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Chiral odd generalized parton distributions from exclusive π^o electroproduction

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Summary. — Exclusive pseudoscalar meson electroproduction in the multi-GeV region was recently proposed as a way to obtain chiral odd generalized parton distributions from data. We explain the idea and we show details of both the formulation of the theory in terms of chiral odd generalized parton distributions, and of the extraction procedure.

PACS 13.60.-r – Photon and charged-lepton interactions with hadrons.
PACS 14.20.-c – Baryons (including antiparticles).
PACS 13.60.Le – Meson production.
PACS 14.65.Bt – Light quarks.

1. – Introduction

QCD factorization theorems allow us to describe Deeply Virtual Compton Scattering (DVCS) and Deeply Virtual Meson Production (DVMP) as the convolution of specific Generalized Parton Distributions (GPDs) with hard scattering amplitudes [1]. Within a collinear factorization scheme it was initially proposed that: i) factorization in DVMP works rigorously for longitudinal virtual photon polarization [2], the transverse polarization case being yet unproven; ii) the only coupling that survives at the pion vertex in the large Q^2 limit is of the type $\gamma_\mu\gamma_5$, the other possible term $\propto \gamma_5 P$, being suppressed. The resulting amplitudes were written in terms of the chiral even GPDs, $\widetilde{H}$ and $\widetilde{E}$ [3-5].

In refs. [6, 7] we took, however, a different approach that brought us to identify the chiral-odd GPDs including $H_T, E_T, \widetilde{H}_T, \widetilde{E}_T$ [8, 9], as the observables in a class of experiments related to Deeply Virtual π^o Production (DVπ^oP), or more generally in deeply virtual neutral pseudoscalar meson production [10]. Of the four chiral-odd GPDs the only one that can be identified at leading order with a parton distribution in the zero momentum transfer limit is H_T. $H_T(X, \zeta = 0, t = 0, Q^2) \equiv h_1(X, Q^2)$, where $h_1(X, Q^2)$ is the transversity function, namely the probability of finding a transversely polarized quark inside a transversely polarized nucleon (X is the Light Cone (LC) momentum

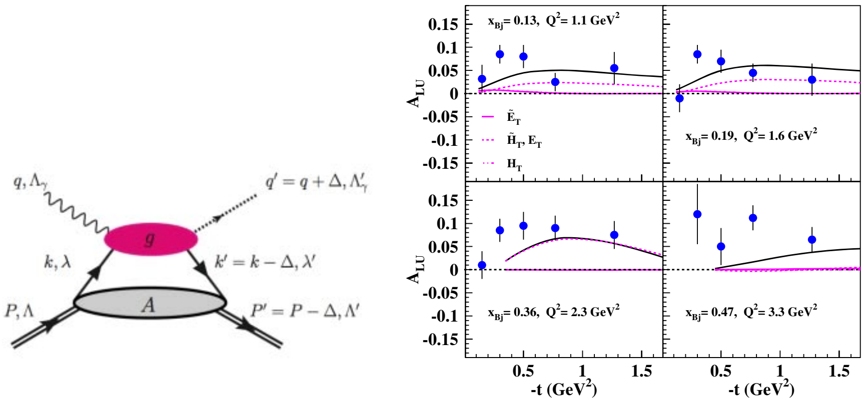

Fig. 1. – Left: Leading order amplitude for DVMP, $\gamma^* + P \to M + P'$. Crossed diagrams are not shown in the figure; Right: Beam spin asymmetry, A_{LU}, plotted *vs.* $-t$ for four different kinematics: $Q^2 = 1.3\,\text{GeV}^2$, $x_{Bj} = 0.13$ (upper left), $Q^2 = 1.6\,\text{GeV}^2$, $x_{Bj} = 0.19$ (upper right), $Q^2 = 2.3\,\text{GeV}^2$, $x_{Bj} = 0.36$ (lower left), and $Q^2 = 3.3\,\text{GeV}^2$, $x_{Bj} = 0.47$ (lower right). Experimental data from ref. [18]. Shown are curves obtained by considering only the GPDs, $\widetilde{E}_T$ (full curve), $(2\widetilde{H}_T + (1 \pm \xi)E_T)$ (dashes), and H_T (dot-dashes). The result obtained including all GPDs is shown in black.

fraction, $X = k^+/P^+$, $t = \Delta^2$ where Δ is the momentum transfer between the initial and final protons, ζ is the fraction of LC momentum transfer, $\zeta = \Delta^+/P^+$, Q^2 is the photon's virtuality, see fig. 1). Transversity has been notoriously an elusive quantity to extract from experiment, only recently accessible through model dependent analyses of semi-inclusive experiments [11].

In our approach we first of all assumed that a form of factorization is working for both longitudinal and transverse virtual photons (notice, however, that a dedicated proof is missing for factorization in the transverse polarization case). The coupling to the outgoing pseudoscalar meson depends on the process' J^{PC} quantum numbers in the t-channel [12]. In ref. [6] we noticed that for pseudoscalar electroproduction one has at leading order $J^{PC} \equiv 1^{--}, 1^{+-}$, corresponding to either vector (V) or axial-vector (A) fermion anti-fermion pairs. This, in turn, corresponds to ${}^{2J+1}L_S \equiv {}^3S_1, {}^1P_0$. The transition from $\gamma^*(q\bar{q})$ into π^o ($J^{PC} \equiv 0^{+-}$), therefore corresponds to a change of Orbital Angular Momentum (OAM), $\Delta L = 0$ for the vector case, and $\Delta L = 1$ for the axial-vector. Our idea is to introduce orbital angular momentum in the calculation of the one gluon exchange mechanism for the transition form factor by using a technique similar to the one first introduced in [13] (our form factor is consistent also with the one proposed in ref. [14]). By doing so we describe the pion vertex with two form factors, an axial vector type, $F_A(Q^2)$, suppressed by $\mathcal{O}(1/Q^2)$ with respect to the vector one, $F_V(Q^2)$. The two form factors enter the helicity amplitudes for the various processes in different combinations. This gives rise to a more articulated form of the Q^2 dependence, which is more flexible and apt to describe the features of the data than the standard one. In particular we can now understand and reproduce the persistence of a large transverse component in the multi-GeV region.

The scenario presented in ref. [6] was tested by estimating the contribution of the chiral odd GPDs to a few observables that are particularly sensitive to the values of the tensor charge. A sound model/parametrization for chiral odd GPDs was however missing in that previous work. More recent work has been dedicated to presenting such a model in detail [7,15]. Differently from the chiral even case where the GPDs integrate to the electromagnetic and weak form factors, very little can be surmised on the size/normalization 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 $2\widetilde{H}_T + E_T$ can be interpreted as the proton's transverse anomalous magnetic moment [16], and $\widetilde{E}_T$'s first moment is null [9]. By using a reggeized quark-diquark model we can however exploit the Parity and Charge Conjugation symmetries obeyed by the helicity amplitudes to obtain further constraints on the chiral odd GPDs.

In this contribution we show these recent developments. We compare our results to the π^0 electroproduction data from Jefferson Lab's Hall B [17,18].

Finally, calculations similar to ours were recently presented in ref. [19,20] based on different model assumptions for the chiral odd GPDs.

2. – Formalism

We consider the loop diagram in fig. 1 integrated over the struck quark's momentum, namely $\mathrm{d}^4k \equiv \mathrm{d}k^+\mathrm{d}k^-\mathrm{d}^2k_\perp \equiv P^+\mathrm{d}X\mathrm{d}k^-\mathrm{d}^2k_\perp$. The hadronic tensor has the form

$$\begin{aligned}(1)\qquad &\mathcal{F}_{\Lambda,\Lambda'}(\zeta,t) = \\ &-i\epsilon^{\mu\,T}\int\frac{\mathrm{d}^4k}{(2\pi)^4}\,\mathrm{Tr}\left[\left(\frac{\gamma^\mu i(\not k+\not q)\Gamma^5}{(k+q)^2+i\epsilon} + \frac{\Gamma^5 i(\not k-\not\Delta-\not q)\gamma^\mu}{(k-\Delta-q)^2-i\epsilon}\right)\mathcal{M}(k,P,\Delta)\right].\end{aligned}$$

where $\Gamma^5_{odd} = g_\pi^{odd}(Q)\gamma^5$. $g_\pi^{even(odd)}$ is the quark-pion coupling in the structure of the upper part of the handbag yielding,

$$\begin{aligned}(2)\ \mathcal{F}^{odd}_{\Lambda,\Lambda'}(\zeta,t) = \frac{g_\pi^{odd}(Q)}{2\overline{P}^+}\int_{-1+\zeta}^{1}\mathrm{d}X\left(\frac{1}{X-\zeta+i\epsilon}+\frac{1}{X-i\epsilon}\right)\Big[\overline{U}(P',\Lambda')\Big(i\sigma^{+i}H_T(X,\zeta,t)\\ +\frac{\gamma^+\Delta^i-\Delta^+\gamma^i}{2M}E_T(X,\zeta,t)+\frac{P^+\Delta^i-\Delta^+P^i}{M^2}\widetilde{H}_T(X,\zeta,t)\\ +\frac{\gamma^+P^i-P^+\gamma^i}{2M}\widetilde{E}_T(X,\zeta,t)\Big)U(P,\Lambda)\Big].\end{aligned}$$

The convolution in eq. (2) yields the following decomposition of the various helicity amplitudes:

$$(3)\qquad f_{10}^{++} = g_\pi^{odd}(Q)\frac{\sqrt{t_0-t}}{2M(1+\xi)^2}\left[2\widetilde{\mathcal{H}}_T + (1-\xi)\left(\mathcal{E}_T - \widetilde{\mathcal{E}}_T\right)\right],$$

$$(4)\qquad f_{10}^{+-} = g_\pi^{odd}(Q)\frac{\sqrt{1-\xi^2}}{(1+\xi)^2}\left[\mathcal{H}_T + \frac{t_0-t}{4M^2}\widetilde{\mathcal{H}}_T + \frac{\xi^2}{1-\xi^2}\mathcal{E}_T + \frac{\xi}{1-\xi^2}\widetilde{\mathcal{E}}_T\right],$$

$$(5)\qquad f_{10}^{-+} = g_\pi^{odd}(Q)\frac{\sqrt{1-\xi^2}}{(1+\xi)^2}\frac{t_0-t}{4M^2}\widetilde{\mathcal{H}}_T,$$

$$f_{10}^{--} = g_\pi^{odd}(Q)\,\frac{\sqrt{t_0-t}}{2M(1+\xi)^2}\left[2\widetilde{\mathcal{H}}_T + (1+\xi)\left(\mathcal{E}_T + \widetilde{\mathcal{E}}_T\right)\right], \tag{6}$$

$$f_{00}^{+-} = g_\pi^{odd}(Q)\,\frac{\sqrt{1-\xi^2}}{(1+\xi)^2}\left[\mathcal{H}_T + \frac{\xi^2}{1-\xi^2}\mathcal{E}_T + \frac{\xi}{1-\xi^2}\widetilde{\mathcal{E}}_T\right], \tag{7}$$

$$f_{00}^{++} = -g_\pi^{odd}(Q)\,\frac{\sqrt{t_0-t}}{2M(1+\xi)^2}\left[2\widetilde{\mathcal{H}}_T + \mathcal{E}_T - \xi\widetilde{\mathcal{E}}_T\right]. \tag{8}$$

3. – Some results

In ref. [21] we calculated the GPDs in the chiral even sector with the aim of interpreting DVCS data. We introduced a reggeized diquark model whose basic structures are covariant quark-proton scattering amplitudes at leading order with proton-quark-diquark vertices. The dominant components of the model are quark-diquark correlations where the diquark system has both a finite radius and a variable mass, M_X, differently from constituent type models. At low mass values one has diquark systems with spin $J = 0^+, 1^+$. Using the $SU(4)$ symmetry the spin 0 and 1 components translate into different values for the u and d quark distributions. More complex correlations ensue at large mass values which are regulated by the Regge behavior of the quark-proton amplitude, $\propto \hat{u}^{\alpha(t)} = (M_X^2)^{\alpha(t)}$. We can immediately deduce that for $S = 0$ the helicity structures on the LHS and RHS of fig. 1 can be described in a factorized form, and transform under Parity independently from one another. For $S = 1$ factorization breaks: there is angular momentum exchange between the LHS and RHS. While this complication did not affect numerical results and it was therefore disregarded in [21], it is instead central for addressing the chiral even-odd connection. The GPD content of one of the many asymmetry observables measured in Hall B is shown in fig. 1 (right panel).

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