Hard exclusive reactions and generalized parton distributions

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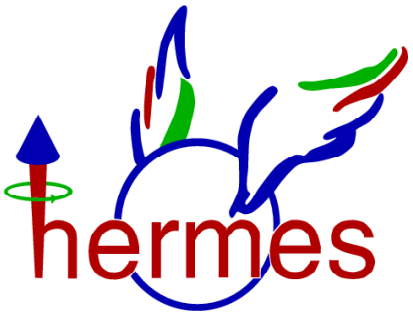
On behalf of the HERMES Collaboration

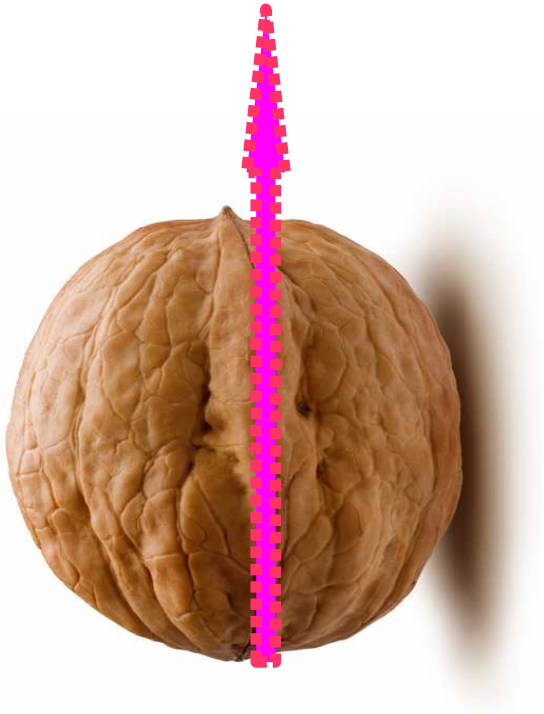


International Conference on New Frontiers in Physics

ICNFP 2014 Crete, Greece

July 27- August 7 OAC

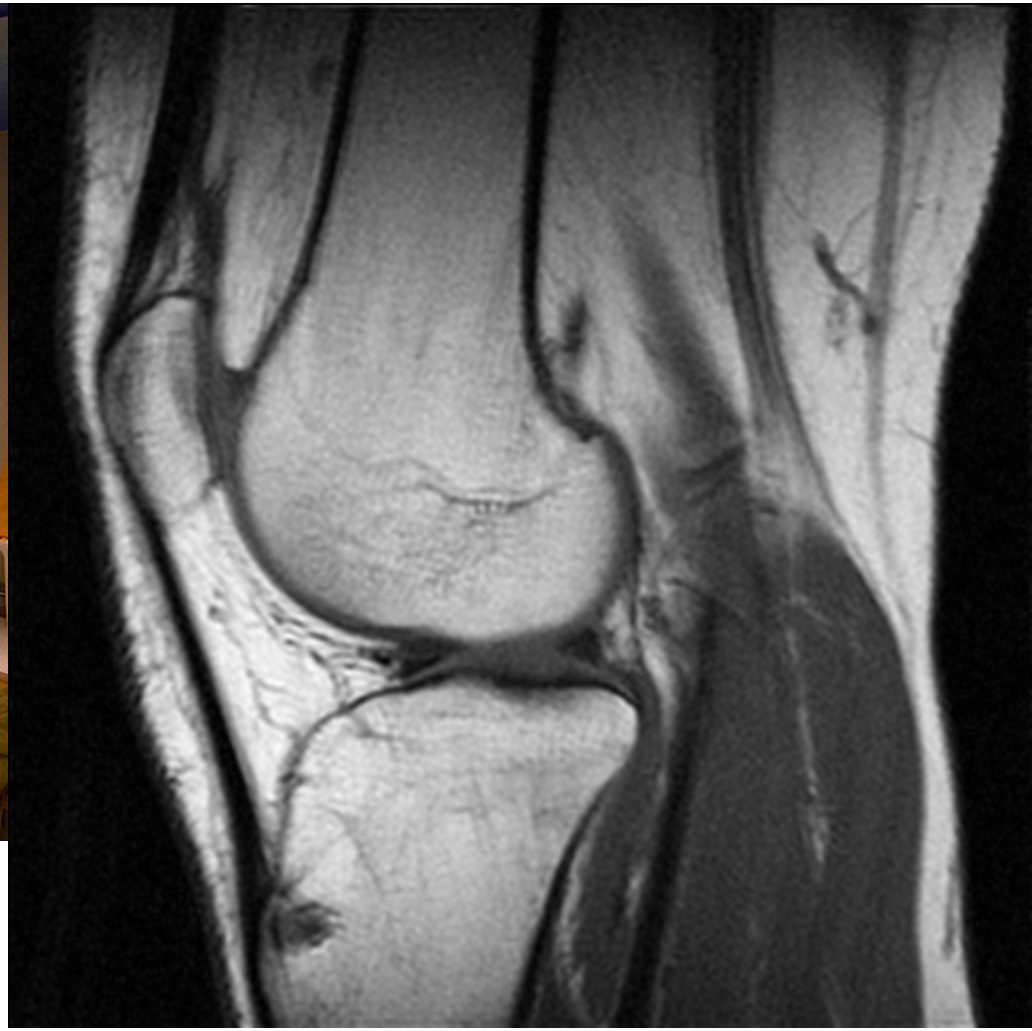
The start point, proton spin



τὸ πρῶτον ,

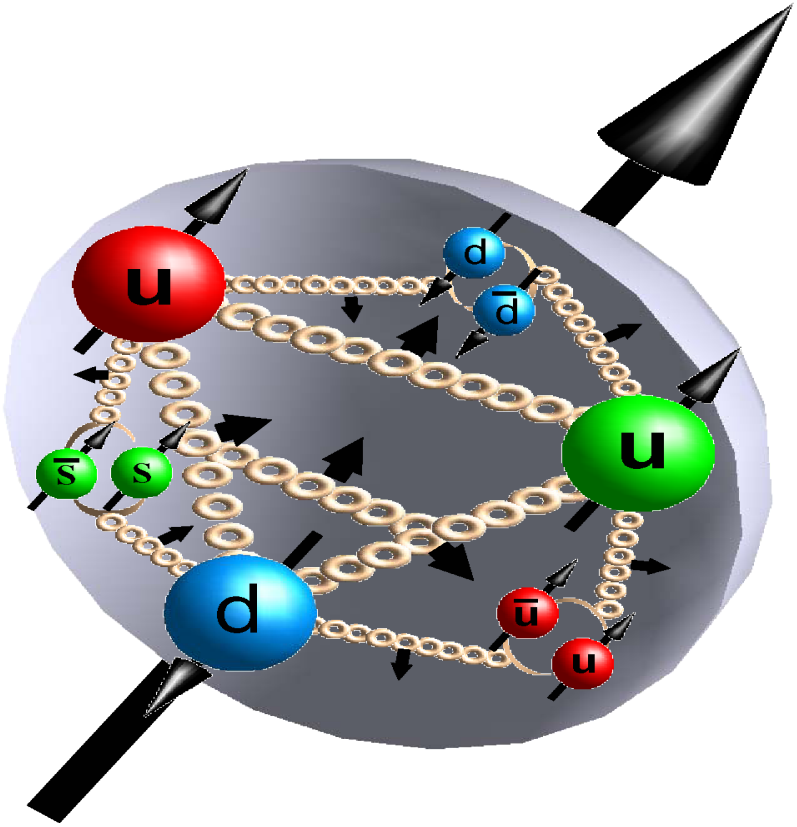
the proton has a spin 1/2

we have learned to use it



With MRI devices you can check whether it make sense to play Football

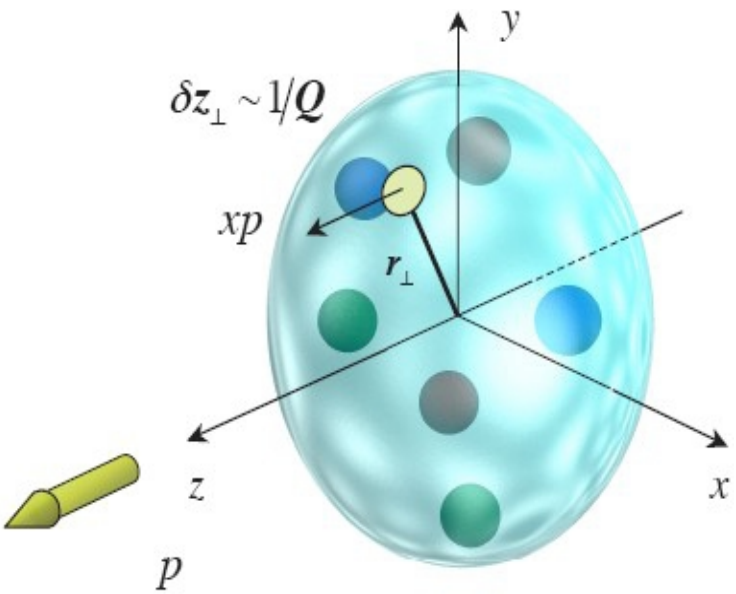
lets open it



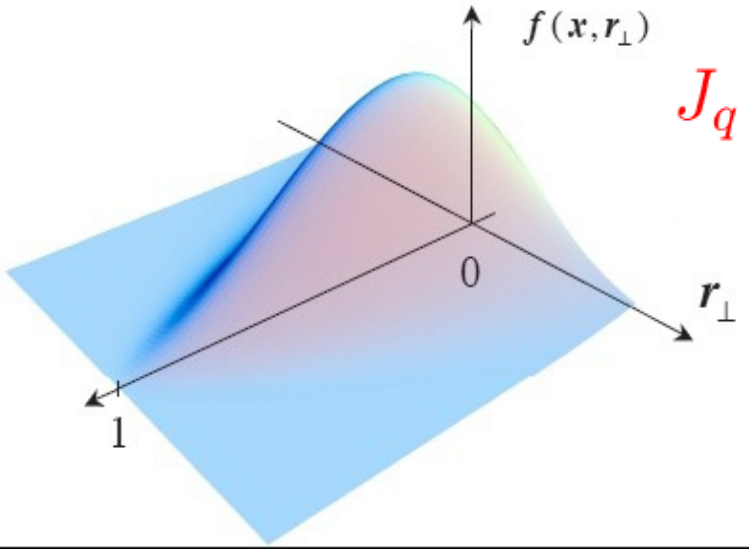
Kindergarden Event

University Event

Why GPDs



- **Multidimensional description of nucleon structure (longitudinal momentum versus 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**



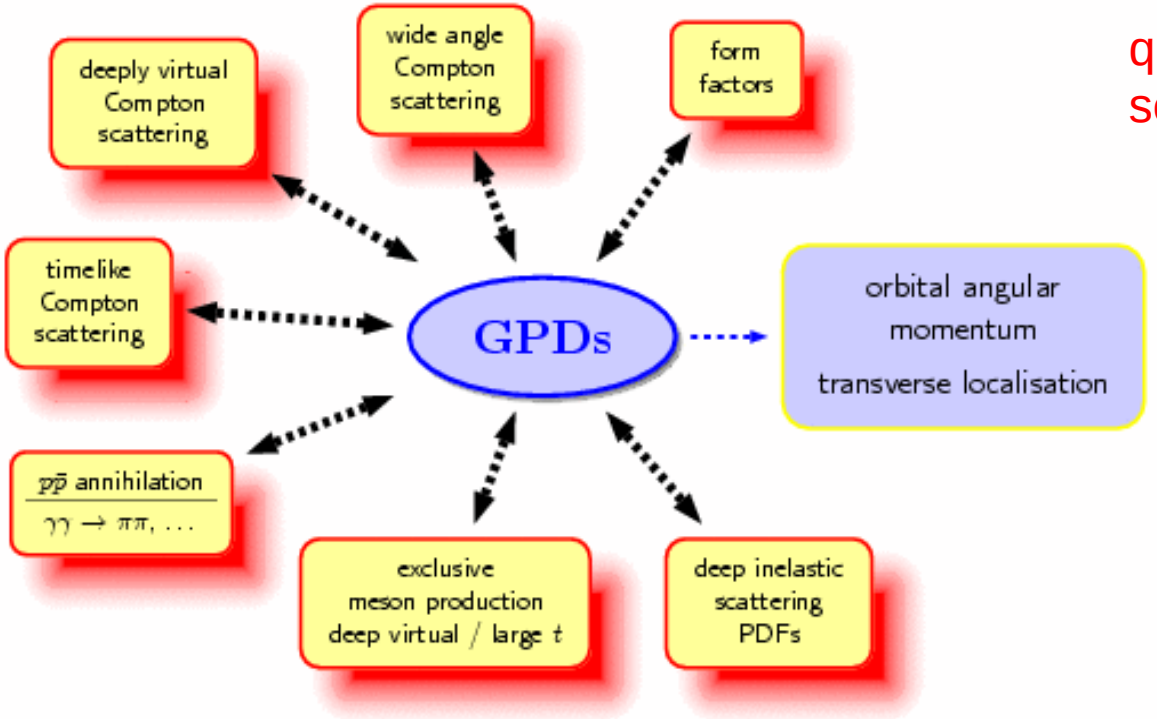
$$J_q = \lim_{t\to 0} \int_{-1}^{1} dx\; x[H_q(x,\xi,t) + E_q(x,\xi,t)]$$

- **In case of proton target four GPDs**

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

X. Ji, D. Mueller, A. Radyushkin, …. (1994-1997)

GPDs, how to access them



quantum number of final state selects different GPDs:

- theoretically very clean
  DVCS (γ): H, E, $\tilde{H}$, $\tilde{E}$
- VM (ρ, ω, ϕ): H, E
- info on quark flavors
  PS mesons (π, η): $\tilde{H}$, $\tilde{E}$

Eur. Phys. J. C(2009)59
P. Kroll, S. Goloskokov

A_{UT} measurement

K. Goeke, M. Polyakov,
M. Vanderhaegen PPNP 47(2001)

$2J^u + J^d$

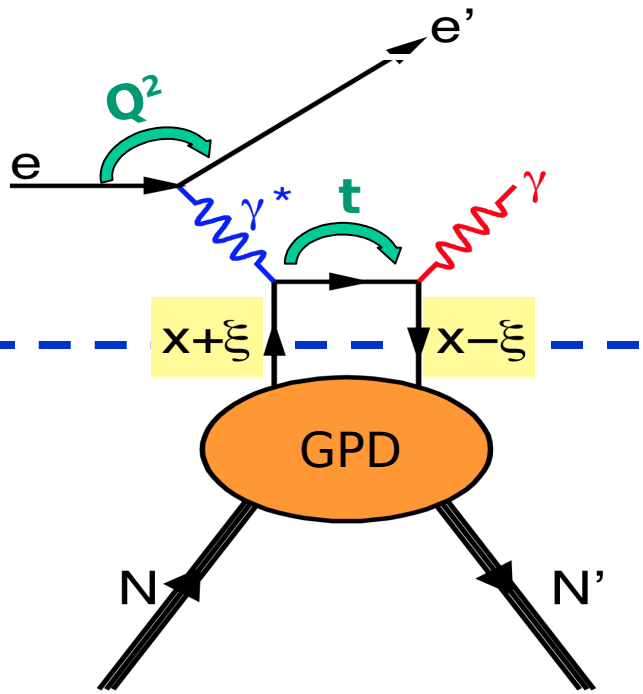
$J^u - J^d$

$2J^u - J^d$

A_{UT} { ρ^0, ρ^+, ω }

Deeply Virtual Compton Scattering (DVCS)

DVCS is the cleanest way to access GPDs



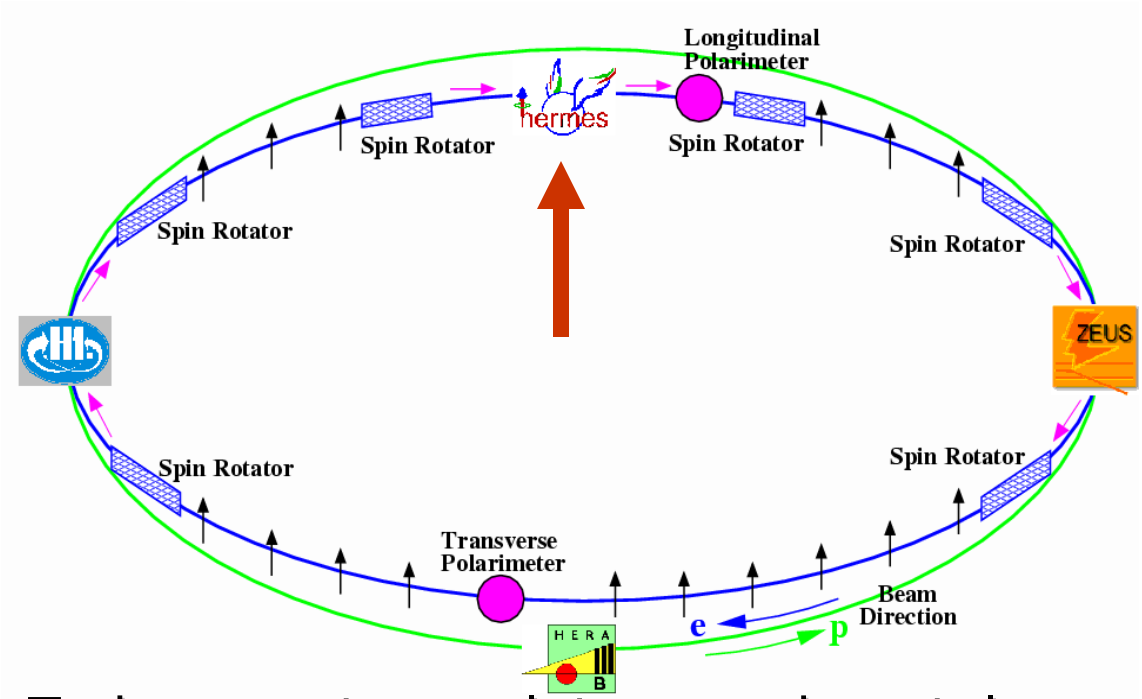
Handbag diagram separates

- 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 $x-\xi$

The Experiment

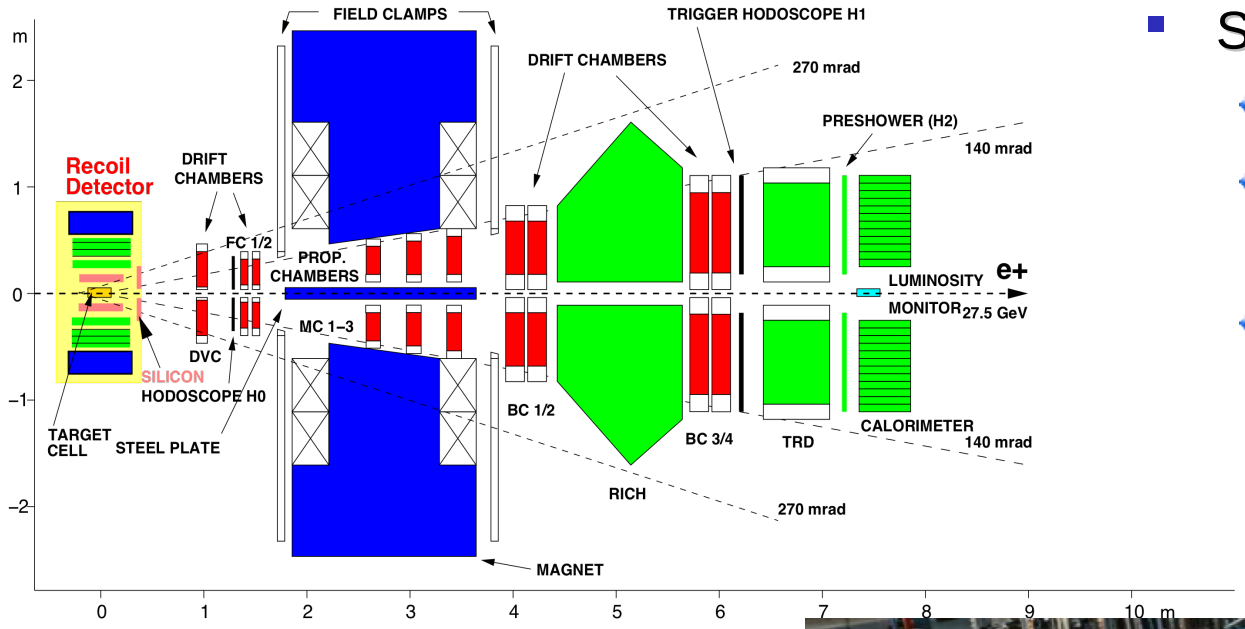


HERA

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

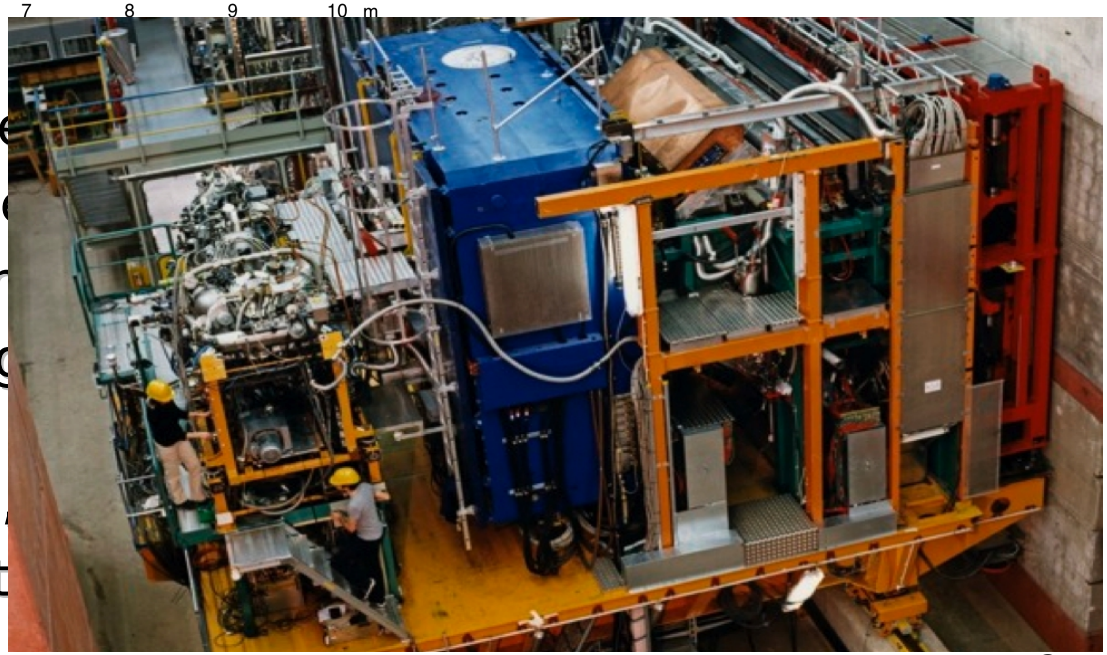
- Today: most complete experimental access:
  - charge reversal (e^+ and e^- beams)
  - beam spin reversal (both beam helicities)
  - target spin reversal (longitudinal, transverse, unpolarized)
  - target mass variation (H, D, He, N, Ne, Kr, Xe)
  - recoil and spectator proton detection

The Detector

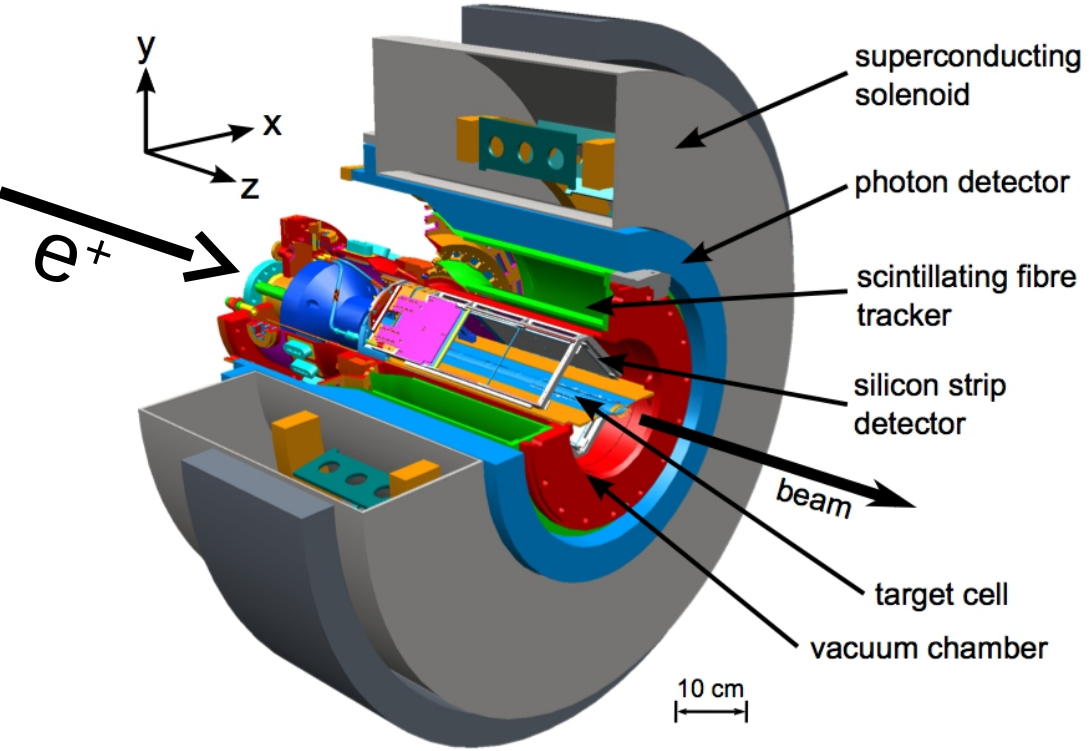


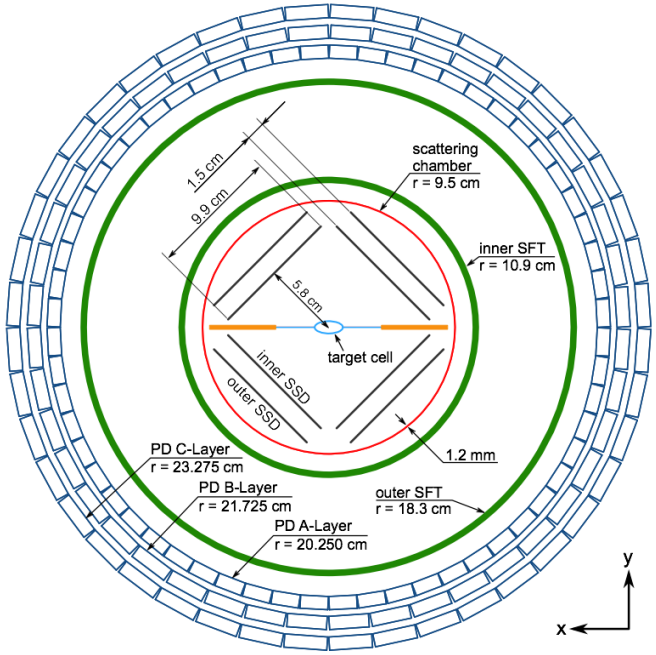
- Spectrometer
  - particle identification
  - recoil proton detection(in 2006-07)
  - complete DVCS kinematics e p → epγ

- Today: most complete expe
  - charge reversal (e^+ and
  - beam spin reversal (both
  - target spin reversal (long unpolarized)
  - target mass variation (H,
  - recoil and spectator prot

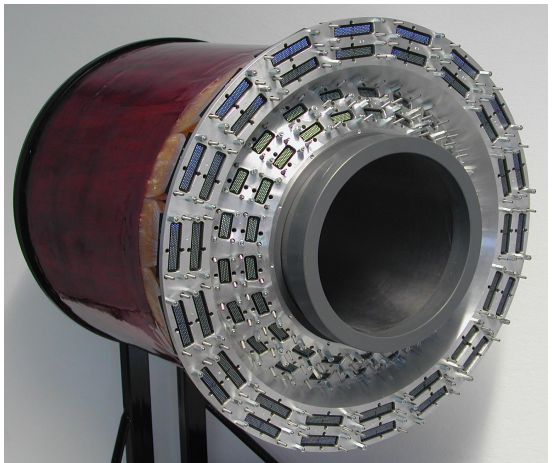


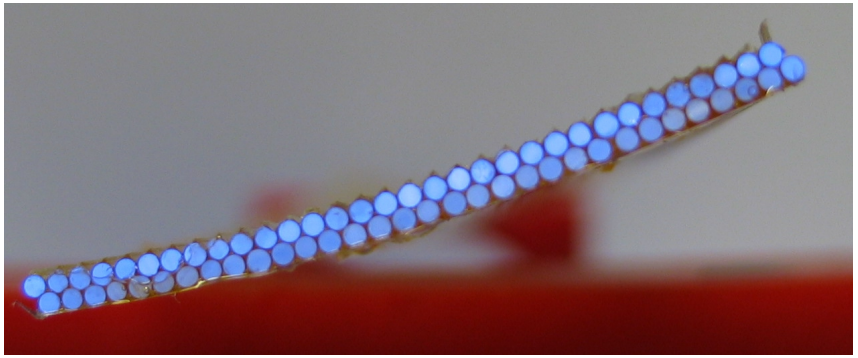
The Recoil Detector





JINST 8 (2013) P05012

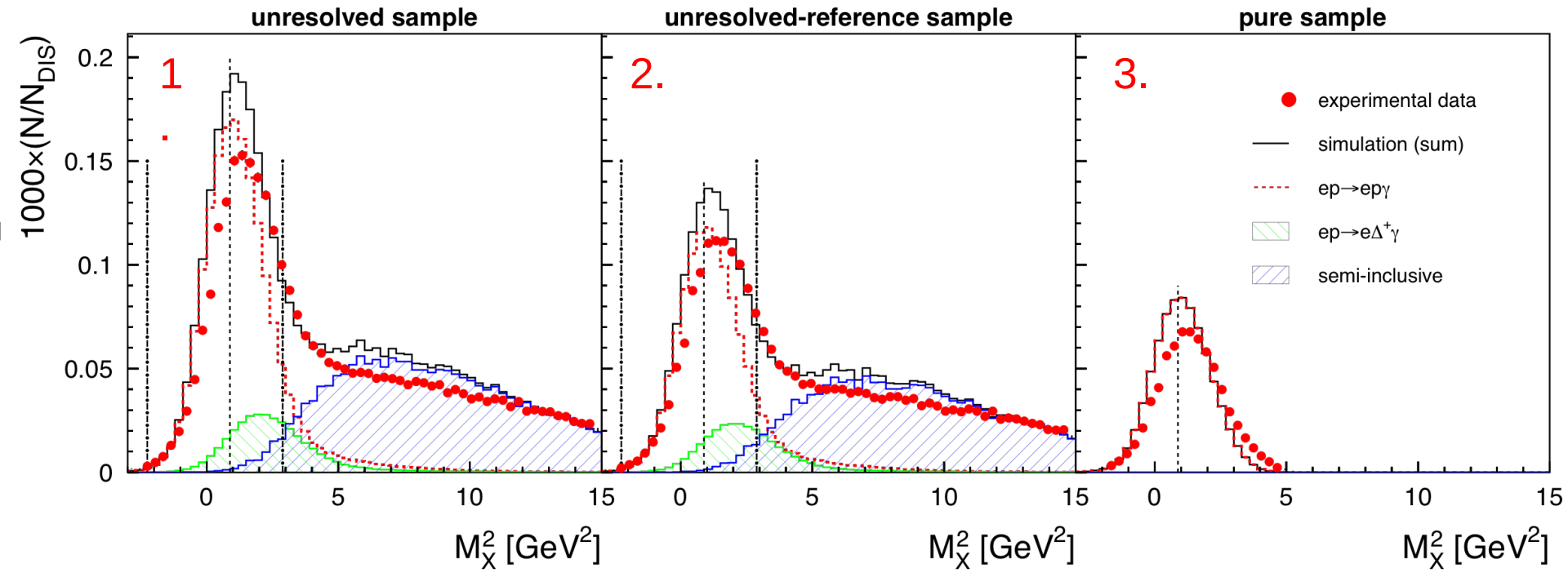




Recoil fibre detector made in Giessen

Detection scheme

”Missing mass” without/with recoil detector



1. unresolved sample

no recoil detector

missing mass technique

88% purity

2. unresolved-reference sample

as 1. (no recoil detector)

proton in recoil acceptance

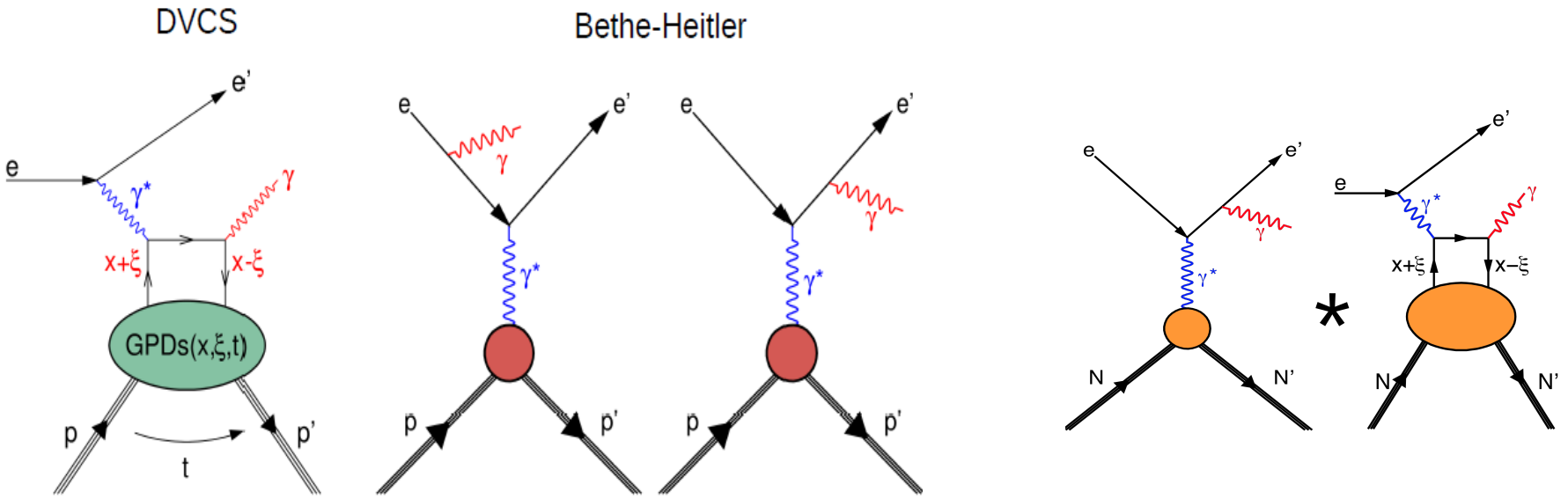
3. pure sample

recoil proton detection

kinematic fit

99,8% purity

But the process ep → epγ is dominated by Bremsstrahlung



- Bethe-Heitler dominates at HERMES kinematics
- The same initial and final state, hence interference

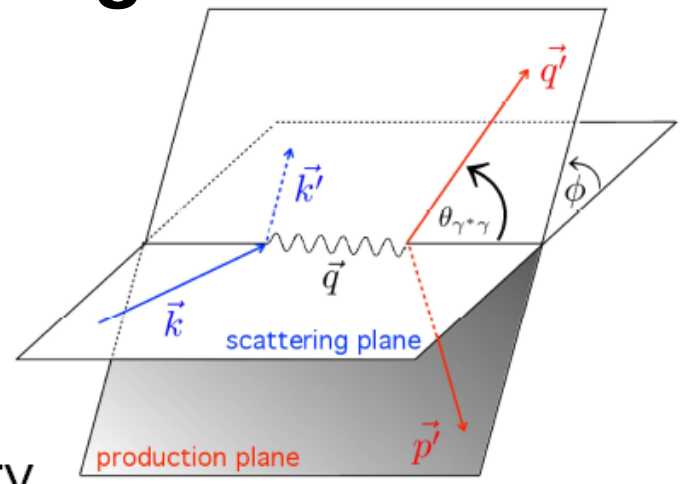
$$|T|^2 = |T_{DVCS}|^2 + |T_{BH}|^2 + \underbrace{T_{DVCS}T^*_{BH} + T^*_{DVCS}T_{BH}}_{I},$$

- Access to GPDs through azimuthal asymmetries

Azimutal Asymmetries in DVCS, **Beam polarization , charge**

- 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

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

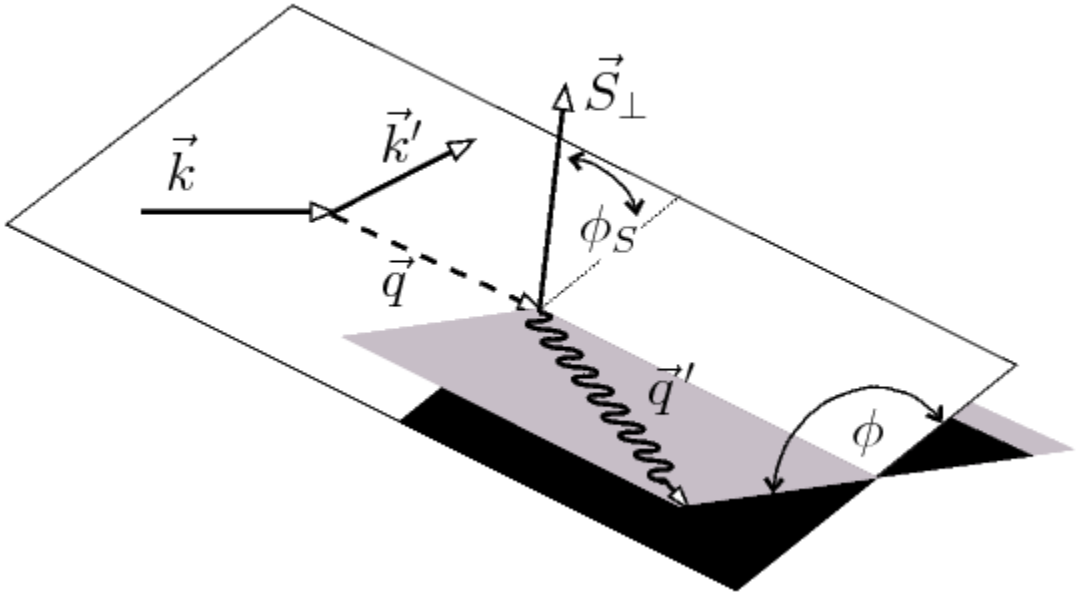
- Charge-averaged beam-helicity asymmetry

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

- Separation of contribution from DVCS and interference term

Dependence from beam Charge(**C_B**) and Polarization(**P_B**)

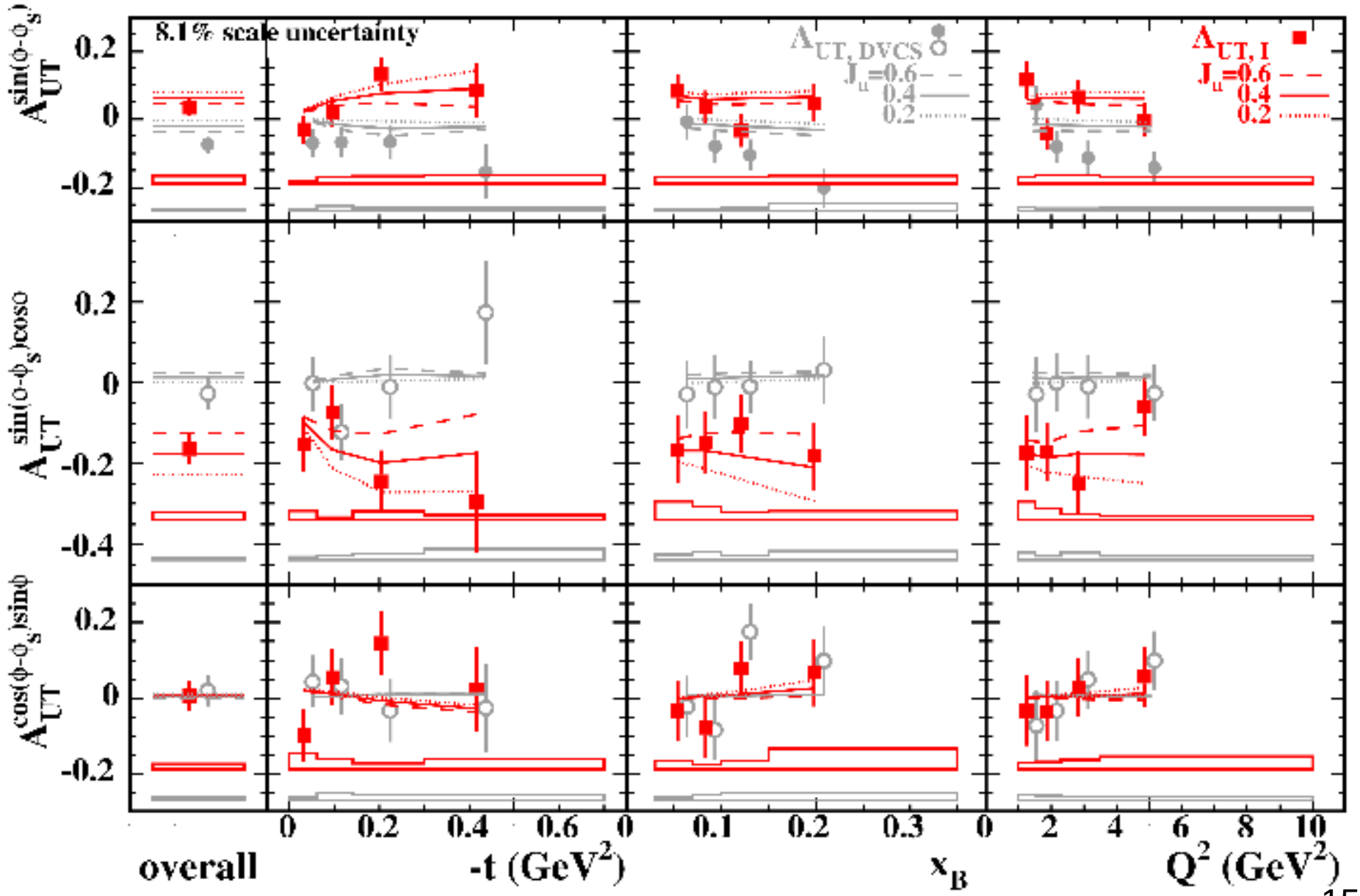
Azimutal Asymmetries in DVCS, **Target Polarization**



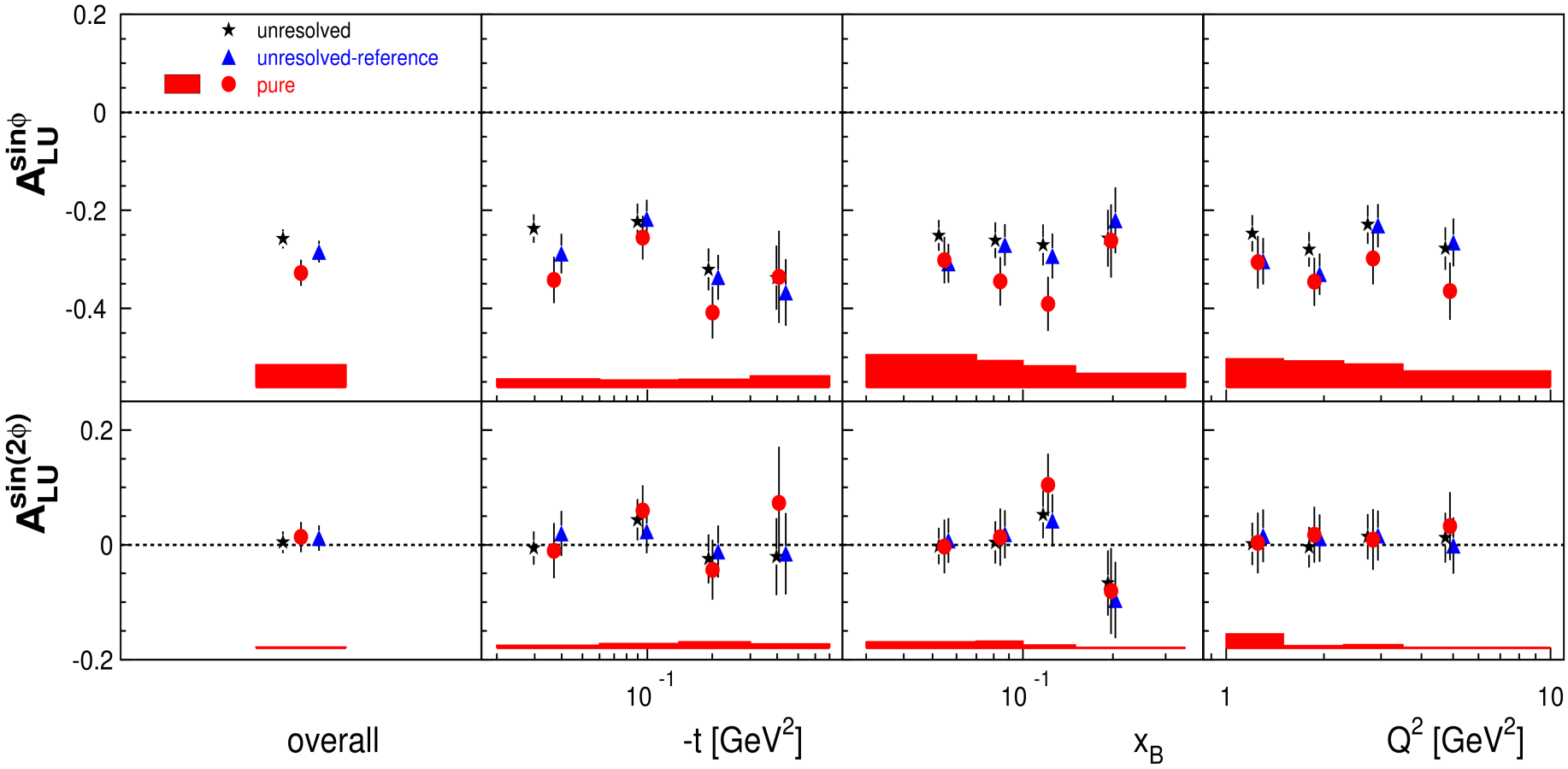
Transverse target-spin asymmetry $A_{UT}(\phi, \phi_s)$ [TTSA]:

$$d\sigma(\phi,\phi_S) - d\sigma(\phi,\phi_S+\pi) \propto \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}] \cdot \sin(\phi-\phi_S)\cos\phi + \mathrm{Im}[F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}] \cdot \cos(\phi-\phi_S)\sin\phi$$

Transverse target asymmetries
Sensitive to GPD E and Orbital angular momentum

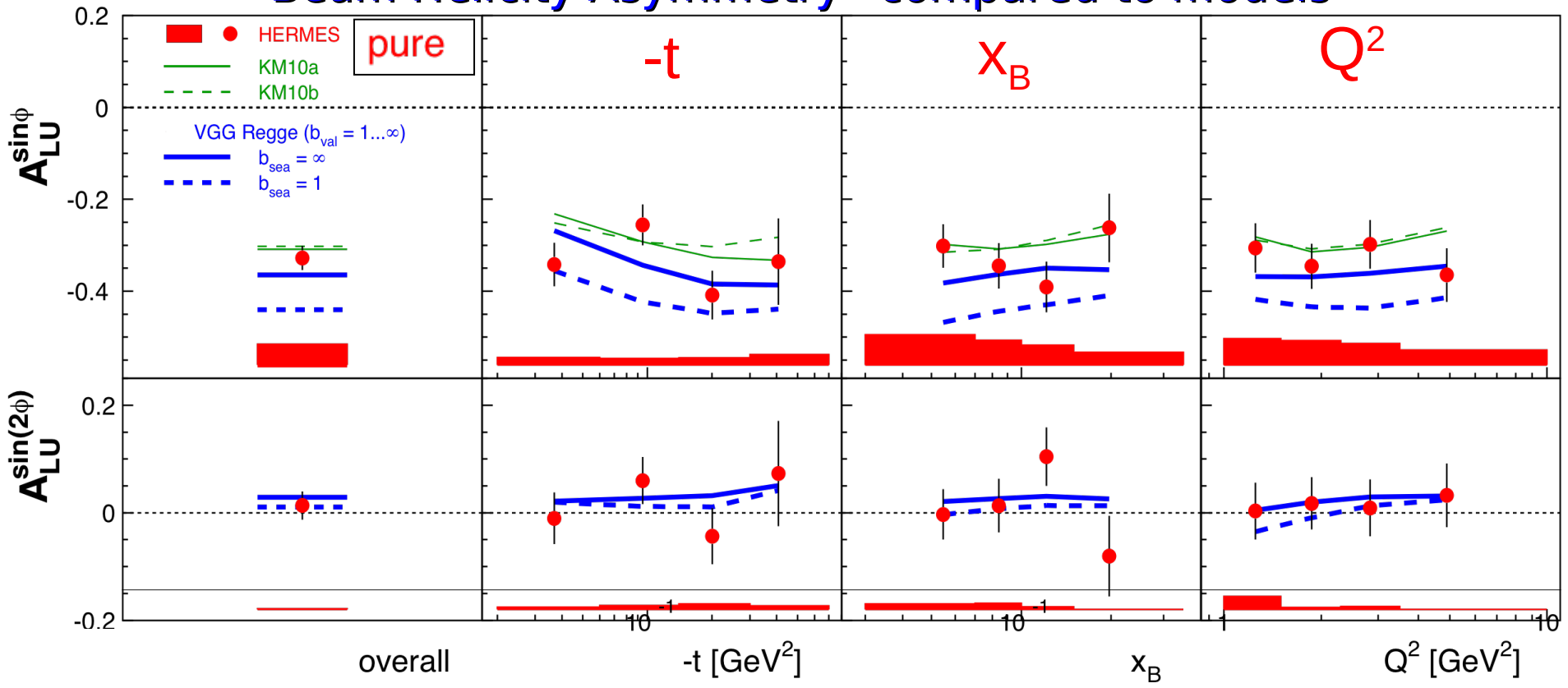


HERMES DVCS results:
"Beam Helicity Asymmetry" WO/with RD



HERMES DVCS results:

"Beam Helicity Asymmetry" compared to models

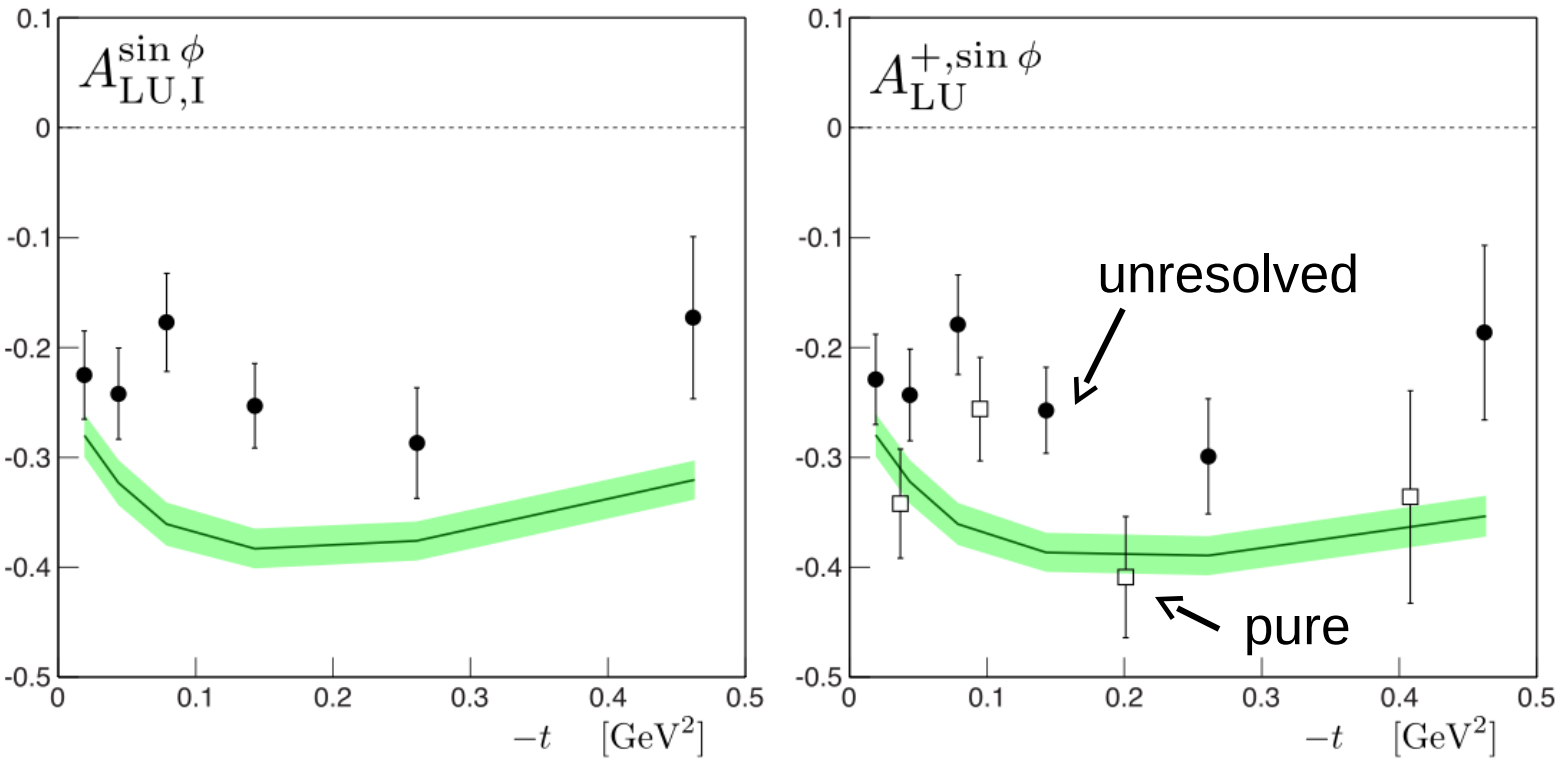


KM= Global fit of world data: Kumericki-Müller, Nucl. Phys. B 841 (2010) 1
(JLab, HERMES and HERA, dashed excludes JLab Hall A cross section)

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:

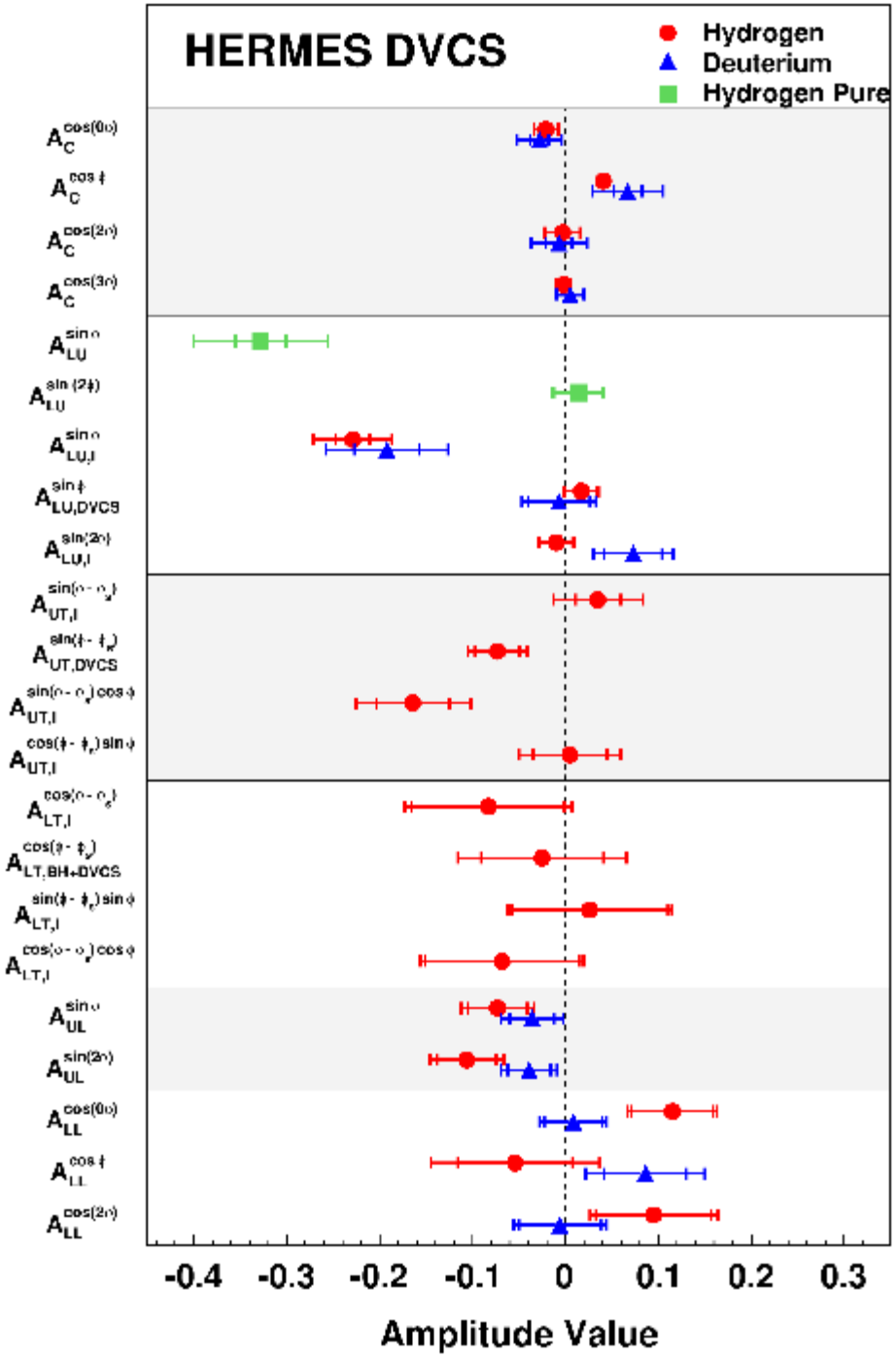
”Beam Helicity Asymmetry” with GPD model from HEMP



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)



GPD sensitivity

$\mathrm{Re}(H)$

$\mathrm{Im}(H)$

$(E \cdot E)$

$\mathrm{Im}(H-E)$

$\mathrm{Re}(\mathrm{H+E})$

$\mathrm{Im}(\tilde{H})$

$\mathrm{Re}(\tilde{H})$

Measurement type

$e^{+/-}$

$e_{R\,/\,L}$

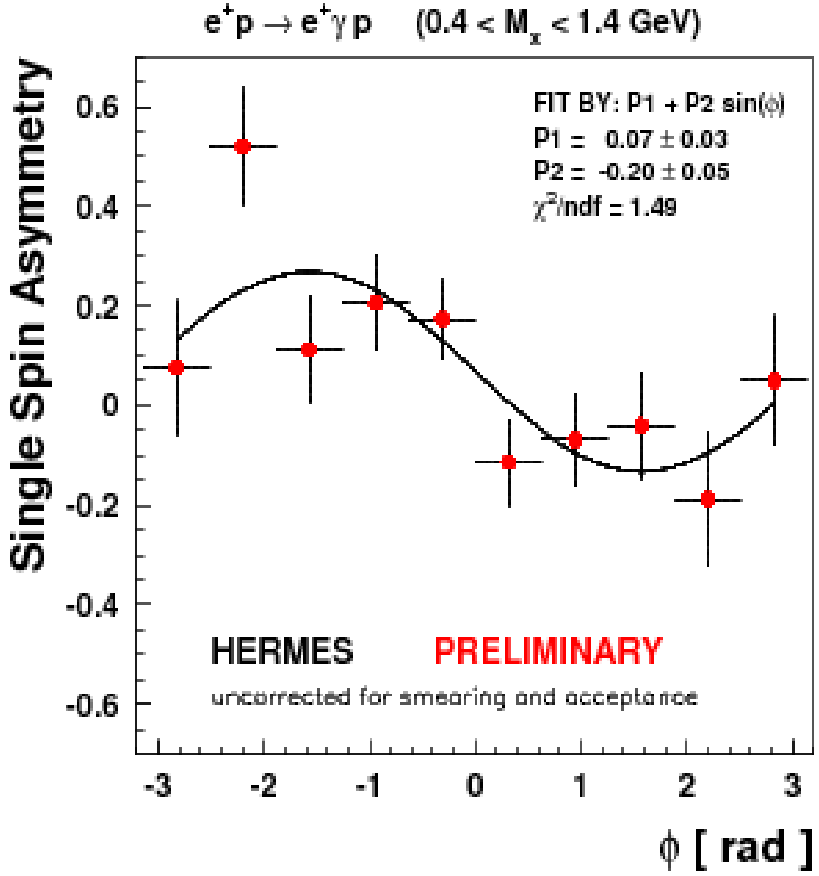
$p_{\perp}$

$e_{R\,/\,L}\,p_{\perp}$

$p_{R\,/\,L}$

$e_{R\,/L}\,p_{R\,/L}$

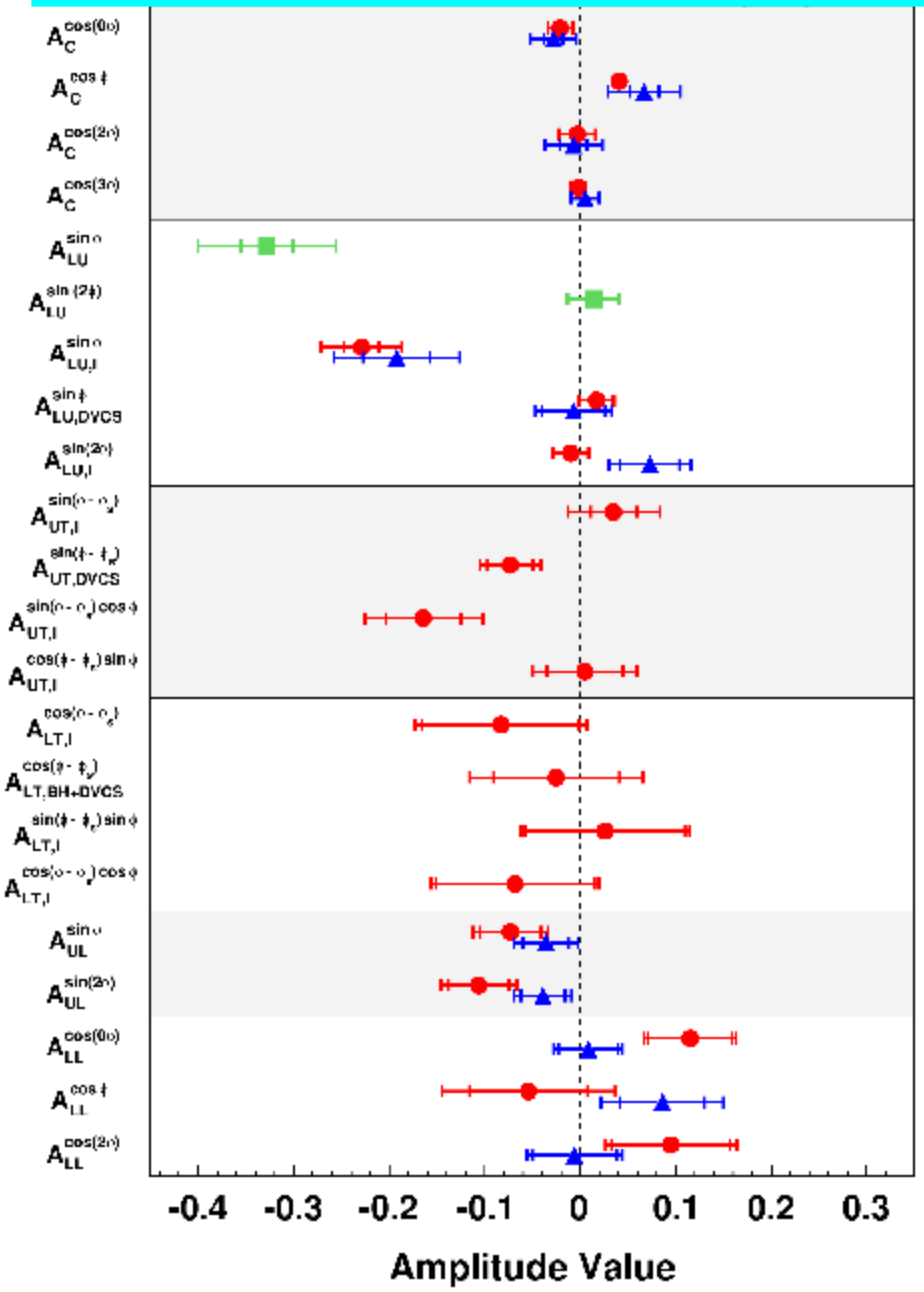
HERMES did its BEST to contribute in GPDs investigation, from pioneering first result ....



first DVCS asymmetry published

FIGURE 1. Single-spin asymmetry as a function of azimuthal angle ϕ.

...to an almost complete coverage



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

Conclusions

I am thankful to the organizers for this opportunity and persons (**M. Düren, K. Rith, M. Murray, S. Yaschenko** and **Colleagues** from **HERMES**) for allowing me to read their slides

GDPs are promising to play a main role in nucleon structure study

- HERMES was a pioneering and the only single experiment that could offer all flavours of DVCS(**+associated+HEMP not shown here**) measurement
- **The recoil data showed importance of clean measurement to be done in future facilities**
- If we add all mentioned results together then it is natural that currently almost all theoretical studies uses HERMES data for constrain GPDs

Let check whether I can type in Armenian

Շնորհակալություն

Danke

Thanks

Спасибо

Ευχαριστούμε

Շնորհակալություն

ուշադրության

համար