Latest News from HERMES

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on behalf of the HERMES Collaboration
Polarized Deep Inelastic Scattering

Important Variables:

\[ Q^2_{\text{lab}} = 4E E' \sin^2 \left( \frac{\theta}{2} \right) \]
\[ \nu_{\text{lab}} = E - E' \]
\[ x_{\text{lab}} = \frac{Q^2}{2m\nu} \]
\[ y_{\text{lab}} = \frac{\nu}{E} = \frac{p\cdot q}{p\cdot k} \]
\[ z_{\text{lab}} = \frac{E_h}{\nu} \]

Cross Section:

\[ \frac{d^2\sigma}{d\Omega dE^2} = \frac{\alpha^2 E'}{Q^2 E} L_{\mu\nu} W^{\mu\nu} \]

\[ L_{\mu\nu} = 2[k_\mu k'_\nu + k_\nu k'_\mu - (k \cdot k' - m_e^2) g_{\mu\nu} + i m_e \epsilon_{\mu\nu\alpha\beta} S^\alpha (k - k')^\beta] \]

\[ W^{\mu\nu} = -g^{\mu\nu} F_1 (x, Q^2) + \frac{p^\mu p^\nu}{\nu} F_2 (x, Q^2) \]
\[ + i \epsilon^{\mu\nu\lambda\sigma} \frac{q_\lambda}{\nu} (S_\sigma g_1 (x, Q^2) + \frac{1}{\nu} (p \cdot q S_\sigma - S \cdot q p_\sigma) g_2 (x, Q^2)) \]

(for spin 1)

\[ -b_1 (x, Q^2) r_{\mu\nu} + \frac{1}{6} b_2 (x, Q^2) (s_{\mu\nu} + t_{\mu\nu} + u_{\mu\nu}) \]
\[ + \frac{1}{2} b_3 (x, Q^2) (s_{\mu\nu} - u_{\mu\nu}) + \frac{1}{2} b_4 (x, Q^2) (s_{\mu\nu} - t_{\mu\nu}) \]

\[ F_1, F_2 / g_1, g_2 \rightarrow \text{Unpolarized} / \text{Polarized} \text{ Structure Functions} \]

NO: relativistic effects, intrinsic \( k_T \), quark masses and correlations
Deuterium - Tensor Polarization

Tensor Polarization:

\[ T = 1 - 3N^0 \]

\[ = \frac{N^+ + N^- - 2N^0}{N^+ + N^- + N^0} \]

State | Injected | \( V \) | \( T \)
--- | --- | --- | ---
Vector + | \( |1\rangle + |6\rangle \) | \( N^+ \) | 1 | 1
Vector - | \( |3\rangle + |4\rangle \) | \( N^- \) | -1 | 1
Tensor | \( \pm \) | \( |3\rangle + |6\rangle \) | \( N^\pm \) | 0 | 1
Tensor | \( 0 \) | \( |2\rangle + |5\rangle \) | \( N^0 \) | 0 | -2

Only possible with a gas target
The Tensor Polarized Structure Function $b^d_1$

In the parton model $b^d_1$ measures the difference in the quark momentum distributions of helicity 1 and 0 targets.

Proton

$F_1(x) : \frac{1}{2} \sum_i e_i^2 (q_i^+(x) + q_i^-(x))$

$g_1(x) : \frac{1}{2} \sum_i e_i^2 (q_i^+(x) - q_i^-(x))$

$b_1(x) : \frac{1}{2} \sum_i e_i^2 (2q_i^0(x) - (q_i^+(x) + q_i^-(x)))$

Deuteron

$F_1(x) : \frac{1}{3} \sum_i e_i^2 (q_i^+(x) + q_i^-(x) + q_i^0(x))$

$g_1(x) : \frac{1}{2} \sum_i e_i^2 (q_i^+(x) - q_i^-(x))$

In the parton model $b^d_1$ measures the difference in the quark momentum distributions of helicity 1 and 0 targets.
Tensor Asymmetry

\[ A_T = \frac{(\sigma^+ + \sigma^-) - 2\sigma^0}{\sigma^+ + \sigma^- + \sigma^0} \]

\[ = \frac{1}{T} \cdot \frac{N^+}{N^+} \frac{N^-}{N^-} + \frac{2N^0}{L^0} \]

\( b_1^d \) enters in the symmetric part of \( W_{\mu\nu} \)

\[ \rightarrow \text{not sensitive to } P_B \]

\( T: \) target polarization \( < T > = 0.83 \pm 0.03 \)

\( L^+/-/0: \) dead-time corrected luminosities
Results on $b_d^1$

$$b_d = -\frac{3}{2} \cdot A_T \cdot F_d^1$$

$$b_1 = \frac{1+\gamma^2}{2 \cdot x (1+R)} \cdot b_2$$

with:

- $F_{d1} = \frac{1+\gamma^2}{2 \cdot x (1+R)} \cdot F_d^d$
- $F_{d2} = F_{P2} (1 + \frac{F_{n2}}{F_{P2}^2})$

- $\frac{F_{n2}}{F_{P2}^2}$: NMC, Nucl. Phys. B371 (1992) 3
- $F_{P2}^P$: ALLM97 (hep-ph 9712415)

no higher twist effects ($b_3, b_4 = 0$)

isolated BH-DVCS interference term:

- imaginary part \( \propto \) beam helicity asymmetry:
  \[
  d\sigma_{e^+} - d\sigma_{e^+} \propto \text{Im} \left( T_{BH} T_{DVCS} \right)
  \propto \sin \phi
  \]

- real part \( \propto \) beam charge asymmetry:
  \[
  d\sigma_{e^+} - d\sigma_{e^-} \propto \text{Re} \left( T_{BH} T_{DVCS} \right)
  \propto \cos \phi
  \]

\( \Rightarrow \) both asymmetries measured by HERMES

\[
d\sigma \propto |T_{BH}|^2 + |T_{DVCS}|^2 + (T_{BH}^* T_{DVCS} + T_{DVCS}^* T_{BH})
\]
Proportional to:

- Charge of the Nucleus
- Formfactor of the Nucleus
Predictions by A.V. Belitsky et al. (hep-ph/0112108):

Deuterium: \[ A_{LU} \sim -0.13 \cdot \sin(\Phi) \quad \text{at} \quad Q^2 = 4 GeV^2, x = 0.1, t = -0.3 GeV^2 \]

Hydrogen: \[ A_{LU} \sim -0.16 \cdot \sin(\Phi) \]

First Hint for coherent scattering on the nucleus.
The 3rd Twist-2 Structure function

Unpolarized quarks and nucleons
vector charge:
\[ < PS|\bar{\psi}\gamma^\mu\psi|PS> = \int_0^1 dx q(x) - \bar{q}(x) \]
q(x): spin averaged well known

Longitudinally polarized quarks and nucleons
axial charge:
\[ < PS|\bar{\psi}\gamma^\mu\gamma_5\psi|PS> = \int_0^1 dx \Delta q(x) + \Delta \bar{q}(x) \]
\[ \Delta q(x): \text{ helicity difference known} \]

Transversely polarized quarks and nucleons
tensor charge:
\[ < PS|\bar{\psi}\sigma^{\mu\nu}\gamma_5\psi|PS> = \int_0^1 dx \delta q(x) - \delta \bar{q}(x) \]
\[ \delta q(x): \text{ helicity flip unmeasured} \]
Characteristics of Transversity

- Non-relativistic quarks: \( \Delta q(x) = \delta q(x) \)
  \( \Rightarrow \delta q \) probes relativistic nature of quarks

- Angular momentum conservation
  \( \Rightarrow \) Transversity has no gluon component
  \( \Rightarrow \) different \( Q^2 \) evolution than \( \Delta q(x) \)

- \( q \) and \( \bar{q} \) contribute with opposite sign to \( \delta q(x) \)
  \( \Rightarrow \) predominantly sensitive to valence quark polarization

- Bounds:
  \( \Rightarrow |\delta q(x)| \leq q(x) \)
  \( \Rightarrow \text{Soffer bound: } |\delta q(x)| \leq \frac{1}{2}[q(x) + \Delta q(x)] \)

- Transversity distribution CHIRAL ODD
  \( \Rightarrow \) No Access In Inclusive DIS
How can one measure Transversity?

Need another chiral-odd object!

\( \delta q(x) \) accessible in semi-inclusive DIS

\[
\sigma^{ep\to ehX} = \sum_q f^H q \otimes \sigma^{eq\to eq} \otimes D^{q\to h} \]

\[
\downarrow \quad \text{chiral-odd} \quad \downarrow \quad \text{chiral-odd}
\]

\[
\text{DF} \quad \text{FF}
\]

Study SSA with a transversely polarized target at HERMES

1. \( ep^\uparrow \to e'\pi X \) \quad \Leftarrow \text{Favorite Process}
   Collins,93, Kotzinian,95, Mulders et al,96

2. \( ep^\uparrow \to e'\Lambda^\uparrow X \)
   Baldracchini,82, Jaffe,96

3. \( ep^\uparrow \to e'\pi\pi X \)
   Jaffe et al,97
First glimpse on Transversity ?!

Longitudinal polarized deuteron target

\[ A_{UL}(\phi) = \frac{1}{\langle P \rangle} \cdot \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)} \]

\( S_T \): transverse component of target spin w.r.t. virtual photon:

\[ S_T \propto \sin \Theta_\gamma \simeq \frac{2Mx}{Q} \sqrt{1 - y} \sim 0.15 \]

longitudinal polarized hydrogen target

\( \pi^0 \): hep-ex/0104005, \( \pi^\pm \): hep-ex/9910062
Original predictions by Collins:

- Proton Target
  Larger for $\pi^+$, $\pi^0$ than for $\pi^-$
  (u-quark dominance)

- Raise with $x_{bj}$
  (valence quark dominance)

- Grow with $p_{\perp}$, peak around 1 GeV
  ($\frac{H^+}{D^1} \propto \frac{M_c M_h}{M^2_c + p^2_{\perp}}$ with $M_c \simeq 1$ GeV)

- First SSA for Kaons
Attempt of Interpretation

- observe non-vanishing $\langle \sin \phi \rangle$-moments
- $\langle \sin 2\phi \rangle$-moment small (consistent with zero)

Attribute asymmetry to **Collins fragmentation** and **Transversity**:

$$A^\sin \phi_{UL} \sim S_L \langle \sin \phi \rangle_{UL} - S_T \langle \sin \phi \rangle_{UT}$$

*Longitudinally polarized in experiment (along beam direction)*

*$L/T$ polarized in theory (along $\gamma^*$ direction)*

$$\langle \sin \phi \rangle_{UL} \sim \frac{1}{Q} \sum_q e_q^2 (h_L^q(x) H_{1}^{\perp(1)},q(z) - \frac{1}{z} h_{1L}^{\perp(1)},q(x) \tilde{H}(z))$$

$$\langle \sin \phi \rangle_{UT} \sim \sum_q e_q^2 x h_L^{q}(x) H_{1}^{\perp(1)},q(z)$$

but $S_T \sim \frac{1}{Q}$ like twist-3

$$\langle \sin 2\phi \rangle_{UL} \sim \sum_q e_q^2 x h_{1L}^{\perp(1)},q(x) H_{1}^{\perp(1)},q(z)$$
Data - Theory

- Assume reduced twist-3 $\widetilde{h}_L = 0$
- $H_1^+$: Collins function parametrisation to fit HERMES proton data

"Optimistic" result from DELPHI $e^+e^- \rightarrow 2\text{jets}$:  
$$\left( \frac{H_1^{(1)}}{D_1} \right) = (12.5 \pm 1.4)\%$$
Attribute asymmetry to Sivers effect:
- Final state interactions (Brodsky et al.)
- Sivers function (Sivers, Mulders et al.)

\[ \langle \sin \phi \rangle_{UL} \sim f_{1T}^{(1)} D_1 \]

Longitudinally polarized target
- Sivers and Collins effect indistinguishable

Transversely polarized target
- \[ \langle \sin \phi \rangle_{UT} \] becomes dominant
- Sivers and Collins distinguishable

\[ \langle \sin(\phi_h - \phi_s) \rangle \] moment
\[ \langle \sin(\phi_h + \phi_s) \rangle \] moment
2002 Data Taking (I)

Background conditions as in 2000

Ready for production data taking

Radiation Doses relevant for the Si-Detector

- Lethal Dose HELIX: 2-5 kGy
- Lethal Dose SI: 20 kGy

No big damage
Need 1.4 Million DIS
Data rate:
70 DIS / mA h → 20 Ah

Both polarimeters worked stable and reliable
Single Spin Asymmetries in 2002

\[ e p^\uparrow \rightarrow e' \pi X \]

**HERMES** is ready to measure $\delta q(x)$

with its transversely polarized target:

\[
A_{UT} \sin(\phi_h + \phi_s) \propto \frac{\sum_q e_q^2 \delta q(x) H_{1,-}^q(z)}{\sum_q e_q^2 q(x) D_1^q(z)}
\]

$H_{1}^\perp(z)$ Collins fragmentation function
Summary

- **Inclusive**
  - first measurement of $b_1(x)$
- **DVCS**
  - First Hint for coherent scattering on the nucleus
- **Transversity**
  - first results with a transversely polarized target coming soon