HERMES Results From a Combined Beam Charge and Spin Analysis of DVCS on Unpolarized Hydrogen and Deuterium Targets

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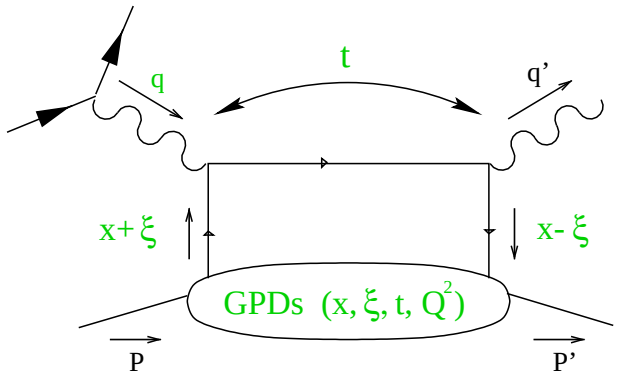
- **Structure of the Nucleon, GPDs and DVCS process**
- **DVCS Measurement at HERMES**
- **HERMES Combined BCA & BSA Analysis**
- **HERMES Combined BCA & BSA Results from unpolarized H and D**
- **Summary and Outlook**

Structure of the Nucleon, GPDs and DVCS Process

GPDs CONTAIN A DETAILED INFORMATION ON THE STRUCTURE OF NUCLEON:

DVCS: ONE OF THE CLEANEST HARD EXCLUSIVE PROCESS TO ACCESS GPDs,
HARD PHOTOPRODUCTION OF A REAL PHOTON $(\gamma^* N \to N' \gamma)$,
VIRTUAL PHOTON GENERATED BY LEPTON SCATTERING $\Rightarrow e N \to e' N' \gamma$

FACTORIZATION THEOREM:



$x \pm \xi$: PARTON LONGITUDINAL MOMENTUM FRACTIONS,
ξ: FRACTION OF THE MOMENTUM TRANSFER, $\xi \simeq \frac{x_B}{2-x_B}$,
t: INVARIANT MOMENTUM TRANSFER, $t \equiv (p - p')^2$

NUCLEON STRUCTURE:

$GPDs: \quad H_q, \widetilde{H}_q, E_q, \widetilde{E}_q$

$GPDs \to PDFs$

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

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

$GPDs \to FFs$

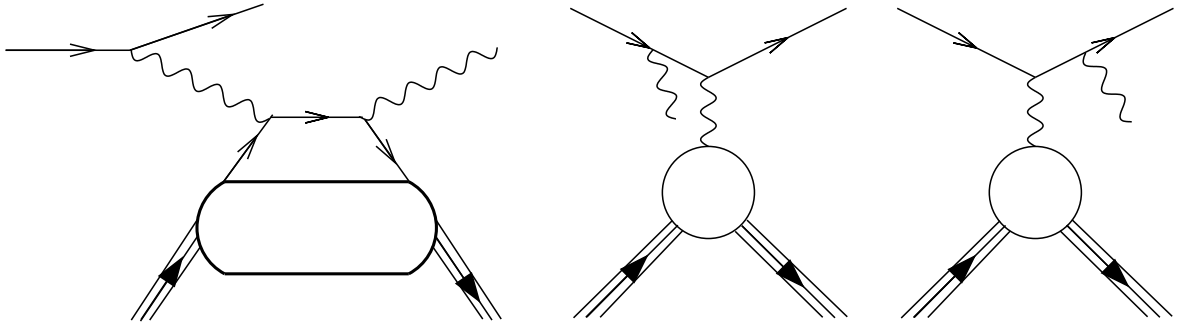
$\int_{-1}^{1} dx\, H_q(x,\xi,t) = F_1^q(t)$,

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

$H_q, \widetilde{H}_q$ — CONSERVE NUCLEON HELICITY
$E_q, \widetilde{E}_q$ — FLIP NUCLEON HELICITY,
NOT ACCESSIBLE IN DIS

DVCS and BH Interference

DVCS (a) and Bethe-Heitler (BH) (b) processes experimentally indistinguishable



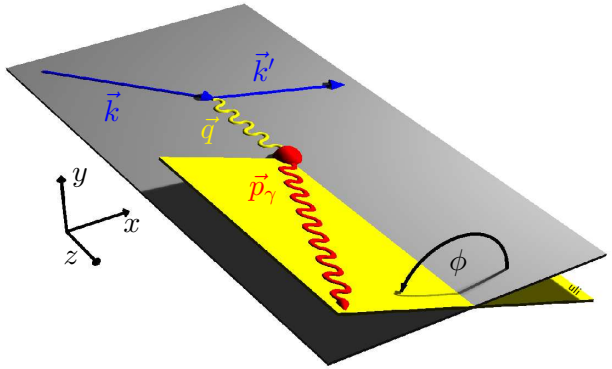
$$d\sigma \propto |\mathcal{T}_{\rm DVCS}|^2 + |\mathcal{T}_{\rm BH}|^2 + \underbrace{(\mathcal{T}^*_{\rm DVCS}\mathcal{T}_{\rm BH} + \mathcal{T}^*_{\rm BH}\mathcal{T}_{\rm DVCS})}_{I}$$

$\mathcal{T}_{\rm BH}$: Calculable in QED $\Rightarrow$ Pauli & Dirac Form factors F_1, F_2

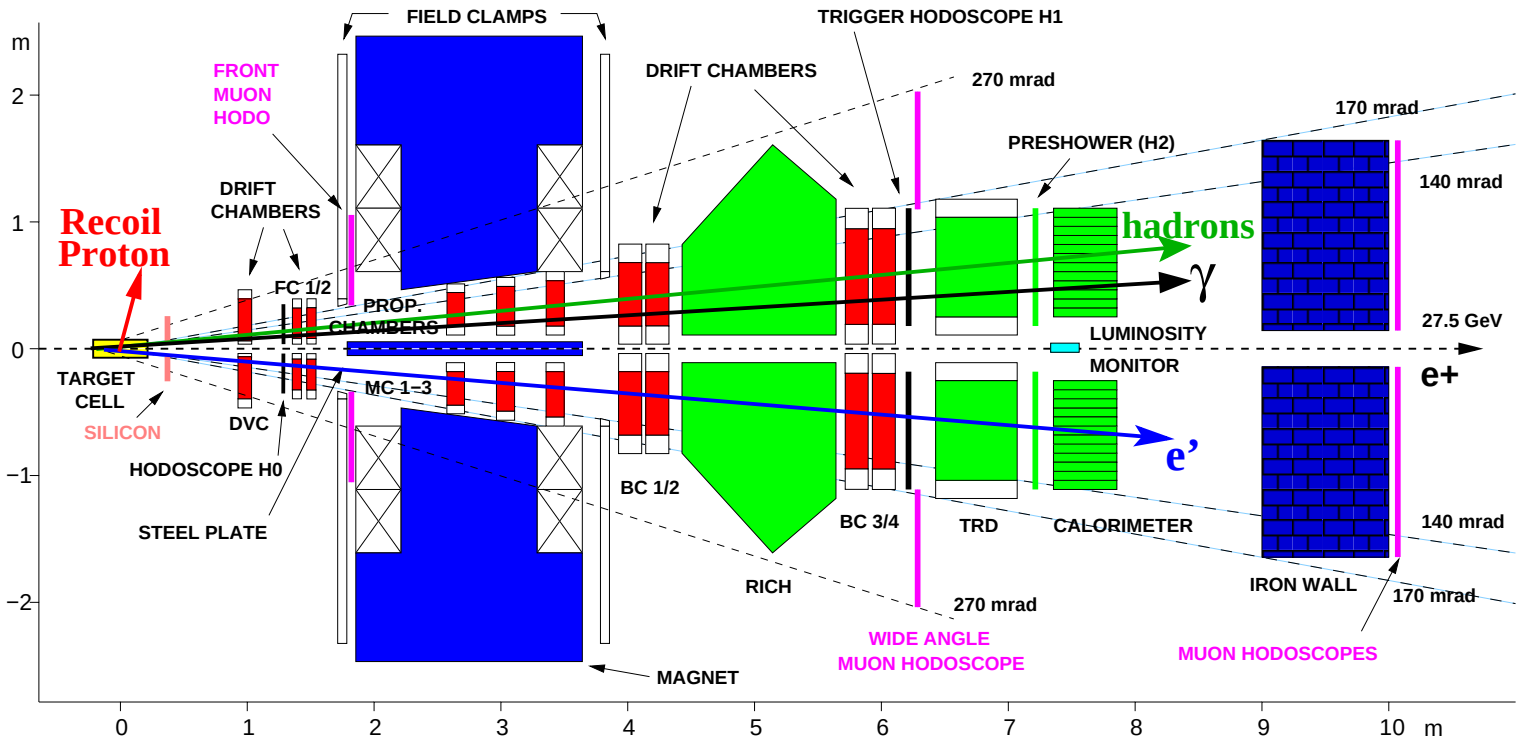
$\mathcal{T}_{\rm DVCS}$: Compton Form Factors $\mathcal{H}, \widetilde{\mathcal{H}}, \mathcal{E}, \widetilde{\mathcal{E}} \Rightarrow$ convolutions of GPDs

GPDs indirectly accessible through azimuthal asymmetries via I

- Beam–Spin Asymmetry (BSA):
  $d\sigma(\overrightarrow{e},\phi) - d\sigma(\overleftarrow{e},\phi) \propto \mathrm{Im}\,[F_1\mathcal{H}] \times \sin(\phi)$
- Beam–Charge Asymmetry (BCA):
  $d\sigma(e^+,\phi) - d\sigma(e^-,\phi) \propto \mathrm{Re}\,[F_1\mathcal{H}] \times \cos(\phi)$



The HERMES Experiment



Gas Target:

- Long. polarized H_2
- Unpolarized H_2, D_2
- Transversely polarized H_2

Beam:

- Long. polarized e^+ and e^-
- Energy 27.6 GeV
- Both helicities

Collected statistics 1996-2005:

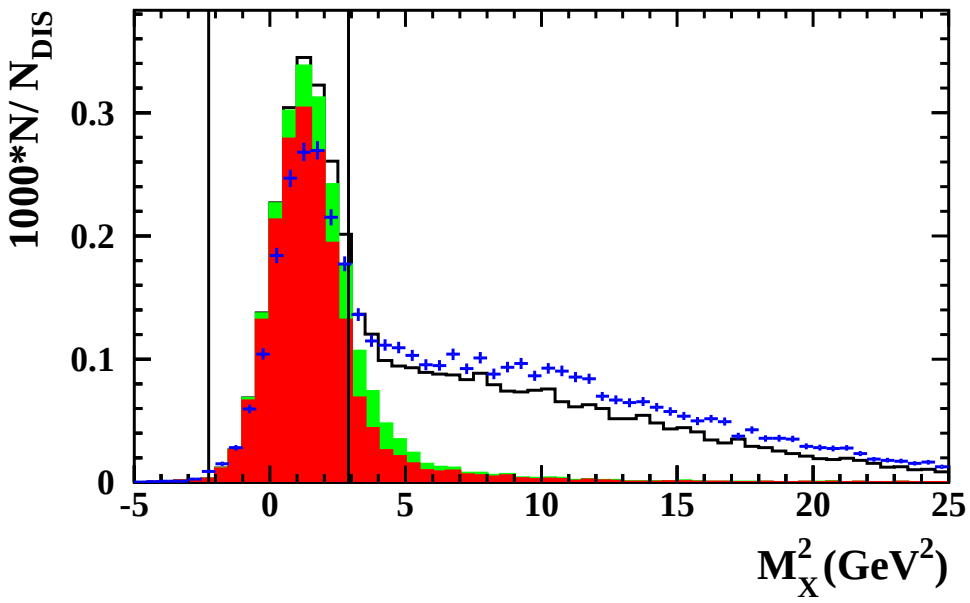
$H_2 \approx$ 17M DIS, unpolarized $D_2 \approx$ 10M DIS

PID: $\epsilon_e > 99\%$, $\delta P/P < 2\%, \delta\theta < 1mrad$, $\delta E_\gamma/E_\gamma \approx 5\%$.

DVCS Event Selection

- Events with exactly one DIS - lepton and exactly one trackless cluster in the calorimeter.
- No recoil detection $\Rightarrow$ Exclusivity via missing mass: $M_X^2 = (q + P - q')^2$

$$5 < \theta_{\gamma^*\gamma} < 45\,mrad$$
$$-t < 0.7\,GeV$$
$$0.03 < x_B < 0.35, \quad 1 < Q^2 < 10\,GeV^2$$
$$W > 3\,GeV, \quad \nu > 22\,GeV$$



MC for background and cuts, systematic uncertainty

$e\,p \to e'\,\gamma\,X$

$e\,p \to e'\,p\,\gamma$; Elastic BH

$e\,p \to e'\,\Delta^+\,\gamma$; Associated BH

$e\,p \to e'\,\pi^0\,X$; Semi-inclusive

Correction; π^0 Background ($\approx 3\%$)

Associated ($\approx 12\%$); part of signal

$e\,d \to e'\,\gamma\,X$

$e\,d \to e'\,d\,\gamma$; Elastic(Coherent)

$e\,d \to e'\,pn\,\gamma$; Quasielastic

$e\,N \to e'\,N^*\,\gamma$; Resonant states

$\Rightarrow$ Exclusive bin $(-(1.5)^2 < M_X^2 < (1.7)^2\ GeV^2)$

HERMES Combined BSA and BCA Analysis

$$\sigma_{\mathrm{LU}}(\phi; P_l, e_l) = \sigma_{UU}(\phi)[1 + e_l A_C(\phi) + e_l P_l A^I_{LU}(\phi) + P_l A^{DVCS}_{LU}(\phi)]$$

Beam Spin Asymmetries:

$$A^I_{LU}(\phi) = -\frac{1}{\mathcal{D}(\phi)} \cdot \frac{x_B}{Q^2} \sum_{n=1}^{3} s^I_n \sin(n\phi)$$

$$A^{DVCS}_{LU}(\phi) = \frac{1}{\mathcal{D}(\phi)} \cdot \frac{x_B^2 t \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}{Q^2} \sum_{n=1}^{2} s^{DVCS}_n \sin(n\phi)$$

Beam Charge Asymmetry:

$$A_C(\phi) = -\frac{1}{\mathcal{D}(\phi)} \cdot \frac{x_B}{y} \sum_{n=0}^{3} c^I_n \cos(n\phi)$$

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

$$\sigma_{UU} = \frac{1}{32(2\pi)^2} \frac{1}{Q^2 x_B t \sqrt{(1+\varepsilon^2}\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \mathcal{D}(\phi)$$

Fit to data: $A_C(\phi) = \sum_{n=0}^{3} A_C^{cosn\phi} \cos(n\phi)$; $A^I_{LU}(\phi) = \sum_{m=1}^{2} A^{sinm\phi}_{LU,I} \sin(m\phi)$; $A^{DVCS}_{LU}(\phi) = A^{sin\phi}_{LU,DVCS} \sin(\phi)$.

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 depends on free parameter b_{val} & b_{sea}.
- Includes twist-3 contributions.

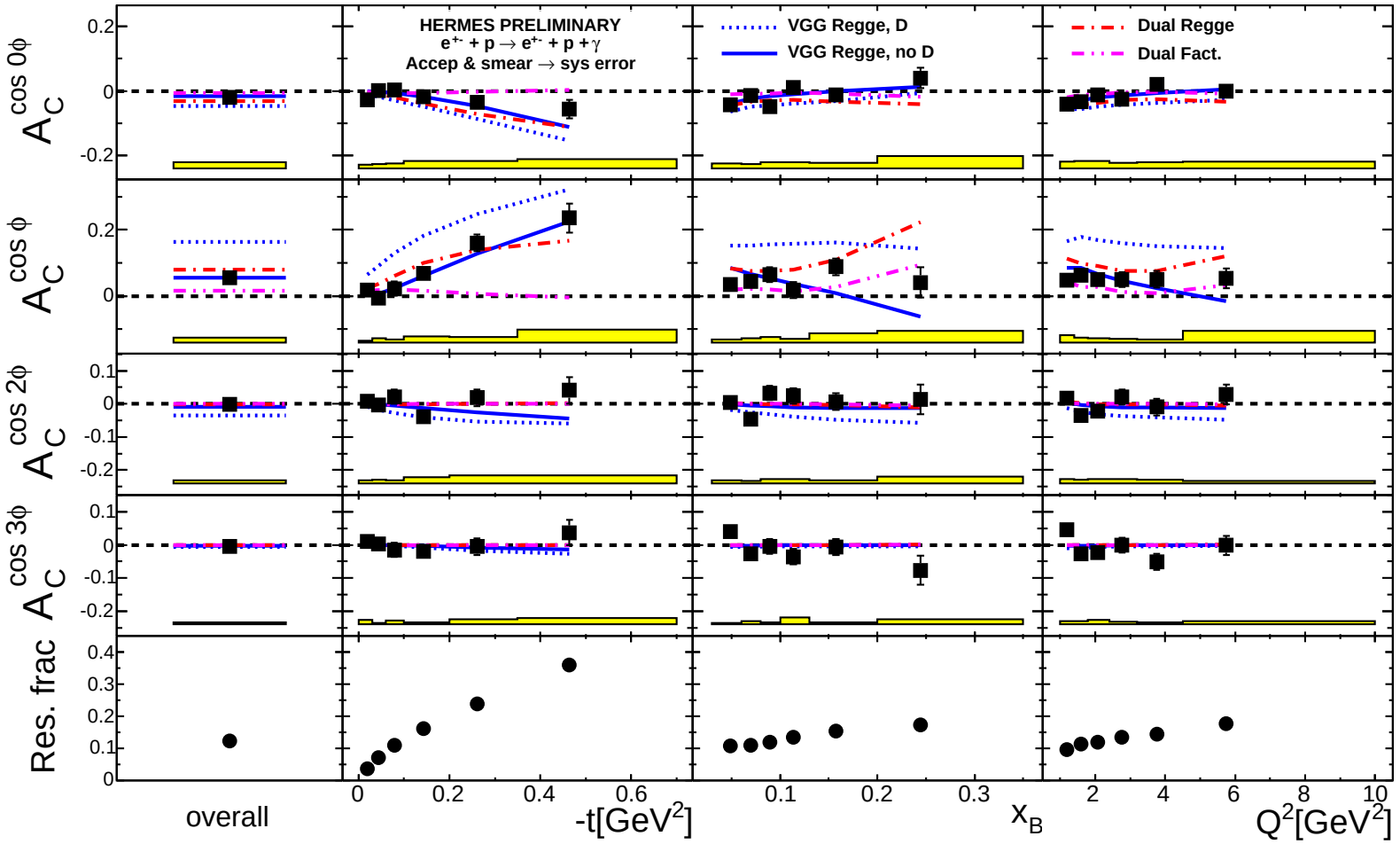
"**Dual**" model: (Guzey, Teckentrup 2006)

- GPDs based on an infinite sum of t-channel resonances.
- Includes a Regge inspired and a factorized t-ansatz.
- Does not include twist-3.

MC simulations based on these GPD models are used:

- for data-theory comparison;
- to estimate the uncertainties from the effect of the acceptance, bin-width, smearing and misalignments.

Beam–Charge Asymmetry on Hydrogen



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

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

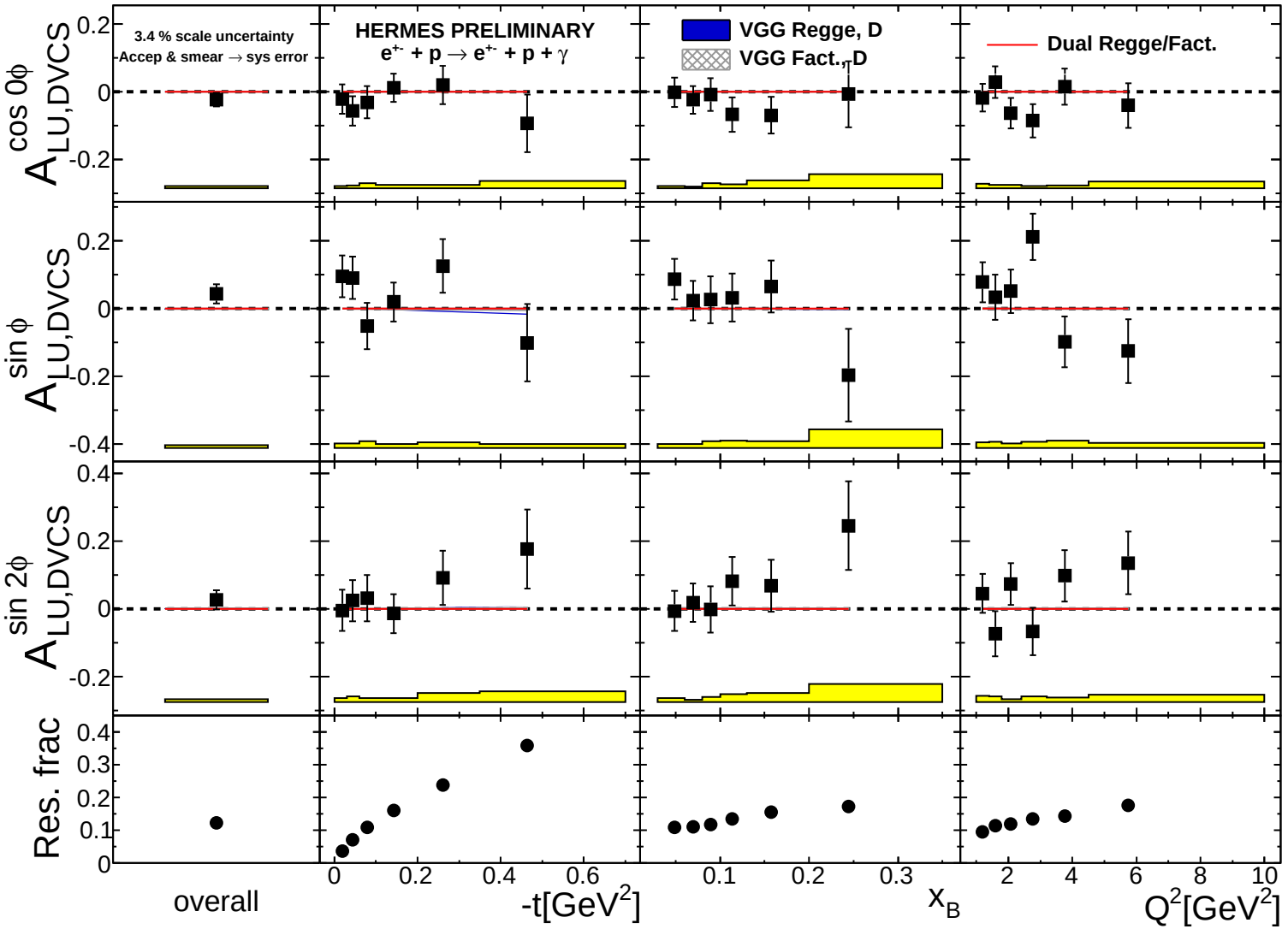
$\Leftarrow$ HIGHER TWIST

$\Leftarrow$ GLUON LEADING TWIST

$\Leftarrow$ RESONANCE FRACTION

- $\cos\phi$ AMPLITUDE OF THE **BCA** $\Rightarrow$ DISFAVOURS: FACTORIZED ANSATZ IN DUAL MODEL; VGG PREDICTION WITH THE D-TERM.

Beam–Spin Asymmetry on Hydrogen



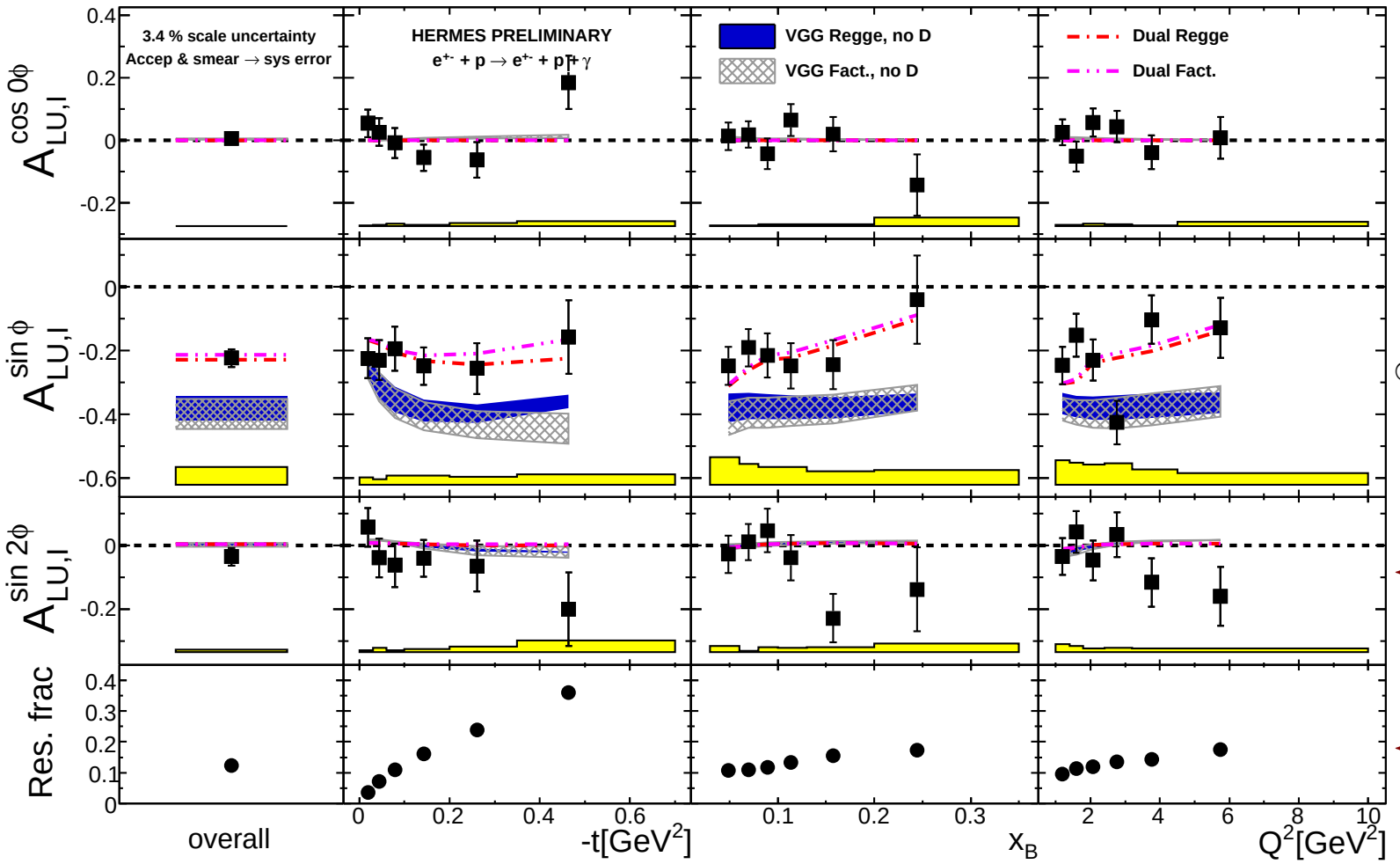
$\propto [\mathcal{H}\mathcal{H}^* + \widetilde{\mathcal{H}}\widetilde{\mathcal{H}}^*]$

$\Leftarrow$ HIGHER TWIST

$\Leftarrow$ RESONANCE FRACTION

• ASYMMETRY AMPLITUDES FOR PURE **DVCS squared term** $\Rightarrow$ COMPATIBLE WITH ZERO IN AGREEMENT WITH MODEL PREDICTIONS.

Beam–Spin Asymmetry on Hydrogen



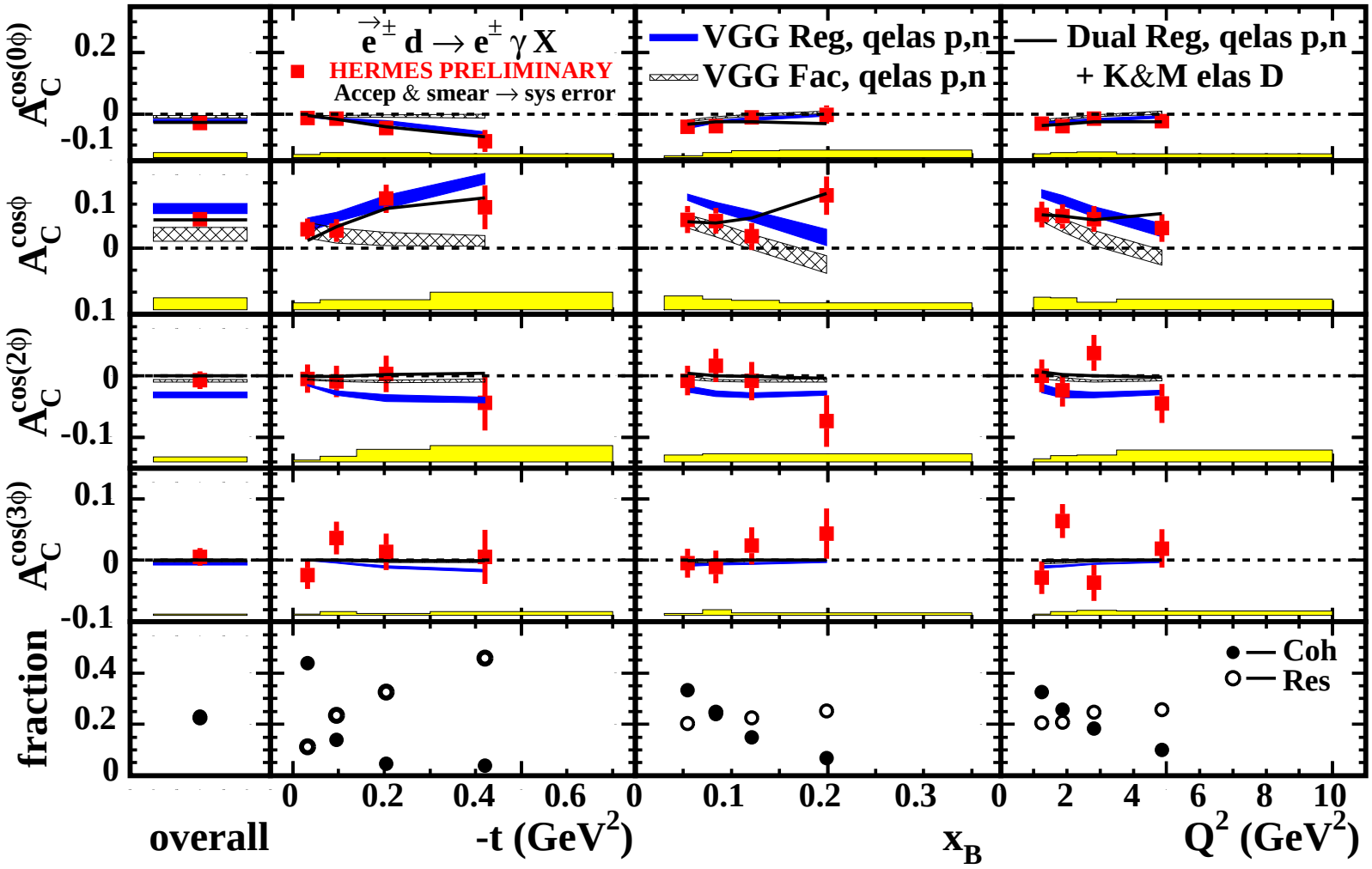
$\propto \mathrm{Im}\,[F_1\mathcal{H}]$

⇐ HIGHER TWIST

⇐ RESONANCE FRACTION

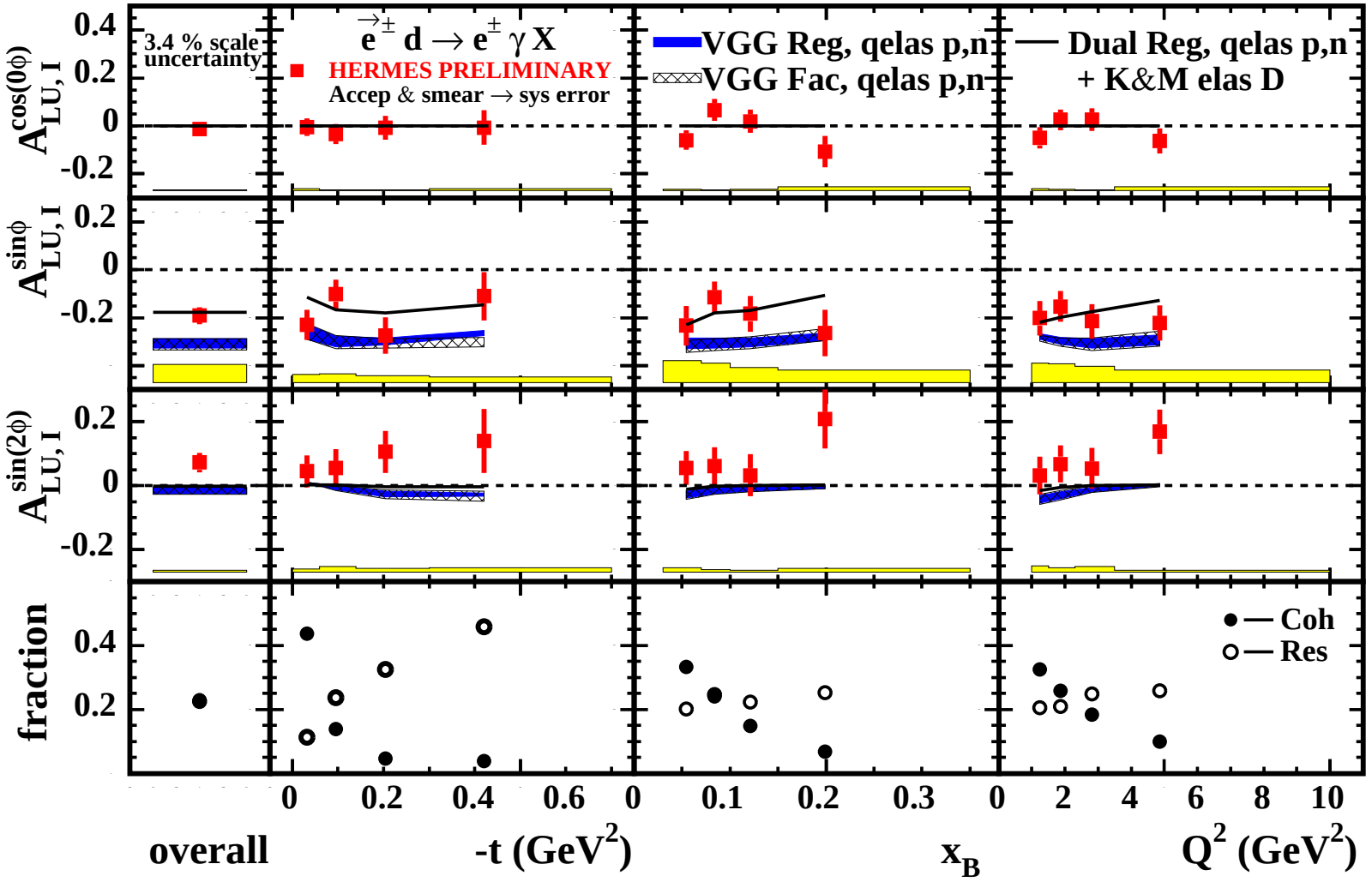
- **BSA** AMPLITUDES ⇒ AGREEMENT WITH DUAL MODEL PREDICTIONS;
- RESULTS: NOT CORRECTED FOR FRACTIONS OF ASSOCIATED BH PROCESS.
- VGG MODEL CLEARLY UNDERSHOOTS **BSA** RESULTS.

Beam–Charge Asymmetry on Deuterium



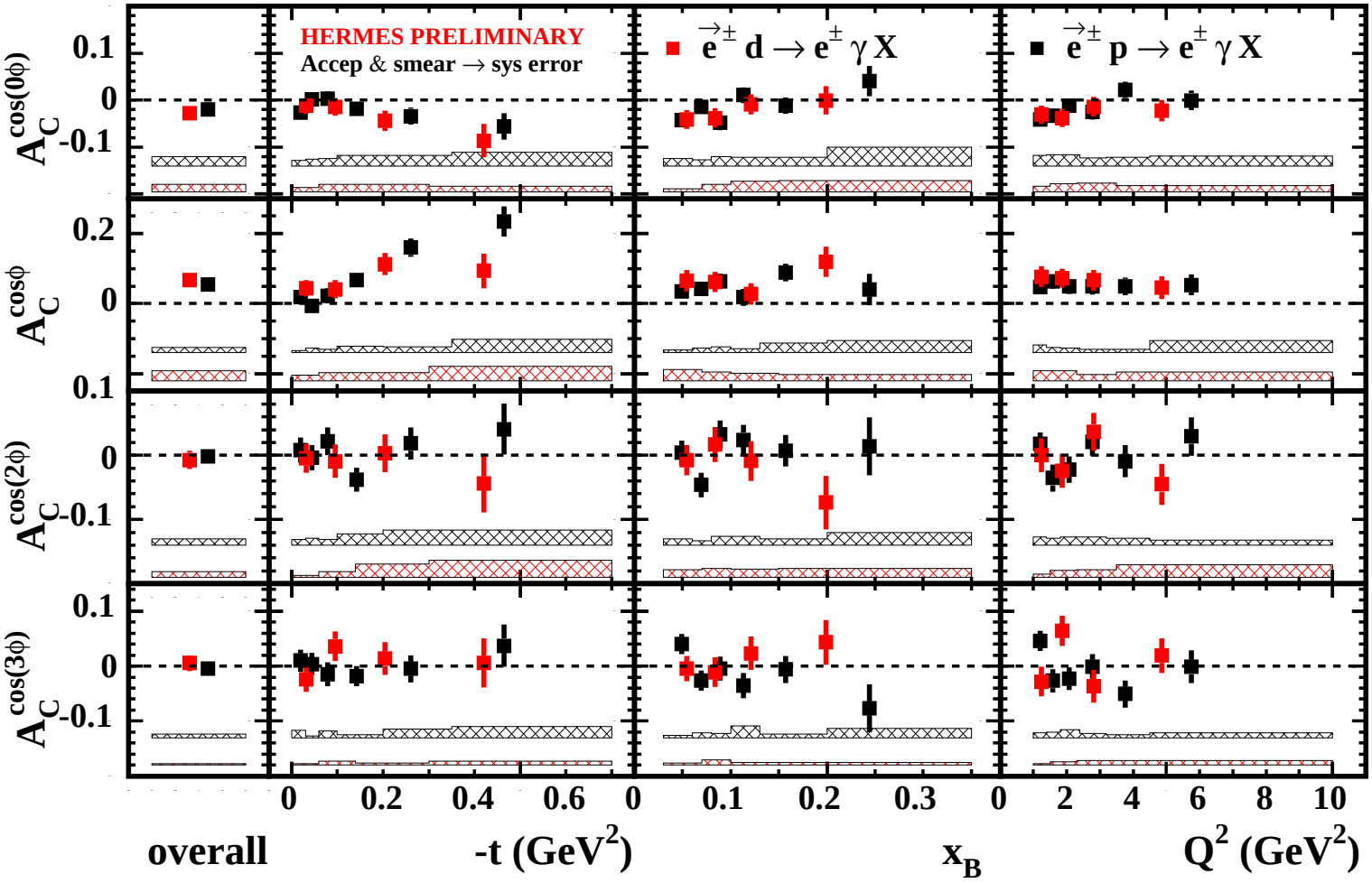
• **BCA** AMPLITUDES ⇒ AGREE WITH PREDICTIONS BASED ON DUAL MODEL (*qelas* SCATTERING ON PROTON AND NEUTRON) PLUS *coherent* SCATTERING ON DEUTERON (*A. Kirchner and D. Müller hep − ph/0202279*).

Beam–Spin Asymmetry on Deuterium



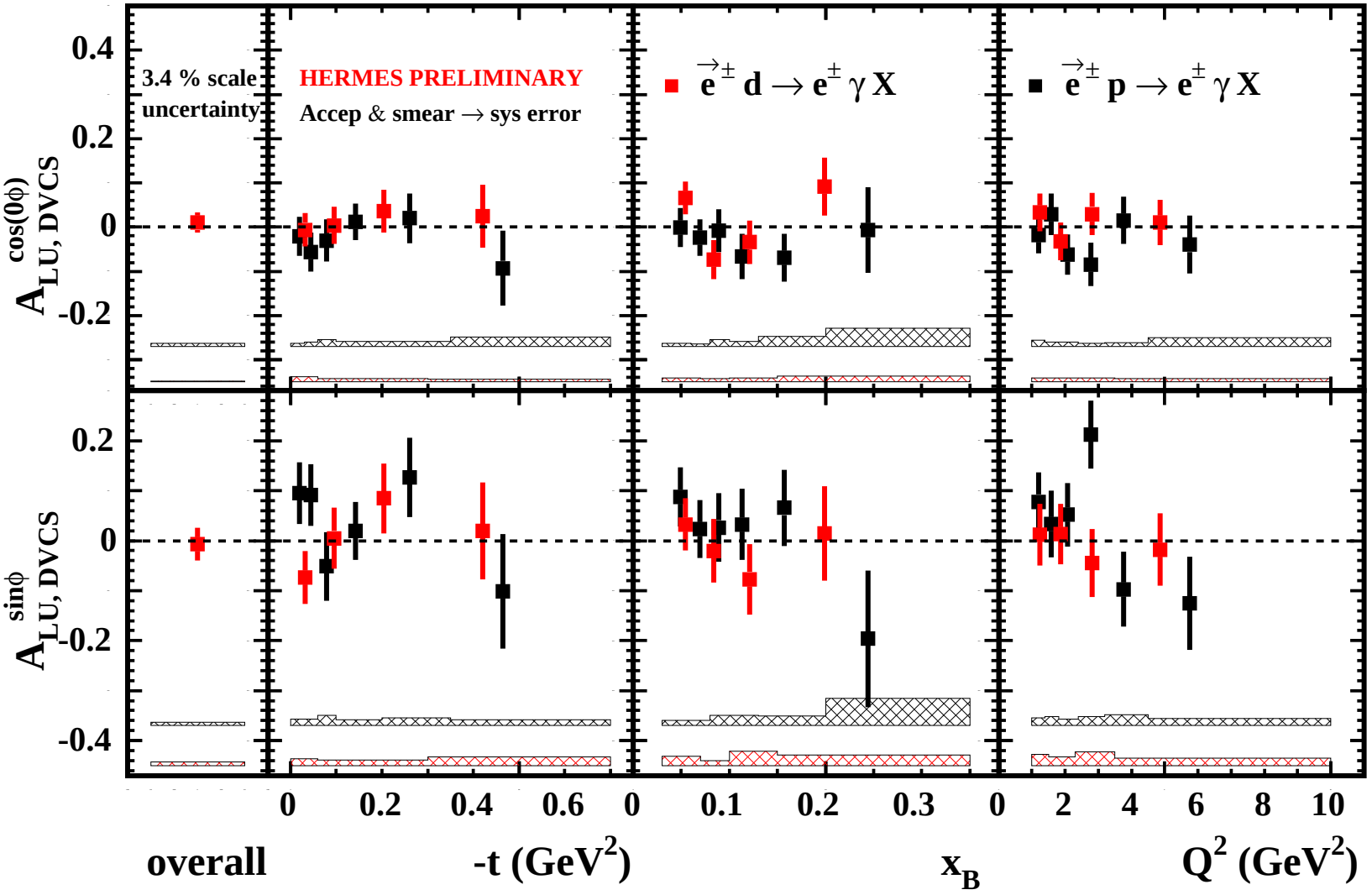
- The $sin\phi$ amplitude of **BSA** ⇒ significantly negative;
- Results ⇒ agree with Dual model predictions over the whole kinematic range.

Beam–Charge Asymmetry: Hydrogen vs. Deuterium



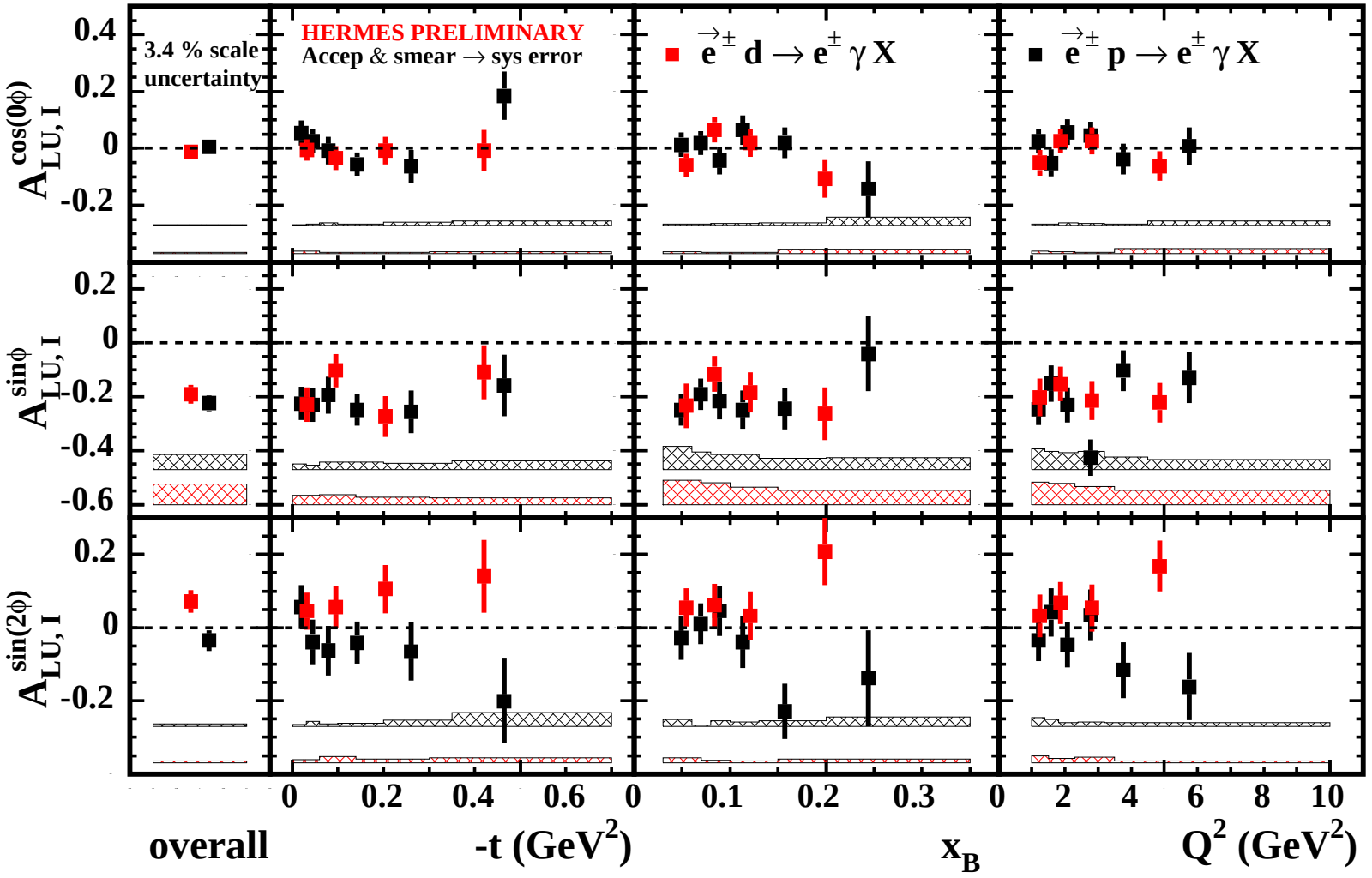
- Proton and Deuteron results ⇒ compatible in low ($-t < 0.06\ GeV^2$; 40 % coherent) and "intermediate" $-t$ regions;
- Difference in last bin ⇒ neutron, resonances ?

Beam–Spin Asymmetry: Hydrogen vs. Deuterium



- **BSA** *sinϕ* AMPLITUDE OF THE $|DVCS|^2$ **term** FOR THE PROTON AND DEUTERON ⇒ COMPATIBLE WITH ZERO.

Beam–Spin Asymmetry: Hydrogen vs. Deuterium



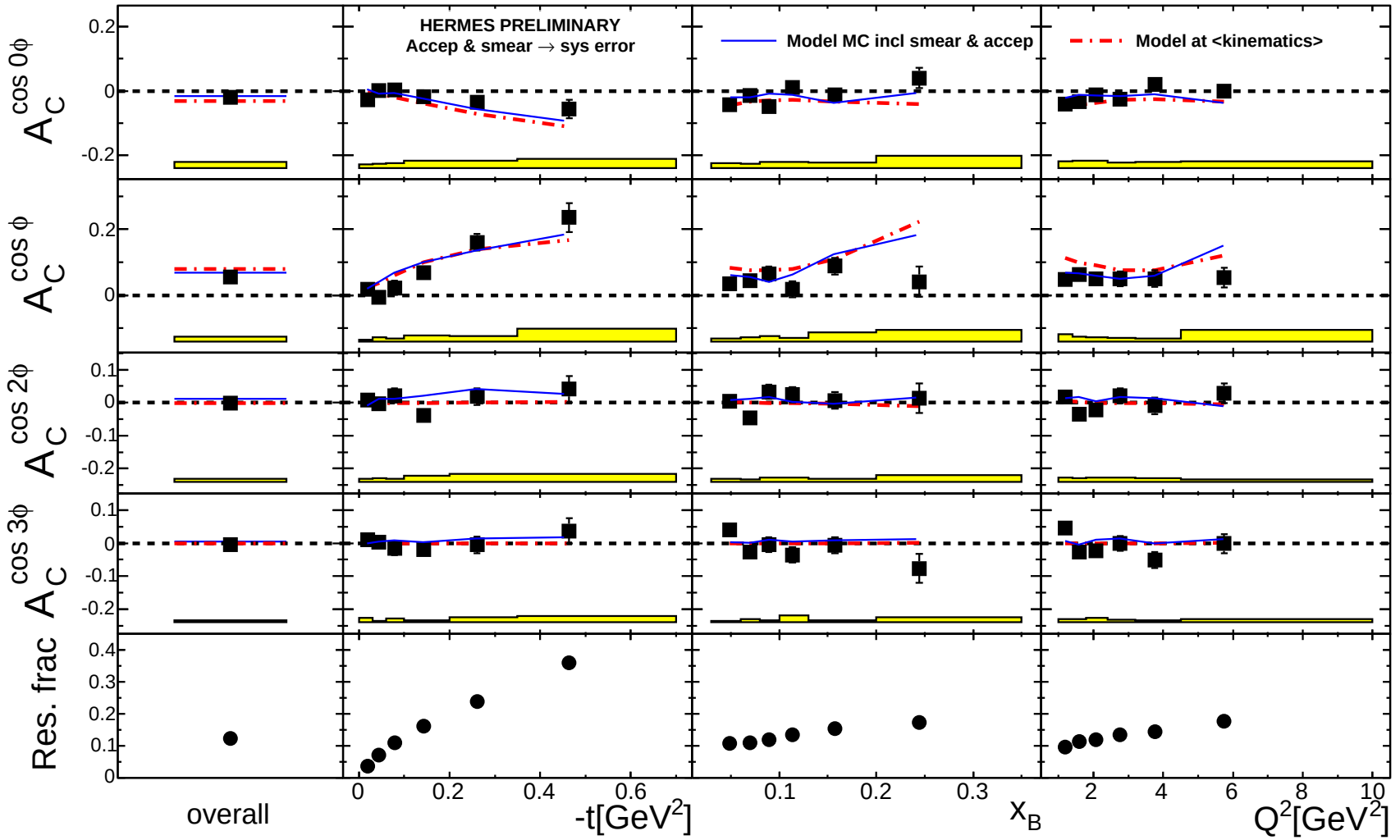
- H_2 AND D_2 DATA ARE COMPATIBLE FOR ALMOST ALL AMPLITUDES;
- **BSA** $sin\phi$ AMPLITUDE FROM THE **Interference term** $\Rightarrow$ SIGNIFICANTLY NEGATIVE FOR BOTH TARGETS.

Summary and Outlook

- Azimuthal Asymmetries ⇒ DVCS-Amplitudes ⇒ GPDs
- The azimuthal asymmetries are measured at HERMES with respect to beam spin (**BSA**) and charge (**BCA**) in combined analysis on proton and deuteron targets.
- The statistical precision allows for strong constraints on GPD models.
- The extracted **BCA** amplitudes on both proton and deuteron targets clearly disfavour **all model** predictions with factorized t-ansatz and **VGG** model with inclusion of the D-term.
- The results on different targets agree very well for all leading twist amplitudes. The associated production needs to be accounted for in **BSA** for both targets.
- High-statistic data collected in 2006/2007 with the Recoil detector at HERMES ⇒ associated process with the unknown asymmetry can be separated from the signal.

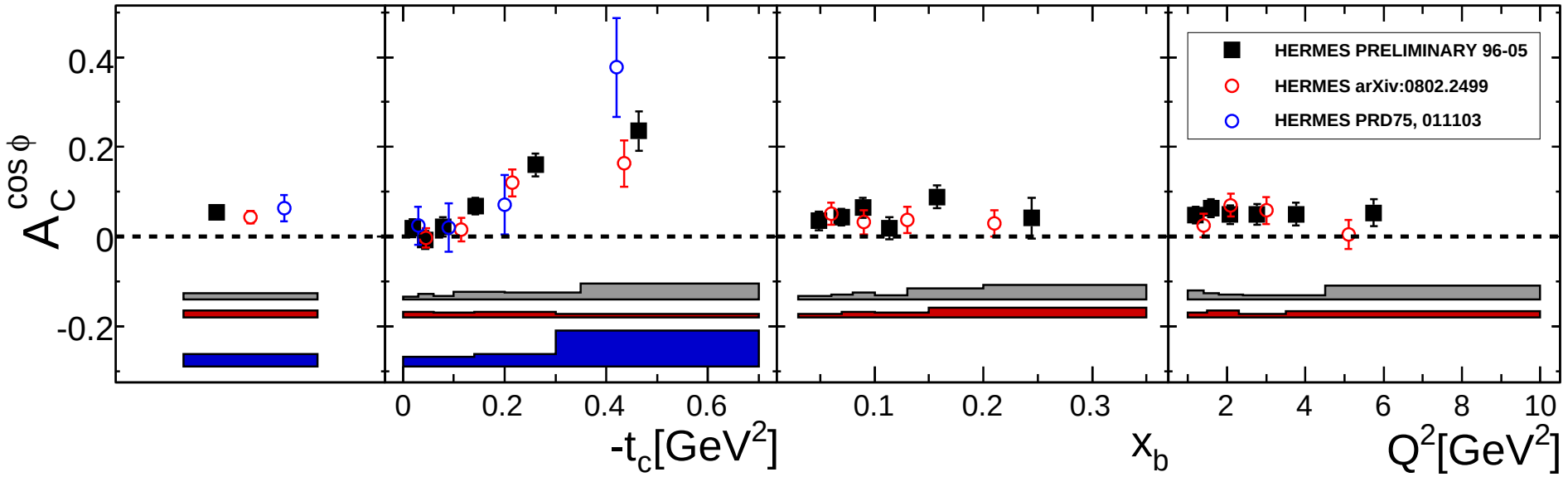
Backup slides!

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.

Beam charge asymmetries



Changes in the new analysis

- 2.5 times higher statistics than in the previous publications.
- 6 bins in all kinematics.
- The systematic errors include new model-dependent studies.

- Results: $\Rightarrow$ agree with former publications.