HERMES Recoil Detector

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On behalf the HERMES Collaboration

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Lecture Week on Hadron Physics
Motivation

The Hermes Recoil Detector

Performance

Outlook
**The Spin Structure of the Nucleon**

Nucleon Spin:

\[
\frac{1}{2} = \frac{1}{2} \left( \Delta \sum \right) + L_q + \Delta G + L_g
\]

- **\( \Delta \sum \)** Spin of quarks
  \( \Delta \sum \approx 20 - 35\% \) measured in DIS
  HERMES: \( \Delta \sum \approx 0.3 \)

- **\( \Delta G \)** Spin of gluons, first Measurements
  - expected to be small

- **\( L_q \)** Orbital angular momentum of quarks

- **\( L_g \)** Orbital angular momentum of gluons
  - \( L_q, L_g \) unknown

Access to \( J_q \) via Deeply Virtual Compton Scattering (DVCS)
Generalized Parton Distributions (GPDs)

Ji Sum Rule – Ji, PRL 78(1997)610

\[ J_{q,g} = \lim_{t \to 0} \int_{-1}^{1} dx \, x \left\{ H_{q,g}(x, \xi, t) + E_{q,g}(x, \xi, t) \right\} \]

(total angular momentum)

\((x \pm \xi)\) parton longitudinal momentum fractions

\(\xi\) fraction of the momentum transfer

\(t\) invariant momentum transfer to the nucleon
GPDs and the DVCS process

**DVCS** final state $e + p \rightarrow e' + p' + \gamma$ is indistinguishable from the Bethe-Heitler Process (BH) $\rightarrow$ Amplitudes add Coherently

Photon-Production cross section:

$$d\sigma \propto \left| \tau_{\text{DVCS}} + \tau_{\text{BH}} \right|^2 = \left| \tau_{\text{DVCS}} \right|^2 + \left| \tau_{\text{BH}} \right|^2 + \left( \tau_{\text{DVCS}}^* \tau_{\text{BH}} + \tau_{\text{BH}}^* \tau_{\text{DVCS}} \right)$$

*Interference Term*
DVCS Measurements

\[ d\sigma \propto \left| \tau_{BH} \right|^2 + \left( \tau^*_{DVCS} \tau_{BH} + \tau^*_{BH} \tau_{DVCS} \right) + \left| \tau_{DVCS} \right|^2 \]

- \( \left| \tau_{BH} \right|^2 \) is calculable in QED with the knowledge of the Form Factors
- \( \left| \tau_{DVCS} \right|^2 \) is parameterized in terms of Compton Form Factors \( \mathcal{H}_q, \widetilde{\mathcal{H}}_q, \mathcal{E}_q, \widetilde{\mathcal{E}}_q \) (convolutions of GPDs \( H_q, \widetilde{H}_q, E_q, \widetilde{E}_q \))
- At HERMES kinematics:
  \[ \left| \mathcal{I}_{DVCS} \right|^2 \ll \left| \mathcal{I}_{BH} \right|^2 \]

GPDs accessible through *cross-section differences* and *azimuthal asymmetries* via interference term \( \mathcal{I} \to \text{Magnitude} + \text{Phase} \) (GPDs enter in linear combinations)
The HERMES Spectrometer (before 2006)

- Polarize gas targets: H, D, He
- Unpolarize gas targets: H, D, N, He, Ne, Xe, Kr

- Fixed target experiment (uses 27.6 GeV/c HERA lepton Beam)
  - Recoiling proton undetected: large background contamination (15%)
Exclusivity for DVCS via Missing Mass

- Exactly one DIS lepton and one photon detected in the Calorimeter.
- Recoiling proton undetected.

\[ t = (p - p')^2 = -Q^2 - 2E_\gamma (\nu - \sqrt{\nu^2 + Q^2 \cdot \cos \theta_{\gamma, \gamma^*}}) \]

- Exclusivity via Missing Mass

\[ M_x^2 = (q + p + q')^2 \]

\[-(1.5)^2 < M_x^2 < (1.7)^2 \text{ GeV}^2\]

Overall background contribution \( \approx 15\% \) in exclusive region
Recoil detector installed for the last two years of data taking

Recoiling proton detected  background contamination <1%
Recoil Detector

- 1 Tesla Superconducting Solenoid
- Photon Detector
  - 3 layers of Tungsten/Scintillator
- Scintillating Fiber Detector
  - 2 Barrels
  - 2 Parallel & 2 Stereo-Layers in each barrel
- Silicon Detector
  - 2 Layer of 16 double-sides sensors
  - 97×97 mm$^2$ active area each
  - Inside HERA vacuum

Silicon & Fiber Tracker:
- $p_p \in [135, 1200]$ MeV/c
- $p/\pi$ PID for $p < 650$ MeV/c
- Photon Detector:
  - $p/\pi$ PID for $p > 600$ MeV/c
  - $\pi^0$ background suppression
Alignment of the SFT

ZEUS beam telescope DESY22 test beam
Results of Alignment of SFT

- Measurements of dedicated SFT run were used and tested on cosmic data collected with Recoil detector.
- Residuals (280 µm) are in good agreement with expectations from ideally aligned Monte-Carlo (220 µm).

Si and PD alignment respect SFT.
Ep Elastic Scattering

- Detect scattered electron in the Forward spectrometer and protons in the Recoil

- Correlation of angles reconstructed in the Forward spectrometer and the Recoil Detector can be used for the relative alignment of these detector systems
Momentum Reconstruction

Low momentum protons (stopped in outer Silicon)

→ Sum of energy deposits
**Momentum Reconstruction**

![Diagram of silicon detector with energy deposits](image)

- **Low momentum protons** (stopped in outer Silicon)
  - Sum of energy deposits
- **Higher momentum protons**
  - \( dE/dx \)
Momentum Reconstruction

Low momentum protons (stopped in outer Silicon)
  → Sum of energy deposits
Higher momentum protons
  → $dE/dx$
High momentum particles
  → Bending in magnetic field
Energy Deposits of MIP’s

- Energy loss of single fiber from pions
- Leading fibers from tracks were selected
- MIP’s position are stable from different time periods

<table>
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<tr>
<th>MIP</th>
<th>Entries</th>
<th>Mean</th>
<th>RMS</th>
<th>$\chi^2$/ndf</th>
<th>Width</th>
<th>MP</th>
<th>Area</th>
<th>GSigma</th>
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<td>1867</td>
<td>5.908</td>
<td>3.836</td>
<td>3.142/28</td>
<td>0.3621±0.0622</td>
<td>3.518±0.157</td>
<td>1425±44.7</td>
<td>3.158±0.208</td>
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</tbody>
</table>

Landau convoluted with Gauss
Recoil Particle Identification

![Graph showing energy deposition for pions and protons.]

- Pions
  - $p_{\text{min}} = 350$ MeV/c
  - $p_{\text{max}} = 400$ MeV/c

- Protons
  - all SFT layers + other SSD layer
  - say "proton"
Data tacking and Performance

- Collected statistic (preliminary) with recoil detector
  - Electron beam 2006 (only SFT operational):
    - $H_2$: 5k DVCS (3Mio. DIS),
    - $D_2$: 1k DVCS (0.8Mio. DIS)
  - Positron beam 2006/07 (all subdetectors fully operational)
    - $H_2$: 41k DVCS (38Mio. DIS),
    - $D_2$: 7.5k DVCS (10Mio. DIS)
Outlook

- Analysis of data with Recoil Detector
  - $A_{LU}(\phi)$ for exclusive photons and mesons
  - Exclusive meson cross-sections
  - Exclusive meson cross-section ratios (e.g. $\frac{\omega}{\phi}, \frac{\pi}{K}$)
  - Spin Density Matrix Elements
  - Exclusive $\pi^-$ and $\pi^0$ impossible without Recoil Detector!