The interference of Deeply Virtual Compton Scattering (DVCS) and Bremsstrahlung leads to a beam-charge asymmetry that can be observed for exclusive photon production in the collision of high energy leptons and nucleons/nuclei. Recent results for a hydrogen and a deuterium target are reported and a consistent tendency for a rise of the cosine $\phi$ coefficient with momentum transfer $|t|$ has been found.

1 Introduction

In high energy collisions of leptons and nucleons/nuclei there are two mechanisms that contribute to the exclusive production of single photons at leading order QED: Either the photon is emitted by the lepton, in which case the process is called Bremsstrahlung or Bethe Heitler process (BH), or it is emitted by the nucleon/nucleus or one of its components.

The description of the latter process depends on the hadronic structure and it was shown that the relevant properties of nucleons/nuclei can be parameterised by generalised parton distributions (GPDs) under the condition that suitable scattering kinematics are selected: If the four-momentum of the incoming (outgoing) lepton is denoted by $k$ ($k'$), the four-momentum of the incoming (outgoing) nucleon/nucleus is denoted by $P$ ($P'$) and the four-momentum of the real photon is denoted by $v$, the following requirements have to be fulfilled: The four-momentum transfer $Q^2 = -(k' - k)^2$ must be much larger than the mass of the nucleon/nucleus, the final state mass $W^2 = (v + P')^2$ must be outside the resonance region and the four-momentum transfer $-t = -(q - v)^2$ must be small compared with the target mass and $Q^2$. Under these conditions the latter process can be interpreted as Deeply Virtual Compton Scattering (DVCS) (fig.1) and the absorption of the virtual photon and the emission of the real photon are due to a single quark. The probability of removing and reinserting the quark is parametrised by the GPDs.
Figure 1: Deeply Virtual Compton Scattering: A virtual photon interacts with a quark from a nucleon/nucleus and the quark returns into the nucleon/nucleus after the emission of a real photon.

In reality BH and DVCS mix due to quantum-mechanical interference and thus the total cross-section involves a GPD-dependent interference term that is sensitive to beam-charge and beam-polarisation for all unpolarised hadronic targets.

For the nucleon 4 leading twist GPDs exist, namely $H$, $E$, $\tilde{H}$ and $\tilde{E}$. Each of them depends on 3 variables: the lightcone momentum fraction $x$ of the quark inside the nucleon/nucleus, the lightcone momentum transfer $\xi$ and the value of $t$. GPDs are constrained by conventional quark distributions and nucleon formfactors and can also be used to describe hard exclusive meson production.

For other targets, different numbers of GPDs are required, e.g. one GPD for a spin-0 target like neon, or nine GPDs for a spin-1 target like deuterium. In addition for all nuclear targets BH/DVCS can also take place on single nucleons, especially at larger momentum transfers $|t|$. Apart from binding effects in this case one effectively probes the GPDs of the nucleon. Moreover, this incoherent process can also occur with simultaneous excitation of the nucleon into a resonant state. Also the coherent formation of nuclear excitations may be possible. If the hadronic final state is not explicitly detected, all these processes are difficult to discriminate experimentally.

2 Experimental Setup and Previous Results

HERMES is a fixed-target experiment based on a multi-purpose forward spectrometer. Its internal gas target has been operated with various unpolarised gases (e.g. H, D, Ne) as well as vector-polarised hydrogen and vector and tensor-polarised deuterium.

In the case of BH/DVCS typically only the lepton and the photon are inside the acceptance of the spectrometer. While the lepton is detected and identified by several driftchambers as well as a transition radiation detector (TRD), a preshower hodoscope (H2) and the electromagnetic calorimeter, the photon is only detected by H2 and the calorimeter. The requirement is imposed that no other charged tracks or untracked clusters in the calorimeter are present in the same event. In addition standard fiducial volume cuts are applied and the energy transfer $\nu$ to the virtual photon in the laboratory system is required to be less than 22 GeV for trigger stability reasons. Furthermore cuts on the event kinematics are applied: As discussed above, $Q^2 > 1$ GeV$^2$, $W^2 > 9$ GeV$^2$ and $-t < 0.7$ GeV$^2$ are required. For acceptance reasons the angle $\theta_{\gamma^*\gamma}$ between the real and the virtual photon (assuming DVCS) is restricted to be less than 45 mrad, while detector smearing is considered to be acceptable above $\theta_{\gamma^*\gamma} = 5$ mrad. A cut on the photon energy of $E_\gamma > 3$ GeV suppresses photons from meson decays.

In order to ensure exclusivity of an event the missing mass $M_x$ of the hadronic final state is calculated under the assumption of a target proton that was at rest. If $M_x^2$ is found to be negative, $M_x$ is defined as $-\sqrt{-M_x^2}$. For exclusive events $-1.5$ GeV $< M_x < +1.7$ GeV is required, which selects coherent as well as incoherent BH/DVCS events for all nuclear targets. The background of other event types - mainly photons from $\pi^0$-decay - is determined from a data/Monte Carlo comparison and subtracted after estimating the background asymmetry.
The remaining event sample for a Deuterium target is dominated by incoherent, elastic BH/DVCS on the proton, which contributes approximately 50% to the event statistics for all values of $t$. Coherent BH/DVCS on the deuteron only has a sizable contribution to the event sample in the lowest $|t|$-region (about 40% in the lowest $|t|$-bin). The remaining fraction is shared between the incoherent process with resonance excitation and the incoherent, elastic process on the neutron.

Already some time ago HERMES has reported the observation of a significant single beam-spin asymmetry on Deuterium as well as on other targets using similar data selection criteria. These results were supported by measurements at JLAB which showed a beam-spin asymmetry of comparable size but the opposite sign, since the opposite beam-charge is used.

3 Beam-charge Asymmetry on Hydrogen and Deuterium

The beam-charge asymmetry $A_C$ of BH/DVCS may be even more interesting for the following reason: It is known that the (here) dominant GPDs $H^q$ approach the ordinary quark distributions as function of $x$ in the limit of $\xi \to 0$ and $t \to 0$. The negative $x$ region corresponds to the antiquark distribution as a function of $|x|$ and with negative sign.

Far away from this kinematic limit only the integral over $x$ is constrained by the Dirac formfactor of the nucleon. This condition does not restrict contributions to $H^q$ that are entirely odd in $x$ and there are at least two candidates for this: The contribution from sea-quarks and the so-called D-term. Little is known about them and $A_C$ picks out exactly these parts.

For the following results the beam-charge asymmetry on deuterium has been calculated as

$$A_C(\phi) = \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)}$$

in 10 bins in $\phi$, where $\phi$ denotes the azimuthal orientation of the real photon about the direction of the virtual photon and $N^+$ and $N^-$ are the luminosity-weighted event numbers for positive and negative beam-charge, respectively. The asymmetry has been fitted by the following function:

$$A(\phi) = A_C^{\text{const.}} + A_C^{\cos \phi} \cos(\phi) + A_C^{\sin \phi} \sin(\phi).$$

Two different deuterium datasets exist at HERMES: one dataset is taken with an unpolarised target and one dataset has a vanishing vector polarisation $V_d$, but a large positive tensor polarisation. Figure 2 (left) shows the beam-charge asymmetries from the second subset as a
asymmetry arises from a mixed dataset, it is more instructive to study the asymmetry as a function of \( t \). This is shown in figure 2 (right). For both datasets there is a tendency that the asymmetry rises to positive values for large values of \( |t| \). In the low \( |t| \)-range there could be a difference due to tensor-effects in the coherent process, but such a difference is not observed. It has to be noted that due to the limited statistics and the comparatively large kinematical bins in \( t \) there is an additional model-dependent binning error on the coefficient \( A_C^{\cos \phi} \) that is estimated to be about 20 to 30 per cent in comparison with the true asymmetry at bin center.

As shown in figure 3 (left) the obtained results are consistent with the proton results that have been extracted using the same procedure. The apparent difference in the highest bin in \( |t| \) can be due to the resonance contributions, which may be different for the proton and the neutron but are essentially unknown.

As an additional cross-check the coefficient \( A_C^{\cos \phi} \) has been obtained as a function of the missing mass. Figure 3 (middle, right) demonstrates that the asymmetry is only found to be non-zero for the exclusive missing mass range - as expected.

The observed results for the beam-charge asymmetry on deuterium can approximately be described by Monte Carlo models\(^{11} \). However, no sea-quark contribution is at present included in these models and also the DVCS amplitude for resonance excitation is omitted. Thus there exists considerable freedom to adjust the model predictions to the observed results.

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