-point energy of the muon decay spectrum (∼52.8 MeV). Secondly, since the event signature is a monoenergetic electron, no coincidence measurement is required. Thirdly, the long lifetime means that backgrounds associated with the beam flash can be eliminated. Thus, the search for this process has the potential to improve sensitivity by using a high muon rate without suffering from accidental background events.

There exist various theoretical models which predict sizable charged lepton mixing branching ratios. Among them, the best motivated models are the supersymmetric (SUSY) extensions of the SM, such as SUSY-GUT or SUSY-Seesaw models. Modern theoretical motivations for lepton flavor violation, data on current experimental bounds and expected improvements are reviewed by Marciano, Mori and Roney.

The COMET experiment will be carried out in two stages: Phase-I and Phase-II. The experimental sensitivity goal for this process in Phase-I is 3.1×10^{-15}, or the 90% upper limit of the branching ratio of 7×10^{-15}, which is a factor of 100 improvement of the existing limit $B(\mu^- + Au \to e^- + Au) \leq 7\times10^{-13}$ from SINDRUM-II at PSI. The goal of Phase-II is a SES of 2.6×10^{-17}, which is a factor of about 10 000 better than the current experimental limit. The expected number of background events is 0.032, with a proton beam inter-bunch extinction factor of 3×10^{-11}. To achieve the target sensitivity and background level, the 3.2 kW 8 GeV proton beam from J-PARC (Japan) will be used. Two types of detectors - CyDet (cylindrical detector system) and StrECAL (straw tracker and electron calorimeter) - will be used for detecting the $\mu^- \to e^-$ conversion events and for measuring beam-related background events.

Scientists from DLNP JINR successfully participate in the preparation stage of the COMET experiment. For Phase-I, JINR

specialists manufactured and tested the entire set of straw tubes with a diameter of 9.8 mm and a length of 1.6 m (more than 2700 pieces), and for Phase-II, they will produce a full set of straw tubes with a diameter of 5 mm. The JINR specialists actively participate in the creation of the straw tracker, the electromagnetic calorimeter and the cosmic ray veto system (CRV) at the stages of modelling and scientific and technical activities. They will also continue to be actively involved in the assembly and maintenance of these detectors. The JINR specialists participate in the analysis of the test measurement data and will participate in the analysis of the COMET experiment data.

Expected results upon completion of the project:
Completion of assembly, testing, calibration, installation, cosmic test and maintenance of the straw detector for Phase-I.

Development and optimization of the crystal calibration method for the calorimeter with allowance for the features of the experiment: the presence of the magnetic field and the high-resolution calorimeter.

Simulation of a complex detector system (tracker, calorimeter, etc.).

Participation in the preparation, engineering and physics run, acquisition and analysis of data of Phase-I.

Research and development for production of straw tubes with a wall thickness of 12 μm and a diameter of 5 mm. Measurement of all mechanical properties and development of quality control standards for manufactured new straw tubes 5 mm in diameter.

Production of straw tubes (about 1000 pcs) for a full-scale prototype.

Production of a full-scale straw station with new tubes (12 μm, 5 mm) at JINR, and measurements on the beam.

Preparation, mass-production and testing of straw tubes for Phase-II.

Full participation in the design, assembly, installation, cosmic test and maintenance of the calorimeter.

Participation in the assembly and maintenance of the CRV for Phase-I and Phase-II.

Participation in the beam tests of the detector components for Phase-II.

Participation in the assembly, testing, installation and maintenance of the entire detector system for Phase-II.

Expected results of the project this year:
Completion of assembly, testing, calibration, installation and cosmic test of the straw detector for Phase-I.

Development and optimization of the crystal calibration method for the calorimeter with allowance for the features of the experiment: the presence of the magnetic field and the high-resolution calorimeter.

Simulation of the complex detector system (tracker, calorimeter, etc.).

Participation in the preparation of the engineering and physics run of Phase-I.

Research and development for production of straw tubes with a wall thickness of 12 μm and a diameter of 5 mm. Measurement of all mechanical properties and development of quality control standards for manufactured new straw tubes 5 mm in diameter.

Participation in the design and assembly of the calorimeter.

Participation in the assembly of the CRV for Phase-I.

Collaboration

Country or International Organization	City	Institute
Belarus	Minsk	BSU
		INP BSU
		IP NASB
Czech Republic	Prague	CU
France	Paris	IN2P3
Georgia	Tbilisi	GTU
		HEPI-TSU
		UG
Germany	Dresden	TU Dresden
Japan	Fukuoka	Kyushu Univ.
	Osaka	Osaka Univ.
	Tsukuba	KEK
Kazakhstan	Almaty	INP
Russia	Novosibirsk	BINP SB RAS
		NSU
United Kingdom	London	Imperial College

Nuclear Physics (03)

03-4-1146-2024

Neutron Nuclear Physics

Theme leaders: Yu.N. Kopatch
P.V. Sedyshev
V.N. Shvetsov

Participating countries and international organizations:
Albania, Armenia, Azerbaijan, Belarus, Botswana, Brazil, Bulgaria, CERN, China, Croatia, Cuba, Czech Republic, Cuba, Egypt, Finland, France, Georgia, Germany, Hungary, IAEA, India, Italy, Japan, Kazakhstan, Moldova, Mongolia, North Macedonia, Poland, Republic of Korea, Romania, Russia, Serbia, Slovakia, Slovenia, South Africa, Switzerland, Thailand, Turkey, USA, Uzbekistan, Vietnam.

The problem under study and the main purpose of the research:
Nuclear physics research with neutrons is traditionally one of the priority areas developed at JINR. These studies are carried out within the framework of the scientific theme "Neutron Nuclear Physics" (03-4-1146-2024). The integrated use of the FLNP basic facilities (IREN pulsed source of resonance neutrons, IBR-2 pulsed reactor, EG-5 electrostatic generator, as well as TANGRA facility) makes it possible to conduct nuclear physics research in a wide range of neutron energies from cold neutrons to ~20 MeV, and the use of external neutron sources, such as the n_TOF neutron time-of-flight facility at CERN, allows expanding the energy range to several hundreds of MeV.

The research and development activities within the framework of the theme are aimed at implementing the tasks formulated in the proposals for the JINR Seven-Year Development Plan 2024-2030 in the field of "Nuclear Physics".

The physics investigations can be grouped into three research areas:

– study of violations of fundamental symmetries in the interactions of neutrons with nuclei, obtaining nuclear data;
– study of fundamental properties of the neutron, physics of ultracold and very cold neutrons;

– applied and methodological research.

The scientific program of the theme "Neutron Nuclear Physics" will be implemented within the framework of three projects: two scientific ones ("Investigations of neutron nuclear interactions and properties of the neutron" and "TANGRA") and one scientific and technical project ("Modernization of the EG-5 accelerator and its experimental infrastructure"). Work on the development of the concept of a UCN source at a pulsed reactor, as well as the development of the neutron radiography technique with resonance neutrons, is planned to be singled out as separate activities.

Projects in the theme:

	Name of the project	Project Leaders	Project Code
1.	TANGRA Development and elaboration of the tagged neutron method for determining the elemental structure of matter and studying nuclear reactions	Yu.N. Kopatch	03-4-1146-1-2014/2028
2.	Modernization of the EG-5 accelerator and its experimental infrastructure	A.S. Doroshkevich	03-4-1146-2-2022/2026
3.	Investigations of neutron nuclear interactions and properties of the neutron	V.N Shvetsov P.V. Sedyshev	03-4-1146-3-2024/2028

Projects:

	Name of the project	Project Leaders	Status
Laboratory	Responsible from laboratories		
1.	**TANGRA** **Development and elaboration of the tagged neutron method for determining the elemental structure of matter and studying nuclear reactions**	**Yu.N. Kopatch**	Upgrade Data acquisition Data analysis

FLNP N.A. Fedorov, D. Grozdanov, C. Hramco, P.I. Kharlamov, P.S. Prusachenko, V.R. Skoy, V.N. Shvetsov, T.Yu. Tretiakova

VBLHEP V.Yu. Aleksakhin, S.V. Khabarov, Yu.N. Rogov, M.G Sapozhnikov, V.M. Slepnev, N.I. Zamiatin, E.V. Zubarev

DLNP A.V. Krasnoperov, A.B. Sadovskii, A.V. Salamatin

Brief annotation and scientific rationale:
Information about neutron-nuclear interactions is extremely important for both fundamental and applied physics. The fact that the neutron has no electric charge makes it a unique probe for studying nuclear forces. Due to electrical neutrality, the high penetrating power of neutron radiation makes it promising for studying the structure of matter at both the nuclear and molecular levels. Neutrons are also widely used for applied purposes: in inspection systems, non-destructive elemental analysis facilities, in instruments for studying the immediate environment of boreholes (logging), as well as in the creation of neutron and gamma radiation detectors used on board orbital and descent spacecraft for analysis of soil and atmosphere of celestial bodies. Information about neutron-nuclear reactions is also necessary for the design of promising nuclear power facilities, as well as for modeling various devices and objects that interact with neutron radiation in one way or another. An indicator of the relevance of studying the characteristics of neutron-nuclear interactions can be the fact that the list of the most requested nuclear data for the most part consists of queries directly related to neutron-nuclear reactions.

The TANGRA (TAgged Neutrons and Gamma Rays) project is aimed at studying neutron-nuclear reactions using the tagged neutron method, finding new ways to use neutron methods in fundamental and applied research, improving existing and creating new approaches to processing the results of nuclear physics experiments. One of the tasks to be solved within the framework of the project is the interpretation of existing experimental data on the reactions of interaction of fast neutrons with atomic nuclei, their systematization and validation. The priority area of work is the acquisition of nuclear data.

Expected results upon completion of the project:
Performing experiments to study the angular distributions of scattered neutrons.

Experimental study of (n,γ) and (n',γ)-correlations.

Theoretical description of the studied reactions.

Conducting experiments to study the reaction (n,2n).

Conclusion on the applicability of the tagged neutron method for elemental analysis of soils. In case of a positive result, the creation of prototypes of stationary and mobile facilities, as well as methodological recommendations for their use for agricultural and environmental monitoring.

The results obtained during the implementation of this project will be valuable for both fundamental and applied science. The obtained experimental data on the yields and angular distributions of γ-rays can be used to increase the accuracy of Monte Carlo simulations of various physics facilities. Another planned application of the obtained experimental results is fast elemental analysis. Optimized model parameters can be used to theoretically describe previously unstudied reactions. The developed prototypes of facilities for elemental analysis of soils can become the basis for creating devices useful for intensifying agriculture and monitoring the state of the environment.

Expected results of the project in the current year:
Measurements of angular correlations and cross sections for characteristic gamma-lines emitted by fast neutron reaction products using high-resolution γ-ray detectors.

Preparation of an experiment to study the (n,2n) reaction.

Development of a theoretical description of angular distributions of gamma-rays emitted during deexcitation of products of reactions with fast neutrons.

Field tests of a mobile facility for determining the carbon content in soil.

2. Modernization of the EG-5 accelerator and its experimental infrastructure **A.S. Doroshkevich**

Upgrade
Data acquisition
Data analysis

FLNP I.A. Chepurchenko, R.Sh. Issaev, Yu.N. Kopach, A.N. Likhachev, V.N. Semenov, K.E. Studnev, S.N. Tkachenko, K.N. Udovichenko, I.A. Zaitsev, T.Yu. Zeleniak

Brief annotation and scientific rationale:
The project is aimed at modernizing the main systems of the electrostatic charged particle accelerator EG-5, developing ion-beam and complementary methods for studying the elemental composition and physical properties of near-surface layers of solids.

***Goals of the project**:* to provide technical feasibility for the implementation of the scientific program of the JINR Topical Plan in studying reactions with fast quasi-monoenergetic neutrons; development of nuclear physics methods for studying the elemental composition; solution of problems of neutron-radiation materials science; implementation of practical applications of neutron physics; ensuring technical feasibility for the implementation of the unique options of the microbeam spectrometer.

Objectives of the project. The main technical task of the project is to restore the energy range of accelerated particles of 900 keV - 4.1 MeV and increase the ion beam current to 100-250 μA while maintaining the energy stability of the ion beam at a level no worse than 15 eV, ensuring the spatial stability of the ion beam, sufficient to implement the option of the microbeam spectrometer / nuclear microprobe.

The main organizational task is the formation and development of human resources potential to ensure the full implementation of the project for at least 3 seven-year periods.

The objectives of the project also include the upgrade of the experimental infrastructure of the accelerator complex, in particular, the development of new methods for studying the physical properties of the surface of materials that can complement and improve the quality of the obtained scientific results, the intensification of international scientific and technical cooperation, the organization of user policy, the formation of an interlaboratory accelerator center on the basis of FLNP JINR to solve a wide range of unique scientific and technological problems.

The main criteria for the successful implementation of the project are providing a neutron flux sufficient to conduct nuclear physics experiments with fast neutrons, and an energy stability of the ion beam sufficient to create a microbeam spectrometer/nuclear microprobe.

Expected results upon completion of the project:
As a result of the implementation of the project, the technical parameters of the accelerator will be restored (energy of accelerated particles of 4.1 MeV at a maximum current of at least 100 μA), which will make it possible to conduct studies of reactions with fast neutrons at JINR, as well as provide technical conditions for the installation of a microbeam spectrometer. A neutron generator based on a solid-state lithium target with a moderator will be added to the existing neutron generator with a gas target, and the chamber for irradiating samples with ion beams will be modified.

A new specialized laboratory will be created for the preparation of objects of study, which will be equipped with complementary methods for studying the optical and electronic properties of the surface, such as ellipsometry, optical and electron microscopy, methods for studying electrical properties at direct and alternating current (voltammetry, impedancemetry).

In addition to modernization and expansion of the instrumental base of the accelerator complex, the formation of personnel potential for the next 20-30 years will be carried out. The available methods of elemental analysis will be supplemented by methods of analysis based on prompt gamma rays from inelastic neutron scattering and neutron activation analysis.

Modernization of EG-5 at JINR, where there are highly qualified specialists, good detecting equipment and valuable developments in the field of neutron investigations of atomic nuclei, will make it possible in the short term to conduct a number of new, unique experiments on obtaining the energy spectra and angular distributions of charged particles from (n, α) and (n, p) / (α, n) and (p, n) reactions and integral and differential cross sections of the latter in the neutron energy range up to ~6 MeV, on processes of fission of atomic nuclei by fast neutrons, activation analysis, experiments in the field of neutron materials science and etc.

Expected results of the project in the current year:

Certification and commissioning of the EG-5 accelerator and its experimental halls.

Replacement of the selsyn control system with an optoelectronic analogue.

Modernization of the radiation monitoring and personnel protection system.

Modernization of the ion beam spectrometer complex.

Commissioning of a solid-state lithium neutron-producing target.

Automation of accelerator service systems.

Implementation of technical projects, in particular, the project with JSC Mikron (Zelenograd) "Ion-beam processing of semiconductor wafers with a diameter of 150 mm in a quantity of up to 200 pcs. ", the project to study the radiation resistance of polymer materials for the cooling system of detectors for the NICA collider, the project "Study of the dependence of sensitivity of the UDKN-04R device on neutron energy" in cooperation with JSC SNNIP (SC ROSATOM, Moscow).

3. Investigations of neutron nuclear interactions and properties of the neutron

V.N. Shvetsov
P.V. Sedyshev

Upgrade
Data acquisition
Data analysis

FLNP Yu.V. Aleksiayenak, A. Asylova, G.S. Ahmedov, V.M. Badawy, D. Berikov, S.B. Borzakov, O. Chaligava, I. Chuprakov, O.-A. Culicov, G.V. Danilyan, R. Djachu, A.Yu Dmitriev, A.S. Doroshkevich, S. Enkhbold, Fan Lyong Tuan, N.A. Fedorov, O.S. Filippova, A.I. Frank, M.V. Frontasyeva, V.I. Furman, Yu.M. Gledenov, E.A. Golubkov, D.N. Grozdanov, D.S. Grozdov, C. Hramco, A.S. Kayukov, G.Ya. Khristozova, A.K. Kirillov, V.L. Kuznetsov, G.V., Kulin, Le H.K., Le Ch.M. Nyat, A.I. Madadzadia, S. Mazhen, A.V. Maletsky, A.G. Malinin, Zh.V. Mezentseva, L.V. Mitsyna, A.Yu. Muzychka, Nguyen, T.B. Mi, A.Yu. Nezvanov, P.S. Nekhoroshkov, I.A. Oprea, S.S. Pavlov, Phan Luong Tuan, Yu.N. Pokotilovski, V.G. Pyataev, N.V. Rebrova, O.V. Sidorova, N.V. Simbirtseva, E.I. Sharapov, M.S. Shvetsova, V.R. Skoy, Z.D. Slavkova, A.V. Strelkov, S.Yu. Taskaev, E.S. Teimurov, T.Yu. Tretyakova, K. Turlybekuly, K.V. Udovichenko, K.N. Vergel, D.C. Vu, A. Yergashov, N.S. Yushin, K.N. Zhernenkov, M.A. Zakharov, Sh.S. Zeinalov, T.Yu. Zeleniak, I.I. Zinicovscaia, 60 engineers, 2 workers

VBLHEP T.L. Enik, A.P. Sumbaev, 3 engineers

Brief annotation and scientific rationale:
Nuclear processes and structural changes in materials induced by slow, resonance and fast neutrons and accelerated charged particles are traditionally in the focus of research attention at FLNP JINR. The interaction of neutrons with atomic nuclei is of interest for both fundamental and applied research.

The integrated use of the FLNP basic facilities (IREN pulsed source of resonance neutrons, IBR-2 pulsed reactor, EG-5 electrostatic generator) makes it possible to conduct nuclear physics research in a wide range of neutron energies from cold neutrons to ~20 MeV, and the use of external neutron sources, such as the n TOF neutron time-of-flight facility at CERN, allows expanding the energy range to several hundreds of MeV. Fundamental research carried out at the FLNP Department of Nuclear Physics includes studies on the violation of space and time symmetry, the mechanism of nuclear reactions, the structure of atomic nuclei, fission processes induced by neutrons, neutron-induced reactions with the emission of light particles, the properties of the neutron as an elementary particle, the properties of ultracold and very cold neutrons, quantum mechanical effects involving neutrons.

Also, in FLNP, a variety of research programs has been developed for applied investigations, such as obtaining nuclear data and information on the radiation resistance of materials for nuclear technologies, power engineering and transmutation, radiation mutagenesis on fast neutrons, neutron activation analysis using thermal and epithermal neutrons, neutron activation analysis using prompt gamma-rays, elemental analysis using neutron resonances, elemental analysis using fast neutrons, analysis of the elemental composition of thin films, investigation of the radiation resistance of materials to the effects of accelerated charged particles on electrostatic accelerator beams, development of radiation-resistant nanostructured materials using accelerated ion beams.

Expected results upon completion of the project:
Refinement of characteristics of known resonances and detection of previously unknown ones. Measurement of reaction cross sections and product correlations in the resonance region with an accuracy sufficient to study P- and T-odd effects.

Performing experiments to study TRI and ROT effects in fission, measuring the mass-energy and angular distributions of fragments, prompt neutrons and gamma-rays; searching for rare and exotic fission modes, using both IBR-2 and third-party sources.

Conducting experimental and theoretical studies of neutron-nuclear reactions in a wide range of energies of incident particles.

Study of the neutron dispersion law in a refractive medium, including in the case of high accelerations.

Development of models for calculating the transport of UCN and CN in the material of nanodiamond reflectors and the extension of their applicability to the range of thermal neutrons.

Study of the structure of graphites after their intercalation and measurement of cross sections for cold neutron scattering by intercalated graphites.

Obtaining data for nuclear power engineering and astrophysics: measurement of integral and differential neutron cross sections, angular correlations in the energy range from cold neutrons to hundreds of MeV.

Study of radiation resistance of various materials, including those promising for use as neutron reflectors and moderators. Development and study of radiation resistance of electronic components, including those operating on new physical principles.

Development of energy and electronics devices using powder nanotechnology and ion beams.

Obtaining new data and monitoring the environmental situation in certain regions of the JINR Member States with the help of NAA.

Study of the influence of neutron irradiation on the properties of biological objects and tissues.

Investigation of layered structures, including high-temperature superconductors using RBS, ERD and PIXE techniques.

Performing elemental analysis of various objects of cultural heritage.

Expected methodological results:
Determination of optimal technologies for the synthesis and modification of substances for use as UCN and CN reflectors.

Development of methods for cleaning water and soil, and assessing the quality of food products.

Study of the processes of accumulation of nanoparticles in the organs of animals and plants, assessment of their impact on the health of living objects under study.

Development of a technique for non-destructive elemental analysis using prompt gamma-rays. Improvement of existing methods of activation analysis using thermal and resonance neutrons.

Development of methods for analyzing the electrical properties of developed electronic devices, power engineering devices, and ionizing radiation sensors based on new physical principles.

The fundamental results obtained during the implementation of the project will be of great importance for understanding the mechanisms of neutron-nuclear reactions and the development of theoretical ideas about these processes. The study of P- and T-odd effects will provide information on the contribution of the weak interaction to nuclear forces and can serve as an alternative method for determining the mixing coefficient Vud of a CKM matrix. Obtaining new information about ROT and TRI effects, as well as exotic fission modes, will make it possible to clarify the features of one of the stages of this process – the scission of a fissile nucleus into fragments. The data obtained during the implementation of the neutron-optical part of the project will be needed to create new neutron moderators and reflectors. In addition, they will allow significant progress in the development of neutron microscopy methods and studies of the magnetic structure of various objects. The implementation of the applied research program of the project will be of great social importance and contribute to the progress of environmental, materials science, archaeological, and nanotechnological investigations, as well as promising developments in the field of modern electronics and energy. The techniques of elemental and structural analysis being created and modernized will be in demand in many branches of human activity.

Expected results of the project in the current year:
Measurement of angular distributions of gamma-rays emitted in the reaction of radiative neutron capture by natural niobium samples and extraction of partial neutron widths of p-wave resonances of 35.85 eV, 42.15 eV, 94.14 eV.

Development of a technique for determining the flux densities of resonance and thermal neutrons from strong resonances, for example, indium (1.457 eV, 3.85 eV, 9.12 eV), silver (5.19 eV) and gold (4.906 eV).

Development of a facility for studying T-odd effects in fission on beamline 1 of the IBR-2 reactor.

Measurement of yields, angular and energy distributions of hydrogen isotopes in the ternary fission of 252Cf.

Carrying out measurements of (n, α) reactions on ^{14}N, ^{16}O, ^{50,52,53}Cr with fast neutrons using solid and gas samples.

Determination of the elemental composition of a number of archaeological samples using the method of neutron resonance analysis at the IREN facility.

Assessment of atmospheric deposition of heavy metals in the JINR Member States using passive and active biomonitoring.

Development of environmentally friendly methods for wastewater and soil treatment.

Achievement of new results in studying the influence of metal nanoparticles and neutron radiation on living organisms.

Preparation of an experiment to measure the speed of a neutron in matter.

Measurement of the Goos-Haenchen shift in an experiment on the total reflection of a neutron wave from a resonant structure (in case of availability of modern high-resolution neutron reflectometer).

Measurement of neutron scattering cross sections on DND powder depending on its density.

Obtaining mutants for breeding drought- and salt-resistant varieties of agricultural plants.

Activities of the theme:

	Name of the activity	Leaders	Implementation period
Laboratory	Responsible from laboratories		Status
1.	**Development of the conceptual design of an ultracold neutron source on a pulsed reactor**	**G.V. Kulin** **A.I. Frank**	2024-2025 Realization

FLNP A.I. Frank, L.V. Mitsyna, A.Yu. Muzychka, A.Yu. Nezvanov, Yu.N. Pokotilovski, V.A. Strelkov, K. Turlybekuly, M.A. Zakharov, 2 engineers, 1 worker

Brief annotation and scientific rationale:
Since the discovery of ultracold neutrons (UCN), a number of intense UCN sources have appeared in the world, and several more of them are under construction. There is no UCN source in Dubna, which is largely due to the features of the IBR-2M reactor. Its average power of 2 MW is relatively low for creating a steady-state UCN source, while the repetition rate of 5 Hz is too high to accumulate neutrons produced in each individual pulse. However, the pulsed flux of thermal neutrons from the reactor is very high, since the interval between pulses is hundreds of times longer than their duration.

A specific feature of the future UCN source at JINR is the pulsed filling of the trap, when neutrons arrive in it only during the pulse, while the rest of the time the trap remains isolated. The practical implementation of this idea is hindered by the fact that, due to the presence of biological shielding, the trap is far from the moderator in which UCNs are generated, and has to be connected to it by a transport neutron guide. In this case, the spread of transport flight times can significantly exceed the intervals between pulses, which makes the very idea of accumulation meaningless. To solve this problem, it was proposed to use a special device — a temporary lens that changes the energy of neutrons in a dosed manner as they arrive at this lens. Such a device makes it possible to restore the pulsed structure of the neutron beam immediately before entering the trap.

Recently, the idea of pulsed filling of a UCN trap has been the subject of intense discussion in the literature. Alternative approaches to time focusing of neutrons and methods for slowing down faster, so-called very cold neutrons (VCN) to energies characteristic of UCN have emerged. There have appeared theoretical works devoted to aspects of the formation of a neutron pulse by a time lens, as well as to the features of the time structure of a neutron beam when using a flipper moderator with a strong magnetic field. As a result, a significant number of ideas and proposals have emerged that can form the basis of a project for a new UCN source.

The aim of the work within the framework of "Activities" is to formulate the concept of a UCN source in a pulsed reactor on the basis of an analysis of both existing and some new ideas regarding the transport of UCN, the evolution of the duration of neutron bunches and the formation of the optimal time structure of bunches at the entrance to the trap. This can be either the IBR-2M reactor available at FLNP or the NEPTUN reactor currently being designed. It is expected that the final UCN spectrum at the entrance to the trap will be formed by slowing down the VCN.

Expected results upon completion of the activity:
Development of a conceptual design for an ultracold neutron (UCN) source at a pulsed reactor.

Expected results of the project in the current year:
Creation of a conceptual design of a UCN source for a pulsed reactor.

Registration and submission of applications for the opening of a project to develop a UCN source.

2.	**Neutron resonance spectroscopy**	**Baldin A.A.** **Shvetsov V.N.**	2025-2026 Implementation Data acquisition

VBLHEP V.I. Astakhov, E.G. Baldina, A.V. Beloborodov, Ver.V. Bleko, Vit.V. Bleko, D.N. Bogoslavsky, E.A. Bushmina, S.A. Chetverikov, P.R. Kharyuzov, E.A. Klevtsova, D.S. Korovkin, V.A. Kukharev, A.B. Safonov, S.V. Semashko, S.S. Shimansky, S.Yu. Starikova, Yu.A. Troyan, A.Yu. Troyan

FLNP N.V. Rebrova

Brief annotation and scientific rationale:
Experimental study of methods for detecting and measuring neutron resonances upon passage of radiation generated by a neutron source through various materials. Neutron resonance spectroscopy and radiography for studying the properties of materials in extreme states.

Development and study of methods of nondestructive testing of samples and materials using thermal and epithermal neutrons.

Within the framework of development of methods of real-time neutron tomography with thermal and resonance neutrons, a neutron image detector with high spatial (20-50 mm) and time (50-100 ns) resolution will be developed. This study is aimed at a broad

range of fast processes in the field of the physics of extreme states of matter and materials research. The method will make it possible to study the physical and chemical composition of machine-building materials, gas cavities inside structural materials with high atomic mass. Another important advantage of neutron radiography is the possibility of visualization of hydrogen-containing substances in a metal matrix.

Expected results at the end of the activity:
Practical implementation of the method of nondestructive measurement of parameters of materials in extreme states. Practical implementation of the method of nondestructive study of composite materials.

Study of the feasibility of development of low-current batteries based on the decay of unstable isotopes produced using a neutron source.

Expected major results in the current year:
Numerical and experimental determination of optimal characteristics of the neutron source.

Experimental determination of an optimal configuration of the experiment design to achieve the required measurement precision.

Improvement of methods for registration of parameters of neutron resonances.

Measurement of experimental neutron spectra from various materials irradiated by accelerated electron beams.

Collaboration

Country or International Organization	City	Institute
Albania	Tirana	UT
Armenia	Yerevan	SRCHCH
Azerbaijan	Baku	BSU
		IGG ANAS
		IRP ANAS
Belarus	Gomel	IRB NASB
	Khoiniki	PSRER
	Minsk	BSU
		IEB NASB
		INP BSU
		SPMRC NASB
Botswana	Palapye	BIUST
Brazil	Itabuna, BA	UFSB
Bulgaria	Plovdiv	PU
		UFT
	Sofia	IE BAS
		INRNE BAS
CERN	Geneva	CERN
China	Beijing	IHEP CAS
	Xi'an	NINT
Croatia	Zagreb	Oikon IAE
		RBI
Cuba	Havana	UH
Czech Republic	Ostrava	VSB-TUO
	Prague	CEI
		CTU
	Rez	CVR
Egypt	Alexandria	Univ.
	Cairo	NRC
	Giza	CU
	Mansoura	MU
	Shibin El Kom	MU
Finland	Jyvaskyla	UJ
	Oulu	UO
France	Cadarache	CC CEA
	Grenoble	ILL

		LPSC
	Saclay	LLB
	Strasbourg	IPHC
Georgia	Tbilisi	AIP TSU
		TSU
Germany	Mainz	JGU
	Munich	TUM
Hungary	Budapest	RKK OU
IAEA	Vienna	IAEA
India	Aizawl	MZU
	Varanasi	BHU
Italy	Rome	ENEA
Japan	Kyoto	KSU
	Tsukuba	KEK
Kazakhstan	Almaty	INP
	Astana	ENU
	Kyzylorda	KazSRIRG
		KU
Moldova	Chisinau	IChem
		IMB ASM
Mongolia	Ulaanbaatar	CGL
		NRC NUM
North Macedonia	Skopje	UKiM
Poland	Gdansk	GUT
	Krakow	INP PAS
	Lodz	UL
	Lublin	UMCS
	Opole	UO
	Otwock (Swierk)	NCBJ
	Poznan	AMU
	Wroclaw	UW
Republic of Korea	Daejeon	KAERI
	Pohang	PAL
	Seoul	Dawonsys
Romania	Baia Mare	TUCN-NUCBM
	Bucharest	IFIN-HH
		IGR
		INCDIE ICPE-CA
		UB
	Cluj-Napoca	INCDTIM
	Constanta	UOC
	Galati	DJUG
	Iasi	NIRDTP
		UAIC
	Magurele	ISS
	Oradea	UO
	Pitesti	ICN
	Ramnicu Valcea	ICSI
	Sibiu	ULBS
	Targoviste	VUT
	Timisoara	UVT
Russia	Arkhangelsk	NArFU
	Borok	IBIW RAS
	Dolgoprudny	MIPT
	Donetsk	DonIPE

	Dubna	Diamant
		Dubna State Univ.
	Elykaevo	Sirius. Kuzbass
	Gatchina	NRC KI PNPI
	Grozny	CSPU
	Irkutsk	LI SB RAS
	Ivanovo	ISUCT
	Izhevsk	UdSU
	Kaliningrad	IKBFU
	Moscow	"SNIIP"
		DSSI
		GIN RAS
		GPI RAS
		IA RAS
		IKI RAS
		IMET RAS
		IPCE RAS
		ITEP
		MISIS
		MSU
		NRC KI
		SC "IASRWA"
		Sechenov Univ.
		SIAS
		SINP MSU
		SM "MK"
		VNIIA
	Moscow, Troitsk	INR RAS
	Moscow, Zelenograd	"Angstrem"
		"Mikron"
	Nizhny Novgorod	IPM RAS
	Obninsk	IPPE
	Perm	PSNRU
	Saint Petersburg	Botanic garden BIN RAS
		FIP
		Ioffe Institute
		KRI
		SPMU
		SPSFTU
	Sevastopol	IBSS
	Staraya Ladoga	SL Museum
	Tula	TSU
	Vladikavkaz	NOSU
	Voronezh	VSU
	Yekaterinburg	UrFU
Serbia	Belgrade	INS "VINCA"
		IPB
		Univ.
	Novi Sad	UNS
Slovakia	Bratislava	CU
		IEE SAS
		IP SAS
Slovenia	Ljubljana	GeoSS
South Africa	Bellville	UWC

	Pretoria	UNISA
	Stellenbosch	SU
Switzerland	Villigen	PSI
Thailand	Hat Yai	PSU
Turkey	Canakkale	COMU
USA	Durham, NC	Duke
	Los Alamos, NM	LANL
	Oak Ridge, TN	ORNL
Uzbekistan	Tashkent	INP AS RUz
Vietnam	Da Lat	DNRI
	Hanoi	IOP VAST
		VNU

03-5-1130-2017

Synthesis and Properties of Superheavy Elements, Structure of Nuclei at the Limits of Nucleon Stability

Theme leader: S.I. Sidorchuk

Deputy: A.V. Karpov

Scientific leader: Yu. Ts. Oganessian

Participating countries and international organizations:
Belarus, Bulgaria, China, France, Germany, India, Italia, Kazakhstan, Mongolia, Republic of Korea, Romania, Russia, Slovakia, South Africa, Switzerland, Vietnam.

The problem under study and the main purpose of the research:
Synthesis of nuclei at stability limits and the investigation of their properties. Investigation of the mechanisms of heavy-ion-induced reactions. Study of the physical and chemical properties of heavy and superheavy elements.

Projects in the theme:

	Name of the project	Project leaders	Project code
1.	Investigation of heavy and superheavy elements	M.G. Itkis A.V. Karpov	03-5-1130-1-2024/2028
2.	Light exotic nuclei at the borders of nucleon stability	G. Kaminski S.I. Sidorchuk *Deputies:* V. Chudoba A.S. Fomichev	03-5-1130-2-2024/2028

Projects:

Laboratory	Responsible from laboratories	Name of the project	Project leaders	Status
1.		**Investigation of heavy and superheavy elements**	**M. G. Itkis** **A. V. Karpov**	Implementation

FLNR A.M. Abakumov, F.Sh. Abdullin, D. Abdusamadzoda, N.V. Aksenov, Yu. V. Albin, A.A. Astakhov, E. Batchuluun, A.Yu. Bodrov, A.A. Bogachev, G.A. Bozhikov,M.L Chelnokov, V.I. Chepigin, E.V. Chernysheva, I. Chuprakov, V.D. Danilkin, H.M. Devaraja, A. Dey, S.N. Dmitriev, A.V. Guljaev, A.V. Guljaeva, A.I. Holtzman, D. Ibadullayev, A.V. Isaev, Yu.M. Itkis, I.N. Izosimov,D.E. Katrasev, S.A. Klygin, G.N. Knyazheva, P. Kohout, A. Kohoutova, A.B. Komarov, G.A. Kononenko, N.D. Kovrizhnykh, E.M. Kozulin, N.I. Kozulina, L. Krupa, K.A. Kulkov, N.Yu. Kurkova, D.A. Kuznetsov, A.A. Kuznetsova, A.Sh. Madumarov, A.Yu. Malokost, O.N. Malyshev, R. Mukhin, I.V. Muravyov, I. V. Novikov, A.S. Novoselov, A. Opihal, I.V. Pchelintsev, O.V. Petrushkin, A.V. Podshibyakin, A.N. Polyakov, A.G. Popeko, Yu. A. Popov, L.S. Porobanyuk, V.A. Rachkov, A.M. Rodin, A.V. Sabelnikov, R.N. Sagaidak, V. Saiko, V.S. Salamatin , S. Sathayan, E.O. Savelieva, B. Saylaubekov, Yu.M. Sereda, V.D. Shubin, M.V. Shumeiko, E.A. Sokol, D.I. Soloviev, V.G. Subbotin, A.I. Svirikhin, M. Tezekbayeva, R.S. Tikhomirov, Yu.S. Tsyganov, V.K. Utenkov, V. Yu. Vedeneev, A.A. Voinov, I.V. Vorobyov, A.N. Vorontsov, M.G. Voronyuk, G.K. Vostokin, S.A. Yuhkimchuk

Brief annotation and scientific rationale:
The Project aims to study the heaviest nuclei and atoms in a comprehensive way: conducting experiments on the synthesis of elements with Z=119 and 120; synthesizing new isotopes of superheavy elements; studying nuclear (spectroscopy) and chemical properties of superheavy elements; and investigating nuclear reaction dynamics, including multi-nucleon transfer, leading to the formation of neutron-rich heavy nuclei.

The project will be implemented mainly at the SHE Factory of JINR commissioned in 2020. The studies on nuclear reaction dynamics will be carried out at the U-400 accelerator complex before it is shut off for upgrade and will be pursued at U-400R after the facility is back in business. During the upgrade, studies on reaction dynamics and mechanisms will be carried out at the U-400M accelerator.

Expected results upon project completion:
Synthesis of new superheavy elements 119 and 120.

Synthesis of superheavy nuclei and study of their decay properties.

Study of the chemical properties of superheavy elements.

Spectroscopy of the radioactive decay of heavy and superheavy nuclei.

First experiments aimed to measure the masses of superheavy nuclei.

Study of the dynamics of heavy-ion nuclear reactions.

Expected results of the project in the current year:
Experiments at the DGFRS-2 separator of the SHE Factory aimed to study production cross sections of nuclei in reactions with ^{48}Ca, ^{50}Ti, ^{54}Cr, ^{58}Fe ions and the properties of synthesized nuclei.

Test experiments for synthesizing elements with Z>118.

Experiments aimed at studying the properties of the radioactive decay (α-, β-decay, spontaneous fission properties) of short-lived isotopes with Z>100 (No, Lr, Rf, and Sg) produced in reactions with Ne, Mg, Ar, Ca, Ti, and Cr ions at the SHELS and GRAND (DGFRS-3) separators using the GABRIELA and SFiNX detecting systems.

Experiments for studying the chemical properties of Cn and Fl at the SHE Factory.

Further development of target and projectile production techniques for the synthesis of superheavy elements and study of their properties at the SHE Factory.

Investigation of mass-energy and angular distributions of fragments formed in multinucleon transfer reactions.

Study of the ^{40,42,44,48}Ca + ^{208}Pb reactions, the influence of structure effects on the reaction mechanism, fusion–fission cross sections and quasifission, and the properties of reaction fragments.

2. Light exotic nuclei at the borders of nuclear stability

G. Kaminski
S.I. Sidorchuk
Deputies:
V. Chudoba
A.S. Fomichev

Implementation

FLNR E. Almanbetova, A. Amer, A. Azhibekov, D. Aznabaev, E. Batchuluun, S.G. Belogurov, A.A. Bezbakh, A.A. Bogachev, I.V. Butusov, D. Ertaeva, E.M. Gazeeva,M.S. Golovkov, A.V. Gorshkov, L.V. Grirogenko, T. Isataev, A. Ismailova, Yu.M. Itkis, B.R. Khamidullin, M. Khirk, S.A. Klygin, A.G. Knyazev, G.N. Knyazheva, G.A. Kononenko, E.M. Kozulin, N.I. Kozulina, S.A. Krupko, K.A. Kulkov, S.M. Lukyanov, V.A. Maslov, B. Mauey, K.A. May, K. Mendibaev, K.D. Molotorenko, I.A. Muzalevskiy, E.Yu. Nikolskii, K.V. Novikov, Yu.L Parfenova, Yu.E. Penionzhkevich, N.H. Phan, S.A. Rimzhanova, E.O. Savelieva, Yu.M. Sereda, A.V. Shakhov, P.G. Sharov, N.K. Skobelev, R.S. Slepnev, V.I. Smirnov, Yu.G. Sobolev, S.V. Stepantsov, S.S. Stukalov, R.S. Tikhomirov, I.V. Vorobyov, A.N. Vorontsov, R. Wolski

Brief annotation and scientific rationale:
The investigations aim to study the structure of light nuclei and nuclear systems near and beyond the borders of nuclear stability using direct nuclear reactions (charge–exchange, one- or two-nucleon transfer), to investigate rare decay channels and the influence of reaction mechanisms on the observed properties of the studied nuclei. Direct reactions employed for studying the structure of isotopes near the borders of nuclear stability allow for more reliable data acquisition and the revision of existing knowledge. The experimental programme will be mainly implemented at the ACCULINNA-1,2 and MAVR setups using the upgraded U-400M accelerator complex of FLNR JINR that allow a wide range of experimental studies of light exotic nuclei using secondary beams in the energy range of 5–50 MeV/nucleon.

The ACCULINNA-2 separator is equipped with a radio frequency filter for additional purification of secondary beams, a magnetic spectrometer for reaction product separation, a cryogenic target complex of hydrogen and helium isotopes, an array of neutron detectors based on stilbene crystals, and systems for the registration of charged particles.

Expected results upon project completion:
Study of the properties of the drip-line isotopes of light nuclei.

First experiments using the tritium target.

Structure of the drip-line isotopes of light nuclei in (d,p) and (d,n), (t,p), (t,a), (p,d), etc. reactions.

Studies of exotic decays, including 2-n, 4-n, and 2-p emission.

Expected results of the project in the current year:
Study of nuclei near the boundaries of nucleon stability. Conduct of the ^{6,8}He+^{4}He experiments at the ACCULINNA-1,2 setups. Preparation for and conduct of experiments at the ACCULINNA-2 fragment separator using radioactive beams and the cryogenic targets D_2, ^{4}He.

Experiments on measuring the cross sections of individual reaction channels at ACCULINNA-1 employing the MULTI spectrometer.

Development of the infrastructure of the ACCULINNA-2 fragment separator (RF kicker, tritium target complex).

Collaboration

Country or International Organization	**City**	**Institute**
Belarus	Minsk	IPE NASB
Bulgaria	Sofia	INRNE BAS
China	Beijing	CIAE
		PKU
		UCAS
	Lanzhou	IMP CAS
France	Orsay	IJCLab
	Strasbourg	IPHC
Germany	Darmstadt	GSI
India	Kolkata	VECC
	Manipal	MU
	Roorkee	IIT Roorkee
Italy	Naples	Unina
Kazakhstan	Almaty	INP
		KazNU
	Astana	ENU
Mongolia	Ulaanbaatar	CGL
Republic of Korea	Daejeon	IBS
Romania	Bucharest	IFIN-HH
Russia	Dimitrovgrad	SSC RIAR
	Dubna	IPTP
	Moscow	INEOS RAS
		MSU
		NRC KI
		SINP MSU
	Moscow, Troitsk	INR RAS
	Saint Petersburg	IAI RAS
		Ioffe Institute
		KRI
		SPbSU
	Sarov	RFNC-VNIIEF
	Sosnovy Bor	VNIPIET
	Voronezh	VSU
Slovakia	Bratislava	CU
South Africa	Pretoria	UNISA
	Richards Bay	UNIZULU
	Somerset West	iThemba LABS
	Thohoyandou	UNIVEN
Switzerland	Villigen	PSI
Vietnam	Hanoi	IOP VAST
	Ho Chi Minh City	HCMUE

03-2-1100-2010

Non-Accelerator Neutrino Physics and Astrophysics

Theme leaders: E.A. Yakushev
S.V. Rozov

Participating countries and international organizations:
Azerbaijan, Belgium, Bulgaria, Czech Republic, France, Germany, Italy, Japan, Kazakhstan, Russia, Slovakia, Switzerland, United Kingdom, USA, Uzbekistan.

The problem under study and the main purpose of the research:
Search for neutrinoless and two-neutrino modes of double beta decay and their investigation, revelation of the neutrino nature, Majorana or Dirac, determination of the absolute neutrino mass scale and hierarchy, search for the magnetic moment of electron neutrinos, search for possible manifestations of dark matter. Investigations of nuclear reactor in-core processes at the Kalinin Nuclear Power Plant. Search for signals from coherent reactor antineutrino scattering and their investigation. Precision study of the coherent scattering spectrum to search for manifestations of New Physics. Search for sterile neutrinos. Spectroscopy of nuclei far from the line of beta stability. Study of interactions between intermediate-energy pions and helium nuclei. Development of new methods for detection of charged and neutral particles. Development of methods for producing and purifying radionuclide preparations for synthesis of radiopharmaceuticals. Application of hyperfine interaction methods to studying radiopharmaceuticals and their precursors. Development and application of methods and techniques to manufacture and analyze low-background materials with an ultra-low content of radioactive impurities.

Projects in the theme:

	Name of the project	Project Leaders	Project Code
1.	Radiochemistry and spectroscopy for astrophysics and nuclear medicine	D.V. Filosofov *Deputies:* A. Baimukhanova A.I. Velichkov Yu.B. Gurov A.Kh. Inoyatov D.V. Karaivanov Zh.Kh. Khushvaktov	03-2-1100-1-2024/2028
2.	Investigations of reactor neutrinos on a short baseline	I.V. Zhitnikov *Deputies:* A.V. Lubashevskiy S.V. Rozov M.V. Shirchenko	03-2-1100-2-2024/2028
3.	Nuclear spectrometry for the search and investigation of rare phenomena	D.R. Zinatulina *Deputies:* K.N. Gusev D.V. Ponomarev S.V. Rozov	03-2-1100-3-2024/2028

Projects:

	Name of the project	Project Leaders	Status
Laboratory	Responsible from laboratories		
1.	**Radiochemistry and spectroscopy for astrophysics and nuclear medicine**	**D.V. Filosofov** *Deputies:* **A. Baimukhanova** **A.I. Velichkov** **Yu.B. Gurov** **A.Kh. Inoyatov** **D.V. Karaivanov** **Zh.Kh. Khushvaktov**	Implementation R&D Production Data taking
DLNP	A.M. Abd, I.V. Alekseesv, K.M. Alshubaki, K.V. Antokhina, J.A.Dadakhanov, K.S. Dadakhanova, E. Denisova, S.A. Evseev, A.N. Emeliyanov, M. ElThoky, V.V. Fariseeva, S.V. Fateev, B.E. Kalinova, I.I. Kamnev, O.I. Kartvtsev, S.A. Katulin, S.L. Katulina, E.Yu. Kulkova, E.S. Kurakina, Yu.K. Khusenova, T. Lednicka, N.V. Mazarskaya, N.A. Mirzaev, V.A. Morozov, N.V. Morozova, T.A. Morozova, N.D. Mokhine, M.V. Mukhina, I.B. Nemchenok, D.V. Ponomarev, A.V. Rakhimov, S.V. Rozov, I.E. Rozova, A.V. Salamatin, D.A. Salamatin, J.K. Samatov, V.G. Sandukovskiy, A.A. Solnyshkin, V.I. Stegailov, I.A. Suslov, N. Temerbulatova, V.V. Timkin, V.N. Trofimov, K.V. Shakhov, M.Yu. Shevchenko, I.S. Sherbakova, Yu.A. Vaganov, O.V. Vagina, N.A. Vinokurov, V.P. Volnykh, M.Yu. Vorobyeva, E.A. Yakushev, A.A. Zaikin		

Brief annotation and scientific rationale:
The project is aimed at developing methods of nuclear spectroscopy and radiochemistry for the use in nuclear medicine, astrophysics and neutrino physics. The project involves novel techniques for particle detection, calibration of experimental facilities, determination of background and also the design of uniquely pure materials, etc., as well as development of methods for nuclear medicine – such as production and purification of radioisotopes, development and synthesis of radiopharmaceuticals, study of mechanisms affecting the tissues at radionuclide decay locations, etc.

Specific area:
– novel detectors (semiconductor detectors, liquid and plastic organic scintillators, composite scintillation detection systems, neutron and radon detectors, etc.).

– post-decay spectroscopy of electrons and other emissions, with the focus on extremely low energies.

– standard gamma-spectroscopy based on semiconductor particle detectors (SPDs), with the focus on precision measurements of emission energy and source activity (of both point-like and volume sources) in order to study decay modes and to determine cross sections of nuclear reactions.

– methods of hyperfine interactions using radioactive tracers, namely the Method of Perturbed Angular Correlations (PAC) and Emission Mössbauer Spectroscopy to study radiopharmaceuticals and their precursors in aqueous systems and other matrices.

– methods for production and purification of radionuclide preparations to synthesize radiopharmaceuticals, including their production with generators, physicochemical methods for evaluating properties of radionuclides and radiopharmaceuticals (their precursors) in homogeneous and heterogeneous systems.

– methods and techniques for production and analysis of low-background materials with a uniquely low content of radioactive impurities, in particular, using Inductively Coupled Plasma Mass Spectrometry (ICP-MS), as well as other analytical techniques and those of nuclear spectroscopy.

Methods of nuclear spectroscopy and radiochemistry for studying neutrino properties, searching for dark matter particles and investigating rare physical processes have long and deservedly proved effective in numerous experiments in fundamental physics and nuclear medicine. The relevance of this topic is certain. The focus on the development of methods and techniques expanding the horizon of the experiments being performed at DLNP JINR guarantees the scientific novelty of the project.

Expected results upon completion of the project:
New detectors:

– detectors based on silicon carbide (SiC) will be designed and then applied to the detection of nuclear radiation; SiC detectors with a high radiation hardness and good operability at high temperatures (> 400°C) are intended to be used for monitoring the operation of high-current accelerators, nuclear reactors, as well as for diagnostics of hot plasma;

– liquid tellurium-loaded scintillators are expected to be designed and applied to search for the neutrinoless double β-decay, as well as other types of liquid and plastic scintillators;

– composite scintillation detection systems will be developed for neutrino experiments;

– ^{3}He counters will be developed and applied to the detection of low neutron fluxes (of below 10^{-6} n×cm^{-2}×s); a compact sensitive radon detector will be designed, as well as the technology to produce low-level radioactive components using 3D printing.

It is planned to experimentally study the spectra of low-energy electrons (0–50 keV) with the ESA-50 spectrometer and the spectra of gamma and X-ray radiation with SPDs during radioactive decay in order to obtain new data on low excited states of nuclei and post-decay relaxation of atomic systems, as well as to search for ways to perform the spectrometry of post-decay photons (from the edge of infrared radiation up to soft X-rays) in the energy range of 1–200 eV.

The method for using the codes (Geant4, MCNP and FLUKA) to simulate parameters of HPGe spectrometers both at the LINAC-200 Electron Accelerator intended to determine yields of photonuclear reactions, and also at other basic facilities of JINR will be developed; decay modes of a wide range of radionuclides will be studied, and their content in samples (^{96}Zr, ^{40}K, ^{138}La, etc.) will be determined in order to investigate rare processes.

It is expected that the methods of Perturbed Angular Correlations (PAC) and Emission Mössbauer Spectroscopy using radioactive tracers ^{111}In, ^{152}Eu, ^{154}Eu, ^{119}Sb, ^{119m}Sn, ^{57}Co, ^{161}Tb, etc., will be mastered in order to study radiopharmaceuticals and their precursors (components) in aqueous systems and other matrices; physicochemical methods to evaluate properties of radionuclides and radiopharmaceuticals in homogeneous and heterogeneous systems will be improved.

Radiochemistry and nuclear medicine:

– sorption processes in various solution-sorbent systems as a chemical basis of methods for purification of radiopharmaceuticals (also of low-background materials) are planned to be studied, and radionuclide generators for production of radiopharmaceuticals to be designed;

– methods for production of radionuclides and their separation (including mass separation) from targets irradiated with protons, neutrons and gammas for production of radiopharmaceuticals (^{103}Pd, ^{119}Sb, ^{161}Tb, some alpha emitters, etc.) will be developed;

– on the basis of reverse-tandem schemes, the development of a wide range of radionuclide generators will be continued in order to expand the possibilities of producing medical radionuclides; the possibility of producing 1–2 generators of significant activity for external users will be considered;

– methods for radiolabelling based on chelators with "slow" kinetics for synthesis of radiopharmaceuticals will be developed; radium chelation will be investigated.

Methods for producing samples (^{82}Se, ^{96}Zr, shielding materials, solder, etc.) with a new ultra-low content of impurities (from mBq/kg to μmBq/kg of Th and U) to solve problems in astrophysics and neutrino physics will be developed and employed; reverse chromatography will be used, low-boiling and other reagents, prepared or selected, will be utilized, as well as reactor materials, selected and prepared;

– it is planned that the methods for the analysis of samples at an ultra-low level of sensitivity (mBq/kg – μmBq/kg of Th and U) using ICP-MS, the neutron activation analysis (NAA) and other techniques will be developed and employed; that the methods for precise determination of the chemical and isotopic composition of materials used in astrophysical and neutrino experiments will be designed.

Expected results of the project this year:

New detectors:

– characteristics of the detectors based on ultra-high purity silicon carbide (SiC) will be determined for spectroscopy of nuclear radiation;

– techniques for manufacturing plastic scintillators applicable to the separation of n/γ-radiation by the pulse shape will be tested;

– results of designing of composite scintillation detection systems for next-generation neutrino experiments will be obtained; a prototype auxiliary detector for large reactor experiments will be developed;

– a novel ^{3}He counter with a low internal background will be tested;

– technology for manufacturing components of low-level radioactive plastics using 3D printing will be developed.

Schemes of post-decay photon spectrometers (from the edge of infrared radiation up to soft X-rays) in the energy range of 1–200 eV will be proposed.

Experimental data on the low-energy electron spectra from the decay of radioisotopes of ^{56}Co, ^{57}Co, ^{83}Rb, ^{155}Eu with the ESA-50 beta spectrometer are planned to be obtained in order to test the available computer codes for evaluating dose components of Auger and conversion electrons in radiation hygiene and radionuclide therapy.

Photonuclear reaction yields will be determined; decay modes of a wide range of radionuclides, their content in samples will be specified to study rare processes.

PAC spectrometers will be upgraded; new Emission Mössbauer Spectrometers will be launched (radioactive tracers ^{111}In, ^{152}Eu, ^{154}Eu, ^{119}Sb, ^{119m}Sn, ^{57}Co, ^{161}Tb, etc., will be used in studies).

Radiochemistry and nuclear medicine: the results of studying sorption processes of various solution-sorbent systems, as well as novel schemes of radionuclide separation are expected.

Methods for obtaining samples (^{96}Zr) with a new ultra-low content of impurities to solve problems in astrophysics and neutrino physics will be developed and utilized.

It is planned to calibrate the mass spectrometer (ICP-MS) with standard samples; methods for sample analysis at an ultra-low level of sensitivity to Th and U will be acquired.

2. Investigation of reactor neutrinos on a short baseline

I.V. Zhitnikov
Deputies:
A.V. Lubashevskiy
S.V. Rozov
M.V. Shirchenko

Implementation
R&D
Upgrade
Data taking

DLNP A.M. Abd, Yu.V. Aksenova, I.V. Alekseesv, V.V. Belov, A. Bystryakov, M.S. Dovbnenko, I.S. Dotsenko, S.A. Evseev, M.E. Elthokhy, A.N. Emeliyanov, SV.V. Fariseeva, S.V. Fateev, D.V. Filosofov, M.V. Fomina, Yu.B. Gurov, K.N. Gusev, A.K. Inoyatov, S.V. Kazarcev, B.E. Kalinova, I.I. Kamnev, D.V. Karaivanov, S.A. Katulin, S.L. Katulina, J.K. Khushvaktov, S.P. Kiyanov, A.S. Kuznetsov, E.Yu. Kulkova, T. Lednicka, N.V. Mazarskaya, D.V. Medvedev, N.A. Mirzaev, V.A. Morozov, T.A. Morozova, I.B. Nemchenok, D.V. Ponomarev, D.S. Pushkov, I.E. Rozova, A.V. Salamatin, D.A. Salamatin, V.G. Sandukovskiy, I.A. Suslov, K.V. Shakhov, M.Yu. Shevchenko, E.A. Shevchik, I.S. Sherbakova, N. Temerbulatova, V.V. Timkin, Y.u.A. Vaganov, O.V. Vagina, S.I. Vasiliev, V.P. Volnykh, M.Yu. Vorobyeva, E.A. Yakushev, A.A. Zaikin

Brief annotation and scientific rationale:
The project combines the experiments DANSS, Ricochet and νGeN focused on the study of antineutrino fluxes from nuclear reactors at distances of less than 20 m. The experiments are united by a common area of research, by scientific problems overlapping and coinciding in many respects and by the ways to solve them. In addition, these studies are united by the common JINR staff and infrastructure resources.

DANSS is an experiment using an antineutrino spectrometer based on plastic scintillators, with a sensitive volume of 1 m^3, located at Power Unit 4 at the Kalinin NPP. The lifting mechanism makes it possible to move the spectrometer 2 m vertically in the online mode, providing the range of measurements at the distance of 11–13 m from the reactor. A high degree of detector segmentation and the use of combined active and passive shielding ensure background suppression down to several percent relative to ~5000 IBD events recorded per day.

The νGeN experiment is aimed at studying the fundamental properties of neutrinos, in particular, searching for the neutrino magnetic moment (NMM), coherent elastic neutrino scattering (CEνNS) and other rare processes. The νGeN spectrometer is located under the reactor core of Power Unit 3 at the Kalinin NPP. Neutrino scatterings are detected with a special low-threshold, low-background germanium detector. With systems of active and passive shielding from background radiation, a low level of background in the region of the search for rare events is achieved. The detection of events of interest ensures the search for New Physics beyond the Standard Model, in addition, it can also be applied practically, for example, in the development of new-generation detectors for monitoring the operation of a nuclear reactor using the antineutrino flux.

Ricochet is a new-generation reactor neutrino experiment aimed at the one-percent-precision measurement of coherent elastic neutrino-nucleus scattering (CEνNS) in the sub-100-eV recoil nucleus energy region, which could reveal New Physics in the electroweak sector. It is planned to install the facility near the research nuclear reactor at the Laue-Langevin Institute (ILL) until the end of 2024. Ricochet will host two cryogenic detector arrays: CRYOCUBE (Ge bolometers based on those developed by the EDELWEISS experiment) and Q-ARRAY (superconducting Zn).

Expected results upon completion of the project:
The main goals of the DANSS experiment are to test the hypothesis of oscillations of reactor antineutrinos into a sterile state and to precisely monitor the operation of the nuclear reactor by measuring the antineutrino flux for a long time. In few years, it is planned to make a new upgraded setup DANSS-2. The aims of the upgrade are to improve energy resolution and to increase the detection volume, thus, the sensitivity to sterile neutrinos will be significantly higher. The search for oscillations into the light sterile neutrino ($\Delta m_{14}^2 \sim 0.1–10$ eV) is one of the current trends in fundamental neutrino physics. The existence of a sterile neutrino could explain several contradictory observations, first of all, the reactor and gallium (anti)neutrino anomalies, and at the same time become a revolutionary discovery of New Physics. Reactor experiments with a short baseline (<30 m) have several competitive advantages in this area of research: a giant antineutrino flux from the most intense available artificial sources of (anti)neutrinos on Earth and a small distance from the radiation source where the hypothesized oscillation pattern is not smeared yet. It should be noted that the DANSS spectrometer is the leader among the facilities of this type.

It is expected that the νGeN project will detect coherent scattering of reactor antineutrinos for the first time and increase the sensitivity to the neutrino magnetic moment to $\sim 1\times10^{-11}$ m_B during several years of measurements to come, which will greatly improve the present-day best limit.

In the Ricochet experiment, according to the elaborated and experimentally proven background model, the statistical significance of the CEνNS detection after only one reactor cycle will be between 7.5 and 13.6 σ, depending on the effectiveness of the muon veto. The targeted ~1%-precision measurement is expected to be reached after about ten reactor cycles (3–5 years onsite). It will increase the probability of discovering New Physics by an order of magnitude compared to that of the ongoing experiments.

Expected results of the project this year:
DANSS: data taking and processing at the DANSS setup will be continued; new results of studies of oscillations of neutrinos into a sterile state are expected; R&D of DANSS-2 is planned, as well as the DANSS-2 manufacture and assembly at the Kalinin NPP.

νGeN: Data taking in the current setup configuration and a simultaneous upgrade of the setup are planned, including a new internal veto, replacement of passive shielding, modernization of the data taking system; it is expected that new results considering the neutrino magnetic moment and CEνNS will be obtained; the backgrounds, including a neutron one, will be measured and analyzed.

Ricochet: new results at the setup at ILL are expected; the upgrade of the detectors will proceed; an improved Monte Carlo model is planned to be developed on the basis of the experimental data.

3. Nuclear spectrometry for the search for and investigation of rare phenomena

D.R. Zinatulina
Deputies:
K.N. Gusev
D.V. Ponomarev
S.V. Rozov

Implementation
Upgrade
Data taking

DLNP A.M. Abd, Yu.V. Aksenova, I.V. Alekseesv, V.V. Belov, I.S. Dotsenko, A.N. Emeliyanov, M.E. ElThoky, V.V. Fariseeva, S.V. Fateev, D.V. Filosofov, M.V. Fomina, Yu.B. Gurov, A.K. Inoyatov, S.V. Kazarcev, B.E. Kalinova, I.I. Kamnev, D.V. Karaivanov, O.I. Kartvtsev, S.A. Katulin, S.L. Katulina, T. Khusainov, A.A. Klimenko, O.I. Kochetov, E.Yu. Kulkova, T. Lednicka, A.V. Lybashevsky, N.V. Mazarskaya, N.A. Mirzaev, V.A. Morozov, T.A. Morozova, I.B. Nemchenok, A.V. Rakhimov, N.S. Rumyantseva, A.V. Salamatin, D.A. Salamatin, V.G. Sandukovskiy, A.A. Smolnikov, E.O, Sushenok, K.V. Shakhov, M.Yu. Shevchenko, E.A. Shevchik, M.V. Shirchenko, A.M. Shihada, I.S. Sherbakova, N. Temerbulatova, V.V. Timkin, V.I. Tretyak, V.N. Trofimov, Yu.A. Vaganov, O.V. Vagina, S.I. Vasiliev, V.P. Volnykh, M.Yu. Vorobyeva, E.A. Yakushev, A.A. Zaikin, I.V. Zhitnikov

Brief annotation and scientific rationale:
The project consists of five main experiments: LEGEND (The Large Enriched Germanium Experiment for Neutrinoless double beta Decay), TGV (Telescope Germanium Vertical), SuperNEMO (Neutrino Ettore Majorana Observatory), MONUMENT (Muon Ordinary capture for the NUclear Matrix elemENTs) and Zr-BNO. The experiments solve the problems of searching for and studying the neutrinoless double beta decay.

Expected results upon completion of the project:
The LEGEND experiment is designed to search for the neutrinoless double beta decay ($0\nu\beta\beta$) of ^{76}Ge. In LEGEND, bare detectors of isotopically enriched ^{76}Ge immersed in liquid argon are used. The ultimate goal of the project is to reach the sensitivity to the $0\nu\beta\beta$ decay of $^{76}Ge > 10^{28}$ years (90% C.L.).

The physics programme of the SuperNEMO Demonstrator Module contains precision measurements of the $2\nu\beta\beta$ decay mode. The programme is aimed at reaching the best limits on $0\nu\beta\beta$ for the isotope ^{82}Se.

The purpose of the MONUMENT experiment is to measure the muon capture by several daughter nuclei, the candidates for the $0\nu\beta\beta$ decay.

The Zr-BNO experiment is aimed at the search for the double beta decay of ^{96}Zr into exited states of ^{96}Mo and at the search for the beta decay of ^{96}Zr into ^{96}Nb.

The TGV spectrometer will be used for further investigations of the ECEC decay of ^{106}Cd and ^{130}Ba. According to estimations and theoretical predictions considering these rare processes, we hope to detect these decays in the direct experiment for the first time.

Expected results of the project this year:
The first results of the large-scale LEGEND experiment searching for the $0\nu\beta\beta$ decay are expected; R&D of hardware components of LEGEND-1000 are planned (detector holders, ASICs, detector immersion system, argon veto, etc.); the start of manufacture of new Ge-enriched detectors and their testing; the start of the assembly of the LEGEND-1000 facility at the host underground lab.

Taking of calibration data with the spectrometer SuperNEMO Demonstrator; taking of data on $0\nu\beta\beta$ and $2\nu\beta\beta$ decays in the ^{82}Se nucleus.

The MONUMENT activities will proceed; a series of new experiments at the PSI site will be prepared (including R&D at JINR – purchase of detectors and targets, calibrations and simulations) and performed; data taking and processing of accumulated data; it is intended to measure the muon capture with a solid ^{48}Ti target and gas targets of carbon enriched in atomic masses 12 and 13 (investigation of light nuclei in terms of validation of theoretical models applicable to double beta decay), as well as with enriched ^{96}Mo; R&D on application of muon capture in other physics-related areas, such as radiobiology and mesonic chemistry.

The upgrade of the TGV spectrometer (both detectors and electronics); measurements of enriched ^{106}Cd with the TGV setup.

Zr-BNO: the results of measurements of the enriched sample of ^{96}Zr at the low-background facilities at JINR and BNO.

Activities of the theme:

Name of the activity	Leaders	Implementation period
Laboratory Responsible from laboratories		Status
1. Nuclear bolometer	**V.N. Trofimov**	2025-2027
		R&D

DLNP A.N. Fedorov, V.G. Kolomiec, A.B. Neganov, A.A. Priladyshev

Brief annotation and scientific rationale:
This project is part of the programme "Study of coherent elastic neutrino scattering off atoms, nuclei and electrons and measurements of electromagnetic neutrino characteristics with the intense antineutrino tritium source" (SATURNE project: SArov TritiUm neutRiNo Experiment) funded by the Federal Budget of RF and Rosatom. In this project, DLNP JINR is involved in developing low-temperature detection systems, namely in manufacturing prototype low-temperature helium and silicon detectors based on the ^{3}He/^{4}He dilution cryostat and also in studying different ways of generation and detection of elementary excitation pulses in superfluid helium.

Expected results of the activity upon completion:
Data on different ways of generation and detection of elementary excitation pulses in superfluid helium.

Expected results of the activity in the current year:
Development and commissioning of the cryogenic system based on the dry ^{3}He/^{4}He dilution cryostat.

2. DUBTO-2	**D.B. Pontecorvo**	2025-2027
		Data processing

DLNP A.M. Rozhdestvensky, B.M. Sabirov, I.A. Belolaptikov, S.V. Rozov, I.E. Rozova, S.A. Gustov, V.M. Grebenyuk, A.G. Molokanov, S.V. Shvydky, V.A. Panyushkin

FLNR M.A. Naumenko, V.N. Frolov

Brief annotation and scientific rationale:
This activity is a follow-up of the projects DUBTO and PAINUC, it means it will be a collaborative experiment of JINR and INFN, Italy, focused on the studies of pion–helium interactions at energies below the Δ-resonance. In this experiment, the data will be used previously obtained at the JINR Phasotron with the technique of self-shunted streamer chambers developed at JINR. The goal is to get additional experimental data on the $\pi^{\pm}$^{4}He interaction at 106 and 68 MeV which is of great value for theorizing and developing models of nuclear matter.

Expected results of the activity upon completion:
The kinematics of the $\pi^{\pm}$^{4}He interaction, such as outgoing momentum of secondary particles and their exit angles, invariant masses of two and three particles, will be obtained. In particular, the probabilities of different channels of the $\pi^{\pm}$^{4}He interaction will be specified.

Expected results of the activity in the current year:
In 2025, the already measured images of $\pi^{\pm}$^{4}He interactions will be analyzed in view of a novel approach to identification of secondary charged particles, and also the processing of raw experimental data (about half of the available statistics) will be prepared and launched.

Collaboration

Country or International Organization	City	Institute or laboratory
Azerbaijan	Baku	IRP ANAS
Belgium	Leuven	KU Leuven
Bulgaria	Sofia	INRNE BAS
Czech Republic	Prague	CTU
		CU
		IEAP CTU
France	Annecy-le-Vieux	LAPP
	Bordeaux	LP2I
	Caen	LPC
	Gif-sur-Yvette	CEA
	Grenoble	CNRS
		ILL
		Neel
	Lyon	UL
	Marseille	CPPM
	Modane	LSM
	Orsay	CSNSM
		UP-S
Germany	Heidelberg	MPIK
	Munich	TUM
	Tubingen	Univ.
Italy	Assergi	INFN LNGS
Japan	Osaka	Osaka Univ.
	Tsuruga	WERC
Kazakhstan	Almaty	INP
Russia	Dubna	Dubna State Univ.
	Gatchina	NRC KI PNPI
	Moscow	ITEP
		LPI RAS
		NNRU "MEPhI"
	Neutrino	BNO INR RAS
	Voronezh	VSU
Slovakia	Bratislava	CU
Switzerland	Villigen	PSI
	Zurich	UZH
United Kingdom	Coventry	Warwick
	Edinburgh	Univ.
	London	Imperial College
		UCL
	Manchester	UoM
USA	Amherst, MA	UMass
	Austin, TX	UT
	Cambridge, MA	MIT
	Chapel Hill, NC	UNC
	Evanston, IL	NU
	Idaho-Falls, ID	INEEL
	Tuscaloosa, AL	UA
Uzbekistan	Tashkent	INP AS RUz

Condensed Matter Physics (04)

04-4-1147-2024

Optical Methods in Condensed Matter Studies

Theme leaders: G.M. Arzumanyan
N. Kučerka

Deputy: K.Z. Mamatkulov

Participating countries and international organizations:
Armenia, Belarus, Egypt, India, Kazakhstan, Russia, Serbia, Uzbekistan, Vietnam.

The problem under study and the main purpose of the research:
Fundamental and applied studies of low-dimensional materials (2D materials and van der Waals heterostructures) using Raman spectroscopy and upconversion luminescence. Fluorescence microscopy and vibrational spectroscopy in studies of photo-activated programmed cell death (netosis and apaptosis). Spectroscopy of lipid-protein interactions and secondary structure of proteins. Mastering low-frequency Raman spectroscopy.

Project in the theme:

Laboratory	**Name of the project** Responsible from laboratories	**Project Leaders**	**Project code** **Status**
1.	**NANOBIOPHOTONICS**	**G.M. Arzumanyan** **K.Z. Mamatkulov**	04-4-1147-1-2024/2028 Data taking Realization
FLNP	Y. Arynbek, M. Balasiou, M.A. Doroshenko, H. Esawii, M.N. Eshonqulova, H.D. Le, Tri N.B. Pham		
BLTP	N.L. Macko, V.A. Osipov		
VBLHEP	V. Vartic		
MLIT	O.I. Streltsova		
LRB	E. Dushanov		

Brief annotation and scientific rationale:
Since the exfoliation of graphene in 2004, two-dimensional materials (2DMs) have attracted much attention due to the qualitative changes in their physical and chemical properties due to quantum size effect associated with their nanoscale thicknesses. Atomically thin two-dimensional transition metal dichalcogenides (TMDCs), such as MoS_2, WSe_2, and others, exhibit strong light-matter coupling, making them potentially interesting candidates for various applications in electronics, optics, and optoelectronics. They can be assembled to form heterostructures and combine the unique properties of their constituent monolayers. Raman spectroscopy is one of the most non-destructive and relatively fast technique for characterizing such materials, providing high spectral resolution. Vibrational frequencies in the Raman spectrum of low-dimensional materials exhibit characteristic features of the sample, including line shape, peak position, spectral width, and intensity. These parameters provide useful information about the physical, chemical, electronic, and transport properties of such materials.

Optical research methods are also very promising in Life Sciences. In particular, combining vibrational spectroscopy with fluorescence microscopy will allow a detailed study of the mechanisms and signalling pathways of photo-activated programmed cell death – NETosis. Raman spectroscopy is also a subtle and very informative tool in revealing the secondary structure of proteins and is sensitive to lipid-protein interactions.

Expected results upon completion of the project:
Measurement and characterization of the transport properties of 2DMs and vdWHs depending on the excitation photon energy.

Mechanism of Raman enhancement effects from analyte molecules adsorbed on two-dimensional materials. Study of their protective properties applied to biomolecules.

Up-conversion luminescence on a low-dimensional platform: studies depending on the sample, temperature and excitation wavelength.

Spectroscopic analysis of conformational transformations in the secondary structure of proteins present in various membrane mimetics, including, temperature, pH, and additives dependance.

Simulation of lipid-protein interaction by MD and DFT.

Identification of the mechanisms and signaling pathways of photoinduced NETosis by UV, visible and IR radiation. Identification of primary acceptors of photo-induced NETosis.

Characterization of the effects of simultaneous and sequential exposure to laser radiation on intact neutrophil cells at two different wavelengths.

Raman spectroscopy of ultra-low frequencies ~ 10 cm^{-1} at different wavelengths of excitation of the Raman signal.

Expected results of the project in the current year:
Raman spectroscopy and MD simulation of the secondary structure of beta-amyloid peptide in the lipid/peptide system depending on pH and temperature.

Initiation of research into the low-frequency Raman spectrum of biological macromolecules.

The influence of simultaneous and sequential irradiation of neutrophil cells on the formation of photonetosis.

Study of Surface-Enhanced Raman spectroscopy of analyte molecules on a plasmonic substrate covered with 2D material.

Modification of 2D materials with rare earth elements and fluorine and their analysis by Raman and photoluminescence spectroscopy.

Plasmonic enhancement of up-conversion photoluminescence of rare-earth-doped nanoparticles.

Collaboration

Country or International Organization	**City**	**Institute or laboratory**
Armenia	Yerevan	YSU
Belarus	Minsk	BSUIR
		SOL instruments
		SPMRC NASB
Egypt	Cairo	NRC
India	Aizawl	MZU
Kazakhstan	Almaty	INP
Russia	Moscow	MSU
	Saint Petersburg	PFSPSMU
	Vladivostok	FEFU
	Yakutsk	NEFU
Serbia	Belgrade	Univ.
Uzbekistan	Jizzakh	JBNUU
Vietnam	Hanoi	IOP VAST

Radiation Research in Life Sciences (05)

05-7-1077-2009

Research on the Biological Effects of Ionizing Radiations with Different Physical Characteristics

Theme leaders: A.N. Bugay
E.A. Krasavin

Participating countries and international organizations:
Armenia, Belarus, Bulgaria, Cuba, Egypt, Italy, Mongolia, Russia, Serbia, Slovakia, South Africa, Uzbekistan, Vietnam.

The problem under study and the main purpose of the research:
Theoretical and experimental research on the biological effects of heavy charged particles of different energies at JINR's basic facilities.

Projects in the theme:

Name of the project	Project Leaders	Project code
1. Molecular, genetic and organism effects of ionizing radiations with different physical characteristics	A.V. Boreyko P.N. Lobachevsky	05-7-1077-1-2024/2028
2. Radiation-biophysical and astrobiological research	A.V. Chizhov A.Yu. Rozanov	05-7-1077-2-2024/2028

Project:

	Name of the project	Project Leaders	Status
Laboratory	Responsible from laboratories		
1.	**Molecular, genetic and organism effects of ionizing radiations with different physical characteristics**	**A.V. Boreyko** **P.N. Lobachevsky**	Data taking Realization Modeling

LRB T.N. Bazlova, N.N. Budionnaya, A.N. Bugay, V.N. Chausov, K. Erzhan, K.N. Golikova, E.V. Golubeva, E.V. Il'ina, M.D. Isakova, Fam Thi Zuen, A.V. Frolova, I. Hernández González, N.A. Koltovaya, O.V. Komova, V.L. Korogodina, I.V. Koshlan, N.A. Koshlan, M.A. Kovalenko, P.A. Kozhina, A.N. Kokoreva, I.A. Kolesnikova, T.S. Khramko, E.A. Krasavin, M.E. Krupnova, P.V. Kutsalo, E.A. Kuzmina, E.A. Kulikova, P.O. Lkhasuren, O.N. Matchuk, Yu.V. Melnikova, L.A. Melnikova, E.A. Nasonova, A. Nurkasova, Nguen Bao Ngok, N.V. Pakhomova, D.V. Petrova, E.V. Pronskih, Yu.S. Severiukhin, D.V. Shamina, N.V. Shvaneva, E.A. Shipilova, I.V. Smirnova, S.I. Tiunchik, G.T. Tilavova, T.V. Tiupikova, D.M. Utina, O.O. Vinogradova, Yu.V. Vinogradova, V.C. Vinogradova, I.A. Zamulaeva, N.I. Zhuchkina

Brief annotation and scientific rationale:
The aim of the research is to study the molecular, genetic and organismal effects of ionizing radiation with different physical characteristics. The use of ionizing radiation of a wide range of linear energy transfer in radiobiological experiments allows obtaining unique information on the nature of the damage to the DNA structure of cells after irradiation, the mechanisms of the induction of gene and structural mutations in cells with different levels of genome organization, and the action of particle radiation on tumor during radiation therapy. Within the framework of the Theme, fundamental and applied problems of modern radiation biology will be addressed: the formation and repair of cluster DNA damage in normal and tumor cells following exposure to accelerated charged particles; the study of the radiosensitizing effect of the DNA repair modifier AraC in combination with various molecular biological complexes during irradiation of tumor cells and tissues; the study of the induction of gene and structural mutations in normal and tumor cells following exposure to charged particles; investigation of acute and long-term morphological and functional changes in the mammalian central nervous system following exposure to radiation with different physical characteristics.

When organizing radiobiological experiments with charged particle beams, it is extremely important to improve physico-dosimetric complexes, provide precision dosimetry, and conduct computer simulation of radiation-induced effects. In this regard, the urgent tasks are: the need for experimental modeling of the energy and spectral composition of cosmic and other types of ionizing radiation; the search for methods for non-destructive analysis of unique samples; and automated processing of biological experiment data. In the course of the research, it is planned to develop new setups and dosimetry systems for irradiating biological samples; introduce methods for non-destructive analysis of unique samples, develop and test systems for automated computer processing of biological data; formulate new mathematical models and computational approaches for radiobiology, bioinformatics

and radiation medicine; and identify mechanisms and pathways of catalytic synthesis of prebiotic compounds under the action of radiation.

Expected results upon completion of the project:
To study clustered DNA DSB formation after exposure to accelerated charged particles of different energies in the nuclei of human skin fibroblasts, tumor cells, and neurons of different parts of the central nervous system of irradiated animals.

To study the repair kinetics of clustered DNA DSB in the post-irradiation period in the nuclei of human skin fibroblasts and radioresistant tumor cells.

To study mechanisms of the radiosensitizing effect of cytosine arabinoside in combination with various molecular biological complexes on normal and tumor cells after exposure to radiation with different LET.

To study quantitatively the survival of normal and tumor cells after radiation exposure in the presence of a combination of DNA repair modifiers.

To continue investigation of point and structural mutation induction in *Saccharomyces cerevisiae* yeast cells by radiation with different LET.

To study the influence of heterogeneity of cell population in haploid yeast on the radiation-induced mutagenesis; estimate mutagenesis in different phases of cell cycle.

To study the influence of respiratory impairment as the result of mitochondrial DNA damage on the sensitivity to the mutagenic effect of radiation.

To study the mechanism of radioresistance and its effect on radiation-induced mutagenesis in yeast mutants.

To continue the study of radiation-induced mutagenesis and to compare the yield of chromosomal aberrations in Chinese hamster cells at the highest and lowest mutagenesis levels depending on the time of expression and LET of accelerated ions.

To analyse structural disorders in the *hprt* gene and their projection on disorders in the chromosome machinery of cells.

To finalise the mFISH study of the biological effectiveness of proton beams.

To study the biological effectiveness of low-energy X-rays following *in vitro* irradiation of human blood lymphocytes using the mFISH method.

To evaluate the contribution of complex chromosome aberrations to the biological effectiveness of densely ionizing radiations following irradiation of human normal and tumour cells *in vitro.*

To study the induction and kinetics of chromatin break repair by premature chromatin condensation in normal and tumour human cells exposed to sparsely and densely ionizing radiation.

To continue the study of primary and late morphological and functional changes in the central nervous system of rats following exposure to ionizing radiation with different physical characteristics.

To conduct studies of pharmacological protection agents' action under ionizing radiation exposure.

To continue the investigation of the activation of microglial cells in cell culture and inflammatory markers in the brain of mice following exposure to ionizing radiation of different quality.

To investigate the possibility to modulate the activation of microglial cells in irradiated culture and neuroinflammation in the brain of irradiated mice by using inhibitors to the receptors of signalling pathways involved in these processes.

To study *in vivo* the radiosensitizing effect of cytosine arabinoside in combination with other molecular biological complexes on melanoma tumor growth in mice following the combined exposure to these agents and proton radiation.

To evaluate the influence of the combined action of AraC and other molecular biological complexes on the survival of different normal and tumor cell lines based on clonogenic survival criterion upon X-ray and proton irradiation.

To study the kinetics of the formation and elimination of DNA damage in U87 glioblastoma and other radioresistant cell cultures after proton and X-ray exposure in the presence of AraC and other molecular biological complexes.

To study DNA DSB formation in different components of the central nervous system after *in vivo* irradiation with protons and X-rays in the presence of a combination of radiomodifiers.

Expected results of the project in the current year:
To continue the analysis of the formation and repair of clustered DNA double-strand breaks after exposure to accelerated charged particles and photon radiation in normal and tumor cells (human fibroblasts, U87 glioblastoma cells, and B16 murine melanoma cells) and in neurons of different parts of the central nervous system of animals.

To continue the analysis of the formation and structure of complex clustered DNA damage using immunocytochemical staining of the repair proteins γH2AX, 53BP1, OGG1, and XRCC1 in normal and tumor cells (human fibroblasts, U87 glioblastoma cells, and B16 murine melanoma cells) after exposure to accelerated charged particles and photon radiation.

To continue the selection of modifiers that increase the radiosensitivity of tumor cells in combination with cytosine arabinoside when exposed *in vivo* and *in vitro* to ionizing radiations with different physical characteristics.

To continue research on the radiosensitizing effect of cytosine arabinoside in various combinations with repair modifiers on the survival, formation, and elimination of DNA damage in normal and tumor cells.

To analyze chromosomal abnormalities in radiation-induced mutants and their descendants expressed in the region of the minimum HPRT mutagenesis level and in the long term after irradiation of V79 Chinese hamster cells with γ-rays and accelerated boron ions.

To continue studying the induction of structural changes in yeast cells by ionizing radiations with different LET.

To continue research on the effect of heterogeneity of the yeast cell population on sensitivity to the lethal and mutagenic action of UV and ionizing radiations.

To continue studying the effect of mitochondrial DNA damage on radiosensitivity and mutagenesis.

To continue metaphase and mFISH analysis of chromosomal aberrations induced in peripheral blood lymphocytes of *Macaca mulatta* monkeys by accelerated carbon ions.

Using the premature chromatin condensation method, to evaluate the induction of primary chromatin damage and the kinetics of its repair in human normal and tumor cells after exposure to photons, accelerated protons, and accelerated nitrogen ions.

To study the genetic stability of mouse neural stem cells in culture using the mFISH method, depending on their origin and duration of cultivation.

Using the mFISH method, to study the biological effectiveness of soft X-rays and the spectrum of chromosomal aberrations they induce.

To continue the study of impairments in long-term memory and learning ability of rats in the Morris test and T-maze test after whole-body irradiation.

To investigate long-term morphological changes in the central nervous system and small intestine of rats after whole-body proton irradiation.

To develop a method for assessing changes in the regenerative capacity of intestinal crypts when using radiomodifiers.

To continue studying behavioral reactions, electroencephalography signals, and morphological changes in rats after local X-ray exposure of the brain using the SARRP facility.

At the SARRP facility, to adapt the experimental B16 melanoma model *in vivo* and optimize the conformal radiation therapy parameters using radiomodifiers.

To assess the effectiveness of radioprotectors using small laboratory animal models.

To study the cytotoxicity, degree of accumulation, and localization in cells of protoporphyrin IX and a complex of protoporphyrin IX and gadolinium using cell lines of human breast carcinoma (Cal-51, MDA-468, and MDA-231) and colorectal cancer (HCT-116) and evaluate their survival when exposed to X-rays.

2.	**Radiation-biophysical and astrobiological research**	**A.V. Chizhov** **A.Yu. Rozanov**	Data taking Realization Modeling

LRB A.N. Afanaseva, S.V. Aksenova, A.S. Batova, L.G. Beskrovnaya, S.A. Budyonny, A.N. Bugay, V.N Chausov, D.V. Davydov, E.B. Dushanov, I.M. Enyagina, A.A Glebov, I.S. Gordeev, M.I. Kapralov, T.S. Khramko, E.A. Kolesnikova, I.A. Kolesnikova, E.A. Krasavin, E.N. Lesovaya, B. Lhagwaa, N.V. Lomakin, B. Munkhbaatar, Nguen Thi Than Huen, M.S. Panina, E.E. Pavlik, A.Yu. Parkhomenko, A.K. Ryumin, O.G. Sadykova,

	E.A. Saprykin, Yu.S. Severyukhin, A.V. Stolyarov, T. Tudevdorzh, T.V. Tyupikova, N.V. Ustinov, D.I. Utina, M.A. Vasilyeva
FLNR	G. Kaminski, S.V. Mitrofanov, L.A. Pavlov, Yu.G. Teterev, K.D. Timoshenko
FLNP	A.V. Churakov, M.V. Frontasyeva, N. Kučerka, V.G. Pyataev, V.N. Shvetsov, K.V. Udovichenko, N.S. Yushin, I. Zinkovskaya
MLIT	A. Khvedelidze, A.V. Nechaevsky, Yu. Palii, O.I. Streltsova, M.I. Zuev
DLNP	V.V. Glagolev, A.Kh. Inoyatov, G.A. Karamysheva, G.V. Mitsyn, V.A. Rozhkov, G.A. Shelkov, R. Sotensky
VBLHEP	A.A. Baldin, E.M. Syresin

Bref annotation and scientific rationale:
A wide range of JINR's ionizing radiation sources, especially heavy ion beams of various energies, offer a unique opportunity to solve a number of fundamental problems of radiobiology and astrobiology, as well as practical problems related to space exploration and the development of radiation medicine.

Due to the high complexity and cost of performing biological experiments at accelerator complexes, it is of paramount importance to improve experimental methods, ensure dosimetry and radiation safety, and perform relevant computer simulations. The most pressing issues here are the need for experimental reproduction of the energy and spectral composition of cosmic and other types of ionizing radiation, the search for methods for non-destructive analysis of unique samples and automated processing of biological experiment data, as well as the high complexity and resource intensity of computer simulation of processes in living systems.

This project is aimed at solving a complex of the above problems arising in radiobiological and astrobiological research. In the course of its implementation, it is planned to develop new stations for irradiation and dosimetry systems; introduce methods for non-destructive analysis of unique samples; develop and test systems for automated computer processing of biological data; formulate new mathematical models and computational approaches for radiobiology, bioinformatics, and radiation medicine; and identify mechanisms and pathways of the catalytic synthesis of prebiotic compounds under radiation exposure.

Expected results upon completion of the project:
Provision of dosimetry and irradiation of biological samples at JINR accelerators.

Upgrade and commissioning of the Genome-3 facility.

Development of a multimodal tomography system for small laboratory animals.

Equipping a room for radiobiological experiments using radionuclides.

Creation of a prototype space radiation simulator.

Development and testing of instruments for neutron dosimetry and spectrometry.

Development of an information system for working with experimental data in the form of two-dimensional images, computed tomography data, and video recordings.

Development of protocols for labeling two-dimensional images and video materials, formation of a labeled database.

Testing the implemented analysis algorithms; development and registration of software designed for automated data processing.

Development of mathematical models of the formation and repair of various types of DNA damage and models of the formation of mutations and chromosomal aberrations.

Molecular dynamics modeling of structural and functional disorders in mutant and oxidized forms of proteins.

Development of mathematical models of radiation-induced death of tumor cells and prediction of tumor growth for promising radiation therapy methods.

Theoretical evaluation of radiation-induced disorders of the CNS on the basis of mathematical models of brain neural networks, taking into account damage to synaptic receptors, oxidative stress, and impaired neurogenesis and gliogenesis.

Study of possible pathways of, and conditions for, the formation of prebiotic compounds by irradiation of cosmic matter or terrestrial rocks in combination with the simplest organic molecules.

Search for, and structural analysis of, microfossils and organic compounds in various meteorites by nuclear physics methods.

Expected results of the project in the current year:
To develop a mathematical model of the formation and repair kinetics of clustered DNA damage induced by accelerated heavy charged particles of different energies, taking into account the cell cycle phase, in mammalian normal and tumor cells.

To develop a mathematical model of the dynamics of the tumor cell population after ionizing radiation exposure in the presence of DNA synthesis inhibitors.

To develop mathematical models of oxidative damage to cell membranes and organelles induced by ionizing radiation.

To develop mathematical models of the survival and population dynamics of stem cells in normal and tumor tissues after exposure to ionizing radiations with different physical characteristics.

To develop a mathematical model of chromosomal aberration induction in mammalian and human cells by ionizing radiations with different characteristics.

Using molecular dynamics methods, to study the accumulation in cell structures and the stability of molecules of promising radiomodifiers, contrast agents, and drugs for neutron capture therapy.

To apply computer vision algorithms to biological data processing in histology and behavioral experiments.

To update and put into practice guidelines for organizing and conducting radiobiological experiments using LRB irradiation facilities.

To continue the development of software systems to improve computational methods for determining the physical characteristics of the radiation field and precision dosimetry for LRB radiobiological experiments.

To continue improving X-ray tomography techniques and planning conformal irradiation of small laboratory animals, taking into account minimizing the negative impact on organs at the SARRP facility.

To ensure the operability of the existing Genom-2M facility; to carry out the assembly, installation, and testing of the Genom-3 facility at applied beams of the U400M cyclotron.

To take part in the modeling and study of radiation fields during the operation of applied research stations (ISKRA and SIMBO) in the Measurement Hall of the NICA complex, at the MSC-230 accelerator, and at the IREN facility as part of working groups (the Laboratory of High Energy Physics, Laboratory of Nuclear Problems, Laboratory of Neutron Physics, and Radiation Safety Department).

To continue calculations and creation of a new neutron dosimeter based on helium and boron counters of a wide energy range.

To investigate the processes of fossilization of microorganisms.

To conduct experiments on the synthesis of prebiotic compounds from formamide under irradiation with accelerated charged particles in the presence of the substance of terrestrial minerals and meteorites.

To conduct an experiment on the synthesis of prebiotic compounds in space (participation in the BION program).

Activities of the theme:

	Name of the Activity	Leaders	Implementation period
Laboratory	Responsible from laboratories		Status
1.	**Training specialists in radiation safety and radiobiology**	**Krasavin E.A.** **Bugay A.N.**	2024-2026 Realization

LRB L.G. Beskrovnaya, A.V. Boreyko, N.N. Budionnaya, V.N. Chausov, A.V. Chizhov, E.B. Dushanov, E.B. Enyagina, I.V. Koshlan, E.N. Lesovaya, P.N. Lobachevsky, Yu.S. Severyukhin

Collaboration

Country or International Organization	City	Institute or laboratory
Armenia	Yerevan	Foundation ANSL
		RAU
		YSU
Azerbaijan	Baku	Khazar Univ.
Belarus	Gomel	IRB NASB
	Minsk	IBCE NASB
		INP BSU

		Inst. Physiology NASB
		SPMRC NASB
Bulgaria	Sofia	IE BAS
		IMech BAS
		Inst. Microbiology BAS
		NCRRP
Cuba	Havana	CEA
		CNEURO
		CPHR
		UH
	San Jose de las Lajas	CENTIS
Egypt	Sadat City	USC
Italy	Viterbo	UNITUS
Mongolia	Ulaanbaatar	NUM
Russia	Borok	IPE RAS
	Chelyabinsk	SUSU
	Kazan	FRC KazSC RAS
	Moscow	FCBN FMBA
		FMBC
		IBMC
		IBMP RAS
		IGEM RAS
		IHNA Ph RAS
		IKI RAS
		MSU
		NRC KI
		PIN RAS
		SAI MSU
	Moscow, Troitsk	ISAN
	Novosibirsk	BIC SB RAS
	Obninsk	NMRRC
	Puschino	IPCBP SS RAS
	Sochi	SRI MP
	Vladivostok	FEFU
		PIBOC
Serbia	Belgrade	IBISS
		INS "VINCA"
		IORS
		Univ.
	Kragujevac	UniKg
Slovakia	Bratislava	CU
South Africa	Bellville	UWC
	Somerset West	iThemba LABS
Uzbekistan	Parkent	IMS
	Tashkent	INP AS RUz
Vietnam	Hanoi	INPC VAST
		ITT VAST
		VINATOM

05-2-1132-2017

Study of Molecular Genetic Mechanisms of Adaptations of Extremophilic Organisms

Theme leader: E.V. Kravchenko

Participating countries and international organizations:
Egypt, Moldova, Russia, USA.

The problem under study and the main purpose of the research:
Study of the mechanisms of adaptation of extremophilic organisms to physical and chemical stresses and their use for protection of other organisms.

Project in the theme:

Name of the Project	Project Leader	Project code
Laboratory Responsible from laboratories		Status
1. TARDISS Protection against physical and chemical stresses with tardigrade proteins	**E.V. Kravchenko**	05-2-1132-1-2021/2028 Implementation

DLNP S.V. Apraksina, A.V. Rzyanina, K.A. Tarasov, A.S. Yakhnenko, T.O. Yurikovskaya, M.P. Zarubin

FLNP O.I. Ivankov, T.N. Murugova

CAP (FLNR) E.V. Andreev, P.Y. Apel, A.N. Nechaev

Brief annotation and scientific rationale:
Mechanisms of adaptation of living organisms to existence in extreme conditions are of great interest for applied and fundamental research, in particular, mechanisms of resistance to ionizing radiation, high mineralization of the environment, effects of heavy metals, high and low temperatures and high pressure. Under the conditions of an increasing level of radiation background due to various man-made components, the problem of cosmic radiation, which prevents the long stay of living organisms in space, the need to protect healthy tissues from radiation during radiation therapy of tumours, and a number of general mechanisms underlying cell aging and their damage by ionizing radiation, the study of new mechanisms for increasing radioresistance is one of the most important areas of molecular biology and radiobiology.

Representatives of Tardigrada (tardigrades) belong to the group of animals most resistant to various types of stress on Earth. Tardigrades are able to survive after exposure to both rare and dense ionizing radiation at doses of about 5 kGy.

The Dsup protein is a new protein discovered in 2016 in the tardigrade *Ramazzottius varieornatus*, one of the most radioresistant species of multicellular organisms. Previously, we created the *D. melanogaster* lines and the HEK293 human cell culture expressing this protein, for which a significant increase in radioresistance was shown when exposed to various types of ionizing radiation. For the *D. melanogaster* lines expressing Dsup, the transcriptomic analysis was performed, which revealed the effect of the Dsup protein on a number of processes at the cellular and organism levels. Our results were published in 2023 in iScience (Q1) (https://doi.org/10.1016/j.isci.2023.106998). In the course of the experiments to determine the structure of the Dsup protein, the physical dimensions of the Dsup protein molecule were estimated for the first time, some parameters of the DNA-Dsup complex were established, and the existence of a possible secondary structure of the Dsup protein was shown.

The problems to be solved during the implementation of the project are new and important not only for fundamental molecular biology and radiobiology but also for applied areas of biotechnology, space research and other disciplines that require an increase in the level of radioresistance of organisms.

Expected results upon completion of the project:
Creation of a regulated scheme for the expression of the gene encoding the Dsup protein in the *melanogaster* model object to develop a controlled system for the temporary increase in radioresistance of the whole organism.

Evaluation of the effect of the Dsup protein on chromatin compaction in cells to establish the fundamental characteristics of the Dsup protein and map new regulatory elements in the *D. melanogaster genome*.

Obtaining data on the stability and properties of the Dsup protein during exposure to high temperatures and ionizing radiation to evaluate the use of this protein in pharmacology and medicine as a cryoprotectant, preservative and stabilizer for vaccines and other DNA/RNA-containing drugs, and as a protective agent for radio- and chemotherapy.

Development of a technique and a material for purification of nucleic acids from solutions and concentrating DNA and RNA from various biological fluids using the Dsup protein.

Expected results of the project this year:
Assessment of induced radioresistance of *D. melanogaster* lines expressing Dsup under the control of the metallothionein gene promoter, and assessment of changes in the level of transcription of target genes upon induction of the promoter by various concentrations of copper compounds and exposure to high doses of radiation (500-1000 Gy).

Determination of structural characteristics of the Dsup-DNA complex and determination of the dissociation constant of Dsup-DNA using cryoelectron microscopy and MST (microscale thermophoresis).

Activities of the theme:

Name of the activity	Leader	Implementation period
Laboratory Responsible from laboratories		Status
1. The molecular genetics of radiation-induced changes at the gene and genome level in Drosophila melanogaster. RADIOGENE	**K.P. Afanasyeva**	2024-2025
		R&D

DLNP I.D. Alexandrov, M.V. Alexandrova, N.E. Kharchenko, S.V. Korablinova, L.N. Korovina, O.P. Solodilova

Brief annotation and scientific rationale:
Modern ideas about de novo genetic changes in the offspring of irradiated parents are based mainly on the data from classical radiation genetics of *Drosophila* and mice characterizing the frequency of hereditary locus-specific mutations in the gametes of parents after exposure to ionizing radiation. These data became the scientific basis for the first assessments of the genetic danger (risk) of ionizing radiation when inducing such mutations. However, the nature and frequency of DNA changes during such mutations remain unknown. The first molecular analysis of radiation mutations in one of the studied genes (*black*) using PCR and Sanger sequencing revealed a spectrum of DNA changes that turned out to be highly specific to γ-radiation and neutrons. The results obtained for the first time allowed danger (risk) of γ-radiation to be assessed at the molecular level inducing DNA base substitutions, which are known to be the mutational basis of a number of human genetic diseases. Further research in this direction will reveal general patterns and gene-specific features of radiation mutagenesis in the generative cells of *D. melanogaster* after exposure to qualitatively different types of radiation. However, hereditary gene mutations are only one component of a complex spectrum of genetic changes caused in generative cells and do not provide a complete picture of the nature and extent of de novo genetic changes obtained by offspring from irradiated parents.

The observed progress in the field of DNA and IT technologies opens up for the first time the possibility of studying the genetic consequences in the offspring of irradiated parents at the DNA level of the entire genome. Research in the field of radiation genomics is new, and the results of the first studies in mice have shown that acute X-ray irradiation (3 Gy, LD50) increases several fold the frequency of heritable structural changes in the DNA of the genome, such as large deletions, duplications (copy number variants - CNV), as well as smaller insertions and deletions (indels). Since the data obtained in the *Drosophila*-mouse system are critical for extrapolation to humans, genomic studies in *D. melanogaster* are of particular relevance. The first results of our pilot experiment on *Drosophila* using whole-genome sequencing and partial bioinformatic analysis showed that almost all of the 9 studied descendants of γ-irradiated males (40 Gy) had latently inherited (recessive) multiple structural changes of different types in DNA (deletions of different sizes, duplications, inversions, etc.). Completing research is the main goal for 2025 within the framework of the Radiogen activity.

Expected results upon completion of the activity:
Completion of analysis of results of the whole genome sequencing of the offspring of male *Drosophila* parents irradiated with γ-radiation at a dose of 40 Gy.

Expected results of the activity this year:
Completion of analysis of the results of whole genome sequencing (WGS) of the offspring of γ-irradiated male parents of *D. melanogaster*.

Collaboration

Country or International Organization	City	Institute or laboratory
Egypt	Aswan	Univ.
	New Borg El-Arab	GEBRI
Moldova	Chisinau	IMB ASM
Russia	Dolgoprudny	MIPT
	Moscow	MSU
USA	Tampa, FL	USF

Information Technology (06)

06-6-1119-2014

Methods, Algorithms and Software for Modeling Physical Systems, Mathematical Processing and Analysis of Experimental Data

Theme leaders: S.V. Shmatov
O. Chuluunbaatar

Deputies: N.N. Voytishin
P.V. Zrelov

Participating countries and international organizations:
Armenia, Belarus, Bulgaria, CERN, China, Egypt, France, Georgia, Italy, Kazakhstan, Mexico, Mongolia, Russia, Serbia, Slovakia, South Africa, United Kingdom, USA, Uzbekistan.

The problem under study and the main purpose of the research:
The theme is aimed at organizing and providing computational, algorithmic and software support for the preparation and implementation of experimental and theoretical research conducted with JINR's participation, at elaborating, developing and using computational methods for modelling complex physical systems studied within the projects of the JINR Topical Plan. Within the theme, mathematical methods and software, including those based on machine and deep learning algorithms using recurrent and convolutional neural networks, will be developed for modelling physical processes and experimental facilities, processing and analysing experimental data in the field of elementary particle physics, nuclear physics, neutrino physics, radiobiology, etc. Particular attention will be paid to the creation of systems for the distributed processing and analysis of experimental data, as well as information and computing platforms to support research conducted at JINR and other research centres.

The main directions of work are mathematical and computational physics to support JINR's large research infrastructure projects, primarily, the NICA flagship project in the fixed target mode (BM@N) and in the collider mode for relativistic heavy ion collisions (MPD) and polarized beams (SPD), the Baikal-GVD neutrino telescope. Cooperation with experiments at the world's accelerator centres (CERN, BNL, etc.), experiments in the field of neutrino physics and astrophysics, radiobiological research programmes will also be continued. The possibility of using the developed methods and algorithms within other projects is being considered.

The major direction in modelling complex physical systems, including the states of dense nuclear matter and quantum systems, will be the development of methods, software packages and numerical research based on the solution of the corresponding systems of nonlinear, spatially multidimensional integral, integro-differential or differential equations in partial derivatives with a large number of parameters characterized by the presence of critical modes, bifurcations and phase transitions with the complex application of methods of computational physics, quantum information theory and hybrid quantum-classical programming methods.

Within the theme, it is also planned to develop work on the quantum intelligent control of technological processes and physical facilities at JINR, as well as quantum computing in quantum chemistry and physics.

In addition, the training of specialists in the field of computational physics and information technology within the IT School will be continued.

Projects in the theme:

	Name of the project	Project Leaders	Project code
1.	Mathematical methods, algorithms and software for modeling physical processes and experimental facilities, processing and analyzing experimental data	S.V. Shmatov *Deputies:* A.S. Ayriyan N.N. Voytishin	06-6-1119-1-2024/2026
2.	Methods of computational physics for the study of complex systems	E.V. Zemlyanaya O. Chuluunbaatar *Deputies:* Yu.L. Kalinovsky A. Khvedelidze	06-6-1119-2-2024/2026

Projects:

Name of the project	Project Leaders	Status
1. Mathematical methods, algorithms and software for modeling physical processes and experimental facilities, processing and analyzing experimental data	**S.V. Shmatov** *Deputies:* **A.S. Ayriyan** **N.N. Voytishin**	Realization

MLIT P.G. Akishin, E.P. Akishina, A.I. Anikina, E.I. Alexandrov, I.N. Alexandrov, D.A. Baranov, T.Zh. Bezhanyan, J. Busa, K.A. Chizhov, S. Hnatich, H. Grigorian, O.Yu. Derenovskaya, A.V. Didorenko, N.D. Dikusar, V.V. Ivanov, I.S. Kadochnikov, A.A. Kazakov, O.L. Kodolova, Yu. V. Korsakov, B.F. Kostenko, Z.K. Khabaev, M.A. Mineev, Zh.Zh. Musulmanbekov, A.V. Nechaevsky, A.N. Nikitenko, E.G. Nikonov, D.A. Oleynik, G.A. Ososkov, V.V. Palichik, V.V. Papoyan, I.S. Pelevanyuk, A.Sh. Petrosyan, D.V. Podgainy, D.I. Pryahina, N. Saktaganov, I. Satyshev, K.V. Slizhevsky, A.G. Soloviev, T.M. Solovjeva, O.I. Streltsova, Z.K. Tuhliev, S.A. Shadmehri, Z.A. Sharipov, S.K. Slepnev, A.V. Uzhinsky, V.V. Uzhinsky, A.V. Yakovlev, V.B. Zlokazov, M.I. Zuev

VBLHEP V. Yu. Aleksakhin, A.A. Aparin, Yu.V. Bespalov, D.V. Budkovski, A.V. Bychkov, I.R. Gabdrakhmanov, A.S. Galoyan, K.V. Gertsenberger, V.M. Golovatyuk, D.K. Dryablov, M.N. Kapishin, V.Yu. Karzhavin, A.A. Korobitsyn, A.V. Krylov, A.V. Lanev, V.V. Lenivenko, S.P. Lobastov, S.P. Merts, A.A. Moshkin, Yu.A. Murin, D.N. Nikiforov, M. Patsyuk, O.V. Rogachevsky, V.G. Riabov, V.V. Shalaev, S.G. Shulga, A.V. Taranenko, I.A. Zhizhin, V. Zhezher, A.I. Zinchenko, D.A. Zinchenko

BLTP D.I. Kazakov, M.V. Savina, O.V. Teryaev, V.D. Toneev, V.A. Zykunov

FLNP M. Balasoiu, M.V. Frontasyeva, A.I. Ivankov, A.H. Islamov, Yu.S. Kovalev, A.I Kuklin, Yu.N. Pepelishev, Yu.L. Ryzhikov, A.V. Rogachev, V.V. Skoy, K.N. Vergel

DLNP V.A. Bednyakov, I.A. Belolaptikov, I.V. Borina, A.N. Borodin, V. Dik, I.I. Denisenko, T.V. Elzhov, A.A. Grinyuk, A.V. Guskov, E.V. Khramov, V.A. Krylov, V.S. Kurbatov, D.V. Naumov, A.E. Pan, A.E. Sirenko, M.N. Sorokovikov, B.A. Shaibonov, E. Sholtan, A.C. Zhemchugov, D.Yu. Zvezdov

LRB I.A. Kolesnikova, Yu.S. Severyukhin, D.M. Utina

UC D.V. Kamanin, A.Yu. Verkheev, B.S. Yuldashev

Brief annotation and scientific rationale:
The project is aimed at organizing and providing computational support for physics research programmes implemented with JINR's participation, at developing mathematical methods and software for modelling physical processes and experimental facilities, processing and analysing experimental data in the field of elementary particle physics, nuclear physics, neutrino physics, condensed matter, radiobiology, etc. The particular attention will be paid to the creation of systems for the distributed processing and analysis of experimental data, as well as information and computing platforms to support research at JINR and other world centres.

The main areas of work are mathematical and computational physics to support JINR's large research infrastructure projects, first of all, the experiments at the NICA accelerator complex and the Baikal-GVD neutrino telescope. Further cooperation with experiments at the largest world accelerator centres (CERN, BNL, etc.), experiments in the field of neutrino physics and astrophysics, radiobiological research programmes will also be continued. The possibility of using the developed methods and algorithms within other megascience projects is being considered.

Expected results upon completion of the project:
Revision of interaction generators and their development for modelling the processes of interactions of light and heavy nuclei, including those at NICA energies (FTF, QGSM, DCM-QGSM-SMM, etc.), and processes beyond the Standard Model, such as the production of candidate particles for the role of dark matter, additional Higgs bosons and processes that violate the lepton number, etc. (QBH, Pythia, MadGraph, etc.) for LHC conditions at a nominal energy and a total integrated luminosity up to 450 fb^{-1}.

Development of algorithms for the reconstruction of charged particle tracks for experimental facilities, including those at NICA and the LHC, creation of appropriate software and its application for data processing and analysis, the study of the physical and technical characteristics of detector systems.

Development of scalable algorithms and software for processing multi-parameter, multi-dimensional, hierarchical data sets of exabyte volume, including those based on recurrent and convolutional neural networks, for machine and deep learning tasks, designed primarily for solving various problems in particle physics experiments, including for the NICA megaproject and neutrino experiments.

Creation and development of data processing and analysis systems and modern research tools for international collaborations (NICA, JINR neutrino programme, experiments at the LHC).

Development of algorithms and software for JINR's research projects in the field of neutron physics.

Development of algorithms, software and computing platforms for radiobiological research, applied research in the field of proton therapy and ecology.

Expected results of the project current year:
Completion of the revision of the Geant4 FTF model, more accurate specification of the functions of fragmentation of quarks and diquarks into strange particles in the Geant4 QGS model, conducting numerical experiments on the production of hypernuclei.

Physics analysis of data obtained in the NICA MPD, NICA BM@N and NA61/SHINE experiments within the Geant4 FTF model.

Considering various effects of the DCM-QGSM-SMM generator: dependence of the lifetime of resonances on the density of the nuclear medium, suppression of the production cross section of pseudoscalar mesons, enhancement of the production of hyperons in a dense nuclear medium, nucleus deformations. Elaboration of a lattice model of the nucleus and a percolation model of multifragmentation.

Mathematical modeling of the production and identification of non-resonant dibaryons at the NICA SPD facility.

Mathematical modeling of the events of knocking out pairs of high-momentum nucleons from atomic nuclei by accelerated particles. Elaboration of a draft of an experimental proposal for the NICA facility.

Evaluation of the cross sections of the processes of production of dark matter particles and new scalars within the extended two-doublet Higgs model (2HDM+a/S, MadGraph generator) in the channel of production of a muon/b-quark pair and the missing energy, performing corresponding modeling and data analysis under LHC RUN2/3 conditions.

Evaluation of the cross sections of the processes of production of dark matter particles and new scalars within the Inert Doublet Model in the final state with two muons and the missing energy, performing corresponding modeling and data analysis under LHC RUN2/3 conditions.

Debugging of the procedure for testing sensitive elements of the high-granularity calorimeter of the CMS experiment, including track reconstruction and the evaluation of the efficiency of each detector cell.

Development and adjustment of algorithms and methods for reconstructing muon trajectories in the Cathode-Strip Chambers (CSCs) of the muon system of the CMS experiment for the comparison of the continuous and discrete approaches of wavelet analysis for separating overlapping signals; estimation of the CSC spatial resolution and the aging effect on data obtained in 2025 at the GIF++ facility at CERN and in proton-proton beam collisions at the LHC.

Development of machine learning models and approaches for their application to particle identification within the BM@N experiment on the basis of a sample balanced by the types of classified particles.

Finding correction parameters in coordinate and angular space for the geometry of the STS and GEM detectors of the BM@N experiment, elaboration and software implementation of modeling and data processing methods, as well as their development and adaptation for the current configurations of a number of GEM and Silicon Profilometer tracking detectors in 2024-2025.

Introduction of alignment corrections to the geometric models of the microstrip tracking detectors (FSD, GEM and CSC) of the BM@N experiment obtained as a result of analysis of the reconstructed trajectories of charged particles on the basis of the first physical run data. Elaboration and software implementation of modeling and data processing methods for the vertex silicon detector plane (VSP) for upcoming experimental runs.

Transition from the global classifier that identifies particles within the MPD experiment in a full momentum range to local classifiers based on gradient boosting and operating in a given momentum range in order to enhance the efficiency of particle detection.

Modernization of the MPD experiment software package to enhance the accuracy and speed of event reconstruction by implementing the ACTS tracker into the MPDroot software shell. Integration of the latest versions of external dependencies into the MPDRoot shell (ACTS, FairRoot, GEANT4, ROOT). Transition of the build system to Alma Linux 9.5.

Optimization of the codes of charged particle trajectory reconstruction programs in the track system of the SPD experiment to speed up the offline event processing procedure.

Application of graph neural networks to detect charged particle trajectories in the MPD experiment.

Investigation of the properties of hadron jet/cluster reconstruction algorithms under SPD conditions. Evaluation of the cross sections of the process of direct photon production in quark-gluon scattering.

Implementation of a model for processing and storing simulated data from the SPD experiment, relevant for 2025-2026, on the basis of the previously created prototype of a distributed mass data processing system and new application software created on the Gaudi software platform.

Functional testing and debugging of components and interfaces between the components of the system that provides multi-stage data processing on the real-time event filtering cluster (SPD OnLine Filter).

Provision of the required level of functioning that meets the needs for the mass modeling of physics processes of the SPD experiment in a distributed computing environment based on the PanDA load management system and a data management system on top of the RUCIO DDM package. Development of processing management systems.

Adaptation of the program code for high-energy cascade reconstruction to the fast Baikal-GVD data processing system.

Elaboration of data processing programs for a complex of scattering detectors, including a position-sensitive detector and a direct beam detector.

Modernization of the ATLAS CREST system to a new architecture with Dto classes, development of the EventIndexPicking service for performing R2R4 Milestone tests, modification of the TDAQ resource manager for use in Run4. Development and support for the operation of information systems for the BM@N and MPD experiments to describe the facility geometry, detector configurations and management process. Participation in the development of the DAQ MDT online system.

Construction of a machine learning model for the hadron and gamma quantum classification task in the TAIGA experiment.

Modeling of the OLVE-HERO detector resolution for a simplified model of various sizes.

Development of mathematical methods and algorithms for trajectory reconstruction in the proton digital calorimeter simulation task.

Application of high-order BEM polynomials to enhance the methodology of processing reactor data and neutron noise from the IBR-2M reactor.

Elaboration of a web service to automate the analysis of data obtained using the Morris Water Maze test system in experiments aimed at studying the behavioral reactions of laboratory animals exposed to various factors.

Research in the field of enhancing the accuracy of models for classifying plant diseases by photos. Assessment of the impact of various data augmentation policies and attention mechanisms on the model performance.

Investigations in the field of predicting soil pollution using remote sensing data and various machine learning methods. Enhancement of the existing functionality and provision of new capabilities for monitoring and predicting the state of the environment.

Elaboration of an algorithm for neutron energy spectrum reconstruction based on the results of measurements with the Bonner spectrometer.

2. Methods of computational physics for the study of complex systems

E.V. Zemlyanaya
O. Chuluunbaatar
Deputies:
Yu.L. Kalinovsky
A. Khvedelidze

Realization

MLIT V. Abgaryan, G. Adam, S. Adam, P.G. Akishin, A.S. Ayriyan, E.A. Ayrjan, D.R. Badreeva, I.V. Barashenkov, M.V. Bashashin, A.A. Bogolubskaya, L. Bordag, A.D. Burakova, M. Bures, J. Buša, Jr. J. Buša, A.M. Chervyakov, G. Chuluunbaatar, Kh. Chuluunbaatar, D. Goderidze, H. Grigorian, A.A. Gusev, T.V. Karamysheva, A.V. Khmelev, V.V. Kornyak, O.O. Kovalev, D.S. Kulyabov, K.V. Lukyanov, N.V. Makhaldiani, S.D. Mavlonberdieva, T.I. Mikhailova, A.V. Nechaevsky, E.G. Nikonov, Yu. Palii , V.V. Papoyan, D.V. Podgainy, R.V. Polyakova, A.R. Rakhmonova, V.S. Rikhvitsky, I.A. Rogojin , B. Saha, I. Sarkhadov, Z.A. Sharipov, O.I. Streltsova, L.A. Syurakshina, O.V. Tarasov, A.G. Torosyan, Z.K. Tukhliev, K.D. Verkhovtseva, A.V. Volokhova, O.O. Voskresenskaya, R.M. Yamaleev, E.P. Yukalova, O.I. Yuldashev, M.B.Yuldasheva, M.I. Zuev

BLTP M.A. Abdelghani, A.A. Donkov, A.V. Friesen, M. Hnatic, K.V. Kulikov, V.K. Lukyanov, R.G.Nazmitdinov, I.R. Rahmonov, Yu.M. Shukrinov, S.I. Vinitsky, D.N. Voskresensky, V.I. Yukalov, V.Yu. Yushankhai

FLNR E. Batchuluun, A.V Karpov, M.N. Mirzayev, V.V. Samarin, Yu.M. Sereda

FLNP M.A. Kiselev, N. Kucerka, E.E. Perepelkin

DLNP O.V. Karamyshev, G.A. Karamysheva, I.N. Kiyan, E.P. Popov

VBLHEP A.V. Bychkov, H.G. Khodzhibagiyan

LRB A.N. Bugay, A.V. Chizhov

Brief annotation and scientific rationale:
The project is aimed at the development and application of mathematical and computational methods for modelling complex physical systems studied within the JINR Topical Plan and described by systems of dynamic nonlinear, spatially multidimensional integral, integro-differential or differential equations that depend on the parameters of models. The evolution of solutions to such systems can be characterized by the occurrence of critical modes, bifurcations and phase transitions. Mathematical modelling is an inseparable part of modern scientific research. It entails an adequate mathematical formulation of problems within the models under study, the adaptation of known numerical approaches or elaboration of new ones to effectively take into account the features of the studied physical processes, the development of algorithms and software packages for high-performance simulation on modern computer systems, including the resources of the JINR Multifunctional Information and Computing Complex.

Expected results upon completion of the project:
Development of methods, algorithms and software packages for conducting the numerical research of interactions of various types in complex systems of nuclear physics and quantum mechanics.

Methods for modelling multifactorial processes in materials and condensed matter under external actions.

Methods for solving simulation tasks in the design of experimental facilities and the optimization of their operating modes.

Methods for modelling complex processes in dense nuclear matter based on the equation of state.

Methods for modelling quantum systems using quantum information theory methods and hybrid quantum-classical programming methods.

Expected results of the project current year:
Numerical study of deep subbarrier fusion and quasi-elastic scattering reactions of heavy nuclei within the coupled channel method with optical potentials. Development of algorithms and programs for calculating the characteristics of heavy nuclei, including the uranium-238 nucleus with a two-well potential, within geometric collective models.

Development of methods for modeling chemical bonds and reactions involving heavy and superheavy elements for the interpretation of FLNR thermochromatographic experimental data.

Investigation of the equilibrium properties and nonequilibrium dynamics of complex statistical systems, including trapped atoms and heterogeneous neural networks, within optimized perturbation theory.

Modification of the method and computer codes for modeling nuclear reactions within the transport-statistical approach. Calculation of the physical characteristics of transfer and fragmentation processes in heavy ion collisions.

Study of the nuclear matter influence on the processes of elastic and inelastic interaction of protons with nuclei in a wide range of energies. Analysis of observables in reactions of various types involving light exotic nuclei.

Computer simulation of complex processes in materials under the irradiation of heavy ion beams based on the combined application of molecular dynamics and continuum mechanics methods. Development of methods for assessing the distribution of energy losses by irradiating particles in such processes.

Simulation of complex processes in superconducting structures. Development of methods for the high-performance computing of physical observables in a wide range of parameters of Josephson junction models. Development and software implementation of a computational scheme for modeling the dynamics of a ring system of parallel j0-junctions. Study of intervortex interaction in intertype superconductors with impurities.

Development of a software module for analytical calculations using Python libraries, allowing one to automate the representation of equations for the numerical modeling of a chain of nanomagnets associated with a Josephson junction, taking into account various types of interactions between the elements.

Modeling of complex processes in physical and chemical systems of various types. Development of methods for the high-performance numerical investigation of the structure and properties of vesicular systems of various types. Computer simulation, by molecular dynamics methods, of the interaction of beta-amyloid peptides with phospholipid membranes in vesicular, bicelle-like and bilayer structures in order to study the influence of the peptide and lipid charge, as well as the composition of the lipids on this interaction in various thermodynamic phases of the lipid. Obtaining on this basis new information about the structural and dynamic properties of phospholipid membranes.

Numerical study of localized structures in systems described by nonlinear dynamic equations, including periodic solutions (oscillons) in one- and three-dimensional field theory models.

Development of methods and computer programs for modeling the formation of magnetic fields of isochronous cyclotrons under various operating modes. Development of finite and boundary element methods in the COMSOL environment to optimize the calculations of electromagnetic and thermal processes of complex physical systems.

Development of methods for modeling matrix elements of volumetric integral equations of magnetostatics. Calculation of the optimized characteristics of superconducting magnets based on three-dimensional computer modeling.

Development of effective methods for solving equations that describe the models of physical fields and the operating modes of experimental facilities. Development of high-performance methods for the numerical solution of elliptic problems. Development and study of the properties of a computational scheme based on Appelrot quadratization and the Kagan difference scheme for the numerical integration of dynamic systems with a polynomial right-hand side.

Study of the Einstein-Maxwell-Dirac system within the astrophysical and cosmological gravitational field. Investigation of the superconducting properties of strongly interacting nuclear matter in the depths of neutron stars on the basis of the automated selection of cooling models for these stars. The introduction of a criterion for assessing the adequacy of the models based on the observational data of the surface temperature and star age.

Development of models of pseudoscalar and vector mesons with nonlocal interaction; calculation of the mass spectrum, interaction constants and other characteristics on this basis. Description of the processes of production and dissociation of heavy quarkoniums.

Development and enhancement of an algorithm for modeling particle tracking within processes that are planned to be studied at the NICA facility (SPD). Study of the applicability of the Bjorken model to the survival of J/ψ particles in a medium formed by the collision of heavy ions under NICA conditions.

Development of constructive methods for describing composite finite-dimensional quantum systems within the Weyl–Schwinger formalism using computer algebra and computational group theory.

Derivation and application of functional relations for the reduction of multi-loop Feynman integrals.

Development and implementation, on the MICC quantum polygon, of a quantum circuit of the QAOA algorithm for finding the ground state of the Schwinger model with a topological term.

Solution to the problem of optimizing the operation of single-qubit gates under the influence of a control radio frequency field.

Comparative analysis of quasiprobability distributions in elementary and composite finite-dimensional quantum systems.

Calculations of the entanglement – positivity correlation of the Wigner function for qudits.

Activities of the theme:

	Name of the activity	**Leaders**	**Implementation period**
Laboratory	Responsible from laboratories		**Status**
1.	**Intelligent control of technological processes and physical equipment's in JINR and quantum computing in quantum chemistry and physics**	**P.V. Zrelov** **S.V. Ulyanov**	2024-2026 Realization

MLIT D.A. Baranov, O.V. Ivantsova, M.S. Katulin, E.A. Kuznetsov, A.G. Reshetnikov, A.R. Ryabov, N.V. Ryabov, L.A. Syurakshina, D.P. Zrelova

VBLHEP Yu.G. Bespalov, O.I. Brovko, D.N. Nikiforov, G.P. Reshetnikov

BLTP V.Yu. Yushankhai

Brief annotation and scientific rationale:

The main addressed issues of the activity are the development and effective application of intelligent computing technologies and the quantum self-organization of inaccurate knowledge in robust control tasks in order to enhance the reliability of the functioning of physical facilities. The solution of the tasks is based on the possibility of increasing the robustness of existing control systems through embedded knowledge bases. Self-organized control systems are designed and supported by software tools developed in the project on the basis of a platform that combines soft computing and quantum knowledge base optimizers. Embedded self-organized controllers will be developed for systems of the intelligent control of JINR's technological processes, devices and facilities (including for cases of unforeseen and unpredictable situations) and intelligent cognitive robotics tasks.

The investigation of the effectiveness of quantum algorithms is aimed at solving the tasks of quantum chemistry and physics of new functional materials. The application of well-known quantum algorithms and their development will be carried out on simulators of classical computing architecture. It is planned to create a software product for calculating the electronic and magnetic structures of molecular complexes and crystal fragments of new functional materials using quantum simulators on classical computing architectures.

Expected results upon completion of the activity:
Creation of a prototype of a quantum fuzzy PID controller and of a demonstration robot with a built-in controller prototype.

Creation of a prototype of an intelligent control system for cryogenic systems of superconducting magnets of the NICA accelerator complex on the basis of the quantum fuzzy PID controller. Preparing a patent.

Methodology of building and structure of an intelligent control system for a high-frequency station.

Verification of the effectiveness of quantum algorithms of variational type implemented on quantum simulators of classical architecture by applying them to the quantitative description of the dissociation of simple molecules, as well as the electronic and spin structure of the ground state of typical lattice models of quantum theory.

Expected results of the activity in the current year:
Elaboration of a platform-independent software library of a quantum simulator for executing a quantum fuzzy inference algorithm in real time on a computer with a classical architecture in relation to the task of constructing a control system for the nitrogen cooling of the booster arm of the NICA accelerator complex.

Development of a reinforcement learning algorithm for a quantum fuzzy neural network with demonstration on an autonomous robot on a robotics polygon.

Elaboration of route formation and obstacle avoidance algorithms based on quantum machine learning for a mobile robotic platform.

Within the task of multi-loop system control, a method of quantum intelligent coordination control on top of quantum fuzzy inference in a control system for superconducting magnet cooling will be developed.

Within the investigation of multi-qubit hidden correlations in self-organizing control systems, the structure of a knowledge base simulator of a quantum coordination regulator in a control system for the nitrogen cooling of a superconducting magnet on a classical computer for 30 input qubits will be elaborated.

Within the construction of a methodology for remote configuration and knowledge exchange for an intelligent control system, protocols for the exchange of knowledge bases and remote configuration of regulators in the TANGO Control environment of a control system for the nitrogen cooling of the booster of the NICA accelerator complex will be developed.

Automation of the preparation of a universal computing environment for quantum computing on various architectures.

Study of the potential of quantum generative adversarial networks (QGANs) using the example of the task of generating synthesized RGB images.

In the context of materials science, a computational description of chemical reactions on crystal surfaces is planned. For this purpose, the process of modeling the adsorption and reaction of molecules on surfaces will be implemented using quantum computing algorithms.

2.	**Training of specialists in the field of computational physics and information technology**	**V.V. Korenkov** **A.V. Nechaevsky** **D.I. Pryahina** **O.I. Streltsov**	2024-2026 Realization

MLIT T.Zh. Bezhanyan, O.Yu. Derenovskaya, E. Mazhitova, I.S. Pelevanyuk, A.S. Vorontsov, E.N. Voytishina, M.I. Zuev

UC D.V. Kamanin, A.Yu. Verkheev

Brief annotation and scientific rationale:
The training and retraining of specialists in computational physics and information technology on the basis of the Multifunctional Information and Computing Complex (MICC) of the Joint Institute for Nuclear Research (JINR) and its educational components are performed for:

– upskilling JINR staff members in order to develop scientific projects, including megascience ones, which are implemented at JINR or with its participation, as well as to create and support the JINR Digital EcoSystem (DES);

– disseminating competencies in computational physics and information technology to the regions of Russia and the JINR Member States to enhance the personnel potential of JINR and organizations cooperating with the Institute;

– the main prerequisite for the creation of the activity is the necessity to form a research environment in order to ensure the professional growth of IT specialists, the creation and development of scientific groups, and the engagement of new specialists in JINR projects. The additional training of the personnel, mainly on request of the JINR Laboratories, should be aimed at developing special competencies, in-depth knowledge and practical skills in computational physics and information technology.

Expected results upon completion of the activity:
Holding events for JINR staff members to study state-of-the-art information technologies and opportunities to work on the MICC components and in the DES.

Forming a set of JINR projects in which students can participate.

Forming a list of competencies and required courses for the implementation of projects.

Elaboration of training courses and educational programmes that will provide personnel training for solving a variety of tasks within projects.

Creation of an ecosystem for the implementation of educational programmes on the basis of the JINR MICC, including the cloud infrastructure, the HybriLIT heterogeneous computing platform, which comprises the education and testing polygon and the "Govorun" supercomputer.

Creation of a software and information environment and a platform for organizing and holding events, lectures, workshops, hackathons, etc.

Involvement of specialists from JINR and JINR Information Centres, researchers from the JINR Member States' organizations, lecturers from leading educational organizations that cooperate with JINR in order to hold educational and scientific events.

Forming event programmes and organizing interaction with universities and JINR Information Centres.

Expected results of the activity in the current year:
Holding scientific seminars on information technologies, including for JINR MICC and DES users.

Elaboration and implementation of educational programs, training courses on information technologies.

Information support of the activity: creation and development of a website containing educational materials, results of work on projects of participants of Schools of Information Technologies.

Development of the ecosystem components for the implementation of educational programs.

Holding Schools of Information Technologies, educational practices for students of universities of the Russian Federation and the JINR Member States.

Collaboration

Country or International Organization	City	Institute or laboratory
Armenia	Yerevan	Foundation ANSL
		YSU
Belarus	Gomel	GSU
	Minsk	IM NASB
		INP BSU
		IP NASB
Bulgaria	Sofia	SU
CERN	Geneva	CERN
China	Beijing	CIAE
Egypt	Cairo	ASRT
	Giza	CU
France	Saclay	IRFU
Georgia	Tbilisi	GTU
		TSU
		UG
Italy	Genoa	INFN
Kazakhstan	Almaty	IETP KazNU
		INP
	Astana	ENU
Mexico	Mexico City	UNAM
Mongolia	Ulaanbaatar	IMDT MAS
		MUST
Russia	Arkhangelsk	NArFU
	Chelyabinsk	SUSU

	Dubna	Dubna State Univ.
		MSU Branch
	Gatchina	NRC KI PNPI
	Irkutsk	ISU
	Moscow	ITEP
		LPI RAS
		MSU
		NNRU "MEPhI"
		NRU HSE
		PFUR
		RCC MSU
		RSTSREC
		SINP MSU
	Moscow, Troitsk	INR RAS
	Petropavlovsk-Kamchatsky	KSU
	Protvino	IHEP
	Puschino	IMPB RAS
	Saint Petersburg	SPbSU
	Samara	SSU
	Saratov	SSU
	Sarov	MSU Branch
	Tomsk	TPU
		TSU
	Tula	TSU
	Tver	TvSU
	Vladikavkaz	NOSU
	Vladivostok	FEFU
	Voronezh	VSU
Serbia	Belgrade	Univ.
Slovakia	Kosice	UPJS
South Africa	Cape Town	UCT
United Kingdom	Oxford	Univ.
USA	Arlington, TX	UTA
Uzbekistan	Tashkent	AS RUz

Applied Innovation Activities (07)

07-1-1107-2011

Applied Research at NICA in Radiation Materials Sciences, Life Sciences and New Methods of Energy Production

Theme leaders: O.V. Belov
E.M. Syresin

Participating countries and international organizations:
Armenia, Azerbaijan, Belarus, Bulgaria, Mexico, Moldova, Russia, South Africa, Uzbekistan.

The problem under study and the main purpose of the research:
Obtaining applied research and technology results within the areas ARIADNA collaborations' activity, including life sciences, biomedical technologies, space research, radiation materials science, radiation hardeness of electronics, development of new technologies for ADS using NICA beams.

Project in the theme:

Name of the Project	Projects Leaders	Project Code
Laboratory	Responsible from laboratories	**Status**
1. ADSR	**S.I. Tyutyunnikov**	07-1-1107-1-2011/2027
Accelerator driven subcritical reactor	**M. Paraipan**	Realization
VBLHEP, FLNP, DLNP, FLNR, BLTB, LRB	see list of activities	

Brief annotation and scientific rationale:
The project is aimed to determine the optimum beam-converter combination meant to optimize the efficiency of an accelerator driven subcritical reactor. The planned research will be oriented in two directions. The first involves the comparative study of the fission distribution and the energy released in enriched fuel blanket, irradiated with proton beams with energy 0.2-2 GeV and ion beams with masses until ^{20}Ne and energies in the interval 0.2 -1 AGeV. The second consists in measurements of the neutron yield from various converters, irradiated with proton and ion beams.

A possibility to realize a nuclear system with increased burning capabilities is to use an accelerator driven subcritical reactor (ADSR). It consists of a particle accelerator coupled with a nuclear reactor. The particle beam striking a converter placed in the central part of the reactor realizes a supplementary source of neutrons which allows the functioning of the reactor in subcritical regime (with criticality coefficient k_{eff} below 0.99), ensuring a safer exploitation of nuclear plants. The harder neutron spectrum obtained ensures a better incineration of the actinides.

In spite of the almost generalized opinion that the optimal beam for ADS is a proton beam with energy around 1–1.5 GeV we have shown in a series of works that ion beams have a superior energetic efficiency than protons. The activities within the project are oriented towards searching the conditions which maximize the energy efficiency of ADSR and ensure high burnup. Within the previous years, aspects related with the core geometry, the material used for the converter, the fuel composition, the working value of k_{eff}, the enrichment and power density distribution were investigated. The influence of the beam characteristics (particle type, energy, beam intensity), and of the accelerator type were also studied. The main conclusions obtained constitute the bases for extending the project in accordance with the stated objectives.

The proposed graphite target “GAMMA4” with fuel rods inserted inside and a central hole for the placement of different converters allows a correct comparison between the number of fissions and the energy released realized with proton and ion beams. The use of a graphite block instead of Pb gives the possibility to diminish the necessary amount of fissile material due to the softer neutron spectrum. Such target is easier to manipulate (due to its lower weight) and cheaper. The proposed graphite target "GAMMA4" is suitable for a comparative study of the efficiency of various beams in terms of the possibility of their use in ADS.

Expected results upon completion of the project:
Selection of an optimal design of a target of the ADS.

Verification of a principally new concept of a system based on the use of ion beams instead of protons.

Implementation of the first stage of experimental programme focused on measurement ofneutron yields with different converter combinations.

Expected results of the project this year:
The realization of technical project for the lead target (block with dimensions of 110x110x150 cm, with central hole for the converters and vertical and horizontal holes for the placement of the fission detectors).

The design of the system for the measurement of the beam intensity (ionization chamber and two plastic scintillators for the absolute calibration of the ionization chamber).

The analysis of the experimental method and the determination of the maximal beam intensities depending on the radiation shielding of the experimental room.

Activities of the theme:

	Name of the activity	Leaders	Implementation period
Laboratory	Responsible from laboratories		Status
1.	**R&D within the research topics of the ARIADNA collaborations: experiments in space research, life sciences, biomedical technologies, materials sciences and structure of matter, radiation hardening of electronics and advanced nuclear physics technologies**	**O.V. Belov** **S.I. Tyutyunnikov**	2024-2026 Data taking Data analysis
VBLHEP	V.A. Artyukh, K.P. Afanasyeva, S. Ceballos, V.B. Dunin, V. Dzhavadova, Yu.S. Kovalev, I.A. Kryachko, I.I. Maryin, Yu.A. Murin, M.S. Novikov, A.N. Osipov, V.A. Pavliukevich, N.E. Pukhaeva, A. Rodriguez, A.V. Rogachev, Z. Sadygov, A.A. Slivin, V.N. Shalyapin, G.I. Smirnov, E.M. Syresin, S.E. Sinelshikova		
DLNP	A.V. Agapov, K.V. Belokopytova, A.G. Molokanov, G.V. Mitsyn, A.V. Rzyanina, V.I. Stegailov, S.V. Shvidkiy		
FLNR	P.Yu. Apel, A.N. Nechaev		
FLNP	M.V. Bulavin		
BLTP	V.A. Osipov		

Brief annotation and scientific rationale:
The launch of the NICA complex and the implementation of beamtime sessions on the main NICA facilities are expected in 2025. The ARIADNA infrastructure, including beamlines, areas for applied research and zones of user infrastructure, will allow for a number of relevant studies aimed at using accelerated ion beams in space research, life sciences and biomedical technologies, as well as in radiation materials science, radiation resistance of electronics, and modern nuclear physics technologies.

Expected results upon completion of the activity:
Obtaining new data on the interaction of heavy ion beams with various types of materials and biological objects in order to create advanced developments based on modern radiation technologies. Obtaining results on specific structural and functional modifications in the studied samples having different nature after exposure to ions with energies from 3.2 MeV/nucleon to 3.5-4.0 GeV/nucleon.

Expected results of the activity this year:
Conducting the planned beamtimes in 2025 will allow:

- simulate the impact of individual components of cosmic radiation with the use of beams of NICA facility and radiation facilities of collaborating organizations. Study the combined effects of radiation and other physical and biological factors in experiments on laboratory animals, tissues and cell cultures;

- obtain information on the relative biological effectiveness of heavy nuclei with energies of up to 4.5 GeV/nucleon. To assess the impact of high-energy charged particles on the physicochemical characteristics, redox properties and biological activity (in vitro and in vivo) of rare earth metal nanoparticles in various modifications;

- implement highly sensitive methods for detecting radiation-induced biological damage at the molecular and cellular levels based on the ARIADNA user infrastructure. Conduct a series of experiments to identify specific time profiles of proteins and protein complexes for the repair of double-strand breaks in nuclear (nDNA) and mitochondrial (mtDNA) DNA associated with various types of cancer, and formulate approaches to developing a diagnostic method based on DNA repair markers;

- evaluate the radiation-protective properties of materials in radiation fields generated by the NICA complex for subsequent use as additional and local protection against ionizing cosmic radiation on board space complexes;

- perform the first stage of developing the method of high-temperature radiation modification of various types of polymer compounds using polytetrafluoroethylene (PTFE) as an example using high-energy ion beams. Study the mechanisms of radiation defect formation and release of volatile compounds – suboxides during irradiation of synthetic sapphire and corundum;

- obtain new information on the radiation stability of ultra-light highly porous materials based on aerogels and ferrites with different crystal structures in terms of the impact of accelerated ions in a wide energy range. Obtain model estimates for the effect of heavy-ion components of cosmic radiation on ultra-high-temperature ceramics HfB2(ZrB2)-SiC;

- obtain new data on the possibility of creating structural and morphological nanosingularities during irradiation of oxide model catalysts with heavy ions in order to tune the activity and selectivity of catalysis;

- perform R&D on the development of analytical devices used for collecting experimental data from biological objects and materials exposed to ionizing radiation.

2.	**R&D on optimization of methods for irradiating samples of various types; development of the supporting equipment for ARIADNA target stations. Development of laboratory areas for deployment of the user equipment**	**O.V. Belov**	2024-2026 Realization

VBLHEP V.B. Dunin, E.S. Matyukhanov, M.S. Novikov, V.A. Pavliukevich, A.V. Shemchuk, S.E. Sinelshikovak

DLNP A.V. Agapov, K.V. Belokopytov, G.V. Mitsyn, A.G. Molokanov

Brief annotation and scientific rationale:
A necessary pre-condition for conducting research using modern radiation technologies is the constant improvement of methodological approaches to conducting irradiation sessions and the development of appropriate sample environment systems. In particular, the development of irradiation stands and the development of the necessary equipment in accordance with the tasks of the proposed experiments is of great importance. Carrying out research within the framework of the ARIADNA collaboration, which implies a multi-user mode of operation, requires the creation of sites for the deployment of users' own equipment in order to carry out the process of sample preparation and analytical studies in a short time after irradiation.

Expected results upon completion of the activity:
Creation and development of sample preparation and analytical research areas within the framework of the ARIADNA scientific work program. Manufacture and commissioning of stands and test chambers for studying the combined effect of accelerated ions and other physical factors on material samples and biological objects.

Expected results of the activity this year:
Implementing of the second stage of equipping the stand for long-term irradiation in the BM@N facility area. Completing the first stage of work on developing the stands and testing the chambers for studying the combined effect of accelerated ions and other physical factors on material samples and biological objects. Studying the effect of ionizing radiation on the main parameters of the resistive-emission layer of the MCP in experiments on heavy ions. Developing a methodology for assessing the integral indicators of the beam intensity and profile for various types of samples studied in the ARIADNA experiments. Developing and testing a detector system for applied research in the BM@N facility area. Developing and testing detectors based on fluorescent screens for applied research.

3.	**Upgrade of spectrum-analitical complex for activation measurements**	**V.N. Shalyapin**	2024-2026 Realization

VBLHEP D.R. Drnoyan, I.A. Kryachko, E.V. Strekalovskaya, Toan Tran Ngor

DLNP V.I. Stegaylov

Brief annotation and scientific rationale:
Activation of irradiated materials and structural elements of heavy ion accelerators is an important aspect of conducting experiments on irradiation of various types of targets. The spectrum analysis complex of VBLHEP Division No 5 allows for a wide range of gamma spectra measurements, including in flow mode. Gamma spectra analysis using the available spectrum analysis complex will be used as a routine technique in most ARIADNA applied research experiments involving irradiation of samples with accelerated ion beams.

Expected results upon completion of the activity:
Updating the set of detectors of the spectrum analysis complex, the corresponding software and the necessary equipment for carrying out measurements using different types of samples. Creating a database of gamma spectra for all ARIADNA experiments.

Expected results of the activity this year:
Updating the detector software; updating the power supplies, backup power supplies and the detector central control system. Conducting routine changes to the gamma spectra for applied research at the NICA complex in the 2025 beamtime sessions.

4.	**Software development and dosimetric calculations for ARIADNA experiments. Simulation of radiation conditions at the NICA complex**	**M. Paraipan**	2024-2026 R&D

VBLHEP O.V. Belov, T. Chan Ngoc, V. Javadova, M. Paraipan, A.A. Slivin

LRB A.V. Chizhov

Brief annotation and scientific rationale:
Software development and dosimetric calculations are an integral part of the preparation of experiments under the ARIADNA scientific program at the NICA complex, as well as an important element of the analysis of dose loads in sessions on irradiation of targets of various types. The use of modern program codes for the interaction of accelerated ions with matter allows planning irradiation sessions using various materials in order to select optimal irradiation parameters and subsequent reconstruction of energy release events in the target material. The data obtained during dosimetric calculations are important input parameters for further studies in terms of structural and functional changes in irradiated samples. An important paretic aspect of this activity is obtaining modeling of radiation conditions in various parts of the NICA complex using the developed modeling approaches and program codes.

Expected results upon completion of the activity:
Obtaining dosimetric data on irradiation of various types of samples with accelerated ion beams in a wide energy range, including composite materials, as well as other objects with a complex structure and elemental composition. Obtaining estimates of radiation fields for various sections of the NICA complex; calculating the necessary elements of biological protection.

Expected results of the activity this year:
Obtaining estimates of dose loads for samples of composite materials, biological objects and electronic elements when irradiated with heavy ion beams with energies in the range from 3.2 MeV/nucleon to 4 GeV/nucleon. Calculation of radiation fields in the areas of applied research facilities taking into account the placement of additional user equipment. Modeling the interaction of accelerated ion beams with materials in sessions planned for 2025 at the NICA complex.

5.	**Study of the radiation effects and superconducting properties of 2nd generation HTSC tapes. Development of magnetic and cryogenic HTSC systems for experimental facilities**	**M.S. Novikov** **S.I. Tyutyunnikov**	2024-2026 R&D

VBLHEP Yu.P. Filippov, E.S. Matyukhanov, M.S. Novikov, A.V. Shemchuk

FLNP A.N. Chernikov

Brief annotation and scientific rationale:
The aim of the research is to develop methods for increasing the critical current of second-generation HTSC tapes using radiation modification technologies. In recent years, results have been obtained at VBLHEP indicating an increase in the critical current of second-generation HTSC tapes after irradiation with accelerated ions and protons. The discovered effects require further study from the standpoint of creating prototypes of equipment based on radiation-modified HTSC tapes and testing their application in various scientific and practical tasks, including accelerator technology.

Expected results upon completion of the activity:
Obtaining information on the patterns of change in the critical current of second-generation HTSC tapes by radiation modification and mechanical deformation. Obtaining results on the stability of the effect of radiation-induced increase in the critical current of HTSC tapes over time under the influence of various physical factors. Second-generation HTSC tapes. Determining the possibilities of practical application of radiation-modified second-generation HTSC tapes.

Expected results of the activity this year:
Study of radiation-stimulated change of critical current of HTSC composites under special conditions of radiation exposure (presence of background magnetic field and low temperature). Study of properties of irradiated second-generation HTSC tapes during subsequent operation in ionizing radiation fields. Obtaining data on structural modifications of HTSC tapes after radiation exposure and mechanical treatment. Calculation of defect formation in HTSC tapes under the influence of charged particles; optimization of radiation defects as magnetic flux pinning centers; calculation of radiation and thermal conditions for a station for rewinding HTSC tapes through a beam of charged particles to create pinning centers.

6.	**Organization and maintenance of the user ARIADNA. Development of ARIADNA collaborations**	**O.V. Belov**	2024-2026 Realization

VBLHEP M.S. Novikov, M. Paraipan, Yu.A. Tsaplina, S.I. Tyutyunnikov

Brief annotation and scientific rationale:
Applied research at the NICA complex is carried out in the form of the ARIADNA collaboration, which includes more than 20 organizations from the JINR member countries. The multi-user mode of operation at the NICA complex applied research facilities implies the presence of a coordinated user program that unites the efforts of the ARIADNA collaboration member organizations in obtaining advanced scientific and scientific-practical results. The main task in this area is to coordinate the user program, as well as to create conditions for the coordinated work of user groups during sessions at the NICA complex.

Expected results upon completion of the activity:
Development of a user program for applied research at the NICA complex, ensuring coordinated work of scientific groups from various organizations.

Expected results of the activity this year:
Launch of the ARIADNA web portal, including a system for electronic submission of applications for experiments using the NICA complex applied research infrastructure. Testing the multi-user mode of operation on elements of the ARIADNA infrastructure. Maintenance of programs to support the work of scientific collaborations on the NICA complex. Development of scientific programs for organizations joining the ARIADNA collaboration. Ensuring the representation of the ARIADNA collaboration at scientific and scientific-organizational events related to applied research and innovation.

Collaboration

Country or International Organization	City	Institute or laboratory
Armenia	Yerevan	CANDLE
		Foundation ANSL
		YSU
Azerbaijan	Baku	AMU
Belarus	Minsk	BSU
		INP BSU
		JIPNR-Sosny NASB
Bulgaria	Plovdiv	MUP
Mexico	Mexico City	INCan
Moldova	Chisinau	MSU
Russia	Dolgoprudny	MIPT
	Dubna	IAS "Omega"
		IPTP
		MSU Branch
	Moscow	"Kvant-R"
		FMBC
		IBMP RAS
		ICP RAS
		IGIC RAS
		ITEP
		JIHT RAS
		NNRU "MEPhI"
		PFUR
		SINP MSU
	Obninsk	NMRRC
	Puschino	ITEB RAS
	Saint Petersburg	SPbSU
	Tomsk	TPU
	Vladikavkaz	NOSU
South Africa	Somerset West	iThemba LABS
	Stellenbosch	SU
Uzbekistan	Tashkent	INP AS RUz

07-5-1131-2017

Radiation Materials Science, Nanotechnological and Biomedical Investigations with Heavy-Ion Beams

Theme leaders: S.N. Dmitriev
P.Yu. Apel

Deputy: V.A. Skuratov

Participating countries and international organizations:
Armenia, Australia, Belarus, Kazakhstan, Russia, Serbia, South Africa, Vietnam.

The problem under study and the main purpose of the research:
Experimental and theoretical studies of radiation tolerance of solids to heavy-ion impact, materials testing, controlled modification of materials properties, and the development of new functional structures.

Projects in the theme:

	Name of the project	Project Leaders	Project code
1.	Radiation tolerance of materials to high-intensity beams of heavy ions	V.A. Skuratov *Deputy:* R.A. Rymzhanov	07-5-1131-1-2024/2028
2.	Nanocomposite and functional track etched membranes	P.Yu. Apel *Deputy:* A.N. Nechaev	07-5-1131-2-2024/2028
3.	High-sensitivity sensor based on molecular recognition for viruses detection	A.N. Nechaev E.G. Zavyalova	07-5-1131-3-2025/2029

Projects:

	Name of the project	Project Leaders	Status
Laboratory	Responsible from laboratories		
1.	**Radiation tolerance of materials to high-intensity beams of heavy ions**	**V.A. Skuratov** *Deputy:* **R.A. Rymzhanov**	Manufacturing

FLNR V.A. Altynov, P.Yu. Apel, I.V. Dukach, O.M. Ivanov, N.S. Kirilkin, D.A. Komarova, E.A. Korneeva, V.A. Kuzmin, N.G. Kuzmina, N.V. Kurylev, Le ThiPhuongThao, N.E. Lizunov, M. Mamatova, A.Yu. Markin, M. Mirzaev, A. Mutali, Nguyen Van Tiep, O.L. Orelovich, E.A. Piyadina, V.K. Semina, A.S. Sokhatsky, V.G. Shmarovoz

Brief annotation and scientific rationale:
The aim of the project is to accumulate a database for a better understanding of the fundamental laws of high-intensity ionization in model and structural materials. The knowledge of fundamental mechanisms is of paramount importance for nuclear power engineering, nanotechnology applications and for the testing of target materials for nuclear physics experiments. As an innovative approach, it is proposed to study the effects of dense ionization on a previously created defect structure formed by exposure to "conventional" radiation (hundreds of keV and units of MeV, ion irradiation), which is the most reliable way to simulate damage produced by fission products. The main approach to achieving the goals of the project will be the use of modern structural analysis techniques – high-resolution transmission electron microscopy in combination with molecular dynamics methods for modeling track formation processes. Structural changes will be also investigated using scanning electron microscopy, X-ray diffraction, confocal Raman and luminescence microscopy, and the real-time optical spectroscopy under ion irradiation. The radiation resistance of promising reactor materials and target materials for nuclear physics experiments will be investigated by micro- and nanomechanical testing methods.

Expected results upon completion of the project:
Advanced understanding of the fundamental physical laws of high-density ionization in solids based on the studied dependencies of the kinetics of swift structural changes in the tracks of fast heavy ions in the near-surface areas of nanostructured dielectrics – nanoparticles, interfacial layers, layered structures.

Results of modeling by molecular dynamics methods of lattice relaxation processes and the formation of regions with a modified structure in the near-surface and interphase regions of composite materials exposed to energetic ions – nanoclusters in matrices, layered materials.

Data on the combined effect of dense ionization and helium on the transport properties of fission fragments in protective layers and inert matrices.

Accumulation of a database on the parameters of ion tracks in conventional and nanostructured ceramics promising for nuclear physics applications.

Data on the long-term stability of target materials during prolonged irradiation with intense heavy-ion beams.

Expected results of the project current year:
Investigation of the track's microstructure in the nanoparticles of TiO2, Cr2O3, CeO2, and AlN irradiated with high-energy heavy ions by high-resolution transmission electron microscopy.

Study of the influence of the uniformly helium-doped austenitic steel structure in gas porosity formation.

Structural studies and micromechanical testing of the high-entropy Fe-Cr-Ni-Co alloy irradiated with high-energy heavy xenon and bismuth ions.

Numerical modeling of structural effects induced by swift-heavy-ion irradiation in massive samples, thin films, and nanoclusters of cerium oxide by molecular dynamics and the Monte Carlo methods.

2.	**Nanocomposite and functional track etched membranes**	**P.Yu. Apel** *Deputy:* **A.N. Nechaev**	Manufacturing

FLNR N.V. Aksenov, V.A. Altynov, E.V. Andreev, ArnoRussou, I.V. Blonskaya, M.V. Gustova, N.A. Drozhzhin, I.V. Dukach, I.N. Fadeikina, E.L. Filatova, O.M. Ivanov, L.I. Kravets, O.V. Kristavchuk, M.A. Kuvaytseva, N.G. Kuzmina, N.E. Lizunov, A.V. Lundup, A.A. Markin, S.V. Mitrofanov, S.A. Mityukhin, L.G. Molokanova, D.A. Murashko, I.F. Myatleva, E.B. Nesterova, D.V. Nikolskaya, O.L. Orelovich, U.V. Pinaeva, O.A. Polezhaeva, R.K. Ragimova, G.V. Serpionov, I.N. Shamshiddinova, V.V. Shirkova, D.V. Schegolev, I.I. Vinogradov, G.N. Volnukhina

DLNP E.V. Kravchenko, M.P. Zarubin

FLNP Yu. E. Gorshkova, O.Yu. Ivanshina, I. Zinkovskaya

LRB I.V. Koshlan

Brief annotation and scientific rationale:
The project's goal is to develop nanocomposite and functional track-etched membranes (TMs) for applications in nanotechnology, biomedicine, sensor technologies, and novel membrane separation processes. TMs are an example of the industrial application of ion-track technology. They have a number of significant advantages over conventional membranes due to their precisely determined structure. Their pore size, shape, and density can be varied in a controllable manner so that a membrane with the required transport and retention characteristics can be produced. The modern trends in biology, medicine, environmental research, green energy harvesting, and other areas formulate the demands for membranes with novel specific functionalities. These functionalities can be provided by tuning (setting) the geometry, morphology, and chemical properties of TMs. The present project will focus on the development of various functional track-etched membranes using the following approaches:
– tuning the pore architecture;

– composite structures;

– hybrid structures;

– targeted chemical and biochemical modification;

– selection of bulk material.

Special attention will be focused on biomedical applications of track-etched membranes.

The main result of the project will be the creation of scientific and technical foundations for the development of new membranes with specific functions. The applicability of the developed membranes in practically important membrane separation processes, biomedical procedures and analytical tasks will be investigated.

Expected results upon completion of the project:
Functionalized TMs obtained from ion-irradiated polymer films using soft photolysis and liquid extraction of degradation products from tracks for electrodialysis and the electro-baromembrane process:
– determination of ion-selective properties of membranes;

– investigation of the possibility of mono- and multivalent-ion separation on nanoporous TMs using electrodialysis and the electro-baromembrane process.

Experimental verification of the possibility of manufacturing nanocomposite, functionalized, and hybrid TMs:
– TMs with asymmetric and modified nanopores for the separation of racemic mixtures;

– microfiltration TMs with immobilized proteins for the detection of free RNA and DNA and their use in biosensors;

– functionalized nanoporous membranes made of polyvinylidene fluoride (PVDF) for selective preconcentration of toxic metals and their quantitative determination;

– TMs functionalized with silver nanoparticles and bioactive substances for the creation of bactericidal and viricidal filtration materials;

– modified TMs with improved cell adhesion for cell culture systems;

– affinity ultra- and microfiltration TMs for exosome separation;

– nanocomposite TMs with immobilized silver and gold nanoconjugates and aptamers for the diagnosis of viral diseases using SERS and fluorescence spectroscopy;

– hybrid TMs with surface polymer nanofiber structures and modified selective complex compounds, ligands and metal-organic frameworks for selective removal of toxic metals from water.

Data on ion-selective, electrokinetic, and osmotic properties of modified nanopores, including asymmetric nanopores, depending on their geometry and functional groups on the surface.

Expected results of the project current year:
Investigation of the electrodialysis process for binary mixtures of electrolytes, including lithium ions, on ion-exchange membranes produced using soft photolysis and liquid extraction of radiolysis products from ion-irradiated polyimide films. Estimates of selectivity and permeability compared to similar membranes made of PETP.

Study of membrane distillation using hybrid membranes obtained by coating PETP track-etched membranes with fluoropolymer nanofibers; taking data on selectivity and productivity of the process.

Study of the radiation induced graft polymerization of 4-vinylpiridyne and N-vinylimidazole in the nanopores of PVDF TMs with a view to preconcentrating dissolved mercury in aqueous media. Determination of optimal conditions for the polymerization reaction and study of the physical and chemical properties of produced membranes.

Construction of a set-up for baromembrane separation of the culture medium of human mesenhymal stem cells and the development of techniques for quantitative determination of exosomes in permeate.

Synthesis of plasmonic gold and silver nanoparticles stabilized by cyclodextrin for the use in synchronous chemoradiotherapy to treat cancer.

Study of adsorption and desorption of model dyes on composite track membranes modified by superstructures based on the metal-organic frame structure of nickel and tryptophan for targeted drug delivery.

3. High-sensitivity sensor based on molecular recognition for viruses detection

A.N. Nechaev
E.G. Zavyalova

Implementation

FLNR V.A. Altynov, E.V. Andreev, P.Yu. Apel, I.V. Blonskaya, N.A. Drozhzhin, I.N. Fadeikina, E.L. Filatova, O.M. Ivanov, M.A. Kuvaytseva, A.V. Lundup, A.A. Markin, S.V. Mitrofanov, S.A. Mityukhin, L.G. Molokanova, D.A. Murashko, O.L. Orelovich, U.V. Pinaeva, O.A. Polezhaeva, G.V. Serpionov, D.V. Schegolev, I.I. Vinogradov

DLNP E.V. Kravchenko, M.P. Zarubin

Brief annotation and scientific rationale:
The purpose of the project is to develop a fundamentally new diagnostic technology characterized by rapid analysis, high sensitivity and specificity, and the ability to adapt for detecting various types of virus-containing analytes. Viruses will be detected

using next-generation specialized medical equipment – the Raman luminescent diagnostic complexes. The method is based on the use of nanocomposite track-etched membranes providing surface enhanced Raman spectroscopy (SERS). SERS active track-etched membranes will ensure the selectivity of virus retention in the studied samples and high detection sensitivity. The use of bio-affinity interactions with functional analogues of antibody aptamers labeled by SERS reporters will be an additional factor in the specificity of marker detection. The project will result in the development and experimental justification of a novel biosensor technology for the diagnosics of animal infectious diseases, in particular the African swine fever (ASF) virus. The experimental justification of the hypotheses and the choice of optimal technical solutions will be based on DNA sequencing of ASF and an artificially synthesized enzyme immunoassay reagent – an aptamer capable of immobilizing onto the surface of silver and gold nanoparticles. At the final stages of the work, an experimental test system will be designed for rapid detection of antigens of one of the ASF viruses in clinical material. The project implementation should ensure the achievement of world-class results through the synergistic interaction of specialists in applied nuclear physics, radiation processing of materials, colloidal chemistry, modern biomedical technologies, and microelectronics.

Expected results upon completion of the project:
The result of the project is theoretical and experimental research for the development and production of new functionalized TMs and highly sensitive biosensors for monitoring viruses of various etiologies posing epidemic risks.
The main results of the project are the following:

Experimental results related to the analysis of the properties and the possibility of manufacturing components for future viral sensors:
– TMs functionalized with plasmonic nanoparticles of silver and gold, as well as their alloys;

– synthesis and characterization of aptamers with the highest affinity to the ASF virus and gold and silver nanoparticles;

- nanocomposite TMs with SERS-active ensembles of nanoparticles, with immobilized aptamers for rapid and sensitive detection of viruses (using the ASF virus as an example);

– proof of the efficacy of the developed algorithms for virus monitoring using ASF as an example.

Development and assembly of sensors based on Raman spectroscopy for TM-based viral detection:

– development of an ASF virus analysis protocol using sensors;

– development of diagnostic kits for rapid analysis of ASF;

– development and fabrication of TM-based test strips for selective ASF detection;

– assessment of the possibility of using sensors and test strips with immobilized aptamers for monitoring and diagnozing diseases having social consequences (influenza, coronavirus, hepatitis, oncology)

Expected results of the project current year:
Functionalization of track membranes with a layer of silver and gold nanoparticles of various structures with a view to obtaining a substrate with the effect of giant Raman scattering of light for further analysis of ASF employing aptamers.

Synthesis of aptamers, including thiolazed aptamers, based on the ASF genome analysis.

Assessment of the genotoxic properties of aptamers in vitro using the "comet" method.

Modification of track-etched membranes by aptamers through functional groups on the membrane surface and through gold and silver nanoparticles. The study of the formation of aptamer complexes with exosomes in solution and on the track membrane.

Collaboration

Country or International Organization	City	Institute
Armenia	Yerevan	ICP NAS RA
		IMB NAS RA
		YSU
Australia	Canberra, ACT	ANU
Belarus	Gomel	GSU
	Minsk	BSU
Kazakhstan	Astana	BA INP
		ENU
		NU
Russia	Chernogolovka	ISSP RAS
	Dolgoprudny	MIPT
	Ivanovo	ISUCT

	Krasnodar	KSU
	Moscow	FMBC
		IGIC RAS
		ISPM RAS
		ITEP
		MPGU
		MSU
		PFUR
		RIVS
		RSMU
		TIPS RAS
	Novosibirsk	ISP SB RAS
Serbia	Belgrade	INS "VINCA"
South Africa	Bellville	UWC
	Durban	UKZN
	Mthatha	WSU
	Port Elizabeth	NMU
	Pretoria	TUT
		UNISA
		UP
	Somerset West	iThemba LABS
	Stellenbosch	SU
Vietnam	Hanoi	IMS VAST

Physics and Technology of Charged Particle Accelerators (08)

08-2-1126-2015

Development of Scientific DLNP Infrastructure for Research Using Semiconductor Detectors, laser Metrology, Electrons, Positrons and Cryogenic Technology

Theme leaders: V.V. Glagolev
G.A. Shelkov

Deputy: V.V. Tereschenko

Participating countries and international organizations:
Armenia, Azerbaijan, Belarus, Bulgaria, Czech Republic, Germany, Russia, Serbia, Uzbekistan, Vietnam.

The problem under study and the main purpose of the research:
In addition to the Projects highlighted below, the task of particular importance is the complete of commissioning of the basis facility of DLNP - the linear electron accelerator LINAC-200.

The main objectives of the research at the LINAC-200 linear electron accelerator for the upcoming 7-year period are:
– providing electron beams with energies of up to 200 MeV (with a possible increase in energy up to 800 MeV) for research and scientific and methodological work on the creation of detectors of elementary particles at JINR and in scientific centres of the member states for experiments at the NICA collider and other facilities, including those outside JINR;

– study of controlled generation of electromagnetic radiation by relativistic electrons based on the use of functional materials, search for new methods and creation of equipment for beam diagnostics in accelerators;

– carrying out research work on the creation of beams of relativistic electrons with a large orbital momentum;

– implementation of educational programmes of the JINR University Centre;

– conducting research, including applied studies in the field of radiation materials science, radiobiology, radiochemistry.

The expected operating time of the accelerator within the framework of the open user programme will be at least 2000 hours per year.

The goal of the project "Design and development of a test zone for methodological studies of detectors at the linear electron accelerator at DLNP" is to create an infrastructure based on the LINAC-200 for methodological studies using electron beams with energies from 20 MeV to 200 MeV.

Within the project "Precision laser metrology for accelerators and detector complexes", the main objectives are to carry out scientific research and methodological studies on the development of Precision Laser Inclinometers for their application to scientific and applied tasks (monitoring the position of collider elements, improving the accuracy of measurements of Gravity antennas, earthquake forecasting); improvement of methods of metrological measurements; creation of a seismically isolated platform.

The goal of the project "Development of experimental techniques and applied research on monochromatic positron beams (PAS)" is to create a facility to study the structure of various materials and defects arising under various physical influences (aging, external loads, radiation exposure). One of the methods is positron annihilation spectroscopy (PAS). This method is sensitive to the detection of various (so-called "open-volume") defects ranging in size from 0.1 to 1 nm with a minimum concentration of up to 10^{-7} cm^{-3}. The PAS method has four orders of magnitude better spatial resolution compared to the transmission electron microscope.

The main goal of the project "New semiconductor detectors for fundamental and applied research" is the development and methodological study of a new class of physical devices - hybrid pixel semiconductor detectors operating in the mode of counting individual particles. These devices first appeared at the turn of the 2000 s and differ from other pixel detectors by the ability to process and digitize the signal directly in the pixel, which makes it possible to obtain data on the energy of each particle falling into an individual pixel in addition to coordinate information.

The goals the project "GDH & SPASCHARM" are the introduction equipment operating at ultralow temperatures and polarized targets into the practice of physical experiment and conduct of polarization studies and participation in innovative projects using cryogenic, magnetic and polarization technologies.

Projects in the theme:

	Name of the project	Project Leader	Project code
1.	Design and development of a test zone for methodological studies of detectors at a linear electron accelerator LINAC-200 in the DLNP	M.I. Gostkin *Deputy:* E.S. Abdelshakur	08-2-1126-1-2024/2028
2.	Precision laser metrology for accelerators and detector complexes	V.V. Glagolev M.V. Lyablin	08-2-1126-2-2016/2028
3.	Development of experimental techniques and applied research with slow monochromatic positron beams (PAS)	A.A. Sidorin *Scientific leader:* I.N. Meshkov	08-2-1126-3-2016/2028
4.	Novel semiconductor detectors for fundamental and applied research	G.A. Shelkov *Deputies:* V.A. Rozhkov V.V. Tereschenko	08-2-1126-4-2015/2028
5.	GDH&SPASCHARM	Yu.A. Usov	08-2-1126-5-2011/2028

Projects:

	Name of the project	Leaders	Status
Laboratory	Responsible from laboratories		
1.	**Design and development of a test zone for methodological studies of detectors at a linear electron accelerator LINAC-200 in the DLNP**	**M.I. Gostkin** *Deputy:* **E.S. Abdelshakur**	Implementation
DLNP	D.L. Demin, M.A. Demichev, Amer Hassan, D.V. Kharchenko, V.G. Kruchonok, A.A. Nozdrin, M.A. Nozdrin, S.Yu. Porokhovoy, A.N. Trifonov, K.E. Unenko, A.S. Zhemchugov		
FLNR	S.V. Mitrofanov, Yu.G. Teterev		
VBLHEP	V.V. Kobets		

Brief annotation and scientific rationale:
Scientific and methodological studies of elementary particle detectors are a necessary condition for the progress of nuclear physics and high energy physics. Preparation of experiments at future accelerators requires new types of detectors capable of coping with large loads and providing the required accuracy and reliability of particle detection. Development of new detectors is also important for applied research based on the use of synchrotron radiation sources and intense X-ray facilities. In particular, creation of new SR sources and super-powerful lasers in the JINR Member States leads to the creation of experimental stations based on detectors with high spatial and energy resolution.

The lack of facilities with test electron beams at JINR significantly slows down progress in development of new types of electromagnetic calorimeters and coordinate detectors for future MPD and SPD experiments at the NICA collider, photon imaging detectors, radiation-resistant detectors and dosimetric instruments. The purpose of the presented project is to create an infrastructure based on the linear electron accelerator LINAC-200 for methodological research on electron beams with an energy of 20 MeV and 200 MeV. It is planned to use a test area based on LINAC-200 and for conducting experiments on the study of photonuclear reactions, for applied research (radiation materials science, radiation genetics, etc.).

Expected results upon completion of the project:
As a result of the implementation of the project, an equipped test zone will appear at the LINAC-200 accelerator of DLNP JINR for carrying out scientific methodological and scientific experimental work by JINR groups and institutes of the JINR Member States.

Expected results of the project this year:
Creation of an additional output of an electron beam at an energy of 130 MeV.

Measurement of electron beam characteristics at energies of 20, 130 and 200 MeV.

Testing narrow-gap proportional chambers using electron beams.

2.	**Presicion laser metrology for accelerators and detector complexes**	**V.V. Glagolev** **M.V. Lyablin**	Implementation

DLNP I.V. Bednyakov, S.A. Bednyakov, K.S. Bunyatov, Yu.I. Davydov, Yu.V. Klemeshov, S.M. Kolomoets, A.V. Krasnoperov, A.M. Kuzkin, R.V. Ni, A.A. Pluzhnikov, K.D. Polyakov, G.D. Shirkov, S.N. Shilov, G.T. Torosyan

BLTP A.N. Baushev

GA&C G.V. Trubnikov

Brief annotation and scientific rationale:
The implementation of the project is aimed at long-term monitoring of the behaviour of the base of the collider (NICA) to track critical design changes that can cause beam deviations from the calculated orbits. Also, monitoring will make it possible to control angular vibrations of the collider elements from microseismic noise of industrial and natural origin in order to identify sources of noise and frequencies that coincide with the resonant frequencies of the collider elements, which can lead to a decrease in luminosity.

An equally important component of the project is development of a compact inclinometer capable of measuring changes in the angles of inclination of the surface with an accuracy of about 10^{-8} radians throughout the year, and further, building of a network of such inclinometers in seismic regions to determine energy accumulation zones and potentially seismic areas.

Expected results upon completion of the project:
Creation of a network of small-sized laser inclinometers (MPLIs) for monitoring the behaviour of the base of the collider (NICA) to track critical design changes that can cause beam deviations from the calculated orbits. Creation of a hardware-software complex for synchronization and processing of MPLI data. Creation of software for visualization of changes in the position of the Earth's surface under the NICA collider.

Modification of the current MPLIversion for long-term stable operation for 6-12 months with angular measurements accuracy of 10^{-7} rad at remote geodetic points, powered by solar panels.

R&D on a new version of the MPLI - an interferometric PLI (IPLI), which has a weak temperature dependence and less expensive production based on available components.

Based on the sets of modified MPLIs and IPLIs, carry out deployment of networks to determine the regions of seismic energy accumulation and monitor objects on the territory of Kamchatka, Armenia, Belarus and Uzbekistan.

Create the necessary software for receiving data from the PLI network, online control, visualization of the Earth's surface by a controlled network, algorithms (including machine learning, neural networks) for determining zones of increased accumulation of seismic energy.

Creation of a prototype of an amplitude interferometric length meter for a length of 16 m, creation of a prototype of a laser reference line for a length of 128 m, creation of a prototype of a seismically stabilized research platform, use of compact MPLIs to improve the frequency parameters of the gravitational antennas of the VIRGO detector.

Expected results of the project this year:
Create a thermal stabilization system for IPLI.

Install the IPLI in the lab of the Kamchatka branch of the EGS RAS.

Install IPLI at the geophysical observatory Naroch in Belarus.

3.	**Development of experimental techniques and applied research with slow monochromatic positron beams (PAS)**	**A.A. Sidorin** *Scientific leader:* **I.N. Meshkov** (VBLHEP)	Implementation

DLNP E.V. Akhmanova, V.I. Hilinov, Nguyen Vu Minh Trung, O.S. Orlov, E.P. Popov, A.Yu. Rudakov, S.F. Samedov

VBLHEP V.V. Kobets

Brief annotation and scientific rationale:
Applied research in the field of solids by PAS methods and the development of experimental techniques using these methods are among the goals of the project. To study defects in materials, the annihilation line Doppler broadening (DBAL) method is used, which is implemented on a flow of slow monochromatic positrons. The DBAL spectrometer is made according to the standard scheme. The Positron Annihilation Lifetime Spectroscopy (PALS) method implemented on an autonomous ^{22}Na source is also

used. To develop the experimental base, the PALS method is being introduced on a flow of slow monochromatic positrons. The group proposed an original version of this method based on the formation of an ordered stream of slow positrons.

Expected results upon completion of the project:
Improvement of the DBAL spectrometer by adding to the measurement scheme the possibility of registering the coincidence of two annihilation gamma quanta.

Completion of the positron ordering system and commissioning of the PALS spectrometer on a monochromatic positron beam.

Development of the ion etching technique using the created etching system and its application to the study of thin-film multilayer materials.

There is a problem of high-temperature vacuum heating, which can be solved by heating samples with an electron beam. The available technical capabilities make it possible to implement this heating method.

Expected results of the project this year:

Continuation of applied research in collaboration with TPU (layered materials Zr/Nb) and SAFU (synthetic diamonds).

Investigation of polymeric materials and thin films (BiVO4) in collaboration with colleagues from Vietnam.

Further research on the radiation resistance of refractory materials (W, WC).

Completion of the automatic control system for the PAS installation.

4.	**Novel semiconductor detectors for fundamental and applied research**	**G.A. Shelkov** *Deputies:* **V.A. Rozhkov** **V.V. Tereschenko**	Implementation

DLNP S. Abdelshakur, N.N. Kaurtsev, V. Kruchonok, A.V. Lapkin, G.K. Lavrov, S.A. Malinin, V. Makarova, R.V. Sotensky, Phi Truong Hoai Bao

FLNR A.T. Isatov, S. Mitrofanov, Yu.G. Teterev

FLNP A.A. Ahmedov, D. Berikov, Yu.N. Kopach

LRB A.N. Bugay, A.V. Chizhov

Brief annotation and scientific rationale:
In 2015, theme 1126 was opened. The main goal of the work is the development and methodological research of a new class of physical devices - hybrid pixel semiconductor detectors operating in the single-particle counting mode. These devices first appeared at the turn of the 2000s. and differ from other pixel detectors by the ability to process and digitize the signal directly in the pixel, which makes it possible to obtain data on the energy of each particle falling into an individual pixel in addition to coordinate information.

The ability to measure the energy of an X-ray gamma ray opens up new possibilities that were previously unavailable. Having such information, you can determine not only the absorption capacity of individual elements of the object under study, but also determine the material of this element. Thus, in medical X-ray tomographs, the identification of substances in individual parts of a living organism provides vital information about metabolic pathways, tissue components and delivery mechanisms of these substances. This task is of particular importance when studying drug delivery. Carrying out such studies using X-ray computed tomography (CT) is currently difficult due to the lack of available detection systems with high spatial resolution and capable of measuring the energy of gamma rays. The goal of this project is to create a hardware and software basis for the development of detection systems with hybrid pixel detectors and radiographic medical and industrial equipment based on them. As a result of the project, prototypes of new energy-sensitive pixel detectors will be developed and manufactured in industry.

Expected results upon completion of the project:
The main direction of further work will be the development of our own ASIC and the production of new energy-sensitive semiconductor X-ray image detectors and equipment for:
– creating a hardware and software basis for the development of new types of X-ray devices for medical and industrial diagnostics, including computed tomography;

– improving methods for identifying substances in x-ray studies using data on the measured energy of gamma quanta.

Expected results of the project this year:
Manufacturing and testing of the first elements of the developed ASIC.

Study of the characteristics of new sensor materials (CdTe and CZT) manufactured at "KristalsNord" LLC.

Continuation of joint work with chemists from Moscow State University on the MARS microtomograph.

5. GDH&SPASCHARM **Yu.A. Usov** Implementation

DLNP N.A. Bazhanov, D.V. Belov, N.S. Borisov, A.S. Dolzhikov, A.N. Fedorov, I.V. Gapienko, I.S. Gorodnov, V.L. Kashevarov, A. Kovalik, E.S. Kuzmin, A.B. Neganov, A.A. Priladyshev, A.B. Sadovsky, Yu.N. Uzikov, V.P. Volnykh

BLTP S.B. Gerasimov

VBLHEP V.V. Fimushkin, M.V. Kulikov, L.V. Kutuzova

Brief annotation and scientific rationale:
Experimental study of one-spin asymmetries in the production of various light particles using a pion beam with an energy of 28 GeV at the first stage, and the study of one-spin and two-spin asymmetries in dozens of reactions, including those with the formation of charmonium, using a polarized proton beam (SPASCHARM project).

The ultimate goal of the SPASCHARM project is to study the spin structure of the proton, starting with determining the contribution of gluons to the spin of the proton at large values of the Björken variable x by studying the spin effects in the formation of charmonium. This will make it possible to understand the hadronic mechanism of charmonium production and to isolate the gluon polarization $\Delta g(x)$ at large values of x.

Experiments with a real photon beam: photoproduction of mesons on nucleons and nuclei and Compton scattering on nucleons. Main objectives: experimental confirmation of the Gerasimov-Drell-Hearn (GDH) sum rule, investigation of the helicity structure of partial reaction channels, resolution of the excitation spectrum of baryons from light quarks, search for missing baryon resonances and exotic states (dibaryons, narrow nucleon resonances), study of the structure of hadrons.

Measurement of $\Delta\sigma T$ and $\Delta\sigma L$ in an experiment on the transmission of polarized neutrons through a polarized deuteron target at neutron energies <16 MeV, where there are limited experimental data and where theory predicts a significant effect of three-nucleon forces (3NF). This part of the project (NN) is a continuation of measurements of the same quantities in the scattering of neutrons by protons, which were carried out earlier.

Research and development of polarization equipment for MESA.

To date, there is no theory that gives a complete and consistent description of all the observed polarization effects in the hadronic sector. Therefore, a systematic experimental study of polarization effects in a wide variety of reactions using polarized beams and polarized targets is of great importance for the development of a theory that consistently describes all the observed spin phenomena.

The observed polarizations are the paramount characteristics of the interactions of elementary particles and nuclear reactions. Formally, the measurement of spin-dependent parameters imposes additional restrictions on the proposed reaction mechanism, the structure of the microobject under study, and the very nature of the fundamental interaction. It should be noted that modern experiments aimed at searching for the effects of CP violation and T invariance violation outside the Standard Model, as well as CPT violation, are based on polarization measurements.

Expected results upon completion of the project:
Development and construction of a new cryostat for a polarized "frozen" target of the SPASCHARM installation.

Development and construction of the main components of a powerful 3He/4He dilution refrigerator for the "MESA" facility.

Completion of work on the creation of a cryostat for a polarized target at the University of Bonn.

Return transport and full launch of the polarized target in Mainz for the "GDH" project.

Carrying out polarization studies using a polarized "frozen" target at the "MAMI C" accelerator.

Carrying out polarization studies on a new polarized target at the Bonn University accelerator, "ELSA".

Assembly, installation and testing of a powerful 3He/4He dilution refrigerator on the beam channel of the MESA setup.

Launch of the modified polarized target of the "SPASCHARM" facility and the beginning of the collection of physical statistics on the accelerator.

According to the NN-interaction program, channeling experiments will be carried out after the upgrade of the stand for the source of polarized deuterons, - 2024-2025.

Carrying out precise measurements of vector and tensor polarizations of the deuteron beam at the VdG accelerator.

Preparation of a special device for using a new target material based on trityl-doped butanol.

Manufacture and installation of equipment for measuring polarization of neutrons using scattering on a 4He target.

Depreservation of the polarized deuteron target and the beginning of measuring the difference between the cross sections $\Delta\sigma T$ and $\Delta\sigma L$ in the experiment on transmission of at neutron energies <16 MeV.

Expected results of the project this year:
Complete creation of a new cryostat for a polarized target at the University of Bonn.

Participation in the physical data taking at the ELSA accelerator.

Collaboration

Country or International Organization	**City**	**Institute**
Armenia	Gyumri	IGES NAS RA
Azerbaijan	Baku	IRP ANAS
Belarus	Minsk	CGM NASB
		INP BSU
Bulgaria	Sofia	INRNE BAS
Czech Republic	Prague	CTU
Germany	Bonn	UniBonn
	Mainz	JGU
Russia	Arkhangelsk	NArFU
	Moscow	"Kristal"
		NNRU "MEPhI"
	Novosibirsk	ISP SB RAS
	Petropavlovsk-Kamchatsky	FRC GC RAS
	Protvino	IHEP
	Saint Petersburg	ETU “LETI”
		NWRSCC
	Tomsk	TPU
		TSU
Serbia	Novi Sad	UNS
Uzbekistan	Tashkent	IS AS RUz
Vietnam	Ho Chi Minh City	CNT VINATOM

08-2-1127-2016

Advanced Studies of Systems of New-Generation Accelerators and Colliders for Fundamental and Applied Research

Theme leaders: G.V. Trubnikov
G.D. Shirkov
B.N. Gikal

Participating countries and international organizations:
Belarus, Belgium, CERN, China, Georgia, Germany, Italy, Moldova, Russia, Slovakia, South Africa.

The problem under study and the main purpose of the research:
Development of the systems and elements of new generation accelerators at JINR, applied research on accelerators. Participation in the development of the international accelerator complexes projects. Participation in the development of the concept of establishment a pilot scientific and clinical center for proton therapy.

Project in the theme:

Name of the project Laboratory Responsible from laboratories	Project Leaders	Project code Status
1. Creation of test benches for testing individual systems of the MSC-230 cyclotron	**G. A. Karamysheva** **S.L. Yakovenko**	08-2-1127-1-2024/2025 Technical project

DLNP A.F. Chesnov, S.N. Dolya, I.V. Evseeva, S.A. Fedorenko,R.V. Galkin, V.A.Gerasimov, A.L.Gonshior, S.V. Gursky, G.G. Kazakova, O.V. Karamyshev, N.V. Kirichkov I.N. Kiyan, O.E. Lepkina, O.V. Lomakina, I.D. Lyapin, V.A. Malinin, D.A. Malysh, I.M.Palnikov, D.S. Petrov, D.V. Popov, D.V. Rogozin, V.M. Romanov, N.A. Rybakov, L.D. Sedov, A.A. Sinitsa, G.M. Skripka, G.D. Shirkov, S.G. Shirkov, A.I. Vlasov

VBLHEP V.V. Borisov, G.G. Khodzhibagiyan, D.N. Nikiforov, M.S. Novikov

MLIT T.V. Karamysheva

Brief annotation and scientific rationale:
The development of the superconducting proton cyclotron MSC-230 will create a source of intense proton beams, opens up possibilities to modernize the equipment for precise control and delivery of high dose rate for studies by the Flash therapy method. MSC-230 may become the first model for a series of specialized medical accelerators of this type. The cyclotron should provide a current up to 1 μA in continuous mode and up to 10 μA in pulsed mode at the proton energy of 230 MeV.

The modeling and testing prototypes of the cyclotron elements, such as a proton source and a deflector, on the test benches and the developing of the magnetic field measurement system are necessary for the successful launch of the MSC-230 cyclotron.

The project actuality is determined primarily by the importance of creating adomestic accelerator for proton therapy using the most modern methods, distinguished by a unique beam intensity, as well as the relevance of medical and biological research that will be conducted at MSC-230.

Expected results upon completion of the project:
The MSC-230 cyclotron commissioning on the beam design parameters necessary for testing equipment and treating patients with modern proton therapy methods.

Expected results of the project this year:
The study of the operability of individual cyclotron systems: deflector, proton source. Development of the magnetic field measurement system including the calibration magnet. Determination of medical and technical conditions for the proton therapy center projecting.

Activities of the theme:

	Name of the activity	Leaders	Implementation period
Laboratory	Responsible from laboratories		Status
1.	**Further development of methods, technologies, schedule modes and provision of radiotherapy**	**G.V. Mitsyn**	2024-2025 R&D
DLNP	A.V. Agapov, I.V. Alexandrova, K.V. Belokopytova, V.M. Breev, S.N. Dima, G.V. Donskaya, V.N. Gaevsky, E.A. Gritskova, S.A. Gustov, M.D. Indiukova, I.I. Klochkov, A.G. Molokanov, S.A. Pisareva, A.V. Rzyanina, S.V. Shvidkiy, S.S. Uglova		

Brief annotation and scientific rationale:
This project is a continuation of the medical and biological research started at the JINR Laboratory of Nuclear Problems in 1967 using proton beams. The project includes the following works: participation in the Determination of medical and technical conditions for the project to create a proton therapy center, calculation of beam transportation channels to the irradiation units, development and manufacture of the detectors for dosimetric support of flash therapy, development and testing of all technological stages of planning and conducting proton therapy. It is planned to conduct medical and biological research at the DLNP linear electron accelerator (LINAC-200), which is supposed to form an electron beam with an energy of 20-25 MeV for irradiating cell cultures and small laboratory animals (mice, rats).

Expected results of the activity upon completion:
The manufacturing and testing of proton beam Bragg peak modifiers (comb filters) using 3D printing for the future radiological center based on the MSC-230 accelerator. Manufacturing and testing of thin-walled multi-wire and strip ionization chambers. Formation of an electron beam with an energy of 20-25 MeV on the LINAC-200 accelerator for medical and biological research.

Expected results of the activity in the current year:
To continue conducting radiobiological research in a wide range of areas: the use of heavy metal nanoparticles as radiomodifiers during radiotherapy, the study of the radiobiological foundations of the flash effect, studies of the effect of ionizing radiation of various qualities on the structures and functions of the central nervous system, and others.

2.	**R&D of Photoinjecting systems**	**M.A. Nozdrin**	2024-2025 Technical Proposal Realization
DLNP	A.V. Afanasiev, A.S. Dyatlov, D.S. Shokin, K.E. Yunenko, P.P. Zhuravlev,		
VBLHEP	V.V. Bleco, N.I. Garanzha, J. Huran, A.V. Skrypnik, V.G. Shabratov		

Brief annotation and scientific rationale:
The most modern free electron lasers, as well as other facilities which require high quality electron beam, the photocathode injectors are being used. Such injectors allow to obtain higher beam quality than thermoemission ones. Replacement of the thermoinjector of the LINAC-200 accelerator to the photoinjector is being considered. This will result in the beam emittance reduction, will give more flexibility in beam temporary profile and eventually will allow to construct LINAC-200-based FEL in the range from far IR to UV and soft X-rays.

Expected results of the activity upon completion:
The photoinjector testbench with the electron energy of up to 6 MeV based on S band RF gun construction. The possibility of replacing the thermoinjector of the LINAC-200 accekerator with a photoinjector to improve beam quality and variability of its parameter's conclusion.

Research of the quantum efficiency of various "transparent" photocathodes based on ultrathin carbon films: depending on deposition method, carbon phases and structures, doping elements and their concentration, cathode shape etc.

Expected results of the activity in the current year:
Design and assembling of the testbench equipment: laser beamline, vacuum and RF systems, synchronization of the laser with RF system, beam focusing and diagnostics. Design of the safety systems.

3.	**Participation in the development of the concept and joint project with FMBA of Russia for the creation of a pilot scientific and clinical center for proton therapy**	**G.D. Shirkov**	2024-2025 Preparation of project
DLNP	S.G. Shirkov, S.L. Yakovenko		
VBLHEP	L.Yu. Stolypina		

Brief annotation and scientific rationale:
The Federal Medical and Biological Agency (FMBA) of Russia expressed its intention to take part together with JINR in the development of a joint concept (and in the future, a project) for the establishment of a pilot scientific and clinical center for proton therapy on the basis of the existing medical center No. 9 of the FMBA in Dubna and based on the MSC-230 accelerator being created at JINR. The objectives of the center will be development of modern methods and technologies of radiation therapy, medical technologies and diagnostics for the use of radiation therapy, advanced scientific research in the field of radiobiology, experimental irradiation and further treatment of patients.

Expected results of the activity upon completion:
Preparation of the project for establishment a proton therapy center.

Expected results of the activity in the current year:
Development of medical and technical conditions for the project of establishment a proton therapy center.

Collaboration

Country or International Organization	City	Institute
Belarus	Minsk	INP BSU
		IP NASB
Belgium	Louvain-la-Neuve	IBA
CERN	Geneva	CERN
China	Hefei	ASIPP
Georgia	Tbilisi	HEPI-TSU
Germany	Hamburg	DESY
Italy	Pisa	INFN
Moldova	Chisinau	MSU
Russia	Moscow	FMBA
		FMBC
		IBMP RAS
	Nizhny Novgorod	IAP RAS
	Petropavlovsk-Kamchatsky	FRC GC RAS
		KSU
	Puschino	ITEB RAS
	Saratov	SSU
Slovakia	Bratislava	IEE SAS
South Africa	Somerset West	iThemba LABS

Organization of Scientific Activities and International Cooperation. Strengthening Human Resources. Educational Programme (09)

09-8-1037-2001

Analytical and Methodological Developments for the Organization of Scientific Research and International Cooperation in the Main Directions of JINR Development

Theme leaders: V. A. Matveev
S.N. Nedelko
O.-A. Culicov

Participating countries and international organizations:
Russia.

The problem under study and the main purpose of the research:
Development of analytical materials concerning prospects of scientific research. Preparation of scientific research plans. Development of science-organization and methodological materials for the special-purpose financing of research areas, themes and projects. Development and application of information systems for the analysis of results of theoretical and experimental research. Organization of international cooperation with the Member States of JINR, with states participating in JINR activities on the basis of bilateral agreements, and with scientific research institutions with which JINR has collaboration agreements.

Expected results in the current year:
Improvement of the organization and coordination of JINR scientific research work.

Analysis of the results of JINR activities for 2024 in the main research areas.

Preparation for the publication of the Topical Plan for the year 2026. Identification of JINR's priority research directions for 2026. Update, administration and support of the electronic system for maintaining the Topical Plan for JINR Research and International Cooperation (Topical Plan).

Development of JINR's grantmaking activities and participation in special-purpose programmes for financing scientific research in 2025.

Preparation of analytical materials for ministries and agencies.

Development and promotion of JINR's information resources on the Internet. Support of the system of accounting of protocols on scientific and technological cooperation.

Promotion of realization of JINR's right to independently confer academic degrees. Support of the operation of JINR's dissertational councils.

Preparation for the publication of the JINR Annual Report for 2024. Preparation of materials for the INIS system.

Scientific and organizational support and preparation of materials of JINR's governing and advisory bodies.

Prompt interaction with representatives of Member States and states participating in the activities of JINR on the basis of bilateral agreements in the fields of scientific research. Organization and holding of meetings of cooperation committees. Interaction with international organizations.

Organization and holding of contests for JINR Prizes, preparation of materials for nominating candidates for memberships in academies of sciences, for conferring honorary titles, for awarding medals and other decorations.

Study of the history of the development of JINR as an international intergovernmental scientific organization. Expert and analytical support for the JINR Museum of Science and Technology, including the historical archive.

Area of the activity	Leaders
Laboratory (Subdivision) Responsible from Subdivision	
1. Preparation for the publication of the Topical Plan	**S.N. Nedelko** **A.S. Zemchugov**
DSOA N.A. Boklagova, D.S. Korobov, N. Kučerka	
2. Support and improvement of the operation of JINR's governing and advisory bodies	**S.N. Nedelko** **O.-A. Culicov**
DSOA T.V. Bogdanova, N.A. Boklagova, T.B. Ivashkevich, D.S. Korobov, N. Kučerka, N.I. Sissakian	
ICD D.O. Al-Maaitah, O.N. Belova, N.M. Dokalenko, O.M. Korotchik, A.A. Kotova, Yu.N. Polykova	
3. Preparation of analytical materials for ministries and agencies	**S.N. Nedelko** **O.-A. Culicov** **A.S. Zhemchugov**
DSOA N.A. Boklagova, D.S. Korobov, O.V. Krupa, N.I. Sissakian	
ICD E.A. Badavi, T.V. Keselis, M.A. Khvedelidze, A.A. Kotova, D. Markovic	
UC D.V. Kamanin	
STL E.V. Ivanova, V.V. Litsitis	
4. Development of JINR's grantmaking activities and participation in special-purpose programmes for financing scientific research	**S.N. Nedelko** **O.-A. Culicov**
DSOA N.A. Boklagova, D.S. Korobov. N.I. Sissakian	
5. Support for the operation of JINR's dissertation councils	**S.N. Nedelko** **A.S. Zhemchugov**
DSOA T.B. Ivashkevich, N.I. Sissakian	
VBLHEP O.V. Belov	
6. Organizational support for JINR's activities under Russian and international protocols and agreements	**S.N. Nedelko** **O.-A. Culicov**
DSOA N.V. Doroshkevich, N. Kučerka, N.I. Sissakian	
ICD E.A. Badavi, T.V. Keselis, A.A. Kotova	
UC D.V. Kamanin	
7. Provision for the operation and development of JINR's Internet resources	**S.N. Nedelko** **O.-A. Culicov**
DSOA N.A. Boklagova, D.S. Korobov, A.G. Nanev, N.I. Sissakian, B.M. Starchenko	
SCSS N.V. Borozna, N.A. Bykova, N.V. Zaikina, K.P. Moisenz	
UC D.V. Kamanin, A.A. Suschevich, A.Yu. Verkheev	
Editorial office of the weeklynewspaper "Dubna: science, community, progress"	E.M. Molchanov

8.	**Preparation for the publication of the quarterly bulletin "JINR News" and the JINR Annual Report**	**S.N. Nedelko** **A.S. Zhemchugov**
DSOA	E.S. Asanova, I.V. Kronshtadtova, B.M. Starchenko, Yu.G. Shimanskaya, I.Yu. Shcherbakova	
9.	**Preparation of materials for the INIS system**	**S.N. Kruglova**
DSOA	B.M. Starchenko	
10.	**International cooperation**	**O.-A. Culicov**
ICD	E.A. Badavi, M.A. Khvedelidze, T.V. Keselis, M.A. Khvedelidze, A.A. Kotova, D. Markovic, Yu.N. Polyakova	
DSOA	N.A. Boklagova, D.S. Korobov, N**.** Kučerka, A.S. Zhemchugov	
11.	**Support for the development and implementation of the services of the JINR digital ecosystem in the part relevant to the profile of DSOA activities**	**N. Kučerka** **O.-A. Culicov**
MLIT	S.D. Belov, D.V. Neopolitansky, A.V. Prihodko	
12.	**Study of the history of the development of JINR as an international intergovernmental scientific organization**	**S.N. Nedelko** **A.S. Zhemchugov**
ICD	E.A. Badavi, M.A. Khvedelidze	
Museum	A.A. Rastorguyev, A.E. Zlotnikova	

Collaboration

Country or International Organization	**City**	**Institute**
Russia	Moscow	IMEMO RAS
		IOS RAS
		MGIMO
		NRU HSE
		PFUR
		RIEPL
	Saint Petersburg	ITMO

09-9-1139-2019

Scientific and Educational Programmes for the Training of Highly Qualified Personnel

Theme leaders: D.V. Kamanin
A.Yu. Verkheev

Participating Countries and International organizations:
Armenia, Azerbaijan, Belarus, Bulgaria, Cuba, Egypt, Kazakhstan, Mongolia, Russia, Serbia, South Africa, Tunisia, Uzbekistan, Vietnam.

The problem under study and the main purpose of the research:
Development of the human resources training programmes at JINR aimed at further employment of the trainees as scientific and engineering specialists of the Institute is a key task, which includes work with various target audiences, including schoolchildren and school teachers.

For these purposes, the UC, together with the universities of the JINR Member States, creates appropriate conditions for students and PhD students from universities of the Member States to enable them to work on their qualification theses based on the research

conducted in the laboratories of the Institute, supports the activities of the JINR-based departments of the universities based in the country of the Institute's location, participates in the creation and development of network training programmes, trains students, PhD students, and interns on the basis of cooperation agreements with the universities of the JINR Member States and international organizations. An important part of the human resources programme is organization and running of international student practices and schools for young people from the Member States of the Institute; building and maintenance of the laboratory environment intended for hands-on training in scientific and engineering disciplines; support and further development of the system of training courses aimed at gaining or improving professional skills and qualifications of JINR technical and engineering personnel.

Development of the JINR outreach programme aimed at promotion of modern science achievements among school students and teachers, organization of excursions and online tours of the JINR main facilities; participation in science festivals, exhibitions, and forums promoting JINR; development of cooperation and communication with educational centres for school students; design and production of information materials for the JINR information centres, administration of the UC groups in the social media.

Expected results upon completion of the theme stages or projects:
Participation in the development of lecture courses and seminars for students and PhD students of the JINR-based departments of the Russian universities.

Training of students and PhD students at JINR on the basis of cooperation agreements with the universities of the JINR Member States and other countries.

Support and further development of the Engineering and Physics Training hands-on activities for students and PhD students from the JINR Member States and partner universities.

Support of the system of assigning Institute employees to JINR for preparation of their PhD theses without completing the academic programme of the PhD course. Participation in the Institute system of attestation of scientific personnel.

Organization and running of the JINR student programme "START", online programme "INTEREST", international student schools and practices.

Launch of the short-term Advanced Science Programmes for Young Researchers and Engineers "ASPYRE" at JINR.

Further development of the licensed system of training courses aimed at gaining or improving professional skills and qualifications of the technical and engineering personnel of the Institute.

Implementation of the advanced training programmes for school teachers from the JINR Member States.

Support of Dubna Interschool Physics and Mathematics Open Classroom and science programmes for school students, interaction with the Physics and Mathematics Lyceum named after Academician V.G. Kadyshevsky and other educational institutions.

Further development of the partner network of JINR information centres.

Organization and running of the JEMS programme.

Development of printed and electronic popular-science informational materials promoting the Institute and modern scientific achievements.

Provision of JINR partner universities and information centres in the Member States with electronic and printed informational materials.

Extension of the JINR partner network through further development of educational programmes.

Expected results in the current year:
Support and supervision of the educational process at the JINR-based departments of the Russian universities.

Support of the system of assigning young researchers to JINR laboratories for preparation of their PhD theses.

Organization and running of the International Student Practices in JINR Fields of Research for students of the JINR Member States' universities. Attraction of new countries for participation in the programme.

Organization and running of the JINR student programme "START" (summer and winter sessions) and online programme "INTEREST" (spring and autumn waves).

Test-running of the school for future teachers.

Organization and running of joint scientific events and schools with partner universities at JINR.

Support and further development of an information system on the preparation of qualification theses by students and PhD students from universities of the JINR Member States in the Institute laboratories.

Organization and running of the Engineering and Physics Training hands-on activities for students and PhD students from the JINR Member States, further development of the existing laboratory works, development of laboratory works at LINAC-200. Further development of educational programmes on the accelerator arrangement and beam diagnostics.

Development of the language courses programme aimed at teaching Russian as a foreign language and English to JINR personnel.

Running of the training courses aimed at gaining or improving professional skills and qualifications of the technical and engineering personnel of the Institute.

Organization of scientific schools for physics teachers from the Institute Member States at JINR.

Further development of educational programmes for high school students from the partner countries of JINR.

Further development of virtual tours of JINR main facilities and video conferences with educational institutions of the JINR Member States. Organization and guidance of group visits to JINR for school and university students.

Promotion of modern educational resources in the JINR Member States.

Organization of the participation of JINR in science festivals on the basis of Russian universities.

Further development of the partner network of JINR information centres.

Organization and running of the JEMS programmes in accordance with the international cooperation plan.

Area of the activity	**Leaders**
Laboratory (Subdivision) Responsible from Laboratories Leaders from Laboratories	
1. Organization of the educational process at JINR	**D.V. Kamanin** **A.Yu. Verkheev**
DLNP Ye. A. Yakushev D.V. Naumov	A. Baimukhanova, A.G. Olshevskiy, A.S. Zhemchugov
BLTP D.I. Kazakov	N.V. Antonenko
FLNP E.V. Lychagin V.N. Shvetsov	M.V. Avdeev, A.V. Belushkin
VBLHEP A.V. Butenko N.A. Strokovsky O.V. Belov	A.I. Malakhov, A.O. Sidorin
FLNR S.I. Sidorchuk	A.V. Karpov, A.G. Popeko
MLIT S.V. Shmatov V.V. Korenkov T.A. Strizh	O.Yu. Derenovskaya, I.S. Pelevanyuk, O.I. Streltsova

LRB A.N. Bugay E.A.Krasavin	I..V. Koshlan
Directorate V.D. Kekelidze L. Kostov B.N. Gikal	V.A. Matveev, B.Yu. Sharkov
ICD O.-A. Culicov	E.A. Badawy

2. Outreach and JINR promotion **A.A. Suschevich**

DLNP	N.V. Anfimov, M.V. Shirchenko
BLTP	A.V. Andreev, A.V. Frizen
FLNP	D.M. Chudoba, C. Khramko
VBLHEP	D.K. Dryablov
FLNR	K.B. Gikal, A.V. Karpov
MLIT	I.S. Pelevanyuk
LRB	T.S. Khramko, I.A. Kolesnikova, Yu.S. Severyukhin
Universal JINR library	M.S. Pilipenko

3. Engineering and physics training **M.A. Nozdrin**

VBLHEP	R.V. Pivin, K.G. Osipov
DLNP	A.N. Trifonov, A.S. Zhemchugov
FLNR	D.S. Belozerov, A.Yu. Bodrov, V.A. Buzmakov, K.B. Gikal, A.M. Kapitonov, A.V. Khalkin, E.V. Pishchalnikova, A.V. Sabelnikov, K.A. Verlamov, V.Yu. Zhegolev, D.A. Zlydenny

4. JINR information centres JEMS programme **D.V. Kamanin**

DLNP D.V. Naumov	E.N. Dubovik
BLTP N.V. Antonenko	A.V. Andreev
FLNP V.N. Shvetsov	D.M. Chudoba
VBLHEP R. Lednicky	A.O. Sidorin
FLNR S.I. Sidorchuk	G. Kaminski, A.V. Karpov
MLIT O.Yu. Derenovskaya O.I. Streltsova	I.S. Pelevanyuk
LRB A.N. Bugay	I.V. Koshlan
DSOA S.N. Nedelko	A.S. Zhemchugov
ISD O.-A. Culicov	E.A. Badawy, Yu.N. Polyakova

Project in the theme:

Name of the project	Project Leader	Project Code
Laboratory Responsibles from laboratories		**Status**
1. Open information and educational environment for supporting fundamental and applied multidisciplinary research at JINR	**Yu.A. Panebrattsev**	09-9-1139-1-2021/2028
		Realization

VBLHEP A.P. Cheplakov K.V. Klygina N.E. Sidorov	A.S. Averichev, A.A. Aparin, O.V. Belov, E.I. Golubeva, A.A. Korobitsyn, N.A. Lashmanov, Vinh Ba Luong, Yu.D. Orlova, M.P. Osmachko, N.E. Pukhaeva, P.D. Semchukov, N.I. Vorontsova, G.A. Yarygin
FLNR A.V. Karpov A.S. Denikin	D. Aznabayev, T. Isatayev, S.M. Lukianov, K. Mendibayev, M.A. Naumenko, V.A. Rachkov
LRB A.N. Bugai I.V. Koshlan	A.V. Chizhov, D.V. Davydov, I.S. Gordeev, M.I. Kapralov, V.A. Krylov, E.E. Pavlik, A.Yu. Rosanov, A.K. Ryumin

Brief annotation and scientific rationale:
The integration of science, education and the achievements of modern technologies is becoming especially important as one of the most important factors for the development of the economy and the social structure of a society based on knowledge-intensive technologies. To solve these tasks, it is necessary to combine the efforts of various universities and research centers to create new training courses and research practices.

Multimedia and interactive methods, combined with real data obtained in one of the research centers, could largely solve this problem. The Joint Institute for Nuclear Research, as an international organization, under whose auspices the participating states, associate members and dozens of collaborating universities from around the world, offers its solution to this problem in the form of the implementation of the project "Open information and educational environment for supporting fundamental and applied multidisciplinary research at JINR"

Project purposes:

– the use of modern educational technologies for the preparation of university students and advanced training of specialists for work at JINR;

– attracting talented young people from the participating countries and countries cooperating with JINR to participate in research projects of the Institute;

– implementation of the results in the field of fundamental and applied research obtained at JINR into the educational process in the member countries and associate members of JINR. Expanding the geography of cooperation;

– cooperation with the world's leading scientific centers and universities in the field of creating educational resources for physics teachers and high school students;

– increasing the awareness of fundamental and applied multidisciplinary research conducted at JINR and the JINR brand among a wide audience. Placement of courses prepared by leading JINR specialists on international platforms of open education;

– creation of educational and exhibition content on JINR topics at the level of leading scientific centers.

Expected results upon completion of the project:
Information support of the main areas of fundamental and applied research at JINR.

Creation of online courses and new educational programs on the subject of the Institute's activities on modern educational platforms.

Development of a project to create virtual, remote and laboratory practicums for the study of nuclear physics and applied research.

Development of exhibition activities about the achievements of JINR and modern science in the Russian Federation and countries cooperating with JINR.

Creation of multimedia resources and web solutions to support JINR information centers.

Creation of electronic educational materials and research laboratory practicums for schoolchildren to study physics and biology at an advanced level in schools of the Russian Federation and partner countries.

Creation and implementation in the educational process of Russian schools of an educational and methodological complex for studying physics at an advanced level "Physics 7-9. Engineers of the Future".

Expected results of the project in the year:
Creation and development of an information system for supporting applied research at the NICA accelerator complex (ARIADNA project).

Development of a web-based knowledge base on low energy nuclear physics “Nuclear Reaction Video 2.0”.

Cooperation with NRNU MEPhI in the field of creating online courses in nuclear physics, engineering, atomic and related technologies and their further publishing at the educational portals of JINR (edu.jinr.ru) and NRNU MEPhI (online.mephi.ru), and website (инженеры-будущего.рф).

Using augmented, extended and virtual reality to prepare exhibition displays dedicated to the basic facilities and experimental research of JINR.

Development of a virtual practicum on radiobiology for working with an electron microscope on the example of the study of microfossils and organic compounds in meteorites and in ancient terrestrial rocks.

Development of a platform for remote practicums together with iThemba LABS.

Development of hands-on practicums and new virtual laboratory works on nuclear electronics and the basics of detection of ionizing particles.

Organizing practices and workshops for university students.

Launch of the JINR – iThemba LABS Corner exposition South Africa. Creation of a series of videos on the basics of experimental nuclear physics for schoolchildren for the JINR – iThemba LABS Corner exposition.

Creation of a website to support the educational and methodological complex for studying physics at an advanced level in Russian schools "Physics 7-9. Engineers of the Future".

Creation of electronic educational materials for the elective course "Nuclear Physics" for a specialized school, including research practicums in nuclear physics (hands-on, virtual and remote).

Collaboration

Country or International Organization	City	Institute
Armenia	Yerevan	YSU
Azerbaijan	Baku	IP ANAS
Belarus	Gomel	GSU
	Minsk	BSTU
		INP BSU
Bulgaria	Sofia	INRNE BAS
		SU
Cuba	Havana	ASC
Egypt	Cairo	ASRT
		EAEA
Kazakhstan	Almaty	KazNU
	Astana	ENU
	Ust-Kamenogorsk	EKSU
Mongolia	Ulaanbaatar	MNUE
		NUM
Russia	Arkhangelsk	NArFU
		NSMU
	Belgorod	BelSU
	Dolgoprudny	MIPT
	Dubna	Dubna State Univ.
	Grozny	CheSU
	Irkutsk	ISU
	Ivanovo	ISU
	Kazan	KFU
	Kostroma	KSU
	Krasnodar	KSU

	Moscow	BMSTU
		MPEI
		MSU
		NNRU "MEPhI"
		NRU HSE
		PFUR
	Novocherkassk	SRSPU NPI
	Petropavlovsk-Kamchatsky	KSU
	Saint Petersburg	SPbSPU
		SPbSU
	Samara	SU
	Smolensk	SSU
	Tomsk	TPU
		TSU
	Tula	TSU
	Vladikavkaz	NOSU
	Vladivostok	FEFU
	Voronezh	VSU
	Yakutsk	NEFU
	Yaroslavl	YSU
	Yekaterinburg	UrFU
Serbia	Novi Sad	UNS
	Sremska Kamenica	Educons Univ.
South Africa	Bellville	UWC
	Pretoria	UNISA
	Somerset West	iThemba LABS
	Stellenbosch	SU
Tunisia	Tunis	AAEA
Uzbekistan	Samarkand	SamSU
	Tashkent	AS RUz
		TashSTU
Vietnam	Hanoi	IOP VAST
		VINATOM

09-3-1117-2014

DIAS-TH
Dubna International Advanced School of Theoretical Physics

Theme leader: I.G. Pirozhenko

Rector of DIAS-TH: D.I. Kazakov

Participating Countries and International organizations:
Armenia, Czech Republic, Russia, Serbia.

The problem under study and the main purpose of the research:
The Dubna International Advanced School of Theoretical Physics (DIAS-TH) is a scientific and educational project aimed, firstly, at training senior students, post-graduate students and young scientists on research topics of the Laboratory of Theoretical Physics, priority scientific areas of JINR research and modern areas of physics. The second goal of the project is to expand international cooperation and attract young scientists from Russia and the participating countries to JINR.

Project in the theme:

	Name of the project	Project Leaders	Project code
Laboratory	Responsible from laboratories		
1.	**DIAS-TH** **Dubna International Advanced School of Theoretical Physics**	**I.G. Pirozhenko** **D.I. Kazakov**	09-3-1117-1-2024/2028

BLTP	N.V. Antonenko, A.N. Baushev, E.A. Davydov, M. Hnatic, A.P. Isaev, M.A. Ivanov, R.V. Jolos, G.V. Kalagov, O.P. Klimenko, E.A. Kolganova, N.M. Lebedev, L. Mizisin, V.A. Osipov, M.V. Savina, S.S. Sidorov, A.S. Sorin, O.V. Teryaev, P.V. Tretyakov, V.I. Zhuravlev, 4 students
MLIT	Yu.L. Kalinovsky, V.V. Korenkov, S.V. Shmatov
FLNP	V.L. Aksenov
VBLHEP	V.D. Kekelidze
DLNP	V.A. Bednyakov, D.V. Naumov
FLNR	A.S. Denikin, V. Khudoba, Yu.Ts. Oganessian

Brief annotation and scientific rationale:
The Dubna International Advanced School of Theoretical Physics (DIAS-TH) is a scientific and educational project that has successfully been developing at the N.N. Bogolyubov Laboratory of Theoretical Physics since 2003.

The project is aimed, firstly, at training senior students, post-graduate students and young scientists on research topics of the Laboratory of Theoretical Physics, priority scientific areas of JINR research and modern areas of physics. For this purpose, schools of various levels are regularly held for students, postgraduates and young scientists from the JINR Member States and other countries, and lectures are published. In addition, review lectures on problems of modern physics are organized for JINR staff. Both researchers of JINR Laboratories and internationally recognized scientists from scientific centers of the Russian Federation and foreign scientific centers are involved in giving lectures. Lectures given by the world's leading experts at DIAS schools stimulate the emergence of new areas of research at BLTP. The project provides in-depth training in the field of modern theoretical and mathematical physics. To this end, the project participants cooperate with the JINR University Center, as well as with the JINR-based Departments at Dubna State University, Moscow Institute of Physics and Technology, Moscow State University.

Secondly, the project is aimed at dissemination of scientific knowledge, namely, informing schoolchildren and people who are not professionally engaged in science about the achievements of modern theoretical physics, in particular, about current research at BLTP. In addition, one of the objectives of the project is to encourage young scientists to cooperate with BLTP JINR.

Expected results upon completion of the project:
Within the framework of the project "Dubna International School of Modern Theoretical Physics", in educational activities it is supposed to organize regular schools on JINR priority topics and modern scientific areas for schoolchildren, students, post-graduate students and young scientists from the JINR Member States and other countries; to carry out review lectures on problems of modern physics for JINR staff; to continue/renew cooperation with scientific organizations of the Russian Federation and foreign scientific organizations, higher educational institutions in educational activities; to participate in the educational activities

at the JINR-based departments of Moscow State University, MEPhI, MIPT, Dubna State University together with the JINR University Center; to organize schools for students, graduate students and young scientists in cooperation with the Moscow Institute of Physics and Technology, Yerevan Institute of Physics, etc.; to take part in international scientific and educational projects.

In the dissemination of physical knowledge, it is planned to collabotate with other projects promoting popular science, such as Post Nauka, with foundations of the Russian Federation (Science Foundation of the Russian Federation, Federal Target Programs) and international foundations in organizing and conducting international schools for students, graduate students and young scientists.

It is also planned to support the DIAS-TH website, to provide video broadcasting of lectures, to record the video of lectures, and to support the digital archive of DIAS-TH.

Expected results of the project in the current year:
Organization at BLTP of four schools on theoretical physics for students, post-graduates and young scientists:
– DIAS school on gravity and cosmology (Chairman of the Organizing Committee D.V. Fursaev);

– School and workshop on modern mathematical physics (Chairman of the Organizing Committee S.O. Krivonos);

– Summer school on condensed matter physics (Chairman of the Organizing Committee V.A. Osipov);

– International Summer School “Advanced Methods of Modern Theoretical Physics: Integrable and Stochastic Systems” (Chairman of the Organizing Committee M. Hnatic).

Organization of one-day lectures/discussions and regular seminars for students and post-graduates and JINR researchers.

Computer processing of video records of lectures, support of digital archive of video record.

Organization of one-day lectures/discussions and regular seminars for students and post-graduates and JINR researchers.

Computer processing of video records of lectures, support of digital archive of video records.

Support of Web-site of DIAS-TH.

Collaboration

Country or International Organization	**City**	**Institute**
Armenia	Yerevan	Foundation ANSL
Czech Republic	Prague	CTU
Russia	Chernogolovka	LITP RAS
	Dolgoprudny	MIPT
	Kazan	KFU
	Moscow	ITEP
		LPI RAS
		MI RAS
		MSU
		NRU HSE
		SAI MSU
		SINP MSU
		Skoltech
	Moscow, Troitsk	INR RAS
	Novosibirsk	NSU
	Protvino	IHEP
	Saint Petersburg	SPbSU
	Saratov	SSU
Serbia	Nis	Univ.

Alphabetical List of Collaborators

Albania

Tirana

UT | University of Tirana | http://www.unitir.edu.al/, 1146

Algeria

Setif

UFAS | Ferhat Abbas University | https://www.univ-setif.dz/, 1136

Argentina

Bariloche

CAB | Bariloche Atomic Centre National Atomic Energy Commission | https://www.argentina.gob.ar/, 1149-4

Armenia

Ashtarak

IPR NAS RA | Institute for Physical Research of the National Academy of Sciences of the Republic of Armenia | http://www.ipr.sci.am/, 1138

IRE NAS RA | Institute of Radiophysics and Electronics | http://www.irphe.am, 1138

Gyumri

IGES NAS RA | Institute of Geophysics and Engineering Seismology named after A. Nazarov | http://iges.am/, 1126

Yerevan

CANDLE SRI | Center for the Advancement of Natural Discoveries using Light Emission Synchrotron Research Institute | http://candle.am/ru/, 1107

Foundation ANSL | A.I. Alikhanian National Science Laboratory Yerevan Physics Institute Foundation | http://www.yerphi.am/, 1065, 1129, 1149-2, 1137, 1138, 1066, 1081, 1083, 1087, 1088, 1077, 1119, 1107, 1117

IAPP NAS RA | Institute of Applied Problems of Physics of the National Academy of Sciences of the Republic of Armenia IAPP NAS RA | https://www.iapp.am/, 1150

IIAP NAS RA | Institute for Informatics and Automation Problems of the National Academy of Sciences of the Republic of Armenia | http://iiap.sci.am/, 1118

IMB NAS RA | Institute of Molecular Biology of the National Academy of Sciences of the Republic of Armenia | http://www.molbiol.sci.am/, 1131

Institute of Chemical Physics named after A.B. Nalbandyan of the National Academy of Sciences of the Republic of Armenia | https://ichph.am/, 1131

RAU | Russian-Armenian University | http://www.rau.am/, 1136, 1077

SRCHCH | Scientific Research Center of the Historical and Cultural Heritage of the Ministry of Education, Science, Culture and Sport of RA (SN-CO) | https://armheritage.am/, 1149-2, 1146

YSU | Yerevan State University | http://www.ysu.am/, 1136, 1137, 1087, 1150, 1147, 1077, 1119, 1107, 1131, 1139

Australia

Canberra, ACT

ANU | Australian National University | http://www.anu.edu.au/, 1137, 1131

Perth, WA

UWA | University of Western Australia | http://www.uwa.edu.au/, 1138

Sydney, NSW

Univ. | University of Sydney | http://sydney.edu.au/, 1137, 1138

Austria

Vienna

HEPHY | Institute of High Energy Physics | http://www.hephy.at/, 1083

SMI | Stefan Meyer Institute for Subatomic Physics of the Austrian Academy of Sciences | https://www.oeaw.ac.at/smi/home/, 1088

Azerbaijan

Baku

ADA | ADA University | https://www.ada.edu.az/, 1118

AMU | Azerbaijan Medical University | https://amu.edu.az/, 1107

AzTU | Azerbaijan Technical University | http://aztu.edu.az/, 1149-2

BSU | Baku State University | http://bsu.edu.az/, 1146

IGG ANAS | Institute of Geology and Geophysics of the Azerbaijan National Academy of Sciences | http://gia.az/, 1146

IP ANAS | Institute of Physics of the Azerbaijan National Academy of Sciences | http://physics.mehdiyev.me/, 1118, 1149-2, 1081, 1151, 1139

IRP ANAS | Institute of Radiation Problems of the Azerbaijan National Academy of Sciences | http://irp.science.az/, 1149-1, 1066, 1151, 1146, 1100, 1126

Khazar Univ. | Khazar University | http://www.khazar.org/, 1077

NNRC | National Nuclear Research Center | http://www.mntm.az/, 1065, 1149-1, 1088

Bangladesh

Dhaka

DU | University of Dhaka | http://www.univdhaka.edu/, 1088

Belarus

Gomel

GSTU | Pavel Sukhoi State Technical University of Gomel | http://www.gstu.by/, 1135, 1136, 1081, 1086

GSU | Francisk Skorina Gomel State University | http://gsu.by/, 1135, 1081, 1083, 1086, 1119, 1131, 1139

IRB NASB | Institute of Radiobiology of the National Academy of Sciences of Belarus | http://www.irb.basnet.by/, 1146, 1077

Khoiniki

PSRER | Polessky State Radiation-Ecological Reserve | https://zapovednik.by/, 1146

Minsk

BSTU | Belarusian State Technological University | http://www.belstu.by/, 1149-4, 1139

BSU | Belarusian State University | http://www.bsu.by/, 1065, 1144, 1146, 1107, 1131

BSUIR | Belarusian State University of Informatics and Radioelectronics | http://www.bsuir.by/, 1086, 1147

CGM NASB | Center for geophysical monitoring of National Academy of Sciences of Belarus | https://cgm.by/, 1126

IAP NASB | State Scientific Institution "Institute of Applied Physics of the National Academy of Sciences of Belarus" | http://iaph.bas-net.by/, 1081, 1086

IBCE NASB | Institute of Biophysics and Cell Engineering NAS of Belarus | http://ibp.org.by/ru/, 1077

IEB NASB | Institute of experimental botanics of the National Academy of Sciences of Belarus | https://botany.by/, 1146

IM NASB | Institute of Mathematics of the National Academy of Sciences of Belarus | http://im.bas-net.by/, 1137, 1119

INP BSU | Institute for Nuclear Problems of Belarusian State University | http://www.new.inp.bsu.by/, 1065, 1118, 1149-3, 1135, 1081, 1083, 1085, 1087, 1096, 1151, 1150, 1144, 1146, 1077, 1119, 1107, 1126, 1127, 1139

Inst. Physiology NASB | Institute of Physiology of the National Academy of Sciences of Belarus | http://physiology.by/, 1077

IP NASB | B.I. Stepanov Institute of Physics of the National Academy of Sciences of Belarus | http://ifan.basnet.by/, 1065, 1135, 1136, 1137, 1081, 1151, 1086, 1144, 1119, 1127

IPE NASB | Institute of Power Engineering of the National Academy of Sciences of Belarus | http://ipe.by, 1151, 1130

JIPNR-Sosny NASB | State Scientific Institution "Joint Institute for Power and Nuclear Research - Sosny" of the National Academy of Sciences of Belarus | http://sosny.bas-net.by/, 1065, 1118, 1149-1, 1149-2, 1135, 1107

PTI NASB | Physical Technical Institute of the National Academy of Sciences of Belarus | http://www.phti.by/, 1065

RI PCP BSU | Research Institute for Physical Chemical Problems of the Belarusian State University | http://fhp.bsu.by/, 1149-2

SOL instruments | SOL instruments LTd. | http://solinstruments.com/, 1147

SPMRC NASB | Scientific and Practical Materials Research Centre of the National Academy of Sciences of Belarus | https://physics.by/, 1137, 1146, 1147, 1077

UIIP NASB | United Institute of Informatics Problems of the National Academy of Sciences of Belarus | http://www.uiip.bas-net.by/, 1118

Belgium

Antwerp

UAntwerp | University of Antwerp | http://www.uantwerpen.be/, 1083

Brussels

ULB | Université Libre de Bruxelles | http://www.ulb.ac.be/ VUB | Vrije Universiteit Brussel | http://www.ulb.be/, 1136, 1083

VUB | Vrije Universiteit Brussel | http://www.vub.ac.be/, 1083

Ghent

Ugent | Ghent University | http://www.ugent.be/, 1083

Leuven

KU Leuven | Catholic University of Leuven | http://www.kuleuven.be/, 1083, 1100

Louvain-la-Neuve

IBA | Ion Beam Applications | http://iba-worldwide.com/, 1127

UCL | Catholic University of Louvain | http://uclouvain.be/, 1136, 1083, 1096

Mons

UMONS | University of Mons | http://web.umons.ac.be/, 1083

Botswana

Palapye

BIUST | Botswana International University of Science and Technology | http://www.biust.ac.bw/, 1146

Brazil

Campinas, SP

UNICAMP | State University at Campinas | http://www.unicamp.br/, 1088

Florianopolis, SC

UFSC | Federal University of Santa Catarina | http://ufsc.br/, 1136

Itabuna, BA

UFSB | Federal University of Southern Bahia | https://ufsb.edu.br/, 1146

Juiz de Fora, MG

UFJF | Federal University of Juiz de Fora | http://www2.ufjf.br/, 1138

Natal, RN

IIP UFRN | International Institute of Physics of the Federal University of Rio Grande do Norte | http://www.iip.ufrn.br/, 1137

Niteroi, RJ

UFF | Federal Fluminense University | http://www.uff.br/, 1136

Porto Alegre, RS

UFRGS | Federal University of Rio Grande de Sul | http://www.ufrgs.br/, 1088

Rio de Janeiro, RJ

CBPF | Brazilian Center for Physics Research | http://portal.cbpf.br/, 1083

UERJ | State University of Rio de Janeiro | http://www.uerj.br/, 1083

Santo Andre, SP

UFABC | University Federal of ABC | http://www.ufabc.edu.br/, 1138, 1088

Sao Jose dos Campos, SP

ITA | Aeronautics Institute of Technology | http://www.ita.br, 1136

Sao Paulo, SP

UEP | Unit of Professional Education Santa Case de São Paulo | http://www.santacasasp.org.br/), 1136

Unesp | São Paulo State University | http://www2.unesp.br/, 1083

USP | University of São Paulo | http://www5.usp.br/, 1137, 1138, 1088

Bulgaria*

Blagoevgrad

AUBG | American University in Bulgaria | http://www.aubg.edu/, 1087

SWU | South-West University "Neofit Rilski" | http://www.swu.bg/, 1096

Plovdiv

MUP | Medical University of Plovdiv | https://mu-plovdiv.bg/, 1107

PU | Plovdiv University "Paisii Hilendarski" | https://uni-plovdiv.bg/, 1065, 1096, 1146

UFT | University of Food Technologies-Plovdiv | http://uft-plovdiv.bg/, 1146

Sofia

IAPS | Institute for Advanced Physics Studies | http://iaps.institute/, 1088

IE BAS | Academician Emil Djakov Institute of Electronics of the Bulgarian Academy of Sciences | http://www.ie-bas.org.bg/, 1149-2, 1146, 1077

IEES BAS | Institute of Electrochemistry and Energy Systems "Academic Evgeni Budevski" of the Bulgarian Academy of Sciences | http://iees.bas.bg/, 1149-2

IMech BAS | Institute of Mechanics of the Bulgarian Academy of Sciences | http://www.imbm.bas.bg/, 1137, 1077

INRNE BAS | Institute for Nuclear Research and Nuclear Energy of the Bulgarian Academy of Sciences | http://www.inrne.bas.bg/, 1118, 1149-2, 1135, 1136, 1138, 1066, 1083, 1087, 1146, 1130, 1100, 1126, 1139

Inst. Microbiology BAS | Stephan Angeloff Institute of Microbiology of the Bulgarian Academy of Sciences | http://microbio.bas.bg/, 1087, 1077

ISSP BAS | Georgi Nadjakov Institute of Solid State Physics of the Bulgarian Academy of Sciences | http://www.issp.bas.bg/, 1149-2, 1137

NBU | New Bulgarian University | http://www.nbu.bg/, 1136

NCRRP | National Centre of Radiobiology and Radiation Protection | http://ncrrp.org/, 1077

SU | Sofia University "St. Kliment Ohridski" | http://www.uni-sofia.bg/, 1118, 1138, 1066, 1081, 1083, 1087, 1088, 1096, 1119, 1139

UCTM | University of Chemical Technology and Metallurgy | http://dl.uctm.edu/, 1149-2, 1097

* The cooperation may be limited by the conditions adopted unilaterally by the State

Canada

Corner Brook

MUN | Memorial University of Newfoundland - Grenfell Campus | http://www.grenfell.mun.ca/, 1135

Montreal

UdeM | University of Montreal | http://www.umontreal.ca/, 1137

Sherbrooke

UdeS | University of Sherbrooke | https://www.usherbrooke.ca/, 1137

Toronto

YU | York University | https://www.yorku.ca/, 1096

Vancouver

TRIUMF | Canada's Particle Accelerator Centre | http://www.triumf.ca/, 1081, 1096

UBC | University of British Columbia | http://www.ubc.ca/, 1096

CERN

Geneva

CERN | European Organization for Nuclear Research (Switzerland) | http://home.cern/), 1118, 1138, 1081, 1083, 1085, 1087, 1088, 1096, 1146, 1119, 1127

Chile

Arica

UTA | University of Tarapacá | https://www.uta.cl/, 1135

Santiago

UNAB CTEPP | Theoretical and Experimental Center for Particle Physics of Andrés Bello National University | https://www.unab.cl/en/, 1135, 1150

Valparaiso

UTFSM | Technical University Federico Santa Maria | http://www.usm.cl/, 1065, 1096

China

Beijing

"Tsinghua" | Tsinghua University | http://www.tsinghua.edu.cn/, 1065, 1137, 1083

CIAE | China Institute of Atomic Energy | http://www.ciae.ac.cn/, 1065, 1136, 1087, 1088, 1130, 1119

IHEP CAS | Institute of High Energy Physics of the Chinese Academy of Sciences | http://www.ihep.ac.cn/, 1065, 1118, 1135, 1083, 1085, 1087, 1099, 1146

ITP CAS | Institute of Theoretical Physics of the Chinese Academy of Sciences | http://english.itp.cas.cn/, 1136

PKU | Peking University | http://www.pku.edu.cn/, 1136, 1083, 1130

UCAS | University of Chinese Academy of Sciences | https://english.ucas.edu.cn/, 1065, 1138, 1130

Guangzhou

SYSU | Sun Yat-Sen University | https://www.sysu.edu.cn/sysuen, 1135, 1138

Haikou

HNU | Hainan University | http://en.hainanu.edu.cn, 1135

Hangzhou

ZJU | Zhejiang University | http://www.zju.edu.cn/english/, 1083

Harbin

HEU | Harbin Engineering University | http://www.hrbeu.edu.cn/, 1149-2

Hefei

ASIPP | Institute of Plasma Physics of the Chinese Academy of Sciences | http://english.ipp.cas.cn/, 1065, 1127

USTC | University of Science and Technology of China | http://www.ustc.edu.cn/, 1065, 1088

Hengyang

USC | University of South China | http://english.usc.edu.cn/, 1065, 1138

Huzhou

HU | Huzhou University | http://www.zjhu.edu.cn/, 1065

Jinan

SDU | Shandong University | http://en.sdu.edu.cn/, 1065

Lanzhou

IMP CAS | Institute of Modern Physics of the Chinese Academy of Sciences | http://www.imp.cas.cn/, 1065, 1129, 1135, 1136, 1066, 1130

Nanchang

NCU | Nanchang University | https://english.ncu.edu.cn/, 1138

Shanghai

Fudan | Fudan University | http://www.fudan.edu.cn/, 1065

SINAP CAS | Shanghai Institute of Applied Physics of the Chinese Academy of Sciences | http://english.sinap.cas.cn/, 1065, 1088

Univ. | Shanghai University | https://en.shu.edu.cn, 1136, 1138

Wuhan

CCNU | Central China Normal University; Institute of Particle Physics | http://physics.ccnu.edu.cn/, 1065, 1066, 1087, 1088

HBUT | Hubei University of Technology | http://www.hbut.edu.cn/, 1088

Xi'an
NINT | Northwest Institute of Nuclear Technology, 1146

Yichang
CTGU | China Three Gorges University | http://eng.ctgu.edu.cn/, 1065

Croatia

Split
Univ. | University of Split | http://www.unist.hr/, 1083, 1088

Zagreb
Oikon IAE Oikon OOO | Oikon Ltd. Institute for Applied Ecology | http://www.oikon.hr/, 1146
RBI | Rudjer Boskovic Institute | http://www.irb.hr/, 1135, 1083, 1088, 1146
UZ | University of Zagreb | http://www.unizg.hr/, 1088

Cuba

Havana
ASC | Academy of Sciences of Cuba | http://www.academiaciencias.cu/, 1139
CEA | Center for Advanced Studies of Cuba | https://www.cea.cu/, 1077
CEADEN | Centre of Technological Applications and Nuclear Development | http://www.ceaden.cu, 1088
CNEURO | Cuban Neuroscience Center | https://www.cneuro.cu/, 1077
CPHR | Center for Radiation Protection and Hygiene | https://www.cphr.edu.cu/, 1077
InSTEC | Higher Institute of Technologies and Applied Sciences | http://www.instec.cu/, 1065, 1149-2, 1066, 1086
UH | University of Havana | http://www.uh.cu/, 1146, 1077

San Jose de las Lajas
CENTIS | Center of Isotopes "CENTIS" | http://www.centis.cu/, 1077

Cyprus

Nicosia
UCY | University of Cyprus | http://www.ucy.ac.cy/, 1083

Czech Republic*

Husinec
ÚJV Řež | Nuclear Research Institute Řež | https://www.ujv.cz/en, 1149-3

Olomouc
UP | Palacky University Olomouc | http://www.upol.cz/, 1065

Ostrava
VSB-TUO | Technical University of Ostrava | http://www.vsb.cz/, 1146

Prague
BC CAS | Biology Centre of the Czech Academy of Sciences | https://www.bc.cas.cz/, 1149-2
CEI | Czech Environmental Institute | http://www.ceu.cz/, 1146
CTU | Czech Technical University in Prague | http://www.cvut.cz/, 1148, 1149-2, 1138, 1085, 1088, 1086, 1146, 1100, 1126, 1117
CU | Charles University in Prague | http://www.cuni.cz/, 1149-2, 1136, 1081, 1083, 1085, 1096, 1099, 1144, 1100
IEAP CTU | Institute of Experimental and Applied Physics of the Czech Technical University in Prague | http://www.utef.cvut.cz/ieap, 1100
IG CAS | Institute of Geology of the Czech Academy of Sciences | http://www.gli.cas.cz/, 1149-2
IP CAS | Institute of Physics of the Czech Academy of Sciences | http://www.fzu.cz/, 1149-2, 1088

Rez
CVR | Centrum Výzkumu Řež - Research Centre Řež | http://cvrez.cz/, 1146
NPI CAS | Nuclear Physics Institute of the Czech Academy of Sciences | http://www.ujf.cas.cz/, 1065, 1149-4, 1066
UJV | "ÚJV Řež, a.s. " | http://www.ujv.cz/, 1088

Denmark

Copenhagen
NBI | Niles Bohr Institute of the University of Copenhagen | http://www.nbi.ku.dk/, 1088

Egypt

Alexandria
Univ. | Alexandria University | http://www.alexu.edu.eg/, 1149-2, 1086, 1146

Aswan
Aswan University | http://www.aswu.edu.eg/, 1132

Cairo
ASRT | Academy of Scientific Research and Technology | http://www.asrt.sci.eg/, 1118, 1119, 1139
ASU | Ain Shams University | http://www.asu.edu.eg/, 1149-2
AUC | American University in Cairo | https://www.aucegypt.edu/, 1066

* The cooperation may be limited by the conditions adopted unilaterally by the State

EAEA | Egyptian Atomic Energy Authority | http://www.eaea.org.eg/, 1129, 1149-2, 1149-3, 1139
ECTP MTI | Egyptian Center for Theoretical Physics of Modern University for Technology and Information (MTI) | https://www.mti.edu.eg/ | http://www.mti.edu.eg/, 1065
FUE | Future University in Egypt | https://www.fue.edu.eg/, 1136
NRC | National Research Centre | http://www.nrc.sci.eg/, 1146, 1147

Giza

CU | Cairo University | http://cu.edu.eg/, 1118, 1149-2, 1136, 1137, 1146, 1119
NILES CU | National Institute of Laser Enhanced Sciences of Cairo University | http://niles.cu.edu.eg/, 1066

Mansoura

MU | Mansoura University | http://www.mans.edu.eg/en/, 1146

New Borg El-Arab

GEBRI | Genetic Engineering & Biotechnology Research Institute | http://srtacity.sci.eg/, 1132

Sadat City

USC | University of Sadat City | https://usc.edu.eg, 1077

Shibin El Kom

MU | Menoufia University | http://mu.menoufia.edu.eg/, 1146

Estonia

Tallinn

NICPB | National Institute of Chemical Physics and Biophysics | http://www.kbfi.ee/, 1083

Finland

Helsinki

HIP | Helsinki Institute of Physics | http://www.hip.fi/, 1135, 1083, 1088
UH | University of Helsinki | http://www.helsinki.fi/, 1137, 1083

Jyvaskyla

UJ | University of Jyväskylä | http://www.jyu.fi/, 1088, 1146

Lappeenranta

LUT | Lappeenranta-Lahti University of Technology | https://www.lut.fi/, 1083

Oulu

UO | University of Oulu; Microelectronics Instrumentation Laboratory | http://www.oulu.fi/, 1146

France

Angers

UA | University of Angers | https://www.univ-angers.fr, 1137

Annecy-le-Vieux

LAPP | Laboratory of Annecy-la-Vieux for Particles Physics of the National Institute for Nuclear Physics and Particles Physics of the National Centre for Scientific Research | http://lapp.in2p3.fr/, 1138, 1100

Bordeaux

LP2I | Laboratoire de Physique des Deux Infinis de Bordeaux | https://www.lp2ib.in2p3.fr/, 1100

Cadarache

CC CEA | Centre de Recherche du Commissariat à l'Energie Atomique et aux Energies Alternatives Cadarache | http://cadarache.cea.fr/cad, 1146

Caen

GANIL | Grand National Heavy Ion Accelerator | http://www.ganil-spiral2.eu/, 1136
LPC | Laboratoire de physique corpusculaire - Caen | https://www.lpc-caen.in2p3.fr/, 1100

Clermont-Ferrand

LPC | Corpuscular Physics Laboratory Clermont-Ferrand of the Blaise Pascal University | http://clrwww.in2p3.fr/, 1081, 1088

Gif-sur-Yvette

CEA | Commissariat à l'énergie atomique et aux énergies alternatives | https://www.cea.fr/, 1100

Grenoble

CNRS | National Centre of Scientific Research | http://www.cnrs.fr/, 1100
IBS | Institute of Structural Biology | http://www.ibs.fr/, 1149-2
ILL | Institute Laue-Langevin | http://www.ill.eu/, 1149-2, 1149-4, 1146, 1100
LPSC | Laboratore de Physique Subatomique et de Cosmologie | http://lpsc.in2p3.fr/, 1088, 1146
Neel | Institute Neel | https://neel.cnrs.fr/, 1100

Lyon

ENS Lyon | Ecole Normale Supérieure de Lyon; Physics Laboratory | http://www.ens-lyon.fr/, 1138
UL | Universite de Lyon | http://www.universite-lyon.fr/, 1083, 1088, 1100

Marseille

CPPM | Centre de Physique des Particules de Marselle | http://cpmm.in2p3.fr/, 1118, 1096, 1100
CPT | Centre of Theoretical Physics | http://www.cpt.univ-mrs.fr/, 1137, 1138

Modane
LSM | Modane Underground Laboratory | http://www-lsm.in2p3.fr/, 1100

Nantes
SUBATECH | Subatomic Physics Laboratory and Associated Technologies; UMR/EMN/IN2P3/CNRS/University of Nantes | http://www-subatech.in2p3.fr/, 1138, 1066, 1088

Orsay
CSNSM | Center for Nuclear and Mass Spectrometry- IN2P3/CNRS | http://www.csnsm.in2p3.fr/, 1100
IJCLab | Laboratory of the Physics of the two Infinities Irène Joliot-Curie | https://www.ijclab.in2p3.fr/, 1136, 1088, 1130
IPN Orsay - IN2P3/CNRS | Institute of Nuclear Physics Orsay - IN2P3/CNRS | http://ipnwww.in2p3.fr/, 1097
LAL - 11 - IN2P3/CNRS | Linear Accelerator Laboratory of the University of Paris-Sid 11 - IN2P3/CNRS | http://www.lal.in2p3.fr/, 1081
UP-S | Paris-Saclay University | https://www.universite-paris-saclay.fr/, 1100

Paris
ENS | École Normale Supérieure Paris | http://www.ens.fr/, 1135, 1138
IN2P3 | National Institute of Nuclear Physics and Physics Particles | http://www.in2p3.cnrs.fr/, 1083, 1144
LPTHE - IN2P3/CNRS | Laboratory of Theoretical Physics and High Energy of the Pierre et Marie Curie - IN2P3/CNRS | http://lpthe.jussieu.fr/, 1151
LUTH | Laboratory Universe and Theories, Observatory of Paris | http://www.luth.obspm.fr/, 1138
UPMC 6 | Pierre et Marie Curie University Henri Poincaré Institute Paris 6 | https://www.sorbonne-universite.fr/, 1135

Saclay
IRFU | Institute of Research into the Fundamental Laws of the Universe | http://irfu.cea.fr/, 1135, 1083, 1088, 1097, 1119
LLB | Léon Brillouin Laboratory CEA-CNRS | http://www-llb.cea.fr/, 1149-2, 1146

Strasbourg
CRN - IN2P3/CNRS | Centre of Nuclear Research - IN2P3/CNRS | http://ireswww.in2p3.fr/, 1099
IPHC - IN2P3/CNRS | Hubert Curien Multidisciplinary Institute of the University of Strasburg - IN2P3/CNRS | http://www.iphc.cnrs.fr/, 1083, 1088, 1146, 1130

Tours
Univ.| University of Tours | http://www.univ-tours.fr/, 1138

Villeurbanne
CC IN2P3 | IN2P3 Computing Center | https://cc.in2p3.fr/, 1088

Georgia

Tbilisi
AIP TSU | Elevter Andronikashvili Institute of Physics of the Ivane Javakhishvili Tbilisi State University | http://www.aiphysics.tsu.ge/, 1146
GRENA | Georgian Research and Educational Networking Association | http://www.grena.ge/, 1118
GTU | Georgia Technical University | http://gtu.ge/, 1065, 1118, 1083, 1144, 1119
HEPI-TSU | High Energy Physics Institute of Ivane Javakhishvili Tbilisi State University | http://www.hepi.tsu.ge/, 1081, 1083, 1144, 1127
TSU | Ivane Javakhishvili Tbilisi State University | http://www.tsu.ge/, 1118, 1146, 1119
UG | University of Georgia | http://www.ug.edu.ge/, 1118, 1144, 1119

Germany*

Aachen
RWTH | Rheinisch-Westfaelische Technische Aachen University | http://www.rwth-aachen.de/, 1083, 1099

Berlin
HZB | Helmholtz Berlin Centre for Materials and Energy of the Helmholtz Association | http://www.helmholtz-berlin.de/, 1149-4, 1136

Bielefeld
Univ. | Bielefeld University | http://www.uni-bielefeld.de/, 1136

Bonn
UniBonn | University of Bonn | http://www.uni-bonn.de/, 1136, 1138, 1085, 1088, 1096, 1126

Cologne
Univ. | University of Cologne | http://www.uni-koeln.de/, 1136

Darmstadt
GSI | Helmholtz-Centre for the Study of Heavy Ions of the Helmholtz Association | http://www.gsi.de/, 1065, 1136, 1085, 1088, 1130

* The cooperation may be limited by the conditions adopted unilaterally by the State

TU Darmstadt | Technical University Darmstadt | http://www.tu-darmstadt.de/, 1149-2, 1136, 1088

Dresden

HZDR | Helmholtz-Zentrum Dresden-Rossendorf of the Helmholtz Association | http://www.hzdr.de/, 1136

TU Dresden | Technical University of Dresden | http://tu-dresden.de/, 1136, 1144

Dusseldorf

HHU | Heinrich Heine University Dusseldorf | http://www.uni-duesseldorf.de/, 1135

Erlangen

FAU | Friedrich Alexander University of Erlangen-Nuremberg | http://www.fau.eu/, 1136

Frankfurt/Main

FIAS | Frankfurt Institute for Advanced Studies | http://fias.institute.de/, 1088

Univ. | Goethe University of Frankfurt on Main | http://www.uni-frankfurt.de/, 1136, 1088

Freiberg

TUBAF | Technical University Bergakademie of Freiberg | http://tu-freiberg.de/, 1085

Giessen

JLU | Justus Liebig University Giessen | http://www.uni-giessen.de/, 1136

Hamburg

DESY | Deutsches Elektronen-Synchrotron DESY of the Helmholtz Association | http://www.desy.de/), 1083, 1127

Univ. | University of Hamburg | http://www.uni-hamburg.de/, 1135, 1136, 1083, 1099

Hannover

LUH | Leibniz University of Hannover | http://www.uni-hannover.de/, 1138

Heidelberg

MPIK | Max Planck Institute for Nuclear Physics | http://www.mpi-hd.mpg.de/, 1100

Univ. | University of Heidelberg | http://www.uni-heidelberg.de/, 1088

Julich

FZJ | Research Centre Jülich of the Helmholtz Association | http://www.fz-juelich.de/, 1065, 1149-4

Karlsruhe

KIT | Karlsruhe Institute of Technology | http://www.kit.edu/, 1135, 1083

Leipzig

UoC | University of Leipzig | http://www.uni-leipzig.de/, 1136, 1137, 1138

Mainz

JGU | Johannes Gutenberg University of Mainz | http://www.uni-mainz.de/, 1136, 1096, 1146, 1126

Munich

LMU | Ludwig-Maximilians University of Munich | http://www.uni-muenchen.de/, 1138

TUM | Technical University of Munich | https://www.tum.de/, 1085, 1088, 1146, 1100

Munster

WWU | Westfalische Wilhelms-Universiry (University of Münster) | http://www.uni-muenster.de/, 1088

Oldenburg

IPO | Institute of Physics of the Cari von Ossietzky University of Oldenburg | http://www.uol.de/en/physics/, 1138

Potsdam

AEI | Max Planck Institute for Gravitational Physics Albert Einstein Institute | http://www.aei.mpg.de/, 1138

Regensburg

UR | University of Regensburg | http://www.uni-regensburg.de/, 1135

Rostock

Univ. | University of Rostock | http://www.uni-rostock.de/, 1136

Siegen

Univ. | University of Siegen | http://www.uni-siegen.de/, 1136

Tubingen

Univ. | Eberhard Karls University of Tübingen | http://uni-tuebingen.de/, 1135, 1088, 1100

Worms

ZTT | Center for Technology Transfer and Telecommunications of the University of Worms | https://www.hs-worms.de/, 1088

Wuppertal

UW | University of Wuppertal | http://www.uni-wuppertal.de/, 1137

Zeuthen

DESY | Deutsches Elektronen-Synchrotron DESY of the Helmholtz Association (Zeuthen) | http://www.desy.de/), 1135, 1081

Greece

Athens

INP NCSR "Demokritos" | Institute of Nuclear and Particle Physics of the National Centre for Scientific Research "Demokritos" | http://www.inp.demokritos.gr/, 1136, 1083

NTU | National Technical University of Athens | http://www.ntua.gr/, 1083

UoA | National and Kapodistrian University of Athens | http://www.uoa.gr/, 1138, 1083, 1088

Ioannina

UI | University of Ioannina | http://www.uoi.gr/, 1083

Rethymno

UoC | University of Crete | https://en.uoc.gr, 1135

Hungary

Budapest

ELTE | Eötvös Loránd University | http://www.elte.hu/, 1135

HUN-REN | HUN-REN Center for Energy Research | https://www.ek.hun-ren.hu, 1149-2

RKK OU | Rejto Sándor Faculty of Light Industry and Environmental Engineering of the Obuda University | http://rkk.uni-obuda.hu/, 1146

Wigner RCP | Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics | http://wigner.mta.hu/, 1149-2, 1149-3, 1149-4, 1136, 1083, 1088

Debrecen

Atomki | Institute of Nuclear Research of the Hungarian Academy of Science | http://www.atomki.hu/, 1136, 1083

UD | University of Debrecen | http://www.unideb.hu/, 1083

IAEA

Vienna

IAEA | International Atomic Energy Agency | http://www.iaea.org/, 1149-4, 1146

India

Aizawl

MZU | Mizoram University | https://mzu.edu.in, 1146, 1147

Aligarh

AMU | Aligarh Muslim University | http://www.amu.ac.in/, 1088

Bhubaneswar

IOP Institute of Physics, Bhubaneswar | http://www.iopb.res.in/, 1088

Chandigarh

PU | Panjab University | http://puchd.ac.in/, 1136, 1066, 1083, 1088

Ettimadai

Amrita Univ. | Amrita Vishwa Vidyapeetham (Amrita University) | https://www.amrita.edu/, 1135

Guwahati

GU| Gauhati University | https://gauhati.ac.in/, 1088

Indore

IIT Indore | Indian Institute of Technology Indore | https://www.iiti.ac.in/, 1088

Jaipur

Univ. | University of Rajasthan | http://www.uniraj.ac.in/, 1087, 1088

Jammu

Univ. | University of Jammu | http://www.jammuuniversity.ac.in/, 1066, 1088

Jatani

NISER | National Institute of Science Education and Research of the Department of Atomic Energy | http://www.niser.ac.in/, 1083, 1088

Kasaragod

CUK | Central University of Kerala | http://cukerala.ac.in/, 1136

Kolkata

BNC | S.N. Bose National Centre for Basic Sciences | http://www.bose.res.in/, 1088

IACS | Indian Association for the Cultivation of Science | http://www.iacs.res.in/, 1135, 1137

SINP | Saha Institute of Nuclear Physics | http://www.saha.ac.in/, 1083, 1088

UC | University of Calcutta | http://www.caluniv.ac.in/, 1088, 1086

VECC | Variable Energy Cyclotron Centre of the Department of Atomic Energy | https://www.vecc.gov.in/, 1088, 1130

Manipal

MU | Manipal University | http://www.manipal.edu/, 1130

Mumbai

BARC | Bhabha Atomic Research Centre of the Department of Atomic Energy | http://www.barc.gov.in/, 1083, 1087, 1088

IIT Bombay | Indian Institute of Technology Bombay | https://www.iitb.ac.in/, 1088

TIFR | Tata Institute of Fundamental Research | http://www.tifr.res.in/, 1083

New Delhi

IUAC | Inter-University Accelerator Center | http://www.iuac.res.in/, 1136

Patna

NIT Patna | National Institute of Technology Patna | http://www.nitp.ac.in/, 1149-2

Roorkee

IIT Roorkee | Indian Institute of Technology Roorkee | https://www.iitr.ac.in/, 1130

Sunabeda

CUO | Central University of Odisha | https://cuo.ac.in/, 1135

Tirupati
IISER | Indian Institute of Science Education and Research, Tirupati | https://www.iisertirupati.ac.in/, 1066

Varanasi
BHU | Banaras Hindu University | http://www.bhu.ac.in/, 1146

Indonesia

Jakarta
LIPI | Indonesian Institute of Sciences | http://lipi.go.id/, 1088

Iran

Isfahan
Univ. | University of Isfahan | https://ui.ac.ir, 1138

Tehran
FU | Farhangian University | https://cfu.ac.ir/en/, 1138
IPM | Institute for Studies in Theoretical Physics and Mathematics of the Institute for Research Fundamental Sciences | http://www.ipm.ac.ir/, 1135, 1138, 1083
Univ. | University of Tehran | https://ut.ac.ir/en, 1135

Zanjan
IASBS | Institute for Advanced Studies in Basic Sciences | http://iasbs.ac.ir/, 1136, 1137

Ireland

Dublin
DIAS | Dublin Institute for Advanced Studies | http://www.dias.ie/, 1138
UCD | University College Dublin | https://www.ucd.ie/, 1083

Israel

Jerusalem
HUJI | Hebrew University of Jerusaliem | http://www.huji.ac.il/, 1138

Rehovot
WIS | Weizmann Institute of Science | http://www.weizmann.ac.il/, 1081

Tel Aviv
TAU | Tel Aviv University | http://www.tau.ac.il/, 1138, 1085, 1086

Italy

Alessandria
DiSIT UPO | Department of Science and Technological Innovation of the University of Eastern Piedmont Amedeo Avogadro | https://www.disit.uniupo.it/, 1088

Assergi
INFN LNGS | Laboratory Nazionali del Gran Sasso of the National Institute for Nuclear Physics | https://www.lngs.infn.it), 1100

Bari
DIF | Interuniversity Department of Physics | https://www.uniba.it/, 1088
INFN | National Institute for Nuclear Physics, Section of Bari | http://www.ba.infn.it/, 1083, 1088
Poliba | Polytechnic University of Bari | http://www.en.poliba.it/, 1088

Bologna
INFN | National Institute for Nuclear Physics, Section of Bologna | http://www.bo.infn.it/, 1083, 1088
UniBo | University of Bologna | http://www.unibo.it/, 1088

Brescia
UNIBS | University of Brescia | https://en.unibs.it/, 1088

Cagliari
INFN | National Institute for Nuclear Physics, Section of Cagliari | http://www.ca.infn.it/, 1088
UniCa | University of Cagliari | http://www.unica.it/, 1088

Catania
INFN | National Institute for Nuclear Physics, Section of Catania | https://www.ct.infn.it/it/, 1088
INFN LNS | National Institute for Nuclear Physics, National Laboratory of the South | http://www.lns.infn.it/, 1136, 1083
UniCT | University of Catania | http://www.unict.it/, 1088

Erice
EMFCSC | Ettore Majorana Foundation and Centre for Scientific Culture | http://www.ccsem.infn.it/, 1088

Ferrara
INFN | National Institute for Nuclear Physics, Section of Ferrara | http://www.fe.infn.it/, 1096

Florence
INFN | National Institute for Nuclear Physics, Section of Florence | http://www.fi.infn.it/, 1083, 1096

Foggia
Unifg | University of Foggia | https://www.unifg.it/, 1088

Frascati
INFN LNF | National Institute for Nuclear Physics, National Laboratory of Frascati | http://www.lnf.infn.it/, 1138, 1083, 1088, 1096, 1151

Genoa
INFN | National Institute for Nuclear Physics, Section of Genoa | http://www.ge.infn.it/, 1083, 1096, 1119

Legnaro
INFN LNL | National Institute for Nuclear Physics, Legnaro National Laboratories | http://www.lnl.infn.it/, 1088

Messina
UniMe | University of Messina | http://www.unime.it/, 1149-2, 1136, 1088

Milan
INFN | National Institute for Nuclear Physics, Section of Milan | http://www.mi.infn.it/, 1083
UNIMI | University of Milan | http://www.unimi.it/, 1099

Naples
INFN | National Institute for Nuclear Physics, Section of Naples | http://www.na.infn.it/, 1135, 1136, 1083, 1096
Unina II | University of Naples Federico II | http://www.unina.it/, 1130

Padua
INFN | National Institute for Nuclear Physics, Section of Padua | http://www.pd.infn.it/, 1083, 1088
UniPd | University of Padua | http://www.unipd.it/, 1138, 1088

Pavia
INFN | National Institute for Nuclear Physics, Section of Pavia | http://www.pv.infn.it/, 1083
UniPv | University of Pavia | http://www.unipv.it/, 1088

Perugia
INFN | National Institute for Nuclear Physics, Section of Perugia | http://www.pg.infn.it/, 1083, 1096

Pisa
INFN | National Institute for Nuclear Physics, Section of Pisa | http://www.pi.infn.it/, 1135, 1081, 1083, 1096, 1151, 1127

Rome
CREF | Enrico Fermi Center for Study and Research | https://www.cref.it/, 1088
ENEA | Italian National Agency for New Technologies, Energy and Sustainable Economic Development | http://www.enea.it/, 1146
INFN | National Institute for Nuclear Physics, Section of Rome | http://www.roma1.infn.it/, 1083, 1088, 1096
Univ. "La Sapienza" | University of Roma "La Sapienza" | http://www.uniroma1.it/, 1088
Univ. "Tor Vergata" | University of Rome "Tor Vergata" | http://web.uniroma2.it/, 1096

Salerno
INFN | National Institute for Nuclear Physics, Section of Salerno | http://www.sa.infn.it/, 1088, 1099

Trento
UniTn | University of Trento | http://www.unitn.it/, 1085

Trieste
INFN | National Institute for Nuclear Physics, Section of Trieste | http://www.ts.infn.it/, 1083, 1085, 1088
SISSA/ISAS | International School for Advanced Studies | http://www.sissa.it/, 1138
UNITR | University of Trieste | http://www.univ.trieste.it/, 1088

Turin
INFN | National Institute for Nuclear Physics, Section of Turin | http://www.to.infn.it/, 1083, 1085, 1088, 1096
Polito | Polytechnic University of Turin | http://www.polito.it/, 1088
UniTo | University of Turin | http://www.unito.it/, 1136, 1138, 1088

Vercelli
UPO | Amedeo Avogadro Piemonte Eastern University | http://www.unipmn.it/, 1088

Viterbo
UNITUS | University of Tuscia | http://www3.unitus.it/, 1077

Japan

Fukuoka
Kyushu Univ. | Kyushu University | http://www.kyushu-u.ac.jp/, 1099, 1144

Hiroshima
Hiroshima Univ. | Hiroshima University | http://www.hiroshima-u.ac.jp/, 1088, 1097

Kobe
Kobe Univ. | Kobe University | http://www.kobe-u.ac.jp/, 1136

Kyoto
KSU | Kyoto Sangyo University | http://www.kyoto-su.ac.jp/, 1146

Minato
Keio Univ. | Keio University - Minato | http://www.keio.ac.jp/, 1149-2

Morioka
Iwate Univ. | Iwate University | http://www.iwate-u.ac.jp/, 1136

Nagasaki
NiAS | Nagasaki Institute of Applied Sciences | https://nias.ac.jp/index.html/, 1088

Nagoya
Nagoya Univ. | Nagoya University | http://www.nagoya-u.ac.jp/, 1099

Nara
NWU | Nara Women's University | http://www.nara-wu.ac.jp/nwu/en/index.html/, 1088

Okinawa
OIST | Okinawa Institute of Science and Technology | https://www.oist.jp, 1138

Osaka
Osaka Univ. | Osaka University | http://www.osaka-u.ac.jp/, 1136, 1144, 1100
RCNP | Research Center for Nuclear Physics of Osaka University | http://www.rcnp.osaka-u.ac.jp/, 1136, 1088

Saga
Saga Univ. | Saga University | http://www.saga-u.ac.jp/, 1088

Tokai
JAEA | Japan Atomic Energy Agency | http://www.jaea.go.jp/, 1088, 1151

Tokyo
Keio Univ. | Keio University - Tokyo | http://www.keio.ac.jp/, 1138
Nihon Univ. | Nihon University | http://www.nihon-u.ac.jp/, 1065
Toho Univ. | Toho University | http://www.toho-u.ac.jp/, 1099
UT | University of Tokyo; Centre for Nuclear Study CNS; Institute for Cosmic Ray Research; Institute Centre for Elementary Particle Physics ICEPP | http://www.u-tokyo.ac.jp/, 1138, 1088, 1151
Waseda Univ. | Waseda University | http://www.waseda.jp/, 1149-2

Tsukuba
KEK | High Energy Accelerator Research Organization | http://legacy.kek.jp/, 1144, 1146
Univ. | University of Tsukuba | http://www.tsukuba.ac.jp/, 1088

Tsuruga
WERC | Wakasa Wan Energy Research Centre | https://www.werc.or.jp/, 1100

Utsunomiya
UU | Utsunomiya University | http://www.utsunomiya-u.ac.jp/, 1137

Wako
RIKEN | RIKEN Wako Institute; Institute of Physical and Chemical Research | http://www.riken.jp/, 1088, 1097

Yamagata
Yamagata Univ. | Yamagata University | http://www.yamagata-u.ac.jp/, 1085

Kazakhstan

Almaty
IETP KazNU | Institute of Experimental and Theoretical Physics of the Al-Farabi Kazakh National University | http://www.ietp.kz/, 1119
INP | Institute of Nuclear Physics of Ministry of Energy of the Republic of Kazakhstan | http://www.inp.kz/, 1065, 1148, 1118, 1149-2, 1149-3, 1136, 1066, 1096, 1144, 1146, 1130, 1100, 1147, 1119
KazNU | Al-Farabi Kazakh National University | http://www.kaznu.kz/, 1149-2, 1136, 1138, 1130, 1139
PhysTI | Physics - Techical Institute | http://www.sci.kz/, 1065

Astana
BA INP | Branch of the Astana Institute of Nuclear Physics of Ministry of Energy of the Republic of Kazakhstan | http://www.inp.kz/, 1118, 1129, 1131
ENU | L.N. Gumilyov Eurasian National University | http://www.enu.kz/, 1146, 1130, 1119, 1131, 1139
NU | Nazarbayev University | http://nu.edu.kz/, 1131

Kyzylorda
KazSRIRG | Kazakh Scientific Research Institute of Rice Growing named after I. Zhakhayev, 1146
KU | Korkyt Ata Kyzylorda University | https://korkyt.edu.kz/, 1146

Ust-Kamenogorsk
EKSU | Sarsen Amanzholov East Kazakhstan State University | http://www.vkgu.kz/, 1139

Kyrgyzstan

Bishkek
BSU | Bishkek State University named after K. Karasaev | https://bhu.kg/en/, 1138

Latvia

Riga
ISSP UL | Institute of Solid State Physics of the University of Latvia | http://www.cfi.lu.lv/, 1149-2

Lithuania

Kaunas
VMU | Vytautas Magnus University | http://www.vdu.lt/, 1136

Vilnius
VU | Vilnius University | http://www.vu.lt/, 1083

Malta

Msida

UM | University of Malta | https://www.um.edu.mt/, 1088

Mexico

Culiacan

UAS | Autonomous University of Sinaloa | https://www.uas.edu.mx/, 1088

Mexico City

Cinvestav | Centre for Advanced Investigations and Studies of the National Polytechnical Institute | http://www.cinvestav.mx/, 1083, 1088

INCan | National Cancer Institute | http://www.incan.salud.gob.mx, 1107

UNAM | National Autonomous University of Mexico (Mexico City) | http://www.unam.mx/, 1065, 1118, 1136, 1066, 1088, 1119

Puebla

BUAP | Autonomous University of Puebla | http://www.buap.mx/, 1065, 1083, 1088

San Luis Potosi

UASLP | Autonomous University of San Luis Potosi | http://www.uaslp.mx/, 1096

Moldova

Chisinau

IAP | Institute of Applied Physics of the Ministry of Education, Culture and Research of the Republic of Moldova | http://www.phys.asm.md/, 1065

IChem | Institute of Chemistry | http://ichem.md/, 1146

IMB ASM | Institute of Microbiology and Biotechnology of the Academy of Sciences of Moldova | http://www.imb.asm.md/, 1146, 1132

MSU | Moldova State University | http://usm.md/, 1107, 1127

Mongolia

Ulaanbaatar

CGL | Central Geological Laboratory | http://cengeolab.com/, 1146, 1130

IMDT MAS | Institute of Mathematics and Digital Technology of the Mongolian Academy | https://imdt.ac.mn/, 1118, 1119

IPT MAS | Institute of Physics and Technology of the Mongolian Academy of Sciences | https://ipt.ac.mn, 1065, 1149-1, 1149-2, 1137, 1087

MNUE | Mongolian National University of Education | http://mnue.mn/, 1066, 1139

MUST | Mongolian University of Science and Technology | http://www.must.edu.mn/, 1119

NRC NUM | Nuclear Research Center of the National University of Mongolia | http://nrc.num.edu.mn/, 1146

NUM | National University of Mongolia | http://www.num.edu.mn/, 1077, 1139

Montenegro

Podgorica

Univ. | University of Montenegro | http://www.ucg.ac.me/, 1083

Netherlands

Amsterdam

AUAS | Amsterdam University of Applied Sciences | https://www.amsterdamuas.com/, 1088

NIKHEF | National Institute for Subatomic Physics | http://www.nikhef.nl/, 1081, 1088

Eindhoven

TU/e | Eindhoven University of Technology | https://www.tue.nl/en/, 1083

Utrecht

UU | Utrecht University | http://www.uu.nl/, 1088

New Zealand

Auckland

Univ. | University of Auckland | http://www.auckland.ac.nz/, 1083

Christchurch

UC | University of Canterbury | http://www.canterbury.ac.nz/, 1083

North Macedonia

Skopje

UKiM | Ss. Cyril and Methodius University in Skopje | http://www.ukim.edu.mk/, 1146

Norway

Bergen

HVL | Western Norway University of Applied Sciences | https://www.hvl.no/en/, 1088

UiB | University of Bergen | http://www.uib.no/, 1136, 1088

Oslo

UiO | University of Oslo | http://www.uio.no/, 1136, 1088

Tonsberg

USN | University College of Southeast Norway | https://www.usn.no/english/, 1088

Pakistan

Islamabad

COMSATS | COMSATS University Islamabad | https://www.comsats.edu.pk/, 1088

PINSTECH | Pakistan Institute of Nuclear Science and Technology, 1088
QAU | Quaid-i-Azam University | http://www.qau.edu.pk/, 1083

Peru

Lima

PUCP | Pontifical Catholic University of Peru | https://www.pucp.edu.pe/, 1088

Poland*

Bialystok

UwB | University of Bialystok | http://www.uwb.edu.pl/, 1149-2, 1138

Gdansk

GUT | Gdańsk University of Technology | http://pg.edu.pl/, 1146

Katowice

US | University of Silesia in Katowice | http://www.us.edu.pl/, 1135

Krakow

AGH | University of Science and Technology | http://www.agh.edu.pl/, 1083, 1088
AGH-UST | AGH University of Science and Technology | http://www.agh.edu.pl/, 1083
INP PAS | Henryk Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences | http://www.ifj.edu.pl/, 1135, 1136, 1088, 1146
JU | Jagiellonian University in Kraków | http://www.uj.edu.pl/, 1138

Lodz

UL | University of Lódź | http://www.uni.lodz.pl/, 1146

Lublin

UMCS | Marie Curie-Sklodowska University in Lublin | http://www.umcs.pl/, 1136, 1146

Opole

UO | University of Opole | http://www.uni.opole.pl/, 1146

Otwock (Swierk)

NCBJ | National Centre for Nuclear Research | http://www.ncbj.gov.pl/, 1135, 1136, 1083, 1085, 1088, 1146

Poznan

AMU | Adam Mickiewicz University in Poznań | http://www.amu.edu.pl/, 1146

Warsaw

IEP WU | Institute of Experimental Physics of Warsaw University | http://en.ifd.fuw.edu.pl/, 1085
UW | University of Warsaw | http://www.uw.edu.pl/, 1136, 1083
WUT | Warsaw University of Technology | http://www.pw.edu.pl/, 1085, 1088

Wroclaw

UW | University of Wroclaw | http://www.uni.wroc.pl/, 1138, 1146
WUT | Wroclaw University of Science and Technology | http://www.pwr.edu.pl/, 1137

Portugal

Aveiro

UA | University of Aveiro | http://www.ua.pt/, 1138, 1085

Coimbra

UC | University of Coimbra | http://www.uc.pt/, 1135

Lisbon

LIP | Laboratory of Instrumentation and Experimental Particle Physics | http://www.lip.pt/, 1085

Republic of Korea

Cheongju

CBNU | Chungbuk National University | http://www.cbnu.ac.kr/, 1088

Daejeon

IBS | Institute for Basic Science | http://www.ibs.re.kr, 1136, 1130
KAERI | Korea Atomic Energy Research Institute | http://www.kaeri.re.kr/, 1146
KIST | Korea Institute of Science and Technology Information | https://eng.kist.re.kr/kist_eng/main/, 1083, 1088

Gangneung

GWNU | Gangneung-Wonju National University | http://www.gwnu.ac.kr/, 1088

Gwangju

CNU | Chonnam National University | http://www.jnu.ac.kr/, 1083

Incheon

Inha | Inha University | https://eng.inha.ac.kr/, 1088

Jeonju

JBNU | JeonBuk National University | http://www.cbnu.edu/eng/, 1136, 1088

Pohang

PAL | Pohang Accelerator Laboratory | http://pal.postech.ac.kr/, 1146

Pusan

PNU | Pusan National University | http://www.pusan.ac.kr/, 1088

* The cooperation may be limited by the conditions adopted unilaterally by the State

Seoul

Dawonsys "Dawonsys o., Ltd" | Company "Dawonsys o., Ltd" | http://www.dawonsys.com/, 1146
Konkuk Univ. | Konkuk University | http://www.konkuk.ac.kr/, 1088
KU | Korea University | http://www.korea.edu/, 1083
SJU | University of Sejong | https://eng.sejong.ac.kr/index.do/, 1083, 1088
SKKU | Sungkyunkwan University | http://www.skku.edu/, 1083
SNU | Seoul National University | http://www.en.snu.ac.kr/, 1136, 1083
Yonsei Univ. | Yonsei University | https://www.yonsei.ac.kr/, 1083, 1088

Romania*

Baia Mare

TUCN-NUCBM | Technical University of Cluj-Napoca - North University Center of Baia Mare | http://www.utcluj.ro/, 1149-2, 1146

Bucharest

IFIN-HH | Horia Hulubei National Institute of Physics and Nuclear Engineering | http://www.ifin.ro/, 1149-1, 1149-3, 1136, 1087, 1088, 1096, 1146, 1130
IGR | Geological Institute of Romania | https://igr.ro/, 1146
INCDIE ICPE-CA | National Institute of Research and Development in Electrical Engineering ICPE-CA | http://www.icpe-ca.ro/, 1149-2, 1149-4, 1097, 1146
UB | University of Bucharest | http://www.unibuc.ro/, 1149-2, 1136, 1137, 1087, 1146
UPB | University Politehnica of Bucharest | http://www.upb.ro/, 1088

Cluj-Napoca

INCDTIM | National Institute for Research and Development of Isotopic and Molecular Technologies | http://www.itim-cj.ro/, 1149-2, 1149-3, 1146
RA BC-N | Romanian Academy Cluj-Napoca Branch | http://www.acad-cluj.ro/, 1149-2
UBB | Babeş-Bolyai University | http://www.ubbcluj.ro/, 1149-2, 1149-3, 1136
UTC-N | Technical University of Cluj-Napoca | http://utcluj.ro/, 1149-3

Constanta

MINAC | Museum of National History and Archeology in Constanța | https://www.minac.ro/, 1149-2
UOC | "Ovidius" University of Constanta | http://www.univ-ovidius.ro/, 1146

Craiova

UC | University of Craiova | https://www.ucv.ro/en/, 1149-2

Galati

DJUG | "Dunarea de Jos" University of Galaţi | http://www.ugal.ro/, 1146

Iasi

IULS | "Ion Ionescu de la Brad" Iași University of Life Sciences | https://iuls.ro/, 1149-2
NIRDTP | National Institute of Research and Development for Technical Physics | http://www.phys-iasi.ro/, 1149-2, 1146
TUIASI | "Gheorghe Asachi" Technical University of Iaşi | http://www.tuiasi.ro/, 1149-2
UAI | University "Apollonia" of Iaşi | http://univapollonia.ro/, 1149-2
UAIC | Alexandru Ioan Cuza University of Iaşi | http://www.uaic.ro/, 1149-2, 1146

Magurele

ISS | Institute of Space Science | https://www2.spacescience.ro/, 1087, 1088, 1099, 1146
NIMP | National Institute of Materials Physics | http://www.infim.ro/, 1149-2

Oradea

UO | University of Oradea | http://www.uoradea.ro/, 1146

Pitesti

ICN | Institute for Nuclear Research - Piteşti | http://www.nuclear.ro/, 1146
UPIT | University of Piteşti | http://www.upit.ro/, 1149-2

Ramnicu Valcea

ICSI | National Research and Development Institute for Cryogenics and Isotopic Technologies | http://www.icsi.ro/, 1146

Sibiu

ULBS | Lucian Blaga University of Sibiu | https://www.ulbsibiu.ro/ro/, 1146

Targoviste

VUT | "VALAHIA" University of Târgovişte | http://www.valahia.ro/, 1149-2, 1149-3, 1146

Timisoara

ICT | "Coriolan Drăgulescu" Institute of Chemistry | http://acad-icht.tm.edu.ro/, 1149-2

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ISIM | National R&D Institute for Welding and Materials Testing - ISIM Timisoara | http://www.isim.ro/, 1149-2

UVT | West University of Timişoara | http://www.uvt.ro/, 1149-2, 1137, 1146

Tulcea

DDNI | "Danube Delta" National Institute for Research and Development | http://www.ddni.ro/, 1149-2

Russia

Arkhangelsk

NArFU | Northern (Arctic) Federal University named after M.B Lomonosov | http://narfu.ru/, 1146, 1119, 1126, 1139

NSMU | Northern State Medical University | http://www.nsmu.ru/, 1139

Belgorod

BelSU | Belgorod National Research State University | http://www.bsu.edu.ru/, 1065, 1087, 1097, 1150, 1139

Erendi Vakuum | LLC "Erendi Vakuum", 1150

Borok

IBIW RAS | Federal State Budgetary Institution of Science "I.D. Papanin Institute for the Biology of Inland Waters of the Russian Academy of Sciences" | http://ibiw.ru/, 1146

IPE RAS | Federal State Budgetary Institution of Science "Schmidt Institute of the Physics of the Earth of the Russian Academy of Sciences" | http://www.ifz.ru/, 1077

Chelyabinsk

SUSU | South Ural State University | https://www.susu.ru/ru/, 1149-2, 1077, 1119

Chernogolovka

ISMAN RAS | Federal State Budgetary Institution of Science "Institute of Structural Macrokinetics and Materials Science of the Russian Academy of Sciences" | http://www.ism.ac.ru/, 1087

ISSP RAS | Federal State Budgetary Institution of Science "Institute of Solid State Physics of the Russian Academy of Sciences" | http://issp.ac.ru/, 1149-2, 1086, 1131

LITP RAS | Federal State Budgetary Institution of Science "L.D. Landau Institute for Theoretical Physics of the Russian Academy of Sciences" | http://www.itp.ac.ru/, 1135, 1138, 1117

SCC IPCP RAS | Federal State Budgetary Institution of Science "Supercomputer Centre of the Institute of Problems of Chemical Physics of the Russian Academy of Sciences" | http://www.icp.ac.ru/, 1118

Dimitrovgrad

SSC RIAR | Joint Stock Company “State Scientific Centre Research Institute of Atomic Reactors” Rosatom State Nuclear Energy Corporation | http://www.niiar.ru/, 1130

Dolgoprudny

MIPT | Moscow Institute of Physics and Technology State University | http://mipt.ru/, 1065, 1149-2, 1149-3, 1136, 1138, 1066, 1146, 1132, 1107, 1131, 1139, 1117

Donetsk

DonIPE | Donetsk Institute for Physics and Engineering named after A.A. Galkin | http://www.donfti.ru/, 1146

Dubna

Diamant | Diamant LLC | http://diamant-sk.ru/, 1146

Dubna State Univ. | Dubna State University | http://www.uni-dubna.ru/, 1118, 1149-2, 1149-3, 1135, 1146, 1100, 1119, 1139

IAS "Omega" | Institute for Advanced Studies "Omega" | http://dubna-oez.ru/, 1150, 1107

IPTP | Institute of Physical and Technical Problems JSC | https://iftp.ru/, 1150, 1130, 1107

MSU Branch | Federal State Budget Educational Institution of Higher Education M.V. Lomonosov Moscow State University MSU Branch in Dubna | https://msu-dubna.ru, 1119, 1107

SCC "Dubna" | "Dubna" Satellite Communication Centre, Branch of the Federal State Unitary Enterprise "Russian Satellite Communication Company" | http://www.rscc.ru/, 1118

SEZ "Dubna" | Special Economic Zone of Technical-Innovative type "Dubna" | http://oezdubna.ru/, 1118

Elykaevo

Sirius. Kuzbass | Regional center for search, supporting and developing abilities and talents among children and youth "Sirius. Kuzbass" | https://kemsirius.ru/, 1146

Fryazino

ISTOK | Joint Stock Company "Research and Production Corporation "ISTOK" named after Shokin" | http://www.istokmw.ru/, 1065

Gatchina

NRC KI PNPI | Federal State Budgetary Institution "B.P. Konstantinov Petersburg Nuclear Physics Institute" of the National Research Centre "Kurchatov Institute" | https://www.pnpi.nrcki.ru/, 1065, 1118, 1149-2, 1149-3, 1149-4, 1136, 1083, 1085, 1088, 1150, 1146, 1100, 1119

Grozny

CheSU | Kadyrov Chechen State University | https://chesu.ru/en/, 1139

CSPU | Chechen State Pedagogical University | https://chspu.ru/, 1146

Irkutsk

ISDCT SB RAS | Federal State Budgetary Institution of Science "Matrosov Institute for System Dynamics and Control Theory of the Siberian Branch of the Russian Academy of Sciences" | http://www.idstu.irk.ru/, 1135

ISU | Irkutsk State University | http://isu.su/, 1148, 1135, 1099, 1119, 1139

LI SB RAS | Federal State Budgetary Institution of Science Limnological Institute of the Siberian Branch of the Russian Academy of Sciences" | http://www.lin.irk.ru/, 1146

Ivanovo

ISU | Ivanovo State University | http://ivanovo.ac.ru/, 1139

ISUCT | Ivanovo State University of Chemistry and Technology | http://isuct.ru/, 1146, 1131

Izhevsk

UdSU | Udmurt State University | http://udsu.ru/, 1146

Kaliningrad

IKBFU | Immanuel Kant Baltic Federal University | http://www.kantiana.ru/, 1149-2, 1146

Kazan

Compressormash | Open Joint Stock Company "Kazancompressormash" | http://compressormash.ru/, 1065

FRC KazSC RAS | Federal Research Center "Kazan Scientific Center of the Russian Academy of Sciences" | https://knc.ru, 1149-2, 1077

KFU | Kazan Volga Region Federal University | http://kpfu.ru/, 1149-2, 1149-3, 1138, 1139, 1117

Spetshmash | Ltd. "Research and Productio Enterprise Spetshmash" | http://spmsh.ru/, 1065

Khabarovsk

PNU | Pacific National University | http://pnu.edu.ru/, 1136

Kostroma

KSU | Kostroma State University | http://ksu.edu.ru/, 1139

Krasnodar

KSU | Kuban State University | http://kubsu.ru/, 1131, 1139

Krasnoyarsk

FRC KSC SB RAS | Federal Research Center "Krasnoyarsk Science Center of the Siberian Branch of the Russian Academy of Sciences" | https://ksc.krasn.ru, 1149-2

KIP SB RAS | Federal State Budgetary Institution of Science "Kirensky Institute of Physics, Siberian Branch of the Russian Academy of Sciences" | http://www.kirensky.ru/, 1149-2

SibFU | Siberian Federal University | http://www.sfu-kras.ru/, 1149-2

Moscow

"FOMOS-MATERIALS" | Open Joint Stock Company "FOMOS-MATERIALS" | http://newpiezo.com/, 1086

"Kvant-R" | "Kvant-R" Ltd., 1107

"SNIIP" | JSC "SNIIP" | https://www.sniip.ru/, 1146

"Azimuth-Photonics" | "Azimuth-Photonics" | http://www.azimp.ru/, 1086

BMSTU | Bauman Moscow State Technical University | https://www.bmstu.ru/, 1118, 1139

Cryogenmash | Public Joint Stock Company "Cryogenmash" | http://cryogenmash.ru/, 1065

DSSI | V.V. Dokuchaev Soil Science Institute | http://www.esoil.ru/, 1146

FCBN FMBA | Federal Center for Brain and Neurotechnologies of the Federal Medical and Biological Agency | https://фцмн.рф/, 1077

FMBA Russia | Federal Medical-Biological Agency (Russia) | https://fmba.gov.ru/, 1127

FMBC | Russian State Research Center − Burnasyan Federal Medical Biophysical Center of Federal Medical Biological Agency | http://fmbafmbc.ru/, 1077, 1107, 1131, 1127

FRC IM RAS | Federal State Institution "Federal Research Center "Informatics and Management of the Russian Academy of Sciences" | http://www.frccsc.ru/, 1118

Geliymash | Open Joint Stock Company "Researching and Production Association "Geliymash" | http://geliymash.ru/, 1065

GIN RAS | Federal State Budgetary Institution of Science “Geological Institute of the Russian Academy of Sciences” | http://www.ginras.ru/, 1146

GPI RAS | Federal State Budgetary Institution of Science "General Physics Institute of the Russian Academy of Sciences" | http://www.gpi.ru/, 1146

IA RAS | Federal State Budgetary Institution of Science "Institute of Archaeology of the Russian Academy of Sciences" | http://archaeolog.ru/, 1149-2, 1146

IBMC | Federal State Budgetary Institution of Science Institute of Biomedical Chemistry | http://www.ibmc.msk.ru/, 1077

IBMP RAS | Federal State Budgetary Institution of Science "State Scientific Centre

of the Russian Federation - Institute for Biomedical Problems of the Russian Academy of Sciences" | http://www.imbp.ru/, 1065, 1077, 1107, 1127

IC RAS | Federal State Institution "Federal Research Center "Crystallography and Photonics" of the Russian Academy of Sciences" | https://kif.ras.ru/, 1149-2

ICP RAS | Semenov Institute of Chemical Physics of the Russian Academy of Sciences | http://chph.ras.ru/, 1149-2, 1107

IEPT RAS | Federal State Budgetary Institution of Science "Institute of Earthquake Prediction Theory and Mathematical Geophysics of the Russian Academy of Sciences" | http://www.mitp.ru/, 1149-2

IGEM RAS | Federal State Budgetary Institution of Science "Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry of the Russian Academy of Sciences" | http://www.igem.ru/, 1149-2, 1077

IGIC RAS | Federal State Budgetary Institution of Science "Kurnakov Institute of General and Inorganic Chemistry of the Russian Academy of Sciences" | http://www.igic.ras.ru/, 1149-2, 1107, 1131

IHNA Ph RAS | Federal State Budgetary Institution of Science "Institute of Higher Nervous Activity and Neurophysiology of the Russian Academy of Sciences" | http://www.ihna.ru/), 1077

IITP RAS | Federal State Budgetary Institute of Science "Institute for Information Transmission Problems (Kharkevich Institute) of the Russian Academy of Sciences" | http://iitp.ru/, 1118

IKI RAS | Federal State Budgetary Institution of Science "Space Research Institute of the Russian Academy of Sciences" | http://www.iki.rssi.ru/, 1146, 1077

IMEMO RAS | Federal State Budgetary Scientific Institution "Primakov National Research Institute of World Economy and International Relations of the Russian Academy of Science" | http://imemo.ru/, 1037

IMET RAS | Federal State Budgetary Institution of Science "A.A. Baikov Institute of Metallurgy and Materials Science of the Russian Academy of Sciences" | http://www.imet.ac.ru/, 1149-2, 1146

INEOS RAS | A.N. Nesmeyanov Institute of Organoelement Compounds of Russian Academy of Sciences| https://ineos.ac.ru/, 1130

INEUM | Institute of Electronic Control Computes named after I.S. Bruk | http://www.ineum.ru/, 1149-1

INMI RAS | Federal State Budgetary Institution of Science "Winogradsky Institute of Microbiology of the Russian Academy of Sciences" | http://www.inmi.ru/, 1149-2

Inst. Immunology | National Research Center – Institute of Immunology Federal Medical-Biological Agency of Russia | http://nrcii.ru/, 1149-2

IOS RAS | Institute of Oriental Studies of the Russian Academy of Sciences | https://www.ivran.ru/, 1037

IPCE RAS | Federal State Budgetary Institution of Science "A.N. Frumkin Institute of Physical Chemistry and Electrochemistry of the Russian Academy of Sciences" | http://www.phyche.ac.ru/, 1146

IPE RAS | Federal State Budgetary Institution of Science “Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences” | http://www.ifz.ru/, 1149-2

IPMech RAS | Federal State Budgetary Institution of Science "Institute for Problems in Mechanics of the Russian Academy of Sciences" | http://www.ipmnet.ru/, 1138

ISP RAS | Federal State Budgetary Institution of Science "Ivannikov Institute for System Programming of the Russian Academy of Sciences" | http://www.ispras.ru/, 1118

ISPM RAS | Federal State Budgetary Institution of Science "Enikolopov Institute of Synthetic Polymeric Materials of the Russian Academy of Sciences" | http://www.ispm.ru/, 1131

ITEP | Federal State Budgetary Institution "Russian Federation State Scientific Centre - Alikhanov Institute for Theoretical and Experimental Physics" of the National Research Centre "Kurchatov Institute" | http://www.itep.ru/, 1065, 1118, 1135, 1138, 1066, 1081, 1083, 1087, 1088, 1146, 1100, 1119, 1107, 1131, 1117

JIHT RAS | Joint Institute for High Temperatures of the Russian Academy of Sciences | http://www.jiht.ru/, 1107

JSC "DC "Crystal" | Joint-stock company "Design Center "Crystal", 1126

JSCC RAS | Joint SuperComputer Center of the Russian Academy of Sciences – Branch of Federal State Institution "Scientific Research Institute for System Analysis of the Russian Academy of Sciences" | https://www.jscc.ru, 1118

KIAM RAS | Federal State Budgetary Institution of Science "Federal Research Center "Keldysh Institute of Applied Mathematics of the Russian Academy of Sciences" | http://www.keldysh.ru/, 1118

LPI RAS | Federal State Budgetary Institution of Science "P.N. Lebedev Physical Institute

of the Russian Academy of Sciences" | http://www.lebedev.ru/, 1065, 1138, 1081, 1083, 1087, 1096, 1097, 1150, 1100, 1119, 1117

Marafon | LLC "Marafon" | http://www.marathon.ru/, 1150

MGIMO | Moscow State Institute of International Relations | https://mgimo.ru/, 1037

MI RAS | Federal State Budgetary Institution of Science “Steklov Mathematical Institute of the Russian Academy of Sciences” | http://www.mi.ras.ru/, 1138, 1117

MIET | National Research University of Electronic Technology | http://www.miet.ru/, 1149-2

MIREA | Moscow State University Information Technology, Radioengineering and Electronics - Russian Technological University | http://www.mirea.ru/, 1065, 1150

MISIS | National University of Science and Technology "MISIS" | http://www.misis.ru/, 1149-2, 1146

MPEI | National Research University "Moscow Power Engineering Institute" | http://mpei.ru/, 1118, 1139

MPGU | Moscow State Pedagogical University | http://mpgu.su/home/, 1131

MSK-IX | Joint-stock company "Center of interaction of computer networks" MSK-IX " | https://www.msk-ix.ru/, 1118

MSU | Lomonosov Moscow State University | http://www.msu.ru/, 1065, 1118, 1149-2, 1136, 1138, 1081, 1087, 1146, 1130, 1147, 1077, 1132, 1119, 1131, 1139, 1117

NIKIET | Joint Stock Company "N.A. Dollezhal Research and Development Institute of Power Engineering" | http://www.nikiet.ru/, 1149-1, 1149-4, 1083

NNRU "MEPhI" | National Nuclear Research University "MEPhI" | http://www.mephi.ru/, 1065, 1118, 1149-2, 1136, 1066, 1088, 1100, 1119, 1107, 1126, 1139

NRC KI | National Research Centre "Kurchatov Institute" | http://www.nrcki.ru/, 1065, 1118, 1149-2, 1149-3, 1149-4, 1136, 1087, 1088, 1097, 1146, 1130, 1077

NRU HSE | National Research University Higher School of Economics | http://www.hse.ru/, 1065, 1118, 1137, 1138, 1119, 1037, 1139, 1117

PFUR | Peoples’ Friendship University of Russia | http://www.rudn.ru/, 1137, 1119, 1107, 1131, 1037, 1139

PIN RAS | Paleontological Institute of the Russian Academy of Sciences | http://www.paleo.ru/, 1149-2, 1077

PRUE | Plekhanov Russian University of Economics | https://www.rea.ru/, 1065, 1118

RCC MSU | Research Computing Center Lomonosov Moscow State University | http://www.srcc.msu.ru/, 1118, 1119

RIEPL | Russian Research Institute of Economics, Politics and Law in Science and Technology | https://riep.ru/, 1037

RIVS | Federal State Budgetary Scientific Institution "Research Institute of Vaccines and Serums named after I.I. Mechnikov" | https://instmech.ru/, 1131

RSCC | Federal State Unitary Enterprise "Russian Satellite Communications Company" | http://www.rscc.ru/, 1118

RSMU | Pirogov Russian National Research Medical University | https://rsmu.ru/, 1131

RSTSREC | Popov Russian Scientific and Technical Society of Radio Engineering, Electronics and Communications | http://www.rntores.ru, 1119

SAI MSU | Sternberg Astronomical Institute of the M.V. Lomonosov Moscow State University | http://www.sai.msu.ru/, 1138, 1077, 1117

SC "IASRWA" | Interregional Agency for Scientific Restoration of Works of Art | http://mnrhu.ru/, 1146

SC "VNIINM" | Stock Company "A.A. Bochvar High-Technology Research Institute of Inorganic Materials" | http://www.bochvar.ru/, 1149-1, 1149-4

Sechenov Univ. | I.M. Sechenov First Moscow State Medical University | https://www.sechenov.ru/, 1146

SIAS | State Institute for Art Studies | http://sias.ru/, 1146

SINP MSU | Skobeltsyn Institute of Nuclear Physics of the M.V. Lomonosov Moscow State University | http://www.sinp.msu.ru/, 1065, 1148, 1118, 1149-2, 1135, 1136, 1083, 1088, 1096, 1086, 1099, 1146, 1130, 1119, 1107, 1117

Skoltech | Skolkovo Institute of Science and Technology | https://www.skoltech.ru/, 1138, 1117

SM "MK" | Federal State Institution "State Museum Moscow Kremlin" | http://www.kreml.ru/, 1146

SSDI | Joint Stock Company "State Specialized Design Institute" | http://aogspi.ru/, 1149-1

SYSTEMATOM | Closed Joint Stock Company "Nuclear and Radiation Safety Systems" | http://www.systematom.ru/, 1149-1

TIPS RAS | A.V. Topchiev Institute of Petrochemical Synthesis of the Russian Academy of Sciences | http://www.ips.ac.ru/, 1131

VEI | Federal State Unitary Enterprise "All-Russian Electrotechnical Institute" | http://www.vei.ru/, 1065

VNIIA | Federal State Unitary Enterprise "All-Russian Research Institute of Automatics" Russian Federal Atomic Energy Agency | http://www.vniia.ru/, 1146

Moscow, Troitsk

HPPI RAS | Federal State Budgetary Institution of Science "Institute for High Pressure Physics of the Russian Academy of Sciences" | http://www.hppi.troitsk.ru/, 1149-2, 1096

INR RAS | Federal State Budgetary Institution of Science "Institute for Nuclear Research of the Russian Academy of Sciences" | http://www.inr.ru/, 1065, 1148, 1118, 1149-2, 1149-3, 1149-4, 1135, 1136, 1138, 1083, 1087, 1088, 1096, 1151, 1097, 1146, 1130, 1119, 1117

ISAN | Federal State Budgetary Institution of Science "Institute of Spectroscopy of the Russian Academy of Sciences" | http://isan.troitsk.ru/, 1077

LPP LPI RAS | "Laboratory of Photomeson Processes Department of High-Energy Physics" Federal State Budgetary Institution of Science "P.N. Lebedev Physical Institute of the Russian Academy of Sciences" | http://www.lebedev.ru/, 1097

Moscow, Zelenograd

"Angstrem" | JSC "Angstrem" | https://www.angstrem.ru/, 1146

"Mikron" | JSC "Mikron" | https://www.mikron.ru/, 1146

RIMST | Joint Stock Company "Research Institute of Material Science and Technology" | http://www.niimv.ru/, 1086

Neutrino

BNO INR RAS | Baksan Neutrino Observatory Federal State Budgetary Institution of Science "Institute for Nuclear Research of the Russian Academy of Sciences" | http://www.inr.ru/bno//, 1100

Nizhny Novgorod

IAP RAS | Federal Research Center Institute of Applied Physics of the Russian Academy of Sciences | http://www.iapras.ru/, 1129, 1127

IPM RAS | Federal State Budgetary Institution of Science "Institute for Physics of Microstructures of the Russian Academy of Sciences" | http://ipmras.ru/, 1149-2, 1146

NNSTU | Nizhny Novgorod State Technical University named after R.E. Alekseev | https://nntu.ru/, 1148

UNN | N.I. Lobachevsky State University of Nizhny Novgorod National Research University | http://www.unn.ru/, 1149-2

Novocherkassk

SRSPU NPI | South Russian State Polytechnic University (NPI) named after M.I. Platov | https://www.npi-tu.ru/, 1065, 1139

Novosibirsk

BIC SB RAS | Federal State Budgetary Institution of Science "Federal Research Center "Boreskov Institute of Catalysis of the Siberian Branch of the Russian Academy of Sciences" | http://www.catalysis.ru/, 1077

BINP SB RAS | Federal State Budgetary Institution of Science "Budker Institute of Nuclear Physics of the Siberian Branch of the Russian Academy of Sciences" | http://www.inp.nsk.su/, 1065, 1118, 1135, 1085, 1088, 1144

ICMMG SB RAS | Institute of Computational Mathematics and Mathematical Geophysics of Siberian Branch of the Russian Academy of Sciences | https://icmmg.nsc.ru, 1118

ISP SB RAS | Federal State Budgetary Institution of Science "A.V. Rzhanov Institute of Semiconductor Physics of the Siberian Branch of the Russian Academy of Sciences" | http://www.isp.nsc.ru/, 1137, 1131, 1126

NIIC SB RAS | Nikolaev Institute of Inorganic Chemistry SB RAS | http://www.niic.nsc.ru/, 1137

NSU | Novosibirsk State University | http://www.nsu.ru/, 1135, 1138, 1144, 1117

SKIF | Synchrotron Radiation Facility - Siberian Circular Photon Source "SKIF" Boreskov Institute of Catalysis of Siberian Branch of the Russian Academy of Sciences | https://srf-skif.ru/, 1118

STL "Zaryad" | STL "Zaryad", 1065

Obninsk

IPPE | Joint Stock Company "State Scientific Centre of the Russian Federation - Institute of Physics and Power Engineering" | http://www.ippe.ru/, 1149-4, 1146

NMRRC | A. Tsyb National Medical Research Radiological Center | https://mrrc.nmicr.ru/, 1077, 1107

Omsk

OmSU | F.M. Dostoevsky Omsk State University | http://www.omsu.ru/, 1136

OSTU | Omsk State Transport University | https://www.omgups.ru/, 1149-2

Perm

ICMM UrB RAS | Federal State Budgetary Institution of Science "Institute of Continuous Media Mechanics of the Russian Academy of Sciences Ural Branch" | http://www.icmm.ru/, 1149-2

ITCh UrB RAS | Federal State Budgetary Institution of Science "Institute of Technical Chemistry of the Russian Academy of Sciences Ural Branch" | http://www.itcras.ru/, 1149-2
PSNRU | Perm State National Research University | http://www.psu.ru/, 1146

Petropavlovsk-Kamchatsky

FRC GC RAS | Kamchatka branch of the Federal Research Center "Geophysical Service of Russian Academy of Sciences" | https://www.emsd.ru/, 1126, 1127
KSU | Kamchatsky State University named after Vitus Bering | https://www.kamgu.ru/, 1119, 1127, 1139

Protvino

IHEP | Federal State Budgetary Institution "Russian Federation State Scientific Centre - Institute for High Energy Physics" of the National Research Centre "Kurchatov Institute" | http://www.ihep.su/, 1065, 1118, 1135, 1137, 1138, 1066, 1081, 1083, 1085, 1087, 1088, 1096, 1086, 1119, 1126, 1117

Puschino

IMPB RAS | Federal State Budgetary Institution of Science "Institute of Mathematical Problems of Biology of the Russian Academy of Sciences" | http://www.impb.ru/, 1118, 1119
IPCBP SS RAS | Institute of Physical, Chemical and Biological Problems of Soil Science of the Russian Academy of Sciences | https://issp.pbcras.ru, 1077
ITEB RAS | Federal State Budgetary Institution of Science "Institute of Theoretical and Experimental Biophysics of the Russian Academy of Sciences" | http://web.iteb.ru/, 1107, 1127

Rostov-on-Don

RIP SFU | Research Institute of Physics of the Southern Federal University | http://ip.sfedu.ru/, 1149-2
SFedU | Southern Federal University | http://www.sfedu.ru/, 1149-2

Saint Petersburg

Botanic garden BIN RAS | Federal State Budgetary Institution of Science "Botanic Garden of the V.L. Komarov Botanic Institute of the Russian Academy of Sciences" | http://botsad-spb.com/, 1146
CRISM "Prometey" | Central Research Institute of Structural Materials "Prometey" named after I.V. Gorynin of National Research Center "Kurchatov Institute" | http://www.crism-prometey.ru/en/, 1149-2
Electron | Joint Stock Company "National Research Institute "Electron" | http://www.electron.spb.ru/, 1083
ETU "LETI" | Saint Petersburg State Electrotechnical University "LETI" | http://www.eltech.ru/, 1126
FIP | V.A. Fock Institute of Physics of the Saint Petersburg State University | http://www.niif.spbu.ru/, 1118, 1087, 1088, 1146
IAI RAS | Institute for Analytical Instrumentation of the Russian Academy of Sciences | http://iairas.ru/, 1129, 1130
IMC RAS | Federal State Budgetary Institution of Science "Institute of macromolecular Compounds of the Russian Academy of Sciences" | http://macro.ru/, 1149-2
Ioffe Institute | Federal State Budgetary Institution of Science "Ioffe Physicl Technical Institute of the Russian Academy of Sciences" | http://www.ioffe.ru/, 1149-2, 1146, 1130
ITMO University | National Research University of Information Technologies, Mechanics and Optics | http://www.itmo.ru/, 1118, 1037
KRI | V.G. Khlopin Radium Institute | http://www.khlopin.ru/, 1146, 1130
NIIEFA | D.V. Efremov Scientific Research Institute of Electrophysical Apparatus | http://www.niiefa.spb.su/, 1129
NWRSCC | North-West Regional Scientific and Clinical Center named after L.G. Sokolov Federal Medical and Biological Agency | https://med122.com/, 1126
PDMI RAS | Federal State Budgetary Institution of Science "St. Petersburg Department of V.A. Steklov Institute of Mathematics of the Russian Academy of Sciences" | http://www.pdmi.ras.ru/pdmi/, 1137, 1138
PFSPSMU | Pavlov First Saint Petersburg State Medical University | https://www.1spbgmu.ru/, 1147
SMTU | Saint-Petersburg State Marine Technical University | https://www.smtu.ru/, 1148
SPbSPU | Saint Petersburg Polytechnic University Peter the Great | http://www.spbstu.ru/, 1065, 1118, 1086, 1150, 1139
SPbSU | Saint Petersburg State University | http://spbu.ru/, 1065, 1118, 1136, 1137, 1066, 1130, 1119, 1107, 1139, 1117
SPMU | Saint Petersburg Mining University | https://www.spmi.ru/, 1146
SPSFTU | Saint Petersburg State Forest Technical University | http://spbftu.ru/, 1146
VNIIM | D.I. Mendeleyev All-Russian Institute for Metrology | https://www.vniim.ru/, 1136

Samara

SSU | Samara State University | http://samsu.ru/, 1119
SU | Samara National Research University | http://www.ssau.ru/, 1065, 1118, 1139

Saratov

SSU | N.G. Chernyshevsky Saratov State University | http://www.sgu.ru/, 1136, 1137, 1119, 1127, 1117

Sarov

MSU Branch | Federal State Budget Educational Institution of Higher Education M.V. Lomonosov Moscow State University MSU Branch in Sarov | https://sarov.msu.ru/, 1119

RFNC-VNIIEF | "Russian Federal Nuclear Centre" – All-Russian Scientific Research Institute of Experimental Physics | http://www.vniief.ru/, 1088, 1150, 1130

Sevastopol

IBSS | Federal Research Center "A.O. Kovalevsky Institute of Biology of the Southern Seas of RAS" | http://imbr-ras.ru/, 1146

Smolensk

SSU | Smolensk State University | http://www.smolgu.ru/, 1087, 1139

Snezhinsk

RFNC-VNIITF | Russian Federal Nuclear Centre - All-Russian Scientific Research Institute of Technical Physics | http://www.vniitf.ru/, 1149-4, 1083

Sochi

SRI MP | Federal State Budgetary Scientific Institution “Scientific Research Institute of Medical Primatology” | http://www.primatologia.ru/, 1077

Sosnovy Bor

JSC SPII "VNIPIET" | All-Russian Scientific Research and Design Institute of Energy Technology | http://ru.vnipiet.ru/, 1130

Stavropol

NCFU | North-Caucasus Federal University | https://ncfu.ru/, 1149-2

Staraya Ladoga

SL Museum | Staraya Ladoga Historical, Architectural and Archaeological Museum-Reserve | https://ladogamuseum.com/, 1146

Sterlitamak

SB BSU | Sterlitamak branch of the Bashkir State University | http://strbsu.ru/, 1149-2

Syktyvkar

DM Komi SC UrB RAS | Federal State Budgetary Institution of Science "Department of Mathematics Komi Sciences Centre of the Russian Academy of Sciences Ural Branch" | http://www.komisc.ru/, 1065

Tomsk

TPU | National Research Tomsk Polytechnic University | http://tpu.ru/, 1149-2, 1136, 1137, 1138, 1083, 1087, 1096, 1150, 1119, 1107, 1126, 1139

TSPU | Tomsk State Pedagogical University | http://www.tspu.edu.ru/, 1138

TSU | National Research Tomsk State University | http://www.tsu.ru/, 1065, 1129, 1119, 1126, 1139

Tula

TSU | Tula State University | http://tsu.tula.ru/, 1149-2, 1146, 1119, 1139

Tver

TvSU | Tver State University | http://tversu.ru/, 1119

Tyumen

UTMN | University of Tyumen | https://www.utmn.ru/, 1149-2

Vladikavkaz

NOSU | North-Ossetian State University named after K.L. Khetagurov | http://www.nosu.ru/, 1065, 1118, 1081, 1087, 1146, 1119, 1107, 1139

VTC "Baspik" | Vladikavkaz Technological Centre "Baspik" | http://baspik.all.biz/, 1087, 1150

Vladivostok

FEFU | Far Eastern Federal University | http://dvfu.ru/, 1135, 1136, 1137, 1147, 1077, 1119, 1139

IACP FEB RAS | Institute of Automation and Control Processes FEB RAS | https://www.iacp.dvo.ru/, 1118

PIBOC | G.B. Elyakov Pacific Institute of Bioorganic Chemistry | http://www.piboc.dvo.ru/, 1077

Voronezh

VSU | Voronezh State University | http://www.vsu.ru/, 1138, 1146, 1130, 1100, 1119, 1139

Yakutsk

NEFU | North-Eastern Federal University in Yakutsk | http://www.s-vfu.ru/, 1147, 1139

Yaroslavl

YSU | P.G. Demidov Yaroslavl State University | https://www.uniyar.ac.ru, 1139

Yekaterinburg

IMP UB RAS | Federal State Budgetary Institution of Science "M.N. Mikheev Institute of Metal Physics of Ural Branch of the Russian Academy of Sciences" | http://www.imp.uran.ru/, 1149-2, 1149-3

UrFU | Urals Federal University named after the First President of Russia B.N. Yeltsin | http://urfu.ru/, 1149-2, 1146, 1139

Zhukovsky

MDB | Joint Stock Company "Myasishchev Design Bureau" | http://www.emz-m.ru/, 1083

TECHNOLOGY | LLC "TECHNOLOGY" | https://geliy24.ru/, 1065

Serbia

Belgrade

AOB | Astronomical Observatory of Belgrade | https://www.aob.rs/, 1135
IBISS | Institute for Biological Research "Siniša Stanković" | https://www.ibiss.bg.ac.rs, 1077
INS "VINČA" | "Vinca" Institute of Nuclear Sciences | http://www.vin.bg.ac.rs/, 1065, 1129, 1149-2, 1135, 1137, 1066, 1083, 1146, 1077, 1131
IORS | Institute of onkology and radiology of Serbia | https://www.ncrc.ac.rs/, 1077
IPB | Institute of Physics Belgrade of the University of Belgrade | http://www.phy.bg.ac.rs/, 1136, 1146
Univ. | University of Belgrade | http://www.bg.ac.rs/, 1146, 1147, 1077, 1119

Kragujevac

UniKg | University of Kragujevac | https://en.kg.ac.rs/, 1077

Nis

Univ. | University of Nis | https://www.ni.ac.rs/en, 1138, 1117

Novi Sad

UNS | University of Novi Sad | http://www.uns.ac.rs/, 1129, 1149-2, 1066, 1146, 1126, 1139

Sremska Kamenica

Educons Univ. | Educons University | https://educons.edu.rs/, 1139

Slovakia*

Banska Bistrica

UMB | Matej Bel University | http://www.umb.sk/, 1086

Bratislava

CU | Comenius University in Bratislava | http://uniba.sk/, 1148, 1135, 1136, 1137, 1081, 1088, 1096, 1099, 1146, 1130, 1100, 1077
IEE SAS | Institute of Electrical Engineering of the Slovak Academy of Sciences | http://www.elu.sav.sk/, 1146, 1127
IP SAS | Institute of Physics of the Slovak Academy of Sciences | http://www.fu.sav.sk/, 1135, 1136, 1066, 1081, 1087, 1097, 1146

Kosice

IEP SAS | Institute of Experimental Physics of the Slovak Academy of Sciences in Košice | http://wwwnew.saske.sk/uef/, 1118, 1149-2, 1137, 1088, 1097
TUKE | Technical University of Košice | http://www.tuke.sk/, 1088
UPJS | Pavol Jozef Šafárik University in Košice | http://www.upjs.sk/, 1065, 1137, 1066, 1087, 1088, 1097, 1119

Nova Dubnica

EVPU | Electrotechnical Research and Projecting Company Nová Dubnica, j.s.c. | http://www.evpu.sk/, 1065

Zilina

UNIZA | University of Žilina | http://www.uniza.sk/, 1097

Slovenia

Ljubljana

GeoSS | Geological Survey of Slovenia | http://www.geo-zs.si/, 1146

South Africa

Bellville

UWC | University of the Western Cape | http://www.uwc.ac.za/, 1146, 1077, 1131, 1139

Cape Town

UCT | University of Cape Town | http://www.uct.ac.za/, 1118, 1088, 1119

Durban

UKZN | University of KwaZulu-Natal | https://www.ukzn.ac.za/, 1131

Johannesburg

WITS | University of the Witwatersrand | http://www.wits.ac.za/, 1136, 1088

Mthatha

WSU | Walter Sisulu University | https://www.wsu.ac.za/, 1131

Port Elizabeth

NMU | Nelson Mandela University | http://www.mandela.ac.za/, 1129, 1131

Pretoria

Necsa | South African Nuclear Energy Corporation | http://www.necsa.co.za/, 1149-2
TUT | Tshwane University of Technology | https://www.tut.ac.za/, 1131
UNISA | University of South Africa | http://www.unisa.ac.za/, 1137, 1146, 1130, 1131, 1139
UP | University of Pretoria | http://up.ac.za/, 1149-2, 1149-4, 1136, 1131

Richards Bay

UNIZULU | University of Zululand | https://www.unizulu.ac.za/, 1130

* The cooperation may be limited by the conditions adopted unilaterally by the State

Somerset West
iThemba LABS | iThemba Laboratory for Accelerator Based Sciences | http://www.tlabs.ac.za/, 1065, 1129, 1136, 1088, 1130, 1077, 1107, 1131, 1127, 1139

Stellenbosch
SU | Stellenbosch University | http://www.sun.ac.za/, 1065, 1129, 1136, 1146, 1107, 1131, 1139

Thohoyandou
UNIVEN | University of Venda | https://www.univen.ac.za/, 1130

Vanderbijlpark
VUT | Vaal University of Technology | https://www.vut.ac.za, 1129

Spain

Barcelona
ICMAB-CSIC | Institute of Materials Science of Barcelona-CSIC | https://icmab.es/, 1149-2
IEEC-CSIC | Institute of Space Science of the Higher Research Council | http://www.ice.csic.es/, 1138
IFAE | Institute for High Energy Physics | http://www.ifae.es/, 1081

Bilbao
UPV/EHU | University of the Basque Country | http://www.ehu.eus/, 1138

Granada
UGR | University of Granada | https://www.ugr.es/en, 1135

Leioa
BCMaterials | Basque Center for Materials, Applications and Nanostructures | https://www.bcmaterials.net/, 1149-2

Madrid
CENIM-CSIC | National Centre for Metallurgical Research of the Higher Research Council | http://www.cenim.csic.es/, 1149-2
CIEMAT | Centre for Energy, Environment and Technological Research | http://www.ciemat.es/, 1083
UAM | Autonoma University of Madrid | http://www.uam.es/, 1083

Oviedo
UO | University of Oviedo | http://www.uniovi.es/, 1083

Palma
UIB | Illes Baleares University | http://www.uib.cat/, 1136

Santander
IFCA | Institute of Physics of Cantabria of the University of Cantabria | http://ifca.unican.es/, 1083

Santiago de Compostela
USC | University of Santiago de Compostela | http://www.usc.es/, 1138

Valencia
IFIC | Institute for Particle Physics of the University of Valencia | http://ific.uv.es/, 1138, 1096

Valladolid
UVa | University of Valladolid | https://universityofvalladolid.uva.es/, 1138

Sri Lanka

Moratuwa
University of Moratuwa | https://uom.lk/, 1088

Sweden

Goteborg
Chalmers | Chalmers University of Technology | http://www.chalmers.se/, 1136

Lund
ESS ERIC | European Spallation Source ERIC Lund University | https://europeanspallationsource.se/, 1149-3, 1149-4
LU | Lund University | http://www.lu.se/, 1136, 1088

Stockholm
KTH | Royal Institute of Technology | http://www.kth.se/, 1135

Uppsala
TSL | Svedberg Laboratory of the Uppsala University | http://www.tsl.uu.se/, 1097

Switzerland

Bern
Uni Bern | University of Bern | http://www.unibe.ch/, 1099

Lausanne
EPFL | Ecole Polytechnique Fédérale de Lausanne | http://www.epfl.ch/, 1096

Villigen
PSI | Paul Scherrer Institute | http://www.psi.ch/, 1149-2, 1083, 1151, 1146, 1130, 1100

Zurich
ETH | Swiss Federal Institute of Technology Zurich | http://www.ethz.ch/, 1083, 1096
UZH | University of Zurich | http://www.uzh.ch/, 1083, 1100

Taiwan

Taipei
ASGCCA | Academia Sinica Grid Computing Certification Authority | http://ca.grid.sinica.edu.tw, 1118

NTU | National Taiwan University | http://www.ntu.edu.tw/, 1083

Taoyuan City

NCU | National Central University | http://www.ncu.edu.tw/, 1083

Tajikistan

Dushanbe

NAST | National Academy of Sciences of the Republic of Tajikistan | https://anrt.tj/en/, 1149-2

PHTI NAST | S.U. Umarov Physical-Technical Institute of the National Academy of Sciences of the Republic of Tajikistan | http://www.phti.tj/, 1149-2

TTU | Tajik Technical University named after academician M.S. Osimi | http://ttu.tj/en/main-en/, 1149-2

Thailand

Bangkok

KMUTT | King Mogkut's University of Technology Thonburi | https://global.kmutt.ac.th/, 1088

Chachoengsao

TMEC | Thai Microelectronics Center | http://tmec.nectec.or.th/, 1088

Hat Yai

PSU | Prince of Songkla University | http://www.psu.ac.th/, 1146

Nakhon Ratchasima

SLRI | Synchrotron Light Research Institute | https://www.slri.or.th/en/, 1088

SUT | Suranaree University of Technology | http://www.sut.ac.th/, 1088

Tunisia

Tunis

AAEA | Arab Atomic Energy Agency | http://www.aaea.org.tn/, 1139

Turkey

Adana

CU | Çukurova University | http://www.cu.edu.tr/, 1083

Ankara

METU | Middle East Technical University | http://www.metu.edu.tr/, 1083, 1099

Canakkale

ÇOMU | Çanakkale Onsekiz Mart University | http://www.comu.edu.tr/, 1146

Istanbul

BU | Boğaziçi University | http://www.boun.edu.tr/, 1083

Univ. | Istanbul University | http://www.istanbul.edu.tr/, 1088

YTU | Yuldiz Technical University | http://www.yildiz.edu.tr/en/, 1083, 1088

Konya

Karatay Univ. | KTO Karatay University | https://www.karatay.edu.tr/, 1088

Ukraine*

Kharkov

NSC KIPT | National Science Centre - Kharkov Institute of Physics and Technology | http://www.kipt.kharkov.ua/, 1088

Kiev

BITP NASU | N.N. Bogolyubov Institute for Theoretical Physics of the National Academy of Sciences of Ukraine | http://bitp.kiev.ua/, 1088, 1086

United Kingdom

Birmingham

Univ. | University of Birmingham | http://www.birmingham.ac.uk/, 1088, 1096

Bristol

Univ. | University of Bristol | http://www.bris.ac.uk/, 1083, 1096

Cambridge

Univ. | University of Cambridge | http://www.cam.ac.uk/, 1138

Canterbury

Univ. | University of Kent | http://www.kent.ac.uk/, 1138

Coventry

Warwick | University of Warwick | https://warwick.ac.uk/, 1137, 1100

Daresbury

DL | Daresbury Laboratory; Council for the Central Laboratory of the Research Councils | http://www.cclrc.ac.uk/Activity/DL, 1088

Derby

Univ. | University of Derby | https://www.derby.ac.uk/, 1088

Didcot

RAL | Rutherford Appleton Laboratory; Science and Technology Facilities Council | http://www.stfc.ac.uk/, 1083

Durham

Univ. | Durham University | http://www.dur.ac.uk/, 1138

* The cooperation may be limited by the conditions adopted unilaterally by the State

Edinburgh
Univ. | University of Edinburgh | http://www.edinburgh.ac.uk/, 1100

Glasgow
U of G | University of Glasgow | http://www.gla.ac.uk/, 1138, 1085, 1096, 1097

Guildford
Univ. | University of Surrey | http://www.surrey.ac.uk/, 1136

Lancaster
LU | Lancaster University | http://www.lancaster.ac.uk/, 1096

Liverpool
Univ. | University of Liverpool | http://www.liv.ac.uk/, 1135, 1088

London
Imperial College | Imperial College London | http://www.imperial.ac.uk/, 1135, 1138, 1083, 1144, 1100
JAI@RHUL | John Adams Institute for Accelerator Science at Royal Holloway, University of London | https://www.adams-institute.ac.uk/, 1150
UCL | University College London | http://www.ucl.ac.uk/, 1100

Manchester
UoM | University of Manchester | http://www.manchester.edu/, 1100

Oxford
Univ. | University of Oxford | http://www.ox.ac.uk/, 1119

USA

Amherst, MA
UMass | University of Massachusetts Amherst | https://www.umass.edu/, 1100

Arlington, TX
UTA | University of Texas Arlington | http://www.uta.edu/, 1118, 1119

Austin, TX
UT | University of Texas at Austin | http://www.utexas.edu/, 1088, 1100

Baltimore, MD
JHU | Johns Hopkins University | http://www.jhu.edu/, 1083

Batavia, IL
Fermilab | Fermi National Accelerator Laboratory | http://www.fnal.gov/, 1118, 1083, 1099

Berkeley, CA
Berkeley Lab | Lawrence Berkeley National Laboratory of the University of California | http://www.lbl.gov/, 1066, 1088
UC | University of California | http://www.universityofcalifornia.edu/, 1149-2, 1088

Bloomington, IN
IU | Indiana University Bloomington | http://www.iub.edu/, 1066

Boston, MA
BU | Boston University | http://www.bu.edu/, 1083, 1096
NU | Northeastern University | http://www.northeastern.edu/, 1083

Boulder, CO
CU | University of Colorado at Boulder | http://www.colorado.edu/, 1083

Buffalo, NY
UB | University at Buffalo of the State University of New York | http://www.buffalo.edu/, 1083

Cambridge, MA
Harvard Univ. | Harvard University | http://www.harvard.edu/, 1099
MIT | Massachusetts Institute of Technology | http://www.mit.edu/, 1083, 1086, 1100

Chapel Hill, NC
UNC | University of North Carolina at Chapel Hill | https://www.unc.edu/, 1100

Charlottesville, VA
UVa | University of Virginia | http://www.virginia.edu/, 1083

Chicago, IL
CSU | Chicago State University | https://www.csu.edu/, 1088
UIC | University of Illinois at Chicago | http://www.uic.edu/, 1066, 1083

College Park, MD
UMD | University of Maryland | http://www.umd.edu/, 1138, 1083

College Station, TX
Texas A&M | Texas A&M University | http://www.tamu.edu/, 1083

Columbia, SC
UofSC | University of South Carolina | https://sc.edu/, 1099

Columbus, OH
OSU | Ohio State University | http://www.osu.edu/, 1083, 1088

Coral Gables, FL
UM | University of Miami | http://welcome.miami.edu/, 1138

Davis, CA
UCDavis | University of California, Davis | http://ucdavis.edu/, 1083

Detroit, MI
WSU | Wayne State University | http://wayne.edu/, 1083, 1088

Durham, NC
Duke | Duke University | http://www.duke.edu/, 1146

Evanston, IL
NU | Northwestern University | http://www.northwestern.edu/, 1083, 1100

Fairfax, VA
GMU | George Mason University | http://www.gmu.edu/, 1096

Gainesville, FL
UF | University of Florida | http://www.ufl.edu/, 1083

Houston, TX
Rice Univ. | William Marsh Rice University | http://www.rice.edu/, 1083
UH | University of Houston | http://www.uh.edu/, 1088

Idaho-Falls, ID
INEEL | Idaho National Engineering and Environmental Laboratory | http://www.inl.gov/, 1100

Indianapolis, IN
IUPUI | Indiana University - Purdue University Indianapolis | http://www.iupui.edu/, 1099

Iowa City, IA
UIowa | University of Iowa | http://www.uiowa.edu/, 1083

Ithaca, NY
Cornell Univ. | Cornell University | http://www.cornell.edu/, 1083

Knoxville, TN
UTK | University of Tennessee of Knoxville | http://www.utk.edu/, 1083, 1088

Lawrence, KS
KU | University of Kansas | http://www.ku.edu/, 1083

Lemont, IL
ANL | Argonne National Laboratory | Argonne, IL http://www.anl.gov/, 1066, 1081

Lincoln, NE
UNL | University of Nebraska-Lincoln | http://www.unl.edu/, 1083

Livermore, CA
LLNL| Lawrence Livermore National Laboratory | http://www.llnl.gov/, 1083

Los Alamos, NM
LANL | Los Alamos National Laboratory; Meson Physics Facility LAMPF | http://www.lanl.gov/, 1085, 1088, 1146

Los Angeles, CA
UCLA | University of California, Los Angeles | http://www.ucla.edu/, 1083

Lubbock, TX
TTU | Texas Tech University | http://www.ttu.edu/, 1083

Madison, WI
UW-Madison | University of Wisconsin-Madison | http://www.wisc.edu/, 1083

Manhattan, KS
KSU | Kansas State University | https://ksiteonline.com/, 1083

Menlo Park, CA
SLAC | SLAC National Accelerator Laboratory is Operated by Stanford University | http://www6.slac.stanford.edu/, 1096

Merced, CA
UCMerced | University of California, Mered Madison | http://www.ucmerced.edu/, 1096

Minneapolis, MN
U of M | University of Minnesota | http://twin-cities.umn.edu/, 1083

Nashville, TN
VU | Vanderbilt University | http://www.vanderbilt.edu/, 1083

New Brunswick, NJ
RU NB | Rutgers University New Brunswick | https://newbrunswick.rutgers.edu/, 1083

New Haven, CT
Yale Univ. | Yale University | http://www.yale.edu/, 1066, 1088

New York, NY
CUNY | City University of New York | http://www2.cuny.edu/, 1138
RU | Rockefeller University | http://www.rockefeller.edu/, 1083
SUNY | State University of New York | http://www.suny.edu/, 1138, 1066

Newport News, VA
JLab | Thomas Jefferson National Accelerator Facility; Southeastern Universities Research Association SURA | http://www.jlab.org/, 1097

Norfolk, VA
NSU | Norfolk State University | http://www.nsu.edu/, 1097

Notre Dame, IN
ND | University of Notre Dame | http://www.nd.edu/, 1136, 1083

Oak Ridge, TN
ORNL | Oak Ridge National Laboratory | http://www.ornl.gov/, 1088, 1146

Omaha, NE
Creighton Univ. | Creighton University | https://www.creighton.edu/, 1088

Oxford, MS
UM | University of Mississippi | http://www.olemiss.edu/, 1083

Pasadena, CA
Caltech | California Institute of Technology | http://www.caltech.edu/, 1137, 1083

Philadelphia, PA
Penn | University of Pennsylvania | http://www.upenn.edu/, 1138

Pittsburgh, PA
CMU | Carnegie Mellon University http://www.cmu.edu/, 1083

Princeton, NJ
PU | Princeton University; Joseph Henry Laboratories of Physics | http://www.princeton.edu/, 1083

Providence, RI
Brown | Brown University | https://www.brown.edu/, 1083

Riverside, CA
UCR | University of California, Riverside | http://www.ucr.edu/, 1083

Rochester, NY
UR | University of Rochester | http://www.rochester.edu/, 1083

San Diego, CA
SDSU | San Diego State University | http://www.sdsu.edu/, 1083

San Luis Obispo, CA
Cal Poly | California Polytechnic State University | California Polytechnic State University | https://www.calpoly.edu/, 1088

Santa Barbara, CA
UCSB | University of California, Santa Barbara | https://www.universityofcalifornia.edu/, 1083

Tallahassee, FL
FSU | Florida State University | http://www.fsu.edu/, 1083

Tampa, FL
USF | University of South Florida | https://www.usf.edu/, 1132

Tuscaloosa, AL
UA | University of Alabama | http://www.ua.edu/, 1083, 1100

University Park, PA
Penn State | Pennsylvania State University | http://www.psu.edu/, 1136, 1066

Upton, NY
BNL | Brookhaven National Laboratory | http://www.bnl.gov/, 1118, 1066, 1096, 1097

Wako, TX
BU | Baylor University | http://www.baylor.edu/, 1135, 1083

West Lafayette, IN
Purdue Univ. | Purdue University | http://www.purdue.edu/, 1083, 1088

Williamsburg, VA
W&M | College of William & Mary | http://www.wm.edu/, 1097

Uzbekistan

Jizzakh
JBNUU | Jizzakh Branch of the National University of Uzbekistan named after Mirzo Ulugbek | http://nuu.uz/, 1147
JDPU | Jizzakh State Pedagogical University | https://jdpu.uz, 1087

Namangan
NamMTI | Namangan Institute of Engineering and Technology | http://nammti.uz/, 1136

Parkent
IMS | Institute of Materials Science of the Physical Technical Institute Association "Physics-Sun" of the Academy of Sciences of the Republic of Uzbekistan | https://imssolar.uz/, 1077

Samarkand
SamSU | Samarkand State University named after Sharof Rashidov | https://www.samdu.uz/, 1136, 1087, 1151, 1139

Tashkent
AS RUz | Academy of Sciences of the Republic of Uzbekistan | http://www.academy.uz/, 1118, 1119, 1139
Assoc. "P.-S. " PTI | Physical Technical Institute Association "Physics-Sun" named after S.A. Azimov of the Academy of Sciences of the Republic of Uzbekistan | http://www.fti.uz/, 1065, 1136, 1087, 1097
IAP NUU | Institute of Applied Physics of the National University of Uzbekistan named after Mirzo Ulugbek | http://nuu.uz/, 1136
INP AS RUz | Institute of Nuclear Physics of the Academy of Sciences of the Republic of Uzbekistan | http://www.inp.uz/, 1118, 1149-2, 1149-3, 1149-4, 1136, 1097, 1146, 1100, 1077, 1107
IS AS RUz | Institute of Seismology named after G. A. Mavlyanov of the Academy of Sciences of the Republic of Uzbekistan | https://www.seismos.uz/, 1126
TashSTU | Tashkent State Technical University | http://tdtu.uz, 1139

Vietnam

Da Lat

DNRI | Dalat Nuclear Research Institute | http://www.nri.gov.vn/, 1066, 1146

Da Nang

DTU | Duy Tan University | http://www.daytan.edu.vn/, 1149-2

Hanoi

IMS VAST | Institute of Material Science of the Vietnam Academy of Science and Technology | http://ims.vast.ac.vn/, 1131

INPC VAST | Institute of Natural Products Chemistry of the Vietnam Academy of Science and Technology | http://vast.ac.vn/, 1077

IOP VAST | Institute of Physics of the Vietnam Academy of Science and Technology | http://www.iop.vast.ac.vn/, 1149-2, 1135, 1146, 1130, 1147, 1139

ITT VAST | Institute for Tropical Technology VAST | http://itt.vast.vn/, 1077

VINATOM | Vietnam Atomic Energy Institute of the Ministry of Science and Technology | https://vinatom.gov.vn/en/, 1077, 1139

VNU | Vietnam National University Hanoi | http://www.vnu.edu.vn/, 1146

Ho Chi Minh City

CNT VINATOM | Center for Nuclear Techniques, VINATOM | https://vinatom.gov.vn/en/, 1126

HCMUE | Ho Chi Minh City University of Education | https://hcmue.edu.vn/en/, 1130

VNUHCM | Vietnam National University, Ho Chi Minh City | https://vnuhcm.edu.vn/, 1135