Transverse Target-spin Asymmetry Associated with Deeply Virtual Compton Scattering on the Proton and a Resulting Model-Dependent Constraint on J_u and J_d

SPIN 2006, Kyoto Japan, Oct. 2-7 2006

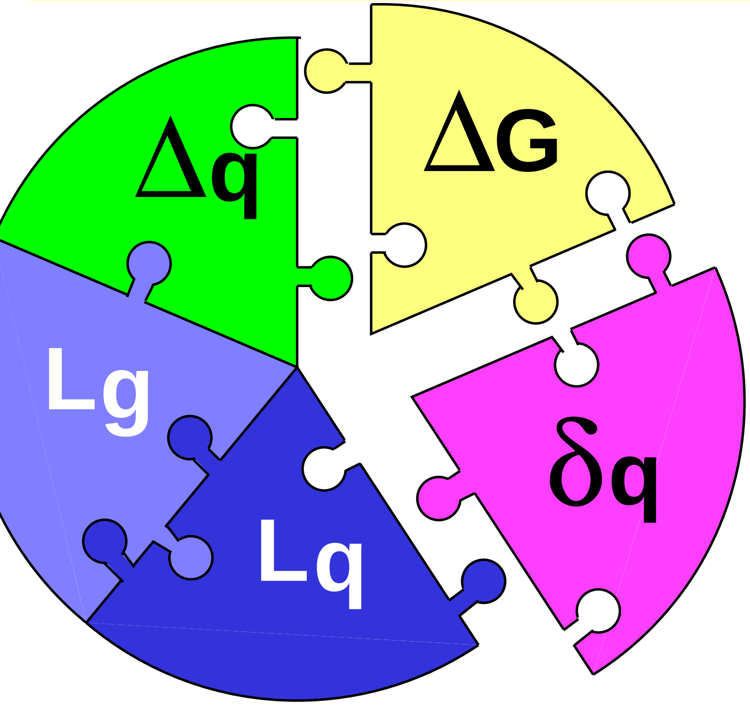
Wolf-Dieter Nowak, for the HERMES collaboration

DESY, D-15738 Zeuthen, Germany

Wolf-Dieter.Nowak@desy.de

- Motivation: Angular momentum structure of the nucleon
- Deeply Virtual Compton Scattering and transverse target-spin asymmetries
- u and d-quark total angular momentum
- Summary and outlook

The Angular Momentum Structure of the Nucleon



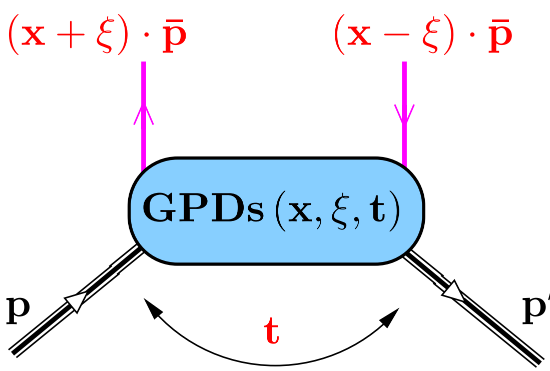
Proton Spin

$$\frac{1}{2} = \underbrace{\frac{1}{2}(\overbrace{\Delta u + \Delta d + \Delta s}^{\sim 20-30\%}) + L_q}_{J_q} + \underbrace{\Delta G + L_g}_{J_g}$$

Δq: well known from DIS & SIDIS

ΔG: COMPASS, HERMES: $\mathcal{O}(0.1)$

L_q, L_g: unknown!

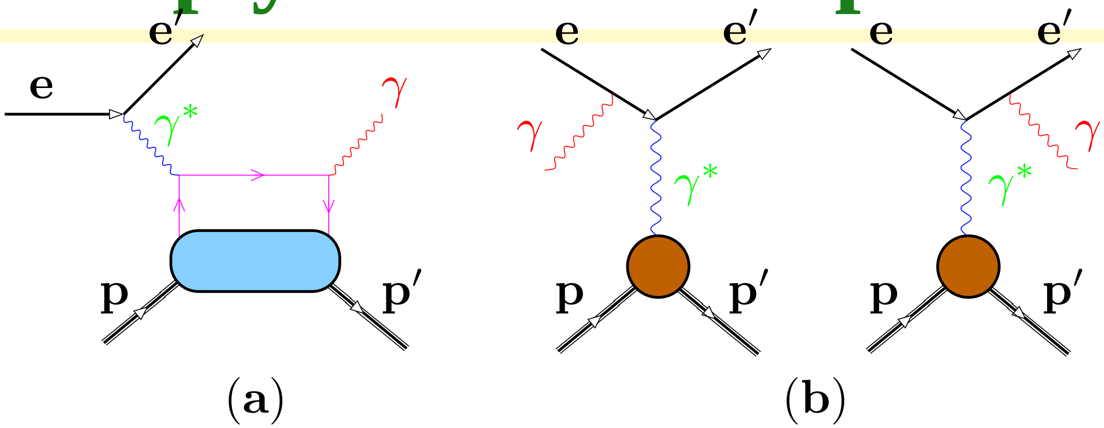


Generalized Parton Distributions $\Rightarrow J_q, J_g$

Ji's relation — Ji, PRL 78 (1997) 610

$$J_{q,g} = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} dx \cdot x \cdot [H_{q,g}(x, \xi, t) + E_{q,g}(x, \xi$$

Deeply Virtual Compton Scattering



- Same final state in DVCS and Bethe-Heitler $\Rightarrow$ Interference!

$$d\sigma(\mathrm{eN} \to \mathrm{eN}\gamma) \propto |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \underbrace{\mathcal{T}_{BH}\mathcal{T}^*_{DVCS} + \mathcal{T}^*_{BH}\mathcal{T}_{DVCS}}_{\mathcal{I}}$$

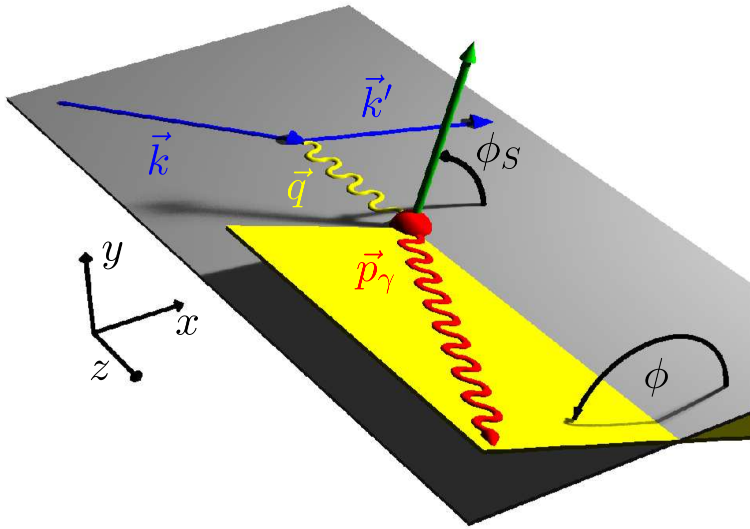
- $\mathcal{T}_{BH}$ is parameterized in terms of Dirac and Pauli Form Factors F_1, F_2, and calculable in QED.
- $\mathcal{T}_{DVCS}$ is parameterized in terms of Compton form factors $\mathcal{H}, \mathcal{E}, \widetilde{\mathcal{H}}, \widetilde{\mathcal{E}}$ (which are convolutions of resp. GPDs $H, E, \widetilde{H}, \widetilde{E}$)
- (Certain Parts of) interference term can be filtered out by forming certain cross section differences (or asymmetries)

$\Rightarrow$ GPDs $H, E, \widetilde{H}, \widetilde{E}$ **indirectly** accessible via interference term $\mathcal{I}$

Azimuthal Asymmetries in DVCS

Interference term $\mathcal{I}$ induces azimuthal asymmetries in cross-sectio

- Beam-charge asymmetry $A_C(\phi)$:
  $d\sigma(e^+,\phi) - d\sigma(e^-,\phi) \propto \mathrm{Re}[F_1\mathcal{H}] \cdot \cos\phi$
- Beam-spin asymmetry $A_{LU}(\phi)$:
  $d\sigma(\overrightarrow{e},\phi) - d\sigma(\overleftarrow{e},\phi) \propto \mathrm{Im}[F_1\mathcal{H}] \cdot \sin\phi$
- Long. target-spin asymmetry $A_{UL}(\phi)$:
  $d\sigma(\overset{\Leftarrow}{P},\phi) - d\sigma(\overset{\Rightarrow}{P},\phi) \propto \mathrm{Im}[F_1\widetilde{\mathcal{H}}] \cdot \sin\phi$



- Transverse target-spin asymmetry $A_{UT}(\phi,\phi_s)$ [TTSA]:

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

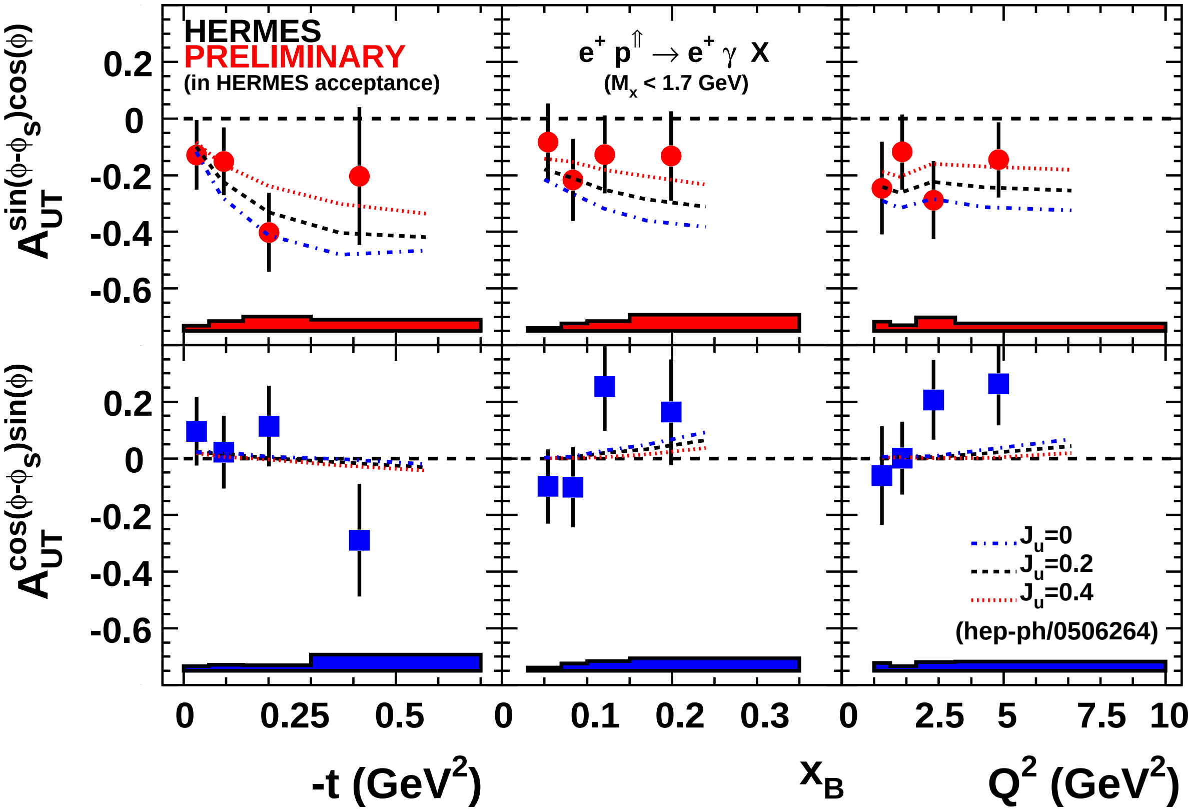
$\Rightarrow$ TTSA is the only asymmetry where $\mathcal{E}$ enters in leading order

As models for $\mathcal{E}$ depend on $J_q \Longrightarrow \mathrm{A}_{\mathrm{UT}}^{\sin(\phi-\phi_S)\cos\phi}$ is sensitive to J

Why TTSA Data are Expected to be Sensitive to J_u

- **ANSATZ** for spin-flip Generalized Parton Distribution E:
  - Factorized ansatz for spin-flip quark GPDs: $E_q(x,\xi,t) = \frac{E_q(x,\xi)}{(1-t/0.71)^2}$
  - t-indep. part via double distribution ansatz: $E_q(x,\xi) = E_q^{DD}(x,\xi) - \theta(\xi - |x|) D_q\left(\frac{x}{\xi}\right)$
  - double distribution: $E_q^{DD}(x,\xi) = \int\limits_{-1}^{1} d\beta \int\limits_{-1+|\beta|}^{1-|\beta|} d\alpha\, \delta(x-\beta-\alpha\xi)\, K_q(\beta,\alpha)$
  - with $K_q(\beta,\alpha) = h(\beta,\alpha)\ e_q(\beta)$ and $e_q(x) = A_q q_{val}(x) + B_q \delta(x)$ based on chiral QSM
  - where coeffi cients A, B constrained by Ji relationand $\int\limits_{-1}^{+1} dx\ e_q(x) = \kappa_q$
  - A_q, B_u, B_d are functions of $J_u, J_d \Rightarrow J_u, J_d$ **are free parameters when calculating TTSA**
- **PROJECTIONS [F. Ellinghaus et al., hep-ph/0506264, subm. to EPJC]**:
  - based on 8M DIS events at HERMES; $J_d = 0$ assumed (u-quark dominance)
  - almost no sensitivity to GPD model parameters found !!!
  - $A_{UT}(\phi-\phi_S) = \frac{d\sigma(\phi-\phi_S) - d\sigma(\phi-\phi_S+\pi)}{d\sigma(\phi-\phi_S)+d\sigma(\phi-\phi_S+\pi)} \simeq$
    $A_{UT}^{\sin(\phi-\phi_S)\cos\phi} \cdot \sin(\phi-\phi_S)\cos\phi + A_{UT}^{\cos(\phi-\phi_S)\sin\phi} \cdot \cos(\phi-\phi_S)\sin\phi$
    with $A_{UT}^{\sin(\phi-\phi_S)\cos\phi} \simeq \mp \frac{t}{4M^2} \cdot \frac{f(x_B,y,Q^2)}{c_{0,unp}^{BH}} Im\left[F_2\mathcal{H} - F_1\mathcal{E}\right] \Leftarrow$ sensitive to GPD E !!!
    and $A_{UT}^{\cos(\phi-\phi_S)\sin\phi} \simeq \mp \frac{t}{4M^2} \cdot \frac{f(x_B,y,Q^2)}{c_{0,unp}^{BH}} Im\left[F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}\right] \Leftarrow$ insensitive to GPD E

DVCS TTSA: HERMES Data vs. Predictions



$$A_{UT}(\phi,\phi_S) = \frac{1}{\langle|P_T|\rangle} \cdot \frac{d\sigma(\phi,\phi_S)-d\sigma(\phi,\phi_S+\pi)}{d\sigma(\phi,\phi_S)+d\sigma(\phi,\phi_S+\pi)}$$

$$= A_{UT}^{\sin(\phi-\phi_S)\cos\phi} \cdot \sin(\phi-\phi_S)\cos\phi + A_{UT}^{\cos(\phi-\phi_S)\sin\phi} \cdot \cos(\phi-\phi_S)\sin\phi$$

HERMES $e^+p^\Uparrow$ 2002-04:

- U: unpolarized beam
- T: transv. pol. target
- ca. 50% of total stat.
- [2004-05 data: $e^-p^\Uparrow$]

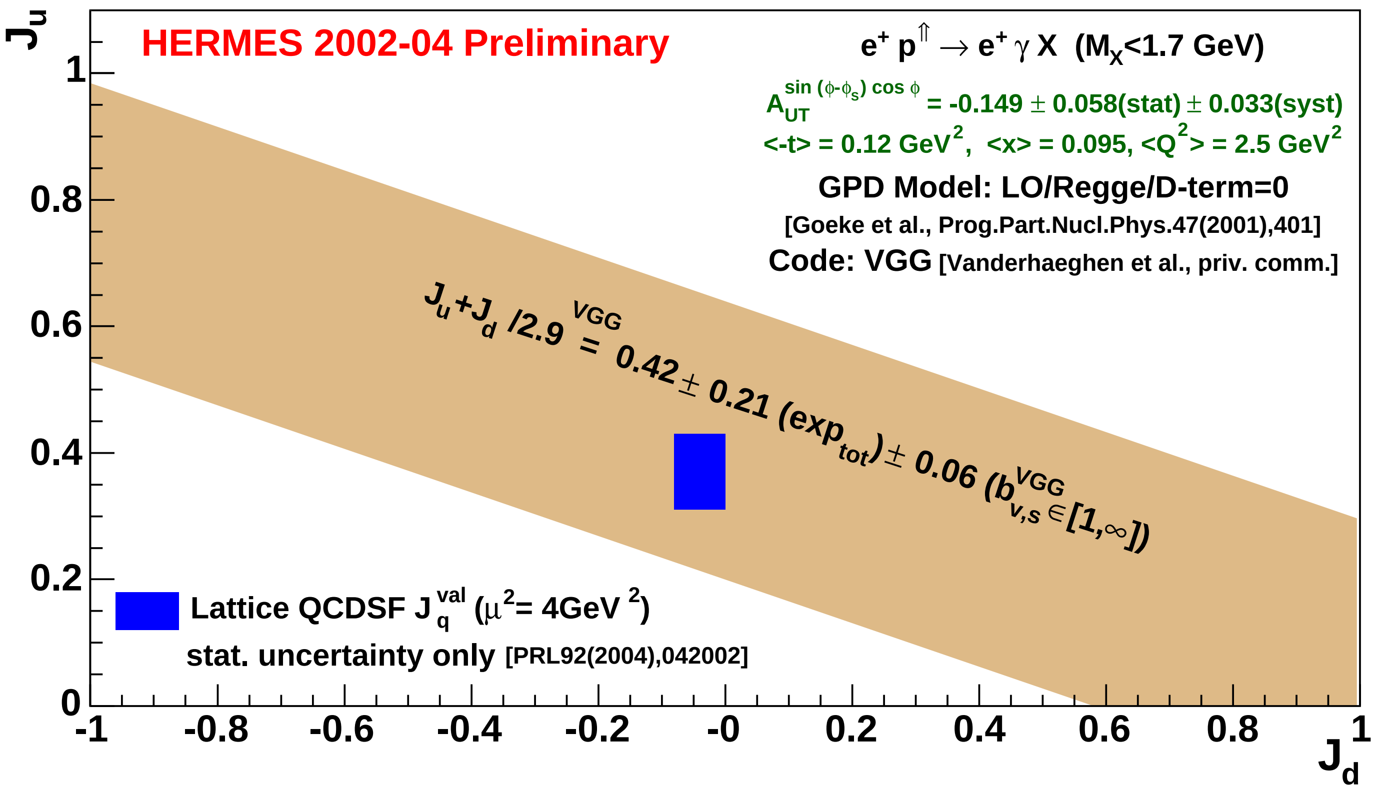
STUDY sensitivity to J_u (with $J_d = 0$) [hep-ph/0506264, based on Prog.Part.Nucl.Phys.47]:

- $A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$ found sensitive to J_u, while $A_{UT}^{\cos(\phi-\phi_S)\sin\phi}$ is not
- only weak sensitivity found to other GPD model parameters

(profi le parameters, Regge/factorized ansatz for t-dependence)

Model-dependent Constraint on J_u vs J_d

Unbinned maximum likelihood fit to $A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$ at average kinematics (fitting prel. HERMES data against VGG-model based calculations), leaving J_u and J_d as free parameters $\Rightarrow$ model-dependent 1-σ constraint on J_u vs. J_d:



- Quenched lattice calculation done with pion masses 1070, 870, and 640 MeV, and then extrapolated linearly in m_π^2 to the physical value
- Uncertainties on VGG model parameters shown as separate uncertainty (± 0.06)

Summary and Outlook

- ▷ Preliminary HERMES data available on transverse target-spin asymmetries (TTSAs) in Deeply Virtual Compton Scattering

- ▷ Significantly non-zero $\sin(\phi - \phi_S)\cos\phi$ amplitude seen

- ▷ For the first time (model-dependent) constraint on u and d-quark total angular momentum obtained (preliminary):

  $J_u + J_d/2.9 \approx 0.42 \pm 0.21$(exp-tot)$\pm 0.06$(models)

- ▷ Final statistics expected to be a factor of 2 higher