New results on SIDIS SSA from Jefferson Lab

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Abstract. We present studies of single-spin and double-spin asymmetries in semi-inclusive electroproduction of pions using the CEBAF 6 GeV polarized electron beam. Kinematic dependences of single and double spin asymmetries have been measured in a wide kinematic range at CLAS with a polarized NH_3 target. Significant target-spin $\sin 2\phi$ and $\sin\phi$ asymmetries have been observed. The hypothesis of factorization has been tested with z-dependence of the double spin asymmetry.

Keywords: quarks,single spin asymmetries,TMD parton distributions
PACS: 13.60.-r, 13.88.+e, 14.20.Dh, 14.65.-q

Single-Spin Asymmetries (SSAs) in azimuthal distributions of final state particles in semi-inclusive deep inelastic scattering play a crucial role in the study of transverse momentum distributions of quarks in the nucleon and provide access to the orbital angular momentum of quarks. Large SSAs, observed for decades in hadronic reactions have been among the most difficult phenomena to understand from first principles in QCD. Recently, significant SSAs were reported in semi-inclusive DIS (SIDIS) by the HERMES collaboration at HERA [1, 2] for longitudinally and transversely polarized targets, and by the CLAS collaboration with a polarized beam [3].

Two fundamental mechanisms have been identified leading to SSAs in hard processes, the Sivers mechanism [4, 5, 6, 7, 8], which generates an asymmetry in the distribution of quarks due to orbital motion of partons, and the Collins mechanism [9, 10], which generates an asymmetry during the hadronization of quarks.

The HERMES Collaboration has recently measured a transverse spin asymmetry in SIDIS providing the cleanest evidence to date for the existence of a non-zero Collins function [2], which describes the fragmentation of a transversely polarized quark into pions. This finding is supported by the preliminary data from BELLE [11] indicating a non-zero Collins effect. The large target SSA in semi-inclusive pion production measured at CLAS and analyzed in terms of the Collins fragmentation [12], also indicate a significant Collins function.

For a longitudinally polarized target the only azimuthal asymmetry arising in leading order is the $\sin 2\phi$ moment [15, 10, 13], involving the transverse momentum dependent (TMD) Collins fragmentation function $H_1^{\perp}$ [9] and the Mulders distribution function $h_{1L}^{\perp}$ [14, 10], describing the transverse polarization of quarks in a longitudinally polarized proton [15, 10, 13]. The same distribution function is accessible in double polarized Drell-Yan, where it gives rise to a $\cos 2\phi$ azimuthal moment in the cross section [16].

Single and double spin asymmetries in SIDIS have been measured using the CLAS [17] in Hall B at Jefferson Lab, a 5.7 GeV longitudinally polarized electron beam, a longitudinally polarized proton (NH_3) target. The average beam polarization was 0.73 ± 0.03 and the average target polarization was 0.72 ± 0.05. The open acceptance of

CLAS and a single electron trigger ensured event recording for a large sample of SIDIS π^+, π^0, and π^- events.

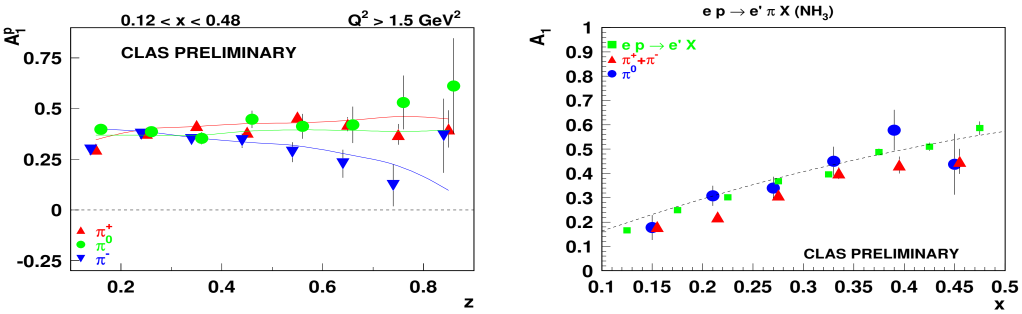

FIGURE 1. The double spin asymmetry for SIDIS π^+, π^-, and π^0 data as a function of z (left) and the comparison of inclusive A_1^p with the A_1^p for the SIDIS sum of π^+ and π^- and A_1^p for SIDIS π^0 (right).

The validity of factorization is crucial to the interpretation of target SSAs in terms of TMDs, which is the main goal of this contribution. A factorization test comes from examining the z-dependence of the double spin asymmetries (A_1^p) for all three pion flavors, as shown in the left panel of Fig. 1. The data cuts included $W > 2$ GeV and $Q^2 > 1.1$ GeV^2 to ensure DIS kinematics, and the average value of x is approximately 0.3. If factorization holds, the asymmetries should be approximately independent of z, broken by the different weights given to the polarized u and d quarks by the favored and unfavored fragmentation functions. We therefore expect the largest z-dependence for the π^- asymmetries. This is indeed born out by the data, which are in excellent agreement in both magnitude and z-dependence up to $z = 0.7$ with predictions of the polarized Lund Monte Carlo using GRSV polarized PDFs as input.

The dependence of the double spin asymmetry on Bjorken x for different pion flavors obtained from the CLAS data for the same kinematic range is presented in Fig. 1 (right panel). The π^0 double spin asymmetry as well as A_1^p for the sum of charged pions are consistent with the inclusive A_1^p as expected in a simple partonic picture.

These studies suggest that factorization works for $W > 2$ GeV, $Q^2 > 1.1$ GeV^2, $0.15 < x < 0.5$, and $0.3 < z < 0.7$ for a 5.7 GeV electron energy.

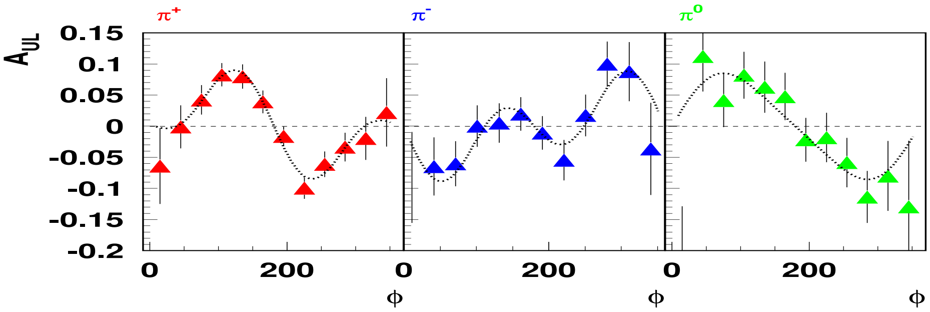

FIGURE 2. The target SSA as a function of azimuthal angle ϕ from data at 5.7 GeV.

The spin-dependent moments $(\sin\phi, \sin 2\phi)$ of the semi-inclusive cross section have been extracted in a fit of the normalized-yield asymmetry

$$A_{UL}(\phi) = \frac{1}{P_T}\frac{N^+ - N^-}{N^+ + N^-}. \quad (1)$$

Here $N^{\pm}$ is the number of events for target polarizations antiparallel/parallel to the incoming beam direction and P_T is the target polarization.

Measurements of the $\sin 2\phi$ SSA allow the study of the Collins effect with no contamination from other mechanisms. A recent measurement of $\sin 2\phi$ moment of σ_{UL} by HERMES [1] is consistent with zero. A measurably large asymmetry has been predicted only at large x ($x > 0.2$), a region well-covered by JLab [18].

The data for π^+ (Fig. 2) show a clear $\sin\phi$ and $\sin 2\phi$ modulations from which a $\sin\phi$ moment of $0.058 \pm 0.011(stat)$ and $\sin 2\phi$ moment of $-0.041 \pm 0.011(stat)$ have been determined.

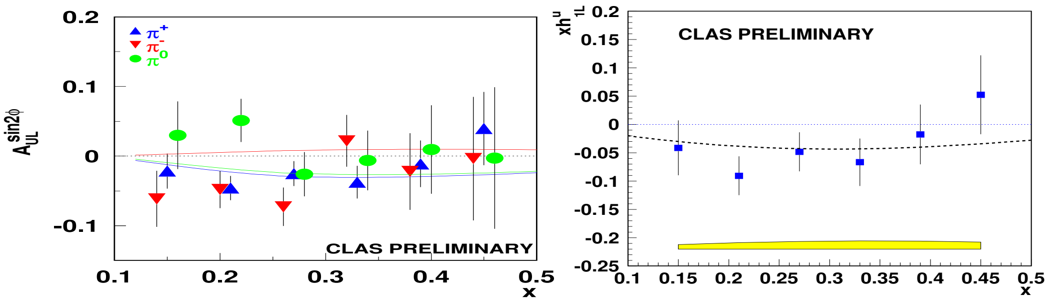

FIGURE 3. The leading twist SSA for the $\sin 2\phi$ moment for π^+, π^0, and π^- as a function of x (left plot). The $h_{1L}^{\perp}$ from the π^+ SSA (right). The contribution from the unfavored production is included in the systematic error band. The variation for the ratio of unfavored to favored Collins functions is from -2.5 to 0. The curves are from [18] using the χQSM calculations of $h_{1L}^{\perp}$.

The x dependence of the SSA for π^+ (Fig. 3) is consistent with predictions [18]. No sign of a large unfavored Collins fragmentation (large π^- SSA with a corresponding π^+ SSA of opposite sign) is seen. The π^+ SSA is dominated by the u-quarks; therefore with some assumption about the ratio of unfavored to favored Collins fragmentation functions, it can provide a first glimpse of the twist-2 TMD function $h_{1L}^{\perp}$ (Fig. 3.) The curve is the calculation by Efremov et al. [18], using $h_{1L}^{\perp}$ from the chiral quark soliton model evolved to Q^2=1.5 GeV^2. The extraction, however, suffers from low statistics and has a significant systematic error from the unknown ratio of the Collins favored and unfavored fragmentation functions, the unknown ratio of $h_{1L}^{\perp d}/h_{1L}^{\perp u}$, as well as from background from exclusive vector mesons.

The $\sin\phi$ moment of the cross section measured with CLAS at 5.7 GeV is in agreement with the HERMES measurement at 27.5 GeV for a longitudinal target [1], indicating a bigger asymmetry for the higher twist contribution compared to the leading twist $\sin 2\phi$ moment. The $P_\perp$ dependence of the $\sin\phi$ moment for π^+ (see Fig. 4) is consistent with an increase with increasing $P_\perp$, as expected for the TMD function [19]. The $\sin\phi$ moment, for π^- is also plotted in Fig. 4, showing first evidence for a non-zero SSA asymmetry for π^- on a longitudinally polarized target.

The $\sin\phi$ moment of the SIDIS cross section itself can be an important source of independent information on the Collins fragmentation mechanism. Several other contributions to the $\sin\phi$ moment were identified recently [20, 21, 22], involving different unknown distribution and fragmentation functions. A global analysis of beam and target SSA may be required to separate different contributions. Drell-Yan process with longitudinally and transversely polarized protons scattering on longitudinally polarized protons will also provide additional information on these distribution functions [23].

In conclusion CLAS target SSAs were measured using the 5.7 GeV data from the CLAS experiment using a polarized NH_3 target. The twist-2 distribution function $h_{1L}^{\perp}$ was extracted for the first time using the π^+ target SSA. No evidence has been found with CLAS for the large unfavored Collins fragmentation indicated by HERMES [2].

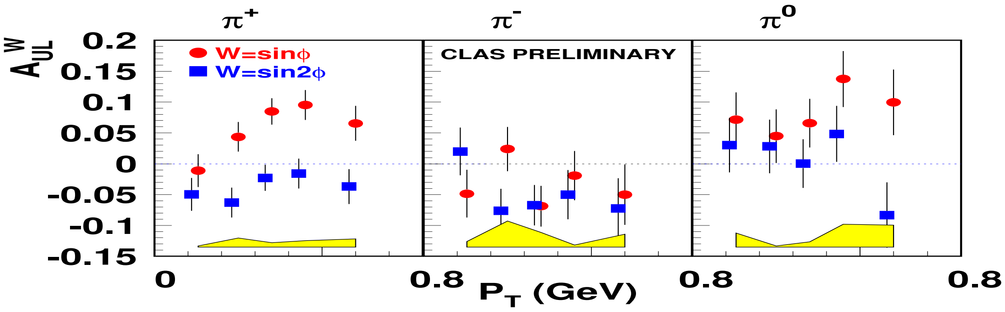

FIGURE 4. The A_{UL} SSA dependence on $P_{\perp}$. The band represents the systematic uncertainty from fit in the measurement of the $sin2\phi$ moment.

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