Beam-Spin Asymmetries in SIDIS at HERMES

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On behalf of the HERMES collaboration
Investigating spin structure of nucleon

- Spin crisis
- Longitudinal and transverse momentum nucleon structure
- Large SSA in pion production
- Quark transverse momentum role

\[ \sum \Delta q \]

\[ L_q \]

\[ L_g \]

\[ \Delta G \]

DESY HERMES V. Zagrebelnyy

25.06.2013
TMD approach

inclusive DIS
integrated DFs

\[ \xi = 0, t = 0 \]

\[ \int d^2 k_T \]

semi-inclusive DIS

GPDs

\[ \int d^2 k_T dr_\parallel \]

TMDs

\[ \int d^3 r \]

theory

W(p,x) Wigner distribution
Can not be measured due to:

\[ \Delta p \Delta x \geq \frac{\hbar}{2} \]

\[ q(x, r_\perp, \vec{S}, \vec{\bar{s}}, Q^2) \]

\[ q(x, k_\perp, \vec{S}, \vec{\bar{s}}, Q^2) \]
SIDIS cross section

\[ e^+ p \rightarrow e^+ h^{+/-} X \]

(inclusive) \hspace{1cm} (semi-inclusive)

\[ f_1(x) \hspace{1cm} f_1(x, p_T) \]
SIDIS cross section

\[ e^+ p \rightarrow e^+ h^{+/−} X \]

Inclusive

\[ f_1(x) \]

Semi-inclusive

\[ f_1(x, p_T) \]

Superposition in basis of \( s_⊥, s_∥, S_∥, S_⊥, \lambda_e \)

**DF**  **TMD**

<table>
<thead>
<tr>
<th>nuclide</th>
<th>quark</th>
<th>U</th>
<th>L</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>( f_1 )</td>
<td>( h_1^+ )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>( g_1 )</td>
<td>( h_1^L )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>( f_{1T} )</td>
<td>( g_{1T} )</td>
<td>( h_1 h_{1T} )</td>
<td></td>
</tr>
</tbody>
</table>

\[
\sigma^{eN→ehX} = \sum DF_{N→q} \otimes \sigma^{eq→eq} \otimes FF^{q→h}
\]

**FF**  **TMD**

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<th>L</th>
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<td>had U</td>
<td>( D_1 )</td>
<td>( H_1^+ )</td>
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</table>
Subleading (twist-3) $A_{LU}^{\sin \phi_h}$

Total SIDIS cross section

$$d\sigma = d\sigma_{UU} + \lambda_e \frac{1}{Q} \sin(\phi_h) d\sigma_{LU} + S_{||} [... ] d_{UL} + S_{\perp} \lambda_e [...] d_{LL} + S_{||} [...] d_{UT} + S_{\perp} \lambda_e [...] d_{LT} = d\sigma_{UU} \left\{ 1 + \lambda_e A_{LU}^{\sin \phi_h} \sin \phi_h \right\}$$

Beam spin asymmetry

$$A_{LU}(\phi_h) = \frac{d\sigma_{LU}}{d\sigma_{UU}} = \frac{d\sigma(\lambda_e) - d\sigma(-\lambda_e)}{d\sigma(\lambda_e) + d\sigma(-\lambda_e)} = A_{LU}^{\sin \phi_h} \sin(\phi_h)$$

$$d\sigma_{LU} \sim A_{LU}^{\sin \phi} \sim f(y) \cdot \frac{2M}{Q} C \left[ - \frac{\vec{h} \cdot k_T}{M_h} \left( x e H_1^\perp + \frac{M_h}{M} f_1 \frac{1}{z} G \right) + \frac{\vec{h} \cdot p_T}{M} \left( x g D_1 + \frac{M_h}{M} h_1^\perp \frac{E}{z} \right) \right]$$
Subleading (twist-3) $A_{LU}^{\sin \phi_h}$

Total SIDIS cross section

$$d\sigma = d\sigma_{UU} + \frac{1}{Q} \lambda_e \sin(\phi_h) d\sigma_{LU} + S_\parallel [...] d_{UL} + S_\perp \lambda_e [...] d_{LL} +$$

$$+ S_\perp [...] d_{UT} + S_\perp \lambda_e [...] d_{LT} = d\sigma_{UU} \left\{ 1 + \lambda_e A_{LU}^{\sin \phi_h} \sin \phi_h \right\}$$

Beam spin asymmetry

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kinematic prefactor

$$d\sigma_{LU} \sim f(y) \frac{2M}{Q} C \left[-\vec{h} \cdot k_T \left( x e H_{1}^1 + \frac{M}{M_h} f_{1} G \right) + \frac{\vec{h} \cdot p_T}{M} \left( x g D + \frac{M}{M} h_1 E \right) \right]$$

Twist-3 DF and FF

Collins

unpolarized

Boer - Mulders
The HERMES experiment at HERA

\[ E_{\text{beam}} = 27.6 \ \text{GeV} \]

lepton-hadron > 98%

π ~ 98%, K ~ 88%, P ~ 85%

Hadron separation
Maximum likelihood function

• Data sample consist of N independent measured events with kinematic variables \( \xi \)
  \( \xi \) is \( \phi_h, x_B, y, z, P_{h\perp} \)
• events are distributed according to Probability Density Function,
  \( p(\xi, \theta) \)

\[ \Theta - \text{is set of parameters( here 1 par):} \quad A_{LU}^{\sin\phi_h} = \frac{d\sigma_{LU}}{d\sigma_{UU}} \]

\[ p(\phi_h, A_{LU}^{\sin\phi_h}) \sim \left\{ 1 + \lambda_e A_{LU}^{\sin\phi_h} \sin\phi_h \right\} \]

Likelihood function

\[ L(\phi_h, A_{LU}^{\sin\phi_h}) = \prod \ p(\phi_h, A_{LU}^{\sin\phi_h}) = \prod_{pol>0}^{N^+} p^{w^+}(\phi_h, A_{LU}^{\sin\phi_h}) \prod_{pol<0}^{N^-} p^{w^-}(\phi_h, A_{LU}^{\sin\phi_h}) \]

Beam Balance

\[ \sum_{i=1}^{DIS^+} P_i + w^- \sum_{i=1}^{DIS^-} P_i = 0 \]

\[ w^+ = 1 \]

\[ w^- = \sum_{i=1}^{DIS^+} P_i / \sum_{i=1}^{DIS^-} P_i \]
Compared to CLAS(E=5.76 GeV) and COMPASS (E=160 GeV) experiments.
New results. Hydrogen target
New results. Deuterium target
Conclusions

- Recently obtained BSA of pions, kaons, proton and antiproton on hydrogen and deuterium target with increased statistics

- kaons BSA asymmetries are measured for the first time

- proton and antiproton BSA are presented for the first time in SIDIS analysis

- pions BSA are slightly positive

- kaon and proton/antiproton BSA are consistent with zero