First Results from the HERMES Recoil Detector

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DPG Spring Meeting
Darmstadt, March 10, 2008
Outline

Physics Motivation
- Spin Structure of the Nucleon and GPD
- DVCS and Exclusive Reactions at HERMES
- HERMES at DESY
- DVCS at HERMES without and with the Recoil Detector

HERMES Recoil Detector
- Silicon Strip Detector
- Scintillating Fiber Tracker
- Photon Detector

First Results of Detector Performance

Summary and Outlook
Spin Structure of the Nucleon

Nucleon spin:

\[ \frac{1}{2} = \Delta \Sigma + L_q + J_g \]

- Quark spin: \( \Delta \Sigma \) measured \( \sim 1/3 \) (HERMES, ...)
  

- Quark orbital momentum: \( L_q \) unknown

- Gluon total angular momentum: \( J_g \) unknown

Ji’s relation - PRL 78 (1997) 610

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

Generalized parton distributions: access the orbital angular momentum of quarks in nucleon

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HERMES Recoil Detector
Generalized Parton Distributions

GPDs: incorporate regular parton distributions and form factors into a framework for phenomenological description of the nucleon.
Generalized Parton Distributions

- **GPDs → PDF**
  \[ H_q(x, 0, 0) = q(x) \]
  \[ \tilde{H}_q(x, 0, 0) = \Delta q(x) \]

- **GPD → FF**
  \[ \int_{-1}^{1} dx H_q(x, \xi, t) = F_1^q(t) \]
  \[ \int_{-1}^{1} dx E_q(x, \xi, t) = F_2^q(t) \]
  \( H_q, \tilde{H}_q \) conserve nucleon helicity
  \( E_q, \tilde{E}_q \) flip nucleon helicity

- **Parton Longitudinal Momentum Fractions**
  - \( x \pm \xi \)
  - \( \xi \) fraction of the momentum transfer
  - \( t \) invariant momentum transfer to the nucleon

\( (x+\xi) \) \( (x-\xi) \)
Access to GPD via Deeply Virtual Compton Scattering (DVCS)

Cleanest way to access GPDs: DVCS

\[ d\sigma(eN \rightarrow eN\gamma) \propto \left| I_{BH} \right|^2 + \left| I_{DVCS} \right|^2 + I_{BH}^* I_{DVCS}^* + I_{BH} I_{DVCS}^* \]

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
Asymmetries Measurable at HERMES

- Beam-Spin Asymmetry (BSA)
  \[ A_{LU} = \frac{d\sigma(e^-, \phi) - d\sigma(e^+, \phi)}{d\sigma(e^-, \phi) + d\sigma(e^+, \phi)} \propto \Im m(\mathcal{H}) \sin(\phi) \]

- Beam-Charge Asymmetry (BCA)
  \[ A_C = \frac{d\sigma(e^+, \phi) - d\sigma(e^-, \phi)}{d\sigma(e^+, \phi) + d\sigma(e^-, \phi)} \propto \Re e(\mathcal{H}) \cos(\phi) \]

- Longitudinal Target Spin Asymmetry (LTSA)
  \[ A_{UL} = \frac{d\sigma(p^-, \phi) - d\sigma(p^+, \phi)}{d\sigma(p^-, \phi) + d\sigma(p^+, \phi)} \propto \Im m(\tilde{\mathcal{H}}) \sin(\phi) \]

- Transverse Target Spin Asymmetry (TTSA)
  \[ A_{UT} = \frac{d\sigma(p^\uparrow, \phi) - d\sigma(p^\downarrow, \phi)}{d\sigma(p^\uparrow, \phi) + d\sigma(p^\downarrow, \phi)} \propto f(\mathcal{H}, \mathcal{E}, \tilde{\mathcal{H}}, \tilde{\mathcal{E}}, \phi, \phi_S) \]

Talk: Dietmar Zeiler HK 16.3, 11.03 9.:15
HERA at DESY

Longitudinally polarized electron (positron) beams
P=27.57 GeV/c
DVCS Measurements at HERMES

Before Recoil
- Reconstruct DVCS by measuring scattered electron and real photon
- Missing-mass method
- Background from
  - associated Bethe-Heitler \((ep \rightarrow e'\Delta^+\gamma) \sim 11\%
  - semi-inclusive \((ep \rightarrow e'\pi^0X) \sim 5\%

With Recoil
- Improve exclusivity by measuring recoil protons, pions and photons
- Suppress background to the level below 1%
- Improve t-resolution
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HERMES with Recoil
Recoil Detector

1 Tesla Superconducting Solenoid

Photon Detector (PD)
- detect gammas
- p/π PID for momentum > 650 MeV/c

Scintillating Fiber Tracker (SFT)
- Momentum reconstruction by bending in magnetic field

Silicon Strip Detector (SSD)
- Momentum reconstruction by energy deposit for low-momentum protons and deuterons

Unpolarized Target Cell
Silicon Strip Detector

- 2 layers of double-sided silicon strip sensors located in beam vacuum
- Strips: pitch=758 \( \mu \text{m} \), 300\( \mu \text{m} \) thick
- Readout by HELIX 3.0 chips: high and low gain to increase dynamic range

Talk: Andreas Mussgiller HK 25.6, 11.03 12:30
Silicon Strip Detector

- 2 layers of double-sided silicon strip sensors located in beam vacuum
- Strips: pitch=758 μm, 300μm thick
- Readout by HELIX 3.0 chips: high and low gain to increase dynamic range

Data

Energy Deposit Outer Silicon [keV] vs. Energy Deposit Inner Silicon [keV]

ADC High vs. ADC Low S1I1 N Side

Talk: Andreas Mussgiller HK 25.6, 11.03 12:30
Scintillating Fiber Tracker

- 2 cylinders:
  - 2 parallel layers
  - 2 10 degree stereo layers
- KURARAY fibers: 1mm diameter
- Read out by multi-anode PMTs
- GASSIPLEX chips
- $p_p$: 250-1200 MeV/c from bending in magnetic field

Talk: Tibor Keri HK 11.5, 10.03 17:45
Sandwich of 3 layers of tungsten-scintillator:
- A-layer parallel to the beam axis
- B/C: under +45/-45 degree angle

- Strips: 2x1x28 cm³
- Read out by multi-anode PMTs
- Detect γ from π⁰ decay
- Reconstruct π⁰ if 2 γ's detected
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Momentum Reconstruction with Recoil
Momentum Reconstruction with Recoil
Momentum Reconstruction with Recoil

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HERMES Recoil Detector
Accuracy of Momentum Reconstruction

![Graph showing the accuracy of momentum reconstruction for protons and pions using SSD and SFT.](image)

S. Yaschenko
HERMES Recoil Detector
Alignment of the SFT

ZEUS beam telescope
DESY22 test beam

Resolution 20 μm

Dz[cm] Resolution[μm]

29.2 78 SF1
36.5 88 SF2
58.3 118 SF3
65.7 130 SF4
Measurements of Positions of SFT fibers
Results of Alignment of SFT

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

SSD and PD aligned relative to the SFT.
Silicon Strip Detector Alignment

\[ \chi^2 / \text{ndf} = 122.7 / 73 \]
- Constant \(687 \pm 10.0\)
- Mean \(-0.009329 \pm 0.003012\)
- Sigma \(0.26 \pm 0.00\)

\[ \chi^2 / \text{ndf} = 325.2 / 90 \]
- Constant \(428.4 \pm 6.5\)
- Mean \(-0.01262 \pm 0.00321\)
- Sigma \(0.276 \pm 0.003\)

Residuals [strip]

Z coordinate [cm]
Beam Position Determination with Recoil

- Beam position from Recoil tracking and beam position monitors (BPM)
- Recoil beam finding for absolute normalization of beam position and alignment relative to the HERMES Forward spectrometer
Ep Elastic Scattering

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

- First observation of ep-elastic at HERMES by detecting protons in the Photon Detector

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

- Particle identification possible in all 3 subdetectors of the Recoil

- Proton-pion separation in momentum range below 700 MeV/c possible with the SSD and SFT

- Photon detector can be used for proton-pion separation at energies above 650 MeV/c
Data Taking in 2006 and 2007

The recoil detector took data until the HERA shutdown - June, 2007

Statistics collected with the recoil detector:
- Electron beam 2006 (only SFT)
  - H2: 5K DVCS (3 Mil. DIS)
  - D2: 1K DVCS (0.8 Mil. DIS)
- Positron beam 2006/07 (all subdetectors)
  - H2: 42K DVCS (28 Mil. DIS)
  - D2: 10K DVCS (7 Mil. DIS)
Summary and Outlook

Recoil detector was installed at HERMES in winter 2005-2006 and was in operation until the end of HERA running in June 2007.

Experimental data on DVCS and other exclusive processes were collected with HERA electron and positron beams.

Physics analysis with Recoil will be possible after detector calibration is finished, tracking and PID are optimized.

Results of pre-Recoil DVCS analysis can be reevaluated after analysis of new data collected with the Recoil.