



# HERMES Recoil Detector

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**Lecture Week on Hadron Physics**

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# Outline

- Motivation
- The Hermes Recoil Detector
- Performance
- Outlook

# The Spin Structure of the Nucleon

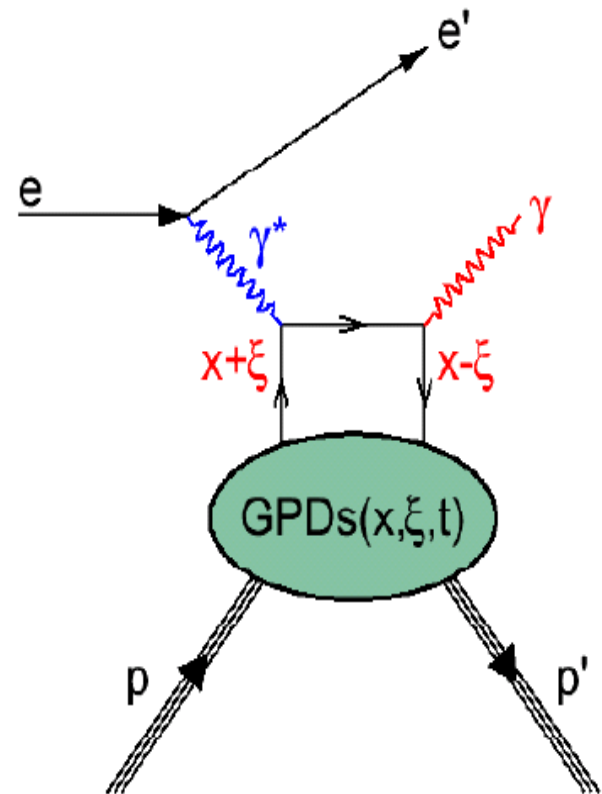
Nucleon Spin:

$$\frac{1}{2} = \frac{1}{2} \underbrace{(\Delta u + \Delta d + \Delta s)}_{J_q} + L_q + \underbrace{\Delta G + L_g}_{J_g}$$

- $\Delta\Sigma$  Spin of quarks
  - $\Delta\Sigma \approx 20 - 35\%$  measured in DIS
  - HERMES:  $\Delta\Sigma \approx 0.3$
- $\Delta G$  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

$$J_{q,g} = \lim_{t \rightarrow 0} \int_{-1}^1 dx x \underbrace{\{H_{q,g}(x, \xi, t) + E_{q,g}(x, \xi, t)\}}_{\text{GPDs}}$$

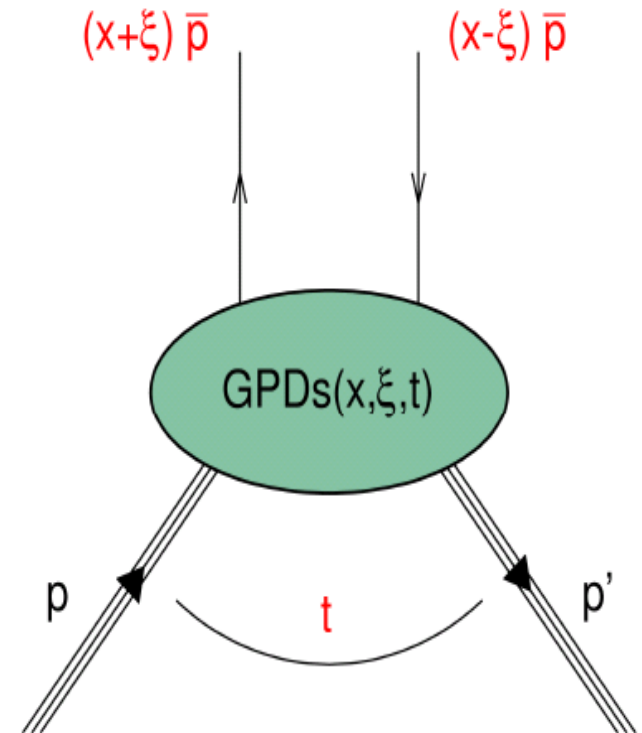


total angular momentum

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

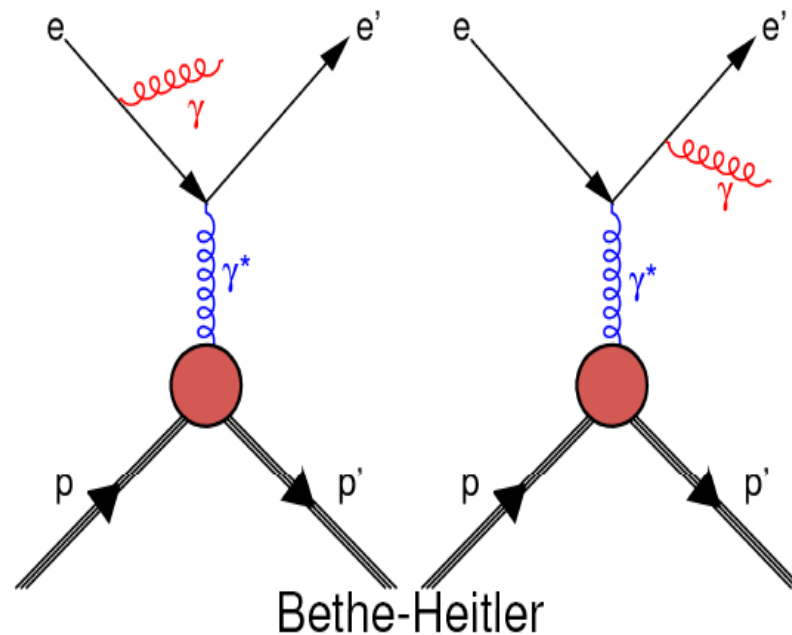
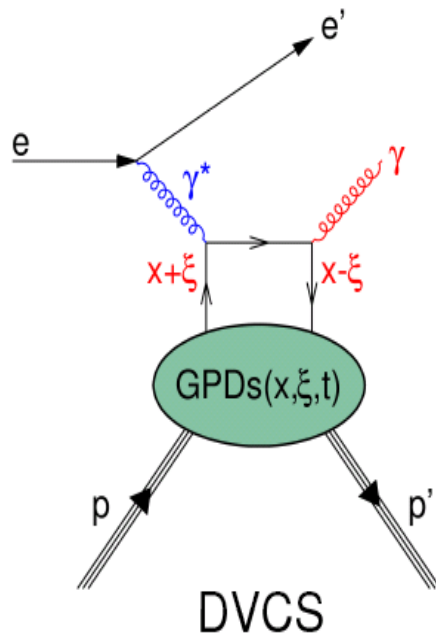
$\xi$  fraction of the momentum transfer

$t$  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

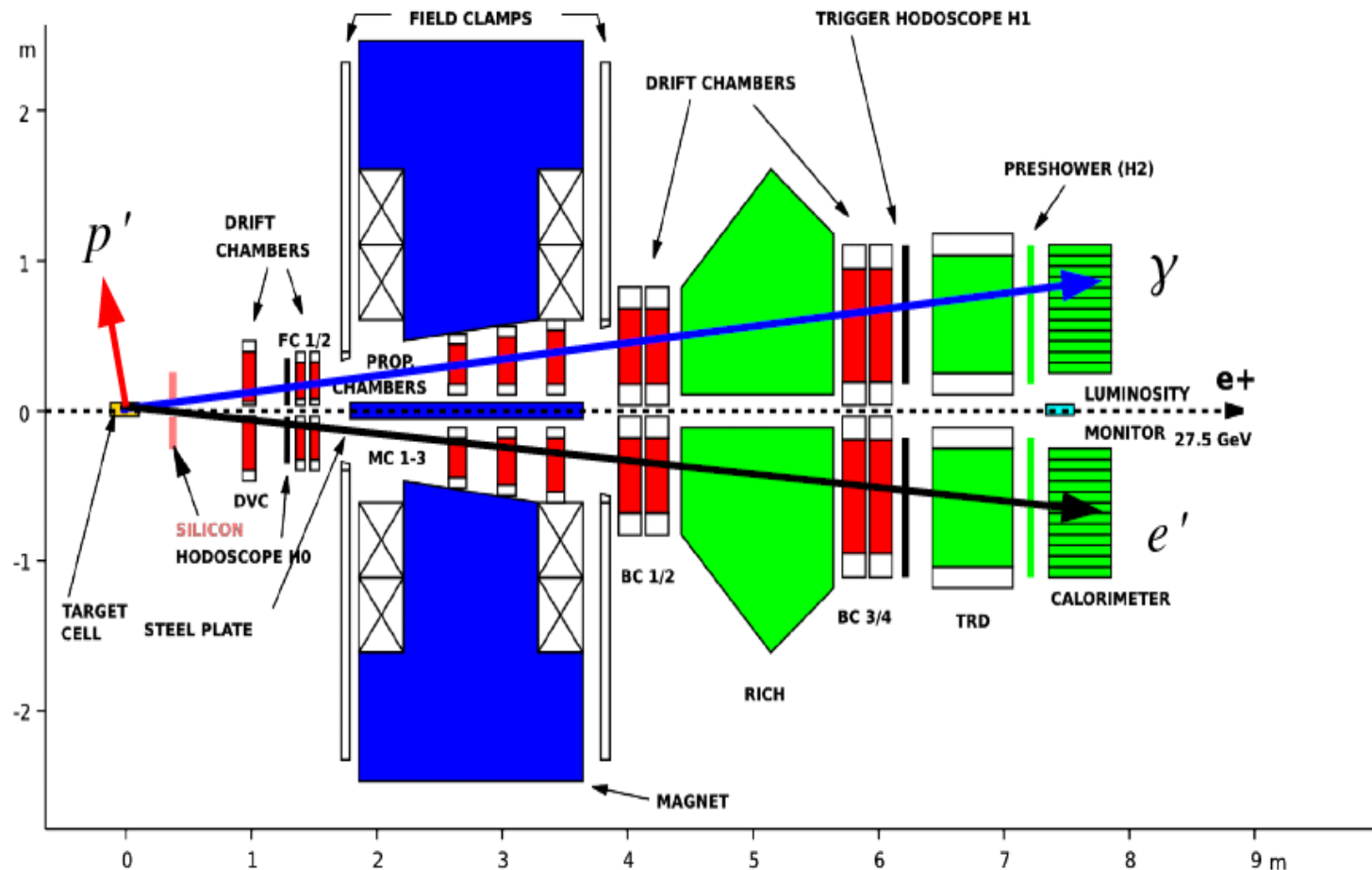


➤ Photon-Production cross section:

$$d\sigma \propto |\tau_{\text{DVCS}} + \tau_{\text{BH}}|^2 = |\tau_{\text{DVCS}}|^2 + |\tau_{\text{BH}}|^2 + \underbrace{(\tau_{\text{DVCS}}^* \tau_{\text{BH}} + \tau_{\text{BH}}^* \tau_{\text{DVCS}})}_{\text{Interference Term}}$$



# The HERMES Spectrometer (before 2006)



- Fixed target experiment (uses 27.6 GeV/c HERA lepton Beam)
  - Polarize gas targets: H,D,He
  - Unpolarize gas targets: H,D,N,He,Ne,Xe,Kr
- Recoiling proton undetected ➡ large background contamination (15%)

# Exclusivity for DVCS via Missing Mass

➤ Exactly one DIS lepton and one photon detected in the Calorimeter.

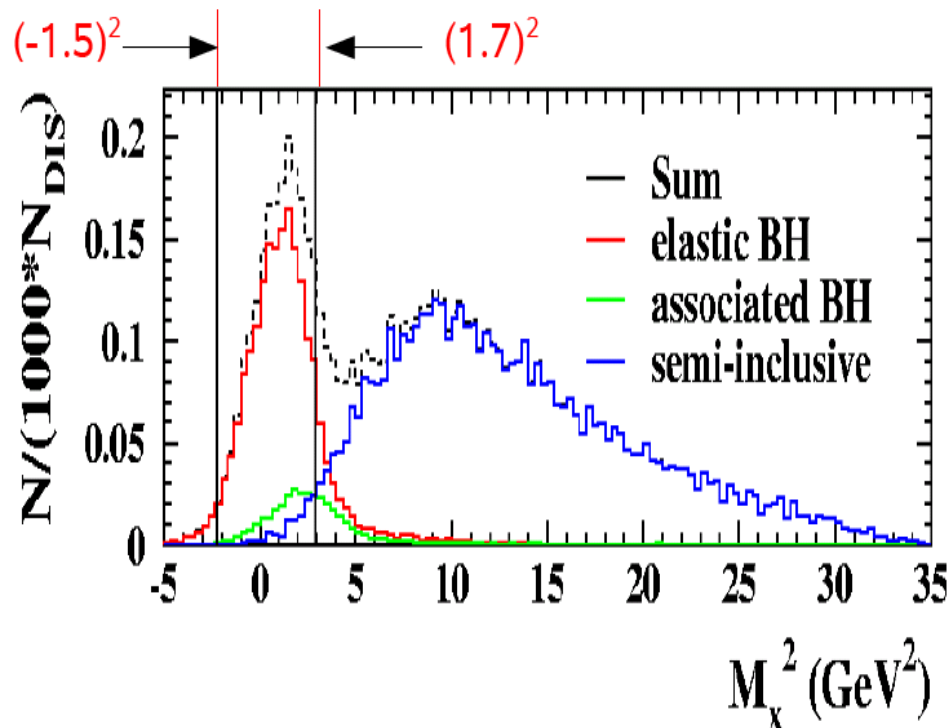
➤ Recoiling proton undetected.

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

➤ Exclusivity via Missing Mass  $M_x^2 = (q + p + q')^2$

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

exclusive region



$ep \rightarrow e'p\gamma$  : Elastic BH

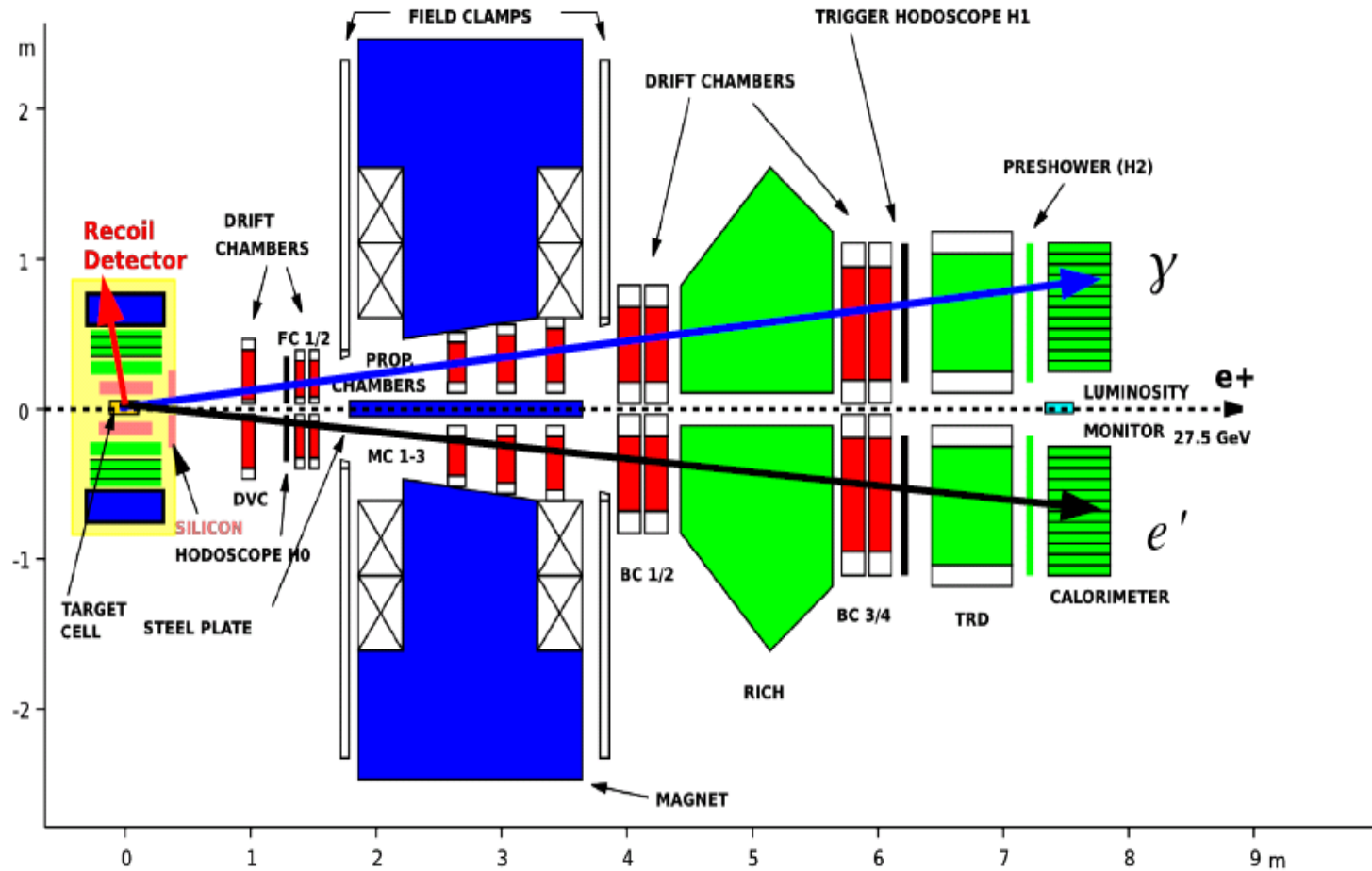
$ep \rightarrow e'\Delta^+\gamma$  : Associated BH

$ep \rightarrow e'\pi^0 X$  : Semi - Inclusive

Overall background contribution  $\approx 15\%$  in exclusive region

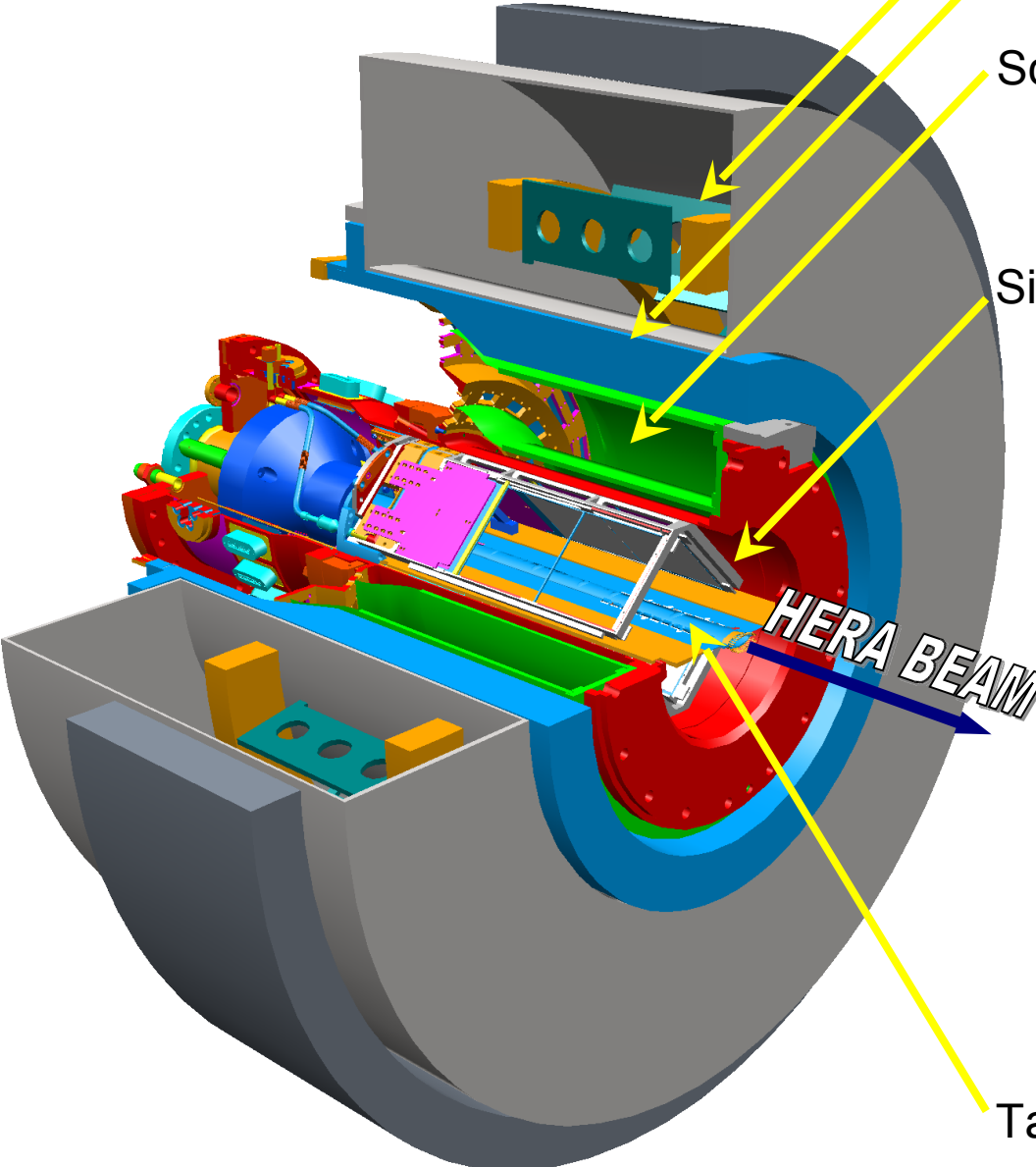


# The HERMES Spectrometer (2006 - 2007)



- 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

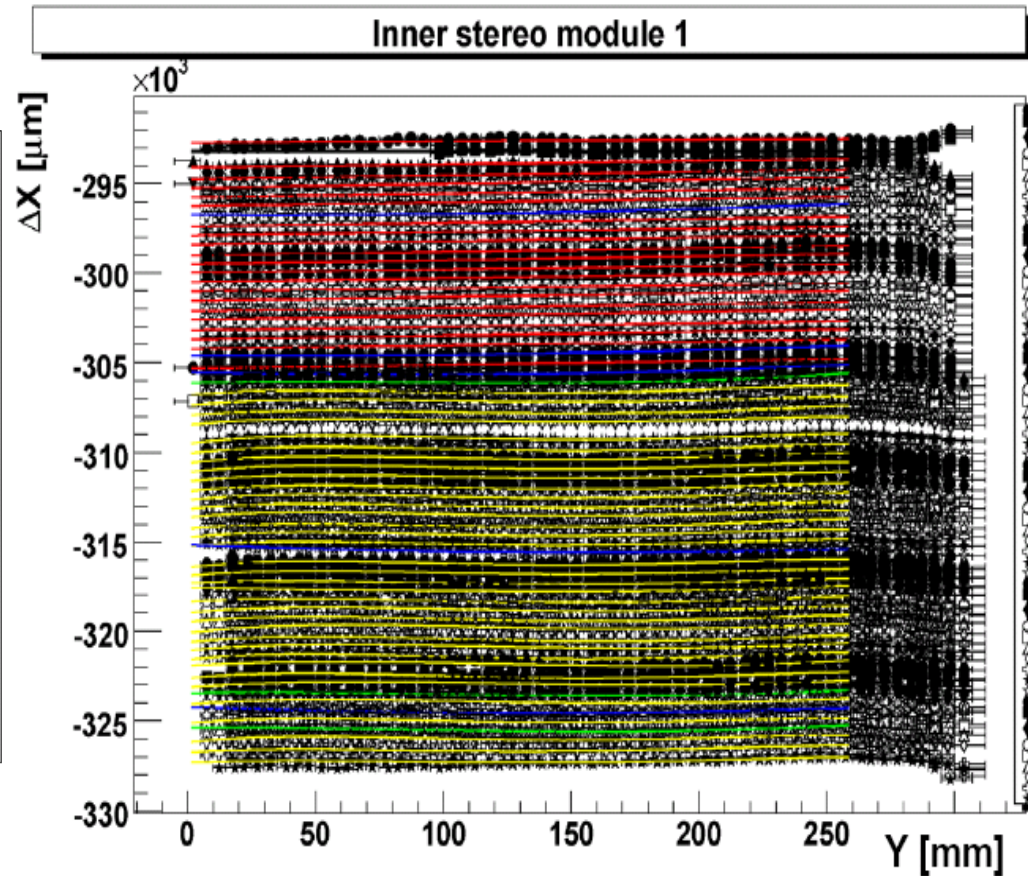
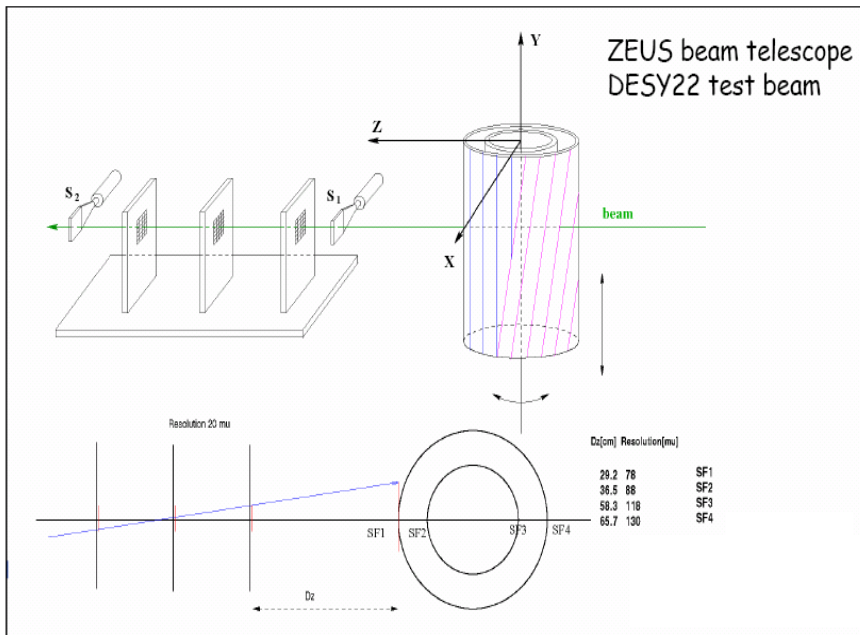
Silicon Detector

- 2 Layer of 16 double-sides sensors
- 97×97 mm<sup>2</sup> active area each
- Inside HERA vacuum

Silicon & Fiber Tracker:  
 $p_p \in [135, 1200] \text{ MeV}/c$   
 $p/\pi$  PID for  $p < 650 \text{ MeV}/c$   
Photon Detector:  
 $p/\pi$  PID for  $p > 600 \text{ MeV}/c$   
 $\pi^0$  background suppression

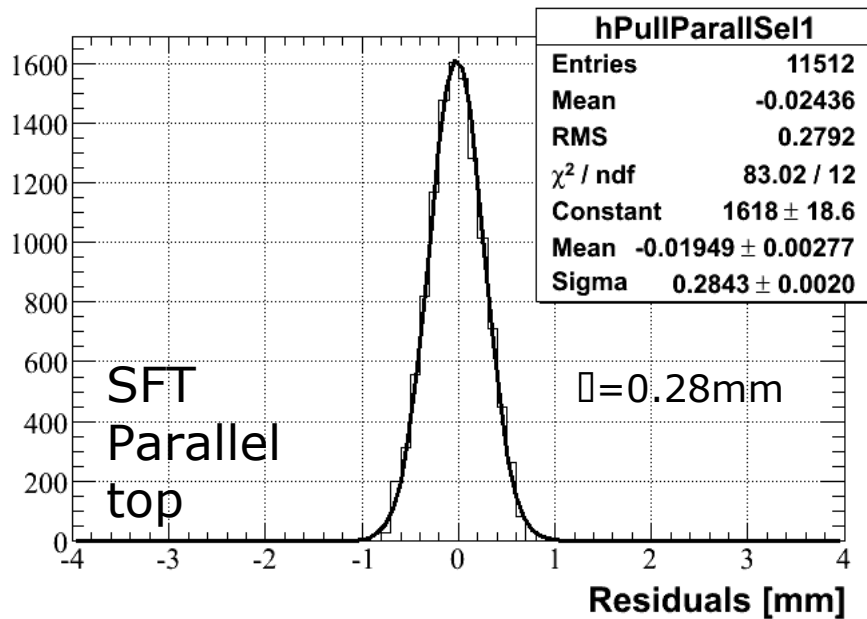
Target Cell

# Alignment of the SFT

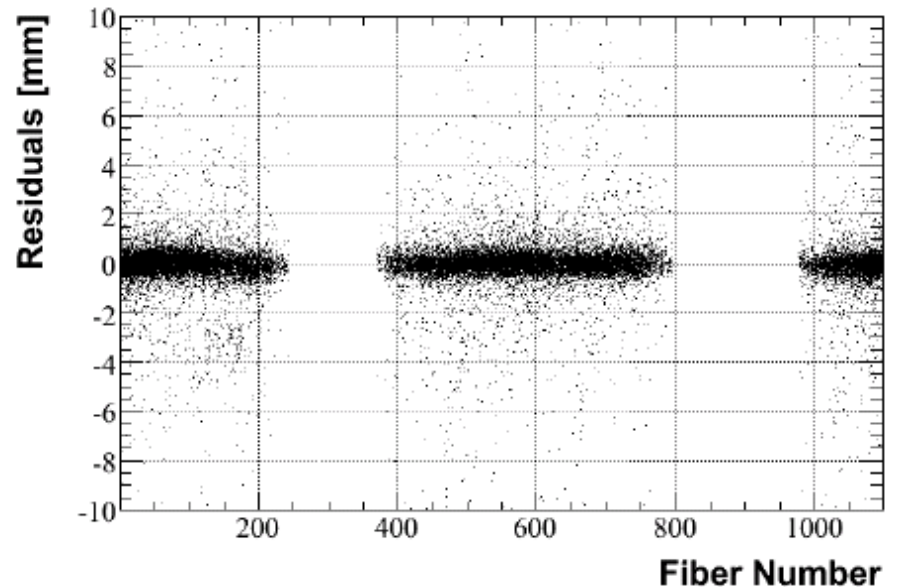
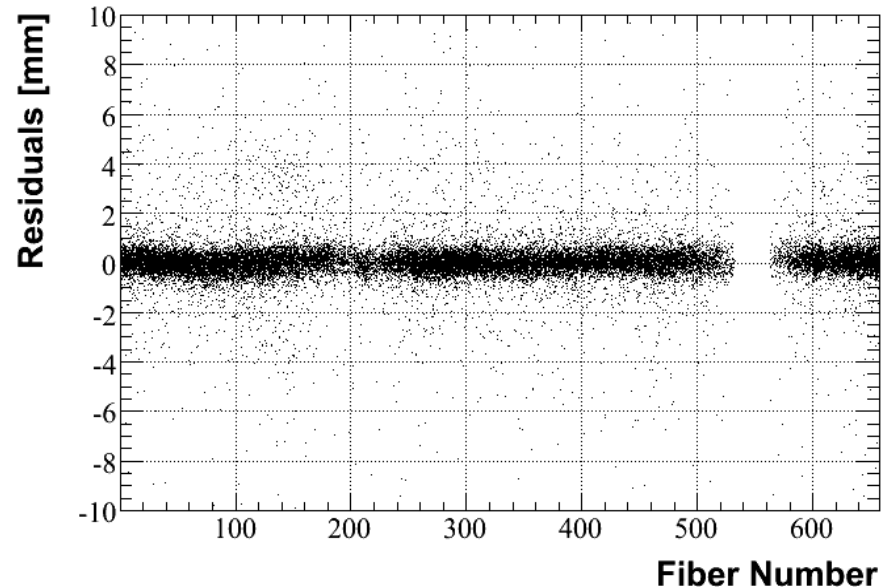


# Results of Alignment of SFT

- Measurements of dedicated SFT run were used and tested on cosmic data collected with Recoil detector
- Residuals (280  $\mu\text{m}$ ) are in good agreement with expectations from ideally aligned Monte-Carlo (220  $\mu\text{m}$ )

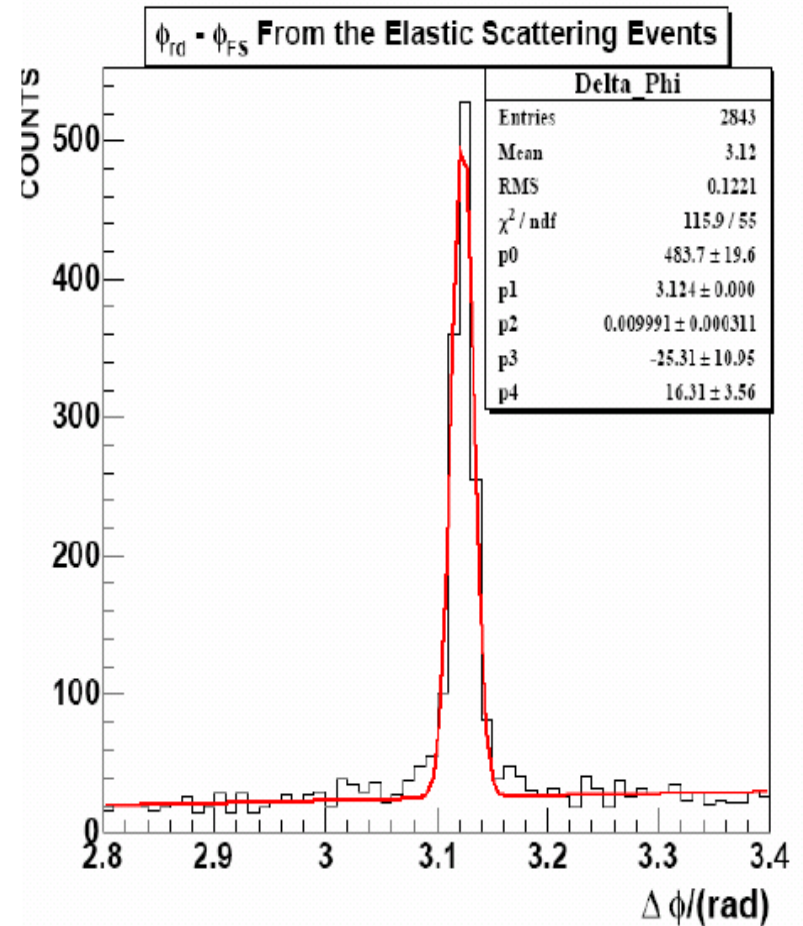


Si and PD alignment respect SFT

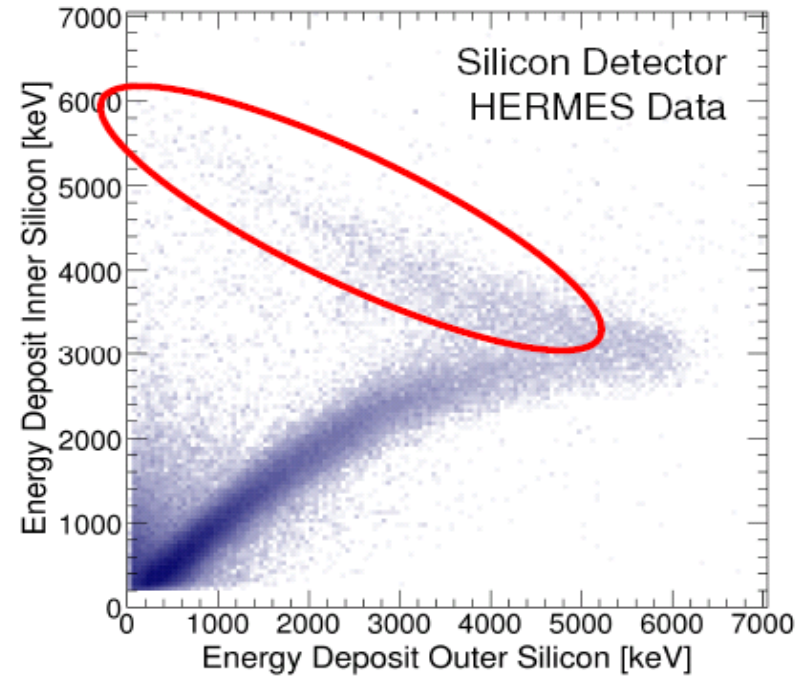
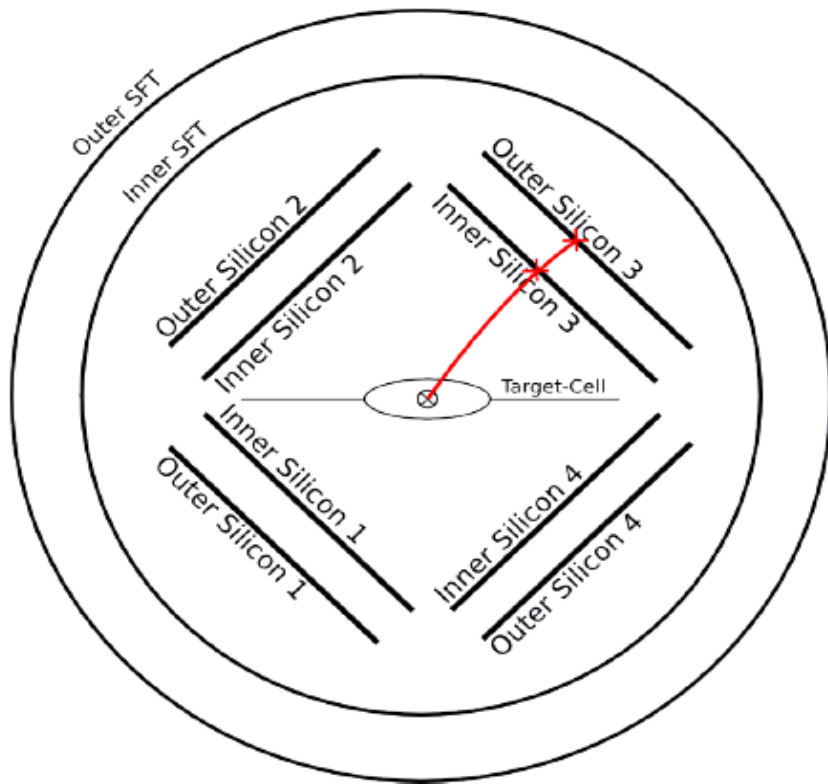


# Ep Elastic Scattering

- 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

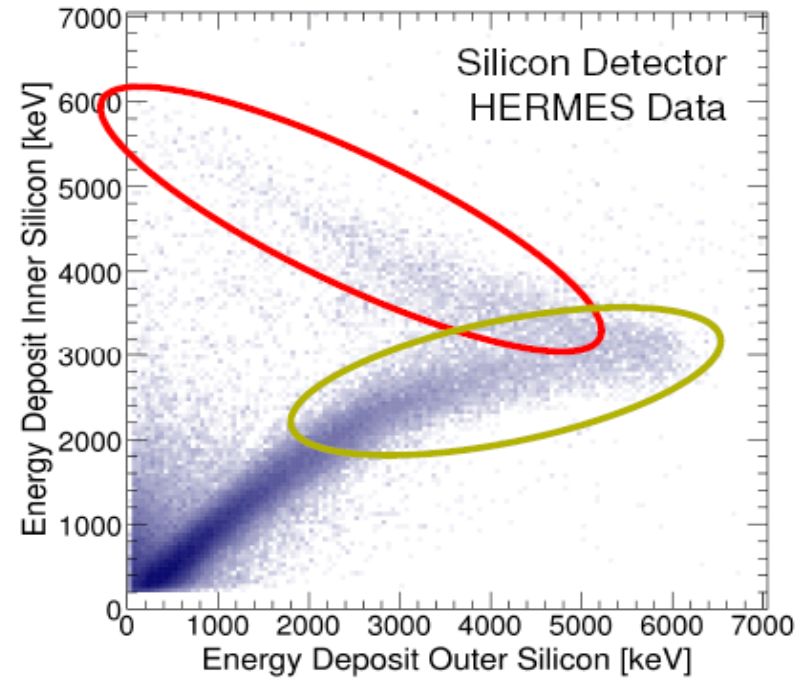
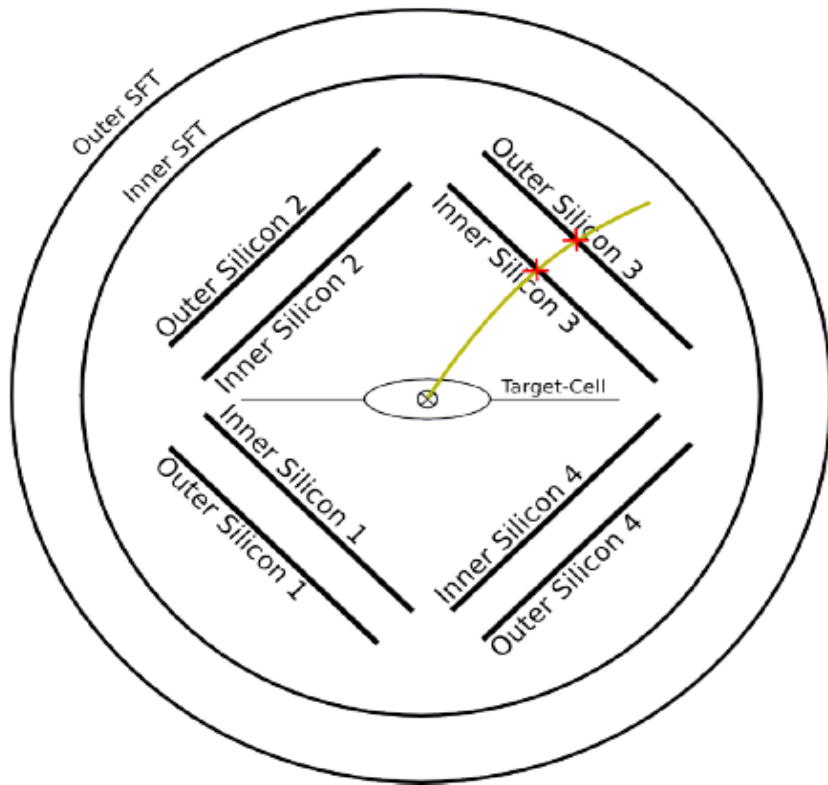


# Momentum Reconstruction



**Low** momentum protons (stopped in outer Silicon)  
→ Sum of energy deposits

# Momentum Reconstruction



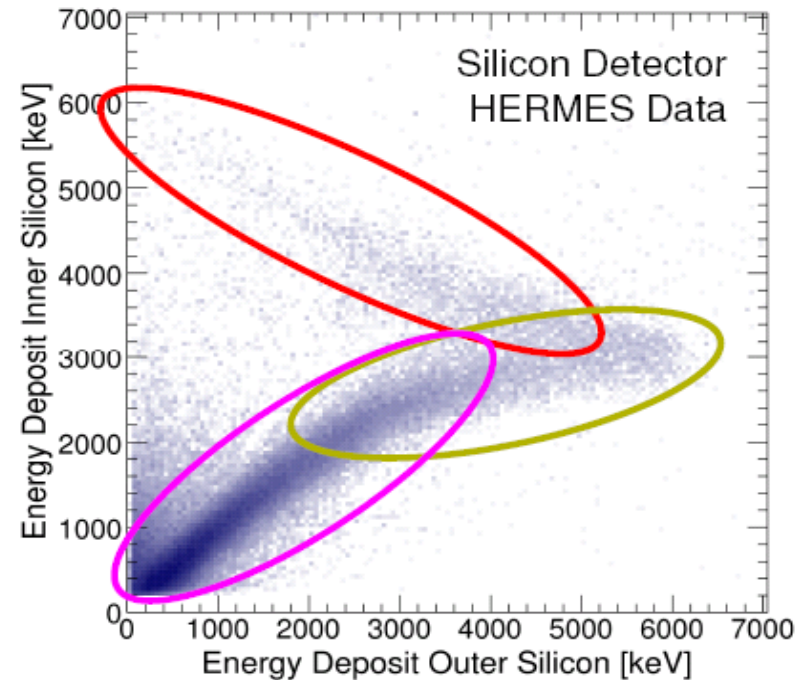
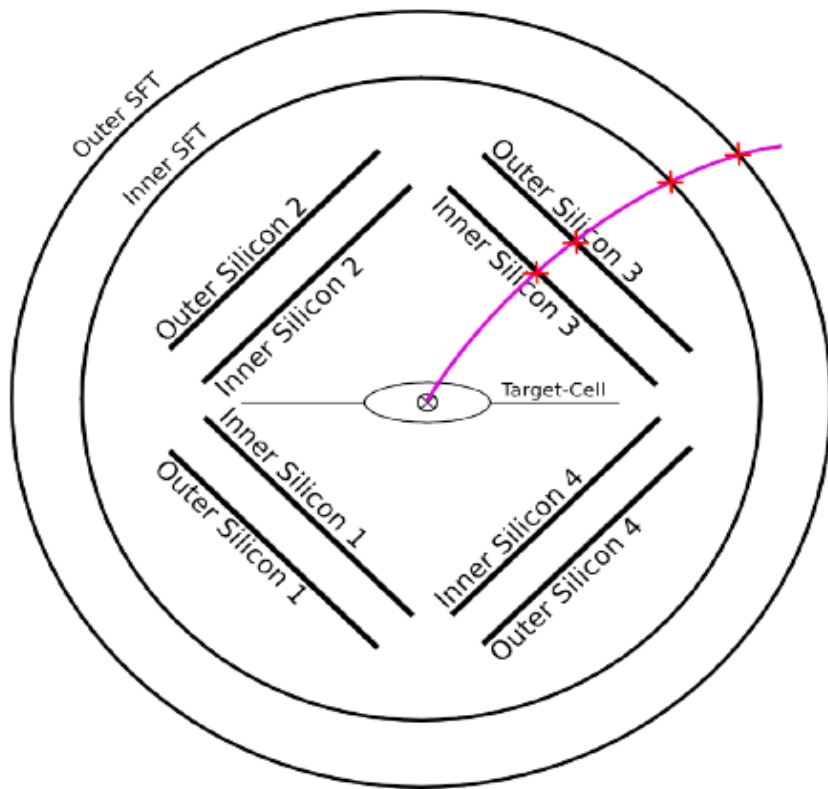
**Low** momentum protons (stopped in outer Silicon)

→ Sum of energy deposits

**Higher** momentum protons

→  $dE/dx$

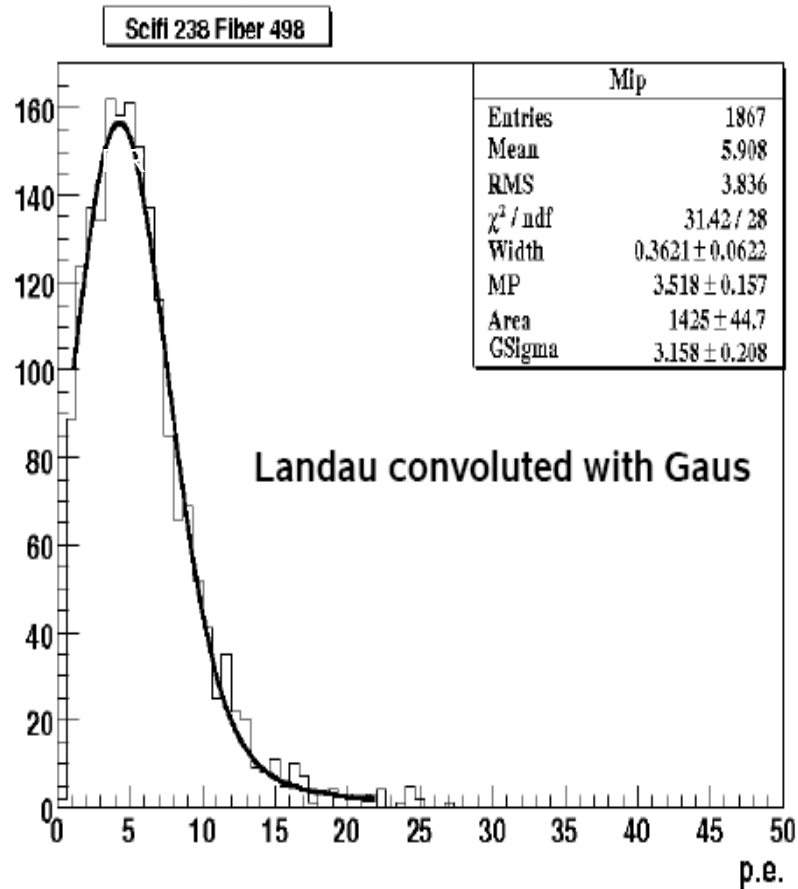
# Momentum Reconstruction



- Low** momentum protons (stopped in outer Silicon)
  - Sum of energy deposits
- Higher** momentum protons
  - $dE/dx$
- High** momentum particles
  - Bending in magnetic field

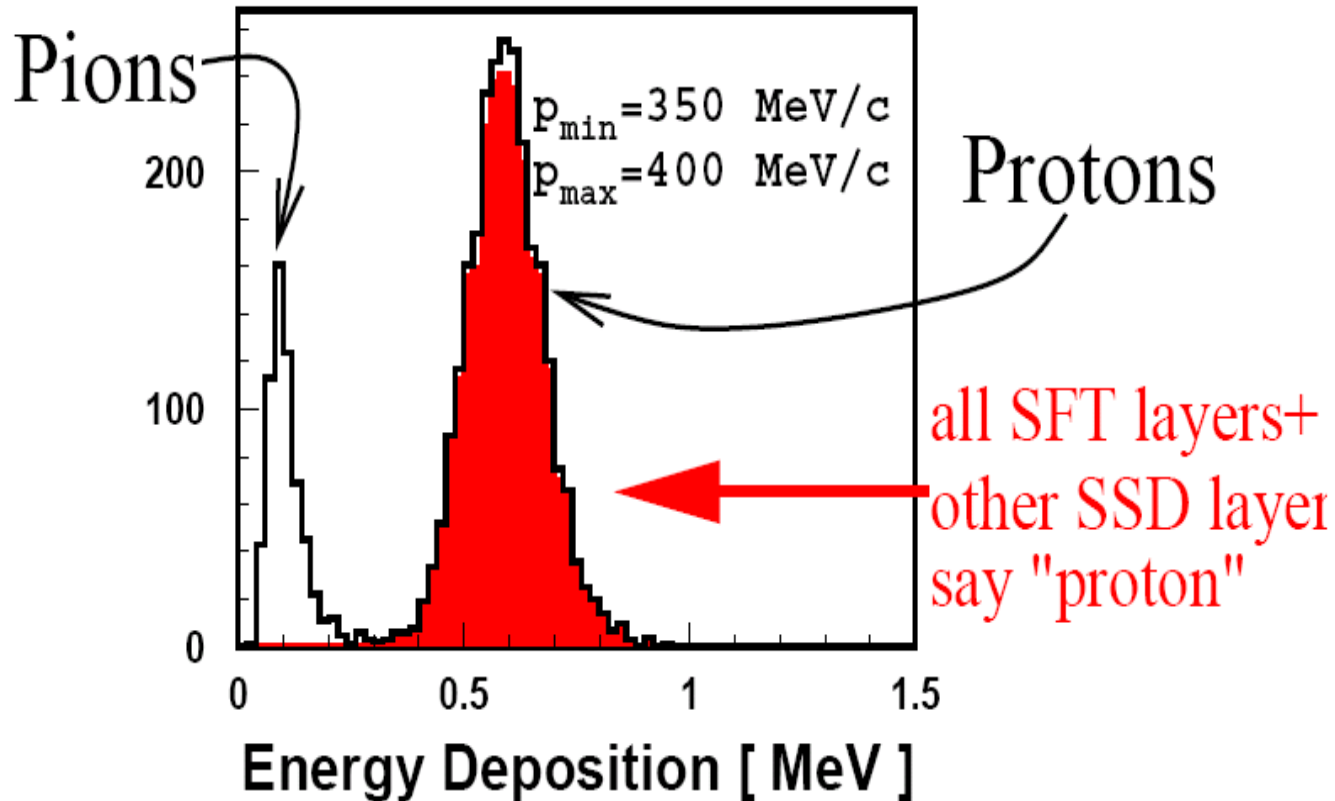


# Energy Deposit of MIP's



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

# Recoil Particle Identification



# Data tacking and Performance

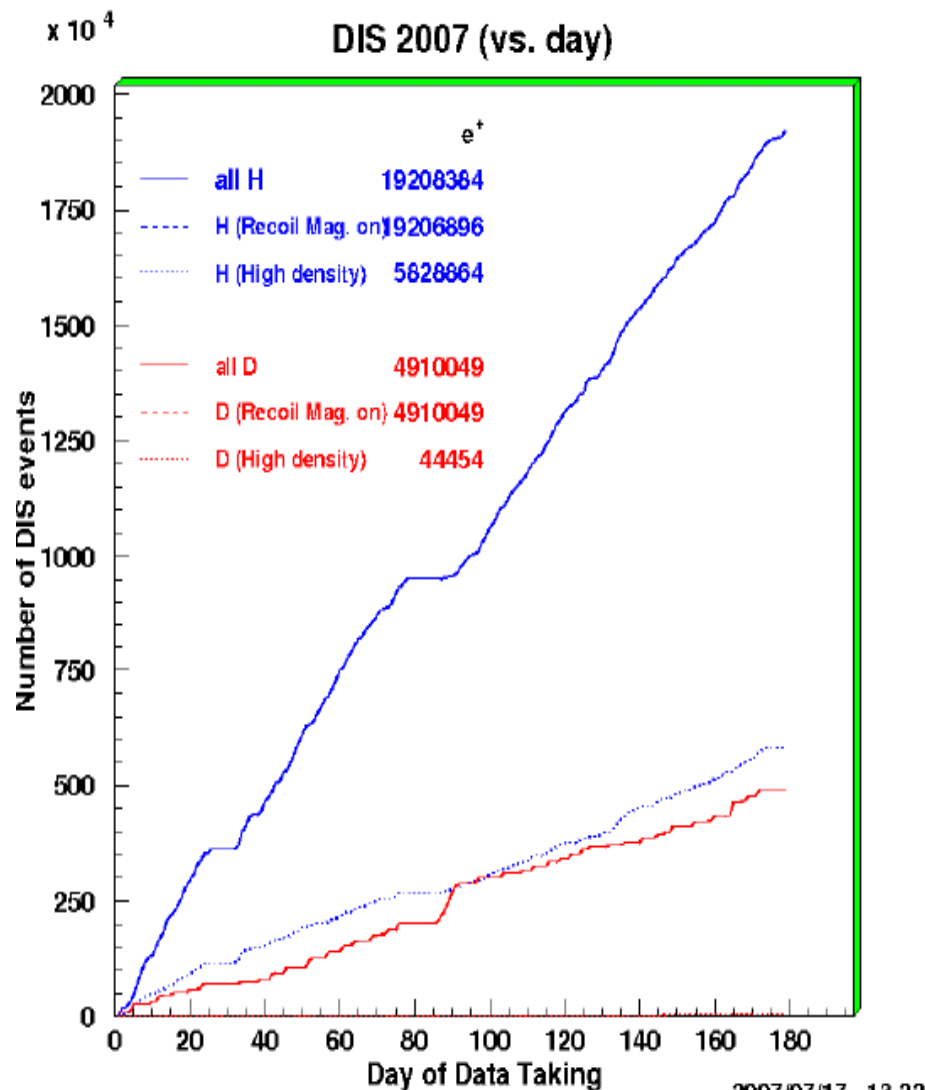
➤ Collected statistic (preliminary) with recoil detector

➤ Electron beam 2006 (only SFT operational):

- H<sub>2</sub>: 5k DVCS (3Mio. DIS),
- D<sub>2</sub>: 1k DVCS (0.8Mio. DIS)

➤ Positron beam 2006/07 (all subdetectors fully operational)

- H<sub>2</sub>: 41k DVCS (38Mio. DIS),
- D<sub>2</sub>: 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!