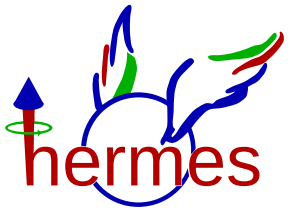
# Status of Commissioning and Analysis with the HERMES Recoil Detector

**Caroline Riedl for the HERMES Collaboration**




XVII International Workshop on
Deep-Inelastic Scattering
and Related Subjects
DIS 2009, 26-30 April, Madrid

# Outline

# The Composition of the Nucleon's Spin

$$\frac{1}{2} = \underbrace{J_{\text{quarks}}}_{=\frac{1}{2}\Delta\Sigma + L_{\text{q}}} + J_{\text{gluons}}$$

- Spin of quarks: $\Delta\Sigma \approx 1/3$ from DIS and SIDIS

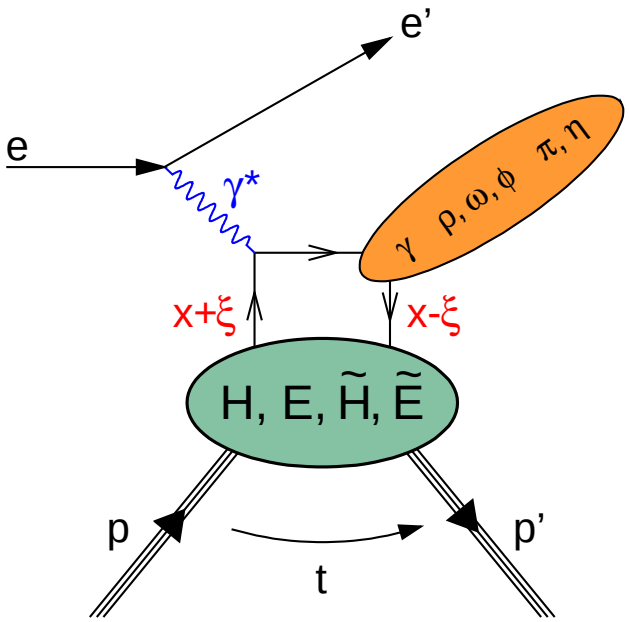
  HERMES: Phys. Rev. **D75** (2007) 012007

  $\Delta\Sigma = 0.330 \pm 0.011\,(\text{theo}) \pm 0.025\,(\text{exp}) \pm 0.028\,(\text{evol})$
- Orbital angular momentum of quarks: $L_{\text{q}}$ ?
  - Ji relation Ji, PRL **78** (1997) 610 :

$$J_{\text{q}} = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} \mathrm{d}x\, x \left[ H_{\text{q}}(x, \xi, t) + E_{\text{q}}(x, \xi, t) \right]$$

  - Generalized Parton Distributions **(GPDs)**

# GPDs: a Unifying Picture of Nucleon Structure




**Accessible through hard exclusive reactions:**

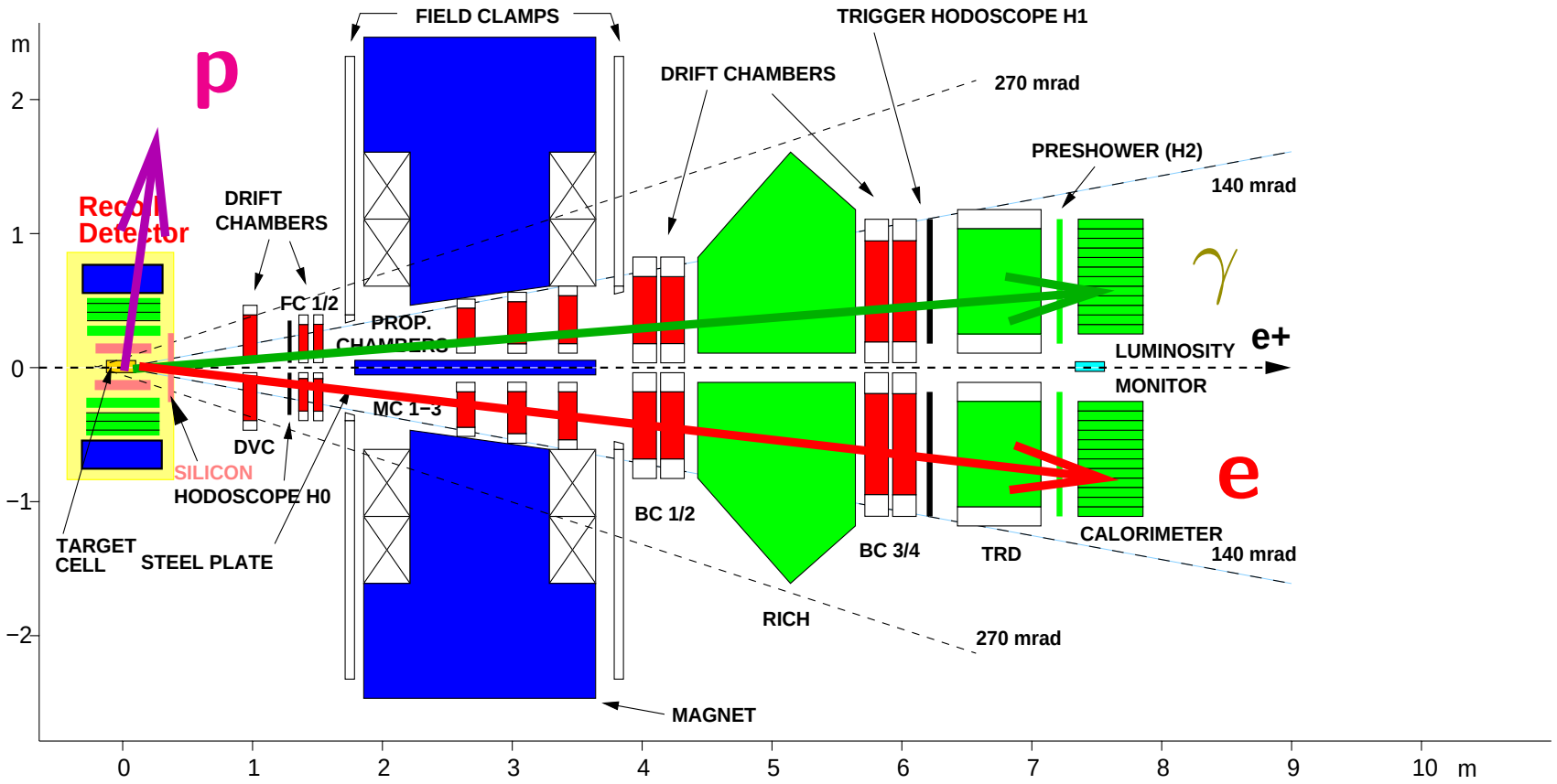
| unpolarized | polarized |
|---|---|
| photon: $J^{\mathcal{P}} = 1^-$ (DVCS) | |
| **H** | $\widetilde{\mathbf{H}}$ |
| **E** | $\widetilde{\mathbf{E}}$ |
| $J^{\mathcal{P}} = 1^-$ mesons | $J^{\mathcal{P}} = 0^-$ mesons |

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

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

Theoretical reviews: PPNP **47** (2001) 401; Phys. Rept. **388** (2003) 41; Phys. Rept. **418** (2005) 1

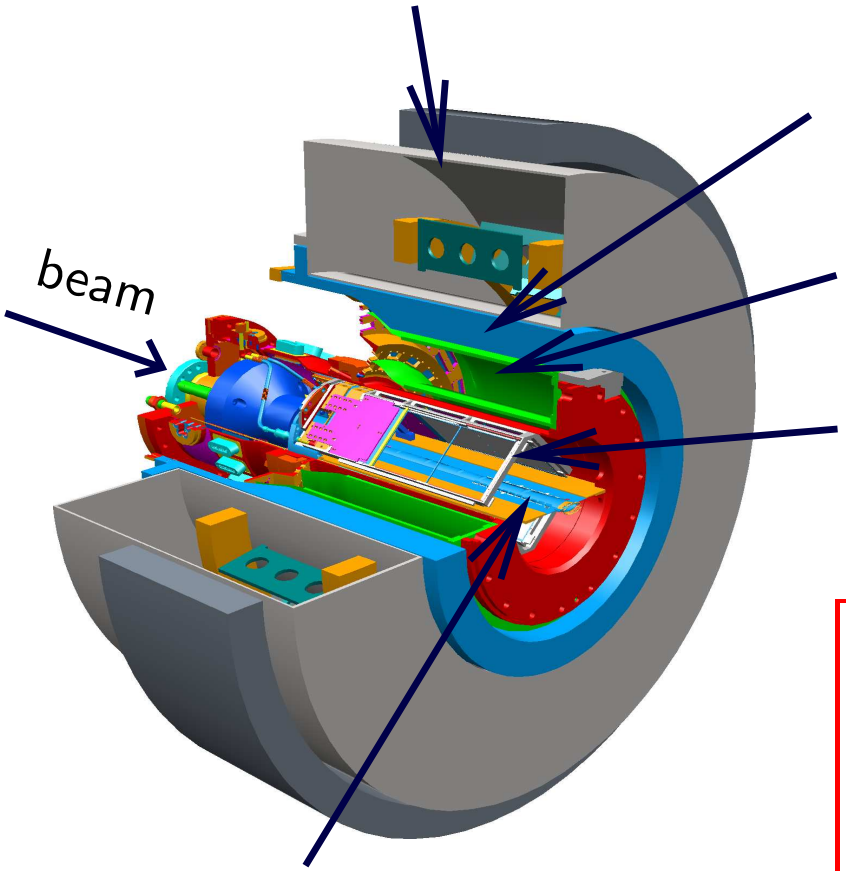
# HERMES with Recoil Detector (2006/2007)




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

# The HERMES Recoil Detector

- **SC Solenoid** (1 Tesla)



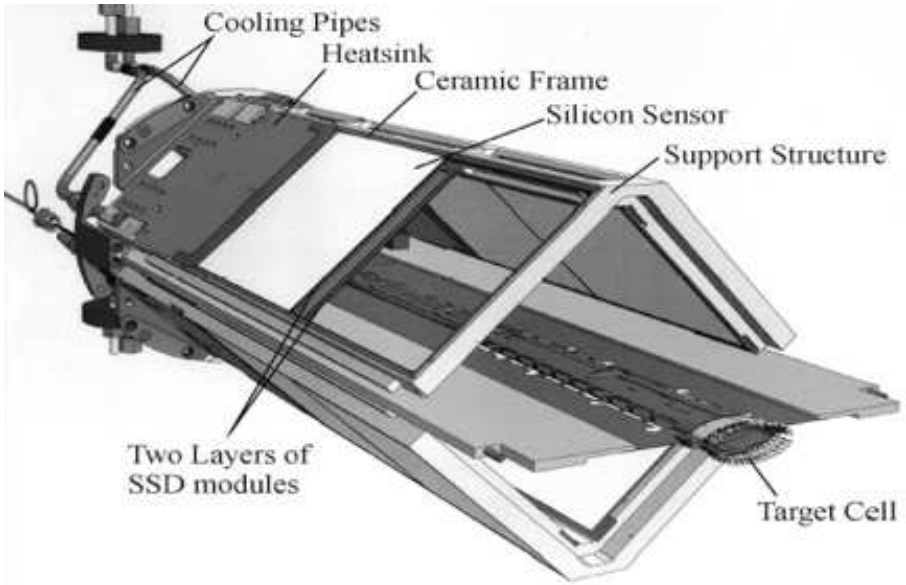

- **Photon Detector**
- **Scintillating Fiber Tracker**
- **Silicon Strip Detector**
- **Target Cell**

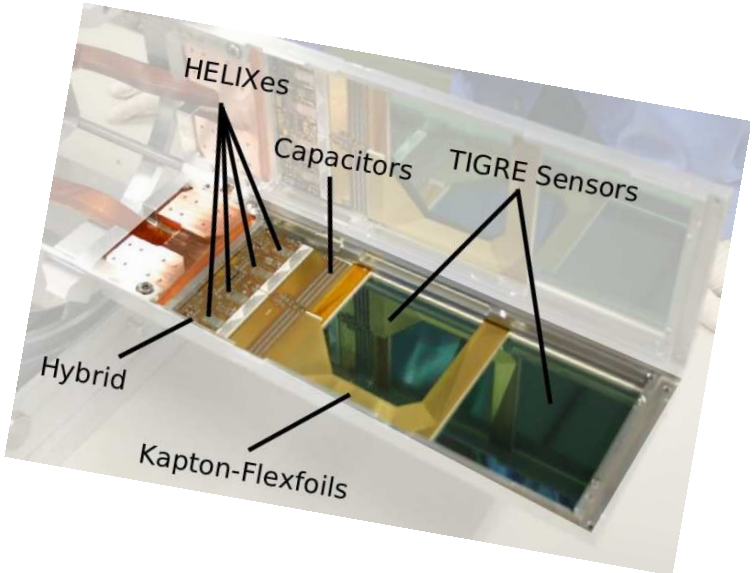
**Purpose:**

★**To tag exclusive events**

- ▶ Identify recoiling target proton
- ▶ Identify particles from background processes

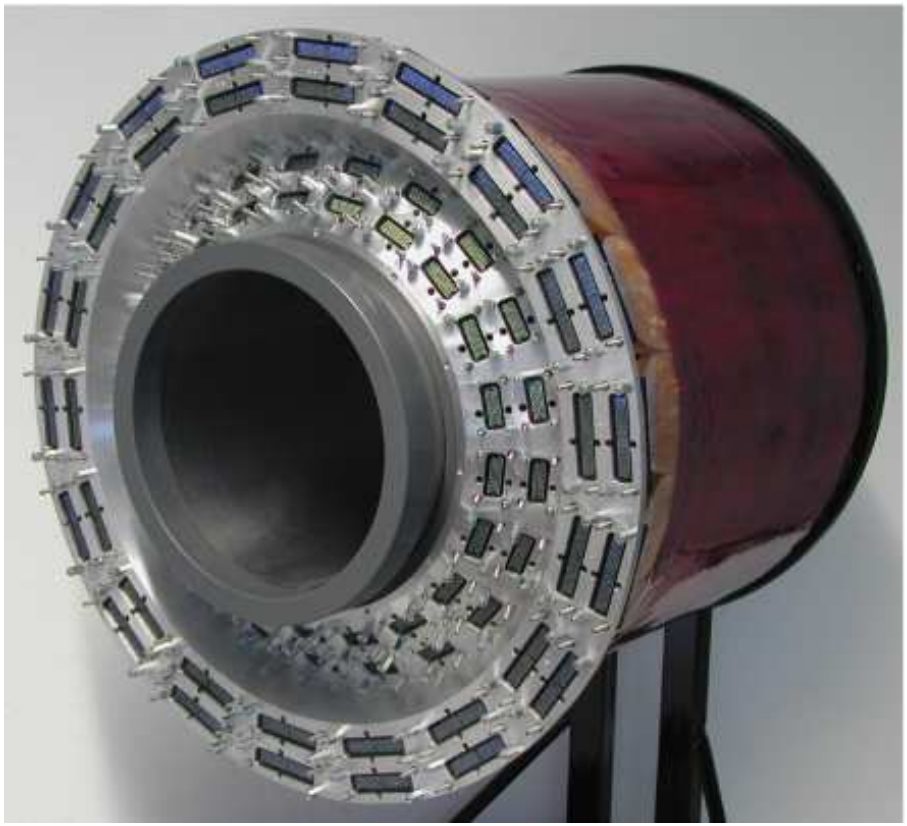
# The Silicon Strip Detector (SSD)



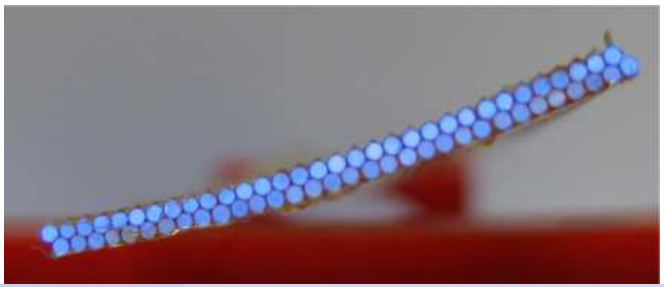




- Purpose:
  - Track reconstruction
  - Momenta: $> 125$ MeV/c
  - PID for low and medium momenta
- 2 layers of 16 double-sided sensors
  - (10 cm $\times$ 10 cm) active area
  - 300 $\mu$m thickness
- Inside accelerator vacuum, 5 cm close to electron beam

# The Scintillating Fiber Tracker (SFT)

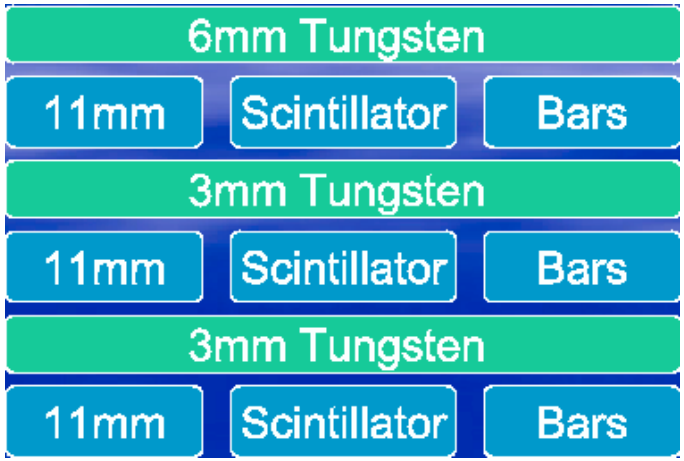


- Purpose:
  - Track reconstruction
  - Momenta: 250-1400 MeV/c (protons)
  - PID for medium and high momenta
- 2 Barrels with each 4 layers of scintillating fibers
- Per Barrel:
  - 2 parallel layers
  - 2 stereo-layers
  - Stereo angle: 10°



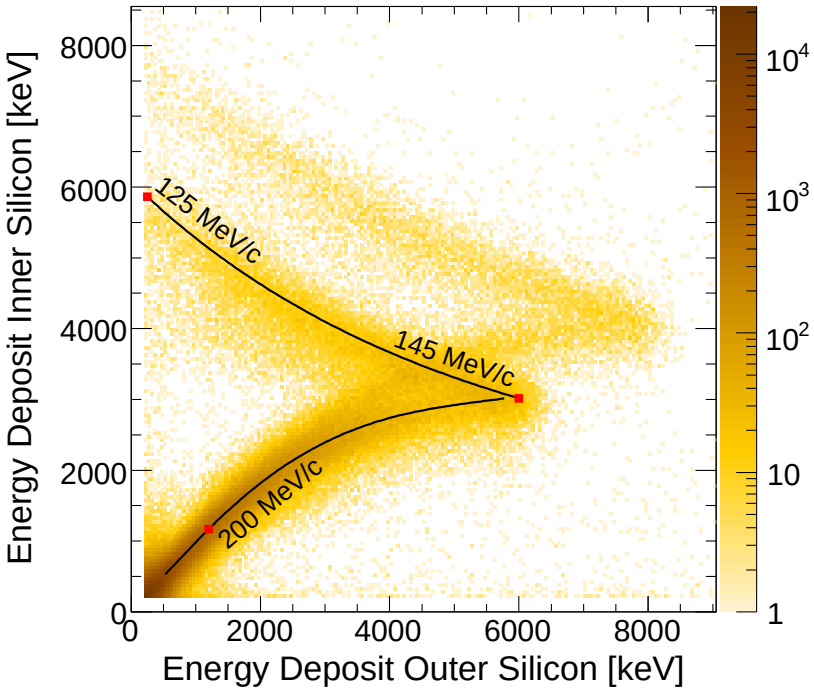
# The Photon Detector (PD)

- 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°/-45° angles

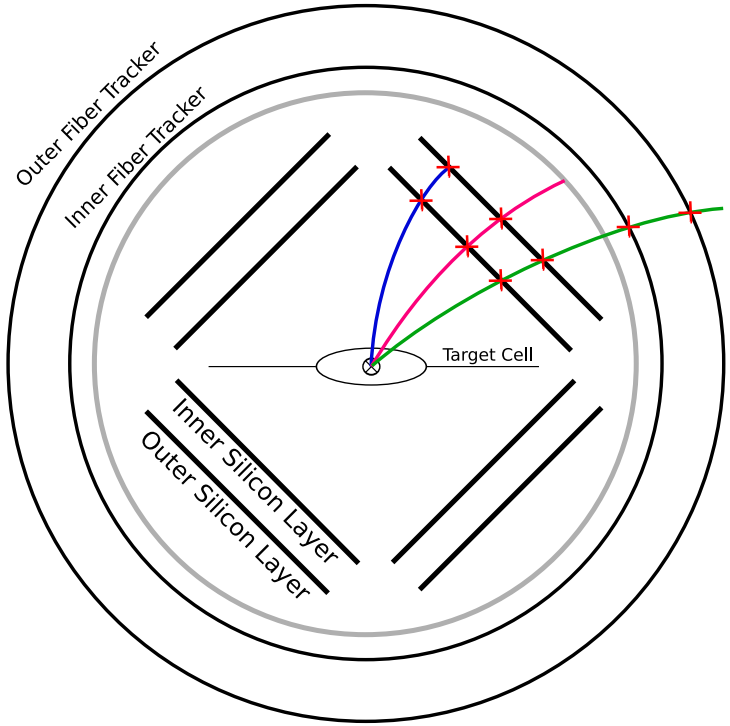


# Recoil Tracking

## Energy Deposit in the SSD

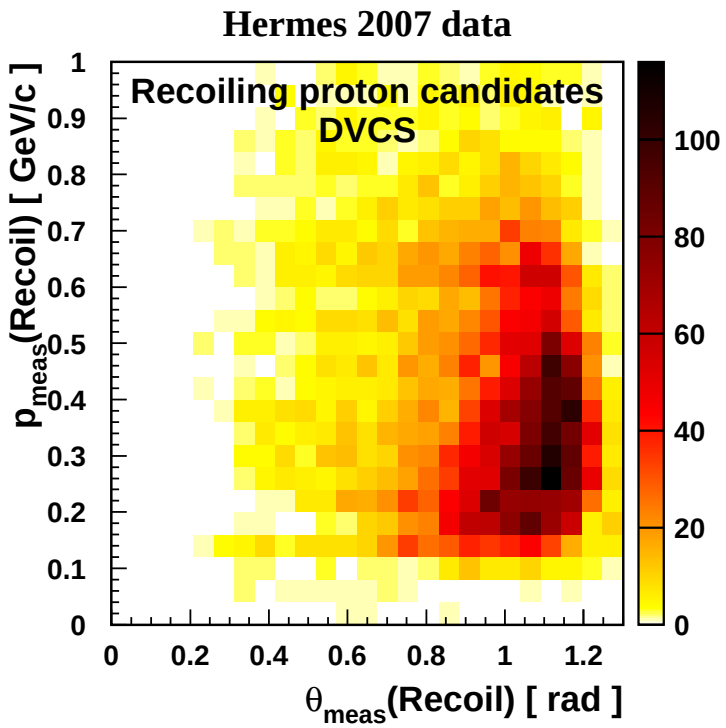



## Transverse View of Detector



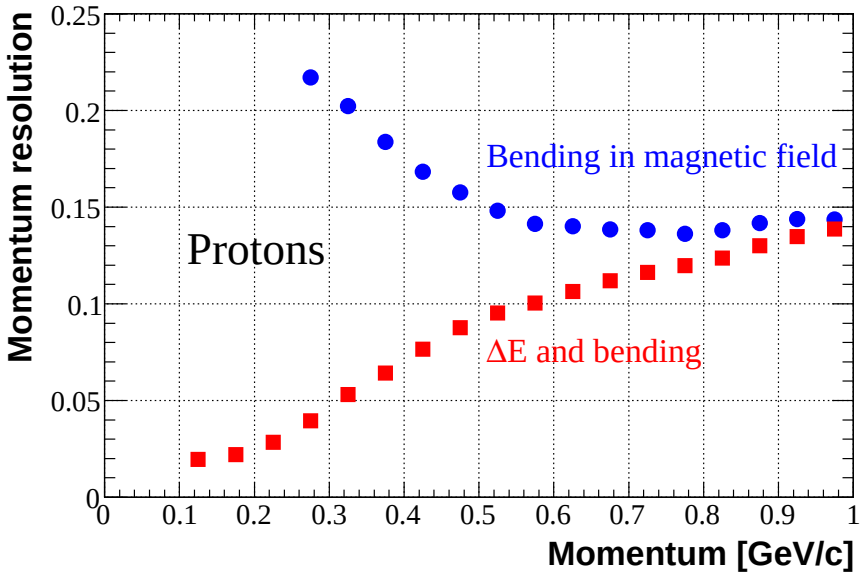

- **Low-energy protons**: momentum $\propto (\sum_i \Delta E_i)^{-1}$
- **Medium-energy protons**: momentum $\propto (\frac{\mathrm{d}E}{\mathrm{d}x})^{-1}$ (Bethe-Bloch)
- **Higher-energy particles (protons/pions)**: momentum $\propto eB\rho$

# Reconstructed Momenta and Angles




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

## Momentum resolution



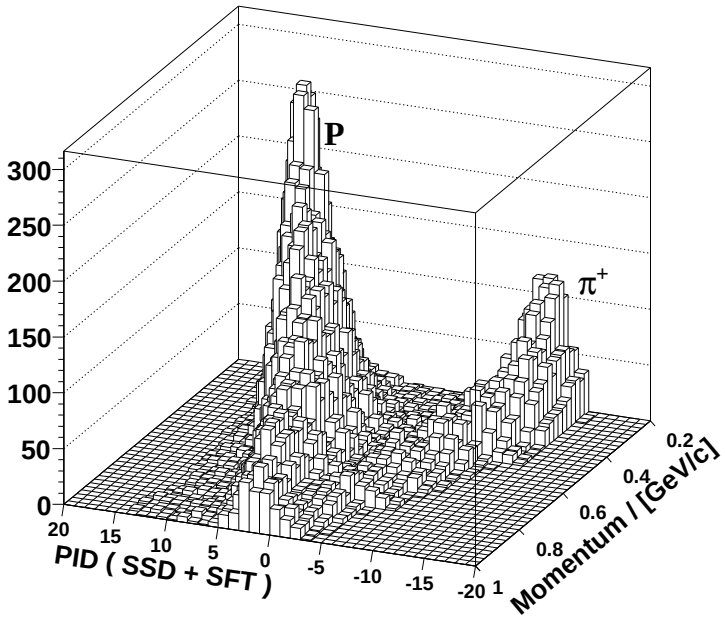

- $\Delta E$ accounted for in track fitting

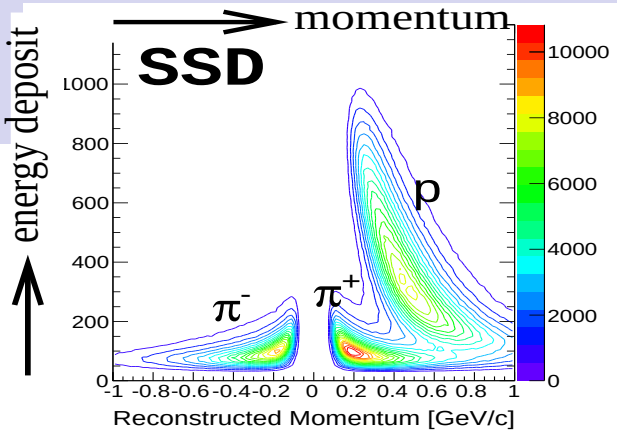
$\Rightarrow \Delta p/p$ improvement

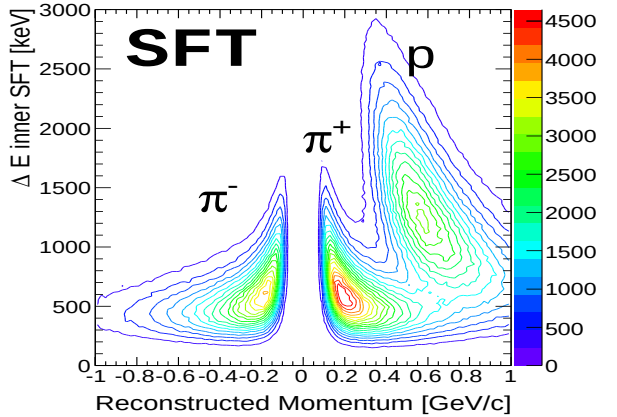
# Proton / Pion Separation

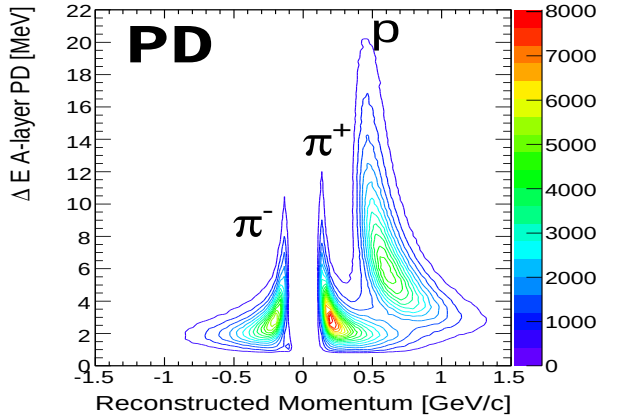
- $p < 600$ MeV/c: SSD + SFT (6 layers)
- $p > 600$ MeV/c: include PD
- Log-likelihood formalism:

$$\mathrm{PID} \equiv \log \frac{\mathcal{P}(\Delta E|\mathrm{proton}, p)}{\mathcal{P}(\Delta E|\mathrm{pion}, p)}$$

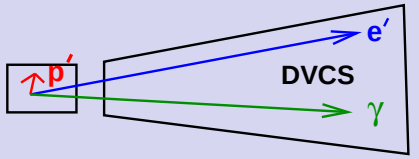


# DVCS and the Recoil Detector

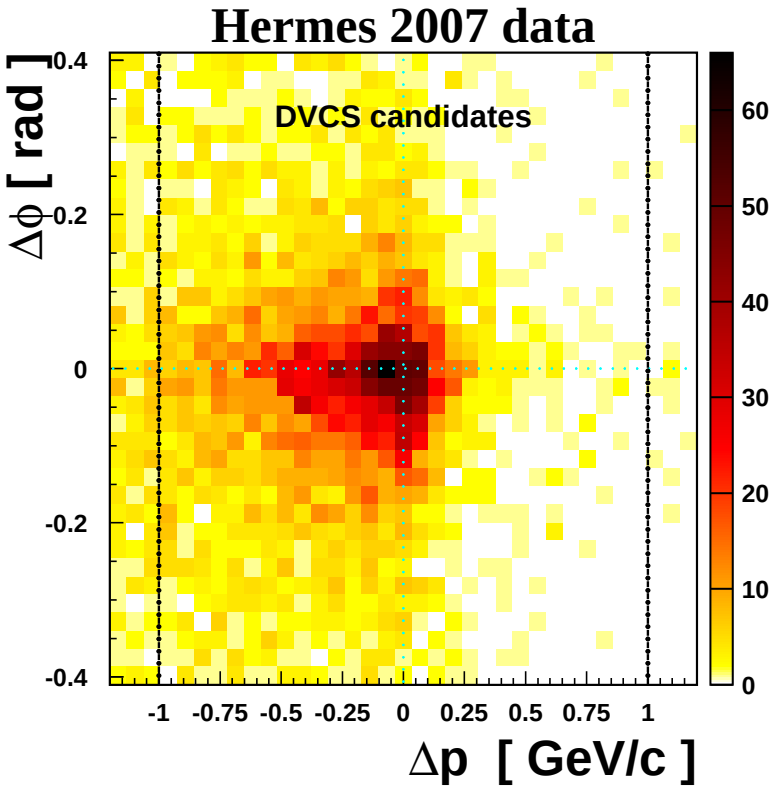


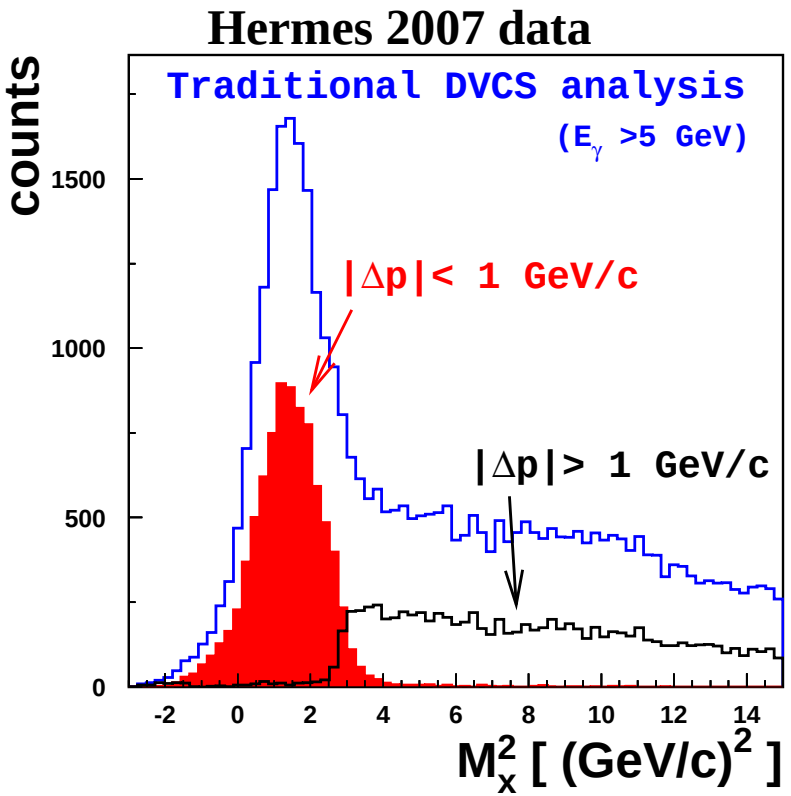

$ep \longrightarrow p'e'\gamma$

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

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

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



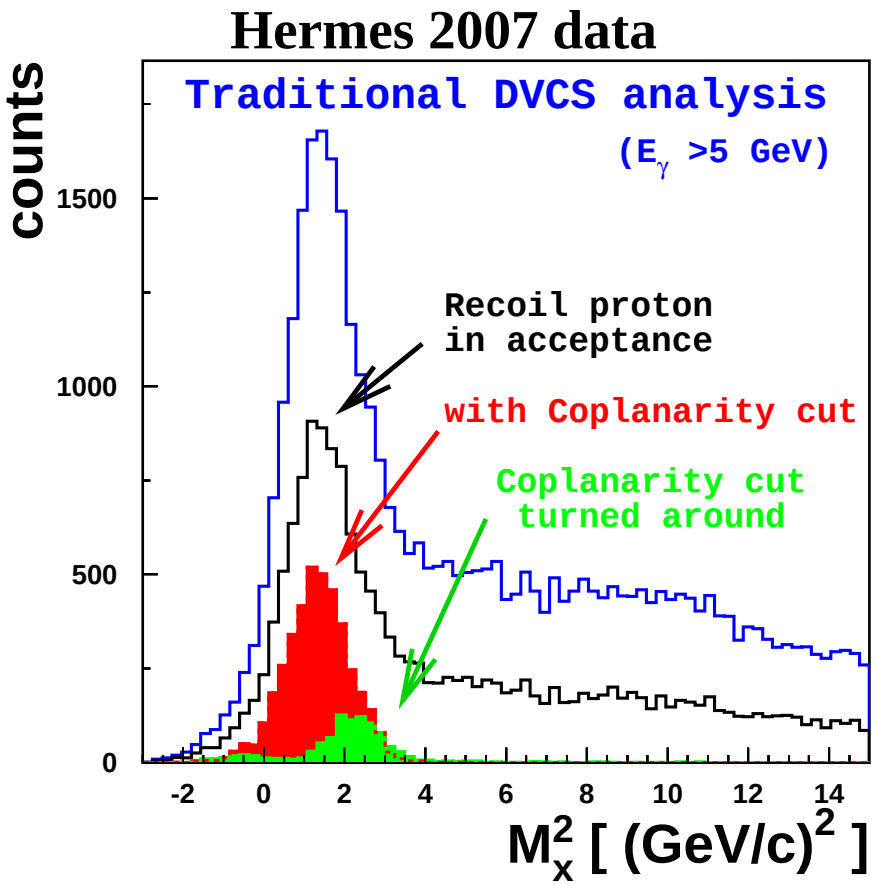
# Separation of Resonant States in DVCS (first look)

## DVCS / Bethe Heitler

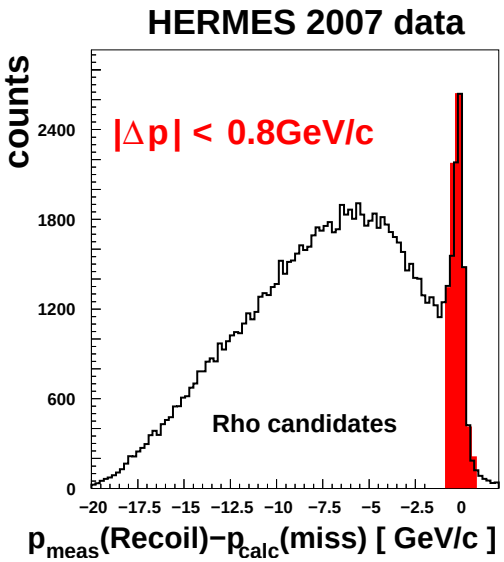
- Elastic:
  - $ep \rightarrow ep\gamma$
- Resonant ('associated'):
  - $ep \rightarrow e\Delta^+\gamma$

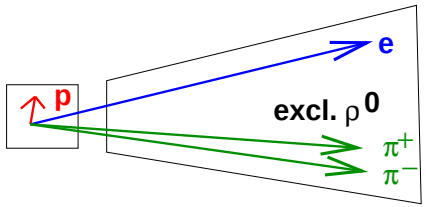
$$\Delta^+ \rightarrow \begin{cases} n\pi^+, & 1/3 \\ p\pi^0, & 2/3 \end{cases}$$

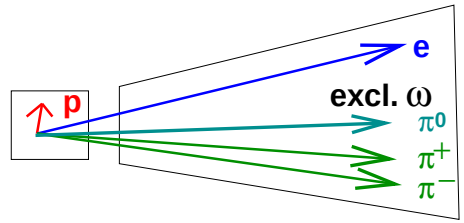
  - 12% of signal
- Presence of $\pi^0 \Rightarrow$ proton fails coplanarity cut
  - Select elastic:
    - ★ $|\Delta\phi| < 0.1$ rad
    - ★ $|p_T^{\mathrm{calc}}|/|p_T^{\mathrm{meas}}| = 0.5 \div 1.5$
  - Select resonant:
    - ★ $|\Delta\phi| > 0.35$ rad

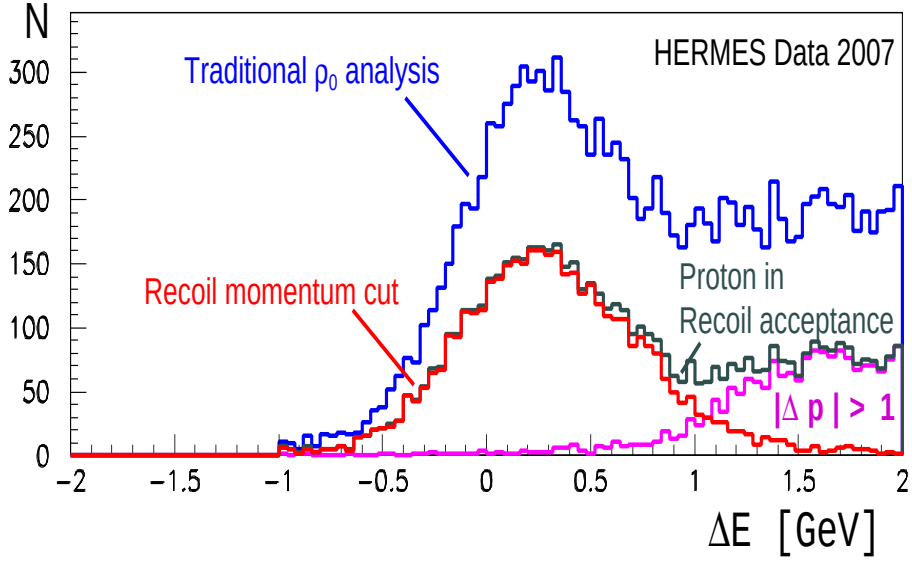


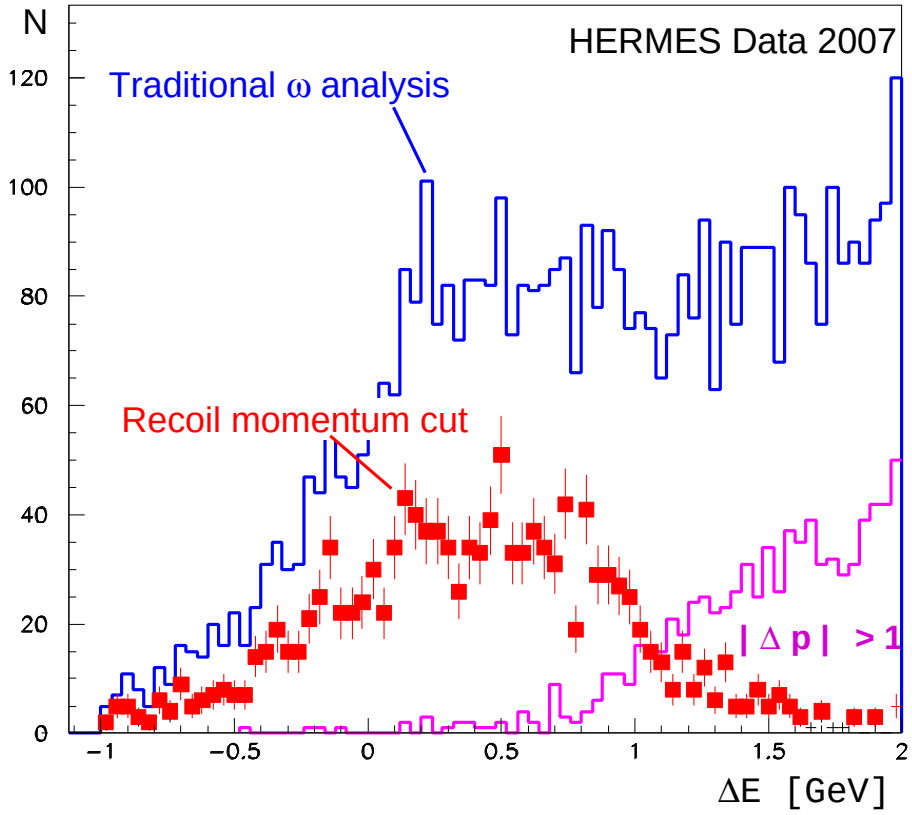
# Exclusive Mesons and the Recoil Detector



# 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