The HERMES Recoil Detector

R. Kaiser
University of Glasgow

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- HERMES and the Spin of the Nucleon
- Generalised Parton Distributions
- Recoil Detector Design and Performance
- Projected Physics Results
The Spin of the Nucleon

\[ S_z = \frac{1}{2} = J_q + J_g = \frac{1}{2} \Delta \Sigma + \Delta G + L_q + L_g \]
The Spin Puzzle

Gluon polarisation is positive (HERMES)
- COMPASS
- RHIC

$\Delta \Sigma = \Sigma \Delta q$
- 0.2...0.3

EMC (1988)
- SMC
- HERMES
- SLAC

Transversity

Gluon orbital angular momentum inaccessible

Quark orbital angular momentum accessible through GPDs

$G$

$q$

$\delta q$

$L_g$

$L_q$
The HERMES Experiment

- $E_b = 27.6$ GeV
- $I_b = 10-30$ mA
- $P_b \sim 50\%$

- Target density $10^{13} - 10^{15}/\text{cm}^2$
- $p$, $d$, He, N, Ne, Kr, Xe targets
- Polarised $e^\pm$ beams
- Sokolov-Ternov effect
Generalised Parton Distributions

- link form factors and parton distribution functions
- provide access to transverse localisation of quarks and to their orbital angular momentum
Generalised Parton Distributions

- Parton distribution functions
  \[ q(x) = H_q(x, 0, 0) \]
  \[ \Delta q(x) = \tilde{H}_q(x, 0, 0) \]
  \[ q(-x) = -\bar{q}(x) \]
  \[ \Delta q(-x) = \Delta \bar{q}(x) \]

- Form factors
  \[ F_1^q(t) = \int_{-1}^1 dx H^q(x, \xi, t) \]
  \[ F_2^q(t) = \int_{-1}^1 dx E^q(x, \xi, t) \]
  \[ g_1^q(t) = \int_{-1}^1 dx \tilde{H}^q(x, \xi, t) \]
  \[ h_1^q(t) = \int_{-1}^1 dx \tilde{E}^q(x, \xi, t) \]

- Quark orbital angular momentum
  \[ J_q = \frac{1}{2} \int_{-1}^1 x \, dx [H_q + E_q] \]
  \[ = \frac{1}{2} \Delta \Sigma + L_q \quad [X. Ji 1997] \]
Generalised Parton Distributions

(a) Usual pdf, representing the probability to find a parton with momentum fraction $x$ in the nucleon (red line).

(b) GPD in the region where it represents the emission of a parton with momentum fraction $x + \xi$ and its re-absorption with momentum fraction $x - \xi$ (outside green lines).

(c) GPD in the region where it represents the emission of a parton pair. Here $x + \xi > 0$ and $x - \xi < 0$ (inside green lines).

(GPD model plot by M. Vanderhaeghen)
GPDs at $\xi = 0$ can be used to obtain quark densities in the mixed representation of longitudinal momentum and transverse position in the infinite momentum frame.

$$q_v(x, b) = \int \frac{d^2 \Delta}{(2\pi)^2} e^{-b\Delta} H^q_v(x, t = -\Delta^2)$$

where $b$ is the 2-dim. impact parameter.

Based on GPD models first fits to existing data are already being carried out.

Hadron Tomography

\[ u_v(x, b) \text{ and } d_v(x, b) \]

left: unpolarised
right: polarised

GPD fit to form factor data

M. Diehl et al.
hep-ph/0408173
Deeply Virtual Compton Scattering

  \[ ep \rightarrow e'p'\gamma \]
- DVCS amplitude can be expressed in terms of GPDs
- at HERMES energies the interference of DVCS- and BH-amplitude allows the separate measurement of the real and the imaginary part of DVCS amplitude
- need to measure beam charge and beam spin azimuthal asymmetries
- requires polarised \( e^\pm \) beam, unpolarised hydrogen target
DVCS Asymmetries and GPDs

Beam Spin

\[ A_{LU}(\phi) = \frac{d\sigma^\uparrow(\phi)-d\sigma^\downarrow(\phi)}{d\sigma^\uparrow(\phi)+d\sigma^\downarrow(\phi)} \propto \sin \phi \Rightarrow \text{Im}(H) \]

Beam Charge

\[ A_{C}(\phi) = \frac{d\sigma^+(\phi)-d\sigma^-(\phi)}{d\sigma^+(\phi)+d\sigma^-(\phi)} \propto \cos \phi \Rightarrow \text{Re}(H) \]

Target Spin

\[ A_{UL}(\phi) = \frac{d\sigma^\uparrow(\phi)-d\sigma^\downarrow(\phi)}{d\sigma^\uparrow(\phi)+d\sigma^\downarrow(\phi)} \propto \sin \phi \Rightarrow \text{Im}(\tilde{H}) \]
Requirements on DVCS Measurements

- **Exclusivity** - measure all reaction products, scattered electron, photon and recoil protons.

- **Measurable effect** - DVCS cross section dominates BH at high energies (ZEUS, H1). At medium energies BH dominates the cross section but interference between DVCS and BH leads to large asymmetries.

- **Polarised e$^\pm$ beam** - to measure beam spin and beam charge asymmetry.

- **t-resolution** - must be sufficient for extrapolation to $t \to 0$ for Ji sum rule.

- **High statistics** - high target density, beam current, polarisation
The HERMES Spectrometer
Spectrometer resolution not sufficient to ensure exclusivity for a given event.
Recoil Detector - Motivation

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- **Suppress background** from soft pions and intermediate $\Delta^+$ production. With increased statistics the resulting systematic error would otherwise become dominant.
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- **t-resolution** of the spectrometer does not allow binning in $t$; important for extrapolation $t \rightarrow 0$. 
HERMES Recoil Detector - 3D CAD

- Iron Shielding
- Cryostat
- SC Coils
- SciFi Connector Plate
- C3 Collimator
- Si Detector Cooling
- Si Detector Connectors
- Hybrid
- Photon Detector
- SciFi Detector
- Silicon Detector
- Target Cell
- Flange

Scale: 0.1 0.2 0.3 m
Silicon Detector

- 16 TIGRE sensors inside beam vacuum
- 300 µm double sided, 4096 channels total
- 76 % $\phi$-acceptance
- p-measurement from $dE/dx$ 135-500 MeV/c
- space points for tracking $p > 135$ MeV/c
- $\pi/p$ PID from $dE/dx$ $p < 250$ MeV/c
Silicon Detector
Silicon Detector Readout

- split signal into high and low gain channel
- 2 Helix 3.0 chips per silicon strip
- adjust dynamic range through capacitor to ±70 MIPs
- S/N (MIP) 6.5
Scintillating Fibre Tracker

- 2 cylinders of $2 \times 2$ layers, $10^\circ$ stereo angle
- 1 mm Kuraray fibres, mirrored ends
- 4992 channels total
- Kuraray lightguides, 64 channel Hamamatsu PMTs
- p-measurement 300-1200 MeV/c
- $\pi/p$ PID from $dE/dx$
  \[
  250 < p < 450 \text{ MeV/c}
  \]
Scintillating Fibre Tracker
SciFi Testbeam Results

SciFi response for different proton momenta

SciFi module efficiencies
(module = double layer of fibres; two modules to get one space point)
Photon Detector

- detect photons from intermediate $\Delta$-resonances
  
  $\Delta^+ \rightarrow p\pi^0 \rightarrow p\gamma\gamma$

- reconstruct $\pi^0$ if both photons are detected

- contribute to pion/proton separation (together with SciFi)

- provide Cosmics Trigger
Photon Detector Cosmics Spectrum

- Cosmics Trigger: OR of lower half of inner layer
- Rate: ~ 20 Hz
- MIP - pedestal separation: ~ 170 channels (data from stand-alone cosmics test)
Recoil Detector Test-Experiment
- Si low momentum cut-off 135 MeV/c (10 MeV), require signal in both layers
- SciFi low momentum cut-off 250 MeV/c
- Si $dE/dx$ measurement up to 500 MeV/c (3 MIPs)
Recoil Detector $t$-Resolution

$\Delta t$ (GeV$^2$) vs $-t$ (GeV$^2$)

- Silicon
- SciFi

Spec, DVCS
Spec, rho

$e^+p \rightarrow e^+\gamma X \quad M_x < 1.7$ GeV

$\langle x_B \rangle = 0.11 \quad \langle Q^2 \rangle = 2.46$ GeV$^2$
Exclusivity

- Combination of coplanarity cuts, single proton requirement, pion rejection, photon cluster from $\pi^0$ (MC simulation)
Current and Future DVCS Experiments
Proton Beam Spin Asymmetry

Projection based on 2 fb$^{-1}$. 

$A_{LU}(\phi)$ for $e^+ p \rightarrow e^+ p \gamma$

$A_{LU}^{\sin\phi}$ for $e^+ p \rightarrow e^+ p \gamma$

$x_B < 0.10$ (red) and $x_B > 0.10$ (blue)
Proton Beam Charge Asymmetry

Projection based on 2 fb$^{-1}$. 

R.Kaiser - HERMES Recoil Detector – p.32/34
HERMES DVCS Projections Overview

- green triangles: HERMES published
- green crosses: CLAS published
- black squares: HERMES 1996-2000
- red circles: HERMES 2005-2007 Recoil Detector 1 fb⁻¹
Summary and Outlook

- **Generalised Parton Distributions** offer exciting new insights into the structure of hadrons, especially spin structure and transverse location.
- **The HERMES Recoil Detector**
  - combines Si-detector inside beam vacuum, SciFi tracker in solenoidal magnetic field of 1 T and photon detector
  - order of magnitude more statistics
  - non-exclusive background $\sim 1\%$ and improved t-resolution
- High statistics measurements of **DVCS beam spin and beam charge asymmetry incl. t-dependence**.
- Currently being tested with cosmics.
- Installation in the summer of 2005; data taking will begin in the fall.