DVCS @ HERMES

M. MURRAY, UNIVERSITY OF GLASGOW

PacSpin 2011

Deeply Virtual Compton Scattering

- Physics - Interests & Constraints
- HERMES DVCS Measurements
- GPDs & Future Measurements

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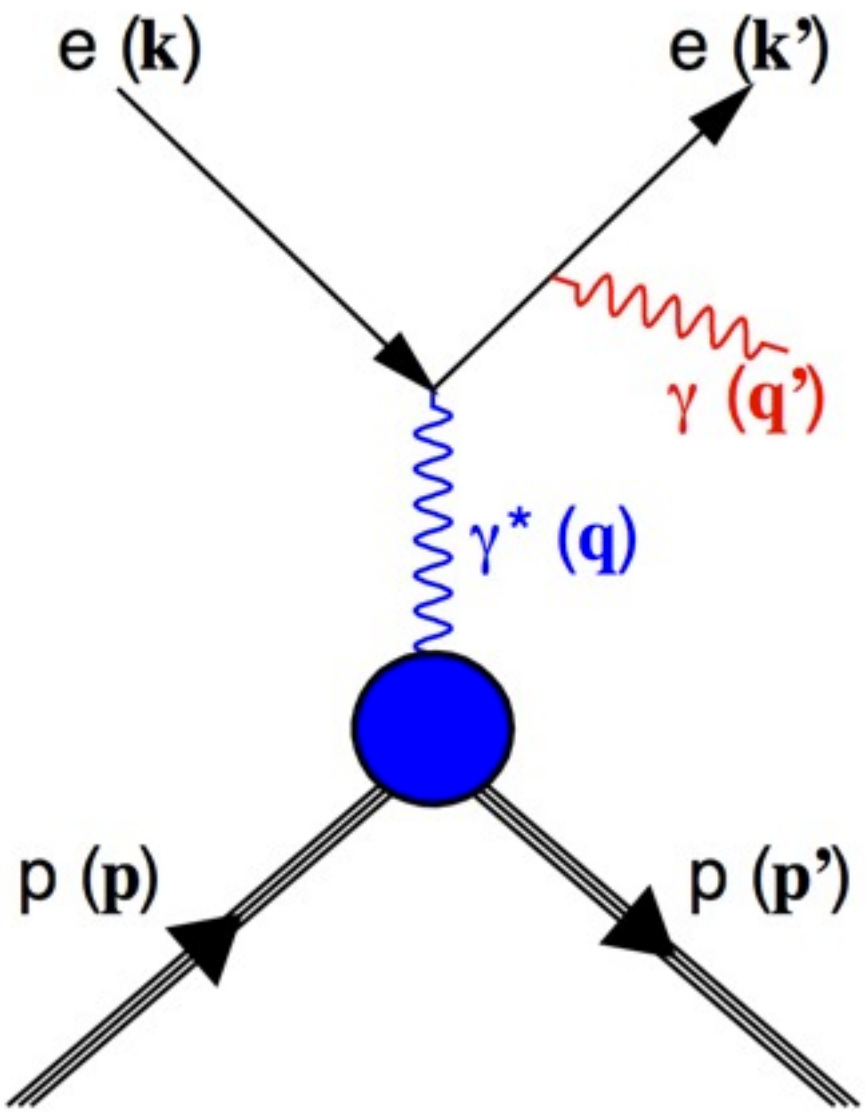
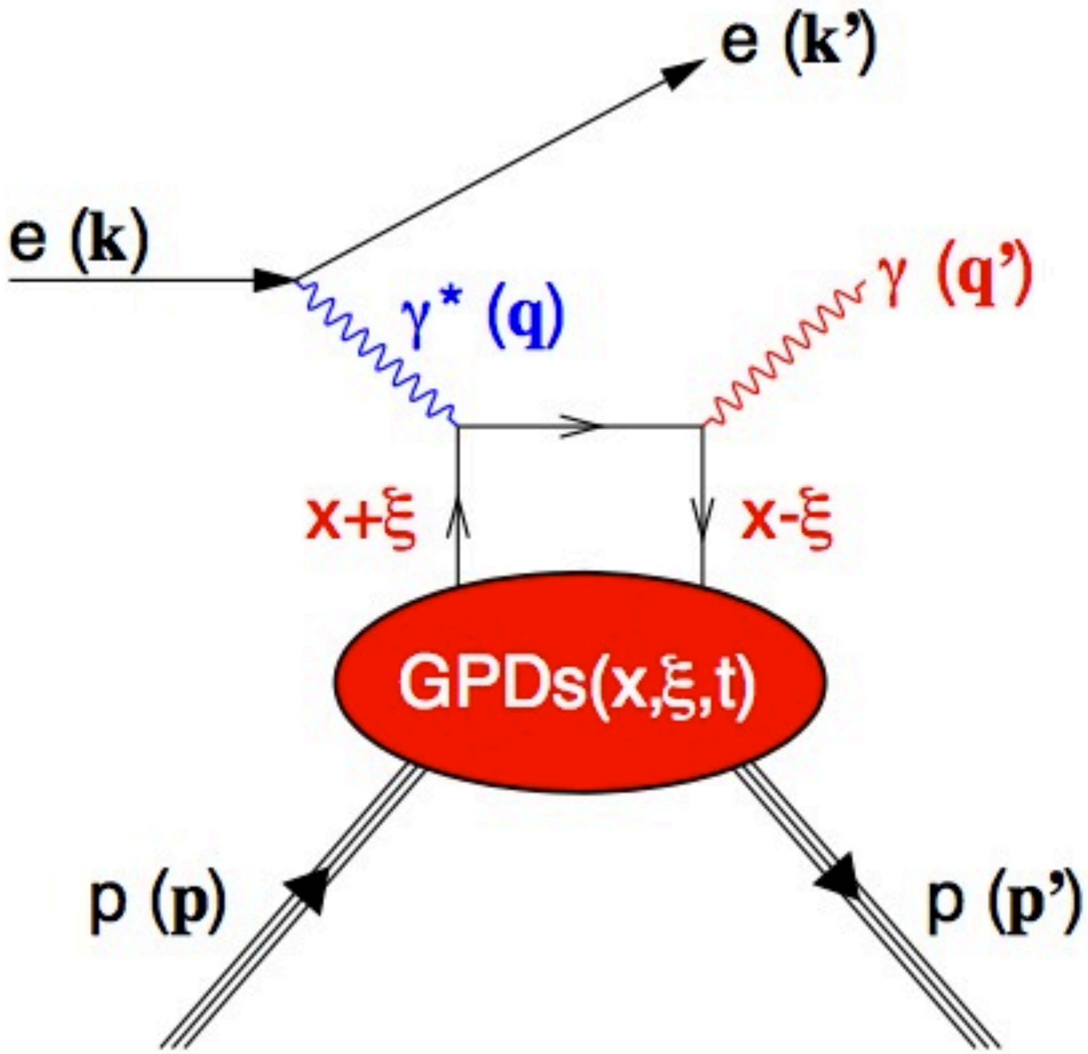
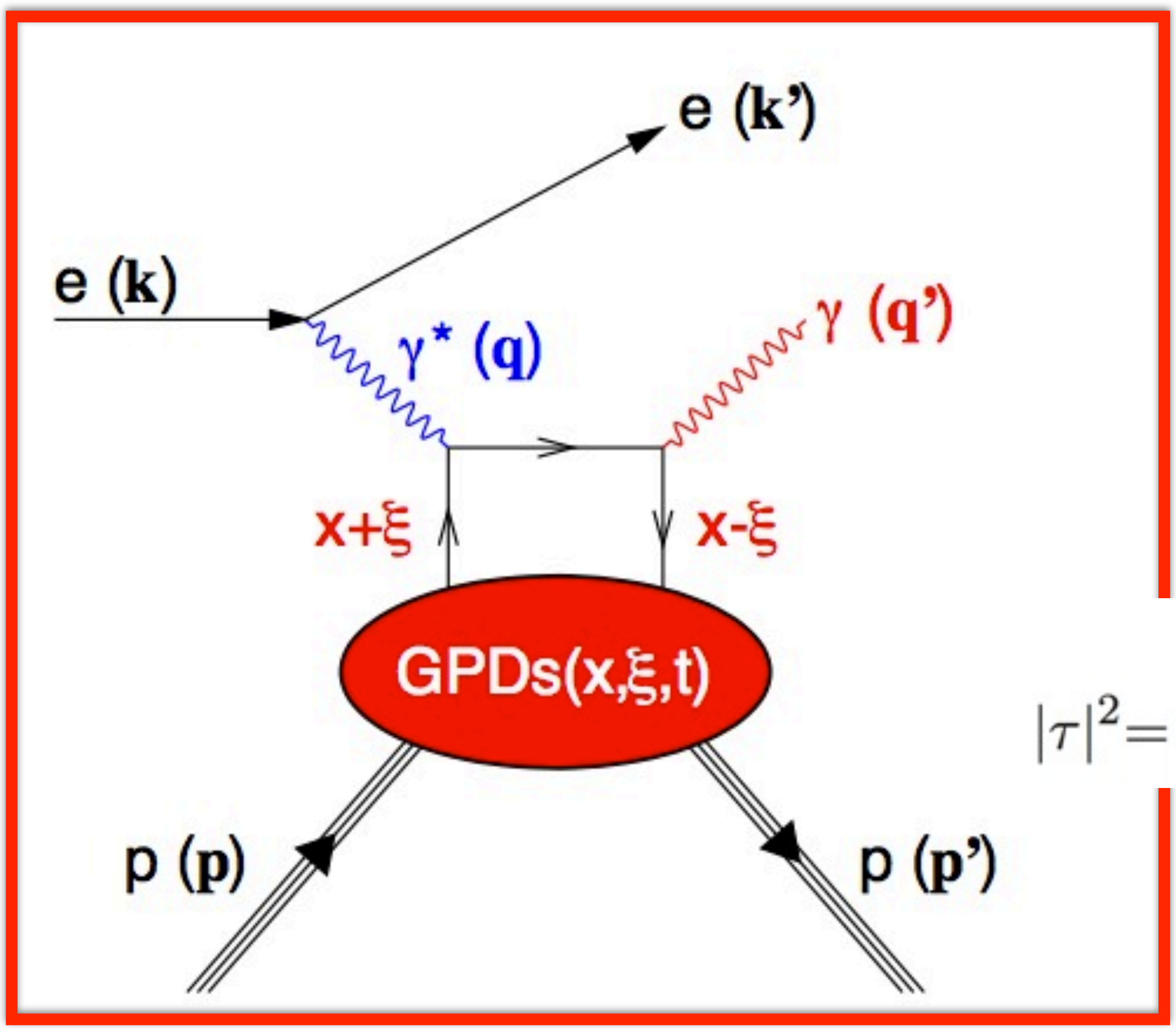
Deeply Virtual Compton Scattering

$e\,p \rightarrow e\,p\,\gamma$





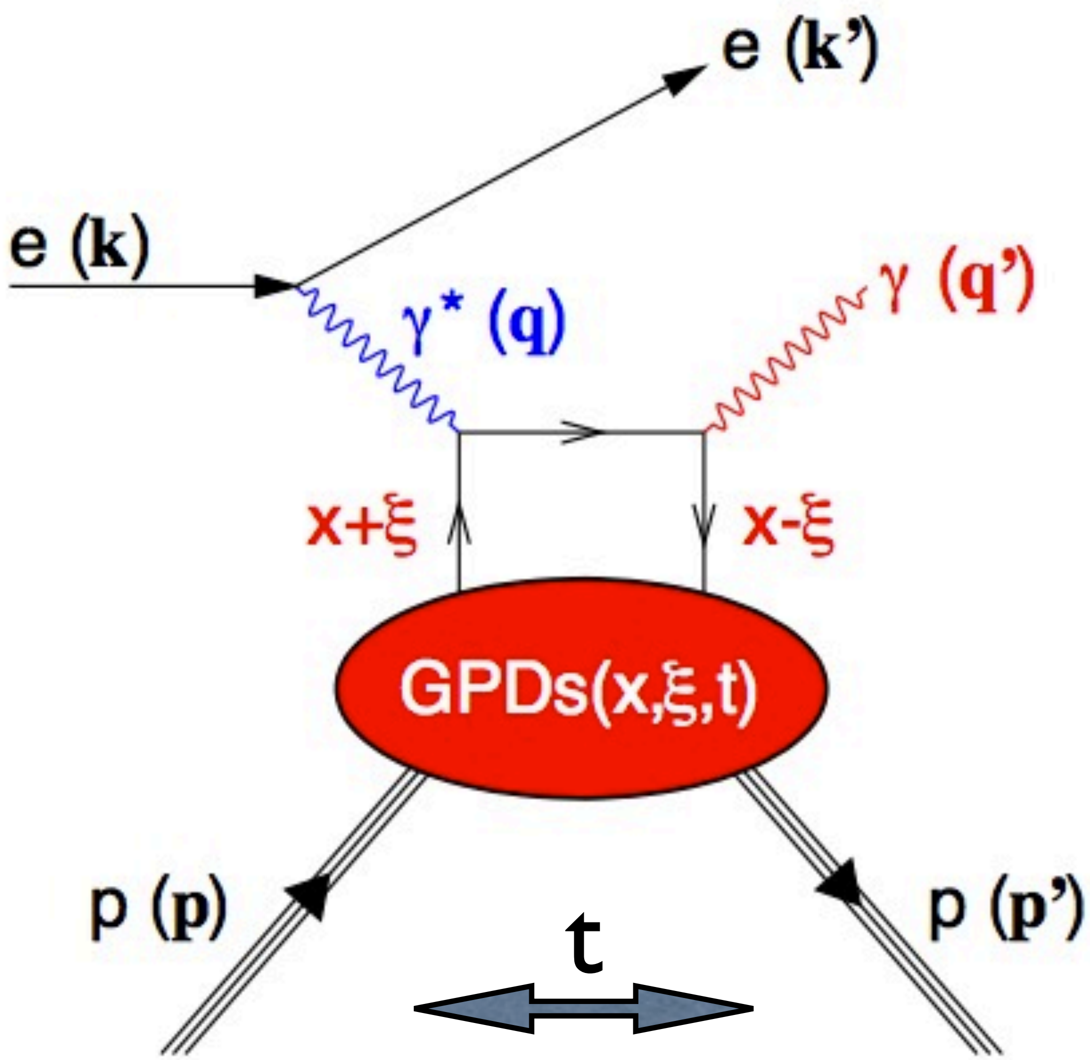
Deeply Virtual Compton Scattering



$$\frac{d\sigma}{dx_B\, dQ^2\, d|t|\, d\phi} = \frac{x_B\, e^6\, |\tau|^2}{32(2\pi)^4\, Q^4\, \sqrt{1+\epsilon^2}}$$

$$|\tau|^2 = |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \overbrace{\tau_{BH}\tau_{DVCS}^* + \tau_{BH}^*\tau_{DVCS}}^{\mathcal{I}}$$

Generalised Parton Distributions

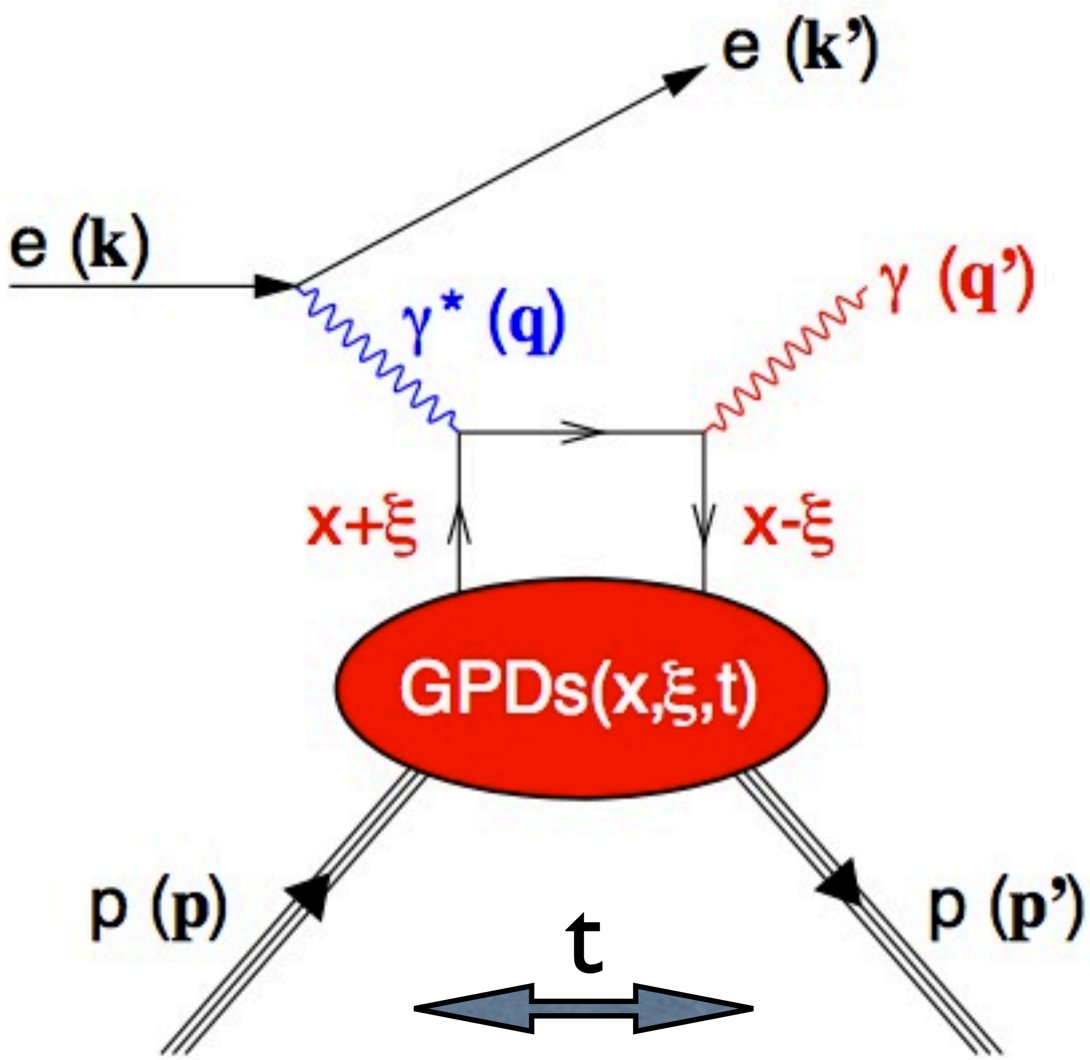


t - Mandelstam variable (squared momentum transfer to nucleon)

x - Fraction of nucleon's longitudinal momentum carried by active quark

ξ - half the change in the longitudinal momentum of the active quark.

Generalised Parton Distributions



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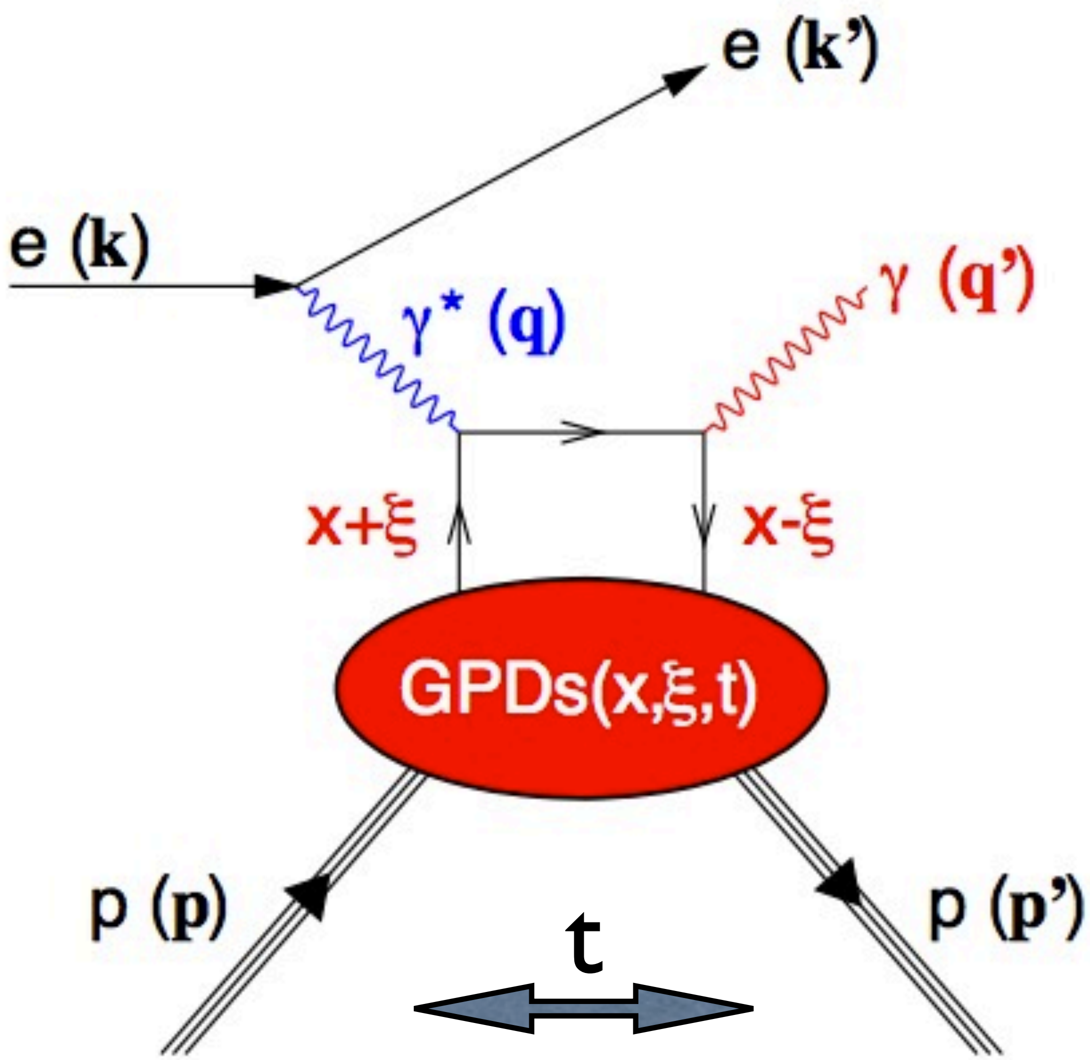

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GPD Physics

Four distributions of interest: H, E, $\tilde{H}$, $\tilde{E}$

H and E integrate over quark helicities

$\tilde{H}$ and $\tilde{E}$ are quark helicity difference distributions

$$J_q = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} \left[H^q(x, \xi, t) + E^q(x, \xi, t) \right] x \, dx$$

GPD Physics

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Nucleon helicity inversion

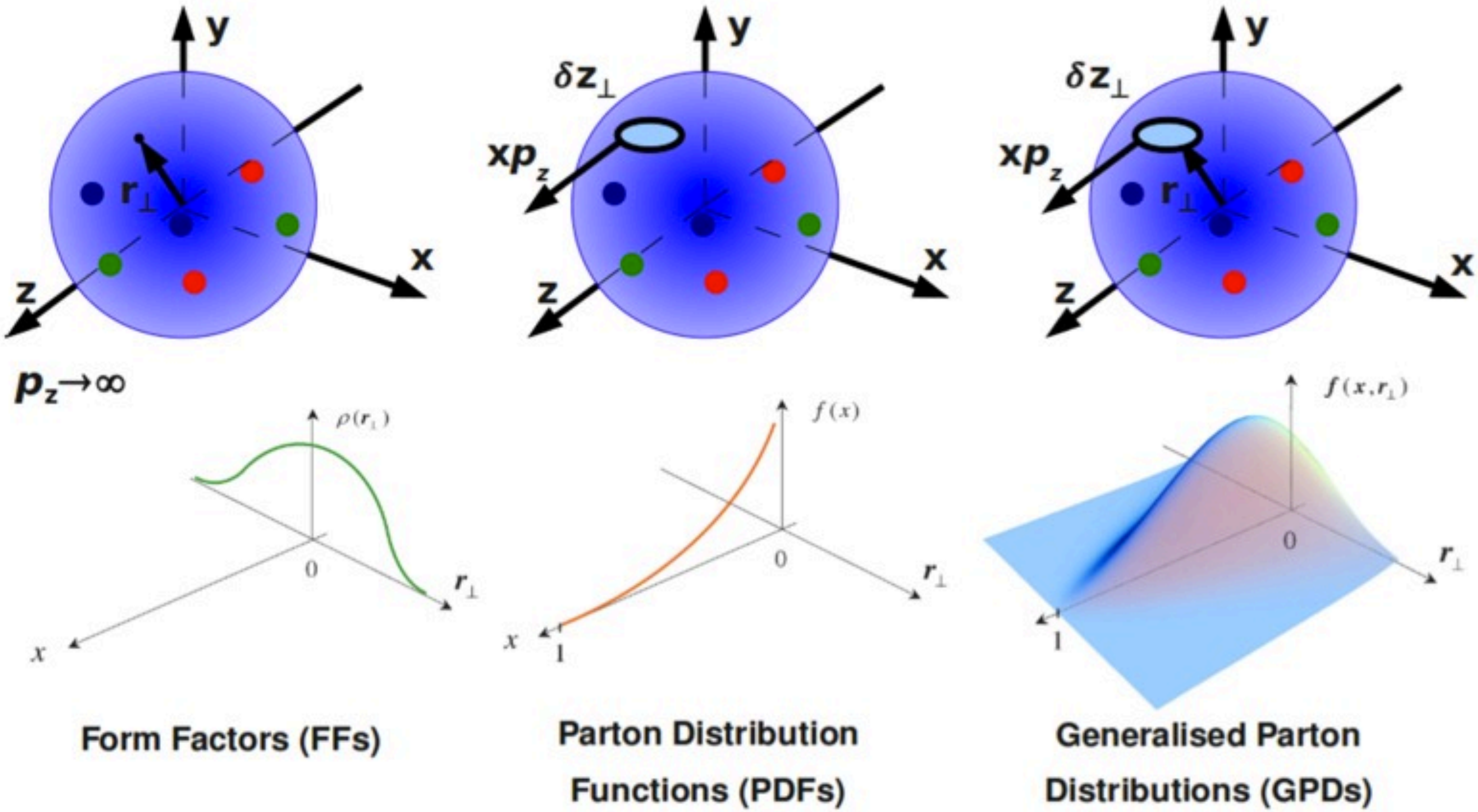
Nucleon helicity conservation

"Ji's Relation"

$$J_q = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} \left[H^q \left(x, \xi, t \right) + E^q \left(x, \xi, t \right) \right] x \, dx$$

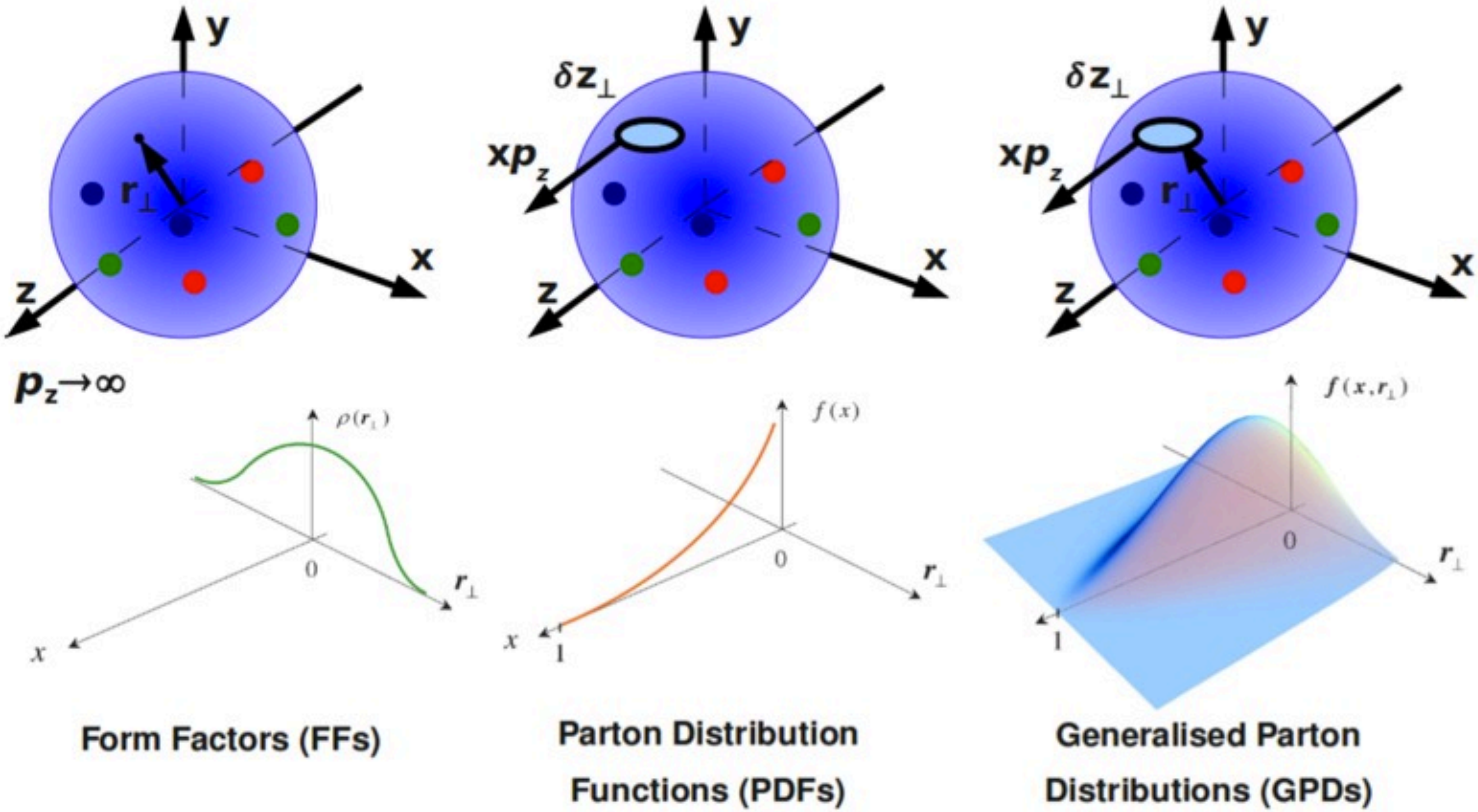
Phys. Rev. Lett. 78:610, 1997

GPD Physics



y
x
z
$r_\perp$
$p_z \to \infty$
$\rho(r_\perp)$
0
$r_\perp$
x
$\delta z_\perp$
xp_z
$f(x)$
1
$f(x, r_\perp)$
Form Factors (FFs)
Parton Distribution Functions (PDFs)
Generalised Parton Distributions (GPDs)

GPD Physics



H - unpolarised nucleon $\tilde{H}$ - polarised nucleon

GPD Physics

GPDs describe only the soft part of the interaction

Accessed via cross-sections and asymmetries:
requires convolution with a hard scattering kernel

$\mathrm{H} \rightarrow \mathcal{H}$ $\tilde{\mathrm{H}} \rightarrow \tilde{\mathcal{H}}$ $\mathrm{E} \rightarrow \mathcal{E}$ $\tilde{\mathrm{E}} \rightarrow \tilde{\mathcal{E}}$

Results in "Compton Form Factors" accessible through DVCS, which have real and imaginary parts

GPD Physics

GPDs describe only the soft part of the interaction

Accessed via cross-sections and asymmetries:
requires convolution with a hard scattering kernel

$$\begin{aligned} \Im m\, \mathcal{F}(\xi, t) &= F(\xi, \xi, t) \pm F(-\xi, \xi, t)\,, \\ \Re e\, \mathcal{F}(\xi, t) &= \mathcal{P}_{\mathrm{C}} \int_{-1}^{1} \frac{F(x, \xi, t)}{x - \xi} \pm \frac{F(x, \xi, t)}{x + \xi}\, dx \end{aligned}$$

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$$\Re e\,\mathcal{F}(\xi, t) = \mathcal{P}_{\mathrm{C}} \int_{-1}^{1} \frac{F(x, \xi, t)}{x - \xi} \pm \frac{F(x, \xi, t)}{x + \xi}\,dx$$

Limited *x* access

DVCS @ HERMES

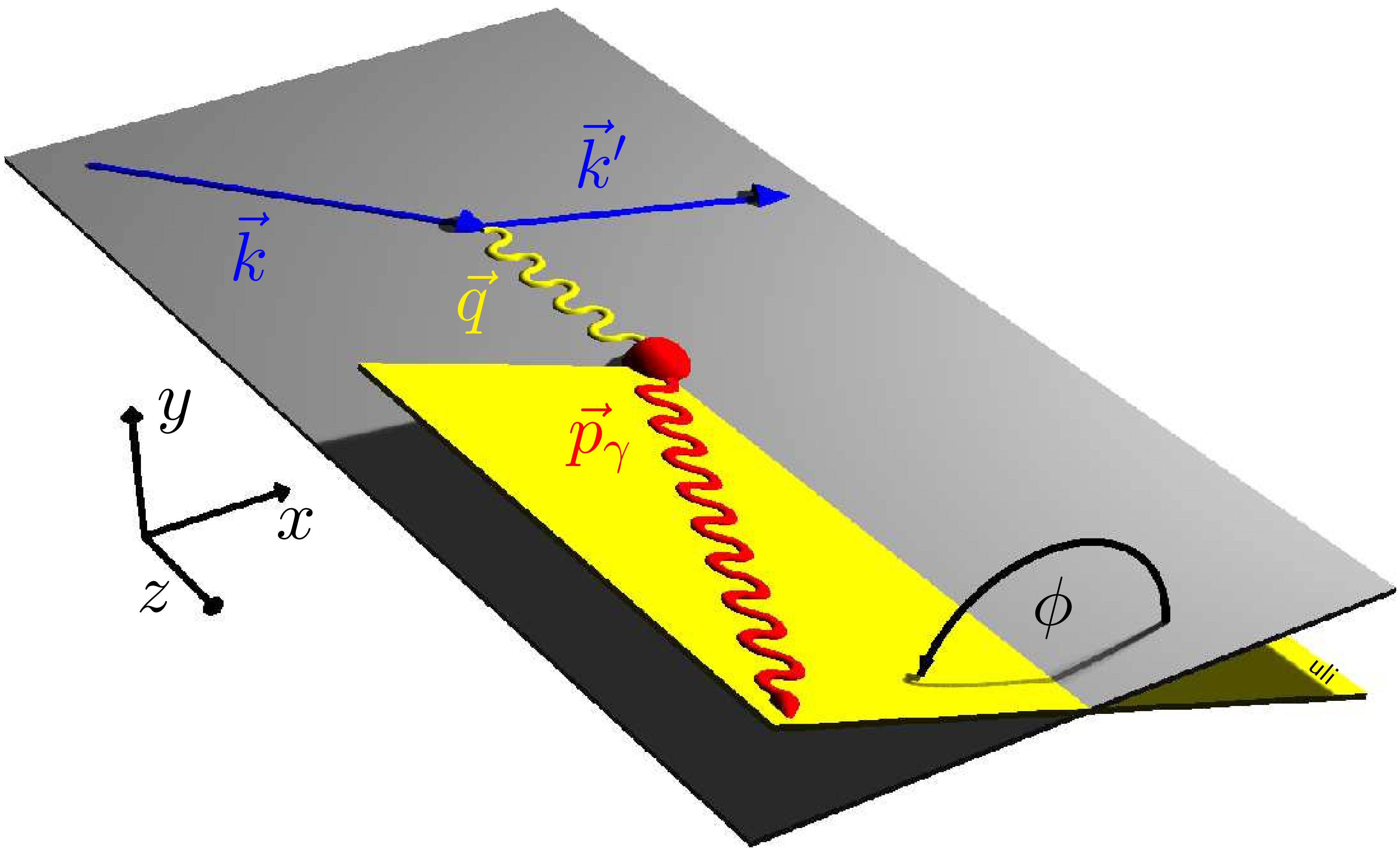
$$\mathcal{A}_C(\phi) \equiv \frac{d\sigma^{+}(\phi) - d\sigma^{-}(\phi)}{d\sigma^{+}(\phi) + d\sigma^{-}(\phi)} \quad \tilde{\propto} \quad \mathrm{Re}(\mathcal{H})$$

$$\mathcal{A}_{\mathrm{LU}}(\phi) \equiv \frac{[\sigma^{\rightarrow\Leftarrow}(\phi) + \sigma^{\rightarrow\Rightarrow}(\phi)] - [\sigma^{\leftarrow\Leftarrow}(\phi) + \sigma^{\leftarrow\Rightarrow}(\phi)]}{[\sigma^{\rightarrow\Leftarrow}(\phi) + \sigma^{\rightarrow\Rightarrow}(\phi)] + [\sigma^{\leftarrow\Leftarrow}(\phi) + \sigma^{\leftarrow\Rightarrow}(\phi)]} \quad \tilde{\propto} \quad \mathrm{Im}(\mathcal{H})$$

$$\mathcal{A}_{\mathrm{UL}}(\phi) \equiv \frac{[\sigma^{\leftarrow\Rightarrow}(\phi) + \sigma^{\rightarrow\Rightarrow}(\phi)] - [\sigma^{\leftarrow\Leftarrow}(\phi) + \sigma^{\rightarrow\Leftarrow}(\phi)]}{[\sigma^{\leftarrow\Rightarrow}(\phi) + \sigma^{\rightarrow\Rightarrow}(\phi)] + [\sigma^{\leftarrow\Leftarrow}(\phi) + \sigma^{\rightarrow\Leftarrow}(\phi)]} \quad \tilde{\propto} \quad \mathrm{Im}(\widetilde{\mathcal{H}})$$

$$\mathcal{A}_{\mathrm{LL}}(\phi) \equiv \frac{[\sigma^{\rightarrow\Rightarrow}(\phi) + \sigma^{\leftarrow\Leftarrow}(\phi)] - [\sigma^{\leftarrow\Rightarrow}(\phi) + \sigma^{\rightarrow\Leftarrow}(\phi)]}{[\sigma^{\rightarrow\Rightarrow}(\phi) + \sigma^{\leftarrow\Leftarrow}(\phi)] + [\sigma^{\leftarrow\Rightarrow}(\phi) + \sigma^{\rightarrow\Leftarrow}(\phi)]} \quad \tilde{\propto} \quad \mathrm{Re}(\widetilde{\mathcal{H}})$$

DVCS @ HERMES



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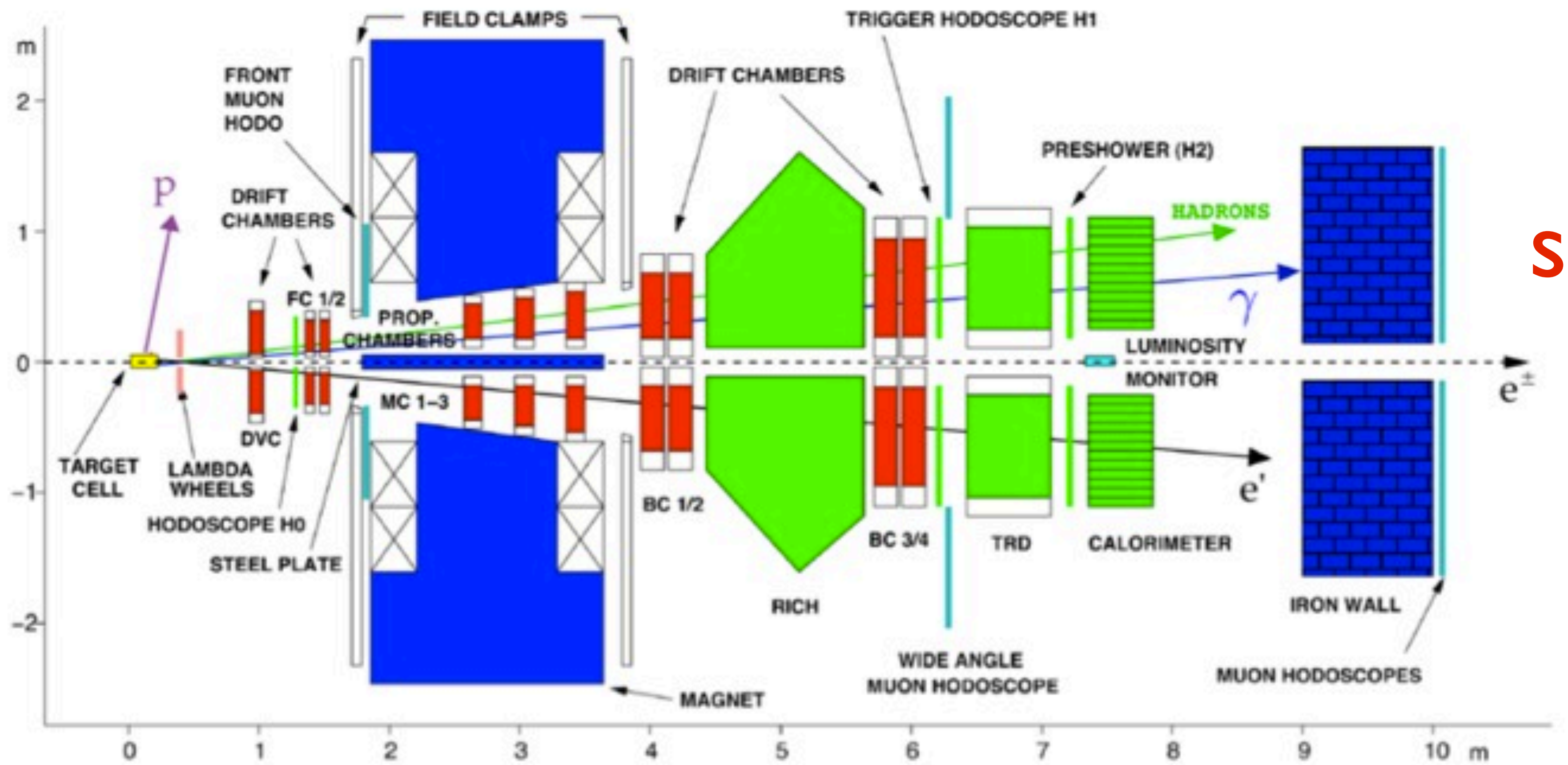


Forward spectrometer ⇒

measure asymmetries directly

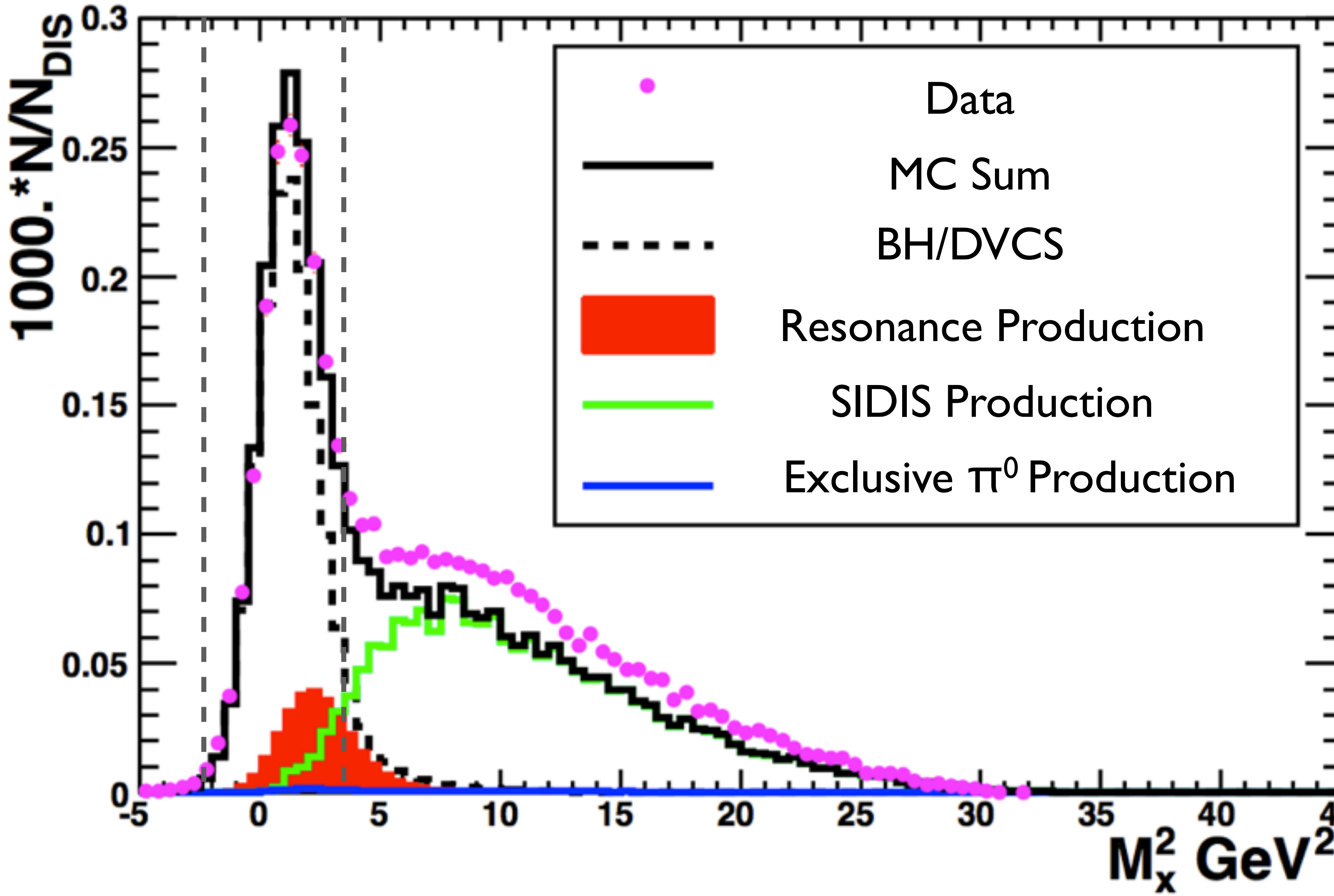
$\langle Q^2 \rangle \cong 2.4\ \mathrm{GeV}^2$

$\langle x_B \rangle \cong 0.1$

$\langle -t \rangle \cong 0.1\ \mathrm{GeV}^2$

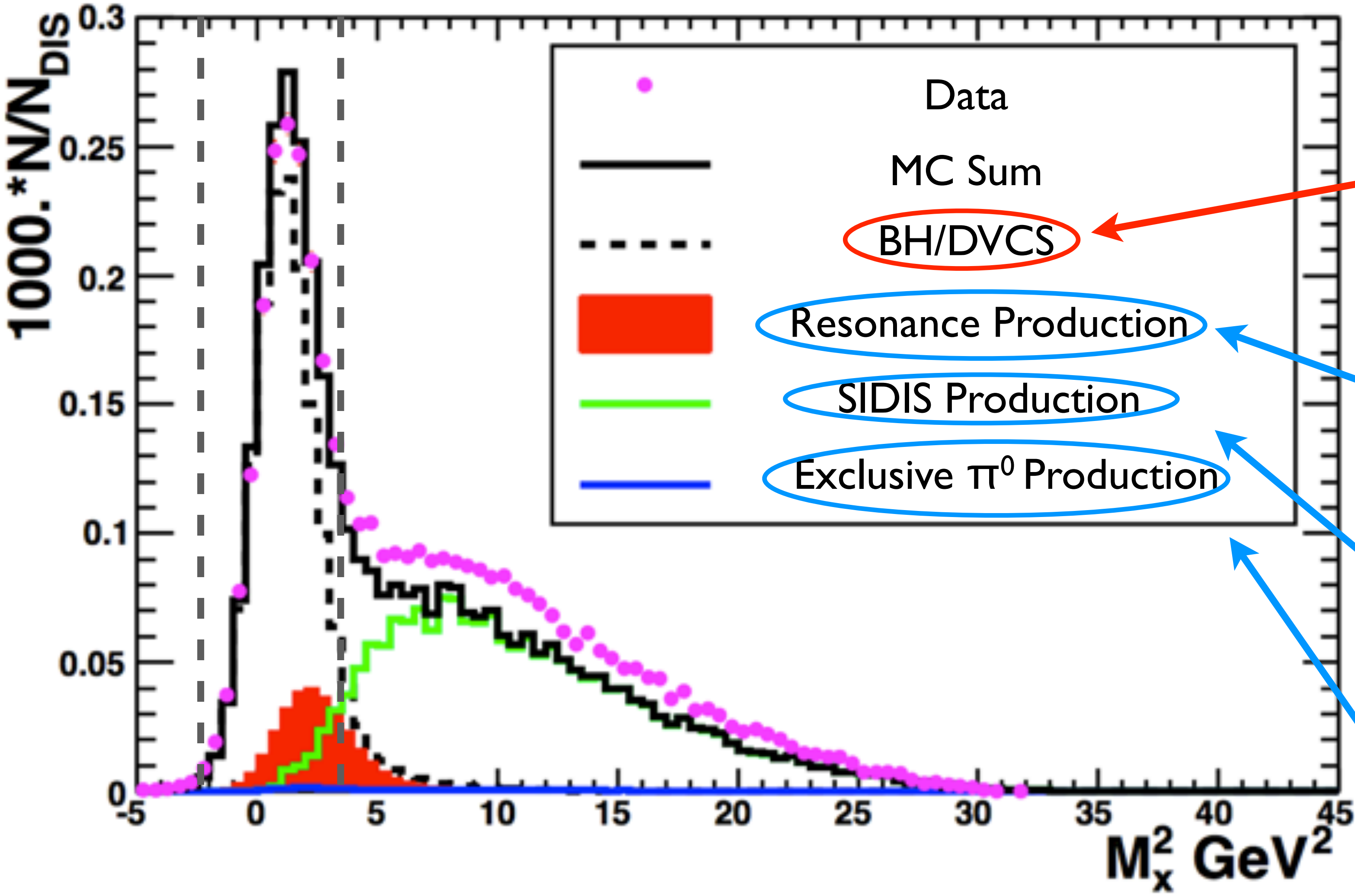
- $1\ \mathrm{GeV}^2 < Q^2 \equiv -q^2 < 10\ \mathrm{GeV}^2$
- $0.03 < x_B < 0.3$
- $0\ \mathrm{GeV}^2 < -t \equiv -(p-p')^2 < 0.7\ \mathrm{GeV}^2$

DVCS @ HERMES



1000.*N/N_DIS
0.3
0.25
0.2
0.15
0.1
0.05
0
-5
0
5
10
15
20
25
30
35
40
45
M_x^2 GeV^2
Data
MC Sum
BH/DVCS
Resonance Production
SIDIS Production
Exclusive π^0 Production

DVCS @ HERMES



Wanted Signal

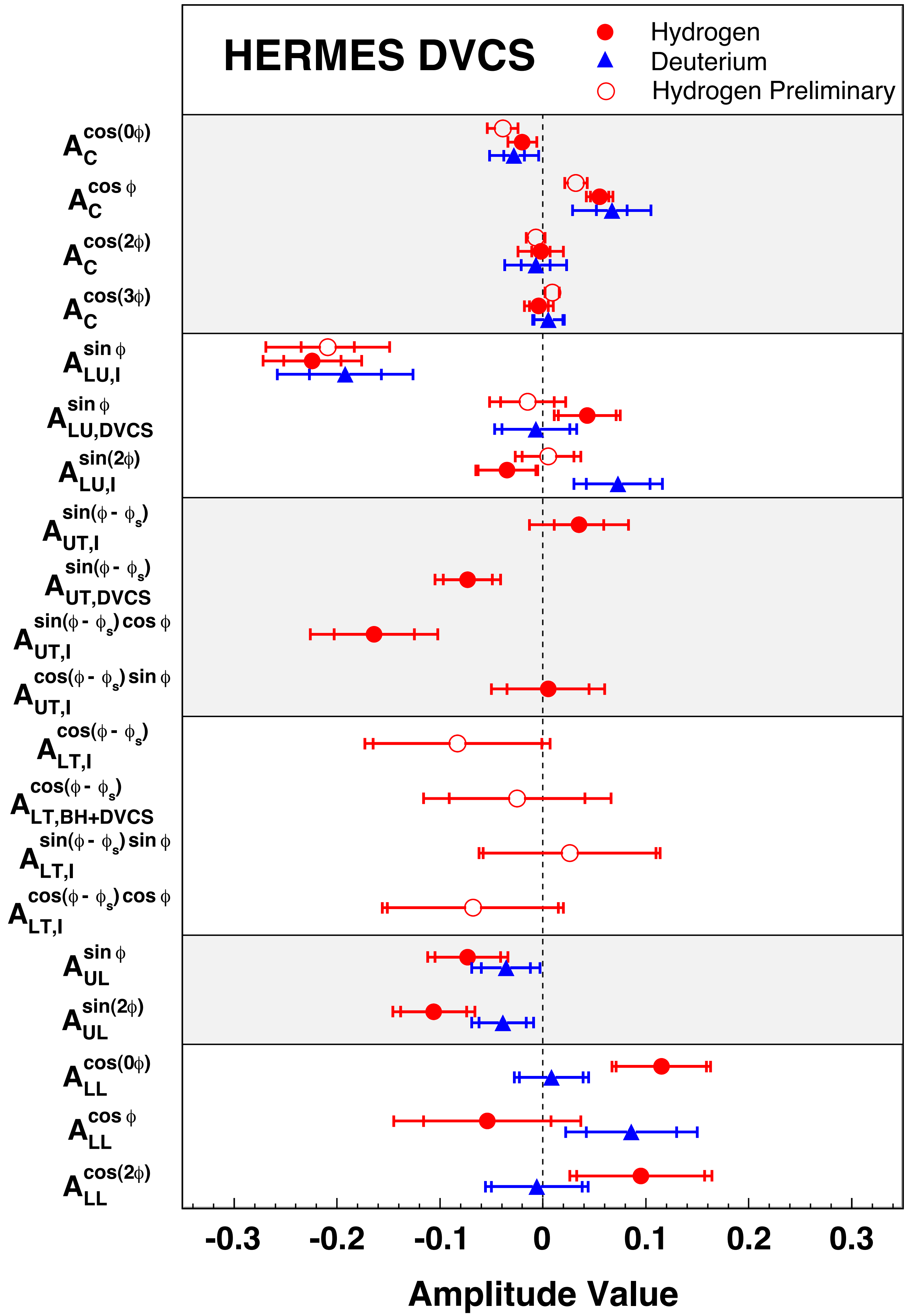
BH/DVCS from Δ, e.g

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

$e\,p \rightarrow e\,X\,\gamma$

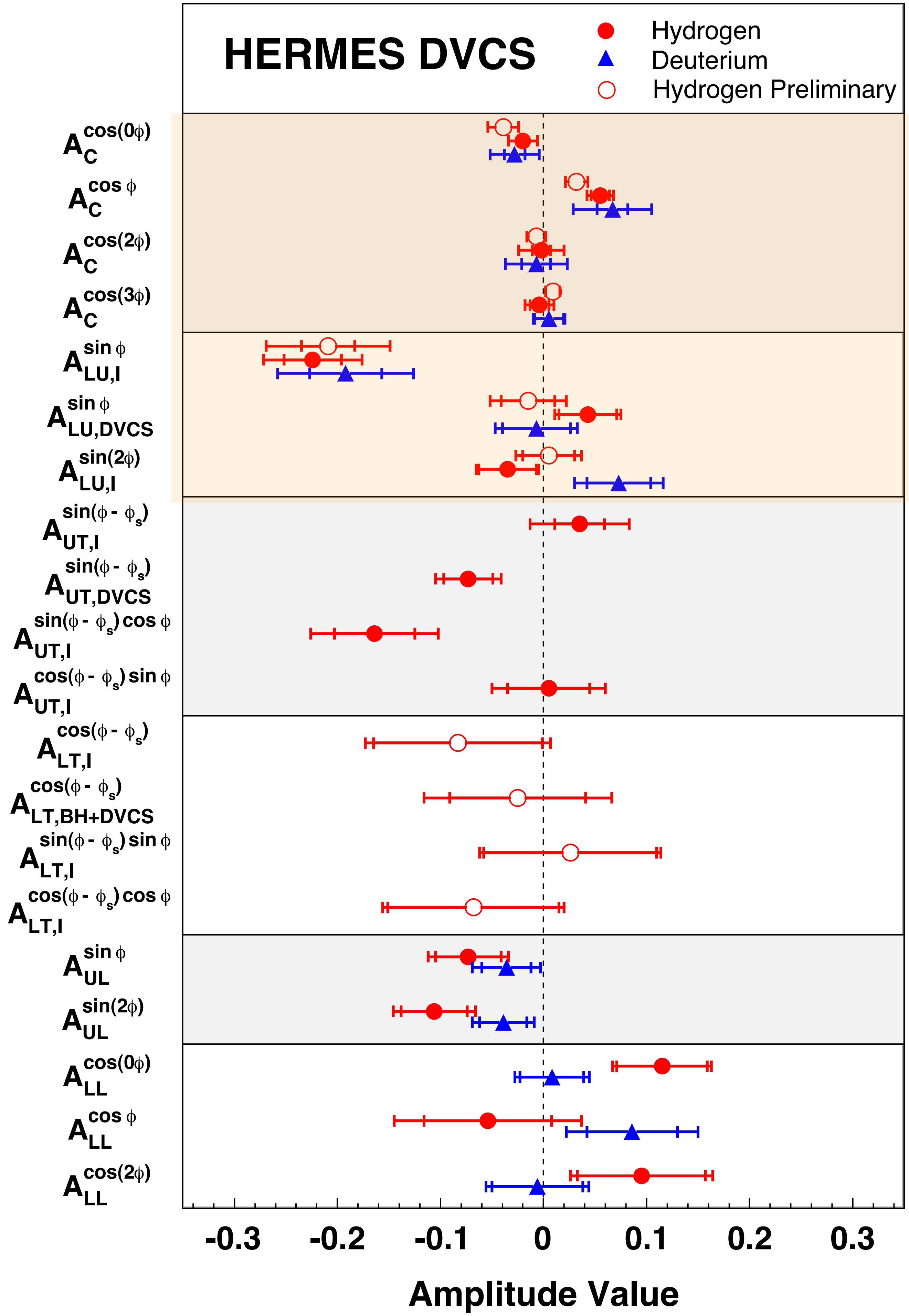
$e\,p \rightarrow e\,p\,\pi^0$

D
V
C
S
@


HERMES DVCS
Hydrogen
Deuterium
Hydrogen Preliminary
$A_C^{\cos(0\phi)}$
$A_C^{\cos\phi}$
$A_C^{\cos(2\phi)}$
$A_C^{\cos(3\phi)}$
$A_{LU,I}^{\sin\phi}$
$A_{LU,DVCS}^{\sin\phi}$
$A_{LU,I}^{\sin(2\phi)}$
$A_{UT,I}^{\sin(\phi-\phi_s)}$
$A_{UT,DVCS}^{\sin(\phi-\phi_s)}$
$A_{UT,I}^{\sin(\phi-\phi_s)\cos\phi}$
$A_{UT,I}^{\cos(\phi-\phi_s)\sin\phi}$
$A_{LT,I}^{\cos(\phi-\phi_s)}$
$A_{LT,BH+DVCS}^{\cos(\phi-\phi_s)}$
$A_{LT,I}^{\sin(\phi-\phi_s)\sin\phi}$
$A_{LT,I}^{\cos(\phi-\phi_s)\cos\phi}$
$A_{UL}^{\sin\phi}$
$A_{UL}^{\sin(2\phi)}$
$A_{LL}^{\cos(0\phi)}$
$A_{LL}^{\cos\phi}$
$A_{LL}^{\cos(2\phi)}$
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
Amplitude Value

H
E
R
M
E
S

DVCS @



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$A_{LT,I}^{\cos(\phi-\phi_s)\cos\phi}$
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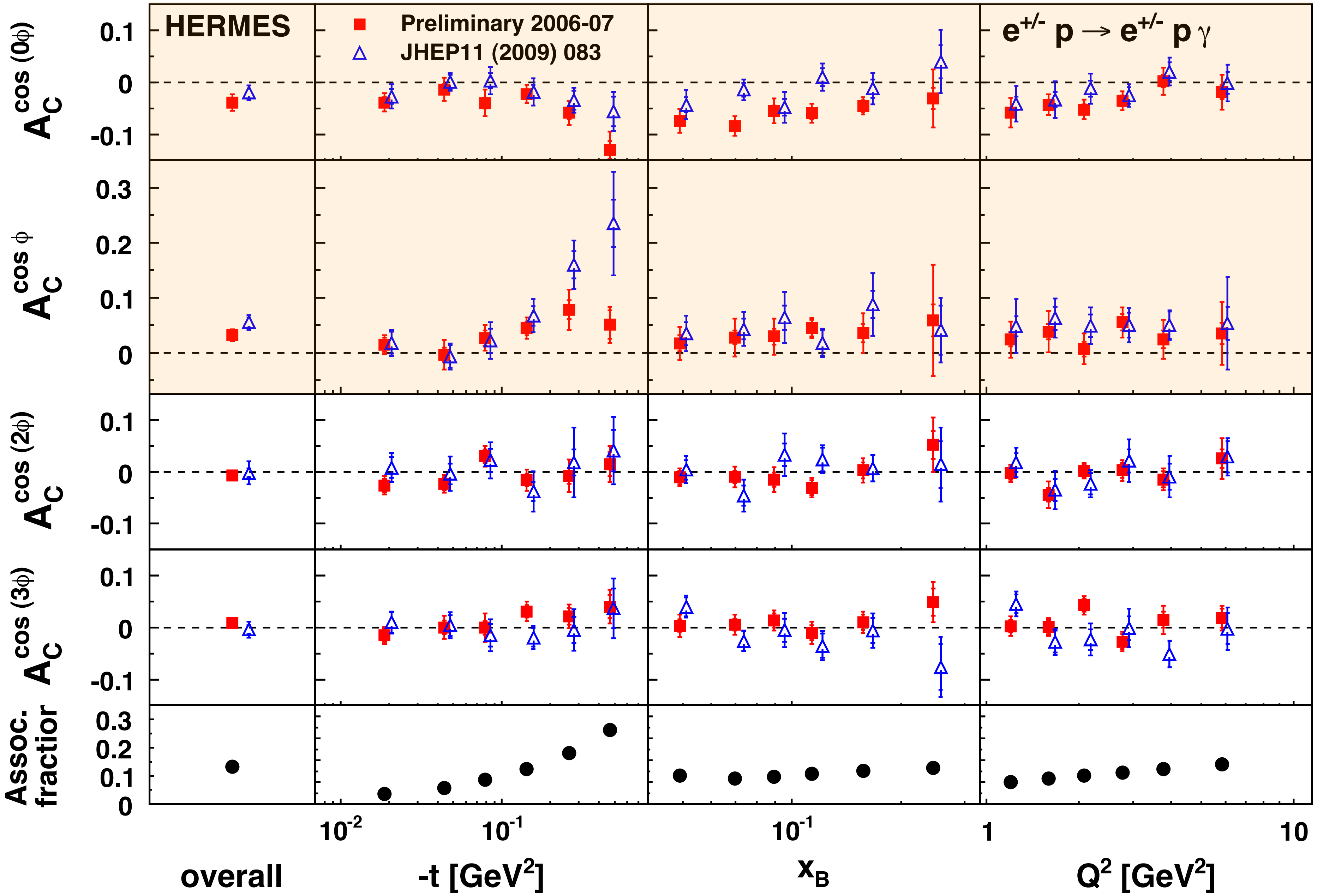
$A_{LL}^{\cos\phi}$
$A_{LL}^{\cos(2\phi)}$
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
Amplitude Value

HERMES

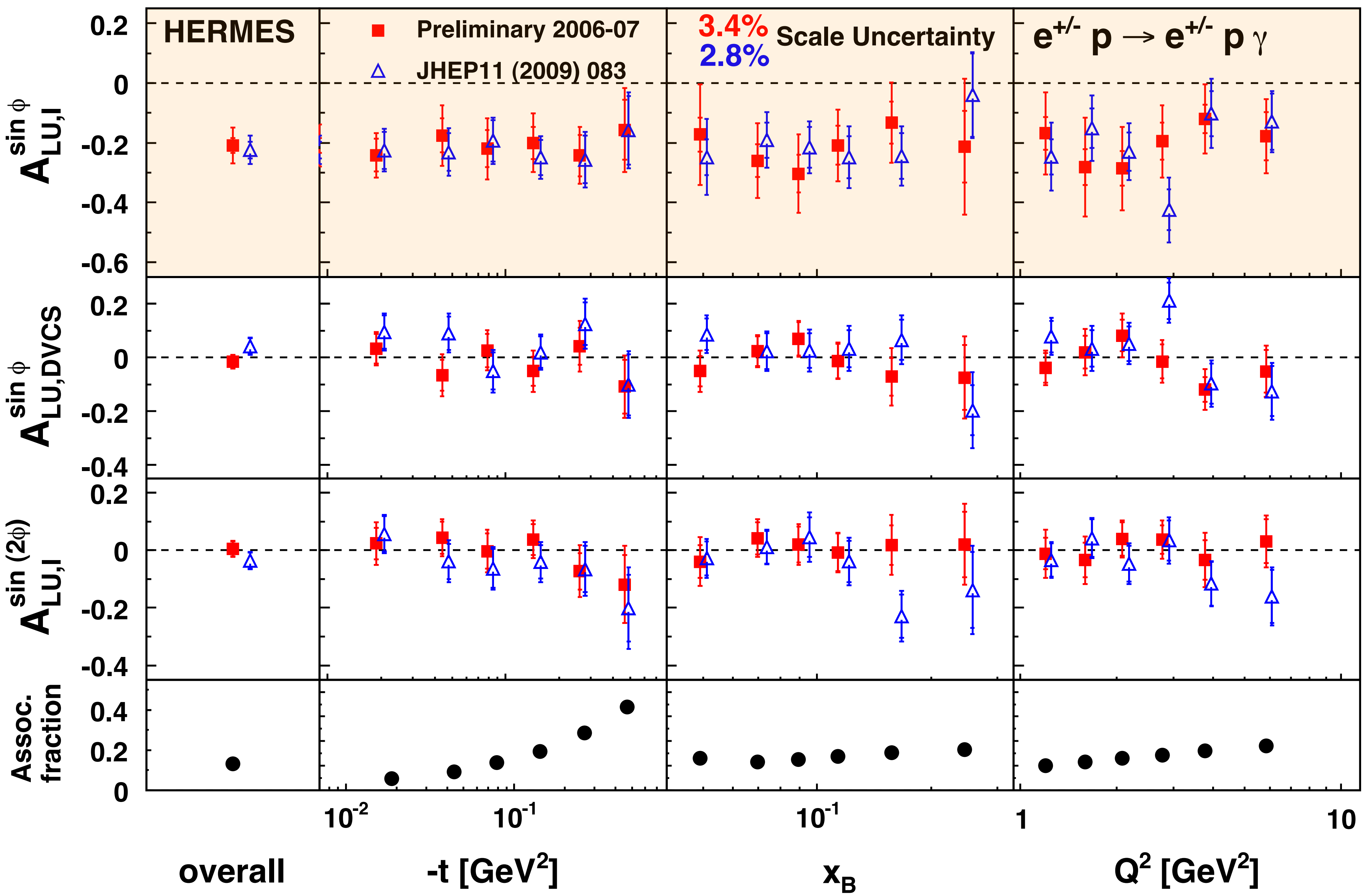
Beam Asymmetries



Beam Charge Asymmetries access Re($\mathcal{H}$)

← Δ-resonance

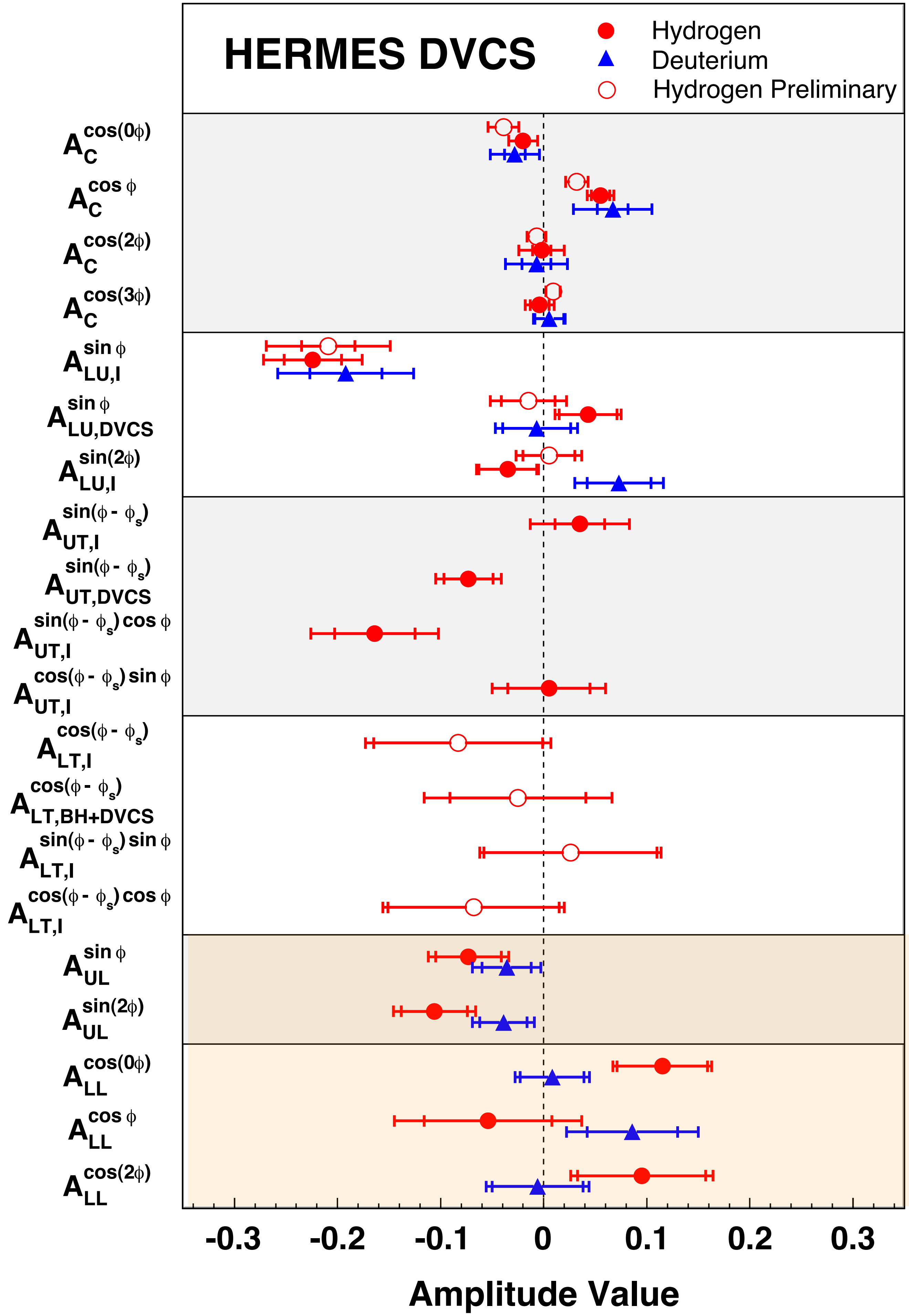
Beam Asymmetries



Beam Helicity Asymmetries access Im($\mathcal{H}$)

Larger values for the BHA than BCA - correlated to the difference in the CFF access?

DVCS@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Hydrogen
Deuterium
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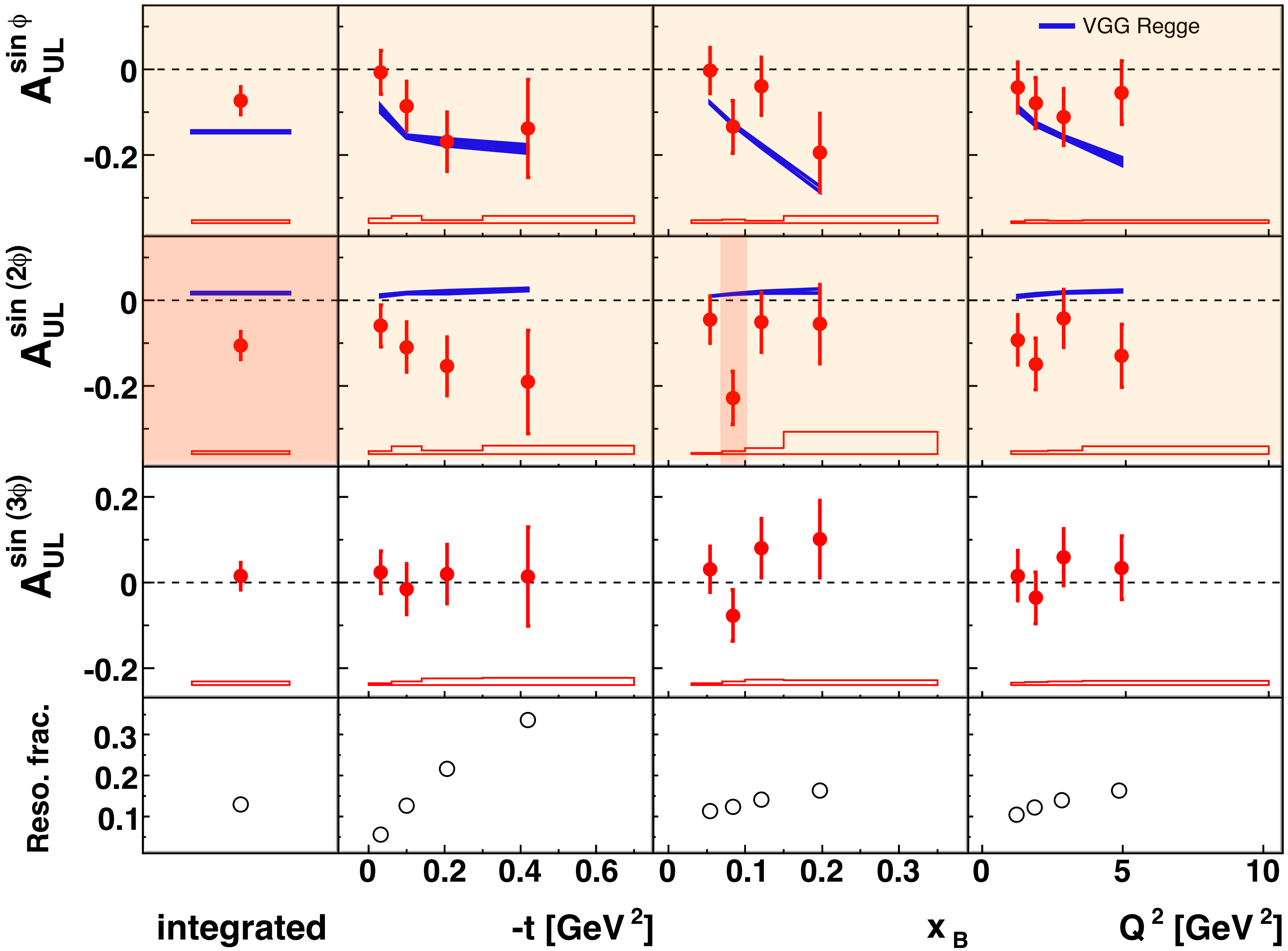
$A_{LT,I}^{\sin(\phi-\phi_s)\sin\phi}$
$A_{LT,I}^{\cos(\phi-\phi_s)\cos\phi}$
$A_{UL}^{\sin\phi}$
$A_{UL}^{\sin(2\phi)}$
$A_{LL}^{\cos(0\phi)}$
$A_{LL}^{\cos\phi}$
$A_{LL}^{\cos(2\phi)}$
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
Amplitude Value

HERMES

Target Asymmetries



Long. Pol. target asymmetries access $Im(\widetilde{\mathcal{H}})$

http://arxiv.org/abs/1004.0177

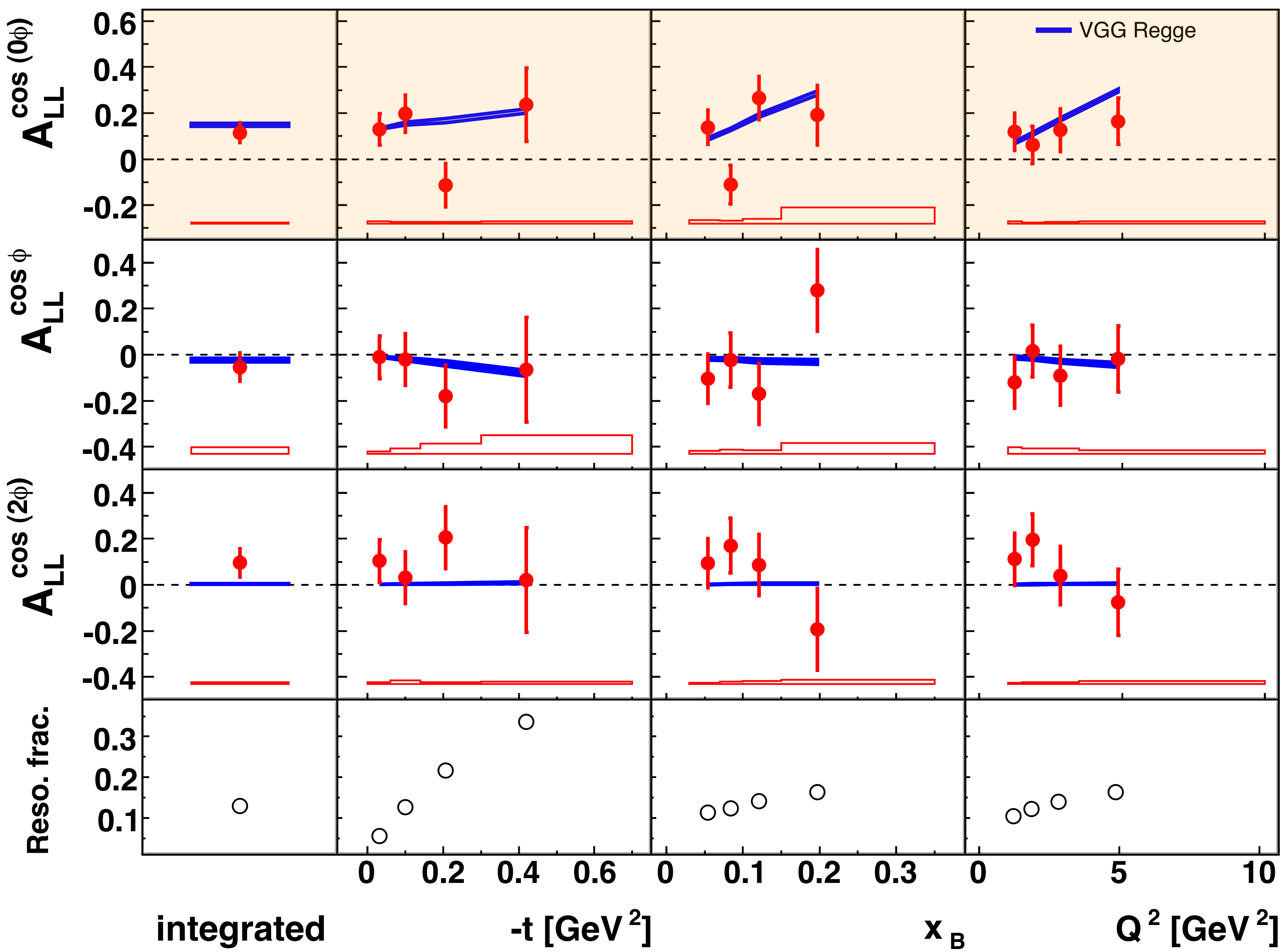
A. Airapetian et al, JHEP 06 (2010) 019

VGG Model:

http://arxiv.org/abs/hep-ph/9905372

Phys.Rev. D60 (1999) 094017

Double Spin Asymmetries



Long. Pol. target / Long. Pol. Beam access Re($\widetilde{\mathcal{H}}$)

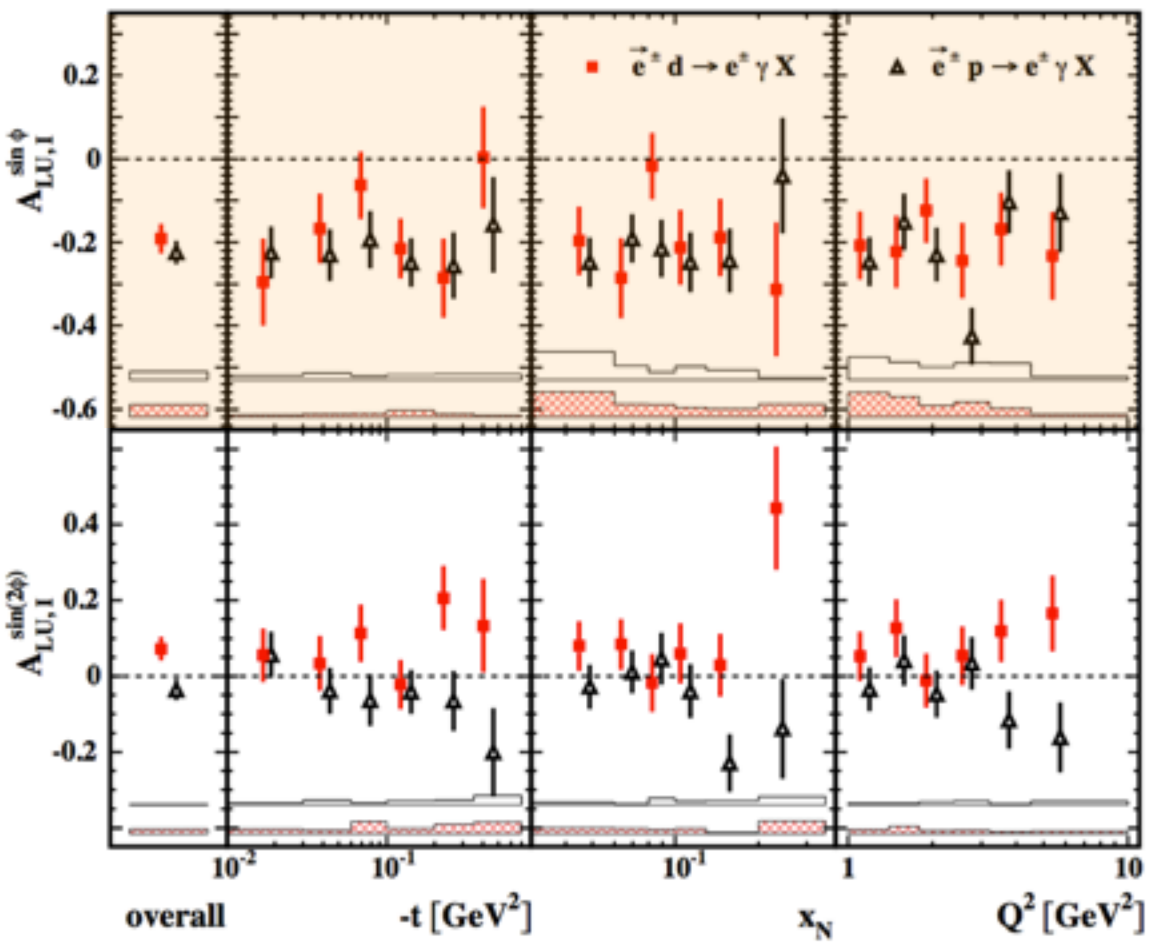
Caveat! Relatively large BH contribution to these asymmetries!

http://arxiv.org/abs/1004.0177

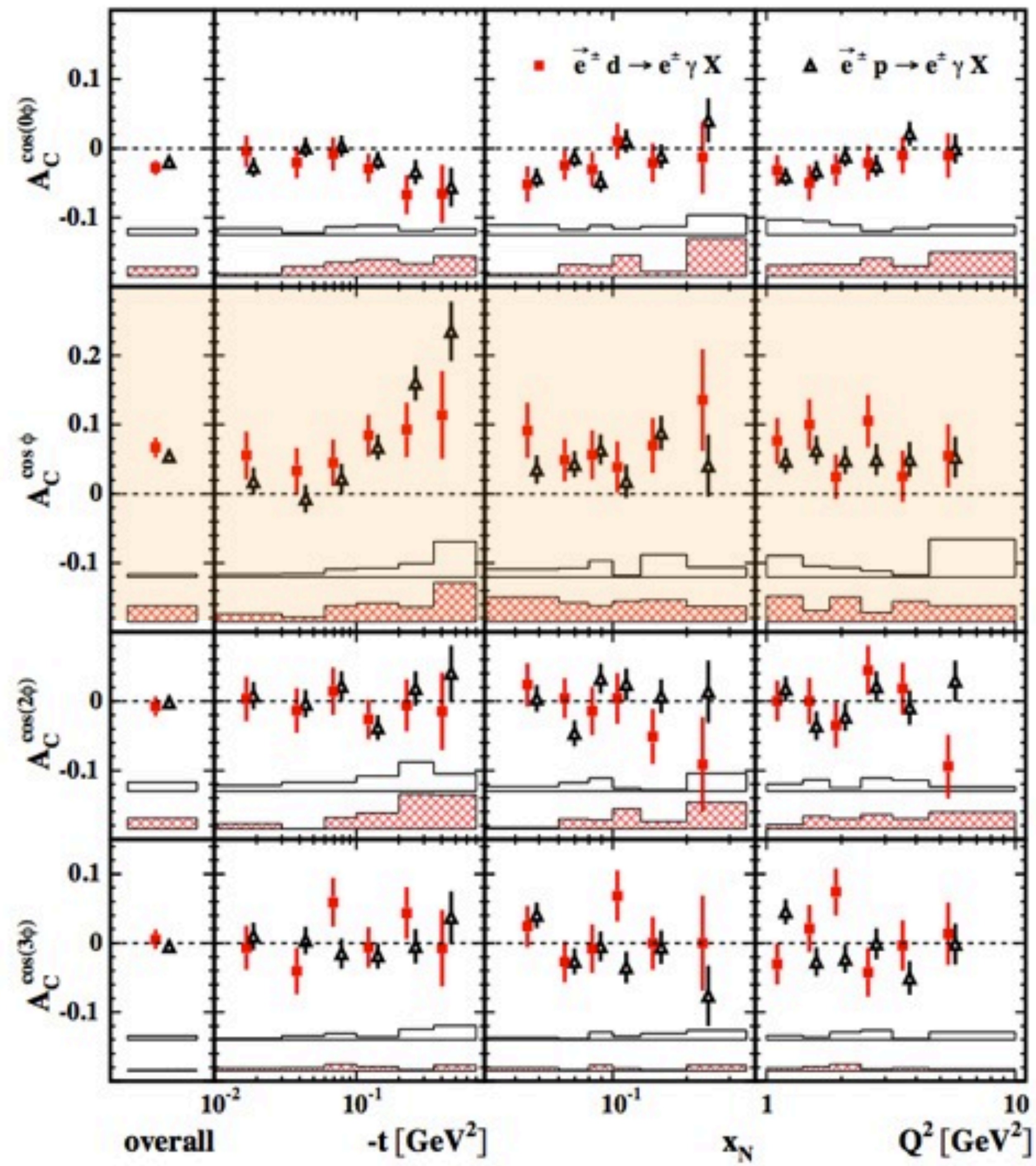
A. Airapetian et al, JHEP 06 (2010) 019

Beam Asymmetries

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

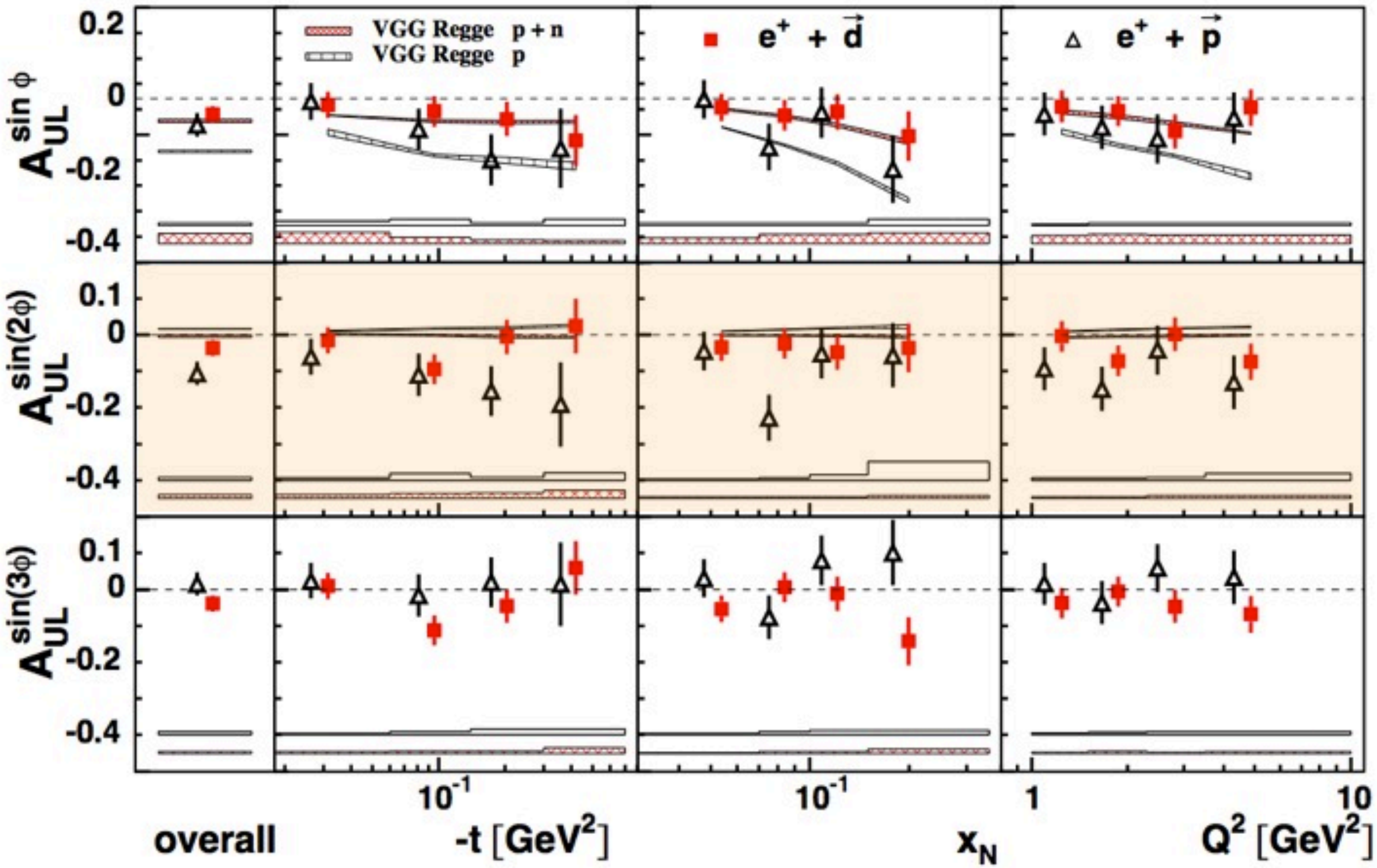


http://www.arxiv.org/abs/0911.0095



Deuterium is governed by different GPDs - but the asymmetry data is not *so* different!

Target Asymmetries

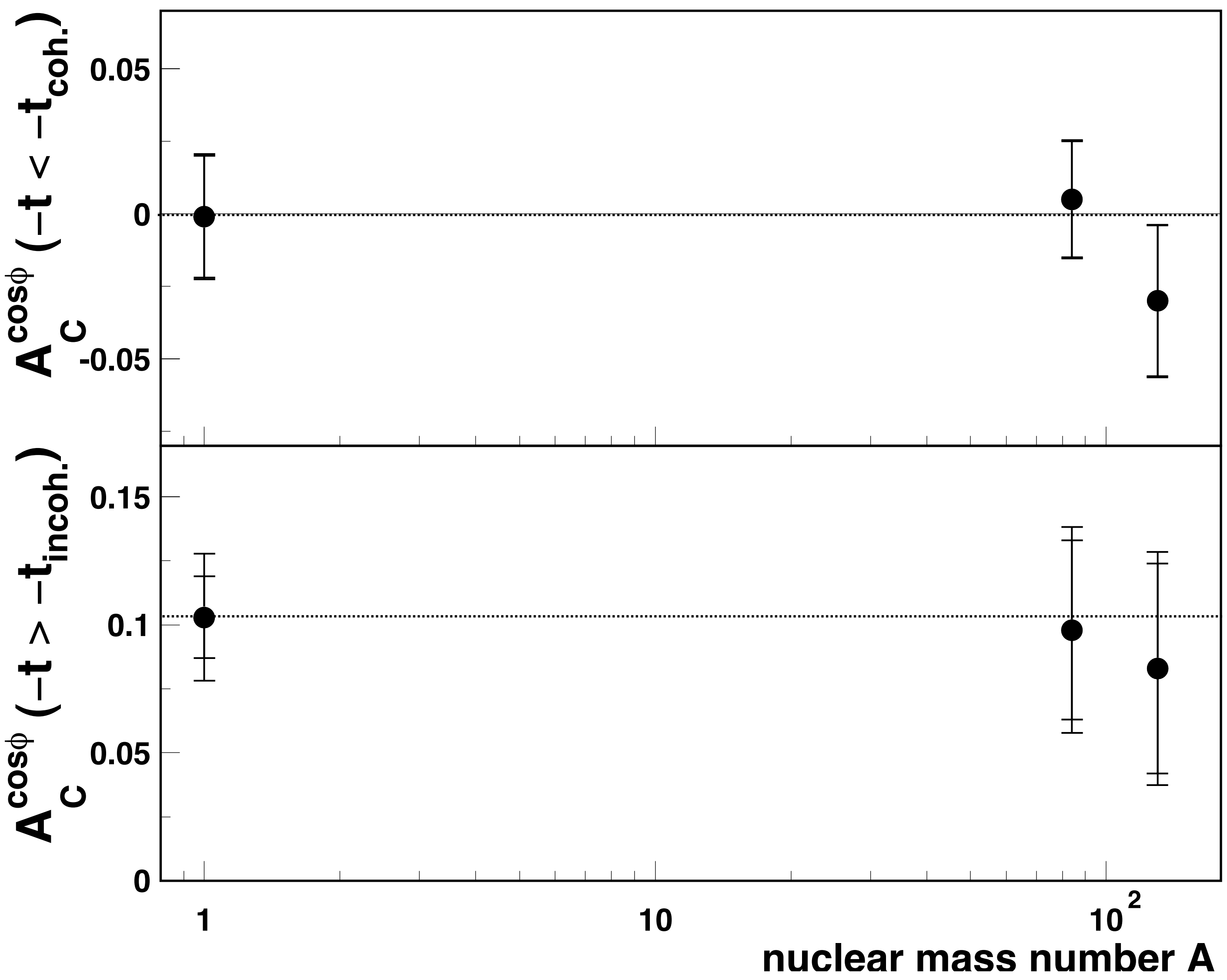


No good idea how to model long. pol. deuterium GPDs. Currently use a proton/ neutron hybrid

http://www.arxiv.org/abs/1008.3996

A. Airapetian et al, Nucl. Phys. B842 (2011) 265-298

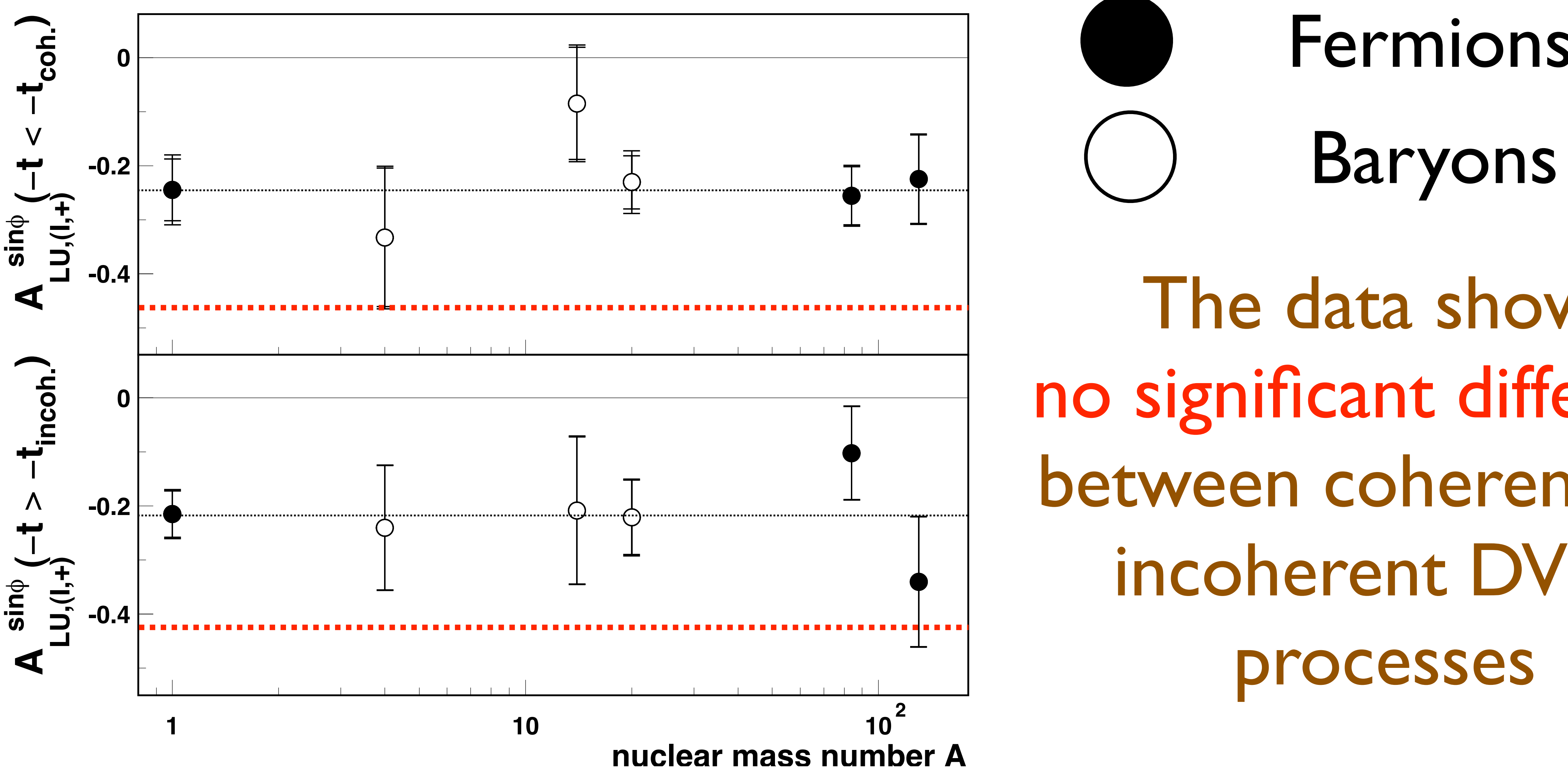
Nuclear Mass Dependence



Nuclear-Binding models expected the DVCS asymmetry for nuclear targets to be ~2x that of the Hydrogen asymmetry.

Nuclear Mass Dependence

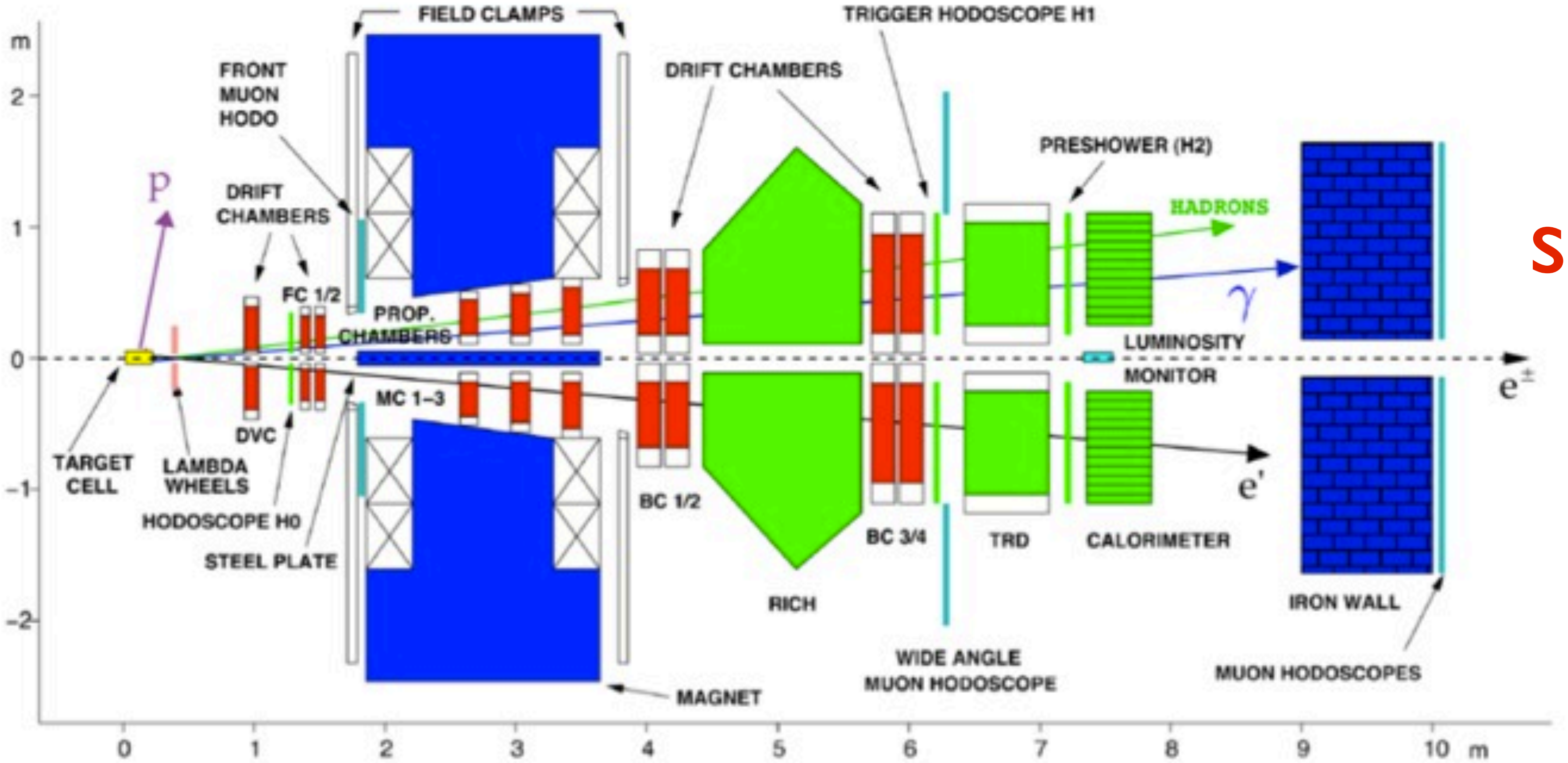
http://arxiv.org/abs/0911.0091



The data shows
no significant difference
between coherent and
incoherent DVCS
processes

A. Airpetian et al. Phys. Rev. C 81, 035202 (2010)

DVCS @ HERMES



Forward spectrometer ⇒ measure asymmetries directly

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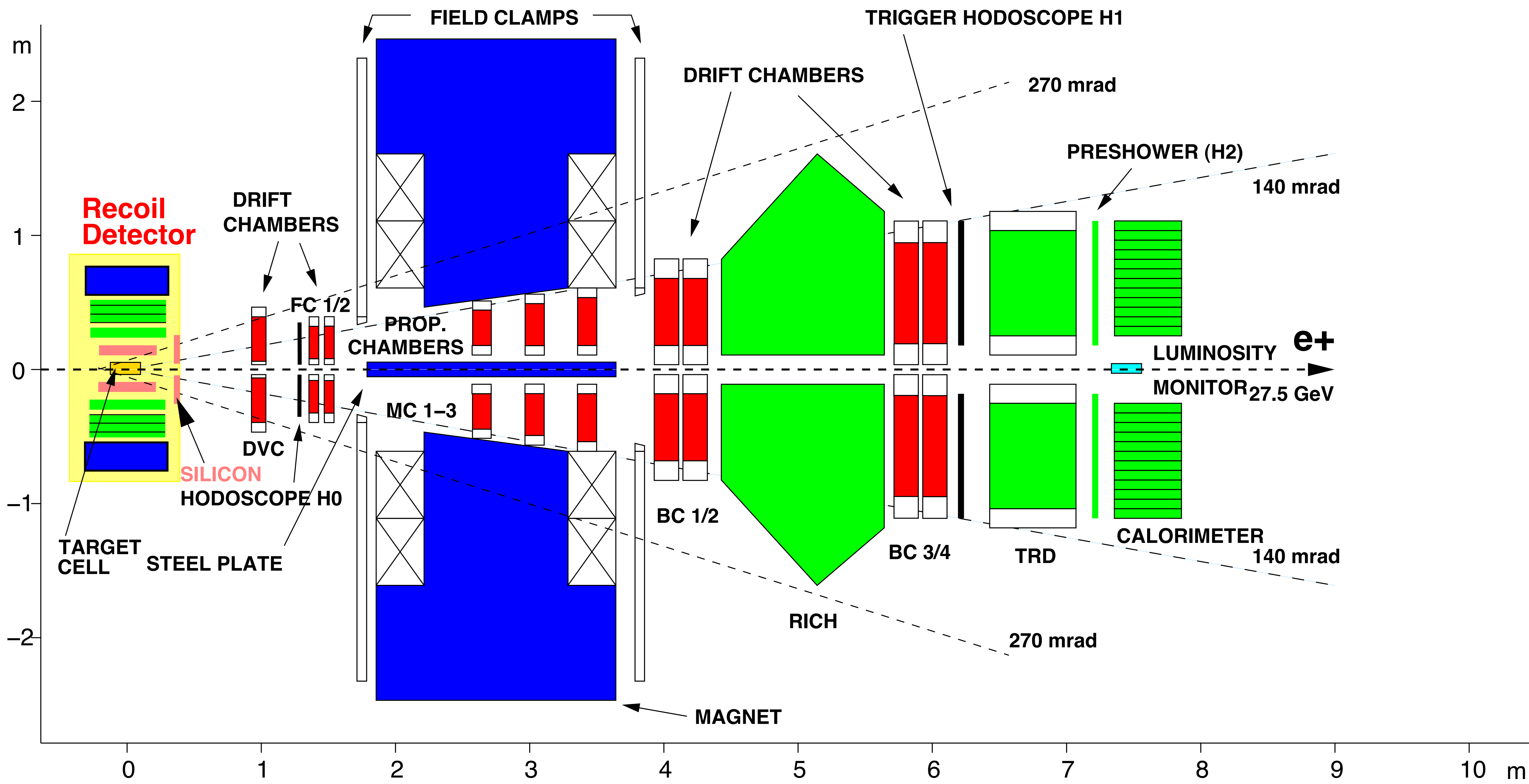
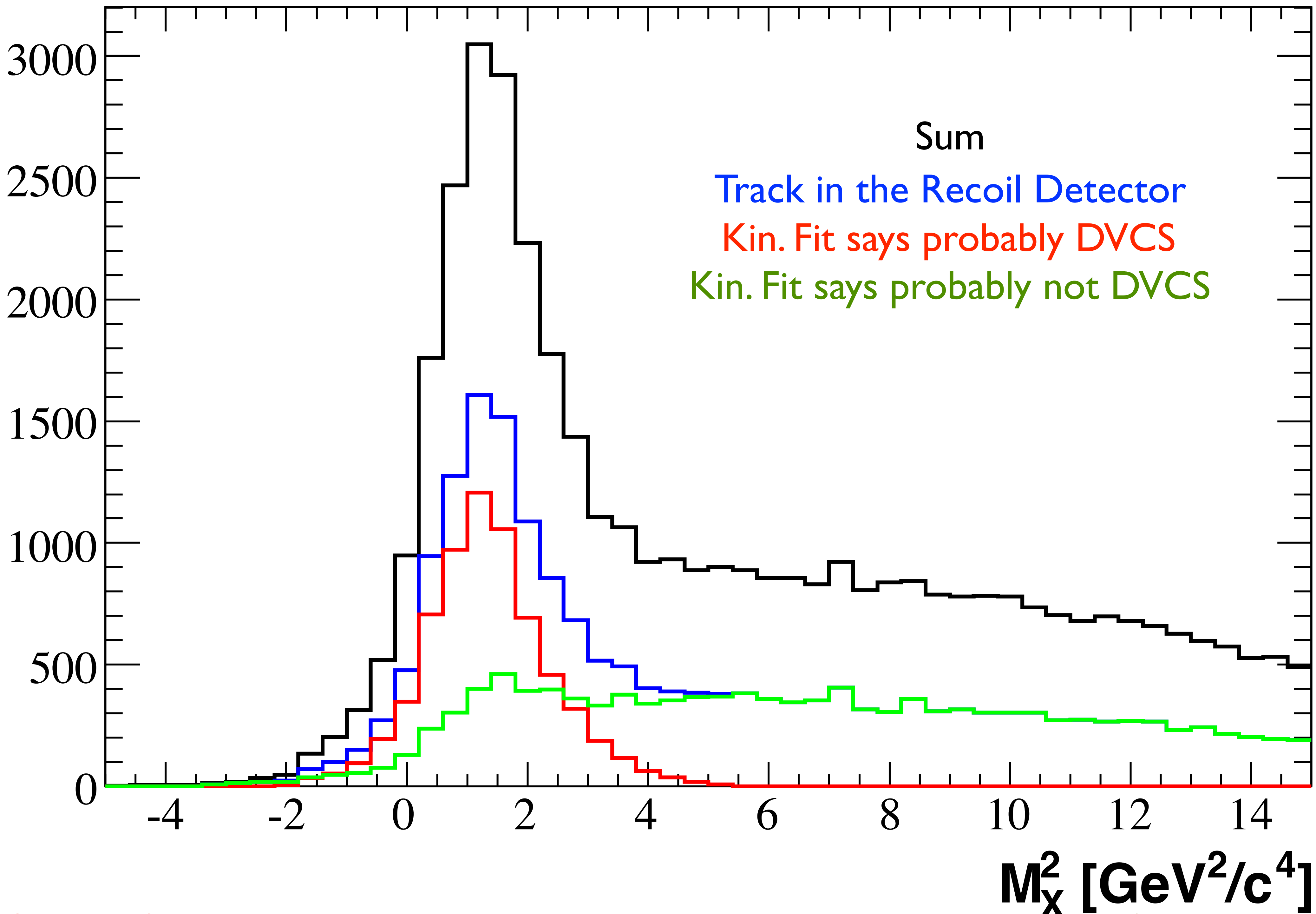
DVCS @ HERMES

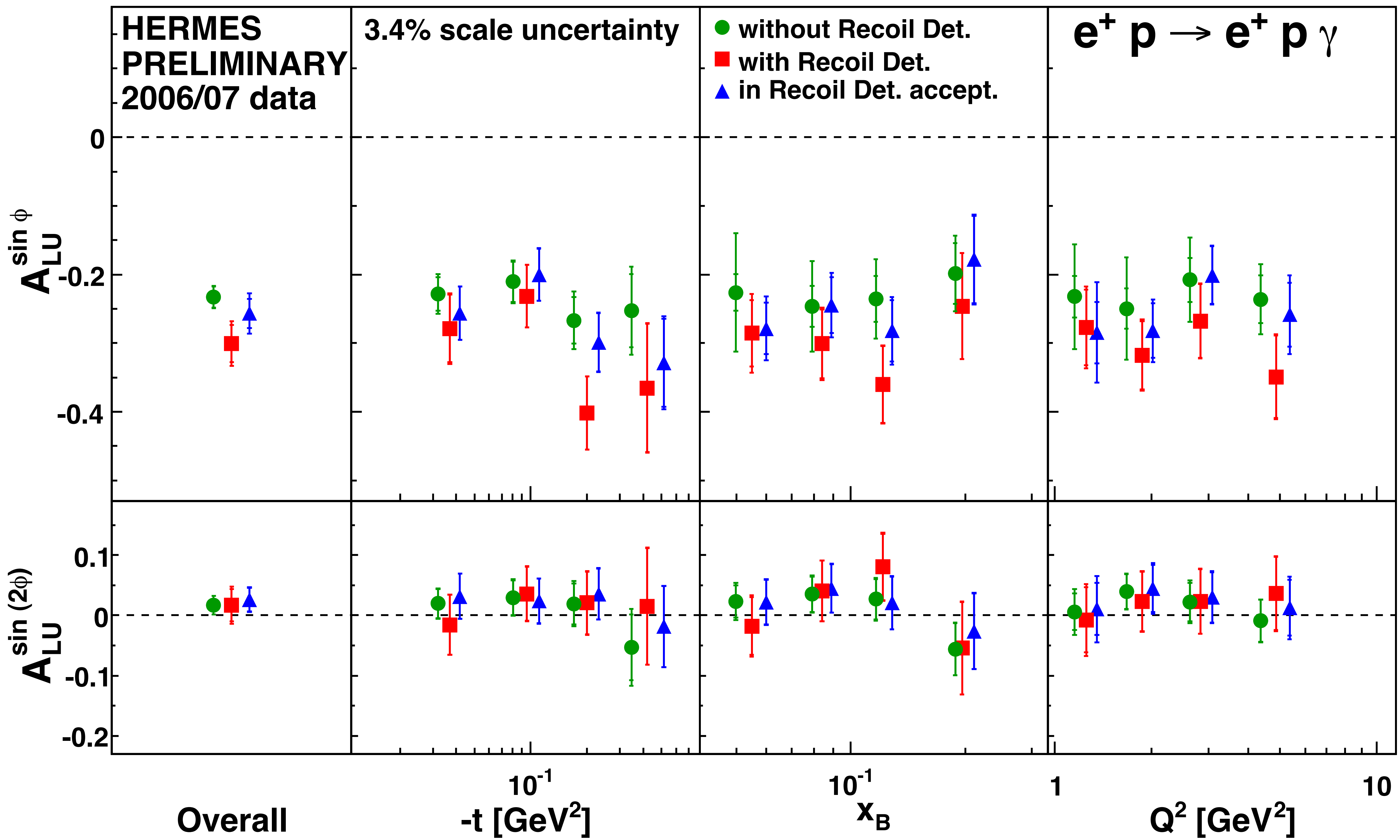

FIELD CLAMPS
TRIGGER HODOSCOPE H1
DRIFT CHAMBERS
270 mrad
PRESHOWER (H2)
140 mrad
Recoil Detector
DRIFT CHAMBERS
FC 1/2
PROP. CHAMBERS
LUMINOSITY MONITOR
e+
27.5 GeV
MC 1–3
DVC
SILICON
HODOSCOPE H0
BC 1/2
CALORIMETER
140 mrad
TARGET CELL
STEEL PLATE
BC 3/4
TRD
RICH
270 mrad
MAGNET
m
2
1
0
–1
–2
0
1
2
3
4
5
6
7
8
9
10
m

Current DVCS Data



Significant improvement in the purity of the signal

Current DVCS Data



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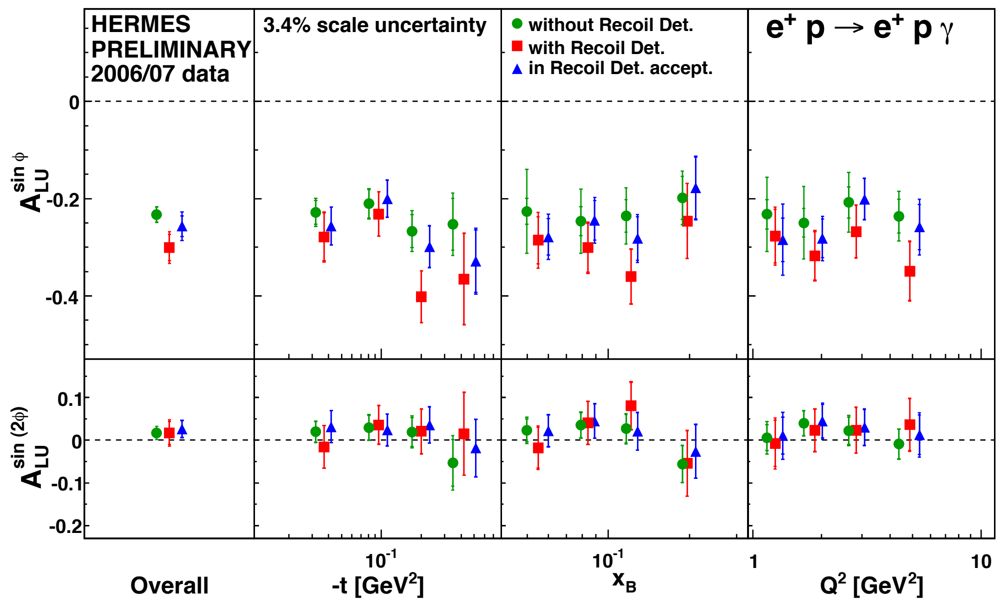
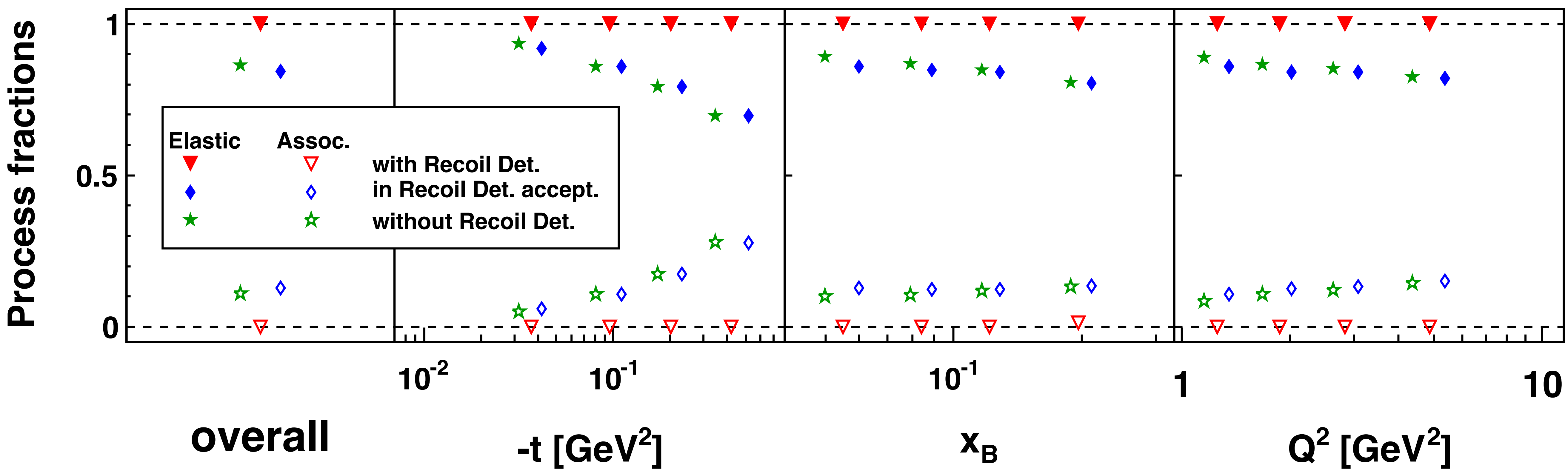
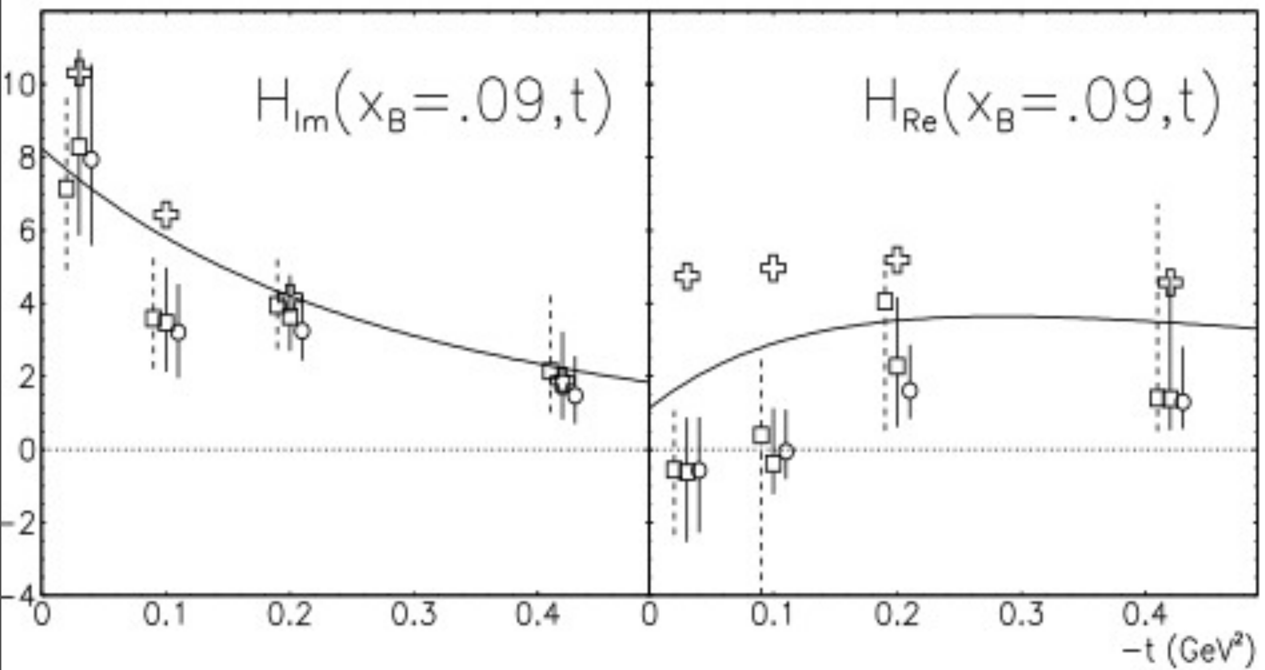




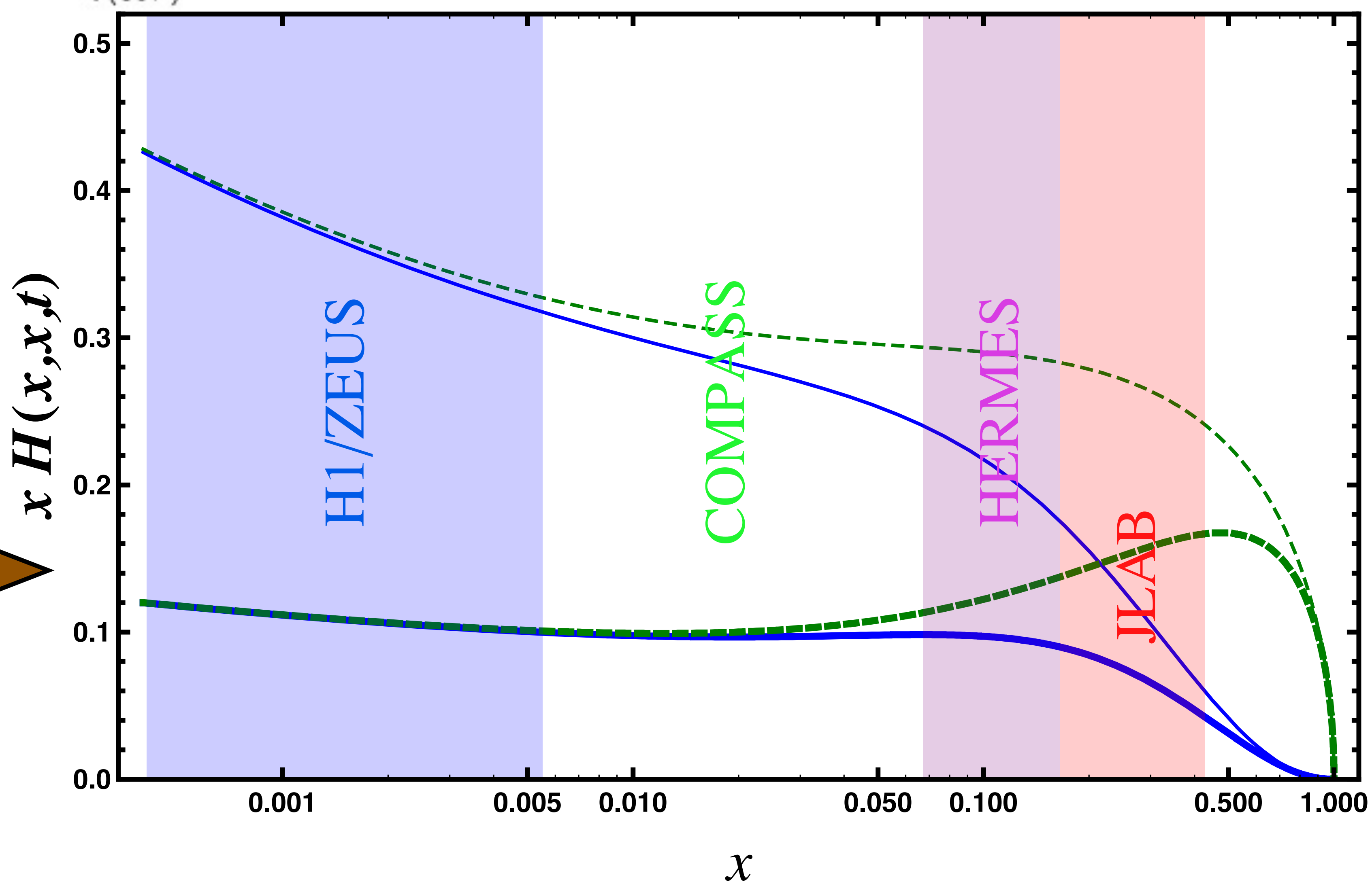
GPD Discovery



http://arxiv.org/abs/1005.4922

M. Guidal

New CFF Fit Result incorporating A_{UL} moments



Postulate GPDs from first principle models

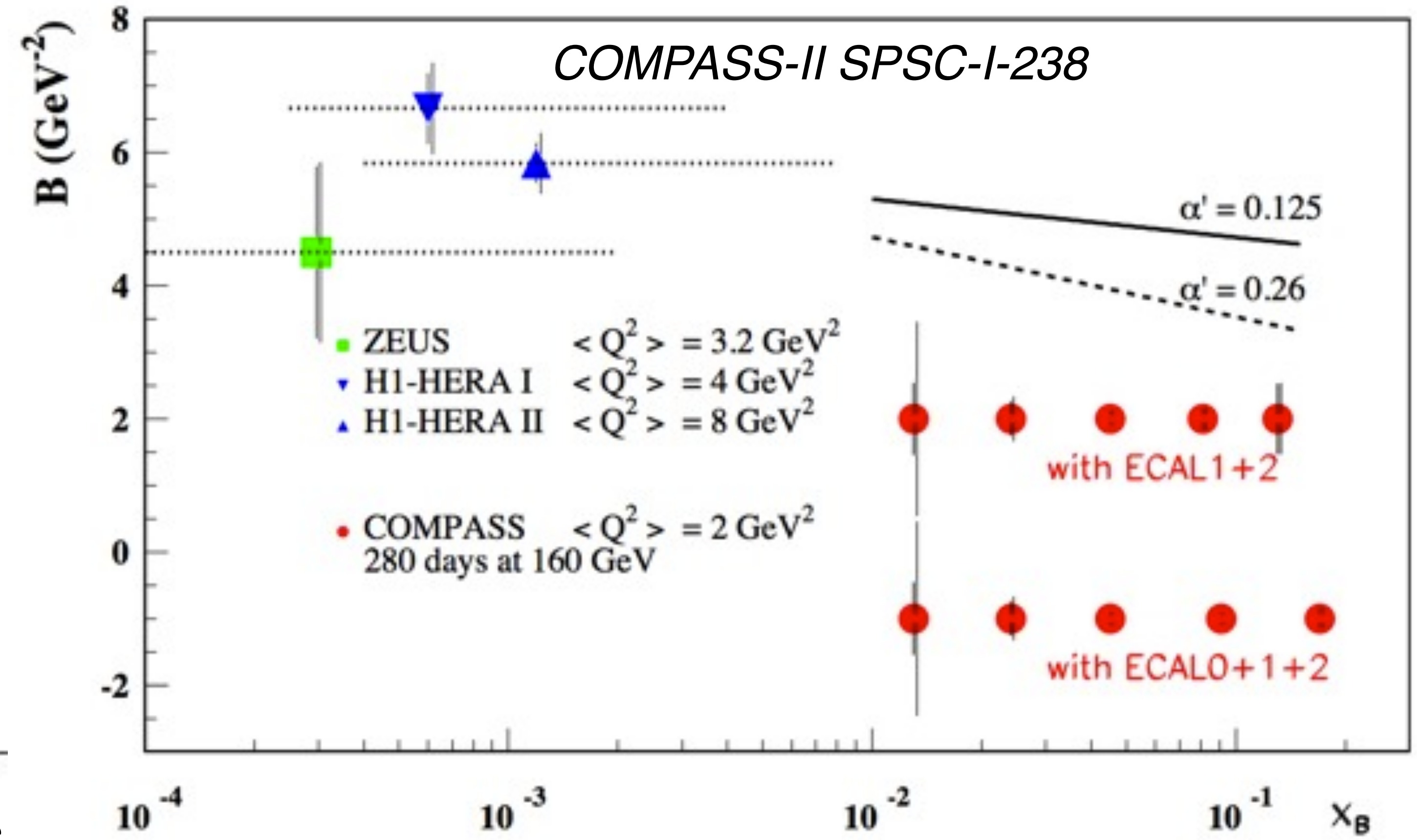
http://arxiv.org/abs/0904.0458

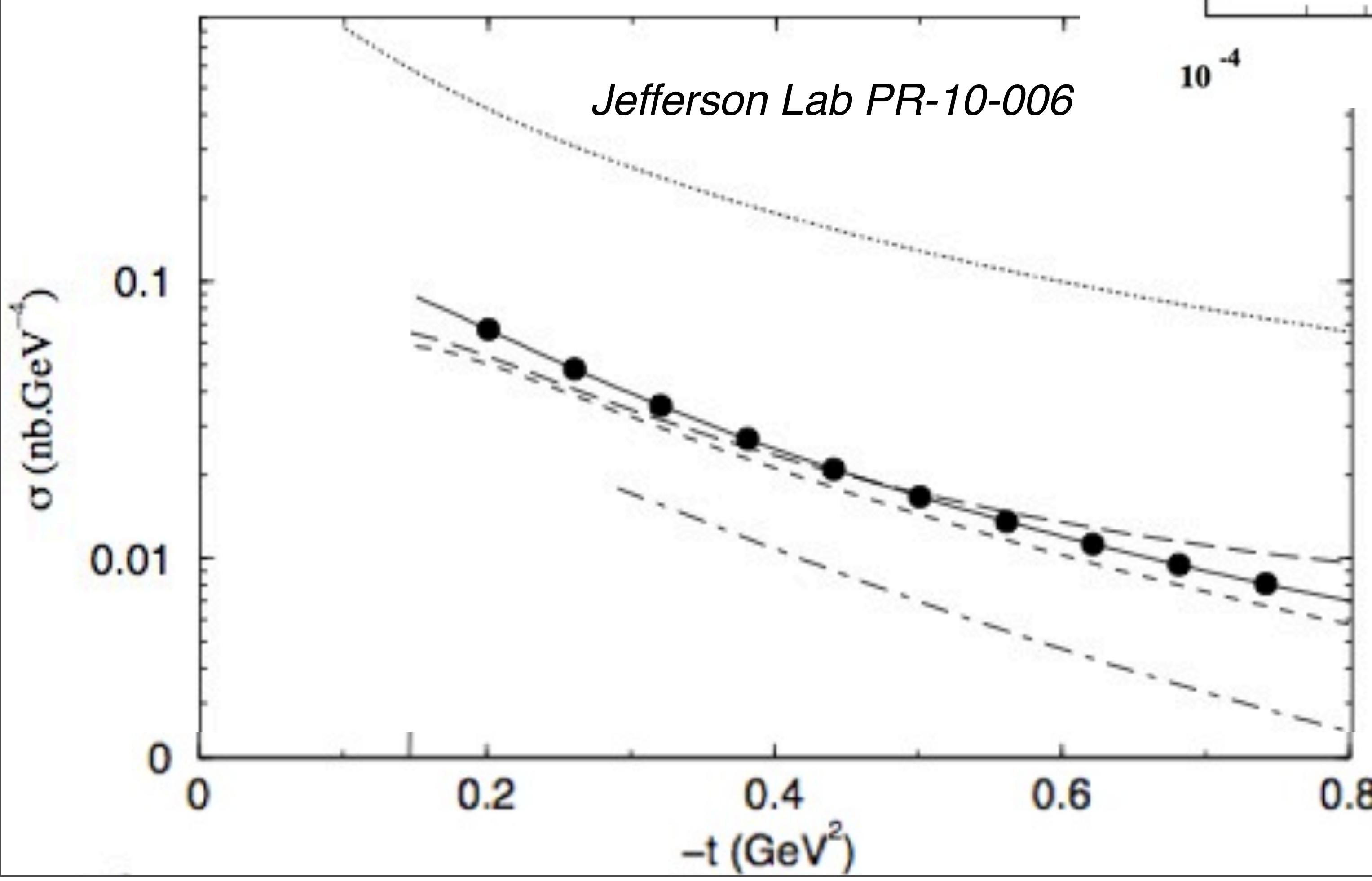
Kumerički and Müller

To appear in Nucl. Phys. B (2010)

Future Data

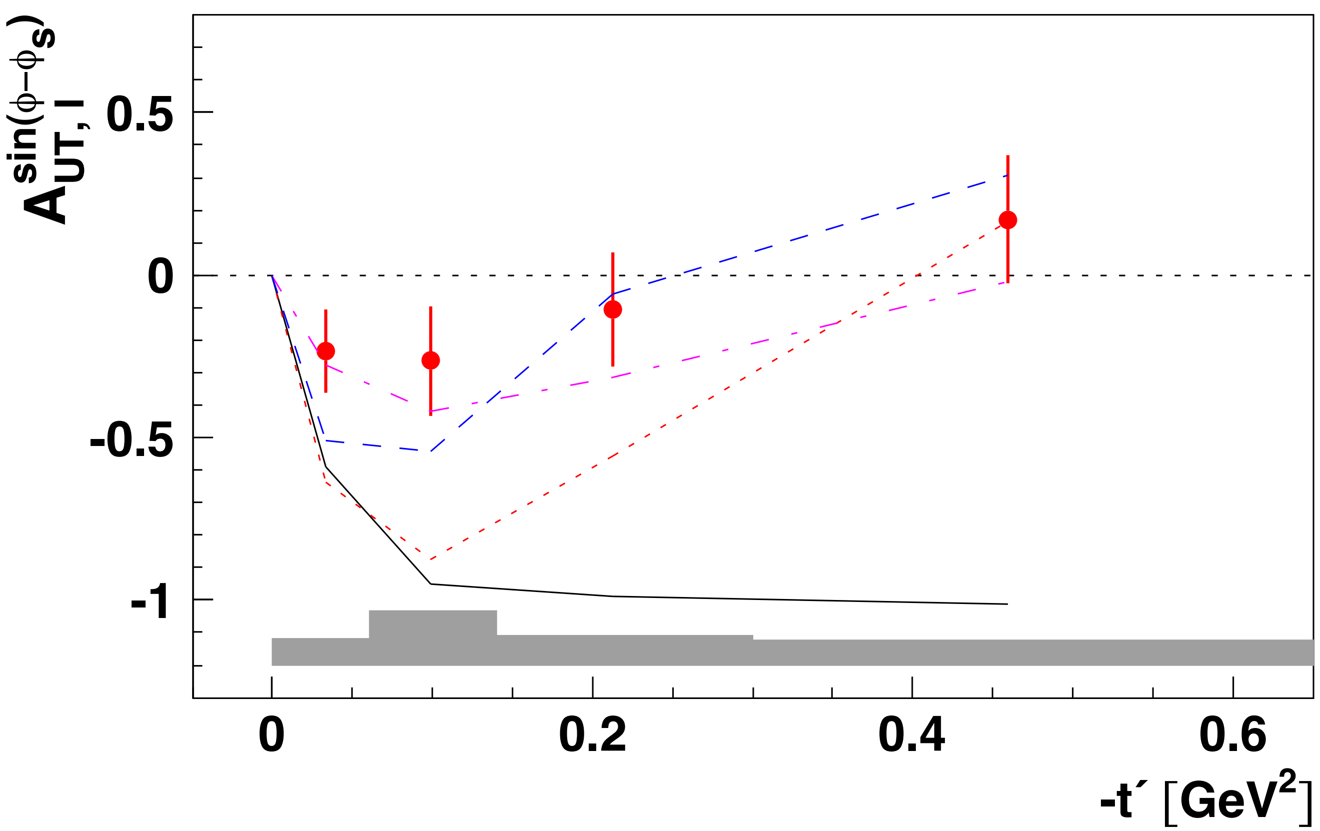
Measurements of the dvcs cross-section can help determine *x* and *t* entanglement





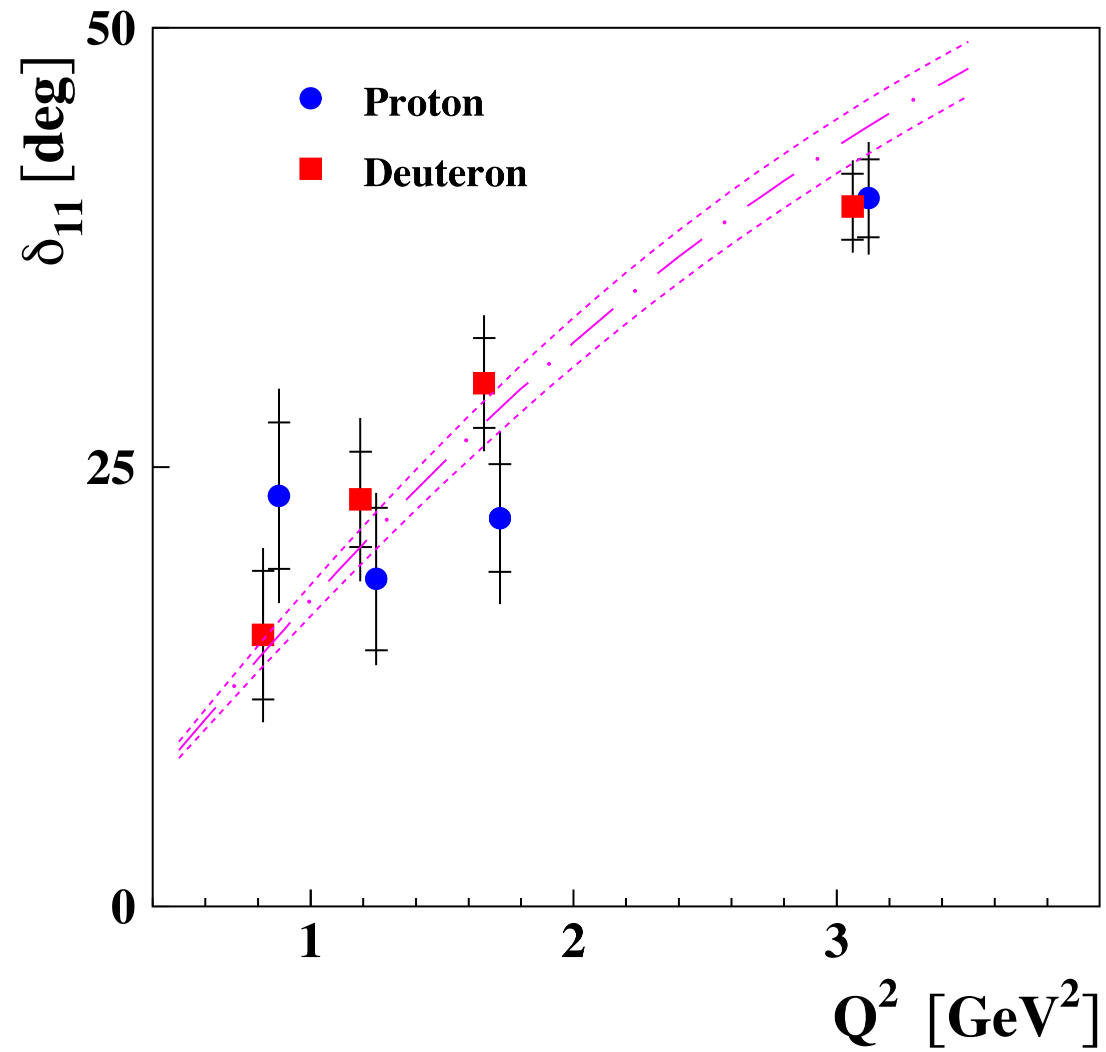
All four GPDs will be accessed in proposed measurements at JLab and COMPASS

Meson Data

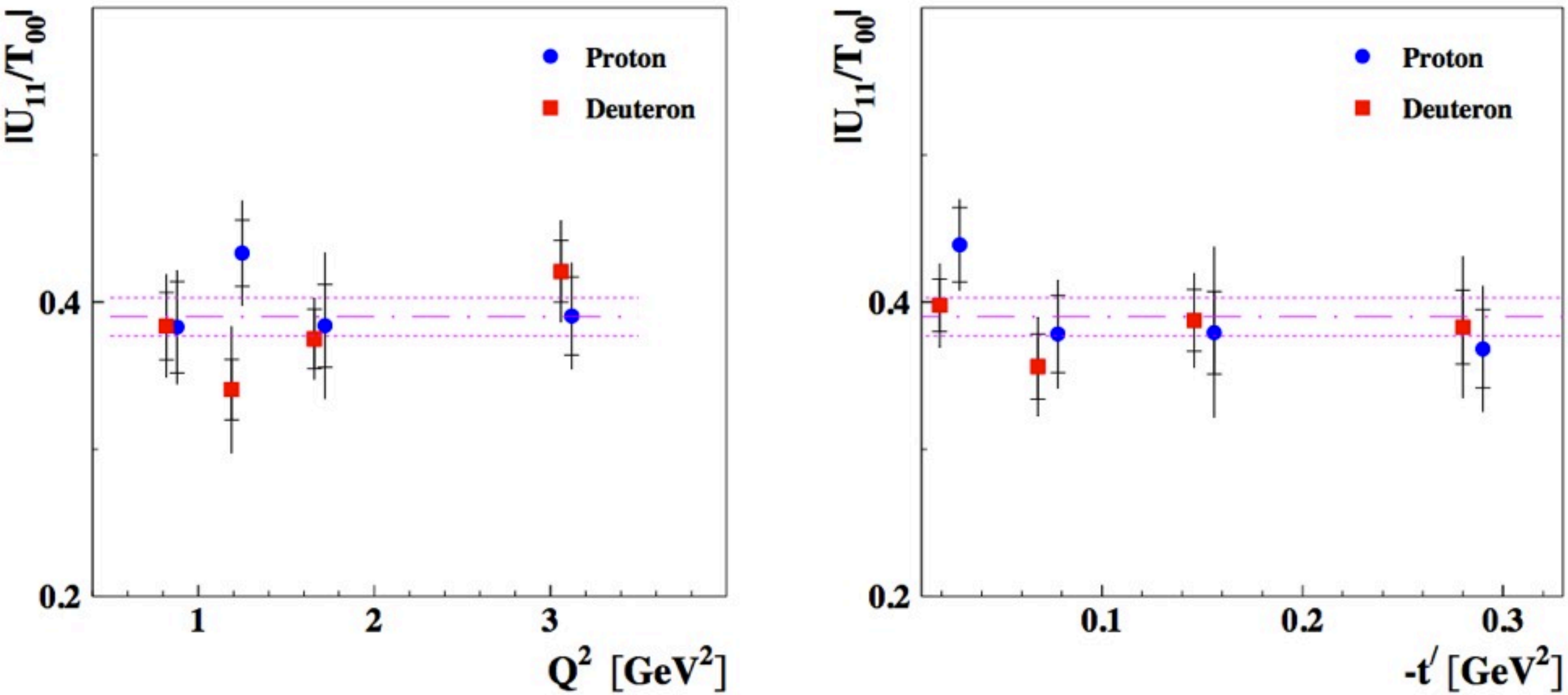


Meson data can also play a vital role in accessing GPDs - especially the "polarised" GPDs $\widetilde{H}$ and $\widetilde{E}$!

Extraction of SDMES and Helicity Amplitude Ratios at HERMES for ρ mesons have shown that the handbag approximation is insufficient!



Meson Data



Throughout the majority of exclusive physics data from HERMES we see that there is very little difference between protons and deuterons!!!

Conclusions

- DVCS can be used to access information on Generalised Parton Distributions
- That information can tell us unique things about nucleon structure
- HERMES has the most diverse DVCS measurements of any experiment.

Conclusions

- There is still no clear idea about how the nuclear medium modifies GPD-dependent behaviour.
- Already, GPDs can be constrained - but there is much left to do!
- DVCS and DVMP both seem to show that there is little difference between proton and deuteron data!!!