Precision Polarized SIDIS Experiments in Hall-A at 12 GeV JLab

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Single (SSA) and double spin asymmetries (DSA) in semi-inclusive DIS reactions using polarized nucleon targets provide a powerful method to probe transverse momentum dependent parton distribution functions (TMDs). The Jefferson Lab 12 GeV upgrade will provide a unique opportunity to perform precision measurements and to map out these multi-dimensional PDFs. Future plans for performing these measurements in Hall-A using the Solenoidal Large Intensity Device (SoLID) and polarized proton and ^{3}He (neutron) targets are discussed. The high luminosities from these targets and the large acceptance of the SoLID spectrometer will allow for a 4-dimensional (x, Q^2, z, P_T) mapping of SSA and DSA. These experiments will provide the most precise data to extract transversity (h_1), Sivers ($f_{1T}^{\perp}$) and Worm-gear (g_{1T} and $h_{1L}^{\perp}$) distributions of u and d-quarks and provide comprehensive information on the correlation between quark angular momentum and the nucleon's spin.

1 Introduction

In recent years, the study of transverse momentum dependent parton distribution functions (TMDs) has become one of the major goals in the investigation of nucleon spin structure. TMDs provide new and fundamental information about the structure of the nucleon by imaging its partonic structure, dynamics, and spin-orbital couplings in three-momentum space. At leading twist there are eight TMD quark distributions [1]: three of them, the unpolarized (f_1), the helicity (g_1) and the transversity (h_1) distributions are integrated over the transverse momenta of quarks, while the other five have an explicit dependence on the transverse momentum of quarks (k_T). While inclusive DIS experiments provide an access to the first two PDFs, semi-inclusive deep inelastic scattering (SIDIS) allows us to probe the other six TMDs. Of these eight TMDs, transversity (h_1), Sivers ($f_{1T}^{\perp}$), pretzelosity ($h_{1T}^{\perp}$), and g_{1T} can be accessed using a tranversely polarized target, while $h_{1L}^{\perp}$ can be accessed using a longitudinally polarized target.

The transversity distribution gives the probability of finding a transversely polarized parton inside a transversely polarized nucleon with certain longitudinal momentum fraction x and certain transverse momentum k_T. The Sivers function [2] provides the number density of unpolarized partons inside a transversely polarized proton, and it requires wave function components with nonzero orbital angular momentum and thus provides information about the correlation between the quark orbital angular momentum (OAM) and nucleon spin. Furthermore, it is a (naive) T-odd function which relies on the final state interactions (FSI) experienced by the active quark in a SIDIS process. In contrast to $f_{1T}^{\perp}$, the functions g_{1T} and $h_{1L}^{\perp}$ are T-even, and thus do not require FSI to be nonzero. Nevertheless, they also require interference between wave function components that differ by one unit of OAM and thus require OAM to be nonzero. Finally, pretzelosity requires interference between wave function components that differ by two units of OAM (e.g. p-p or s-d interference). Combining the wealth of information from all these functions could thus be invaluable for disentangling the spin orbit correlations in the nucleon wave function, providing important information about the quark orbital angular momentum, and for imaging of the nucleon in full momentum space.

Single spin asymmetries (SSA) using SIDIS on a transversely polarized proton target were measured by both HERMES [4, 5] and COMPASS [6] collaborations. Non-zero asymmetries were observed for both Collins and Sivers moments in the π^+ channel. However, for the π^- channel the Collins asymmetry was non-zero, whereas Sivers asymmetry was small and consistent with zero within the statistical precision of these experiments. Recently, JLab measured these asymmetries on a polarized ^{3}He target and extracted Collins and Sivers asymmetry moments [7] using SSA and A_{LT} using double spin asymmetries (DSA) [8].

The target single spin asymmetry from the SIDIS reaction, in the leading twist, can be obtained by

$$\begin{aligned} A_{UT} &\equiv \frac{1}{|S_T|}\frac{Y^{\uparrow}(\phi_h,\phi_S)-Y^{\downarrow}(\phi_h,\phi_S)}{Y^{\uparrow}(\phi_h,\phi_S)+Y^{\downarrow}(\phi_h,\phi_S)} \\ &= A_{UT}^{\sin(\phi_h+\phi_S)}\sin(\phi_h+\phi_S)+A_{UT}^{\sin(\phi_h-\phi_S)}\sin(\phi_h-\phi_S)+A_{UT}^{\sin(3\phi_h-\phi_S)}\sin(3\phi_h-\phi_S) \end{aligned}$$

where ϕ_S and ϕ_h are the azimuthal angles of the produced hadron and the target spin as defined by the Trento convention [3], S_T is the transverse polarization of the target w.r.t the virtual photon direction, and $Y^{\uparrow\downarrow}(\phi_h,\phi_S)$ is the normalized yield for the up-down transverse spin direction of the target. The three terms correspond to the Collins, Sivers and pretzelosity asymmetries, respectively. Similarly, the beam-target double spin asymmetry, A_{LT}, gives access to the $\cos(\phi_h-\phi_S)$ term.

2 Proposed Experiment

The proposed experimental setup consists of the Solenoidal Large Intensity Device (SoLID) and a polarized target as shown in Fig. 1. The SoLID spectrometer has a full 2π azimuthal angular coverage, which is essential to control the systematic uncertainties in extracting various azimuthal moments from the measured asymmetries. Two SIDIS measurements using polarized ^{3}He (transverse and longitudinal) target [9, 10] and one with a transversely polarized NH_3 (proton) target were proposed [11]. The luminosity for the ^{3}He target is about 10^{36} nucleons/cm^2/s while that for NH_3 target it is 10^{35} nucleons/cm^2/s. Two different beam energies, 11 GeV and 8.8 GeV, will be used to measure the asymmetries. The lower beam energy will provide precision data on the radiative corrections along with increased Q^2 coverage.

The SoLID detector consists of two regions. The forward region with polar angle coverage of 8.5° to 16° has a total solid angle of 95 msr, and covers a momentum range from 1 GeV/c to 7 GeV/c for both electrons and pions. Tracking will be done by GEM detectors and particle identification will be provided by the combination of a gas Cerenkov, an aerogel counter, and an electromagnetic calorimeter. A thin layer of scintillator and one layer of Multi-gap Resistive Plate Chamber (MRPC) will be used for the timing information. The large angle region with

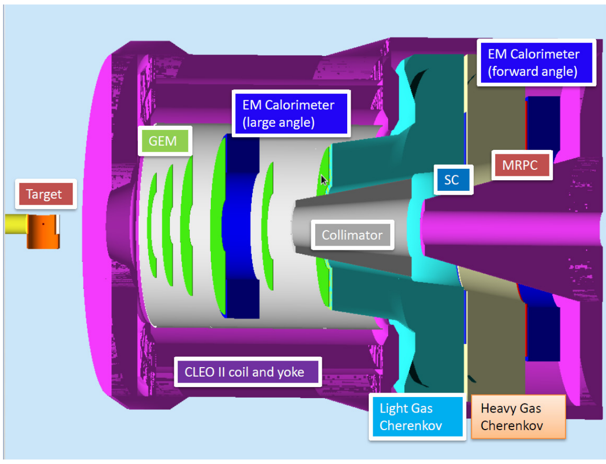

Figure 1: The experimental layout of the SoLID and polarized target in the proposed measurement. The subdetectors are labeled with colors corresponding to the detector regions.

polar angle coverage of 16° to 25° has a solid angle of 280 msr, and is mainly used for the electron detection in the momentum range of 4 to 6 GeV/c. GEMs and an electromagnetic calorimeter will be used in this region to provide accurate momentum and energy reconstruction of the scattered electron.

Figure 2 shows the projected results for the π^+ Collins asymmetry in one bin of Q^2 and z that can be obtained in 90 days with a ^{3}He target. The theoretical predictions of Collins asymmetries are from Anselmino *et al.* [12], Vogelsang and Yuan [13] and Pasquini [14]. The x-axis shows the bjorken-x, y-axis on the left side shows the P_T coverage, and y-axis on the right side shows the scale of the asymmetries. The overall kinematic coverage is as follows: P_T from 0-1.6 GeV/c, Q^2 from 1-8 (GeV/c)^2, z from 0.3-0.7, and x from 0.05-0.65. P_T and z coverage is divided into 8 bins each, and the Q^2 range is divided into 6 bins. The combined data from two beam energies will be divided into a total of 1400 bins for the SIDIS measurement with a ^{3}He target. This will allow us to study the measured asymmetries in 4 dimension (x, Q^2, z, P_T). Along with the SSA, the DSA data will allow us to measure A_{LT}, which is related to the g_{1T} distribution. Moreover, SIDIS with longitudinally polarized beam on a longitudinally polarized target will provide A_{LL} and A_{UL} data which will be used to extract g_{1L} and $h_{1L}^{\perp}$, respectively.

3 Summary

The proposed SIDIS measurements at Jefferson Lab will provide the most precise 4-D (x, Q^2, z, P_T) data of SSA and DSA on both proton and neutron targets. The combined analysis of the data from these measurements will help in extracting various TMDs for both u and d-quarks. This will also enable us to do a model independent extraction of the u and d-quark tensor charges within a 10% accuracy. Measurement of Sivers, pretzelosity and g_{1T} distribution functions will enable a comprehensive understanding of quark orbital angular momentum, its relativistic effects and spin-orbit correlations.

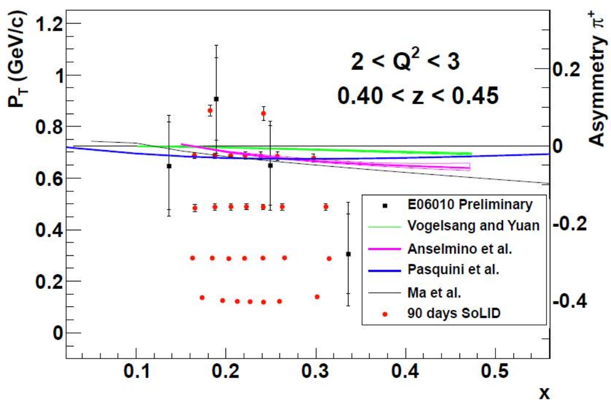

Figure 2: Projected results for π^+ Collins asymmetry in one bin of Q^2 and z. The y-axis on the left side shows P_T coverage and y-axis shows on the right side shows the scale of the asymmetry. The data from the Hall-A 6 GeV experiment (E06-010) is shown in black point with large errors.

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