DVCS at HERMES

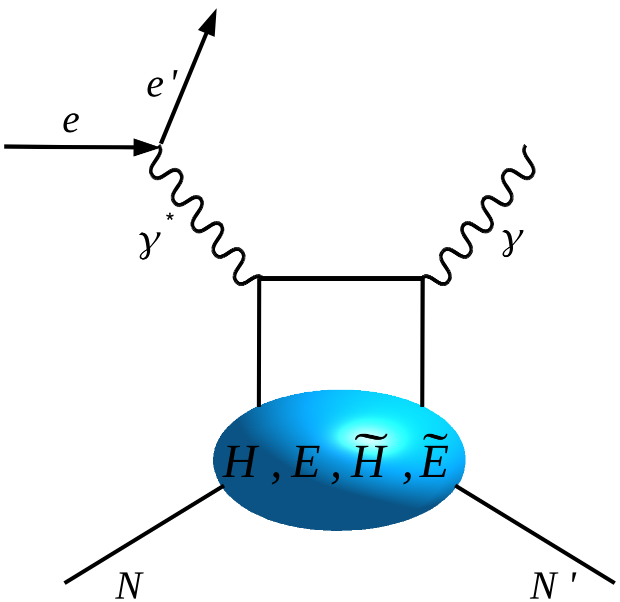
Orbital Angular Momentum of Partons in Hadrons, Trento, Italy, 2009

Ami Rostomyan

(on behalf of the HERMES collaboration)

probing the orbital angular momentum

- Generalised Parton Distributions (GPDs)
- hard exclusive reactions
  - Deeply Virtual Compton Scattering (DVCS)



$(\gamma^* \to \gamma)$: H, E, $\widetilde{H}$, $\widetilde{E}$ (twist-2, chiral even)

- H and $\widetilde{H}$ conserve the nucleon helicity
- E and $\widetilde{E}$ describe the nucleon helicity flip
- Ji relation

$$J_q = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} dx\, x\, [H_q(x,\xi,t) + E_q(x,\xi,t)] = \frac{1}{2}\Delta\Sigma_q + L_q$$

why DVCS?

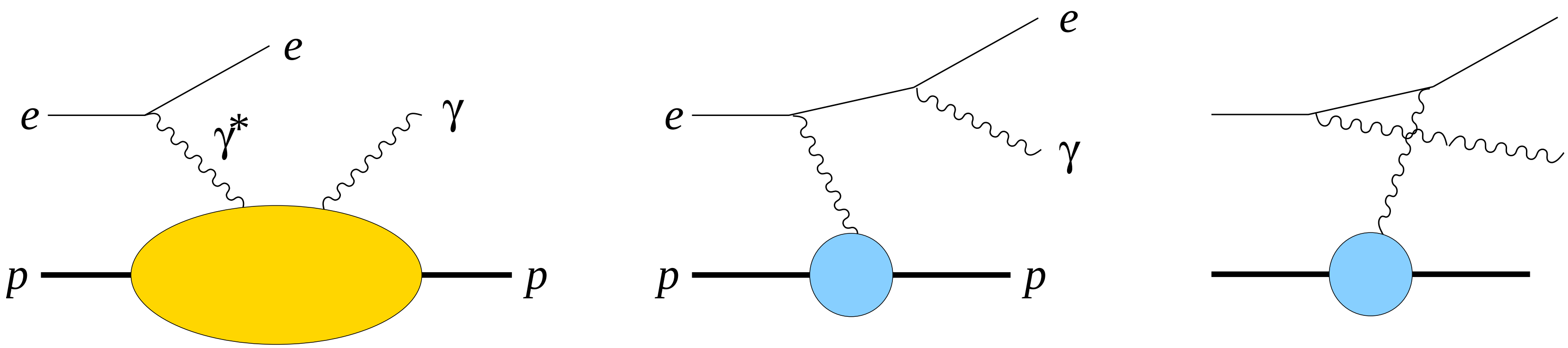
- the cleanest probe of GPDs
- theoretical accuracy at NNLO
- no gluons in the LO

Compton form factors

- convolutions of GPDs ($F: H, E, \widetilde{H}, \widetilde{E}$) and hard scattering functions

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

Deeply Virtual Compton Scattering (DVCS)



same initial and final states in DVCS and Bethe-Heitler ⇒ Interference!

$$\sigma_{ep} \propto |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \underbrace{\mathcal{T}_{BH}\mathcal{T}^*_{DVCS} + \mathcal{T}^*_{BH}\mathcal{T}_{DVCS}}_{\mathcal{I}}$$

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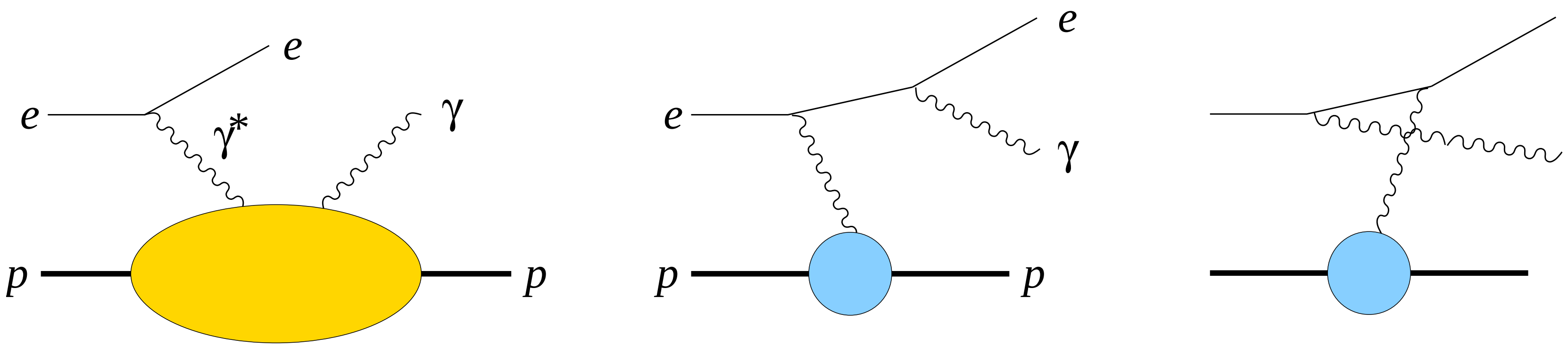

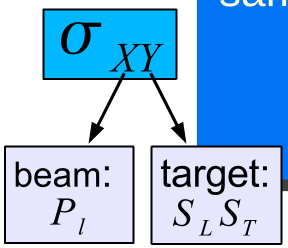

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$$\begin{aligned}
d\sigma \sim d\sigma^{BH}_{UU} \quad &+ \quad e_\ell d\sigma^{I}_{UU} + d\sigma^{DVCS}_{UU} \\
&+ \quad e_\ell P_\ell d\sigma^{I}_{LU} + P_\ell d\sigma^{DVCS}_{LU} \\
&+ \quad e_\ell S_L d\sigma^{I}_{UL} + S_L d\sigma^{DVCS}_{UL} \\
&+ \quad e_\ell S_T d\sigma^{I}_{UT} + S_T d\sigma^{DVCS}_{UT} \\
+P_\ell S_L d\sigma^{BH}_{LL} \quad &+ \quad e_\ell P_\ell S_L d\sigma^{I}_{LL} + P_\ell S_L d\sigma^{DVCS}_{LL} \\
+P_\ell S_T d\sigma^{BH}_{LT} \quad &+ \quad e_\ell P_\ell S_T d\sigma^{I}_{LT} + P_\ell S_T d\sigma^{DVCS}_{LT}
\end{aligned}$$

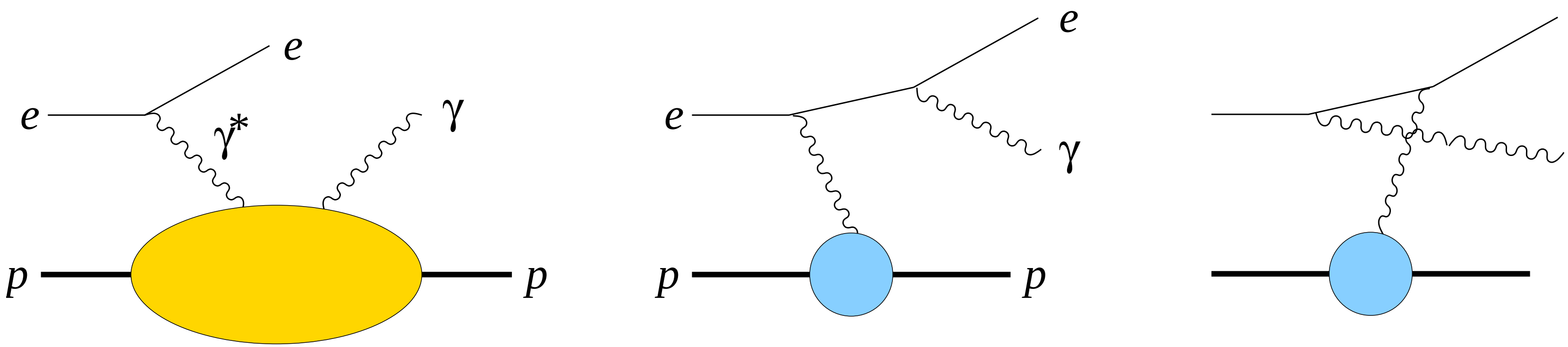
single spin terms: LU, UL, UT

- no pure Bethe-Heitler contribution
- project imaginary parts of Compton form factors

unpolarized and double-spin terms: UU, LL, LT

- project real parts of Compton form factors

Deeply Virtual Compton Scattering (DVCS)



same initial and final states in DVCS and Bethe-Heitler ⇒ Interference!

$$\sigma_{ep} \propto |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \underbrace{\mathcal{T}_{BH}\mathcal{T}^*_{DVCS} + \mathcal{T}^*_{BH}\mathcal{T}_{DVCS}}_{\mathcal{I}}$$

σ_{XY}

beam: P_l

target: $S_L S_T$

$$\begin{aligned}
d\sigma \sim d\sigma^{BH}_{UU} &+ e_\ell d\sigma^{I}_{UU} + d\sigma^{DVCS}_{UU} \\
&+ e_\ell P_\ell d\sigma^{I}_{LU} + P_\ell d\sigma^{DVCS}_{LU} \\
&+ e_\ell S_L d\sigma^{I}_{UL} + S_L d\sigma^{DVCS}_{UL} \\
&+ e_\ell S_T d\sigma^{I}_{UT} + S_T d\sigma^{DVCS}_{UT} \\
+P_\ell S_L d\sigma^{BH}_{LL} &+ e_\ell P_\ell S_L d\sigma^{I}_{LL} + P_\ell S_L d\sigma^{DVCS}_{LL} \\
+P_\ell S_T d\sigma^{BH}_{LT} &+ e_\ell P_\ell S_T d\sigma^{I}_{LT} + P_\ell S_T d\sigma^{DVCS}_{LT}
\end{aligned}$$

Bethe-Heitler contribution:

- calculated at QED

DVCS contribution:

- HERMES: $|\mathcal{T}_{DVCS}|^2 << |\mathcal{T}_{BH}|^2$

interference term:

- depend on a linear combination of Compton form factors
- access to GPD combinations through azimuthal asymmetries

express asymmetries in terms of Fourier coefficients

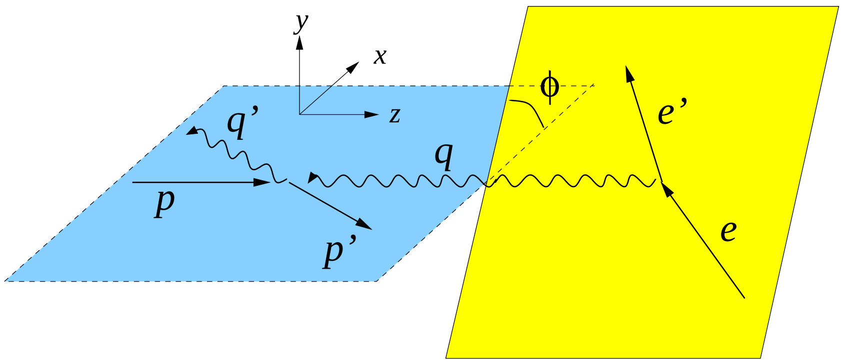
$$\sigma(\phi, P_\ell, e_\ell) = \sigma_{UU}(\phi) \times \left[1 + P_\ell A_{LU}^{DVCS}(\phi) + e_\ell P_\ell A_{LU}^{I}(\phi) + e_\ell A_C(\phi)\right]$$

Fourier expansion in azimuthal angle ϕ

$$|\tau_{\mathrm{BH}}|^2 \propto \sum_{n=0}^{2} c_n^{\mathrm{BH}} \cos(n\phi)$$

$$|\tau_{\mathrm{DVCS}}|^2 \propto \sum_{n=0}^{2} c_n^{\mathrm{DVCS}} \cos(n\phi) + P_\ell\, s_1^{\mathrm{DVCS}} \sin\phi$$

$$\mathrm{I} \propto \sum_{n=0}^{3} c_n^{\mathrm{I}} \cos(n\phi) + \sum_{n=1}^{2} P_\ell\, s_n^{\mathrm{I}} \sin(n\phi)$$



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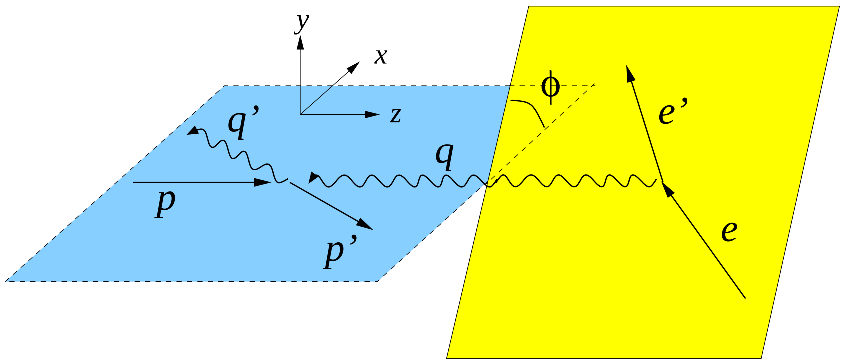

$$c_1^{\mathrm{I}} \propto F_1 \mathrm{Re}\mathcal{H}$$

$$c_0^{\mathrm{I}} \propto -\frac{-t}{Q} c_1^{\mathrm{I}}$$

$$s_1^{\mathrm{I}} \propto F_1 \mathrm{Im}\mathcal{H}$$

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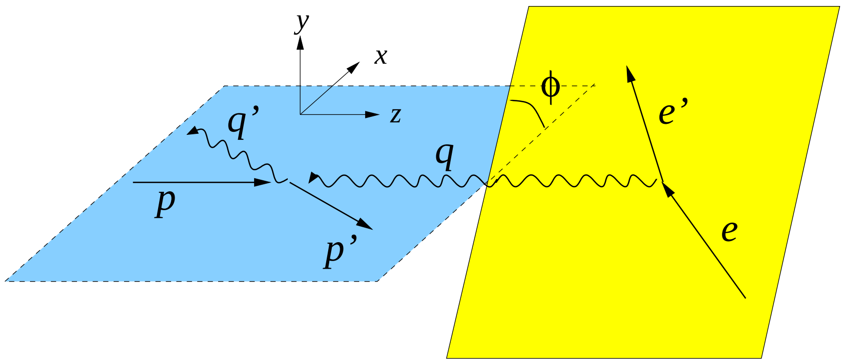

DVCS term:

azimuthal modulation	$\gamma^*(\mu) \to \gamma(\mu')$	relative order
constant	$+1 \to +1$	1
$\cos\phi, \sin\phi$	$0 \to +1$	$1/Q$
$\cos 2\phi, \sin 2\phi$	$-1 \to +1$	1 (gluon GPDs)
		$1/Q^2$ (quark GPDs)

$$c_1^{\text{I}} \propto F_1 \text{Re}\mathcal{H}$$

$$c_0^{\text{I}} \propto -\frac{-t}{Q} c_1^{\text{I}}$$

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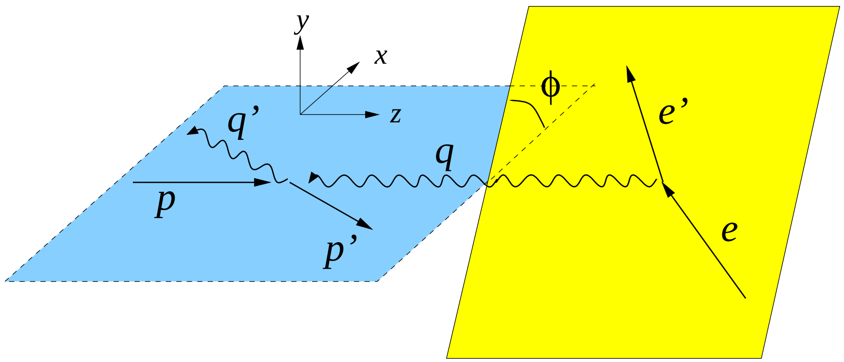


interference term:

azimuthal modulation	$\gamma^*(\mu) \to \gamma(\mu')$	relative order
constant	$+1 \to +1$	$1/Q$
$\cos\phi, \sin\phi$	$+1 \to +1$	1
$\cos 2\phi, \sin 2\phi$	$0 \to +1$	$1/Q$
$\cos 3\phi, \sin 3\phi$	$-1 \to +1$	$1/Q^2$ *or* α_s

$$c_1^{\mathrm{I}} \propto F_1 \mathrm{Re}\mathcal{H}$$

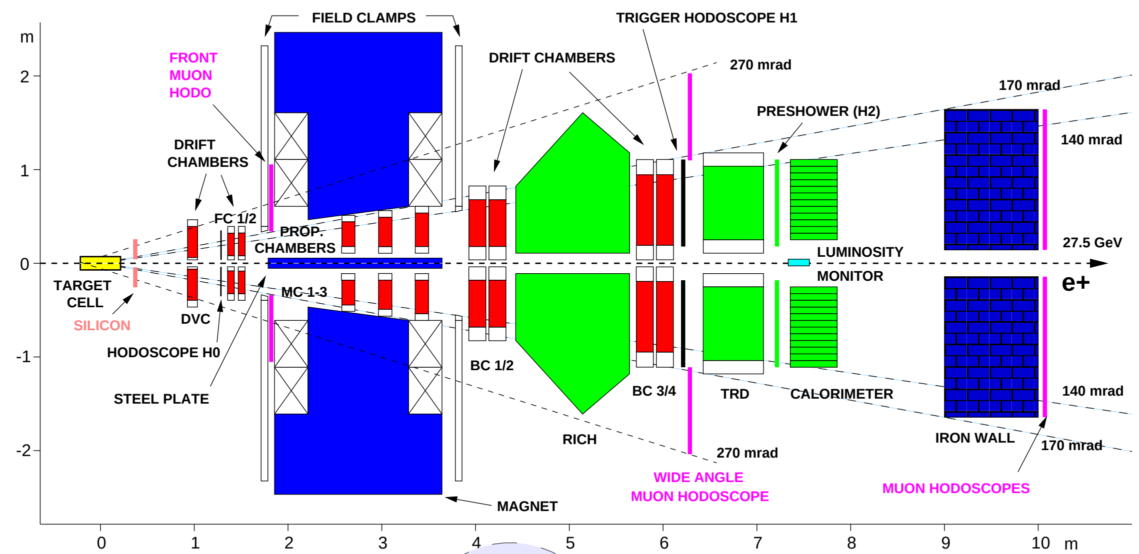
$$c_0^{\mathrm{I}} \propto -\frac{-t}{Q} c_1^{\mathrm{I}}$$

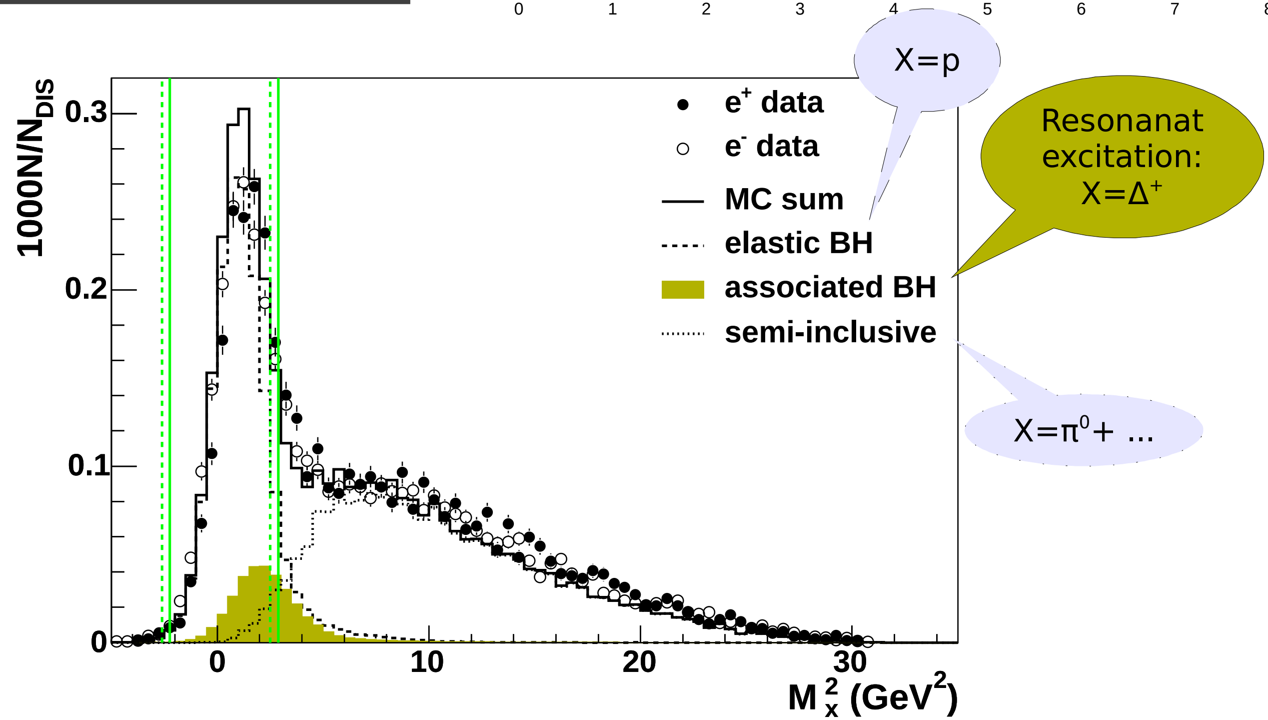
$$s_1^{\mathrm{I}} \propto F_1 \mathrm{Im}\mathcal{H}$$

DVCS at HERMES (pre-recoil data)

$$e + p \to e' + \gamma + p'$$

- detected particles: lepton and photon
- missing mass technique for $ep \to e'\gamma X$: $M_X^2 = (p + e - e' - \gamma)^2$





unpolarized-target asymmetries

$$\sigma(\phi, P_\ell, e_\ell) = \sigma_{UU}(\phi) \times \left[1 + P_\ell \mathcal{A}_{LU}^{DVCS}(\phi) + e_\ell P_\ell \mathcal{A}_{LU}^{I}(\phi) + e_\ell \mathcal{A}_C(\phi)\right]$$

beam-helicity asymmetry (single charge):

$$\mathcal{A}_{LU}(\phi) \equiv \frac{d\sigma^{\rightarrow} - d\sigma^{\leftarrow}}{d\sigma^{\rightarrow} + d\sigma^{\leftarrow}}$$

- projects the imaginary part of τ_{DVCS}
- no separate access to s_1^{DVCS} and s_1^I

beam-helicity asymmetry (new approach):

- charge-difference beam-helicity asymmetry

$$\mathcal{A}_{LU}^{I}(\phi) \equiv \frac{(d\sigma^{+\rightarrow} - d\sigma^{+\leftarrow}) - (d\sigma^{-\rightarrow} - d\sigma^{-\leftarrow})}{(d\sigma^{+\rightarrow} + d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} + d\sigma^{-\leftarrow})}$$

- charge-averaged beam-helicity asymmetry

$$\mathcal{A}_{LU}^{DVCS}(\phi) \equiv \frac{(d\sigma^{+\rightarrow} - d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} - d\sigma^{-\leftarrow})}{(d\sigma^{+\rightarrow} + d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} + d\sigma^{-\leftarrow})}$$

- s_1^{DVCS} and s_1^I can be disentangled

beam-charge asymmetry:

$$\mathcal{A}_C(\phi) \equiv \frac{d\sigma^{+} - d\sigma^{-}}{d\sigma^{+} + d\sigma^{-}}$$

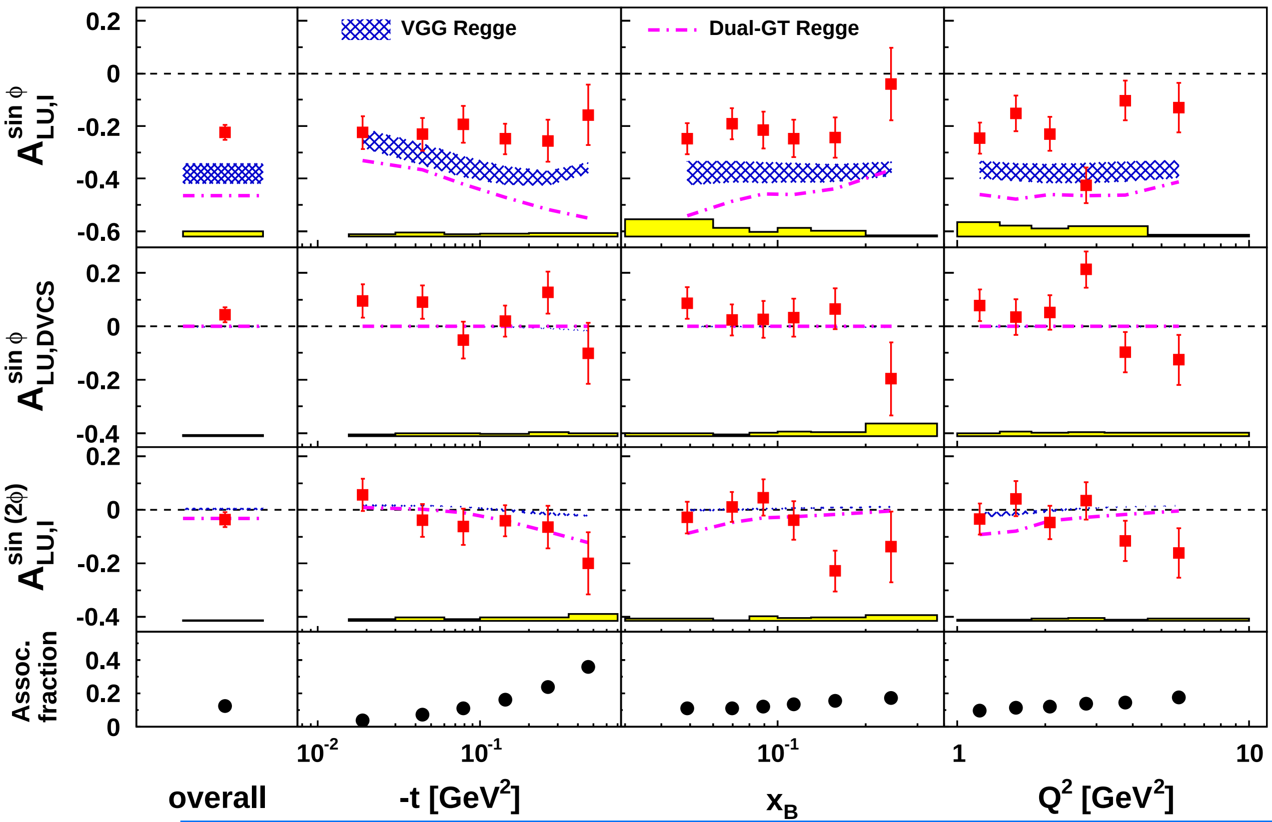
- projects the real part of τ_{DVCS}

beam helicity asymmetry

$$\mathcal{A}^{I}_{LU}(\phi) = \sum_{n=1}^{2} A^{\sin(n\phi)}_{LU,\mathrm{I}} \sin(n\phi) \propto \sum_{n=1}^{2} s^{\mathrm{I}}_{n} \sin(n\phi)$$

$$A^{\sin\phi}_{LU,\mathrm{DVCS}} \propto s^{\mathrm{DVCS}}_{1} \sin\phi$$

-HERMES Collaboration: arXiv:0909.3587 (2009)-



$A^{\sin\phi}_{LU,\mathrm{I}}$

- twist-2:

  $\propto F_1 \mathrm{Im}\mathcal{H}$

- large overall value
- no kin. dependencies

$A^{\sin\phi}_{LU,\mathrm{DVCS}}$, $A^{\sin 2\phi}_{LU,\mathrm{I}}$

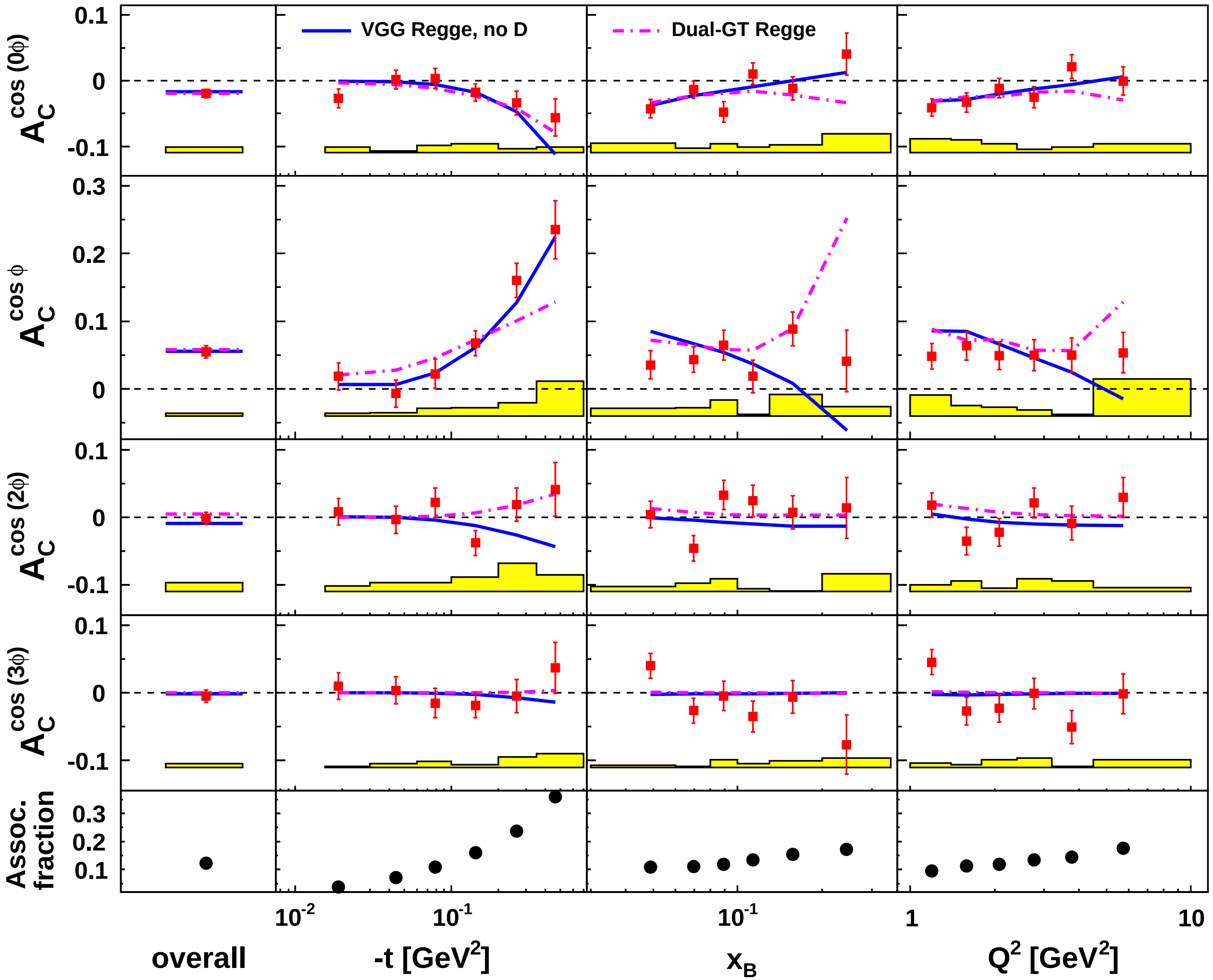
- twist-3
- overall value compatible with 0
- no kin. dependencies

- overshoot the magnitude of $A^{\sin\phi}_{LU,\mathrm{I}}$ by a factor of 2
- describe the shape of kin dependencies on x_B and Q^2, but not on t
- overestimation is not due to the associated production

beam charge asymmetry

$$\mathcal{A}_C(\phi) = \sum_{n=0}^{3} A_C^{\cos(n\phi)} \cos(n\phi) \propto \sum_{n=0}^{3} c_i^{\mathrm{I}} \cos(n\phi)$$

-HERMES Collaboration: arXiv:0909.3587 (2009)-



twist-2 $A_C^{\cos\phi}$, twist-3 $A_C^{\cos 0\phi}$

- strong t-dependence
- no x_B, Q^2 dependencies

$$A_C^{\cos\phi} \propto F_1 \mathrm{Re}\mathcal{H}$$

$$A_C^{\cos 0\phi} \propto -\frac{t}{Q} A_C^{\cos\phi}$$

$A_C^{\cos(2\phi)} \approx 0$: twist-3 GPDs
$A_C^{\cos(3\phi)} \approx 0$: gluon helicity-flip GPDs

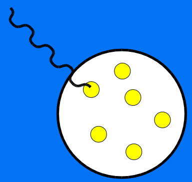
theoretical predictions:

- does not describe the beam-helicity data, but in good agreement with this data

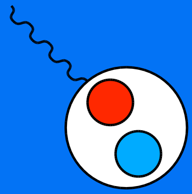
unpolarized deuterium targets

coherent: $e^{\pm}d \rightarrow e^{\pm}d\gamma$

- DVCS



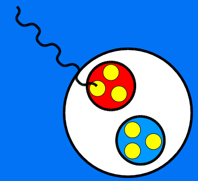
- Bethe-Heitler



- target stays intact
- spin-1 targets described by 9 GPDs:
$H_1^q, H_2^q, H_3^q, H_4^q, H_5^q, \widetilde{H}_1^q, \widetilde{H}_2^q, \widetilde{H}_3^q, \widetilde{H}_4^q$

incoherent: $e^{\pm}d \rightarrow e^{\pm}pn\gamma$

- DVCS



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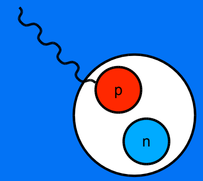
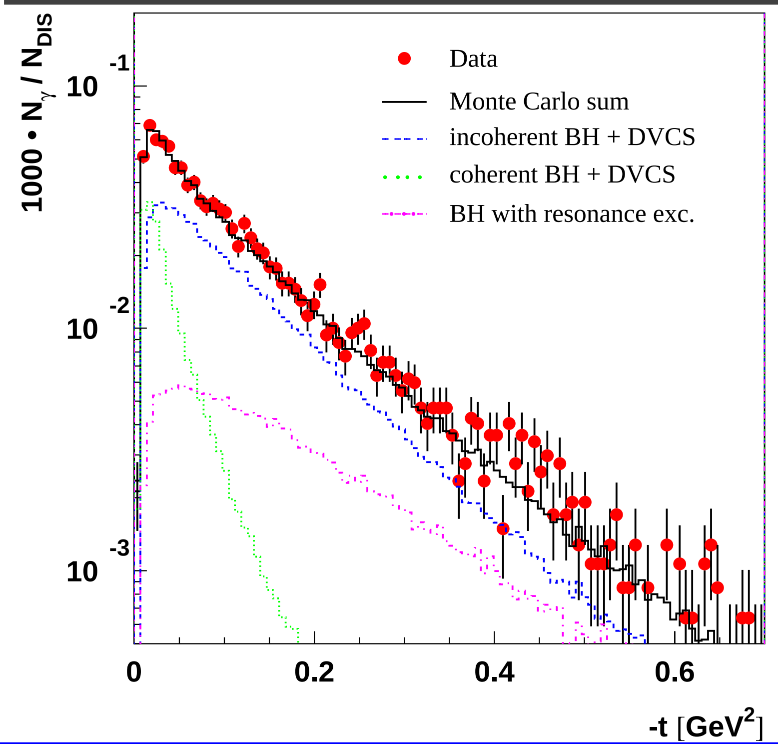


- target brakes up
- spin$-\frac{1}{2}$ targets described by 4 GPDs:
$H, E, \widetilde{H}, \widetilde{E}$



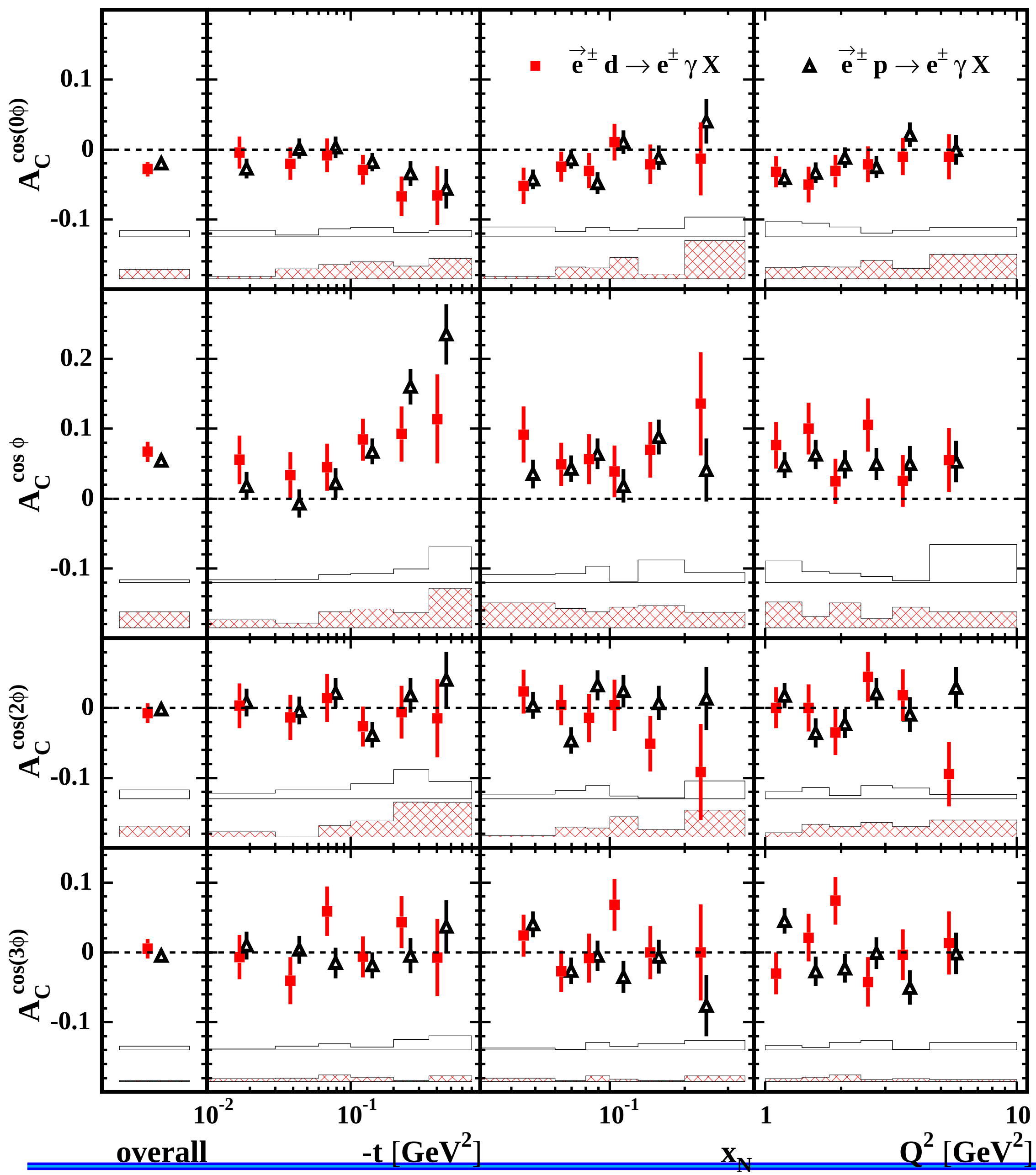
coherent:

- contribution at small $-t$

incoherent:

- contribution at larger $-t$
- contribution from coherent $[0.06 : 0.7]$ GeV^2: 20%

beam-charge asymmetry



$$\mathcal{A}_C(\phi) \quad = \quad \sum_{n=0}^{3} A_C^{\cos(n\phi)} \cos(n\phi)$$

-HERMES Collaboration: arXiv:0911.0091 (2009)-

twist-2:

$$A_{C,coh}^{\cos\phi} \propto G_1 \mathrm{Re}\mathcal{H}_1$$

$$A_{C,incoh}^{\cos\phi} \propto F_1 \mathrm{Re}\mathcal{H}$$

higher twist :

$$A_C^{\cos 0\phi} \quad \propto \quad -\frac{t}{Q} A_C^{\cos\phi}$$

$$A_C^{\cos(2\phi)} \quad \approx \quad 0$$

$$A_C^{\cos(3\phi)} \quad \approx \quad 0$$

- d and p results consistent
- small values of $-t$: differences due to coherent contribution
- larger values of $-t$: differences due to neutron contribution

longitudinal target polarization

$$\sigma(\phi, P_\ell, S_L) = \sigma_{UU}(\phi) \times [1 + P_\ell \mathcal{A}_{LU} + S_L \mathcal{A}_{UL}(\phi) + S_L P_\ell \mathcal{A}_{LL}(\phi)]$$

beam helicity asymmetry:

$$\mathcal{A}_{LU}(\phi) \equiv \frac{d\sigma^{\rightarrow} - d\sigma^{\leftarrow}}{d\sigma^{\rightarrow} + d\sigma^{\leftarrow}}$$

- projects the imaginary part of τ_{DVCS}
- no separate access to s_1^{DVCS} and s_1^I

longitudinal target-spin asymmetry:

$$\mathcal{A}_{UL}(\phi) \equiv \frac{(d\sigma^{\rightarrow\Rightarrow} + d\sigma^{\leftarrow\Rightarrow}) - (d\sigma^{\rightarrow\Leftarrow} + d\sigma^{\leftarrow\Leftarrow})}{(d\sigma^{\rightarrow\Rightarrow} + d\sigma^{\leftarrow\Rightarrow}) + (d\sigma^{\rightarrow\Leftarrow} + d\sigma^{\leftarrow\Leftarrow})}$$

- projects the imaginary part of τ_{DVCS}

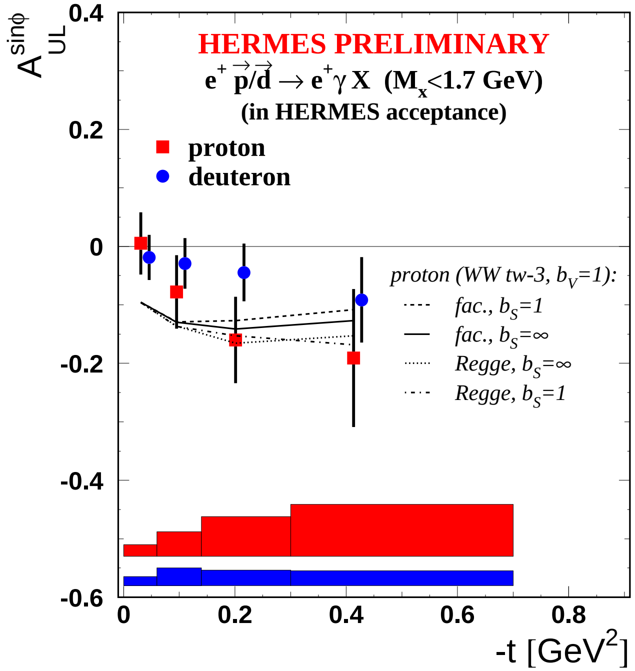
double-spin asymmetry:

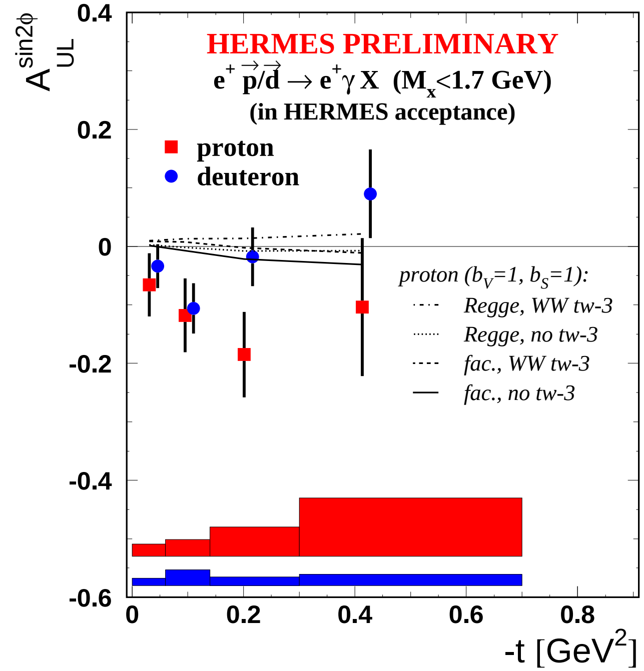
$$\mathcal{A}_{LL}(\phi) \equiv \frac{(d\sigma^{\rightarrow\Rightarrow} + d\sigma^{\leftarrow\Leftarrow}) - (d\sigma^{\leftarrow\Rightarrow} + d\sigma^{\rightarrow\Leftarrow})}{(d\sigma^{\rightarrow\Rightarrow} + d\sigma^{\leftarrow\Leftarrow}) + (d\sigma^{\leftarrow\Rightarrow} + d\sigma^{\rightarrow\Leftarrow})}$$

- projects the real part of τ_{DVCS}

longitudinal target-spin asymmetry

$$\mathcal{A}_{UL}(\phi) = \sum_{n=1}^{2} A_{UL}^{\sin(n\phi)} \sin(n\phi) \propto \sum_{n=1}^{2} s_n^{\mathrm{I}}, s_n^{\mathrm{DVCS}}$$





- s_1^{I}: twist-2

$$A_{UL}^{\sin\phi} \propto s_1^{\mathrm{I}} \propto F_1 \mathrm{Im}\widetilde{\mathcal{H}}$$

- s_1^{DVCS}: twist-3

model in good agreement with data

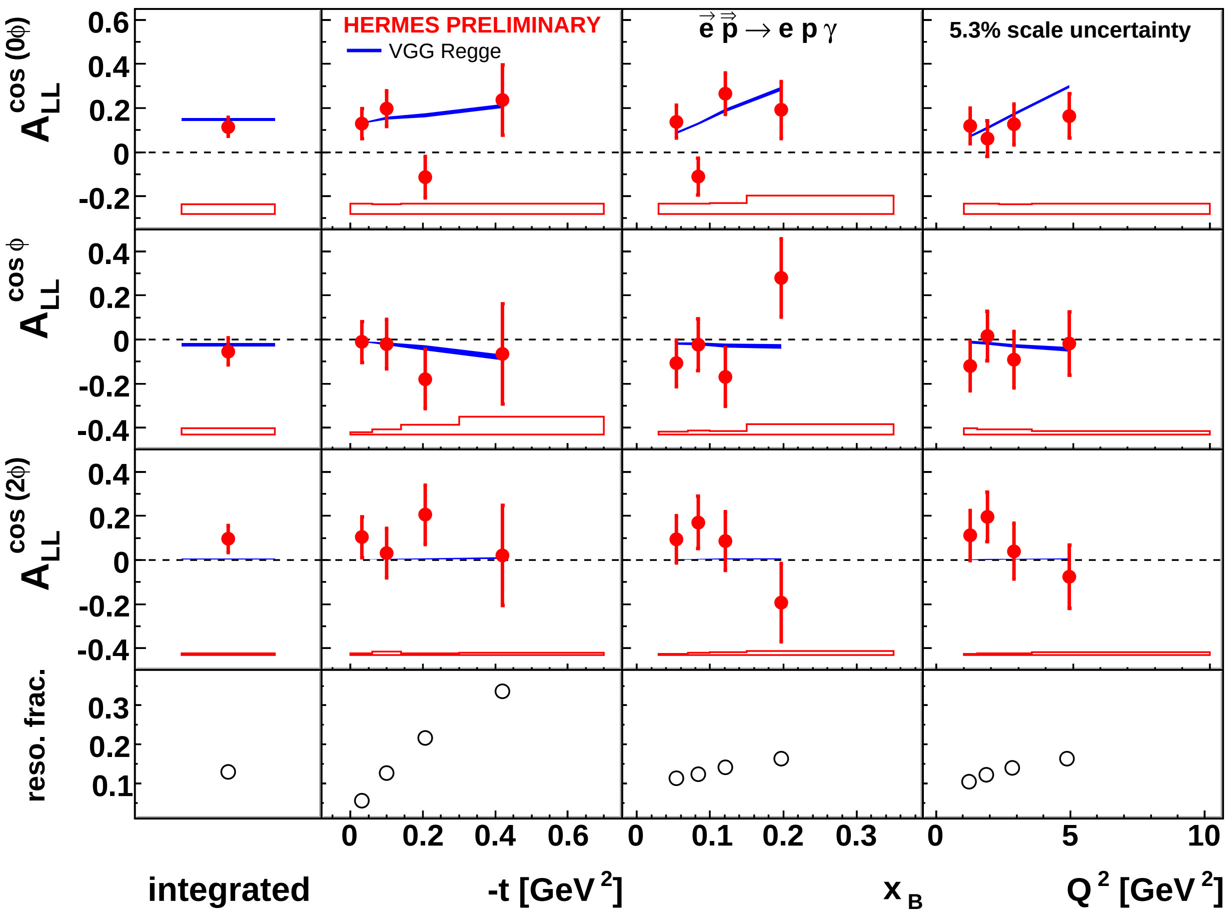
unexpected large value

- s_2^{I}: quark twist-3 or gluon twist-2
- s_2^{DVCS}: twist-4

model does not describe the data

double-spin asymmetry

$$\mathcal{A}_{LL}(\phi) \propto \sum_0^2 A_{LL}^{\cos(n\phi)} \cos(n\phi) \propto \sum_{n=0}^{2} c_n^{\mathrm{I}}, c_n^{\mathrm{DVCS}}$$



twist-2: $\propto F_1 \mathrm{Re}\widetilde{\mathcal{H}}$

$$A_{LL}^{\cos 0\phi} \propto \begin{cases} c_0^{\mathrm{DVCS}} \\ c_0^{\mathrm{I}} \end{cases}$$

twist-2 / twist-3:

$$A_{LL}^{\cos\phi} \propto \begin{cases} c_1^{\mathrm{DVCS}} \\ c_1^{\mathrm{I}} \end{cases}$$

twist-3:

$$A_{LL}^{\cos 2\phi} \propto \{ \; c_2^{\mathrm{I}}$$

model predictions:

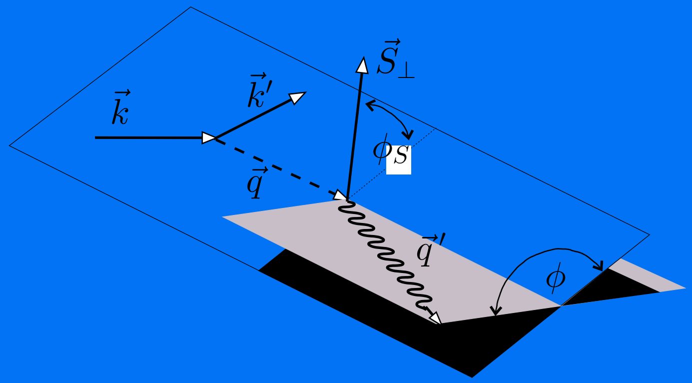
- the same model, as for BCA and BHA
- in good agreement with data

transversely polarized target

$$\sigma(\phi, P_\ell, S_T) = \sigma_{UU}(\phi) \times \left[1 + S_T \mathcal{A}_{UT}^{\mathrm{DVCS}}(\phi,\phi_s) + S_T e_\ell \mathcal{A}_{UT}^{\mathrm{I}}(\phi,\phi_s) + e_\ell \mathcal{A}_C(\phi)\right]$$

transverse target-spin asymmetry:

$$\mathcal{A}_{UT}(\phi,\phi_S) = \frac{1}{S_T} \cdot \frac{d\sigma^{\Uparrow}(\phi,\phi_S) - d\sigma^{\Downarrow}(\phi,\phi_S)}{d\sigma^{\Uparrow}(\phi,\phi_S) + d\sigma^{\Downarrow}(\phi,\phi_S)}$$



beam-charge asymmetry:

$$\mathcal{A}_C(\phi) \equiv \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-}$$

$$\mathcal{A}_{UT}^{\mathrm{DVCS}}(\phi,\phi_S) \equiv \frac{1}{S_T} \cdot \frac{d\sigma^{+\Uparrow}(\phi,\phi_S) - d\sigma^{+\Downarrow}(\phi,\phi_S) + d\sigma^{-\Uparrow}(\phi,\phi_S) - d\sigma^{-\Downarrow}(\phi,\phi_S)}{d\sigma^{+\Uparrow}(\phi,\phi_S) + d\sigma^{+\Downarrow}(\phi,\phi_S) + d\sigma^{-\Uparrow}(\phi,\phi_S) + d\sigma^{-\Downarrow}(\phi,\phi_S)}$$

$$\mathcal{A}_{UT}^{\mathrm{I}}(\phi,\phi_S) \equiv \frac{1}{S_T} \cdot \frac{d\sigma^{+\Uparrow}(\phi,\phi_S) - d\sigma^{+\Downarrow}(\phi,\phi_S) - d\sigma^{-\Uparrow}(\phi,\phi_S) + d\sigma^{-\Downarrow}(\phi,\phi_S)}{d\sigma^{+\Uparrow}(\phi,\phi_S) + d\sigma^{+\Downarrow}(\phi,\phi_S) + d\sigma^{-\Uparrow}(\phi,\phi_S) + d\sigma^{-\Downarrow}(\phi,\phi_S)}$$

- separation of s_i^{DVCS}, c_i^{DVCS} and s_i^{I}, c_i^{I} terms with same harmonic signatures
- projects the imaginary part of τ_{DVCS}

transverse target-spin asymmetry

$$\mathcal{A}_{UT}^{\mathrm{DVCS}}(\phi,\phi_S) = \sum_{n=0}^{2} A_{UT\,DVCS}^{\sin(\phi-\phi_S)\cos(n\phi)} \sin(\phi-\phi_S)\cos(n\phi)$$

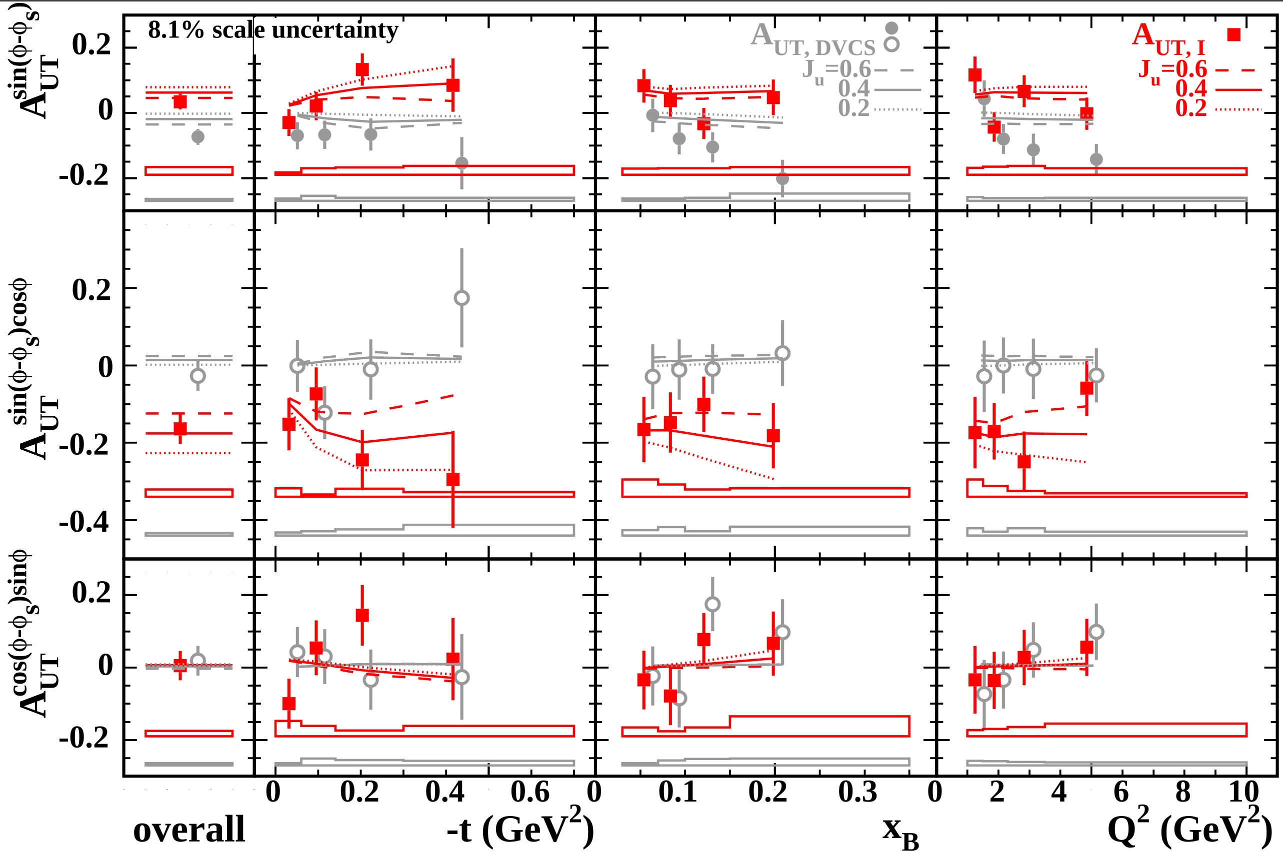
$$+ \sum_{n=1}^{2} A_{UT,\,DVCS}^{\cos(\phi-\phi_S)\sin(n\phi)} \cos(\phi-\phi_S)\sin(n\phi)$$

$$\mathcal{A}_{UT}^{\mathrm{I}}(\phi,\phi_S) = \sum_{n=0}^{2} A_{UT,\,I}^{\sin(\phi-\phi_S)\cos(n\phi)} \sin(\phi-\phi_S)\cos(n\phi)$$

$$+ \sum_{n=1}^{2} A_{UT,\,I}^{\cos(\phi-\phi_S)\sin(n\phi)} \cos(\phi-\phi_S)\sin(n\phi)$$

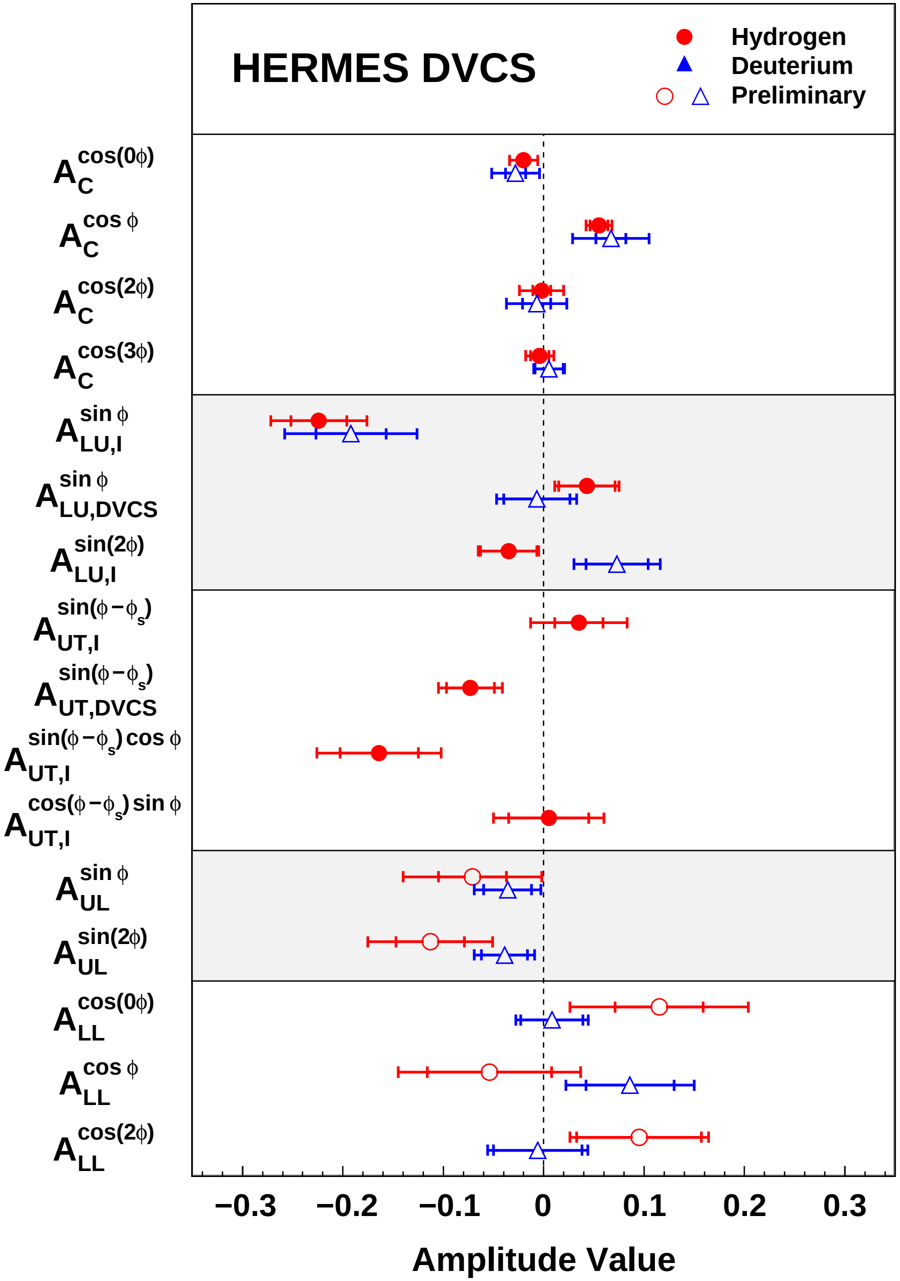
transverse target-spin asymmetry

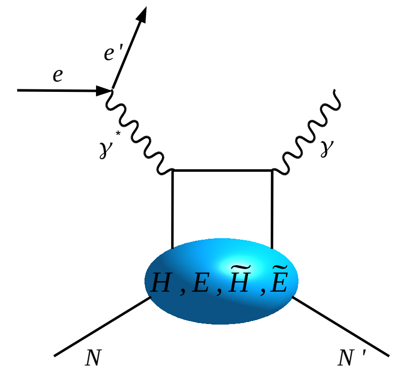
$$\mathcal{A}_{UT}(\phi,\phi_S) \propto \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}]\sin(\phi-\phi_S)\cos\phi + \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}]\sin(\phi-\phi_S)$$
$$+ \mathrm{Im}[\mathcal{H}\mathcal{E}^* - \mathcal{E}\mathcal{H}^* + \xi\widetilde{\mathcal{E}}\,\widetilde{\mathcal{H}}^* - \widetilde{\mathcal{H}}\,\xi\widetilde{\mathcal{E}}^*]\sin(\phi-\phi_S) + \ldots$$



- $A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$ found much more sensitive to J_u then others
- insensitive to J_d, assumed $J_d = 0$ (supported by lattice QCD)
- with a good model, allows a model-dependent constraint

Summary





beam-charge asymmetry:

- Re$\mathcal{H}$

beam-helicity asymmetry:

- Im$\mathcal{H}$

transverse target-spin asymmetry:

- Im$(\mathcal{H}\,\mathcal{E})$

longitudinal target-spin asymmetry:

- Im$\widetilde{\mathcal{H}}$

double-spin asymmetry:

- Re$\widetilde{\mathcal{H}}$

backup slides

beam helicity asymmetry

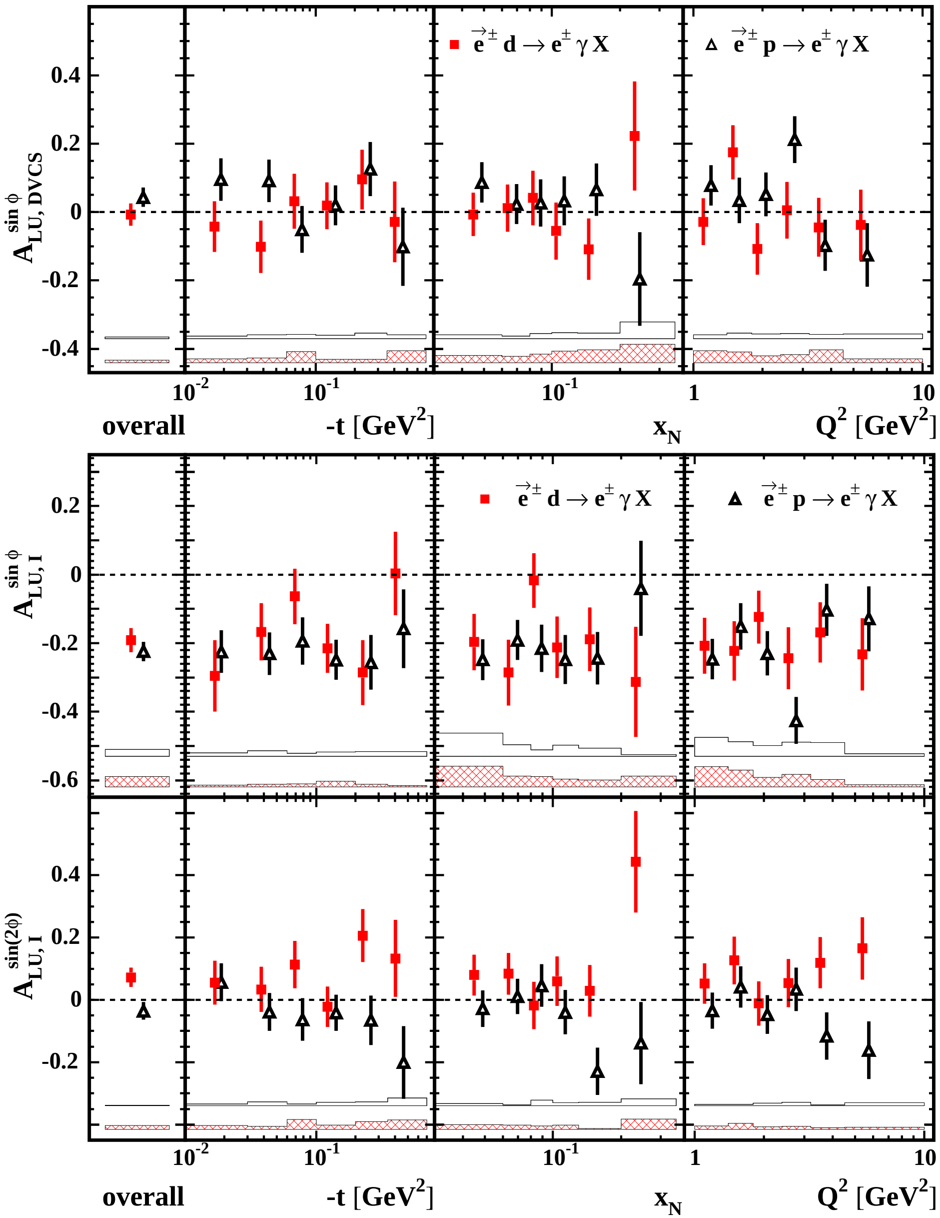
$$A_{LU}(\phi) \equiv \frac{d\sigma^{\rightarrow} - d\sigma^{\leftarrow}}{d\sigma^{\rightarrow} + d\sigma^{\leftarrow}}$$

$$= \frac{-e_\ell \frac{K_{\rm I}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left[\sum_{n=1}^{2} s_n^{\rm I} \sin(n\phi)\right] + \frac{1}{Q^2} s_1^{\rm DVCS} \sin\phi}{\frac{1}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left[K_{\rm BH} \sum_{n=0}^{2} c_n^{\rm BH} \cos(n\phi) - e_\ell K_{\rm I} \sum_{n=0}^{3} c_n^{\rm I} \cos(n\phi)\right] + \frac{1}{Q^2} \sum_{n=0}^{2} c_n^{\rm DVCS} \cos(n\phi)}. \quad (1)$$

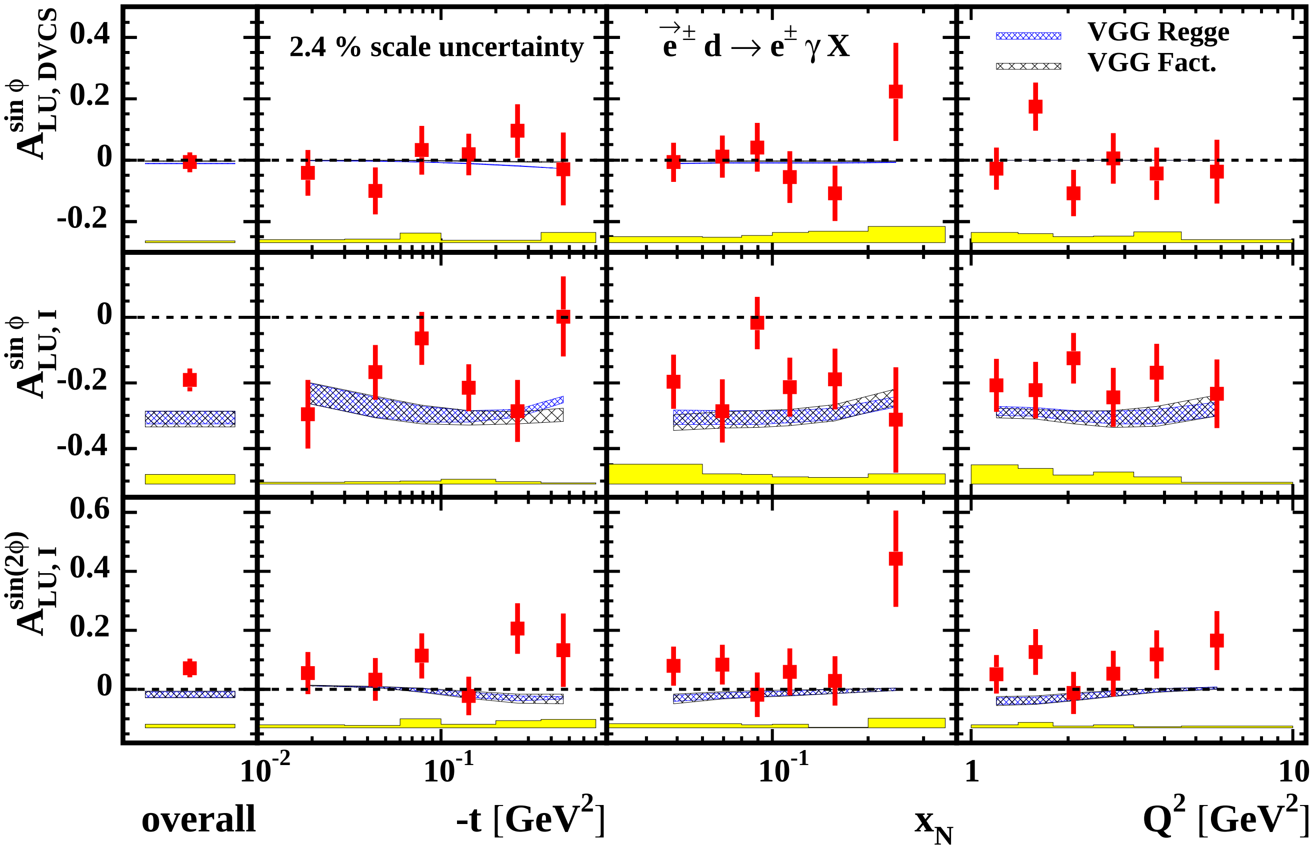
$$A_{LU}^{I}(\phi) \equiv \frac{(d\sigma^{+\rightarrow} - d\sigma^{+\leftarrow}) - (d\sigma^{-\rightarrow} - d\sigma^{-\leftarrow})}{(d\sigma^{+\rightarrow} + d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} + d\sigma^{-\leftarrow})}$$

$$= \frac{-\frac{K_{\rm I}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left[\sum_{n=1}^{2} s_n^{\rm I} \sin(n\phi)\right]}{\frac{K_{\rm BH}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \sum_{n=0}^{2} c_n^{\rm BH} \cos(n\phi) + \frac{1}{Q^2} \sum_{n=0}^{2} c_n^{\rm DVCS} \cos(n\phi)}, \quad (2)$$

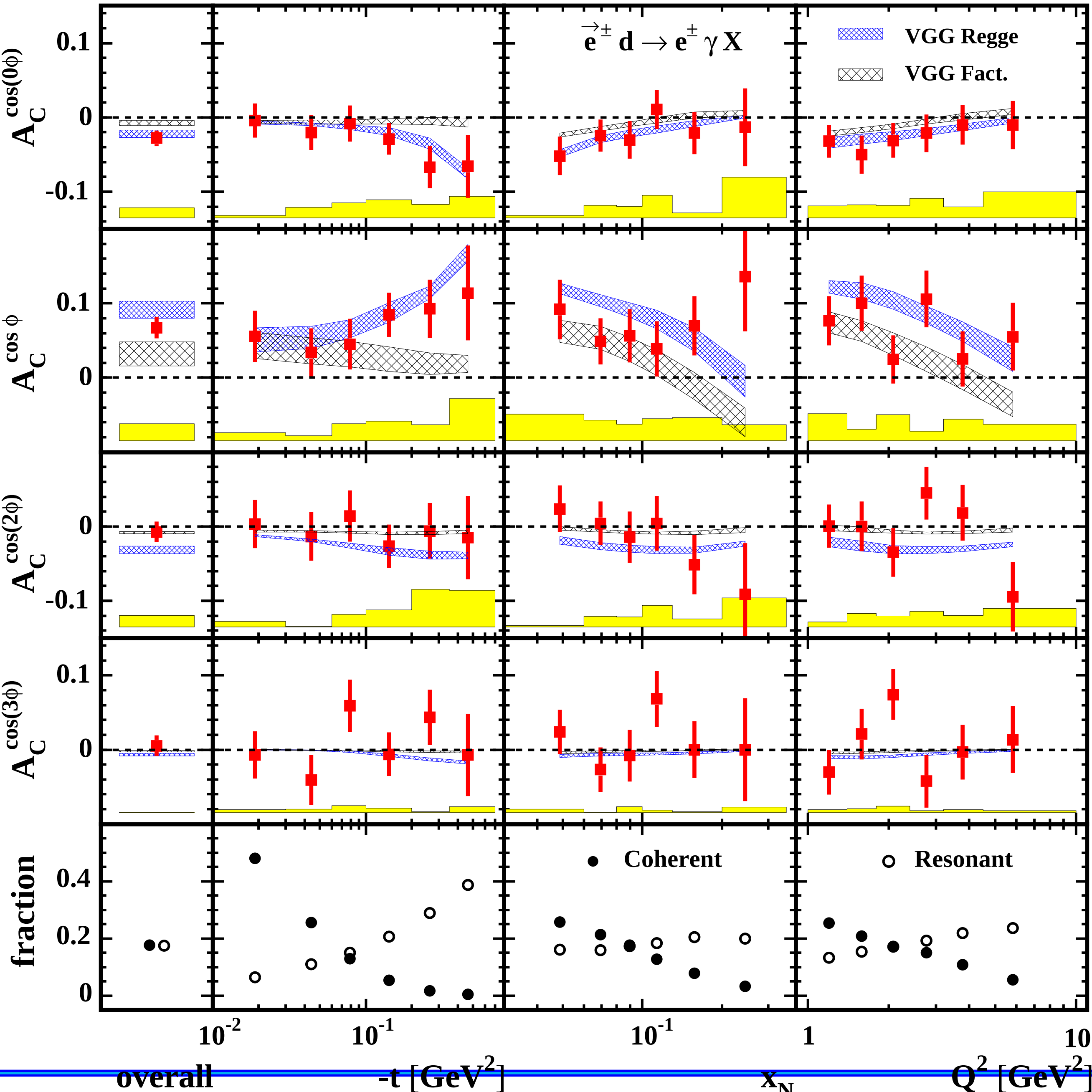
beam-helicity asymmetry



beam-helicity asymmetry



beam-helicity asymmetry



nuclear targets: He, N, Ne, Kr, Xe