Cross sections and spin asymmetries in vector meson leptoproduction

S.V. Goloskokov

Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna 141980, Moscow region, Russia

Abstract

Light vector meson leptoproduction is analyzed on the basis of the generalized parton distributions. Our results on the cross section and spin effects are in good agreement with experiment at HERA, COMPASS and HERMES energies. Predictions for $A_{UT}$ asymmetry for various reactions are presented.

In this report, investigation of vector meson leptoproduction is based on the handbag approach where the leading twist amplitude at high $Q^2$ factorizes into hard meson electroproduction off partons and the Generalized Parton Distributions (GPDs) [1]. The higher twist (TT) amplitude which is essential in the description of spin effects exhibits the infrared singularities, which signals the breakdown of factorization [2]. These problems can be solved in our model [3] where subprocesses are calculated within the modified perturbative approach 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 amplitudes so that it can be calculated.

In the model, the amplitude of the vector meson production off the proton with positive helicity reads as a convolution of the partonic subprocess $\mathcal{H}^V$ and GPDs $H^i(\vec{H}^i)$

$$\mathcal{M}_{\mu',\mu}^{Vi} = \frac{e}{2} \sum_a e_a C_a^V \sum_\lambda \int_{x_i}^1 dx_i \mathcal{H}_{\mu',\mu,\lambda}^{Vi} H_i(\vec{x}, \xi, t),$$

where $i$ denotes the gluon and quark contribution, sum over $a$ includes quarks flavor $a$ and $C^V_a$ are the corresponding flavor factors [3]; $\mu$ ($\mu'$) is the helicity of the photon (meson), and $\vec{x}$ is the momentum fraction of the parton with helicity $\lambda$. The skewness $\xi$ is related to Bjorken-$x$ by $\xi \simeq x/2$. In the region of small $x \leq 0.01$ gluons give the dominant contribution. At larger $x \sim 0.2$ the quark contribution plays an important role [3].

To estimate GPDs, we use the double distribution representation [4]

$$H_i(\vec{x}, \xi, t) = \int_{-1}^1 d\beta \int_{-1+|\beta|}^{1-|\beta|} d\alpha \delta(\beta + \xi \alpha - \vec{x}) f_i(\beta, \alpha, t).$$

The GPDs are related with PDFs through the double distribution function

$$f_i(\beta, \alpha, t) = h_i(\beta, t) \frac{\Gamma(2n_i + 2)}{2^{2n_i+1} \Gamma^2(n_i + 1)} \frac{[(1 - |\beta|)^2 - \alpha^2]^{n_i}}{(1 - |\beta|)^{2n_i+1}}.$$
To calculate GPDs, we use the CTEQ6 fits of PDFs for gluon, valence quarks and sea [5]. Note that the $u$($d$) sea and strange sea are not flavor symmetric. In agreement with CTEQ6 PDFs we suppose that $H_{sea}^u = H_{sea}^d = \kappa_s H_{sea}^s$, with

$$
\kappa_s = 1 + 0.68/(1 + 0.52 \ln(Q^2/Q_0^2))
$$

(4)

The parton subprocess $H^V$ contains a hard part which is calculated perturbatively and the $k_{\perp}$-dependent wave function. It contains the leading and higher twist terms describing the longitudinally and transversally polarized vector mesons, respectively. The quark transverse momenta are considered in hard propagators decrease the $LL$ amplitude and the cross section becomes in agreement with data. For the $TT$ amplitude these terms regularize the end point singularities.

We consider the gluon, sea and quark GPDs contribution to the amplitude. This permits us to analyse vector meson production from low $x$ to moderate values of $x$ ($\sim 0.2$) typical for HERMES and COMPASS. The obtained results [3] are in reasonable agreement with experiments at HERA [6, 7], HERMES [8], COMPASS [9] energies for electroproduced $\rho$ and $\phi$ mesons.

![Figure 1](image)

**Figure 1:** (a) The ratio of cross sections $\sigma_\phi/\sigma_\rho$ at HERA energies- full line and HERMES-dashed line. Data are from H1 -solid, ZEUS -open squares, HERMES solid circles. (b) The longitudinal cross section for $\phi$ at $Q^2 = 3.8$ GeV$^2$. Data: HERMES, ZEUS, H1, open circle- CLAS data point.

In Fig 1a, we show the strong violation of the $\sigma_\phi/\sigma_\rho$ ratio from 2/9 value at HERA energies and low $Q^2$, which is caused by the flavor symmetry breaking (4) between $\bar{u}$ and $\bar{s}$. The valence quark contribution to $\sigma_\rho$ decreases this ratio at HERMES energies. It was found that the valence quarks substantially contribute only at HERMES energies. At lower energies this contribution becomes small and the cross section decreases with energy. This is in contradiction with CLAS results which innereve essential increasing of $\sigma_\rho$ for $W < 5$ GeV. On the other hand, we found good description of $\phi$ production at CLAS [10] Fig 1b. This means that we have problem only with the valence quark contribution at low energies.

The results for the $R = \sigma_L/\sigma_T$ ratio are shown in Fig 2a for HERA, COMPASS and HERMES energies. We found that our model describe fine $W$ and $Q^2$ dependencies of $R$. 

2
Figure 2: (a) The ratio of longitudinal and transverse cross sections for $\rho$ production at low $Q^2$. Full line - HERA, dashed-dotted - COMPASS and dashed - HERMES. (b) Predicted $A_{UT}$ asymmetry at COMPASS for various mesons. Dotted-dashed line $\rho^0$; full line $\omega$; dotted line $\rho^+$ and dashed line $K^{*0}$.

Figure 3: (a) The integrated cross sections of vector meson production at $W = 10\text{GeV}$. Lines are the same as in Fig 2b. (b) Predictions for $A_{UT}$ asymmetry $W = 8\text{GeV}$. Preliminary COMPASS data at this energy are shown [11].

The analysis of the target $A_{UT}$ asymmetry for electroproduction of various vector mesons was carried out in our approach too [12]. This asymmetry is sensitive to an interference between $H$ and $E$ GPDs. We constructed the GPD $E$ from double distributions and constrain it by the Pauli form factors of the nucleon, positivity bounds and sum rules. The GPDs $H$ were taken from our analysis of the electroproduction cross section. Predictions for the $A_{UT}$ asymmetry at $W = 10\text{GeV}$ are given for $\omega$, $\rho^+$, $K^{*0}$ mesons [12] in Fig 2b. It can be seen that we predicted not small negative asymmetry for $\omega$ and large positive asymmetry for $\rho^+$ production. In these reactions the valence $u$ and $d$ quark
GPDs contribute to the production amplitude in combination $\sim E^u - E^d$ and do not compensate each other ($E^u$ and $E^d$ GPDs has different signs). The opposite case is for the $\rho^0$ production where one have the $\sim E^u + E^d$ contribution to the amplitude and valence quarks compensate each other essentially. As a result $A_{UT}$ asymmetry for $\rho^0$ is predicted to be quite small. Unfortunately, it is much more difficult to analyse experimentally $A_{UT}$ asymmetry for $\omega$ and $\rho^+$ production with respect to $\rho^0$ because the cross section for the first reactions is much smaller compared to $\rho^0$, Fig. 3a. Our prediction for $A_{UT}$ asymmetry of $\rho^0$ production at COMPASS reproduces well the preliminary experimental data Fig. 3b.

Thus, we can conclude that the vector meson electroproduction at small $x$ is a good tool to probe the GPDs. In different energy ranges, information about quark and gluon GPDs can be extracted from the cross section and spin observables of the vector meson electroproduction.

This work is supported in part by the Russian Foundation for Basic Research, Grant 09-02-01149 and by the Heisenberg-Landau program.

References

[1] X. Ji, Phys. Rev. D55 (1997), 7114; 
A.V. Radyushkin, Phys. Lett. B380 (1996) 417; 
J.C. Collins et al., Phys. Rev. D56 (1997) 2982.

[2] L. Mankiewicz, G. Piller, Phys. Rev. D61 (2000) 074013; 
I.V. Anikin, O.V. Teryaev, Phys. Lett. B554 (2003) 51.

[3] S.V. Goloskokov, P. Kroll, Euro. Phys. J. C50 (2007) 829; ibid C53 (2008) 367.

[4] I. V. Musatov, A. V. Radyushkin, Phys. Rev. D61 (2000) 074027.

[5] J. Pumplin, D. R. Stump, J. Huston, H. L. Lai, P. Nadolsky, W. K. Tung, JHEP 0207 (2002) 012.

[6] C. Adloff et al. [H1 Collab.], Eur. Phys. J. C13 (2000) 371; 
S.Aid et al. [H1 Collab.], Nucl. Phys. B468 (1996) 3.

[7] J. Breitweg et al. [ZEUS Collab.], Eur. Phys. J. C6 (1999) 603; 
S. Chekanov et al. [ZEUS Collab.], Nucl. Phys. B718 (2005) 3; 
S. Chekanov et al. [ZEUS Collab.], PMC Phys. A1 (2007) 6.

[8] A. Airapetian et al. [HERMES Collab.], Eur. Phys. J. C17 (2000) 389; 
A. Borissov, [HERMES Collab.], ”Proc. of Diffraction 06”, PoS (DIFF2006), 014.

[9] D. Neyret [COMPASS Collab.], ”Proc. of SPIN2004”, Trieste, Italy, 2004; 
V. Y. Alexakhin et al. [COMPASS Collab.], Eur. Phys. J. C52 (2007) 255.

[10] J. P. Santoro et al. [CLAS Collab.], Phys. Rev. C78 (2008) 025210.

[11] A. Sandacz [COMPASS Collab.], this proceedings.

[12] S.V. Goloskokov, P. Kroll, Eur. Phys. J. C59 (2009) 809.