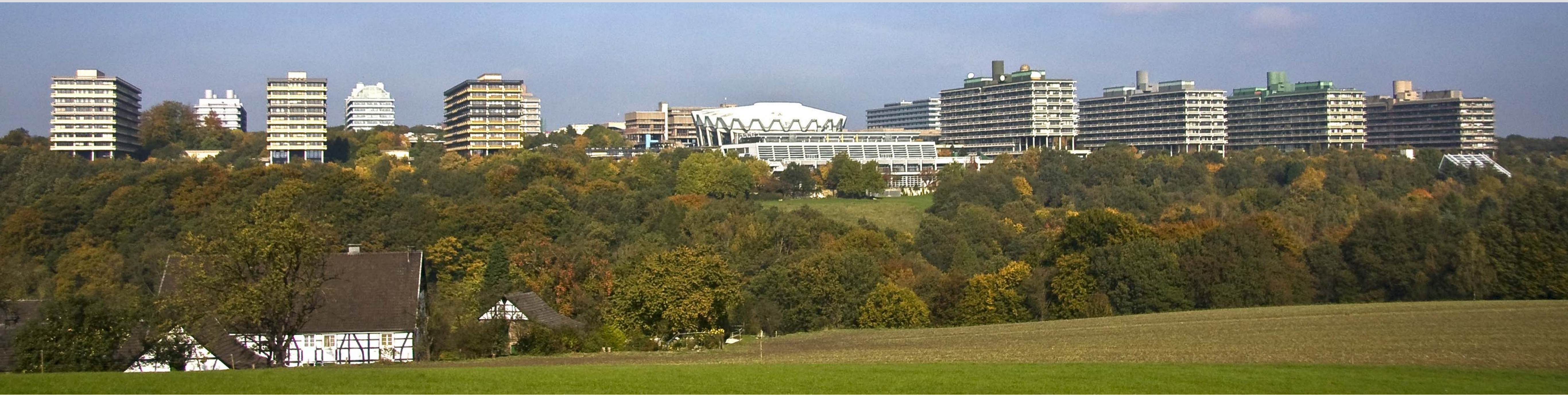
International Workshop on

Deeply Virtual Compton Scattering: From Observables to GPDs

Ruhr-Universität Bochum, February 10-12, 2014



DVCS measurements with the hermes recoil detector

Gunar.Schnell @ desy.de

ikerbasque
Basque Foundation for Science

eman ta zabal zazu
Universidad del País Vasco
Euskal Herriko Unibertsitatea

Generalized parton distributions

- I am not supposed to explain those ...

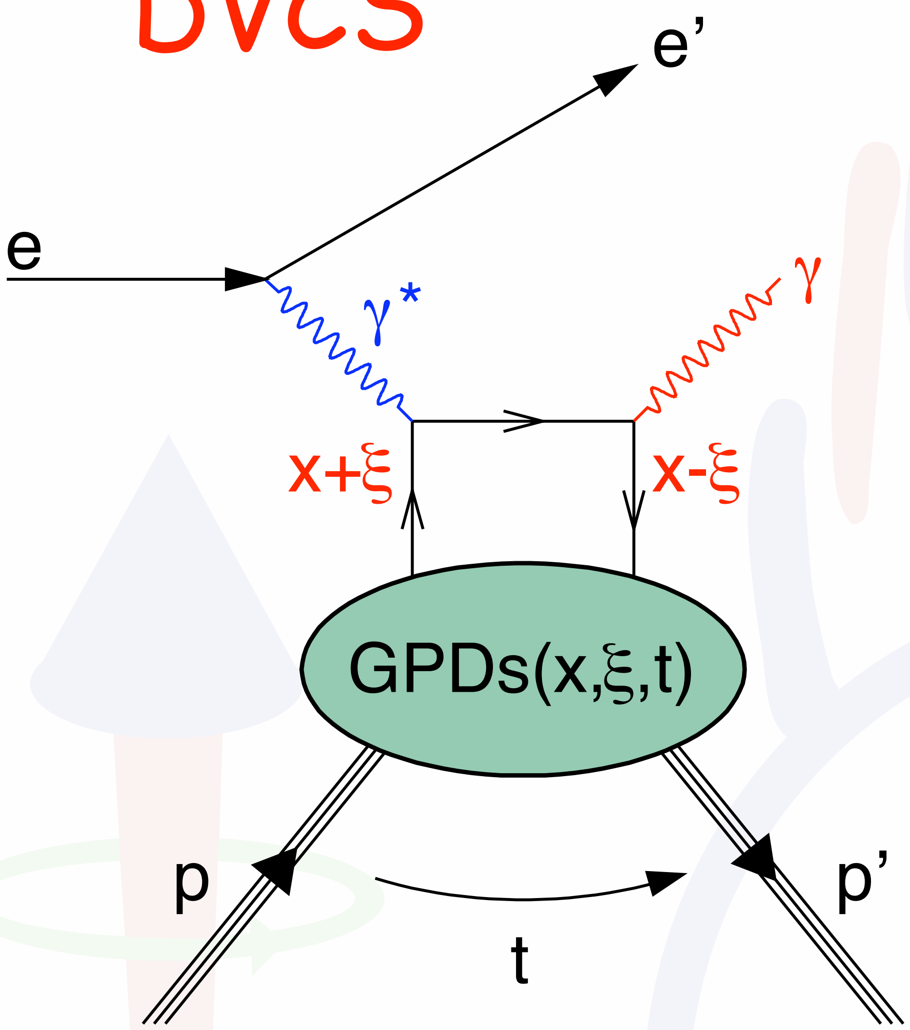
Generalized parton distributions

- I am not supposed to explain those ...

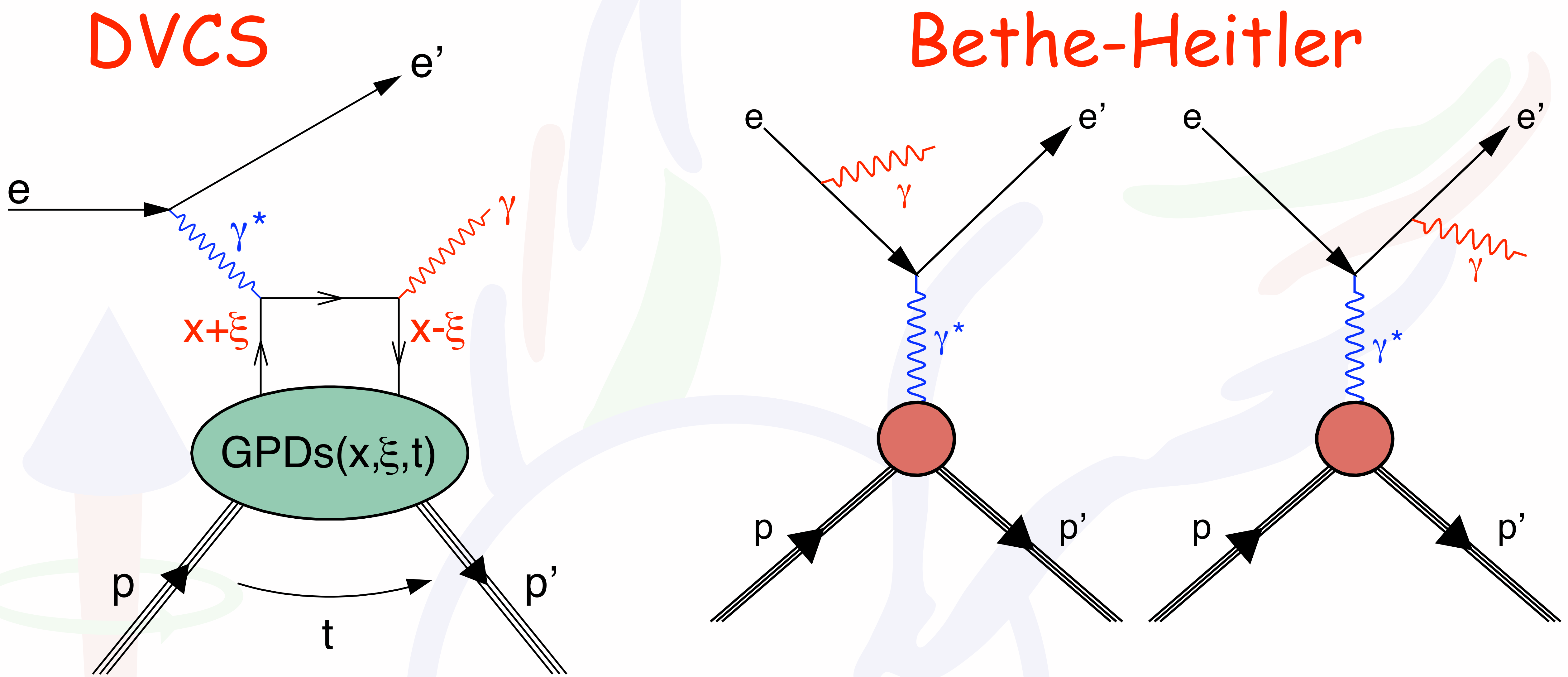
- ... thanks to E. Etzelmüller for a number of (backup) slides

Real-photon production

DVCS



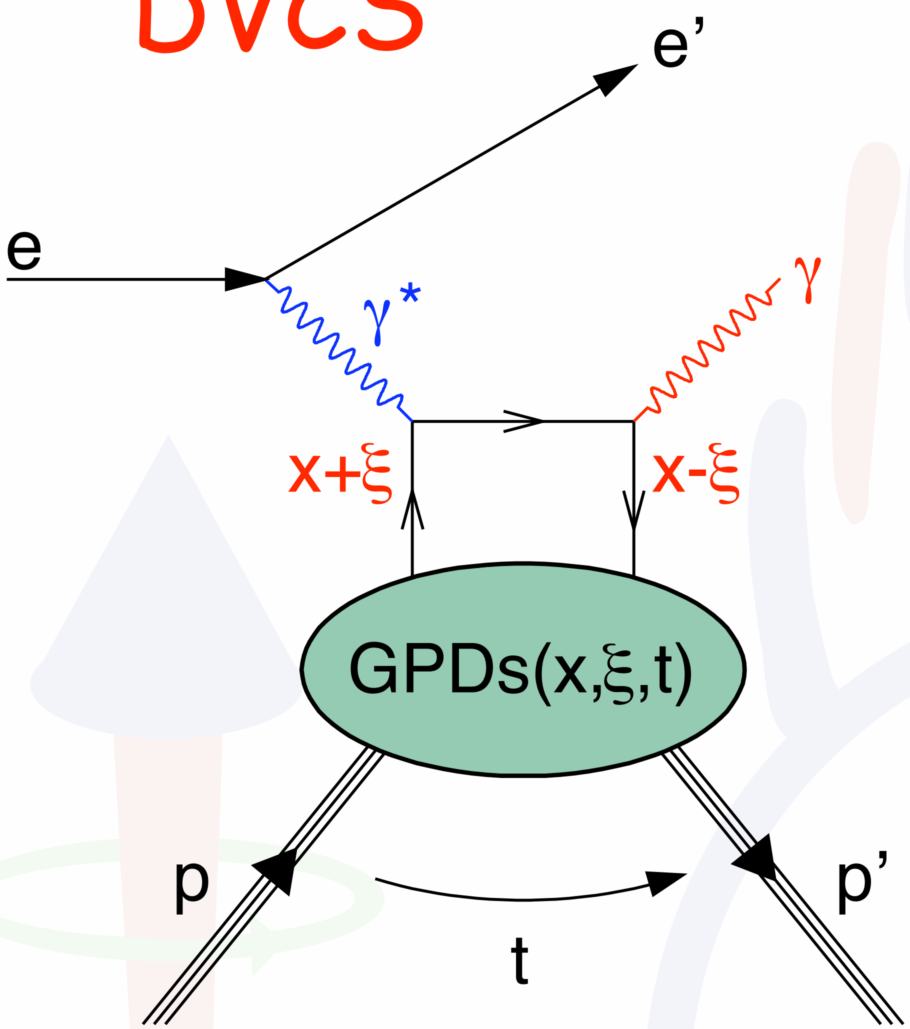
Real-photon production



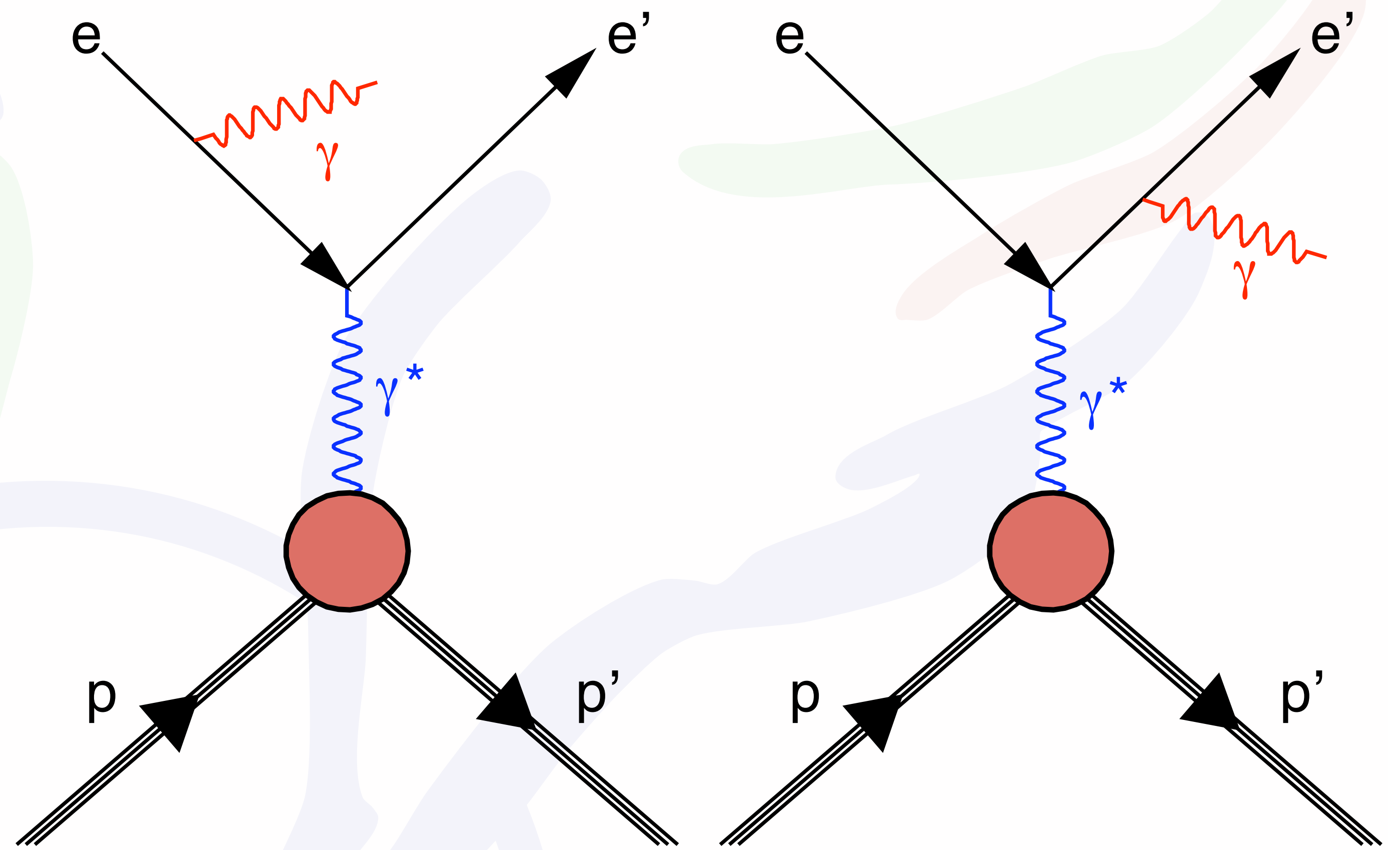
$$\frac{d^4\sigma}{dQ^2\,dx_B\,dt\,d\phi} = \frac{y^2}{32(2\pi))^4\sqrt{1+\frac{4M^2x_B^2}{Q^2}}}\left(|\mathcal{T}_{\mathrm{DVCS}}|^2 + |\mathcal{T}_{\mathrm{BH}}|^2 + \mathcal{I}\right)$$

Real-photon production

DVCS



Bethe-Heitler



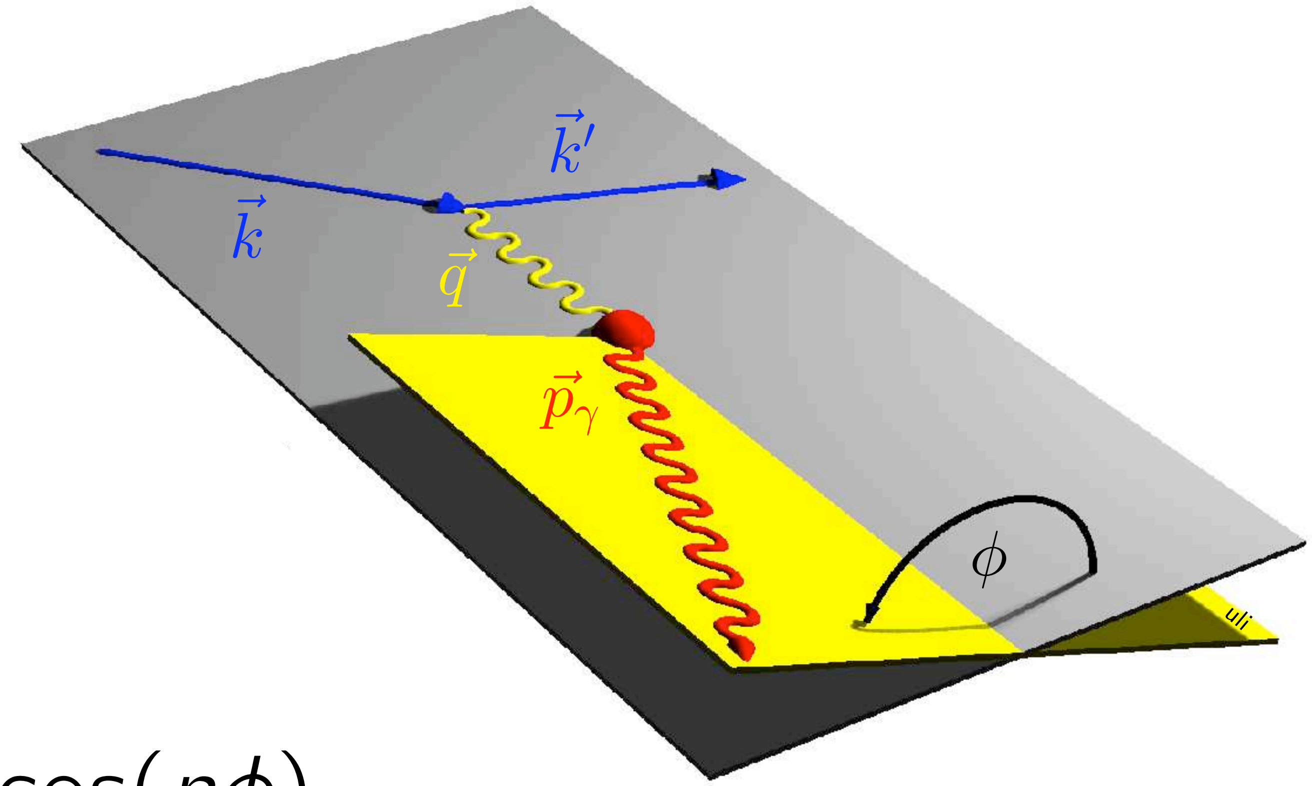
Amplitude of Bethe-Heitler scattering is dominant at HERMES kinematics

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

DVCS amplitude is amplified by BH in the interference term

Azimuthal dependences in DVCS/BH

- beam polarization P_B
- beam charge C_B
- here: unpolarized target



Fourier expansion for ϕ:

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

calculable in QED (using FF measurements)

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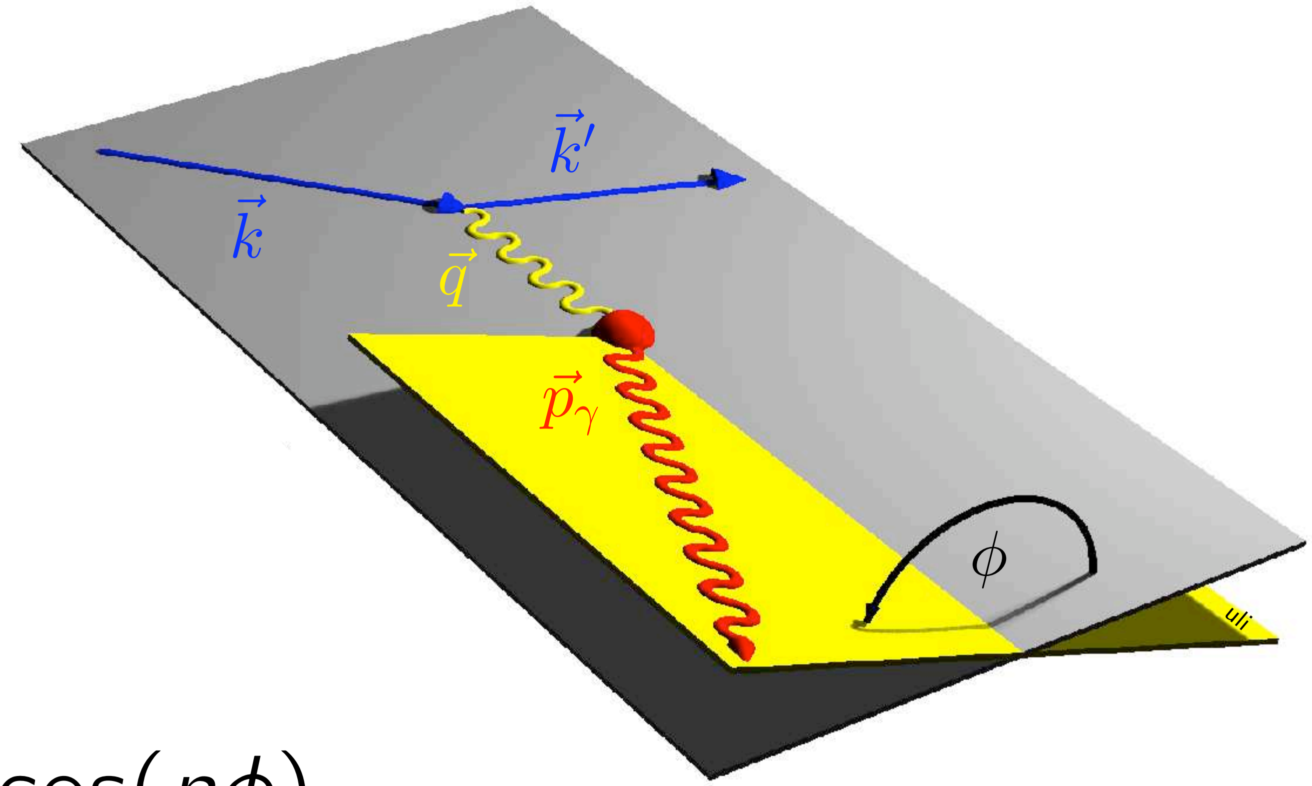

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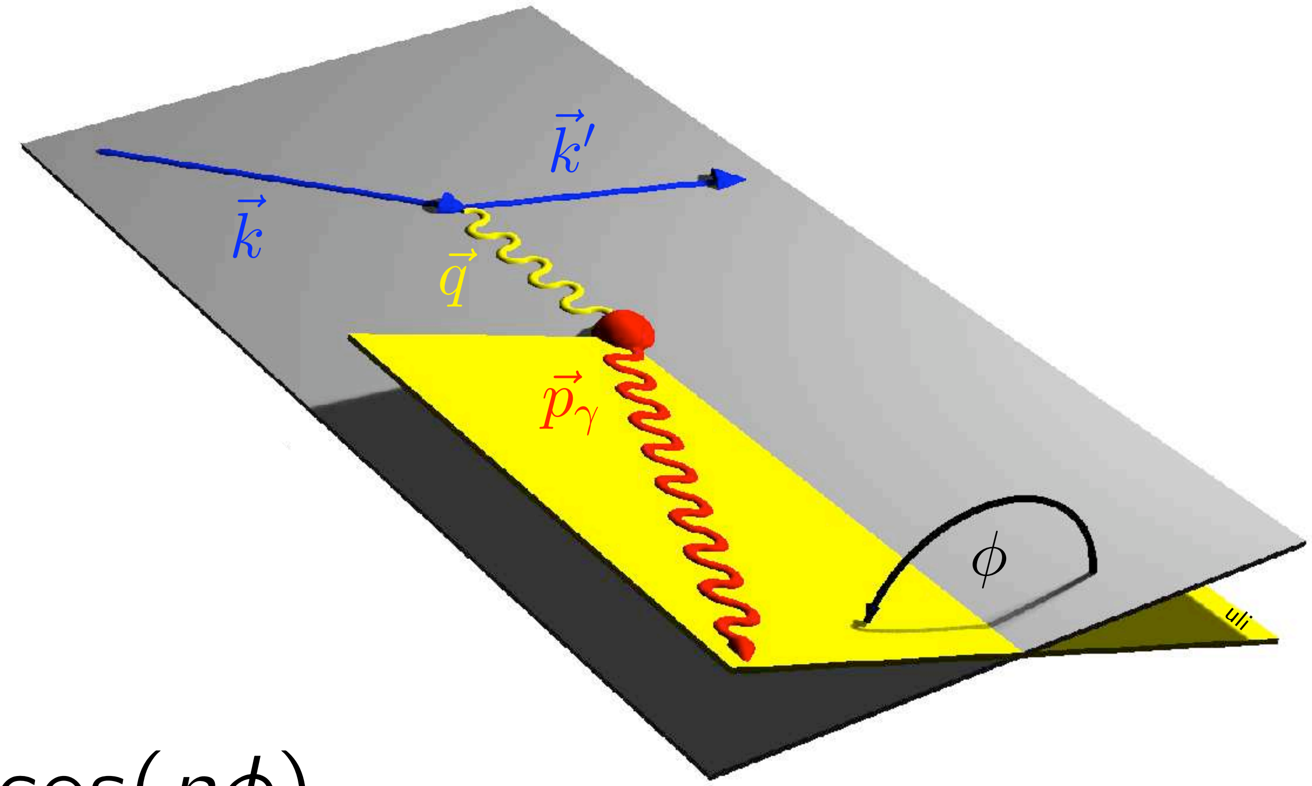

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$$\mathcal{I} = \frac{C_B K_{\mathcal{I}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left[\sum_{n=0}^{3} c_n^{\mathcal{I}} \cos(n\phi) + P_B \sum_{n=1}^{2} s_n^{\mathcal{I}} \sin(n\phi) \right]$$

Azimuthal dependences in DVCS/BH

- beam polarization P_B
- beam charge C_B
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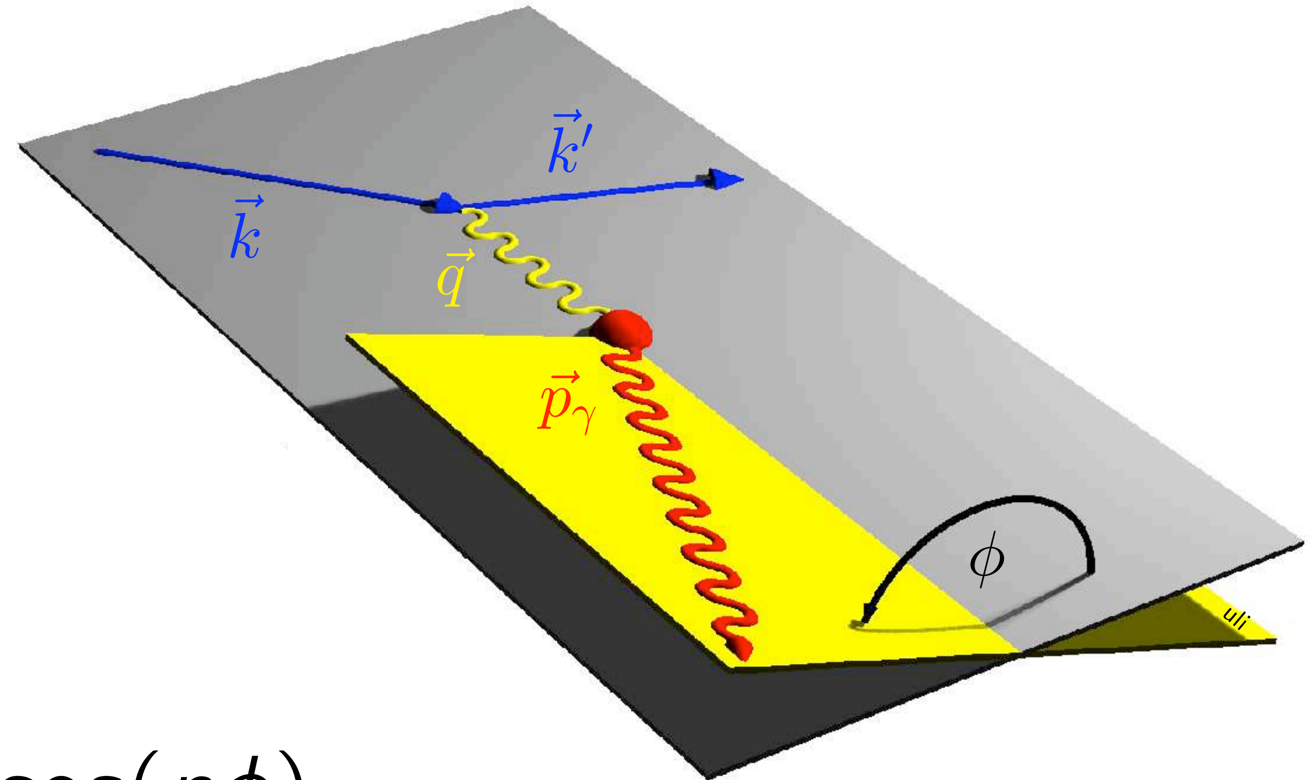

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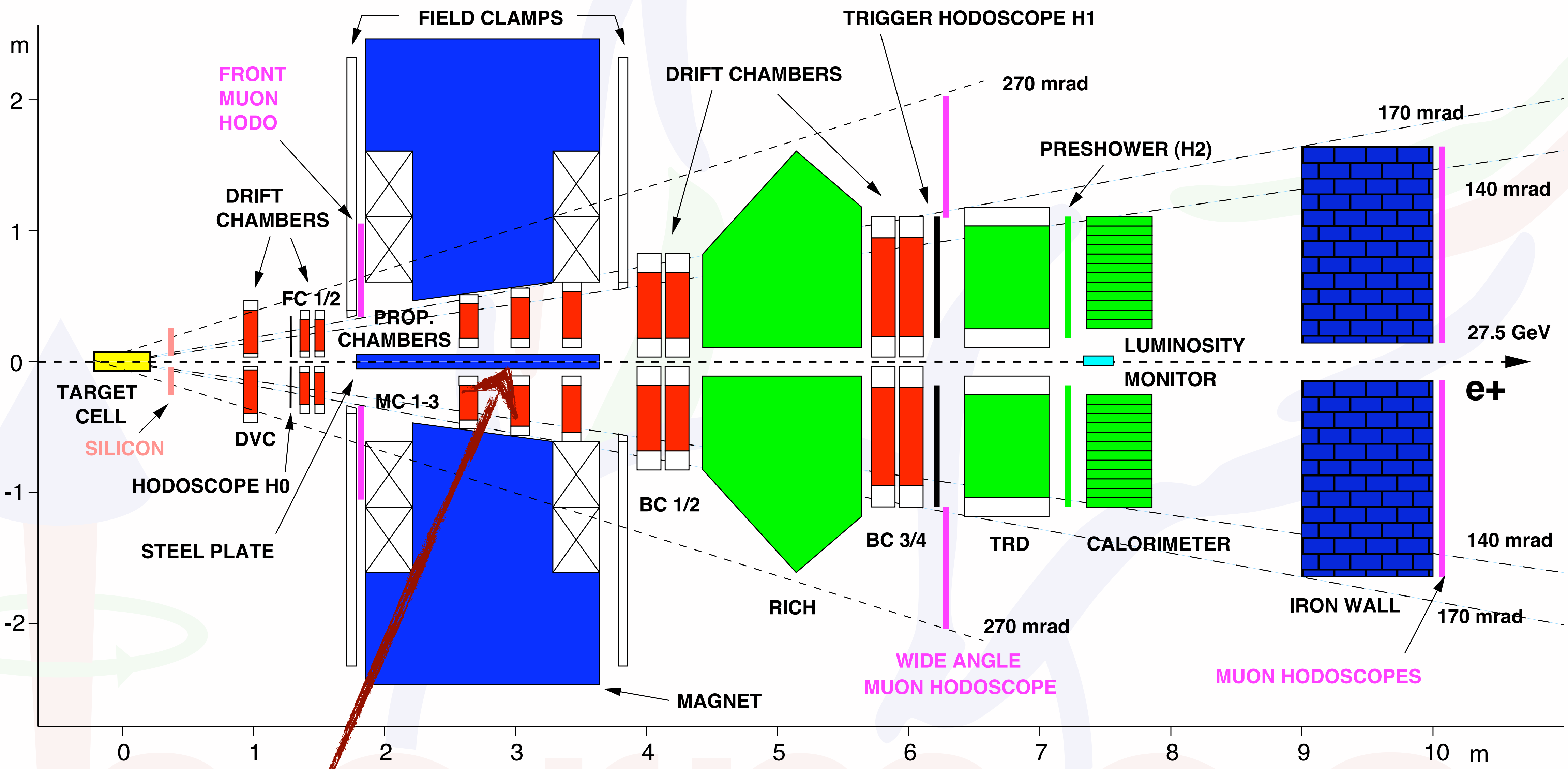
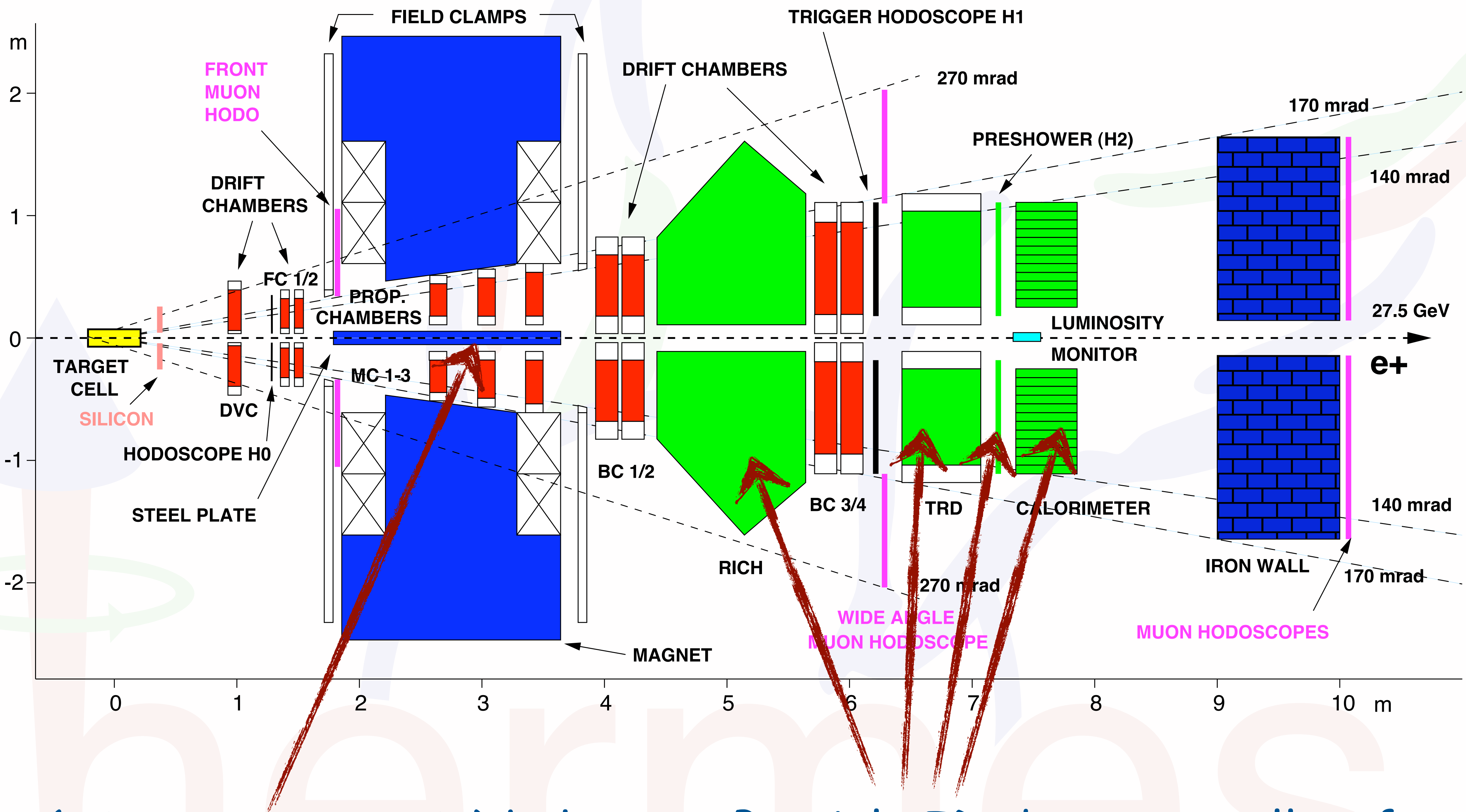
bilinear ("DVCS") or linear ("I") in GPDs

HERMES (1998-2005) schematically



two (mirror-symmetric) halves
-> no homogenous azimuthal coverage

HERMES (1998-2005) schematically



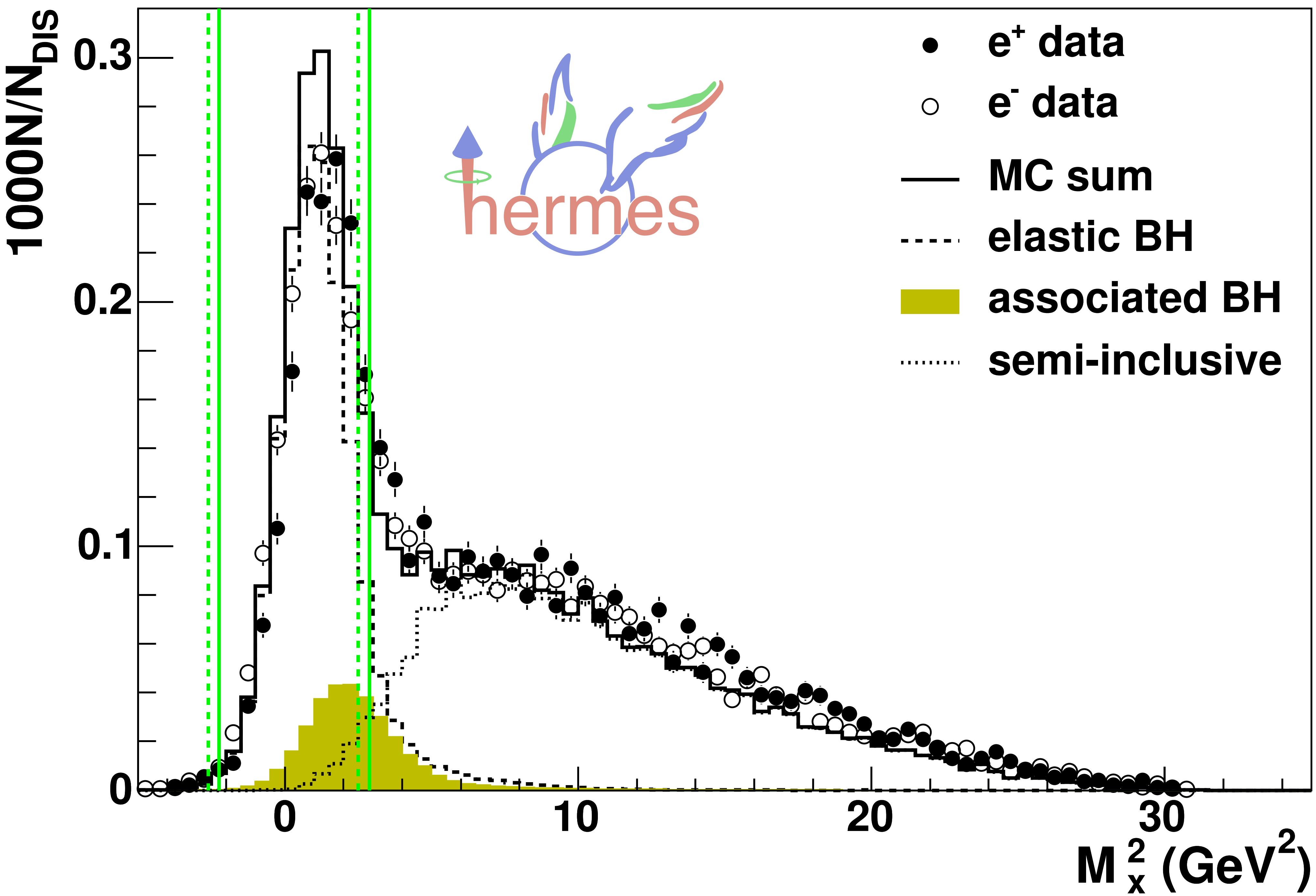
two (mirror-symmetric) halves -> no homogenous azimuthal coverage

Particle ID detectors allow for
- lepton/hadron separation
- RICH: pion/kaon/proton discrimination 2GeV<p<15GeV

Exclusivity: missing-mass technique

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

ep -> e γ X



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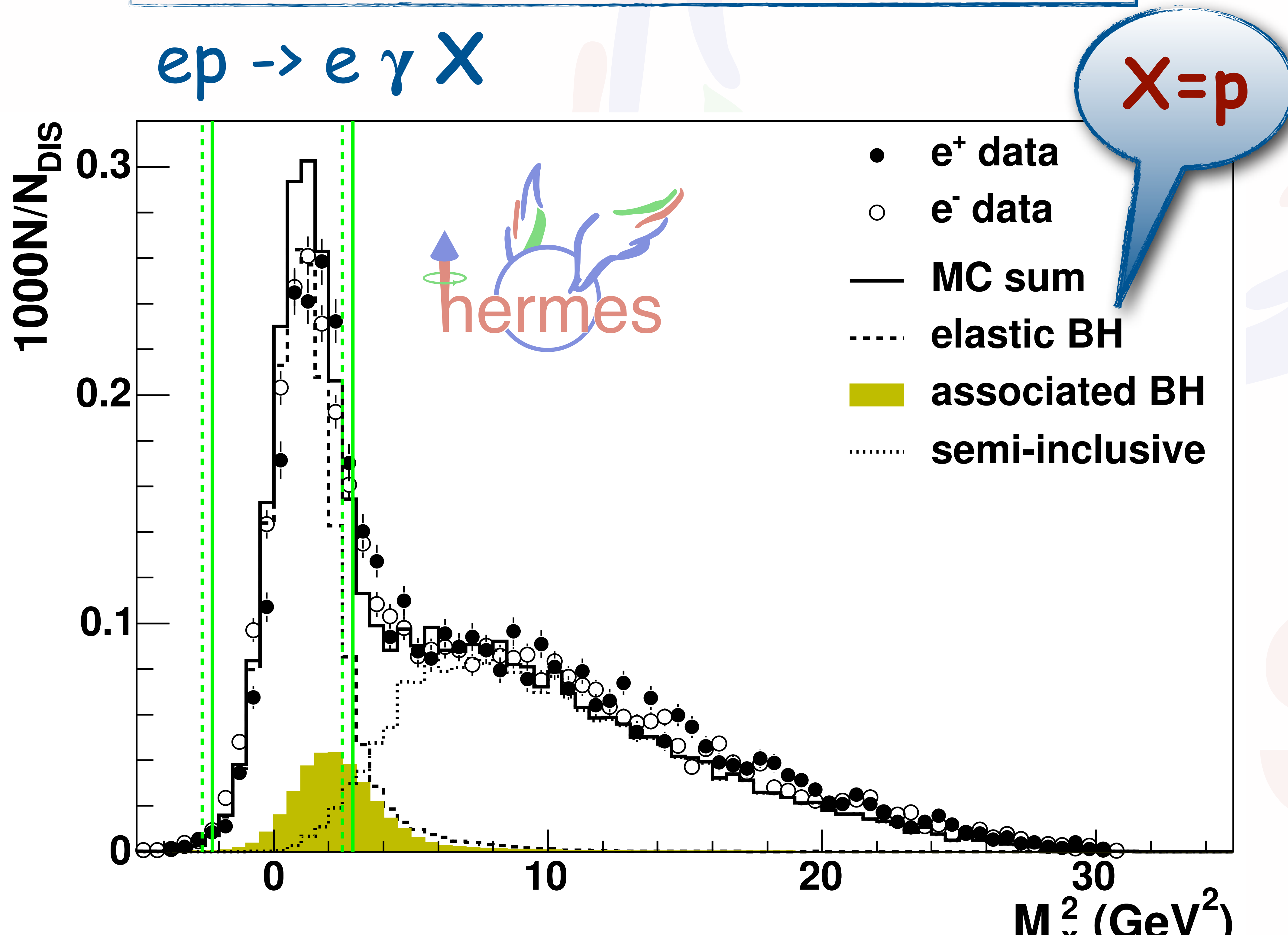

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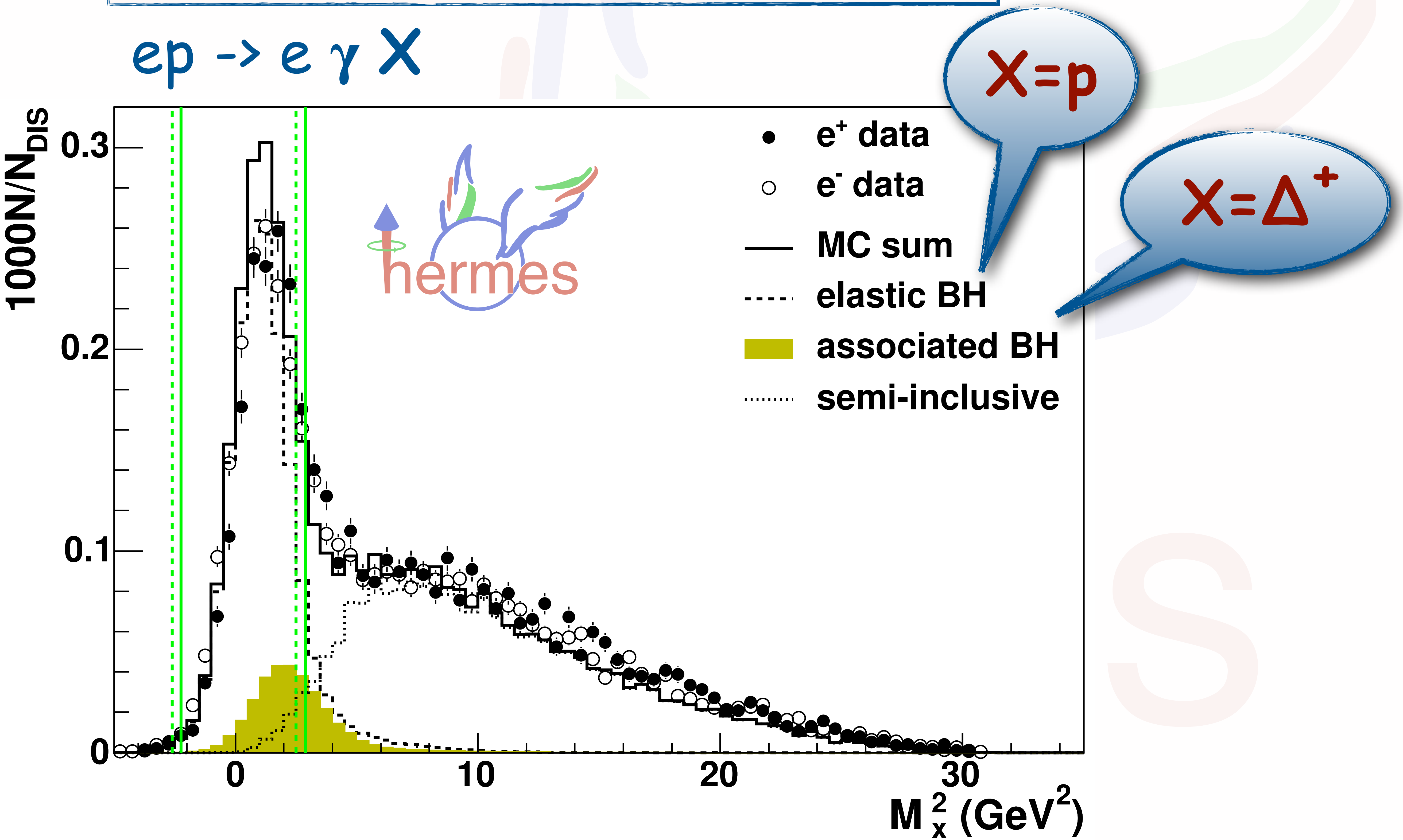

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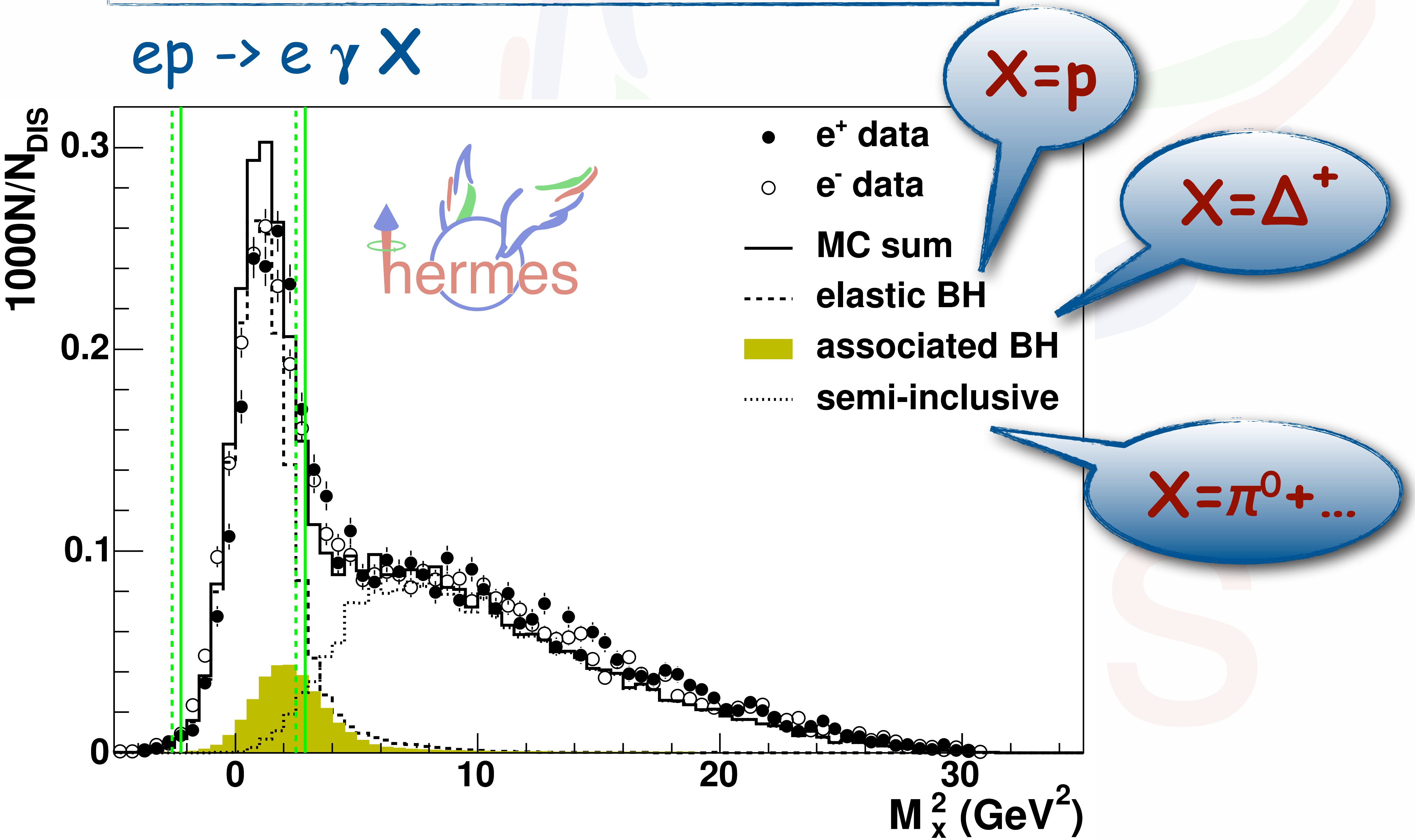
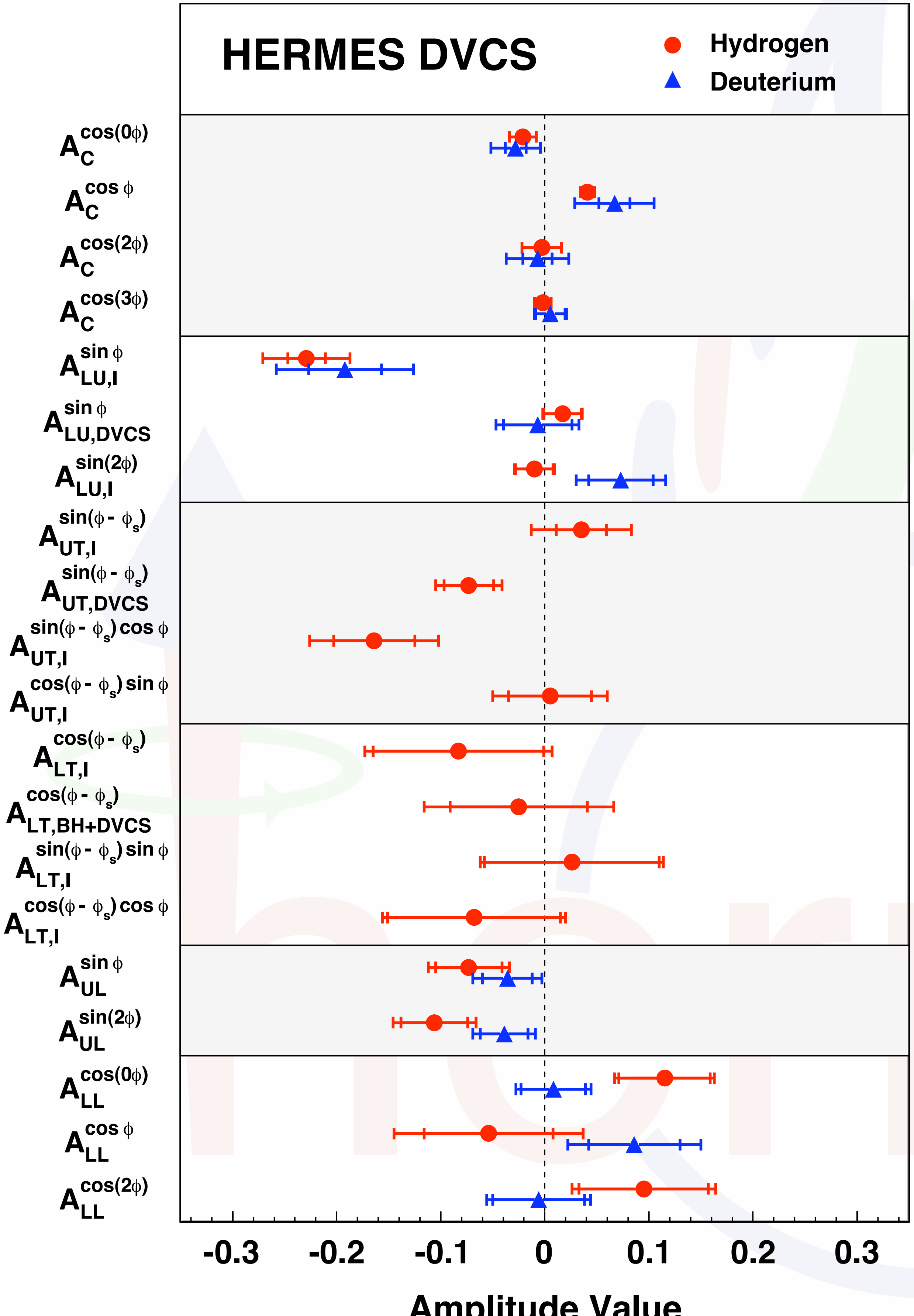


A wealth of azimuthal amplitudes



Beam-charge asymmetry:

GPD H

PRD 75 (2007) 011103
NPB 829 (2010) 1
JHEP 11 (2009) 083
PRC 81 (2010) 035202
PRL 87 (2001) 182001
JHEP 07 (2012) 032

Beam-helicity asymmetry:

GPD H

Transverse target spin asymmetries:

GPD E from proton target

JHEP 06 (2008) 066
PLB 704 (2011) 15

Longitudinal target spin asymmetry:

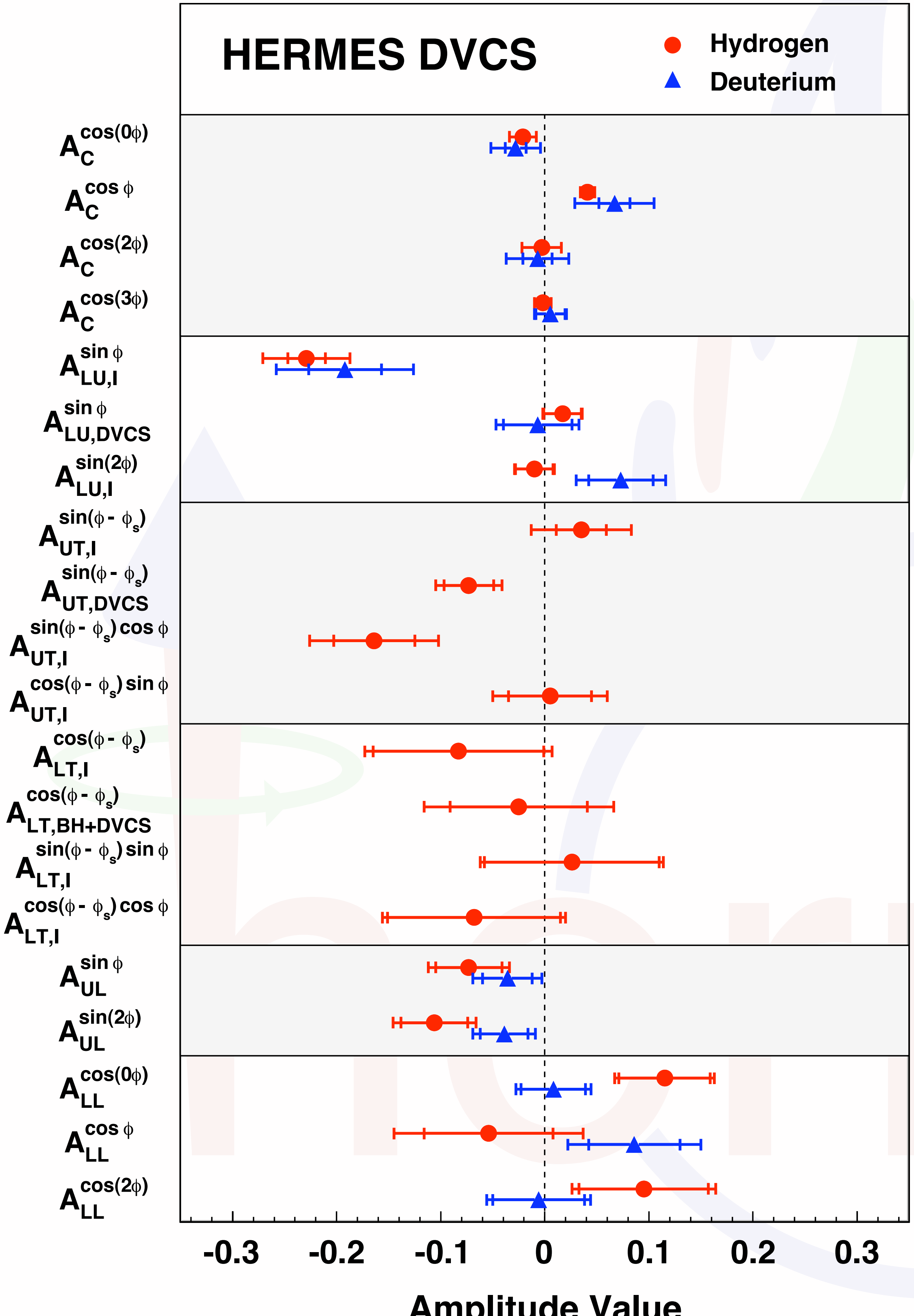
GPD $\tilde{H}$

JHEP 06 (2010) 019
NPB 842 (2011) 265

Double-spin asymmetry:

GPD $\tilde{H}$

A wealth of azimuthal amplitudes



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Double-spin asymmetry:

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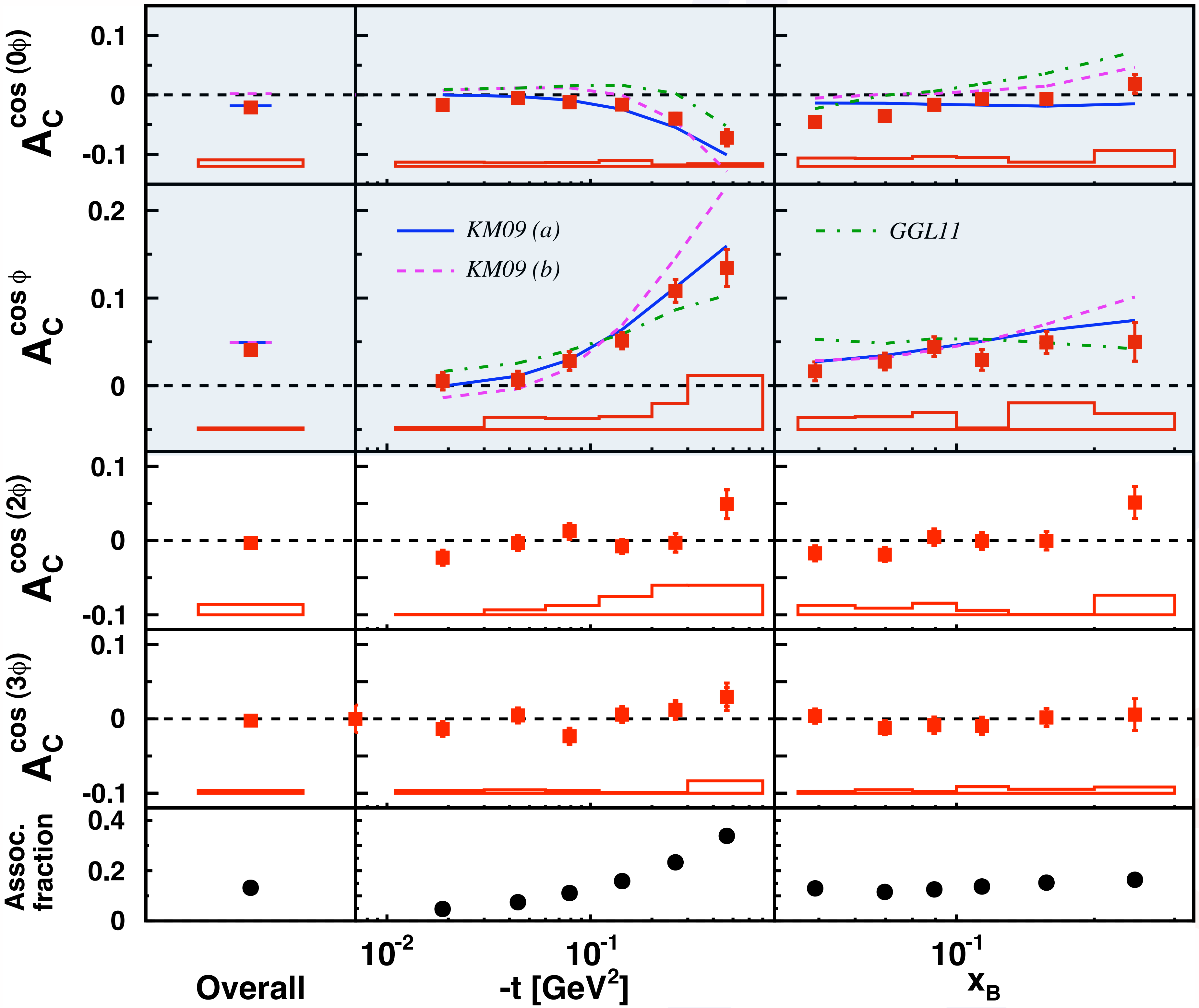
complete data set!

Beam-charge asymmetry

[Airapetian et al., JHEP 07 (2012) 032]



constant term:

$\propto -A_C^{\cos\phi}$

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

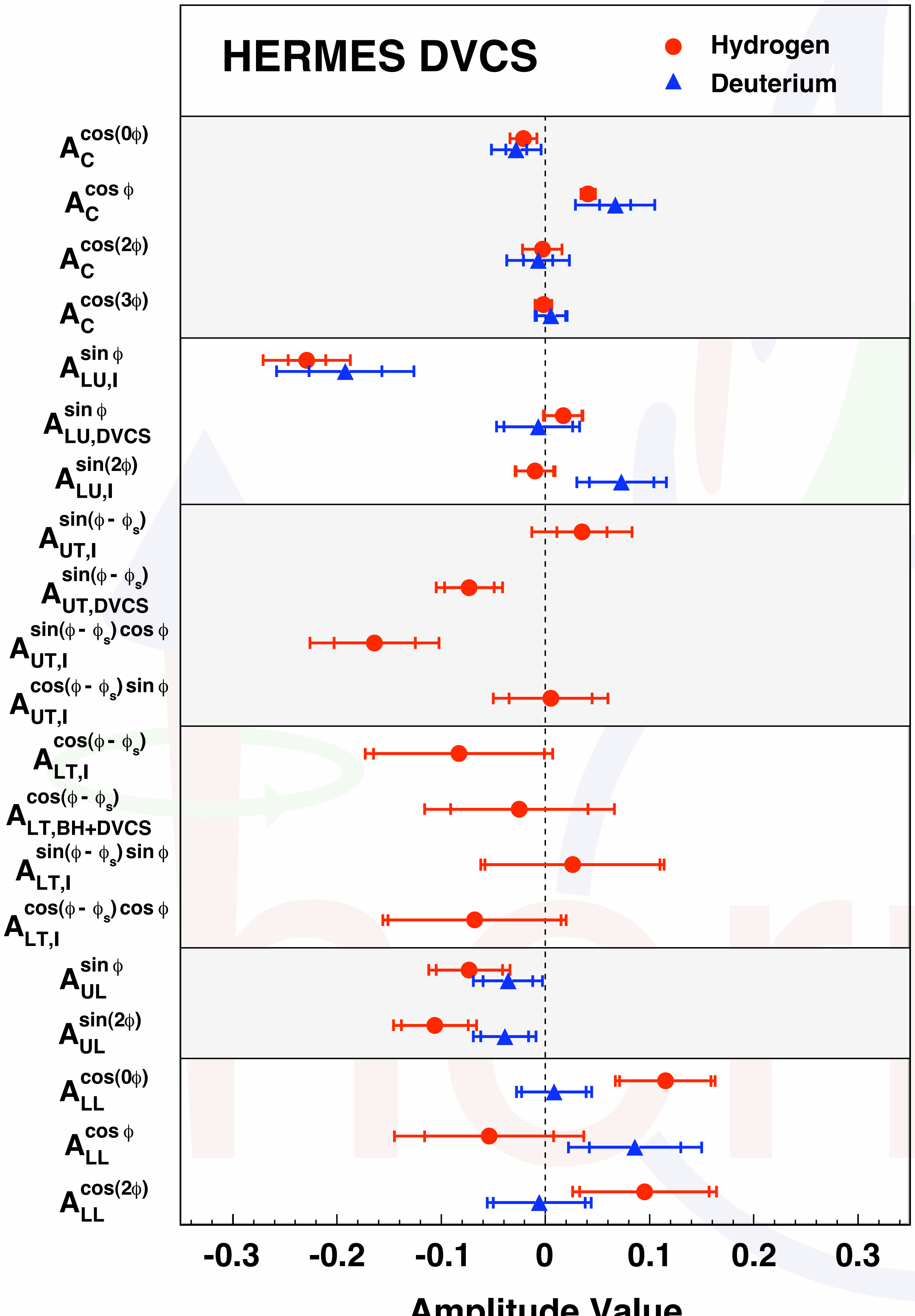
[higher twist]

[gluon leading twist]

Resonant fraction:

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

A wealth of azimuthal amplitudes



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Beam-spin asymmetry

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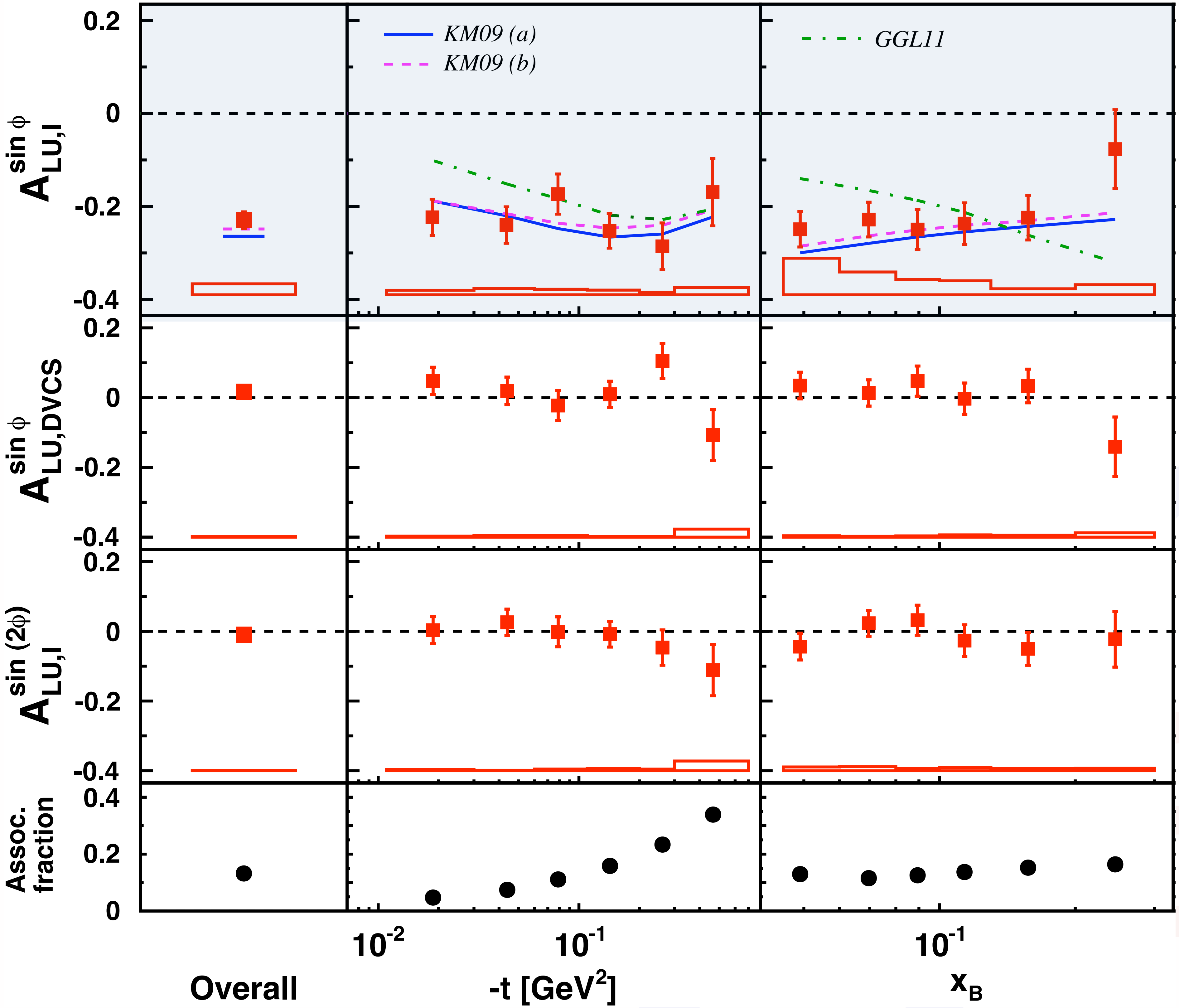


$\propto \mathrm{Im}[F_1\mathcal{H}]$

[higher twist]

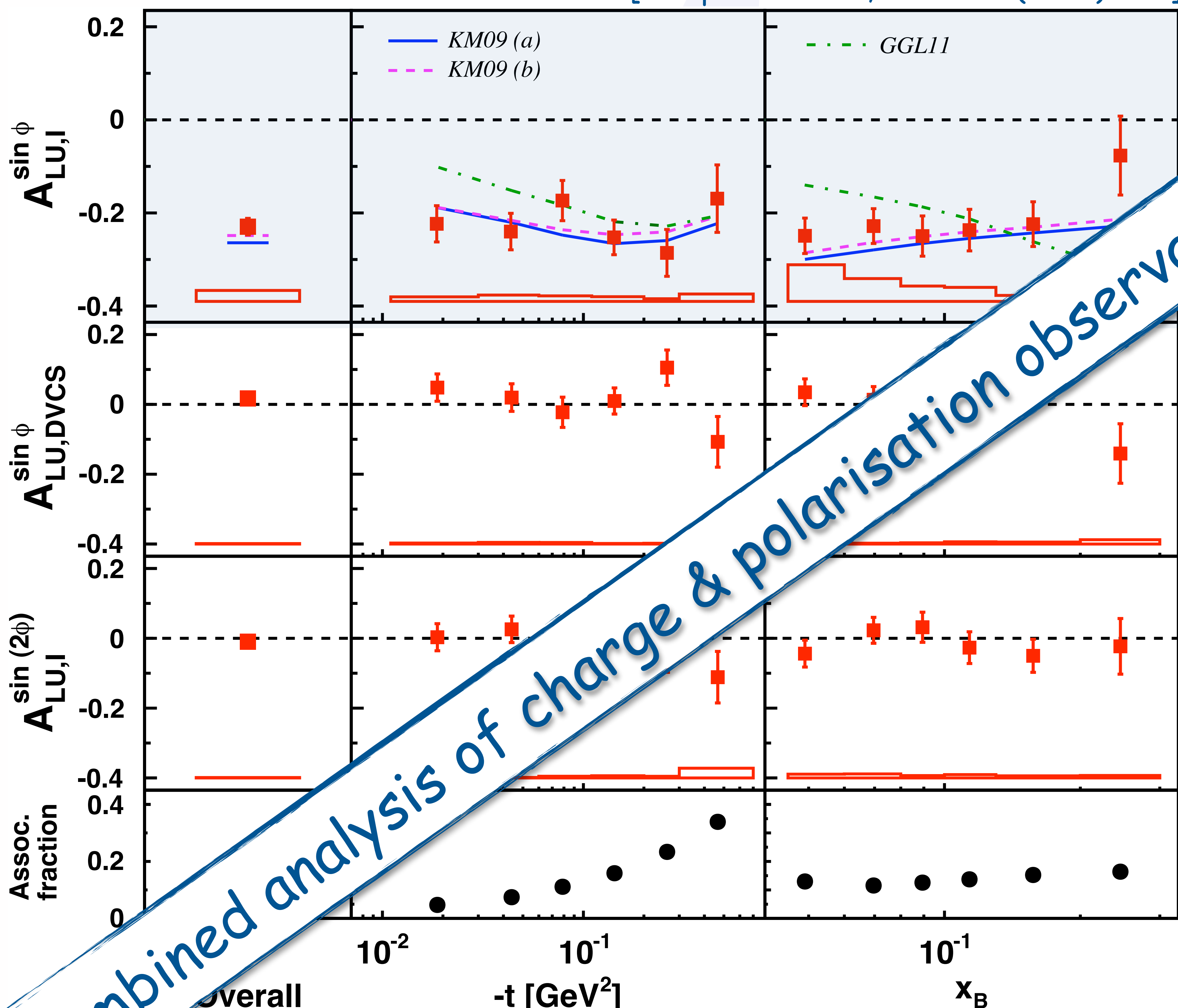
Resonant fraction:

$\boxed{ep \to e\Delta^+\gamma}$

complete data set!

Beam-spin asymmet...

[Airapetian et al., JHEP 07 (2012) 032]



combined analysis of charge & polarisation observables unique to HERA!

...$[F_1\mathcal{H}]$

[higher twist]

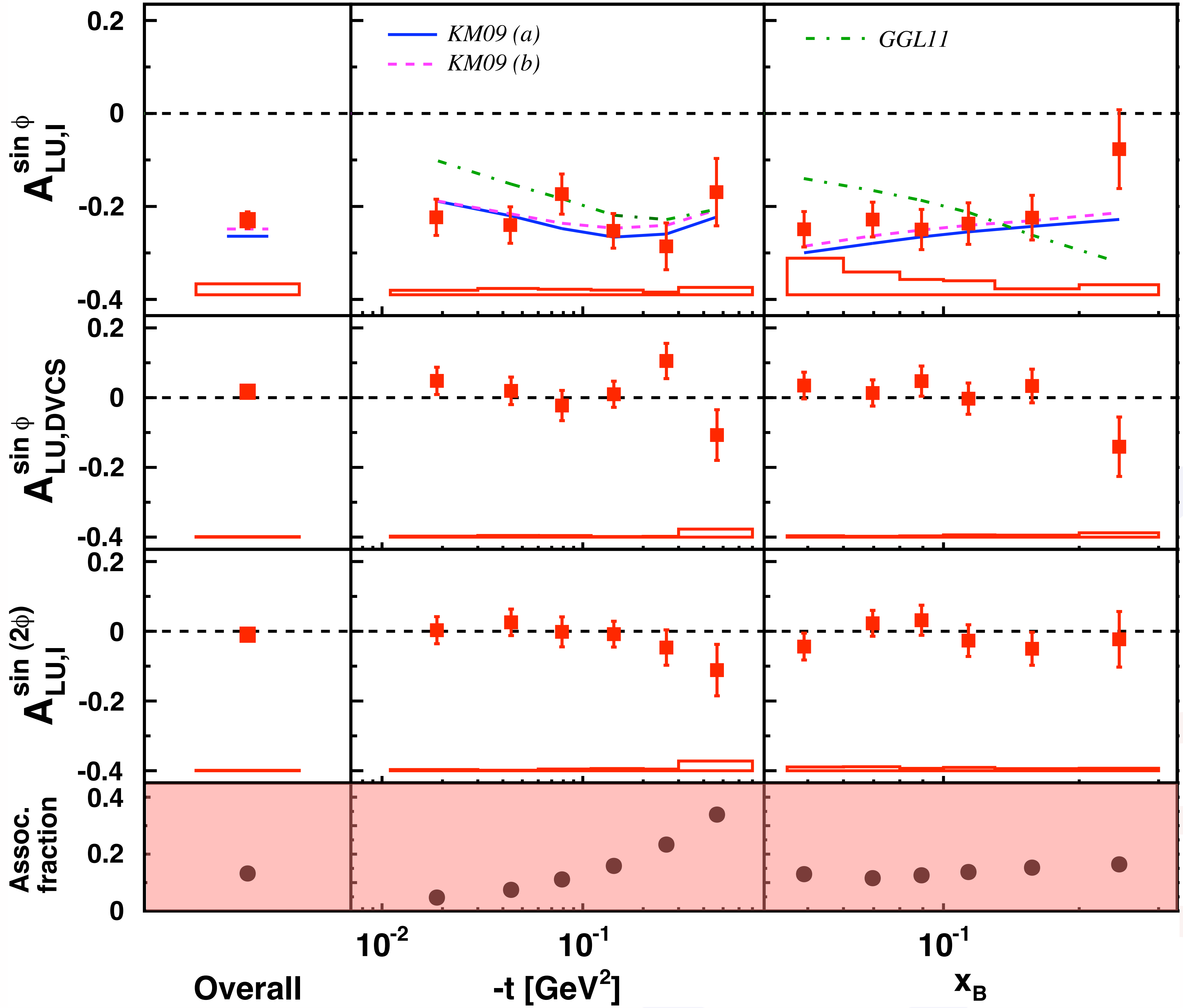
Resonant fraction:

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

complete data set!

Beam-spin asymmetry

[Airapetian et al., JHEP 07 (2012) 032]



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

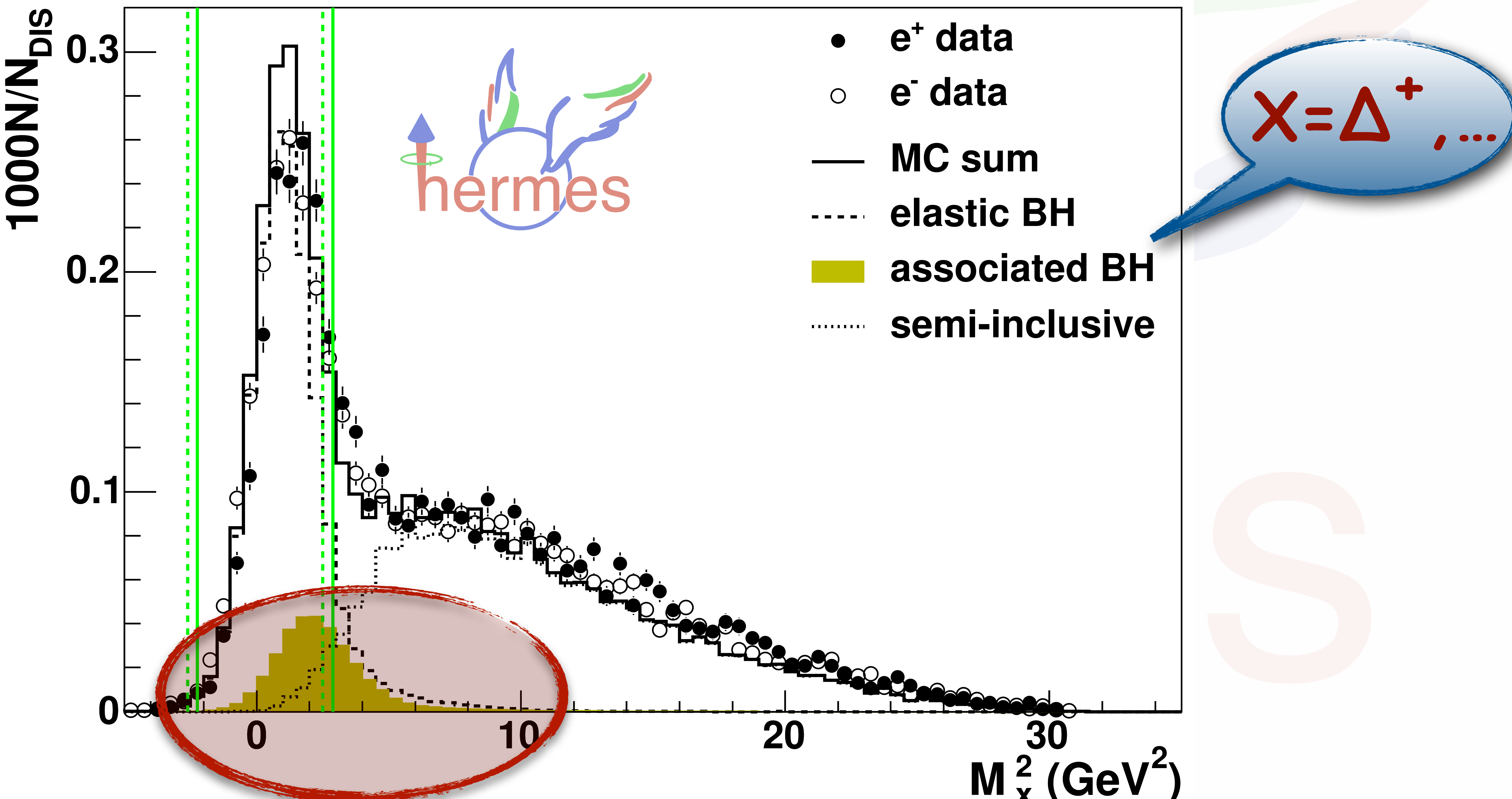
[higher twist]

Resonant fraction:

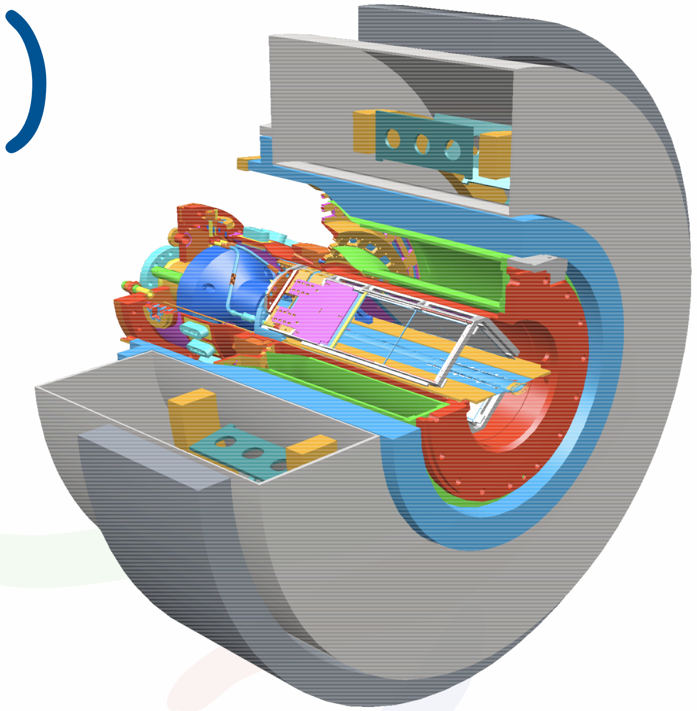
$$ep \to e\Delta^+\gamma$$

Exclusivity: missing-mass technique

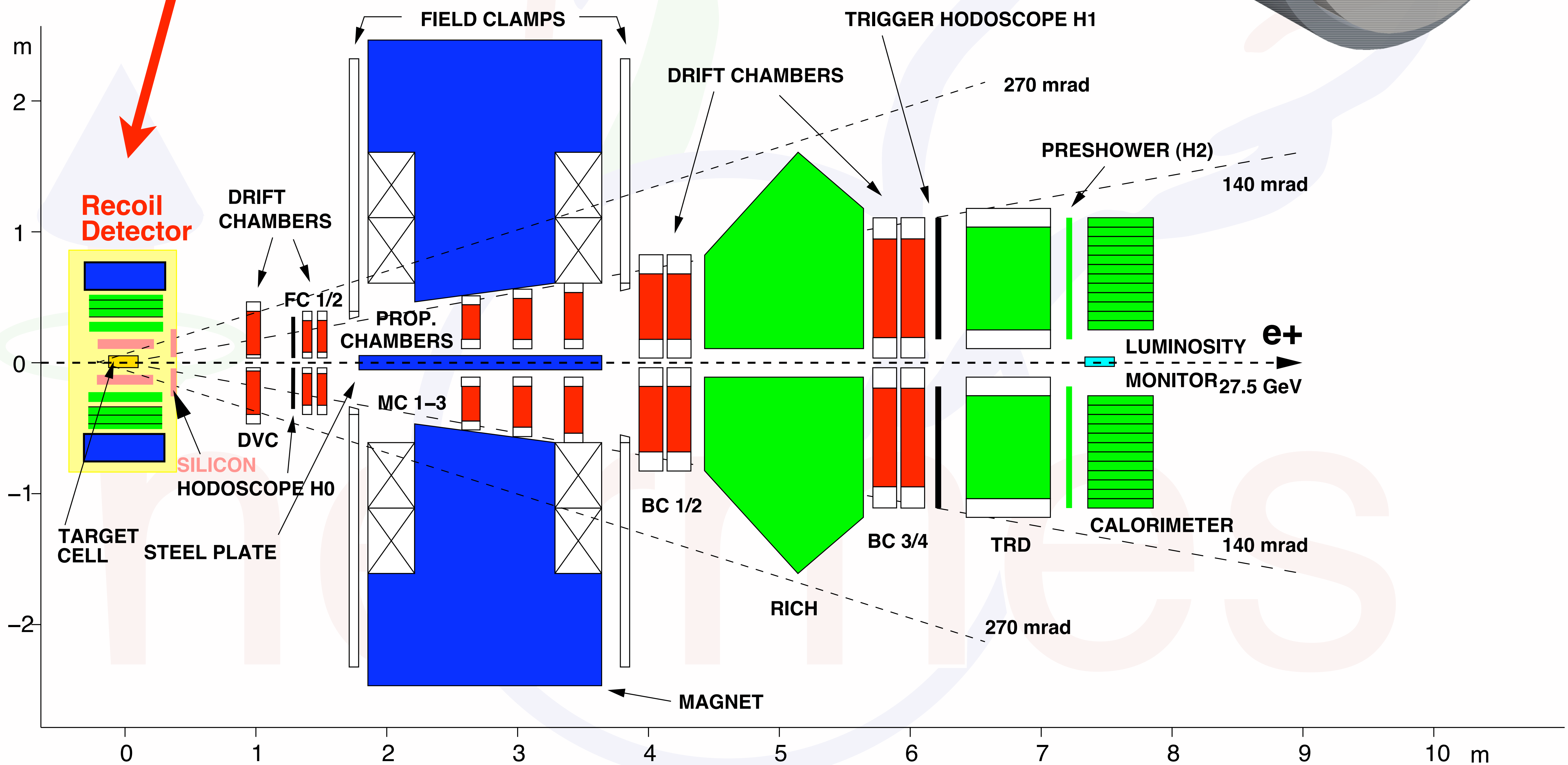
ep -> e γ X



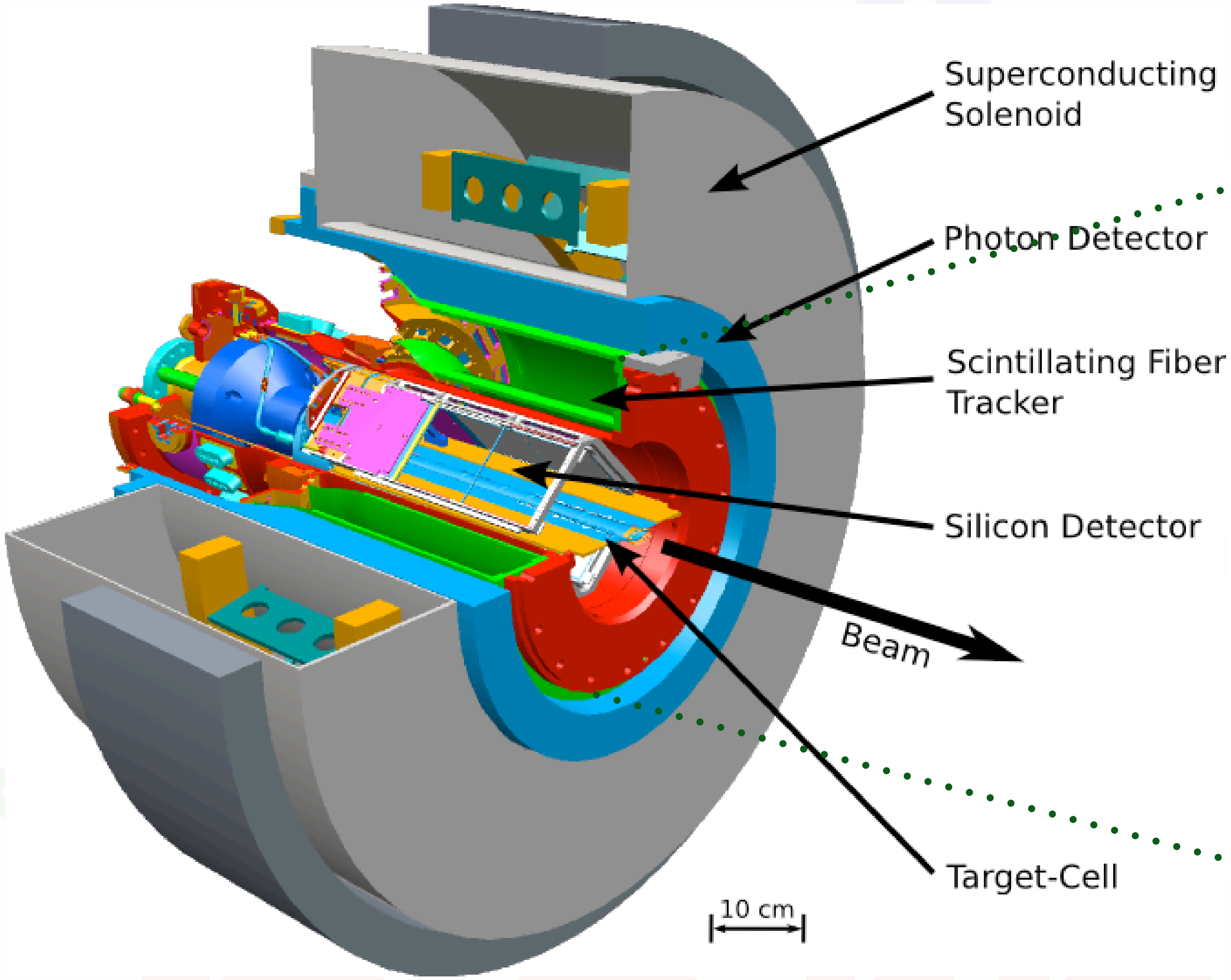
HERMES detector (2006/07)

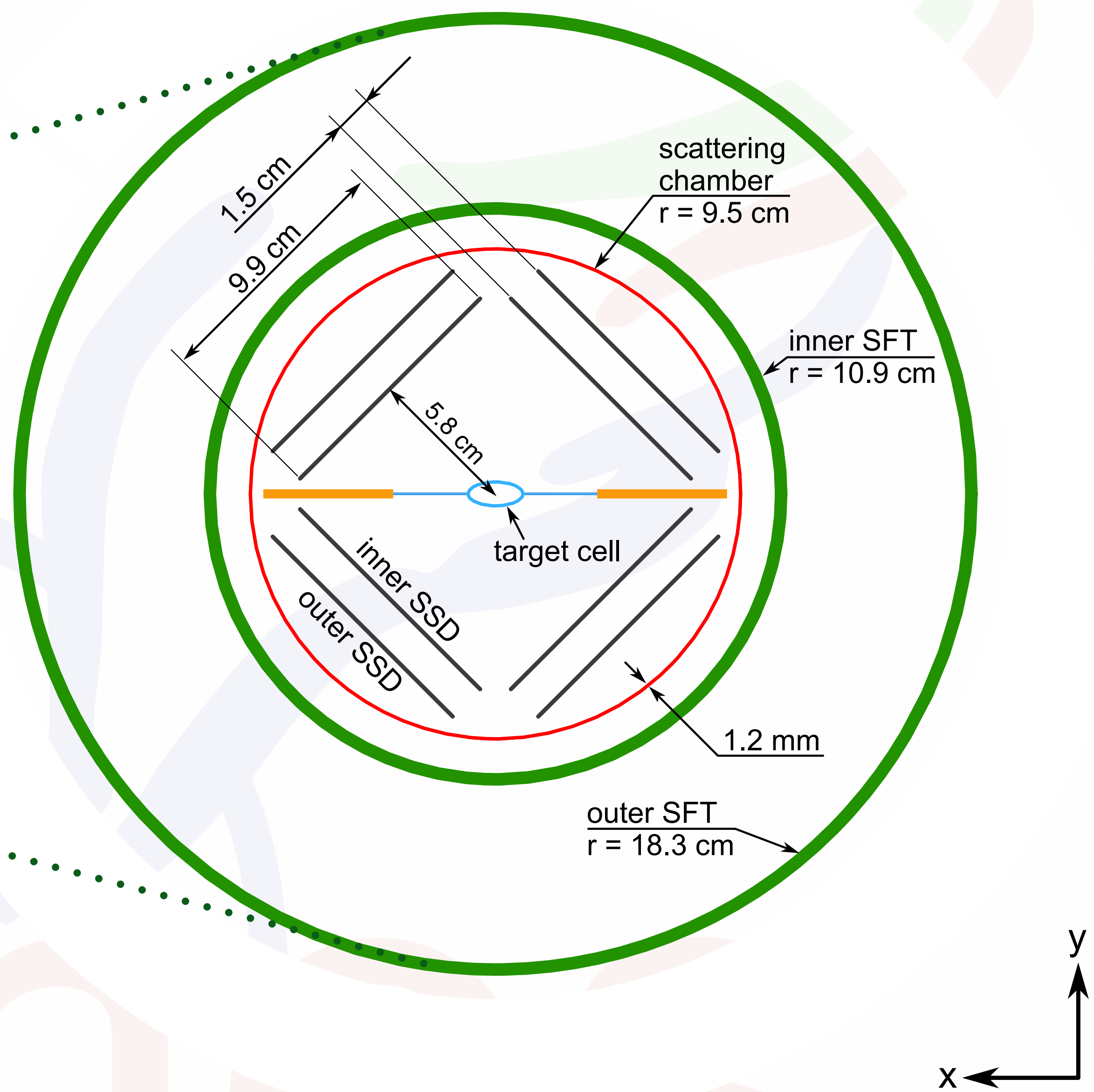


detection of recoiling proton



The HERMES Recoil detector

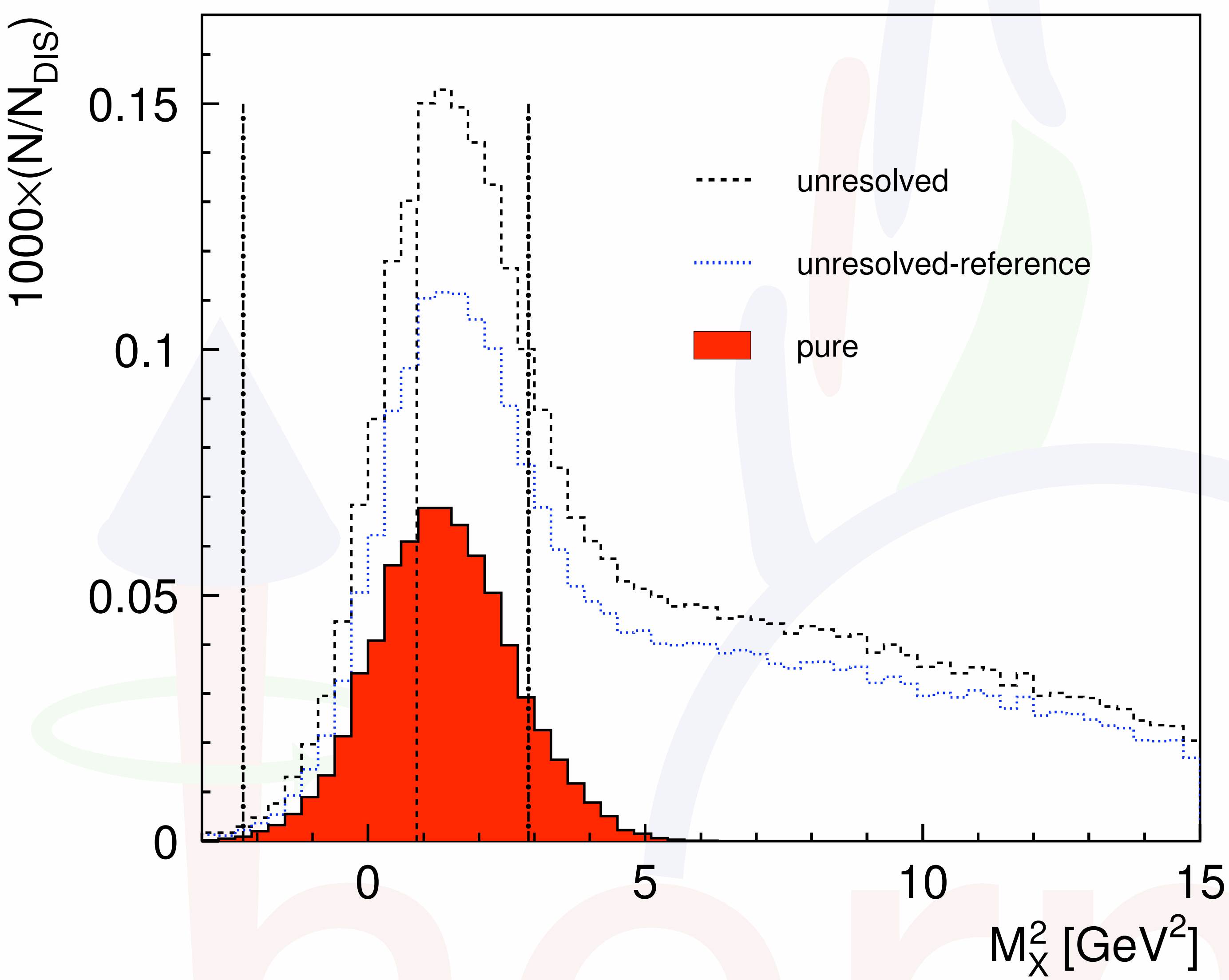


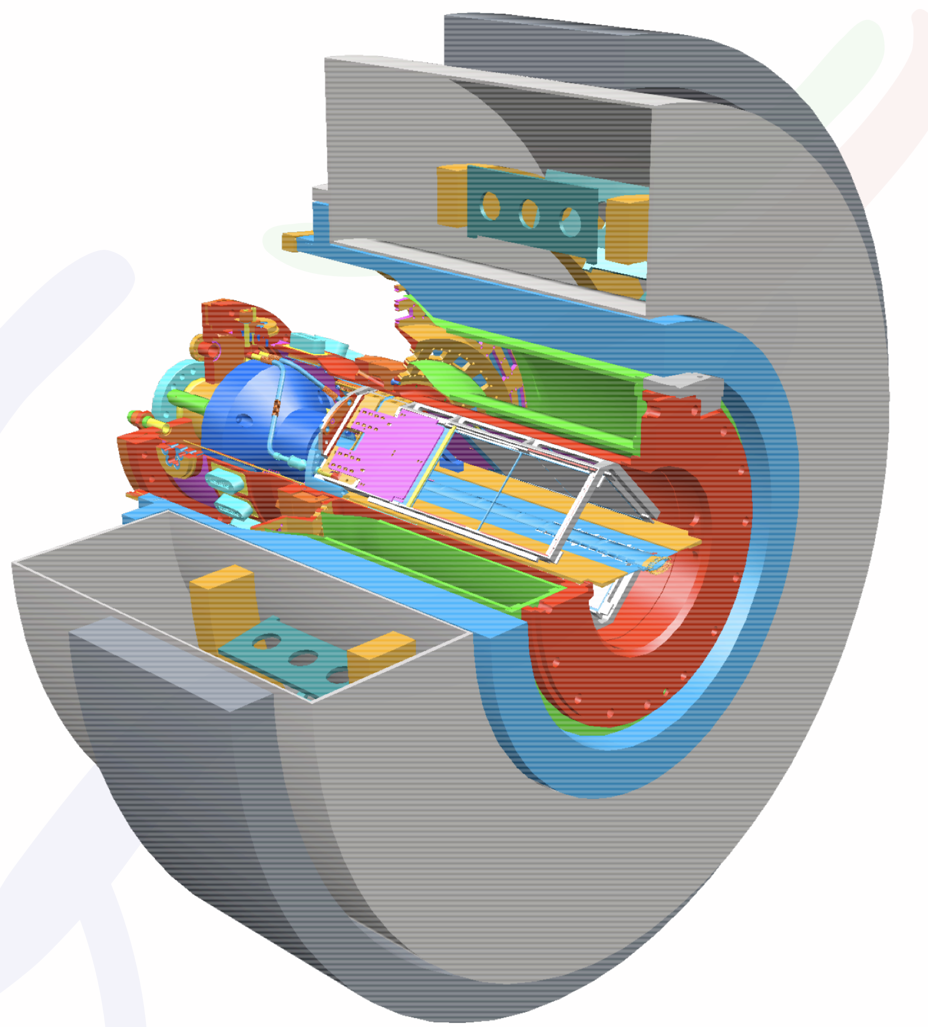


Enables the measurement of the recoiling charged particle and therefore full $ep \rightarrow ep\gamma$ event reconstruction

HERMES detector (2006/07)

kinematic fitting





- All particles in final state detected → 4 constraints from energy-momentum conservation
- Selection of pure BH/DVCS ($ep\rightarrow ep\gamma$) with **high efficiency** (~83%)
- Allows to suppress background from associated and semi-inclusive processes to a negligible level (<0.2%)

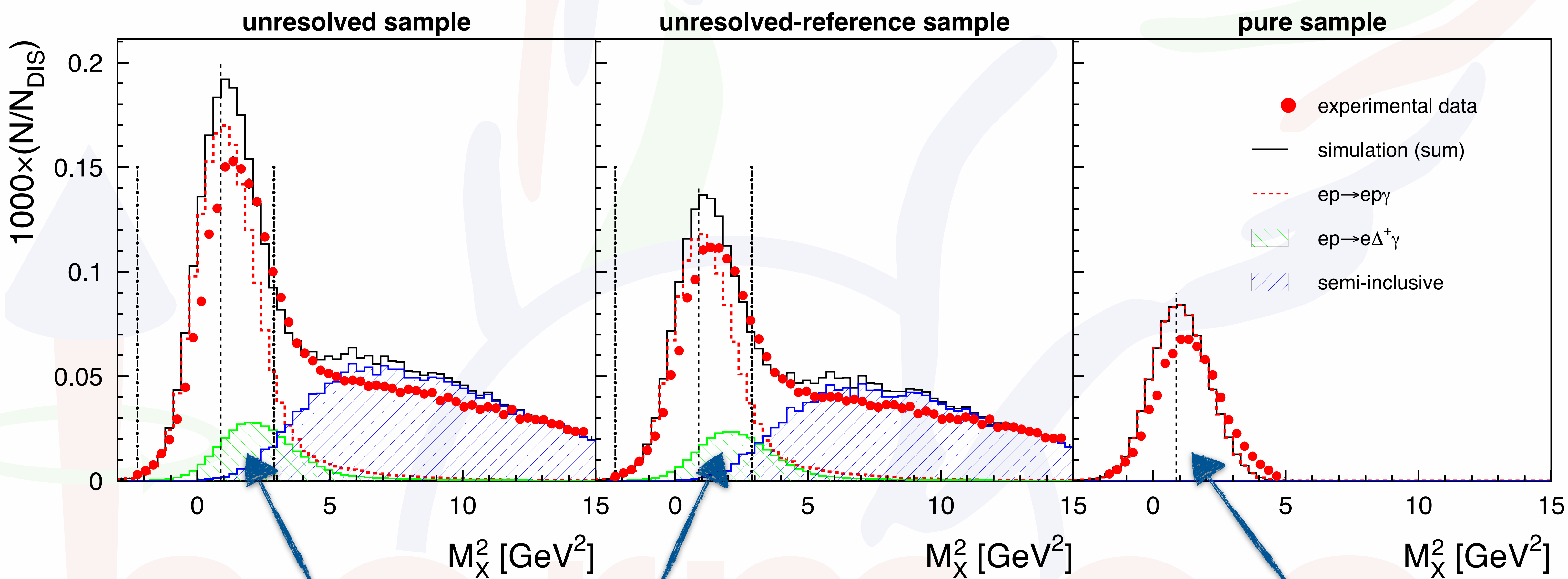
Exclusivity with recoil detector

forward spectrometer only

similar background

measured proton

same kinematic acceptance



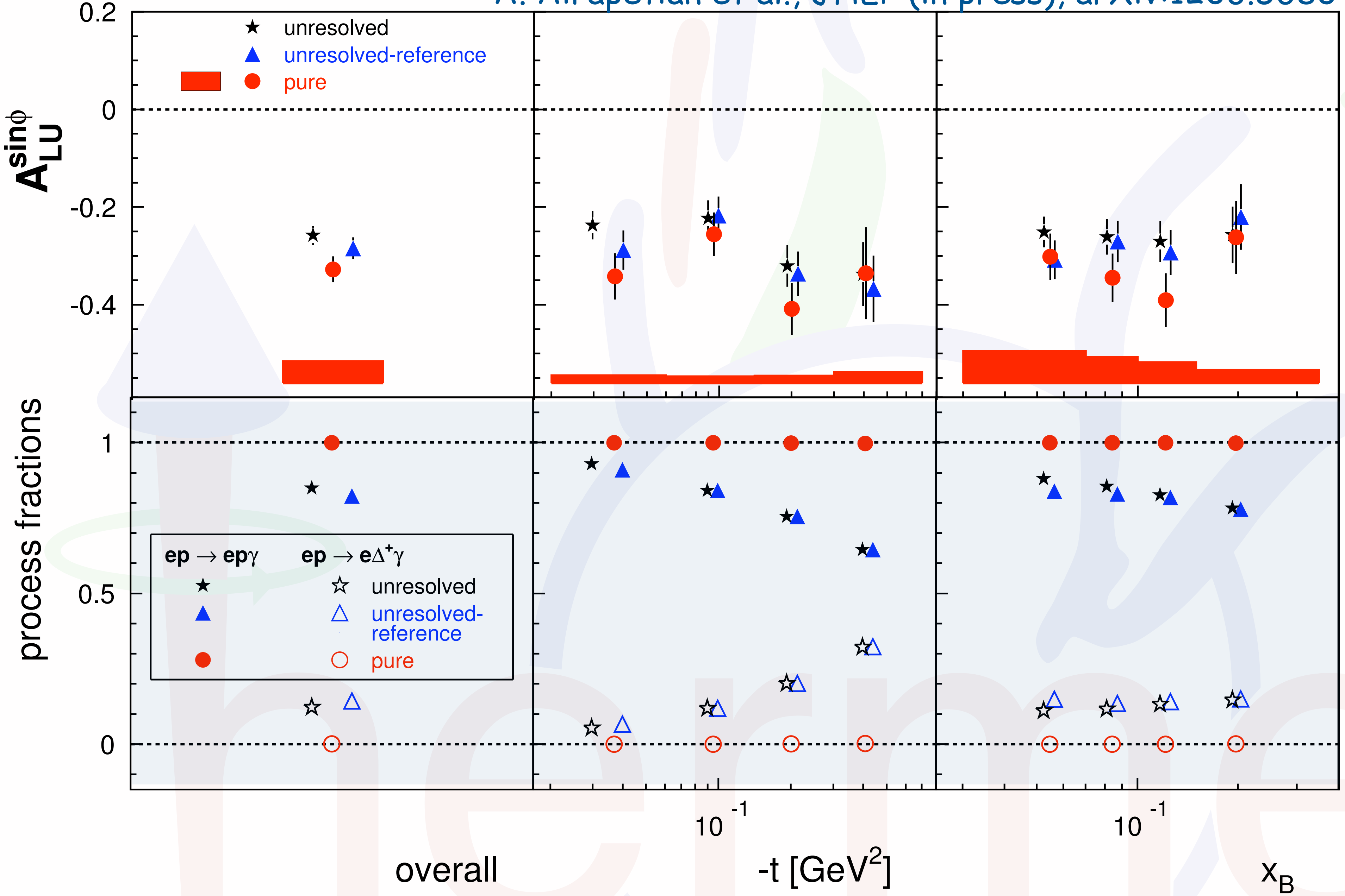
associated processes (ep→e γ Δ^+)

pure ep→e γ p

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

Single-charge BSA with recoil proton

A. Airapetian et al., JHEP (in press), arXiv:1206.5683



basically **no contamination**

-> clear interpretation

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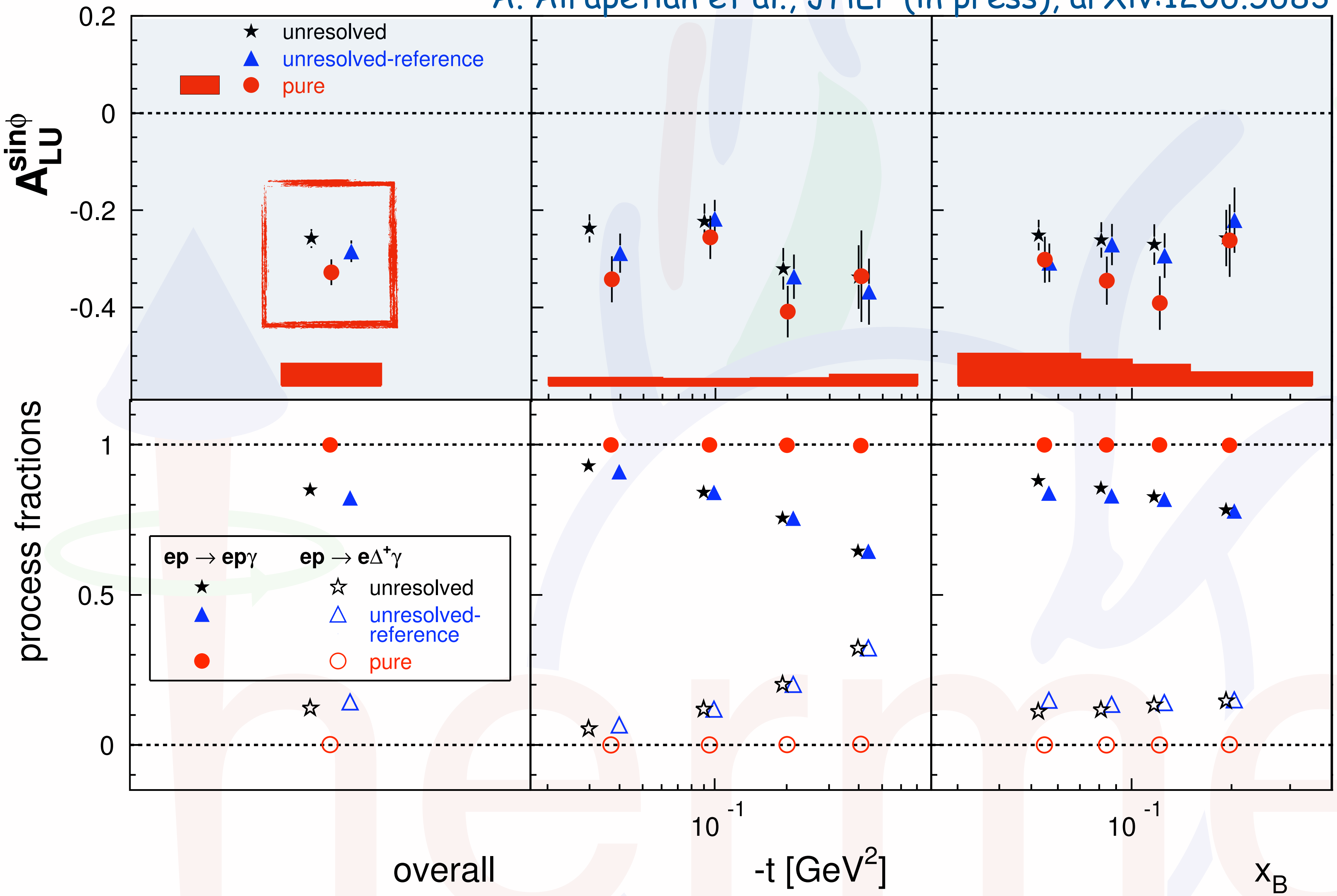


Magnitude of the leading asymmetry has increased by 0.054 ± 0.016

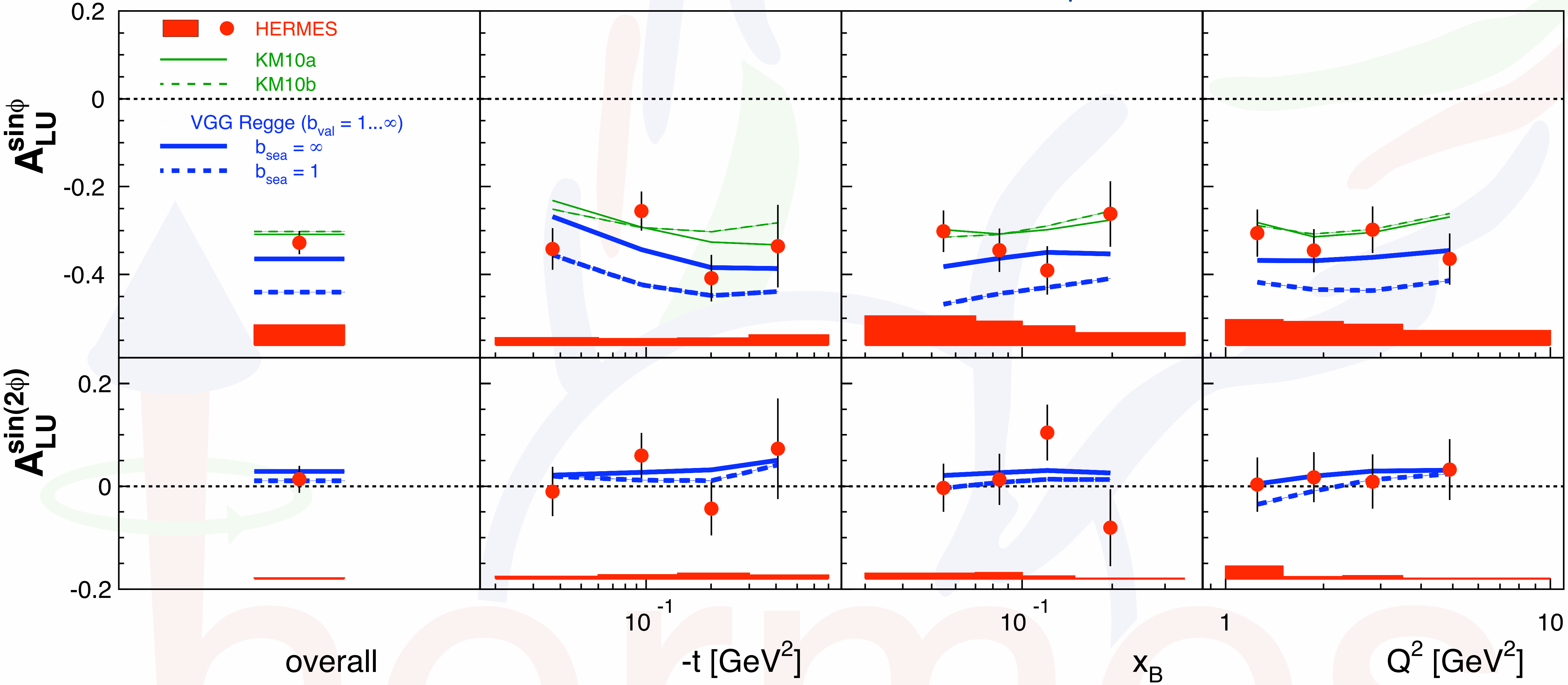
(-> assoc. in traditional analysis mainly dilution)

basically **no contamination**

-> clear interpretation

Single-charge BSA with recoil proton

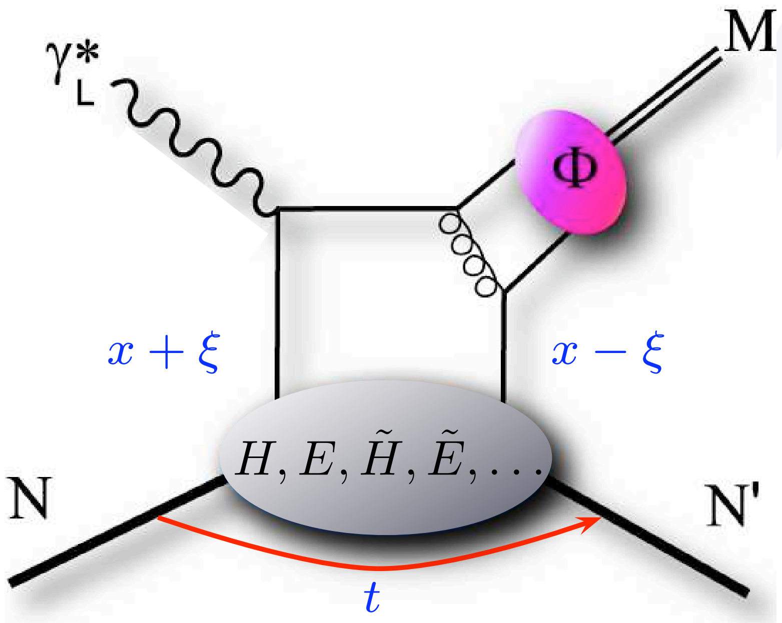
[A. Airapetian et al., JHEP 10 (2012) 042]



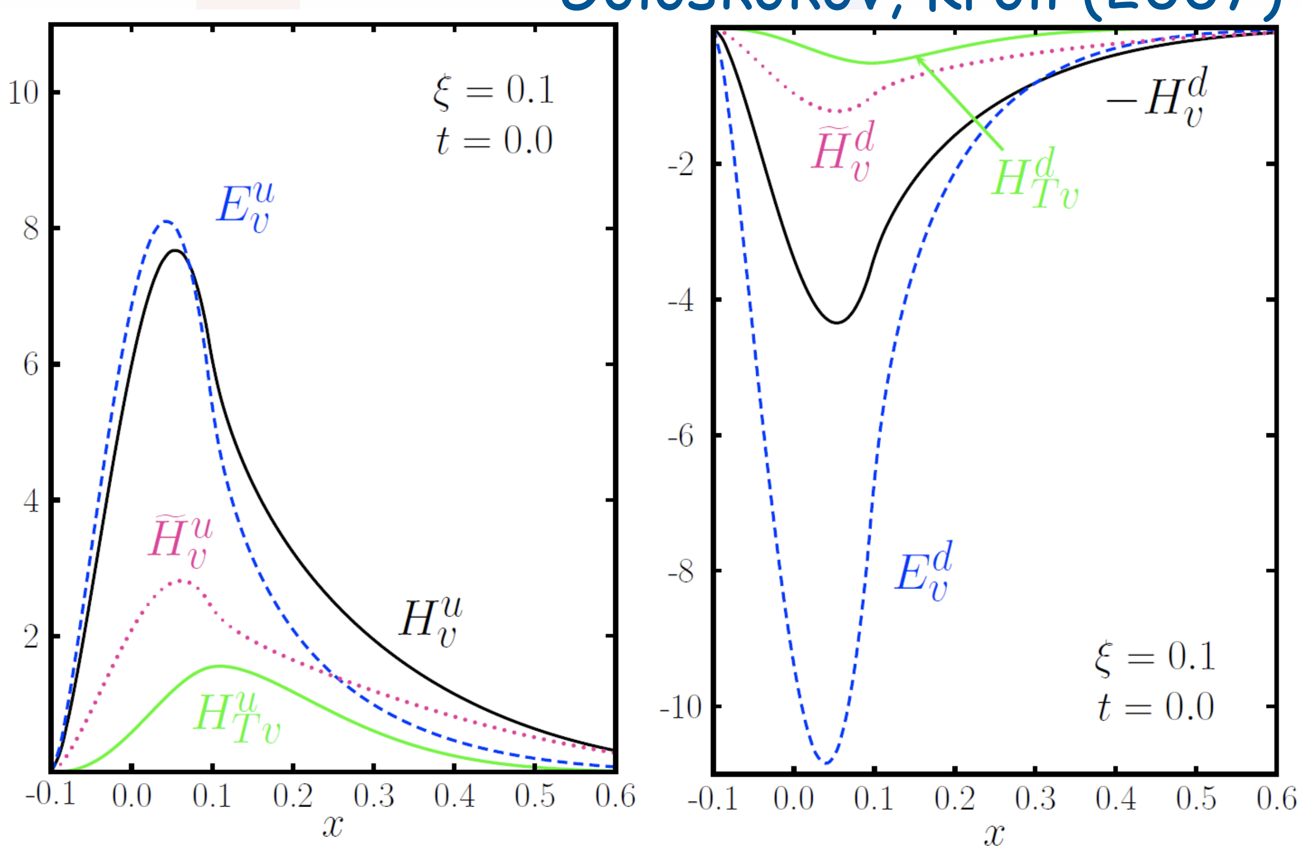
good agreement with models

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

GPDs - a nice success story!



Goloskokov, Kroll (2007)



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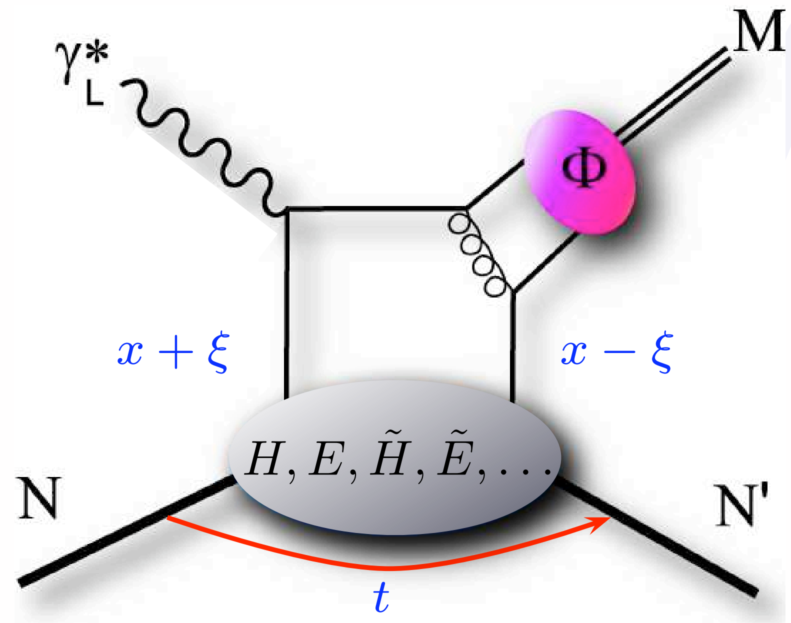

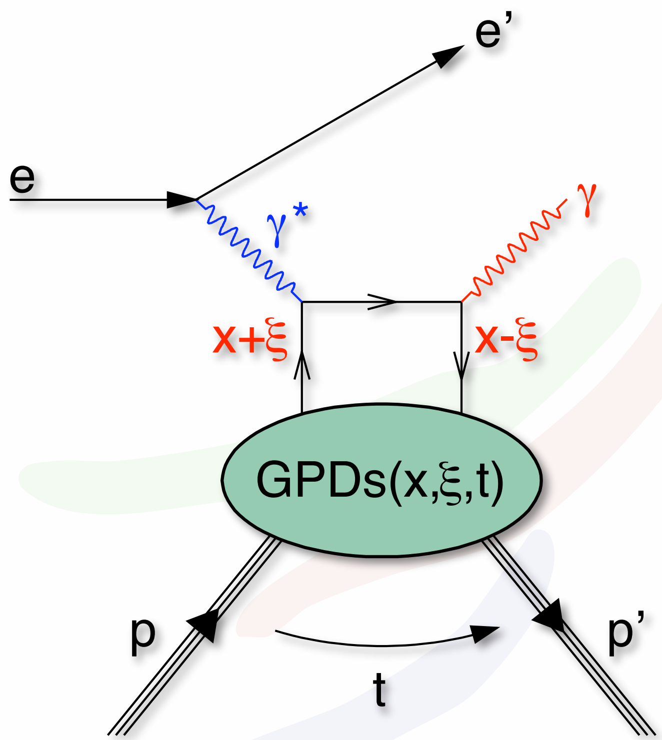

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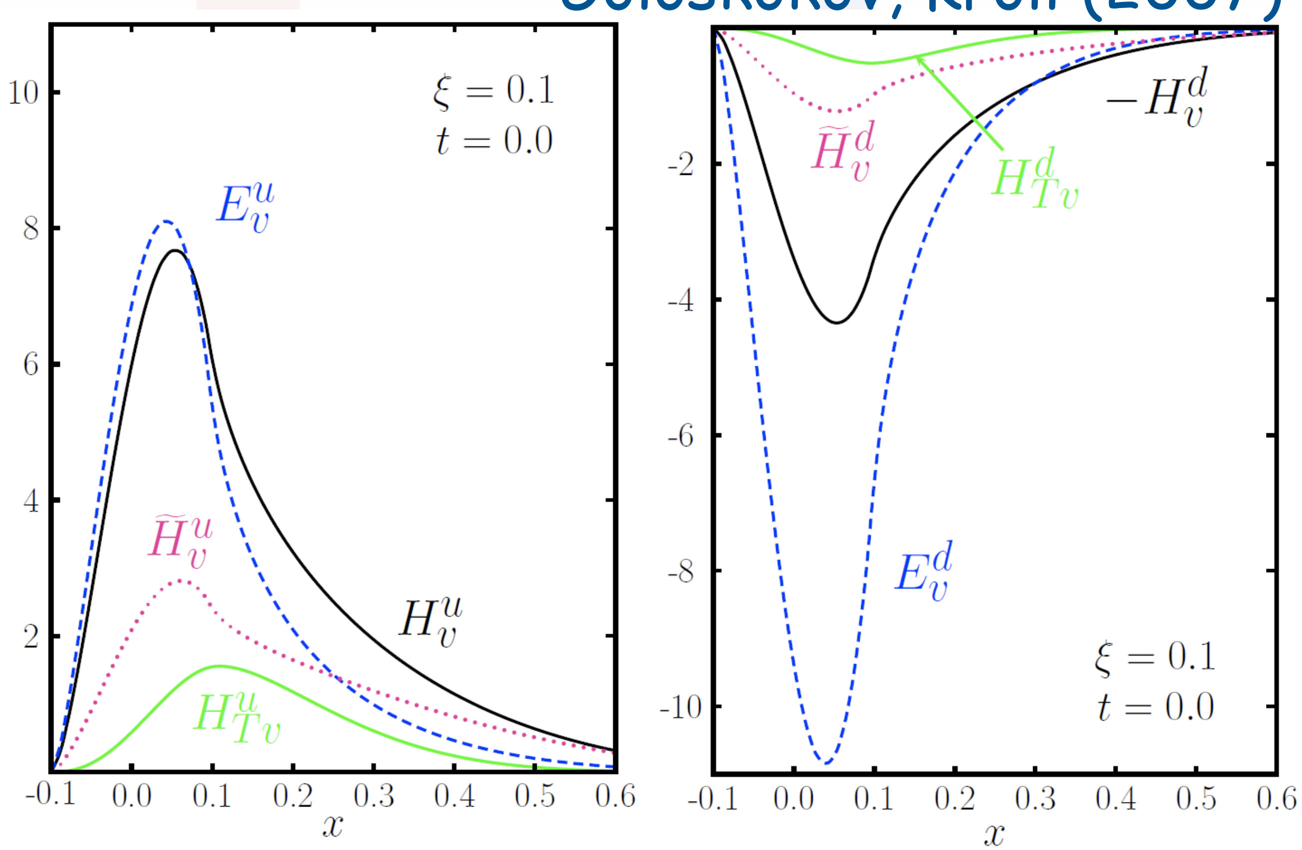
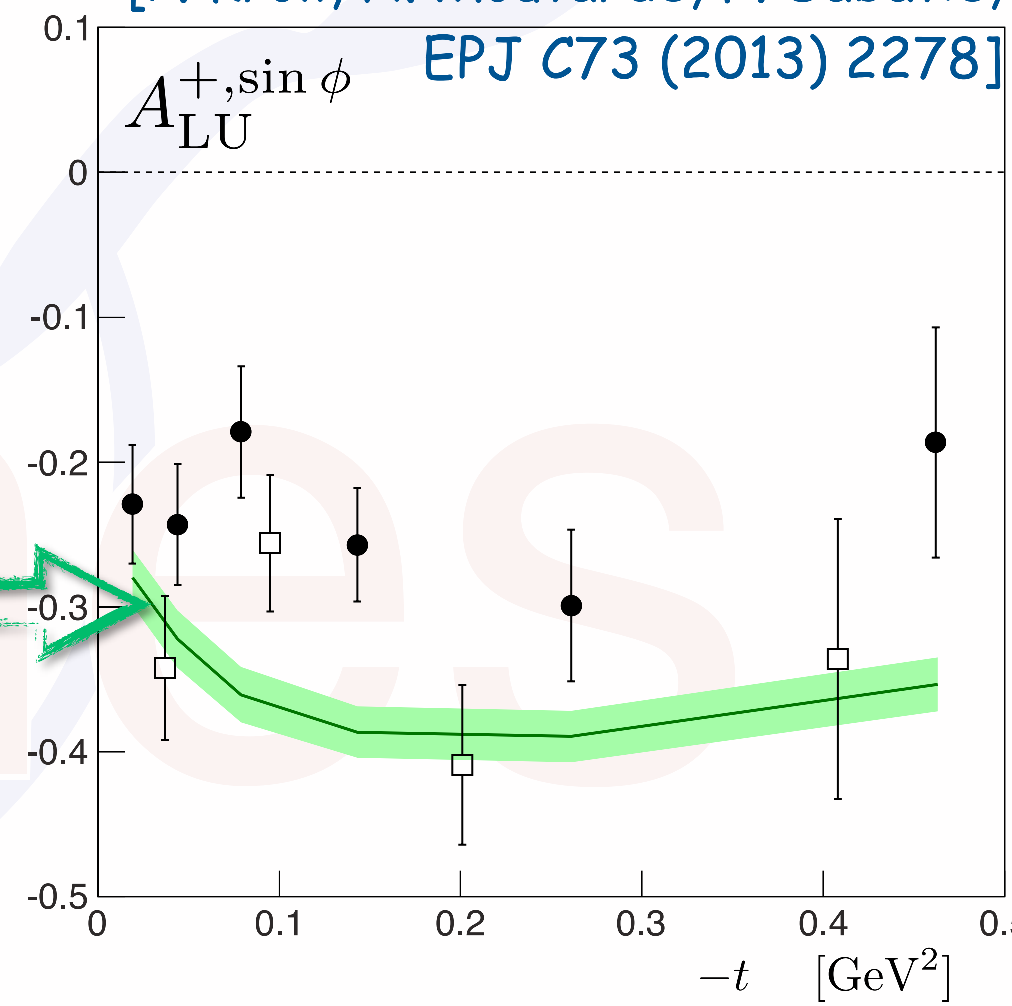
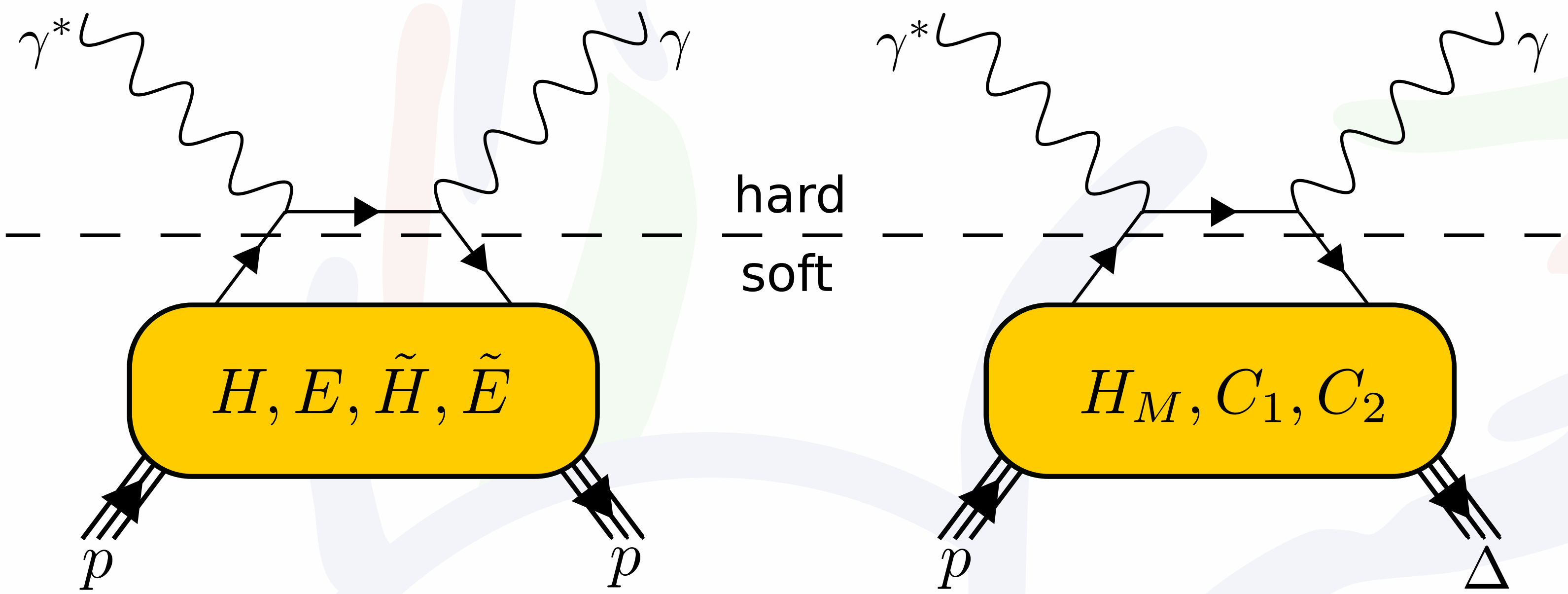


[P. Kroll, H. Moutarde, F. Sabatie, EPJ C73 (2013) 2278]



Beam-spin asymmetries ep→e γ Nπ

Besides a better understanding of the unresolved sample, associated DVCS in principle also allows further access to GPDs.

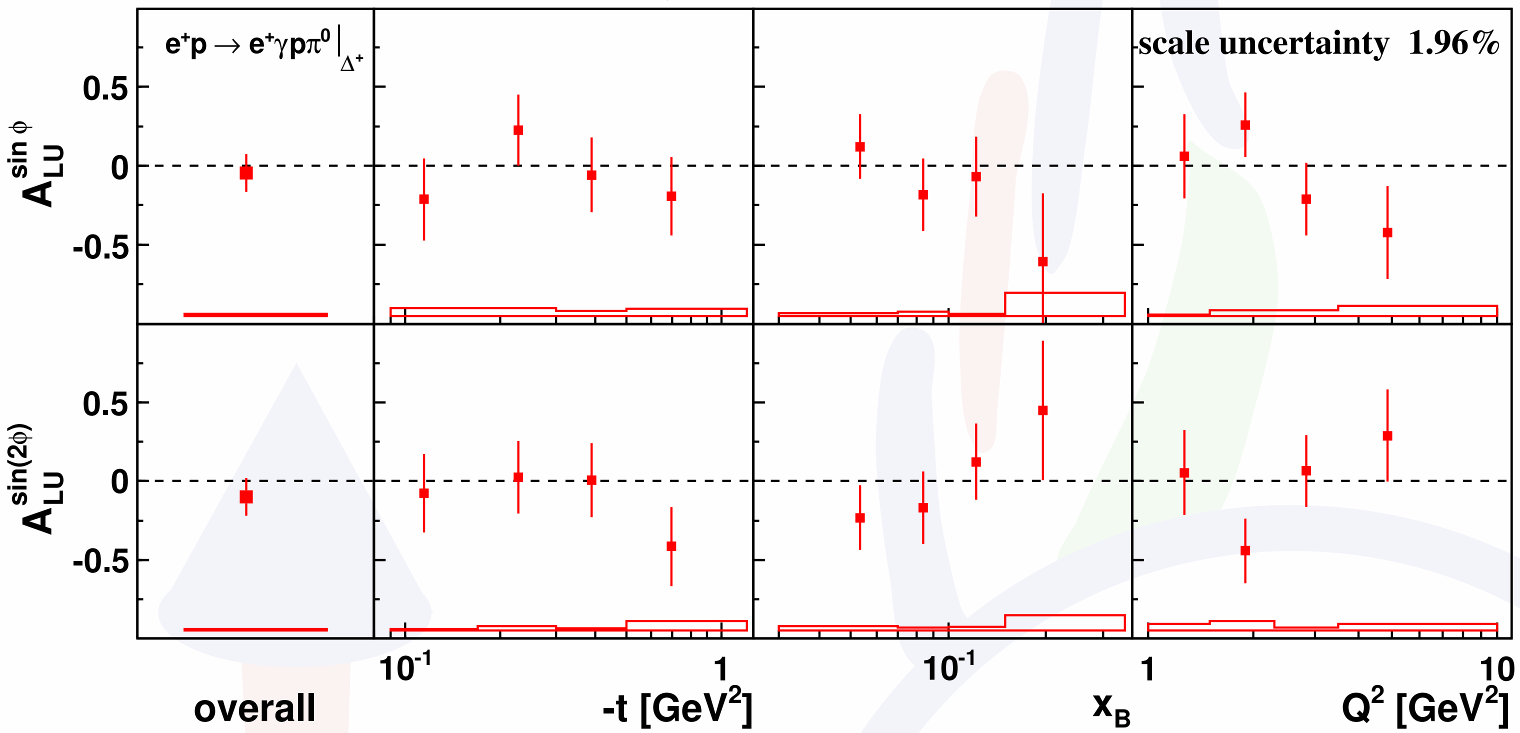


In the large-N$_c$ limit the remaining N→Δ GPDs can be related to the N→N iso-vector GPDs:

$$\boxed{\begin{aligned} H_M(x,\xi,t) &= \frac{2}{\sqrt{3}}\left[E^u(x,\xi,t) - E^d(x,\xi,t)\right], \\ C_1(x,\xi,t) &= \sqrt{3}\left[\tilde{H}^u(x,\xi,t) - \tilde{H}^d(x,\xi,t)\right], \\ C_2(x,\xi,t) &= \frac{\sqrt{3}}{4}\left[\tilde{E}^u(x,\xi,t) - \tilde{E}^d(x,\xi,t)\right] \end{aligned}}$$

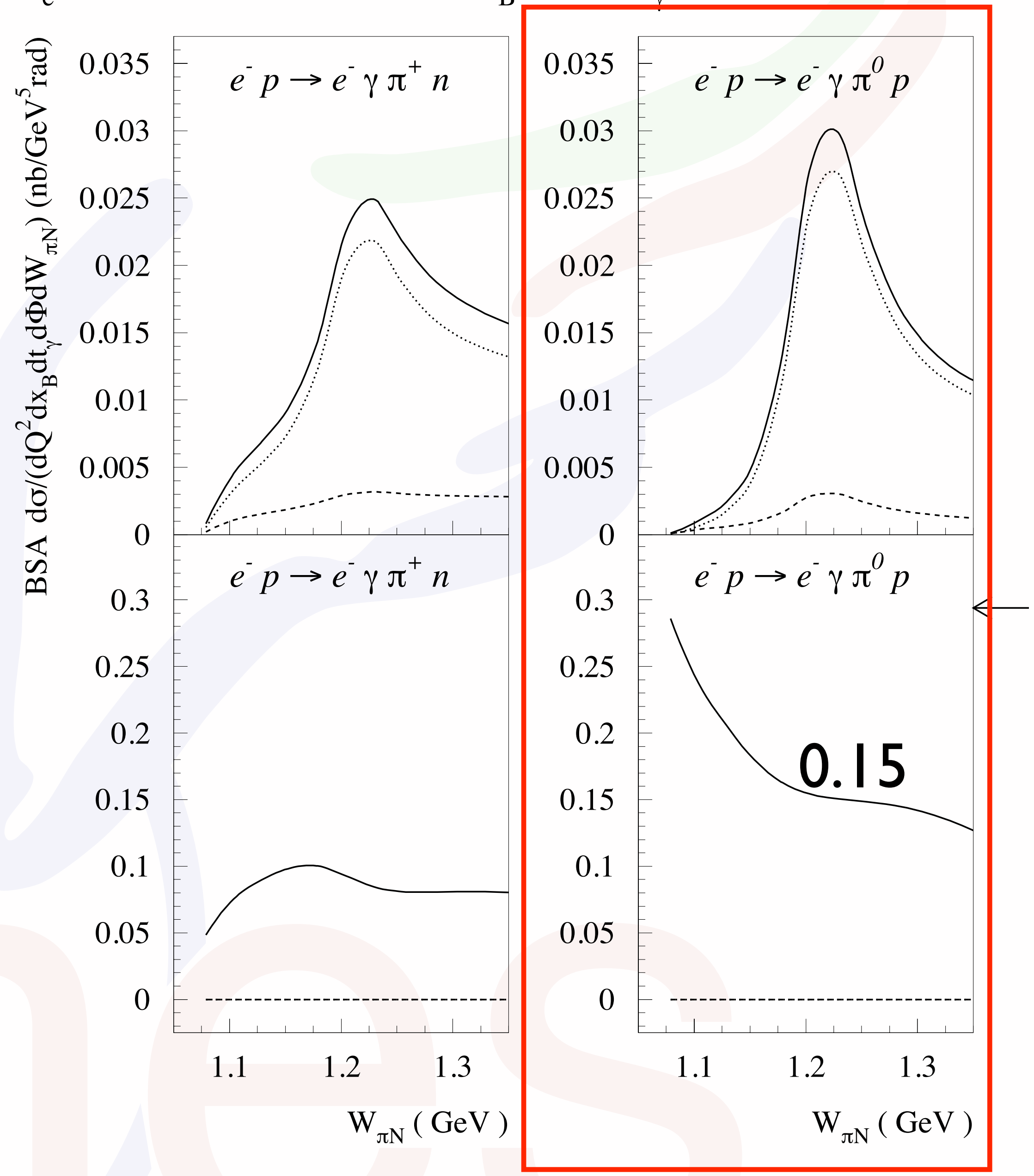
Beam-spin asymmetries ep→e γ pπ^0

[A. Airapetian et al, JHEP 01 (2014) 077]



[Guichon et al., PRD 68 (2003) 034018]

E_e = 27 GeV, Q^2 = 2.5 GeV^2, x_B = 0.15, t_γ = -0.25 GeV^2, Φ = 90°



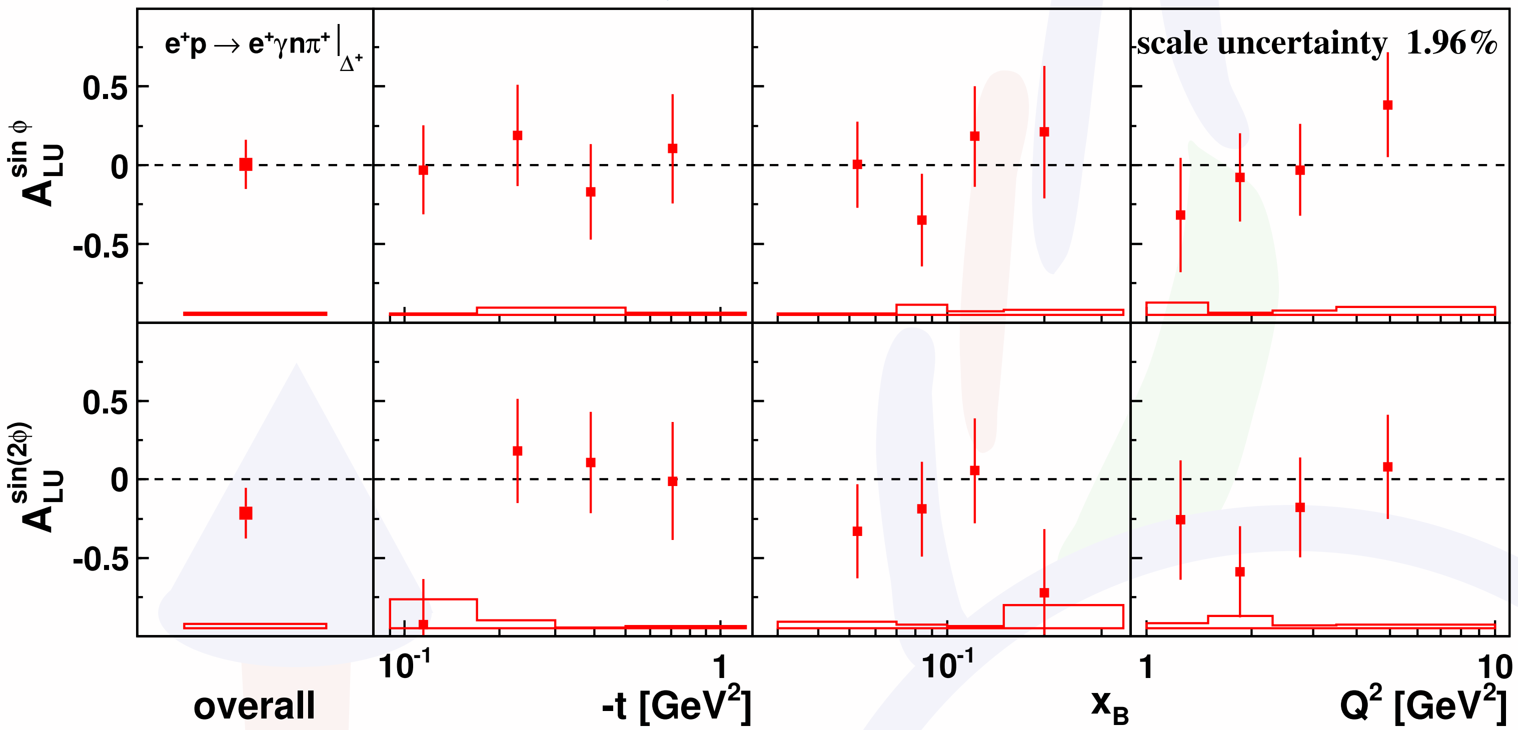
Shown amplitudes corrected for background (only overall fractions are listed here):

Associated DVCS/BH (ep→e γ pπ^0)	85 ± 1
Elastic DVCS/BH (ep→e γ p)	4.6 ± 0.1
SIDIS (ep→eXπ^0)	11 ± 1

opposite sign convention!

Beam-spin asymmetries $ep \rightarrow e\gamma n\pi^+$

[A. Airapetian et al, JHEP 01 (2014) 077]



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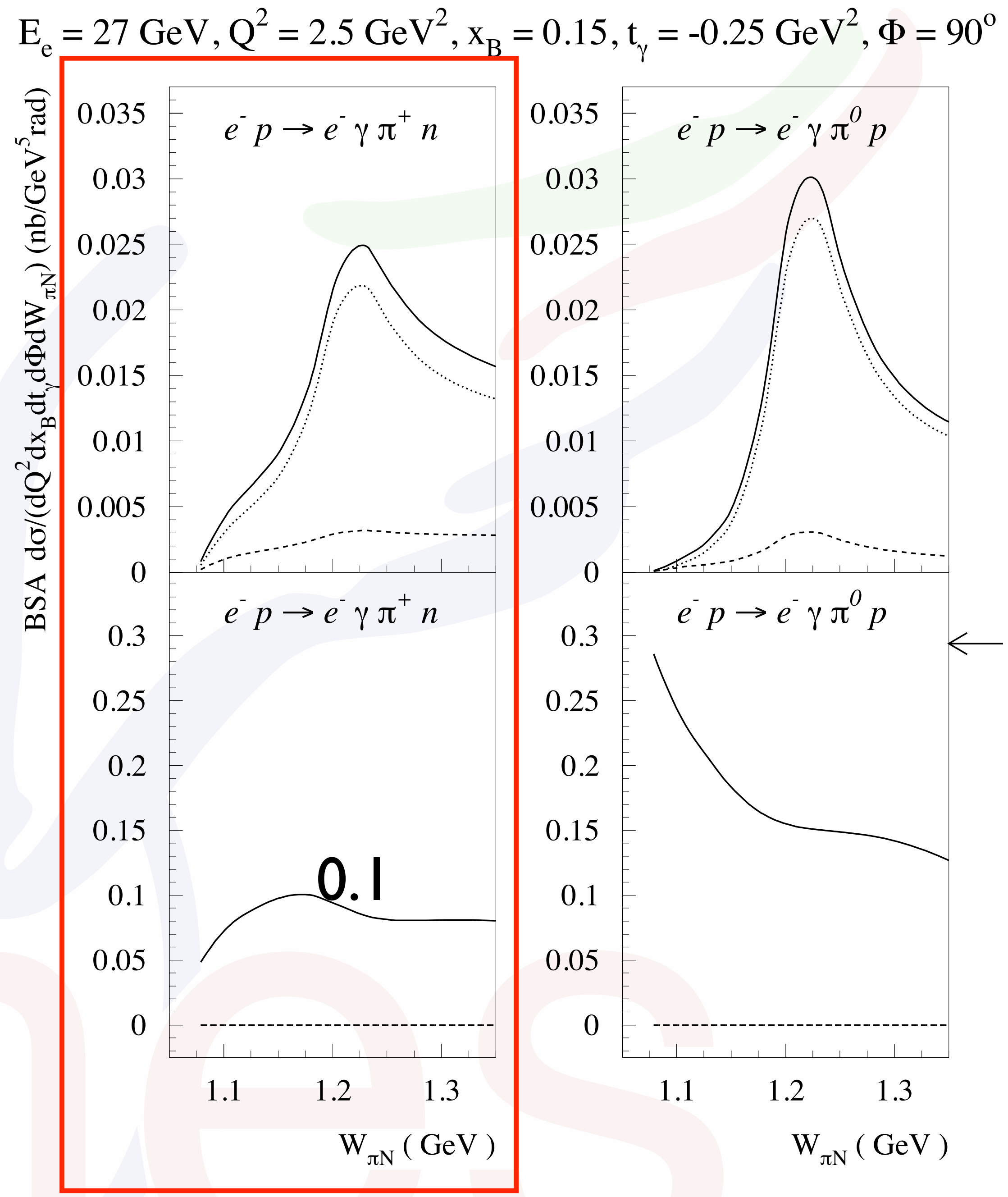
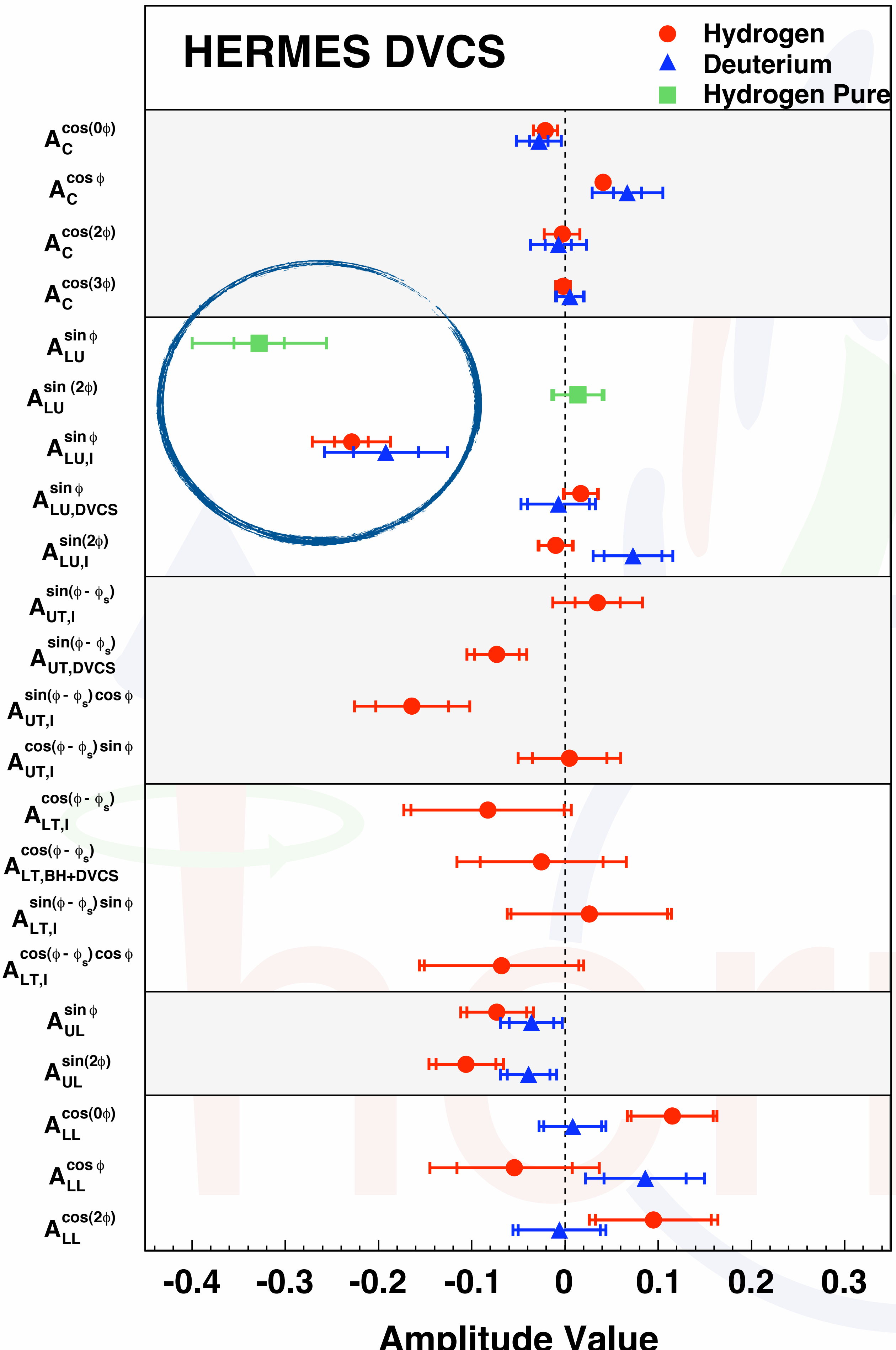


Shown amplitudes corrected for background (only overall fractions are listed here):

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

opposite sign convention!

DVCS at HERMES



HERMES analyzed a wealth of DVCS-related asymmetries on nucleon and nuclear targets

data with recoil-proton detection allows clean interpretation

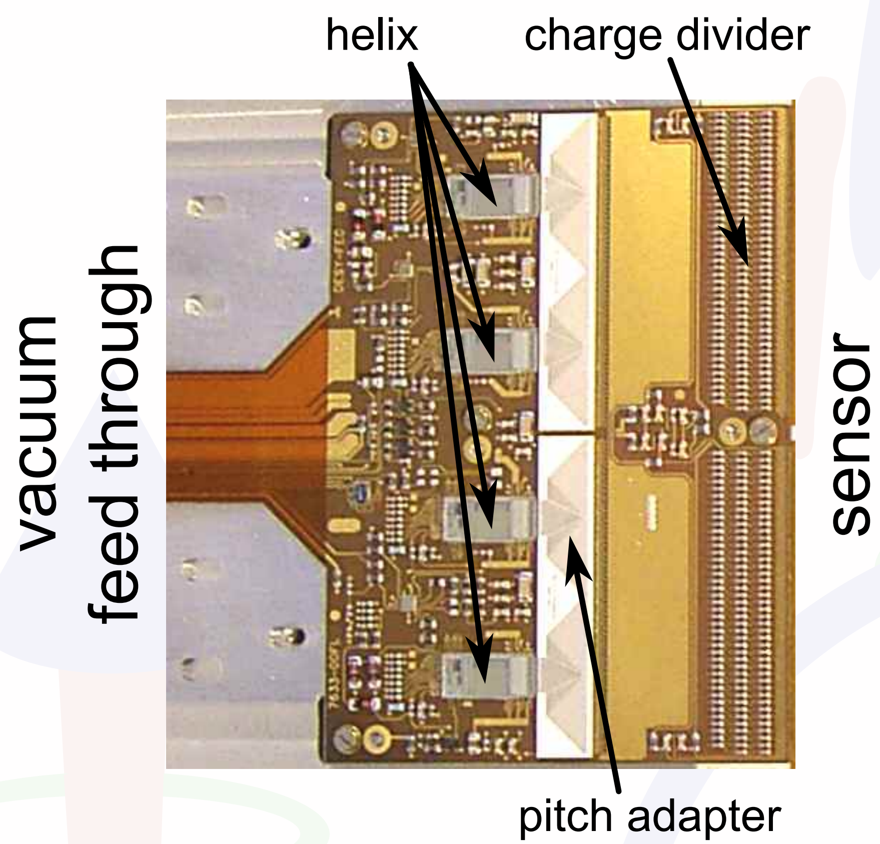
indication of larger amplitudes for pure sample

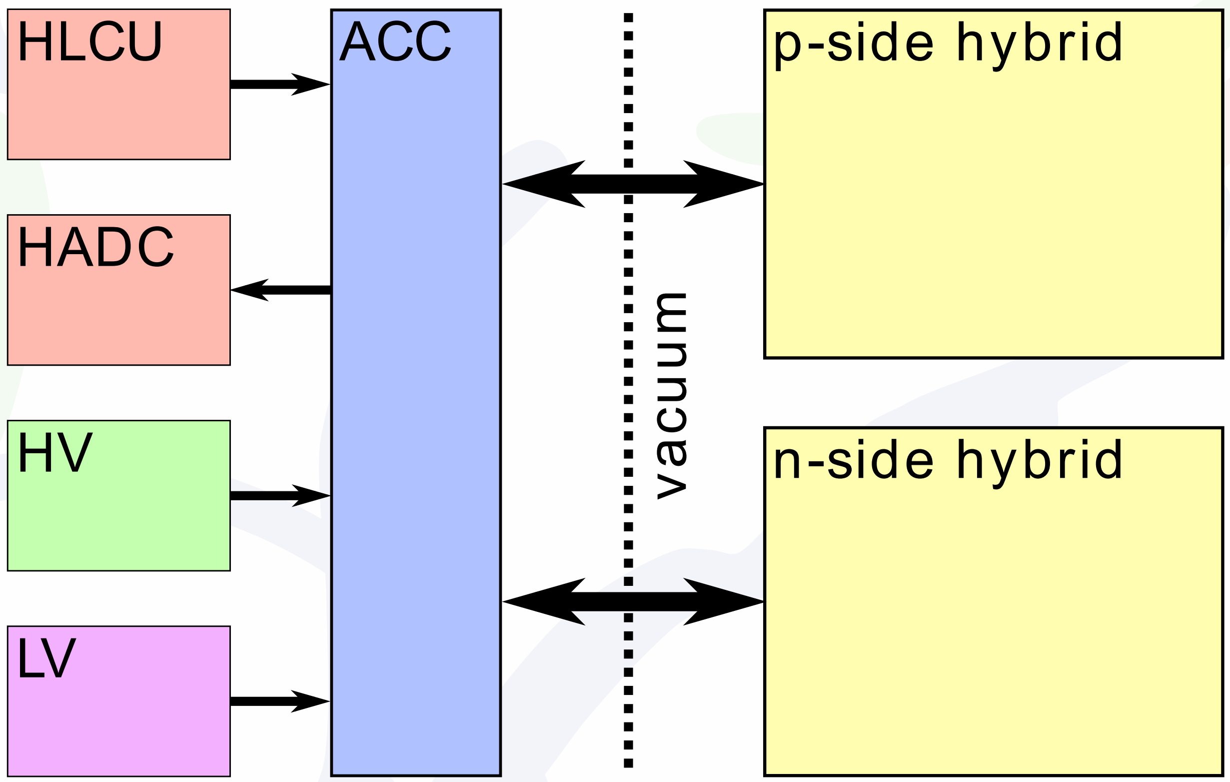
-> assoc. DVCS in "traditional" analysis mainly dilution, supported by **recent results from HERMES [JHEP 01 (2014) 077]:**

assoc. DVCS results consistent with zero but also with model prediction

Backup

SSD (silicon strip detector)





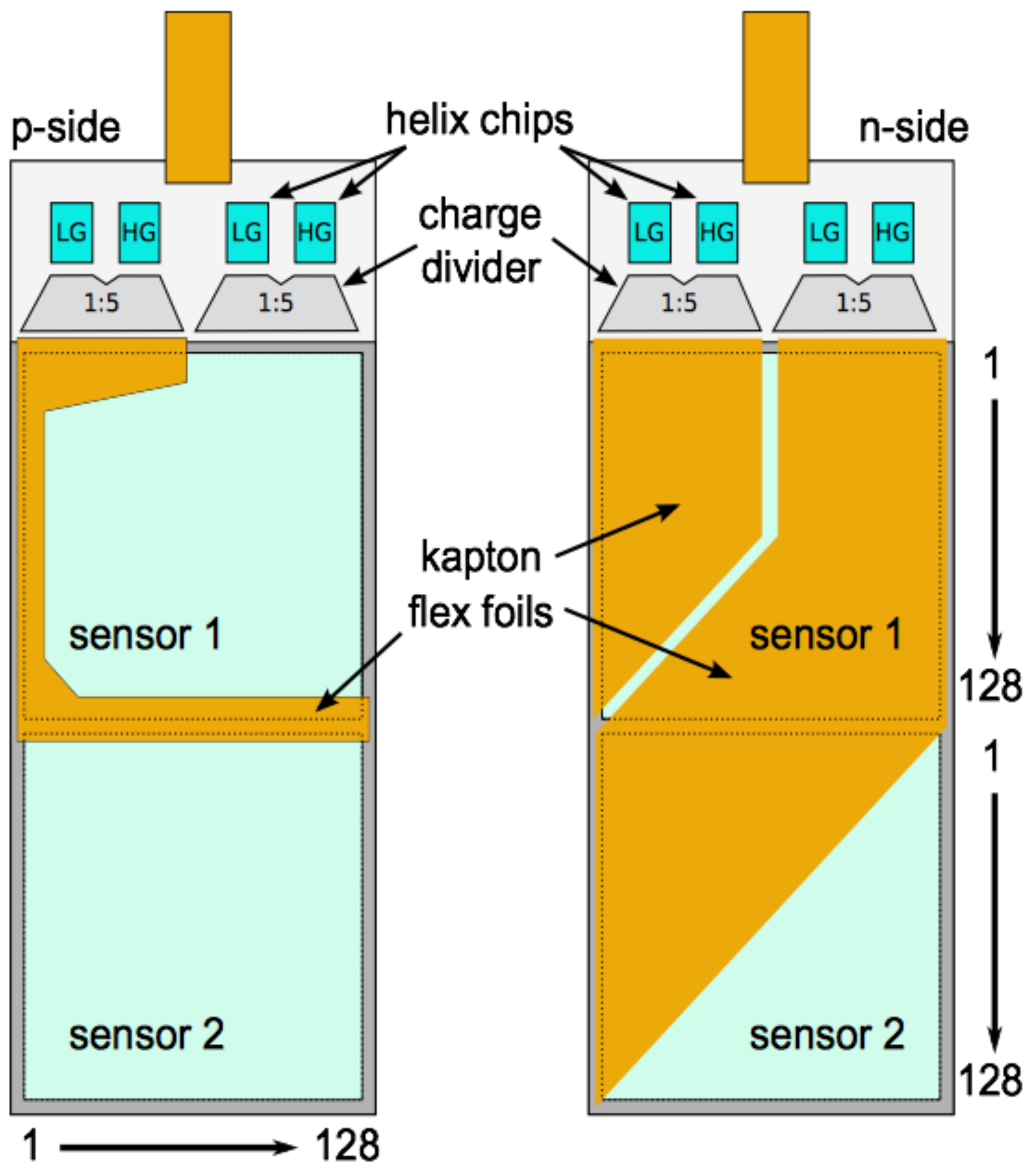
5.8 cm away from lepton beam, 1.5 cm gap

sensor thickness 295 μm - 315 μm

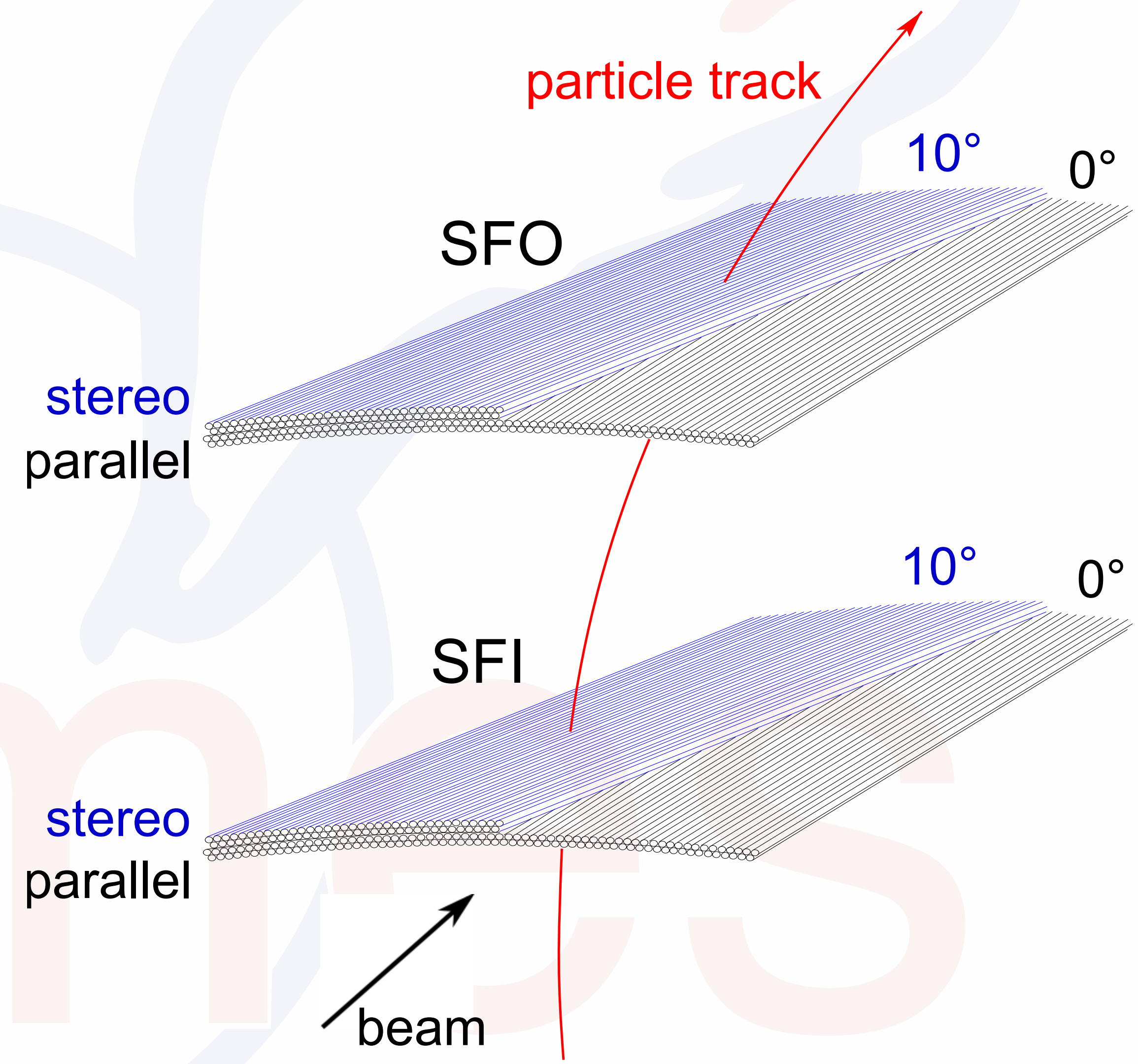
thickness of target cell 75 μm

The HERMES recoil detector

Sketch of front- and backside of a silicon strip detector module (SSD)

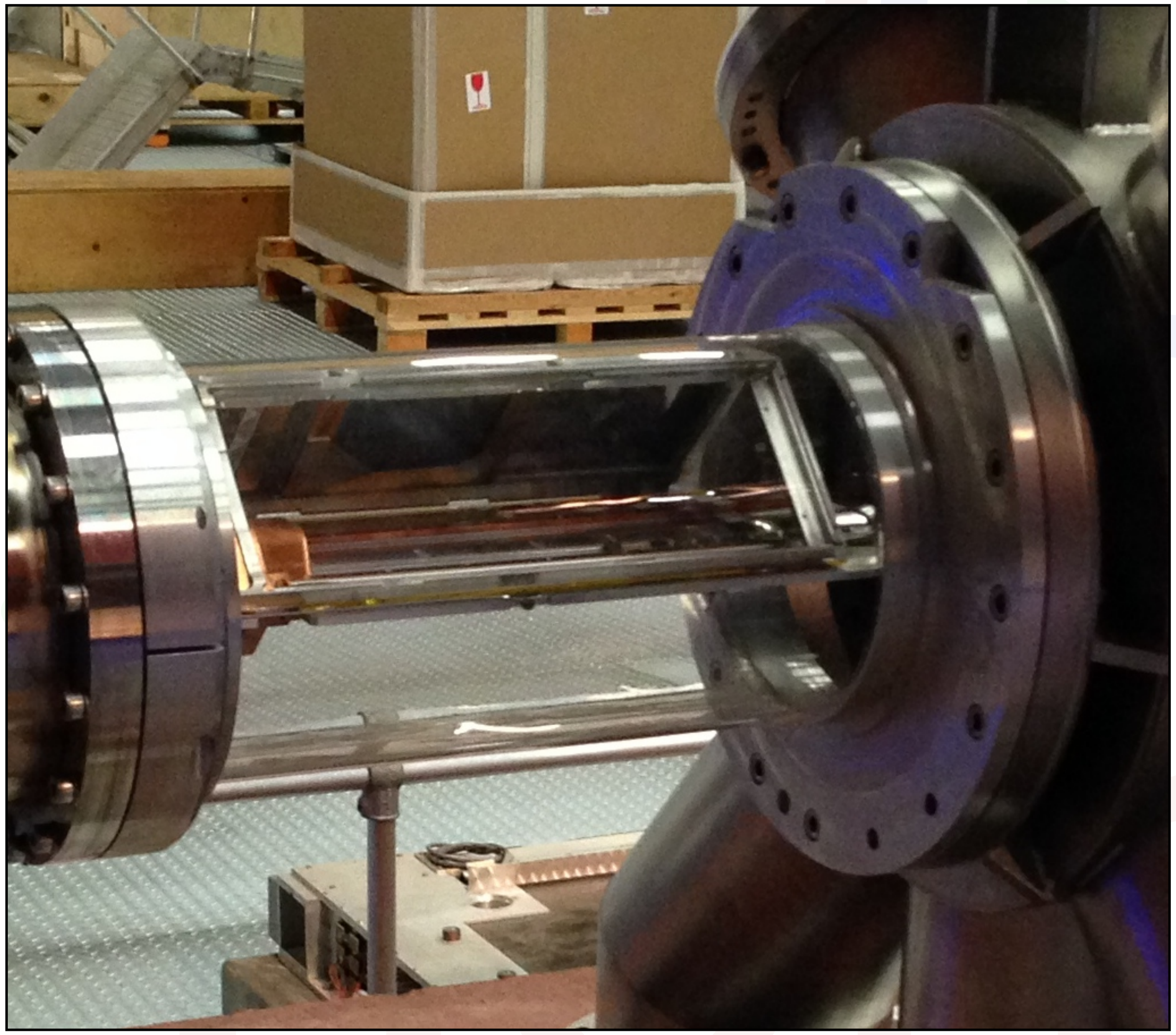


Schematic design of the scintillating fibre tracker (SFT)

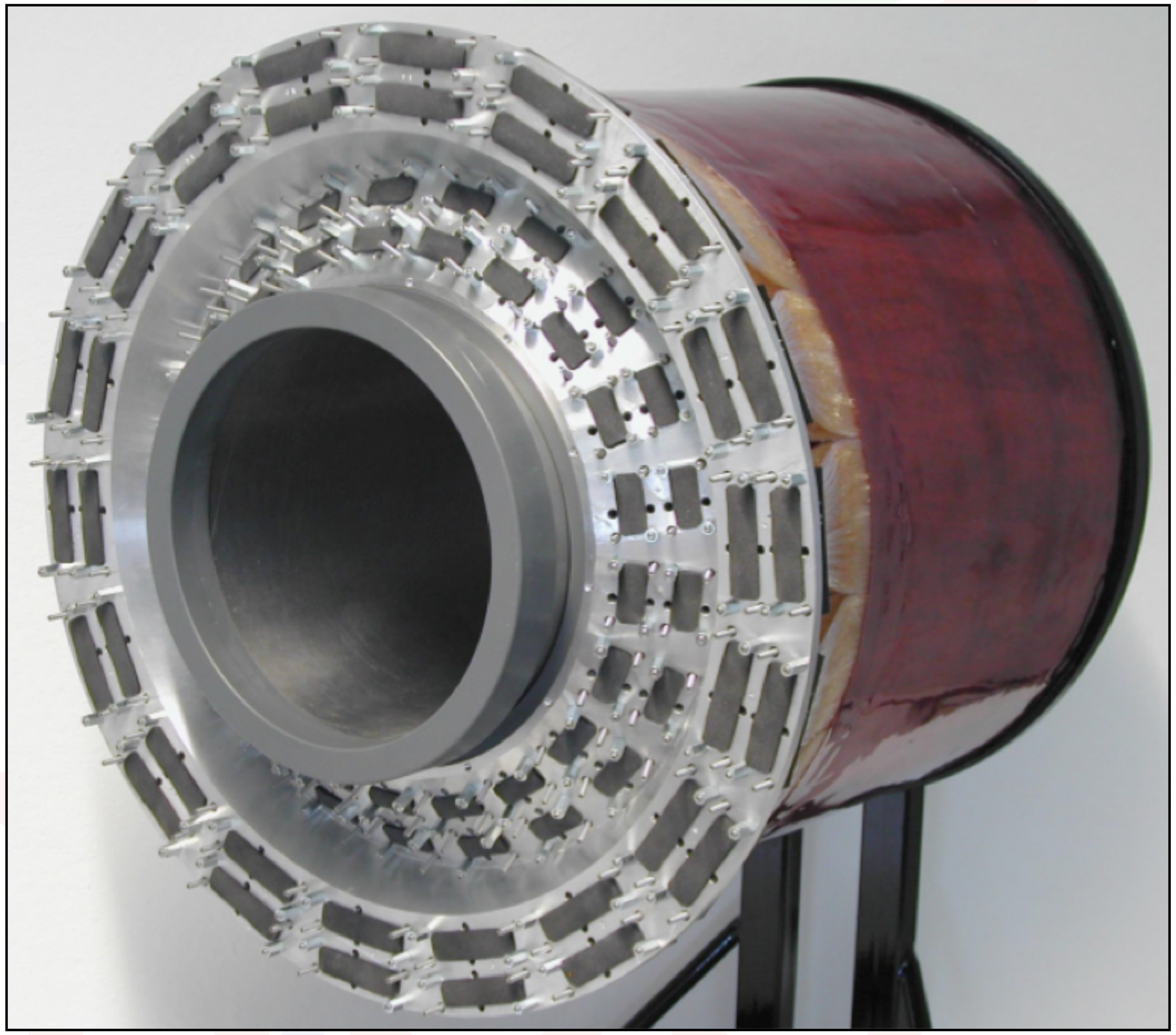


The HERMES recoil detector

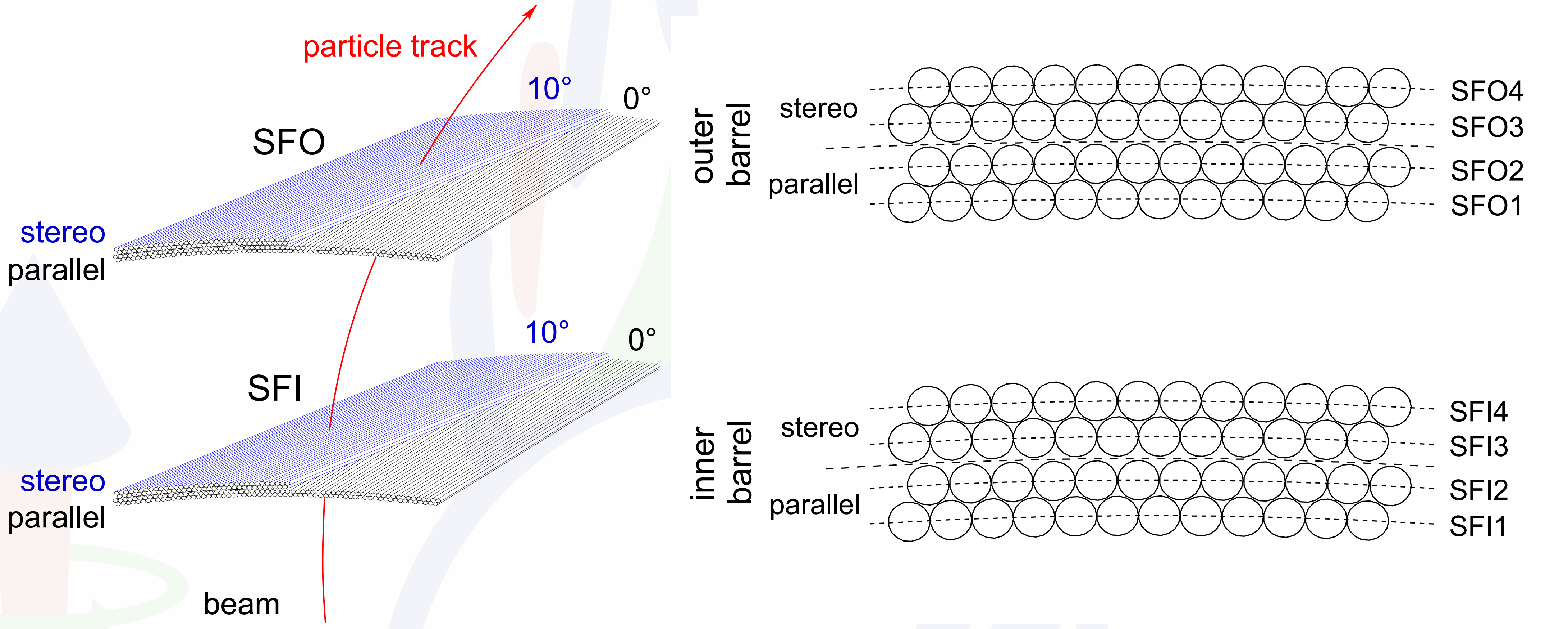
The silicon strip detector (SSD)



The scintillating fibre tracker (SFT)



SFT (scintillating fibre tracker)

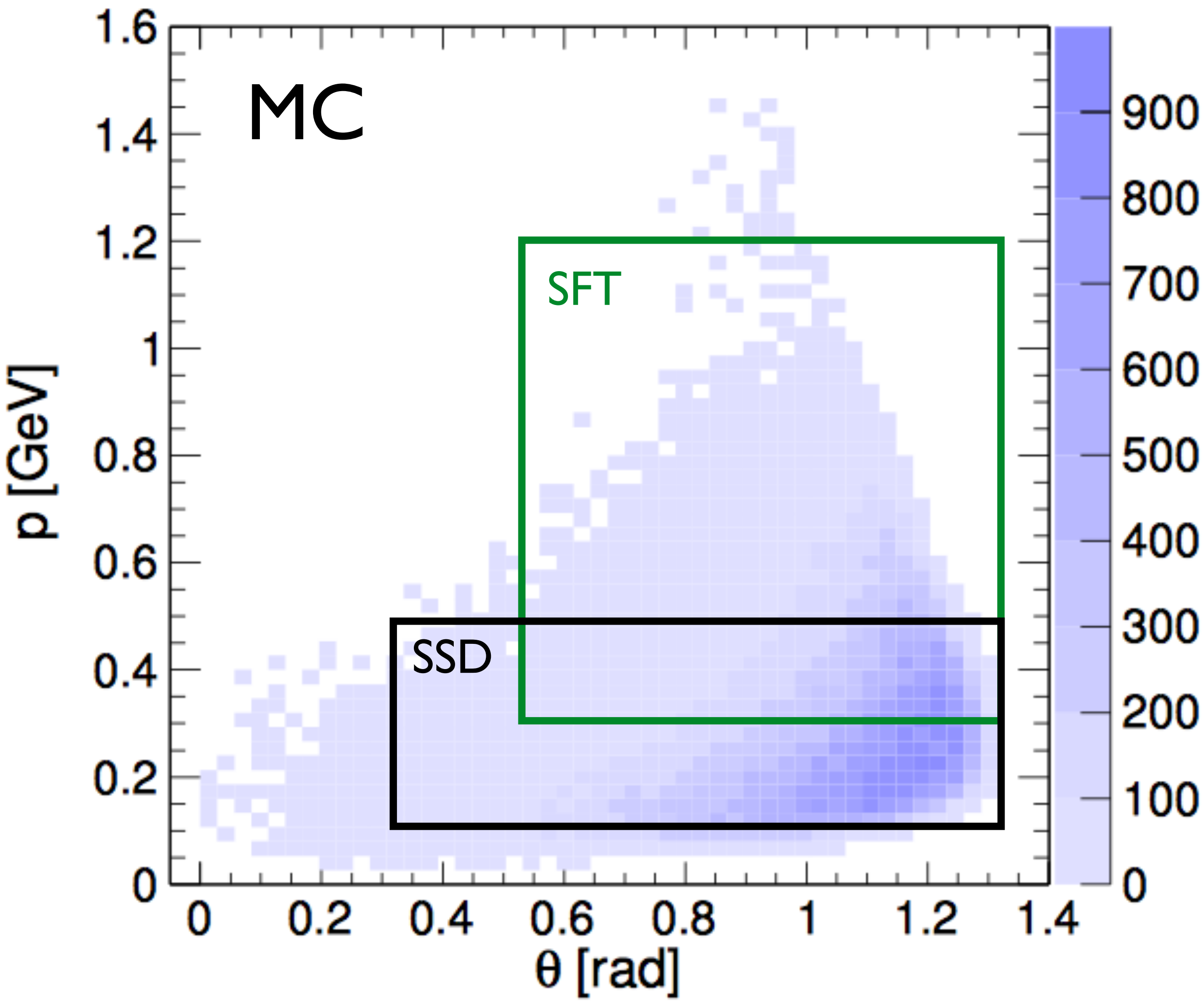


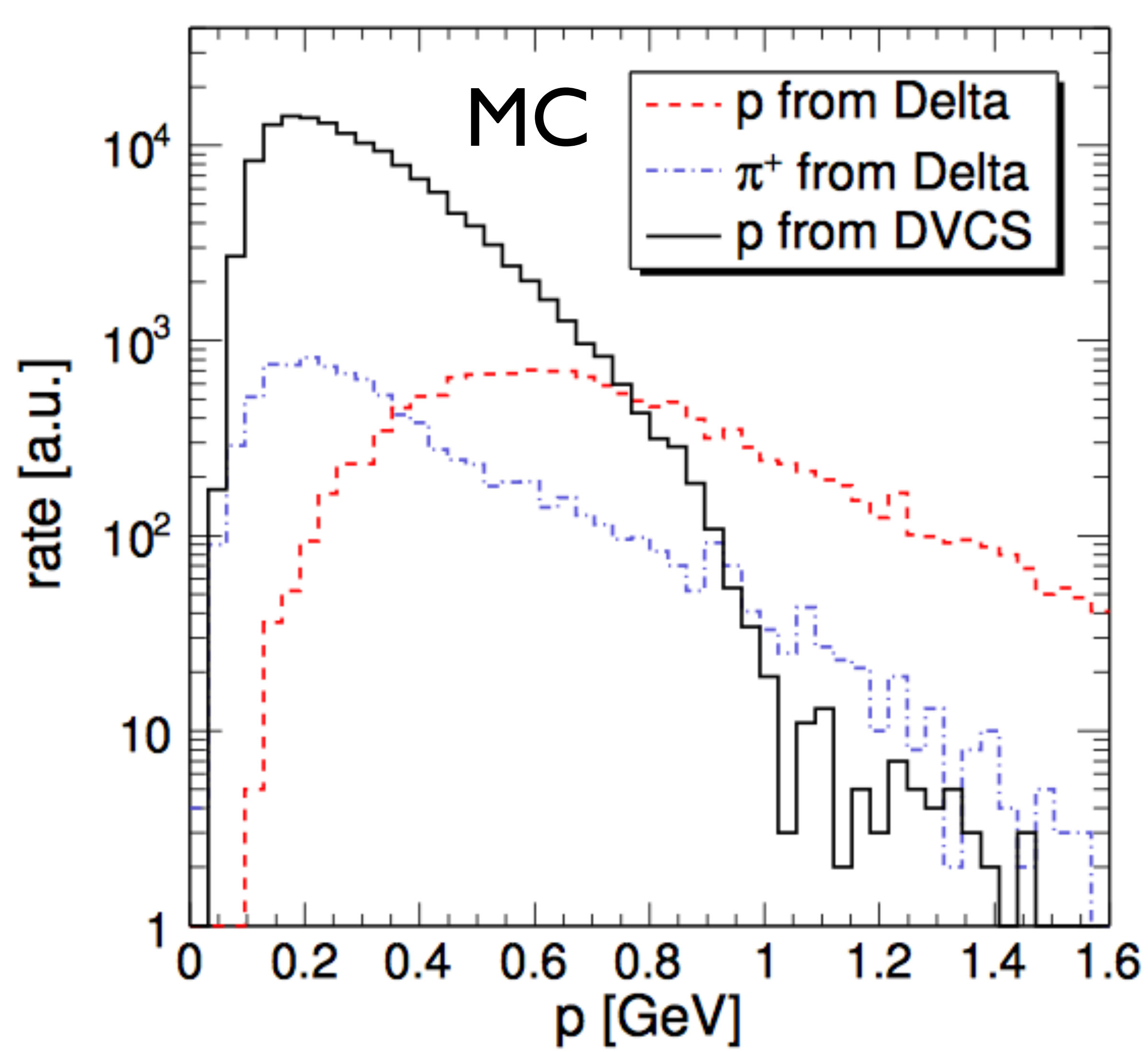
11.5 cm (18.5 cm) inner (outer) radius

1318+1320 (2198+2180) fibers with a diameter of 1 mm each

readout by 64-channel Hamamatsu H7546B MAPMTs

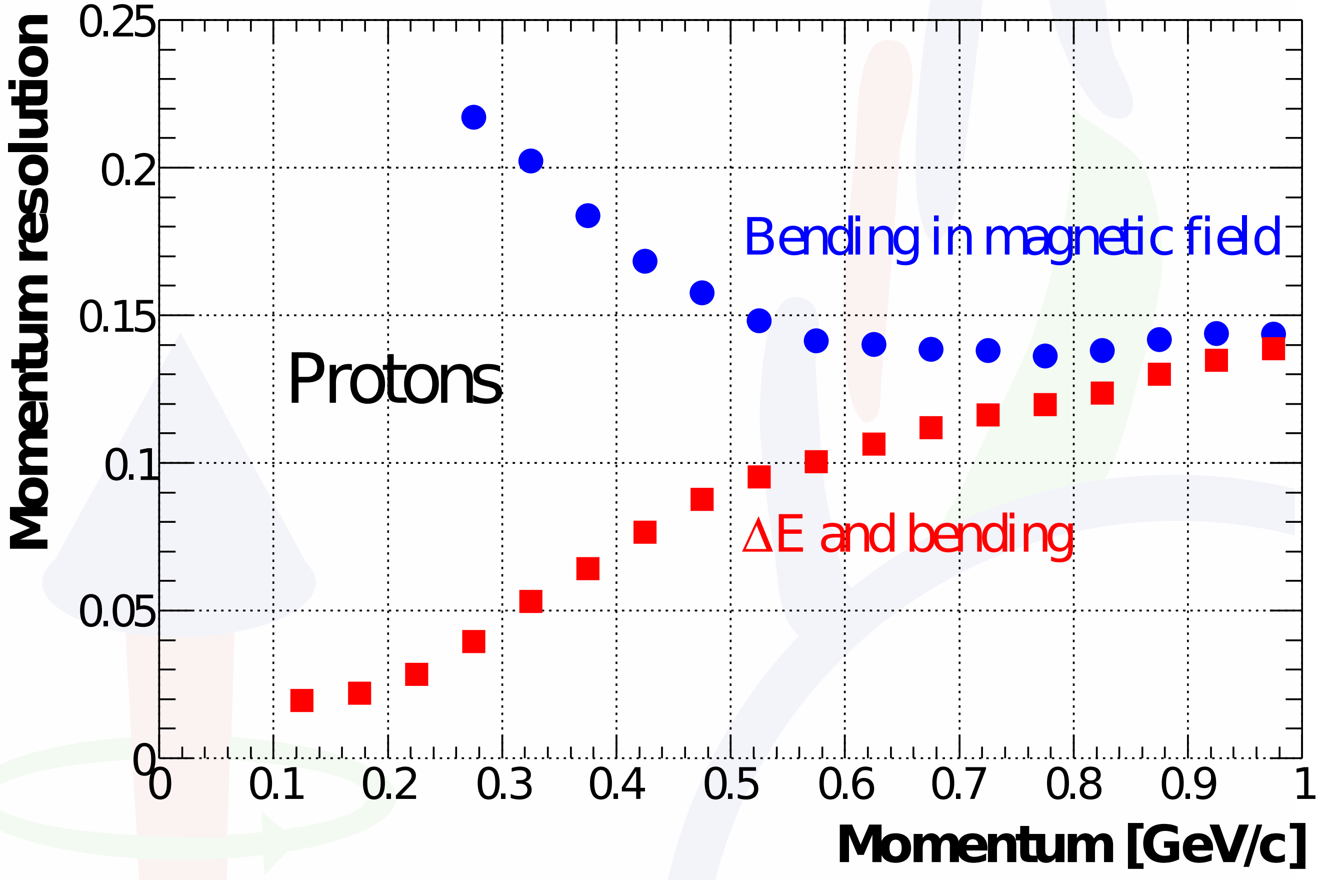
Kinematic coverage of the HERMES RD

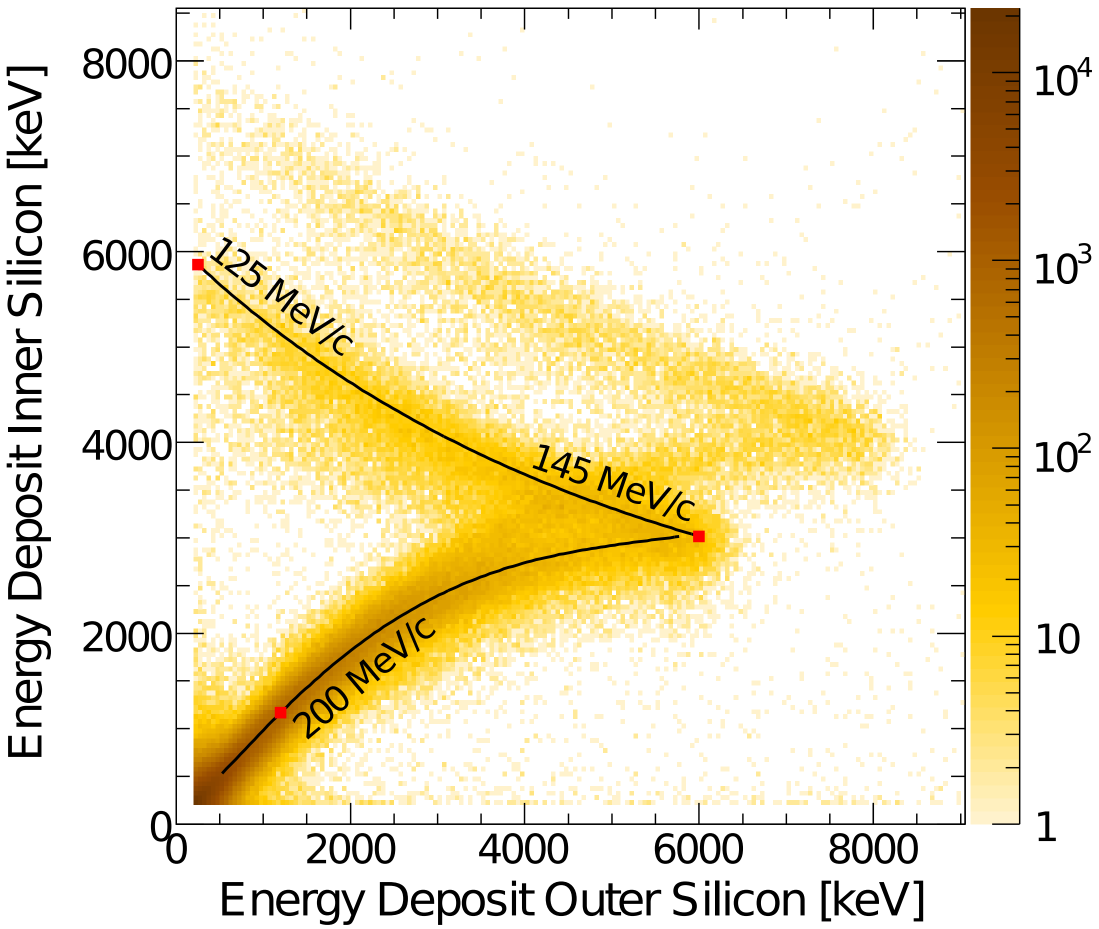




Scintillating fibre tracker (SFT) and silicon strip detector (SSD) complement each other

Recoil-detector tracking



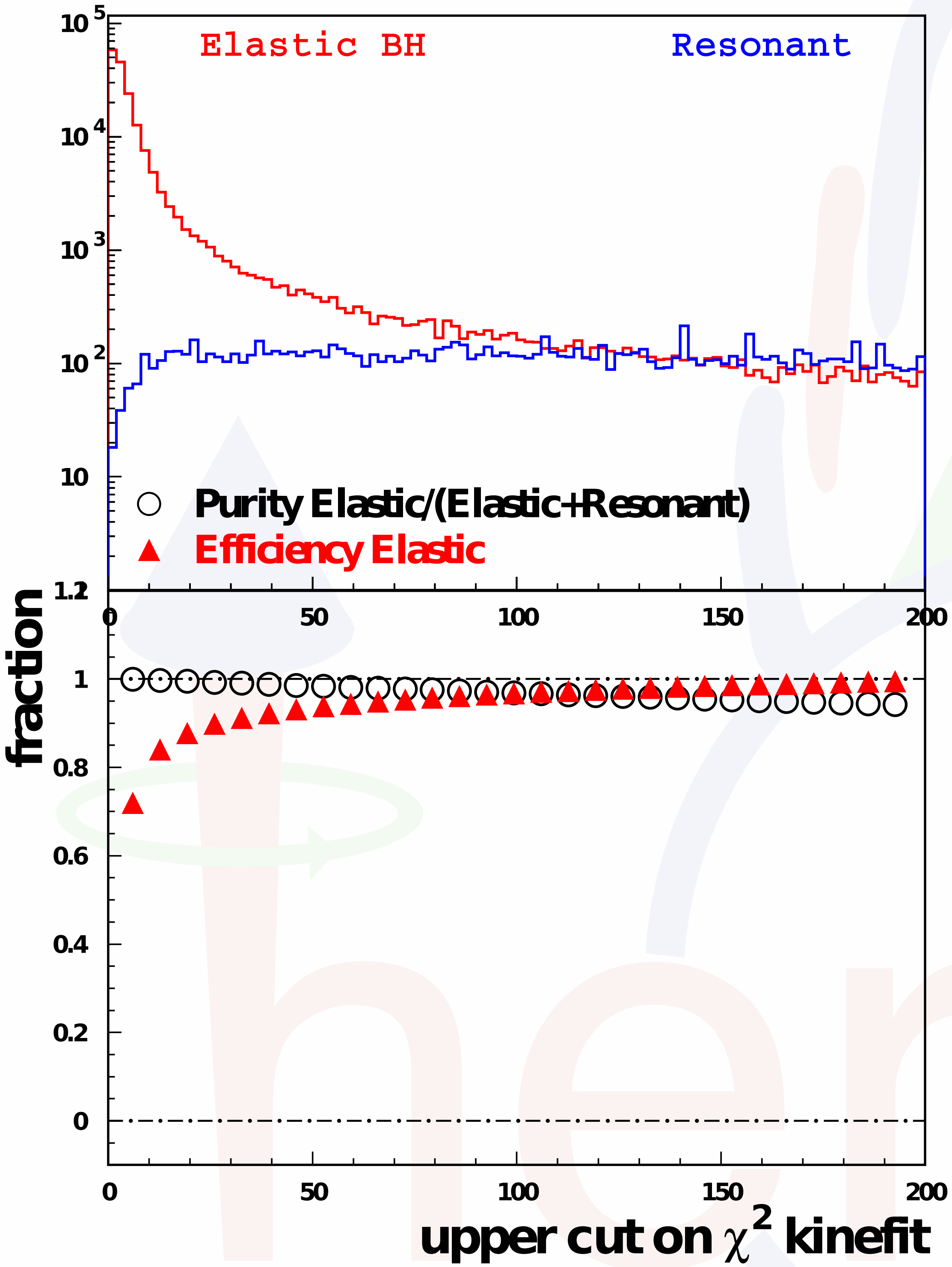


taking energy loss into account improves momentum resolution for low p

azimuthal-angle resolution: 4 mrad

polar-angle resolution: 10 mrad (for p>0.5 GeV)

Kinematic event fitting

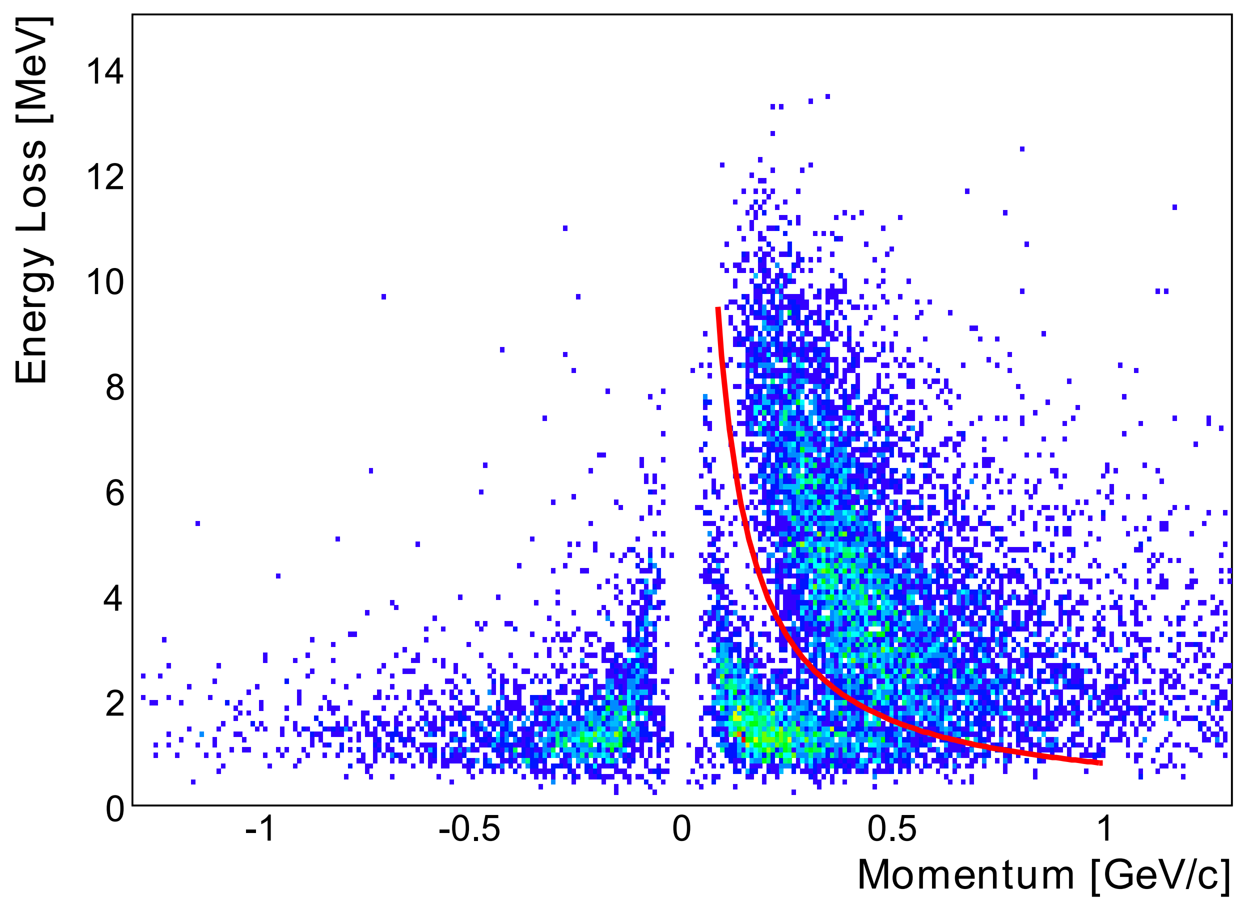


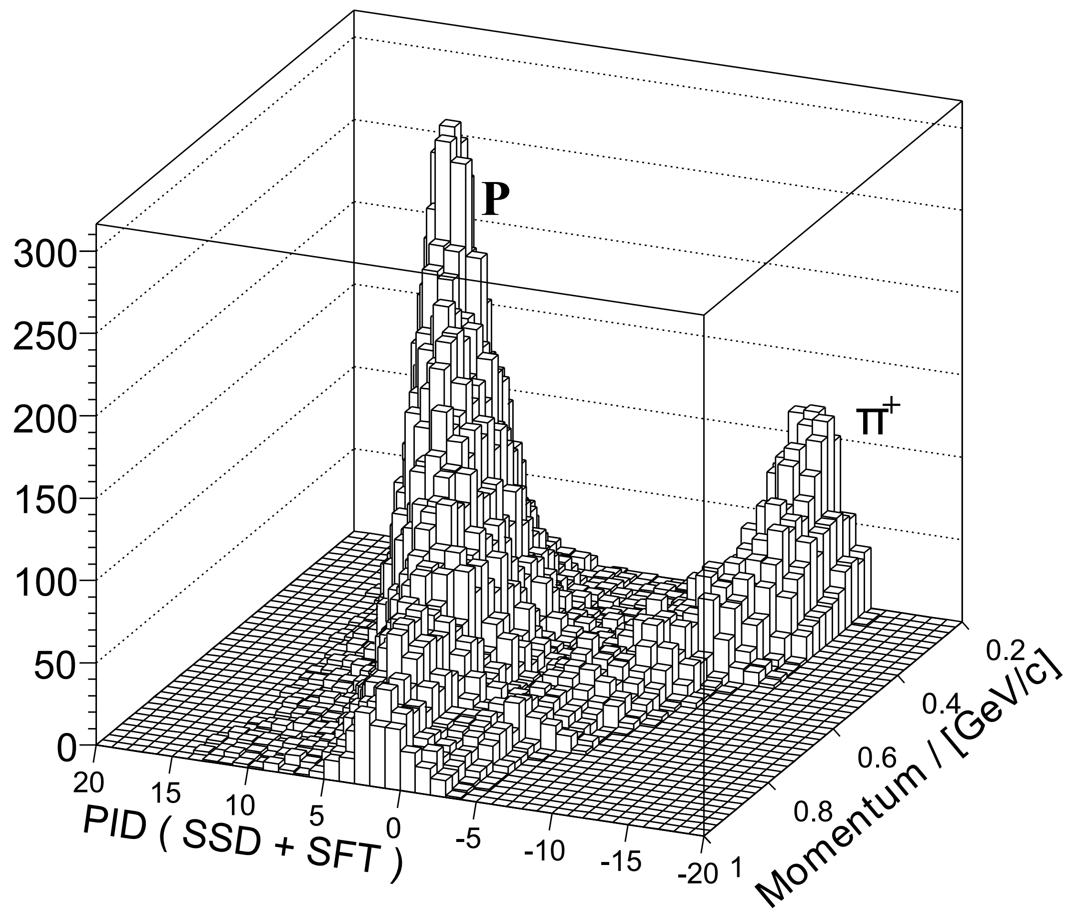
$$\chi^2_{pen} = \underbrace{\boxed{\sum_{i=1}^{9} \frac{(r_i^{fit} - r_i^{meas})^2}{\sigma_i^2}}}_{\chi^2\text{-value of interest}} + \underbrace{\boxed{T \cdot \sum_{j=1}^{4} \frac{\left[\boxed{f_j(r_1^{fit}, \ldots, r_9^{fit})}\right]^2}{(\sigma_j^f)^2}}}_{\text{penalty term}}$$

χ^2-value of interest penalty term constraints

- 4-momentum conservation as constraints
- lowest χ^2-value in case of multiple recoil tracks per event
- minimum of 1 % fit probability required, which corresponds to $\chi^2 < 13.7$

Recoil PID



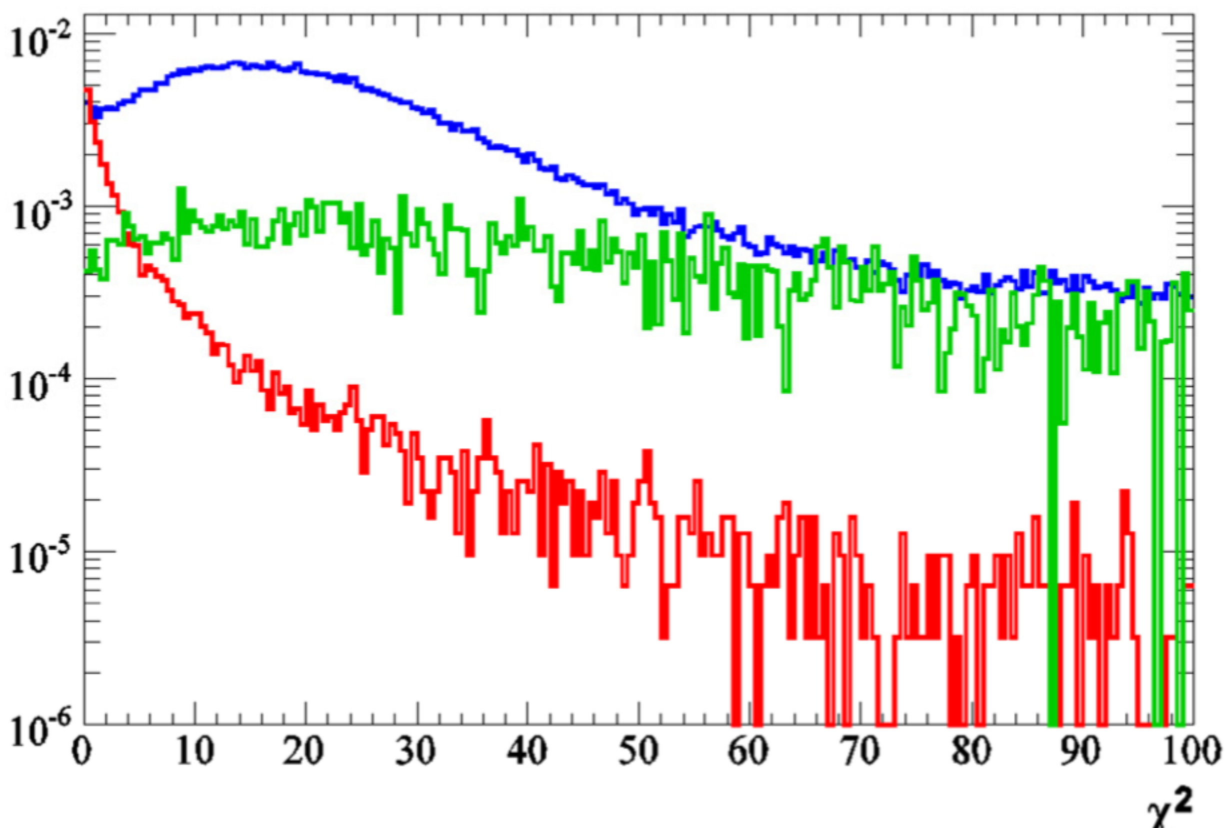


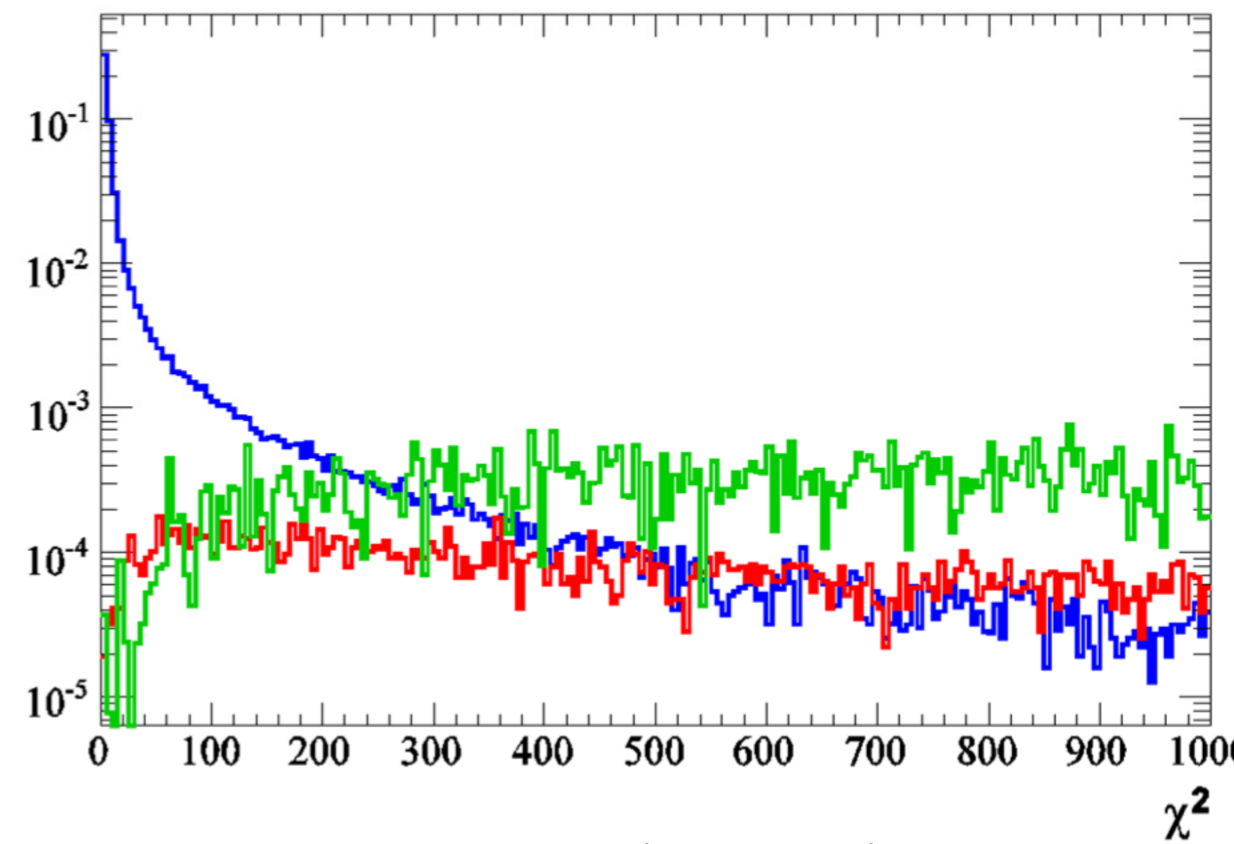
discrimination between protons and positively charged pions

parent distributions were crucial and determined experimentally

Kinematic fitting for ep→e γ pπ^0

ep→e γ pπ^0 ep→e γ p   SIDIS





ep→e γ pπ^0 hypothesis

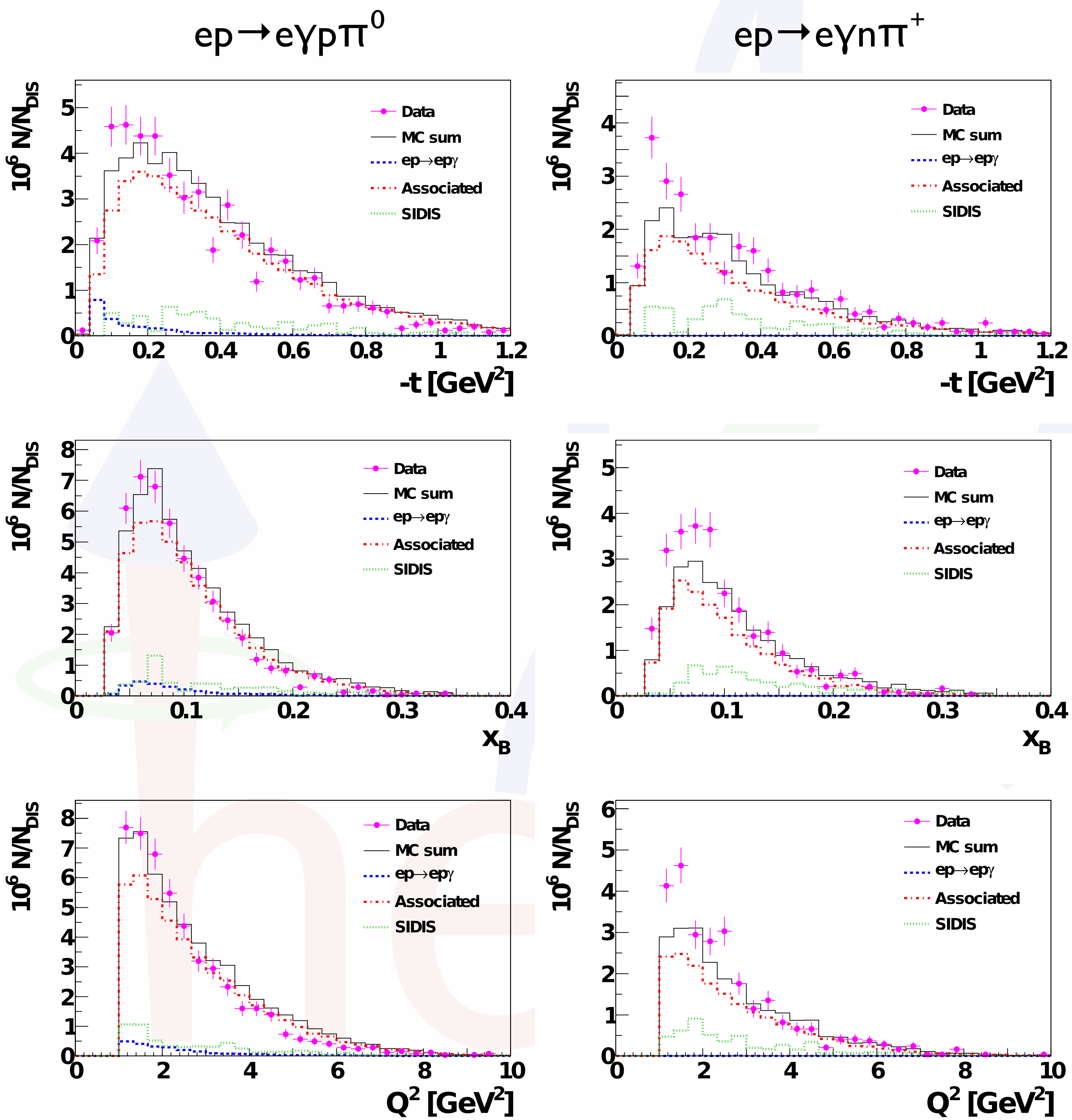
$\chi^2_{ep\to e\gamma p\pi^0} < 4.6$

ep→e γ p hypothesis

$\chi^2_{ep\to e\gamma p} > 50$

Using powerful kinematic fitting of ep→e γ p hypothesis is crucial for the ep→e γ Nπ analysis

Selection of associated events



Uncharged particle remains undetected

Kinematic fitting in case of $ep \rightarrow e\,\gamma\,N\pi$ hypothesis therefore not as strong

Additional selection criteria:

- Recoil PID information
- Lower-cut on $ep \rightarrow e\,\gamma\,p$ hypothesis