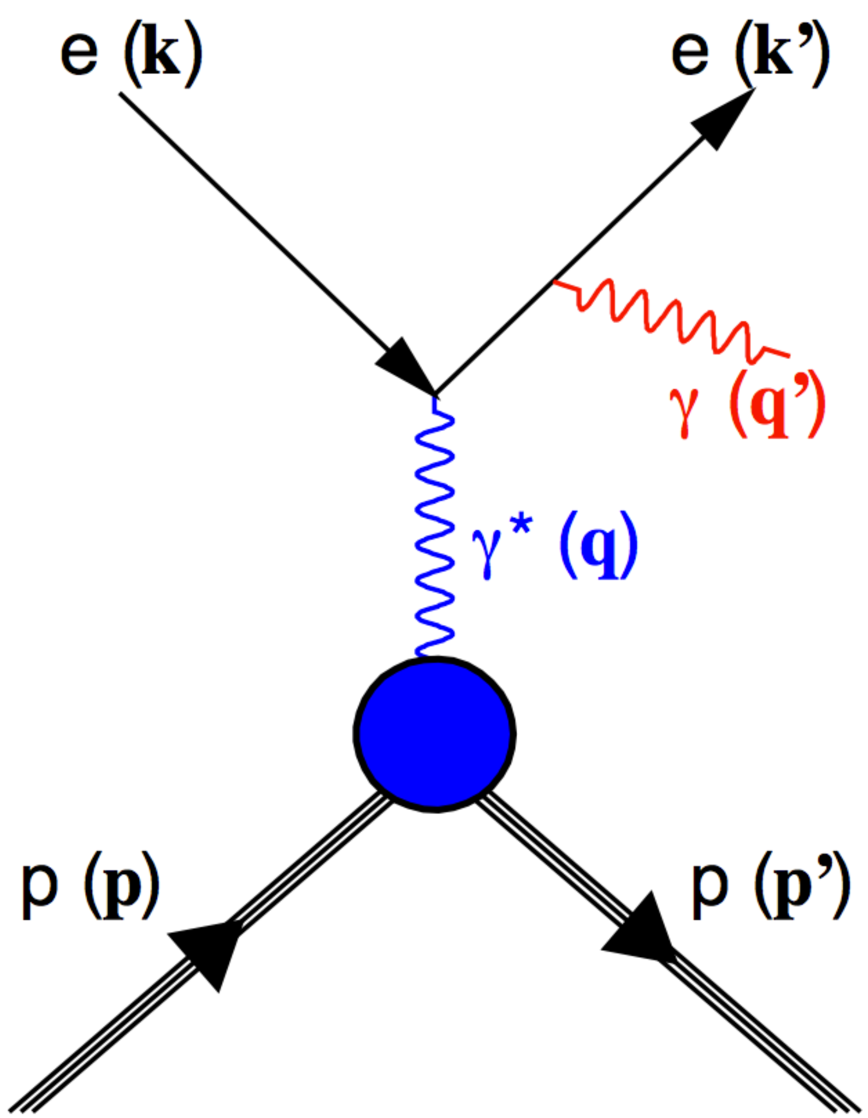
DVCS @ HERMES

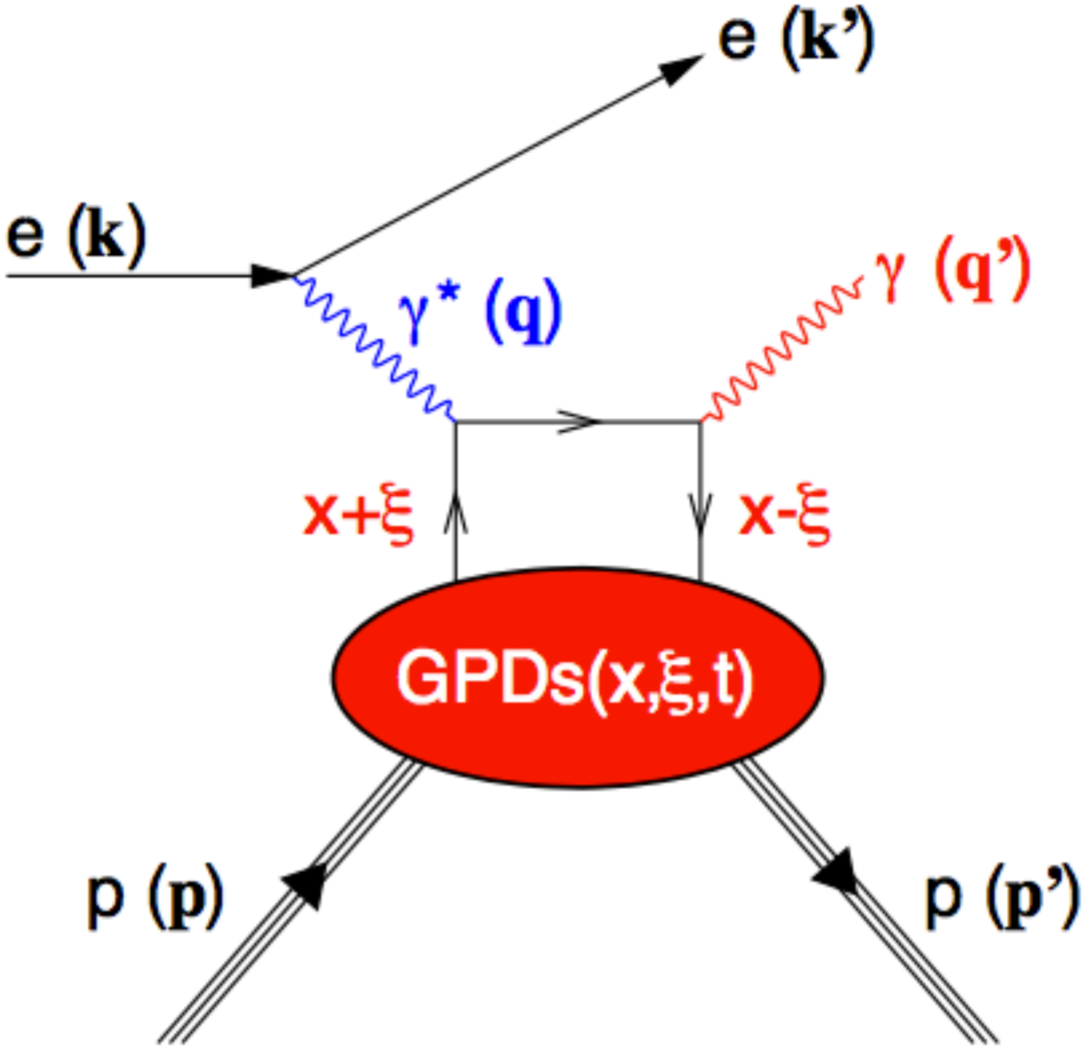
M. MURRAY, UNIVERSITY OF GLASGOW

GPD 2010

Deeply Virtual Compton Scattering

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

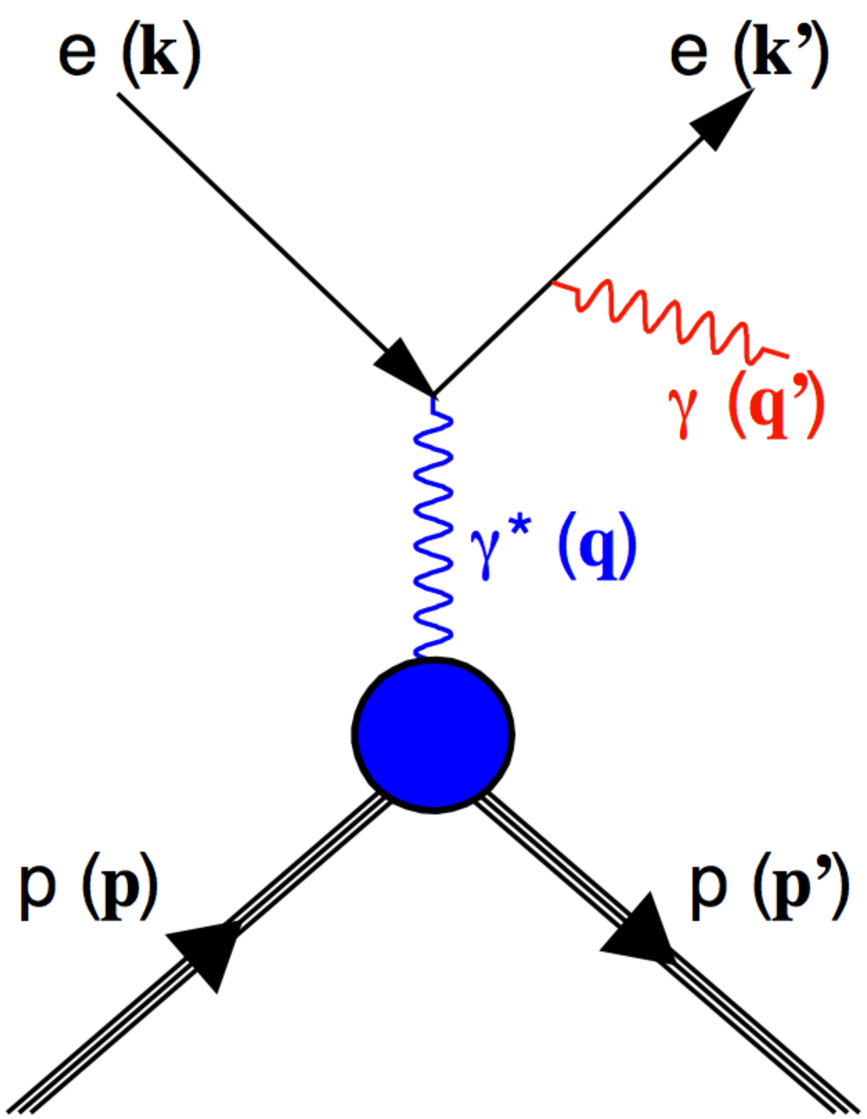


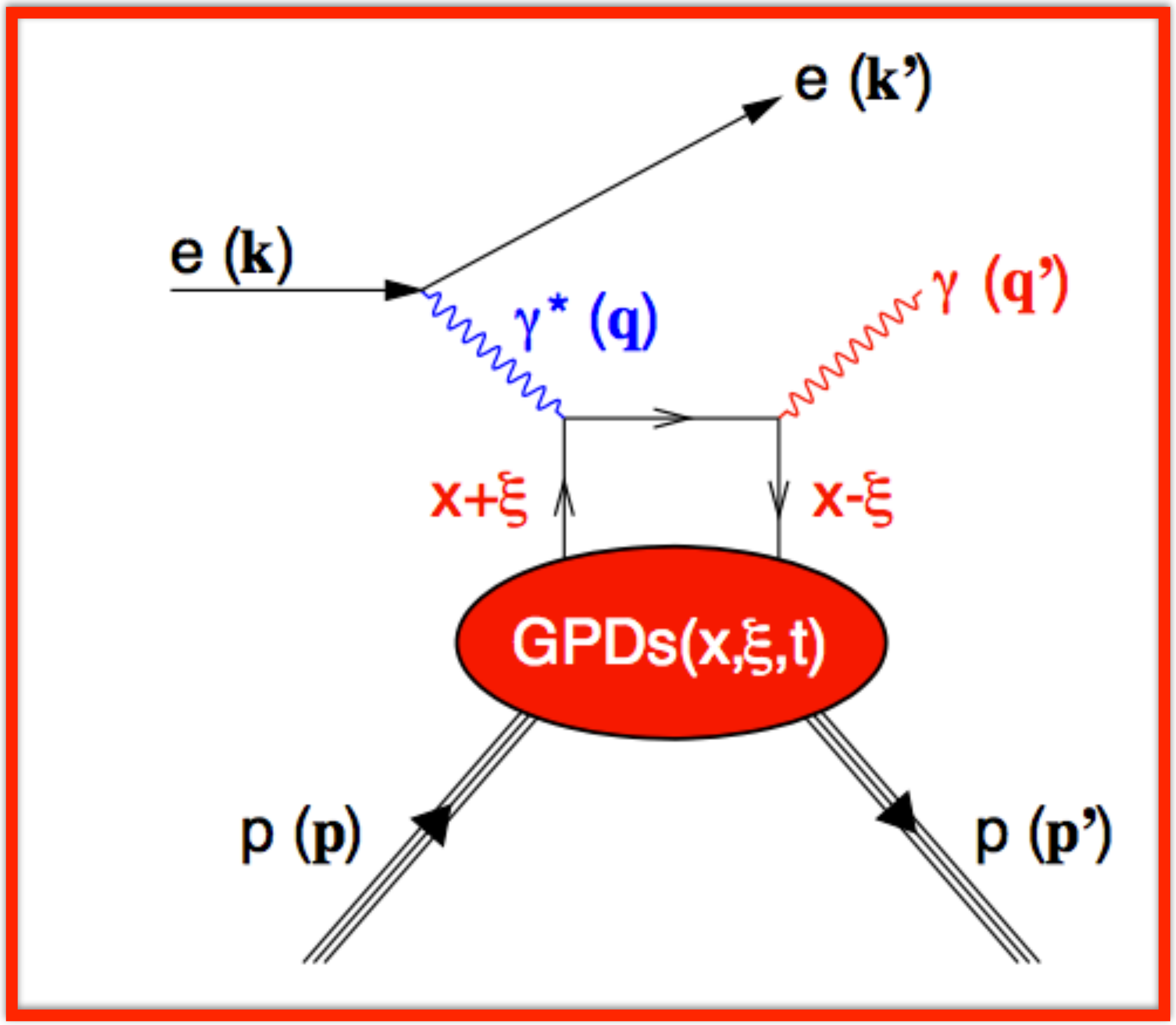


Deeply Virtual Compton Scattering

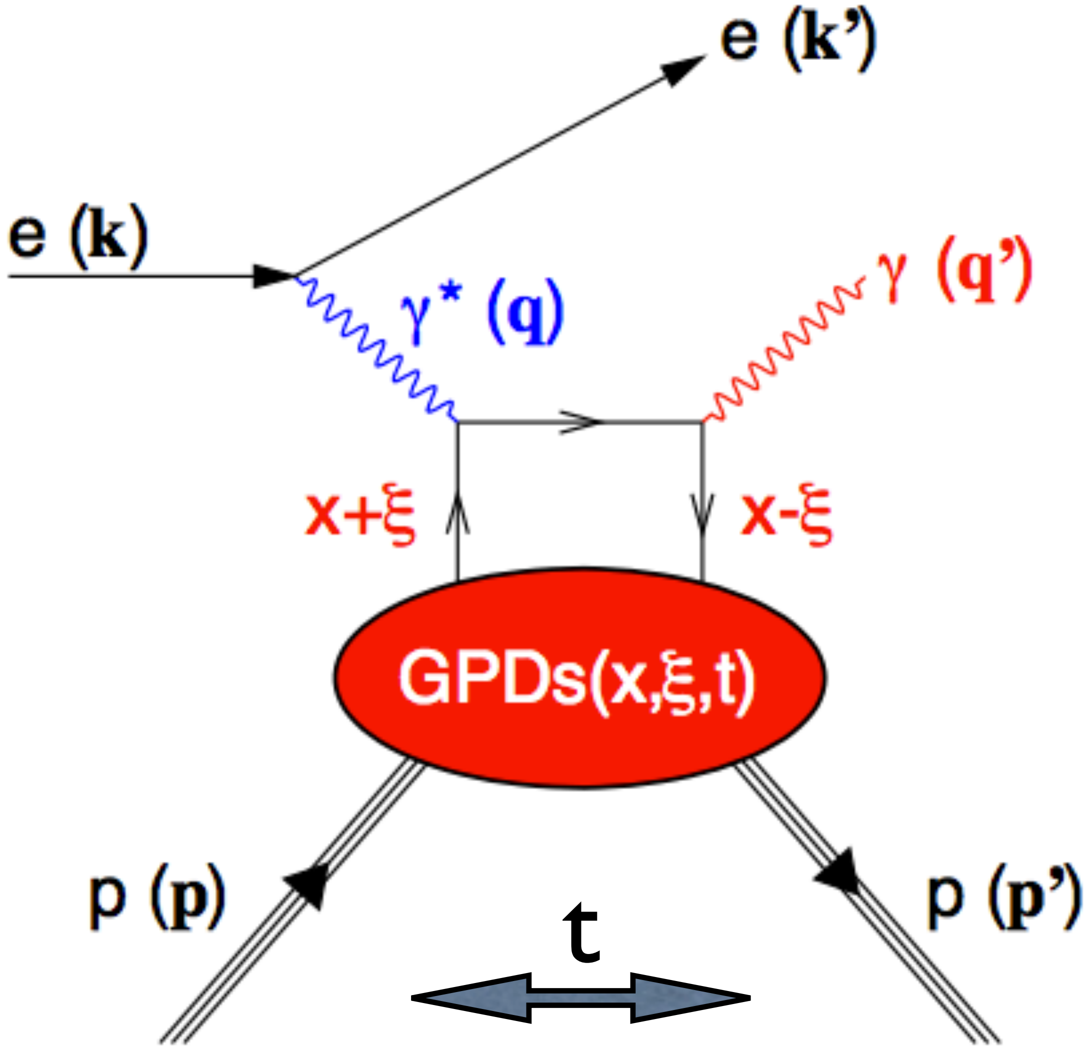
$$\frac{d\sigma}{dx_B\, dQ^2\, d|t|\, d\phi} = \frac{x_B\, e^6\, |\tau|^2}{32(2\pi)^4\, Q^4\, \sqrt{1+\epsilon^2}}$$

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





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.

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

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

Nucleon helicity inversion

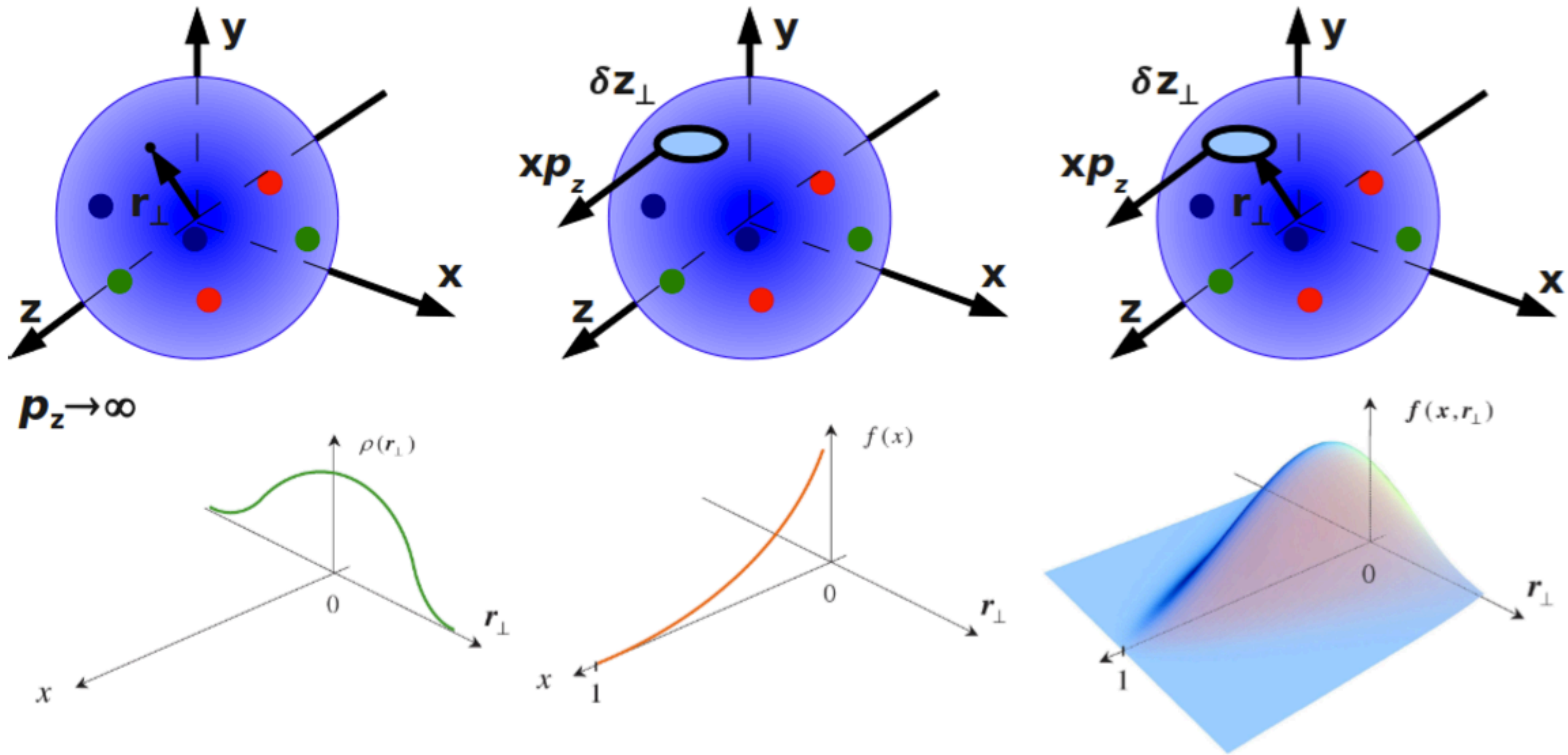
Nucleon helicity conservation

"Ji's Relation"

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

Phys. Rev. Lett. 78:610, 1997

GPD Physics

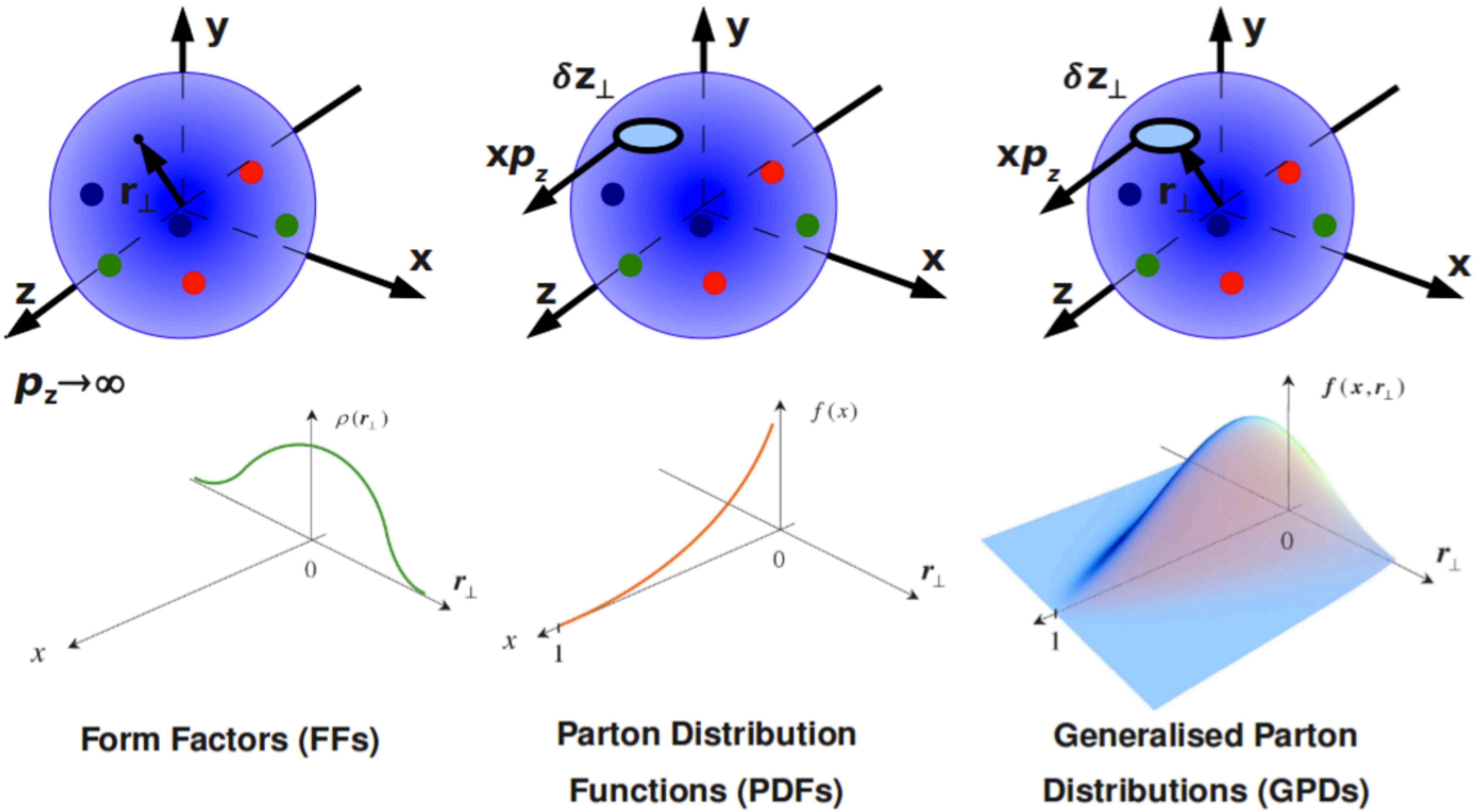


Form Factors (FFs)

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

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

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

$$\Im m\,\mathcal{F}(\xi,\,t) \;=\; F(\xi,\,\xi,\,t) \pm F(-\xi,\,\xi,\,t)\,,$$

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

GPD Physics

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Limited *x* access

DVCS @ HERMES

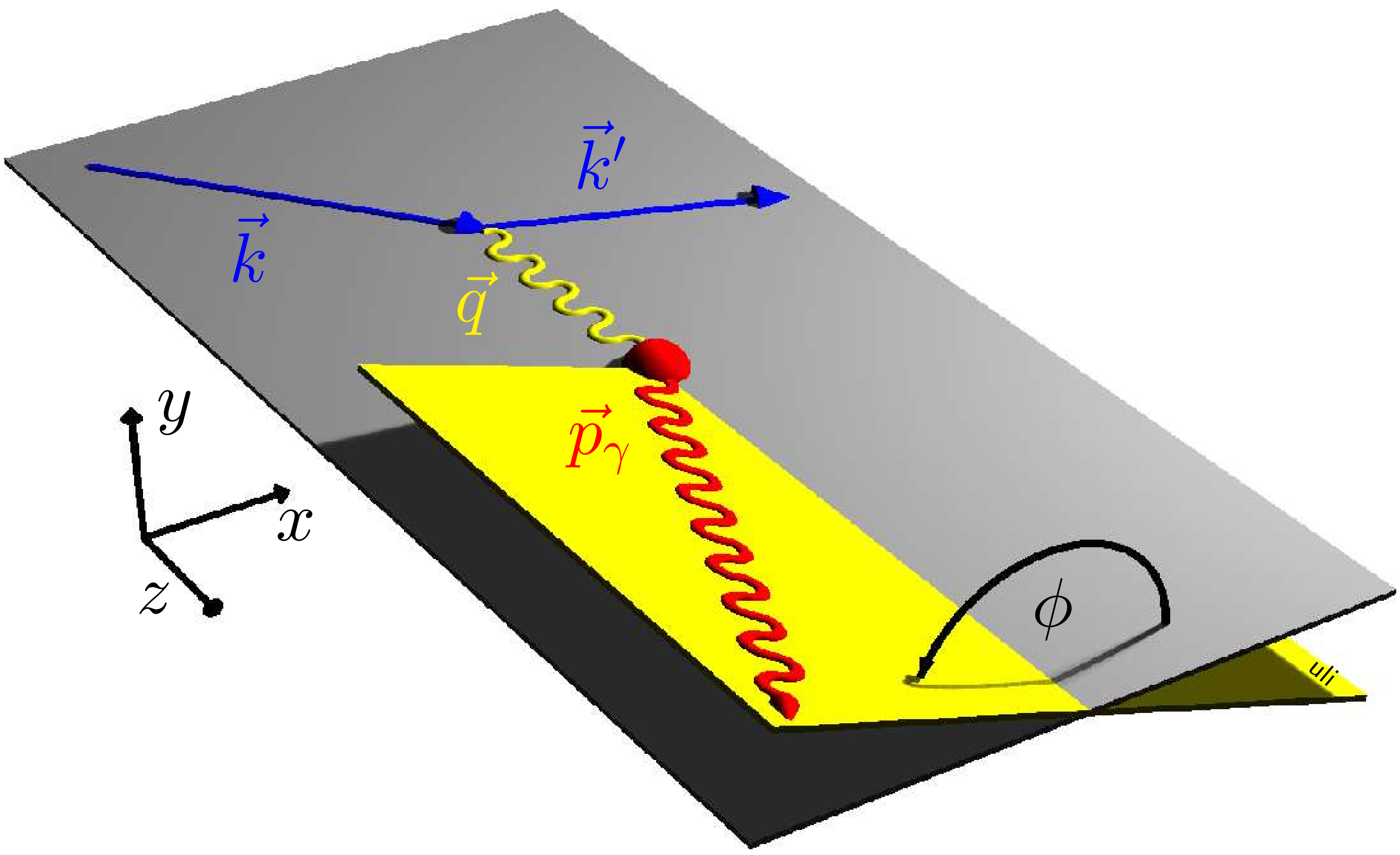
$$\mathcal{A}_C(\phi) \equiv \frac{\mathrm{d}\sigma^+(\phi) - \mathrm{d}\sigma^-(\phi)}{\mathrm{d}\sigma^+(\phi) + \mathrm{d}\sigma^-(\phi)} \quad \propto \quad \mathrm{Re}(\mathcal{H})$$

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

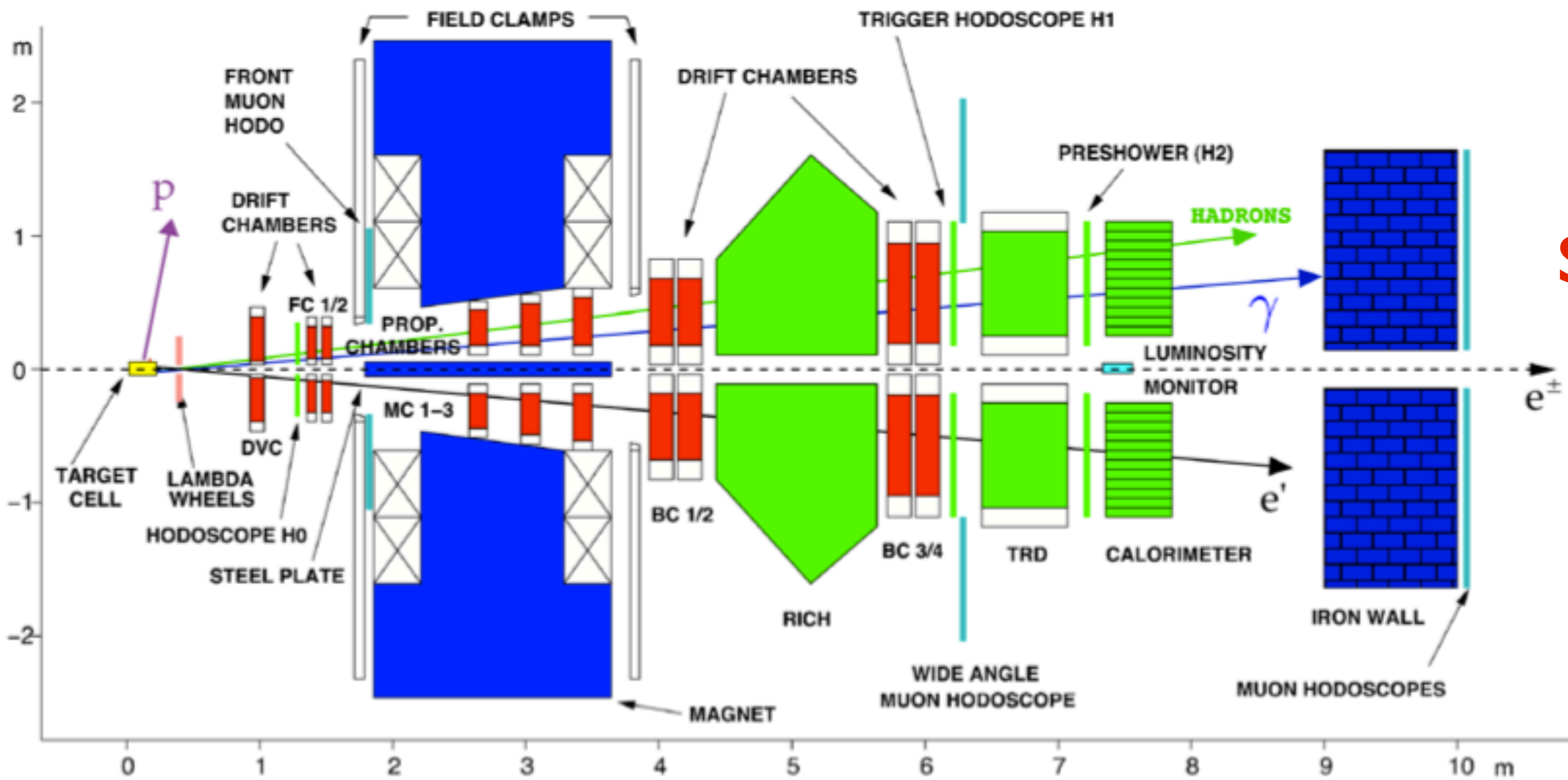
$$\mathcal{A}_{\mathrm{UL}}(\phi) \equiv \frac{[\sigma^{\leftarrow\Rightarrow}(\phi) + \sigma^{\rightarrow\Rightarrow}(\phi)] - [\sigma^{\leftarrow\Leftarrow}(\phi) + \sigma^{\rightarrow\Leftarrow}(\phi)]}{[\sigma^{\leftarrow\Rightarrow}(\phi) + \sigma^{\rightarrow\Rightarrow}(\phi)] + [\sigma^{\leftarrow\Leftarrow}(\phi)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

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

DVCS @ HERMES



DVCS @ HERMES



Forward spectrometer ⇒

measure asymmetries directly

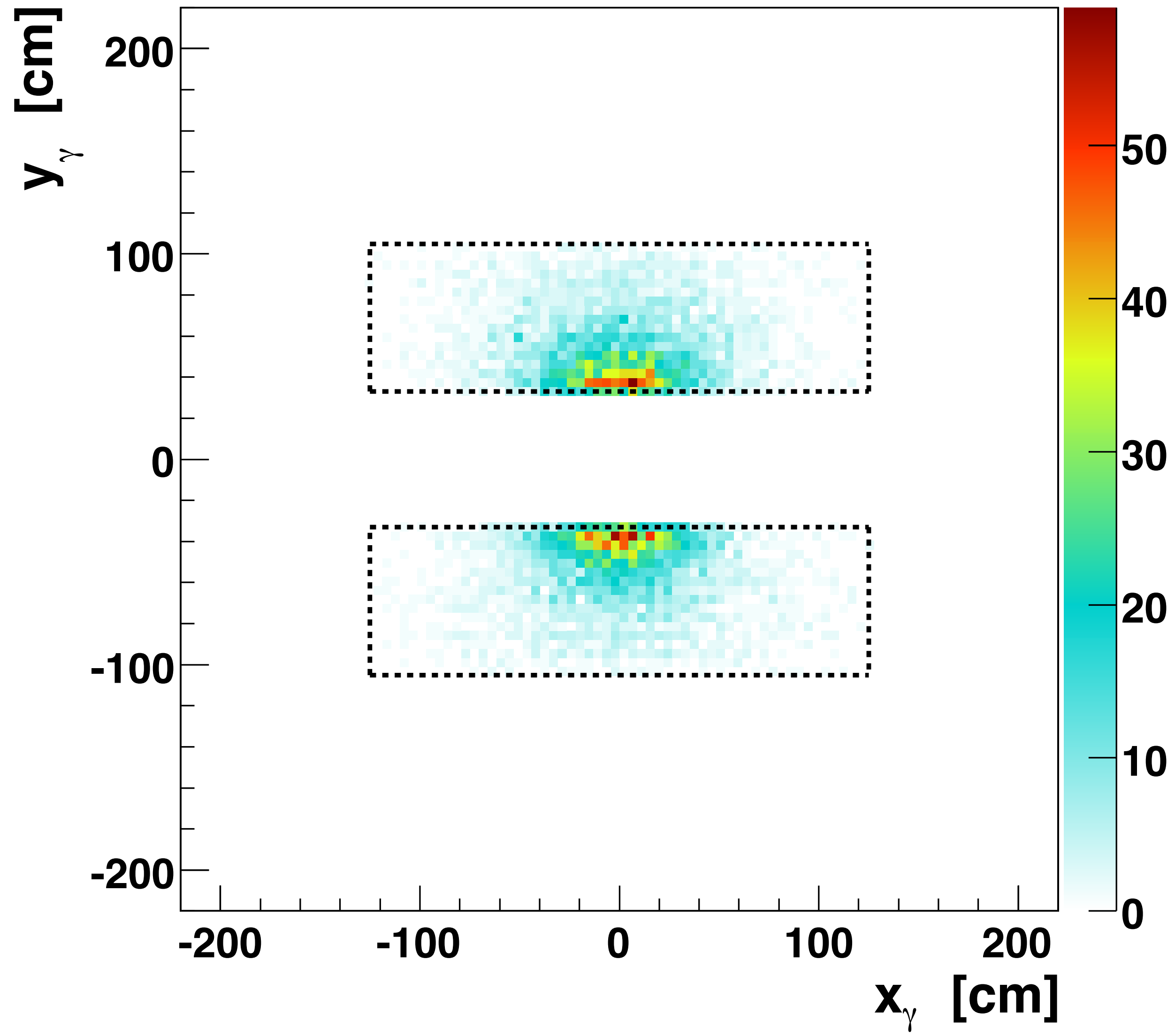
$\langle Q^2 \rangle \cong 2.4\ \mathrm{GeV}^2$

$\langle x_B \rangle \cong 0.1$

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

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

DVCS @ HERMES



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$\langle x_B \rangle \cong 0.1$

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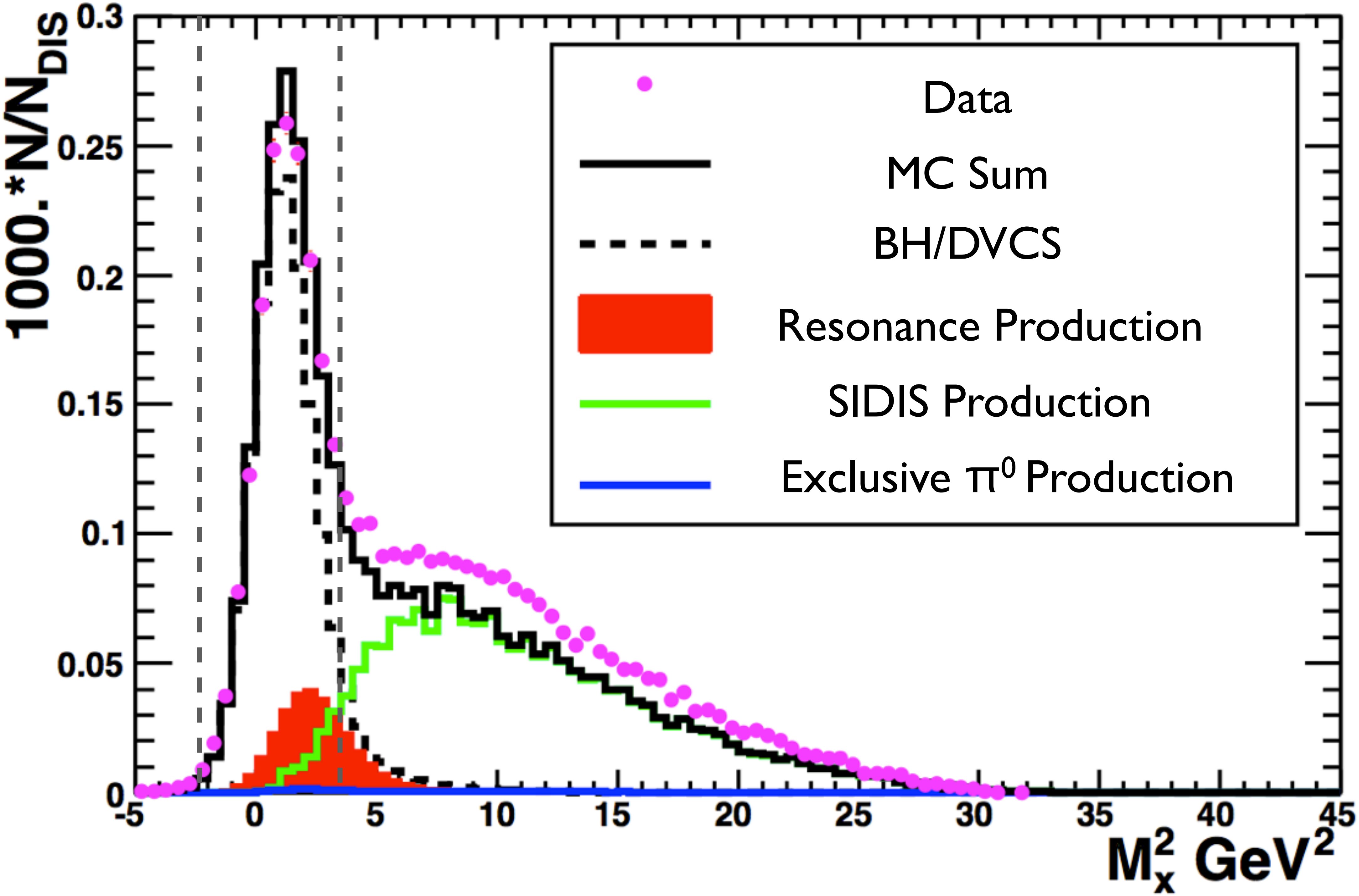
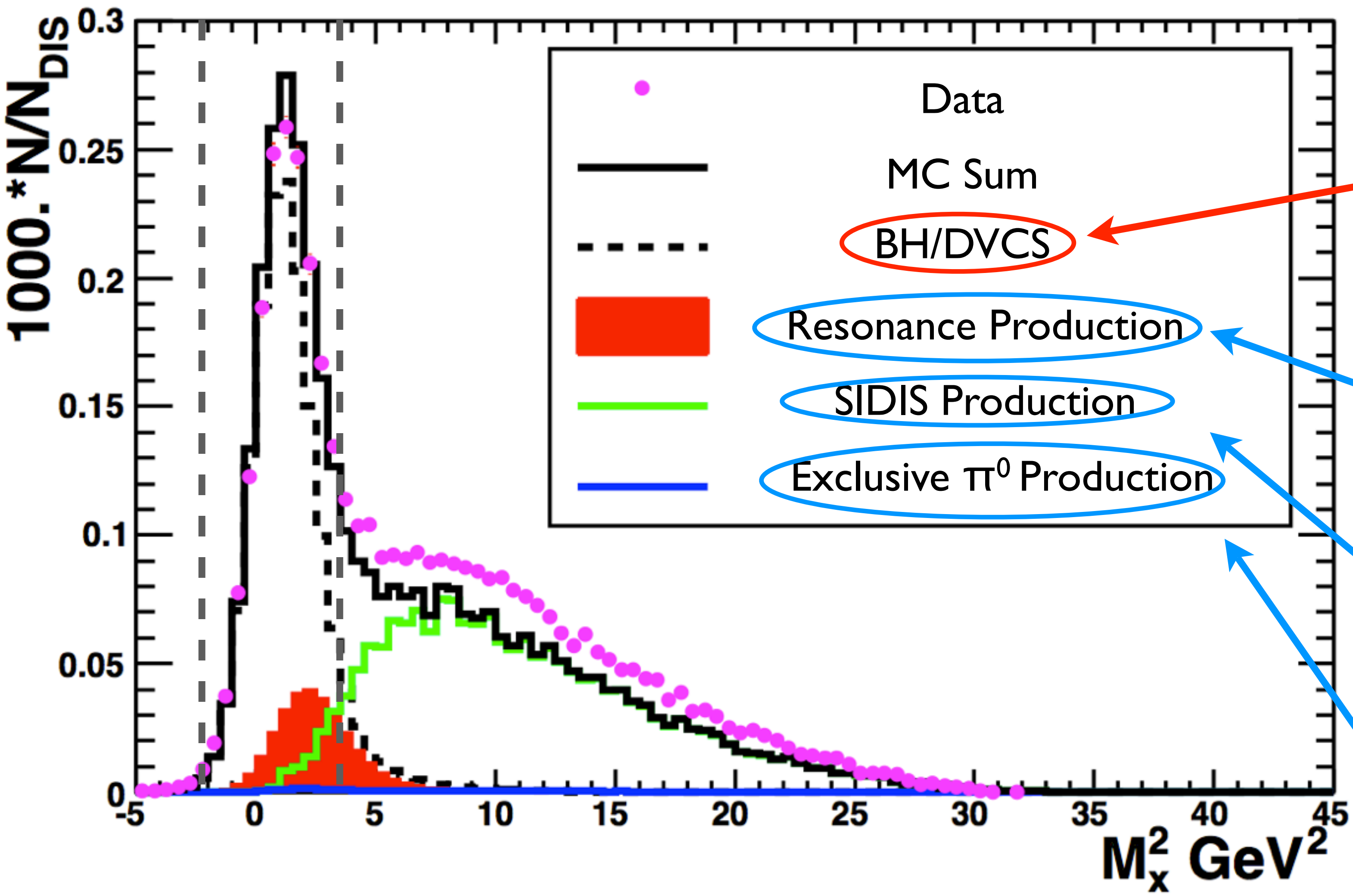
DVCS @ HERMES



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

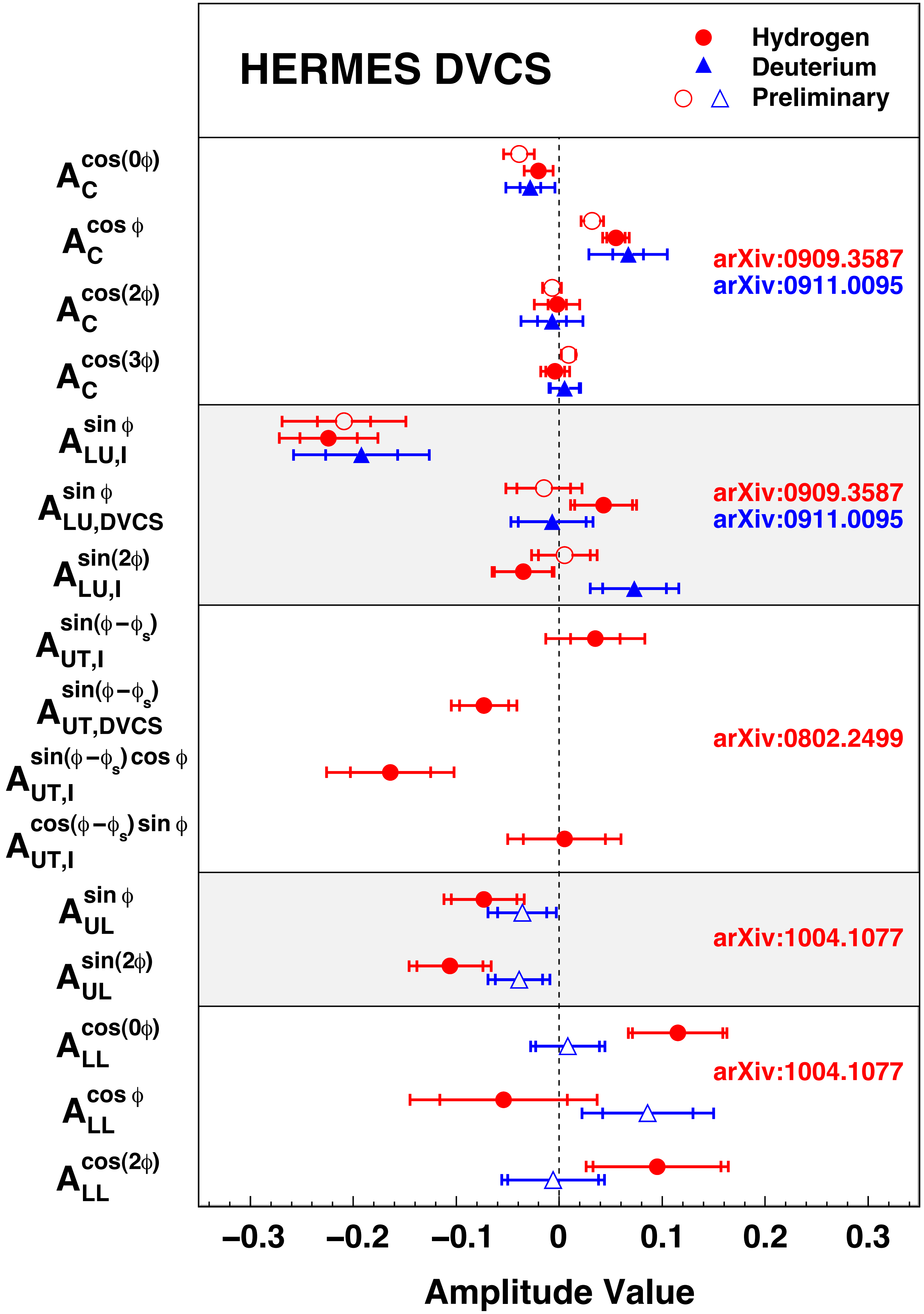
BH/DVCS from Δ, e.g

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

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

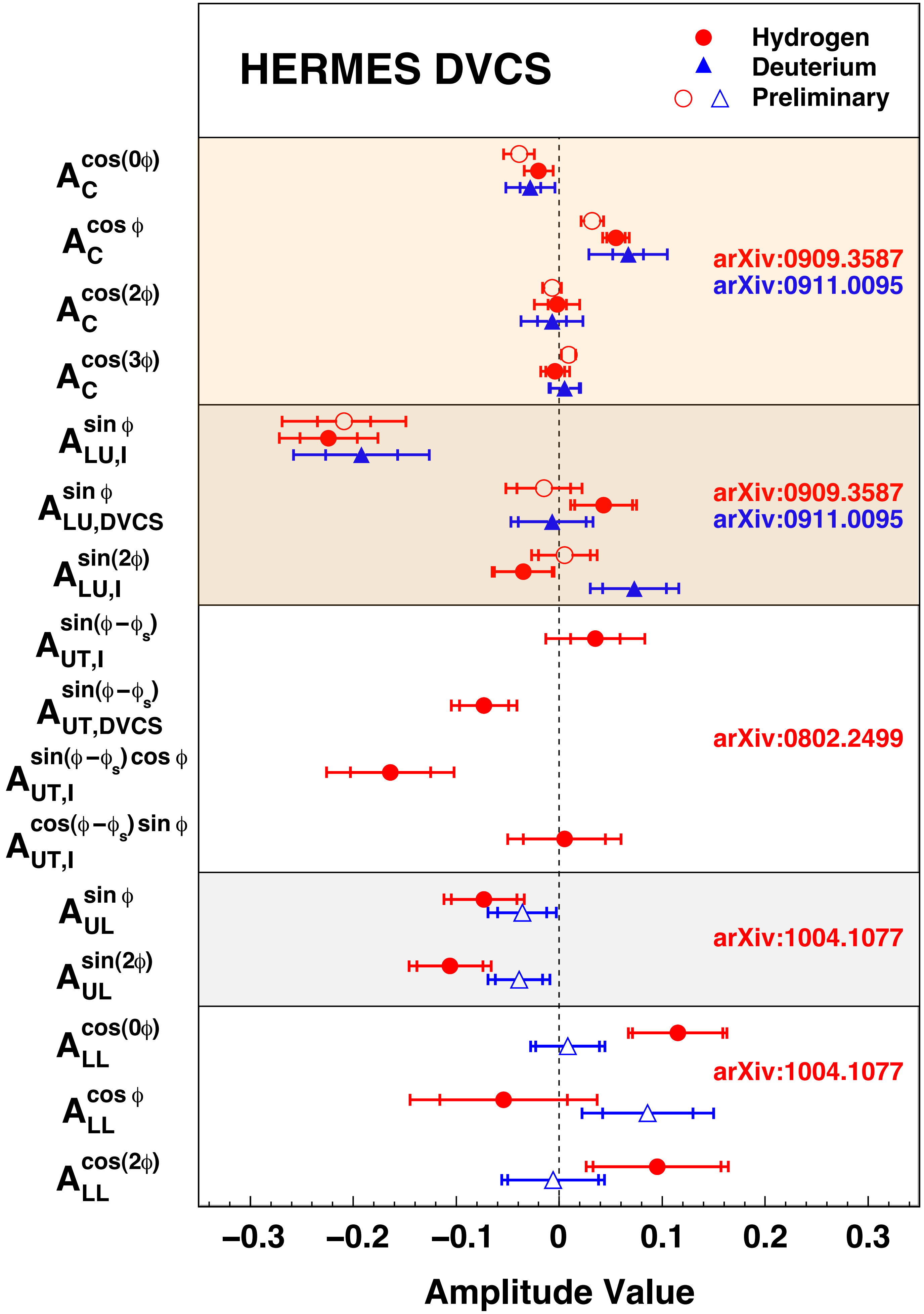
$e\,p \rightarrow e\,p\,\pi^0$

DVCS @


HERMES DVCS
Hydrogen
Deuterium
Preliminary
$A_C^{\cos(0\phi)}$
$A_C^{\cos\phi}$
$A_C^{\cos(2\phi)}$
$A_C^{\cos(3\phi)}$
$A_{LU,I}^{\sin\phi}$
$A_{LU,DVCS}^{\sin\phi}$
$A_{LU,I}^{\sin(2\phi)}$
$A_{UT,I}^{\sin(\phi-\phi_s)}$
$A_{UT,DVCS}^{\sin(\phi-\phi_s)}$
$A_{UT,I}^{\sin(\phi-\phi_s)\cos\phi}$
$A_{UT,I}^{\cos(\phi-\phi_s)\sin\phi}$
$A_{UL}^{\sin\phi}$
$A_{UL}^{\sin(2\phi)}$
$A_{LL}^{\cos(0\phi)}$
$A_{LL}^{\cos\phi}$
$A_{LL}^{\cos(2\phi)}$
arXiv:0909.3587
arXiv:0911.0095
arXiv:0909.3587
arXiv:0911.0095
arXiv:0802.2499
arXiv:1004.1077
arXiv:1004.1077
−0.3
−0.2
−0.1
0
0.1
0.2
0.3
Amplitude Value

HERMES

DVCS@



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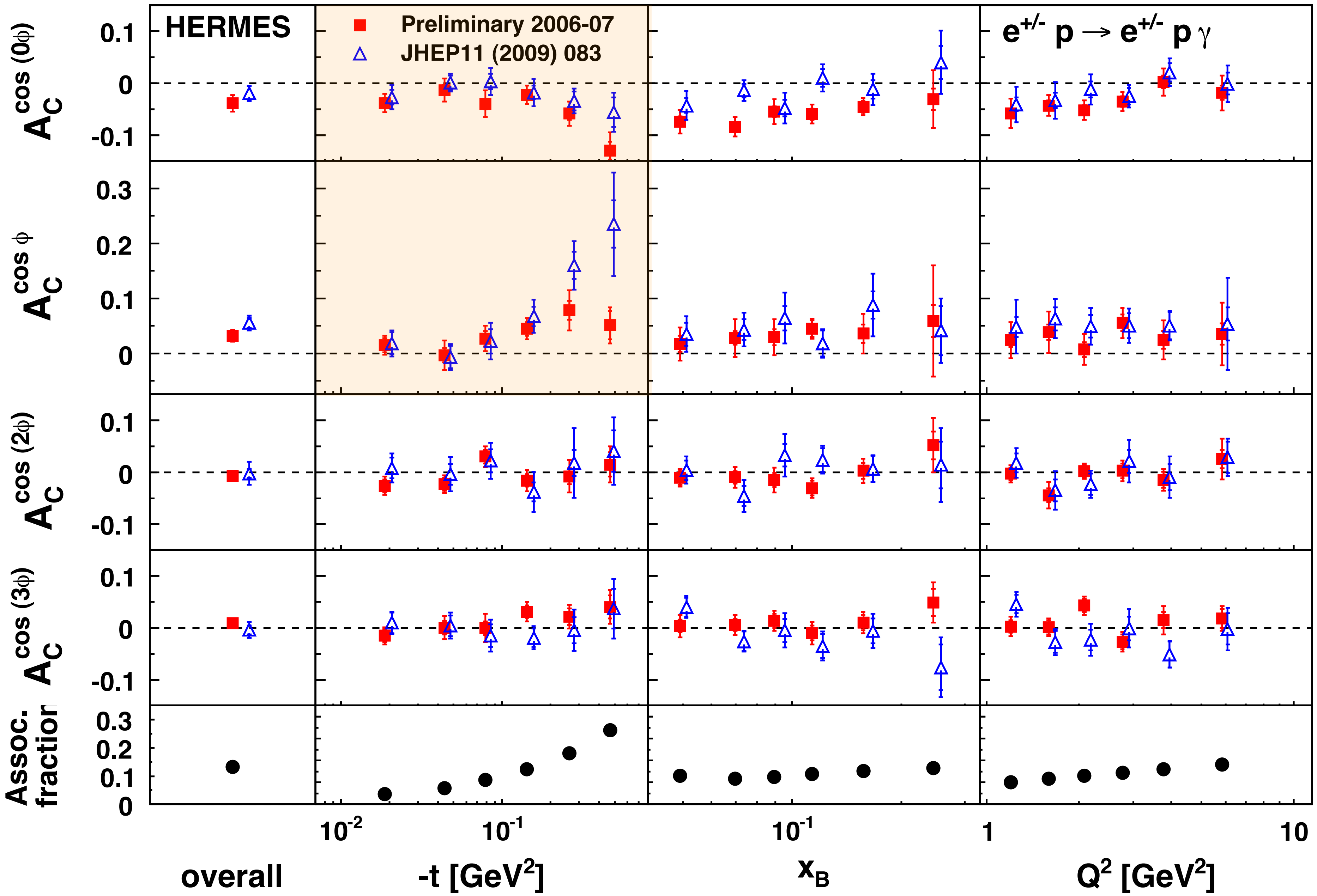
−0.3
−0.2
−0.1
0
0.1
0.2
0.3
Amplitude Value

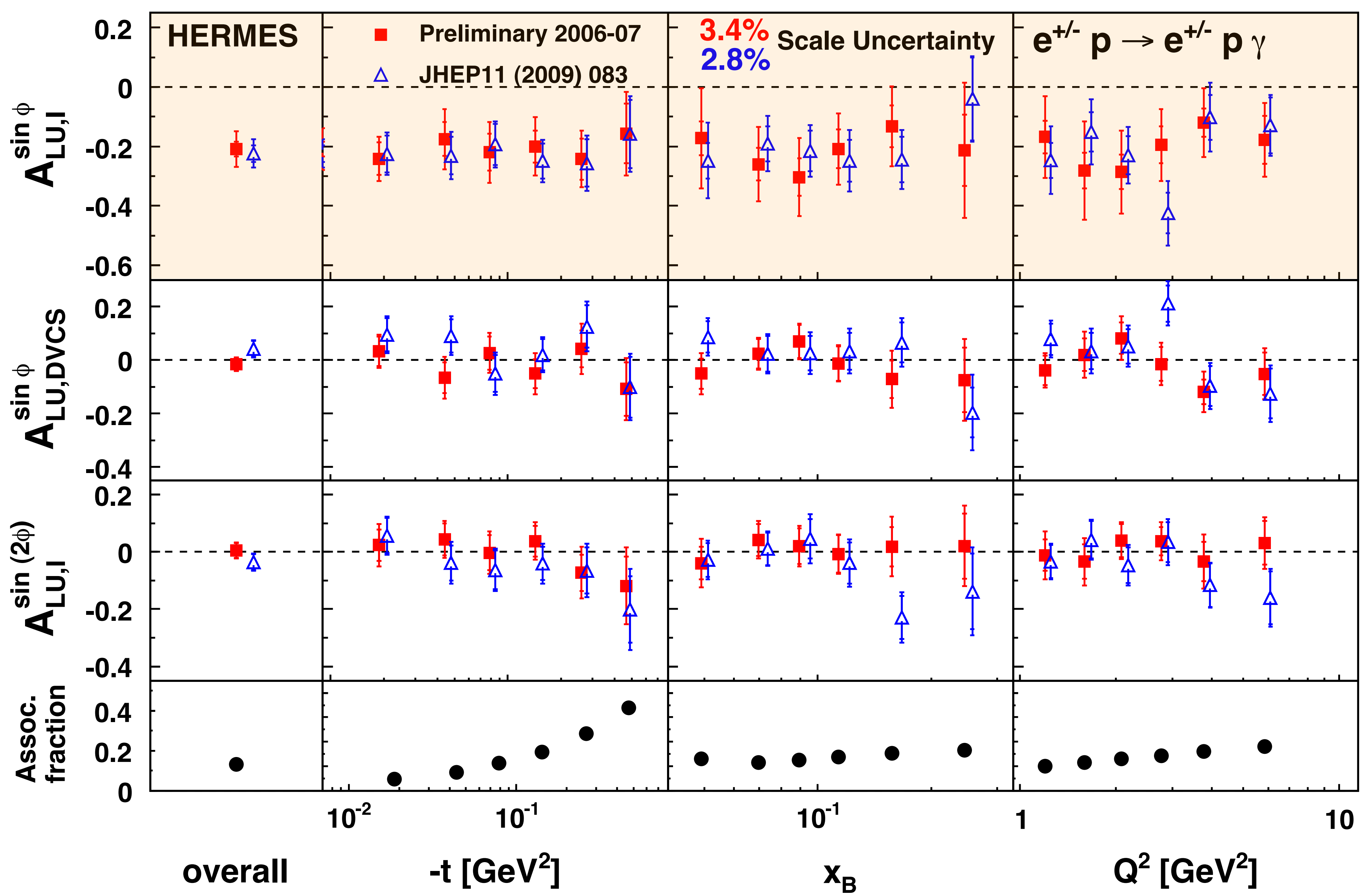
HERMES

Beam Asymmetries



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

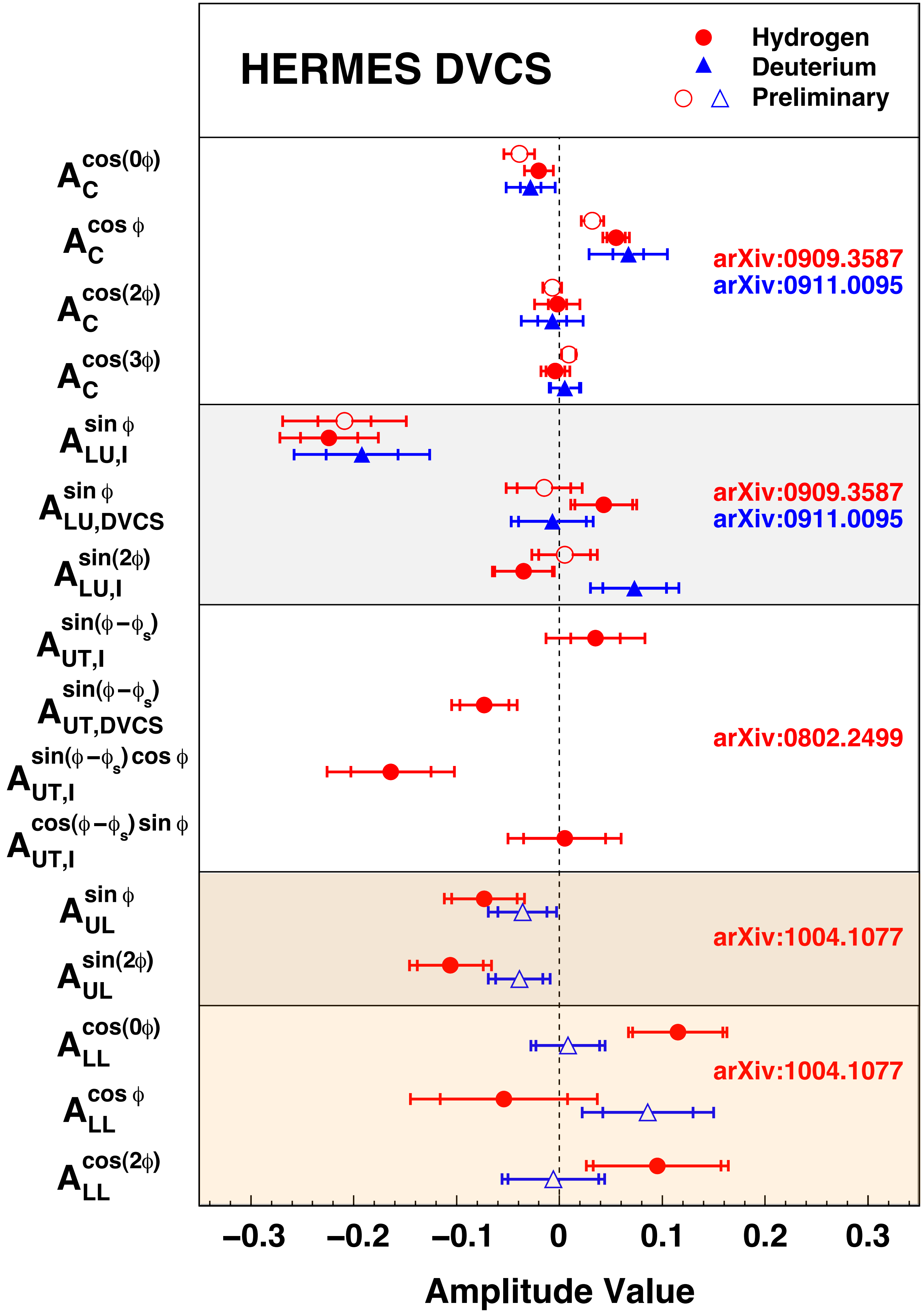
Beam Asymmetries



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

Larger values for the BHA than BCA - node in the small-x region near to the HERMES kinematics?

DVCS@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$A_{UT,I}^{\cos(\phi-\phi_s)\sin\phi}$
$A_{UL}^{\sin\phi}$
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$A_{LL}^{\cos\phi}$
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arXiv:0909.3587
arXiv:0911.0095
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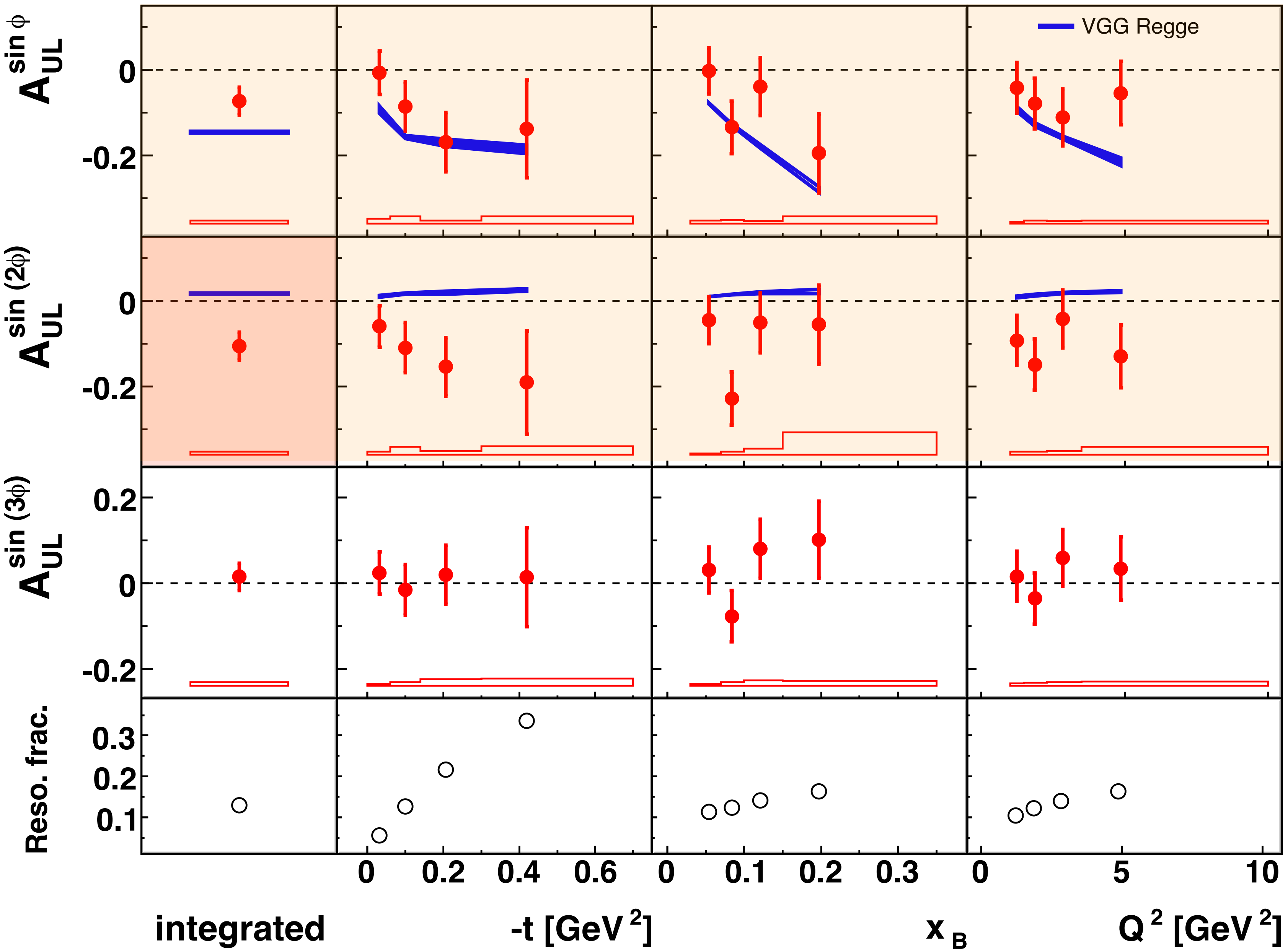
arXiv:0802.2499
arXiv:1004.1077
arXiv:1004.1077
−0.3
−0.2
−0.1
0
0.1
0.2
0.3
Amplitude Value

HERMES

Target Asymmetries



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

http://arxiv.org/abs/1004.0177

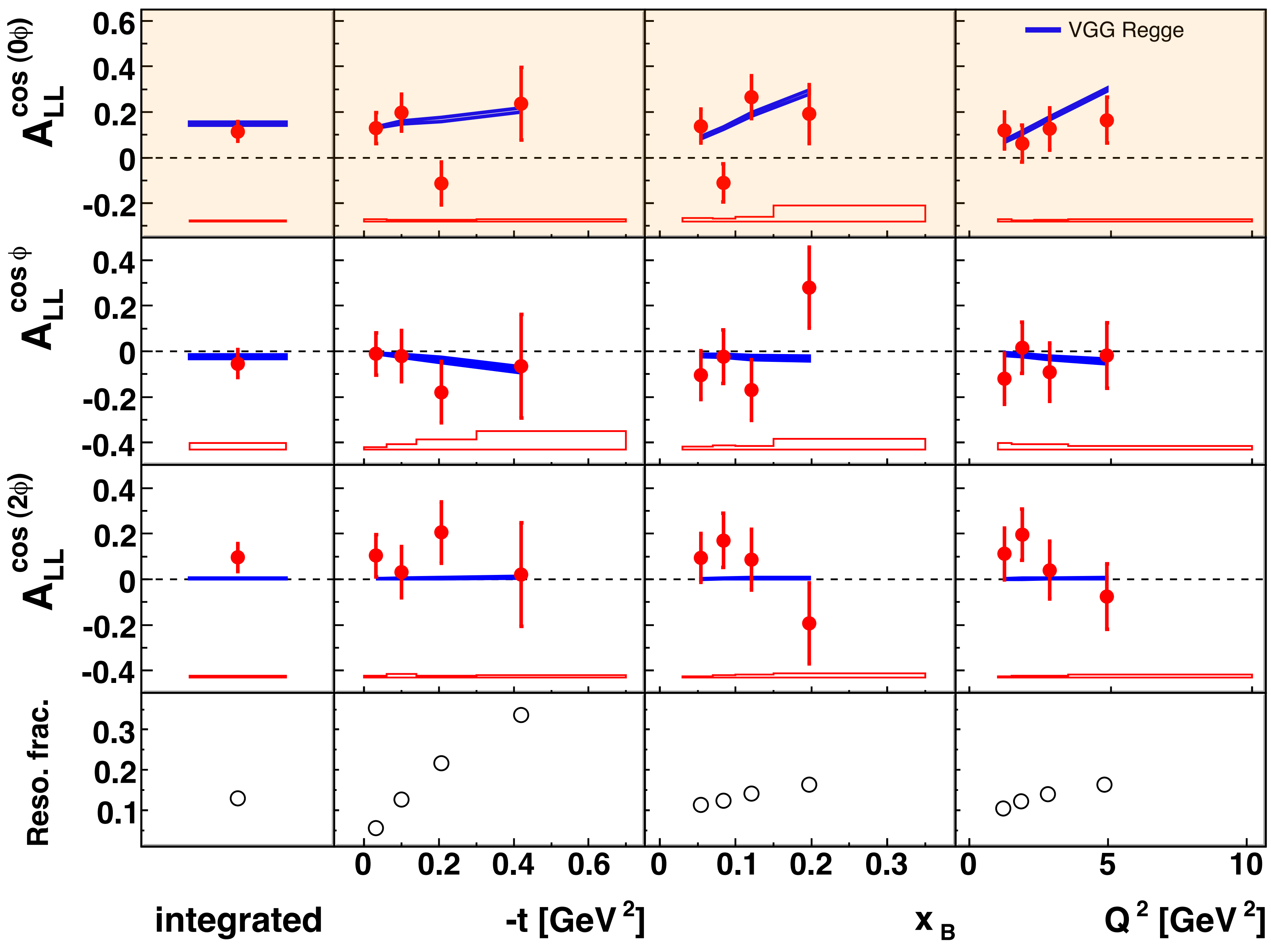
A. Airapetian et al, JHEP 06 (2010) 019

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($\tilde{\mathcal{H}}$)

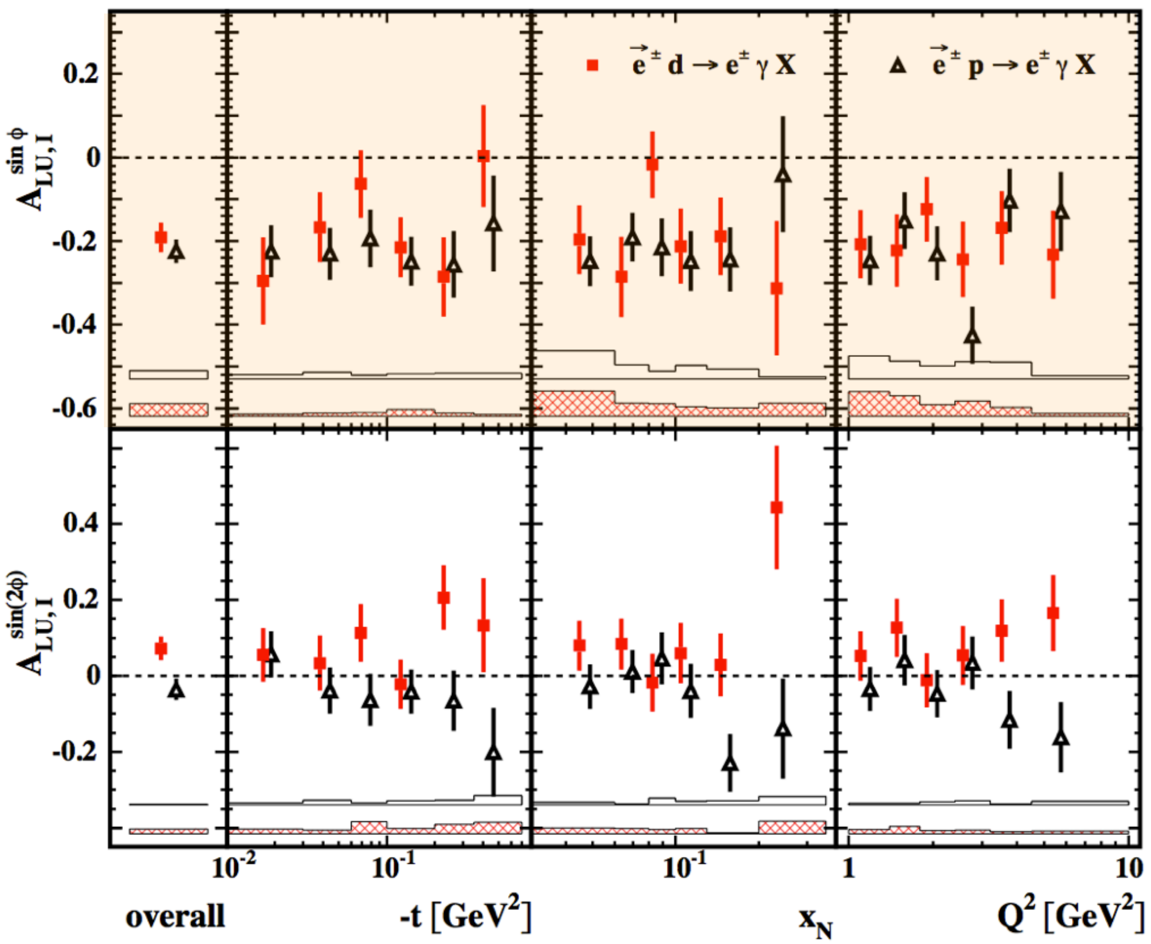
Caveat! Relatively large BH contribution to these asymmetries!

http://arxiv.org/abs/1004.0177

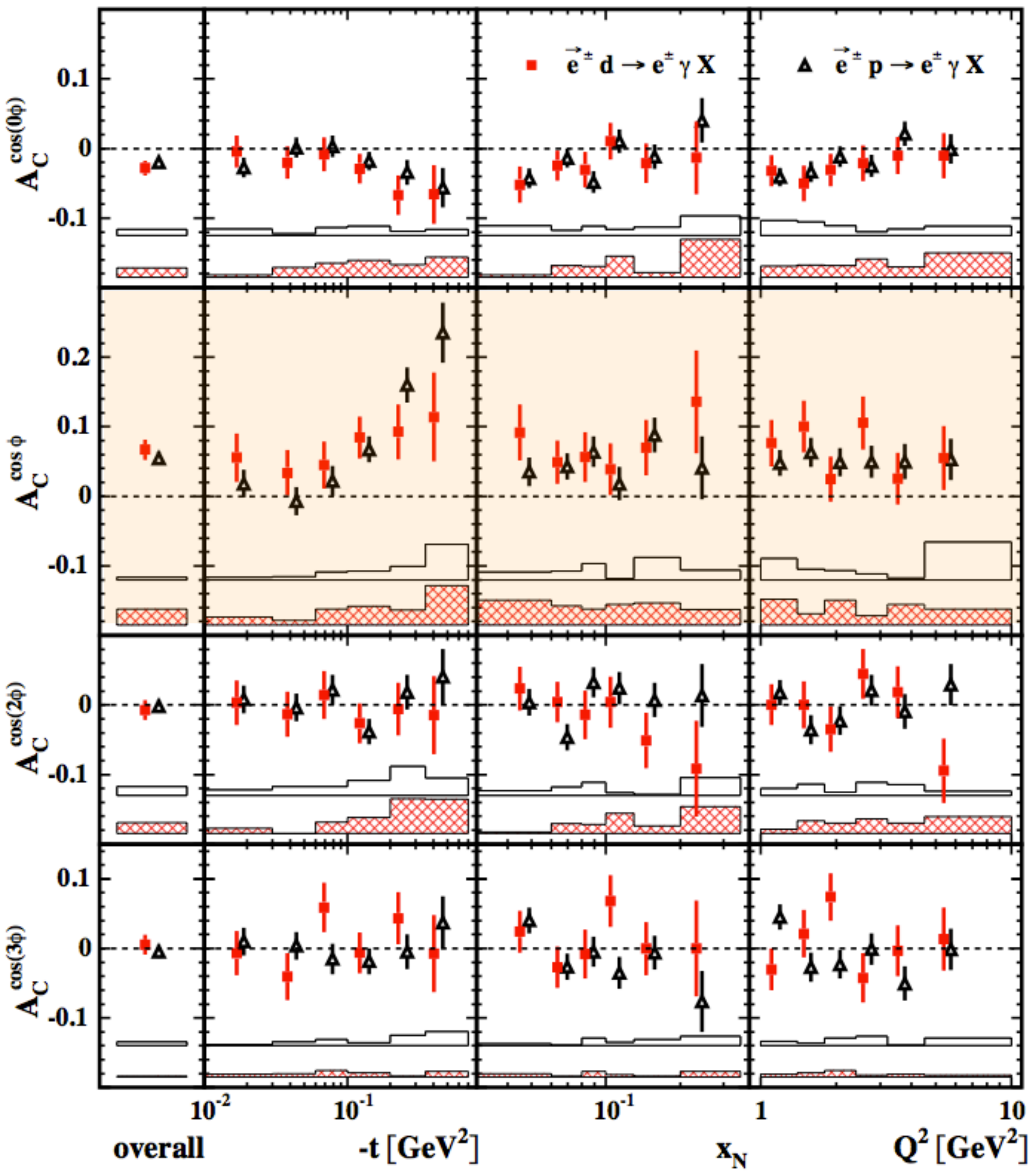
A. Airapetian et al, JHEP 06 (2010) 019

Beam Asymmetries

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

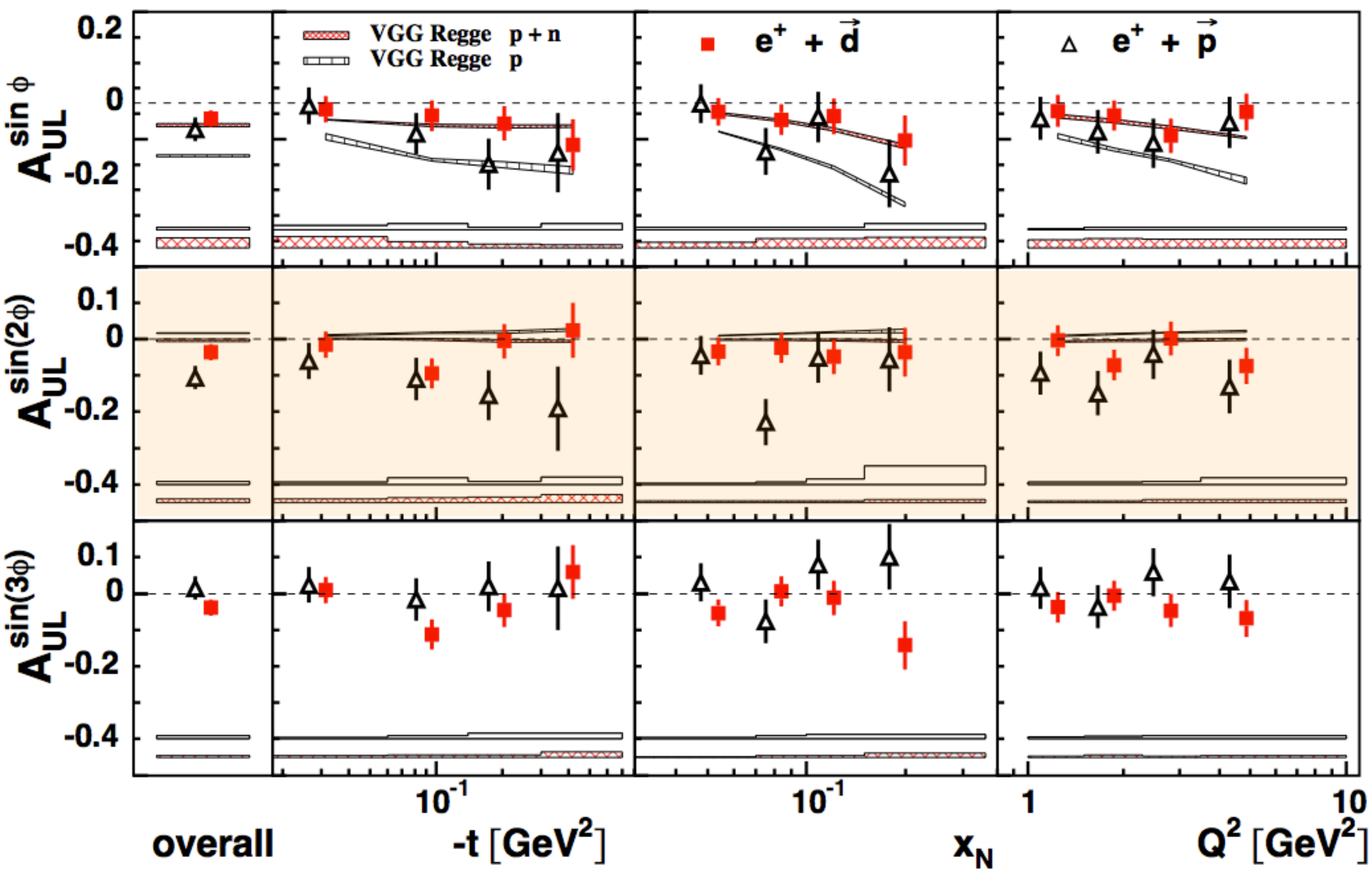


http://www.arxiv.org/abs/0911.0095



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

Target Asymmetries



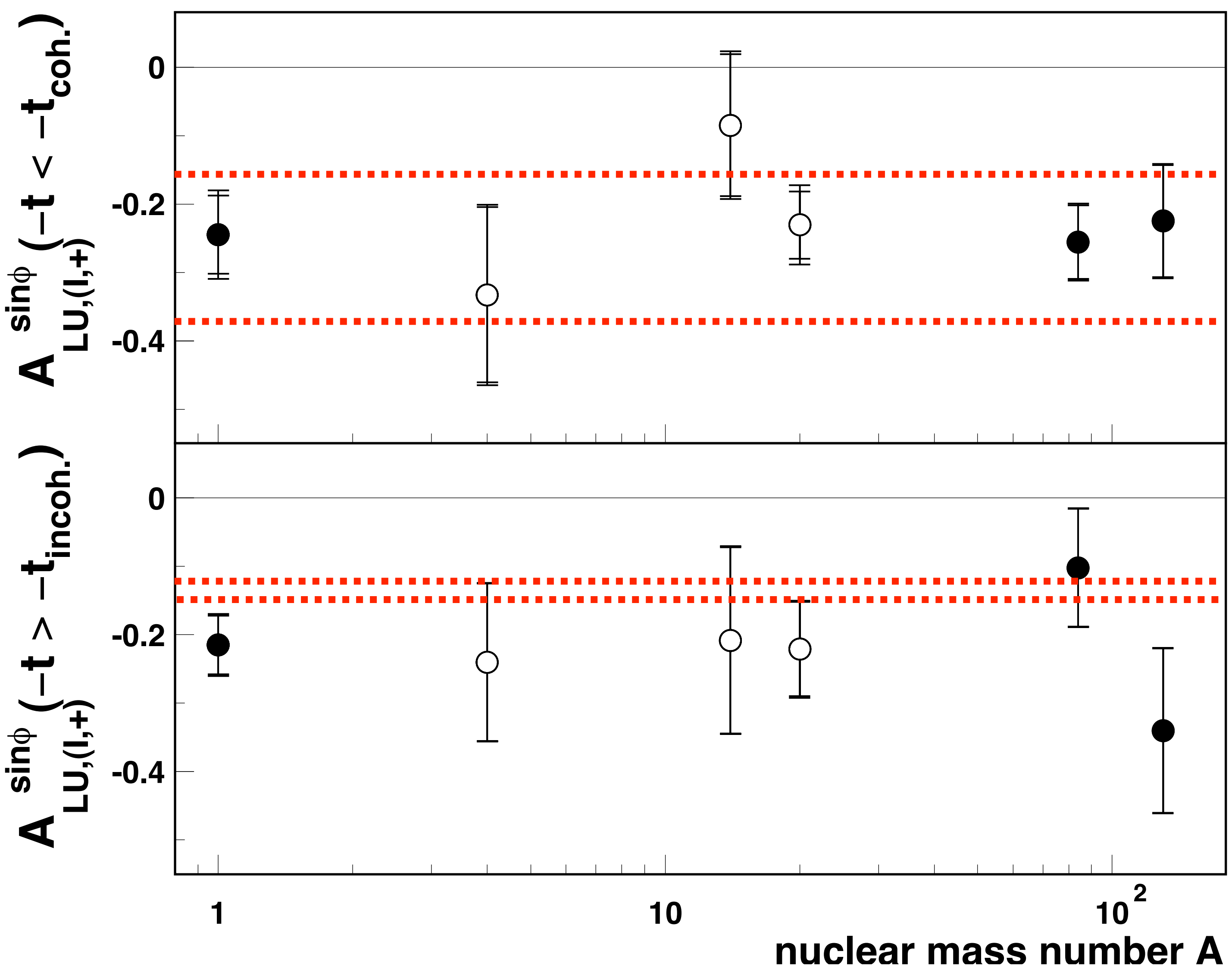
No good idea how to model long. pol. deuterium GPDs. Currently use a proton/ neutron hybrid

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

Will appear in Nucl. Phys. B

Nuclear Mass Dependence

http://arxiv.org/abs/0911.0091 *A. Airapetian et al. Phys. Rev. C 81, 035202 (2010)*



● Interference Term

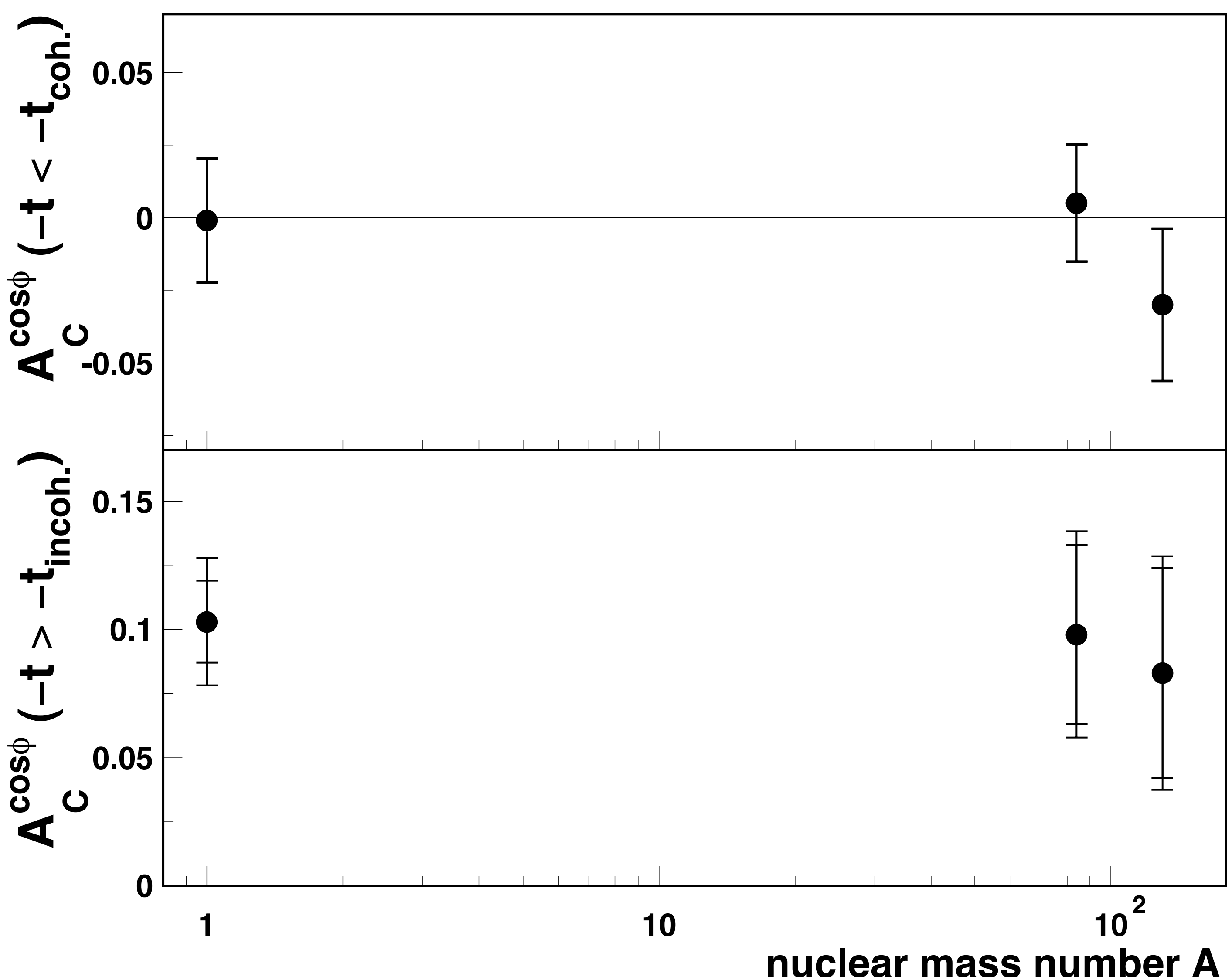
○ Interference + $|DVCS|^2$

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

A. Kirchner and D. Mu¨ller, Eur. Phys. J. C 32 (2003) 374

Nuclear Mass Dependence

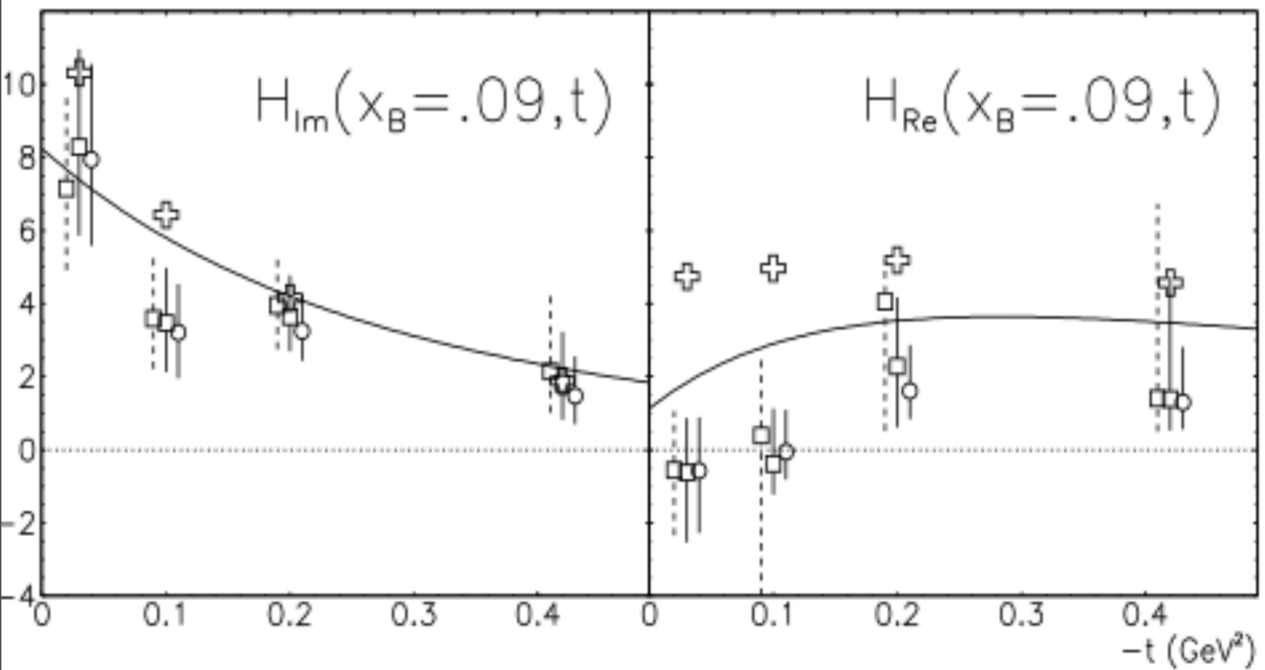
http://arxiv.org/abs/0911.0091 *A. Airapetian et al. Phys. Rev. C 81, 035202 (2010)*



Beam Charge Asymmetries are essentially 0 for coherent scattering

Consistent with the Proton asymmetry for heavier targets

GPD Discovery

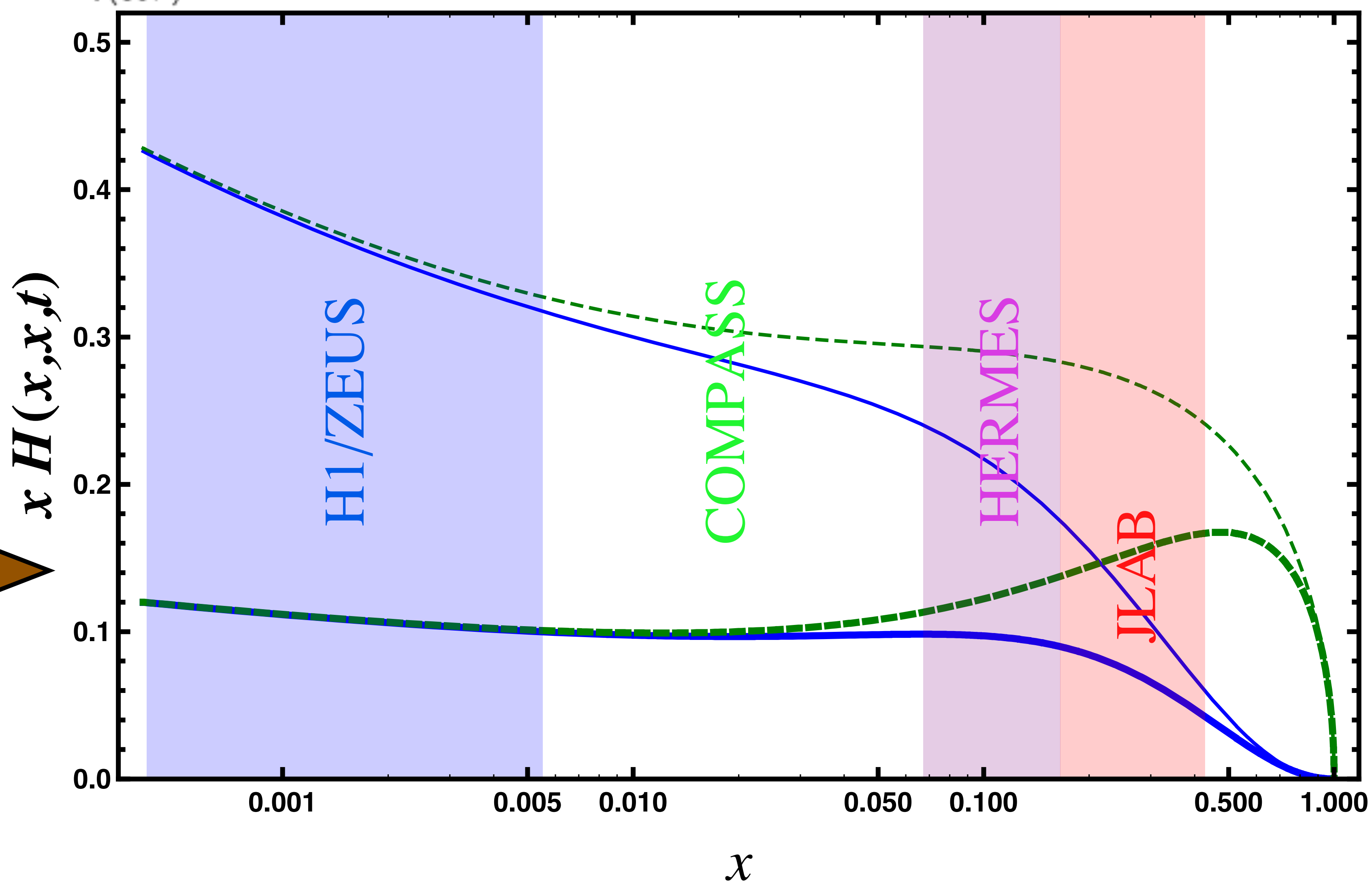


http://arxiv.org/abs/1005.4922

M. Guidal

New CFF Fit Result incorporating A_{UL} moments

Postulate GPDs from first principle models

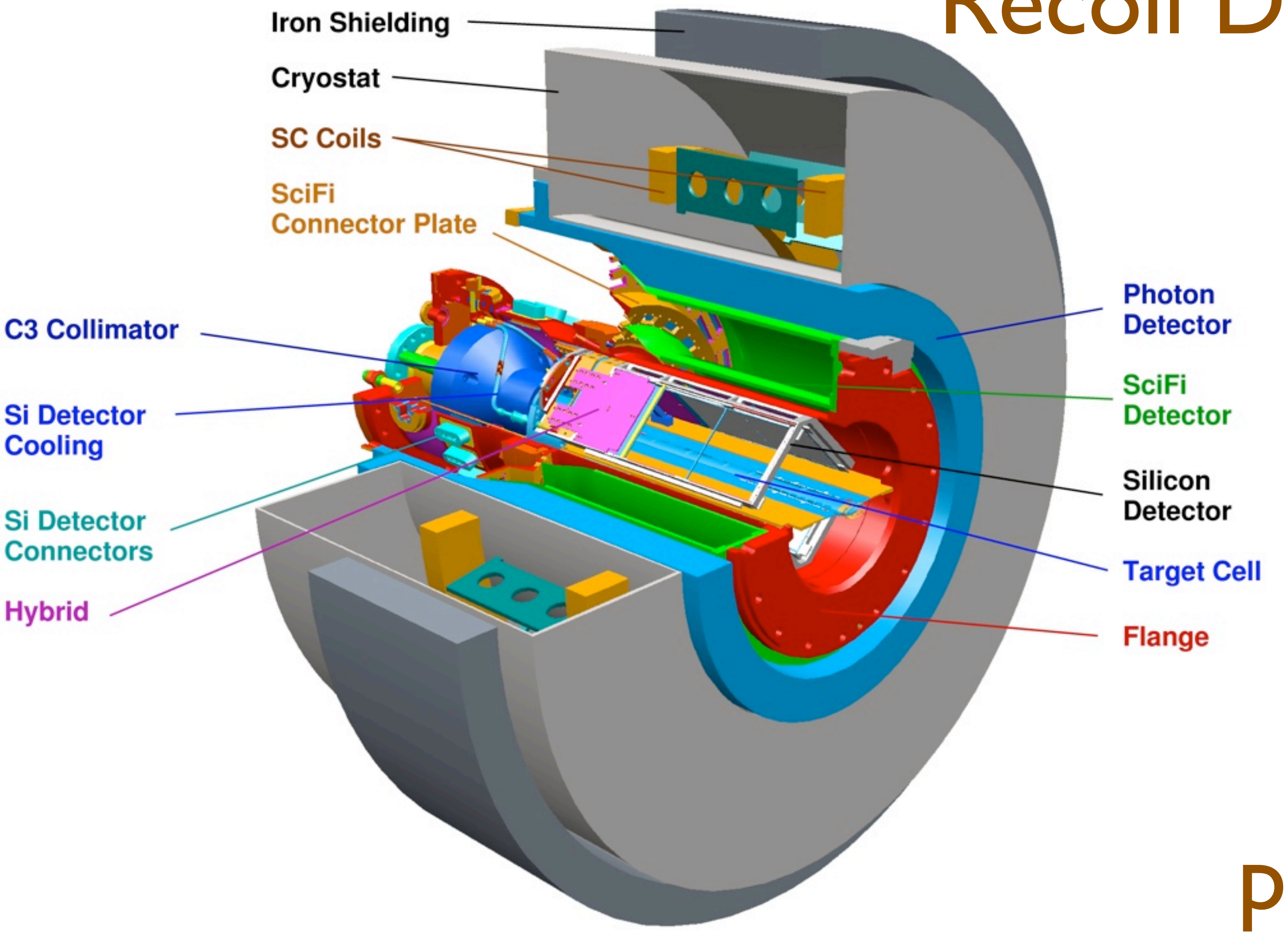


http://arxiv.org/abs/0904.0458

Kumerički and Müller

Nucl. Phys. B841 1 (2010)

Future Data

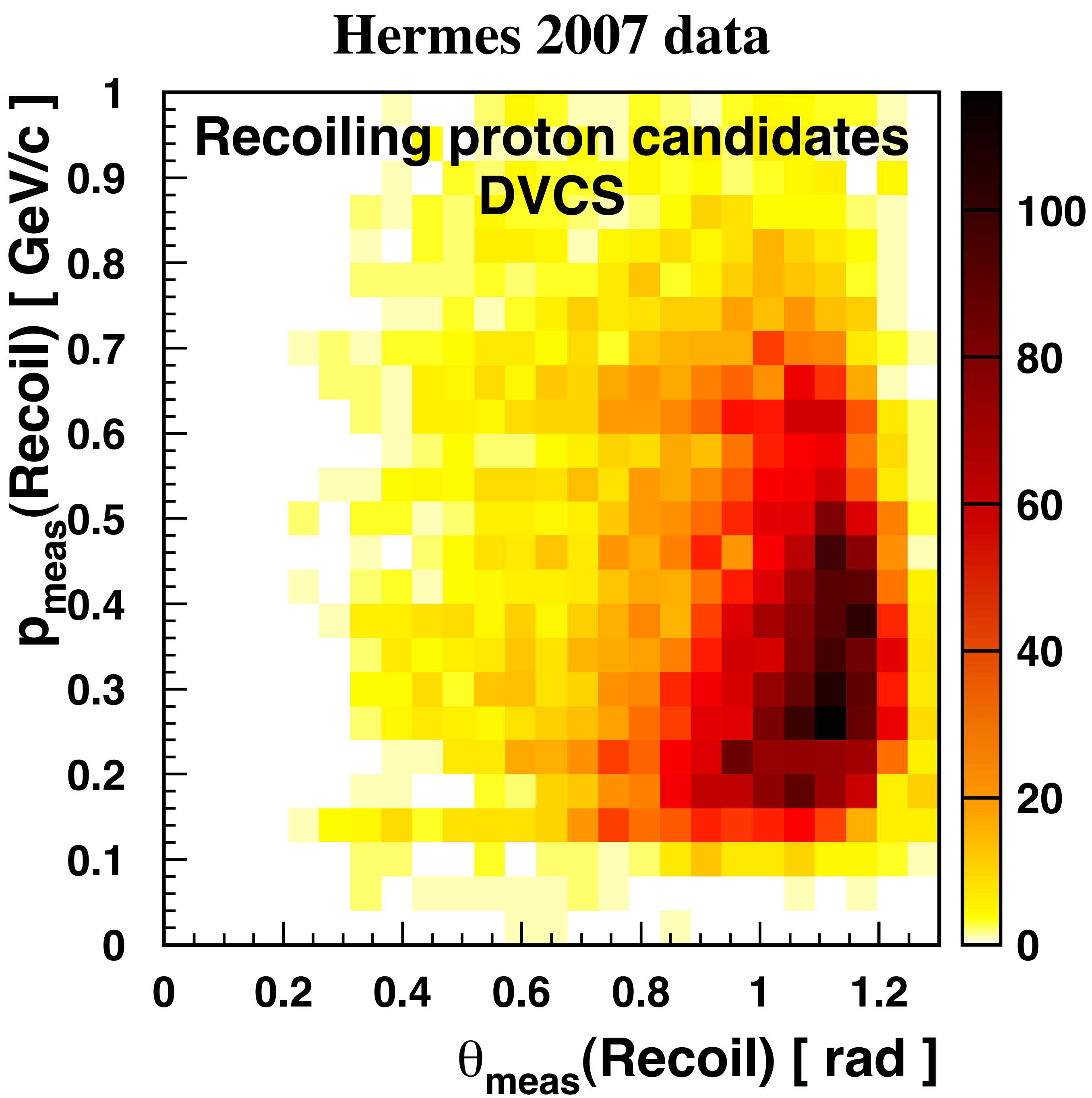


Recoil Detector - True Exclusivity!

Almost pure BH/DVCS signal - background <1%

Potential for measuring other exclusive physics processes - Δ-DVCS, HEMP physics, DVCS on neutron...

Future DVCS Data

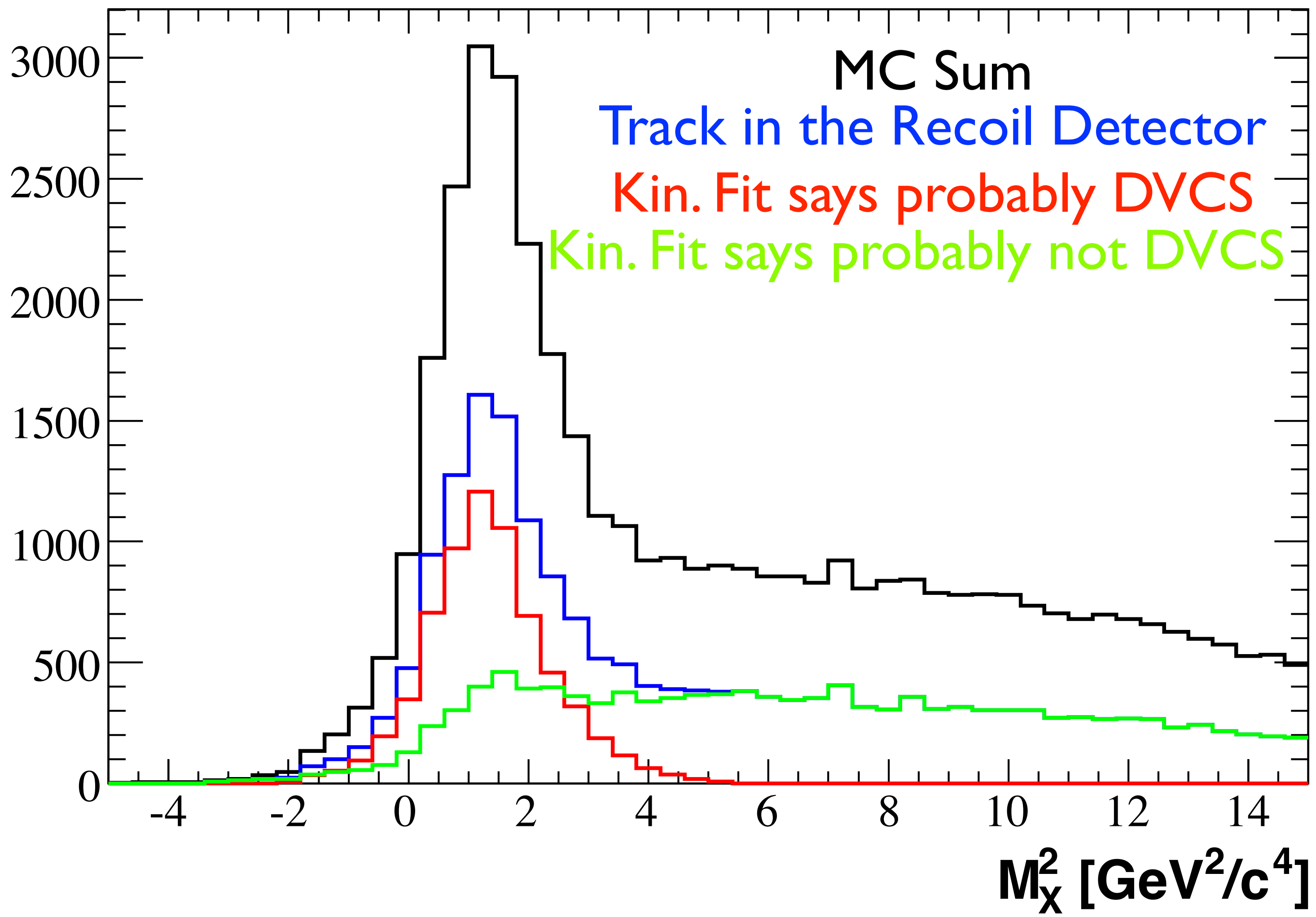


Calibrations finalised

Kinematic Fitting routines implemented

Event selection method finalised - asymmetry extraction techniques to be finalised and systematic studies still to be completed.

Future DVCS Data



Significant improvement in the purity of signal

No hard-and-fast idea on the feasibility of a Δ-DVCS measurement

Expect first publicly-available results in Q2 2011

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 clearly correct idea about how the nuclear medium modifies GPD-dependent behaviour. More data?
- Already, GPDs can be constrained - but there is much left to do!
- Experimental extractions of GPDs and related physical quantities can work in harmony with Lattice QCD.