Report from HERMES

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for the HERMES collaboration

68. DESY PRC Meeting, November 5, 2009
Study of spin structure of the nucleon at HERMES

- Longitudinal Spin/Momentum Structure, Hadronization
- Transverse Spin/Momentum Structure → Transversity, TMDs
- DVCS, Exclusive Meson Production → GPDs, “Nucleon Tomography”
- Strange-Baryon Production
Publications since the last PRC

Four papers published (accepted for publication)
- Spin density matrix elements in exclusive $\rho^0$ electroproduction on $^1$H and $^2$H targets at 27.6 GeV beam energy, *EPJC* 62 (2009) 659-694, arXiv:0901.0701 (hep-ex) and DESY-08-203
- Separation of contributions from deeply virtual Compton scattering and its interference with the Bethe-Heitler process in measurements on a hydrogen target, *JHEP* (in press), arXiv:0909.3587 (hep-ex) and DESY-09-143

Five papers submitted to journals
- Measurement of azimuthal asymmetries associated with deeply virtual Compton scattering on an unpolarized deuterium target, arXiv: 0911.0095 and DESY-09-189
- Nuclear-mass dependence of beam-helicity and beam-charge azimuthal asymmetries in DVCS, arXiv: 0911.0091 and DESY-09-190

Three papers near submission
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Results from transverse target running

Single Spin Asymmetries in Semi-Inclusive Deep Inelastic Scattering

\[ \Delta \sigma_{UT}(\phi, \phi_S) \approx 2\langle \sin(\phi - \phi_S) \rangle_{UT}^h \sin(\phi - \phi_S) + 2\langle \sin(\phi + \phi_S) \rangle_{UT}^h \sin(\phi + \phi_S) + \cdots \]

Sivers moment

\[ \propto f_{1T}^{\perp q}(x) D_1^q(z) \]

Collins moment

\[ \propto h_1(x) H_1^{\perp q}(z) \]

Sivers distribution function

- Chiral-even and naive T-odd transverse momentum dependent function
- Describes correlation between intrinsic quark p_T and transverse nucleon spin
- Non-zero Sivers DF requires non-vanishing orbital angular momentum
Sivers asymmetries for pions and kaons

Published: Phys. Rev. Lett. 103 (2009) 152002

- Significantly positive for $\pi^+$ and $K^+$
  - Implies non-zero orbital angular momentum of quarks
  - Suggests large and negative Sivers function for u-quarks

- Consistent with zero for $\pi^-$
  - Require cancellation effects, opposite sign for u- and d-quark Sivers functions
Pion-difference Sivers asymmetry and difference between $K^+$ and $\pi^+$ Sivers asymmetries

Pion-difference asymmetry

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

\[ 10^{-1} \quad 0.4 \quad 0.6 \quad 0.5 \quad 1 \]

\[ x \]

\[ P_{h\perp} [\text{GeV}] \]

- Contribution from $\rho^0$ mesons cancels
- Helps to isolate the valence-quark Sivers function
- Assumption of charge-conjugation and isospin symmetry among pion fragmentation

Difference between $K^+$ and $\pi^+$ asymmetries

$\pi^+ = |u\bar{d}\rangle$  $K^+ = |u\bar{s}\rangle$

- Possible significant role of sea quarks
- Higher-twist effects in kaon production might also contribute
Access to Generalized Parton Distributions (GPDs) via Deeply Virtual Compton Scattering (DVCS)

**DVCS and Bethe-Heitler**: the same initial and final state, Bethe-Heitler dominates at HERMES kinematics.

GPDs accessible through cross section differences and azimuthal asymmetries via interference term.

GPDs include knowledge about Parton Distribution Functions and Form Factors.

Four chiral-even GPDs for proton in leading order and leading twist for each quark flavor $H_q, \tilde{H}_q, E_q, \tilde{E}_q$.

GPDs can provide access to the quark total angular momentum via $J_i$ relation:

$$J_q = \lim_{t \to 0} \int_{-1}^{1} dx \left[ H_q(x, \xi, t) + E_q(x, \xi, t) \right]$$
Azimuthal asymmetries in DVCS

Cross section

\[ \sigma_{LU}(\phi; P_B, C_B) = \sigma_{UU}[1 + P_B A_{LU}^{DVCS} + C_B P_B A_{LU}^I + C_B A_C] \]

Beam-charge asymmetry

\[ A_C(\phi) = \frac{\left(\sigma^{→→} + \sigma^{←←}\right) - \left(\sigma^{←→} + \sigma^{→←}\right)}{\left(\sigma^{→→} + \sigma^{←←}\right) + \left(\sigma^{←→} + \sigma^{→←}\right)} = -\frac{1}{D(\phi)} \frac{x_B^2}{y} \sum_{n=0}^{3} c_n^l \cos(n\phi) \]

Charge-difference beam-helicity asymmetry

\[ A_{LU}^I(\phi) = \frac{\left(\sigma^{→→} + \sigma^{←←}\right) - \left(\sigma^{←→} + \sigma^{→←}\right)}{\left(\sigma^{→→} + \sigma^{←←}\right) + \left(\sigma^{←→} + \sigma^{→←}\right)} = -\frac{1}{D(\phi)} \frac{x_B^2}{Q^2} \sum_{n=1}^{2} s_n^l \sin(n\phi) \]

Charge-averaged beam-helicity asymmetry

\[ A_{LU}^{DVCS}(\phi) = \frac{\left(\sigma^{→→} - \sigma^{←←}\right) - \left(\sigma^{←→} - \sigma^{→←}\right)}{\left(\sigma^{→→} + \sigma^{←←}\right) + \left(\sigma^{←→} + \sigma^{→←}\right)} = \frac{1}{D(\phi)} \frac{x_B^2 t p_1(\phi) p_2(\phi)}{Q^2} s_{1}^{DVCS} \sin(\phi) \]

Measurements of these beam-helicity asymmetries allow to separate contributions from DVCS and interference term

This separation is impossible in measurements of single-charge beam-helicity asymmetry

\[ A_{LU}(\phi) = \frac{\sigma^{→} - \sigma^{←}}{\sigma^{→} + \sigma^{←}} \]
Central analysis topic since the last PRC
DVCS asymmetries and connections with GPDs

- Beam charge asymmetry
  \( GPD \ H \)

- Beam helicity asymmetry
  \( GPD \ H \)

- Transverse target spin asymmetry
  \( JHEP \ 06 \ (2008) \ 066, \ arXiv:0802.2499 \)
  \( GPD \ E \)

- Longitudinal target spin asymmetry
  \( GPD \ \tilde{H} \)

- Double spin asymmetry
  \( GPD \ \tilde{H} \)

\[ \begin{align*}
A_C^{\cos(0\phi)} & \propto \mathcal{R}(\mathcal{H}) \\
A_C^{\cos \phi} & \propto \mathcal{R}(\mathcal{H}) \\
A_C^{\cos(2\phi)} & \propto \mathcal{R}(\mathcal{H}) \\
A_C^{\cos(3\phi)} & \propto \mathcal{R}(\mathcal{H}) \\
A_{UL,I}^{\sin \phi} & \propto \mathcal{R}(\mathcal{H}) \\
A_{LU,DVCS}^{\sin(2\phi)} & \propto \mathcal{R}(\mathcal{H}) \\
A_{LU,I}^{\sin(\phi-\phi')} & \propto \mathcal{R}(\mathcal{H}) \\
A_{UT,I}^{\sin(\phi-\phi')} & \propto \mathcal{R}(\mathcal{H}) \\
A_{UT,DVCS}^{\sin(\phi-\phi') \cos \phi} & \propto \mathcal{R}(\mathcal{H}) \\
A_{UT,I}^{\sin(\phi-\phi') \sin \phi} & \propto \mathcal{R}(\mathcal{H}) \\
A_{UL}^{\sin \phi} & \propto \mathcal{R}(\mathcal{H}) \\
A_{UL}^{\sin(2\phi)} & \propto \mathcal{R}(\mathcal{H}) \\
A_{LL}^{\cos(0\phi)} & \propto \mathcal{R}(\mathcal{H}) \\
A_{LL}^{\cos \phi} & \propto \mathcal{R}(\mathcal{H}) \\
A_{LL}^{\cos(2\phi)} & \propto \mathcal{R}(\mathcal{H}) \\
\end{align*} \]
Results on beam-charge and beam-helicity asymmetry amplitudes in DVCS

Accepted for publication in JHEP, arXiv:0909.3587 (hep-ex)

Comparisons with GPD model, Vanderhaeghen, Guichon, Guidal

Resonance fraction from $ep \rightarrow e\Delta^+ \gamma$ is about 12%

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Recoil Detector analysis

Technical development
- Calibration SSD, SFT, PD - done
- Detector efficiency - done
- Particle Identification - done
- Tracking - done
- Refinements - possible after input from physics analysis

Analysis tools
- Kinematic fitting is developed and tested on DVCS Monte Carlo and data, will be applied with modifications for other exclusive processes

Physics analysis
- Members of the Recoil group moved to physics analysis of DVCS and exclusive meson production processes

Recoil Detector publication in preparation
Event selection, uncertainties and corrections before the Recoil Detector installation

- Scattered electron and photon are detected in the Forward Spectrometer
- Recoil proton is undetected
- Identification by missing mass technique \((ep \rightarrow e'\gamma X)\)
- Semi-inclusive corrected as dilutions for charge dependent asymmetries
- Associated Bethe-Heitler \(ep \rightarrow e'\Delta^+\gamma \sim 12\%\) stays part of the signal
DVCS event selection with the Recoil detector using kinematic fitting

- **Missing mass for Monte Carlo**
  - No requirement for Recoil
  - Positively charged Recoil track
  - Kinematic fit probability > 1%
  - Kinematic fit probability < 1%

- **Fit works well for Monte-Carlo**
  - After chi-square cut associated Bethe-Heitler and semi-inclusive background is suppressed to negligible level

- **Data**
  - Preliminary optimization done
  - Systematic studies are in progress
First signal of exclusive $\pi^0$ production at HERMES

- Exclusive $\pi^0$ process can provide access to chiral-even and chiral-odd GPDs
- Impossible without recoil proton detection
- After a cut on the difference between transverse momentum and $\phi$ angle of missing particle and measured Recoil proton is applied, clear signal is observed

Recoil proton required

Cuts on momentum and angle difference applied
Summary

Since the last PRC meeting
- Four papers published
- Five papers submitted
- Four physics results released and presented at conferences

Many results are expected to be finalized soon

Recoil Detector physics analysis underway
- Transition from technical development stage to physics analysis finished
- Publication about the detector in preparation
Backup slides
Sivers amplitudes for $\pi^+$ and $K^+$ for different ranges in $Q^2$

- Examine the influence of exclusive vector-meson decay and other possible $1/Q^2$ suppressed contributions
- No visible influence on the asymmetries
Sivers amplitudes for $\pi^+$ and $K^+$ for different ranges in $Q^2$

- No significant change of asymmetries for $Q^2$ ranges change by a factor of 1.7
- Fully consistent for two $Q^2$ regions for $\pi^+$
- Hint of systematically smaller $K^+$ asymmetries in the large $Q^2$ region
Beam charge asymmetry amplitudes in DVCS

\[ A_C \cos (\phi) \]

\[ A_C \cos (2\phi) \]

\[ A_C \cos (3\phi) \]

\[ 0.03 < x_b < 0.08 \]

\[ \langle Q^2 \rangle = 1.55 \text{ GeV}^2 \]

\[ 0.08 < x_b < 0.12 \]

\[ \langle Q^2 \rangle = 2.53 \text{ GeV}^2 \]

\[ 0.12 < x_b < 0.35 \]

\[ \langle Q^2 \rangle = 4.32 \text{ GeV}^2 \]
Beam helicity asymmetry amplitudes in DVCS

\[ A_{LU,I}^{\sin \phi} \]
\[ A_{LU,DVCS}^{\sin \phi} \]
\[ A_{LU,I}^{\sin (2\phi)} \]

\[ 0.03 < x_B < 0.08 \quad \langle Q^2 \rangle = 1.55 \text{ GeV}^2 \]
\[ 0.08 < x_B < 0.12 \quad \langle Q^2 \rangle = 2.53 \text{ GeV}^2 \]
\[ 0.12 < x_B < 0.35 \quad \langle Q^2 \rangle = 4.32 \text{ GeV}^2 \]
Kinematic fitting for DVCS

Monte-Carlo

Data

Monte-Carlo

Data

Probability

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

0 10 20 30 40 50 60 70 80 90 100

0 10 20 30 40 50 60 70 80 90 100

0 100 200 300 400 500 600

0 10 20 30 40 50 60 70 80 90 100

0 100 200 300 400 500 600

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Report from HERMES
Released results since the last PRC meeting

- Direct extraction of helicity amplitude ratios in exclusive $\rho^0$ electroproduction
- Study of $A_T$, $A_2$ and $g_2$
- The other (than Sivers and Collins) amplitudes in the Fourier decomposition of the transverse single-spin asymmetry on transversely polarized protons
- Exclusive leptoproduction of real photons on a longitudinally-polarised hydrogen target