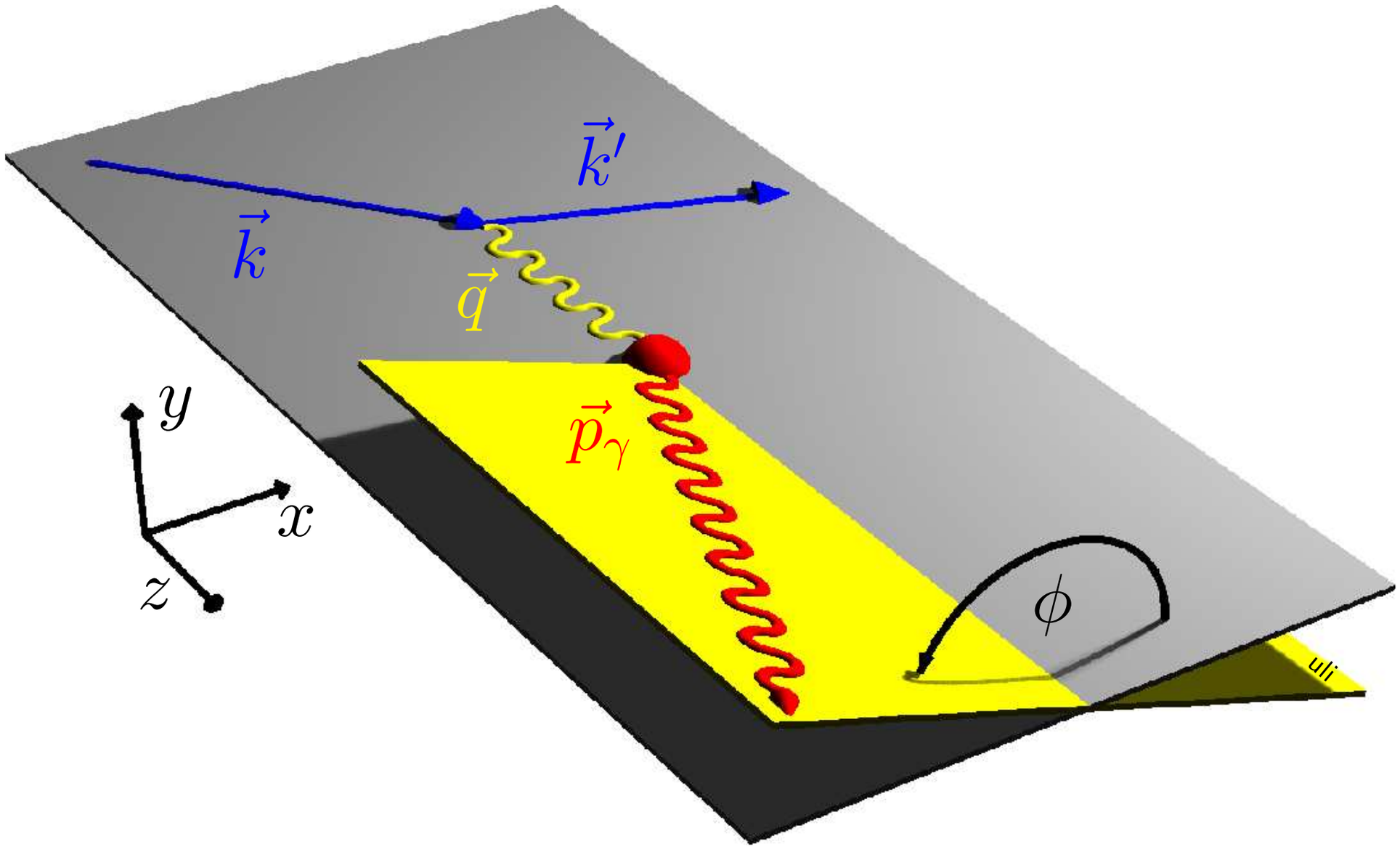
DVCS @ HERMES

M. MURRAY, UNIVERSITY OF GLASGOW

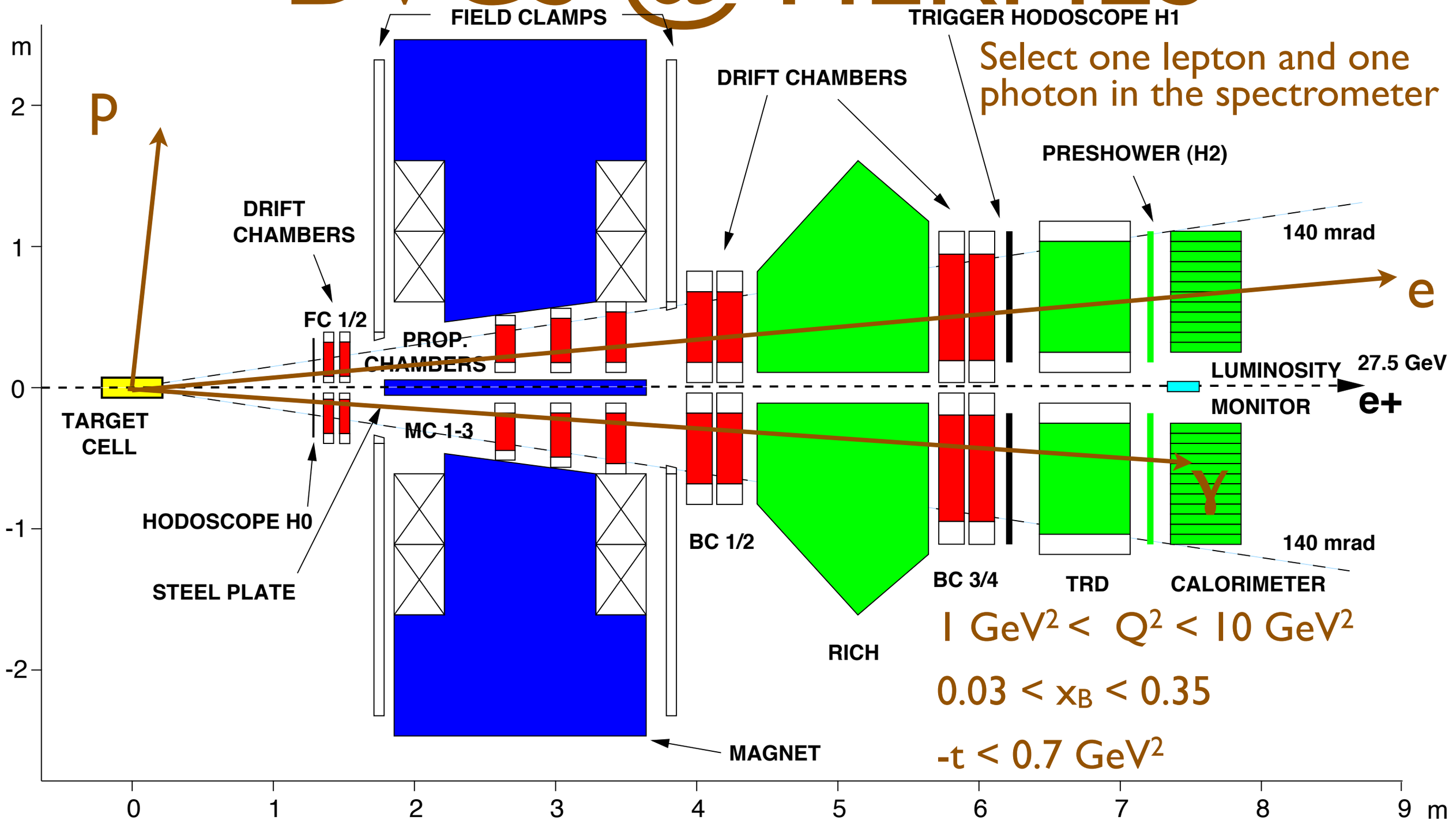
Baryons, Glasgow 2013

DVCS @ HERMES



DVCS @ HERMES

Select one lepton and one photon in the spectrometer



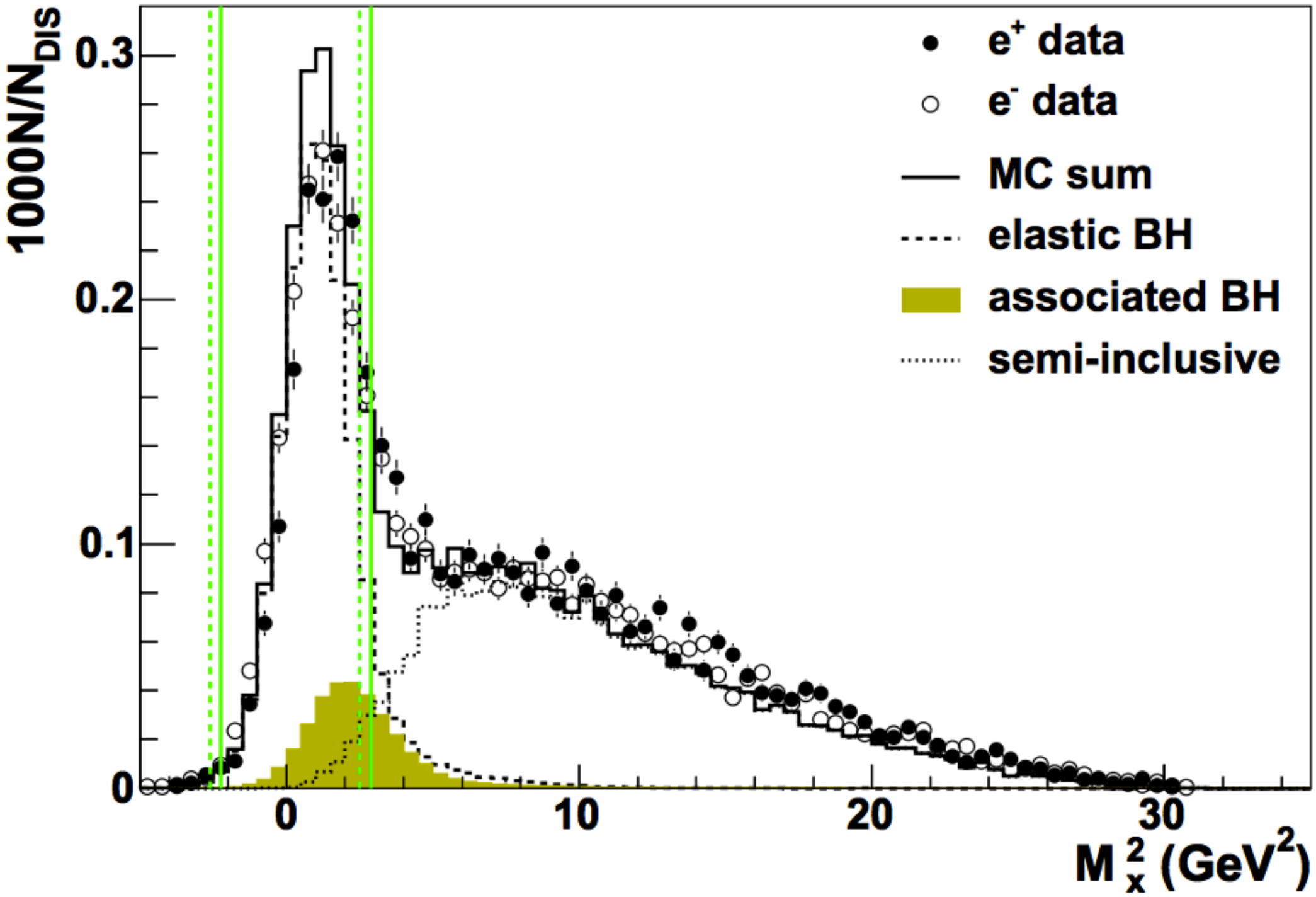
$1\ \text{GeV}^2 < Q^2 < 10\ \text{GeV}^2$

$0.03 < x_B < 0.35$

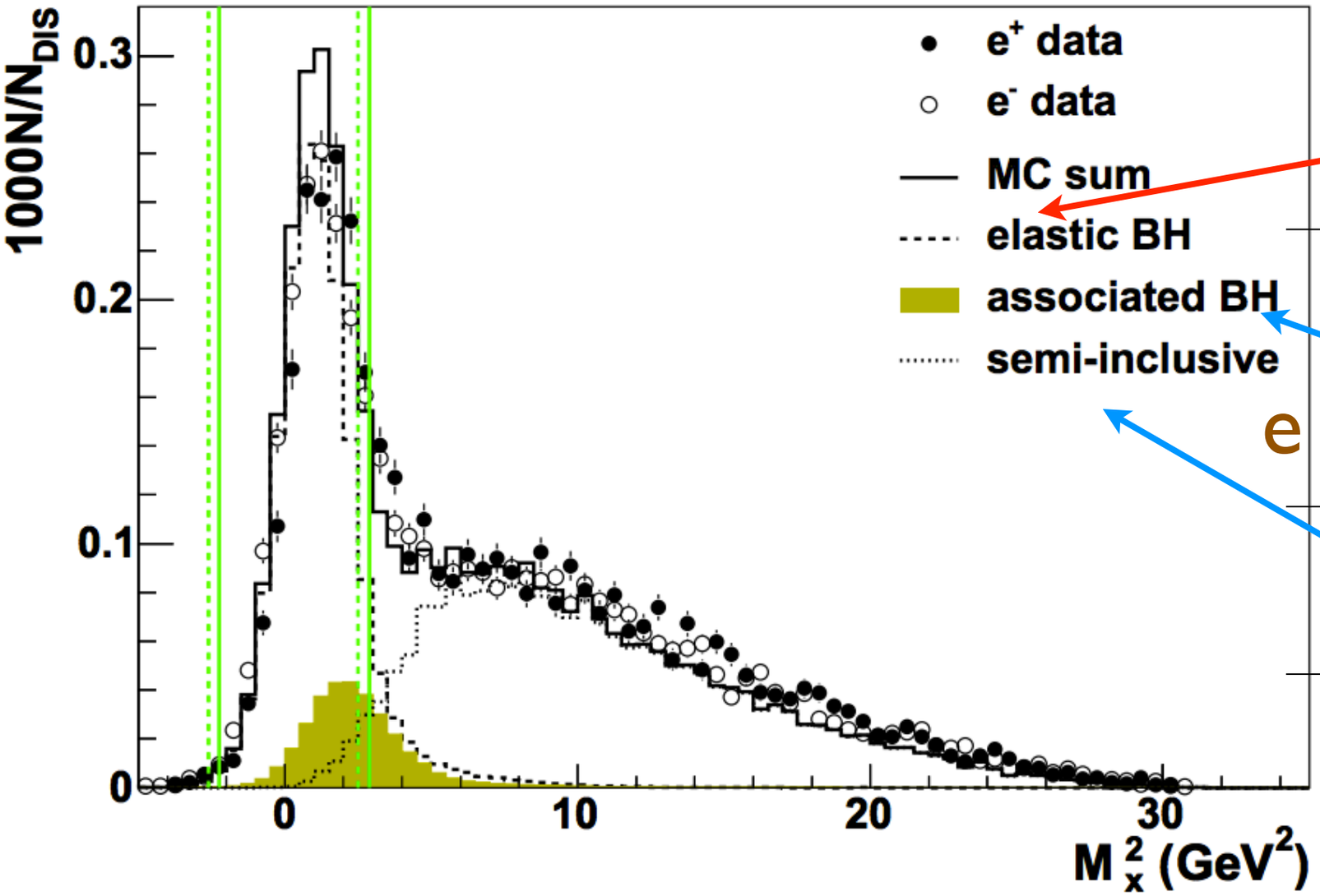
$-t < 0.7\ \text{GeV}^2$

$\langle Q^2 \rangle \cong 2.4\ \text{GeV}^2$ $\langle x_B \rangle \cong 0.1$ $\langle -t \rangle \cong 0.1\ \text{GeV}^2$

DVCS @ HERMES


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

DVCS @ HERMES



Wanted Signal

BH from Δ, e.g

e Δ → e γ Δ → eγp π^0

e p → e X γ

e p → e p π^0

DVCS @ HERMES

First BSA Measurement Published

2001

2007

First A_C Measurement

2008

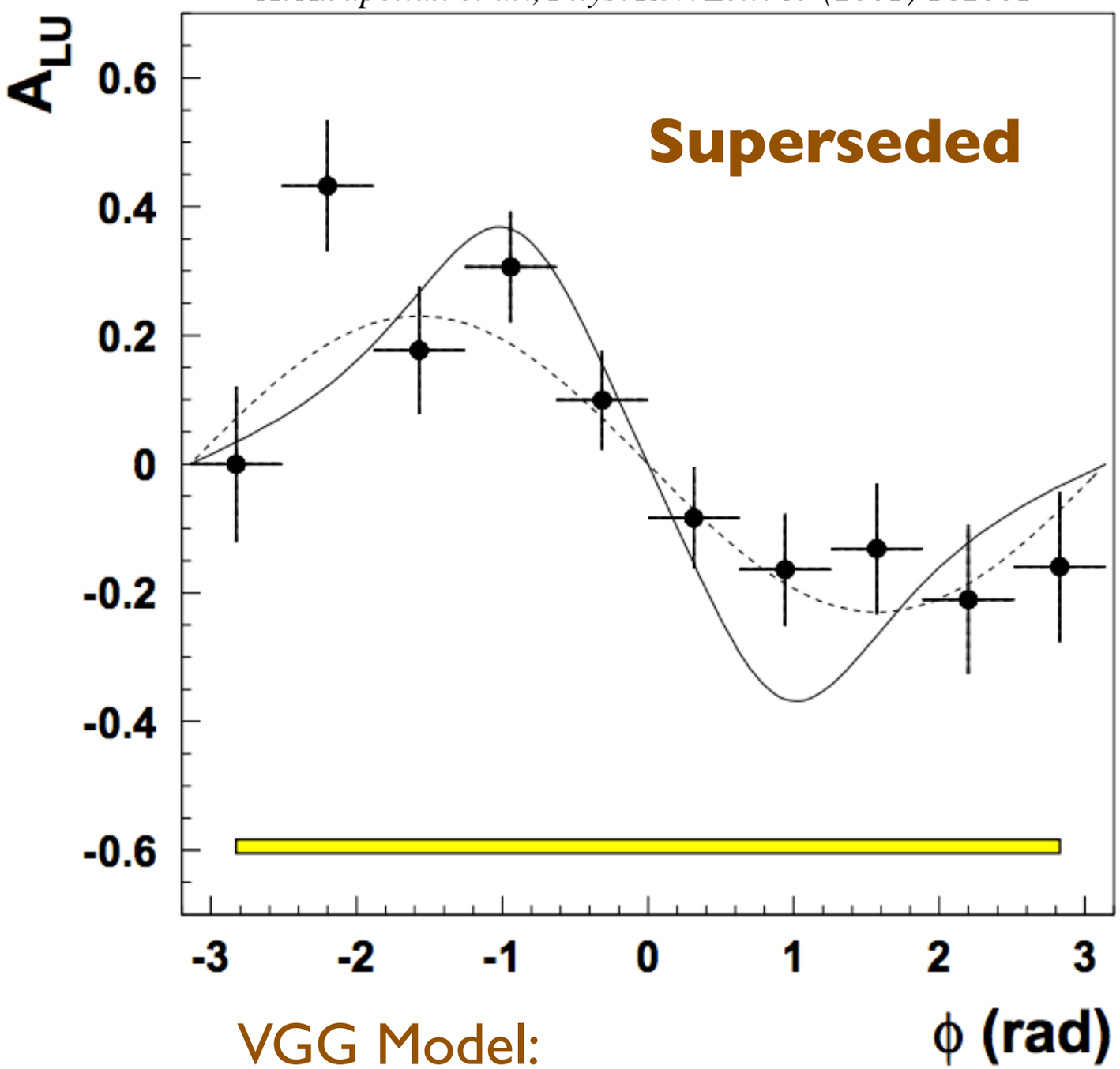
First A_{UT} Measurement Published

2009

Combined A_{LU} and A_C Measurement

DVCS @ HERMES

A. Airapetian et al., Phys. Rev. Lett. 87 (2001) 182001



VGG Model:
http://arxiv.org/abs/hep-ph/9905372
Phys.Rev. D60 (1999) 094017

First measurement of DVCS made on little data

Simple binned χ^2 fit with a rudimentary analysis

Little data means no kinematic projections

DVCS @ HERMES

First BSA Measurement Published

First Aut Measurement Published

2001

2007

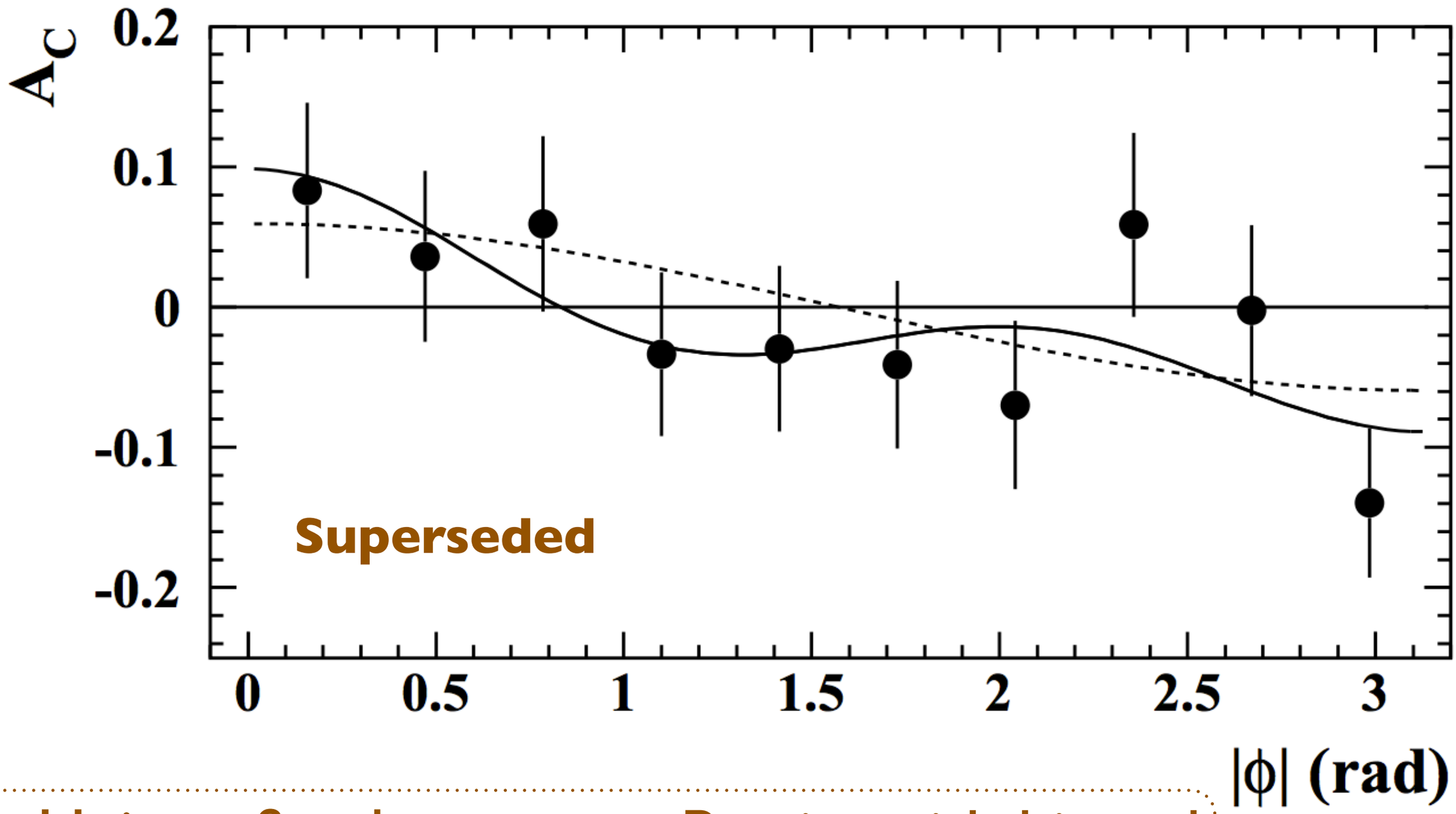
First Ac Measurement

2008

2009

Combined ALU and Ac Measurement

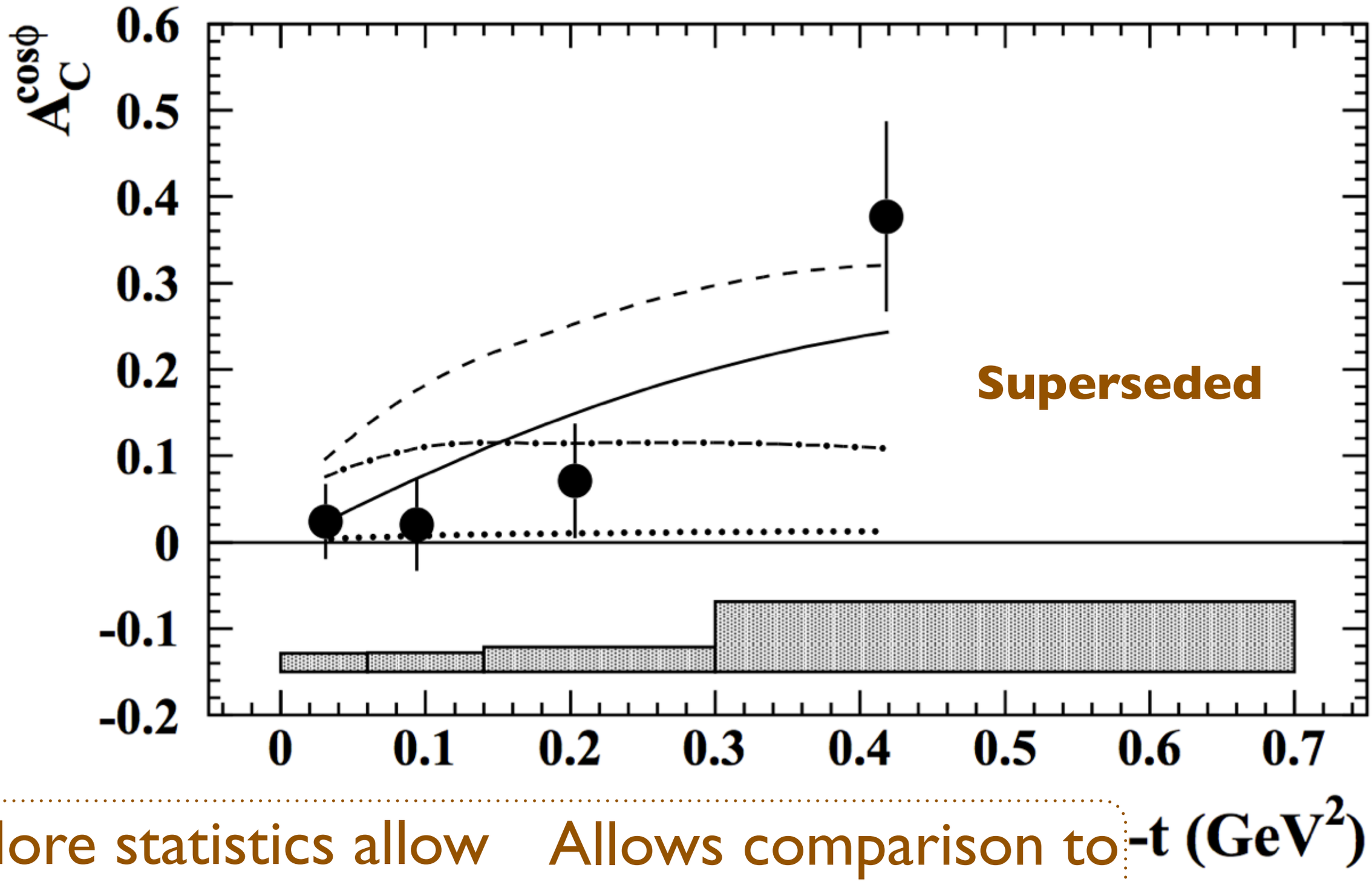
DVCS @ HERMES



Unique fixed-target measurement.

Persist with binned χ^2-squared fit

DVCS @ HERMES



More statistics allow kinematic projection.

Allows comparison to models of Re{H}

DVCS @ HERMES

First BSA Measurement Published

2001

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2007

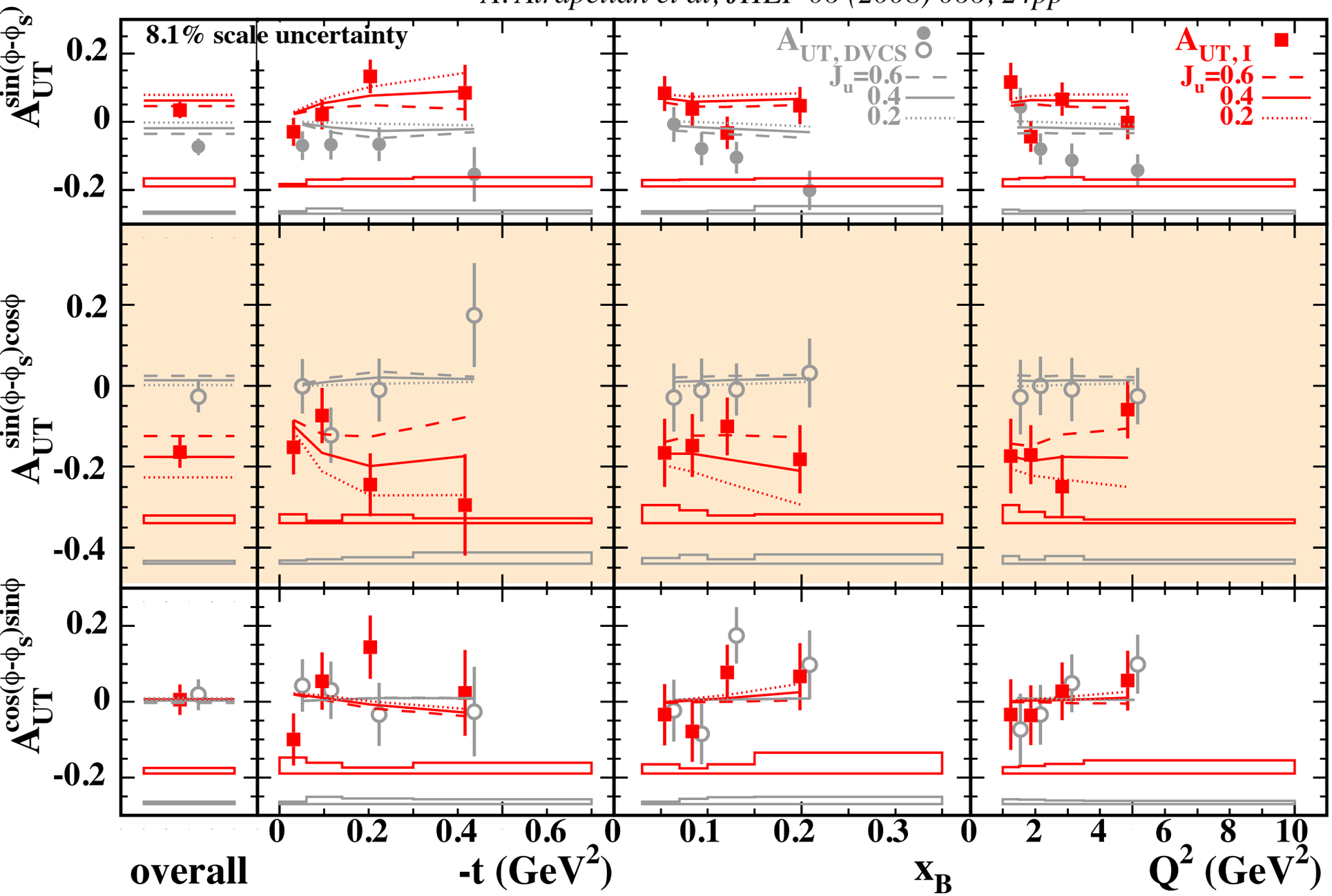
First A_C Measurement

2009

Combined A_{LU} and A_C Measurement

Transverse-Target Asymmetries

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



Surprisingly large $A_{UT,DVCS}\sin(\phi-\phi_S)$ term with strong xB dependence

First usage of Max. Likelihood fitting for DVCS

Published with a quickly superseded BCA result

DVCS @ HERMES

First BSA Measurement Published

First Aut Measurement Published

2001

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First Ac Measurement

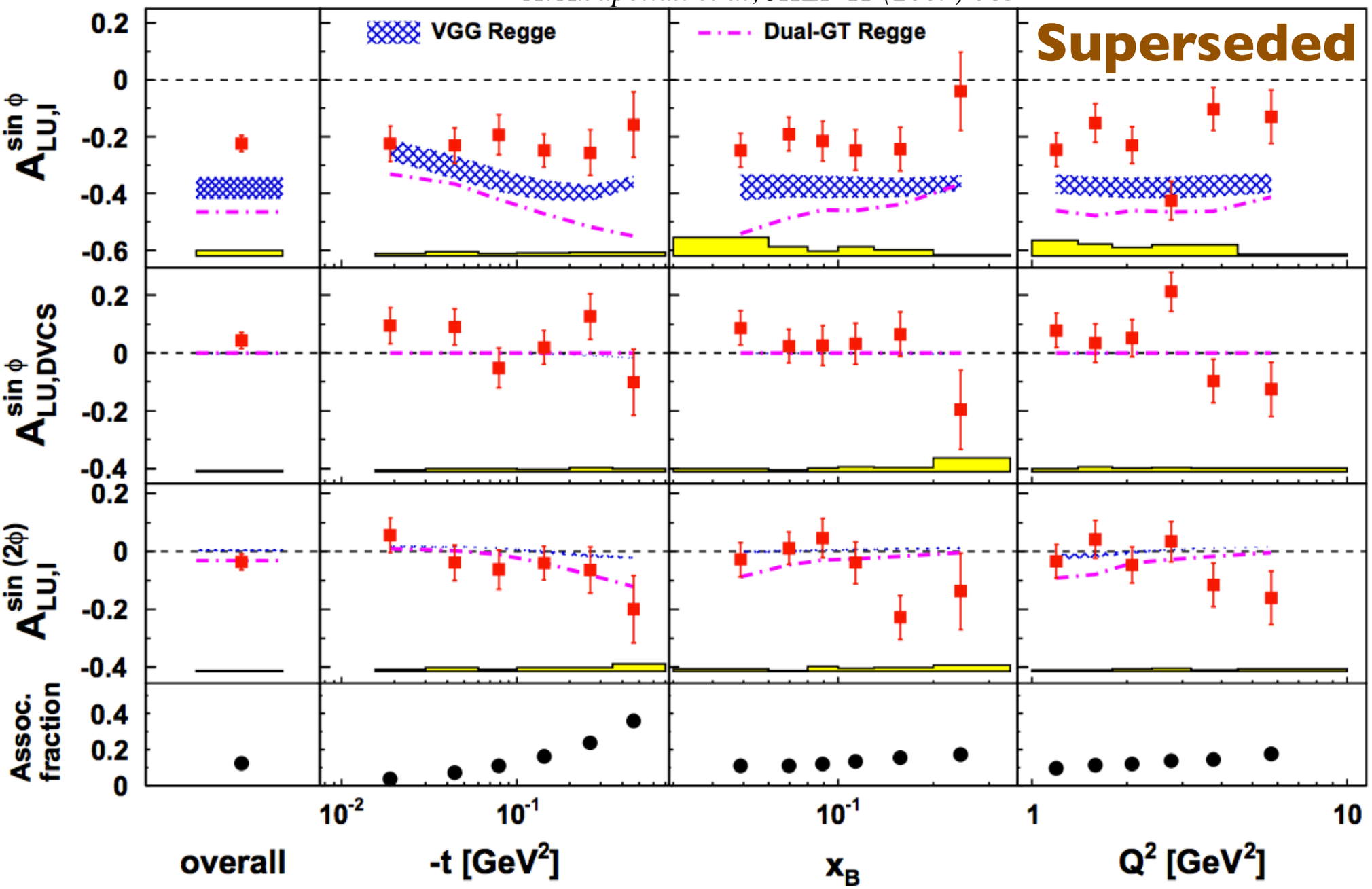
2008

2009

Combined ALU and AC Measurement

DVCS @ HERMES

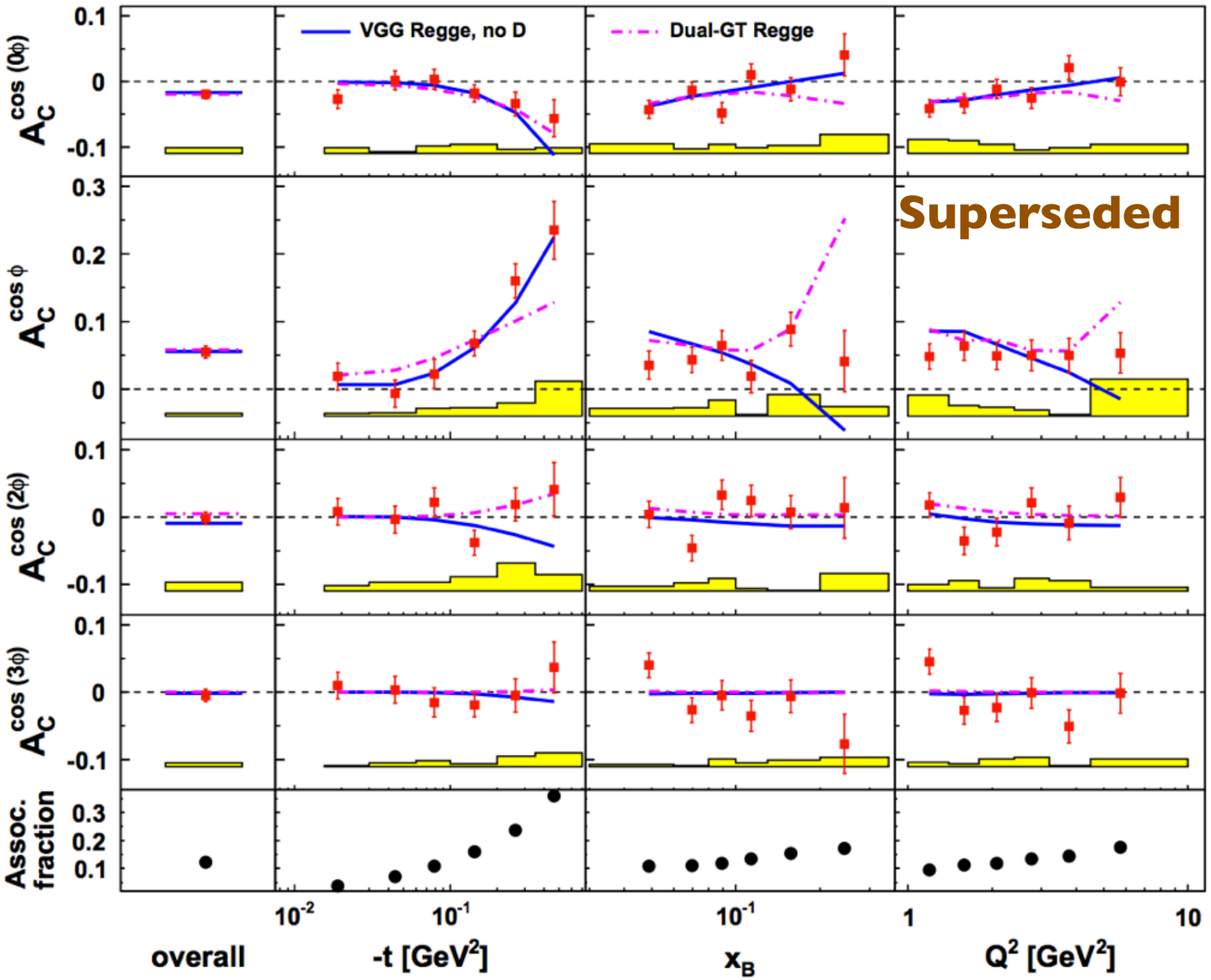
A. Airapetian et al, JHEP 11 (2009) 083



Dual model shown here later proven to have extraneous factor of 2 that renders model obsolete.

One decade of HERMES operation. Compared to models for Im($\mathcal{H}$)

DVCS @ HERMES



Higher precision of A_C than A_{LU} due to no 'dilution' of data from unpolarised beam.

Compared to models for Re($\mathcal{H}$)

DVCS @ HERMES

First A_{LT} Measurement Published

Publication of Recoil Data Set on BSA

2010

2012

2009

2011

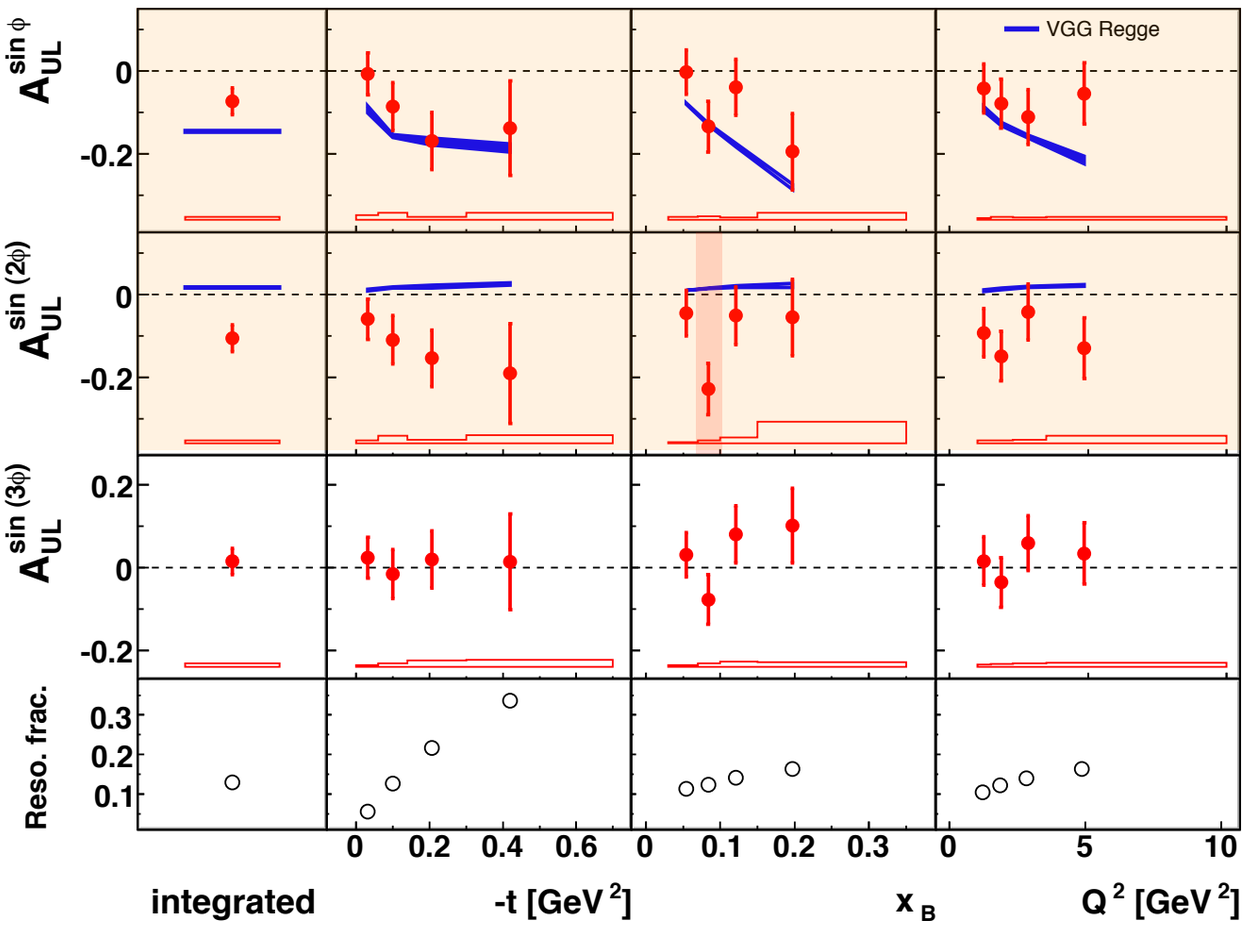
2013

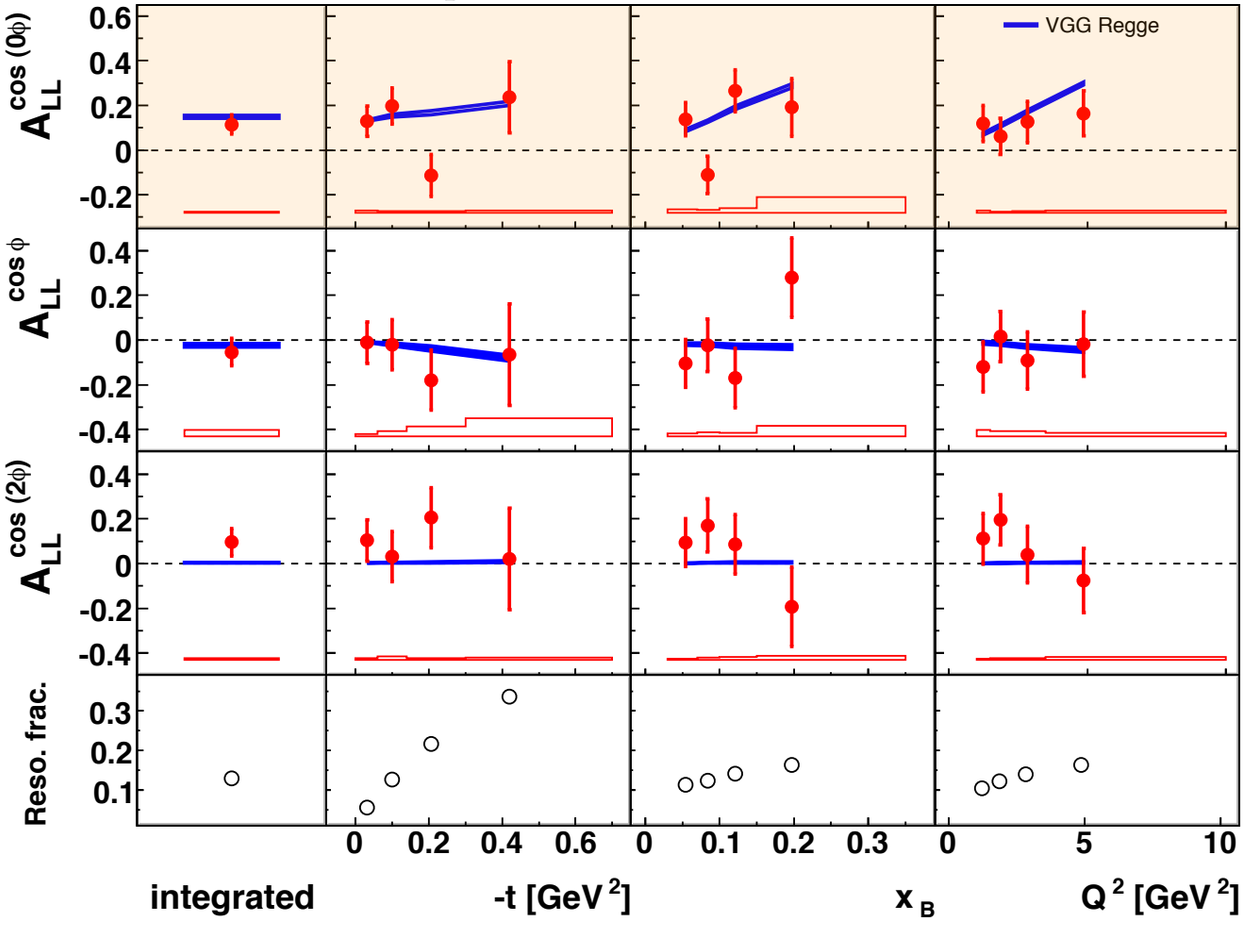
A_{UL} & A_{LL} Measurement Published

Total Data Set extraction of ALU and AC

DVCS @ HERMES

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





A_{UL} measurement allows access to $\mathrm{Im}(\tilde{\mathcal{H}})$ - $\sin(2\phi)$ behaviour not understood

First A_{LL} measurement published - allows access to $\mathrm{Re}(\tilde{\mathcal{H}})$ (albeit BH dominated)

DVCS @ HERMES

First A_{LT} Measurement Published

Publication of Recoil Data Set on BSA

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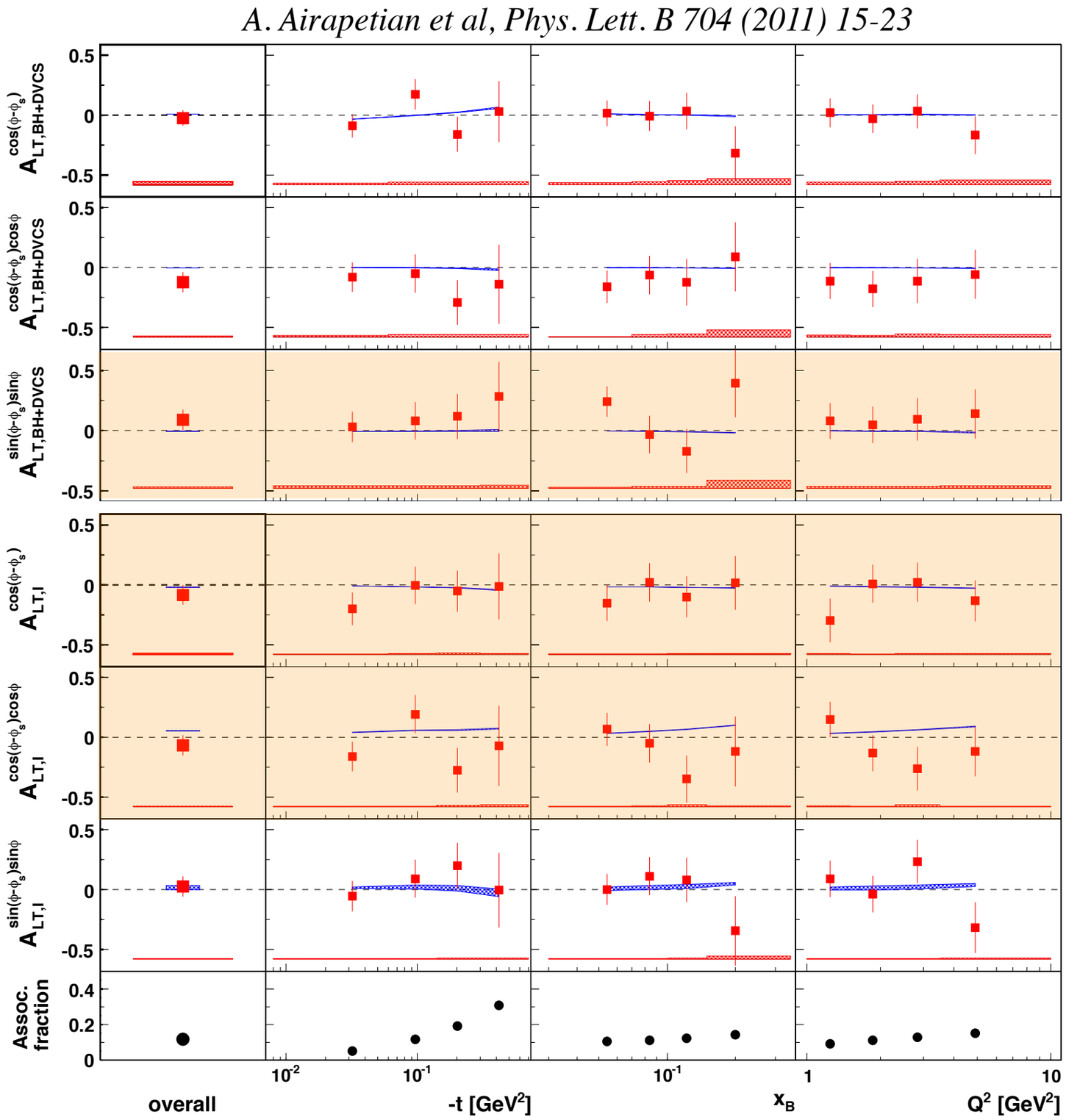
A_{UL} & A_{LL} Measurement Published

Total Data Set extraction of ALU and AC

Double-Spin Asymmetries



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 @ HERMES

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2009

2011

2013

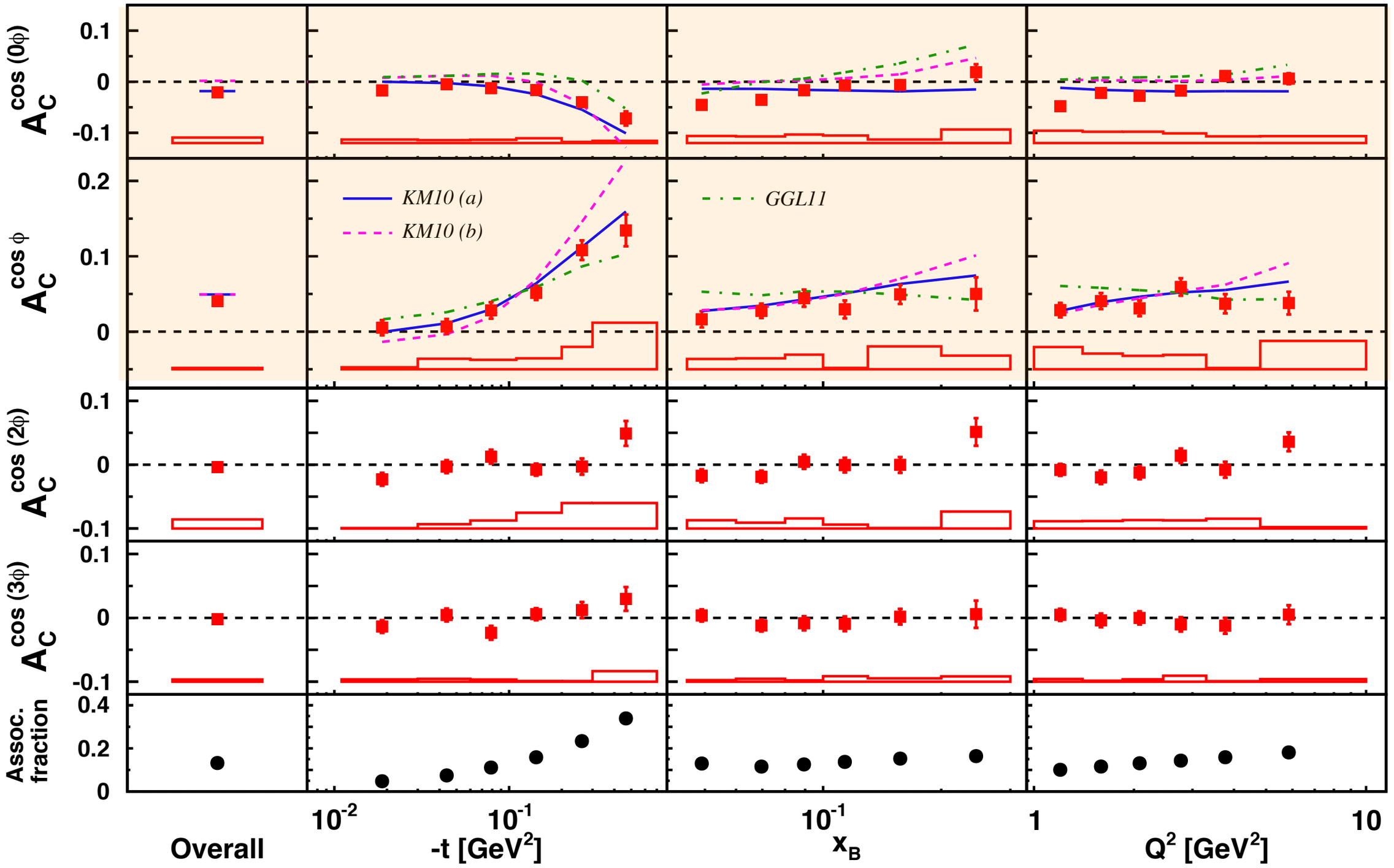
A_{UL} & A_{LL} Measurement Published

Total Data Set extraction of ALU and AC

(Also available in 4 bins at Durham)

Beam-Charge Asymmetries

A. Airapetian et al, JHEP 07 (2012) 032 http://arxiv.org/abs/1203.6287



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

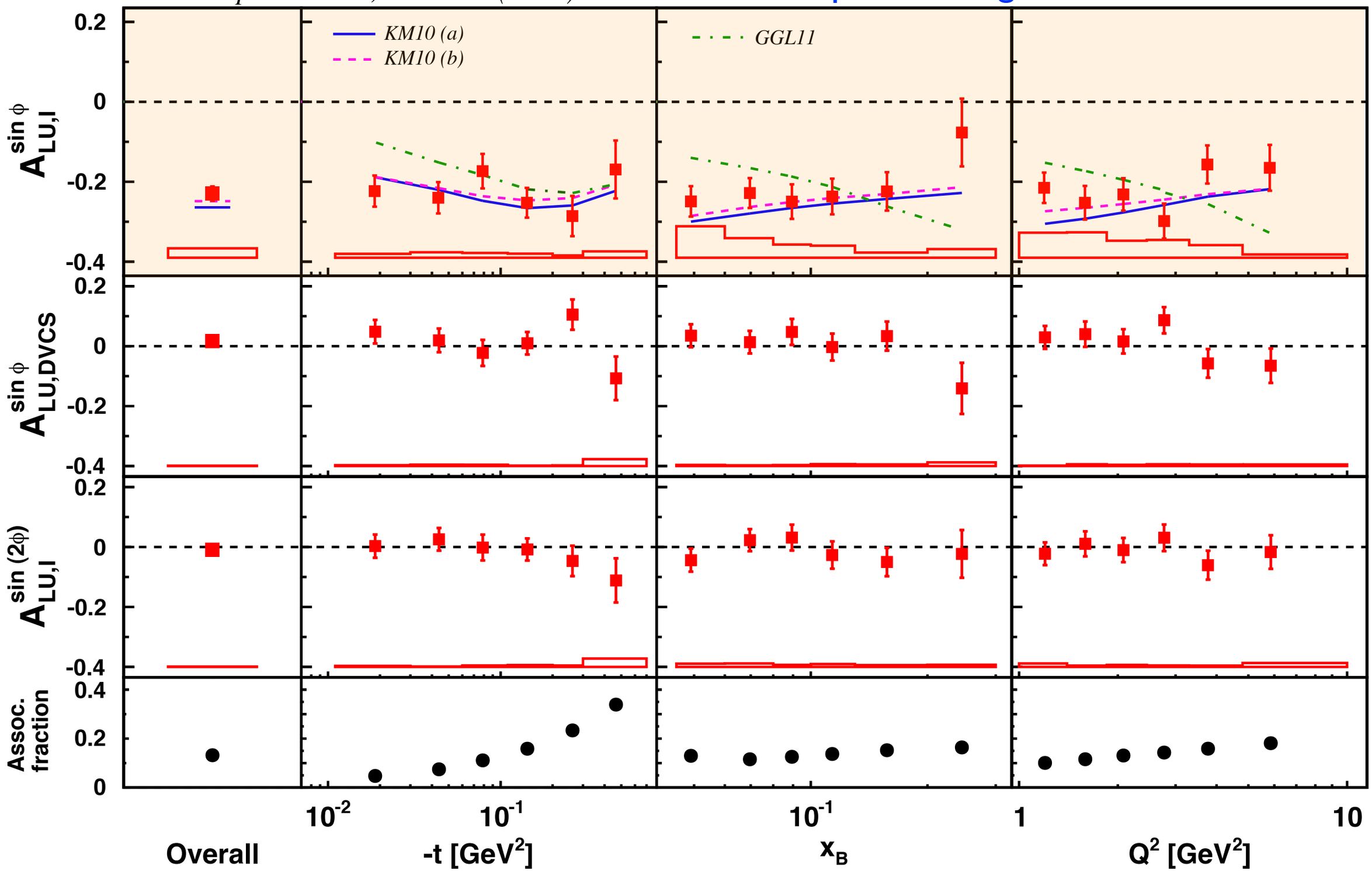
G. Goldstein, J. Hernandez and S. Liuti, ***Phys. Rev. D84*** *(2011)* http://arxiv.org/abs/1012.3776

(Also available in 4 bins at Durham)

Beam-Spin Asymmetries

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

http://arxiv.org/abs/1203.6287



DVCS @ HERMES

First A_{LT} Measurement Published

2010

2009

2011

2012

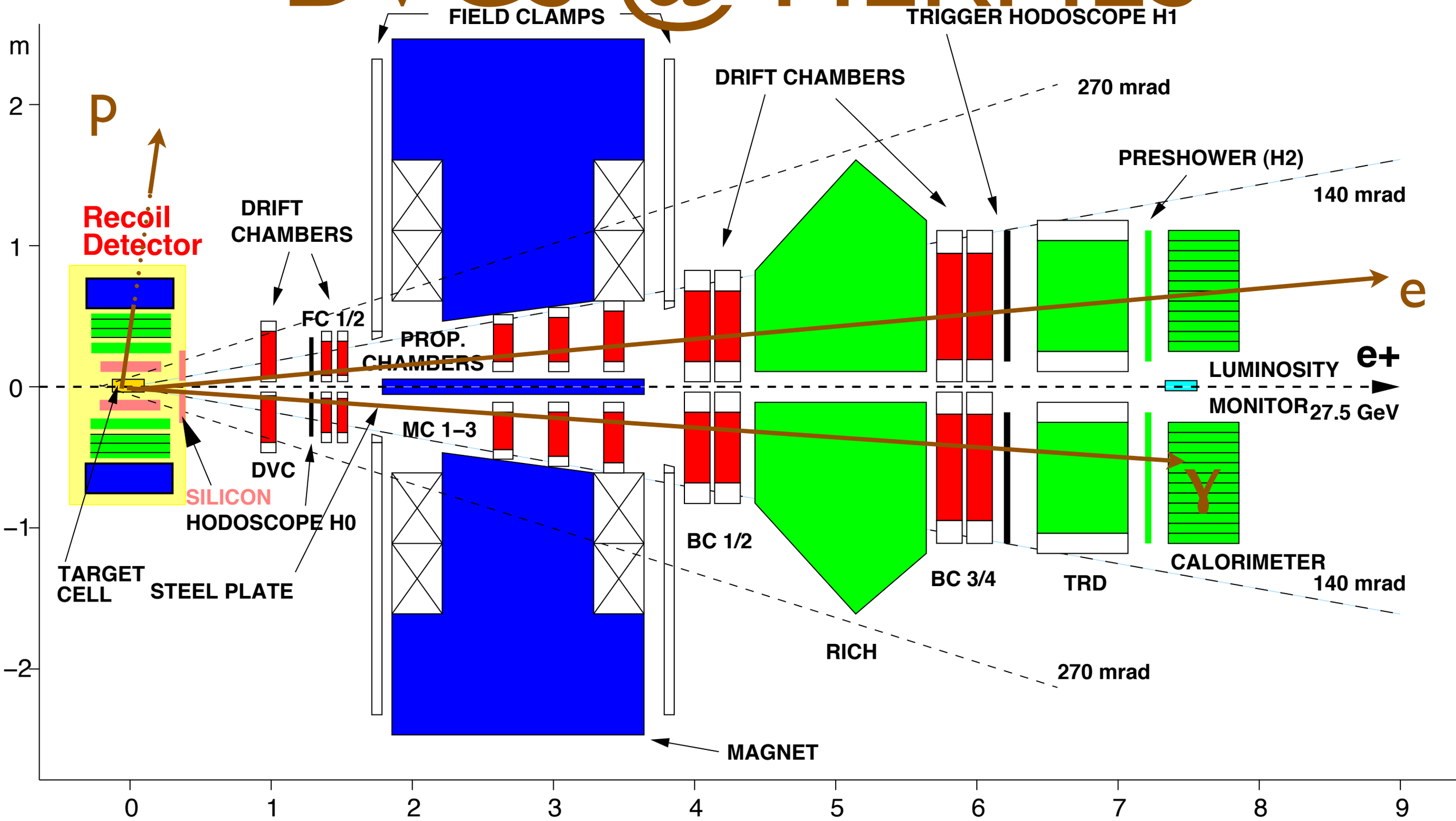
2013

Publication of Recoil Data Set on BSA

A_{UL} & A_{LL} Measurement Published

Total Data Set extraction of ALU and AC

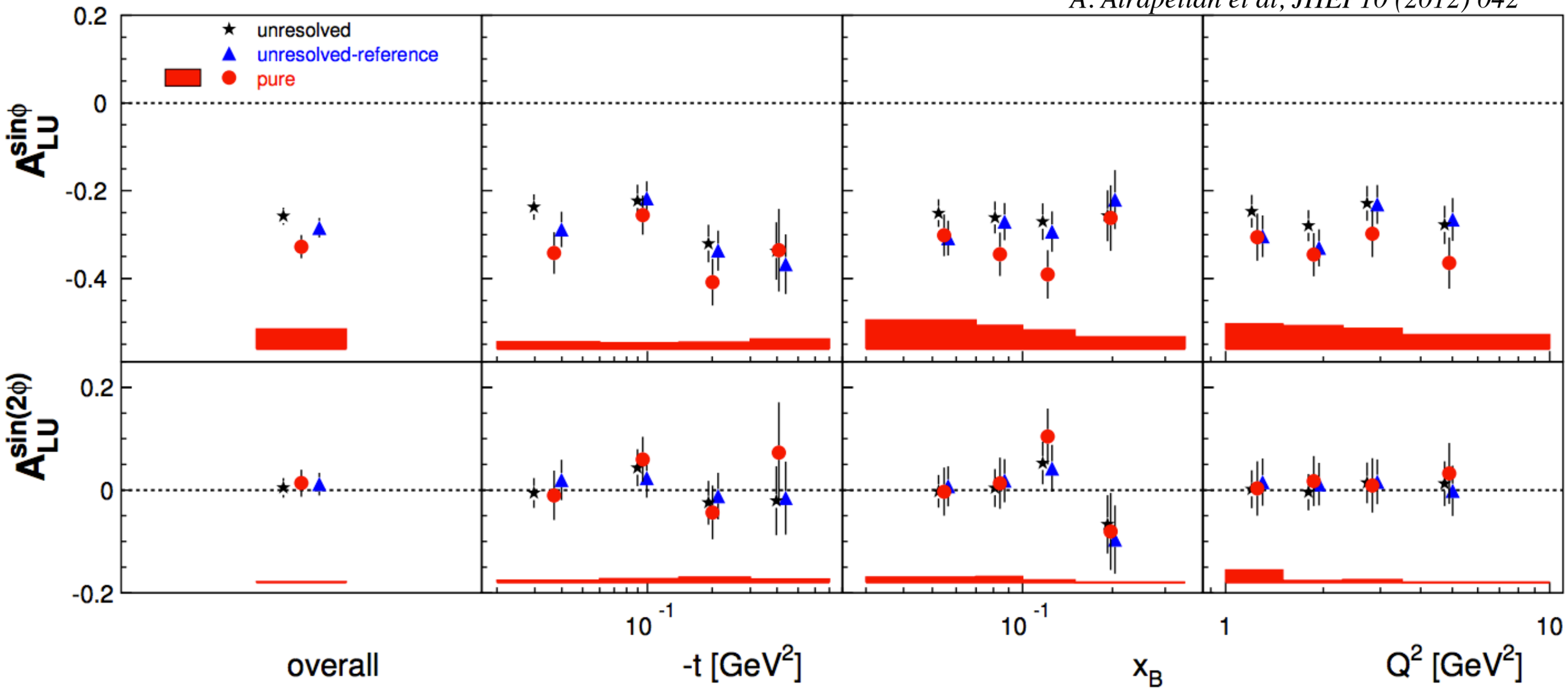
DVCS @ HERMES



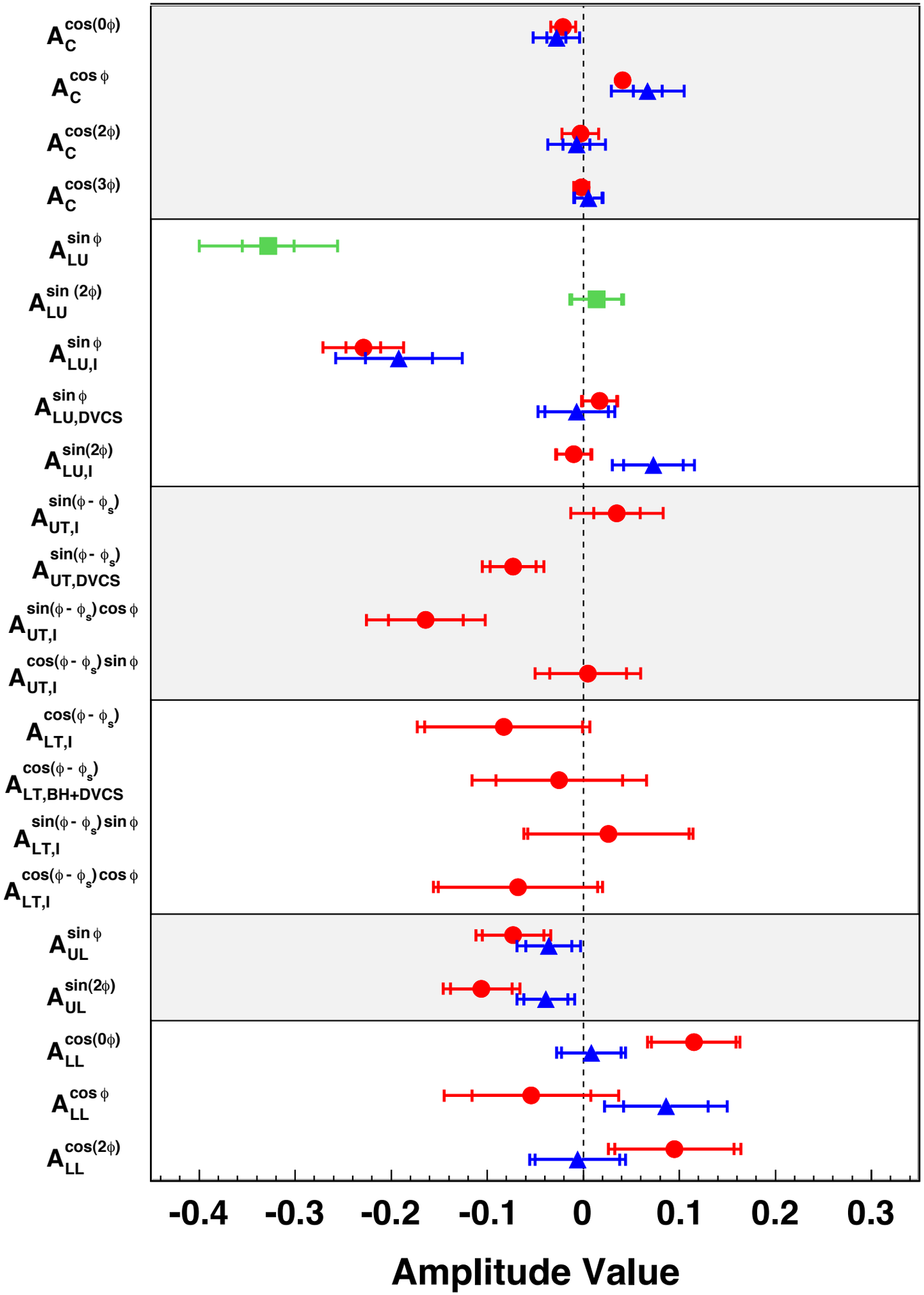
$\langle Q^2 \rangle \cong 2.4\ \text{GeV}^2$ $\langle x_B \rangle \cong 0.1$ $\langle -t \rangle \cong 0.1\ \text{GeV}^2$

DVCS @ HERMES

A. Airapetian et al, JHEP10 (2012) 042



High-purity event selection shows that there is only a small influence on the extracted BSA amplitudes from events involving an intermediate Δ particle



Data on disassociated Hydrogen is in red

Data on Deuterium is in blue

Green shows data from the recoil detector

Nuclear data is not shown!

More Data?

DVCS @ HERMES

First A_{LT} Measurement Published

Publication of Recoil Data Set on BSA

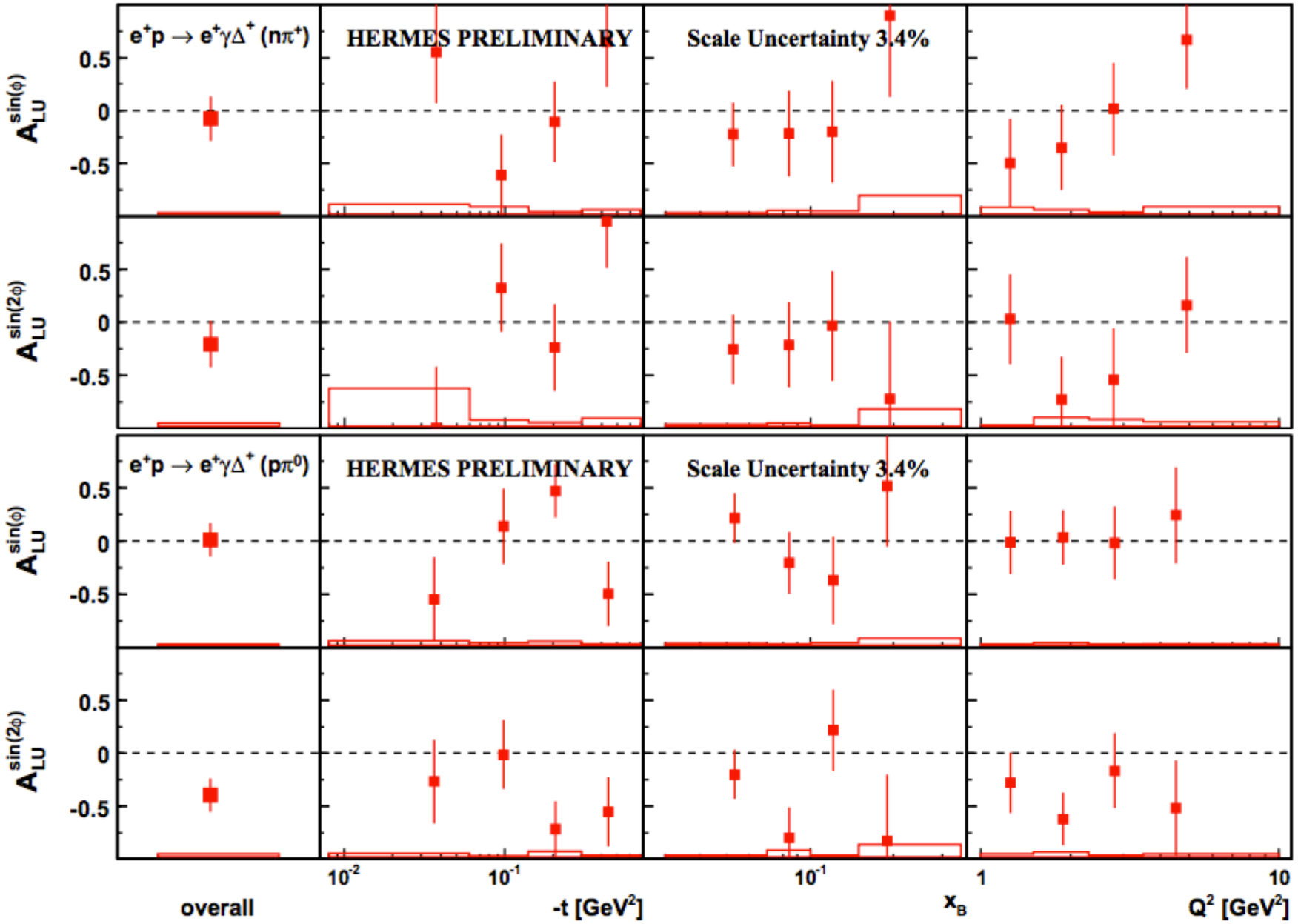
2010 **2012** **Recoil BCA and publication of resonance data?**

2011 **2013**

A_{UL} & A_{LL} Measurement Published

Total Data Set extraction of ALU and AC

DVCS @ HERMES



Preliminary results show a '0' amplitude for BSA on Δ events.

DVCS @ HERMES

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

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

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

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

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

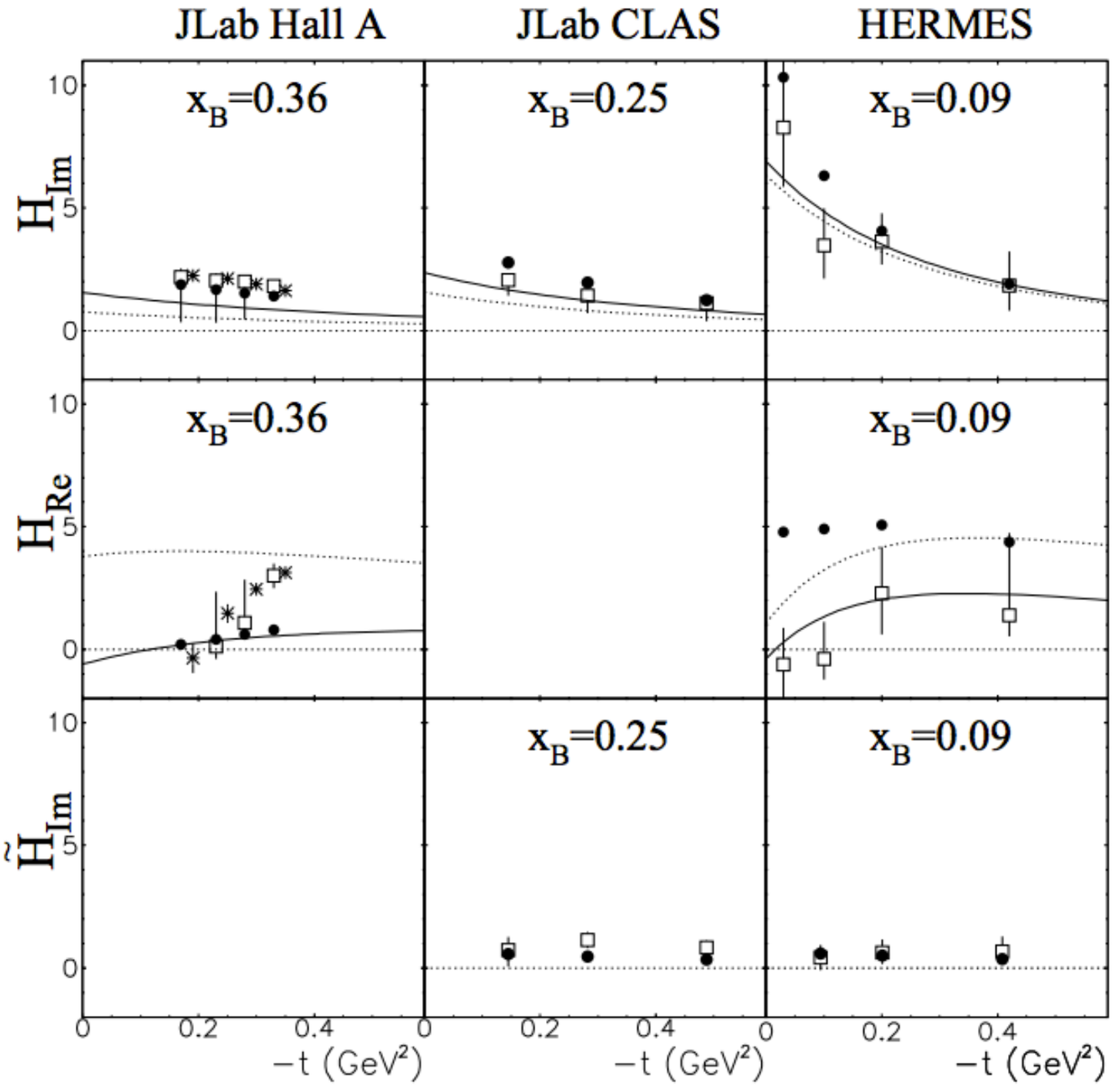
$$\mathcal{A}_{\mathrm{LT}}^{\mathrm{BH+DVCS}}(\phi,\phi_S) \equiv \frac{1}{8d\sigma_{\mathrm{UU}}}\left[(d\overrightarrow{\sigma}^{+\uparrow} - d\overrightarrow{\sigma}^{+\downarrow} - d\overleftarrow{\sigma}^{+\uparrow} + d\overleftarrow{\sigma}^{+\downarrow}) + (d\overrightarrow{\sigma}^{-\uparrow}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

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

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

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

CFF Extraction



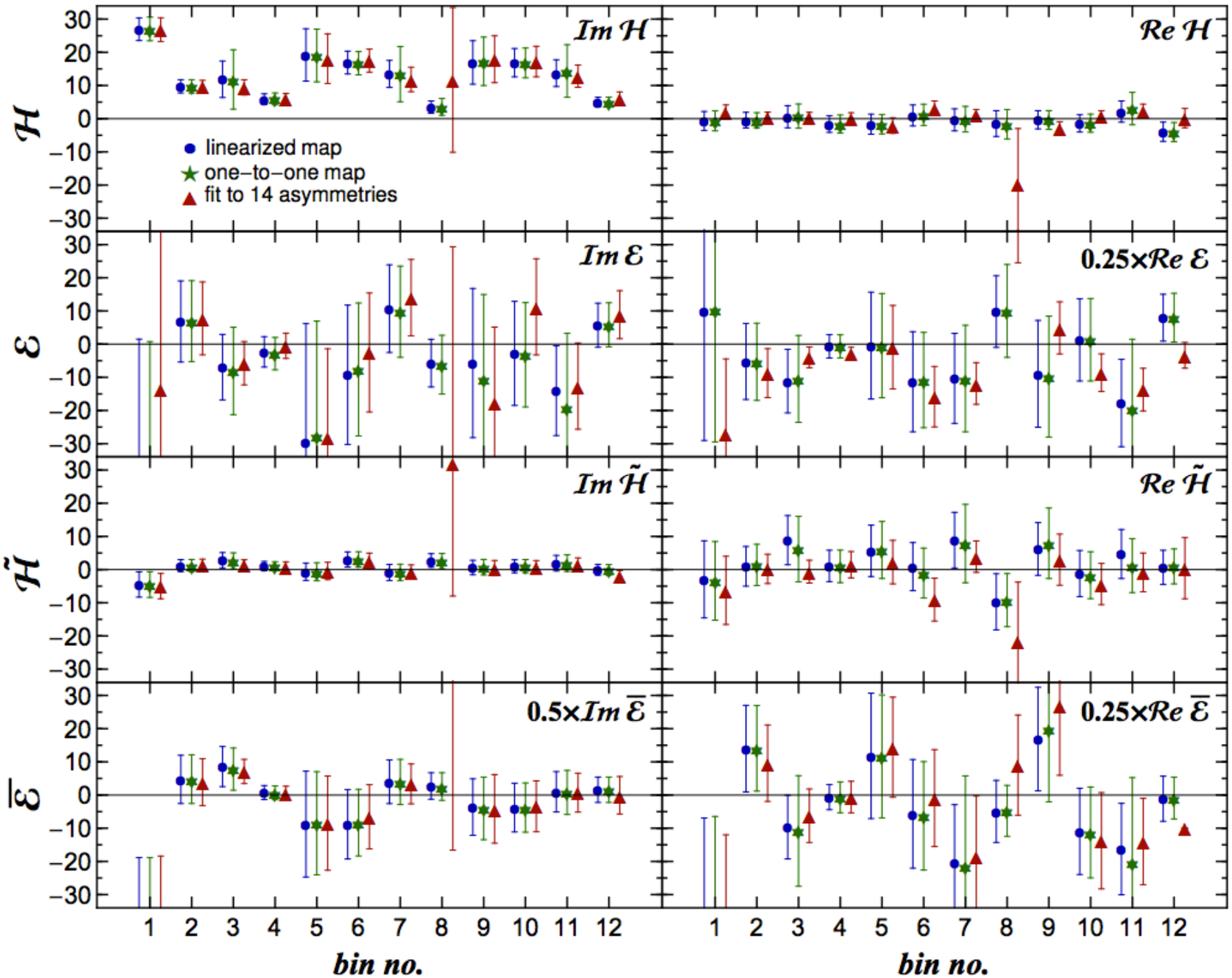
Even for H, VGG model GPDs are shown not to be consistent with experimental measurements when CFFs are extracted from data.

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)*

CFF Extraction



The latest work on extracting CFFs from HERMES DVCS shows that the impact of E is not understood at all.

Without constraining CFF E, can we really constrain GPDs further?

http://arxiv.org/abs/1301.1230

Kumerički, Müller and Murray
To appear in Phys. Part. Nucl. (2013)

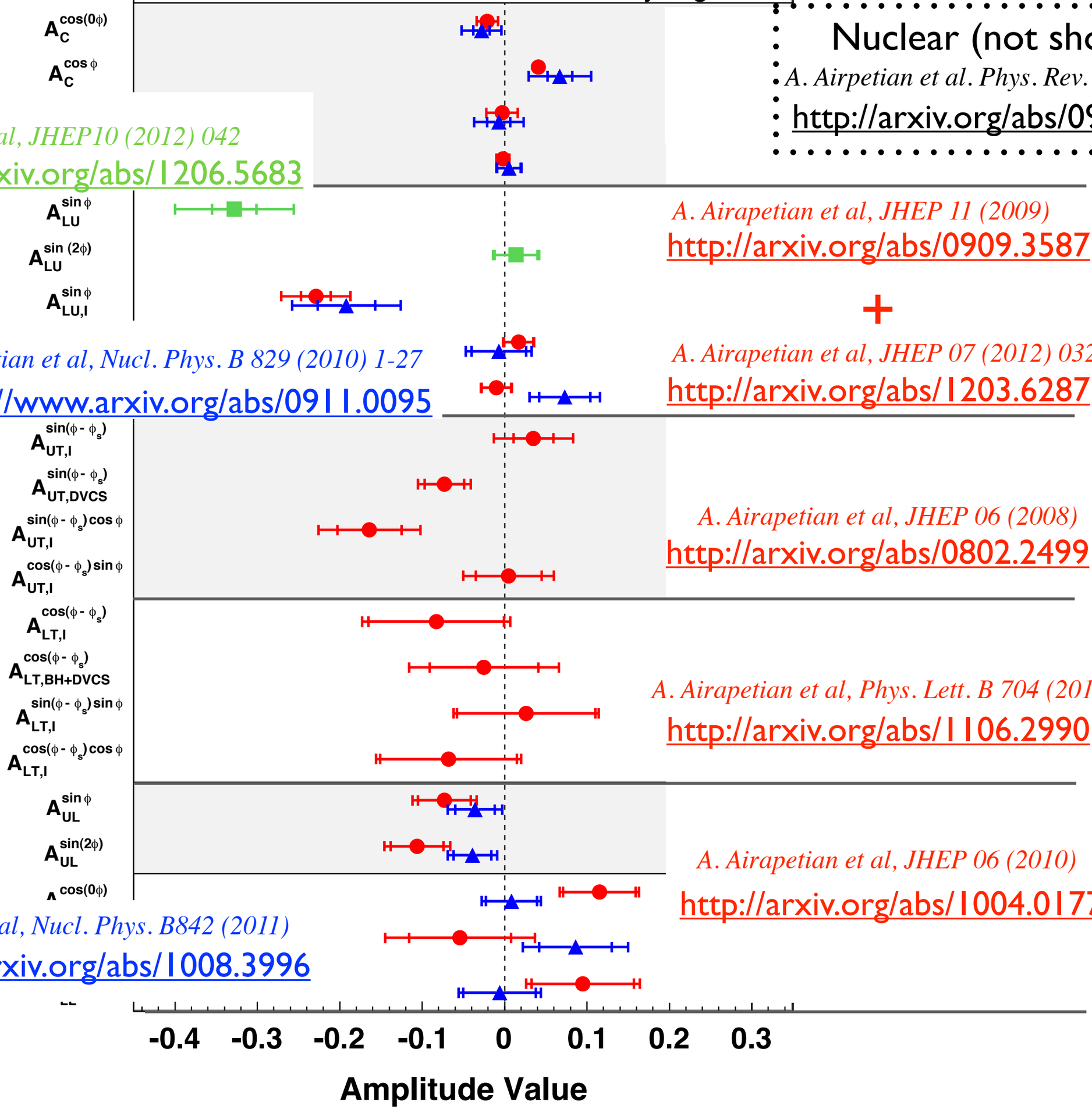
Conclusions - What did we learn at HERMES?

- DVCS is measurable and can be used to access information on Generalised Parton Distributions
- HERMES has the most diverse DVCS measurements of any experiment.
- Polarised target and beam charge 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 are the contributions from higher-twist distributions?

DVCS@HERMES



Nuclear (not shown!)
A. Airpetian et al. Phys. Rev. C 81 (2010)
http://arxiv.org/abs/0911.0091

A. Airapetian et al, JHEP10 (2012) 042
http://www.arxiv.org/abs/1206.5683

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

+

A. Airapetian et al, JHEP 07 (2012) 032
http://arxiv.org/abs/1203.6287

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

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

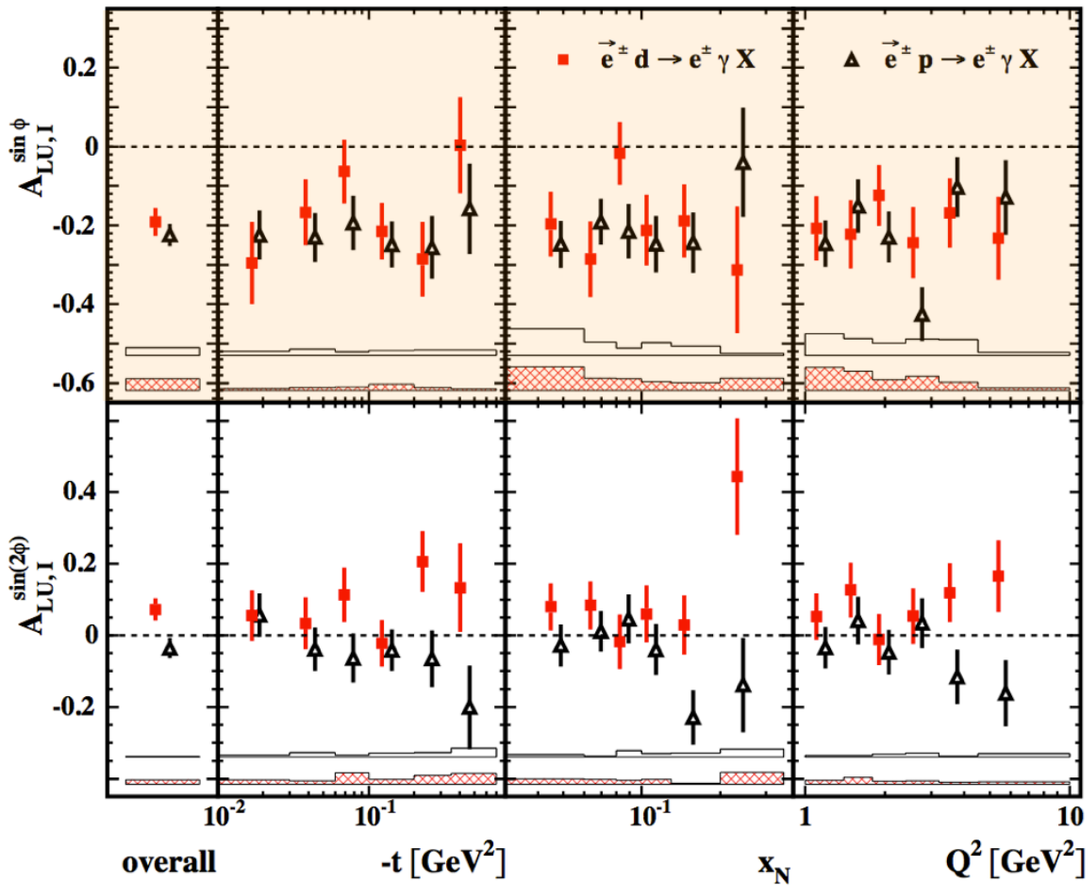
A. Airapetian et al, JHEP 06 (2010)
http://arxiv.org/abs/1004.0177

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

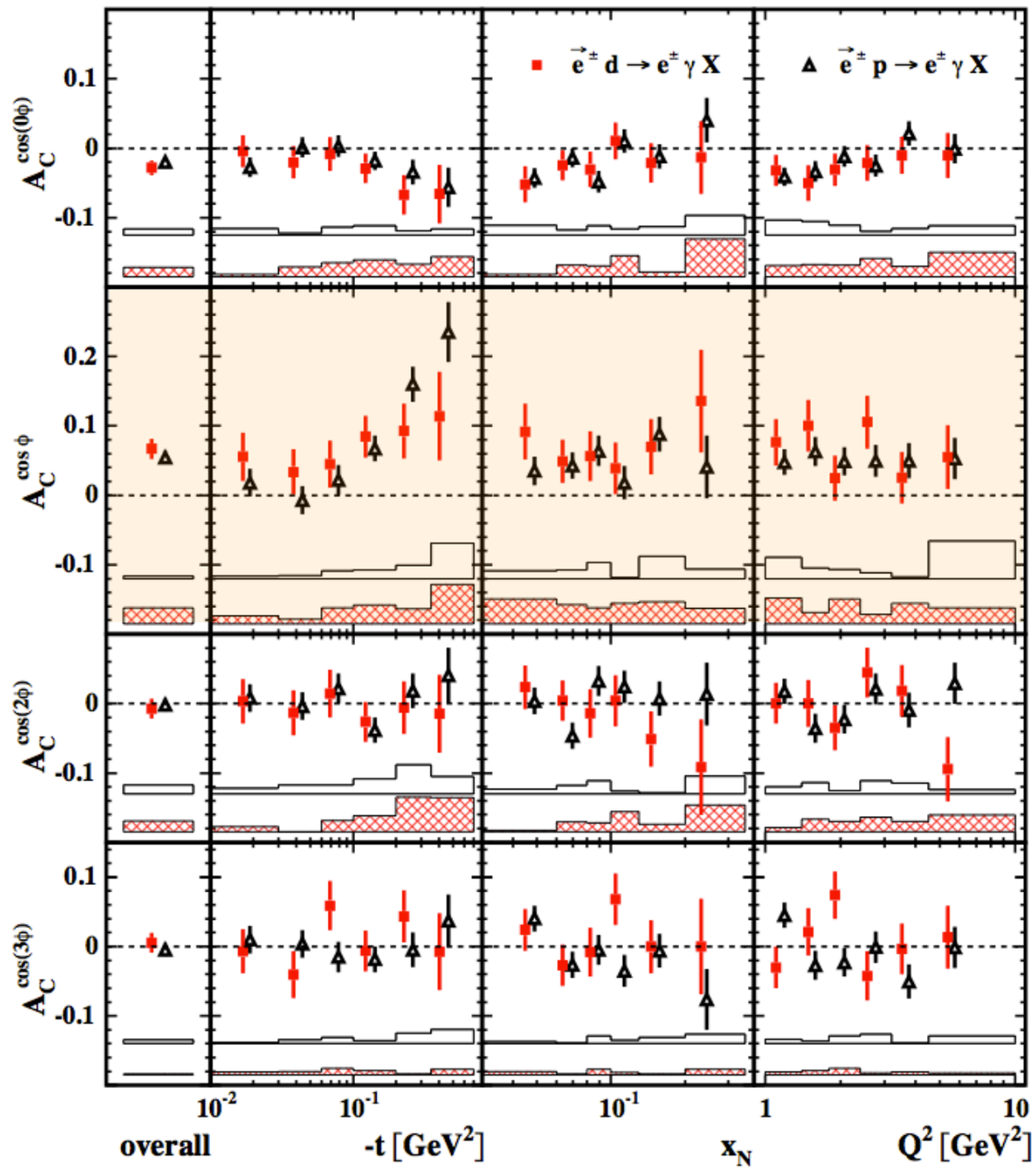
Other Data?

Deuterium Beam-Asymmetries

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



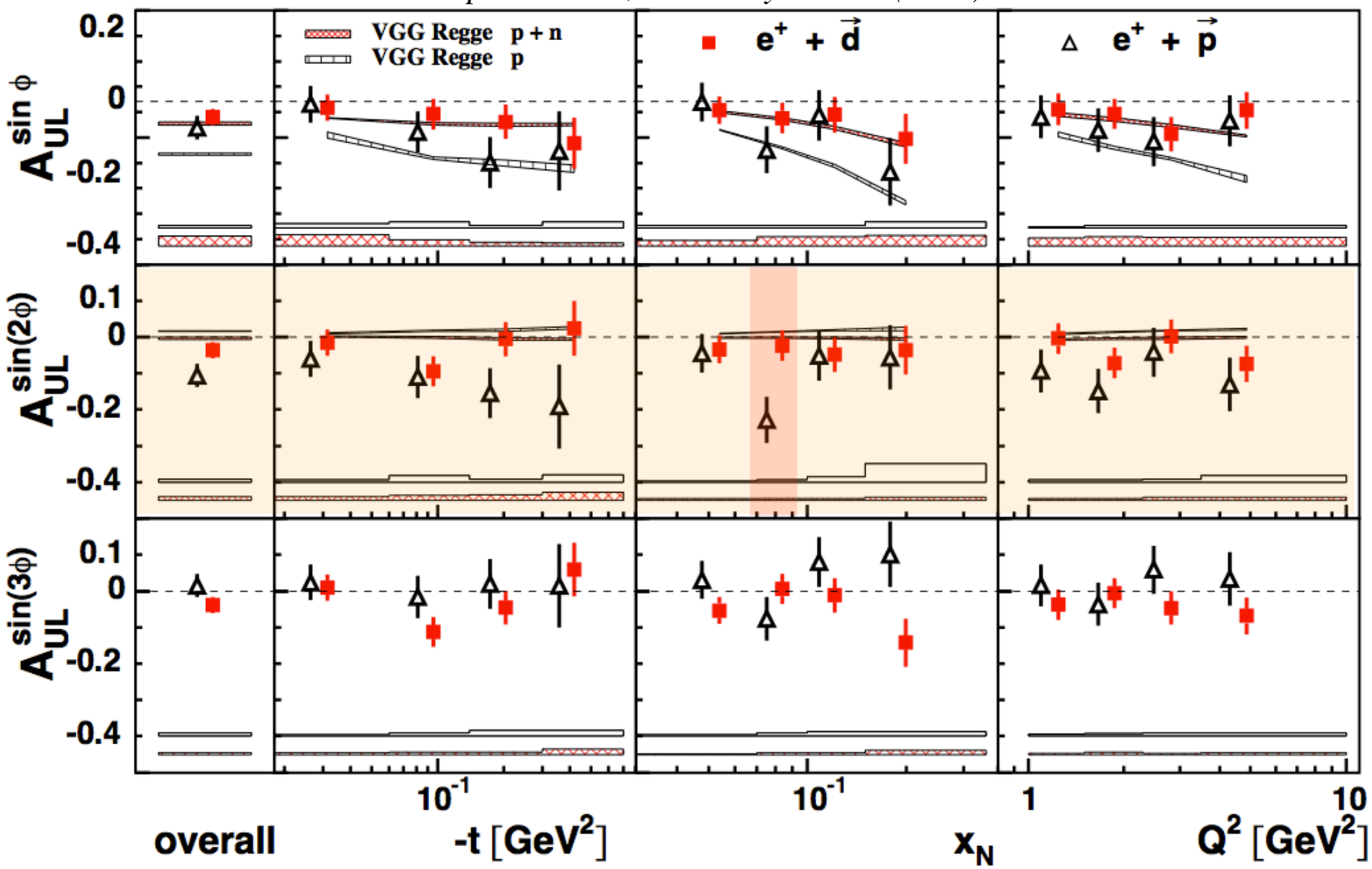
http://arxiv.org/abs/0911.0095



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

Deuterium-Target Asymmetries

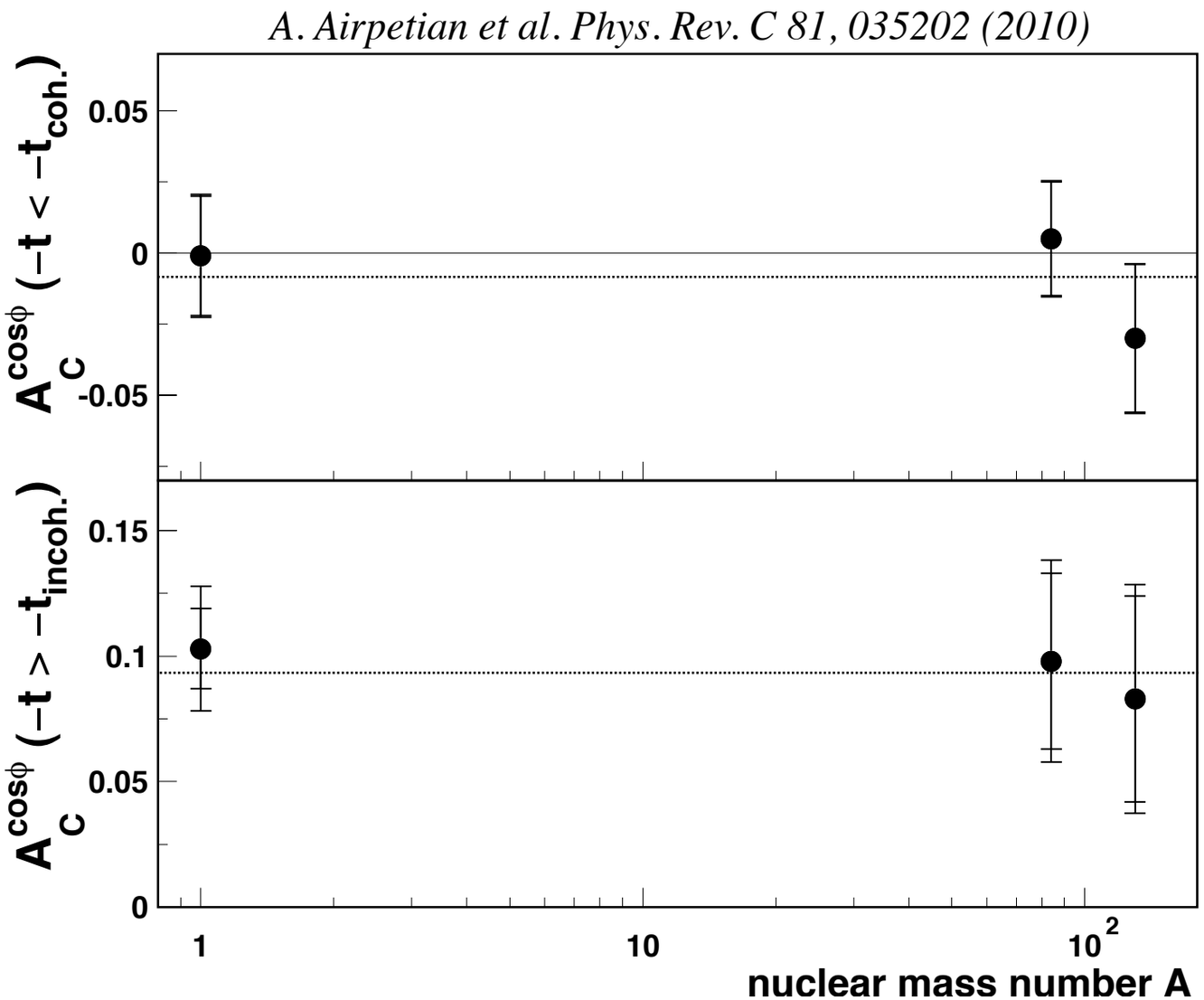
A. Airapetian et al, Nucl. Phys. B842 (2011) 265-298



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

http://arxiv.org/abs/1008.3996

Nuclear Mass Dependence

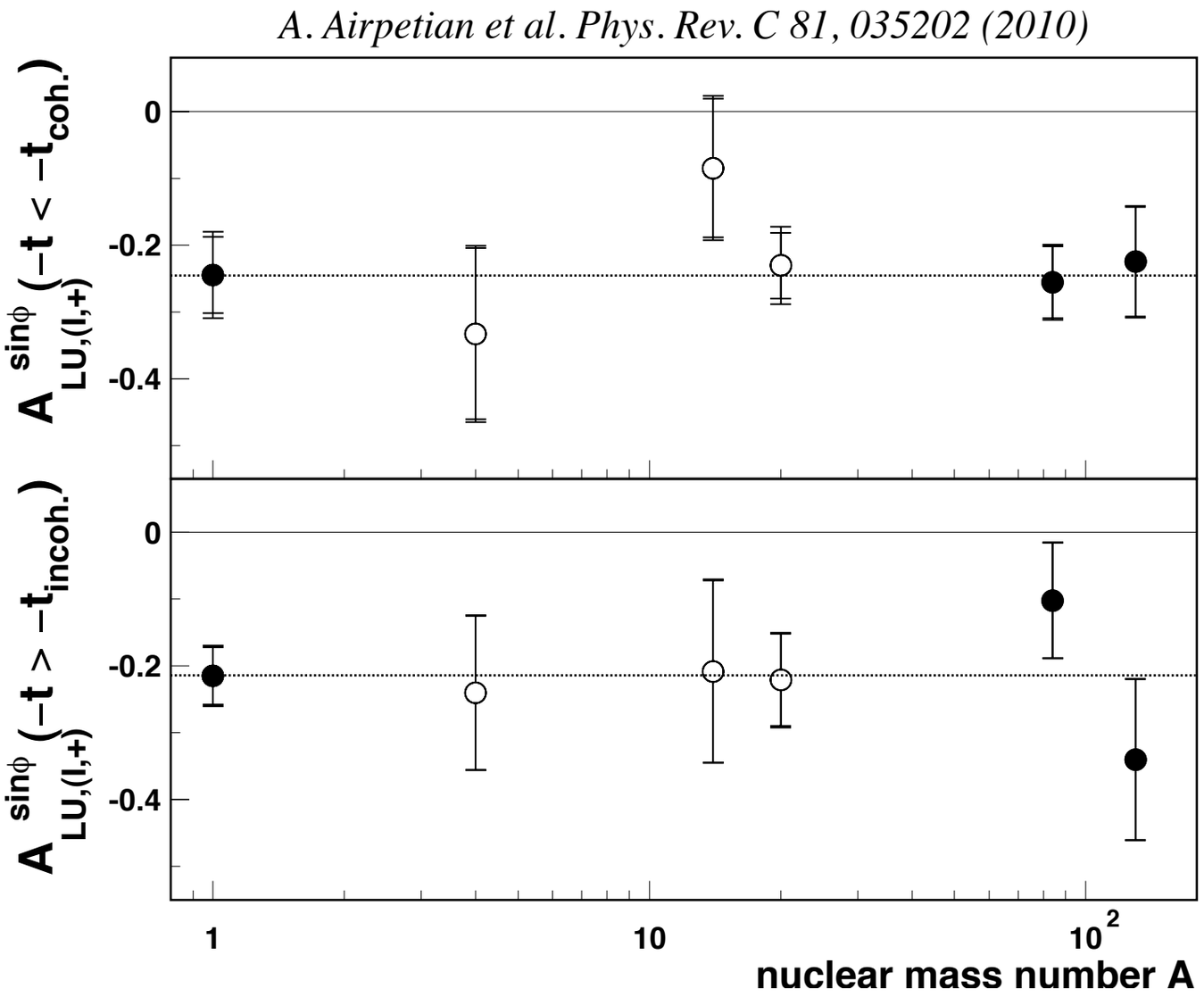


Several considerations may lead to the expectation that nuclear asymmetries would be larger than proton asymmetries

Not observed!

http://arxiv.org/abs/0911.0091

Nuclear Mass Dependence



A_I

$A_I + A_{DVCS}$

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

http://arxiv.org/abs/0911.0091