

# Latest DVCS results from HERMES

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on behalf of the HERMES collaboration



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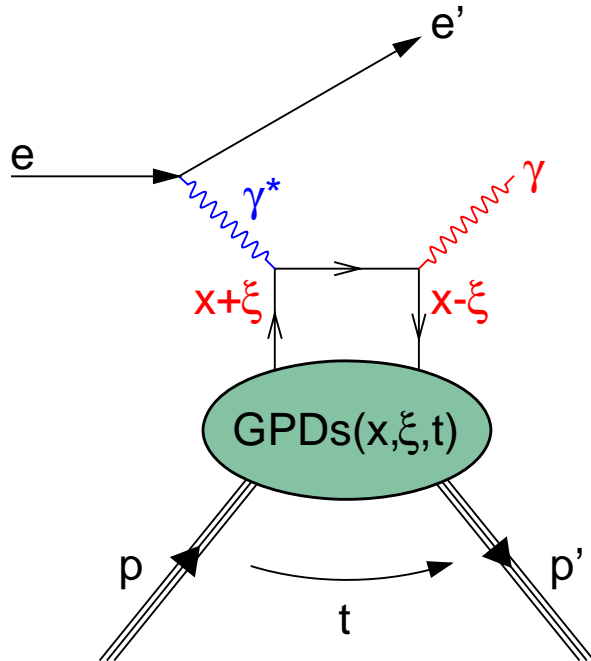


# Outline

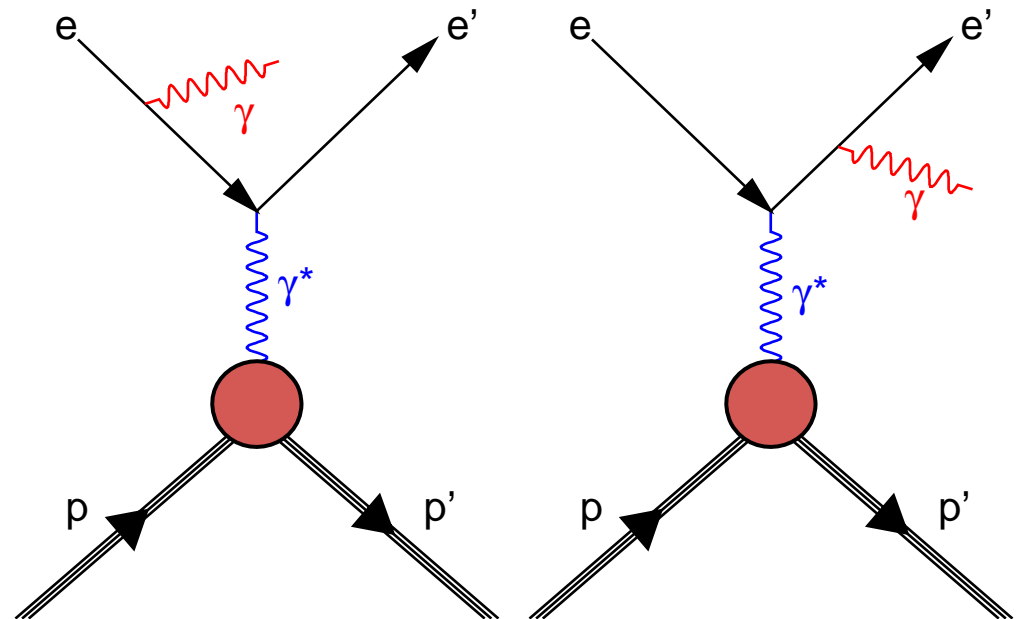
- Physics motivation
  - DVCS as a tool to access GPDs
- HERMES experiment
- Recent results on DVCS from HERMES
  - Combined analysis of beam-helicity and beam-charge asymmetries on proton and deuteron
  - Transverse target polarization asymmetry
  - Nuclear-mass dependence of beam-helicity and beam-charge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

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

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

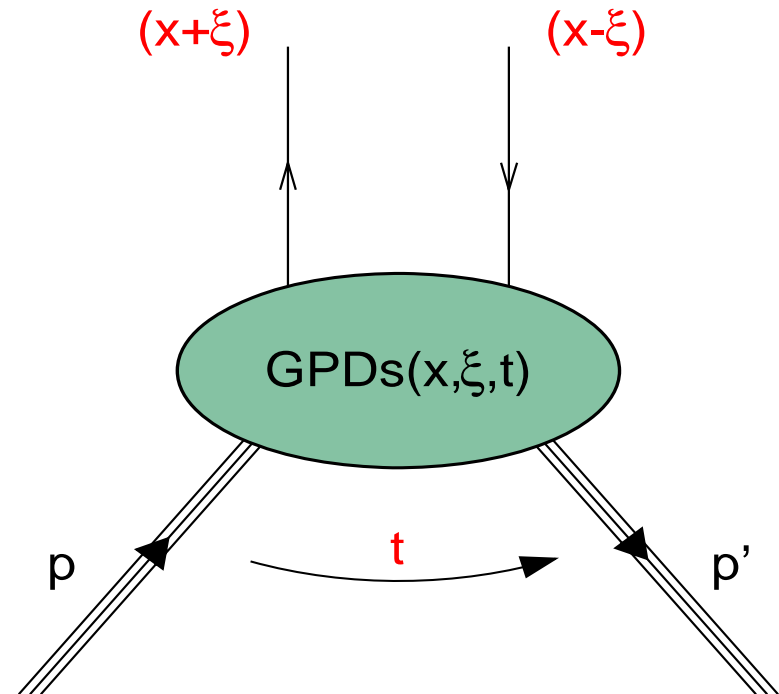
- GPDs  $\rightarrow$  FFs

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

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

- $H_q, E_q$  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
- $\xi$  fraction of the longitudinal momentum transfer
- $t$  squared 4-momentum transfer to the nucleon



# Azimuthal asymmetries

## • Cross section

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

## • Beam-helicity asymmetry

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

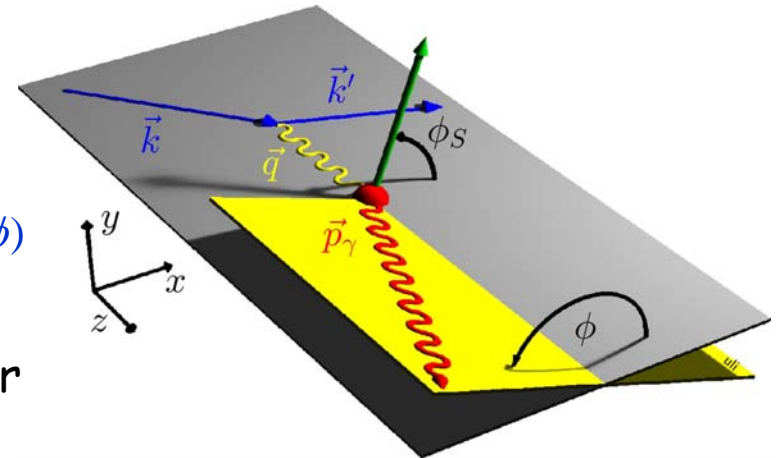
$$A_{LU}^I(\phi) = \frac{(\sigma^{++} + \sigma^{-+}) - (\sigma^{+-} + \sigma^{--})}{(\sigma^{++} + \sigma^{-+}) + (\sigma^{+-} + \sigma^{--})} = -\frac{1}{D(\phi)} \frac{x_B^2}{Q^2} \sum_{n=1}^2 \boxed{s_n^I} \sin(n\phi)$$

## • Beam-charge asymmetry

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

## • 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 of asymmetry amplitudes to GPDs

- Connections of Fourier coefficients to GPDs (leading contributions)

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

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

- Extraction of effective asymmetry amplitudes

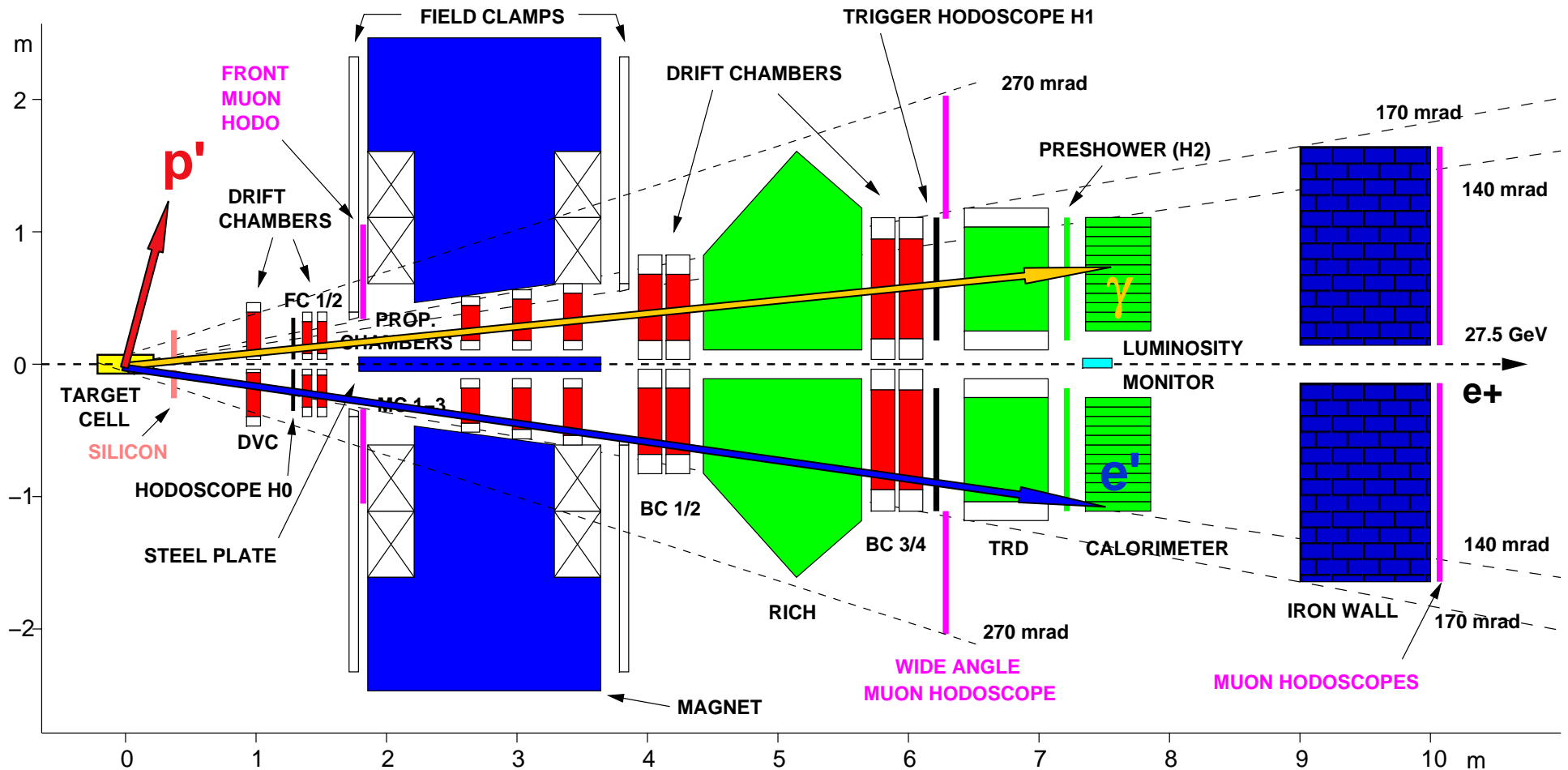
$$A_{LU}^{DVCS}(\phi) = \sum_{n=1}^2 A_{LU,DVCS}^{\sin(n\phi)} \sin(n\phi) + \sum_{n=0}^1 A_{LU,DVCS}^{\cos(n\phi)} \cos(n\phi)$$

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

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

- Combined analysis allows separation of DVCS and interference terms
- Comparison with theoretical model (Vanderhaeghen, Guichon, Guidal) [Phys. Rev. D 60 (1999) 094017]

# The HERMES experiment



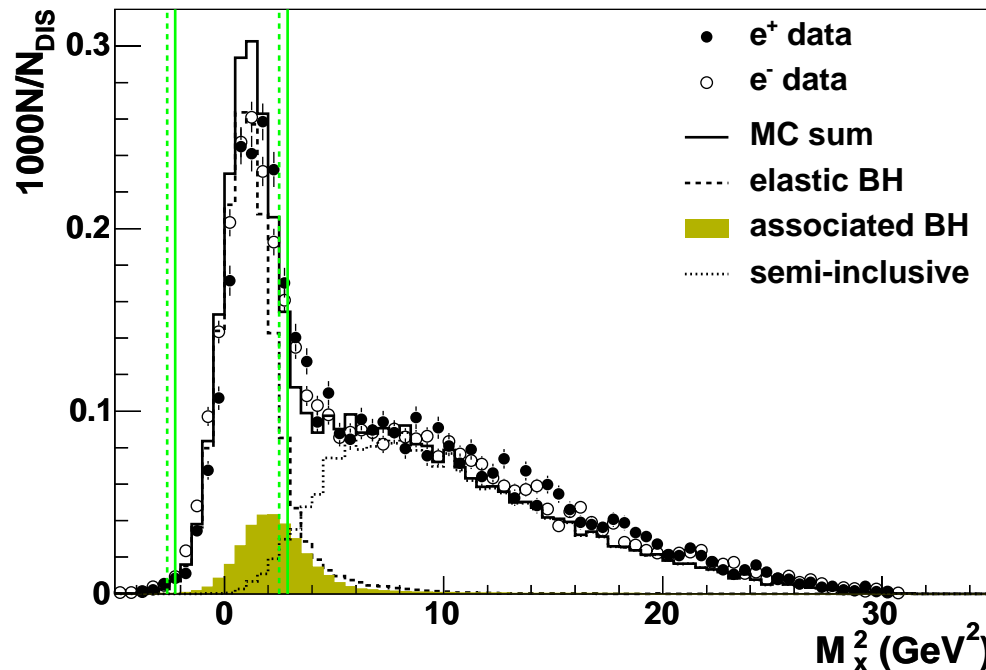
## Gas targets:

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

## Beam:

- Longitudinally polarized  $e^+$  and  $e^-$  with both helicities
- Energy  $27.6 \text{ GeV}$

# Event selection, uncertainties and corrections



Kinematic requirements

$$0.03 < x_B < 0.35$$

$$1 \text{ GeV}^2 < Q^2 < 10 \text{ GeV}^2$$

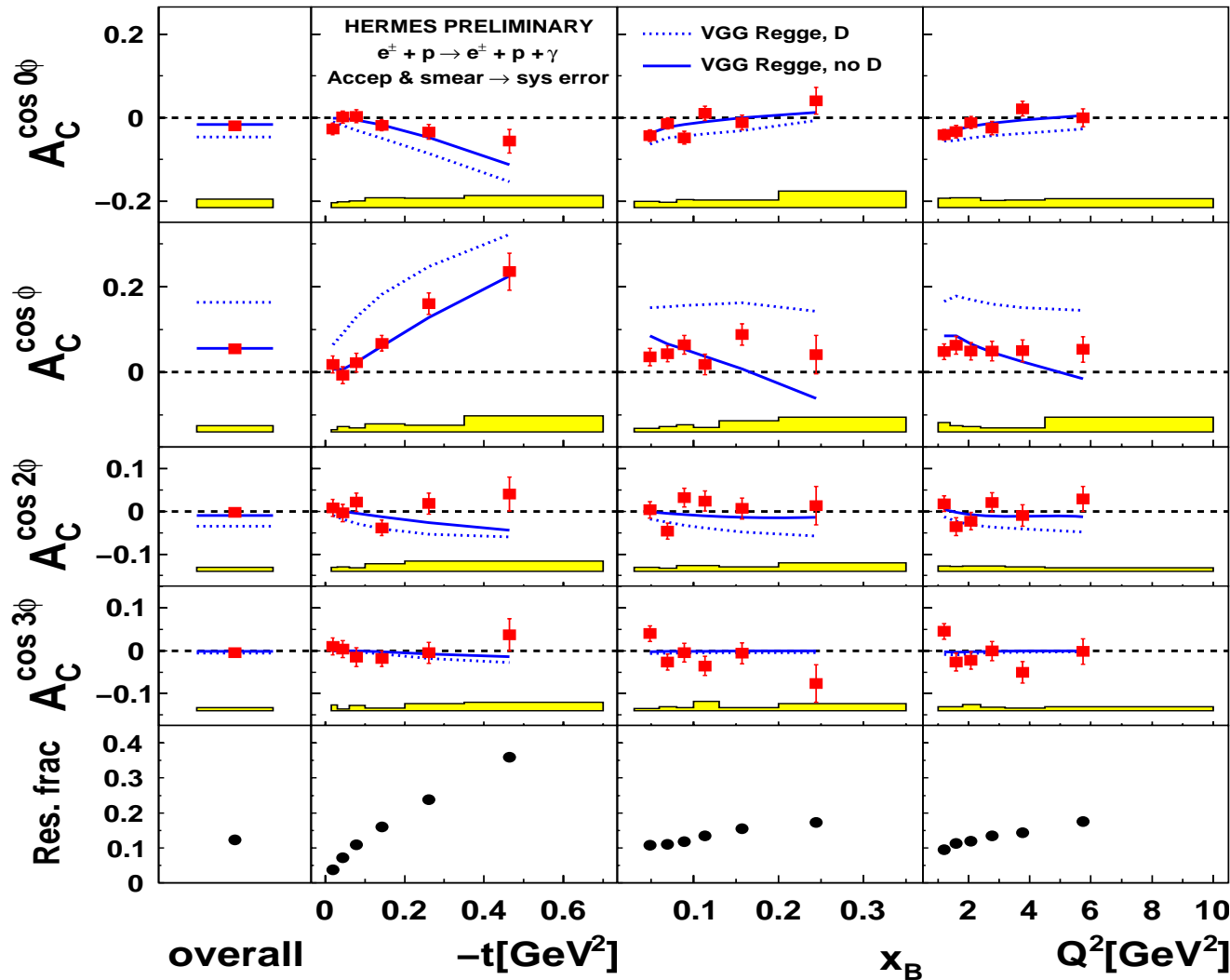
$$-t < 0.7 \text{ GeV}^2$$

$$E_\gamma > 5 \text{ GeV}$$

- 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  $\pi^0$  ( $z_\pi > 0.8$ ) data
- Associated Bethe-Heitler  $ep \rightarrow e'\Delta^+\gamma \sim 12\%$  stays part of the signal



# Results on proton: beam-charge asymmetry amplitudes



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

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

← Higher twist

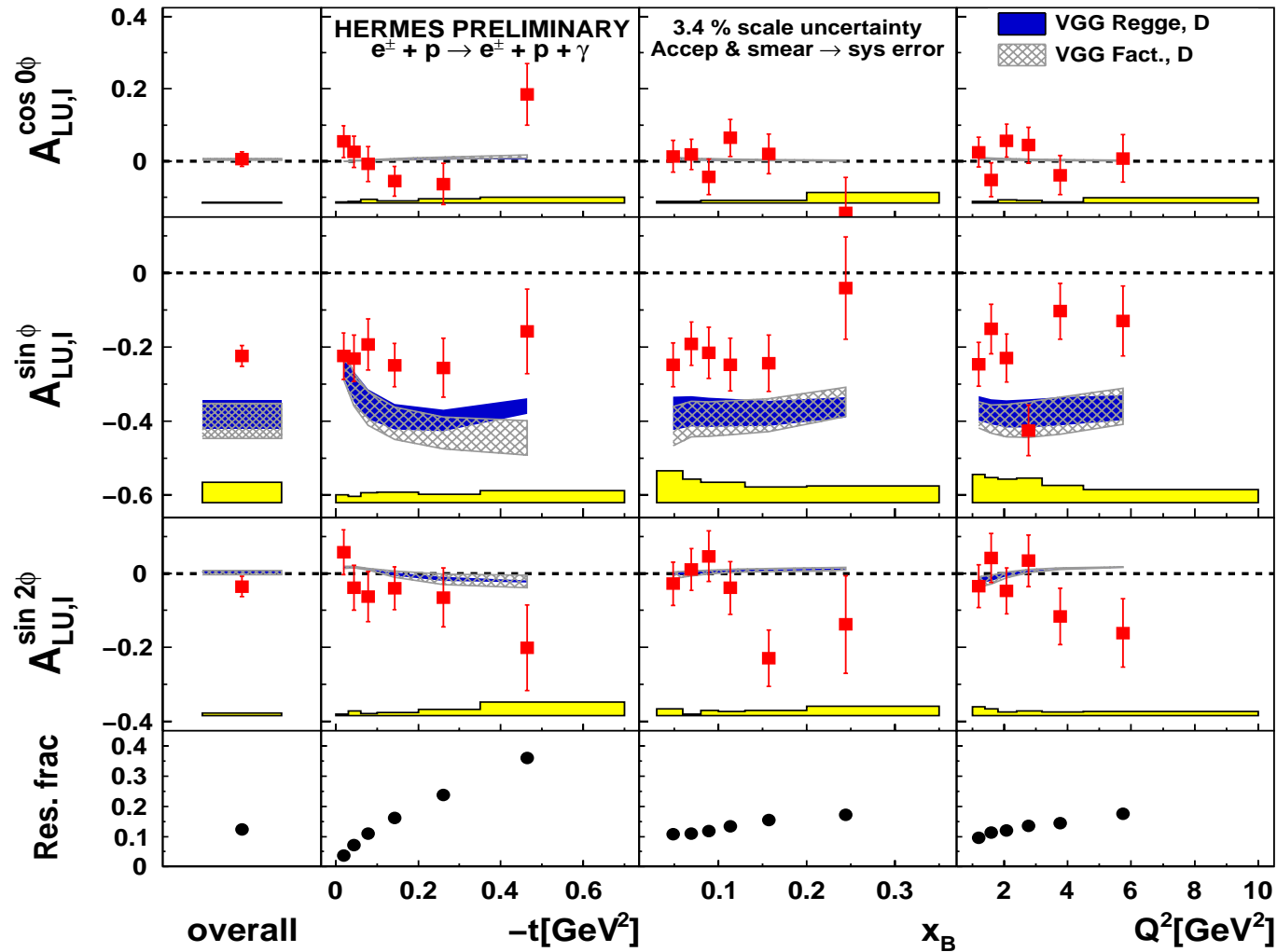
← Gluon leading twist

← Resonance fraction

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

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

# Results on proton: beam-helicity asymmetry amplitudes (interference term)



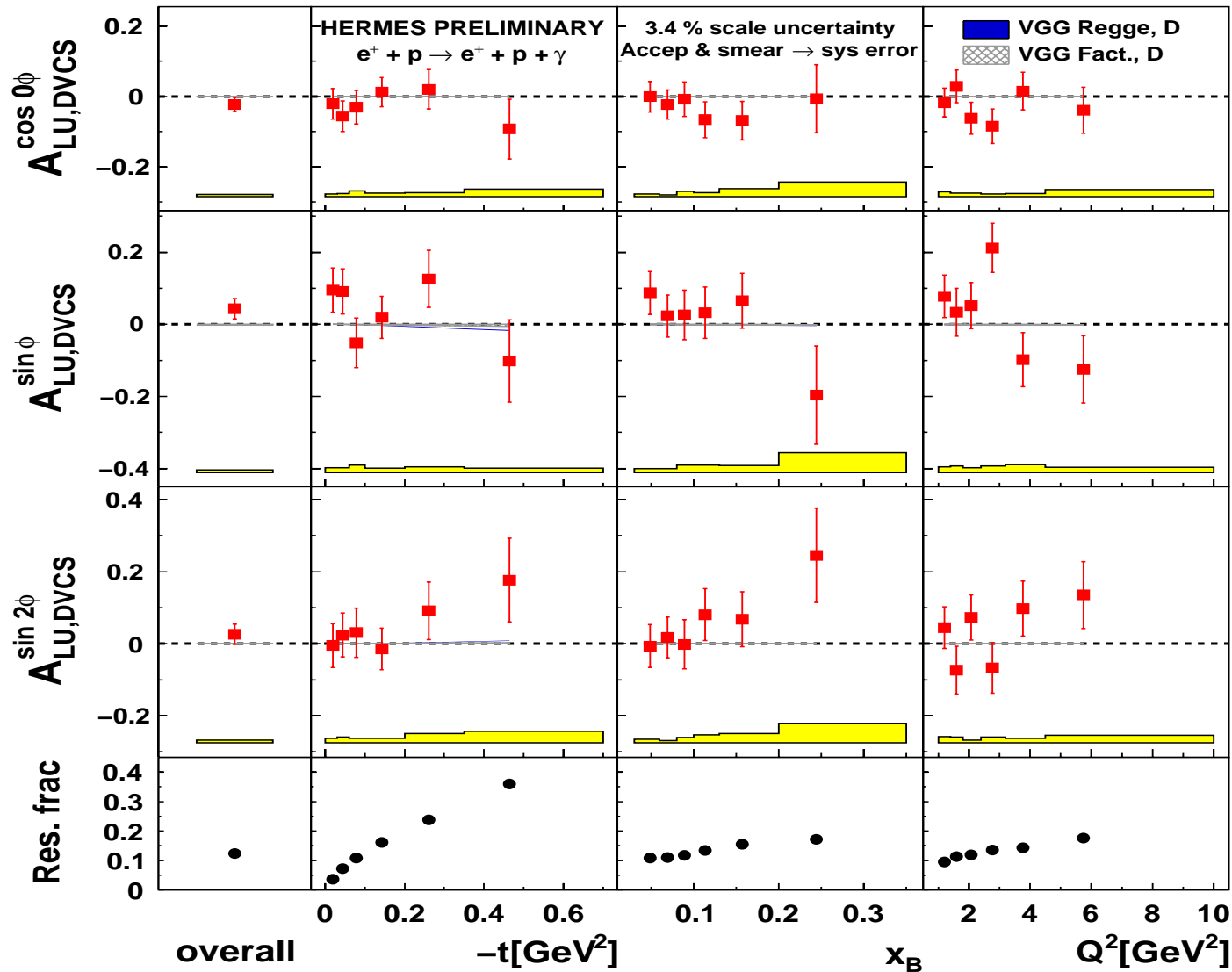
$$\propto \Im[F_1 H]$$

← Higher twist

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

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

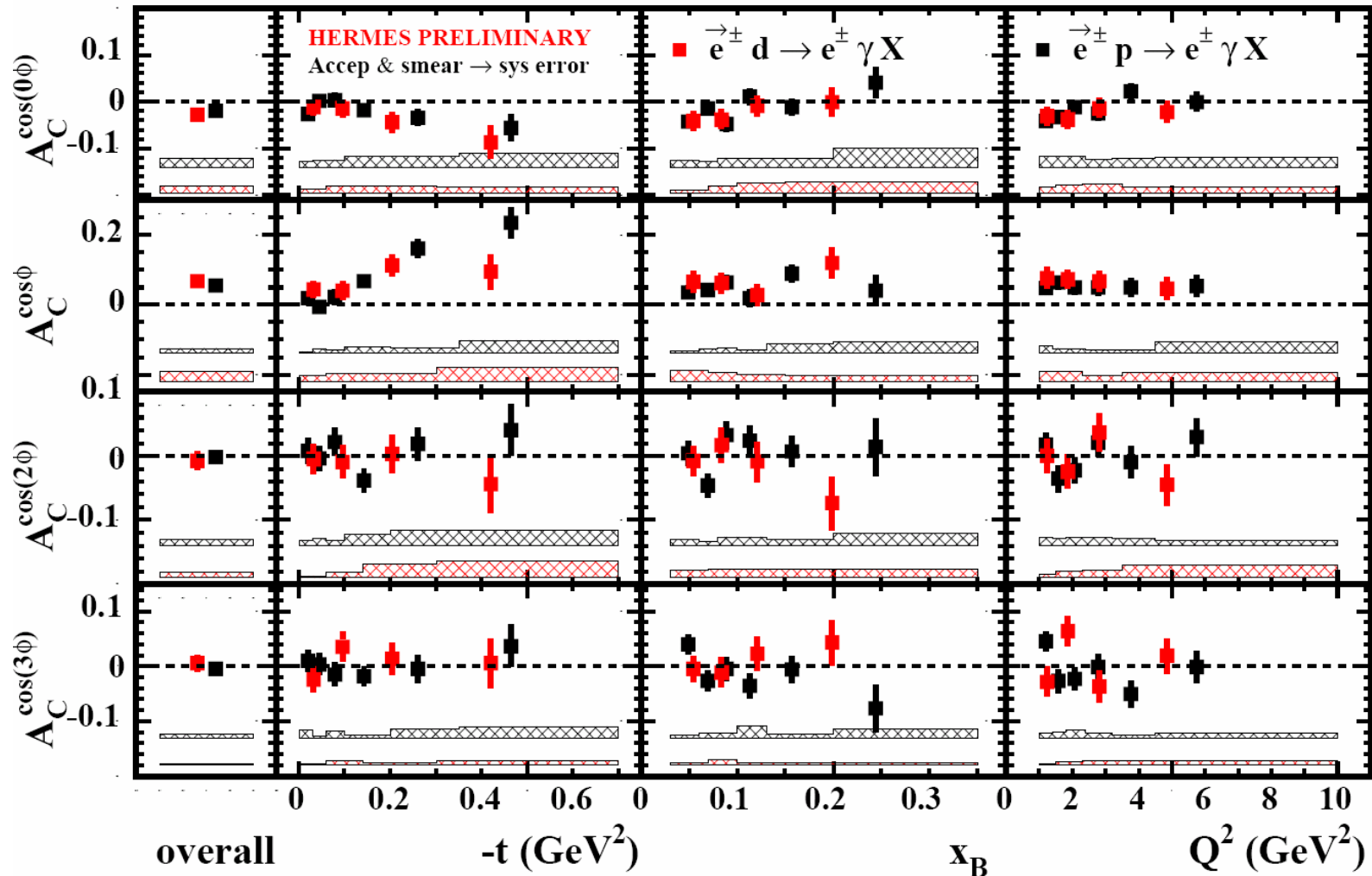
# Results on proton: beam-helicity asymmetry amplitudes (DVCS term)



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

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

# Comparison to deuteron data (beam-charge asymmetry)



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

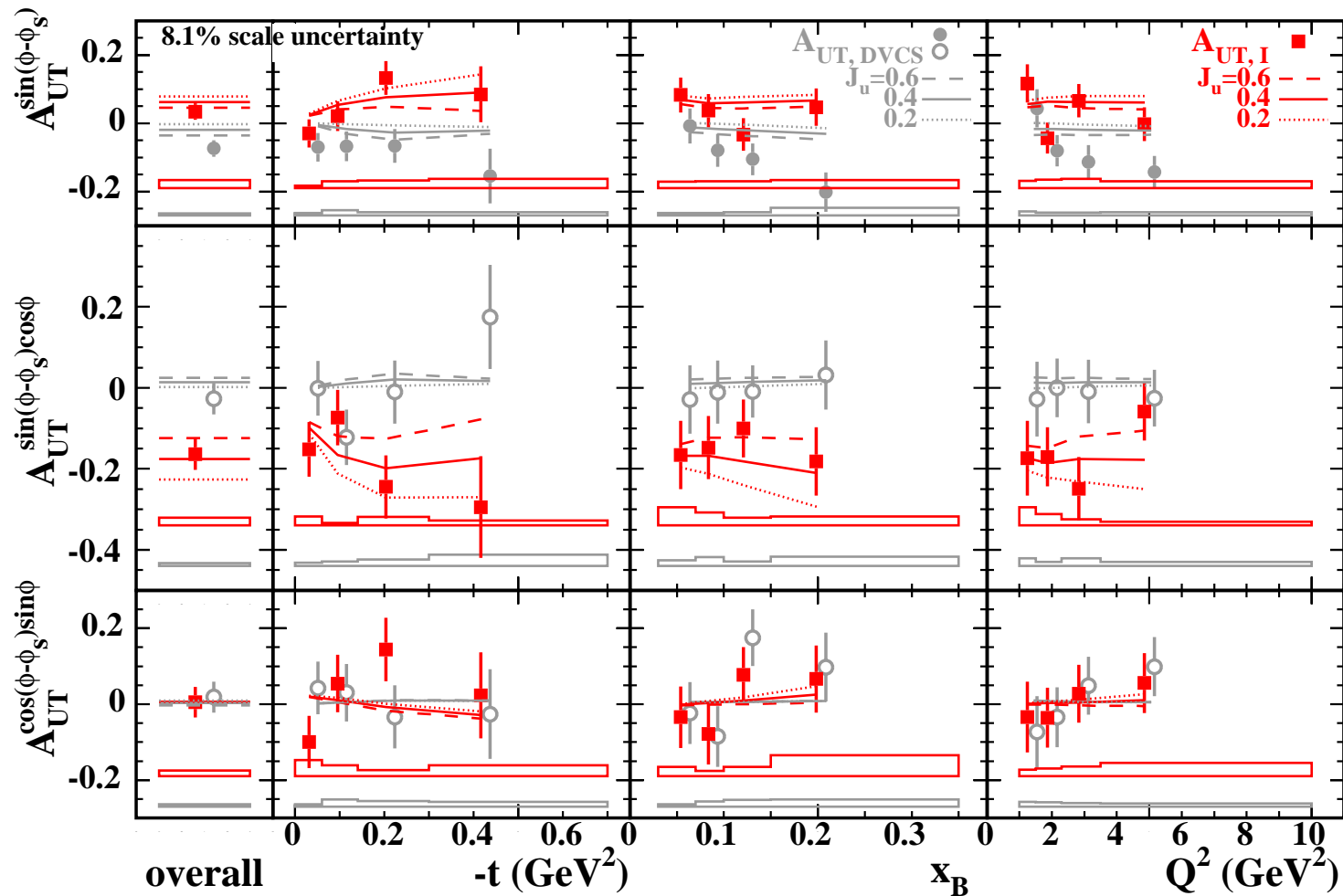
## Transverse target polarization asymmetry

- 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

$$J_q = \lim_{t \rightarrow 0} \int_{-1}^1 dx x [H_q(x, \xi, t) + E_q(x, \xi, t)]$$

- Model-dependent constraints on  $J_u, J_d$

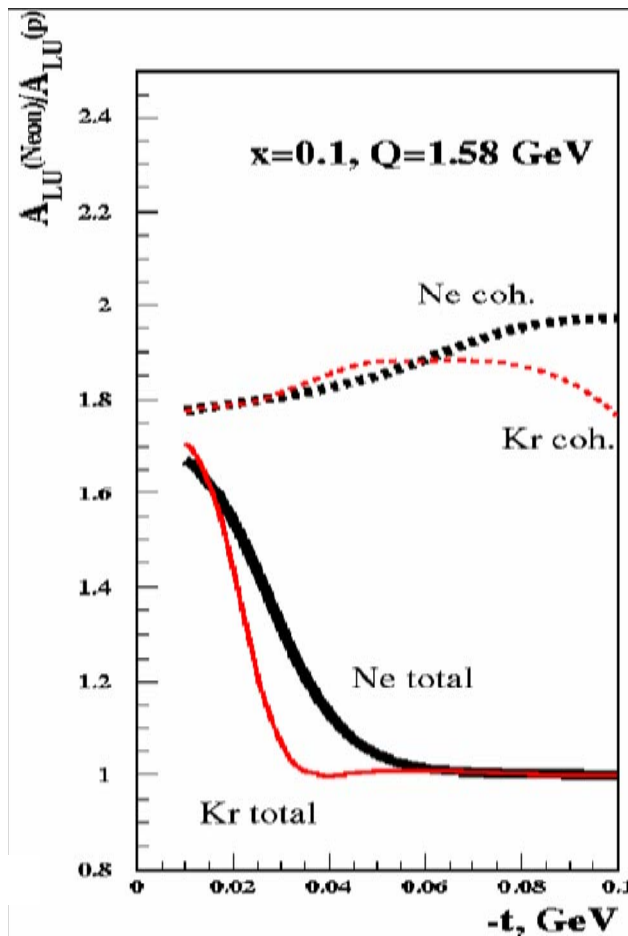
# Transverse target polarization asymmetry amplitudes



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

$$\Rightarrow R_{\text{coh}} = 1.8-2.0 \text{ for } A=12-90$$

Guzey, Strikman [PRC 68 (2003) 015204]

$$R_{\text{coh}} = 1.0-1.1 \text{ for } A=^4\text{He}$$

Liuti, Taneja [PRC 72 (2005) 032201]

$$R_{\text{coh}} = 5/3 \text{ for spin-0, } \frac{1}{2}$$

Kirchner, Müller [EPJ C32 (2003) 347]

$$A_{\text{LU,nucleus}}^{\sin\phi} / A_{\text{LU,proton}}^{\sin\phi} \propto A/Z$$

Guzey, Siddikov [JPG 32 (2006) 251]

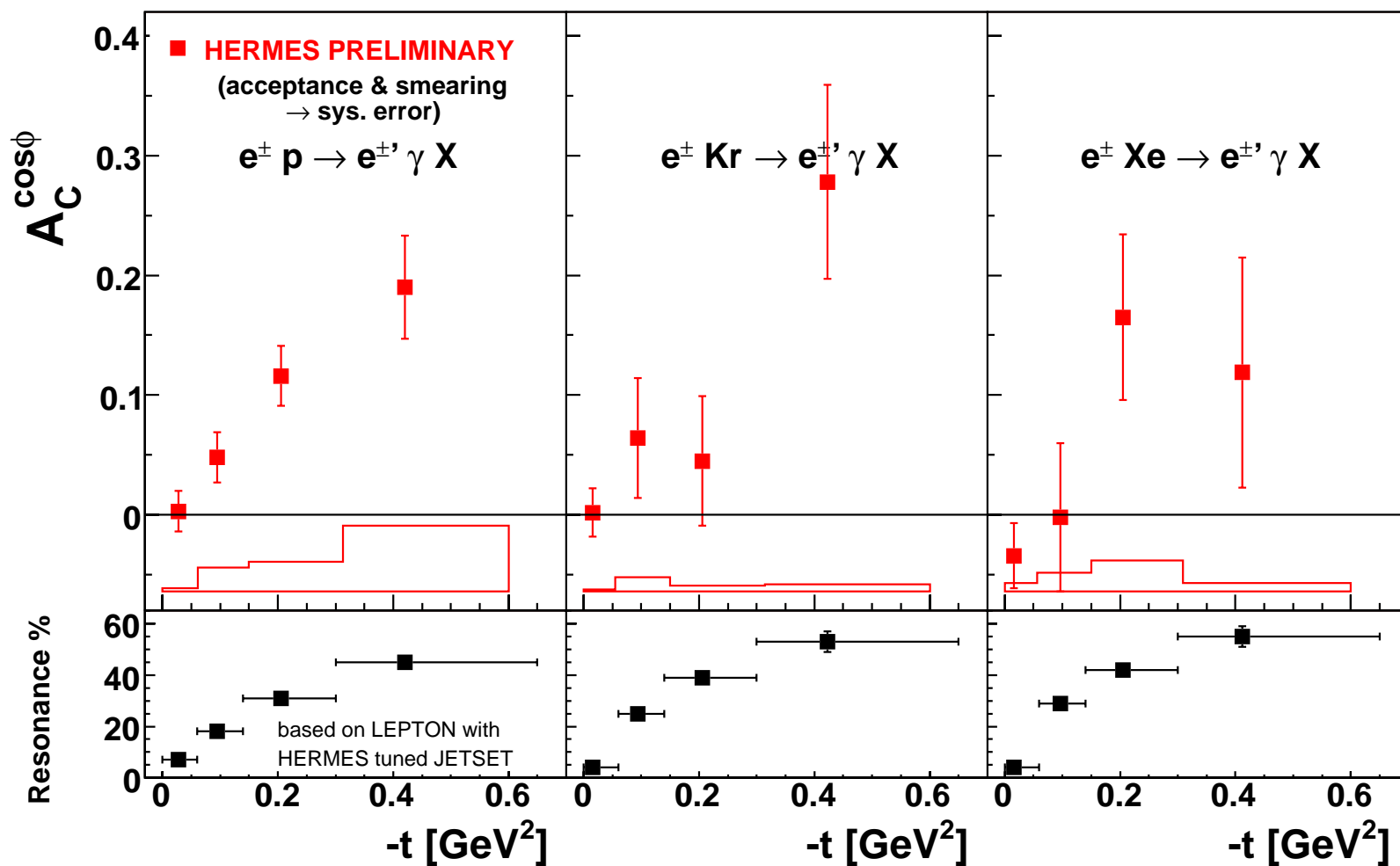
## Coherent/incoherent separation

- 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:  $\langle -t \rangle = 0.018 \text{ GeV}^2$
  - incoherent:  $\langle -t \rangle = 0.20 \text{ GeV}^2$

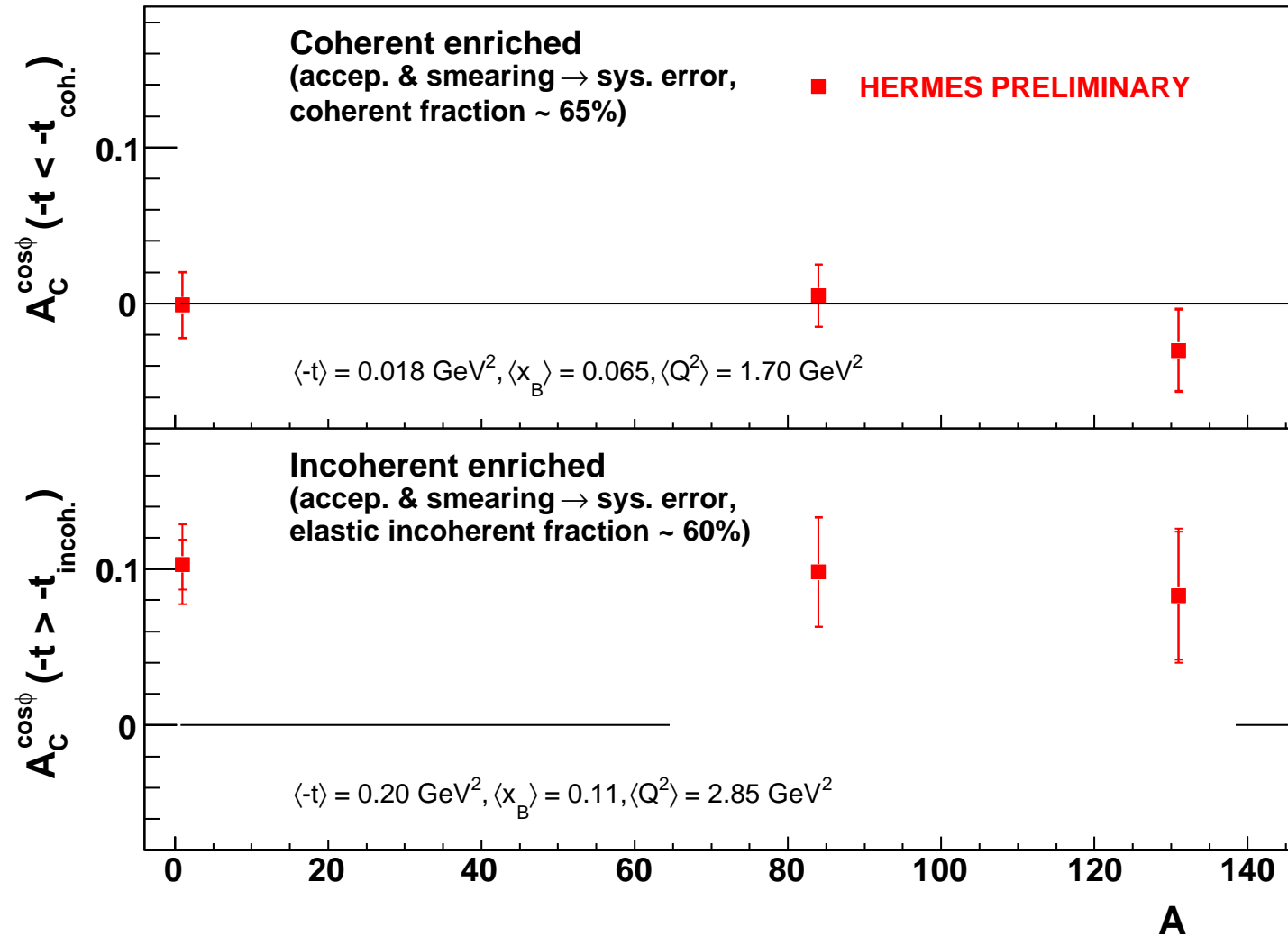
Target	$t$ cutoff	estimated %elas. coh. incoh. (by MC)	$\langle t \rangle$ (RMS)	$\langle x_B \rangle$ (RMS)	$\langle Q^2 \rangle$ (RMS)
H	$-t < -t_{coh.}$	–	-0.018(0.008)	0.070(0.023)	1.81(0.75)
	$-t > -t_{incoh.}$	–	-0.200(0.120)	0.109(0.059)	2.89(1.62)
Kr	$-t < -t_{coh.}$	70	-0.018(0.015)	0.064(0.023)	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)

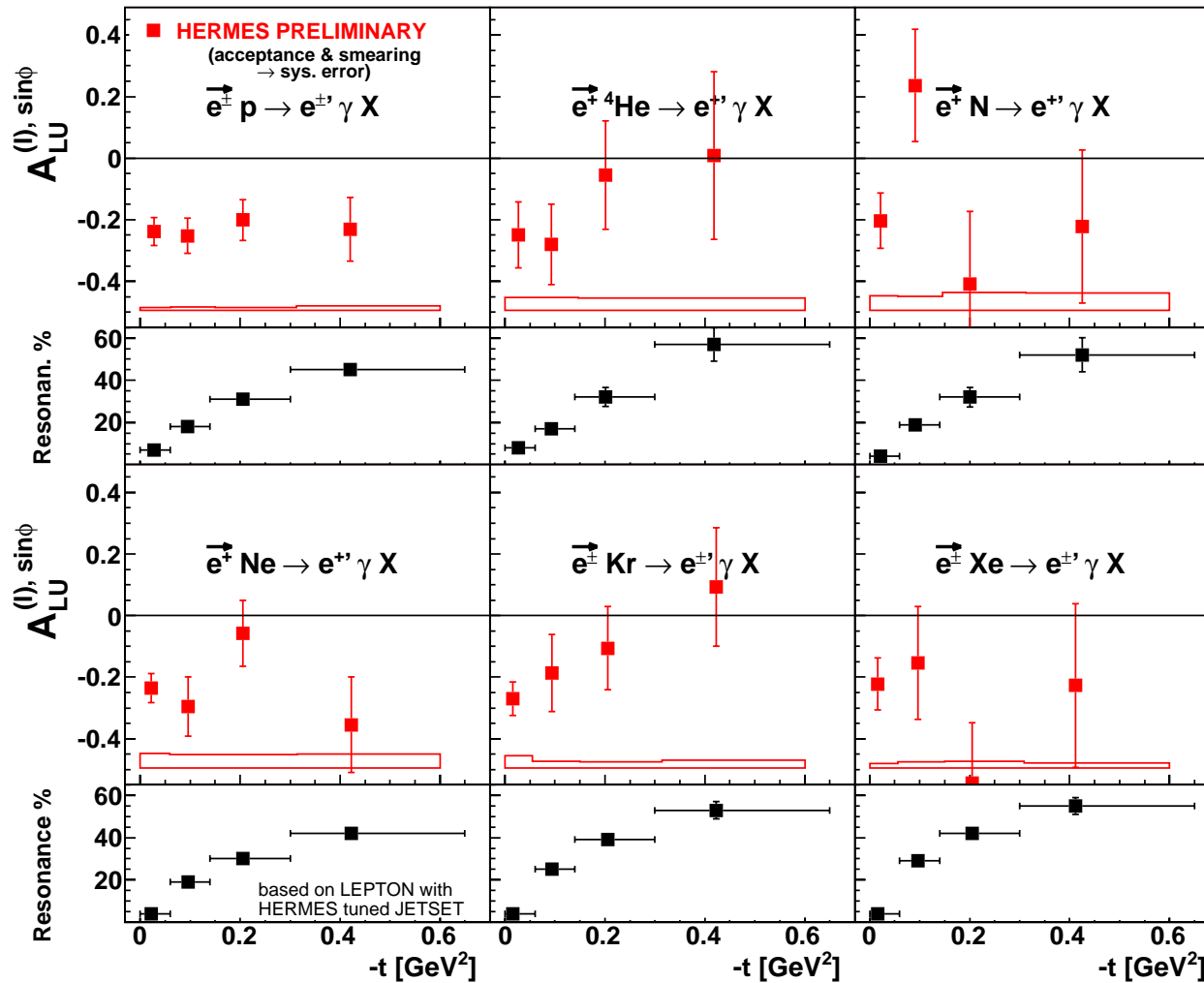


# Beam-charge asymmetry amplitudes (A dependence)

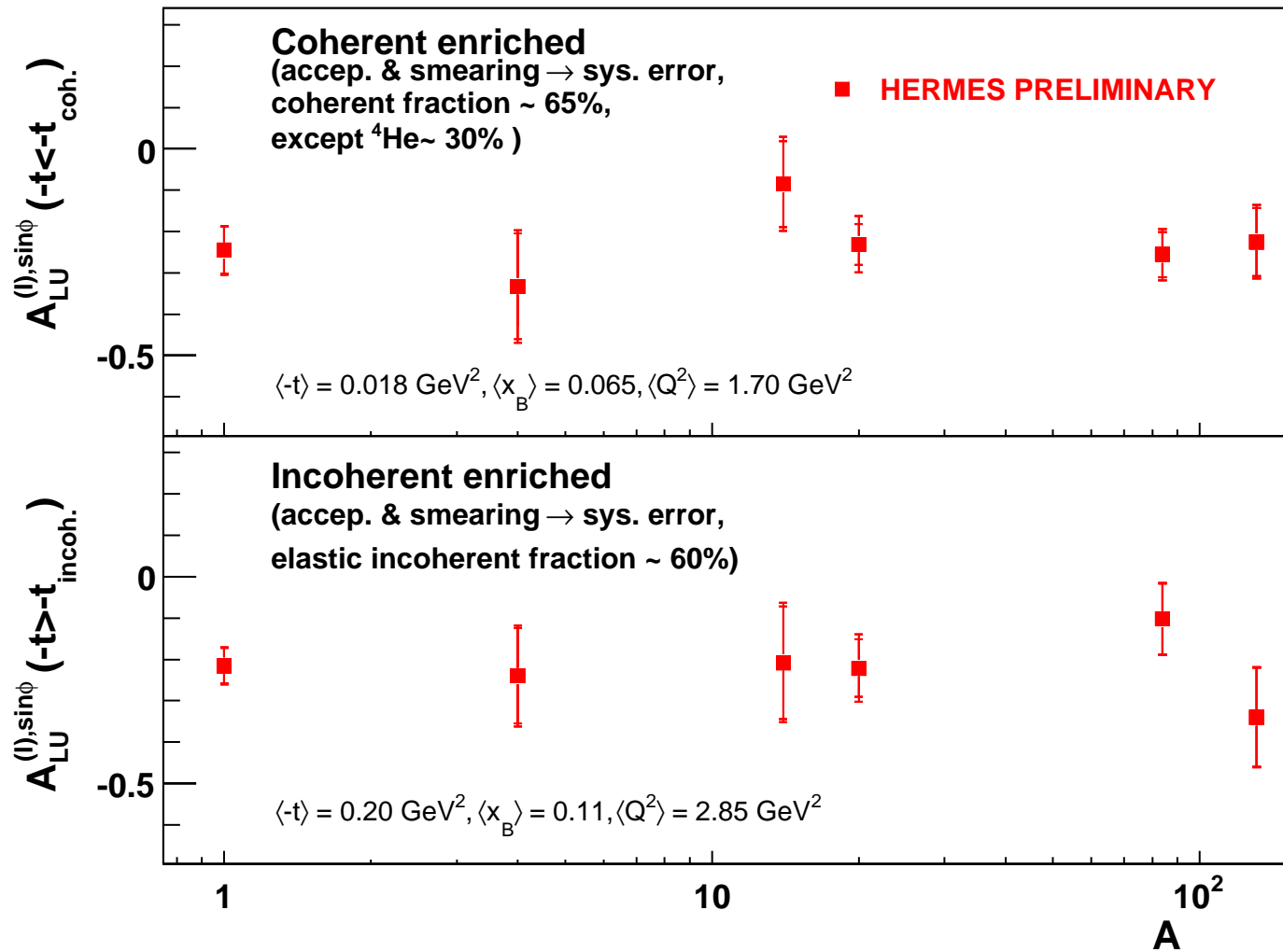


# Beam-helicity asymmetry amplitudes ( $t$ dependence)

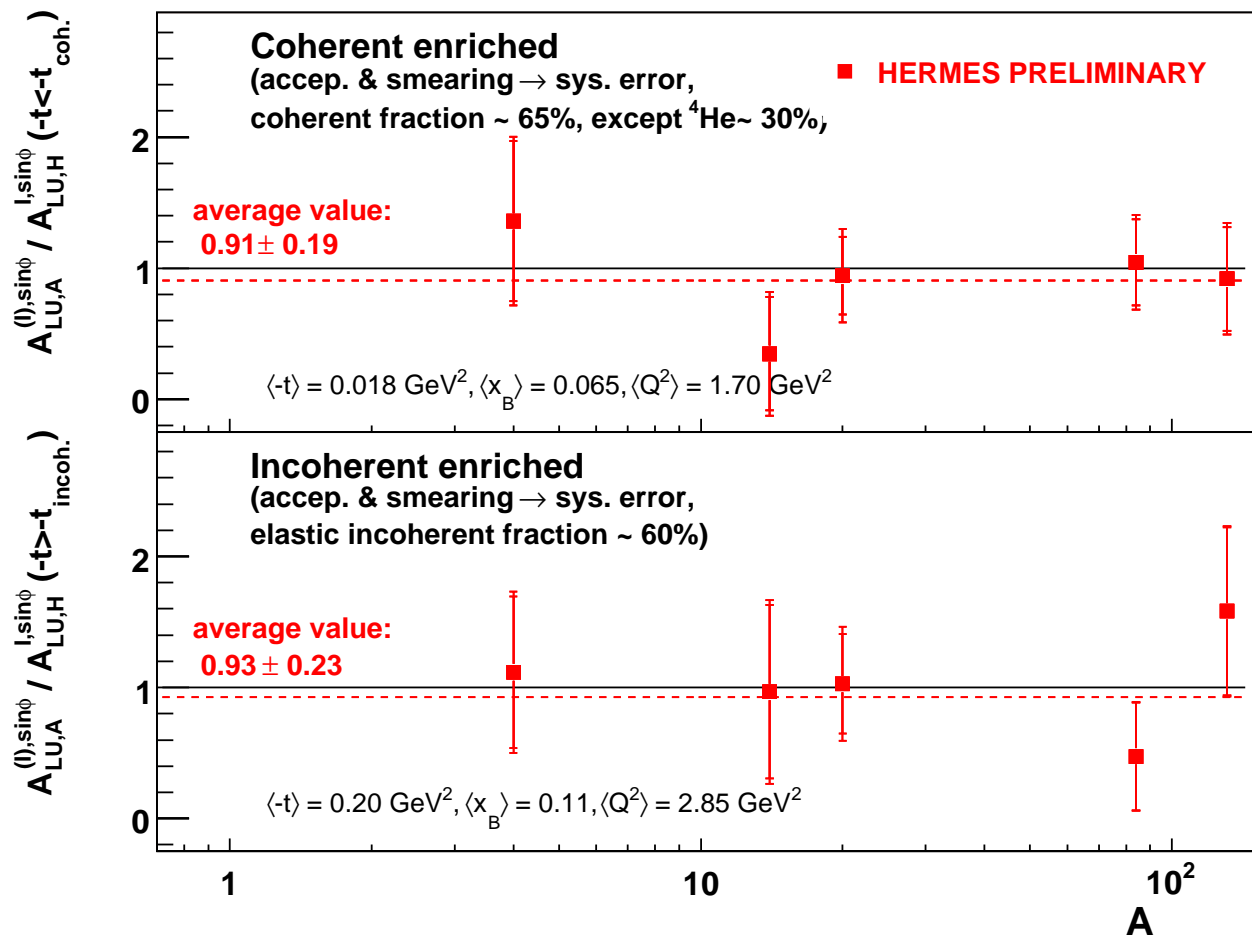
$$H, Kr, Xe: A_{LU}^I(\phi) = \frac{(\sigma^{+\rightarrow} + \sigma^{-\leftarrow}) - (\sigma^{+\leftarrow} + \sigma^{-\rightarrow})}{(\sigma^{+\rightarrow} + \sigma^{-\leftarrow}) + (\sigma^{+\leftarrow} + \sigma^{-\rightarrow})} \quad {}^4He, N, Ne: A_{LU}^I(\phi) = \frac{\sigma^{\rightarrow} - \sigma^{\leftarrow}}{\sigma^{\rightarrow}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



# Beam-helicity asymmetry amplitudes (A dependence)

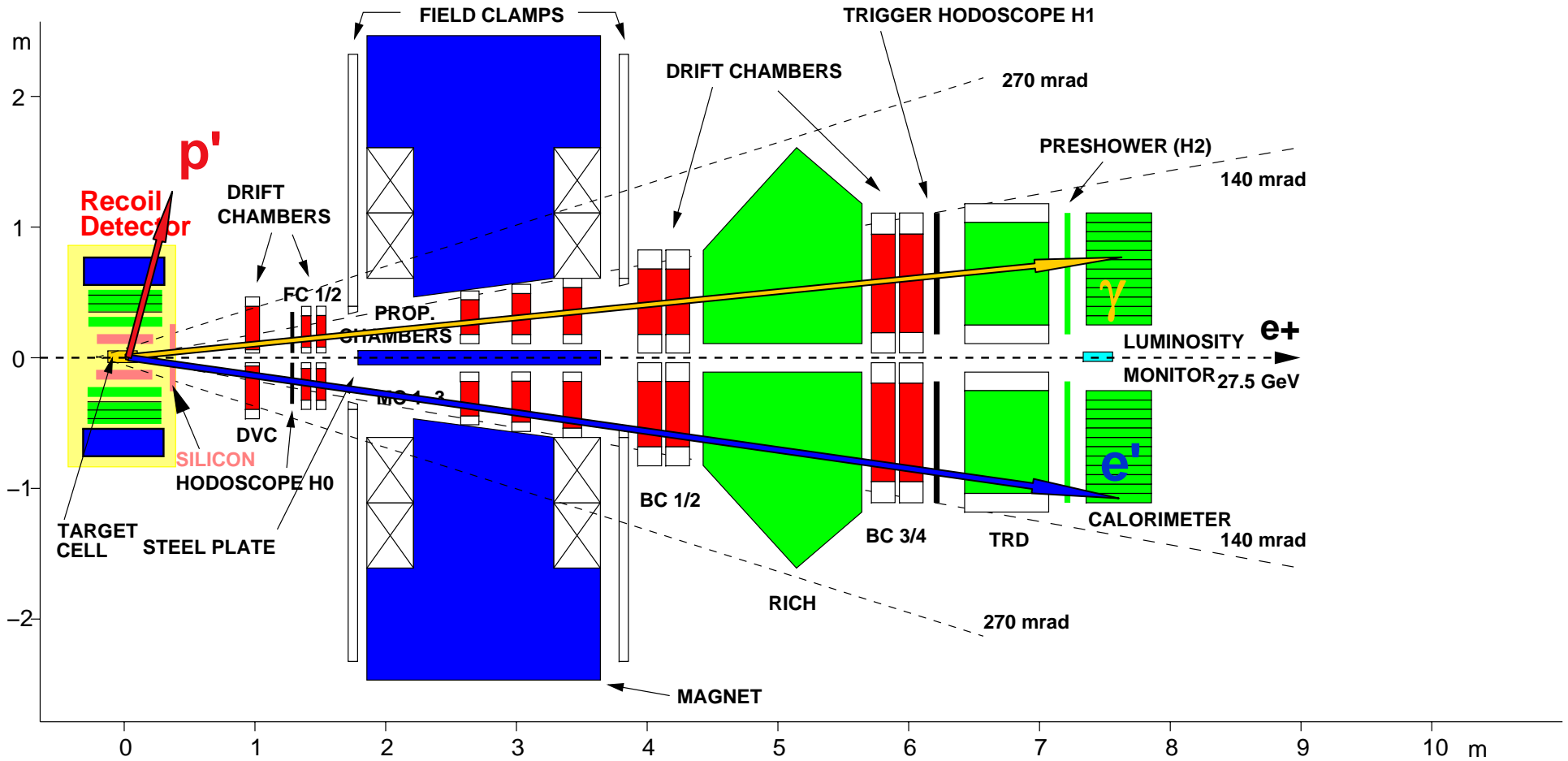


# Ratio of leading beam-helicity asymmetry amplitudes



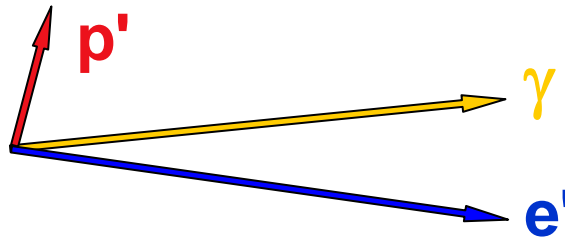
- The results do not support models which predict an enhancement of nuclear asymmetries
- Data contradict the predicted strong  $A$ -dependence of the asymmetries resulting from mesonic degrees of freedom in the nuclei

# Exclusivity at HERMES: Recoil detector



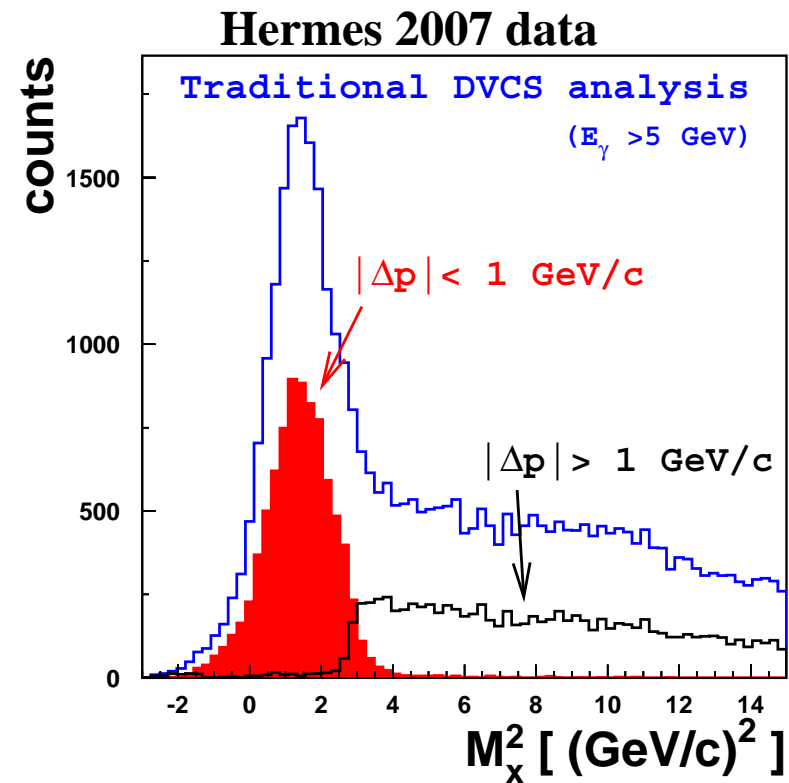
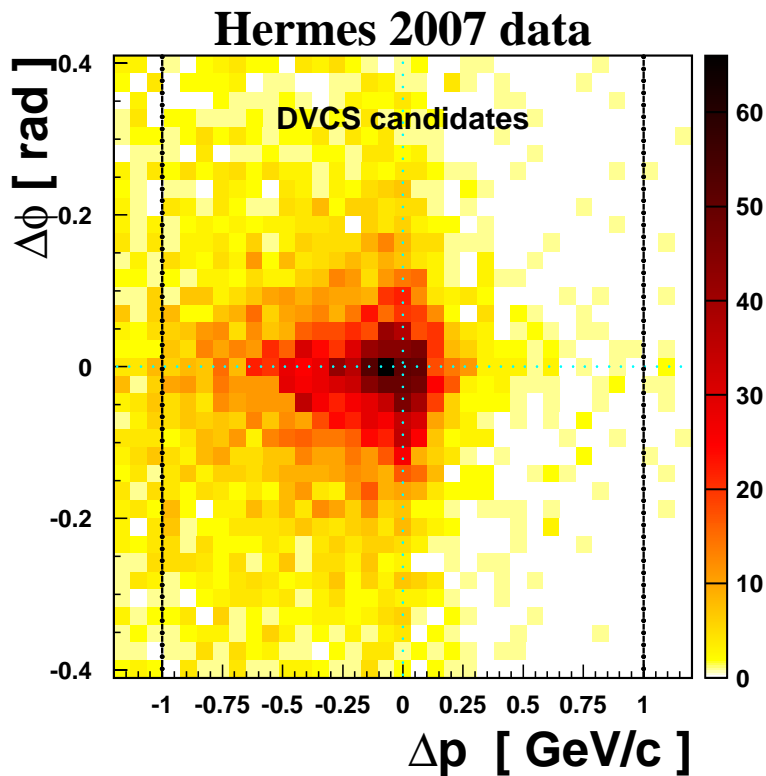
- Unpolarized hydrogen target: 38 Mio DIS (41.000 DVCS)
- Unpolarized deuterium target: 10 Mio DIS (7.500 DVCS)
- Two beam helicities, electron and positron beams

# DVCS event selection with the Recoil detector



Missing azimuthal angle  
versus missing momentum

Missing mass reconstructed using  
measured lepton and photon



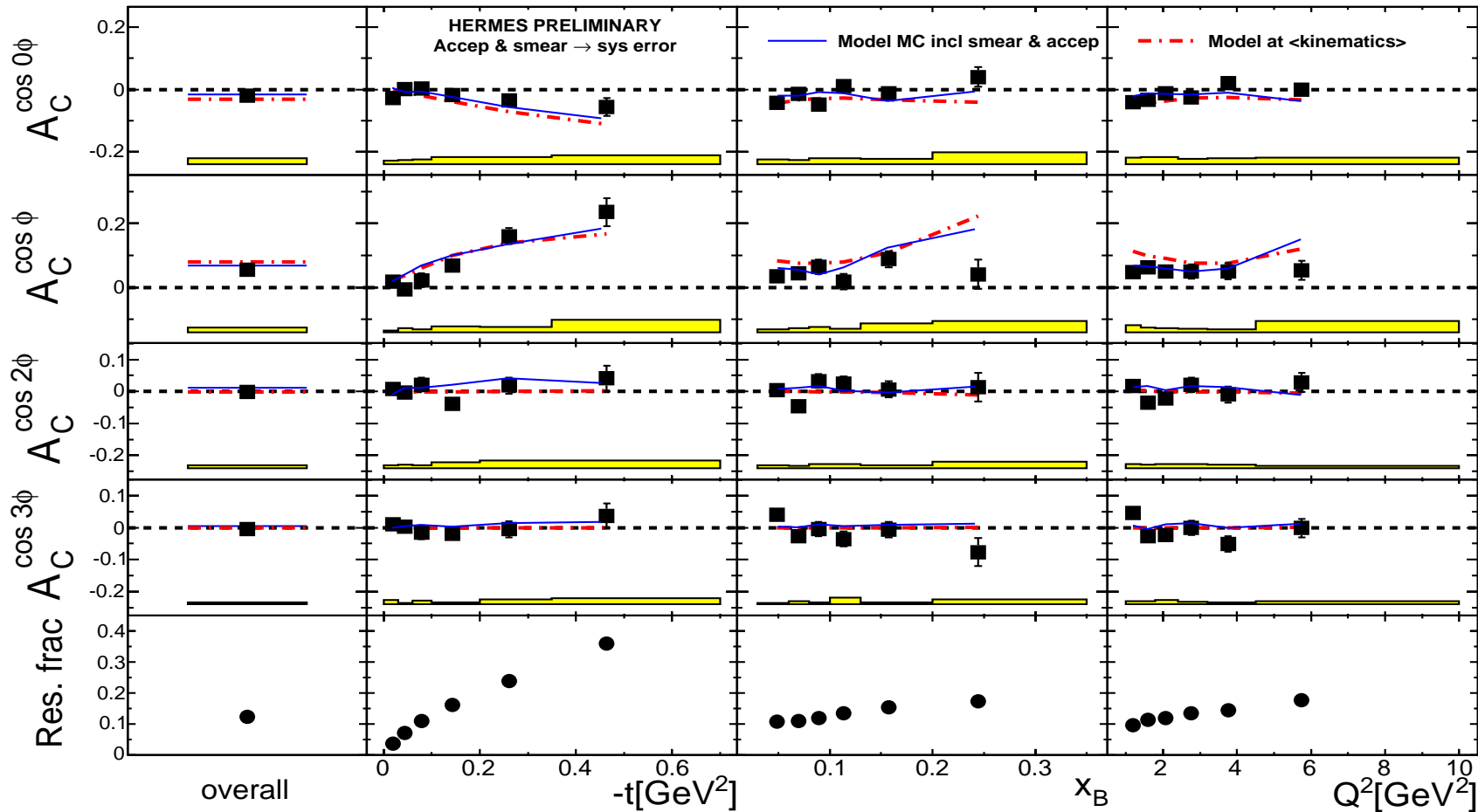
## Summary and outlook

- 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



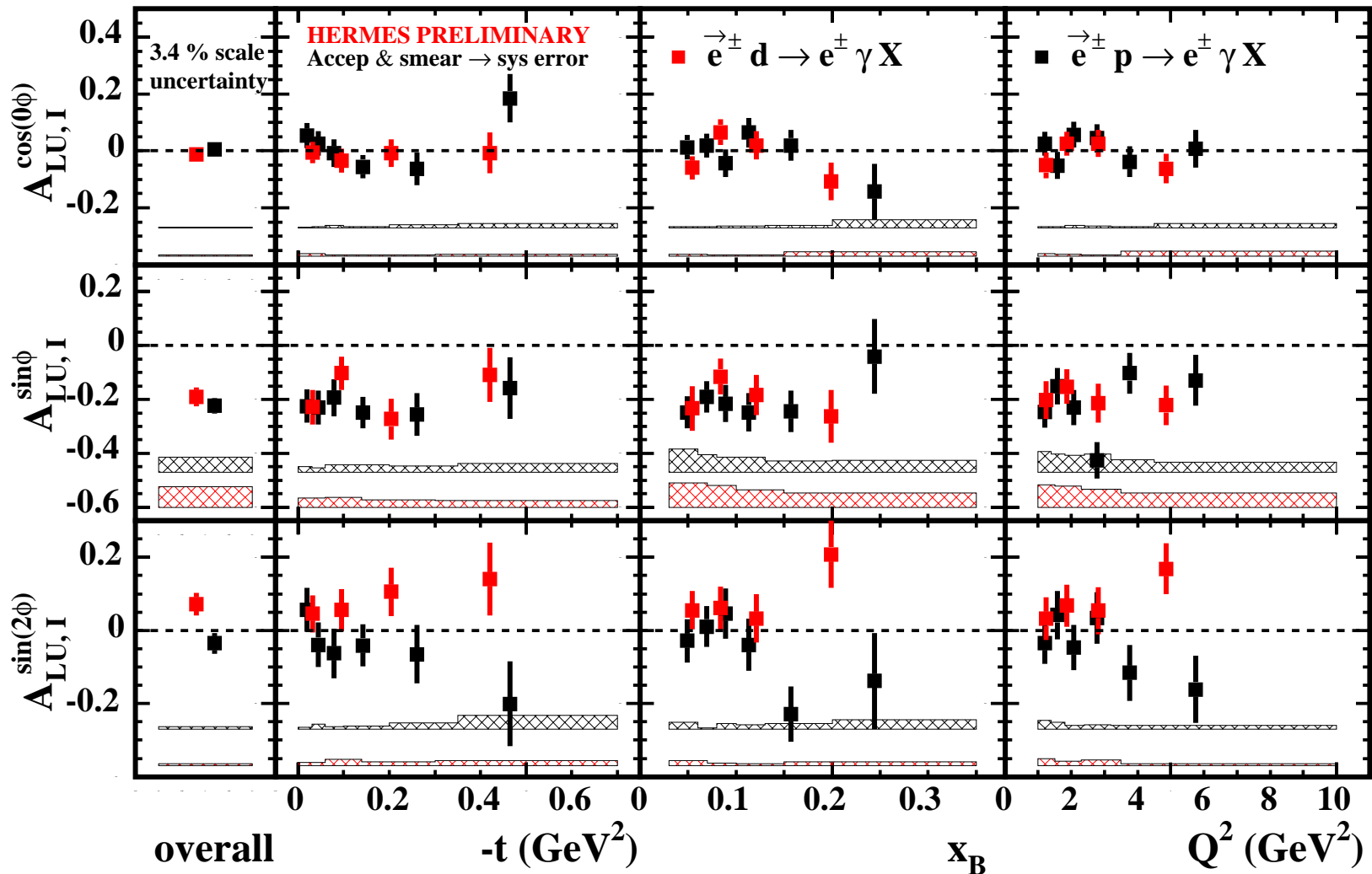
# Backup slides

# 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)

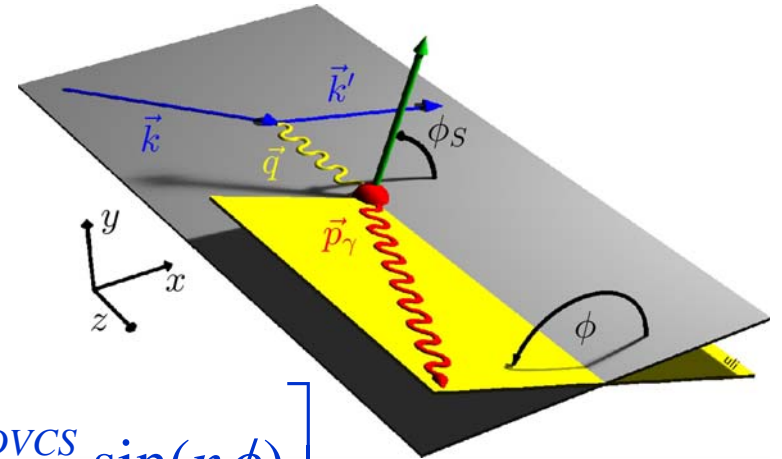


- Proton (black) and Deuteron (red) data are compatible for all leading amplitudes

## Azimuthal dependences

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

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



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

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