PROCEEDINGS OF SCIENCE

Measuring Transversity in Di-Hadron Correlations with the ePIC Detector

Seth Reiman[a,*] **and Gregory Matousek**[b]

a Durham Technical Community College,
E Lawson St, Durham, United States of America

b Duke University
Durham, United States of America

E-mail: reimanseth87@gmail.com, gregory.matousek@duke.edu

Transversity is the least understood of the three Parton Distribution Functions (PDFs) that are used to describe the proton's substruction in a collinear picture using dihadron fragmentation. The upcoming Electron-Ion Collider (EIC) being constructed at Brookhaven National Laboratory is expected to provide better insight into the transversity distribution. Using epic-analysis, an analysis software for semi-inclusive deep inelastic scattering (SIDIS), we built the transverse single spin asymmetry (SSA) with projected uncertainties at different bins of x (the momentum fraction of the parent proton carried by the struck quark) [5].

25th International Spin Physics Symposium (SPIN 2023)
24-29 September 2023
Durham, NC, USA

[*]Speaker

PoS(SPIN2023)042

1. Introduction

The proton has evolved from a fundamental particle, which could be entirely described by Maxwell's laws, to a composite of numerous relativistic bodies whose interactions can be described with QCD. However, emergent properties of the proton, such as its mass or spin, still elude a description by first principles. By analyzing hadron pairs in Semi Inclusive Deep Inelastic Scattering (SIDIS) at the upcoming Electron-Ion Collider (EIC), the distribution of transversely polarized quarks in the proton, the so-called transversity distribution $h_1(x)$, can be measured [1,2,3].

1.1 Spin Composition

One property of the proton that still eludes a description is that of its spin composition. In the 1980s, the EMC-experiment showed that the proton's spin could not be entirely accounted for by the summation of the spin of the valence quarks. The proton's spin is believed to be able to be decomposed into contributions from the quark plus antiquark spin, the gluon spin, and parton orbital angular momenta [1]. Measuring transversity will allow a better understanding of the proton's spin composition [5].

2. Electron-Ion Collider

The Electron-Ion Collider (EIC) will be the first polarized $e-p$ collider [1]. The collider will have a polarization of around 70%, a center-of-mass energy of 20-140 GeV, and an electron-nucleon luminosity of 10^{33}-10^{34} cm^{-2} s^{-1} [1]. It is planned for construction at Brookhaven National Lab on Long Island, New York. It will reuse infrastructure from the Relativistic Heavy Ion Collider (RHIC). The goals of the EIC are to create tomographic 3D images of the proton and study gluon saturation, color confinement, and the mass and spin composition of the proton [1].

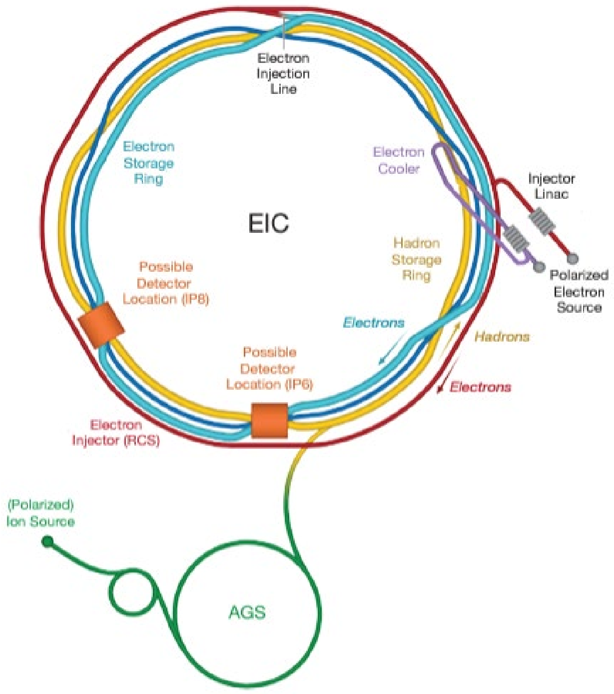

Figure 1: Current EIC construction plan [1]

3. Deep Inelastic Scattering and Physics Measurements

Deep inelastic scattering (DIS) is the process by which the negative 4-momentum squared (Q^2) exchanged between the lepton probe and proton during a collision is high enough that the collision can be treated as an interaction between the lepton and a proton's valence quark. The quark can leave the proton and hadronize into final state hadrons via color confinement. In Semi-Inclusive Deep Inelastic Scattering (SIDIS), one or more final state hadrons are measured in addition to the scattered lepton. The primary purpose of measuring final state hadrons is to gain access to Parton Distribution Functions (PDFs) and Fragmentation Functions (FFs) [3][6].

3.1 Fragmentation Functions

Fragmentation Functions (FFs) describe the probability distribution of the formation of a hadron h from a quark q. Knowledge of FFs thus allows us to learn about the quantum numbers of the struck quark, such as flavor, from the detected hadron.

3.2 Parton Distribution Functions

Parton Distribution Functions (PDFs) describe the probability of finding a specific quark in the proton. In a collinear picture, the spin structure of the proton is described by three PDFs, $f_1(x)$, $g_1(x)$, $h_1(x)$, with x being the momentum fraction of the parent proton carried by the struck quark [5].

- $f_1(x)$ describes the probability of finding an unpolarized quark in an unpolarized proton [6].
- $g_1(x)$ describes the helicity distribution of quarks inside a longitudinally polarized proton [6].
- $h_1(x)$ describes the transverse polarization of the struck quark. It is less known than f_1 and g_1 since it is chiral odd and can only be detected in semi-inclusive processes where it couples to a chiral-odd FF.

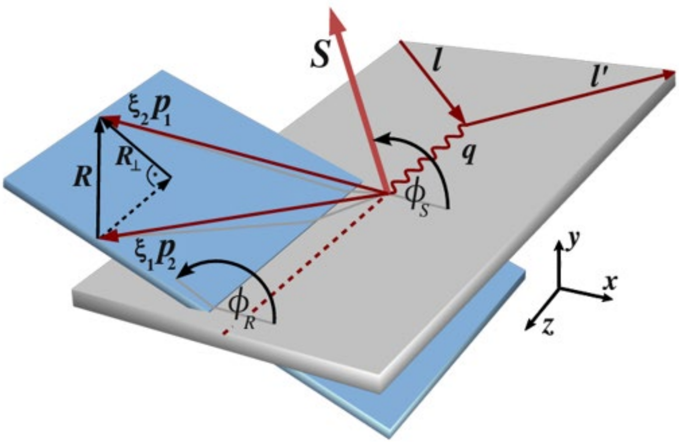

Figure 2: Dihadron SIDIS. S is the polarization of the struck quark. Φ_S and Φ_R are the azimuthal angles between the scattering plane (gray) and the proton's spin, and the scattering plane and the dihadron plane (blue) respectively. These azimuthal angles are measured to describe $h_1(x)$ [7].

4. Transverse Single Spin Asymmetry

Transverse single spin asymmetry (SSA) in SIDIS is the measured difference in the cross sections of target partons whose transverse spin is flipped. We measure this asymmetry with the number of events (N) with opposite polarization. The asymmetry acquires a $\phi_{RS} = \phi_S - \phi_R$ dependence:

$$A_{UT}(\phi_{RS}) = \frac{N^{\uparrow}(\phi_{RS}) - N^{\downarrow}(\phi_{RS})}{N^{\uparrow}(\phi_{RS}) + N^{\downarrow}(\phi_{RS})} \approx sin\phi_{RS}A_{UT} \quad (1)$$

As does the transversely polarized cross-section:

$$\sigma^{(ep^{\uparrow} \to e'\pi^+\pi^-)} \propto f_1 D_1 + h_1 H_1^{\sphericalangle}$$

$H_1^{\sphericalangle}$ describes the azimuthal dependence of final-state hadron pairs (here: $\pi^+\pi^-$) on the initial quark transverse polarization (spin analyzer), and D_1 is the unpolarized fragmentation function. Measuring SSA in SIDIS can give access to h_1, given knowledge of $H_1^{\sphericalangle}$.

5. Methods

In order to measure SSA in dihadron SIDIS, reconstructed data was used from ePIC full simulations acquired from the Pythia Monte Carlo event generator and smeared with Geant 4. The electron and proton center-of-mass energy was set to 18/275 GeV. The simulations were given the following cuts:

$$Q^2 > 1\ GeV^2$$
$$y > 0.01\ W$$
$$W > 5\ GeV$$
$$p_{T,lab} > 100\ MeV$$

y is the fraction of the lepton's energy carried by the virtual photon, W is the mass of the virtual photon, and $p_{T,lab}$ is the transverse momentum in the lab frame [5].

Epic-analysis [4], a general-purpose analysis software for SIDIS at the EIC, written for the ROOT framework, was used. The asymmetry was built using Eq.(1) and its amplitude was extracted in each x bin.

PoS(SPIN2023)042

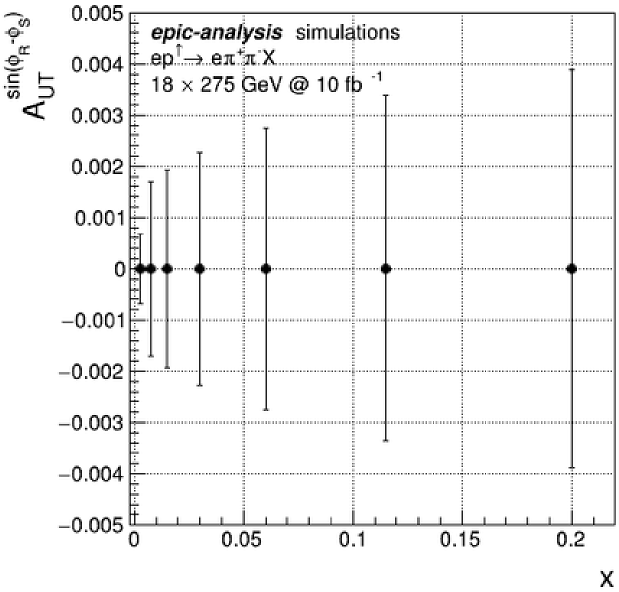

Figure 3: Projected statistical uncertainties in the SSA vs. x for an integrated luminosity of $10fb^{-1}$. This data is projected to be collected in less than one year. Uncertainties are already < 1%, enabling a significant measurement [1].

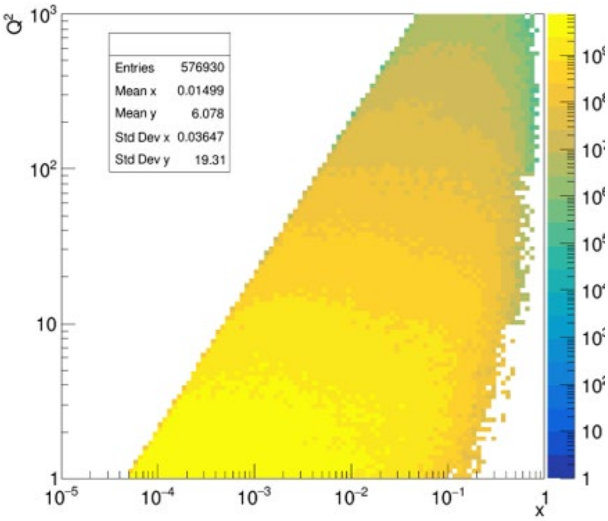

Figure 4: $x - Q^2$ coverage at $\sqrt{s} = 140\ GeV$. The majority of of the data is below valence quark region $x < 0.1$. Valence quarks are accessed at high Q^2.

References

[1] R. Abdul Khalek *et al.,* Science Requirements and Detector Concepts for the Electron-Ion Collider : EIC Yellow Report Nucl.Phys.A 1026 (2022)

[2] A. Bacchetta and M. Radici, “Partial-wave analysis of two-hadron Fragmentation functions”, Phys. Rev. D67 (2003) 094002

[3] M. Anselmino, A. Mukherjee, A. Vossen, “Transverse spin effects in hard semi-inclusive collisions”, Prog.Part.Nucl.Phys. 114 (2020) 103806

[4] epic-analysis, https://github.com/eic/epic-analysis

[5] T. B. Hayward, "Dihadron Beam Spin Asymmetries On An Unpolarized Hydrogen Target With Clas12", Dissertations, Theses, and Masters Projects. William & Mary. (2021)

[6] A. Vossen, “Transverse Spin Asymmetries at the COMPASS Experiment”, PhD thesis, Physikalisches Institut Freiburg. (2008)

[7] C. Adolph *et al.,* Transverse spin effects in hadron-pair production from semi-inclusive deep inelastic scattering, Phys.Letters.B 713 (2012)