Target Single Spin Asymmetry Measurements in the Inclusive Deep-Inelastic $\vec{N}(e, e')$ Reaction on Transversely Polarized Proton and Neutron ($^3$He) Targets using the SoLID Spectrometer

Hall A Collaboration Meeting

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Outline

Introduction

The Experiment

Summary
Deep Inclusive elastic Scattering, unpolarized beam, transversely polarized NH$_3$ and $^3$He.

Measure single-spin asymmetry (SSA) $A_{UT} = \frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow} = A_y \sin \phi_S$, $A_y = \frac{d\sigma_{UT}}{d\sigma_{UU}}$ from target spin flip.
Motivated by discrepancy between Rosenbluth/Polarization Transfer measurement of $G_E/G_M$, many calculations now exist for the two-photon exchange reaction.

$$A_y = \frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow} \frac{1}{\sin \phi_S} = \frac{d\sigma_{UT}}{d\sigma_{UU}}$$

$$d\sigma_{UU} \propto \text{Re}(\mathcal{M}_1 \gamma \mathcal{M}^*_1 \gamma)$$ and $$d\sigma_{UT} \propto \text{Im}(\mathcal{M}_1 \gamma \mathcal{M}^*_1 \gamma) = 0$$ at Born level

$$d\sigma_{UT} \propto \text{Im}(\mathcal{M}_1 \gamma \mathcal{M}^*_2 \gamma) \neq 0$$ with one- and two-photon interference
Physical Motivation (con’t)

- Evaluation of $2\gamma$ box diagram involves \textit{full nucleon response} to doubly virtual Compton scattering. Elastic intermediate contribution well-known. Calculate inelastic response using e.g. GPD’s, nucleon resonances, DIS form factors.

- $A_\gamma$ provides a unique new tool to study nucleon structure.

- This experiment will test parton-models for protons and neutrons in DIS.
Theoretical Predictions

- A. Afanasev et al. assumes the scattering is dominated by two-photon exchange with a single quark. They predict $A_n^y \sim 10^{-4}$ and $A_p^y \sim -2 \times 10^{-4}$ at $x \sim 0.3$ and $Q^2 = 2.0 \text{ GeV}^2$. 

![Graphs showing $A_N$ vs. $x$ for proton and neutron with $s = 10 \text{ GeV}^2$ and $Q^2 = 2 \text{ GeV}^2$.]
A. Metz et al. argue that the DIS asymmetry is dominated by the process in which one of the photons couples to an active quark and the other couples to one of the quarks in the spectator di-quark system. They predict an asymmetry with magnitude $A_y^p < 10^{-2}$ that crosses zero in the mid-$x$ range. The magnitude of $A_y^n$ is predicted to be $\sim \pm 10^{-2}$ depending on the quark-gluon-quark correlators $T_F^f$ for quarks of flavor $f$. 

![Graphs showing theoretical predictions for DIS asymmetry at different energies](image-url)
An additional contribution to $d\sigma_{UT}$ at $\mathcal{O}(\alpha_{em}^3)$ may arise from interference between real photon emission (bremsstrahlung) by the electron and the hadronic system.
Existing Proton Data

Figure: $A_{UT}^{\sin \phi_S}$ ($= A_Y^p$) measured with an electron beam (top) and a positron beam (center). The open (closed) circles identify the data with $Q^2 < 1$ GeV$^2$ ($Q^2 > 1$ GeV$^2$). The error bars show the statistical uncertainties, while the error boxes show the systematic uncertainties. The asymmetries integrated over $x$ are shown on the left. Bottom panel: average $Q^2$ vs. $x$ from data (squares), and the fraction of elastic background events to the total event sample from a Monte Carlo simulation (triangles).
**Existing Neutron Data**

**Figure:** Neutron asymmetry results (color online). **Left panel:** Solid black data points are DIS data \((W > 2 \text{ GeV})\) from the BigBite spectrometer; open circle has \(W = 1.72 \text{ GeV}\). BigBite data points show statistical uncertainties with systematic uncertainties indicated by the lower solid band. The square point is the LHRS data with combined statistical and systematic uncertainties. The dotted curve near zero (positive) is the calculation by A. Afanasev et al. The solid and dot-dashed curves are calculations by A. Metz et al. [?] (multiplied by \(-1\)). **Right panel:** The average measured asymmetry for the DIS data with combined systematic and statistical uncertainties.
Overview

- The goal is to determine $A_y$ for both proton and neutron with a statistical precision of $10^{-4} - 10^{-3}$ (kinematic dependent) over a broad range of $x$ and $1.5 < Q^2 < 7.5$ GeV$^2$ ($0.05 < x < 0.65$, $W > 2$ GeV) by measuring the $\phi_S$-dependence of $A_{UT}$.
- Systematic uncertainties will be kept to the $\sim 10^{-4} - 10^{-3}$-level.
- The polarized NH$_3$ (100 nA, 3 cm) and $^3$He targets (15 $\mu$A, 40 cm) with 8.8 and 11 GeV beam.
- SoLID will be used as the detector for this experiment.
- Run concurrent with neutron and proton SIDIS. No more equipments and beam time are required.
- The singles trigger rate in the detector will be as large as 80-100 kHz (DAQ limited).
NH$_3$ Kinematics

Figure: Kinematic coverage with polarized NH$_3$ target. The upper plots are for 11 GeV. The lower plots are for 8.8 GeV. Black (red) is for forward (large) angle.
$^3$He Kinematics

Figure: Kinematic coverage with polarized $^3$He target. The upper plots are for 11 GeV. The lower plots are for 8.8 GeV. Black (red) is for forward (large) angle.
Rate Estimation

- Most recent acceptance.
- “line of flame” cut on NH$_3$ target.
- FAEC trigger (conservative about 90% of the one from the transversity).
- LAEC trigger ( $> 3$ GeV).
- GC trigger.
- Impose a maximum rate of 80 kHz on the singles trigger.
Figure: Good electron rates (after PID and DIS cuts) in each $Q^2$ vs $x$ bin for the NH$_3$ target. Units for rates are Hz. Left one is for 11 GeV. Right one is for 8.8 GeV.
Figure: Good electron rates (after PID and DIS cuts) in each $Q^2$ vs x bin for the $^3$He target. Units for rates are Hz. Left one is for 11 GeV. Right one is for 8.8 GeV.
Project Results

Corrections used to determine the $A_{UT}^{\text{phys}}$ from $A_{UT}^{\text{raw}}$.

- Dilution factor 13% for NH$_3$, 85% for $^3$He.
- Target polarization 70% for NH$_3$, 60% for $^3$He.
- Nuclear effect 80% for $^3$He.
- Detector efficiency 70%.
Figure: Expected uncertainties in $A_{UT}$ vs. $\phi_S$ at different $Q^2$ for the NH$_3$ target. Left 9 figures are for 11 GeV from $1.5 \leq Q^2 \leq 9.5$ (GeV$^2$). Right 6 figures are for 8.8 GeV from $1.5 \leq Q^2 \leq 6.5$ (GeV$^2$).
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Systematic Uncertainties (NH₃)

<table>
<thead>
<tr>
<th>Sources</th>
<th>Type</th>
<th>$\delta A_y^{\text{raw}}$</th>
<th>$\delta A_y^{\text{phys}}$</th>
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<tr>
<td>False Asymmetries</td>
<td>absolute</td>
<td>$3 \times 10^{-4}$</td>
<td>$3 \times 10^{-3}$</td>
</tr>
<tr>
<td>Background Subtraction</td>
<td>absolute</td>
<td>$4 \times 10^{-4}$</td>
<td>$4 \times 10^{-3}$</td>
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<tr>
<td>Target Polarization</td>
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<td>3%</td>
</tr>
<tr>
<td>Dilution Factor</td>
<td>relative</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>Radiative Correction</td>
<td>relative</td>
<td>2%</td>
<td>2%</td>
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**Table:** Systematic uncertainties on the proton asymmetries for the proposed NH₃ experiment.
Systematic Uncertainties ($^3\text{He}$)

<table>
<thead>
<tr>
<th>Sources</th>
<th>Type</th>
<th>$\delta A_y^{\text{raw}}$</th>
<th>$\delta A_y^{\text{phys}}$</th>
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<tr>
<td>False Asymmetries</td>
<td>absolute</td>
<td>$3 \times 10^{-4}$</td>
<td>$1 \times 10^{-4}$</td>
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<td>Background Subtraction</td>
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<tr>
<td>Target Polarization</td>
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<tr>
<td>Dilution Factor</td>
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<td>Neutron Extraction</td>
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**Table:** Systematic uncertainties on the neutron asymmetries for the proposed $^3\text{He}$ experiment.
Measurements of $A_{UT}(\phi_S)$ and $A_y$ in a large number of $x$ and $Q^2$ bins ($1.5 < Q^2 < 7.5$ GeV$^2$, $0.05 < x < 0.65$, $W > 2$ GeV) for both proton and neutron.

The statistical uncertainties of $10^{-4} - 10^{-3}$ (kinematic dependent) with similar expected systematic uncertainties will provide information on the transverse target single spin asymmetry at a level never before achieved.

The precision will discriminate between various parton model predictions.

Provide an answer to the important sign mis-match in the neutron predictions using either the Sivers or KQVY input for quark-gluon correlations.

A new opportunity to access the dynamics of the nucleon beyond the non-interacting parton level without the significant contribution from Born scattering.
Extra Slides
Figure: The $\pi^-/e^-$ ratio for the SIDIS experiment with a 15 $\mu$A beam on a 40 cm $^3$He target. The momentum and polar angles are at the vertices in the target where particles are created.
The \( \pi/e^- \) ratio from combined Cherenkov and Calorimeter detector performance as a function of the scattered momentum \( P \) and polar angle \( \theta \). The numerical values are the ratios corresponding to that cell in \((P,\theta)\). The curves indicate various regions of \( Q^2 \), \( x \) or scattered energy \( E \).
Singles trigger

<table>
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<tr>
<th></th>
<th>$e^-$</th>
<th>$e^-(\pi^0)$</th>
<th>$\gamma(\pi^0)$</th>
<th>hadron</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>FA rate (kHz)</td>
<td>90</td>
<td>16.75</td>
<td>1.32</td>
<td>18.7</td>
<td>127</td>
</tr>
<tr>
<td>LA rate (kHz)</td>
<td>4.7</td>
<td>0.16</td>
<td>0.8</td>
<td>12.4</td>
<td>18</td>
</tr>
</tbody>
</table>

**Table:** Contributions to the singles electron trigger rates in the forward (FA) and large (LA) detectors. From left to right they are: good electrons, electrons from pair production in $\pi^0$ decay, photons from $\pi^0$ decay, and hadrons.
Figure: GEANT3 simulation results of background with NH$_3$ target field ON. The $x$-axis is the azimuthal angle in lab frame. The $y$-axis is the radius of GEM chambers (1-6). Narrow regions of high rate (compared to rest of the acceptance) are clearly seen as a function of azimuthal angle $\phi$. 
More results

$A_{UT}(Q^2=1.5 \text{ GeV}^2, x=0.05) \text{ trigger\_ratio}=0.56$

$A_y=(-1.00\times10^{-2}\pm2.88\times10^{-5})$

$A_{UT}(Q^2=2.5 \text{ GeV}^2, x=0.15) \text{ trigger\_ratio}=0.56$

$A_y=(-1.00\times10^{-2}\pm5.21\times10^{-5})$

$A_{UT}(Q^2=2.5 \text{ GeV}^2, x=0.25) \text{ trigger\_ratio}=0.56$

$A_y=(-1.00\times10^{-2}\pm3.90\times10^{-5})$

$A_{UT}(Q^2=3.5 \text{ GeV}^2, x=0.25) \text{ trigger\_ratio}=0.56$

$A_y=(-1.00\times10^{-2}\pm1.19\times10^{-5})$
Figure: $A_y$ vs $Q^2$ for $x = 0.65$ for the $^3$He target at 11 GeV.