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Studies of Chiral-Odd GPDs in Hard Exclusive Pseudoscalar Meson Production Using the CLAS12 Detector

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Abstract

Deeply virtual exclusive electroproduction of pseudoscalar mesons in hard scattering processes provides a unique avenue to access chiral-odd GPDs. The latter enter the soft matrix elements in transverse virtual photon-proton scattering. Transverse photon polarization dominates π^o, η, and K production in the multi GeV region owing to the fact that t-channel meson pole contribution either does not occur (π^o and η), or is predicted to be relatively small (K^+, K^o). This is at variance with the longitudinal charged pion production channel which is enhanced by a large meson pole contribution. We propose a combination of measurements of cross sections, spin and azimuthal asymmetries with a longitudinally polarized beam and both an unpolarized and longitudinally polarized proton target for π^o, η and K^+, K^o electroproduction with the aim of: *i)* providing a detailed test of the mechanism for pseudoscalar meson electroproduction including strangeness, in the multi GeV region; *ii)* separating out the contributions from the different chiral-odd GPDs; *iii)* providing a flavor decomposition of underlying chiral-odd GPDs.

1 Introduction

The introduction of Generalized Parton Distributions (GPDs) in Refs.[1, 2, 3] defines an important new and far-ranging theoretical framework that allows us to describe the angular momentum components of quarks and gluons in the proton in terms of density distributions in both longitudinal momentum fraction, x, and transverse spatial degrees of freedom, (see reviews in Refs.[4]). GPDs complement the Transverse Momentum Distributions (TMDs), the parton distributions in both x, and intrinsic transverse momentum [5, 6]. Together, GPDs and TMDs can, in principle, give information on the orbital motion of partons while rendering a three dimensional view of hadron structure [7].

Understanding the distribution of the nucleon's spin among its constituents has been one of the most important pursuits of QCD practitioners in the last few decades. Quarks have been observed to contribute to only $\approx 30\%$ of the proton's spin. The gluons contribution, although it has not yet been pinned down accurately, seems to be insufficient to fill the remaining gap in the proton spin sum rule. This situation suggests a picture in which orbital angular momentum must make a major contribution. The total angular momentum distribution of quarks and gluons can be described in terms of GPDs.

GPDs are the soft matrix elements in deeply virtual exclusive photon and meson electroproduction (Fig. 1). By using the connection between GPDs and helicity amplitudes and applying parity constraints one singles out eight GPDs at leading twist [4]. Four correspond to parton helicity conserving (chiral-even) processes. They are denoted by H^q, E^q, $\tilde{H}^q$, $\tilde{E}^q$. The remaining four, H_T^q, E_T^q, $\tilde{H}_T^q$, $\tilde{E}_T^q$, correspond to parton helicity-flip (chiral-odd) processes [4].

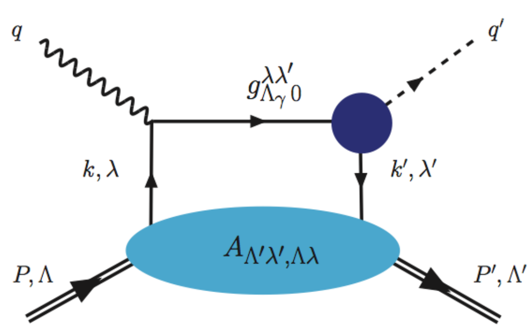

Figure 1: Leading order amplitude for deeply virtual exclusive photon (meson) electroproduction, $\gamma^* + P \to \gamma(M) + P'$. Crossed diagrams are not shown in the figure.

The chiral-odd GPDs encode unique information on the transverse spin structure of the proton and on the tensor charge since they are defined as a generalization of the quarks transversity distribution, $h_1(x)$. The latter cannot be measured directly in inclusive deep inelastic scattering since the quark coupling to the photon conserves chirality. Information on the tensor charge has been pursued, so far, in semi-inclusive scattering experiments, and in dihadron production processes, *e.g.* $e^+e^- \to h_1 h_2 X$ [8].

Neutral single pseudoscalar meson electroproduction allows us to access transversity through a relatively more straightforward process [9].

There is a price to pay for this simplicity in that the γ_5 coupling to the quark-π^o vertex which singles out the chiral-odd GPDs, is of twist three, $\propto 1/\sqrt{Q^2}$, and the Distribution Amplitude (DA) of the produced meson will therefore be subleading compared to the leading twist, chiral-even contribution to the quark-π^o vertex, $\propto \gamma_\mu \gamma_5$ [10]. However, as demonstrated from the comparison with recent measurements [11], it is exactly by introducing these twist three contributions that we could understand and interpret in terms of chiral-odd GPDs the large transverse photon cross sections observed in the experimental data from Jefferson Lab Hall B.

A key point for this proposal is, in fact, the dominance of transverse virtual photon scattering over longitudinal scattering which is dictated by the J^{PC} quantum numbers characterizing the transition of a virtual photon ($J^{PC} = 1^{--}$), to a final pseudoscalar meson ($J^{PC} = 0^{-+}$) thus requiring odd C-parity t-channel quantum numbers [12, 13, 14].

In charged pion electroproduction, on the contrary, the presence of a pion pole in the t-channel makes the longitudinal channel dominate. Similarly, for K^+, K^o, one has $J^P = 0^-$, and no definite C, therefore a kaon pole contribution to the longitudinal electroproduction scattering process is, in principle, possible. However, previous experimental analysis of pion and kaon photoproduction corroborated by SU(3) based estimates, have determined that the kaon pole contribution is negligibly small [15].

Exclusive pseudoscalar meson electroproduction provides therefore, a unique possibility to access the "transversity" or chiral-odd GPDs through polarized scattering measurements.

Although one of the major goals of this proposal is to extract the GPD H_T, hence the tensor charge, measurements of chiral-odd GPDs will afford us a much richer program, allowing us to address additional properties of the transverse spin configurations of the nucleon. A potentially new discovery emerging from the proposed measurement would be the confirmation of the existence of a transverse anomalous magnetic moment which was predicted to be observable through the combination $2\widetilde{H}_T + E_T$ [16], containing proton flip chiral-odd GPDs. Furthermore, the longitudinal-transverse (LT) correlation provided by $\widetilde{E}_T$ could bear important consequences on the interpretation of orbital angular momentum [17].

The GPDs which define specific correlations between the quark and nucleon polarizations are listed in Table 1.

Finally, by triggering on the different final state mesons, namely π^o, η and K will allow us to perform a flavor decomposition of the various GPDs [18, 19]. This

N/q	U	L	T
U	H		$\bar{E}_T$
L		$\widetilde{H}$	$\widetilde{E}_T$
T	E	$\widetilde{E}$	H_T,$\widetilde{H}_T$

Table 1: GPDs describing the correlations between quark and nucleon polarizations. $\bar{E}_T = 2\tilde{H}_T + E_T$ [16].

important information will help us determine more precisely the value of the tensor charge. The current status of the flavor decomposition for this quantity is shown in Fig. 2. The flavor separation allowed by the proposed measurements will be key in reducing the errors bars shown in the figure.

2 Cross Sections and Asymmetries

In the electron scattering process, the incoming electrons are scattered off protons, and a virtual photon interacts with a parton in the nucleon. in Fig. 3, the DVMP process is sketched. The four-momentum of the incoming electrons is e and after scattering at polar angle θ the four-momentum of scattered electrons is e'. The four-momentum of the virtual (exchanged) photons is q. One also has the initial proton P and the final meson four-momentum π^0. From these variables, the squared four-momentum of the virtual photon $Q^2 = -(e - e')^2$, the momentum transfer between the initial and final nucleons is $t = (p' - p)^2$, where p and p' are the initial and final four momenta of the nucleon, and the Bjorken variable $x_{Bj} = Q^2/2(pq)$. The kinematical variables that define the GPDs are: x, ξ, t, and Q^2, where x is the average parton longitudinal momentum fraction and ξ (skewness) is approximately a half of the longitudinal momentum fraction transferred to the struck parton. The skewness can be expressed in terms of x_{Bj} as $\xi \simeq x_{Bj}/(2 - x_{Bj})$.

The differential cross section for exclusive meson electroproduction for longitudinally polarized beam and target is given by [27]:

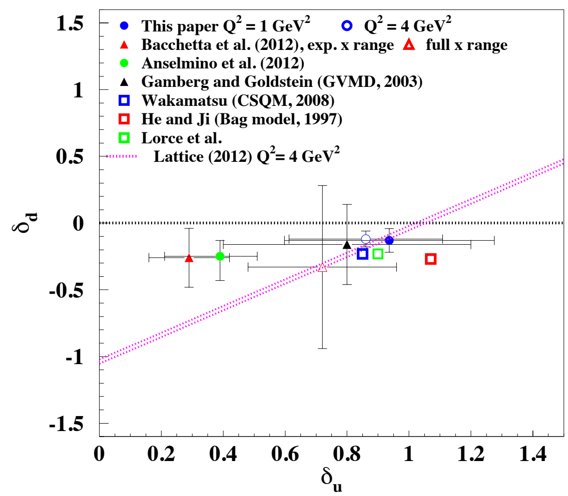

Figure 2: (Color online) Tensor charge values for the d quark, δ_d plotted vs. the u quark, δ_u, obtained from Ref.[20] and from other extractions from experimental data existing to date (Q^2= 2 GeV^2), Anselmino *et al.*, Ref.[8], and Bacchetta *et al.* Ref.[21] (Q^2= 1 GeV^2, flexible set), and model calculations: Ref.[22] (Q^2= 1 GeV^2); Wakamatsu, CQSM Q^2=0.8 GeV^2 Ref.[23], Lorcé *et al.*; CQSM, Ref.[24] (Q^2= 1 GeV^2); He and Ji, Bag Model Ref.[25]. The effect of PQCD evolution from Q^2=1 GeV^2 to Q^2= 4 GeV^2 is also shown. The thin band delimited by the dotted curves is the recent lattice QCD result for the isovector component [26] (Q^2= 4 GeV^2) (adapted from Ref.[20].

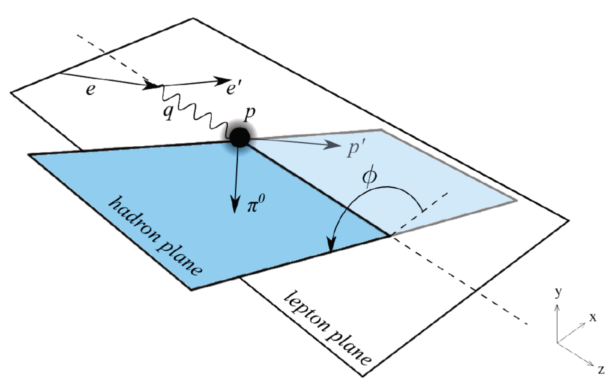

Figure 3: Kinematics of the hard exclusive hadron production in the target rest frame. The lepton plane is defined by the direction of incoming and scattering electrons, while the hadron plane is defined by the direction of the hadron and recoiled proton. ϕ is the angle between lepton plane and hadron plane.

$$
\begin{aligned}
\frac{2\pi}{\Gamma(Q^2,x_B,E)}\frac{d^4\sigma}{dQ^2dx_Bdtd\phi_\pi} &= \sigma_T+\epsilon\sigma_L+\epsilon\sigma_{TT}\cos 2\phi+\sqrt{2\epsilon(1+\epsilon)}\sigma_{LT}\cos\phi \\
&+ P_b\sqrt{2\epsilon(1-\epsilon)}\sigma_{LT'}\sin\phi \\
&+ P_t\left(\sqrt{2\epsilon(1+\epsilon)}\sigma_{UL}^{\sin\phi}\sin\phi+\epsilon\sigma_{UL}^{\sin 2\phi}\sin 2\phi\right) \\
&+ P_bP_t\left(\sqrt{1-\epsilon^2}\sigma_{LL}+\sqrt{\epsilon(1-\epsilon)}\sigma_{LL}^{\cos\phi}\cos\phi\right) \qquad (1)
\end{aligned}
$$

where P_b is the beam polarization, P_t is the target polarization, ϵ is virtual photon polarization, ϕ is an azimuthal angle between the electron scattering plane and the hadronic reaction plane, σ_T, σ_L, σ_{TT}, σ_{LT}, $\sigma_{LT'}$, $\sigma_{UL}^{\sin\phi}$, $\sigma_{UL}^{\sin 2\phi}$, σ_{LL}, $\sigma_{LL}^{\cos\phi}$ are the structure functions depending on Q^2, x_B, t.

Within a standard collinear factorization scheme it was initially proposed that factorization in DVMP works rigorously for longitudinal virtual photons with the transverse photon case being yet unproven [28]. It was found that the asymptotically dominant leading-twist contributions are not sufficient to describe the experimental results on leptoproduction of pseudoscalar mesons. The data can be instead interpreted in terms of transversity GPDs. During the past few years, two parallel approaches have been developed that use chiral-odd GPDs in the calculation of pseudoscalar electroproduction. While different in details, both lead to sizable transverse photon amplitudes, as evidenced in the CLAS data. Estimates for electroproduction of pseudoscalar mesons have been performed assuming factorization into the hard parton subprocess and the soft generalized parton distributions (GPDs) in [9, 14, 29, 30, 20] and, within the small ξ approximation in [10, 31].

Pseudoscalar meson electroproduction was identified as being especially sensitive to the helicity-flip subprocesses. The interpretation of π^+ production is complicated by the dominance of the longitudinal π^+-pole term. For K^+ the pole term is suppressed, and for the π^0 production that contribution is absent. That makes π^0, η and K^+ production a unique source of information on transversity GPDs [10, 31]. The inclusion of chiral-odd, twist-3 components in the hard exclusive amplitude brings results into good agreement with the measured cross sections [11].

The helicity structure of the GPDs is taken into account in by introducing the helicity amplitudes for DVMP namely, $\mathcal{A}_{\Lambda_\gamma 0}^{\Lambda\Lambda'}$, where the helicities of the virtual photon and the initial proton are, Λ_γ, Λ, and the helicities of the produced pion and final proton are 0, and Λ', respectively.

The helicity amplitude of the meson electroproduction off the proton reads as a convolution of the partonic subprocess amplitude $h_{\Lambda_\gamma 0}^{\lambda\lambda'}$ and the quark-proton helicity amplitudes, $A_{\Lambda'\lambda',\Lambda\lambda}$ [4] (see Fig. 1)

$$
\mathcal{A}_{\Lambda_\gamma 0}^{\Lambda\Lambda'}(\xi,t)=\sum_{\lambda,\lambda'} h_{\Lambda_\gamma 0}^{\lambda\lambda'}(x,\xi,t,Q^2)\otimes A_{\Lambda'\lambda',\Lambda\lambda}(x,\xi,t), \qquad (2)
$$

The amplitudes $A_{\Lambda'\lambda',\Lambda\lambda}$ implicitly contain an integration over the unobserved quark's transverse momentum, k_T, and are functions of $x_{Bj} = Q^2/2M\nu \approx 2\xi, t$ and Q^2. The convolution integral in Eq. (2) is given by $\otimes \to \int_{-1}^{1} dx$, as we explain in detail later on, thus yielding the analogues of the so-called Compton form factors in DVCS. The convolution is valid in the kinematic region of small $-t$ but large Q^2 and large photon-proton invariant mass, W.

The helicity amplitudes are calculated as linear combinations of convolutions of the GPDs with an appropriate subprocess amplitude that is calculated from a set of Feynman graphs. In addition to the production amplitudes with longitudinal photons, which in the leading twist is determined by $\tilde{H}$ and $\tilde{E}$, a twist three contribution to the amplitudes is required to describe the polarized data at low Q^2. These amplitudes are generated by the leading, twist two, transversity GPDs with a twist three meson wave function. For most pseudoscalar-meson channels the combination, $2\widetilde{H}_T + E_T$, plays a particularly prominent role.

The expressions for the chiral-odd helicity amplitudes in terms of GPDs involved in the process $\gamma_T^* p \to \pi^o p$ are given by [4],

$$\mathcal{A}_{10}^{+-} = \mathcal{H}_T + \frac{t'}{4m^2}\widetilde{\mathcal{H}}_T + \frac{\xi^2}{1-\xi^2}\mathcal{E}_T + \frac{\xi}{1-\xi^2}\widetilde{\mathcal{E}}_T \tag{3}$$

$$\mathcal{A}_{10}^{++} = \frac{\sqrt{-t'}}{4m}\left[2\widetilde{\mathcal{H}}_T + (1+\xi)(\mathcal{E}_T + \widetilde{\mathcal{E}}_T)\right] \tag{4}$$

$$\mathcal{A}_{10}^{-+} = \frac{t'}{4m^2}\,\widetilde{\mathcal{H}}_T \tag{5}$$

$$\mathcal{A}_{10}^{--} = \frac{\sqrt{-t'}}{4m}\left[2\widetilde{\mathcal{H}}_T + (1-\xi)(\mathcal{E}_T - \widetilde{\mathcal{E}}_T)\right], \tag{6}$$

where $\mathcal{H}_T, \mathcal{E}_T, ...$, are the convolutions of the GPDs with $C^+(x,\xi)$ which at leading order in PQCD are given by,

$$\mathcal{F}_T(\xi, t, Q^2) = \int_{-1}^{1} dx\; C^+ \, F_T(x, \xi, t, Q^2) \tag{7}$$

where $\mathcal{F}_T \equiv \mathcal{H}_T, \mathcal{E}_T, \widetilde{\mathcal{H}}_T, \widetilde{\mathcal{E}}_T$, $t' = t - t_0$, and

$$C^+(X, \zeta) = \frac{1}{x - \xi + i\epsilon} + \frac{1}{x + \xi - i\epsilon}.$$

2.1 Observables

Neglecting terms of order $\sqrt{-t}/Q$ in the low $-t$ region, the beam, target and double spin asymmetries can be expressed as a functions of the corresponding helicity amplitudes,

$$A_{LU}^{\sin\phi}\sigma_0 = -\sqrt{\epsilon(1-\epsilon)}\ \mathrm{Im}\left[(\mathcal{A}_{00}^{+-})^*(\mathcal{A}_{10}^{+-}+\mathcal{A}_{10}^{-+})+(\mathcal{A}_{00}^{++})^*(\mathcal{A}_{10}^{++}-\mathcal{A}_{10}^{--})\right] \tag{8}$$

$$A_{UL}^{\sin\phi}\sigma_0 = -\sqrt{\epsilon(1+\epsilon)}\ \mathrm{Im}\left[(\mathcal{A}_{00}^{+-})^*(\mathcal{A}_{10}^{+-}-\mathcal{A}_{10}^{-+})+(\mathcal{A}_{00}^{++})^*(\mathcal{A}_{10}^{++}+\mathcal{A}_{10}^{--})\right] \tag{9}$$

$$A_{UL}^{\sin 2\phi}\sigma_0 = -\epsilon\ \mathrm{Im}\left[(\mathcal{A}_{10}^{++})^*\mathcal{A}_{10}^{--}-\mathcal{A}_{10}^{+-}\mathcal{A}_{10}^{-+}\right] \tag{10}$$

$$A_{LL}^{const}\sigma_0 = \sqrt{1-\epsilon^2}\frac{1}{2}\left[\mid \mathcal{A}_{10}^{++}\mid^2 + |\mathcal{A}_{10}^{+-}|^2 - |\mathcal{A}_{10}^{-+}|^2 - |\mathcal{A}_{10}^{--}|^2\right] \tag{11}$$

$$A_{LL}^{\cos\phi}\sigma_0 = -\sqrt{\epsilon(1-\epsilon)}\ \mathrm{Re}\left[(\mathcal{A}_{00}^{+-})^*(\mathcal{A}_{10}^{+-}-\mathcal{A}_{10}^{-+})+(\mathcal{A}_{00}^{++})^*(\mathcal{A}_{10}^{++}+\mathcal{A}_{10}^{--})\right] \tag{12}$$

The integrated cross section σ_0 is defined as:

$$\sigma_0 = \quad \frac{1}{2}\left[|\mathcal{A}_{10}^{++}|^2+|\mathcal{A}_{10}^{--}|^2+|\mathcal{A}_{10}^{+-}|^2+|\mathcal{A}_{10}^{-+}|^2\right]+\epsilon\left[|\mathcal{A}_{00}^{++}|^2+|\mathcal{A}_{00}^{+-}|^2\right] \tag{13}$$

An extraction of the azimuthal modulations of the polarized cross section will provide several observables whose combined analysis will allow us to separate the contributions from the various chiral-odd GPDs.

2.2 Model Calculations

Recently, two different models for the chiral-odd GPDs have been proposed. The Goldstein-Gonzalez Hernandez-Liuti (GGL) approach [29] is inspired by a physically motivated picture of the nucleon as a quark-diquark system with Regge behavior (reggeized diquark model). The spin structure of each of the four GPDs is determined via a covariant quark-nucleon scattering amplitude, with a diquark exchange. The varying parameters in this model are the quark and diquark masses, the proton-quark-diquark couplings, and the Regge power behavior. For the chiral-even GPDs sector these are fixed via a *progressive/recursive* fit to the flavor dependent proton electromagnetic and weak form factors, to the PDFs, and to presently available DVCS data from Jefferson Lab and HERMES [32, 33].

Differently from the chiral-even case very little is known on the size/normalization (transversity form factors) and shape of the chiral-odd GPDs. Few constraints from phenomenology exist, namely H_T becomes the transversity structure function, h_1, in the forward limit, and it integrates to the tensor charge; the first moment of $2\tilde{H}_T+E_T$ can be interpreted as the proton's transverse anomalous magnetic moment [16], and $\tilde{E}_T$'s first moment is null [34].

In the GGL approach it was shown that specific parity relations at the proton-quark-diquark vertex allow one to relate the chiral-even and chiral-odd amplitudes are taken from the structure These relations hold within a class of spectator models. This led to parameterizing the chiral-odd GPDs, normalized by the chiral-even GPDs. A set of linear relations resulted for the two possible diquark structures, scalar and axial vector spins. The normalizations set as well as the full x, ξ, t, Q^2 dependence was determined from these relations and the evolution with Q^2.

In the Goloskokov-Kroll (GK) model [35, 10, 31] the partonic subprocess is calculated within the modified perturbative approach in which quark transverse degrees of freedom are taken into account. While the transverse size of the produced meson is not ignored as in the collinear (leading-twist) approach, the partons entering the subprocess are viewed as being emitted and reabsorbed by the nucleon co-linearly to the nucleon momenta.

The following approximations are used in the GK approach,

$$\mathcal{A}_{10}^{+-} \approx \sqrt{1-\xi^2}\,\mathcal{H}_T \tag{14}$$

$$\mathcal{A}_{10}^{++} = \mathcal{A}_{10}^{--} \approx \frac{\sqrt{-t'}}{4m}\left(2\widetilde{\mathcal{H}}_T + \mathcal{E}_T\right) \equiv \frac{\sqrt{-t'}}{4m}\,\overline{\mathcal{E}}_T, \tag{15}$$

$$\mathcal{A}_{10}^{-+} = 0. \tag{16}$$

GK single out two main contributions from the chiral-odd GPDs, H_T and $\overline{\mathcal{E}}_T$, while GGL include in addition, the contributions from $\widetilde{\mathcal{H}}_T$, and $\widetilde{\mathcal{E}}_T$. The integral of $\widetilde{\mathcal{E}}_T$ over x is 0 (Diehl), however, GGL calculations show a node in the x dependence for this function yielding a value considerably different from zero for any given (ξ, t).

We can summarize the main differences between the GL and GK approaches are that: *i)* in GK $\mathcal{A}_{10}^{+-} = \mathcal{A}_{10}^{-+}$, whereas this equality does not hold in GGL due to the node in $\widetilde{\mathcal{E}}_T$; *ii)* in GGL the GPD H_T is approximately normalized to the average of the proton Dirac and axial form factors at $t \to 0$, and it therefore dominates over the contributions of the other chiral-odd GPDs in this limit, while H_T does not dominate the small t behavior in the GK model.

Although the two models differ from one another, both predict sizable transverse components of the cross section, therefore indicating that an accurate extraction of the transversity GPDs is at reach with the proposed measurements.

3 Transversity GPDs from π^0 and η exclusive production

Measurements of the unpolarized cross section for π^0 and η exclusive production were performed at CLAS [11]. The two theoretical calculations agree quite well with the CLAS data for the π^o cross sections (see Fig. 4) indicating that transversity effects at JLab energies may be indeed significant. However, due to the limited number of measurements, and in particular to the lack of a separation of the σ_L and σ_T cross sections, no quantitative extraction of transversity and of the tensor charge from experimental data could be made.

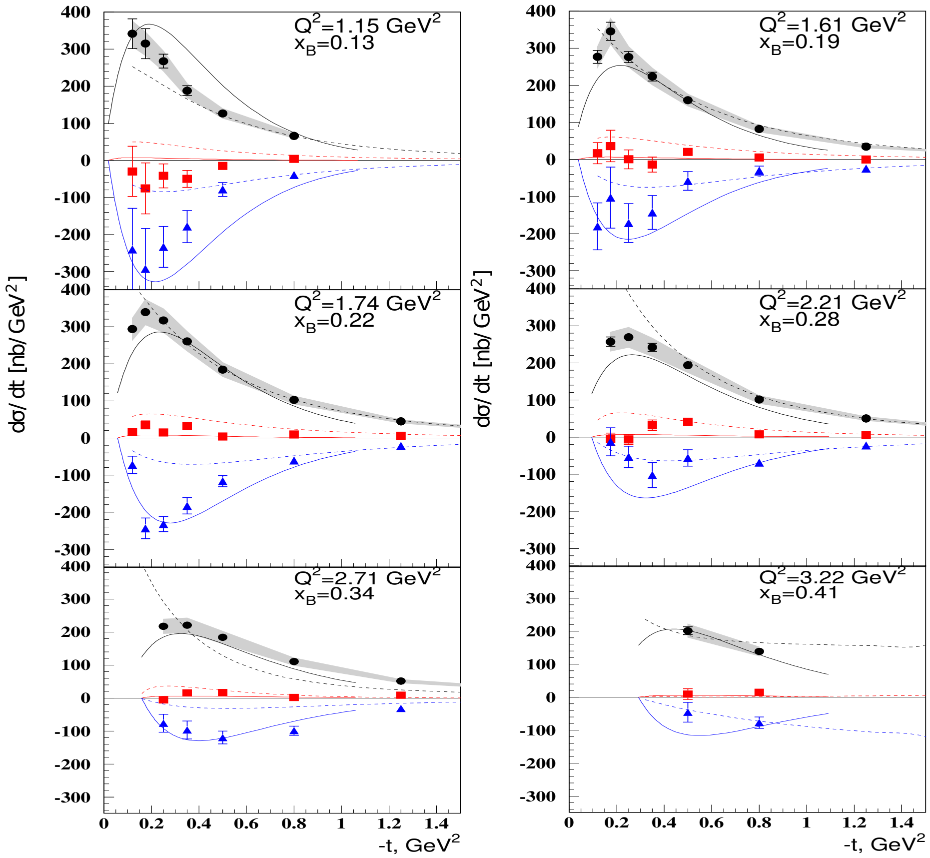

Figure 4: The extracted structure functions vs $-t$ for π^0 production. The CLAS data [11] are as follows: black - $\sigma_U(= \sigma_T + \epsilon\sigma_L)$, blue - σ_{TT}, and red - σ_{LT}. The curves are theoretical predictions produced with the models of ref. [31] and ref. [29] represented by solid and dashed lines respectively.

Recently, the CLAS collaboration performed measurements with a longitudinally polarized proton target, providing additional, complementary observables to access the transversity GPDs. The kinematic restrictions imposed on the DVπ^0P process were, $Q^2 > 1$ GeV^2, and $W > 2$ GeV, to ensure that the events were in the DIS region. The various terms in the double polarized cross section defined in Eq. 1 are plotted in Fig. 5 in comparison with the two different model predictions. The polarized target observables are predicted to be much more sensitive to the chiral-odd flip GPD, $\overline{E}_T = 2\widetilde{H}_T + E_T$, which in turn, describes transverse spatial distributions of quarks anti-aligned with the proton spin [36, 37, 29]. The disagreement between data and model calculation could be to large extent due to the approximation in the t-dependences of the transversity GPDs. The polarized target data provide a direct access to pin down the t dependence of the transversity GPDs.

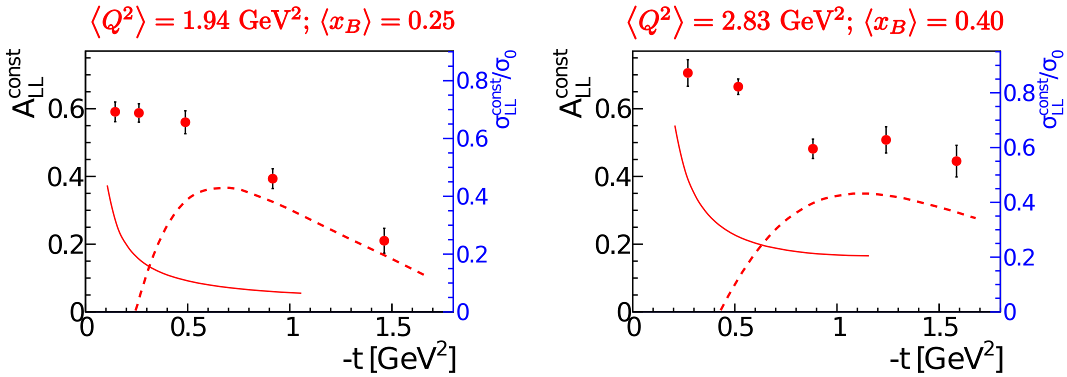

Figure 5: Double spin asymmetry moments. The axes on the right shows the ratio of structure functions to represent the data independently of the experimental setup and beam energy. The solid and dashed curves represent theoretical calculations from GK and GGL model respectively.

4 Transversity effects in Kaon Production

The measurements for π^o and η SSAs over a large kinematic range are challenging, since their cross sections are small (compared to charged pions). In addition the clean detection of π^os and ηs requires the measurement of their two decay photons. Since the precision attainable in charge particle detection is typically much higher, charged kaons provide a very attractive alternative to neutral mesons channels in studies of transversity GPDs. In this reaction, a kaon pole can be present. However, its contribution has been estimated to be much smaller with respect to the π^+ pole ($\approx 10\%$ [15]).

A comparison of the cross sections for different pseudoscalar channels using the GK model is shown in Fig. 6.

The model results for the cross section of the $K^+\Lambda$ and $K^+\Sigma^0$ leptoproduction [31] are shown on Fig. 7. It has been argued that the H_T effects are essential in the $K^+\Lambda$ channel while in the $K^+\Sigma^0$ leptoproduction the $\bar{E}_T$ contribution is mostly important.

The large transversity H_T effects in the $K^+\Lambda$ channel contribute to the large σ_T cross section without a forward dip (see Fig. 7),which dominates in σ_L. For the $K^+\Sigma^0$ production the H_T contribution is much smaller and the $\bar{E}_T$ effects become essential. It provides the cross section with a forward dip (Fig. 7, Right). In both cases σ_T determined by the transversity H_T and $\bar{E}_T$ contribution is large at low Q^2 with respect to the leading twist σ_L cross section. The twist-3 effects decrease with Q^2 growing and at sufficiently high Q^2 the σ_L may dominate. Large single spin asymmetries, $\sin\phi$ moments of the cross section for polarized beam or target (see Fig. 8) were also predicted for all channels [31]. While the CLAS result for π^+ production is in reasonable agreement with GK result, SSAs in π^0 production are significantly larger,

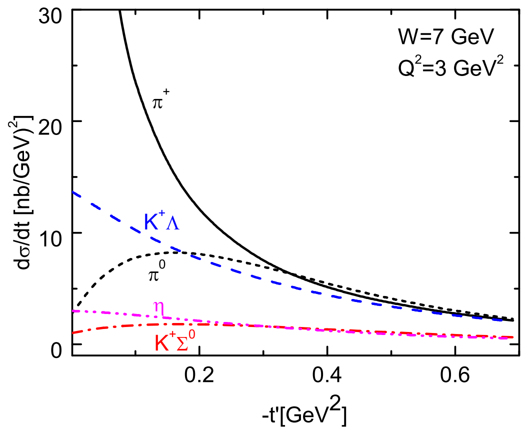

Figure 6: The cross sections for various pseudoscalar meson channels at HERMES energies from GK model.

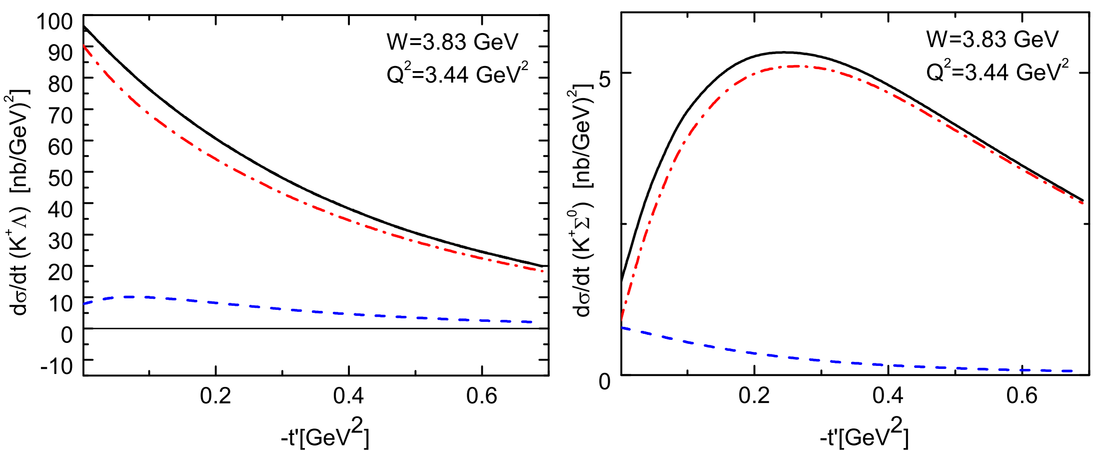

Figure 7: Left: the $K^+\Lambda$ production cross sections from GK model. Right: the $K^+\Sigma^0$ production cross sections at HERMES energies from GK model. Full line - unseparated cross section, dashed - σ_L, dashed-dotted line - σ_T.

indicating that certain assumptions were not completely justified.

Kaon production is an unique reaction where in different channels we can test H_T and $\bar{E}_T$ transversity GPDs

- $K^+\Lambda$ production. This channel should be predominated by transversity H_T contribution. This can be checked by the absence of forward dip in unseparated (or transverse if possible) cross section. From cross section, information about H_T transversity GPDs can be extracted.

- $K^+\Sigma^0$ production channel should be determined mainly by the $\bar{E}_T$ transversity GPD. This can be tested by the t' dependence of the cross section. Assuming the

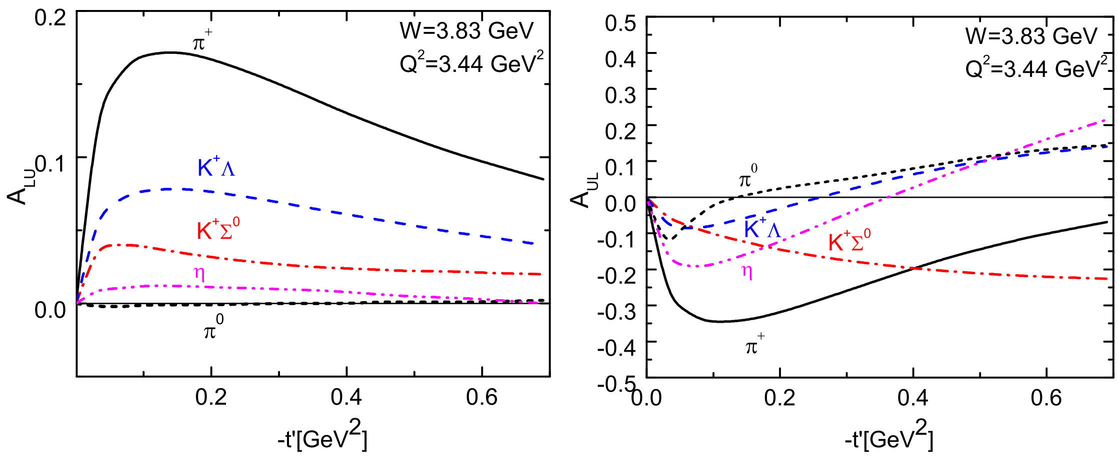

Figure 8: The beam spin asymmetry (left) and the asymmetry for a longitudinally polarized target (right) for various pseudoscalar-meson channels versus t' from GK model.

Σ cross section has essential dip near $t' = 0$ and maximum near $-t' = 0.2\text{GeV}^2$ the information about $\bar{E}_T$ transversity GPD can be obtained from cross section analyses.

- The $K^+\Sigma^0$ production would also allow an additional test of $\bar{E}_T$ transversity GPD dominance using σ_{TT} cross section analyses. In case the $\bar{E}_T$ contribution is indeed essential one would expect $\sigma_{TT} \sim -\sigma_T$.

5 Flavor decomposition of chiral-odd GPDs

An analysis of the different observables, by being sensitive to different helicity amplitudes can single out the various GPDs contributions. For example, in the GGL model:
– The unpolarized cross section is dominated by H_T at low $-t$ ($-t < 0.1$ GeV^2), and it therefore allows one to access transversity and the tensor charge. At larger $-t$ the GPD $\widetilde{\mathcal{E}}_T$ is dominant. The latter is sensitive to the transverse anomalous magnetic moment, κ_T [7].
– The term σ_{LT} measures the difference of the amplitudes $\mathcal{A}_{10}^{++}$ and $\mathcal{A}_{10}^{--}$ and it therefore allows us to extract a relatively unexplored GPD, $\widetilde{\mathcal{E}}_T$.
– The longitudinally polarized target cross section terms are dominated by the $\overline{E}_T$ contribution.

This type of analysis can be extended to all the production channels examined in this proposal so that a clean flavor separation of the various GPD components will be attained.

The following flavor decomposition of valence contribution to different channel of pseudoscalar meson is valid:

$$H_T^{\gamma^* p\to\pi^+ n} \sim [H_T^u - H_T^d] \tag{17}$$

$$H_T^{\gamma^* p\to\pi^0 p} \sim [2H_T^u + H_T^d] \tag{18}$$

$$H_T^{\gamma^* p\to\eta p} \sim [2H_T^u - H_T^d] \tag{19}$$

$$H_T^{\gamma^* p\to K^+\Lambda} \sim [2H_T^u - H_T^d - H_T^s] \tag{20}$$

$$H_T^{\gamma^* p\to K^+\Sigma^0} \sim [H_T^d - H_T^s] \tag{21}$$

For proton-hyperon transition GPDs we use SU(3) flavor symmetry hypotheses. Using this flavor decomposition, information about chiral-odd GPDs for valence u and d quarks may be extracted from analyses of different channels of meson production.

An additional motivation for measuring precisely the flavor dependence of the transversity GPDs and of both the tensor charge and the transverse anomalous magnetic moment is that a precise determination of these values will allow us to improve the limits on the tensor interaction Beyond the Standard Model (BSM) contribution to the weak current structure. Measurements of neutron beta decay are currently ongoing. However, only lattice gauge theory calculations of the hadronic component of the tensor charge have been used so far to set limits on these interactions [38].

6 The Experiment

We propose to study the exclusive kaon leptoproduction with CLAS12 detector and polarized JLab 12 GeV electron beam. One of the main challenges will be the separation of exclusive $K^+\Lambda$ and $K^+\Sigma^0$ channels. Detection of just the Kaon itself, using the the missing mass cut already provides separation of exclusive states. Distributions over the missing mass of K^+ for inbending and outbending configurations are shown on Fig. 9. The CLAS12 resolution is not good enough to separate $K^+\Lambda$ and $K^+\Sigma^0$ channels, and an additional selection is required, when using just the Kaon missing mass technique.

Alternative possibility to study exclusive Kaon production is provided by detection of the proton and negative pion defining the final state Lambda by its invariant mass. Distributions over the invariant mass of produced Λs for inbending and outbending configurations are shown on Fig. 10. Imposing a cut on the missing mass of identified Lambdas (shown on Fig. 11) allows selection of exclusive K^+ and K^{*+} channels.

The outbending configuration for CLAS12 provides much higher efficiency in reconstruction of direct Lambdas.

Clean separation could be done using the technique similar to one used in separation of exclusive DVCS and π^0 channels [39]. Detection of all final states allows to impose an additional cut on the difference between angles of the final state particle

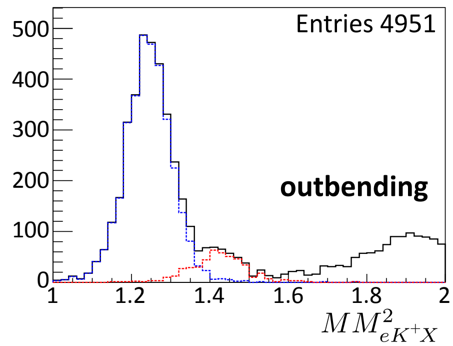

Figure 9: The missing mass squared $MM^2_{eK^+X}$ with $K^+\Lambda$ (blue) and $K^+\Sigma^0$ (red) for inbending and outbending configurations for 2 hours of CLAS12 running at $10^{35}\text{sec}^{-1}\text{cm}^{-2}$.

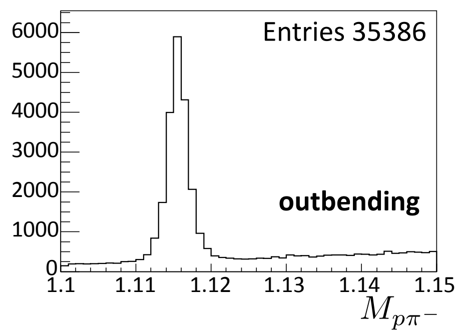

Figure 10: The invariant mass of proton and π^- for 2 hours of CLAS12 running at $10^{35}\text{sec}^{-1}\text{cm}^{-2}$.

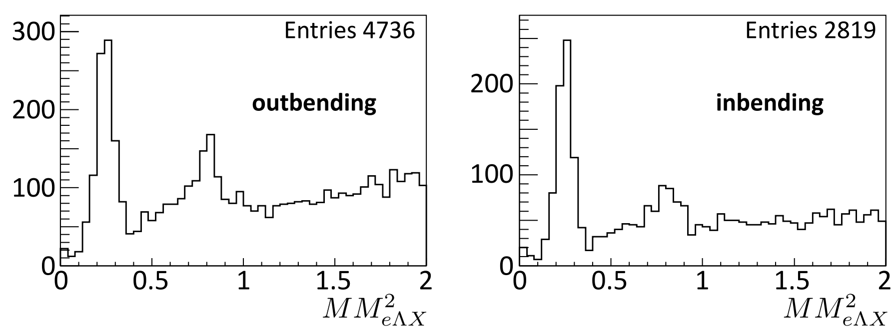

Figure 11: The missing mass squared $MM^2_{e\Lambda X}$, where Λ is identified by a cut on invariant mass of proton and π^- in a range $1.112 < M_{p\pi-} < 1.119$ for inbending and outbending configurations for 2 hours of CLAS12 running at $10^{35}\text{sec}^{-1}\text{cm}^{-2}$.

(kaon in this case), compared to the one calculated using remaining particles (proton and π^-). Events with proton and π^- in final state, with invariant mass matching within 3σ the Lambda mass accompanied with an additional positive track at angles roughly matching (within $\sim 10^0$) the direction of the K^+, assuming the event is an exclusive $K^+\Lambda$, have been selected. Distributions over that angle (θ_{KX}) for two states from a MC simulation including exclusive $K^+\Lambda$ and $K^+\Sigma^0$ channels are shown in Fig. 12. The fraction of exclusive Lambda events in overall number of exclusive K^+ events reduces significantly with a cut on θ_{KX}. As shown on Fig. 13, a cut of 4 degrees changes the fraction of exclusive Σ events from $\sim 15\%$ to $\sim 90\%$.

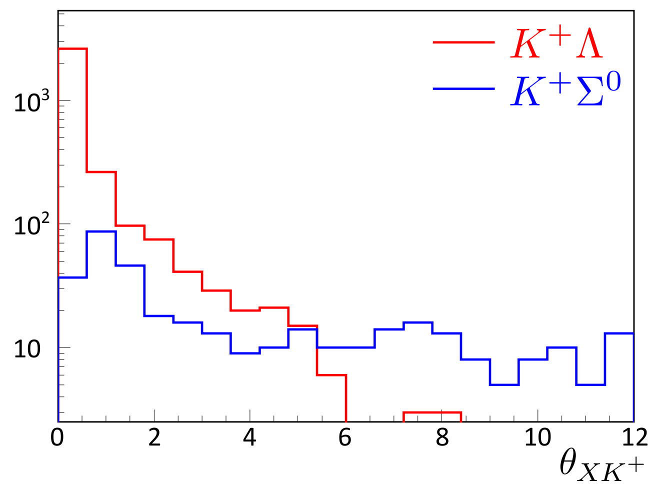

Figure 12: The $K^+\Lambda$ (red) and $K^+\Sigma^0$ (blue) counts as a function of the angle between calculated and measured K^+.

7 Summary

In this experiment we propose a study of the chiral-odd GPDs via measurements of exclusive production of pseudoscalar mesons in the hard scattering kinematics ($Q^2 > 1\text{GeV}^2$, $W^2 > 4\text{GeV}^2$), using a longitudinally polarized 11 GeV electron beam, unpolarized hydrogen and polarized NH_3 targets and the CLAS12 detector. Detection of 4 final state particles would allow clean separation of different exclusive channels in strange hyperon production using the cut on the angle between calculated and measured kaons. Further identification of positive tracks with K^+, will reduce the random background. The data will be collected during the E12-09-008 and E12-09-009 experiments approved for 56 days and 30 days of unpolarized and 30 days of polarized hydrogen target running, respectively.

Proposed analysis of cross sections and spin-azimuthal asymmetries in exclusive Λ^0, Σ^0, π^0 and η production in terms of the handbag approach with contribution from chiral-odd leading-twist GPDs together with the twist-3 effects would allow measurements of chiral-odd GPDs and provide access to different flavor combinations of GPDs.

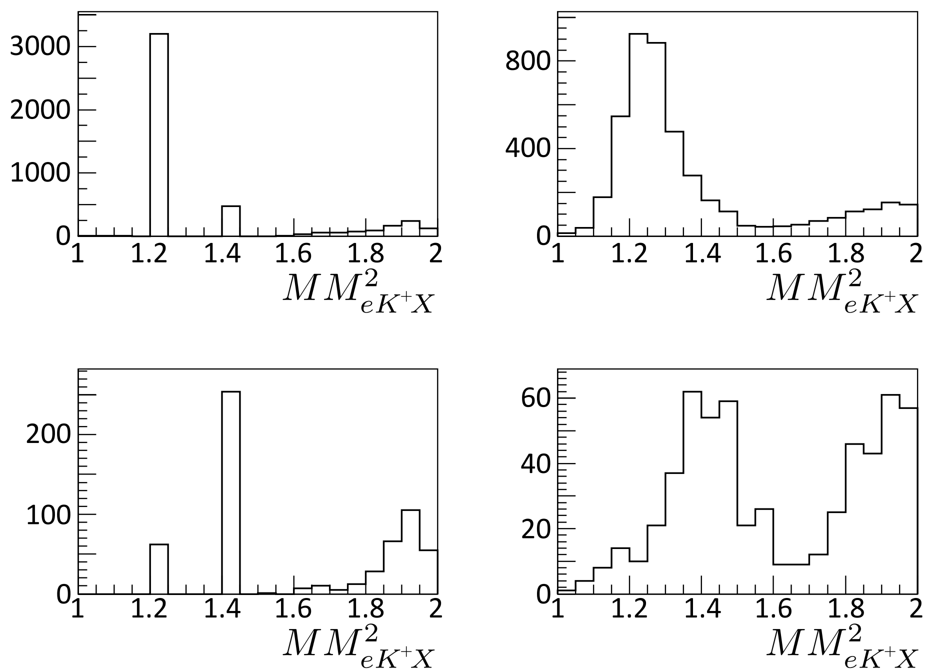

Figure 13: The missing mass squared $MM^2_{eK^+X}$ distribution of all events for generated (left column) and reconstructed (right columns) events. The top row shows a dominance of $K^+\Lambda$ over $K^+\Sigma^0$ events before the cut on angle between calculated and measured K^+, and bottom row shows the suppression of $K^+\Lambda$ after the cut: $\theta_{XK^+} > 4^\circ$

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