# SPIN-AZIMUTHAL ASYMMETRIES IN DIS AT CLAS

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We present latest measurements of beam and target single-spin asymmetries in the single pion electroproduction in the DIS. In addition to significant target single-spin asymmetries the CLAS detector at Jlab also measures a significant beam-spin asymmetry when the analysis is restricted to events for which the pion carries a large fraction of the virtual photon momentum.

## 1. Introduction

Single-spin asymmetries (SSA) in azimuthal distributions of final state particles in deep inelastic scattering (DIS) play a crucial role in the study of the spin structure of hadrons in terms of their elementary constituents. They give access to subtle distribution and fragmentation functions, which cannot easily be accessed in other ways. The list of physical observables accessible in SSA includes the chiral-odd distribution functions, among which the transversity [1] and recently introduced [2,3,4] *time-reversal odd* distribution functions are the most prominent examples. Other important quantities in this list are so-called *time-reversal odd* (T-odd) fragmentation functions, in particular the Collins function [5] . It is also argued that in both semi-inclusive [6] and in hard exclusive [7] pion production, scaling sets in for different cross section ratios and in particular, for SSA observables at lower $Q^2$ than it does for the absolute cross section. This makes it possible for the measurement of spin-asymmetries to be a major tool for the study of T-odd and Generalized Parton Distribution Function (GPDF) measurements in $Q^2$ domain of few $GeV^2$. The total cross section for single pion production by longitudinally polarized leptons scattering off unpolarized protons is defined by a set of structure functions. The two most important ones are the beam-spin independent cross section ($\sigma_{UU}$ in [10]), which arises from the symmetric part of the hadronic tensor, and the helicity ($\lambda_e$) dependent part ($\sigma_{LU}$), which arises from the anti-symmetric part of the hadronic tensor:

$$\frac{d\sigma_{LU}}{dxdy\,dzd^2P_\perp} \propto \lambda_e\,\sqrt{y+\gamma^2}\sqrt{1-y-\frac{1}{4}\gamma^2}\,\sin\phi\;H'_{LT}. \qquad (1)$$

The subscript "$L$" stands for the longitudinally polarized beam and "$U$"(second index) for the unpolarized target, $\phi$ is the azimuthal angle between the scattering plane defined by the initial and final electron momenta, $\vec{k}_1$ and $\vec{k}_2$, and the production plane defined by the momenta of the observed hadron and the virtual photon, $\vec{P}_h$ and $\vec{q}$. The kinematical scaling variables, $x$, $y$ and $z$ are defined as: $x = Q^2/2(P_1q), y = (P_1q)/(P_1k_1), z = (P_1P)/(P_1q)$, where $Q^2 = -q^2$, $q = k_1 - k_2$ is the momentum of the virtual photon, $P_1$ and $P$ are the target and observed final-state hadron momenta, and $\gamma^2 = 4M^2x^2/Q^2$.

Assuming that the quark scattering process and the fragmentation process factorize and that the fragmentation functions scale and depend only on the fractional energy $z$, the structure functions could be presented as a convolution of a distribution function (DF) and a fragmentation function (FF). Both assumptions have yet to be experimentally confirmed at Jlab energies.

Distribution and fragmentation functions responsible for non zero $H'_{LT}$ in semi-inclusive deep inelastic scattering (SIDIS) were first identified by Levelt and Mulders [8]. They include the twist-3 unpolarized distribution function $e(x)$ introduced by Jaffe and Ji [1] and the polarized fragmentation function $H_1^\perp(z)$ first discussed by Collins [5].

In this contribution, we focus on beam and target single-spin dependent asymmetries in pion azimuthal distributions in one particle inclusive leptoproduction. Latest results from Jefferson Lab's Large Acceptance Spectrometer (CLAS) [13] detector reveal very significant single-spin asymmetries in pion azimuthal distributions in electroproduction in the DIS range ($Q^2 > 1, W^2 > 4$) at large $z$.

## 2. The Experiment

The scattering of 4.25 GeV longitudinally polarized electrons from a liquid hydrogen target (JLAB E1 experiment) and polarized ammonia (JLAB EG1 experiment) was studied in a wide range of kinematics. The cuts used to extract the asymmetry for the semi-inclusive sample at CLAS were defined from the comparison of data and the Lund (PEPSI+LEPTO+JETSET) [14] based Monte-Carlo. Very good agreement in different kinematic distributions between data and LUND predictions

was found even though the LUND MC was developed for much higher beam energies.

The region of $z$, where the separation of target and current fragmentation is expected to hold, shrinks at low beam energies. At Jlab energies $(4-6GeV)$ the data exhibit behavior consistent with scattering in the current dominated regime at relatively large $z$.

A cut, $x_F > 0.15$ ($x_F = P_L/|\vec{q}|$), was used to define a minimum longitudinal momentum fraction of the pion in CM frame. A second cut $z > 0.5$ was applied to the fraction of the virtual photon energy carried by the pion to restrict the kinematics to the region where the predictions based on the semi-inclusive approach are consistent with the data. In this region the LUND model predicts that the major part of the $\pi^+$ mesons are produced directly from string fragmentation.

The upper limit, $z < 0.8$, was chosen to exclude the kinematic region where the higher-twist effects and diffractive effects could be dominant. In addition, in this intermediate range of $z$ ($0.5 < z < 0.8$) the $z$-distribution of final state pions at CLAS is in good agreement with LUND-MC and high energy experiments from SLAC and HERMES, showing no dependence on $x$, which suggests a "precocious" onset of scaling at energies as low as 4.25GeV. A cut on the missing mass of the $e'\pi^+$ system, $M_X > 1.1$, was used to eliminate exclusive events. An additional cut on the transverse momentum of the pion, $P_T > 0.02GeV$, was used to restrict the range where the azimuthal angle is well defined. To minimize the radiative corrections a cut on the fraction of the energy of the incoming electron carried by the virtual photon $y = \nu/E < 0.85$ is imposed, limiting corrections to the unpolarized cross section to a few percent [15].

The $\phi$-dependent spin asymmetries are isolated by extracting moments of the cross section for two helicity states weighted by the corresponding $\phi$ dependent functions. The $\sin\phi$ moment is given by

$$A_{LU(UL)}^{\sin\phi} = \frac{2}{P^{\pm}N^{\pm}} \sum_{i=1}^{N^{\pm}} \sin\phi_i, \tag{2}$$

where $N^{\pm}$ is the number of events and $P^{\pm}$ is the luminosity weighted polarization for positive/negative helicities of the electron (proton).

The analyzing power is evaluated as an average of two independent measurements – one for each helicity state. The main contributions to systematic error arises from the corrections to the acceptance, which affects the $\sin\phi$, $\cos\phi$, and $\cos 2\phi$ modulation of the cross section. The contribution to uncertainties in these corrections is estimated to be less than 20% of the

value of the statistical errors. The systematic error in the measurement of the beam polarization contributes at even lower level. In case of the $NH_3$ target a significant contribution to the systematic error is coming from the dilution factor $f$ of $NH_3$ ($f \approx$0.15) .

The $A_{LU}^{\sin\phi}$ averaged over two spin states as a function of $z$ and $x$ is plotted in Fig. 1. The $z$ dependence of beam SSA in SIDIS analyzed in terms of the fragmentation effect probes the ratio of polarized (Collins) and unpolarized fragmentation functions, while the $x$ dependence is defined by the ratio of the twist-3 unpolarized distribution function $e(x)$ and the leading twist distribution function $f_1(x)$ [8].

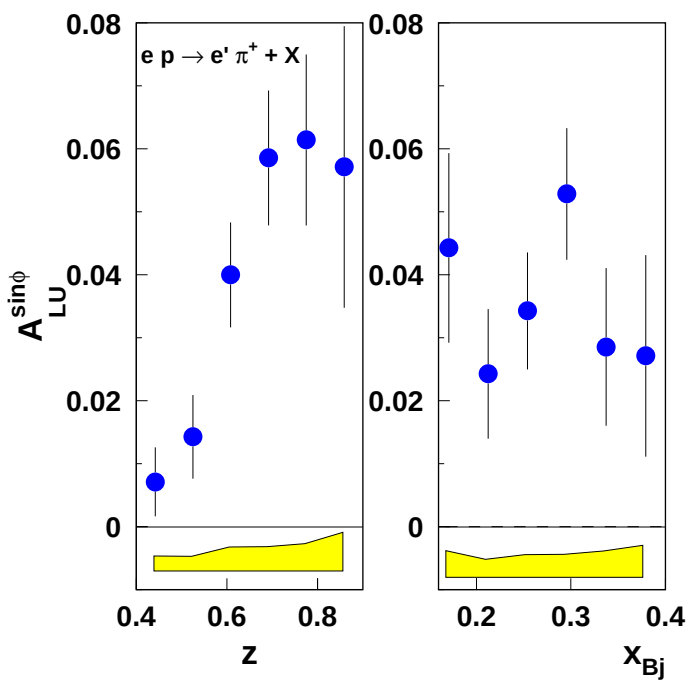


Figure 1. The beam-spin azimuthal asymmetry ($\sin\phi$ moment in the cross section) extracted from hydrogen data at 4.25GeV as a function of $x$ and $z$. Error bars show the statistical uncertainty and the band represents the systematic uncertainties.

Within statistical errors no significant dependence on $x$ was observed in single-spin asymmetry $z$-dependence for different ranges of $x$ (see Fig.2).

This behavior is consistent with factorization in the kinematic range $0.5 < z < 0.8$.

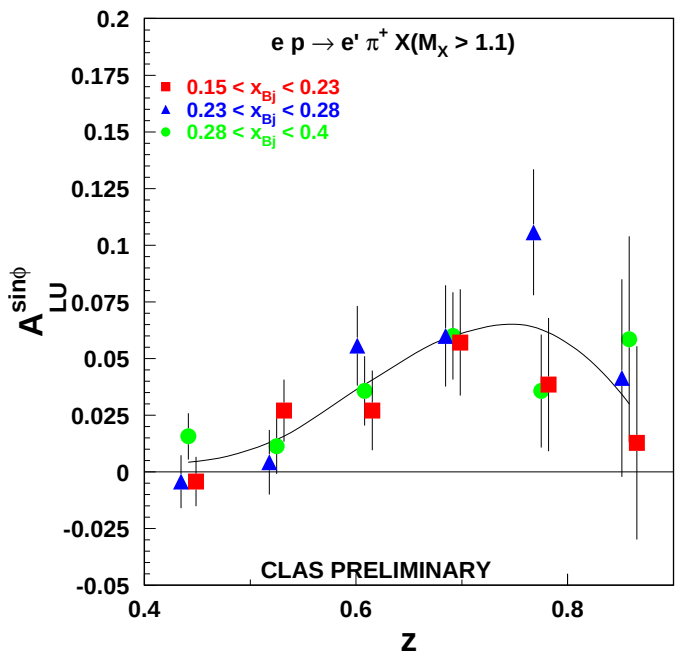


Figure 2. The beam-spin azimuthal asymmetry ($\sin\phi$ moment in the cross section) extracted from hydrogen data at 4.25GeV as a function of $z$ for different ranges of $x$.

The measured beam SSA $A_{LU}^{\sin\phi}$ is positive for the positive electron helicity in the range of $0.15 < x < 0.4$. The relatively flat $x$ dependence of $e(x)$ expected from the CLAS data in the $x$ range 0.15-0.4 is in qualitative agreement with an existing calculation of $e(x)$ in the Bag model at $Q^2$=1 [17].

The SSA $A_{LU}^{\sin\phi}$ averaged over $z$ in $0.2 < z < 0.7$ range was measured at HERMES[11] and was consistent with 0 ($-0.0047 \pm 0.008$), which may be due to the kinematic suppression of $A_{LU}^{\sin\phi}$ at low $y$ covered by HERMES in the chosen range in $z$.

The target SSA measured by HERMES [11,12] analyzed in terms of the

fragmentation effect, in addition to a contribution from the Collins function, contains other contributions which in a certain kinematic range might be significant [18,19]. This makes the beam-spin SSA a cleaner observable for extraction of the Collins fragmentation function at large $z$, where the analyzing power is large.

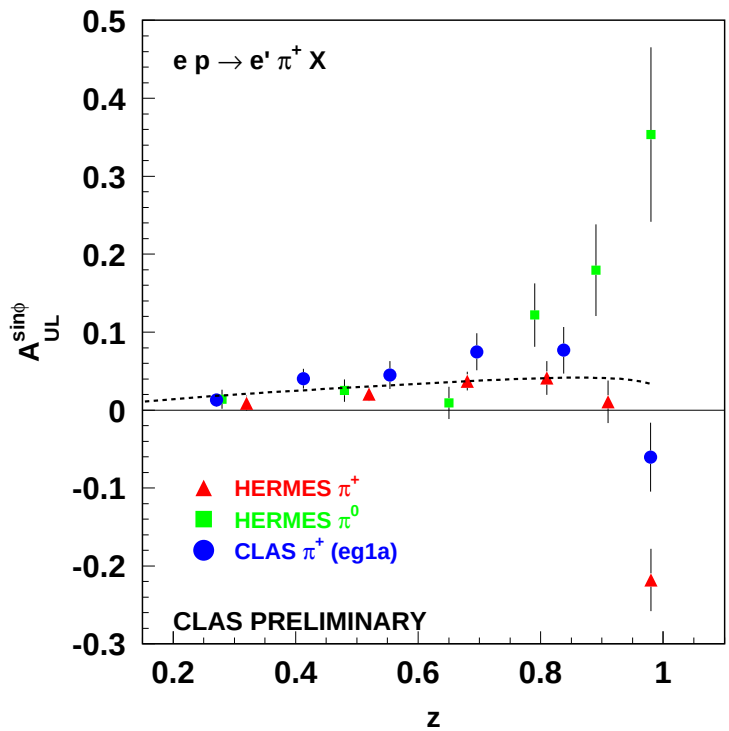


Figure 3. Target single-spin asymmetries from HERMES and CLAS. The dashed line is a curve from [20] for HERMES kinematics.

Recently, the Collins function for pions was calculated in a chiral invariant approach at a low scale [6] and it was shown that at large $z$ the function indeed rises much faster than previously predicted [16,20] in the analysis using the HERMES data on target SSA. In fact, the $z$-dependence of target-spin SSA ($A_{UL}$) for positive pions measured by HERMES [11,12]

differs significantly from the shape of the $z$-dependence of beam-spin SSA ($A_{LU}$) measured at CLAS (Fig. 1). The preliminary analysis of target SSA($A_{UL}$) with the CLAS polarized $NH_3$ target (CLAS eg1 experiment) is in agreement with the HERMES result, confirming the striking difference in the $z$-dependence of beam and target SSA (see Fig.3).

Assuming factorization the $z$ and $x$ dependencies of SSA in SIDIS provide information on underlying polarized fragmentation and corresponding distribution functions [8,10,5,4].

In a recent publication S.Brodsky et al. [3] discussed an alternative source of SSA in DIS at leading twist in perturbative QCD, namely final state interactions from gluon exchange between the outgoing quark and the target spectator system. They showed that there is a non trivial phase structure of QCD amplitudes resulting in T-odd effects. They also predicted that rescattering corrections are not power-law suppressed at large photon virtuality $Q^2$ at fixed $x$. This opens a unique possibility to measure T-odd distribution functions in SSA measurements in SIDIS [4].

Ongoing experiments with CLAS at 6 GeV using hydrogen and deuteron targets will study the flavor dependence of the corresponding functions[21,22]. Significantly higher statistics in the DIS range for higher beam energies will enable extraction of the important $Q^2$ dependence at fixed $x$ to reveal the source of the observed asymmetries.

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