Spin-Orbit Correlations Studies at JLab

Zein-Eddine Meziani
Temple University

- Boer-Mulders distribution function
  - Semi-Inclusive Deep Inelastic Measurement with unpolarized proton target (a proposal for the 12 GeV upgrade)

- Sivers distribution function
  - SIDIS measurement with a transversely polarized target (in this case a polarized $^3$He target to access neutron information)
Azimuthal Asymmetries in SIDIS as a Clean Test of QCD?

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Clean Tests of Quantum Chromodynamics in $\mu p$ Scattering

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Hard gluon bremsstrahlung in $\mu p$ scattering produces final-state hadrons with a large component of momentum transverse to the virtual-photon direction. Quantum chromodynamics can be used to predict not only the absolute value of the transverse momentum, but also its angular distribution relative to the muon scattering plane. The angular correlations should be insensitive to nonperturbative effects.

In this Letter we report selected results from a study of semi-inclusive $\mu p$ scattering. Our analysis is based on QCD (quantum chromodynamics) perturbation theory and the parton-model idea of decay functions. Let $k_1$ ($k_2$) be the initial (final) muon four-momentum and $P_1$ ($P_2$) be the target (observed final-state hadron) four-momentum. At high energy, the hadrons will be produced in a jet with momenta nearly parallel to the virtual-photon direction, $q^\mu = k_1^\mu - k_2^\mu$. Some of our most interesting results involve the transverse momentum $P_{z\perp}$, perpendicular to $q$.

Integrating over the azimuthal angle of the final muon, we can write the differential cross section in terms of the variables
Azimuthal dependence in leptoproduction: A simple parton model calculation*1

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Abstract

Semi-inclusive leptoproduction, \( \ell + p \rightarrow \ell' + h + X \), is considered in the naive parton model. The scattered parton shows an azimuthal asymmetry about the momentum transfer direction. Simple derivations for the effects in ep, \( \nu p \) and \( \nu p \) scattering are given. Reduction of the asymmetry due to fragmentation of partons into hadrons is estimated. The results cast doubt on the utility of such azimuthal asymmetry as a clean test of quantum chromodynamics.
Structure of the Cross Section

\[ d\sigma_{\lambda,S} \propto f_1 \otimes D_1 + \frac{k_T}{Q} f_1 \otimes D_1 \cdot \cos \phi + \text{RC} \]

\[ + \left[ \frac{k_T^2}{Q^2} f_1 \otimes D_1 + h_1^\perp \otimes H_1^\perp \right] \cdot \cos 2\phi + \text{RC} \]

\[ + |S_T| \cdot f_{1T}^\perp \otimes D_1 \cdot \sin (\phi - \phi_s) \]

\[ + |S_T| \cdot h_1 \otimes H_1^\perp \cdot \sin (\phi + \phi_s) \]
Leading-Twist Quark Distributions

(A total of eight distributions)

<table>
<thead>
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<th>N/q</th>
<th>U</th>
<th>L</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>$f_1$</td>
<td></td>
<td>$h_1$</td>
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<tr>
<td>L</td>
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<td>$g_1$</td>
<td>$h_{1L}$</td>
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<tr>
<td>T</td>
<td>$f_{1T}$</td>
<td>$g_{1T}$</td>
<td>$h_1, h_{1T}$</td>
</tr>
</tbody>
</table>

No $K_{\perp}$ dependence

$K_{\perp}$ - dependent, $T$-odd

$g_{1T}$
Boer-Mulders distribution function

\[ d\sigma_{\lambda,S} \propto f_1 \otimes D_1 + \frac{k_T}{Q} f_1 \otimes D_1 \cdot \cos \phi + \text{RC} \]

\[ + \left[ \frac{k_T^2}{Q^2} f_1 \otimes D_1 + h_1^+ \otimes H_1^+ \right] \cdot \cos 2\phi + \text{RC} \]

- Can be measured in Drell-Yan and SIDIS
- Allows the test of universality
- Provides some indication on the role of angular momentum
Comprehensive extraction of $h_{1}^{+}$

Need a study of “backgrounds” with high statistics measurements

- Higher twists (kinematical, dynamical)
  - Different dependences on $z, x, P_{t}$ and $Q^{2}$
- Radiative corrections

- Understanding the systematic errors in the acceptance

- Comparisons between $\cos \phi$ and $\cos 2\phi$ in the same experiment are important

- Checking $\pi^{+} + \pi^{-}$ versus $\pi^{0}$ need to be consistent

- Checking $\pi^{+} - \pi^{-}$
Large $Q^2$ accessible with CLAS12 are important for $\cos 2\phi$ studies (all background contributions are HT)
CLAS12: kinematic distributions using LUND-MC

Covers a full \( z (E_\pi/\nu) \)-range

Provides access to large transverse momentum of hadrons

Significant moments in the acceptance (different for \( \pi^{+/0} \))
The Boer-Mulders Asymmetry: $Q^2$-dependence

\[ A_{UU}^{\cos 2\phi} \propto h_{1L} \bar{H}_{1L} \]

0.5 < $P_T$ < 0.6 (2000h)

Higher twist contributions $\sim P_T/Q$

**approximation:**

\[ h_{1L} \approx f_{1T} \]

\[ H_{1L} u \rightarrow \pi^+ \approx -H_{1L} u \rightarrow \pi^- \]

Uncertainty in $A_{UU}^{\cos \phi}$ defined by unknown Collins (1σ) and BM-functions

- Power counting rules $h_{1L} \sim (1 - x)^4$

Brodsky, Vogelsang & Yuan 2006

The $Q^2$ dependence of BM-asymmetry will test its leading twist nature.
Boer-Mulders Asymmetry: $P_T$-dependence

$A_{UU}^{\cos 2\phi} \propto h_1 \cdot H_1$

In the perturbative limit, $1/P_T^2$ behavior expected (F. Yuan)

$H_1^{u \rightarrow \pi^+} \approx -H_1^{u \rightarrow \pi^-}$

$4 < Q^2 < 5$ (2000h @ 11 GeV with $10^{35}\text{sec}^{-1}\text{cm}^{-2}$)

$\Lambda_{QCD} \ll P_T \ll Q$

$P_T$-dependence of azimuthal moments allows studies of transition from non-perturbative to perturbative description (Unified theory by Ji et al).

Newport News, VA
Measurements of kinematic \((x,Q^2,z,P_T)\) dependences of beam SSA will provide a test of its HT nature and will probe HT distribution functions.
Unpolarized target azimuthal asymmetries

- Significant $\cos \phi, \cos 2\phi$ observed at large $P_T$ at 5.7 GeV
- CLAS12 covers significantly wider kinematic range (large $Q^2$ and $P_T$)

06/24/2007 Exclusive Reactions at High Momentum Transfer, Newport News, VA
Study the Collins fragmentation for all 3 pions with a **transversely polarized target** and measure the transversity distribution function. JLAB12 cover the valence region.
Exclusive Reactions at High Momentum Transfer, Newport News, VA

Jlab Hall A E06-010,011 / $^3\text{He} \neq (e,e'\pi^-/\pi^+)X$

- **Beam**
  - Polarized ($P\sim80\%$) $e^-$, 15 $\mu$A, helicity flip at 60Hz

- **Target**
  - Optically pumped Rb+spin exchange $^3\text{He}$, 50 mg/cm$^2$, $\sim40\%$ polarization
  - Transversely polarized with tunable direction

- **Electron detection**
  - Bigbite spectrometer, Solid angle 60 msr, $\theta=30$ deg

- **Charged pion detection**
  - HRS spectrometer, $\theta=16$deg
Transversely polarized $^3$He target

Target polarization orientation can be rotated to increase the coverage in $\Phi_S'$
Single Target-Spin Asymmetry in Semi-Inclusive \( n^\uparrow(e,e'\pi^{+/−}) \) Reaction on a Transversely Polarized \(^3\)He Target

Collins

Sivers

Students:
K. Allada,
C. Dutta,
X. Qian,
M. Shabestari,
One from UIUC.
Solenoid Projection vs $P_T$ and $x$ for $\pi^+$ (60 days)

- For one $z$ bin (0.5-0.6)
- Will obtain 4 $z$ bins (0.3-0.7)
- Also $\pi^-$ at same time
- With upgraded PID for $K^+$ and $K^-$
**Conclusion**

Near Term: Collins and Sivers effects on a neutron target

Long Term: 12 GeV upgrade allows for a comprehensive study of TMDs in the large x region on proton and neutron targets