Measurement of Deeply Virtual Compton Scattering at HERMES

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Abstract. The measurement of azimuthal cross section asymmetries from deeply virtual Compton scattering on the proton and deuteron at HERMES is discussed. In particular results on the longitudinal target spin asymmetry as a function of the azimuthal angle and the Mandelstam t are given. The t-dependence of the asymmetry is compared with calculations based on generalized parton distribution models.

Keywords: GPD, DVCS, azimuthal asymmetry, target-spin asymmetry, HERMES
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1. INTRODUCTION

Generalized Parton Distributions (GPD) were introduced a decade ago as a unified description of hard exclusive processes in the Bjorken regime [1, 2]. As a generalization of the usual Parton Distribution Functions (PDF) they give additional information about quark and gluon properties in the nucleon. Because of their off-forward nature GPDs contain information about both PDF and nucleon form factors.

Strong interest in the physics properties of GPDs was triggered by the work of Ji [3] who demonstrated that in the forward limit GPDs can give information about the total angular momentum carried by quarks (and gluons) in the nucleon.

2. DEEPLY VIRTUAL COMPTON SCATTERING

The presently cleanest way to access GPDs is to study Deeply Virtual Compton Scattering (DVCS), the hard exclusive electroproduction of a real photon. This process occurs always together with the Bethe-Heitler process where the photon is radiated from one of the involved leptons. Both processes have identical final states, making them experimentally indistinguishable, and leading to interference between amplitudes. This yields the following amplitude for real photon production

$$\frac{d\sigma}{dx_B dQ^2 d|t| d\phi} \propto |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \overbrace{\tau_{DVCS}\tau^*_{BH} + \tau^*_{DVCS}\tau_{BH}}^{I}, \qquad (1)$$

where x_B represents the Bjorken scaling variable, $-Q^2$ the virtual-photon four-momentum squared and t the square of the four-momentum transfer to the target. The azimuthal angle ϕ is defined by the lepton scattering plane and by the photon production plane.

In leading twist the dependence of the interference term I on the azimuthal angle ϕ can be written as [4]

$$I \propto \frac{e_l}{P(cos\phi)}\Big(cos\phi\,\mathrm{Re}\widehat{M}_{++} - P_l\sqrt{1-\varepsilon^2}sin\phi\,\mathrm{Im}\widehat{M}_{++} - \\ - S_L\left[sin\phi\,\mathrm{Im}\widehat{M}^L_{++} - P_l\sqrt{1-\varepsilon^2}cos\phi\,\mathrm{Re}\widehat{M}^L_{++}\right]\Big), \tag{2}$$

where $e_l = \pm 1$ is the charge of the lepton beam with polarization P_l scattered on a target with longitudinal polarization S_L. Here ε is the ratio of fluxes of longitudinal to transverse initial photons in the DVCS process and the factor $P(cos\phi)$ coming from the lepton propagators in the Bethe-Heitler process gives an additional ϕ dependence.

In case of an *unpolarized* target ($S_L = 0$) the ϕ dependence of the cross section asymmetry with respect to the charge (spin) of the lepton beam gives access to the real (imaginary) part of the DVCS amplitude $\widehat{M}_{++}$ which is a linear combination of the so-called Compton form factors (CFFs) $\mathscr{H}$, $\tilde{\mathscr{H}}$ and $\mathscr{E}$:

$$\widehat{M}_{++} = \sqrt{1-\xi^2}\frac{\sqrt{t_0-t}}{2M_p}\left[F_1\mathscr{H} + \xi(F_1+F_2)\tilde{\mathscr{H}} - \frac{t}{4M_p^2}F_2\mathscr{E}\right], \tag{3}$$

where $\xi \simeq \frac{x_B}{2-x_B}$ in Bjorken limit is the skewedness parameter, t_0 is the minimum possible value of $-t$ at a given ξ, and F_1 and F_2 are the Dirac and Pauli form factors, respectively.

In case of a *polarized* target ($S_L \neq 0$) the dependence of the asymmetry with respect to the target polarization state gives access to the imaginary part of $\widehat{M}^L_{++}$ which is defined by another linear combination of the CFFs $\mathscr{H}$, $\tilde{\mathscr{H}}$, $\mathscr{E}$ and $\tilde{\mathscr{E}}$:

$$\widehat{M}^L_{++} = \sqrt{1-\xi^2}\frac{\sqrt{t_0-t}}{2M_p}\left[F_1\tilde{\mathscr{H}} + \xi(F_1+F_2)\big(\mathscr{H} + \frac{\xi}{1+\xi}\mathscr{E}\big) - \big(\frac{\xi}{1+\xi}F_1 + \frac{t}{4M_p^2}F_2\big)\xi\tilde{\mathscr{E}}\right]. \tag{4}$$

These complex CFFs are flavor sums of convolutions of corresponding leading-twist GPDs H, $\tilde{H}$, E and $\tilde{E}$ with the hard scattering amplitudes that are available up to NLO in pQCD [5].

3. DVCS AT HERMES

HERMES is a fixed-target experiment at the 27.6 GeV electron or positron beam of HERA [6]. Its gas target provides polarized H, D, ^{3}He as well as unpolarized H, D, Ne, Kr and Xe targets. In this paper only result for H and D targets are discussed.

The selected DVCS events are required to have a detected photon in addition to one charged track identified as the scattered lepton. The kinematic requirements imposed on the scattered lepton were $Q^2 > 1$ GeV^2, $W^2 > 8$ GeV^2 and $\nu < 23$ GeV. The polar angle $\theta_{\gamma^*\gamma}$ between the virtual and the real photon is required to be between 5 and 45 mrad. Since the recoiling proton was not detected the exclusive events were selected with a cut on the missing mass M_x of the reaction $ep \to e\gamma X$ that requires M_x to correspond to the proton mass. Due to the limited detector resolution the missing mass range $-1.5 < M_x < 1.7$ GeV was selected using an MC simulation for the optimum separation of exclusive events from the semi-inclusive background.

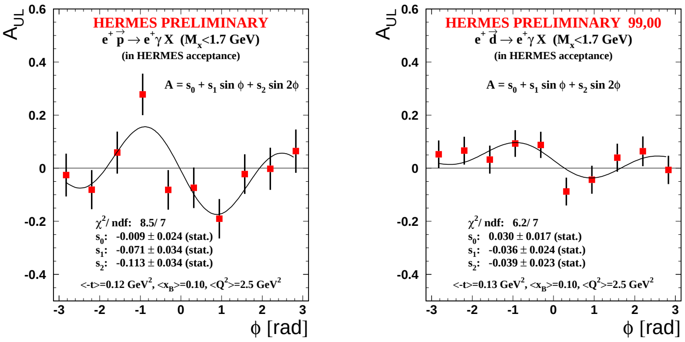

FIGURE 1. Longitudinal target spin asymmetry A_{UL} for hard electroproduction of photons off the proton (left) and the deuteron (right) as a function of the azimuthal angle ϕ for the exclusive sample. The solid curves show the results of the indicated fits with the values given in the plots.

4. AZIMUTHAL CROSS SECTION ASYMMETRIES

The discussion on the beam-spin asymmetry (BSA) and the beam-charge asymmetry (BCA) is beyond the scope of this paper, since the HERMES results on these two asymmetries for the proton and the deuteron have been reported before (the BSA dependence on ϕ is discussed in [7, 8], the BCA dependence on ϕ and t in [9]).

4.1. Longitudinal Target Spin Asymmetry

The single-spin asymmetry w.r.t. the polarization of a *longitudinally* (L) polarized target (LTSA) as a function of ϕ is calculated as

$$A_{UL}(\phi) = \frac{1}{<|S_L|>} \frac{(N^{\leftarrow\Leftarrow} + N^{\rightarrow\Leftarrow}) - (N^{\leftarrow\Rightarrow} + N^{\rightarrow\Rightarrow})}{(N^{\leftarrow\Leftarrow} + N^{\rightarrow\Leftarrow}) + (N^{\leftarrow\Rightarrow} + N^{\rightarrow\Rightarrow})}, \tag{5}$$

where $\Leftarrow$ ($\Rightarrow$) or $\leftarrow$ ($\rightarrow$) denote target spin or beam helicity antiparallel (parallel) to the beam direction, respectively, and $N^{\leftarrow(\rightarrow)\Leftarrow(\Rightarrow)}$ represents the single photon yield normalized to the acquired luminosity for the corresponding target spin and beam helicity states. The imposed requirement on the beam polarization $< |P_l^{\leftarrow\Leftarrow(\Rightarrow)}| >=< |P_l^{\rightarrow\Leftarrow(\Rightarrow)}| >$ excludes a possible influence of the double-spin asymmetry on A_{UL}.

Since the main contribution to the DVCS amplitude $\widehat{M}^L_{++}$ at HERMES kinematics originates from the CFFs $\mathscr{H}$ and $\tilde{\mathscr{H}}$, measurements of the LTSA can constrain models for the imaginary parts of GPDs H and $\tilde{H}$. The asymmetries on proton and deuteron as function of ϕ are shown in Fig. 1. These results demonstrate the expected $sin\phi$ dependence [9]. A sizeable $sin2\phi$ amplitude $A_{UL}^{sin2\phi}$ is found which is expected to be kinematically suppressed w.r.t. $A_{UL}^{sin\phi}$; it can be sensitive to the next-to-leading contributions to the asymmetry (e.g. twist-3 GPDs H^3, $\tilde{H}^3$). In Fig. 2 the dependences of the $sin\phi$ and $sin2\phi$ amplitudes of the LTSA on proton and deuteron are shown as function of $-t$ derived from fits for every $-t$ bin. No difference is observed between the asymmetries on

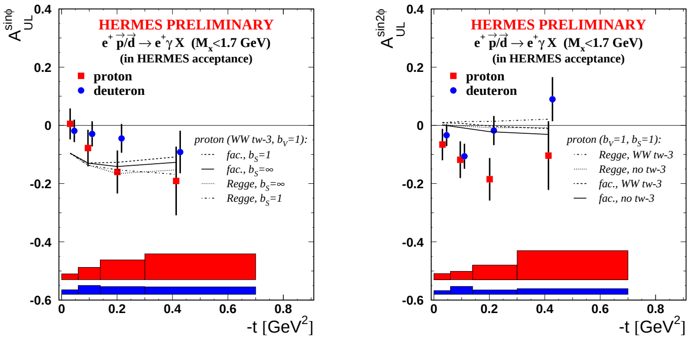

FIGURE 2. The *sinϕ* (left) and *sin*2*ϕ* (right) amplitudes of the longitudinal target-spin asymmetry on the proton and the deuteron as a function of $-t$. The GPD model calculations use a factorized or a Regge-inspired t-dependence with or without a Wandzura-Wilczek (WW) term.

H and D targets in the first t-bin, where effects from coherent scattering on the deuteron may be expected. The difference between the two targets in higher t-bins might be due to incoherent scattering on the neutron.

Calculations based on a GPD model developed in [10] were carried out at the average kinematics of every t bin for the proton. Although the model describes the *sinϕ* amplitude well, it does not agree with the data for *sin*2*ϕ*. This can be due to the fact that the twist-3 GPDs are modeled only by the Wandzura-Wilczek term, hence no information on quark-gluon correlations is included.

5. OUTLOOK

The measurement of azimuthal asymmetries in DVCS performed at HERMES can give access to a variety of GPDs. The BSA and BCA constrains both *imaginary* and *real* part of the GPD H, respectively. The longitudinal TSA is sensitive to the imaginary part of the GPD $\tilde{H}$. The present HERMES data taking with a transversely polarized target allows to measure the transverse TSA that is sensitive to the GPD E. These results may allow to constrain the total angular momentum of u-quark J^u for the first time [11].

REFERENCES

1. D. Mueller et al., Fortsch. Phys. **42** (1994) 101.
2. A.V. Radyushkin, Phys. Lett. **B385** (1996) 333.
3. X. Ji, Phys. Rev. Lett. **78** (1997) 610, Phys. Rev. **D55** (1997) 7114.
4. M. Diehl, Physics Reports **388** (2003) 41.
5. A.V. Belitsky, D. Müller, A. Kirchner, Nucl. Phys. **B629** (2002) 323-392.
6. HERMES Coll., K. Ackerstaff et al., Nucl. Instr. and Meth. **A417** (1998) 230.
7. A. Airapetian et al., Phys. Rev. Lett. **87** (2001) 182001.
8. HERMES Coll., F. Ellinghaus et al., hep-ex/0212019.
9. W.-D. Nowak, hep-ex/0503010
10. K. Goeke, M.V. Polyakov and M. Vanderhaegen, Prog. Part. Nucl. Phys. **47** (2001) 401.
11. F. Ellinghaus et al., hep-ph/0506264.