Theoretical Description of the Multichannel ep and $pp - \pi d$ Scattering Reactions

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During the least 25 years the ep scattering reactions in the low and $Q^2 \sim few\ GeV^2$ energy regions was studied in the several high precision experiments [1, 2, 3, 4]. In particular the the electromagnetic form factors of the proton and the polarization observables are under study in many high precision experiments in Germany (ELSA/Bonn, GSI/Darmstadt and MAMI/Mainz) and in other countries (CERN/Switzerland, CLEO/USA, FNAL/USA, JLAB/USA, SLAC/USA, TRIUMF/Canada and KEK/Japan). The interest in high precision measurements is generated by drastic differences for the same observables obtained by different experiments and theoretical models. The newest measurements have generated the following questions: Are the two photon exchange corrections, observed in high energy four momentum transfer, also important at very low energy momentum transfer? Can the multi-photon exchange explain the difference between various extraction of the proton electromagnetic vertices and polarization observables? Indicates the difference between the proton charge radius obtained in the electron proton and in the muon proton scattering, that something is missing in our description of the hydrogen like atoms and or our understanding in the electron and muon interaction with the proton?

The theoretical description of the high energy experiments was performed within the two photon exchange models. The main uncertainty of the two photon exchange models [2, 3, 4] arise from the off shell extension of the $\gamma^* pp$ vertexes [5] because $\gamma^* pp$ vertexes with the off mass shell nucleons depend on the two or three variables. Therefore there was suggested the additional approximations which allow to extract the one variable $\gamma^* pp$ vertexes with the on mass shell protons. An other uncertainty is generated by mixing of the quark-parton and intermediate hadron (resonance) degrees of freedom which are important in this energy region.

In order to avoid these principal uncertainties of the two-photon exchange models we have derived [9] the relativistic field-theoretical Lippmann-Schwinger type equation $A_{e'p',ep} = V_{e'p',ep} + V_{e'p',e''p''} G_o A_{e''p'',ep}$ for the electron-proton (ep) scattering amplitude $A_{e'p',ep}$ in the Coulomb and Lorentz gauges within the usual quantum electrodynamic (QED), where G_o is the free Green function of the ep system. The ep scattering potential $V_{e'p',ep}$ consists of the one off mass shell photon exchange part V_{OPE} and the nonlocal potential v which contains all other possible contributions. Unlike to the other field-theoretical equations, both protons in $V_{e'p',ep}$ are on mass shell, i.e. there is not required the off mass shell nucleon variables for the input photon-nucleon vertexes. In the present formulation the standard form of the leading order one photon exchange potential V_{OPE} is generated by the canonical equal-time anticommutators $Y \;=< out; \mathbf{p}'_{\mathbf{N}} | \Big\{ \eta_e(x_o, \mathbf{x}), \psi^+_e(x_o, \mathbf{y}) \Big\} | \mathbf{p}_{\mathbf{N}}; in \;>= V_{OPE} + V_{NL}$ between the electromagnetic field of the electron ψ_e and its source η_e in the Heisenberg picture. Besides of the leading one photon exchange term Y produces also the next-to leading order terms V_{NL}. which are produced by the static electric (Coulomb) interaction. It is demonstrated, that the one-photon exchange amplitude in the Born approximation $A_{e'p',ep} \simeq V_{OPE}$ is the same in the Coulomb and Lorentz gauges. But the nonlocal (contact) terms V_{NL} in the Lorentz gauge is much more complicated as in the Coulomb gauge. Moreover, we present the transformation of the potentials V_{OPE} and V_{NL} in the Lorentz gauges into Coulomb gauge. The protons in the amplitude and in the potential of the presented equations are on mass shell. Therefore according to the Haag-Nishijima-Zimmermann treatment of the bound (cluster) states in the quantum field theory [10, 11, 12, 13] in the suggested equations the quark-parton degrees of freedom can only change the input electromagnetic vertexes.

The polarization effects in the multichannel proton-proton and proton deuteron scattering are also subject of the forthcoming experiments in JINR within the NICA project[6]. We have suggested the new relativistic three-body equations for the amplitude of the coupled $nucleon - deuteron \Longleftrightarrow three\ nucleon$ ($nd \Longleftrightarrow 3N$) reactions [8] based on the standard field-theoretical S-matrix approach. These relativistic field theoretical equations are three-dimensional from the beginning. Consequently they are free of the ambiguities which appear due to the three dimensional reduction of the four dimensional Bethe-Salpeter equations. The solutions of the considered equations satisfy automatically the unitarity condition. The form of these three-body equations does not depend on the choice of the model of the Lagrangian and they are same for the formulations with and without quark degrees of freedom. The effective potential of the suggested equations is defined by the vertices with two on-mass shell particles. It is emphasized that these vertices can be constructed directly from the experimental data. The final form of the equations are compared with the three-body Faddeev equations. Unlike to these equations, the suggested three-body equation have the form of the Lippmann-Schwinger-type equations with the connected potential. Within the suggested approach the complete set of the three body forces is obtained.

In the modern particle physic the multidimensional formulation of the several modern theories in the particle physic allow to maintain the general unification and avoid the troubles of the usual 3D and 4D theories. In our paper [9] was suggested the general model which allow to explain doubling of the particle states with the same quantum numbers but with the different masses in the framework of the conformal group of the transformations in the momentum space. For this aim the 6D and 5D representations of the four-dimensional (4D) interacted fields and the corresponding equations of motion are studied using equivalence of the conformal transformations of the four-momentum q_μ ($q'_\mu = q_\mu + h_\mu$, $q'_\mu = \Lambda^\nu_\mu q_\nu$, $q'_\mu = \lambda q_\mu$ and $q'_\mu = -M^2 q_\mu/q^2$) and the corresponding rotations on the 6D cone $\kappa_A \kappa^A = 0$ ($A = \mu; 5, 6 \equiv 0, 1, 2, 3; 5, 6$), where $q_\mu = M\ \kappa_\mu/(\kappa_5 + \kappa_6)$ and M is the scale parameter. The 4D reduction of the 6D fields on the cone $\kappa_A \kappa^A = 0$ is fulfilled by the intermediate 5D projection into two 5D hyperboloids $q_\mu q^\mu + q_5^2 = M^2$ and $q_\mu q^\mu - q_5^2 = -M^2$ in order to cover the whole domains $-\infty < q_\mu q^\mu < \infty$ and $q_5^2 \geq 0$. The resulting 5D and 4D fields in the coordinate space consist of two parts $\varphi_1(x, x_5)$, $\varphi_2(x, x_5)$ and $\Phi_1(x) = \varphi_1(x, x_5 = 0)$, $\Phi_2(x) = \varphi_2(x, x_5 = 0)$, where the Fourier conjugate of $\varphi_1(x, x_5)$ and $\varphi_2(x, x_5)$ are defined on the hyperboloids $q_\mu q^\mu + q_5^2 = M^2$ and $q_\mu q^\mu - q_5^2 = -M^2$ respectively. Consequently, the 4D reduction of the 6D fields generate two kinds of the 5D and 4D interacted fields $\varphi_\pm = \varphi_1 \pm \varphi_2$ and $\varphi_\pm(x, x_5 = 0) = \Phi_\pm(x) = \Phi_1(x) \pm \Phi_2(x)$ with the same quantum numbers but with the different masses and the sources. This doubling of the 4D fields $\Phi_\pm = \Phi_1 \pm \Phi_2$ can be applied for unified description of the interacted fields of the electron and muon, π and $\pi(1300)$-mesons, N and $N(1440)$-nucleons and other particles with the same quantum numbers but different masses and interactions.

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