The HERMES DVCS Roadmap

Frank Ellinghaus

University of Colorado

for the HERMES-Collaboration

DIS 2004, Štrbské Pleso, Slovakia, April 2004

- Motivation
- Generalized Parton Distributions
- Deeply-Virtual Compton Scattering
- HERMES-Experiment
- The Past
- The Present
- The Future

THE SPIN STRUCTURE OF THE NUCLEON

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

STATUS:

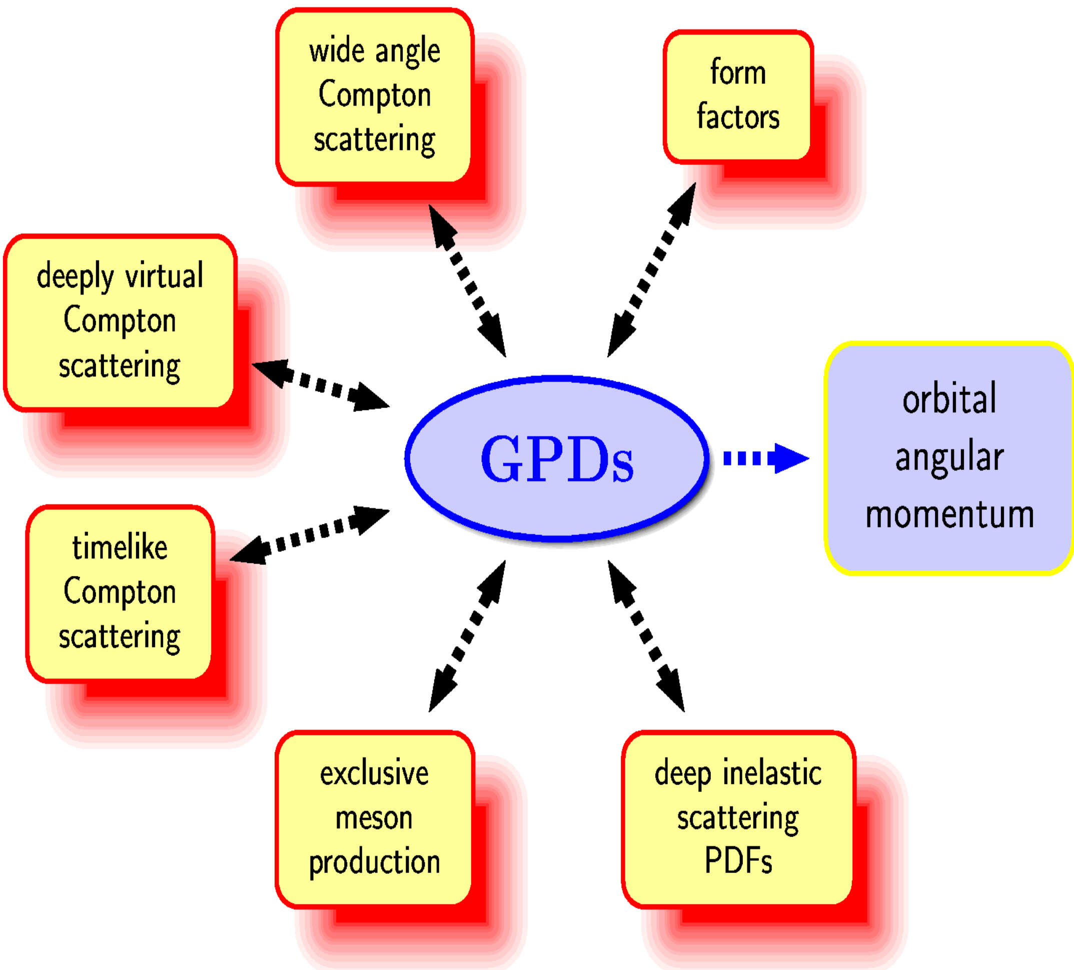
- VALENCE- AND SEAQUARK CONTRIBUTION ($\Delta\Sigma$) NOT BIGGER THAN 30%
- QUARK ORBITAL ANGULAR MOMENTUM (L_q) UNKNOWN
- GLUON TOTAL ANGULAR MOMENTUM (J_g) UNKNOWN

X.JI, 1997:
THE GENERALIZED PARTON DISTRIBUTIONS (GPDS) ARE RELATED TO THE TOTAL QUARK ANGULAR MOMENTUM $J_q \Rightarrow L_q,\ J_g$

GPDs $\longleftrightarrow$ Nucleon Structure

GPDs $(H, \tilde{H}, E, \tilde{E})$: Parameterization of the nucleon structure

GPDs: Description of inclusive and (hard) exclusive processes
$\rightarrow$ Constraint by known quantities

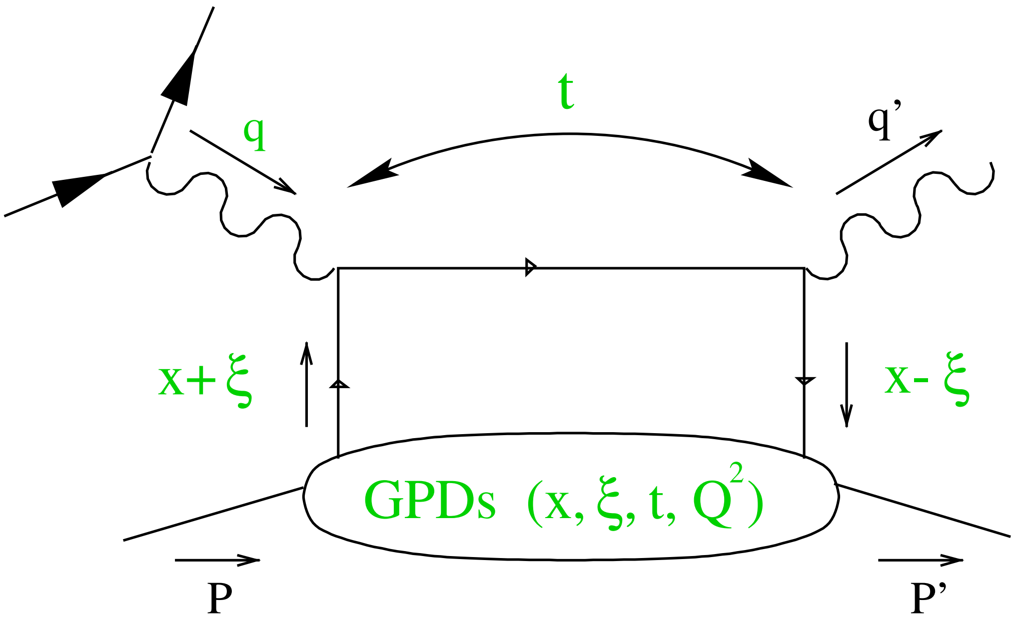


GPDs accessible in exclusive reactions $\Rightarrow$

Motivation to study DVCS

Simplest hard exclusive process:
Deeply-virtual electroproduction of real photons $\Rightarrow e\,p \to e'\,p'\,\gamma$

Deeply-virtual Compton Scattering (DVCS)



Variables:

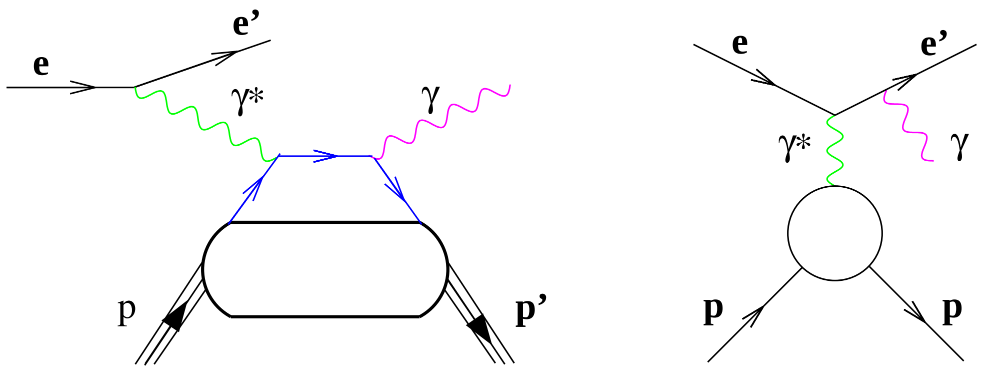
- Longitudinal momentum fractions:
  $x \in [-1, 1]$ (not accessible)
  $\xi \approx x_B/(2 - x_B)$
- $t = (q - q')^2$ ($\gamma^* \to \gamma$ Momentum transfer)
- $Q^2 = -q^2$

Original motivation:

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

Deeply-Virtual Compton Scattering

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



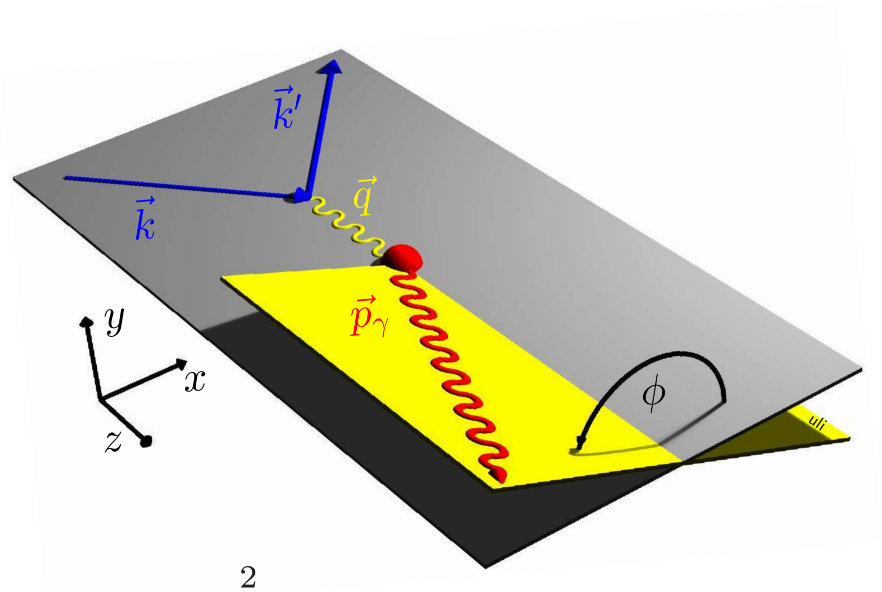
Photon-Production cross section:

$$
\begin{aligned}
d\sigma &\propto \left|\tau_{\mathrm{DVCS}} + \tau_{\mathrm{BH}}\right|^2 \\
&= \left|\tau_{\mathrm{DVCS}}\right|^2 + \left|\tau_{\mathrm{BH}}\right|^2 + \underbrace{\left(\tau^*_{\mathrm{DVCS}}\tau_{\mathrm{BH}} + \tau^*_{\mathrm{BH}}\tau_{\mathrm{DVCS}}\right)}_{I}
\end{aligned}
$$

BH Process calculable, $I \approx 0 \Rightarrow$
DVCS cross section measurements (H1, ZEUS)

$\left|\tau_{\mathrm{DVCS}}\right|^2 << \left|\tau_{\mathrm{BH}}\right|^2$ at HERMES

$\Rightarrow$ Access amplitudes (+ Phase!) via I



$$|\tau_{BH}|^2 \propto c_0^{BH} + \sum_{n=1}^{2} c_n^{BH} \cos(n\phi)$$

$$|\tau_{DVCS}|^2 \propto c_0^{DVCS} + \sum_{n=1}^{2} c_n^{DVCS} \cos(n\phi) + \lambda\, s_1^{DVCS} \sin(\phi)$$

$$I \propto \pm \left(c_0^I + \sum_{n=1}^{3} c_n^I \cos(n\phi) + \lambda \sum_{n=1}^{2} s_n^I \sin(n\phi) \right)$$

BCA AND BSA AT LEADING TWIST:

$$d\sigma(e^+p) - d\sigma(e^-p) \sim c_1^I \cos(\phi) \sim \cos(\phi) \times \mathrm{Re}\, M^{1,1}$$

$$d\sigma(\overrightarrow{e^+}p) - d\sigma(\overleftarrow{e^+}p) \sim s_1^I \sin(\phi) \sim \sin(\phi) \times \mathrm{Im}\, M^{1,1}$$

$\Rightarrow$ REAL AND IMAGINARY PART OF THE HELICITY CONSERVING AMPLITUDE $M^{1,1}$ CAN BE ACCESSED VIA BEAM–CHARGE AND BEAM–SPIN ASYMMETRY

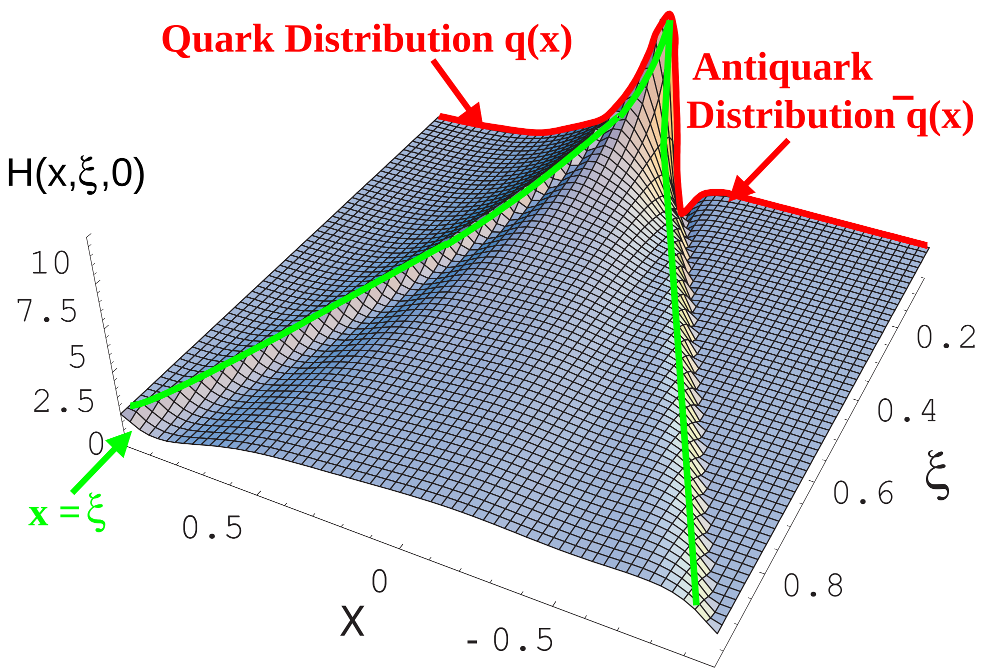
(OTHER AMPLITUDES $\rightarrow \cos 2\phi,\ \cos 3\phi,\ \sin 2\phi$)

From Amplitudes to GPDs

BSA: $\mathrm{Im}\, M^{1,1}$ mainly accesses the GPD $H^q(x, \xi, t)$ at $x = \xi \Rightarrow$ measures $H^q(\xi, \xi, t)$

BCA: $\mathrm{Re}\, M^{1,1}$ contains full x–dependence of the GPD $H^q(x, \xi, t)$, x is not accessible $\Rightarrow$ GPD Model $\rightarrow$ Observables $\leftarrow$ Measurement

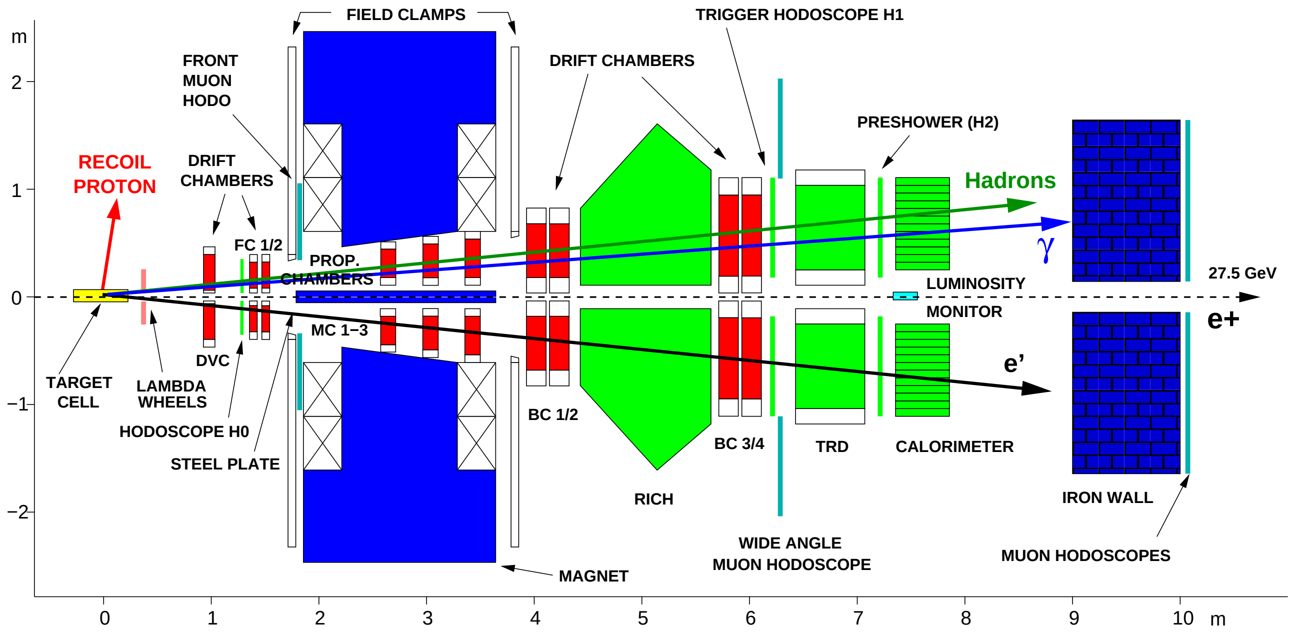
Use relations to Nucleon Structure (PDFs, ...) to model GPDs $\Rightarrow$



(Goeke, Polyakov, Vanderhaeghen, hep-ph/0106012)

Need both charges and polarized beam $\Rightarrow$ HERA!!!

The HERMES-Spectrometer



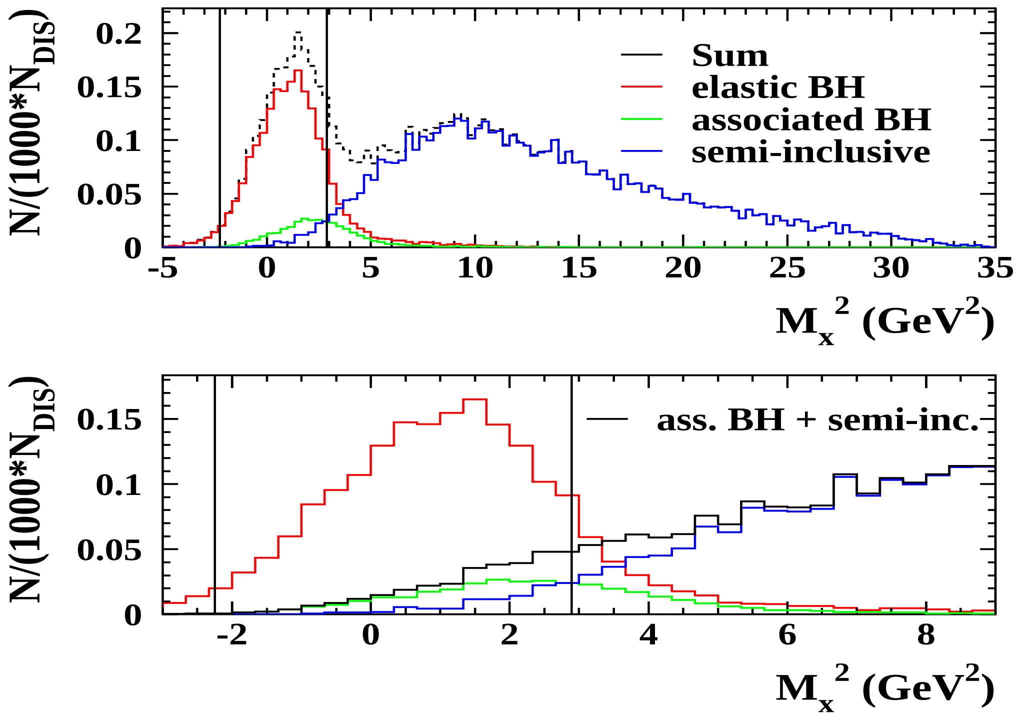
- Beam: 27.6 GeV, e^+ or e^-, $\langle P \rangle \approx 55\%$
- Momentum reconstruction via tracking chambers $\Rightarrow$ resolution $\approx 1.5\%$
- Electron/Positron Identification via TRD, Preshower, Calorimeter (no RICH) $\Rightarrow$ Hadron contamination of the Lepton-Sample $\leq 1\%$
- Identify Photon via signal in Preshower and trackless cluster in Calorimeter $\Rightarrow$ Resolution $\approx 5\%$
- No recoil detection
  $\Rightarrow$ Exclusivity via missing mass

Data Selection

Resolution ⇒ MC for background and cuts!

Processes taken into account:

- elastic BH $(e\,p \rightarrow e'\,p'\,\gamma)$
- associated BH (mainly $e\,p \rightarrow e'\,\Delta^+\,\gamma$)
- semi–inclusive (mainly $e\,p \rightarrow e'\,\pi^0\,X$)



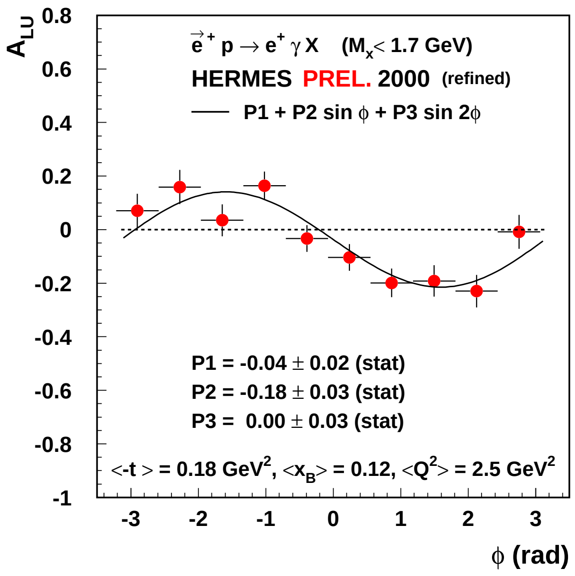
⇒ "Exclusive" bin (-1.5 $< M_x <$ 1.7 GeV)

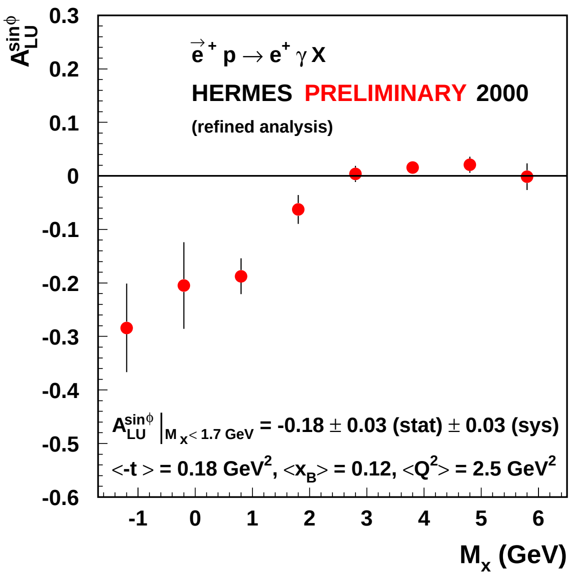
⇒ Overall contribution 10.9% (associated) and 4.9% (semi–inclusive)

Good agreement between Monte–Carlo and data achieved!

BEAM–SPIN ASYMMETRY (BSA) $A_{\mathrm{LU}}(\phi)$:
(BEAM POL. (L), TARGET UNPOL. (U))

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





A_{LU} IN EXCLUSIVE BIN:
EXPECTED $\sin(\phi)$ DEPENDENCE $\Rightarrow$ $\mathrm{Im}\, M^{1,1}$,
$\sin(2\phi)$ COMPATIBLE WITH ZERO (HIGHER TWIST)

$\sin(\phi)$–MOMENT IN EXCLUSIVE BIN:

$$A_{\mathrm{LU}}^{\sin\phi} = 2 \sum_{i=1}^{\overrightarrow{N}+\overleftarrow{N}} \frac{\sin(\phi_i)}{(P_l)_i} = -0.18 \pm 0.03 \pm 0.03$$

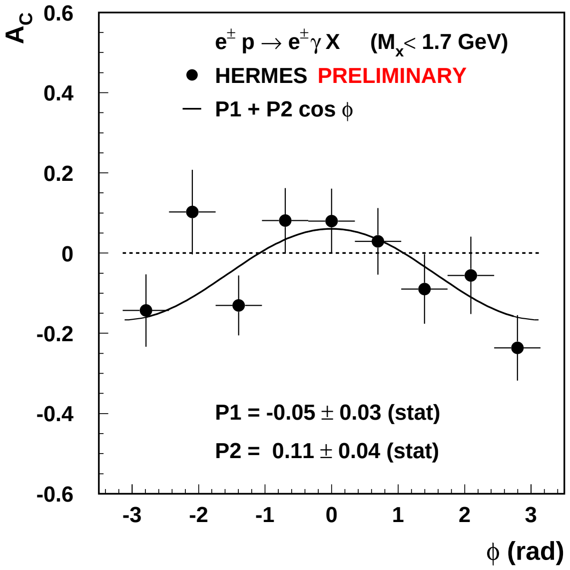
$\sin(\phi)$–MOMENT IN NON–EXCLUSIVE REGION:
SMALL AND SLIGHTLY POSITIVE ($\rightarrow \pi^0$)

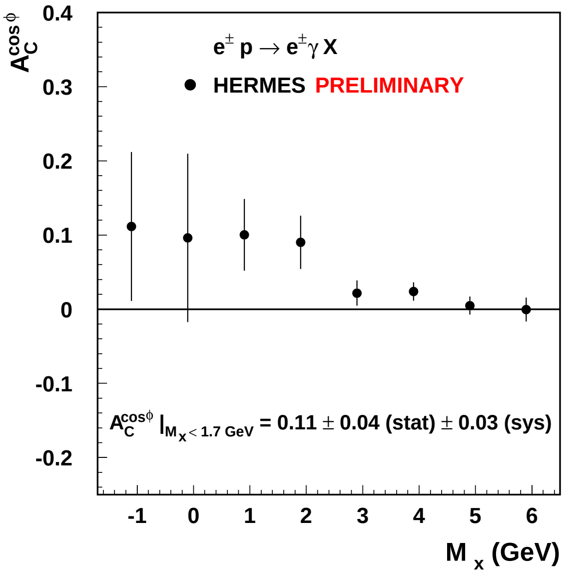
(RESULTS FROM 1996/97 $\rightarrow$ PRL **87**, 182001 (2001))

Beam–Charge Asymmetry

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

$$I \propto \pm(c_0^I + \sum_{n=1}^{3} c_n^I \cos(n\phi) + \lambda \sum_{n=1}^{2} s_n^I \sin(n\phi))$$





A_C in exclusive bin:
Expected $\cos(\phi)$ dependence $\Rightarrow \mathrm{Re}\, M^{1,1}$

$\cos(\phi)$–Moment in exclusive bin:

$$A_C^{\cos\phi} = 2\frac{\sum_{i=1}^{N^+}\cos\phi_i - \sum_{i=1}^{N^-}\cos\phi_i}{N^+ + N^-} = 0.11 \pm 0.04 \pm 0.03$$

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

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

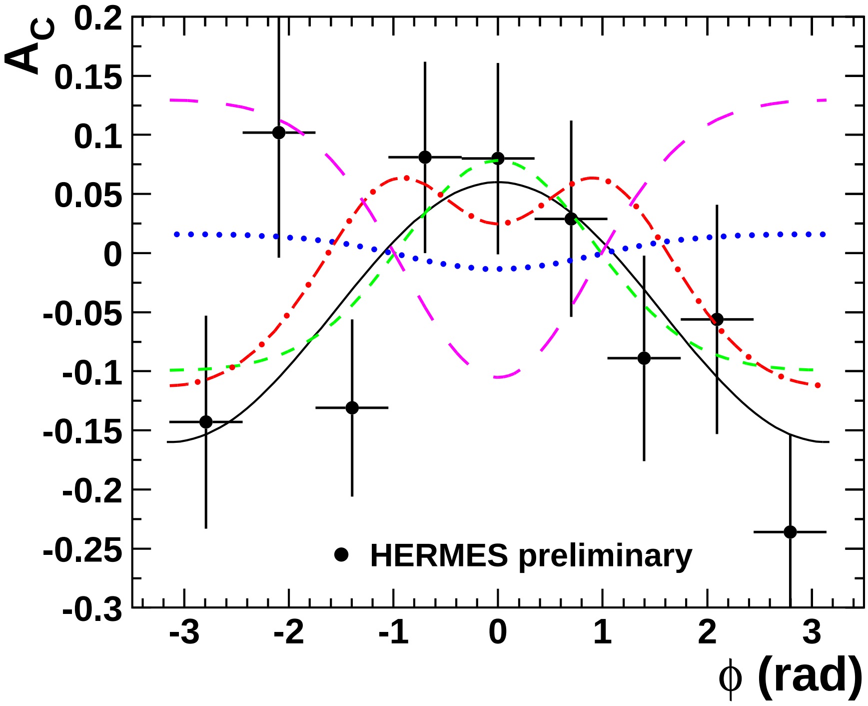
$\Rightarrow$ Basic concept seems to work !!!

The "D-Term" ...

t-independent part can be parameterized by:

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

D–Term negative (Chiral Quark–Soliton Model)

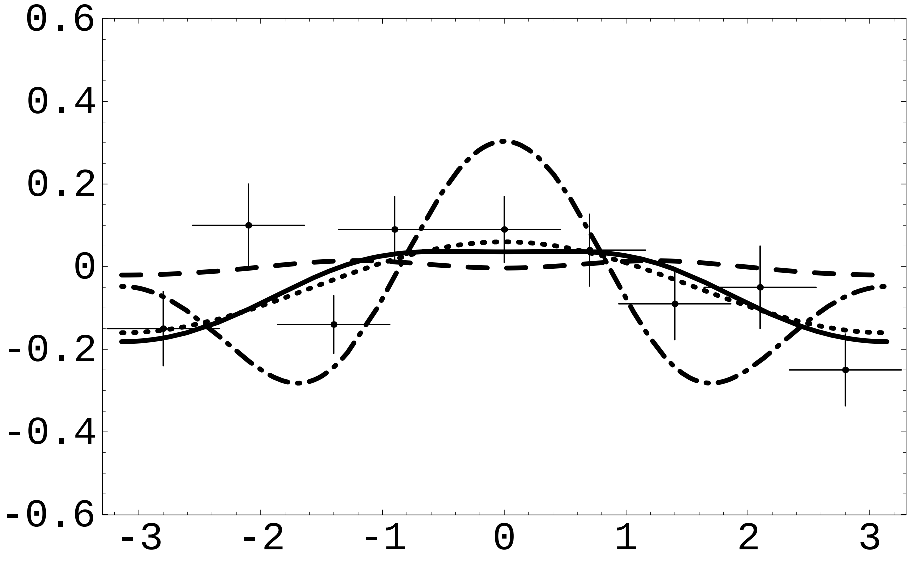


GPD-model calculation for HERMES kinematics (M. Vanderhaeghen, hep-ph/0207176)

⇒ Data exclude positive D-Term.

⇒ Data seem to favor parameterization with D-Term contribution.

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



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

⇒ Data seem to favor parameterization without D-Term contribution.

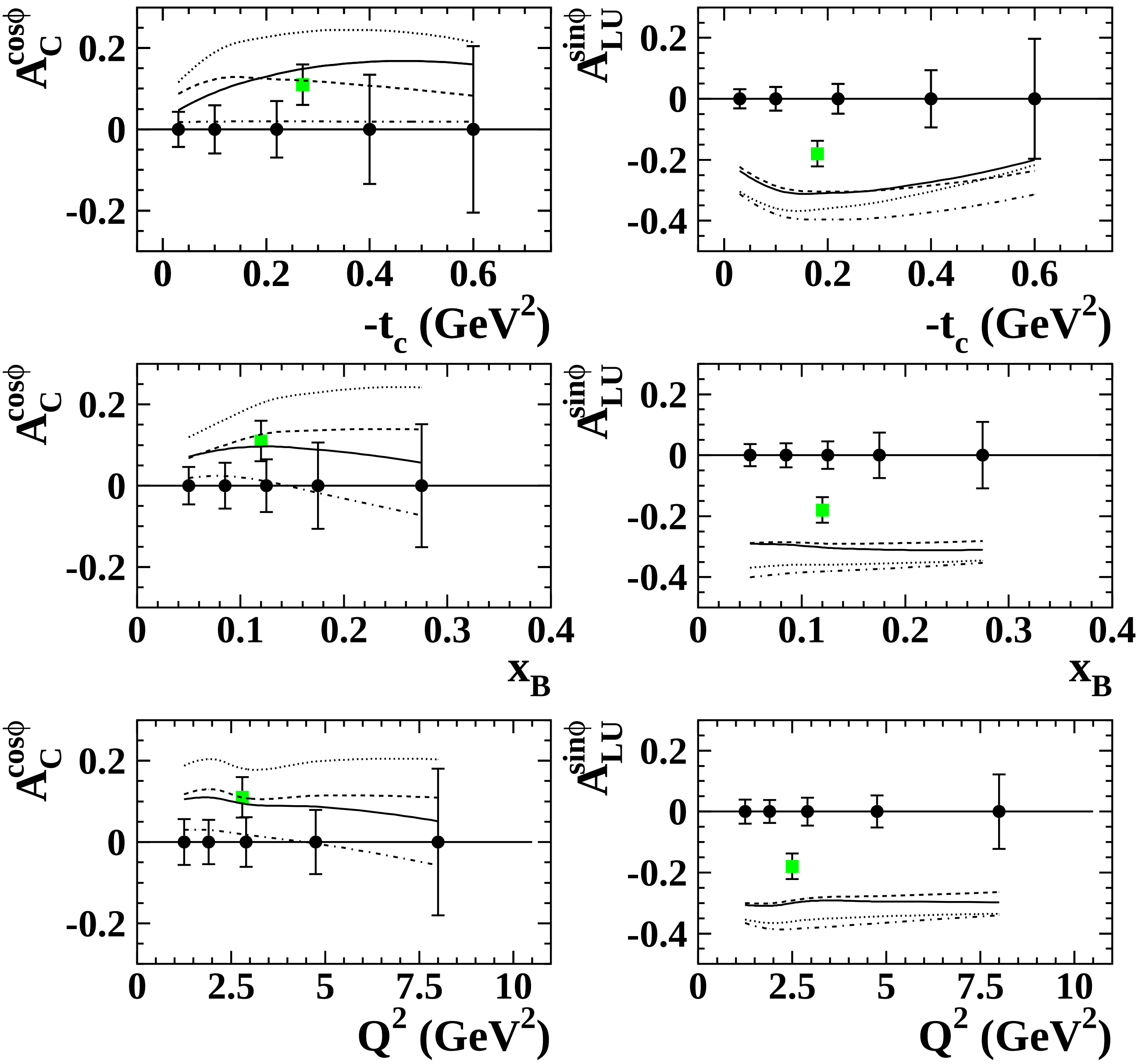
Other models (e.g. A. Freund et al., hep-ph/0208160) describe available data as well.

⇒ More (precise) data needed to constrain models.

. . . Kinematic dependences already help ! ⇒

Next Step: Kinematical Dependences

Select representative set of model parameters (Vanderhaeghen, Guichon, Guidal)

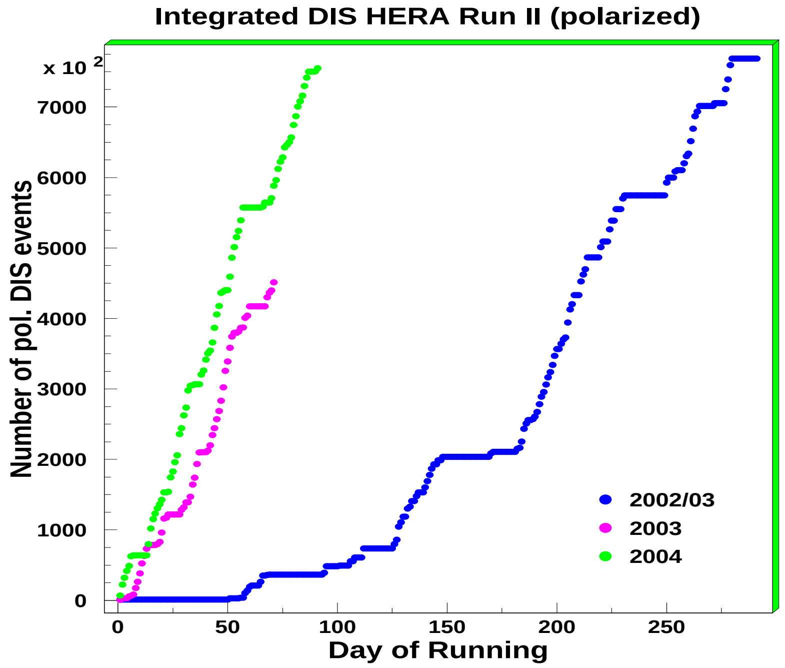


HERA I data, Analysis almost completed

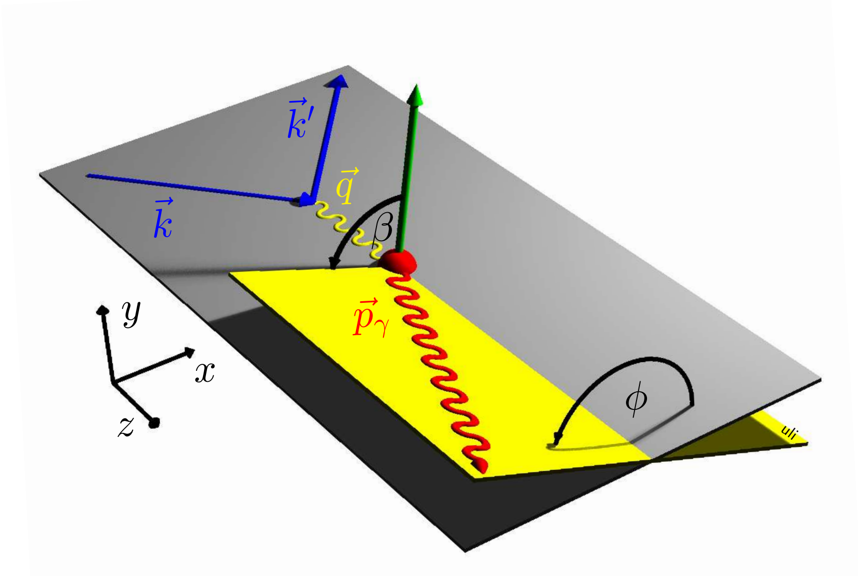
HERA I: some range for the model parameters (GPD H) can be constrained !

What about the GPD E ?

Data taking with transverse Hydrogen target in progress ... $\approx$ 2M events on tape



$\approx$ 6M events expected by summer 2005

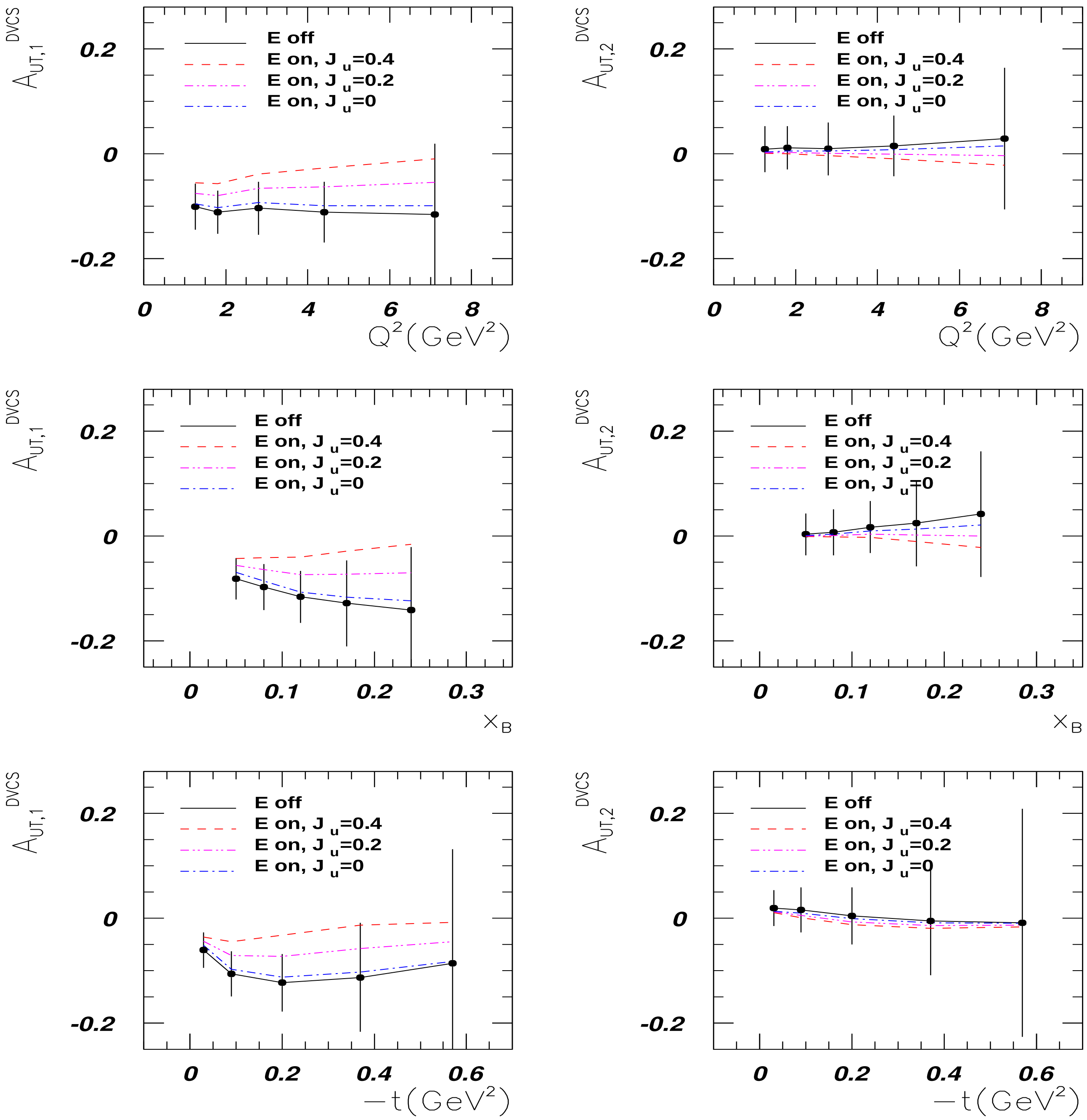


$A_{UT,1}$ (Left–Right): access to H and E

$A_{UT,2}$ (Up–Down): access to $\tilde{H}$ and $\tilde{E}$

Projection for transverse Target

based on 4M DIS, Target Pol. = 80 %

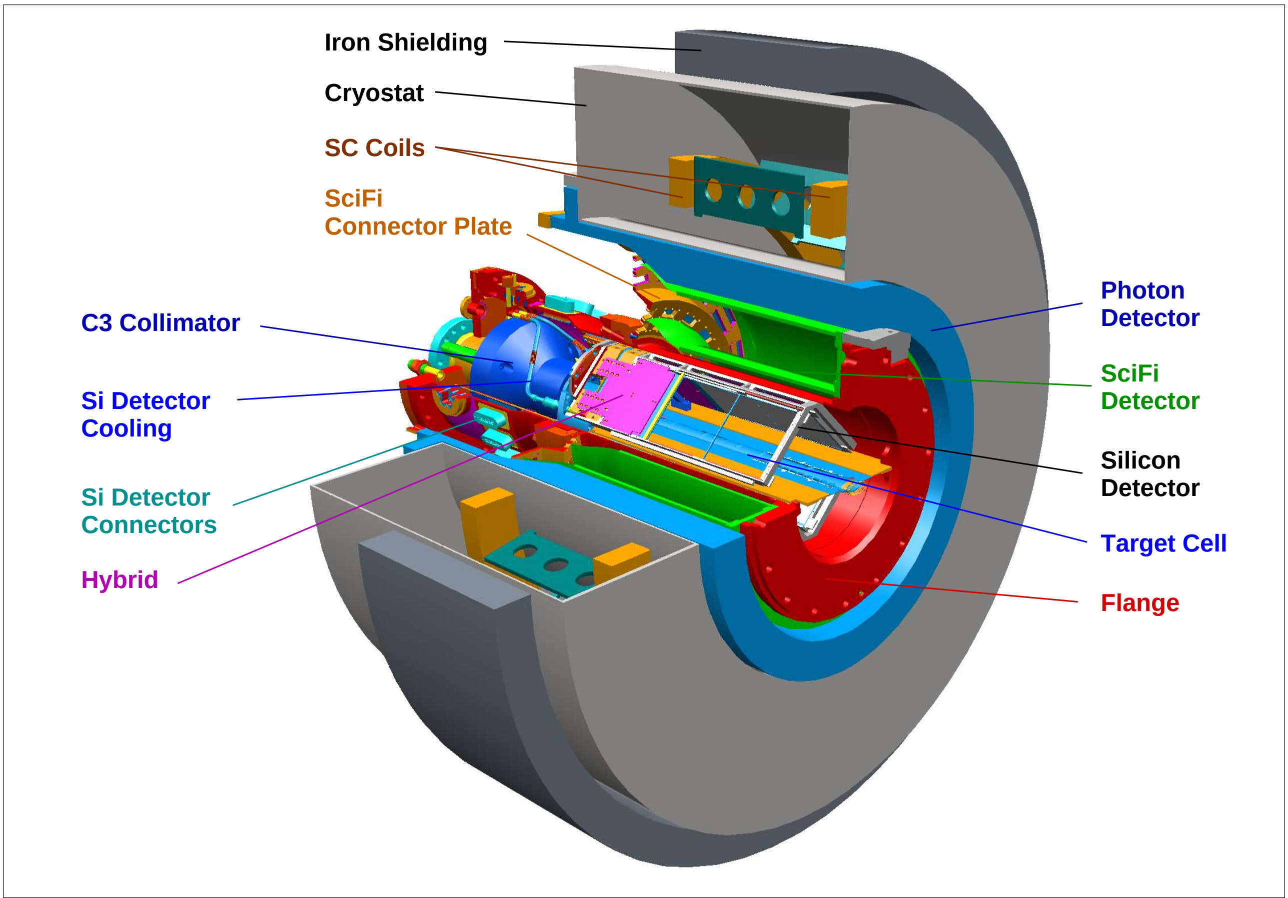


Change model parameters only for $E \rightarrow A_{UT,1}$

first glimpse on GPD E^u (J_u) possible if GPD H^u well known $\Rightarrow$ The last two years !

Recoil Detector (Summer 2005–2007)

- ensures exclusivity of events
- improves intrinsic t-resolution



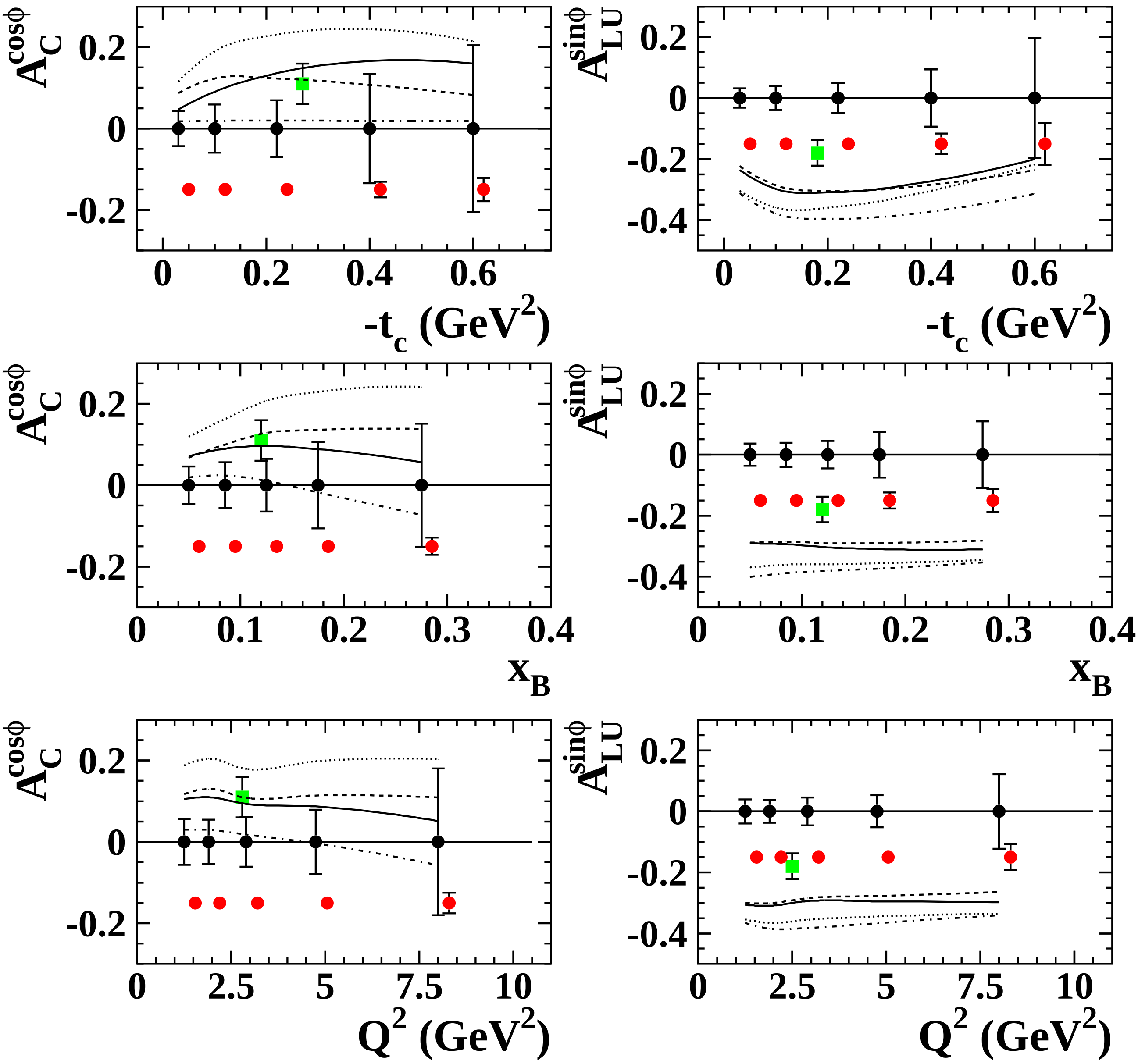
Semi–inclusive background 5% $\Rightarrow \ll 1\%$

Associated background 11% $\Rightarrow \approx 1\%$

Projection for unpolarized Target

HERA I: ● Analysis almost completed

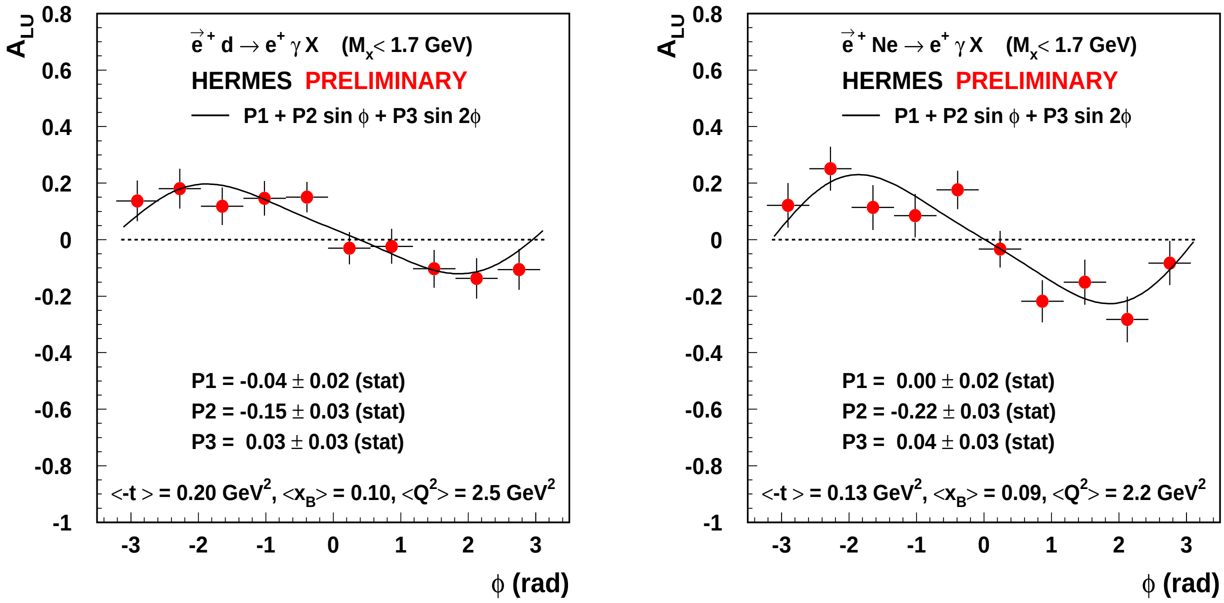
HERA II: ● 1–2 years ($1fb^{-1}\,e^{+}$ and $1fb^{-1}\,e^{-}$)



Possibility to "map out" GPD H^u in the final two HERA years.

Investigate the internal structure of Nucleons inside a Nucleus

DVCS on Deuterium and Neon



(hep-ex/02012019)

. . . triggered first calculations for DVCS on (heavier) Nuclei (Kirchner, Müller, hep-ph/0302007, Guzey, Strikman, hep-ph/0301216, . . .)

Status:

- Analysis on D, Ne is ongoing
- Preliminary Result on Kr
- Data taking on Kr, Xe

Summary

- Azimuthal Asymmetries ⇒ DVCS-Amplitudes ⇒ GPDs ⇒ Structure of Hadrons (L_q, J_g)

- First Measurements of the Beam–Spin Asymmetry (+CLAS@JLab) and Beam–Charge Asymmetry proof the basic concept

- HERA I data will put first constraints on models

- HERA II data can probably map out the GPD H^u and give a glimpse on the GPD E^u and J_u