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

\[
\frac{1}{2} = \frac{1}{2}(\Delta u + \Delta d + \Delta s) + L_q + \Delta G + L_g
\]

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

\(\Delta G\): First measurements

\(L_q, L_g\): Unknown!

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

\[ F(x, \xi, t, \mu^2) \]

- \( F \): GPDs, defined through ME \( \langle P' | O_{q/g} | P \rangle \)
- \( x \pm \xi \): Parton longitudinal momentum fractions
- \( t \): Invariant momentum transfer to the target
- \( \mu^2 \): Renormalization scale

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

<table>
<thead>
<tr>
<th></th>
<th>unpolarized</th>
<th>polarized</th>
</tr>
</thead>
<tbody>
<tr>
<td>nucleon-helicity non-flip</td>
<td>( H )</td>
<td>( \tilde{H} )</td>
</tr>
<tr>
<td>nucleon-helicity flip</td>
<td>( E )</td>
<td>( \tilde{E} )</td>
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GPDs provide an access to \( J_q \) (Ji 1997):

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

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

  ![Diagram](image)

- $T_{BH}$ is parameterized in terms of nucleon FFs $F_1$ and $F_2$, calculable in QED.

- $T_{DVCS}$ 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, $T_{BH} \gg T_{DVCS}$, $T_{DVCS}$ can be accessed through $I$: both its amplitude and phase!
Transverse target-spin asymmetry (Elligehaus, Nowak, Vinnikov, Ye, hep-ph/0506012)

\[ A_{UT}(\phi, \phi_s) = \frac{d\sigma(\phi, \phi_s) - d\sigma(\phi, \phi_s + \pi)}{d\sigma(\phi, \phi_s) + d\sigma(\phi, \phi_s + \pi)} \simeq \frac{T_{TP}}{|T_{BH}^{\text{unp}}|^2} \]

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

\[ \Rightarrow A_{UT}^{\sin(\phi - \phi_s)} \cos \phi \] sensitive to \( J_q = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} dx \, x (H_q + E_q) \)
The HERMES Experiment

- Recoiling protons were not detected.
The HERMES Experiment

- Exclusivity of the measurement is maintained from the missing mass:
  \[ M^2_x = (P_e + P_p - P_{e'} - P_\gamma)^2 \]

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

exclusive peak \( e p \rightarrow e'p\gamma \)

semi-incl. bkd. \( e p \rightarrow e'X(\pi^0 \ldots) \rightarrow \gamma \)
The presented result is based on the HERMES 2002-2004 data, $\int Ldt \simeq 60 \text{ pb}^{-1}$:

- $\sim 4k$ 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 $\chi$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

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

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

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

Zhenyu Ye, QCDN 2006, Rome, Italy, June 2006 – p.9
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 $\chi$QSM, the constraint on $J_u + J_d/2.9$ is shifted upwards by 0.11.
A Model-Dependent Constraint on $J_u$ vs $J_d$

\[ e^+ p \uparrow \rightarrow e^+ \gamma X \ (M_X < 1.7 \text{ GeV}) \]

\[
A_{UT}^{\sin \phi \cdot \cos \phi} = -0.149 \pm 0.058 \text{(stat)} \pm 0.033 \text{(syst)}
\]

\[
\langle t \rangle = 0.12 \text{ GeV}^2, \quad \langle x \rangle = 0.095, \quad \langle Q^2 \rangle = 2.5 \text{ GeV}^2
\]

GPD Model: LO/Regge/D-term=0


Code: VGG [Vanderhaeghen et al., priv. comm.]

\[ J_u + J_d / 2.9^{\text{VGG}} = 0.42 \pm 0.21 \text{ (exp}_{\text{tot}}) \pm 0.06 \text{ (b}_{\text{VGG}}^{\text{VGG}} \in [1, \infty)) \]

The quenched Lattice calculation was done with the the pion masses 1070, 870, and 640 MeV, and extrapolated linearly in $m_{\pi}^2$ 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 predictions 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.