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Recent Results on Deeply Virtual Compton Scattering at HERMES

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HERMES has measured azimuthal asymmetries in the hard electroproduction of real photons, the so-called Deeply Virtual Compton Scattering (DVCS) process, using 27.6 GeV HERA positron and electron beams and various polarized and unpolarized gaseous targets. New results have recently been obtained for the t , x and Q^2 dependencies of the transverse target-spin asymmetry (TTSA) from data accumulated in 2002–2004 with the positron beam and a transversely polarized hydrogen target. A model-dependent constraint on the total angular momentum carried by u- and d-quarks, J_u and J_d , is obtained by comparing the extracted TTSA amplitude with theoretical predictions based on a certain GPD model.

1. Introduction

An essential task in QCD is to understand the hadron structure at the level of quarks and gluons. Particularly, the contributions of these basic constituents to the nucleon's spin both via their intrinsic spin and their orbital motion is of great interest.

Recent interest in hard exclusive processes has resulted from the theoretical description of these processes in terms of the Generalized Parton Distribution (GPD) formalism [1–3]. This formalism offers a consistent description of the nucleon structure. It incorporates as limiting cases the well-known nucleon form factors determined from elastic scattering as well as parton momentum distributions (PDFs) determined from measurements of inclusive and semi-inclusive deep inelastic lepton-nucleon scattering (DIS). Interest in the GPD framework has also been motivated by the fact that the unknown total angular momenta of quarks and gluons within the nucleon are encoded in the GPDs [4]. The latter allows in principle access to the orbital angular momentum of quarks using the knowledge of their intrinsic spin contribution to the nucleon's spin.

One of the theoretically cleanest processes with which to probe GPDs is Deeply-Virtual Comp-

ton Scattering (DVCS), in which a highly virtual photon is absorbed by a parton within the target, which produces a single real photon in the final state, along with the recoiling nucleon being in its ground state.

2. DVCS at HERMES

The DVCS process is experimentally indistinguishable from the Bethe-Heitler (BH) process, in which a real photon is radiated by the incoming or outgoing lepton rather than the quark. The cross section for the lepton production of real photons is therefore given by the coherent sum of the BH and DVCS amplitudes squared:

$$d\sigma \propto |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \tau_{BH}^* \tau_{DVCS} + \tau_{DVCS}^* \tau_{BH} \quad (1)$$

At HERMES kinematics the BH process dominates over DVCS in the cross section. However, the DVCS amplitude can be studied via the interference term by measuring various cross section asymmetries and their dependences on the azimuthal angle ϕ , defined as the angle between the lepton scattering plane and the photon production plane. The interference term $\tau_{BH}^* \tau_{DVCS} + \tau_{DVCS}^* \tau_{BH}$ (I) can be written in a series of Fourier moments in ϕ [5]

$$I \propto \pm \left(c_0^I + \sum_{n=1}^3 c_n^I \cos(n\phi) + \sum_{n=1}^3 s_n^I \sin(n\phi) \right), \quad (2)$$

where sign $+$ ($-$) stands for the electron(positron) beam, c_0^I , c_n^I and s_n^I are given by a linear combina-

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tion of the Compton form factors (CFFs), which in general depend on the beam and target polarizations. The CFFs can be expressed as convolutions of the corresponding GPDs with the hard scattering amplitudes.

By flipping the charge and the helicity of the longitudinally polarized lepton beam scattered off an unpolarized proton target, HERMES accesses correspondingly the real and the imaginary part of the helicity conserving amplitude $\widehat{M}_{++}$ [6] while the imaginary part of the another amplitude $\widehat{M}_{++}^L$ can be determined by flipping only the helicity of the longitudinally polarized proton target. The GPDs enter in linear combinations in these amplitudes. The expressions for the cross section differences with respect to the charge and spin of the lepton beam and the longitudinal target spin in leading order and leading twist are

$$\begin{aligned} d\sigma(e^+p) - d\sigma(e^-p) &\propto \cos(\phi) \text{Re } \mathcal{H}, \\ d\sigma(\vec{e}^+p) - d\sigma(\overleftarrow{e}^+p) &\propto \sin(\phi) \text{Im } \mathcal{H}, \\ d\sigma(e^+\vec{p}) - d\sigma(e^+\overleftarrow{p}) &\propto \sin(\phi) \text{Im } \widetilde{\mathcal{H}}. \end{aligned} \quad (3)$$

Here the lepton propagators of the BH process, which distort the above mentioned ϕ dependences, are omitted but they cancel in usual asymmetries assuming that the denominators in these asymmetries are dominated by a ϕ -independent BH contribution.

It should be noted that HERA is the only place in the world where the complete analysis of the Compton amplitude is possible due to its unique ability to flip between electrons and positrons.

In the case of a transversely (T) polarized hydrogen target using an unpolarized (balanced) (U) lepton beam, an additional dependence on the azimuthal angle ϕ_S of the target spin vector appears in the amplitudes [6]. Two azimuthal amplitudes appearing to leading order in α_s and $1/Q$ can be approximated as:

$$\begin{aligned} A_{UT}^{\sin(\phi-\phi_S)\cos\phi} &\propto \text{Im} [F_2\mathcal{H} - F_1\mathcal{E}], \\ A_{UT}^{\cos(\phi-\phi_S)\sin\phi} &\propto \text{Im} [F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}], \end{aligned} \quad (4)$$

where ξ is the skewedness parameter $\simeq \frac{x_B}{2-x_B}$, and F_1 and F_2 are the Dirac and Pauli form factors of the proton, respectively.

3. The experiment

HERMES is a fixed target experiment in the 27.6 GeV electron or positron beam at HERA [7]. In order to extract the above mentioned asymmetries from the data, events were selected that contained one photon and one scattered lepton track and no further tracks. Lepton-hadron identification is performed by a transition-radiation detector, a preshower counter and an electromagnetic calorimeter. Photons were identified by the energy deposition in the calorimeter and preshower counter in the absence of a track in the drift and proportional chambers. The following requirements were imposed on the lepton kinematics $Q^2 > 1 \text{ GeV}^2$, $W > 3 \text{ GeV}$. The opening angle $\Theta_{\gamma^*\gamma}$ between the virtual and real photon was limited to a range of 5 to 45 mrad.

Since the recoiling nucleon was not detected, the exclusive DVCS events were selected imposing an additional constraint on the missing mass M_X . The exclusive region was defined as $(-1.5 \text{ GeV})^2 < M_X^2 < (1.7 \text{ GeV})^2$ (negative M_X^2 values are obtained as a consequence of the finite energy resolution of the spectrometer).

4. Azimuthal cross section asymmetries

The HERMES results on the azimuthal asymmetry with respect to the beam spin (BSA) on hydrogen has been reported before [8,9]. The asymmetry shows the $\sin\phi$ dependence as expected from the Eqn. 3.

Also the expected $\cos\phi$ behavior for the beam-charge asymmetry A_C (see Eqn. 3) on hydrogen has been observed at HERMES [10]. The $|\phi|$ dependence of the BCA is presented in Fig. 1. Taking the absolute value $|\phi|$ symmetrizes the BCA as the sinusoidal contributions due to the non-zero polarization of the lepton beams both in the numerator and denominator of the asymmetry formula cancel. The shown four-parameter fit yields a non-zero $\cos\phi$ amplitude of 0.060 ± 0.027 , while the constant term as well as the $\cos 2\phi$ and $\cos 3\phi$ terms are compatible with zero.

The comparison of the $\cos\phi$ amplitude $A_C^{\cos\phi}$ derived from the fits in four bins in $-t$ (the square of the four-momenta transfer to the target) with

Figure 1. Beam-charge azimuthal asymmetry A_C for the hard exclusive electroproduction of photons off protons as a function of the azimuthal angle $|\phi|$. The solid curve represent the four-parameter fit. The dashed line shows the pure $\cos\phi$ dependence.

different model predictions [11,12] are shown in Fig. 2. The calculations use either a factorized or a Regge-inspired t -dependence with or without

Figure 2. The $\cos\phi$ amplitude of the asymmetry A_C as a function of $-t$. The calculations are based on GPD models from [11,12]

the D-term contribution. The data disfavor the model based on the Regge-inspired t -dependence with the D-term contribution.

HERMES was taking data with a transversely polarized hydrogen target in 2002-2005. The measured kinematic dependence of the transverse target-spin asymmetry (TTSA) amplitude has been reported before [13]. Here we present the integrated 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 average kinematics $\langle -t \rangle = 0.12 \text{ GeV}^2$, $\langle x_B \rangle = 0.095$, $\langle Q^2 \rangle = 2.5 \text{ GeV}^2$.

Figure 3. Model-dependent constraint on the total angular momentum of the u - and d -quarks, J_u vs J_d . The Lattice result from the QSDSF collaboration is also shown.

A comparison of the measured transverse target spin asymmetries A^{exp} and calculated asymmetries from the models [11,12] has been used to constrain J_u and J_d , using the reduced χ^2 value, defined as

$$\Delta\chi^2 = \chi^2 - \chi^2_{\text{minimum}} = [A^{exp} - A^{VGG}(J_u, J_d)]^2 / [\delta A_{\text{stat}}^2 + \delta A_{\text{syst}}^2], \quad (5)$$

for different values of J_u and J_d .

The area in the (J_u, J_d) -plane, in which the reduced χ^2 value is not larger than one, is defined as the one-standard-deviation constraint on J_u vs J_d . It is shown in Fig. 3 and can be parameterized as $J_u + J_d / 2.9 = 0.42 \pm 0.21 \pm 0.06$. The first

Figure 4. The $\cos\phi$ dependence of the BCA (left panel, filled triangles) from the HERMES [10] and the $\sin\phi$ dependence of the BSA (right panel) from the 96/97 HERMES data [8] (filled triangle), from the 2000 HERMES data [9] (opened triangle) and from CLAS [14] (grey triangle) as a function of $-t$. Models are taken from [5]. The circles denote the projected error bars for the full HERMES data taking period.

uncertainty denotes the experimental uncertainty in the measured TTSA amplitude while the second one is a model uncertainty arising from the unknown profile parameter b [12]. The D-term contribution to the GPDs H and E is set to zero, as suggested by the HERMES results on BCA.

5. Summary

The projected BCA and BSA results for the HERA II running period (2002 - 2007) are presented in Fig. 4. The upcoming HERMES data on unpolarized targets will put serious constraints on the GPD H and will be able to distinguish between various GPD models. The HERMES data taken in 2005 on the transversely polarized hydrogen target will double the statistics for the TTSA asymmetry. Finally, the recoil detector installed in 2006 can improve the selection and the determination of the kinematics of the DVCS process by registering the recoiling nucleon.

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