Latest Results from DVCS at HERMES

Sergey Yaschenko
Friedrich-Alexander-Universität Erlangen-Nürnberg

On behalf of the hermes Collaboration

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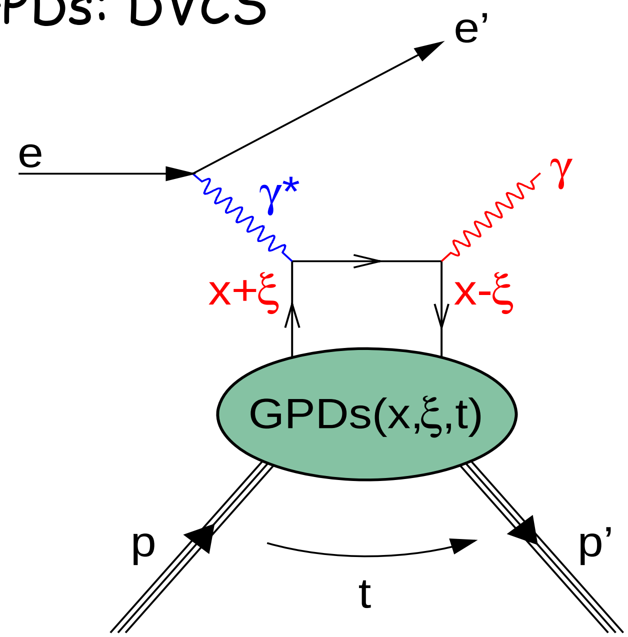
Outline

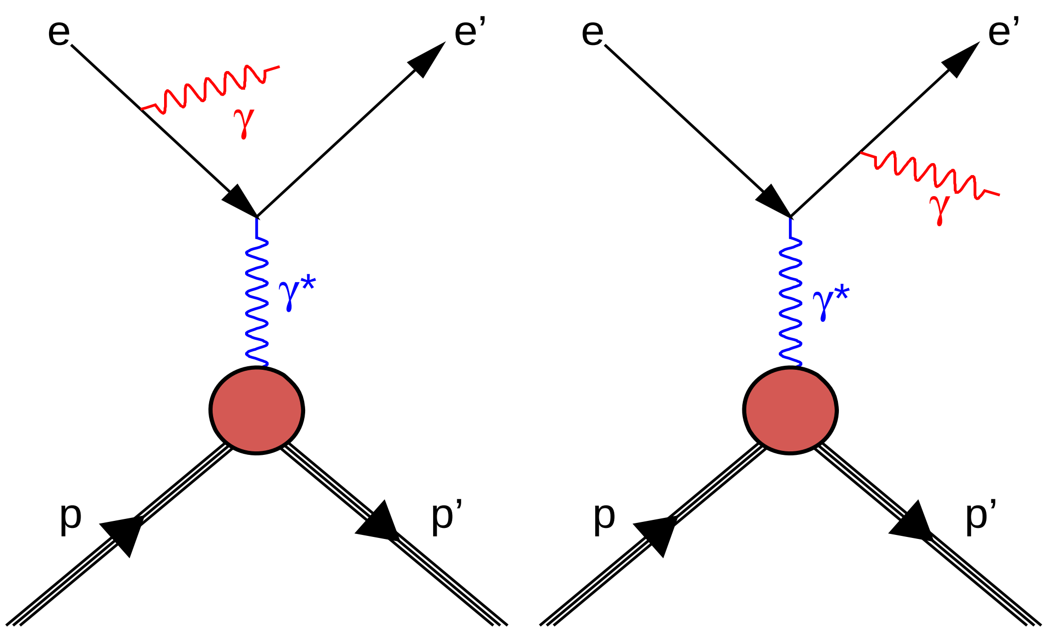
- Physics Motivation
  - DVCS as a tool to access GPDs
- HERMES Experiment
- Recent Results on DVCS at HERMES
  - Combined Analysis of Beam Charge and Beam Spin Asymmetries on Proton and Deuteron (Released)
  - Transverse Target Spin Asymmetry (Published)
- Exclusivity at HERMES
  - HERMES Recoil Detector
- Summary and Outlook

Access to Generalized Parton Distributions (GPDs) via Deeply Virtual Compton Scattering (DVCS)

Cleanest way to access GPDs: DVCS



Bethe-Heitler



- DVCS and Bethe-Heitler: the same initial and final state
- Bethe-Heitler dominates at HERMES kinematics
- GPDs accessible through cross-section differences and azimuthal asymmetries via interference term

Generalized Parton Distributions (GPDs)

- GPDs → PDFs

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

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

- GPDs → FFs

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

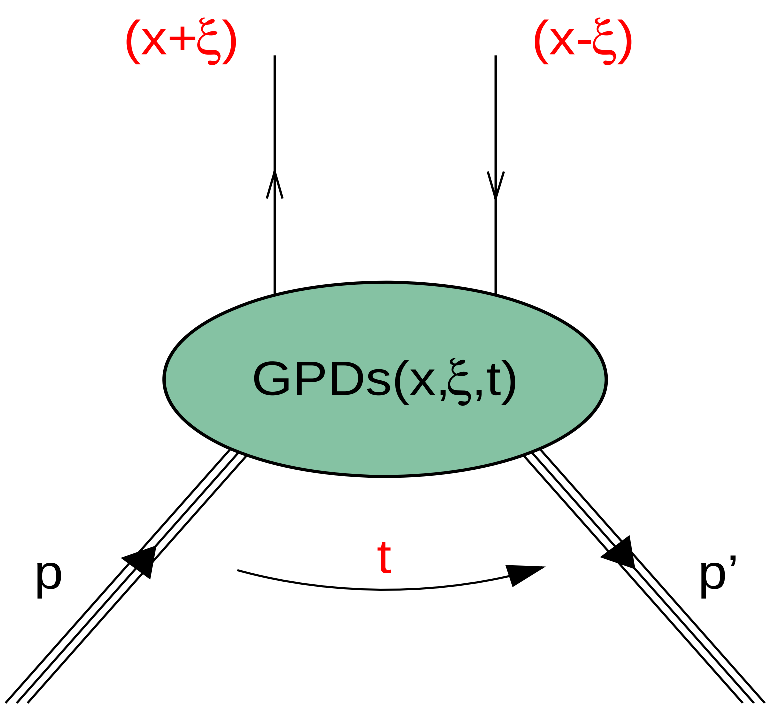
$$\int_{-1}^{1} dx E_q(x,\xi,t) = F_2^q(t)$$

- H_q, E_q unpolarized GPDs
- $\widetilde{H}_q, \widetilde{E}_q$ polarized GPDs
- $H_q, \widetilde{H}_q$ conserve nucleon helicity
- $E_q, \widetilde{E}_q$ flip nucleon helicity

x average parton longitudinal momentum fraction

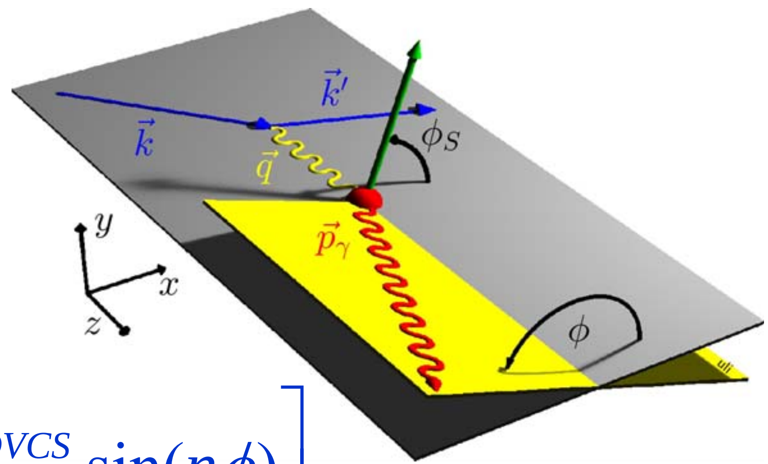
ξ fraction of the momentum transfer

t invariant momentum transfer to the nucleon



Azimuthal Dependences

$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} = \frac{y^2 x_B}{32(2\pi)^4 Q^4 \sqrt{1+\frac{4M^2 x_B^2}{Q^2}}} \left(|T_{DVCS}|^2 + |T_{BH}|^2 + I\right)$$



$$|T_{BH}|^2 = \frac{K_{BH}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \sum_{n=0}^{2} c_n^{BH} \cos(n\phi)$$

$$|T_{DVCS}|^2 = K_{DVCS}\left[\sum_{n=0}^{2} c_n^{DVCS} \cos(n\phi) + P_B \sum_{n=1}^{1} s_n^{DVCS} \sin(n\phi)\right]$$

$$I = \frac{C_B K_I}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} K_{DVCS}\left[\sum_{n=0}^{3} c_n^{I} \cos(n\phi) + P_B \sum_{n=1}^{2} s_n^{I} \sin(n\phi)\right]$$

Measured Azimuthal Asymmetries

- Cross Section

$$\sigma_{LU}(\phi; P_B, C_B) = \sigma_{UU}[1 + P_B A_{LU}^{DVCS} + C_B P_B A_{LU}^{I} + C_B A_C]$$

- Beam Spin Asymmetry

$$A_{LU}^{DVCS}(\phi) = \frac{1}{D(\phi)} \cdot \frac{x_B^2 t \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}{Q^2} s_1^{DVCS} \sin(\phi)$$

$$A_{LU}^{I}(\phi) = \frac{1}{D(\phi)} \cdot \frac{x_B^2}{Q^2}[s_1^I \sin(\phi) + s_2^I \sin(2\phi)]$$

- Beam Charge Asymmetry

$$A_C(\phi) = -\frac{1}{D(\phi)} \cdot \frac{x_B^2}{y}[c_0^I + c_1^I \cos(\phi) + c_2^I \cos(2\phi) + c_3^I \cos(3\phi)]$$

- Dilution factor through lepton propagators $\mathcal{P}_1(\phi), \mathcal{P}_2(\phi)$

$$D(\phi) = \frac{\sum_{n=0}^{2} c_n^{BH} \cos(n\phi)}{(1+\varepsilon^2)^2} + \frac{x_B^2 t \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}{Q^2} \sum_{n=0}^{2} c_n^{DVCS} \cos(n\phi)$$

Connection to GPDs

- Data with different beam charges and beam helicities were combined and fit simultaneously

- Connections to GPDs (leading contributions)

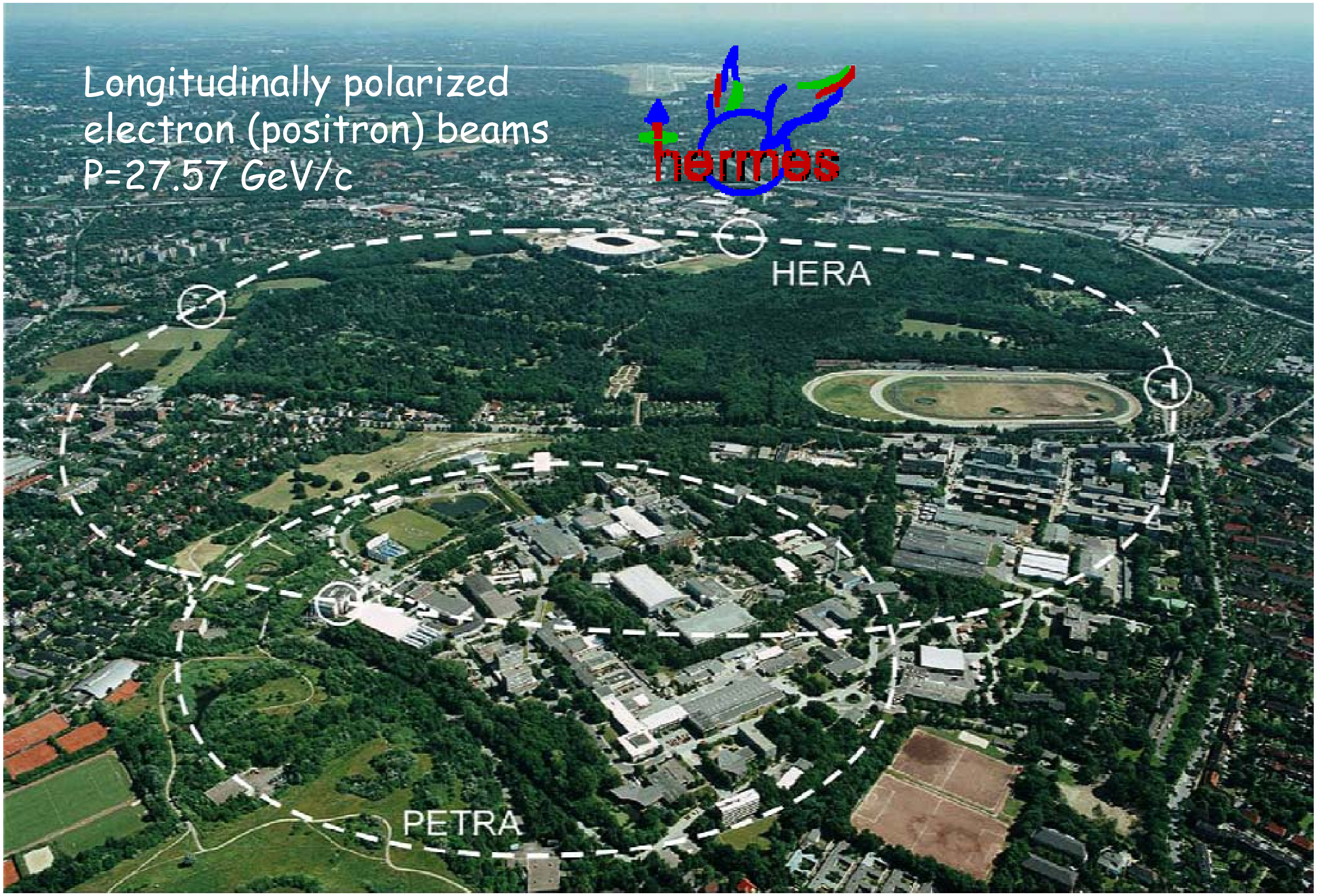
$$c_1^I \propto \frac{\sqrt{-t}}{Q} \Re e\left[F_1 \mathcal{H} + \xi (F_1 + F_2) \widetilde{\mathcal{H}} - \frac{t}{4M^2} F_2 \mathcal{E} \right] \propto -\frac{Q}{\sqrt{-t}} c_0^I$$

$$s_1^I \propto \frac{\sqrt{-t}}{Q} \Im m\left[F_1 \mathcal{H} + \xi (F_1 + F_2) \widetilde{\mathcal{H}} - \frac{t}{4M^2} F_2 \mathcal{E} \right]$$

where $\mathcal{H}, \widetilde{\mathcal{H}}, \mathcal{E}, \widetilde{\mathcal{E}}$ are Compton form factors – convolutions of hard scattering amplitude and twist-2 GPDs $H, \widetilde{H}, E, \widetilde{E}$

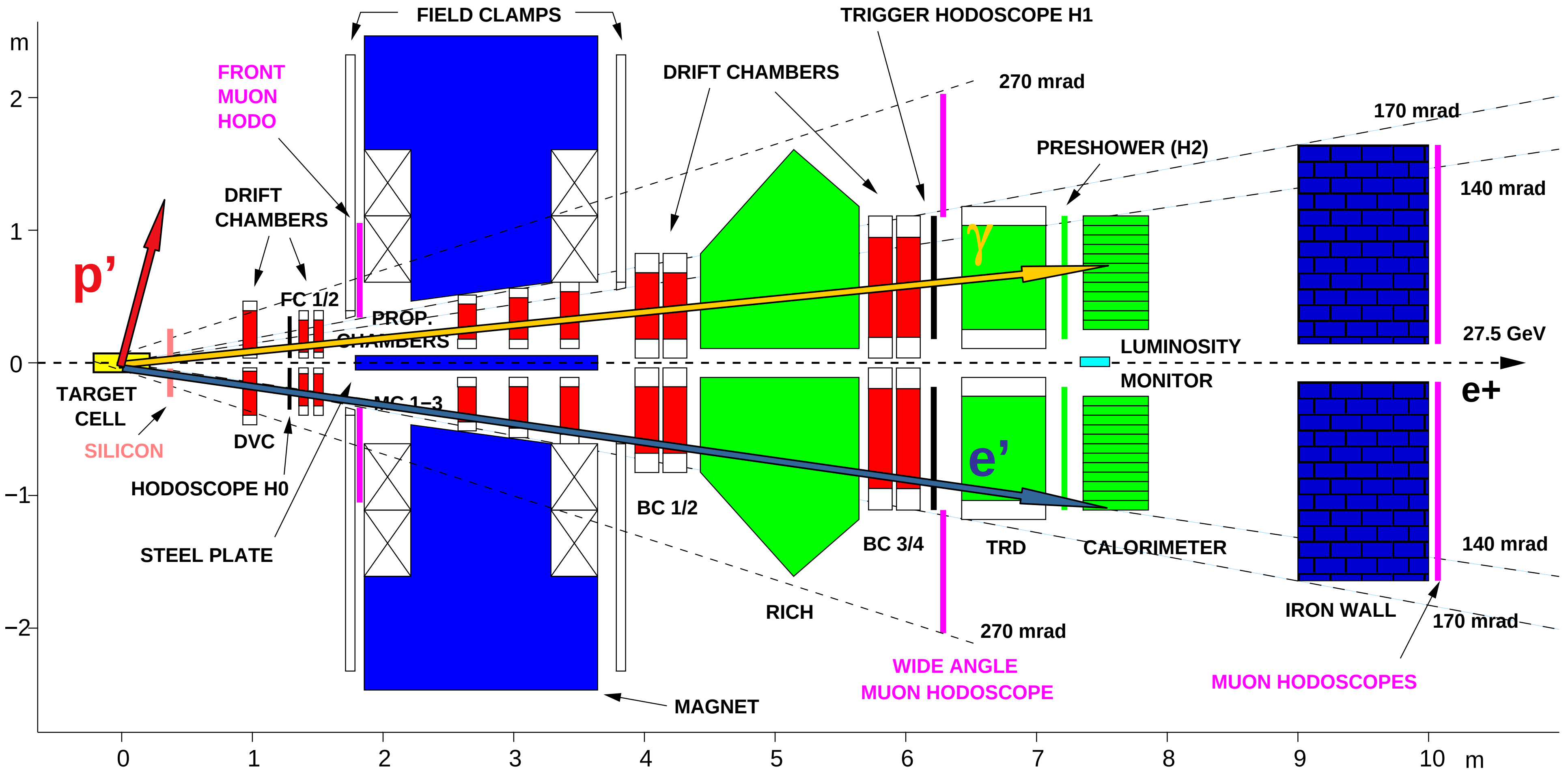
F_1, F_2 are Dirac and Pauli form factors of the nucleon

HERA at DESY

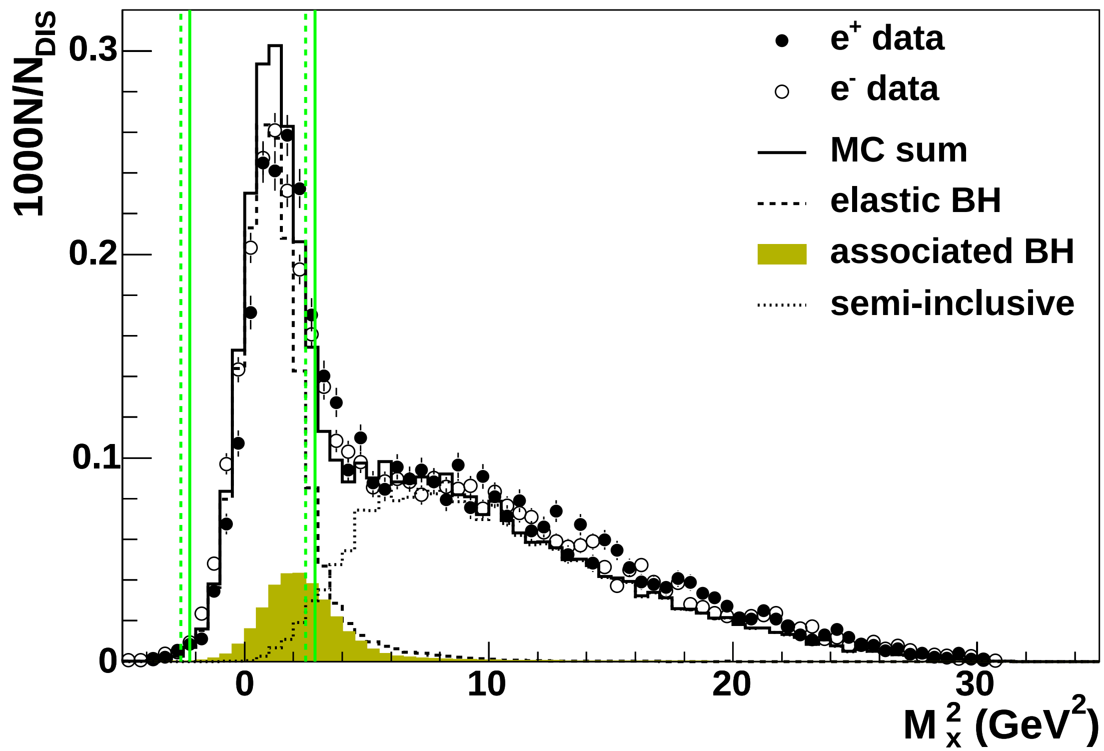


Longitudinally polarized
electron (positron) beams
P=27.57 GeV/c
hermes
HERA
PETRA

The HERMES Experiment



Event Selection, Uncertainties and Corrections



- Identification by missing mass technique ($ep \rightarrow e'\gamma X$)
- Associated Bethe-Heitler $ep \rightarrow e'\Delta^{+}\gamma$ ~12% stays part of the signal
- Semi-inclusive (mainly pion production) corrected as dilutions for charge dependent asymmetries. For pure DVCS term asymmetry extracted from π^0 ($z_\pi > 0.8$) data. Fractional contribution taken from Monte Carlo

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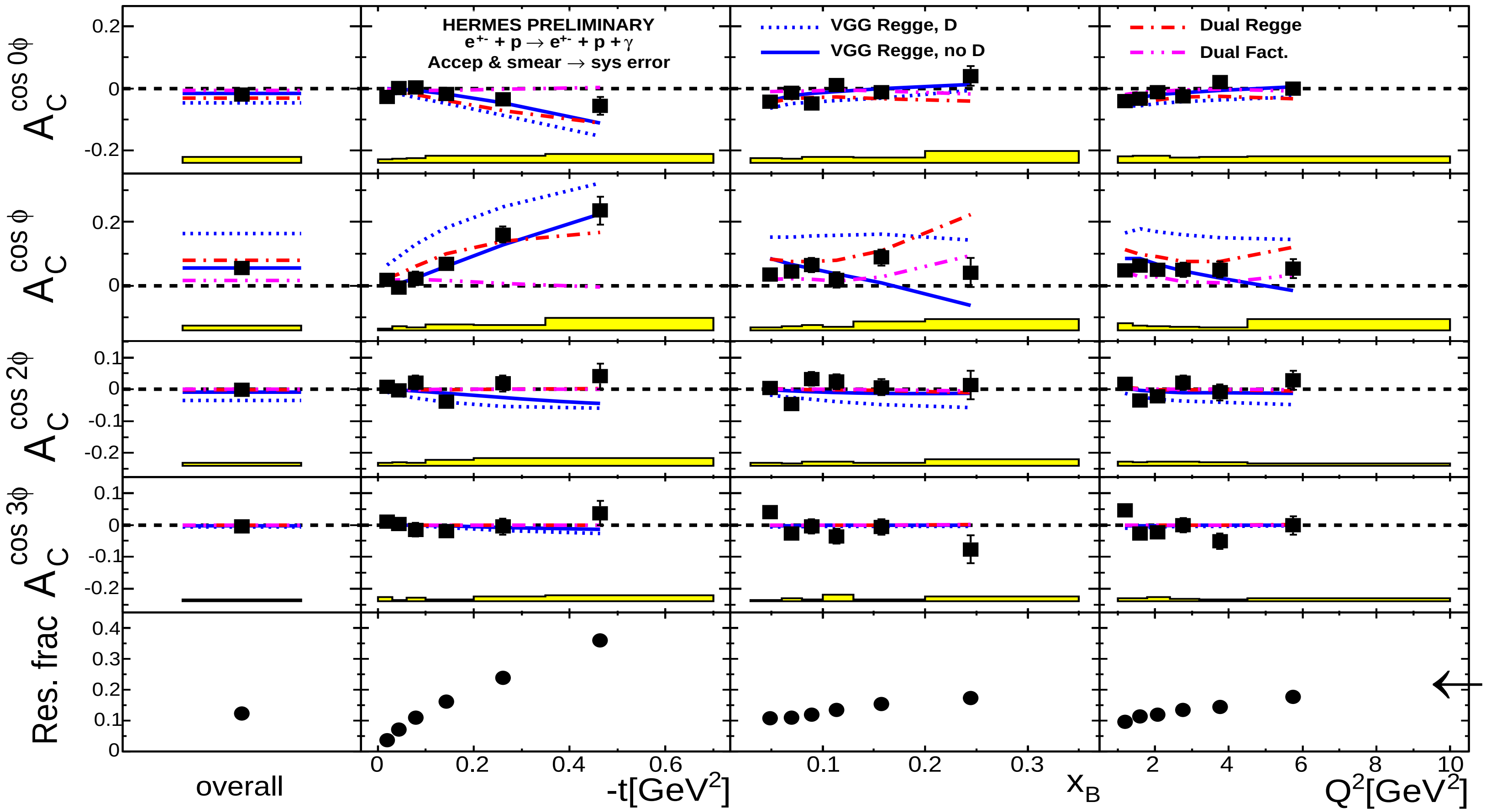
GPD Models

- VGG model (Vanderhaeghen, Guichon, Guidal 1999):
  - Based on double distributions
  - Includes a D-term to restore full polynomiality
  - Includes a Regge inspired and a factorized t-ansatz
  - Skewness depending on free parameters b_{val} and b_{sea}
  - Includes twist-3 contributions

- Dual model: (Guzey, Teckentrup 2006)
  - GPDs based on an infinite sum of t-channel resonances
  - Includes a Regge inspired and a factorized t-ansatz
  - Does not include twist-3

Beam Charge Asymmetry (all data 1996-2005)



$\propto -A_C^{\cos\phi}$

$\propto \Re e[F_1 \mathcal{H}]$

← Higher twist

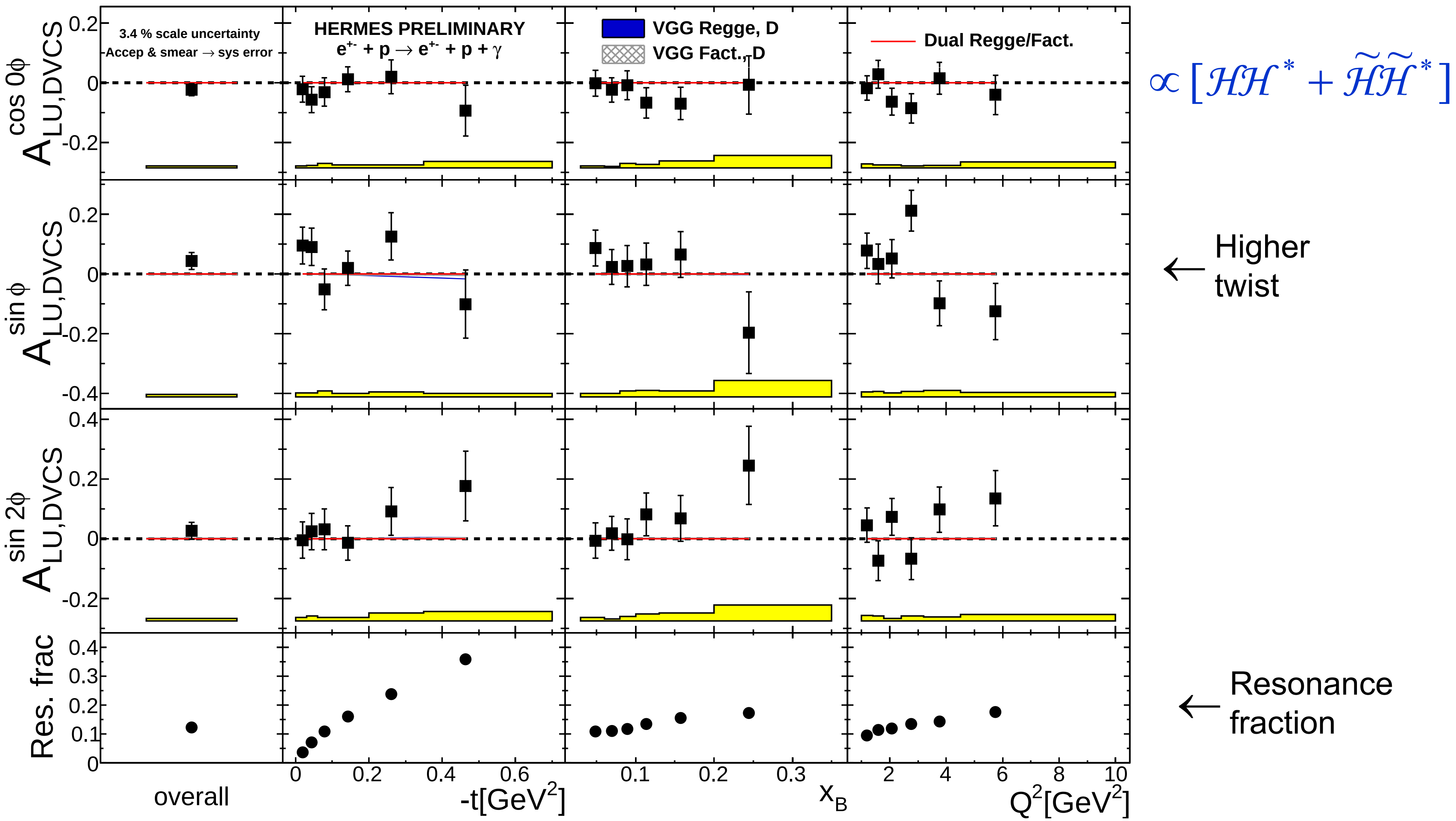
← Gluon leading twist

← Resonance fraction

$ep \rightarrow e\Delta^{+}\gamma$

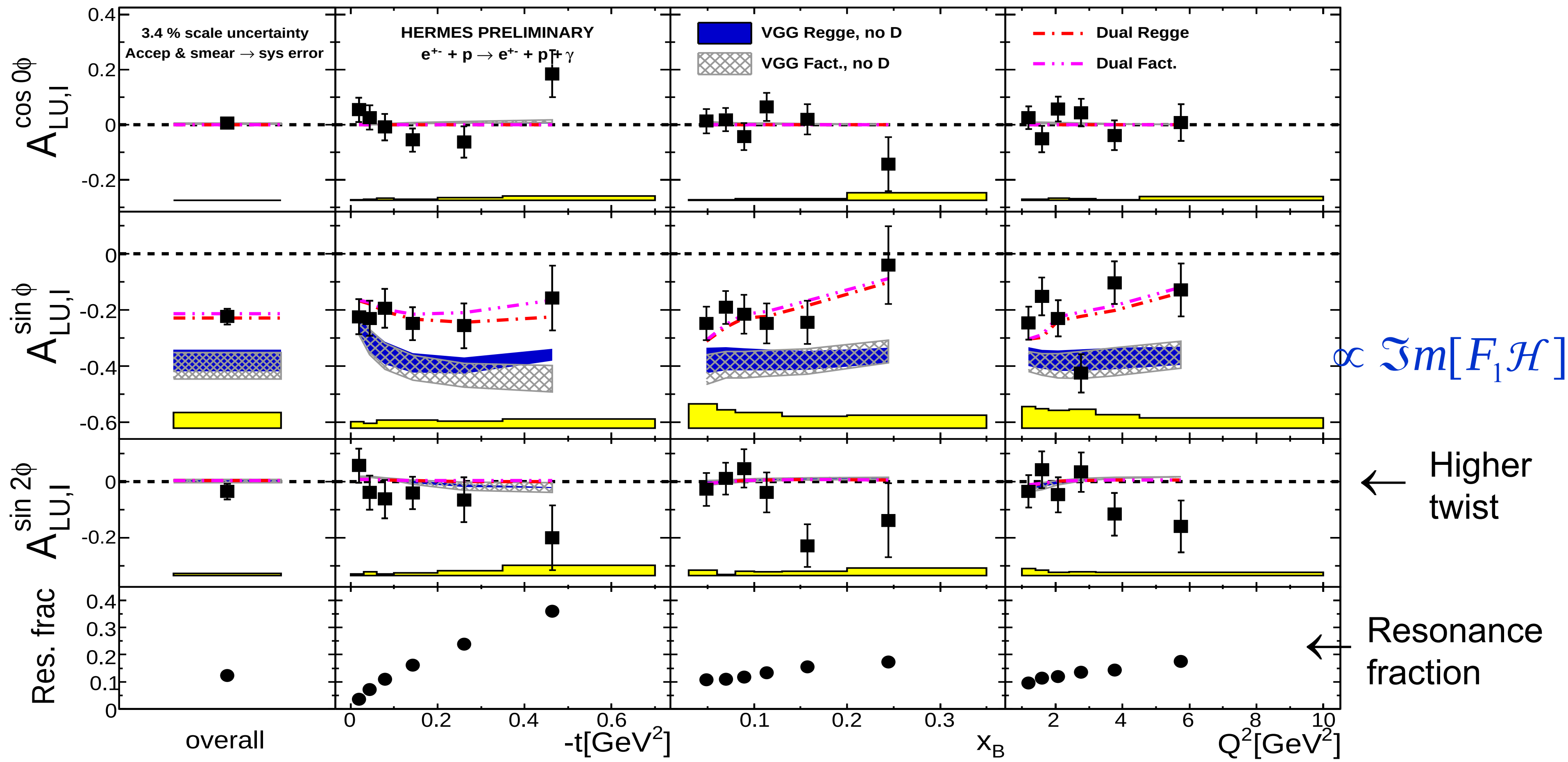
- The factorized ansatz and the VGG variant with the D-term are dis-favored by the beam charge asymmetry

Beam Spin Asymmetry (all data 1996-2005)



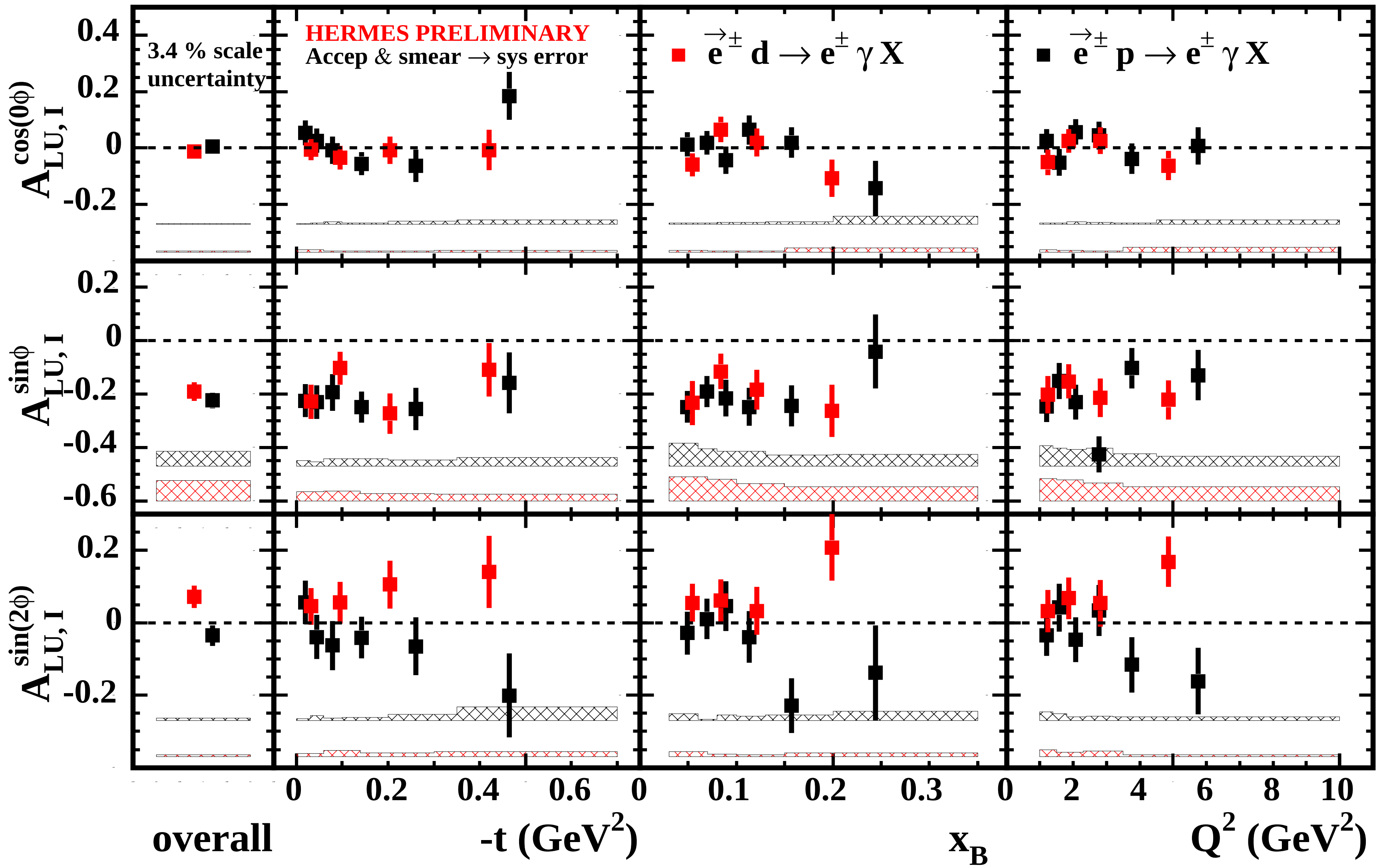
- Pure DVCS squared asymmetries are compatible with zero, in agreement with model assumptions

Beam Spin Asymmetry (all data 1996-2005)



- Result agrees with Dual model predictions, but fractions of associated productions are not corrected for

Comparison to Deuterium Data (all data 1996-2005)

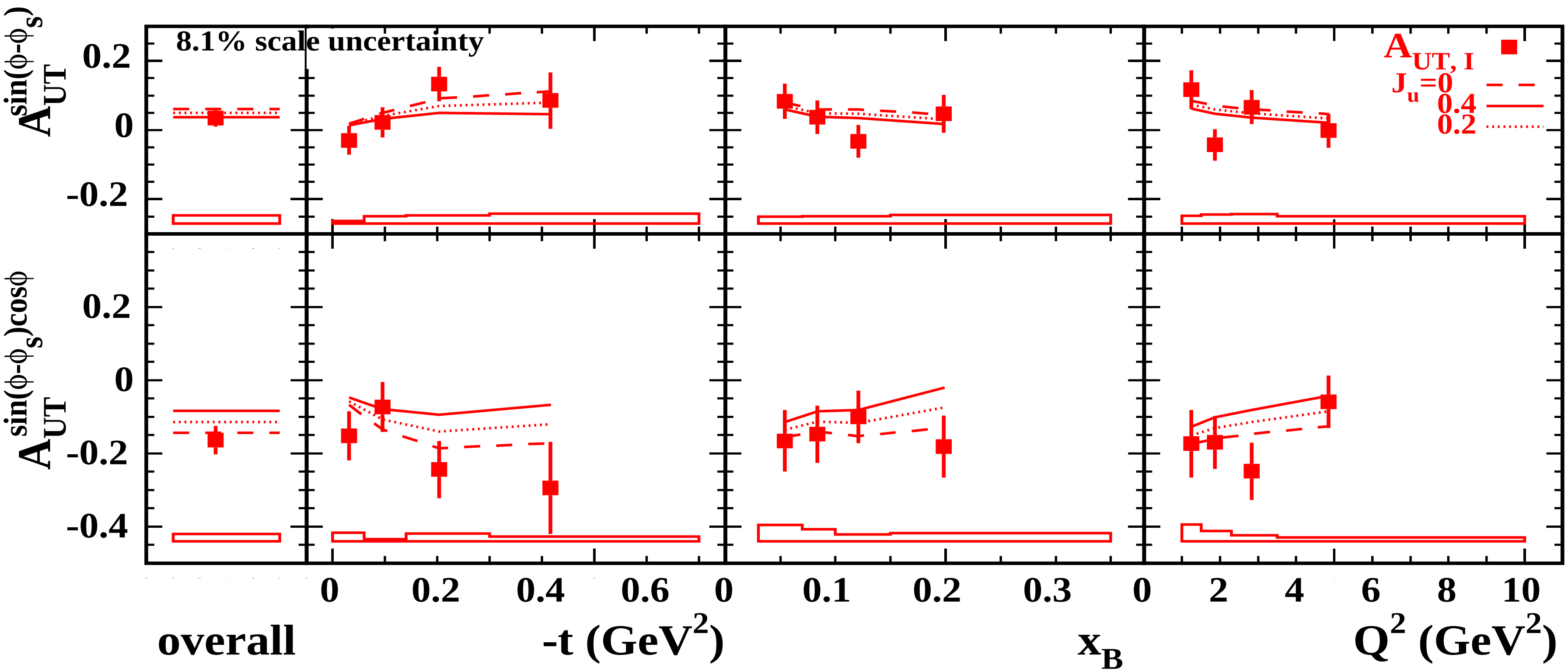


- Proton (black) and Deuteron (red) data are compatible for almost all amplitudes

Transverse Target Spin Asymmetry (TTSA)

- Results on transverse target spin asymmetry are published [*A. Airapetian et al, JHEP 06 (2008) 066*]
- Data with Transversely Polarized Target (2002-2005)
- Access to GPD E
- Model-dependent constraints on J_u, J_d
  - Two GPD models (Double Distribution and Dual Parameterization)
- Comparison with JLAB data on neutron cross section data
- Comparison with lattice QCD calculations

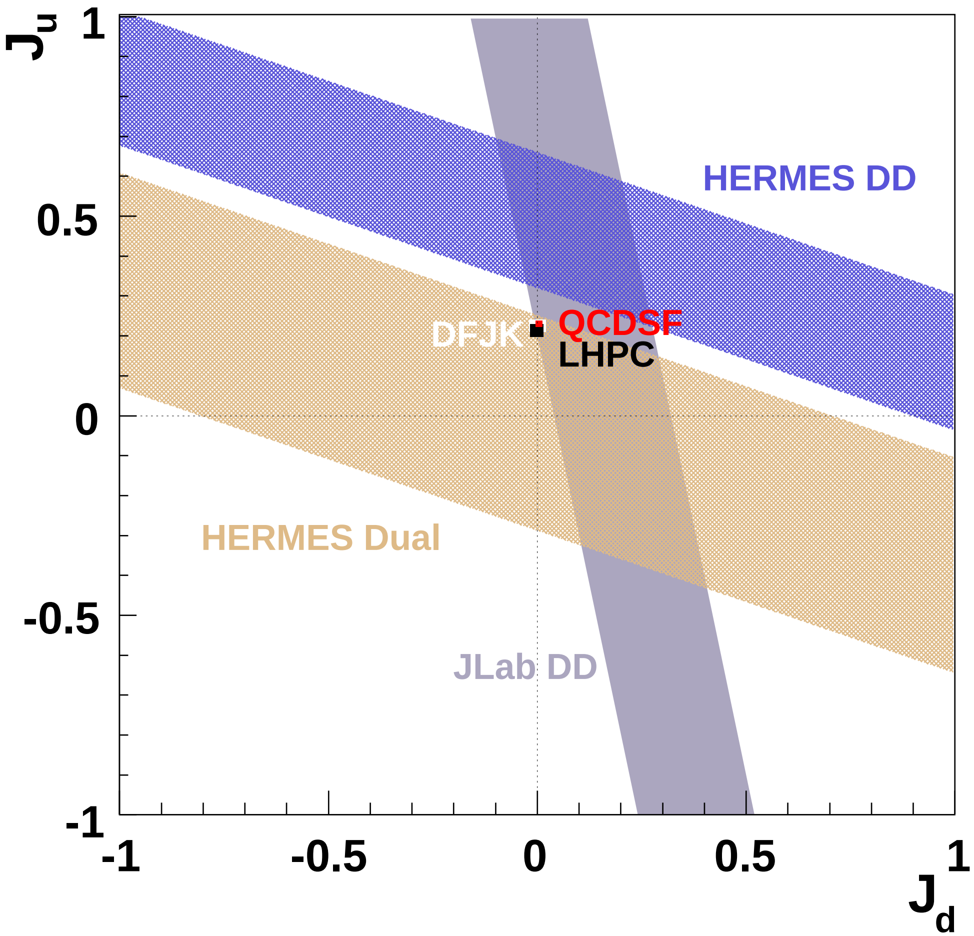
Results on TTSA Amplitudes



Sensitivity of GPD model predictions to J_u at fixed J_d=0
[Phys. Rev. D74(2006) 054027]

Model-Dependent Constraint on J_u, J_d

$$\chi^2(J_u,J_d) = \left(A_{UT,I}^{\sin(\varphi-\varphi_s)\cos n\varphi}\Big|_{exp} - A_{UT,I}^{\sin(\varphi-\varphi_s)\cos n\varphi}\Big|_{theo}(J_u,J_d) \right)^2 \Big/ \left(\delta A_{stat}^2 + \delta A_{syst}^2 \right)$$



- J_u, J_d are free parameters in GPD models
- Double Distribution (DD)
  [Phys.Rev.D 60 (1999) 094017,
  Prog. Part. Nucl. Phys. 47(2001)401]

$$J_u + J_d/2.8 = 0.48 \pm 0.17$$

- Dual Parameterization (Dual)
  [hep-ph/0207153,
  Phys. Rev. D74(2006) 054027]

$$J_u + J_d/2.8 = -0.02 \pm 0.27$$

- Jlab DD (neutron cross section data)
  [Phys. Rev. Lett. 99(2007)242501]
- Lattice calculations QCDSF, LHPC

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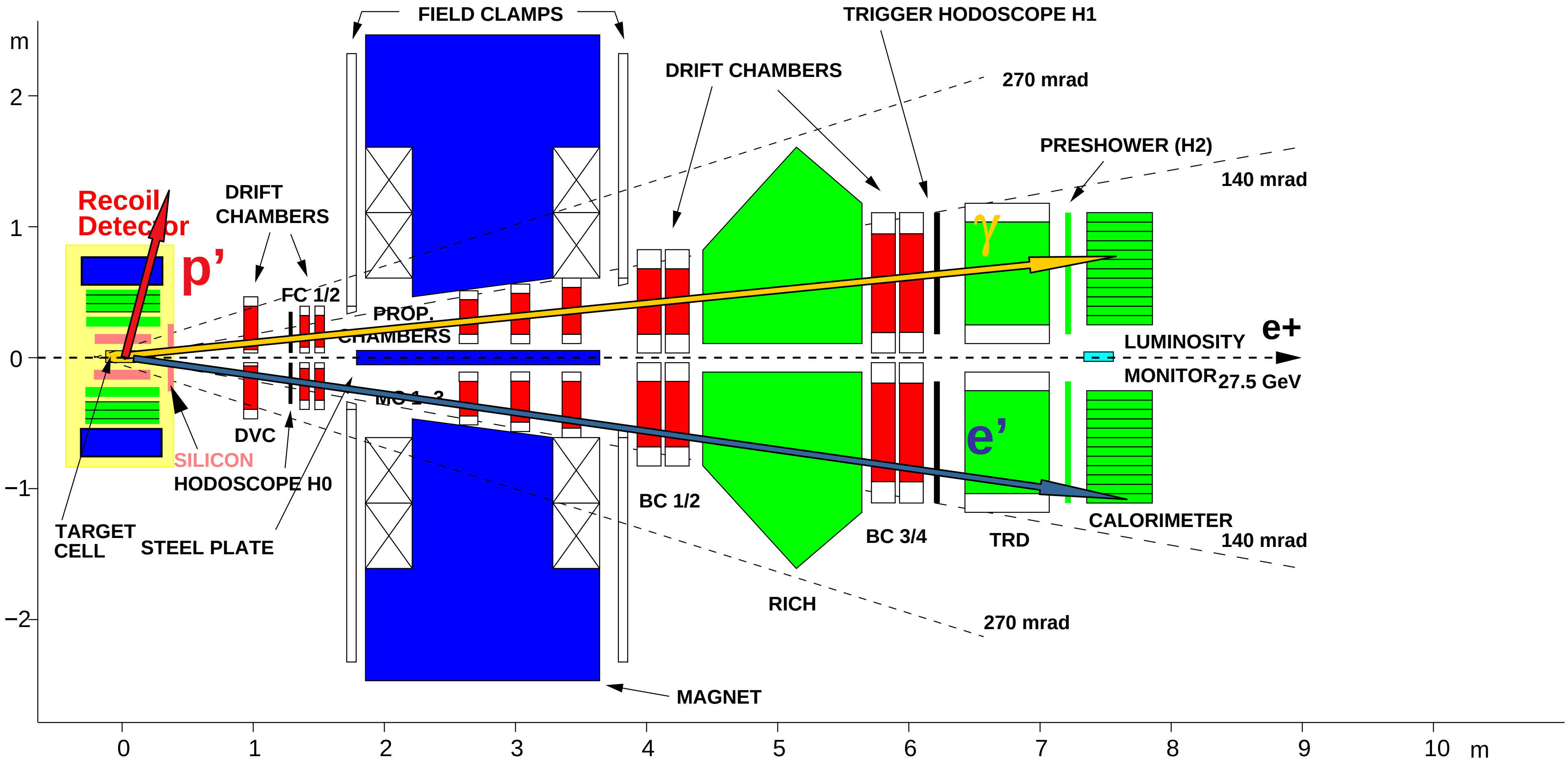
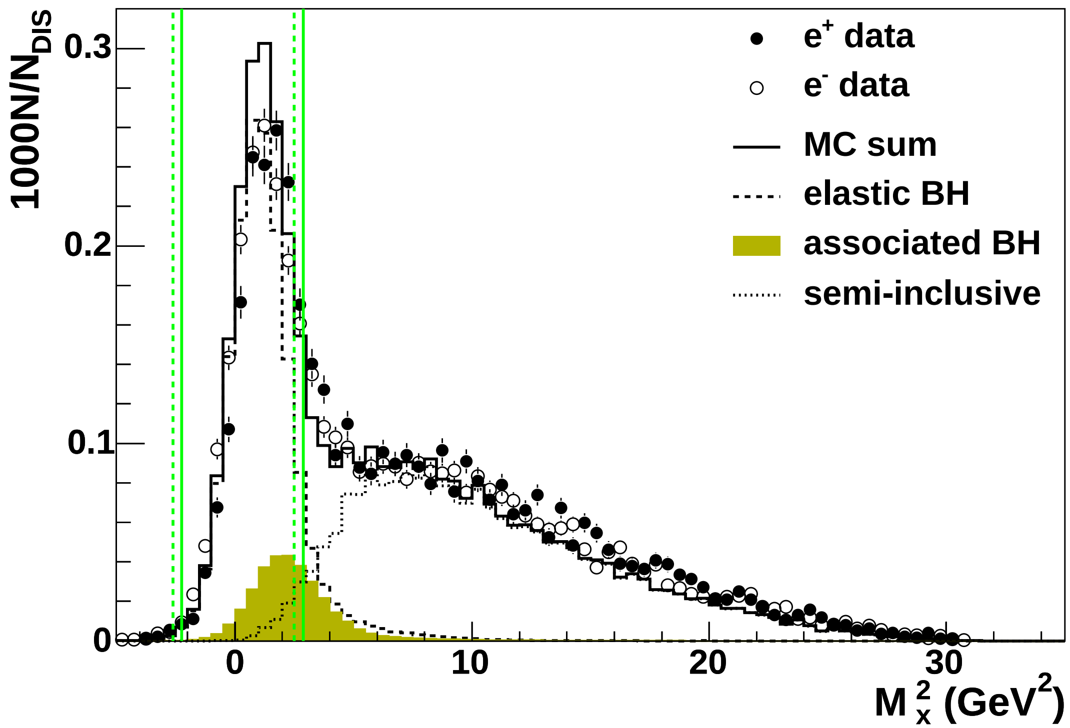
HERMES with the Recoil Detector



- Unpolarized hydrogen target: 38 Mio DIS (41.000 DVCS)
- Unpolarized deuterium target: 10 Mio DIS (7.500 DVCS)
- Two beam helicities, electron and positron beams

DVCS Measurements at HERMES



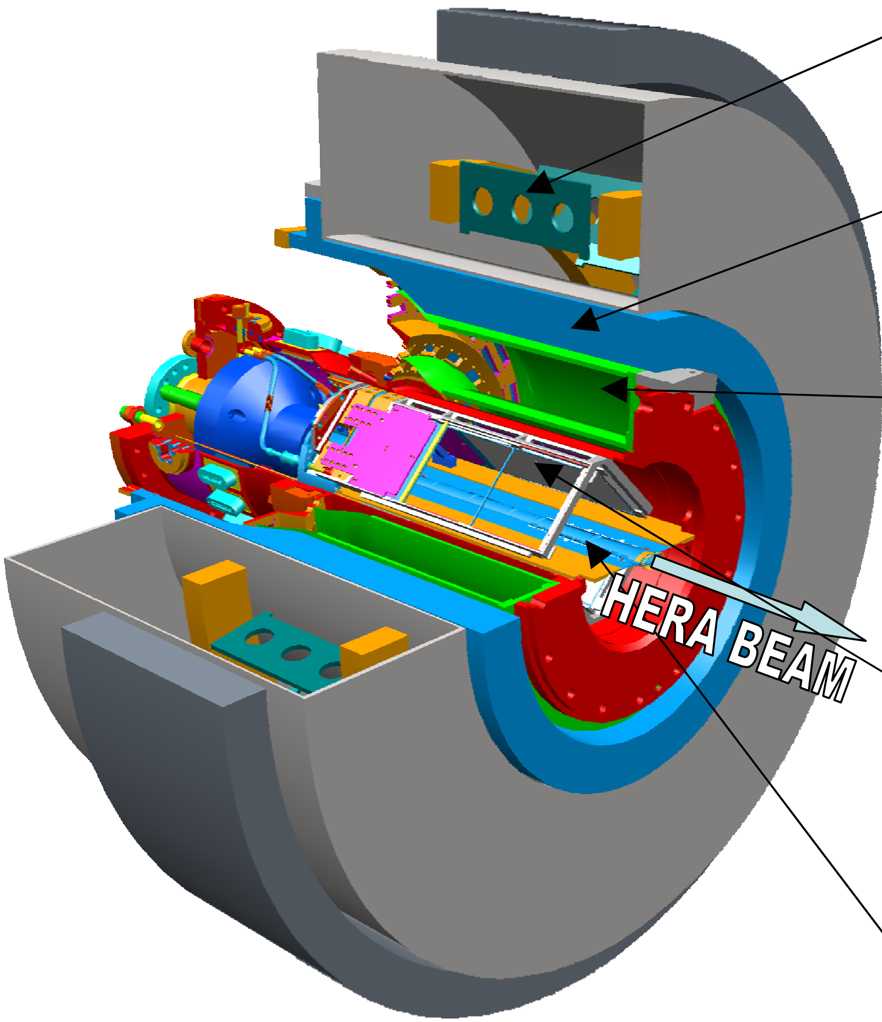
Before Recoil

- Reconstruct DVCS by measuring scattered electron and real photon
- Missing-mass method
- Background from associated Bethe-Heitler ~12%, semi-inclusive ~3%

With Recoil

- Improve exclusivity by measuring recoil protons, pions and photons
- Suppress background to the level below 1%
- Improve t-resolution

HERMES Recoil Detector



1 Tesla Superconducting Solenoid

Photon Detector (PD)

- 3 layers of tungsten-scintillator
- detect gammas, p/π PID

Scintillating Fiber Tracker (SFT)

- 2 barrels of scintillation fibers with 2 parallel and 2 stereo layers
- Momentum reconstruction by bending in magnetic field

Silicon Strip Detector (SSD)

- Momentum reconstruction by energy deposit for low-momentum protons and deuterons
- Inside the HERA vacuum

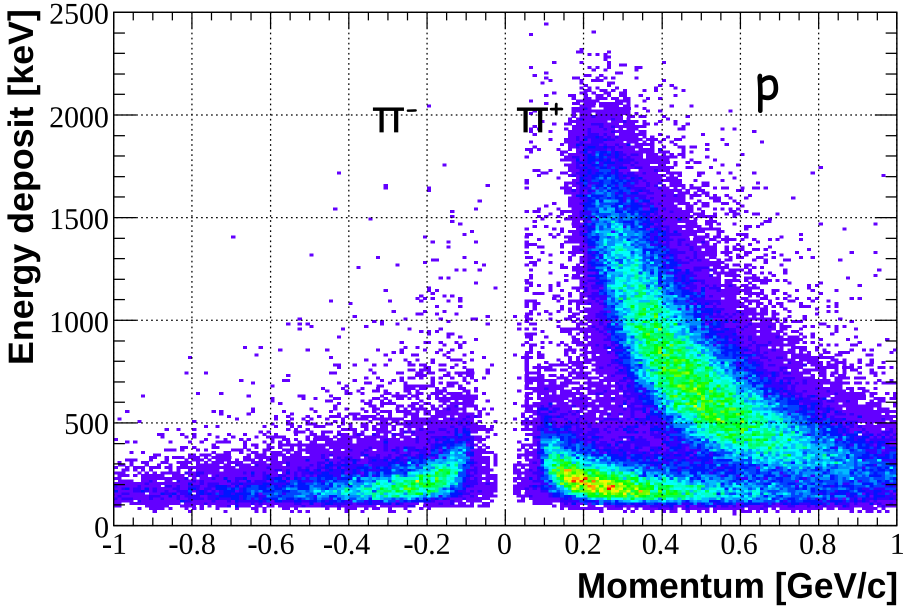
Target Cell of Unpolarized Target

Recoil Detector Status

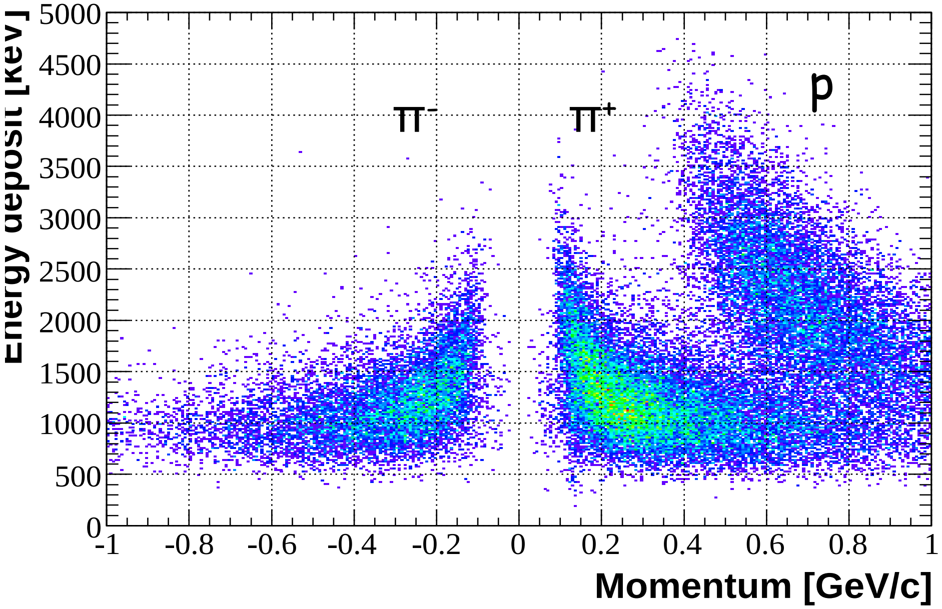
- All sub-detectors are calibrated
- Tracking and momentum reconstruction is done by curvature in the magnetic field and by energy deposit in the Silicon Strip Detector for low-momentum particles
- Sub-detectors are aligned relative to each other using cosmic data and data with and without magnetic field
- Particle identification for protons and pions is possible in all sub-detectors for momentum below 0.7 GeV/c
- Data processing production for physics analysis started

Particle Identification in the Recoil Detector

Silicon Strip Detector



Scintillating Fiber Tracker



Summary and Outlook

- New preliminary DVCS results on BCA and BSA at HERMES from an analysis on the proton and deuteron
  - The BCA clearly dis-favors all factorized model variants and the inclusion of a D-term in VGG
  - The associated production needs to be accounted for in the BSA. The statistical precision allows for strong constraints on GPDs
- DVCS data on transverse target spin asymmetry are published
  - Model-dependent constraints on J_u, J_d
- In the 2006/2007 high-statistics data the associated process can be separated with the information from the Recoil Detector
- Refined analysis of pre-Recoil DVCS data can be performed