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Transversity in exclusive electroproduction of pseudoscalar mesons

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In this talk it is reported on an analysis of hard exclusive electroproduction of pseudoscalar mesons within the handbag approach. It is argued that recent measurements of pion electroproduction performed by HERMES and CLAS clearly indicate the occurence of strong contributions from transversely polarized photons. Within the handbag approach such $\gamma_T^* \to \pi$ transitions are described by the transversity GPDs accompanied by twist-3 pion wave functions. It is shown that this handbag approach leads to results on cross sections and single-spin asymmetries in fair agreement with experiment. The surprising result is that the π^0 cross section is dominated by $\gamma_T^* \to \pi$ transitions. Predictions for other pseudoscalar meson channels are also discussed.

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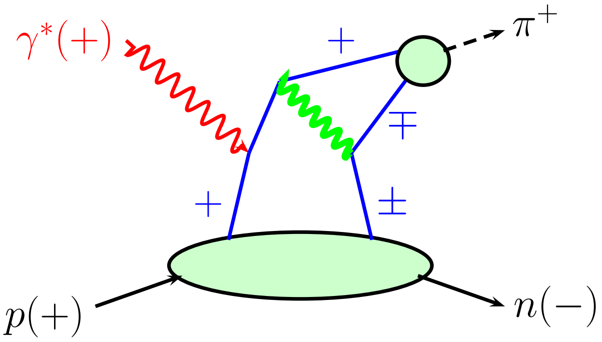
In this talk it is reported upon an analysis of hard exclusive electroproduction of pseudoscalar mesons [1, 2] within the framework of the handbag approach which offers a partonic description of meson electroproduction provided the virtuality of the exchanged photon, Q^2, and the energy, W, in the photon-proton center of mass frame are sufficiently large. The theoretical basis of the handbag approach is the factorization of the process amplitudes in hard partonic subprocesses and soft hadronic matrix elements, so-called generalized parton distributions (GPDs), as well as wave functions for the produced mesons, see Fig. 1. In collinear approximation factorization has been shown [3, 4] to hold rigorously for exclusive meson electroproduction in the limit $Q^2 \to \infty$. It has also been shown that the transitions from a longitudinally polarized photon to the pion, $\gamma_L^* \to \pi$, dominate at large Q^2. Transitions from transversely polarized photons to the pion are suppressed by inverse powers of the hard scale. In Refs. [1, 2] a variant of the handbag approach is utilized for the interpretation of the data in which the subprocess amplitudes are calculated using $k_\perp$ factorization. The partons are still emitted and re-absorbed by the nucleon collinearly. It has been shown [5] that within this handbag approach the data on cross sections and spin density matrix elements for vector-meson production are well fitted for small values of skewness ($\xi \simeq x_{Bj}/2 \lesssim 0.1$).

The HERMES collaboration [6] has measured the π^+ electroproduction cross section with a transversely polarized target. The $\sin\phi_s$ moment of this cross section is displayed in Fig. 2 (ϕ_s specifies the orientation of the target spin vector). Particularly striking is the fact that the $\sin\phi_S$ moment exhibits a mild t'-dependence and does not show any indication for a turnover towards zero for $t' \to 0$. This behavior of $A_{UT}^{\sin\phi_s}$ at small $-t'$ can only be produced by the interference term $\mathrm{Im}\big[\mathcal{M}^*_{0-,++}\mathcal{M}_{0+,0+}\big]$. Both the contributing amplitudes, one for a transversely and one for a longitudinally polarized photon, are helicity non-flip ones and are therefore not forced to vanish in the forward direction by angular momentum conservation. The amplitude $\mathcal{M}_{0-,++}$ has to be sizable in order to account for the HERMES data. Moreover, the amplitude $\mathcal{M}_{0-,-+}$ which vanishes $\propto t'$ for $t' \to 0$, cannot be large given that the $\sin(2\phi - \phi_s)$ moment is small [6].

A second hint at large $\gamma_L^* \to \pi$ transitions comes from the CLAS measurement of the π^0 elec-



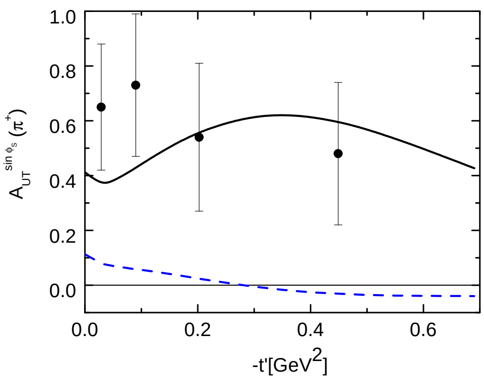
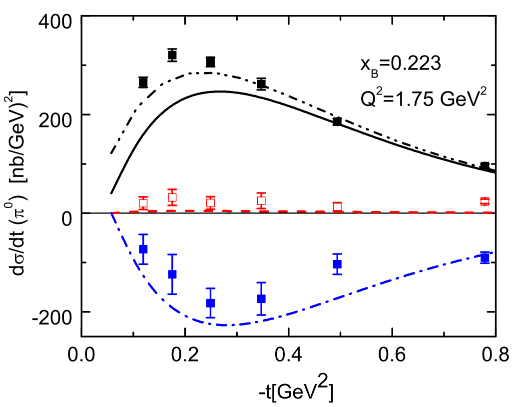


Figure 1: A typical lowest order Feynman graph for pion electroproduction. The signs indicate helicity labels for the handbag contribution to the amplitude $\mathcal{M}_{0-,++}$, see text.

Figure 2: The $\sin\phi_s$ moment of the pion electroproduction cross section measured with a transversely polarized target at $Q^2 \simeq 2.45\,\mathrm{GeV}^2$ and $W = 3.99\,\mathrm{GeV}$. The handbag prediction [1] is shown as a solid line. The dashed line is obtained disregarding the twist-3 contribution. Data are taken from Ref. [6].



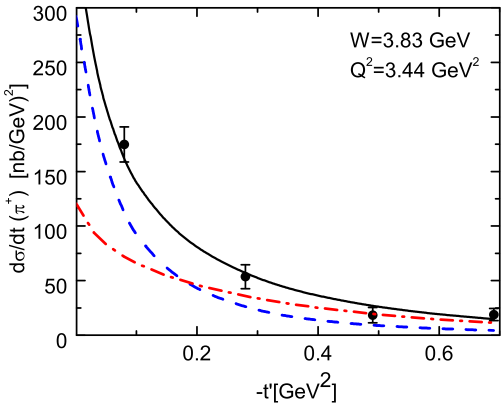


Figure 3: Left: The unseparated π^0 cross section as well as the longitudinal-transverse (open symbols) and the transverse-transverse interference (solid symbols) cross section. Preliminary data are taken from [7]. The curves represent the results obtained in [2].

Figure 4: Left: The unseparated π^+ cross section. Data taken from [14]. The solid (dashed,dash-dotted) curve represents the results for the unseparated (longitudinal, transverse) cross section [2].

troproduction cross section [7]. As can be seen from Fig. 3 the transverse-transverse interference cross section is negative and, in absolute value, amounts to a substantial fraction of the unseparated cross section. It is convenient to introduce sum and difference of the two single-flip amplitudes (photon helicity $\mu = \pm 1$)

$$\mathcal{M}^{N(U)}_{0+,\mu+} = \frac{1}{2}\Big[\mathcal{M}_{0+,\mu+} \pm \mathcal{M}_{0+,-\mu+}\Big], \qquad (1)$$

which respect the symmetry relation

$$\mathcal{M}^{N(U)}_{0+,-+} = \pm\mathcal{M}^{N(U)}_{0+,++}. \qquad (2)$$

This relation is known from one-particle exchange of either natural or unnatural parity. If the amplitude $\mathcal{M}_{0-,-+}$ is neglected the transverse and the transverse-transverse interference cross section can be written as (κ is a phase space factor)

$$\begin{aligned} \frac{d\sigma_T}{dt} &= \frac{1}{2\kappa}\Big[|\mathcal{M}_{0-,++}|^2 + 2|\mathcal{M}^N_{0+,++}|^2 + 2|\mathcal{M}^U_{0+,++}|^2\Big], \\ \frac{d\sigma_{TT}}{dt} &= -\frac{1}{\kappa}\Big[|\mathcal{M}^N_{0+,++}|^2 - |\mathcal{M}^U_{0+,++}|^2\Big]. \end{aligned} \qquad (3)$$

The CLAS π^0 data tell us that the amplitude $\mathcal{M}^N_{0+++}$ is large and $\mathcal{M}^U_{0+++}$ small, see Fig. 3.

How can the amplitudes for $\gamma^*_T \to \pi$ transitions be modeled in the framework of the handbag approach? From Fig. 1 where the helicity configuration for the amplitude $\mathcal{M}_{0-,++}$ is indicated, it is clear that contributions from the usual helicity non-flip GPDs $\widetilde{H}$ and $\widetilde{E}$ to this amplitude do not have the properties required by the data on the $\sin\phi_s$ moment. Angular momentum conservation forces both the parton-nucleon vertex and the subprocess, to vanish as $\sqrt{-t'}$ at least. There is a second set of GPDs, the helicity-flip or transversity ones $H_T, E_T, \ldots$ [8, 9] for which the emitted and reabsorbed partons have opposite helicities. As an inspection of Fig. 1 reveals the parton-nucleon vertex as well as the subprocess amplitude $\mathscr{H}_{0-,++}$ are now of helicity non-flip nature and are therefore not forced to vanish in the forward direction. The prize to pay is that quark and antiquark forming the pion have the same helicity. Therefore, the twist-3 pion wave function is needed instead of the familiar twist-2 one. This dynamical mechanism which is of twist-3 accuracy, also applies to the amplitudes $\mathscr{M}_{0+,\pm+}$.

In Ref. [1, 2] the twist-3 pion wave function is taken from [10] with the three-particle Fock component neglected. This wave function contains a pseudoscalar and a tensor component. The latter one provides a contribution to the subprocess amplitude $H_{0-,++}$ which is proportional to t'/Q^2 and is neglected. The contribution from the pseudoscalar component to $H_{0-,++}$ has the required properties. It is proportional to the parameter $\mu_\pi = m_\pi^2/(m_u+m_d) \simeq 2\,\mathrm{GeV}$ at the scale of $2\,\mathrm{GeV}$ as a consequence of the divergency of the axial-vector current (m_u and m_d are current quark masses). Although parametrically suppressed by μ_π/Q as compared to the longitudinal amplitudes, it is sizeable for Q of the order of a few GeV. The other quark helicity-flip subprocess amplitude $H_{0-,-+}$ is $\propto t/Q^2$ and therefore neglected in [1, 2].

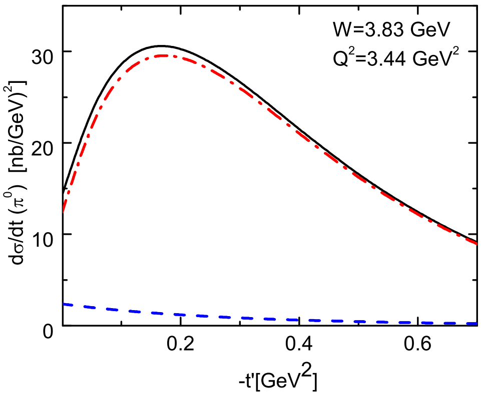
The general structure of the handbag approach for the $\gamma_T^* \to \pi$ amplitudes is in perfect agreement with the experimental findings discussed above

$$\begin{aligned} \mathscr{M}_{0-,++} &= e_0\sqrt{1-\xi^2}\int dx\, H_{0-++}\, H_T + \mathscr{O}(\xi^2) \\ \mathscr{M}_{0+,\pm+} &= -e_0\frac{\sqrt{-t'}}{4m}\int dx\, H_{0-++}\, \overline{E}_T + \mathscr{O}(\xi^2)\,, \end{aligned} \tag{4}$$

where $\overline{E}_T \equiv 2\widetilde{H}_T + E_T$ and $\mathscr{M}_{0+,\pm+}$ behaves like a natural parity exchange; the unnatural part is $\mathscr{O}(\xi)$ and neglected as well as the double-flip amplitude $\mathscr{M}_{0-,-+}$ which behaves $\propto t'$.

In order to make predictions also the GPDs are needed. In [1, 2] they are constructed with the help of the double distribution ansatz [11] consisting of the product of a zero-skewness GPD and an appropriate weight function which generates the skewness dependence. The zero-skewness GPDs are parameterized as their forward limits multiplied by a Regge-like t dependence, $\exp\left[t(b_i - \alpha_i' \ln x)\right]$. In the case of $\widetilde{H}$ the forward limit is given by the polarized parton distributions. The GPD H_T is constrained by the transversity PDF $\delta(x)$ for which the results of an analysis of the asymmetries in semi-inclusive electroproduction are taken [12]. The lowest moments of this variant of H_T are smaller by about a factor of 2 than lattice QCD results [13]. Therefore, an alternative variant of H_T is also considered which is normalized to the lattice results [13]. The second transversity GPD $\overline{E}_T$ is parameterized in the same spirit as the others and normalized to the lattice results as well because other information on it is lacking at present. It is important to stress that $\overline{E}_T$ has the same sign and almost the same size for u and d quarks in which aspect it differs from H_T. The remaining parameters of the GPDs are fitted to the only available small-skewness data, namely the π^+ electroproduction data from HERMES [6, 14]. With regard to the uncertainties in the parameterization of the GPDs the predictions for pseudoscalar meson electroproduction given in [2], with the exception of π^+ at small skewness, are to be considered as estimates of trends and magnitudes.

A few of the results obtained in [1, 2] are shown in Figs. 2 – 8. As can be seen from Figs. 2 and 4 the transverse target asymmetries [6] as well as the cross section [14] for π^+ electroproduction are nicely fitted. The prominent role of the twist-3 mechanism for understanding the behavior of the



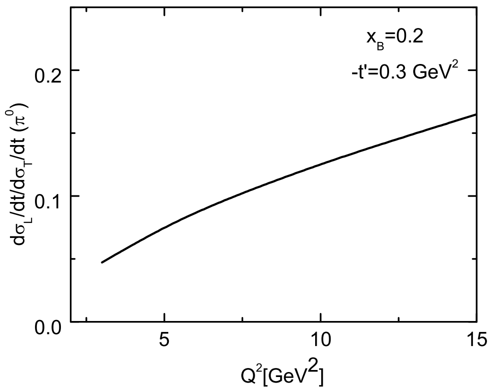


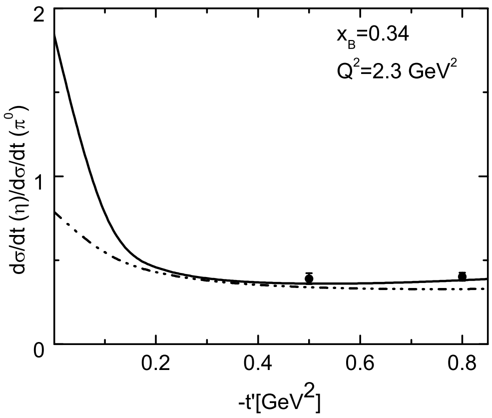
Figure 5: Left: As Fig. 4 but for π^0 electroproduction. The alternative parameterization of H_T is used.

Figure 6: Right: The ratio of the longitudinal and transverse cross section for π^0 electroproduction.

$\sin\phi_s$ moment is obvious from the two curves shown in Fig. 2. While the π^+ cross section obtains substantial contributions from both longitudinally polarized photons (at small $-t'$) and transverse ones (at large $-t'$) is the π^0 cross section strongly dominated by the $\gamma^* \to \pi^0$ transitions, see Figs. 3–5. The strong dip of the forward cross section signals the dominance of the single helicity-flip amplitudes $\mathcal{M}_{0+\pm+}$, i.e. of contributions from $\bar{E}_T$. Although the $\gamma^* \to \pi$ transitions are suppressed by μ_π/Q as compared to the asymptotically dominant contributions from longitudinally polarized photons the ratio σ_L/σ_T is very small for π^0 production at small Q^2 but it increases with Q^2, see Fig. 6. The longitudinal cross section takes the lead only for very large values of Q^2.

In Fig. 7 the ratio of the η and π^0 cross section is shown. Except in the proximity of the forward direction where the contributions from H_T dominate, the ratio is small and in good agreement with preliminary CLAS data [7]. The smallness of the ratio is a consequence of the properties of the dominant GPD $\bar{E}_T$, namely the same signs and about the same size of $\bar{E}_T^u$ and $\bar{E}_T^d$. Finally, in Fig. 8 predictions for the cross sections of various pseudoscalar meson channels are shown for typical COMPASS kinematics. Except of the case of the π^+ all channels are dominated by $\gamma_T^* \to$ meson transitions although the degree of dominance differs.

In summary, there is strong evidence for transversity in hard exclusive electroproduction of pions. The most striking effects are seen in the experimental data on the π^+ target asymmetry $A_{UT}^{\sin\phi_s}$ and on the π^0 cross section. The interpretation of these effects requires a large helicity non-flip amplitude $\mathcal{M}_{0-,++}$ and the flip amplitudes $\mathcal{M}_{0+++} \simeq \mathcal{M}_{0+-+}$. Within the handbag approach these amplitudes are generated by the helicity-flip or transversity GPDs in combination with a twist-3 pion wave function [1, 2]. The GPDs are constructed from double distributions. They are fitted to the HERMES small-skewness data on π^+ and are therefore optimized for that region. At larger values of skewness the parameterizations of the GPDs are perhaps to simple and may require improvements. It is also important to realize that the GPDs are probed by the HERMES data only for x less than about 0.6. This does not mean that one cannot compare with experimental data from Jefferson Lab., e.g. [7] but one cannot expect that all details of the data will be correctly reproduced. However, as is shown, the trends and magnitudes of the CLAS data are reasonably



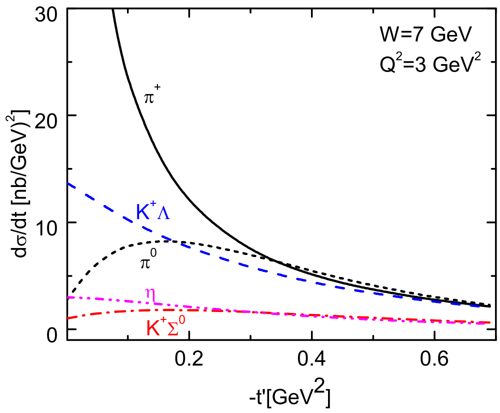


Figure 7: Left: The ratio of the η and π^0 cross sections versus $-t'$. The predictions given in [2] are shown as a solid line. The dash-dot-dotted line is the result obtained with the alternative variant of H_T. The preliminary data are taken from [7].

Figure 8: Right:The cross sections for various pseudoscalar meson channels.

well explained. Further studies of transversity in exclusive reactions are certainly demanded. Good data on π^0 electroproduction from the upgraded Jlab or from the COMPASS experiment would be welcome. They would not only allow for further tests of the twist-3 mechanism but also provide the opportunity to verify the parameterizations of the GPDs $\widetilde{H}$ and $\widetilde{E}$ as used in Ref. [1, 2].

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