HERMES Results: Hard Exclusive Processes

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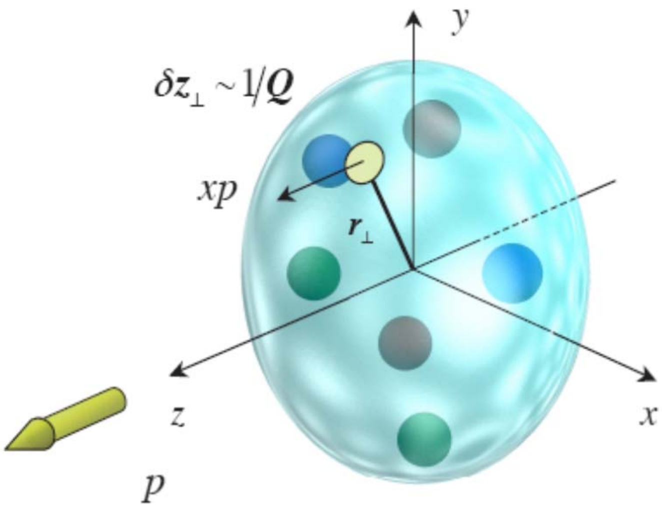
on behalf of the hermes collaboration

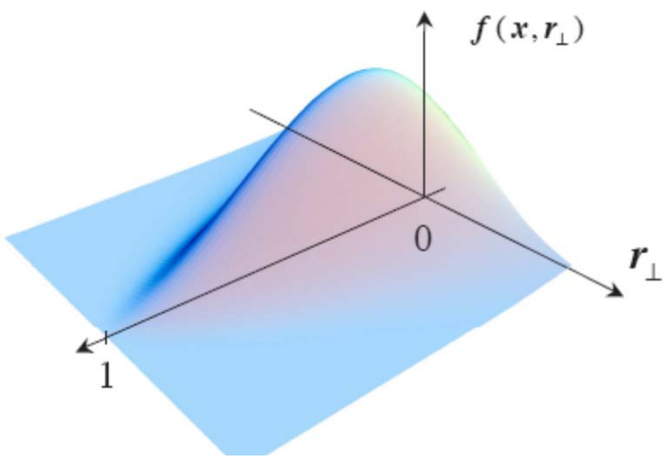
HELMHOLTZ ASSOCIATION

TRANSVERSITY 2011, Veli Lošinj, September 2, 2011

DESY

Generalized Parton Distributions (GPDs)



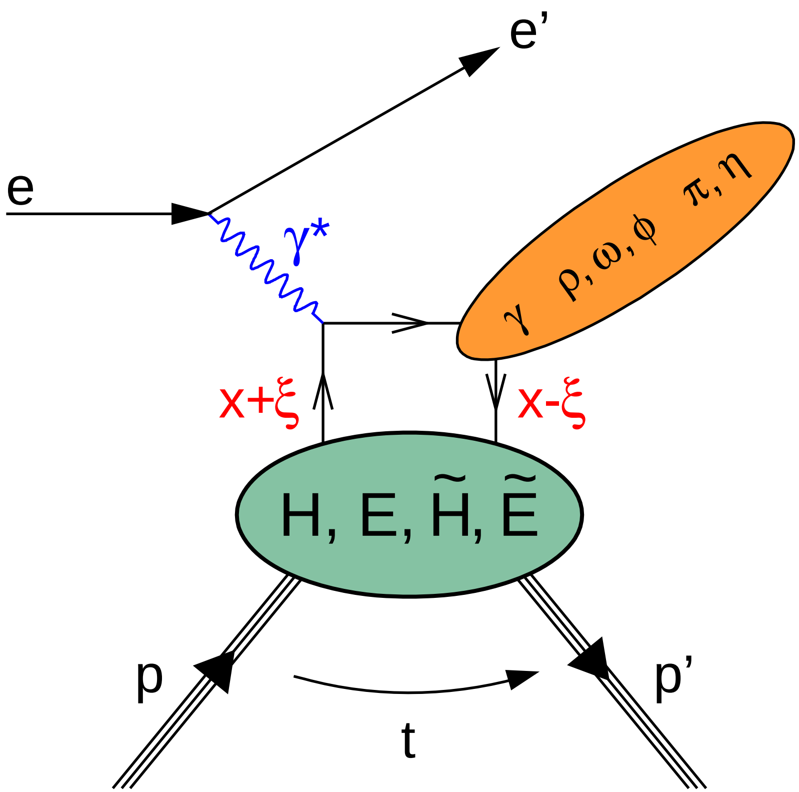


- Include Form Factors and Parton Distribution Functions as moments and forward limits, respectively
- Multidimensional description of nucleon structure (longitudinal momentum vs. transverse position)
- Access to the quark total angular momentum via Ji relation

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

X. Ji, Phys. Rev. Lett. 78 (1997) 610

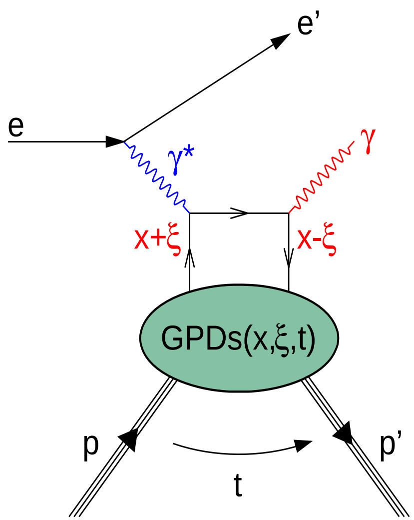
Access to GPDs via Exclusive Processes



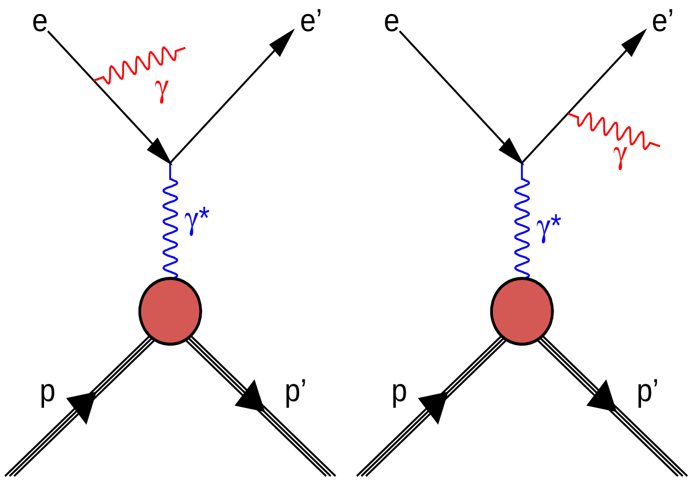
- Sensitivity of different final states to different GPDs
- For spin-1/2 target 4 chiral-even leading-twist quark GPDs: $H,E,\tilde{H},\tilde{E}$
- $H,\tilde{H}$ conserve nucleon helicity, $E,\tilde{E}$ involve nucleon helicity flip
- DVCS (γ) → $H,E,\tilde{H},\tilde{E}$
- Vector mesons (ρ, ω, ϕ) → H,E
- Pseudoscalar mesons (π, η) → $\tilde{H},\tilde{E}$

Deeply Virtual Compton Scattering (DVCS)

DVCS



Bethe-Heitler



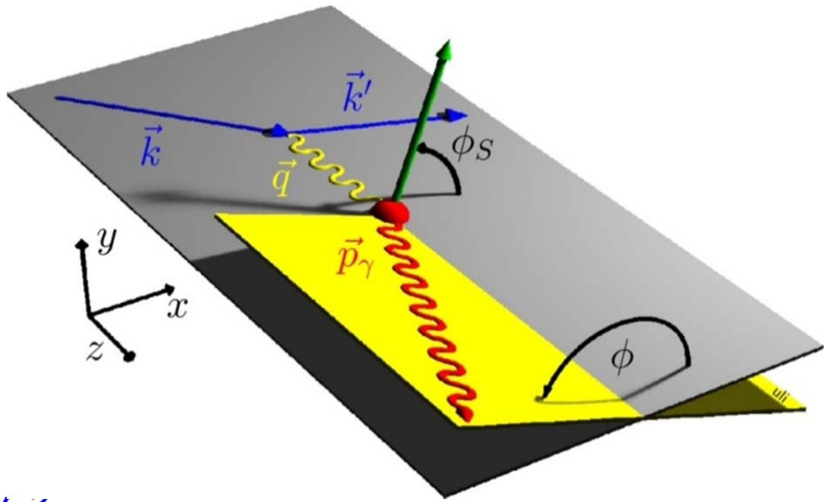
- DVCS and Bethe-Heitler: same initial and final state → interference

$$\frac{d\sigma}{dx_B dQ^2 d|t| d\phi} \propto |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + I$$

- Bethe-Heitler dominates at HERMES kinematics
- GPDs accessible through azimuthal asymmetries

Unique DVCS Measurements at HERMES

- Both beam charges
- Longitudinal beam polarization (both helicities)
- Unpolarized H, D and nuclear targets
- Longitudinally polarized H and D targets
- Transversely polarized H target
- Recoil Detector



ϕ - angle between the lepton scattering and real photon production planes

ϕ_S - angle between the target spin direction and the lepton scattering plane

Azimuthal Asymmetries in DVCS

- 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-charge asymmetry

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

- Charge-difference beam-helicity asymmetry

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

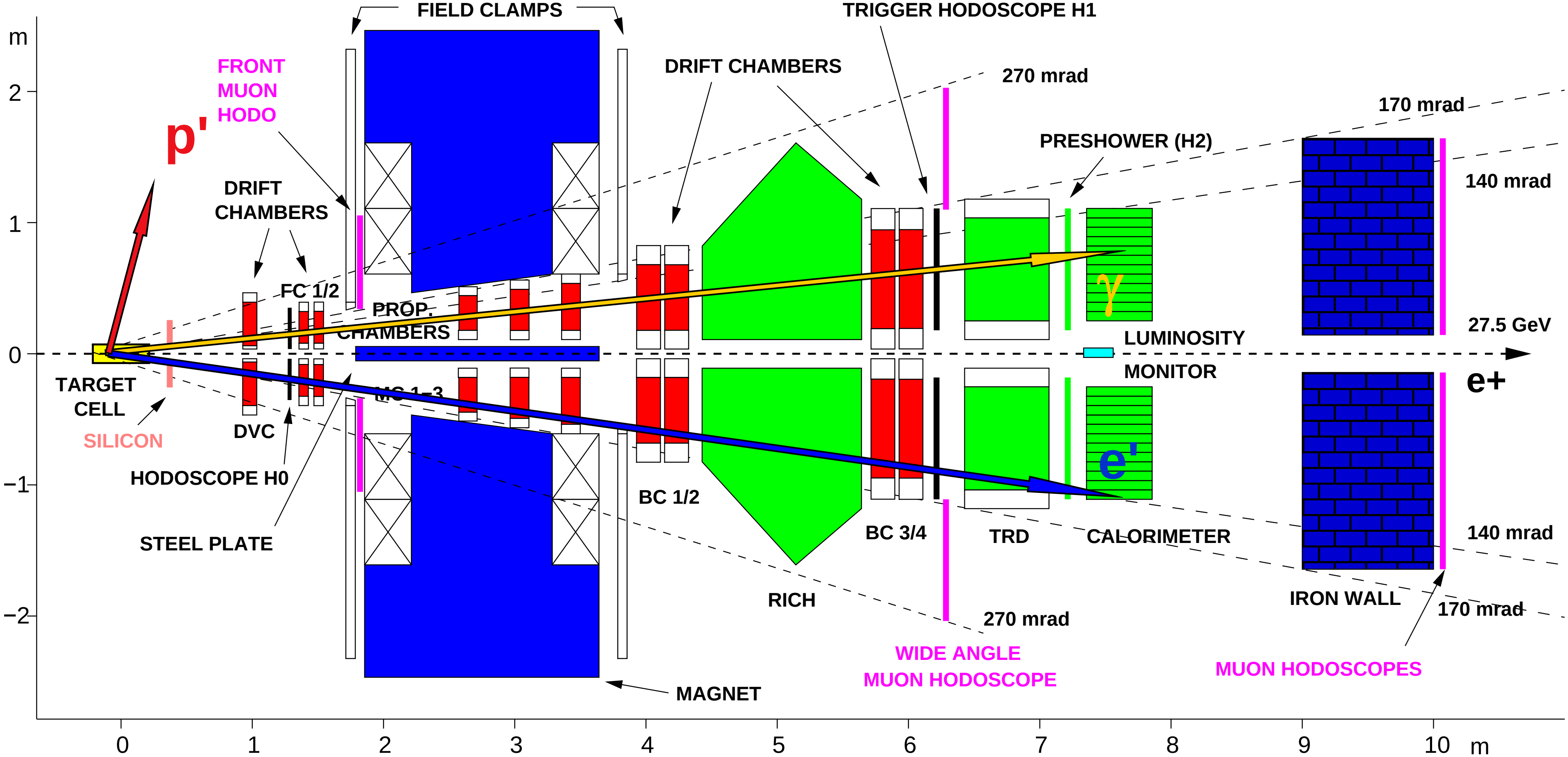
- Charge-averaged beam-helicity asymmetry

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

- Separation of contributions from DVCS and interference term
- Impossible in case of single-charge beam-helicity asymmetry

$$A_{LU}(\phi) = \frac{\sigma^{\rightarrow} - \sigma^{\leftarrow}}{\sigma^{\rightarrow} + \sigma^{\leftarrow}}$$

The HERMES Spectrometer



Internal gas targets:

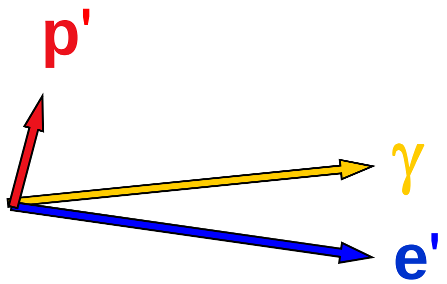
- Longitudinally polarized *H, D*
- Transversely polarized *H*
- Unpolarized *H, D, ^{4}He, N, Ne, Kr, Xe*

Forward magnetic spectrometer

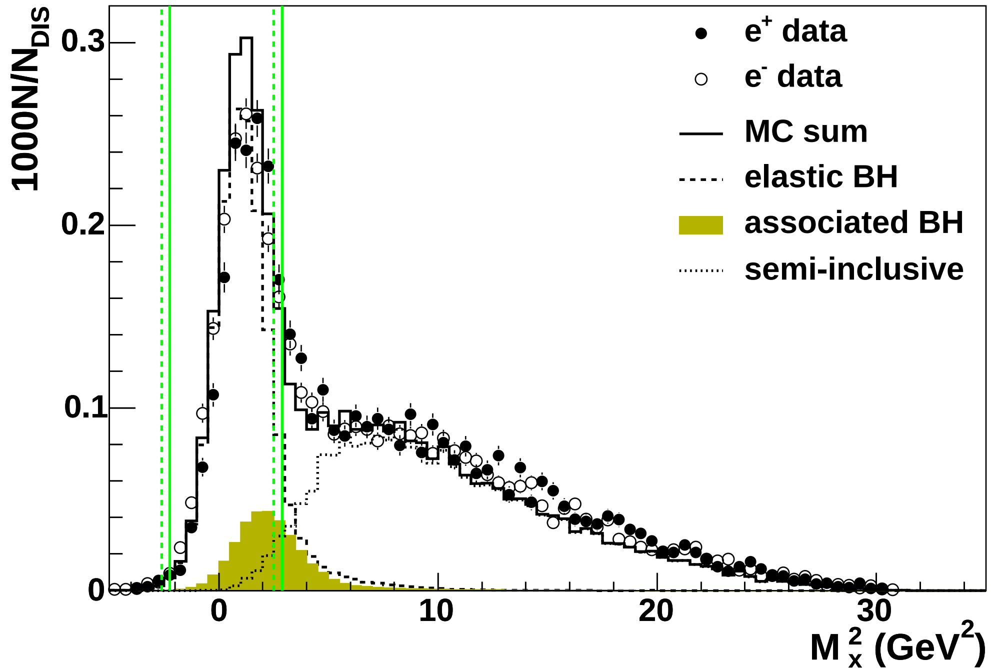
- Momentum resolution *1-2%*
- Particle identification:
  RICH, TRD, H2, calorimeter

DVCS Measurements without Recoil Detector

$ep \rightarrow e'p'\gamma$



$M_X^2 = (p_{e'}+p_{\gamma}-p_e-p_p)^2$



- Pre-Recoil data
  - Scattered lepton and photon were detected in the forward spectrometer
  - Recoil proton was not detected
  - Exclusivity achieved via missing mass technique
  - Associated processes (e.g. $ep \rightarrow e\Delta\gamma$) were not resolved (12% contribution)

Extraction of Asymmetry Amplitudes

- Distribution in the expectation value of measured yield

$$\langle N(e_l, P_l, S_t, \phi, \phi_S) \rangle \propto$$

$$\sigma_{UU}(\phi)\left[1 + e_l A_C + P_l A_{LU}^{DVCS} + e_l P_l A_{LU}^{I} + S_t A_{UT}^{DVCS} + e_l S_t A_{UT}^{I} + P_l S_t A_{LT}^{BH+DVCS} + e_l P_l S_t A_{LT}^{I}\right]$$

- Expansion of the asymmetries:

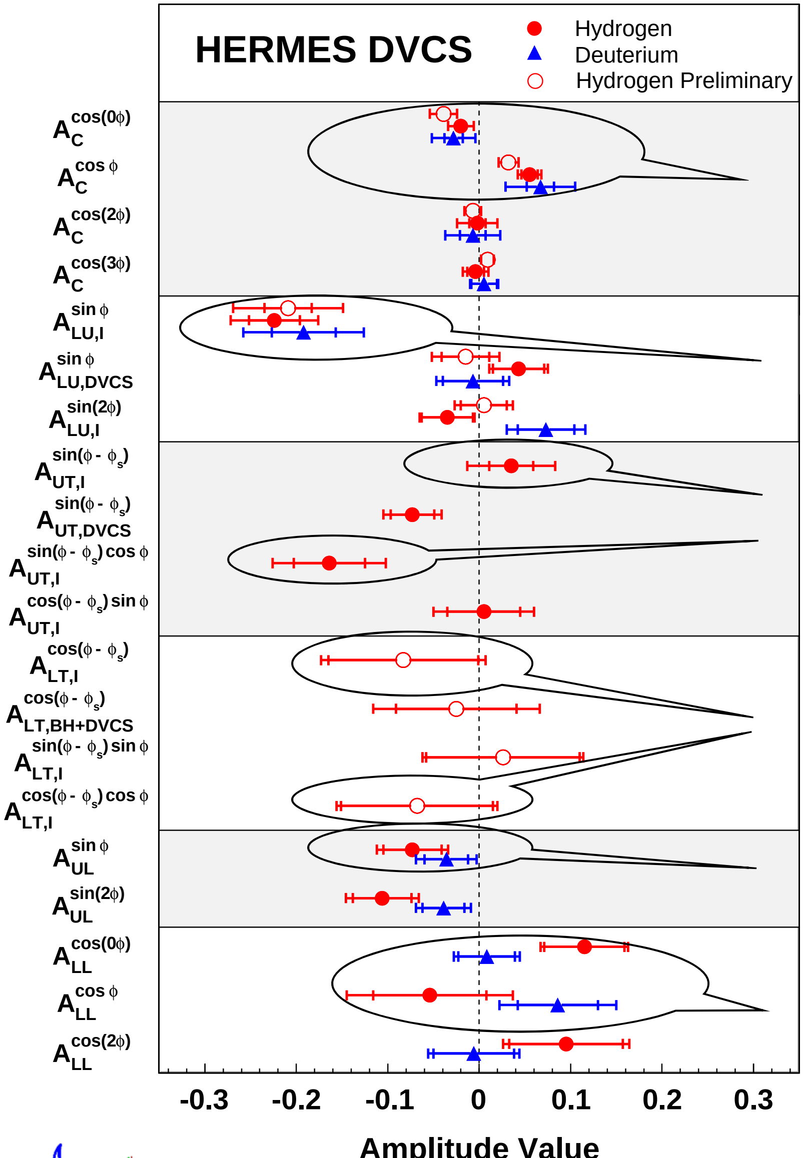
$$A \approx \sum_{n=0}^{3} A^{\cos(n\phi)} \cos(n\phi) \qquad \left[A \approx \sum_{n=1}^{2} A^{\sin(n\phi)} \sin(n\phi)\right]$$

- Simultaneous extraction of asymmetry amplitudes with Maximum Likelihood Method

- Asymmetry amplitudes provide information about Compton Form Factors (CFFs), convolution of GPDs with hard scattering amplitudes

$$\mathcal{F}(\xi,t) = \sum_q \int_{-1}^{1} dx\, C_q^{\mp}(\xi,x) F^q(x,\xi,t)$$

DVCS Results



$\propto \Re e(\mathcal{H})$

$\propto \Im m(\mathcal{H})$

$\propto \Im m(\mathcal{H} - \mathcal{E})$

$\propto \Re e(\mathcal{H} - \mathcal{E})$

$\propto \Im m(\widetilde{\mathcal{H}})$

$\propto \Re e(\widetilde{\mathcal{H}})$

JHEP 11 (2009) 083

Nucl. Phys. B 829 (2010) 1

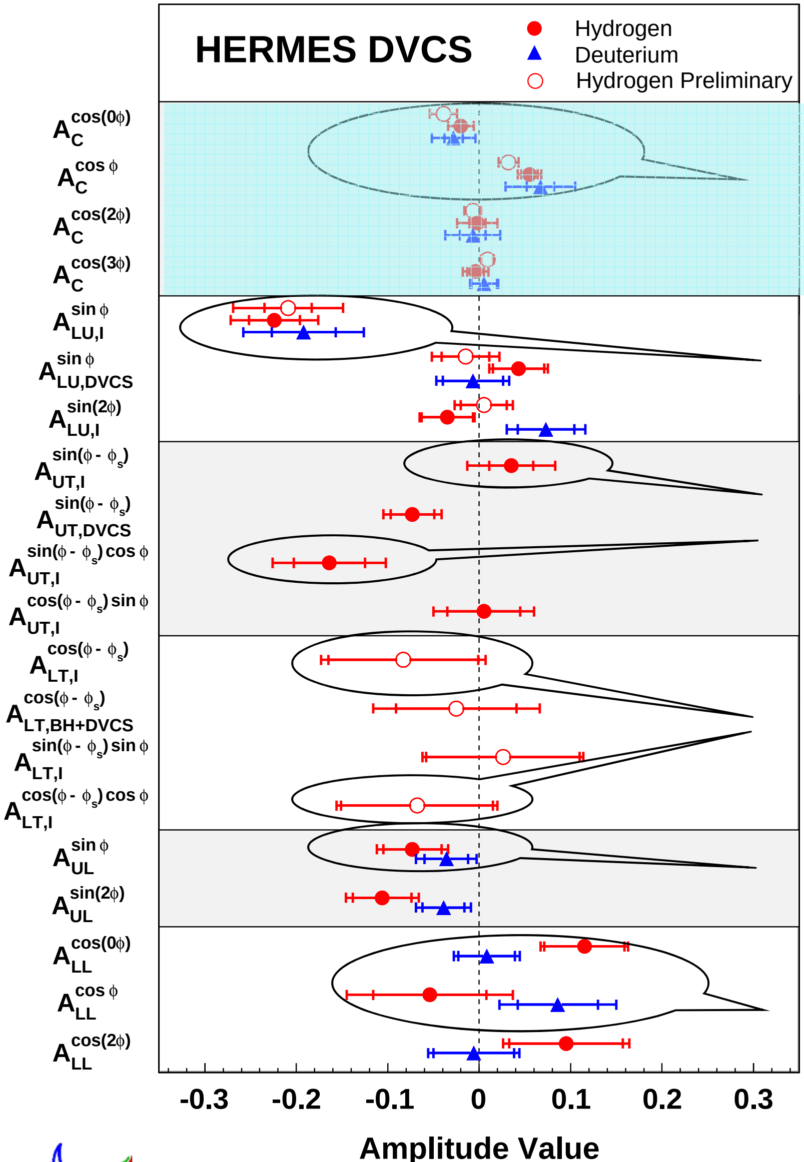
JHEP 06 (2008) 066

arXiv:1106.2990 (hep-ex)

JHEP 06 (2010) 019

Nucl. Phys. B 842 (2011) 265

DVCS Results



$\propto \Re e(\mathcal{H})$

$\propto \Im m(\mathcal{H})$

$\propto \Im m(\mathcal{H} - \mathcal{E})$

$\propto \Re e(\mathcal{H} - \mathcal{E})$

$\propto \Im m(\widetilde{\mathcal{H}})$

$\propto \Re e(\widetilde{\mathcal{H}})$

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Beam-Charge Asymmetry

$$A_C = \sum_{n=0}^{3} A_C^{\cos(n\phi)} \cos(n\phi) \propto \sum_{n=0}^{3} c_n^I \cos(n\phi)$$

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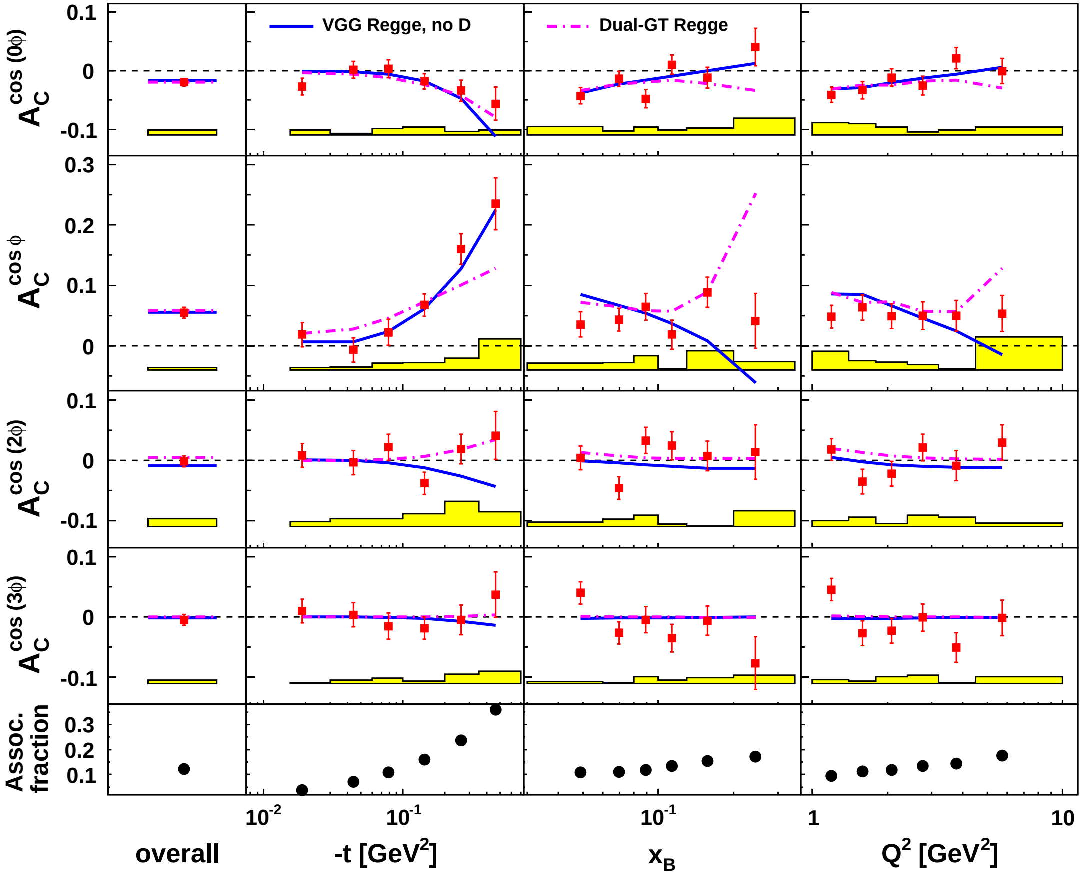


$\propto -\frac{t}{Q}\Re e(\mathcal{H})$

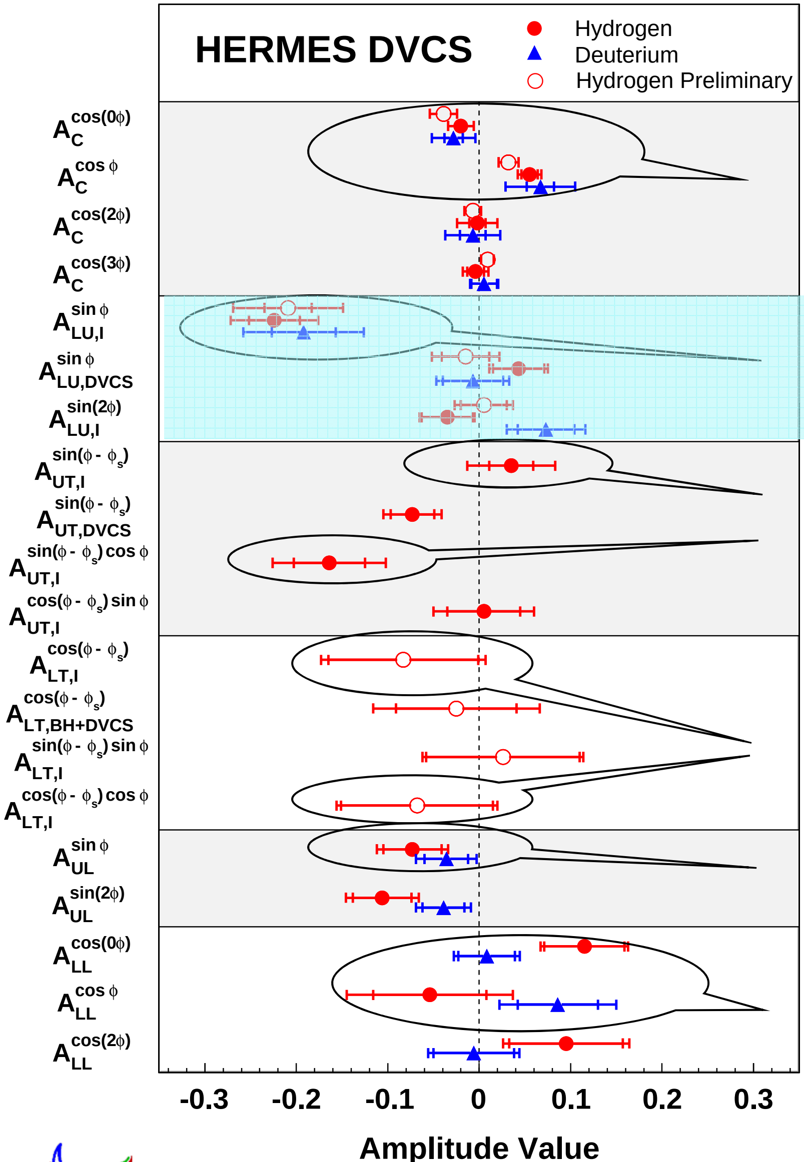
$\propto \Re e(\mathcal{H})$

Twist-3 GPDs

Gluon GPDs

- VGG model: Phys. Rev. D60 (1999) 094017, Prog. Nucl. Phys. 47 (2001) 401
- Dual model: Phys. Rev. D74 (2006) 054027, Phys. Rev. D79 (2009) 017501

DVCS Results



$\propto \mathfrak{Re}(\mathcal{H})$

$\propto \mathfrak{Im}(\mathcal{H})$

$\propto \mathfrak{Im}(\mathcal{H} - \mathcal{E})$

$\propto \mathfrak{Re}(\mathcal{H} - \mathcal{E})$

$\propto \mathfrak{Im}(\widetilde{\mathcal{H}})$

$\propto \mathfrak{Re}(\widetilde{\mathcal{H}})$

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arXiv:1106.2990 (hep-ex)

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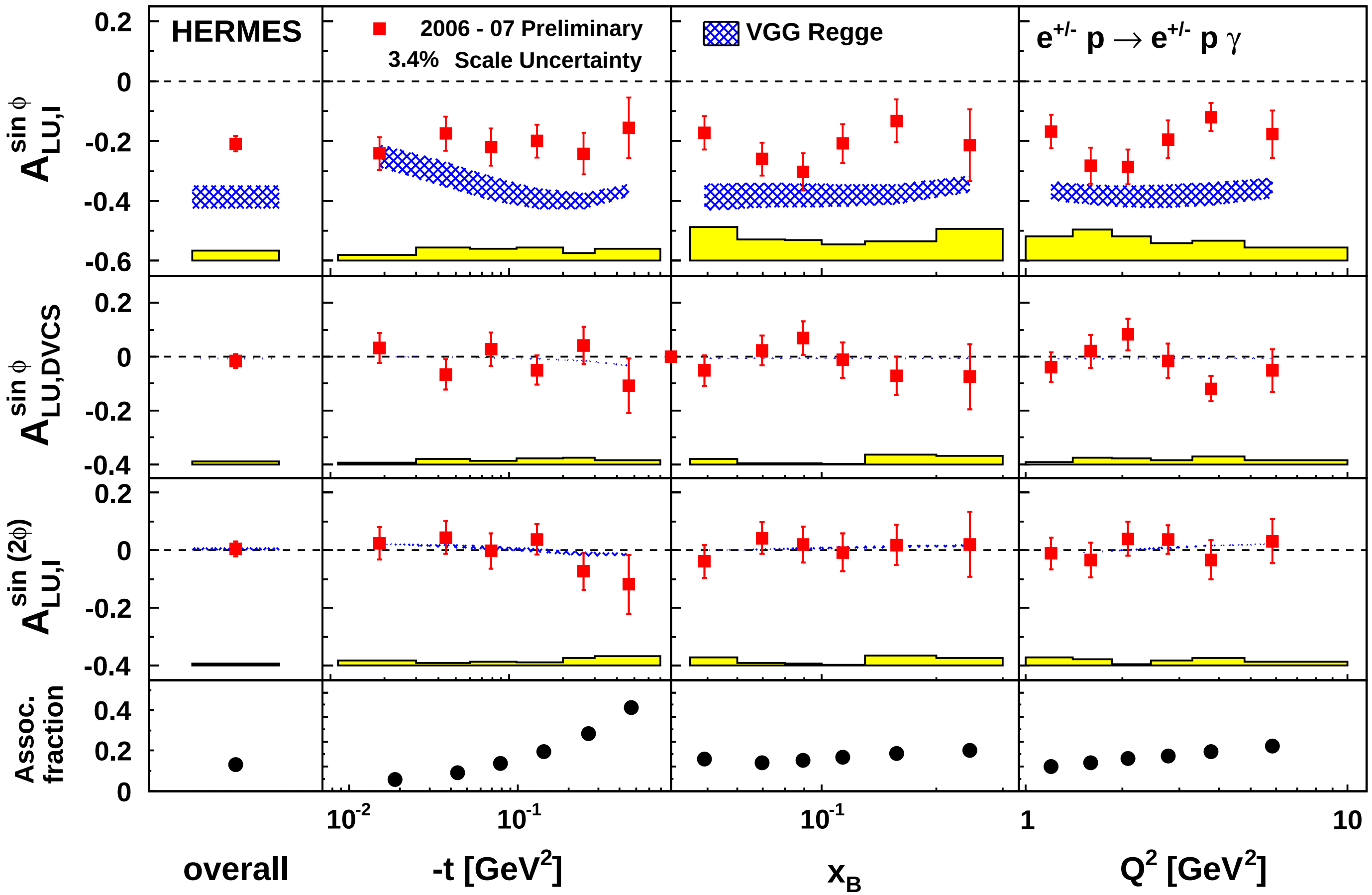
Beam-Helicity Asymmetry

$$A_{LU,I}(\phi) = \sum_{n=1}^{2} A_{LU}^{\sin(n\phi)} \sin(n\phi) \propto \sum_{n=1}^{2} s_n^I \sin(n\phi) \qquad A_{LU,DVCS}^{\sin\phi} \propto s_1^{DVCS} \sin\phi$$

New



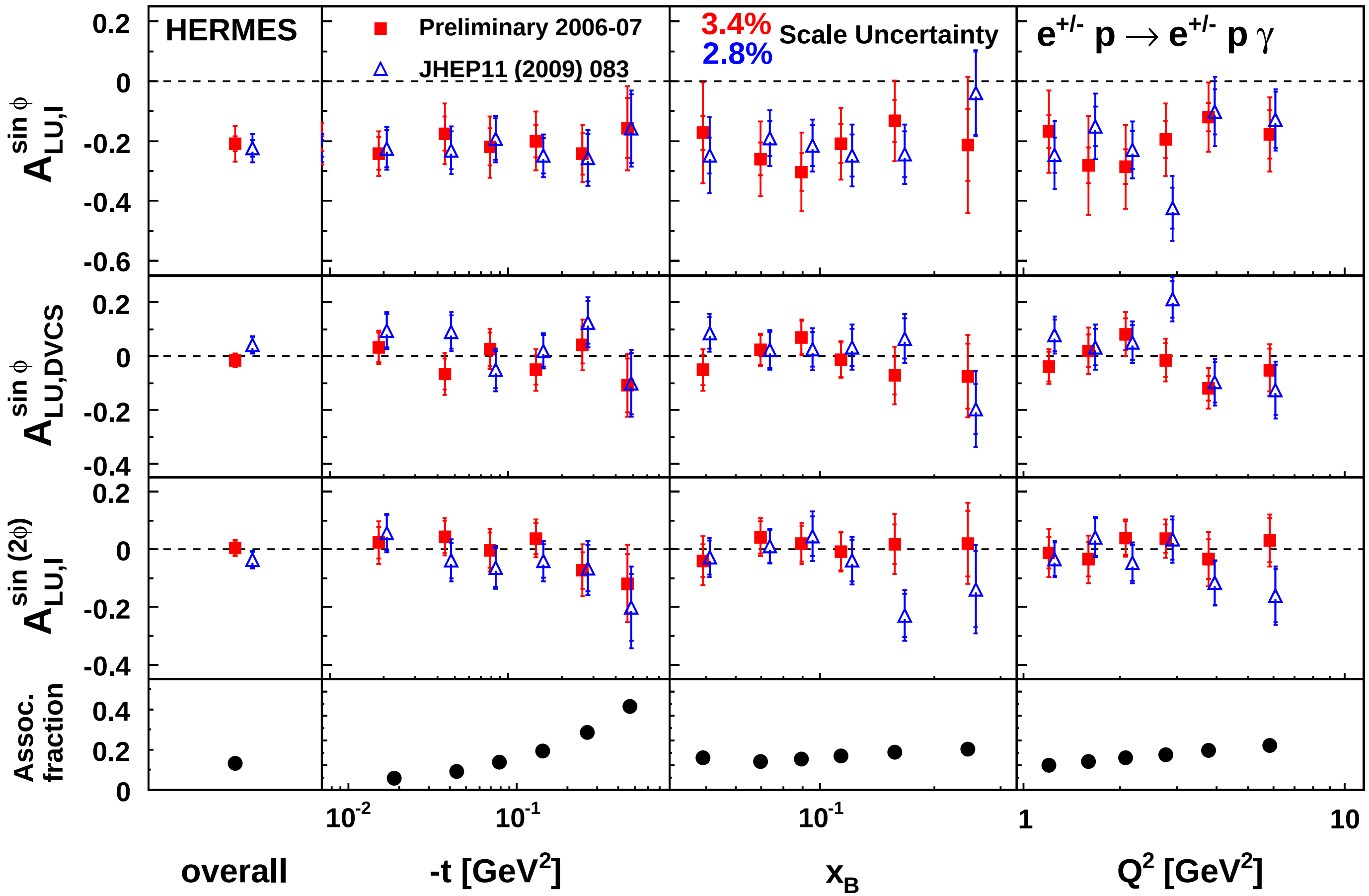
$\propto \Im m(\mathcal{H})$

Twist-3 GPDs

- VGG overestimates the magnitude of leading asymmetry amplitude

Beam-Helicity Asymmetry (New vs Published)

New

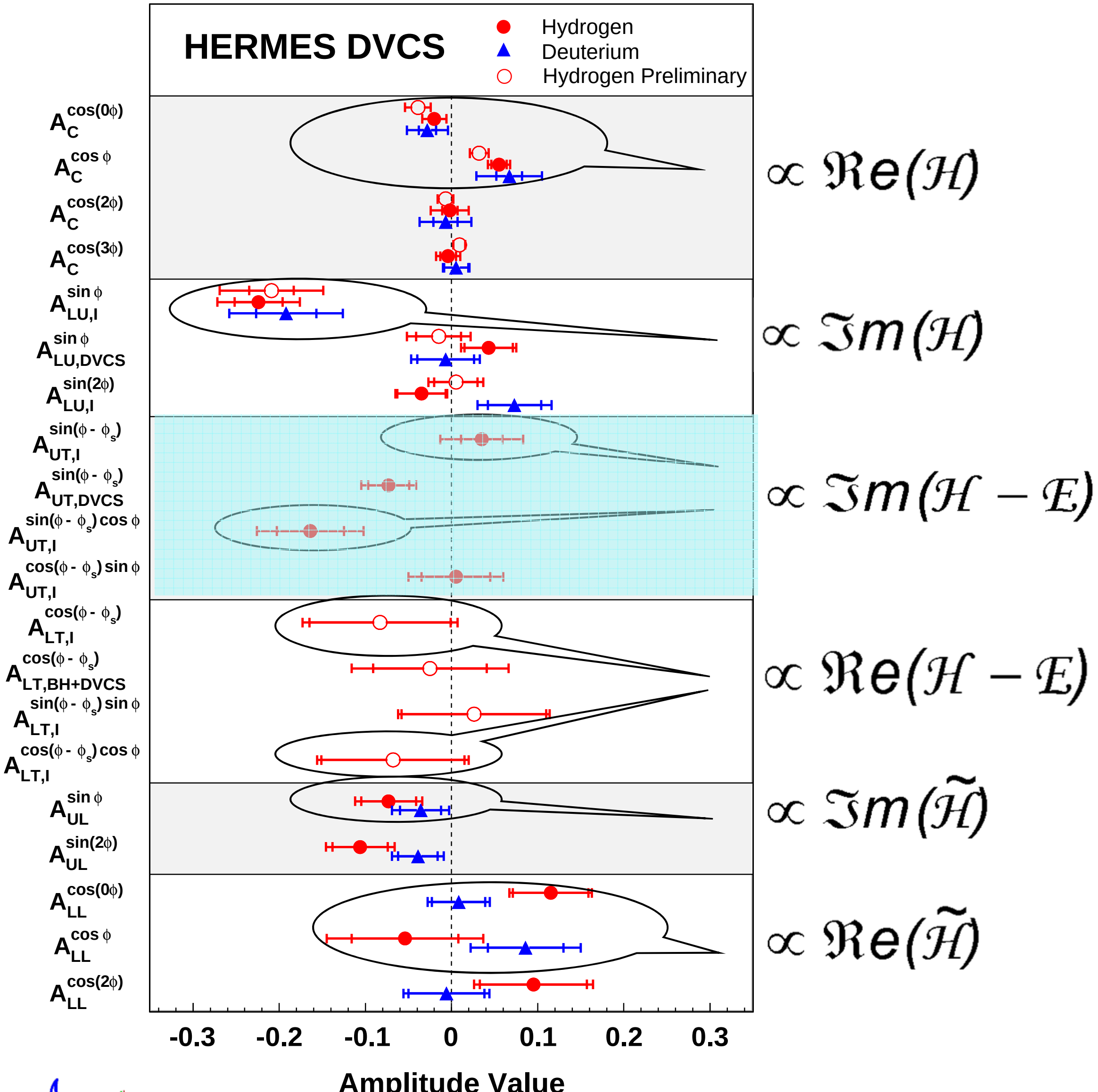


$\propto \Im m(\mathcal{H})$

Twist-3 GPDs

- New results are in agreement with published (*JHEP 11 (2009) 083*)

DVCS Results



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arXiv:1106.2990 (hep-ex)

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Transverse-Target Spin Asymmetry

$$A_{UT}(\phi,\phi_S) = A_{UT}^{\sin(\phi-\phi_S)} \sin(\phi-\phi_S) + A_{UT}^{\sin(\phi-\phi_S)\cos\phi} \sin(\phi-\phi_S)\cos\phi + \ldots$$

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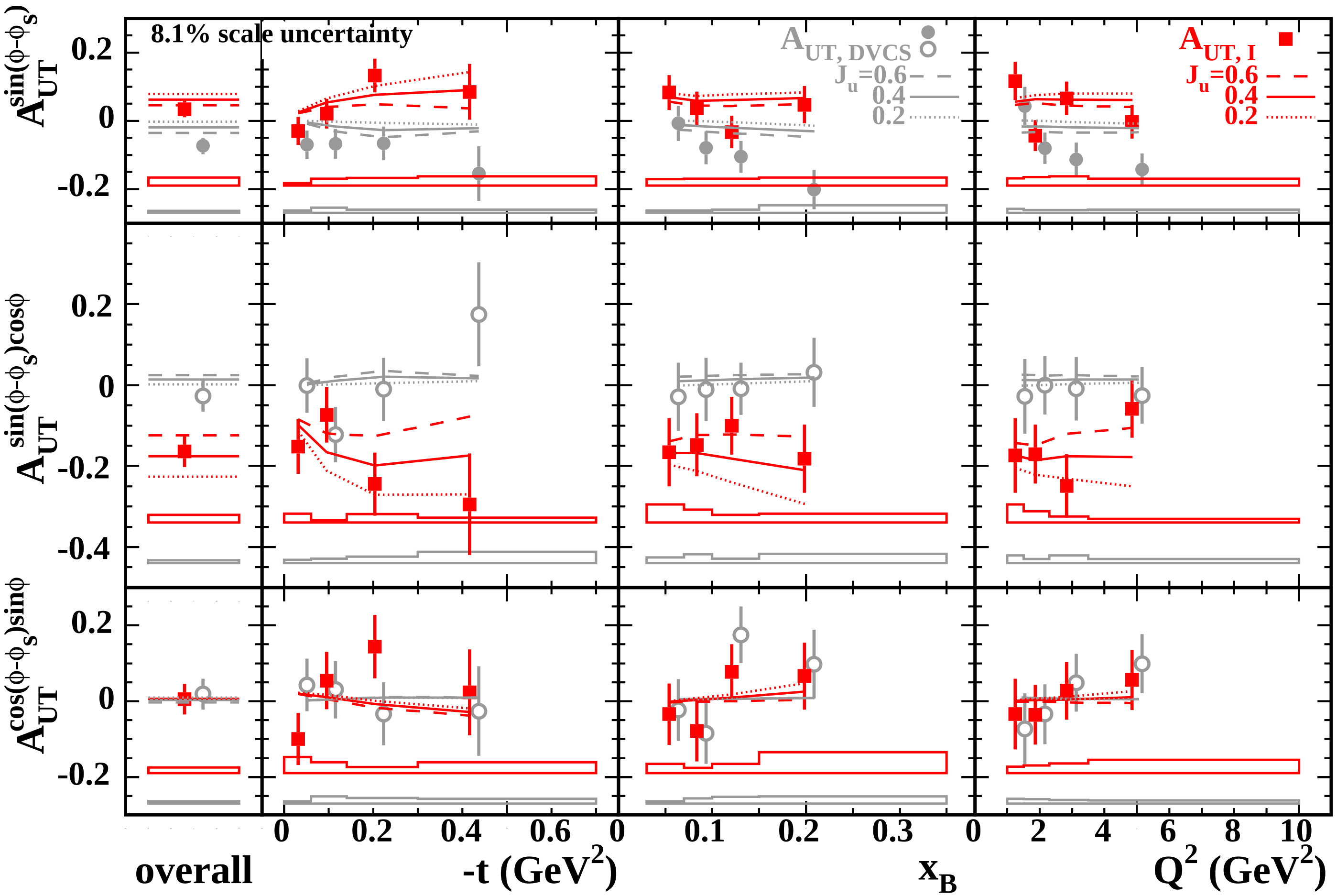
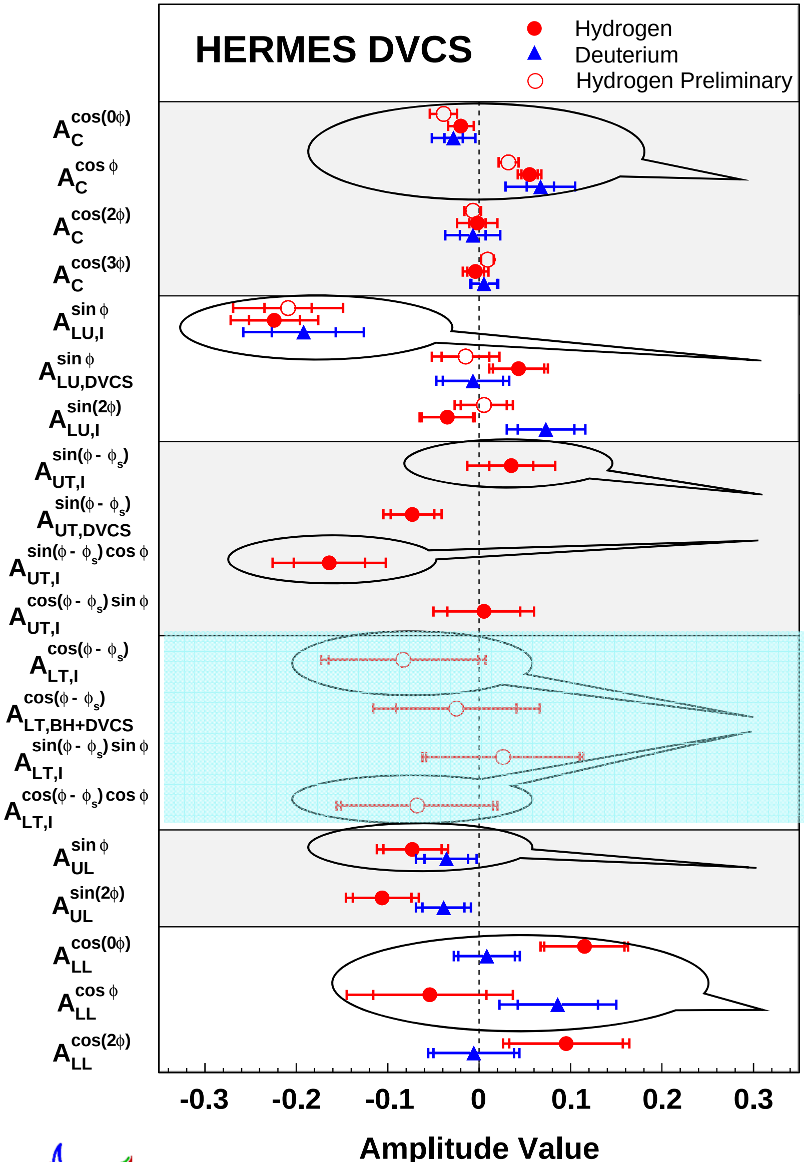


$$\propto \Im m(F_2\mathcal{H} - F_1\mathcal{E})$$

- $A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$ sensitive to J_u, allows a model-dependent constraint

DVCS Results



$\propto \Re e(\mathcal{H})$

$\propto \Im m(\mathcal{H})$

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$\propto \Im m(\mathcal{H} - \mathcal{E})$

JHEP 06 (2008) 066

$\propto \Re e(\mathcal{H} - \mathcal{E})$

arXiv:1106.2990 (hep-ex)

$\propto \Im m(\widetilde{\mathcal{H}})$

$\propto \Re e(\widetilde{\mathcal{H}})$

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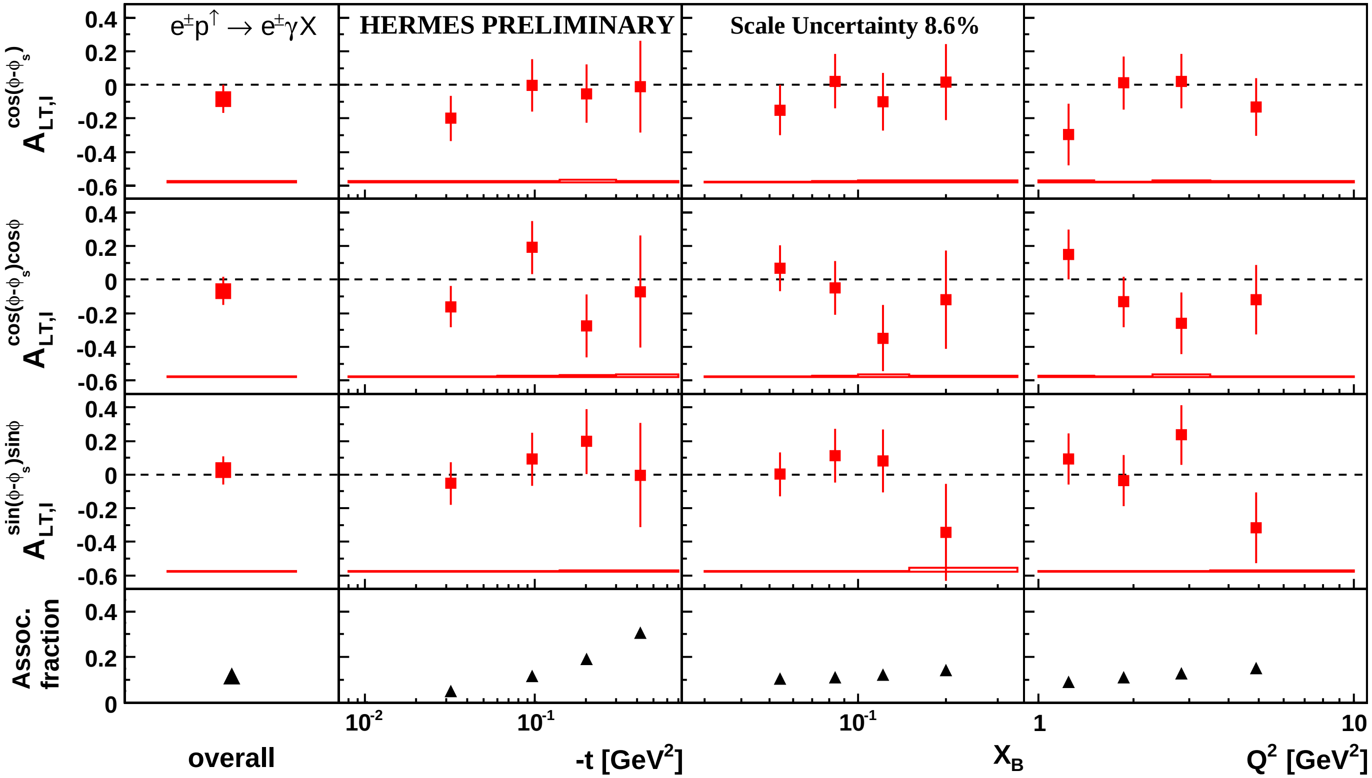
Double-Spin Asymmetry

$$A_{LT}^{l}(\phi,\phi_S) = A_{LT,l}^{\sin(\phi-\phi_S)}\cos(\phi-\phi_S) + A_{LT,l}^{\cos(\phi-\phi_S)\cos\phi}\cos(\phi-\phi_S)\cos\phi + \ldots$$

New

arXiv:1106.2990 (hep-ex)

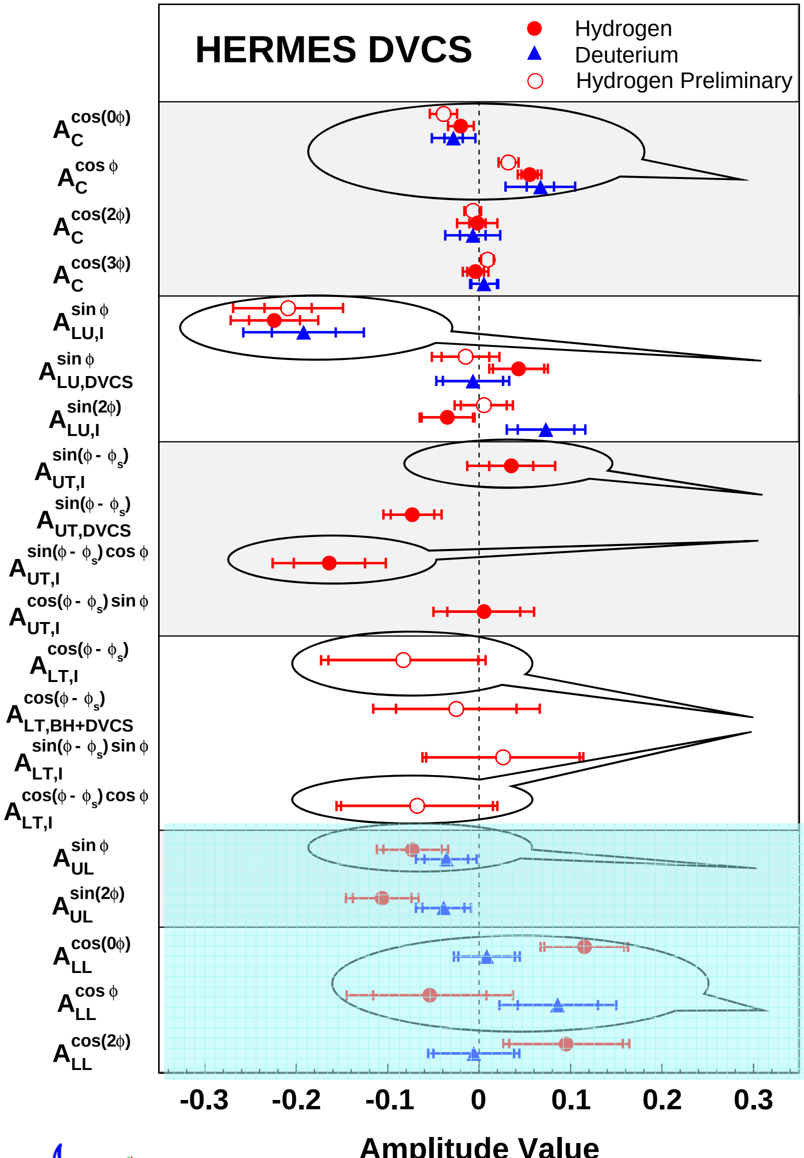


$\propto A_{LT,I}^{\cos(\phi-\phi_S)\cos\phi}$

$\propto \Re e(F_2\mathcal{H} - (F_1 + \xi F_2)\mathcal{E})$

- Sensitivity to J_u suppressed by kinematic pre-factor

DVCS Results



$\propto \Re e(\mathcal{H})$

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$\propto \Im m(\mathcal{H})$

$\propto \Im m(\mathcal{H}-\mathcal{E})$

JHEP 06 (2008) 066

$\propto \Re e(\mathcal{H}-\mathcal{E})$

arXiv:1106.2990 (hep-ex)

$\propto \Im m(\widetilde{\mathcal{H}})$

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$\propto \Re e(\widetilde{\mathcal{H}})$

Longitudinal-Target Spin Asymmetry

$$A_{UL}(\phi) = \sum_{n=1}^{2} A_{UL}^{\sin(n\phi)} \sin(n\phi) \propto \sum_{n=1}^{2} s_n^I, s_n^{DVCS} \sin(n\phi)$$

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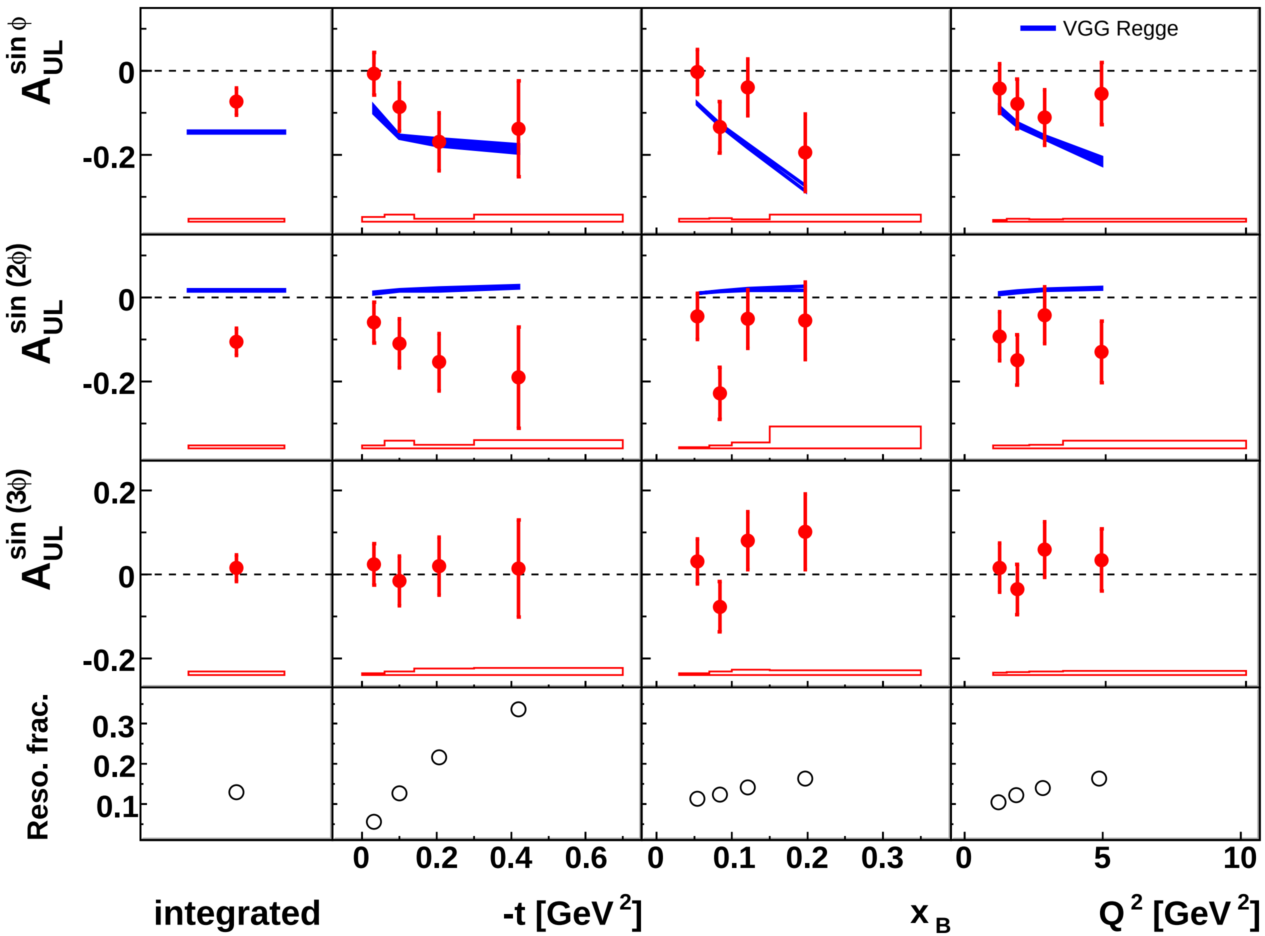

$\propto \Im m(\widetilde{\mathcal{H}})$

Twist-3 quark or

Twist-2 gluon GPDs

- Unexpectedly large $A_{UL}^{\sin(2\phi)}$ asymmetry amplitude

Longitudinal-Target Spin Asymmetry (Deuteron vs Proton)

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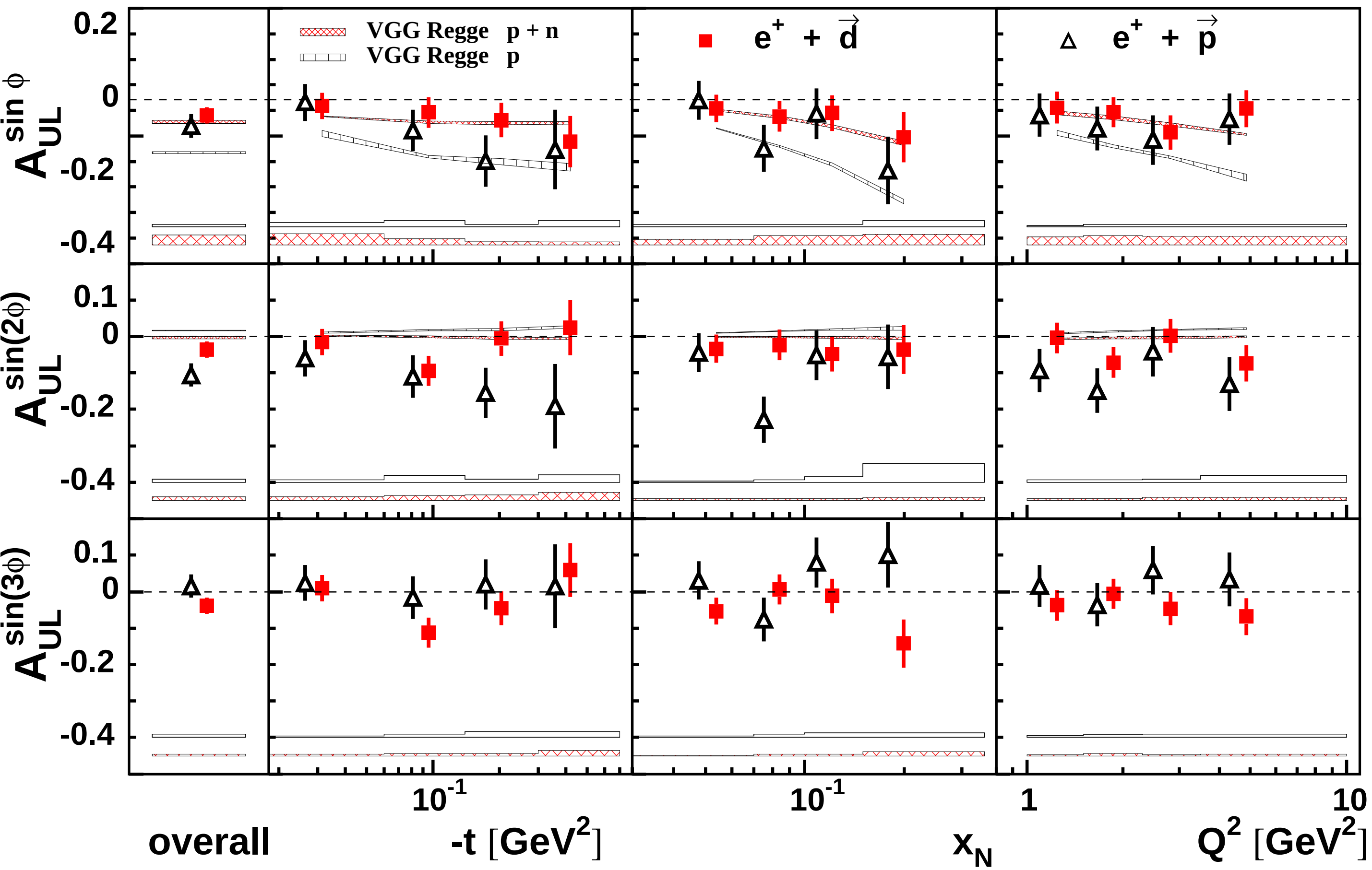
New



- 9 chiral-even GPDs in case of spin-1 target

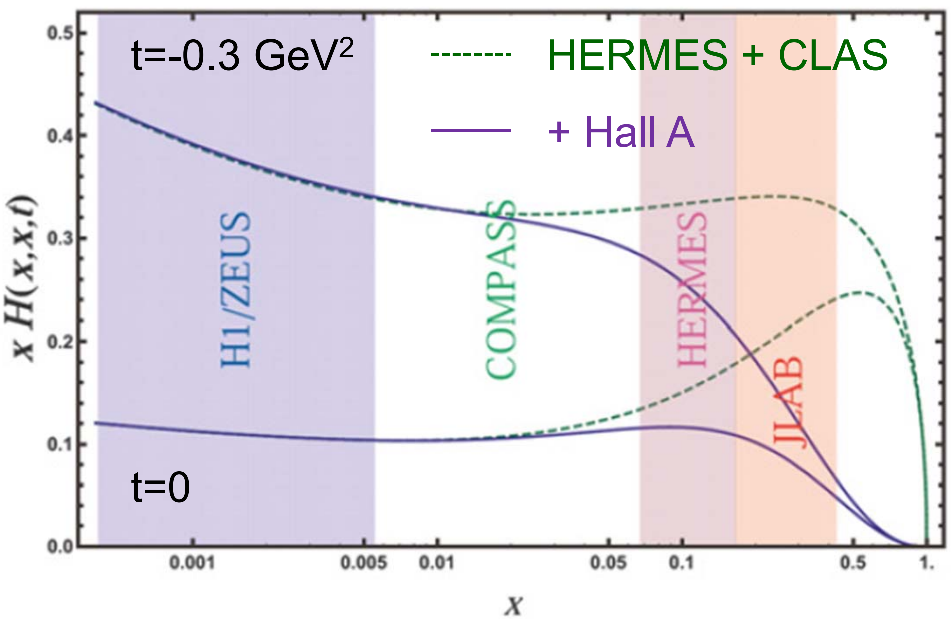
$H_1, H_2, H_3, H_4, H_5,$

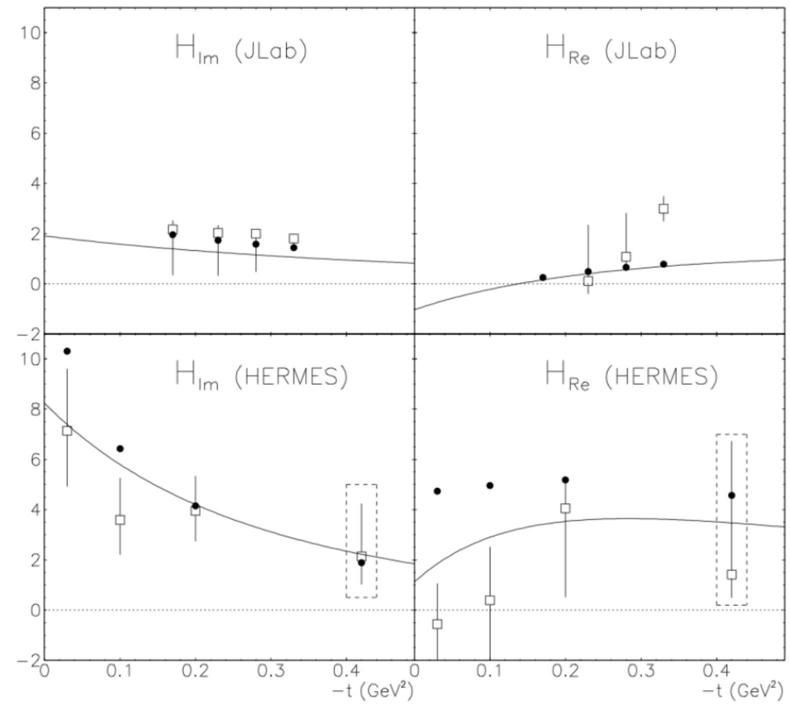
$\tilde{H}_1, \tilde{H}_2, \tilde{H}_3, \tilde{H}_4,$

- Search for coherent signature

- Results for deuteron are compatible with that for proton for leading amplitudes
- Different result for $A_{UL}^{\sin(2\phi)}$: compatible with zero for deuteron

Extractions of GPDs

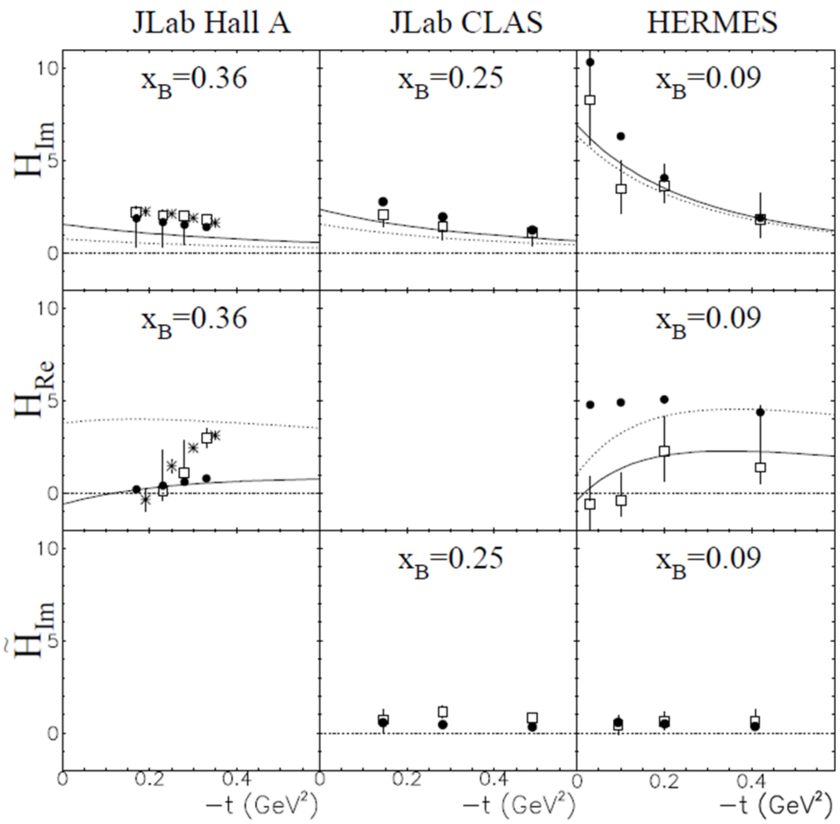




- *K. Kumerički and D. Müller, Nucl. Phys. B 841, (2010) 1*
  - Global fit to extract GPD H
  - A_C from HERMES, A_{LU} from CLAS, cross section from Hall A
  - Small x behaviour from HERA collider data

- *M. Guidal and H. Moutarde, Eur.Phys.J. A 42 (2009) 71*
  - Model-independent extraction of Compton form factors
  - Data from HERMES and JLAB

Extractions of GPDs

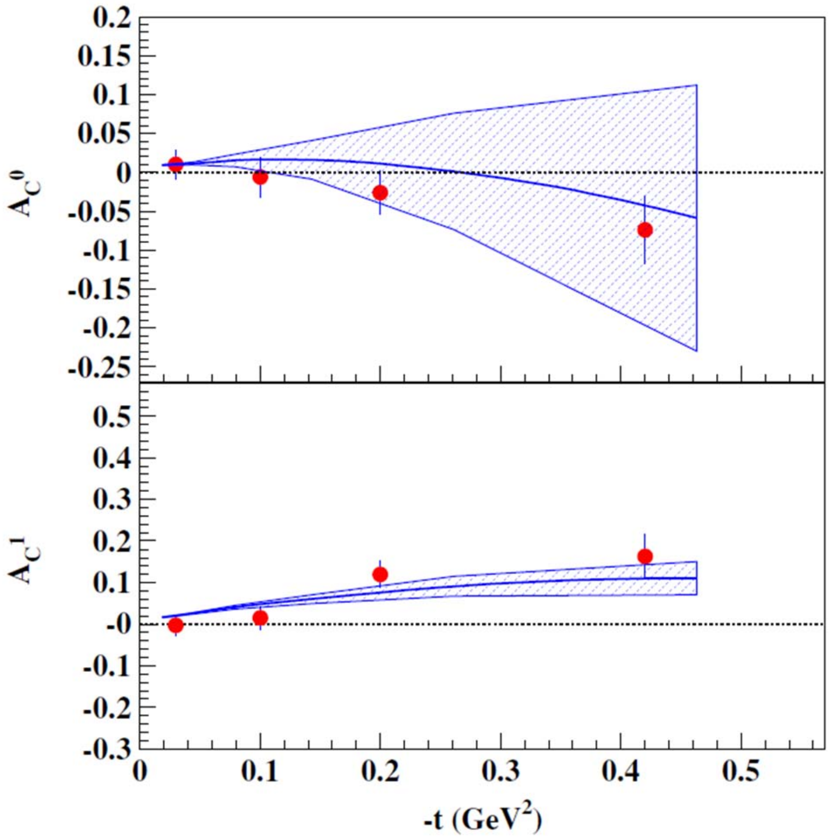


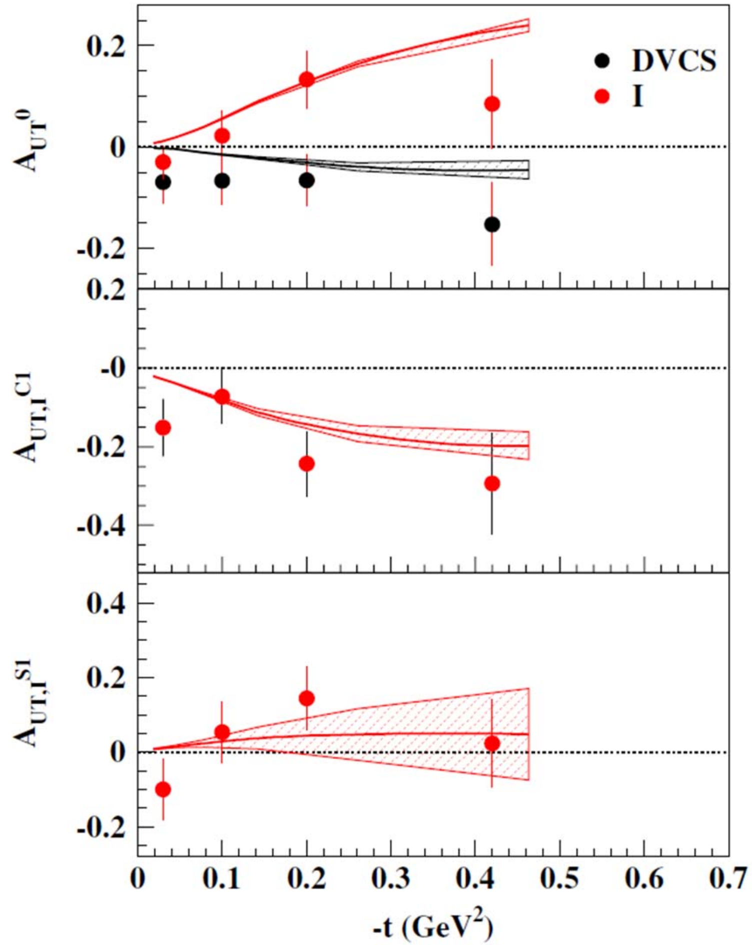
- *M. Guidal, arXiv:1011:4195*
  - Model-independent fit of CFFs
  - HERMES A_{LU}, A_C, A_{LL}, A_{UT}, A_{UL}
  - CLAS A_{LU}, A_{UL}
  - Hall A cross section
- Comparison with
  - — *K. Kumerički and D. Müller*
  - * *H. Moutarde, PRD 79 (2009) 094021*
  - □ *VGG*

Parameterizations of GPDs

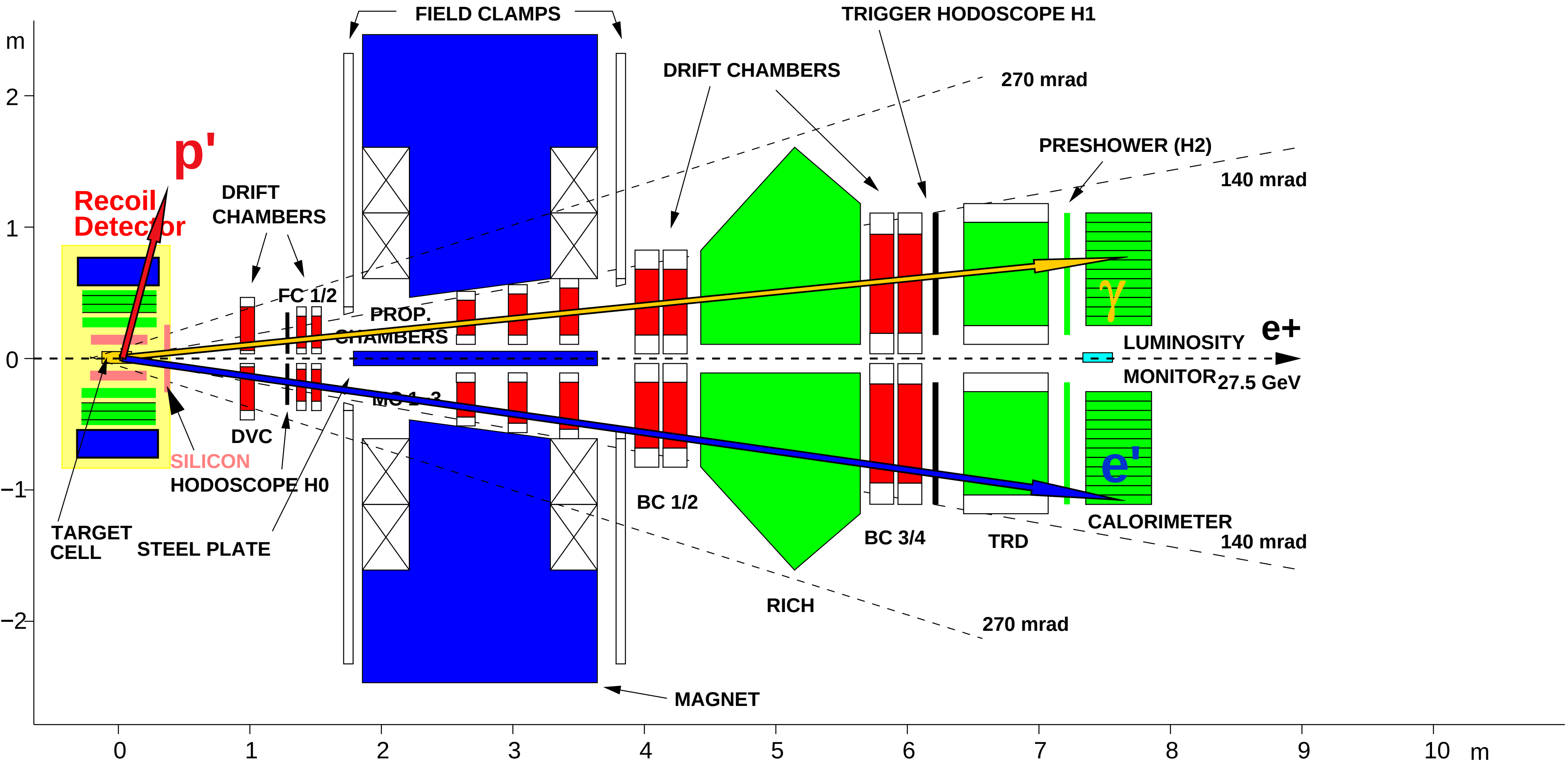
- *G. Goldstein, J. Hernandez, S. Liuti, Phys. Rev. D 84 034007 (2011)*
  Flexible Parameterization of Generalized Parton Distributions from DVCS Observables

- Fit JLAB data, predictions for HERMES



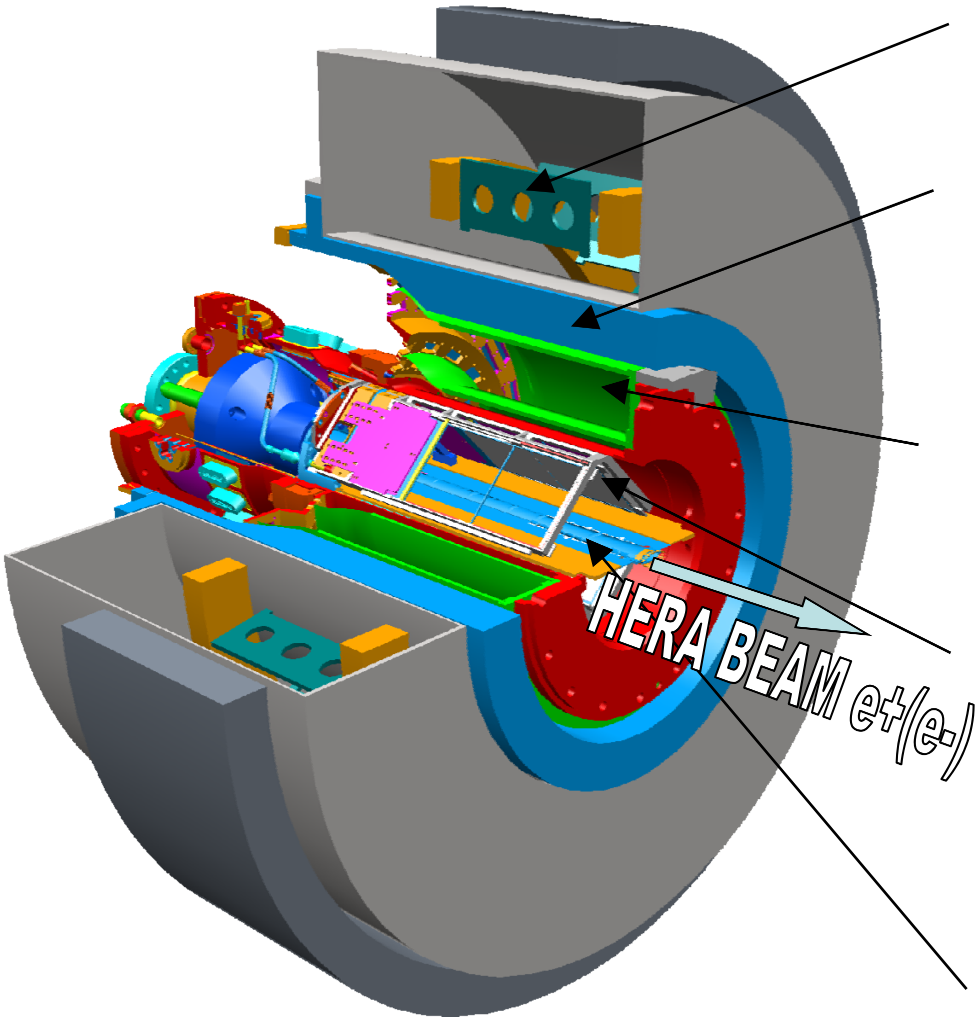


HERMES with the Recoil Detector (2006-2007)



- Two beam helicities, 27.57 GeV electron and positron beams
- Unpolarized hydrogen and deuterium targets

HERMES Recoil Detector



1 Tesla superconducting solenoid

Photon Detector (PD)

- detect gammas
- p/π PID for momentum > 600 MeV/c

Scintillating Fiber Tracker (SFT)

Momentum reconstruction by bending in magnetic field

Silicon Strip Detector (SSD)

- Inside the HERA vacuum
- 5 cm close to the beam
- Momentum reconstruction by energy deposit for protons and deuterons

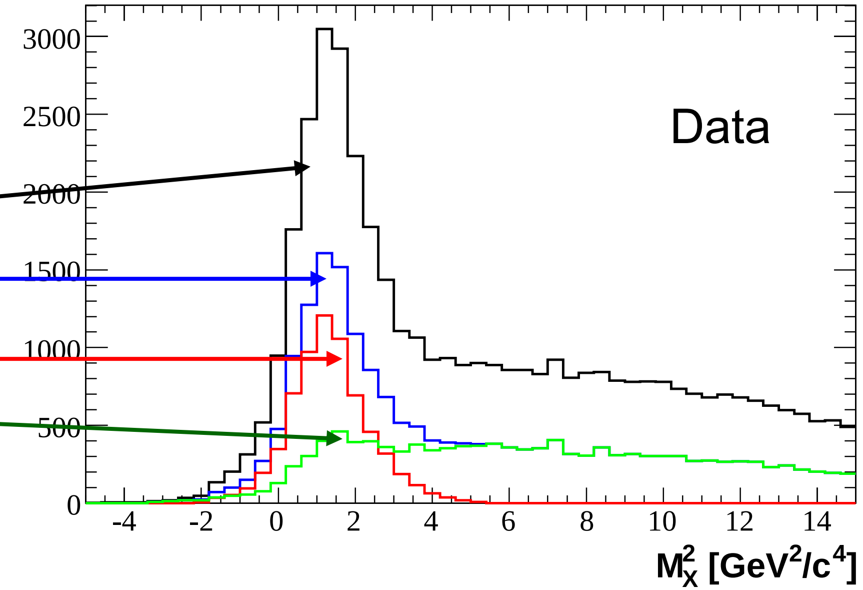
Target cell

- Unpolarized hydrogen and deuterium targets

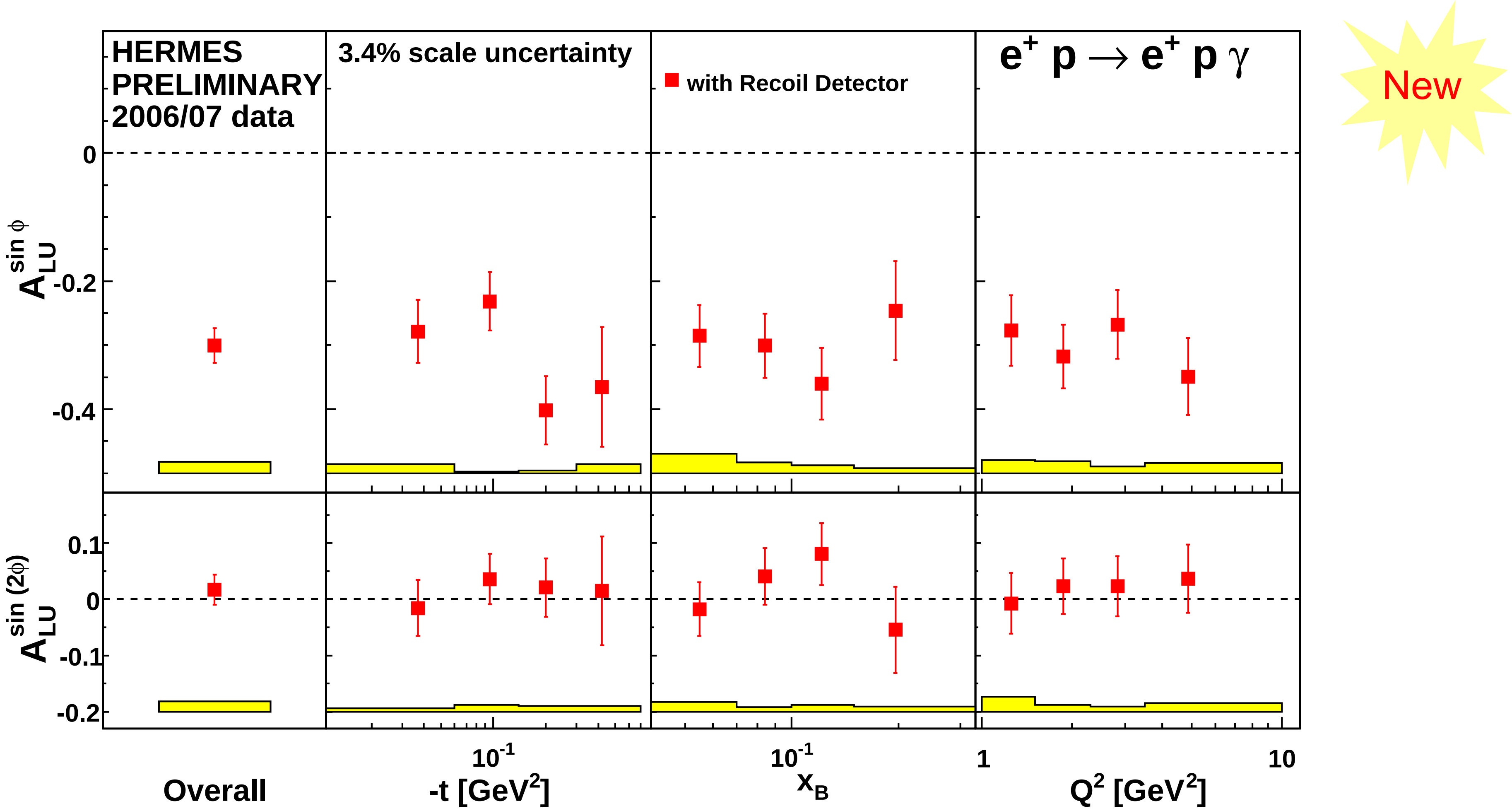
DVCS Event Selection with the Recoil Detector

- Kinematic event fitting technique
  - All 3 particles in final state detected → 4 constraints from energy-momentum conservation
  - Selection of pure BH/DVCS (ep→epγ) with high efficiency (~84%)
  - Allows to suppress background from associated and semi-inclusive processes to a negligible level (~0.1%)

- Missing mass distribution
  - No requirement for Recoil
  - Positively charged Recoil track
  - Kinematic fit probability > 1%
  - Kinematic fit probability < 1%



Beam-Helicity Asymmetry with the Recoil Detector



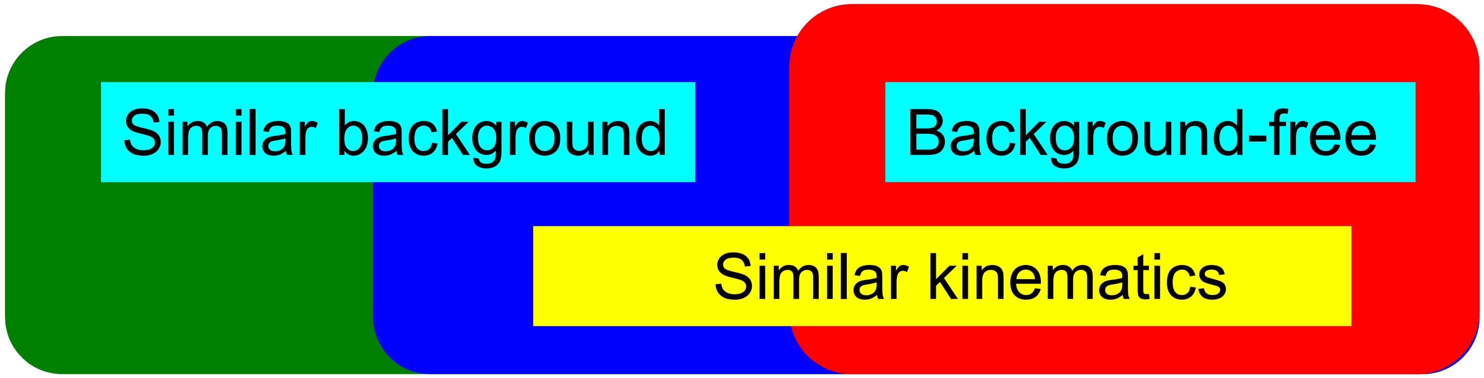
- Asymmetry amplitudes for pure BH/DVCS sample (background < 0.1%)

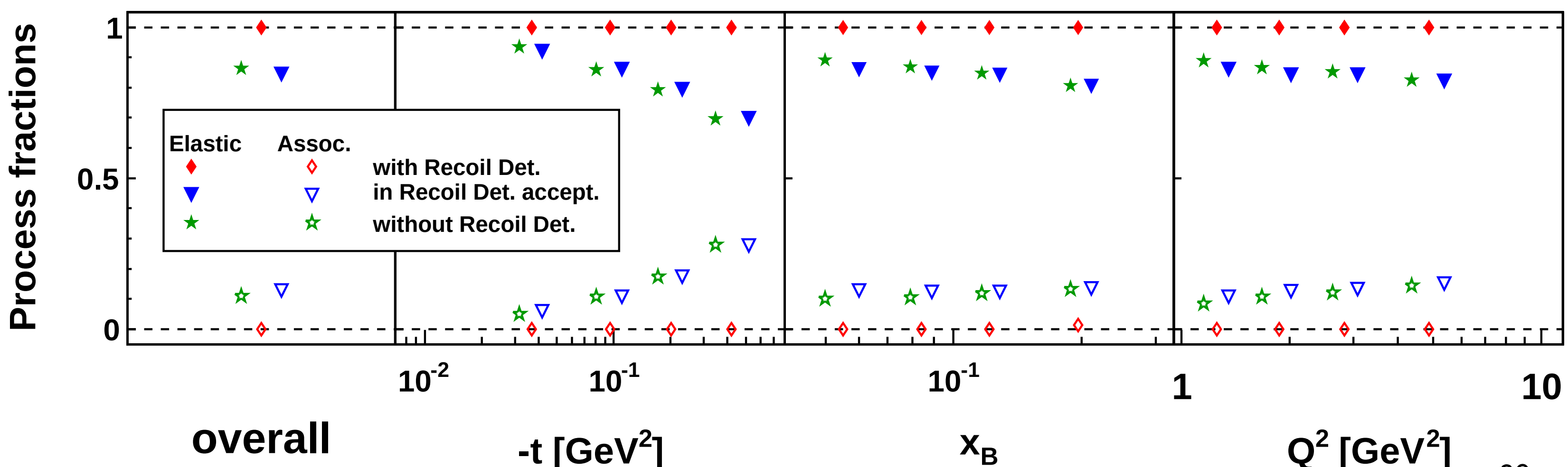
DVCS Event Samples

Without Recoil Detector

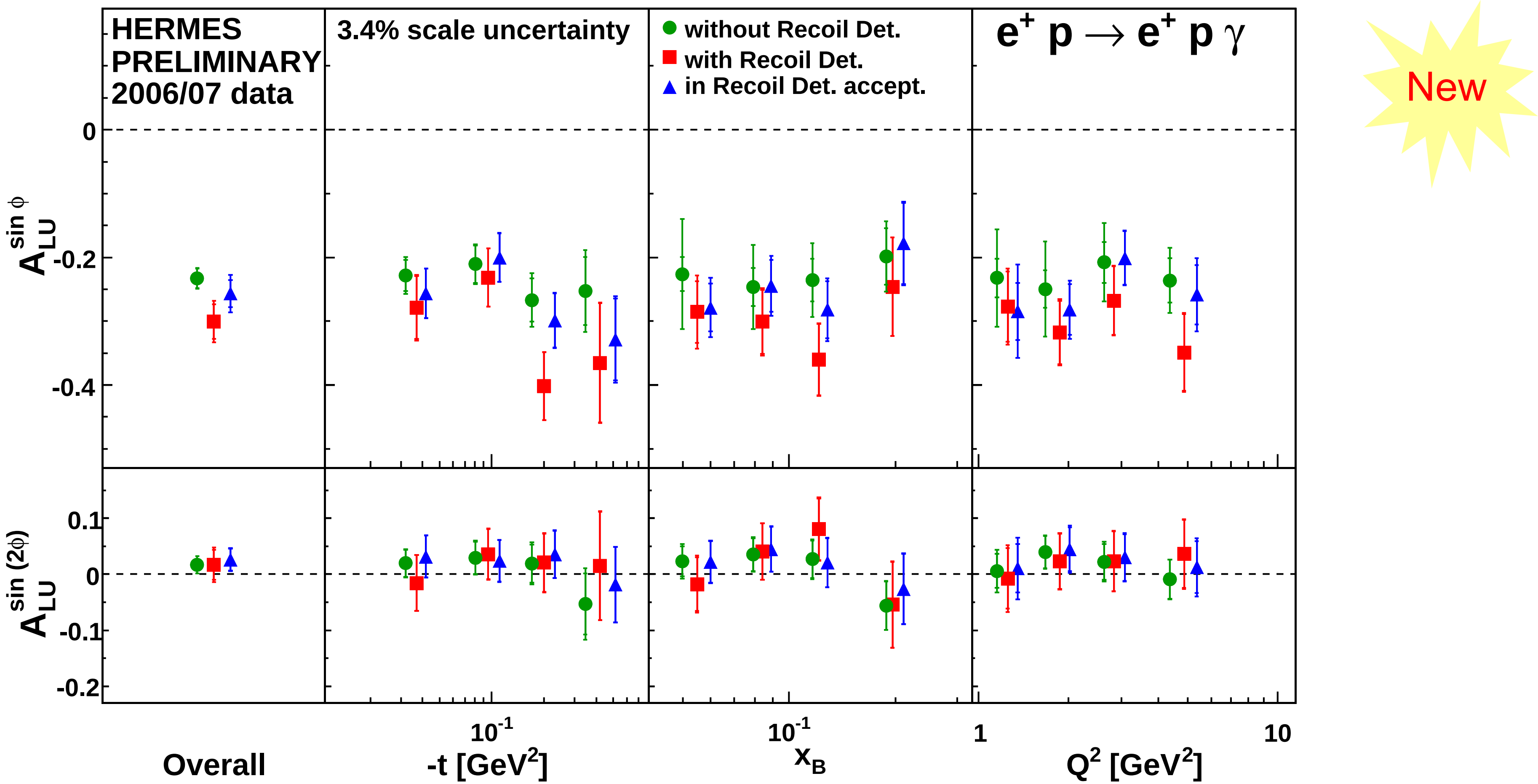
In Recoil Detector acceptance

With Recoil Detector





Comparison of All DVCS Data Samples



- Indication that the leading amplitude for pure BH/DVCS (background < 0.1%) is slightly larger in magnitude than the one in Recoil Detector acceptance
- Extraction of asymmetry amplitudes for associated processes is a subject of ongoing dedicated analysis

Summary

- HERMES produced and published many results on asymmetries in hard exclusive processes
- Essential input to the global GPD fits
- First results with Recoil Detector