HARD MESON ELECTROPRODUCTION AND TWIST-3 EFFECTS.

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Abstract

We analyze light meson electroproduction within the handbag model. We study cross sections and spin asymmetries for various mesons. The essential role of the transversity $\tilde{H}_T$ and $\tilde{E}_T$ GPDs in electroproduction of pseudoscalar mesons is found. Our results are in good agreement with experiment.

In this report, investigation of the pseudoscalar 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 amplitude of the meson electroproduction off the proton reads as a convolution of the partonic subprocess amplitude $H$ and GPDs $H$

$$\mathcal{M}^a_{\mu_\pm,\mu_+} = \sum_a \langle H^a \rangle \times \sum_\lambda \int_{x_i}^1 d\bar{x} H^a_{\mu'_\lambda,\mu_\lambda}(Q^2, \bar{x}, \xi) H^a(\bar{x}, \xi, t),$$

where $a$ denotes the gluon and quark contribution with the corresponding flavors; $\mu$ ($\mu'$) is the helicity of the photon (meson), and $\bar{x}$ is the momentum fraction of the parton with helicity $\lambda$. The skewness $\xi$ is related to Bjorken-$x$ by $\xi \simeq x/2$.

The subprocess amplitudes $H^V$ are calculated within the modified perturbative approach (MPA) [2] where the quark transverse momenta $k_\perp$ are taken into account together with the gluonic radiation, condensed as a Sudakov factor. The amplitude $H^V$ contains a convolution of a perturbatively calculated hard part where we keep in the propagators the $k_\perp^2$ terms and the $k_\perp$-dependent wave function [3].

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

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

The GPDs are related with PDFs through the double distribution function

$$f_i(\beta, \alpha, t) = h_i(\beta, t) \frac{3[(1-|\beta|)^2 - \alpha^2]}{(1-|\beta|)^3}.$$
PDFs [5] e.g. or from the nucleon form factor analysis [6]. The model results on the cross sections and spin density matrix elements (SDME) for vector meson production obtained in [7,10] are in good agreement with experimental data in a wide energy range.

The hard exclusive pseudoscalar meson lepton production in the leading twist is sensitive to the polarized GPDs $\tilde{H}$ whose parameterization can be found in [9] and $\tilde{E}$. The pseudoscalar meson production amplitude with longitudinally polarized photons $\mathcal{M}_{0^+0^+}^P$ dominates at large $Q^2$. The amplitudes with transversally polarized photons are suppressed as $1/Q$. The pseudoscalar meson production amplitude can be written as [11]:

$$\mathcal{M}_{0^+0^+}^P \propto \left[ \langle \tilde{H}^P \rangle - \frac{2\xi mQ^2}{1 - \xi^2} \frac{\rho_P}{t - m_P^2} \right]; \quad \mathcal{M}_{0^-0^+}^P \propto \frac{\sqrt{-t}}{2m} \left[ \xi \langle \tilde{E}^P \rangle + 2mQ^2 \frac{\rho_P}{t - m_P^2} \right]. \quad (5)$$

The first terms in (5) represent the handbag contribution to the pseudoscalar (P) meson production amplitude [11] calculated within the MPA with the corresponding transition GPDs. For the $\pi^+$ production we have the $p \to n$ transition GPD where the combination $\tilde{F}^{(3)} = \tilde{F}^{(u)} - \tilde{F}^{(d)}$ contributes. The second terms in (5) appear for charged meson production and are connected with the P meson pole. In calculations we use the fully experimentally measured electromagnetic form factor of P meson.

In addition to the pion pole and the handbag contribution, which in the leading twist is determined by the $\tilde{H}$ and $\tilde{E}$ GPDs, a twist-3 contribution to the amplitudes $\mathcal{M}_{0^-++}$ and $\mathcal{M}_{0^+++}$ is required to describe the polarized data at low $Q^2$. To estimate this effect, we use a mechanism that consists of the transversity GPD $H_T$, $E_T$ in conjugation with the twist-3 pion wave function. For the $\mathcal{M}_{0^-\mu+}$ amplitude we have [11]

$$\mathcal{M}_{0^-\mu+}^{P, twist-3} \propto \int_{-1}^{1} d\tau H_{0^-\mu+}(\tau, ...) \left[ H_T^P + ...O(\xi^2 E_T^P) \right]. \quad (6)$$

The $H_T$ GPD is connected with transversity PDFs as

$$H_T^P(x, 0, 0) = \delta^a(x); \quad \delta^a(x) = CN_T x^{1/2} \left( 1 - x \right) \left[ g_a(x) + \Delta g_a(x) \right]. \quad (7)$$

Here we parameterize the PDF $\delta$ using the model [12]. The DD form [23] is used to calculate GPD $H_T$. It is important that the $H_T^a$ and $H_T^d$ GPDs are different in sign.

The twist-3 contribution to the amplitude $\mathcal{M}_{0^+\mu+}$ has a form [13] similar to (6)

$$\mathcal{M}_{0^+\mu+}^{P, twist-3} \propto \frac{\sqrt{-t}}{4m} \int_{-1}^{1} d\tau H_{0^-\mu+}(\tau, ...) \tilde{E}_T^P. \quad (8)$$

The information on $\tilde{E}_T$ was obtained only in the lattice QCD [14]. The lower moments of $\tilde{E}_T^u$ and $\tilde{E}_T^d$ were found to be quite large, have the same sign and a similar size. This means that we have an essential compensation of the $\tilde{E}_T$ contribution in the $\pi^+$ amplitude: $\tilde{E}_T^{(3)} = \tilde{E}_T^u - \tilde{E}_T^d$. $H_T$ does not compensate in this process. For the $\pi^0$ production we have the opposite case. We find here a large contribution from $\tilde{E}_\pi^{\pi^0} = 2/3 \tilde{E}_T^u + 1/3 \tilde{E}_T^d$, $H_T$ effects are not so essential here. The parameters for individual PDFs were taken from the lattice results, and DD model was used to estimate $E_T$.

In Fig. 1a, we show the full unseparated cross section of the $\pi^+$ production which describes fine the HERMES data [15]. The longitudinal cross section determined by leading-twist dominates at small momentum transfer $-t < 0.2 \text{GeV}^2$. At larger $-t$ we
Figure 1: (a) The cross section of the $\pi^+$ production together with HERMES data. (b) $\pi^0$ production at HERMES. For both: full line- unseparated cross section, dashed-dotted-$\sigma_L$, dotted line-$\sigma_T$.

Figure 2: (a) $Q^2$ dependence of $\pi^0$ production cross section at HERMES. (b) Predictions for the moments of $A_{UT}$ asymmetry of $\pi^0$ production at HERMES.

find a not small contribution from the transverse cross section. Effects of $E_T$ is negligible here.

For the $\pi^0$ production we show above that the transversity effect should be essential. They lead to a large transverse cross section $\sigma_T$. The longitudinal cross section, which is under control of the leading twist contribution and expected to play an important role, is much smaller with respect to the transverse $\sigma_T$ cross section. The predominated role of transversally polarized photons is mainly generated by the $E_T$ GPDs contribution.
This surprising result for the cross section of the $\pi^0$ production at HERMES energies is presented in Fig. 1b. It was found that the transversity GPDs leads to a large $\sigma_T$ for all reactions of pseudoscalar meson production with the exception of $\pi^+$ and $\eta'$ channels. These twist-3 effects have $1/Q$ suppression with respect to the leading twist contribution. The $Q^2$ dependence of the transverse cross section in Fig. 2a shows a rapid decrease of $\sigma_T$ at HERMES energies. It is important that the $M^{\text{P, twist-3}}_{0+,\mu+}$ amplitude which is under control of $E_T$ GPDs has a zero for $-t' = 0$. This provides a minimum of the cross section at zero momentum transfer, Figs. 1b, 2a.

In Fig. 2b, our predictions for the $\sin(\phi - \phi_s)$ and $\sin(\phi)$ moments of $A_{UT}$ asymmetry for the transversally polarized target are presented. Predicted asymmetries are quite large and can be measured experimentally.

If Fig. 3a we show the ratio of the $\eta/\pi^0$ cross section at CLAS energies for two parameterizations of $H_T$ GPDs. Different combinations of the quark contributions to these processes leads to the essential role of $H_T$ effects at $-t < 0.2\text{GeV}^2$ in this ratio. At larger momentum transfer the $E_T$ contributions predominate. That leads to the rapid $t$-dependence of the $\eta/\pi^0$ cross section ratio. The preliminary CLAS data confirm the large $E_T$ effects in $\pi^0$ production found in the model.

Figure 3: (a) The ratio of the $\eta/\pi^0$ cross section at CLAS together with preliminary CLAS data. (b) The $\pi^0$ cross section at CLAS together with preliminary CLAS data. Full line- unseparated cross section, dashes- $\sigma_{LT}$, dashed dotted- $\sigma_{TT}$. Dashed-dot-dotted line- the alternative parameterizations of $H_T$.

In Fig 3b, we show our prediction for $\pi^0$ production at the CLAS energy range together with preliminary experimental data. The data are not far from our predictions at the CLAS energy and definitely show the dip at low momentum transfer which is less with respect to the standard $H_T$ parameterization (full line). The alternative $H_T$ parameterization shows a smaller dip at $t' = 0$ and a smaller cross section at large $t'$ as well. The main prediction of the model- large $\sigma_T$ cross section can be checked if the data on the separated $\sigma_L$ and $\sigma_T$ cross section will be available.

In a similar way we can estimate $E_T$ effects in the vector meson leptoproduction. Some
details can be found in [11]. The $M_{0++,++}$ amplitude and correspondingly the transversity twist-3 effects are essential in the $r_{10}^*$ and $r_{50}^*$ SDME. Our results are shown in Fig. 4. They are consistent in signs and values with HERMES data [17] without any free parameters. However, such estimations now can be made only for the quark contribution and cannot be used for the low $x_B$ range.

In this report, the hard pseudoscalar meson electroproduction is calculated within the MPA which takes into account the quark transverse degrees of freedom and the Sudakov suppressions. At the leading-twist accuracy this class of reactions is sensitive to the GPDs $\tilde{H}$ and $\tilde{E}$. However, rather strong contributions from the amplitudes $M_{0-,++}$ and $M_{0,++}$ are required to describe experimental data. These amplitudes are generated by the transversity GPDs $H_T$ and $E_T$ accompanied by the twist-3 pseudoscalar meson wave functions. Our parameterizations of GPDs are consistent with the lattice QCD results and other information like nucleon form factors. The model predicts the large $\eta/\pi^0$ cross section ratio $\sim 1$ at small momentum transfer and its small value $\sim .3$ at $-t' > 0.2\text{GeV}^2$. The small value of the ratio is compatible with the CLAS data. At the same time, JLAB data on unseparated cross section have definite dip at $t' \sim 0$. These model results are determined by the twist-3 transversity $E_T$ effects compatible with the data.

Our calculations of the twist-3 transversity effects in SDME of $\rho^0$ production are not far from the HERMES data. Since our parameterization of $E_T$ fully depends on the lattice QCD estimations, our results for the cross sections of electroproduction of pseudoscalar mesons are real predictions. All these observations can indicate the large transversity effects in the mentioned reactions. To check them, additional investigation is needed. For example, the analysis of separated $\sigma_L$ and $\sigma_T$ cross section in $\pi^0$ production is important to get the definite conclusion about $E_T$ GPDs.

We describe fine the well-known data on the cross section and spin observables for various meson productions [7–10]. We give predictions for cross sections and spin asymmetries for all pseudoscalar meson channels [11,13] at low skewness and small momentum transfer. Our predictions can be examined in future experiments and shed light on the role of transversity effects in these reactions.

Thus, we can conclude that information about twist-3 transversity effects can be obtained from pseudoscalar meson electroproduction for example at JLAB energies.

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