Experimental overview of DVCS results from HERMES

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on behalf of the HERMES collaboration

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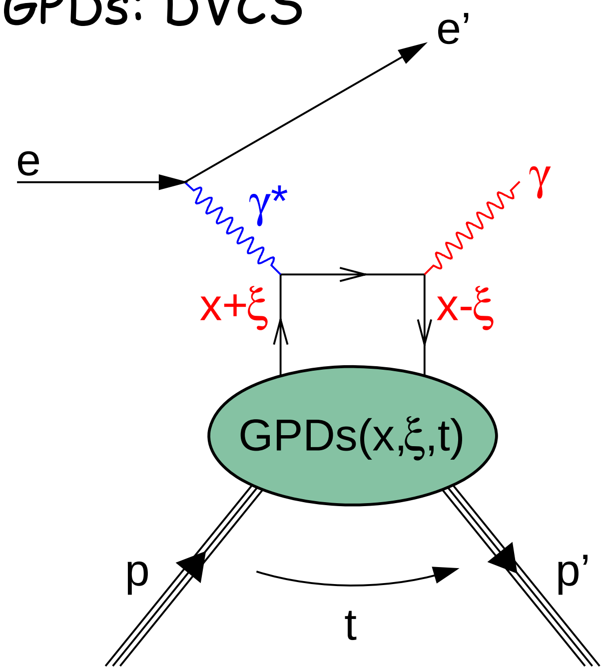
Outline

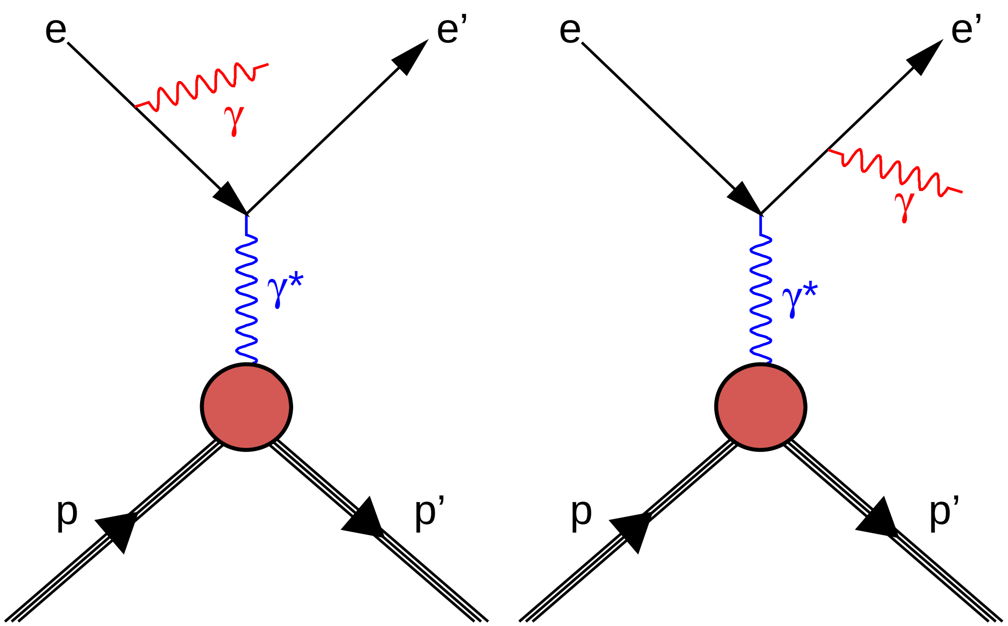
- Physics motivation
  - DVCS as a tool to access GPDs
- HERMES experiment
- Recent results on DVCS from HERMES
  - Combined analysis of beam-helicity and beam-charge asymmetries on proton and deuteron
  - Transverse target polarization asymmetry
  - Nuclear-mass dependence of beam-helicity and beam-charge asymmetries
- Exclusivity at 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

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

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

- GPDs → FFs

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

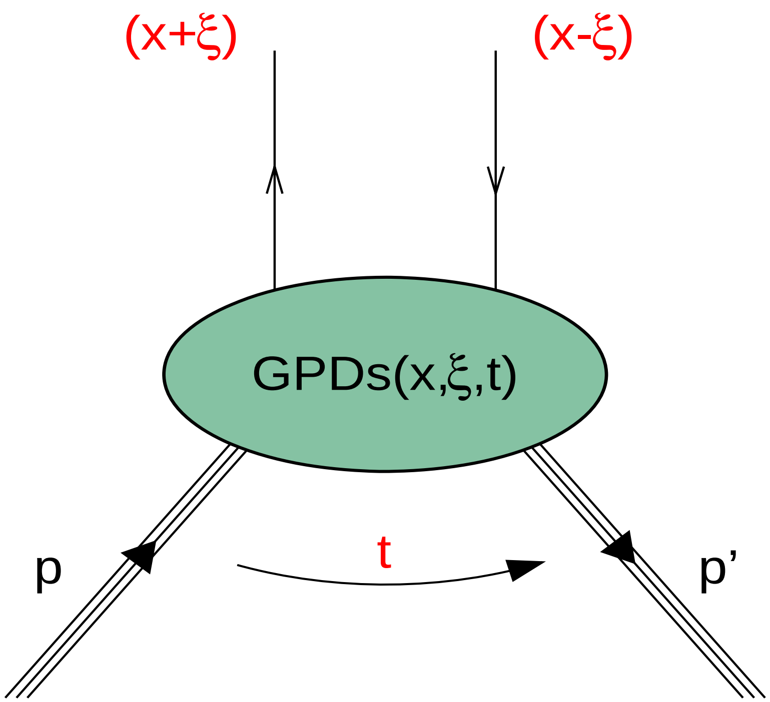
$$\int_{-1}^{1} dx\, E_q(x,\xi,t) = F_2^q(t)$$

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

x average parton longitudinal momentum fraction

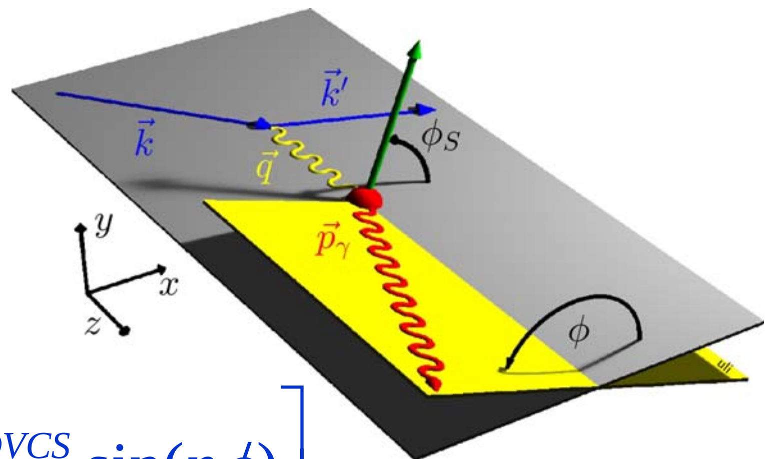
ξ fraction of the longitudinal momentum transfer

t squared 4-momentum transfer to the nucleon



Azimuthal dependences

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



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

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

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

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-helicity asymmetry

$$A_{LU}^{DVCS}(\phi) = \frac{\left(\sigma^{+\rightarrow} - \sigma^{+\leftarrow}\right) - \left(\sigma^{-\leftarrow} - \sigma^{-\rightarrow}\right)}{\left(\sigma^{+\rightarrow} + \sigma^{+\leftarrow}\right) + \left(\sigma^{-\leftarrow} + \sigma^{-\rightarrow}\right)} = \frac{1}{D(\phi)} \cdot \frac{x_B^2 t \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}{Q^2} s_1^{DVCS} \sin(\phi)$$

$$A_{LU}^{I}(\phi) = \frac{\left(\sigma^{+\rightarrow} + \sigma^{-\leftarrow}\right) - \left(\sigma^{+\leftarrow} + \sigma^{-\rightarrow}\right)}{\left(\sigma^{+\rightarrow} + \sigma^{-\leftarrow}\right) + \left(\sigma^{+\leftarrow} + \sigma^{-\rightarrow}\right)} = -\frac{1}{D(\phi)} \frac{x_B^2}{Q^2} \sum_{n=1}^{2} s_n^I \sin(n\phi)$$

- Beam-charge asymmetry

$$A_C(\phi) = \frac{\left(\sigma^{+\rightarrow} + \sigma^{+\leftarrow}\right) - \left(\sigma^{-\leftarrow} + \sigma^{-\rightarrow}\right)}{\left(\sigma^{+\rightarrow} + \sigma^{+\leftarrow}\right) + \left(\sigma^{-\leftarrow} + \sigma^{-\rightarrow}\right)} = -\frac{1}{D(\phi)} \frac{x_B^2}{y} \sum_{n=0}^{3} c_n^I \cos(n\phi)$$

- Azimuthal angle dependence in the denominator

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

Connection to GPDs

- Connections of Fourier coefficients to GPDs (leading contributions)

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

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

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

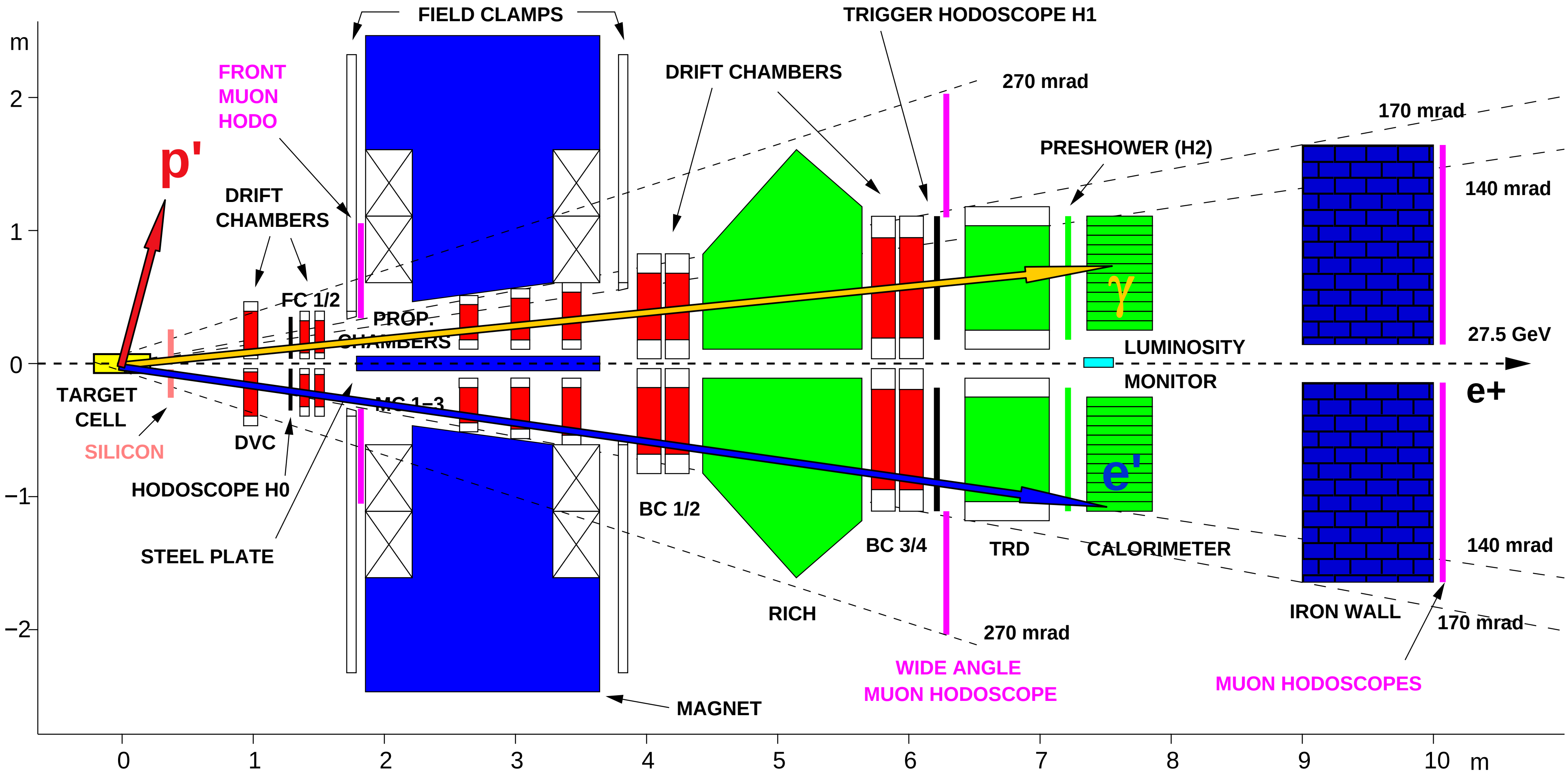
F_1, F_2 - Dirac and Pauli form factors of the nucleon

- At HERMES kinematics

$$c_1^I \propto \frac{\sqrt{-t}}{Q} \Re e\left[F_1 \mathcal{H} \right]$$

$$s_1^I \propto \frac{\sqrt{-t}}{Q} \Im m\left[F_1 \mathcal{H} \right]$$

The HERMES experiment



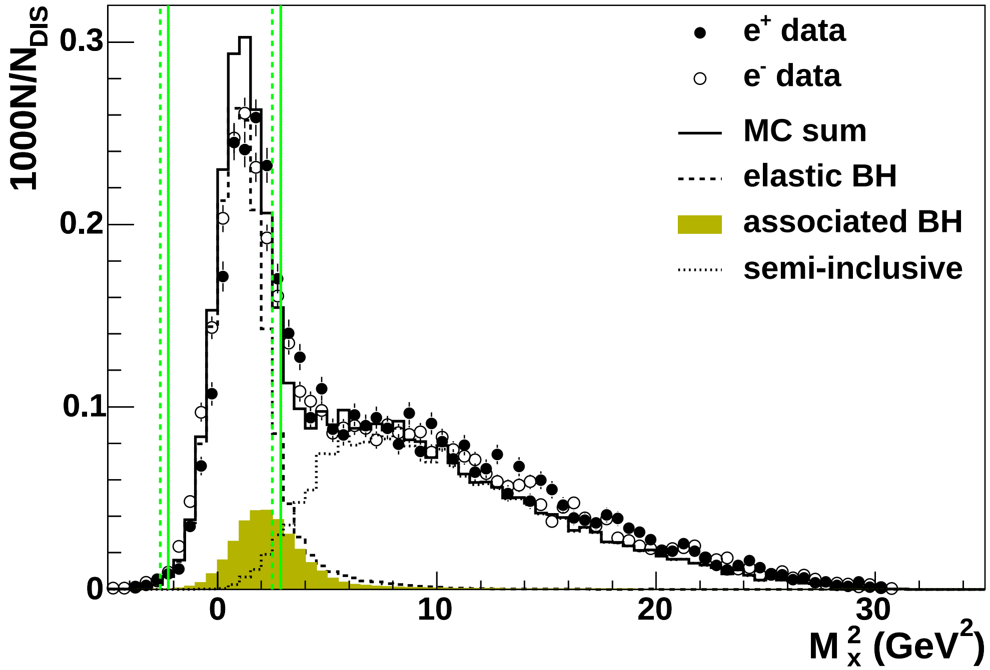
Gas targets:

- Longitudinally polarized H, D
- Unpolarized H, D, ^{4}He, N, Ne, Kr, Xe
- Transversely polarized H

Beam:

- Longitudinally polarized e^+ and e^- with both helicities
- Energy 27.6 GeV

Event selection, uncertainties and corrections



Kinematic requirements

$0.03 < x_B < 0.35$

$1\ GeV^2 < Q^2 < 10\ GeV^2$

$-t < 0.7\ GeV^2$

$E_\gamma > 5\ GeV$

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

Extraction of asymmetry amplitudes

- Fourier expansion of asymmetries

$$A_C(\phi) = \sum_{n=0}^{3} A_C^{\cos(n\phi)} \cos(n\phi) + A_C^{\sin(\phi)}$$

$$A_{LU}^{I}(\phi) = \sum_{n=1}^{2} A_{LU,I}^{\sin(n\phi)} \sin(n\phi) + \sum_{n=0}^{1} A_{LU,I}^{\cos(n\phi)} \cos(n\phi)$$

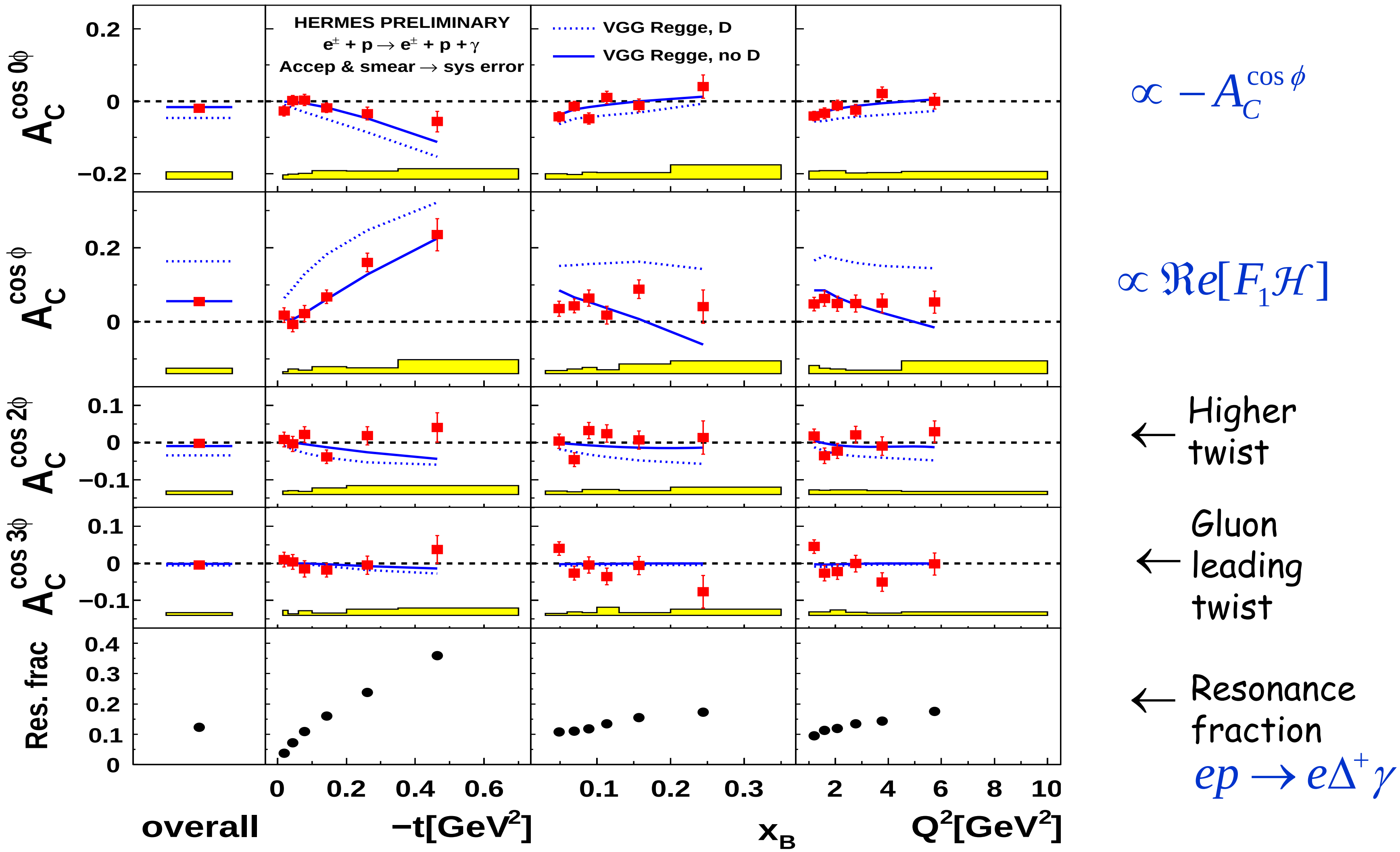
$$A_{LU}^{DVCS}(\phi) = \sum_{n=1}^{2} A_{LU,DVCS}^{\sin(n\phi)} \sin(n\phi) + \sum_{n=0}^{1} A_{LU,DVCS}^{\cos(n\phi)} \cos(n\phi)$$

- Asymmetry amplitudes are extracted simultaneously with a Maximum Likelihood method

- Combined analysis allows separation of DVCS and interference terms

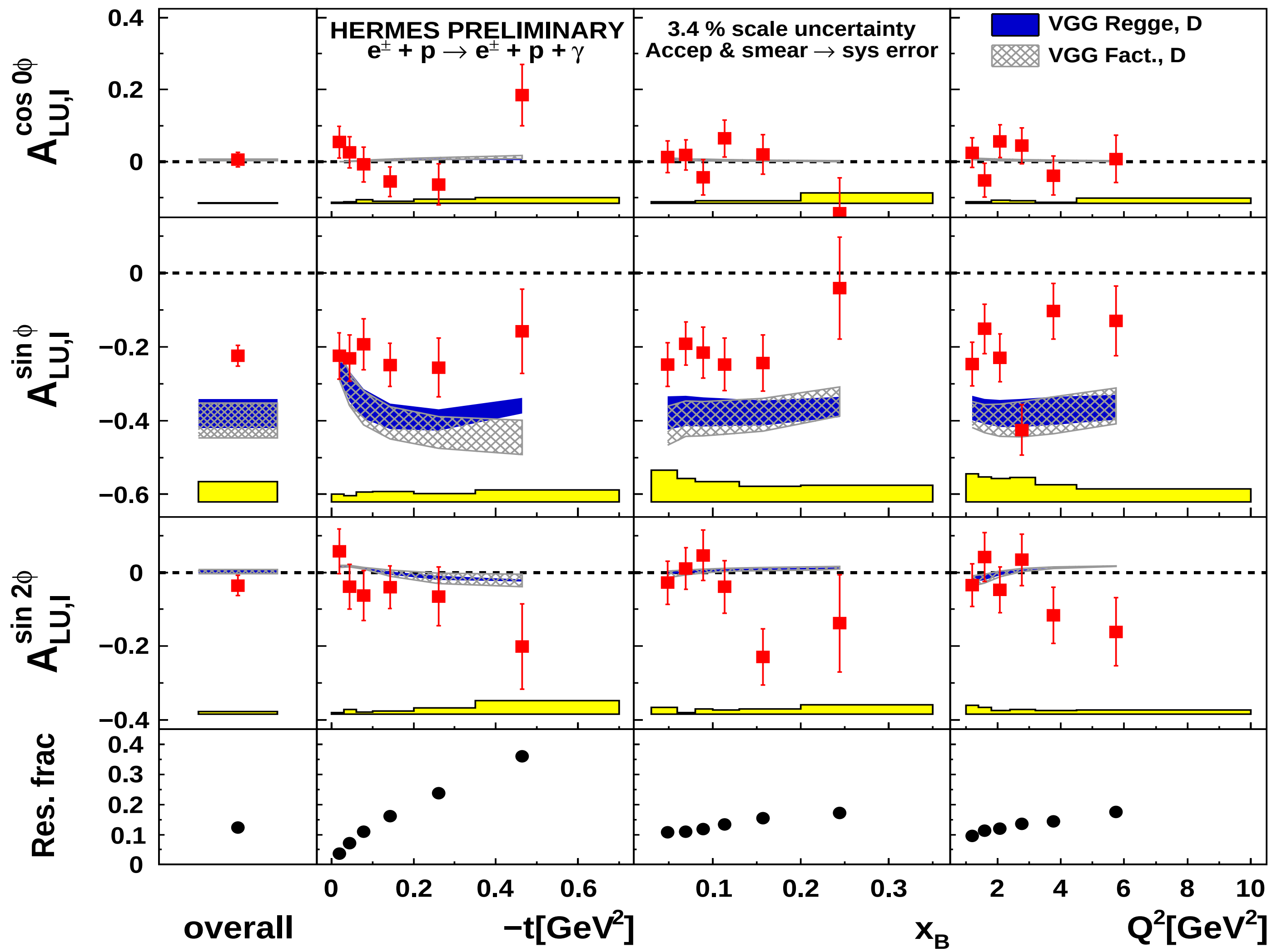
- Comparison with theoretical model (Vanderhaeghen, Guichon, Guidal) [Phys. Rev. D 60 (1999) 094017]

Beam-charge asymmetry amplitudes



- The VGG variant with the D-term is disfavored by the beam charge asymmetry

Beam-helicity asymmetry amplitudes (interference term)



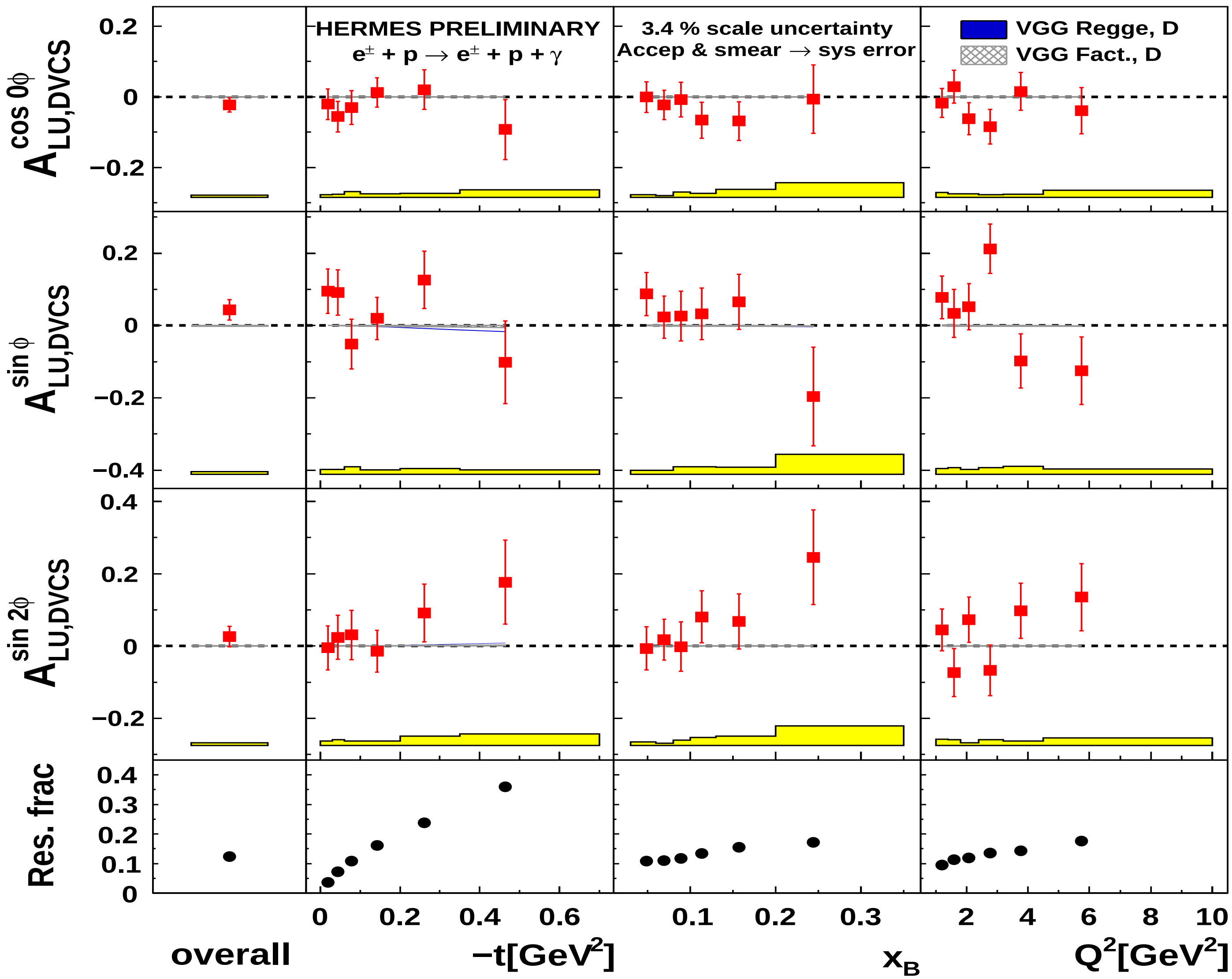
$\propto \Im m[F_1 \mathcal{H}]$

← Higher twist

← Resonance fraction $ep \to e\Delta^+\gamma$

- VGG bands obtained by varying input parameters b_{val} and b_{sea}
- VGG model predictions overestimate the size of asymmetry

Beam-helicity asymmetry amplitudes (DVCS term)

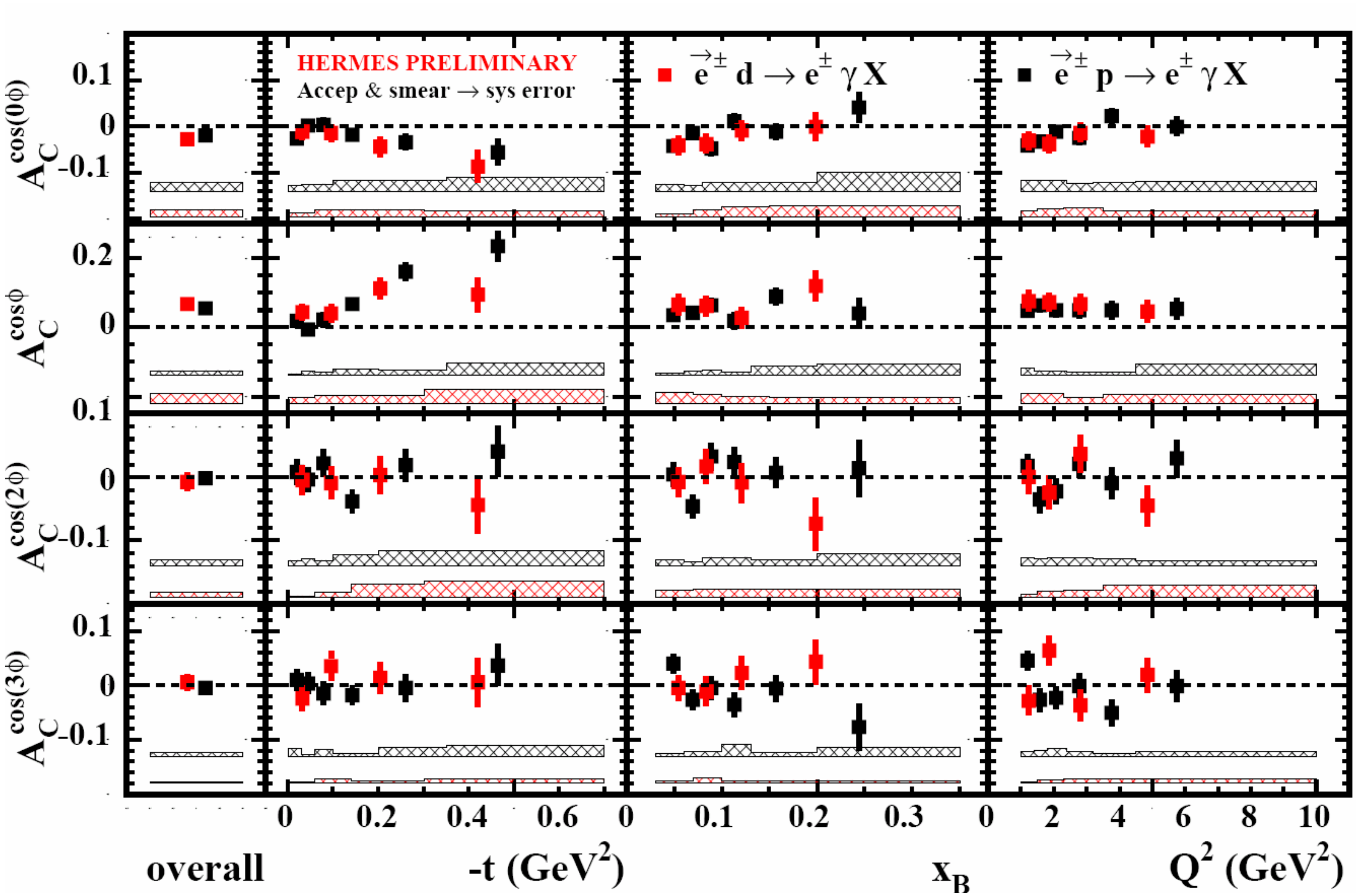


$\propto [\mathcal{H}\mathcal{H}^* + \tilde{\mathcal{H}}\tilde{\mathcal{H}}^*]$

← Resonance fraction

$ep \to e\Delta^+\gamma$

Comparison to deuterium data (beam-charge asymmetry amplitudes)



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

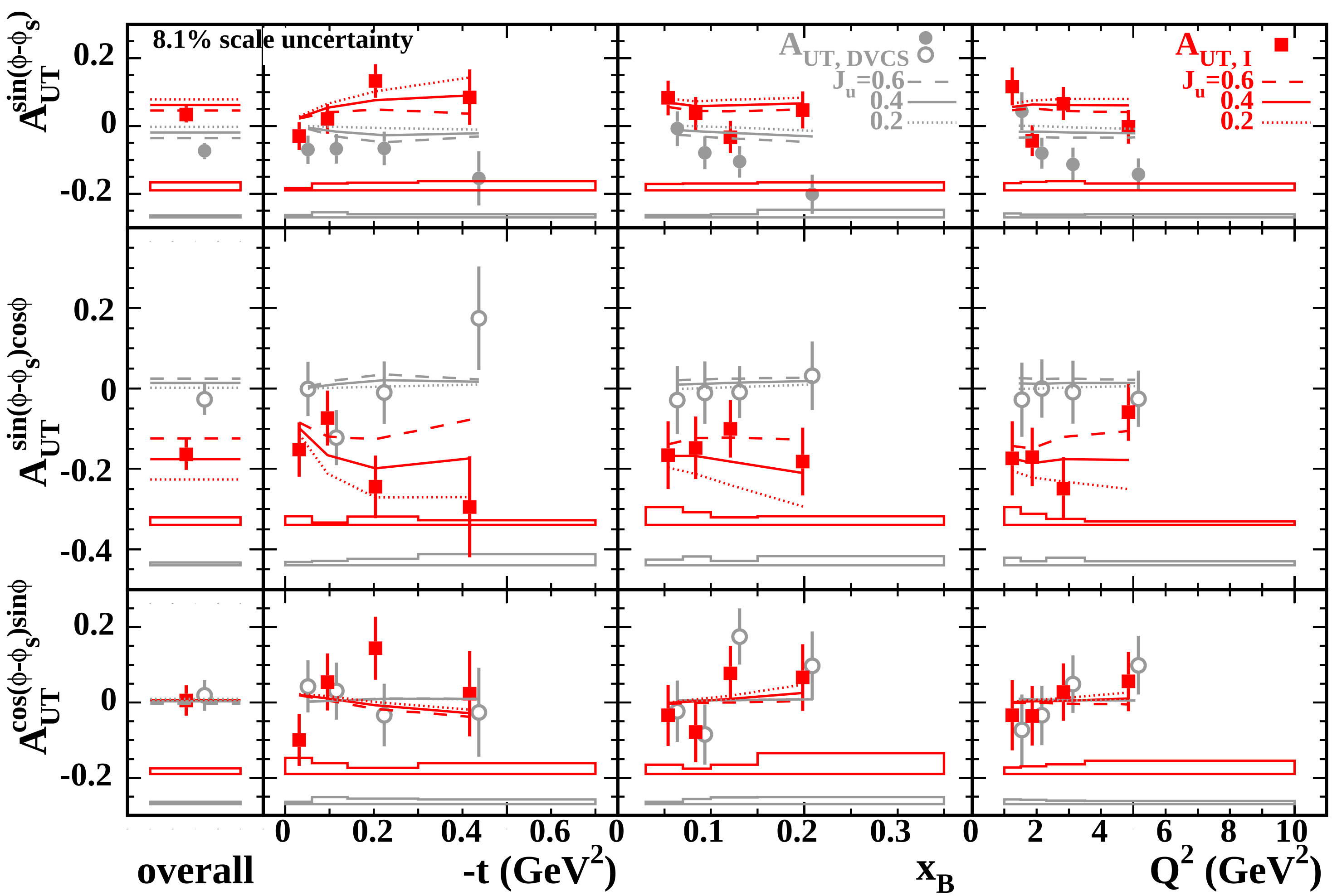
Transverse target polarization asymmetry

- Results on transverse target polarization asymmetry are published [*A. Airapetian et al, JHEP 06 (2008) 066*]
- Data with transversely polarized hydrogen target (2002-2005)
- Access to GPD E - access to the total angular momentum of quarks in the nucleon via Ji relation

$$\mathrm{J}_{\mathrm{q}} = \lim_{t \to 0} \int_{-1}^{1} dx\, x \left[H_q(x, \xi, t) + E_q(x, \xi, t) \right]$$

- Model-dependent constraints on J_u, J_d

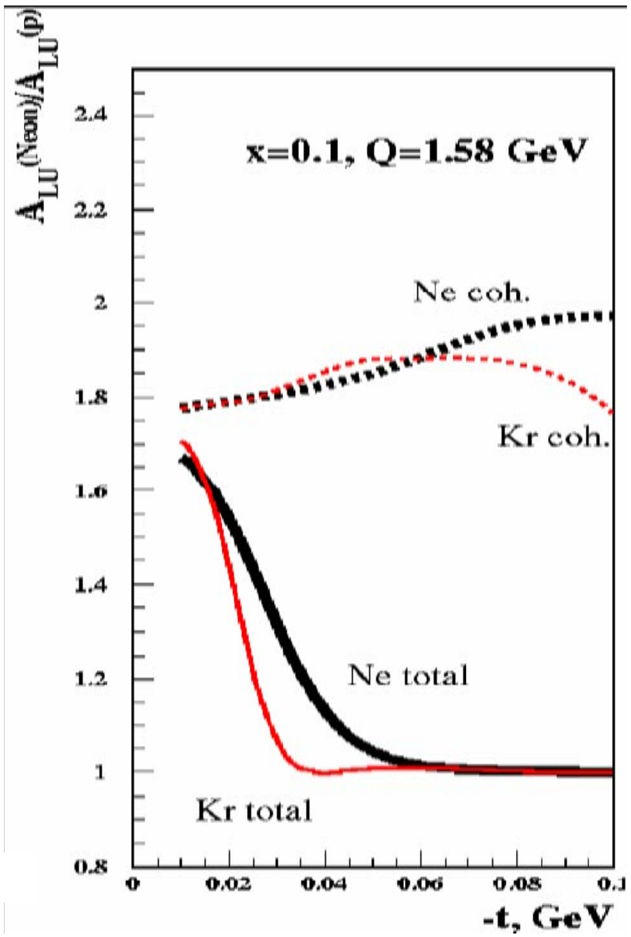
Transverse target polarization asymmetry amplitudes



Sensitivity of GPD model predictions to J_u at fixed J_d=0

DVCS on nuclear targets

- Additional information on GPDs and their modification in nuclear matter
- New opportunity to study the origin of nuclear forces
- Access to 3-D distribution of quarks and gluons in nuclei



Ratio of asymmetries measured on nuclear targets to asymmetries measured with proton target

⇒ R_{coh}=1.8-2.0 for A=12-90
Guzey, Strikmann [PRC 68 (2003) 015204]

R_{coh}=1.0-1.1 for A=^{4}He
Liuti, Taneja [PRC 72 (2005) 032201]

R_{coh}=5/3 for spin-0, $\frac{1}{2}$
Kirchner, Müller [EPJ C32 (2003) 347]

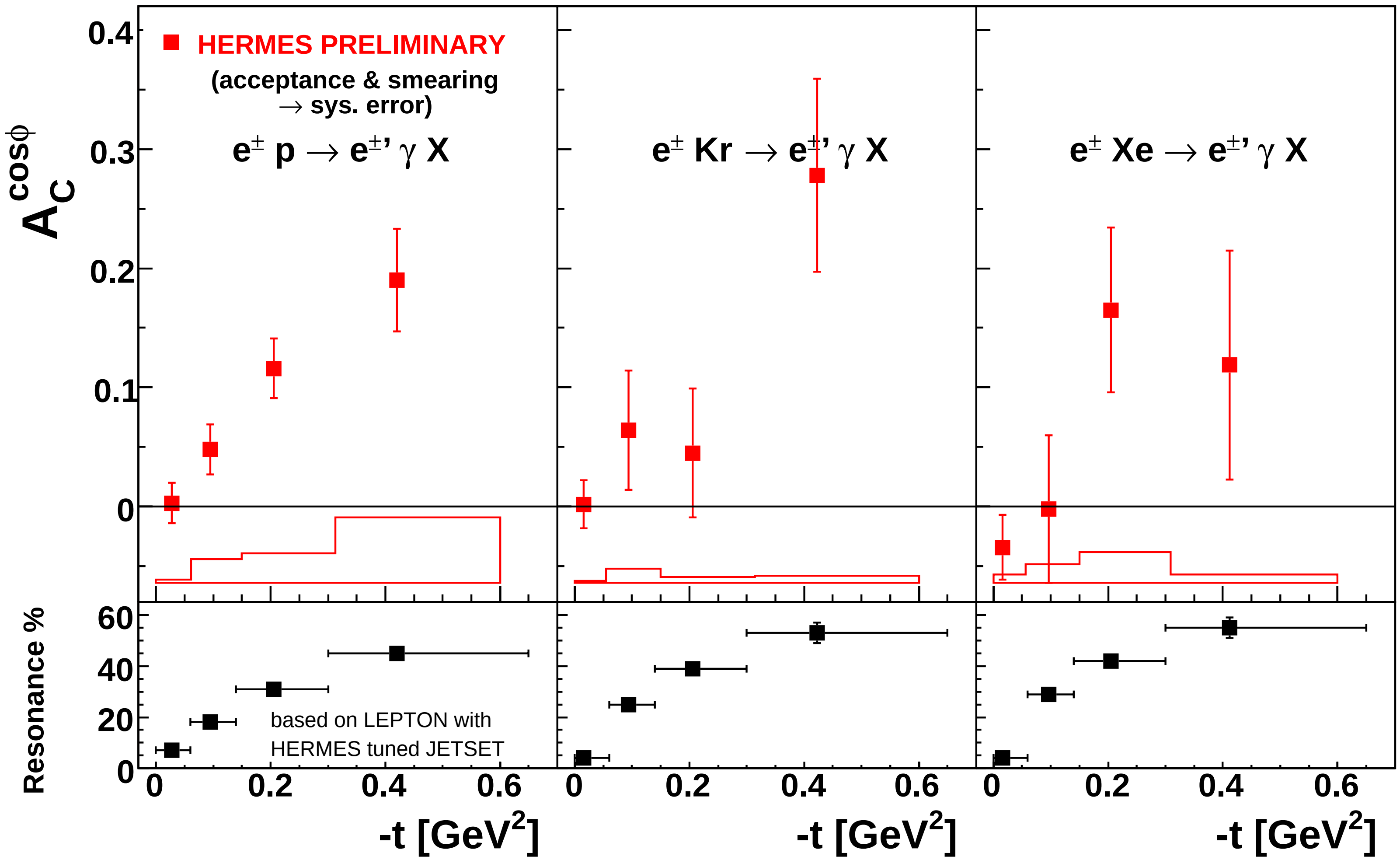
$A^{\sin\varphi}_{LU,nucleus}/A^{\sin\varphi}_{LU,proton} \propto A/Z$
Guzey, Siddikov [JPG 32 (2006) 251]

Coherent/incoherent separation

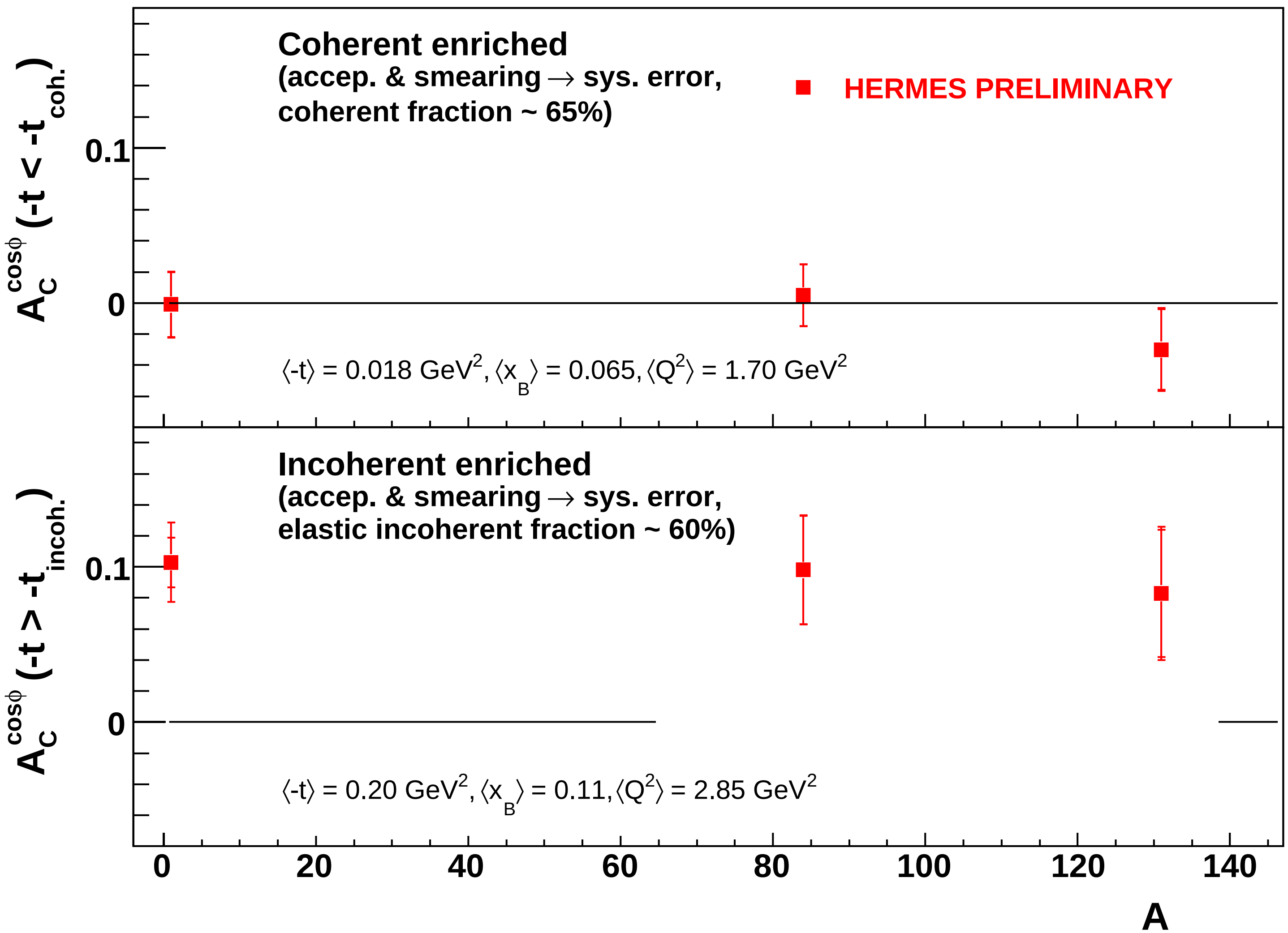
- Nuclear DVCS involves two contributions:
  - Coherent process: nuclear target stays intact
  - Incoherent process: nuclear target breaks up, photon is emitted by a particular proton or neutron
- Separate coherent/incoherent part by cutoff values for t
- Find upper (lower) –t cut for each target. Asymmetries for coherent (incoherent) production at similar average kinematics
  - coherent: $\langle -t \rangle = 0.018\ GeV^2$
  - incoherent: $\langle -t \rangle = 0.20\ GeV^2$

Target	t cutoff	estimated %elas. coh. incoh. (by MC)	$\langle t \rangle$ (RMS)	$\langle x_B \rangle$ (RMS)	$\langle Q^2 \rangle$ (RMS)
H	$-t < -t_{coh.}$	–	-0.018(0.008)	0.070(0.023)	1.81(0.75)
	$-t > -t_{incoh.}$	–	-0.200(0.120)	0.109(0.059)	2.89(1.62)
Kr	$-t < -t_{coh.}$	70	-0.018(0.015)	0.064(0.023)	1.63(0.68)
	$-t > -t_{incoh.}$	58	-0.200(0.125)	0.108(0.058)	2.84(1.61)
Xenon	$-t < -t_{coh.}$	66	-0.018(0.017)	0.062(0.023)	1.60(0.66)
	$-t > -t_{incoh.}$	56	-0.200(0.126)	0.107(0.058)	2.86(1.63)

Beam-charge asymmetry amplitudes (t dependence)

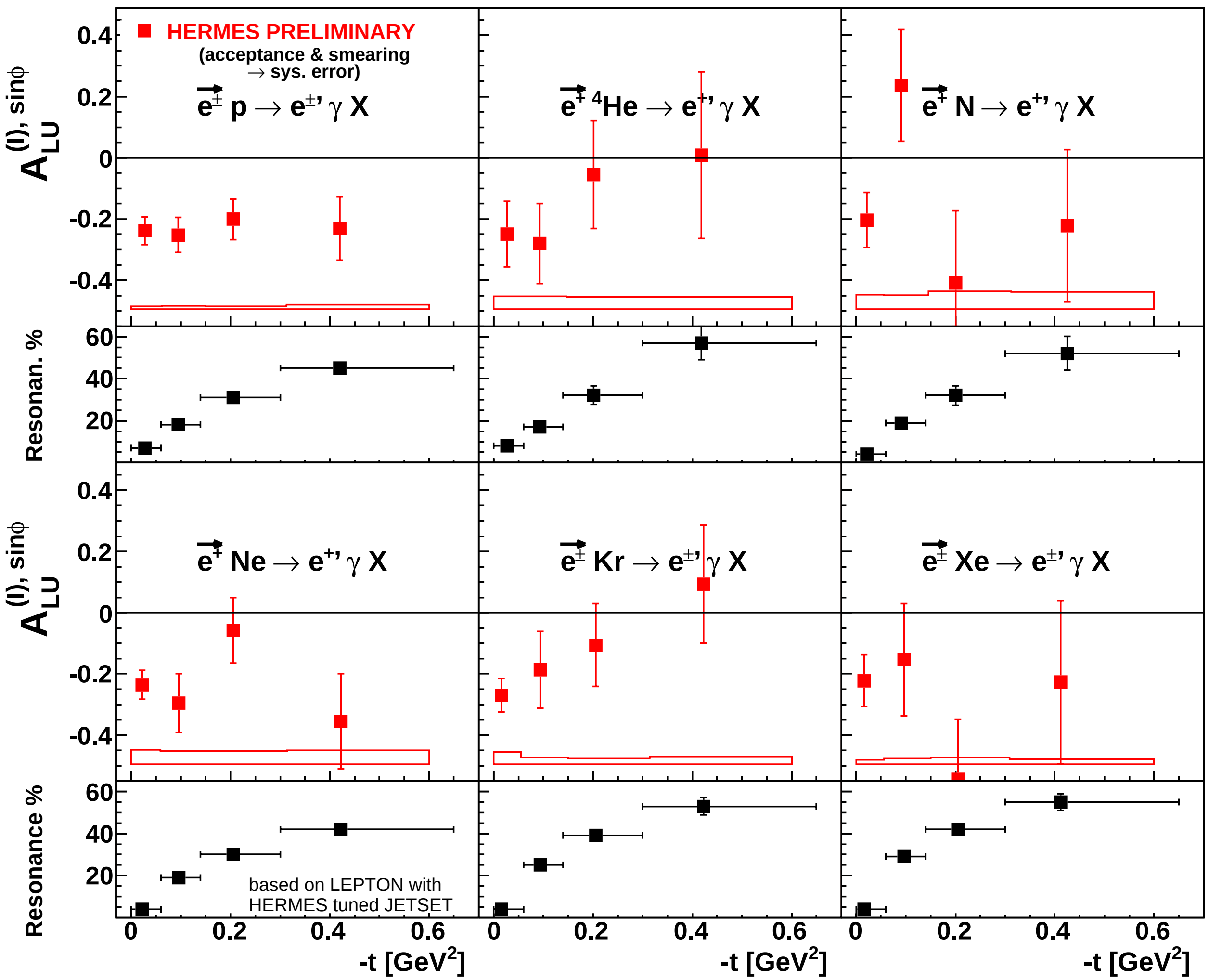


Beam-charge asymmetry amplitudes (A dependence)

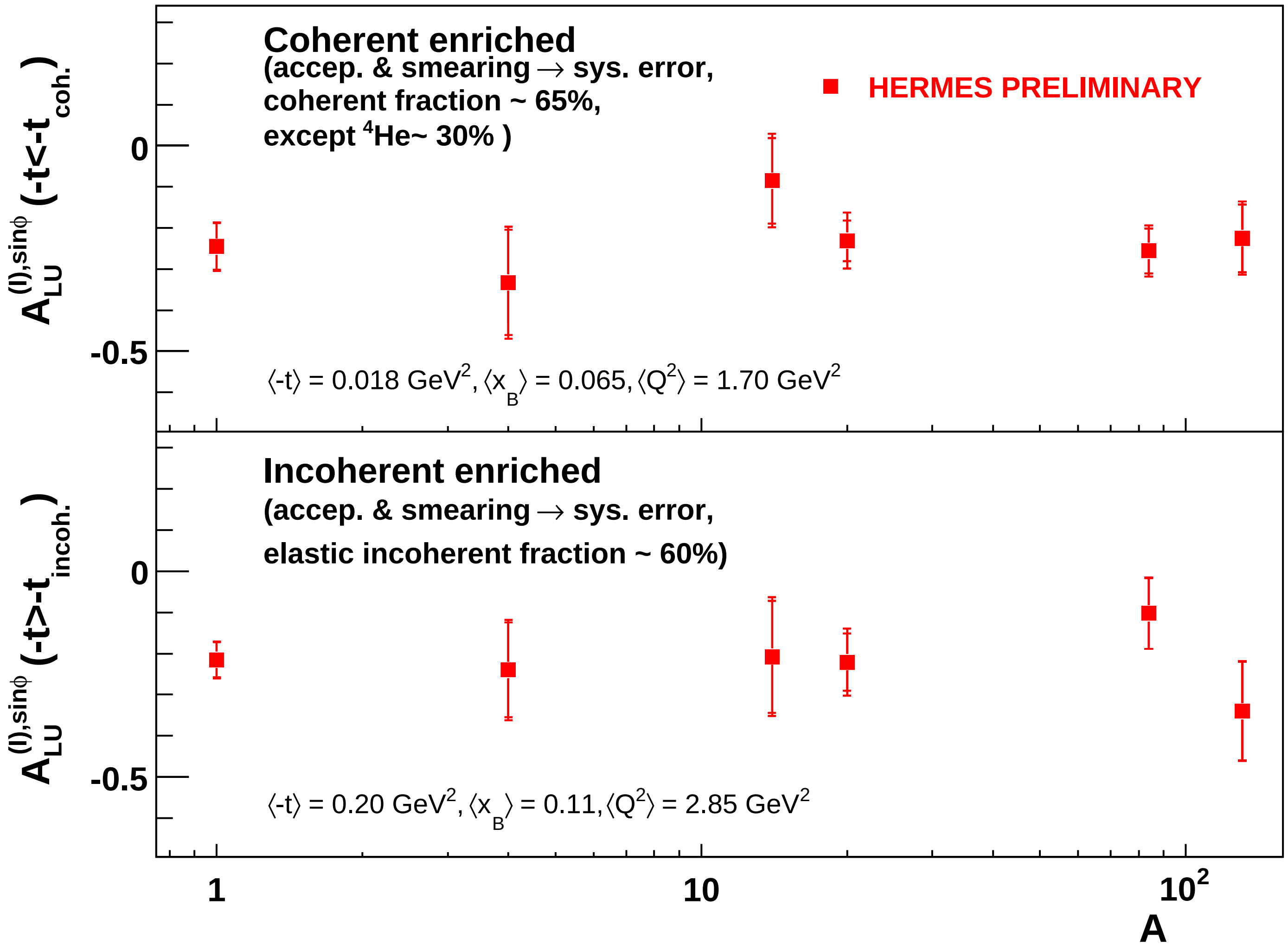


Beam-helicity asymmetry amplitudes (t dependence)

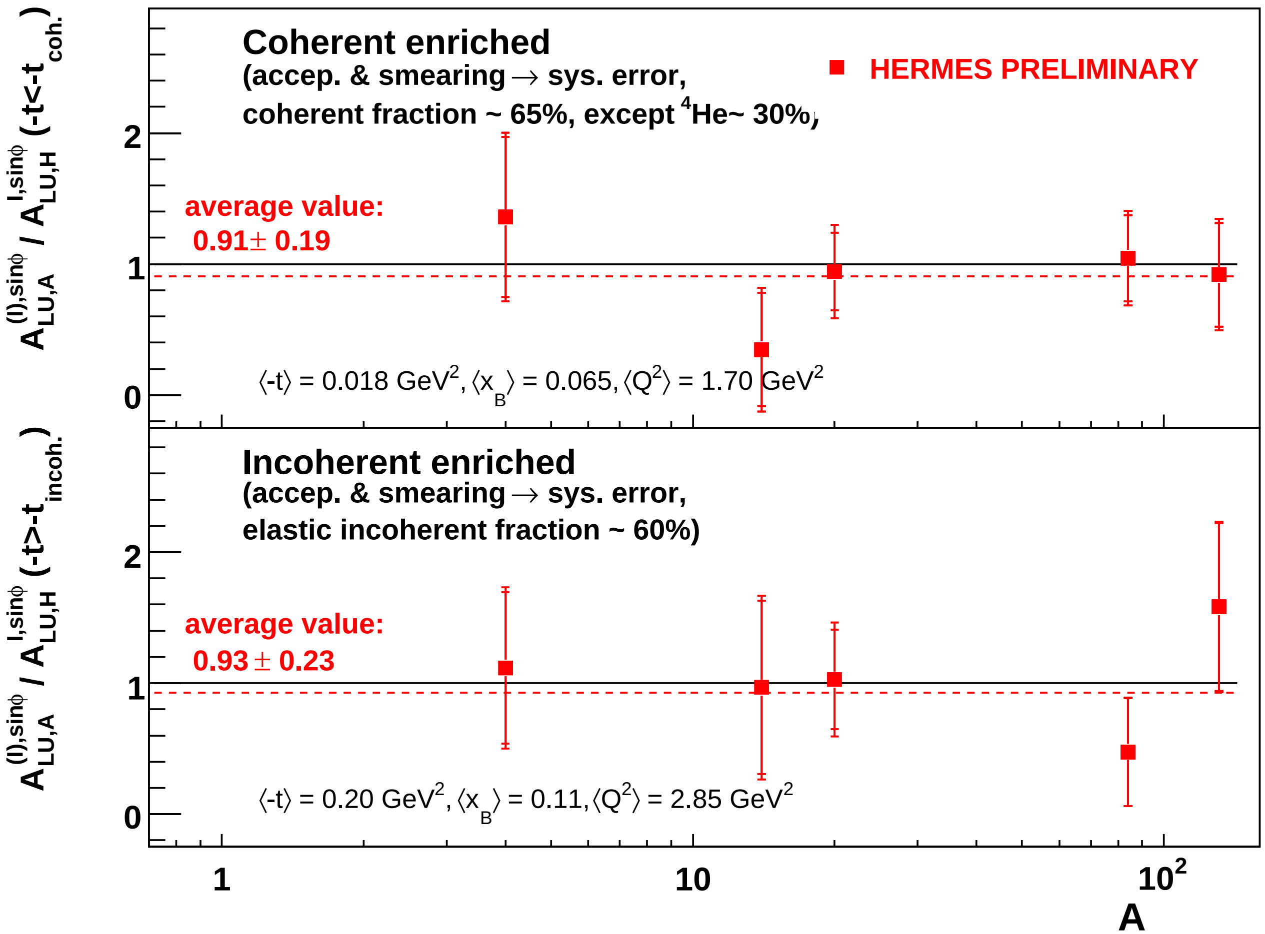
$$H, Kr, Xe: \; A_{LU}^{I}(\phi) = \frac{\left(\sigma^{+\rightarrow} + \sigma^{-\leftarrow}\right) - \left(\sigma^{+\leftarrow} + \sigma^{-\rightarrow}\right)}{\left(\sigma^{+\rightarrow} + \sigma^{-\leftarrow}\right) + \left(\sigma^{+\leftarrow} + \sigma^{-\rightarrow}\right)} \qquad {}^{4}He, N, Ne: \; A_{LU}^{I}(\phi) = \frac{\sigma^{\rightarrow} - \sigma^{\leftarrow}}{\sigma^{\rightarrow} + \sigma^{\leftarrow}}$$



Beam-helicity asymmetry amplitudes (A dependence)

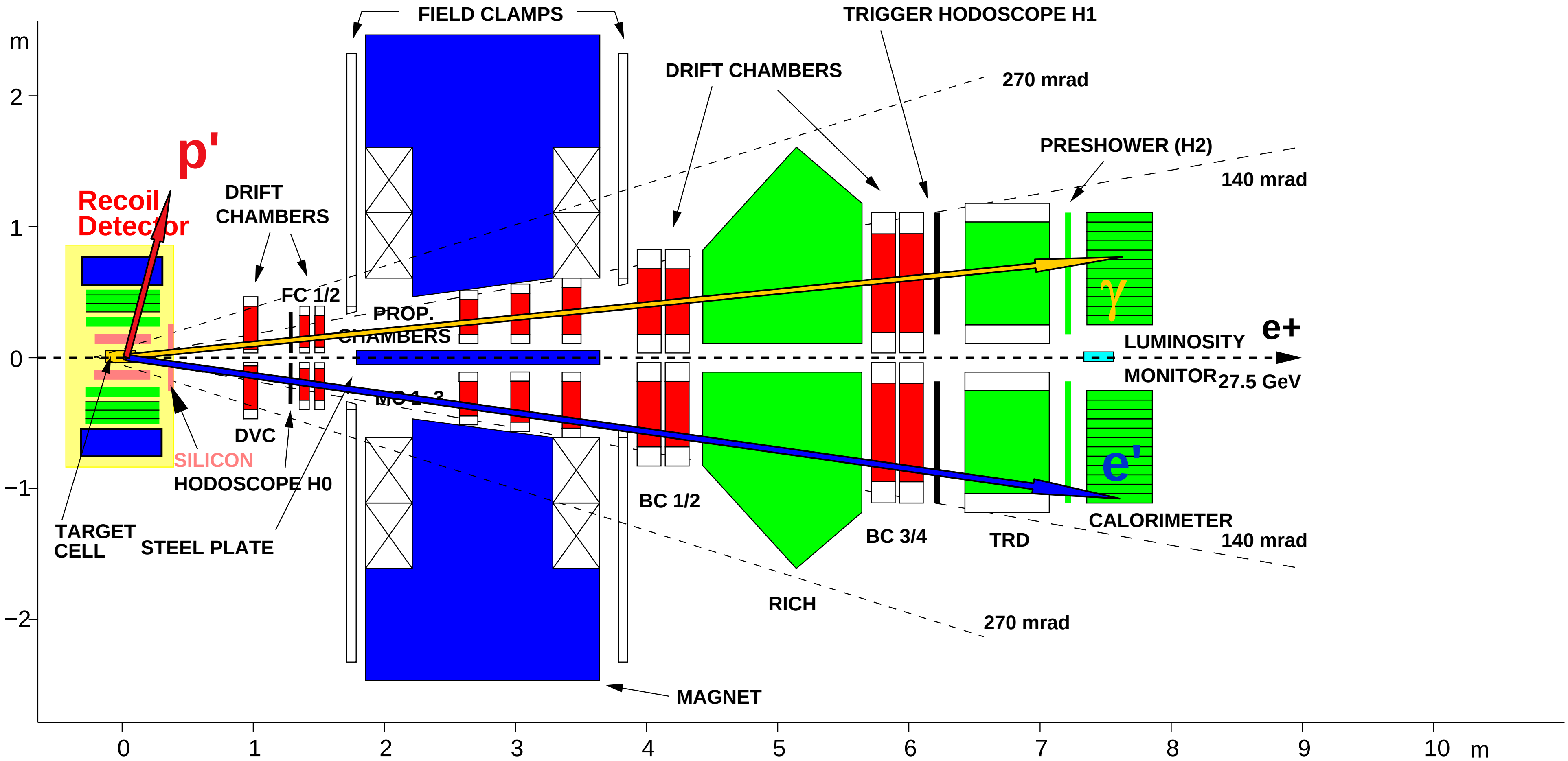


Ratio of leading beam-helicity asymmetry amplitudes



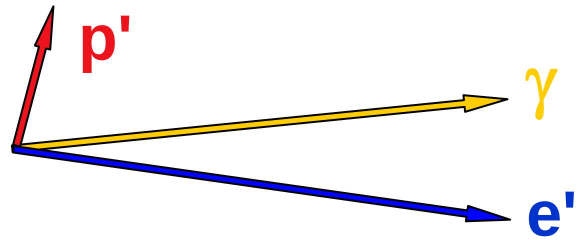
- The results do not support models which predict an enhancement of nuclear asymmetries
- Data contradict the predicted strong A-dependence of the asymmetries resulting from mesonic degree of freedom in the nuclei

Exclusivity at HERMES: Recoil detector

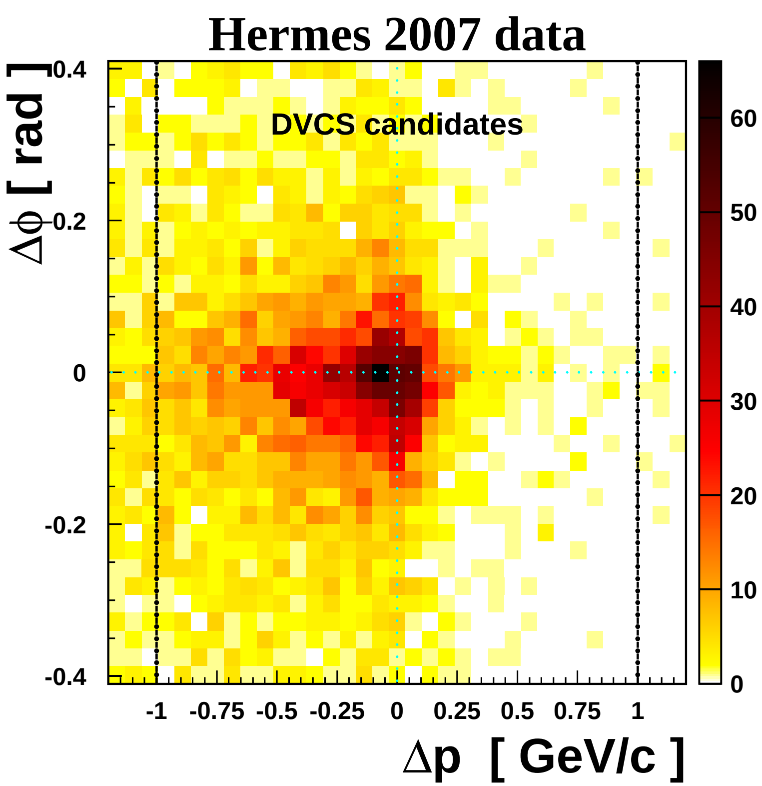


- Unpolarized hydrogen target: 38 Mio DIS (41.000 DVCS)
- Unpolarized deuterium target: 10 Mio DIS (7.500 DVCS)
- Two beam helicities, electron and positron beams

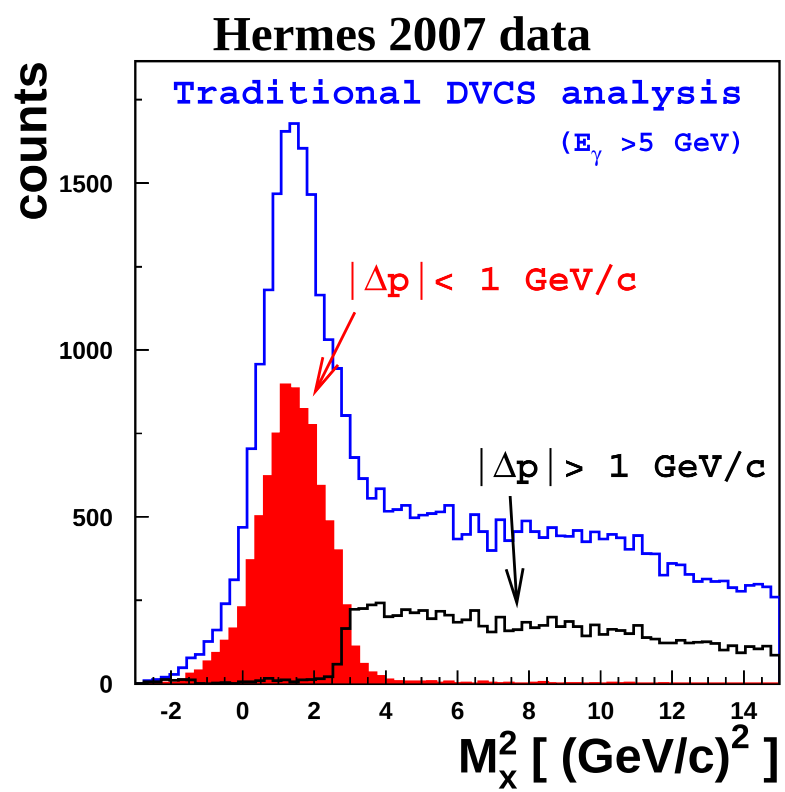
DVCS event selection with the Recoil detector



Missing azimuthal angle versus missing momentum



Missing mass reconstructed using measured lepton and photon

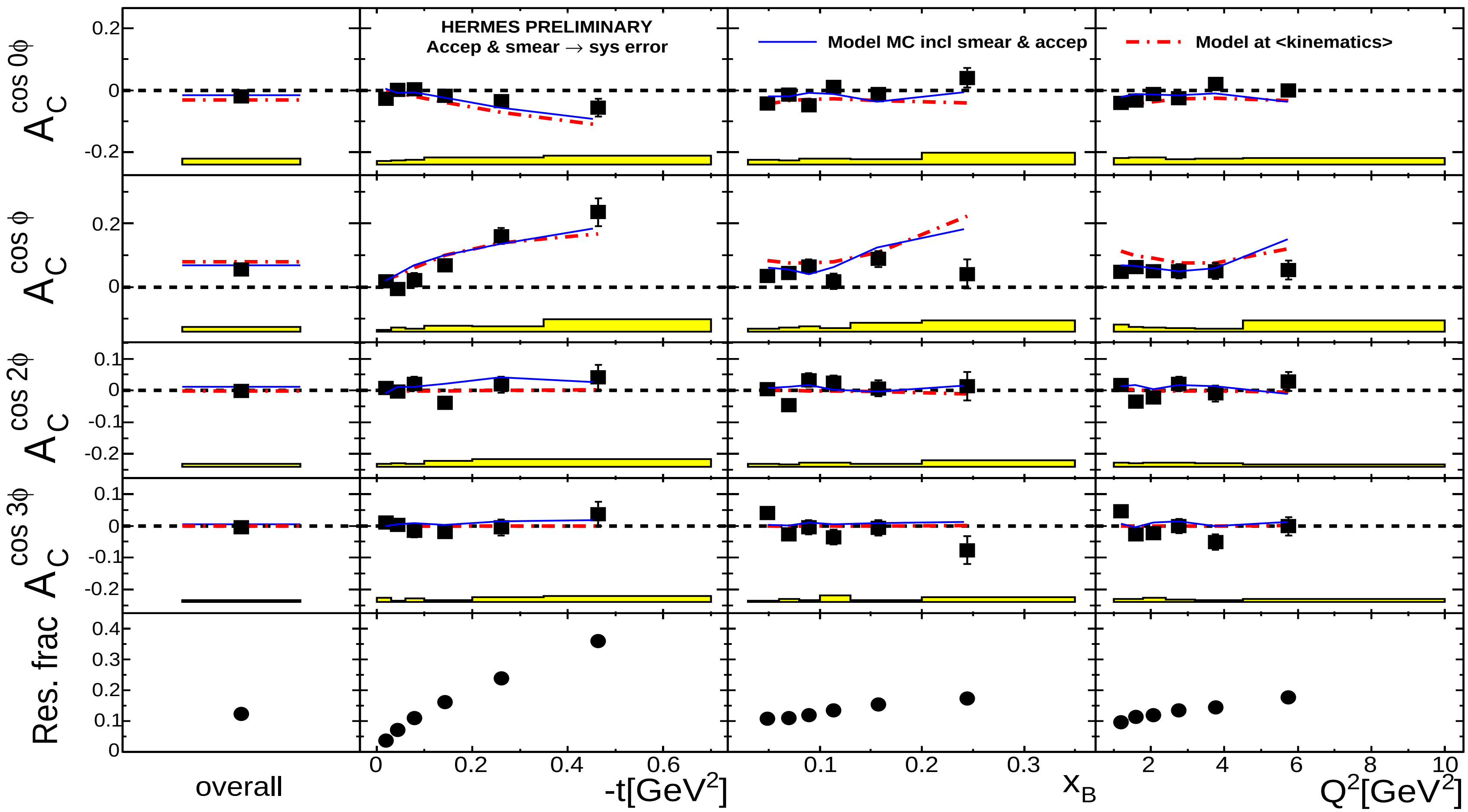


Summary and outlook

- HERMES produced several interesting results on DVCS which allow to constrain GPD models
  - Beam-charge and beam-helicity asymmetries on proton and deuteron: constraints on GPD H
  - Transverse target polarization asymmetry: constraints on GPD E, model-dependent constraints on J_u, J_d
  - No nuclear-mass dependence of asymmetry amplitudes is observed on nuclear targets: constraints on nuclear GPD models
  - Longitudinal target polarization asymmetry: access to GPD $\tilde{H}$
- In the 2006/2007 high-statistics data the associated Bethe-Heitler process can be separated using the Recoil Detector information
- Refined analysis of data collected before the Recoil detector installation can be performed

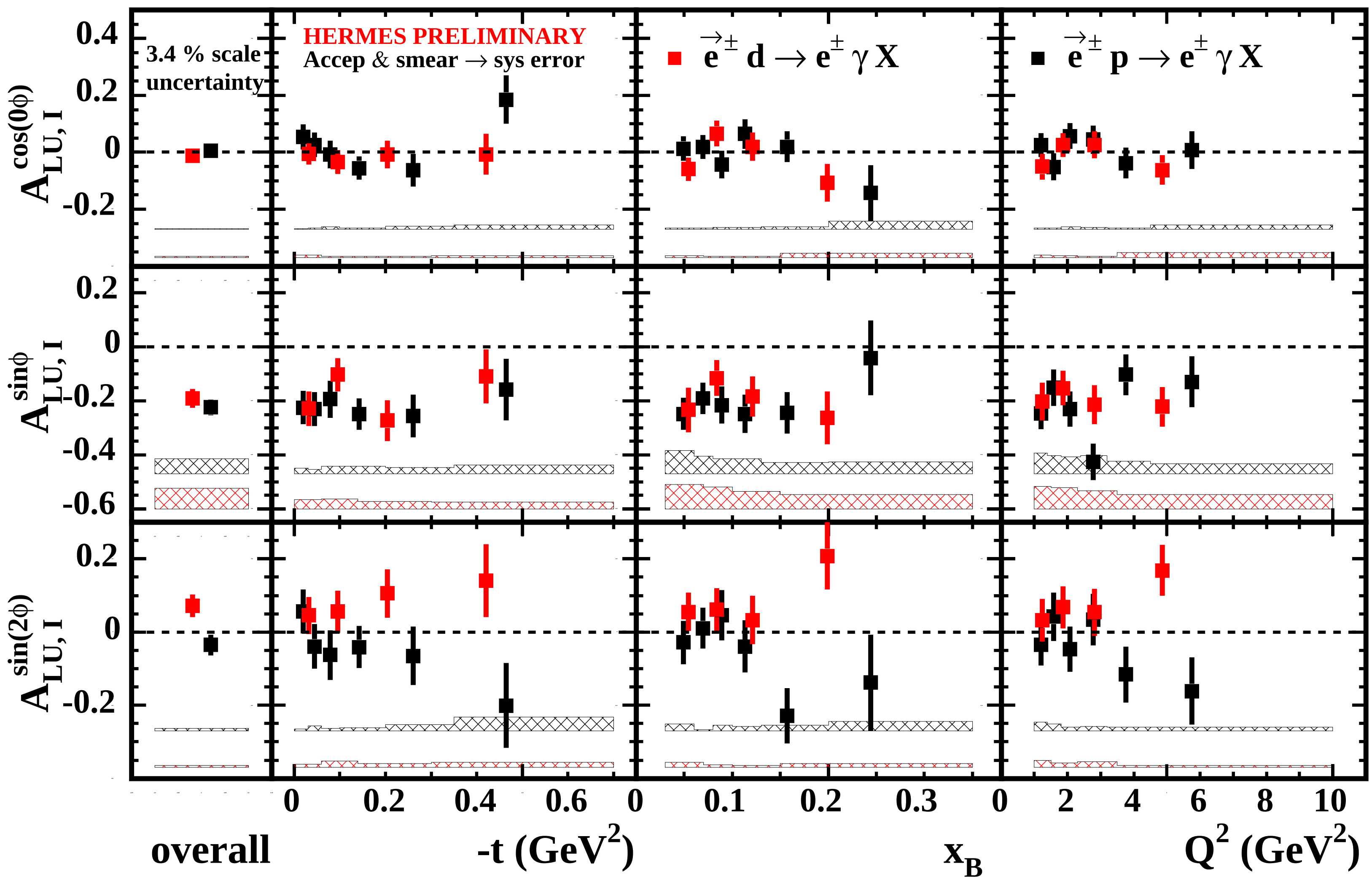
Backup slides

Acceptance, bin-width, smearing and misalignment effects



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

Comparison to deuterium data (beam-helicity asymmetry)



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