Hard Exclusive Leptoproduction of Photons and Mesons at HERMES

Recent Results

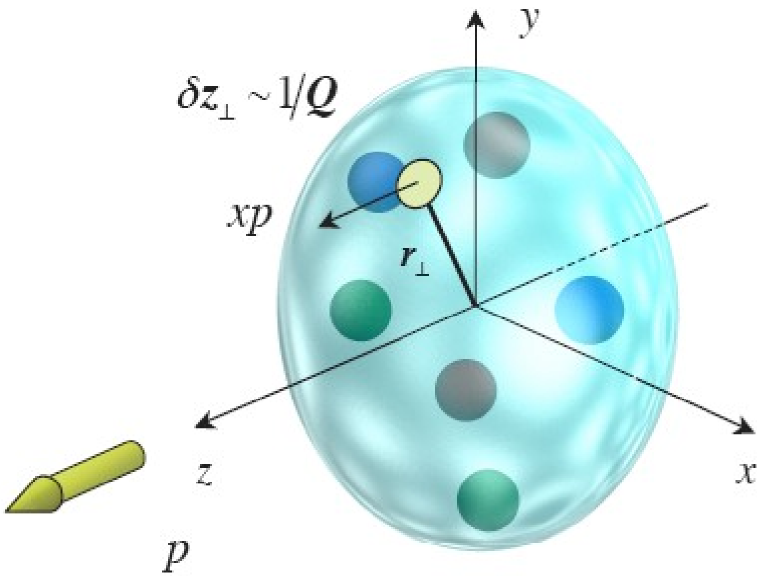
Sergey Yashchenko (DESY)
on behalf of the HERMES Collaboration
Hamburg University, 26.08.2014

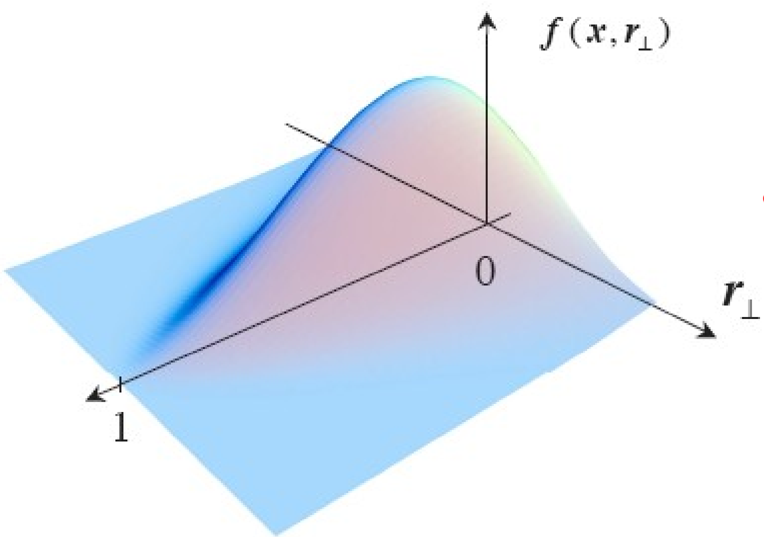
HELMHOLTZ ASSOCIATION

hermes

DESY

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:

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

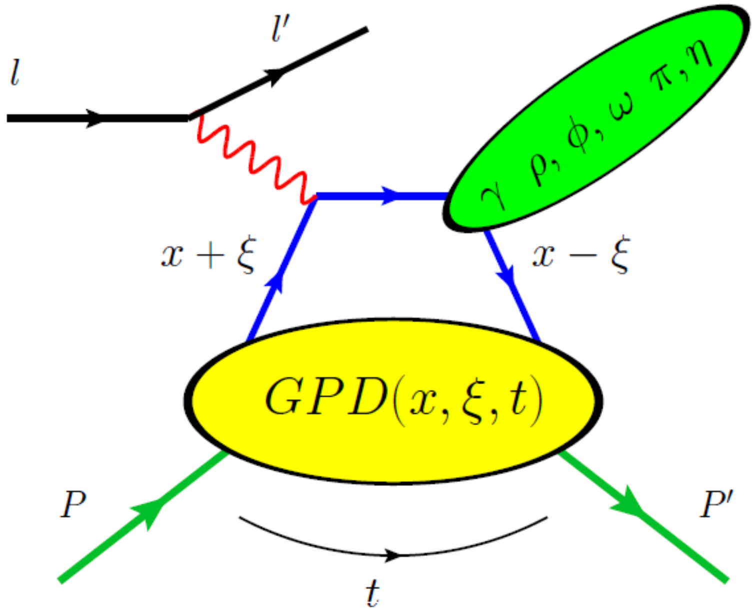
Experimental Probes of GPDs: Hard Exclusive Reactions

> Deeply virtual Compton scattering (DVCS)

- Theoretically the cleanest probe of GPDs
- GPDs are accessed through convolution integrals with hard scattering amplitude
- Sensitivity to all GPDs $H, \widetilde{H}, E, \widetilde{E}$
- Observables: azimuthal asymmetries, cross sections, cross section differences

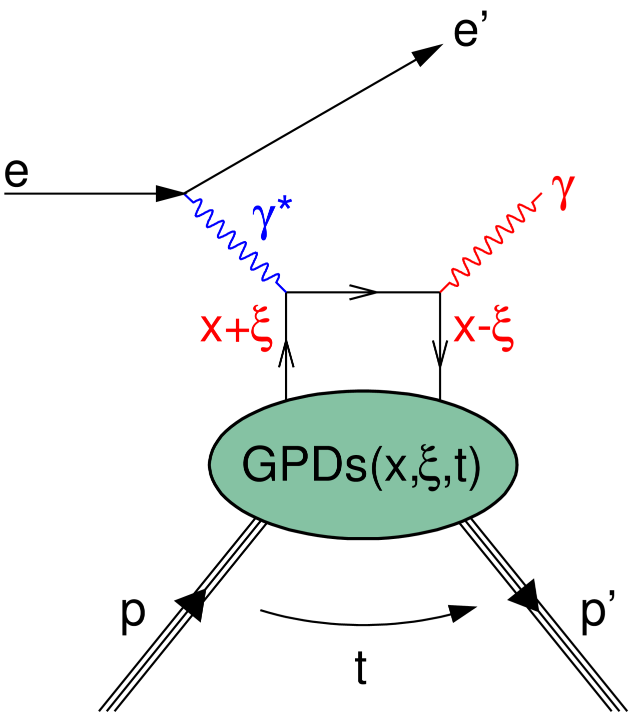
> Exclusive meson production

- Complementary information about GPDs
- Observables for different mesons provide a possibility of flavor tagging
- Vector mesons: sensitivity to GPDs H, E , pseudoscalar mesons: to GPDs $\widetilde{H}, \widetilde{E}$
- Observables: cross sections, SDMEs, azimuthal asymmetries, helicity amplitude ratios

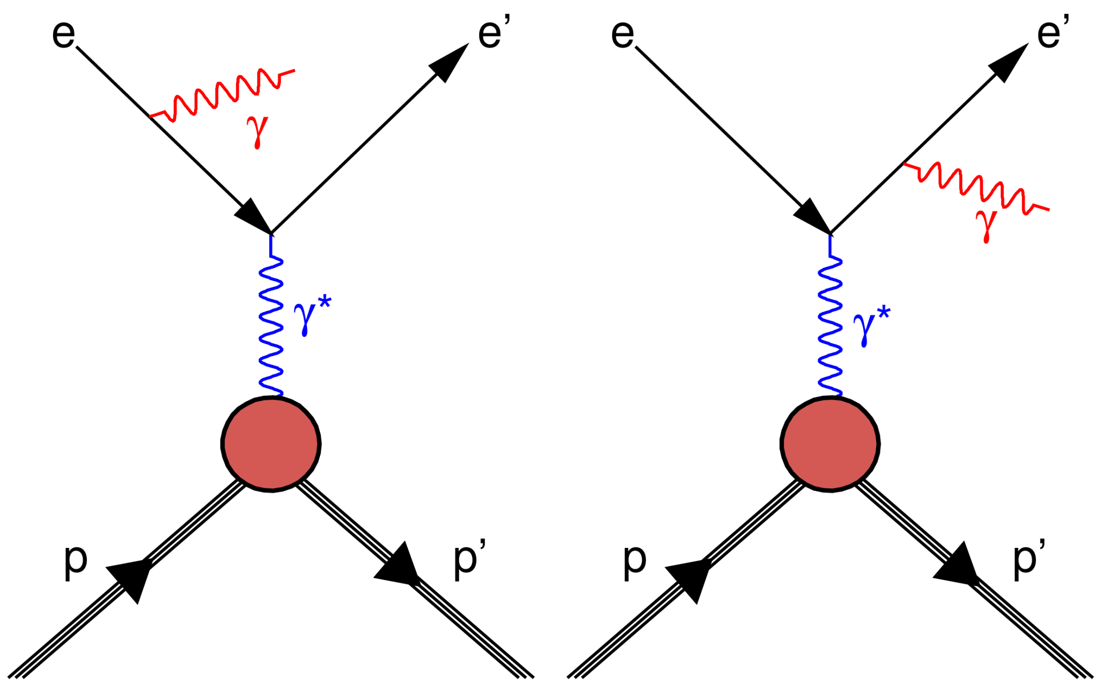


Deeply Virtual Compton Scattering (DVCS)

DVCS

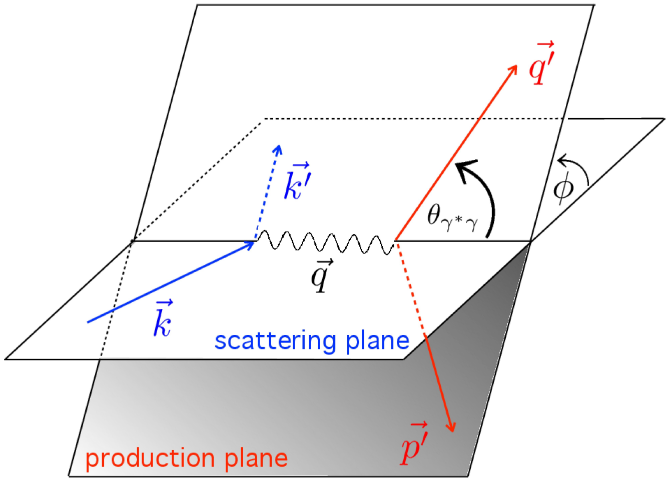


Bethe-Heitler



- 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

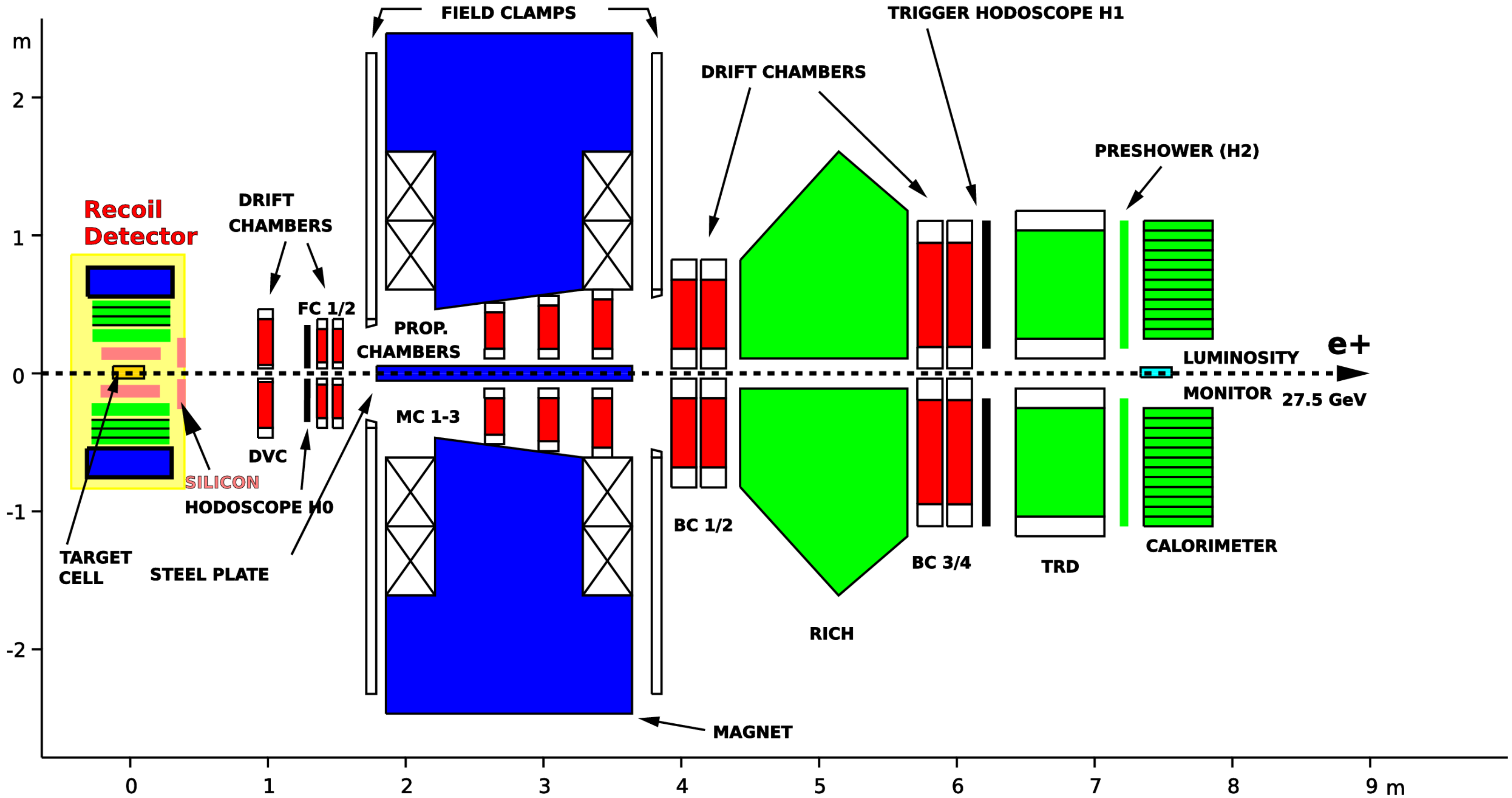
$$A_{LU}^{I}(\phi) = \frac{(\sigma^{+\rightarrow}(\phi) - \sigma^{+\leftarrow}(\phi)) - (\sigma^{-\rightarrow}(\phi) - \sigma^{-\leftarrow}(\phi))}{(\sigma^{+\rightarrow}(\phi) - \sigma^{+\leftarrow}(\phi)) + (\sigma^{-\rightarrow}(\phi) - \sigma^{-\leftarrow}(\phi))} \propto \Im m \mathcal{H}$$

- 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

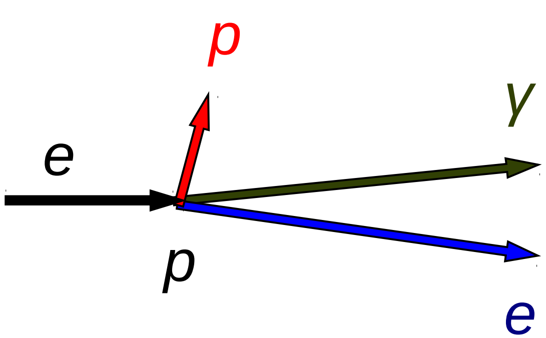
> Unpolarized Hydrogen and Deuterium targets

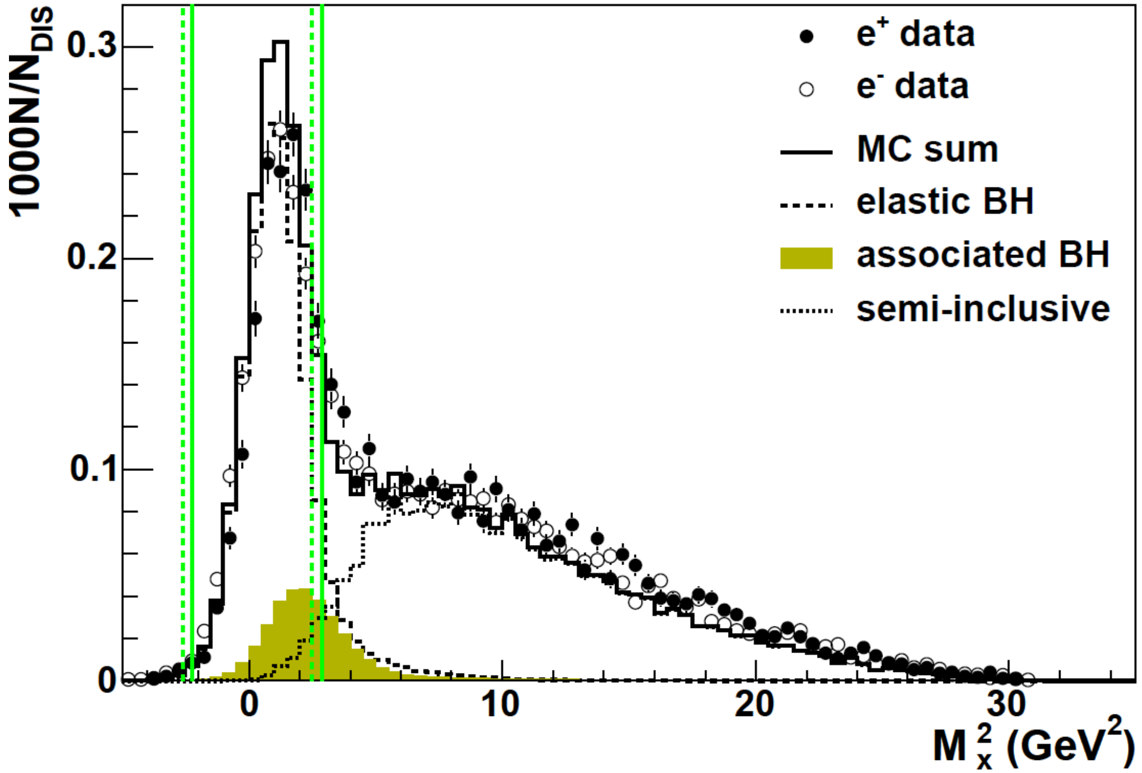
> Good momentum resolution (<2%), excellent particle identification

Selection of DVCS Events without Recoil Detector

- Selection of $ep \rightarrow e\gamma p$ events using missing-mass method
- Corrections for SIDIS background (3%)
- Background from associated process (12%) is part of the signal

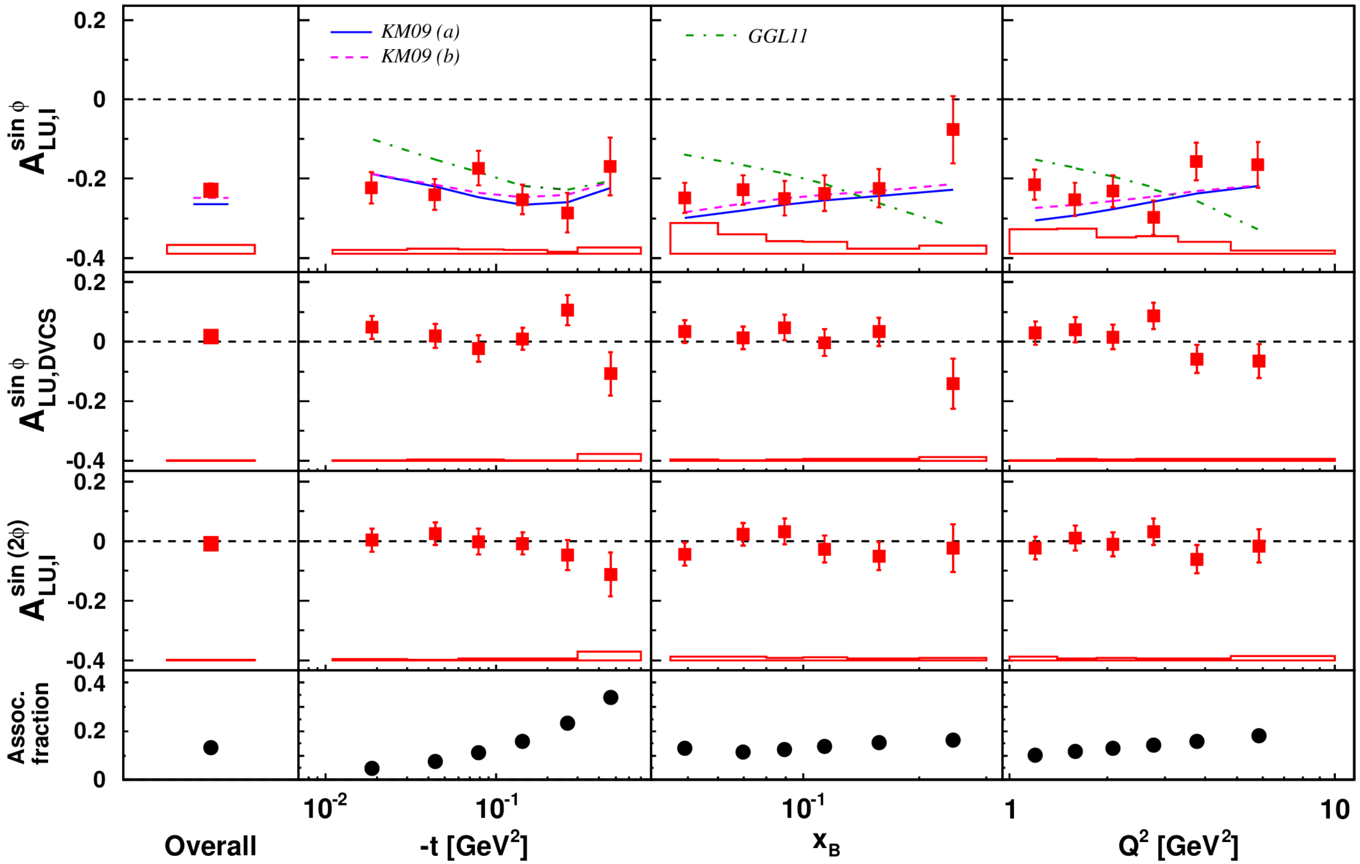
$ep \rightarrow e\gamma p$





Beam-Helicity Asymmetry

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



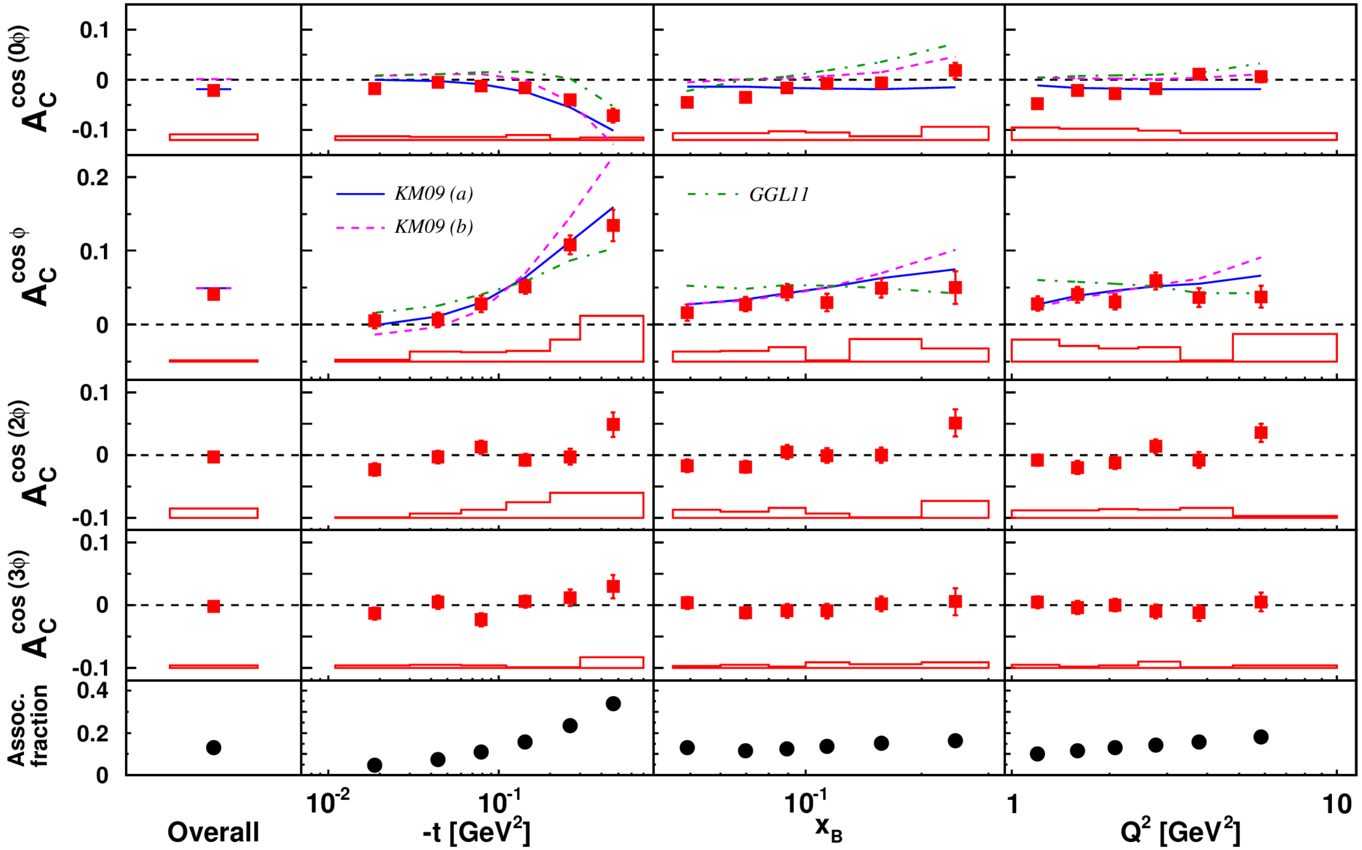
$\propto \Im m\mathcal{H}$

> 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

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

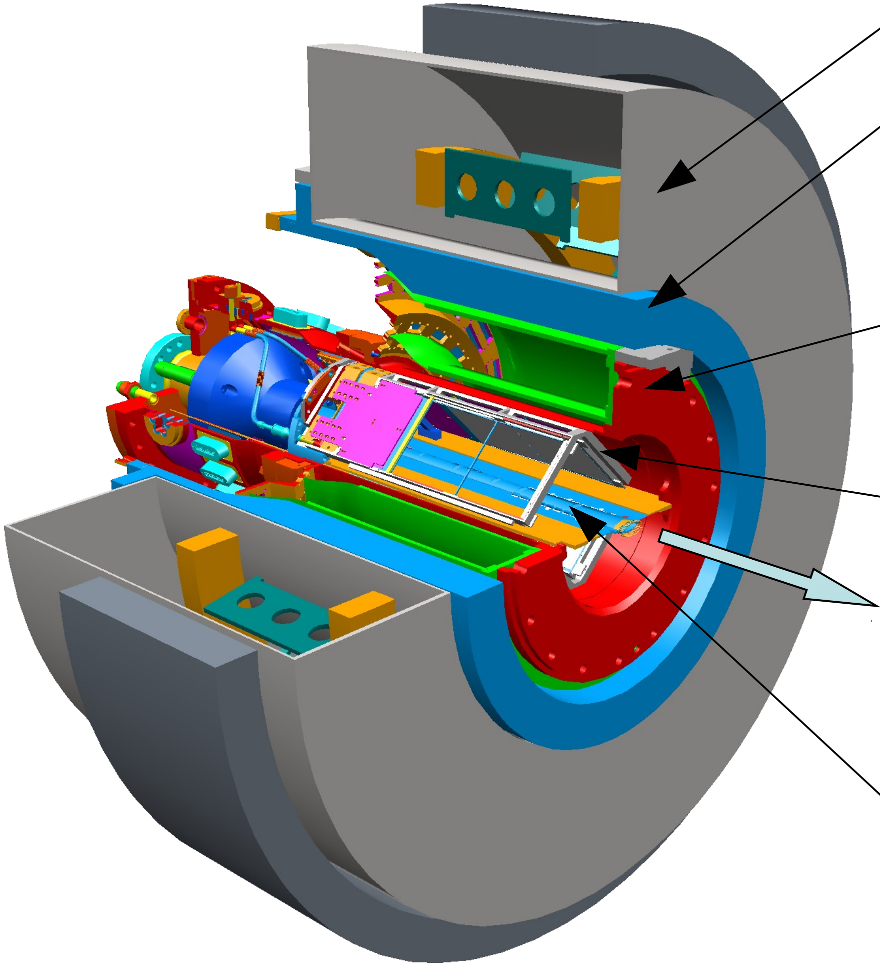


$\propto \Re e\mathcal{H}$

> 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)*

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

JINST 8 (2013) P05012

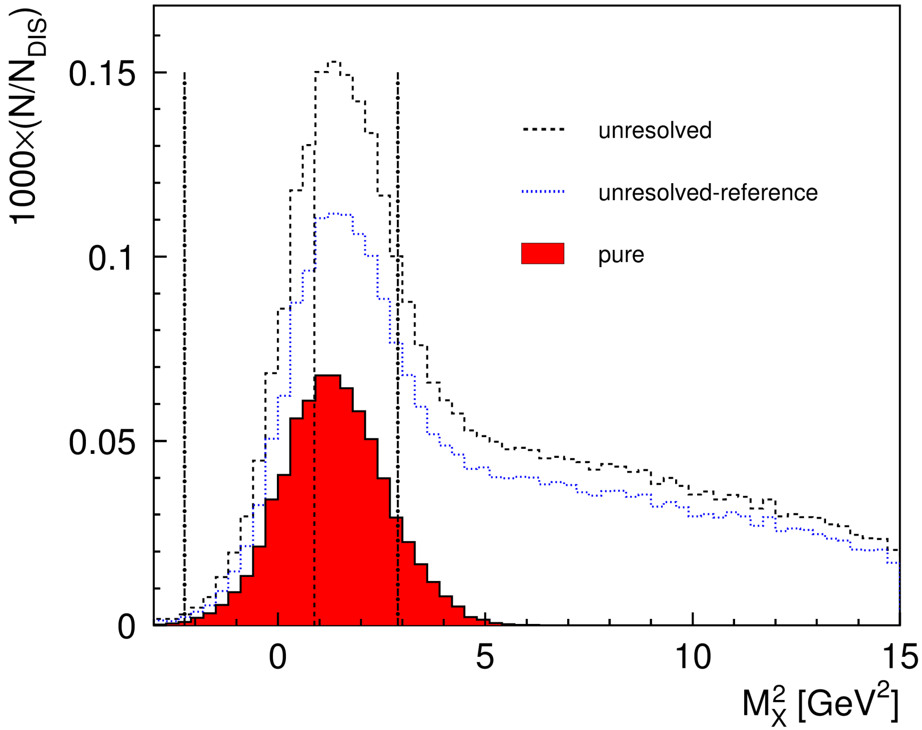
Selection of DVCS Events with Recoil Detector

> All particles in the final state detected

> Kinematic fitting: 4 constraints from energy-momentum conservation

> Selection of pure *ep* → *eγp* events with background below 0.2%

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

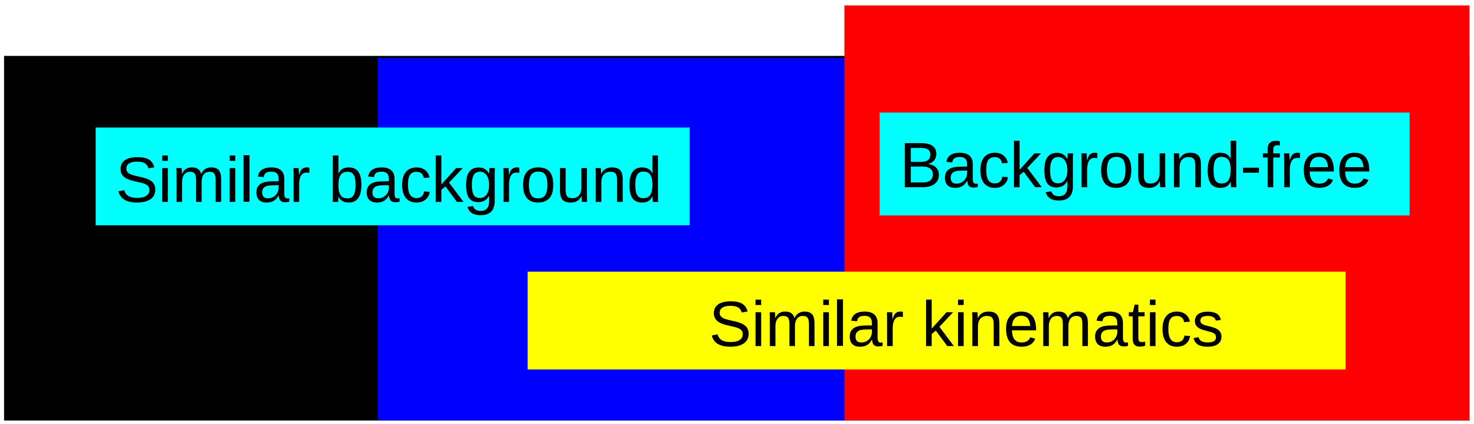


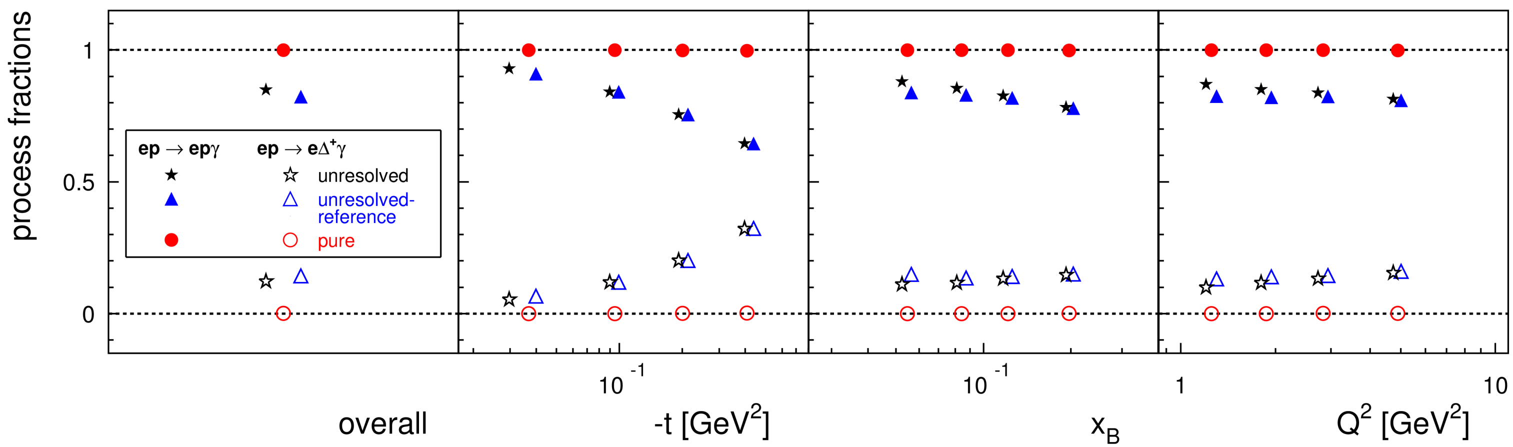
DVCS Event Selection with Recoil Detector

Unresolved (without Recoil Detector)

Unresolved-reference (in RD acceptance)

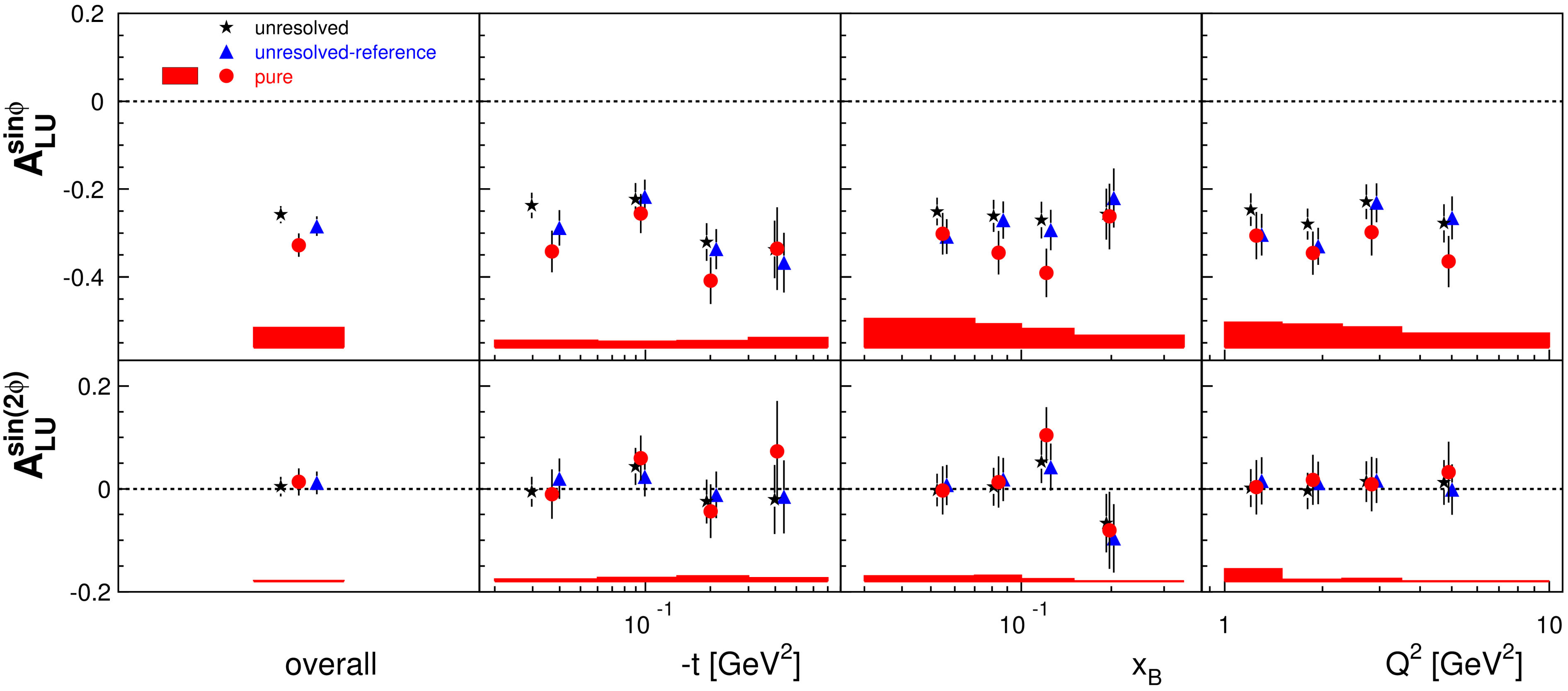
Pure (with RD)





Results for all DVCS Data Samples

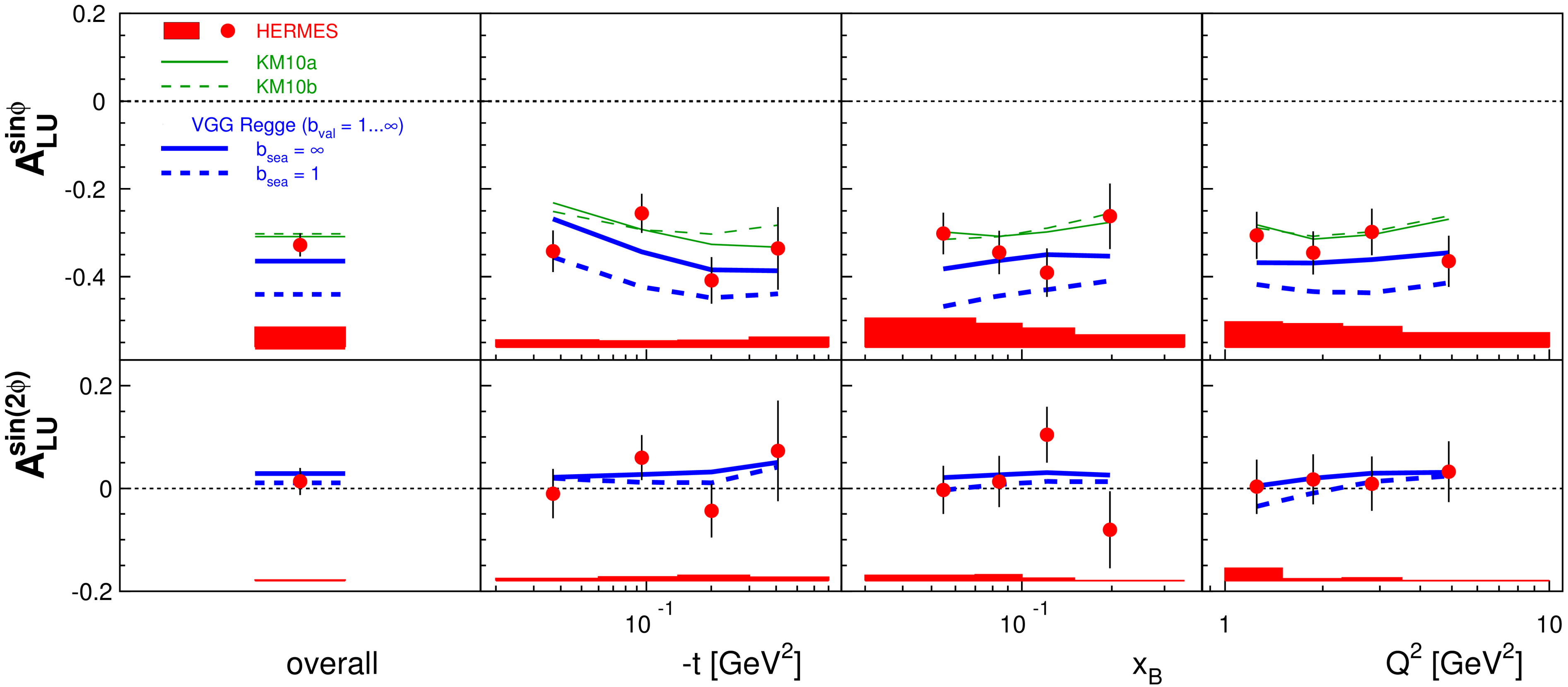
JHEP 10 (2012) 042



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

Comparison with Theoretical Calculations

JHEP 10 (2012) 042

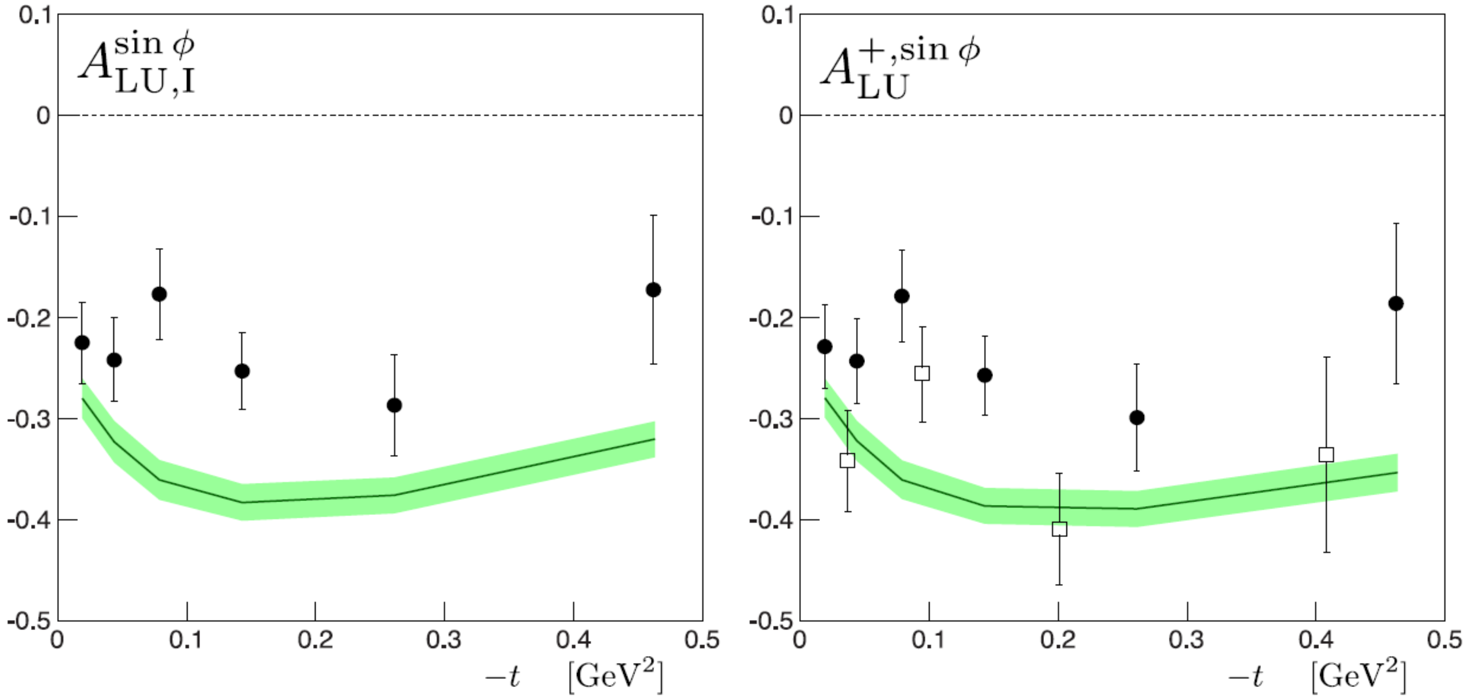


> GPD models and fits reasonably describe data

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

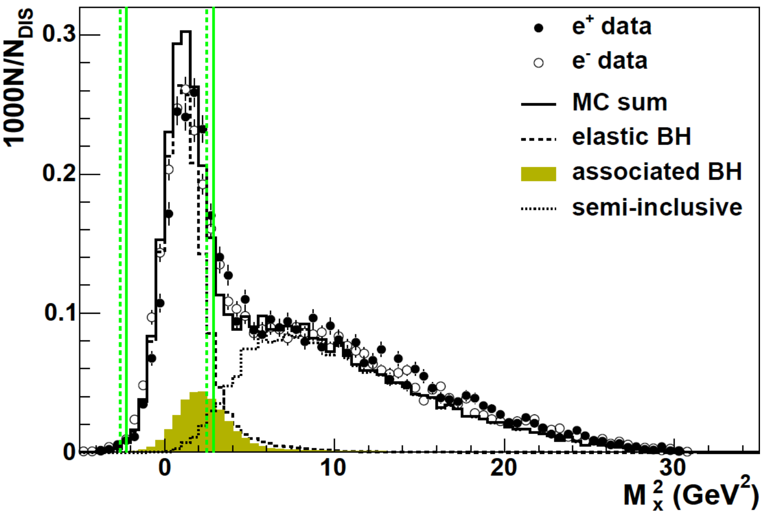
In comparison with HERMES data

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%)

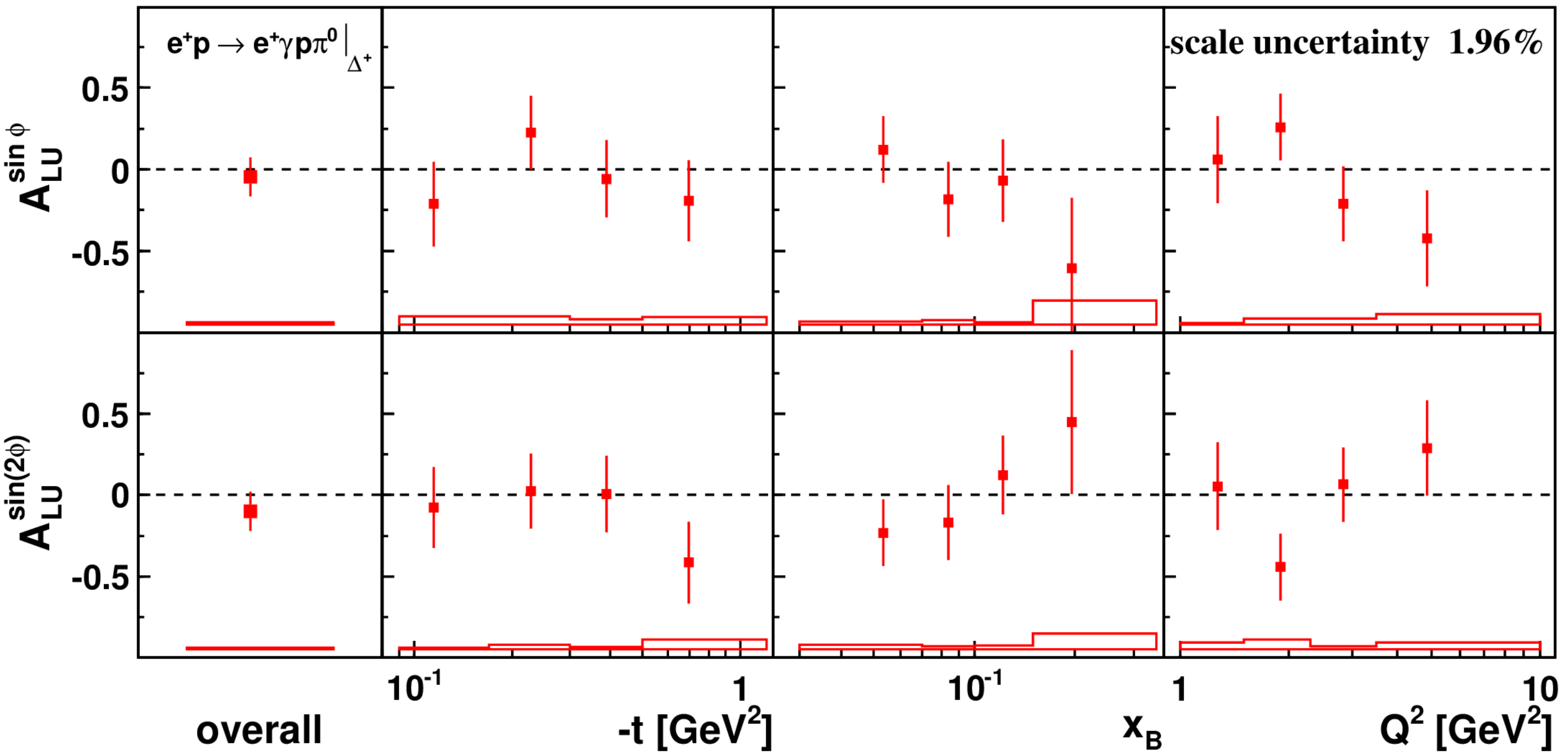
> Particle identification in the Recoil Detector

> Results are corrected for SIDIS background

- 11% in case of $ep \rightarrow e\gamma p\pi^0$, 23% in case of $ep \rightarrow e\gamma n\pi^+$

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

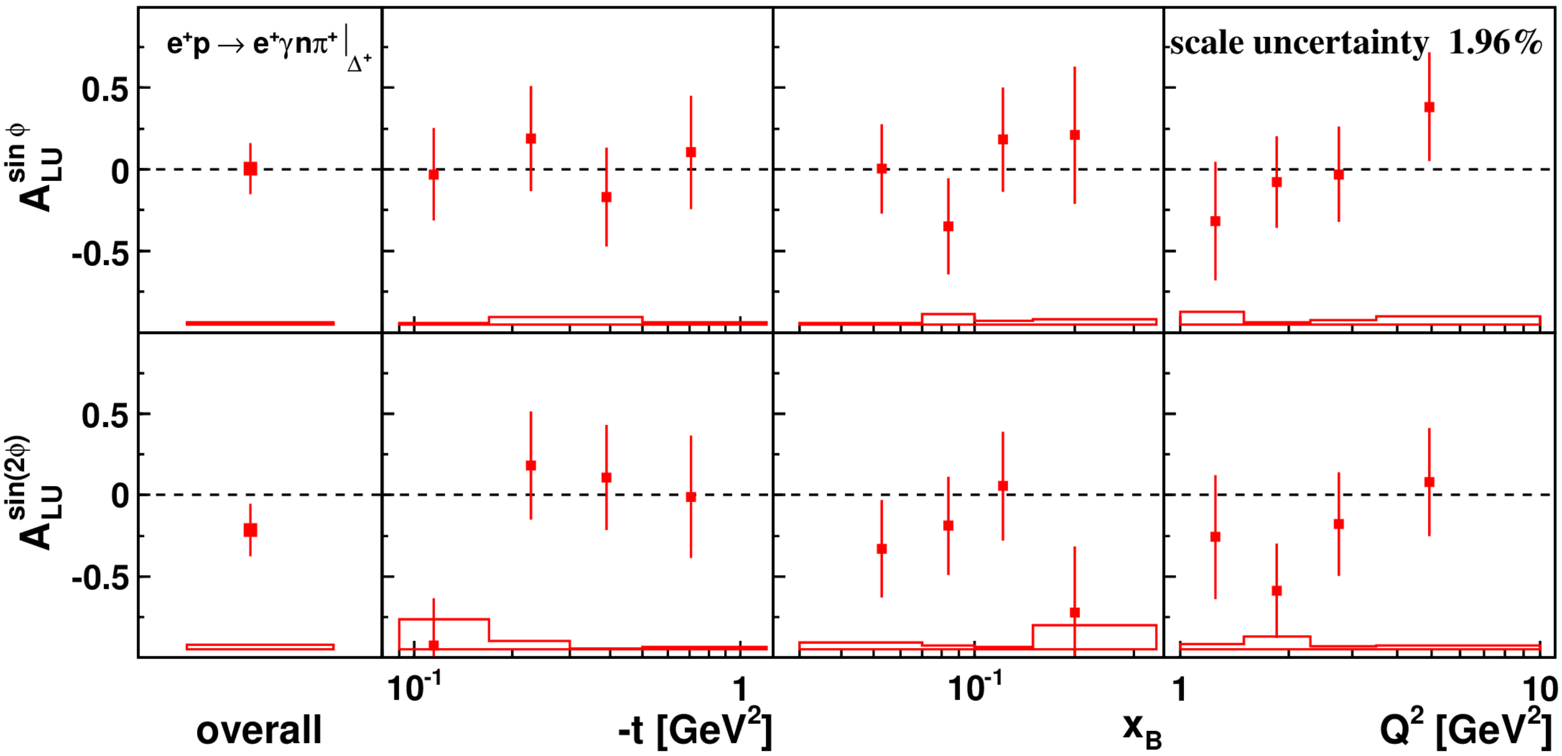
JHEP01 (2014) 077



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

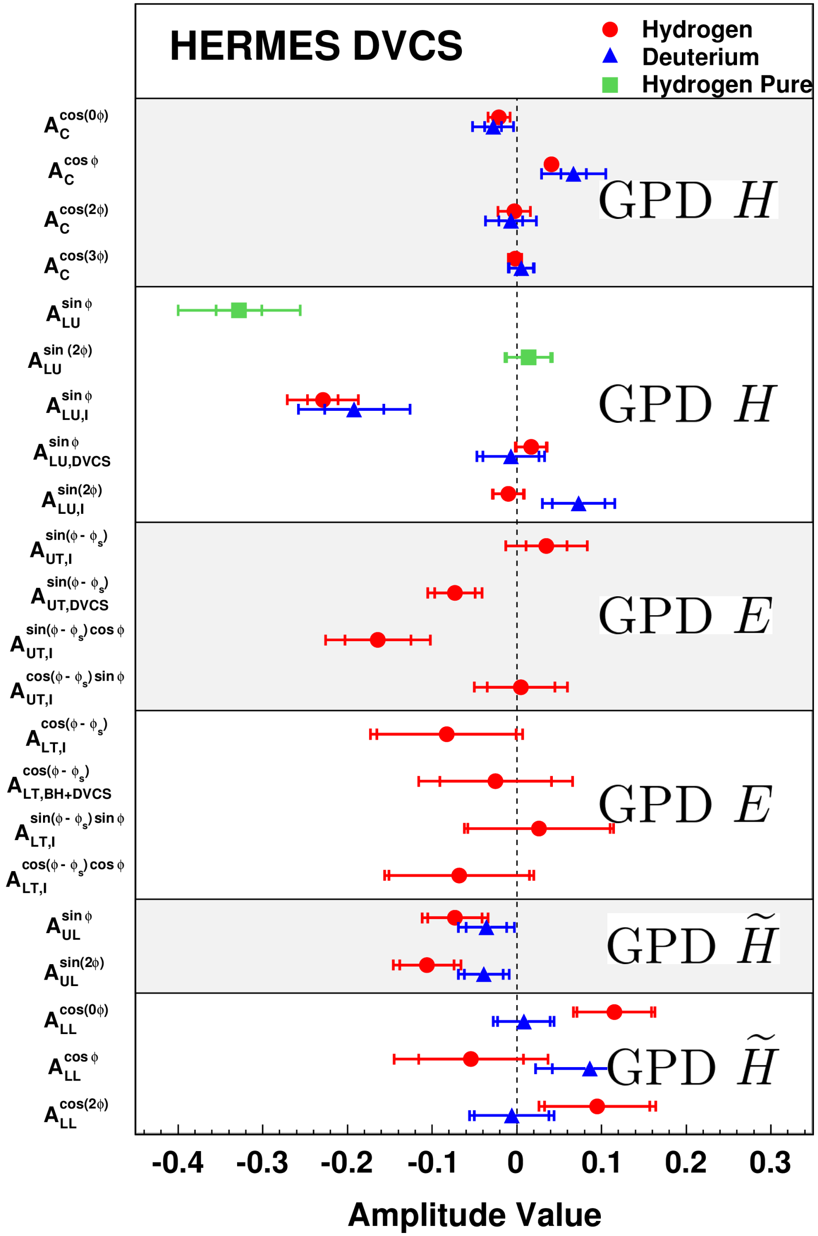
Results on Beam-Helicity Asymmetry for $ep \to e\gamma n\pi^+$

JHEP01 (2014) 077



- 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

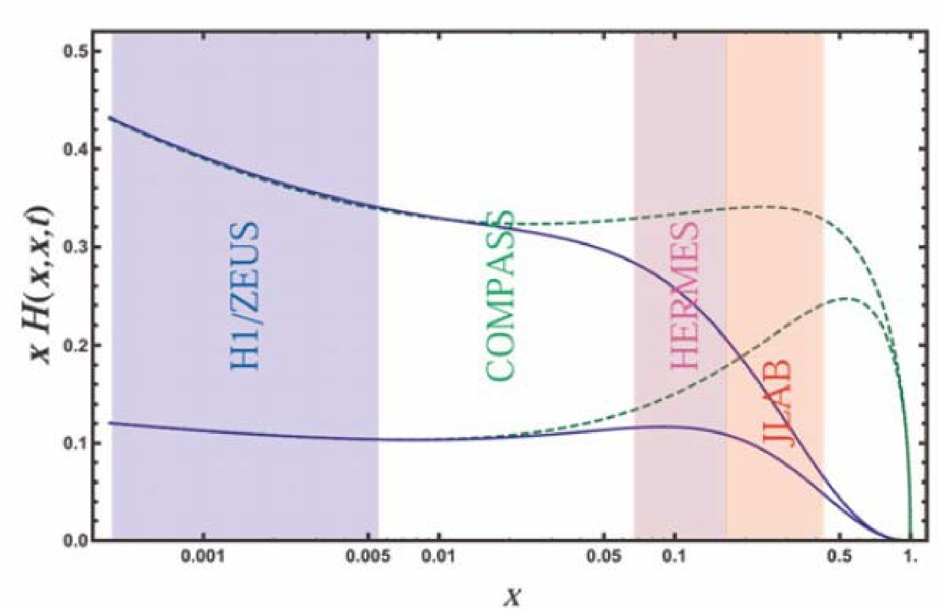
JHEP 06 (2010) 019

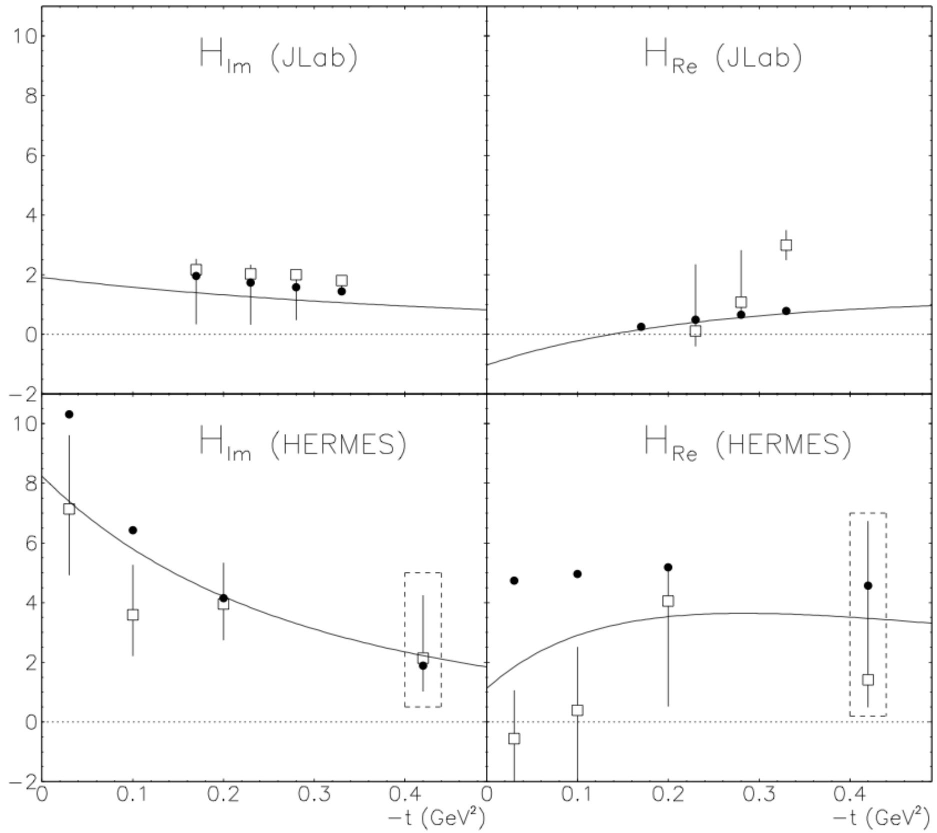
> Longitudinal target & double spin asymmetry

Nucl. Phys. B 842 (2011) 265

DESY

Extraction of GPDs and Compton Form Factors





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

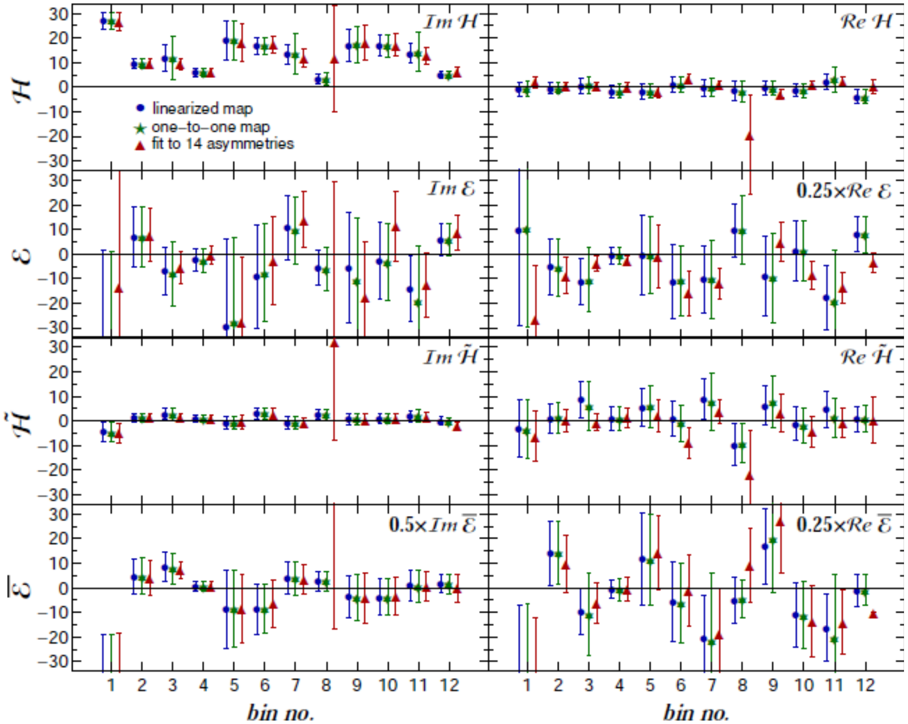
M. Guidal and H. Moutarde, Eur.Phys.J. A 42 (2009) 71

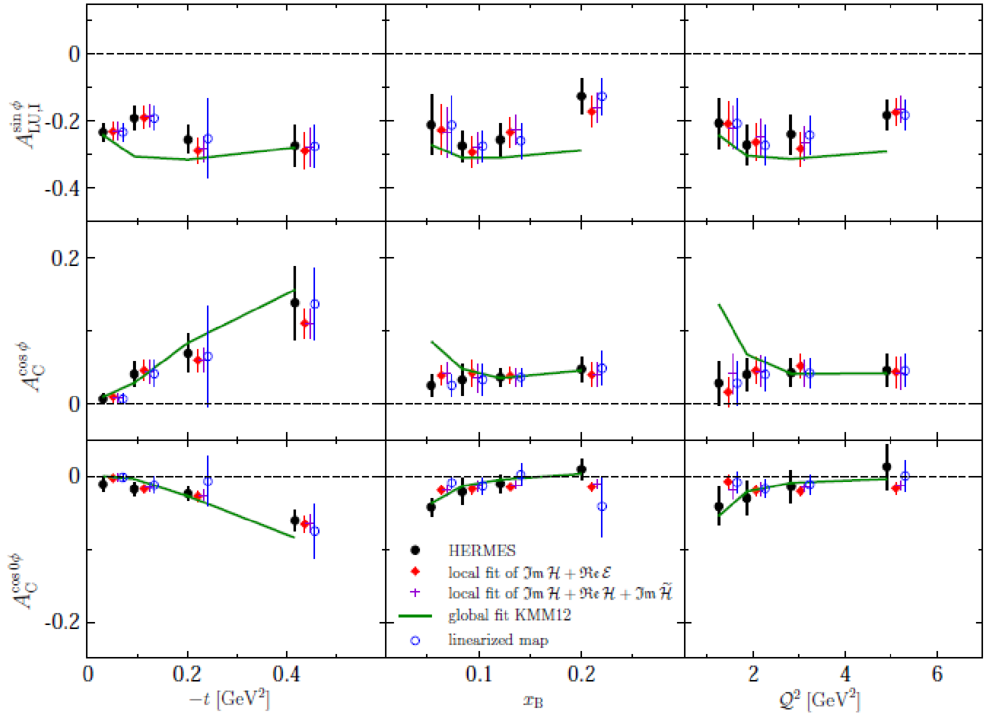
HERMES Impact for the Access of Compton Form Factors

> 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

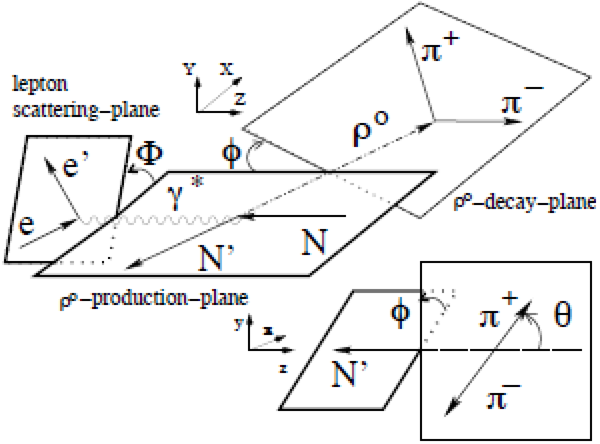




K. Kumerički, D. Müller, and M. Murray,
Phys. Part. Nucl. 45 (2014), 723

Exclusive Vector Meson Production

> pQCD description of the process
  - dissociation of the virtual photon into quark-antiquark pair
  - scattering of a pair on a nucleon
  - formation of the observed vector meson



> Natural parity exchange → GPDs H, E

> Unnatural parity exchange → GPDs $\widetilde{H}, \widetilde{E}$

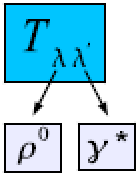
> Cross section

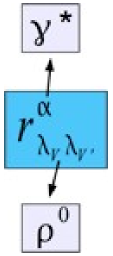
$$\frac{d\sigma}{dx_B dQ^2 dt d\Phi d\cos\theta d\phi} \propto \frac{d\sigma}{dx_B dQ^2 dt} W(x_B, Q^2, t, \Phi, \cos\theta, \phi)$$

> Production and decay angular distribution: W decomposition

$$W = W_{UU} + P_\ell W_{LU} + S_L W_{UL} + P_\ell S_L W_{LL} + S_T W_{UT} + P_\ell S_T W_{LT}$$

> Parameterization in terms of helicity amplitudes or SDMEs
  - Diehl (2007)
  - Schilling, Wolf (1973)

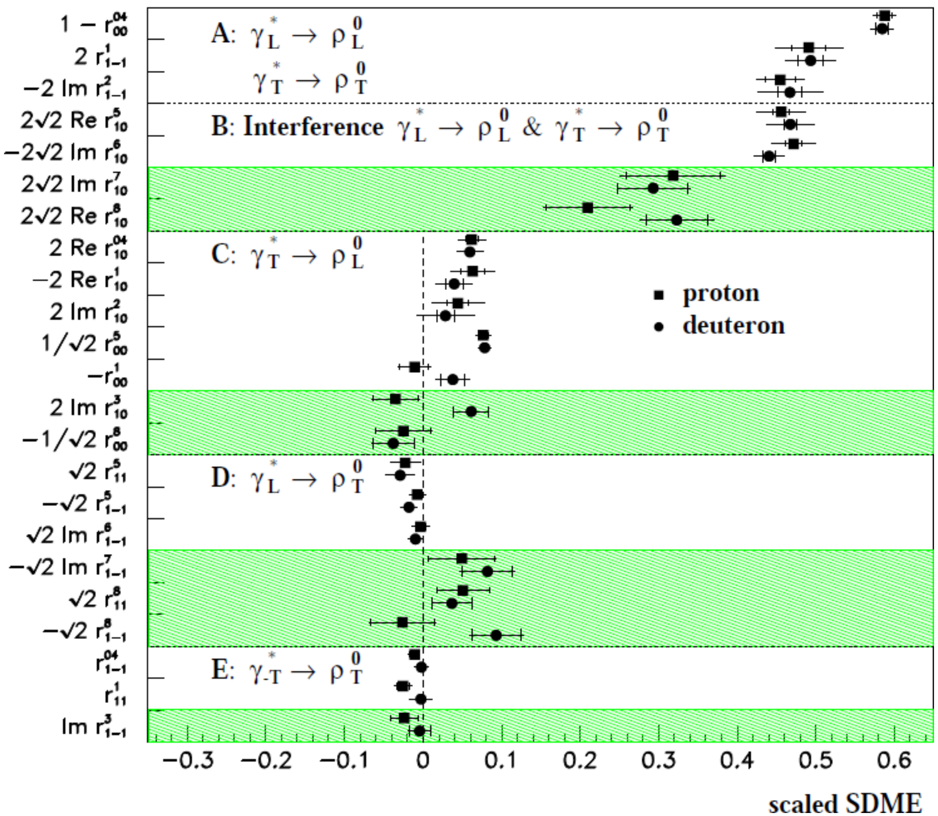




SDMEs in Exclusive ρ^0 Production

> Hierarchy of NPE helicity amplitudes confirmed

$$|T_{00}| \sim |T_{11}| \gg |T_{01}| > |T_{10}| \geq |T_{1-1}|$$



Phys. Lett. B679 (2009) 100

> Class A and B

- SDMEs significantly different from zero
- SDMEs of Class B smaller than SDMEs of Class A

> Class C

- Some SDMEs significantly different from zero (up to 10σ)
- Violation from SCHC

> Class D

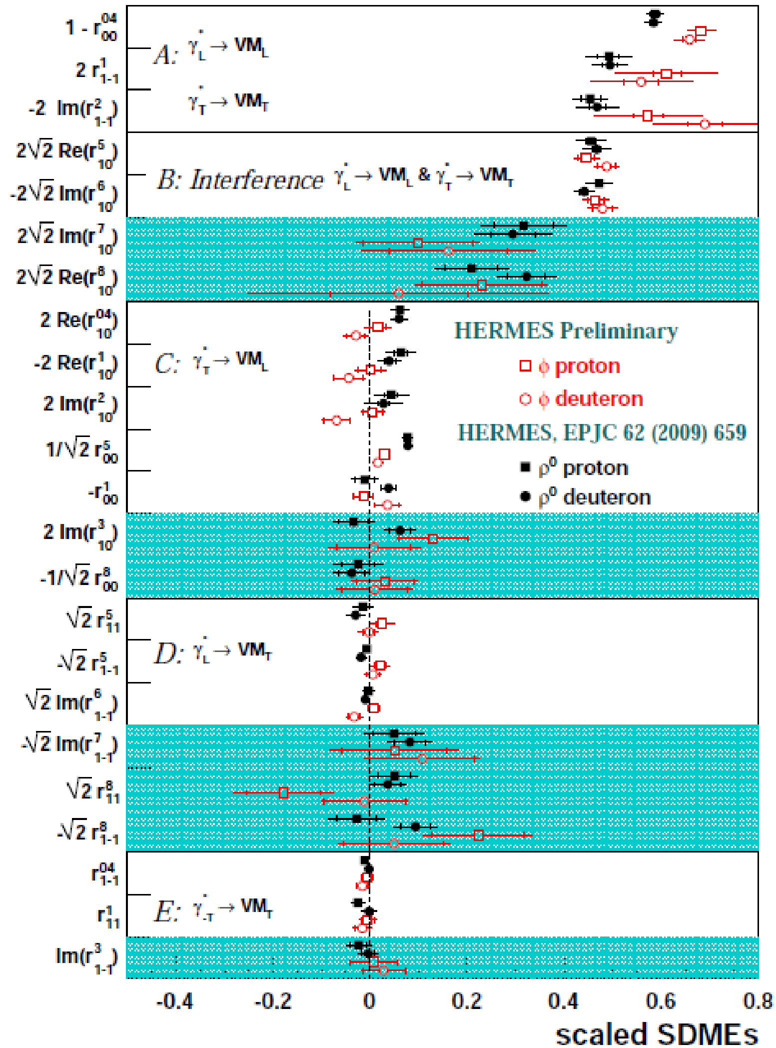
- Unpolarized SDMEs slightly negative
- Polarized SDMEs slightly positive

> Class E

- SDMEs on deuteron consistent with zero
- Small deviation from zero for SDMEs on proton

SDMEs in Exclusive φ Production

> Hierarchy of NPE helicity amplitudes confirmed



> Class A and B

- SDMEs significantly different from zero
- 10-20% difference between ρ and φ SDMEs

> Class C

- SDMEs consistent with zero
- SDMEs on deuteron slightly negative
- No strong indication of SCHC violation

> Class D

- Unpolarized and polarized SDMEs consistent with zero for both proton and deuteron

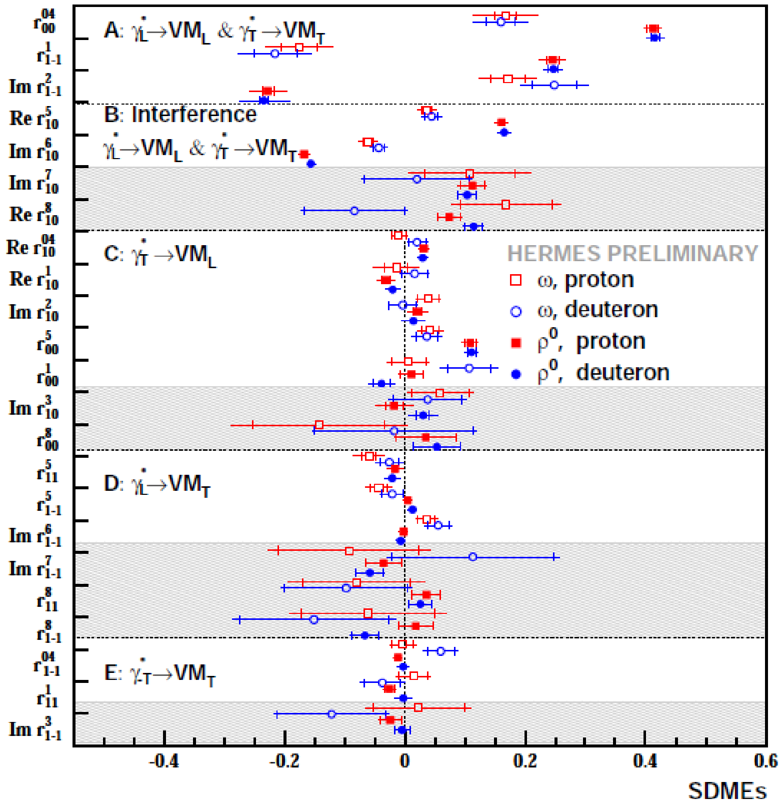
> Class E

- Unpolarized and polarized SDMEs consistent with zero for both proton and deuteron

SDMEs in Exclusive ω Production

> Hierarchy of NPE helicity amplitudes not confirmed

> Importance of UPE



arXiv:1407.2119

> Class A and B

- SDMEs significantly different from zero
- Significant difference between ρ and ω SDMEs

> Class C

- SDMEs consistent with zero for both proton and deuteron

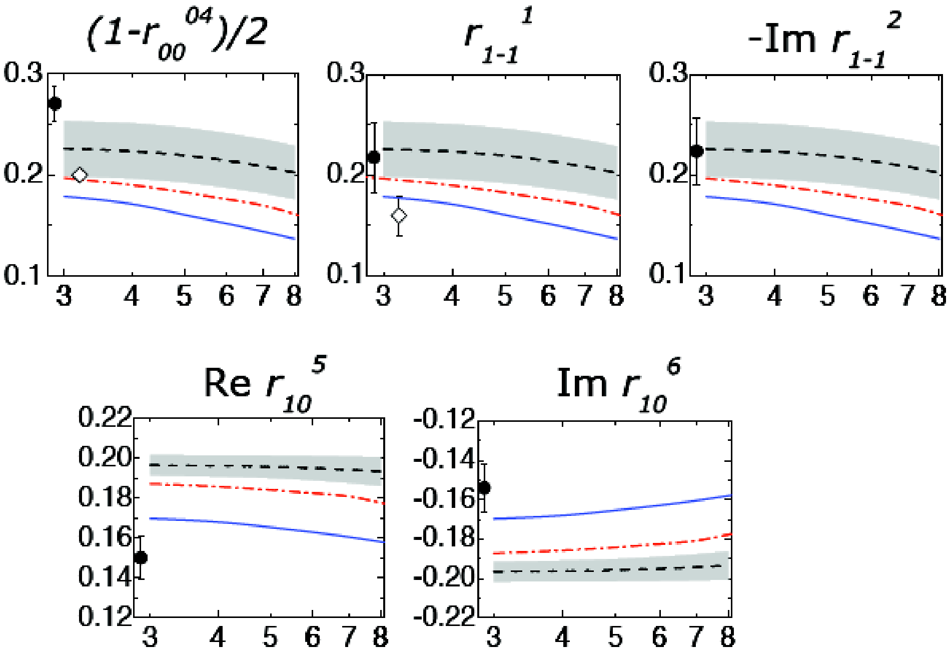
> Class D

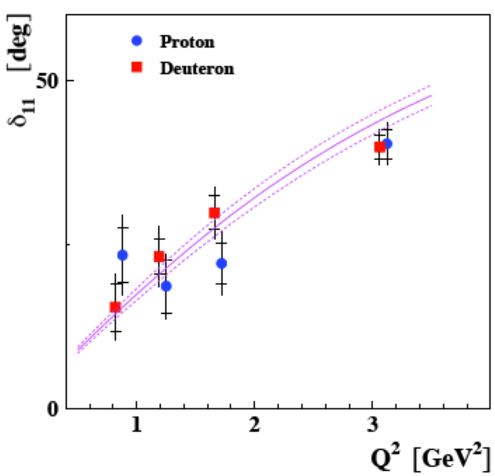
- Unpolarized SDMEs differ from zero
- Small evidence for violation from SCHC

> Class E

- Unpolarized and polarized SDMEs consistent with zero for both proton and deuteron

Comparison with GPD Model





> GPD model Goloskokov, Kroll (2008)

> Agreement for

$$\gamma^*_L \rightarrow \rho^0_L \text{ and } \gamma^*_T \rightarrow \rho^0_T$$

$$1 - r^{04}_{00}, r^1_{1-1}, -Im r^2_{1-1} \propto T_{11}$$

> Disagreement for interference

$$\gamma^*_L \rightarrow \rho^0_L \text{ and } \gamma^*_T \rightarrow \rho^0_T$$

> The model used value δ_{11} = 3.1 deg. for

$$tan\,\delta_{11} = \frac{Im(T_{11}/T_{00})}{Re(T_{11}/T_{00})}$$

> HERMES result: δ_{11} = 31.5 ± 1.4 deg.

> H1 measured δ_{11} = 20 deg.

Summary

- Recent HERMES results on DVCS and meson production
  - High-statistics results on beam-helicity and beam-charge asymmetries in DVCS
  - Beam-helicity asymmetry in DVCS (with Recoil detector)
  - 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 (with Recoil detector)
  - Preliminary results on φ and ω SDMEs

- Significant contribution from HERMES to constrain GPDs

Backup

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