# HERMES Results on Hard-Exclusive Processes and Prospects Utilising the New Recoil Detector

Inti Lehmann
University of Glasgow

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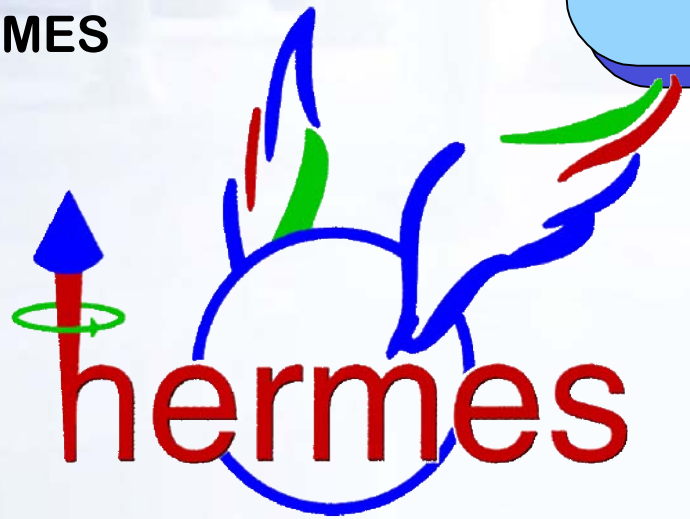
- Glimpse on physics
- Results from HERMES
- Recoil at HERMES

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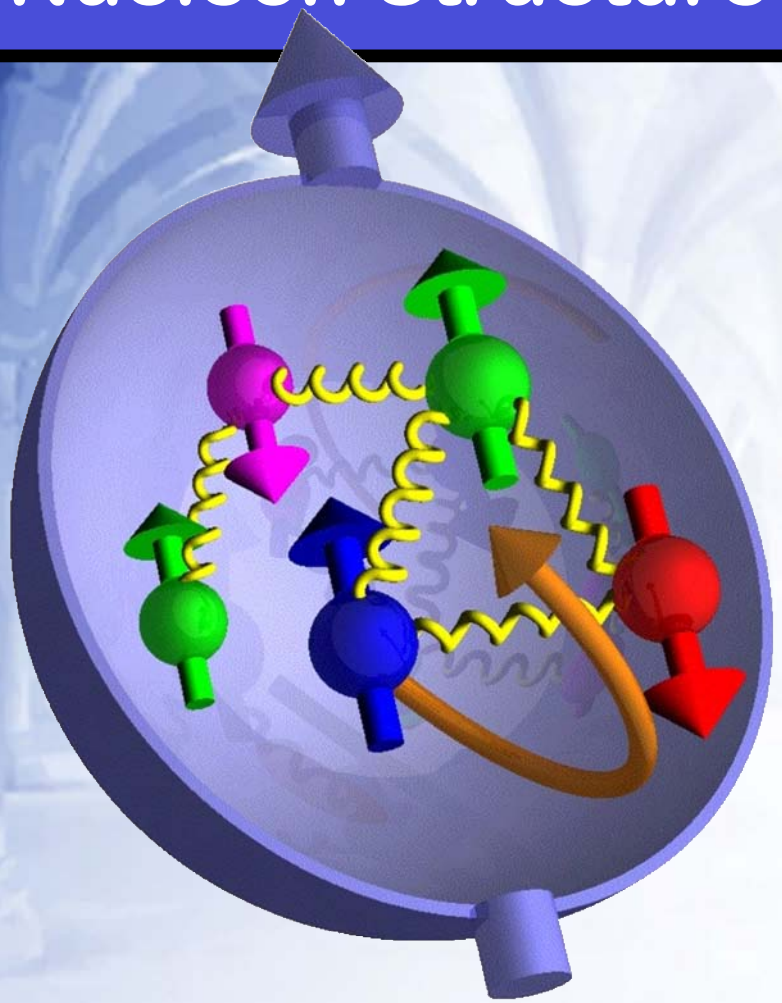
# Nucleon Structure



- **Proton spin**

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + J_g$$

- $\Delta\Sigma$ : **quark spin**
  - about 1/3 (HERMES,…)
  - See P.Kravchenko's talk
- $L_q$ : **quark ang. momentum**
  - unknown
- $J_g$ : **gluon tot. ang. mom.**
  - unknown

- **How is the spin distributed?**

# Nucleon Structure

- **Proton spin**

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + J_g$$

- **Ji Sum Rule:**

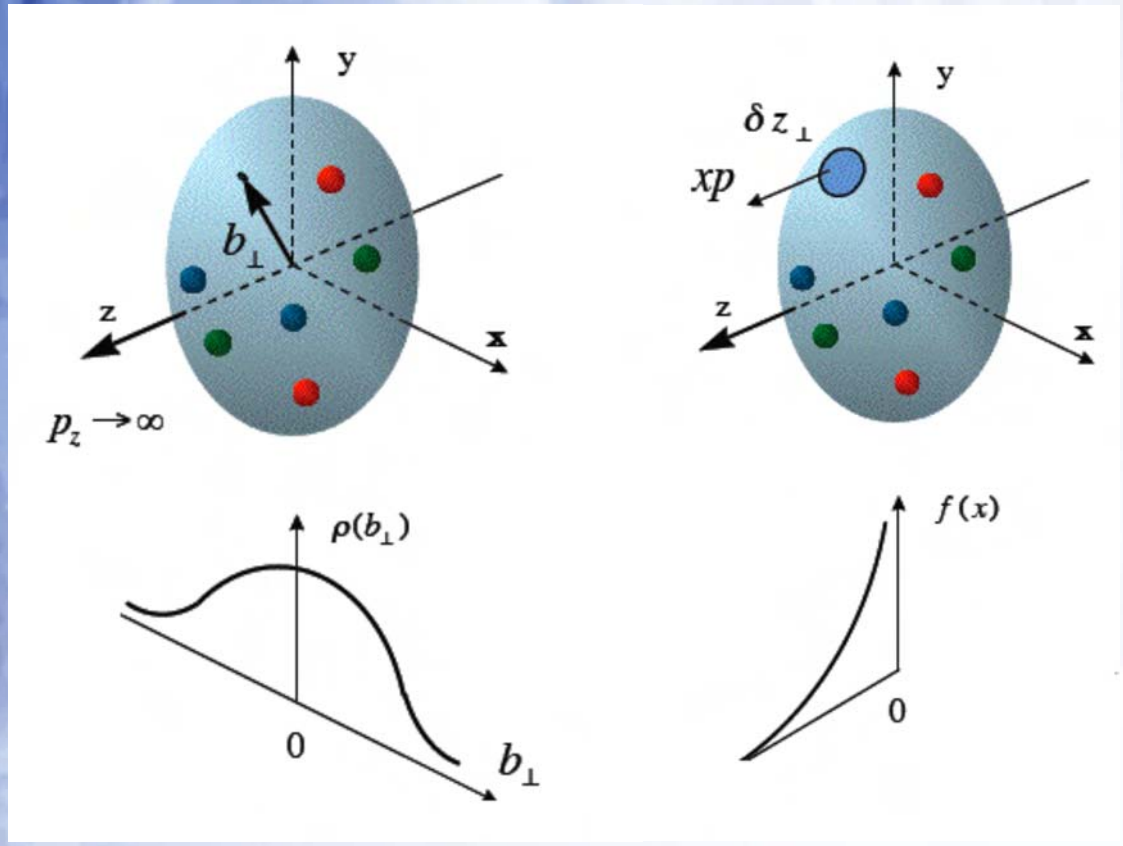
$$J_q \underset{t \to 0}{=} \frac{1}{2}\int_{-1}^{1} x\, dx \left[H_q + E_q\right]$$

**GPDs**

- **Knowing of GPDs $H_q$, $E_q$:**
  - determine $L_q$ !

- $\Delta\Sigma$ **: quark spin**
  - about 1/3 (HERMES,…)
  - See P. Kravchenko's talk
- $L_q$ **: quark ang. momentum**
  - unknown
- $J_g$ **: gluon tot. ang. mom.**
  - unknown

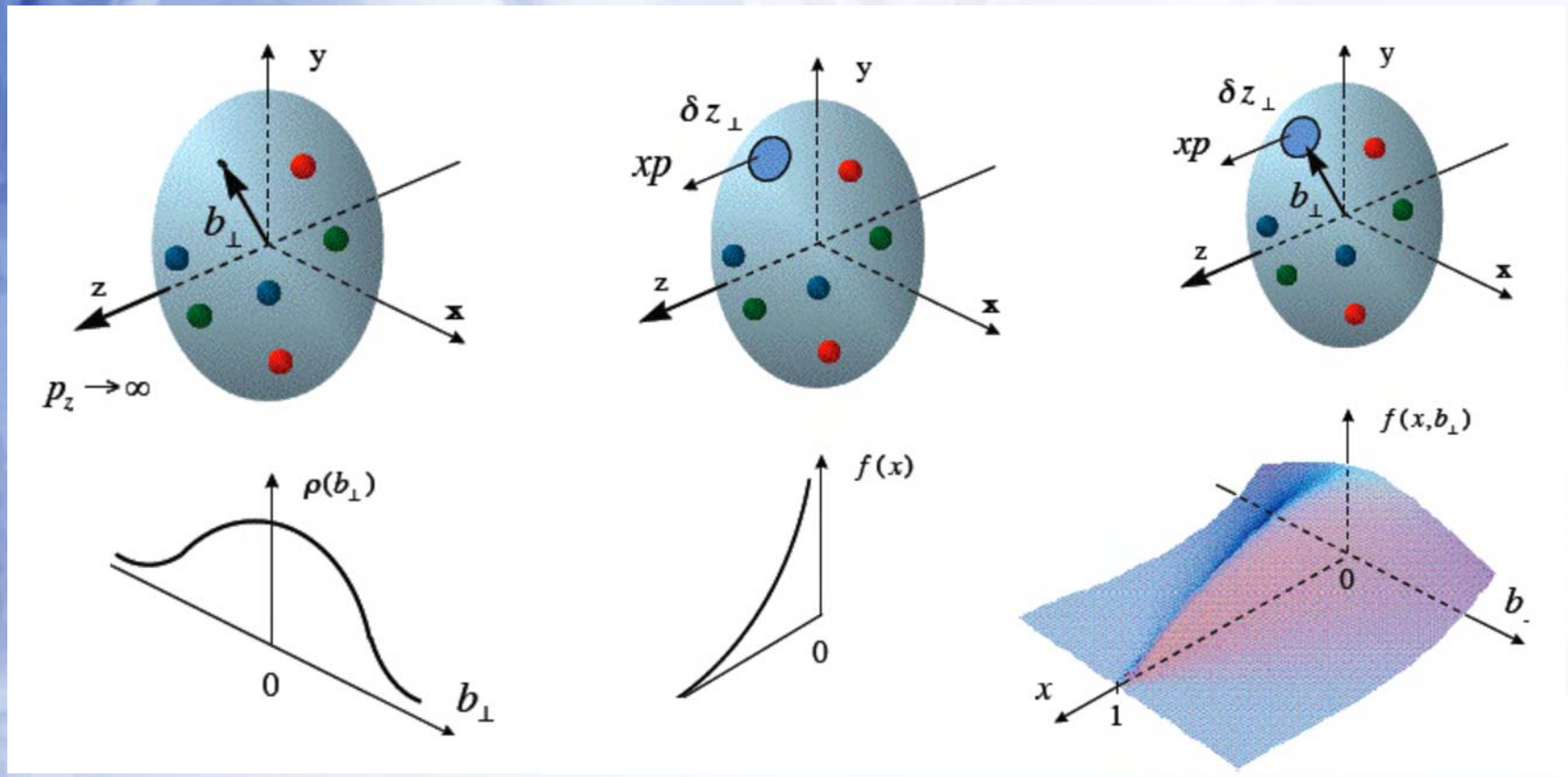
# What are GPDs?




**Form Factor**

**Parton Distribution Function**

# Generalised Parton Distributions

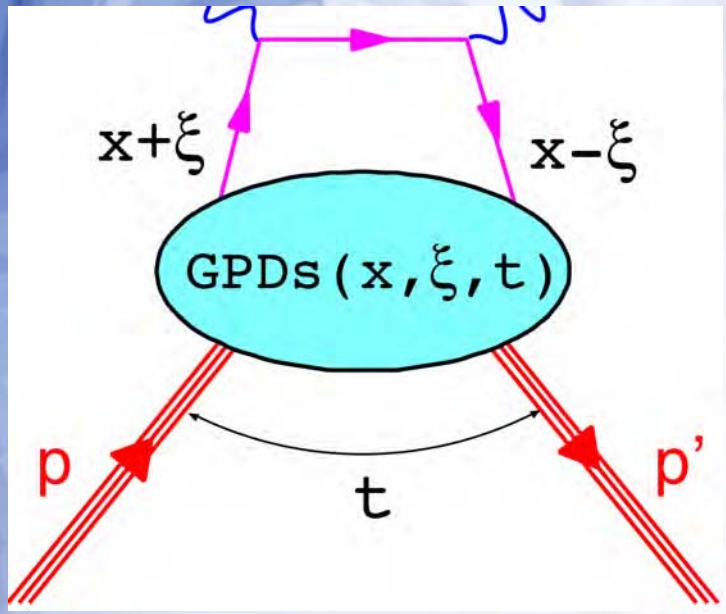



**Form Factor**

**Parton Distribution Function**

**Generalised Parton Distribution**

# Generalised Parton Distributions GPDs




- **Functions of 3 variables**
  - parton momentum fraction x
  - skewedness ξ
  - p momentum transfer t
- **4 (chirality conserving) quark GPDs**
  - unpolarised

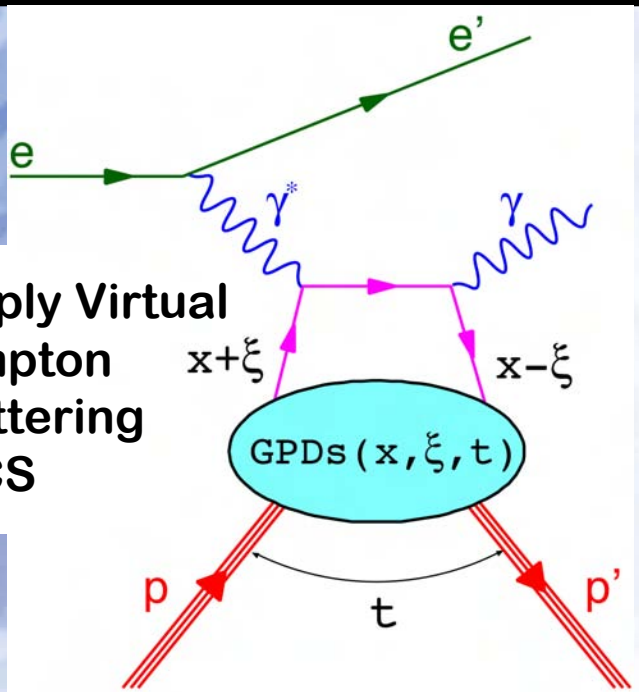
$$H(x,\xi,t), E(x,\xi,t),$$

  - polarised

$$\widetilde{H}(x,\xi,t), \widetilde{E}(x,\xi,t)$$

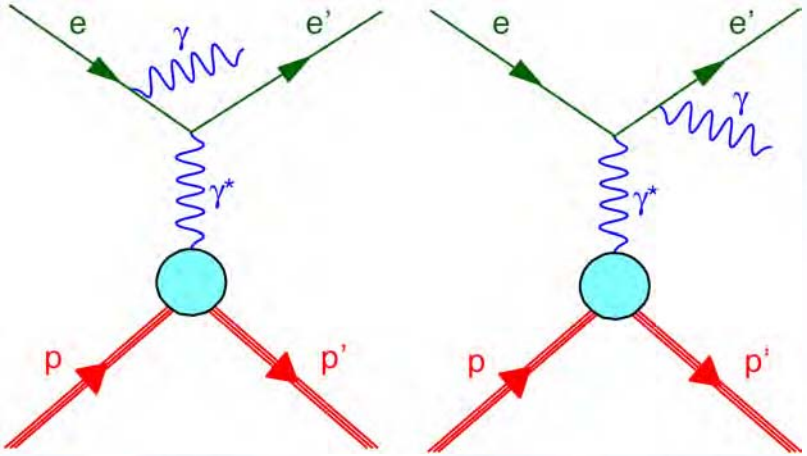
spin even spin odd

# How to Measure GPDs → DVCS




**Deeply Virtual Compton Scattering DVCS**

**Bethe-Heitler Scattering BH**




- **Indistinguishable and cross section dominated by BH**
  - **extraction using interference term**

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

**BH: precisely known from QED** **DVCS: access to the GPDs**

# Measure Asymmetries

- **Beam Spin Asymmetry**

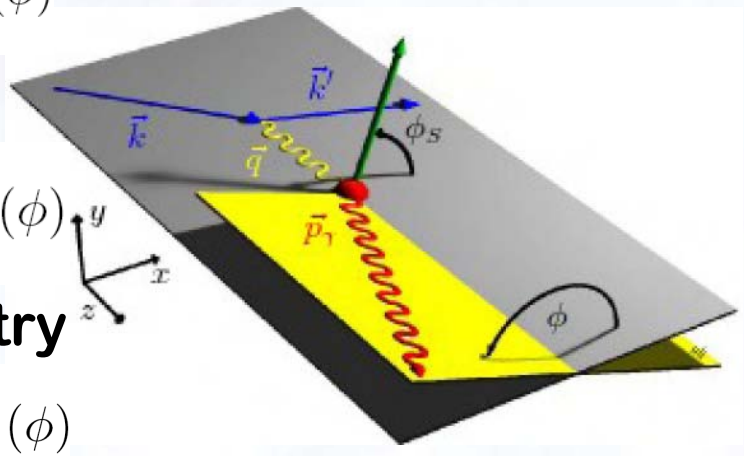
$$A_{LU} = \frac{d\sigma(e^{\rightarrow},\phi) - d\sigma(e^{\leftarrow},\phi)}{d\sigma(e^{\rightarrow},\phi) + d\sigma(e^{\leftarrow},\phi)} \propto \Im m(\mathcal{H}) \sin(\phi)$$

- **Beam Charge Asymmetry**

$$A_C = \frac{d\sigma(e^{+},\phi) - d\sigma(e^{-},\phi)}{d\sigma(e^{+},\phi) + d\sigma(e^{-},\phi)} \propto \Re e(\mathcal{H}) \cos(\phi)$$

- **Longitudinal-Target Spin Asymmetry**

$$A_{UL} = \frac{d\sigma(p^{\rightarrow},\phi) - d\sigma(p^{\leftarrow},\phi)}{d\sigma(p^{\rightarrow},\phi) + d\sigma(p^{\leftarrow},\phi)} \propto \Im m(\widetilde{\mathcal{H}}) \sin(\phi)$$



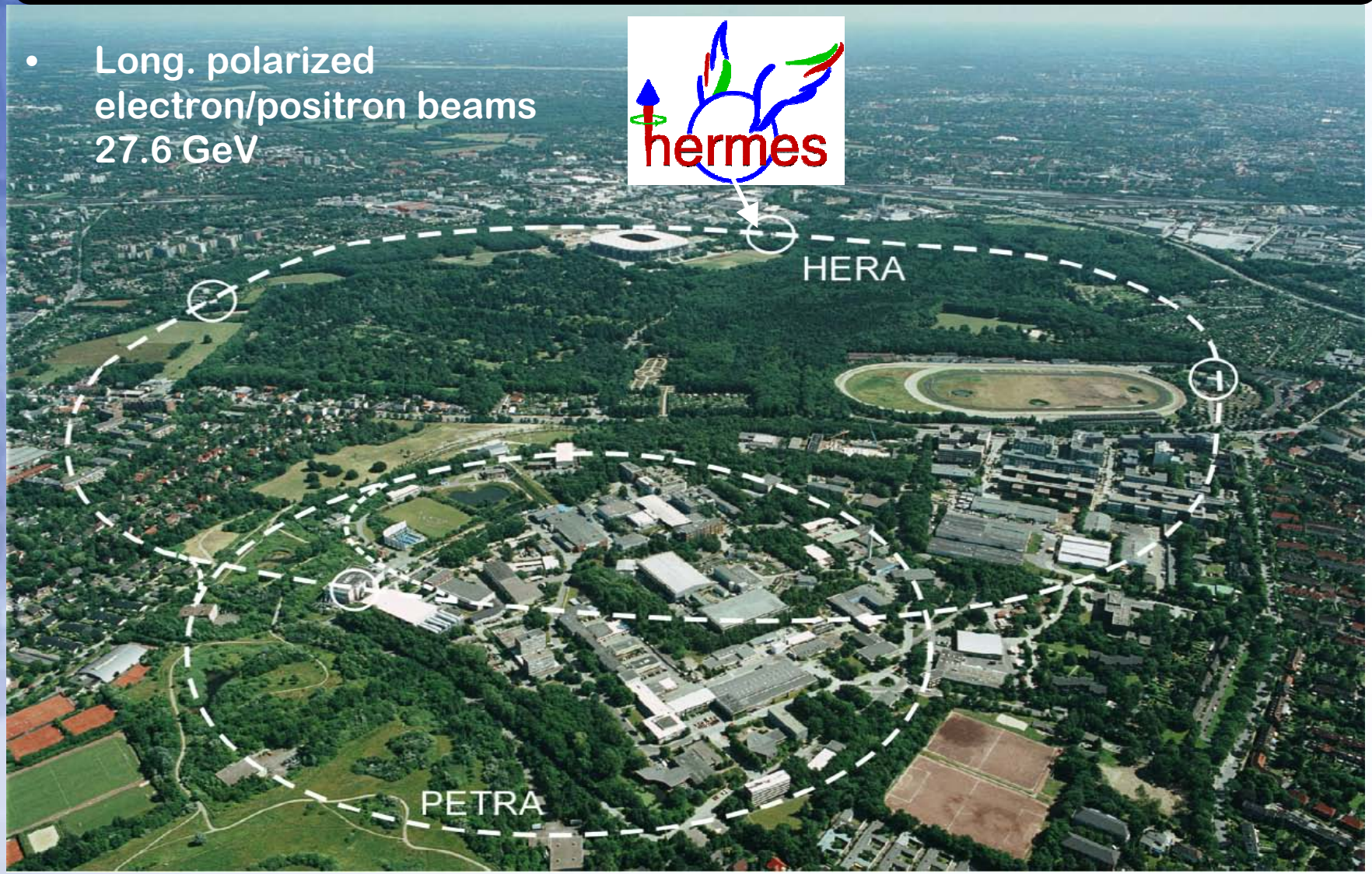

- **Transverse-Target Spin Asymmetry**

$$A_{UT} = \frac{d\sigma(p^{\uparrow},\phi) - d\sigma(p^{\downarrow},\phi)}{d\sigma(p^{\uparrow},\phi) + d\sigma(p^{\downarrow},\phi)} \propto f(\mathcal{H},\mathcal{E},\widetilde{\mathcal{H}},\widetilde{\mathcal{E}},\phi,\phi_S)$$

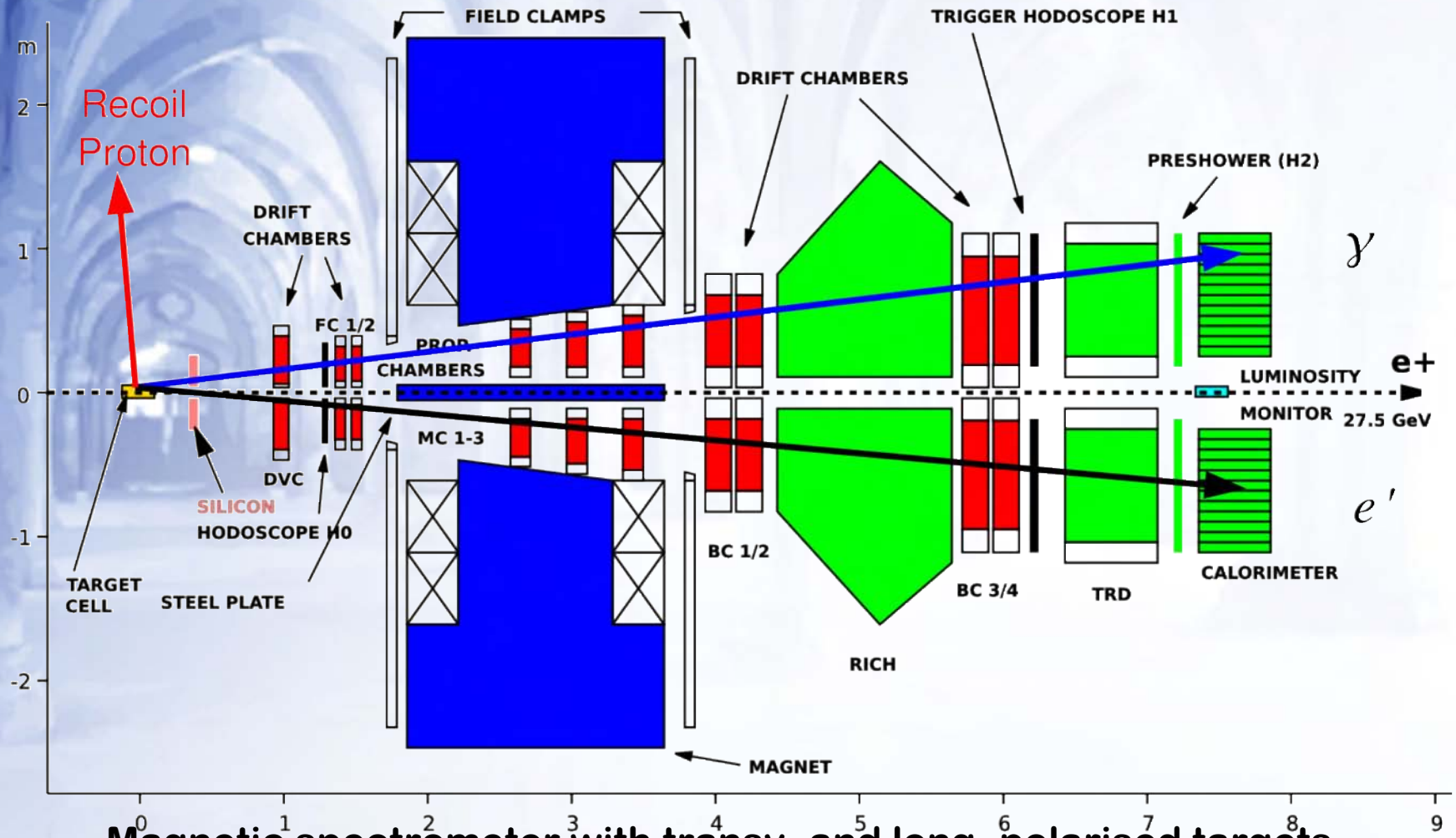
  - **Imaginary and real parts of $\mathcal{H},\mathcal{E},\widetilde{\mathcal{H}},\widetilde{\mathcal{E}}$ are directly related to GPDs** $H(x,\xi,t), E(x,\xi,t), \widetilde{H}(x,\xi,t), \widetilde{E}(x,\xi,t)$

# HERMES at HERA, DESY

- Long. polarized electron/positron beams 27.6 GeV



# HERMES at HERA, DESY

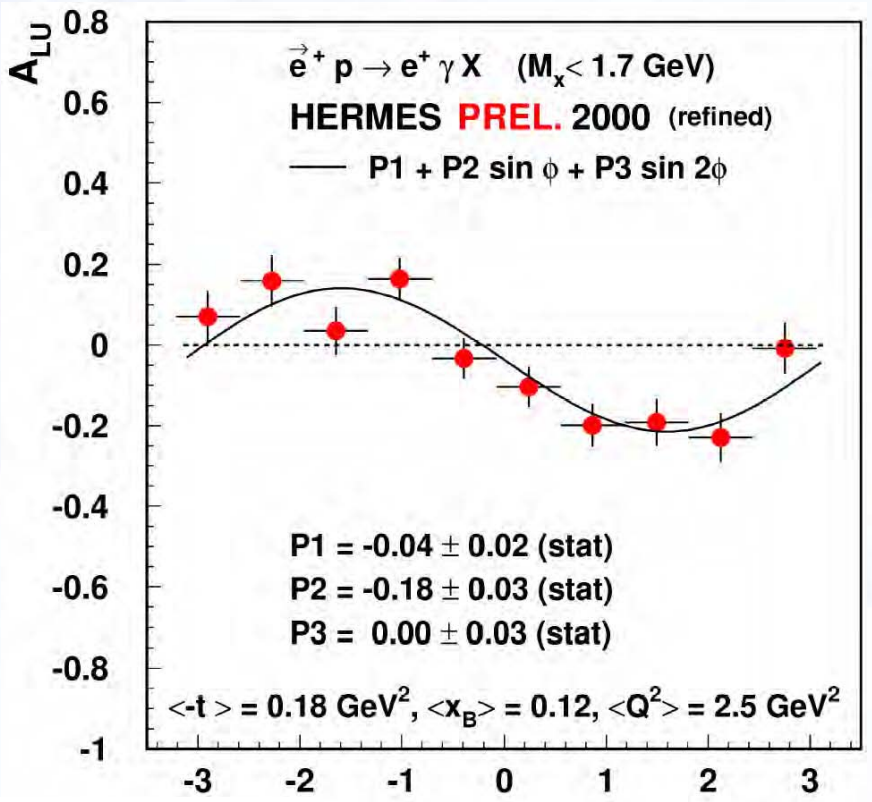



**Magnetic spectrometer with transv. and long. polarised targets**

# DVCS Asymmetries: Beam Spin

$$A_{LU} = \frac{d\sigma(e^{\rightarrow},\phi) - d\sigma(e^{\leftarrow},\phi)}{d\sigma(e^{\rightarrow},\phi) + d\sigma(e^{\leftarrow},\phi)} \propto \Im m(\mathcal{H}) \sin(\phi)$$

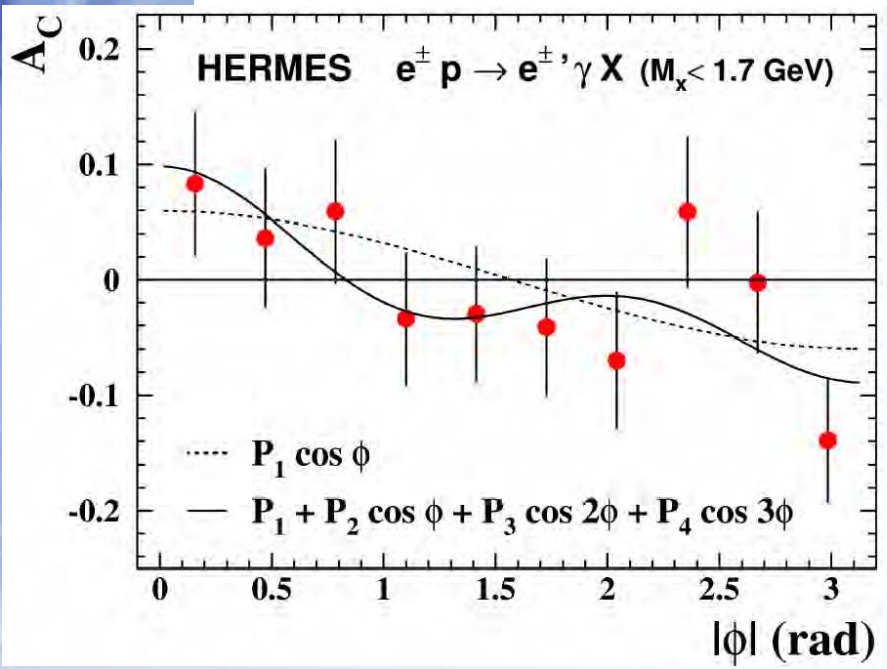
- First measurements of DVCS asymmetries:
  - Beam-spin asymmetry by HERMES and CLAS, both published in PRL87(2001).
- Refined analysis:
  - consistent result
- Constrains the GPD H

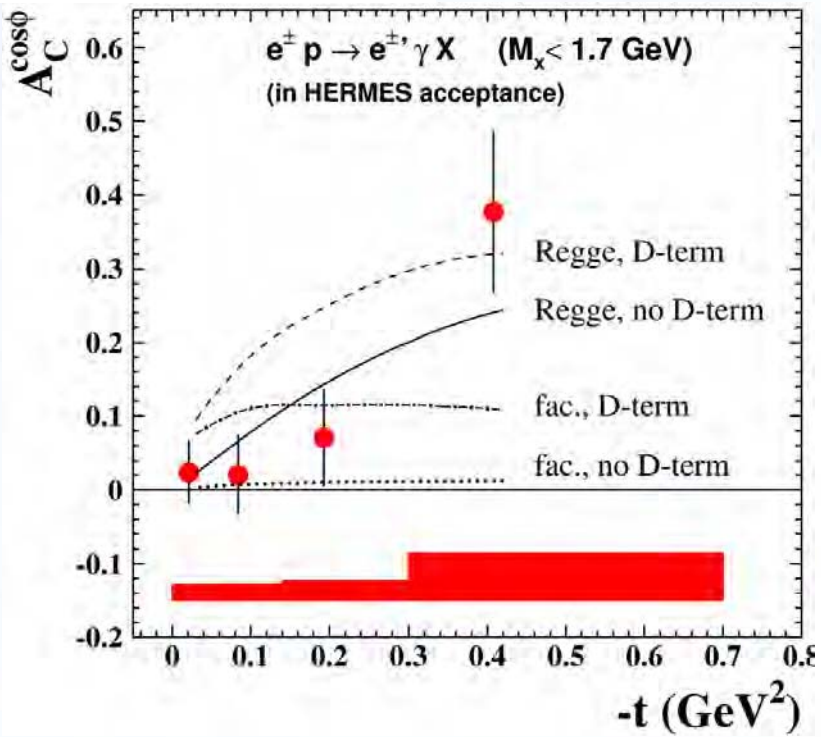



$A_{LU}^{\sin\phi}\big|_{M_x < 1.7\ \text{GeV}} = -0.18 \pm 0.03\ (\text{stat}) \pm 0.03\ (\text{sys})$

# DVCS Asymmetries: Beam Charge

$$A_C = \frac{d\sigma(e^+,\phi) - d\sigma(e^-,\phi)}{d\sigma(e^+,\phi) + d\sigma(e^-,\phi)} \propto \Re e(\mathcal{H}) \cos(\phi)$$



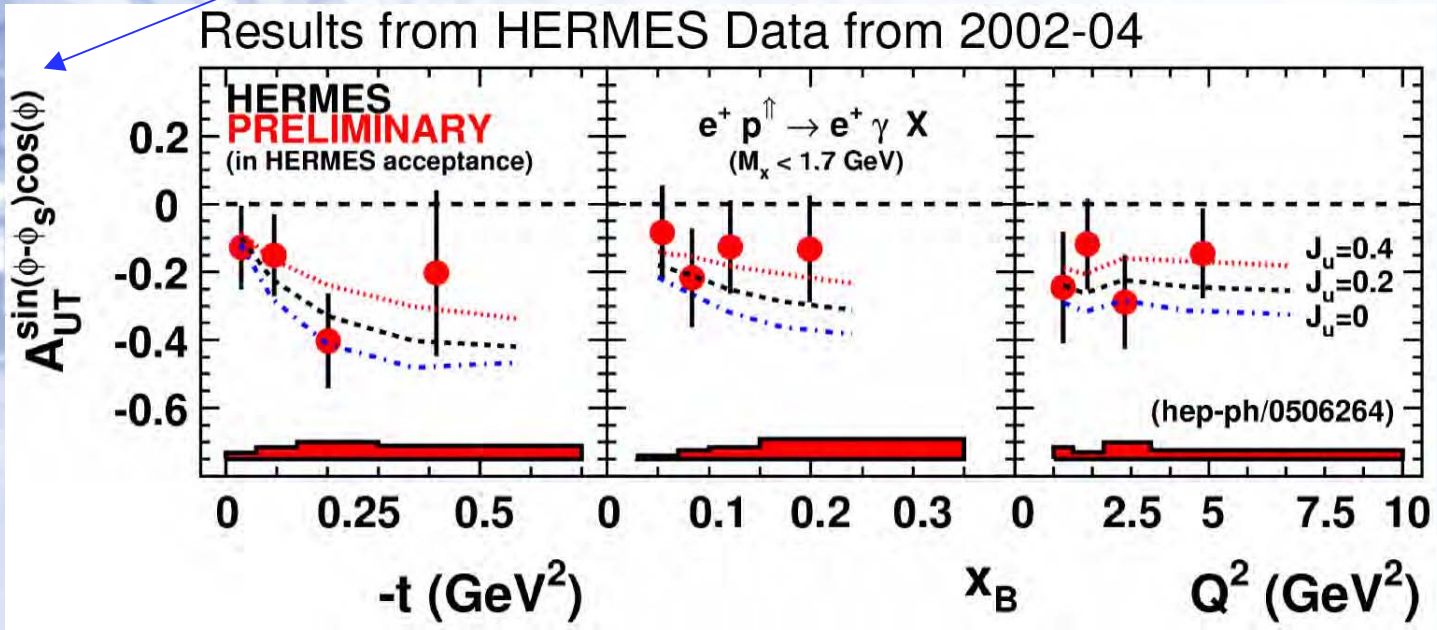




$$A_C^{\cos\phi} = 0.063 \pm 0.029(stat.) \pm 0.026(sys.)$$

- **Constrains the GPD H**
- **t-dependence constrains models**

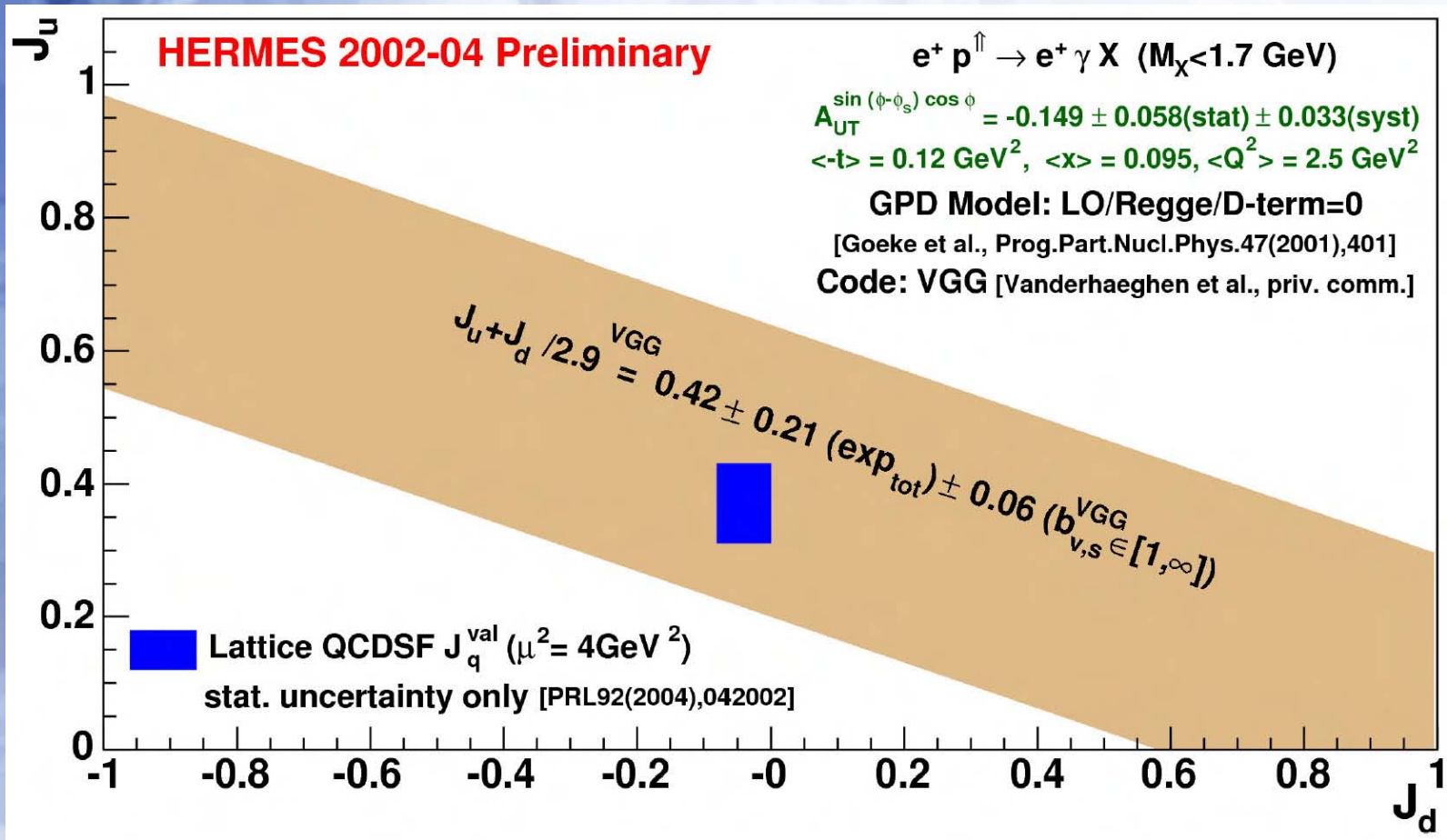
# DVCS Asymmetries: Transverse Target

$$A_{UT} = \frac{d\sigma(\boldsymbol{p}^{\uparrow}, \phi) - d\sigma(\boldsymbol{p}^{\downarrow}, \phi)}{d\sigma(\boldsymbol{p}^{\uparrow}, \phi) + d\sigma(\boldsymbol{p}^{\downarrow}, \phi)} \propto Im[F_2\mathcal{H} - F_1\mathcal{E}] \cdot \sin(\phi - \phi_S) \cdot \cos\phi + Im[F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}] \cdot \cos(\phi - \phi_S) \cdot \sin\phi$$




- **Here E is not suppressed**
- **Sensitive to variation in quark angular momentum $J_q$**

# DVCS Asymmetries: Constrain $J_q$

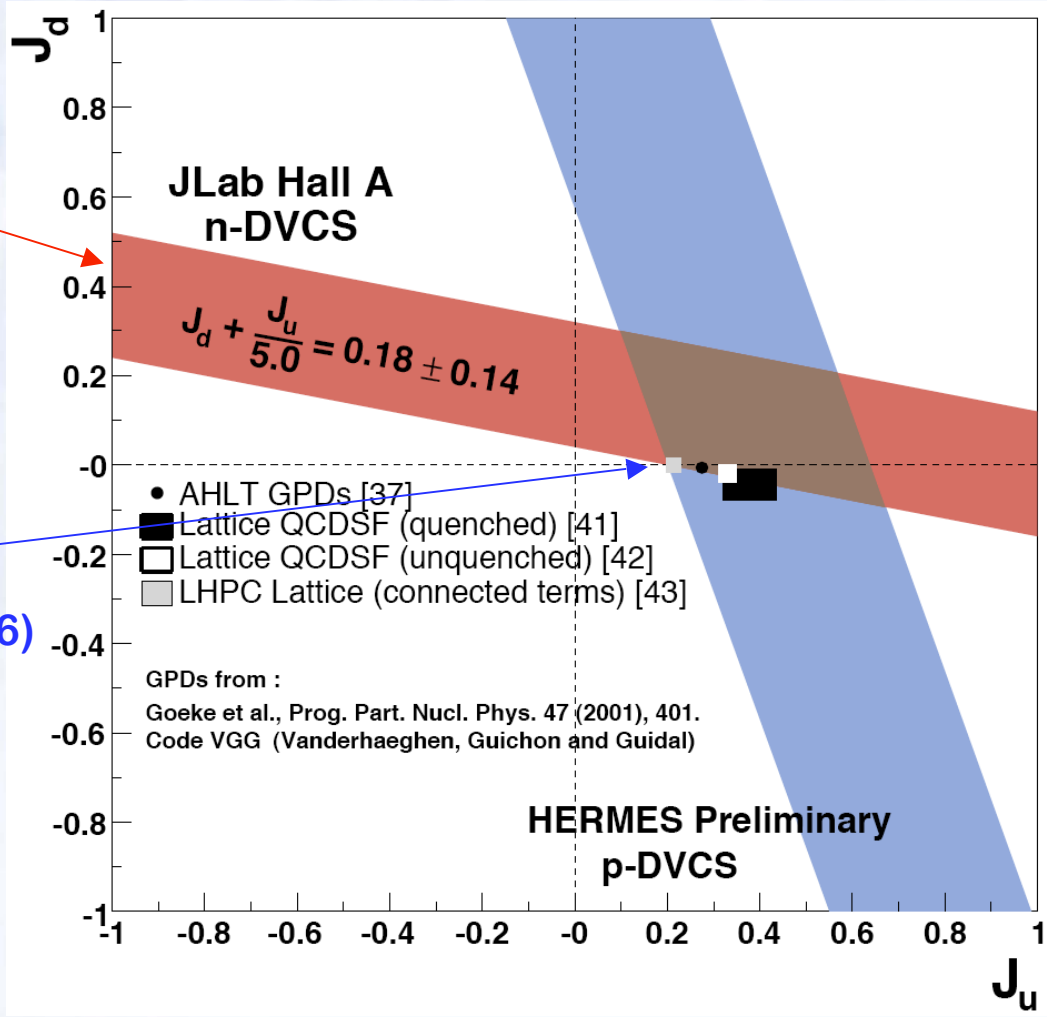



- Large 2005 data sample not yet included

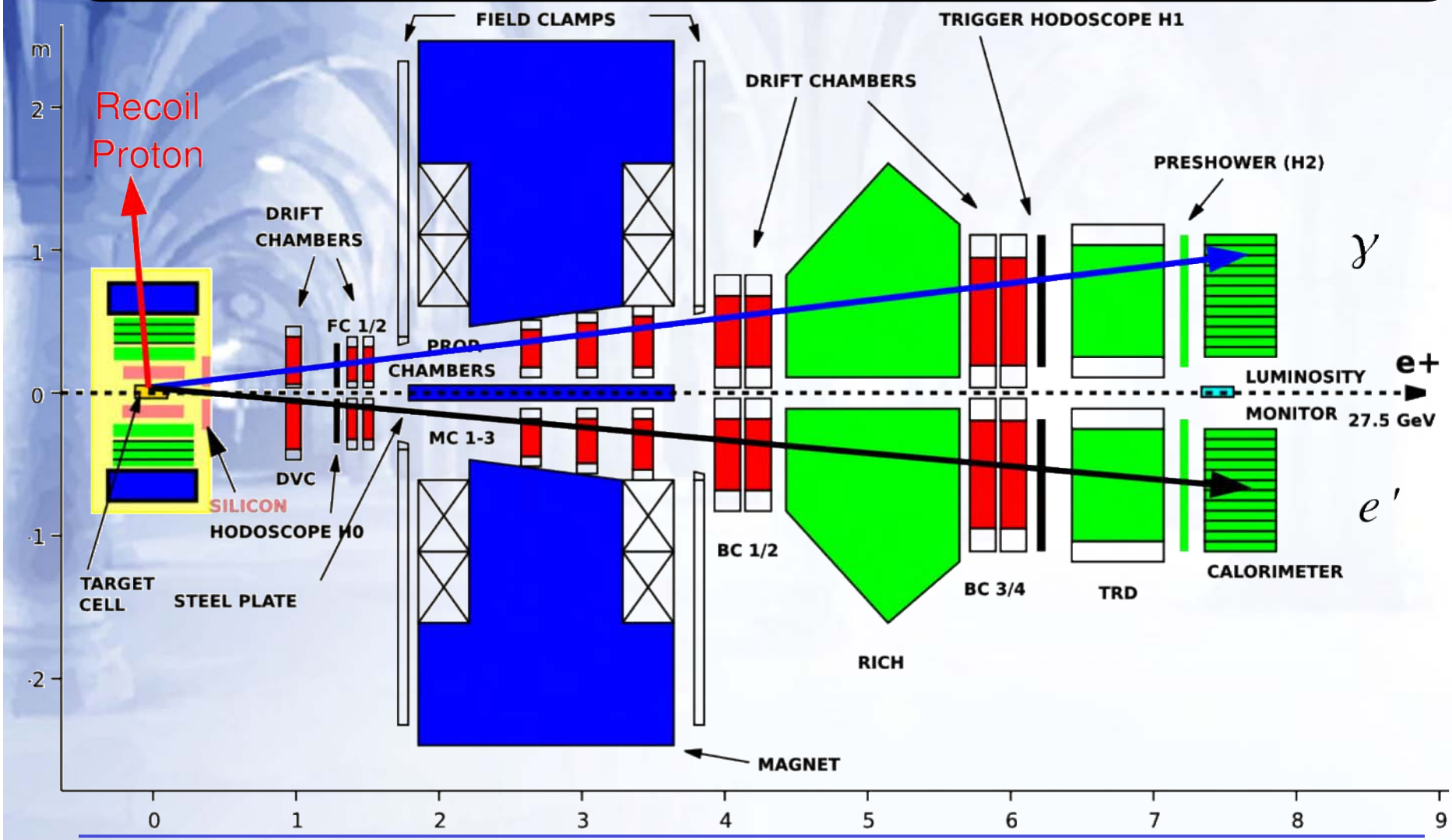
# DVCS Asymmetries: Constrain $J_q$

New HallA result on the neutron:
M. Mazouz et al.
arXiv:0709.0450 [nucl-ex]

New lattice point:
Ju , Jd = 0.214(16) , 0.001(16)
Ph. Haegler et al.
arXiv:0705.4295 [hep-lat]

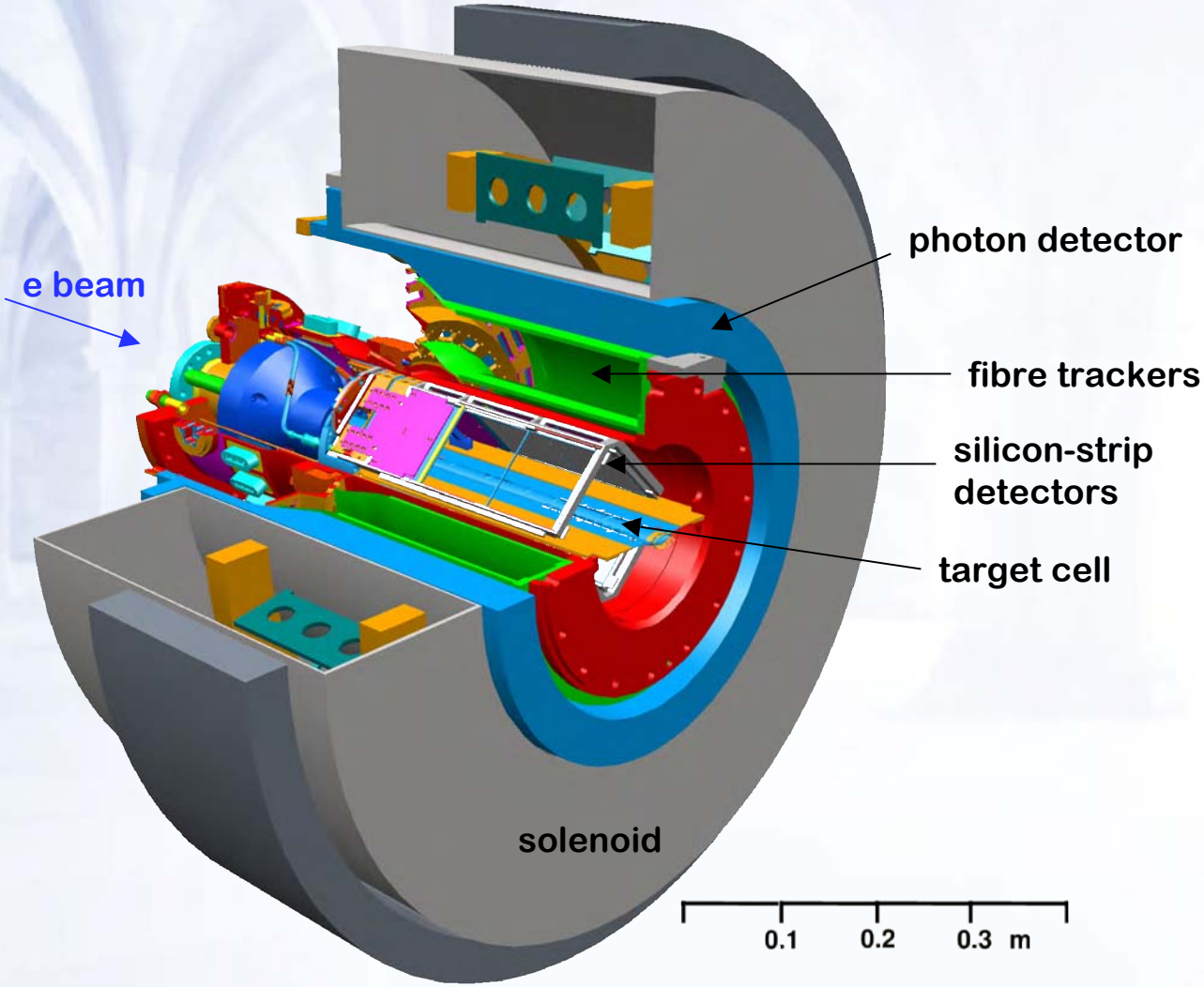


# HERMES with Recoil Detector

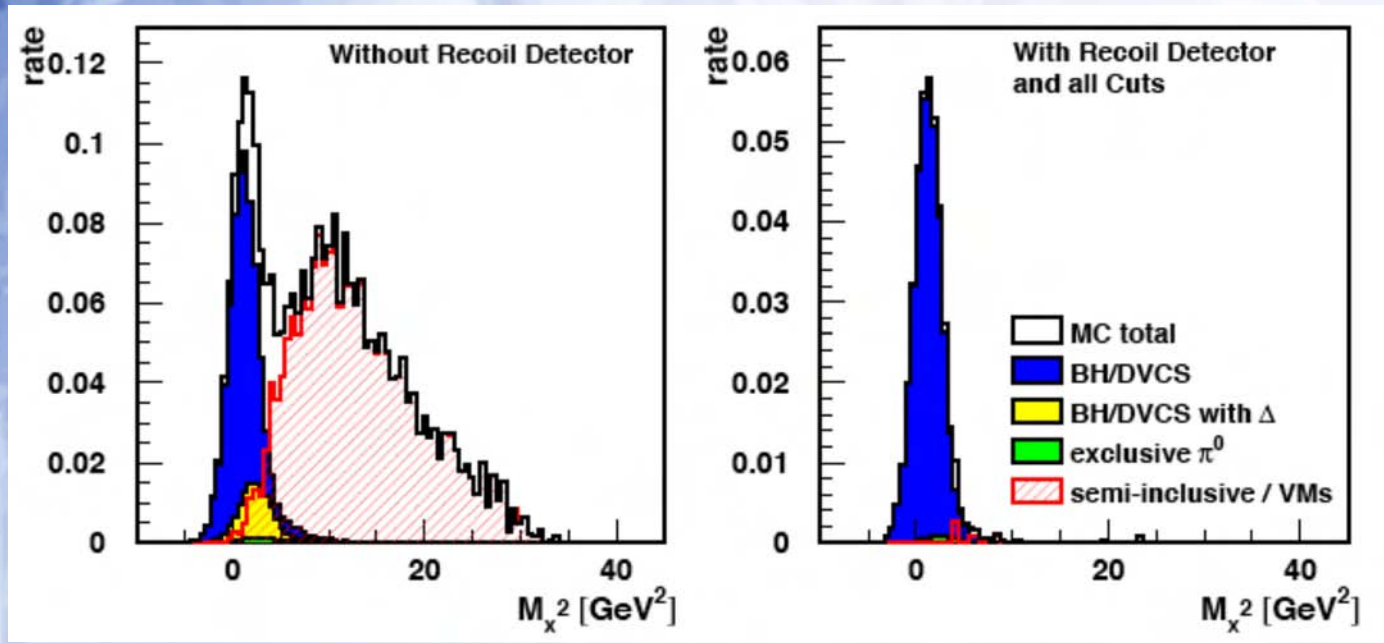


# HERMES Recoil Detector

- Unpolarised gas targets
- Challenging detectors



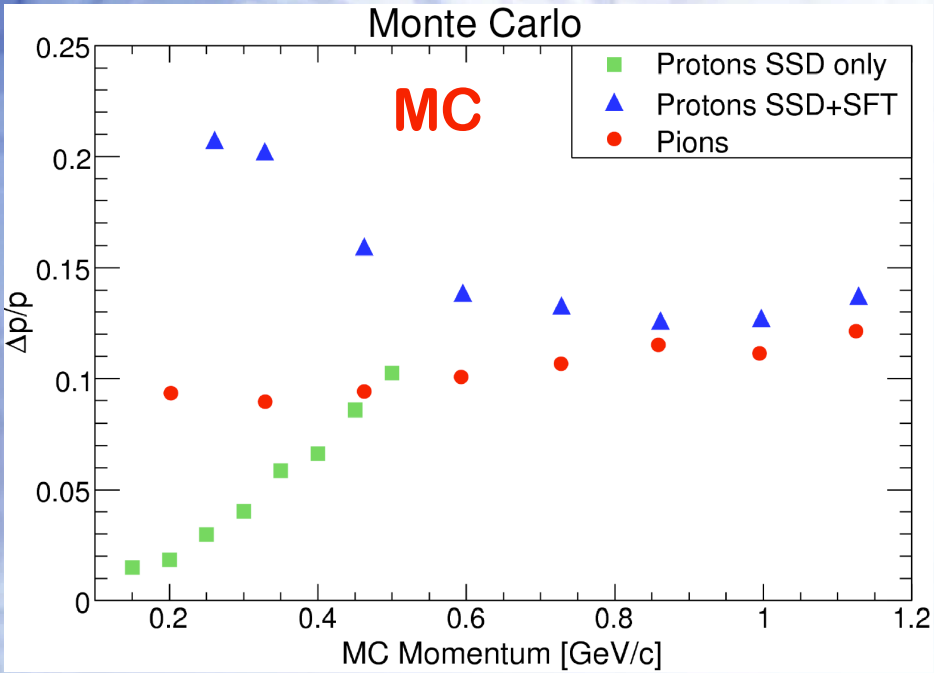
# Advantages of the Recoil Detector



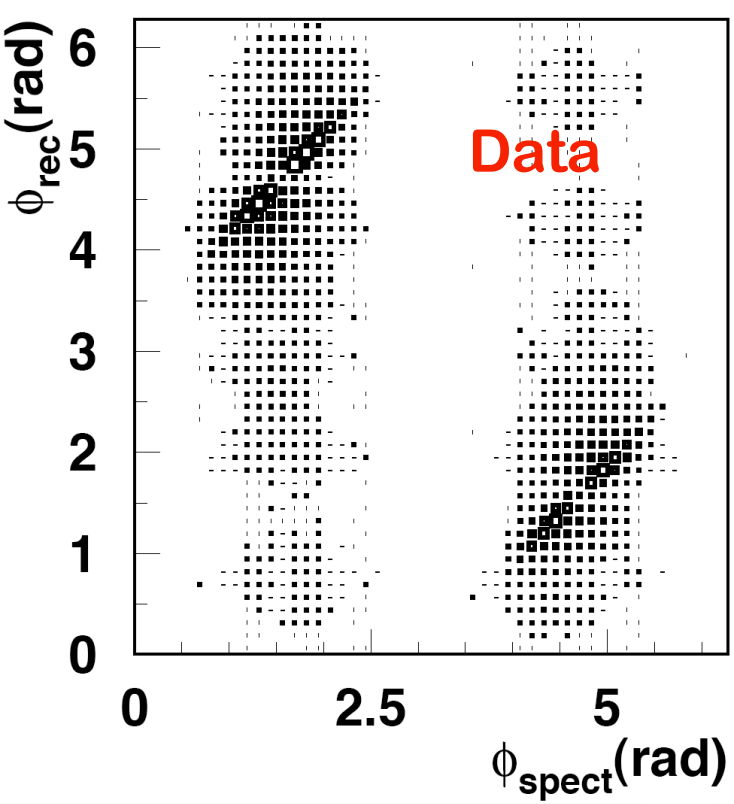

- Remove background from associated BH/DVCS with intermediate Δ-production and from semi-inclusive processes
  - Reduction from 17% to about 1%
- Improve t-resolution at small t (with Si-detector)
- High luminosity with unpolarised target

# First Results From the Recoil Detector

**Momentum resolution:**
**$\Delta p/p$ = 1-10% for protons**

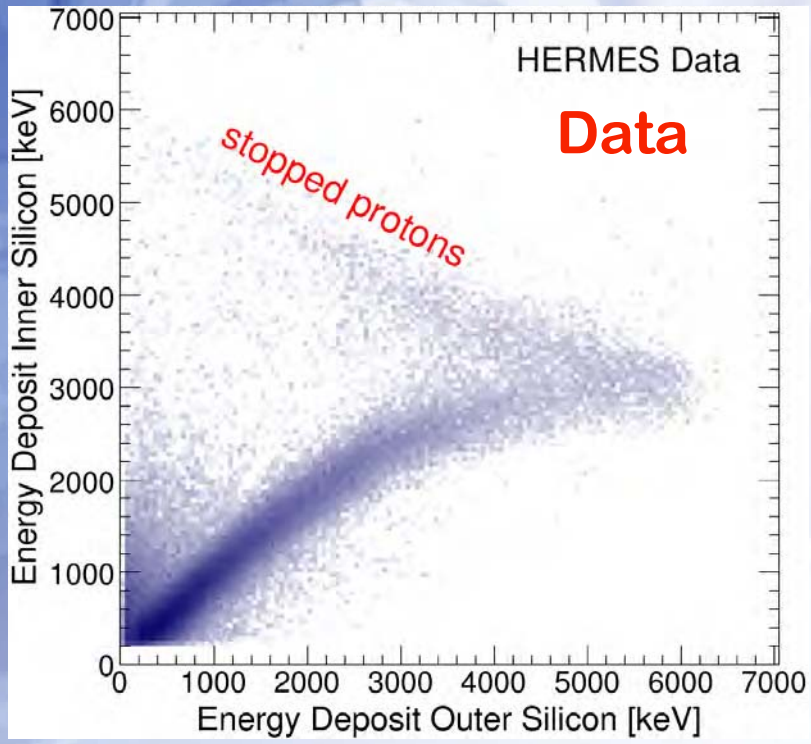



**Elastic scattering:**
**e and p back-to-back**

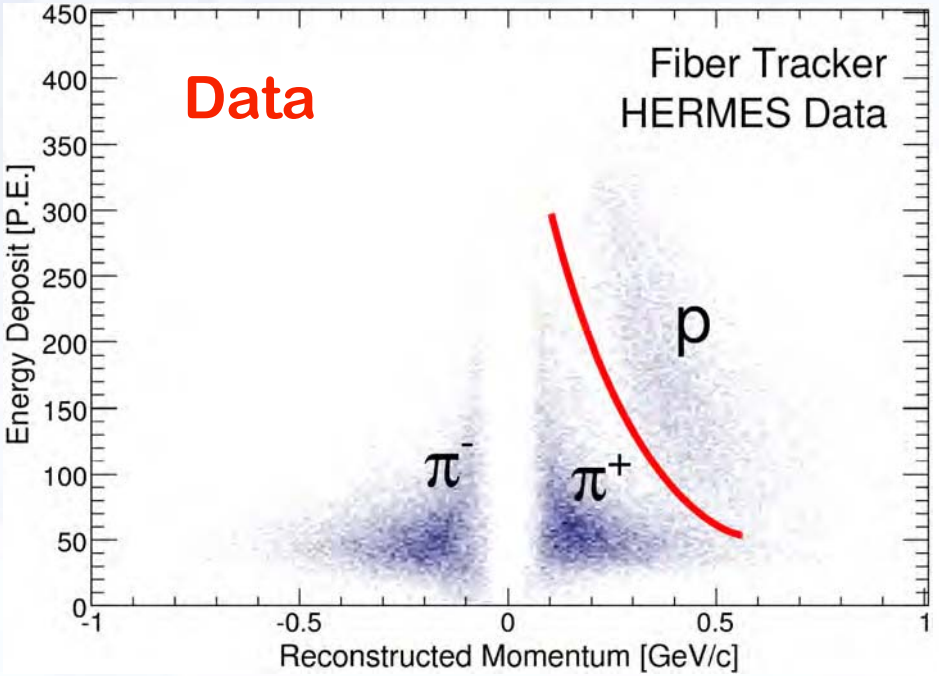


# First Results From the Recoil Detector

**Energy Deposit in Silicon Detectors**




**Track Reconstruction Through Curvature**




- **Detectors operational:**
  - **Momentum reconstruction**
  - **Particle identification: pions, protons, photons, …**

# Summary and Outlook

- DVCS has the potential to picture the nucleon
- HERMES has contributed a lot
  - Many results were not shown
- Much more data is on tape
  - Currently under analysis
- Data with Recoil Detector
  - Exclusive beam-spin and beam-charge asymmetries
  - Hard exclusive meson production
  - “Background free” data set
  - Improved t-resolution
  - Lots of statistics for beam-spin asymmetry
- There are a lot of results to come