DVCS measurements at HERMES

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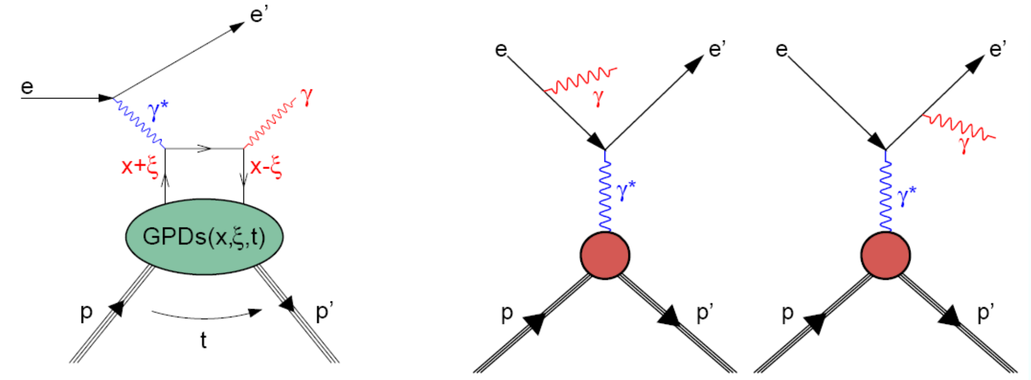
University of Erlangen-Nürnberg

(on behalf of the hermes Collaboration)

Deeply Virtual Compton Scattering

- Theoretically cleanest way to access GPDs
- Interference between DVCS and Bethe-Heitler amplitude
- $|\mathcal{T}_{DVCS}| << |\mathcal{T}_{BH}|$ @ HERMES



DVCS Bethe-Heitler

- Access to GPD combinations through azimuthal asymmetries A_{XY}

X: beam, Y: target polarisation

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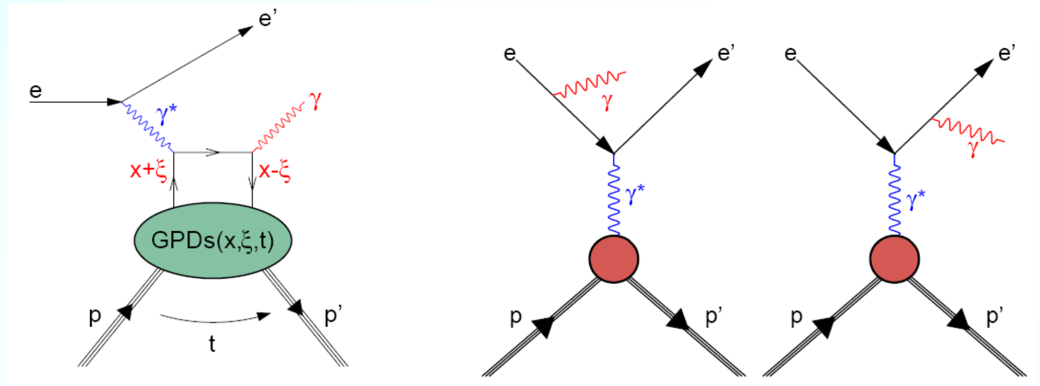


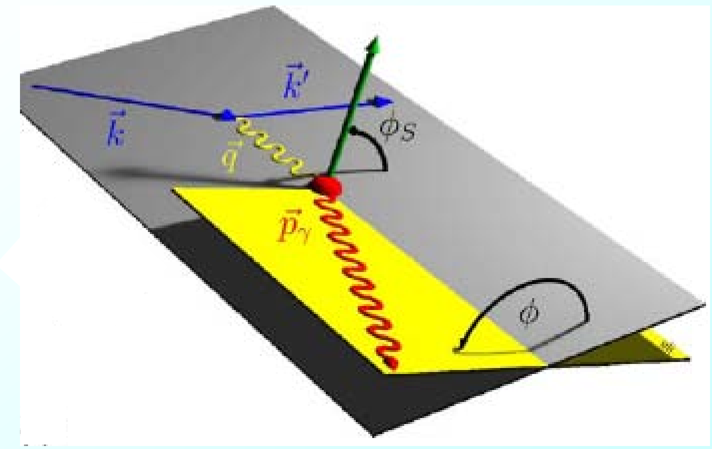
DVCS Bethe-Heitler

- Access to GPD combinations through azimuthal asymmetries A_{XY}

X → beam, Y → target polarisation

HERMES: Complete set of asymmetries

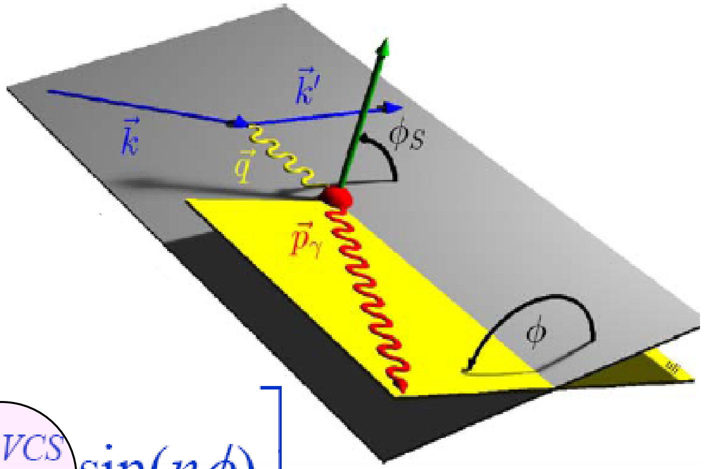
- Both beam charges
- Both beam helicities
- Unpolarised H, D and nuclear targets
- Longitudinally polarised H and D targets
- Transversely polarised H target
- Recoil detector



Azimuthal dependences in DVCS

Example: unpolarised proton target

$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} = \frac{y^2 x_B}{32(2\pi)^4 Q^4 \sqrt{1+\frac{4M^2 x_B^2}{Q^2}}} \left(|T_{DVCS}|^2 + |T_{BH}|^2 + I \right)$$



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

$$|T_{DVCS}|^2 = K_{DVCS} \left[\sum_{n=0}^{2} c_n^{DVCS} \cos(n\phi) + P_B \sum_{n=1}^{1} s_n^{DVCS} \sin(n\phi) \right]$$

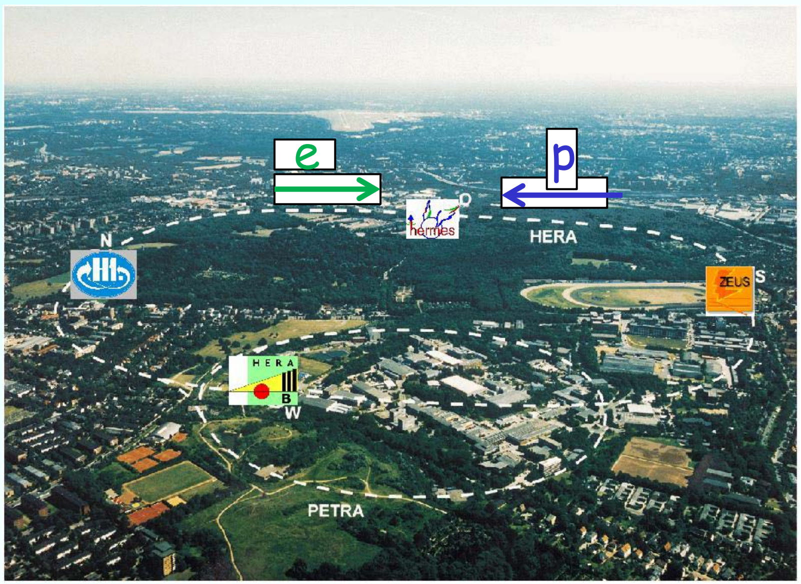
bilinear in GPDs

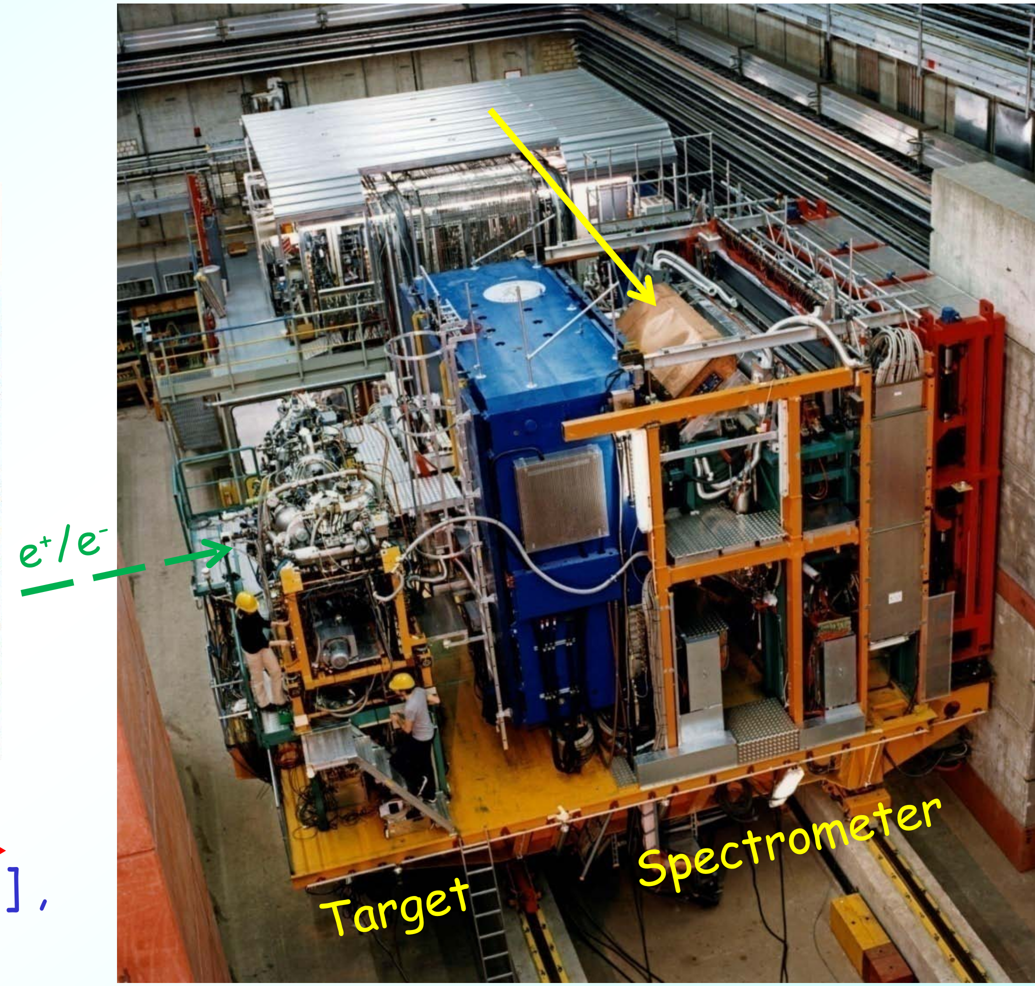
$$I = \frac{-C_B K_I}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} K_{DVCS} \left[\sum_{n=0}^{3} c_n^{I} \cos(n\phi) + P_B \sum_{n=1}^{2} s_n^{I} \sin(n\phi) \right]$$

linear in GPDs

HERMES Experiment

Longitudinally polarised
27.6 GeV e^+/e^- beam of HERA

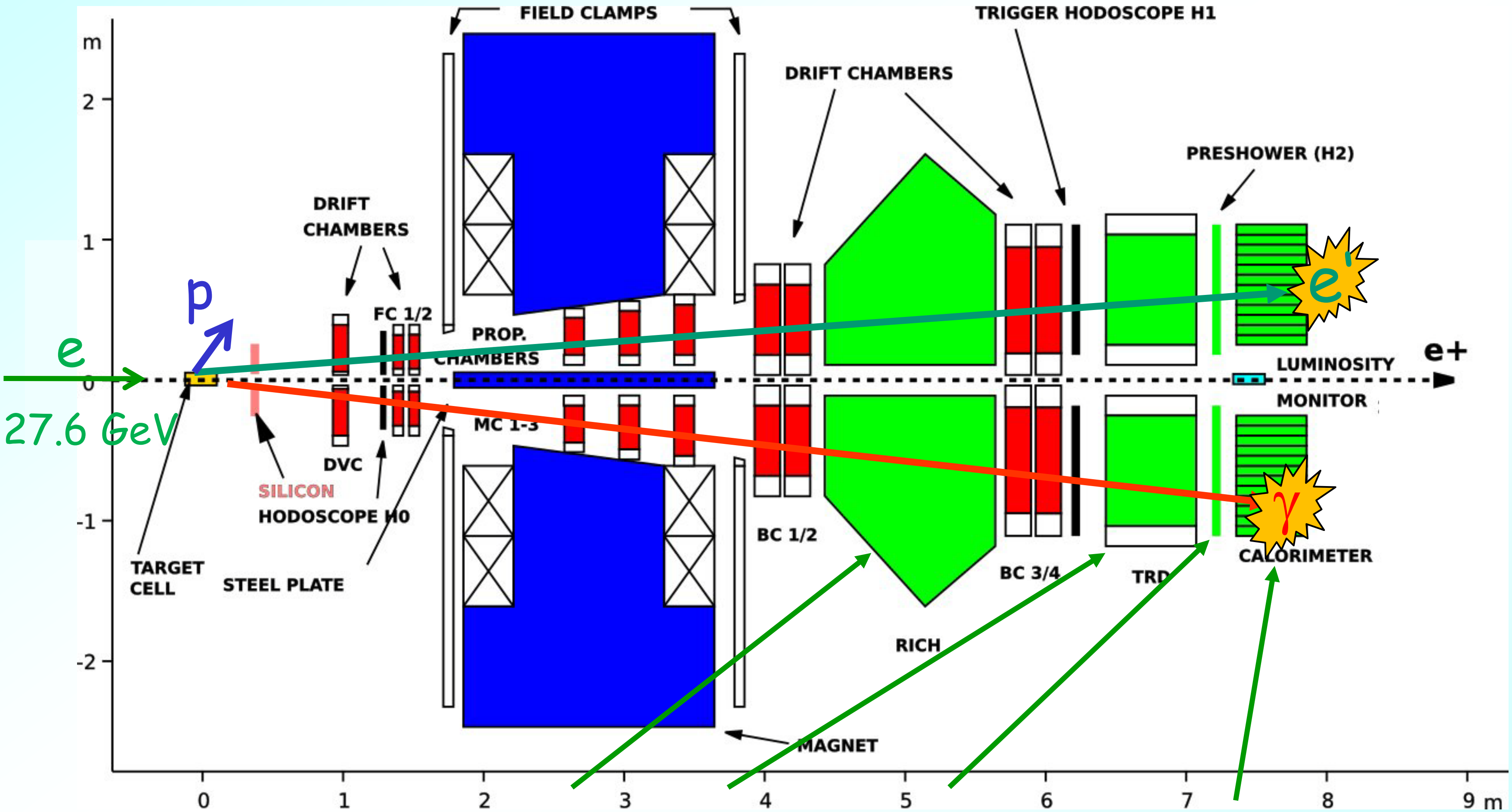




Internal gas targets:
longitudinally polarised [$^3\vec{He}$, $^1\vec{H}$, $^2\vec{H}$],
transversely polarised [$^1H^{\uparrow}$]
and unpolarised [^1H (1200pb^{-1}), ^2H (800 pb^{-1}),
He, N, Ne, Kr, Xe (300 pb^{-1})]

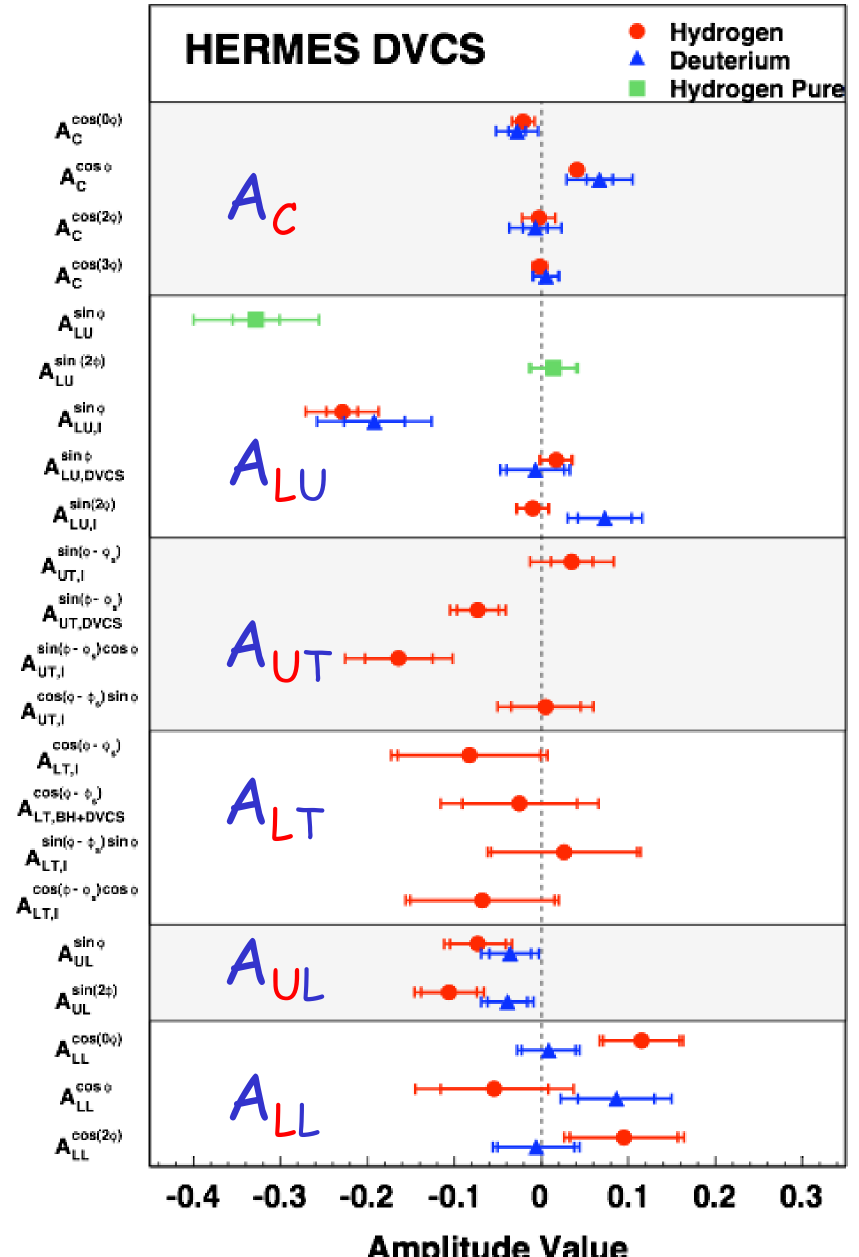
HERMES Spectrometer (1995 - 2005)

ep -> e' X



- PID: RICH, TRD, Preshower, Calorimeter

DVCS asymmetries measured @ HERMES



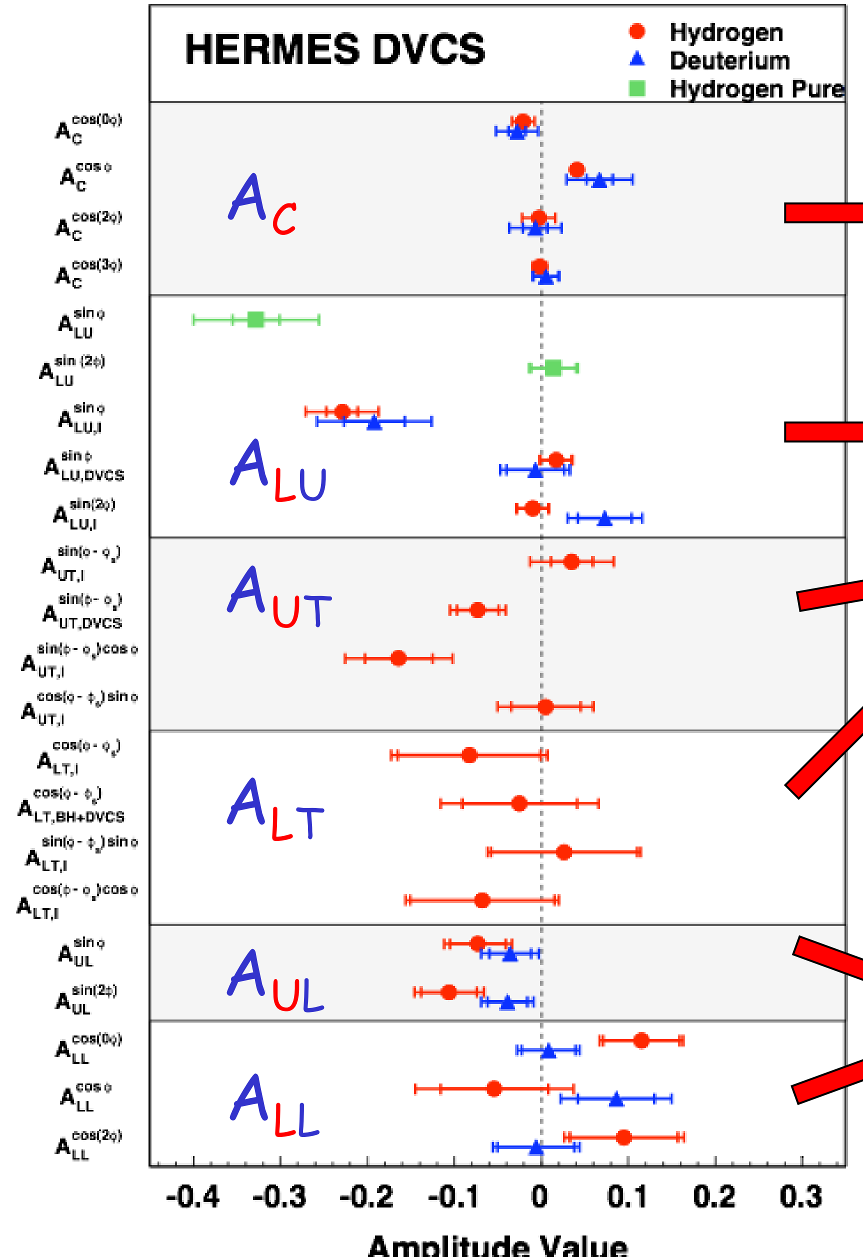
- **Beam charge asymmetry**
  GPD H
  - H: PRL 87 (2001) 182001
  - PR D 75 (2007) 011103
  - JHEP 11 (2009) 083
  - JHEP 07 (2012)032
  - JHEP 10 (2012) 042 (recoil det.)
  - JHEP 01 (2014) 077 (recoil det.)
  - D: Nucl. Phys. B 829 (2010) 1
  - nuclei: PR C 81 (2010) 035202

- **Beam helicity asymmetry**
  GPD H

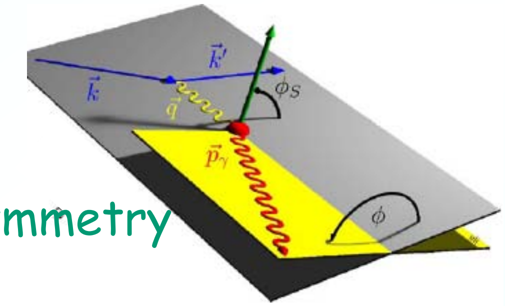
- **Transverse target-spin asymmetries**
  GPD E
  - H: JHEP 06 (2008) 066
  - H: PLB 704 (2011) 15

- **Longitudinal target spin asymmetries**
  GPD $\tilde{H}$
  - H: JHEP 06 (2010) 019
  - D: Nucl. Phys. B 842 (2011) 265

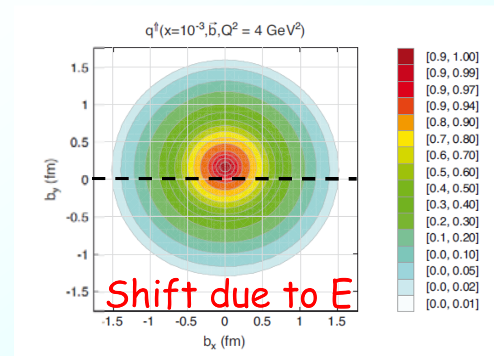
DVCS asymmetries measured @ HERMES



- Beam charge asymmetry
  GPD H



- Beam helicity asymmetry
  GPD H
- Transverse target-spin asymmetries
  GPD E

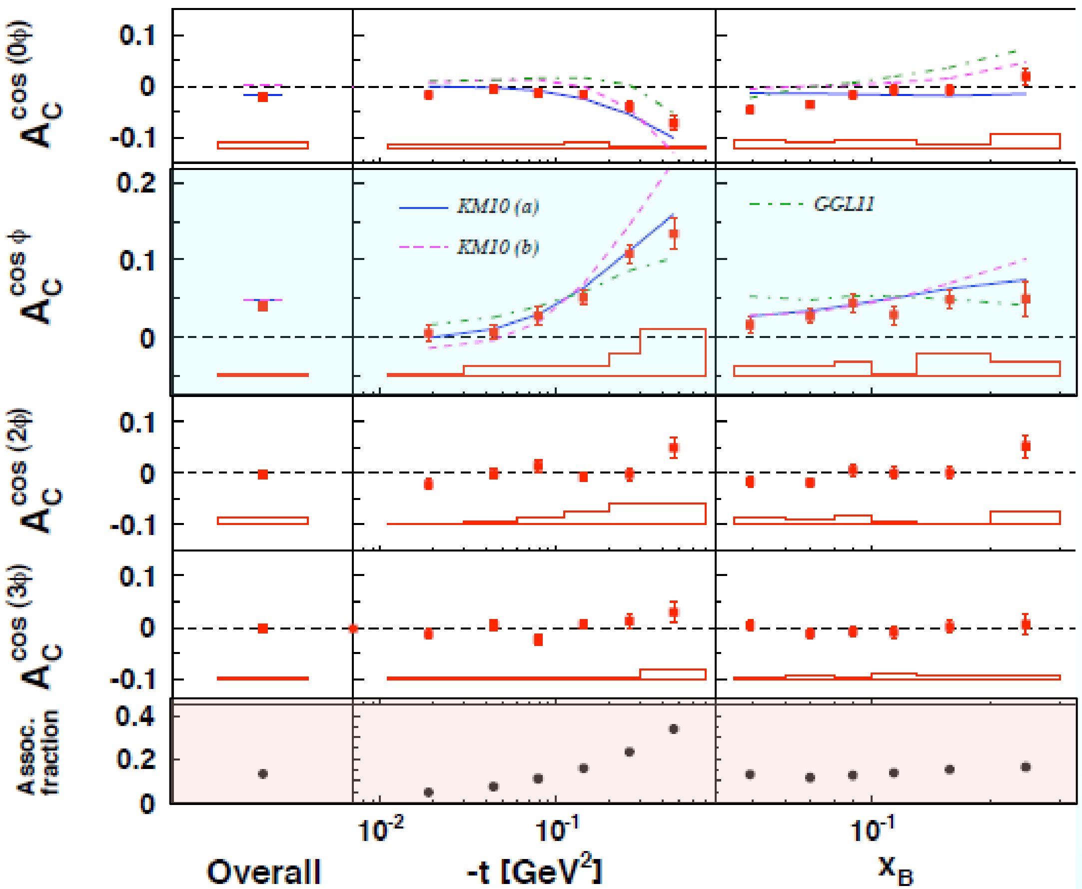


- Longitudinal target spin asymmetries
  GPD $\tilde{H}$

$$\Delta q = \lim_{\zeta,t\to 0} \int_{-1}^{+1} dx \times [\tilde{H}^q(x,\zeta,t)$$

Beam-charge asymmetry A_C

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



constant term: $\propto -A_C^{\cos\phi}$

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

higher twist

gluon leading twist

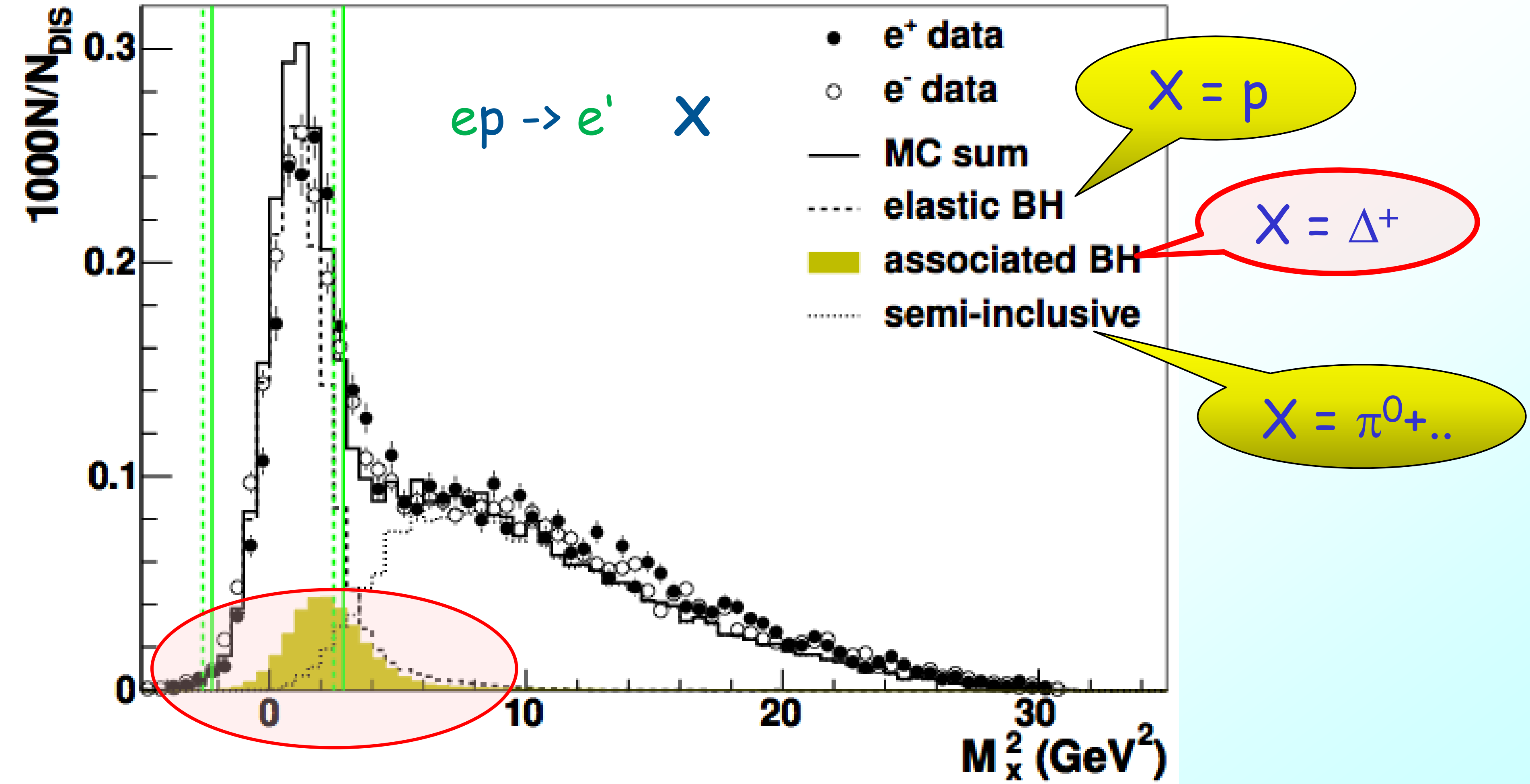
resonant fraction

$ep \to e\Delta^+\gamma$

Complete data set including 2006-07

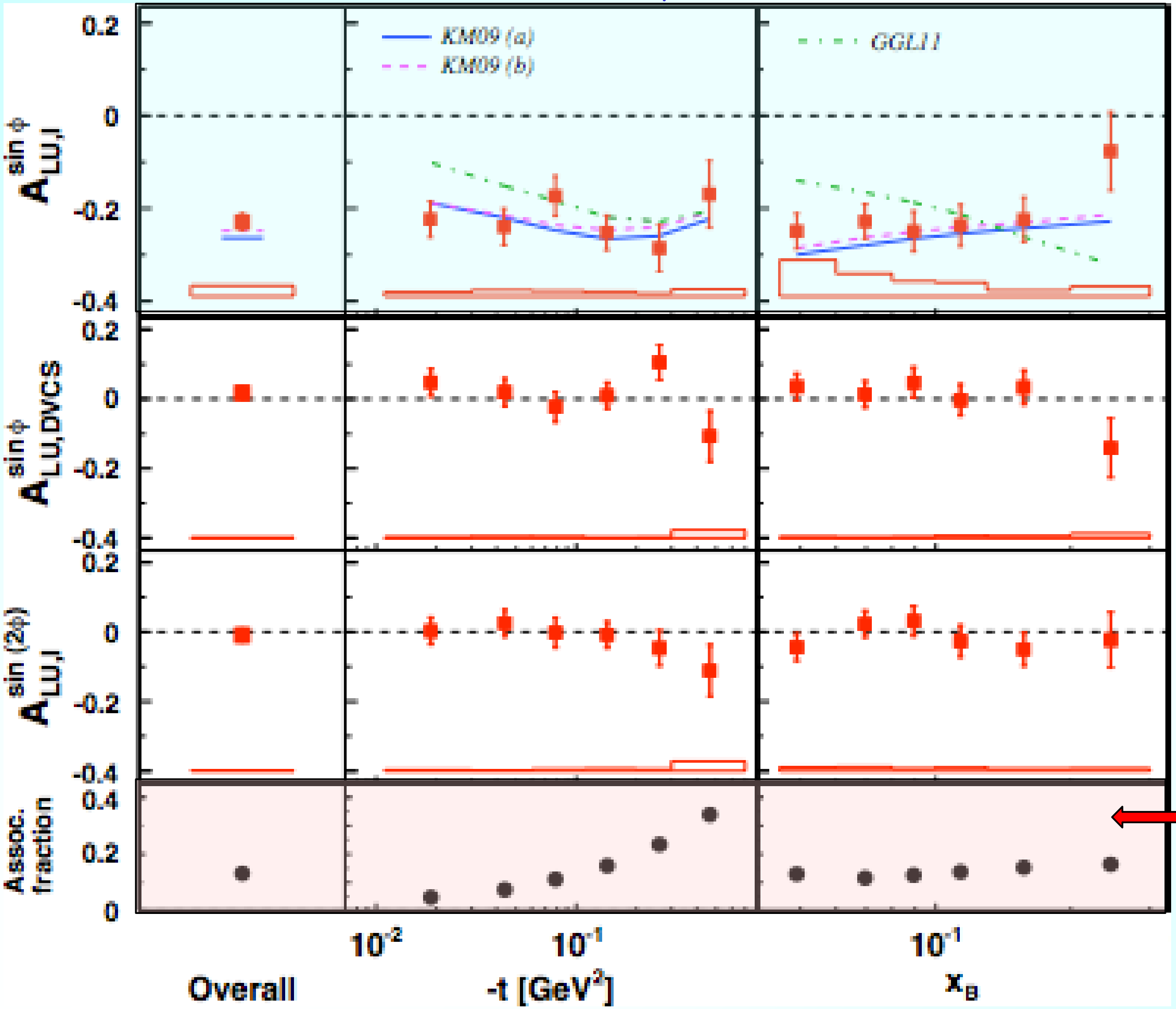
Exclusivity: missing-mass technique

$$M_X^2 = (P_e + P_p - P_{e'} - P_\gamma)^2$$



Beam-spin asymmetry A_{LU}

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



$\propto \mathrm{Im}[F_1\mathcal{H}]$

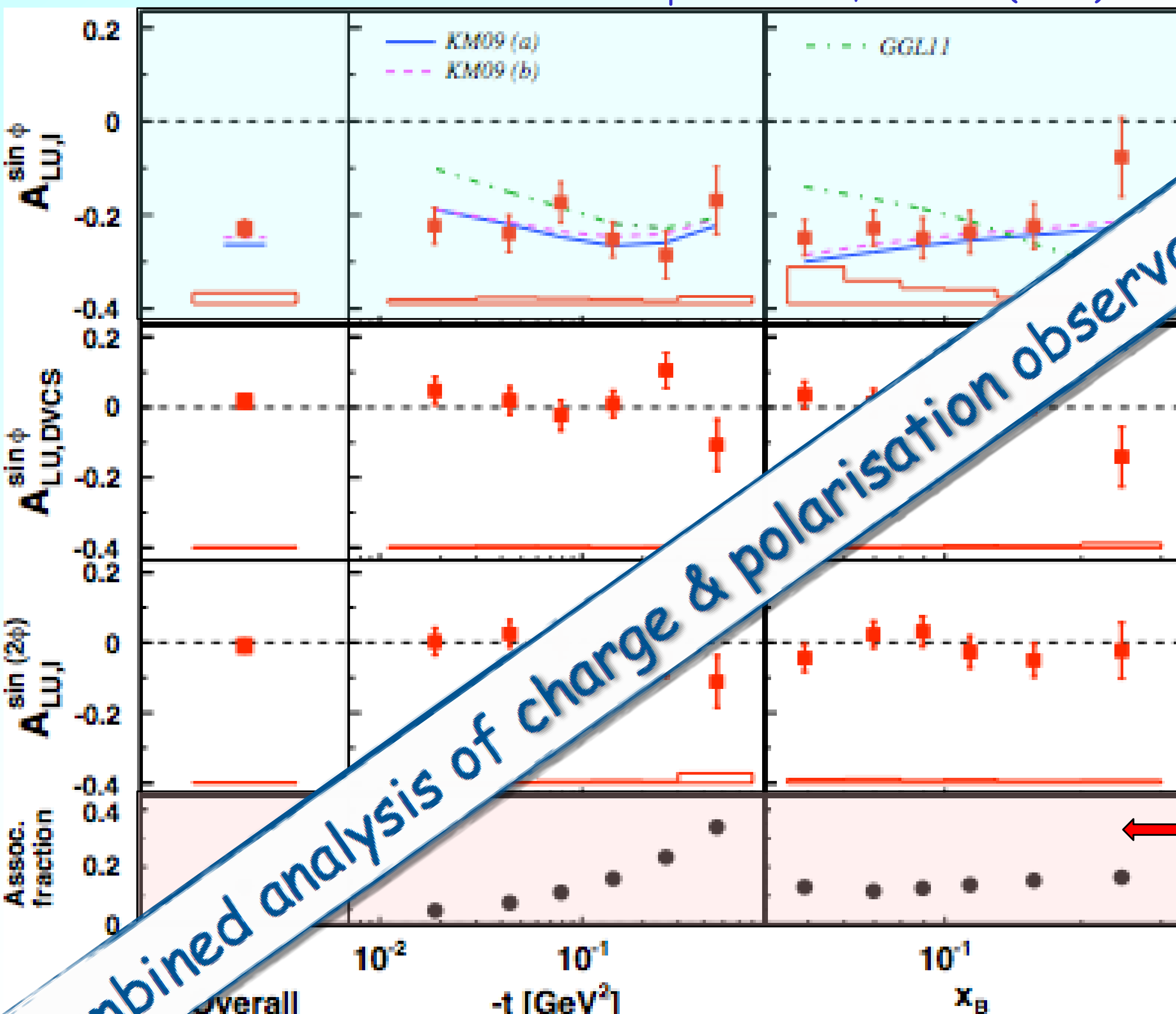
higher twist

resonant fraction

$ep \rightarrow e\Delta^+\gamma$

Beam-spin asymmetry

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



combined analysis of charge & polarisation observables unique to HERA!

$\propto \mathrm{Im}[F_1\mathcal{H}]$

higher twist

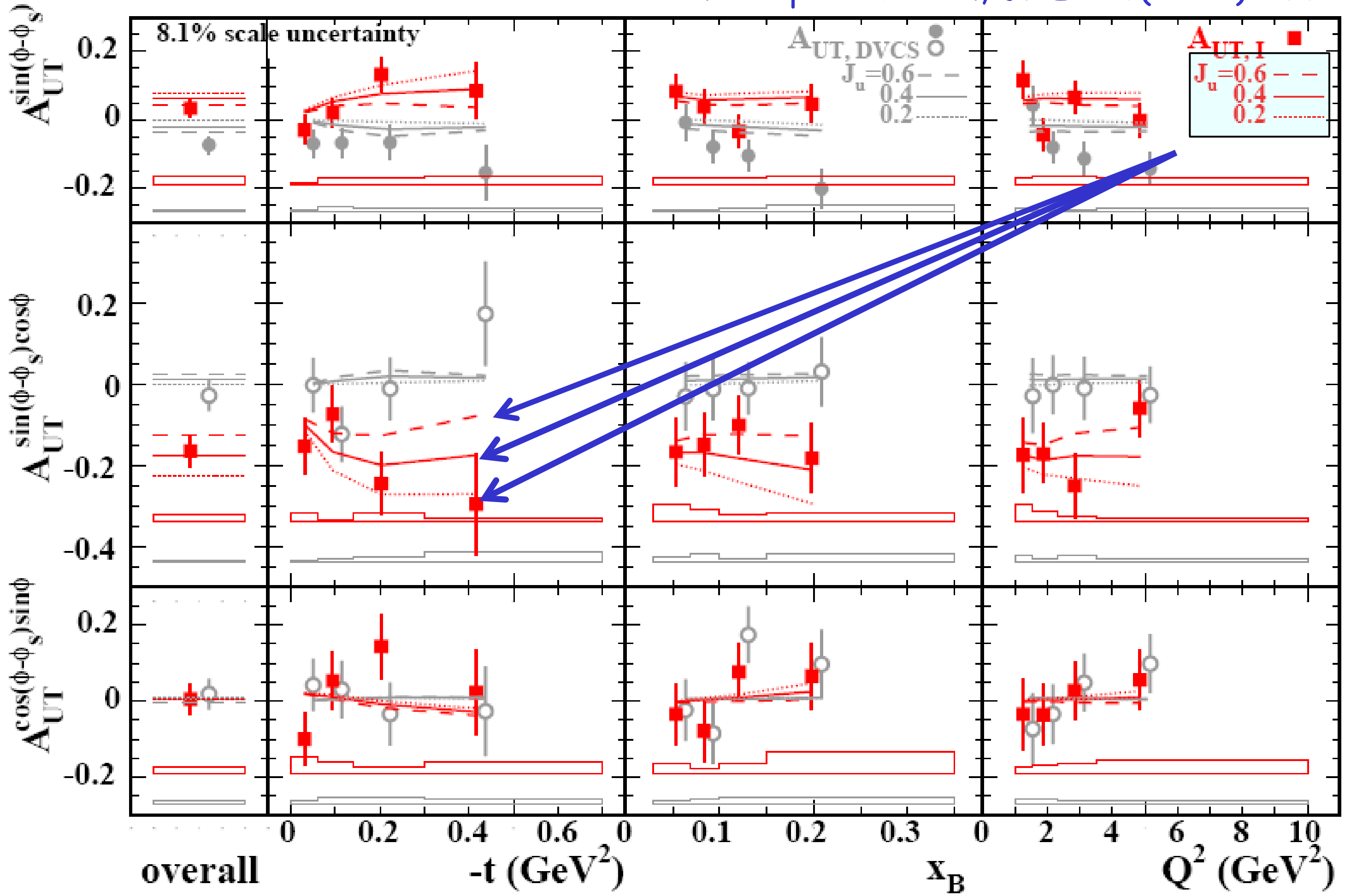
resonant fraction

$ep \rightarrow e\Delta^+\gamma$

Transverse target polarisation asymmetry A_{UT}

Sensitive to GPD E and OAM

A. Airapetian et al., JHEP 06(2008) 066



$\propto \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}]$

$\propto \mathrm{Im}[F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}]$

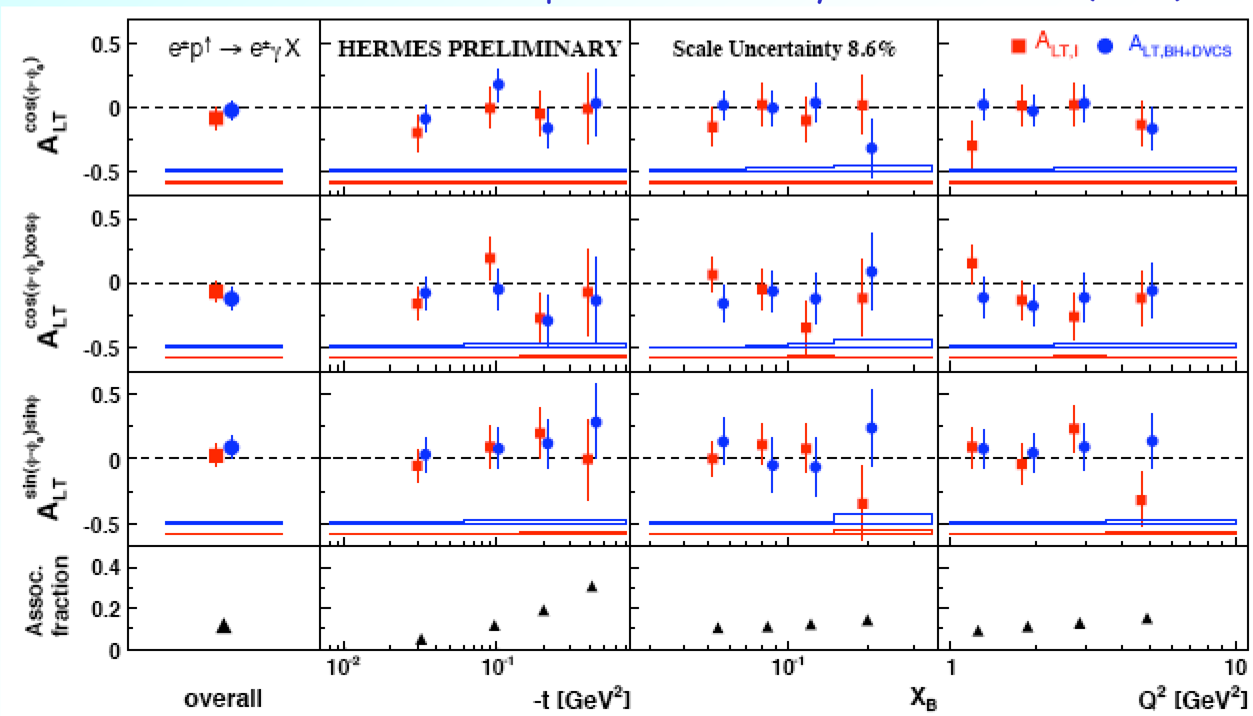
Model: „VGG" (Phys. Rev. D60 (1999) 094017 & Prog. Nucl. Phys. 47 (2001) 401)

Transverse double-spin asymmetry A_{LT}

Beam charge | Beam polarisation | Target polarisation

$$\langle \mathcal{N}(e_\ell, P_l, S_t, \phi, \phi_S)\rangle \propto \sigma_{UU}(\phi)[1 + \cdots + P_l S_t \mathcal{A}_{LT}^{BH+DVCS} + e_\ell P_l S_t \mathcal{A}_{LT}^{I}]$$

A. Airapetian et al., Phys. Lett. B 704 (2011) 15



$$\propto \mathcal{A}_{LT}^{\cos(\phi-\phi_S)\cos(\phi)}$$

$$\propto \frac{\mathcal{R}e[F_2\widetilde{\mathcal{H}} - (F_1 + \xi F_2)\widetilde{\mathcal{E}}]}{\mathcal{R}e[\mathcal{H}\mathcal{E}^* - \mathcal{E}\mathcal{H}^* - \xi(\widetilde{\mathcal{H}}\widetilde{\mathcal{E}}^* - \widetilde{\mathcal{E}}\widetilde{\mathcal{H}}^*)]}$$

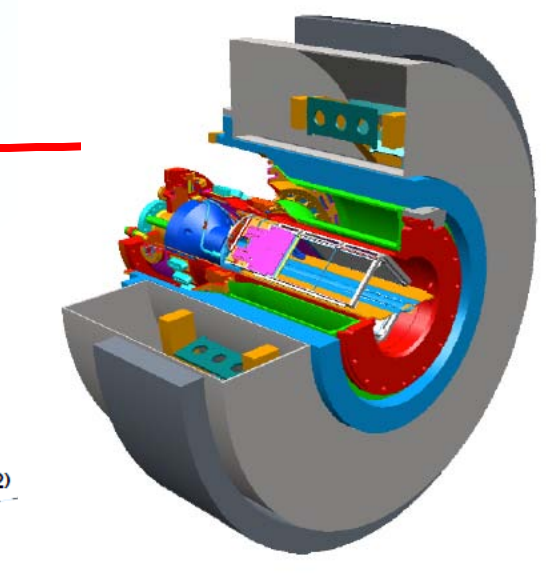
$$\propto \frac{\mathcal{R}e[F_2\mathcal{H} - F_1\mathcal{E}]}{\mathcal{R}e[-\widetilde{\mathcal{H}}\mathcal{E}^* - \widetilde{\mathcal{H}}^*\mathcal{E} + \xi(\mathcal{H}\widetilde{\mathcal{E}}^* + \widetilde{\mathcal{E}}\mathcal{H}^*)]}$$

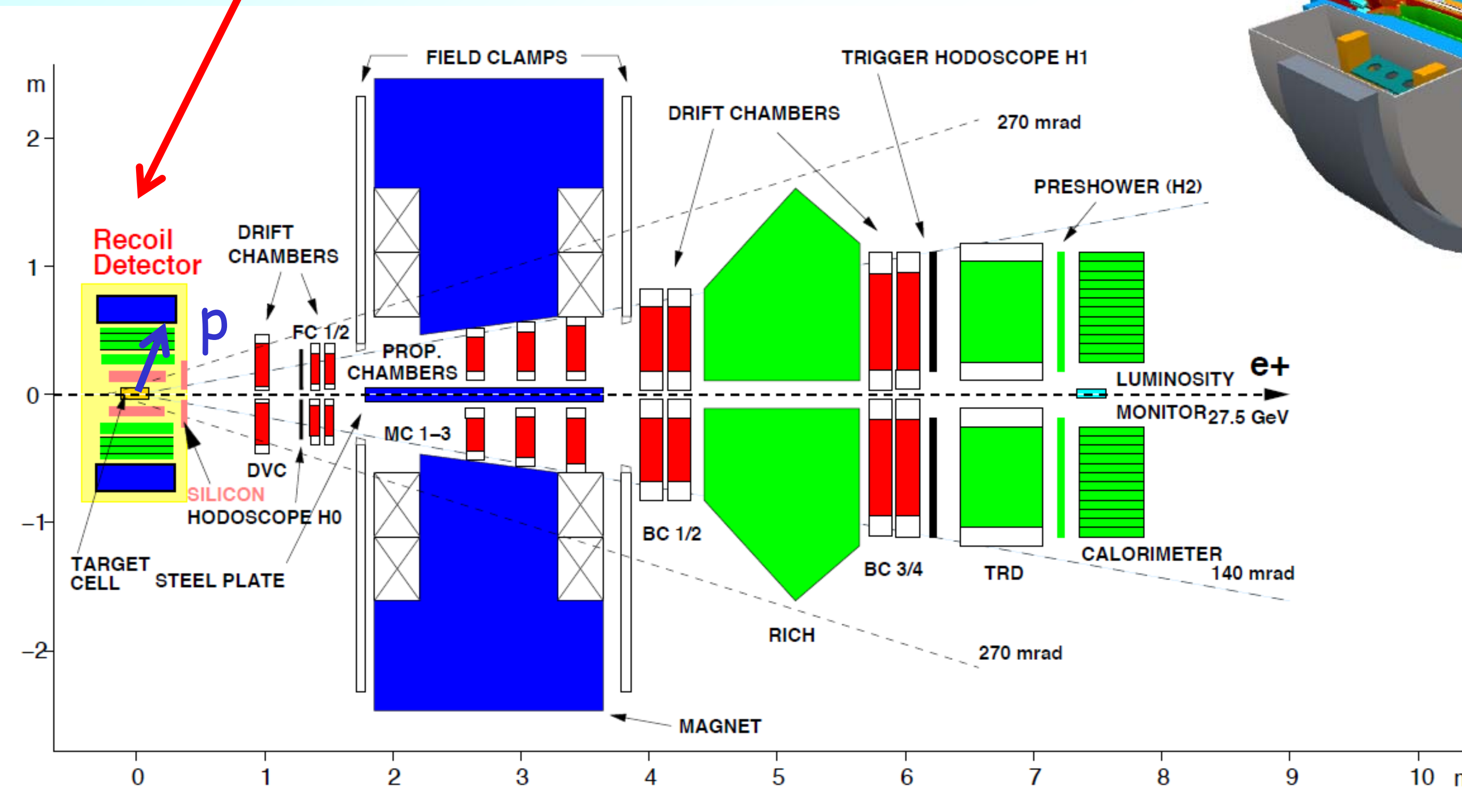
Sensitive to both GPDs entering the Ji sum rule

- Consistent with zero, cancellations between E and H
  Sensitivity to J_u suppressed by kinematic factors

HERMES spectrometer (2006-07)

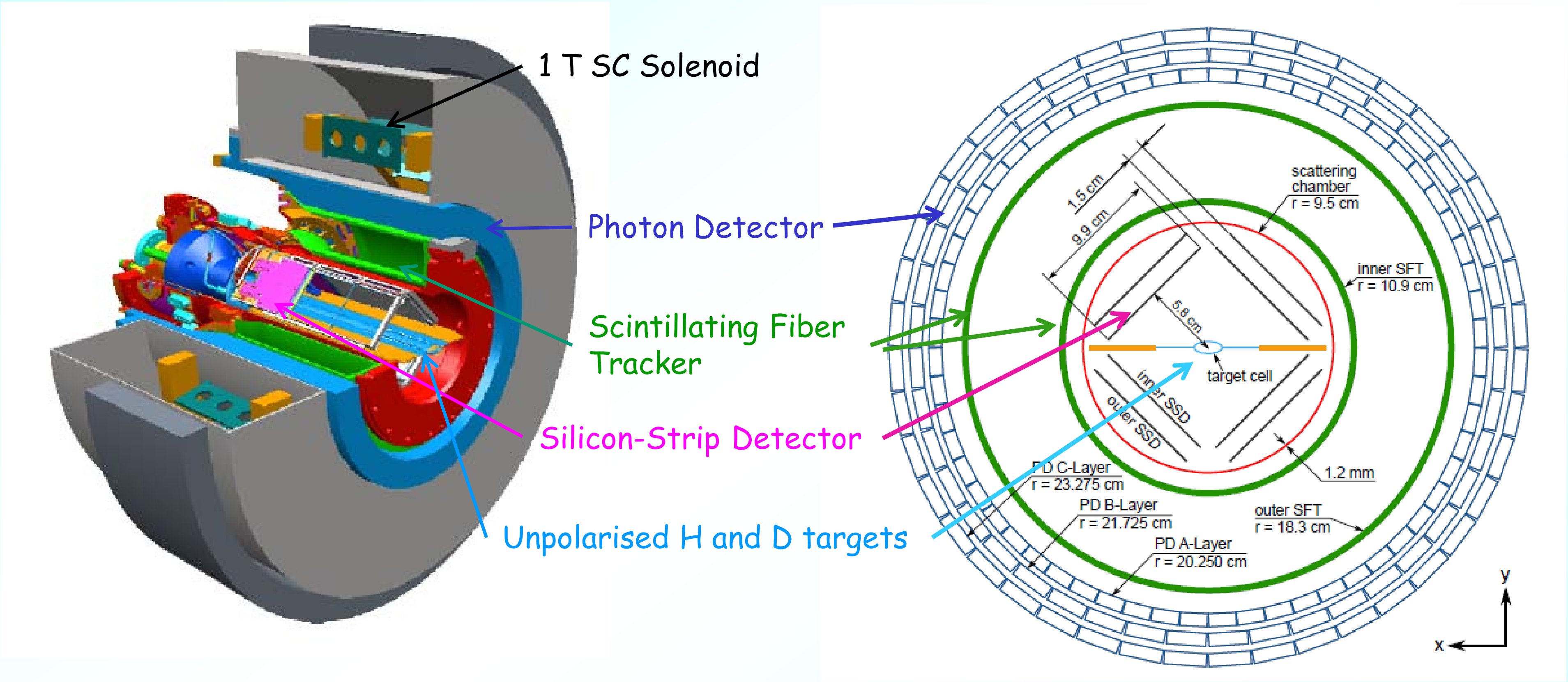
detection of
recoiling proton





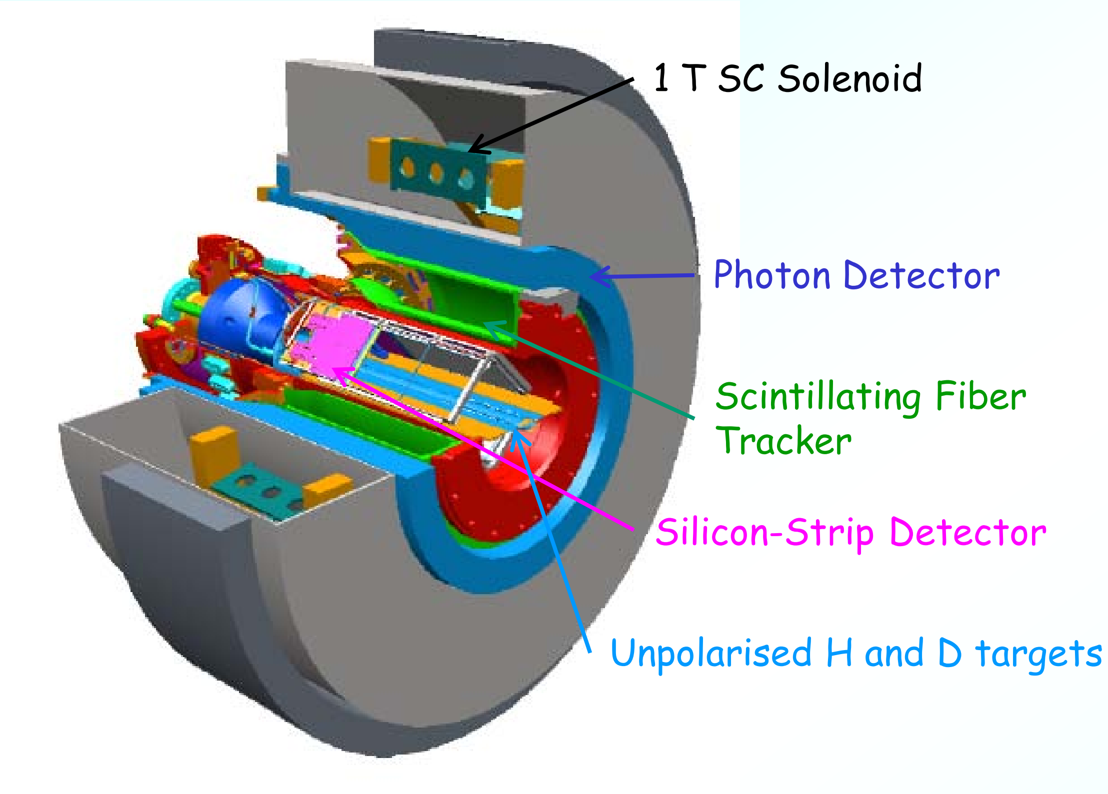
HERMES recoil detector

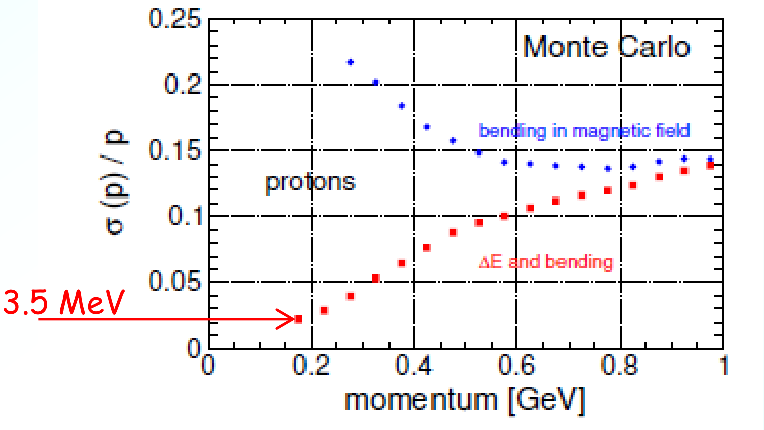
A. Airapetian et al., JINST 8 (2013) P05012

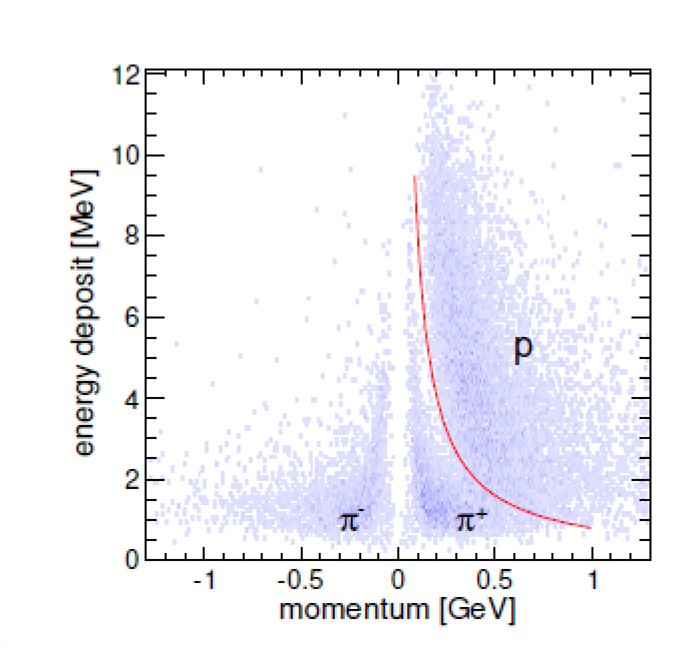


HERMES recoil detector

A. Airapetian et al., JINST 8 (2013) P05012







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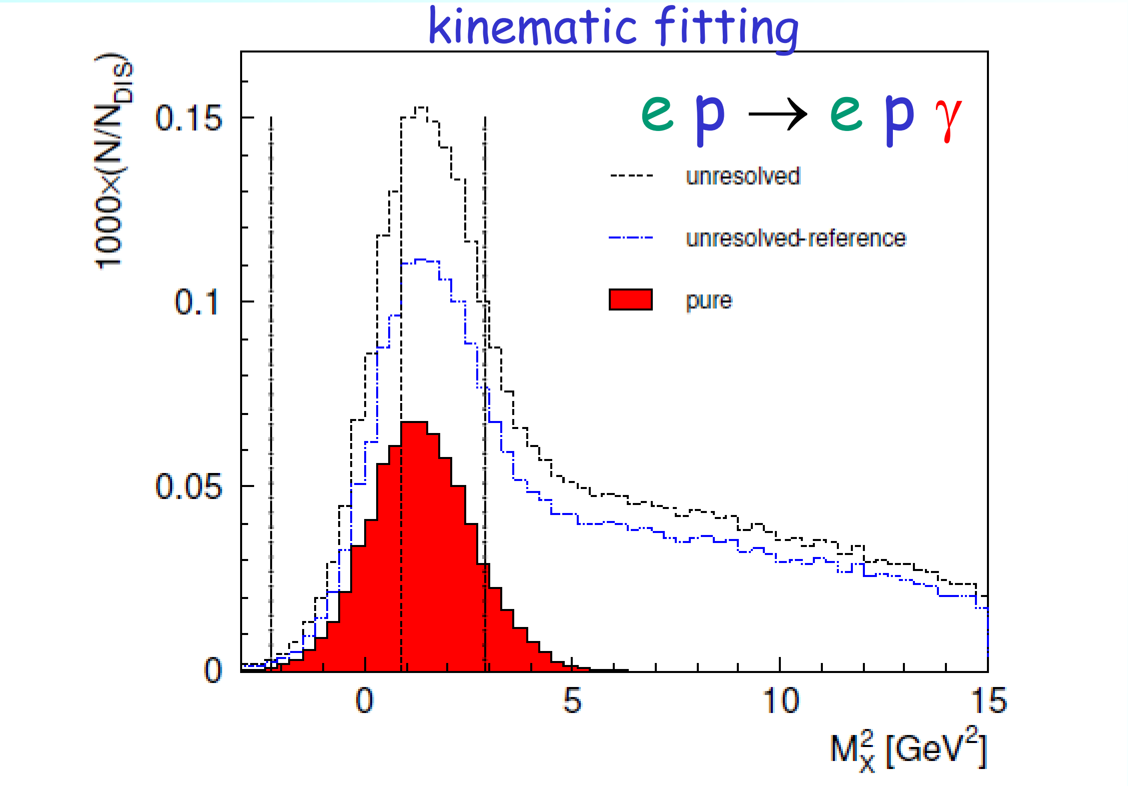
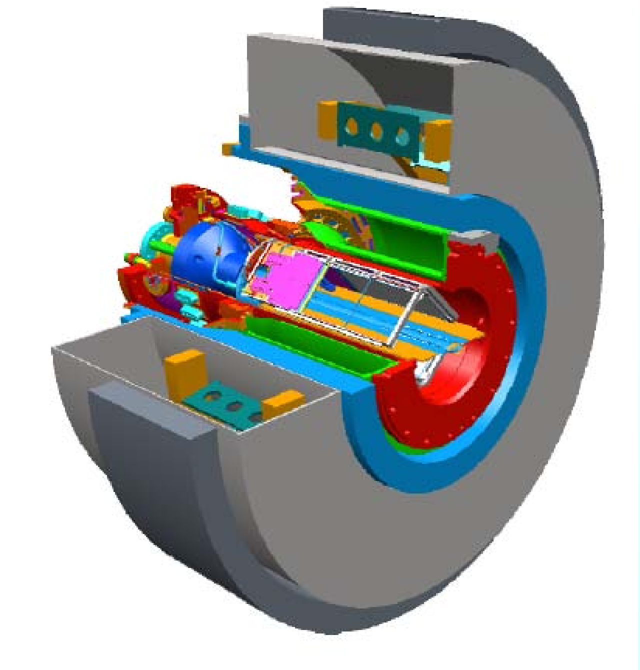
A. Airapetian et al., JINST 8 (2013) P05012



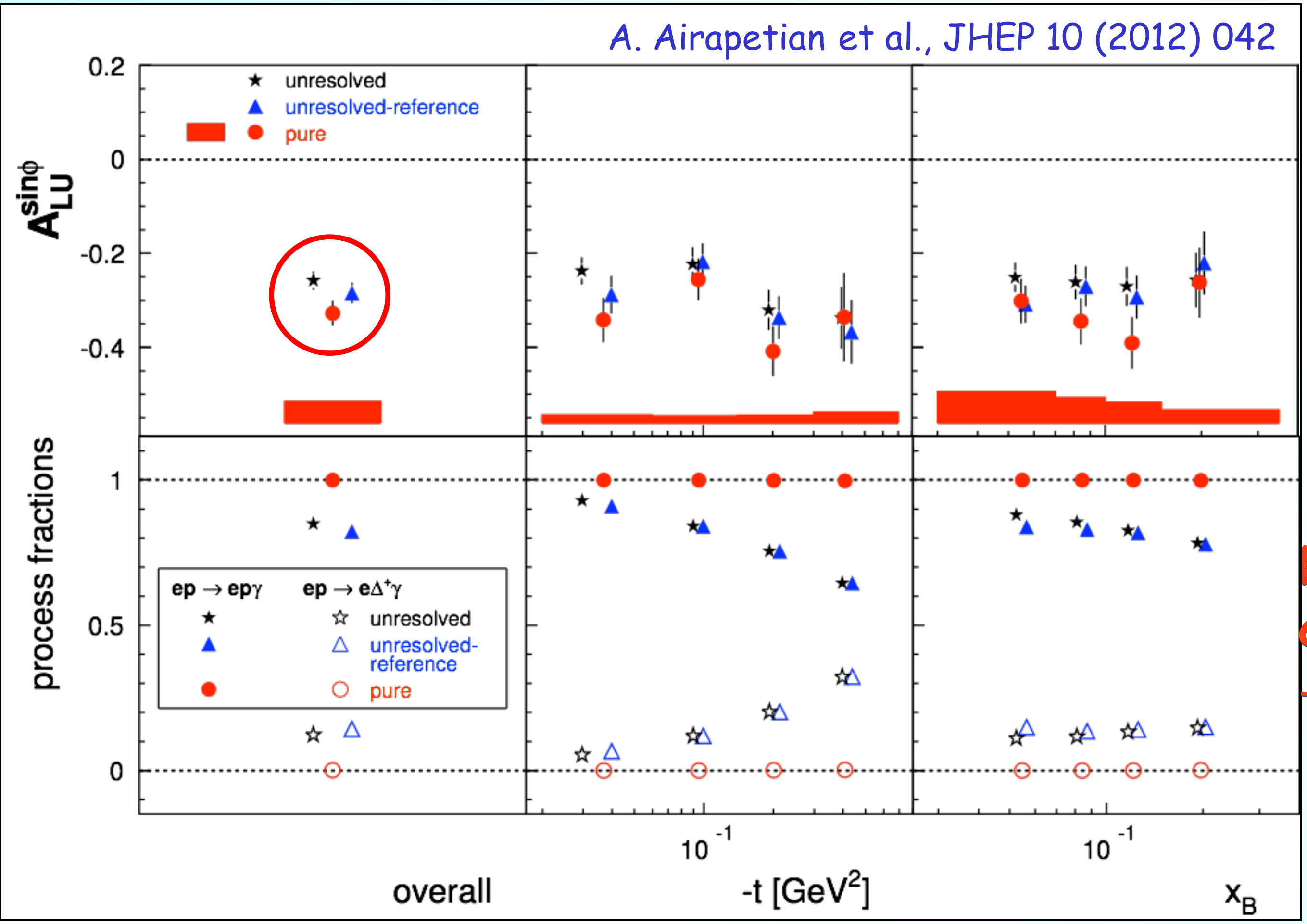


- All particles in final state detected → 4 constraints from energy-momentum conservation

- Selection of pure BH/DVCS (ep→ epγ) with high efficiency (~ 83%)

- Allows to suppress background from associated and semi-inclusive processes to a negligible level

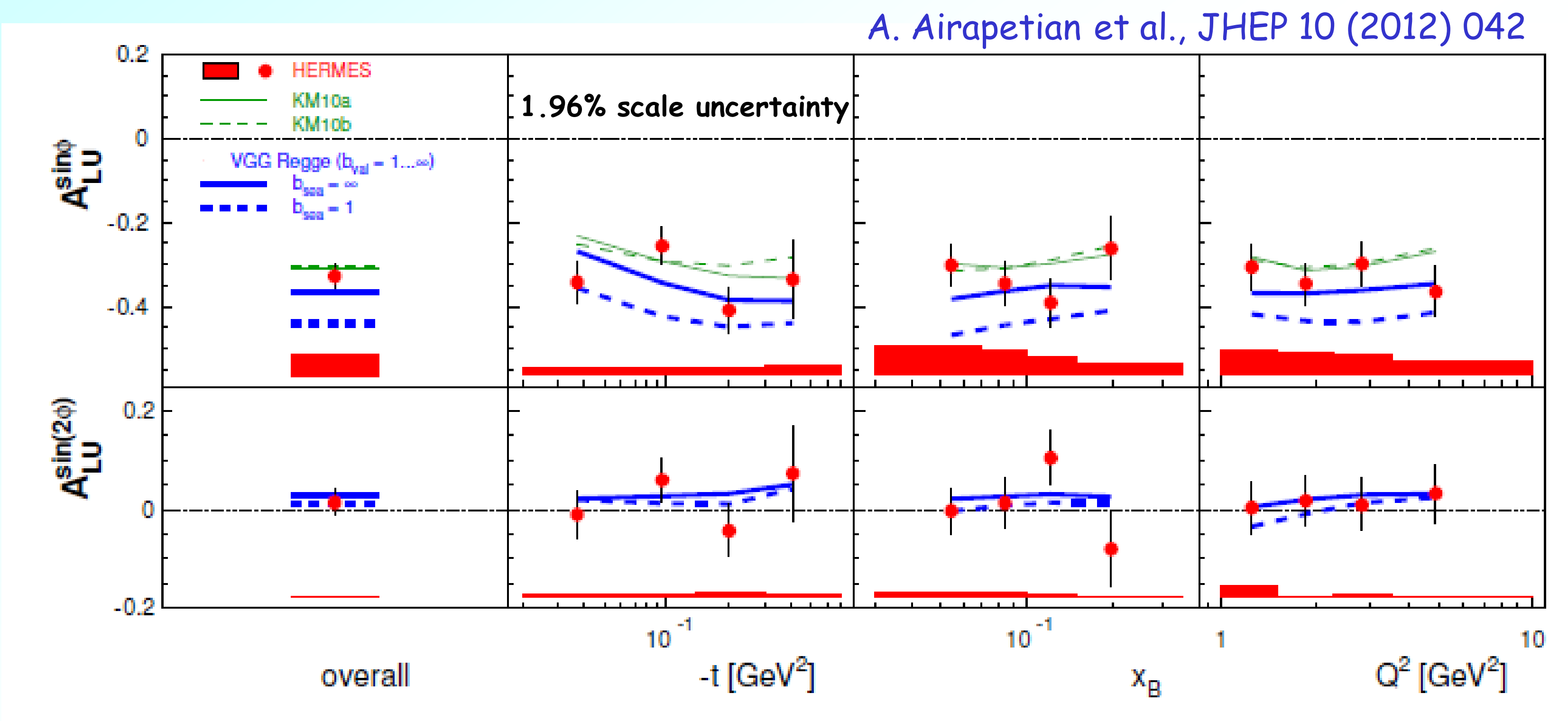
Single-charge BSA with recoil proton



Magnitude of the leading asymmetry has increased by 0.054 ± 0.016
(-> assoc. in traditional analysis mainly dilution)

basically **no contamination**
-> clear interpretation

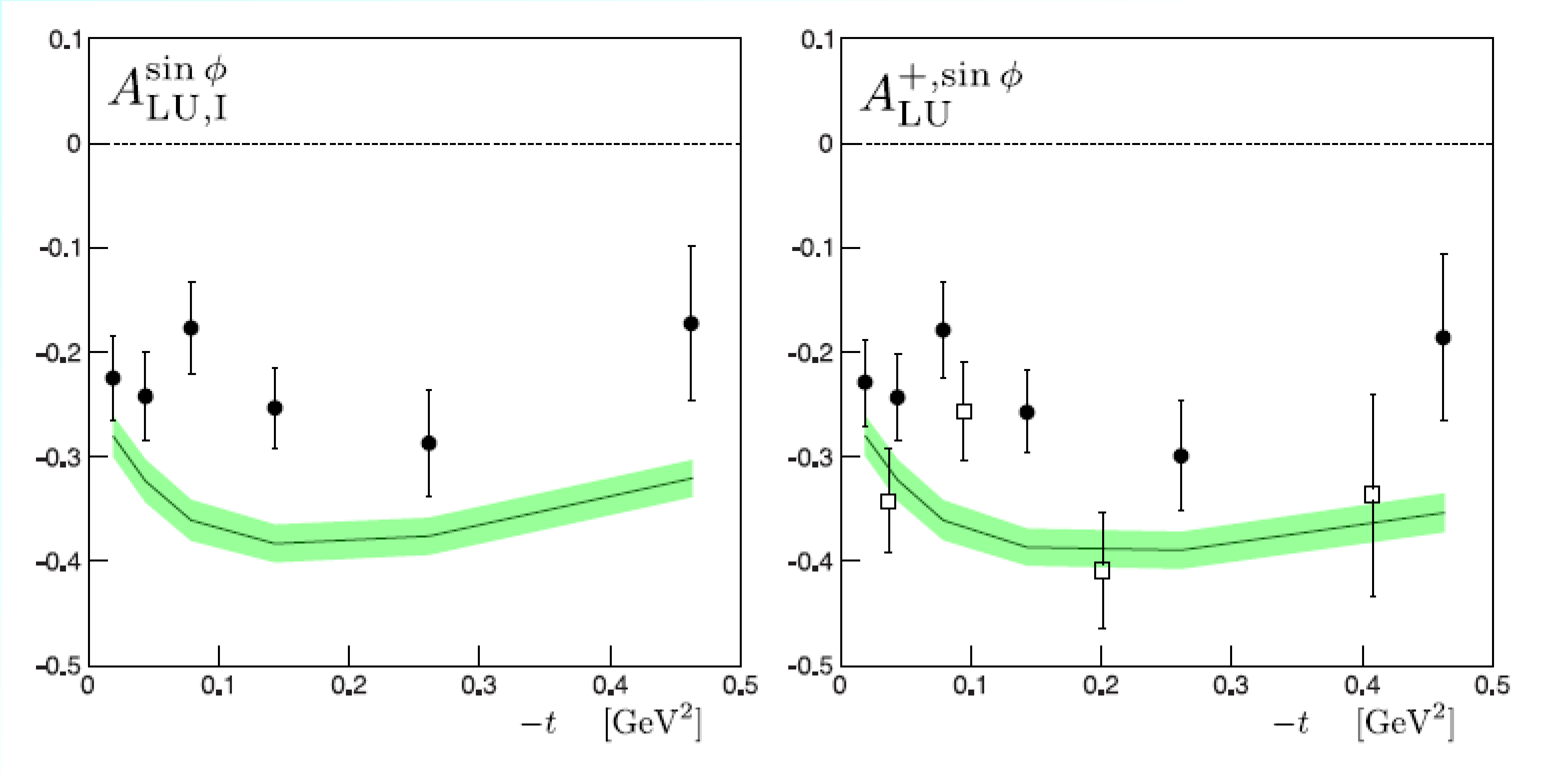
Single-charge BSA with recoil proton



Rather good agreement with models

KM10 – K. Kumericki and D. Müller, Nucl. Phys. B 841 (2010) 1
VGG - M. Vanderhaeghen et al., Phys. Rev. D 60 (1999) 094017

Single-charge BSA with recoil proton



HERMES (without Recoil)   HERMES (with Recoil)

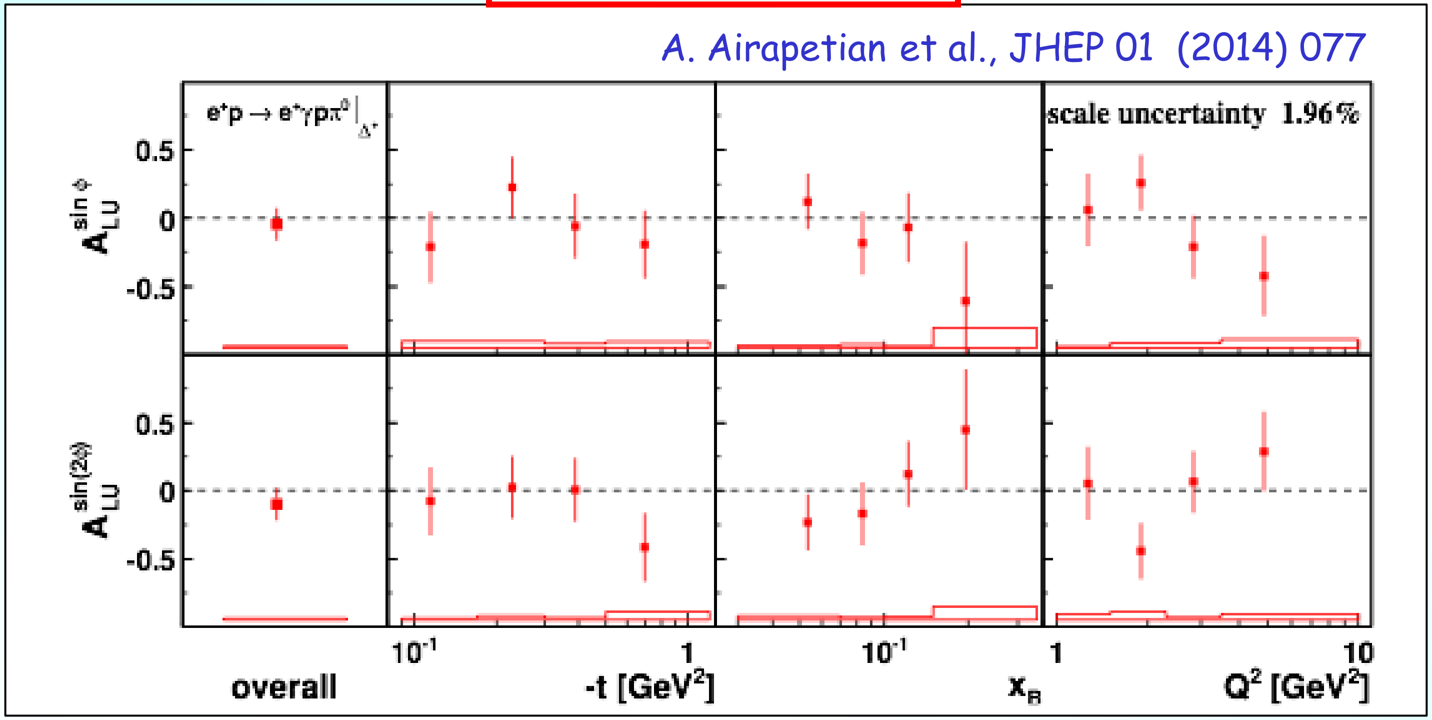
Derived from GPDs, which are extracted from HEMP

P. Kroll, H. Moutarde, F. Sabatié, Eur. Phys. J. C (2013) 73:2278

Recoil data leads to a significantly better overlap with HEMP data

Beam-spin asymmetries for associated DVCS

$e\,p \rightarrow e\,\gamma\,p\,\pi^0$



Asymmetry amplitudes consistent with zero

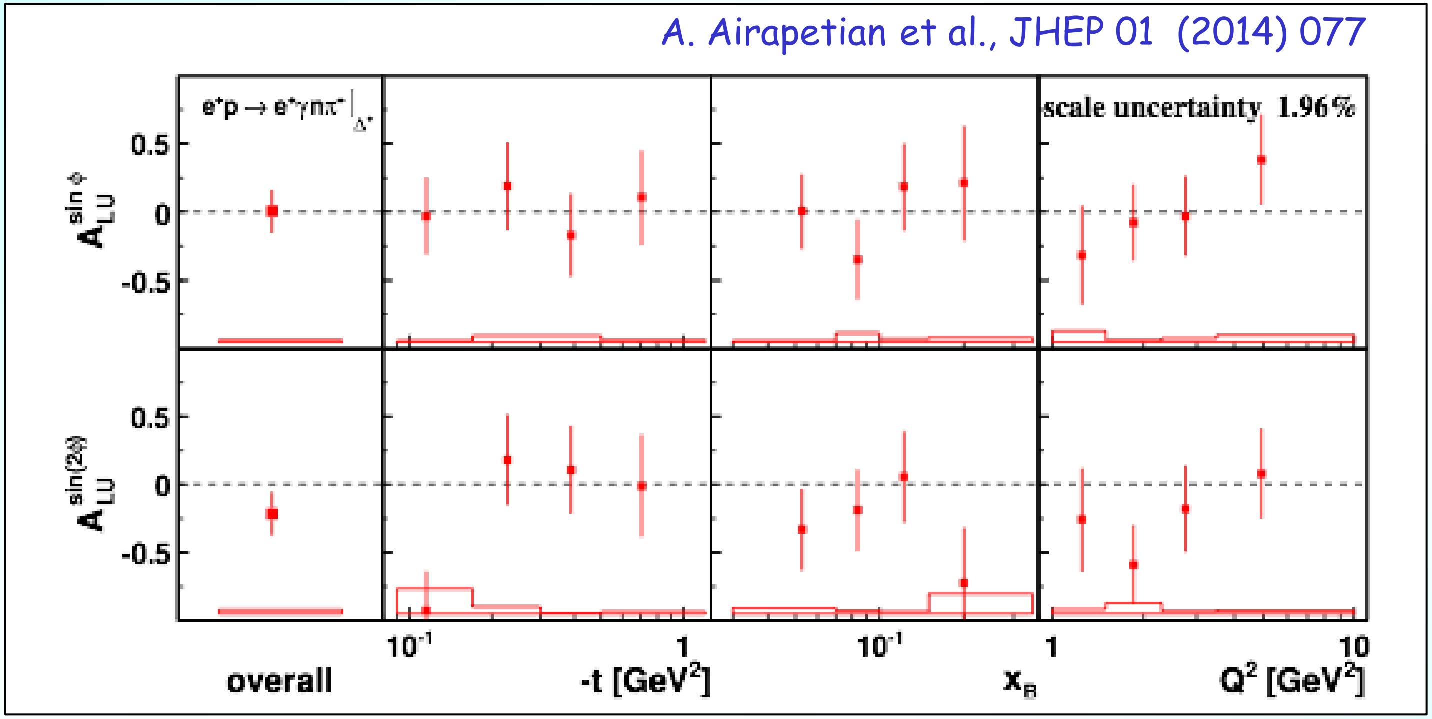
(in agreement with theor. exp.; P. Guichon et al., PRD 68 (2003) 034018)

Shown amplitudes corrected for background (only overall fractions are listed):

Associated DVCS/BH ($e\,p \rightarrow e'\,\gamma\,p\,\pi^0$)	85 ± 1
Elastic DVCS/BH ($e\,p \rightarrow e'\,\gamma\,p$)	4.6 ± 0.1
SIDIS ($e\,p \rightarrow e'\,X\,\pi^0$)	11 ± 1

Beam-spin asymmetries for associated DVCS

$e\,p \rightarrow e\,\gamma\,n\,\pi^+$



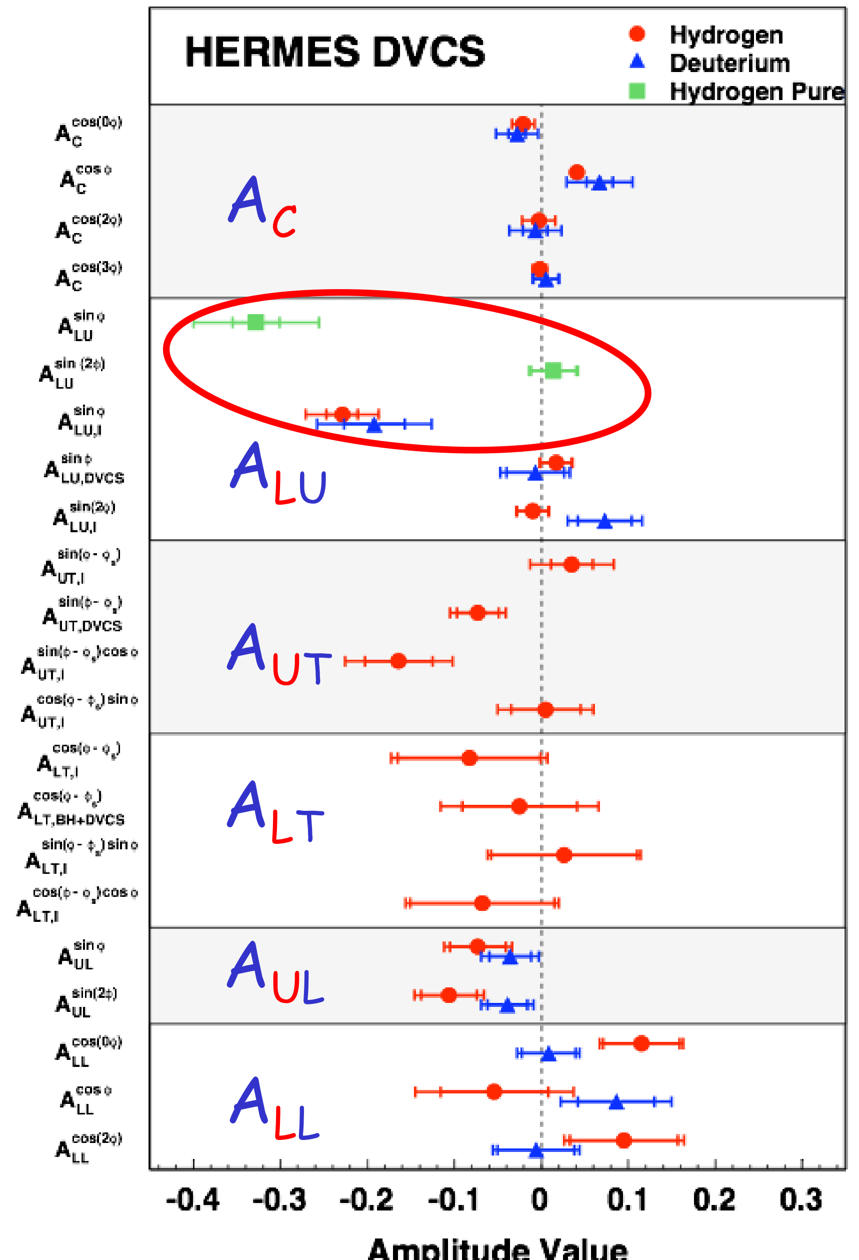
Asymmetry amplitudes consistent with zero

(in agreement with theor. exp.; P. Guichon et al., PRD 68 (2003) 034018)

Shown amplitudes corrected for background (only overall fractions are listed):

Associated DVCS/BH ($e\,p \rightarrow e'\,\gamma\,n\,\pi+$)	77 ± 2
Elastic DVCS/BH ($e\,p \rightarrow e'\,\gamma\,p$)	0.2 ± 0.1
SIDIS ($e\,p \rightarrow e'\,X\,\pi^0$)	23 ± 3

DVCS @ HERMES



- HERMES analyzed a wealth of DVCS-related asymmetries on nucleon and nuclear targets
- data with recoil-proton detection allows clean interpretation
- indication of larger amplitudes for pure sample
  ➡ assoc. DVCS in "traditional" analysis mainly dilution
- assoc. DVCS results consistent with zero but also with model prediction

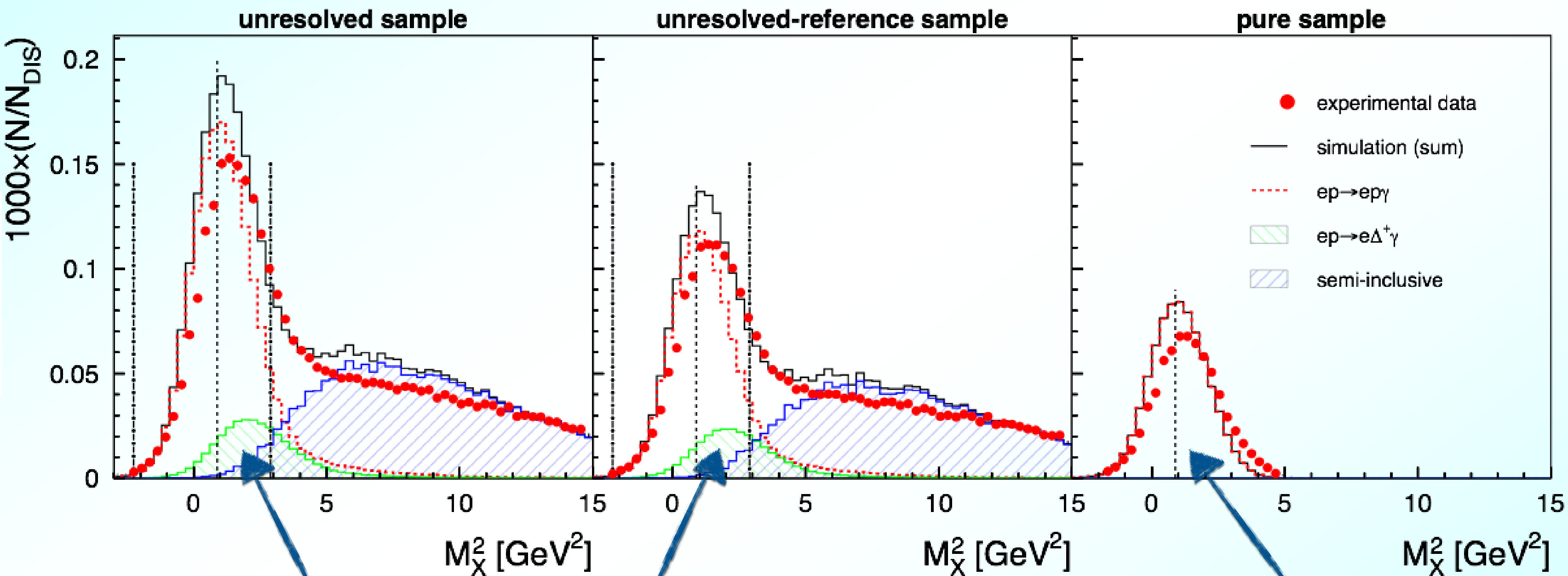
Backup

forward spectrometer only

similar background

measured proton

same kinematic acceptance



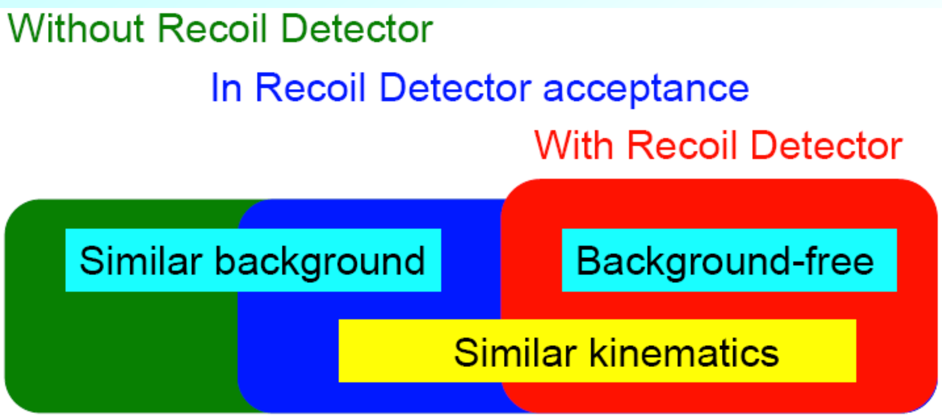
associated processes ($ep \to e\gamma\Delta^+$)

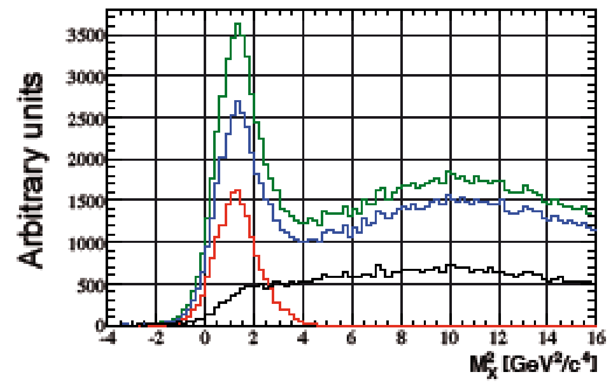
pure $ep \to e\gamma p$

Missing mass:

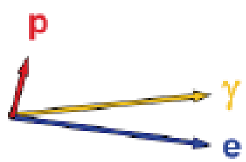
$$M_x^2 = (k - k' + P_0 - P_\gamma)^2 = M^2 + 2M(\nu - E_\gamma) + t$$

DVCS with Recoil Detector





Kinematic event fitting technique: all 3 particles in the final state detected should satisfy 4-constraints on energy-momentum conservation



- No requirement for Recoil
- Charged recoil track in acceptance
- Kinematic fit probability > 1 %
- Kinematic fit probability < 1 %