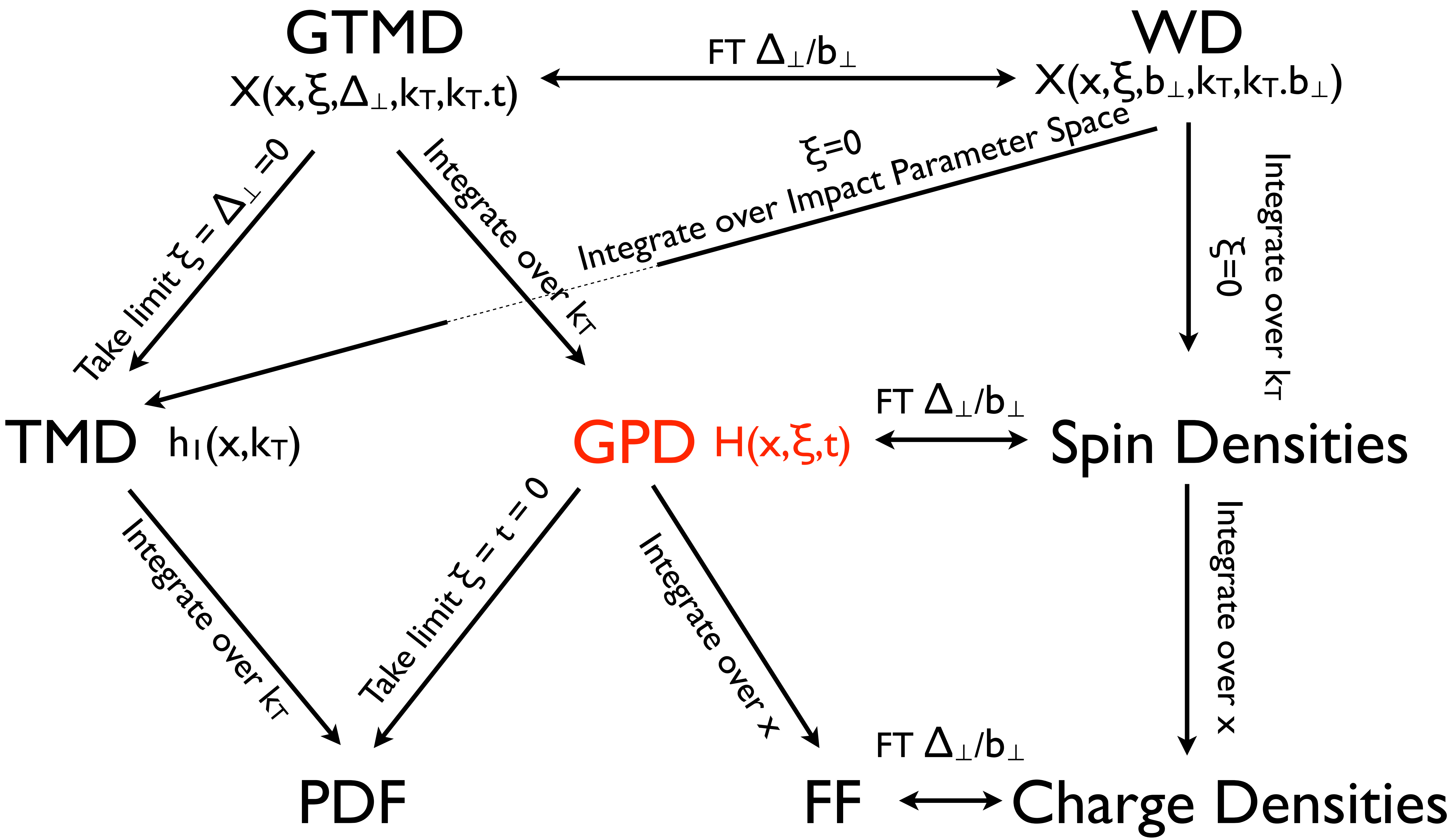
DVCS @ HERMES

M. MURRAY, UNIVERSITY OF GLASGOW

DIS 2012

Distribution Graph



GPD Physics

GPDs describe only the soft part of the interaction

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

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

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

GPD Physics

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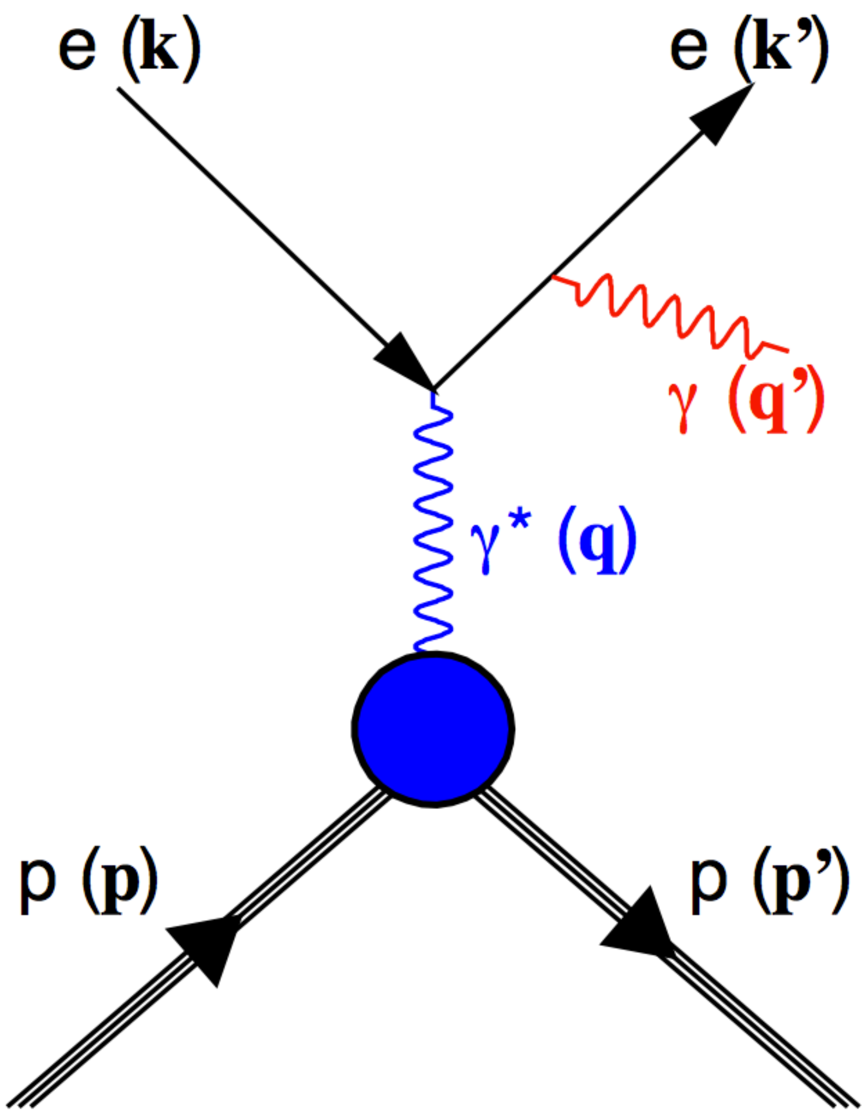
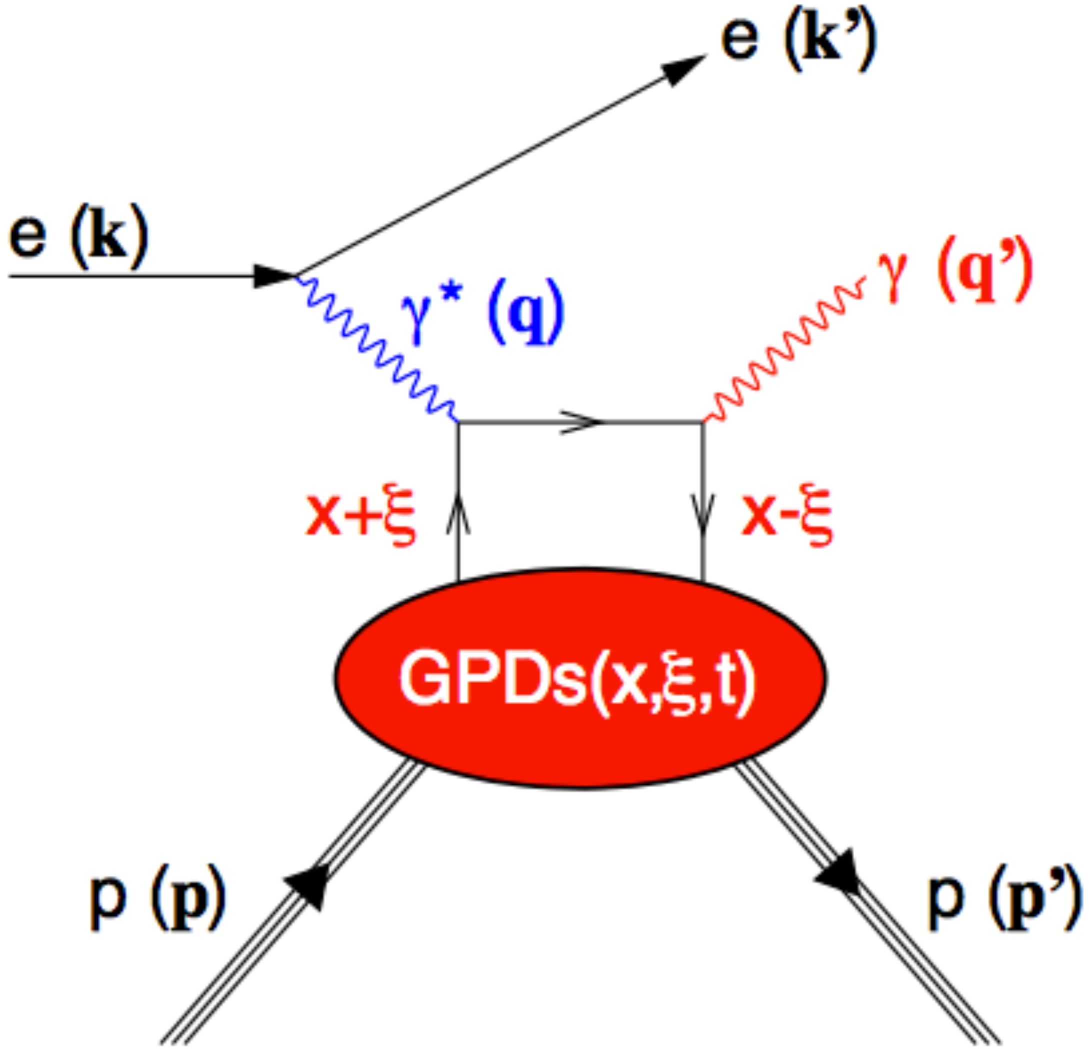
$$\begin{aligned} \Im m\,\mathcal{F}(\xi,\,t) &= F(\xi,\,\xi,\,t) \pm F(-\xi,\,\xi,\,t)\,, \\ \Re e\,\mathcal{F}(\xi,\,t) &= \mathcal{P}_{\rm C}\int_{-1}^{1} \frac{F(x,\,\xi,\,t)}{x-\xi} \pm \frac{F(x,\,\xi,\,t)}{x+\xi}\,dx \end{aligned}$$

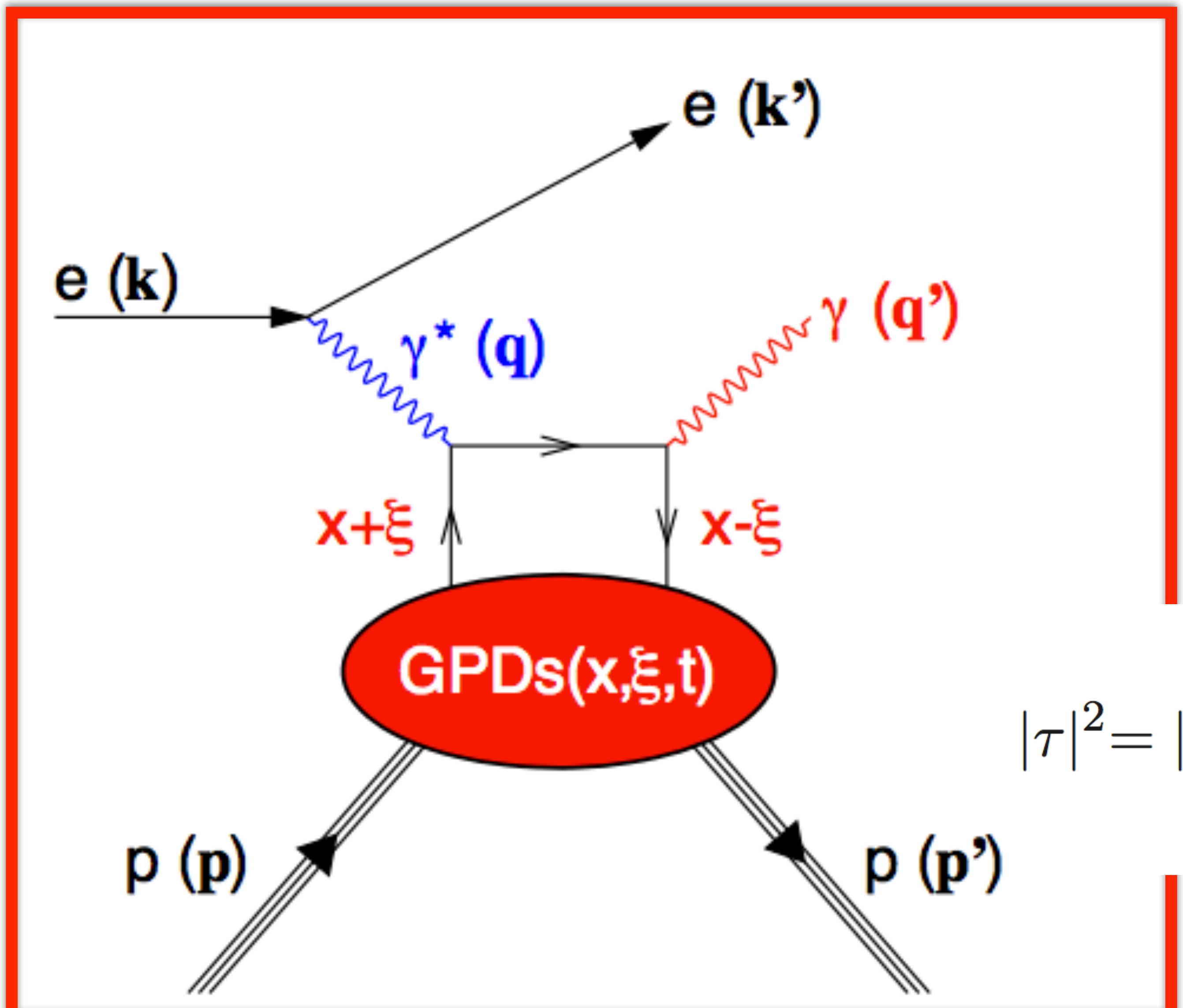
Deeply Virtual Compton Scattering

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





Deeply Virtual Compton Scattering



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

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

DVCS @ HERMES

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

$$\mathcal{A}_{\mathrm{LU}}^{\mathrm{I}}(\phi) \equiv \frac{(\mathrm{d}\sigma(\phi)^{+\rightarrow} - \mathrm{d}\sigma(\phi)^{+\leftarrow}) - (\mathrm{d}\sigma(\phi)^{-\rightarrow} - \mathrm{d}\sigma(\phi)^{-\leftarrow})}{(\mathrm{d}\sigma(\phi)^{+\rightarrow} + \mathrm{d}\sigma(\phi)^{+\leftarrow}) + (\mathrm{d}\sigma(\phi)^{-\rightarrow} + \mathrm{d}\sigma(\phi)^{-\leftarrow})} \quad \overset{\sim}{\propto} \quad \mathrm{Im}(\mathcal{H})$$

$$\mathcal{A}_{\mathrm{LU}}^{\mathrm{DVCS}}(\phi) \equiv \frac{(\mathrm{d}\sigma(\phi)^{+\rightarrow} + \mathrm{d}\sigma(\phi)^{-\rightarrow}) - (\mathrm{d}\sigma(\phi)^{+\leftarrow} + \mathrm{d}\sigma(\phi)^{-\leftarrow})}{(\mathrm{d}\sigma(\phi)^{+\rightarrow} + \mathrm{d}\sigma(\phi)^{-\rightarrow}) + (\mathrm{d}\sigma(\phi)^{+\leftarrow} + \mathrm{d}\sigma(\phi)^{-\leftarrow})} \quad \overset{\sim}{\propto} \quad \mathrm{Im}[\mathcal{H}\mathcal{H}^* + \widetilde{\mathcal{H}}\widetilde{\mathcal{H}}^*]$$

$$\mathcal{A}_{\mathrm{UT}}^{\mathrm{I}}(\phi,\phi_S) \equiv \frac{d\sigma^+(\phi,\phi_S) - d\sigma^+(\phi,\phi_S+\pi) - d\sigma^-(\phi,\phi_S) + d\sigma^-(\phi,\phi_S+\pi)}{d\sigma^+(\phi,\phi_S) + d\sigma^+(\phi,\phi_S+\pi) + d\sigma^-(\phi,\phi_S) + d\sigma^-(\phi,\phi_S+\pi)} \quad \overset{\sim}{\propto} \quad \mathrm{Im}(\mathcal{E})$$

$$\mathcal{A}_{\mathrm{UT}}^{\mathrm{DVCS}}(\phi,\phi_S) \equiv \frac{d\sigma^+(\phi,\phi_S) - d\sigma^+(\phi,\phi_S+\pi) + d\sigma^-(\phi,\phi_S) - d\sigma^-(\phi,\phi_S+\pi)}{d\sigma^+(\phi,\phi_S) + d\sigma^+(\phi,\phi_S+\pi) + d\sigma^-(\phi,\phi_S) + d\sigma^-(\phi,\phi_S+\pi)} \quad \overset{\sim}{\propto} \quad \mathrm{Im}(\mathcal{E})$$

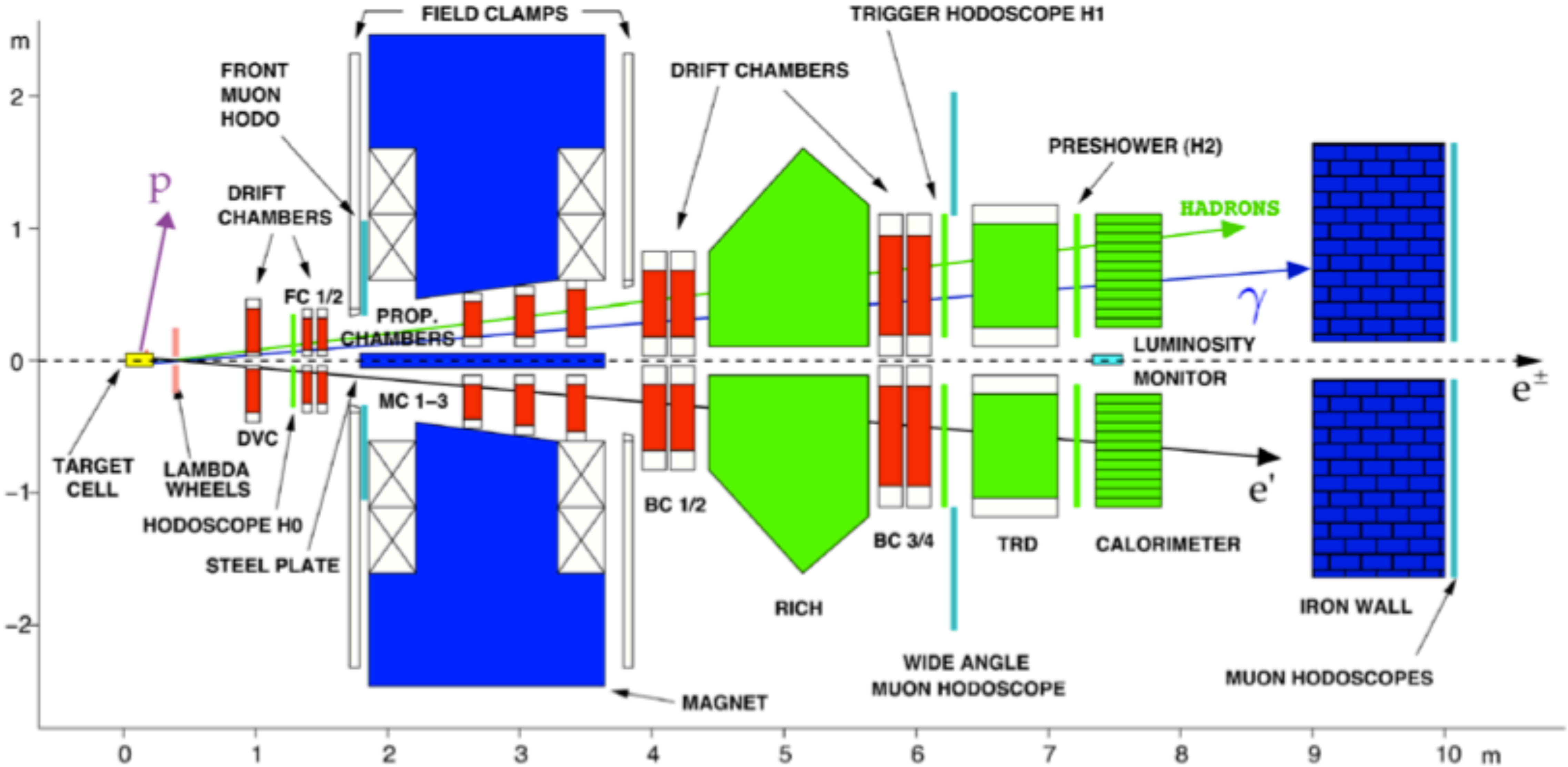
$$\mathcal{A}_{\mathrm{LT}}^{\mathrm{BH+DVCS}}(\phi,\phi_S) \equiv \frac{1}{8d\sigma_{\mathrm{UU}}}\left[(d\overrightarrow{\sigma}^{+\uparrow} - d\overrightarrow{\sigma}^{+\downarrow} - d\overleftarrow{\sigma}^{+\uparrow} + d\overleftarrow{\sigma}^{+\downarrow}) + (d\overrightarrow{\sigma}^{-\uparrow} - d\overrightarrow{\sigma}^{-\downarrow} - d\overleftarrow{\sigma}^{-\uparrow} + d\overleftarrow{\sigma}^{-\downarrow})\right] \quad \overset{\sim}{\propto} \quad \mathrm{Re}(\mathcal{H}+\mathcal{E})$$

$$\mathcal{A}_{\mathrm{LT}}^{\mathrm{I}}(\phi,\phi_S) \equiv \frac{1}{8d\sigma_{\mathrm{UU}}}\left[(d\overrightarrow{\sigma}^{+\uparrow} - d\overrightarrow{\sigma}^{+\downarrow} - d\overleftarrow{\sigma}^{+\uparrow} + d\overleftarrow{\sigma}^{+\downarrow}) - (d\overrightarrow{\sigma}^{-\uparrow} - d\overrightarrow{\sigma}^{-\downarrow} - d\overleftarrow{\sigma}^{-\uparrow} + d\overleftarrow{\sigma}^{-\downarrow})\right] \quad \overset{\sim}{\propto} \quad \mathrm{Re}(\mathcal{H})$$

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

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

DVCS @ HERMES



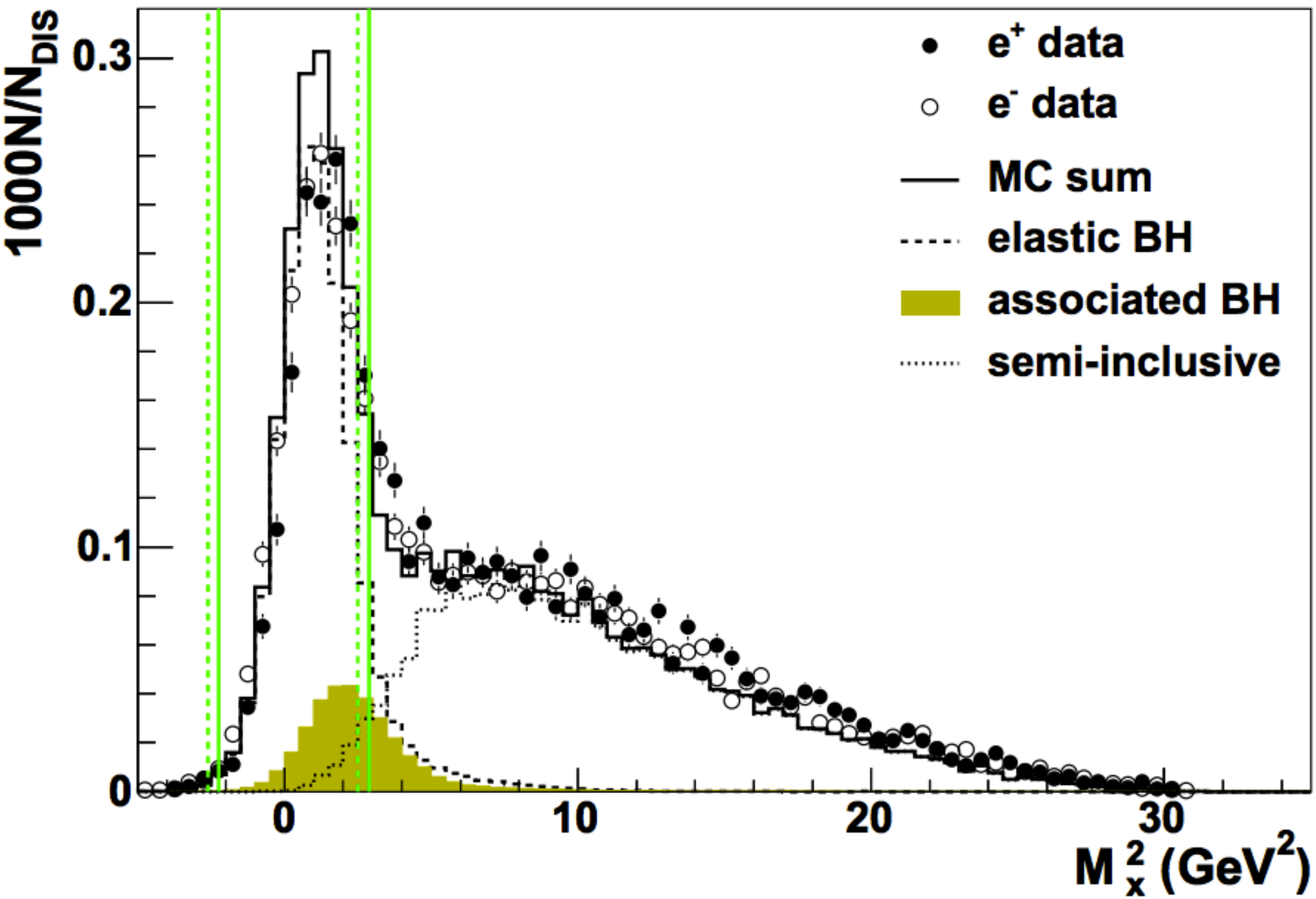
$\langle Q^2 \rangle \cong 2.4$ GeV^2

$\langle x_B \rangle \cong 0.1$

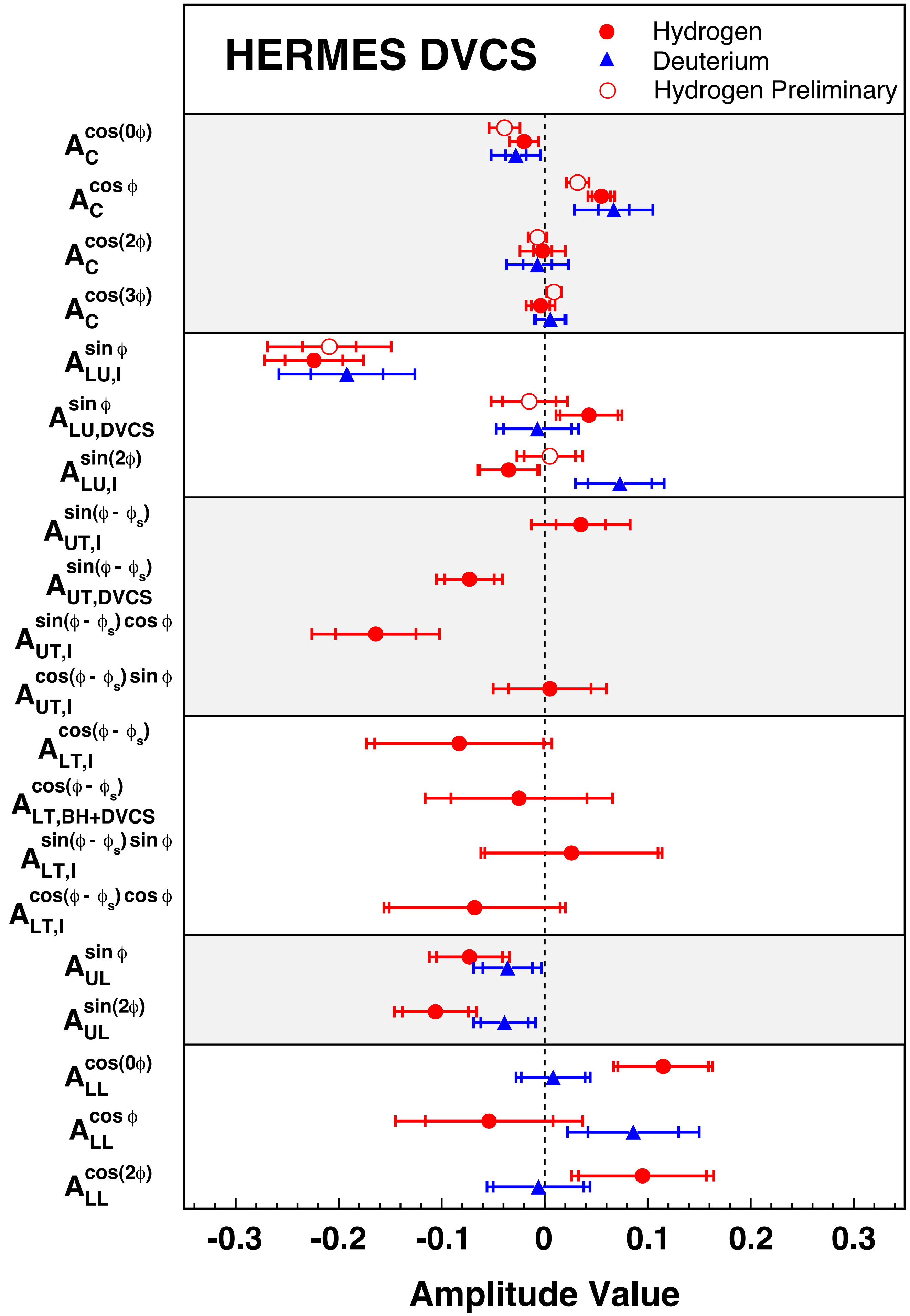
$\langle -t \rangle \cong 0.1$ GeV^2

- 1 GeV$^2 < Q^2 \equiv -q^2 < 10$ GeV^2
- $0.03 < x_B < 0.35$
- 0 GeV$^2 < -t \equiv -(p-p')^2 < 0.7$ GeV^2

DVCS @ HERMES


1000N/N_DIS
0.3
0.2
0.1
0
0
10
20
30
M x 2 (GeV2)
e+ data
e- data
MC sum
elastic BH
associated BH
semi-inclusive

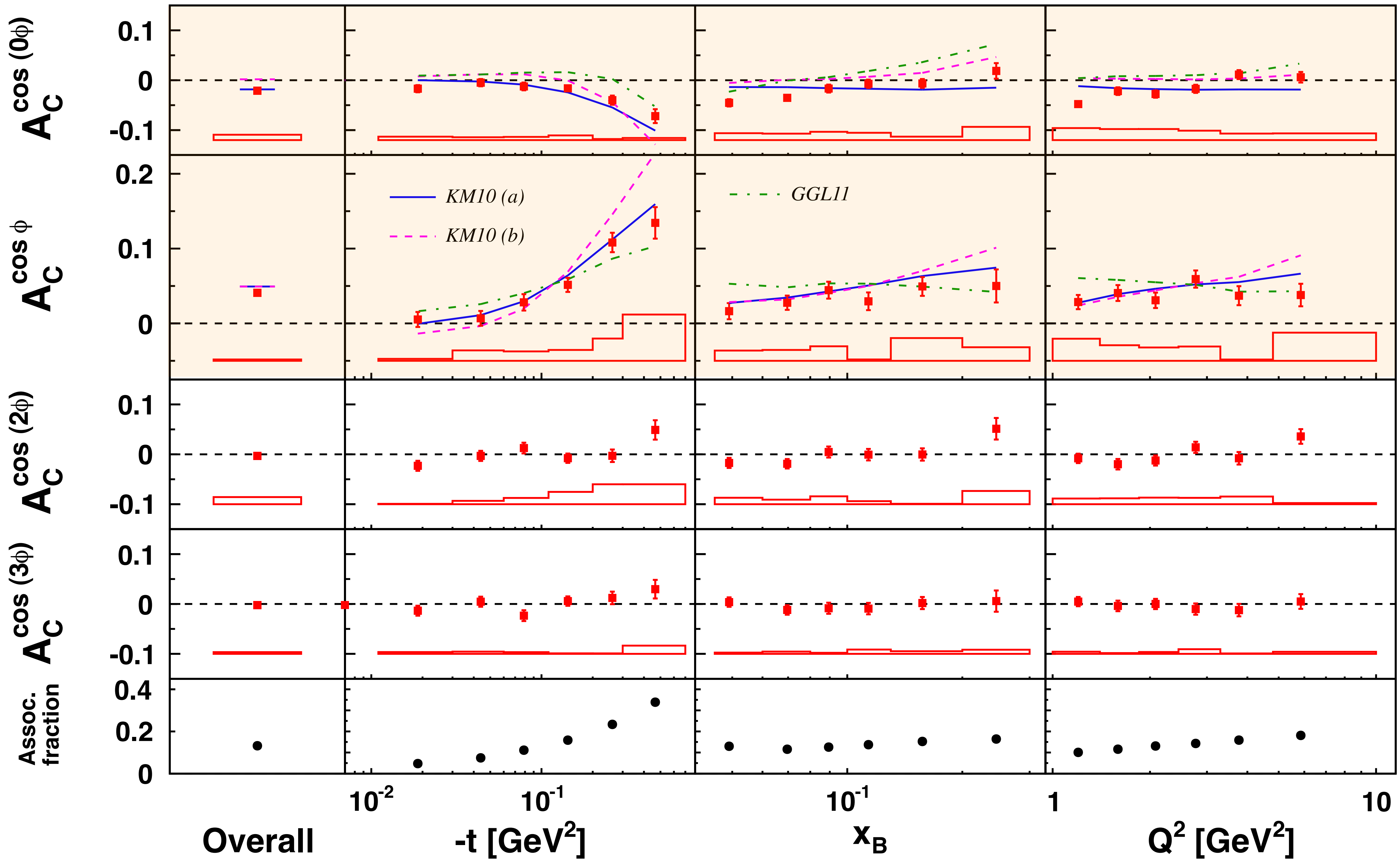
DVCS @


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

HERMES

Beam-Charge Asymmetries

A. Airapetian et al, JHEP (2012), submitted http://arxiv.org/abs/1203.6287



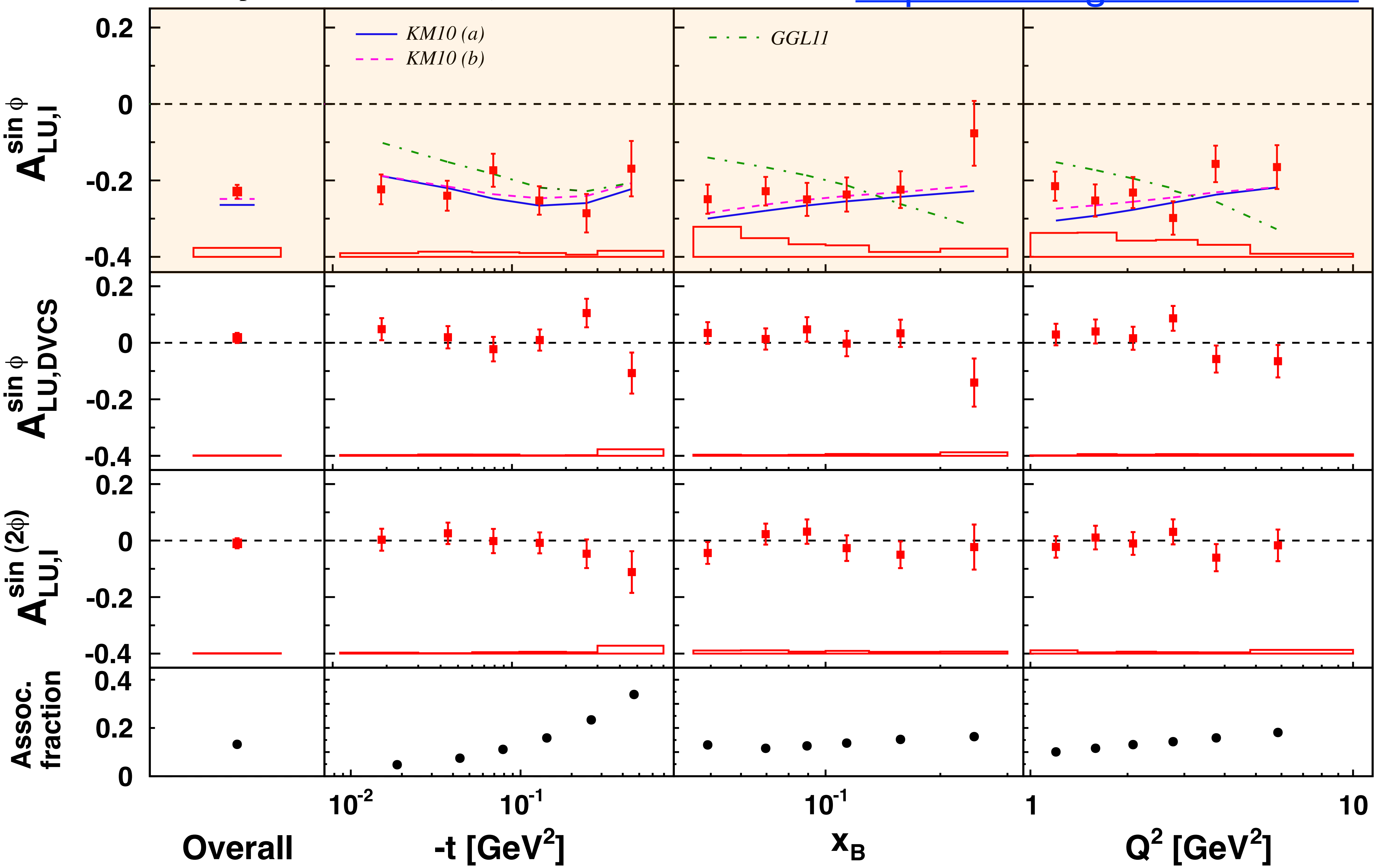
Beam Charge Asymmetries access Re($\mathcal{H}$)

Kumerički and Müller, Nucl. Phys. **B841** (2010) http://arxiv.org/abs/0904.0458

G. Goldstein, J. Hernandez and S. Liuti, **Phys. Rev. D84** (2011) http://arxiv.org/abs/1012.3776

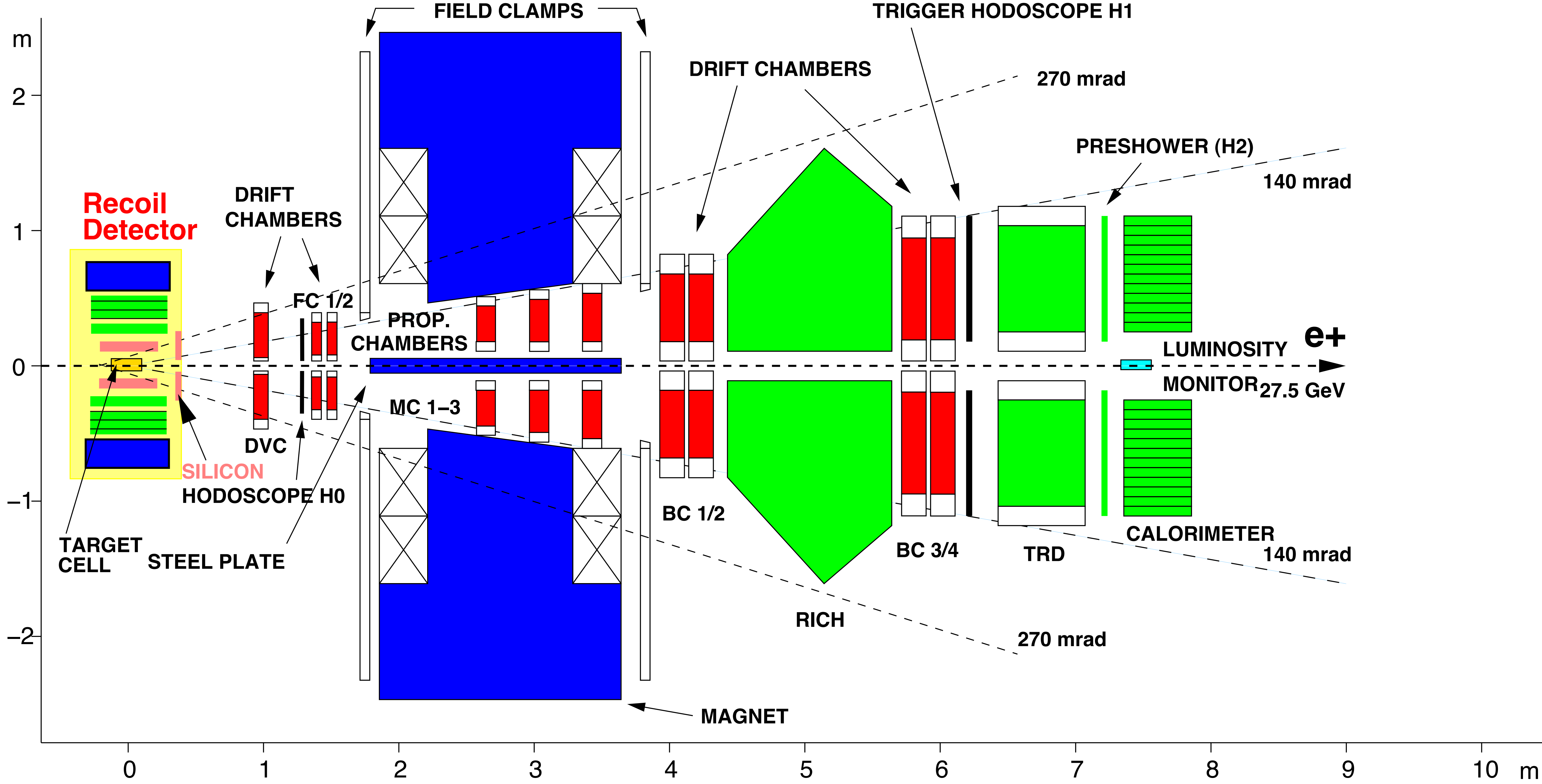
Beam-Spin Asymmetries

A. Airapetian et al, JHEP (2012), submitted http://arxiv.org/abs/1203.6287



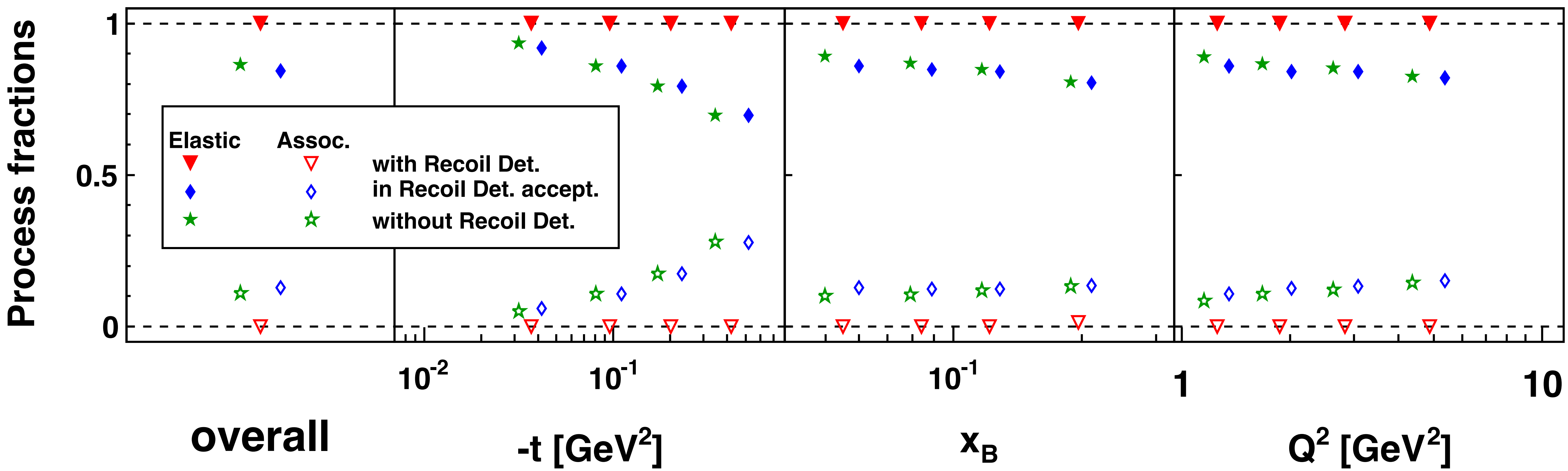
Beam Helicity Asymmetries access Im($\mathcal{H}$)

DVCS @ HERMES

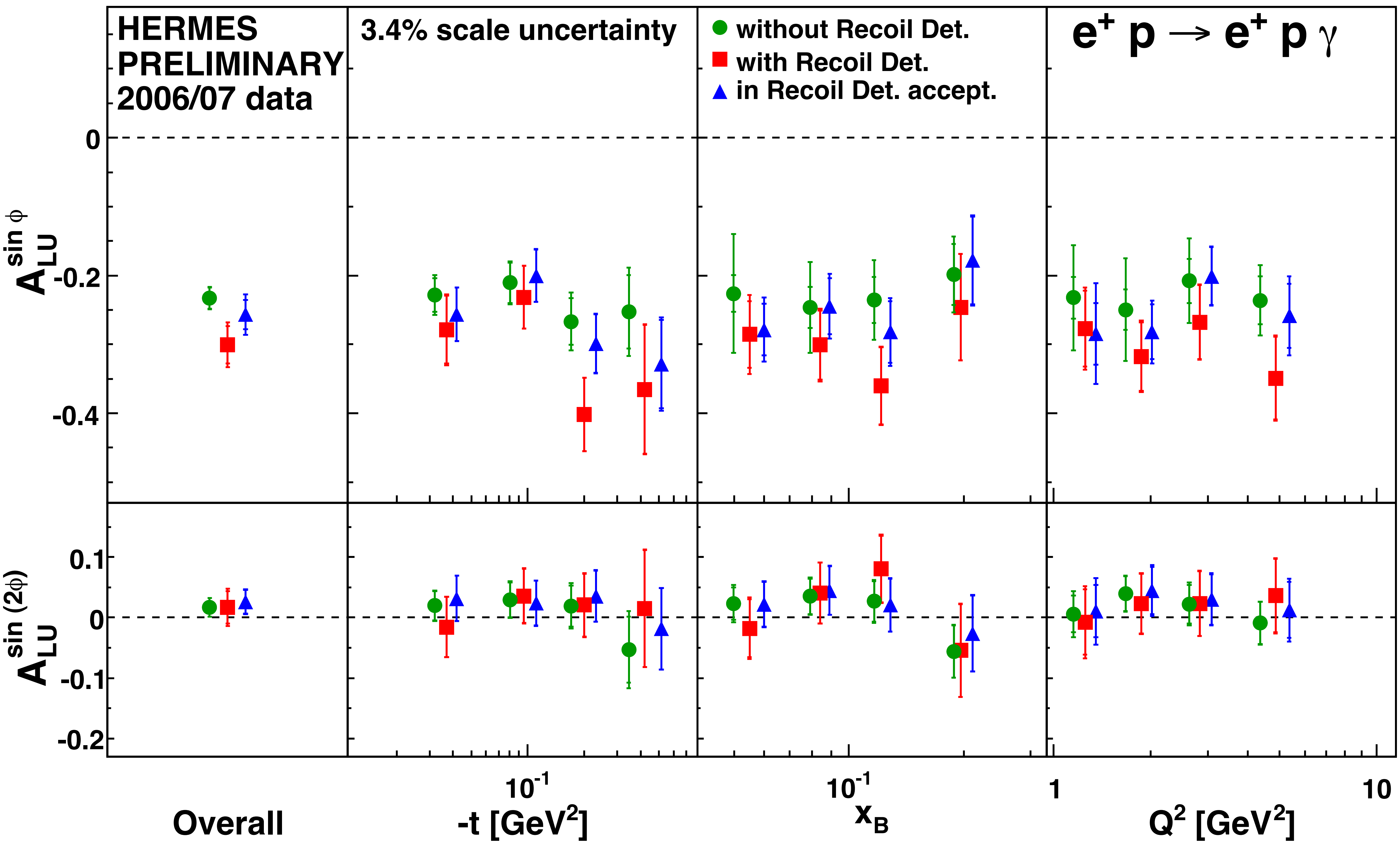


FIELD CLAMPS
TRIGGER HODOSCOPE H1
DRIFT CHAMBERS
270 mrad
PRESHOWER (H2)
140 mrad
Recoil Detector
DRIFT CHAMBERS
FC 1/2
PROP. CHAMBERS
MC 1–3
DVC
SILICON
HODOSCOPE H0
TARGET CELL
STEEL PLATE
BC 1/2
RICH
BC 3/4
TRD
CALORIMETER
140 mrad
LUMINOSITY MONITOR
e+
27.5 GeV
270 mrad
MAGNET
m
2
1
0
−1
−2
0
1
2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

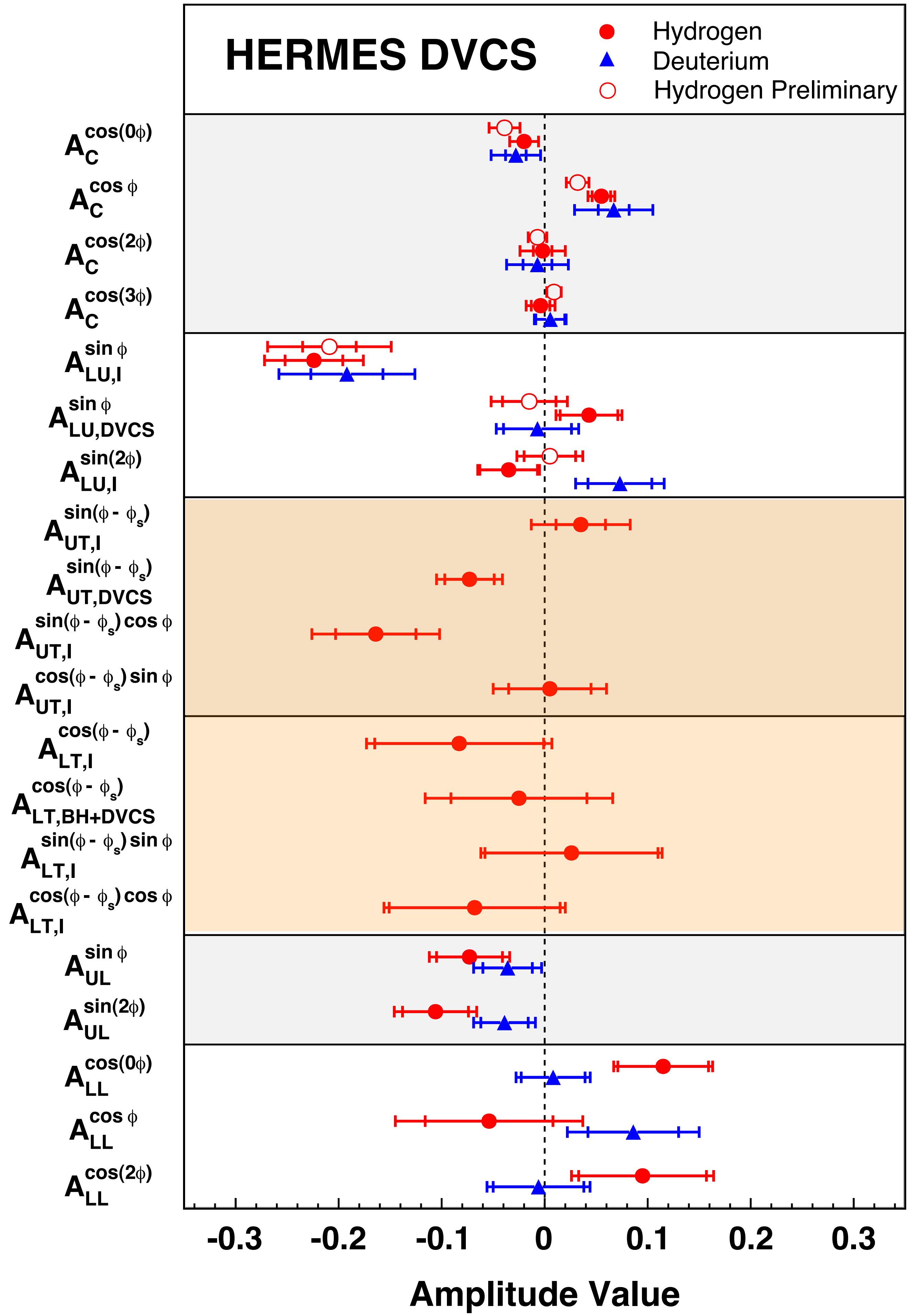
Exclusive Measurement



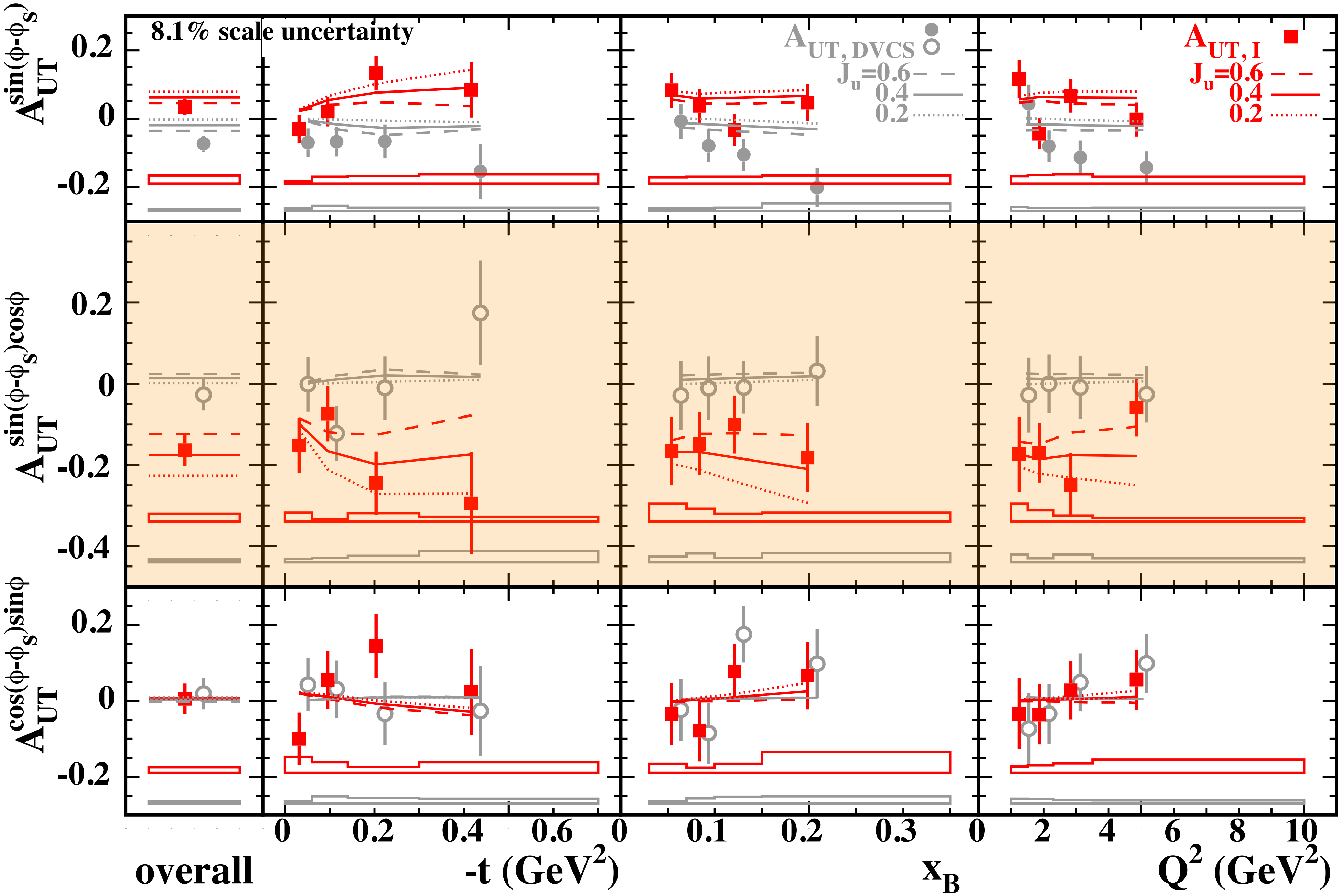
Exclusive Measurement



DVCS @ HERMES


HERMES DVCS
Hydrogen
Deuterium
Hydrogen Preliminary
-0.3 -0.2 -0.1 0 0.1 0.2 0.3
Amplitude Value

Transverse-Target Asymmetries



DVCS amplitude involves transversity GPDs

Transverse Target Asymmetries can access E?

Pioneering measurement to be repeated at CLAS12 and the EIC

VGG Model:

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

Phys.Rev. D60 (1999) 094017

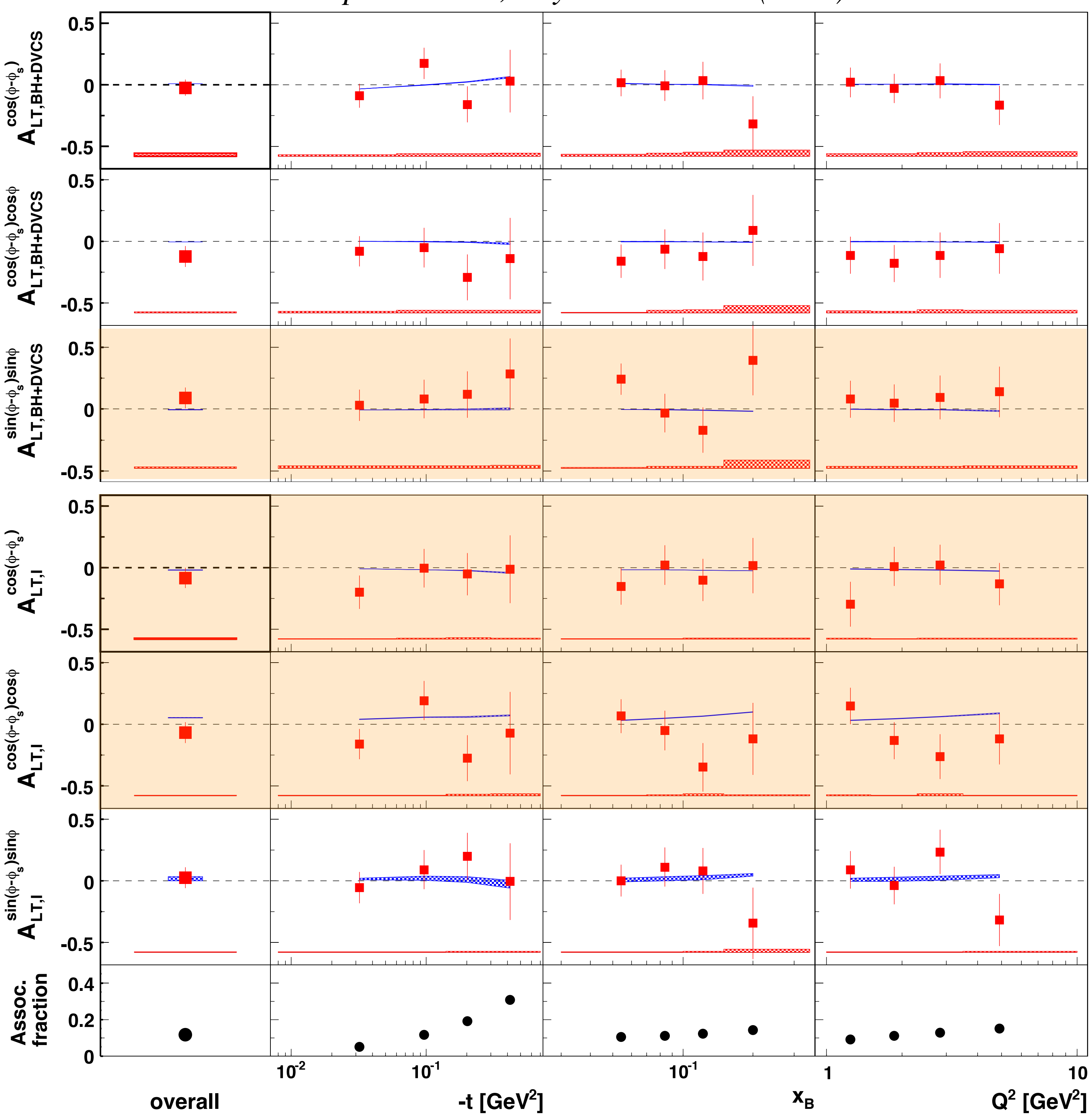
HERMES Data:

http://arxiv.org/abs/0802.2499

A. Airapetian et al, JHEP 06 (2008) 066, 24pp

Double-Spin Asymmetries

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



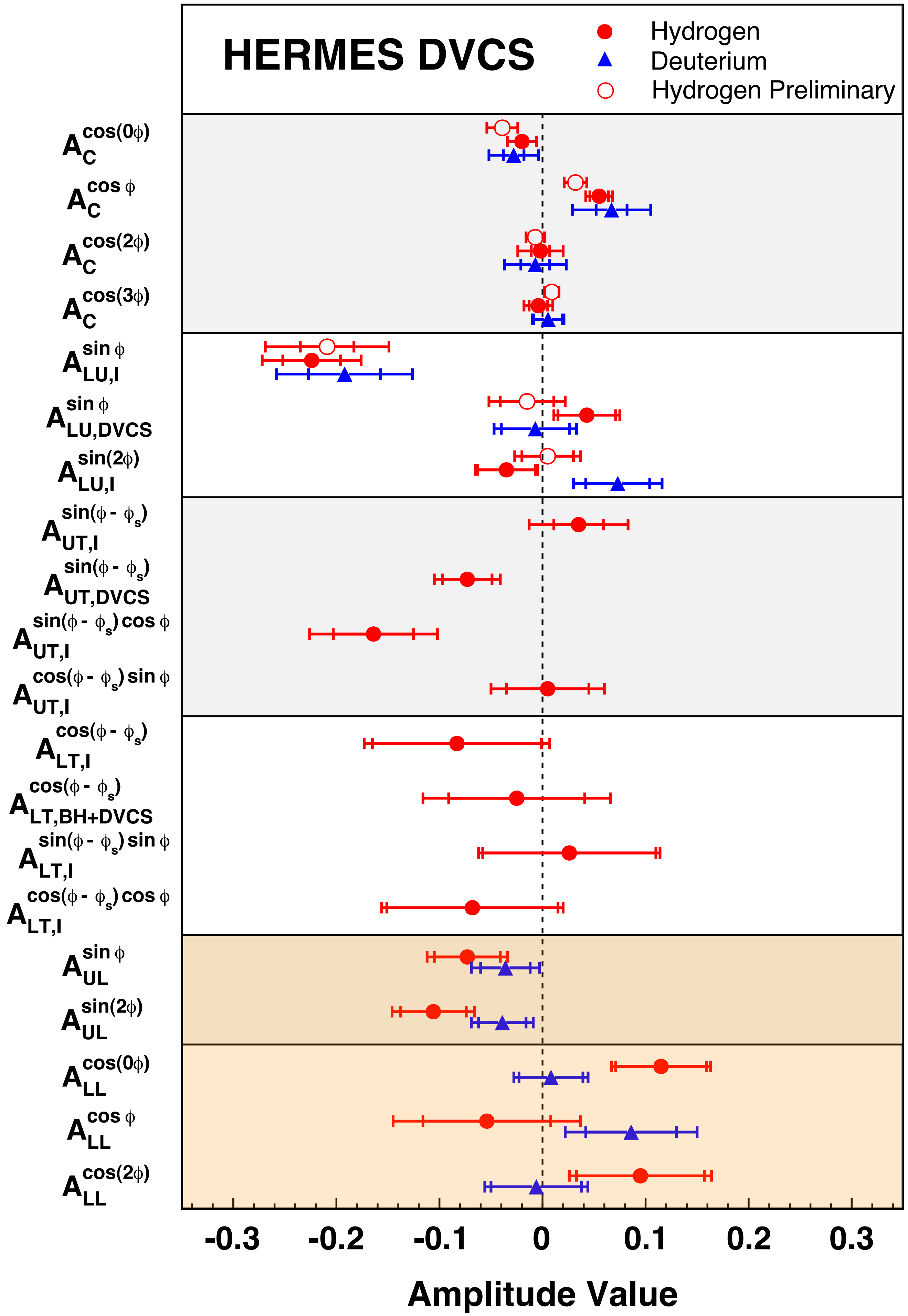
Tran. Pol. target / Long. Pol. Beam

Real parts of $\mathcal{H}$ and $\mathcal{E}$

Extracted to be 0; compatible with VGG predictions.

http://arxiv.org/abs/1106.2990

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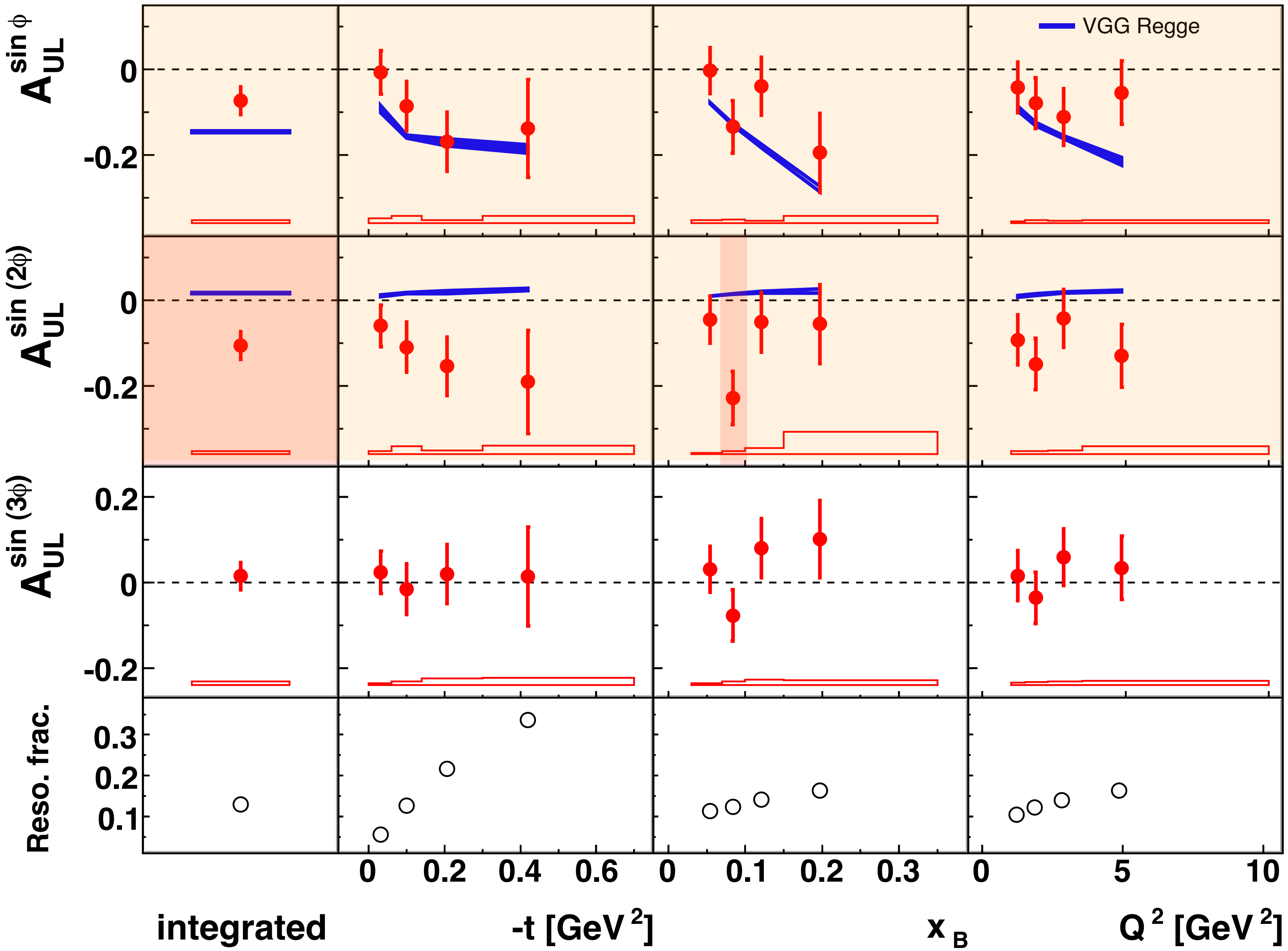
$A_{LT,BH+DVCS}^{\cos(\phi-\phi_s)}$
$A_{LT,I}^{\sin(\phi-\phi_s)\sin\phi}$
$A_{LT,I}^{\cos(\phi-\phi_s)\cos\phi}$
$A_{UL}^{\sin\phi}$
$A_{UL}^{\sin(2\phi)}$
$A_{LL}^{\cos(0\phi)}$
$A_{LL}^{\cos\phi}$
$A_{LL}^{\cos(2\phi)}$
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
Amplitude Value

HERMES

Longitudinal-Target Asymmetries



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

http://arxiv.org/abs/1004.0177

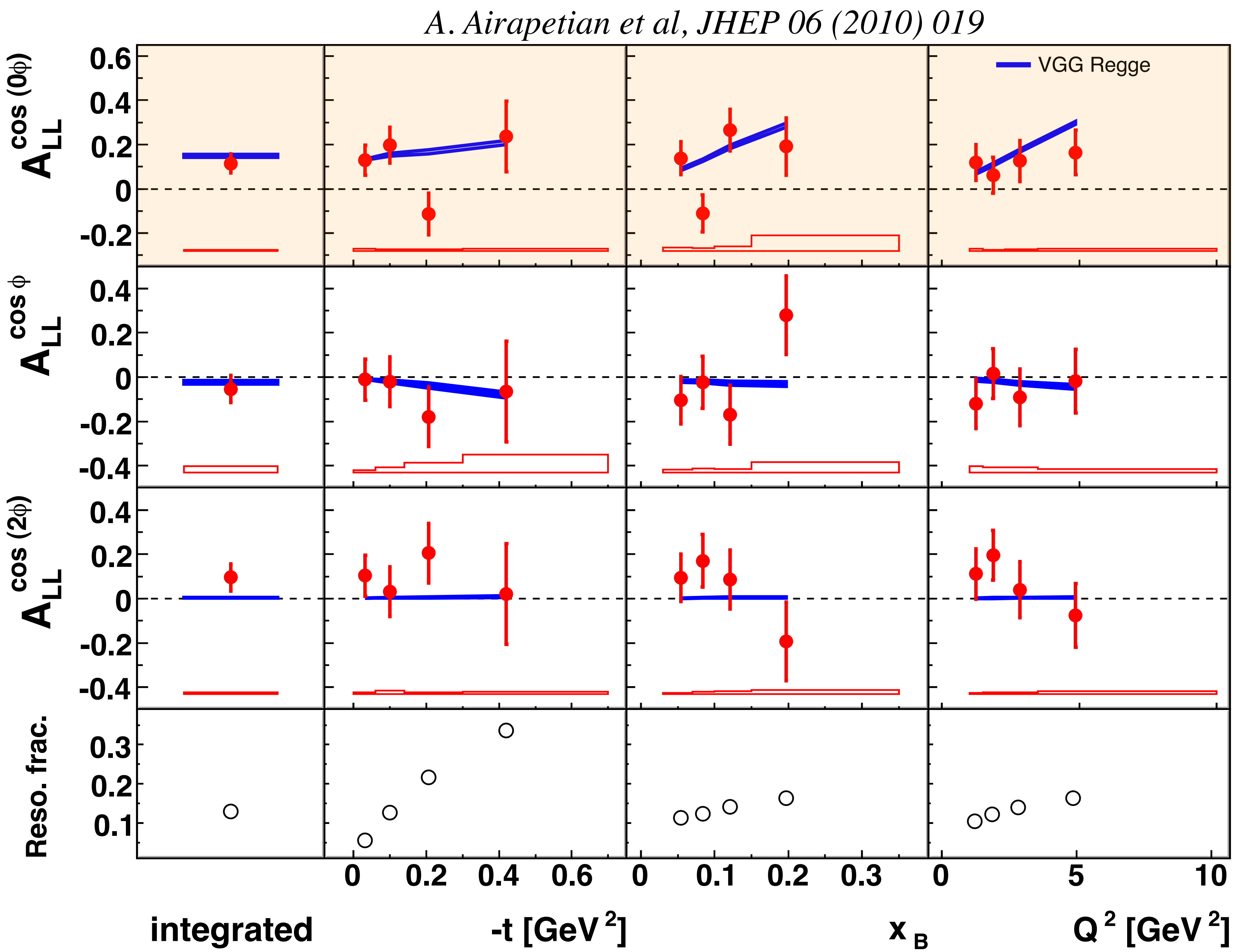
A. Airapetian et al, JHEP 06 (2010) 019

VGG Model:

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

Phys.Rev. D60 (1999) 094017

Double-Spin Asymmetries

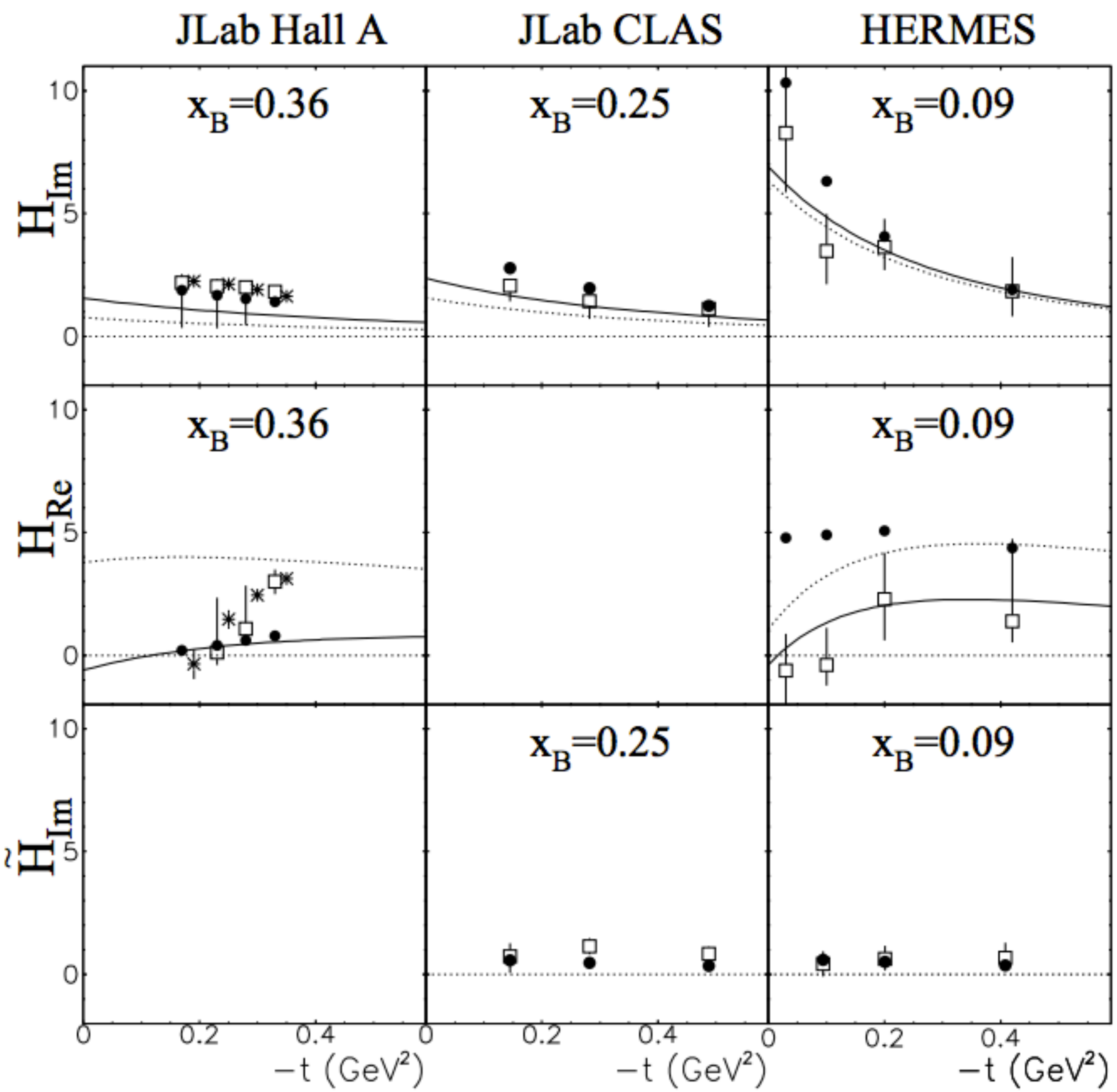


Long. Pol. target / Long. Pol. Beam access Re($\widetilde{\mathcal{H}}$)

Caveat! Relatively large BH contribution to these asymmetries!

http://arxiv.org/abs/1004.0177

GPD Extraction



Even for H, VGG model GPDs are shown not to be consistent with experimental measurements when CFFs are extracted from data.

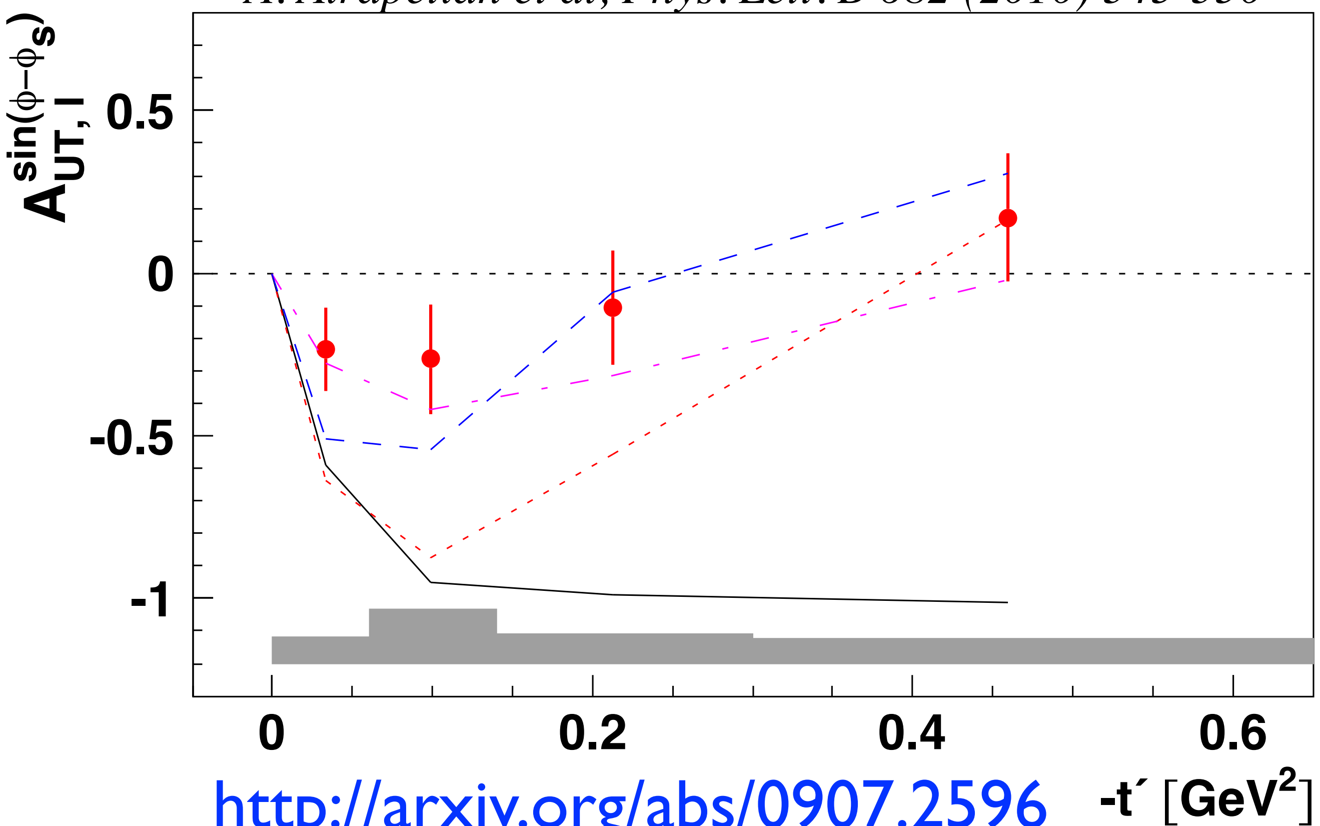
http://arxiv.org/abs/1011.4195
*Guidal, **ICHEP Procs.** (2010)*

http://arxiv.org/abs/0904.1648
*H. Moutarde, **Phys. Rev. D79** (2009)*

http://arxiv.org/abs/0904.0458
*Kumerički and Müller, Nucl. Phys. **B841** (2010)*

Other Data?

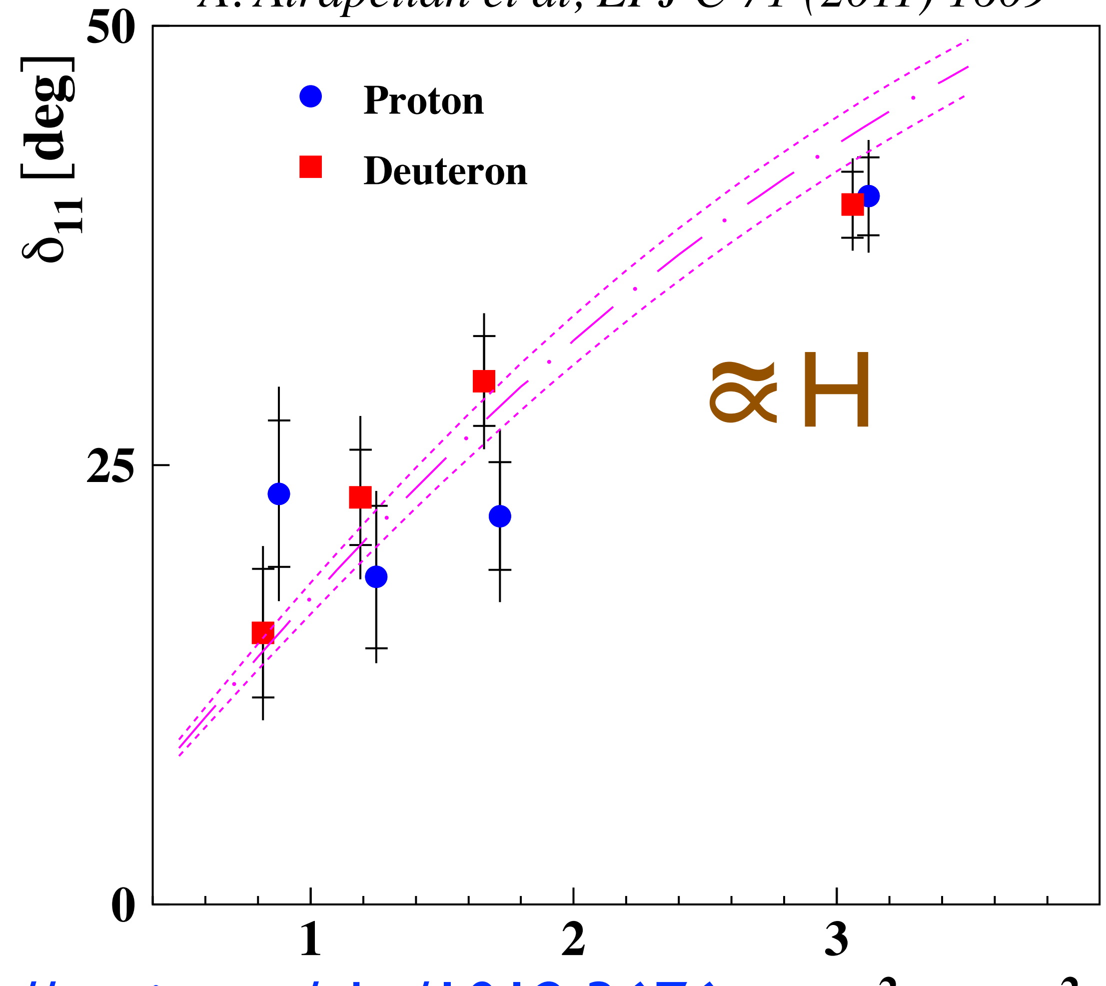
A. Airapetian et al, Phys. Lett. B 682 (2010) 345-350



http://arxiv.org/abs/0907.2596

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

A. Airapetian et al, EPJ C 71 (2011) 1609



http://arxiv.org/abs/1012.3676

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

Conclusions - What did we learn at HERMES?

- DVCS can be used to access information on Generalised Parton Distributions
- HERMES has the most diverse DVCS measurements of any experiment.
- Polarised target experiments are essential for the extraction of GPDs; should be seen as a fundamental experimental priority!

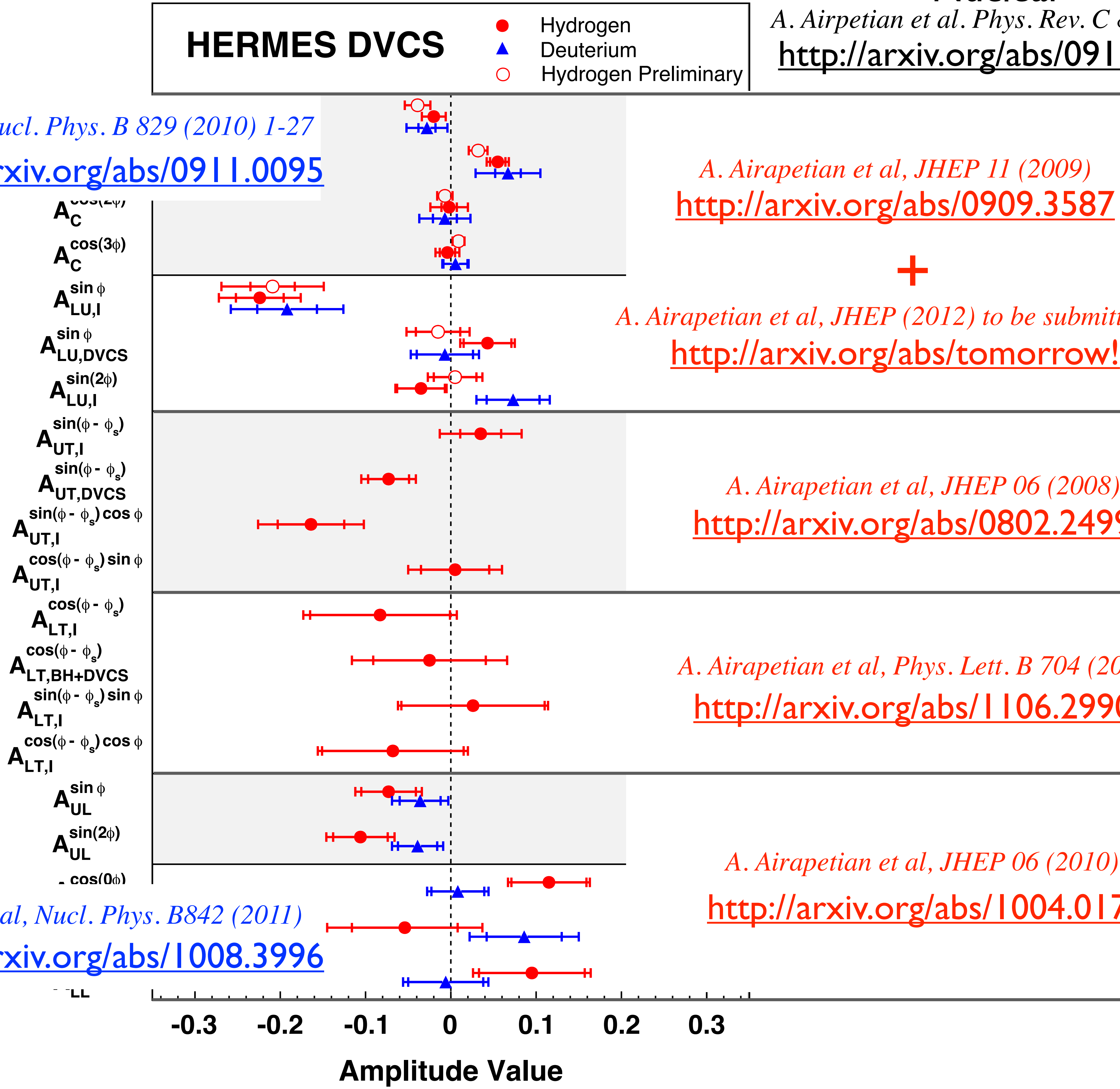
Conclusions - What did we learn at HERMES?

- Lack of data means that nuclear effects on GPDs are not quantified! Incentive for new experiments at JLab, COMPASS and the EIC!
- Already, GPDs can be constrained - but there is much left to do!
- What effects do chiral-odd GPDs or higher-twist distributions have?

Nuclear
A. Airpetian et al. Phys. Rev. C 81 (2010)
http://arxiv.org/abs/0911.0091

A. Airapetian et al, Nucl. Phys. B 829 (2010) 1-27
http://www.arxiv.org/abs/0911.0095

D V C S @



A. Airapetian et al, JHEP 11 (2009)
http://arxiv.org/abs/0909.3587

+

A. Airapetian et al, JHEP (2012) to be submitted
http://arxiv.org/abs/tomorrow!

A. Airapetian et al, JHEP 06 (2008)
http://arxiv.org/abs/0802.2499

A. Airapetian et al, Phys. Lett. B 704 (2011)
http://arxiv.org/abs/1106.2990

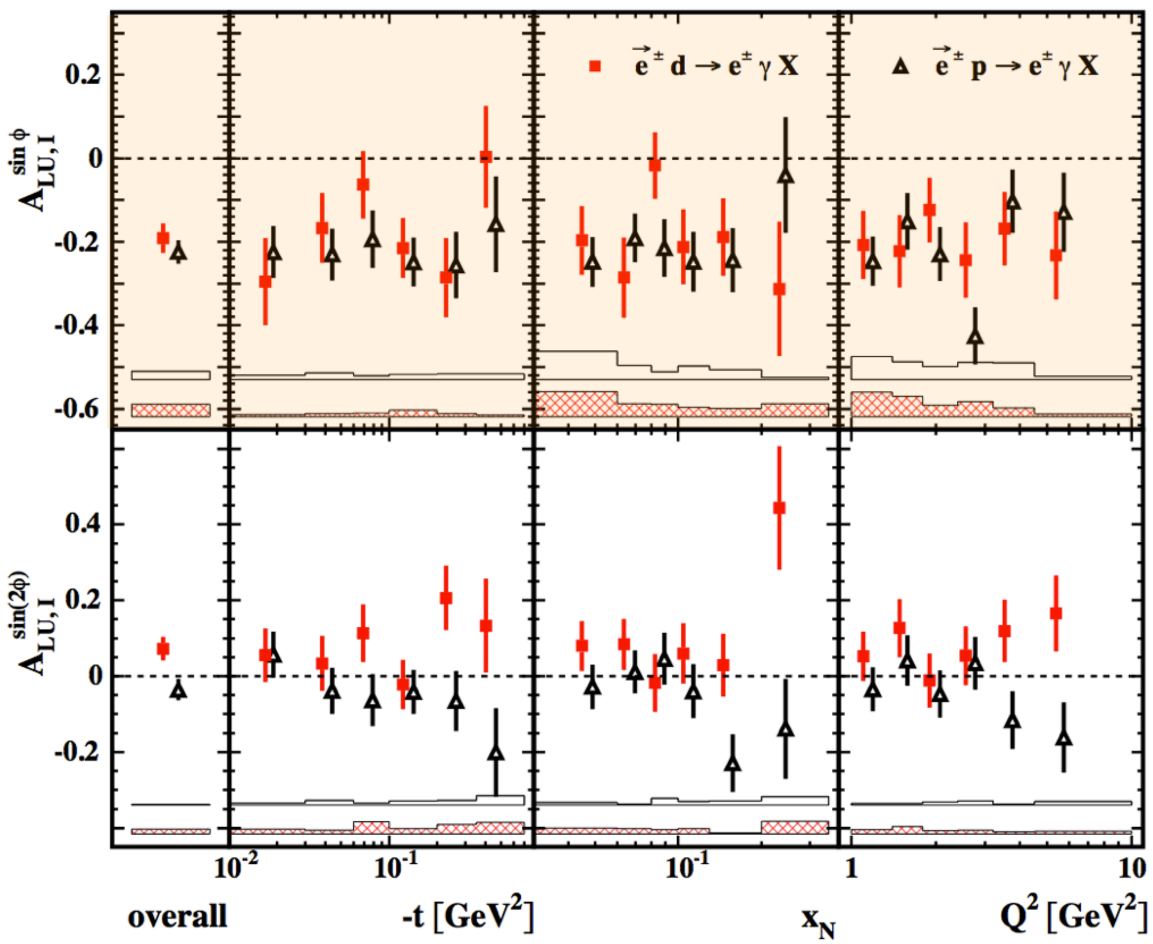
A. Airapetian et al, JHEP 06 (2010)
http://arxiv.org/abs/1004.0177

A. Airapetian et al, Nucl. Phys. B842 (2011)
http://www.arxiv.org/abs/1008.3996

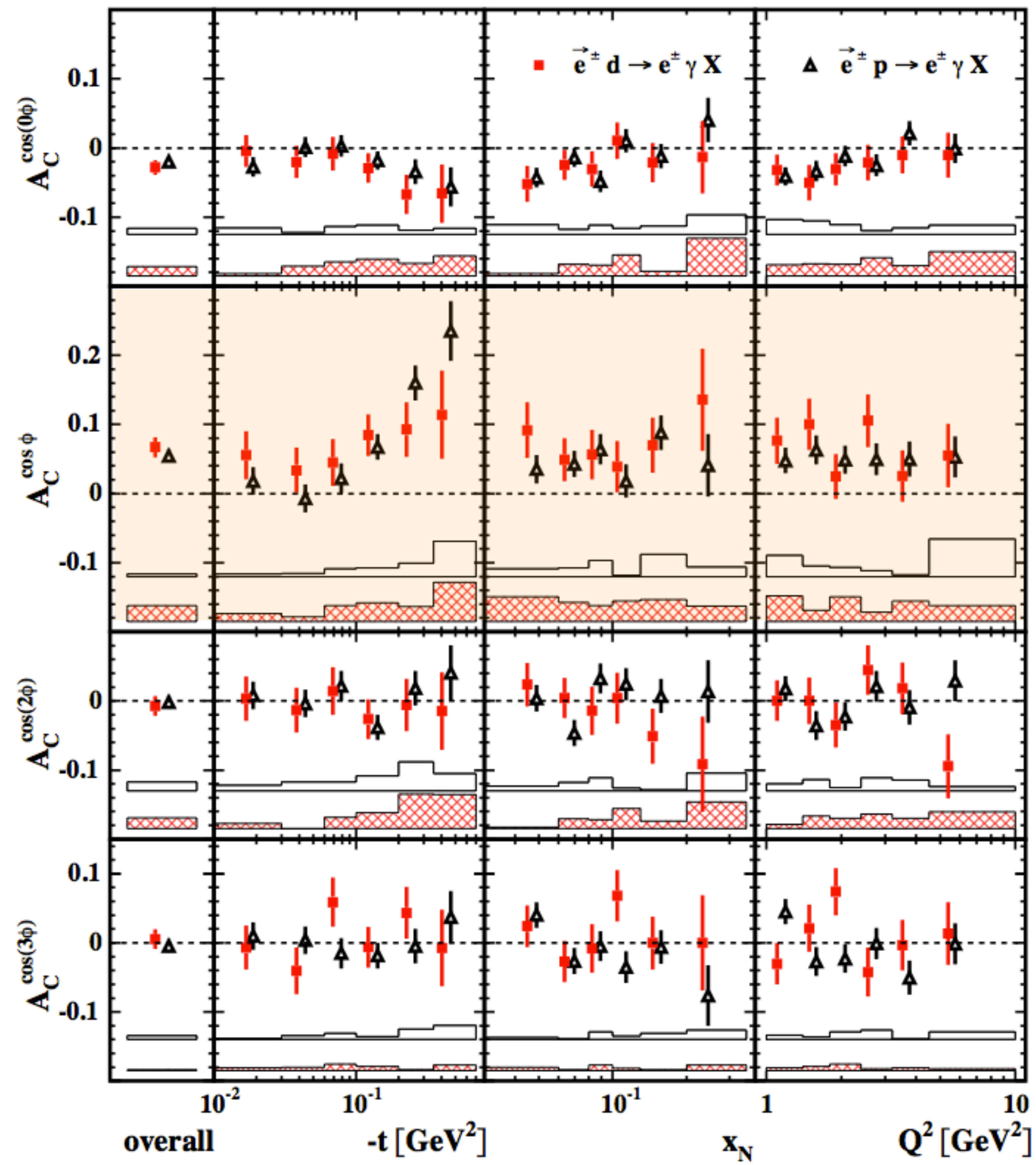
H E R M E S

Deuterium Beam-Asymmetries

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



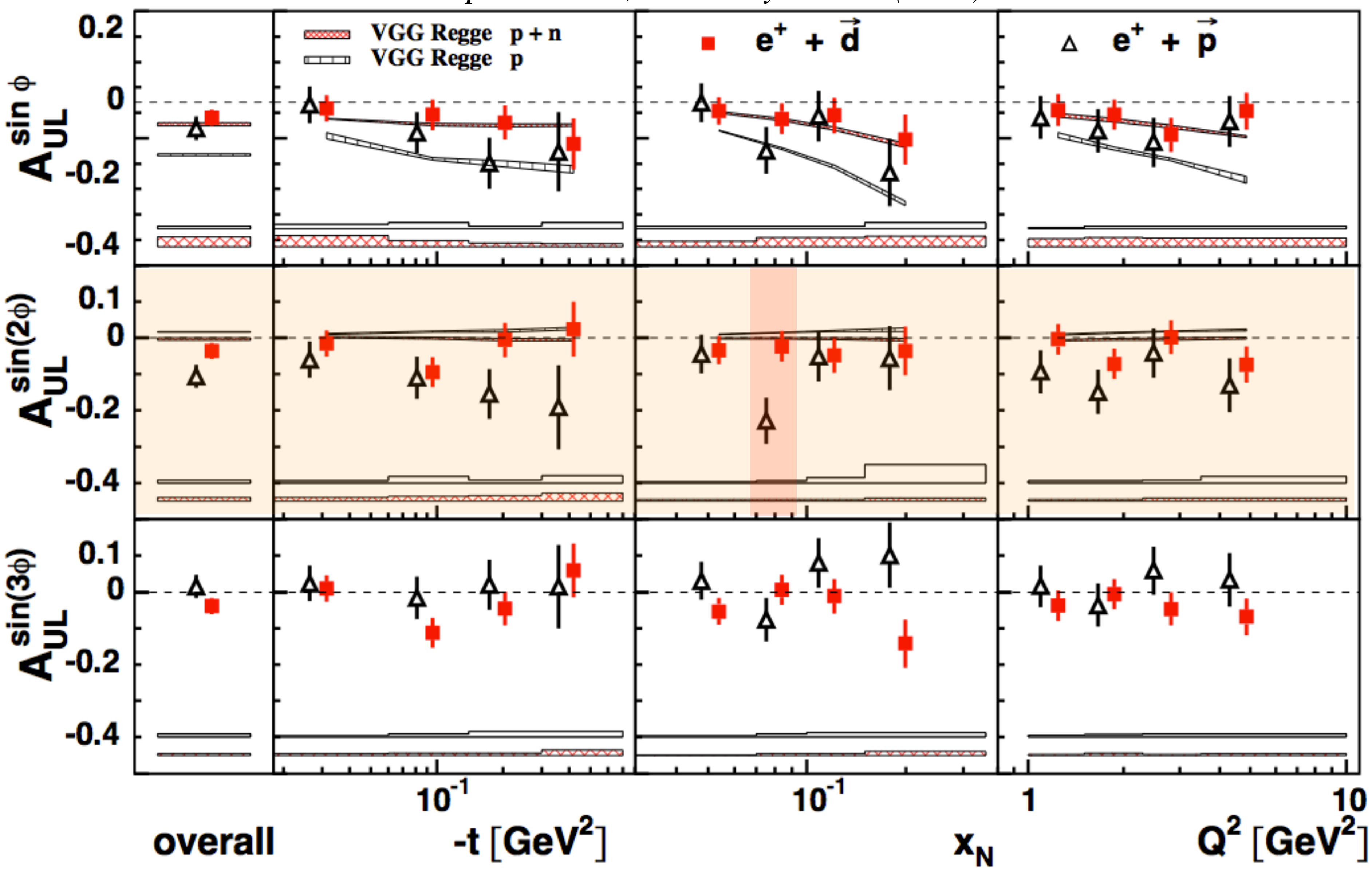
http://arxiv.org/abs/0911.0095



Deuterium is governed by different GPDs - but the asymmetry data is not *so* different even at low *t*!

Deuterium-Target Asymmetries

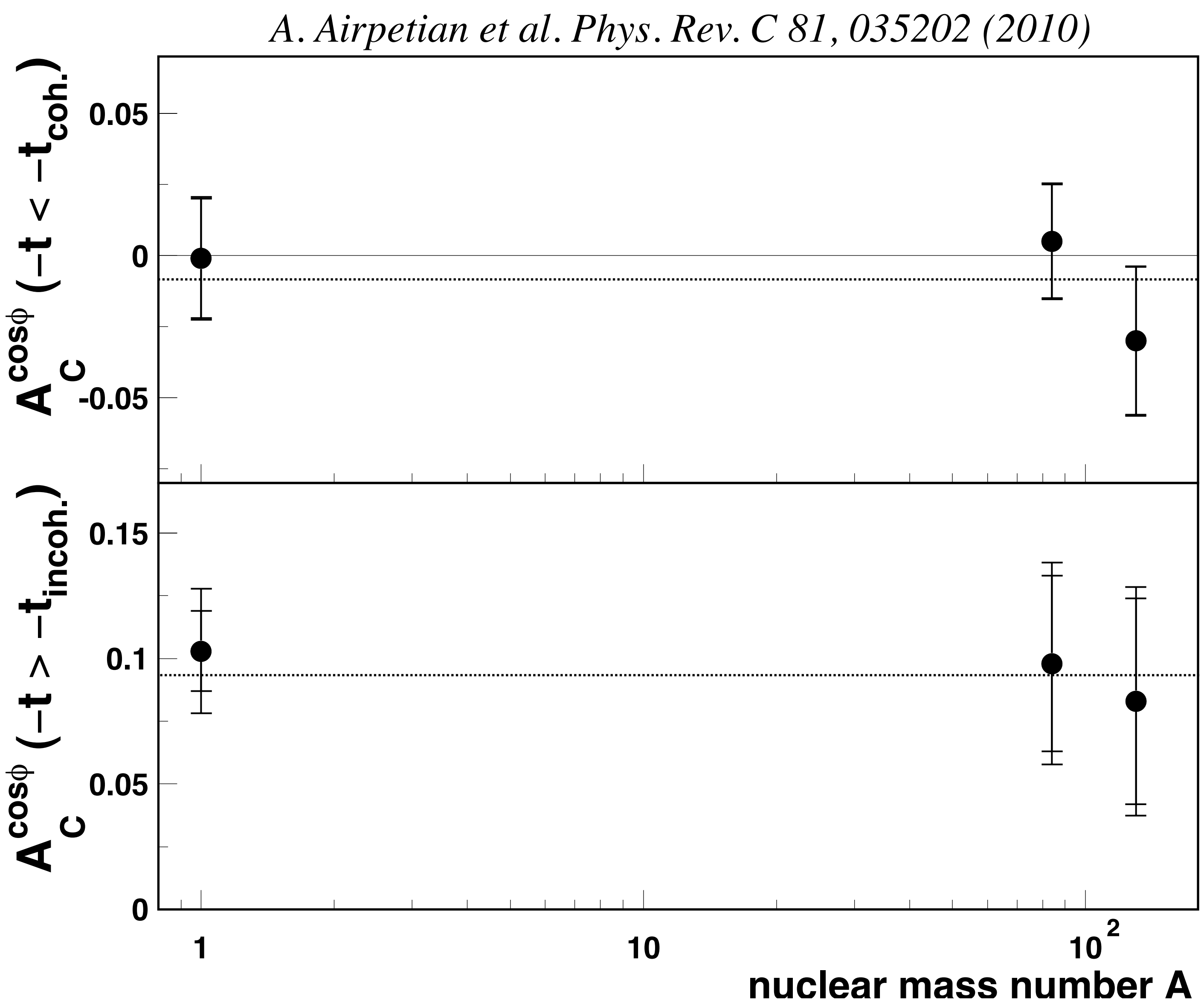
A. Airapetian et al, Nucl. Phys. B842 (2011) 265-298



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

http://arxiv.org/abs/1008.3996

Nuclear Mass Dependence

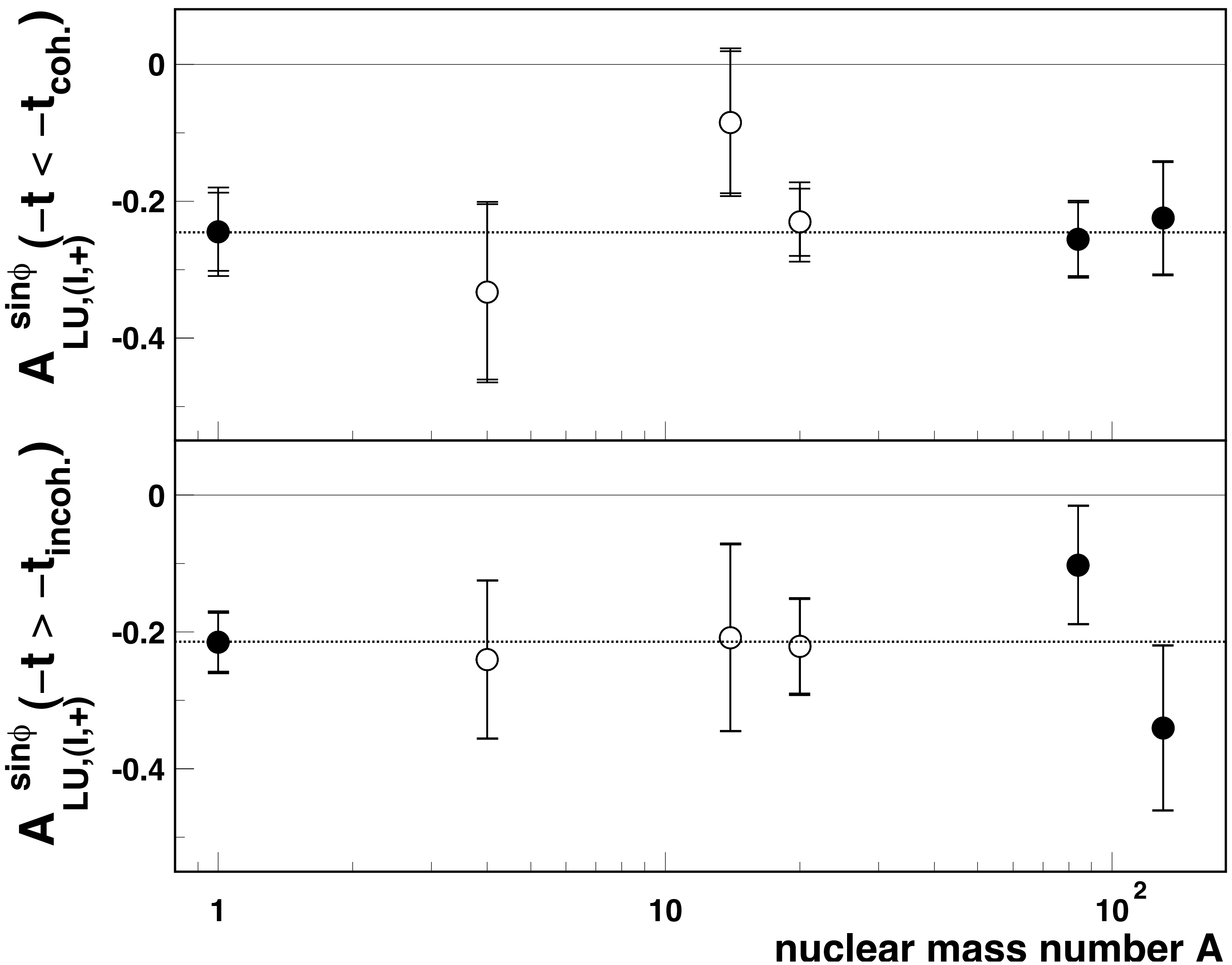


Nuclear-Binding models expected the DVCS asymmetry for nuclear targets to be 160-180% of the Hydrogen asymmetry.

http://arxiv.org/abs/0911.0091

Nuclear Mass Dependence

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



● spin ½

○ spin 1

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

http://arxiv.org/abs/0911.0091