Measurement of **D**eeply **V**irtual **C**ompton **S**cattering at HERMES

- Introduction
- DVCS at HERMES
- Measured Asymmetries
- Outlook

XII International Workshop on Deep Inelastic Scattering
Madison, Wisconsin USA

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for the HERMES collaboration

Motivation.
Nucleon Spin Composition

30%

unknown !

Proton's Spin = $\frac{1}{2}\left(\Delta u + \Delta d + \Delta s\right) + L_q + J_g$

J_q

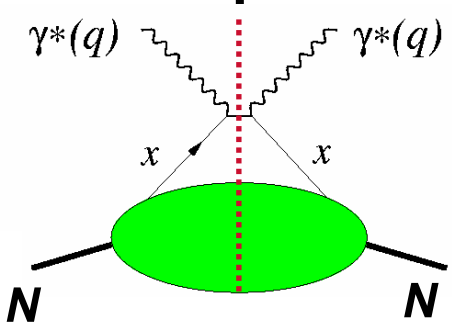
Ji's relation:

GPDs

$$J_q^3\left(Q^2\right) = \lim_{t\to 0}\int_{-1}^{1} dx\, x\left[\mathrm{H}_q\left(x,\xi,t\right) + \mathrm{E}_q\left(x,\xi,t\right)\right]$$

We study DVCS to constrain GPDs

Factorization: DIS & DVCS

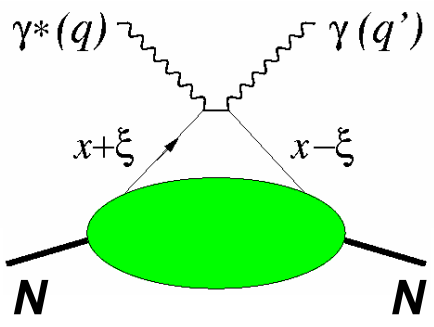


DIS

$ep \to e'X$

DVCS

$ep \to e'p\gamma$



Amplitude:

$$A\left(\gamma^* N \to \gamma^* N\right)$$

$$A\left(\gamma^* N \to \gamma N\right)$$

Forward Compton
Mandelstam $t = 0$

Non-forward Compton
Mandelstam $t \neq 0$

Factorization:

A = hard scattering $\otimes$

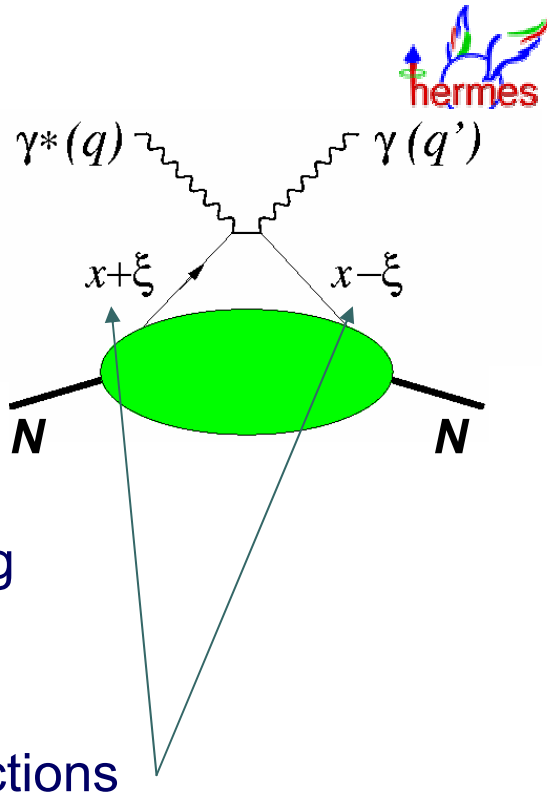
$\otimes$ **P**arton **D**istribution

only diagonal matrix elements

$\otimes$ *Generalized*
Parton **D**istribution (GPD)

non-diagonal matrix elements

GPDs for DVCS on a spin-½ target



twist 2 GPDs:

$H(x,\xi,t), \widetilde{H}(x,\xi,t)$ target helicity conserving

$E(x,\xi,t), \widetilde{E}(x,\xi,t)$ target helicity non conserving

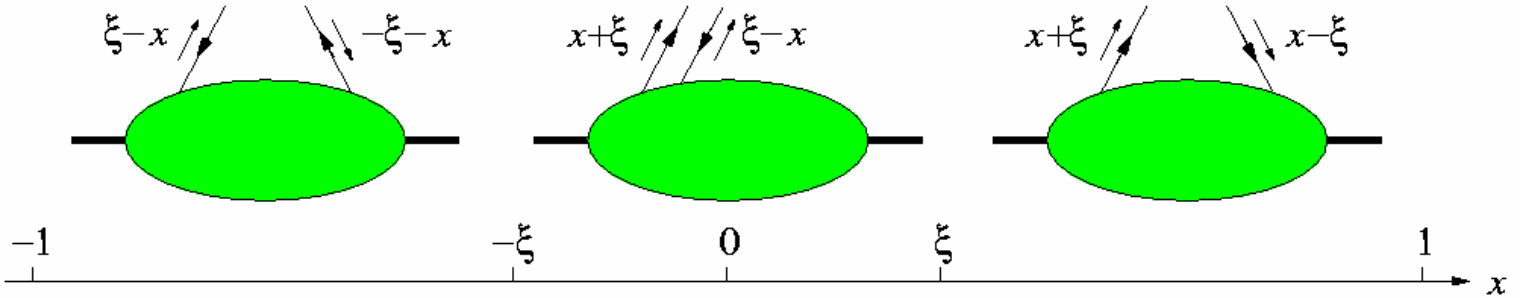
where:

t momentum transfer (Mandelstam ***t***)

$x \pm \xi$ parton's longitudinal momentum fractions

x unobservable internal variable in DVCS

$\xi \cong \dfrac{x_B}{2 - x_B}$ longitudinal momentum transfer between two partons



Properties of GPDs

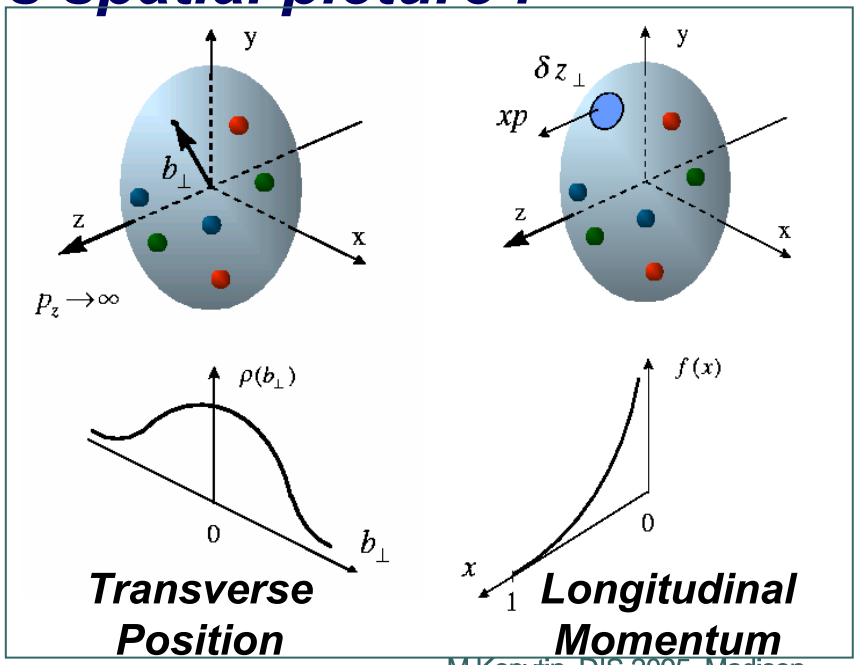
Forward limit: $\mathrm{H}^q(x,0,0) = q(x) \quad \widetilde{\mathrm{H}}^q(x,0,0) = \Delta q(x)$

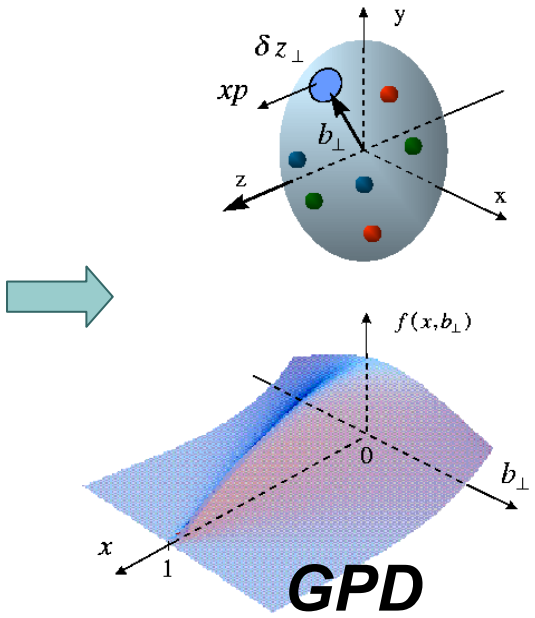
t = 0, ξ = 0

Sum Rules: $\int_{-1}^{1} dx \mathrm{H}^q(x,\xi,t) = F_1(t) \quad \int_{-1}^{1} dx \mathrm{E}^q(x,\xi,t) = F_2(t)$

F_1, F_2 – Dirac and Pauli form factors

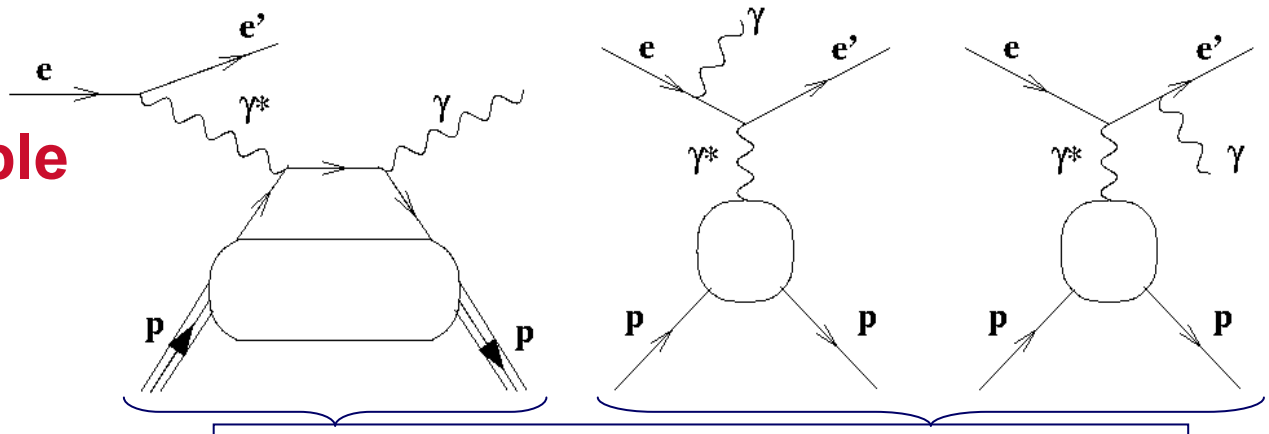
Nucleon's spatial picture :





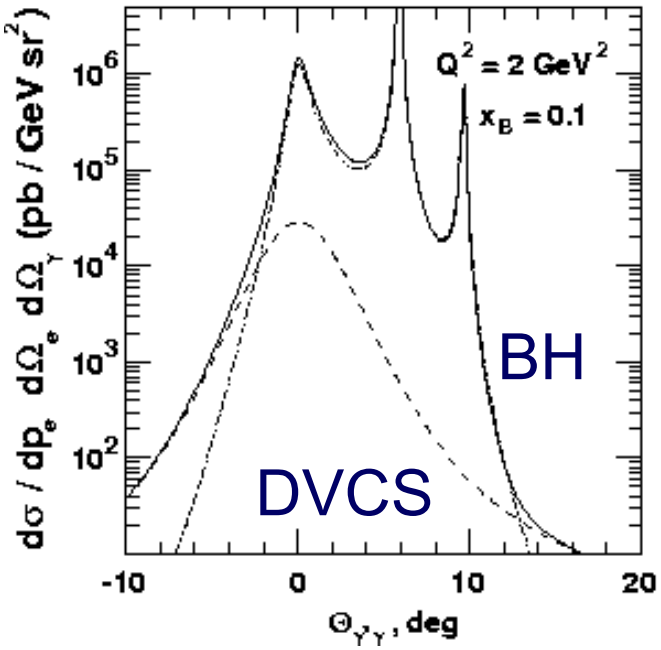
DVCS & **B**ethe-**H**eitler (BH)

indistinguishable final state



DVCS & Bethe-Heitler

@ HERMES



$$\tau = \left|\tau_{BH}\right|^2 + \left|\tau_{DVCS}\right|^2 + \underbrace{\tau_{DVCS}\tau^*_{BH} + \tau^*_{DVCS}\tau_{BH}}_{I}$$

one measures interference of two processes

but BH is calculable in QED

DVCS is suppressed in respect to BH

@ HERMES

HERA & Hermes

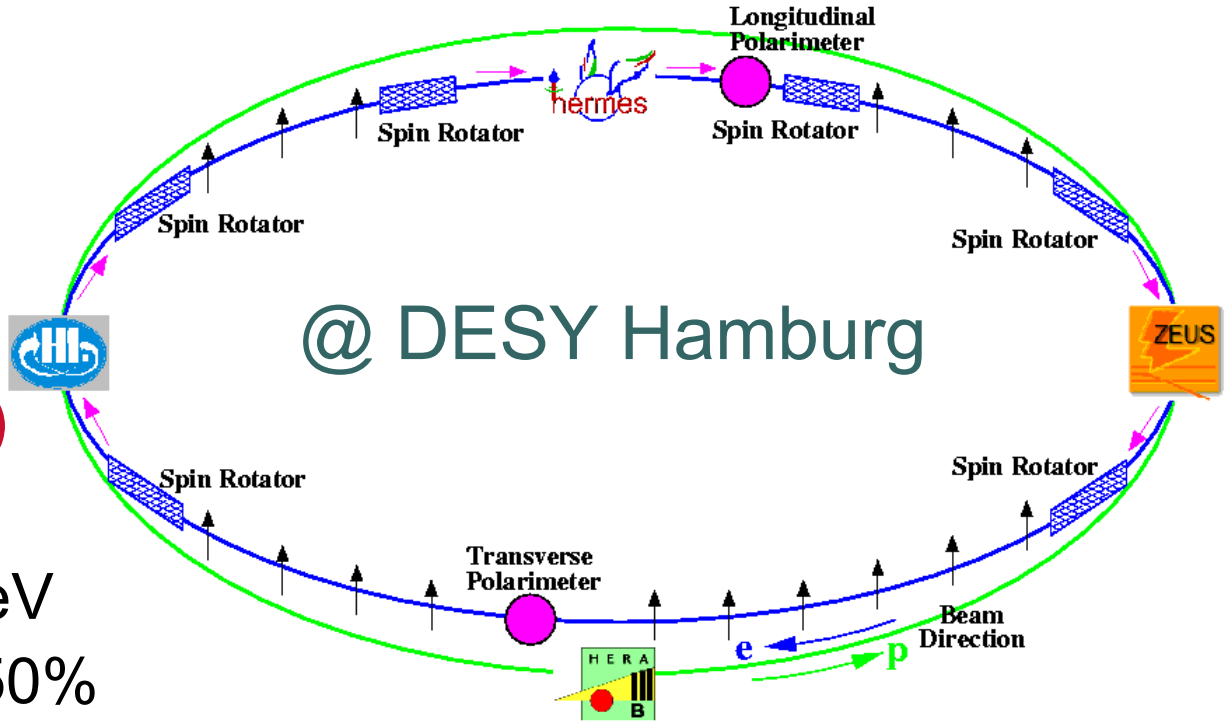
HERA *ep* collider

- e^- and e^+

→ **Beam Charge Asymmetry (BCA)**

- $e^\pm$ beam
  - Energy 27,5 GeV
  - Polarization ~ 50%
- Spin Rotators
  - @ Hermes **longitudinal beam polarization**
  - have both beam helicities

→ **Beam Spin Asymmetry (BSA)**

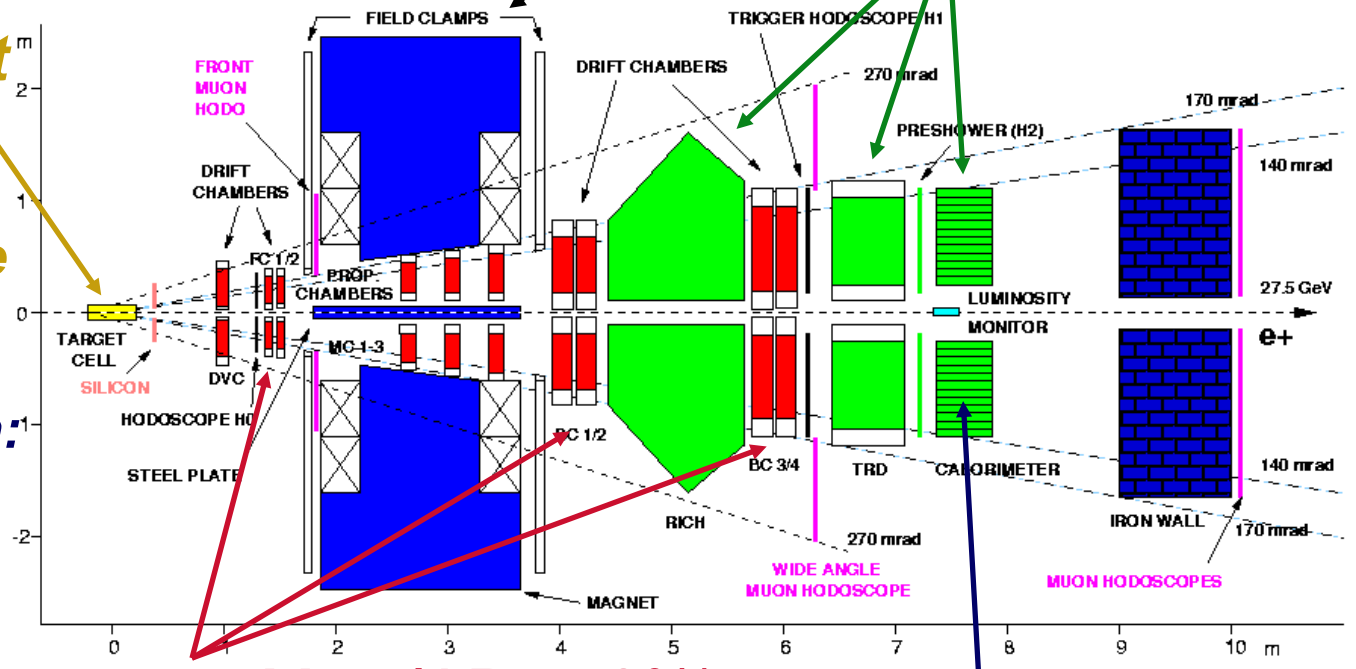


HERMES

magnet ***particle ID***

pure gas target
pol. H, D
unpol.
H, D, Ne, Kr, Xe

$e^{\pm}$



Target Polarization:

1996 -2000 :
Longitudinal

2002 – now :
Transverse

tracking ($\Delta P_e \sim 2\%$)

Calorimeter
($\Delta E_\gamma \sim 5\%$)

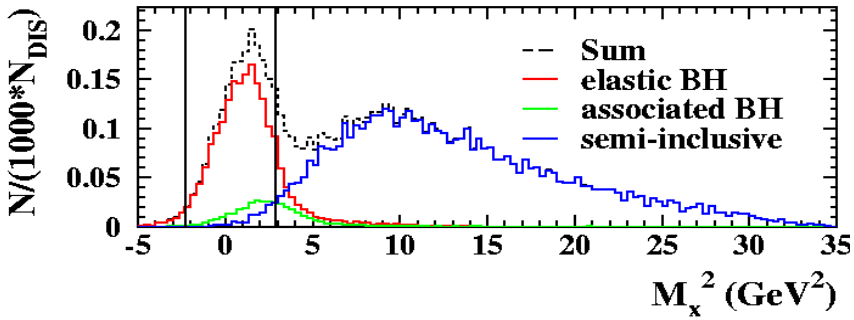
Target Spin Asymmetry

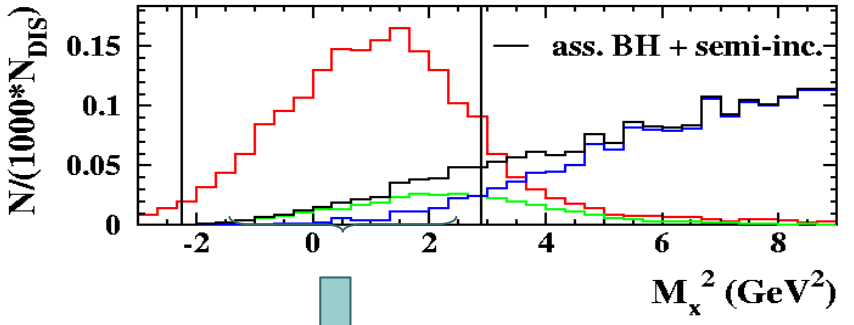
DVCS:

detected: ***scattered lepton and photon***

not detected: ***Recoiled nucleon*** ➡ ***Missing mass reconstruction***

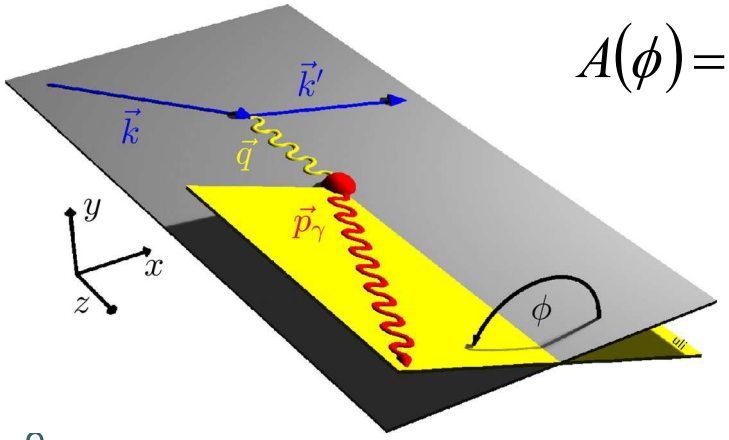
Asymmetry Measurement





MC (M_x < 1.7 GeV):

- ✓ Elastic (85 %)
- ✓ Associated (with excitation of the nucleon into resonance state, e.g. Δ) (10%)
- ✓ Semi-inclusive background (mostly from π^0) (5%)



$$A(\phi) = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} \approx \frac{d\sigma_I^+ - d\sigma_I^-}{d\sigma^{BH}}$$

BCA (e^+,e^-) ~ $\mathrm{Re}\mathbf{H}\cdot\cos\phi$

BSA (P_{beam}^+,P_{beam}^-) ~ $\mathrm{Im}\mathbf{H}\cdot\sin\phi$

LTSA ($P_{targ.}^+$,$P_{targ.}^-$) ~ $\mathrm{Im}\widetilde{\mathbf{H}}\cdot\sin\phi$

Beam Spin Asymmetry. The Proton and the Deuteron

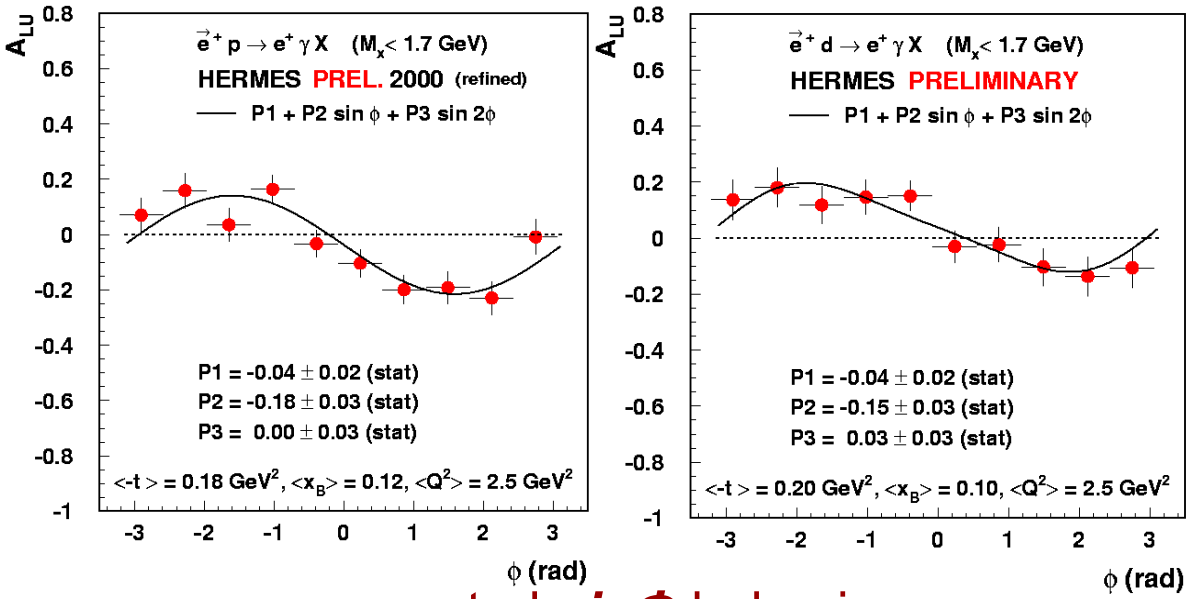
Longitudinally polarized e⁺ beam
Unpolarized target

Accessing $A_{LU}^{\sin\phi} \propto \mathrm{Im}\, H$

$$A_{LU}(\phi) = \frac{1}{\langle P_{\mathrm{beam}} \rangle} \frac{\vec{N}(\phi) - \overleftarrow{N}(\phi)}{\vec{N}(\phi) + \overleftarrow{N}(\phi)}$$

Fit function:

$$f(\phi) = const. + A_{LU}^{\sin\phi} \sin\phi + A_{LU}^{\sin 2\phi} \sin 2\phi$$



expected ***sinΦ*** behavior

Proton:

$$A_{LU}^{\sin\phi} = -0.18 \pm 0.03$$

$$A_{LU}^{\sin 2\phi} = 0.00 \pm 0.03$$

Deuteron:

$$A_{LU}^{\sin\phi} = -0.15 \pm 0.03$$

$$A_{LU}^{\sin 2\phi} = 0.03 \pm 0.03$$

Beam Charge Asymmetry. The Proton and the Deuteron.

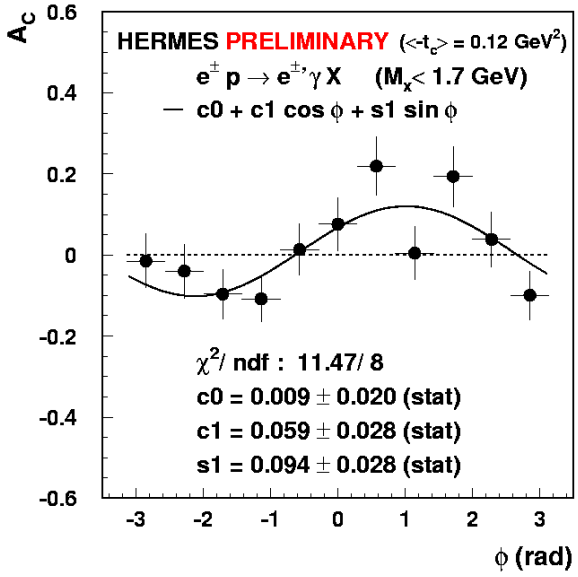
Positive and negative beam **C**harge
Unpolarized target

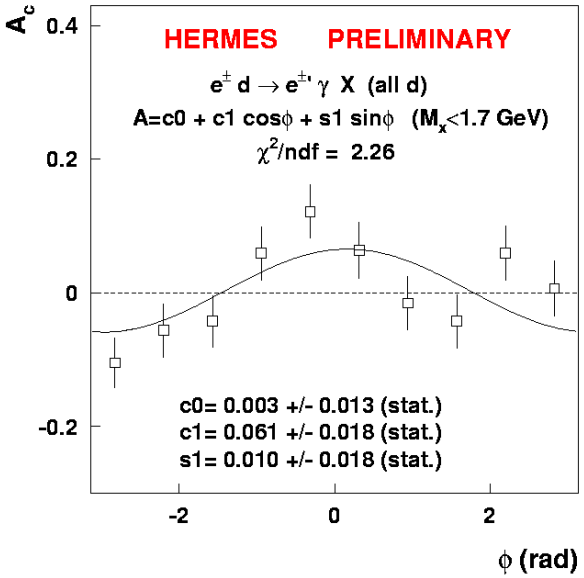
Accessing $A_C^{\cos\phi} \propto \mathrm{Re}\, H$

$$A_C(\phi) = \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)}$$

Fit function:

$$f(\phi) = const. + A_C^{\cos\phi}\cos\phi + A_C^{\sin\phi}\sin\phi$$





expected ***cosΦ*** behavior

Proton:

$$A_C^{\cos\phi} = 0.059 \pm 0.028$$

$$A_C^{\sin\phi} = 0.094 \pm 0.028$$

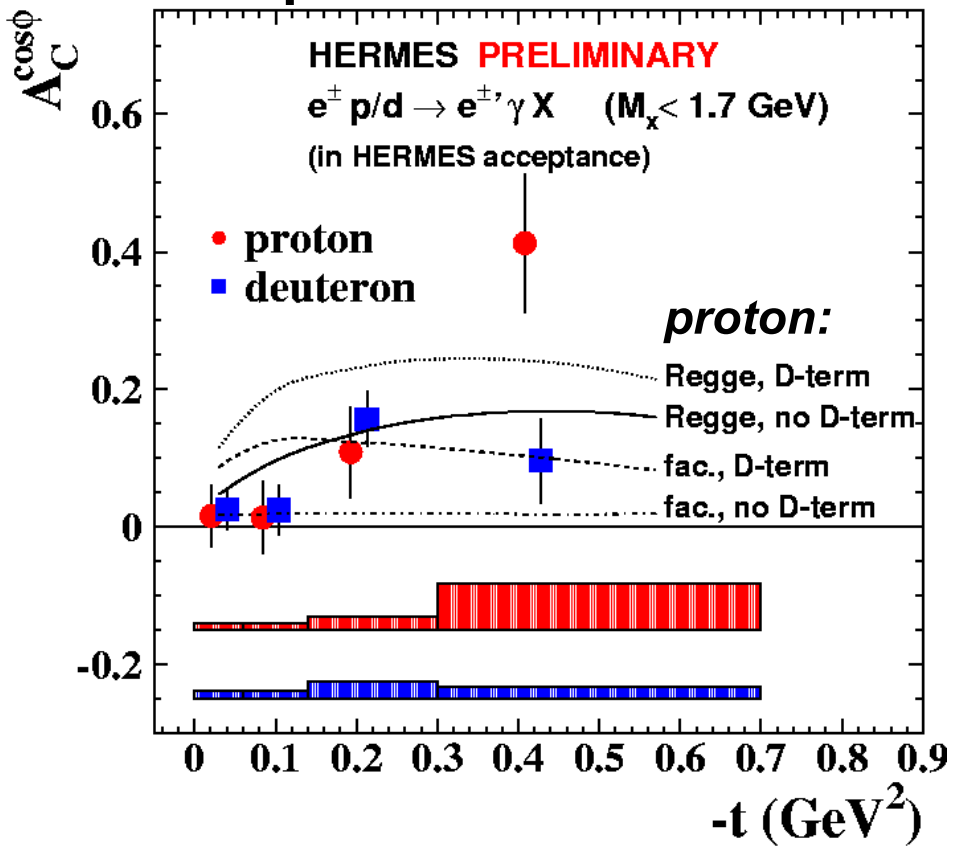
(Non zero P_B)

Deuteron:

$$A_C^{\cos\phi} = 0.061 \pm 0.018$$

$$A_C^{\sin\phi} = 0.010 \pm 0.018$$

Beam Charge Asymmetry vs. *t*



Proton vs. Deuteron:

- 1st Deuterium bin is 40% coherent
  - No difference between ***eP*** and ***eD***
- Difference in the last bin due to increasing neutron form factors
- *BCA may constrain GPD models*

GPD model:

M. Vanderhaeghen et. al.

New !
Longitudinal Target Spin Asymmetry.
The Proton and the Deuteron

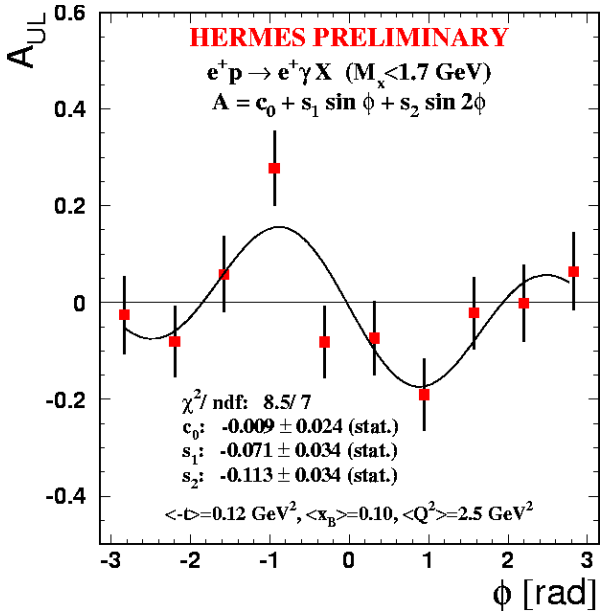
Longitudinally polarized target
Unpolarized beam

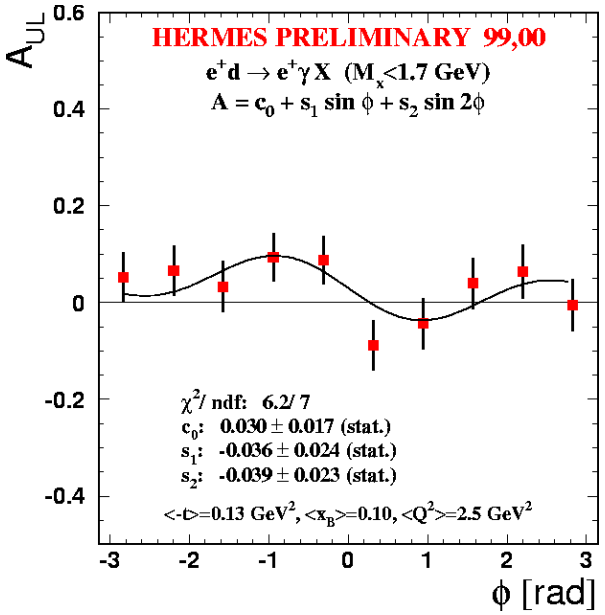
$$A_{UL}(\phi) = \frac{1}{\langle P_{\text{targ.}} \rangle} \frac{\vec{N}(\phi) - \overleftarrow{N}(\phi)}{\vec{N}(\phi) + \overleftarrow{N}(\phi)}$$

Accessing $A_{UL}^{\sin\phi} \propto \mathrm{Im}\,\tilde{H}$

Fit function:

$$f(\phi) = const. + A_{UL}^{\sin\phi} \sin\phi + A_{UL}^{\sin 2\phi} \sin 2\phi$$





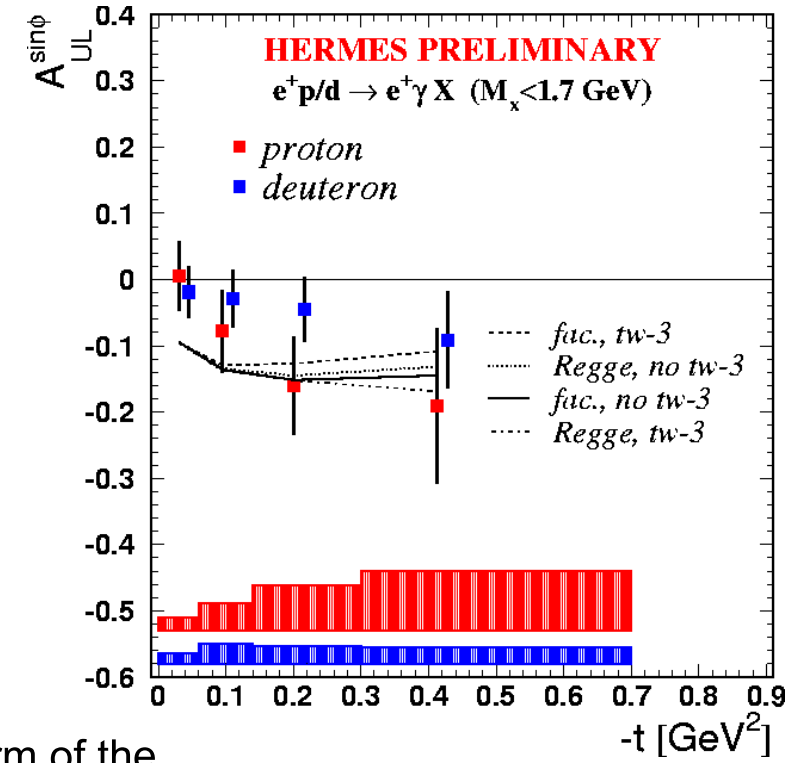
	P	**D**
$A_{UL}^{\sin\phi}$	-0.071±0.034	-0.036±0.024
$A_{UL}^{\sin 2\phi}$	-0.113±0.034	-0.039±0.023

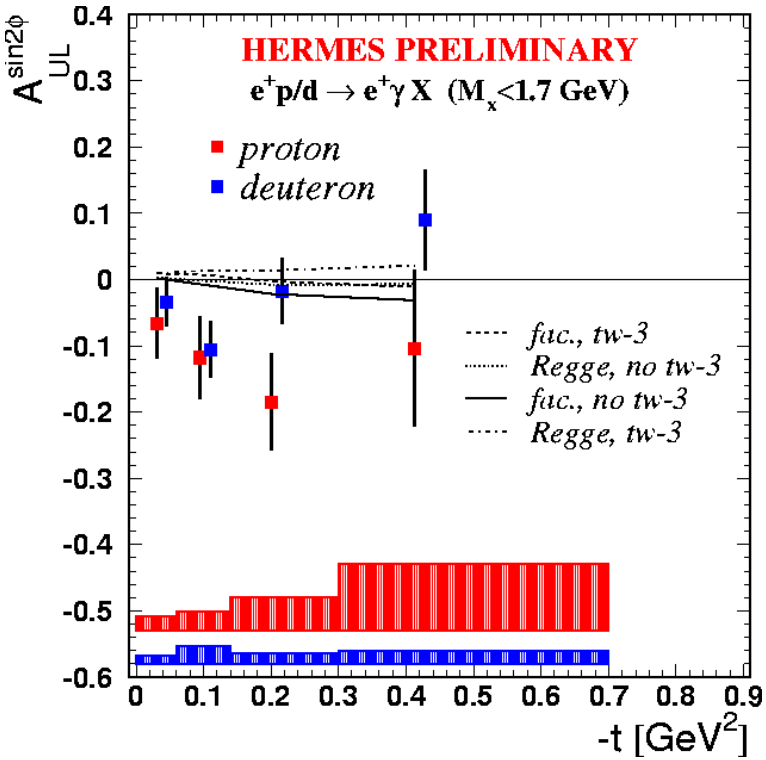
Sizeable $A_{UL}^{\sin 2\phi}$?

sensitive to e.g.
twist-3 $\mathrm{Im}(H^3, \tilde{H}^3)$

expected ***sinΦ*** behavior

New !: Longitudinal Target Spin Asymmetry vs. *t*





GPD model:

only W.W. term of the twist-3 GPDs

$$\left\{H^3, \widetilde{H}^3, E^3, \widetilde{E}^3\right\} \rightarrow F^3 = F^3_{WW} + F^3_{qGq}$$

from twist-2 GPDs

- ***eD*** coherent production (40% 1st bin)
  - No effect is seen
- high ***t*** : $A_{UL}(ep) \neq A_{UL}(ed) \Rightarrow A_{UL}(ep) \neq A_{UL}(en)$
- $A_{UL}^{\sin 2\Phi}$ is bigger than predicted by the model
  - interaction dependent (qGq) twist-3 is missing

DVCS at HERMES. Outlook.

Existing data on Proton and Deuteron:

- BSA $\rightarrow \mathrm{Im}\mathbf{H}$
- BCA $\rightarrow \mathrm{Re}\mathbf{H}$
- LTSA $\rightarrow \mathrm{Im}\widetilde{\mathbf{H}}$

$\rightarrow A_{UL}^{\sin 2\phi}$ is significant *(twist-3 GPDs ?)*

DVCS on nuclei

- ***sinΦ*** is already observed for BSA on **Ne** and **Xe**
- Dependence of coherent production on nuclei will be studied (*N, Ne, Kr, Xe*)

Present Data Taking:

Transverse Polarized Target

- TTSA $\rightarrow \mathbf{E} \rightarrow \boldsymbol{J_u}$

Future.

Recoil Detector

- Background ´free´ DVCS:
  - Semi-inclusive bgd:
    - 5% → << 1%
  - Associated bgd:
    - 10% → 1%