Latest DVCS measurements at HERMES and the Recoil Detector

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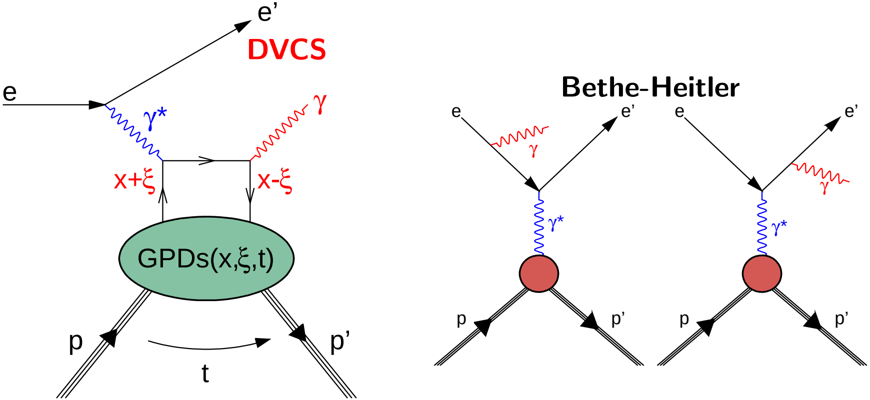
Outline

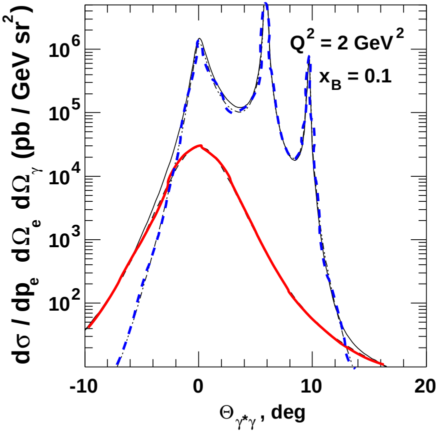
- Hard exclusive processes:
  - How to access GPDs via azimuthal asymmetries
- New HERMES DVCS results (1996-2005):
  - Unpolarized hydrogen and deuterium targets
- The HERMES Recoil Detector (2006/2007):
  - Direct Exclusivity

DVCS/Bethe-Heitler interference in $\mathrm{eN} \rightarrow \mathrm{eN}\gamma$



$$\frac{\mathrm{d}^4\sigma}{\mathrm{d}Q^2\mathrm{d}x_B\mathrm{d}t\mathrm{d}\phi} = \frac{y^2 x_B}{32(2\pi)^4 Q^4 \sqrt{1+\frac{4M^2x_B^2}{Q^2}}} \left(|\mathcal{T}_{\mathrm{DVCS}}|^2 + |\mathcal{T}_{\mathrm{BH}}|^2 + \mathcal{I}\right)$$

DVCS/Bethe-Heitler interference in $\mathrm{eN} \to \mathrm{eN}\gamma$



At HERMES kinematics:

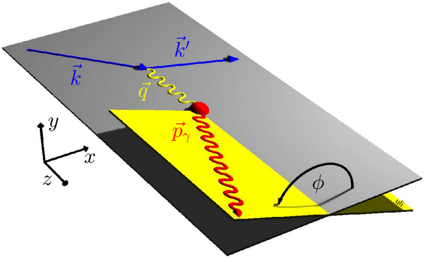
$|\mathcal{T}_{\mathrm{DVCS}}|^2 < |\mathcal{T}_{\mathrm{BH}}|^2$

$$\frac{\mathrm{d}^4\sigma}{\mathrm{d}Q^2\mathrm{d}x_B\mathrm{d}t\mathrm{d}\phi} = \frac{y^2 x_B}{32(2\pi)^4 Q^4 \sqrt{1+\frac{4M^2x_B^2}{Q^2}}} \left(|\mathcal{T}_{\mathrm{DVCS}}|^2 + |\mathcal{T}_{\mathrm{BH}}|^2 + \mathcal{I}\right)$$

Azimuthal dependencies in $\mathrm{eN} \to \mathrm{eN}\gamma$ (twist-3)

Fourier expansion in ϕ for

- **beam polarization P_B**
- **beam charge C_B**
- **unpolarized target**:



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

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

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

Measured Azimuthal Asymmetries in $\mathrm{eN} \longrightarrow \mathrm{eN}\gamma$

$$\sigma_{\mathrm{LU}}(\phi; P_B, C_B) = \sigma_{\mathrm{UU}} \cdot \left[1 + P_B A_{\mathrm{LU}}^{\mathrm{DVCS}} + C_B P_B A_{\mathrm{LU}}^{\mathcal{I}} + C_B A_{\mathrm{C}}\right]$$

- **Beam Spin Asymmetries:**

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

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

- **Beam Charge Asymmetry:**

$$A_{\mathrm{C}}(\phi) = -\frac{1}{\mathcal{D}(\phi)} \cdot \frac{x_B}{y} \left[c_0^{\mathcal{I}} + c_1^{\mathcal{I}} \cos(\phi) + c_2^{\mathcal{I}} \cos(2\phi) + c_3^{\mathcal{I}} \cos(3\phi)\right]$$

Measured Azimuthal Asymmetries in $\mathrm{eN} \longrightarrow \mathrm{eN}\gamma$

- **Beam Spin Asymmetries:**

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

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

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

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

From Azimuthal Asymmetries to GPDs

- To obtain Fourier coefficients = asymmetry amplitudes:
  ▶ Data with different beam charges and beam helicities are combined and **fit simultaneously**
- Connection to GPDs (leading contributions):

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

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

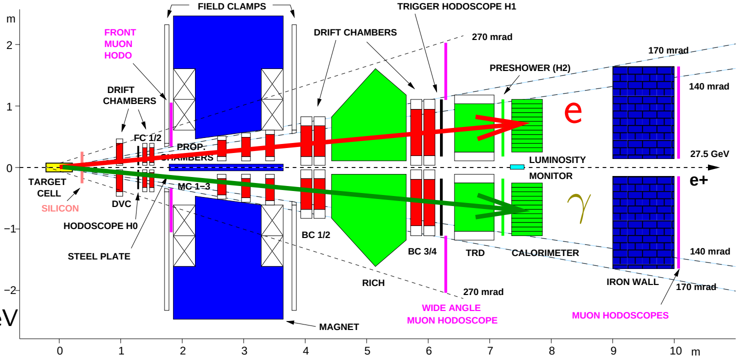
- $\mathcal{H}$, $\widetilde{\mathcal{H}}$, $\mathcal{E}$, $\widetilde{\mathcal{E}}$: COMPTON form factors
  = convolutions of hard scattering amplitude and twist-2 GPDs H, $\widetilde{H}$, E, $\widetilde{E}$
- F_1, F_2: PAULI, DIRAC form factors of the nucleon

DVCS with the HERMES forward spectrometer

gas target: H_2/D_2 unpol/pol nuclear

$e^+, \overrightarrow{\leftarrow}$

$e^-, \overrightarrow{\leftarrow}$



$E_{\text{beam}} = 27.6$ GeV

Collected statistics 1996-2005:
hydrogen: $\approx$ 17 Mio DIS
unpolarized deuterium: $\approx$ 10 Mio DIS

GPD models used for data-theory comparison

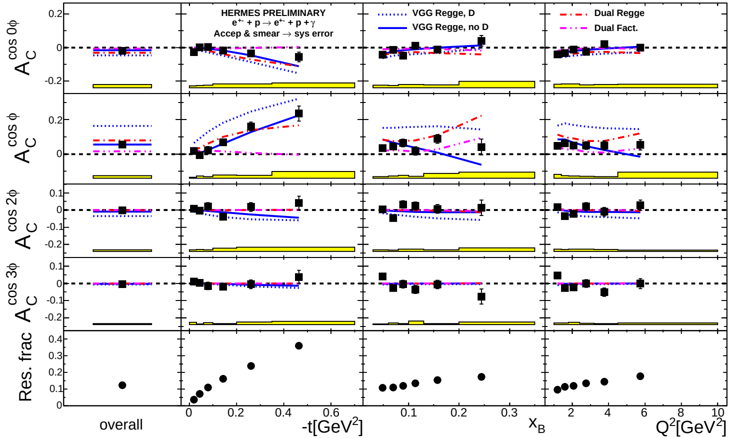
	"VGG" model Vanderhaeghen, Guichon, Guidal 1999	"Dual" model Guzey, Teckentrup 2006
Based on	double distributions	Σ_∞(t-channel resonances)
Regge-inspired ansatz	$\surd$	$\surd$
Factorized t-ansatz	$\surd$	$\surd$
twist-3	$\surd$	$\times$

VGG model: variation of some ingredients possible:

- Skewedness depends on free parameters $b_{\rm val}$, $b_{\rm sea}$
- D-term (to restore full polynomiality) on/off

HERMES DVCS A_C on a hydrogen target

All data 1996-2005



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

$\propto \mathrm{Re}\,[F_1\mathcal{H}]$

←[higher twist]

←[gluon leading twist]

←Resonance fraction▼

e.g. : $eN \to e\Delta^+\gamma$

Avg. 12%, **stays part of signal!**

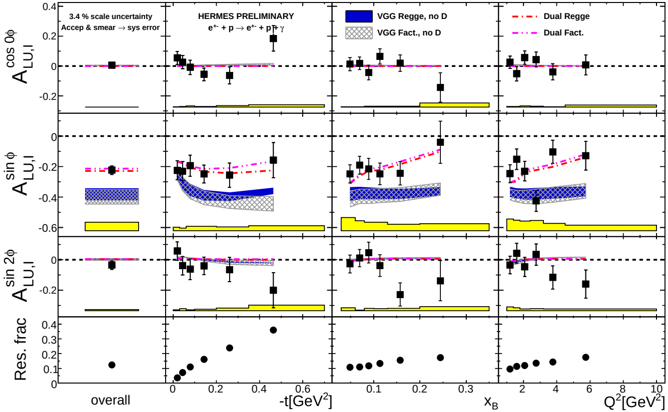
Underlying asy. unknown!

Disfavoured:

- Dual Factorized ansatz
- VGG with D-term

HERMES DVCS $A_{LU}^{\mathcal{I}}$ on a hydrogen target

All data 1996-2005



$\propto \text{Im}\,[F_1\mathcal{H}]$

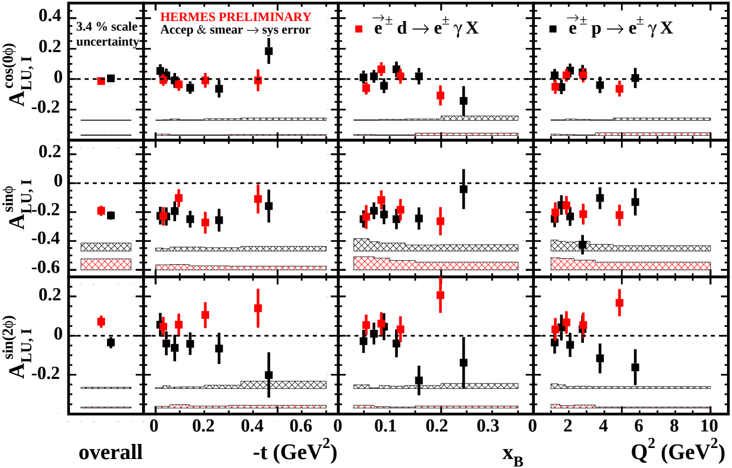
←[higher twist]

←Resonant fraction

- Result agrees with Dual model predictions
- VGG bands: obtained by varying input param's b_{val} and b_{sea}

HERMES DVCS $A_{LU}^{\mathcal{I}}$: H_2 vs. D_2 target

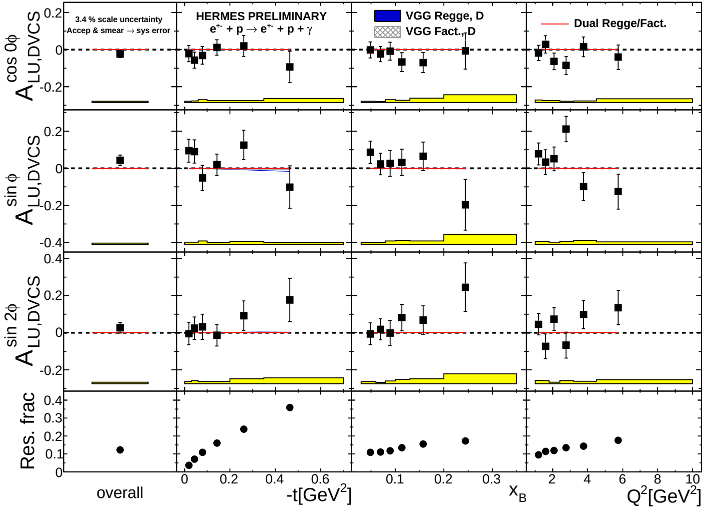
All data
1996-2005



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

HERMES DVCS $A_{\mathrm{LU}}^{\mathrm{DVCS}}$ on a hydrogen target

All data 1996-2005



$\propto [\mathcal{H}\mathcal{H}^* + \widetilde{\mathcal{H}}\widetilde{\mathcal{H}}^*]$

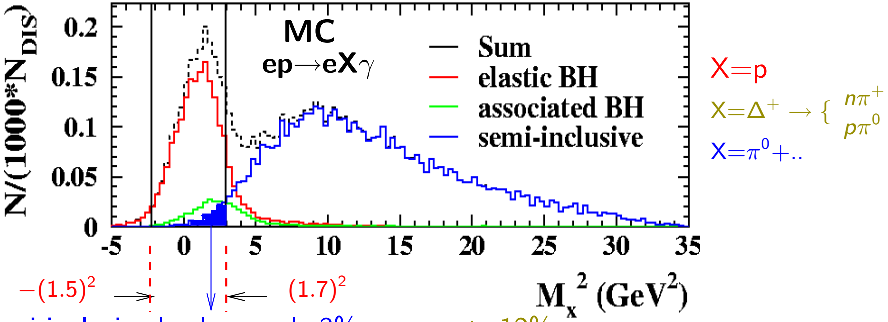
←[higher twist]

←Resonant fraction

$|\mathcal{T}_{\mathrm{DVCS}}|^2$ asymmetries compatible with 0, in agreement with model assumptions

Exclusivity at HERMES

- Until now: **missing mass technique**

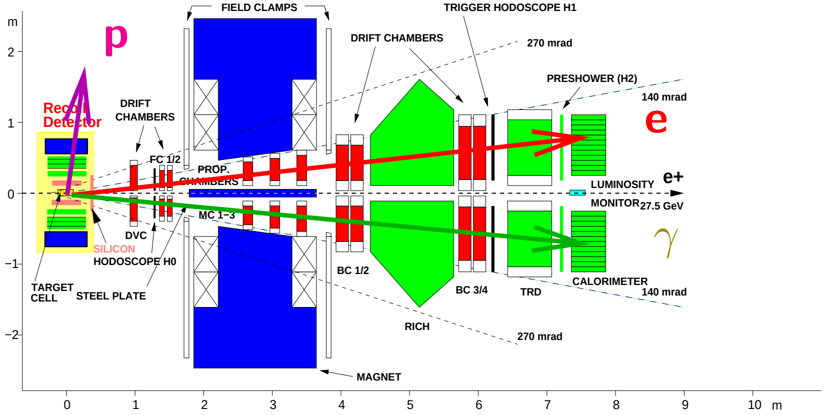


semi-inclusive background: 3%, resonant: 12%

- With the **Recoil Detector**: genuine exclusivity
  - Identify recoiling protons
  - Identify particles from background processes

    ⇒ semi-inclusive DIS: 3% $\searrow \ll$ 1%, resonant: 12% $\searrow$ 1%

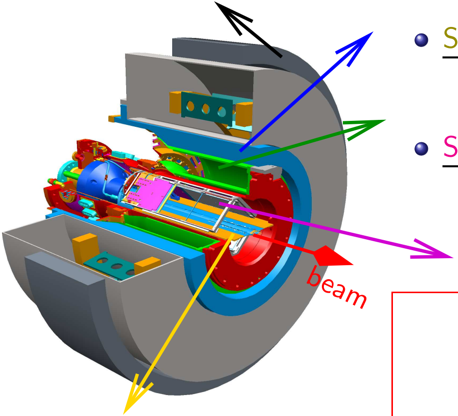
Dedicated high lumi run 2006/2007 with Recoil



- Unpolarized hydrogen target: **38 Mio DIS** (41.000 DVCS)
- Unpolarized deuterium target: **10 Mio DIS** (7.500 DVCS)
- **2 Beam helicities**, positron beam

The HERMES Recoil Detector

- SC Solenoid (1 Tesla)



- Target Cell with unpol. H_2 or D_2

- Photon Detector
  - 3 layers of Tungsten/Scintillator
- Scintillating Fiber Tracker
  - 2 Barrels
  - Each 2 parallel- & 2 stereo-layers
- Silicon Strip Detector
  - 2 Layers of 16 double-sided sensors
  - (10cm$\times$10cm) active area
  - Inside accelerator vacuum

Silicon & Fiber Tracker:

$p_{\mathrm{p}} \in [135, 1200]$ MeV/c

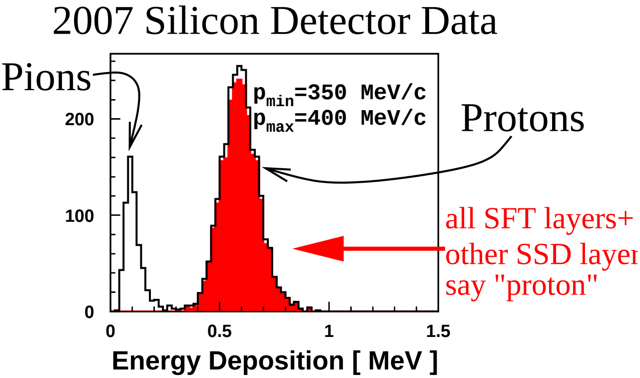
p/π **PID** for $p < 650$ MeV/c

Photon Detector:

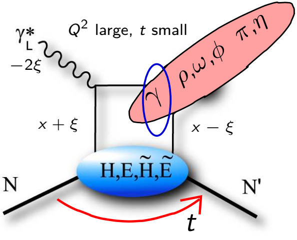
p/π **PID** for $p > 600$ MeV/c

π^0 background supression

Demonstration of Recoil Particle Identification



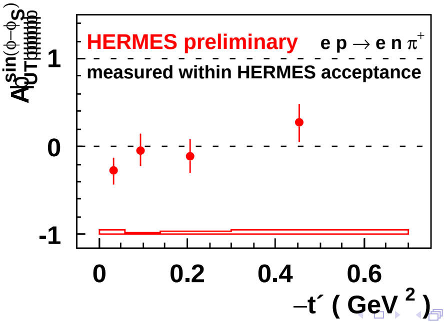
Exclusivity at HERMES in a nutshell



GPD access at HERMES:

unpolarized	polarized
photon: $J^{\mathcal{P}} = 1^-$ (DVCS)	
H: A_C, A_{LU}, A_{UT} **E**: A_{UT}	$\widetilde{\mathbf{H}}$: A_{UL} , $[A_{UT}]$ $\widetilde{\mathbf{E}}$: $[A_{UT}]$
$J^{\mathcal{P}} = 1^-$ mesons	$J^{\mathcal{P}} = 0^-$ mesons

$\Downarrow$ **excl.** π^+



Summary and Outlook

- Presented analysis:
  - Extraction of azimuthal harmonics wrt beam spin and charge in DVCS (1996-2005)
  - The high statistical precision allows for strong constraints on GPDs
- Coming up: Analysis of data **with Recoil Detector**
  - A_{LU} 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 π^- and π^0 impossible without Recoil Detector!
- Refined analysis of **pre-Recoil** DVCS and other exclusive data: background contributions can be directly measured

BACKUP

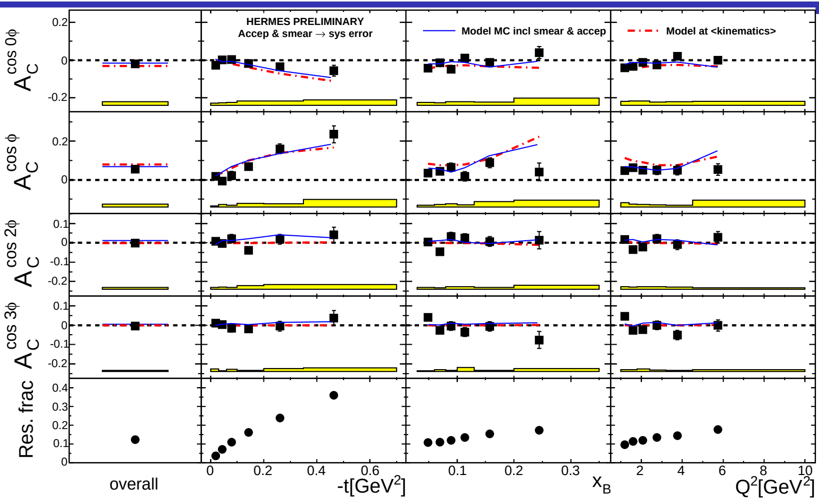
Corrections √ and systematic uncertainties ■

- (√, ■) Shift of exclusive peak between e^- and e^+ data (small)
- (√, ■) Semi-inclusive and exclusive background
  ⇒ Fractions from Monte Carlo
- (■) Acceptance, bin-width, smearing and detector misalignment (main contribution)
  ⇒ Estimated from Monte Carlo simulation employing range of available models
  ⇒ Model dependence
- The contributions from the resonance region, e.g.

$$eN \rightarrow e\Delta^+\gamma$$

  stays part of the signal, in average 12%!
  The underlying **"associated" asymmetry is unknown!**

Acceptance, bin-width, smearing and misalignment effects



The difference between "model-generated" and in the HERMES acceptance reconstructed MC amplitudes is taken as sytematic uncertainty

Demonstration of Recoil PID (all p-bins)