Exclusive Reactions at HERMES

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3rd Workshop on the QCD Structure of the Nucleon (QCD-N'12), Bilbao, Spain, Oct. 22-26, 2012

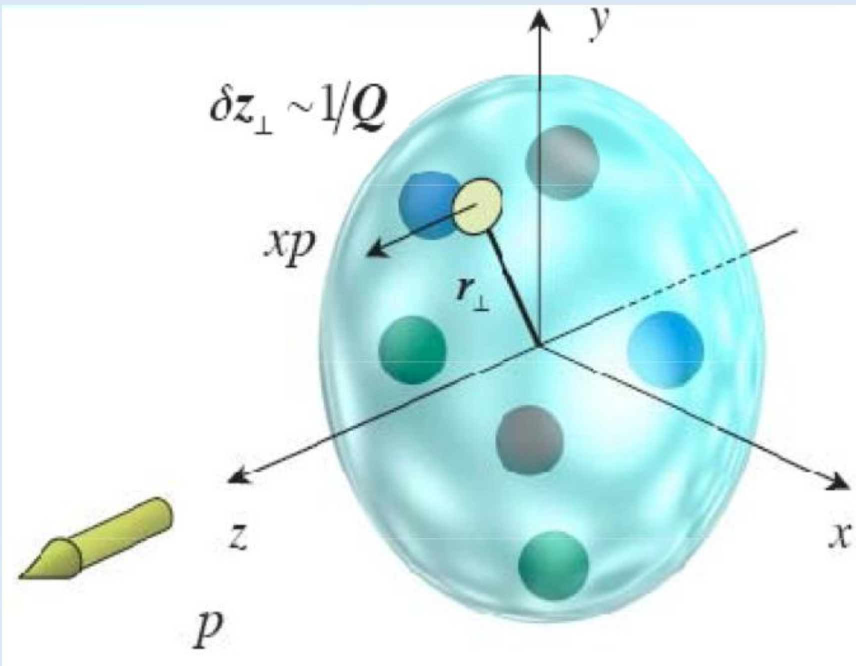
- Exclusive measurements and GPDs
- HERMES experiment at HERA
- DVCS measurement at HERMES: azimuthal asymmetries
- Exclusive meson production: cross section, asymmetries, SDMEs
- Summary

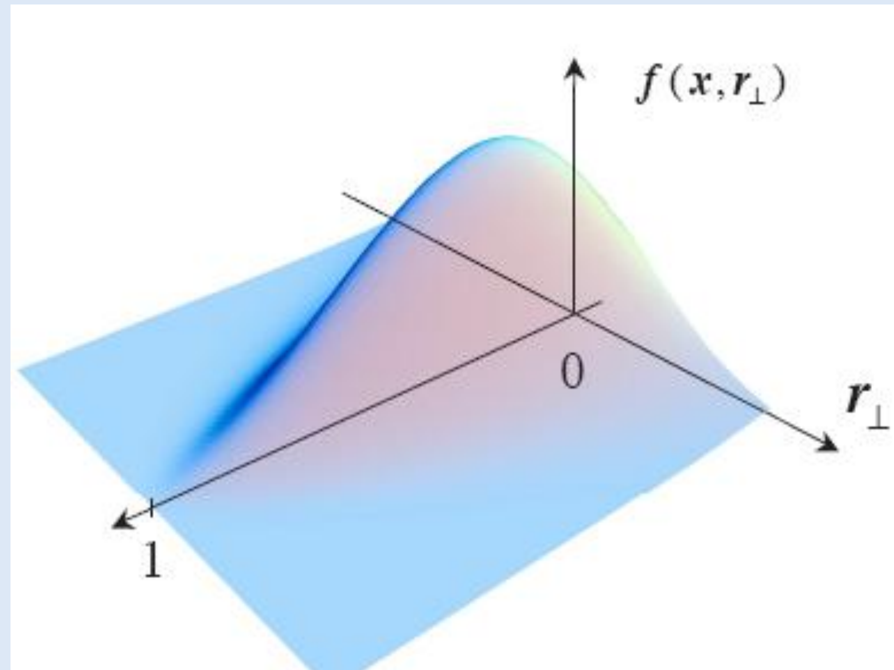
Generalized Parton Distributions

Generalized Parton Distributions (GPDs)

Generalization of Form Factors (moments of GPDs) and PDFs (forward limit)

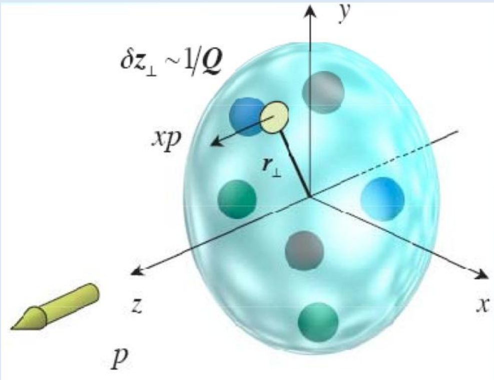
Generalized description of nucleon structure in 2+1 dim

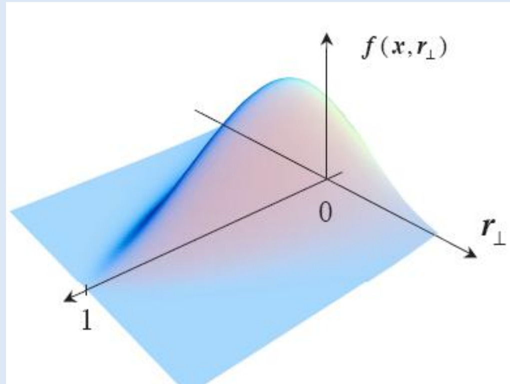




Number density of quarks with longitudinal momentum fraction x at radial position $r_\perp$

Exclusive measurements & GPDs





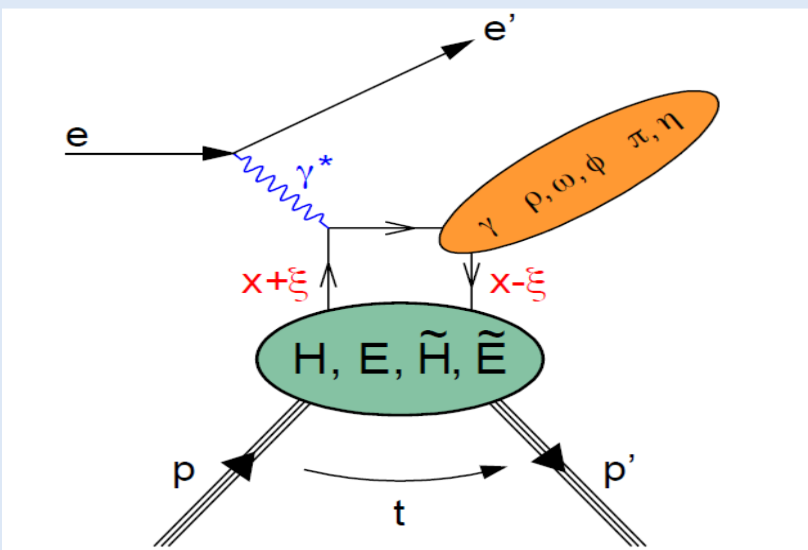
Ji sum rule $\Longrightarrow$ access OAM

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

$$\tfrac{1}{2} = \tfrac{1}{2}\Delta\Sigma + L_q + J_q$$

Correlated information about longitudinal momentum xp and transverse spatial position $r_\perp$

H^q and E^q : quark Generalized Parton Distributions (GPDs)



Spin-½ target: 4 chiral-even leading-twist quark GPDs $H, E, \widetilde{H}, \widetilde{E}$

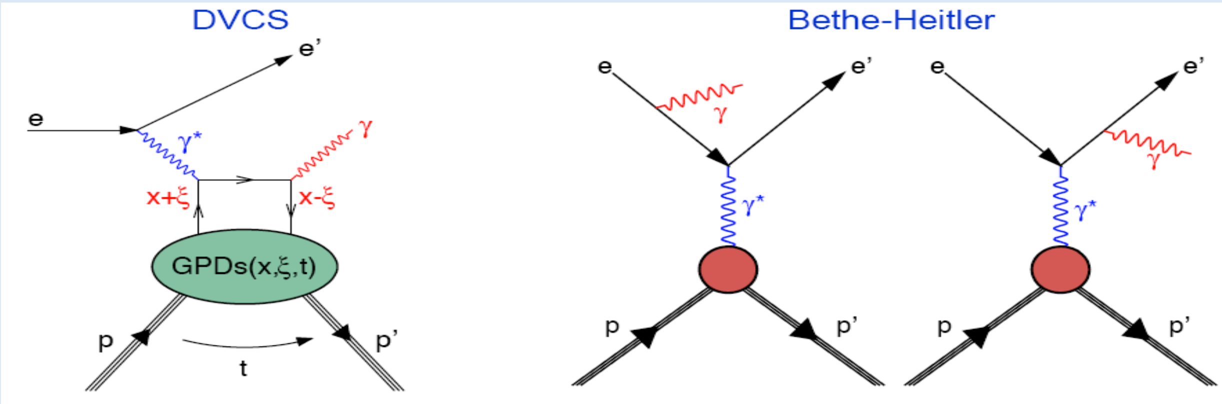
Final state sensitive to different GPDs

DVCS (γ) $H, E, \widetilde{H}, \widetilde{E}$

Vector mesons (ρ, ω, ϕ) $H, E,$

Pseudoscalar mesons (π,η) $\widetilde{H}, \widetilde{E}$

DVCS & GPDs



- Theoretically cleanest way to access GPDs
- Interference between DVCS and Bethe-Heitler amplitude
- $|\tau_{DVCS}| \ll |\tau_{BH}|$ at HERMES

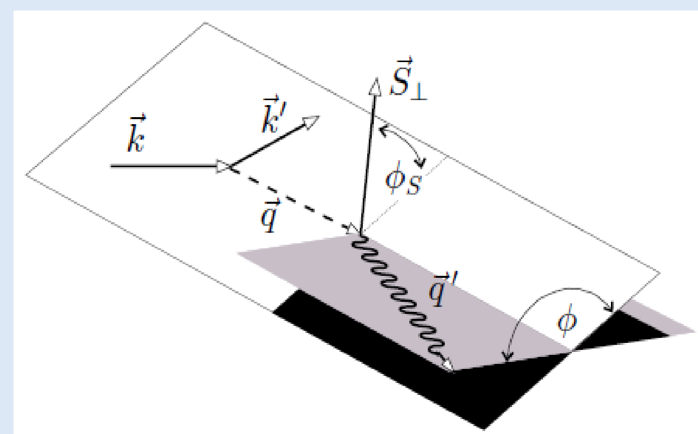
Access to GPD combinations through azimuthal asymmetries

A_{XY}

X → beam, Y → target

<u>HERMES: Complete set of asymmetries</u>

- Both beam charges
- Both beam helicities
- Unpolarized H, D and nuclear targets
- Longitudinally polarized H and D targets
- Transversely polarized H target



Accessing GPDs in DVCS

- Beam-Charge Asymmetry

$$\sigma(e^+,\phi)-\sigma(e^-,\phi)\propto \Re e[F_1\mathcal{H}]$$

- Beam-Spin Asymmetry

$$\sigma(\vec{e},\phi)-\sigma(\overleftarrow{e},\phi)\propto \Im m[F_1\mathcal{H}]$$

- Longitudinal Target-Spin Asymmetry

$$\sigma(\overset{\Rightarrow}{P},\phi)-\sigma(\overset{\Leftarrow}{P},\phi)\propto \Im m[F_1\widetilde{\mathcal{H}}]$$

- Longitudinal Double-Spin Asymmetry

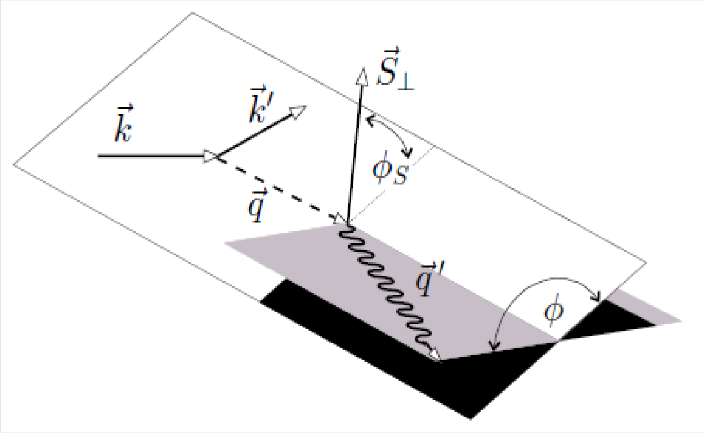
$$\sigma(\overset{\Rightarrow}{P},\vec{e},\phi)-\sigma(\overset{\Leftarrow}{P},\overleftarrow{e},\phi)\propto \Re e[F_1\widetilde{\mathcal{H}}]$$

- Transverse Target-Spin Asymmetry

$$\sigma(\phi,\phi_S)-\sigma(\phi,\phi_S+\pi)\propto \Im m[F_2\mathcal{H}\text{ - }F_1\mathcal{E}]$$

- Transverse Double-Spin Asymmetry

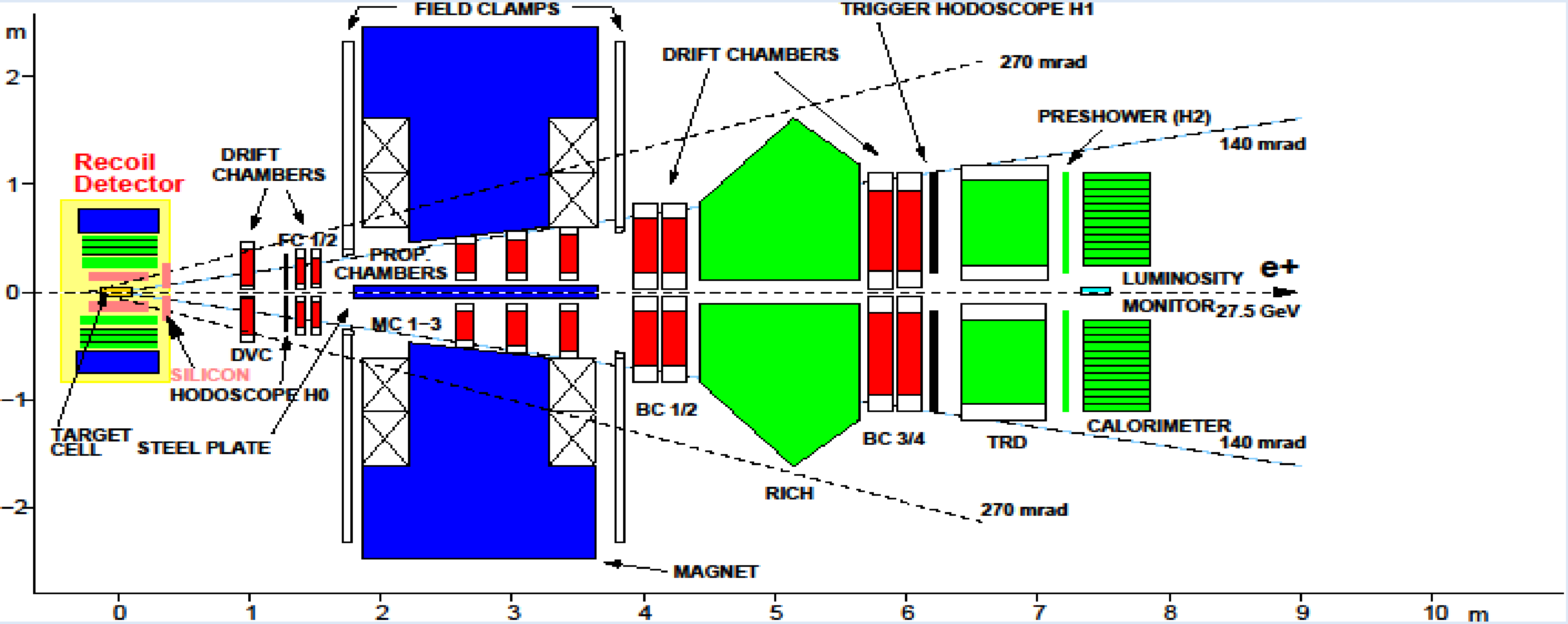
$$\sigma(\vec{e},\phi,\phi_S)-\sigma(\overleftarrow{e},\phi,\phi_S+\pi)\propto \Re e[F_2\mathcal{H}\text{ - }F_1\mathcal{E}]$$



Compton Form Factors: convolutions of GPDs with hard scattering kernels

$$\mathcal{F}(\xi,t)=\sum_q\int_{-1}^{1}\mathrm{d}x C_q^{\mp}(\xi,x)F^q(x,\xi,t)$$

The HERMES Spectrometer



Data taking:1996-2005

Gas Target:

- *Long. polarized H(50 pb^{-1}), D(200 pb^{-1})*
- *Unpolarized H(400 pb^{-1}), D(300 pb^{-1})*
- *Unpolarized He,N,Ne,Kr,Xe (all : 400 pb^{-1})*
- *Transverse polarized H(170 pb^{-1})*

Beam:

- *Long. polarized e+ and e−*
- *Energy 27.6 GeV*
- *Both helicities*

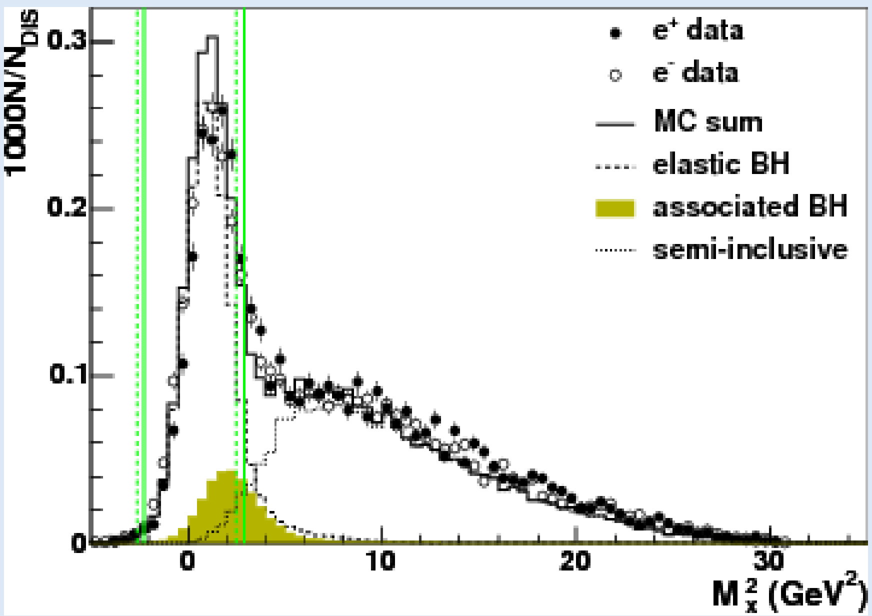
Data taking: 2006-2007, Recoil detector

DVCS without recoil detector

- Event with exactly one DIS – lepton and exactly one trackless cluster in the calorimeter.
- No recoil detection → Exclusivity via missing mass: $M_X^2 = (q + P - q')^2$

$5 < \Theta_{\gamma^*\gamma} < 45$ mrad
$-t < 0.7$ GeV^2, $E_\gamma > 5$ GeV
$0.03 < x_B < 0.35$, $1 < Q^2 < 10$ GeV^2
$W > 3$ GeV, $\nu < 22$ GeV

MC for background and cuts, systematic uncertainty



$e\ p \rightarrow e'\ X\ \gamma$

$e\ p \rightarrow e'\ p\ \gamma$; elastic BH

$e\ p \rightarrow e'\ \Delta^+\ \gamma$; associated BH

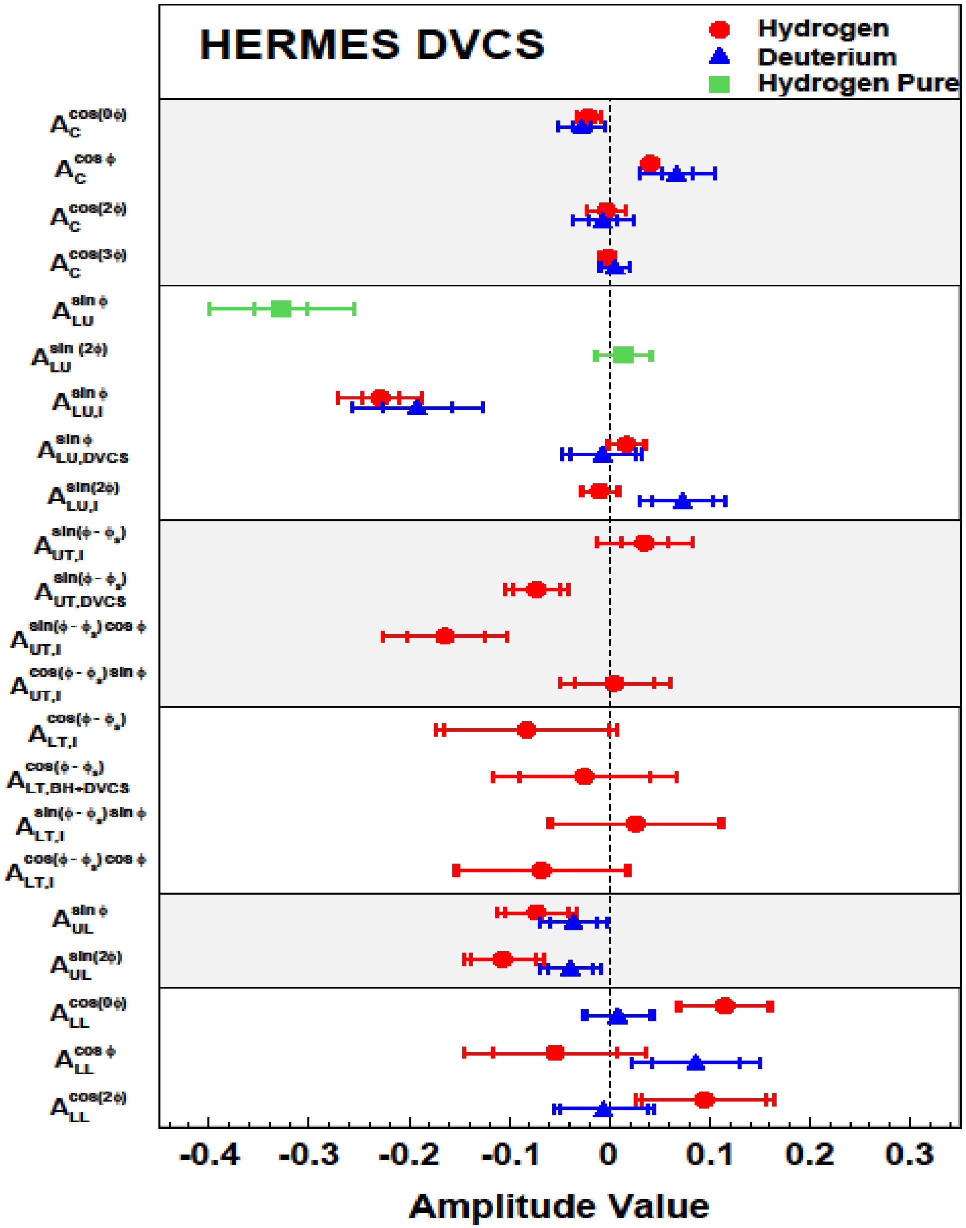
$e\ p \rightarrow e'\ \pi^0\ X$; semi-inclusive

Correction; π^0 background ($\approx 3\%$)

Associated ($\approx 12\%$); part of signal

→ Exclusive bin ($-(1.5)^2 < M_X^2 < (1.7)^2$ GeV^2)

Exclusive measurements: DVCS asymmetries at HERMES



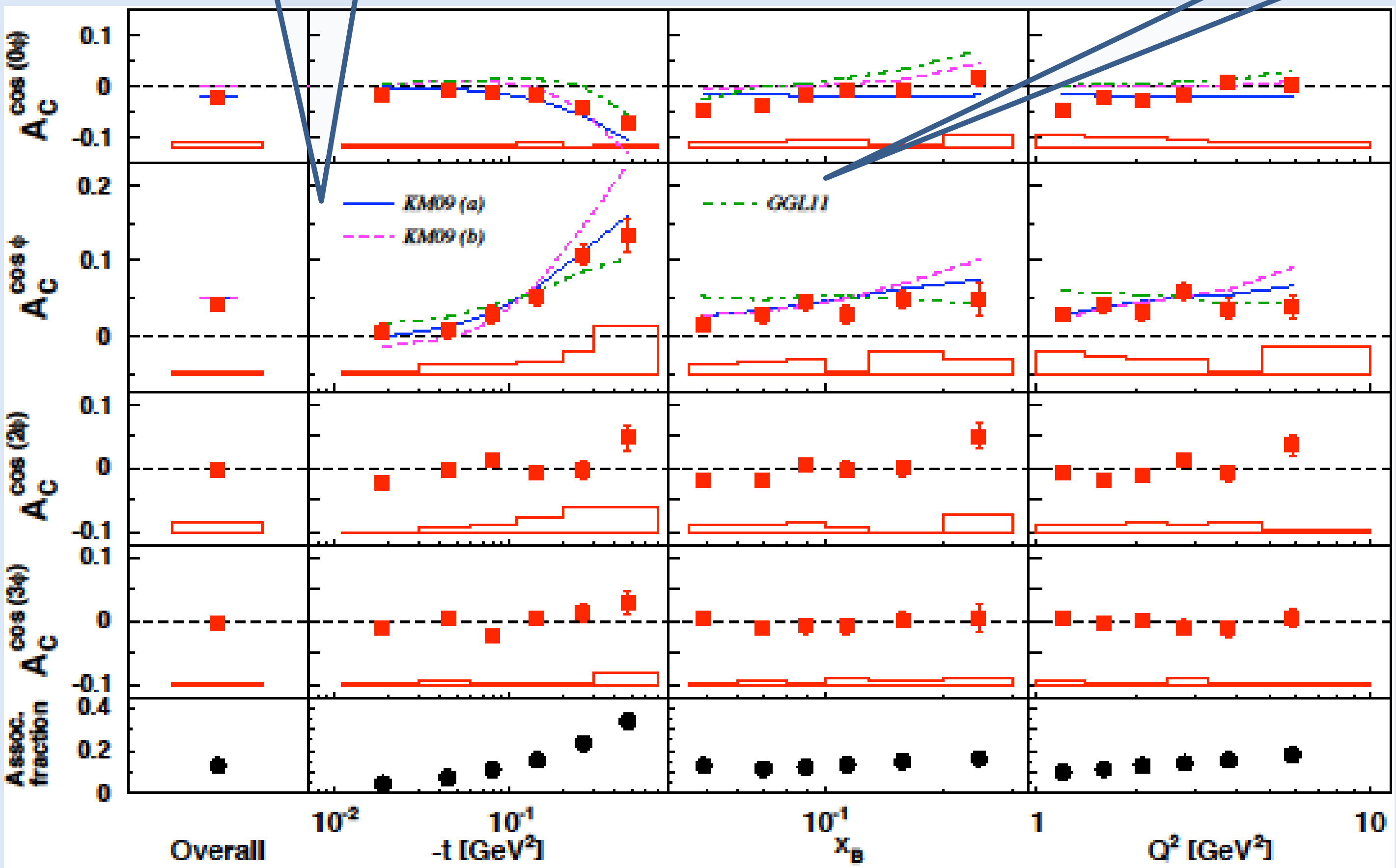
- Beam-charge asymmetry
  GPD H
  H: PRL 87 (2001) 182001
  PRD 75 (2007) 011103
  JHEP 11 (2009) 083
  JHEP 07 (2012) 032 JHEP 10 (2012) 042
  D: Nucl. Phys. B 829 (2010)1
- Beam-spin asymmetry
  GPD H
- Transverse target-spin asymmetry
  GPD E H: JHEP 06 (2008) 066
- Transverse double-spin asymmetry
  GPD E H: Phys. Lett. B 704 (2011) 15
- Longitudinal target spin asymmetry
  GPD $\tilde{H}$ H: JHEP 06 (2010) 019
  D: Nucl. Phys. B 842 (2011) 265
- Longitudinal double spin asymmetry
  GPD $\tilde{H}$

Beam-Charge Asymmetry

KM09:global fit
Including data from HERA
HERMES and Jlab
K. Kumericki, D. Muller
Nucl. Phys. **B 84** (2010) 1

GGL11:model calculation
G. Goldstain, S. Liuti,
J. Hernandez
Phys. Rev. **D 84** 034007 (2010)

JHEP 07 (2012) 032, arXiv:1203.6287



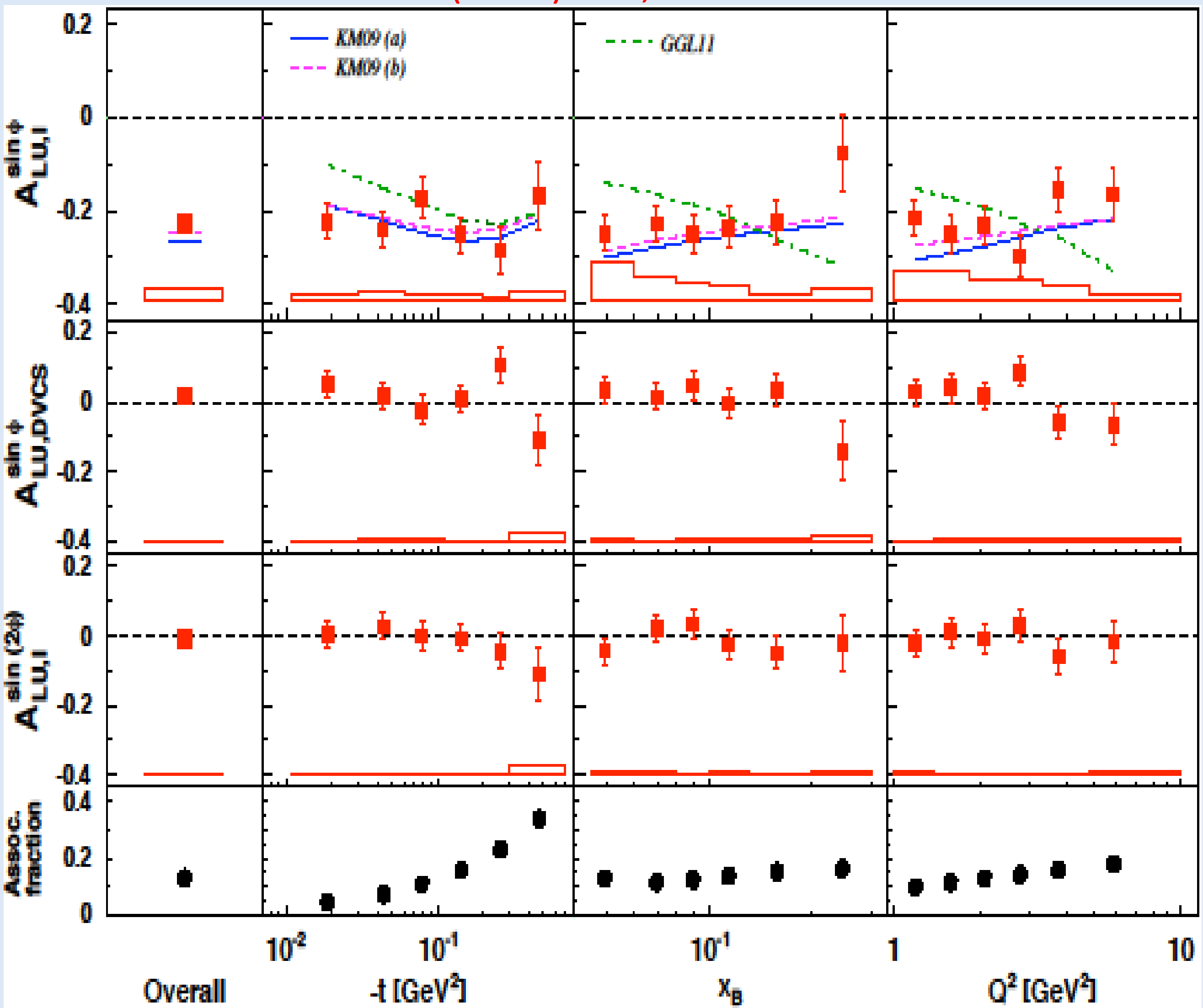
$\propto -A_C^{\cos(\phi)}$

$\propto \Re e[F_1\mathcal{H}]$

Fractions of associated process from MC

Beam-Spin Asymmetry

JHEP 07 (2012) 032, arXiv:1203.6287



$\propto \Im m[F_1 \mathcal{H}]$

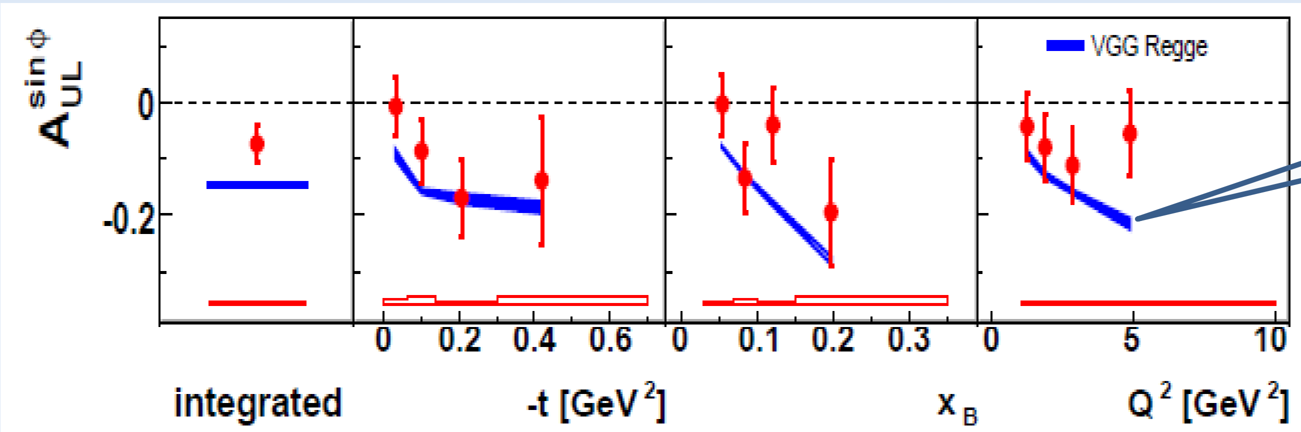
$\propto \Im m[\mathcal{H}\mathcal{H}^* + \tilde{\mathcal{H}}\tilde{\mathcal{H}}^*]$

Fractions of associated process from MC

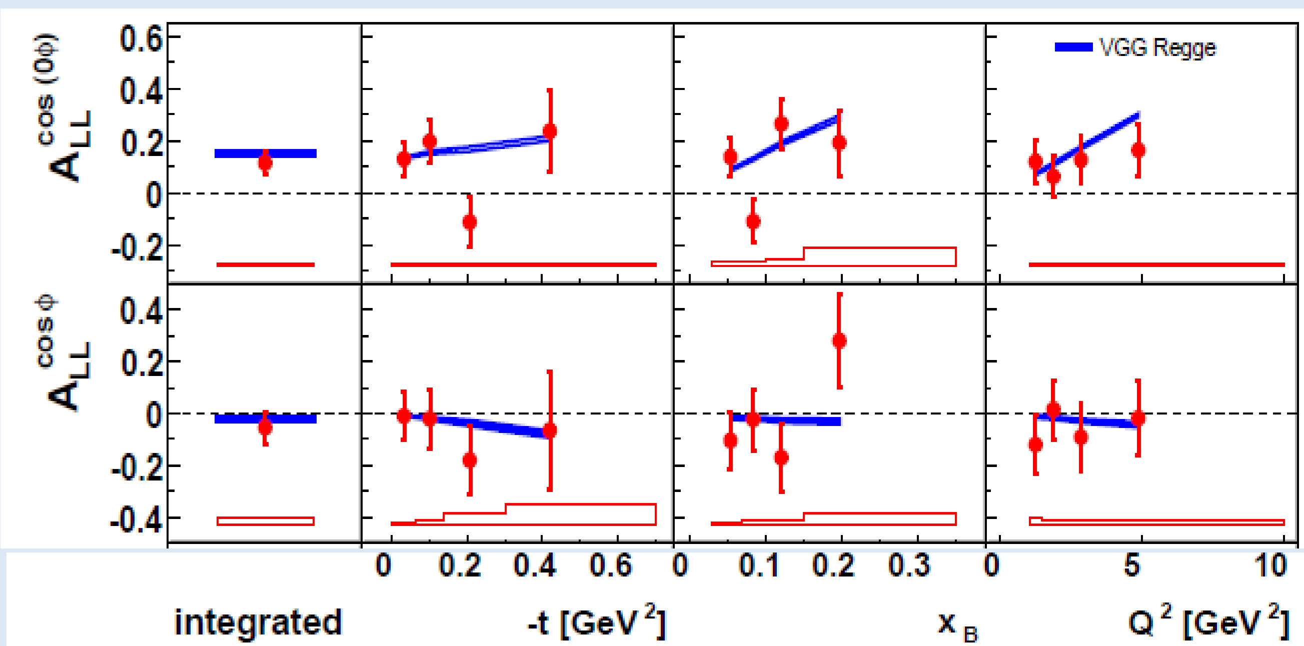
Longitudinal Single- and Duble-Spin Asymmetries

JHEP 06 (2010) 019, arXiv:1004.0177

VGG: model calculation
M. Vanderhaeghen, P. Guichon, M. Guidal
Phys. Rev. **D60** (1999) 0940177
Prog. Nucl. Phys. **47** (2001) 401



$\propto \Im m[F_1 \tilde{\mathcal{H}}]$

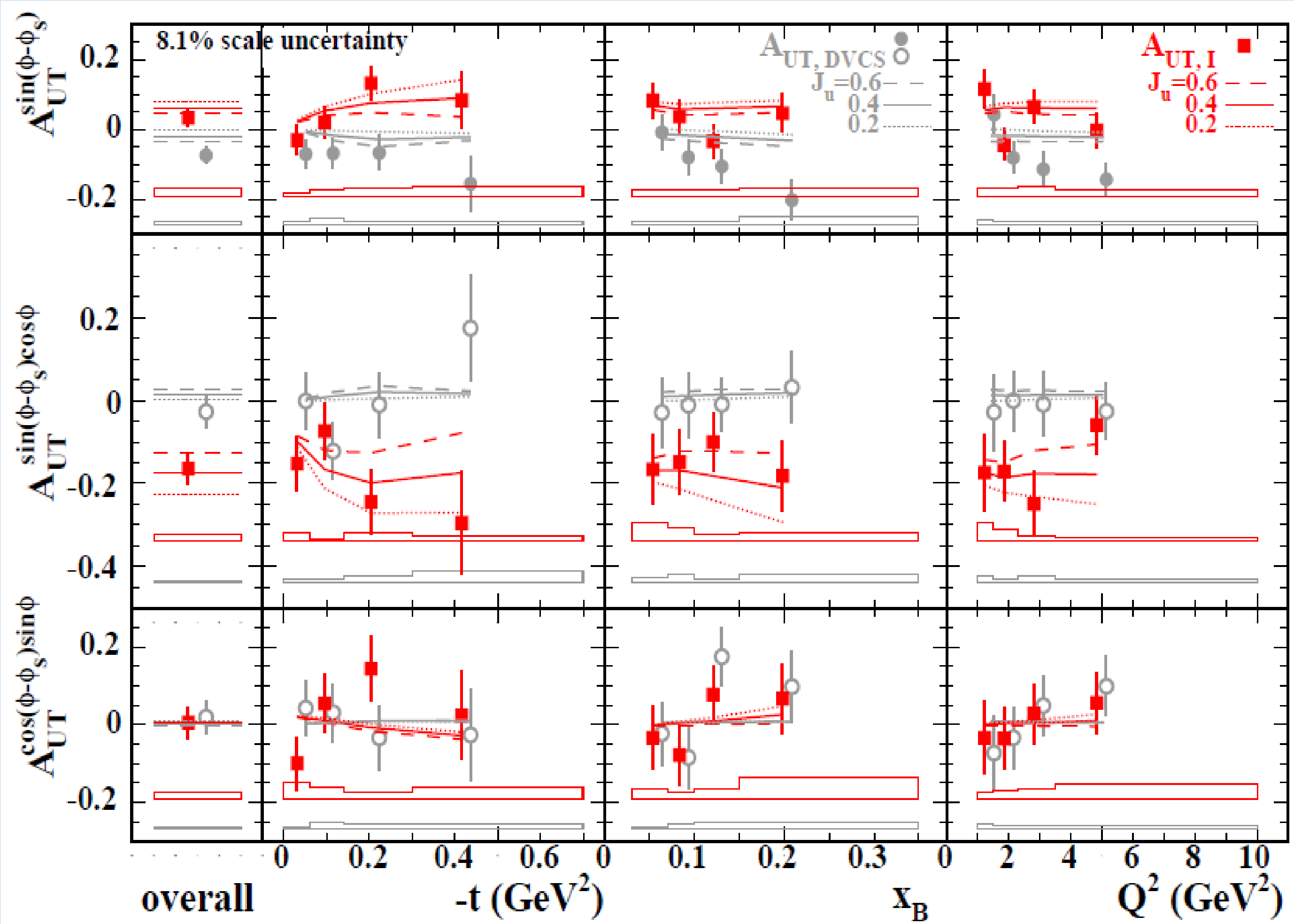


Relatively large BH contribution to these asymmetries

$\propto \Re e[F_1 \tilde{\mathcal{H}}]$

DVCS: Transverse Target-Spin Asymmetry A_{UT}

Sensitive to GPD E   JHEP 06 (2008) 066, arXiv:0802.2499



Sensitive to J_u

$$\propto \Im m[F_2\mathcal{H} - F_1\mathcal{E}]$$

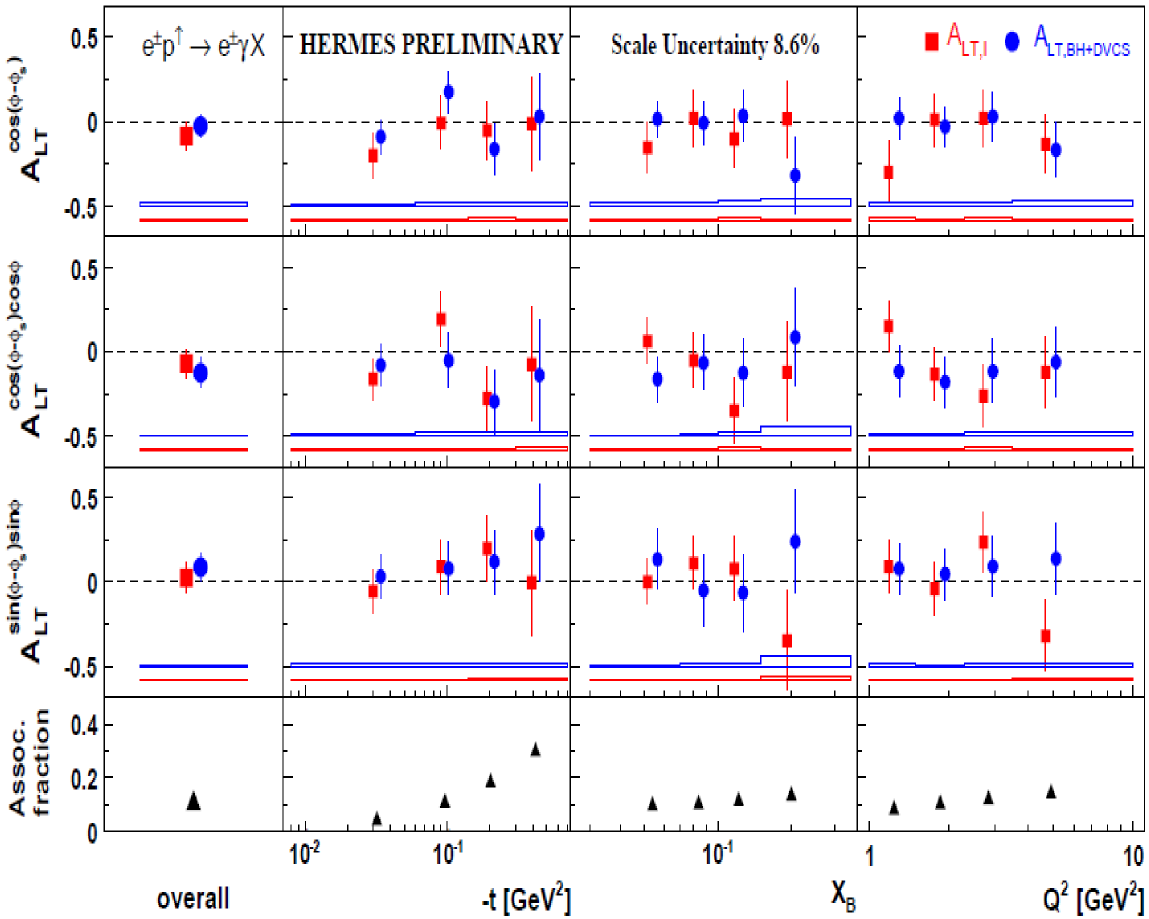
Not sensitive to J_u

$$\propto \Im m[F_2\tilde{\mathcal{H}} - (F_1 + \xi F_2)\tilde{\mathcal{E}}]$$

Model: VGG with variation of J_u, while J_d=0

DVCS: Transverse Double-Spin Asymmetry A_{LT}

Phys Lett. B704 (2011) 15, arXiv:1106.2990



$$\propto A_{LT}^{\cos(\phi-\phi_S)\cos(\phi)}$$

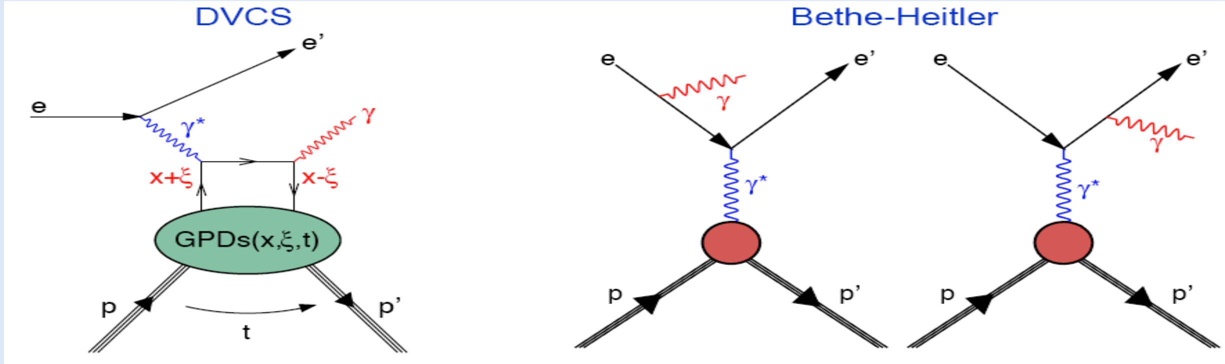
$$\propto \begin{array}{l} \Re e\left[F_2\tilde{\mathcal{H}} - (F_1+\xi F_2)\tilde{\mathcal{E}}\right] \\ \Re e\left[\mathcal{H}\mathcal{E}^* - \mathcal{E}\mathcal{H}^* - \xi\left(\tilde{\mathcal{H}}\tilde{\mathcal{E}}^* - \tilde{\mathcal{E}}\tilde{\mathcal{H}}^*\right)\right] \end{array}$$

$$\propto \begin{array}{l} \Re e\left[F_2\mathcal{H} - F_1\mathcal{E}\right] \\ \Re e\left[-\tilde{\mathcal{H}}\mathcal{E}^* - \tilde{\mathcal{H}}^*\mathcal{E} + \xi\left(\mathcal{H}\tilde{\mathcal{E}}^* + \tilde{\mathcal{E}}\mathcal{H}^*\right)\right] \end{array}$$

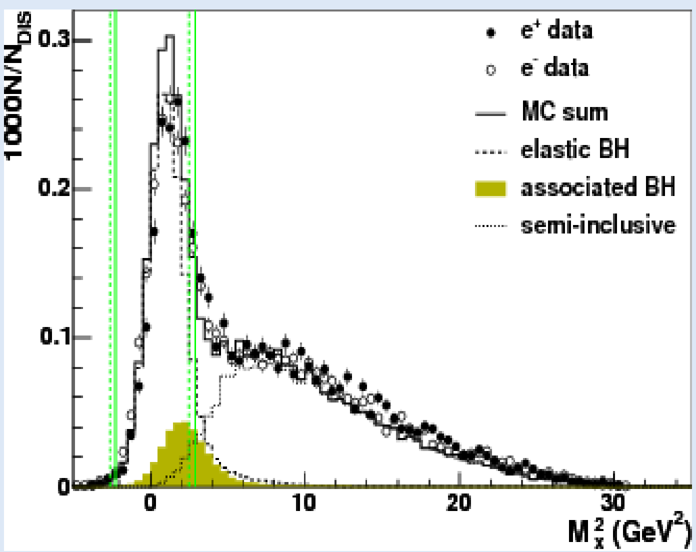
Sensitive to both GPDs entering the Ji sum rule

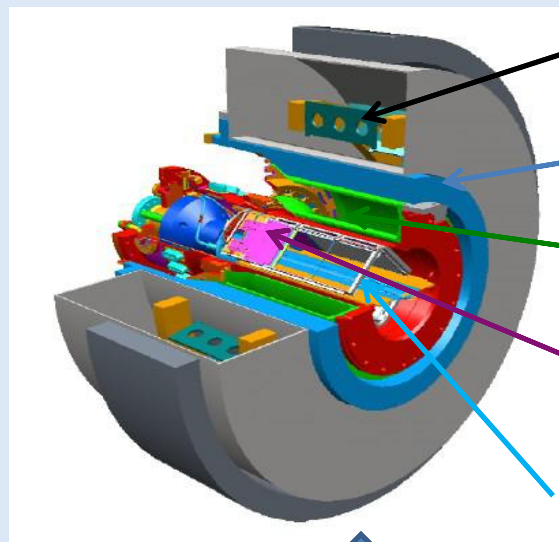
Consistent with zero, cancellations between E and H
Sensitivity to J_u is suppressed by kinematic factors

DVCS with Recoil Detector



e p → e' γ X





1 T SC Solenoid

Photon Detector

Scintillating fiber Tracker

Silicon-Strip Detector

Unpolarized H and D targets

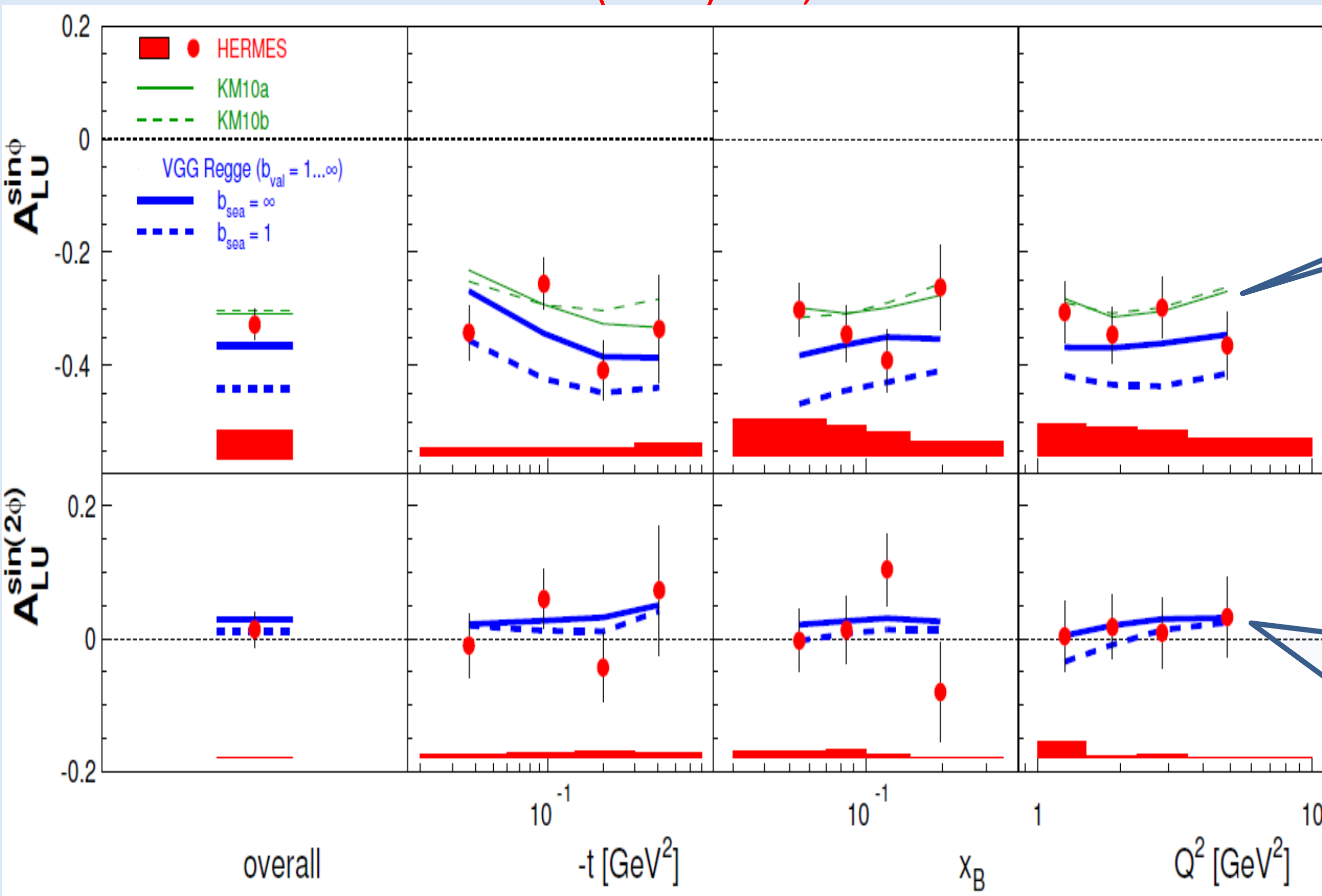
Exclusivity via missing mass:

$M_X^2 = (q + P - q')^2$

Recoil Detector to tag exclusivity

Pure elastic DVCS

JHEP 10 (2012) 042, arXiv:1206.5683



KM10:global fit
Including data from HERA
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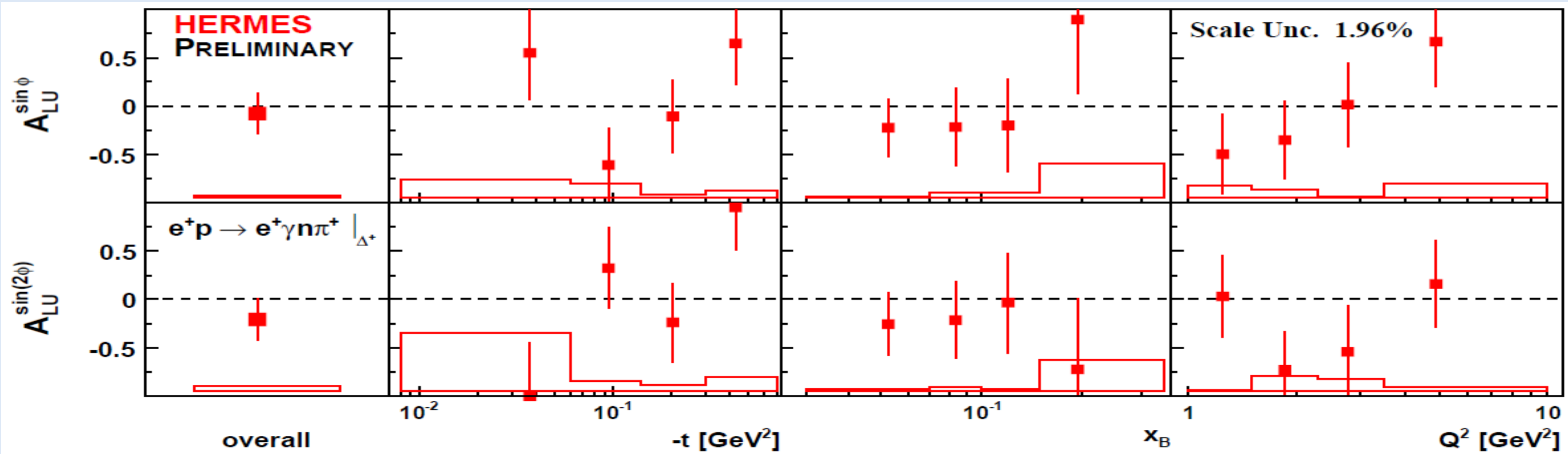
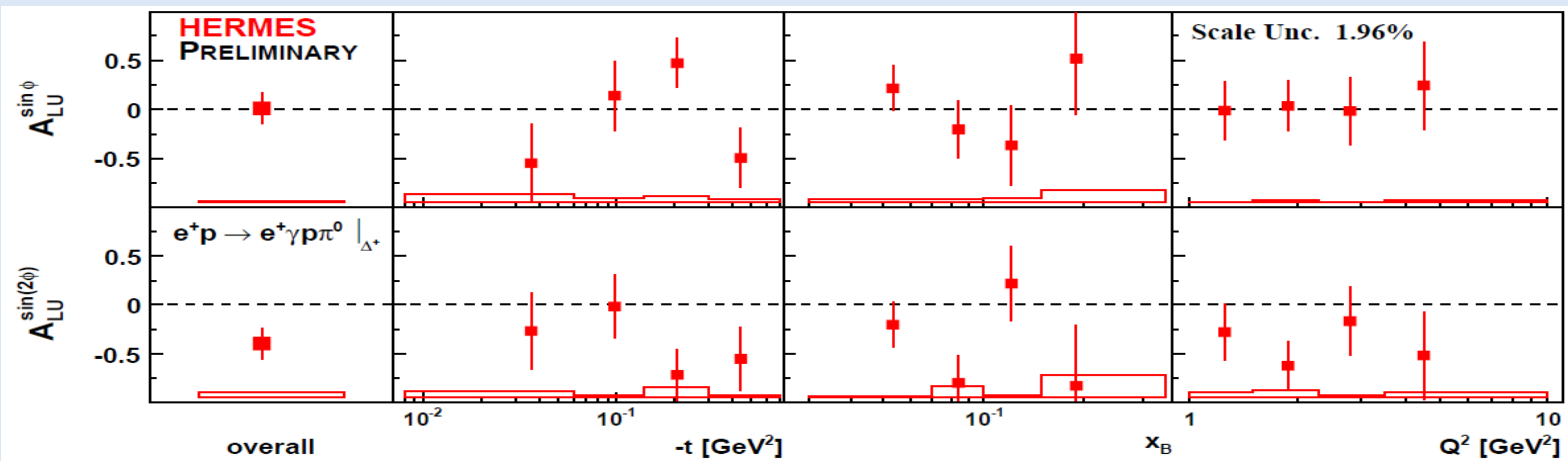
Prog. Nucl. Phys. **47** (2001) 401

The leading amplitude for pure elastic process is larger than for unresolved signal (elastic+associated) and well described by recent fits to previously published data

Beam-Spin Asymmetry in „associated“ DVCS : $ep \rightarrow e\gamma\Delta^{+}$



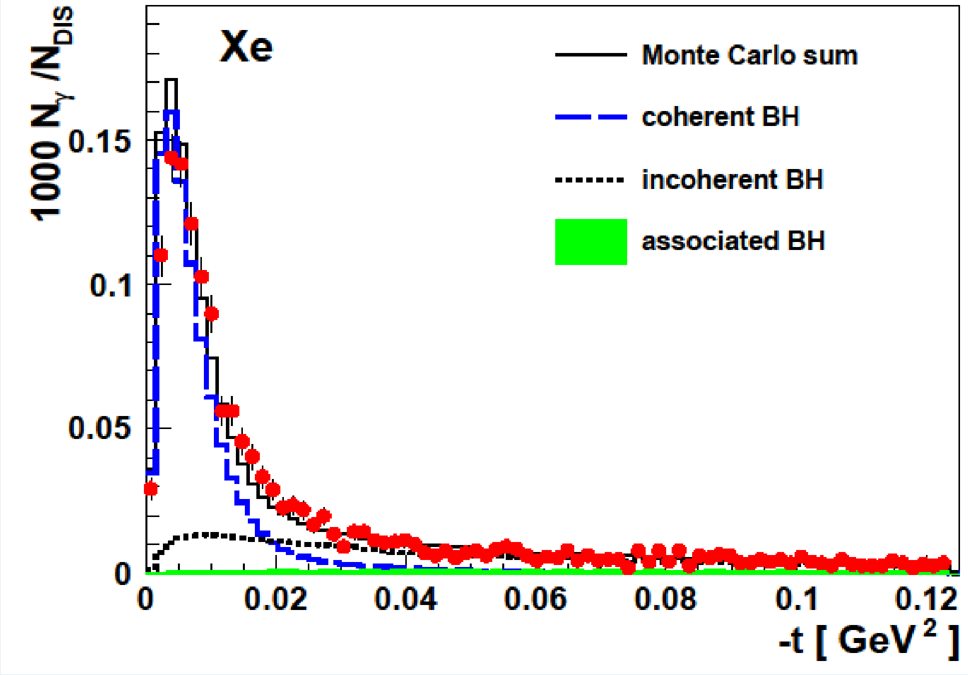


Correction: π^0 SIDIS background (5-25% for $p\pi^0$, and 8-44% for $n\pi^+$ channel)
Elastic (≈ 1%)

Beam-Charge /Spin Asymmetries on heavier nuclei

Phys. Rev. C 81 (2010) 035202

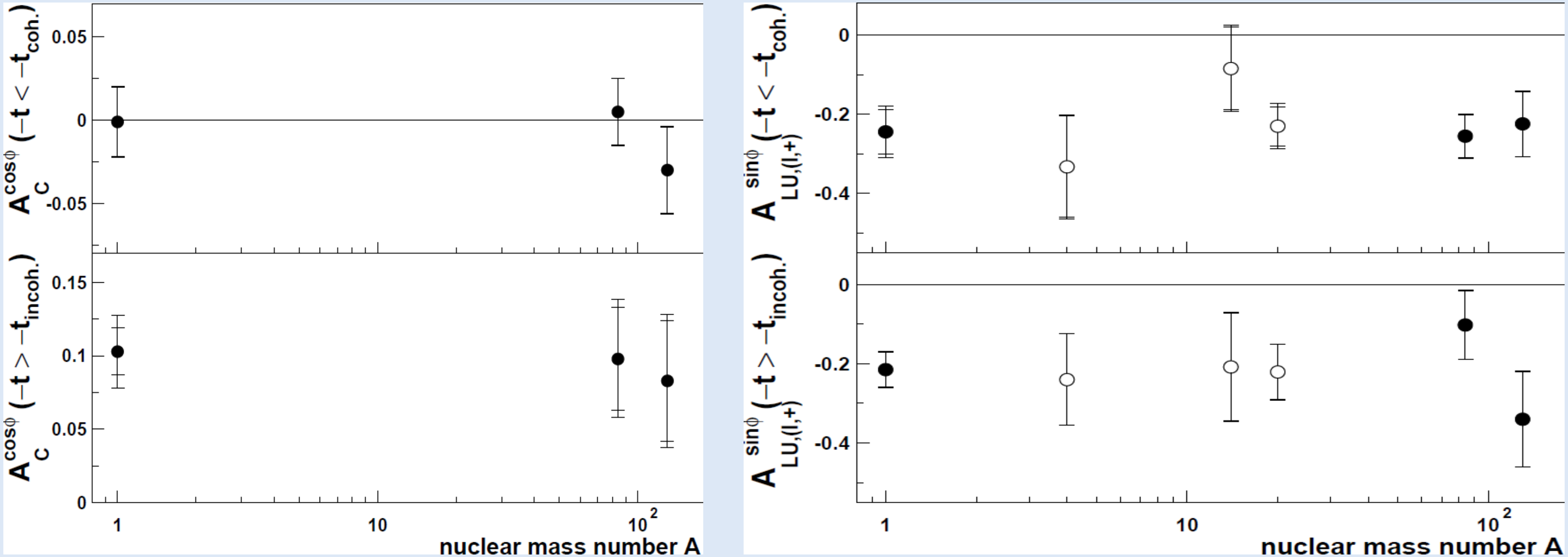
Target	Spin	L (pb^{-1})
^{1}H	1/2	227
He	0	32
N	1	51
Ne	0	86
Kr	0	77
Xe	0, 1/2, 3/2	47



- Separation of coherent-enriched and incoherent-enriched data samples by t- cutoffs : similar average kinematics
- Coherent-enriched samples: ≈ 65 %
- Incoherent enriched samples: ≈ 60 %

Nuclear-mass dependence of asymmetries

$A_C^{\cos\phi}$ vs. A $\qquad$ $A_{LU}^{\sin\phi}$ vs. A



A_{LU}^{A} / A_{LU}^{H} ⟹

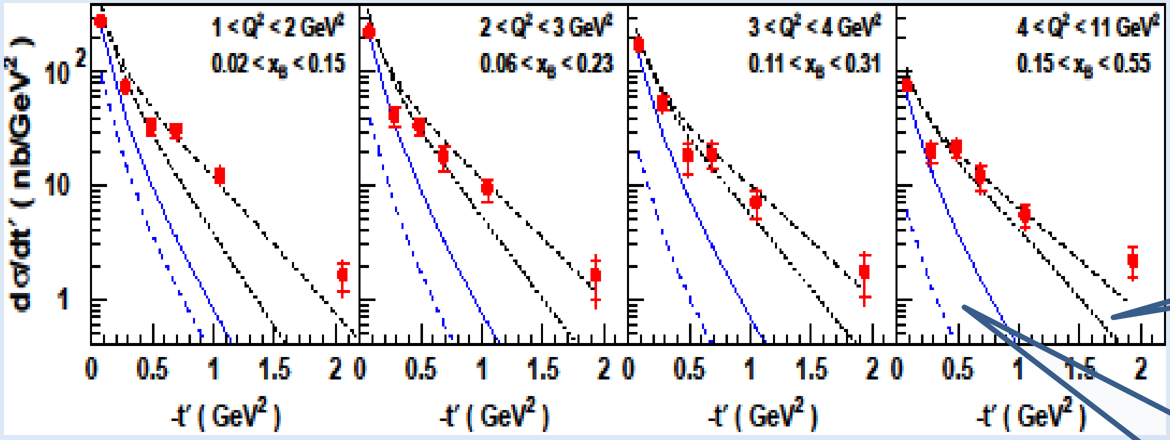
Coherent-enriched: 0.91 ± 0.19

Incoherent-enriched: 0.93 ± 0.23

Cross section of exclusive π^+ production

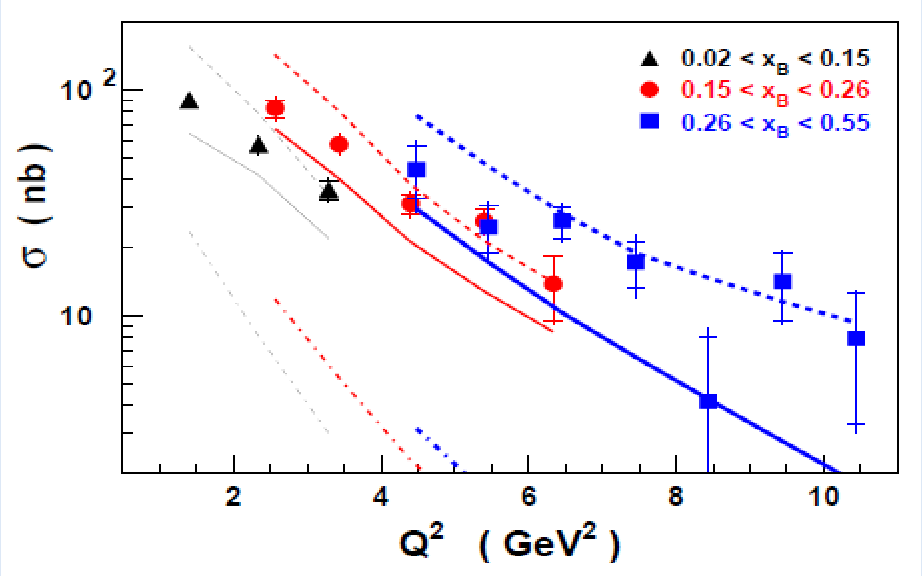
$\gamma p \rightarrow \pi^+ n$ $\quad \sigma_L \propto (1-\xi^2)|\tilde{\mathcal{H}}|^2 - \xi^2 t|\tilde{\mathcal{E}}|^2 - \xi^2 \Re e(\tilde{\mathcal{E}} * \tilde{\mathcal{H}})$

Phys. Lett. B 659 (2008) 486, arXiv:0707.0222



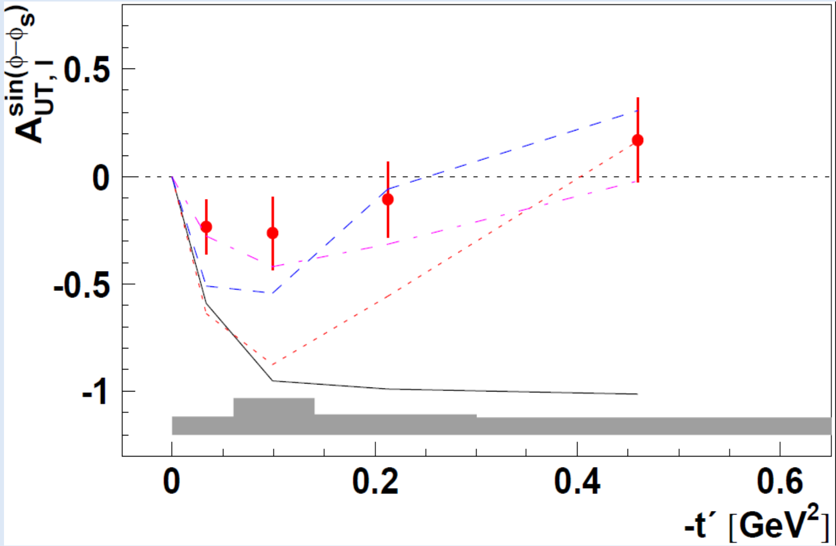
Regge model: J. M. Laget
Phys Rev. D 70 (2004) 054023
- - - $d\sigma/dt'$
…… $d\sigma_L/dt'$

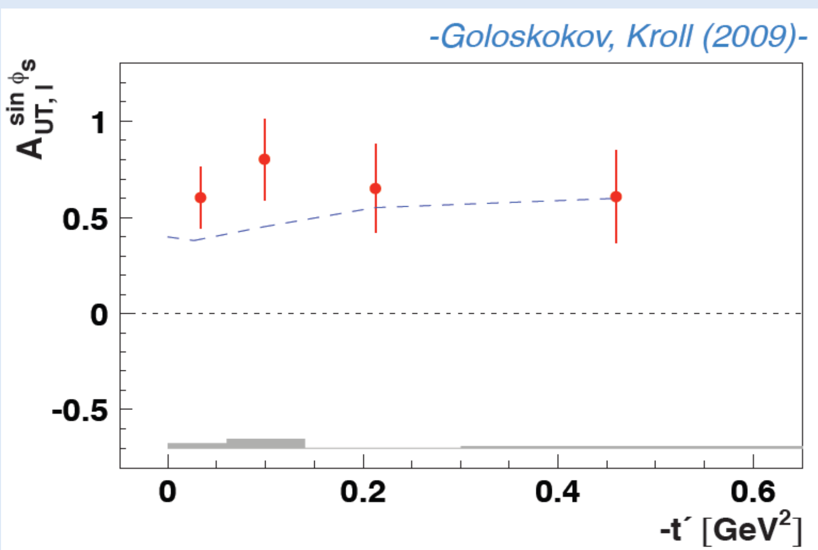
GPD model: VGG
Phys. Rev. D 60 (1999) 094017
- • - $d\sigma_L/dt'$ leading order
---- with power correction



GPD model:
Fair agreement at lower t'
Regge model:
Good description of the data

Target-Spin asymmetry in exclusive π^+ production





Phys. Lett. B 682 (2010) 351, arXiv:0907.5369

$$A_{UT}^{\sin(\phi-\phi_S)} \propto \Im m[\tilde{\mathcal{E}}^* \tilde{\mathcal{H}}^*]$$

Small value with possible change of the sign

Theoretical expectations:

Large negative value:

L. L. Frankfurt et al. (2000)

A. V. Belitsky, D. Muller (2001)

Difference could be due to the $\gamma^\star_T$:

S. Goloskokov, P. Kroll (2009)

Ch. Bechler, D. Muller (2009)

$$A_{UT}^{\sin\phi}$$

Large positive value can be explained by sizable interference between the $\gamma^\star_L$ and $\gamma^\star_T$

Exclusive vector meson production

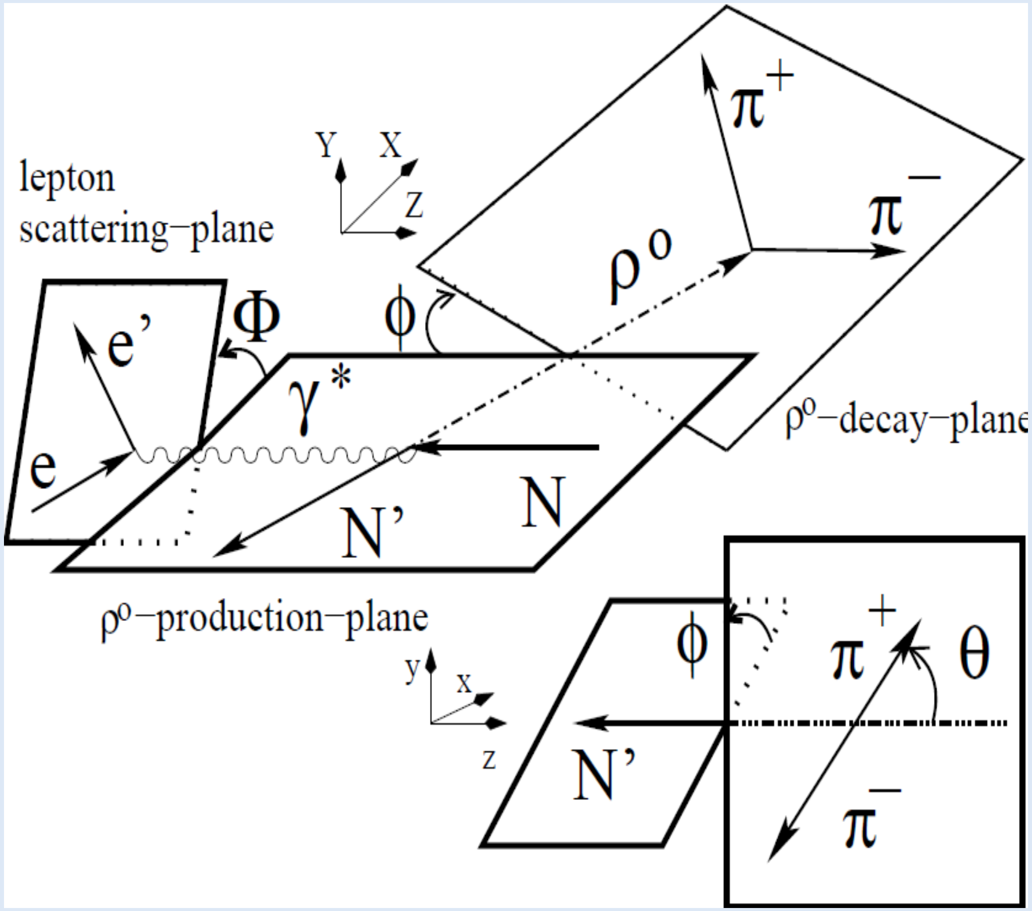
Meson SDMEs
EPJC 62 (2009) 659

Photon SDMEs

$$r^{\eta}_{\lambda_V \mu_V} = \frac{1}{2N} \sum_{\lambda_\gamma \mu_\gamma \lambda'_N \lambda_N} F_{\lambda_V \lambda'_N \lambda_\gamma \lambda_N} \Sigma^{\eta}_{\lambda_\gamma \mu_\gamma} F^{*}_{\mu_V \lambda'_N \mu_\gamma \lambda_N}$$

Helicity amplitudes

$$F_{\lambda_V \lambda_\gamma} = T_{\lambda_V \lambda_\gamma} + U_{\lambda_V \lambda_\gamma}$$



- Helicity amplitudes are the fundamental quantities to be compared with theory
- They form a basis for the SDMEs
- Natural Parity Exchange (NPE)

  $T_{\lambda_V \lambda_\gamma}$ $GPDs(\mathcal{H}, \mathcal{E})$
- Unnatural Parity Exchange (UPE)

  $U_{\lambda_V \lambda_\gamma}$ $GPDs(\widetilde{\mathcal{H}}, \widetilde{\mathcal{E}})$

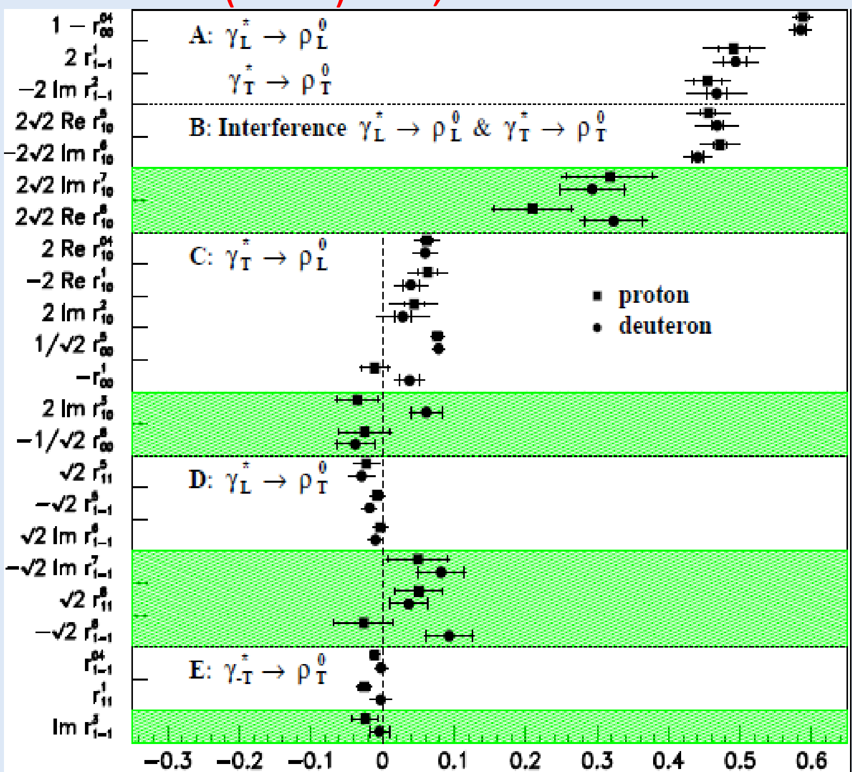
SDMEs on unpolarized targets: ρ^0 & ϕ productions

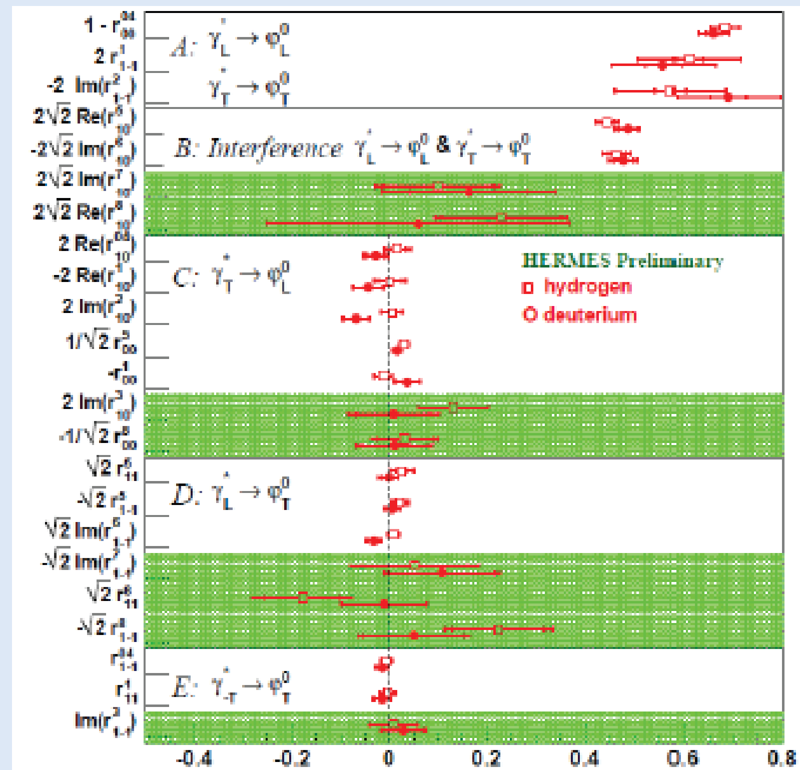
Hierarchy predicted by theory: confirmed by HERMES

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

$\gamma^*_L \to V_L$ $\quad$ $\gamma^*_T \to V_T$ $\quad$ $\gamma^*_T \to V_L$ $\quad$ $\gamma^*_L \to V_T$

EPJ C 62 (2009) 659, arXiv:0901.0701





$\gamma^*_L \to V_L$ & $\gamma^*_T \to V_T$:
10-20% difference between ρ^0 & ϕ

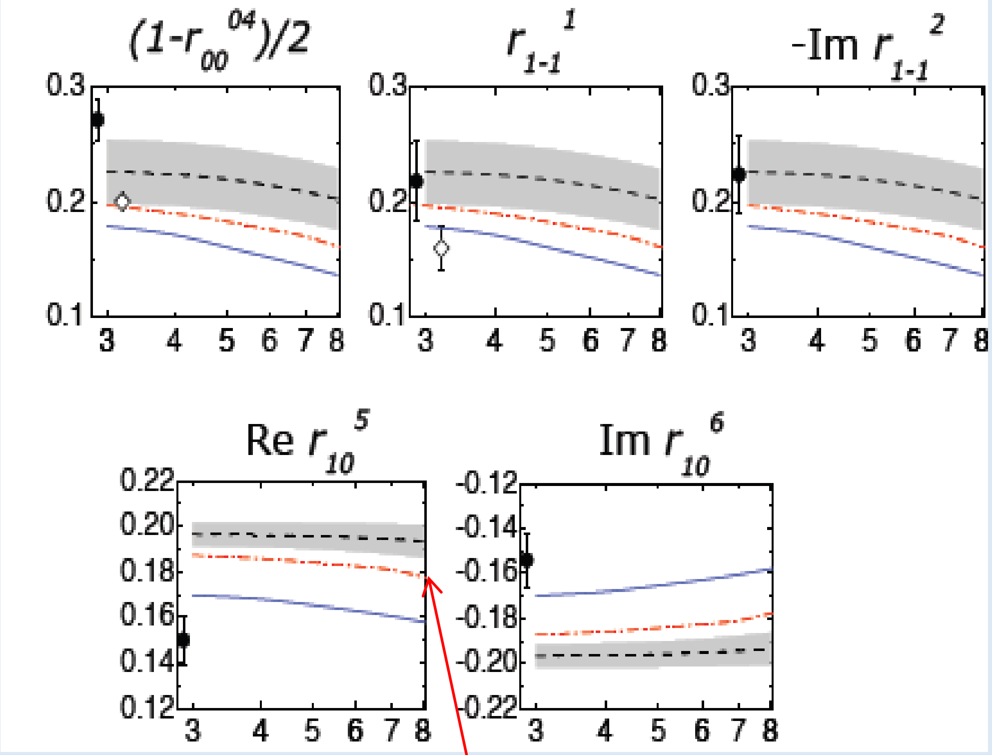
$\gamma^*_T \to V_L$:
pronounced difference between ρ^0 & ϕ

Comparison of ρ^0 SDMEs to GPD model

$\gamma^*_L \to \rho^0_L$ & $\gamma^*_T \to \rho^0_T$

$$1 - r^{04}_{00}, r^1_{1-1}, -\Im m r^2_{1-1} \propto T_{11}$$

GPD model: S. Goloskokov, P. Kroll (2007)



W = 5 GeV, 10 GeV and 75 GeV

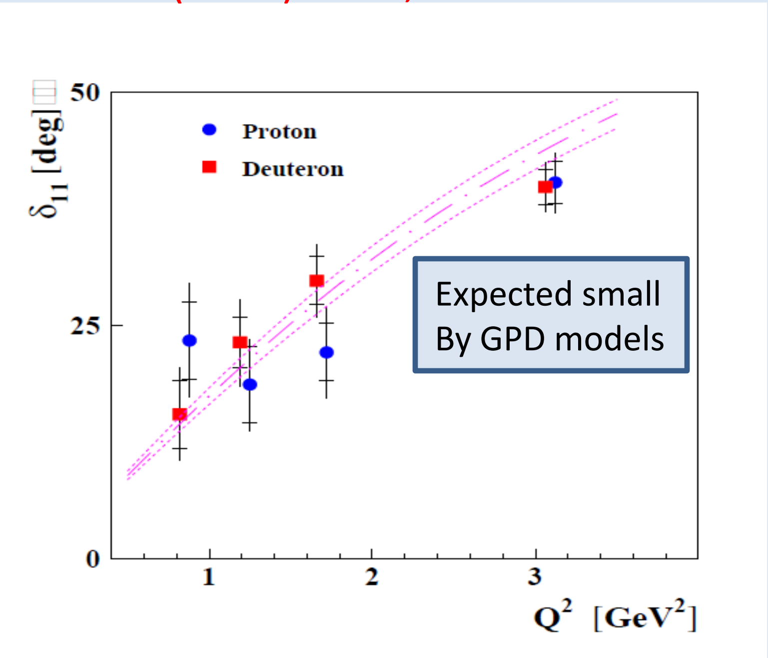
Model is in an agreement with data

Interference

$\gamma^*_L \to \rho^0_L$ & $\gamma^*_T \to \rho^0_T$

$$\tan(\delta_{11}) = \Im m(T_{11}/T_{00}) / \Re e(T_{11}/T_{00})$$

EPJ C 71 (2011) 1609, arXiv:1012.3676



Model predicts phase difference between T_{11} and T_{00}, $\delta_{11} = 3.1$ deg.

$\delta_{11} \simeq 20$ deg. observed by H1

Observation of Unnatural Parity Exchange

At large W^2 and Q^2 the transition expected to be suppressed

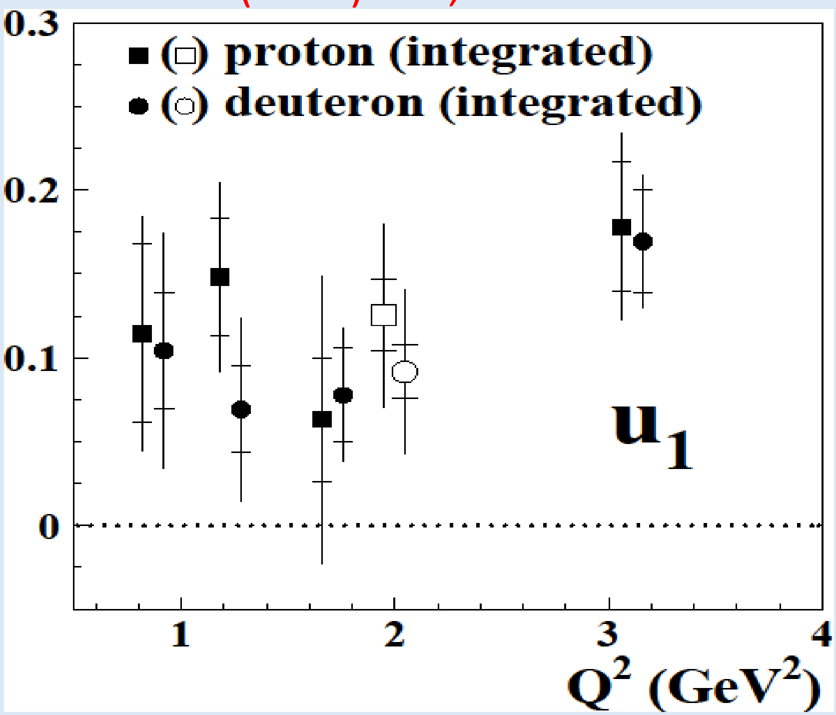
The combinations of SDMEs are expected to be zero in case of NPE:

$$u_1 = 1 - r^{04}_{00} + 2r^{04}_{1-1} - 2r^{1}_{11} - 2r^{1}_{1-1}$$

$$u_2 = r^{5}_{11} + r^{5}_{1-1}$$

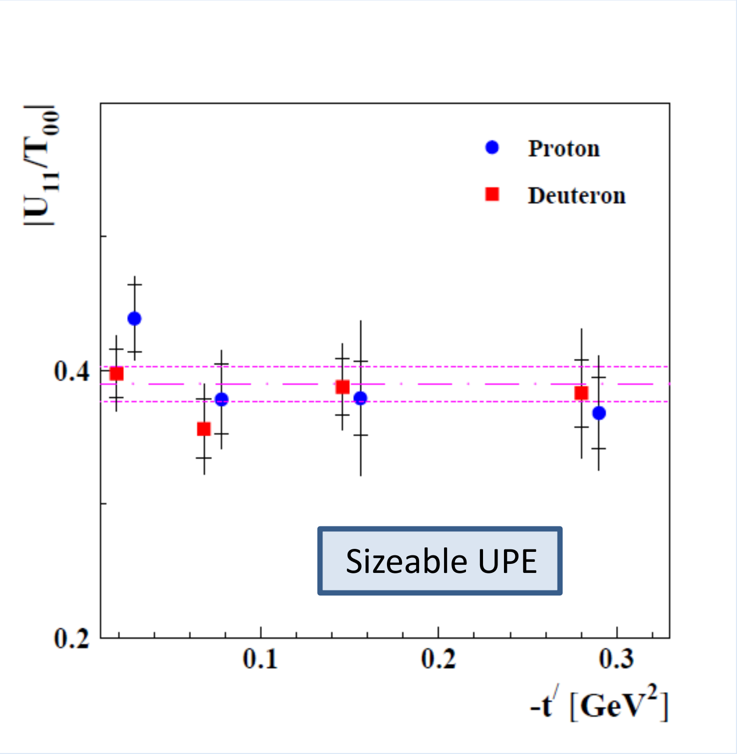
$$u_3 = r^{8}_{11} + r^{8}_{1-1}$$

EPJ C 62 (2009) 659, arXiv:0901.0701



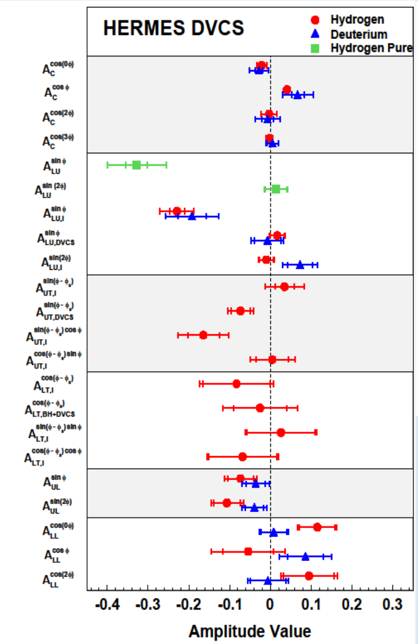
Direct analysis of amplitude ratio

EPJ C 71 (2011) 1609, arXiv:1012.3676

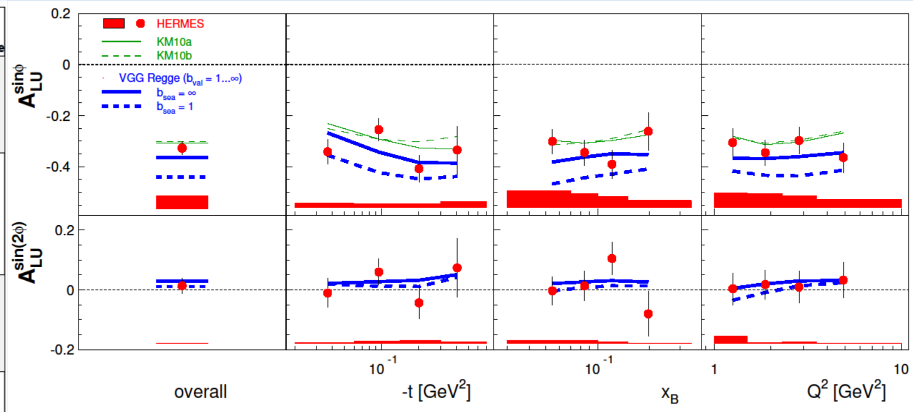


Significant UPE contribution for ρ^0, sensitivity to GPD $\tilde{\mathcal{H}}$

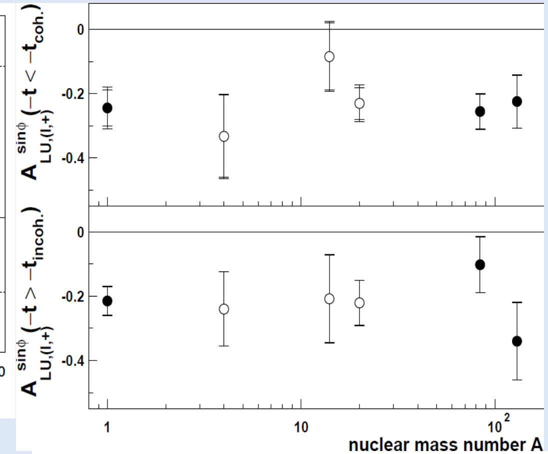
Summary



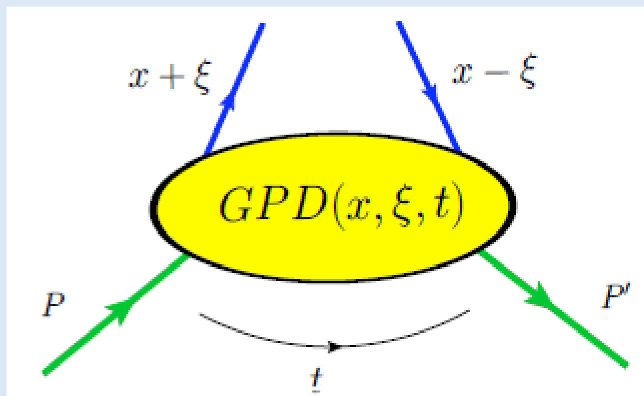
HERMES DVCS
Hydrogen
Deuterium
Hydrogen Pure
Amplitude Value



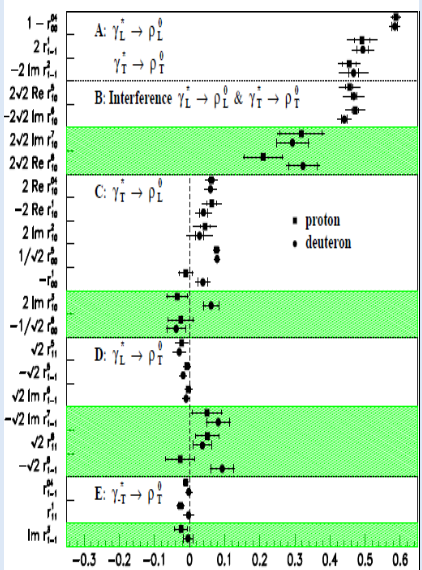
HERMES
KM10a
KM10b
VGG Regge
overall
-t [GeV²]
x_B
Q² [GeV²]



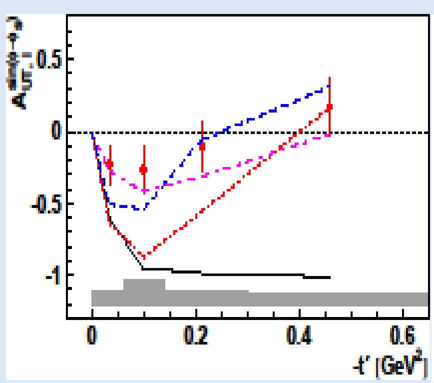
nuclear mass number A



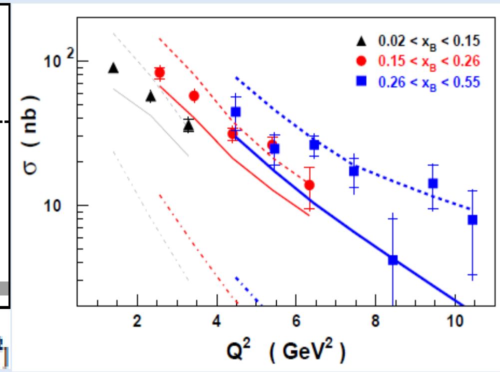
$x+\xi$
$x-\xi$
$GPD(x,\xi,t)$
P
P'
t



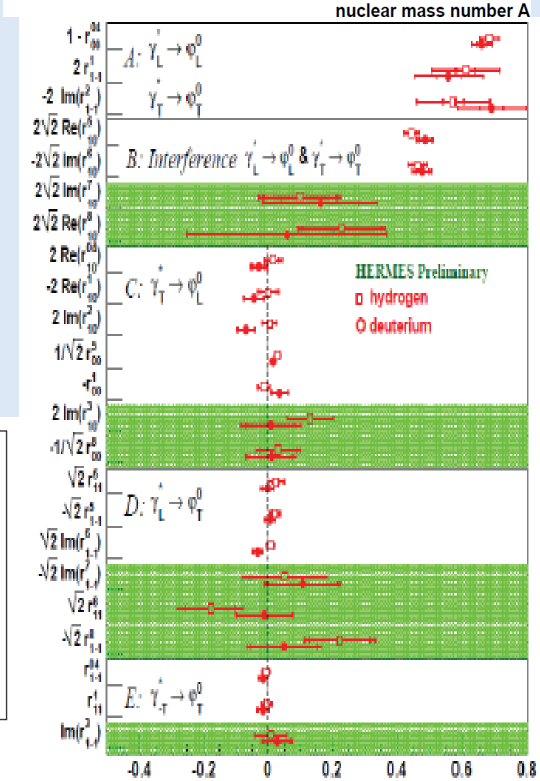
proton
deuteron



-t' [GeV²]



0.02 < x_B < 0.15
0.15 < x_B < 0.26
0.26 < x_B < 0.55
σ (nb)
Q² (GeV²)



HERMES Preliminary
hydrogen
deuterium

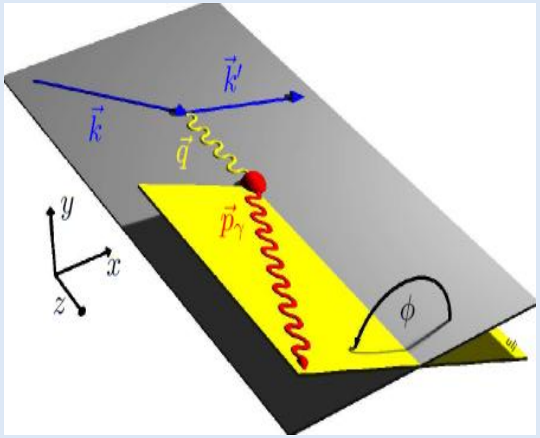
Backup Slides

Azimuthal dependences in DVCS

$$|\tau_{\mathrm{BH}}|^2 = \frac{K_{\mathrm{BH}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \sum_{n=0}^{2} C_n^{\mathrm{BH}} \cos(n\phi)$$

$$|\tau_{\mathrm{DVCS}}|^2 = K_{\mathrm{DVCS}} \left\{ \sum_{n=0}^{2} C_n^{\mathrm{DVCS}} \cos(n\phi) + \sum_{n=1}^{2} S_n^{\mathrm{DVCS}} \sin(n\phi) \right\}$$

$$\mathrm{I} = -\frac{e_l K_{\mathrm{I}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left\{ \sum_{n=0}^{3} C_n^{\mathrm{I}} \cos(n\phi) + \sum_{n=1}^{3} S_n^{\mathrm{I}} \sin(n\phi) \right\}$$



Fourier coefficients are related to certain linear or bi-linear combinations of Compton Form factors (CFFs):

$$\mathcal{F}(\xi,t) = \sum_q \int_{-1}^{1} \mathrm{d}x C_q^{\mp}(\xi,x) F^q(x,\xi,t)$$

Azimuthal asymmetries in DVCS off unpolarized targets

$$\sigma_{LU}(\phi, P_l, e_l) = \sigma_{UU}[1 + e_l A_C(\phi) + e_l P_l A_{LU}^{I}(\phi) + P_l A_{LU}^{DVCS}(\phi)]$$

Charge-difference beam-helicity asymmetry:

$$A_{LU}^{I}(\phi) = \frac{(\sigma^{+\rightarrow} - \sigma^{+\leftarrow}) - (\sigma^{-\rightarrow} - \sigma^{-\leftarrow})}{(\sigma^{+\rightarrow} + \sigma^{+\leftarrow}) + (\sigma^{-\rightarrow} + \sigma^{-\leftarrow})} = -\frac{1}{D(\phi)} \frac{x_B}{y} \sum_{n=1}^{2} s_n^I \sin(n\phi)$$

Charge-averaged beam-helicity asymmetry:

$$A_{LU}^{DVCS}(\phi) = \frac{(\sigma^{+\rightarrow} - \sigma^{+\leftarrow}) + (\sigma^{-\rightarrow} - \sigma^{-\leftarrow})}{(\sigma^{+\rightarrow} + \sigma^{+\leftarrow}) + (\sigma^{-\rightarrow} + \sigma^{-\leftarrow})} = \frac{1}{D(\phi)} \cdot \frac{x_B^2 t \mathcal{P}_1(\phi) \mathcal{P}_2(\phi)}{Q^2} s_1^{DVCS} \sin(\phi)$$

Beam-Charge asymmetry:

$$A_C(\phi) = \frac{(\sigma^{+\rightarrow} + \sigma^{+\leftarrow}) - (\sigma^{-\rightarrow} + \sigma^{-\leftarrow})}{(\sigma^{+\rightarrow} + \sigma^{+\leftarrow}) + (\sigma^{-\rightarrow} + \sigma^{-\leftarrow})} = -\frac{1}{D(\phi)} \frac{x_B}{y} \sum_{n=0}^{3} c_n^I \cos(n\phi)$$

A_{LU}

beam target

- Measurement with both beam helicity and both beam charges
  ⟹ separate contributions from DVCS and Interference term
- This separation is impossible in measurements of single-charge beam-helicity asymmetry $A_{LU}(\phi) = (\sigma^{\rightarrow} - \sigma^{\leftarrow})/(\sigma^{\rightarrow} + \sigma^{\leftarrow})$

Asymmetries on longitudinally polarized targets

Single-charge target-spin asymmetry (Hydrogen/Deuterium):

$$A_{UL}(\phi, e_l) = \frac{[\sigma^{\rightarrow\Rightarrow}(\phi, e_l) + \sigma^{\leftarrow\Rightarrow}(\phi, e_l)] - [\sigma^{\rightarrow\Leftarrow}(\phi, e_l) + \sigma^{\leftarrow\Leftarrow}(\phi, e_l)]}{[\sigma^{\rightarrow\Rightarrow}(\phi, e_l) + \sigma^{\leftarrow\Rightarrow}(\phi, e_l)] + [\sigma^{\rightarrow\Leftarrow}(\phi, e_l) + \sigma^{\leftarrow\Leftarrow}(\phi, e_l)]}$$

Single-charge double-spin asymmetry (Hydrogen/Deuterium):

$$A_{LL}(\phi, e_l) = \frac{[\sigma^{\rightarrow\Rightarrow}(\phi, e_l) + \sigma^{\leftarrow\Leftarrow}(\phi, e_l)] - [\sigma^{\leftarrow\Rightarrow}(\phi, e_l) + \sigma^{\rightarrow\Leftarrow}(\phi, e_l)]}{[\sigma^{\rightarrow\Rightarrow}(\phi, e_l) + \sigma^{\leftarrow\Leftarrow}(\phi, e_l)] + [\sigma^{\leftarrow\Rightarrow}(\phi, e_l) + \sigma^{\rightarrow\Leftarrow}(\phi, e_l)]}$$

Single-charge beam-helicity asymmetry (Deuterium):

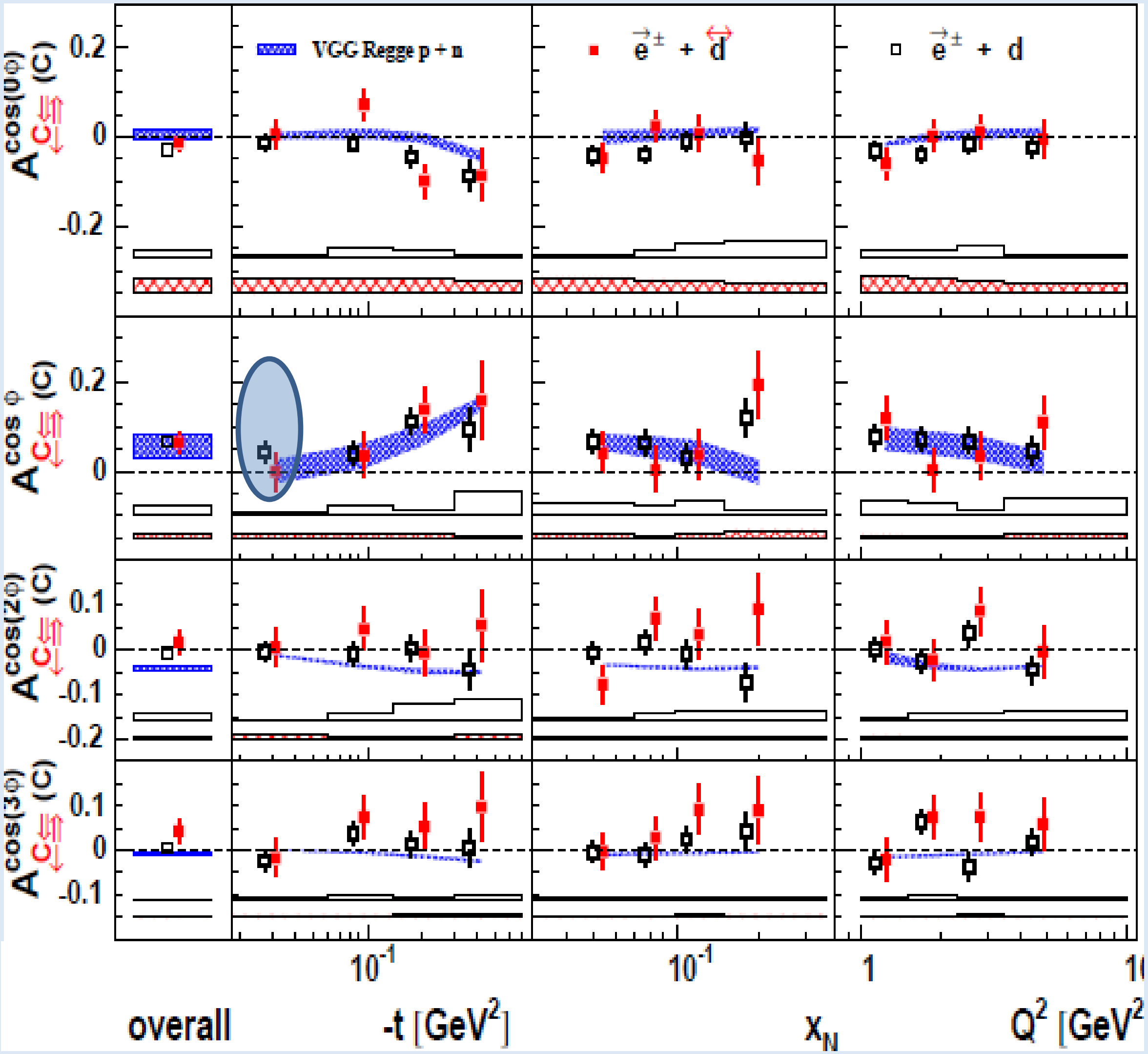
$$A_{L\overset{\Rightarrow}{\Leftarrow}}(\phi, e_l) = \frac{[\sigma^{\rightarrow\Rightarrow}(\phi, e_l) + \sigma^{\rightarrow\Leftarrow}(\phi, e_l)] - [\sigma^{\leftarrow\Rightarrow}(\phi, e_l) + \sigma^{\leftarrow\Leftarrow}(\phi, e_l)]}{[\sigma^{\rightarrow\Rightarrow}(\phi, e_l) + \sigma^{\rightarrow\Leftarrow}(\phi, e_l)] + [\sigma^{\leftarrow\Rightarrow}(\phi, e_l) + \sigma^{\leftarrow\Leftarrow}(\phi, e_l)]}$$

Single-helicity (⟵) beam-charge asymmetry (Deuterium):

$$A_{C\overset{\Rightarrow}{\Leftarrow}}(\phi) = \frac{[\sigma^{+\Rightarrow}(\phi) + \sigma^{+\Leftarrow}(\phi)] - [\sigma^{-\Rightarrow}(\phi) + \sigma^{-\Leftarrow}(\phi)]}{[\sigma^{+\Rightarrow}(\phi) + \sigma^{+\Leftarrow}(\phi)] + [\sigma^{-\Rightarrow}(\phi) + \sigma^{-\Leftarrow}(\phi)]}$$

A_C ($A_{C\leftrightarrow}$) on (un)polarized Deuterium

Nucl. Phys. B 842 (2011) 265



For coherent scattering

$$\Re e(\mathcal{H}_1)$$

$$\Re e(\mathcal{H}_1 - \tfrac{1}{3}\mathcal{H}_5)$$

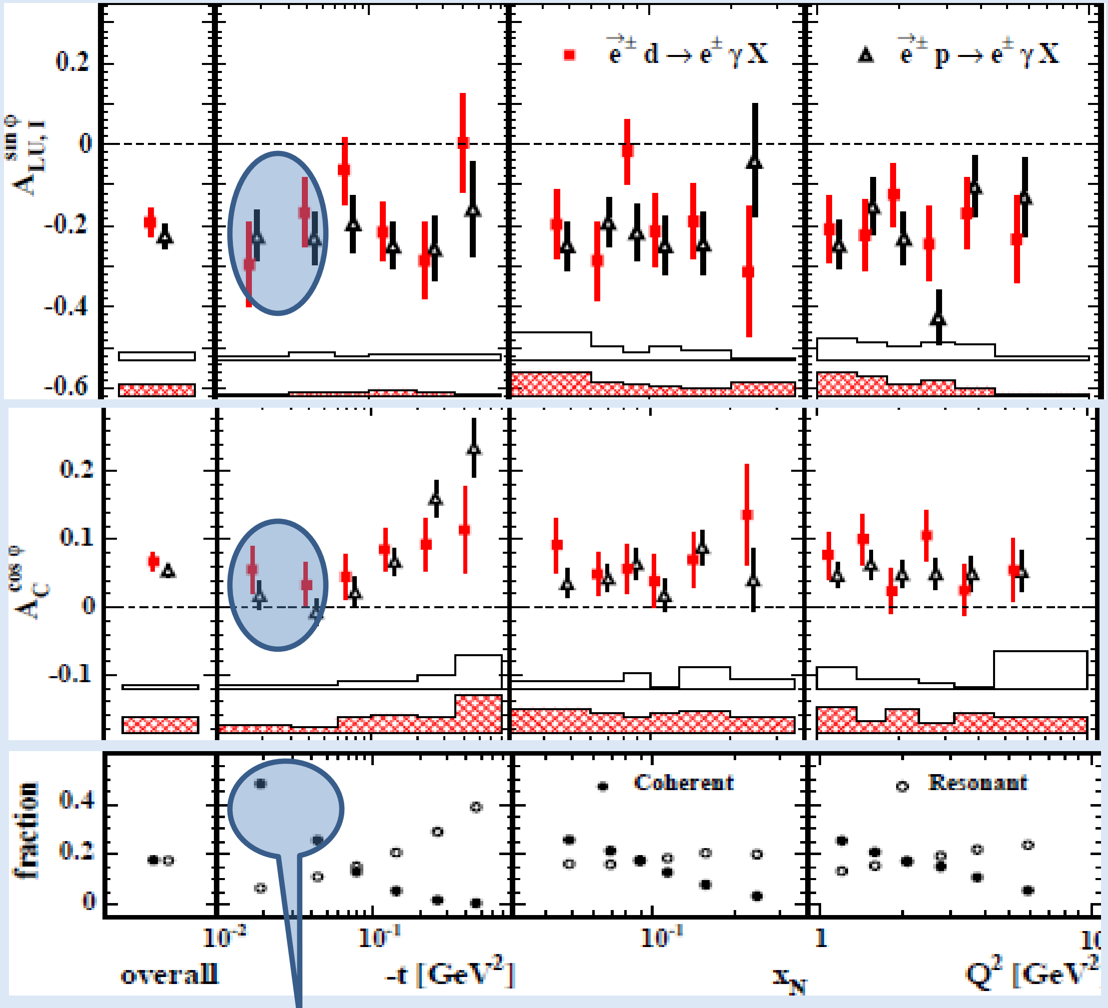
$$\Im m(H_5)$$

A_{LZZ} sin ϕ amplitude:

$0.074 \pm 0.196 \pm 0.022$

($-t$ < 0.06 GeV2, 40% coherent)

Deuterium (Hydrogen): Unpolarized target



JHEP 11 (2009) 083

Nucl. Phys. B 829 (2010) 1

$\mathfrak{Im}(\mathcal{H})$

$\mathfrak{Im}(\mathcal{H}_1)$

$\mathfrak{Re}(\mathcal{H})$

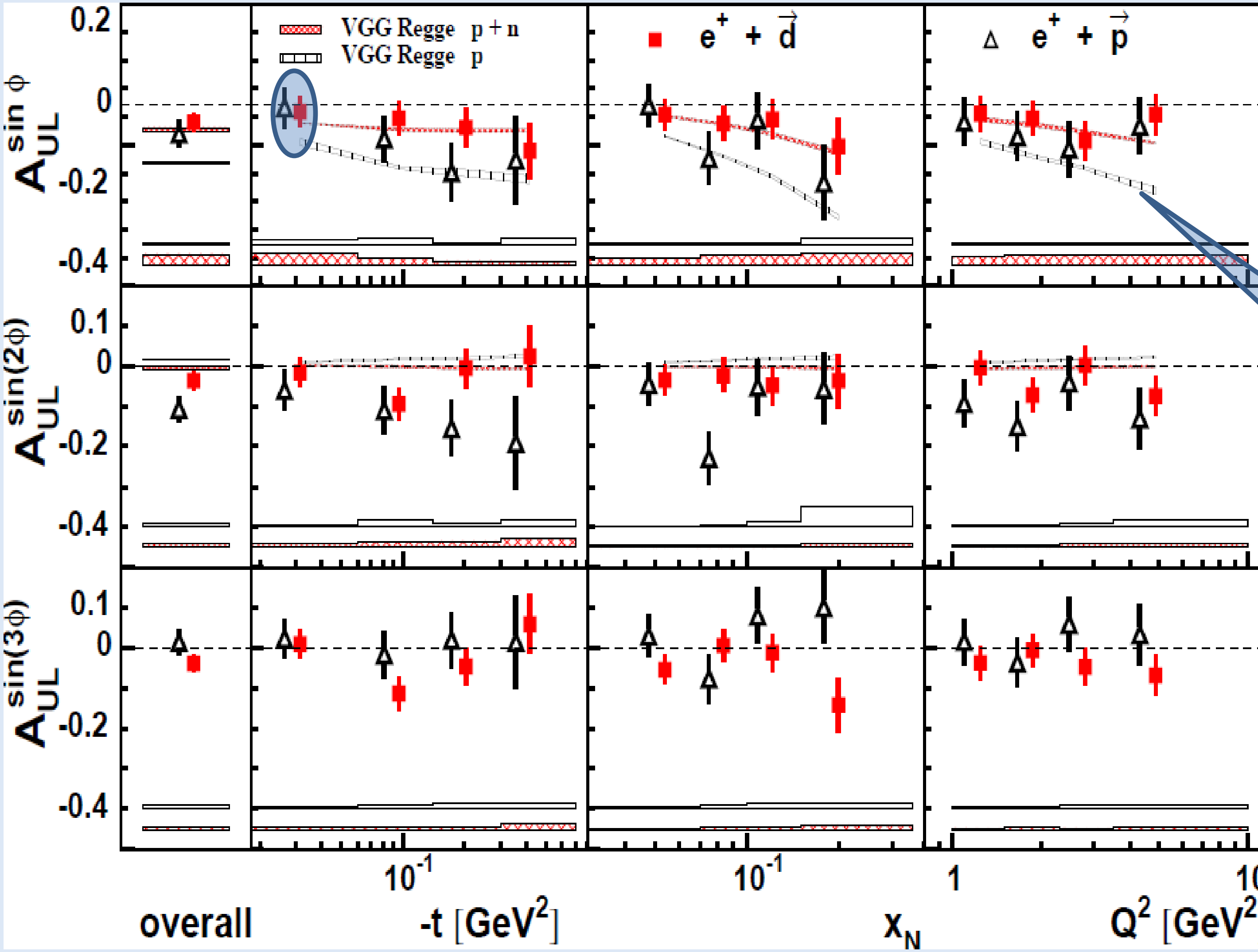
$\mathfrak{Re}(\mathcal{H}_1)$

- $A^{\sin\phi}_{LU,I,Coh}$ -0.29 ± 0.18 (stat) ± 0.03 (syst)
- $A^{\cos\phi}_{C,Coh}$ 0.11 ± 0.07 (stat) ± 0.03 (syst)

Deuterium (Hydrogen): Target-Spin Asymmetry

JHEP 11 (2009) 083

Nucl. Phys. B 842 (2011) 265



$\Im m(\widetilde{H})$

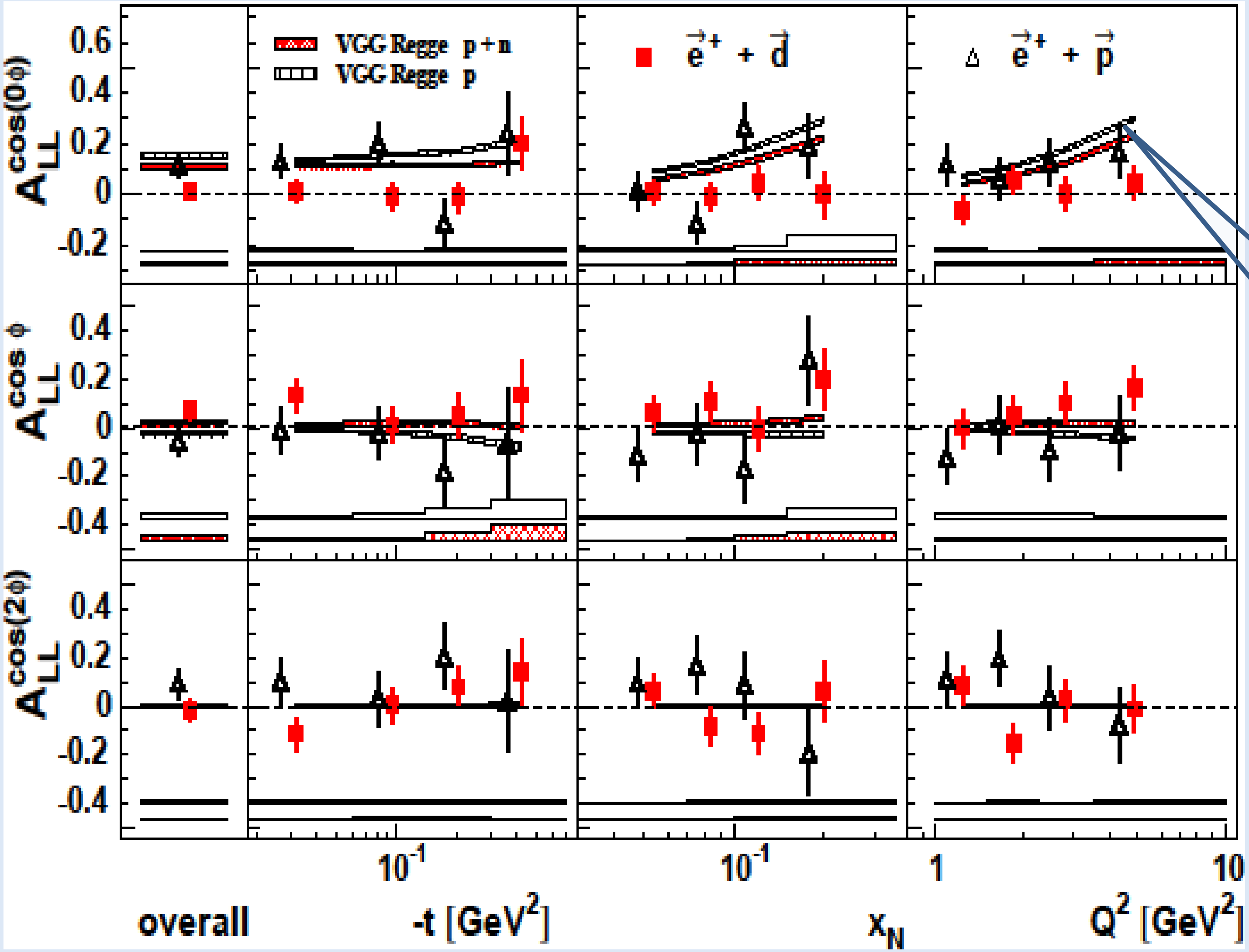
$\Im m(\widetilde{H}_1)$

VGG:
Phys. Rev. **D60** (1999) 0940177
&
Prog. Nucl. Phys. **47** (2001) 401

Deuterium (Hydrogen): Double-Spin Asymmetry

JHEP 11 (2009) 083

Nucl. Phys. B 842 (2011) 265

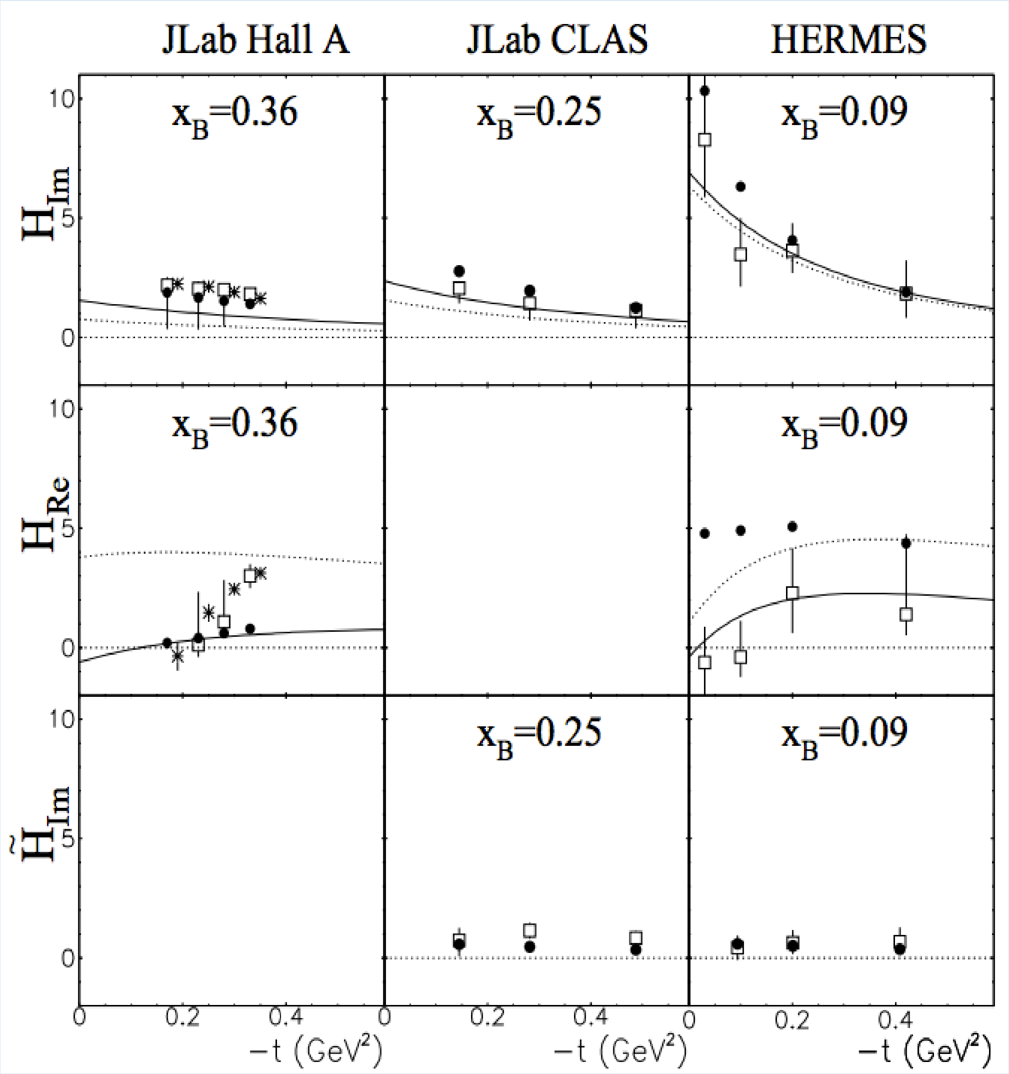


$\propto$ (BH)

VGG:
Phys. Rev. **D60** (1999) 0940177
&
Prog. Nucl. Phys. **47** (2001) 401

GPD extraction

M. Guidal ICHEP Proc. (2010) 148



CFFs are extracted from experimental measurements

- VGG model:
  GPD H in this model is not consistent with experimental results.

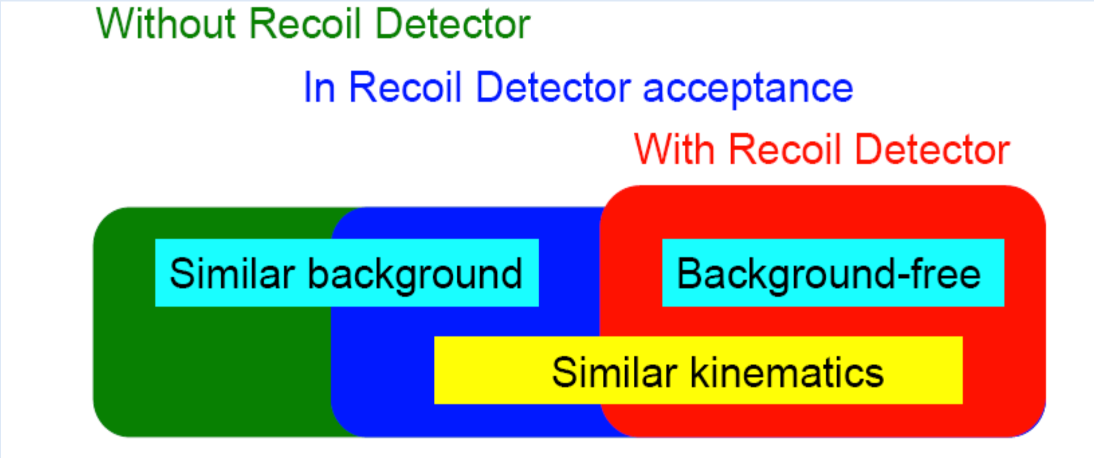
❑ M. Guidal, ICHEP Proc. (2010) 148

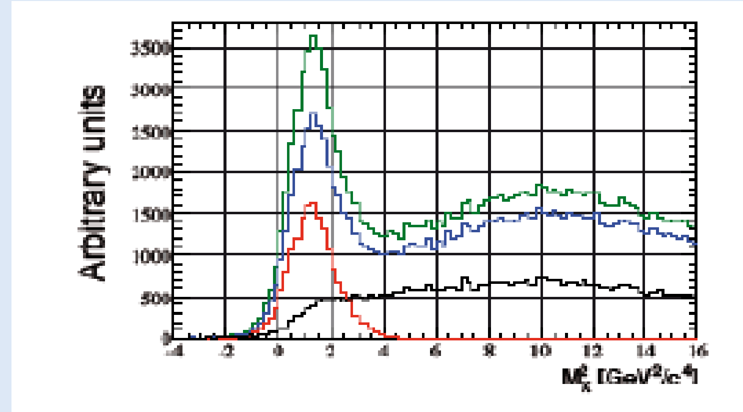
⋆ H. Moutarde, Phys. Rev. **D** 79 (2009)

Curves:

K. Kumericki, D. Muller
Nucl. Phys. **B** 841 (2010)

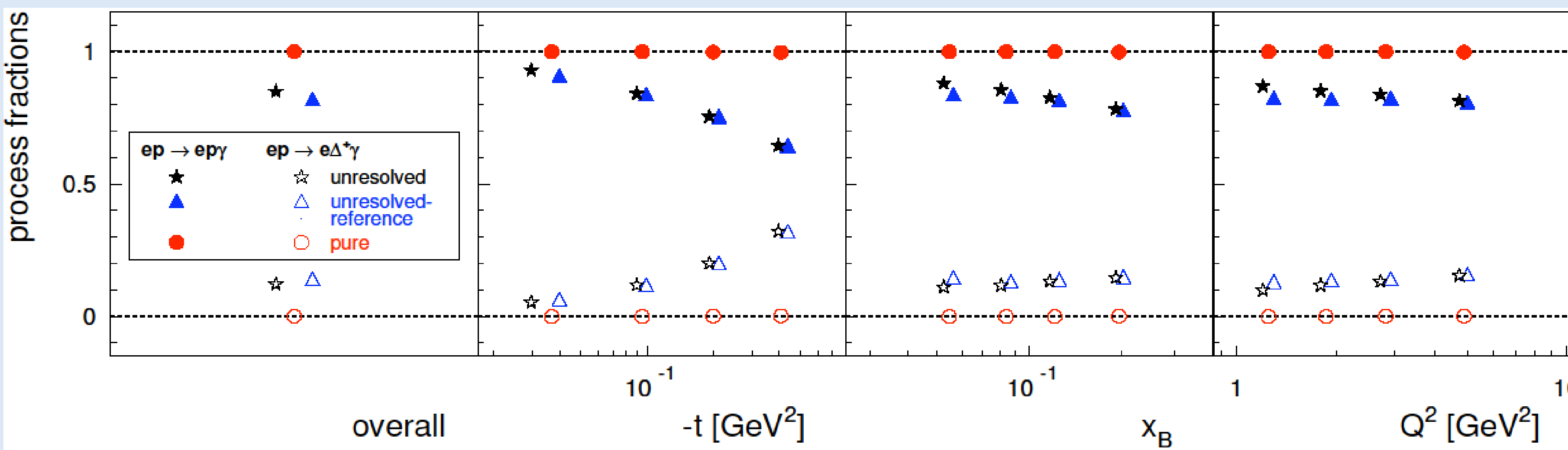
DVCS with Recoil Detector



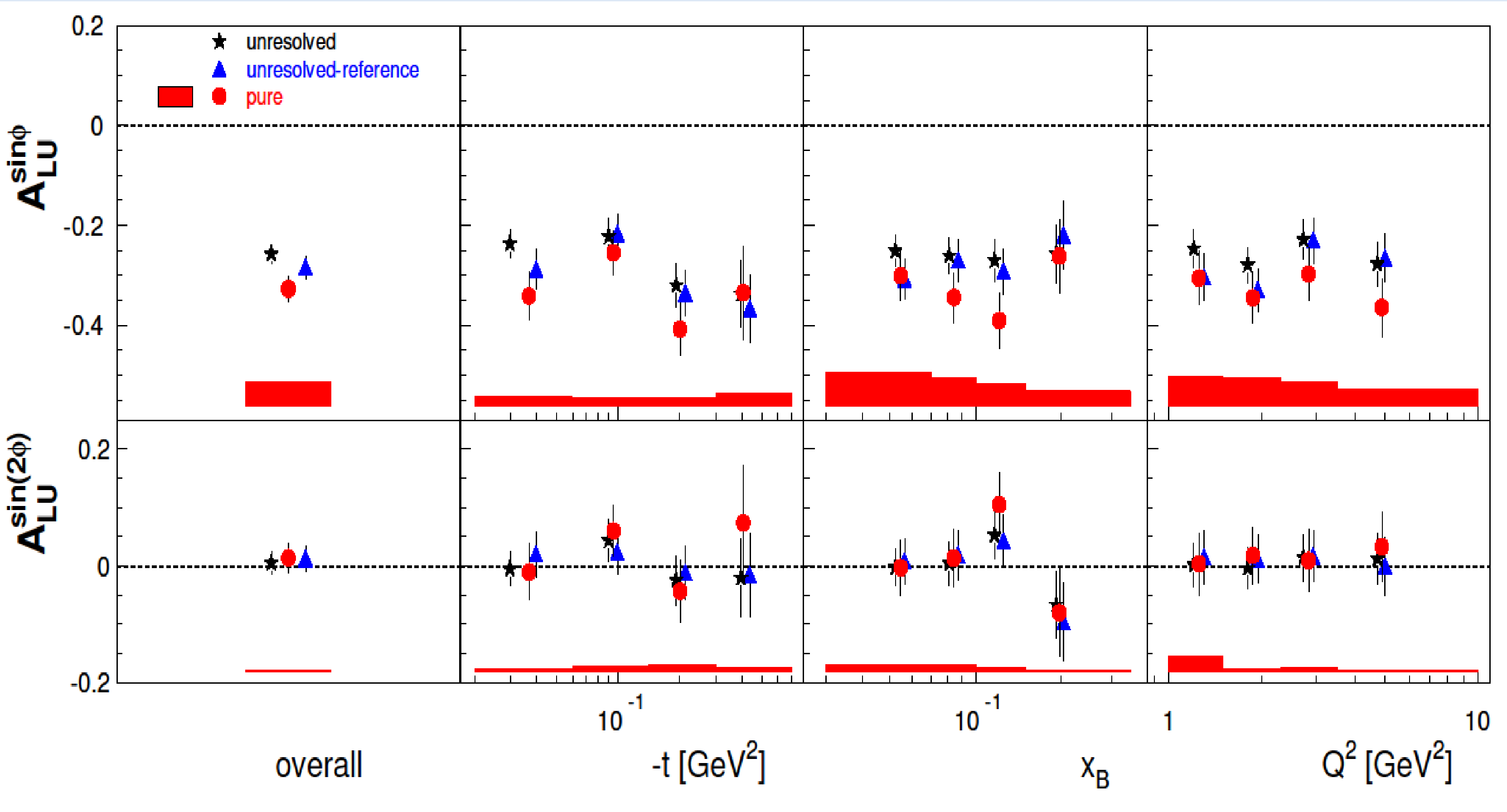


- No requirement for Recoil
- Charged recoil track in acceptance
- Kinematic fit probability > 1 %
- Kinematic fit probability < 1 %

Kinematic event fitting technique: all 3 particles
In the final state detected should satisfy
4-constraints on energy-momentum conservation



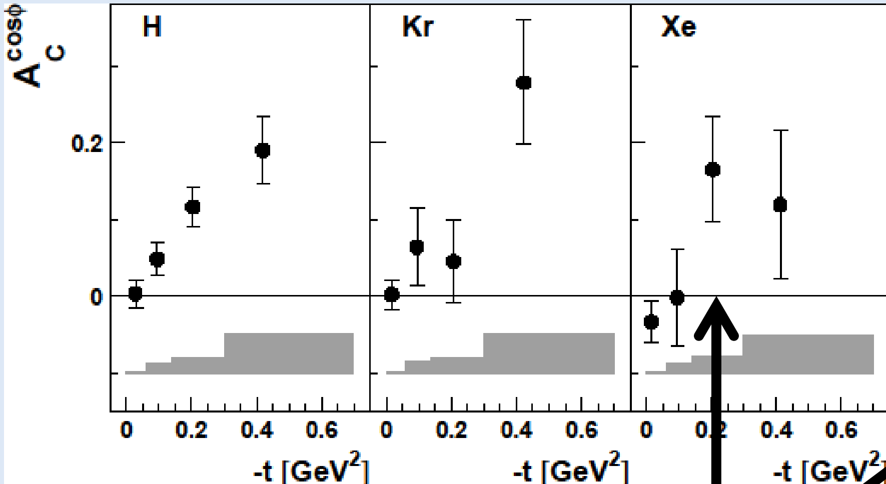
Pure elastic DVCS



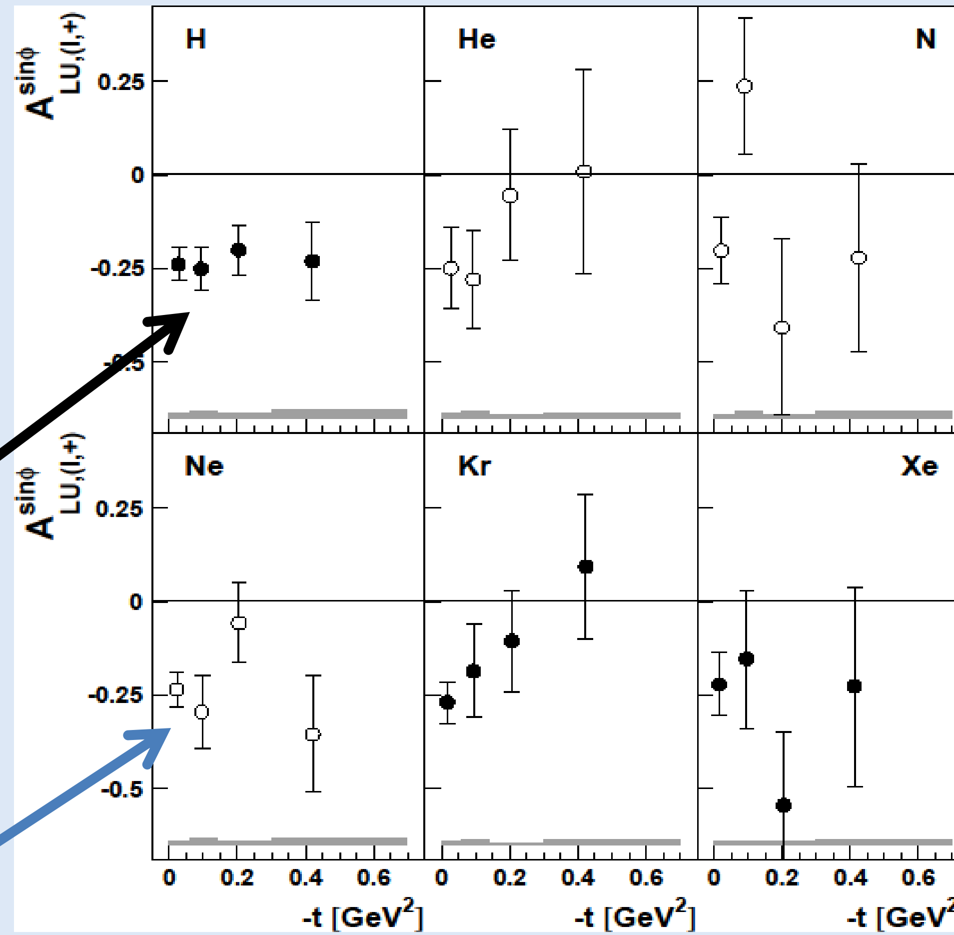
Indication that leading amplitude for pure elastic process is slightly larger than for unresolved signal (elastic+associated)

Leading amplitudes of asymmetries on nuclei

Leading amplitude of Beam-charge asymmetry



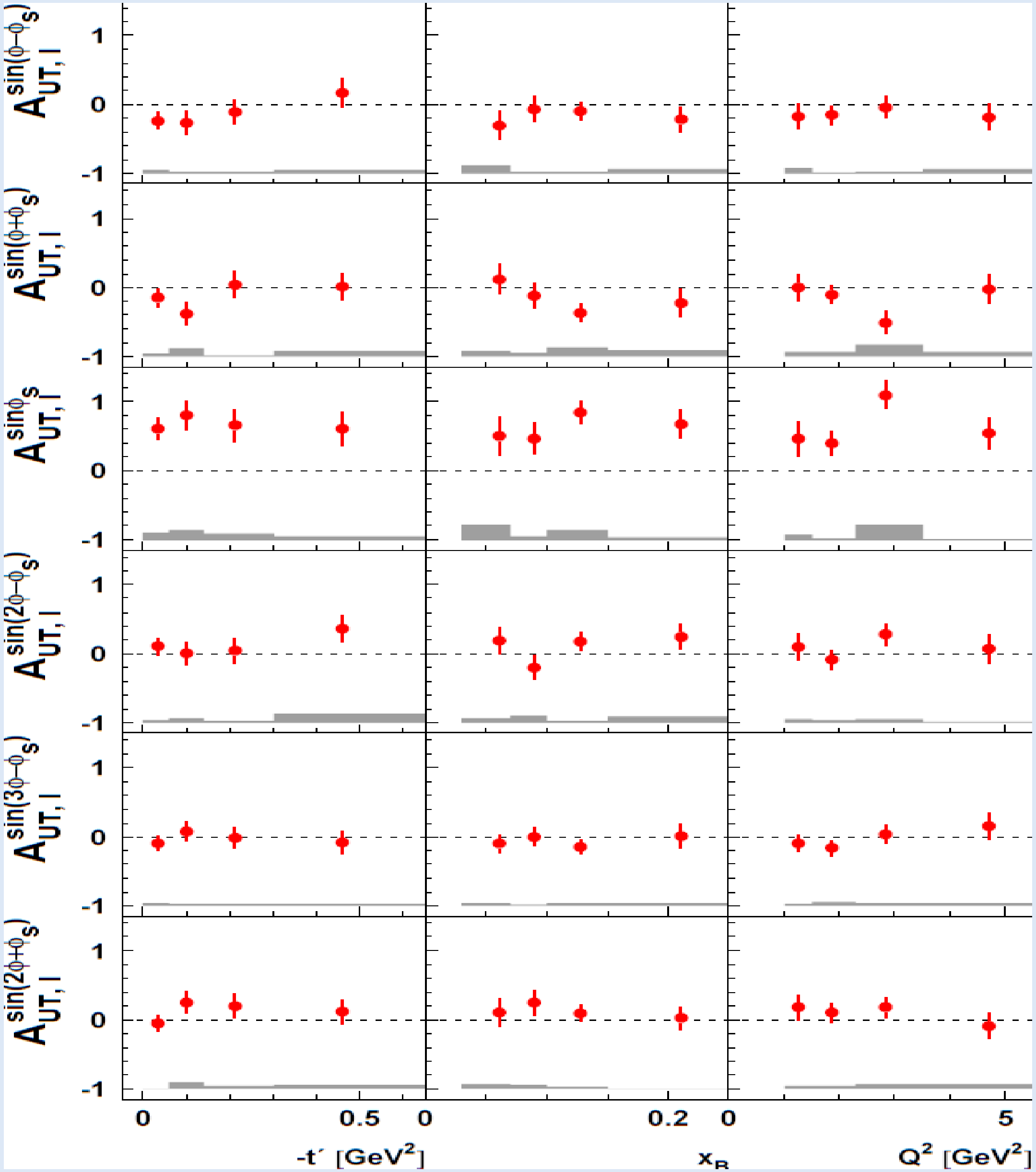
Leading amplitudes of Beam-helicity asymmetry



- ● Two beam charges available

- ○ Only one beam charge available: single-charge asymmetry without entanglement of squared DVCS and Interference terms

Target-Spin asymmetry in exclusive π^+ production



Phys. Lett. B 682 (2010) 351,
arXiv:0907.5369

- No L/T separation
- Small value for the leading asymmetry amplitude $A_{UT}^{\sin(\phi-\phi_S)}$
- Unexpected large value for the asymmetry amplitude $A_{UT}^{\sin(\phi_S)}$
- All other asymmetry amplitudes are consistent with zero
- Evidence for interference of contributions from longitudinal and transverse photons

Exclusive ρ^0-meson production

Meson SDMEs
EPJC 62 (2009) 659

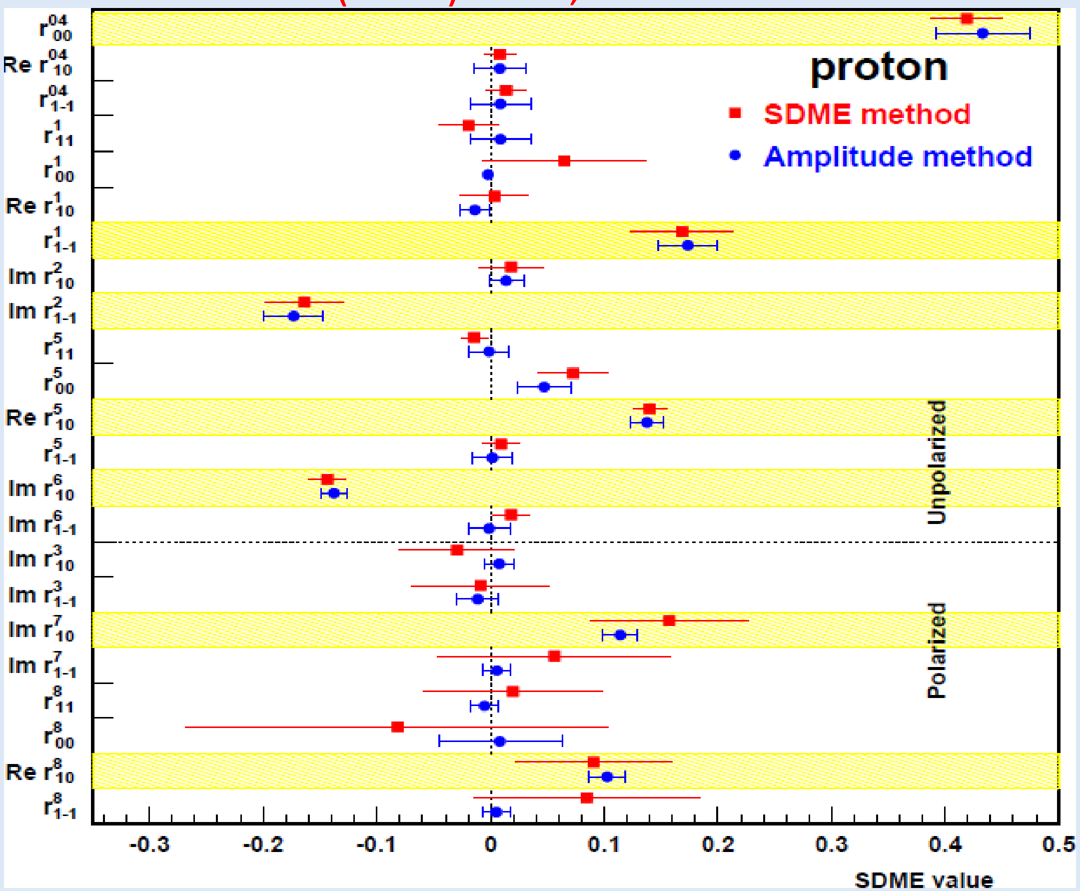
Photon SDMEs

$$r^{\eta}_{\lambda_V \mu_V} = \frac{1}{2N}\sum_{\lambda_\gamma \mu_\gamma \lambda'_N \lambda_N} F_{\lambda_V \lambda'_N \lambda_\gamma \lambda_N}\, \Sigma^{\eta}_{\lambda_\gamma \mu_\gamma}\, F^{*}_{\mu_V \lambda'_N \mu_\gamma \lambda_N}$$

Helicity amplitudes

$$F_{\lambda_V \lambda_\gamma} = T_{\lambda_V \lambda_\gamma} + U_{\lambda_V \lambda_\gamma}$$

EPJ C 71 (2011) 1609, arXiv:1012.3676



- Helicity amplitudes are the fundamental quantities to be compared with theory
- They form a basis for the SDMEs
- Natural Parity Exchange (NPE)

$$T_{\lambda_V \lambda_\gamma}\ GPDs(\mathcal{H}, \mathcal{E})$$

- Unnatural Parity Exchange (UPE)

$$U_{\lambda_V \lambda_\gamma}\ GPDs(\widetilde{\mathcal{H}}, \widetilde{\mathcal{E}})$$