Recent Results on Deeply Virtual Compton Scattering at HERMES

Hrachya Marukyan

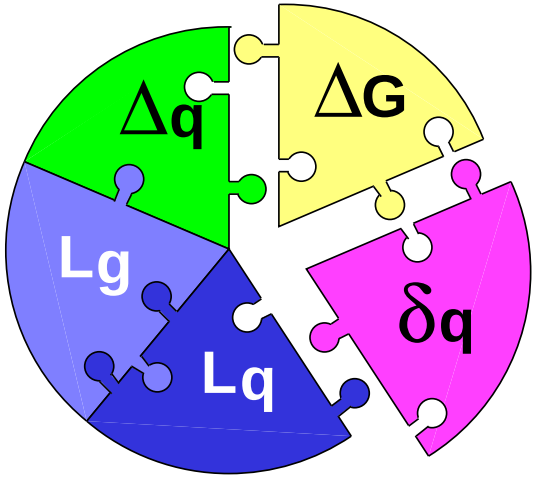
Yerevan Physics Institute, Armenia

for the HERMES Collaboration

QCD 06, Montpellier, France, July 3-7, 2006

- Motivation: Spin Composition of the Nucleon
- Generalized Parton Distributions and DVCS process
- DVCS Measurement at HERMES
- HERMES Results on Azimuthal Asymmetries
- Summary and Outlook

Nucleon Spin Composition



Nucleon Spin:

$$\frac{1}{2} = \underbrace{\frac{1}{2}\overbrace{(\Delta u + \Delta d + \Delta s)}^{\Delta\Sigma} + L_q}_{J_q} + \underbrace{\Delta G + L_g}_{J_g}$$

$\Delta\Sigma \sim 20 - 35\%$: measured in DIS,
HERMES ~ 0.3

ΔG: First measurements

L_q, L_g: Unknown!

Ji's relation: Total angular momentum — **Ji, PRL 78 (1997) 610**

$$J_{q,g} = \lim_{t\to 0} \frac{1}{2} \int_{-1}^{1} dx\, x \underbrace{[H_{q,g} + E_{q,g}]}_{GPDs}$$

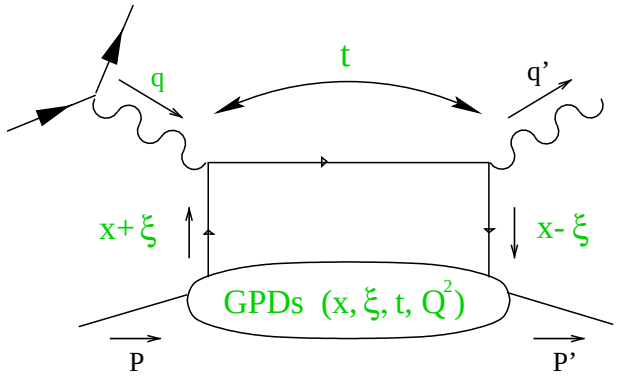
$\Longrightarrow$ The Hunt for L_q

GPDs and DVCS Process

GPDs accessible in hard exclusive processes:

DVCS: Hard photoproduction of a real photon ($\gamma^* N \to N' \gamma$),
virtual photon generated by lepton scattering $\Rightarrow e N \to e' N' \gamma$

Factorization theorem:



$x \pm \xi$: parton longitudinal momentum fractions,
ξ: fraction of the momentum transfer, $\xi \simeq \frac{x_B}{2-x_B}$,
t: invariant momentum transfer, $t \equiv (p - p')^2$

Nucleon structure:

$$GPDs: \quad H_q, \widetilde{H}_q, E_q, \widetilde{E}_q$$

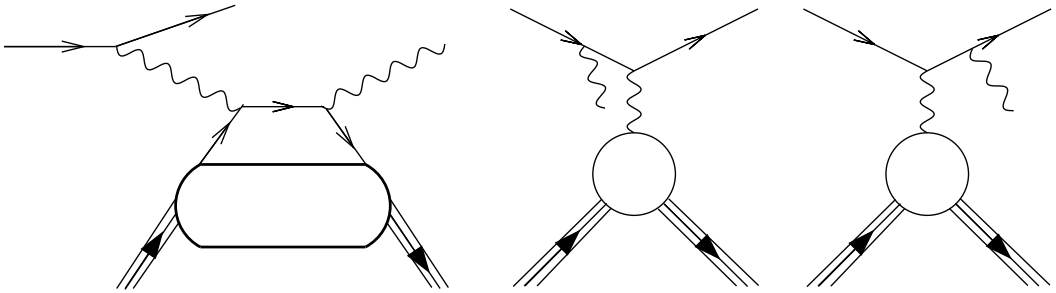
$$GPDs \to PDFs$$
$$H_q(x,0,0) = q(x)$$
$$\widetilde{H}_q(x,0,0) = \Delta q(x)$$

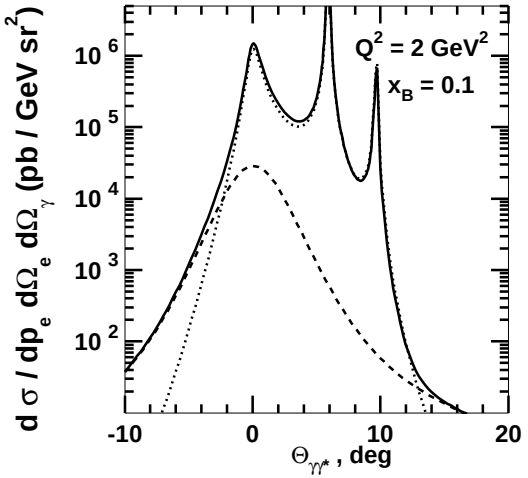
$$GPDs \to FFs$$
$$\int_{-1}^{1} dx\, H_q(x,\xi,t) = F_1^q(t),$$
$$\int_{-1}^{1} dx\, E_q(x,\xi,t) = F_2^q(t)$$

$H_q, \widetilde{H}_q$ — conserve nucleon helicity
$E_q, \widetilde{E}_q$ — flip nucleon helicity,
not accessible in DIS

DVCS and BH Interference

DVCS (a) AND BETHE-HEITLER (BH) (b) PROCESSES EXPERIMENTALLY INDISTINGUISHABLE



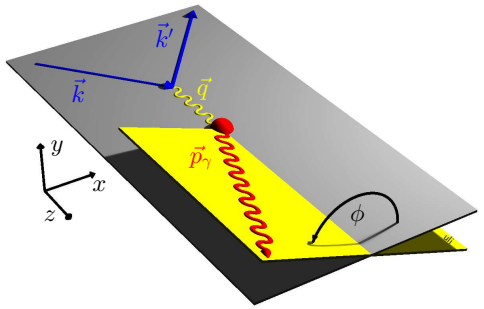


$$d\sigma \propto |\tau_{\mathrm{DVCS}}|^2 + |\tau_{\mathrm{BH}}|^2 + \underbrace{(\tau^*_{\mathrm{DVCS}}\tau_{\mathrm{BH}} + \tau^*_{\mathrm{BH}}\tau_{\mathrm{DVCS}})}_{I}$$

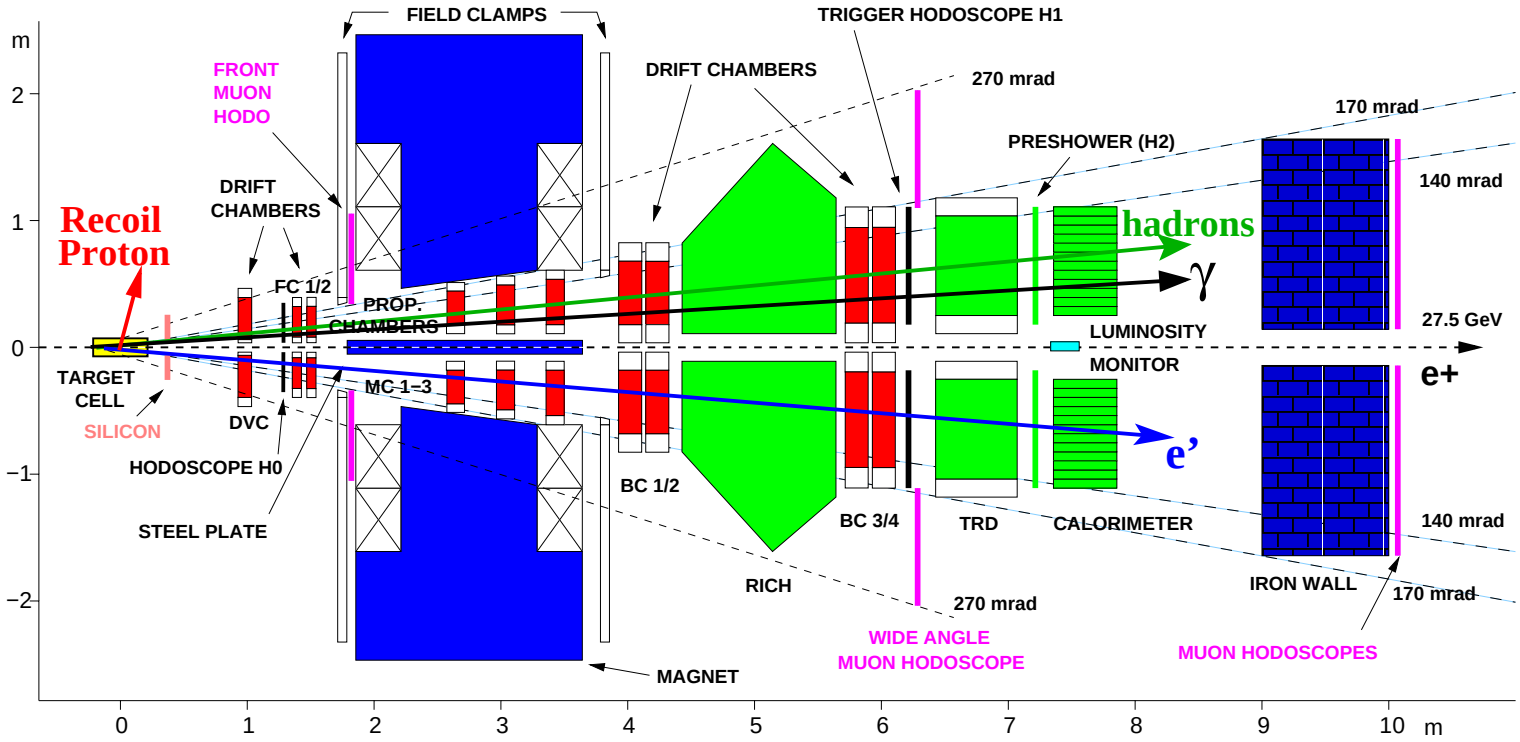
HERMES KINEMATICS: $|\tau_{\mathrm{DVCS}}|^2 << |\tau_{\mathrm{BH}}|^2$

DVCS AMPLITUDES: ACCESSIBLE THROUGH AZIMUTHAL ASYMMETRIES VIA I (GPDS ENTER IN LINEAR COMBINATIONS IN AMPLITUDES)

- BEAM–SPIN ASYMMETRY (BSA):
$$d\sigma(\overrightarrow{e^+}p) - d\sigma(\overleftarrow{e^+}p) \propto \mathrm{Im}\,[F_1\mathcal{H}] \times \sin(\phi)$$
- BEAM–CHARGE ASYMMETRY (BCA):
$$d\sigma(e^+p) - d\sigma(e^-p) \propto \mathrm{Re}\,[F_1\mathcal{H}] \times \cos(\phi)$$



The HERMES Experiment



Gas Target:

- Long. polarized H, D
- Unpolarized H, D, Ne, Kr, Xe
- Transversely polarized H

$$\langle |P_T| \rangle \approx 85\%$$

Beam:

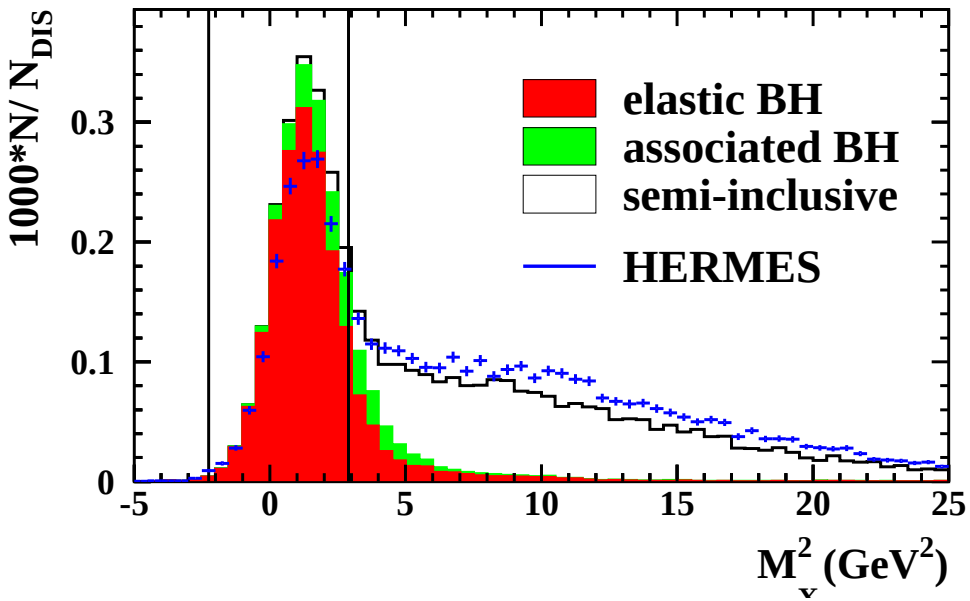
- Long. polarized e^+ and e^-
- Energy 27.6 GeV
- Both helicities

$$\langle |P_B| \rangle \approx 55\% \text{ (HERA I)}$$

PID: $\epsilon_e > 99\%$, $\delta P/P < 2\%, \delta\theta < 1mrad$, $\delta E_\gamma/E_\gamma \approx 5\%$.

DVCS Event Selection

- Events with exactly one DIS - lepton and exactly one trackless cluster in the calorimeter.
- No recoil detection $\Rightarrow$ Exclusivity via missing mass: $M_X^2 = (q + P - q')^2$



MC for background and cuts

$$e\,p \rightarrow e'\,\gamma\,X$$

Contributed Processes:

$e\,p \rightarrow e'\,p\,\gamma$; Elastic BH

$e\,p \rightarrow e'\,\Delta^+\,\gamma$; Associated BH

$e\,p \rightarrow e'\,\pi^0\,X$; Semi-inclusive

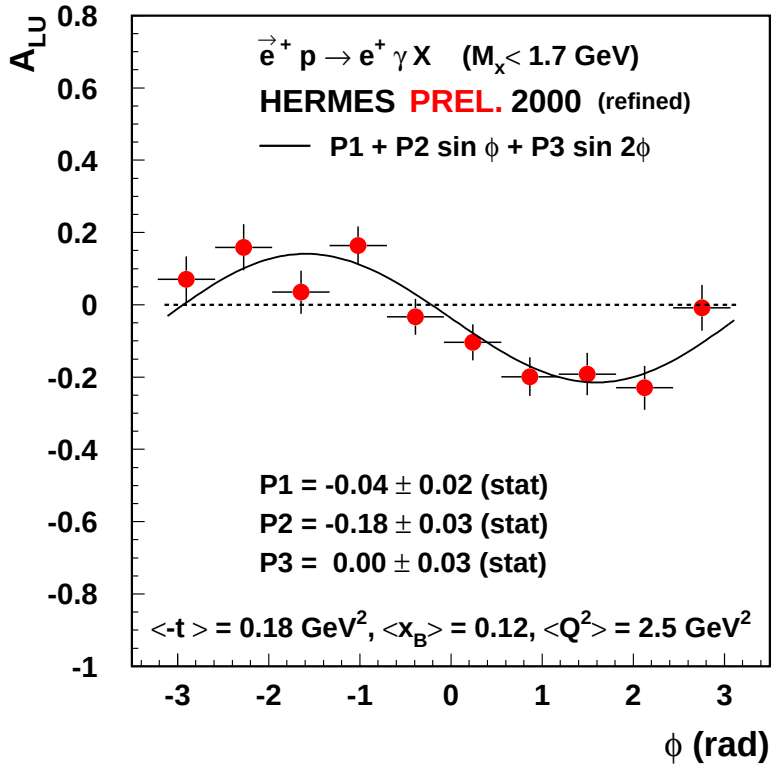
Correction on Background $\Rightarrow$ Mostly Decay Photons From Semi-inclusive π^0 ($\approx 6\%$)

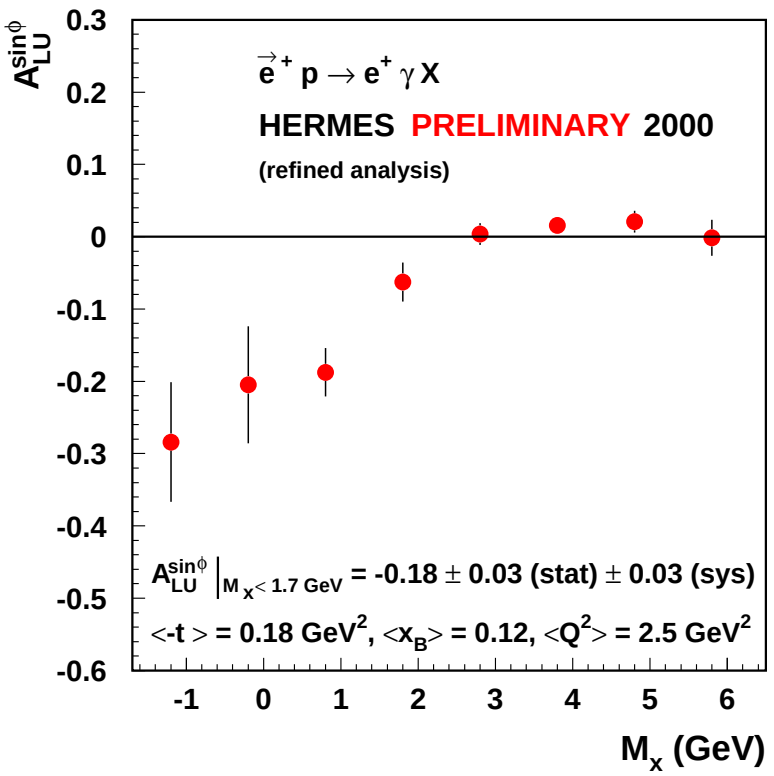
Background Contribution Overall ≈ 15 %

$\Rightarrow$ Exclusive bin $(-(1.5)^2 < M_X^2 < (1.7)^2\ GeV^2)$

Beam–Spin Asymmetry on Proton

$$A_{\mathrm{LU}}(\phi) = \frac{1}{\langle |P_b| \rangle} \frac{\overrightarrow{N}(\phi) - \overleftarrow{N}(\phi)}{\overrightarrow{N}(\phi) + \overleftarrow{N}(\phi)} \propto \frac{\mathrm{Im}\,\mathcal{H}}{F_1} \sin\phi$$





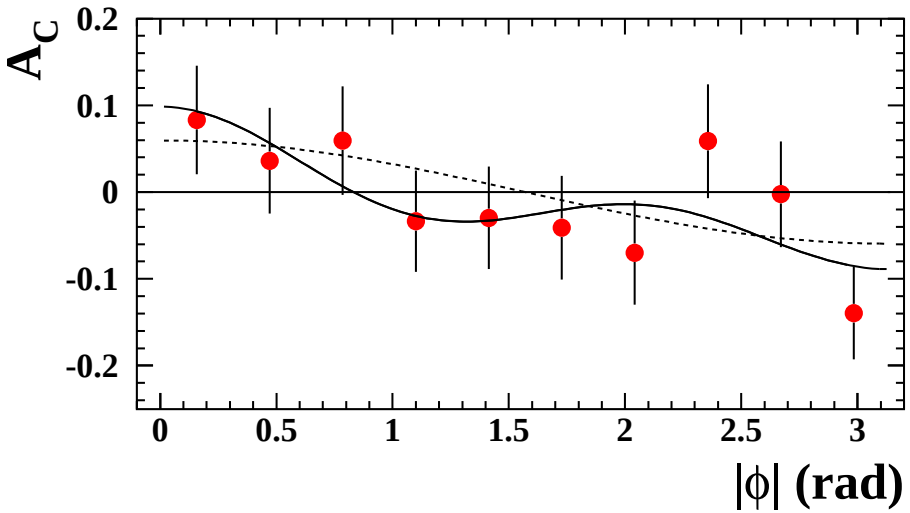
A_{LU} IN EXCLUSIVE BIN: EXPECTED $\sin(\phi)$ DEPENDENCE $\Longrightarrow \mathrm{Im}\,\mathcal{H}$

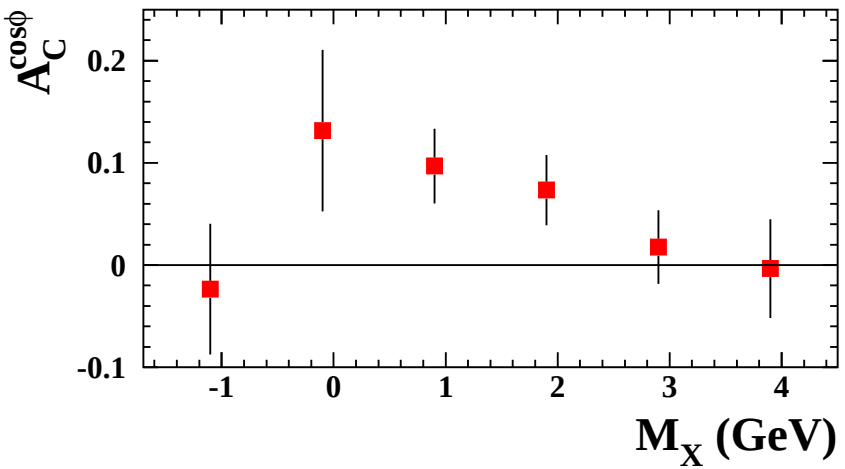
$\sin(\phi)$-MOMENTS IN NON-EXCLUSIVE REGION IS SMALL AND POSITIVE

BSA RESULTS: HERMES-PRL **87**, 182001 (2001)

Beam–Charge Asymmetry on Proton

$$A_C(\phi) = \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)} \propto \frac{\mathrm{Re}\,\mathcal{H}}{F_1} \cos\phi$$





'SYMMETRIZED' BCA IN EXCLUSIVE BIN $(\phi \to |\phi|) \Longrightarrow$ CANCEL SINUSOIDAL TERMS (DUE TO POLARIZED BEAM)

THE SOLID CURVE → 4-PARAMETER FIT:

$P_0 + P_1 \cos\phi + P_2 \cos 2\phi + P_3 \cos 3\phi$

THE DASHED CURVE → PURE $\cos\phi$

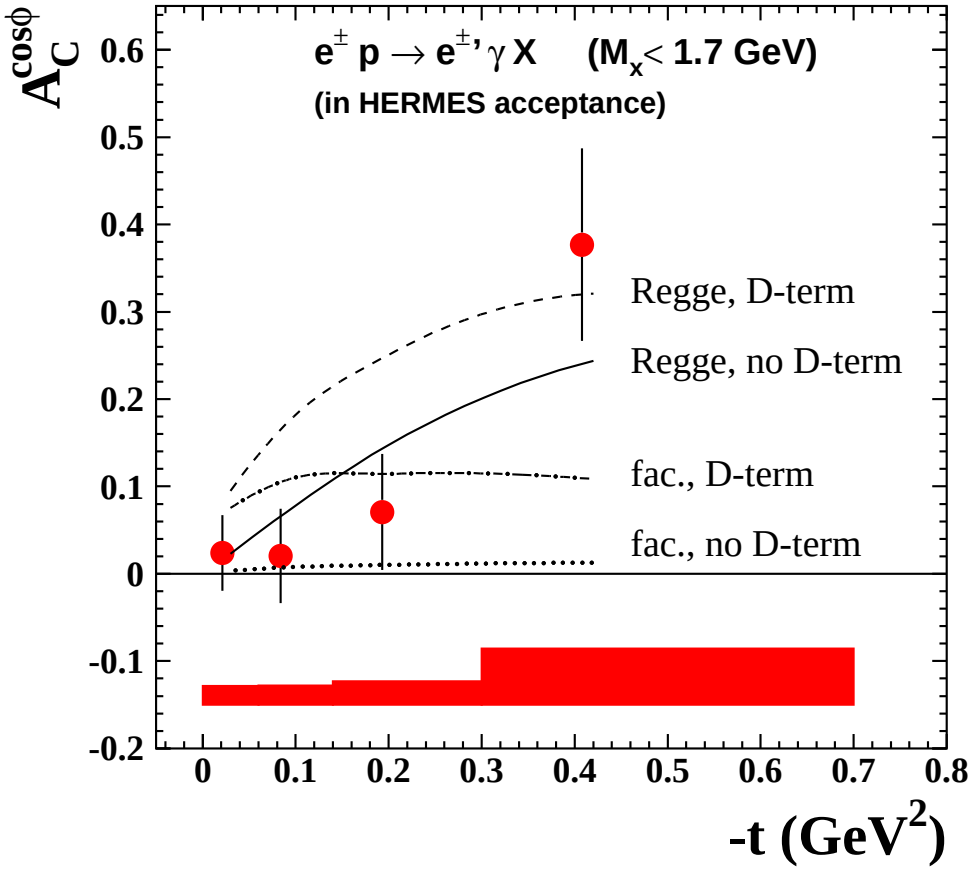
EXPECTED $\cos\phi$ DEPENDENCE

$\cos(\phi)$-MOMENTS ZERO AT HIGHER MISSING MASS

$$A_{C,Proton}^{\cos(\phi)} = 0.063 \pm 0.029(\text{STAT.}) \pm 0.026(\text{SYS.})$$

A. AIRAPETIAN *et al.*, HEP-EX/0605108 , SUBMITTED TO PRL

Comparison to model calculations



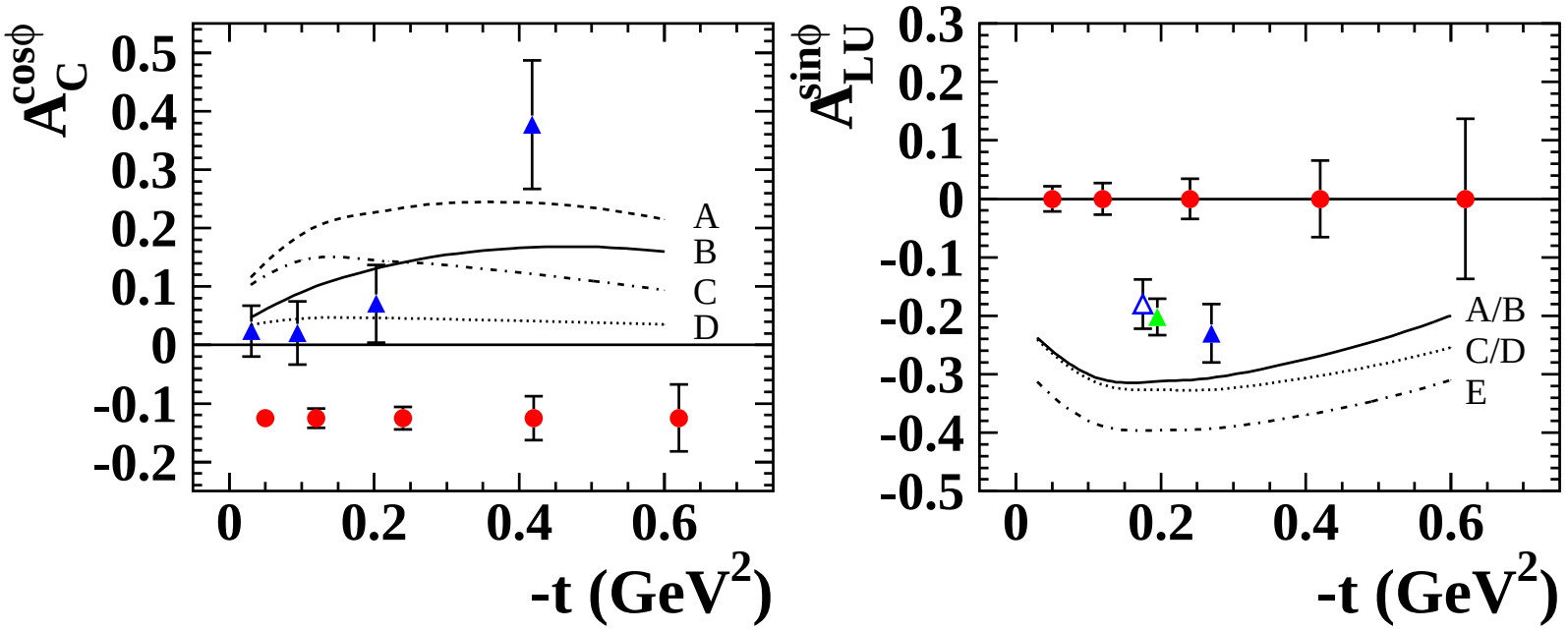
GPD MODELS: M. VANDERHAEGHEN *et al.*, PHYS. REV. D60 (1999) 094017; K. GOEKE *et al.*, PROG. PART. NUCL. PHYS. 47 (2001) 401.

- GPD H DOMINATES, E SUPPRESSED
- CURVES: 4 DIFFERENT PARAMETER SETS
- MODEL CALCULATIONS AT AVERAGE KINEMATIC VALUES PER BIN

IN LAST t-BIN: LARGE CONTRIBUTION FROM THE ASSOCIATED PRODUCTION (NOT INCLUDED IN MODEL CALCULATION) $\Rightarrow$
DATA DISFAVOR REGGE-INSPIRED t-DEPENDENCE WITH D-TERM

SMALL e^-p SAMPLE ($L \approx 10$ PB^{-1})
$\Rightarrow$ t–DEPENDENCE OF BCA $\rightarrow$ POSSIBLE TOOL TO CONSTRAIN GPD H

Projection for GPD H (HERA II)



Left panel: ▲ (hep-ex/0605108) Right panel: ▲ HERMES (PRL 2001) △ HERMES (preliminary hep-ex/0212019) ▲CLAS (PRL 2001)

- BCA: 1 fb^{-1} e^+ and 0.25 fb^{-1} e^-
- BSA: 1 fb^{-1} e^+, Beam pol. $\approx 35\%$

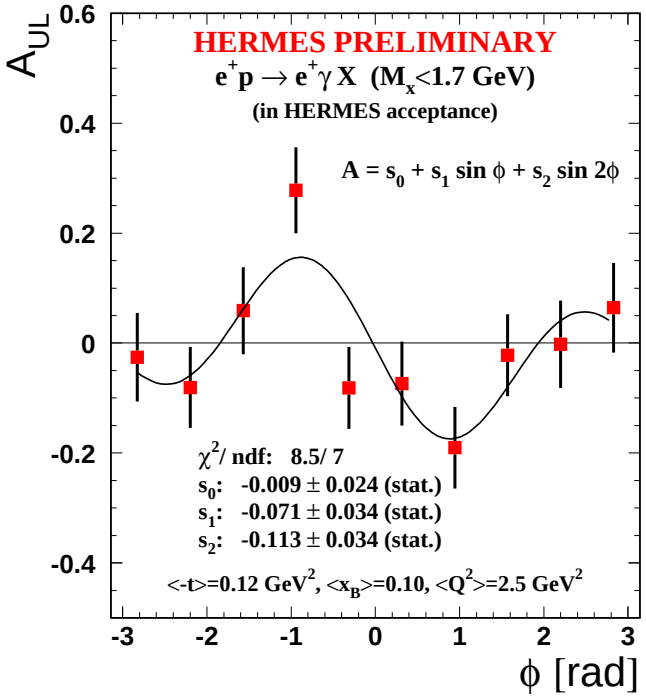
BCA: high sensitivity to t-dependence

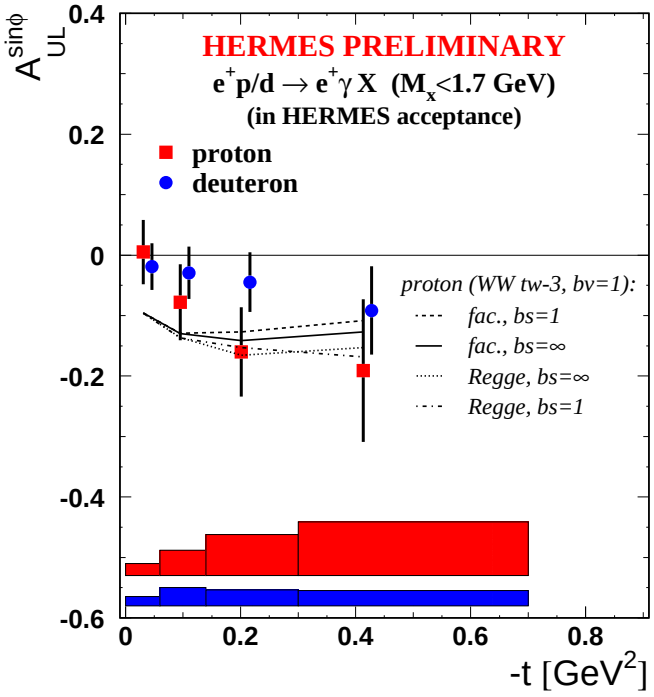
BSA: highest sensitivity to b_{sea} parameter in profile function

Possibility to constrain GPD H_u

Longitudinal Target–Spin Asymmetry

$$A_{\rm UL}(\phi) = \frac{1}{\langle |P_T| \rangle} \frac{N^{\rightleftarrows}(\phi) + N^{\leftleftarrows}(\phi) - N^{\rightrightarrows}(\phi) - N^{\leftrightarrows}(\phi)}{N^{\rightleftarrows}(\phi) + N^{\leftleftarrows}(\phi) + N^{\rightrightarrows}(\phi) + N^{\leftrightarrows}(\phi)} \propto \frac{\mathrm{Im}\,\widetilde{\mathcal{H}}}{F_1} \sin\phi$$





$A_{\rm UL}$ IN EXCLUSIVE BIN: EXPECTED $\sin(\phi)$ DEPENDENCE $\Longrightarrow \mathrm{Im}\,\widetilde{\mathcal{H}}$

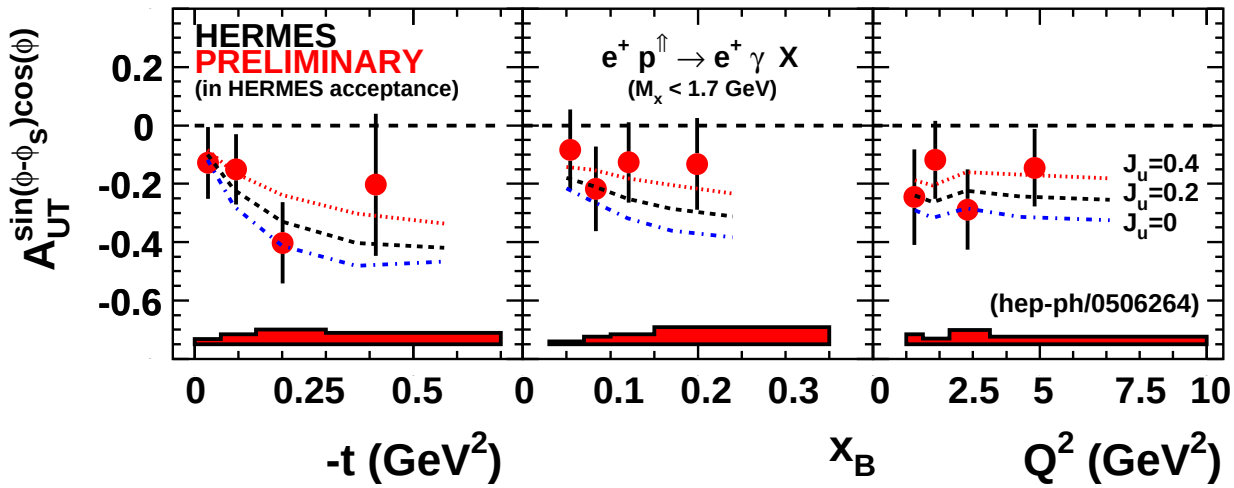
- GPD MODEL: TWIST-3 IS A SIMPLE W.W. TWIST-3
- $A_{UL}^{\sin 2\phi} \Longrightarrow (qGq)$ TWIST-3 IS MISSING ?

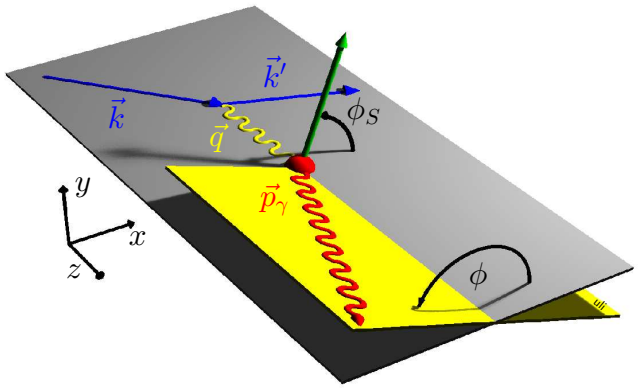
Transverse Target–Spin Asymmetry from HERMES

$$d\sigma(e^+p^{\uparrow}) - d\sigma(e^+p^{\downarrow}) \propto \mathrm{Im}\left[F_2\mathcal{H} - F_1\mathcal{E}\right] \times \sin(\phi - \phi_S)\cos(\phi) + \cdots$$

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

$$A_{\mathrm{UT}}(\phi,(\phi-\phi_S)) = \frac{1}{\langle|P_T|\rangle}\frac{N^{\uparrow}(\phi,(\phi-\phi_S)) - N^{\downarrow}(\phi,(\phi-\phi_S))}{N^{\uparrow}(\phi,(\phi-\phi_S)) + N^{\downarrow}(\phi,(\phi-\phi_S))}$$



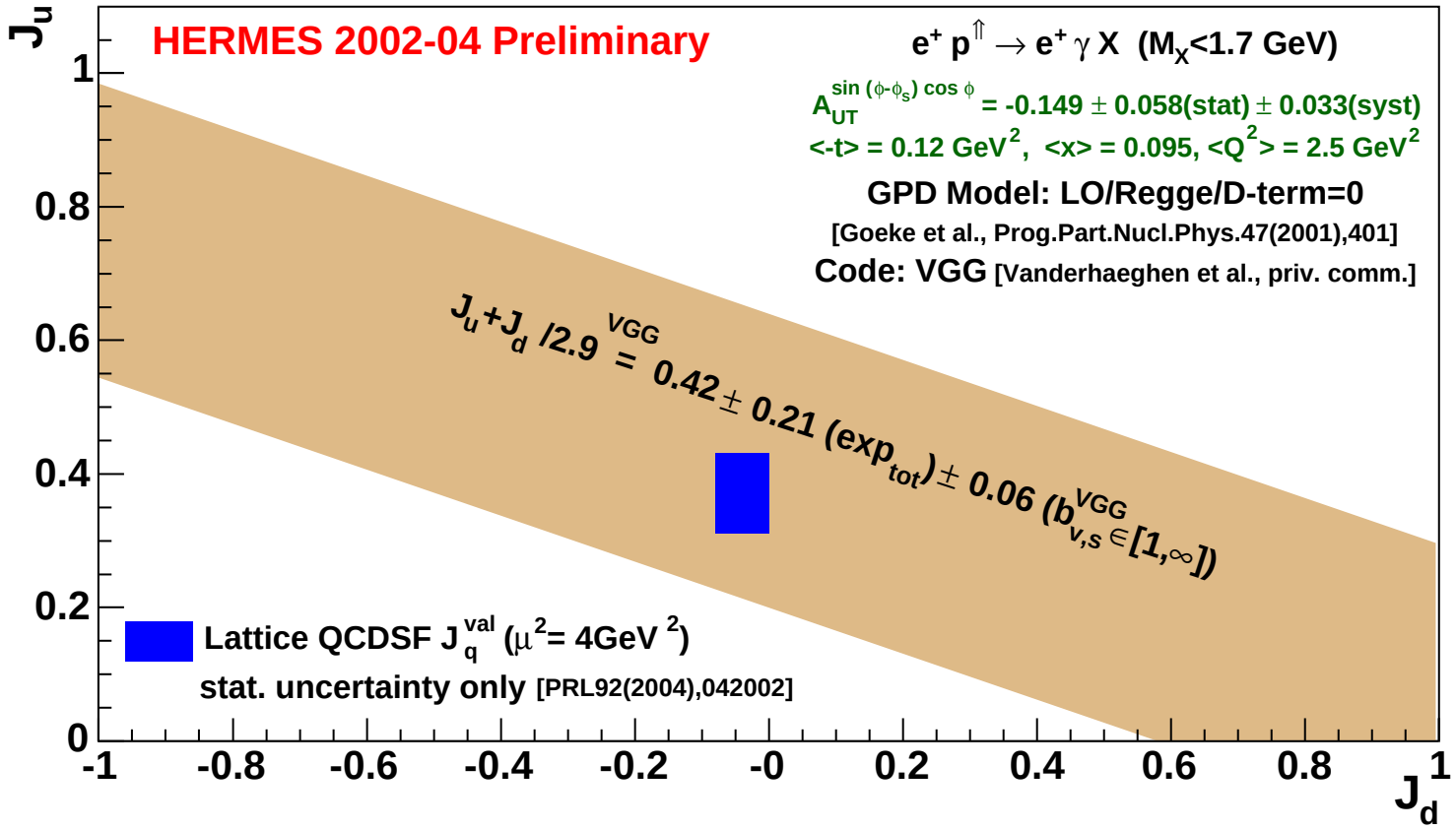


- Results from HERMES 2002-2004 data only; $\simeq 60pb^{-1}$
- Model from Goeke *et al.*: The GPD E is unknown in the forward limit; parametrized according to χQSM model
- $A_{\mathrm{UT}}^{\sin(\phi-\phi_S)cos(\phi)}$ sensitive to J_u (J_d=0)

First Model–Dependent Constraint on J_u vs J_d

$$\chi^2(J_u, J_d) = \frac{\left[A_{\rm UT}^{\sin(\phi-\phi_S)cos(\phi)}|_{exp} - A_{\rm UT}^{\sin(\phi-\phi_S)cos(\phi)}|_{VGG(J_u,J_d)}\right]^2}{\delta A^2_{stat} + \delta A^2_{sys}}$$

- CALCULATED IN STEP OF 0.2 IN J_u AND J_d, INTERPOLATED BY A 5TH ORDER POLYNOMIAL.
- THE 1-σ CONSTRAINT ON J_u VS J_d DETERMINED BY $\chi^2(J_u, J_d) \leq \chi^2_{min} + 1$.



Summary and Outlook

Azimuthal Asymmetries $\Rightarrow$ DVCS-Amplitudes $\Rightarrow$ GPDs
$\Rightarrow$ Structure of Nucleons (L_q)

Existing HERA I data on H:

- Beam–Spin Asymmetry $\Rightarrow$ ImH
- Beam–Charge Asymmetry $\Rightarrow$ ReH
- First constraints on GPD models

Longitudinally polarized H $\Rightarrow$ LTSA $\Rightarrow$ Im$\widetilde{H}$

Transverse polarized H $\Rightarrow$ TTSA $\Rightarrow$ E

- First model-dependent constraint on J_u vs J_d

Outlook

- Including the 2005 data will double the statistics for TTSA
- HERA II(2002-2007) data on H probably map out the GPD H_u
- improvement of t-resolution with Recoil Detector