ELECTROPRODUCTION OF LIGHT VECTOR MESONS

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Abstract

An analysis of light vector meson photoproduction at small Bjorken $x \leq 0.2$ is done on the basis of the generalized parton distributions (GPDs). Our results on the cross section and spin density matrix elements (SDME) are in good agreement with experiments.

This report is devoted to the study of the vector meson leptoproduction at Bjorken $x \leq 0.2$ based on our results [1, 2, 3]. At large photon virtualities the amplitude for longitudinally polarized virtual photons and vector meson (LL amplitude) factorizes [4] into a hard meson photoproduction off partons and GPDs. Unfortunately, in the collinear approximation the LL cross section exceeds the data by an order of magnitude [5]. Moreover, in this approximation the amplitude for transversally polarized photons (TT amplitude) exhibits infrared singularities [6], which signals the factorization breakdown.

In this report, we discuss the spin effects in the vector meson leptoproduction. Our calculations [2, 3] are based on the modified perturbative approach (MPA) [7] which includes the quark transverse degrees of freedom accompanied by Sudakov suppressions. The contribution from the end-point region to the LL amplitude is suppressed in our model and the cross section is close to the experiment. The TT amplitudes can be calculated in the model because the transverse quark momentum regularizes the singularities. Within the MPA we calculate the cross sections and the spin observables in the energy range $5 \text{GeV} < W < 90 \text{GeV}$. Our results on the cross section and SDME are in good agreement with experiments [8, 9, 10, 11].

The model is based on the handbag approach where the $\gamma^* p \rightarrow V p$ amplitude factorizes into hard partonic subprocess and GPDs. In the region of small $x \leq 0.01$ gluons give the dominant contribution [1]. At larger $x \sim 0.2$, in addition to the gluon GPD the inclusion of quark contribution is important [2, 3]. For small $t$ 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 $H^i (\bar{H}^i)$

$$
\mathcal{M}^V_{\mu^+, \mu^+} = \frac{\epsilon}{2} C^V \sum_\lambda \int d\bar{x} \mathcal{H}^V_{\mu^+, \mu^+} H^i (\bar{x}, \xi, t),
$$

where $i$ denotes the gluon and quark contribution, $\mu (\mu')$ is the helicity of the photon (meson), $\bar{x}$ is the momentum fraction of the parton with helicity $\lambda$, and the skewness $\xi$ is related to Bjorken-$x$ by $\xi \simeq x/2$. The flavor factors are $C^p = 1/\sqrt{2}$ and $C^\phi = -1/3$. In the analysis of the cross section at small $x$ the main contribution is determined by the unpolarized GPDs $H^i$. 

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The $k$-dependent wave function [12] that contains the leading and higher twist terms
describing the longitudinally and transversally polarized vector meson is used to calculate
the partonic subprocess $H$ in (1); $H$ is estimated within the MPA [7] where we keep the $k_\perp^2$
terms in the denominators of the amplitudes and in the numerator of the TT amplitude.
The gluonic corrections are treated in the form of the Sudakov factors which additionally
suppress the end-point integration regions.

The GPDs are modeled using the double distribution

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

Here the double distribution function $f_i(\beta, \alpha, t)$ is connected with the corresponding parton
distributions (PDFs) which are taken from the CTEQ6M results [14]. The simple
Regge ansatz is used to consider $t$ dependencies of PDFs. For details see [2, 3].

Figure 1: Left: The cross sections of $\phi$ production at $W = 75\text{GeV}$ with error band from
CTEQ6 PDFs uncertainties. Data are from H1 [8] -solid symbols and ZEUS [9] -open symbols.
Dashed line- LO result. Right: The cross sections of $\rho$ production via $W$ at different $Q^2$.

The cross section for the $\gamma^* p \to \phi p$ production integrated over $t$ is shown in Fig.1 (full line).
Good agreement with DESY experiments [8, 9] is observed. The shared bands in the figures reflect uncertainties of our results caused by the errors in the CTEQ6 PDFs.
The leading twist results are also presented in Fig. 1. The $k_\perp^2/Q^2$ corrections in the hard amplitude decrease the cross section by a factor of about 10 at $Q^2 \sim 3\text{GeV}^2$.

Our results reproduce well the energy dependence of the $\rho$ cross section [9] as shown
in Fig.1. The cross section at HERA energies is dominated by the gluon and sea quark contributions.

The model describes properly spin effects determined by the TT transition amplitude.
Our results for the ratio of the longitudinal and transverse cross sections and SDME in
the energy range $5\text{GeV} < W < 75\text{GeV}$ can be found in [3]. In Fig.2, we present the SDME on the $\rho$ production at $W = 5, 10, 75\text{GeV}$. At HERMES energy $W = 5\text{GeV}$ the valence quark contribution to the amplitudes is essential. At COMPASS $W = 10\text{GeV}$ quark effects are not so large and they are negligible at HERA $W = 75\text{GeV}$. This is
Figure 2: The $Q^2$ dependence of SDME on the $\rho$ production and $W = 75(10,5)\text{GeV}$-solid(dash-dotted, dashed) line. Preliminary data are taken from HERMES [10] (solid circles) and COMPASS [11] (diamonds).

the main reason of the energy dependencies of SDME shown in Fig.2. A similar energy dependence is observed experimentally.

The $A_{LL}$ asymmetry for a longitudinally polarized beam and target is sensitive to the polarized GPD. The leading term in $A_{LL}$ asymmetry integrated over the azimuthal angle is determined through the interference between the $H$ and $\tilde{H}$ distributions. In Fig. 3, we show our results for the $\rho$ production at $W = 5\text{GeV}$ and $W = 10\text{GeV}$. At HERMES energies the valence quark contribution generates large asymmetry of the order of 0.1 which is compatible with the experimental results [10]. At COMPASS [11], the valence quark contribution is small and asymmetry close to zero is predicted. Note that we observe an essential cancellation of the gluon and sea quark contributions. This leads to small $A_{LL}$ asymmetry for the $\phi$ production.

In summary: Light vector meson electroproduction at small $x$ was analyzed here within the GPD approach. The partonic subprocesses have been calculated using the MPA with the wave function dependent on the transverse quark momentum. The higher order $k^2_\perp/Q^2$ corrections which are considered in the propagators of the partonic subprocess decrease the cross section by a factor of about 10 at $Q^2 \sim 3\text{GeV}^2$. The same higher order effects in the denominators of the hard subprocess regularize the singularities in the TT amplitude. This gives a possibility to calculate the TT amplitude and study spin effects in the vector meson production in our model.

In our previous calculations [1] we analysed the low $x \leq 0.01$ region where the gluon contribution has a predominant role. In this report, we extend our analysis to $x \sim 0.2$ [2, 3]. In the moderate $x$ region we consider gluon, sea and valence quark GPDs. The GPDs are modeled via double distribution based on the CTEQ6M distributions. In the model we find a good description of the cross section and the spin observables from HERMES to HERA energies [2]. It is found that the gluon and sea contributions control the amplitude behaviour at energies $W \geq 10\text{GeV}$. Valence quarks are essential only at
HERMES energies, where their contribution to the $\rho(\omega)$ cross section is about 40(65%). This shows that the $\omega$ production at low energies is much more sensitive to valence quarks than $\rho$ production.

The model describes well the ratio of the longitudinal and transverse cross sections and SDME in the energy range $5\text{GeV} < W < 75\text{GeV}$ [3]. We predict large $A_{LL}$ asymmetry at HERMES energies determined by the valence quark contribution which is compatible with experiment. At COMPASS the $A_{LL}$ asymmetry is small, about zero. Our first results on SDME for transversally polarized target and $A_{UT}$ asymmetry can be found in [3].

Thus, we can conclude that the vector meson photoproduction at small $x$ is a good tool to probe the GPDs. Study of SDME gives important information on the structure of different helicity amplitudes in the vector meson production.

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