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TMD measurements at CLAS

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Summary. — We present recent results on studies of spin orbit correlations using the Jefferson Lab CLAS detector and discuss future plans with CLAS, including measurements with unpolarized and longitudinally polarized targets.

PACS `12.38.-t` – Quantum chromodynamics.
PACS `13.60.-r` – Photon and charged-lepton interactions with hadrons.
PACS `13.88.+e` – Polarization in interactions and scattering.
PACS `25.30.Dh` – Inelastic electron scattering to specific states.

1. – Introduction

In recent years, measurements of azimuthal moments of polarized hadronic cross sections in hard processes, and in particular the single-spin asymmetries (SSAa), have emerged as a powerful tool to probe nucleon structure through measurements of Generalized Parton Distributions (GPDs) and Transverse Momentum Dependent parton distribution function (TMDs) in hard exclusive and semi-inclusive production of final states particles, respectively. Two fundamental QCD mechanisms giving rise to single spin asymmetries in semi-inclusive deep inelastic scattering (SIDIS) were identified. First the Collins mechanism [1-3], where the asymmetry is generated in the fragmentation of transversely polarized quarks, and second the Sivers mechanism [4-6], where it arises due to final state interactions at the distribution function level.

2. – SSA measurements in semi-inclusive and exclusive DIS

Higher-twist observables, such as longitudinally polarized beam or target SSAs, are important for understanding long-range quark-gluon dynamics. Recently, higher-twist effects in SIDIS were interpreted in terms of an average transverse force acting on the active quarks in the instant after being struck by the virtual photon [7].

The beam-spin asymmetries in single-pion production off the unpolarized target are higher-twist by their nature [8, 9]. The higher twist observables may also be accessible as leading contributions through the measurements of certain asymmetries [10, 2, 3, 11] and in particular beam SSAs.

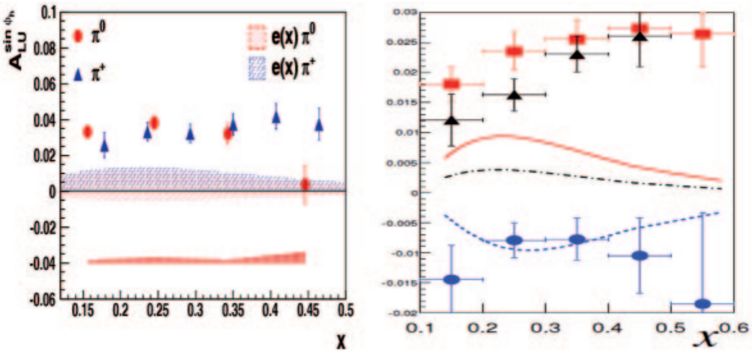

Fig. 1. – The π^0 beam-spin asymmetry moment $A_{LU}^{\sin\phi_h}$ *vs.* x compared to that of π^+ from an earlier CLAS measurement [14] (left panel). For both data sets $\langle P_T\rangle \approx 0.38\,\mathrm{GeV}$ and $0.4 < z < 0.7$. The right-hatched and left-hatched bands are model calculations involving solely the contribution from the Collins-effect [15]. Beam-spin analyzing powers (rigt panel) in the $\sin\phi$ moment as a function of transverse momentum, for π^+ (squares) and π^- (circles) and π^0 (circles). Error bars show the statistical uncertainties and the band represents the systematic uncertainties.

The comparison of beam SSA for all 3 pions [12] with contribution from only the Collins effect (see fig. 1) indicate that Sivers type contribution ($g^\perp \otimes D_1$) [13] may be significant for π^+ and π^0 and small for π^-. That is consistent with latest observations by HERMES and COMPASS, where large Collins effect was observed for charged pions, while the Sivers effect was found to be significant only for π^+.

At large x ($x > 0.2$), a region well-covered by JLab, large $\sin 2\phi$ target SSA has been predicted (see fig. 2), sensitive to the distribution function $h_{1L}^\perp$ [16-20]. The $\sin\phi$ moment of the spin-dependent cross section for the longitudinally polarized target, first measured by the HERMES Collaboration [21], is dominated by higher-twist contributions which are suppressed by $1/Q$ at large momentum transfer.

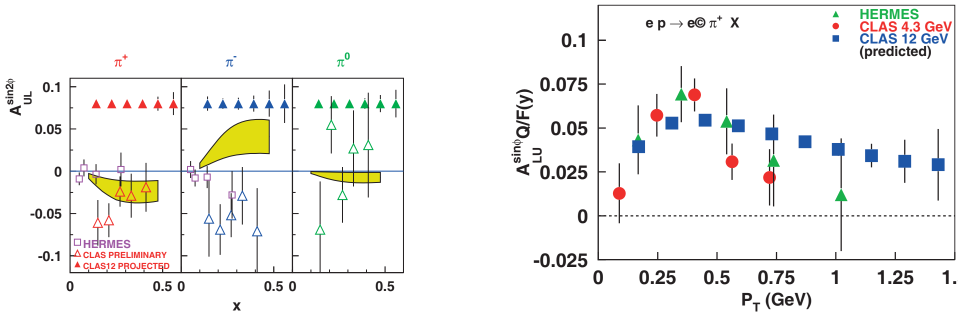

Fig. 2. – The projected x-dependence of the target SSA at 11 GeV. The triangles illustrate the expected statistical accuracy. The open squares and triangles show the existing measurement of the Mulders TMD from HERMES and the preliminary results from CLAS 5.7 GeV CLAS data sets, respectively. The curves are calculated using ref. [22]. Beam-spin analyzing powers (right panel) in the $\sin\phi$ moment as a function of transverse momentum, for π^+ (squares) and π^- (circles) and π^0 (circles). Error bars show the statistical uncertainties and the band represents the systematic uncertainties.

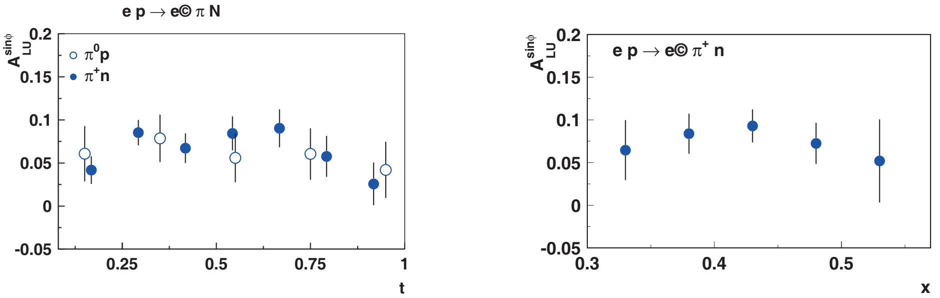

Fig. 3. – The beam SSA for exclusive π^+ and π^0 in hard scattering kinematics ($W^2 > 4, Q^2 > 1.5$ with $\langle Q^2 \rangle \approx 2.5$, $\langle x \rangle \approx 0.34$) as a function of t (left panel), and as a function of x for exclusive π^+ for $W^2 > 5, Q^2 > 2.5$ with $\langle Q^2 \rangle \approx 3$ (right panel).

Measurements of the dependencies of various observables in hard exclusive production on the momentum transfer to nucleon, t, on other hand provide the information necessary for transverse nucleon imaging [23]. Pseudoscalar meson electroproduction, and in particular π^0 production in the reaction $ep \to e'p'\pi^0$, was identified as especially sensitive to the helicity-flip subprocesses. In the handbag approach developed recently by Liuti and Goldstein [24] and Kroll and Goloskokov [25, 26] the helicity amplitudes depend on hard partonic subprocess and the GPD and the beam spin asymmetries of exclusive pions combined with other spin and azimuthal asymmetries can provide a unique possibility to access the elusive transversity GPDs within the handbag approach.

While the interpretation of π^+ production is complicated by the dominance of the longitudinal π^+-pole term, the π^0 production, where that contribution is absent may become a unique source of information on transversity GPDs. In addition, for π^0 production the structure of the amplitudes further suppresses the quark helicity conserving amplitudes relative to the helicity-flip amplitudes [25, 26]. Considering the kinematical region of small ξ and small $-t$ but large Q^2 and large photon-proton c.m.s. energy, W, and neglecting terms of order $\sqrt{-t}/Q$, the beam and target spin asymmetries can be expressed as a function of corresponding helicity amplitudes [25, 26].

Extraction of azimuthal moments of the polarized cross section provides several observables, combined analysis of which may allow separation of contributions from different underlying GPDs and provide a unique possibility to access "transversity" GPDs through measurements of different azimuthal moments of the cross section.

The asymmetry A_{LU} for incoming electron energy of 5.754 GeV and an unpolarized 5 cm long liquid-hydrogen target, was measured in several bins in x and t and fitted by a simple sinusoidal dependence to extract the amplitude of modulation. The beam $\sin\phi$ SSA for exclusive events in the hard scattering kinematics ($W^2 > 4\,\mathrm{GeV}^2$, $Q^2 > 1\,\mathrm{GeV}^2$) can be very significant (see fig. 3), and unlike the case of the target $\sin\phi$ SSA [27, 28] is positive and compatible with the $A_{LU}^{sin\phi}$ for the semi-inclusive sample at large z [29]. Results on beam spin asymmetries for neutral pions are consistent with latest CLAS measurements using a setup with CLAS inner calorimeter [30], allowing more efficient detection of photons in CLAS.

Even though the power corrections for the absolute cross section of exclusive pion electroproduction analyzed in terms of generalized parton distributions are expected to be large, there are indications of a *precocious scaling* in ratios of observables [31], making spin-azimuthal asymmetries a very attractive observables in studies of of 3D PDFs.

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