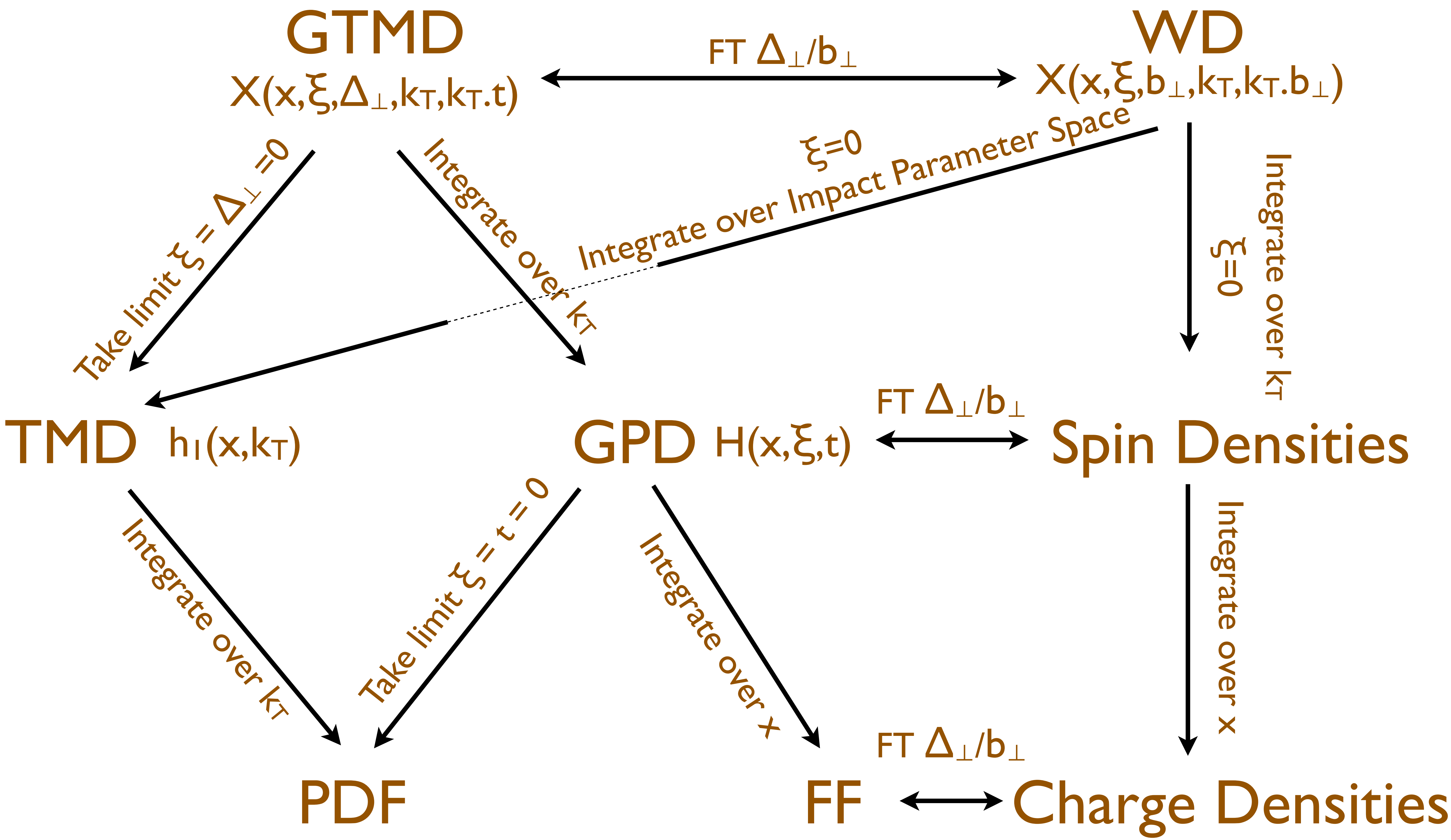
Physics Updates from HERMES

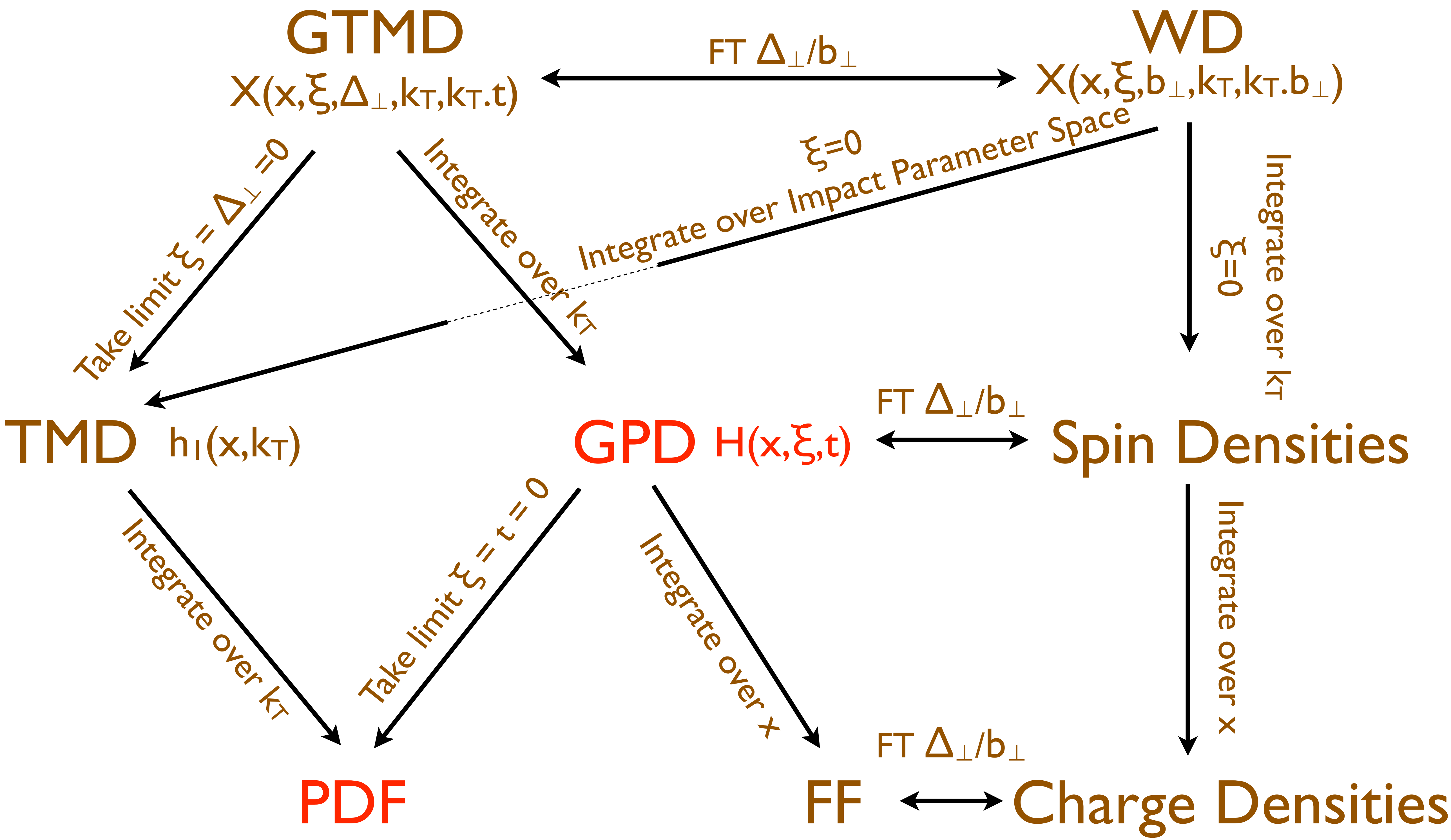
M. MURRAY, UNIVERSITY OF GLASGOW

Diffraction 2012

Distribution Graph



Distribution Graph



PDFs & Inclusive Physics

F_1, F_2 and g_1 all comparatively well-known

New HERMES data on A_2 and g_2 available - also measured at CERN and SLAC

$$g_2(x, Q^2) = g_s^{WW}(x, Q^2) + \overline{g}_2(x, Q^2)$$

A. Airapetian et al, Eur. Phys. J. C 72 (2012) 1921

PDFs & Inclusive Physics

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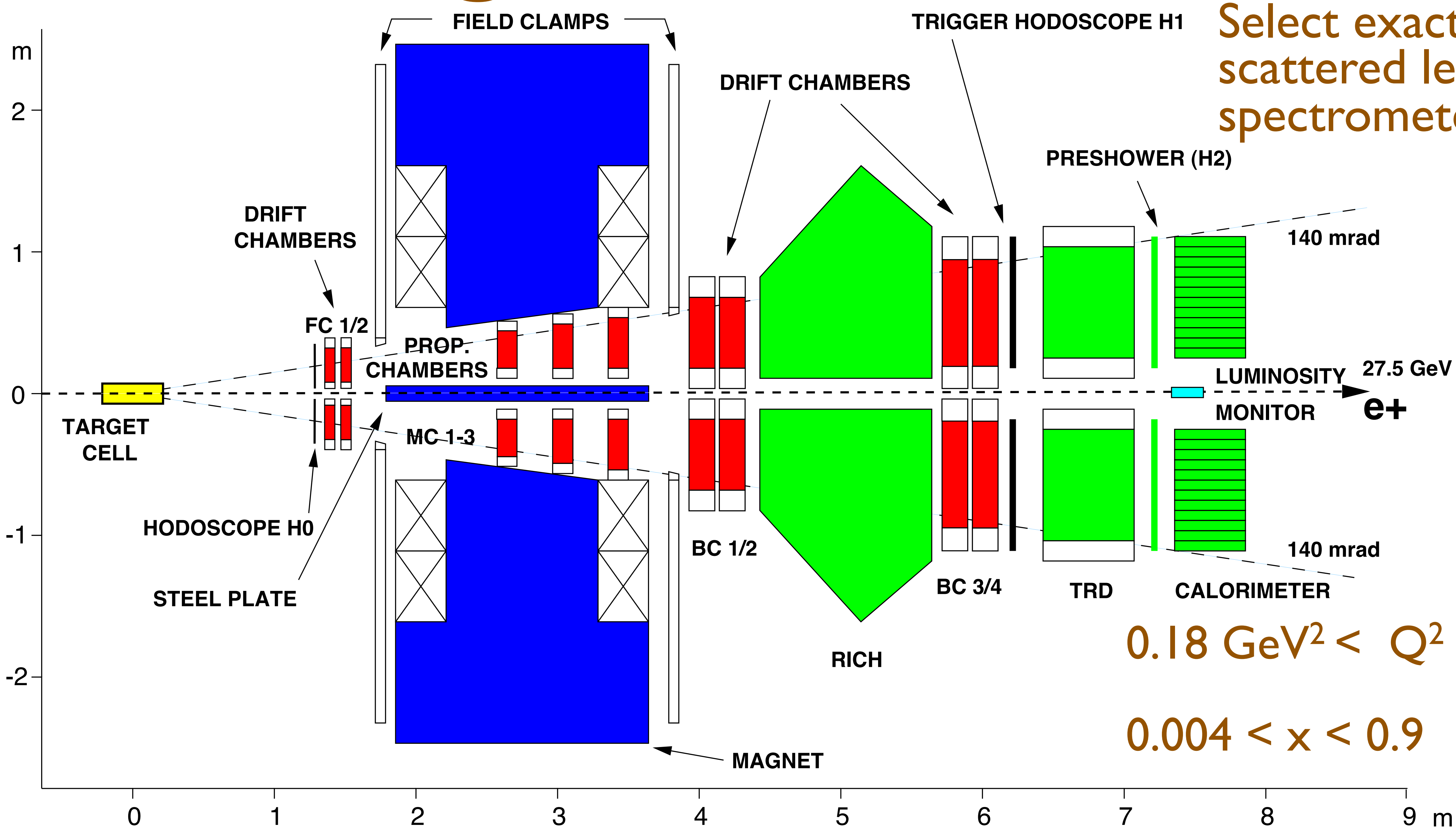
$$g_2(x, Q^2) = g_s^{WW}(x, Q^2) + \overline{g}_2(x, Q^2)$$

"pure" twist-3; related to quark-gluon correlations

A. Airapetian et al, Eur. Phys. J. C 72 (2012) 1921

g_2 @ HERMES



Select exactly one scattered lepton in the spectrometer

$0.18\ \text{GeV}^2 < Q^2 < 20\ \text{GeV}^2$

$0.004 < x < 0.9$

$$A_{LT}(x,Q^2,\phi,h_\ell) = h_\ell \frac{N^{h_\ell\Uparrow}(x,Q^2,\phi)\mathcal{L}^{h_\ell\Downarrow} - N^{h_\ell\Downarrow}(x,Q^2,\phi)\mathcal{L}^{h_\ell\Uparrow}}{N^{h_\ell\Uparrow}(x,Q^2,\phi)\mathcal{L}_p^{h_\ell\Downarrow} + N^{h_\ell\Downarrow}(x,Q^2,\phi)\mathcal{L}_p^{h_\ell\Uparrow}}$$

A_2, g_2 Extraction Procedure

Unfold in bins of (x, Q^2, ϕ)

$$A_{LT}(x,Q^2,\phi,h_\ell) = h_\ell \frac{N^{h_\ell \Uparrow}(x,Q^2,\phi)\mathcal{L}^{h_\ell \Downarrow} - N^{h_\ell \Downarrow}(x,Q^2,\phi)\mathcal{L}^{h_\ell \Uparrow}}{N^{h_\ell \Uparrow}(x,Q^2,\phi)\mathcal{L}_p^{h_\ell \Downarrow} + N^{h_\ell \Downarrow}(x,Q^2,\phi)\mathcal{L}_p^{h_\ell \Uparrow}}$$

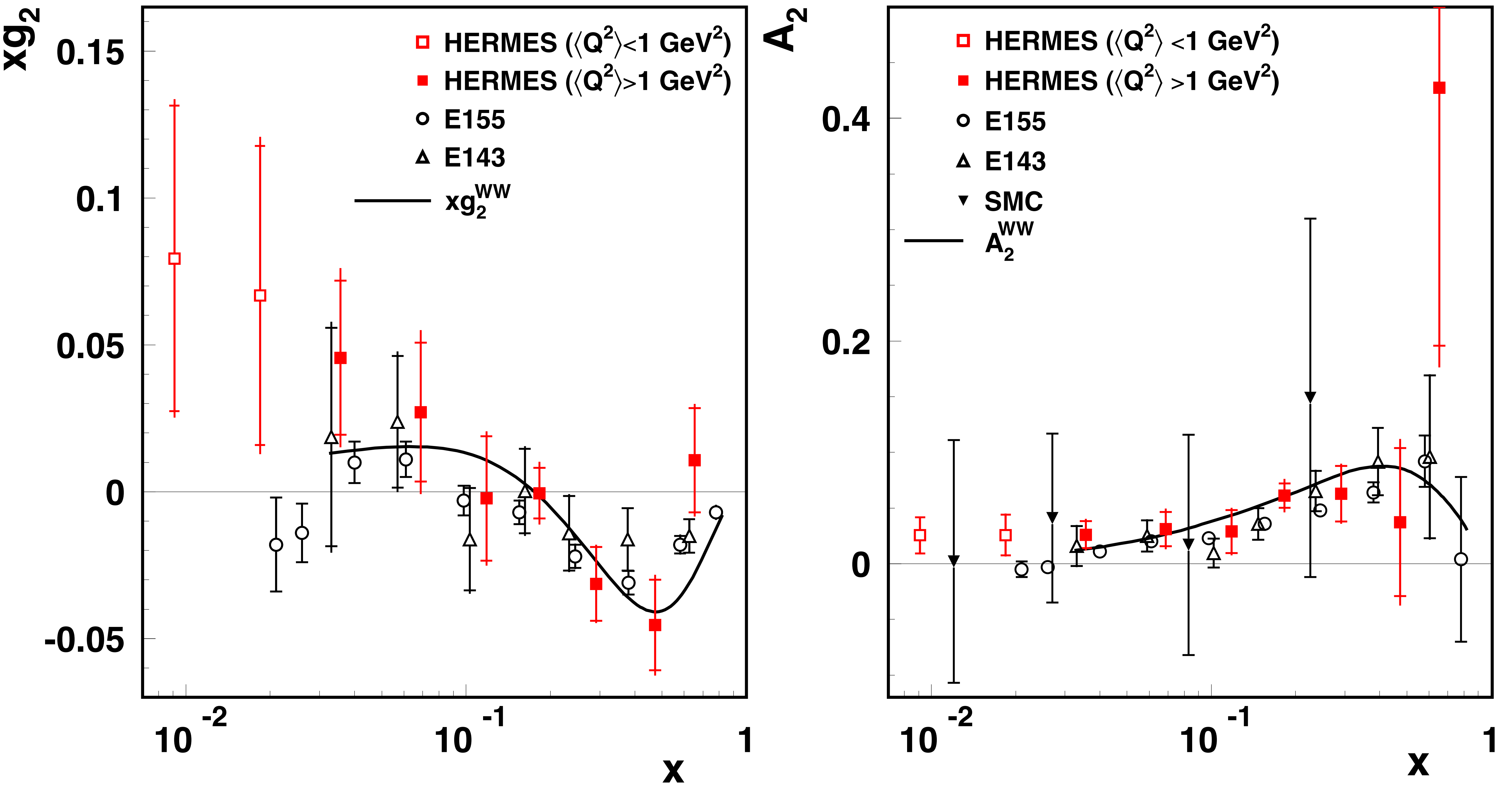
Fit result with functional form:

$$A_{LT}(x,Q^2,\phi,h_\ell) = -A_T(x,Q^2)\cos\phi$$

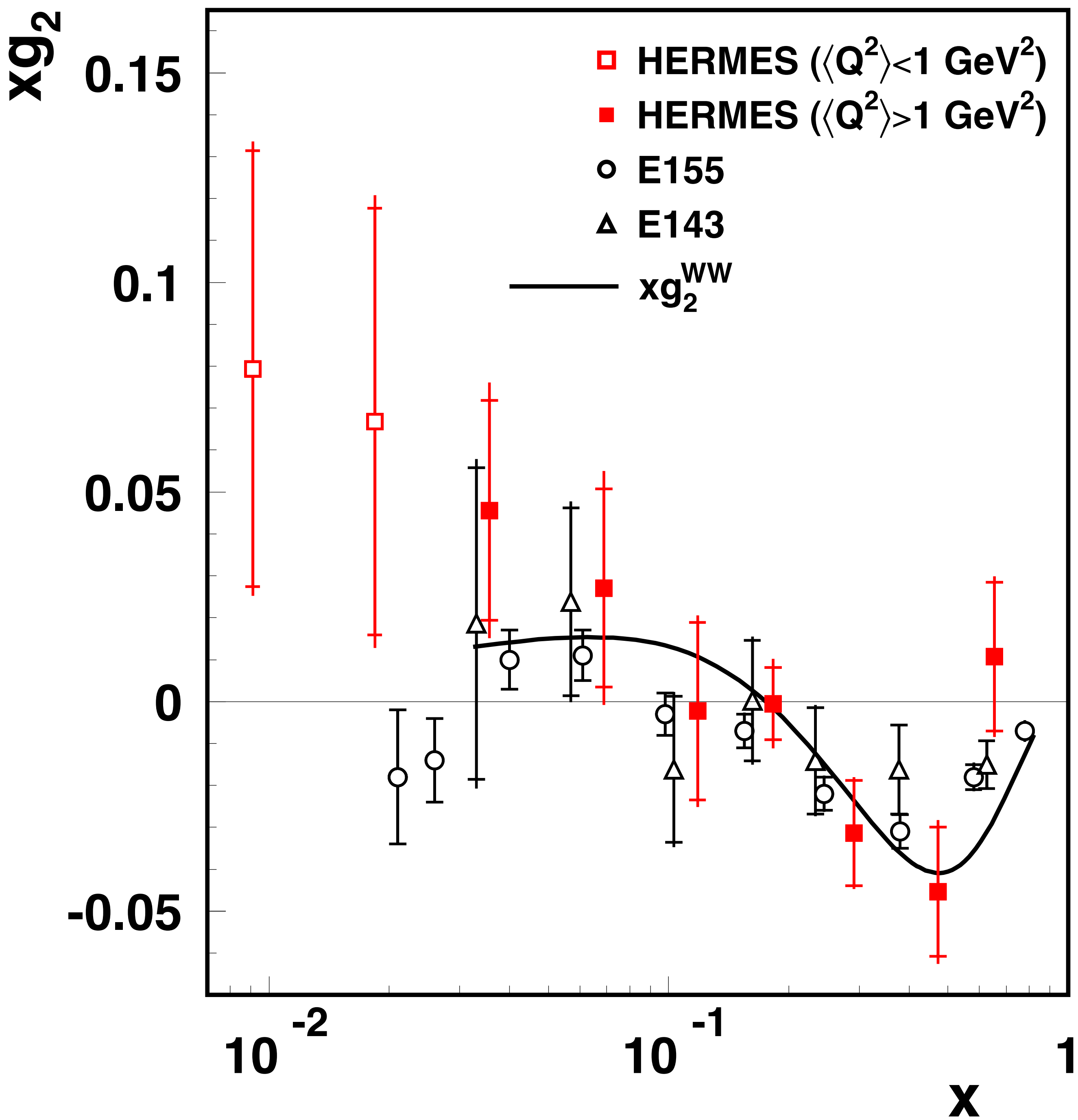
Calculate g_2 and A_2 using:

$$g_2 = \frac{F_1}{\gamma(1+\gamma\xi)}\left(\frac{A_T}{d} - (\gamma-\xi)\frac{g_1}{F_1}\right) \qquad A_2 = \frac{1}{1+\gamma\xi}\left(\frac{A_T}{d} + \xi(1+\gamma^2)\frac{g_1}{F_1}\right)$$

A_2, g_2 Extraction Procedure



A_2, g_2 Extraction Procedure



Results are separated into <1 GeV^2 and >1GeV^2 series

Compared to SLAC E143 and E155 experiments

Also shown against a theoretical prediction from

[E155 Coll., P.L. Anthony et al., Phys. Lett. B 493, 19(2000).]

Consistent with CB sum-rule

A_2, g_2 Extraction Procedure

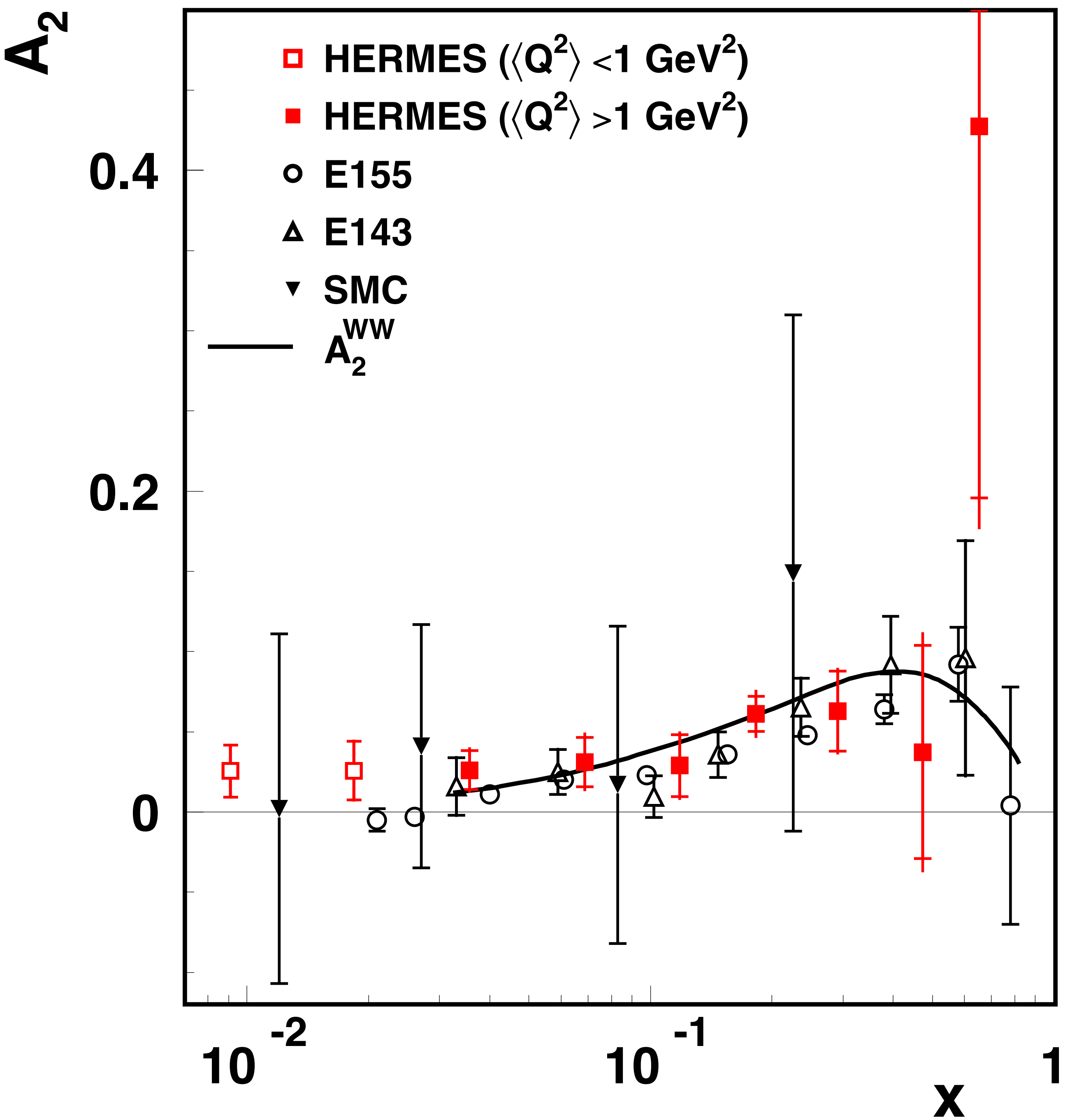
Results are separated into <1 GeV^2 and >1GeV^2 series

Compared to SLAC E143 and E155 experiments and SMC

Also shown against a theoretical prediction from

[E155 Coll., P.L. Anthony et al., Phys. Lett. B 493, 19(2000).]

Statistical precision not enough to determine non-WW behaviour



g_2, A_2 Conclusions

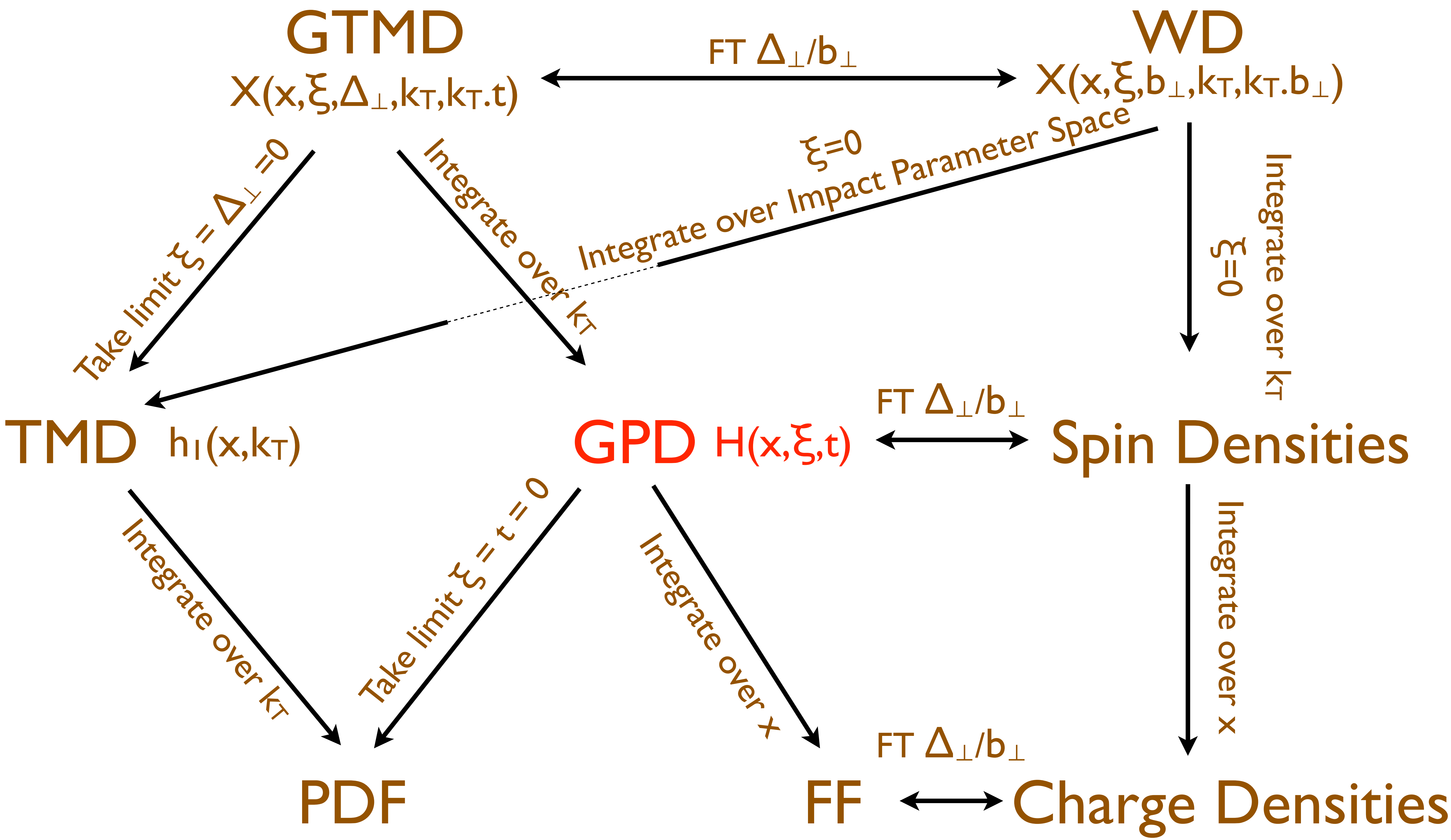
A_2 and g_2 have been extracted at HERMES from the A_{LT} inclusive asymmetry.

The results confirm the Burkhardt-Cottingham sum-rule for g_2 and are consistent with SLAC and CERN data (A_2 only).

Sit alongside measurements of F_2 and g_1 as contributions from HERMES to inclusive structure functions

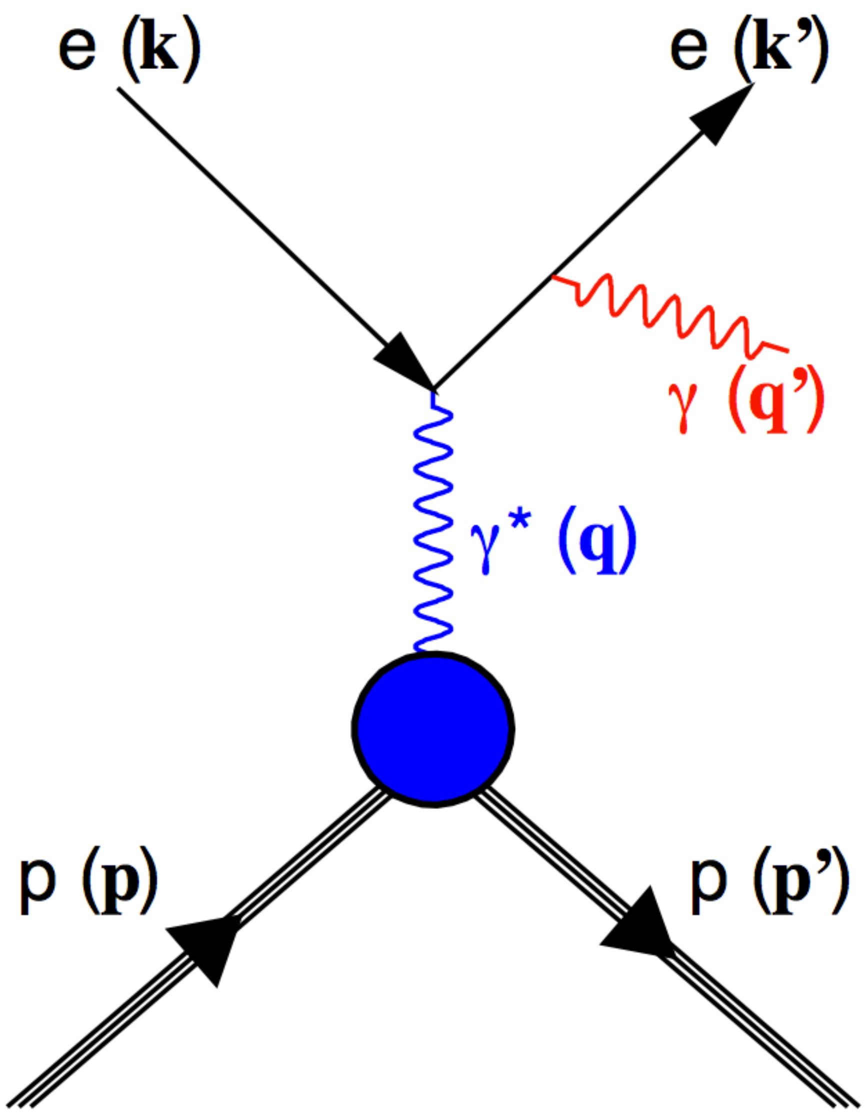
F_2: A. Airapetian et al, JHEP 05 (2011) 126
g_1: A. Airapetian et al, Phys. Rev. D 75 (2007) 012007

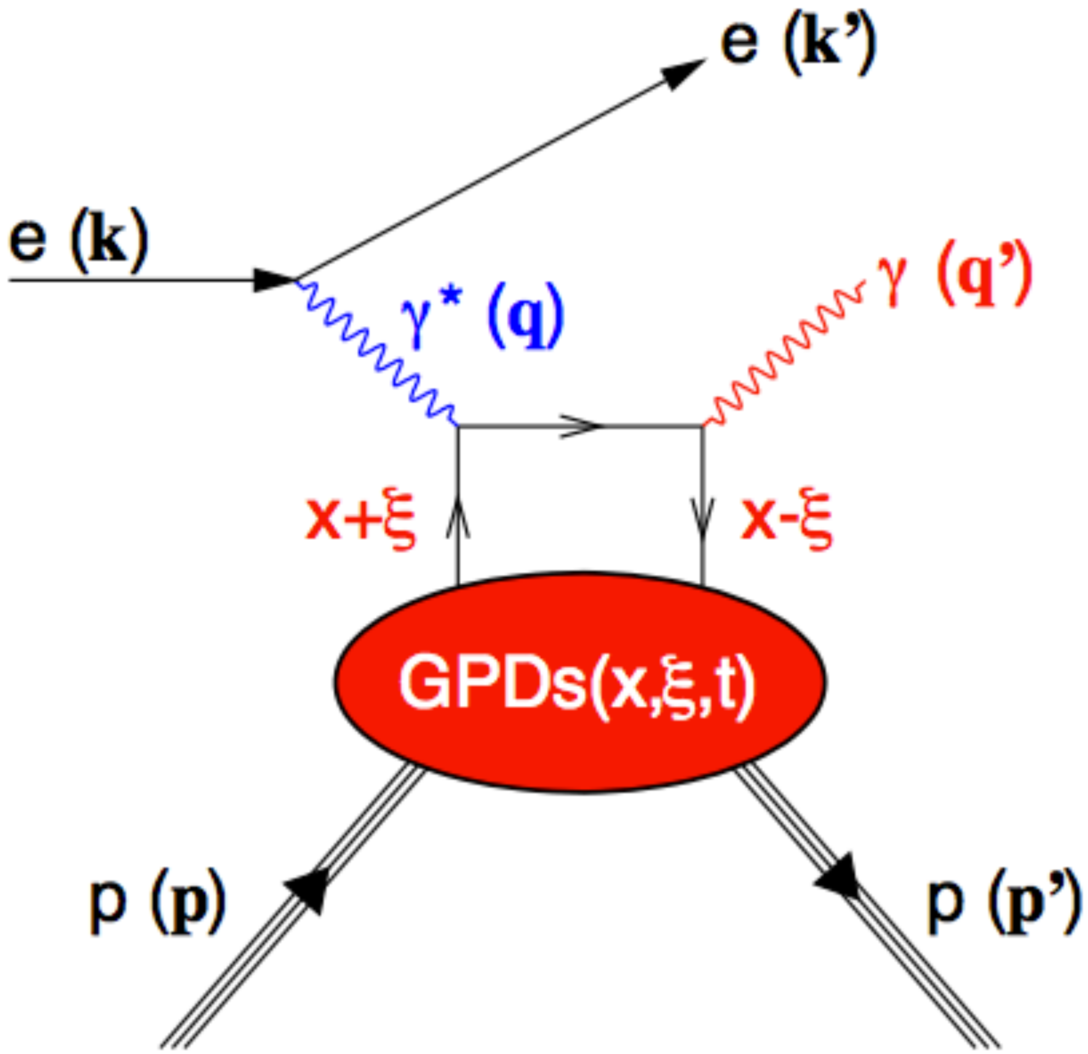
Distribution Graph



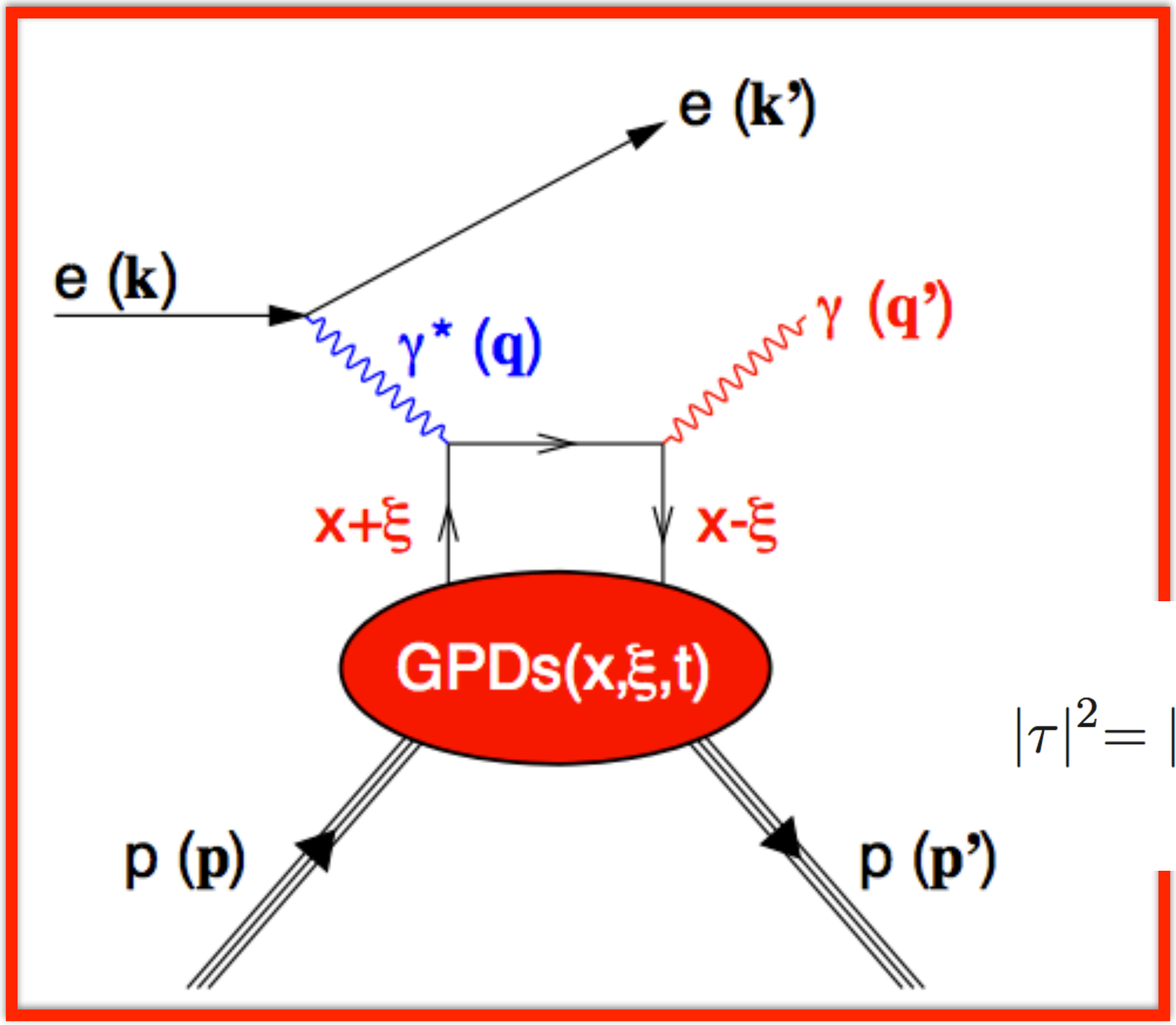
Deeply Virtual Compton Scattering

$$\boxed{e\,p \rightarrow e\,p\,\gamma}$$





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

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

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

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

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

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

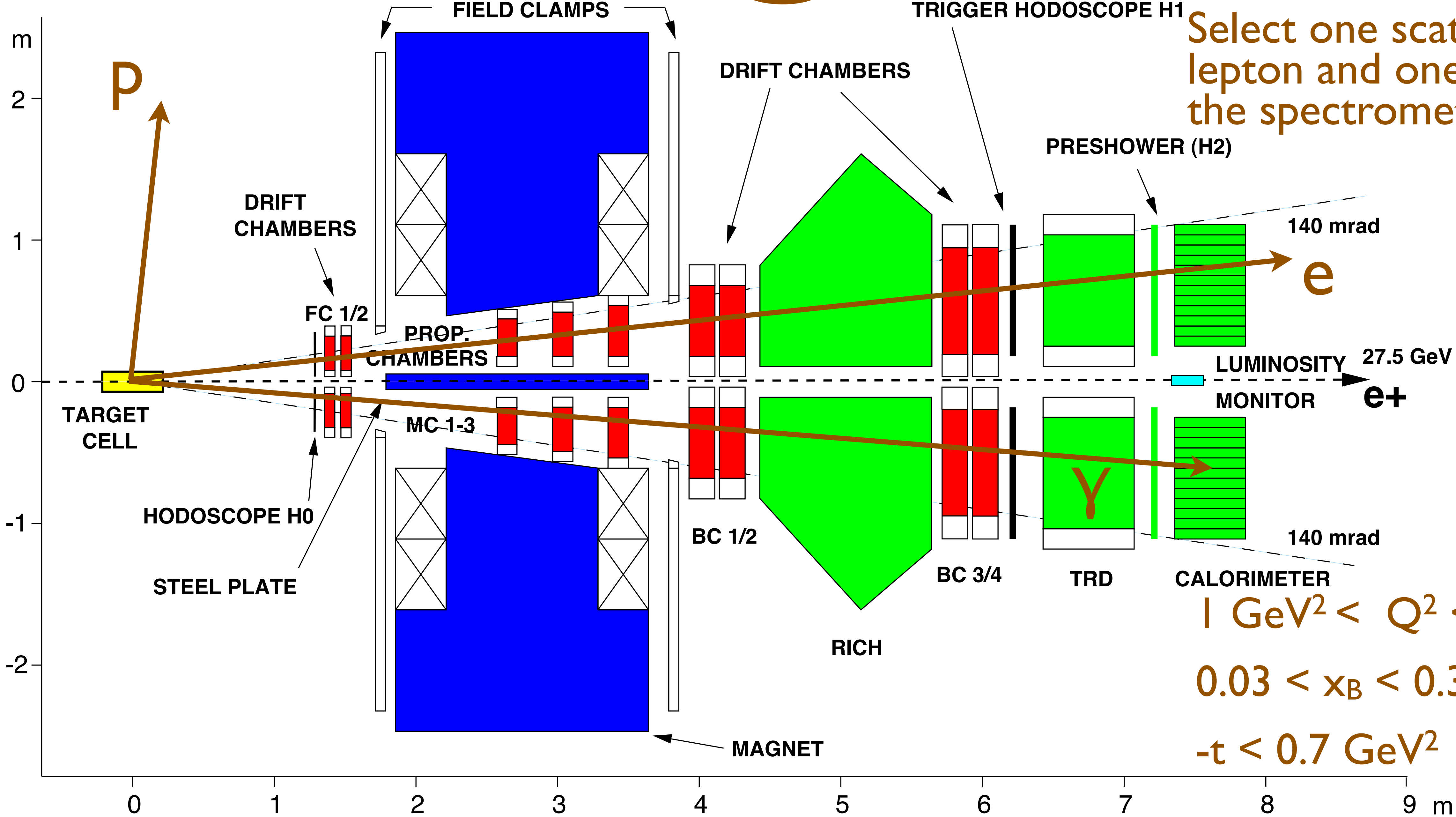
$$\mathcal{A}_{\mathrm{LT}}^{\mathrm{BH+DVCS}}(\phi,\phi_S) \equiv \frac{1}{8d\sigma_{\mathrm{UU}}}\left[(d\overrightarrow{\sigma}^{+\uparrow} - d\overrightarrow{\sigma}^{+\downarrow} - d\overleftarrow{\sigma}^{+\uparrow} + d\overleftarrow{\sigma}^{+\downarrow}) + (d\overrightarrow{\sigma}^{-\uparrow}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

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

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

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

DVCS @ HERMES



Select one scattered lepton and one photon in the spectrometer

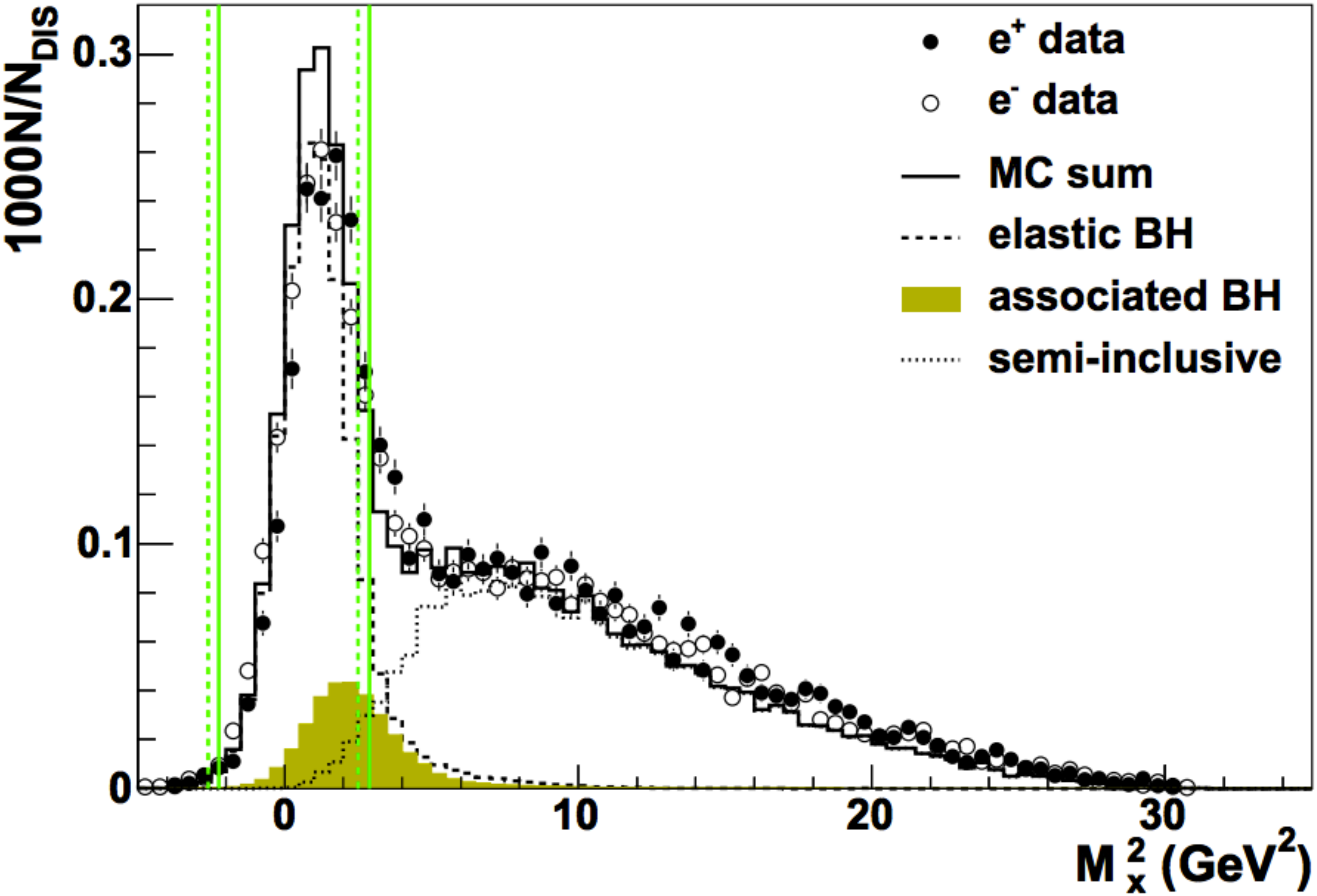
$1\ \mathrm{GeV}^2 < Q^2 < 10\ \mathrm{GeV}^2$

$0.03 < x_B < 0.35$

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

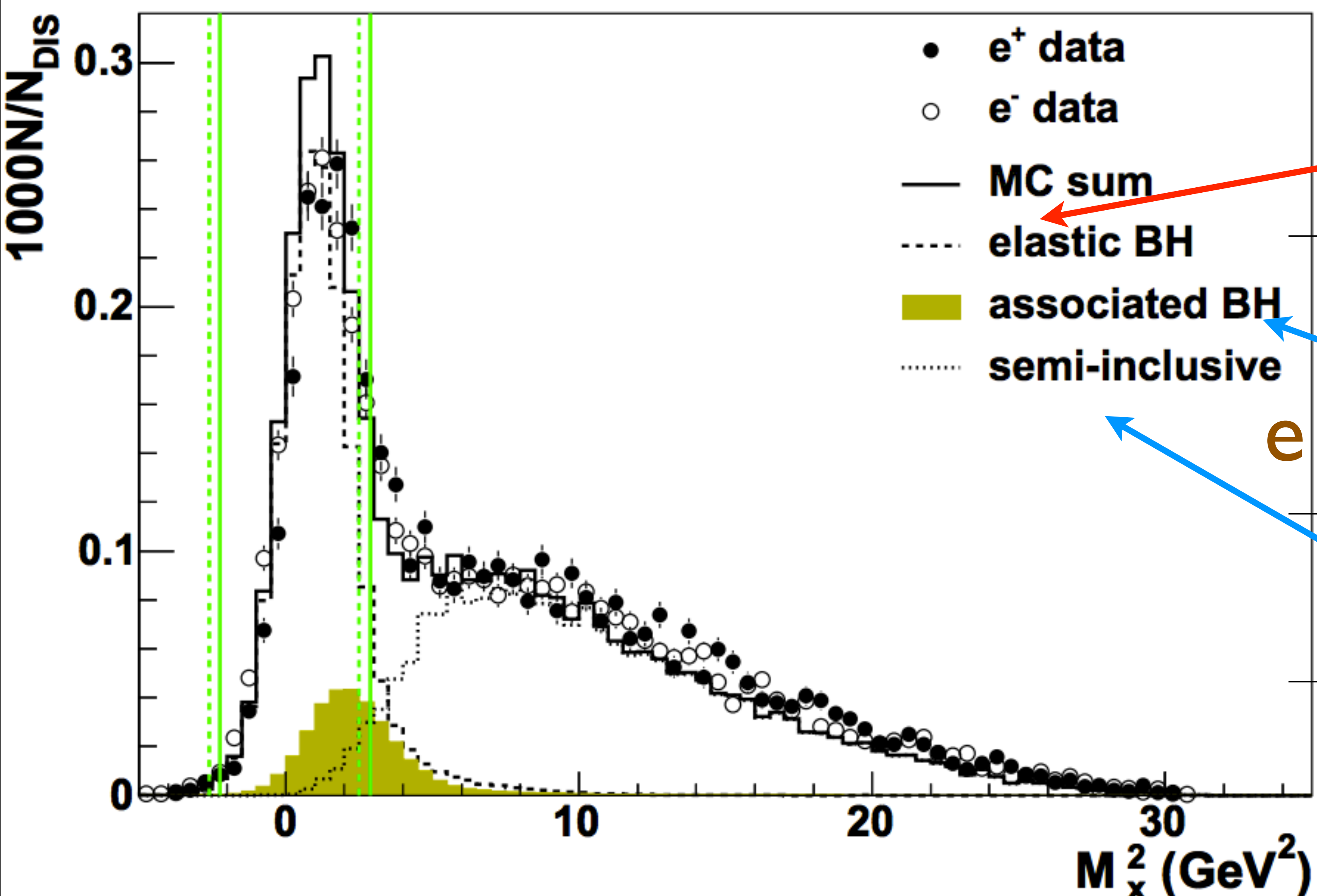
$\langle Q^2 \rangle \cong 2.4\ \mathrm{GeV}^2$ $\langle x_B \rangle \cong 0.1$ $\langle -t \rangle \cong 0.1\ \mathrm{GeV}^2$

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

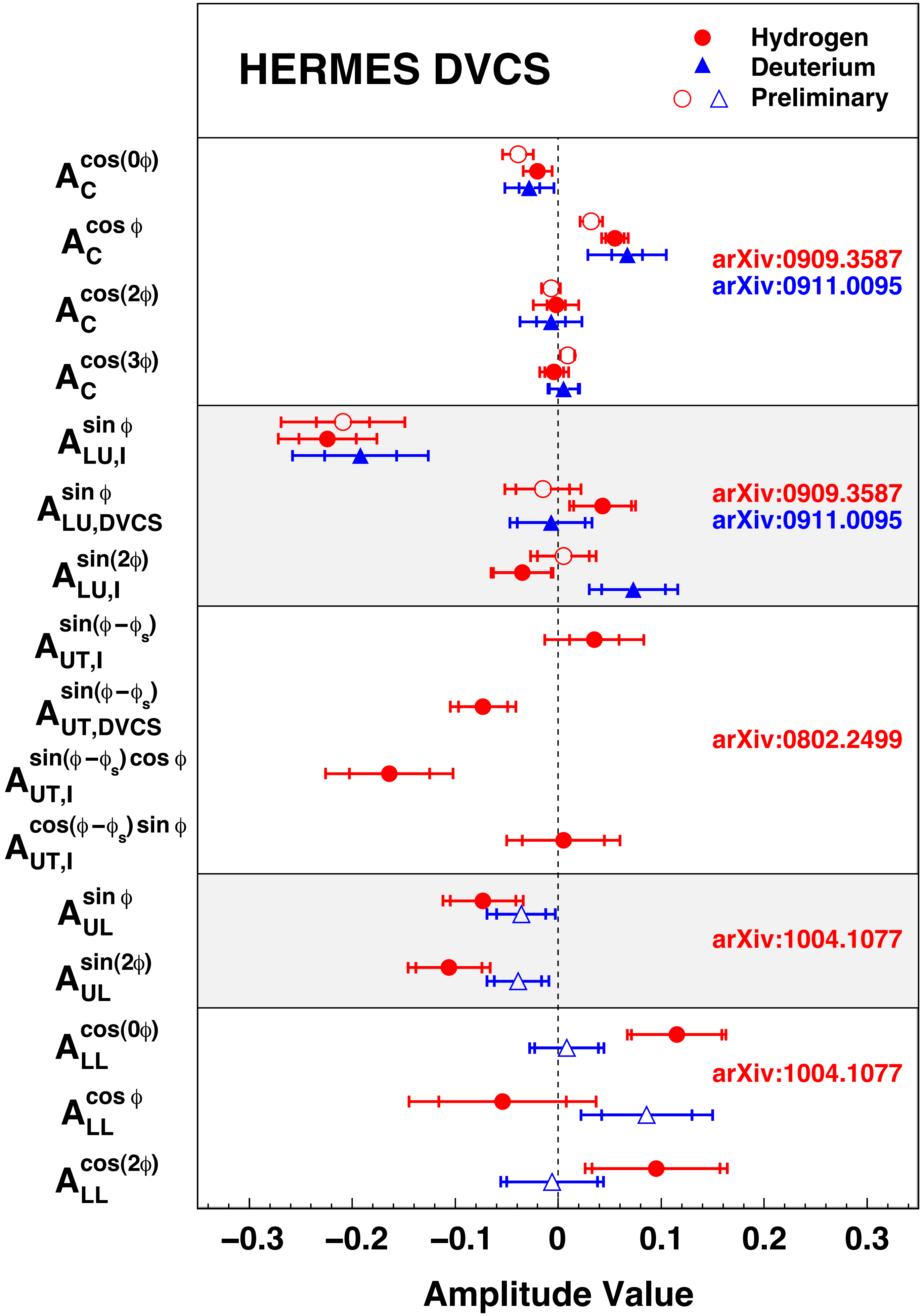
BH from Δ, e.g

e Δ → e γ Δ → eγp π^0

e p → e X γ

e p → e p π^0

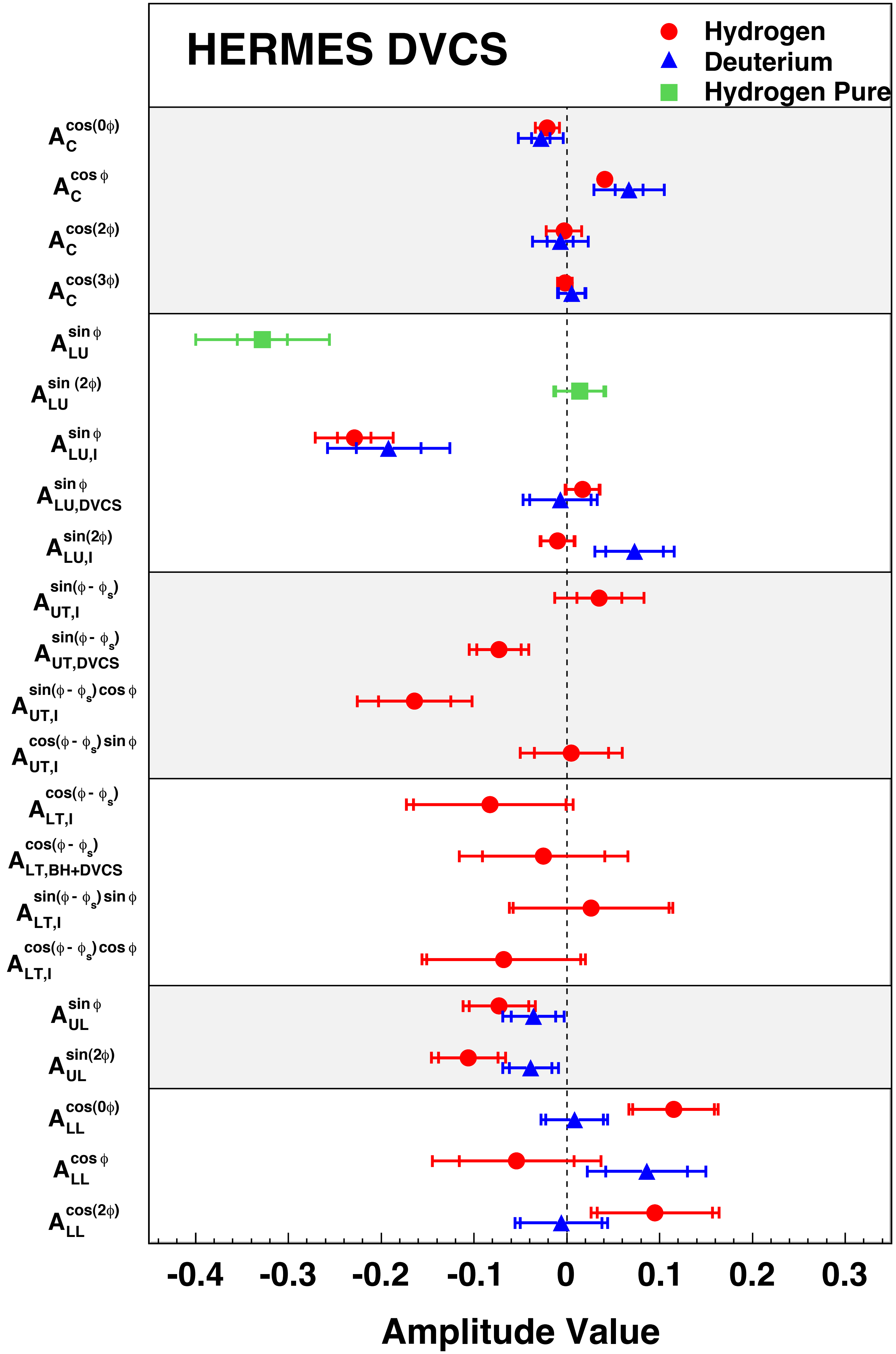
DVCS @



HERMES 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 @

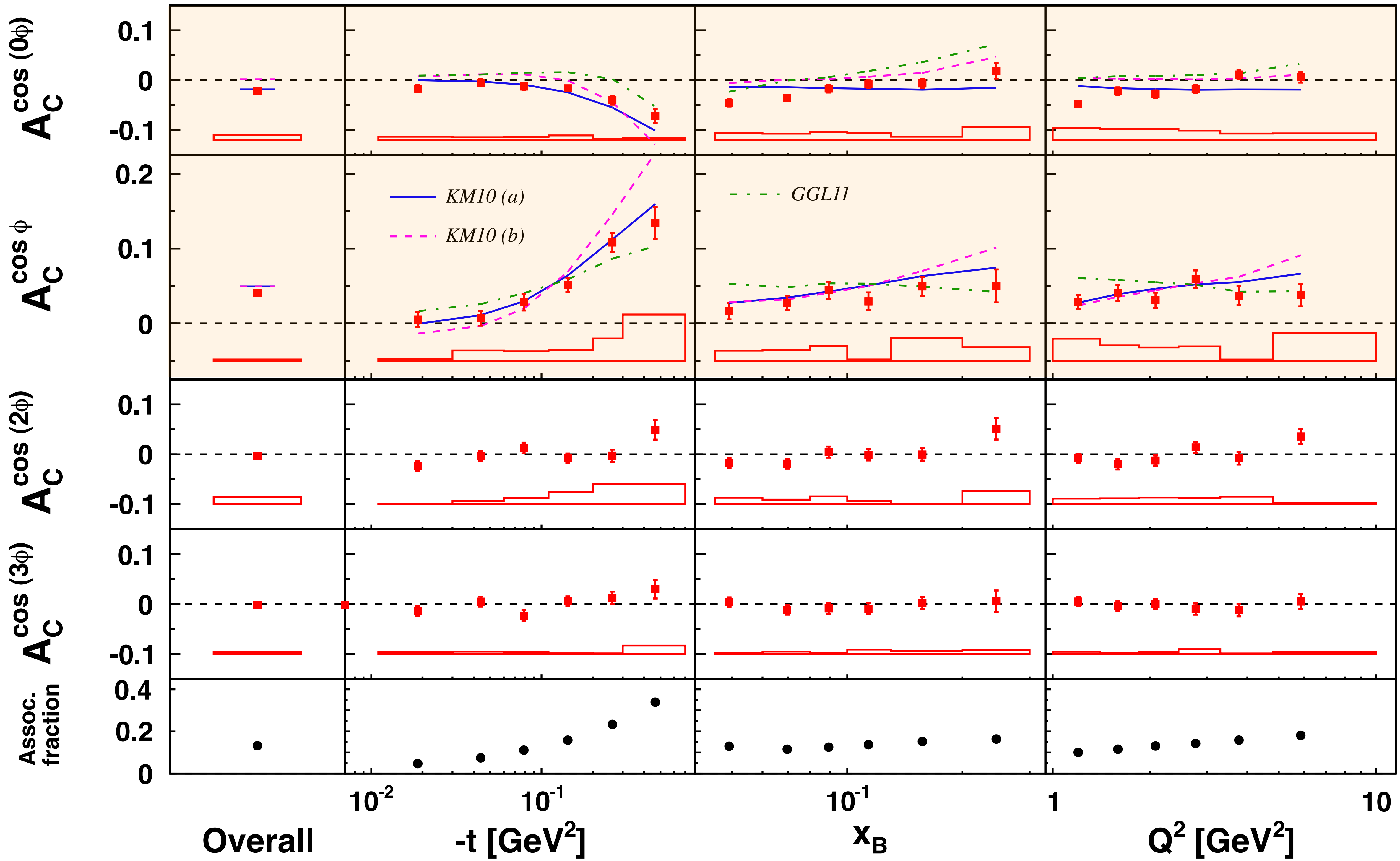


HERMES DVCS
Hydrogen
Deuterium
Hydrogen Pure
$A_{C}^{\cos(0\phi)}$
$A_{C}^{\cos\phi}$
$A_{C}^{\cos(2\phi)}$
$A_{C}^{\cos(3\phi)}$
$A_{LU}^{\sin\phi}$
$A_{LU}^{\sin(2\phi)}$
$A_{LU,I}^{\sin\phi}$
$A_{LU,DVCS}^{\sin\phi}$
$A_{LU,I}^{\sin(2\phi)}$
$A_{UT,I}^{\sin(\phi-\phi_s)}$
$A_{UT,DVCS}^{\sin(\phi-\phi_s)}$
$A_{UT,I}^{\sin(\phi-\phi_s)\cos\phi}$
$A_{UT,I}^{\cos(\phi-\phi_s)\sin\phi}$
$A_{LT,I}^{\cos(\phi-\phi_s)}$
$A_{LT,BH+DVCS}^{\cos(\phi-\phi_s)}$
$A_{LT,I}^{\sin(\phi-\phi_s)\sin\phi}$
$A_{LT,I}^{\cos(\phi-\phi_s)\cos\phi}$
$A_{UL}^{\sin\phi}$
$A_{UL}^{\sin(2\phi)}$
$A_{LL}^{\cos(0\phi)}$
$A_{LL}^{\cos\phi}$
$A_{LL}^{\cos(2\phi)}$
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
Amplitude Value

HERMES

Beam-Charge Asymmetries

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



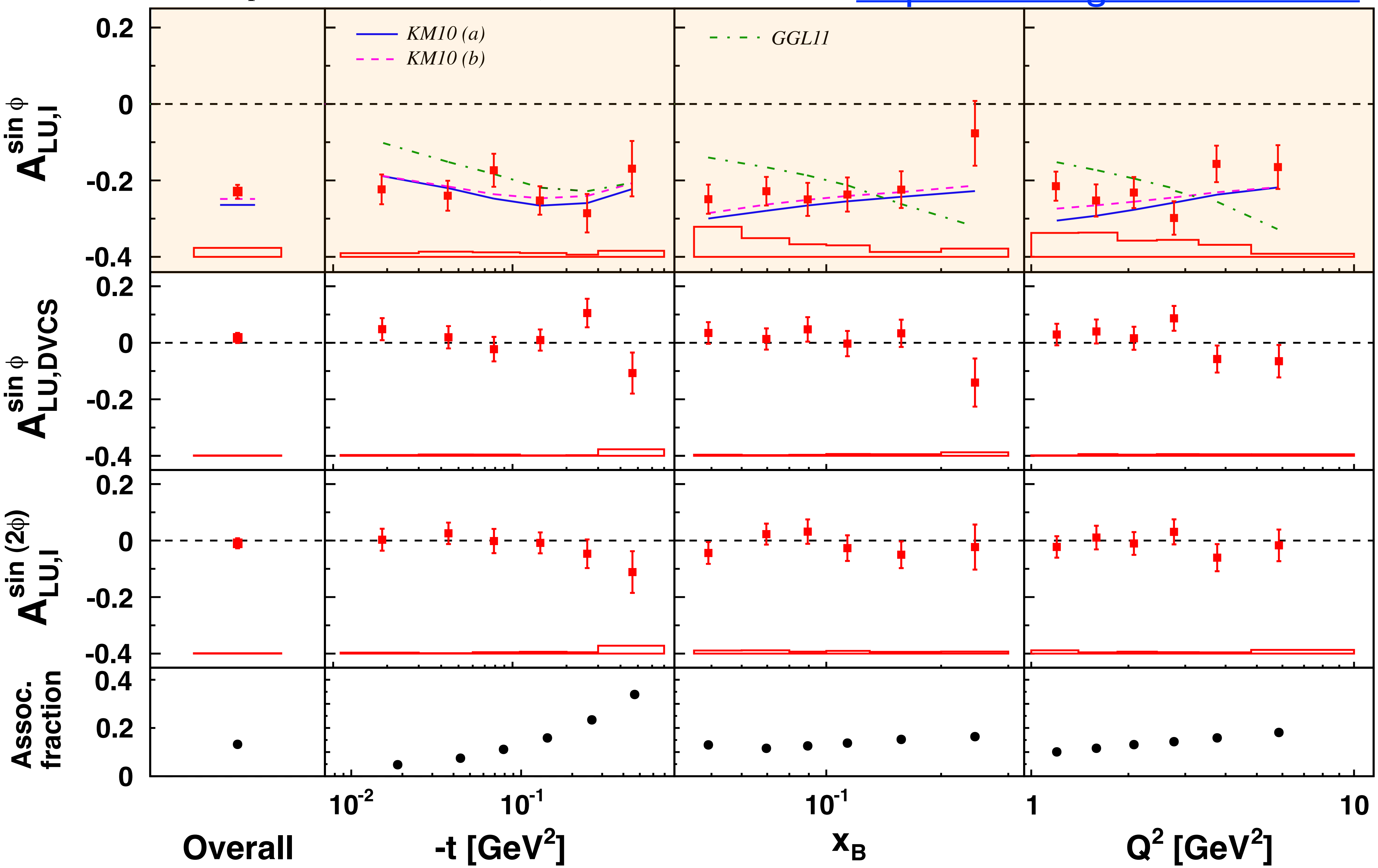
Beam Charge Asymmetries access Re($\mathcal{H}$)

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

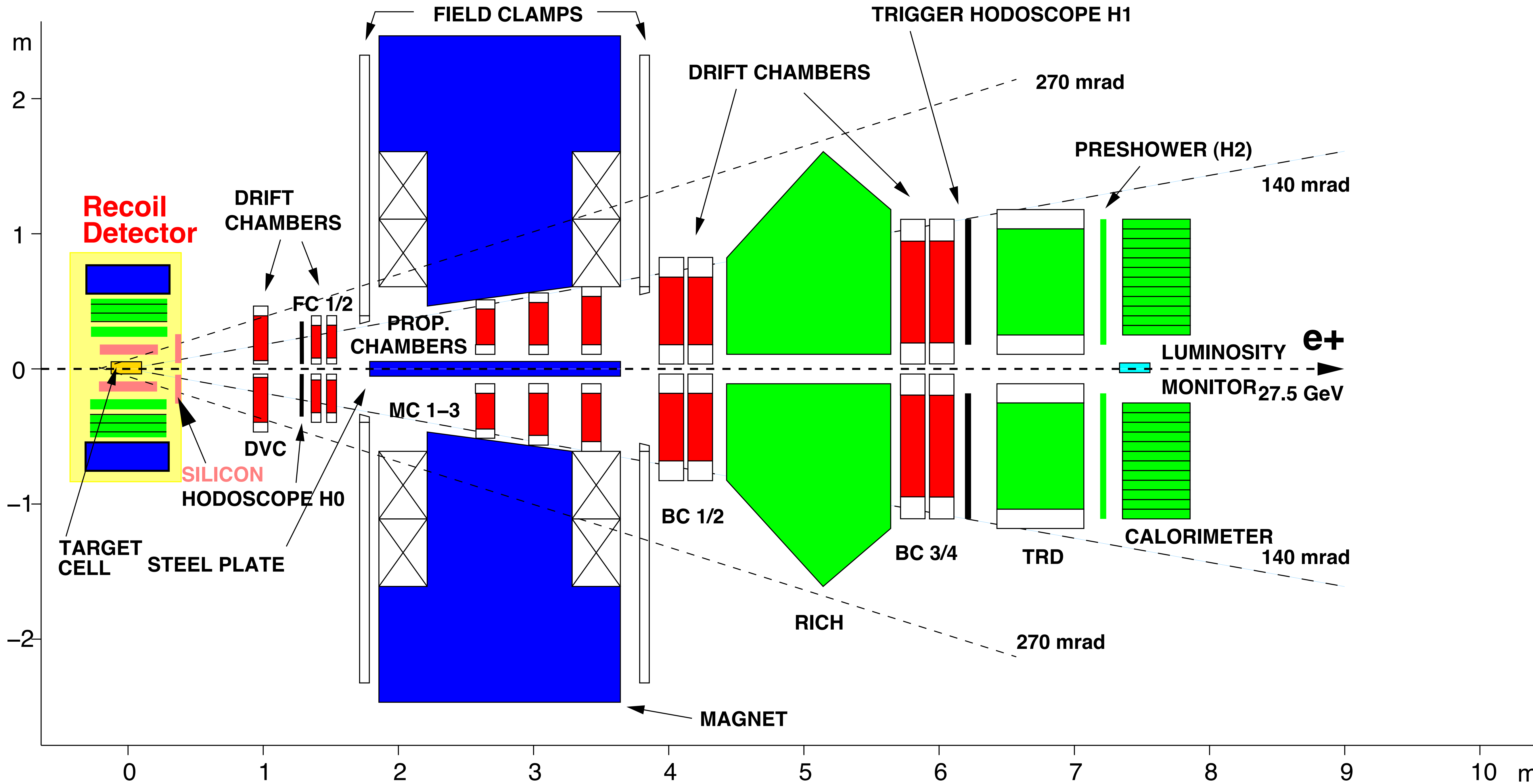
Beam-Spin Asymmetries

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



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

DVCS @ HERMES

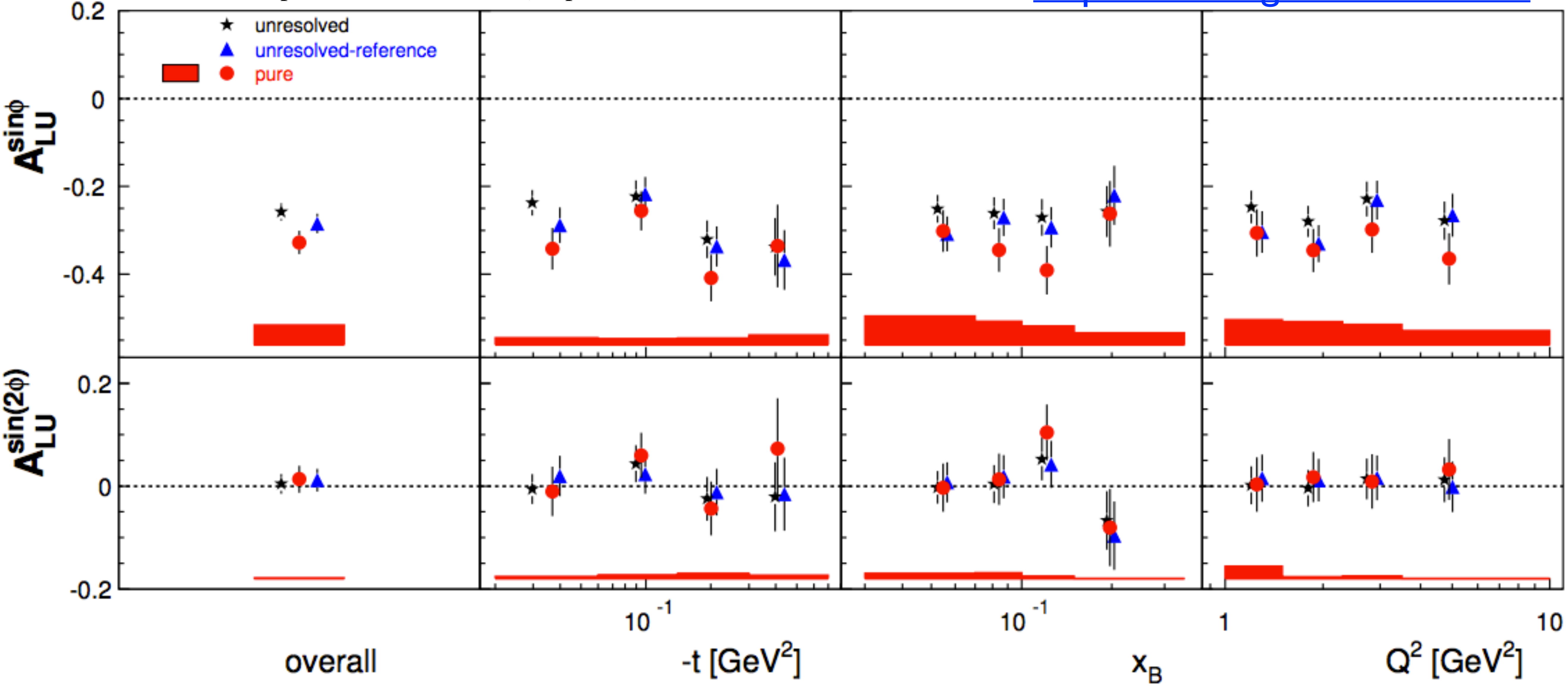


FIELD CLAMPS
TRIGGER HODOSCOPE H1
DRIFT CHAMBERS
270 mrad
PRESHOWER (H2)
140 mrad
Recoil Detector
DRIFT CHAMBERS
FC 1/2
PROP. CHAMBERS
LUMINOSITY MONITOR
e+
27.5 GeV
MC 1–3
DVC
SILICON
HODOSCOPE H0
BC 1/2
TARGET CELL
STEEL PLATE
BC 3/4
TRD
CALORIMETER
140 mrad
RICH
270 mrad
MAGNET
m
2
1
0
−1
−2
0
1
2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

Exclusive Measurement

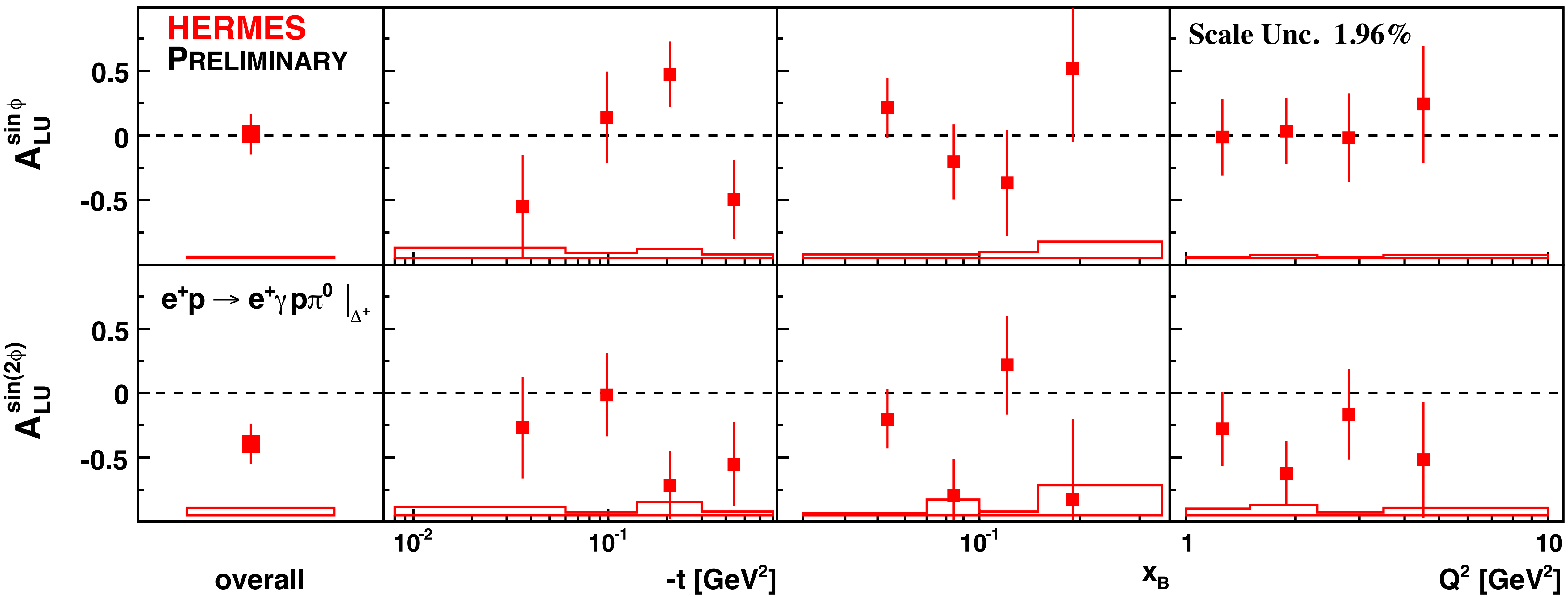
A. Airapetian et al, JHEP (in press)

http://arxiv.org/abs/1206.5683



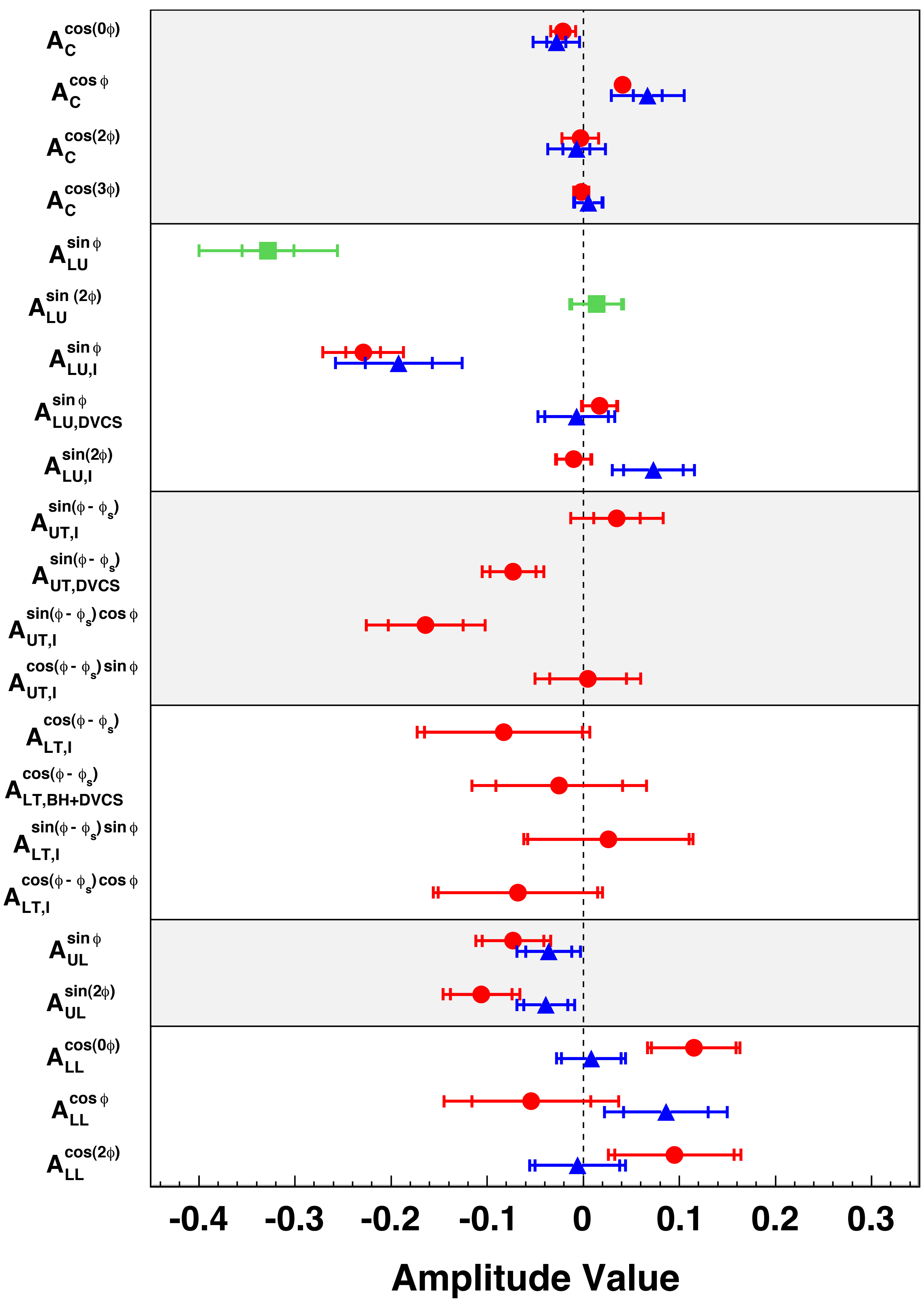
Fully reconstructed measurement of ep→epϒ

Exclusive Measurement

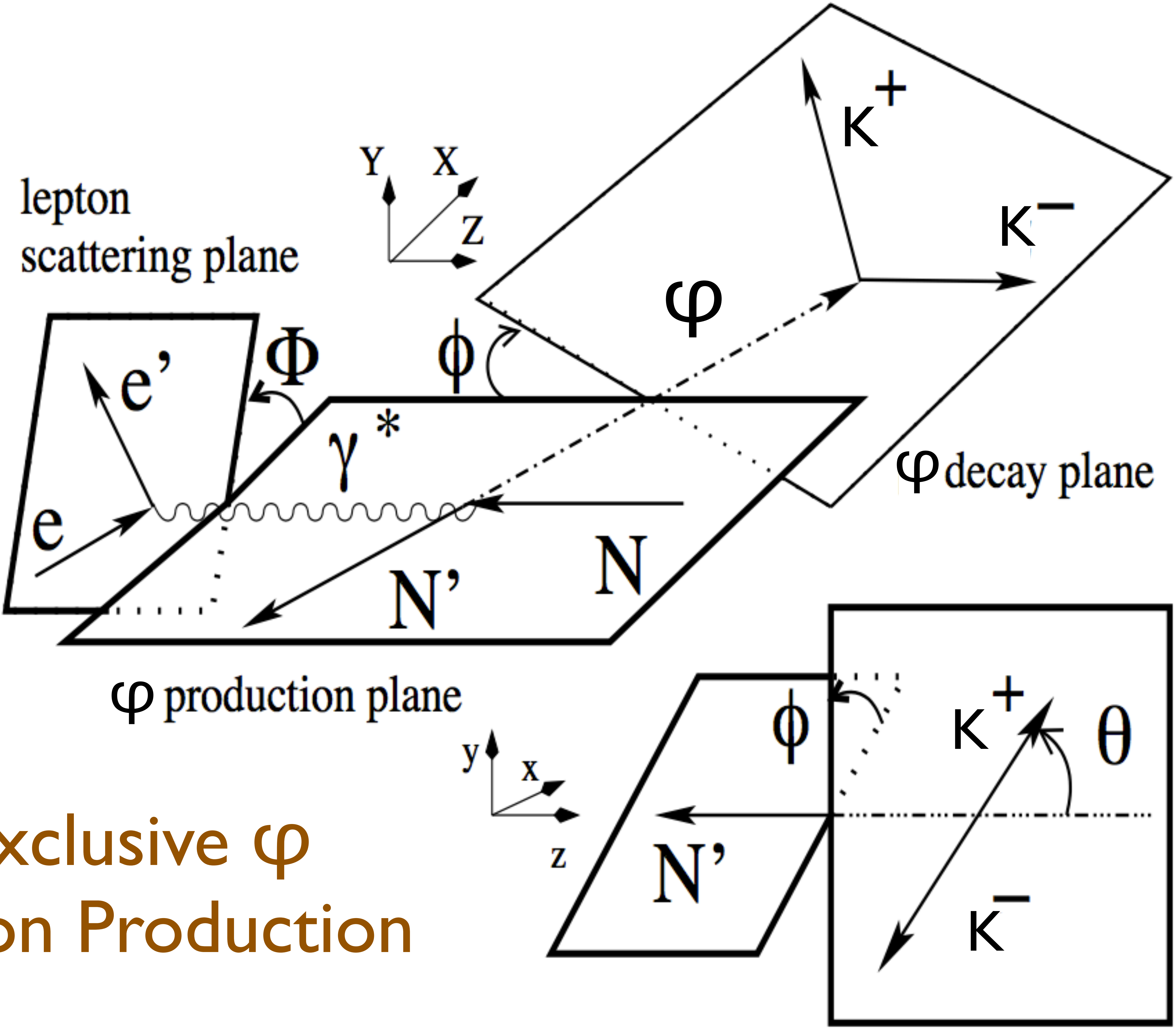


Results taken from measurement of $ep \to ep\pi^0\gamma$

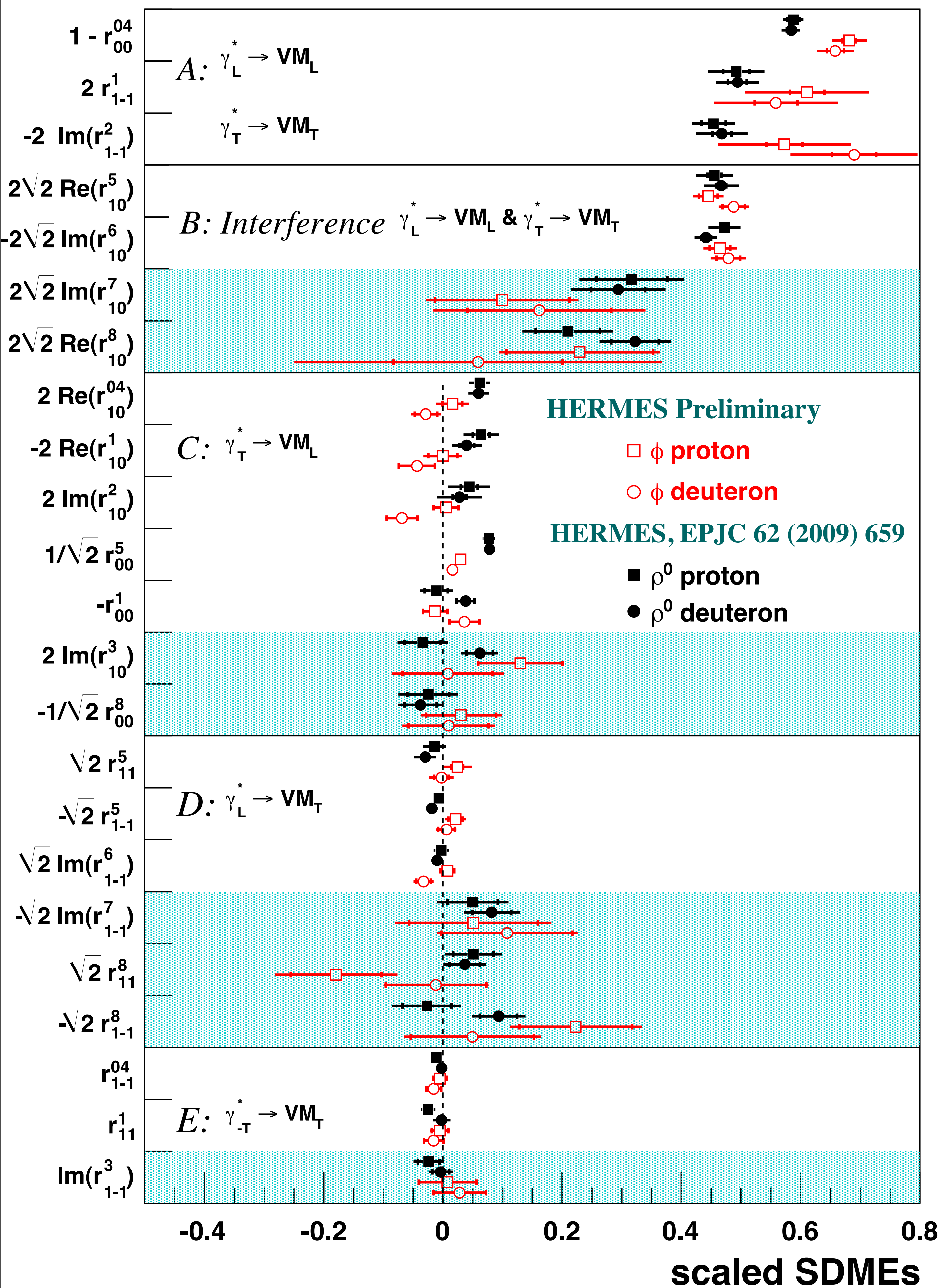
(Overall 'zero' asymmetry implies that the 'associated' fraction in the non-exclusive results acts as a dilution)



- DVCS remains the leading process for access to 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!



Exclusive φ Meson Production

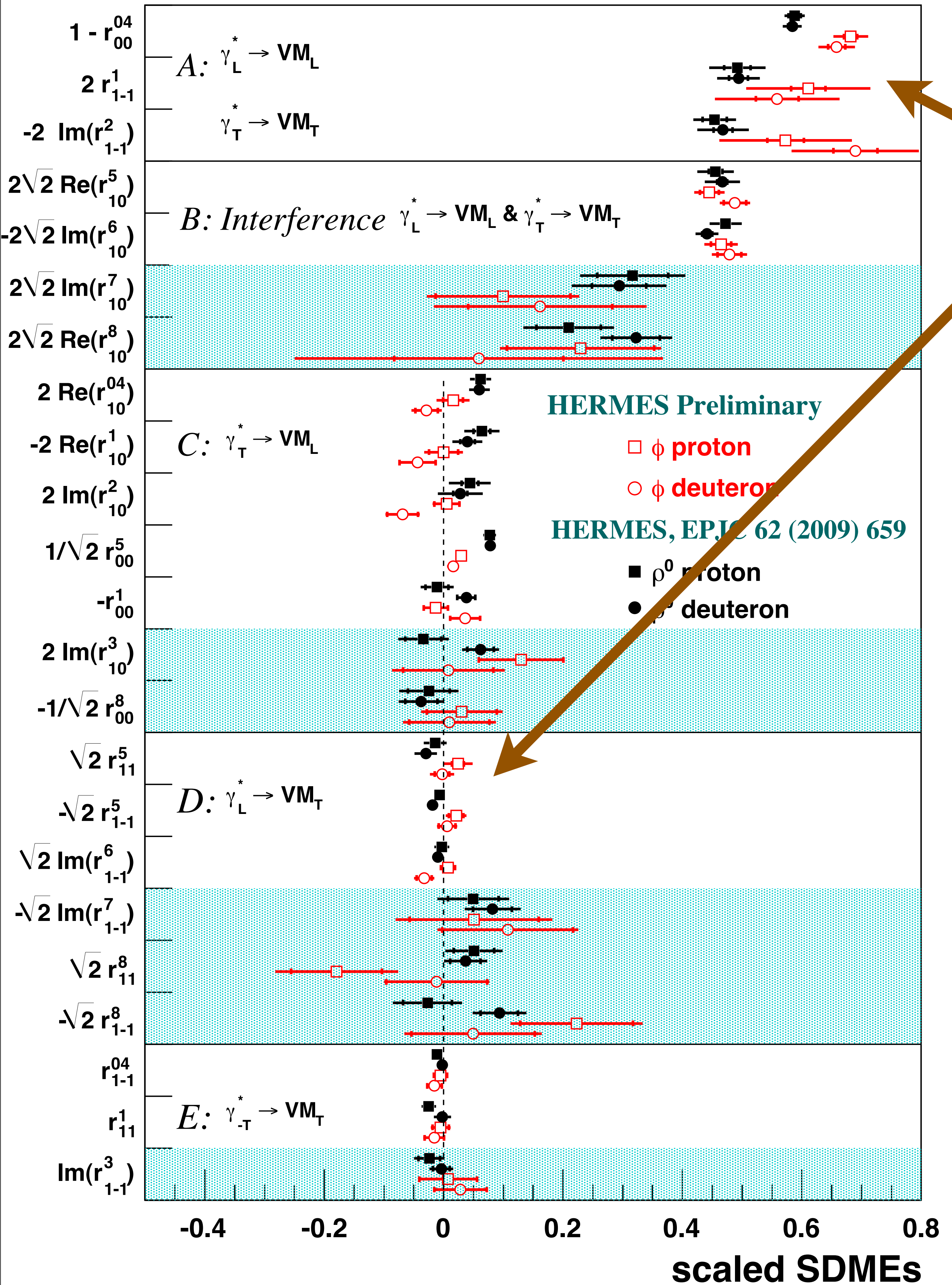


Exclusive Meson Production

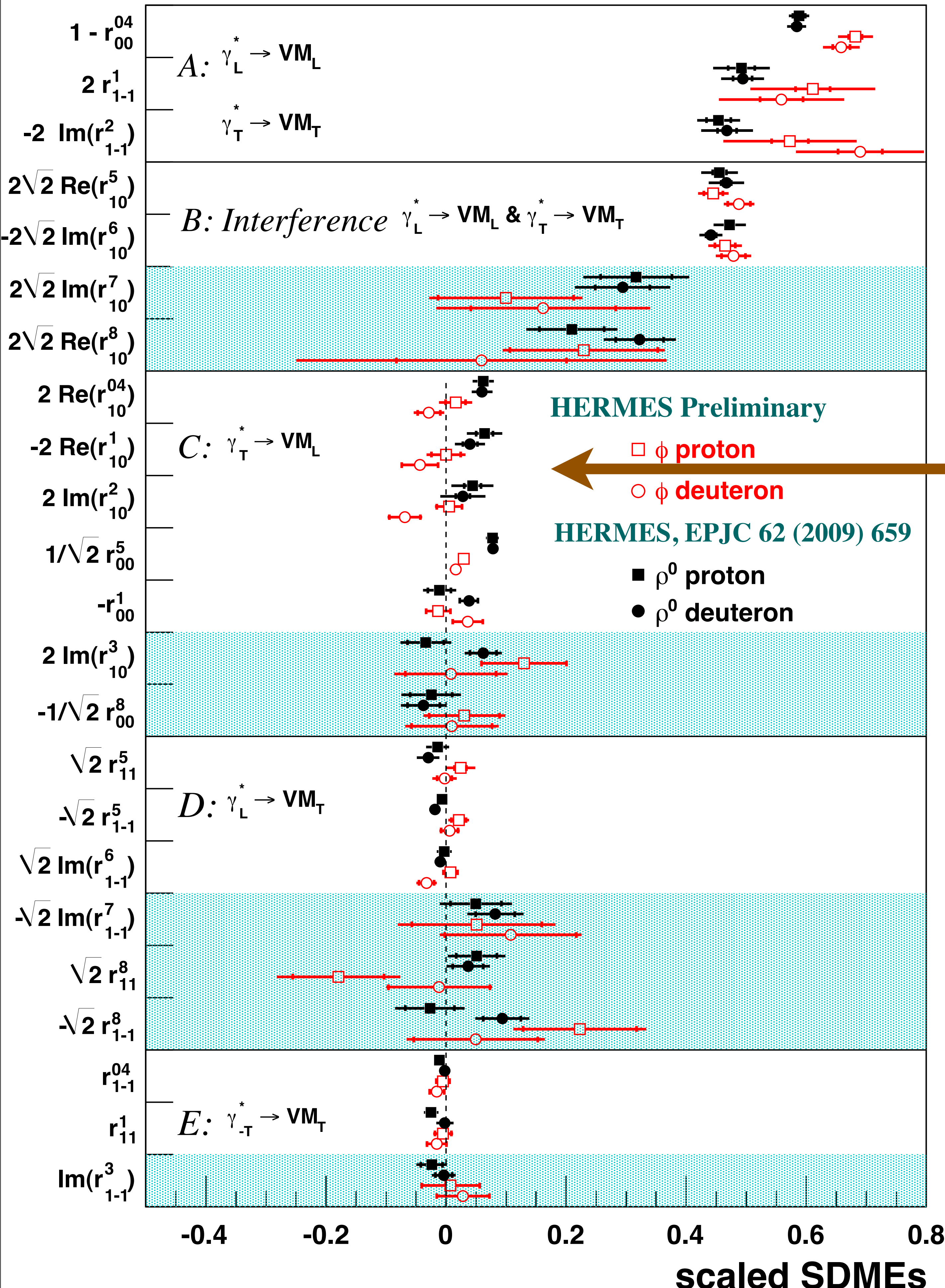
Results taken from measurement of $ep \rightarrow eX\varphi$.

No measured distinction between proton and deuteron data.

Leading-twist transitions are typically larger than the ρ^0-equivalent.

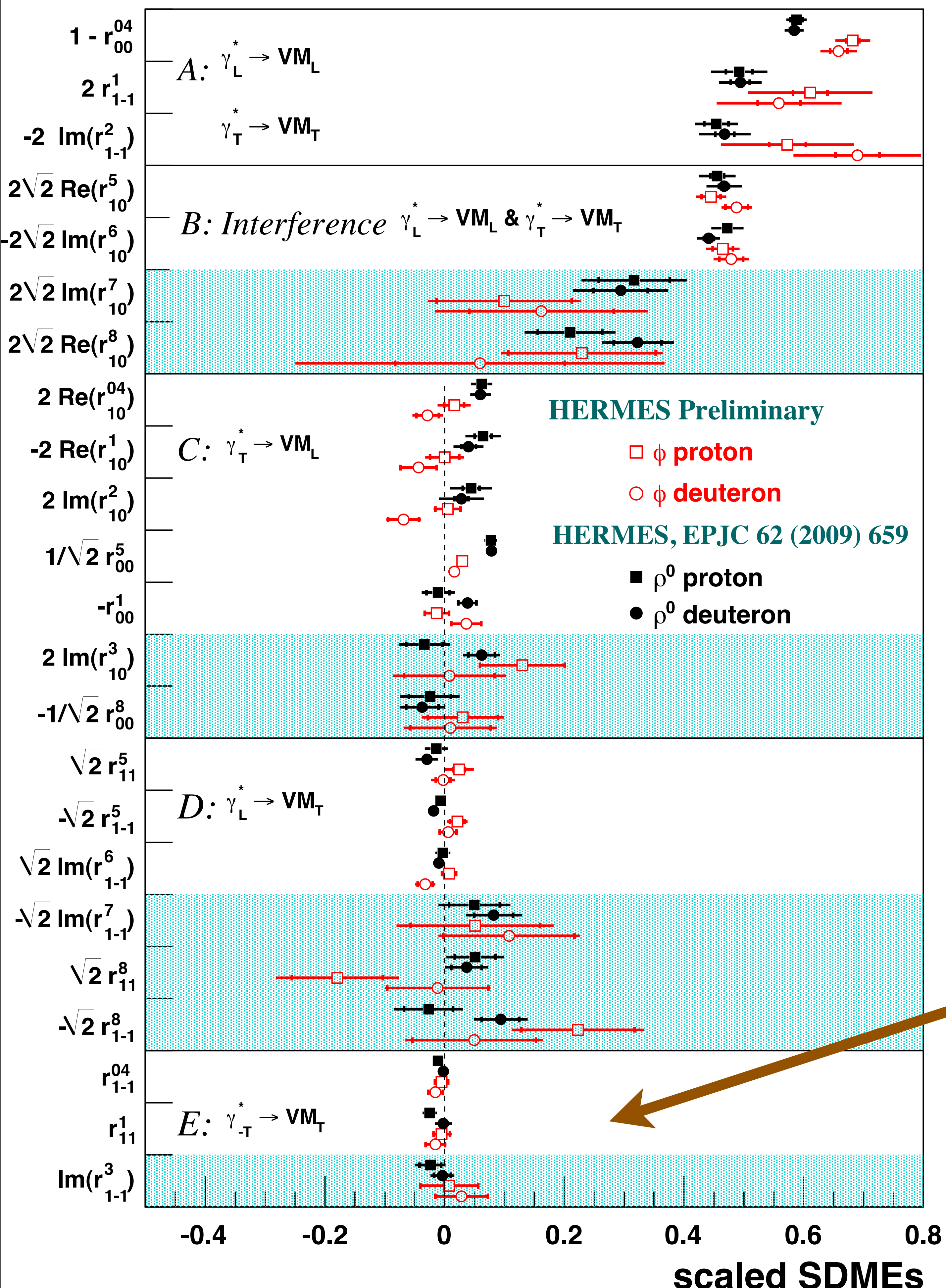


Longitudinal photons mostly produce longitudinal mesons



Longitudinal photons mostly produce longitudinal mesons

Some small indication that transverse photons can produce longitudinal mesons



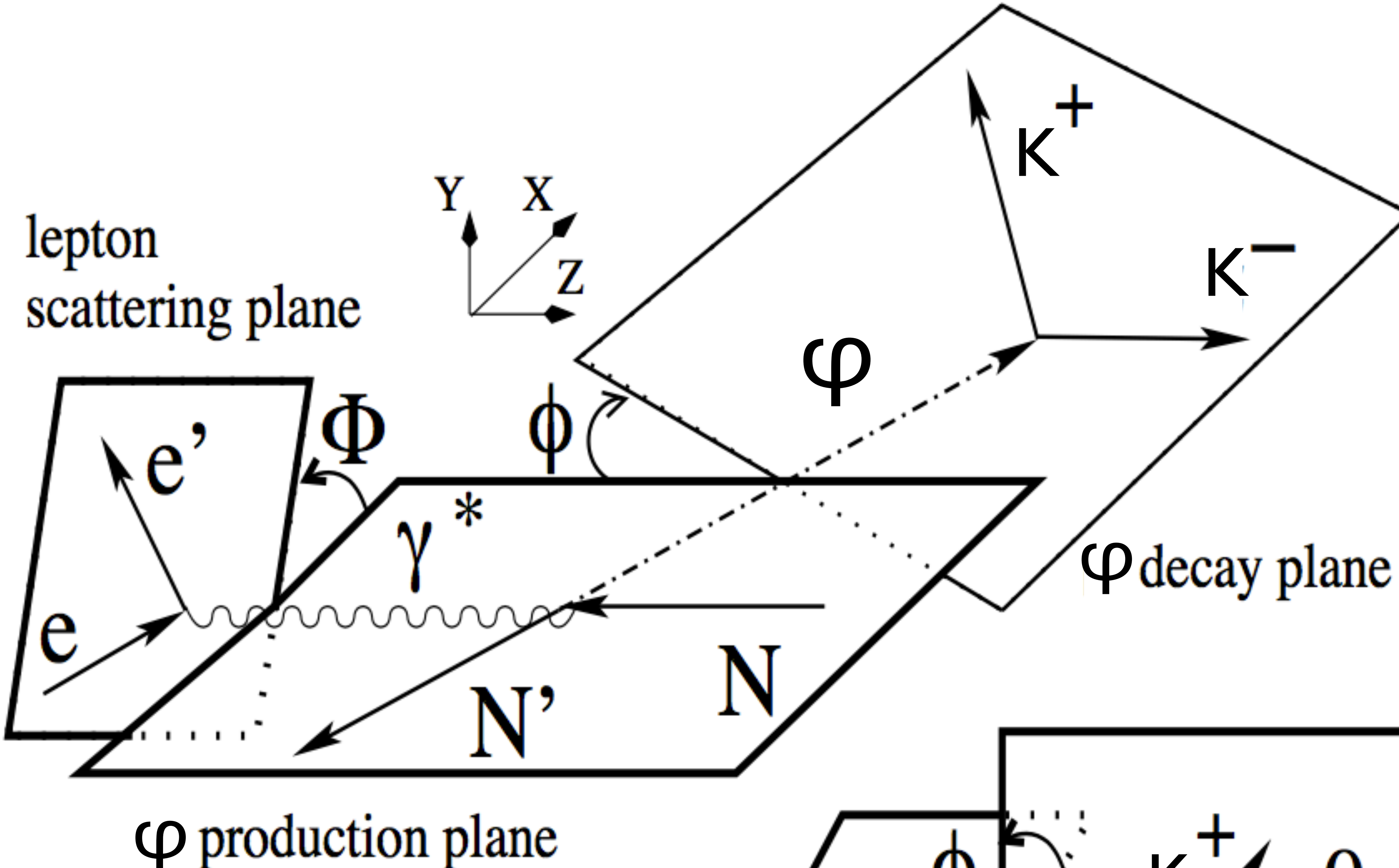
Longitudinal photons mostly produce longitudinal mesons

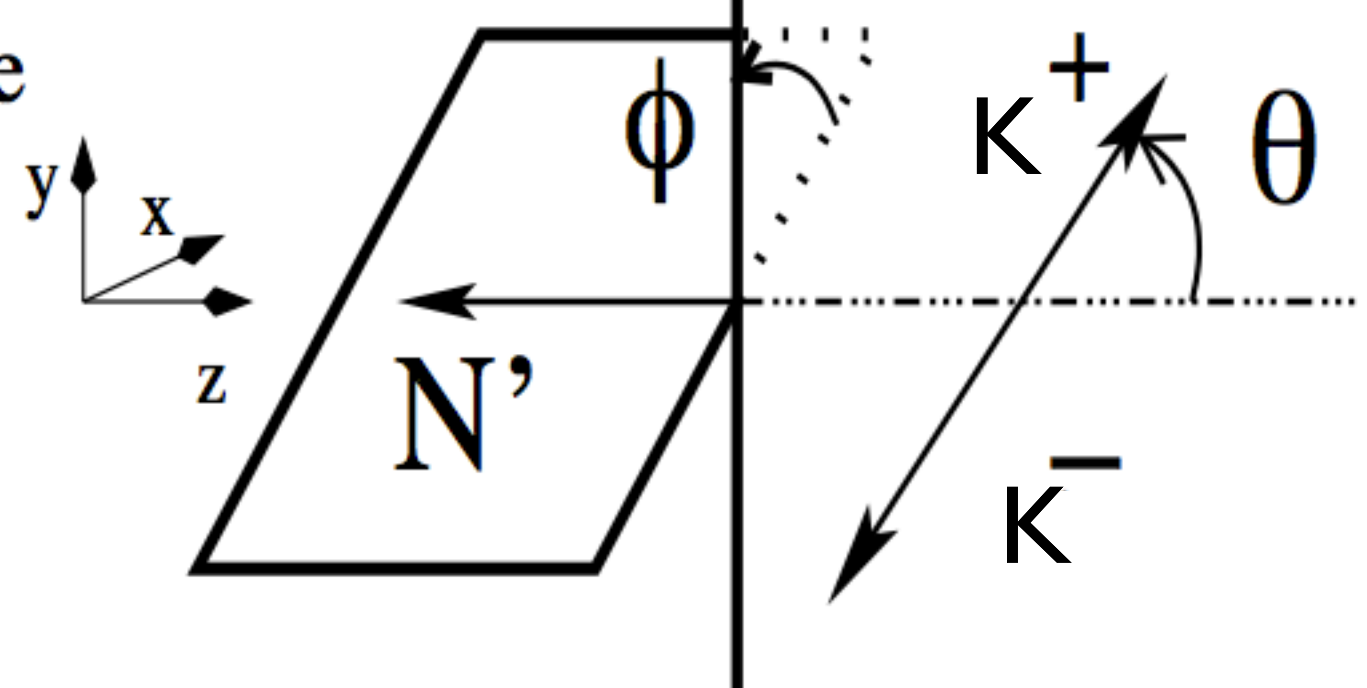
Some small indication that transverse photons can produce longitudinal mesons

Zero indication of two units of angular momentum change (-T γ makes +T φ)

Physics Update from HERMES

- New inclusive measurement of g_2 and A_2 released, compatible with SLAC and SMC.
- HERMES has very diverse DVCS measurements available - programme almost complete.
- Exclusive meson results also available; φ SDMEs seem mostly to match ρ^0 SDMEs.





Exclusive φ Meson Production

Angular Distribution

$$W^{U+L}(\Phi,\phi,\cos\Theta) = W^{UU}(\Phi,\phi,\cos\Theta) + W^{LU}(\Phi,\phi,\cos\Theta)$$

For unpolarized target and beam:

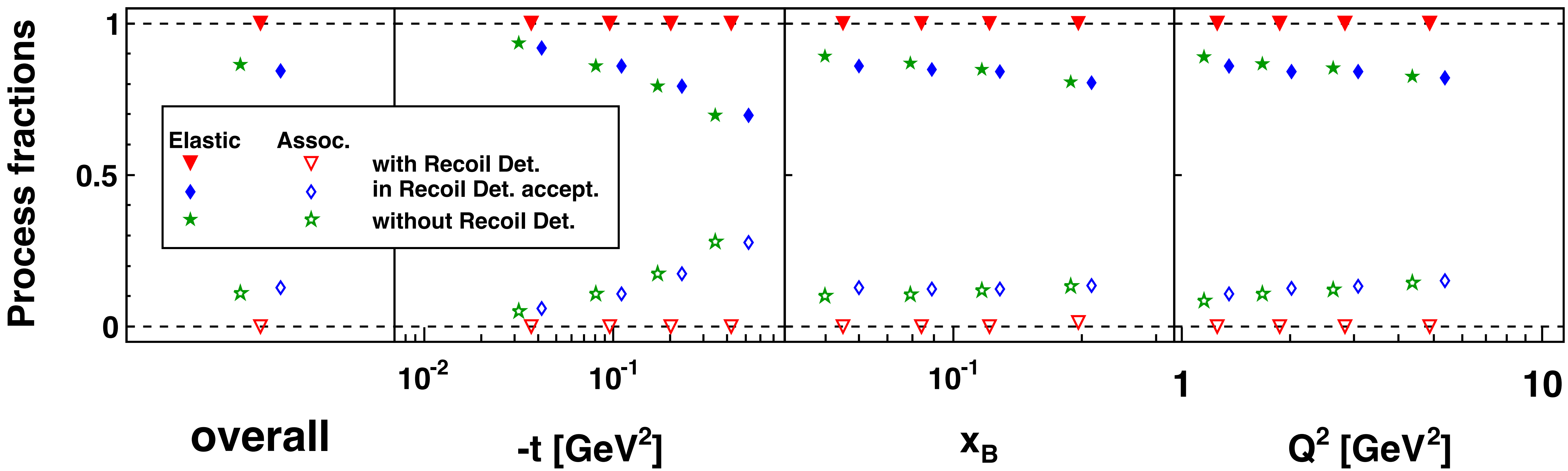
$$\begin{aligned} W^{UU}(\Phi,\phi,\cos\theta) = \frac{3}{8\pi^2}[& \frac{1}{2}\left(1-r_{00}^{04}\right)+\frac{1}{2}\left(3r_{00}^{04}-1\right)\cos^2\theta-\sqrt{2}\,\mathrm{Re}\left\{r_{10}^{04}\right\}\sin 2\theta\cos\phi-r_{1-1}^{04}\sin^2\theta\cos 2\phi \\ & -\varepsilon\cos 2\Phi\left(r_{11}^{1}\sin^2\theta+r_{00}^{1}\cos^2\theta-\sqrt{2}\,\mathrm{Re}\left\{r_{10}^{1}\right\}\sin 2\theta\cos\phi-r_{1-1}^{1}\sin^2\theta\cos 2\phi\right) \\ & -\varepsilon\sin 2\Phi\left(\sqrt{2}\,\mathrm{Im}\left\{r_{10}^{2}\right\}\sin 2\theta\sin\phi+\mathrm{Im}\left\{r_{1-1}^{2}\right\}\sin^2\theta\sin 2\phi\right) \\ & +\sqrt{2\varepsilon(1+\varepsilon)}\cos\Phi\left(r_{11}^{5}\sin^2\theta+r_{00}^{5}\cos^2\theta-\sqrt{2}\,\mathrm{Re}\left\{r_{10}^{5}\right\}\sin 2\theta\cos\phi-r_{1-1}^{5}\sin^2\theta\cos 2\phi\right) \\ & +\sqrt{2\varepsilon(1+\varepsilon)}\sin\Phi\left(\sqrt{2}\,\mathrm{Im}\left\{r_{10}^{6}\right\}\sin 2\theta\sin\phi+\mathrm{Im}\left\{r_{1-1}^{6}\right\}\sin^2\theta\sin 2\phi\right)] \end{aligned}$$

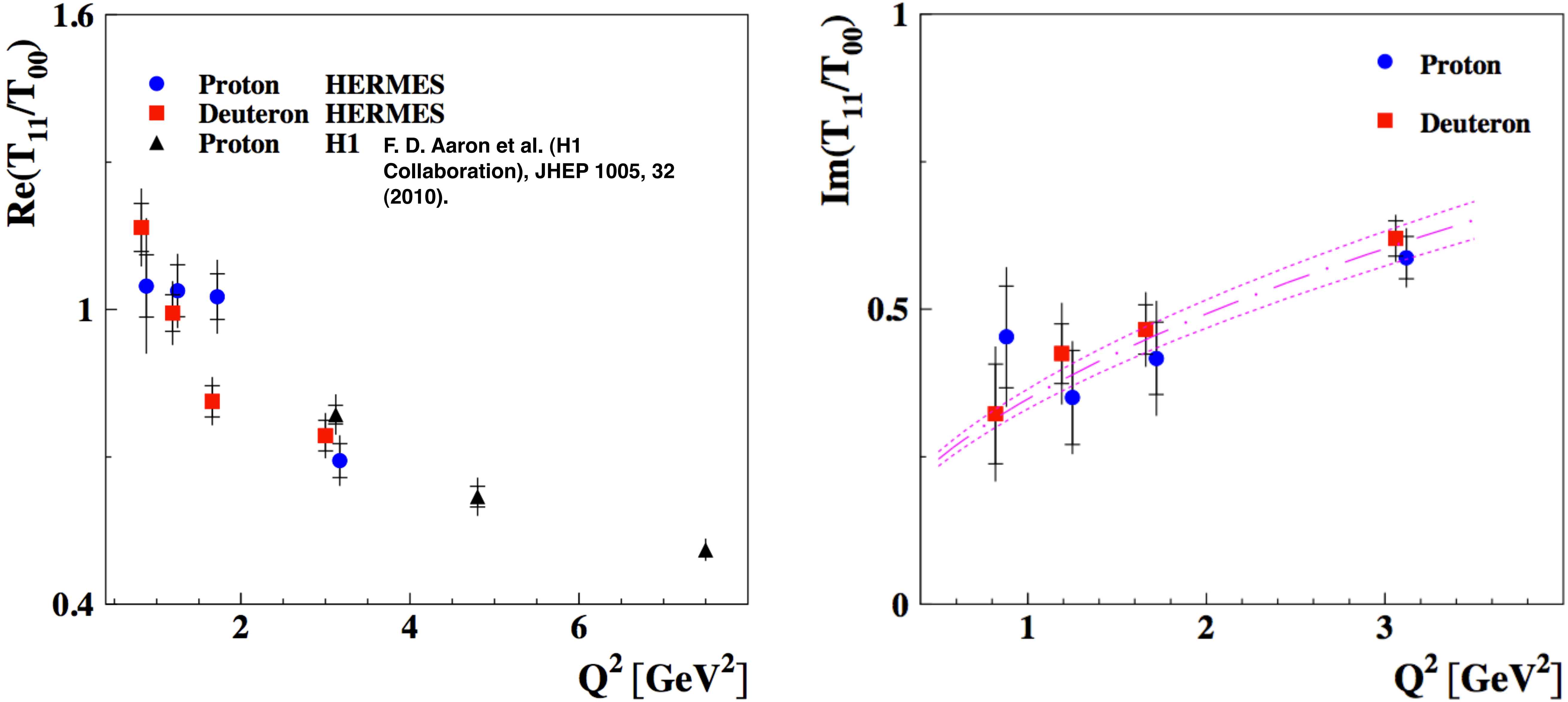
For unpolarized target and longitudinally polarized beam:

$$\begin{aligned} W^{LU}(\Phi,\phi,\cos\theta) = \frac{3}{8\pi^2}P_{Beam}[& \sqrt{1-\varepsilon^2}\left(\sqrt{2}\,\mathrm{Im}\left\{r_{10}^{3}\right\}\sin 2\theta\sin\phi+\mathrm{Im}\left\{r_{1-1}^{3}\right\}\sin^2\theta\sin 2\phi\right) \\ & +\sqrt{2\varepsilon(1-\varepsilon)}\cos\Phi\left(\sqrt{2}\,\mathrm{Im}\left\{r_{10}^{7}\right\}\sin 2\theta\sin\phi+\mathrm{Im}\left\{r_{1-1}^{7}\right\}\sin^2\theta\sin 2\phi\right) \\ & +\sqrt{2\varepsilon(1-\varepsilon)}\sin\Phi\left(r_{11}^{8}\sin^2\theta+r_{00}^{8}\cos^2\theta-\sqrt{2}\,\mathrm{Re}\left\{r_{10}^{8}\right\}\sin 2\theta\cos\phi-r_{1-1}^{8}\sin^2\theta\cos 2\phi\right)] \end{aligned}$$

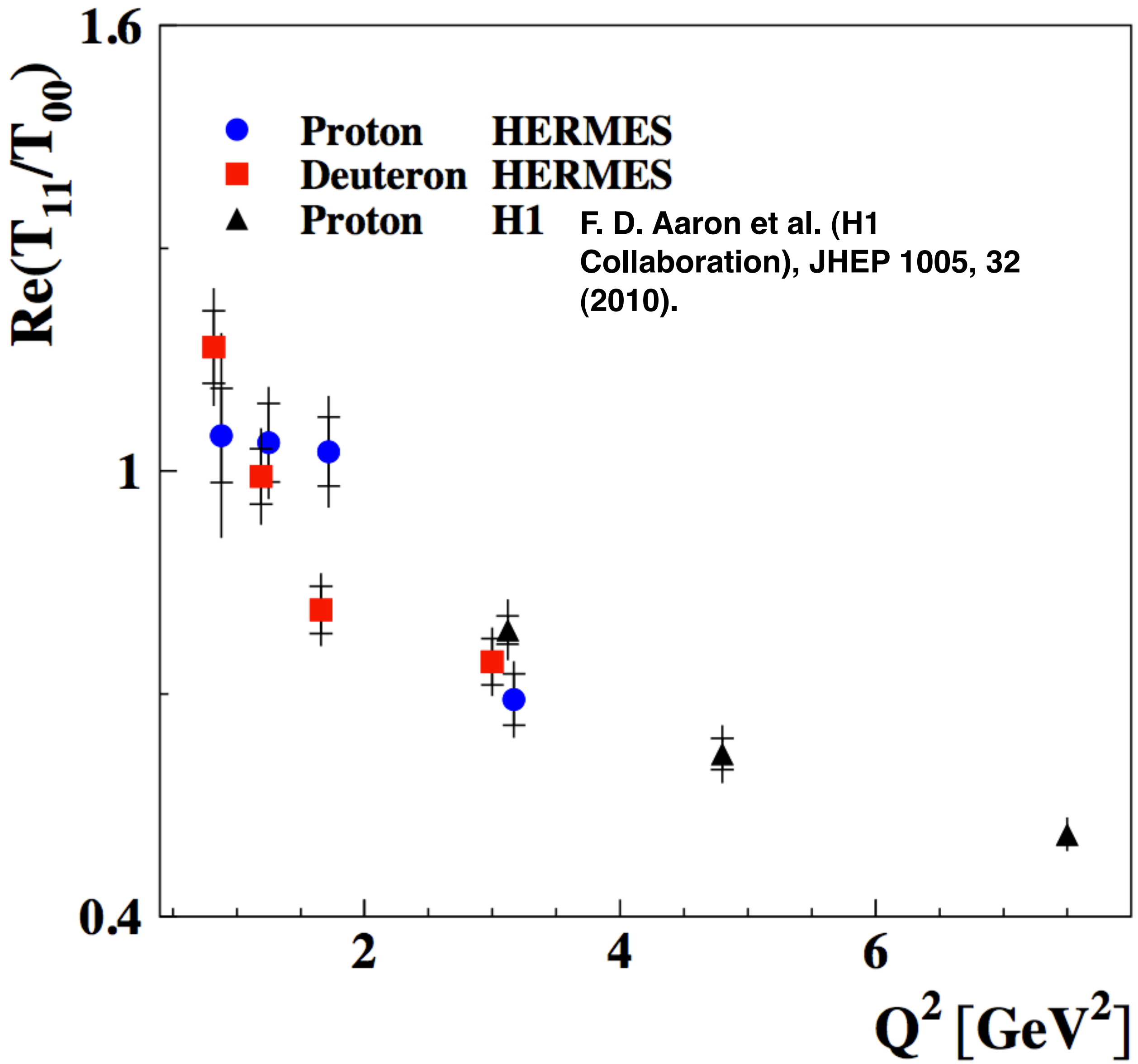
$$\varepsilon = \frac{1-y-y^2\frac{Q^2}{4\nu^2}}{1-y+\frac{1}{4}y^2(\frac{Q^2}{\nu^2}+2)}$$ - the ratio of virtual photon fluxes for longitudinal and transverse polarization

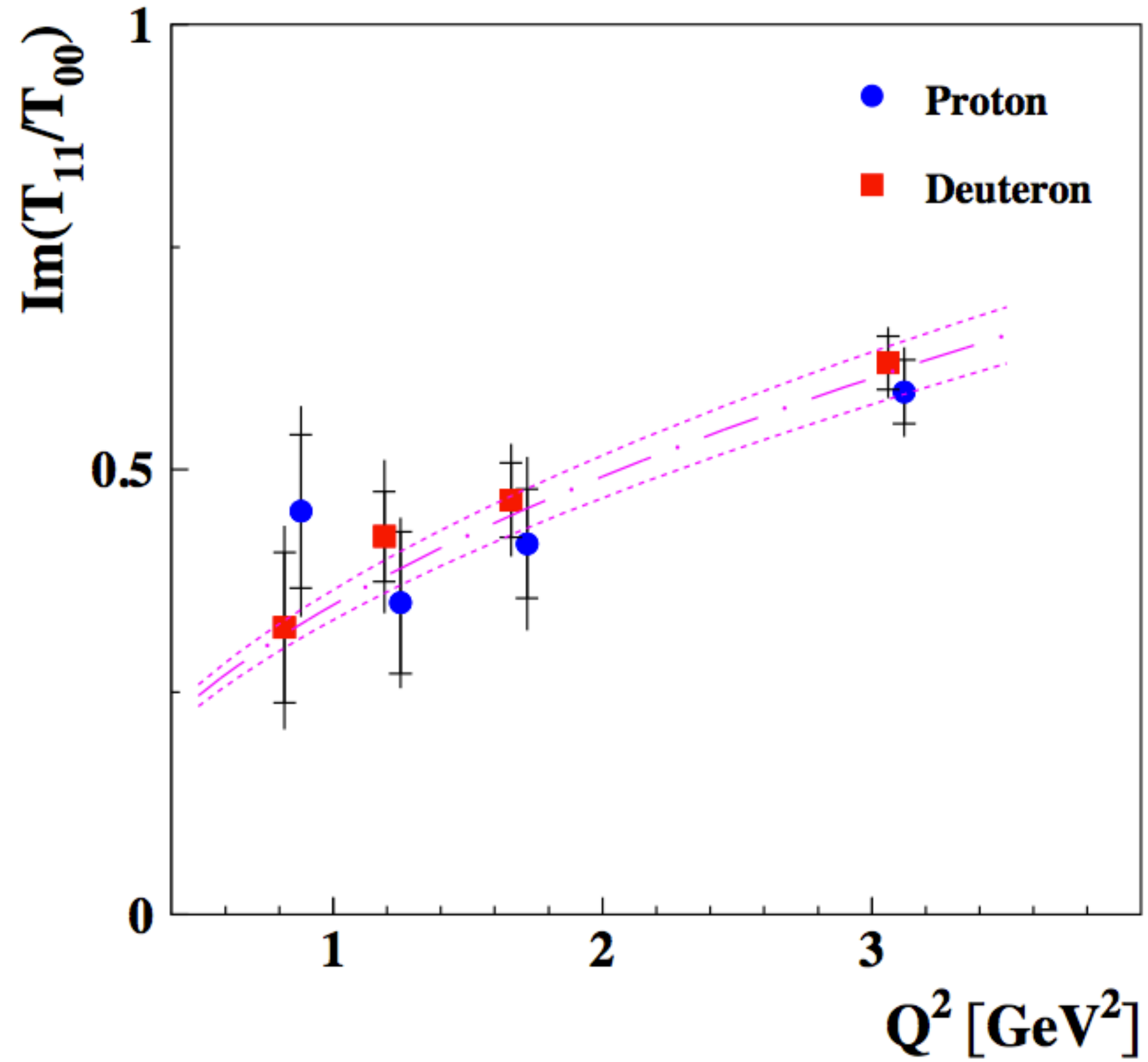
Exclusive Measurement





Kinematic Dependence of t_{11}





Real Part follows a/Q
with a=1.11±0.03GeV
as expected!

Imaginary Part follows bQ
with $b=0.34\pm0.02\,\mathrm{GeV}^{-1}$
(fit has no basis in theory)

Phase Differences of HARs

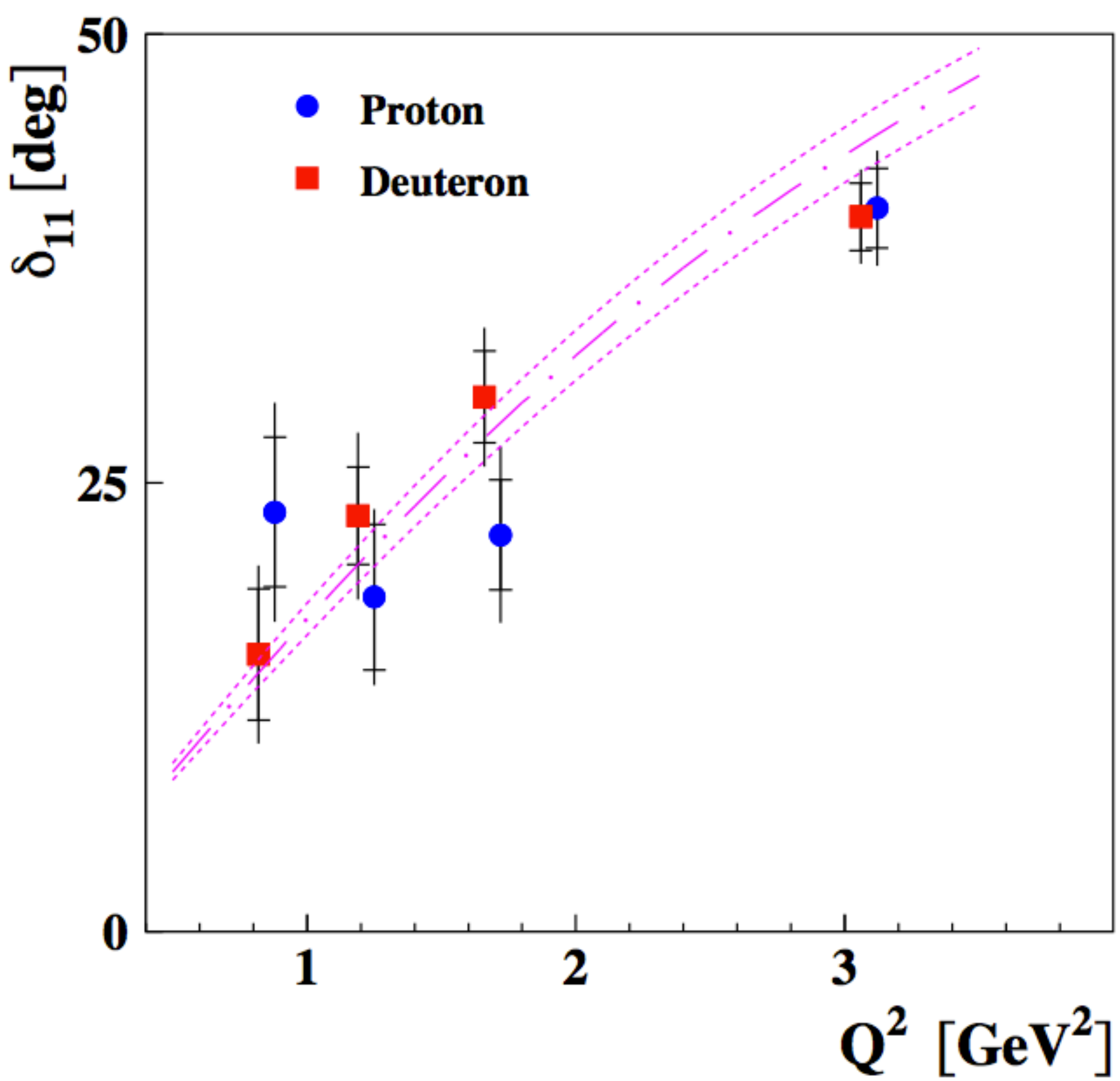
- GPD model predicts small phase difference for $\tan(\delta_{11})=\mathrm{Im}(t_{11})/\mathrm{Re}(t_{11})$

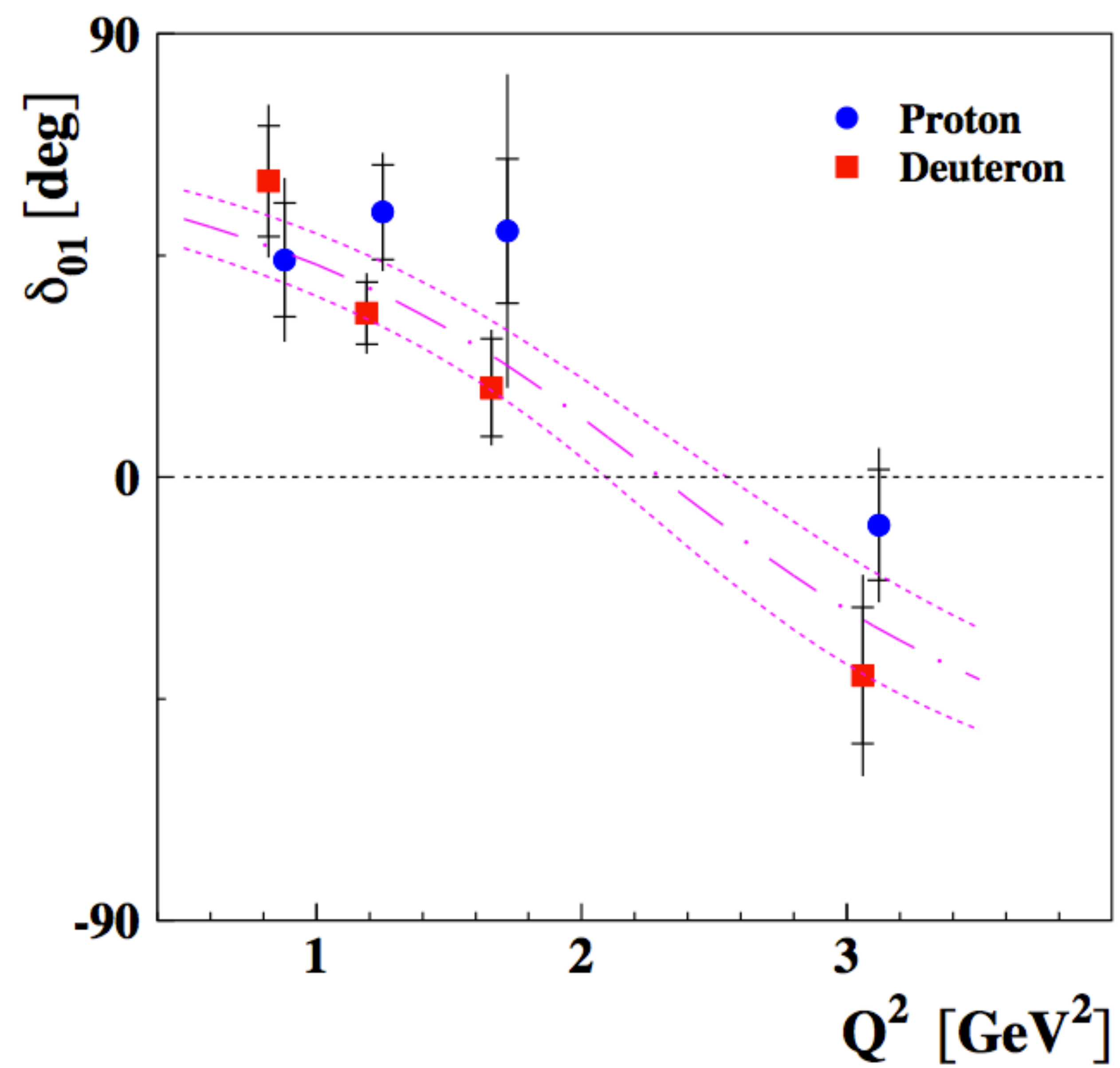
S. V. Goloskokov and P. Kroll, Eur. Phys. J. C 53, 367 (2008)

- t_{01} is expected to be the largest SCHC-violating amplitude and δ_{01} should be constant

D. Yu. Ivanov and R. Kirschner, Phys. Rev. D 58, 114026 (1998)

Phase Difference of HARs

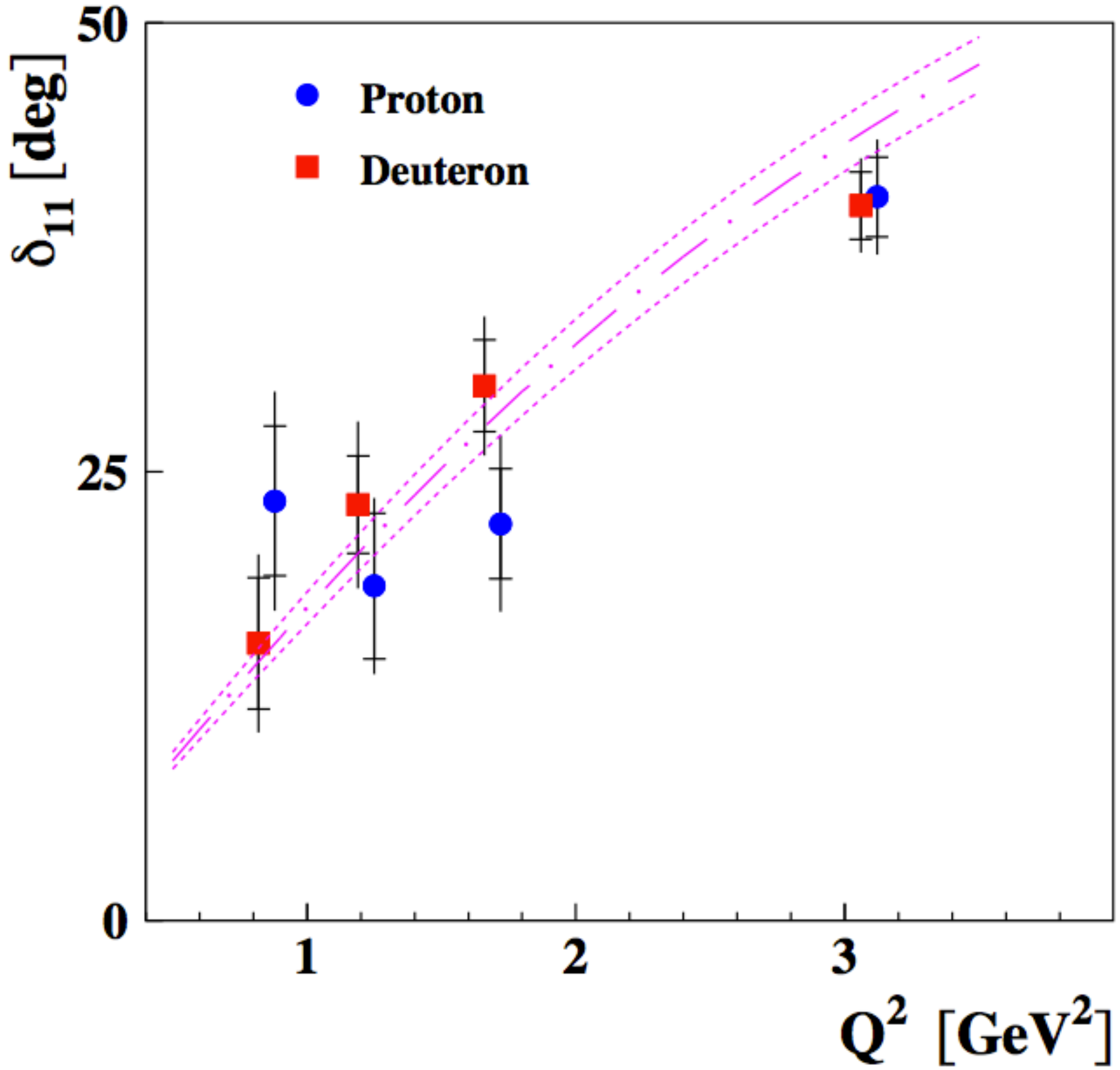


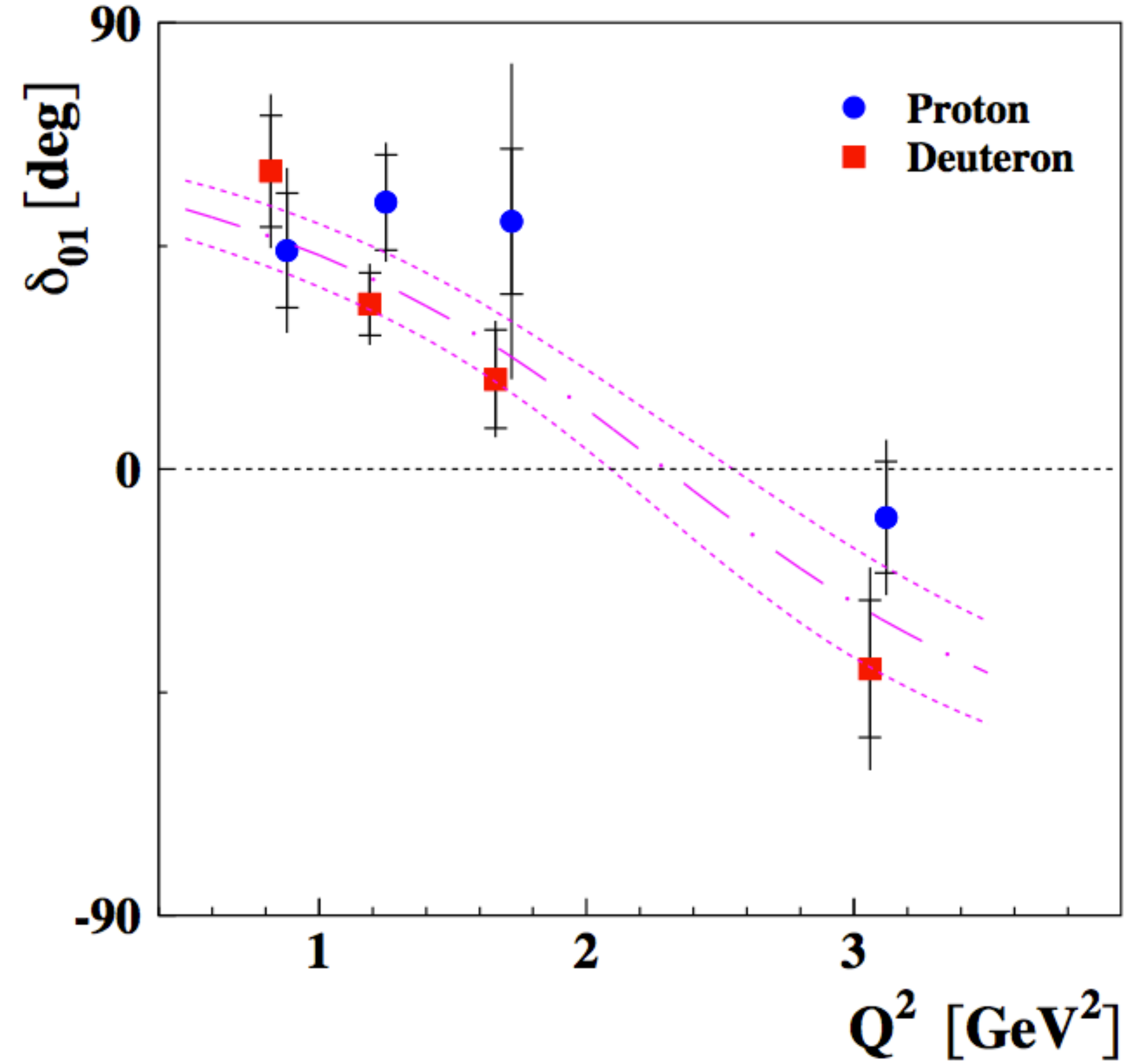


Large value contradicts GPD-based models

Should be a constant

(Neither Re(t_{01}) nor Im(t_{01}) follow theoretical dependence predictions!!!)





N.B: Fits have no basis in theory

Helicity Amplitude Hierarchy

Behaviour of UPE

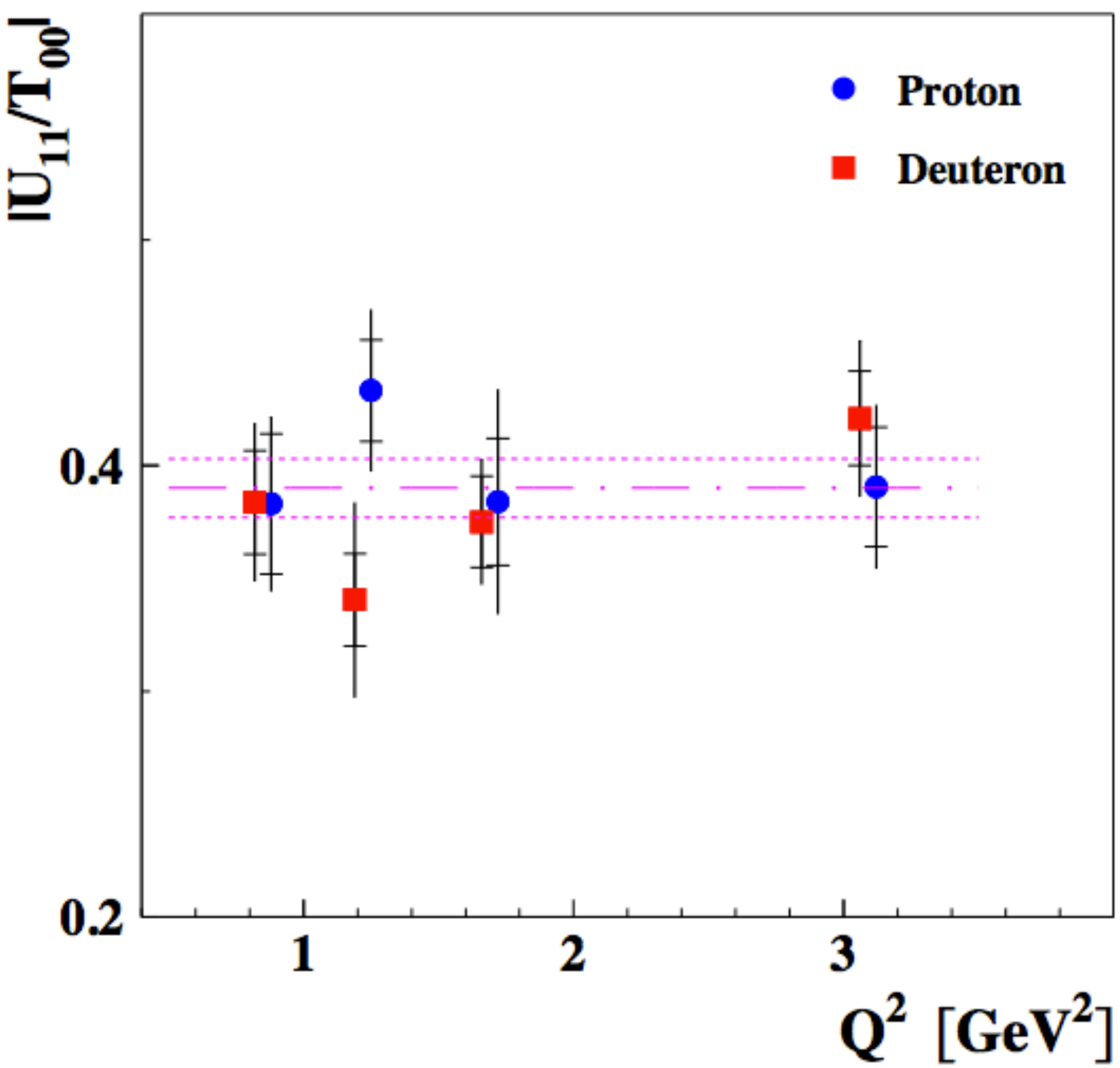
$$|T_{00}|^2 \approx |T_{11}|^2 >> |U_{11}|^2 > |T_{01}|^2 >> |T_{10}|^2 \ldots$$

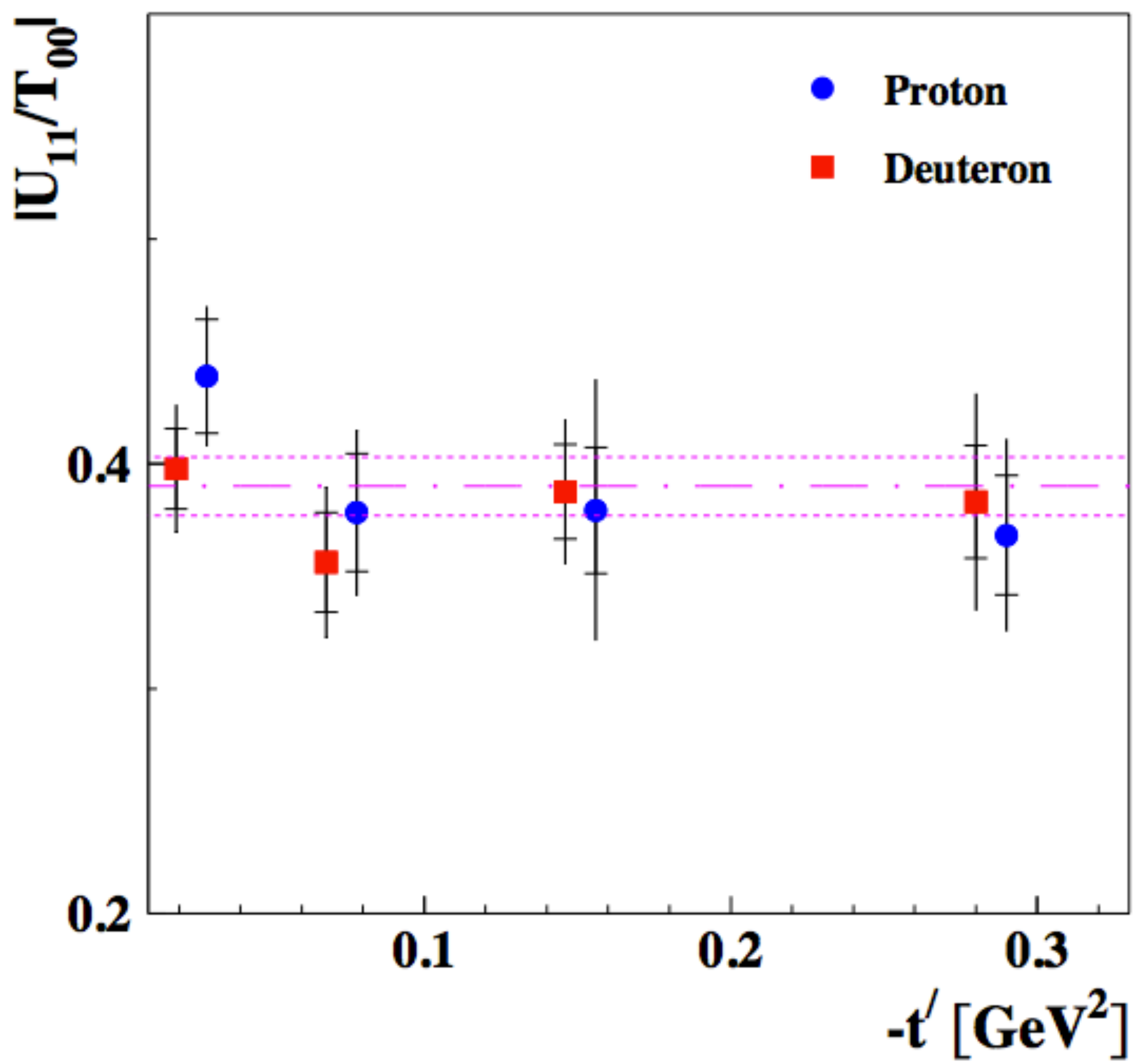
- $u_{11} = |U_{11}|/|T_{00}|$ should be small ($u_{11} \approx 0.2$) but visible (only) for ρ^0 at HERMES!

- May naively expect a $1/Q$ dependence in u_{11}

- UPE is one-pion exchange => may also see some influence of the pion-pole at small *t?*

Unnatural Parity Exchange

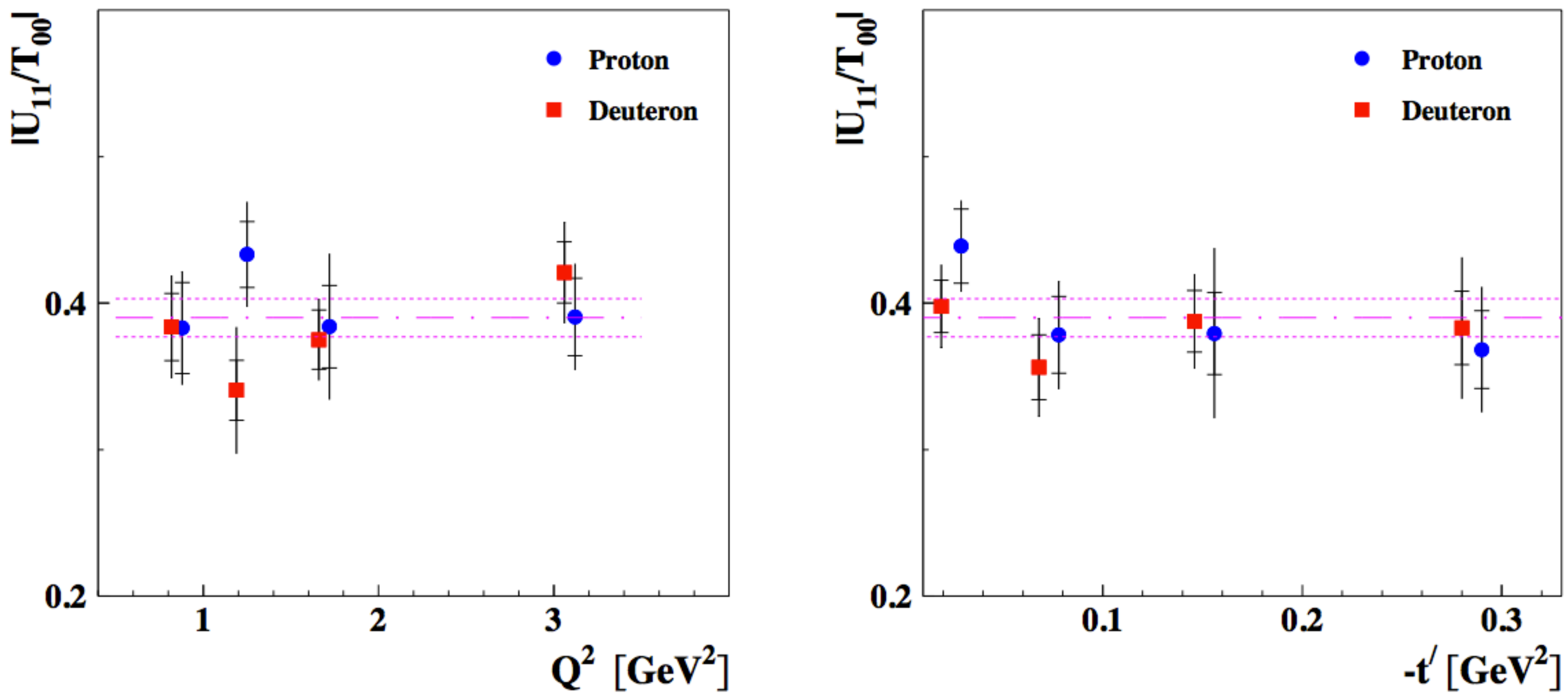




Unnatural Parity Exchange

No dependence on Q^2!

No dependence on t'!



Existence established to 20σ (integrated extraction)

Magnitude of U_{11} is 2.5x smaller than T_{00}

Unnatural Parity Exchange

- No dependence on Q^2 may be because HERMES is far from the asymptotic region ?

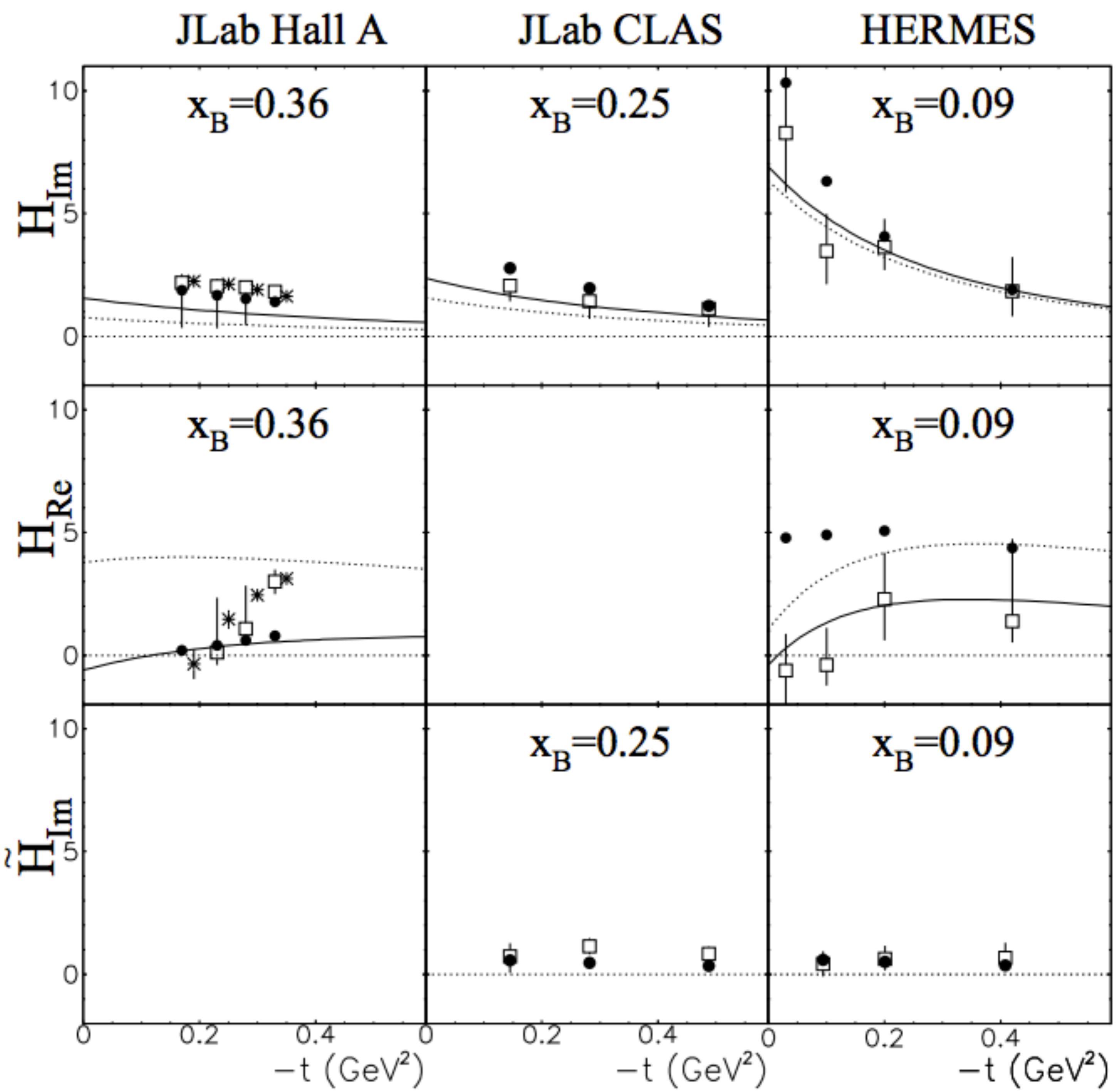
- No dependence on t′

➡ Too far from pion-pole ?

➡ U_{11} not dominated by one-pion exchange ?

➡ An underlying dependence of T_{00} on t' ?

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)*