Theoretical support for experiments at colliders

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The research area of the series of works covers the physics of electroweak and strong interactions of particles within the framework of the Standard Model.

The accuracy of experimental studies is constantly growing with the increase in collected statistics, development of analysis methods, improvement of detector calibration, etc. This leads to a constant increase in the requirements for the accuracy of theoretical predictions of observables studied at the Large Hadron Collider, electron-positron colliders, muon factories and others. In connection with plans to launch experiments with polarized beams (NICA, Belle II, ILC, CLIC, RHIC), theoretical predictions are needed taking into account the polarization of the initial and final particles.

The main objective of the work is to develop and enhance the SANC computer system for semiautomatic analytical calculations for various particle interaction processes taking into account radiative corrections. The results of analytical calculations are implemented in the MCSANC Monte Carlo integrator and the ReneSANCe Monte Carlo unweighted event generator, which allow taking into account experimental conditions. These computer programs provide results for observables and pseudo observables, taking into account full one-loop electroweak radiative corrections and certain leading higher-order effects in the full phase volume taking into account the masses of all particles for both unpolarized and polarized cases. These unique properties make the computer code in demand for modeling modern and future experiments.

To date, the following processes are implemented in the MCSANC/ReneSANCe Monte Carlo codes.

I. A precise theoretical description of the following processes for lepton colliders is obtained, taking into account all masses and polarization of the initial particles:

1) the Bhabha scattering ($e^+e^- \to e^-e^+$) at the one-loop level of accuracy;

2) the process of Higgs boson production associated with the Z boson production ($e^+e^- \to ZH$) at the one-loop level, as well as the leading higher-order logarithmic contributions in the QED structure function formalism due to radiation from the initial state;

3) electron-positron annihilation into a photon and Z-boson pair ($e^+e^- \to Z\gamma$) at the one-loop precision level;

4) elastic muon-electron scattering $\mu^\pm e^- \to \mu^\pm e^-$ at the one-loop precision level taking into account two-loop electroweak corrections of order $O(G_\mu^2)$ and two-loop mixed electroweak/QCD corrections of order $O(G_\mu \alpha_s)$;

5) the Møller process for the $e^-e^- \to e^-e^-$ and $\mu^+\mu^+ \to \mu^+\mu^+$ channels at the one-loop precision level;

6) fermion pair production ($e^+e^- \to \mu^+\mu^-$, $e^+e^- \to \tau^+\tau^-$, $e^+e^- \to tt$) at the one-loop precision level taking into account two-loop electroweak corrections of order $O(G_\mu{}^2)$ and two-loop mixed electroweak/QCD corrections of order $O(G_\mu \alpha_s)$;

7) photon pair production ($e^+e^- \to \gamma\gamma$) at the one-loop precision level.

II. For hadron colliders, the Drell-Yan processes were calculated with radiative corrections:

1) with neutral current ($pp[pp\ ] \to Z, \gamma \to \ell^+\ell^-$);

2) with charged current ($pp[pp] \to W^- \to \ell^-\nu_\ell$, $pp[pp] \to W^+ \to \ell^+\nu_\ell$);

3) the possibility of estimating longitudinal polarization for the Drell-Yan process with neutral current was implemented.

Future high-energy electron-positron colliders are expected to study physics in the energy range of the order of the Z boson mass at a essentially new level of precision. This has generated a new wave of interest in the programs created for the analysis of experimental data at LEP. Our group has continued to support and develop two such programs: the DIZET library of electroweak corrections and the ZFITTER semi-analytical program for calculating cross sections of electron-positron annihilation processes.

The programs we created have been transferred to experimentalits and are actively used for simulation and data analysis in the ATLAS, CMS, Belle II and other collaborations.

Thus, a contribution has been made to the theoretical support of modern and future experimental research in the field of high-energy physics, in particular, at the existing colliders LHC (CERN), VEPP-2000 (Novosibirsk), Belle II (Japan), BEPC-II (Beijing) and future installations such as the Super Charm-Tau Factory (Sarov), FCC_ee (CERN), CEPC (China) and others.

The results obtained by the project participants were presented in publications in peer-reviewed journals and reported at numerous international seminars and conferences.

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