Transversity experiment (E06-010) at JLab

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Evaristo Cisbani(INFN, Rome), Jen-Chieh Peng(UIUC)
Outline

• Overview of Jefferson Lab – 6GeV
• Introduction of Transversity (E06-010) experiment at Jefferson Lab Hall A
  ✓ Physics motivation
  ✓ Setup of the experiment
• Published/submitted and preliminary results
• Summary
Thomas Jefferson National Accelerator Facility
--- 6 GeV

- Located in Newport News, Virginia, USA
- 2 linear accelerator provides continuous polarized electron beam
  - $E_{\text{beam}} = 6$ GeV
  - $P_{\text{beam}} = 85\%$
- 3 experimental halls
Introduction of Transversity (E06-010) experiment at Jefferson Lab Hall A

- Physics motivation
- Setup of the experiment
# Leading-Twist TMD PDFs (TMDs)

<table>
<thead>
<tr>
<th>Nucleon Polarization</th>
<th>Quark polarization</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unpolarized (U)</td>
<td>Longitudinallly Polarized (L)</td>
<td>Transversely Polarized (T)</td>
</tr>
<tr>
<td>U</td>
<td>$f_1 = , \cdot$</td>
<td>$g_1 = -, \cdot$</td>
<td>$h_{1L} = , \cdot$</td>
</tr>
<tr>
<td>L</td>
<td>$g_1 = , \cdot$</td>
<td>$h_{1L} = -, \cdot$</td>
<td>$h_{1T} = , \cdot$</td>
</tr>
<tr>
<td>T</td>
<td>$f_{1T} = , \cdot$</td>
<td>$g_{1T} = -, \cdot$</td>
<td>$h_{1T} = , \cdot$</td>
</tr>
</tbody>
</table>

- $f_1$: Sivers
- $g_1$: Helicity
- $h_{1T}$: Pretzelosity
- $h_{1L}$: Worm Gear

- Probed with transversely polarized target HERMES, COMPASS, JLab E06-010
TMDs in SIDIS Cross Section

\[ \frac{d\sigma}{dxdydzd\phi_h dp_{h\perp}^2} = \frac{\alpha^2}{x y Q^2 2(1-\varepsilon)} \]

- Unpolarized
  \[ \{F_{UU,T} + \ldots\]  
  \[ + \varepsilon \cos(2\phi_h) \cdot F_{UU}^{\cos(2\phi_h)} + \ldots\]  
  \[ + S_T [\varepsilon \sin(2\phi_h) \cdot F_{UT}^{\sin(2\phi_h)} + \ldots]\]  
  \[ + S_T [\varepsilon \sin(\phi_h + \phi_S) \cdot F_{UT}^{\sin(\phi_h + \phi_S)} + \ldots]\]  
  \[ + \sin(\phi_h - \phi_S) \cdot (F_{UL}^{\sin(\phi_h - \phi_S)} + \ldots)\]  
  \[ + \varepsilon \sin(3\phi_h - \phi_S) \cdot F_{UT}^{\sin(3\phi_h - \phi_S)} + \ldots]\]  
  \[ + S_T \lambda_e [\sqrt{1-\varepsilon^2} \cdot F_{LL} + \ldots]\]  
  \[ + S_T \lambda_e [\sqrt{1-\varepsilon^2} \cos(\phi_h - \phi_S) \cdot F_{LT}^{\cos(\phi_h - \phi_S)} + \ldots]\]  

- Polarized Target

- Polarized Beam and Target

\(S_L, S_T: \text{Target Polarization}; \lambda_e: \text{Beam Polarization}\)
Separation of Collins, Sivers and pretzelosity effects through azimuthal angular dependence

\[
A_{\text{UT}}(\phi_h^l, \phi_S^l) = \frac{1}{P} \frac{N^\uparrow - N^\downarrow}{N^\uparrow + N^\downarrow}
\]

\[
= A_{\text{UT}}^{\text{Collins}} \sin(\phi_h + \phi_S) + A_{\text{UT}}^{\text{Sivers}} \sin(\phi_h - \phi_S)
\]

\[
+ A_{\text{UT}}^{\text{Pretzelosity}} \sin(3\phi_h - \phi_S)
\]

\textbf{UT:} Unpolarized beam + Transversely polarized target

\[
A_{\text{UT}}^{\text{Collins}} \propto \langle \sin(\phi_h + \phi_S) \rangle_{\text{UT}} \propto h_1 \otimes H_1^\perp
\]

\[
A_{\text{UT}}^{\text{Sivers}} \propto \langle \sin(\phi_h - \phi_S) \rangle_{\text{UT}} \propto f_{1T}^\perp \otimes D_1
\]

\[
A_{\text{UT}}^{\text{Pretzelosity}} \propto \langle \sin(3\phi_h - \phi_S) \rangle_{\text{UT}} \propto h_{1T}^\perp \otimes H_1^\perp
\]

\(\rightarrow\) TMD: Transversity

\(\rightarrow\) TMD: Sivers

\(\rightarrow\) TMD: Pretzelosity
Introduction of E06-010 experiment

- Beam energy: 5.89 GeV (30Hz)
- Target: (World record!!!)
  - $^3$He: transversely and vertically polarized
  - In beam Polarization: ~60%
  - Spin flips: 20 minutes
- BigBite:
  - 3 Drift chambers, pre-shower, scin., shower
  - Momentum: 0.6 ---2.5 GeV
- LHRS:
  - VDC, S1, S2m(CTOF), A1, CO$_2$ gas Cer., RICH, pion rejector
  - Momentum: 2.35 GeV
  - PID: pion, kaon, proton separation

- Trigger: Singles on HRS or BigBite Coincidence trigger
- Polarized target and Beam

- SIDIS or Inclusive
- SSA or DSA
Published/submitted and preliminary results

- SIDIS results
- Inclusive hadron SSA/DSA
Single Spin Asymmetries in Charged Pion Production from Semi-Inclusive Deep Inelastic Scattering on a Transversely Polarized $^3$He Target at $Q^2 = 1.4-2.7$ GeV$^2$

Beam-Target Double-Spin Asymmetry $A_{LT}$ in Charged Pion Production from Deep Inelastic Scattering on a Transversely Polarized $^3$He Target at $1.4 < Q^2 < 2.7$ GeV$^2$

X. Qian et al. (Hall A Collaboration)

J. Huang et al. (Hall A Collaboration)
Kaon SIDIS SSA
---why kaon is interesting

- Collins effect
  - Hermes: $\pi^- \to \pi^+$ and kaon $\to$ pion
  - Unfavored Collins fragmentation function plays a more important role???
  - Importance of favored or unfavored Collins fragmentation function

- Sivers effect
  - Difference between $\pi^+$ and $K^+$: $d$-bar $\leftrightarrow$ $s$-bar
    - "Sea quark effect"
    - "Fragmentation effect"
    → difference is small through calculation, quark mass difference cancels in ratio

- Important inputs to the global kaon data from He-3 target

- Current theoretical understanding or phenomenological fits could be tested or improved
Kaon PID

- Contamination of pion in kaon sample is well controlled:
  - $\pi^+$ in $k^+$: <2%
  - $\pi^-$ in $k^-$: <5%
Kaon Collins and Sivers asymmetries on He-3 target

Y. X. Zhao, Y. Wang et al. (Hall A Collaboration)

Accepted by PRC, in Production  arXiv: 1404.7204
Assuming TMD factorization valid in inclusive hadron production:

- Sivers contribution dominates SSA
- Collins contribution is negligible
Inclusive hadron SSA

- Indication of our false asymmetry: <0.1%

\[
A_{UT}(x_F, p_T) = \frac{1}{P} \frac{d\sigma^\uparrow - d\sigma^\downarrow}{d\sigma^\uparrow + d\sigma^\downarrow} \sin\phi_S = A_N \sin\phi_S
\]

- \( \phi_S = 90^\circ \)
- Clear non-zero asymmetries are observed for \( \pi^+ \) and \( \pi^- \) and \( K^+ \)
- \( \pi^+ \) and \( \pi^- \) asymmetries have opposite sign

\[ e + ^3\text{He}^\uparrow \rightarrow h + X \quad <p_T> = 0.64 \text{ GeV/c} \]
Inclusive hadron SSA

K. Allada, Y. X. Zhao et al.
(Hall A Collaboration)
Phys. Rev. C 89, 042201(R)
Inclusive hadron DSA

- Andrei & Carl Carlson:
  - Fragmentation process
  - Direct photoproduction
  - Resolved photon process
- Collinear twist-3 framework:
  - $g_{1T}$

\[
A_{LT} = \frac{1}{|P_B P_{target}|} \frac{d\sigma^{\uparrow\rightarrow} - d\sigma^{\downarrow\rightarrow}}{d\sigma^{\uparrow\rightarrow} + d\sigma^{\downarrow\rightarrow}}
\]
Summary

• Transversity experiment (E06-010) is introduced
• Several results are presented
• It's just the beginning...
  ✓ More 12 GeV experiments at Jlab
  ✓ Kalyan Allada’s talk on Friday, S3 session
    ◆ “Key Future Measurements of TMDs at Jlab and Other Facilities”
  ✓ Jian-ping Chen’s talk on Friday, S11 session
    ◆ “TMD Studies and More with SoLID at Jlab”
E06010 (6-GeV Transversity) collaboration

Institutions (38)


Collaboration members (115)


Co-spokesperson, Graduate student, Leading Postdoc
Backup
Kaon SIDIS
DSA --- Preliminary
DSA---fragmentation process
DSA---direct photoproduction
DSA---resolved photon process
Target-Beam Double spin asymmetry
---Vertically polarized target

\[ A_{LT} = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{|S_TP_B| \left( d\sigma^{\uparrow} + d\sigma^{\downarrow} \right)} \]

- Hadron momentum direction
- Electron momentum direction
- Electron spin direction
- Target spin direction, view from top

Naiive P transformation: No \( A_{LT} \)

Naiive T transformation: No constrains On \( A_{LT} \)

P conservation
Target-Beam Double spin asymmetry
---Transversely polarized target

\[ A_{LT} = \frac{1}{|S_TP_B|} \left( \frac{d\sigma^{\uparrow \downarrow}}{d\sigma^{\uparrow \downarrow}} - \frac{d\sigma^{\downarrow \uparrow}}{d\sigma^{\uparrow \downarrow}} \right) \]
Asymmetry **sign change** by reversing target spin transversely

\[ \text{Asy}_1 = \quad - \quad \]

\[ \text{Asy}_2 = \quad - \quad \]

\[ = \quad - \quad \]

\[ = \quad -\text{Asy}_1 \]