LATEST NEWS ON DVCS FROM HERMES

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EIC Meeting at BNL
August 25, 2009
Latest News on DVCS from HERMES

Appetizer: HERA and HERMES

Motivation: Generalized Parton Distributions, orbital angular momentum and 3-dimensional nucleon structure

Measurements of azimuthal asymmetries in DVCS
  - Beam helicity and charge asymmetries on hydrogen and nuclear targets
  - Transverse target spin asymmetry on hydrogen

A Recoil Detector for HERMES
* Polarized electron/positron beam of 27.6 GeV and 40mA
* Beam polarization 30...65%, 2 beam helicities
* Proton beam of 920 GeV / 90 mA
HERA @ DESY in Hamburg, Germany

- Polarized electron/positron beam of 27.6 GeV and 40mA
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HERMES: HERa MEasurement of Spin

Diagram showing the layout of HERMES components, including DRIFT CHAMBERS, TARGET CELL, STEEL PLATE, CALORIMETER, LUMINOSITY MONITOR, and various other detectors and elements.
HERMES: HERa MEasurement of Spin

e^{±} 27.6 GeV

TARGET CELL
STEEL PLATE

DRIFT CHAMBERS
FIELD CLAMPS

DVC

MC 1-3
PROP. CHAMBERS

FC 1/2

TRIGGER HODOSCOPE H1

PRESHOWER (H2)

LUMINOSITY

MONITOR

CALORIMETER

MAGNET

RICH

BC 1/2

BC 3/4

TRD
HERMES: HERa MEasurement of Spin

$e^\pm$ 27.6 GeV

H, H, D
HERMES: HERa MEasurement of Spin

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\[ e^\pm \]

H, H, D

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He, N, Ne, Kr, Xe
HERMES: HERa MEasurement of Spin

e±

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Tracking
momentum resolution:
≤ 2%
age angular resolution:
0.3...0.6 mrad

H, H, D

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**Tracking**
- momentum resolution: ≤ 2%
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**Particle IDentification**
- electron ID: 98-99%
- hadron contamination <1%
- RICH: 2...15 GeV

```
H, H, D
H, D
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```

e± 27.6 GeV
e^± 27.6 GeV

**HERMES: HERa MEasurement of Spin**

- **Target Cell**
- **Steel Plate**
- **Recoil Detector**
- **DRIFT CHAMBERS**
- **PROP. CHAMBERS**
- **DVC**
- **MC 1-3**
- **FIELD CLAMPS**
- **TRIGGER HODOSCOPE H1**
- **PRESHOWER (H2)**
- **CALORIMETER**
- **MAGNET**
- **BUC 1/2**
- **BUC 3/4**
- **TRD**
- **RICH**
- **MONITOR**
- **LUMINOSITY**

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**Recoil Detector**
- H, H, D
- He, N, Ne, Kr, Xe
Deep Inelastic Scattering in ep collisions

Inclusive kinematics

**Virtual photon virtuality:**
\[ Q^2 \equiv -q^2 := (k - k')^2 \]
\[ \approx 4EE' \sin^2(\theta/2) \]

**Bjørken scaling variable:**
\[ x_B := \frac{Q^2}{2Pq} \frac{\text{lab}}{2M(E - E')} \]

**Invariant mass squared of X:**
\[ W^2 := (P + q)^2 \]
\[ \approx M^2 + 2M(E - E') - Q^2 \]
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\[ \sigma_{DIS} \sim \sum_X \left( \frac{d^2\sigma}{dE'd\Omega} \right)_{\gamma^*} = \frac{\alpha^2}{2MQ^4} \frac{E'}{E} L_{\mu\nu} W_{\mu\nu} \]
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**Semi-inclusive kinematics**
involve kinematics of produced hadrons

**Exclusive kinematics**
complete spectrum of X known
The Composition of the Nucleon's Spin

\[ \frac{1}{2} \hbar = J_{\text{quarks}} + J_{\text{gluons}} \]
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\[ \frac{1}{2} \Delta \Sigma + L_q \]
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Spin of quarks: \( \Delta \Sigma \approx \frac{1}{3} \) from DIS and SIDIS

Hermes Phys. Rev. D75 (2007) 012007: \( \Delta \Sigma = 0.330 \pm 0.011 \text{(theo)} \pm 0.025 \text{(exp)} \pm 0.028 \text{(evol)} \)
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Orbital angular momentum of quarks: \( L_q \)?

\[ J_q = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} dx \ x \ [H^q(x, \xi, t) + E^q(x, \xi, t)] \]

Ji relation

Ji, PRL 78 (1997) 610
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Generalized Parton Distributions (GPDs)
**Generalized Parton Distributions**

- **Access through hard exclusive reactions**
  - $t$: squared momentum transfer to target
  - $x$: average longitudinal momentum fraction of quark before/after
  - $\xi$: $1/2$ difference

- **GPDs $F^q(x,\xi,t)$** parameterize the non-perturbative nucleon structure
  - ➤ contain info on parton-parton correlations

- **4 GPDs that conserve quark chirality** (Spin-1/2 target, leading-twist)

<table>
<thead>
<tr>
<th>nucleon helicity ↓</th>
<th>quark helicity independent</th>
<th>quark helicity dependent</th>
</tr>
</thead>
<tbody>
<tr>
<td>conserved</td>
<td>$H$</td>
<td>$\bar{H}$</td>
</tr>
<tr>
<td>flipped</td>
<td>$E$</td>
<td>$\bar{E}$</td>
</tr>
</tbody>
</table>

- Photon: $J^P=1^-$ (DVCS)

- $J^P=1^-$ mesons
- $J^P=0^-$ mesons
GPDs: A unifying picture of nucleon structure

Parton Distribution Functions: longitudinal momentum

GPDs $F^q(x, \xi, t)$

Form Factors: transverse position

$$H^q(x, 0, 0) = q(x)$$
forward limit $\xi=0$, $t=0$

$$\int_{-1}^{1} dx H^q(x, \xi, t) = F_1^q(t)$$
moments of GPDs
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GPDs
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moments of GPDs

\[ H(1, -0.3, -0.2, -0.1, 0, 0.1, 0.2, 0.3) \]
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“Nucleon Tomography”

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moments of GPDs
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moments of GPDs

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GPDs: A unifying picture of nucleon structure

Parton Distribution Functions:
- longitudinal momentum
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  \[ F^q(x, \xi, t) \]

Form Factors:
- transverse position

\[ H^q(x, 0, 0) = q(x) \]  
forward limit \( \xi = 0, t = 0 \)

Global fit to \( H(x, \xi=x, t) \) from DVCS data

Small-x behavior extracted from collider data

\[ \int_{-1}^{1} dx H^q(x, \xi, t) = F_1^q(t) \]  
moments of GPDs

“Nucleon Tomography”

[arXiv:0904.0458 [hep-ph]]
Deeply Virtual Compton Scattering (DVCS)
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Reminder: inclusive DIS

\[ \sigma_{\text{DIS}} \sim \sum X \left| \begin{array}{c} \text{forward Compton scattering amplitude} \\ \text{optical theorem} \end{array} \right|^2 \]
Reminder: inclusive DIS

\[ \sigma_{\text{DIS}} \sim \sum_x \left| \langle x | \begin{array}{c} \text{Compton scattering amplitude} \\ \text{optical theorem} \end{array} \rangle \right|^2 \]

\[ \Im \left( \langle q | \begin{array}{c} \text{Compton scattering amplitude} \\ q \end{array} \rangle \right) \]

DVCS = hard electroproduction of a real photon

Skewing due to mass difference of photons

the 2 partons have different longitudinal momenta!

Skewness \( \xi \neq 0 \)

Leading order: \( \xi \approx x_B/(2-x_B) \)

DVCS: \( q \neq q' \)
Deeply Virtual Compton Scattering (DVCS)

Reminder: inclusive DIS

$$\sigma_{\text{DIS}} \sim \sum_X \left| \frac{\langle q^2 \rangle}{x} \right|^2$$

$$\sim \text{Im} \left( \frac{\langle q^2 \rangle}{x} \right)$$

optical theorem

forward Compton scattering amplitude

DVCS = hard electroproduction of a real photon

Skewing due to mass difference of photons

the 2 partons have different longitudinal momenta!
Skewness $\xi \neq 0$
Leading order: $\xi \approx x_B/(2-x_B)$

Forward limit: $\xi=0$, $t=0$

DVCS: $q \neq q'$
The $\gamma^*N \rightarrow \gamma N$ Cross Section

$$\sigma_{\gamma^*N} = |\tau_{DVCS}|^2 + |\tau_{BH}|^2 + |\tau_{DVCS}\tau_{BH}^* + \tau_{DVCS}^*\tau_{BH}|^2$$

Contribution at colliders.

Fixed target:

$$|\tau_{DVCS}|^2 \ll |\tau_{BH}|^2$$

DVCS-BH interference term

Bjørken limit:
large $Q^2$ (small distances)
large energy of $\gamma^*$ (small times)
small $t$, fixed $x_B$

exactly calculable in QED
given the nucleon elastic form factors $F_1$ and $F_2$
Azimuthal Dependences in $\gamma^* N \rightarrow \gamma N$

- Unpolarized target
- Lepton beam with charge $C_B$
  and polarization $P_B$

Fourier expansion in azimuthal angle $\phi$

\[
|T_{BH}|^2 = \frac{K_{BH}}{P_1(\phi)P_2(\phi)} \sum_{n=0}^{2} c_n^{BH} \cos(n\phi)
\]

\[
|T_{DVCS}|^2 = K_{DVCS} \left[ \sum_{n=0}^{2} c_n^{DVCS} \cos(n\phi) + P_B \sum_{n=1}^{1} s_n^{DVCS} \sin(n\phi) \right]
\]

\[
I = \frac{C_B K_I}{P_1(\phi)P_2(\phi)} \left[ \sum_{n=0}^{3} c_n^I \cos(n\phi) + P_B \sum_{n=1}^{2} s_n^I \sin(n\phi) \right]
\]
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Bethe-Heitler propagators $P(\phi)$
Azimuthal Dependences in $\gamma^*N \rightarrow \gamma N$

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\[ T = \frac{C_B K_I}{P_1(\phi)P_2(\phi)} \left[ \sum_{n=0}^{3} c_n^{I} \cos(n\phi) + P_B \sum_{n=1}^{2} s_n^{I} \sin(n\phi) \right] \]

Wanted: Fourier coefficients $s_n$ and $c_n$ of BH, DVCS, and $I$ terms
Measured Azimuthal Asymmetries in DVCS

**Born cross-section:**
\[
\sigma(\phi; P_B, C_B) = \sigma^{}_{\text{UU}}(\phi) \cdot [1 + P_B A^{}_{LU}^{}(\phi) + C_B P_B A^T_{LU}(\phi) + C_B A_C(\phi)]
\]

Beam helicity asymmetries

**BSA:**
projects out imaginary part of \( \tau^{}_{\text{DVCS}} \)

no separate access to \( s_1^q \) and \( s_1^{\text{DVCS}} \)

Beam charge asymmetry

**BCA:**
projects out real part of \( \tau^{}_{\text{DVCS}} \)

Old approach at HERMES and CLAS: single charge BSA
Measured Azimuthal Asymmetries in DVCS

**Born cross-section:**

\[
\sigma(\phi; P_B, C_B) = \sigma_{UU}(\phi) \cdot [1 + P_B A_{LU}^{DVCS}(\phi) + C_B P_B A_{LU}^I(\phi) + C_B A_C(\phi)]
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- **Beam helicity asymmetries**
- **Beam charge asymmetry**
  - **BCA:** projects out real part of \( \tau_{DVCS} \)
  - **BSA:** projects out imaginary part of \( \tau_{DVCS} \)

**Old approach at HERMES and CLAS:** single charge BSA

**New approach at HERMES:**

- \( s_{1Q} \) and \( s_{1DVCS} \) can be disentangled

**Charge average BSA:**

\[
A_{C}(\phi) \equiv \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-}
\]

**Charge difference BSA:**

\[
A_{LU}^I(\phi) \equiv \frac{(d\sigma^{++} - d\sigma^{+-}) - (d\sigma^{-+} - d\sigma^{--})}{(d\sigma^{++} + d\sigma^{+-}) + (d\sigma^{-+} + d\sigma^{--})}
\]

**Beam charge asymmetry:**

\[
A_{LU}^{DVCS}(\phi) \equiv \frac{(d\sigma^{++} - d\sigma^{+-}) + (d\sigma^{-+} - d\sigma^{--})}{(d\sigma^{++} + d\sigma^{+-}) + (d\sigma^{-+} + d\sigma^{--})}
\]
Relation: asymmetries ↔ Fourier coefficients

Beam helicity asymmetries:

\[ \mathcal{A}_{LU}^{\uparrow}(\phi) = \frac{1}{D(\phi)} \cdot \frac{x_B}{Q^2} \left[ s_{1}^{\uparrow} \sin(\phi) + s_{2}^{\uparrow} \sin(2\phi) \right] \]

\[ \mathcal{A}_{LU}^{DVCS}(\phi) = \frac{1}{D(\phi)} \cdot \frac{x_B^2 t P_1(\phi) P_2(\phi)}{Q^2} s_{1}^{DVCS} \sin(\phi) \]

Beam charge asymmetry:

\[ \mathcal{A}_C(\phi) = -\frac{1}{D(\phi)} \cdot \frac{x_B}{y} \left[ c_0^{\uparrow} + c_1^{\uparrow} \cos(\phi) + c_2^{\uparrow} \cos(2\phi) + c_3^{\uparrow} \cos(3\phi) \right] \]
Relation: asymmetries ↔ Fourier coefficients

Beam helicity asymmetries:

\[
\mathcal{A}_{LU}^{I}(\phi) = \frac{1}{D(\phi)} \cdot \frac{x_B}{Q^2} \left[ s_1^I \sin(\phi) + s_2^I \sin(2\phi) \right]
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\]

\[
D(\phi) = \sum_{n=0}^{2} \frac{c_n^{BH} \cos(n\phi)}{(1 + \epsilon^2)^2} + \frac{x_B^2 t P_1(\phi) P_2(\phi)}{Q^2} \sum_{n=0}^{2} c_n^{DVCS} \cos(n\phi)
\]

Additional \( \phi \) dependence in denominator through BH propagators
From Azimuthal Asymmetries to GPDs

To obtain Fourier coefficients = asymmetry amplitudes:

➤ Combine data with different beam charges and helicities and 
fit all amplitudes simultaneously

Compton Form Factors (CFFs)

\[ F(\xi, t) = \sum_{q} \int_{-1}^{1} dx \, C_{q}^{\mp}(\xi, x) F_{q}(x, \xi, t) \]

* Define linear combination of CFFs:

\[ C_{unp}^{I} = F_{1}^{H} + \xi (F_{1} + F_{2}) \tilde{H} - \frac{t}{4M^{2}} F_{2} \mathcal{E} \]

* \( F_{1}(t), F_{2}(t) \): Dirac, Pauli nucleonic form factors

Leading twist level (twist-2):

\[ c_{I}^{1} \propto \frac{\sqrt{-t}}{Q} \Re \left[ C_{unp}^{I} \right] \propto -\frac{Q}{\sqrt{-t}} c_{0}^{I} \]

\[ s_{I}^{1} \propto \frac{\sqrt{-t}}{Q} \Im \left[ C_{unp}^{I} \right] \]

constant term

BCA

BSA
Holographic Principle / Femtophotography

➤ Wanted: 3-dim spatial picture

➢ (FT)$^{-1}$ of diffraction pattern, given amplitude $\tau = Ae^{i\varphi}$
➢ Need both magnitude $A$ & phase $\varphi$
➢ Usually $|\tau|^2$ is measured, phase is lost (e.g. PDFs)

➤ Holography technique:

➢ Known BH process as reference amplitude that magnifies DVCS effect
➢ Measure phase of DVCS through its interference with BH

Belitsky, Müller, hep-ph/0206306
Detected particles: electron and photon

Missing mass technique for \( ep \rightarrow e X \gamma \)

\[ M_X^2 = (p + q - p_\gamma)^2 \]

- \( e^+ \) data
- \( e^- \) data
- MC sum
- elastic BH
- associated BH
- semi-inclusive

- hydrogen target: 25k events (400 pb\(^{-1}\))
- unpolarized deuterium: 15k events (300 pb\(^{-1}\))

\( X = p \)

Resonant excitation: \( X = \Delta^+ \)

\( X = \pi^0 + \ldots \)

\( p \pi^0 \)

\( n \pi^+ \)
DVCS at HERMES 1996-2005 (w/o Recoil)

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$p\pi^0$

$n\pi^+$
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\[ M_X^2 = (p+q-p_γ)^2 \]

\[ X=p \]
\[ X=π^0+... \]
\[ X=Δ^+ \]

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HERMES: BSA from $I$ on hydrogen

GPD model: Vanderhaeghen, Guichon, Guidal “VGG” (*)

Based on Radyushkin’s double distribution ansatz:
“$DF(x, \xi) \otimes \text{profile}(t)$”. Twist-3 included

$\propto \Im [F_1 \mathcal{H}]$

$\leftarrow$ Higher twist (twist-3)

$\leftarrow$ Fraction of resonant excitation

**HERMES: BSA from $I$ on hydrogen**

GPD model: Vanderhaeghen, Guichon, Guidal “VGG” (*)

Based on Radyushkin’s double distribution ansatz:

“$DF(x, \xi) \otimes \text{profile}(t)$”. Twist-3 included

$\propto \mathcal{S}[F_1 \mathcal{H}]$

$\leftarrow$ Higher twist (twist-3)

$\leftarrow$ Fraction of resonant excitation

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\[ A_{LU,1}^\sin\phi \]
\[ A_{LU,1}^\sin2\phi \]

\[ \propto \mathcal{S} [F_1 \mathcal{H}] \]

D-term to restore polynomiality

Bands by variation of skewness parameters

← Higher twist (twist-3)

← Fraction of resonant excitation

HERMES: BSA from $|T_{DVCS}|^2$ on hydrogen

\[ \propto \left[ H^* H^* + \tilde{H} \tilde{H}^* \right] \]

bilinear combination of CFFs

"Higher twist (twist-3)"

GPD model: Vanderhaeghen, Guichon, Guidal ("VGG")


Based on double distribution ansatz: "DF(x, ξ) \otimes profile(t)".

Twist-3 included
HERMES: BCA on hydrogen

constant term:
\[ \propto -A_C^{\cos \phi} \]

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

← Higher twist (twist-3)

← Gluon leading twist
HERMES: BCA on hydrogen

\[ \cos \alpha \]

\[ \cos 2\alpha \]

\[ \cos 3\alpha \]

constant term:
\[ \propto -A_C \cos \phi \]
\[ \propto \Re [F_1 \mathcal{H}] \]

← Higher twist (twist-3)

← Gluon leading twist

VGG with D-term disfavored
DVCS on Nuclear Targets

- How does the nuclear environment modify parton-parton correlations?
- How do nucleon properties change in the nuclear medium?

(Bethe-Heitler)
**DVCS on Nuclear Targets**

- How does the nuclear environment modify parton-parton correlations?
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**DVCS in coherent region:**
new insights into ‘generalized EMC effect’?

- Nuclear GPDs ≠ GPDs of free nucleon
- Enhancement of effect when leaving forward limit?
  - caused by transverse motion of partons in nuclei?
  - important role of mesonic degrees of freedom?
  - manifest in strong increase of real part of \( \tau_{DVCS} \) with atomic mass number \( A \)?
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</tr>
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DVCS on Nuclear Targets

- How does the nuclear environment modify parton-parton correlations?
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**HERMES measurements on nuclear targets**

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+ deuterium, spin-1, 300 pb\(^{-1}\)

**DVCS in coherent region:**

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HERMES: BCAs on hydrogen and deuterium
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HERMES PRELIMINARY
Accep & smear \(\rightarrow\) sys error

- e^+ d \(\rightarrow\) e^+ \(\gamma\) X
- e^\pm p \(\rightarrow\) e^\pm \(\gamma\) X

overall
-t (GeV^2)
xB
Q^2 (GeV^2)

low t: coherent
high t: incoherent

Proton
elastic
inelastic

Nucleus
coherent
quasi-elastic
inelastic
DVCS at HERMES: Nuclear mass dependence

Select for each target two samples (t-cutoffs):

- coherent enriched
  \( \approx 65\% \) coherent fraction

- incoherent enriched
  \( \approx 60\% \) incoherent fraction
DVCS at HERMES: Nuclear mass dependence

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DVCS at HERMES: Nuclear mass dependence

Select for each target two samples (t-cutoffs):
- coherent enriched
  ($\approx 65\%$ coherent fraction)
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  ($\approx 60\%$ incoherent fraction)

No nuclear mass dependence of BCA and BSA observed within uncertainties

$\Rightarrow$ no enhancement of $\tau_{DVCS}$
Exclusivity at HERMES in a Nutshell

GPD access at HERMES:

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$J_q = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} dx \ x \ [H^q(x, \xi, t) + E^q(x, \xi, t)]$
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vector mesons $\rho^0$, $\omega$, $\phi$
pseudoscalar mesons $\pi^+$, $\eta$
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- Vector mesons: \( \rho^0, \omega, \phi \)
- Pseudoscalar mesons: \( \pi^+, \eta \)

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$J^P=1^-$ mesons
- vector mesons $\rho^0, \omega, \phi$
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$$J_q = \frac{1}{2} \lim_{t \rightarrow 0} \int_{-1}^{1} dx \ x \ [H^q(x, \xi, t) + E^q(x, \xi, t)]$$
DVCS Transverse Target Spin Asymmetry $A_{UT}(\phi, \phi_s)$

- $A_{UT}$: the only DVCS asymmetry on the proton for which **GPD E is not suppressed**
  (Hall-A: BSA on neutron)

- **HERMES**: transversely polarized hydrogen, 170 pb$^{-1}$, 2 beam charges
  ➢ Separation of DVCS and interference terms possible

$$A_{UT}^T(\phi, \phi_s) \propto \left[ d\sigma^+(\phi, \phi_s) - d\sigma^-(\phi, \phi_s) \right] - \left[ d\sigma^+(\phi, \phi_s + \pi) - d\sigma^-(\phi, \phi_s + \pi) \right]$$

$$A_{UT}^T(\phi, \phi_s) \propto \text{Im} \left( F_2 \mathcal{H} - F_1 \mathcal{E} \right) \sin(\phi - \phi_s) \cos\phi$$

$$+ \text{Im} \left( F_2 \mathcal{\tilde{H}} - (F_1 + \xi F_2) \mathcal{\tilde{E}} \right) \cos(\phi - \phi_s) \sin\phi$$
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- **HERMES:** transversely polarized hydrogen, 170 pb\(^{-1}\), 2 beam charges

  - Separation of DVCS and interference terms possible

  Also sensitive to GPD E (bilinear combination)

\[
A_{UT}^T(\phi, \phi_s) \propto \left[ d\sigma^+(\phi, \phi_s) - d\sigma^-(\phi, \phi_s) \right] + \left[ d\sigma^+(\phi, \phi_s + \pi) - d\sigma^-(\phi, \phi_s + \pi) \right]
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\[
+ \text{Im} \left( F_2 \tilde{\mathcal{H}} - (F_1 + \xi F_2) \tilde{\mathcal{E}} \right) \cos(\phi - \phi_s) \sin \phi
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HERMES DVCS $A_{UT}$ Amplitudes

Model: VGG with variation of $J_u$, while $J_d=0$
HERMES DVCS $A_{UT}$ Amplitudes

Model: VGG with variation of $J_u$, while $J_d=0$

With a GPD model describing the data, one could in principle extract a constraint on $J_u + k \cdot J_d$

$$\text{Im}(F_2 \mathcal{H} - F_1 \mathcal{E}) \cdot \sin(\phi - \phi_s) \cos(n\phi)$$

$$\text{Im} \left( F_2 \tilde{\mathcal{H}} - (F_1 + \xi F_2) \tilde{\mathcal{E}} \right) \cdot \cos(\phi - \phi_s) \sin \phi$$

sensitive to $J_u$:

NOT sensitive to $J_u$:
HERMES 2006-2007: Recoil Detector

Purpose:
★ To tag exclusive events
➢ Identify recoiling target proton
➢ Identify particles from background processes

$^1$H ($^2$H): factor of 1.6 (0.5) more than 1996-2005
The Silicon Strip Detector (SSD)

- **Purpose:**
  - Track reconstruction
  - Momenta: $> 125$ MeV/c
  - PID for low and medium momenta

- **2 layers of 16 double-sided sensors**
  - $(10 \text{ cm } \times 10 \text{ cm})$ active area
  - $300 \mu\text{m}$ thickness

- **Inside accelerator vacuum,**
  5 cm close to electron beam

- $E_{\text{kin}} \approx 8$ MeV for protons
The Scintillating Fiber Tracker (SFT)

- **Purpose:**
  - Track reconstruction
  - Momenta: 250-1400 MeV/c (protons)
  - PID for medium and high momenta

- **2 Barrels with each 4 layers of scintillating fibers**

- **Per Barrel:**
  - 2 parallel layers
  - 2 stereo-layers
  - Stereo angle: 10°
The Photon Detector (PD)

- **Purpose:**
  - Detection of photons from resonance decay $\Delta^+ \rightarrow p\pi^0$
  - PID for $p > 600$ MeV/c
- 3 layers of tungsten/scintillator sandwich
  - 1 layer parallel to beam axis
  - 2 layers under $+45^\circ/-45^\circ$ angles

![Image of the Photon Detector](image_url)
Tracking with the Recoil Detector

- **Low-energy protons**: momentum $\propto (\sum_i \Delta E_i)^{-1}$
- **Medium-energy protons**: momentum $\propto \left(\frac{dE}{dx}\right)^{-1}$ (Bethe-Bloch)
- **Higher-energy particles (protons/pions)**: momentum $\propto eB\rho$
Tracking with the Recoil Detector

**Energy Deposit in the SSD**

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Reconstructed Momenta and Angles

- Recoiling target protons
  - Large $\theta$-angles $\lesssim 90^\circ$
  - Small momenta $< 1$ GeV/c

- Azimuthal $\phi$ coverage: 76%

\[ \Delta E \text{ accounted for in track fitting} \]
\[ \Rightarrow \Delta p/p \text{ improvement} \]
Proton / Pion Separation with the Recoil

- $p < 600$ MeV/c: SSD + SFT (6 layers)
- $p > 600$ MeV/c: include PD
- Log-likelihood formalism:

$$\text{PID} \equiv \log \frac{\mathcal{P}(\Delta E | \text{proton, } p)}{\mathcal{P}(\Delta E | \text{pion, } p)}$$

$p < 450$ MeV/c, PIDcut=0: pion contamination $\approx 0.1\%$
proton efficiency $> 99\%$
**DVCS and the Recoil**

- **Missing $\phi$:** $\Delta \phi = \phi_{\text{meas}} - \phi_{\text{calc}}$
- **Missing $p$:** $\Delta p = p_{\text{meas}} - p_{\text{calc}}$

**Missing Mass ($M_P^2$):**

$$M_X^2 = (p + p_{\gamma^*} - p_{\gamma})^2$$

---

**Hermes 2007 data**

- **$\Delta \phi$ [rad]**
- **$\Delta p$ [GeV/c]**

**Counts**

- $|\Delta p| < 1 \text{ GeV/c}$
- $|\Delta p| > 1 \text{ GeV/c}$
- $M_X^2 [(\text{GeV/c})^2]$
Separation of Resonant States in DVCS

**DVCS / Bethe Heitler**

- **Elastic:**
  - $ep \rightarrow ep\gamma$

- **Resonant (’associated’):**
  - $ep \rightarrow e\Delta^+\gamma$
    - $\Delta^+ \rightarrow \{ n\pi^+, 1/3
    - $p\pi^0, 2/3$
  - 12% of signal

- **Presence of $\pi^0$ ⇒ proton fails coplanarity cut**
  - Select elastic:
    - $|\Delta\phi| < 0.1$ rad
    - $|p_T^{\text{calc}}|/|p_T^{\text{meas}}| = 0.5:1.5$
  - Select resonant:
    - $|\Delta\phi| > 0.35$ rad
Separation of Resonant States in DVCS

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Preliminarily tuned on MC
Exclusive Mesons and the Recoil
DVCS Beam Helicity Asymmetry with Recoil

Pre-preliminary, private analysis
DVCS Beam Helicity Asymmetry with Recoil

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DVCS Beam Helicity Asymmetry with Recoil

HERMES 2007 hydrogen
- Recoil: elastic selected
- Classical analysis

Pre-preliminary, private analysis
DVCS Beam Helicity Asymmetry with Recoil

Pre-preliminary, private analysis

Elastic fraction: >95%
Summary

Generalized Parton Distributions
- Give glimpse of three-dimensional structure of nucleons
- Allow to access total angular momentum carried by quarks

Deeply Virtual Compton Scattering:
  - the golden channel to study GPDs
  - Measurements of cross sections and asymmetries as input to GPD constraints and fits
  - Measurement of various azimuthal asymmetries at HERMES and other fixed target experiments

HERMES high lumi run 2006/2007 with Recoil detector
- Exclusive event tagging
- First time: separation of elastic and resonant BSA in DVCS