Single-spin asymmetries in two hadron production of polarized deep inelastic scattering at HERMES

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HERMES experiment at DESY

**Positron (electron) beam**
- 27.6 [GeV]
- current ~ 30[mA]

**Transversely polarized hydrogen target (2002~2005)**
- polarization ~ 75[%]

\[ e + p \uparrow \rightarrow e + \pi^+ + \pi^- + X \]
**HERMES Spectrometer**

- **Internal gas target**: H(pol), D(pol), He, Ne, Kr, Xe
- **e+ beam**: 27.6 GeV

**.acceptance**: 40 mrad $\Theta$ < 220 mrad

- **Tracking resolution**: $\delta P/P = (0.7-1.3)\%$, $\delta \Theta = 0.6$ mrad
- **PID**: Hodoscope, Calorimeter, TRD and RICH

Lepton ID efficiency > 97%, Hadron contamination < 1%

Hadron ID($\pi$, K, P) at 2 $\pi$5 GeV/c
Quark distribution functions

At leading twist

Quark momentum distribution: \( q(x) = \)

Quark Helicity: \( \Delta q(x) = \)

Quark Transversity: \( \delta q(x) = \)

\( \delta q(x) \): unknown chiral odd

- quark’s relativistic nature \( \Rightarrow \delta q(x) \neq \Delta q(x) \)
- positivity bound : \( |\delta q(x)| \leq q(x) \)
  
  Soffer bound : \( |\delta q(x)| \leq \frac{1}{2} [q(x) + \Delta q(x)] \)
Access to transversity

\( \delta q(x) \): chiral odd \( \Rightarrow \) Need another chiral odd objects.

Transversity \( \delta q(x) \) couples to …
- Collins fragmentation function (FF)
- 2-hadron interference FF
- Polarized Lambda FF
- Spin-1 FF
Single-spin asymmetry of 2-hadron production

Azimuthal single-spin asymmetries (data taken in 2002...2004)

\[ A_{UT}(\phi_{R\perp}, \phi_S, \theta) = \frac{1}{|S_T|} \frac{N_{\uparrow}(\phi_{R\perp}, \phi_S, \theta) / N_{\text{DIS}} - N_{\downarrow}(\phi_{R\perp}, \phi_S, \theta) / N_{\text{DIS}}}{N_{\text{DIS}}(\phi_{R\perp}, \phi_S, \theta) / N_{\text{DIS}} + N_{\text{DIS}}(\phi_{R\perp}, \phi_S, \theta) / N_{\text{DIS}}} \]

\[ \sim \sin(\phi_{R\perp} + \phi_S) \sin \theta \, \delta q(x) \, H_1^\chi(z) \]

Transversity Interference FF (chiral odd)

\[ \delta q(x) \] can be extracted using \( H_1^\chi(z) \) measured by e+ e- collider, BELLE

\[ H_1^\chi(z) \] describes interference between different production channels of pion pairs

\[ e(k) + p^\uparrow \rightarrow e(k') + \pi^+(P_1) + \pi^-(P_2) + X \]
$H_1^\xi: s$-p wave interference in $\pi \pi$ scattering theory

Partial wave expansion

$$H_1^\xi(z,\cos\theta, M_{\pi\pi}^2) = H_1^{\xi, sp}(z, M_{\pi\pi}^2) + \cos\theta H_1^{\xi, pp}(z, M_{\pi\pi}^2)$$

$M_{\pi\pi}$ dependence of Interference FF


$$H_1^{\xi, sp}(z, M_{\pi\pi}^2) = \sin\delta_0 \sin\delta_1 \sin(\delta_0 - \delta_1) H_1^{\xi, sp'}(z)$$

$\pi\pi$ phase shift analysis using $\pi^- p \rightarrow \pi^- \pi^+ n$ scattering


Sign of the phase shift changes at $M_{\pi\pi} = M_{\rho^0}$

$A_{UT}$ might depend strongly on $M_{\pi\pi}$
Spectator model for $\pi^+\pi^-$ fragmentation

Partial wave expansion

$$H_1^q(z, \cos \theta, M_{\pi\pi}^2) = H_1^{q,sp}(z, M_{\pi\pi}^2) + \cos \theta H_1^{q,pp}(z, M_{\pi\pi}^2)$$

No strong $M_{\pi\pi}$ dependence.
Single-spin asymmetry in 2-hadron production

First observation of transverse asymmetries in interference process

\[ A_{UT} \sim \sin(\phi_{R\perp} + \phi_S)\langle\sin\theta\rangle \delta qH_1^< \]
(no \(\theta\) binning)

\[ \langle \sin\theta \rangle = 0.89 \]
\[ 0.51 < M_{\pi\pi} < 0.97 \]
Single-spin asymmetry in 2-hadron production

Single-spin asymmetries

\[ \frac{A_{UT}}{\langle \sin \theta \rangle} \sim \sin(\phi_{R\perp} + \phi_S) \delta q H_{1}^{Q} \]

with

\[ a_0 + a_1 \sin(\phi_{R\perp} + \phi_S) \]

\[ a_0 = 0.000 \pm 0.006 \]
\[ a_1 = 0.040 \pm 0.009 \]

Amplitude of the asymmetry modulation

\[ a_1 = 0.040 \pm 0.009 \text{ Stat} \pm 0.003 \text{ Syst} \]

\[ \delta q \cdot H_{1}^{Q} \neq 0 \]
Single-spin asymmetry in 2-hadron production

If we look at $M_{\pi\pi}$ dependence, ($M_{\pi\pi}$: invariant mass of pion pair)

Asymmetry is fitted with

$$A_{UT} \sin(\phi_{R\perp} + \phi_S) \sin \theta$$

Positive asymmetry is observed around $M_{\pi\pi} = M_{\rho^0}$
Spectator model for $\pi^+ \pi^-$ fragmentation

Partial wave expansion

$$H_1^\xi(z, \cos \theta, M_{\pi\pi}^2) = H_1^{\xi,sp}(z, M_{\pi\pi}^2) + \cos \theta H_1^{\xi,pp}(z, M_{\pi\pi}^2)$$

Marco Radici at Como, 7 - 10 Sept 2005
Conclusion

• Single-spin asymmetry in $\pi^+$, $\pi^-$ production is measured with transversely polarized hydrogen target at HERMES.

• This is the first observation of transverse target spin asymmetry in interference process.

• $\sin(\phi_{R\perp} + \phi_S)$ modulation of $A_{UT}$ is observed at 4 sigma level.

$$\frac{A_{UT}^{\sin(\phi_{R\perp} + \phi_S)}}{\langle \sin \theta \rangle} = 0.040 \pm 0.009_{\text{Stat}} \pm 0.003_{\text{Syst}}$$

• Positive asymmetry is observed for measured $\pi^+$, $\pi^-$ invariant mass range. ( $M_{\pi\pi} = 0.25 - 2.0$ [GeV/c$^2$])

$$\delta q \cdot H_1 \neq 0$$
Outlook

- 4~5 M more DIS events are expected in 2005, compared to 3.5 M DIS events in 2002~2004.
backup
Event selection

Data set: 2002~2004

SIDIS events with at least pion pair (\( \pi^+, \pi^- \)) appeared were analyzed.

\[ ep \uparrow \rightarrow e' \pi^+ \pi^- X \]

Kinematic cuts:

\[ Q^2 \geq 1 \text{ GeV}^2 \]
\[ W^2 \geq 4 \text{ GeV}^2 \]
\[ x \geq 0.023 \]
\[ 0.1 < y < 0.85 \]
\[ p_{\text{track}} > 2.5 \text{ GeV} \text{ (for DIS lepton)} \]
\[ p_{\text{track}} > 1 \text{ GeV} \text{ (for Hadron)} \]

To cut exclusive channel.

\[ \Delta E > 2 \text{ GeV}, \text{ where } \Delta E = \frac{M_x^2 - M_p^2}{2M_p} \]
Evaluate $A_{UT}$

What is measured

$$A_{UT}(\phi_{R\perp}, \phi_{S}, \theta) = \frac{1}{|S_T|} \frac{N^{\uparrow}(\phi_{R\perp}, \phi_{S}, \theta)/N_{\mathrm{DIS}}^{\uparrow} - N^{\downarrow}(\phi_{R\perp}, \phi_{S}, \theta)/N_{\mathrm{DIS}}^{\downarrow}}{N^{\uparrow}(\phi_{R\perp}, \phi_{S}, \theta)/N_{\mathrm{DIS}}^{\uparrow} + N^{\downarrow}(\phi_{R\perp}, \phi_{S}, \theta)/N_{\mathrm{DIS}}^{\downarrow}}$$

$$\sim \sin(\phi_{R\perp} + \phi_{S}) \sin \theta \ h_{1} H_{1}^{\xi} + \ldots ,$$

where $|S_T|$ is the average target polarization. ( $|S_T| = 75.4 \pm 5.0$ )
Single-spin asymmetry in 2-hadron production

\[ M_{\pi\pi} \text{ dependence of } A_{UT}^{\sin(\phi_R + \phi_S) \sin \theta} \]

\[ M_{\pi\pi} : \text{ invariant mass of pion pair} \]

Asymmetry is fitted with

\[ a_0 + a_1 \sin(\phi_R + \phi_S) \sin \theta \]

\[ A_{UT}^{\sin(\phi_R + \phi_S) \sin \theta} = a_1 \]

Positive asymmetry is observed around \( M_{\pi\pi} = M_{\rho^0} \)

\( M_{\pi\pi} \) binning: 0.25, 0.40, 0.55, 0.77, 2.0 [GeV]
$M_{\pi\pi}$ spectrum

With or without $\Delta E > 0.2[\text{GeV}]$ cut

$$\Delta E = \frac{M_x^2 - M_p^2}{2M_p}$$
With or without $\Delta E > 0.2[\text{GeV}]$ cut

$$\Delta E = \frac{M_x^2 - M_p^2}{2M_p}$$
double spin asymmetry

Fit

\[ A_{UT} \sim \sin(\phi_R + \phi_S) \sin \theta \ h_1 H_1 \]

for both beam polarization.

\[ A_{UT}^{\sin(\phi_R + \phi_S)\sin \theta} = b \]

\[ = 0.041 \pm 0.011 \text{ for } P_{\text{beam}} \geq 0 \]
\[ = 0.040 \pm 0.012 \text{ for } P_{\text{beam}} \leq 0 \]

No double spin asymmetry

Beam polarization don’t affect to the asymmetry

<table>
<thead>
<tr>
<th>pol (\geq 0)</th>
<th>a (\pm) b</th>
<th>c (\pm) d</th>
<th>(&lt;\text{ pol } &gt;)</th>
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<tr>
<td>0.002 (\pm) 0.008</td>
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<td>0.017 (\pm) 0.013</td>
<td>-23.97</td>
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Polarized cross section for 2 hadron SIDIS

2 hadron semi-inclusive DIS

\[ d\sigma_{UL} \propto \sum_q e_q^2 \sin \phi_{R\perp} \left( h_L^q H_1^\Psi + A g_1^q \tilde{G}^\Psi \right) \]

\[ d\sigma_{UT} \propto \sum_q e_q^2 \sin(\phi_R + \phi_S) h_1^q H_1^\Psi + B \sin \phi_S (\ldots) \]

\[ d\sigma_{LU} \propto \sum_q e_q^2 \sin \phi_{R\perp} \left[ e^q H_1^\Psi + C f_1^q \tilde{G}_1^\Psi \right] \]

Single spin asymmetries

\[ A_{UL}^{\sin \phi_{R\perp}} \propto h_L^q H_1^\Psi + A g_1^q \tilde{G}^\Psi \]

\[ A_{UT}^{\sin(\phi_R + \phi_S)} \propto h_1^q H_1^\Psi \]

\[ A_{LU}^{\sin \phi_{R\perp}} \propto e H_1^\Psi + C f_1^q \tilde{G}_1^\Psi \]
Polarized cross section for 2 hadron SIDIS

\[ d\sigma_{UU} \propto \sum_q e_q^2 \left\{ A(y) f_1 D_1 - V(y) \cos\phi_R \sin\theta \frac{R}{Q} \left[ \frac{f_1}{z} \tilde{D}^\xi + \frac{M_x}{M_h} hH_1^\xi \right] \right\} \]

\[ d\sigma_{UL} \propto \sum_q e_q^2 \sin\phi_R \left\{ S_L |V(y)| \sin\theta \frac{R}{Q} \left[ \frac{M_x}{M_h} h_L H_1^\xi + \frac{1}{z} g_1 \tilde{G}^\xi \right] \right\} \]

\[ B(y) \sin(\phi_R + \phi_S) \sin\theta \frac{R}{M_h} h_1 H_1^\xi \]

\[ d\sigma_{UT} \propto \sum_q e_q^2 |S_\perp| \left\{ V(y) \sin\phi_S \frac{M_h}{Q} \left[ h_1 \left( \frac{1}{z} \tilde{H} + \sin^2 \theta \frac{R^2}{M_h^2} H_1^\xi_{a(1)} \right) - \frac{M}{M_h} x f_1 D_1 \right] \right\} \]

\[ d\sigma_{LU} \propto \sum_q e_q^2 \lambda e W(y) \sin\phi_R \sin\theta \frac{R}{Q} \left[ \frac{M_x}{M_h} e H_1^\xi + \frac{1}{z} f_1 \tilde{G}^\xi \right] \]

In Wandzura-Wilzcek approx., function with tilde vanish.