Review of DVCS results at HERMES

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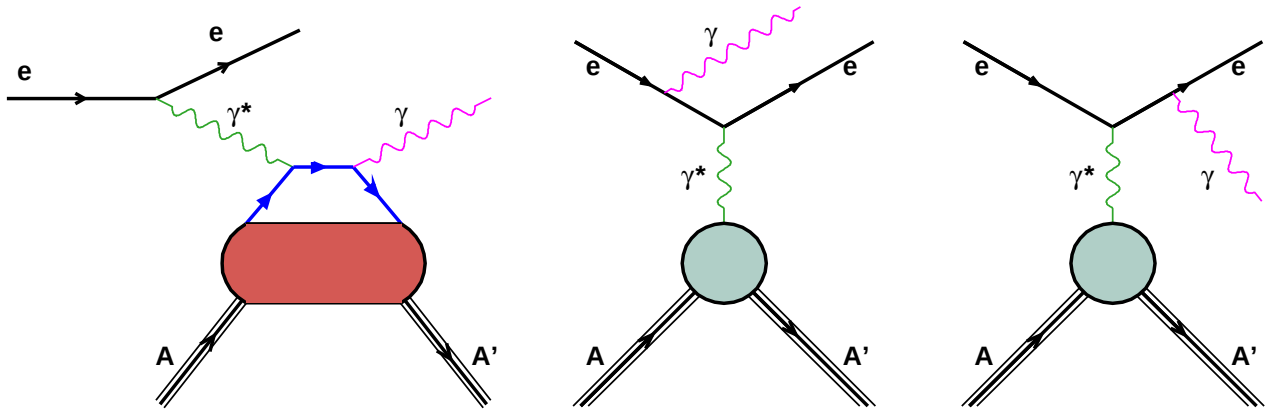
DIS 2010, Florence, Italy, April 19-23, 2010

- DVCS as a Tool to Access GPDs
- DVCS Measurement at HERMES
- Results from Unpolarized (Longitudinally Polarized) H and D Targets
- Exclusivity at HERMES: Recoil Detector

Deeply Virtual Compton Scattering

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



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

$\mathcal{T}_{\rm BH}$: Calculable in QED (using electromagnetic Form factors)
$\mathcal{T}_{\rm DVCS}$: **Compton Form Factors** $\Rightarrow$ convolutions of **GPDs**
GPDs indirectly accessible through azimuthal asymmetries via I

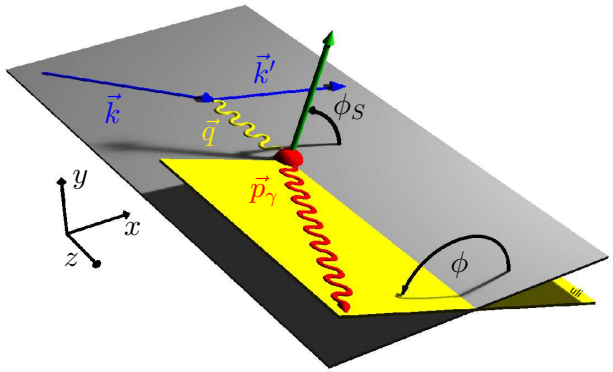
- Spin-1/2 targets described by:
  $F_1, F_2; \mathcal{H}, \mathcal{E}, \widetilde{\mathcal{H}}, \widetilde{\mathcal{E}}$
- Spin-1 targets described by:
  $G_1, G_2, G_3; \mathcal{H}_1, \mathcal{H}_2, \mathcal{H}_3, \mathcal{H}_4, \mathcal{H}_5, \widetilde{\mathcal{H}}_1, \widetilde{\mathcal{H}}_2, \widetilde{\mathcal{H}}_3, \widetilde{\mathcal{H}}_4$

Azimuthal dependences in DVCS

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

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

$$\mathrm{I} = -\frac{e_\ell K_{\rm I}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left\{ \sum_{n=0}^{3} c_n^{\rm I} \cos(n\phi) + \sum_{n=1}^{3} s_n^{\rm I} \sin(n\phi) \right\}$$



Longitudinally polarized targets:

$$\left.\begin{aligned} c_n &= c_{n,\rm unp} + \lambda\Lambda c_{n,\rm LP} \\ s_n &= \lambda s_{n,\rm unp} + \Lambda s_{n,\rm LP} \end{aligned}\right\} \text{Spin} - 1/2$$

λ - Beam helicity

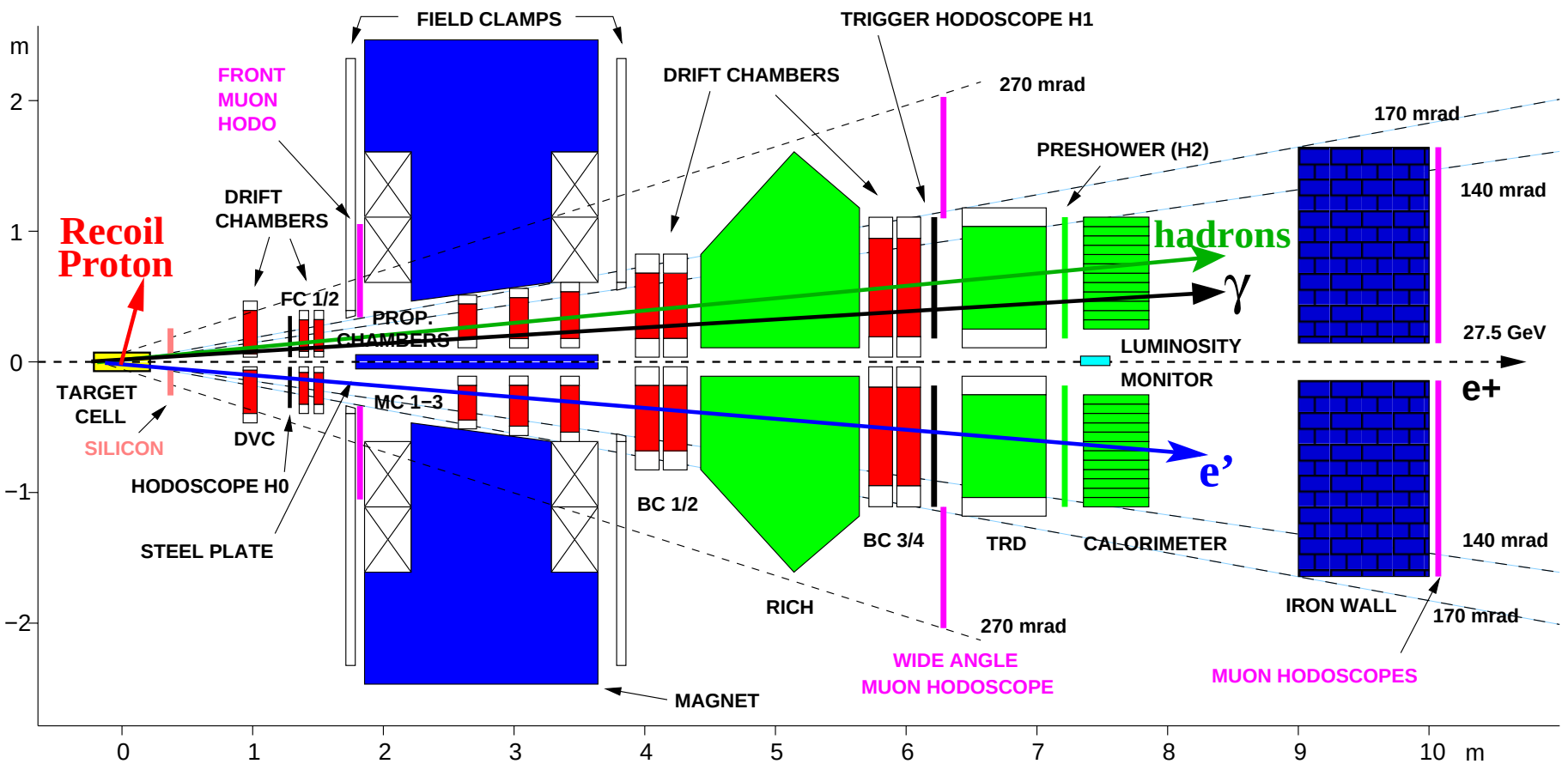
Λ - Target spin projection

$$\left.\begin{aligned} c_n &= \tfrac{3}{2}\Lambda^2 c_{n,\rm unp} + \lambda\Lambda c_{n,\rm LP} + (1 - \tfrac{3}{2}\Lambda^2) c_{n,\rm LLP} \\ s_n &= \tfrac{3}{2}\lambda\Lambda^2 s_{n,\rm unp} + \Lambda s_{n,\rm LP} + (1 - \tfrac{3}{2}\Lambda^2) s_{n,\rm LLP} \end{aligned}\right\} \text{Spin} - 1$$

Transversely polarized target:

$$\left.\begin{aligned} c_n &= c_{n,\rm unp} + \Lambda c_{n,\rm UT} \sin(\phi - \phi_s) \\ s_n &= \Lambda s_{n,\rm UT} \cos(\phi - \phi_s) \end{aligned}\right\} \text{Spin} - 1/2, \text{“unpolarized” beam}$$

The HERMES Experiment



Gas Target:

- Long. polarized H, D
- Unpolarized H, D, He, N, Ne, Kr, Xe
- Transversely polarized H

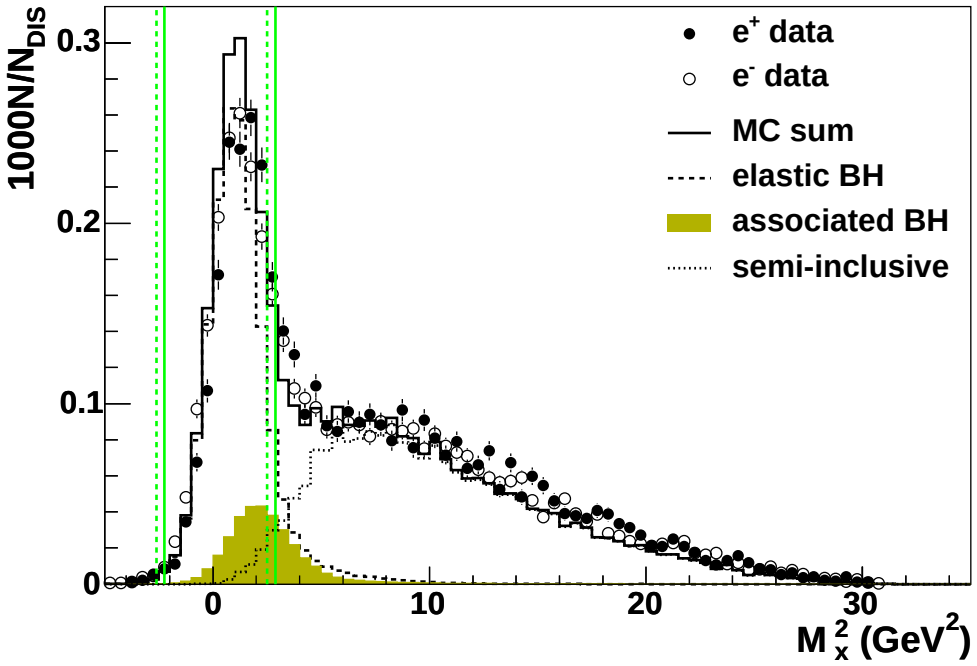
Beam:

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

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: $M_X^2 = (q + P - q')^2$

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



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

Azimuthal asymmetries in DVCS off unpolarized targets

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

Charge-difference beam-helicity asymmetry:

$$A^I_{LU}(\phi) \equiv \frac{(\sigma^{+\rightarrow} - \sigma^{+\leftarrow}) - (\sigma^{-\rightarrow} - \sigma^{-\leftarrow})}{(\sigma^{+\rightarrow} + \sigma^{+\leftarrow}) + (\sigma^{-\rightarrow} + \sigma^{-\leftarrow})} = -\frac{1}{\mathcal{D}(\phi)} \cdot \frac{x_B}{y} \sum_{n=1}^{3} s^I_n \sin(n\phi)$$

Charge-averaged beam-helicity asymmetry:

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

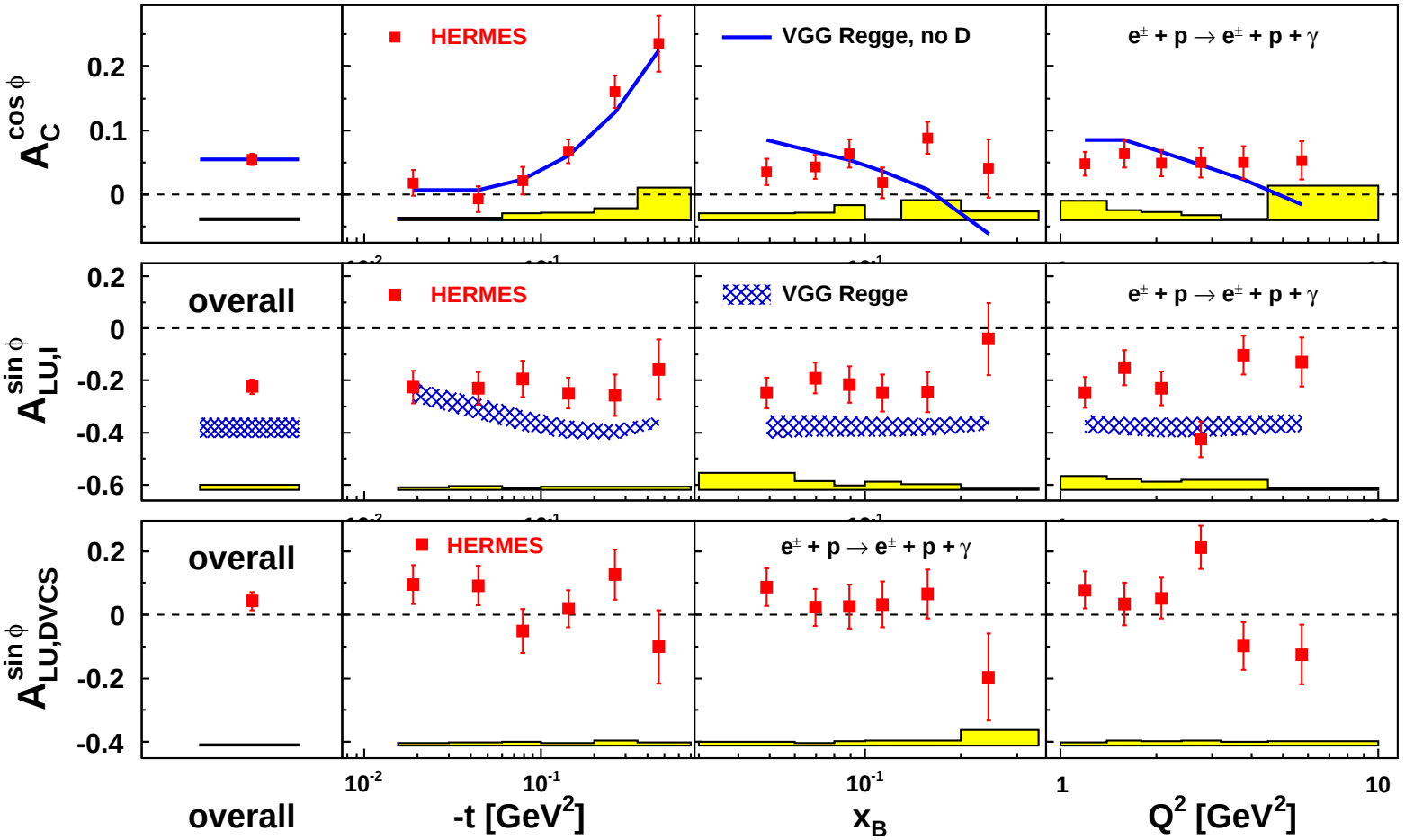
Beam-charge asymmetry:

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

- **Measurements with** BOTH BEAM HELICITY AND BOTH BEAM CHARGES
  $\Rightarrow$ **separate** CONTRIBUTIONS FROM DVCS AND INTERFERENCE TERM
- **This separation is impossible** IN MEASUREMENTS OF SINGLE-CHARGE BEAM-HELICITY ASYMMETRY $A_{LU}(\phi) = (\sigma^{\rightarrow} - \sigma^{\leftarrow})/(\sigma^{\rightarrow} + \sigma^{\leftarrow})$

Beam–Charge and Beam-Helicity Asymmetries on Hydrogen

JHEP 11 (2009) 083



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

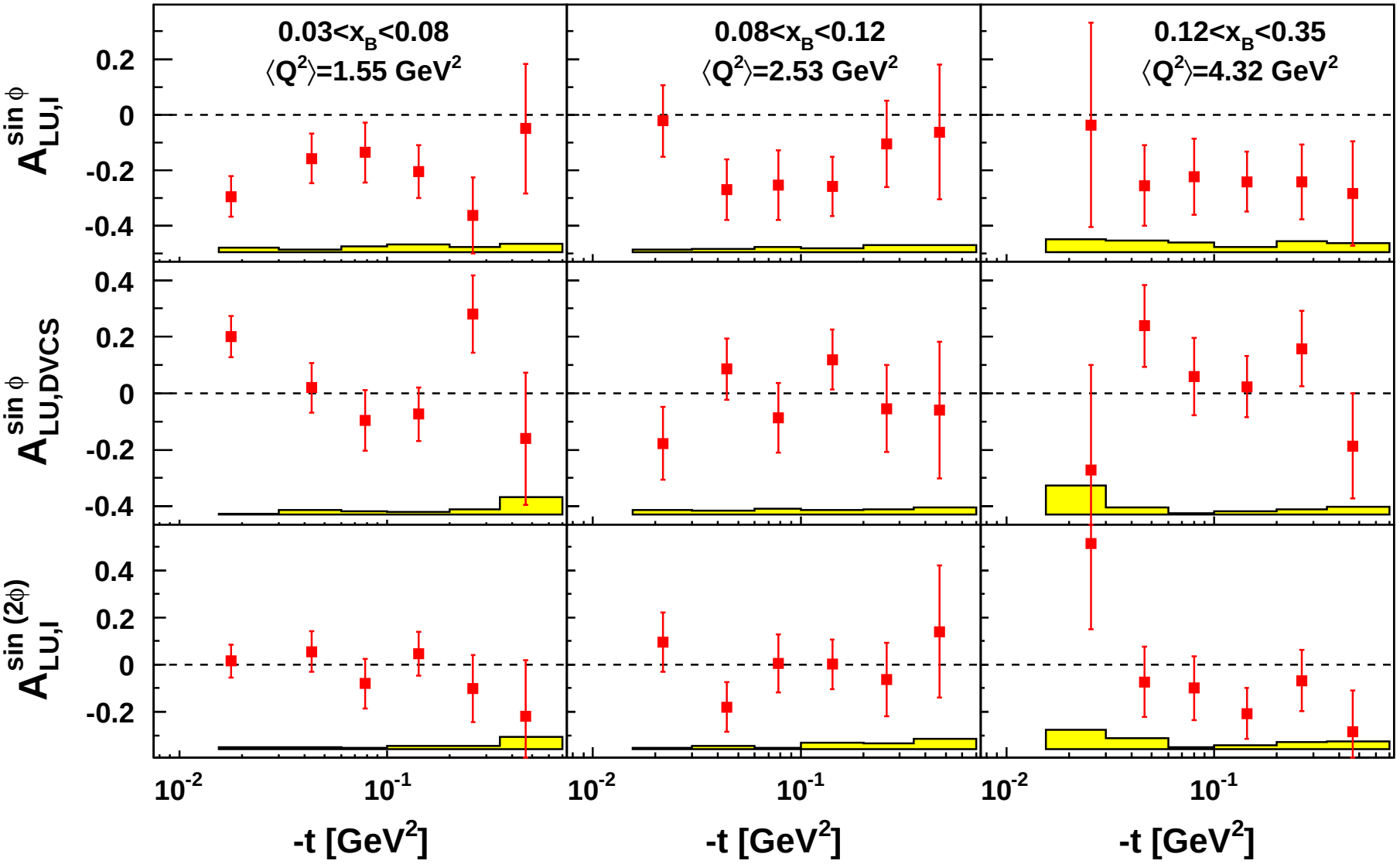
$\propto \Im m\,[F_1\mathcal{H}]$

$\Leftarrow$ HIGHER TWIST

- **GPD** MODEL, (MC CODE VANDERHAEGEN, GUICHON, GUIDAL)
  Phys. Rev. D60 (1999) 094017, Prog. Part. Nucl. Phys. 47 (2001) 401
- **Resonance fraction**: OVERALL $\approx 12\%$, HIGHEST $-t$ BIN $\approx 40\%$

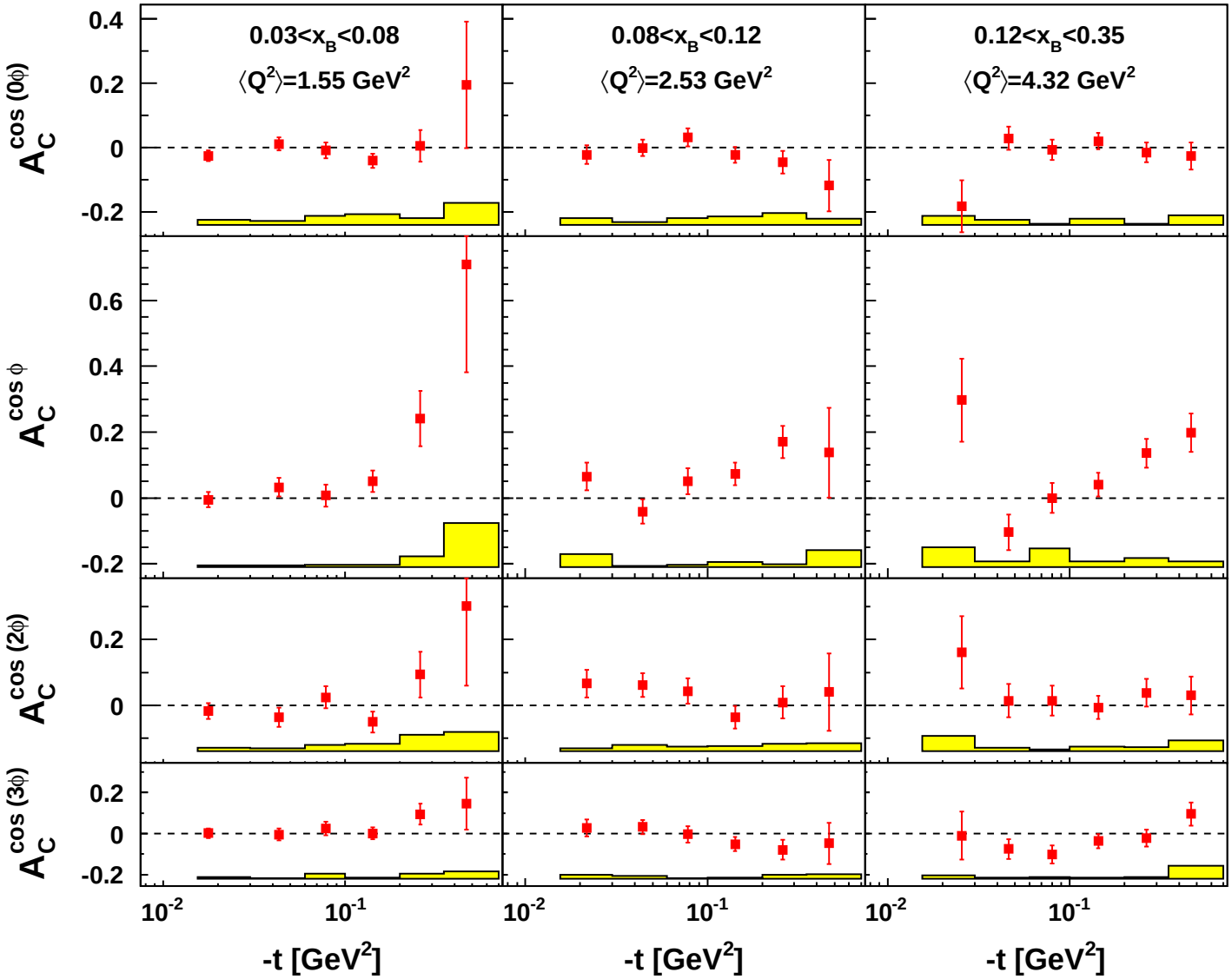
Beam–Helicity Asymmetries: Hydrogen, 2D binning

JHEP 11 (2009) 083

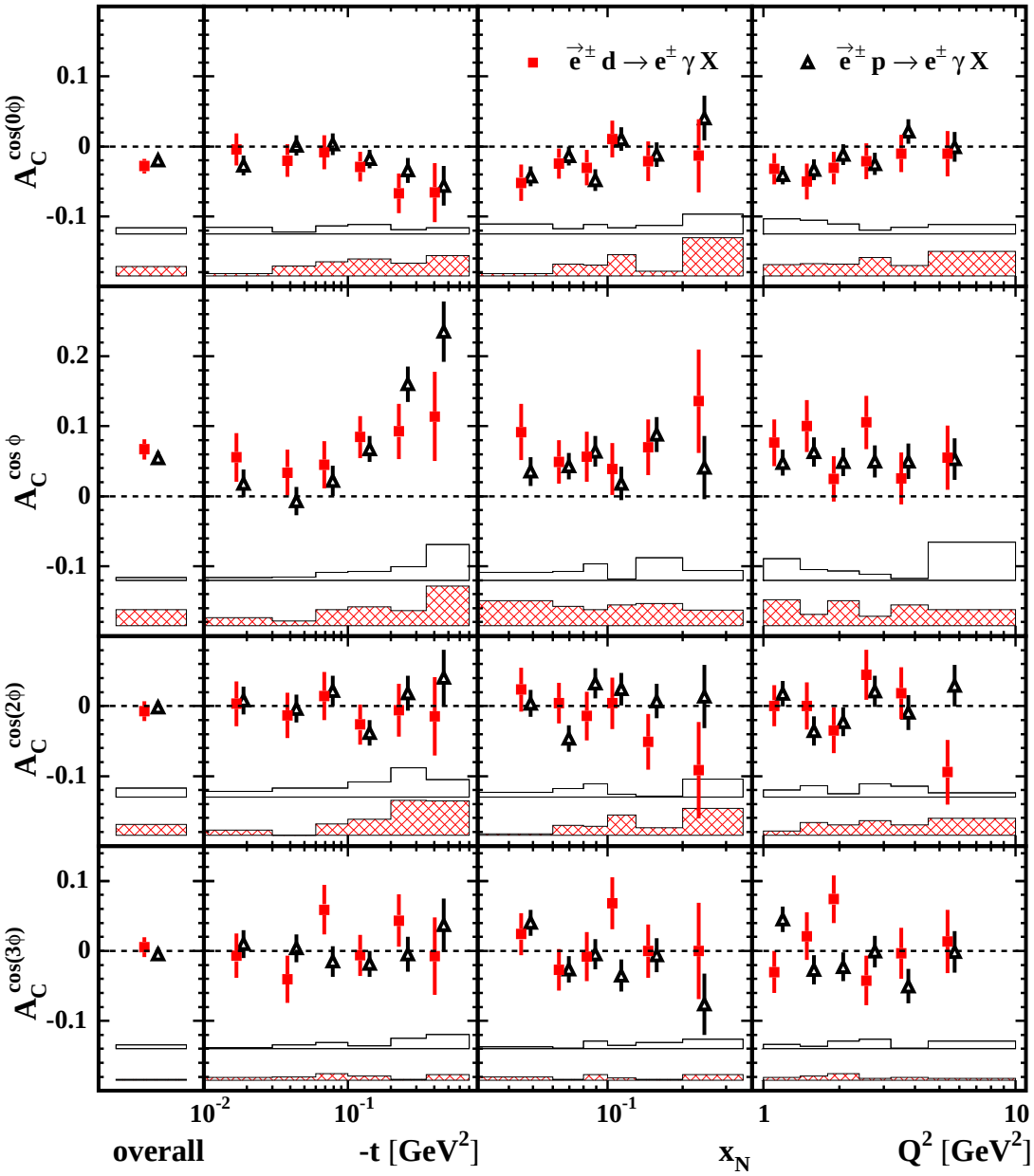


Beam–Charge Asymmetry: Hydrogen, 2D binning

JHEP 11 (2009) 083



Beam–Charge Asymmetry A_C: Hydrogen vs. Deuterium



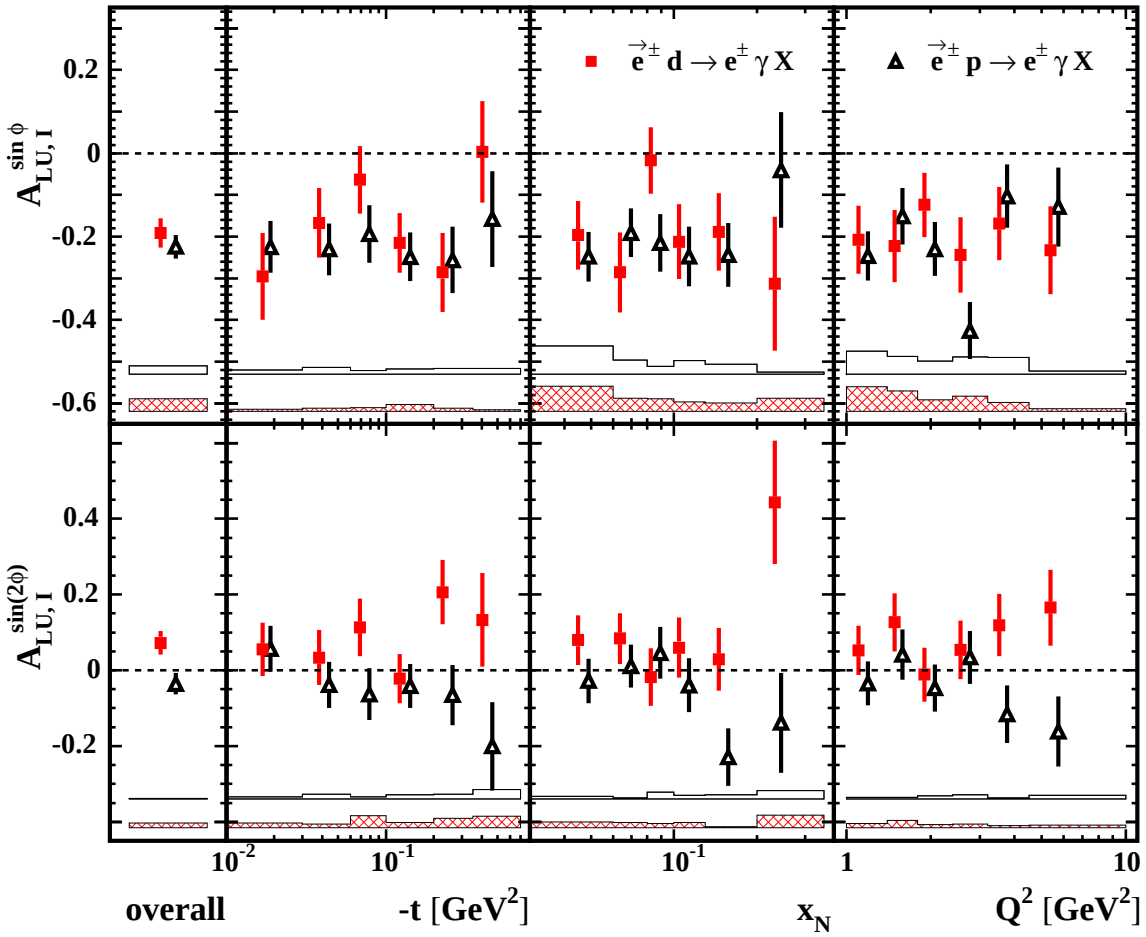
Nucl. Phys. B 829 (2010) 1

- PROTON AND DEUTERON RESULTS $\Rightarrow$ COMPATIBLE IN LOW ($-t < 0.06\ GeV^2$; ≈ 40 % COHERENT) AND "INTERMEDIATE" $-t$ REGIONS;

- **Possible difference** IN LAST TWO $-t$ BINS $\Rightarrow$ NEUTRON, RESONANCES ?

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

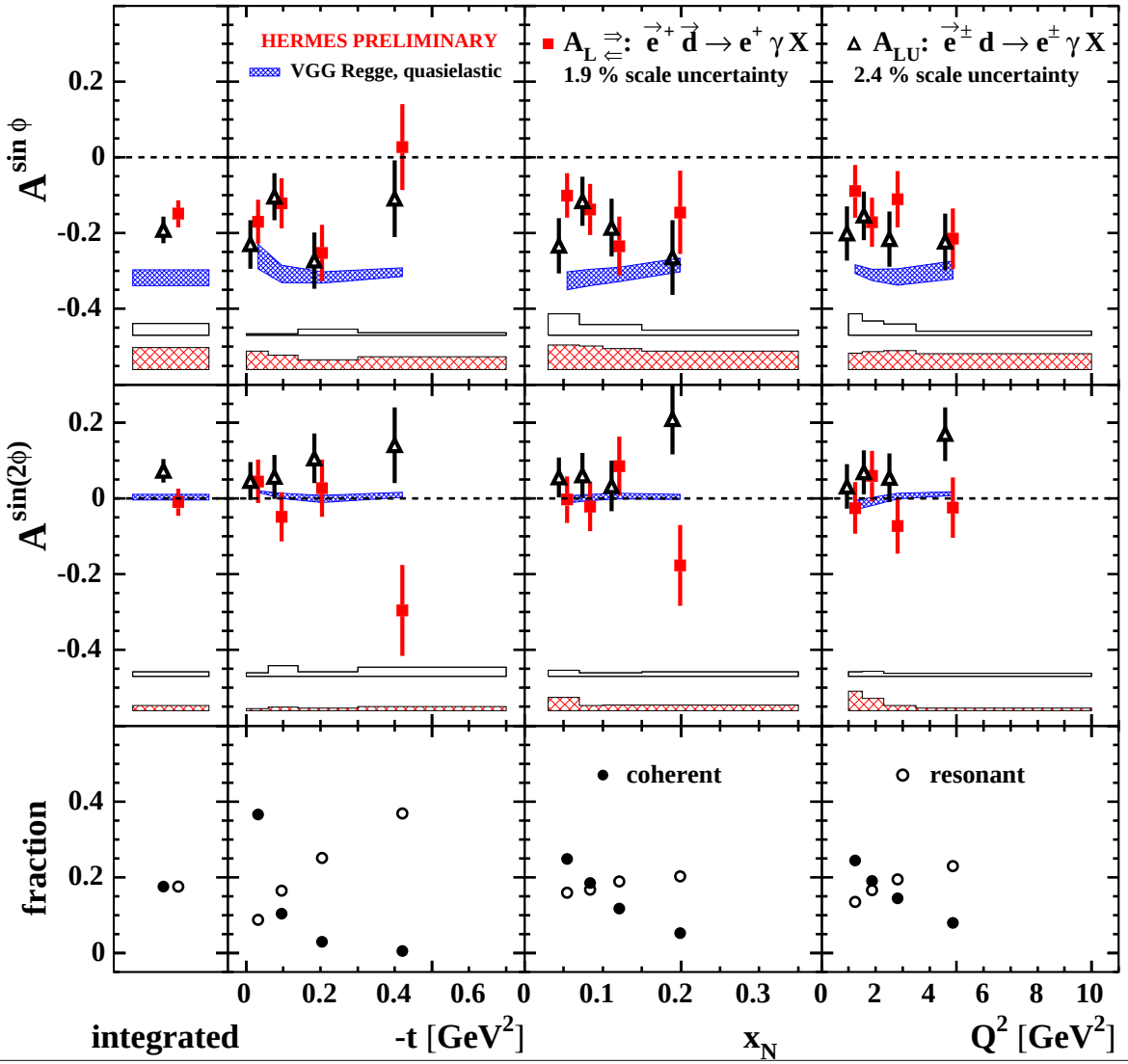
Nucl. Phys. B 829 (2010) 1



- Proton and Deuteron data: compatible for leading amplitudes;
- $A_{LU,I}^{\sin\phi}$ amplitude (from the **Interference term**) $\Rightarrow$ significantly negative for both targets.

Beam–Helicity Asymmetry: Longitudinally polarized Deuteron

$$\mathcal{A}_{\mathrm{L}\overleftarrow{\Rightarrow}}(\phi) = \frac{(\sigma^{\overrightarrow{\Rightarrow}} + \sigma^{\overrightarrow{\Leftarrow}}) - (\sigma^{\overleftarrow{\Rightarrow}} + \sigma^{\overleftarrow{\Leftarrow}})}{(\sigma^{\overrightarrow{\Rightarrow}} + \sigma^{\overrightarrow{\Leftarrow}}) + (\sigma^{\overleftarrow{\Rightarrow}} + \sigma^{\overleftarrow{\Leftarrow}})}$$



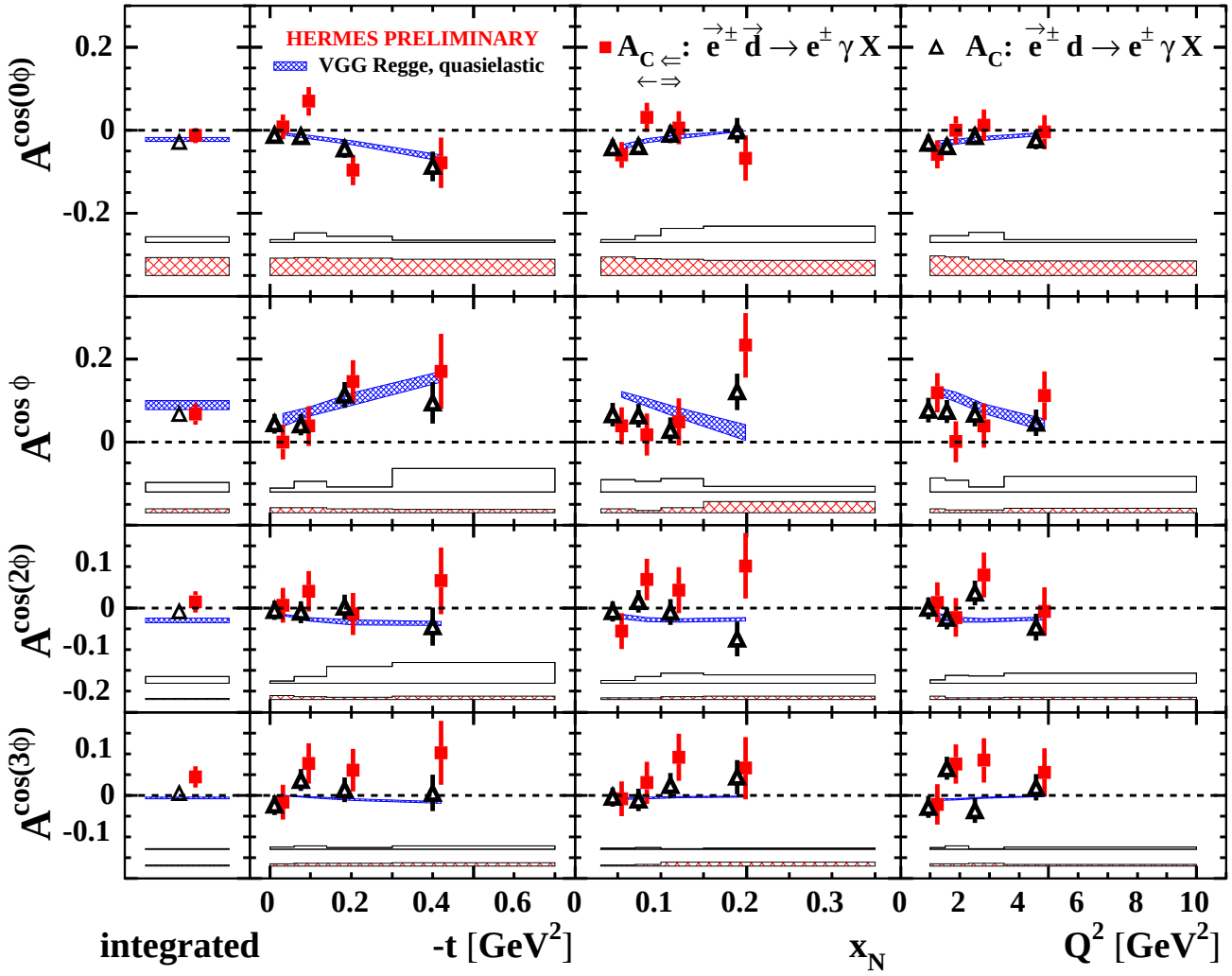
$$\propto \begin{cases} \Im m[G_1\mathcal{H}_1] \\ \Im m[G_1(\mathcal{H}_1 - \frac{1}{3}\mathcal{H}_5)] \end{cases}$$

$\propto$ Higher twist

$\Leftarrow$ Resonance, coherent fractions

Beam–Charge Asymmetry: Longitudinally polarized Deuteron

$$\mathcal{A}_{C\,\overleftarrow{\Leftrightarrow}}(\phi) = \frac{(\sigma^{\overleftarrow{\Rightarrow}+} + \sigma^{\overleftarrow{\Leftarrow}+}) - (\sigma^{\overleftarrow{\Rightarrow}-} + \sigma^{\overleftarrow{\Leftarrow}-})}{(\sigma^{\overleftarrow{\Rightarrow}+} + \sigma^{\overleftarrow{\Leftarrow}+}) + (\sigma^{\overleftarrow{\Rightarrow}-} + \sigma^{\overleftarrow{\Leftarrow}-})}$$



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

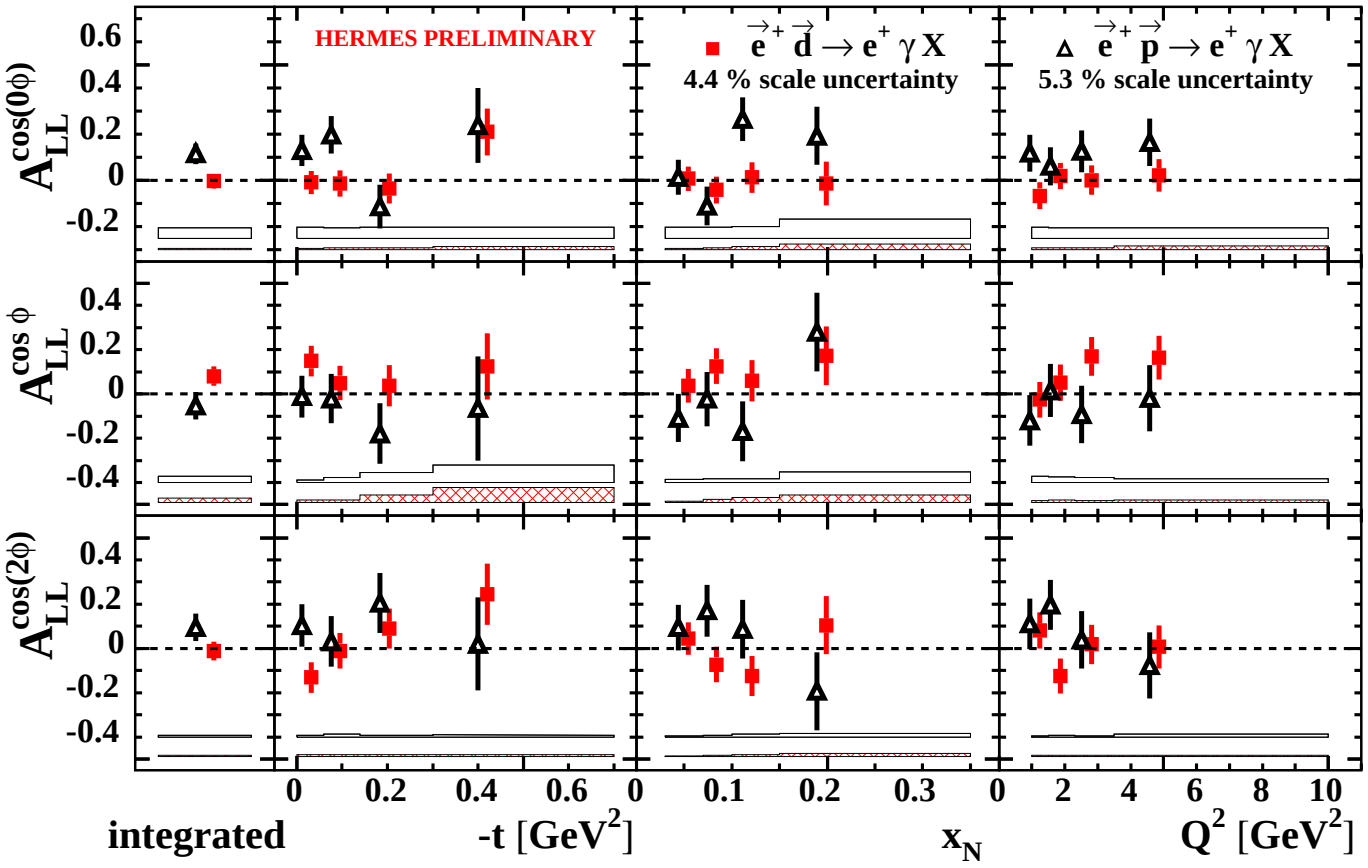
$\propto \begin{cases} \Re e[G_1\mathcal{H}_1] \\ \Re e[G_1(\mathcal{H}_1 - \frac{1}{3}\mathcal{H}_5)] \end{cases}$

$\propto$ Higher twist

$\propto \begin{cases} \text{Gluon} \\ \text{Leading twist} \end{cases}$

Double–Spin Asymmetry A_{LL}: Hydrogen vs. Deuterium

$$\mathcal{A}_{\mathrm{LL}}(\phi) = \frac{(\sigma^{\vec{\Rightarrow}} + \sigma^{\vec{\Leftarrow}}) - (\sigma^{\vec{\Leftarrow}} + \sigma^{\vec{\Rightarrow}})}{(\sigma^{\vec{\Rightarrow}} + \sigma^{\vec{\Leftarrow}}) + (\sigma^{\vec{\Leftarrow}} + \sigma^{\vec{\Rightarrow}})}$$

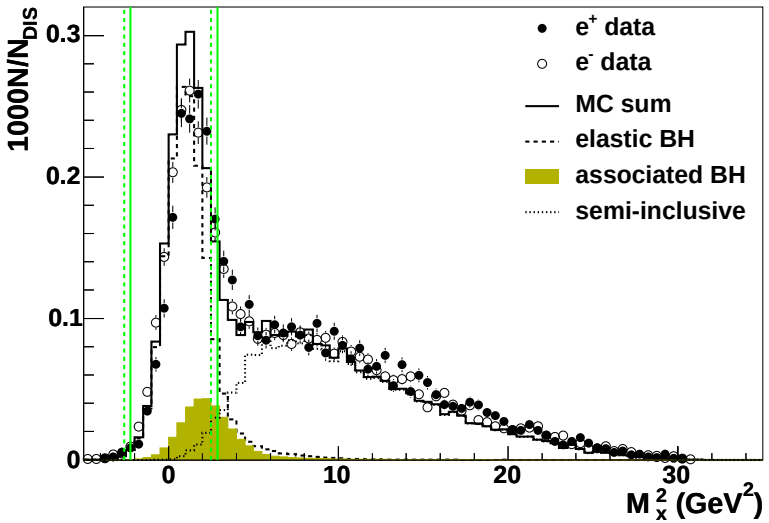


$$\begin{cases} \Im m\,[F_1\widetilde{\mathcal{H}}] \\ \Im m\,[G_1\widetilde{\mathcal{H}}_1] \end{cases}$$

Higher twist

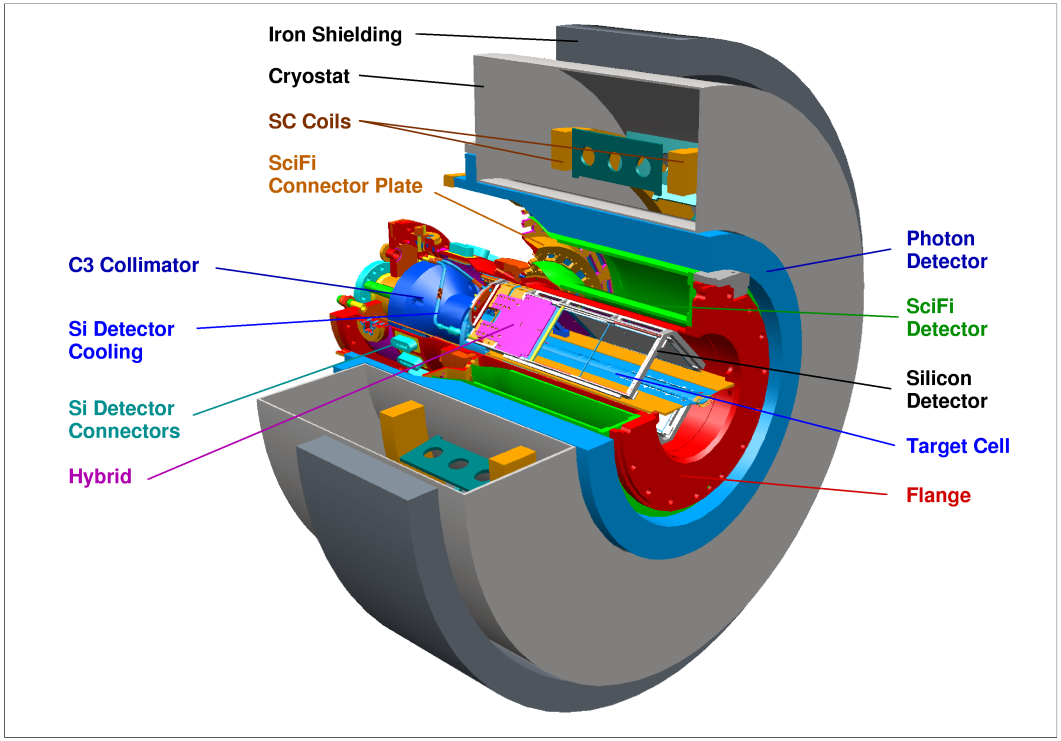
- Asymmetry amplitudes on Proton and Deuteron are compatible;
- no obvious signature of coherent scattering in data

DVCS measurement at HERMES



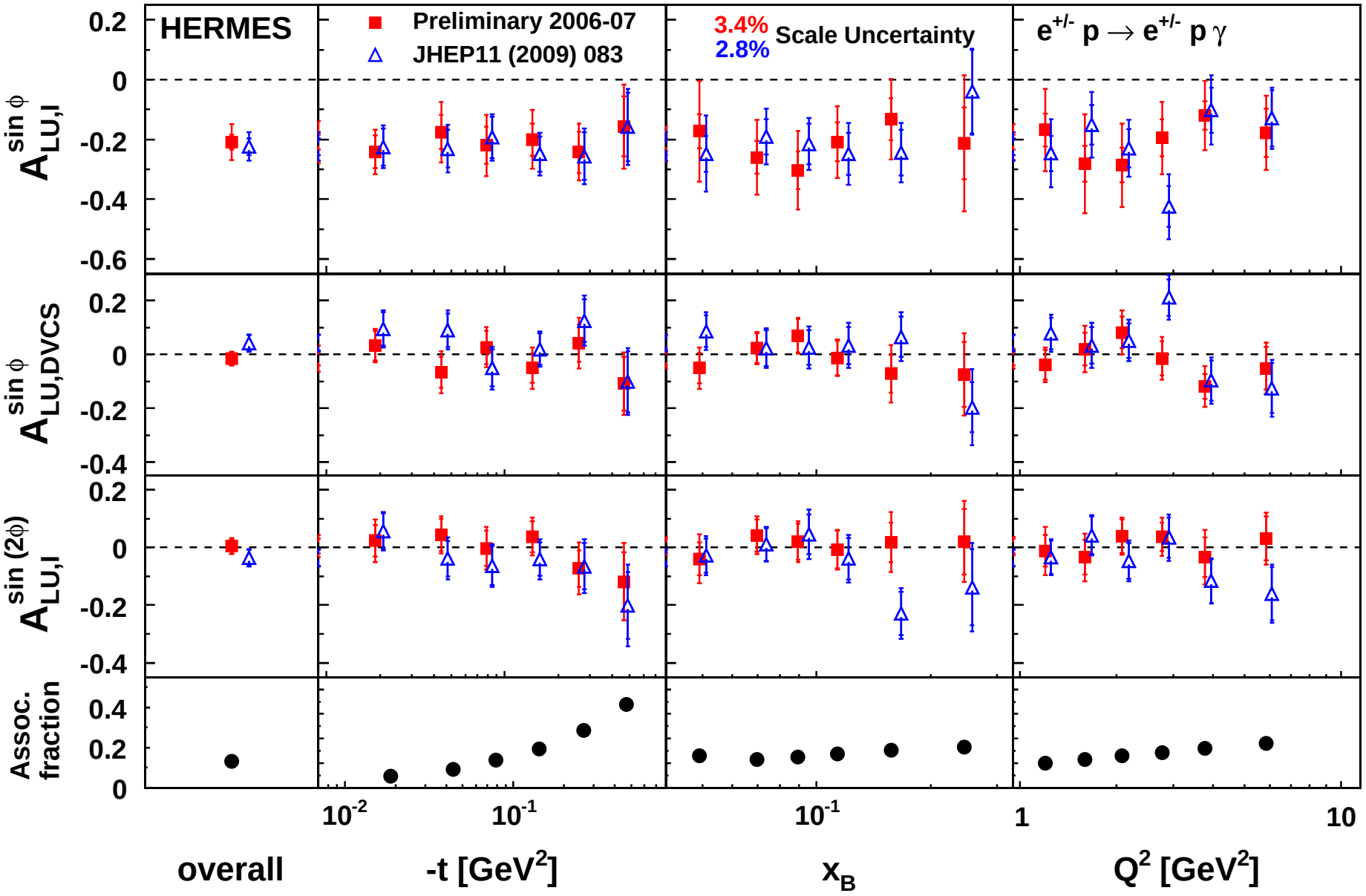
- **Pre-Recoil data (1996-2005)**
  - e' and $\gamma \Rightarrow$ in forward spectrometer
  - Recoil proton $\Rightarrow$ not detected
  - Exclusivity $\Rightarrow$ missing mass technique
  - Associated processes $\Rightarrow$ not resolved

- **Recoil data (2006-2007)**
  - Recoil proton detection
  - Background suppression to $< 1\%$ level

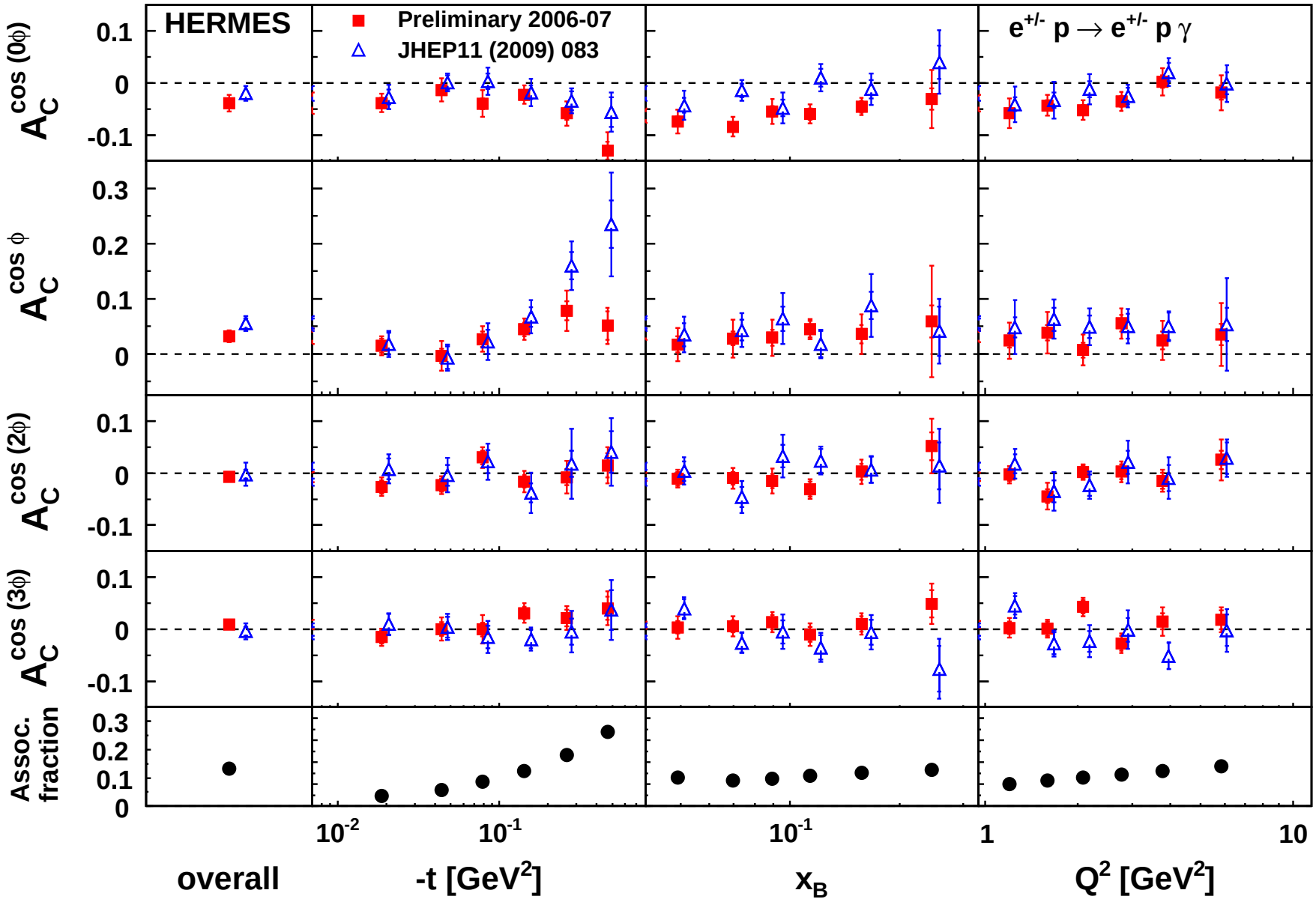


see talk by:
Alberto de la Ossa

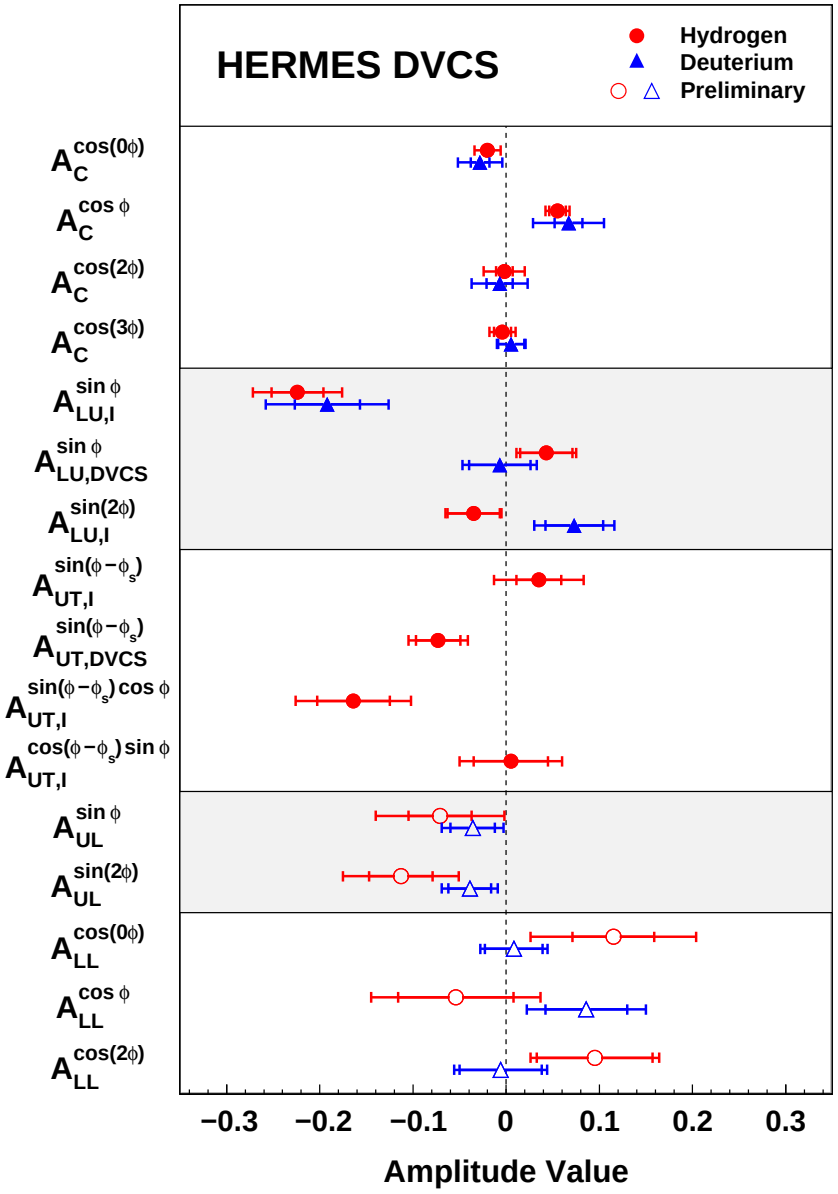
Beam–Helicity Asymmetry: Hydrogen, New (2006-2007)



Beam–Charge Asymmetry: Hydrogen, New (2006-2007)



Summary and Outlook



- JHEP 06 (2008) 066, JHEP 11 (2009) 083
- ▲ Nucl. Phys. B 829 (2010
- ○ Arxiv:1004.0177(hep-ex)
- △ Hermes preliminary

⇐ **Beam-charge asymmetry:** $\cos(0\phi), \cos\phi$
$\propto \Re e(\mathcal{H}),\ \Re e(\mathcal{H}_1)$

⇐ **Beam-helicity asymmetry:** $\sin\phi$
$\propto \Im m(\mathcal{H}),\ \Im m(\mathcal{H}_1)$

⇐ **Transverse Target-spin asymmetry:**
$\sin(\phi-\phi_s)\cos(n\phi) \propto \Im m(\mathcal{H}-\mathcal{E})$

⇐ **longitudinal Target-spin asymmetry:** $\sin\phi$
$\propto \Im m(\widetilde{\mathcal{H}}),\ \Im m(\widetilde{\mathcal{H}}_1)$

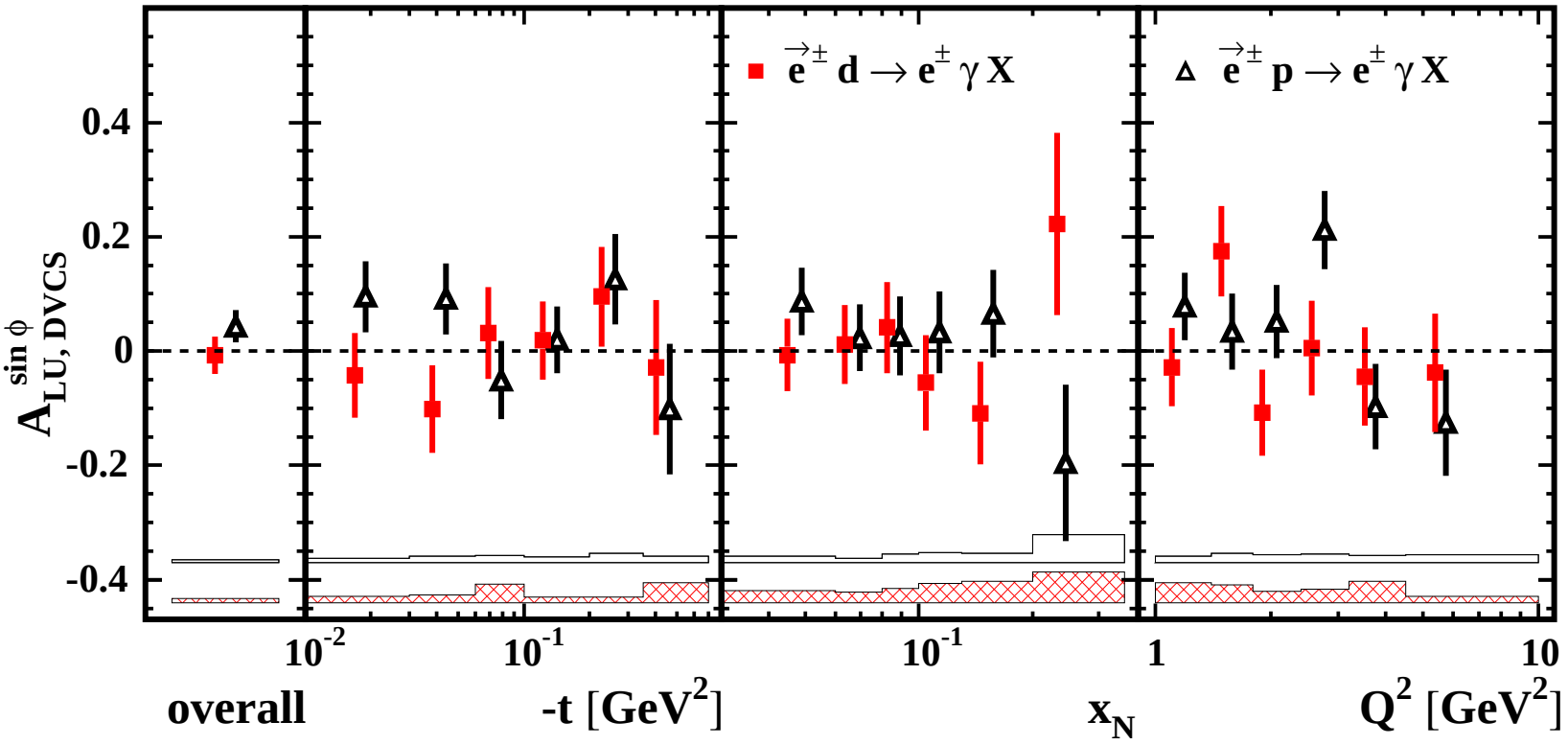
⇐ **Double spin asymmetry:** $\cos(0\phi), \cos\phi$
$\propto \Re e(\widetilde{\mathcal{H}}),\ \Re e(\widetilde{\mathcal{H}}_1)$

DVCS with Recoil: coming soon

Backup slides!

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

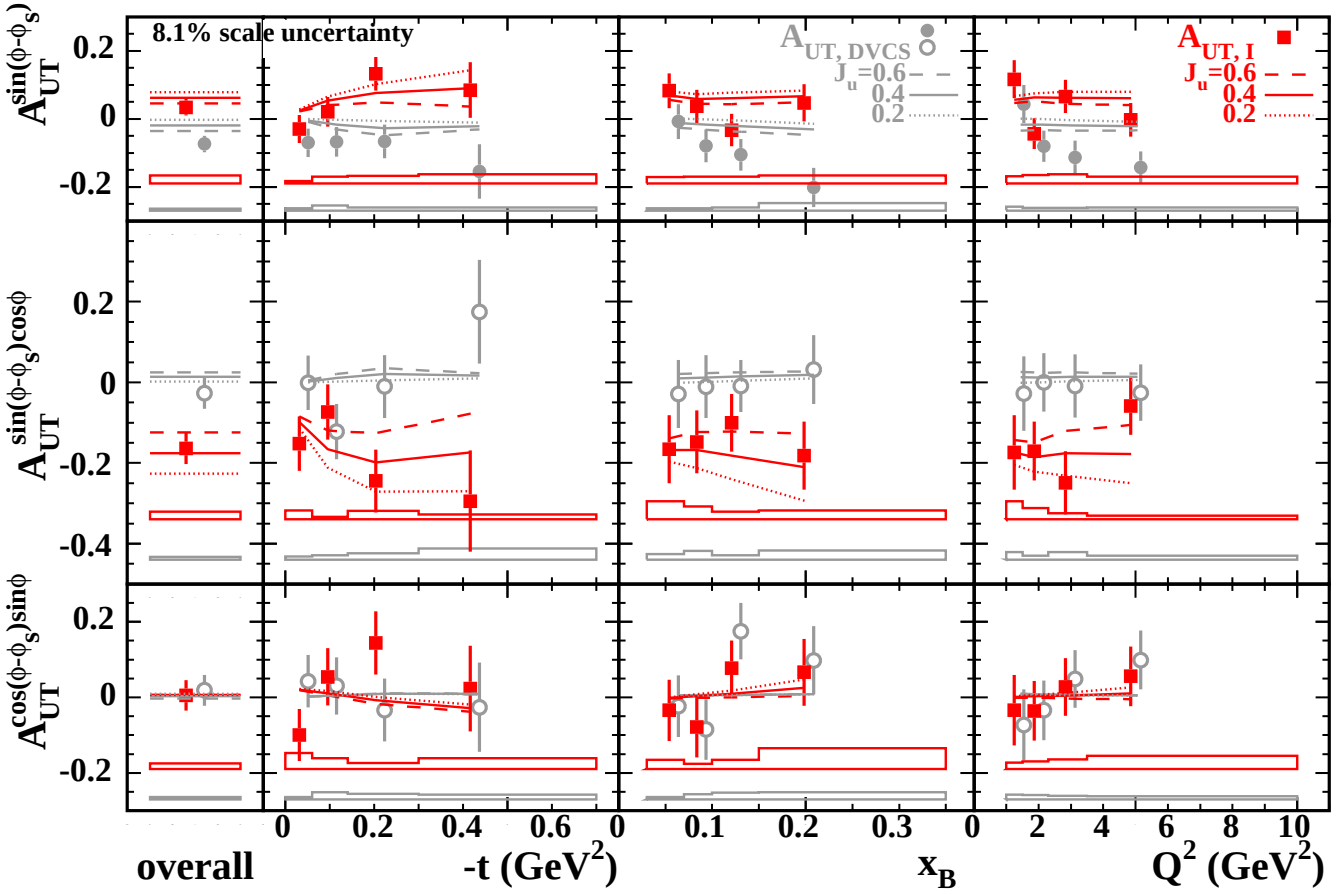
JHEP 11 (2009) 083



- $sin\phi$ AMPLITUDE OF THE $|DVCS|^2$ **term** FOR THE PROTON AND DEUTERON $\Rightarrow$ **compatible with zero**.

Transverse Target–Spin Asymmetry: Hydrogen

JHEP 06 (2008) 066



$$\underline{Sensitive\ to\ J_u}$$

$$\Im m\left[F_2\mathcal{H} - F_1\mathcal{E}\right]$$

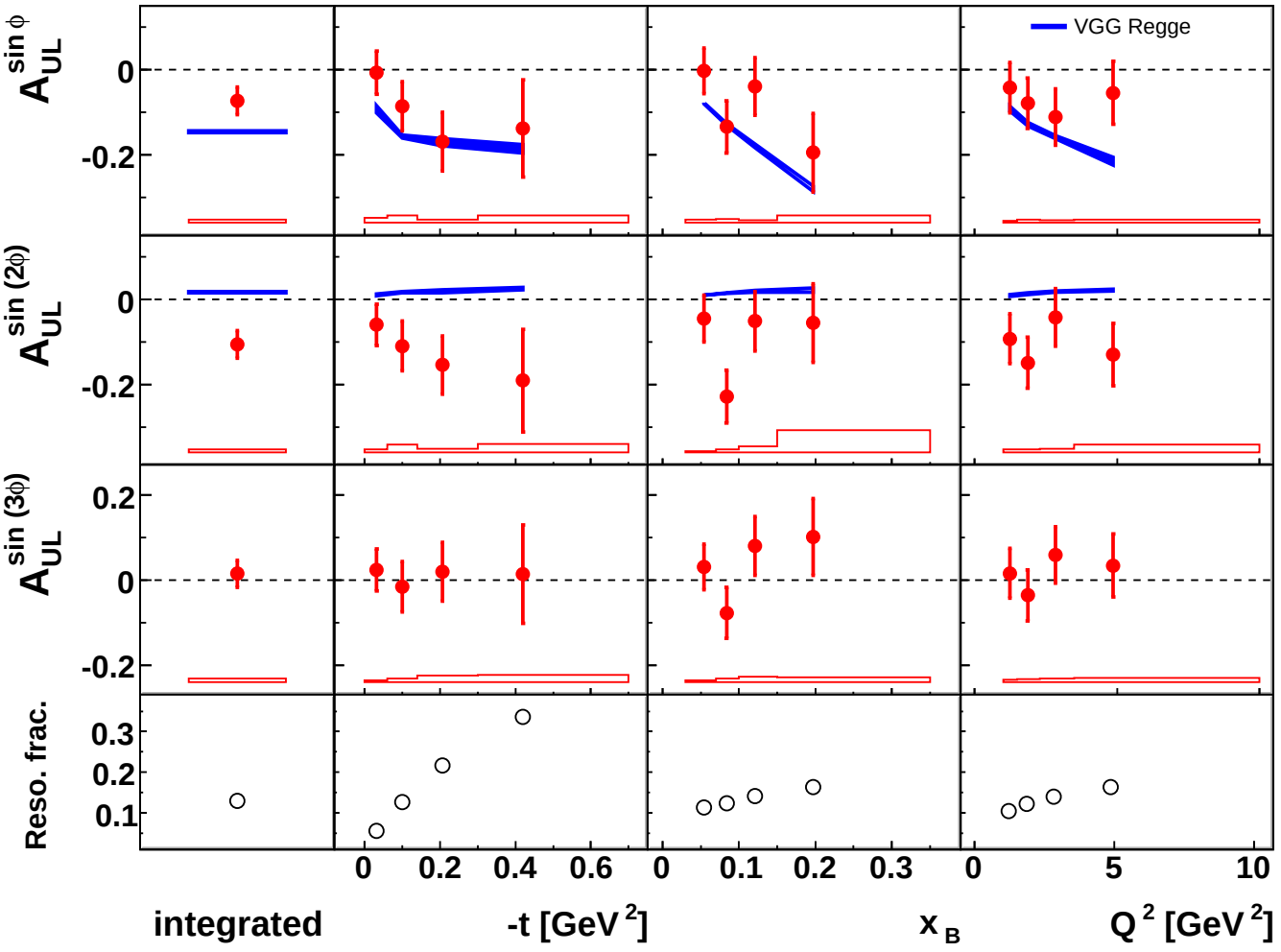
$$\underline{Not\ sensitive\ to\ J_u}$$

$$\Im m\left[F_2\widetilde{\mathcal{H}} - (F_1 + \xi F_2)\widetilde{\mathcal{E}}\right]$$

- The $\sin(\phi-\phi_s)\cos(n\phi)$ amplitudes are sensitive to **GPD** E
- Model: **'VGG'** with variation of J_u $(J_d = 0)$
- **Possibility** to extract **model dependent constraint** on $J_u + kJ_d$

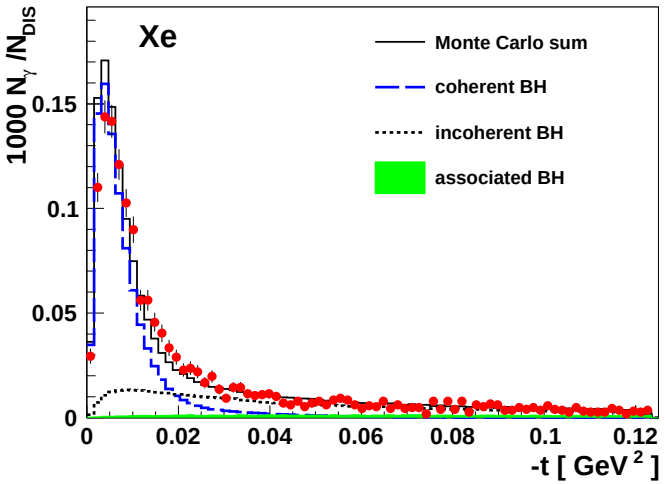
Longitudinal Target–Spin Asymmetry on Hydrogen

(see also talk of David Mahon)



- **GPD** MODEL (**'VGG'**): VARIATION OF INPUT PARAMETERS, b_{val} AND b_{see}
- $A_{UL}^{\sin 2\phi} \Longrightarrow$ MODEL DOES NOT DESCRIBED THE HYDROGEN DATA

DVCS: Nuclear Mass Dependence



FIND UPPER (LOWER) $-t$ CUT FOR EACH TARGET;
ASYMMETRIES FOR COHERENT(INCOHERENT)
PRODUCTION AT SIMILAR AVERAGE KINEMATICS

$\Rightarrow$ COHERENT: $< -t >= 0.018 GeV^2$

$\Rightarrow$ INCOHERENT: $< -t >= 0.20 GeV^2$

TARGETS

H, He, N, Ne, Kr, Xe

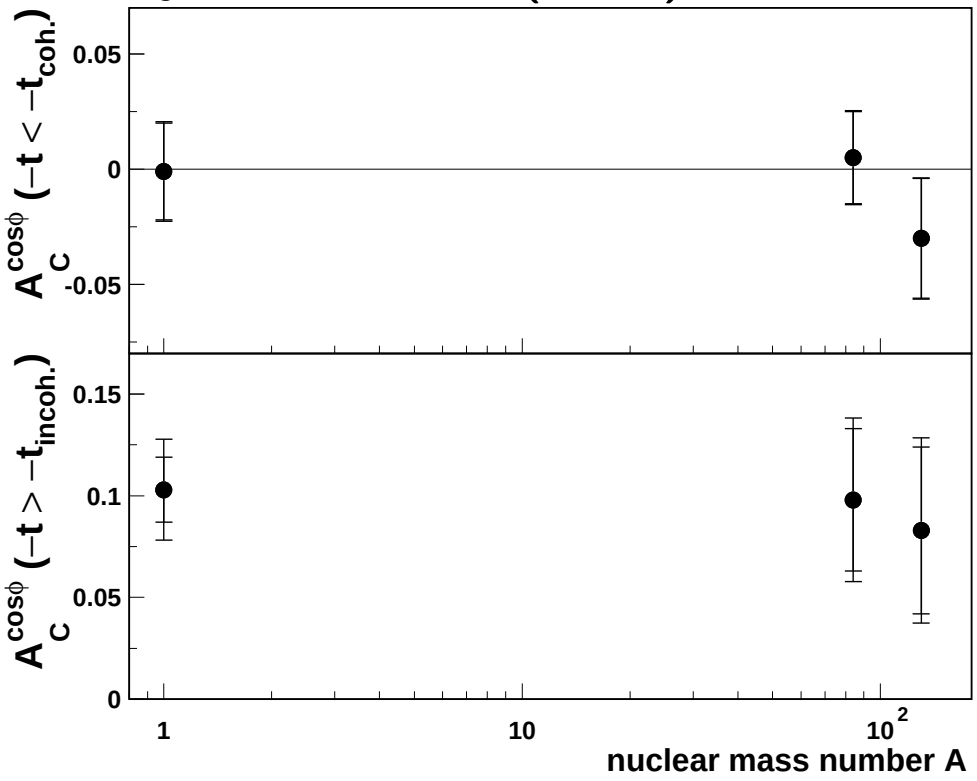
COHERENT ENRICHED

$\approx$ **65% coherent**

INCOHERENT ENRICHED

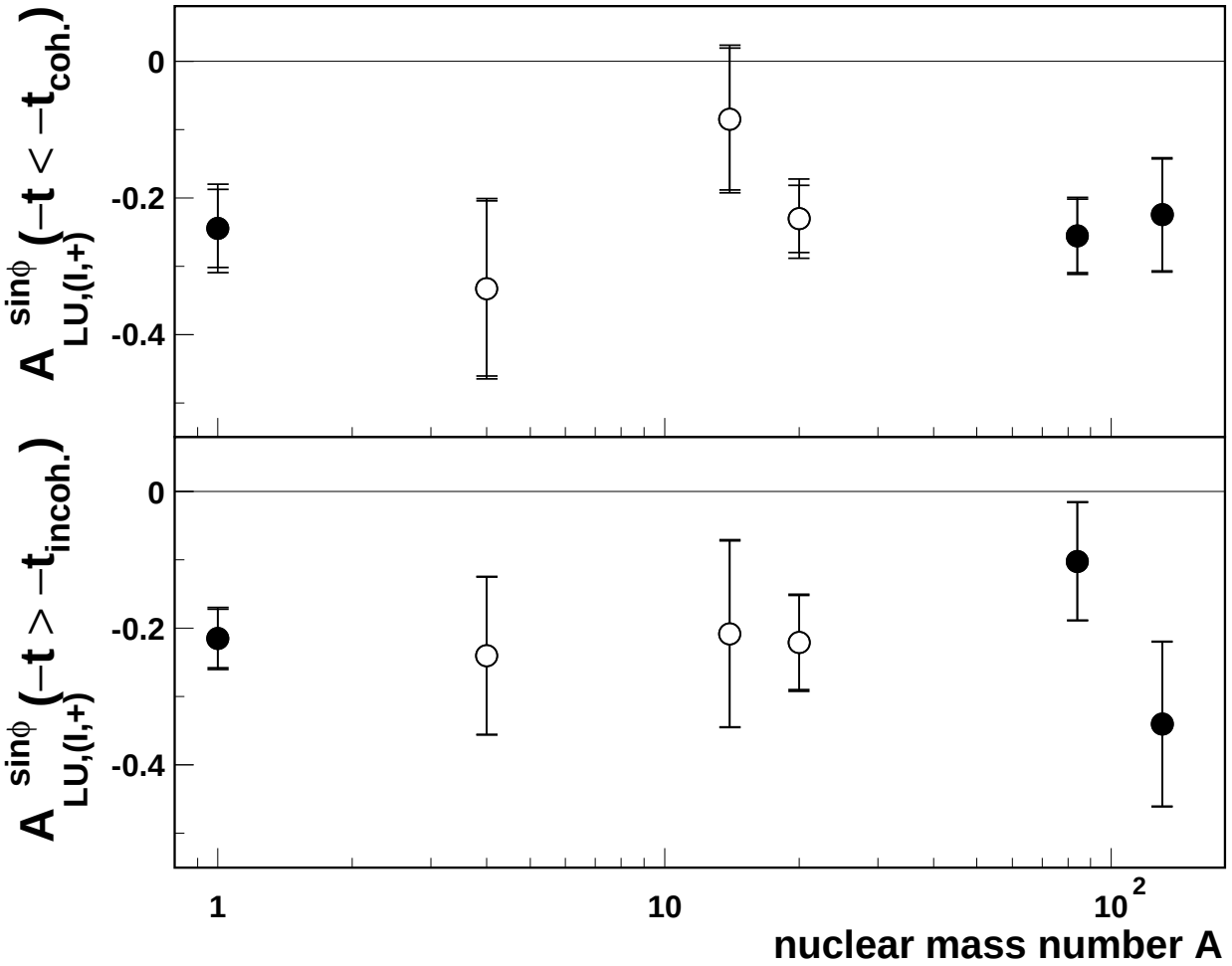
$\approx$ **60% incoherent**

Phys. Rev. C 81 (2010) 035202



Beam–Helicity Asymmetry Amplitude $A_{LU,(I,+)}^{\sin\phi}$: A-dependence

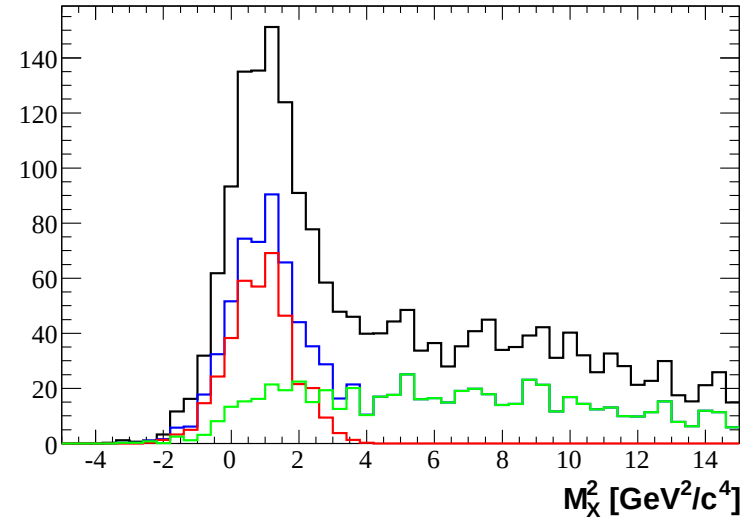
Phys. Rev. C 81 (2010) 035202



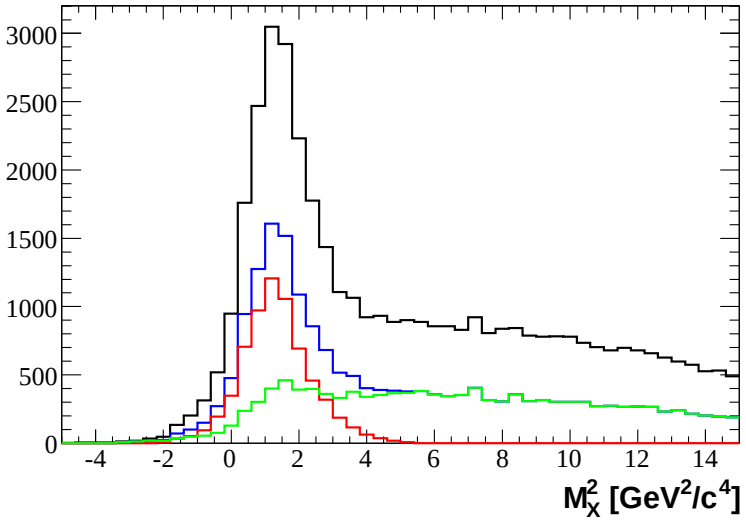
- $A_{LU,(I,+)}^{\sin\phi}$ **amplitude**: **no dependence** ON **A**
- **Not supported models** WITH **enhancement of nuclear asymmetries**

DVCS: Event Selection with Recoil Detector

Monte Carlo



Data



- **Missing mass distribution (MC)**
  - **No requirement for Recoil**
  - **Positively charged track in Recoil**
  - **Kinematic fit probability** $> 1\%$
  - **Kinematic fit probability** $< 1\%$
- **Kinematic parameters fit (MC)**
  - χ^2 **cut rejects the background**
- **Optimization of measured errors**
  - **Preliminary optimization done**
  - **Systematic studies are in progress**