HERMES Results From a Combined Beam Charge and Spin Analysis of DVCS on Unpolarized Hydrogen and Deuterium Targets

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- Structure of the Nucleon, GPDs and DVCS process
- DVCS Measurement at HERMES
- HERMES Combined BCA & BSA Analysis
- HERMES Combined BCA & BSA Results from unpolarized H and D
- Summary and Outlook
Structure of the Nucleon, GPDs and DVCS Process

**GPDs** contain a detailed information on the **structure of nucleon**:

**DVCS**: one of the cleanest hard exclusive process to access GPDs, hard photoproduction of a real photon ($\gamma^* N \rightarrow N' \gamma$),

virtual photon generated by lepton scattering $\Rightarrow e N \rightarrow e' N' \gamma$

**FactORIZATION THEOREM**:

$x \pm \xi$: parton longitudinal momentum fractions,

$\xi$: fraction of the momentum transfer, $\xi \simeq \frac{x B}{2 - x B}$,

t: invariant momentum transfer, $t \equiv (p - p')^2$

**Nucleon structure**:

$GPDs : \ H_q, \bar{H}_q, E_q, \bar{E}_q$

$GPDs \rightarrow PDFs$

$H_q(x, 0, 0) = q(x)$

$\bar{H}_q(x, 0, 0) = \Delta q(x)$

$GPDs \rightarrow FFs$

$\int_{-1}^{1} dx \ H_q(x, \xi, t) = F_1^q(t)$,

$\int_{-1}^{1} dx \ E_q(x, \xi, t) = F_2^q(t)$

$H_q, \bar{H}_q$ — conserve nucleon helicity

$E_q, \bar{E}_q$ — flip nucleon helicity,

not accessible in DIS

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DVCS (a) and Bethe-Heitler (BH) (b) processes experimentally indistinguishable

\[
\frac{d\sigma}{d\Omega} \propto |T_{\text{DVCS}}|^2 + |T_{\text{BH}}|^2 + \left( T_{\text{DVCS}}^{*} T_{\text{BH}} + T_{\text{BH}}^{*} T_{\text{DVCS}} \right)
\]

\( T_{\text{BH}} \): Calculable in QED \( \Rightarrow \) Pauli & Dirac Form factors \( F_1, F_2 \)

\( T_{\text{DVCS}} \): Compton Form Factors \( \mathcal{H}, \tilde{\mathcal{H}}, \mathcal{E}, \tilde{\mathcal{E}} \) \( \Rightarrow \) convolutions of GPDs

GPDs indirectly accessible through azimuthal asymmetries via I

**Beam–Spin Asymmetry (BSA):**

\[
d\sigma(\overrightarrow{e}, \phi) - d\sigma(\overleftarrow{e}, \phi) \propto \text{Im} [F_1 \mathcal{H}] \times \sin(\phi)
\]

**Beam–Charge Asymmetry (BCA):**

\[
d\sigma(e^+, \phi) - d\sigma(e^-, \phi) \propto \text{Re} [F_1 \mathcal{H}] \times \cos(\phi)
\]
**The HERMES Experiment**

**Gas Target:**
- Long. polarized \( H_2 \)
- Unpolarized \( H_2, D_2 \)
- Transversely polarized \( H_2 \)

**Beam:**
- Long. polarized \( e^+ \) and \( e^- \)
- Energy 27.6 GeV
- Both helicities

**Collected statistics 1996-2005:**
\[ H_2 \approx 17 \text{M DIS}, \text{ unpolarized } D_2 \approx 10 \text{M DIS} \]

**PID:** \( \epsilon_e > 99\%, \delta P/P < 2\%, \delta \theta < 1\text{mrad}, \delta E_\gamma/E_\gamma \approx 5\% \).
DVCS Event Selection

- Events with exactly one DIS - lepton and exactly one trackless cluster in the calorimeter.
- No recoil detection \( \Rightarrow \) Exclusivity via missing mass: \( M_X^2 = (q + P - q')^2 \)

\[
5 < \theta_{\gamma^*\gamma} < 45 \text{ mrad} \\
-t < 0.7 \text{ GeV} \\
0.03 < x_B < 0.35, \quad 1 < Q^2 < 10 \text{ GeV}^2 \\
W > 3 \text{ GeV}, \quad \nu > 22 \text{ GeV}
\]

MC for background and cuts, systematic uncertainty

- \( e p \rightarrow e' \gamma X \)
- \( e p \rightarrow e' p \gamma \); Elastic BH
- \( e p \rightarrow e' \Delta^+ \gamma \); Associated BH
- \( e p \rightarrow e' \pi^0 X \); Semi-inclusive

Correction; \( \pi^0 \) Background (\( \approx 3\% \))
Associated (\( \approx 12\% \)); part of signal

- \( e d \rightarrow e' \gamma X \)
- \( e d \rightarrow e' d \gamma \); Elastic(Coherent)
- \( e d \rightarrow e' pn \gamma \); Quasielastic
- \( e N \rightarrow e' N^* \gamma \); Resonant states

\( \Rightarrow \) Exclusive bin \( -(1.5)^2 < M_X^2 < (1.7)^2 \text{ GeV}^2 \)
\[
\sigma_{LU}(\phi; P_l, e_l) = \sigma_{UU}(\phi)[1 + e_l A_C(\phi) + e_l P_l A_{LU}^I(\phi) + P_l A_{LU}^{DVCS}(\phi)]
\]

**Beam Spin Asymmetries:**

\[
A_{LU}^I(\phi) = -\frac{1}{\mathcal{D}(\phi)} \cdot \frac{x_B}{Q^2} \sum_{n=1}^{3} s_n^I \sin(n\phi)
\]

\[
A_{LU}^{DVCS}(\phi) = \frac{1}{\mathcal{D}(\phi)} \cdot \frac{x_B^2 t \mathcal{P}_1(\phi) \mathcal{P}_2(\phi)}{Q^2} \sum_{n=1}^{2} s_n^{DVCS} \sin(n\phi)
\]

**Beam Charge Asymmetry:**

\[
A_C(\phi) = -\frac{1}{\mathcal{D}(\phi)} \cdot \frac{x_B}{y} \sum_{n=0}^{3} c_n^I \cos(n\phi)
\]

\[
\mathcal{D}(\phi) = \frac{1}{(1 + \varepsilon^2)^2} \sum_{n=0}^{2} c_n^{BH} \cos(n\phi) + \frac{x_B^2 t \mathcal{P}_1(\phi) \mathcal{P}_2(\phi)}{Q^2} \sum_{n=0}^{2} c_n^{DVCS} \cos(n\phi)
\]

\[
\sigma_{UU} = \frac{1}{32(2\pi)^2 Q^2 x_B t} \frac{1}{\mathcal{D}(\phi)}
\]

**Fit to data:**

\[
A_C(\phi) = \sum_{n=0}^{3} A_n^{\cos n\phi} \cos(n\phi); A_{LU}^I(\phi) = \sum_{m=1}^{2} A_{LU,I}^{\sin m\phi} \sin(m\phi);
\]

\[
A_{LU}^{DVCS}(\phi) = A_{LU,DVCS}^{\sin \phi} \sin(\phi).
\]
“VGG” model: (Vanderhaeghen, Guichon, Guidal 1999):

- Based on double distributions.
- Includes a D-term to restore full polynomiality.
- Includes a Regge inspired and a factorized $t$-ansatz.
- Skewness depends on free parameter $b_{val}$ & $b_{sea}$.
- Includes twist-3 contributions.

“Dual” model: (Guzey, Teckentrup 2006)

- GPDs based on an infinite sum of $t$-channel resonances.
- Includes a Regge inspired and a factorized $t$-ansatz.
- Does not include twist-3.

MC simulations based on these GPD models are used:

- For data-theory comparison;
- To estimate the uncertainties from the effect of the acceptance, bin-width, smearing and misalignments.
Beam–Charge Asymmetry on Hydrogen

\[ A_C \propto -A_C^{\cos \phi} \]

\[ \propto \Re [F_1 H] \]

\[ \Leftarrow \text{HIGHER TWIST} \]

\[ \Leftarrow \text{GLUON LEADING TWIST} \]

\[ \Leftarrow \text{RESONANCE FRACTION} \]

- \( \cos \phi \) AMPLITUDE OF THE BCA \( \Rightarrow \) DISFAVOURS: FACTORIZED ANSATZ IN DUAL MODEL; VGG PREDICTION WITH THE D-TERM.
Beam–Spin Asymmetry on Hydrogen

\[ \propto [\mathcal{H}H^* + \tilde{\mathcal{H}}\tilde{H}^*] \]

\[ \Leftarrow \text{HIGHER TWIST} \]

\[ \Leftarrow \text{RESONANCE FRACTION} \]

- Asymmetry amplitudes for pure DVCS squared term \( \Rightarrow \) Compatible with zero in agreement with model predictions.

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Beam–Spin Asymmetry on Hydrogen

- **BSA amplitudes** ⇒ **Agreement with Dual model predictions**;
- **Results**: not corrected for fractions of associated BH process.
- **VGG model clearly undershoots BSA results.**
BCA AMPLITUDES ⇒ AGREE WITH PREDICTIONS BASED ON DUAL MODEL (qelas SCATTERING ON PROTON AND NEUTRON) PLUS coherent SCATTERING ON DEUTERON (A. Kirchner and D. Müller hep − ph/0202279).
Beam–Spin Asymmetry on Deuterium

- The $\sin\phi$ amplitude of BSA $\Rightarrow$ significantly negative;
- Results $\Rightarrow$ agree with Dual model predictions over the whole kinematic range.

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Beam–Charge Asymmetry: Hydrogen vs. Deuterium

HERMES PRELIMINARY

Accep & smear → sys error

\[ \vec{e}^\pm d \rightarrow e^\pm \gamma X \]
\[ \vec{e}^\pm p \rightarrow e^\pm \gamma X \]

<table>
<thead>
<tr>
<th>( A_C \cos(0\phi) )</th>
<th>( A_C \cos(2\phi) )</th>
<th>( A_C \cos(3\phi) )</th>
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\(-t (GeV^2)\) \( x_B \) \( Q^2 (GeV^2) \)

\( \cos(0\phi) \) \( \cos(2\phi) \) \( \cos(3\phi) \)

- \( t \) regions; 40% coherent

\( \vec{e}^\pm d \rightarrow e^\pm \gamma X \)

\( \vec{e}^\pm p \rightarrow e^\pm \gamma X \)

• **Proton and Deuteron results ⇒ compatible in low \((-t < 0.06 GeV^2; 40% coherent)\) and “intermediate” \(-t\) regions;

• **Difference in last bin ⇒ neutron, resonances?**
Beam–Spin Asymmetry: Hydrogen vs. Deuterium

- **BSA** \( \sin\phi \) AMPLITUDE OF THE \(|DVCS|^2\) term FOR THE PROTON AND DEUTERON ⇒ COMPATIBLE WITH ZERO.

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Beam–Spin Asymmetry: Hydrogen vs. Deuterium

- $H_2$ and $D_2$ data are compatible for almost all amplitudes;
- BSA $\sin\phi$ amplitude from the interference term $\Rightarrow$ significantly negative for both targets.
Summary and Outlook

- **Azimuthal Asymmetries** ⇒ **DVCS-Amplitudes** ⇒ **GPDs**

- The azimuthal asymmetries are measured at HERMES with respect to beam spin (BSA) and charge (BCA) in combined analysis on proton and deuteron targets.

- The statistical precision allows for strong constraints on GPD models.

- The extracted BCA amplitudes on both proton and deuteron targets clearly disfavour all model predictions with factorized $t$-ansatz and VGG model with inclusion of the $D$-term.

- The results on different targets agree very well for all leading twist amplitudes. The associated production needs to be accounted for in BSA for both targets.

- High-statistic data collected in 2006/2007 with the Recoil detector at HERMES ⇒ associated process with the unknown asymmetry can be separated from the signal.
Backup slides!

Backup slides!
The difference between "model-generated" and in the HERMES acceptance reconstructed MC amplitudes is taken as systematic uncertainty.
Changes in the new analysis

- 2.5 times higher statistics than in the previous publications.
- 6 bins in all kinematics.
- The systematic errors include new model-dependent studies.

Results: ⇒ agree with former publications.