ROLE OF TRANSVERSITY IN SPIN EFFECTS IN MESON
LEPTOPRODUCTION.

S.V. Goloskokov†

Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna
141980, Moscow region, Russia
† E-mail: goloskkv@theor.jinr.ru

Abstract

We analyze the light meson leptoproduction within the handbag approach. We show that effects determined by the transversity Generalized Parton Distributions (GPDs), $H_T$ and $E_T$, are essential in the description of pseudoscalar and vector meson leptoproduction.

1 Introduction

In our papers [1], we calculated the processes of light meson leptoproduction within the handbag approach, where the amplitudes factorize into hard subprocesses and in (GPDs) [2] which encode soft physics. The modified perturbative approach [3], where the quark transverse degrees of freedom accompanied by Sudakov suppressions are taken into account, was used to calculate the hard subprocess amplitudes. We discuss some details of this approach for vector meson (VM) production in section 2.

The pseudoscalar meson (PM) production was analyzed in [4, 5]. It was found that the transversity GPDs $H_T$ and $E_T$ are essential in the description of these reactions at low $Q^2$. Within the handbag approach the transversity GPDs are accompanied by twist-3 meson distribution amplitudes. These transversity contributions provide large transverse cross sections for most of the pseudoscalar meson channels [6] (see section 3).

The role of transversity GPDs in the VM leptoproduction [6] is discussed in section 4. The importance of the transversity GPDs was examined in the Spin Density Matrix Elements (SDMEs) and in asymmetries measured with a transversely polarized target. For the transversity GPDs $H_T$ and $E_T$ we used the same parameterizations as in our study of the PM leptoproduction. Our results for SDMEs are in good agreement with HERMES experimental data on the $\rho^0$ production. We also estimated the moments of transverse target spin asymmetries $A_{UT}$ which contain the transversity contributions. The $A_{UT}^{\sin(\phi_s)}$ asymmetry is found to be not small [6] at COMPASS energies.

2 Meson leptoproduction and handbag approach

The amplitude of meson leptoproduction at large $Q^2$ is assumed to factorize [2] into a hard subprocess amplitude $H$ and a soft proton matrix element, parameterized in terms of GPDs $F(\overline{x}, \xi, t)$, $E(\overline{x}, \xi, t)$, ....
The proton non-flip and spin-flip amplitude can be expressed in terms of gluons, quarks or sea contributions

\[ M_{\mu'\mu+} \propto \int_{-1}^{1} dx H_{\mu'\mu+}^a(x, \xi, t), \quad M_{\mu'\mu+} \propto \frac{\sqrt{-t}}{2m} \int_{-1}^{1} dx H_{\mu'\mu+}^a(x, \xi, t). \]  

(1)

The subprocess amplitude is calculated within the MPA \[3\]. The amplitude \( H^a \) is a contraction of the hard part \( F^a \) which includes the transverse quark momentum \( k_\perp \) in the propagators and the nonperturbative meson wave function \( \Psi(k_\perp) \). The gluonic corrections are treated in the form of the Sudakov factors. The resummation and exponentiation of the Sudakov corrections \( S \) can be performed in the impact parameter space \( b \), and the amplitude reads as

\[ H_{\lambda,0\lambda}^a \propto \int d\tau d^2b \Psi(\tau, -b) F_{0\lambda,0\lambda}^a(x, \xi, \tau, Q^2, b) \alpha_s \exp[-S(\tau, b, Q^2)]. \]

Here \( \tau \) is the momentum fraction of the quark that enters into the meson.

The GPDs contain extensive information about the hadron structure. Hadron form factors and parton angular momenta can be related with GPDs. At zero skewness \( \xi \) and momentum transfer GPDs are equal to ordinary PDFs

\[ F^a(x, 0, 0) = f^a(x), \quad E^a(x, 0, 0) = e^a(x) \]  

(2)

Here quarks (valence and sea) and gluon PDFs \( f^a \) are determined from CTEQ6 parameterization \[8\]. The PDFs \( e^a \) are taken from the Pauli form factor \[9\].

The GPDs are estimated using the double distribution representation \[10\] which connects GPDs with PDFs through the double distribution function \( \omega \). For the valence quark contribution it looks like

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

(3)

The functions \( h \) are determined in the terms of PDFs and parameterized in the form

\[ h(x, t) = N e^{bt} x^{-\alpha(t)} (1 - x)^n. \]  

(4)

Here the \( t \)-dependence is considered in a Regge form and \( \alpha(t) \) is the corresponding Regge trajectory. The parameters in (4) are obtained from the known information about PDFs e.g., \[8,9\].

The handbag approach was successfully applied to light meson leptoproduction \[11\]. In Fig.1, we show our results for \( Q^2 \) and \( W \) dependencies of the \( \rho \) leptoproduction which are in good agreement with experimental data. It can be seen in Fig. 1, (left) that the leading twist results do not reproduce data at low \( Q^2 \). The power \( k_\perp^2/Q^2 \) corrections in the propagators of hard subprocess amplitude are important in the description of the data. Corrections can be regarded as effective consideration of the higher twist effects. From Fig 1 (right) we see that the model describes the \( \rho \) meson leptoproduction quite well for \( W > 4 \text{GeV} \). The rapid growth of the cross section at lower energies has not been understood within the handbag model till now.
Figure 1: Left: Cross sections of the $\rho$ production at $W = 75\text{GeV}/10$ and $W = 90\text{GeV}$. Dashed line: leading twist results. Right: The longitudinal cross section for the $\rho^0$ production at $Q^2 = 4.0\text{GeV}^2$. References to experimental data can be found in [1].

3 Transversity in pseudoscalar mesons production

Exclusive electroproduction of PM was studied within the handbag approach [4, 5]. It was shown that the asymptotically dominant leading-twist contributions, which are determined by the GPDs $\tilde{H}$ and $\tilde{E}$, are not sufficient to describe the experimental results on electroproduction of PM at low $Q^2$. It can be seen, for example, from $A_{UT}^{\sin(\phi_s)}$ asymmetry

$$A_{UT}^{\sin(\phi_s)} \propto \text{Im}[M_{0-,++}^* M_{0+,0+}].$$

This asymmetry was found to be small in the handbag model based on the leading twist amplitudes. This result is inconsistent with the data where $A_{UT}^{\sin(\phi_s)} \sim 0.5$.

A new twist-3 contribution to the $M_{0-,++}$ amplitude, which is not small at $t' \sim 0$, is needed to understand the data. The inclusion in our consideration of the $M_{0+,++}$ amplitude which has a similar twist-3 nature is also extremely important to explain the PM production at low $Q^2$. We estimate these contributions by the transversity GPD $H_T$, $E_T$ in conjugation with the twist-3 pion wave function in the hard subprocess amplitude $H_{0-\mu+}$ [5]

$$M_{0-,\mu+}^{M,tw-3} \propto \int_{-1}^{1} d\overline{x} H_{0-\mu+}(\overline{x},...) H_T^M; \quad M_{0+,\mu+}^{M,tw-3} \propto \frac{\sqrt{-t'}}{4m} \int_{-1}^{1} d\overline{x} H_{0-\mu+}(\overline{x},...) \overline{E}_T^M. \quad (6)$$

The $H_T$ GPD is connected with transversity PDFs as

$$H_T^a(x, 0, 0) = \delta^a(x); \quad \text{and} \quad \delta^a(x) = C N_T^a x^{1/2} (1 - x) [q_a(x) + \Delta q_a(x)]. \quad (7)$$

We parameterize the PDF $\delta$ (see [4, 5]) by using the model [11]. The double distribution (3) is used to calculate GPD $H_T$.

At the moment, the information on $E_T$ is very poor. Some results were obtained only in the lattice QCD [12]. The lower moments of $E_T^u$ and $E_T^d$ were found to be of the same sign, similar in size and quite large. At the same time, $H_T^u$ and $H_T^d$ have different signs. These properties of GPDs provide essential compensation of the $E_T$ contribution in the $\pi^+$ amplitude, but $H_T$ effects are not small there. For the $\pi^0$ production we have the opposite case – the $E_T$ contributions are large and the $H_T$ effects are small.
Figure 2: Left: $\pi^0$ production in the CLAS energy range together with the data [14]. Dashed-dot-dotted line- $\sigma = \sigma_T + \epsilon \sigma_L$, dashed line-$\sigma_{LT}$, dashed-dotted- $\sigma_{TT}$. Right: $\eta/\pi^0$ production ratio in the CLAS energy range together with preliminary data [15].

In Fig. 2 (left), we present our results for the cross section of the $\pi^0$ production. The transverse cross section where the $\bar{E}_T$ and $H_T$ contributions are important [4] dominates. At small momentum transfer the $H_T$ contribution is visible and provides a nonzero cross section. At $-t' \sim 0.2\text{GeV}^2$ the $\bar{E}_T$ contribution becomes essential and gives a maximum in the cross section. A similar contribution from $\bar{E}_T$ is observed in the interference cross section $\sigma_{TT}$. The fact that we describe well both unseparated $\sigma$ and $\sigma_{TT}$ cross sections can indicate that transversity effects were probably observed in CLAS [14]. In Fig. 2 (right), we show the $\eta$ and $\pi^0$ cross section ratio obtained in the model (for details see [5]). At small momentum transfer this ratio is controlled by the $H_T$ contribution. At larger $-t$ the $E_T$ contributions become important. The value about 1/3 for the cross section ratio in the momentum transfer $-t' > 0.2\text{GeV}^2$ is a consequence of the flavor structure of the $\eta$ and $\pi^0$ amplitudes. This result was confirmed by the preliminary CLAS data [15].

Figure 3: Left: Cross sections of the $K^0 \Sigma^+$ production at HERMES energies. Right: Predicted moments of $A_{UT}$ asymmetries for the $K^0 \Sigma^+$ channel at HERMES.

A similar essential transversity $E_T$ contribution is observed in the kaon production. An example of our results for the $K^0 \Sigma^+$ cross section is shown in Fig. 3 (left). As in the $\pi^0$ production, we find here a dip near $-t' = 0$. It was found that the longitudinal cross...
section $\sigma_L$, which is expected to play an important role, is much smaller with respect to the transverse cross section $\sigma_T$ at low $Q^2$. At sufficiently large $Q^2$ the leading-twist $\sigma_L$ contribution will dominate because transversity twist-3 effects, which contribute to $\sigma_T$, decrease quickly with $Q^2$ growing. The same result was found in the $\pi^0$ production \[16\]. The predicted asymmetries in $K^0\Sigma^+$ channel are shown in Fig. 3 (right).

4 Transversity in vector mesons production

Now we extend our analysis of transversity effects to the VM production \[6\]. Transversity will be essential in the amplitudes with a transversely polarized photon and a longitudinally polarized vector meson. The twist-3 amplitudes have a form of (6) where the transversity GPDs occur in combination with twist-3 meson wave functions. The asymptotic form for the twist-3 chiral-odd DA $h_{V}(s)\lambda_{V}=6\tau(1-\tau)$ is used.

Note that the transversity contribution in the VM production contains the parameter $m_V=0.77\text{GeV}$ instead of $\mu_\pi=2\text{GeV}$ for PM production \[6\]. As a result, the transversity contribution to the VM amplitudes is parametrically about 3 times smaller with respect to PM case. In calculation of the amplitude we use the same parameterizations for transversity GPDs $H_T$ and $\bar{E}_T$ which was obtained in our study of the PM leptoproduction in the section 3.

![Figure 4: Transversity effects at SDMEs at $W=5\text{GeV}$ together with HERMES data \[17\].](image)

The importance of the transversity GPDs was examined in the SDMEs and in asymmetries measured with a transversely polarized target. The $M_{0+,++} = \langle \bar{E}_T \rangle$ amplitude is essential in some SDMEs. Really,

$$r_{00}^5 \sim \text{Re}[M^*_{0+,0+}M_{0+,++}]; \quad r_{00}^1 \sim -|M_{0+,++}|^2; \quad r_{10}^{04} \sim \text{Re}[M^*_{+++,++}M_{0+,++}].$$ (8)

Our results for these SDMEs in the $\rho^0$ meson production at HERMES are shown in Fig. 4. These values and signs are in good agreement with HERMES experimental data \[17\]. We observe that large $\bar{E}_T$ effects found in the $\pi^0$ channel are compatible with SDME of the $\rho$ production at HERMES energies.

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

$$A_{UT}^{\sin(\phi - \phi_s)} \sim \text{Im}[M^*_{0-,0+}M_{0+,0+} - M^*_{0-,++}M_{0+,++}]$$ (9)
at HERMES and COMPASS energies. This asymmetry is determined essentially by interference of the \( \langle \bar{E} \rangle \) and \( \langle F \rangle \) contributions (1) and is consistent with the data. The effects of transversity are quite small here.

The \( \sin(\phi_s) \) moment of the \( A_{UT} \) asymmetry is determined by the \( H_T \) GPDs.

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

This asymmetry is found to be not small at COMPASS [6] and compatible with the data [19, Fig 6 (left)]. The energy dependence of \( A_{UT}^{\sin(\phi_s)} \) from CLAS to HERMES is quite rapid and shown in Fig. 6 (right). This prediction can be verified in a future CLAS experiment to test the \( x \)- dependence of GPDs \( H_T \).

In Fig.7, we show the \( Q^2 \) dependencies of \( A_{UT}^{\sin(\phi_s)} \) and \( A_{LT}^{\cos(\phi_s)} \) which is determined by a similar to (10) equation only with the replacement of the imaginary to the real part there. The model results are close to experimental data.
Figure 7: $Q^2$ dependences of Left: $A_{UT}^{\sin(\phi_s)}$ asymmetry. Right: $A_{LT}^{\cos(\phi_s)}$ asymmetry at COMPASS together with data [19]

5 Conclusion

The handbag approach, where the amplitudes factorize into the hard subprocesses and GPDs [2], was successfully applied to light meson production. The results based on this approach on cross sections and various spin observables were found to be in good agreement with data at HERMES, COMPASS and HERA energies at high $Q^2$ [1].

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. It was found that the leading twist contributions are not sufficient to describe spin observables in PM production at sufficiently low photon virtualities $Q^2$. We observe that the experimental data on the PM lepton production also require contributions from the transversity GPDs from $H_T$ and $E_T$. Within the handbag approach the transversity GPDs are accompanied by twist-3 meson distribution amplitudes. These transversity contributions provide large transverse cross sections for most of the pseudoscalar meson channels [5]. There is some indication that large transversity effects are available now at CLASS [14]. Thus, the transversity GPDs are extremely essential in understanding spin effects in the PM production.

The role of transversity GPDs in the VM lepton production was investigated within the handbag approach [6]. The transversity GPDs in combination with twist-3 meson wave functions occur in the amplitudes with the transversely polarized virtual photon and a longitudinal polarized vector meson. The importance of the transversity GPDs was examined in the SDMEs and in asymmetries measured with a transversely polarized target. The SDMEs for the light VM production were found to be in good agreement with HERMES experimental data on the $\rho^0$ production [17]. We also estimated the $A_{UT}^{\sin(\phi_s-\phi_s)}$ transverse target spin asymmetry [6]. The results are consistent with HERMES and COMPASS data [18,19]. The $A_{UT}^{\sin(\phi_s)}$ asymmetry is found in the model to be not small at COMPASS [6] and also compatible with the data [19]. Our predictions were compared with the COMPASS experimental data in the COMPASS paper [19].

We described well the cross section and spin observables for various meson productions. Thus, we can conclude that the information on GPDs discussed above should not be far from reality. Future experimental results at COMPASS, JLAB12 can give important
information on the role of transversity effects in these reactions.

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