Deeply virtual compton scattering at HERMES

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Deeply Virtual Compton Scattering at HERMES

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Abstract. Single-spin asymmetries in the hard exclusive electroproduction of real photons have been measured for the first time. The data have been accumulated by the HERMES experiment at DESY using polarized and unpolarized hydrogen gas target internal to the 27.5 GeV polarized positron beam.

Inclusive deep-inelastic lepton-nucleon scattering experiments played a significant role in our understanding of the internal structure of the nucleon. Recent progress in this field is related to exclusive reactions and the *skewed parton distributions (SPD's)* which take into account the dynamical correlations between partons of different momenta. The SPD-framework can be used to evaluate a wide range of observables, such as electromagnetic form factors, inclusive parton distributions and exclusive meson-production cross sections.

One of the cleanest channels that can be used to measure SPD's is deeply virtual Compton scattering (DVCS), i.e. the observation of a multi-GeV photon radiated from a single quark in deep-inelastic lepton-nucleon scattering , when highly virtual photon (with large Q^2) is absorbed and the squared four-momentum transfer between initial- and final state nucleon, t, is small. This reaction is unique, as the produced real photon carries direct information about partonic structure of the nucleon without being distorted by hadronization processes. Another particular interest to DVCS measurements was triggered by its connection to the spin structure of the nucleon. In [1] it has been argued that DVCS provides information on the total angular momentum ($J = 1/2(\Delta\Sigma) + L$) of the partons in the nucleon. In view of the non-trivial spin structure of the nucleon, independent information on the angular momentum decomposition of the nucleon spin is highly desirable. It should be noted, though, that the exact relation between DVCS measurements and spin decomposition of the nucleon is still a subject of continued theoretical debate. Significant progress has been made in the last few years in our understanding of not

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only DVCS, but also other exclusive processes in the deep-inelastic domain [2–5]. However, a full overview of theoretical papers related to this subject is out of scope of our presentation.

On the other hand, experimental information on DVCS is almost absent. Recently, both collider experiments at HERA, ZEUS and H1 [8,7], have presented an excess of the real γ-production rate over background, which was interpreted as evidence of DVCS in the range of very low x_{Bj} (the Bjorken scaling parameter). In this paper we present the first measurement of a single-spin asymmetry in DVCS, which was obtained by the HERMES collaboration using the HERA polarized positron beam. Both, unpolarized and polarized (spin averaged) hydrogen target data have been included in this analysis.

In order to access the DVCS amplitudes either one has to select a kinematical domain where the Bethe-Heitler (BH) amplitudes are suppressed, or one has to use the interference between the BH and DVCS processes. In the present experiment we exploit the latter option. Following [6] the cross section for leptoproduction of real photons can be written as

$$\frac{d\sigma}{d\phi dt dQ^2 dx_{Bj}} = \frac{x_{Bj} y^2}{32\,(2\pi^4)\,Q^4} \frac{|\tau_{BH} + \tau_{DVCS}|^2}{\left(1 + 4x_{Bj}^2 m^2/Q^2\right)^{1/2}}, \tag{1}$$

where τ_{BH}, τ_{DVCS} are the BH and DVCS amplitudes, $y = \nu/E_e$ is the fraction of the incoming lepton energy carried by the virtual photon, Q^2 its negative four-momentum squared, and m the proton mass. The full expression with all terms included is very lenghty, therefore it is omitted here. However interference term can be expressed as follows

$$(\tau_{BH}^* \tau_{DVCS} + \tau_{DVCS}^* \tau_{BH})_{pol} \sim e_l P_l \left[-sin\phi \cdot \sqrt{\frac{1+\epsilon}{\epsilon}} \mathrm{Im}\tilde{M}^{1,1} + sin2\phi \cdot \mathrm{Im}\tilde{M}^{0,1} \right] \tag{2}$$

In this equation the quantities $\tilde{M}^{\lambda,\lambda'}$ are linear combinations of the DVCS helicity amplitudes $M_{h,h'}^{\lambda,\lambda'}$ with λ, λ' (h, h') representing the helicities of the initial and final-state photon (target nucleon). $e_l = \pm 1$ (lepton charge) and $P_l = \pm 1$ (lepton helicity) of the incident lepton show the sensitivity of the interference term to the difference between electron and positron scattering and spin direction of incoming beam respectively. ϕ is defined as the angle between the lepton scattering plane and the plane defined by the virtual and real photon. The dependence of the cross section on ϕ gives rise to azimuthal asymmetries. The kinematical quantity ϵ represents the longitudinal-transverse polarization of the virtual photon.

Since $|\tau_{DVCS}|^2$ is very small and $|\tau_{BH}|^2$ does not depend on the lepton beam helicity, the interference term given above will dominate measurements of the cross-section asymmetry with respect to the lepton beam helicity P_l. From the equation above it can be seen that such measurements provide information on the imaginary part of the DVCS amplitudes $\tilde{M}^{1,1}$ and $\tilde{M}^{0,1}$.

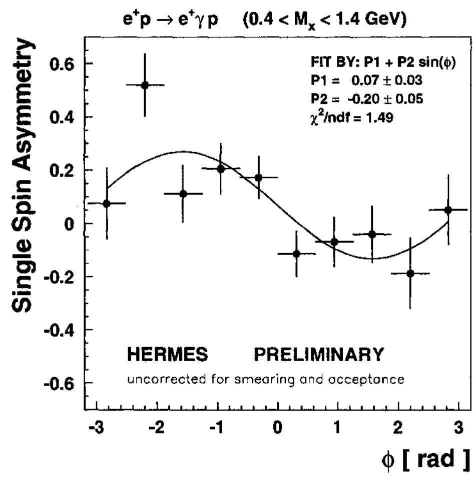

FIGURE 1. Single-spin asymmetry as a function of azimuthal angle ϕ.

The HERMES detector [9] is a forward spectrometer that identifies charged particles in the scattering angle range of $0.04 < \theta < 0.22$ rad. The electromagnetic lead-glass calorimeter and preceding scintillator counters with preshower were used to measure the energy deposition of a cluster without a track in the wire chamber detectors, that was identified as a photon.

The exclusive photons observed in the present analysis can be contaminated by decay photons from π^0 mesons. This contamination has been estimated by comparing exclusive π^+ and π^0 mesons observed within the HERMES acceptance in the range $0 < M_x < 2$ GeV, where $M_x^2 = (q + P_p - P_\gamma)^2$ with q, P_p and P_γ being four-momenta of virtual gamma, target nucleon and produced real photon respectively. It was found that the π^+ production rate is 5 times higher than that of the π^0's. Then in the same M_x-domain the real photon rate is 10 times higher than π^+ rate. Hence, the contamination of real photons due to π^0 decay is at most 2%.

A better measure of the sensitivity of the data to DVCS can be obtained from the ϕ-dependence of the cross-section asymmetry with respect to the beam helicity. In order to have a full coverage in the azimuthal angle ϕ and in order to ensure near collinearity of the virtual photon and the produced photon, the following requirement was introduced. Only data were selected with $0.015 < \theta_{\gamma\gamma^*} < 0.07$, where $\theta_{\gamma\gamma^*}$ represents the angle between the direction of the virtual photon and the produced real photon. The minimum value of $\theta_{\gamma\gamma^*}$ is dictated by the granularity of the calorimeter, and has been derived from a Monte-Carlo study. The obtained single-spin asymmetry is displayed in Fig.1. In this figure data have been selected with a missing mass between 0.4 and 1.4 GeV, i.e. including both the proton and the $\Delta(1232)$-resonance. As the data show a clear azimuthal asymmetry, which can only be caused by the DVCS subprocess, this result provides strong evidence for the observation of photons due to deeply virtual Compton scattering. Average values of relevant kinematical variables in this measurement are: $< Q^2 > = 2.5\ GeV^2$, $< -t > = 0.2\ GeV^2$ and $< x_{Bj} > = 0.1$. The contribution of the BH-subprocess to the single-spin asymmetry shown in Fig.1 has been estimated using the aforementioned Monte-Carlo calculation. The false asymmetry due the BH subprocess was thus estimated to be at the level of only 2-3% of the measured asymmetry. Further checks of this result were carried out by dividing the acceptance of the HERMES spectrometer into four quadrants and extracting the single-spin asymmetry for each piece separately. In a similar fashion the single-spin asymmetry has also been determined for 3 different (with roughly the same number of events) time periods. Taken together all of these checks imply that the results are stable to within 5% of the measured asymmetry. In order to be able to compare the ϕ-dependence of the single-spin asymmetries for different mass bins, we introduce the $sin\phi$-weighted single-spin azimuthal asymmetry:

$$A_l = \frac{2 < sin\phi >_{LU}}{< |P_B| >} = \frac{2 \int_0^{2\pi} d\phi\ (d\sigma/d\phi)\ sin\phi}{< |P_b| > \int_0^{2\pi} d\phi\ (d\sigma/d\phi)}, \tag{3}$$

where $|P_b|$ represents the average absolute value of the beam polarization as measured with lepton type l. The superscript LU means polarized beam and unpolarized target.

In Fig.2 (left panel) the measured value of the $sin\phi$-moment of the azimuthal asymmetry is plotted versus missing mass M_x for two helicity states of the positron beam. Also shown are the data for both helicity states together, weighted by the integrated luminosities for each helicity state. As can be seen the sign of the asymmetry is clearly opposite for the two beam helicities. Also, the beam-spin averaged data are consistent with zero, as it is expected. In fact, the beam-spin averaged data can be used as a measure of the false-asymmetry of the data, which – averaged between 0 and 2 GeV – yields a false asymmetry of 5%.

As the data in Fig.2 (left panel) for the two beam-helicity states represent the same physics information, it is natural to combine the two results. To this end, we define the difference of the sine-weighted single-spin azimuthal asymmetry for the two beam-helicity states by:

$$A_{LU}^{sin\phi} = \frac{2 \int_0^{2\pi} d\phi\ (d\sigma^+/d\phi - d\sigma^-/d\phi)\ sin\phi}{< |P_b| > \int_0^{2\pi} d\phi\ (d\sigma^+/d\phi + d\sigma^-/d\phi)}, \tag{4}$$

where the superscripts +,- refer to the two beam-helicity states. The data for this sine-weighted asymmetry $A_{LU}^{sin\phi}$ are presented in Fig.2 (right panel) versus missing mass. A large asymmetry is observed in the missing mass region close to $M_x = m_p$. It is of interest to note that the asymmetry observed in the M_x-bins below m_p is

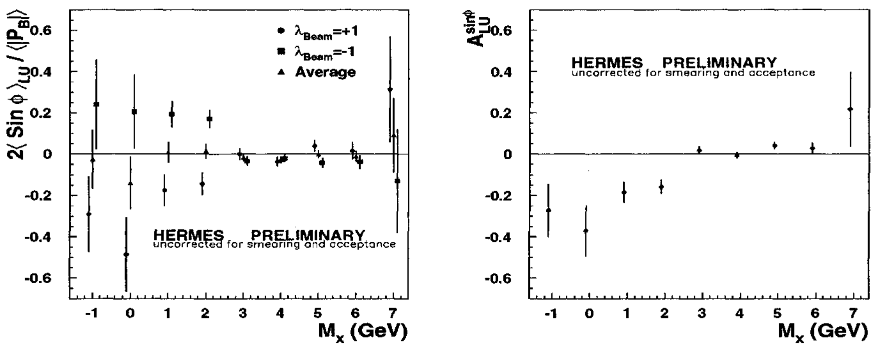

FIGURE 2. Sin-weighted azimuthal asymmetry for each beam-helicity state and averaged (left panel). The same for two beam-helicity states combined (right panel).

within errors the same as the asymmetry near m_p, which is to be expected as the observed strength below m_p is entirely due to the limited energy resolution of the experiment. If we combine the sine-weighted asymmetry $A_{LU}^{sin\phi}$ in the full M_x region that corresponds to exclusive photon production, a value of 0.20 ± 0.05 (stat) is found.

In summary, the single-spin asymmetry for the hard exclusive electroproduction of photons has been measured for the first time. A large value of asymmetry is observed in the exclusive limit, i.e. for $M_x \approx m_p$. The observed azimuthal asymmetry has the $sin\phi$ dependence and beam-helicity dependence expected for the interference amplitude between deeply virtual Compton scattering and the Bethe-Heitler process. Further information on DVCS in deep-inelastic lepton scattering can be obtained by also studying the lepton-charge asymmetry. Togeteher with the single-spin asymmetry measurement this will allow to access imaginary and real parts of all leading-, as well as non-leading amplitudes.

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