Status of Commissioning and Analysis with the HERMES Recoil Detector

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1 Motivation: Exclusive Processes and Generalized Parton Distributions

2 The HERMES Recoil Detector

3 Tracking and PID

4 Hard Exclusive Photon- and Meson-Production and the Recoil

5 Summary and Outlook
The Composition of the Nucleon’s Spin

\[ \frac{1}{2} = J_{\text{quarks}} + J_{\text{gluons}} = \frac{1}{2} \Delta \Sigma + L_q \]

- **Spin of quarks**: \( \Delta \Sigma \approx 1/3 \) from DIS and SIDIS
  - **HERMES**: Phys. Rev. D75 (2007) 012007
  - \( \Delta \Sigma = 0.330 \pm 0.011 \) (theo) \( \pm 0.025 \) (exp) \( \pm 0.028 \) (evol)

- **Orbital angular momentum of quarks**: \( L_q \)
  - Ji relation Ji, PRL 78 (1997) 610:

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

- Generalized Parton Distributions (GPDs)
GPDs: a Unifying Picture of Nucleon Structure

Accessible through hard exclusive reactions:

<table>
<thead>
<tr>
<th>Unpolarized</th>
<th>Polarized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon: $J^P = 1^-$ (DVCS)</td>
<td></td>
</tr>
<tr>
<td>$H$</td>
<td>$\tilde{H}$</td>
</tr>
<tr>
<td>$E$</td>
<td>$\tilde{E}$</td>
</tr>
<tr>
<td>$J^P = 1^-$ mesons</td>
<td>$J^P = 0^-$ mesons</td>
</tr>
</tbody>
</table>

- PDFs: $H^q(x, 0, 0) = q(x)$, $\tilde{H}^q(x, 0, 0) = \Delta q(x)$ forward limit
- Form Factors: $\int dx [\text{GPD}] = f(t)$, independent of $\xi$

$\Rightarrow$ GPDs: simultaneous description of transverse position (FF) and longitudinal momentum distribution (PDF): “Nucleon Tomography”

- Longitudinally polarized $e^+$ or $e^-$ beam with energy of 27.6 GeV
- Unpolarized gas targets ($H_2$, $D_2$)
- Example: Deeply Virtual Compton Scattering $ep \rightarrow ep\gamma$
**The HERMES Recoil Detector**

- **SC Solenoid** (1 Tesla)

- **Photon Detector**

- **Scintillating Fiber Tracker**

- **Silicon Strip Detector**

**Purpose:**

- To tag exclusive events
  - Identify recoiling target proton
  - Identify particles from background processes

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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 cm × 10 cm) active area
  - 300 µm thickness

- Inside accelerator vacuum, 5 cm close to electron beam
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 (PD) with layers of tungsten and scintillator](image-url)
Recoil Tracking

Energy Deposit in the SSD

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

Transverse View of Detector
Reconstructed Momenta and Angles

Hermes 2007 data

- Recoiling target protons
  - Large $\theta$-angles $\lesssim 90^\circ$
  - Small momenta $< 1$ GeV/c
- Azimuthal $\phi$ coverage: 76%

$\Delta E$ accounted for in track fitting
$\Rightarrow \Delta p/p$ improvement

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Proton / Pion Separation

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

$$\text{PID} \equiv \log \frac{\mathcal{P}(\Delta E|\text{proton}, p)}{\mathcal{P}(\Delta E|\text{pion}, p)}$$
**DVCS and the Recoil Detector**

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

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

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

**Hermes 2007 data**

**Traditional DVCS analysis**

$(E_\gamma > 5 \text{ GeV})$

- $|\Delta p| < 1 \text{ GeV/c}$
- $|\Delta p| > 1 \text{ GeV/c}$

**Counts**

- $M_X^2 [\text{(GeV/c)}^2]$
Separation of Resonant States in DVCS (first look)

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 \( \pi^0 \Rightarrow \) proton fails coplanarity cut
  - Select elastic:
    - \(|\Delta\phi| < 0.1 \text{ rad}\)
    - \(|p_T^{\text{calc}}/|p_T^{\text{meas}}| = 0.5 \div 1.5\)
  - Select resonant:
    - \(|\Delta\phi| > 0.35 \text{ rad}\)

Hermes 2007 data

Traditional DVCS analysis \((E_\gamma > 5 \text{ GeV})\)

Recoil proton in acceptance with Coplanarity cut turned around

\(M_x^2 \text{ [ (GeV/c)^2 ]}\)
Exclusive Mesons and the Recoil Detector

HERMES 2007 data

|Δp| < 0.8GeV/c

Rho candidates

p_{meas}^{(Recoil)} - p_{calc}^{(miss)} [GeV/c]

HERMES Data 2007

Traditional ρ analysis

Recoil momentum cut

N

ΔE [GeV]

HERMES Data 2007

Recoil momentum cut

Traditional ω analysis

Δp > 1

ΔE [GeV]

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Summary and Outlook: HERMES Recoil Detector

- Commissioning of Recoil detector in final stage
  - Calibrations and tracking suitable for first physics analyses
  - Mapping of detector efficiencies and acceptance
  - PID: determination of efficiencies, contamination and fluxes

- Tuning of event reconstruction
  - Simultaneous consideration of all track parameters (kinematic fitting)
  - Background contributions can be directly measured

- Exclusive photons and mesons
  - Beam helicity asymmetries
  - DVCS: separation of elastic and resonant states
  - Refined analysis of exclusive pre-Recoil detector data

- Spectator protons from deuterium target
  - Tagged Structure Functions