Hard Exclusive Leptoproduction of Photons and Mesons at HERMES

Recent Results

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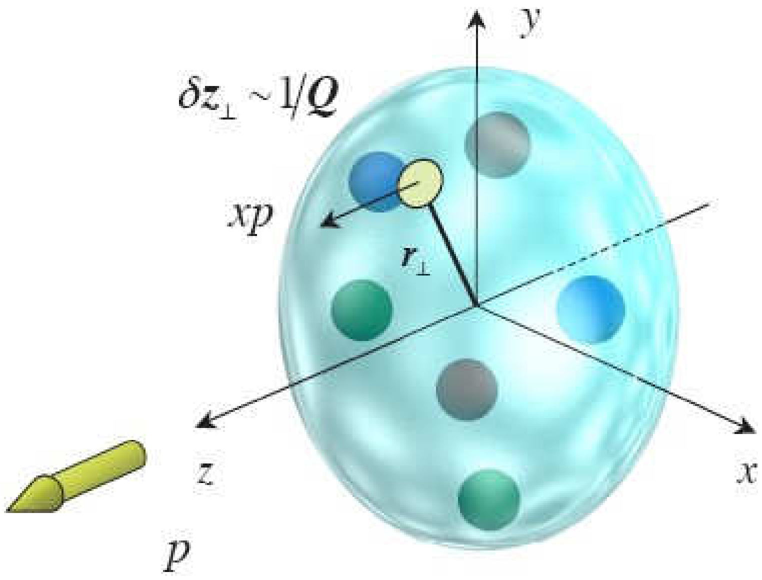
on behalf of the HERMES Collaboration
Hamburg University, 26.08.2014

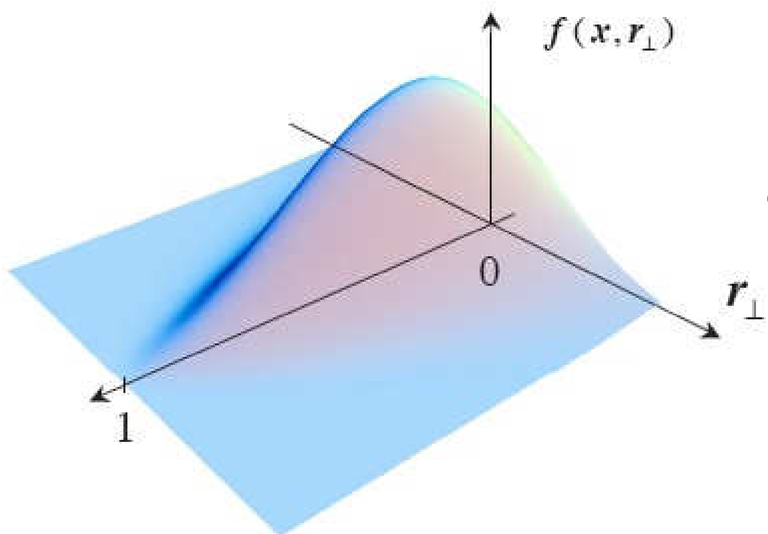
HELMHOLTZ ASSOCIATION

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:

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

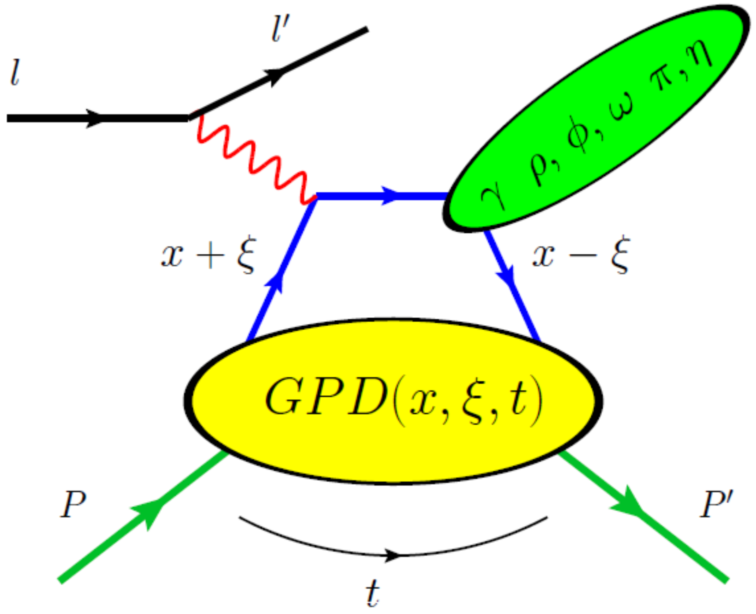
Experimental Probes of GPDs: Hard Exclusive Reactions

> Deeply virtual Compton scattering (DVCS)

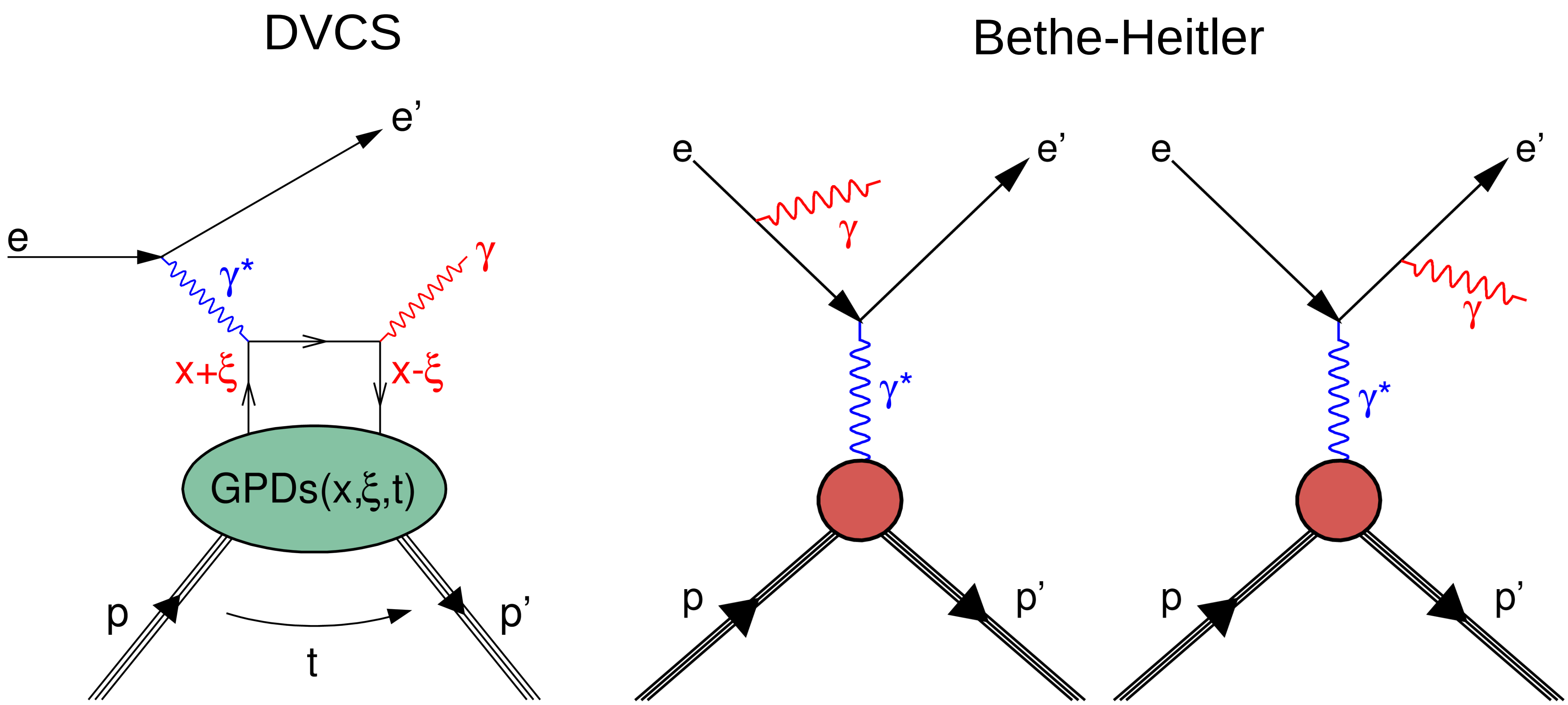
- Theoretically the cleanest probe of GPDs
- GPDs are accessed through convolution integrals with hard scattering amplitude
- Sensitivity to all GPDs $H, \widetilde{H}, E, \widetilde{E}$
- Observables: azimuthal asymmetries, cross sections, cross section differences

> 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

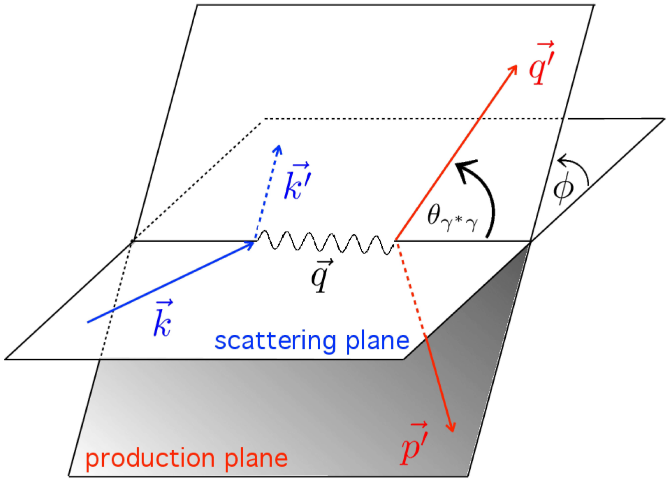


Deeply Virtual Compton Scattering (DVCS)



- 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

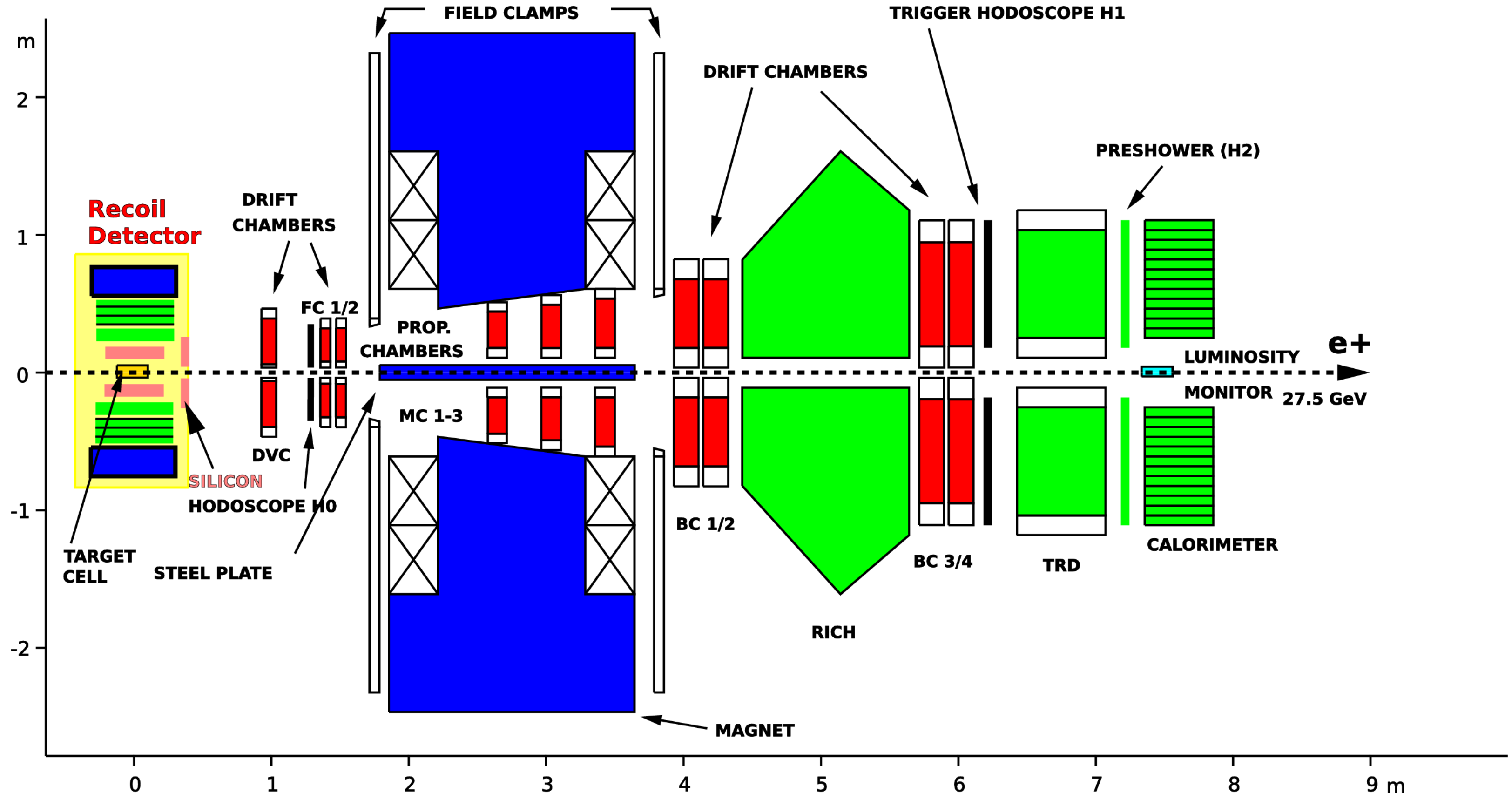
$$A_{LU}^{I}(\phi) = \frac{(\sigma^{+\rightarrow}(\phi) - \sigma^{+\leftarrow}(\phi)) - (\sigma^{-\rightarrow}(\phi) - \sigma^{-\leftarrow}(\phi))}{(\sigma^{+\rightarrow}(\phi) - \sigma^{+\leftarrow}(\phi)) + (\sigma^{-\rightarrow}(\phi) - \sigma^{-\leftarrow}(\phi))} \propto \Im m\mathcal{H}$$

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

HERMES Spectrometer



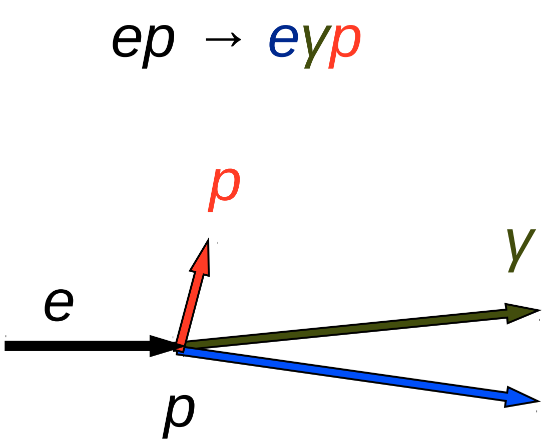
- Electron and positron beams 27.6 GeV
- Unpolarized Hydrogen and Deuterium targets
- Good momentum resolution (<2%), excellent particle identification

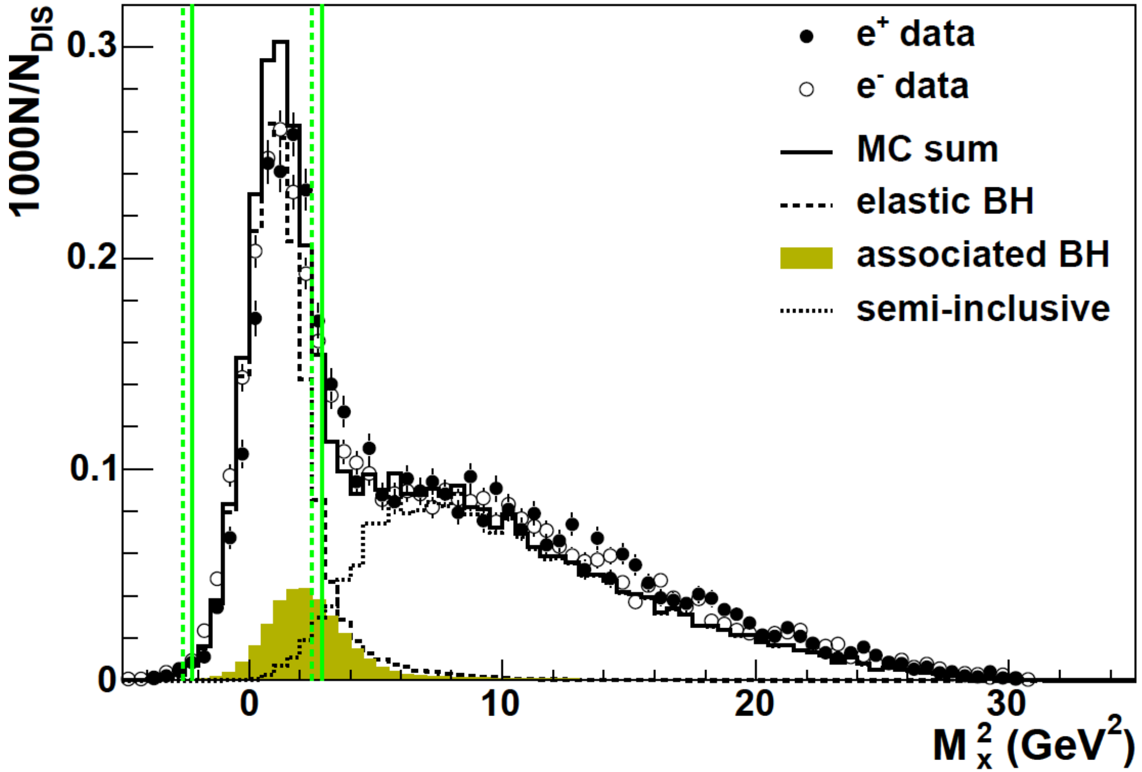
Selection of DVCS Events without Recoil Detector

> Selection of *ep → eγp* events using missing-mass method

> Corrections for SIDIS background (3%)

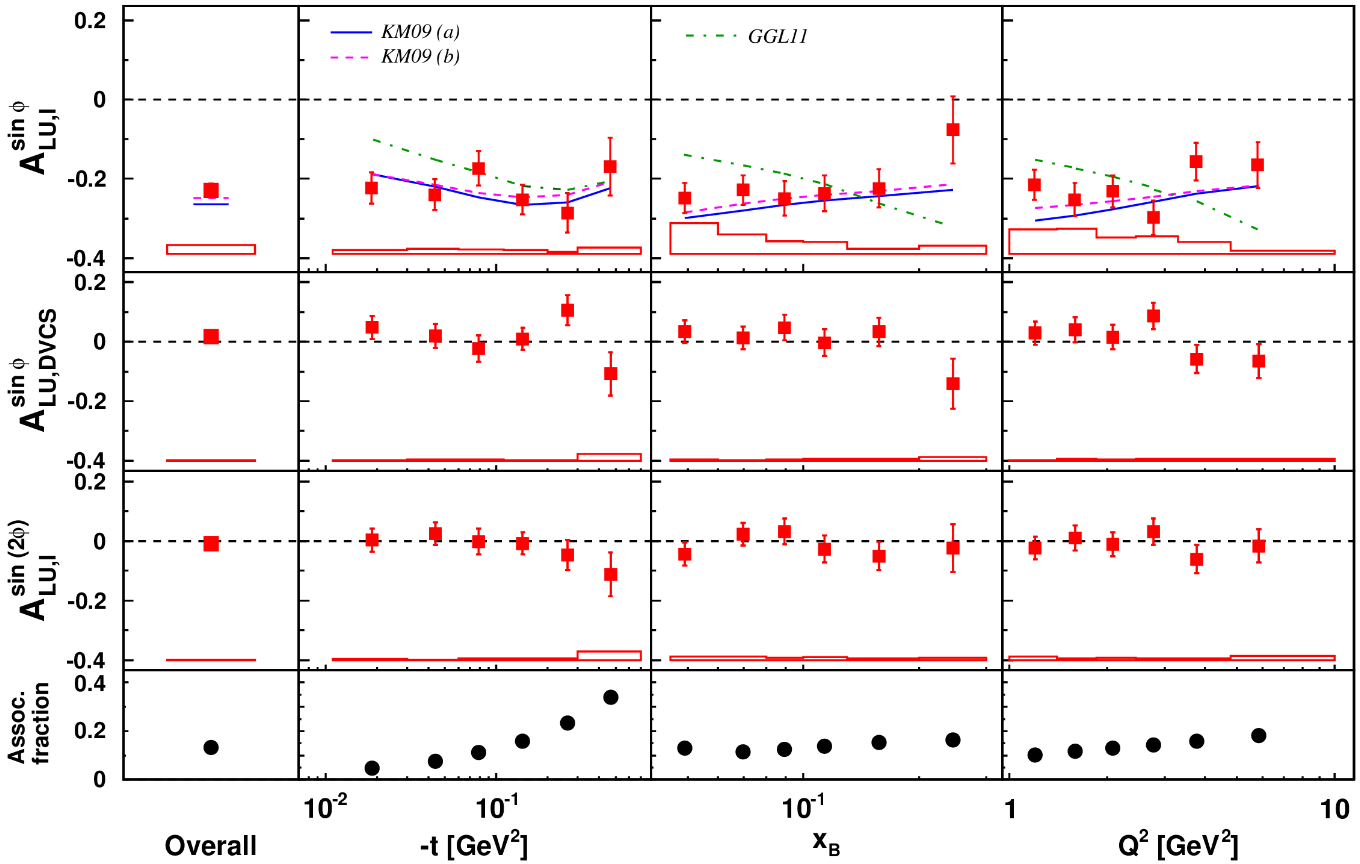
> Background from associated process (12%) is part of the signal





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

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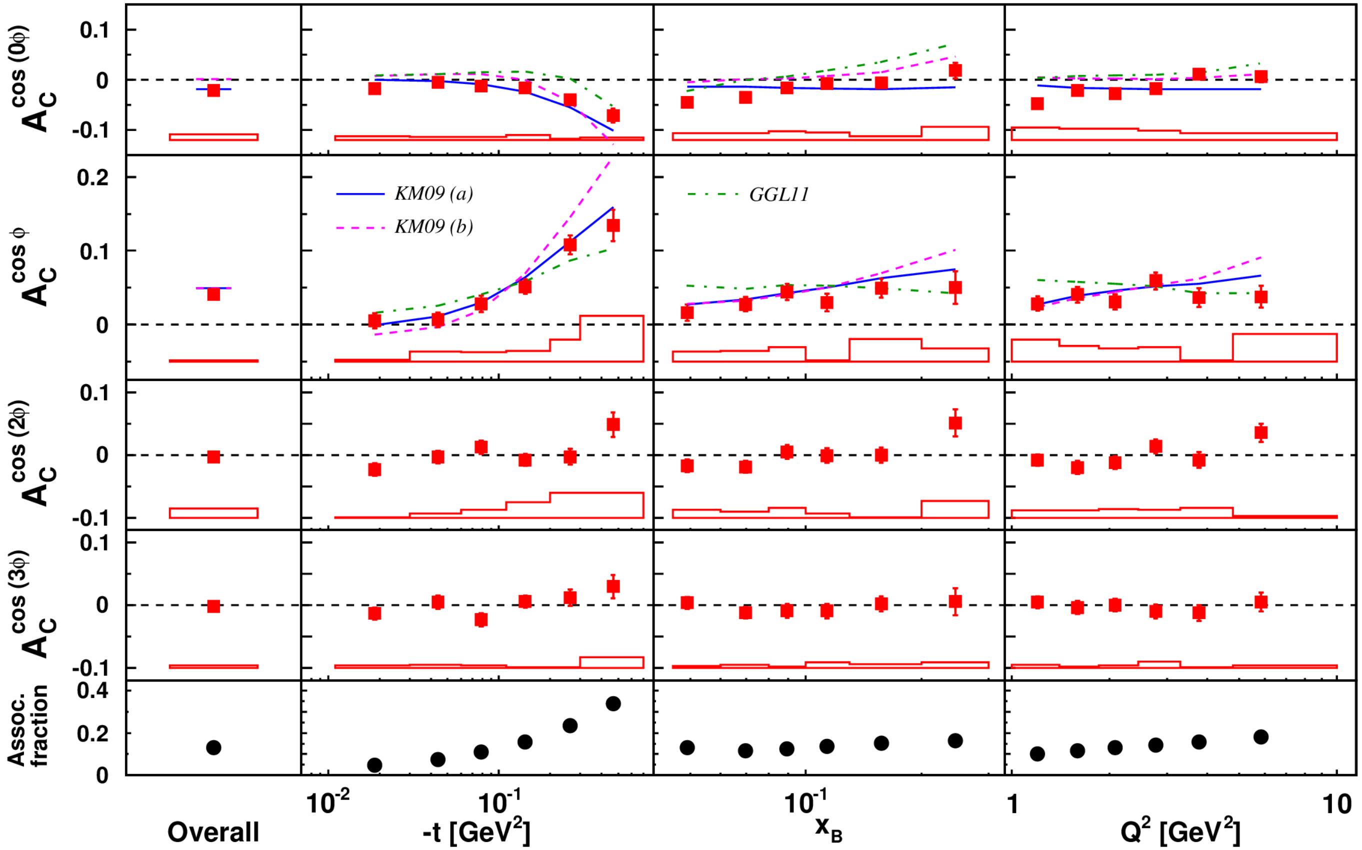

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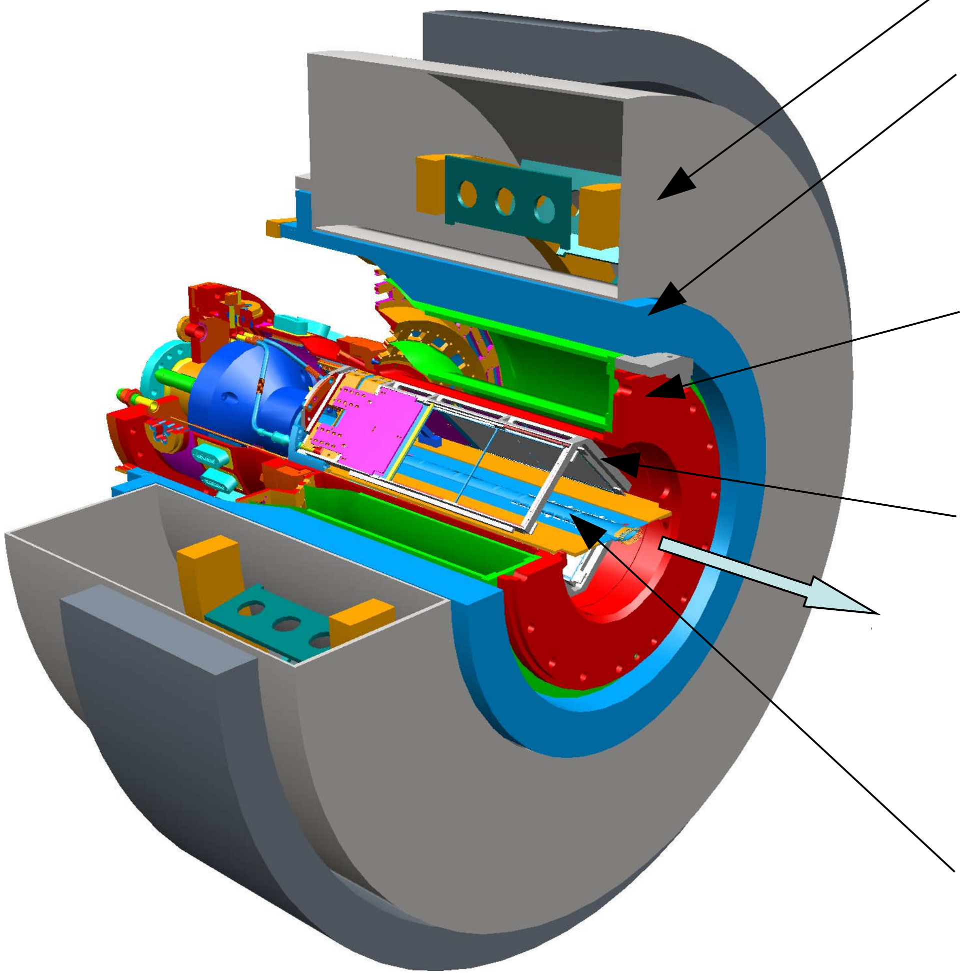
HERMES Recoil Detector



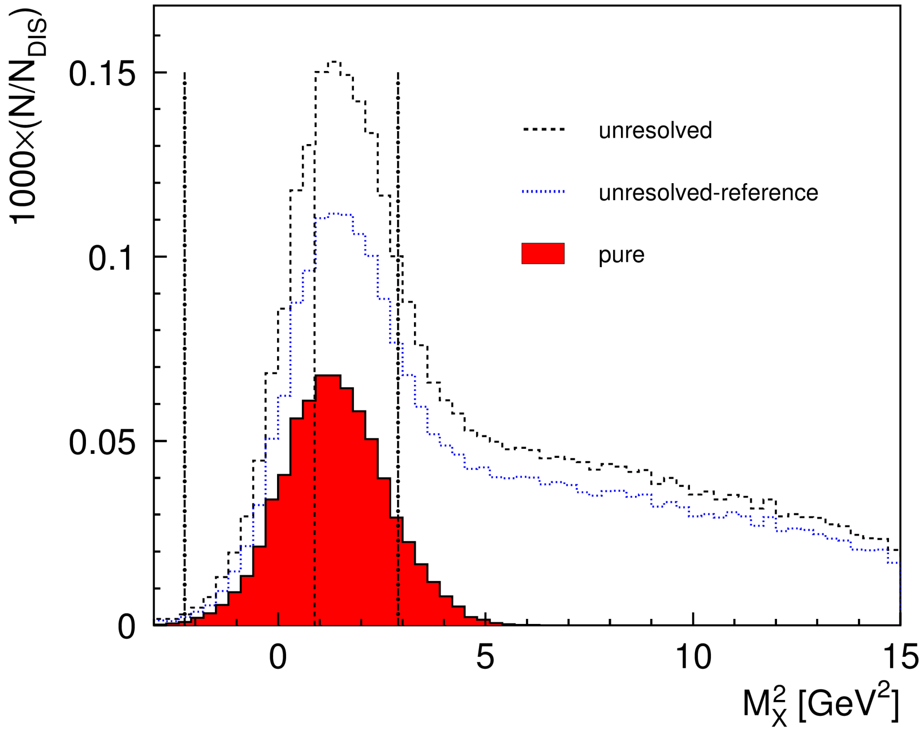
- 1 Tesla superconducting solenoid
- Photon Detector (PD)
  - Detect photons
  - p/π PID for momentum > 600 MeV/c
- Scintillating Fiber Tracker (SFT)
  - Momentum reconstruction by bending in the magnetic field
- Silicon Strip Detector (SSD)
  - Inside the HERA vacuum
  - 5 cm close to the HERA beam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

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 $ep \rightarrow e\gamma p$ events with background below 0.2%

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

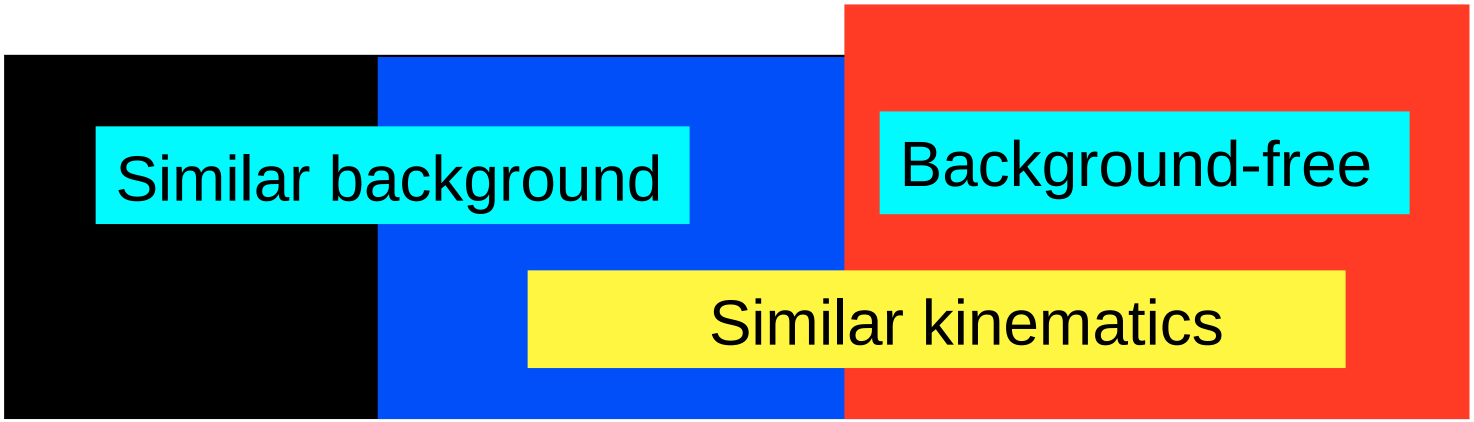


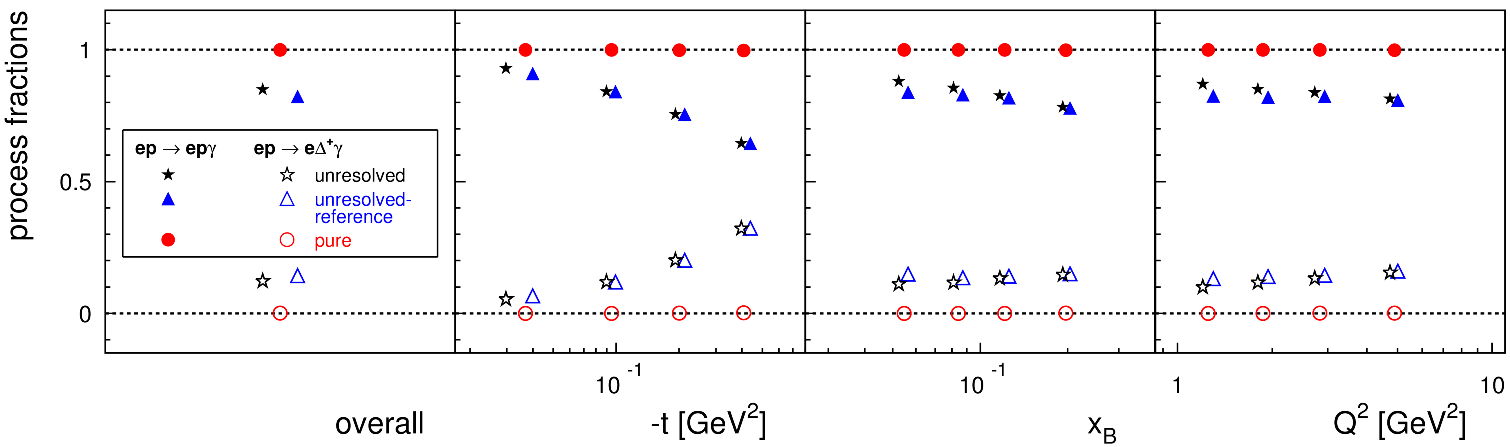
DVCS Event Selection with Recoil Detector

Unresolved (without Recoil Detector)

Unresolved-reference (in RD acceptance)

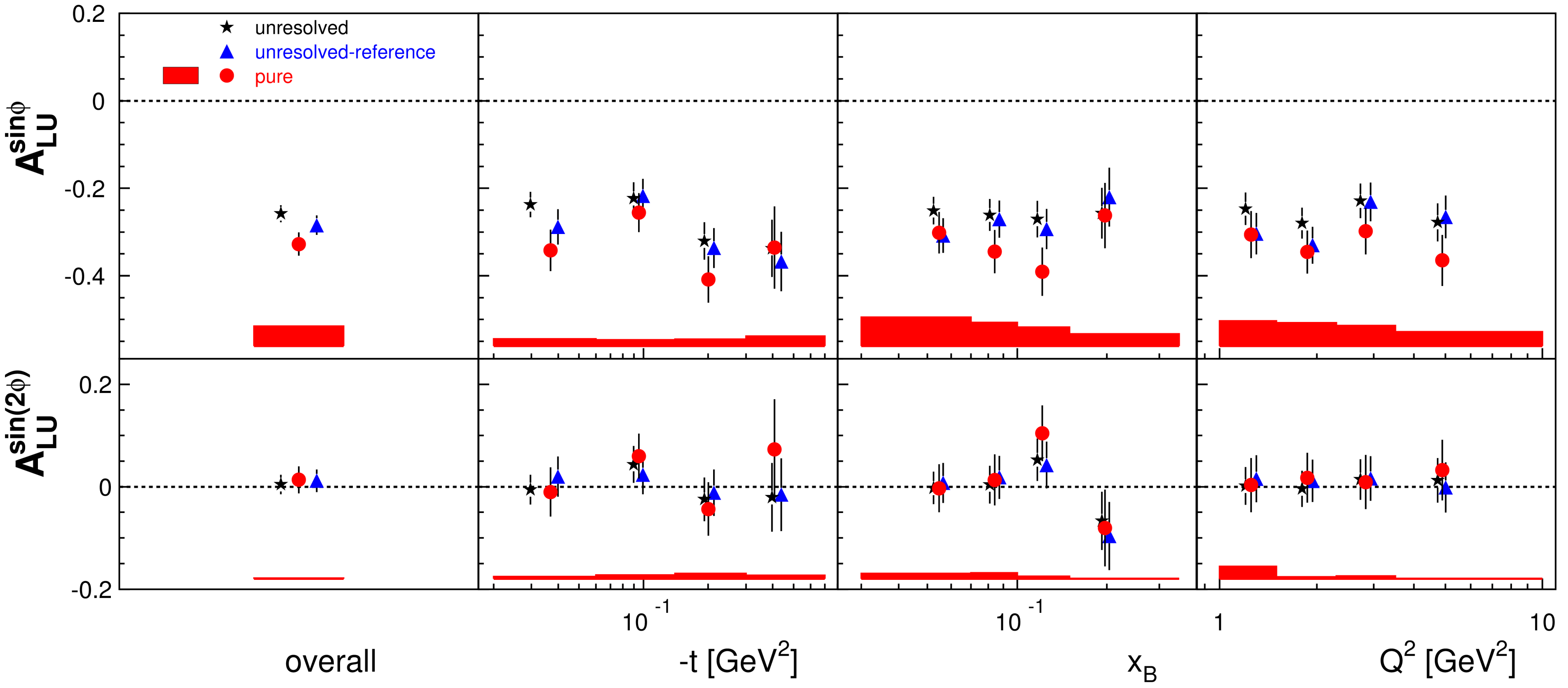
Pure (with RD)





Results for all DVCS Data Samples

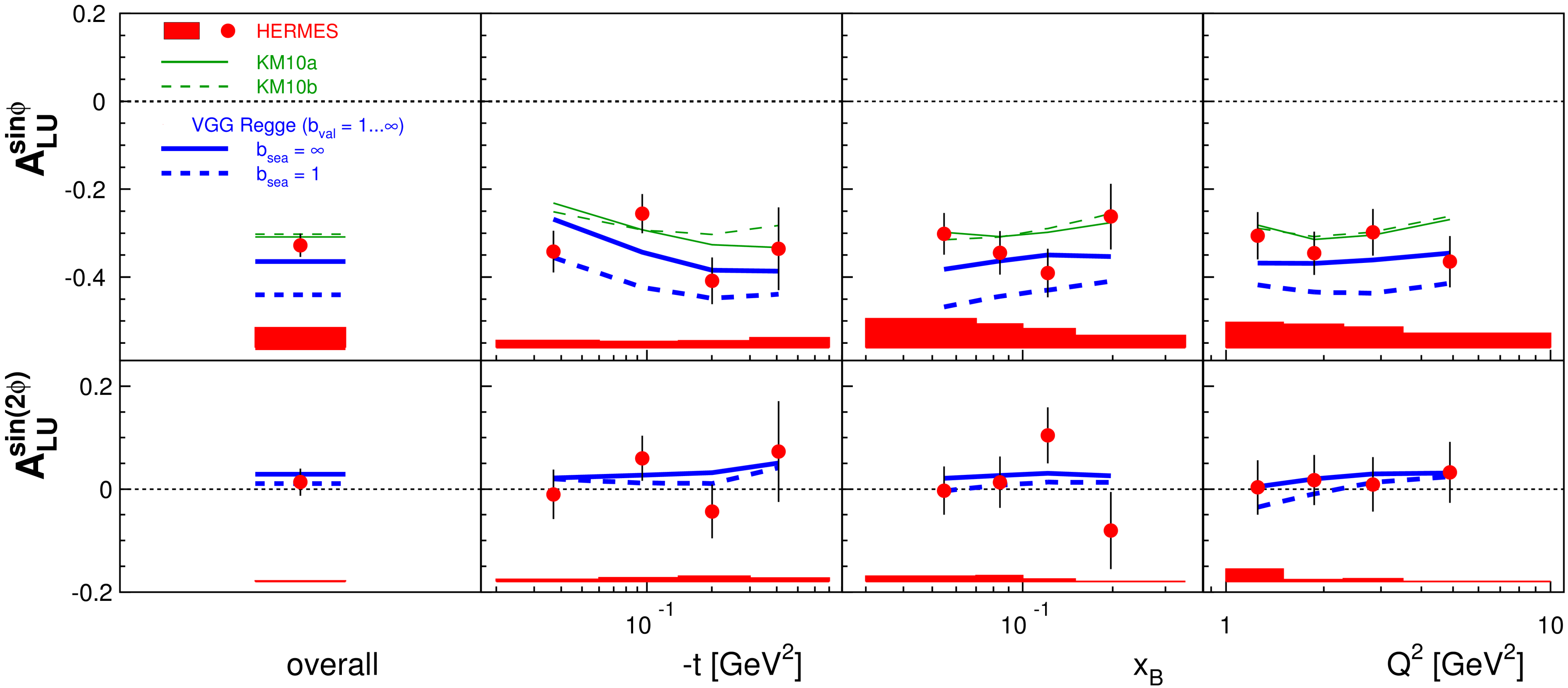
JHEP 10 (2012) 042



> 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

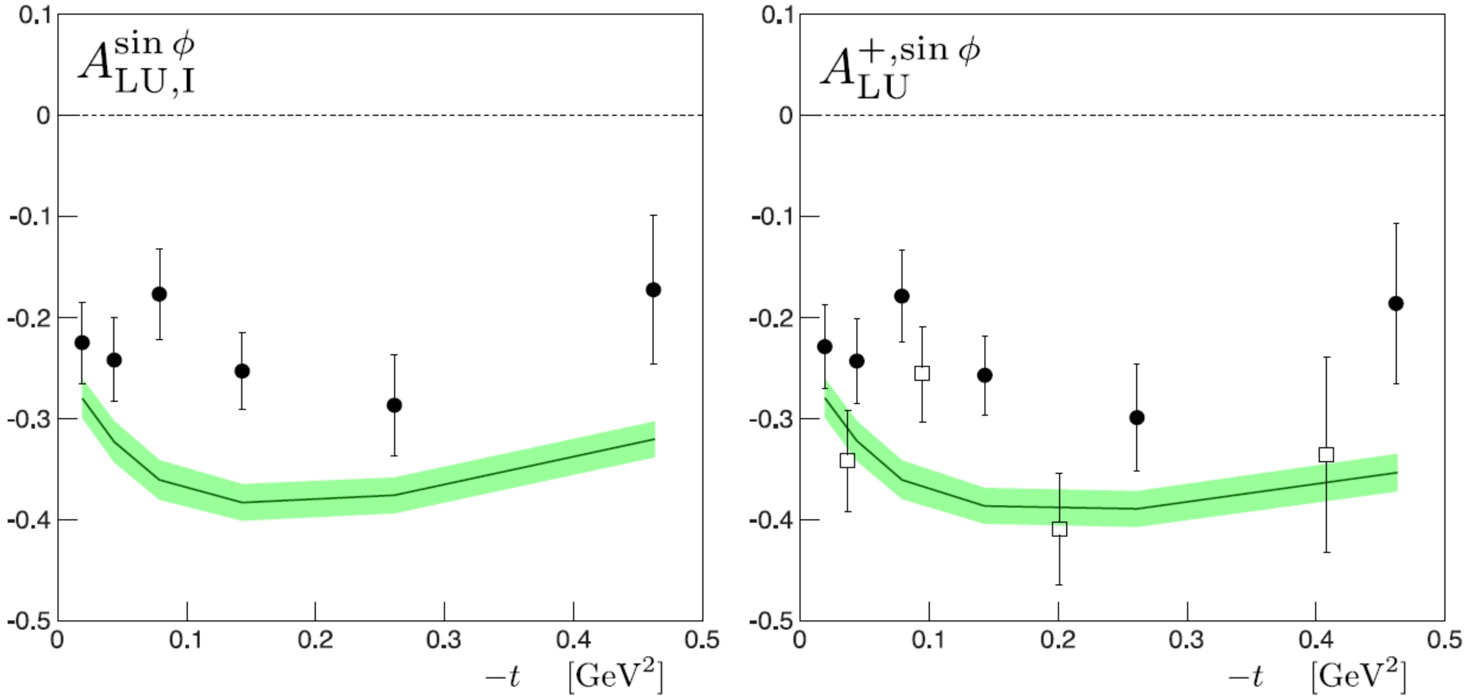


> GPD models and fits reasonably describe data

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

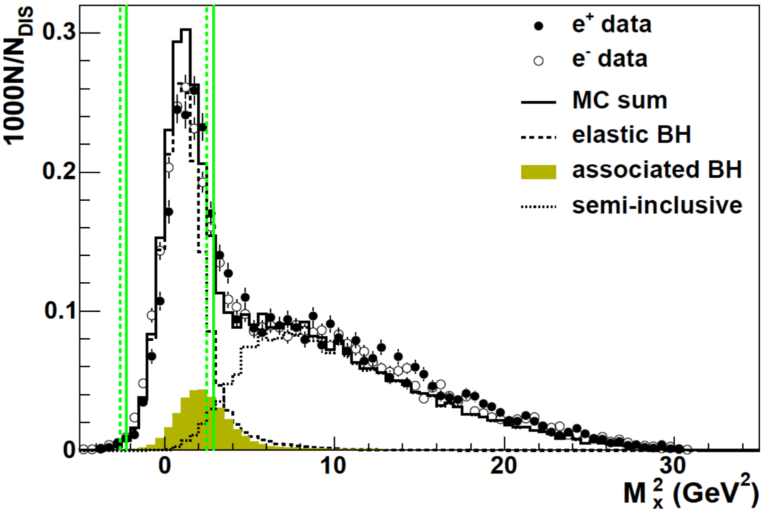
In comparison with HERMES data

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

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

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

> Delta resonance region → possible access to transition GPDs



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

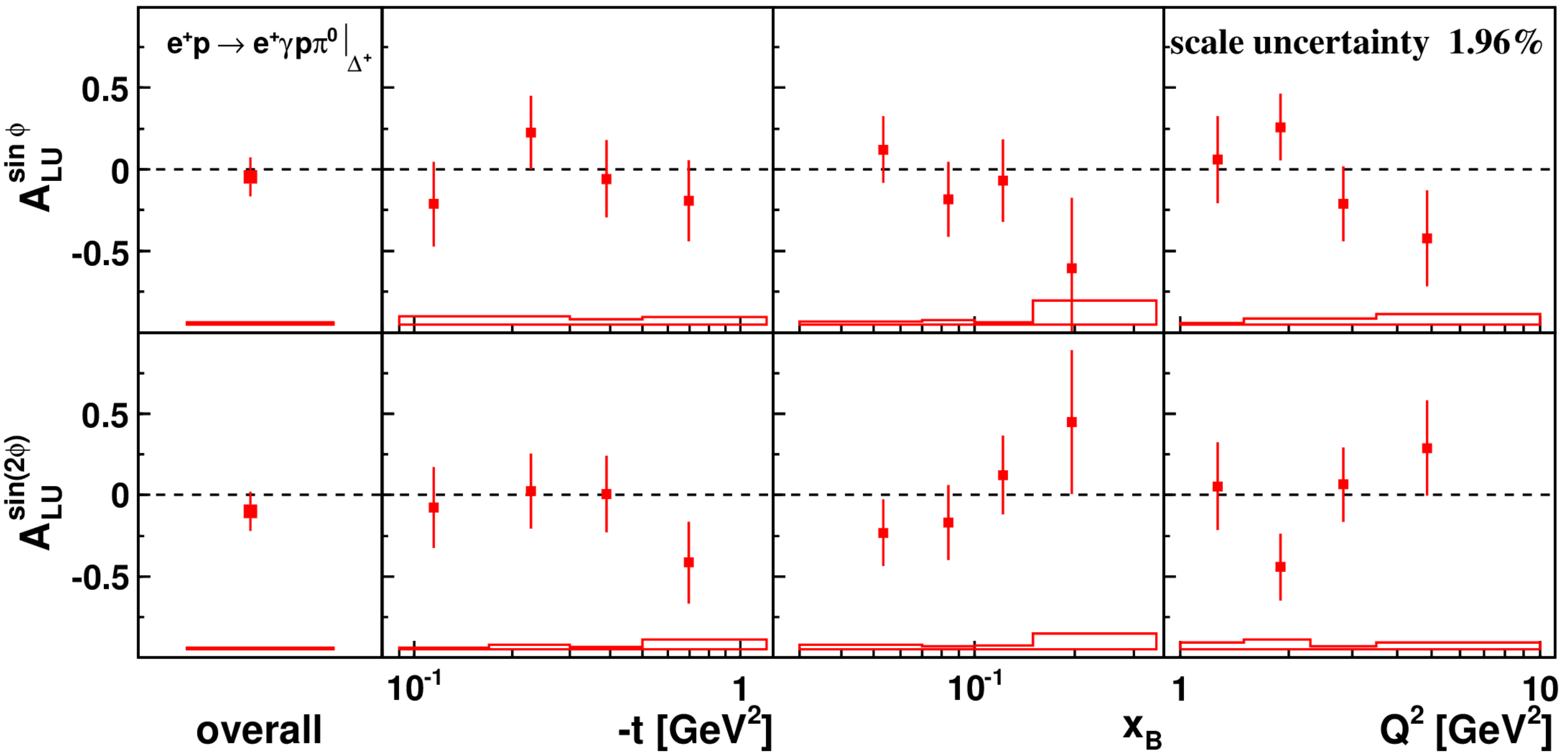
> Kinematic fitting under hypotheses of $ep \to e\gamma N\pi$ and $ep \to e\gamma p$
  - To select associated processes $ep \to e\gamma p\pi^0$ and $ep \to e\gamma n\pi^+$
  - To reject background from $ep \to e\gamma p$ (to the level below 1%)

> Particle identification in the Recoil Detector

> Results are corrected for SIDIS background
  - 11% in case of $ep \to e\gamma p\pi^0$, 23% in case of $ep \to e\gamma n\pi^+$

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

JHEP01 (2014) 077

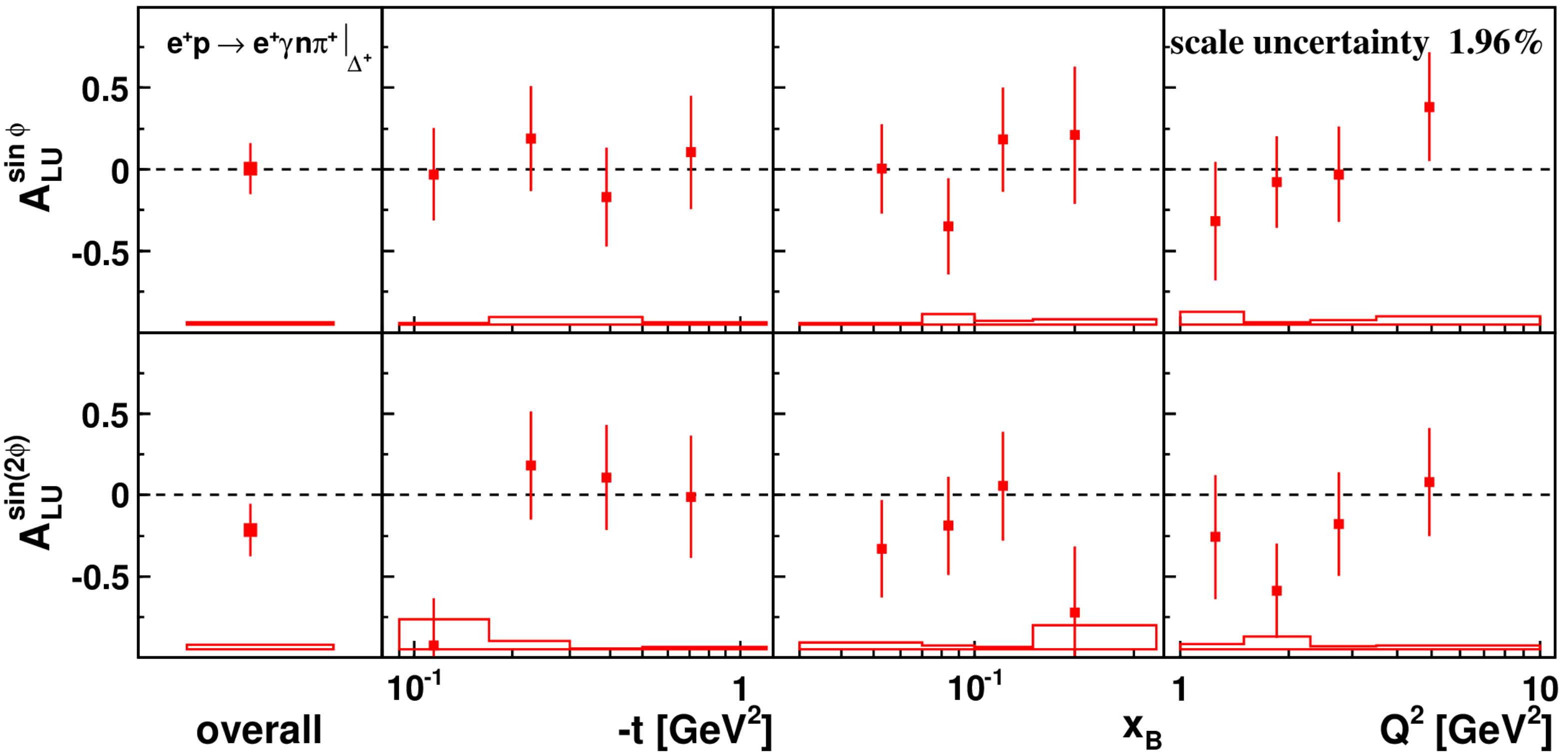


> Asymmetry amplitudes consistent with zero

> Contributes as a dilution in DVCS/BH asymmetry

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

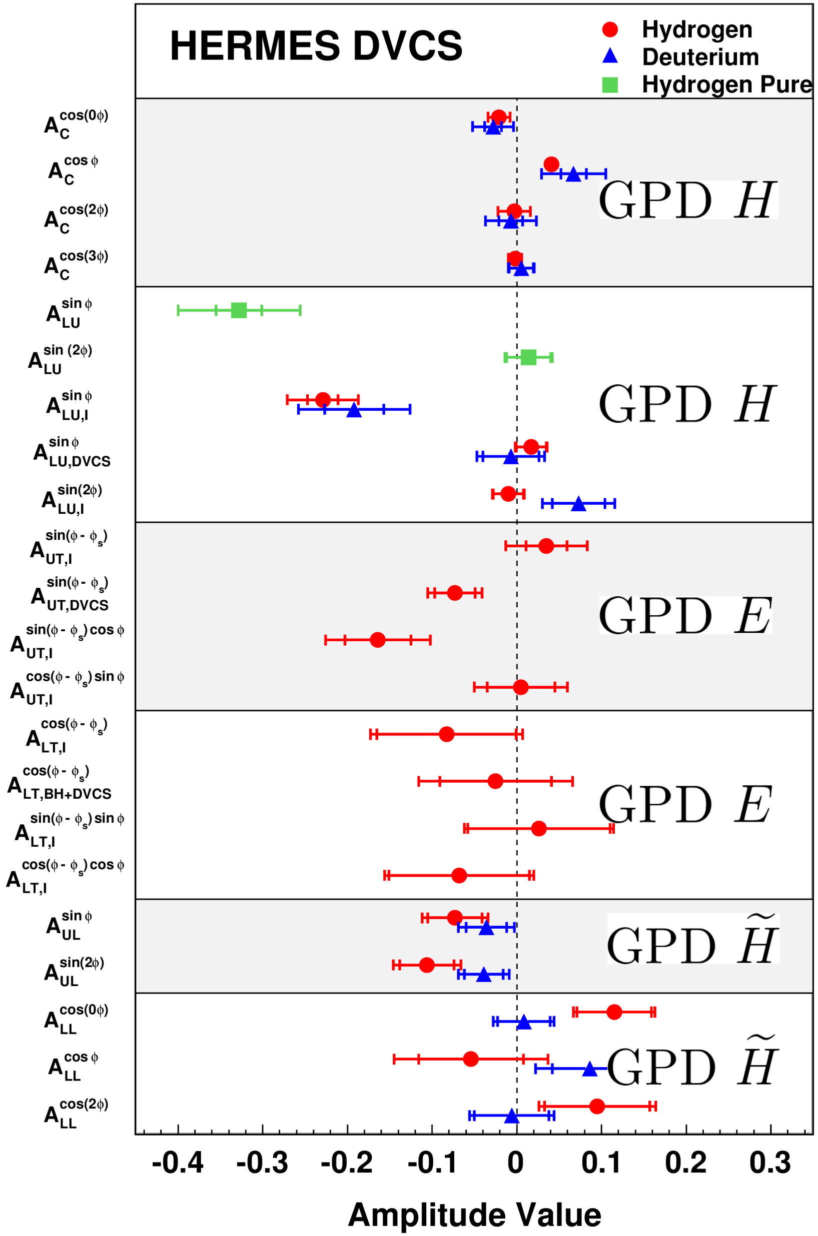
JHEP01 (2014) 077



> 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

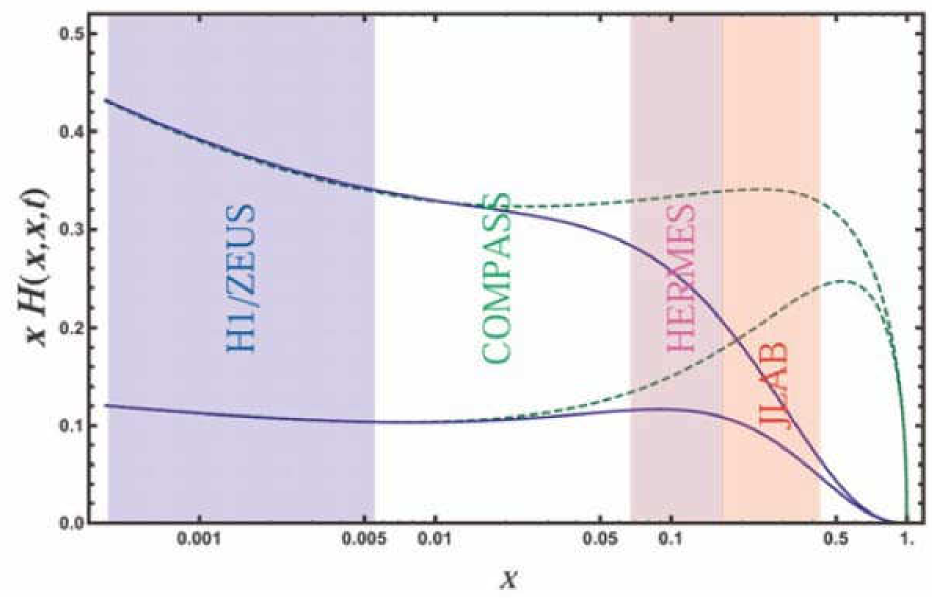
> Longitudinal target spin asymmetry

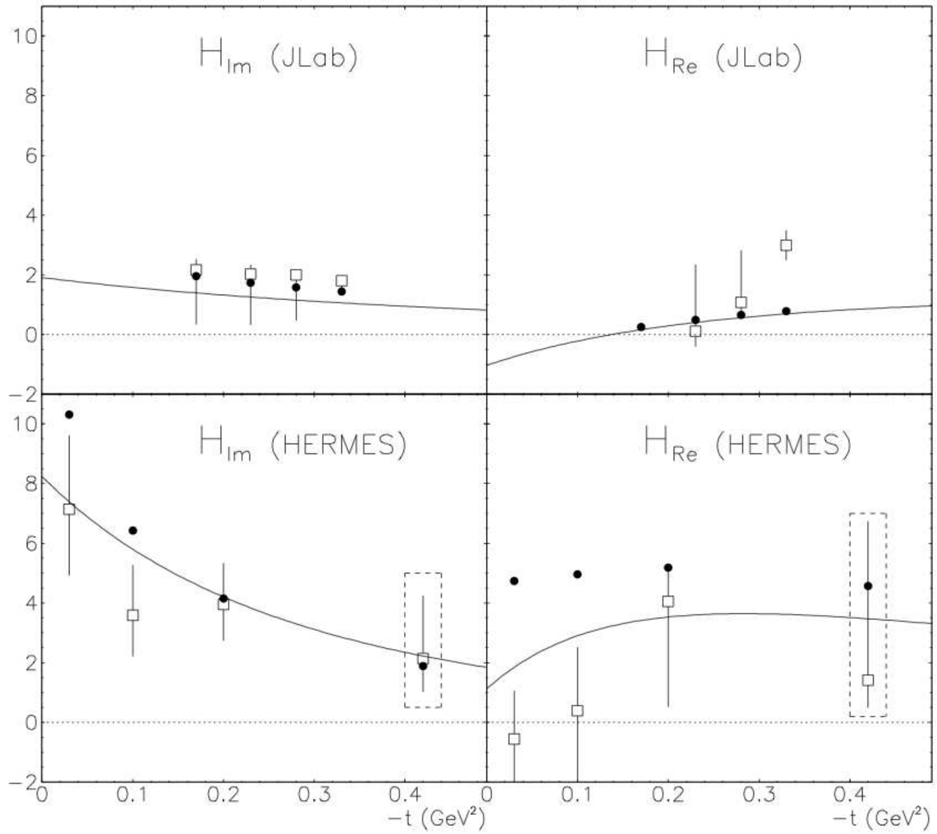
JHEP 06 (2010) 019

> Longitudinal target & double spin asymmetry

Nucl. Phys. B 842 (2011) 265

Extraction of GPDs and Compton Form Factors



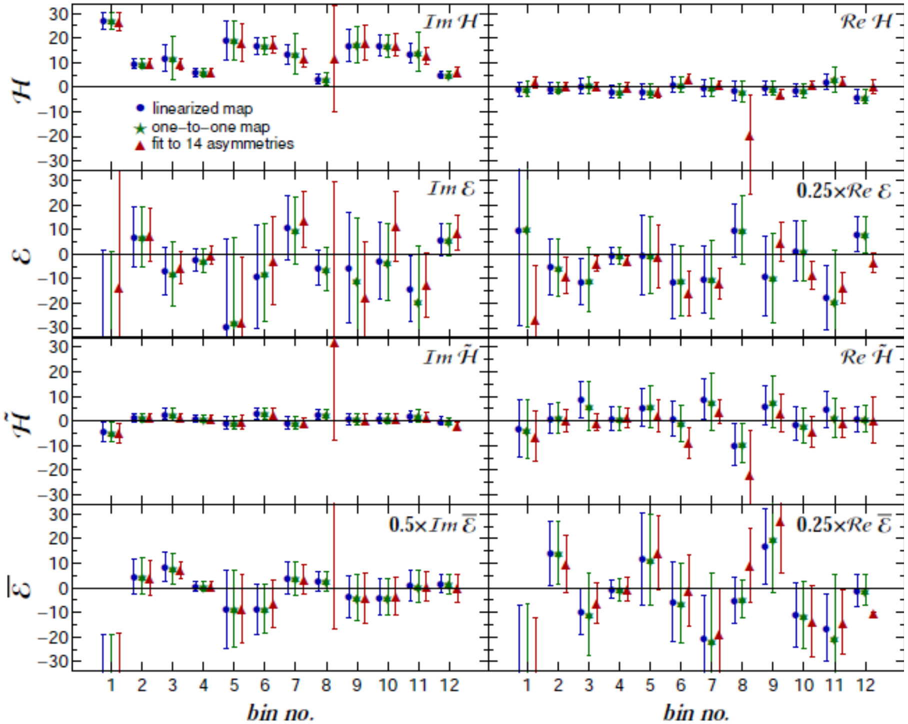


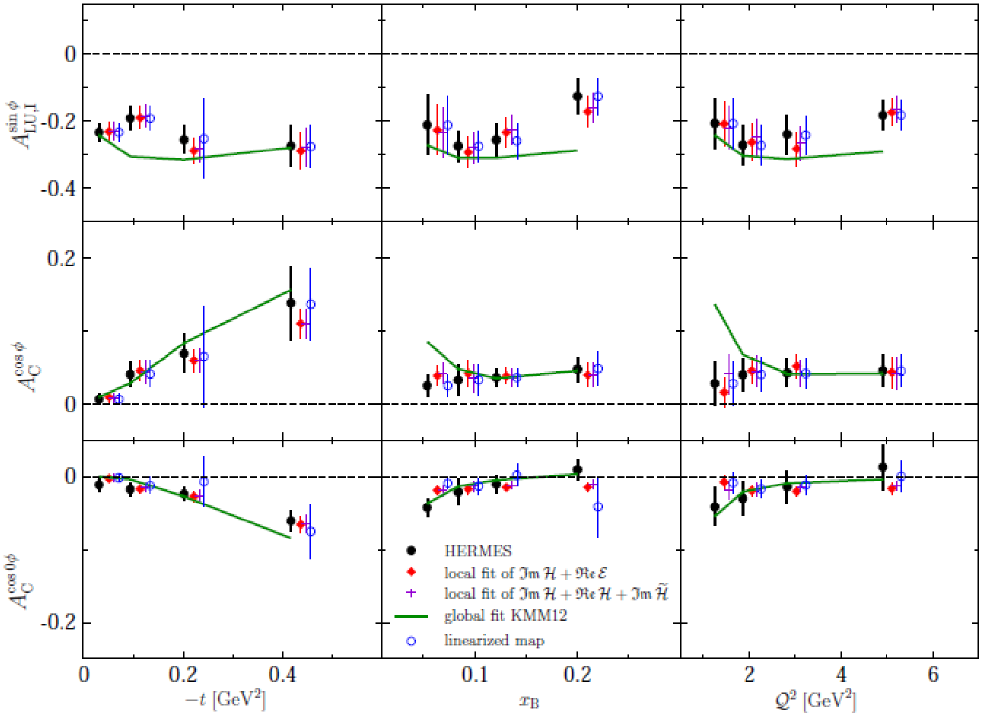
K. Kumerički and D. Müller, Nucl. Phys. B 841, (2010) 1

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

HERMES Impact for the Access of Compton Form Factors

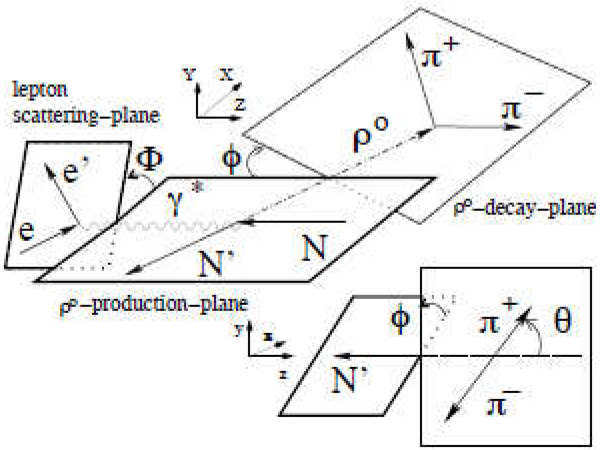
- Map various asymmetries into the space of Compton form factors
- Rely on dominance of twist-two Compton form factors
- Compare with local CFF fits and a model dependent global fit





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

Exclusive Vector Meson Production



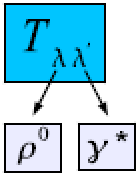
- pQCD description of the process
  - dissociation of the virtual photon into quark-antiquark
  - scattering of a pair on a nucleon
  - formation of the observed vector meson
- Natural parity exchange → GPDs H, E
- Unnatural parity exchange → GPDs $\widetilde{H}, \widetilde{E}$
- Cross section

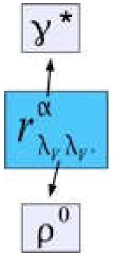
$$\frac{d\sigma}{dx_B dQ^2 dt d\Phi d\cos\theta d\phi} \propto \frac{d\sigma}{dx_B dQ^2 dt} W(x_B, Q^2, t, \Phi, \cos\theta, \phi)$$

- 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)

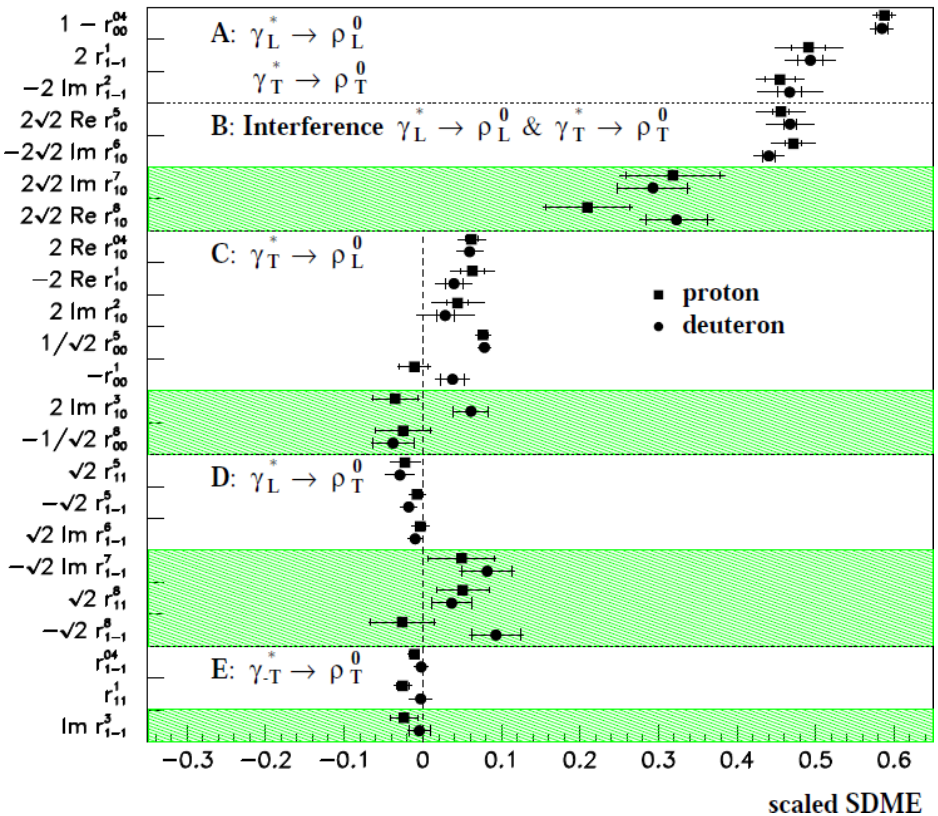




SDMEs in Exclusive ρ^0 Production

> 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

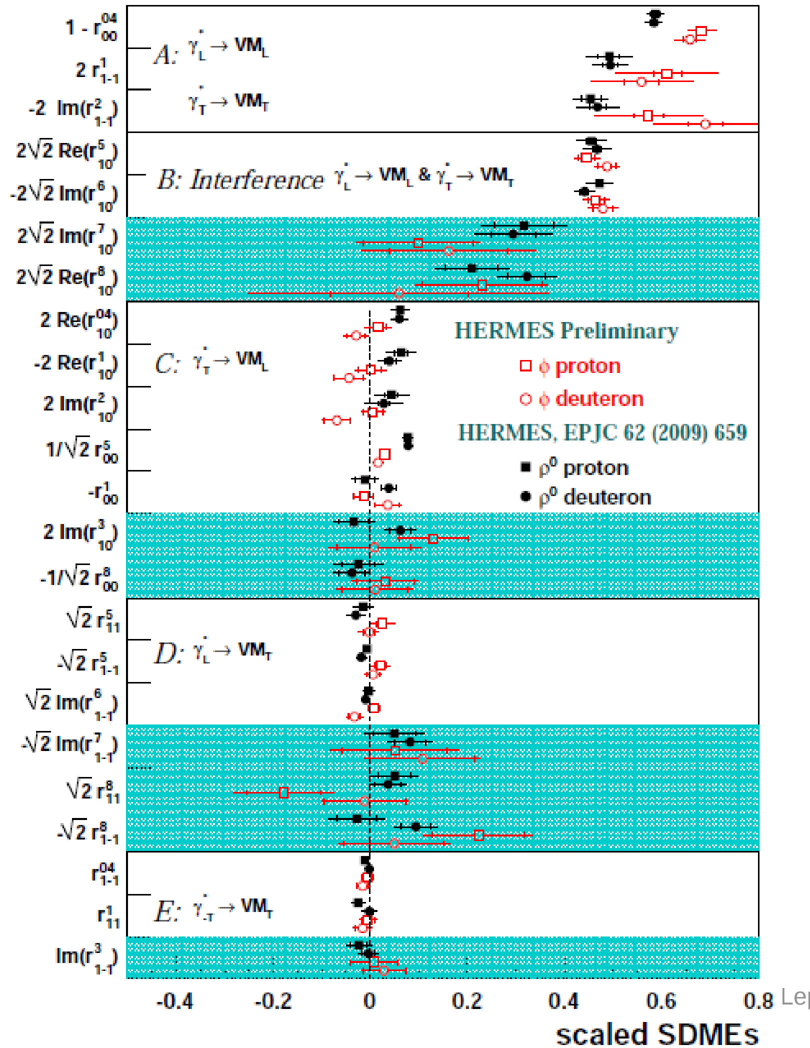
- Unpolarized SDMEs slightly negative
- Polarized SDMEs slightly positive

> 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

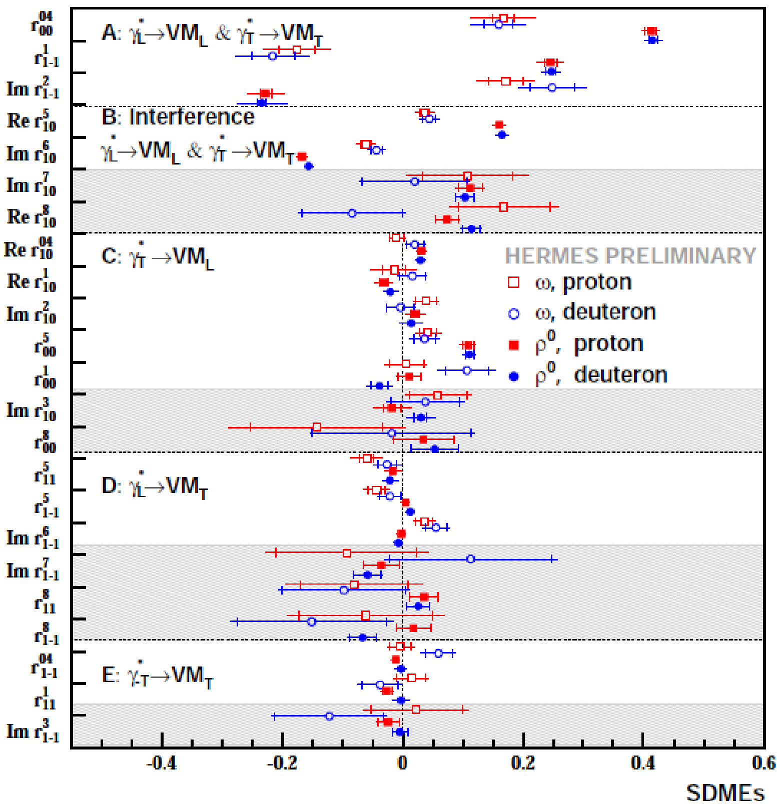
- Unpolarized and polarized SDMEs consistent with zero for both proton and deuteron

> Class E

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

SDMEs in Exclusive ω Production

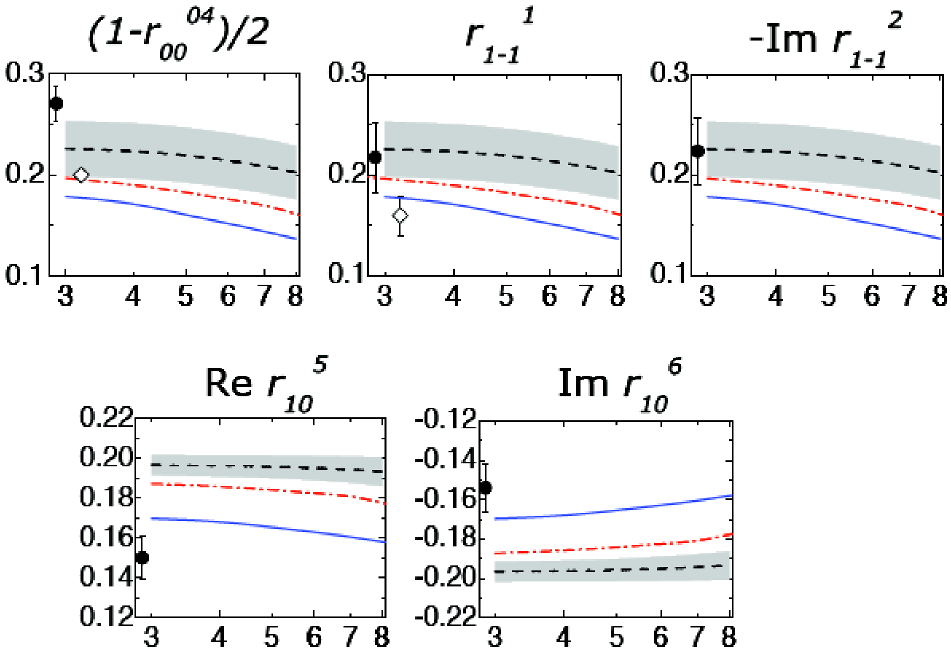
- Hierarchy of NPE helicity amplitudes not confirmed
- Importance of UPE

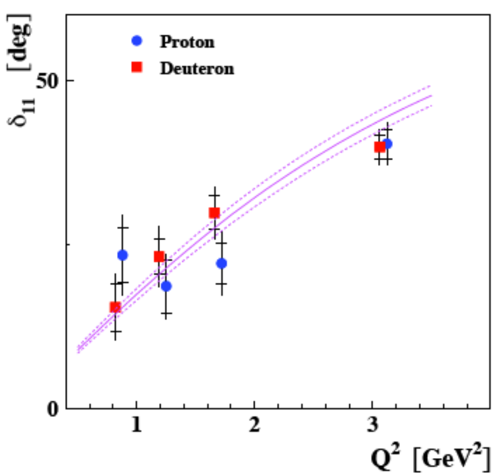


arXiv:1407.2119

- 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

  $\gamma^*_L \to \rho^0_L$ and $\gamma^*_T \to \rho^0_T$

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

- Disagreement for interference

  $\gamma^*_L \to \rho^0_L$ and $\gamma^*_T \to \rho^0_T$

- 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 $ep \rightarrow e\gamma N\pi$ near threshold
  - Soft pion limit ($k_\pi \rightarrow 0$)
  - Based on chiral symmetry ($m_\pi \rightarrow 0$)
- Predictions for HERMES, JLAB, and Compass
- Model dependent estimate of $ep \rightarrow e\gamma\Delta$
  - Large N_c limit
  - Relate the GPDs of the $N \rightarrow \Delta$ transition to those of the $N \rightarrow N$ transition