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Amplitude ratios in ρ^0 leptoproductions and GPDs

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Abstract. We investigate exclusive leptoproduction of ρ^0 meson. These reactions were analyzed within the factorizing handbag approach. In our model good agreement of observables for light meson production with experimental data in a wide energy range was found.
Using the model results we calculate the ratio of different helicity amplitudes for a transversely polarized proton target to the leading twist longitudinal amplitude. Our results are close to the amplitude ratios measured by HERMES.

1 Introduction

In this report, investigation of ρ^0 meson leptoproduction is based on the handbag approach. Here the amplitudes at high Q^2 factorize into hard meson electroproduction off partons and the Generalized Parton Distributions (GPDs) [1]. Good agreement of our results for the cross sections and spin observables, expressed in terms of GPDs H, E, with experimental data were obtained in [2, 3]. We consider transversity effects H_T, $\bar{E}_T$, that have a twist-3 character [4]. This gives us a possibility to describe spin observables that are equal to zero without twist-3 contributions. Essential contributions from unnatural parity exchanges were found by HERMES [5] in the ω production. It was shown that the pion pole (PP) contributions [6] are significant for explanation of the large unnatural-parity effects at HERMES in ω and ρ^0 production. We discuss the amplitude properties and physical observables in section 2.

In section 3, using the model results [2–4, 6], we calculate the ratio of different helicity amplitudes to the leading twist longitudinal amplitude and compare the results with preliminary HERMES data [7].

2 ρ^0 meson leptoproduction. Physical observables

We can define Natural and Unnatural parity NP (UP) amplitudes as

$$T(U)_{\lambda\nu',\mu\nu} = \frac{1}{2}\,[M_{\lambda\nu',\mu\nu} \pm (-1)^{\mu-\lambda}\, M_{-\lambda\nu',-\mu\nu}]. \qquad (1)$$

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Here ν, ν' are the initial and final proton helicities and μ, λ are the helicities of the photon and final ρ^0 meson. In what follows, according to [8], we use the notations for the proton spin-non flip and spin-flip amplitudes, respectively,

$$T(U)^{(1)}_{\lambda,\mu} = N(U)_{\lambda+,\mu+}; \quad T(U)^{(2)}_{\lambda,\mu} = N(U)_{\lambda-,\mu+}. \tag{2}$$

We calculate ρ^0 leptoproduction off proton within the handbag approach where the leading amplitude at high photon virtuality Q^2 can be represented in a factorized form [1] as a convolution of a hard meson subprocess amplitude off partons $\mathcal{H}^a_{\mu'+,\mu+}$, which is calculated perturbatively, and GPDs as

$$T^{(1)}_{\lambda\mu} \propto \int_{-1}^{1} d\overline{x}\, \mathcal{H}^a_{\lambda+,\mu+} F^a(\overline{x},\xi,t); \;\; T^{(2)}_{\lambda\mu} \propto -\frac{\sqrt{-t'}}{2m} \int_{-1}^{1} d\overline{x}\, \mathcal{H}^a_{\lambda+,\mu+}\, E^a(\overline{x},\xi,t). \tag{3}$$

Here a is a flavor factor. Generally, factorization is not valid for the not leading amplitudes. These problems can be solved in our model [2, 3] where subprocesses are calculated within the modified perturbative approach [9] in which quark transverse degrees of freedom accompanied by Sudakov suppressions are considered. The quark transverse momentum regularizes the end-point singularities in the TT amplitude thus it can be calculated.

GPDs contain broad information on the hadron structure. With the help of sum rules GPDs are connected with the hadron form factors, and information on the parton angular momenta can be extracted. In the forward limit $t = 0$ and zero skewness $\xi = 0$ GPDs are equivalent to ordinary Parton Distribution Functions (PDFs). The GPDs are estimated by us using the double distribution representation [10], which connects GPDs with PDFs through the double distribution function ω. For the valence quark contribution ω looks like

$$\omega_i(x,y,t) = h_i(x,t)\, \frac{3}{4}\, \frac{[(1-|x|)^2 - y^2]}{(1-|x|)^3}. \tag{4}$$

The functions h in (4) are parameterized as PDFs in the form

$$h(x,t) = N\, e^{b_0 t} x^{-\alpha(t)}\, (1-x)^n, \tag{5}$$

with the t- dependence which is considered in a Regge form, and $\alpha(t)$ is the corresponding Regge trajectory. The parameters for PDFs h in (5) are obtained from the analysis [11]; information about PDFs e is taken from [12]. The handbag approach describes successfully the light meson leptoproduction at HERMES, COMPASS and HERA energies [2, 3]. It can be seen from figure 1, (left) that we describe properly the energy dependence of the ρ^0 cross section from HERMES to HERA energies. Here GPDs H are essential. At $W < 5$GeV the cross section grows unexpectedly. This effect is not understood.

In figure 1, (right) we show the $A_{UT}^{\sin(\phi-\phi_s)}$ asymmetry for ρ^0 production at COMPASS energy which is determined mainly by the interference of GPDs H, E

$$A_{UT}^{\sin(\phi-\phi_s)} \sim \mathrm{Im}[< E >^* < H >]. \tag{6}$$

We describe properly t dependence of $A_{UT}^{\sin(\phi-\phi_s)}$ asymmetry at COMPASS.

Unfortunately, some asymmetries and Spin Density Matrix Elements (SPMEs), which are not small experimentally, are equal to zero in the leading-twist approximation of our GPD model. To describe the experimental data on the meson electroproduction at low Q^2, we consider the amplitudes $T_{01}^{(1,2)}$, which are determined in terms of the transversity GPDs H_T and $\bar{E}_T$. Within the handbag

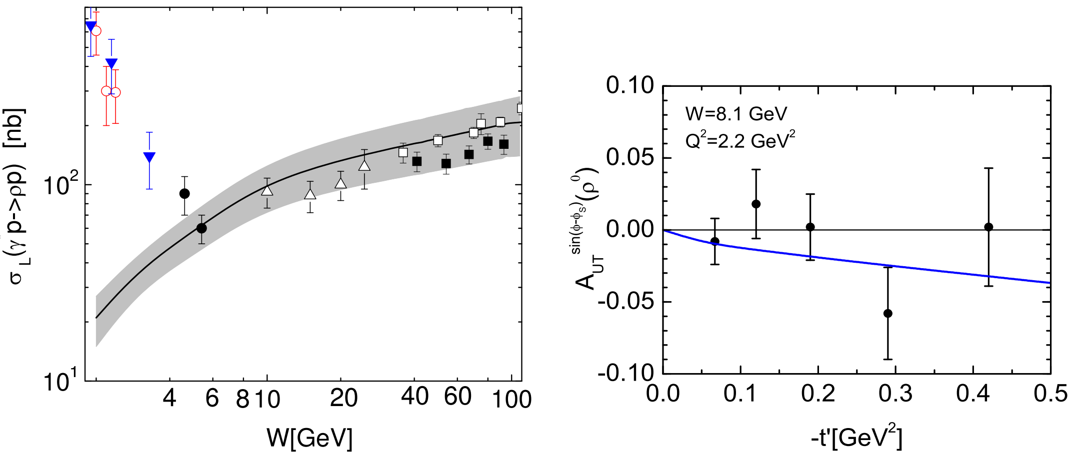

Figure 1. Left: Longitudinal ρ^0 cross section at $Q^2 = 4.0\,\mathrm{GeV}^2$. HERMES (solid circle), ZEUS (open square), H1 (solid square), E665 (open triangle), open circles- CLAS, CORNEL -solid triangle. **Right**: Model results for $A_{UT}^{\sin(\phi-\phi_s)}$ asymmetry for ρ^0 production with COMPASS data [13].

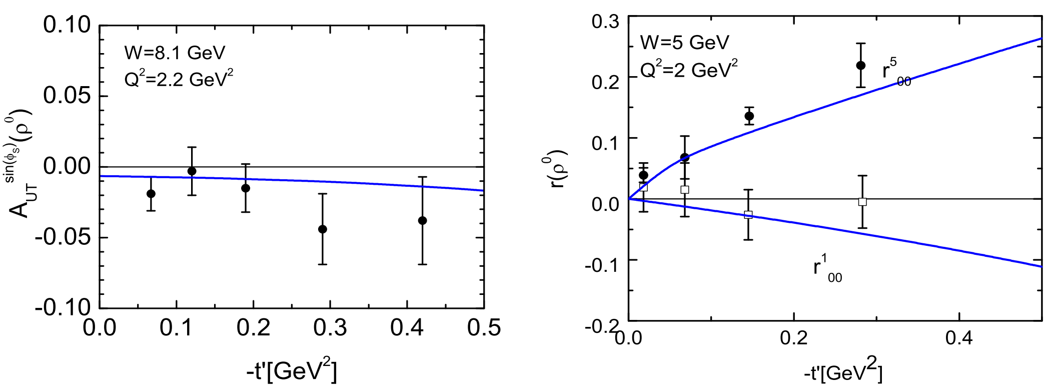

Figure 2. Left: Model results for $A_{UT}^{\sin(\phi_s)}$ asymmetry of ρ^0 production with COMPASS data [13]. **Right**: $\bar{E}_T$ effects in SDMEs of ρ^0 production. HERMES data are shown [14].

approach the transversity GPDs are accompanied by a twist-3 meson wave function in the hard subprocess amplitude $\mathcal{H}$ [4], which is the same for both the $M_{01}^{(1,2)}$ amplitudes:

$$T_{01}^{(1)} \propto \frac{\sqrt{-t'}}{4m} \int_{-1}^{1} d\overline{x} \mathcal{H}_{0-,++}\, \bar{E}_T(\overline{x},\xi,t);\;\; M_{01}^{(2)} \propto \int_{-1}^{1} d\overline{x} \mathcal{H}_{0-,++}\, H_T(\overline{x},\xi,t). \tag{7}$$

The H_T GPDs in the forward limit and $\xi = 0$ are equal to transversity PDFs δ and are parameterized by using the model [15]. Information on $\bar{E}_T$ is obtained now only from the lattice QCD [16]. We estimate the corresponding $\bar{e}_T$ PDFs from the lattice results using form (5). The double distribution is used to calculate transversity GPDs as before. Note that the amplitude $M_{01}^{(2)}$ has no definite parity. Really, $M_{01}^{(2)} = M_{0-++} = -T_{01}^{(2)} + U_{01}^{(2)}$ and $M_{0--+} = -T_{01}^{(2)} - U_{01}^{(2)}$. The last amplitude is equal to zero in the model and $T_{01}^{(2)} = -U_{01}^{(2)}$. Thus NP and UP contributions to the $M_{01}^{(2)}$ amplitude have the same value.

In figure 2, we show transversity effects in spin observables. In figure 2, (left) the $A_{UT}^{\sin(\phi_s)}$ asymmetry is presented together with COMPASS data. This asymmetry is determined by the H, H_T interference

$$A_{UT}^{\sin(\phi_s)} \sim \mathrm{Im}[< H_T >^* < H >]. \tag{8}$$

The data are described quite well by the model results. In figure 2, (right) the SDMEs r_{00}^5 and r_{00}^1 are shown. The first SDME is determined by the H, $\bar{E}_T$ interference and the second one by the $\bar{E}_T$ contribution only

$$r_{00}^5 \sim \mathrm{Re}[< H >^* < \bar{E}_T >]; \quad r_{00}^1 \sim - < \bar{E}_T > |^2. \tag{9}$$

We find that we describe properly both SDMEs at HERMES.

Now we shall discuss UP effects. The UP contribution to the $U_{11}^{(1)}$ amplitude is determined by the polarized $\tilde{H}$ quarks GPDs and can be observed in the A_{LL} asymmetry [3]. It was found that the $\tilde{H}$ effects provide the A_{LL} asymmetry that is a little bit smaller with respect to experiment [3].

The HERMES data for the ω production indicate the strong contributions from UP effects [5]. This can be seen, e.g., from the ratio of the unnatural and natural parity cross sections, which was found to be larger than unity. This effect can be caused [6] by the large PP contribution to this process.

The UP helicity amplitudes determined by PP contribution to ρ^0 leptoproduction looks as follows [6]. The dominant contributions are:

$$U_{11}^{(1)} \sim \frac{\rho_{\pi\rho}}{t - m_\pi^2} \frac{m\, \xi\, Q^2}{\sqrt{1-\xi^2}}, \quad U_{11}^{(2)} \sim -\frac{\rho_{\pi\rho}}{t - m_\pi^2} \frac{\sqrt{-t'}\, Q^2}{2}. \tag{10}$$

Here $\rho_{\pi\rho}$ is proportional to the $\pi\rho$ transition form factor $g_{\pi\rho}$. It can be determined from the ρ^0 meson radiative decay. For ρ^0 production the absolute value of the $\pi\rho$ transition form factor (FF) at zero photon virtuality can be estimated as [6]

$$\Gamma(\rho \to \pi\gamma) \sim \frac{\alpha_{elm}}{24} |g_{\pi\rho}(0)|^2 M_V^3; \quad |g_{\pi\rho}(0)| = .85\mathrm{GeV}^{-1}. \tag{11}$$

This value of $g_{\pi\rho}$ was used in [6] in analysis of PP effects in ρ^0 production.

3 Amplitude ratios of ρ^0 meson leptoproduction.

Our GPD model with NP amplitudes determined by H, E, H_T, $\bar{E}_T$ GPDs and UP effects caused by $\tilde{H}$ and PP contributions describes well physical observables [2–4, 6]. However, observables in terms of GPDs have usually a quite complicated form. More direct information about GPDs can be found from the ratio of different helicity amplitudes on transversely polarized proton target to the leading twist longitudinal amplitude

$$t_{\lambda\mu}^{(i)} = T_{\lambda\mu}^{(i)}/T_{00}, \quad u_{\lambda\mu}^{(i)} = U_{\lambda\mu}^{(i)}/T_{00}, \tag{12}$$

which can be calculated using the model results [2–4, 6].

To be consistent with the HERMES analysis, we study the ratios $t(u)_{\lambda,\mu}^{(i)}$ in the handbag approach using the HERMES definitions of the amplitude signs. The UP amplitudes (10) are dependent on the $g_{\pi\rho}$ sign. The model results for positive $g_{\pi\rho}$ transition FF (squares) and negative FF (triangles) together with HERMES data are shown in figure 3. We present here only the amplitude ratios which are not zero in the model.

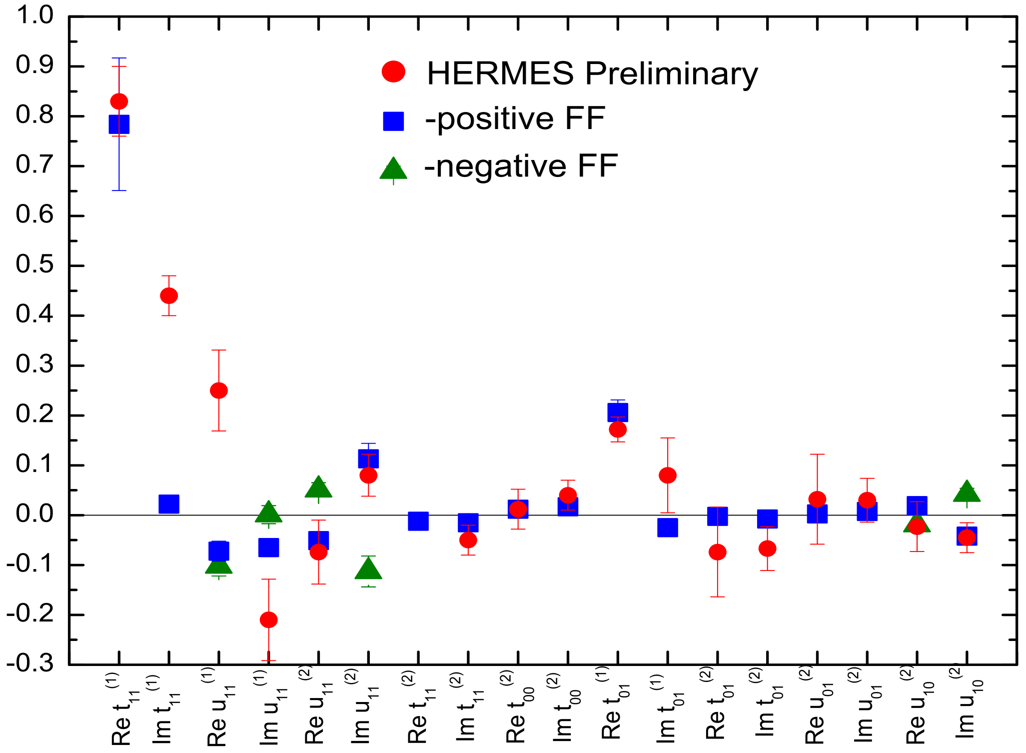

Figure 3. Model results for amplitude ratios of ρ^0 meson leptoproduction for positive and negative $\pi\rho$ transition FF together with HERMES preliminary data [7].

- t^1_{11} is the ratio of transverse to longitudinal amplitudes dominated by H GPDs. The amplitudes are mainly imaginary that give large Ret^1_{11}, which is consistent with data. Imt^1_{11} is rather small in the model. That is caused by the small relative phase between transverse to longitudinal amplitudes [3].
- Small value of u^1_{11} can be related to not so large value of $\tilde{H}$ and the corresponding PP contribution. See the discussion of the A_{LL} asymmetry.
- u^2_{11} is determined by PP effects. We have found a good result for the positive $\pi\rho$ transition FF.
- t^2_{11} is connected with the E GPDs contribution to the proton spin-flip amplitude for the transversely polarized photon and meson. The result is good for the imaginary part of the ratio. There are no experimental data for the real part.
- t^2_{00}- is determined by the E GPDs contribution to the longitudinal amplitude. The model results are not far from experiment.
- t^1_{01} is connected with the twist-3 transversity $\bar{E}_T$ effects. Our results are consistent with HERMES data.
- t^2_{01} and u^2_{01} are determined by the twist-3 transversity H_T effects. It was mentioned that we have connection $t^2_{01} = -u^2_{01}$ for these amplitudes. The amplitude ratios are in agreement with the model results, but they may be a little bit larger.

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- u^2_{10}- is determined by PP contribution. The obtained results are consistent with experiment for the positive $\pi\rho$ transition FF.

We have analyzed meson electroproduction within the handbag approach. Modified perturbative approach was used to calculate the hard subprocess amplitude. GPDs were calculated using PDFs on the basis of the double distribution representation. Good description of different spin observables was found in the model [2–4, 6]. The ratio of different helicity amplitudes on the transversely polarized proton target to the leading twist longitudinal amplitude was calculated. The PP contribution to the UP amplitude ratios is dependent on the sign of the $\pi\rho$ transition FF. The model results for the positive sign of the $\pi\rho$ transition FF are compatible with HERMES data. For the negative sign of FF the results are worse. We can conclude that the positive sign of transition FF is preferable. This is consistent with conclusion done in HERMES and COMPASS papers [5, 17].

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