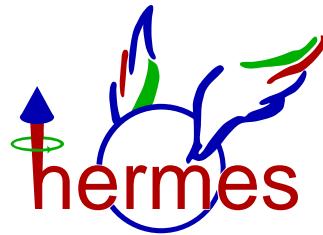


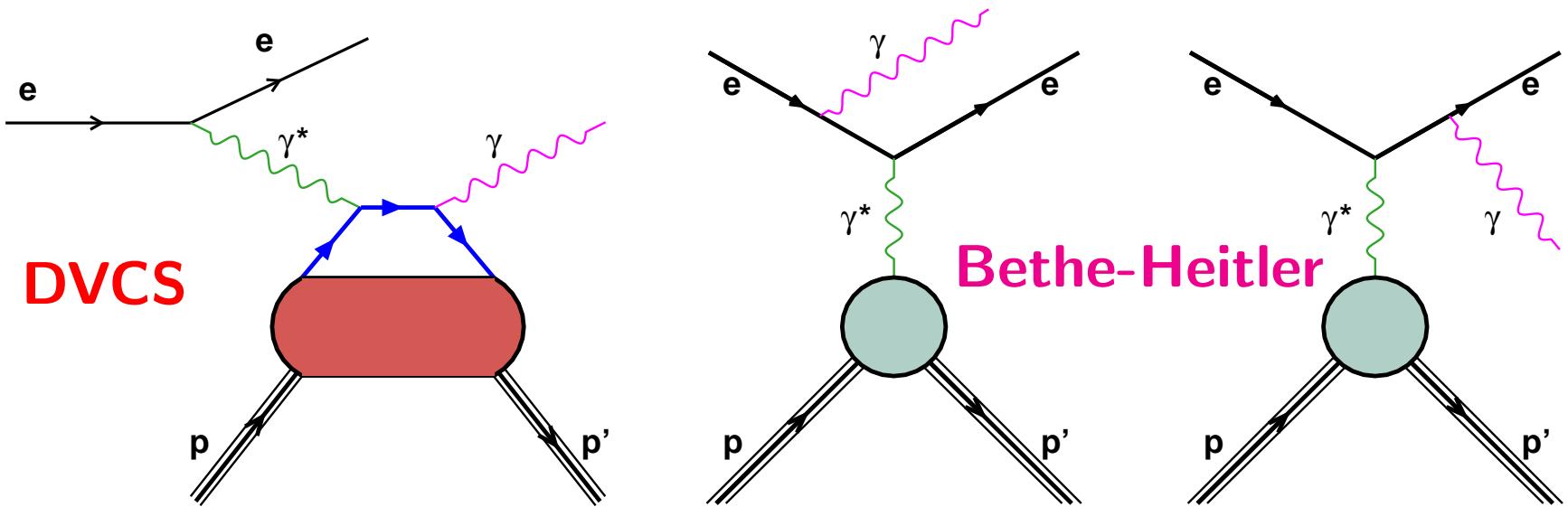
HERMES results on DVCS off Deuterium

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for the HERMES collaboration
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Deeply Virtual Compton Scattering



DVCS and Bethe-Heitler \Rightarrow Same final state \Rightarrow Interference

$$\frac{d\sigma}{dQ^2 dx_B dt d\phi} \propto |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \underbrace{\tau_{DVCS} \tau_{BH}^* + \tau_{BH} \tau_{DVCS}^*}_I$$

At HERMES kinematics $|\tau_{DVCS}|^2 \ll |\tau_{BH}|^2$

DVCS amplitudes can be accessed through **Interference**

Azimuthal Dependencies and Relations to GPDs

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

$$|\tau_{DVCS}|^2 = K_{DVCS} \left[\sum_{n=0}^2 c_n^{DVCS} \cos(n\phi) + \lambda s_1^{DVCS} \sin(\phi) \right]$$

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

λ - beam helicity e_l - beam charge

Relation to GPDs:

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

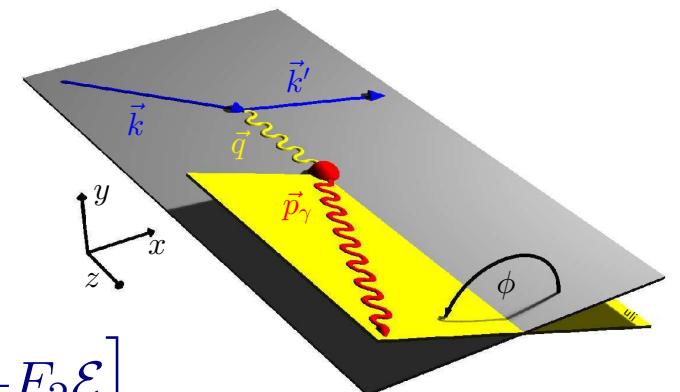
$$s_1^I \propto \frac{\sqrt{-t}}{Q} \text{Im} \left[F_1 \mathcal{H} + \xi(F_1 + F_2) \tilde{\mathcal{H}} - \frac{t}{4M^2} F_2 \mathcal{E} \right]$$

$\mathcal{H}, \tilde{\mathcal{H}}, \mathcal{E}, \tilde{\mathcal{E}}$ - Compton Form Factors of 'spin 1/2' nucleons

= Convolutions of hard scattering amplitudes and GPDs $H, \tilde{H}, E, \tilde{E}$:

$\mathcal{H}_1 \dots \mathcal{H}_5, \tilde{\mathcal{H}}_1 \dots \tilde{\mathcal{H}}_4$ - Compton Form Factors of 'spin 1' Deuteron

F_1, F_2 (G_1, G_2, G_3) - nucleon (Deuteron) elastic Form Factors



Asymmetries

$$\begin{aligned}
 A_C(\phi) &= \frac{\sigma^{+\rightarrow} + \sigma^{+\leftarrow} - \sigma^{-\rightarrow} - \sigma^{-\leftarrow}}{\sigma^{+\rightarrow} + \sigma^{+\leftarrow} + \sigma^{-\rightarrow} + \sigma^{-\leftarrow}} \\
 A_{LU}^I(\phi) &= \frac{\sigma^{+\rightarrow} - \sigma^{+\leftarrow} - \sigma^{-\rightarrow} + \sigma^{-\leftarrow}}{\sigma^{+\rightarrow} + \sigma^{+\leftarrow} + \sigma^{-\rightarrow} + \sigma^{-\leftarrow}} \\
 A_{LU}^{DVCS}(\phi) &= \frac{\sigma^{+\rightarrow} - \sigma^{+\leftarrow} + \sigma^{-\rightarrow} - \sigma^{-\leftarrow}}{\sigma^{+\rightarrow} + \sigma^{+\leftarrow} + \sigma^{-\rightarrow} + \sigma^{-\leftarrow}}
 \end{aligned}$$

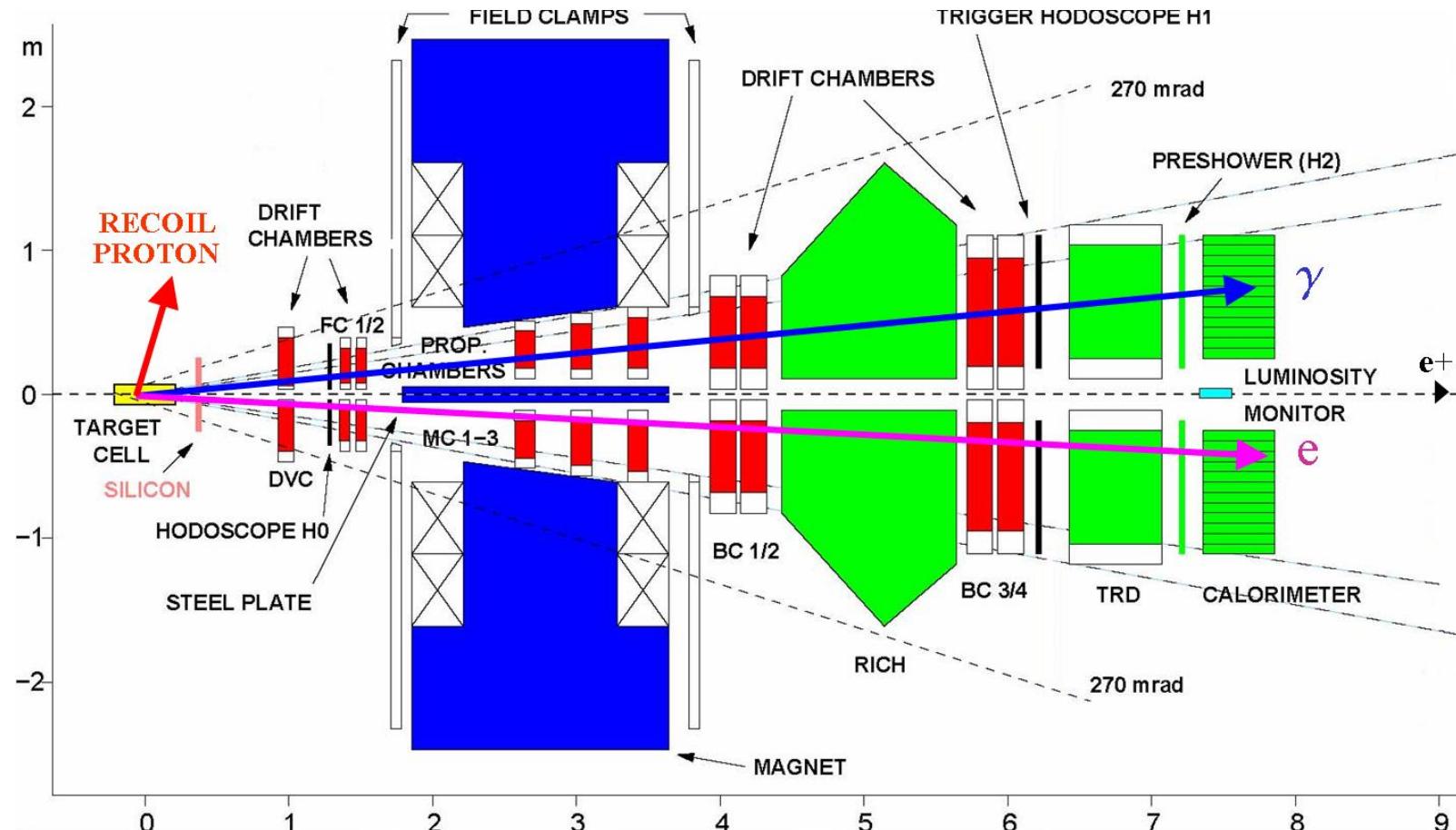
Effective asymmetries:

$$A_C(\phi) = -\frac{\frac{x_B}{y} \sum_{n=0}^3 c_n^I \cos(n\phi)}{\sum_{n=0}^2 c_n^{BH} \cos(n\phi) + \frac{x_B^2 t \mathcal{P}_1(\phi) \mathcal{P}_2(\phi)}{Q^2} \sum_{n=0}^2 c_n^{DVCS} \cos(n\phi)}$$

$$A_{LU}^{DVCS}(\phi) = \frac{\frac{x_B^2 t \mathcal{P}_1(\phi) \mathcal{P}_2(\phi)}{Q^2} s_1^{DVCS} \sin(\phi)}{\sum_{n=0}^2 c_n^{BH} \cos(n\phi) + \frac{x_B^2 t \mathcal{P}_1(\phi) \mathcal{P}_2(\phi)}{Q^2} \sum_{n=0}^2 c_n^{DVCS} \cos(n\phi)}$$

$$A_{LU}^I(\phi) = \frac{\frac{x_B}{Q^2} \sum_{n=1}^2 s_n^I \sin(n\phi)}{\sum_{n=0}^2 c_n^{BH} \cos(n\phi) + \frac{x_B^2 t \mathcal{P}_1(\phi) \mathcal{P}_2(\phi)}{Q^2} \sum_{n=0}^2 c_n^{DVCS} \cos(n\phi)}$$

HERMES Experiment



Gas Target:

- Unpolarized H,D
- Longitudinally Polarized H
- Transversely Polarized H

Beam:

- Energy 27.6 GeV
- Longitudinally Polarized e^+ and e^-
- Both Helicities

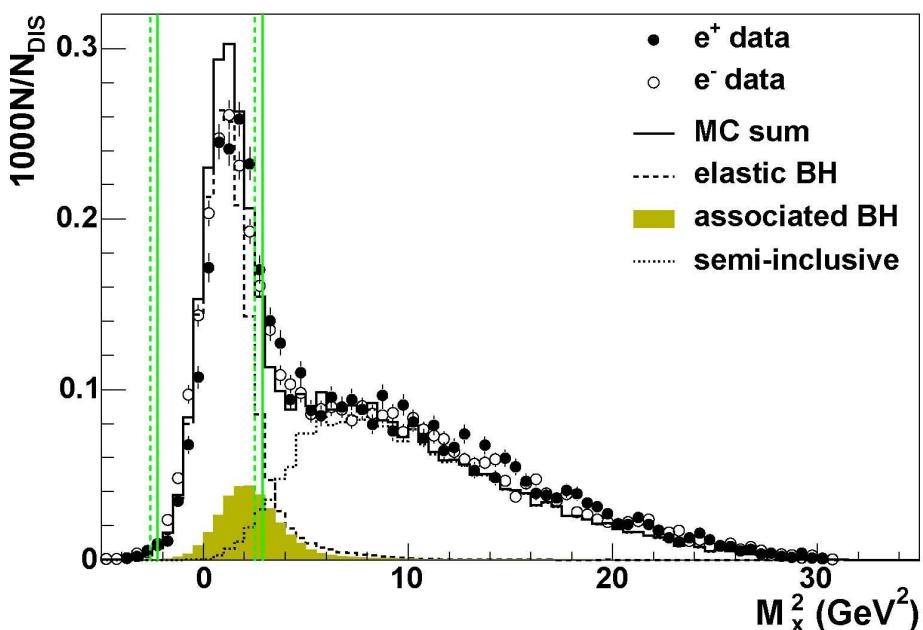
Collected Statistics 1996-2005:(within the cuts of this analysis)

$H \approx 17 \text{ M DIS}$, Unpolarized $D \approx 10 \text{ M DIS}$

Event Selection

- Events with one DIS lepton and one trackless cluster in the calorimeter.
- Recoiling nucleon/nucleus was not detected
⇒ Exclusivity via missing mass technique: $M_x^2 = (P + q - q')^2$

$$0.03 < x_B < 0.35, \quad 1 \text{ GeV}^2 < Q^2 < 10 \text{ GeV}^2 \\ -t < 0.7 \text{ GeV}^2, \quad E_\gamma > 5 \text{ GeV}$$



$$-2.25 \text{ GeV}^2 < M_x^2 < 2.89 \text{ GeV}^2$$

Associated cannot be resolved → defined as a part of signal.

Proton:

- Elastic; $ep \rightarrow ep\gamma$
- Associated; mainly $ep \rightarrow e\Delta^+\gamma$
- Semi-Inclusive; mainly $ep \rightarrow e\pi^0 X$

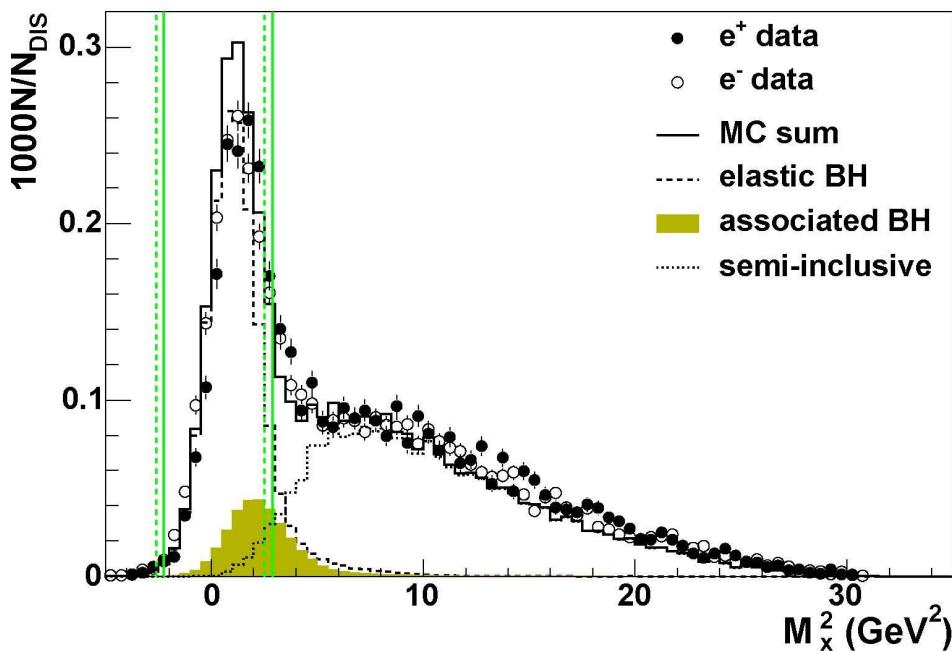
Deuteron:

- Elastic(Coherent); $ed \rightarrow ed\gamma$
- Quasi-elastic; $ed \rightarrow epn\gamma$
- Associated; $eN \rightarrow eN^*\gamma$
- Semi-Inclusive; $eN \rightarrow e\pi^0 X$

Corrections and Uncertainties

The exclusive window was shifted according to the shift of exclusive peak position for different beam charges.

One quarter of the effect was applied as systematic uncertainty.



Background Correction:

mainly π^0 production. $\approx 3\%$

$$A_{excl.} = \frac{1}{1-f}[A_{meas.} - f A_{semi}]$$

For $A_{CU}(\phi)$ and $A_{LU}^I(\phi)$:

Corrected as dilutions.

For A_{LU}^{DVCS} :

A_{semi} - extracted from data.

The effect of the acceptance, smearing, finite bin-width and misalignment between lepton beam and spectrometer were estimated from Monte Carlo.

Extraction Procedure

Distributions in the expectation value of the total combined yield

$$\langle \mathcal{N}(\phi, P_l, e_l) \rangle \propto \sigma_{UU} [1 + \textcolor{red}{P}_l A_{LU}^{DVCS}(\phi) + \textcolor{brown}{e}_l A_C(\phi) + \textcolor{brown}{e}_l \textcolor{red}{P}_l A_{LU}^I(\phi)]$$

Expansion of asymmetries:

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

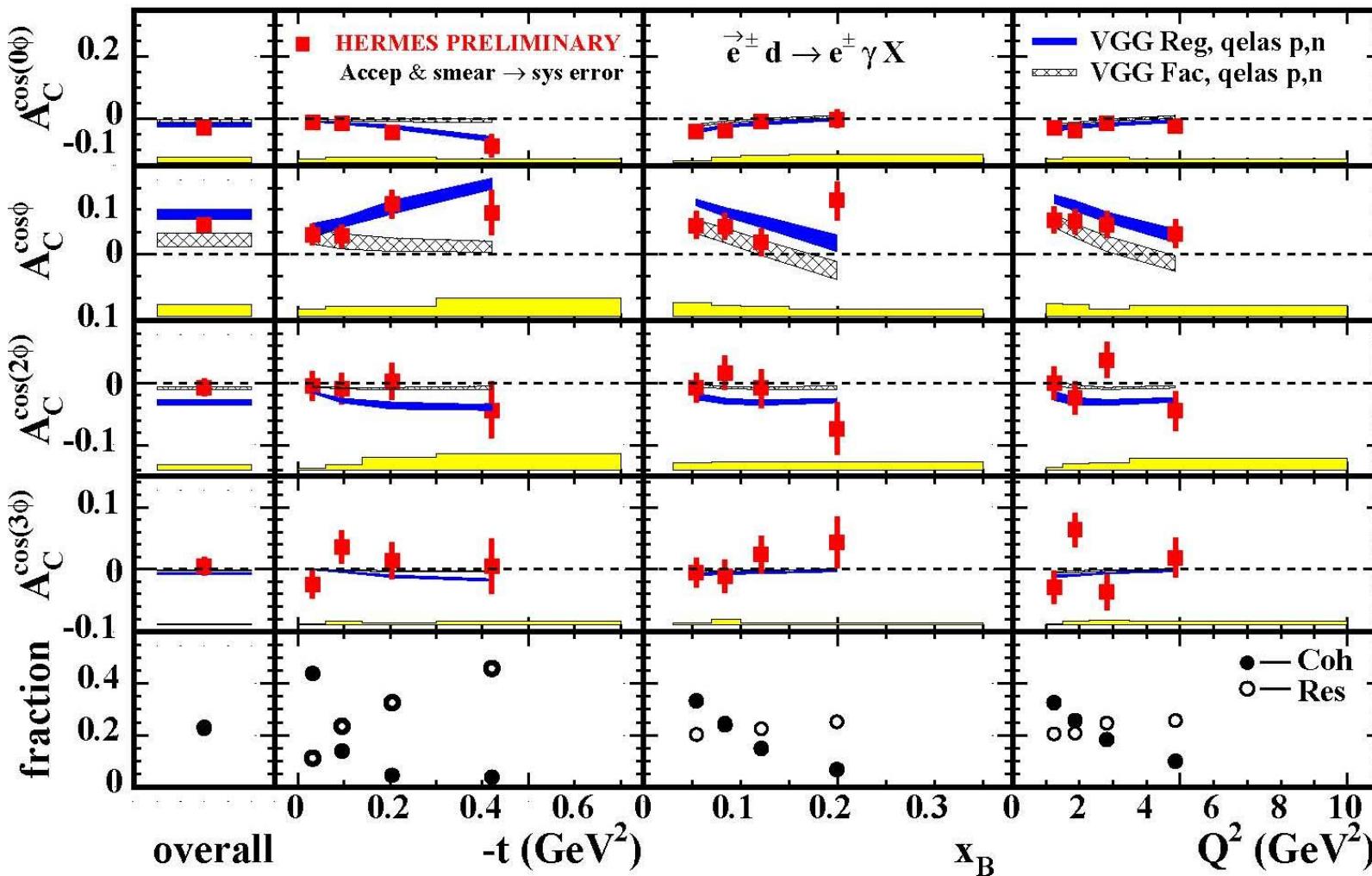
$$A_{LU}^{DVCS}(\phi) \simeq A_{LU,DVCS}^{\cos(0\phi)} + A_{LU,DVCS}^{\sin(\phi)} \sin(\phi)$$

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

Asymmetry amplitudes are extracted simultaneously with Maximum Likelihood method.

Combined analysis allows separation of DVCS and Interference terms.

Beam–Charge Asymmetry A_C



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

$$\propto \text{Re}[F_1 \mathcal{H}] \\ (\text{Re}[G_1 \mathcal{H}_1])$$

higher twist

gluon leading
twist

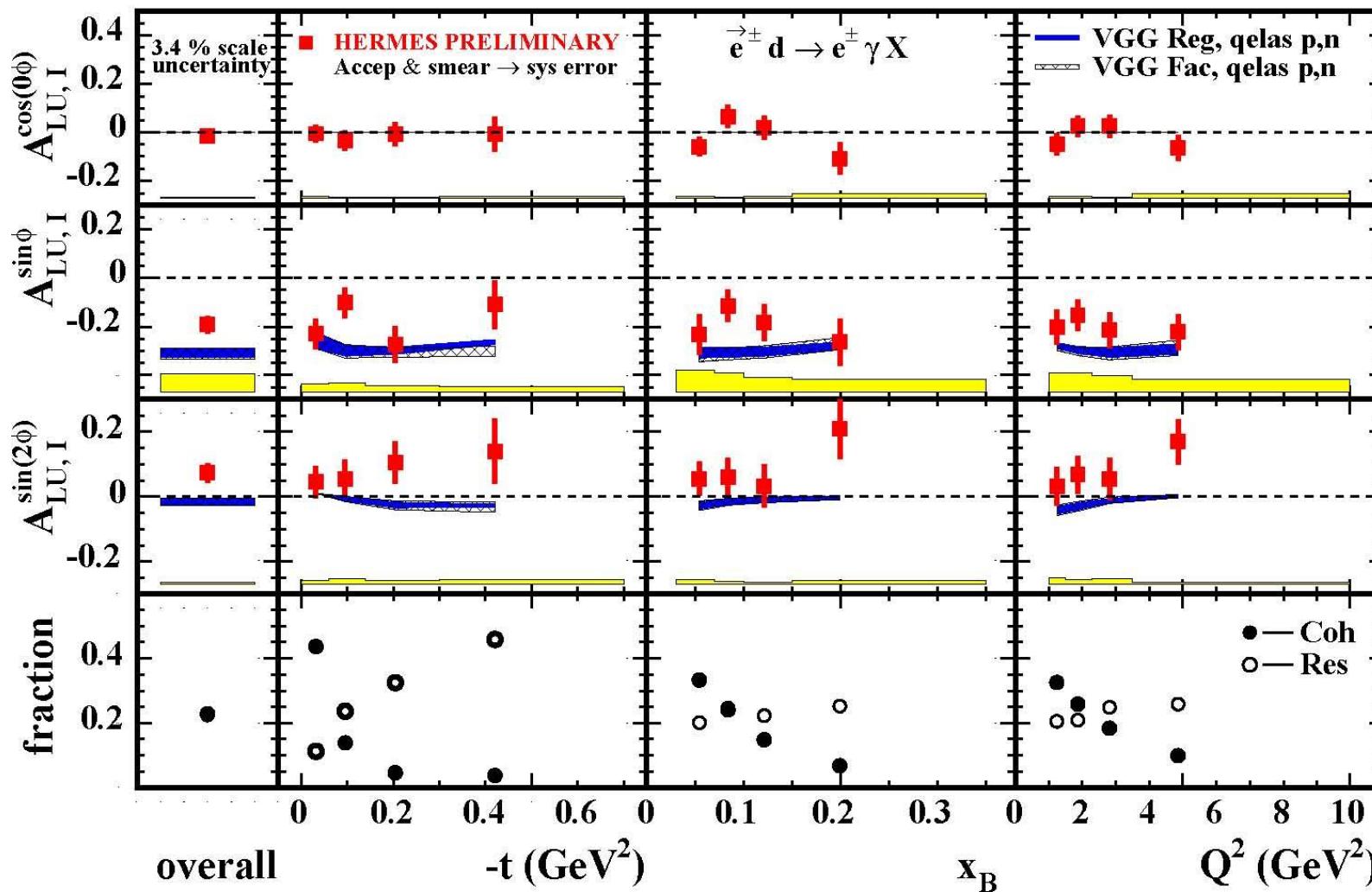
fractions of
various processes.

Model (Vanderhaeghen, Guichon, Guidal 1999)

VGG bands obtained by varying input parameters b_{val} & b_{sea} .

VGG (quasi-elastic p,n) with Regge ansatz can describe the data.

Beam–Helicity Asymmetry A_{LU}^I

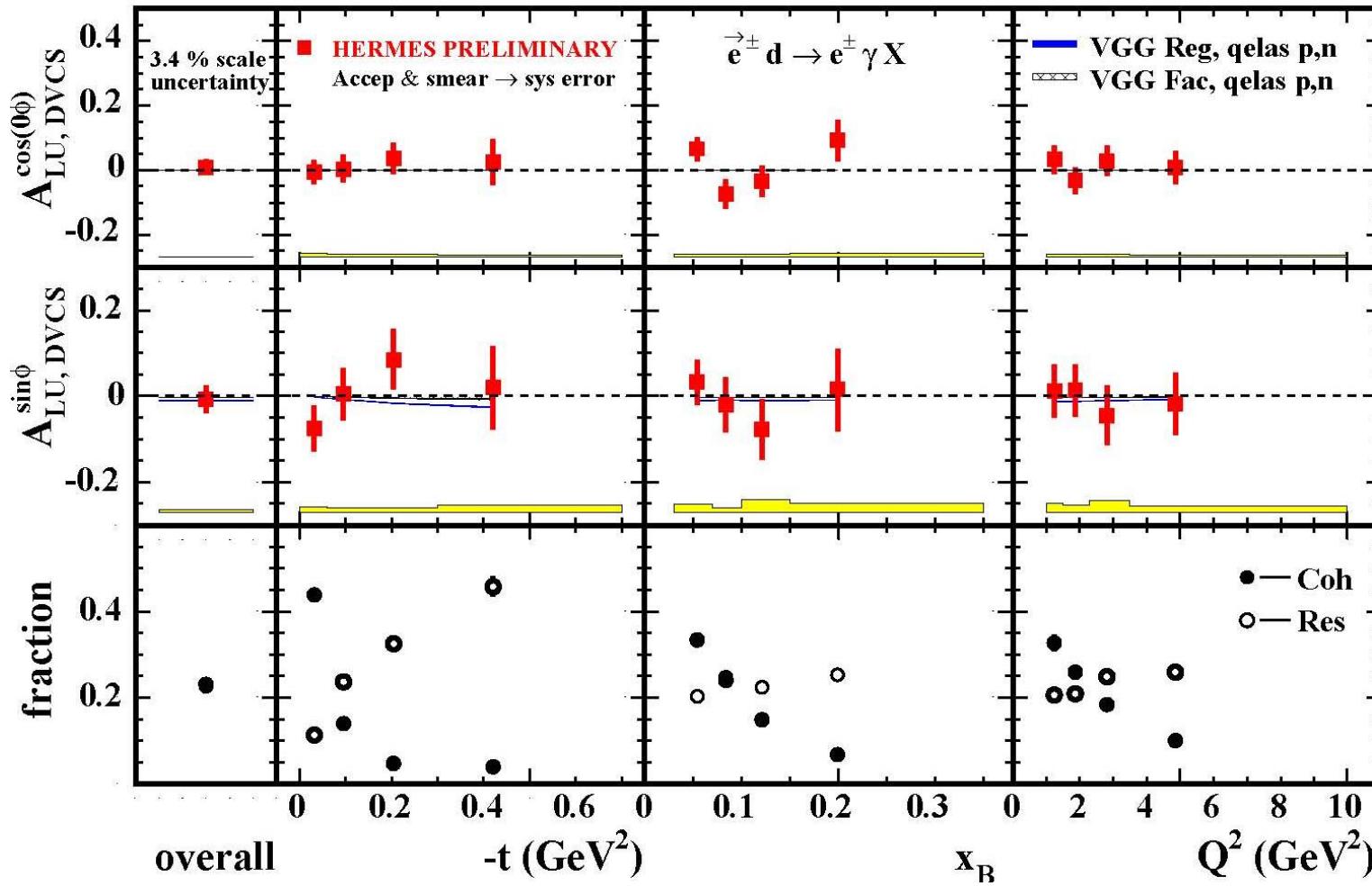


The $\sin(\phi)$ amplitude is significantly negative.

VGG (quasi-elastic p,n) model predictions overestimate measured $\sin(\phi)$ amplitude.



Beam–Helicity Asymmetry A_{LU}^{DVCS}

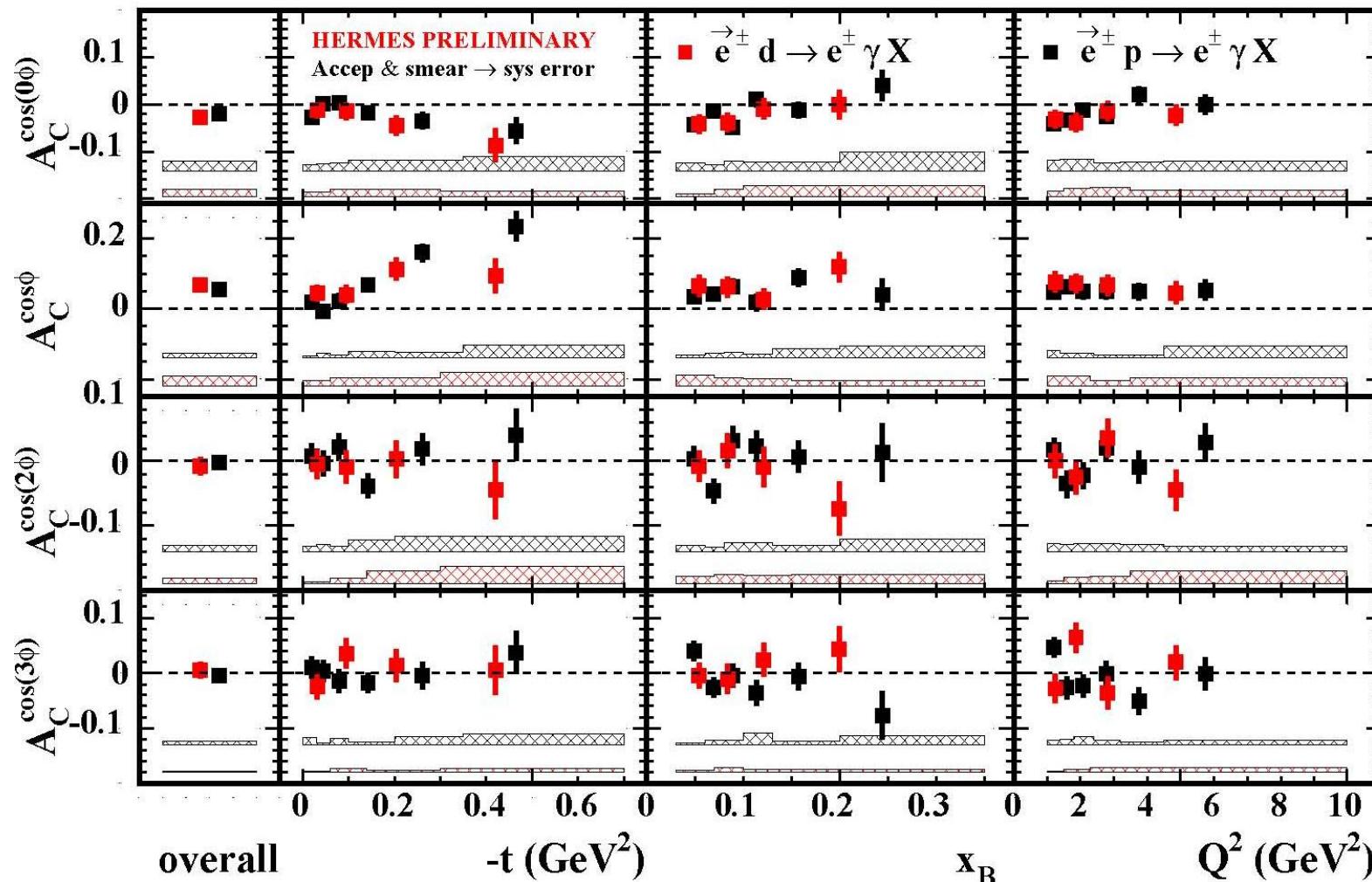


$$\propto [\mathcal{H}\mathcal{H}^* + \tilde{\mathcal{H}}\tilde{\mathcal{H}}^*] \\ (\mathcal{H}_1\mathcal{H}_1^* + \dots)$$

fractions of
various processes.

Amplitudes of the beam–helicity asymmetry that are sensitive to the DVCS term are compatible with zero.

Beam–Charge Asymmetry A_C : Deuterium vs Hydrogen

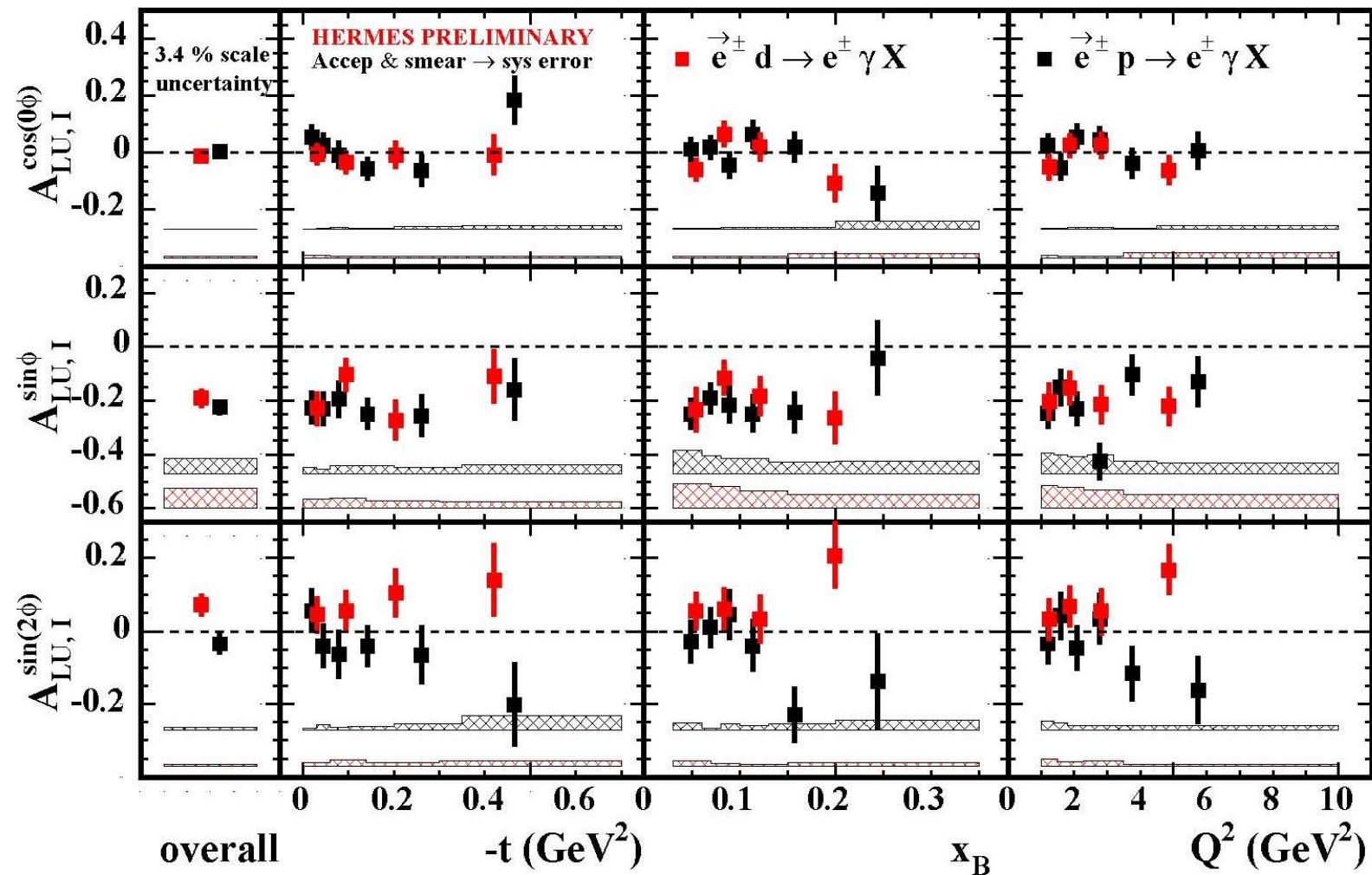


Proton and Deuteron results are compatible at low ($-t < 0.06 \text{ GeV}^2$;

40% coherent) and "intermediate" $-t$ regions.

Difference at large $-t$ for $A_C^{\cos\phi} \rightarrow$ Additional resonant states, Neutron contribution ?

Beam–Helicity Asymmetry A_{LU}^I : Deuterium vs Hydrogen



The $\sin(\phi)$ amplitude is significantly negative for both targets.
 Proton and Deuteron results are compatible for leading amplitude.

Summary and Outlook

- Azimuthal asymmetries with respect to beam charge and helicity are measured at HERMES in a combined analysis on an unpolarized Deuterium target.
- The results for all leading amplitudes on Deuterium target agree very well with the similar results extracted from the Hydrogen data at HERMES.
- The statistical precision allows for strong constraints on GPD models.
- The measured BCA amplitudes disfavor VGG model predictions with factorized t-ansatz.
- Associated process can be separated in data collected from 2006-2007 with the recoil detector.

BACKUP



Beam–Helicity Asymmetry A_{LU}^{DVCS} : Deuterium vs Hydrogen

