Single and Double Spin Asymmetry Measurements in Semi-Inclusive DIS on Polarized ^{3}He

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Jefferson Lab experiment E06-010 measured the target-single spin (SSA) and double spin asymmetries (DSA) in semi-inclusive deep inelastic $^3\mathrm{He}^{\uparrow}(\mathrm{e},\mathrm{e}'\pi^{\pm})\mathrm{X}$ reactions on a polarized ^{3}He target. The measured asymmetry (A_{UT}) is sensitive to the nucleon transversity and Sivers distribution functions, whereas the measured A_{LT} asymmetry is related to the transverse momentum dependent PDF g_{1T}. The kinematics were chosen to be in the valence quark region with $x \sim$ 0.16-0.35 and $Q^2 \sim$ 1.4-2.7 (GeV/c)^2. The Collins moment, which is sensitive to transversity, the Sivers and A_{LT} moments, which are sensitive to the orbital motion of the quarks, were extracted using the azimuthal angular dependence of the measured asymmetries. The final semi-inclusive results for the electroproduction of pions are presented and discussed.

1 Introduction

Over the past few decades, the study of nucleon spin structure has been an active field, both experimentally and theoretically. This endeavor has lead to our current knowledge of the unpolarized and polarized parton distribution functions (PDFs) f_1^q and g_1^q, which describe the longitudinal momentum and helicity of the quarks inside the nucleon. Only recently, the study has proceeded to study the aspects of quark transverse spin and transverse momenta. The transverse momentum dependent parton distribution functions (TMDs) [1] describe the nucleon structure in terms of quarks and gluons in all three directions of momentum space. Access to the transverse spin and momentum of the partons provides important information on the quark orbital angular momentum (OAM).

All of the eight leading-twist TMDs are accessible in semi-inclusive deep inelastic scattering (SIDIS) and can be separated by their azimuthal angular dependencies. For unpolarized lepton scattering from a transversely polarized target, the target spin-dependent asymmetry is

$$A_{\mathrm{UT}}\left(\phi_h, \phi_s\right) = \frac{1}{P_T} \frac{Y^{\uparrow}_{\phi_h,\phi_s} - Y^{\downarrow}_{\phi_h,\phi_s}}{Y^{\uparrow}_{\phi_h,\phi_s} + Y^{\downarrow}_{\phi_h,\phi_s}} \approx A_{\mathrm{C}} \sin\left(\phi_h + \phi_s\right) + A_{\mathrm{S}} \sin\left(\phi_h - \phi_s\right),$$

where ϕ_h and ϕ_s are the azimuthal angles of the produced hadron and the target spin as defined in the Trento convention [2], $Y^{\uparrow(\downarrow)}$ is the normalized yield for the up (down) spin direction of the target and P_T is the target polarization. The Collins moment is related to the convolution of the transversity distribution h_1^q and the Collins Fragmentation Function (FF), which are both chiral-odd functions. The transversity distribution describes transverse polarization of quarks in a transversely polarized nucleon. The Sivers moment involves a convolution of the naive T-odd Sivers function $f_{1T}^{\perp}$ [3] and the unpolarized FF. The Sivers function is a correlation between the nucleon spin and the quark transverse momentum, which requires an interference between quark wave function components that differ by one unit of quark orbital angular momentum.

The beam helicity asymmetry, $A_{\rm LT}$, for a longitudinally polarized lepton beam and a transversely polarized target can be written in a similar manner. At leading twist, this asymmetry is proportional to the convolution of g_{1T}^{q} and the unpolarized FF [1, 4]. Recently, the Collins and Sivers moments and the $A_{\rm LT}$ asymmetry were published from data taken at Jefferson Lab on a polarized ^{3}He; the experiment and final results will be discussed in these proceedings.

2 The Experiment

Experiment E06-010 [5, 6] acquired data at Jefferson Lab in Hall A [7]. A longitudinally polarized electron beam was scattered from a transversely polarized ^{3}He target [7] to measure the semi-inclusive reaction $^3\text{He}^{\uparrow}(e, e'h^{\pm})X$, where h is a charged hadron: either pion, kaon or proton. An electron beam with an energy of 5.9 GeV and an average current of 12 μA was used. A Møller polarimeter was used to periodically measure the beam polarization with an average polarization of (76.8±3.5)%. For the SSA, unpolarized beam was accomplished by summing together the two electron helicity states.

The scattered electrons were detected in the BigBite Spectrometer at an angle of 30° with momenta 0.6-2.5 GeV/c on the beam-right side. The BigBite detector package consisted of a dipole magnet, three multi-wire drift chambers (MWDC) for tracking, a scintillator plane for timing and a lead glass calorimeter for particle identification (PID). The solid angle acceptance was 64 msr. The coincident charged hadrons were detected in the left high resolution spectrometer (HRS) [7] with a central momentum of 2.35 GeV/c and at an angle of 16°. The HRS has a momentum acceptance of ±4.5% and a angular accepance of 6 msr. The spectrometer detector package contained drift chambers for tracking, two scintillator planes for triggering the data acquisition and time-of-flight, and a gas Cerenkov counter and a two layer electromagnetic calorimeter for PID. Additionally, a ring imagining Čerenkov (RICH) and an aerogel Čerenkov were used for hadron ID.

For this experiment, we used a polarized ^{3}He target as an effective polarized neutron target. This is possible due to the fact that the ground state ^{3}He wave function is predominately in an S state, where the two proton spins cancel. The ^{3}He nuclei were polarized by spin-exchange optical pumping with a Rb-K mixture [8], and the maximum polarization was significantly improved by using spectrally narrowed lasers, which aided in the laser absorption efficiency. An electron-polarized neutron luminosity of 10^{36} cm^{-2} s^{-1} was achieved with about 10 atm of ^{3}He gas contained within a 40 cm long target. The spin state of the nuclei were flipped every 20 minutes via adiabatic fast passage to reduce the systematic uncertainties. NMR polarimetry was used to measure the polarization with each spin flip, which was calibrated using electron paramagnetic resonance. The average in-beam target polarization was (55.4±2.8)%.

3 Results and Summary

From the measured data discussed in Section 2, the SIDIS event selection was chosen with PID and kinematic cuts, including $Q^2 > 1$ (GeV/c)^2, $W > 2.3$ GeV/c^2 and missing mass $W' >$

1.6 GeV/c^2. The extraction of the Collins, Sivers and $A_{\rm LT}$ moments were cross-checked by two independent methods: a local-pair binning-fitting [5] and a maximum likelihood method [6]. Reasonable consistency was achieved between the two techniques. The moments were corrected for the N_2 dilution of about 10%, where a small amount of nitrogen is used inside the target cells to reduce depolarization effects. The neutron Sivers and Collins moments and $A_{\rm LT}$ asymmetry were extracted from the ^{3}He results using the prescription discussed in [5].

The final results for the neutron Collins and Sivers moments are shown in Fig. 1 in the top and bottom panels, respectively. The left-hand side of the plot shows the results for the π^+ and the right-hand side shows the results for π^-. The error bars on the points indicate the statistical

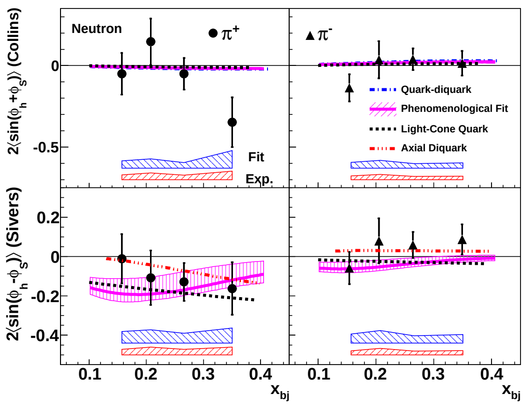

Figure 1: The Collins (top) and Sivers (bottom) neutron moments vs $x_{\rm bj}$ for the electroproduction of π^+ (left) and π^- (right). The bands below the data points represent the experimental and model uncertainties, which are labeled as `Exp` and `Fit`, respectively.

precision of the data, whereas the bands below the data show the experimental (`Exp`) and model (`Fit`) systematic uncertainties. The total experimental uncertainties are less than 25% of the statistical uncertainty in each bin. The fitting uncertainties result from ignoring other ϕ_h- and ϕ_S-dependent terms in the extraction of the moments. The data are compared with a phenomenological fit [9] and model calculations, which include a light-cone constituent quark model (LCCQM) [10] and quark-diquark calculations [11]. Both the data and the calculations indicate that the Collins asymmetries are small, though the data at $x_{\rm bj} = 0.34$ is more negative at the 2σ level. For the Sivers moments, the π^+ asymmetries favor negative values, whereas the π^- results are consistent with zero within the uncertainties.

The $A^n_{\rm LT}$ asymmetries are shown in Fig. 2 along with model calculations, which include Wandzura-Wilczek (WW)-type approximations using parameterizations from Ref. [12], a LCCQM [10] and a light-cone quark-diquark model (LCQDM) [13]. The extracted asymmetries are consistent with zero for positive pion production; however, the negative pion asymmetries are positive at the level of 2.8σ with all four bins averaged together. This observation is consistent with the model predictions though favoring larger magnitudes.

In summary, the first SSA and DSA results were reported for charged pion electroproduction on a polarized ^{3}He target in SIDIS. From this data, the neutron Collins and Sivers moments were extracted. The Collins moments were found to be small, which is consistent with the

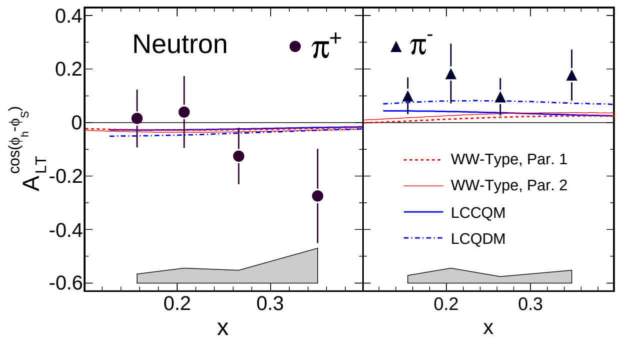

Figure 2: The neutron $A_{\rm LT}$ asymmetry for π^+ (left) and π^- (right) vs $x_{\rm bj}$ compared with model calculations.

model calculations. On the other hand, the π^+ Sivers moment favors negative values, while the π^- moments are close to zero. For the $A_{\rm LT}$ asymmetry, a positive value for π^- production is seen, which provides the first indication for a nonzero $A_{\rm LT}$ and infers a nonzero g_{1T} at leading twist. These measurements are the foundation for future high-precision measurements following the Jefferson Lab 12-GeV upgrade [14].

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