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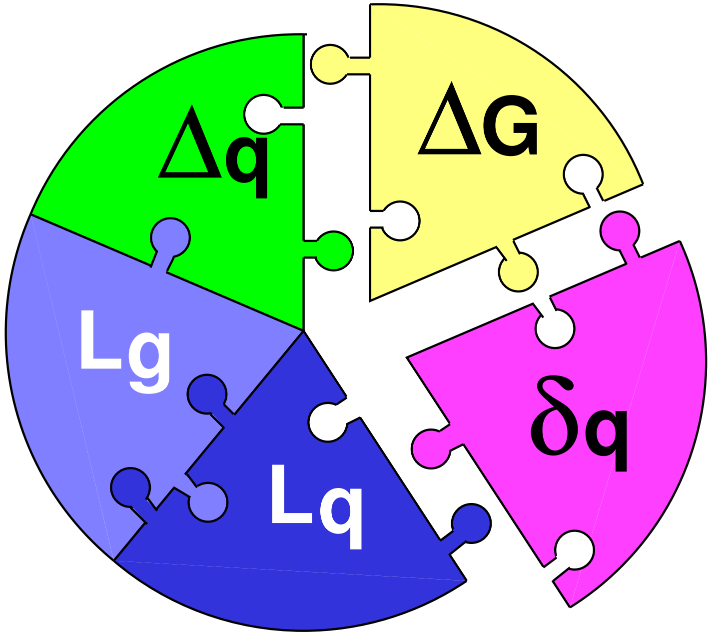
- Motivation: Spin Structure of the Nucleon from Generalized Parton Distributions
- Deeply Virtual Compton Scattering and Transverse Target-Spin Asymmetry
- The HERMES Experiment and the Preliminary Result on the TTSA
- A Model-Dependent Constraint on the Quark Total Angular Momenta in the Nucleon
-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

Motivation: Spin Structure of the Nucleon



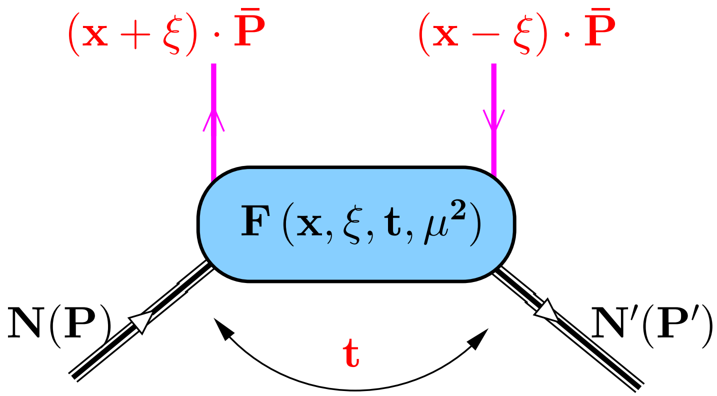
Nucleon Spin

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

$\Delta\Sigma \sim 20 - 35\%$:	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, $\widetilde{H}$, and $\widetilde{E}$:

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

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

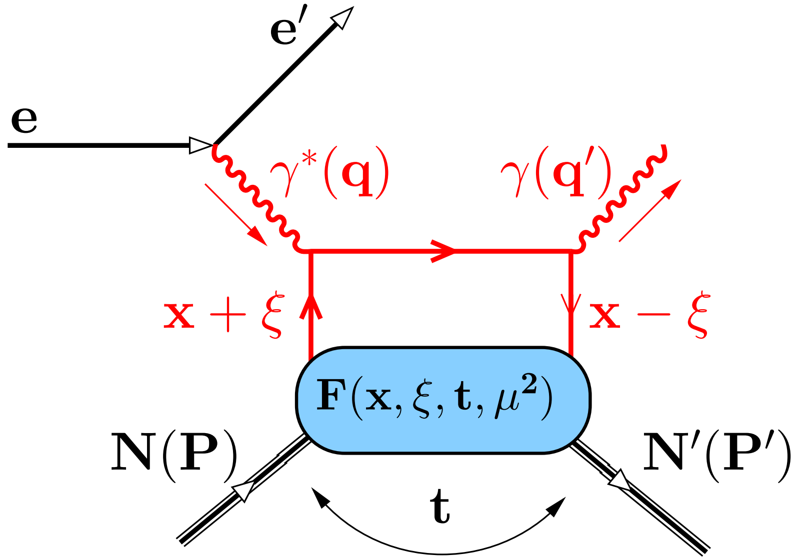
$$J_q(\mu^2)=\frac{1}{2}\lim_{t\to 0}\int_{-1}^{1} dx\, x[H_q(x,\xi,t,\mu^2)+E_q(x,\xi,t,\mu^2)].$$

How to Study Generalized Parton Distributions

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

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

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



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

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

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

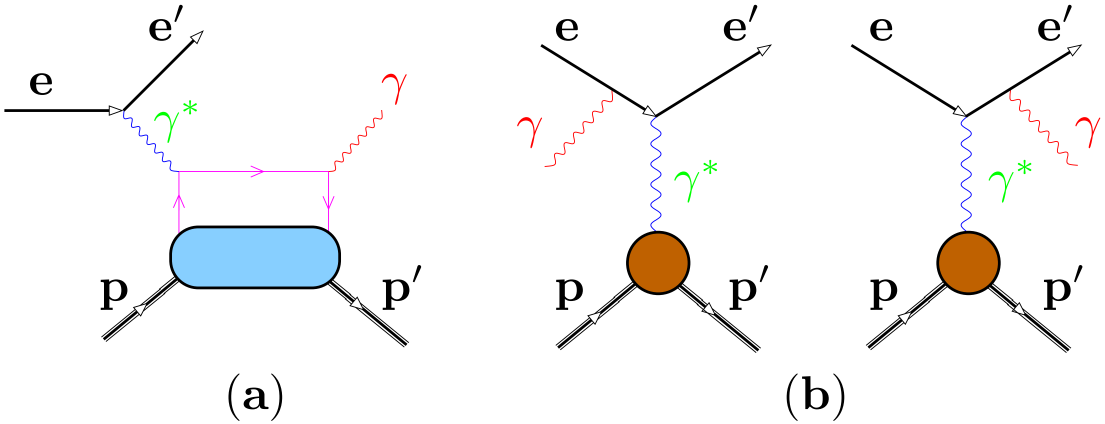
At large Q^2, fixed x_B and t,

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

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

Deeply Virtual Compton Scattering

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



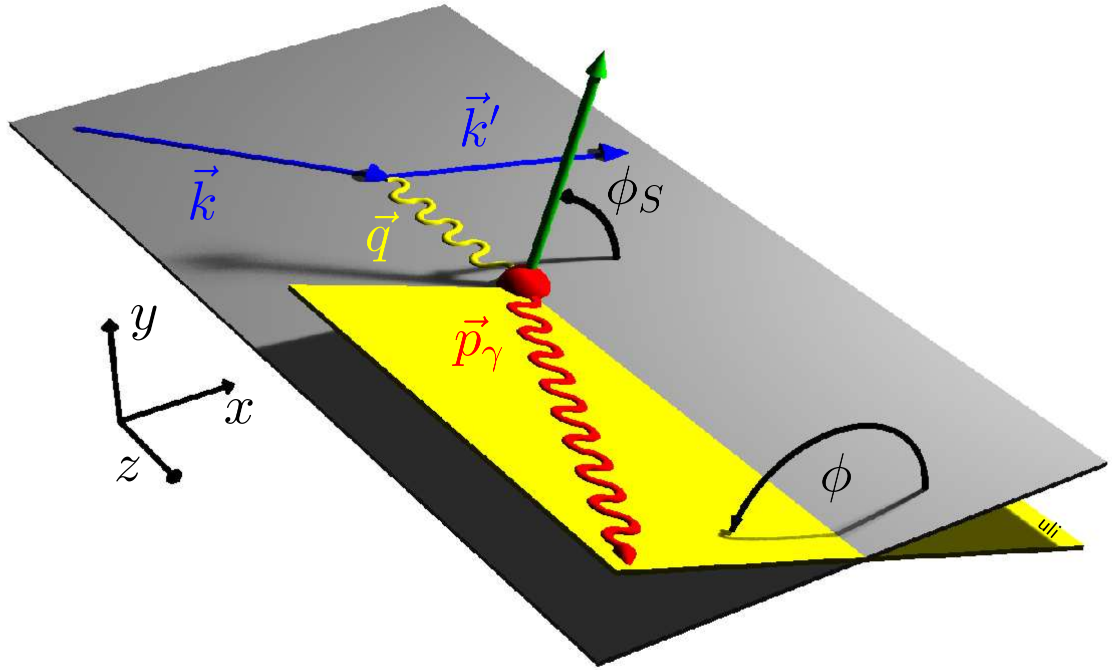
$$\sigma \propto \quad |\mathcal{T}_{\rm BH}|^2 + |\mathcal{T}_{\rm DVCS}|^2 + \underbrace{(\mathcal{T}_{\rm BH}\mathcal{T}^*_{\rm DVCS} + \mathcal{T}^*_{\rm BH}\mathcal{T}_{\rm DVCS})}_{I}$$

- $\mathcal{T}_{\rm BH}$ is parameterized in terms of nucleon FFs F_1 and F_2, calculable in QED.

- $\mathcal{T}_{\rm DVCS}$ is parameterized in terms of Compton FFs $\mathcal{H}$, $\mathcal{E}$, $\widetilde{\mathcal{H}}$, and $\widetilde{\mathcal{E}}$, which are convolutions of the respective GPDs with the hard-scattering kernels.

- At HERMES, $\mathcal{T}_{\rm BH} \gg \mathcal{T}_{\rm DVCS}$, $\mathcal{T}_{\rm DVCS}$ can be accessed through $\mathcal{I}$: both its amplitude and phase!

Transverse Target-Spin Asymmetry on the Proton



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

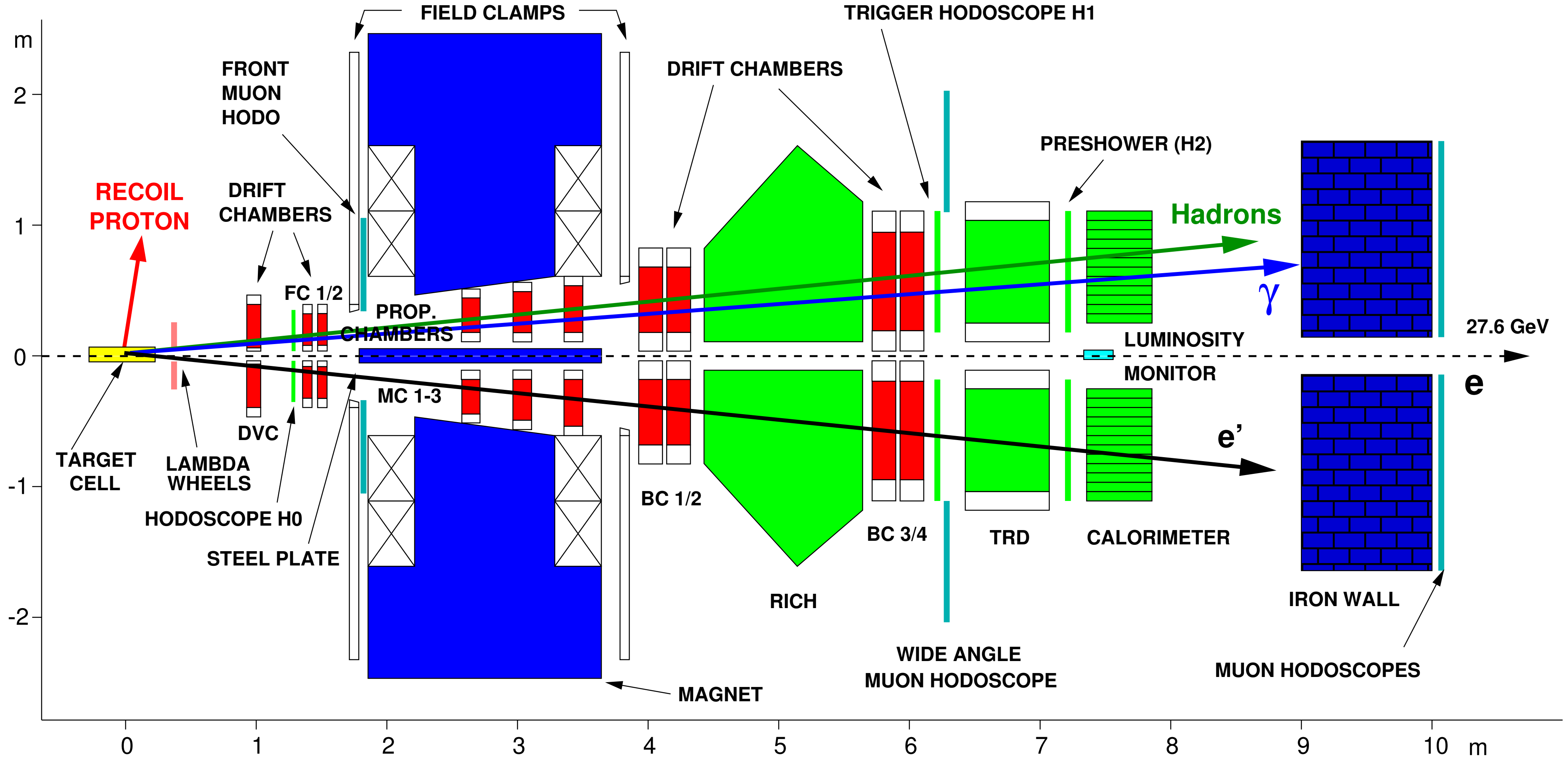
$$A_{UT}(\phi,\phi_s) = \frac{d\sigma(\phi,\phi_S) - d\sigma(\phi,\phi_S+\pi)}{d\sigma(\phi,\phi_S) + d\sigma(\phi,\phi_S+\pi)} \simeq \frac{\mathcal{I}^{\mathrm{TP}}}{\left|\mathcal{T}_{\mathrm{BH}}^{\mathrm{unp}}\right|^2}$$

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

$\Longrightarrow$ $\mathrm{A}_{\mathrm{UT}}^{\sin(\phi-\phi_{\mathrm{S}})\cos\phi}$ sensitive to $J_q = \frac{1}{2}\lim_{t\to 0}\int_{-1}^{1} dx\, x\,(H_q + E_q)$

The HERMES Experiment

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



The HERMES Experiment

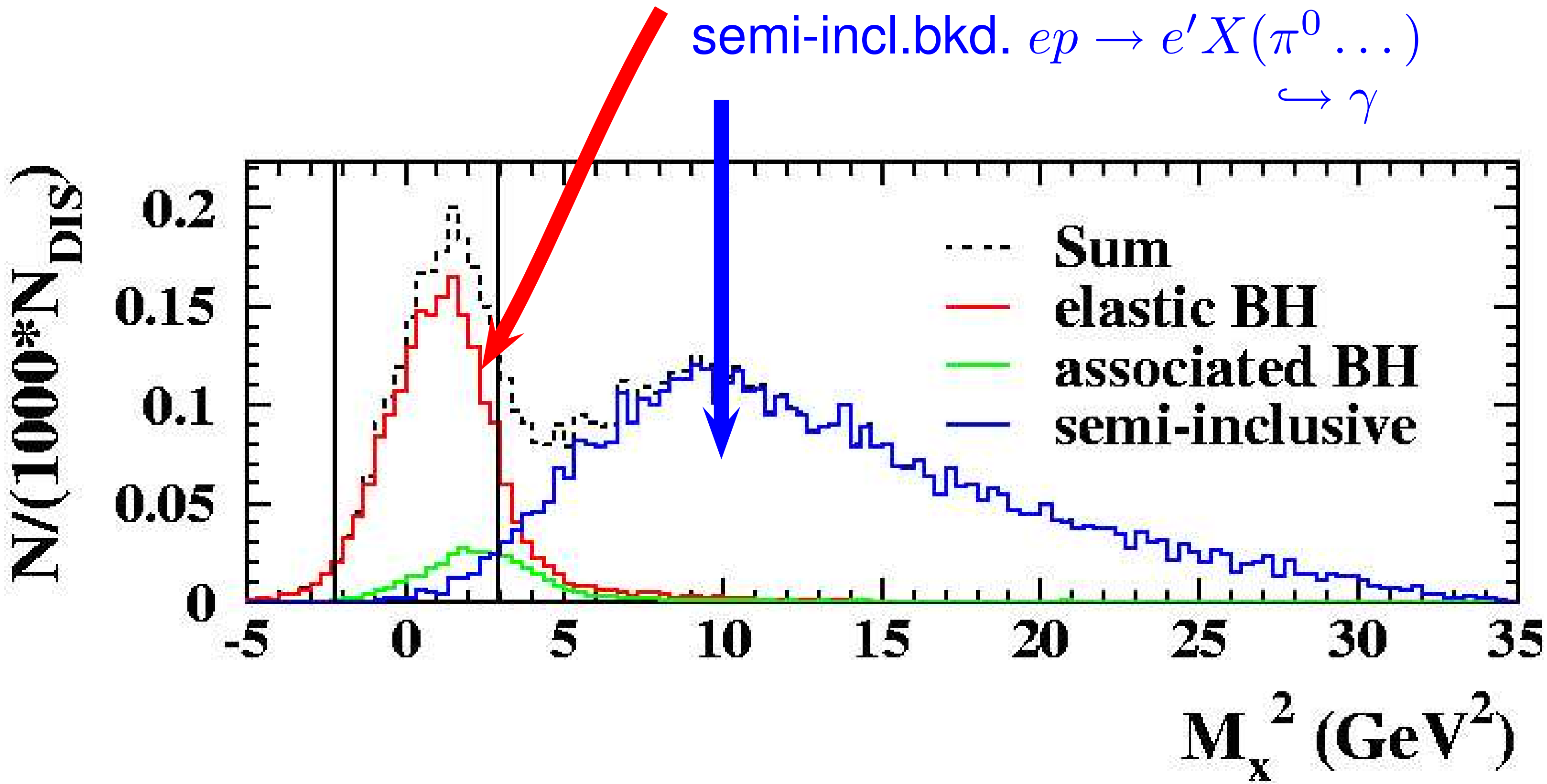
- Exclusivity of the measurement is maintained from the missing mass:

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

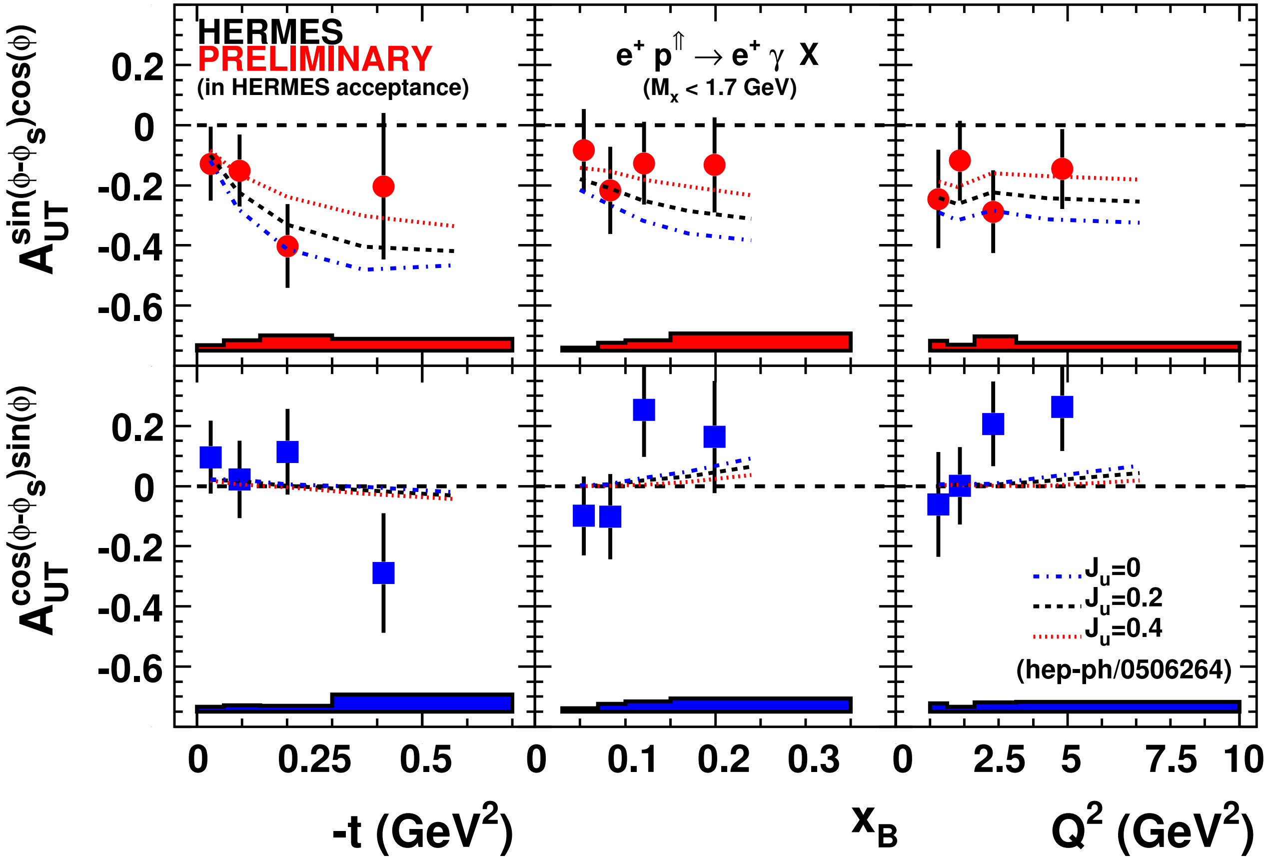
- Background contribution $\sim 5\%$ is determined from MC and corrected.

exclusive peak $ep \to e'p\gamma$

semi-incl.bkd. $ep \to e'X(\pi^0 \ldots)$ $\hookrightarrow \gamma$



Transverse Target-Spin Asymmetry from HERMES



$\propto \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}]$

$\propto \mathrm{Im}[F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}]$

- The presented result is based on the HERMES 2002-2004 data, $\int Ldt \simeq 60$ pb^{-1}:
  ~4 k events in $|t| < 0.7$ GeV^2, $0.03 < x_B < 0.35$, $1 < Q^2 < 10$ 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 χQSM 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 insensitve to the other parameters.

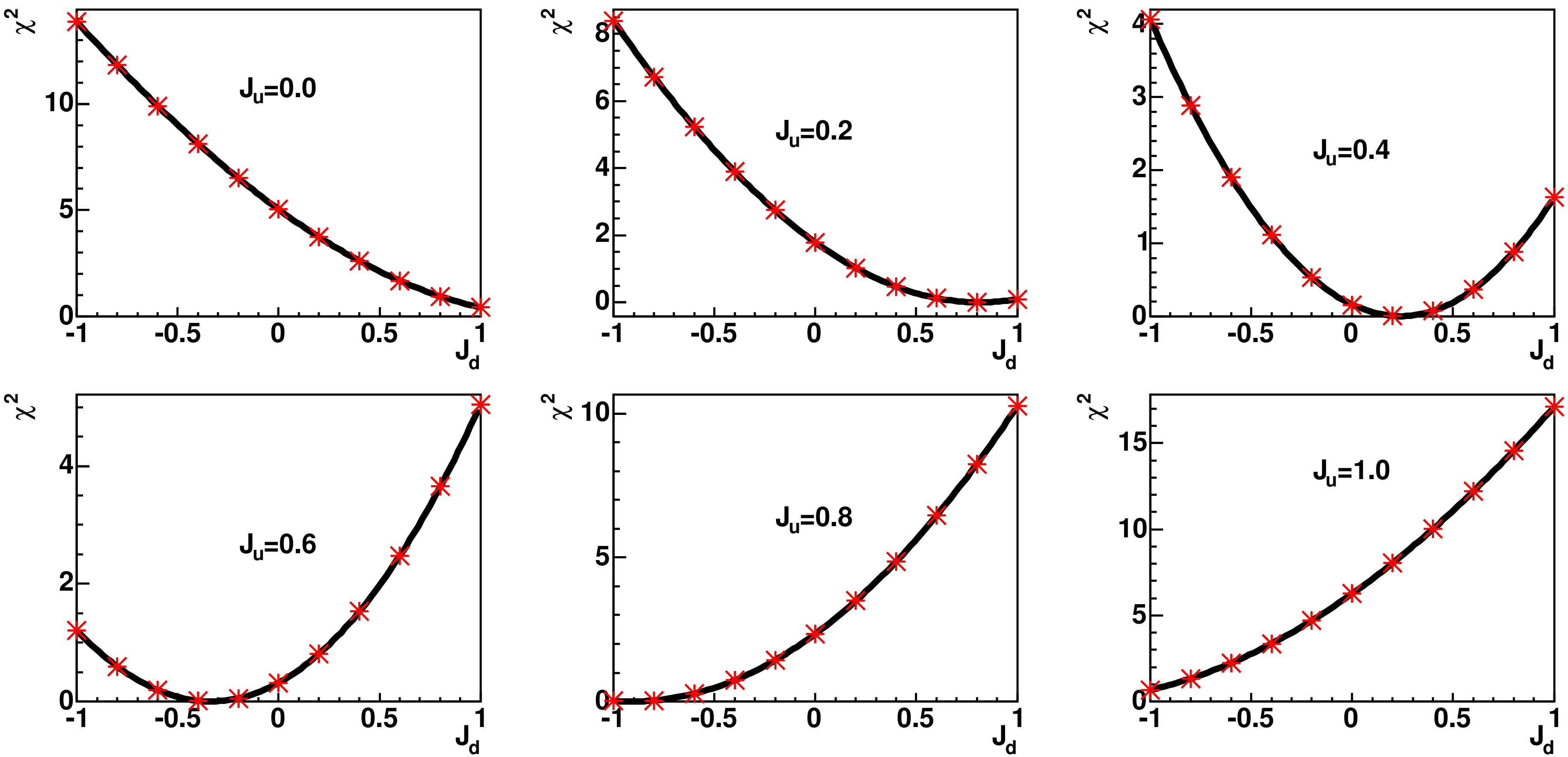
A Model-Dependent Constraint on J_u vs J_d

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

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

  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 $\chi^2(J_u, J_d) \leq \chi^2_{min} + 1$.



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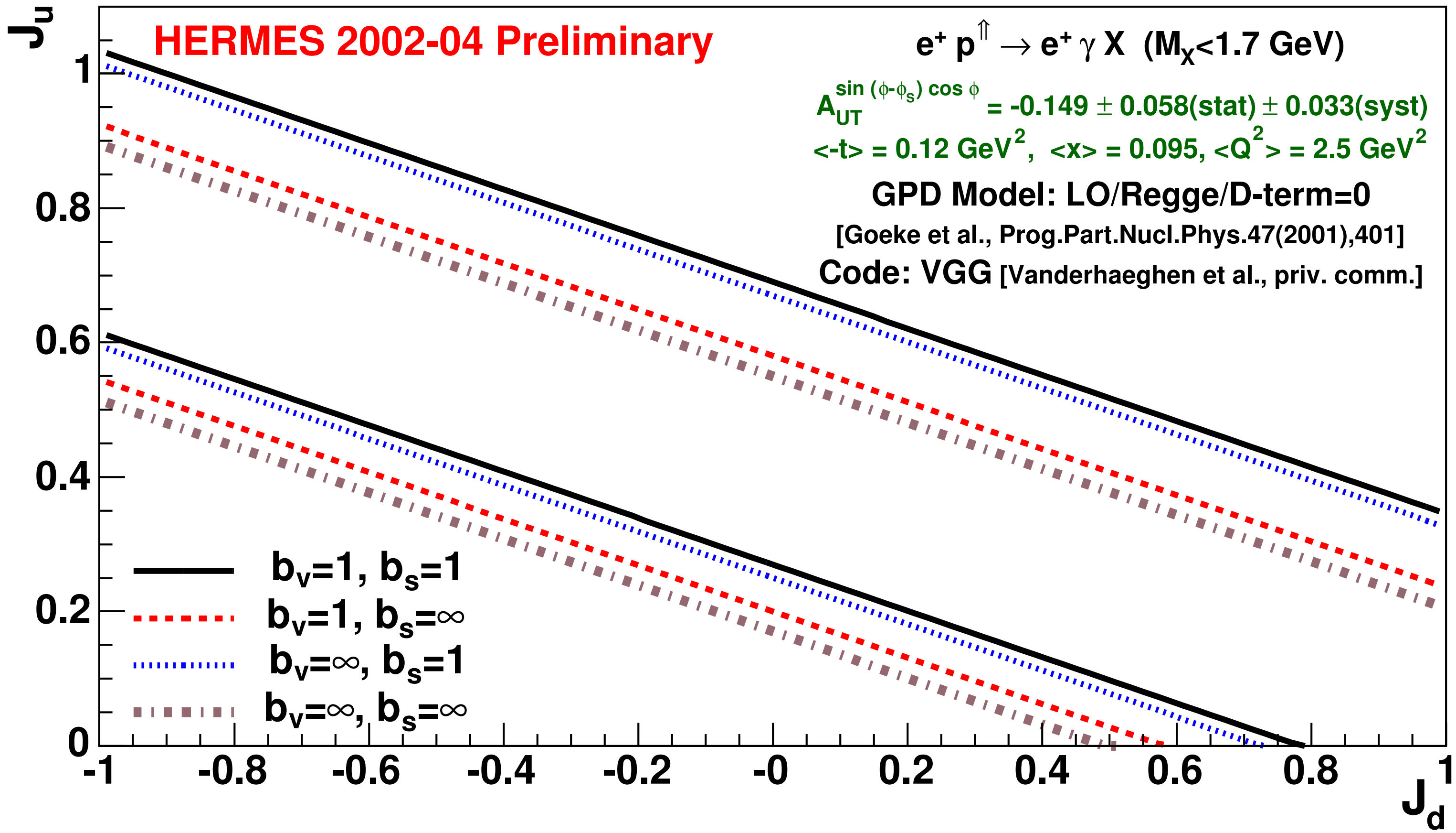

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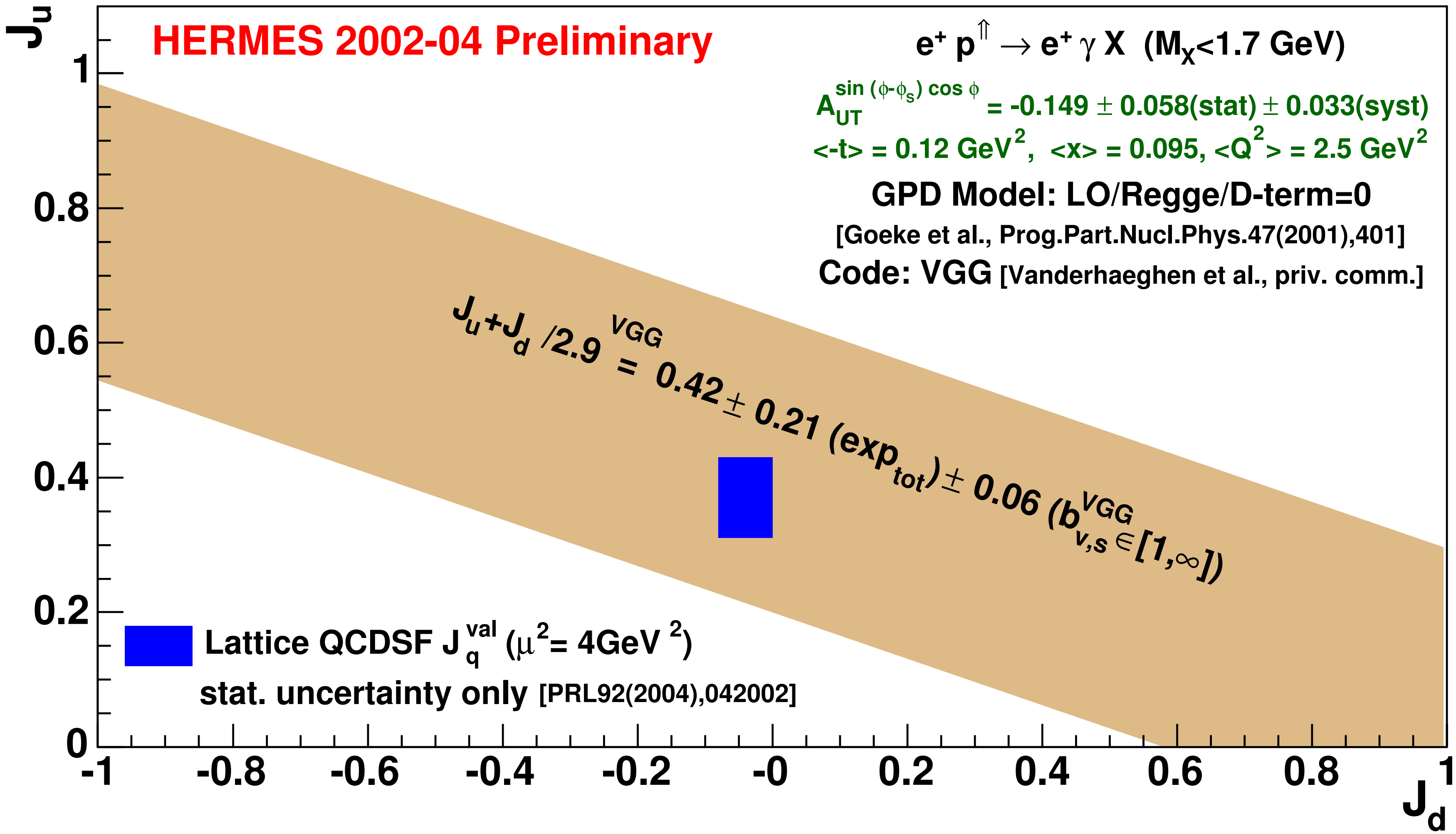

- The quenched Lattice calculation was done with the the pion masses 1070, 870, and 640 MeV, and extrapolated linearly in m_π^2 to the physical value.

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 theorectical 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.