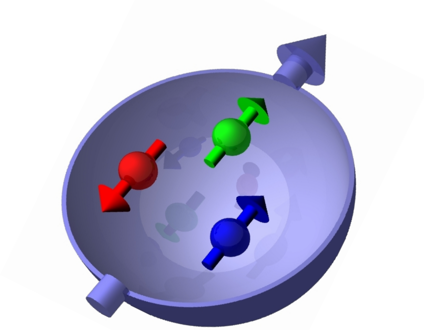
DVCS and associated processes at HERMES



Michael Düren

Universität Gießen

— MENU2013 conference, Rome, Oct. 2nd, 2013 —

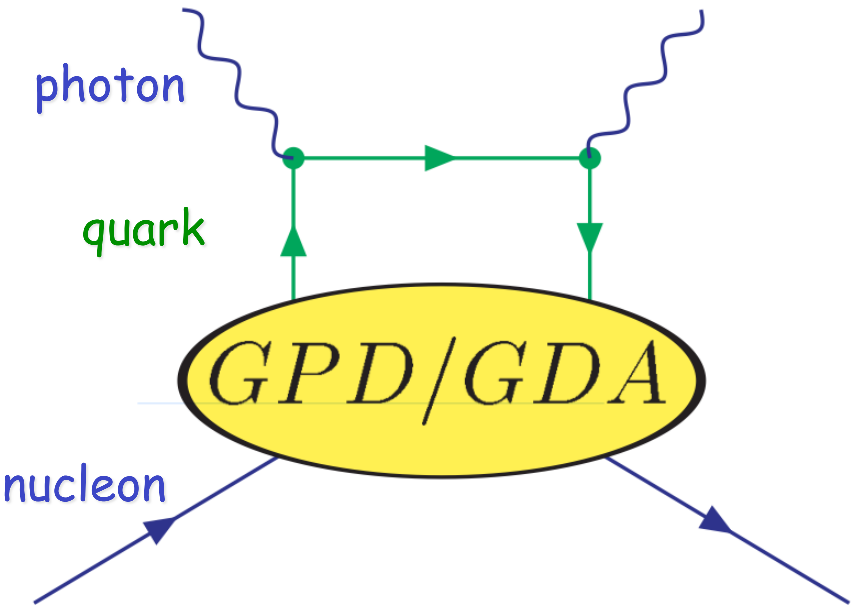
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Generalized Parton Distributions

Quantum phase-space „tomography"
of the nucleon

Generalized Parton Distributions
and Generalized Distribution Amplitudes

GPDs and GDAs describe quarks and gluons in the nucleon



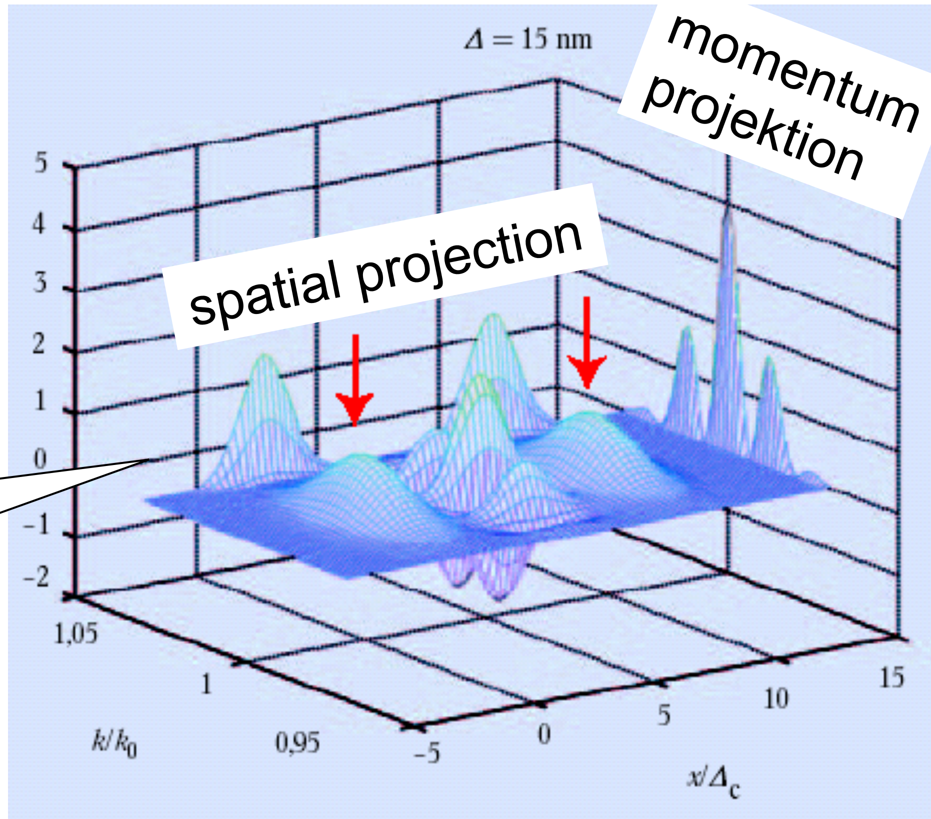
- spatial distributions (Form Factors)
- momentum distributions (Structure Functions)
- correlations in phase space (Wigner Distribution)
- spin and orbital angular momentum (Ji Sum Rule)
- TMDs: HERMES-talk by Luciano PAPPALARDO

Wigner distribution in QM phase-space

- Wigner introduced the first well-defined phase-space distribution in quantum mechanics (1932)
  (despite of the uncertainty principle)
- Wigner function: $W(x,p) = \int \psi^*(x-\eta/2)\psi(x+\eta/2)e^{ip\eta}d\eta$

The Wigner function contains the *most complete (one-body) info* about a quantum system.

Example of a Wigner function
(a particle passing an interferometer)



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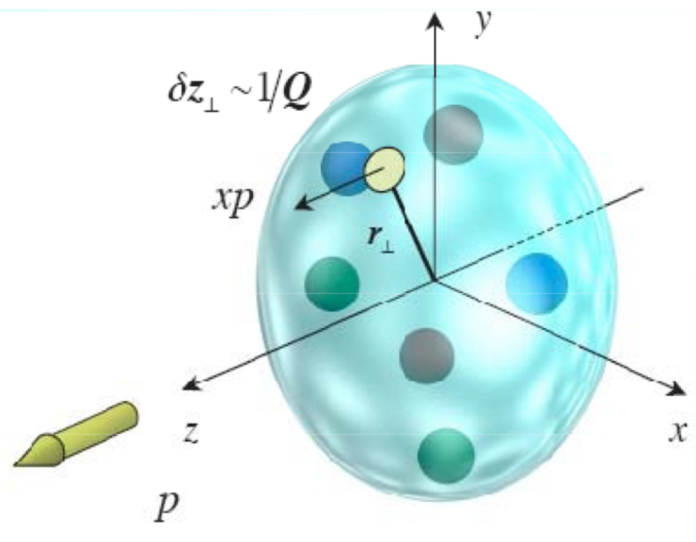
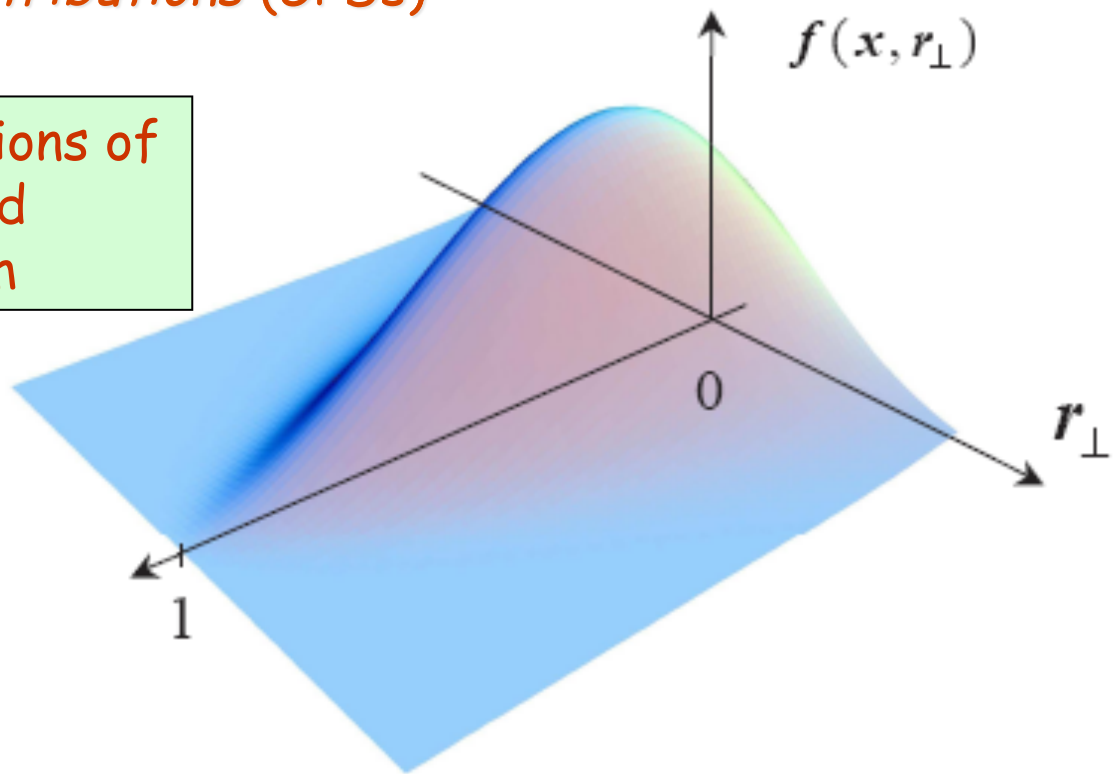
Generalized Parton Distribution

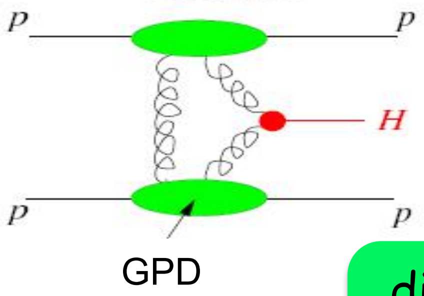
- A Wigner operator can be defined that describes quarks and gluons in the nucleon
- The reduced Wigner distribution is related to *Generalized Parton distributions* (GPDs)

GPDs describe e.g. correlations of transverse position and longitudinal momentum





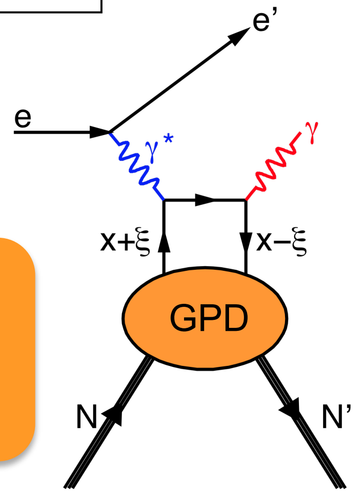
Are GPDs/GDAs universal?



deep inelastic scattering

diffractive higgs production

deeply virtual Compton scattering

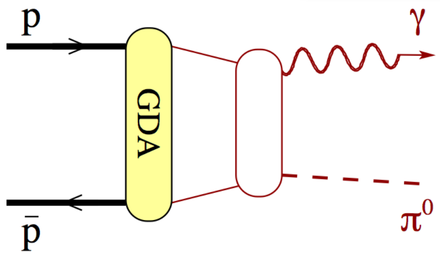


this talk

holographic picture of quarks in the nucleon

proton-antiproton annihilation

form factors



timelike Compton scattering

exclusive meson production (timelike and spacelike)

HERMES-talk by Aram MOVSISYAN

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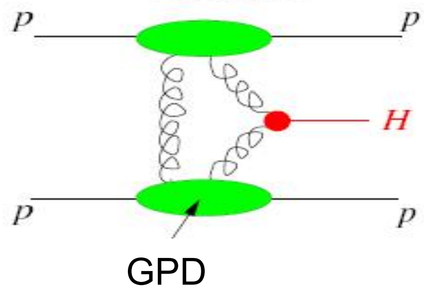
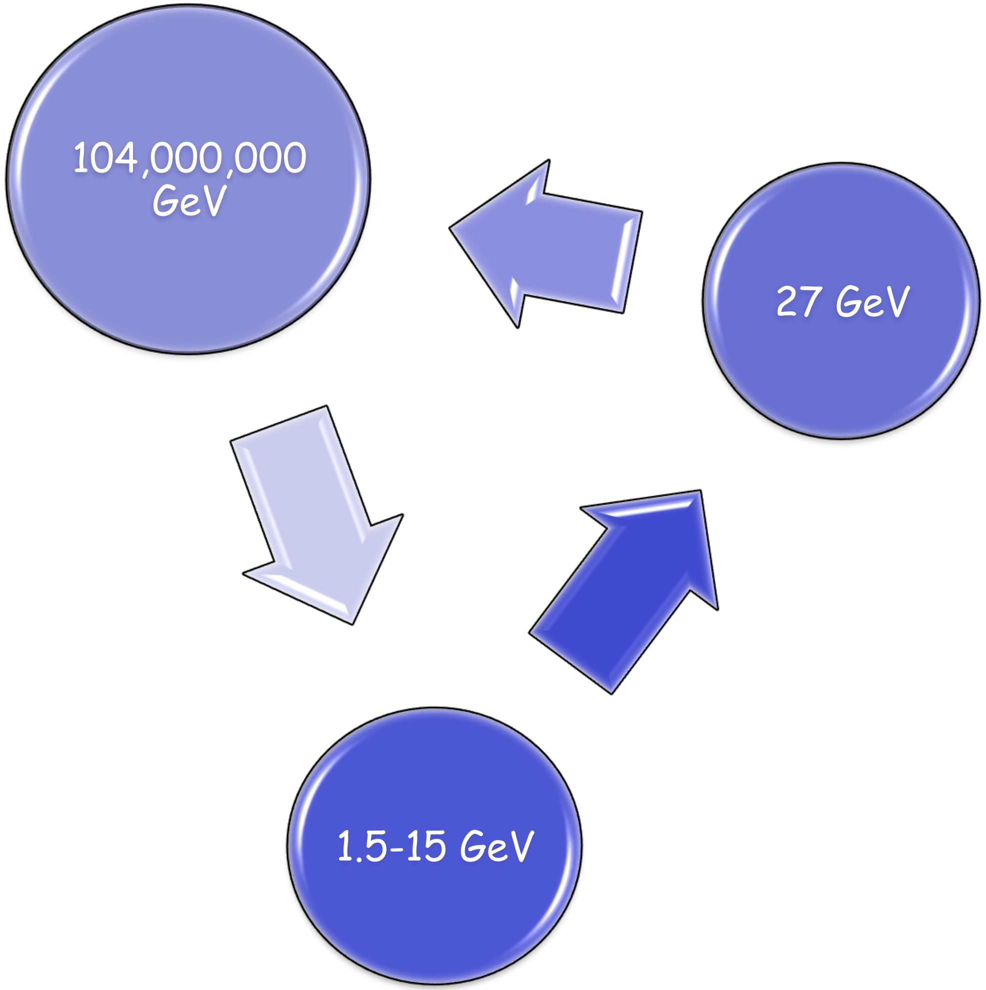
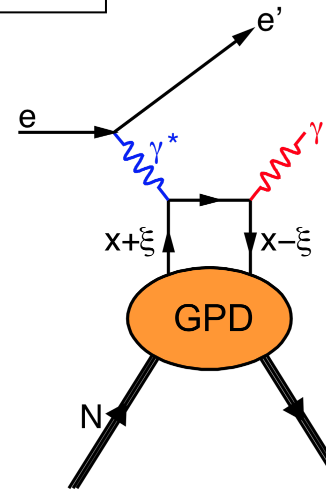
Are GPDs/GDAs universal?



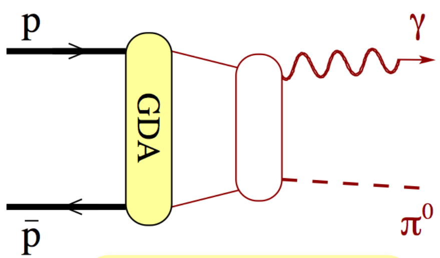
ATLAS/AFP
CERN





HERMES
DESY

this talk



PANDA
FAIR

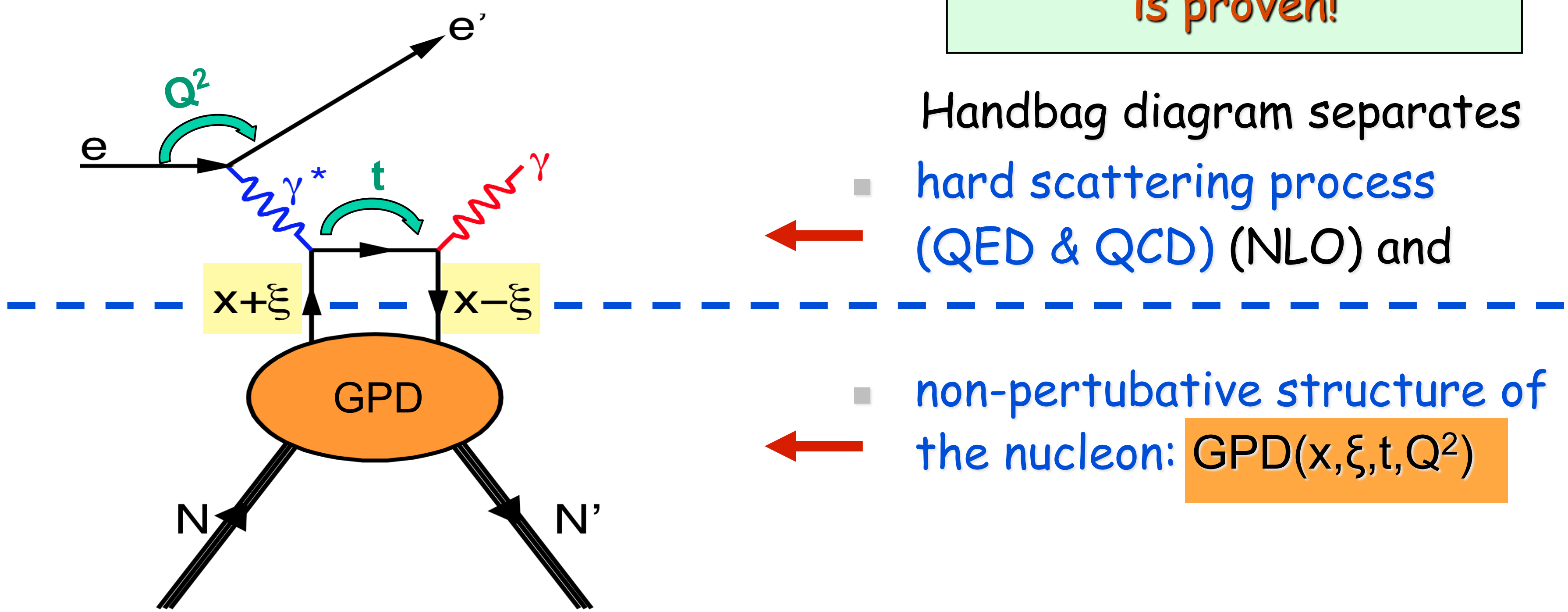
Energy of projectile
in proton rest frame

M. Düren, Univ. Giessen

Deeply Virtual Compton Scattering (DVCS)

DVCS is the cleanest way to access GPDs

Factorization theorem is proven!



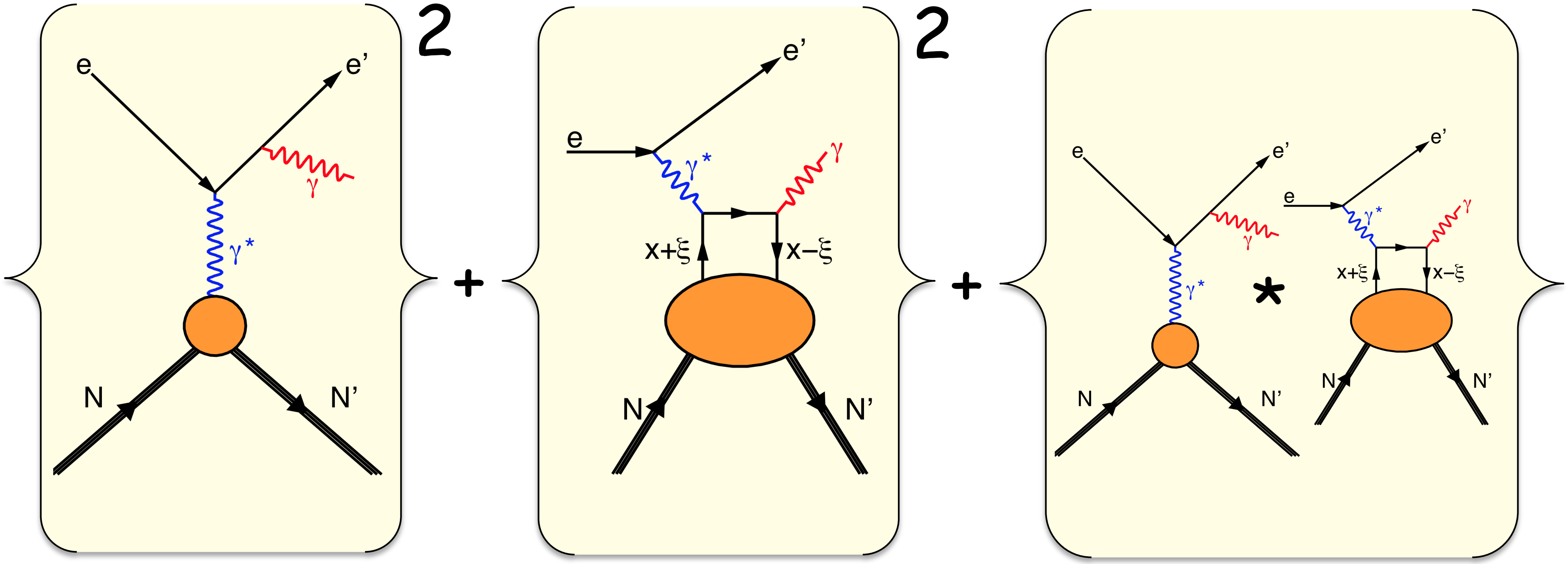
Handbag diagram separates

- hard scattering process (QED & QCD) (NLO) and
- non-pertubative structure of the nucleon: GPD(x,ξ,t,Q^2)

GPDs = probability amplitude for a nucleon to emit a parton with $x+\xi$ and to absorb it with momentum fraction $x-\xi$

$$\xi \approx \frac{x_{Bj}}{2 - x_{Bj}}$$

Exclusive ep → epγ cross section at HERMES



BH: LARGE
+ known

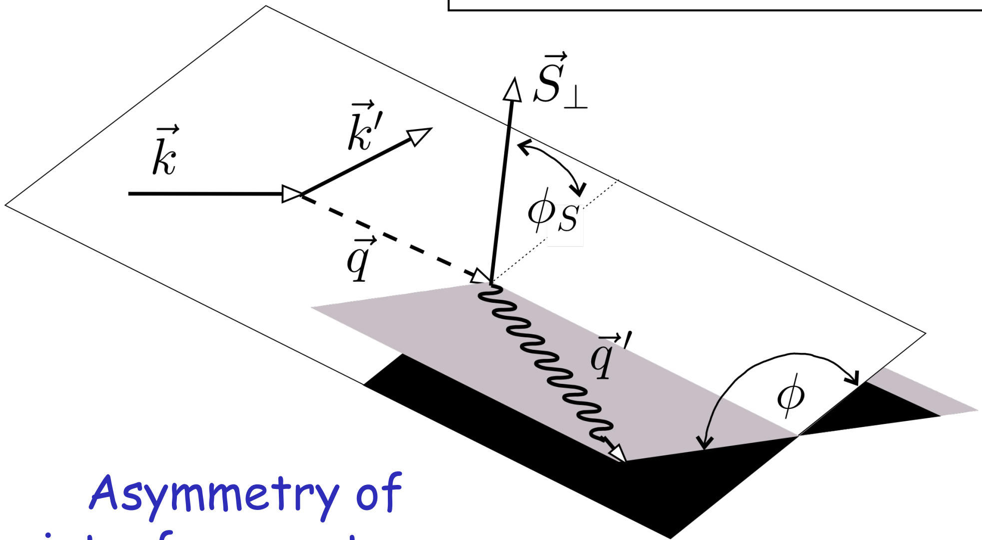
DVCS: small
+ unknown

Interference: medium
+ non-zero azimuthal
asymmetries

$$\frac{d\sigma}{dx_B\, dQ^2\, d|t|\, d\phi} = \frac{x_B\, e^6}{32\,(2\pi)^4\, Q^4\, \sqrt{1+\epsilon^2}} \left[|\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \overbrace{\tau_{DVCS}\, \tau_{BH}^* + \tau_{DVCS}^*\, \tau_{BH}}^{I} \right]$$

Direct access to DVCS matrix elements

Separation of amplitudes



- reversal of charge **and** spin

Asymmetry of interference term

$$\mathcal{A}^{\mathrm{I}}_{\mathrm{LU}}(\phi) \equiv \frac{(d\sigma^{+\rightarrow} - d\sigma^{+\leftarrow}) - (d\sigma^{-\rightarrow} - d\sigma^{-\leftarrow})}{(d\sigma^{+\rightarrow} + d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} + d\sigma^{-\leftarrow})}$$

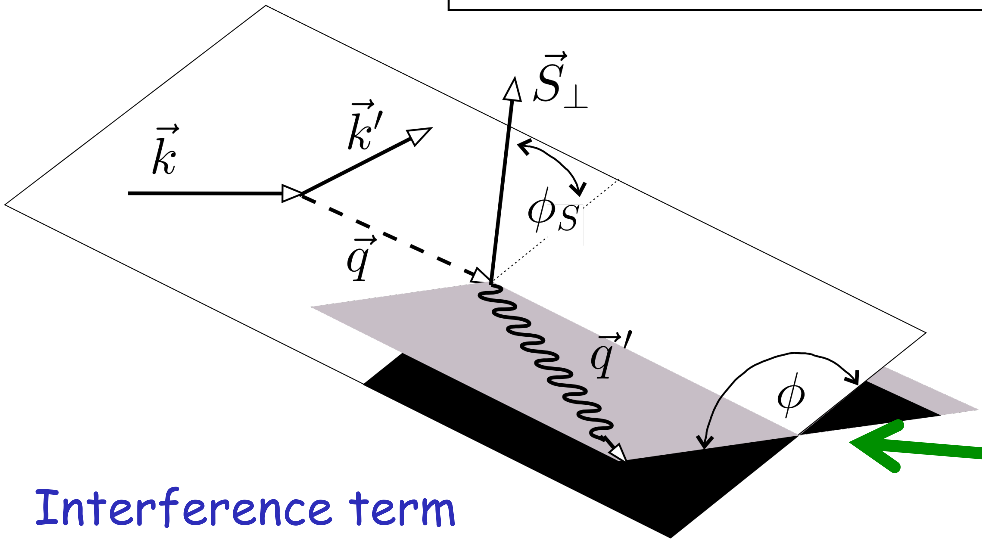
Asymmetry of DVCS

$$\mathcal{A}^{\mathrm{DVCS}}_{\mathrm{LU}}(\phi) \equiv \frac{(d\sigma^{+\rightarrow} - d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} - d\sigma^{-\leftarrow})}{(d\sigma^{+\rightarrow} + d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} + d\sigma^{-\leftarrow})}$$

longitudinal beam spin

unpolarized target spin

Separation of amplitudes



- reversal of charge **and** spin
- Fourier analysis of **azimuthal** modulation

Interference term asymmetrie

$$\mathcal{A}_{\mathrm{LU}}^{\mathrm{I}}(\phi) \equiv \frac{(d\sigma^{+\rightarrow} - d\sigma^{+\leftarrow}) - (d\sigma^{-\rightarrow} - d\sigma^{-\leftarrow})}{(d\sigma^{+\rightarrow} + d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} + d\sigma^{-\leftarrow})}$$

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

Fourier coefficients

Separation of amplitudes

"Direct" access to GPDs:

- Fourier coefficients are linear combinations of certain Compton Form Factors (CFFs)
- CFFs are convolutions of certain GPDs

see talk by Michel GUIDAL

Interference term asymmetrie

$$\mathcal{A}_{\rm LU}^{\rm I}(\phi) \equiv \frac{(d\sigma^{+\rightarrow} - d\sigma^{+\leftarrow}) - (d\sigma^{-\rightarrow} - d\sigma^{-\leftarrow})}{(d\sigma^{+\rightarrow} + d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} + d\sigma^{-\leftarrow})}$$

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

Fourier coefficients

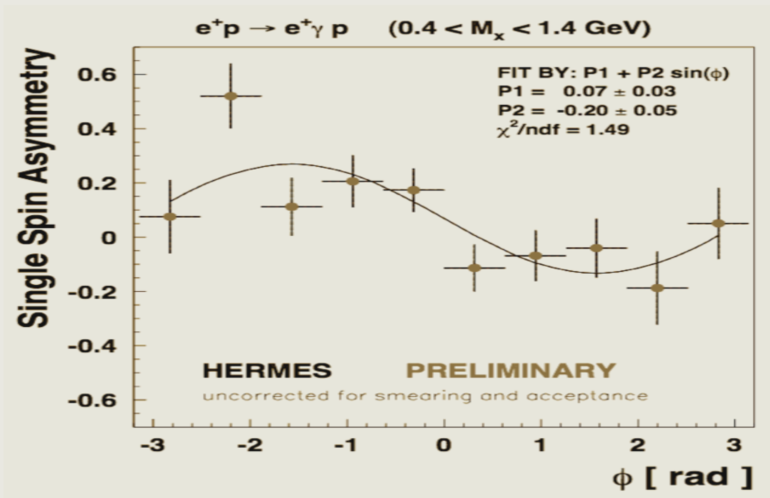
HERMES: a pioneering experiment

… from Ellis-Jaffe to Ji et al. …

The HERMES Experiment

- Designed at times of the spin crisis
  - Ellis-Jaffe & Bjorken sum rule
  - strange quark polarization
- 12 years data taking 1995-2007

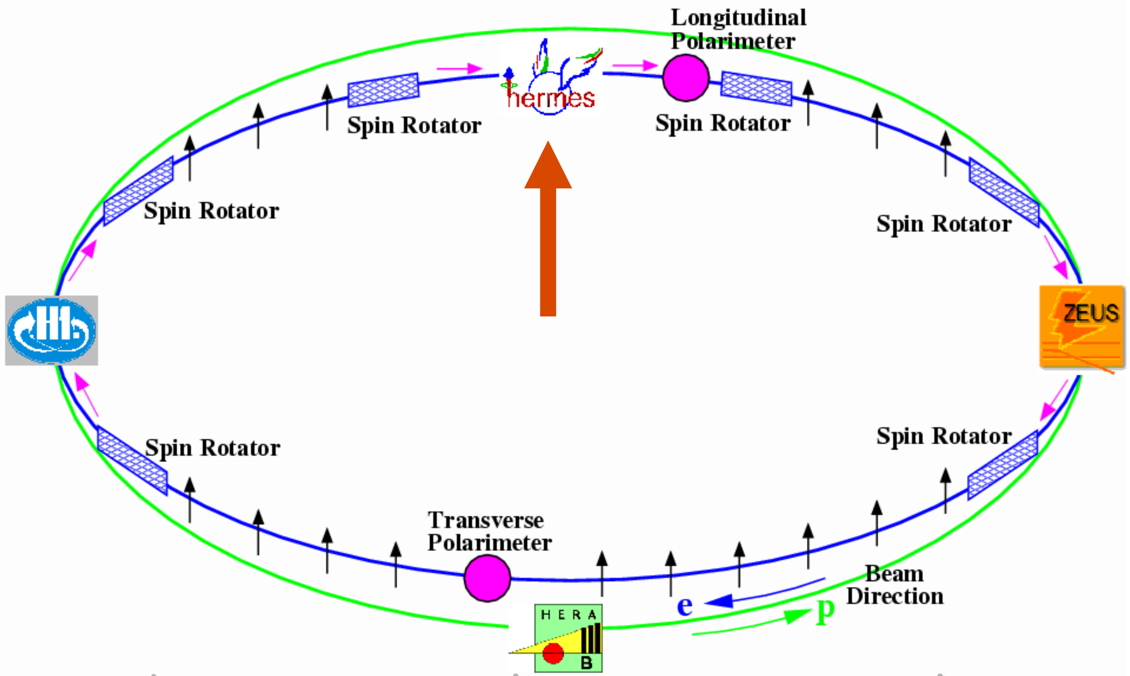
- Pioneering results of DVCS … 13 years ago



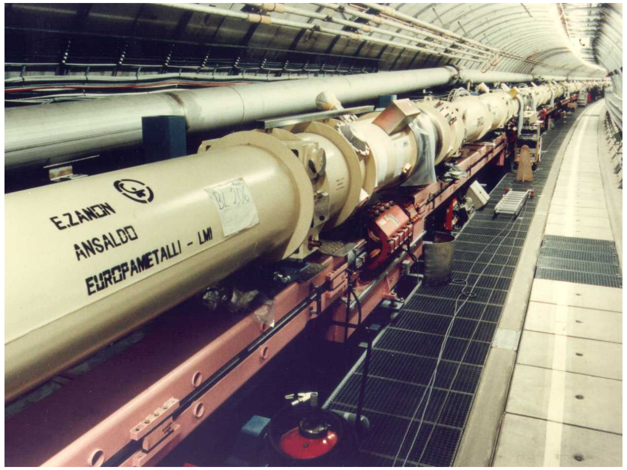
First non-zero DVCS SSA (2000)

- Today: most complete experimental access:
  - charge reversal (e^+ and e^- beams)
  - beam spin reversal (both beam helicities)
  - target spin reversal (longitudinal, transverse, unpolarized)
  - target mass variation (H, D, He, N, Ne, Kr, Xe)
  - recoil and spectator proton detection
  - …

The HERMES Experiment



- HERA
  - 27.5 GeV
  - e^+ and e^-
  - spin rotators



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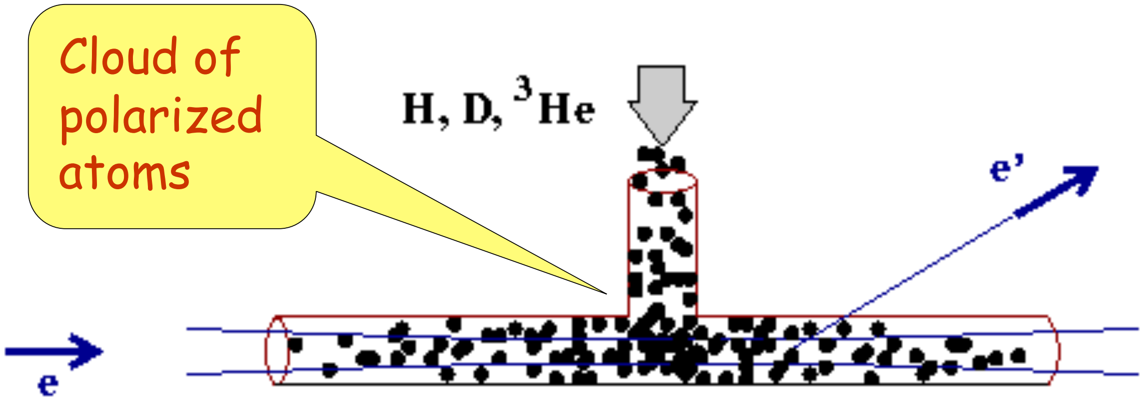
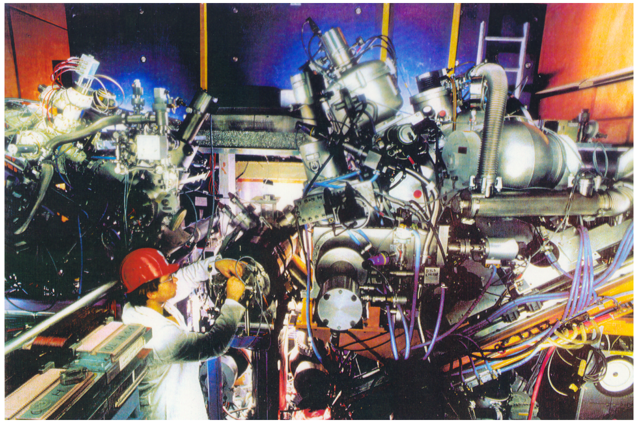
The HERMES Experiment



- Target
  - storage cell target
  - atomic beam source
  - fast spin reversal



- Today: most complete experimental access:
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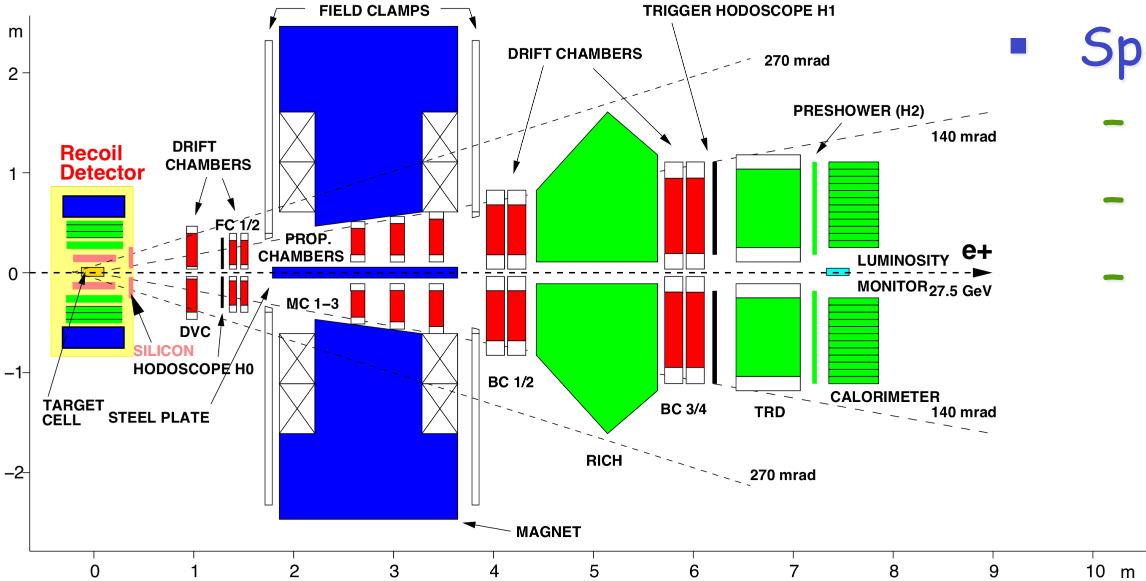
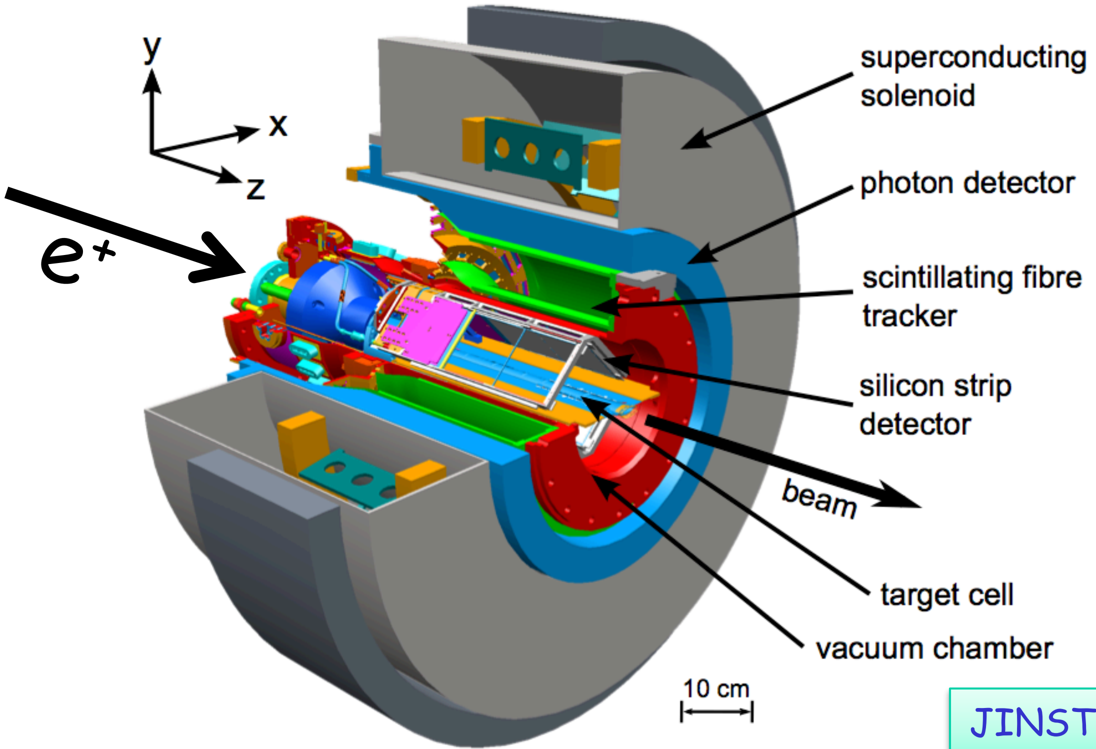
The HERMES Experiment

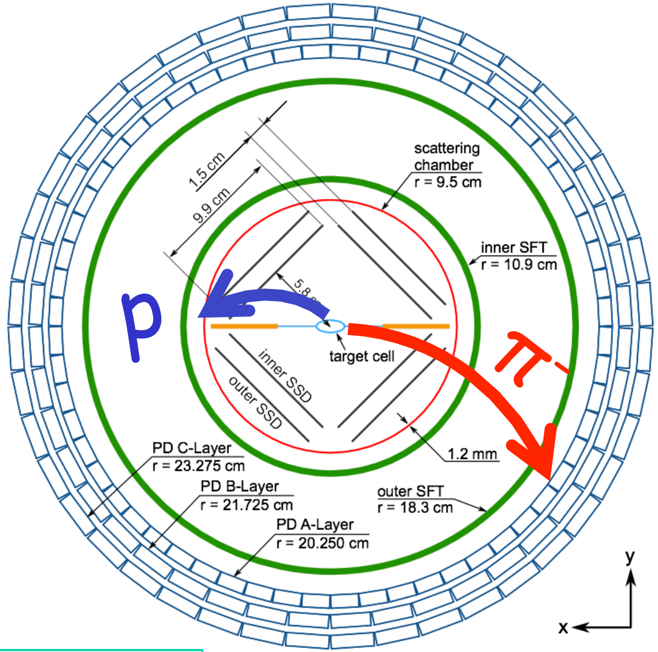


- Spectrometer
  - particle identification
  - recoil proton detection
  - complete DVCS kinematics e p → e p γ

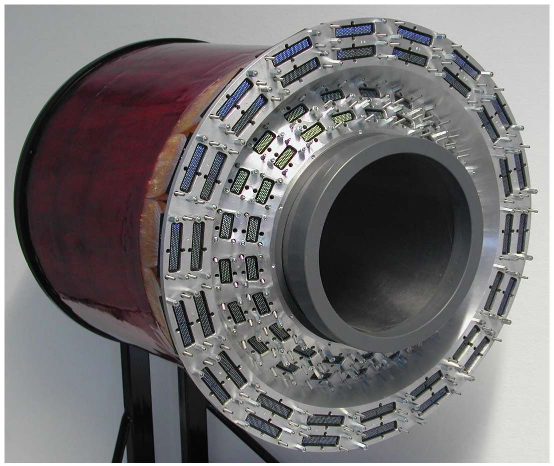
- Today: most complete experimental access:
  - charge reversal (e^+ and e^- beams)
  - beam spin reversal (both beam helicities)
  - target spin reversal (longitudinal, transverse, unpolarized)
  - target mass variation (H, D, He, N, Ne, Kr, Xe)
  - recoil and spectator proton detection
  - ...

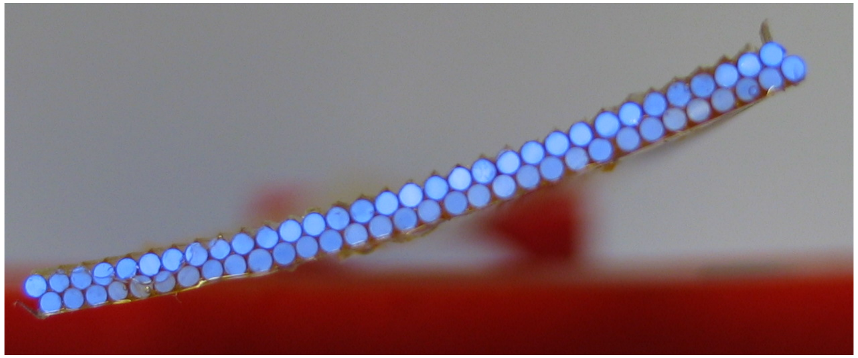
The Recoil Detector





JINST 8 (2013) P05012

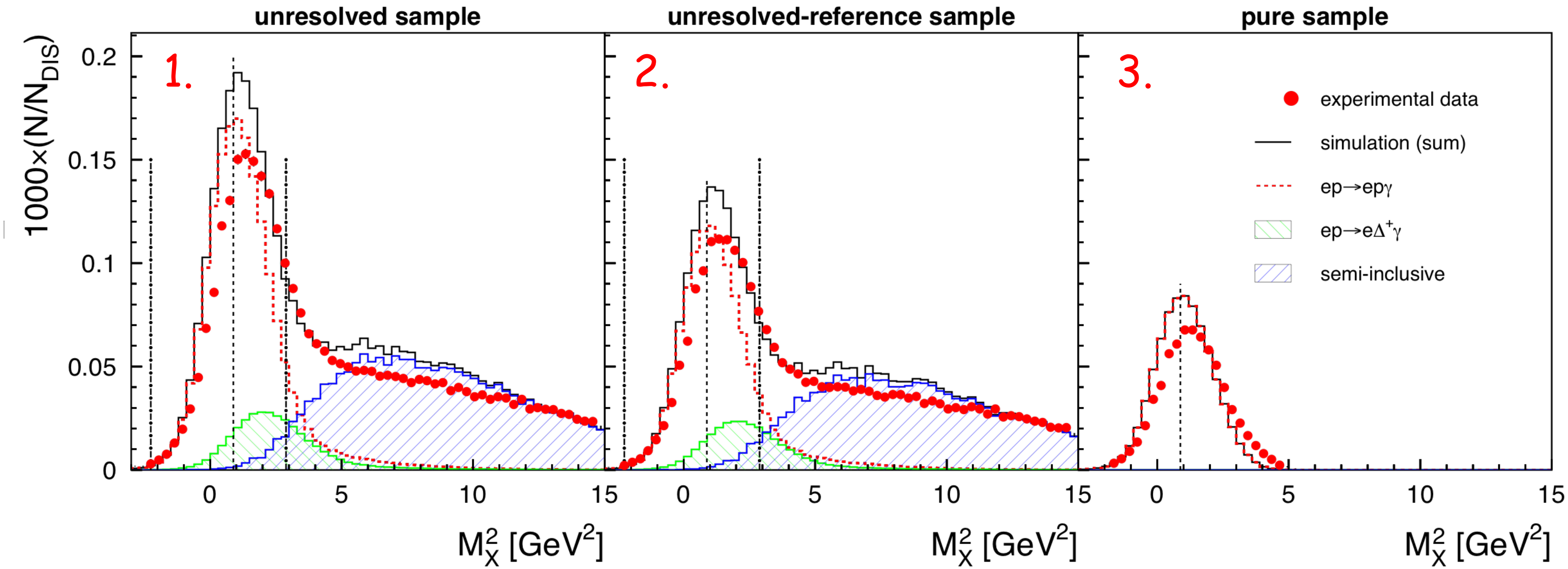




Recoil fibre detector made in Giessen

HERMES DVCS analysis:

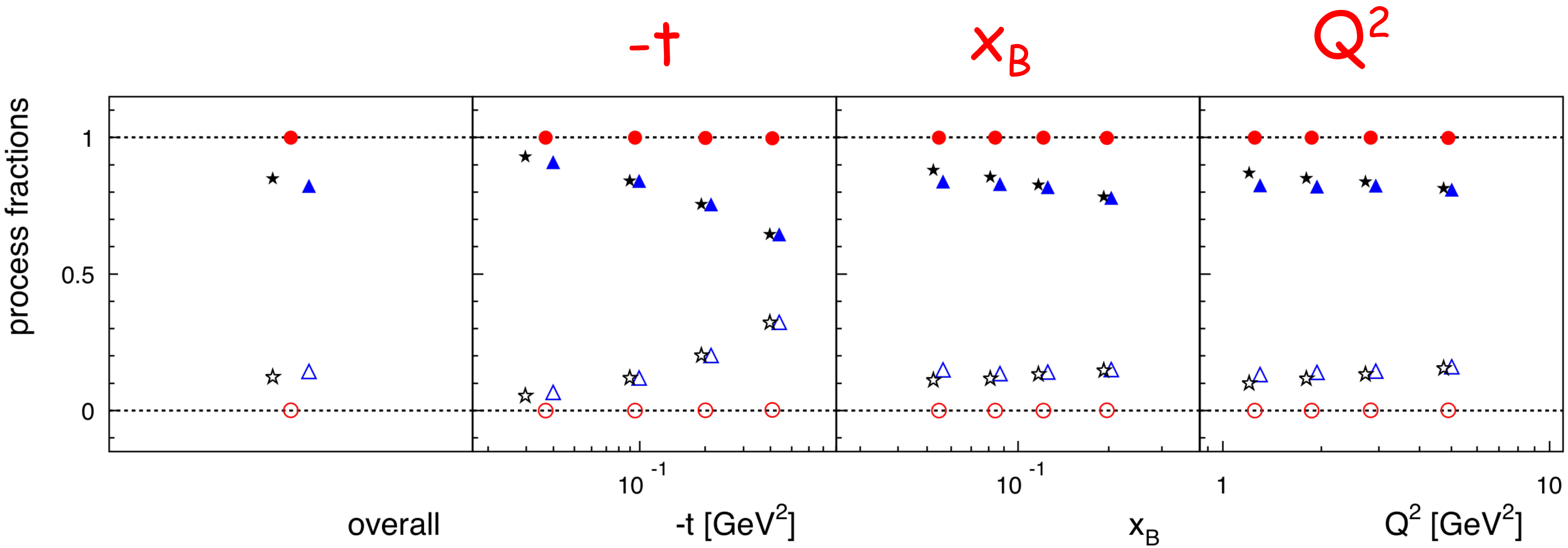
"Missing mass" without/with recoil detector

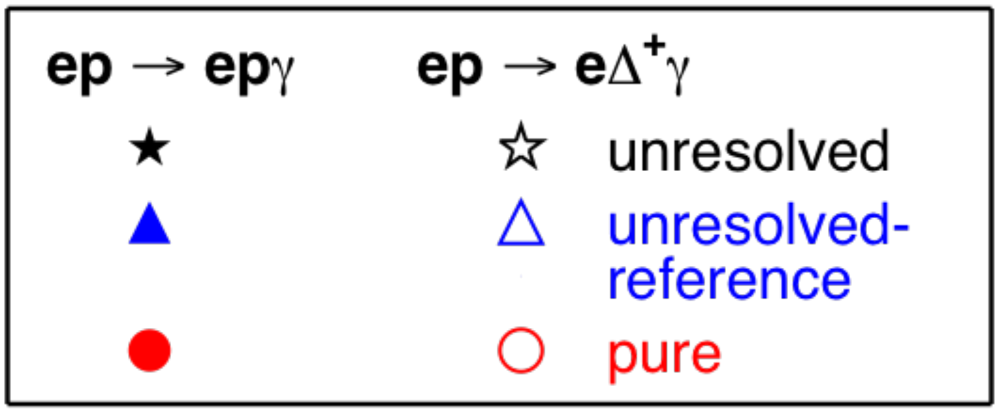


1. unresolved sample	2. unresolved-reference sample	3. pure sample
no recoil detector	as 1. (no recoil detector)	recoil proton detection
missing mass technique	proton in recoil acceptance	kinematic fit
88% purity		99,8% purity

HERMES DVCS analysis:

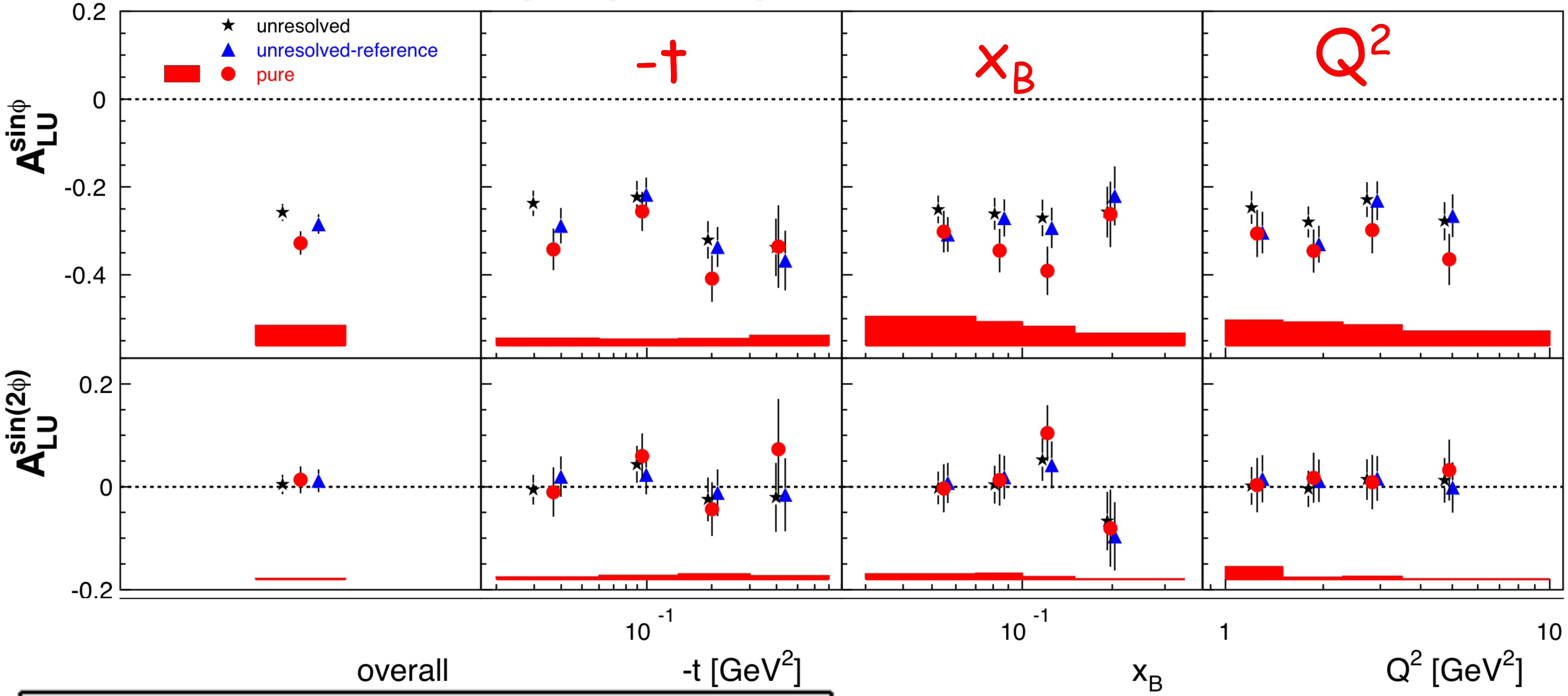
"Purity" without/with recoil detector



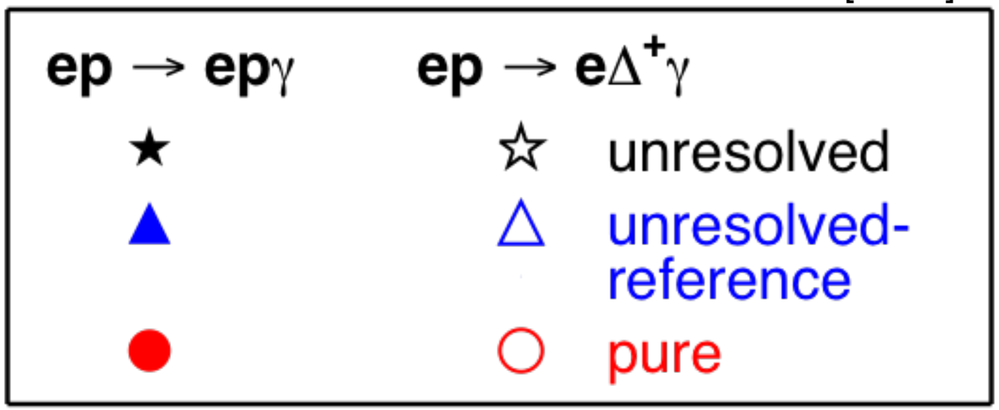


HERMES DVCS results:

”Beam Helicity Asymmetry” without/with recoil detector

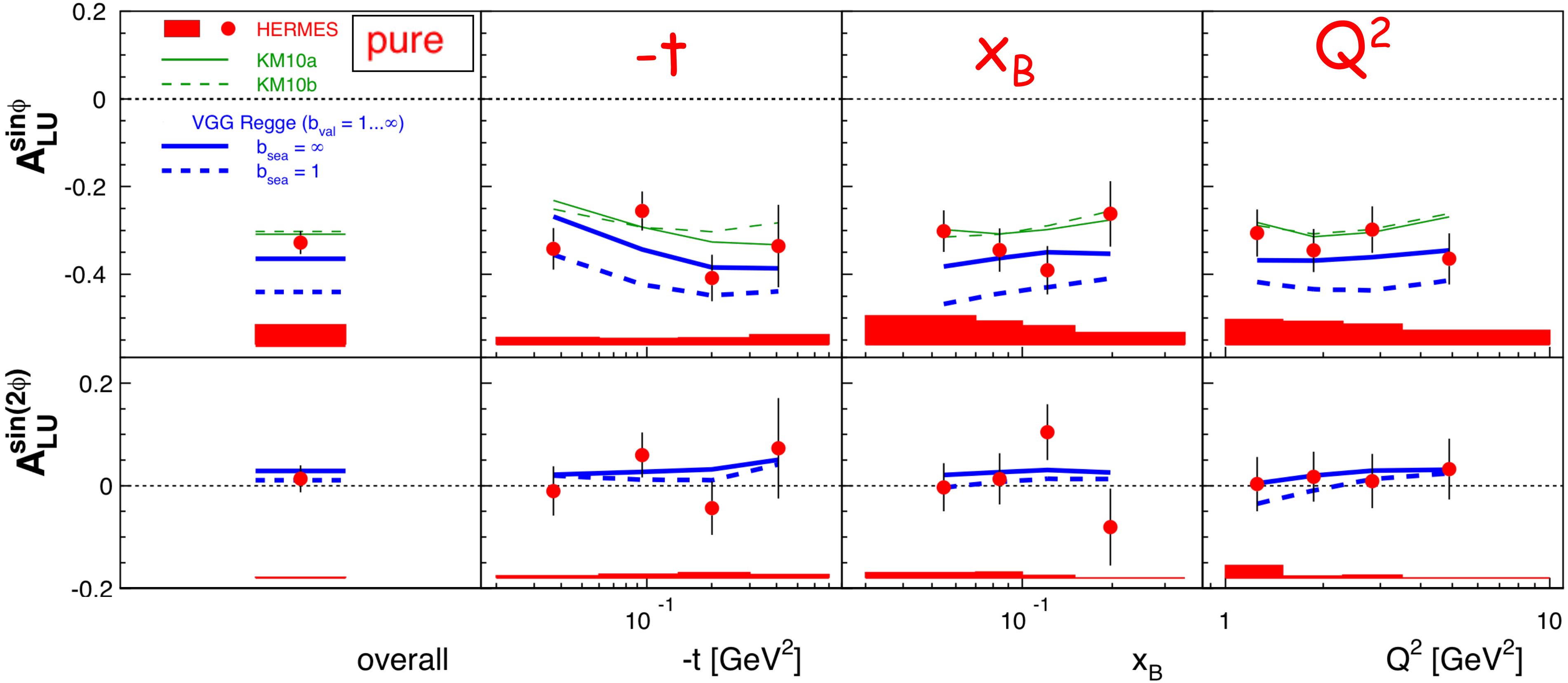


JHEP 10 (2012) 042



HERMES DVCS results:

"Beam Helicity Asymmetry" compared to models



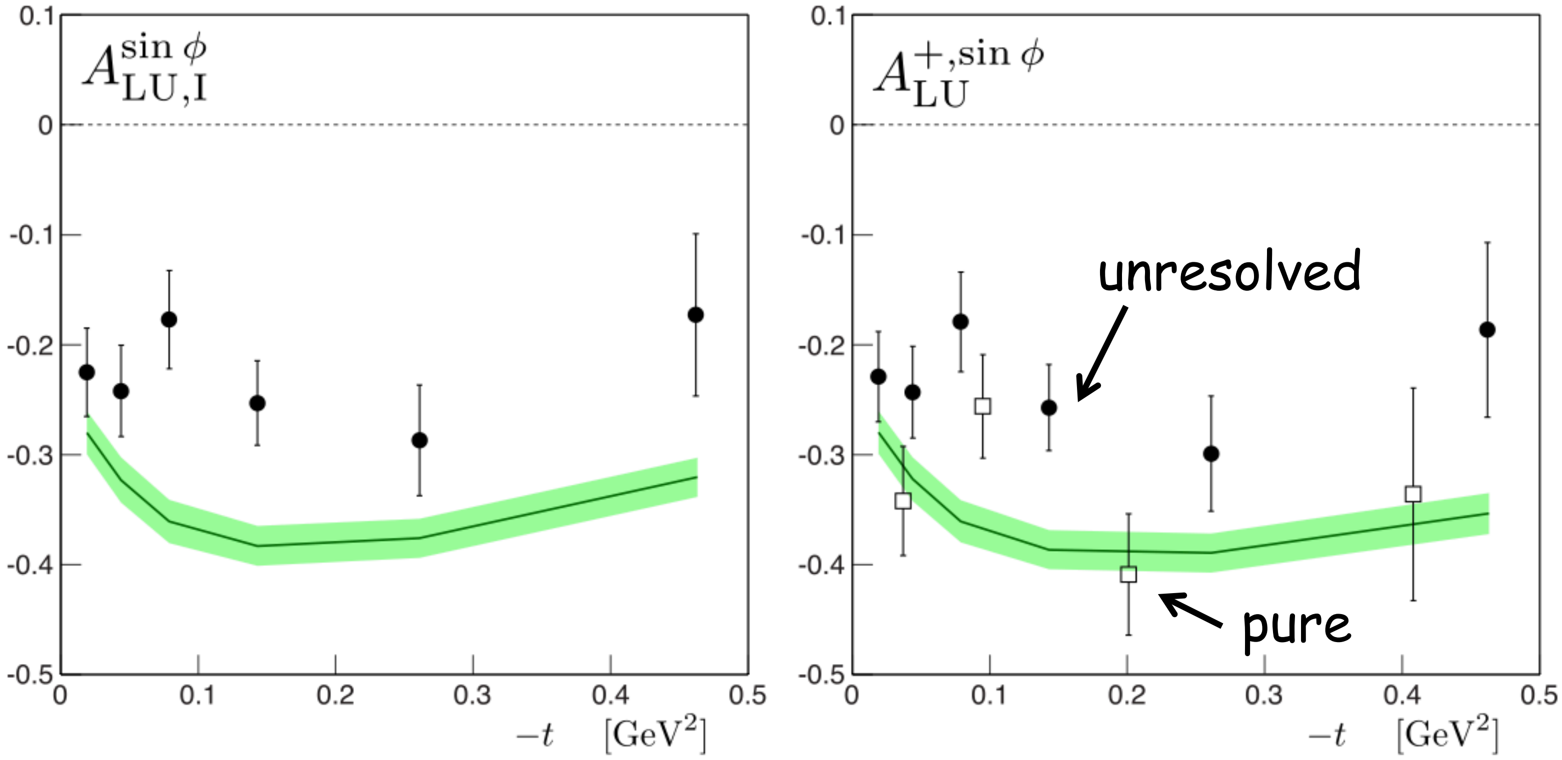
KM= Global fit of world data: Kumericki-Müller, Nucl. Phys. B 841 (2010) 1
(JLab, HERMES and HERA, dashed excludes JLab Hall A cross section)

JHEP 10 (2012) 042

VGG Regge= Model calculation: Vanderhaeghen-Guichon-Guidal, Phys. Rev. D60 (1999) 094017
and K. Goeke, M.V. Polyakov, M. Vanderhaeghen Prog. Nucl. Phys. 47 (2001) 401

HERMES DVCS results:

"Beam Helicity Asymmetry" compared to models



GPD Model for exclusive meson production: Kroll, Moutarde, Sabatié, Eur. Phys. J. C (2013) 73:2278 compared to HERMES data:

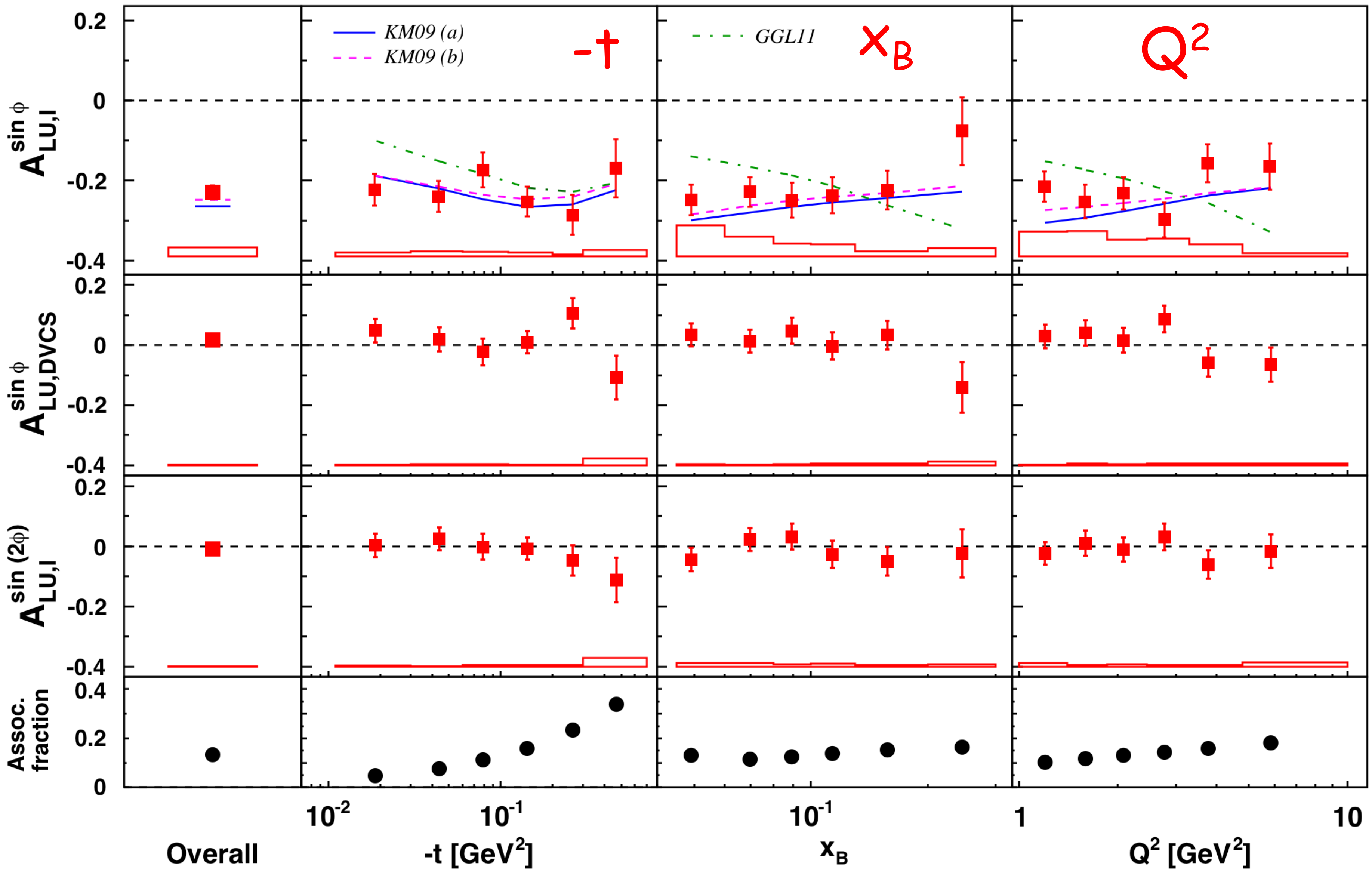
● = no recoil
□ = HERMES recoil (pure)

JHEP 07 (2012) 032

JHEP 10 (2012) 042

HERMES DVCS results:

"Beam Helicity Asymmetry": no recoil, but BCA-BSA combined fit



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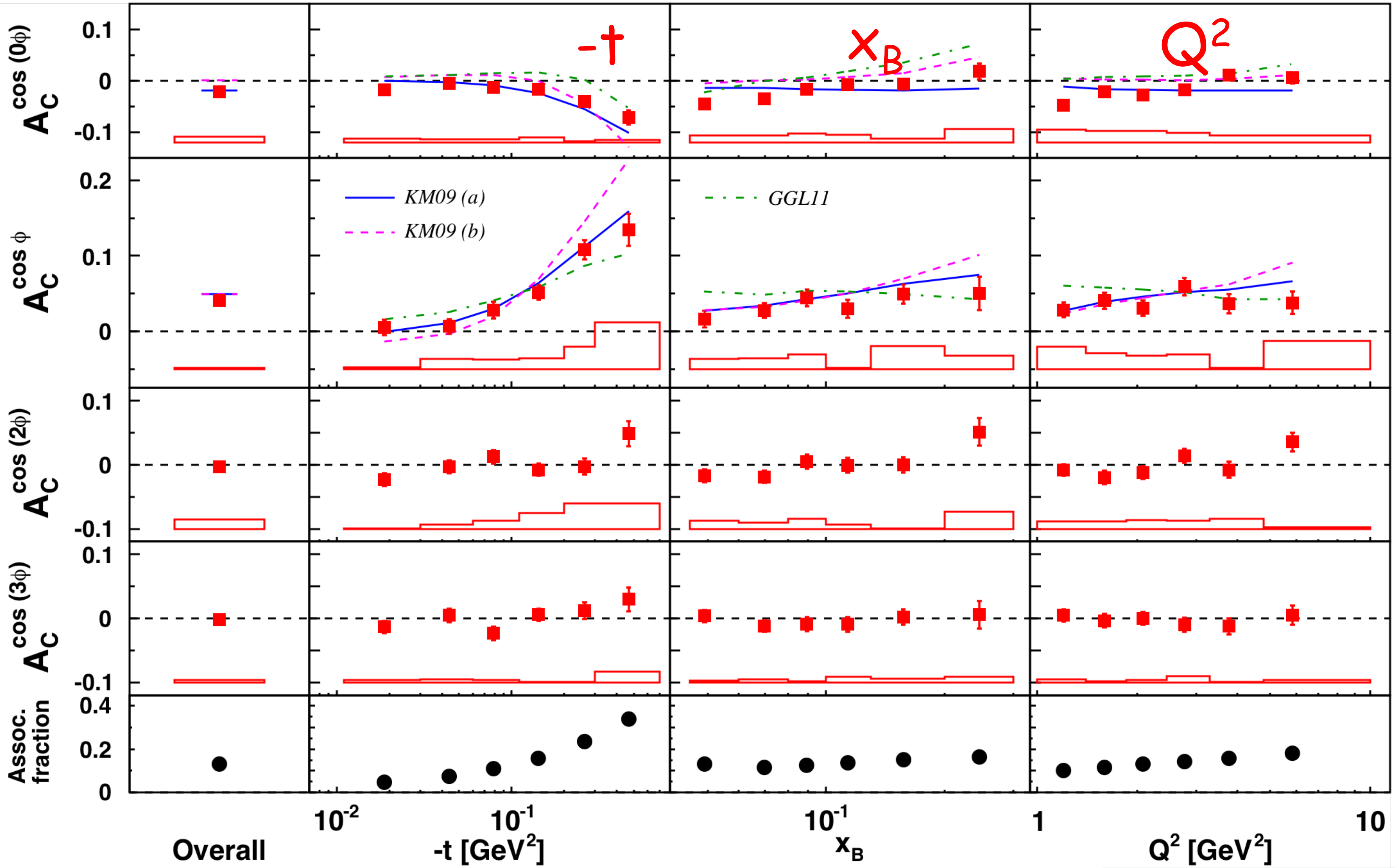
JHEP 07 (2012) 032

HERMES DVCS results:

"Beam Charge Asymmetry": no recoil, but BCA-BSA combined fit



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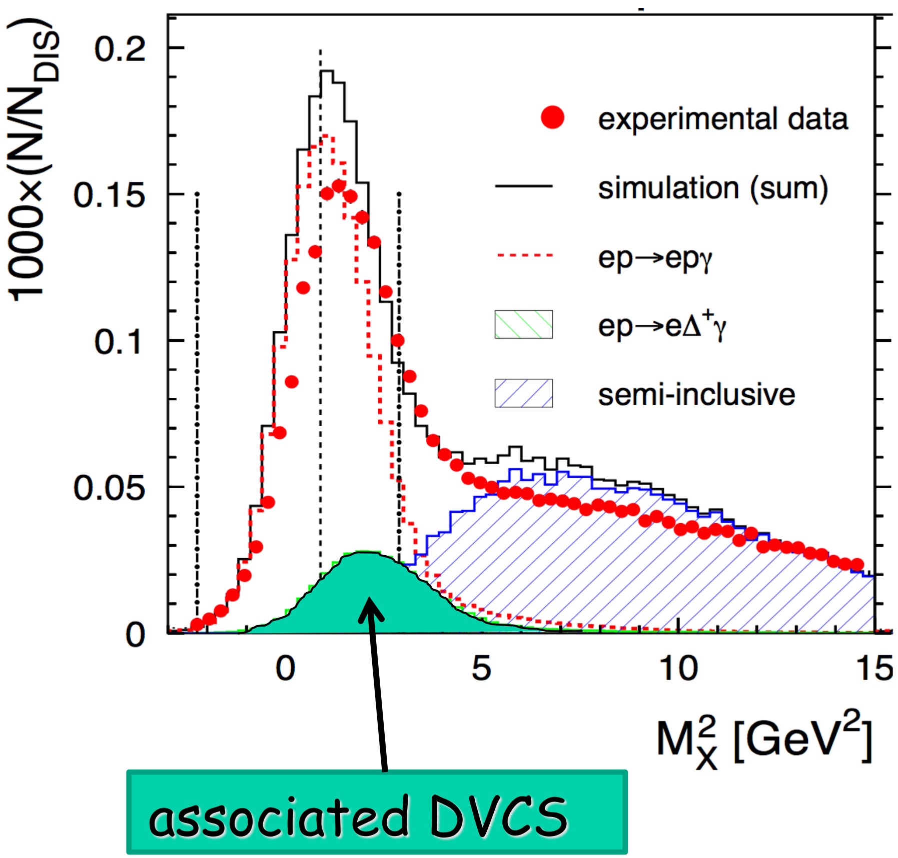
JHEP 07 (2012) 032

HERMES DVCS analysis:

"Associated DVCS"



$$ep \rightarrow e\Delta^+\gamma$$
$$\Delta^+ \rightarrow p\pi^0$$
$$\Delta^+ \rightarrow n\pi^+$$

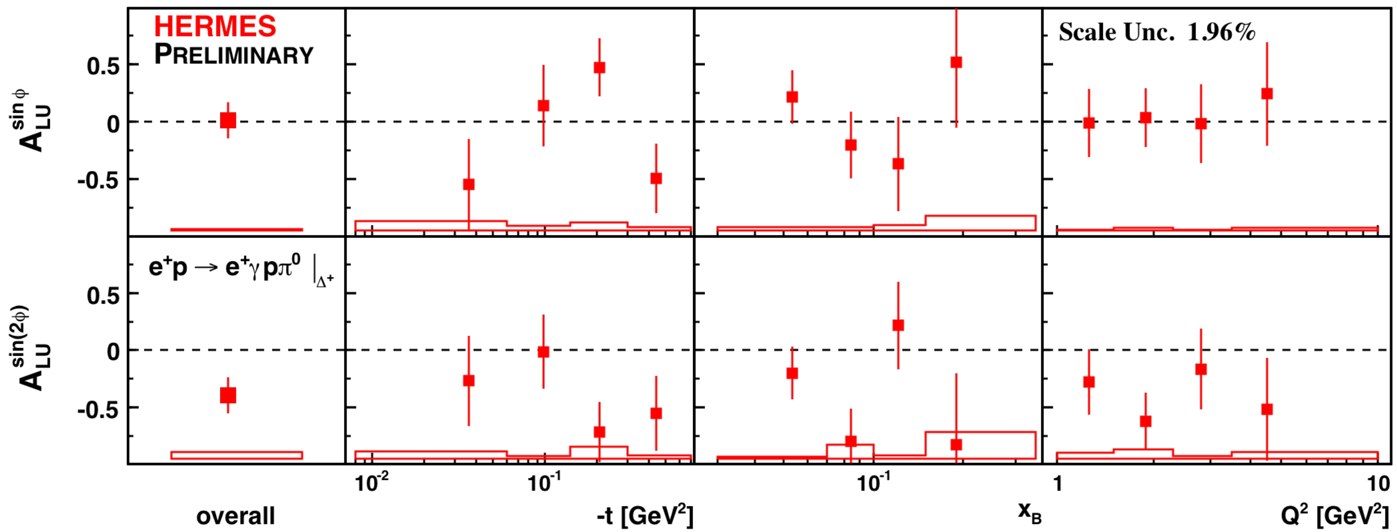
Select associated DVCS by:

- recoil detector
- measure all but 1 particle
- use kinematic fit and recoil PID

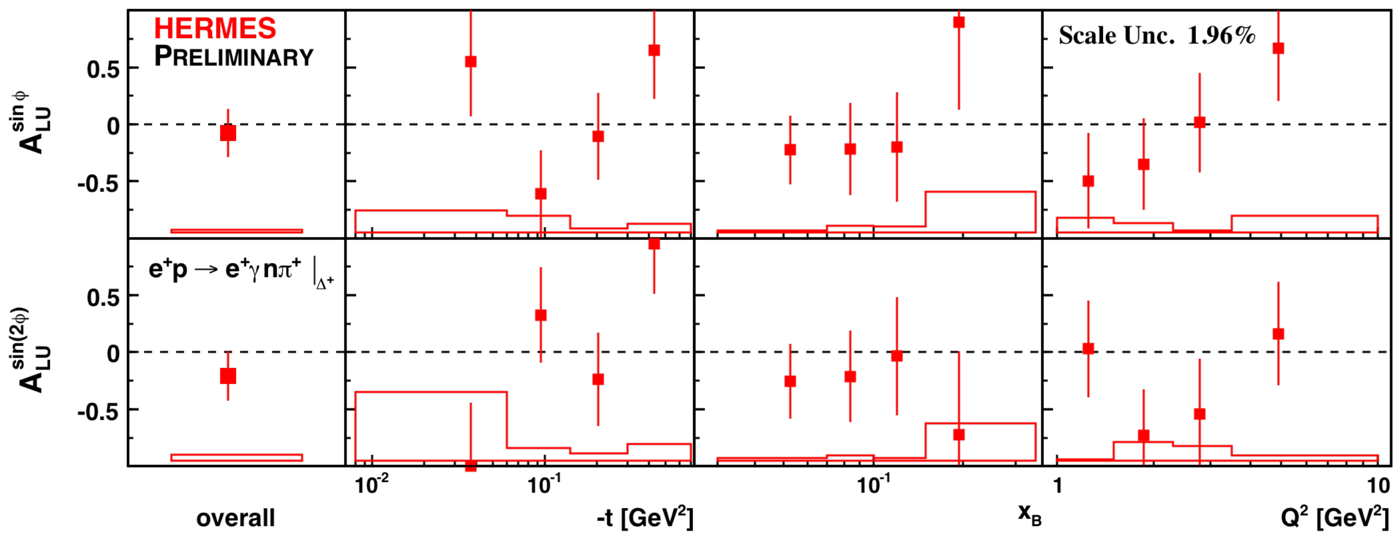
→ access to transition GPDs

HERMES DVCS results:

"Associated DVCS"



$$ep \rightarrow e\Delta^+\gamma$$
$$\hookrightarrow p\pi^0$$



$$ep \rightarrow e\Delta^+\gamma$$
$$\hookrightarrow n\pi^+$$

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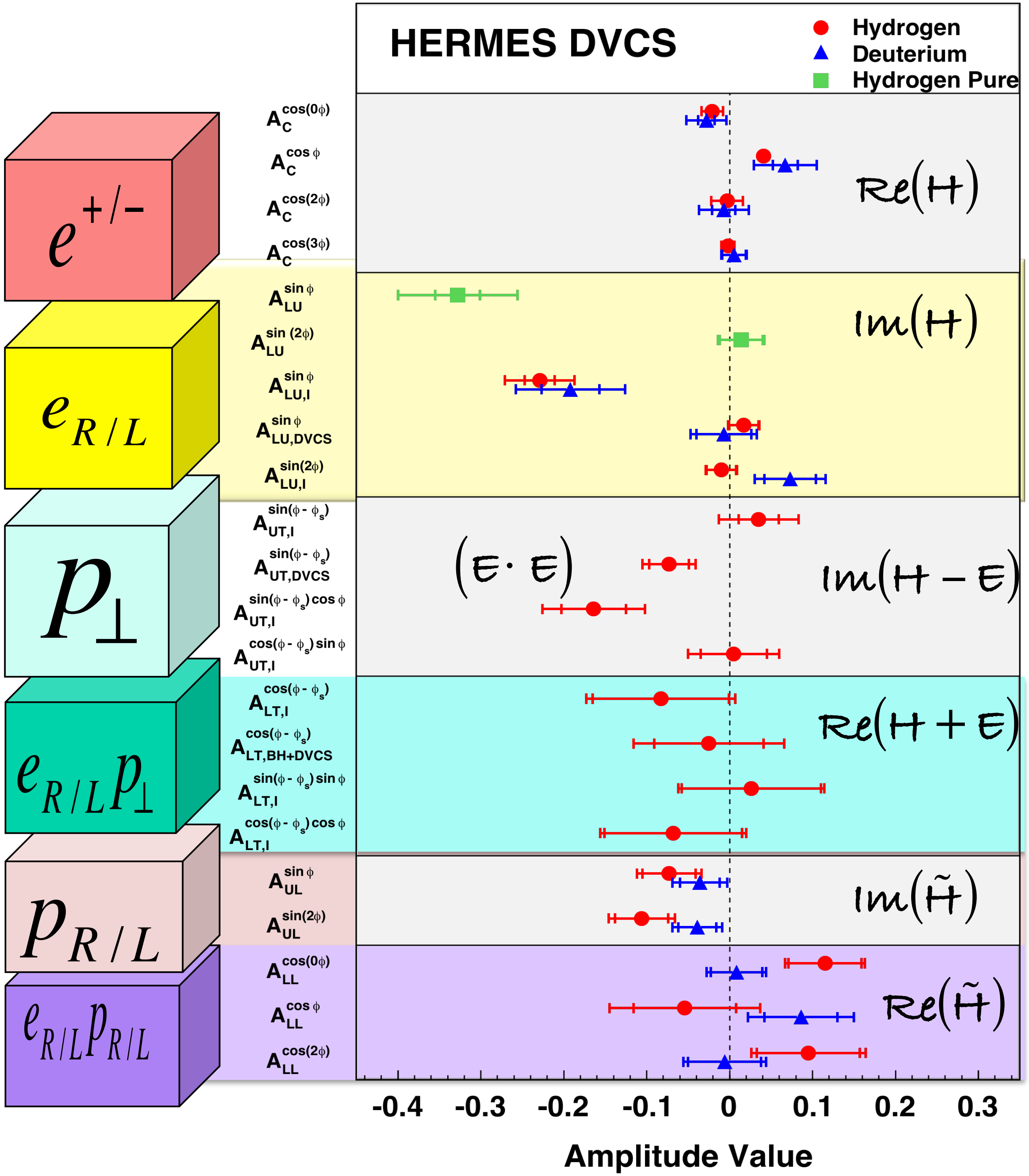
HERMES Preliminary

Access to GPD H, $\tilde{H}$, E



- JHEP 07 (2012) 032
- Nucl. Phys. B829 (2010) 1
- JHEP 10 (2012) 042

sensitive to J_u

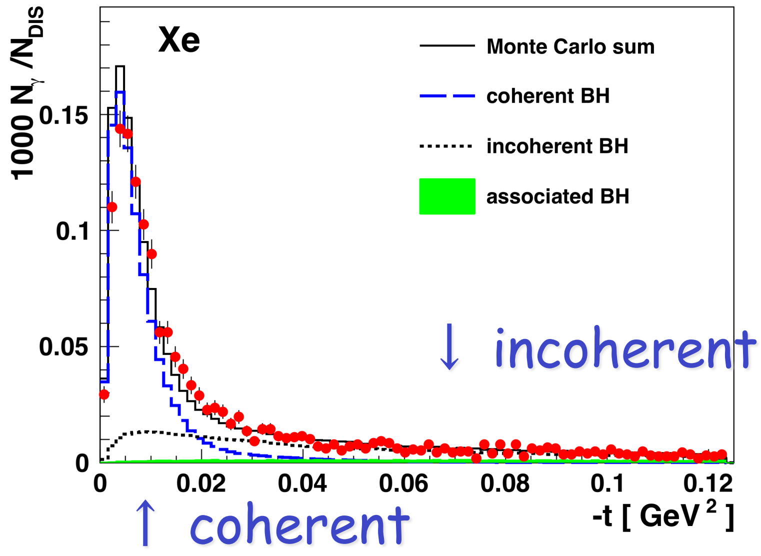
- JHEP 06 (2008) 066

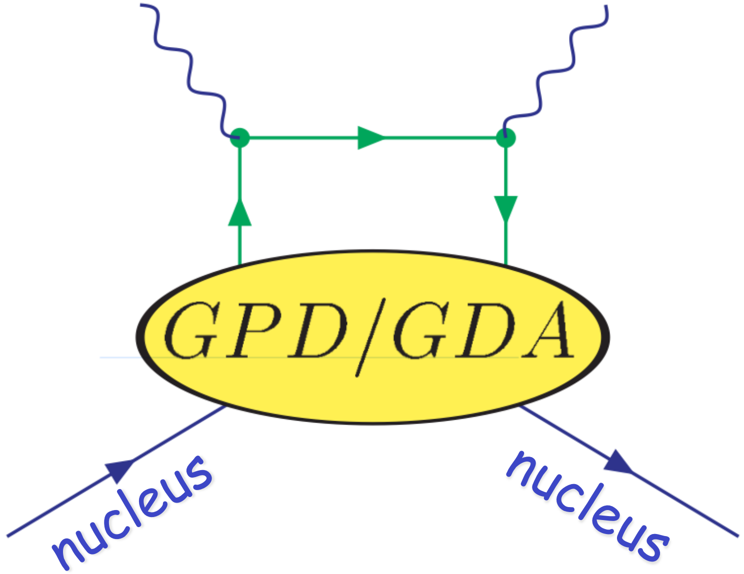
- Phys. Lett. B 704 (2011) 15

- JHEP 06 (2010) 019
- Nucl. Phys. B 842 (2011) 265

HERMES DVCS analysis:

"Nuclear DVCS"

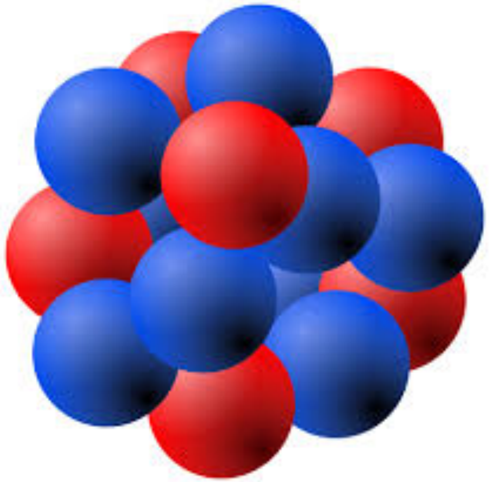


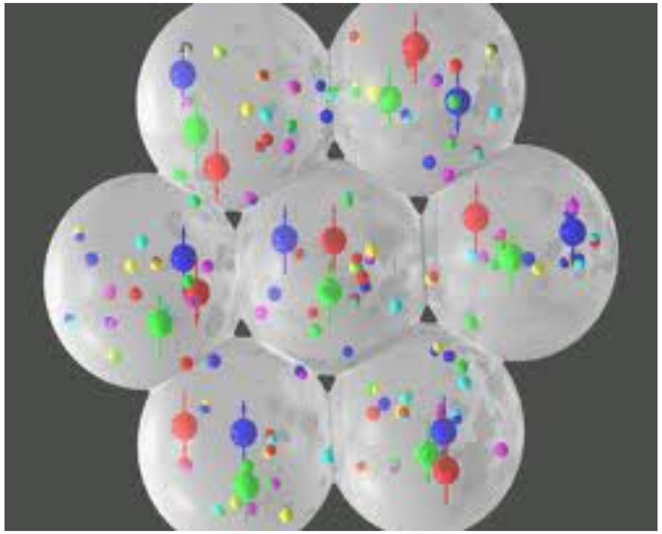


EMC-Effect:

quarks in nucleus

≠ ∑ quarks in nucleon



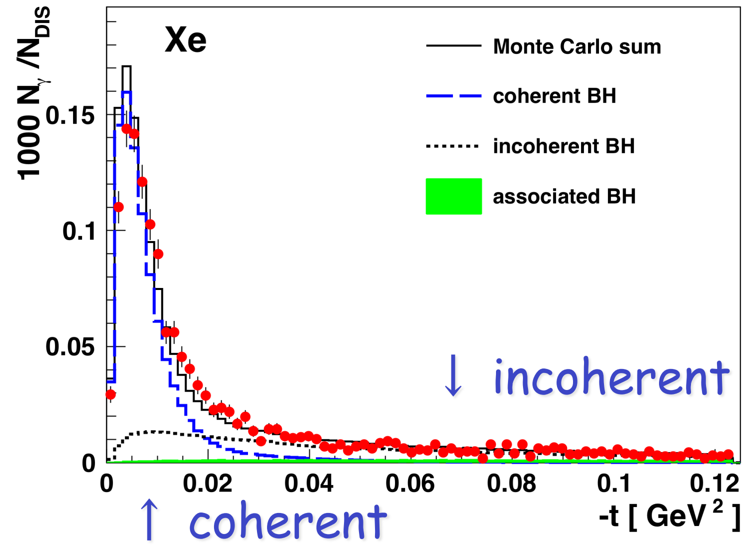


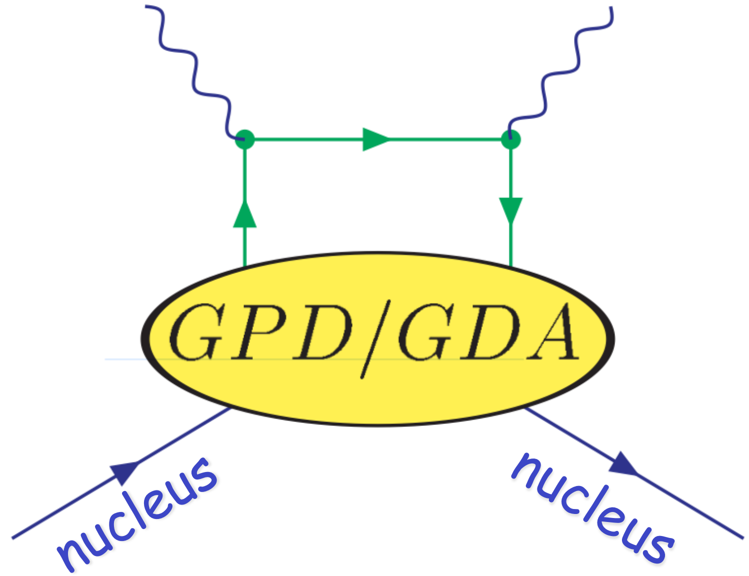
Nuclear DVCS:

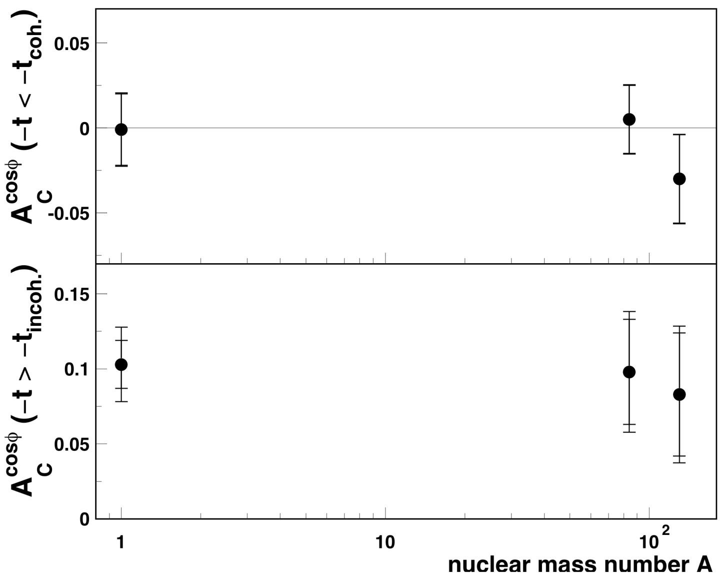
study phase space of quarks in nuclei

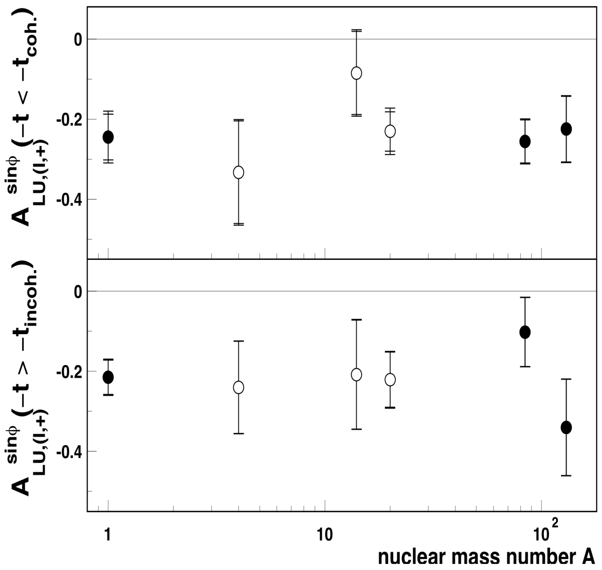
HERMES DVCS results:

"Nuclear DVCS"









← 60% coherent

← 65% incoherent

Phys. Rev. C 81 (2010) 035202

Conclusion

- GDPs are the royal road to study nucleon structure
- HERMES is a pioneering experiment in DVCS
- HERMES has unique conditions and a variety of DVCS results:
  - BCA, BSA, target spin, double spin, nuclear DVCS, associated DVCS, …
- DVCS studies are completed by results on exclusive meson production, polarised PDFs and fragmentation functions

Next:

- BCA with recoil detector coming soon….

Special thanks for transparencies and support by I. Brodski, Riedl, Rostomyan, Schnell, Yaschenko, and other colleagues from Giessen, HERMES and elsewhere …