Model-Dependent Constraint on Quark Total Angular Momentum Based on the Transverse Target-spin Asymmetry Measured in Deeply Virtual Compton Scattering at HERMES

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Abstract. Results are reported on the transverse target-spin asymmetry (TTSA) associated with deeply virtual Compton scattering on the proton. The data have been accumulated in the years 2002-2004 by the HERMES experiment at DESY, in which the HERA 27.6 GeV e+ beam scattered on a transversely polarized hydrogen target. Two azimuthal amplitudes of the TTSA appearing to LO in $1/Q$ and α_s, $A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$ and $A_{UT}^{\cos(\phi-\phi_S)\sin\phi}$, are given as a function of $-t, x_B, Q^2$ in the kinematic range $|t| < 0.7$ GeV^2, $0.03 < x_B < 0.35$ and $1 < Q^2 < 10$ GeV^2. The first amplitude is found to be sensitive to the generalized parton distribution (GPD) E of the proton, which can be parameterized in a GPD model through quark total angular momentum $J_q(q = u, d)$. Within the context of this model, a constraint in the (J_u, J_d) plane is obtained from HERMES TTSA data.

Keywords: proton structure, GPDs, DVCS, hard exclusive, transverse target-spin asymmetry
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DEEPLY VIRTUAL COMPTON SCATTERING

Hard exclusive leptoproduction of a real photon off a nucleon, by the virtual photon emitted by the incoming lepton, is called deeply virtual Compton scattering (DVCS). This process is the presently most practical tool to constrain generalized parton distributions (GPDs) which provide a detailed description of the structure of the nucleon. Great interest in GPDs arose after it was realized that the total angular momentum carried by quarks in the nucleon, J_q, may be accessed once the GPDs H_q and E_q for the quark species q have been constrained by experimental data [1].

The DVCS final state is experimentally indistinguishable from that of the Bethe-Heitler (BH) process, in which the real photon is radiated from the incoming or scattered lepton. Hence their amplitudes add coherently and the cross section contains an interference term I:

$$\frac{d\sigma}{dx_B dQ^2 d|t|d\phi} \quad \propto \quad |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \underbrace{\tau_{DVCS}\tau_{BH}^* + \tau_{DVCS}^*\tau_{BH}}_{I}. \tag{1}$$

Here x_B represents the Bjorken scaling variable, $-Q^2$ the virtual–photon four-momentum squared, and $-t$ the squared four-momentum transfer to the target. The azimuthal angle ϕ is measured between the scattering plane, spanned by the incoming and outgoing leptons, and the production plane made up by the virtual and real photons.

While at HERMES energies the BH cross section dominates over the DVCS cross section, the DVCS amplitude can still be investigated by studying the interference term I. This task is accomplished by measuring various azimuthal cross section asymmetries.

TRANSVERSE TARGET-SPIN ASYMMETRY

A transverse single target-spin asymmetry (TTSA) associated with DVCS on the proton can be measured with an unpolarized lepton beam (U) and a transversely polarized (T) hydrogen target [2]:

$$A_{UT}(\phi, \phi_S) = \frac{d\sigma(\phi, \phi_S) - d\sigma(\phi, \phi_S + \pi)}{d\sigma(\phi, \phi_S) + d\sigma(\phi, \phi_S + \pi)}. \tag{2}$$

Here ϕ_S is the azimuthal orientation of the target polarization vector with respect to the scattering plane. At leading order in α_S and $1/Q$, the 2 azimuthal TTSA amplitudes are:

$$
\begin{aligned}
A_{UT}^{\sin(\phi - \phi_S)\cos\phi} &\propto Im\left[F_2 H - F_1 E\right], \\
A_{UT}^{\cos(\phi - \phi_S)\sin\phi} &\propto Im\left[F_2 \widetilde{H} - F_1 \xi \widetilde{E}\right].
\end{aligned} \tag{3}
$$

The Compton form factors H, E, $\widetilde{H}$ and $\widetilde{E}$ are convolutions of the respective GPDs H, E, $\widetilde{H}$ and $\widetilde{E}$ with hard scattering kernels, while F_1 and F_2 are the Dirac and Pauli form factors of the proton, respectively. The skewness parameter ξ is given by $\xi \simeq \frac{x_B}{2 - x_B}$.

Direct access to total quark angular momentum $J_q(q = u, d)$ is made possible with a GPD model [3] that parameterizes the GPD E using J_u and J_d as free parameters. Within the context of this GPD model the TTSA amplitude $A_{UT}^{\sin(\phi - \phi_S)\cos\phi}$ is found to be sensitive to J_u and J_d and insensitive to the other model parameters [2].

In this paper first results are reported, obtained at the HERMES experiment, on the TTSA associated with DVCS on the proton. Furthermore, a model-dependent constraint on J_u vs J_d is extracted by comparing the TTSA results of HERMES with theoretical predictions based on the above mentioned GPD model.

DEEPLY VIRTUAL COMPTON SCATTERING AT HERMES

HERMES is a fixed–target experiment using the 27.6 GeV longitudinally polarized electron or positron beam of the HERA accelerator at DESY Hamburg. The HERMES forward spectrometer [4] is instrumented with tracking chambers providing momentum and angular measurements for charged particles. Lepton–hadron separation is achieved by a transition-radiation detector, a pre-shower counter and an electromagnetic calorimeter. The latter detects both the scattered lepton and the photon produced in the BH/DVCS process. As recoil proton detection was not possible for the analyzed data sets, kinematic requirements are imposed on scattered lepton and produced real photon in order to ensure the exclusivity of the reaction. In particular, the requirement $-(1.5)^2 < M_x^2 < (1.7)^2$ GeV^2 is imposed on the missing mass, as determined from Monte-Carlo simulations which include the finite resolution of the spectrometer, by comparing signal and background distributions.
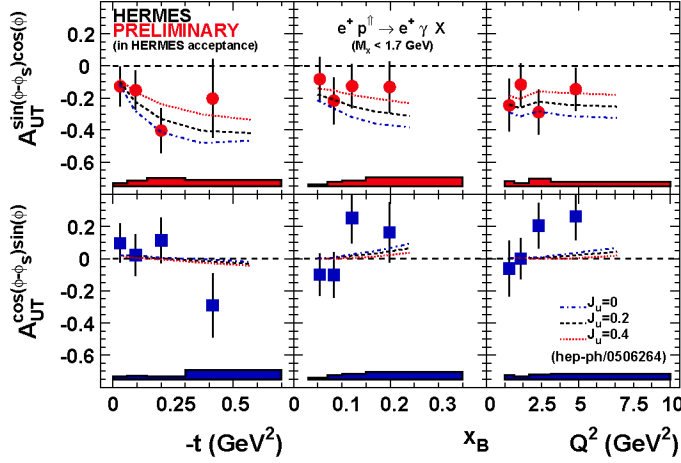
FIGURE 1. The $A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$ and $A_{UT}^{\cos(\phi-\phi_S)\sin\phi}$ amplitudes of the transverse target-spin asymmetry associated with DVCS, shown as a function of $-t$, x_B and Q^2 for the exclusive sample ($-(1.5)^2 < M_x^2 < (1.7)^2$ GeV^2) after background correction. The error bars (bands) represent the statistical (systematic) uncertainties. The curves are the predictions from a GPD model with different u-quark total angular momentum J_u and fixed d-quark total angular momentum $J_d = 0$ [2].
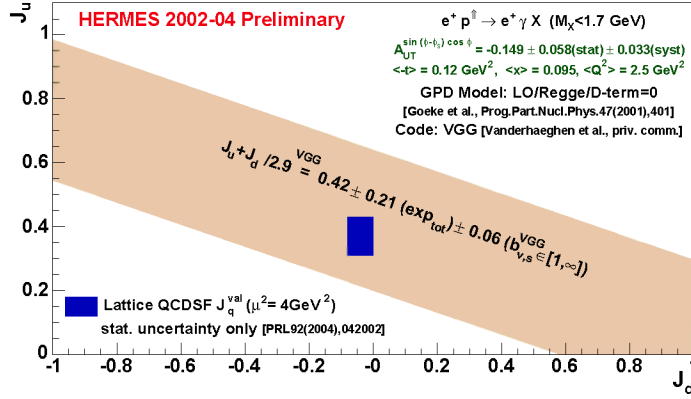
RESULTS

Figure 1 shows the two TTSA amplitudes $A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$ and $A_{UT}^{\cos(\phi-\phi_S)\sin\phi}$ as a function of $-t$, x_B and Q^2, as extracted from HERMES data accumulated in 2002-2004 using a transversely polarized hydrogen target. Corrections for background and smearing have been applied. The main contributions to the systematic uncertainty are those from the determination of the target polarization and in the background correction. Also shown in figure 1 are theoretical predictions based on a phenomenological model of GPDs [3]. For both amplitudes, the experimental results are in general agreement with the theoretical predictions.

Sensitivity to J_u is seen only for the first amplitude. Hence the integrated TTSA result $\langle A_{UT}^{\sin(\phi-\phi_S)\cos\phi} \rangle = -0.149 \pm 0.058(\text{stat.}) \pm 0.033(\text{syst.})$, extracted from the 2002-2004 data at the average kinematics $\langle -t \rangle$=0.12 GeV^2, $\langle x_B \rangle$=0.095, $\langle Q^2 \rangle$=2.5 GeV^2, is input to a fit in order to constrain J_u and J_d. The reduced χ^2 value, defined as

$$\Delta\chi^2 = \chi^2 - \chi^2_{minimum} = \left[A^{exp} - A^{VGG}(J_u, J_d)\right]^2 / \left[\delta A^2_{stat} + \delta A^2_{syst}\right], \qquad (4)$$

is calculated on a grid for J_u and J_d. Here A^{exp} denotes the measured (integrated) TTSA amplitude, δA_{stat} (δA_{syst}) its statistical (systematic) uncertainty, and A^{VGG} is the value calculated at the average kinematics by a code [5] based on the above mentioned GPD model [3].

The one-standard-deviation constraint on J_u vs J_d is defined as the area in the (J_u, J_d)-plane, in which the reduced χ^2 value is below one: $J_d/2.9 + J_u = 0.42 \pm 0.21 \pm 0.06$

FIGURE 2. Model-dependent constraint on u-quark total angular momentum J_u vs d-quark total angular momentum J_d, obtained by comparing the experimental result and theoretical predictions on the TTSA amplitude $A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$. Also shown is a Lattice result from the QCDSF collaboration, obtained at the scale $\mu^2 = 4$ GeV^2 for valence quark contributions only.

(see Fig. 2). The first uncertainty is due to the experimental uncertainty in the measured TTSA amplitude. The second one is a model uncertainty, obtained by varying from one to infinity the unknown profile parameter b which controls the skewness dependence of GPDs [3]. The t-dependence of GPDs is modelled using the Regge ansatz [3]. The impact of using it or its alternative – the factorized ansatz – on the theoretical predictions on the TTSA amplitudes has been found to be negligible [2]. The D-term contribution to the GPDs H and E is set to zero, as suggested by the HERMES results on the beam-charge asymmetry [6]. If the D-term were modelled according to the chiral quark soliton model [3], the resulting constraint is shifted to $J_d/2.9 + J_u = 0.53 \pm 0.21 \pm 0.06$.

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REFERENCES

1. X. Ji, Phys. Rev. Lett. **78** (1997) 610, Phys. Rev. **D55** (1997) 7114.
2. F. Ellinghaus *et al.*, arXiv:hep–ex/0506264, Eur. Phys. J. **C46** (2006) 729.
3. K. Goeke et al., Prog. Part. Nucl. Phys. **47** (2001) 401.
4. HERMES Coll., K. Ackerstaff et al., Nucl. Instr. and Meth. **A417** (1998) 230.
5. M. Vanderhaeghen, P.A.M. Guichon and M. Guidal, priv. comm., 2003.
6. HERMES coll., A. Airapetian *et al.*, submitted to *Phys. Rev. D*, hep-ex/0605108.