A Silicon Recoil Detector for the HERMES Experiment

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INW inside-out
Outline

1. The HERMES Experiment
2. A proton’s Structure
3. Recoil Detector
4. Silicon Recoil Detector
   - Sensors, Frame, Hybrid, Foils, Tests
5. Summary
The HERMES Experiment

→ Experiment at DESY Hamburg

→ 27.5 GeV longitudinally polarised $e^\pm$ from HERA accelerator

→ Spin like Charge fundamental property
Determining a proton’s structure

\[ \frac{1}{2} = \Delta \Sigma + L_q + J_g \]
Determining a proton’s structure

- **Deep Inelastic Scattering:** \( e + p \rightarrow e' + X \)
- **Leading to Structure function** \( F_2(x, Q^2) \)
- **Interpretation:** probability to find a quark with momentum fraction \( x \)
Determining a proton’s structure

→ Elastic Scattering: \( e + N \rightarrow e' + N' \)

→ Leading to Form Factors (eg Electromagnetic)

→ Interpretation: eg Charge Distribution
Towards GPD’s

→ An understandable picture: The Infinite Momentum Frame
Towards GPD’s

Exclusive processes give access to Generalised Parton Distribution functions

- 4 for each flavor $q$: $H, E, \tilde{H}, \tilde{E}$
- Variables $H(x, \xi, t)$:
  - longitudinal momentum fraction $x$
  - $\xi$ skewedness ($2\xi$ long. mom. transf.)
  - $t = (p_p - p_{p'})^2$ related to transverse momentum transfer
Towards GPD’s

Related to ‘classical’ distribution functions and form factors:

- \( H^q(x, 0, 0) = q(x) \)
- \( \tilde{H}^q(x, 0, 0) = \Delta q(x) \)
- \( \int_{-1}^{1} dx \left( H^q(x, \xi, t) \right) = F_1^q(t) \)
- \( \int_{-1}^{1} dx \left( E_u(x, \xi, t) - \tilde{E}_d(x, \xi, t) \right) = F_2^q(t) \)
Towards GPD’s

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Routes to total angular quark momentum
\[ J^q(= \frac{1}{2} \Delta \Sigma + L_q) = \lim_{t \to 0} \frac{1}{2} \int (H^q + E^q)dx \]

Access to quark orbital momentum \[ L_q \]
Detecting Exclusive processes

- Internal polarized gas target (H, D, He, Ne, Kr)
- Tracking: Silicon, Drift Chambers
- PID: RICH, TRD, E/π Calorimeter
Detecting Exclusive processes

Exclusive Processes: initial and final state fully known!

Deeply Virtual Compton Scattering
A Recoil Detector for HERMES

To improve the measurement of exclusive processes a Recoil Detector is presently being built.
A Recoil Detector for HERMES

- Silicon measuring low momenta protons
- SciFi for momentum and tracking
- Photon detector to improve exclusivity
- Superconducting Magnet providing field for SciFi
- A new collimator to reduce background hits
A Recoil Detector for HERMES
A Recoil Detector for HERMES
A Recoil Detector for HERMES
A Recoil Detector for HERMES
Silicon Detector
Principle of Operation

Readout Strips

− Potential

+ Potential
Principle of Operation

Readout Strips

Ionising Particle

Potential

+ Potential

- Potential
Principle of Operation

- Potential
- Potential

Ionising Particle

average energy loss in 300 μm Si

\[
dE (\text{MeV}) = 10^{-1} \times \frac{1}{p (\text{proton}) \ (\text{GeV/c})}
\]

Recoil Silicon Detector

- Inside beam vacuum
- Diamond shape around target cell
- 2 layers of silicon
- 76% of $\phi$
- $23^\circ < \theta < 80^\circ$

Project of DESY, Erlangen, Gent, Glasgow
Recoil Silicon Detector
Recoil Silicon Detector
Recoil Silicon Detector

Most important Requirements:

→ Large Dynamic Range required
→ Vacuum compatible components
→ Response linear with particle momentum
Silicon Sensors
TIGRE sensors

- Largest commercially available silicon sensor
- Double sided
- $99 \times 99 \text{ mm}^2$, 300 $\mu\text{m}$ thick
- 758 $\mu\text{m}$ pitch
- Strip width: 702 $\mu\text{m}$
- SiO$_2$ layer ensures AC-coupling
TIGRE sensors

All TIGREs have been tested by means of a probe station

- Bias resistors
- Overall I/V–C/V characteristics: diode functionality, depletion voltage
- Long Term Test
- . . .
The Holding Frame
A Holding Frame

Requirements for the holding frame:

- Sufficient stability
- Suitable for vacuum applications
- Thermal expansion coefficient close to that of silicon
## A Holding Frame

<table>
<thead>
<tr>
<th>Property</th>
<th>Silicon</th>
<th>Aluminium</th>
<th>Graphite</th>
<th>Shapal-M</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance</td>
<td>$10^{-4} - 10^4$</td>
<td>$5 \cdot 10^{-6}$</td>
<td>0.02</td>
<td>$10^{12}$</td>
<td>$\Omega \cdot cm$</td>
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<tr>
<td>Thermal Expansivity</td>
<td>2.6</td>
<td>23</td>
<td>7.4</td>
<td>4.4</td>
<td>$\frac{10^{-6}}{K}$</td>
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<tr>
<td>Modulus of Elasticity</td>
<td>170</td>
<td>70</td>
<td>15</td>
<td>160</td>
<td>GPa</td>
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<tr>
<td>Thermal Conductivity</td>
<td>150</td>
<td>130</td>
<td>65</td>
<td>100</td>
<td>$\frac{W}{m \cdot K}$</td>
</tr>
<tr>
<td>Outgassing Rate</td>
<td>n.a.</td>
<td>$10^{-10}$</td>
<td>$8 \cdot 10^{-11}$</td>
<td>$2.3 \cdot 10^{-11}$</td>
<td>mbar.l/s.cm²</td>
</tr>
<tr>
<td>Costs per frame</td>
<td>n.a.</td>
<td>30</td>
<td>110</td>
<td>1200</td>
<td>€</td>
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**Go for Shapal-M**

Sensors are glued with two component epoxy glue at 150°
Readout Hybrid
Two readout chip candidates were tested: APC and HELIX128-3.0
Extend Dynamic range with Charge division method:

- Strip readout pad
- 10pF
- High gain HELIX
- Low gain HELIX
Readout Hybrid

Extend Dynamic range with Charge division method:

- Strip readout pad
- 10pF
- High gain HELIX
- Low gain HELIX

→ Sufficient Dynamic Range
→ HELIX already used in HERMES
Readout Hybrid

- Helix Chip
- Receivers
- Coupling Capacitors
- Flexfoil
- Line Drivers
- Pitch Adaptor

- 4 layers, with kapton cores
- Glued to aluminum heatsink
Chip Tests

- Basic functionality (addressing, programming)
- Uniformity checked with internal testpulse
- 372 chips tested
  - 64 chips needed
  - 153 Class A chips
  - 100 Class A1
Kapton Readout foils

⇒ Readout Foils needed!
Kapton Readout foils

Beam
Scattered Proton
Target Cell
Silicon 1
Silicon 2
Flexfoil 1
Flexfoil 2
Flexfoil 3
Flexfoil 4
Traces
Kapton Readout foils

Different designs: (μm)

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<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
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<tr>
<td>Kapton2</td>
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</table>
A Module
An SRD Module
Assembly-Glueing

Stempel

Foil

Glue

Keramik

Glue: 2-Component Epoxy
Epotek H77 (Polytec)

Air bubbles below bondpads
Glue on foil

Preform: Woven material filled with Epoxy Glue.
Polytec TFT D18-1 SP4
Readout Scheme
Readout Scheme

VME

HLCU

HADC

~ 30 m

ACC

~ 3 m

LV

Readout Scheme

HLCU: Programming, Clock, Triggering
Readout Scheme

ACC: Repeater board, drivers/receivers

VME

HLCU

HADC

~ 30 m

ACC

LV

~ 3 m
Readout Scheme

ACC: Repeater board, drivers/receivers

VME

HLCUHADC

LV ~ 3 m ~ 30 m

Readout Scheme

HADC: ADC, CMC, Zero Suppression

VME

HLCU

HADC

128 channels

Trailers

Low Gain

High Gain

LV

10 pF

22 pF

18 Sep 2003
09:46:04
Testing
Prototype Testing

- Testbeams
  - DESY: MIP
  - Erlangen: Low Energy protons
- Laser Test Stand
- Detailed noise optimisation
- Parameter tests
- Bench Test
Testbeam at DESY

- Electrons from pre-accelerator DESYII (1-6 GeV)
- Use Zeus Telescope
  - 6 Reference detectors
  - $\frac{S}{N} > 60$
  - pitch 25 (50) $\mu m$
Testbeam at DESY

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<td>RMS</td>
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$\chi^2/\nu$ = 355.9 / 73

$P_1$ = 1341.0

$P_2$ = 15.64

$P_3$ = 0.3644
Testbeam at DESY

‘Pre’ Prototype:

\[ \frac{S}{N} = 7.5 \]

\[ \epsilon = 99.73 \pm 0.04\% \]

‘Final’ Prototype:

\[ \frac{S}{N} \approx 6.2 \]
Laser Test

- Black Box
- Red Laser
- X-Y Table
- Spot \(\sim 20\mu m\)
Laser Test

- Uniformity
- Linearity
- Pipe Spread

ADC counts vs Channel Nr
Parameter Tests

HELIX high gain $V_{fs}=208$

Amplitude [ADC channel]

Time [10 ns]

$I_{pre}=040$

$I_{pre}=080$

$I_{pre}=120$

$I_{pre}=160$

$I_{pre}=200$

$I_{pre}=240$

2 chan
Bench Test
Installation Pictures
Installation Pictures
Installation Pictures
Installation Pictures
Summary

→ Interest in Exclusive Physics
→ Development of a Silicon Recoil Detector for HERMES
→ Mechanical construction fixed and working
→ Test installation running, take cosmics data