DVCS at HERMES

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Abstract. An overview of HERMES results on the measurement of deeply virtual Compton scattering is presented, including new preliminary results on double-spin asymmetries off a transversely polarized hydrogen target. Throughout the last decades HERMES has collected wealth of data on scattering a longitudinally polarized lepton (electron/positron) beam off unpolarized, longitudinally and transversely polarized hydrogen targets, as well as off unpolarized and longitudinally polarized deuterium targets. Available data allow to extract azimuthal asymmetries with respect to beam charge, beam helicity and target polarization alone and also with respect to their different combinations. The variety of measured asymmetries provides sensitivity to real and/or imaginary parts of different combination of Compton Form Factors, and can be used to constrain different Generalized Parton Distributions.

Keywords: DVCS, GPD, Nucleon Structure
PACS: 21.10.Hw, 25.30.Rw

INTRODUCTION

During last decade Deeply Virtual Compton Scattering (DVCS) has been under intense investigation from both, theoretical and experimental sides. DVCS is the process of hard leptoproduction of real photons, where the photon is radiated by a struck quark. Currently DVCS is known as one of the simplest processes that provides an access to Generalized Parton Distributions (GPDs) [1]. GPDs embody parton distribution functions and elastic form-factors as special limiting cases and first moments, respectively, and provide a comprehensive multidimensional description of the nucleon. In addition, GPDs contain information about the total angular momentum of partons in the nucleon [2]. The spin-1/2 nucleon is described by four leading-twist quark-chirality-conserving GPDs $H, E, \widetilde{H}, \widetilde{E}$ [3], while the spin-1 deuteron requires nine GPDs – $H_1, H_2, H_3, H_4 H_5, \widetilde{H}_1, \widetilde{H}_2, \widetilde{H}_3, \widetilde{H}_4$ [4] to describe all experimental observables.

DVCS is experimentally indistinguishable from the Bethe-Heitler (BH) process, where the final state photon is radiated by an incoming or outgoing lepton. Hence, the total cross section of leptoproduction of real photons involves an interference term I. For the particular case of a transversely polarized hydrogen target the cross section reads

$$\frac{d\sigma}{dx_B dQ^2 d|t| d\phi d\phi_S} = \frac{x_B e^6}{32(2\pi)^4 Q^4 \sqrt{1+\varepsilon^2}} \left[|\tau_{BH}|^2 + |\tau_{DVCS}|^2 + I \right]. \tag{1}$$

Here Q^2 is the squared four-momentum of the exchanged virtual photon, x_B is the Bjorken variable, t squared four-momentum transfer to the target, e represents the elementary charge, and $\varepsilon = 2x_B M/\sqrt{Q^2}$. The azimuthal angle ϕ is defined as the angle between lepton scattering plane and photon production plane, and the angle ϕ_S is defined as the angle between the lepton scattering plane and the transverse component of the target polarization.

At HERMES the DVCS process is accessed through measurements of cross section asymmetries that appear in the azimuthal distributions of final state photons. Utilizing data collected with longitudinally polarized electron/positron beam with both target polarization states, it is possible to measure asymmetries with respect to beam charge, beam polarization and target polarization alone and also with respect to their different combinations. As an example, the asymmetries in the cross section for scattering a longitudinally polarized electron/positron beam off a transversely polarized hydrogen target can be described as

$$\begin{aligned} d\sigma &= d\sigma_{UU}(\phi)\Big[1+e_\ell A_C(\phi)+P_\ell A_{LU}^{DVCS}(\phi)+S_\perp A_{UT}^{DVCS}(\phi,\phi_S)+e_\ell P_\ell A_{LU}^{I}(\phi) \\ &+ e_\ell S_\perp A_{UT}^{I}(\phi,\phi_S)+P_\ell S_\perp A_{LT}^{BH+DVCS}(\phi,\phi_S)+e_\ell P_\ell S_\perp A_{LT}^{I}(\phi,\phi_S)\Big]. \end{aligned} \quad (2)$$

Here $d\sigma_{UU}$ is the cross section of scattering an unpolarized lepton beam off an unpolarized target averaged over both beam charges, e_ℓ and P_ℓ are the beam charge and polarization respectively, and the $S_\perp$ is the transverse target polarization. For the case of longitudinally polarized hydrogen or deuterium target, it is possible to measure another set of asymmetries with respect to the longitudinal polarization of the target. Asymmetries as defined in Eq. 2 are expressed in terms of different combinations of so-called Compton Form Factors (CFFs) [3, 4], which in turn are convolutions of hard scattering amplitudes with the corresponding GPDs.

DATA ANALYSIS

During data taking period from 1996 up to 2005 the HERMES experimental setup [5] was operating as forward spectrometer without the recoil detector, that was added later. Therefore, for the selection of exclusive sample only those events were accepted that contain exactly one photon and one lepton in the forward spectrometer. The following requirements were imposed on the kinematics of the event: $Q^2 > 1\ GeV^2$, $0.03 < x_B < 0.35$, $-t < 0.7\ GeV^2$, and the energy of the photon was required to be larger then 5 GeV. Since the recoiling nucleon or nuclei was not detected, exclusivity was achieved via the missing mass technique. The exclusive missing mass window was defined as $-2.25\ GeV^2 < M_X^2 < 2.89\ GeV^2$ (negative M_X^2 values were obtained due to the finite resolution of the spectrometer). By using the missing mass technique, it is not possible to separate the signal from the associated process where the final nucleon is exited into a resonant state. Based on Monte Carlo simulation an overall contribution from associated processes was estimated to be of an order of 12%.

The asymmetries from Eq. 2 were expanded into Fourier harmonics in the azimuthal angles ϕ and ϕ_S and the corresponding asymmetry amplitudes were extracted simultaneously using a maximum likelihood fit method.

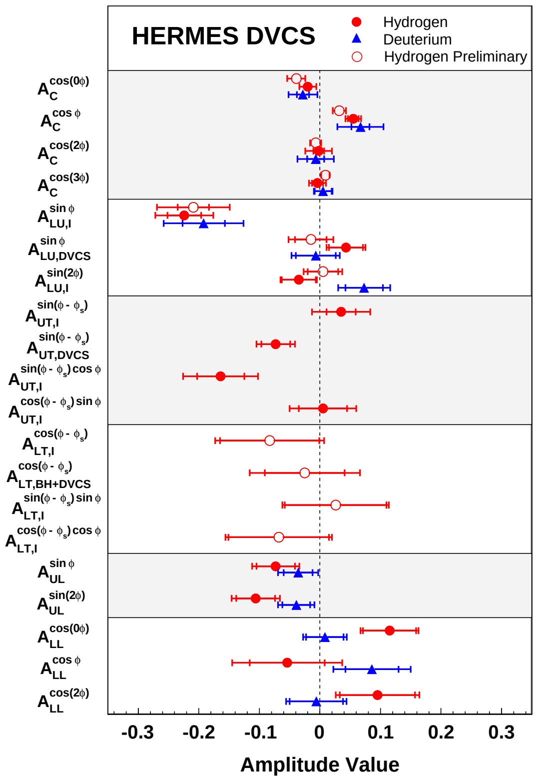

FIGURE 1. Overview of azimuthal asymmetry amplitudes extracted at HERMES.

RESULTS

An overview of all extracted azimuthal asymmetry amplitudes corresponding to the entire HERMES kinematics is presented in Figure 1, for both Hydrogen and Deuterium targets. The amplitudes of the beam–helicity and beam–charge asymmetries $A_{LU}^{DVCS}(\phi)$, $A_{LU}^{I}(\phi)$ and $A_C(\phi)$ were first reported in Ref. [6] for Hydrogen target and in Ref. [7] for deuterium target. A significant non-zero $\cos(\phi)$ and $\sin(\phi)$ amplitudes were observed respectively for beam-charge $A_C(\phi)$ and beam–helicity $A_{LU}^{I}(\phi)$ asymmetries. These two amplitudes are sensitive to the real and imaginary parts of CFF $\mathscr{H}$ respectively. For the case of deuterium target the leading amplitudes of beam-charge and beam-helicity asymmetries are sensitive respectively to the real and imaginary parts of CFF $\mathscr{H}_1$. Within the precision of current measurement the results on both targets agree with each other. The results for $\sin(\phi)$ amplitude of the asymmetry $A_{LU}^{DVCS}(\phi)$ are consistent with zero for both targets.

On the bottom panels of Figure 1, the results of the longitudinal single-target-spin $A_{UL}(\phi)$ and double-spin $A_{LL}(\phi)$ asymmetries are presented, that were first reported in Refs. [8, 9]. For the case of hydrogen target, the leading amplitudes of these asymmetries are sensitive to the imaginary and real parts of CFF $\widetilde{\mathscr{H}}$ respectively, while for the deuterium target they are sensitive to CFF $\widetilde{\mathscr{H}}_1$. The results obtained on both targets are consistent with each other.

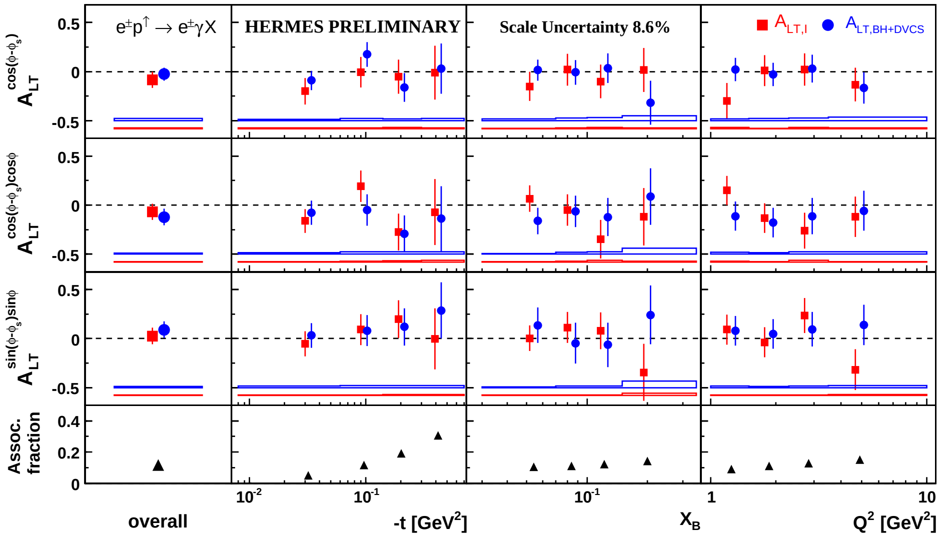

FIGURE 2. The leading amplitudes of transverse double–spin asymmetries $A^{I}_{LT}(\phi,\phi_S)$ and $A^{BH+DVCS}_{LT}(\phi,\phi_S)$ in hard exclusive electroproduction of real photons at the HERMES experiment.

Also shown on Figure 1 are the leading amplitudes of transverse single–target–spin asymmetry, measured on Hydrogen target [10]. The amplitude $A^{\sin(\phi-\phi_S)\cos(\phi)}_{UT,I}$ that has significant negative value, is sensitive to the imaginary part of CFF $\mathscr{E}$, while the real part of CFF $\mathscr{E}$ can be accessed through measurement of transverse–double-spin asymmetries. The leading amplitudes of double-spin asymmetries $A^{I}_{LT}(\phi,\phi_S)$ and $A^{BH+DVCS}_{LT}(\phi,\phi_S)$, corresponding to the entire HERMES kinematics are shown on Figure 1 and Figure 2 (left column). On Figure 2 also presented are the results in bins of $-t, x_B$ and Q^2. The error bars (bands) represent the statistical (systematic) uncertainties. The systematic uncertainties include the contributions from the effects of acceptance, smearing, bin width, and the alignment of the detectors with respect to the beam direction and are estimated from a Monte Carlo simulation. The results of double-spin asymmetries are consistent with zero over almost all kinematic regions. The bottom panel shows relative contribution of associated processes that were obtained by Monte Carlo simulations.

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