Deeply Virtual Compton Scattering Studies at HERMES

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for the HERMES–Collaboration

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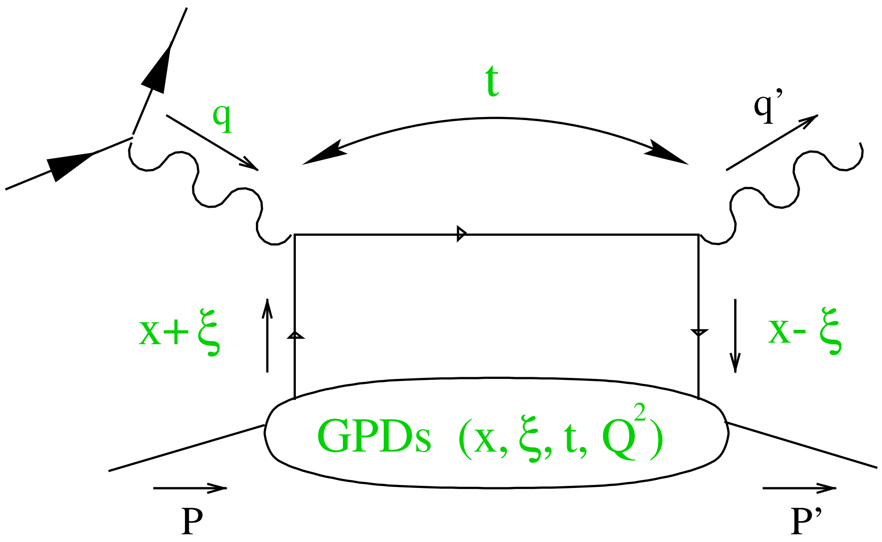
- GPDs, DVCS and BH
- Azimuthal Asymmetries at HERMES
  - The GPD H via BSA and BCA
  - The GPD $\widetilde{H}$ via LTSA
  - The GPD E via TTSA
- Summary and Outlook

Generalized Parton Distributions (GPDs)

Generalized Parton Distributions (GPDs) accessible in exclusive reactions ⇒ Use the simplest/cleanest one ...
Simplest/cleanest (hard exclusive) process: $\gamma^* p \rightarrow p' \gamma$

Deeply virtual photon generated by lepton scattering
⇒ $e\,p \rightarrow e'\,p'\,\gamma$ (DVCS)

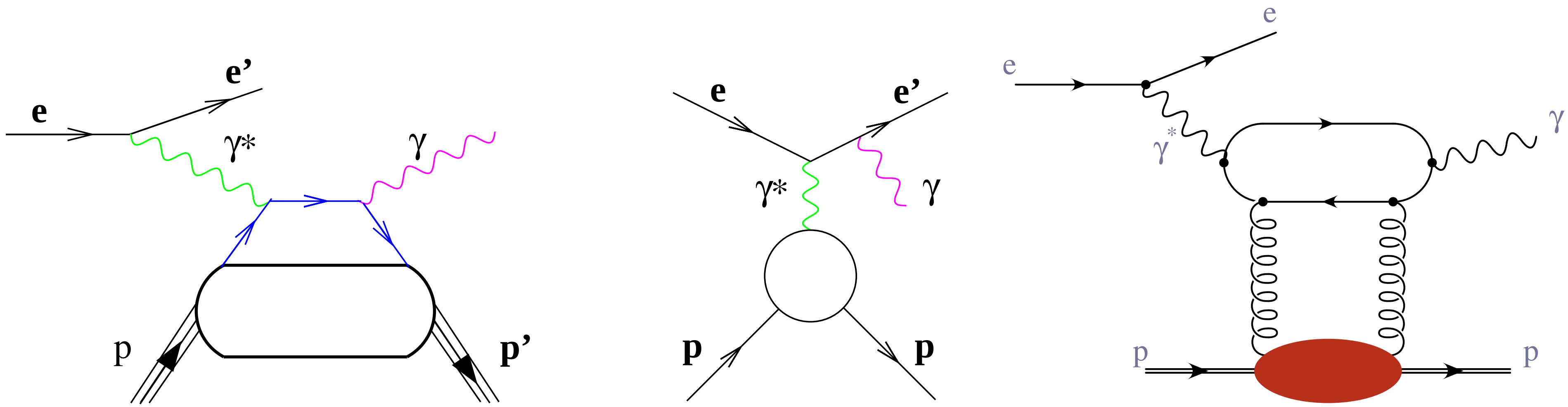


- Longitudinal momentum fractions:
  $x \in [-1, 1]$ (not accessible)
  $\xi \approx x_B/(2 - x_B)$
- $t = (q - q')^2$
  ($\gamma^* \rightarrow \gamma$ Momentum transfer)
- $Q^2 = -q^2$

⇒ Measurements as function of x_B, t, Q^2

DVCS–BH Interference

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



Fixed-Target, Collider

Collider

Photon-Production cross section:

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

DVCS Measurements

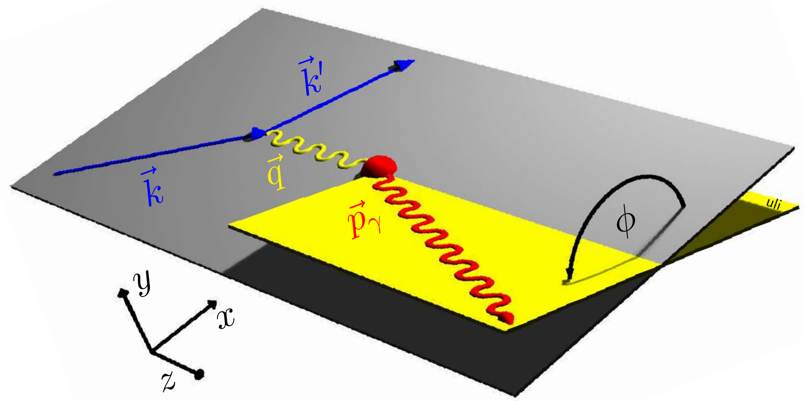
$$d\sigma \propto |\tau_{\mathrm{BH}}|^2 + \underbrace{(\tau^*_{\mathrm{DVCS}}\tau_{\mathrm{BH}} + \tau^*_{\mathrm{BH}}\tau_{\mathrm{DVCS}})}_{I} + |\tau_{\mathrm{DVCS}}|^2$$

$|\tau_{\mathrm{BH}}|^2$ calculable in QED with the knowledge of the form factors

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

DVCS cross section:
Measurement integrated over ϕ
$\rightarrow I = 0$ (at Twist–2), subtract $|\tau_{\mathrm{BH}}|^2$

Azimuthal asymmetries:
DVCS amplitudes directly accessible via I
(GPDs enter in linear combinations in amplitudes)



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

Beam–Charge Asymmetry (BCA) and Beam–Spin Asymmetry (BSA)

$$\text{BCA}: \quad d\sigma(e^+p) - d\sigma(e^-p) \sim c^I_{1,unp} \cos(\phi) \sim \cos(\phi) \times \mathrm{Re}\, M^{1,1}_{unp}$$

$$\text{BSA}: \quad d\sigma(\overrightarrow{e^+}p) - d\sigma(\overleftarrow{e^+}p) \sim s^I_{1,unp} \sin(\phi) \sim \sin(\phi) \times \mathrm{Im}\, M^{1,1}_{unp}$$

(Higher Twist/Order $\rightarrow$ $\cos 2\phi$, $\cos 3\phi$, $\sin 2\phi$)

$$M^{1,1}_{unp} = F_1(t)\, H_1(\xi,t) + \frac{x_B}{2-x_B}(F_1(t)+F_2(t))\, \widetilde{H}_1(\xi,t) - \frac{t}{4M^2} F_2(t)\, E_1(\xi,t)$$

$\langle x_B \rangle, \langle -t \rangle \approx 0.1 \Rightarrow$ CFF $H_1 \Rightarrow$ GPD H

Longitudinal Target–Spin Asymmetry (LTSA)

$$\text{LTSA}: \quad d\sigma(e^+\overleftarrow{p}) - d\sigma(e^+\overrightarrow{p}) \sim s^I_{1,LP} \sin(\phi) \sim \sin(\phi) \times \mathrm{Im}\, M^{1,1}_{LP}$$

(Higher Twist/Order $\rightarrow$ $\sin 2\phi$, $\sin 3\phi$)

$$M^{1,1}_{LP} = \frac{x_B}{2-x_B}(F_1+F_2)\,(H_1 + \frac{x_B}{2}E_1) + F_1 \widetilde{H}_1 - \frac{x_B}{2-x_B}(\frac{x_B}{2}F_1 + \frac{t}{4M^2}F_2)\, \widetilde{E}_1$$

$\langle x_B \rangle, \langle -t \rangle \approx 0.1 \Rightarrow$ CFF $\widetilde{H}_1 \Rightarrow$ GPD $\widetilde{H}$

HERMES Event Selection

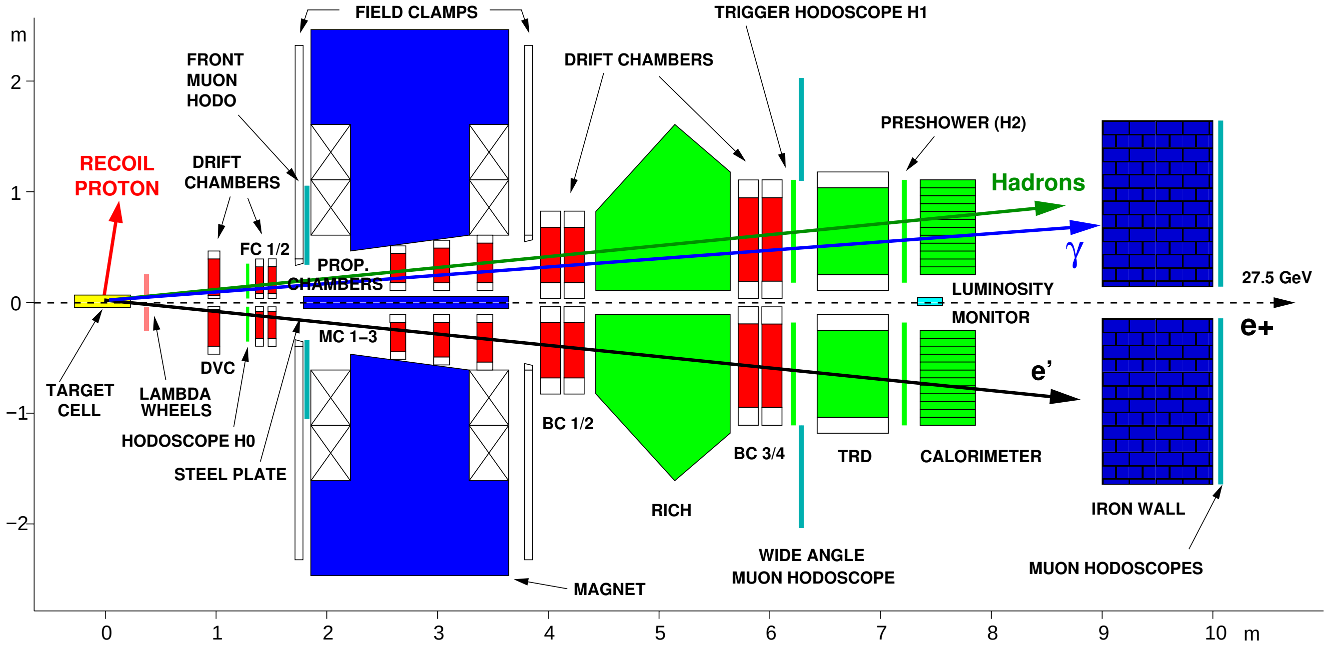
Gas Targets:
H/D/Ne/Kr/..

Beam:

27.6 GeV

e^+ and e^-

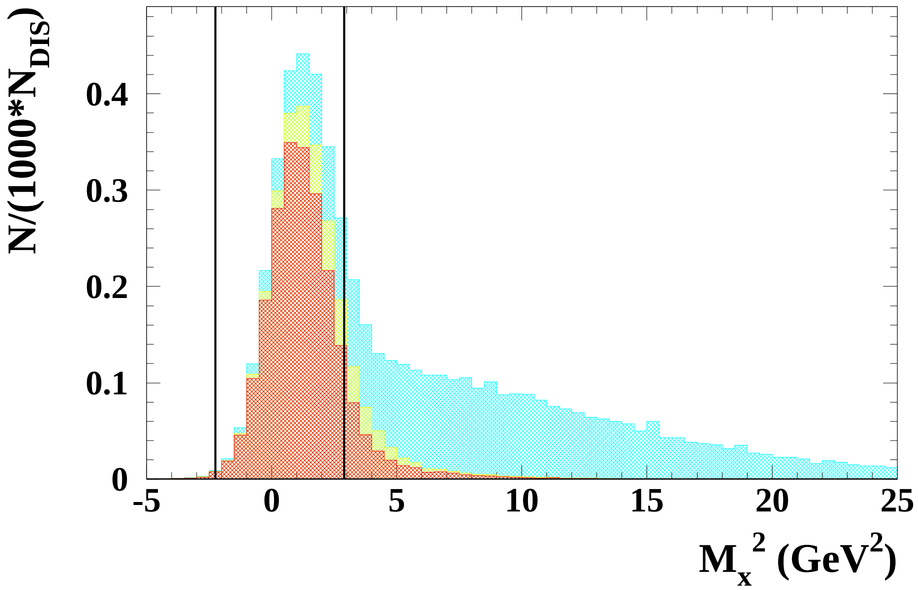
$\langle P \rangle \approx 55\%$



- Events with exactly one DIS-positron/DIS-electron and one trackless cluster in the calorimeter
- Cuts on scattered lepton:
  $Q^2 > 1\ \mathrm{GeV}^2, \ldots$
- Photon Selection:
  $\theta_{\gamma^*\gamma} < 45$ mrad, $E_\gamma > 5$ GeV, ...
- No recoil detection (yet) $\Rightarrow$ Exclusivity via missing mass $\Rightarrow$ MC

MC Status

Resolution ⇒ MC for background and cuts!



Processes taken into account:

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

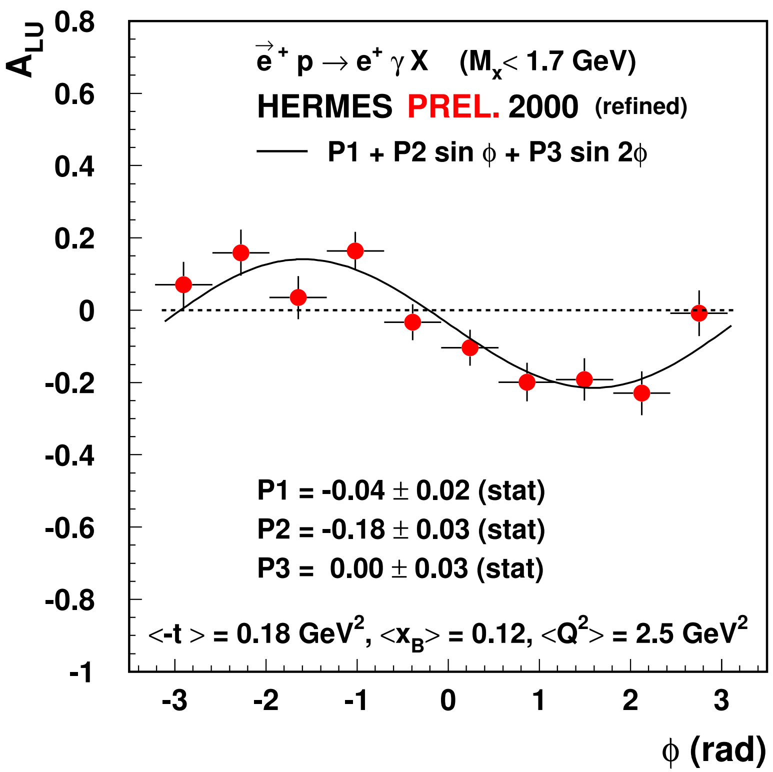
⇒ "Exclusive" bin ($-1.5 < M_x < 1.7$ GeV)

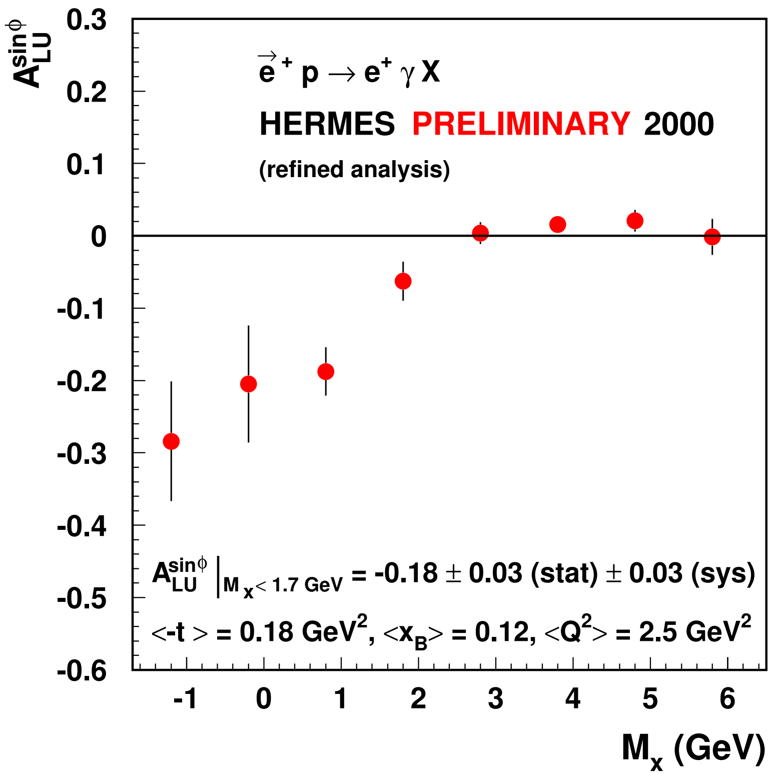
⇒ Overall background contribution ≈ 15%

No radiative corrections to BH/DVCS in MC generator, no solid estimates available ...

Beam–Spin Asymmetry (BSA)

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





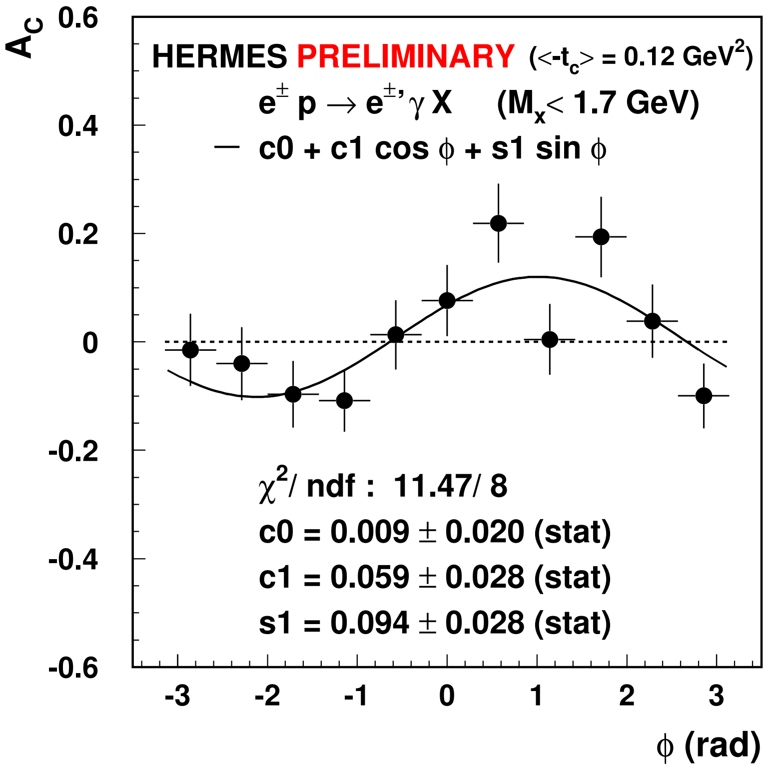
A_{LU} in exclusive bin: Expected $\sin(\phi)$ dependence $\Rightarrow$ $\mathrm{Im}\, M^{1,1}_{unp}$

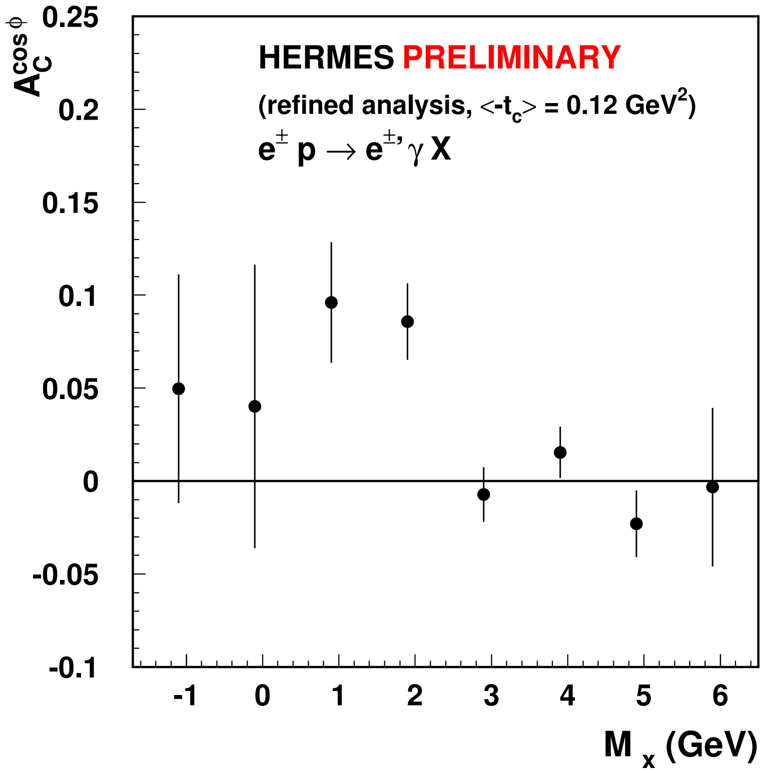
$\sin(\phi)$–Moment in non–exclusive region: small and slightly positive ($\rightarrow \pi^0$)

(Results from 1996/97 $\rightarrow$ PRL **87**, 182001 (2001))

Beam–Charge Asymmetry (BCA)

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

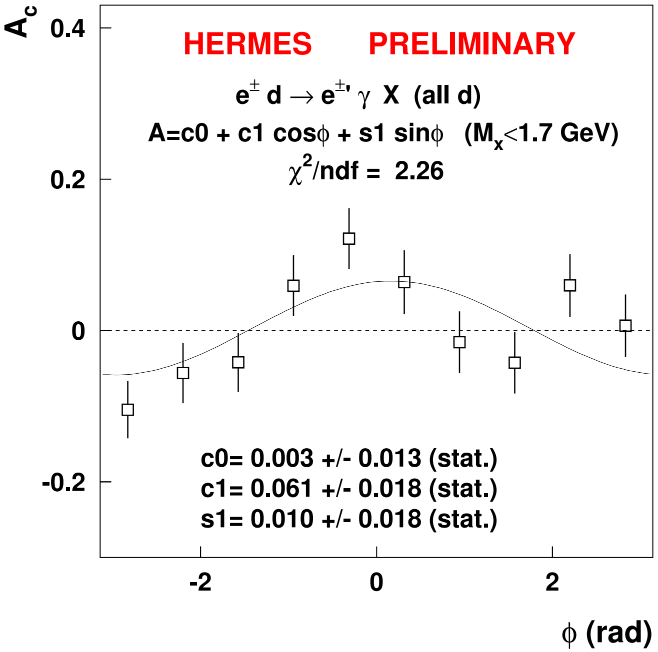


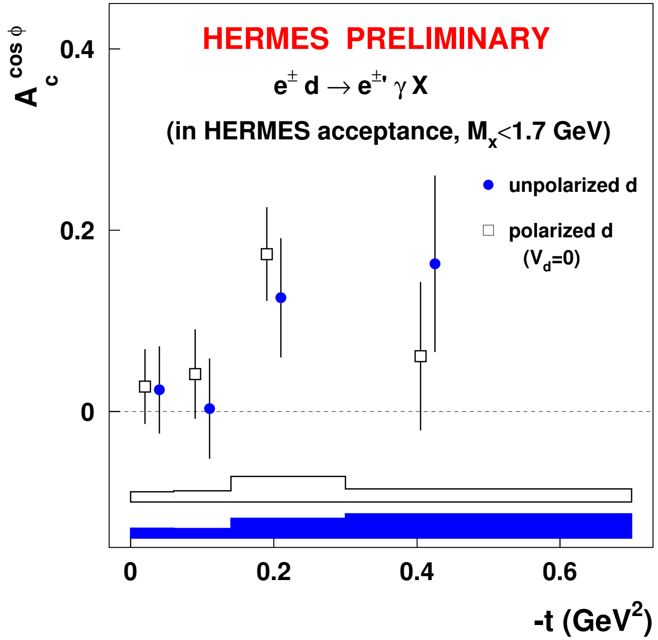


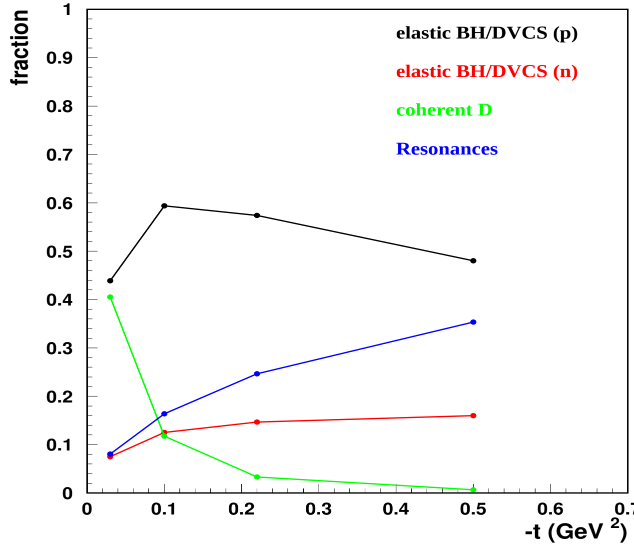
A_C in exclusive bin: Expected $\cos(\phi)$ dependence $\Rightarrow \mathrm{Re}\, M_{unp}^{1,1}$
$\sin\phi$ due to polarized beam

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

Beam–Charge Asymmetry (BCA) on Deuterium

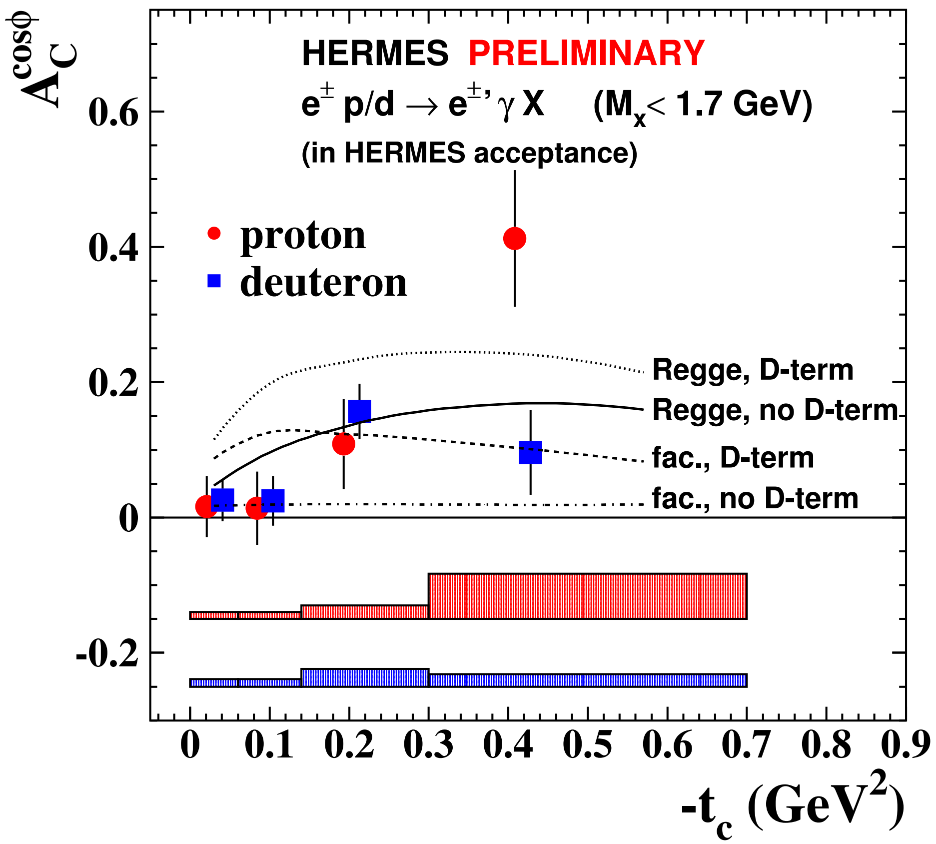






- $A_C^{\cos\phi}(d) \approx A_C^{\cos\phi}(p)$
- Spin-1 particle $\rightarrow$ 9 GPDs, but coherent production only $\approx 20\%$
- 40% coherent in first t-bin
  $\Rightarrow$ no Tensor effect seen
  $\Rightarrow$ Data can (indeed) be combined

Beam–Charge Asymmetry (BCA) versus t



Coherent production on d only in first t-bin ($\approx 40\%$)
⇒ No effect seen
→ ≈ p-target

Possible difference in last bin (→ neutron)

GPD Model (Vanderhaeghen et al.) calc. at average kinematic values per bin

Data averaged over x_B, Q^2 range → Model curves can change up to 20% (model dep.) when calc. at real events kinematics

tiny e^-p sample ($L \approx 10$ pb^{-1})

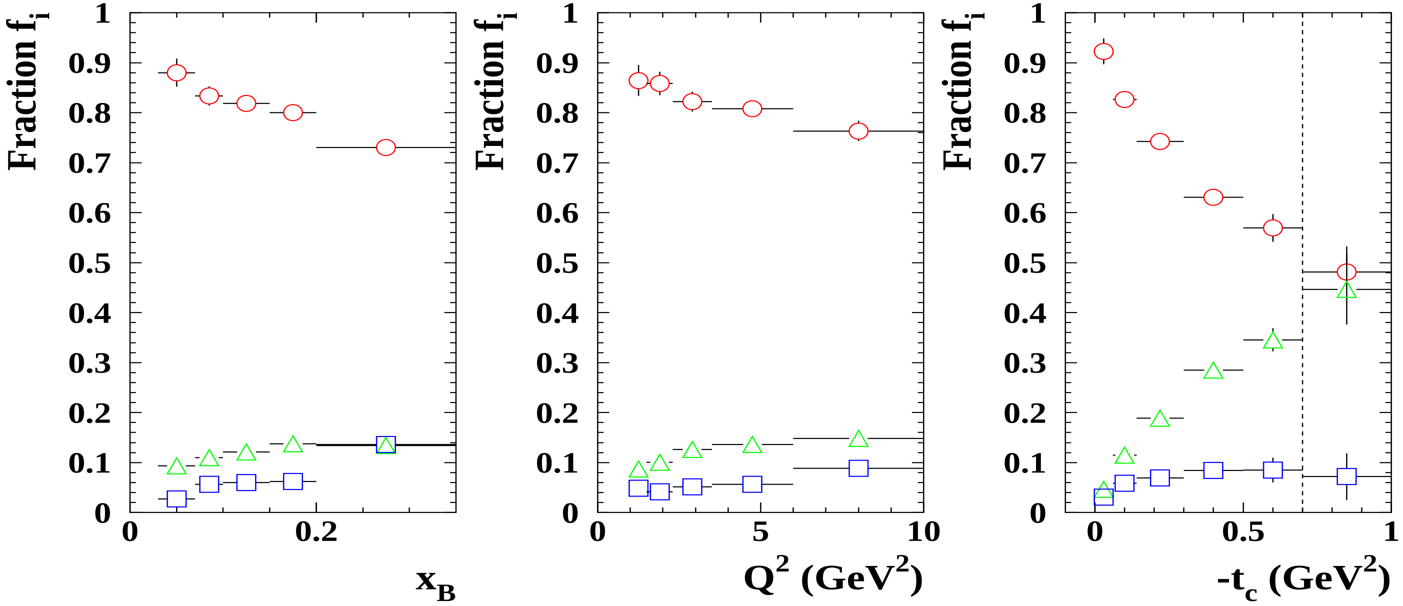
If multidimensional binning possible (Statistics !) or fast generator/lookup-table available

⇒ t–dependence of BCA has high sensitivity to GPD models!

More on H to come

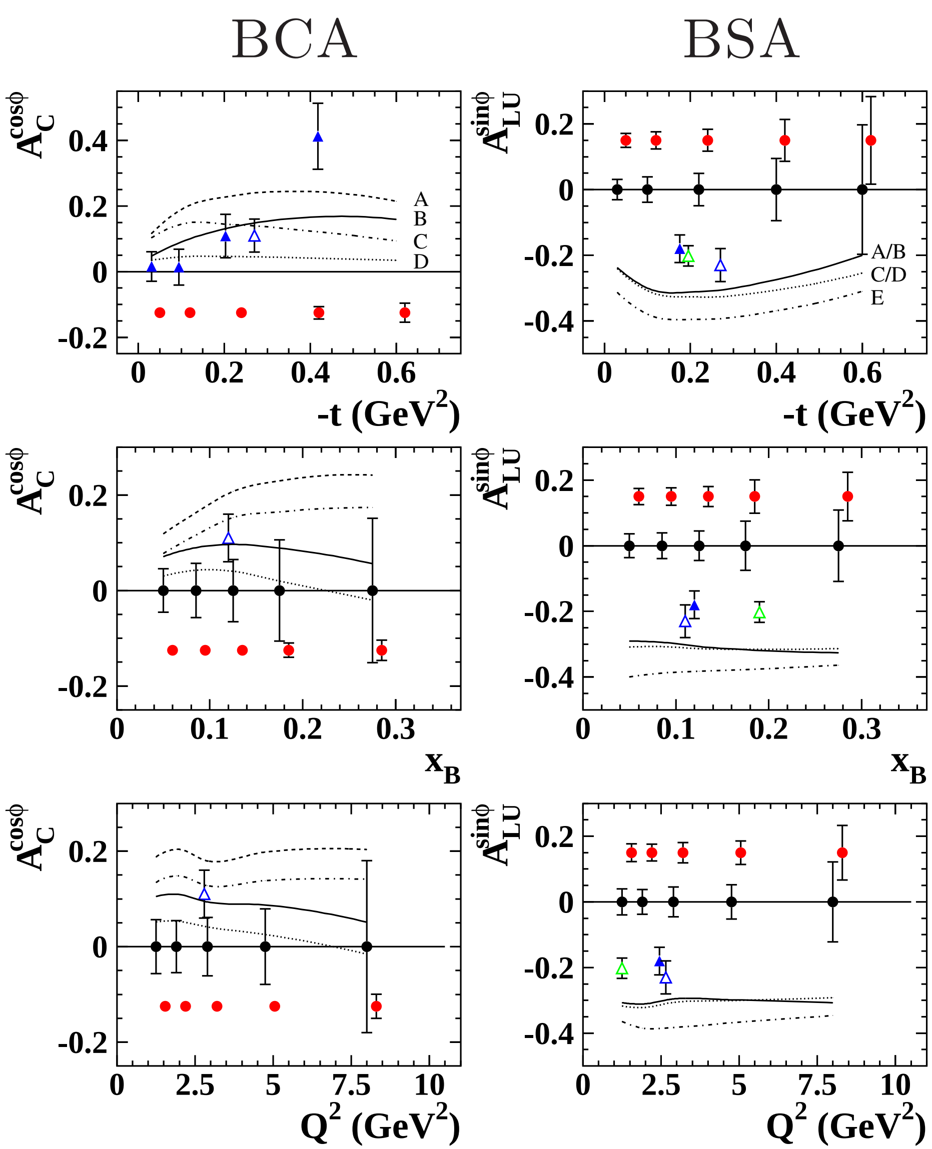
Recoil Detector and unpol. Targets (2006/2007)

- ensures exclusivity of events
  - Semi–inclusive background 5% $\Rightarrow$ $\ll$ 1%
  - Associated background 10% $\Rightarrow$ $\approx$ 1%



$\Rightarrow$ Essential at larger $-t$ values

The GPD H, Summary and Outlook



△: HERMES prelim./published

△: CLAS, PRL, 2001 $(\times - 1)$

● Hydrogen data (1996-2000), Analysis almost completed

● BCA: $1 fb^{-1}\, e^+$ and $1 fb^{-1}\, e^-$

● BSA: $1 fb^{-1}\, e^+$, Pol. = 40%

(exp. 2006/2007 Recoil data)

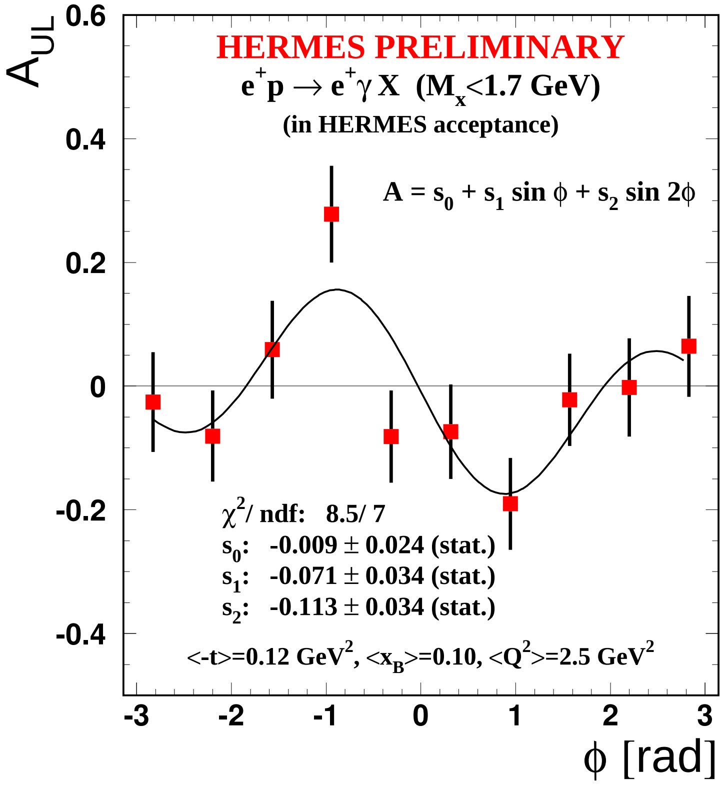
BCA: high sensitivity to t-dependence (fact./Regge) and D-term

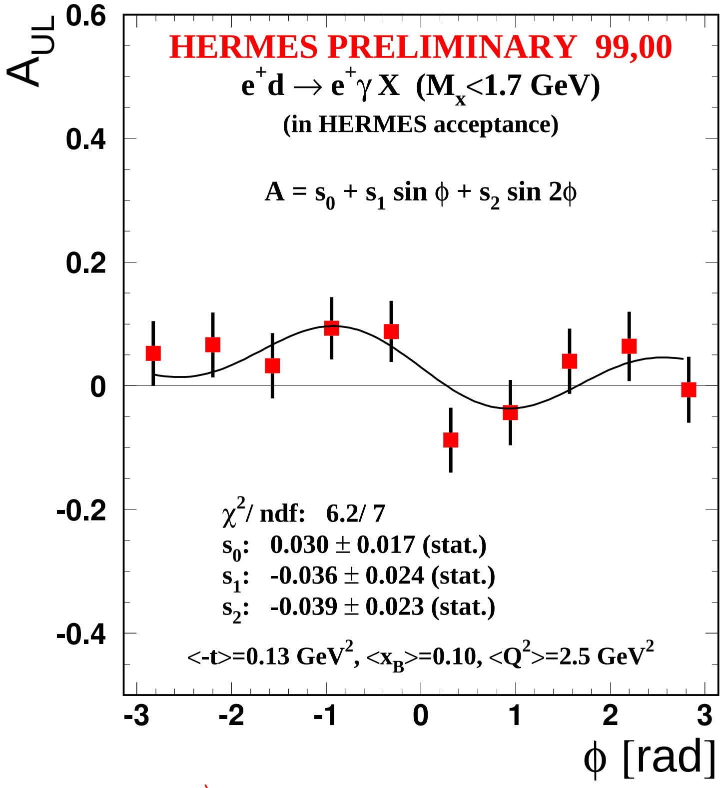
BSA: highest sensitivity to b_s parameter in profile function

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

The GPD $\widetilde{H}$, Long. Target–Spin Asymmetry (LTSA)

$$A_{\rm UL}(\phi) = \frac{1}{<|P_T|>} \frac{\overleftarrow{N}(\phi) - \overrightarrow{N}(\phi)}{\overleftarrow{N}(\phi) + \overrightarrow{N}(\phi)}$$

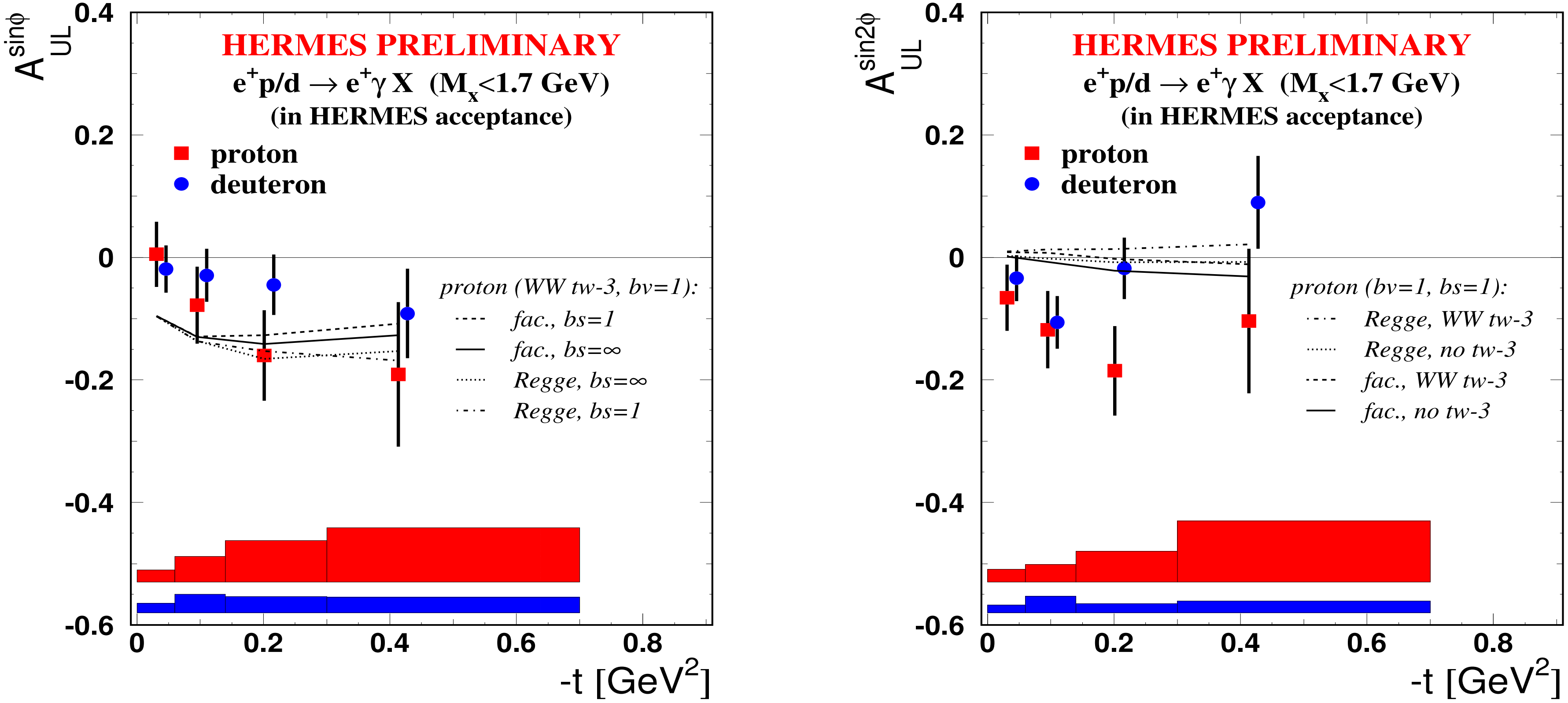




$A_{\rm UL}(\overrightarrow{p})$ in exclusive bin:
Expected $\sin(\phi)$ dep. $\Rightarrow$ Im$M_{LP}^{1,1}$,
Unexpected $\sin(2\phi)$ dependence

$A_{\rm UL}(\overrightarrow{d})$ in exclusive bin:
$\Rightarrow$ consistent with zero

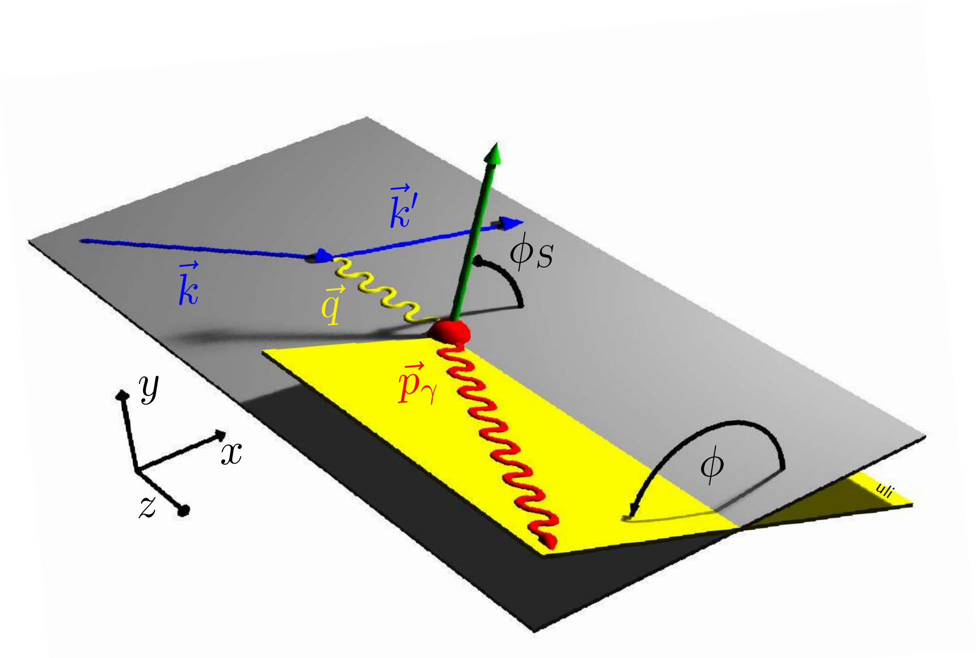
The GPD $\widetilde{H}$, Long. Target–Spin Asymmetry (LTSA)



- No effect seen from 40% coherent contribution in first bin
- Difference at higher $-t$
  $\Rightarrow$ Different asymmetry on the neutron when comp. to proton
- $A_{UL}^{\sin 2\phi}$ $\Rightarrow$ Difference due to missing qGq twist-3 in the models?

What about the GDP E ?

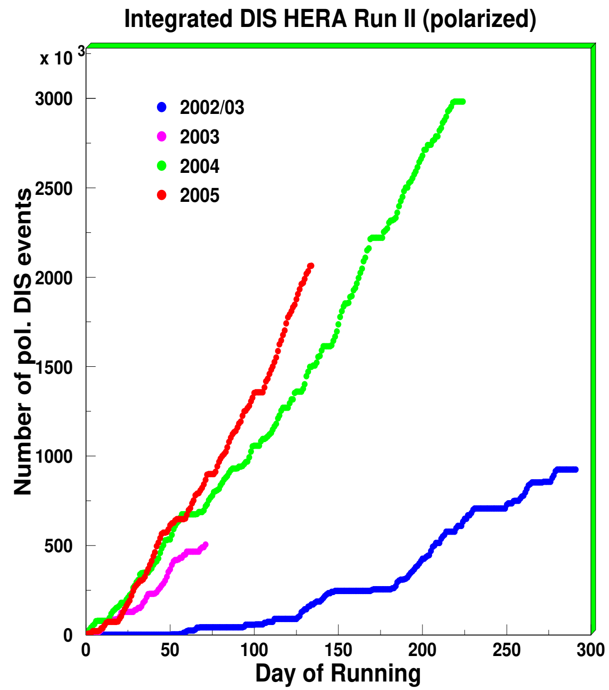
A_{UT}: unpolarized beam, transversely pol. target



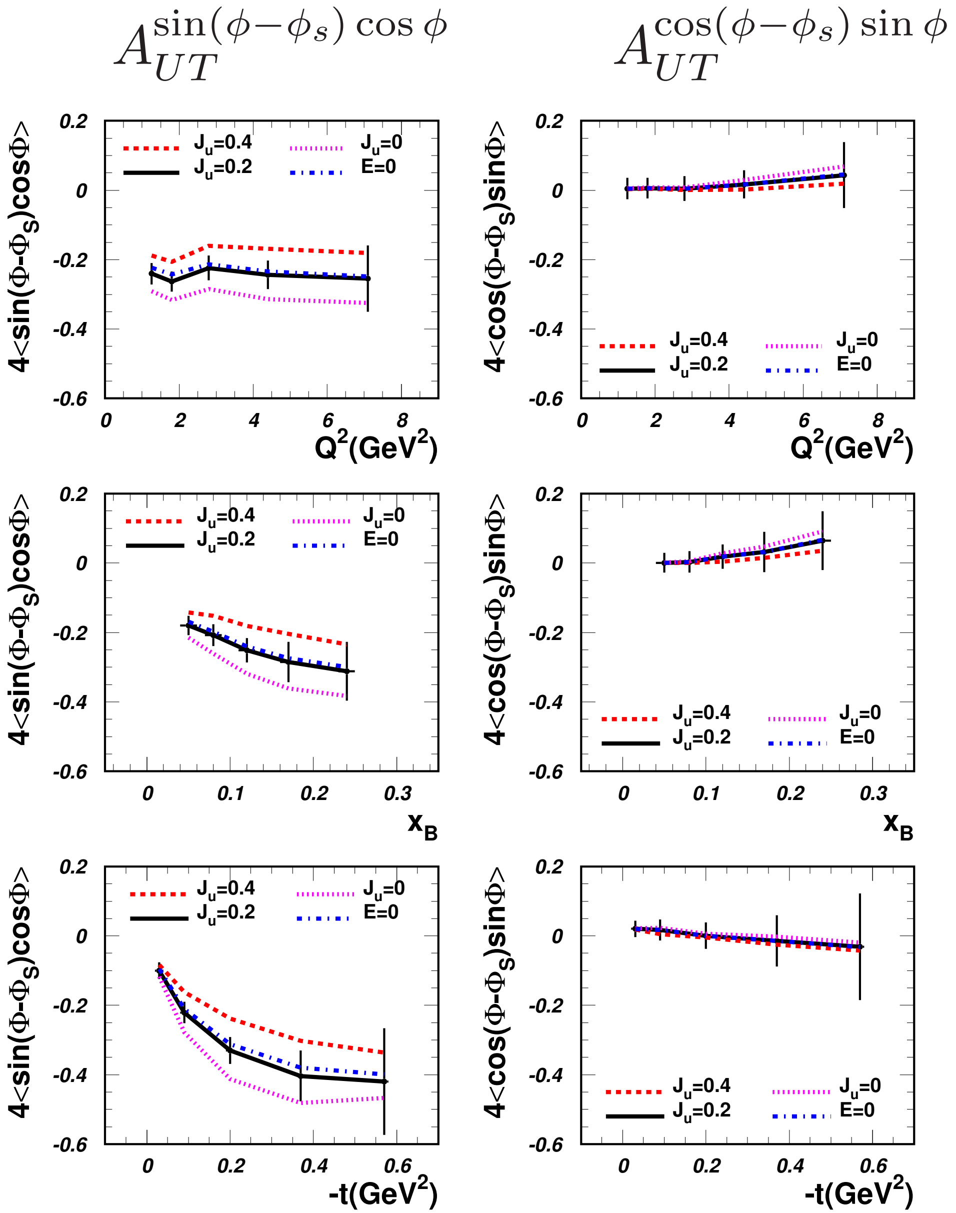
$$A_{UT}^{\sin(\phi-\phi_s)\cos\phi} \sim \frac{-t}{4M_p}(F_2H_1 - F_1E_1)$$

$$A_{UT}^{\cos(\phi-\phi_s)\sin\phi} \rightarrow \frac{-t}{4M_p}(F_2\widetilde{H}_1 - \xi F_1\widetilde{E}_1)$$

Data taking with transverse Hydrogen target in progress . . . $\approx$ 6 million on tape



$\approx$ 8 Mio expected in total (November 2005)



Based on 8 million DIS, Target Pol. = 75 %

Change model parameters only for E ($\rightarrow$ J_u)
$\rightarrow$ only $A_{UT}^{\sin(\phi-\phi_s)\cos\phi}$ sensitive

After GPD H^u well known $\Rightarrow$

- E=0 "baseline" known
- some/many model parameters are the same for H and E ?!?

Models show same kinematic dependences
$\Rightarrow$ integrate over kinematics

4σ difference (total exp unc.) between $J_u = 0.4$ and 0.0

Summary

- Not shown: BSA on D, Ne (hep–ex/0212019) and Kr averaged over kinematics, t-dependences (i.e coherent/incoherent separation) to come...
- Results shown mostly in agreement with basic models and assumptions.
- Needed: Fast DVCS/BH generators including radiative corrections and maybe 'real' Twist–3
- Azimuthal Asymmetries at HERMES:
  - GPD H: "map out" GPD H^u in the final two HERA years, BCA especially sensitive to model parameters
  - GPD $\widetilde{H}$: Different asymmetry on the neutron and proton, $A_{UL}^{\sin 2\phi}$ hint on twist-3?
  - GPD E: first glimpse on GPD E^u and thus on J_u possible