# Estimation of GPDs using DVCS at HERMES

Summary of separation of rare electromagnetic processes at PANDA

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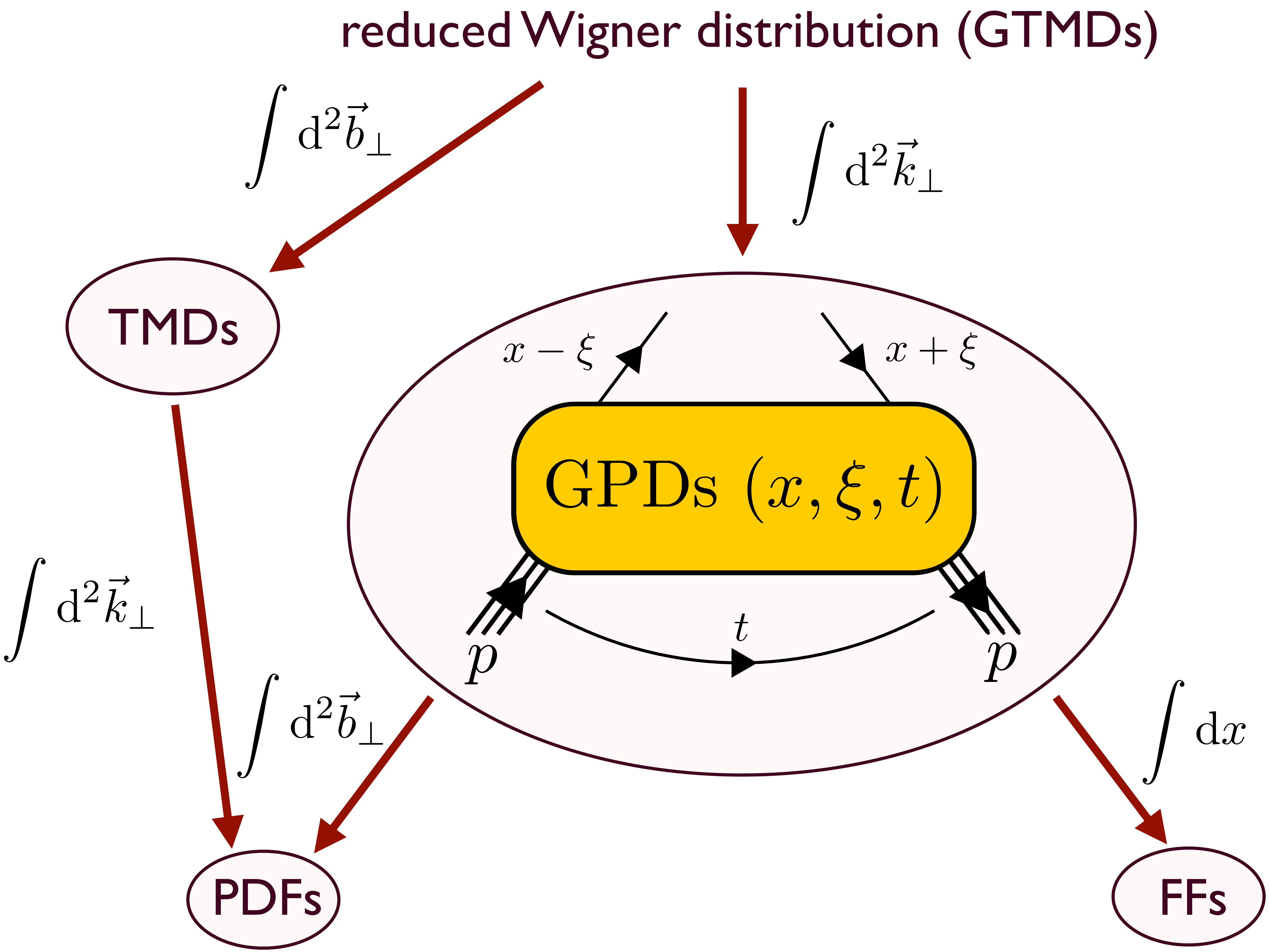
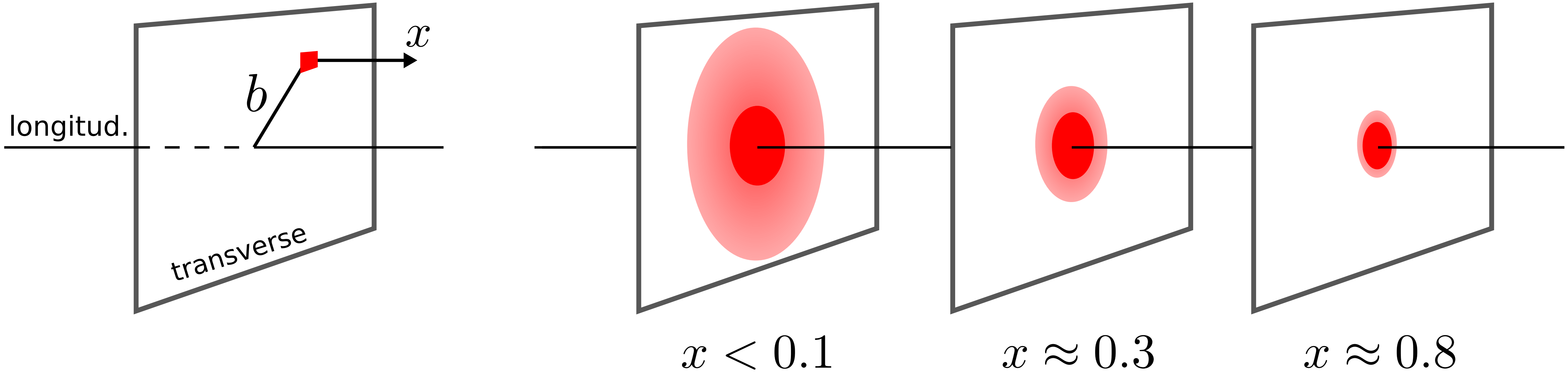
# Content

- GPDs (Generalized Parton Distributions)
- DVCS (Deeply Virtual Compton Scattering)
- The HERMES experiment
- Overview of the results
- Associated DVCS
- Outlook for GPD/GDA measurements with PANDA

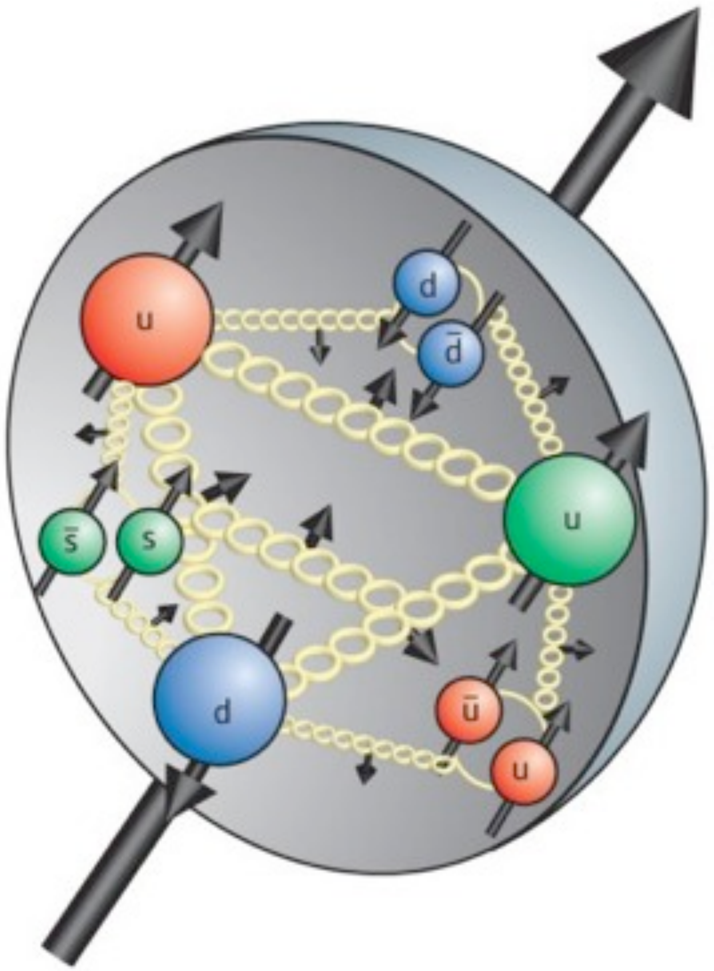

reduced Wigner distribution (GTMDs)
$\int d^2\vec{b}_\perp$
$\int d^2\vec{k}_\perp$
TMDs
$x-\xi$
$x+\xi$
GPDs $(x,\xi,t)$
$p$
$t$
$p$
$\int d^2\vec{k}_\perp$
$\int d^2\vec{b}_\perp$
$\int dx$
PDFs
FFs

## Nucleon tomography

GPDs are able to reveal a three dimensional picture of hadrons by correlating transverse spacial with longitudinal momentum distributions.




[M. Guidal, arXiv:1011.4195 [hep-ph] (2010)]




The proton spin puzzle

$$s_z = \frac{1}{2} = \frac{1}{2} \cdot \Delta\Sigma + \Delta G + L_q + L_g$$

contribution by quarks lower than expected from naive quark model

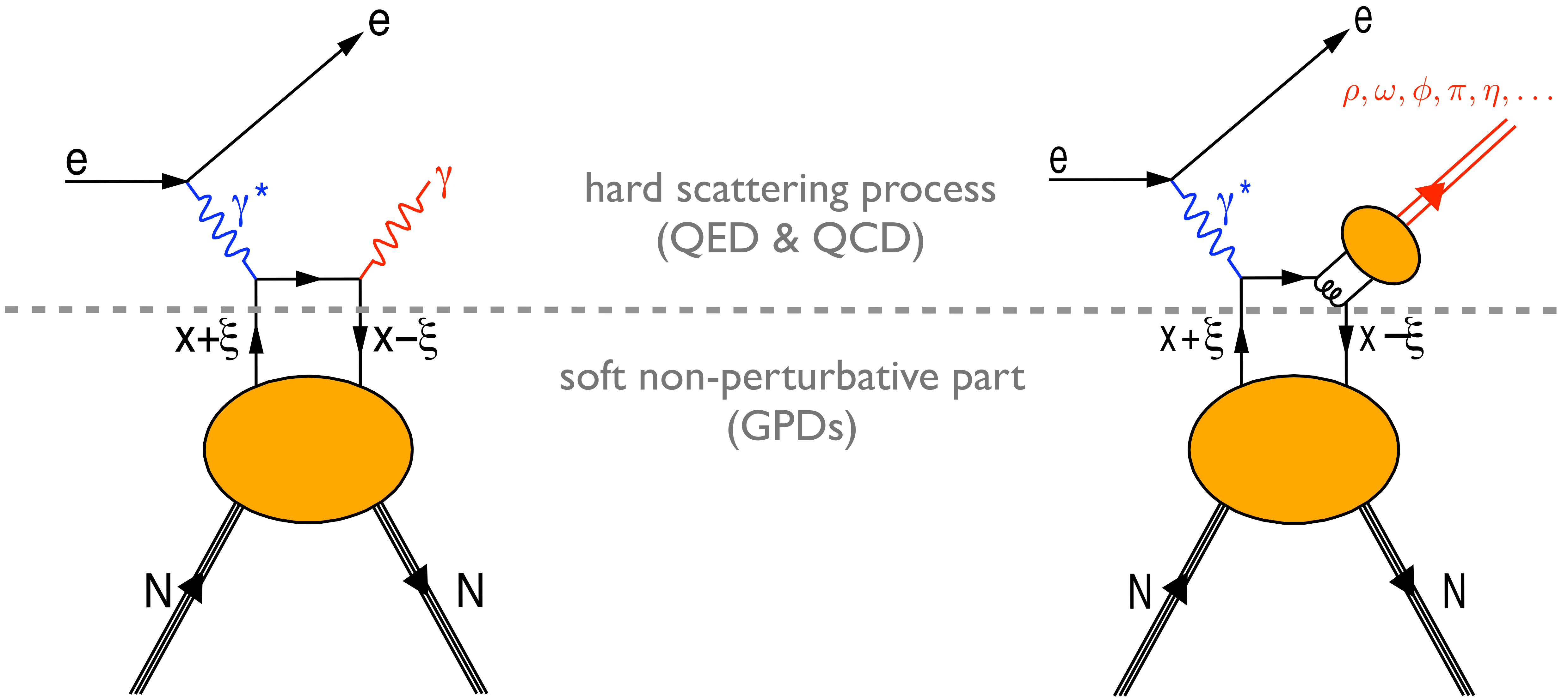
$$J_q = \frac{1}{2} \cdot \Delta\Sigma + L_q$$

Ji found a way to access total angular momentum through GPDs [X. Ji, Phys. Rev. Lett. 78 (1997) 610]:

$$J_q = \frac{1}{2} \int_{-1}^{1} \mathrm{d}x \, x \left[ H_q(x, \xi, \Delta^2 = 0) + E_q(x, \xi, \Delta^2 = 0) \right]$$

**GPDs**

Experimentally GPDs can be accessed through measurements of hard exclusive lepton-nucleon scattering processes.

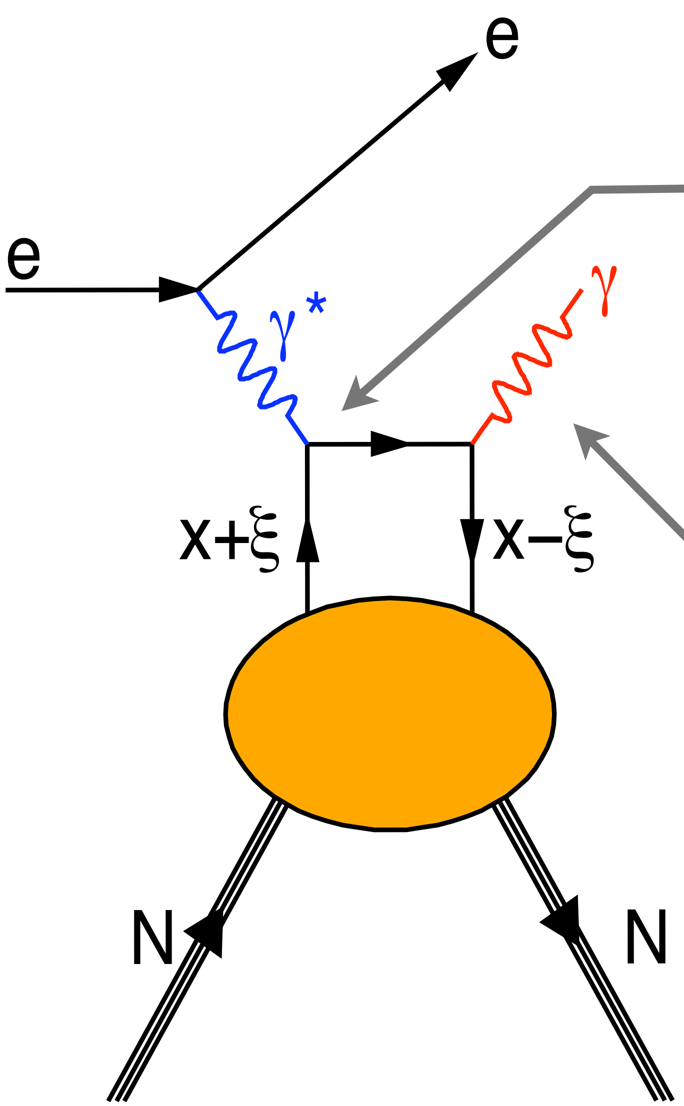



**DVCS** **HEMP**

# DVCS

Theoretically cleanest access to GPDs through DVCS

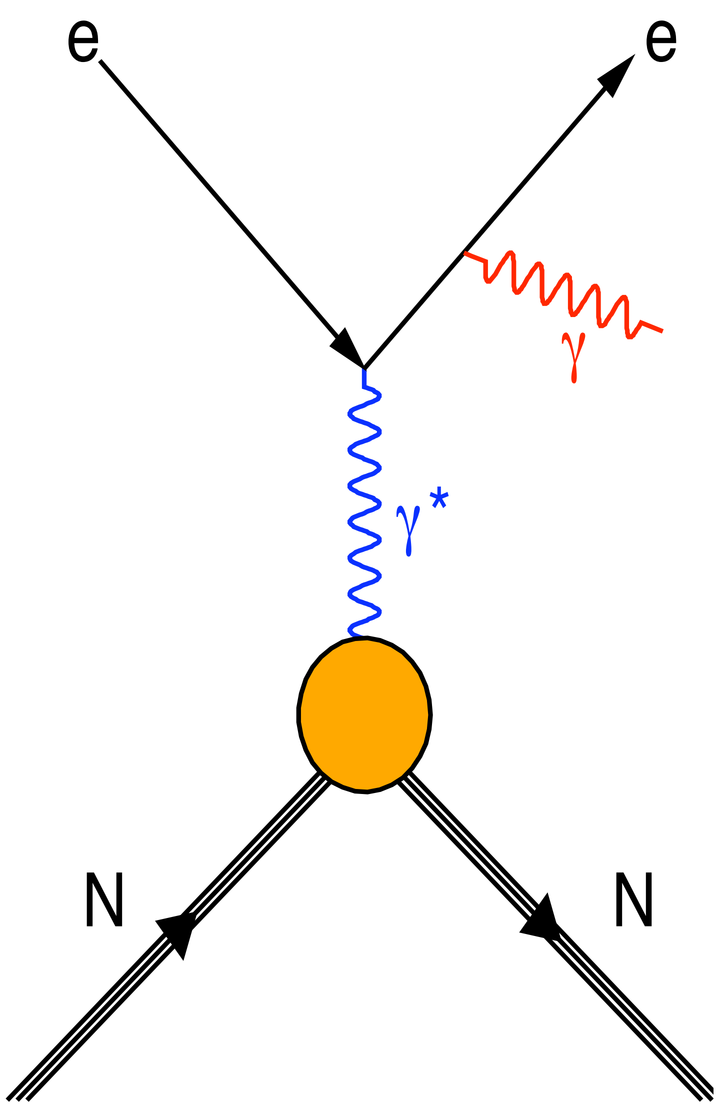
But: final state is equal to Bethe-Heitler scattering (BH)




virtual photon
interacts with quark
inside the nucleon

real photon
is emitted

**DVCS**

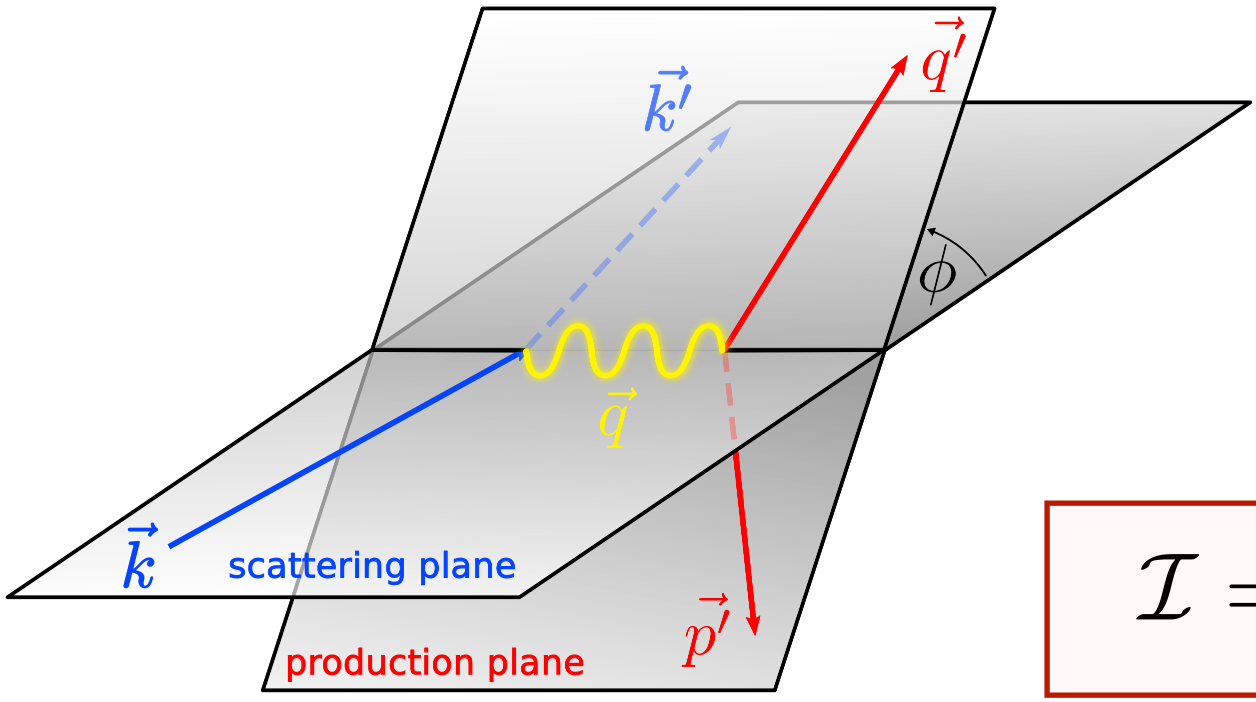



**BH**

$$\boxed{\frac{\mathrm{d}^4}{\mathrm{d}Q^2\mathrm{d}x_B\mathrm{d}t\mathrm{d}\phi} = \frac{x_B e^6}{32(2\pi)^4 Q^4\sqrt{1+\epsilon^2}}\left|\mathcal{T}_{ep\to ep\gamma}\right|^2}$$

Amplitude of Bethe-Heitler scattering is dominant at HERMES kinematics

$$\boxed{\left|\mathcal{T}_{ep\to ep\gamma}\right|^2 = \left|\mathcal{T}_{BH}\right|^2 + \left|\mathcal{T}_{DVCS}\right|^2 + \boxed{\mathcal{I}}}$$




DVCS amplitude is amplified by BH in the interference term

$$\boxed{\mathcal{I} = \mathcal{T}_{BH}\mathcal{T}^*_{DVCS} + \mathcal{T}_{DVCS}\mathcal{T}^*_{BH}}$$

## Access through the measurement of asymmetries:

$$\mathcal{A}_{\boxed{\mathrm{LU}}}(\phi, e_l) = \frac{\sigma_{\mathrm{LU}}(\phi, e_l, \lambda = +1) - \sigma_{\mathrm{LU}}(\phi, e_l, \lambda = -1)}{\sigma_{\mathrm{LU}}(\phi, e_l, \lambda = +1) + \sigma_{\mathrm{LU}}(\phi, e_l, \lambda = -1)}$$
$$= \frac{1}{\sigma_{\mathrm{UU}(\phi, e_l)}} \left[ K_{DVCS} \boxed{s_1^{DVCS}} \sin\phi - \frac{e_l K_{\mathcal{I}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \sum_{n=1}^{2} \boxed{s_n^{\mathcal{I}}} \sin(n\phi) \right]$$

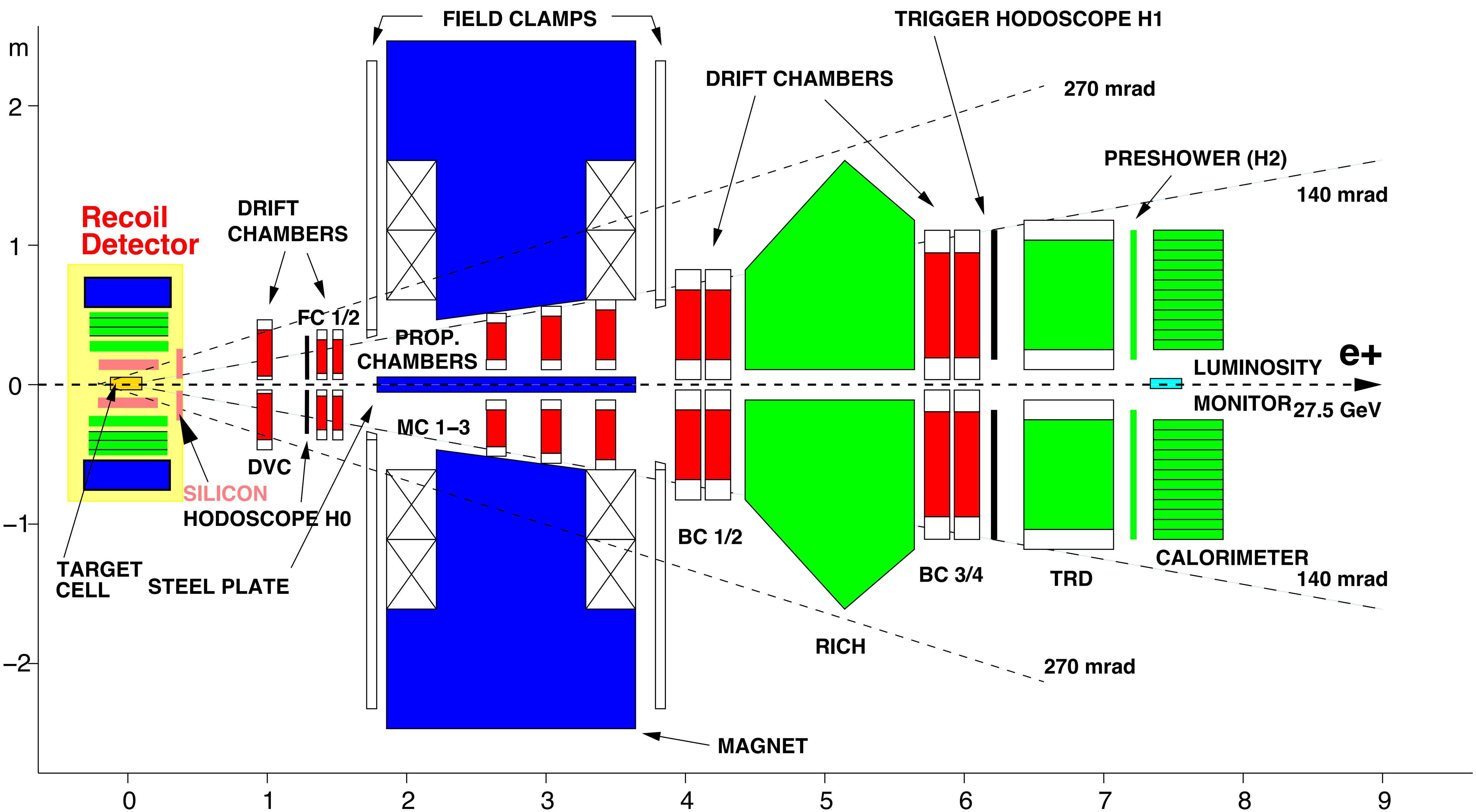
longitudinal polarized beam, unpolarized target

Fourier coefficients comprise Compton-Form factors (CFFs) which are convolutions of the GPDs on the hard scattering kernel.

## Example:

$$A_{\mathrm{LU}}(\phi) \sim \pm \frac{x_B}{y} \frac{s_1^{\mathcal{I}}}{c_0^{\mathrm{BH}}} \sin(\phi) \propto \Im\mathrm{m} \left\{ F_1 \mathcal{H} + \frac{x_B}{2 - x_B}(F_1 + F_2)\widetilde{\mathcal{H}} - \frac{\Delta^2}{4M^2} F_2 \mathcal{E} \right\} \sin(\phi)$$

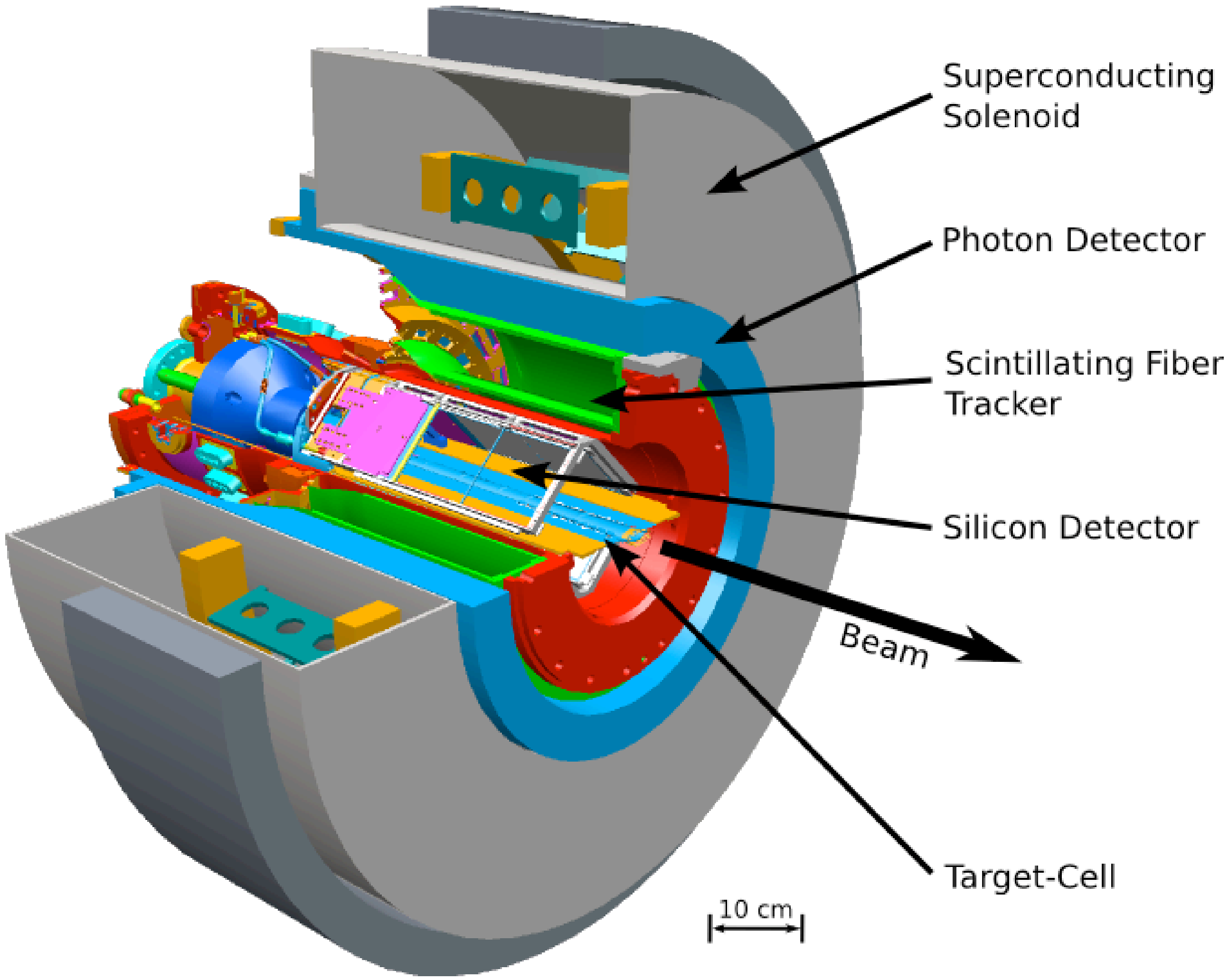
# The HERMES experiment



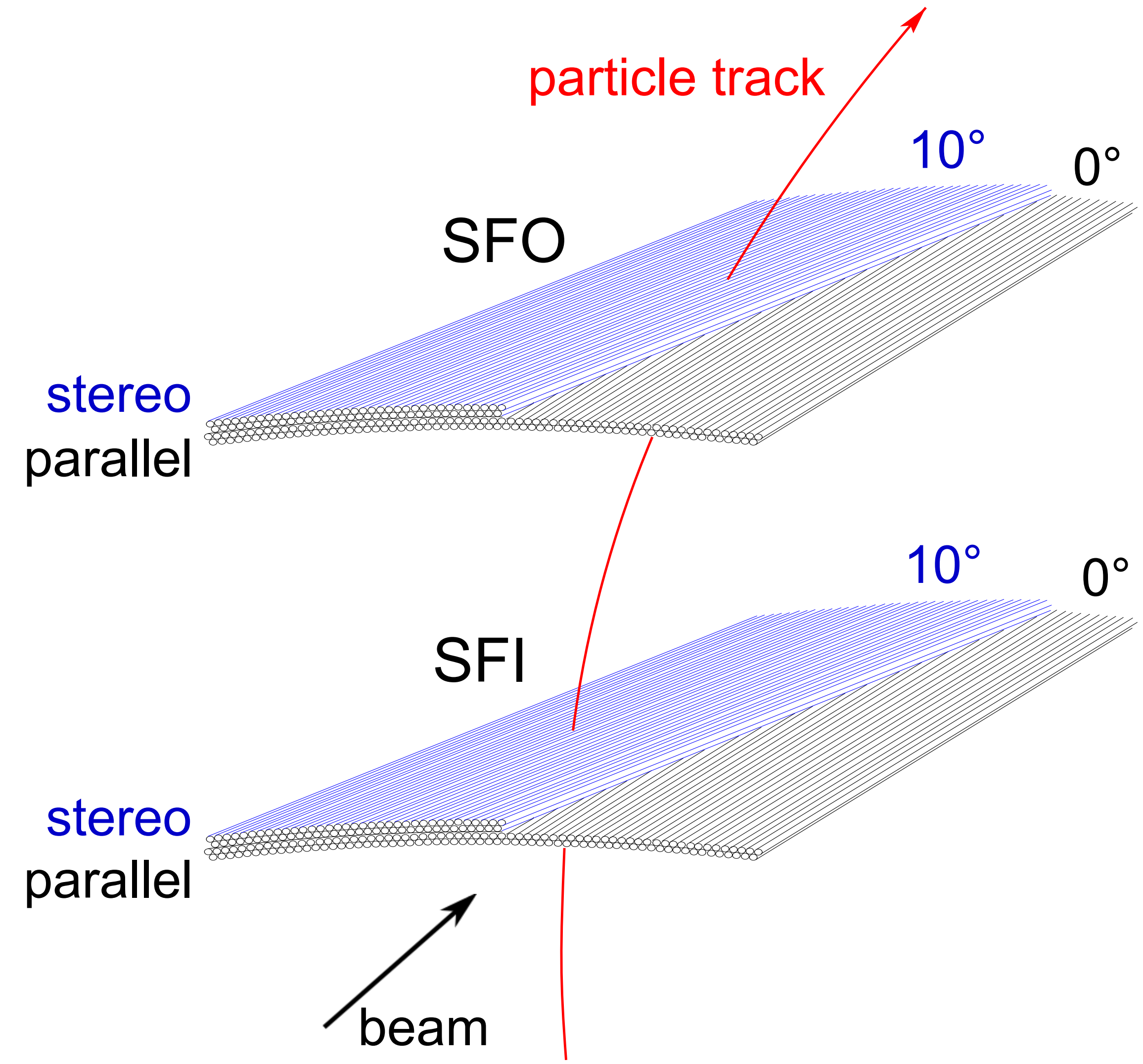

Schematic view of the HERMES experiment after being upgraded with the recoil detector during the years 2006 and 2007

# The HERMES recoil detector

## Side view of the recoil detector



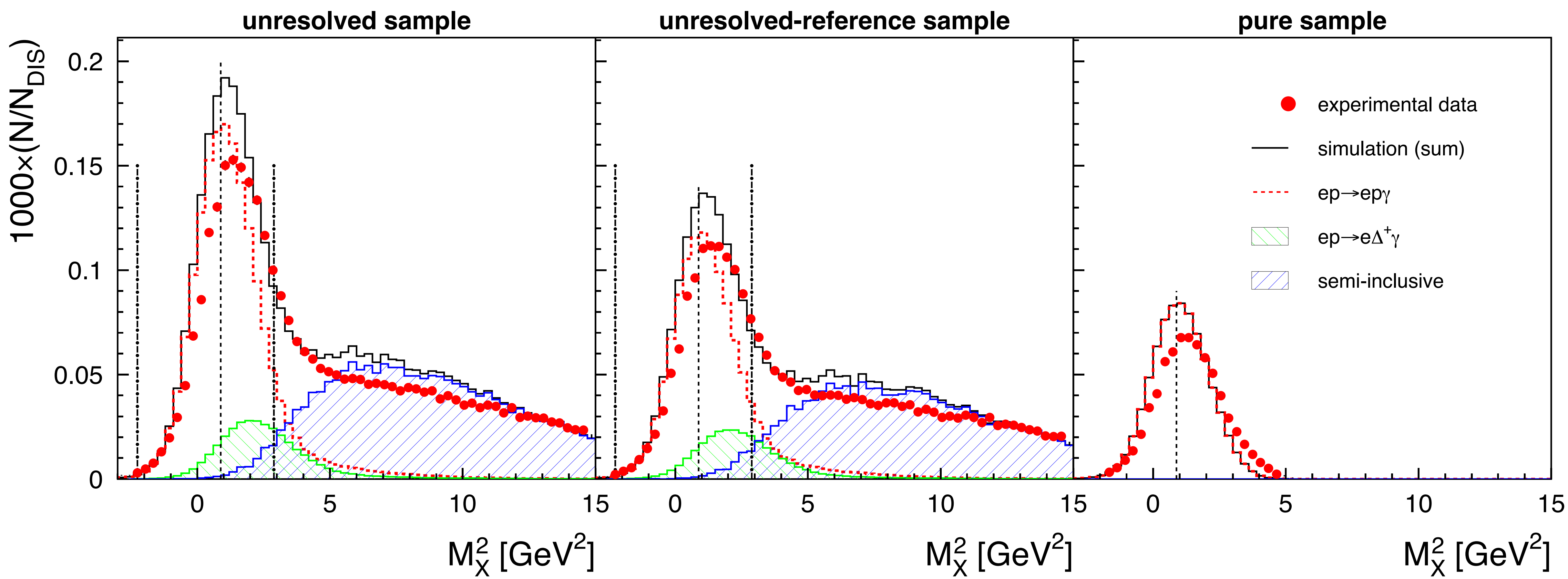

## Schematic design of the scintillating fibre tracker (SFT)




Enables the measurement of the recoiling particle and therefore full event reconstruction in case of $ep \rightarrow ep\gamma$

# Improvement through the recoil detector






Kinematic fitting allows a background free selection of events of the type $ep \rightarrow ep\gamma$

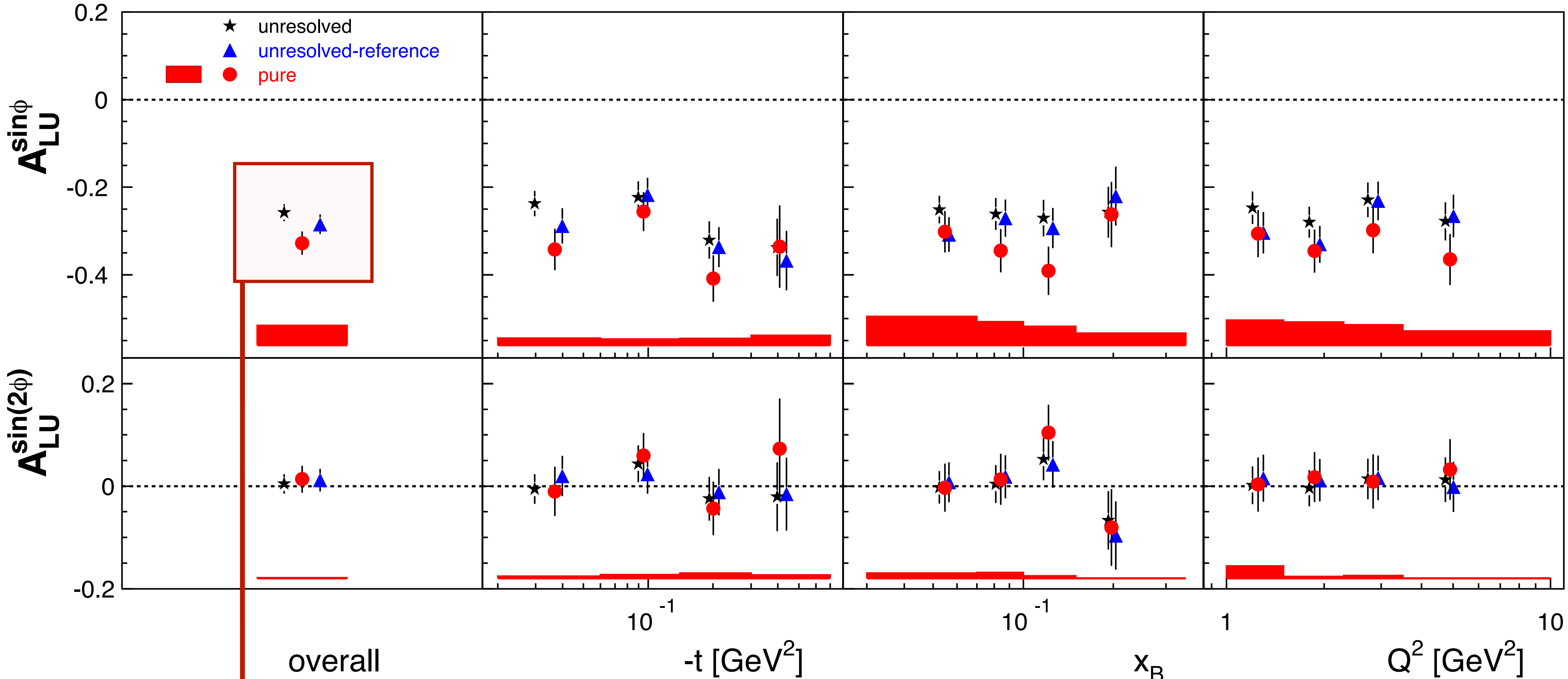
$$\chi^2_{pen} = \boxed{\sum_{i=1}^{9} \frac{(r_i^{fit} - r_i^{meas})^2}{\sigma_i^2}} + \boxed{T \cdot \sum_{j=1}^{4} \frac{\boxed{\left[f_j(r_1^{fit}, \ldots, r_9^{fit})\right]}^2}{(\sigma_j^f)^2}}$$

$\chi^2$-value of interest     penalty term     constraints

# Beam-spin asymmetries ep→eγp

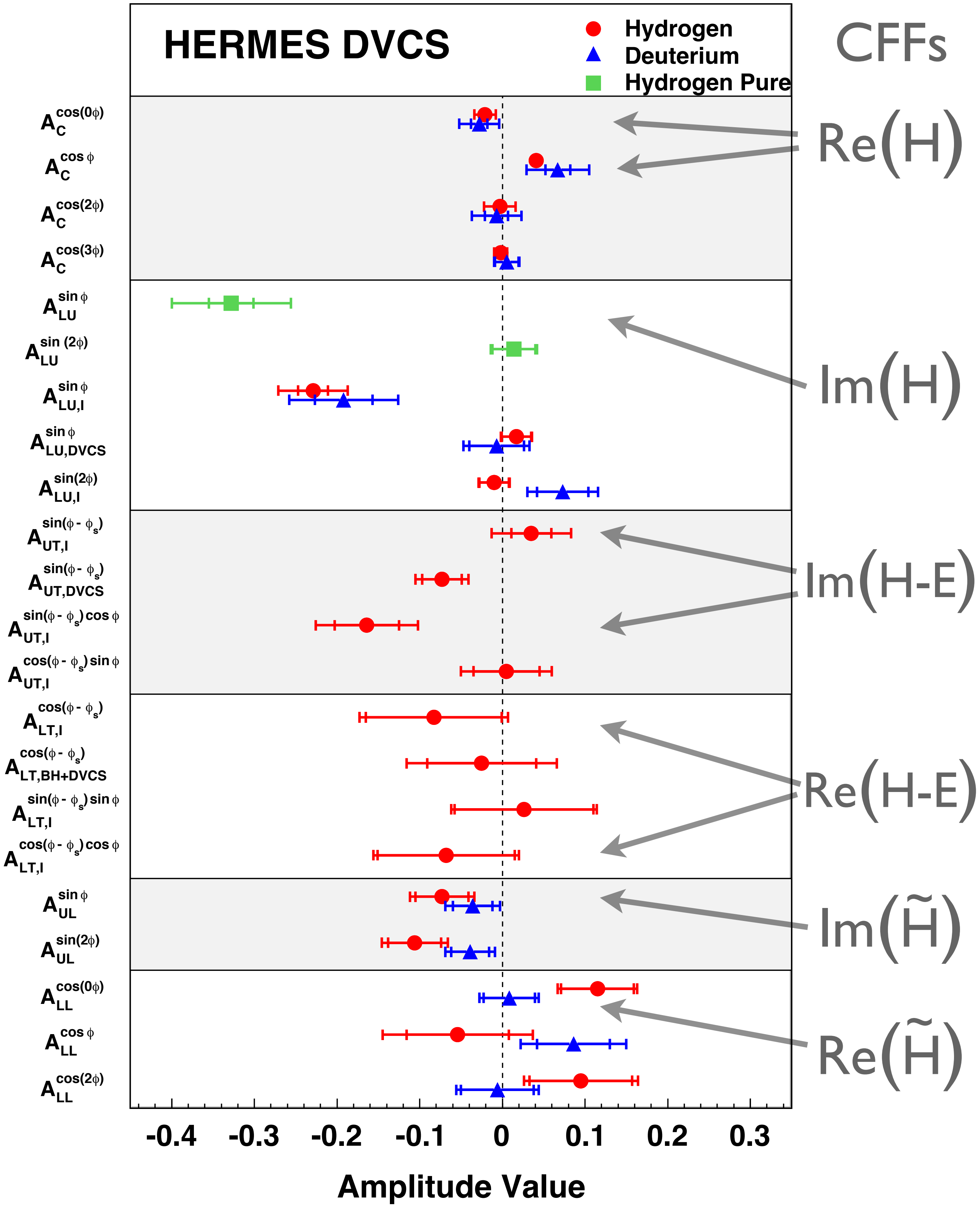


A. Airapetian et al, JHEP10 (2012) 042




Magnitude of the leading asymmetry has increased by 0.054 ± 0.016

All sets are strongly correlated but the unresolved samples contain an average contribution of 12 -14 % of associated processes




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

A. Airapetian et al, Nucl. Phys. B 829 (2010) 1-27

A. Airapetian et al, JHEP 06 (2010) 019

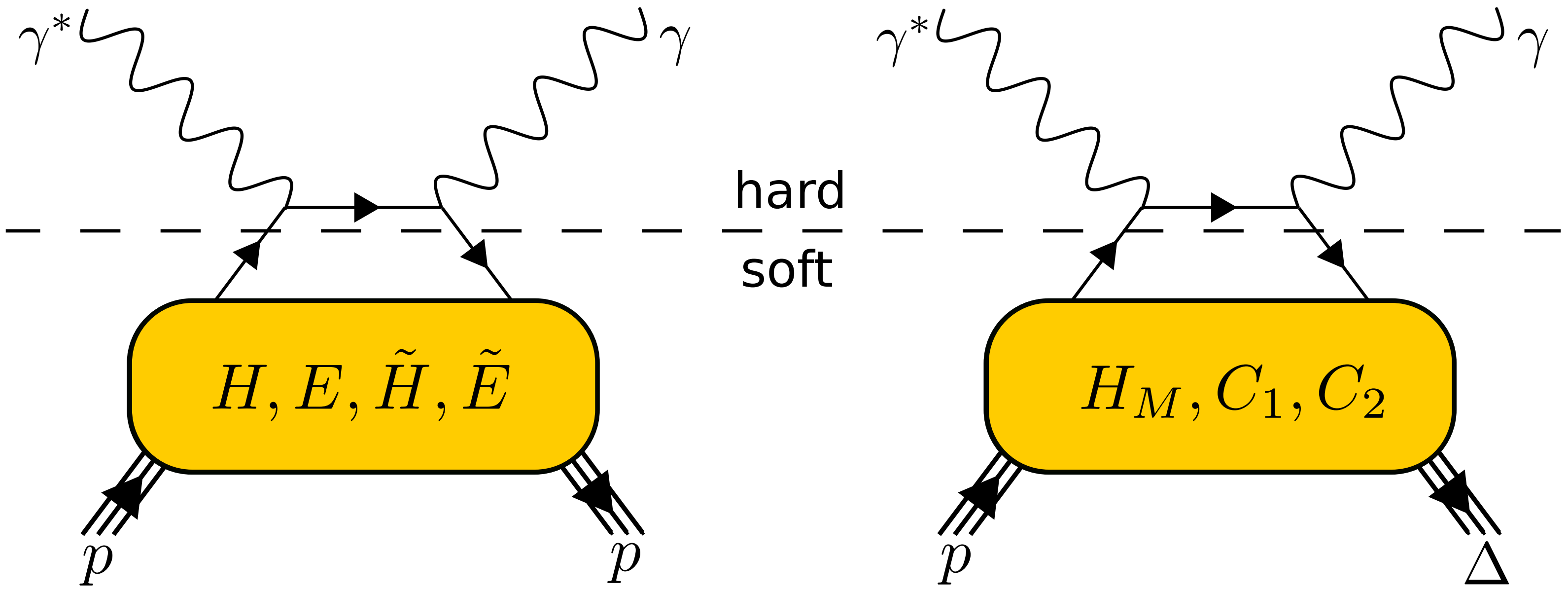
A. Airapetian et al, Nucl. Phys. B 842 (2011) 265-298

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

A. Airapetian et al, Phys. Lett. B 704 (2011) 15-23

A. Airapetian et al, JHEP 10 (2012) 042

Besides a better understanding of previous measurements it in principle also allows further access to GPDs.




In the large N$_c$-limit the remaining N→Δ GPDs can be related to the N→N isovector GPDs:

$$H_M(x,\xi,\Delta^2) = \frac{2}{\sqrt{3}}\left[E^u(x,\xi,\Delta^2) - E^d(x,\xi,\Delta^2)\right],$$

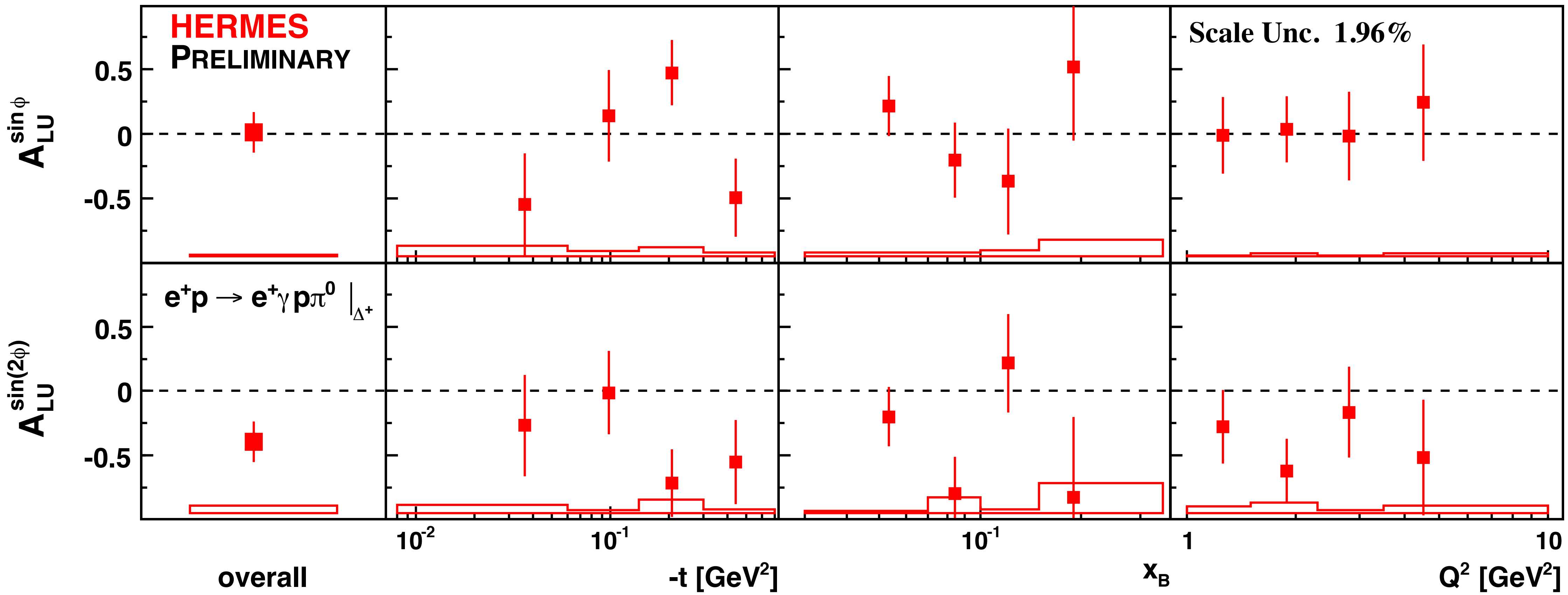
$$C_1(x,\xi,\Delta^2) = \sqrt{3}\left[\tilde{H}^u(x,\xi,\Delta^2) - \tilde{H}^d(x,\xi,\Delta^2)\right],$$

$$C_2(x,\xi,\Delta^2) = \frac{\sqrt{3}}{4}\left[\tilde{E}^u(x,\xi,\Delta^2) - \tilde{E}^d(x,\xi,\Delta^2)\right]$$

# Beam-spin asymmetries $ep \to e\gamma(\Delta^+ \to p\pi^0)$



Selection feasible due to measurement of the recoiling particle and kinematic fitting with an additional lower cut on the elastic hypothesis and considering particle identification



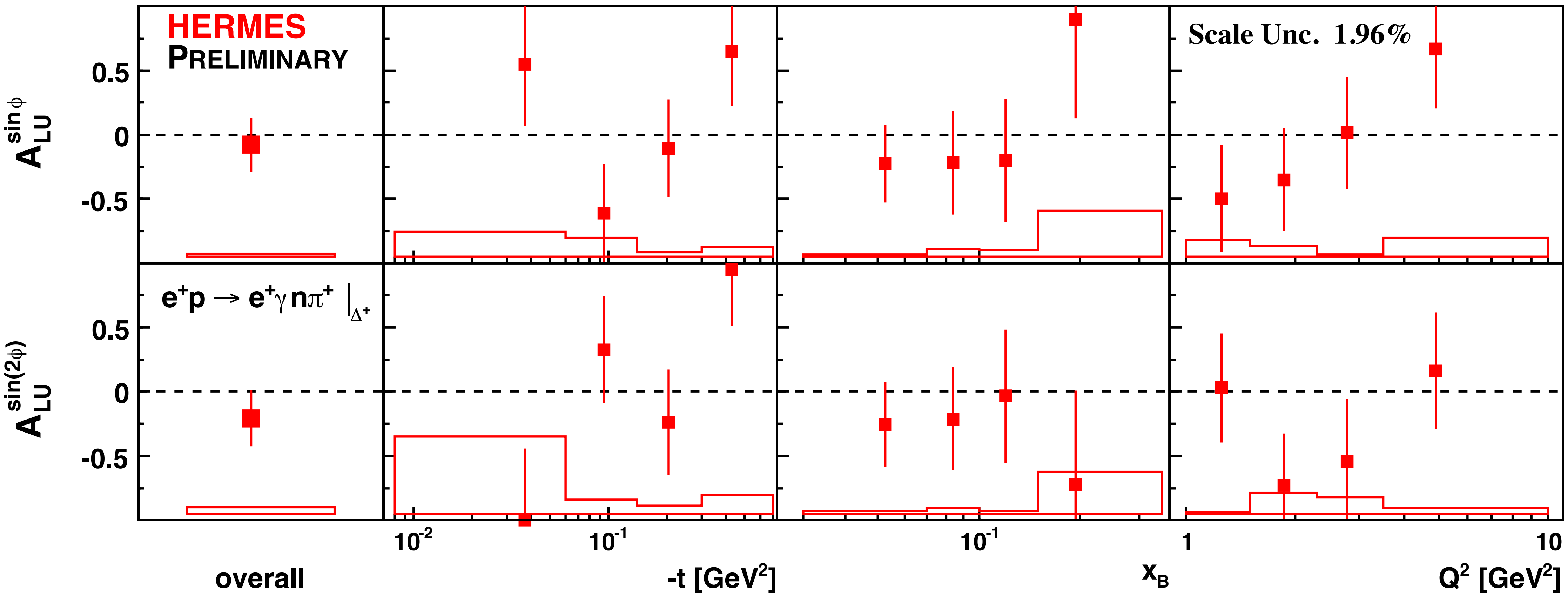

Shown amplitudes are corrected for background (only overall fractions are shown):

| | |
|---|---|
| Associated DVCS/BH ($ep \to e\gamma p\pi^0$) | 85.7 ± 1.8 |
| Elastic DVCS/BH ($ep \to e\gamma p$) | 1.1 ± 0.1 |
| SIDIS | 13.2 ± 1.9 |

# Beam-spin asymmetries $ep \rightarrow e\gamma(\Delta^+ \rightarrow n\pi^+)$



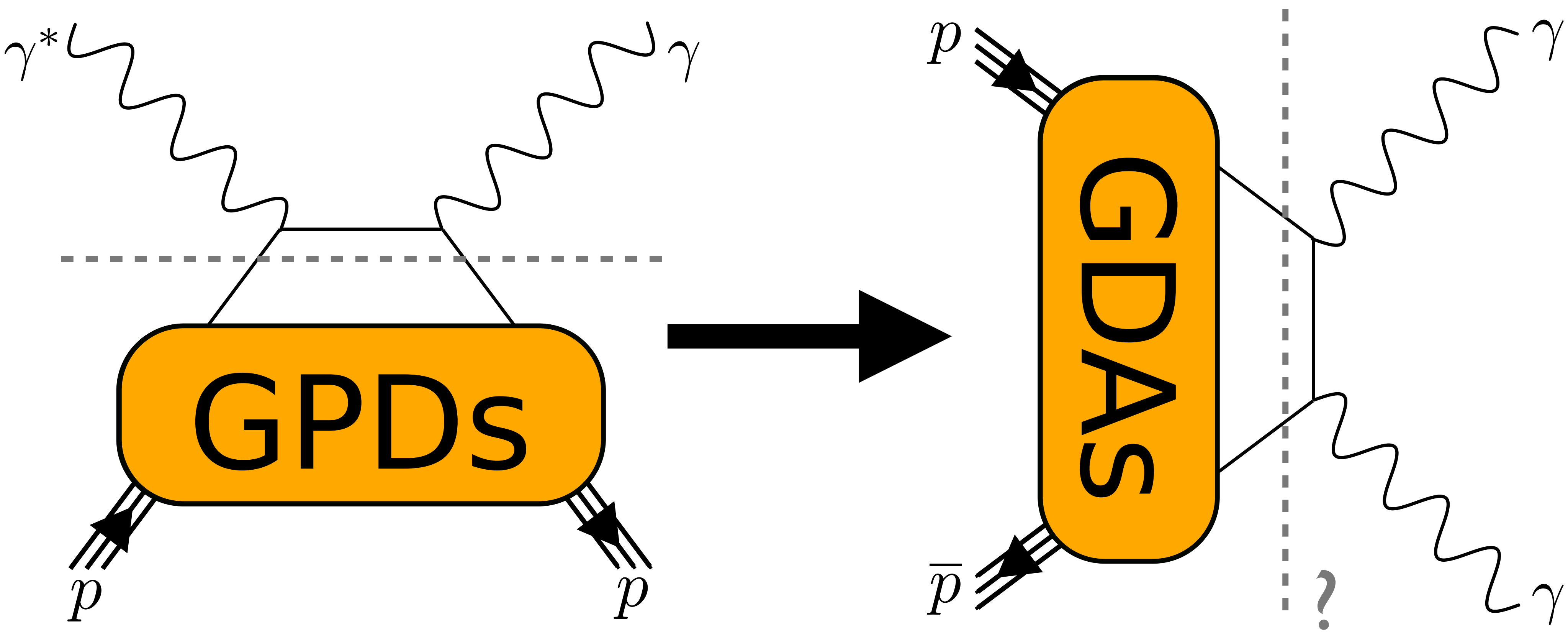
Selection feasible due to measurement of the recoiling particle and kinematic fitting with an additional lower cut on the elastic hypothesis and considering particle identification




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

| | |
|---|---|
| Associated DVCS/BH ($ep \rightarrow e\gamma n\pi^+$) | 75.6 ± 2.6 |
| Elastic DVCS/BH ($ep \rightarrow e\gamma p$) | 0.1 ± 0.1 |
| SIDIS | 24.4 ± 3.4 |

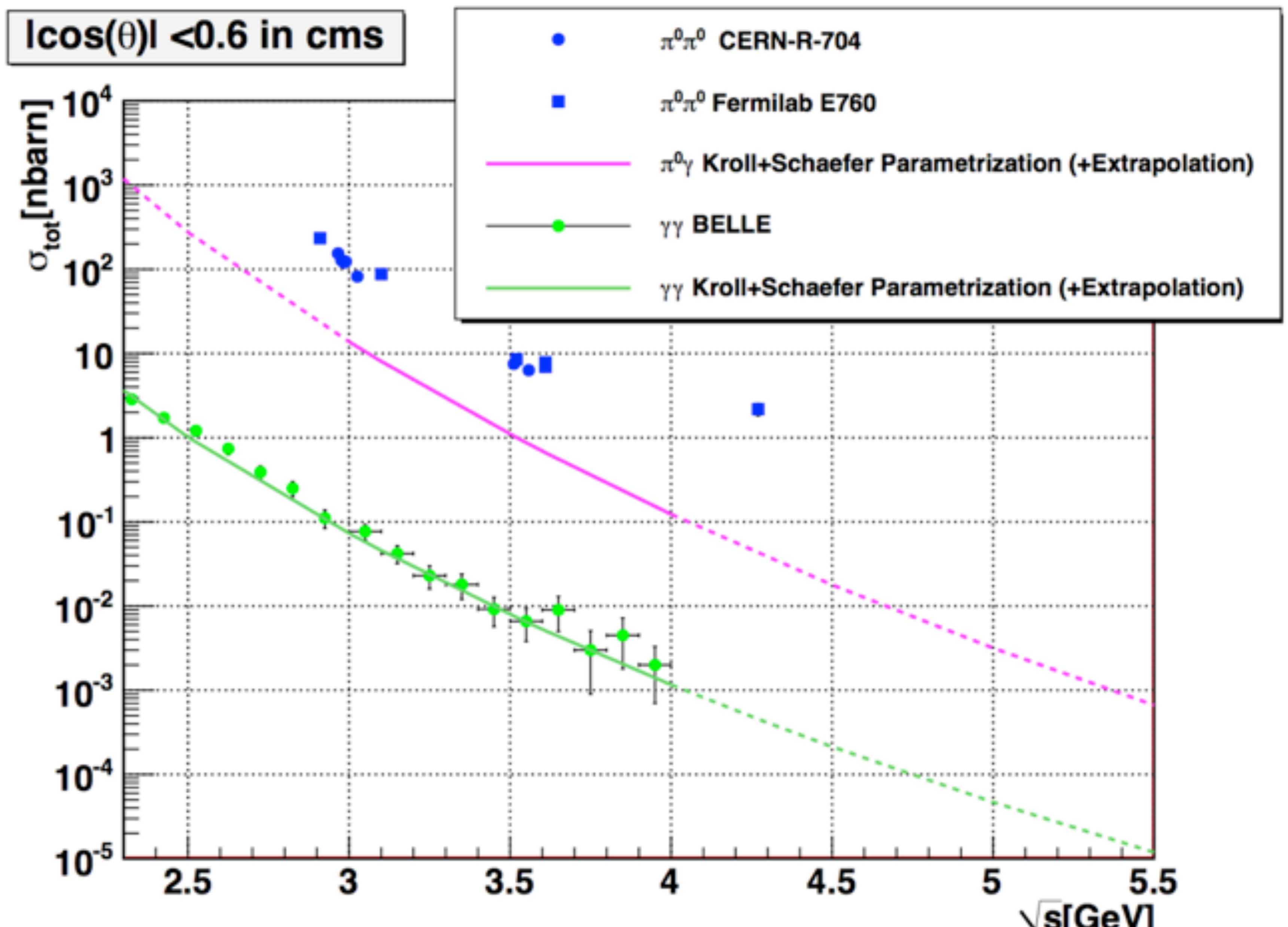
From HERMES to PANDA:




Latest progress is already 4 years old

„Separation einiger seltener elektromagnetischer Prozesse für PANDA“ Diploma-Thesis by I.Brodski (2009)

Clean γγ-Signal, but background arises from processes with more than 2 γs in the final state of which only 2 are detected



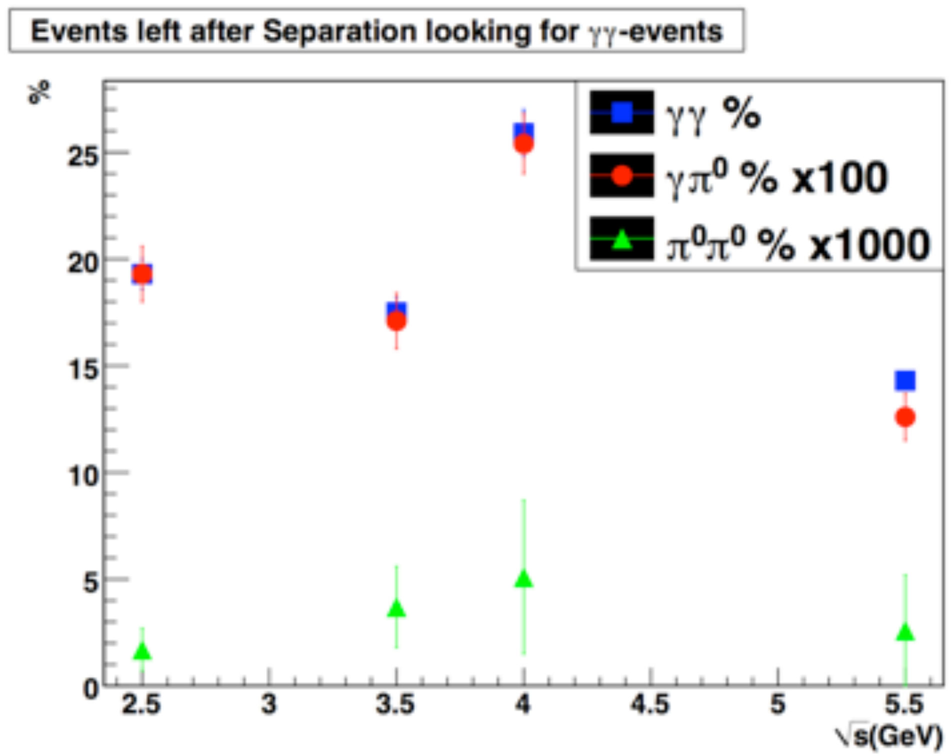

Similar for the detection of the $\gamma\pi^0$-channel

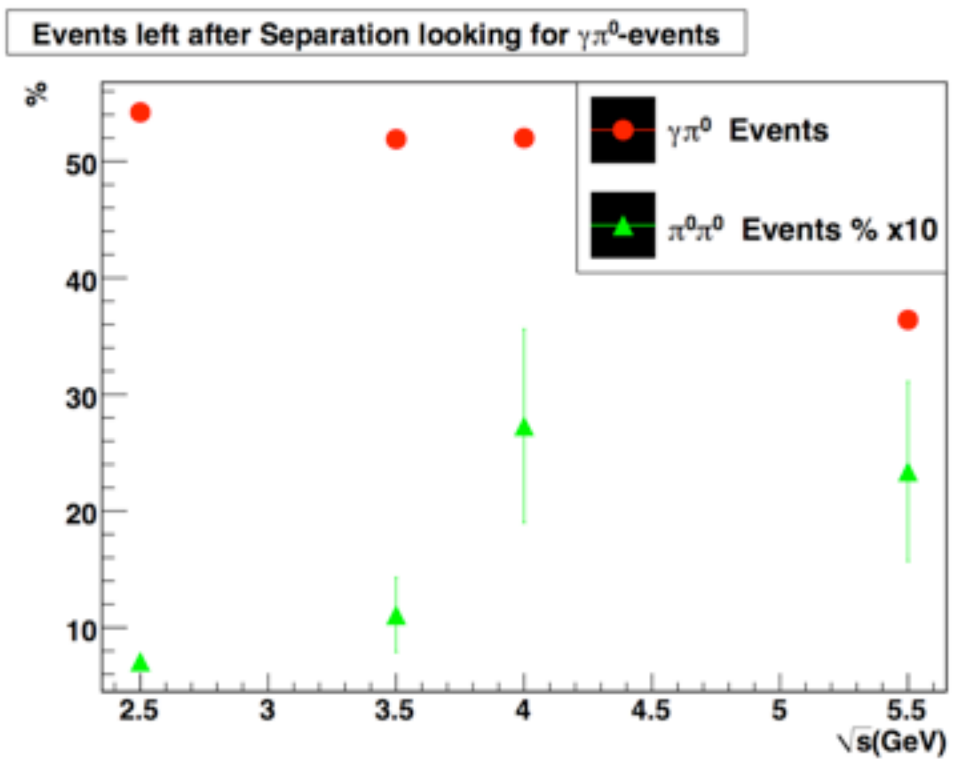
## Possible ways of separating $p\bar{p} \rightarrow \gamma\gamma$ and $p\bar{p} \rightarrow \gamma\pi^0$

- total energy of the event
- bumps in the ECAL have the same energy
- angular deviation

→ signal-to-background-ratio only 0.8 (@√s=5 GeV) for $\gamma\gamma$

→ signal-to-background-ratio about 20 (@√s=5 GeV) for $\gamma\pi^0$



## Summary and outlook

- simulations suggest that these interesting exclusive reactions can be successfully measured at PANDA (but caveat in case of $\gamma\gamma$)
- measurements of GDA would be helpful for theoreticians (link to GPDs, factorization theorem)
- extend search for events with pseudoscalar and vector mesons?
- old results should be reviewed and repeated using up to date software and prerequisites