Recent HERMES Results on DVCS and Associated Processes

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for the HERMES Collaboration
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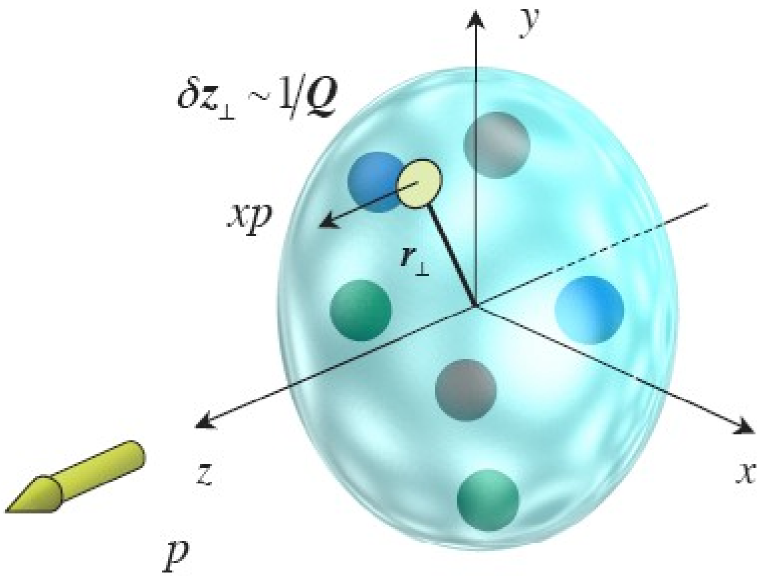
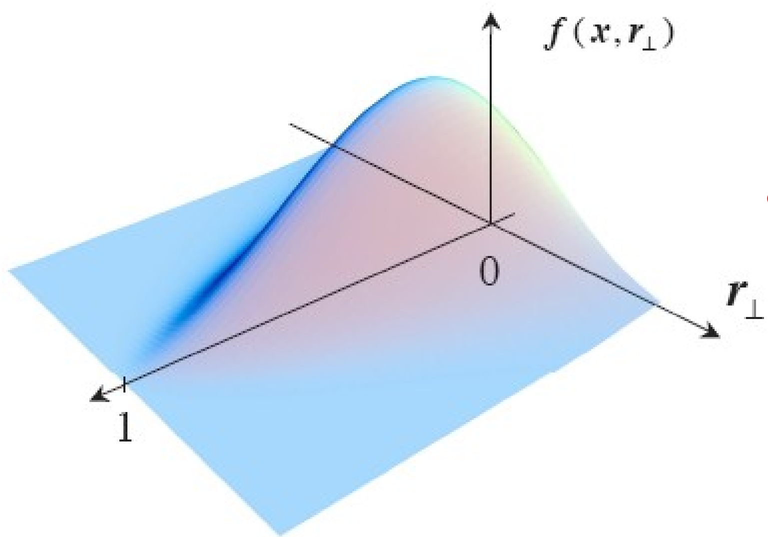
HELMHOLTZ ASSOCIATION

Generalized Parton Distributions (GPDs)





- Multidimensional description of nucleon structure (longitudinal momentum vs transverse position)
- Include parton distribution functions and form factors as forward limits and moments, respectively
- Can provide access to the total (and hence orbital) angular momentum of quarks in the nucleon via Ji relation:

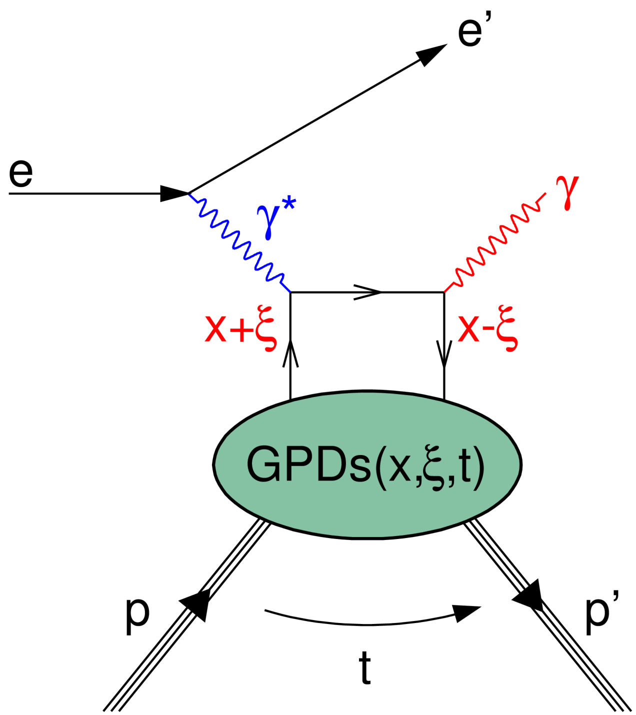
$$J_q = \lim_{t \to 0} \int_{-1}^{1} dx \; x[H_q(x,\xi,t) + E_q(x,\xi,t)]$$

- Four GPDs in case of proton target:

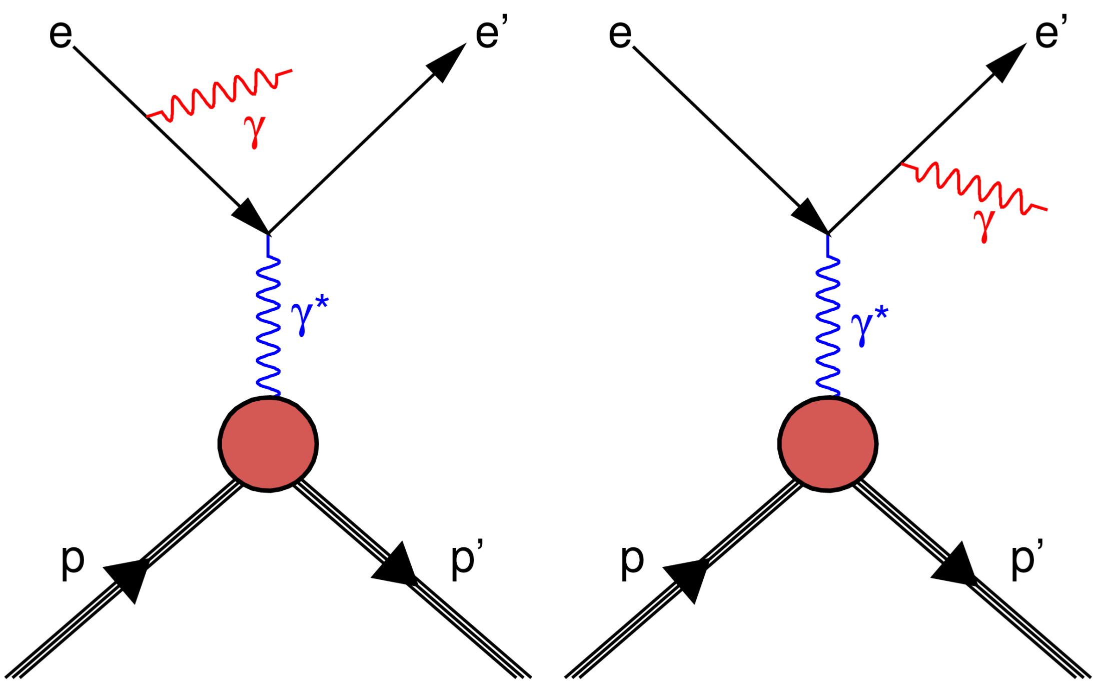
$$H, \widetilde{H}, E, \widetilde{E}$$

Deeply Virtual Compton Scattering (DVCS)

DVCS



Bethe-Heitler

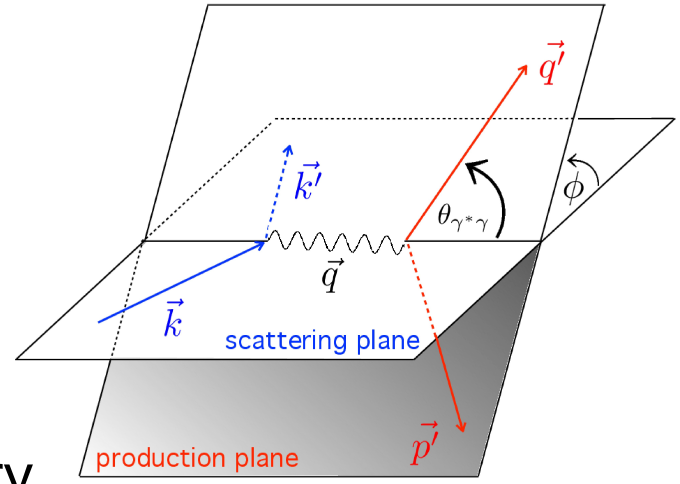


- The same initial and final state → interference
- Bethe-Heitle dominates at HERMES kinematics
- Access to GPDs through azimuthal asymmetries

Azimuthal Asymmetries in DVCS

- Cross section $\sigma_{LU}(\phi, P_B, C_B) =$

$$\sigma_{UU}[1 + P_B A_{LU}^{DVCS} + C_B P_B A_{LU}^{I} + C_B A_C$$



- Beam-charge asymmetry

$$A_C(\phi) = \frac{\sigma^+(\phi) - \sigma^-(\phi)}{\sigma^+(\phi) + \sigma^-(\phi)} \propto \Re e\mathcal{H}$$

- Charge-difference beam-helicity asymmetry

$$A_{LU}^{I}(\phi) = \frac{(\sigma^{+\rightarrow}(\phi) - \sigma^{+\leftarrow}(\phi)) - (\sigma^{-\rightarrow}(\phi) - \sigma^{-\leftarrow}(\phi))}{(\sigma^{+\rightarrow}(\phi) - \sigma^{+\leftarrow}(\phi)) + (\sigma^{-\rightarrow}(\phi) - \sigma^{-\leftarrow}(\phi))} \propto \Im m\mathcal{H}$$

- Charge-averaged beam-helicity asymmetry

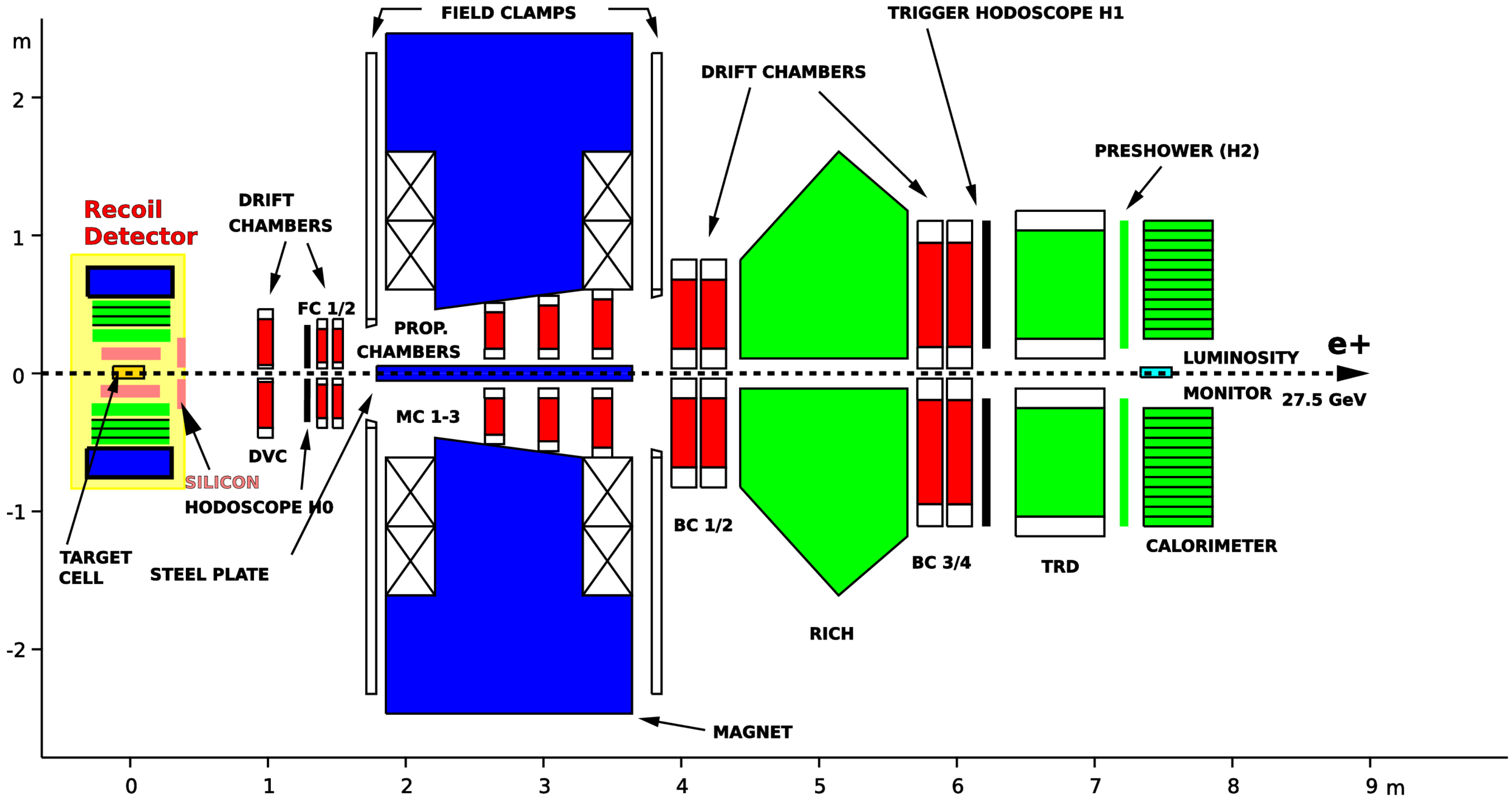
$$A_{LU}^{DVCS}(\phi) = \frac{(\sigma^{+\rightarrow}(\phi) + \sigma^{-\rightarrow}(\phi)) - (\sigma^{+\leftarrow}(\phi) + \sigma^{-\leftarrow}(\phi))}{(\sigma^{+\rightarrow}(\phi) + \sigma^{-\rightarrow}(\phi)) + (\sigma^{+\leftarrow}(\phi) + \sigma^{-\leftarrow}(\phi))} \propto \Im m[\mathcal{H}\mathcal{H}^* + \widetilde{\mathcal{H}}\widetilde{\mathcal{H}}^*]$$

- Separation of contribution from DVCS and interference term

- Impossible in case of single-charge asymmetry

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

HERMES Spectrometer

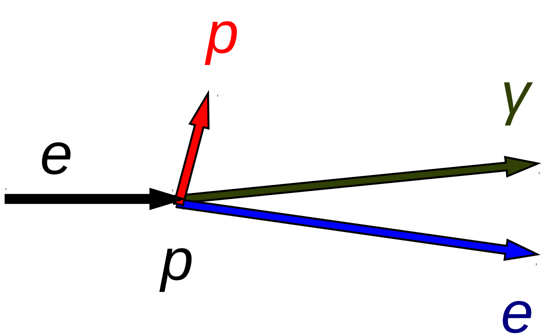


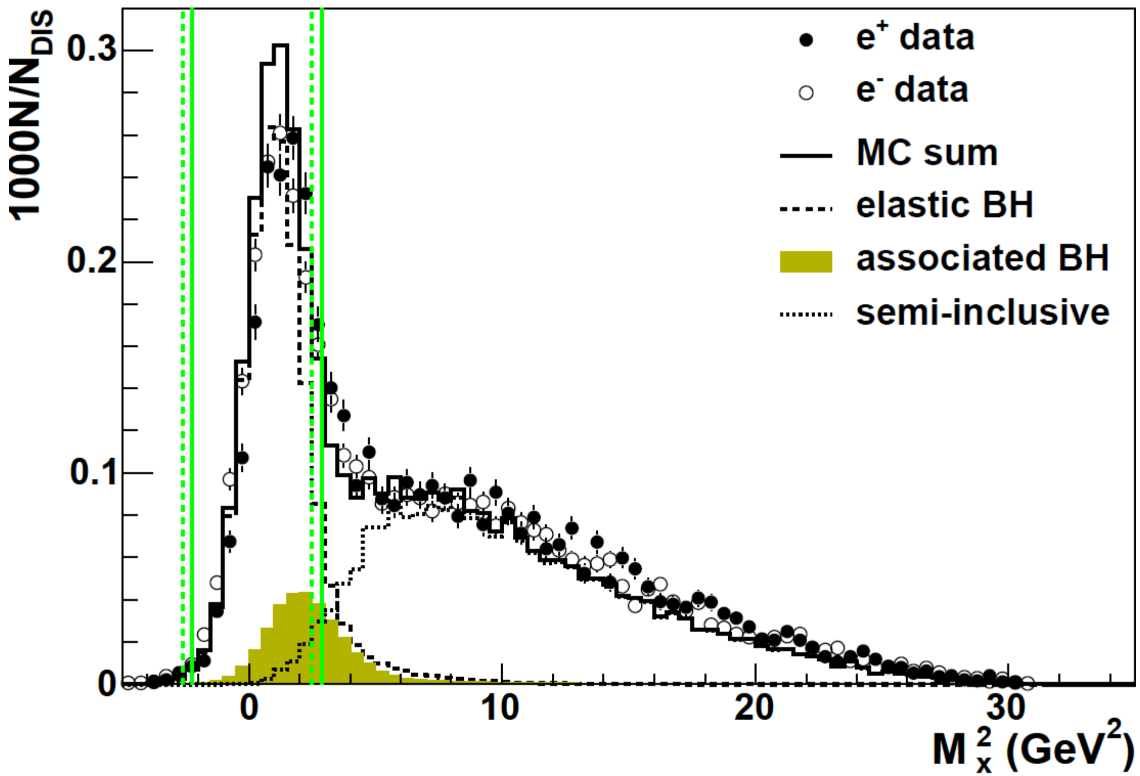
- Electron and positron beams 27.6 GeV
- Unpolarized Hydrogen and Deuterium targets
- Good momentum resolution (<2%)
- Excellent particle identification

Selection of DVCS Events without Recoil Detector

- Selection of *ep → eγp* events using missing-mass method
- Corrections for SIDIS background (3%)
- Background from associated process (12%) is part of the signal

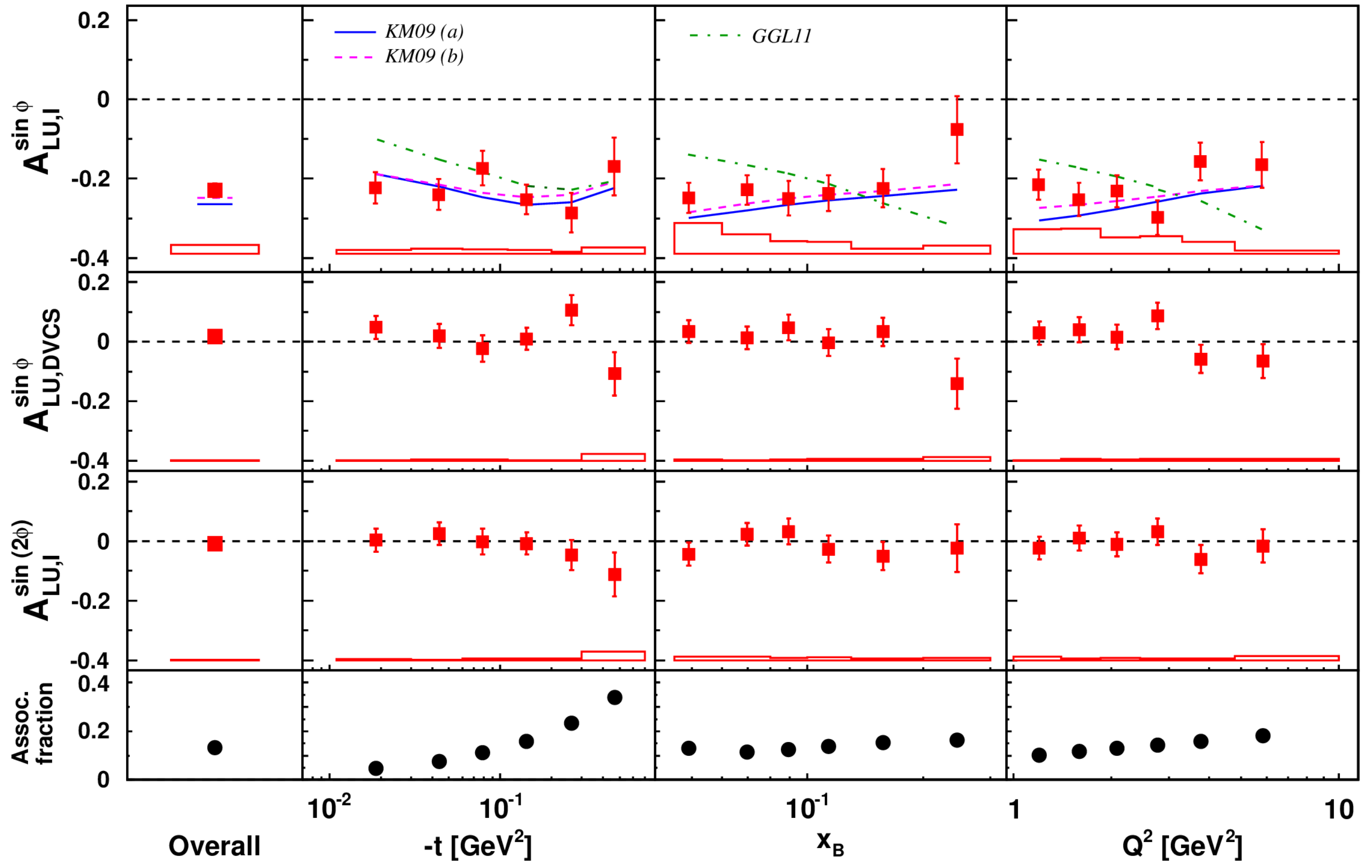
ep → eγp





Beam-Helicity Asymmetry

Published: *A. Airapetian et al, JHEP 07 (2012) 032*

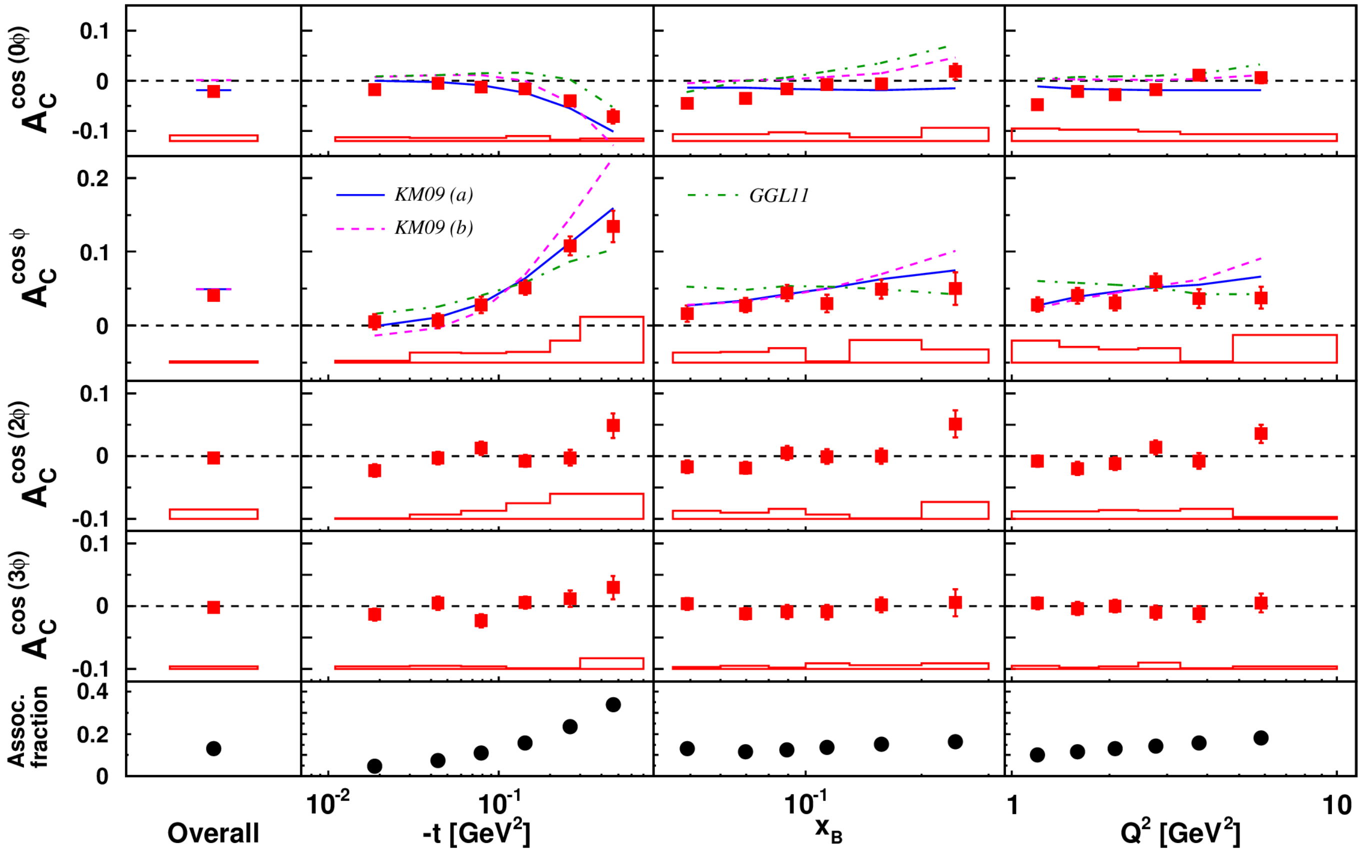


$\propto \Im m \mathcal{H}$

- Compared with GPD models/fits
  - Blue, magenta: *K. Kumerički and D. Müller, Nucl. Phys. B841 (2010)*
  - Green: *G. Goldstein, J. Hernandez and S. Liuti, Phys. Rev. D84 (2011)*

Beam-Charge Asymmetry

Published: *A. Airapetian et al, JHEP 07 (2012) 032*



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- Compared with GPD models/fits
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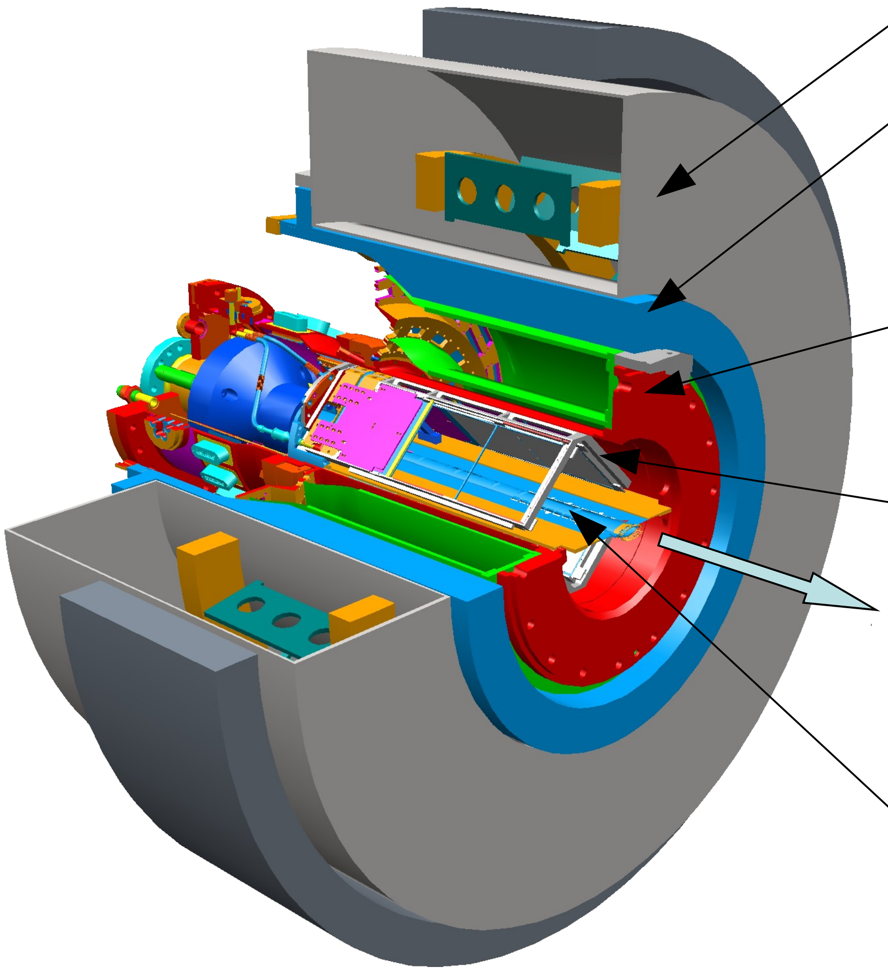
HERMES Recoil Detector



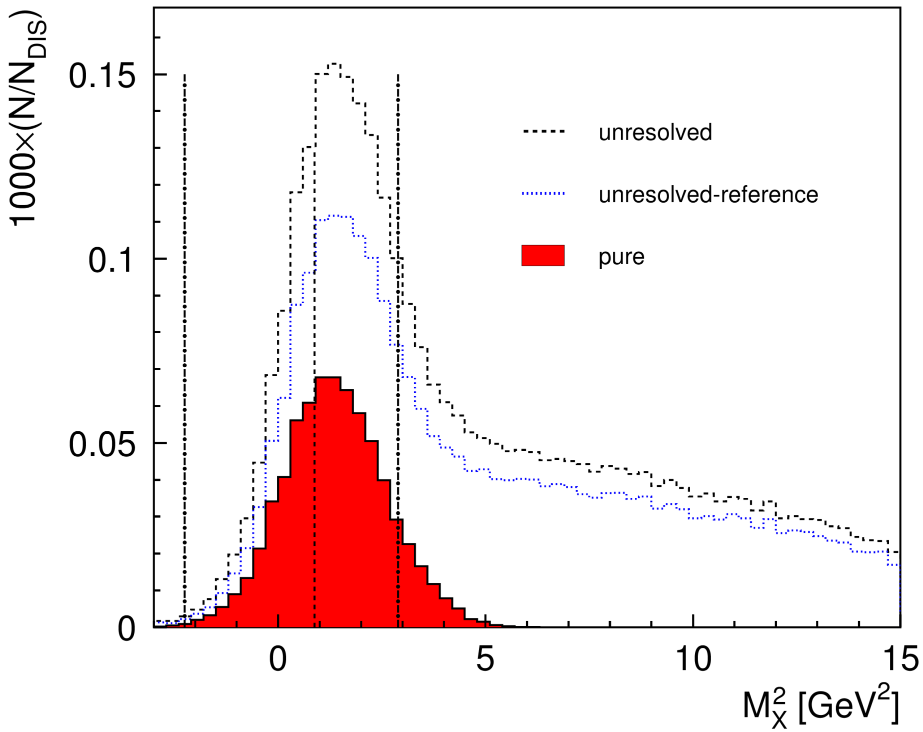
- 1 Tesla superconducting solenoid
- Photon Detector (PD)
  - Detect photons
  - p/π PID for momentum > 600 MeV/c
- Scintillating Fiber Tracker (SFT)
  - Momentum reconstruction by bending in the magnetic field
- Silicon Strip Detector (SSD)
  - Inside the HERA vacuum
  - 5 cm close to the HERA beam
  - Momentum reconstruction by energy deposit for protons and deutrons
- Target cell
  - Unpolarized hydrogen and deuterium targets

arXiv:1302.6092, accepted by JINST

Selection of DVCS Events with the Recoil Detector

- All particles in the final state detected
- Kinematic fitting: 4 constraints from energy-momentum conservation
- Selection of pure $ep \rightarrow e\gamma p$ events with background below 0.2%

Missing mass distribution
- No requirement for Recoil
- In the Recoil acceptance
- Kinematic fit probability > 1%

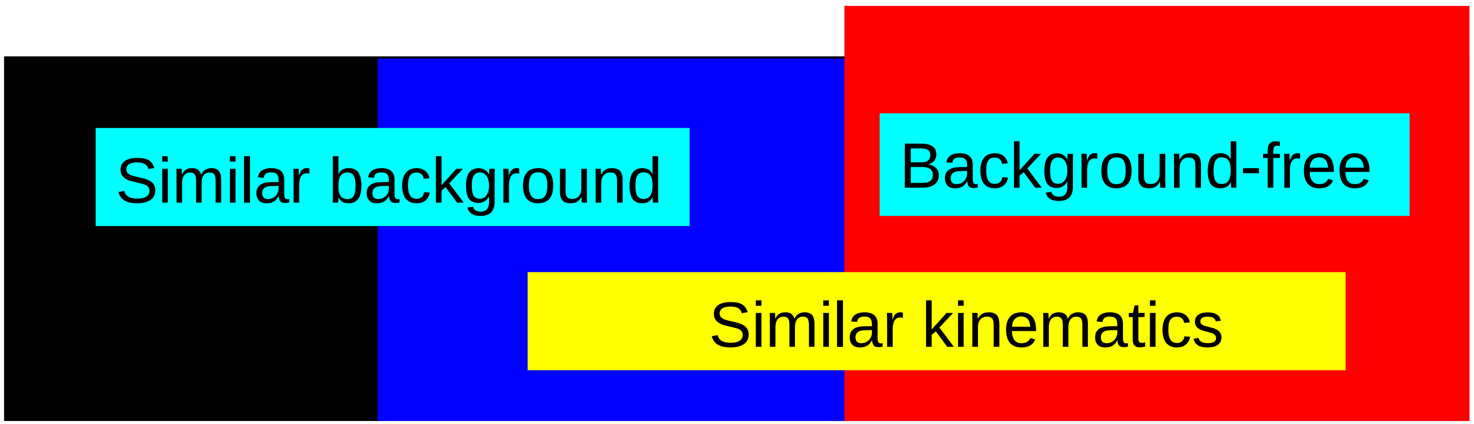


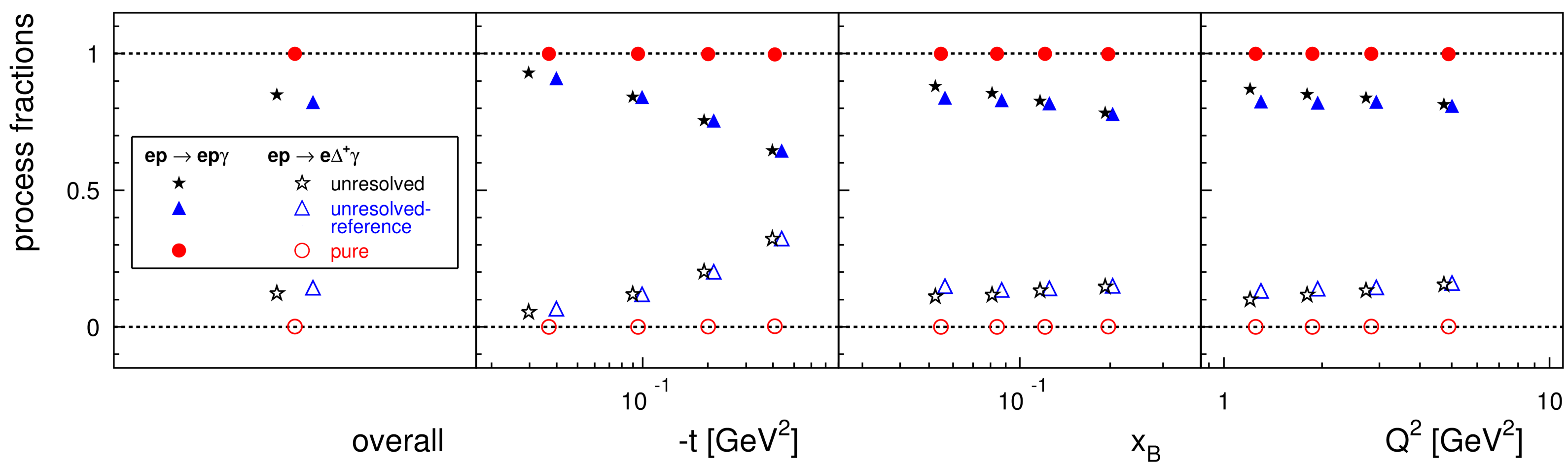
DVCS Event Selection with the Recoil Detector

Unresolved (without Recoil Detector)

Unresolved-reference (in RD acceptance)

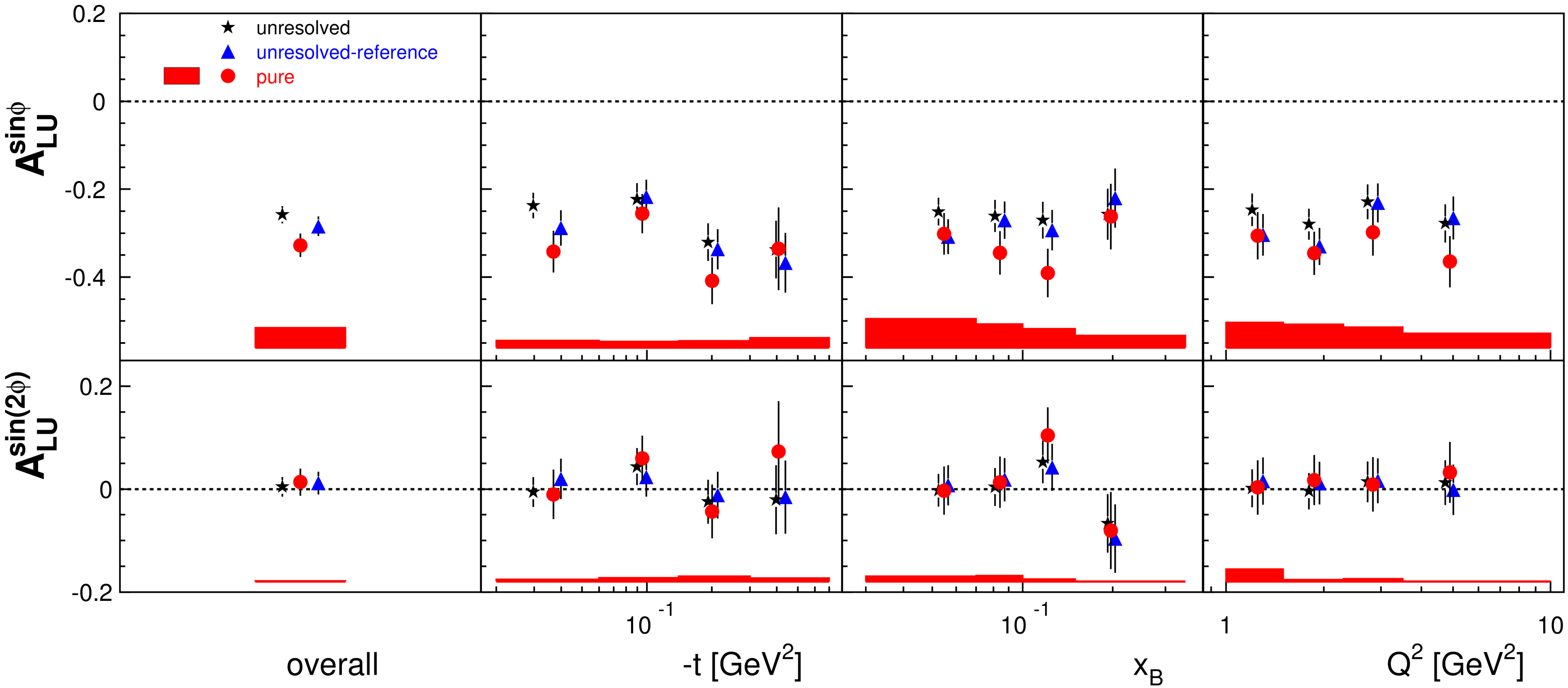
Pure (with RD)





Results for all DVCS Data Samples

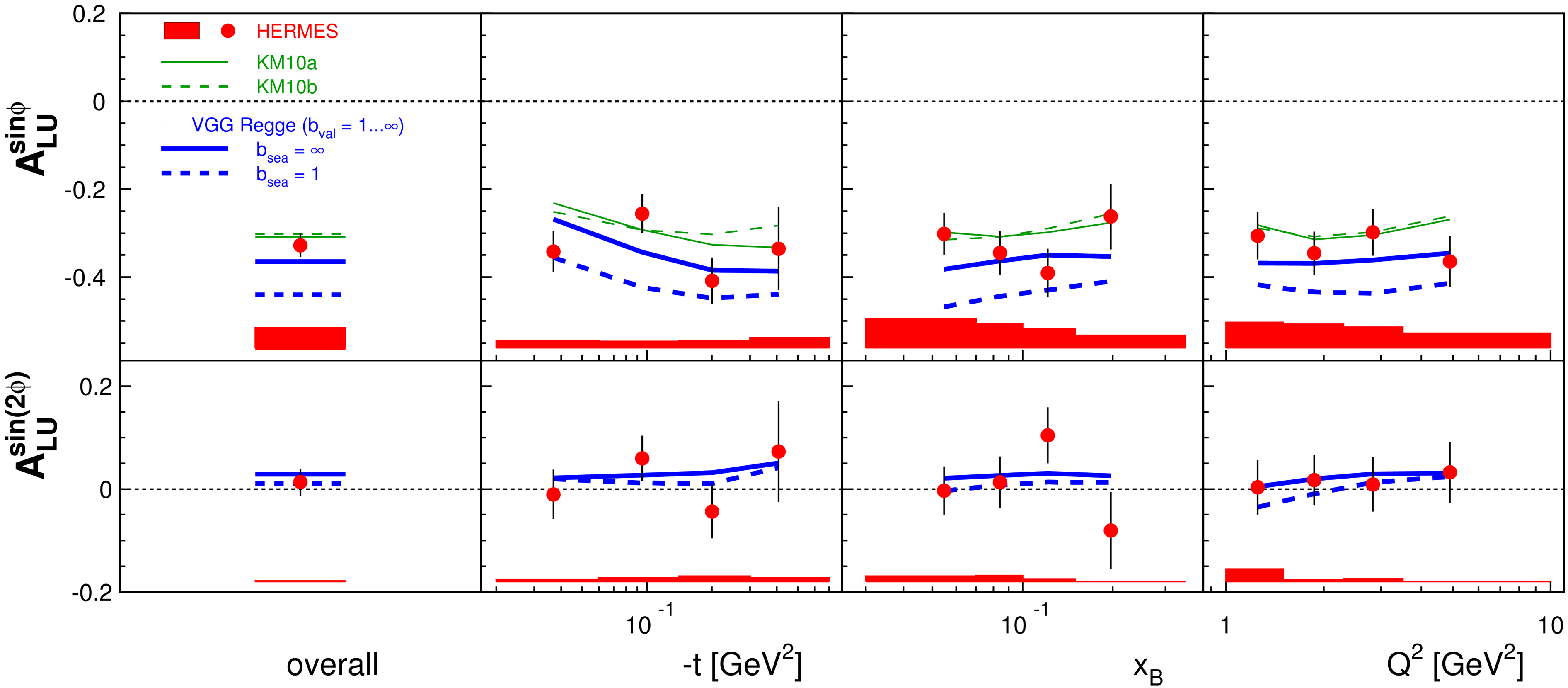
Published: *JHEP 10 (2012) 042*



- Leading amplitude for pure DVCS/BH is slightly larger in magnitude than the one in the Recoil Detector acceptance

Comparison with Theoretical Calculations

Published: *JHEP 10 (2012) 042*

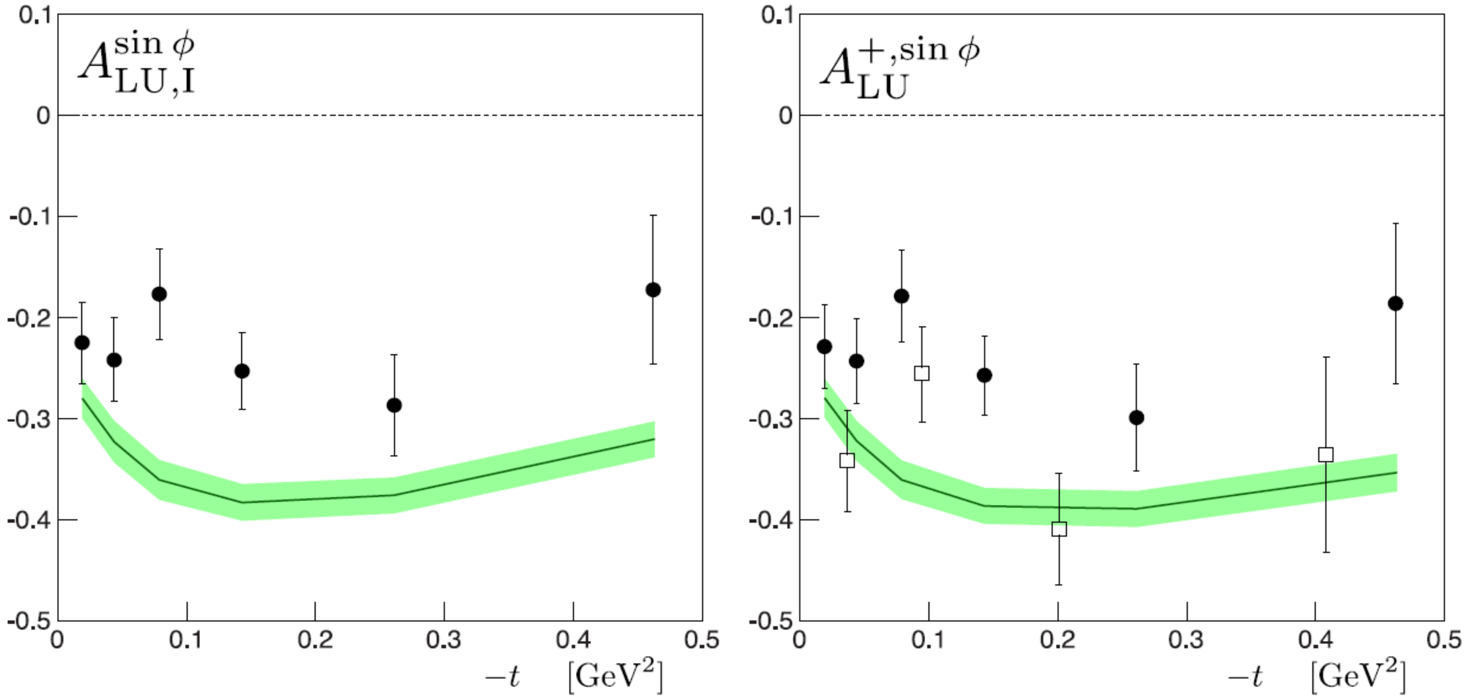


- GPD models and fits reasonably describe data

  M. Vanderhaeghen, P.A.M. Guichon, and M. Guidal, Phys. Rev. D 60 (1999) 094017

  K. Kumerički and D. Müller, Nucl. Phys. B 841 (2010) 1

Comparison with Theoretical Calculations



- GPD model originally developed to describe exclusive meson production

  Peter Kroll, Hervé Moutarde, Franck Sabatié, From hard exclusive meson electroproduction to deeply virtual Compton scattering, Eur. Phys. J. C (2013) 73:2278

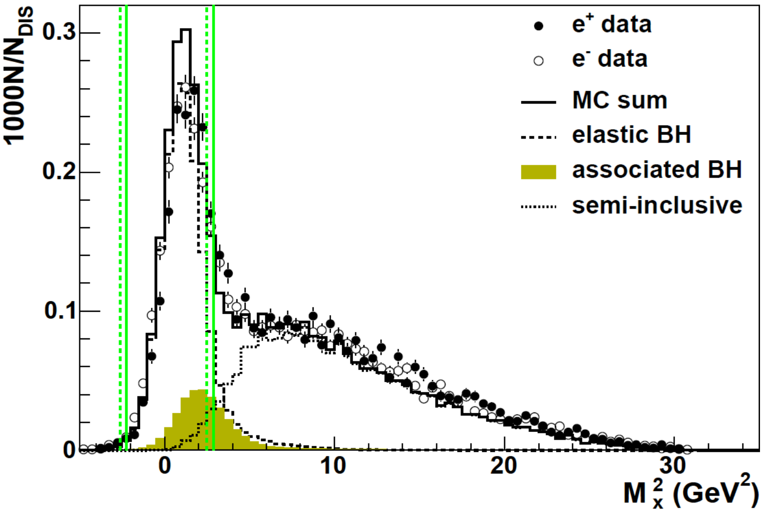
  In comparison with HERMES data

  Full points – DVCS pre-Recoil data, *JHEP 07 (2012) 032*

  Open points – DVCS Recoil data, *JHEP 10 (2012) 042*

Associated Production $ep \rightarrow e\gamma N\pi$ in the Δ-resonance Region

- Delta resonance region → possible access to transition GPDs

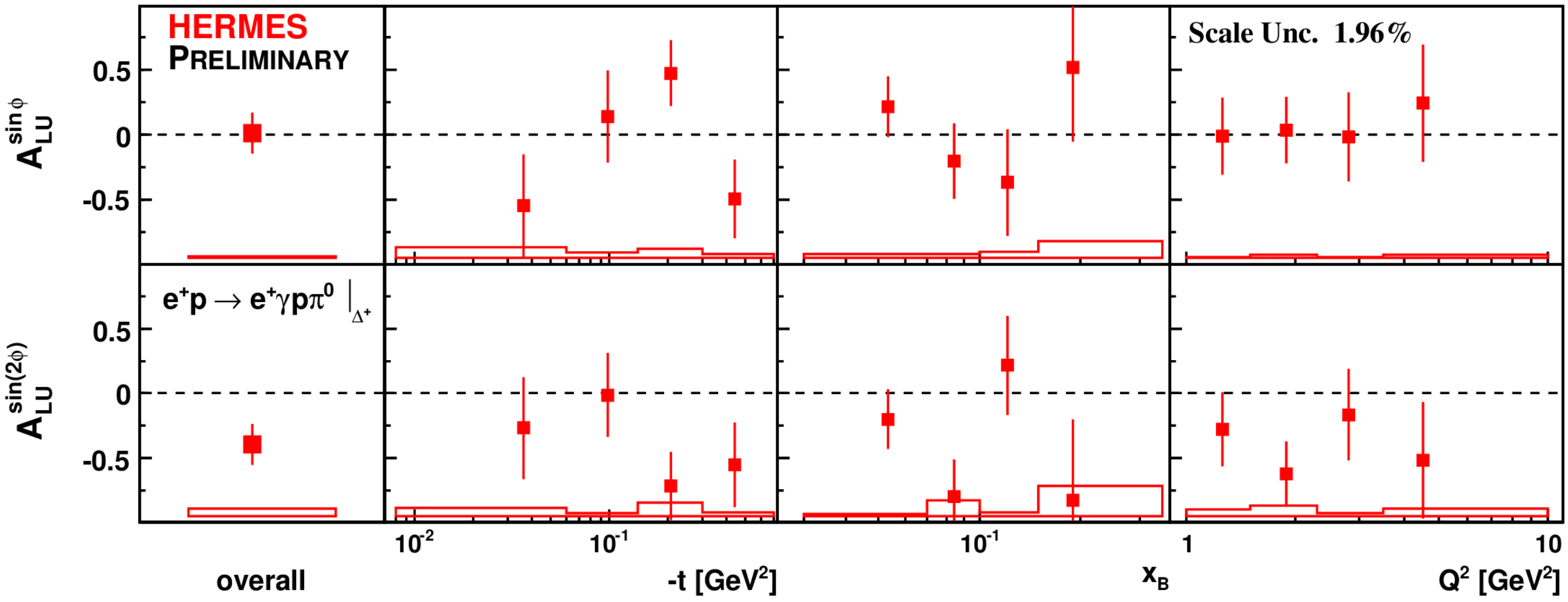


- Selection of associated events $ep \rightarrow e\gamma p\pi^0$ and $ep \rightarrow e\gamma n\pi^+$:
  - The yield is much smaller than that of $ep \rightarrow e\gamma p$
  - The SIDIS yield is not negligible
  - One particle is undetected

- Kinematic fitting under hypotheses of $ep \rightarrow e\gamma N\pi$ and $ep \rightarrow e\gamma p$
  - To select associated processes $ep \rightarrow e\gamma p\pi^0$ and $ep \rightarrow e\gamma n\pi^+$
  - To reject background from $ep \rightarrow e\gamma p$ (to the level below 1%)
- Particle identification in the Recoil Detector
- Results are corrected for SIDIS background
  - 13% in case of $ep \rightarrow e\gamma p\pi^0$, 24% in case of $ep \rightarrow e\gamma n\pi^+$

Results on Beam-Helicity Asymmetry for $ep \rightarrow e\gamma p\pi^0$

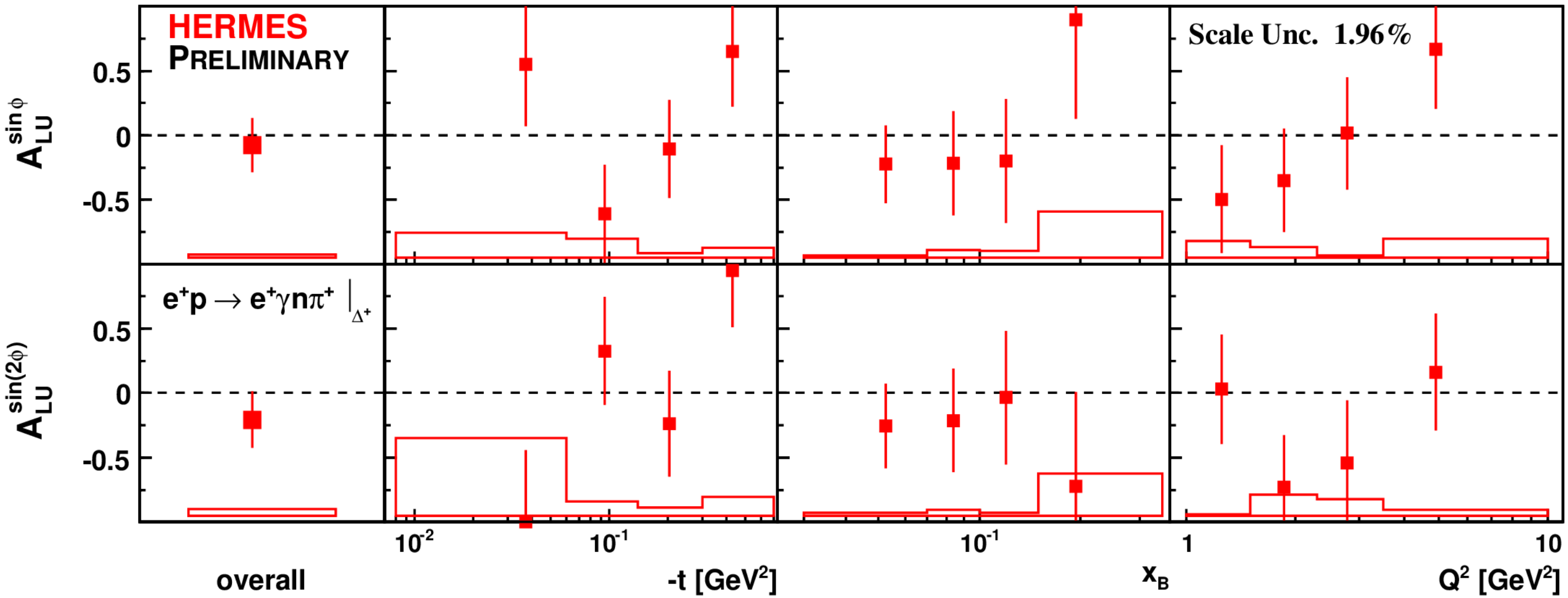
New



- Leading asymmetry amplitude consistent with zero
- Contributes as a dilution in DVCS/BH asymmetry

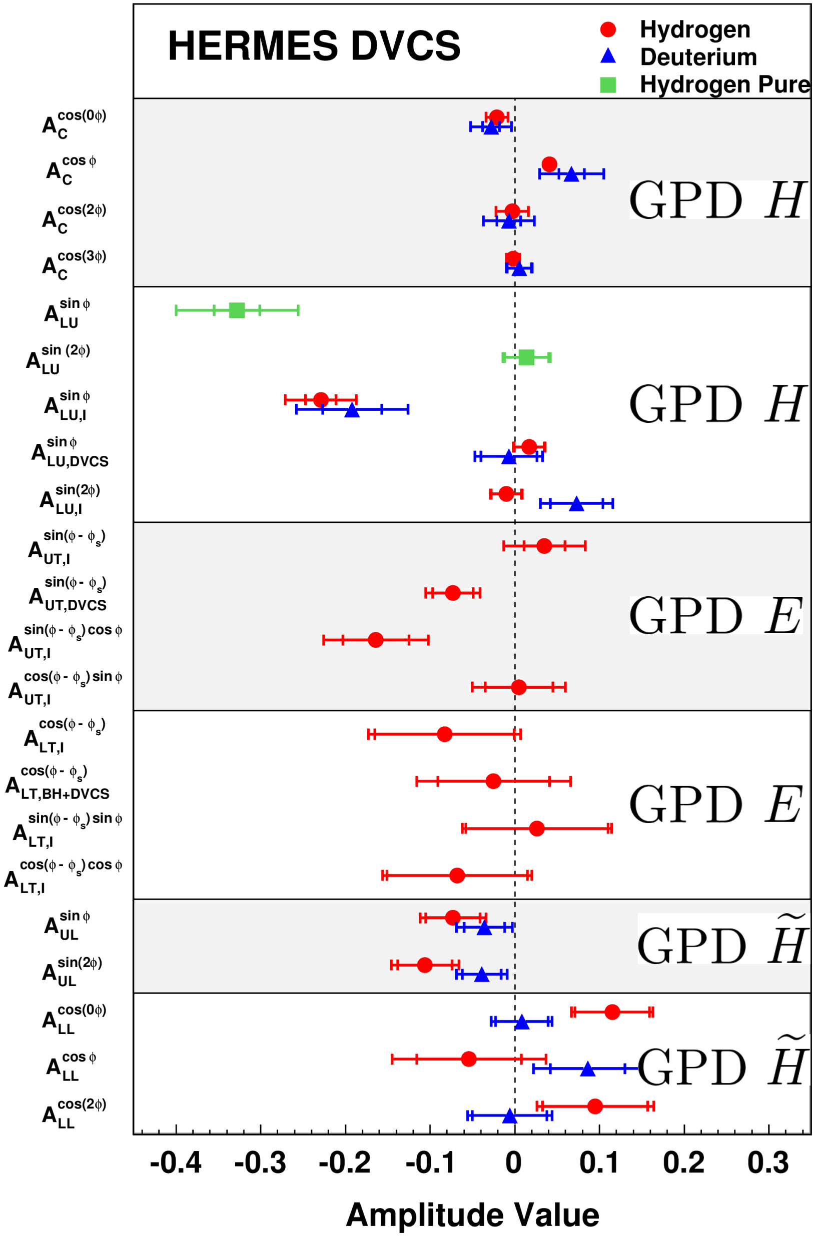
Results on Beam-Helicity Asymmetry for $ep \rightarrow e\gamma n\pi^+$

New



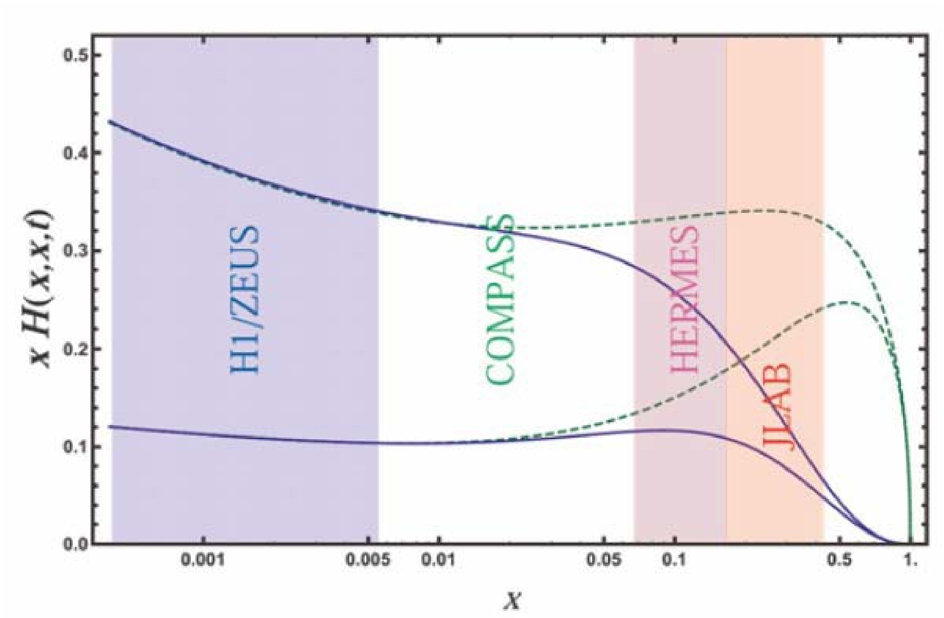
- All asymmetry amplitudes consistent with zero
- Contributes as a dilution in DVCS/BH asymmetry

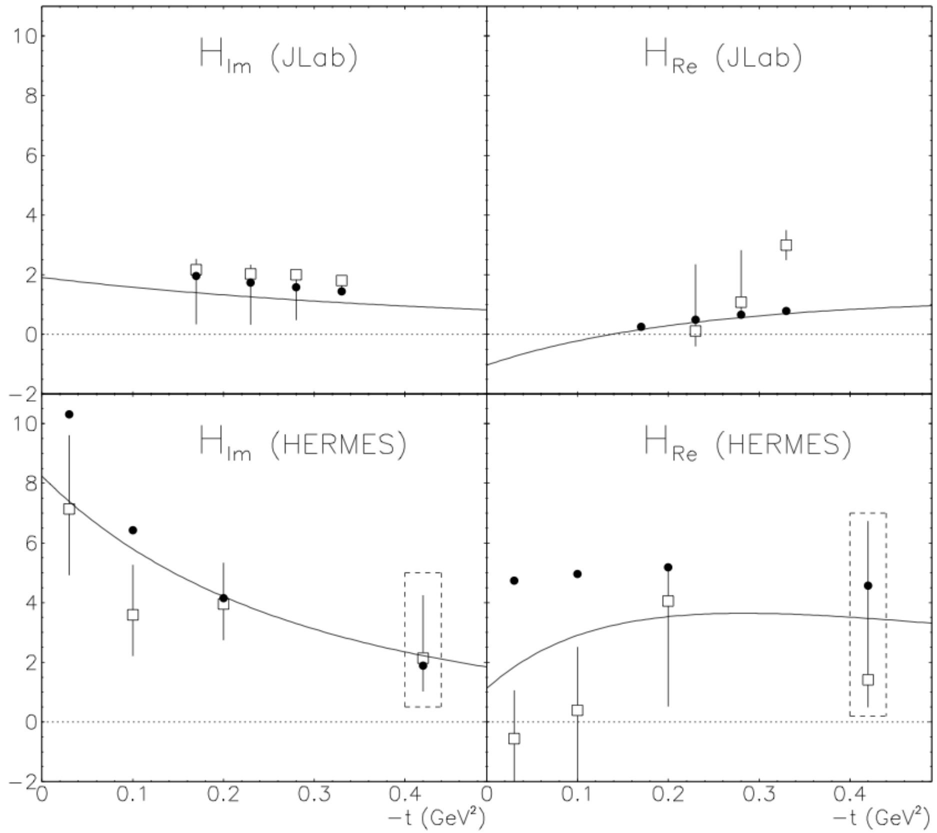
Overview of Published HERMES DVCS Results



- Beam-charge and beam-spin asymmetry
  - *PRL 87 (2001) 182001*
  - *PRD 75 (2007) 011103*
  - *JHEP 11 (2009) 083*
  - *JHEP 07 (2012) 032*, *JHEP 10 (2012) 042*
  - *Nucl. Phys. B 829 (2010) 1*
- Transverse target-spin asymmetry
  - *JHEP 06 (2008) 066*
- Transverse double-spin asymmetry
  - *Phys. Lett. B 704 (2011) 15*
- Longitudinal target spin asymmetry
  - *JHEP 06 (2010) 019*
- Longitudinal target & double spin asymmetry
  - *Nucl. Phys. B 842 (2011) 265*

Extraction of GPDs and Compton Form Factors



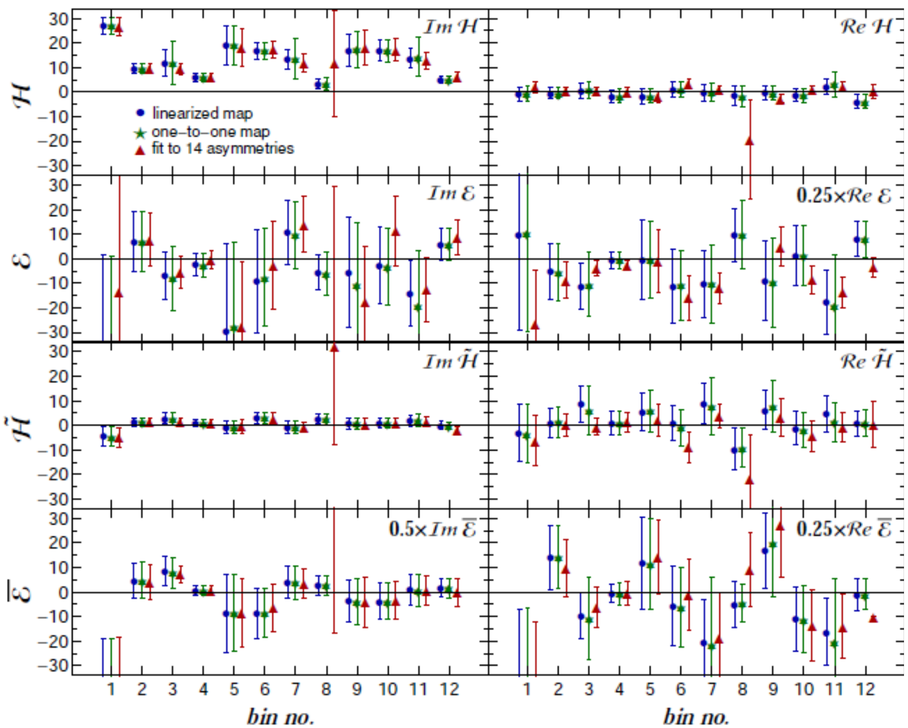


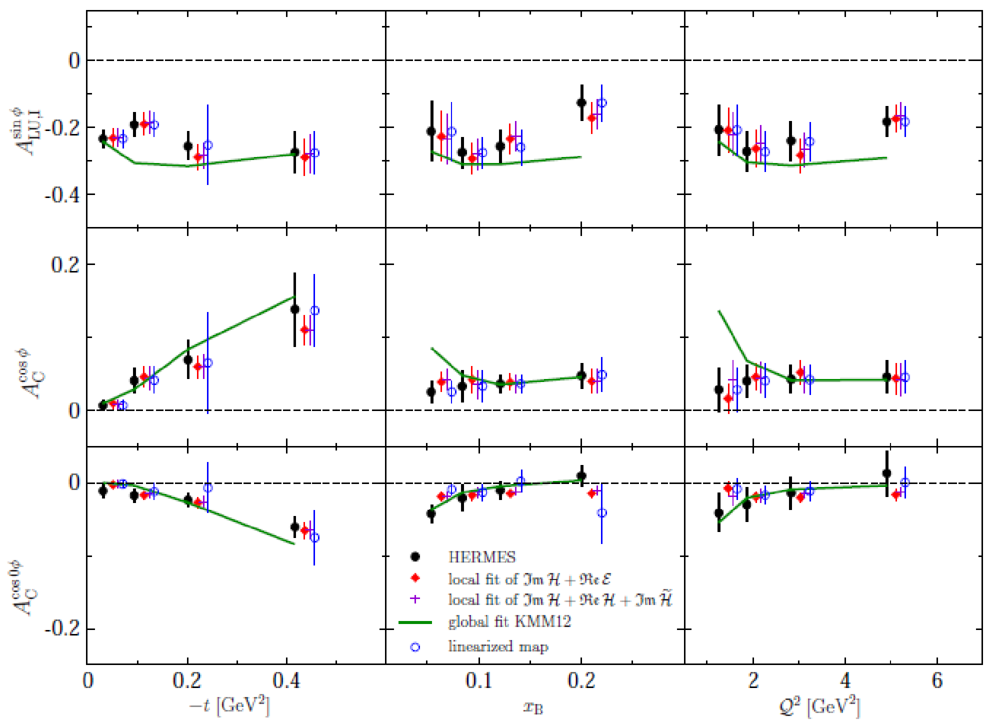
K. Kumerički and D. Müller,
Nucl. Phys. B 841, (2010) 1

M. Guidal and H. Moutarde,
Eur.Phys.J. A 42 (2009) 71

HERMES Impact for the Access of Compton Form Factors

- Map various asymmetries into the space of Compton form factors
- Rely on dominance of twist-two Compton form factors
- Compare with local CFF fits and a model dependent global fit





K. Kumerički, D. Müller, and M. Murray, arXiv:1301.1230

Summary

- High-statistics results on beam-helicity and beam charge asymmetries in DVCS – published

- Results with the Recoil detector
  - Beam-helicity asymmetry in DVCS – published
  - Beam-helicity asymmetry in associated processes $ep \rightarrow e\gamma p\pi^0$ and $ep \rightarrow e\gamma n\pi^+$ in the Δ-resonance region – preliminary

- Significant contribution to constrain GPDs

Backup: Theoretical Model for Associated Processes

- *P. Guichon, L. Mosse, M. Vanderhaegen, Phys. Rev. D 68, 034018 (2003)*
- Twist-2 level
- Pion production ep→eγNπ near threshold
  - Soft pion limit ($k_\pi \to 0$)
  - Based on chiral symmetry ($m_\pi \to 0$)
- Predictions for HERMES, JLAB, and Compass
- Model dependent estimate of ep→eγΔ
  - Large N_c limit
  - Relate the GPDs of the N→Δ transition to those of the N→N transition