

Transverse Target-Spin Asymmetry Associated with DVCS on the Proton and a Resulting Model-Dependent Constraint on J_u vs J_d

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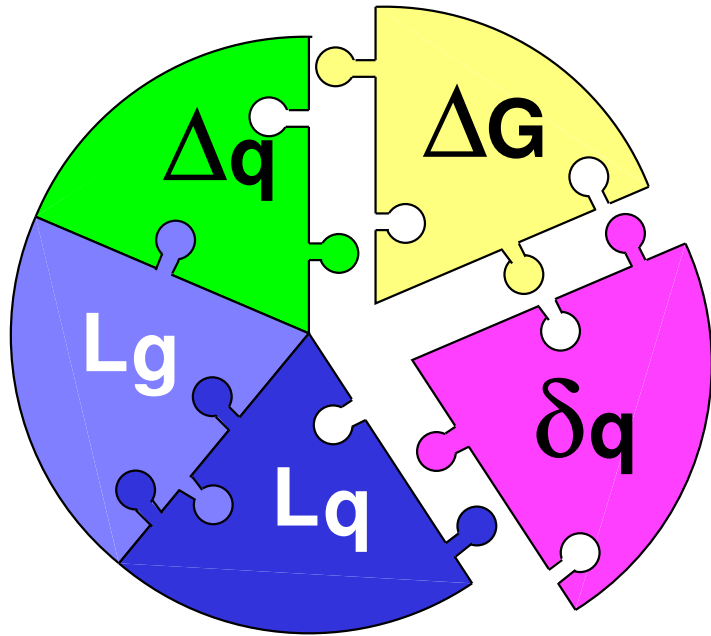
for the HERMES Collaboration

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- Motivation: Spin Structure of the Nucleon from Generalized Parton Distributions
- Deeply Virtual Compton Scattering and Transverse Target-Spin Asymmetry
- The HERMES Experiment and the Preliminary Result on the TTSA
- A Model-Dependent Constraint on the Quark Total Angular Momenta in the Nucleon
- Summary and Outlook



Motivation: Spin Structure of the Nucleon



Nucleon Spin

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

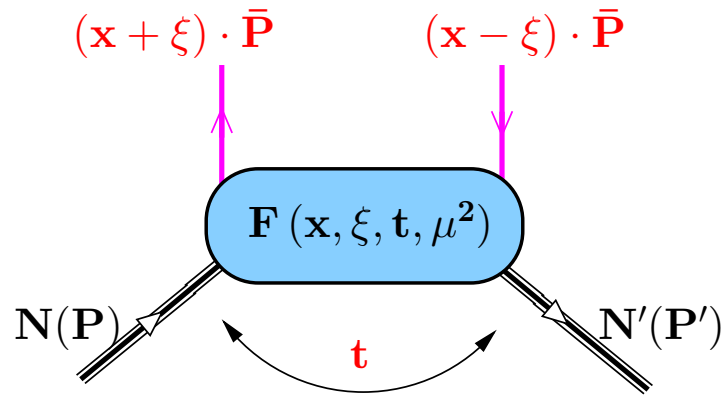
$\Delta\Sigma \sim 20 - 35\%$: Measured in DIS

ΔG : First measurements

L_q, L_g : **Unknown!**

Generalized Parton Distributions $\Rightarrow J_q, J_g (L_q, L_g)$

Generalized Parton Distributions



F : GPDs, defined through ME $\langle P' | \mathcal{O}_{q/g} | P \rangle$
 $x \pm \xi$: Parton longitudinal momentum fractions
 t : Invariant momentum transfer to the target
 μ^2 : Renormalization scale

- For a $S = \frac{1}{2}$ hadron, there are 4 twist-2 parton-helicity non-flip GPDs, H , E , $\tilde{H}$, and $\tilde{E}$:

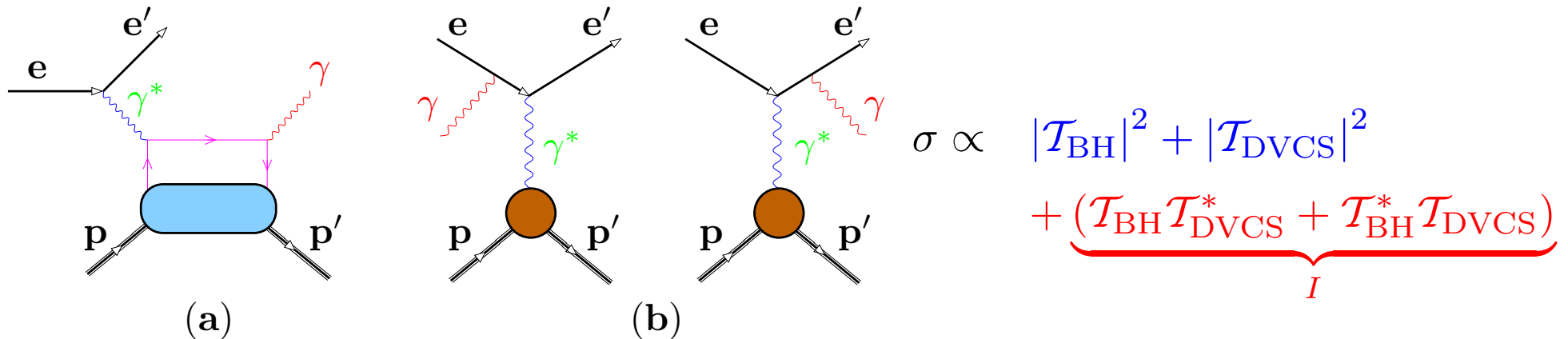
	unpolarized	polarized
nucleon-helicity non-flip	H	$\tilde{H}$
nucleon-helicity flip	E	$\tilde{E}$

- GPDs provide an access to J_q (Ji 1997):

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

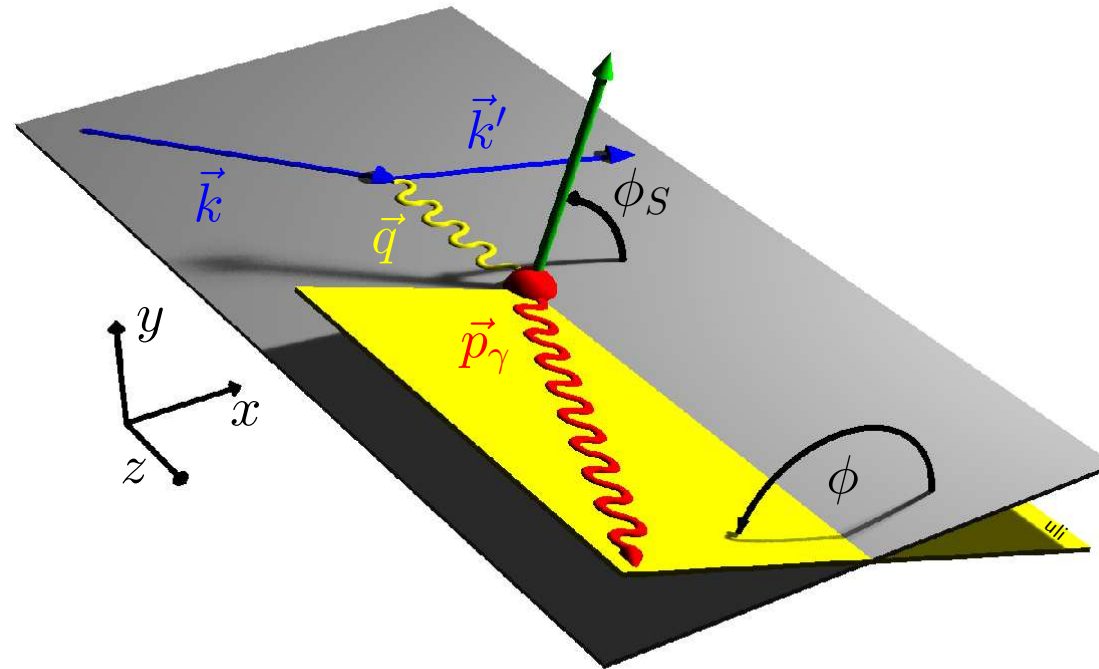
Deeply Virtual Compton Scattering

- The same final state in DVCS (a) and Bethe-Heitler (b) $\Rightarrow$ interference:



- $\mathcal{T}_{\text{BH}}$ is parameterized in terms of nucleon FFs F_1 and F_2 , calculable in QED.
- $\mathcal{T}_{\text{DVCS}}$ is parameterized in terms of Compton FFs $\mathcal{H}$, $\mathcal{E}$, $\tilde{\mathcal{H}}$, and $\tilde{\mathcal{E}}$, which are convolutions of the respective GPDs with the hard-scattering kernels.
- At HERMES, $\mathcal{T}_{\text{BH}} \gg \mathcal{T}_{\text{DVCS}}$, $\mathcal{T}_{\text{DVCS}}$ can be accessed through I : both its amplitude and phase!

Transverse Target-Spin Asymmetry on the Proton



Transverse target-spin asymmetry (Ellignhaus, Nowak, Vinnikov, Ye, hep-ph/0506012)

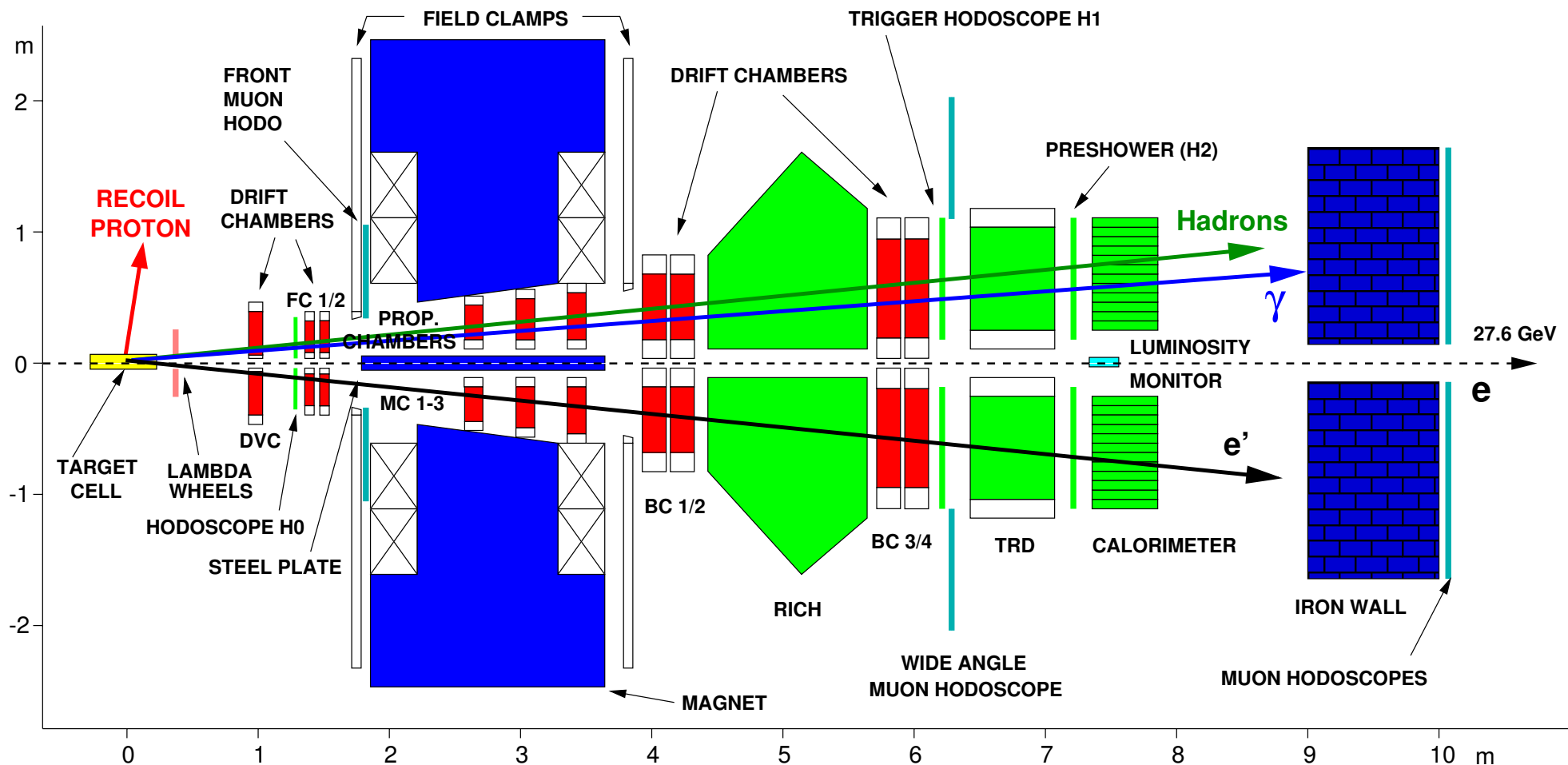
$$A_{UT}(\phi, \phi_S) = \frac{d\sigma(\phi, \phi_S) - d\sigma(\phi, \phi_S + \pi)}{d\sigma(\phi, \phi_S) + d\sigma(\phi, \phi_S + \pi)} \simeq \frac{\mathcal{I}^{\text{TP}}}{|\mathcal{T}_{\text{BH}}^{\text{unp}}|^2}$$

$$\propto \text{Im}[F_2 \mathcal{H} - F_1 \mathcal{E}] \cdot \sin(\phi - \phi_S) \cos \phi + \text{Im}[F_2 \tilde{\mathcal{H}} - F_1 \xi \tilde{\mathcal{E}}] \cdot \cos(\phi - \phi_S) \sin \phi$$

$$\Rightarrow A_{\text{UT}}^{\sin(\phi - \phi_S) \cos \phi} \text{ sensitive to } J_q = \frac{1}{2} \lim_{t \rightarrow 0} \int_{-1}^1 dx x (H_q + E_q)$$

The HERMES Experiment

- Transversely polarized hydrogen target data taking in 2002-2005.
- Recoiling protons were not detected.

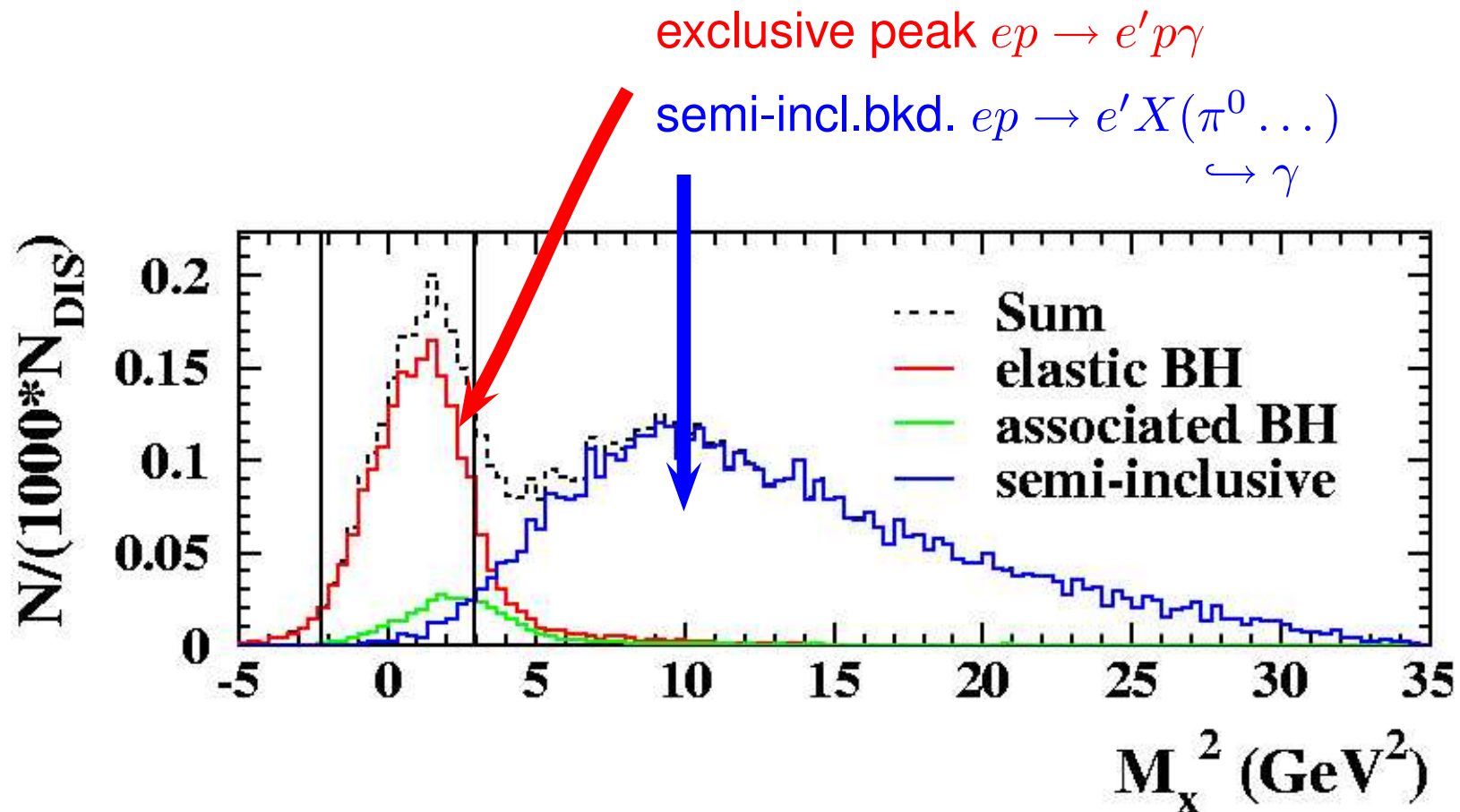


The HERMES Experiment

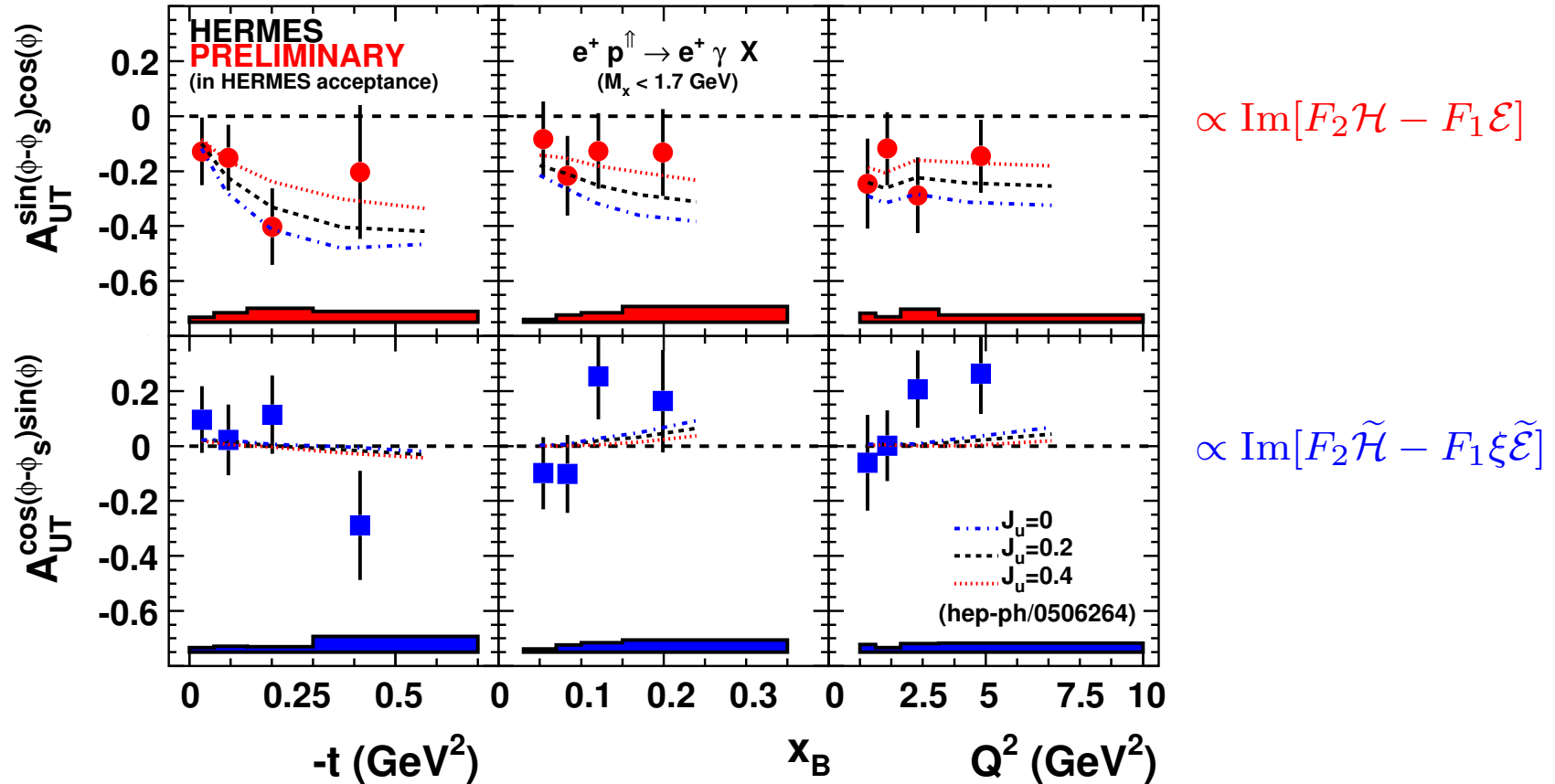
- Exclusivity of the measurement is maintained from the missing mass:

$$M_x^2 = (P_e + P_p - P_{e'} - P_\gamma)^2$$

- Semi-inclusive background contribution $\sim 5\%$ is determined from MC and corrected. Associated production contributes $\sim 11\%$.



Transverse Target-Spin Asymmetry from HERMES



- The presented result is based on the HERMES 2002-2004 data, $\int L dt \simeq 60 \text{ pb}^{-1}$:
 $\sim 4 \text{ k events in } |t| < 0.7 \text{ GeV}^2, 0.03 < x_B < 0.35, 1 < Q^2 < 10 \text{ GeV}^2$.
- Goeke et al., Prog.Part.Nucl.Phys.47 (2001) 401: The nucleon-helicity flip GPD E in the forward limit is modeled by $e(x) = A \cdot q_{val}(x) + B \cdot \delta(x)$, according to χ QSM model. The values A and B are related to J_q by: $\int dx x[q(x) + e(x)] = J_q$, $\int dx e(x) = F_2^q(0) = k^q$.
- hep-ph/0506264: $A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$ sensitive to J_u and insensitive to the other parameters.

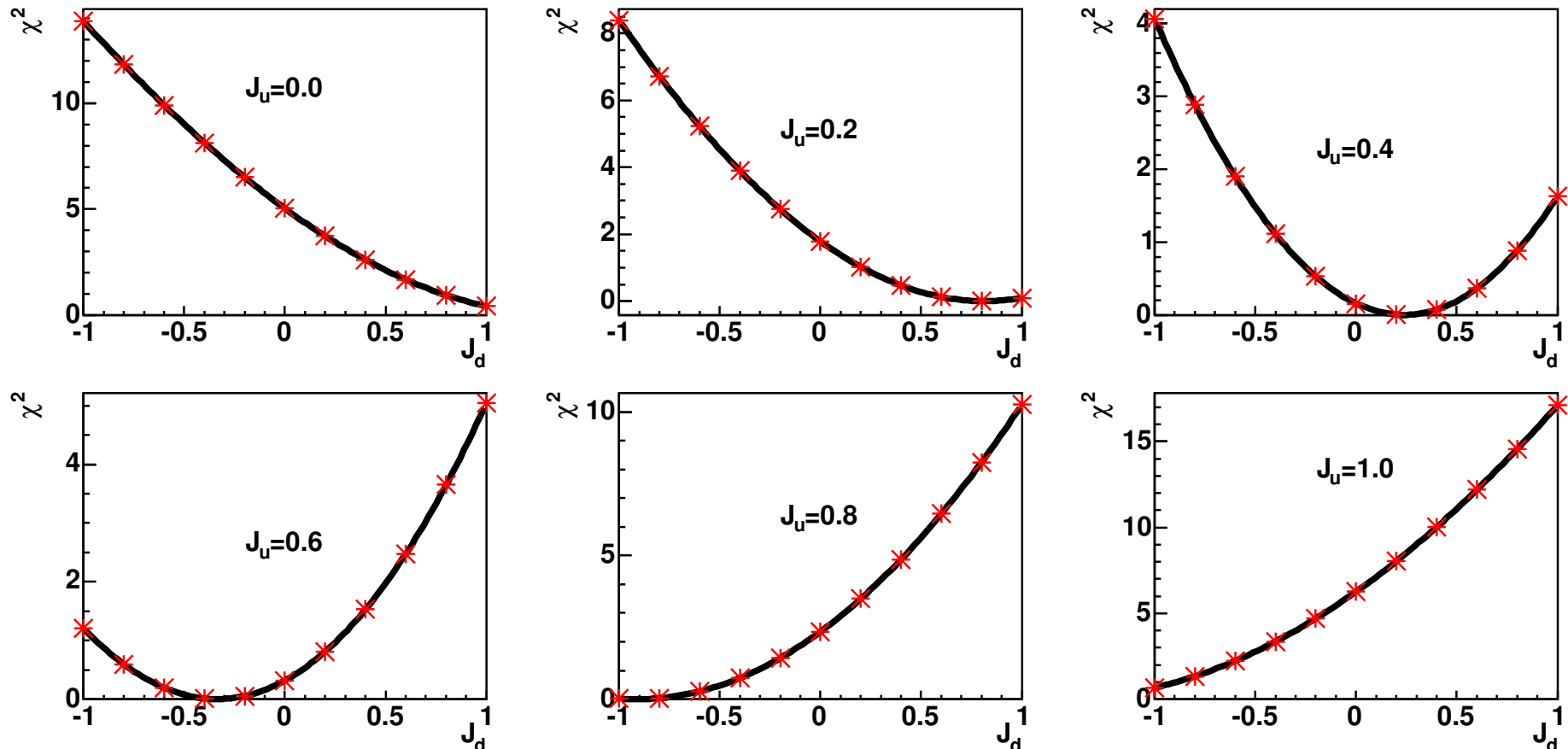
A Model-Dependent Constraint on J_u vs J_d

- In order to compare the theoretical predictions with the experimental results, calculate

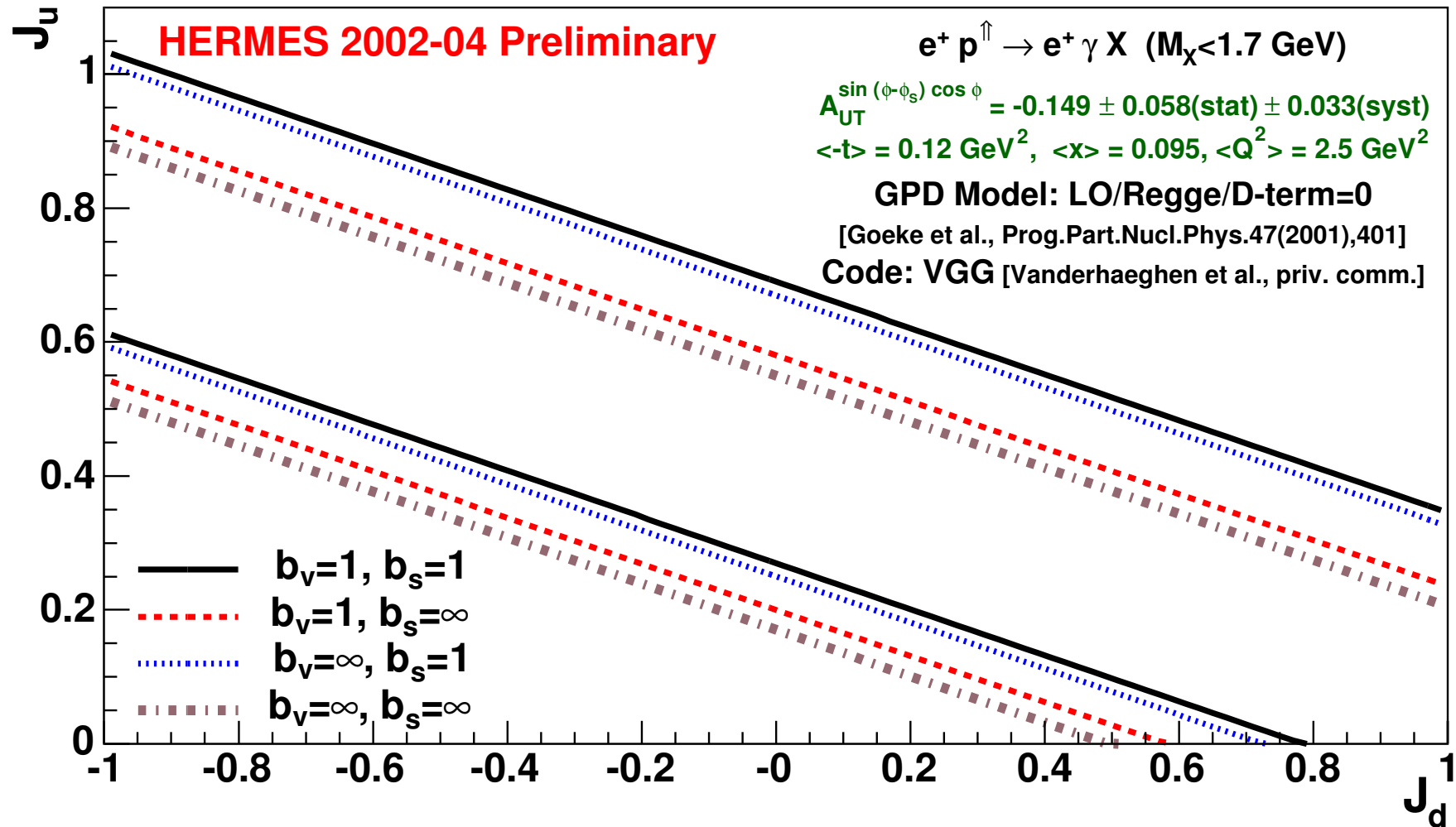
$$\chi_{exp}^2(J_u, J_d) = \frac{\left[A_{UT}^{\sin(\phi - \phi_S) \cos \phi} |_{exp} - A_{UT}^{\sin(\phi - \phi_S) \cos \phi} |_{VGG(J_u, J_d)} \right]^2}{\delta A_{stat}^2 + \delta A_{syst}^2}$$

in a step of 0.2 in J_u and J_d , and interpolate inbetween by a 5th order polynomial.

- The 1- σ constraint on J_u vs J_d is determined by $\chi^2(J_u, J_d) \leq \chi_{min}^2 + 1$.

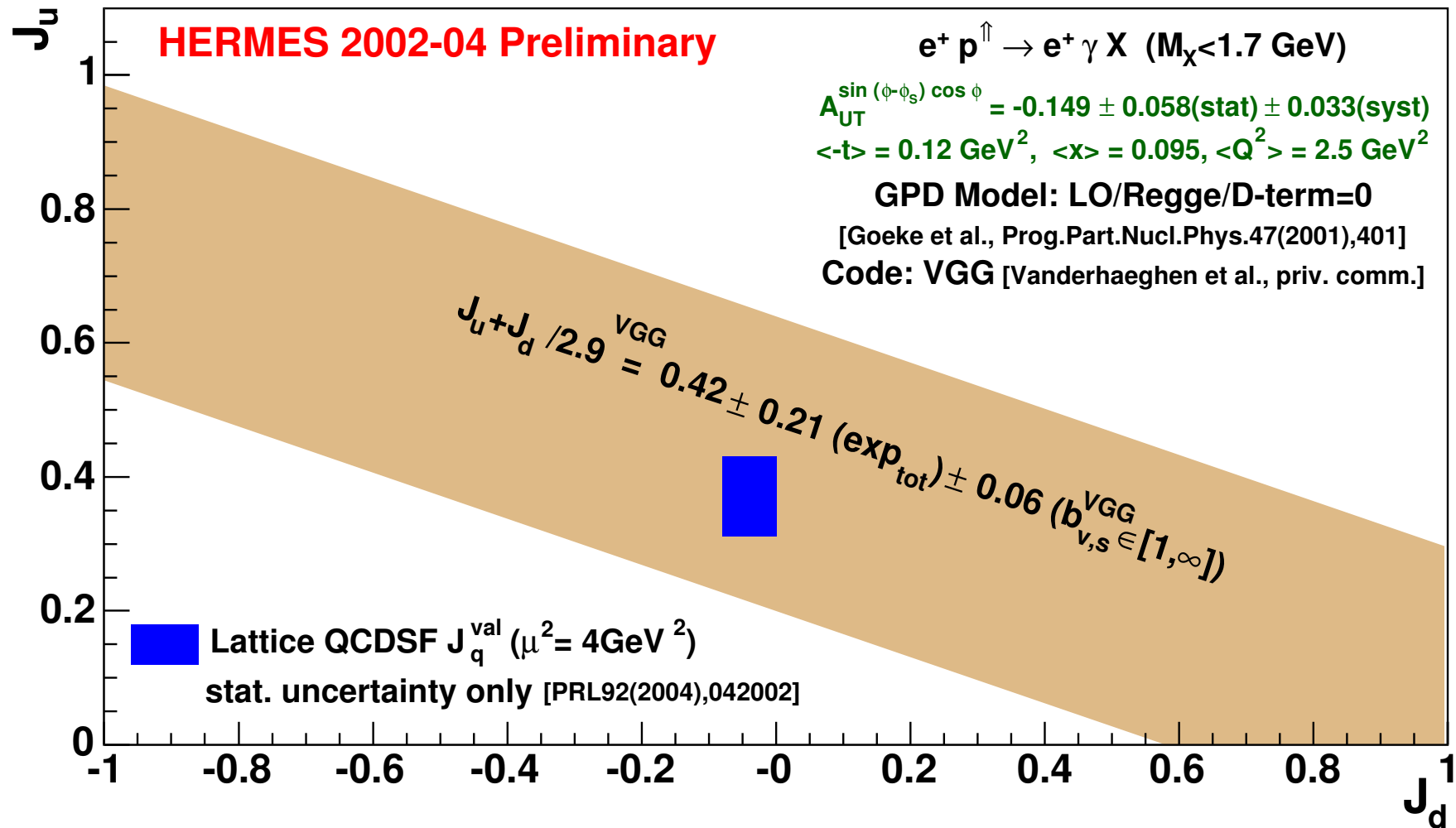


A Model-Dependent Constraint on J_u vs J_d



- The Regge ansatz is used to parameterize the t -dependence of the GPDs. The impact of using it or the factorized ansatz is found to be negligible (hep-ph/0506264).
- The D-term is set to zero, suggested by the HERMES results on the beam-charge asymmetry (hep-ex/0605108). If the D-term were modeled according to the χ QSM, the constraint on $J_u + J_d/2.9$ is shifted upwards by 0.11.

A Model-Dependent Constraint on J_u vs J_d



- The quenched Lattice calculation was done with the pion masses 1070, 870, and 640 MeV, and extrapolated linearly in m_π^2 to the physical value.

Summary and Outlook

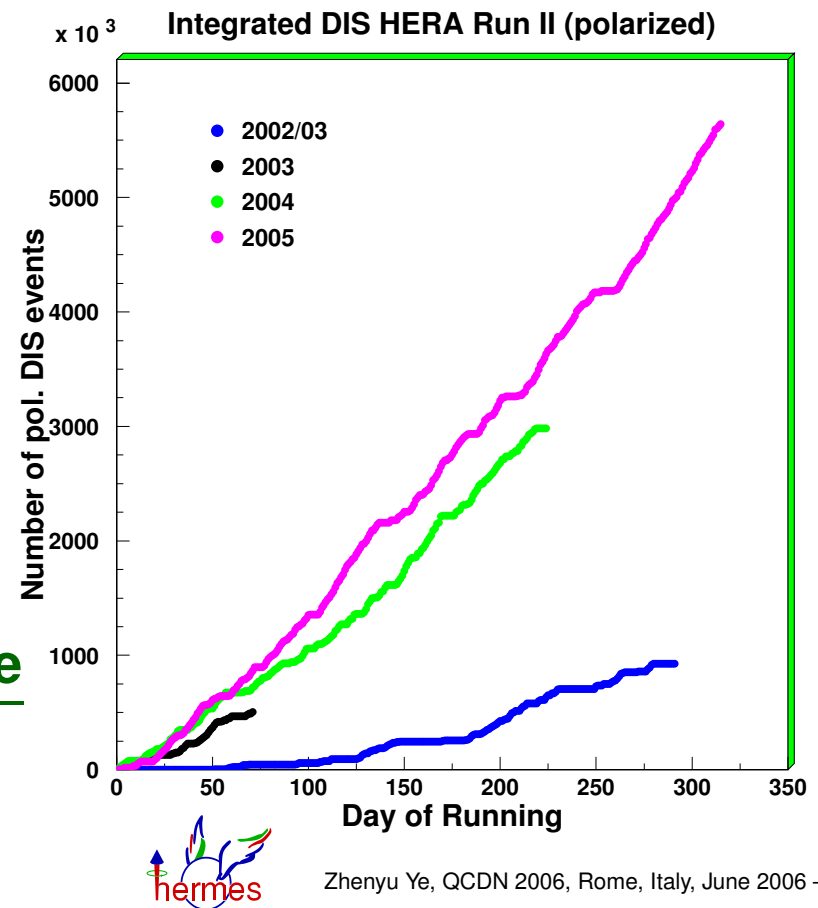
Summary

- The **TTSA associated with DVCS** on the proton has been firstly measured at HERMES. This asymmetry is sensitive to the GPD E and to the quark total angular momentum J_q .
- A model-dependent constraint on J_u vs J_d is obtained by comparing the HERMES result on the TTSA and the theoretical predications based on a GPD model.

Outlook

- At present, the uncertainty is dominated by the statistical one.
The situation will be improved after including the 2005 data:
the statistics will be doubled.

HERMES is aiming at providing a more complete picture of nucleon spin.

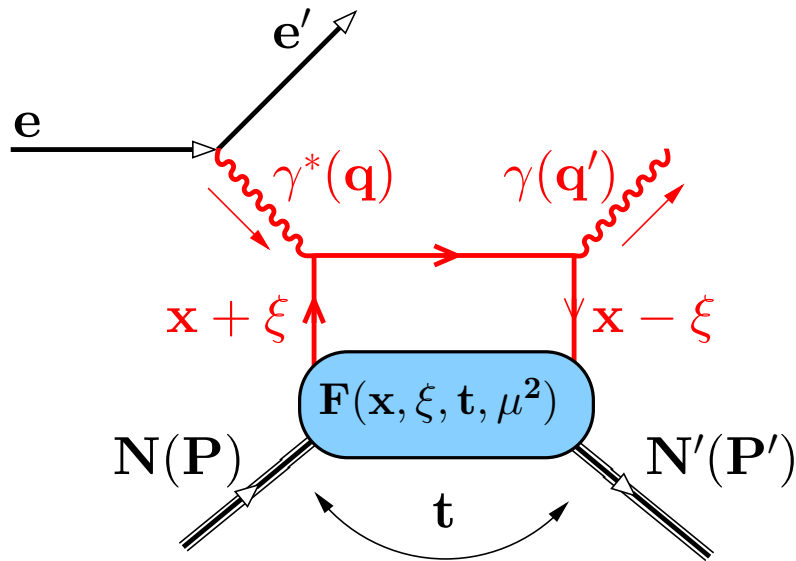


How to Study Generalized Parton Distributions

- GPDs are related to known quantities (parton densities, nucleon FFs):

in the forward limit:	$H_q(x, 0, 0, \mu^2) = q(x, \mu^2)$	E_q not measurable through DIS
nucleon FFs:	$\int_{-1}^1 dx H_q(x, \xi, t, \mu^2) = F_1^q(t)$	$\int_{-1}^1 dx E_q(x, \xi, t, \mu^2) = F_2^q(t)$

- GPDs enter in hard exclusive reactions, e.g., DVCS:



Kinematics:

$$Q^2 = -q^2,$$

$$t = (P - P')^2,$$

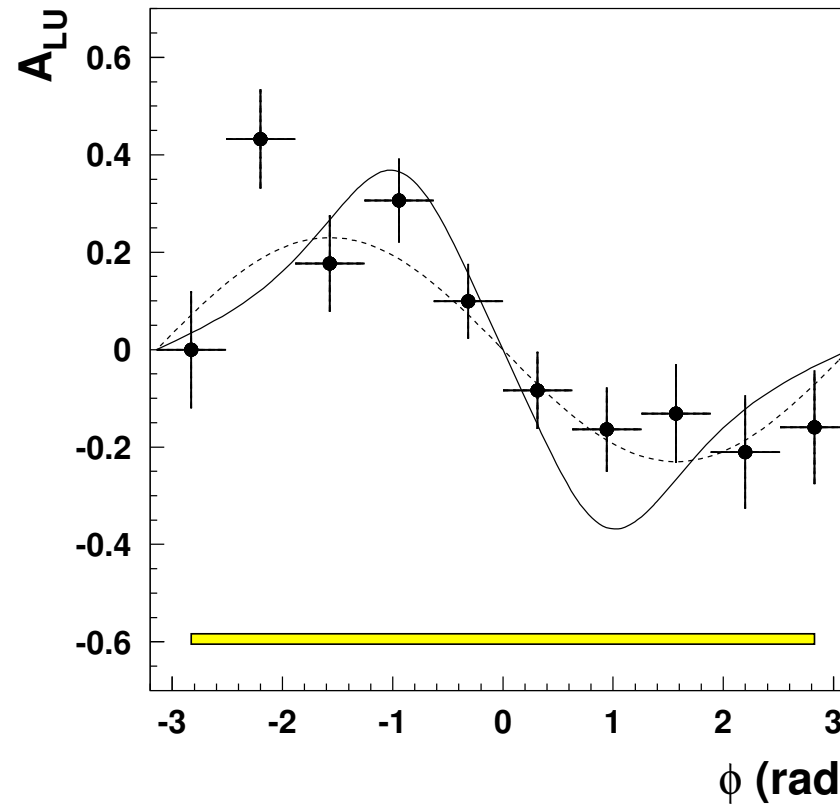
$$x_B = \frac{Q^2}{2Pq} \simeq \frac{2\xi}{1 + \xi}.$$

At large Q^2 , fixed x_B and t ,

$$A_{LO}^{\gamma^* p \rightarrow \gamma p} = \sum_q e_q^2 \int_{-1}^1 dx K_{\text{pert.}}(x, \xi, Q^2) F_q(x, \xi, t, Q^2).$$

- The Mellin moments in x of GPDs can be calculated in Lattice QCD.

Beam-Spin Asymmetry in DVCS

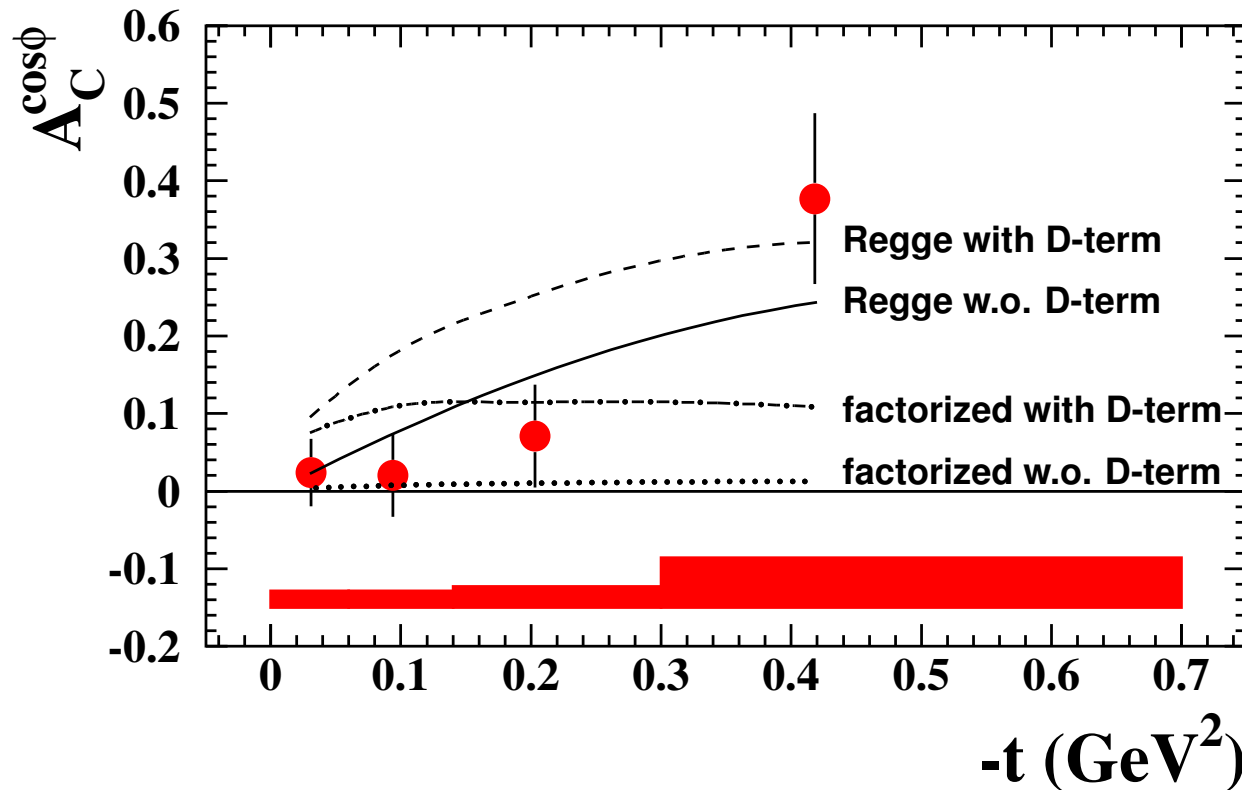


GPD Model: K. Goeke, M. V. Polyakov and M. Vanderhaeghen, *Prog. Part. Nucl. Phys.* **47** (2001) 401.

Beam-Spin Asymmetry: [HERMES, PRL 87 (2001) 182001]

$$A_{LU}(\phi) = \frac{1}{|P_B|} \cdot \frac{d\sigma(\vec{e}, \phi) - d\sigma(\overleftarrow{e}, \phi)}{d\sigma(\vec{e}, \phi) + d\sigma(\overleftarrow{e}, \phi)} \propto \text{Im} [F_1 \mathcal{H}] \cdot \sin \phi$$

Beam-Charge Asymmetry in DVCS



GPD Model: K. Goeke, M. V. Polyakov and M. Vanderhaeghen, *Prog. Part. Nucl. Phys.* **47** (2001) 401.

Beam-Charge Asymmetry: [HERMES, submitted to PRL, hep-ex/0605]

$$A_C(\phi) = \frac{d\sigma^+(\phi) - d\sigma^-(\phi)}{d\sigma^+(\phi) + d\sigma^-(\phi)} \propto \text{Re} [F_1 \mathcal{H}] \cdot \cos \phi$$