# Access to u-quark Total Angular Momentum

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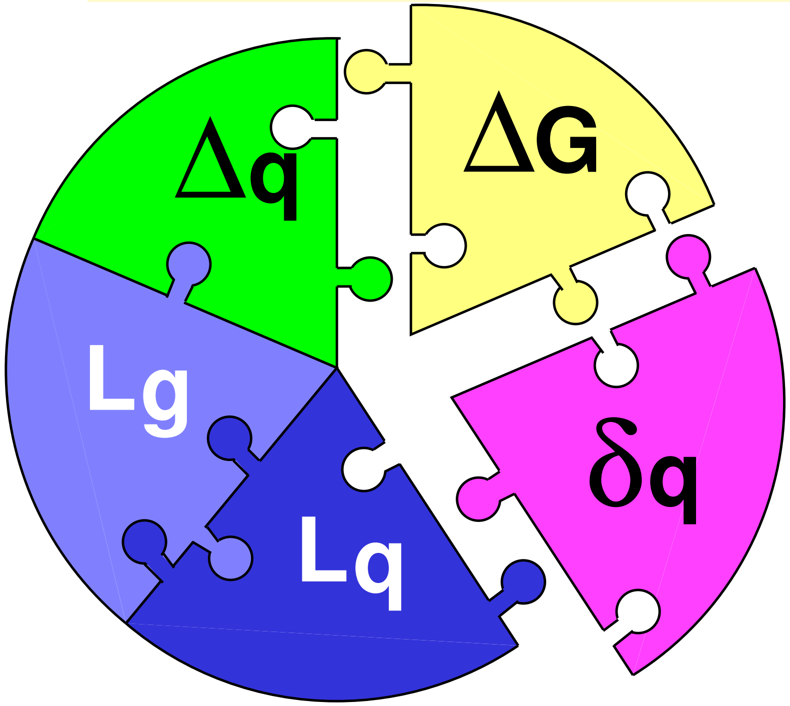
- Motivation: Angular momentum structure of the nucleon
- Deeply Virtual Compton Scattering and transverse target-spin asymmetries
- Access to $u$-quark total angular momentum
- Comparison to HERMES DVCS and exclusive $\rho^0$ data
- Summary and outlook

# The Angular Momentum Structure of the Nucleon



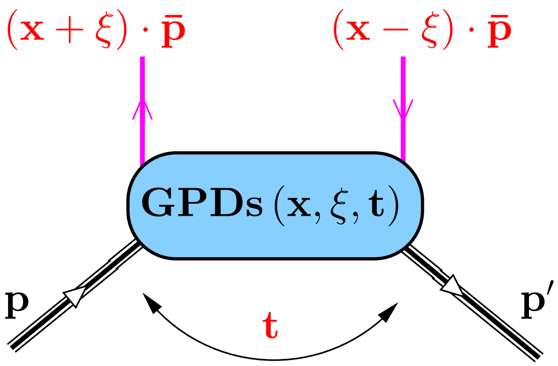

## Proton Spin

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

$\Delta q$: well known from DIS & SIDIS

$\Delta G$: first indications from DIS

$L_q$, $L_g$: unknown!

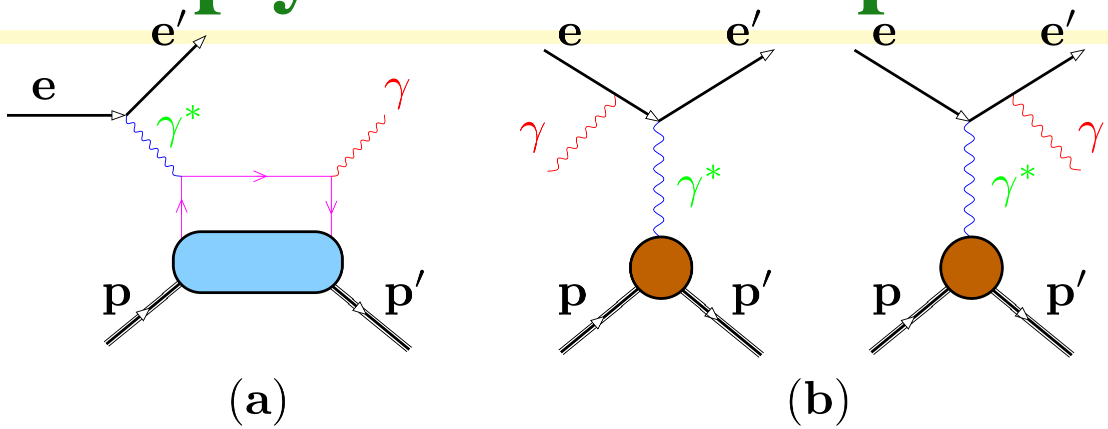



Generalized Parton Distributions $\Rightarrow J_q,\, J_g$

## Ji's relation — Ji, PRL 78 (1997) 610

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

# Deeply Virtual Compton Scattering




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

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

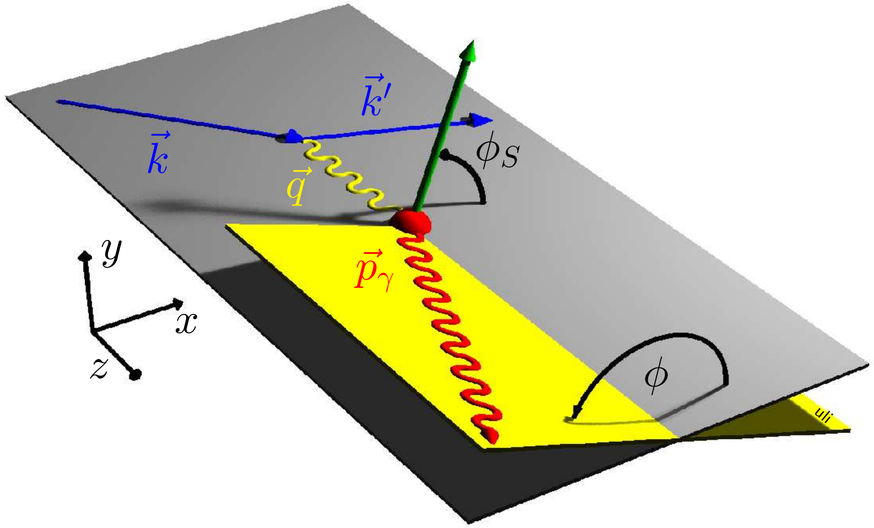
- $\mathcal{T}_{BH}$ is parameterized in terms of Dirac and Pauli Form Factors $F_1, F_2$, calculable in QED.
- $\mathcal{T}_{DVCS}$ is parameterized in terms of Compton form factors $\mathcal{H}, \mathcal{E}, \widetilde{\mathcal{H}}, \widetilde{\mathcal{E}}$ (which are convolutions of resp. GPDs $H, E, \widetilde{H}, \widetilde{E}$)
- (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-section:

- 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 $J_q$ !

($F_1, F_2$ are the Dirac and Pauli form factors, calculable in QED)

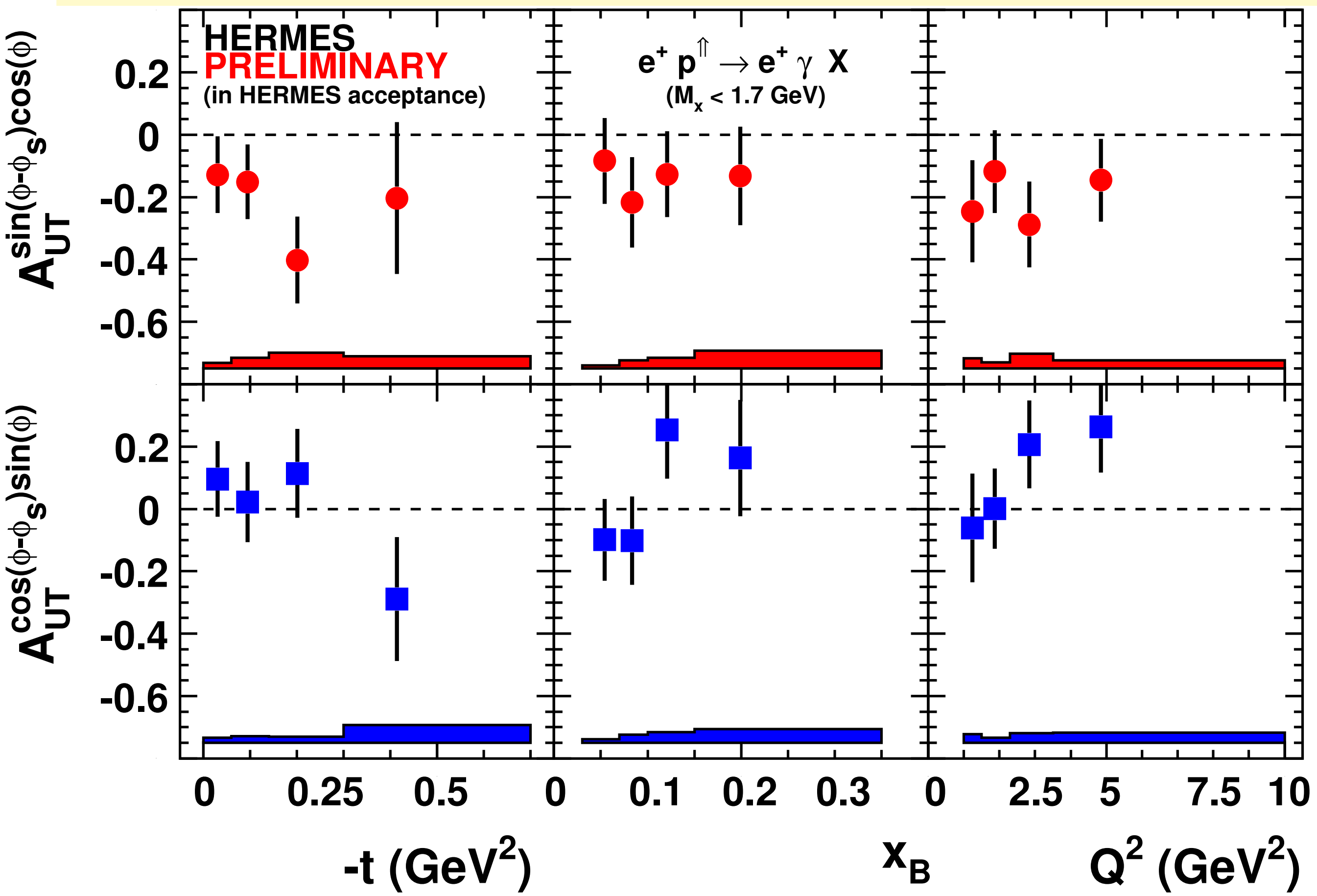
# Why TTSA Data are Expected to be Sensitive to $J_u$ ?

- **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 coefficients $A, B$ constrained by Ji relation and $\int\limits_{-1}^{+1} dx\ e_q(x) = \kappa_q$
  - $A_q, B_u, B_d$ 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: Preliminary HERMES Data




Exclusive events:

$$
\begin{array}{rcl}
5 < & \theta_{\gamma^*\gamma} & < 45\ mrad \\
-1.5 < & M_x & < 1.7\ GeV \\
 & -t_c & < 0.7\ GeV \\
0.03 < & x_B & < 0.35 \\
1 < & Q^2 & < 10\ GeV^2
\end{array}
$$

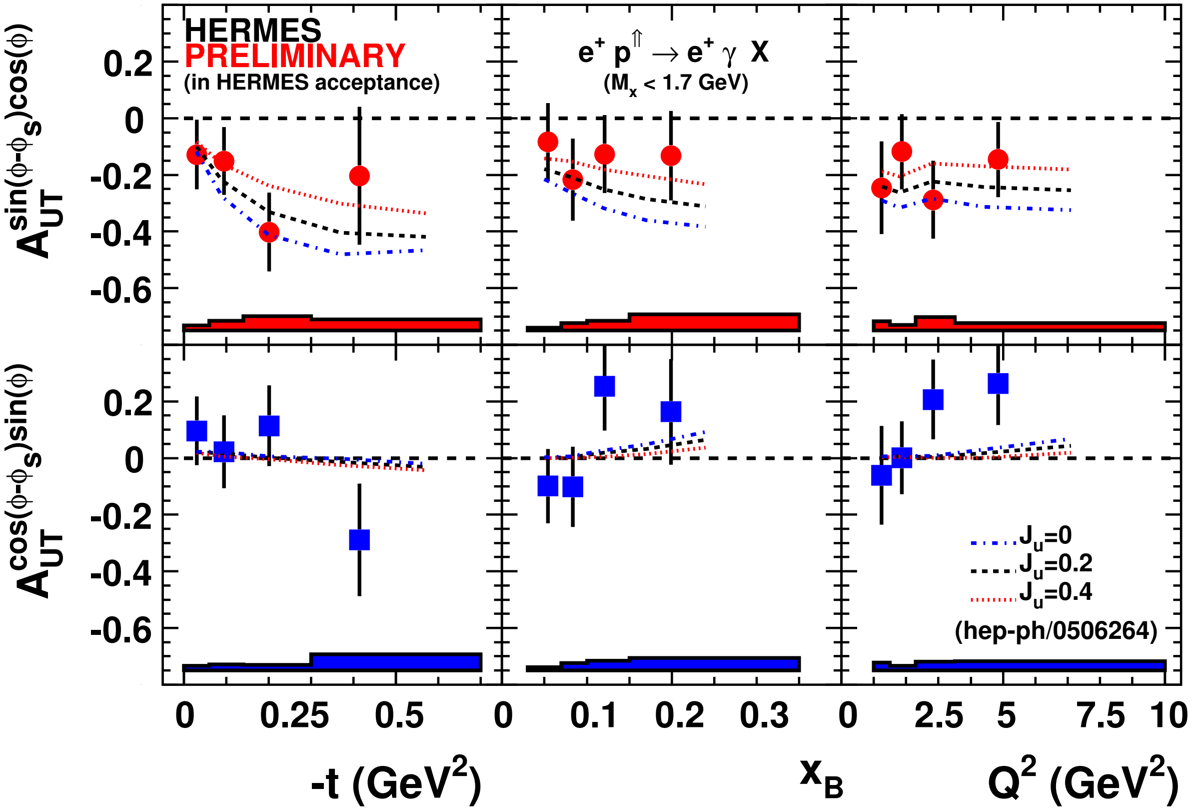
HERMES $e^+p^{\Uparrow}$ 2002-04:

- U: unpolarized beam
- T: transv. pol. target
- ca. 50% of total stat.

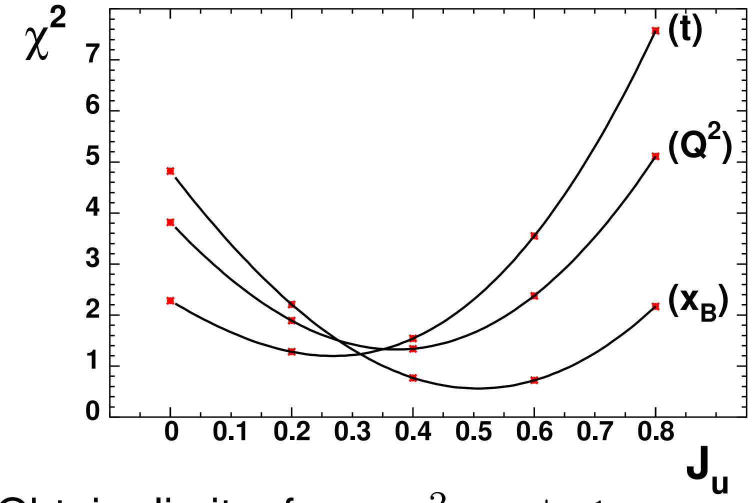
[2004-05 data: $e^-p^{\Uparrow}$]

$$
\begin{aligned}
A_{UT}(\phi,\phi_s) &= \frac{1}{|P_T|} \cdot \frac{d\sigma(p^{\Uparrow},\phi,\phi_s) - d\sigma(p^{\Downarrow},\phi,\phi'_s)}{d\sigma(p^{\Uparrow},\phi,\phi_s) + d\sigma(p^{\Downarrow},\phi,\phi'_s)} \\
&\propto \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}] \cdot \sin(\phi-\phi_S)\cos\phi \\
&+ \mathrm{Im}[F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}] \cdot \cos(\phi-\phi_S)\sin\phi
\end{aligned}
$$

# Extract u-quark Total Angular Momentum




$\chi^2$ of data vs. projections:




Obtain limits from $\chi^2_{min} \pm 1$:

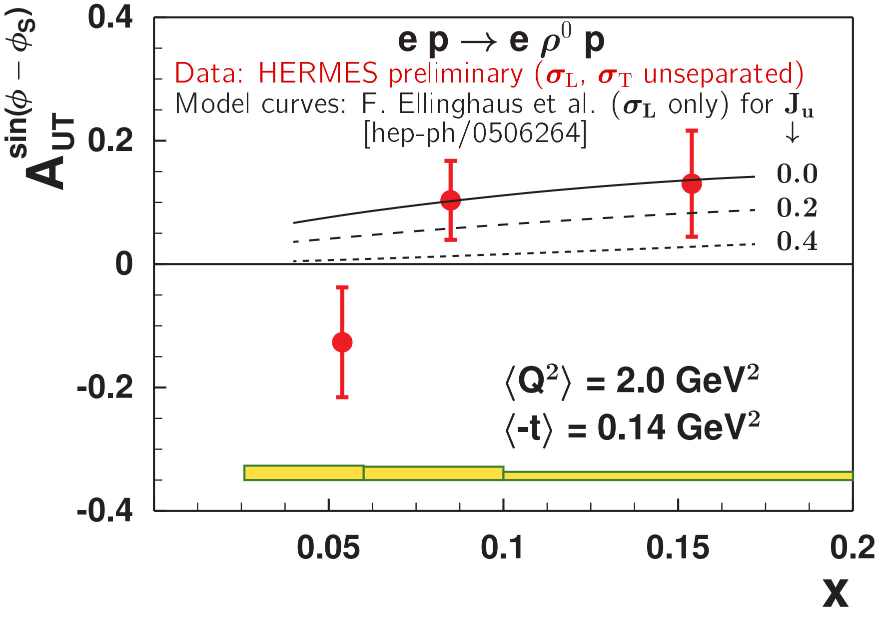
| | | | |
|---|---|---|---|
| -t: | 0.26 | +0.22 | -0.24 |
| $Q^2$ : | 0.35 | +0.25 | -0.22 |
| $x_B$ : | 0.50 | +0.24 | -0.24 |

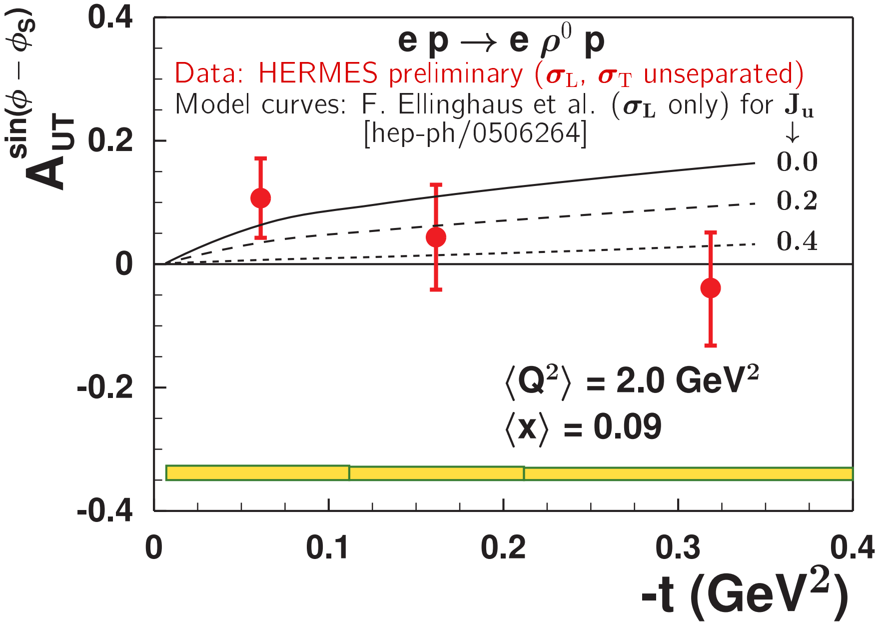
- above projections for one variable calculated at average Hermes kinematics for the other two ($\Rightarrow$ acceptance 'included'; for beam-spin asymmetries acceptance effect is $\mathcal{O}$(5-10%))
- systematic uncertainties included in $\chi^2$ calculation
- central values from all 3 variables are averaged while keeping uncertainty:

$$\boxed{\langle J_u \rangle \approx 0.37 \pm 0.24}$$

Projections assume $J_d = 0$ ($u$-quark dominance)

# Transv. Target-spin Asymmetry in $\rho$ Production




## TTSA projections (also from hep-ph/0506264)

Strongly simplified: $A_{UT}^{\rho} \propto \frac{E_q+E_g}{H_q+H_g}$

- **Only in $\rho$ prod. gluon contribution enters in leading order**
- asymmetry projections shown left are for **passive gluons**, i.e. $H_g \neq 0$ but $E_g = 0$
- for **active gluons**, i.e. $H_g \neq 0$ **and** $E_g \neq 0$, the asymmetry **may be** considerably larger

## Preliminary Hermes data 2002-04

- ca. 50% of total expected statistics used ($e^+ p^{\Uparrow}$ data)
- $\sigma_L, \sigma_T$ still unseparated
  - $\sigma_T$ expected to fall with some power of 1/Q
  - ⇒ mostly 1st point in $x$ affected!

## Compare data vs. projections

- statistics yet to low to extract value of $\langle J_u \rangle$
- present HERMES $\rho$ TTSA data points compatible with $\langle J_u \rangle$ value extracted from DVCS data $(0.37 \pm 0.24)$
- no conclusion yet on possible active gluon contribution

# Summary and Outlook

- Preliminary HERMES data available on transverse target-spin asymmetries in Deeply Virtual Compton Scattering and exclusive $\rho^0$-electroproduction:

$\Rightarrow$ Significantly non-zero $\sin(\phi - \phi_S)\cos\phi$ TTSA seen in DVCS

$\Rightarrow$ $\sin(\phi - \phi_S)$ TTSA in $\rho$-production is (still) inconclusive due to low statistics

- Projections for both channels worked out based on available GPD models:

$\Rightarrow$ For the first time $u$-quark total angular momentum extracted: $J_u \approx 0.37 \pm 0.24$ (model-dependent, preliminary)

- Data taking with transversely polarized target will continue till end of 2005:

$\Rightarrow$ Final statistics expected to be a factor of 2 higher

  - acceptance issues to be studied by MC
  - systematic error analysis to be completed

  $\Rightarrow$ significant $J_u$ result expected from DVCS

  - information on gluon contribution in reach via $\rho$-production ?