Transverse Momentum Distributions: Recent News from HERMES

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Wigner Distributions

Transverse Momentum Dependent Distributions (TMDs)

W (x, k⊥, r⊥)

Generalized Parton Distributions (GPDs)

δ z⊥ ~ 1/Q

Parton Distribution Functions

Form Factors
Azimuthal moments in hadron production in SIDIS provide access to different structure functions and underlying transverse momentum dependent distribution and fragmentation functions.

\[ \nu = \frac{(qP)}{M} \]
\[ Q^2 = (k - k')^2 \]
\[ y = \frac{(qP)}{(kP)} \]
\[ x = \frac{Q^2}{2(qP)} \]
\[ z = \frac{(qP_h)}{(qP)} \]

Azimuthal moments in hadron production in SIDIS provide access to different structure functions and underlying transverse momentum dependent distribution and fragmentation functions.

\[ \sigma = F_{UU} + P_t F_{UL}^{\sin \phi} \sin 2\phi + P_b F_{LU}^{\sin \phi} \sin \phi \ldots \]

\[ F_{XY}^h (x, z, P_T, Q^2) \propto \sum H^q \times f^q (x, k_T, \ldots) \otimes D^{q \to h} (z, p_T, \ldots) + Y(Q^2, P_T) + \mathcal{O}(M/Q) \]

Slide from H. Avakian
Azimuthal Moments in SIDIS

Experiment for a given target polarization measures all moments simultaneously.

Higher Twist PDFs

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<thead>
<tr>
<th>N/q</th>
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The (long gone) Scene of Action

Beam Direction
Polarimeter
Transverse Polarimeter
Spin Rotator

Longitudinal
Recipe for a successful experiment: azimutal asymmetries in SIDIS

- Polarised electron beam
- Precise measurement of scattered electron $e^-$
- (transversely) polarised target
- Precise measurement produced hadron
- High virtuality $Q^2 = -q^2 > 1 \text{GeV}^2$
The HERMES Experiment

Ideal for SIDIS

Precise measurement of scattered $e^-$ (transversely)

Precise measurement produced hadron
Collins Effect

- Transverse polarization of quarks leads to large effects!
- Opposite in sign for charged pions
- Disfavoured Collins FF large and opposite in sign to favoured one
- Non-zero transversity
- Non-zero Collins function

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[Airapetian et al., PLB 693 (2010) 11]
Collins Effect - part II

- positive Collins SSA amplitude for positive kaons
- consistent with zero for negative kaons and (anti)protons

→ vanishing sea-quark transversity and baryon Collins effect?
Consistent with zero; but suppressed by two powers of $P_{h\perp}$ with respect to transversity and Collins
signs of Boer-Mulders modulations are not zero!

opposite sign for charged pions with larger magnitude for \( \pi^- \)

intriguing behavior for kaons available in multidimensional binning, e.g., before projecting: http://www-hermes.desy.de/cosnphi/

HERMES preliminary [Airapetian et al., PRD 87 (2013) 012010]
measured periodically by Møller polarimetry. Through nuclear magnetic resonance, which was calibrated regularly using electron paramagnetic resonance, each spin flip using nuclear magnetic resonance, which through adiabatic fast passage, was divided equally among two target spin orientations transverse to the beamline, parallel and perpendicular to the vector of the systematic uncertainty.

The left High Resolution Spectrometer (HRS) was inserted in the path of the laser at the source, providing polarized 5.9 GeV electron beam with an average current of 2.35 GeV with a momentum acceptance of 

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Sivers effect

\[ 2 \langle \sin(\phi - \phi_s) \rangle_{UT} \]

similar amplitudes for positive pions and protons

\( u \)-quark dominance (and not a FF effect)?
All things longitudinal - a new analysis of $A_{LL}$
All things longitudinal - a new analysis of $A_{LL}$

![Graphs and plots showing different asymmetry measurements](image)
amplitudes. In the most conservative approach adopted
A < the experimental SIDIS background in the region 2 GeV
gion,
where
ground asymmetry according to
factor
over the
longitudinal-to-transverse separated fit and the sum runs
the unseparated fit or 14 asymmetry amplitudes of the
and systematic uncertainties added in quadrature. The results receive an additional 8.2% scale uncertainty corresponding to
Fig. 5.
The five amplitudes describing the strength of the sine modulations of the cross section for hard exclusive
Lines are model predictions from S. Goloskov & P. Kroll Eur. Phys. J. A50 (2014) 146
Dashed lines without π-pole contribution
Solid and dash-dotted lines show positive and negative πω transition form factor
Summary

- HERMES conceived to solve the ‘spin puzzle’
- Semi Inclusive Deep Inelastic Scattering with hadron identification key to success
- Versatile experiment design opened avenue to access new physics:
  - Transversity and Transverse Momentum distributions
  - Evidence for Boer-Mulders, Collins, Sivers, Pretzelosity, Worm-Gears …
  - Hard exclusive reactions and Generalised Parton Distributions
- Be prepared to be surprised …
Thank you very much for your attention

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