Transversity effects in light meson leptoproduction.

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Abstract. The light meson electroproduction is analyzed within the handbag approach. We consider the leading-twist contribution together with the transversity effects. We show that the transversity Generalized Parton Distributions (GPDs), $H_T$ and $E_T$ are essential in the description of spin effects in the pseudoscalar and vector meson leptoproduction.

1 Introduction

The handbag approach where the amplitudes factorize into the hard subprocess and GPDs [1] was successfully applied to the light vector meson (VM) leptoproduction at high photon virtualities $Q^2$ [2] and the pseudoscalar meson (PM) leptoproduction [3].

In the leading twist approximation the amplitudes of the PM leptoproduction are sensitive to the GPDs $\tilde{H}$ and $\tilde{E}$. It was found that these contributions are not sufficient to describe spin effects in the PM production at sufficiently low $Q^2$ [3]. The essential contributions from the transversity GPDs $H_T$, $E_T$ are needed [4] to be consistent with experiment. Within the handbag approach the transversity GPDs contribute to the amplitude together with the twist-3 meson wave function. We discuss the handbag approach and properties of meson production amplitudes in section 2.

In section 3 of this report we study the experimental evidence of transversity effects in the cross sections of the PM leptoproduction at HERMES and CLAS energies. Our results are in good agreement with experiment on the $\pi^0$ production. We show that the transversity GPDs lead to a large transverse cross section for most reactions of the pseudoscalar meson production [4] which has the twist-3 nature.

We investigate the role of transversity GPDs in the VM leptoproduction in section 3 within the handbag approach [5]. The importance of the transversity GPDs was found in the SDMEs and in asymmetries measured with a transversely polarized target. The obtained results are in good agreement with CLAS, HERMES and COMPASS data.

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2 Handbag approach. Properties of meson production amplitudes

Within the handbag approach the meson production amplitude is factorized at sufficiently high $Q^2$ \[1\] into a hard subprocess amplitude $\mathcal{H}$ and GPDs $F$ which contain information on the hadron structure see, Fig.1.

The subprocess amplitude is calculated within the MPA \[6\]. We consider the power $k^2/Q^2$ corrections in the propagators of the hard subprocess $\mathcal{H}$ together with the nonperturbative $k^2$-dependent meson wave function \[7\]. The power corrections can be regarded as an effective consideration of the higher twist effects. The gluonic corrections are treated in the form of the Sudakov factors whose resummation can be done in the impact parameter space \[6\].

The leading contributions to the proton non-flip amplitude can be expressed in terms various parton effects

$$M_{\mu',\mu+} \propto \int_{-1}^{1} dx \mathcal{H}_{\mu',\mu+}^{a} F^{a}(x, \xi, t).$$

(1)

Here $a$ is a flavor factor. In the VM production we have $F^{a}$ GPDs contributions from gluons, quarks and sea. In PM production polarized GPDs $\tilde{F}^{a}$ contributes.

The GPDs are estimated using the double distribution representation \[8\] which connects GPDs $F$ with PDFs $h$ through the double distribution function $\omega$. For the valence quark contribution it looks like

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

(2)

The $t$- dependence in PDFs $h$ is considered in the Regge form

$$h(\beta, t) = N e^{b_{0,t} \beta - \alpha(t)} (1 - \beta)^n,$$

(3)

and $\alpha(t)$ is the corresponding Regge trajectory. The parameters in \[3\] are obtained from the known information about PDFs \[9\] e.g, or from the nucleon form factor analysis \[10\].

At the leading-twist accuracy the PM production is only sensitive to the GPDs $\tilde{H}$ and $\tilde{E}$ which contribute to the amplitudes for longitudinally polarized virtual photons \[3\]. It was found that at low $Q^2$ data on the PM leptoproduction also require the contributions from the transversity GPDs $H_T$ and $E_T$ which determine the amplitudes $M_{0-,++}$ and $M_{0++,+}$ respectively. Within the handbag approach the transversity GPDs are accompanied by a twist-3 meson wave function in the hard amplitude $\mathcal{H}$ \[4\] which is the same for both the $M_{0\pm,+}$ amplitudes in \[4\].

$$M_{0-,++}^{M,tw-3} \propto \int_{-1}^{1} d\xi \mathcal{H}_{0-,++}(\xi, ...) H^M_T; \ M_{0++,+}^{M,tw-3} \propto \sqrt{-t} \int_{-1}^{1} d\xi \mathcal{H}_{0-,,++}(\xi, ...) E^M_T.$$

(4)
The $H_T$ GPDs are connected with transversity PDFs as

$$H_T^a(x, 0, 0) = \delta^a(x); \quad \text{and} \quad \delta^a(x) = CN_T Q^{1/2} x (1 - x) [q_a(x) + \Delta q_a(x)]. \quad (5)$$

We parameterize the PDF $\delta$ by using the model [11].

The information on $\bar{E}_T$ is obtained now only in the lattice QCD [12]. The lower moments of $\bar{E}_T^u$ and $\bar{E}_T^d$ were found to be quite large, have the same sign and a similar size. As a result, we have large $\bar{E}_T$ contributions to the $\pi^0$ production.

For the VM production the transversity $M_{0,+,+}$ and $M_{0,++,}$ amplitudes have the form [11] but they are parametrically about 3 times smaller [5] with respect to the PM case. In calculations we use the same parameterizations for transversity GPDs $H_T$ and $\bar{E}_T$ which were obtained in our study of the PM leptoproduction and can be found in [4,5]. The double distribution is used to calculate GPDs in all cases.

### 3 Transversity effects in meson leptoproduction

In this section, we present our results on the PM and the VM leptoproduction based on the handbag approach. In calculation, we use the leading contribution (1) together with the transversity effects (4) which are essential at low $Q^2$. In Fig. 2 (left), we present the model results for the $\pi^0$ production cross section. The transverse cross section, where the $\bar{E}_T$ and $H_T$ contributions are important [4], dominates at low $Q^2$. At small momentum transfer the $H_T$ effects are visible and provide a nonzero cross section. At $-t' \sim 0.2 GeV^2$ the $\bar{E}_T$ contribution becomes essential in $\sigma_T$ and gives a maximum in the cross section. A similar contribution from $\bar{E}_T$ is observed in the interference cross section $\sigma_{TT}$ [4]. The fact that we describe well both unseparated $\sigma = \sigma_T + \epsilon \sigma_L$ and $\sigma_{TT}$ cross sections can probably indicate that the transversity effects were observed at CLAS [13].

![Fig. 2.](image_url) Left: $\pi^0$ production in the CLAS energy range together with the data [13]. Dashed-dot-dotted line-$\sigma = \sigma_T + \epsilon \sigma_L$, dashed line-$\sigma_{LT}$, dashed-dotted-$\sigma_{TT}$. Right: Cross sections of the $K^+ \Sigma^0$ production at HERMES energies.

Using the same model approach the kaons leptoproduction was considered. We show the model results [4] for the $K^+ \Sigma^0$ leptoproduction in Fig. 2 (right). Both $H_T$ and $\bar{E}_T$ transversity GPDs contribute here and provide a cross section similar in form to the $\pi^0$ case. In both reactions the leading-twist longitudinal cross section
is small, see Fig. 2 (right), at low $Q^2$ where the transverse cross section dominates. At sufficiently high $Q^2$ the $\sigma_T$ cross section which decreases rapidly with $Q^2$ will be small with respect to the leading twist $\sigma_L$.

![Fig. 3. Transversity effects in the $r_{00}^5$, $r_{10}^1$ SDMEs. Left: at $W = 5\text{GeV}$ together with HERMES data \[14\]. Right: SDMEs at CLAS (dot-dashed line) and COMPASS energies](image)

Now we shall consider the effects of transversity in the VM production. We use here the same GPDs as for the PM case. The importance of the transversity GPDs was examined in the SDMEs and in the transversely polarized target asymmetries. The $M_{0+,++} = \langle E_T \rangle$ amplitude is essential in some SDMEs. Really,

$$r_{00}^5 \sim \text{Re}[M_{0+,0+}^* M_{0+,++}]; \quad r_{10}^1 \sim -|M_{0+,++}|^2; \quad r_{10}^{05} \sim \text{Re}[M_{++,++}^* M_{0+,++}]. \quad (6)$$

Our results for these the $r_{00}^5$, $r_{10}^1$ SDMEs in the $\rho^0$ meson production at HERMES are shown in Fig. 3(left). The values and signs are in good agreement with HERMES experimental data \[13\]. The $r_{10}^{05}$ SDME is reproduced well too. We observe that large $E_T$ effects found in the $\pi^0$ channel are compatible with SDME of the $\rho$ production at HERMES energies. The model prediction \[5\] for these SDMEs at CLAS and COMPASS energies are shown in Fig 3 (right). The predicted SDMEs are quite large and can be measured experimentally.

The transversity effects in $A_{UT}$, $A_{LT}$ asymmetries was analyzed in \[5\] too. The $\sin(\phi_s)$ moment of the $A_{UT}$ asymmetry is determined by the interference transversity $H_T$ contribution and the non-flip amplitude $M_{0+,0+}$.

$$A_{UT}^{\sin(\phi_s)} \sim \text{Im}[M_{0-,++}^* M_{0+,0+}]; \quad M_{0-,++} = \langle H_T \rangle \quad (7)$$

It was found that the asymmetry is not small. The energy dependence of the $A_{UT}^{\sin(\phi_s)}$ asymmetry from CLAS to HERMES is quite rapid and shown in Fig. 4 (left). This prediction can be verified at a future CLAS experiment to test the $x$- dependence of GPDs $H_T$. At COMPASS energies our results are shown in Fig. 4 (right). In Fig. 5 (left) the $Q^2$ dependence of $A_{UT}^{\sin(\phi_s)}$ is presented. Our results at COMPASS are compatible with the data \[13\].

In Fig. 5 (right) we show our results for the $\sin(\phi - \phi_s)$ moment of the $A_{UT}$ asymmetry

$$A_{UT}^{\sin(\phi - \phi_s)} \sim \text{Im}[M_{0-,0+}^* M_{0+,a+}^* - M_{0-,++}^* M_{0+,++}] \quad (8)$$
4 Conclusion

The exclusive electroproduction of vector and pseudoscalar mesons was analyzed here within the handbag approach where the amplitude factorized in two parts. The first one is the subprocess amplitudes which are calculated using the $k_\perp$ factorization \cite{6}. The other essential ingredients are the GPDs which contain information about the hadron structure. The results based on this approach on the cross sections and various spin observables were found to be in good agreement with data at HERMES, COMPASS and HERA energies at high $Q^2$ \cite{2}.

The leading-twist accuracy is not sufficient to describe the PM lepto-production at rather low $Q^2$. It was also found that rather strong twist 3 contributions are required at COMPASS energies which are compatible with experiment. This asymmetry is determined essentially by the interference of the $<E>$ and $<F>$ contributions \cite{1} and is consistent with the data. The effects of transversity is quite small here. We describe well \cite{5} the $A_{UT}^{\sin(\phi_s)}$ asymmetry at HERMES energies \cite{16} too.
by experiment. In the handbag approach they are determined by the transversity GPDs $H_T$ and $\bar{E}_T$ in convolution with a twist-3 pion wave function. It turned out that the transversity GPDs lead to a large transverse cross section for most reactions of the PM production. There are some indications that the large transversity effects are available now at CLASS [13].

In the VM leptoproduction the transversity GPDs occur in the amplitudes with a transversely polarized virtual photon and a longitudinal polarized vector meson. The structure of the twist-3 amplitudes in the VM production is similar to the PM case. We show the importance of the transversity GPDs in the SDMEs $r_{00}$, $r_{10}$ and $r_{10}^{\rho_0}$ of $\rho_0$ production which were found to be essentially dependent on the $\bar{E}_T$ transversity affects. Our results are in good agreement with HERMES experimental data [13].

The asymmetries measured with a transversely polarized target were estimated as well. The $A_{UT}^{\sin(\phi_0)}$ transverse target spin asymmetry [5] is consistent with HERMES and COMPASS data [10,15]. We find a large $H_T$ contribution to the $A_{UT}^{\sin(\phi_0)}$ asymmetry which is not small at COMPASS [5] and also compatible with the experimental data [15]. Our predictions were compared by COMPASS [15] with the COMPASS experimental data. Thus, we can conclude that the transversity GPDs are extremely essential in understanding the spin effects in the light meson leptoproduction at moderate $Q^2$.

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$W = 8.1 \text{ GeV}$

$Q^2 = 2.2 \text{ GeV}^2$

$\cos(\phi_s)$

$-t'[\text{GeV}^2]$
