Deeply-Virtual Compton Scattering at HERMES

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for the HERMES-Collaboration

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- Motivation
- Generalized Parton Distributions
- Deeply-Virtual Compton Scattering
- HERMES-Experiment
- Results
- Summary
- Outlook

THE SPIN STRUCTURE OF THE NUCLEON

longitudinally polarized nucleon

$$\frac{1}{2} = \underbrace{\frac{1}{2}\Delta\Sigma + L_q}_{J_q} + \underbrace{\Delta G + L_g}_{J_g}$$

STATUS:

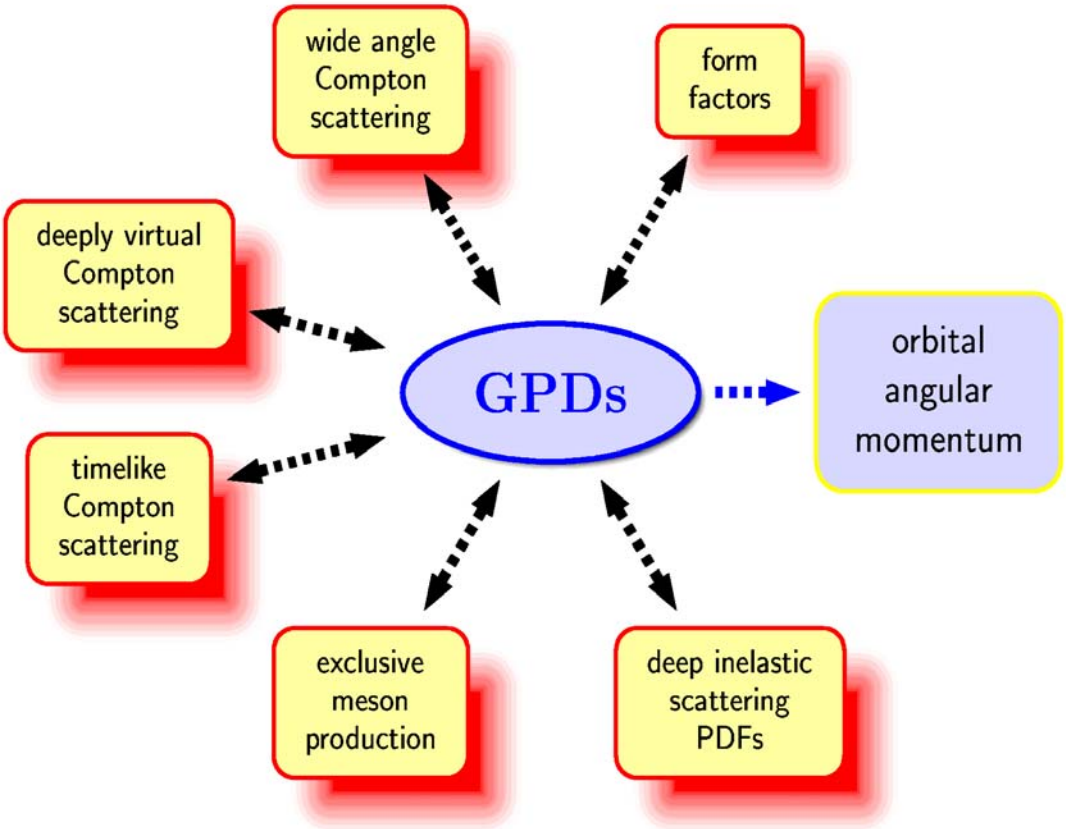
- VALENCE- AND SEAQUARK CONTRIBUTION ($\Delta\Sigma$) APPROXIMATELY 30 %
- GLUON CONTRIBUTION (ΔG) POSITIVE ($\rightarrow$ NLO QCD FITS, HERMES)

X.JI, 1997: THE SECOND MOMENT OF THE UNPOLARIZED GPD'S IS RELATED TO J_q.

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

Generalized Parton Distributions

GPDs: Generalized theoretical description of inclusive and (hard) exclusive processes.



GPDs → "usual" PD's

$$H(x,0,0) = q(x)$$
$$\tilde{H}(x,0,0) = \Delta q(x)$$

(→ M. Vanderhaeghen)

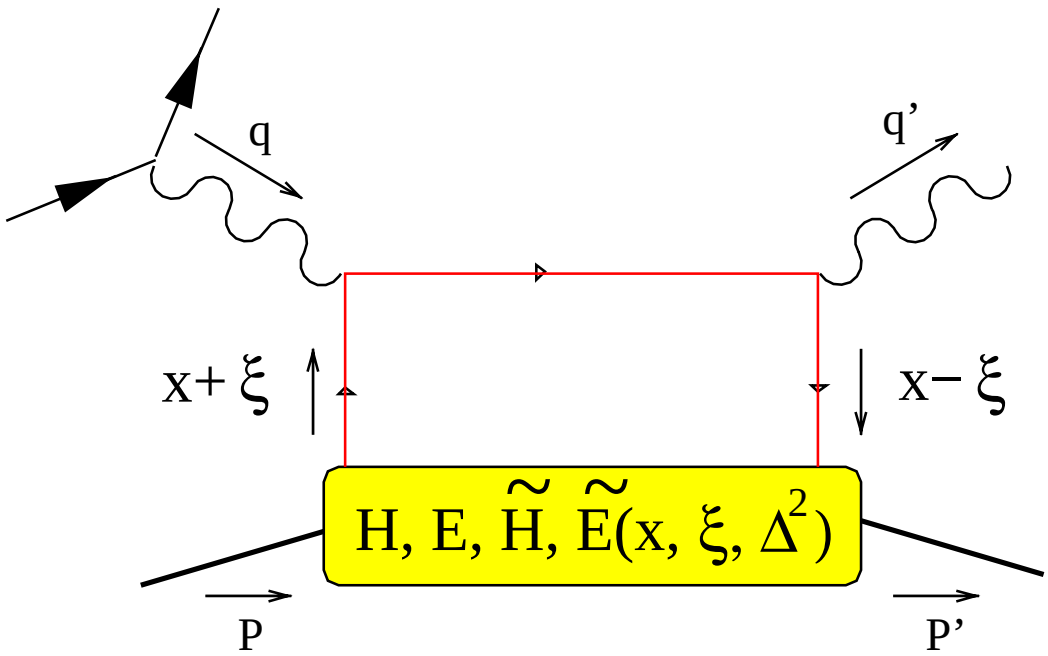
GPDs → FF's

$$\int_{-1}^{1} dx H(x,\xi,t) = F_1(t)$$
$$\int_{-1}^{1} dx E(x,\xi,t) = F_2(t)$$
$$\int_{-1}^{1} dx \tilde{H}(x,\xi,t) = G_A(t)$$
$$\int_{-1}^{1} dx \tilde{E}(x,\xi,t) = G_P(t)$$

GPDs and DVCS

Simplest hard exclusive process:
Deeply-virtual electroproduction of real photons.

⇒ Deeply-virtual Compton Scattering



Variables:

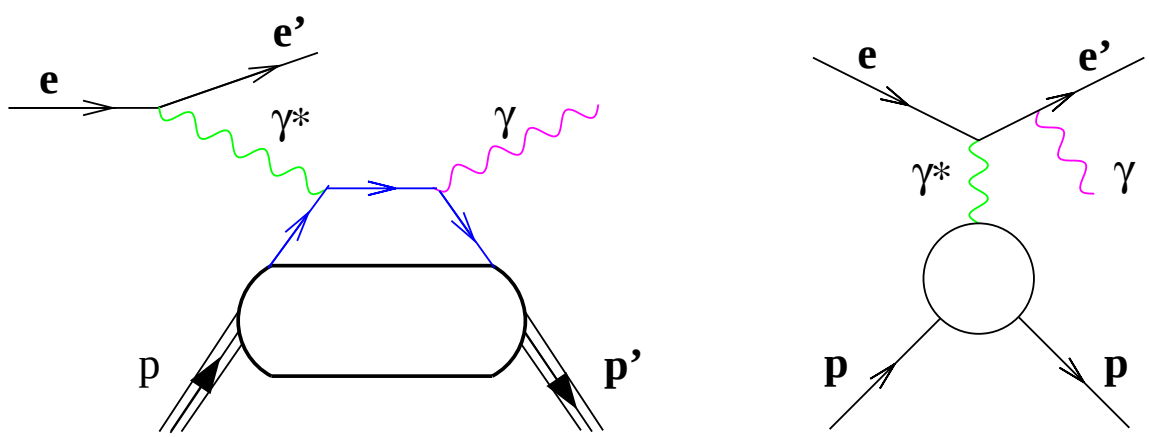
- Momentum fractions on the lightcone x and ξ
- $\gamma^* \rightarrow \gamma$ Momentum transfer $\Delta^2 = (p^*_\gamma - p_\gamma)^2 = -t$

Real and Imaginary parts of the DVCS-Amplitudes can be expressed in terms of the GPDs H, $\tilde{H}$, E, $\tilde{E}$.

Deeply-Virtual Compton Scattering

DVCS final state $e + p \rightarrow e' + p' + \gamma$
is indistinguishable from the Bethe-Heitler Process (BH)

DVCS cross section smaller than BH cross section



$\rightarrow$ Amplitudes add coherently

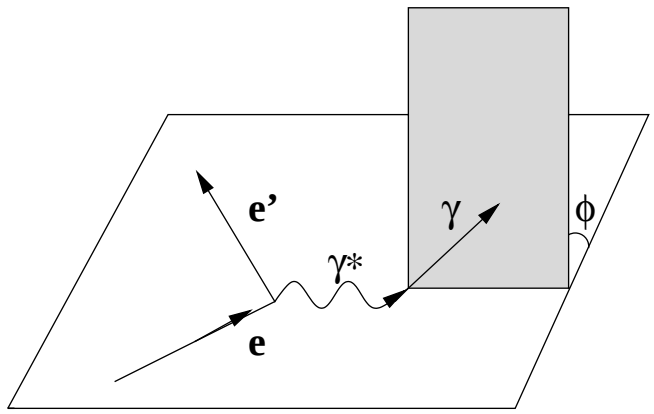
BH Process calculable in QED with the knowledge of the Proton Form Factors

Photon-Production cross section:

$$d\sigma \propto |\tau_{\mathrm{DVCS}} + \tau_{\mathrm{BH}}|^2$$
$$= |\tau_{\mathrm{DVCS}}|^2 + |\tau_{\mathrm{BH}}|^2 + (\tau^*_{\mathrm{DVCS}}\tau_{\mathrm{BH}} + \tau^*_{\mathrm{BH}}\tau_{\mathrm{DVCS}})$$

Charge and Spin Asymmetry

$$I \propto \pm(c_0^I + \sum_n [c_n^I \cos(n\phi) + \lambda s_n^I \sin(n\phi)])$$



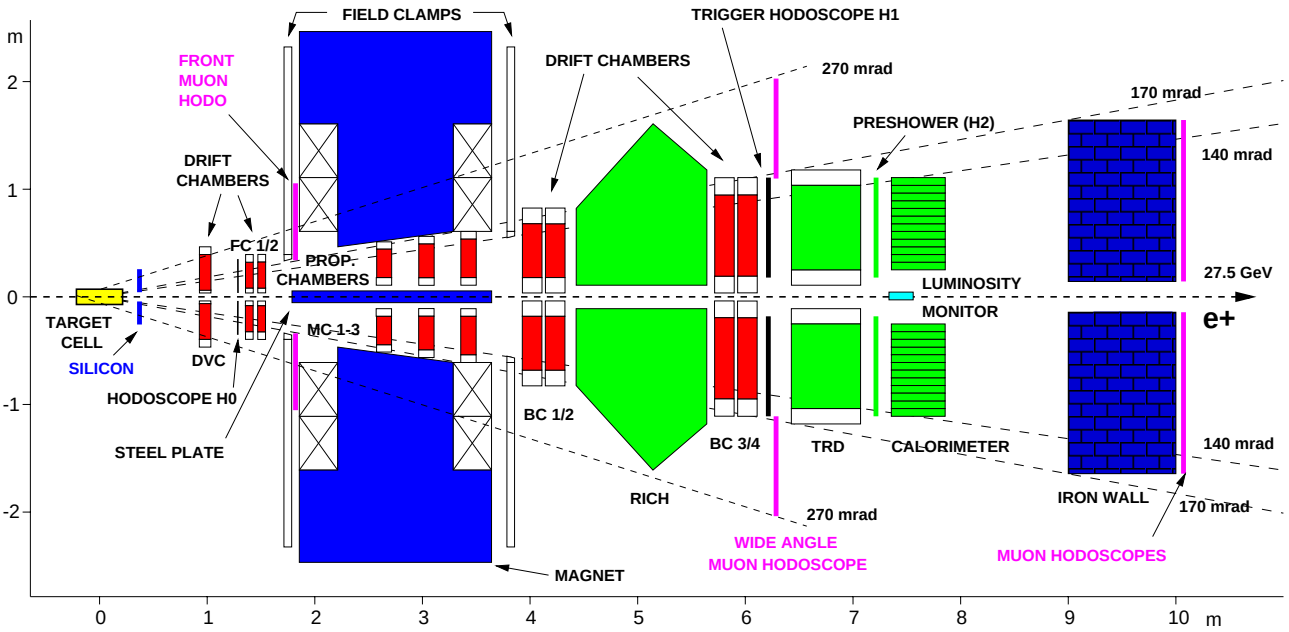
Imaginary Part of the Interference-Term can be accessed via Beam–Spin Asymmetry using polarized beam and unpolarized target:

$$d\sigma(\overrightarrow{e^+}p) - d\sigma(\overleftarrow{e^+}p) \sim \sin(\phi_\gamma) \times \mathrm{Im}\,(\tau_{\mathrm{DVCS}}\tau_{\mathrm{BH}})$$

Real Part of the Interference-Term can be accessed via Lepton Charge Asymmetry using unpolarized beam and target:

$$d\sigma(e^+p) - d\sigma(e^-p) \sim \cos(\phi_\gamma) \times \mathrm{Re}\,(\tau_{\mathrm{DVCS}}\tau_{\mathrm{BH}})$$

The HERMES-Spectrometer



- Electron/Positron Identification via TRD, Preshower, Calorimeter
  $\Rightarrow$ Hadron contamination of the Lepton-Sample $\leq 1\%$

- momentum reconstruction via tracking chambers $\Rightarrow$ resolution $\approx 1.5\%$

- Identify Photon via Preshower and trackless cluster in Calorimeter

- energy reconstruction via Calorimeter
  $\Rightarrow$ about 5% for DVCS Photons ($\approx$ 13 GeV)

Data Selection

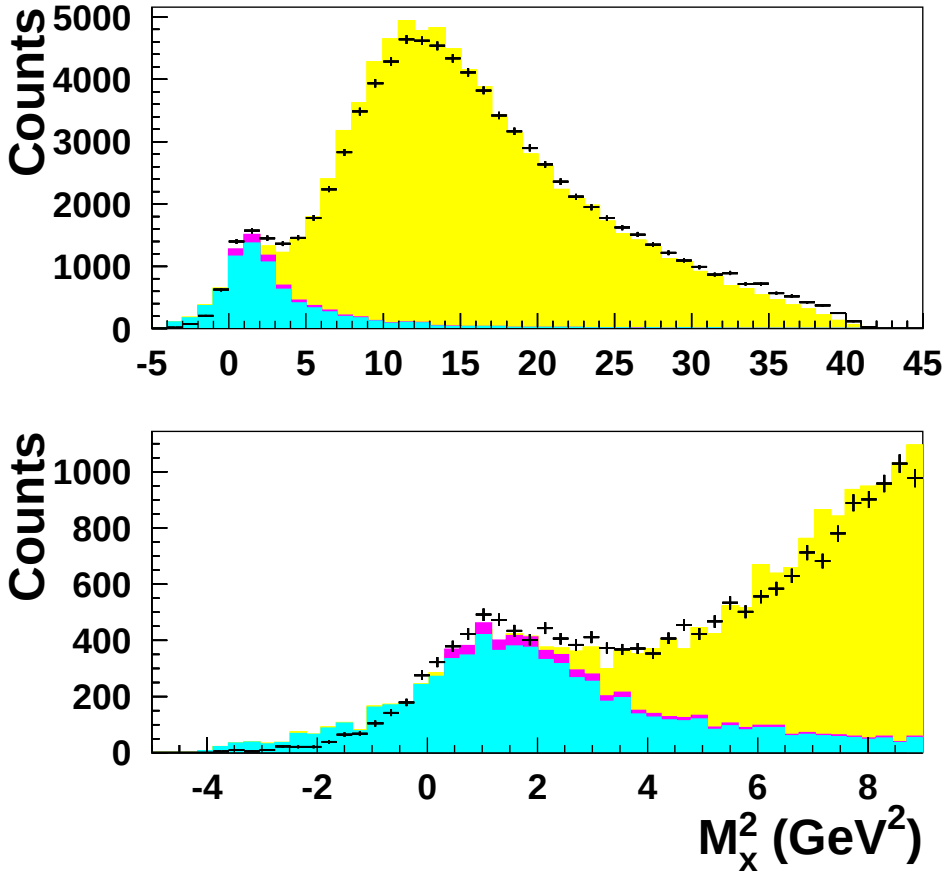
- Select events with exactly one DIS-positron/DIS-electron and one trackless cluster in the calorimeter

- Standard Data-Quality and DIS Cuts
  * $Q^2 > 1$ GeV^2
  * $W^2 > 4$ GeV^2
  * $\nu < 23$ GeV
  * ...

- Photon Selection:
  * $2\ (15) < \theta_{\gamma^*\gamma} < 70$ mrad
    new (old) photon position reconstruction agorithm
  * Signal in Preshower
  * ...

Few thousand/hundred events in the "exclusive" bin in the case of Beam–Spin/Beam–Charge Asymmetry.

Exclusive Reaction?



Exclusive Reaction:

$$M_x^2 \equiv (q + p - p_\gamma)^2 = M_p^2$$

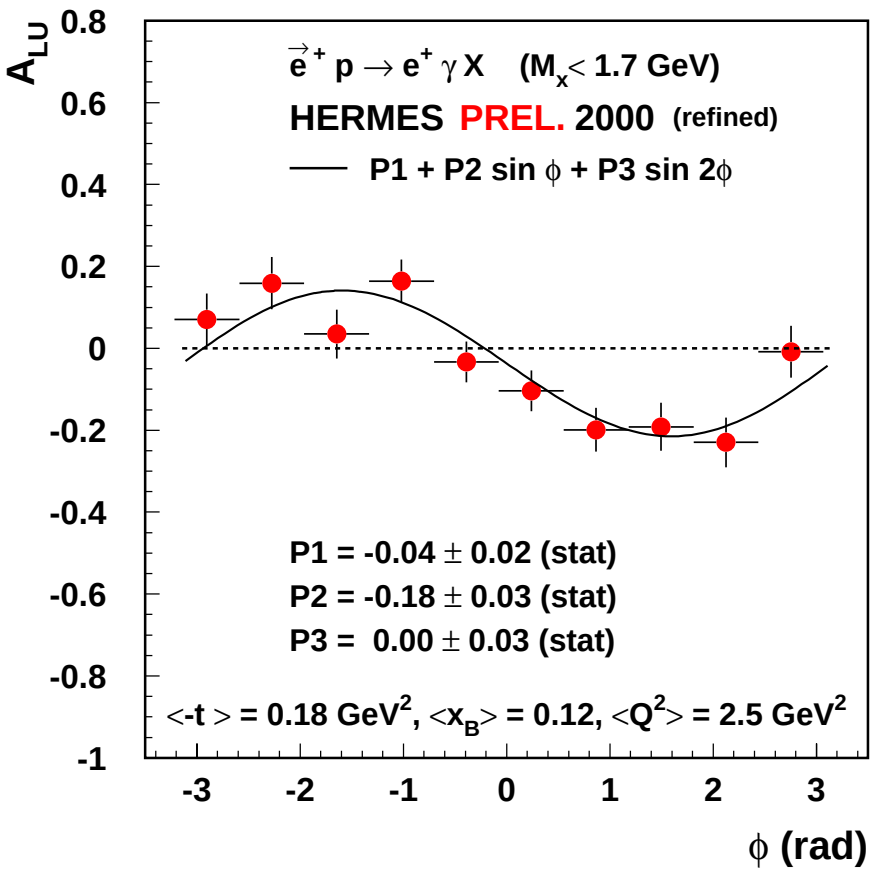
Missing Mass (M_x) resolution $\approx$ 0.8 GeV ($\rightarrow$ Calorimeter)

$\Rightarrow$ no separation between exclusive and associated DVCS

$\Rightarrow$ "Exclusive" bin (-1.5 $< M_x <$ 1.7 GeV)

Beam–Spin Asymmetry (BSA) $A_{\mathrm{LU}}(\phi)$:
Beam pol. (L), Target unpol. (U)

$$A_{\mathrm{LU}}(\phi) = \frac{1}{<|P_b|>} \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)}$$

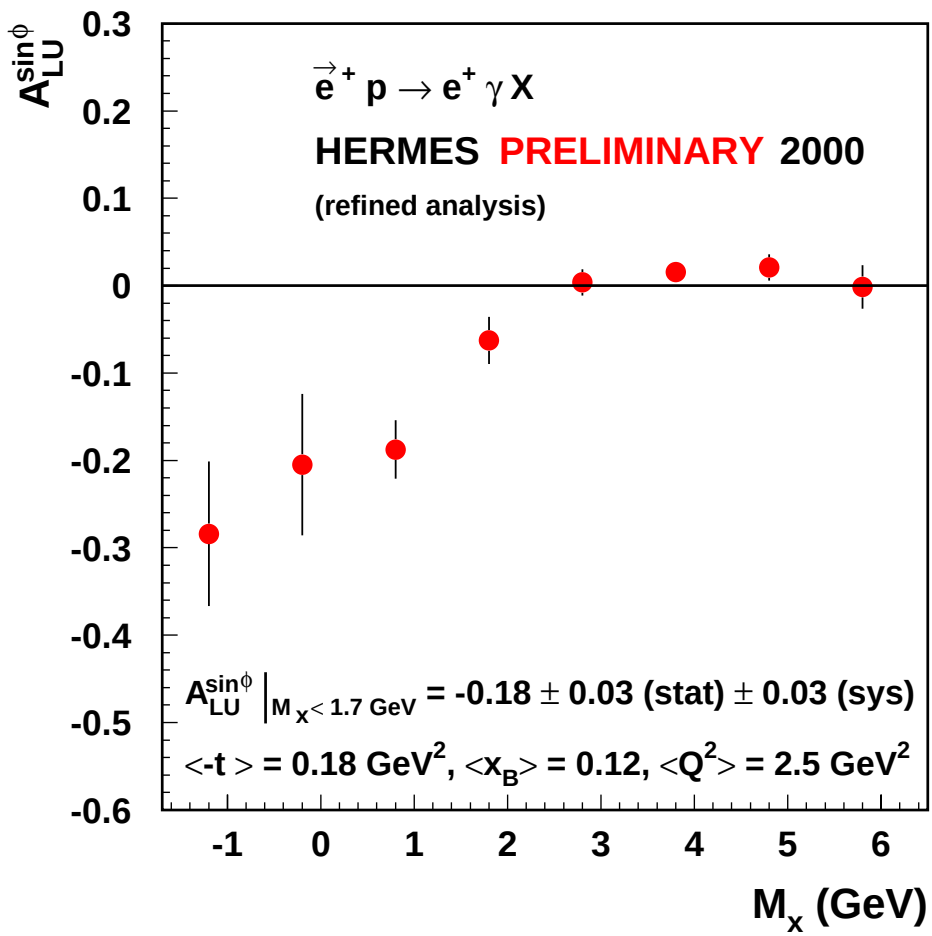


In the exclusive bin (-1.5 < M_x < 1.7 GeV)
A_{LU} exhibits the expected $\sin(\phi)$ dependence.

(Results from 1996/97 → PRL **87**, 182001 (2001))

$\sin(\phi)$–Moment

$$A_{\mathrm{LU}}^{\sin\phi} = \frac{2}{N^+ + N^-} \sum_{i=1}^{N^+ + N^-} \frac{\sin(\phi_i)}{(P_l)_i}$$

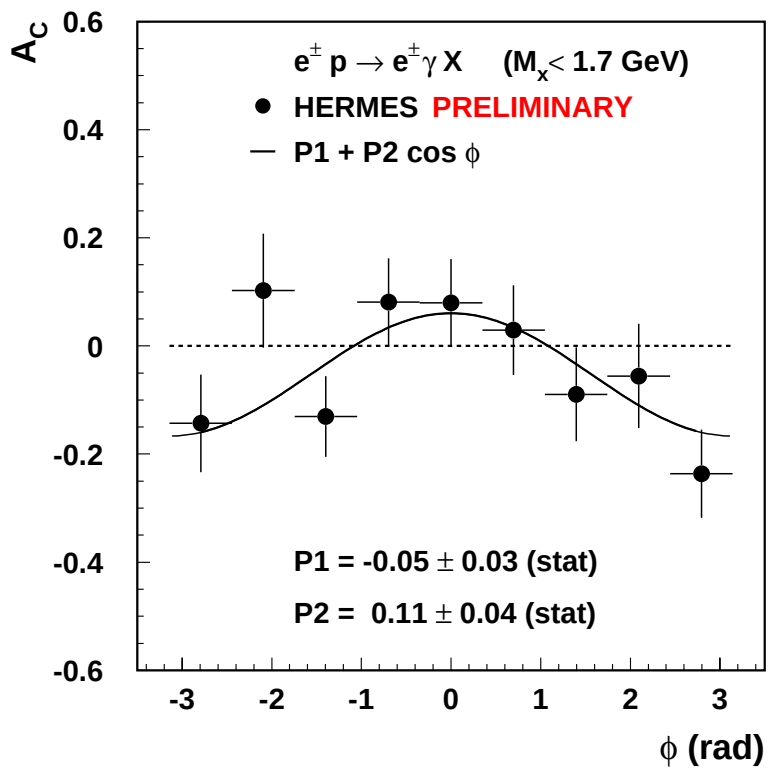


$\Rightarrow$ $\sin(\phi)$–Moments small at higher missing mass.

Beam–Charge Asymmetry

$$I \propto \pm(c_0^I + \sum_n [c_n^I \cos(n\phi) + \lambda s_n^I \sin(n\phi)])$$

$\Rightarrow$ Use "Helicity balanced" sample to get rid of $\sin(\phi)$–dependence in the numerator.



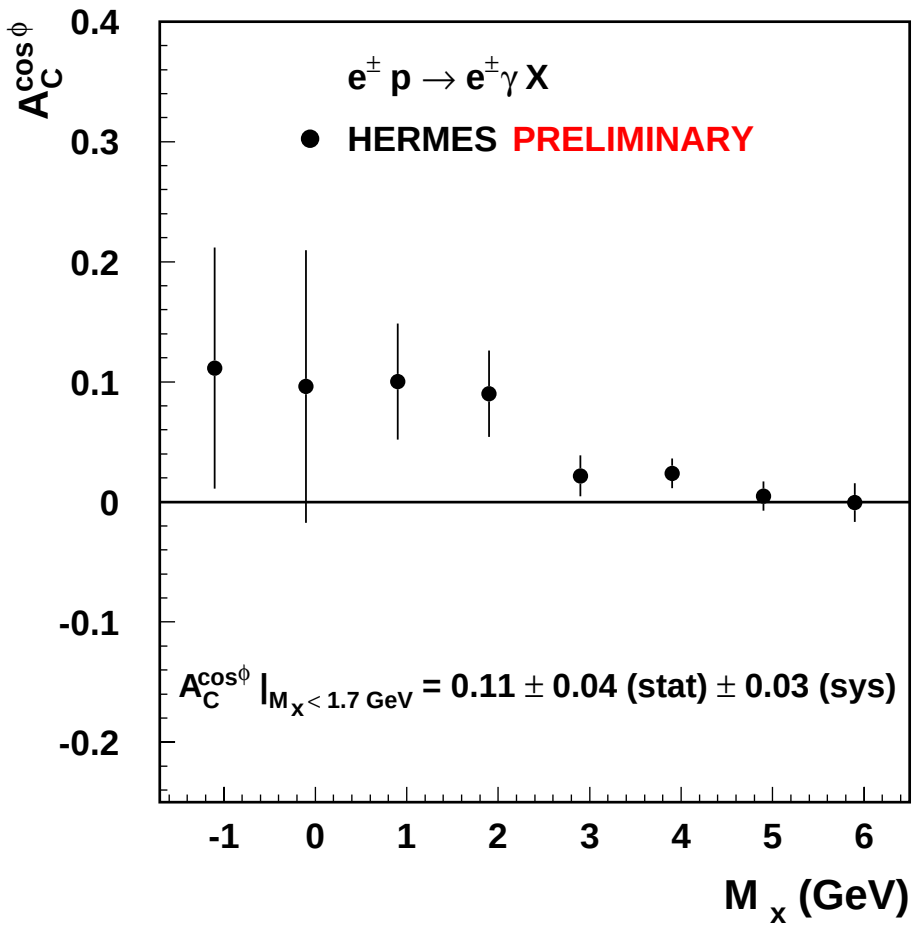
Beam–Charge Asymmetry $A_{\mathrm{C}}(\phi)$:

$$A_{\mathrm{C}}(\phi) = \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)}$$

In the exclusive bin (-1.5 $< M_x <$ 1.7 GeV) A_{C} exhibits the expected $\cos(\phi)$–dependence.

$\cos(\phi)$–Moment

$$A_C^{\cos\phi} = \frac{\int_0^{2\pi} d\phi \cos\phi \frac{d\sigma^+}{d\phi}}{\int_0^{2\pi} d\phi \frac{d\sigma^+}{d\phi}} - \frac{\int_0^{2\pi} d\phi \cos\phi \frac{d\sigma^-}{d\phi}}{\int_0^{2\pi} d\phi \frac{d\sigma^-}{d\phi}}$$



(HEP-EX/0207029)

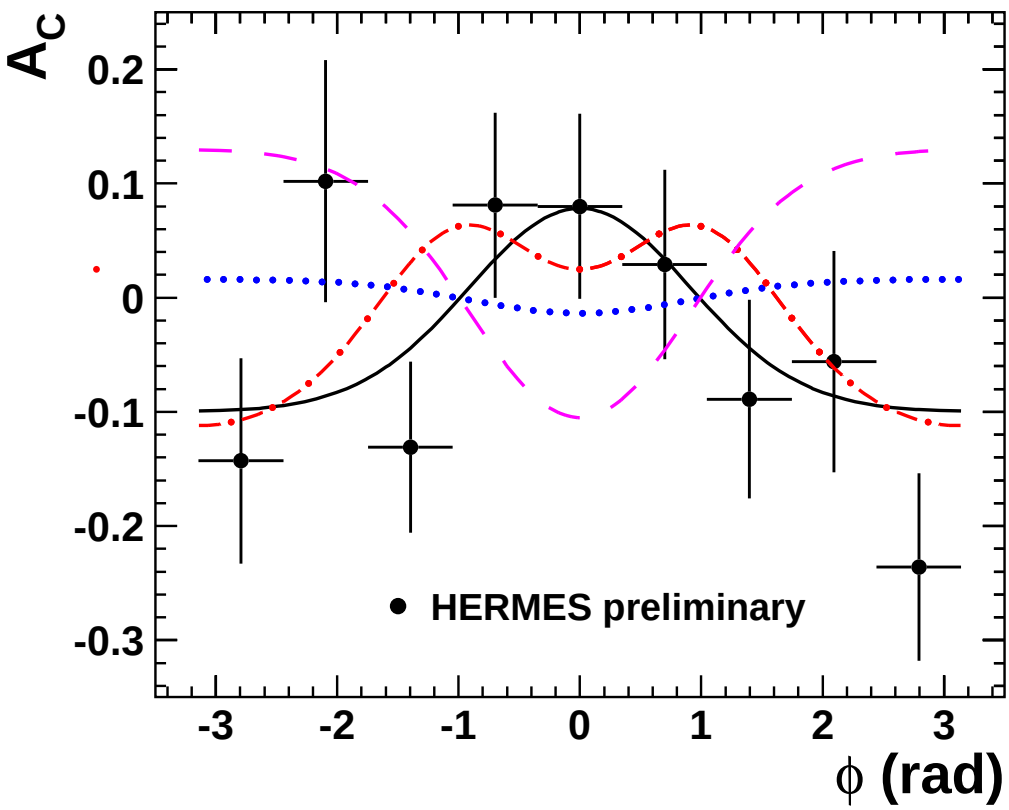
$< Q^2 >= 2.8\ \mathrm{GeV}^2,\ < x >= 0.12,\ < -t >= 0.27\ \mathrm{GeV}^2$

$\Rightarrow$ $\cos(\phi)$–Moments small at higher missing mass.

The "D-Term" ...

t-independent part can be parametrized by:

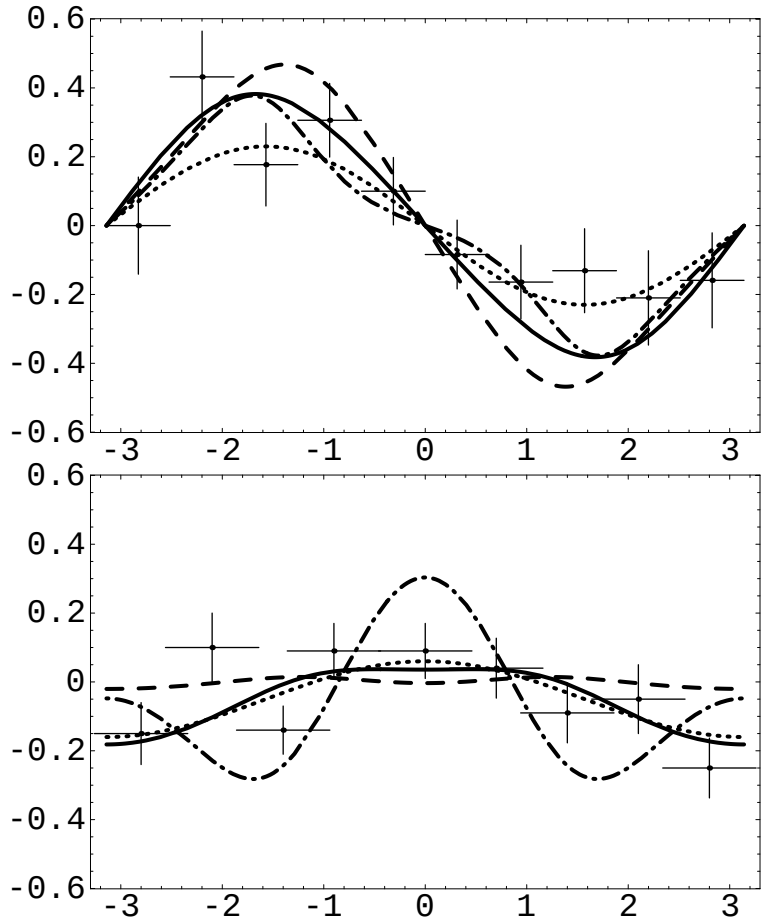
$$H^q(x,\xi) = H^q_{DD}(x,\xi) + \text{D-Term}$$
$$E^q(x,\xi) = E^q_{DD}(x,\xi) - \text{D-Term}$$



GPD-model calculation for HERMES kinematics (M. Vanderhaeghen, hep-ph/0207176)

$\Rightarrow$ Data seem to favour parametrization with D-Term contribution.

. . . or not the "D-Term" ?



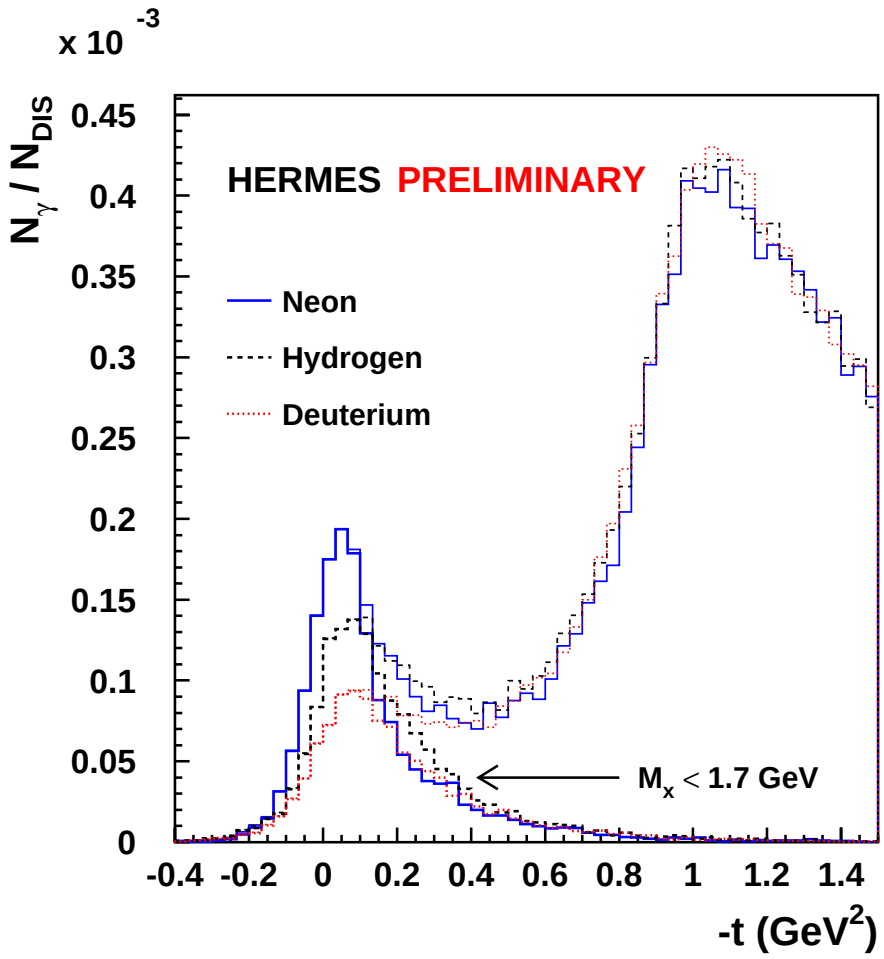
Complete twist–3 calculation for HERMES kinematics (Belitsky, Müller, hep-ph/0206306)

⇒ Data seem to favour parametrization without D-Term contribution.

Other models (e.g. A. Freund et al., hep-ph/0208160) describe available data as well.

⇒ More (precise) data needed to constrain models.

Measurement of DVCS on Deuterium and Neon.

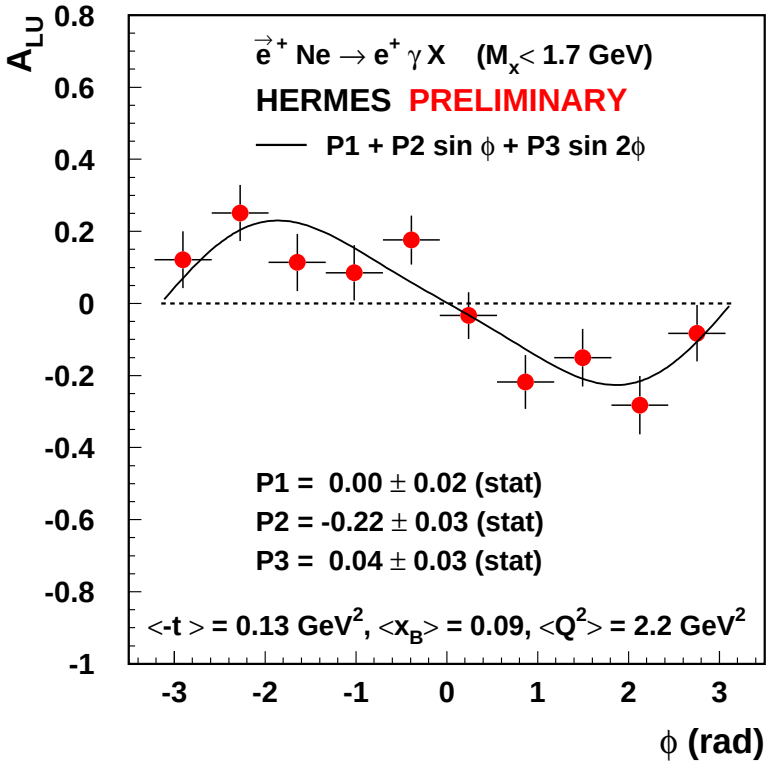


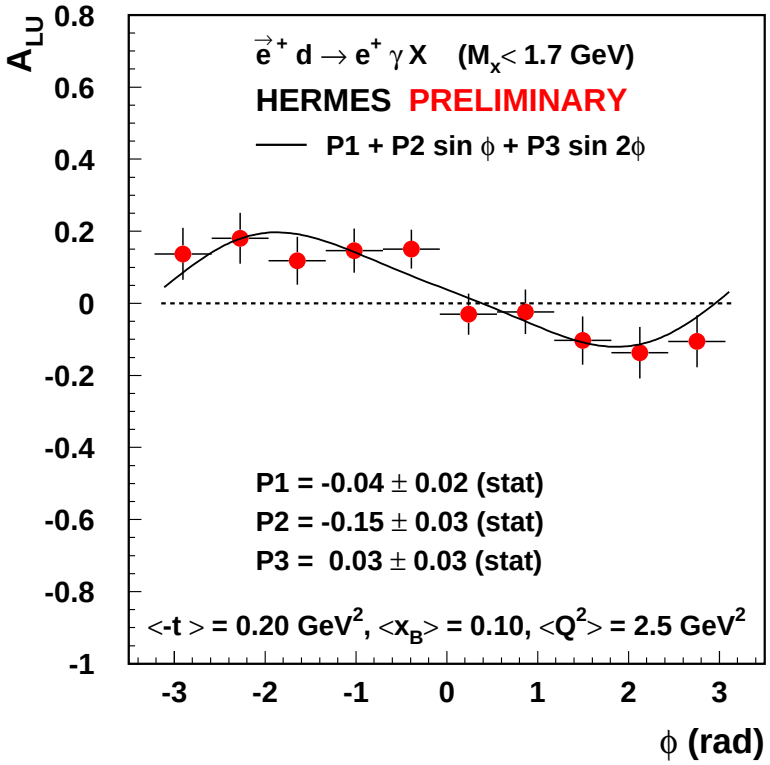
DVCS on Deuteron expected to be slightly smaller than on proton

M^2/Q^2 corrections are not under control (Kirchner, Müller, hep-ph/0202279 and Cano, Pire, hep-ph/0206215)

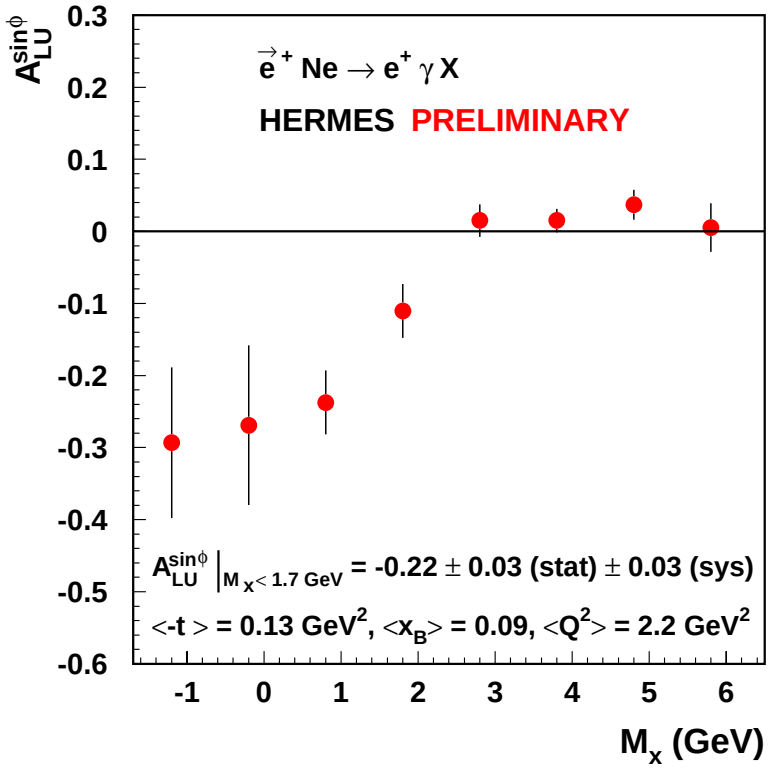
No projections for DVCS on (heavier) Nuclei.

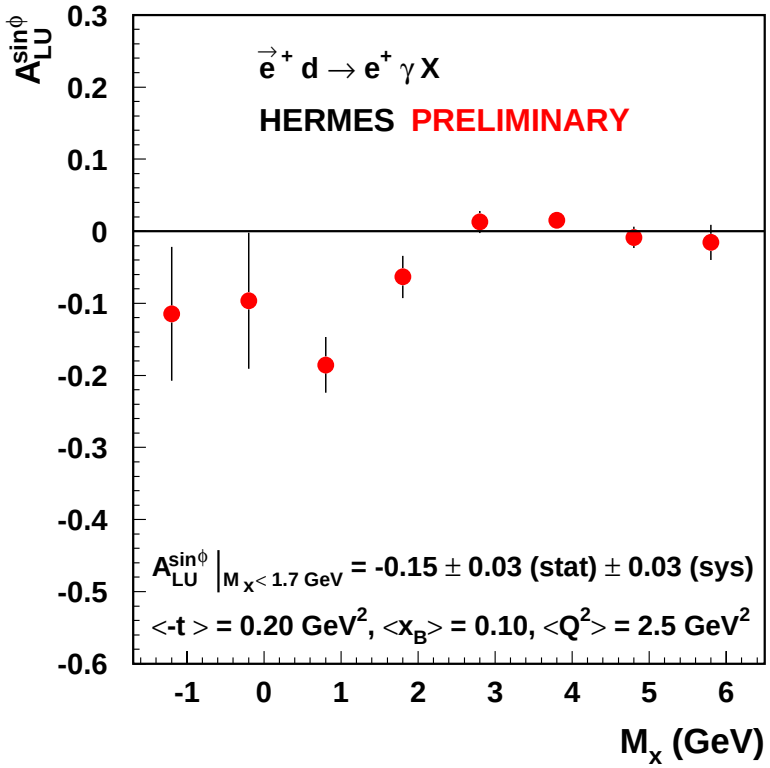
DVCS on Nuclei (BSA)





DVCS on Nuclei ($\sin(\phi)$–Moment)





Summary

- Real and Imaginary Part of the DVCS-Amplitudes can be expressed in terms of the GPDs and accessed through the DVCS-BH interference.

- Measurement of the Beam–Spin Asymmetry at HERMES (PRL **87**, 182001 (2001)) confirmed with 2000 data, preliminary value:
  $A_{\mathrm{LU}}^{\sin\phi}$ (Hydrogen): $0.18 \pm 0.03(\mathrm{stat}) \pm 0.03(\mathrm{sys})$

- First Measurement of the Beam–Charge Asymmetry (hep-ex/0207029), preliminary value:
  $A_{\mathrm{C}}^{\cos\phi}$ (Hydrogen): $0.11 \pm 0.04(\mathrm{stat}) \pm 0.03(\mathrm{sys})$

- First Measurement of the Beam–Spin Asymmetry on neon and deuterium, preliminary values:
  $A_{\mathrm{LU}}^{\sin\phi}$ (Neon): $0.22 \pm 0.03(\mathrm{stat}) \pm 0.03(\mathrm{sys})$
  $A_{\mathrm{LU}}^{\sin\phi}$ (Deuterium): $0.15 \pm 0.03(\mathrm{stat}) \pm 0.03(\mathrm{sys})$

Outlook

- short term:
  - Target Spin Asymmetry on Deuterium
  - Kinematical dependences of the Beam–Spin Asymmetries (H,D,Ne)
  - Applying new Method of photon position reconstruction to e^- data-set:
    $\Rightarrow$ gain 70–90% events
    + Update Beam Charge Asymmetry on Hydrogen
    + Beam Charge Asymmetry on Deuterium
- long term upgrade:
  - Large-Acceptance Recoil Detector for HERMES ($\rightarrow$ D. Hasch):
    * Ensure the exclusivity of measured events
    * Improve resolution in t