HERMES Measurements of DVCS from Proton and Deuteron Targets

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Status and Prospects for the HERMES Recoil Detector

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for the HERMES Collaboration

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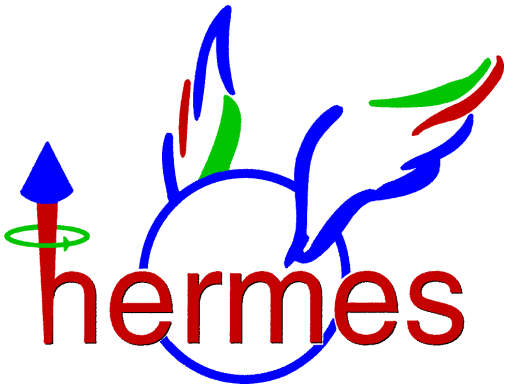
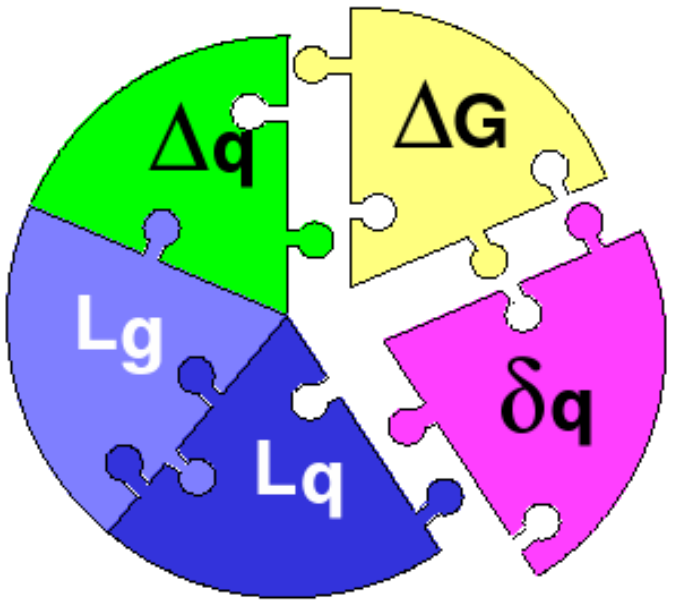


Outline

- Motivation
  - The Spin Structure of the Nucleon
  - GPDs and the DVCS process
- Recent HERMES results
  - Beam Charge Asymmetry (BCA)
  - Beam Spin Asymmetry (BSA)
  - Transverse Targe-Spin Asymmetry (TTSA)
- The HERMES Recoil Detector
  - Introduction
  - Current Status
- Outlook

The Spin Structure of the Nucleon



Nucleon Spin:

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

$\Delta\Sigma \approx 20 - 35\%$ measured in DIS

HERMES : $\Delta\Sigma \approx 0.3$

ΔG first Measurements

L_q, L_g unknown

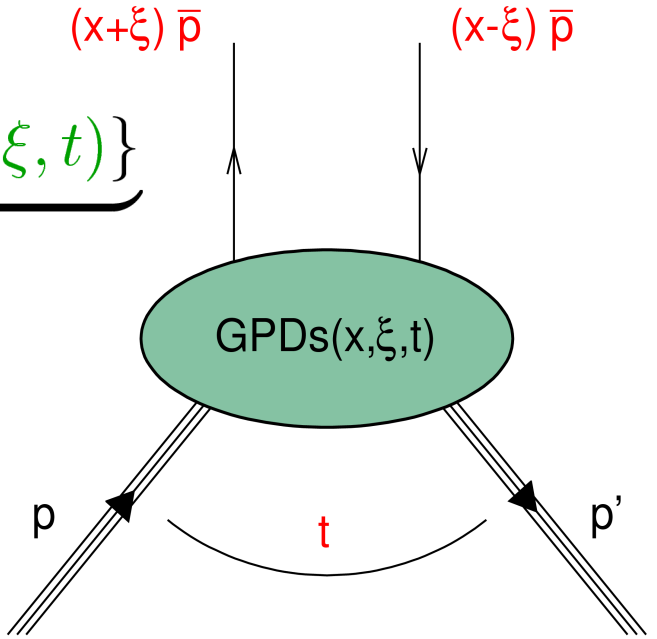
Ji Sum Rule - **Ji, PRL 78 (1997) 610**

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

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

ξ fraction of the momentum transfer

t invariant momentum transfer to the nucleon



Generalized Parton Distributions

Nucleon Structure: GPDs $H_q, \widetilde{H}_q, E_q, \widetilde{E}_q$

GPDs $\rightarrow$ PDFs

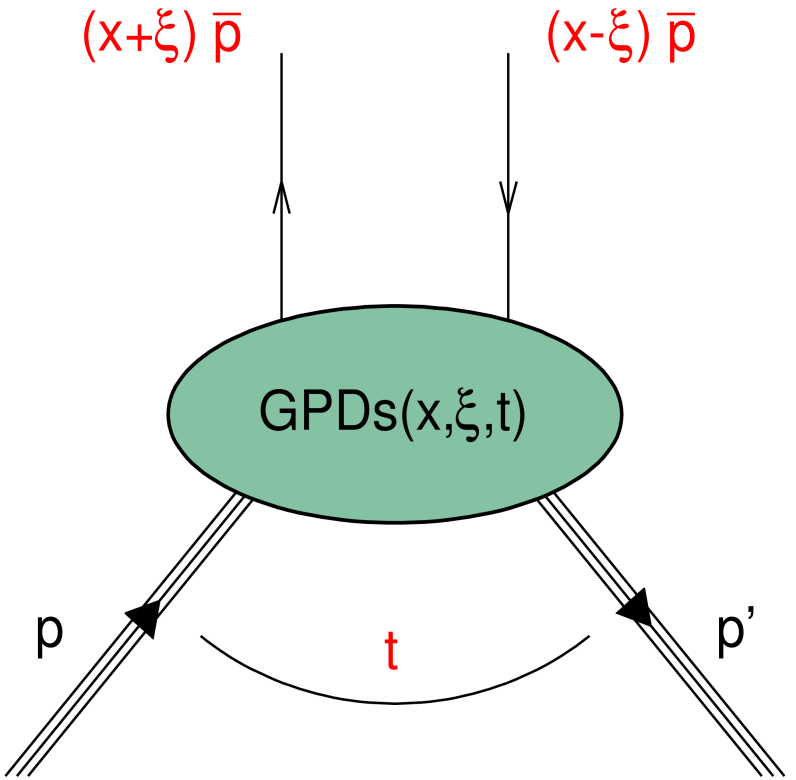
$$H_q(x,0,0) = q(x)$$

$$\widetilde{H}_q(x,0,0) = \Delta q(x)$$

GPDs $\rightarrow$ FFs

$$\int_{-1}^{1} dx H_q(x,\xi,t) = F_1^q(t)$$

$$\int_{-1}^{1} dx E_q(x,\xi,t) = F_2^q(t)$$



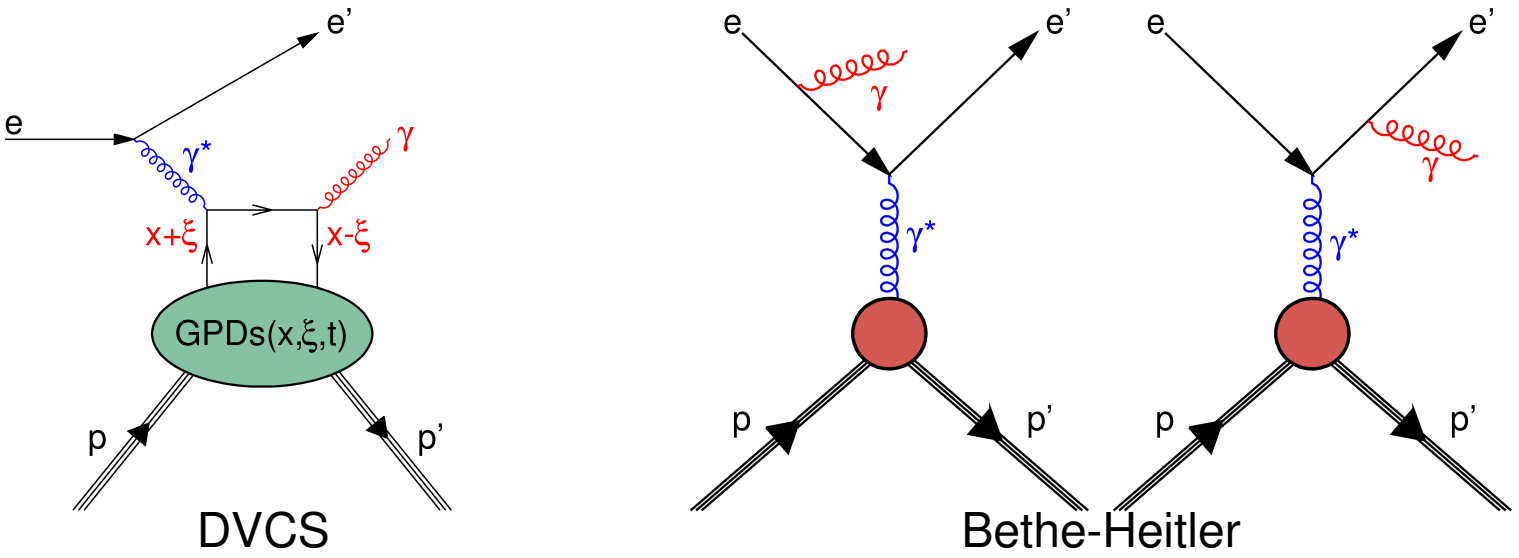
$H_q, \widetilde{H}_q$ conserve nucleon helicity

$E_q, \widetilde{E}_q$ flip nucleon helicity

GPDs are accessible in hard exclusive processes:

DVCS – Hard photoproduction of a real photon $(\gamma^* N \rightarrow N'\gamma)$

GPDs and the DVCS process



- Same final state in DVCS and Bethe-Heitler

$$d\sigma(eN \to eN\gamma) \propto |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \underbrace{\mathcal{T}_{BH}\mathcal{T}^*_{DVCS} + \mathcal{T}^*_{BH}\mathcal{T}_{DVCS}}_{\text{Interference Term}}$$

- $\mathcal{T}_{BH}$ is exactly calculable in QED
- $\mathcal{T}_{DVCS}$ is parameterized in terms of Compton form factors $\mathcal{H}_q, \widetilde{\mathcal{H}}_q, \mathcal{E}_q, \widetilde{\mathcal{E}}_q$ (convolutions of GPDs $H_q, \widetilde{H}_q, E_q, \widetilde{E}_q$)
- At HERMES kinematics: $|\mathcal{T}_{DVCS}|^2 \ll |\mathcal{T}_{BH}|^2$

GPDs accessible through cross-section differences and azimuthal asymmerties via interference term

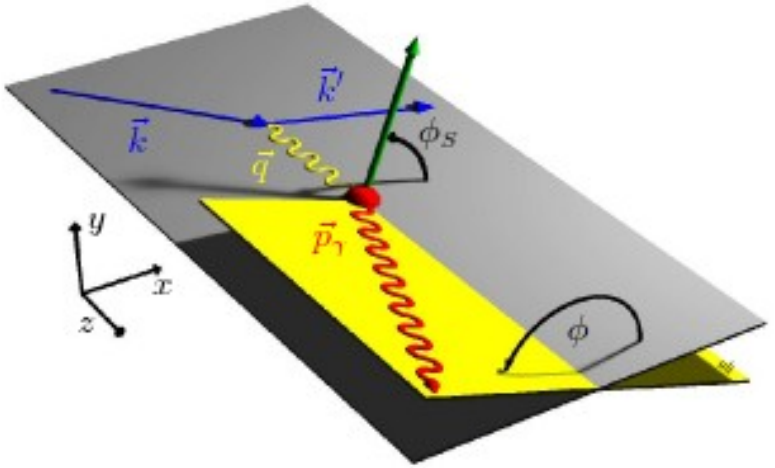
Azimuthal Asymmetries

- Beam Charge Asymmetry (BCA) $A_C(\phi)$

$$d\sigma(e^+,\phi) - d\sigma(e^-,\phi) \propto Re[F_1\mathcal{H}] \cdot \cos\phi$$

- Beam Spin Asymmetry (BSA) $A_{LU}(\phi)$

$$d\sigma(\overrightarrow{e},\phi) - d\sigma(\overleftarrow{e},\phi) \propto Im[F_1\mathcal{H}] \cdot \sin\phi$$



- Longitudinal Target Spin Asymmetry (LTSA) $A_{UL}(\phi)$

$$d\sigma(P^{\Rightarrow},\phi) - d\sigma(P^{\Leftarrow},\phi) \propto Im[F_1\tilde{\mathcal{H}}] \cdot \sin\phi$$

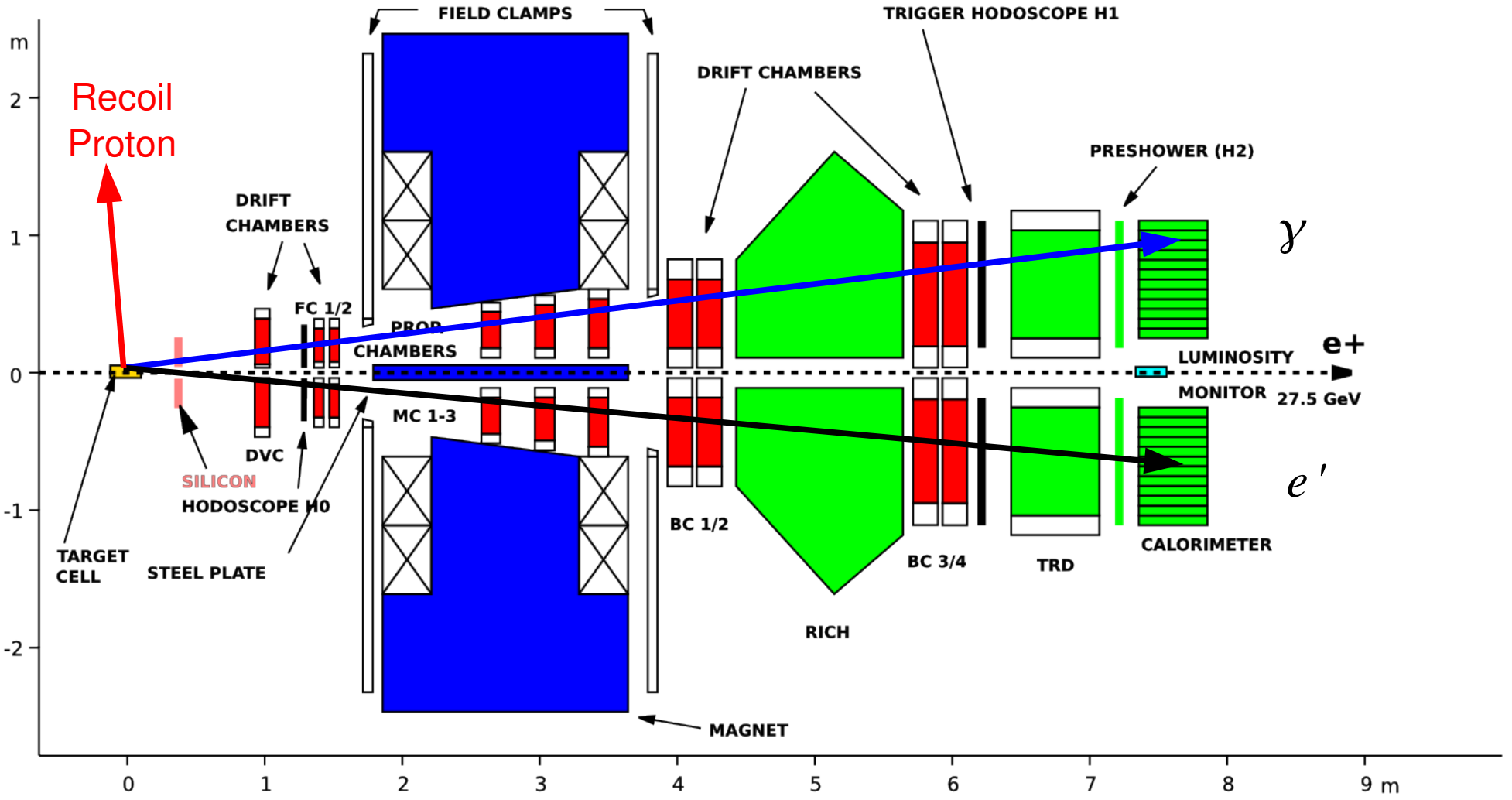
- Transverse Target Spin Asymmetry (TTSA) $A_{UT}(\phi,\phi_S)$

$$d\sigma(\phi,\phi_S) - d\sigma(\phi,\phi_S+\pi) \propto Im[F_2\mathcal{H} - F_1\mathcal{E}] \cdot \sin(\phi-\phi_S) \cdot \cos\phi$$
$$+ Im[F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}] \cdot \cos(\phi-\phi_S) \cdot \sin\phi$$

➡ TTSA is only asymmetry where GPD E is not suppressed

Models for E depend on J_q ➡ TTSA is sensitive to J_q

The HERMES Spectrometer



DVCS Event Selection

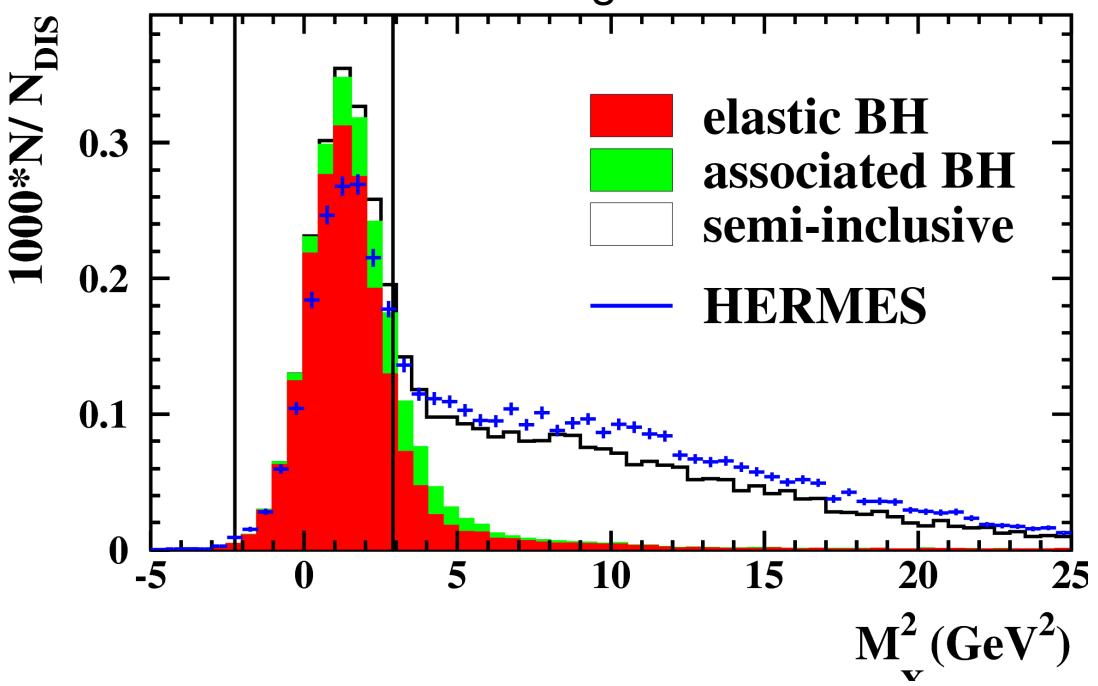
- Exactly one DIS lepton and one photon detected in the calorimeter
- Recoiling proton undetected

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

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

$$\underbrace{-(1.5)^2 < M_x^2 < (1.7)^2 \text{ GeV}^2}_{\text{exclusive region}}$$

Monte Carlo of background



$ep \to e'p\,\gamma$: Elastic BH

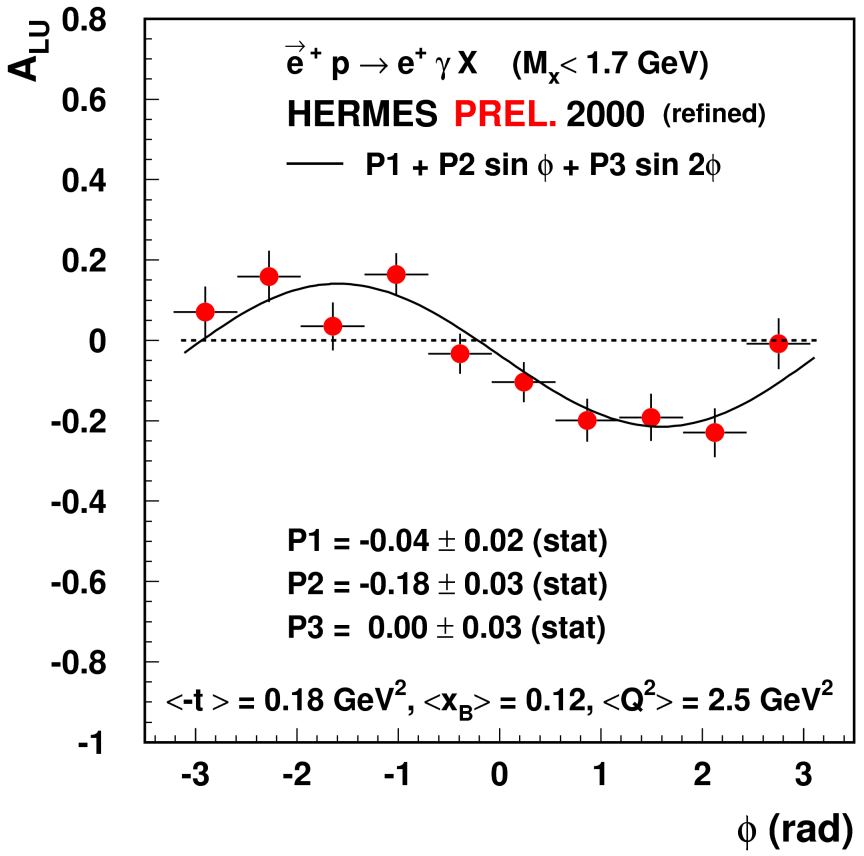
$ep \to e'\Delta^+\,\gamma$: Associated BH

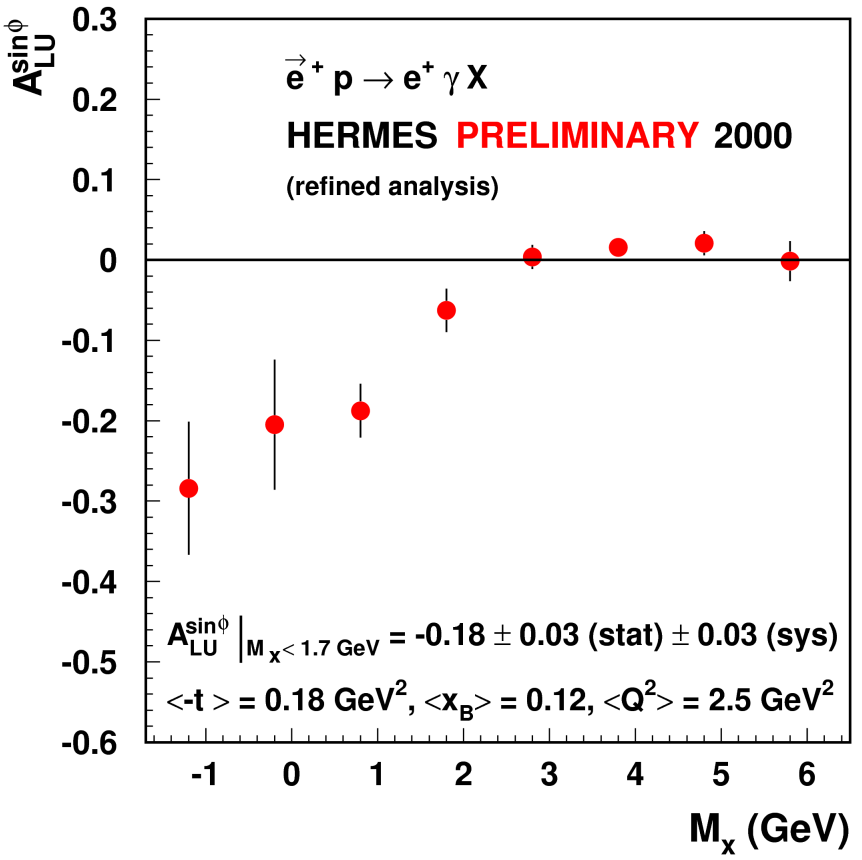
$ep \to e'\pi^0\,X$: Semi − Inclusive

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

Beam Spin Asymmetry (BSA)

$$A_{LU}(\phi) = \frac{1}{<|P_b|>} \frac{N^{\rightarrow}(\phi) - N^{\leftarrow}(\phi)}{N^{\rightarrow}(\phi) + N^{\leftarrow}(\phi)} \propto \frac{Im\mathcal{H}}{F_1} \cdot sin\phi$$





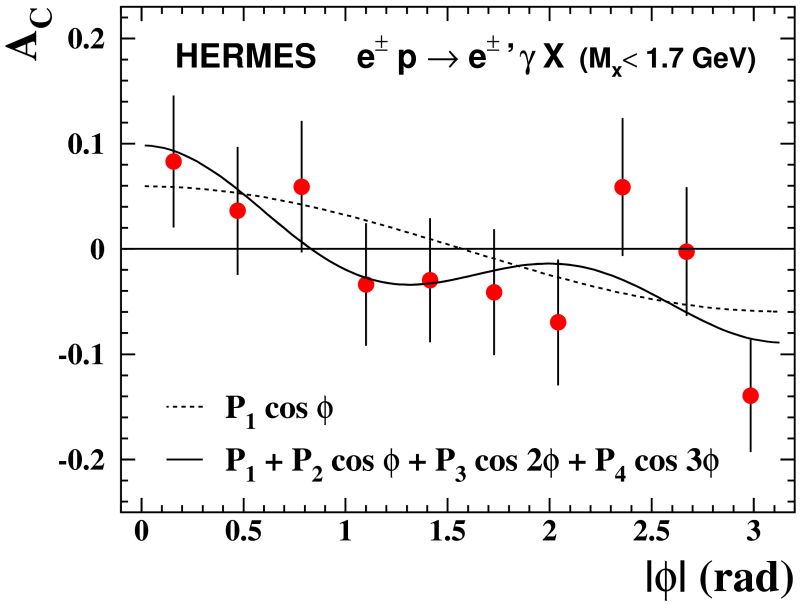
Expected $\sin\phi$ dependence in exclusive region $\Rightarrow Im\mathcal{H}$

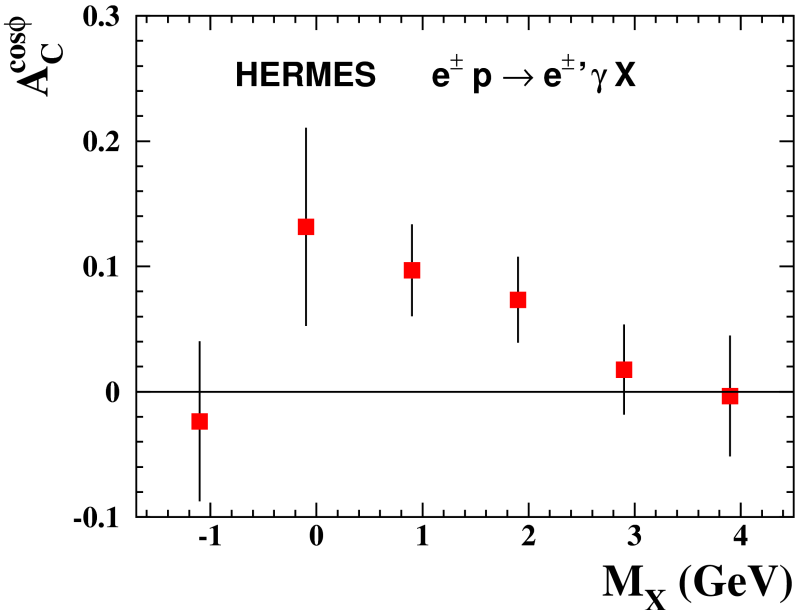
$\sin\phi$ amplitudes small and positive above exclusive region

A. Airapetian et al, Phys. Rev. Lett. 87 (2001) 182001

Beam Charge Asymmetry (BCA)

$$A_C(\phi) = \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)} \propto \frac{Re\mathcal{H}}{F_1} \cdot cos\phi$$





Symmetrizised BCA in exclusive bin

$\phi \to |\phi| \Rightarrow$ Cancel $\sin(\phi)$ dependence

$\cos\phi$ - amplitudes zero for higher missing masses

Solid curve – 4 Parameter Fit

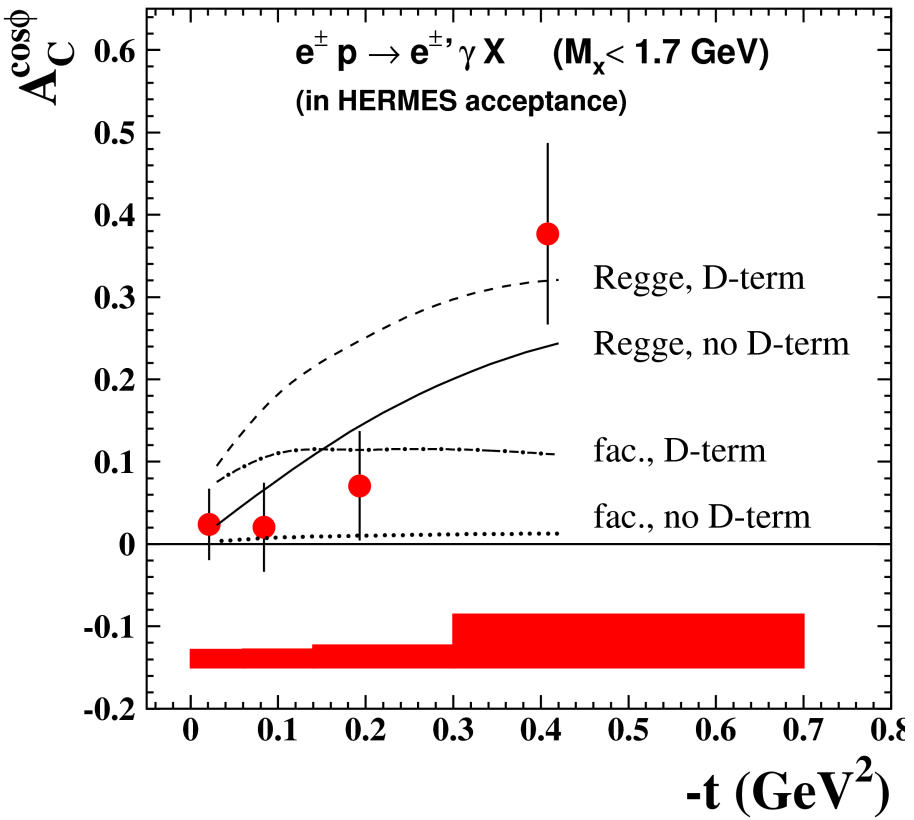
$P_1 + P_2 \cos\phi + P_3 \cos 2\phi + P_4 \cos 3\phi$

$$A_{C,Proton}^{\cos\phi} = 0.063 \pm 0.029(stat.) \pm 0.026(sys.)$$

Expected $\cos(\phi)$ dependence $\Rightarrow Re\mathcal{H}$

A. Airapetian et al, Phys. Rev. D 75 (2007) 011103(R)

BCA – Comparison to Model Calculations



- GPD Models
  - M. Vanderhaegen *et al.*, Phys. Rev. D 60 (1999)
  - K. Goeke *et al.*, Prog. Part. Nucl. Phys. 47 (2001)
- Dominated by GPD H, GPD E suppressed
- Curves represent 4 different parameter sets
- Model calculation at average kinematical values of bin

- Large contribution from associated production in last t-bin (not included in models)
- Regge-inspired t-dependence disfavoured by data

→ t-dependence of BCA gives possibility to constrain GPD H

Transverse Target-Spin Asymmetry

$$d\sigma(e^+, p^\uparrow) - d\sigma(e^+, p^\downarrow) \propto \; Im[F_2\mathcal{H} - F_1\mathcal{E}] \cdot \sin(\phi - \phi_S) \cdot \cos\phi + \ldots$$

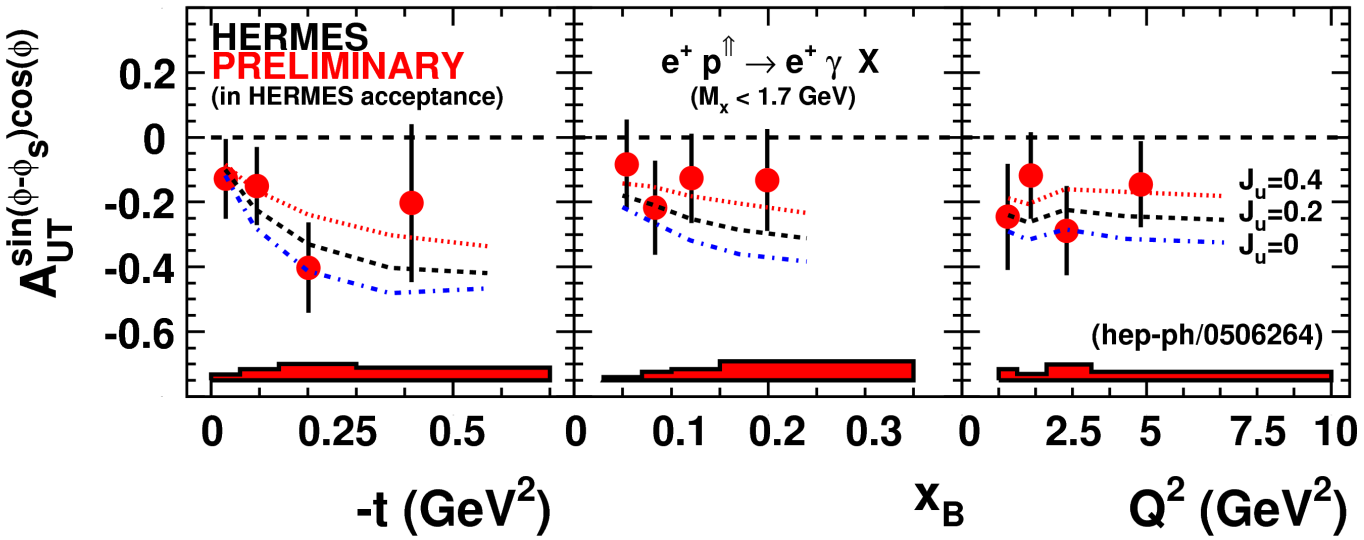
only asymmetry with GPD E is not suppressed

$J_q = \lim_{t\to 0} \frac{1}{2} \int_{-1}^{1} dx\, x[H_q(x,\xi,t) + E_q(x,\xi,t)]$ ➡ Access total angular momentum

$$A_{UT}(\phi,\phi_S) = \frac{1}{<|P_T|>} \frac{N^\uparrow(\phi,\phi_S) - N^\downarrow(\phi,\phi_S)}{N^\uparrow(\phi,\phi_S) + N^\downarrow(\phi,\phi_S)} =$$

$$A_{UT}^{\sin(\phi-\phi_S)\cos\phi} \cdot \sin(\phi - \phi_S)\cos\phi + A_{UT}^{\cos(\phi-\phi_S)\sin\phi} \cdot \cos(\phi - \phi_S)\sin\phi$$

Results from HERMES Data from 2002-04



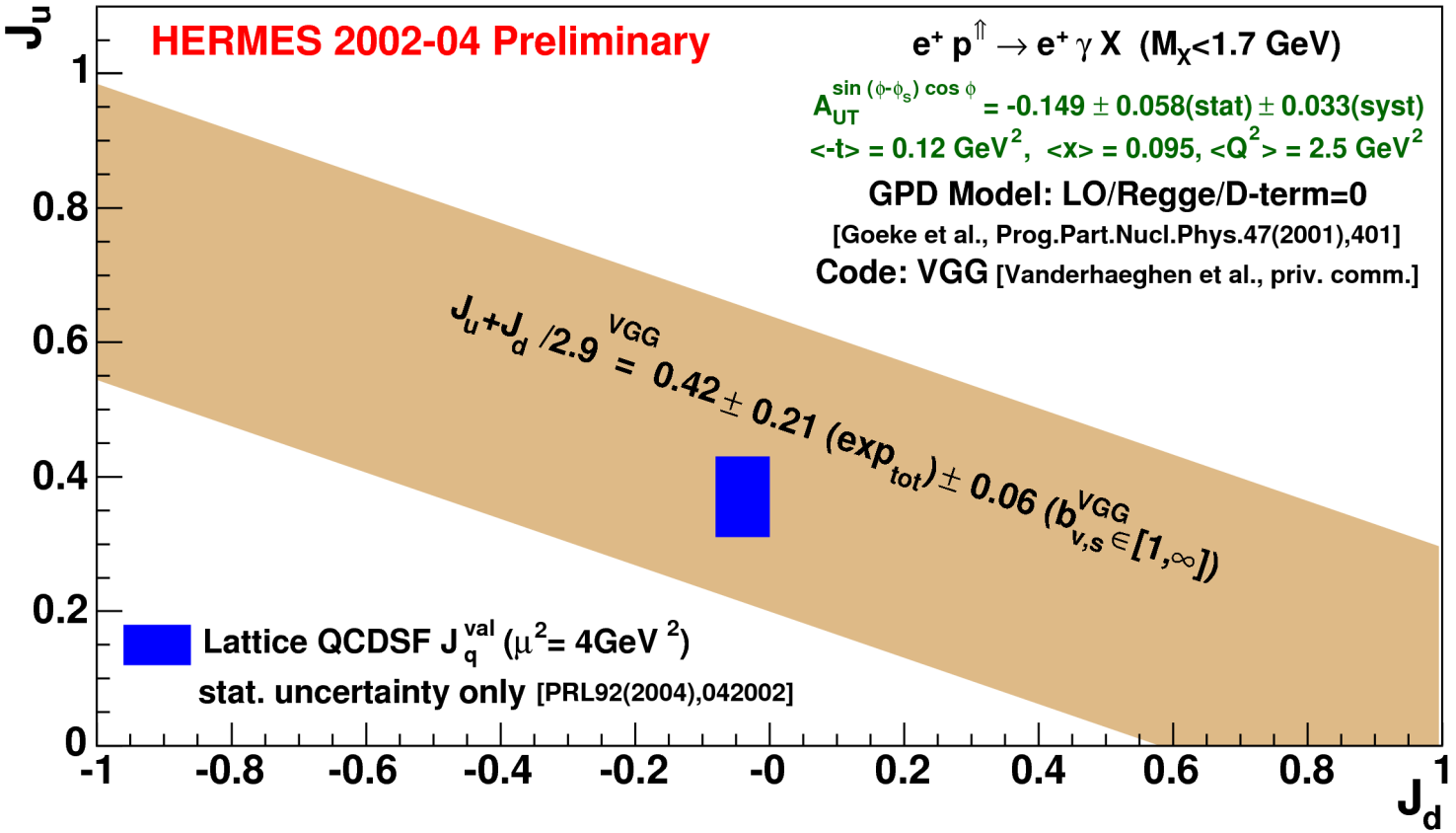
$A_{UT}^{\sin(\phi-\phi_S)\cos(\phi)}$ sensitive to J_u (calculations for $J_d = 0$)

First (Model-Dependent) Constraint on J_u, J_d

$$\chi^2(J_u, J_d) = \frac{\left[A_{UT}^{sin(\phi-\phi_S)cos(\phi)}|_{exp} - A_{UT}^{sin(\phi-\phi_S)cos(\phi)}|_{VGG(J_u,J_d)}\right]^2}{\delta A^2_{stat.} + \delta A^2_{sys.}}$$

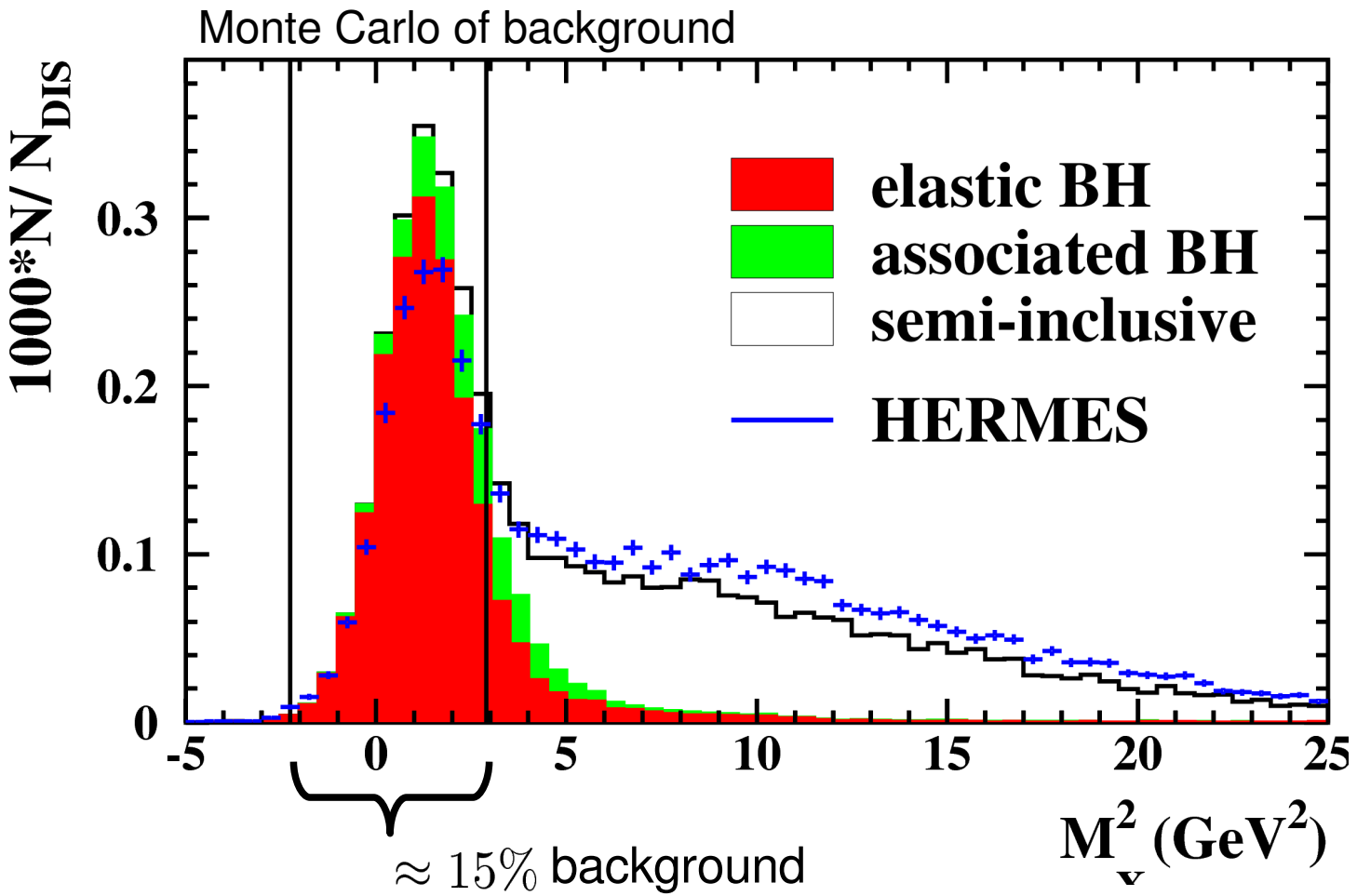
J_u and J_d free parameters in GPD-Model (*VGG*)

1σ constraint on J_u vs. J_d given by $\chi^2(J_u, J_d) \leq \chi^2_{min} + 1$

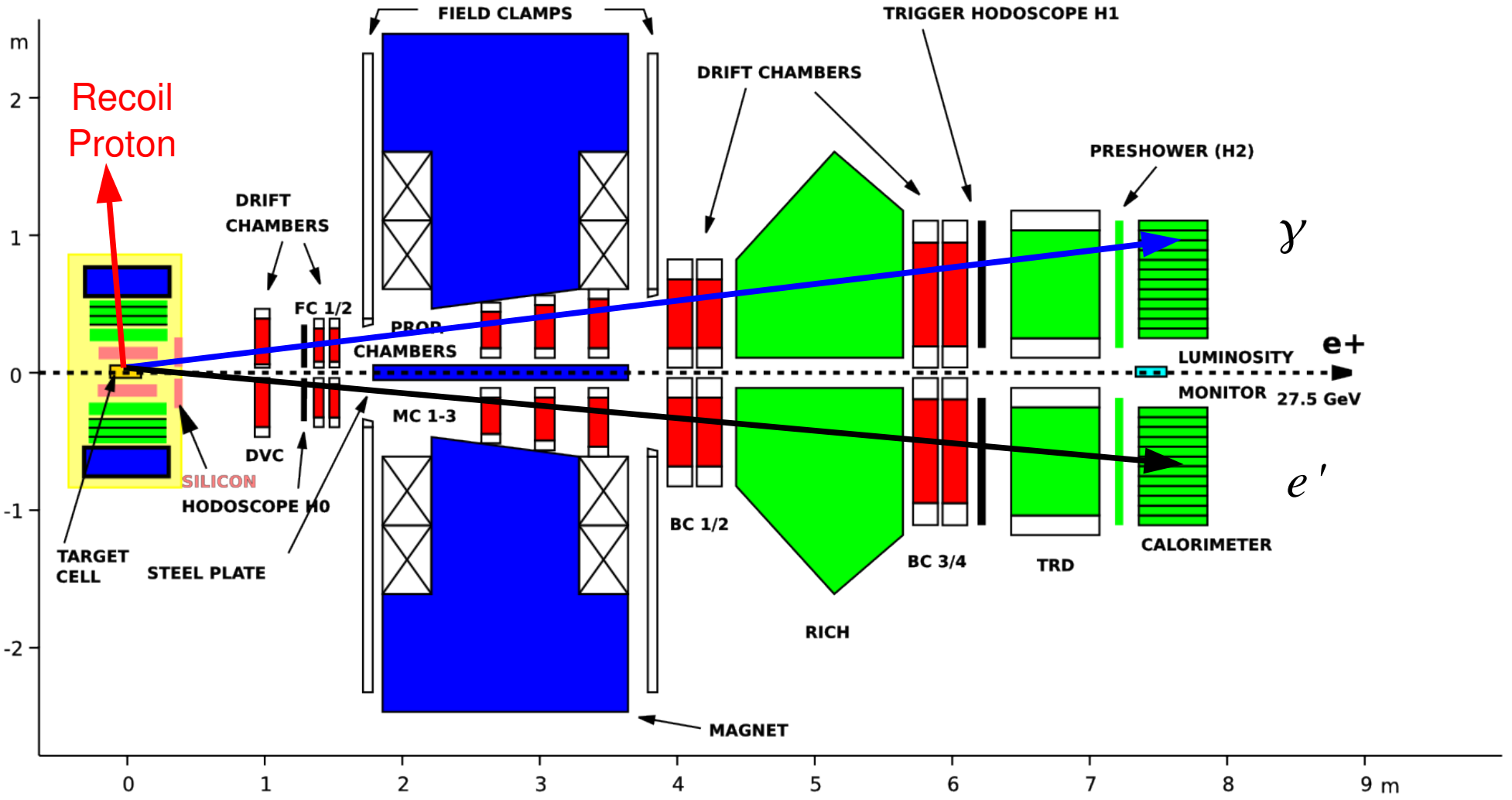


Large 2005 data sample yet to be added

DVCS Event Selection (revisited)

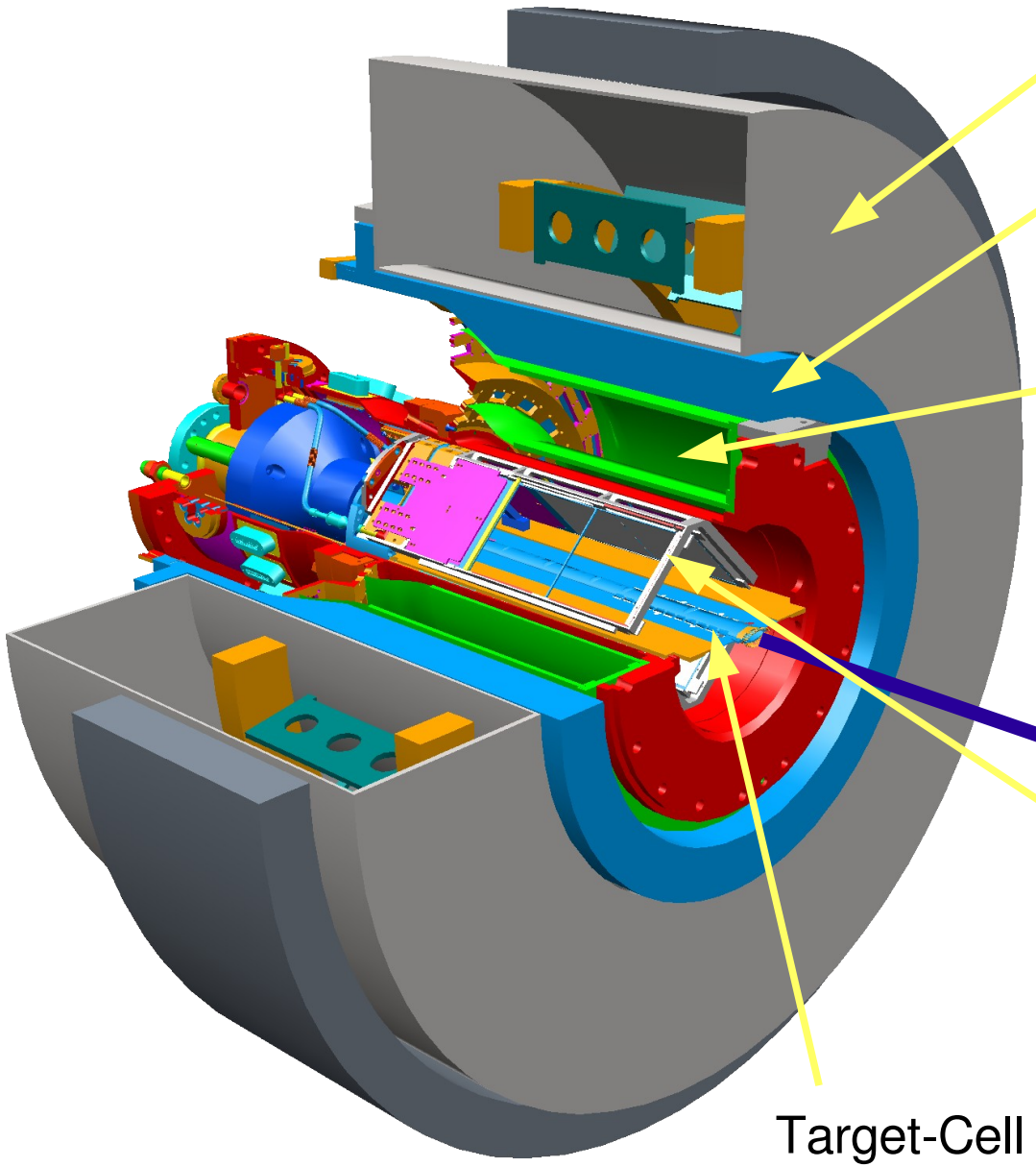


The HERMES Spectrometer with Recoil Detector



Installed in December 2005

The HERMES Recoil Detector



1 Tesla Superconducting Solenoid

Photon Detector
- 3 Layers of Tungsten/Scintillator
- PID for higher momenta
- detects $\Delta^+ \rightarrow p\pi^0$

Scintillating Fiber Detector
- 2 Barrels
- 2 Parallel- and 2 Stereo-Layers in each barrel
- 10° Stereo Angle
- Momentum reconstruction & PID

Beam

Silicon Detector
- 16 double-sided sensors
- 10 x 10 cm² active area
- 2 layers
- Inside beam vacuum
- Momentum reconstruction & PID

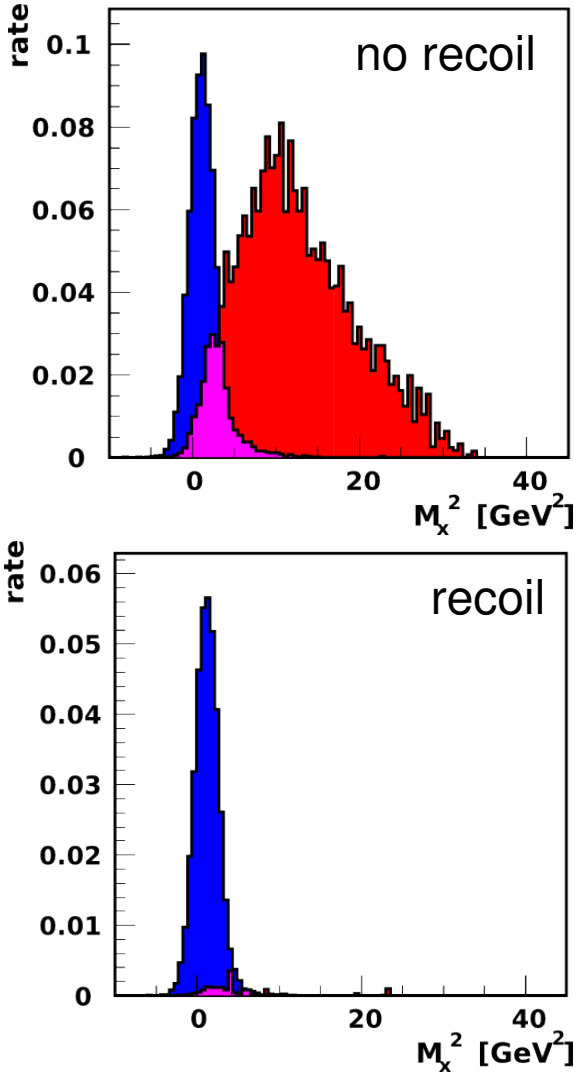
Target-Cell

The HERMES Recoil Detector

- 4 spacepoints from Silicon and Fiber Tracker
- Precise measurement of energy deposit in Silicon
  - Direct measurement of the momentum of the recoiling proton
    - Improved t resolution
- Proton / Pion PID
  - p < 0.6 GeV/c: energy deposits in Silicon and Fiber Tracker
  - p > 0.6 GeV/c: energy deposits in Photon detector
    - Reduction of background from semi-inclusive processes
- Identification of $\Delta^+ \to \pi^0 + p \to 2\gamma + p$
  - Reduction of background from associated BH

  ⇒ suppress background to ~ 1%

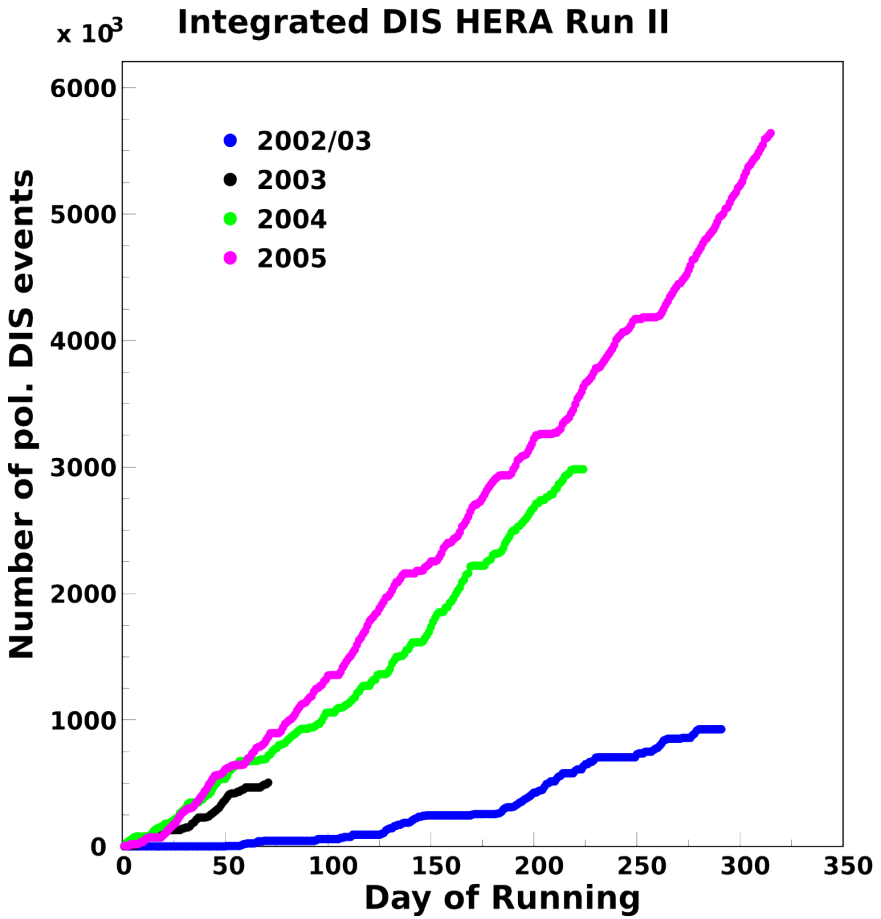
- Unpolarized target
  - Beam Charge Asymmetry (BCA)
  - Beam Spin Asymmetry (BSA)



The Target

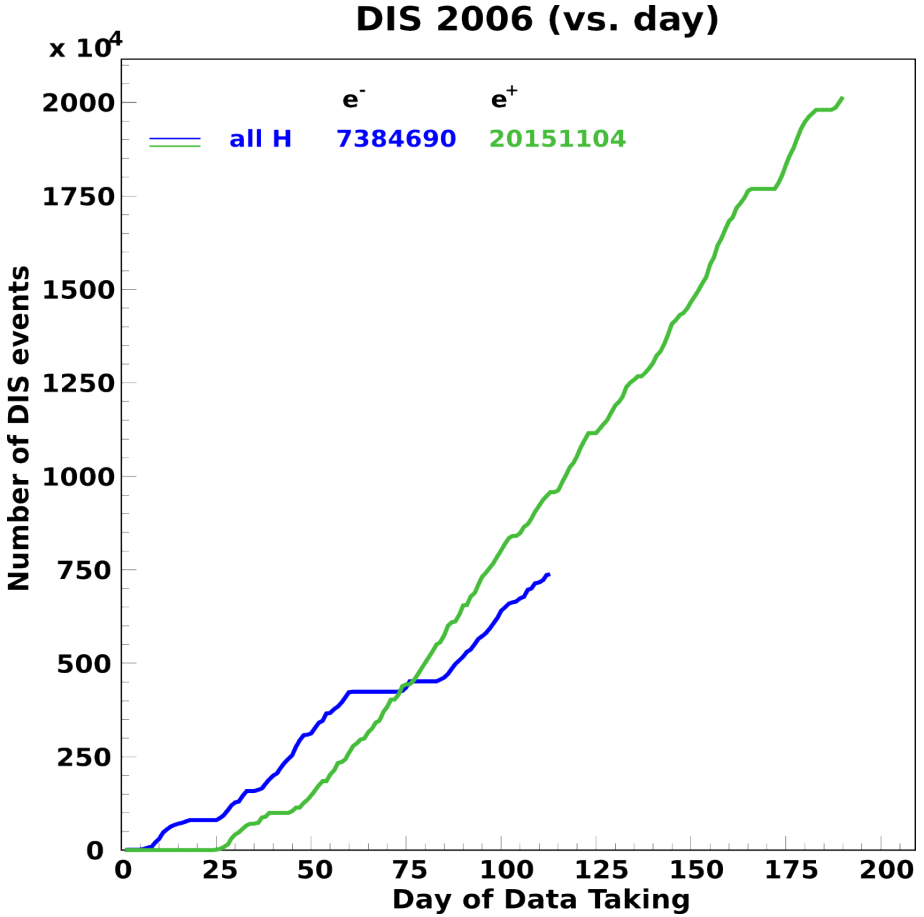
Order of magnitude higher density than polarized target

polarized



2002 – 2005:
~ 10 Mio. DIS events

unpolarized + Recoil



2006 only:
~ 27 Mio. DIS events

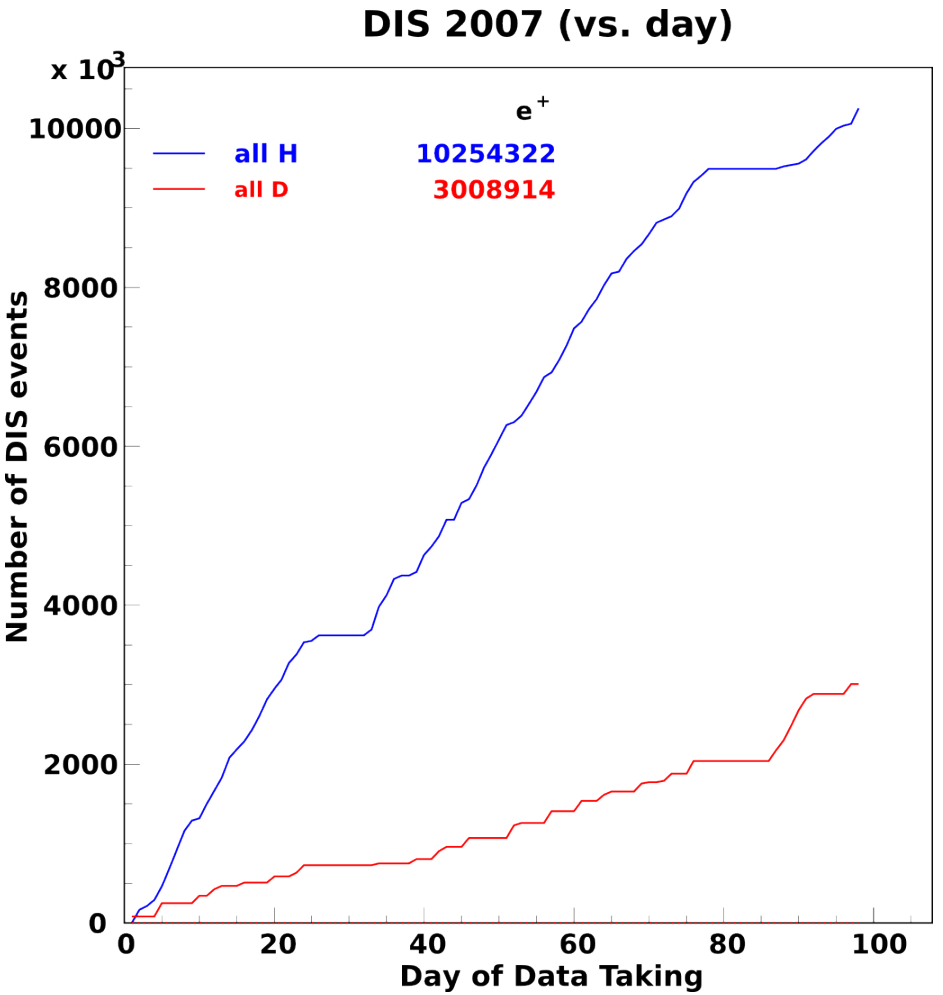
Data Taking and General Performance

- Data taking started in February 2006 with electron beam
  - ~ 7.4 Mio. DIS events from hydrogen target
  - ~ 1.4 Mio. DIS events from deuterium target
  - Fiber Tracker fully operational

- Switch to positron beam in July 2006
  - ~ 20.1 Mio. DIS events from hydrogen target
  - ~ 5.1 Mio. DIS events from deuterium target
  - Fiber Tracker and Photon detector fully operational
  - Finished commissioning of Silicon detector in September 2006

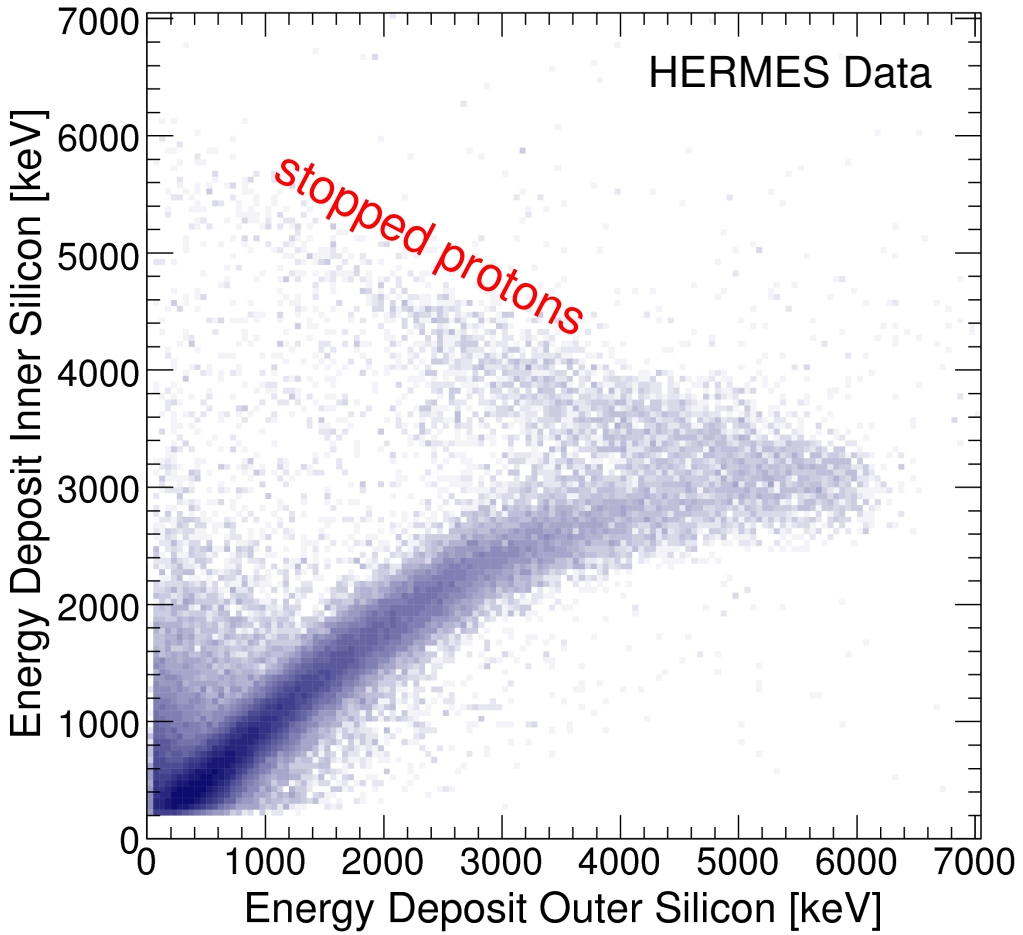
→ Recoil Detector fully commissioned and running stable

- Already 13 Mio. DIS events in 2007



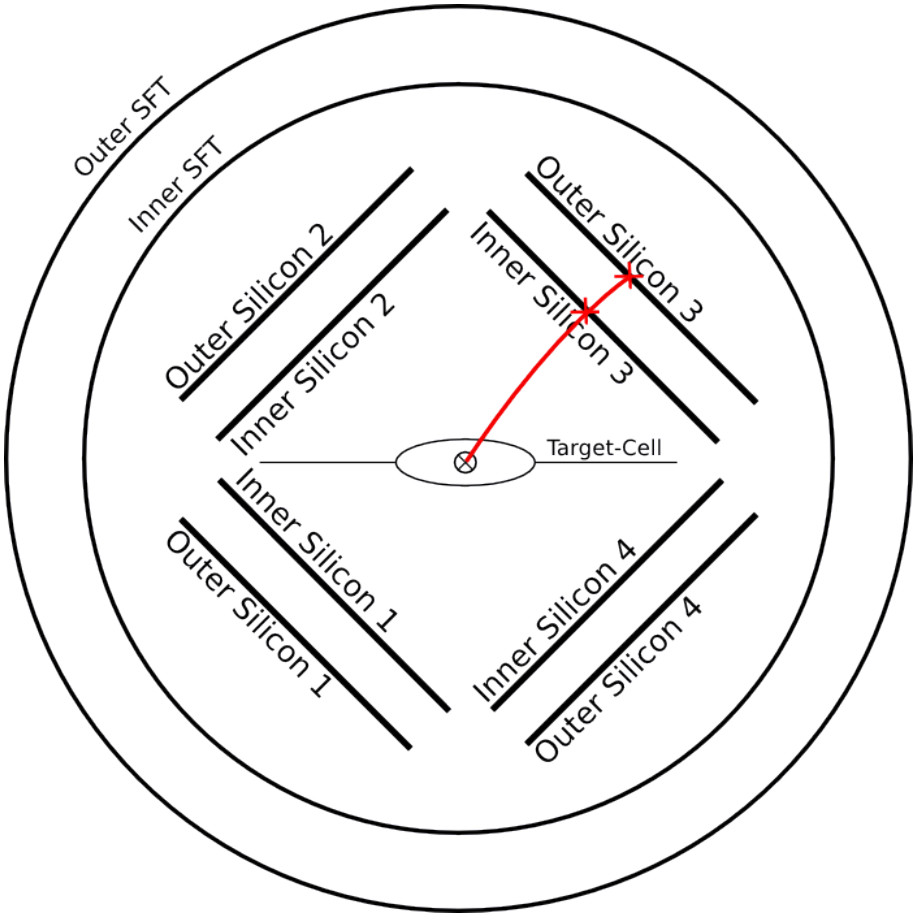
First Recoil Detector Results

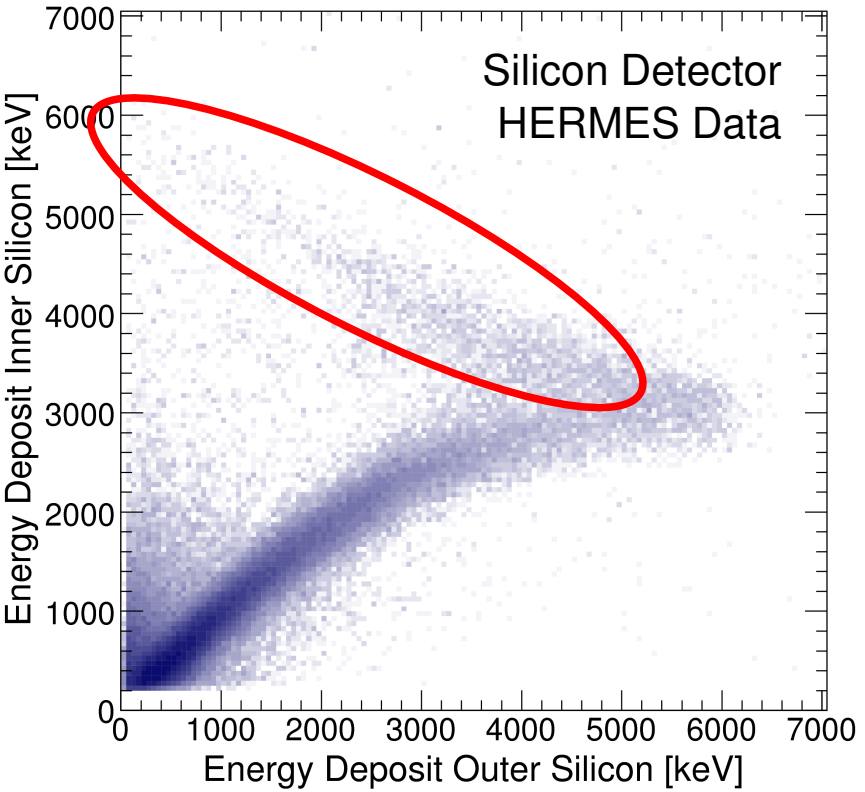
Energy deposits in inner Silicon detector vs. outer Silicon detector



Silicon sensors and front-end electronics 5 cm close to 27.6 GeV electron beam with 10.4 MHz bunch frequency

Momentum Reconstruction

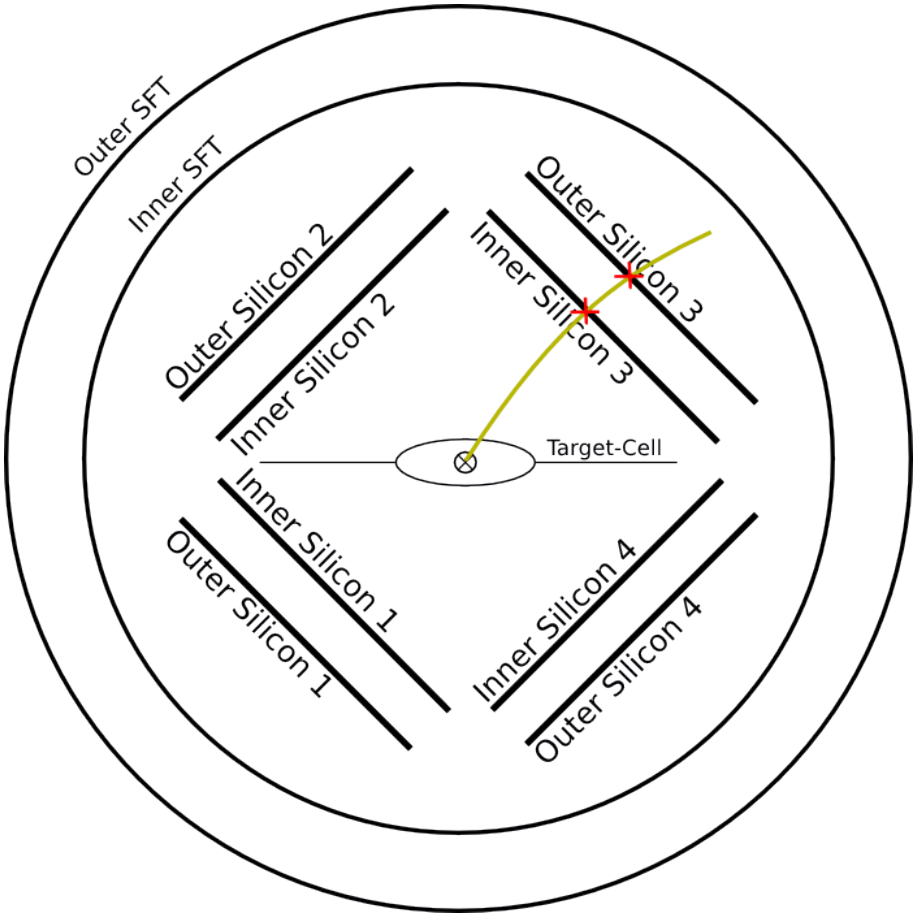


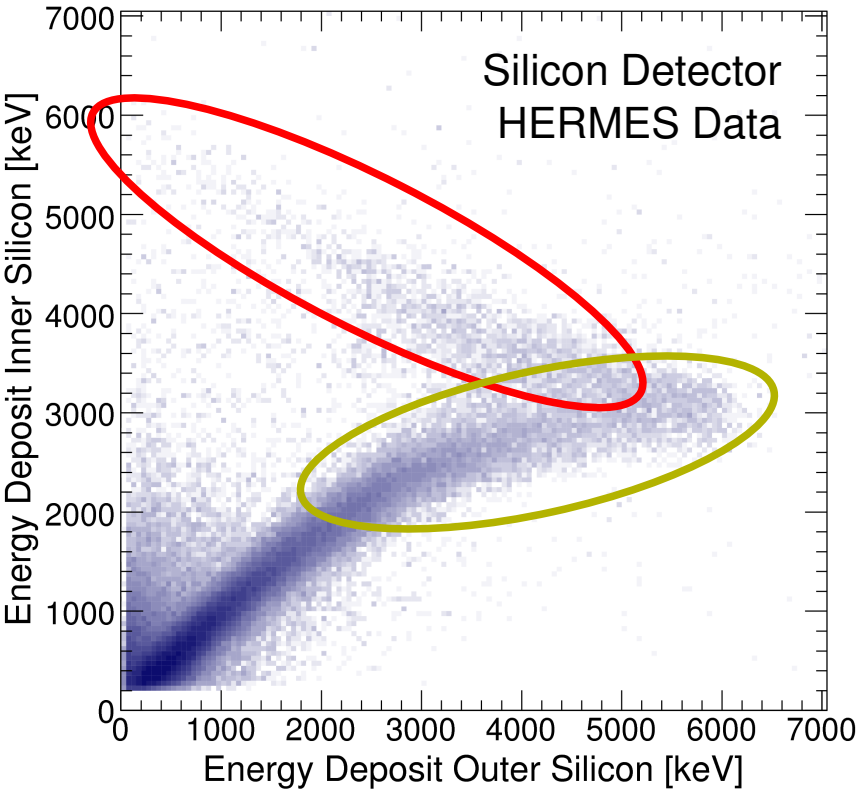


Low momentum protons (stopped in outer Silicon)

➔ Sum of energy deposits

Momentum Reconstruction





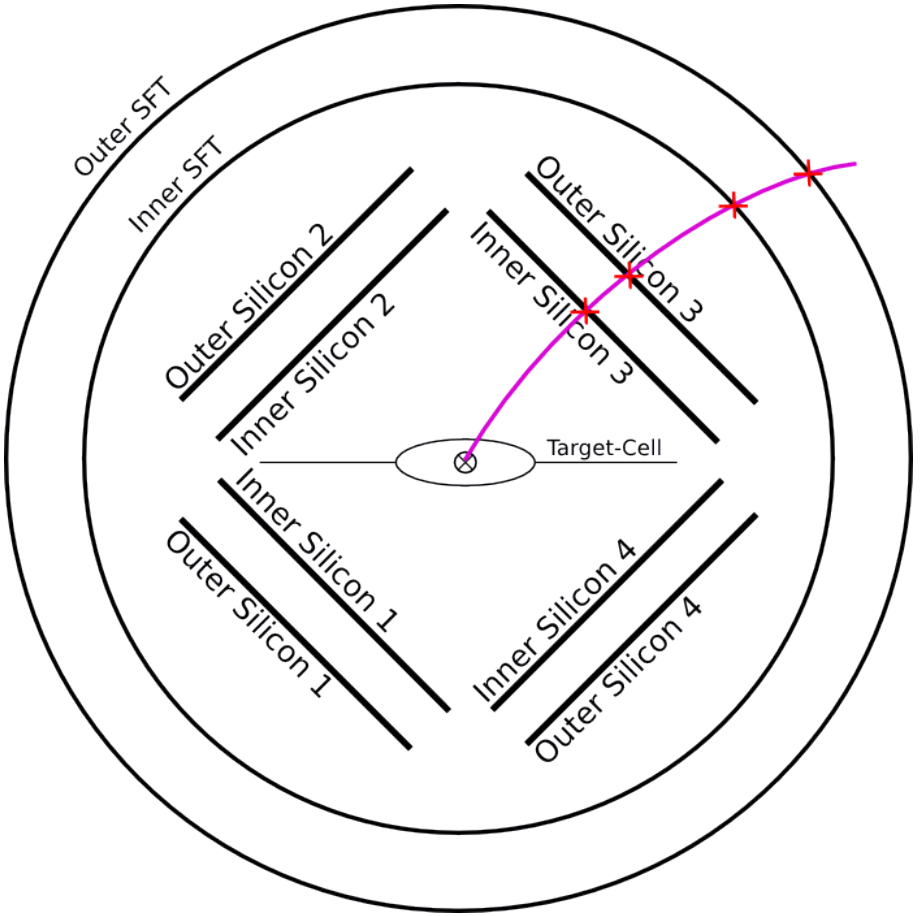
Low momentum protons (stopped in outer Silicon)

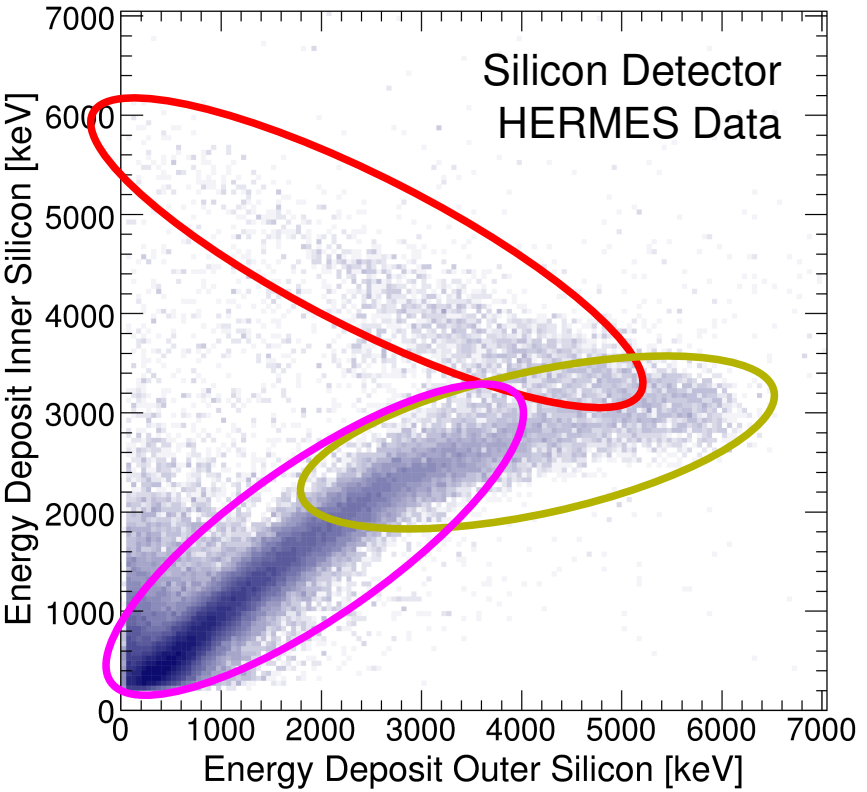
➔ Sum of energy deposits

Higher momentum protons

➔ dE/dx

Momentum Reconstruction





Low momentum protons (stopped in outer Silicon)

➔ Sum of energy deposits

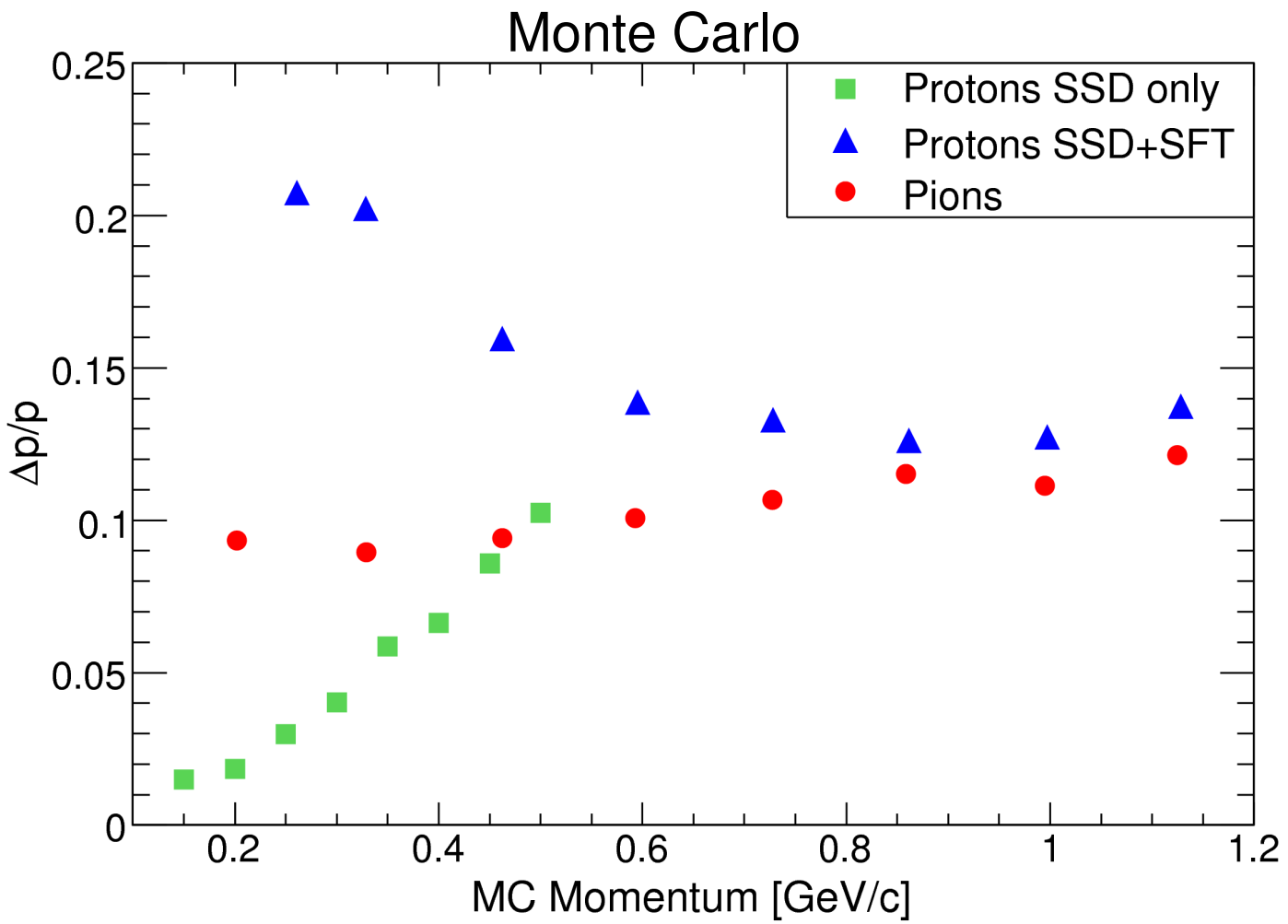
Higher momentum protons

➔ dE/dx

High momentum particles

➔ Bending in magnetic field

Momentum Resolution

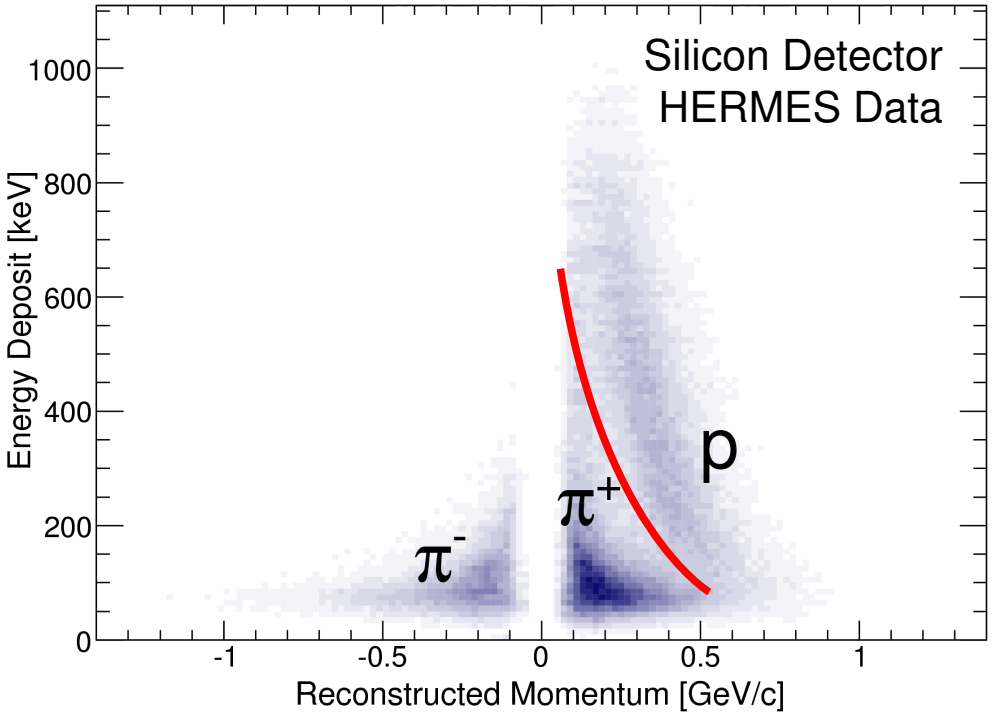


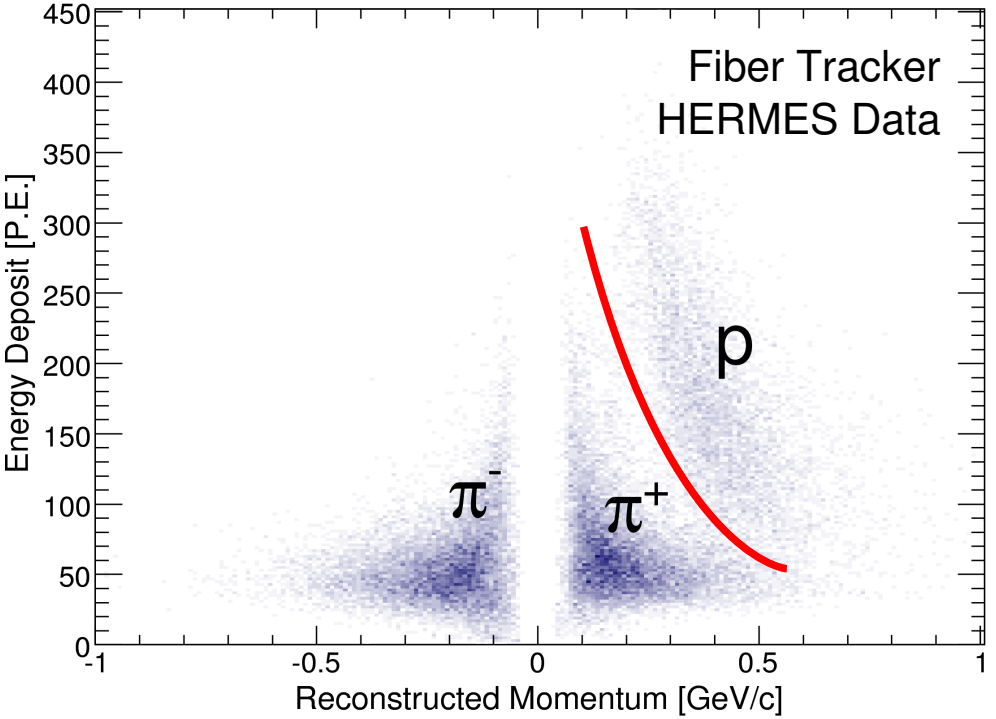
- Δp/p < 15% over the full proton momentum range

Particle Identification

Energy deposits in individual detection layers allow Proton / π^+ separation

- Tracks reconstructed with Silicon and Fiber Tracker information
- Measured residuals from magnet-off data: 210 µm for Silicon
  350 µm for Fiber Tracker





Preliminary energy calibration

- Use energy signal from MIPs (pions) for calibration

Outlook

- Take data until July, 2nd (10 a.m.)
- Analysis with Recoil Detector
  - DVCS Beam Charge Asymmetry (BCA)
    - challanging as only Fiber Tracker operational
  - DVCS Beam Spin Asymmetry (BSA)
  - Hard exclusive meson production $(\pi^{\pm}, \pi^{0}, K^{\pm}, \rho^{0}, ...)$
    - different flavor combinations of GPD's
- Conventional analysis (without Recoil Detector)

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    - different flavor combinations of GPD's
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... see you next year with physics results from HERMES with Recoil Detector ...

Projections for DVCS with Recoil Detector