measurement of the Collins and Sivers asymmetries from a transversely polarized hydrogen target

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For the hermes collaboration
HERA MEasurement of Spin

HERA storage ring @ DESY
Electron beam (27.6GeV/c) off a transversely polarised atomic hydrogen target

$<P>\sim 74\pm 3\%$
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HERMES spectrometer

Resolution: $\Delta p/p \sim 1\%-2\%$  $\Delta \theta < \sim 0.6$ mrad

Electron-hadron separation efficiency $\sim 98\%-99\%$

Hadron identification with dual-radiator RICH
HERMES spectrometer

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Dual radiator **Ring Imaging C**H**erenkov**
Dual radiator Ring Imaging CHerenkov

Aerogel $n=1.03$

$C_4F_{10}$ $n=1.0014$
Dual radiator **Ring Imaging C**H**erenkov**

![Diagram showing Cerenkov imaging with different radiator materials](image)

- **Aerogel** $n=1.03$ with $\varepsilon \approx 98\%$
- **$C_4F_{10}$** $n=1.0014$ with $\varepsilon \approx 88\%$
- **$C_4F_{10}$** $n=1.0014$ with $\varepsilon \approx 85\%$
Nucleon quark structure

At leading twist there are 3 fundamental quark distribution functions:

Momentum distribution $q(x)$

\[ q(x) = \text{const} + \text{const} \]
Nucleon quark structure

At leading twist there are 3 fundamental quark distribution functions:

Momentum distribution $q(x)$

WELL KNOWN

$\bullet = \bullet + \bullet$
Nucleon quark structure

At leading twist there are 3 fundamental quark distribution functions:

Momentum distribution $q(x)$

Helicity distribution $\Delta q(x)$
Nucleon quark structure

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At leading twist there are 3 fundamental quark distribution functions:

Momentum distribution \( q(x) \)

Helicity distribution \( \Delta q(x) \)

Transversity distribution \( \delta q(x) \)
Nucleon quark structure

At leading twist there are 3 fundamental quark distribution functions:

- Momentum distribution $q(x)$
- Helicity distribution $\Delta q(x)$
- Transversity distribution $\delta q(x)$
Transversity

The transversity distribution function is associated with an helicity flip of the struck quark. For this reason it is known as a chiral-odd function, and it cannot be probed in Inclusive Deep Inelastic Scattering.
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Semi Inclusive Deep Inelastic Scattering: transversity is coupled to a chiral-odd Fragmentation Function;
Transversity

The transversity distribution function is associated with an helicity flip of the struck quark. For this reason it is known as a **chiral-odd** function, and it cannot be probed in Inclusive Deep Inelastic Scattering.

**Semi Inclusive Deep Inelastic Scattering:** transversity is coupled to a chiral-odd **Fragmentation Function**;

\[
\delta q \otimes FF \rightarrow h
\]

- **chiral-odd DF**
- **chiral-odd FF**

**CHIRAL-EVEN!**
Collins mechanism

The Collins Fragmentation Function $H_1^+(z,k_T^2)$ describes the correlation between the transverse polarization of the struck quark and the transverse momentum of the produced unpolarised hadron.

The Collins mechanism produces an **azimuthal asymmetry** in the direction of the outgoing hadrons.
Azimuthal Single Spin Asymmetries

\[ A_{UT}^h = \frac{\sigma_h^{\uparrow \downarrow} - \sigma_h^{\uparrow \uparrow}}{\sigma_h^{\uparrow \downarrow} + \sigma_h^{\uparrow \uparrow}} \]
Azimuthal Single Spin Asymmetries

\[ A_{UT}^h = \frac{\sigma_h^{\uparrow\downarrow} - \sigma_h^{\uparrow\uparrow}}{\sigma_h^{\uparrow\downarrow} + \sigma_h^{\uparrow\uparrow}} \]

\[ A_{UT}^h \propto 2 |S_T| \sin(\phi + \phi_s) \sum q e_q^2 I\left[\frac{(k_T \cdot \hat{P}_{h\perp})}{M_h} \delta q(x, p_T^2) H_1^{\perp q}(z, k_T^2)\right] \]

\[ \frac{A(y)\sum q e_q^2 q(x, k_T^2) D_1^q(z, k_T^2)}{A(y)\sum q e_q^2 q(x, k_T^2) D_1^q(z, k_T^2)} \]
Azimuthal Single Spin Asymmetries

\[ A_{UT}^h = \frac{\sigma_{h \uparrow \downarrow} - \sigma_{h \uparrow \uparrow}}{\sigma_{h \uparrow \downarrow} + \sigma_{h \uparrow \uparrow}} \]

\[ A_{UT}^h \propto 2|S_T| \sin(\varphi + \varphi_S) \sum_q e_q^2 \frac{I[(\vec{k}_T \cdot \hat{P}_{h\perp})]}{M_h} \left\{ \delta q(x, p_T^2) H_1^{\perp q}(z, k_T^2) \right\} \]

\[ \frac{A(y) \sum_q e_q^2 q(x, k_T^2) D_1^q(z, k_T^2)}{A(y) \sum_q e_q^2 q(x, k_T^2) D_1^q(z, k_T^2)} \]
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\[ + 2S_T \sin (\varphi - \varphi_s) \sum_q e_q^2 \frac{I[(\vec{p}_T \cdot \hat{P}_{h \perp})]}{M} f_{1T}^q (x, k_T^2) D_1^q (z, k_T^2) \]

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Azimuthal Single Spin Asymmetries

\[ A^h_{UT} = \frac{\sigma_{h}^{\uparrow \downarrow} - \sigma_{h}^{\uparrow \uparrow}}{\sigma_{h}^{\uparrow \downarrow} + \sigma_{h}^{\uparrow \uparrow}} \]

\[ A^h_{UT} \propto 2|S_T| \sin(\varphi + \varphi_s) \sum_q e_q^2 I\left(\frac{\vec{k}_T \cdot \hat{P}_{h\perp}}{M_h}\right) \delta q(x, p_{T}^2) H_{1,q} (z, k_T^2) \]

\[ + 2|S_T| \sin(\varphi - \varphi_s) \sum_q e_q^2 I\left(\frac{\vec{p}_T \cdot \hat{P}_{h\perp}}{M}\right) f_{1T} (x, k_T^2) D_{1}^q (z, k_T^2) \]
Azimuthal Single Spin Asymmetries

\[ A_U^h = \frac{\sigma^{\uparrow\downarrow}_h - \sigma^{\uparrow\uparrow}_h}{\sigma^{\uparrow\downarrow}_h + \sigma^{\uparrow\uparrow}_h} \]

\[ A_U^h \propto 2|S_T| \sin(\varphi + \varphi_s) \]

\[ + 2|S_T| \sin(\varphi - \varphi_s) \] 

Collins signature

Sivers signature
The Sivers function $f_{1T}^{\perp q}(x, p_T^2)$ describes the correlation between the transverse polarization of the nucleon and the transverse momentum of the quark within the spin-orbit structure of the nucleon.

A non-zero Sivers function requires a non-vanishing orbital angular momentum inside the nucleon.
Collins amplitudes for charged pions

\[ 2 \langle \sin(\phi + \phi_S) \rangle_{\text{UT}} \]

- Large positive for $\pi^+$
- Large negative for $\pi^-$
Collins amplitudes for charged pions

$-0.12$ $-0.1$ $-0.08$ $-0.06$ $-0.04$ $-0.02$ $0$ $0.02$ $0.04$ $0.06$ $0.08$ $0.1$

$2 \langle \sin(\phi + \phi_S) \rangle_{\nu \tau}$

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lepton beam asymmetry, Collins amplitudes
8.1% scale uncertainty

$\rightarrow$ Large positive for $\pi^+$

$\rightarrow$ Large negative for $\pi^-$

$u \rightarrow \pi^+ H_1 \perp, fav$

$2 \langle \sin(\phi + \phi_S) \rangle_{\nu \tau}$

$0.1$ $0.2$ $0.3$ $0.4$ $0.5$ $0.6$

$x$

$0.2$ $0.4$ $0.6$ $0.8$ $1$

$z$

$0.2$ $0.4$ $0.6$ $0.8$ $1$

$P_{h\perp}$ [GeV]

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Collins amplitudes for charged pions

\[ 2 \langle \sin(\phi + \phi_S) \rangle_{\text{UT}} \]

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**HERMES PRELIMINARY 2002-2005**

lepton beam asymmetry, Collins amplitudes

8.1% scale uncertainty

\[ u \rightarrow \pi^+ H_{1,\perp,\text{fav}} \]

\[ u \rightarrow \pi^- H_{1,\perp,\text{unfav}} \]
Collins amplitudes for charged pions

\[ 2 \langle \sin(\phi_+ + \phi_S^\perp) \rangle \]

\[ \pi^+ \]

\[ \pi^- \]

\( \rightarrow \) Large positive for \( \pi^+ \)

\( \rightarrow \) Large negative for \( \pi^- \)

\[ u \rightarrow \pi^+ H_1^\perp, \text{ fav} \]

\[ u \rightarrow \pi^- H_1^\perp, \text{ unfav} \]

\[ H_{1, \text{unfav}} \approx -H_{1, \text{fav}} \]
Sivers amplitudes for charged pions

→ Large positive for $\pi^+$
→ Consistent with zero for $\pi^-$
Sivers amplitudes for charged pions

- Large positive for $\pi^+$
- Consistent with zero for $\pi^-$

Non zero quark orbital angular momentum!
The neutral pions

Collins amplitudes

Sivers amplitudes

Isospin symmetry fulfilled for $\pi$-mesons SSA amplitudes!
Collins amplitudes for charged kaons

→ No significant non-zero Collins amplitudes for Kaons
Collins amplitudes for charged kaons

→ No significant non-zero Collins amplitudes for Kaons

→ Collins amplitudes for $K^+$ compatible with $\pi^+$

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Sivers amplitudes for charged kaons

$\rightarrow$ Large positive for $K^+$

$\rightarrow$ Consistent with zero for $K^-$

but….
Sivers amplitudes for charged kaons

- Large positive for $K^+$
- Consistent with zero for $K^-$
- $K^+$ amplitudes are larger than the $\pi^+$ amplitudes!
Sivers amplitudes for charged kaons

- Large positive for $K^+$
- Consistent with zero for $K^-$
- $K^+$ amplitudes are larger than the $\pi^+$ amplitudes!

Significant sea quark contribution?
Conclusion

• The first evidence of a significant SSA Collins amplitudes for π-mesons
Conclusion

• The first evidence of a significant SSA Collins amplitudes for $\pi$-mesons

$$A_{UT}^{\sin(\varphi+\varphi_S)} \propto \delta q(x) \otimes H_{1q}^\perp (z)$$
Conclusion

- The first evidence of a significant SSA Collins amplitudes for $\pi$-mesons

\[ A_{UT} \sin(\phi + \phi_S) \propto \delta q(x) \otimes H_{1}^{\perp q}(Z) \]

- R. Seidl et al.

- E. S. Ageev et al.

- A. Airapetian et al.
Conclusion

• The first evidence of a significant SSA Collins amplitudes for $\pi$-mesons

\[ A_{UT} \sin(\phi + \phi_S) \propto \delta q(x) \otimes H_1^\perp q(z) \]

First extraction of transversity!

Conclusion

• The first evidence of a significant SSA Collins amplitudes for $\pi$-mesons

• Significant SSA Sivers amplitudes for $\pi^+$ and $K^+$
Conclusion

• The first evidence of a significant SSA Collins amplitudes for $\pi$-mesons

• Significant SSA Sivers amplitudes for $\pi^+$ and $K^+$ non-zero quark orbital angular momenta!
Thanks!
Vector meson contributions

![Graph showing vector meson contributions to different particles](image-url)