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Deeply Virtual Compton Scattering and its Beam Charge Asymmetry in $e^{\pm}p$ collisions at HERA

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A measurement of elastic deeply virtual Compton scattering $\gamma^* p \to \gamma p$ using $e^+ p$ and $e^- p$ collision data recorded with the H1 detector at HERA is presented. The analysed data sample corresponds to an integrated luminosity of 306 pb^{-1}, almost equally shared between both beam charges. The cross section is measured as a function of the virtuality Q^2 of the exchanged photon and the centre-of-mass energy W of the $\gamma^* p$ system in the kinematic domain $6.5 < Q^2 < 80$ GeV^2, $30 < W < 140$ GeV and $|t| < 1$ GeV^2, where t denotes the squared momentum transfer at the proton vertex. The cross section is determined differentially in t for different Q^2 and W values and exponential t-slope parameters are derived. Using $e^+ p$ and $e^- p$ data samples, a beam charge asymmetry is extracted for the first time in the low Bjorken x kinematic domain. The observed asymmetry is attributed to the interference between Bethe-Heitler and deeply virtual Compton scattering processes. The measurements are discussed in terms of QCD interpretation comparing it to a NLO QCD calculation based on generalised parton distributions (GPDs) and to colour dipole approach predictions. The skewedness factor and the ratio between real and imaginary parts of the DVCS amplitude are extracted from the data.

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Deeply Virtual Compton Scattering (DVCS), sketched in figure 1, consists of the hard diffractive scattering of a virtual photon off a proton. The interest of the DVCS process resides in the particular insight it gives to the applicability of perturbative Quantum Chromo Dynamics (QCD) in the field of diffractive interactions and to the nucleon partonic structure.

The study of hard exclusive reactions in the Bjorken limit is crucial to constrain further the partons densities towards low x and to obtain information on their transverse distributions and dynamical correlations in the nucleon. DVCS cross section measurements [1, 2, 3, 4, 5] at HERA, similar to diffractive vector meson electroproduction [6] but with a real photon replacing the final state vector meson, is an important source of information to study the partons, in particular gluons, inside the proton for nonforward kinematics and its relation with the forward one. In the presence of a hard scale, the DVCS scattering amplitude factorises into a hard scattering part calculable in perturbative QCD and parton distributions which contain the non-perturbative effects due to the proton structure. In hard exclusive production the proton structure has to be encoded in a generalized form (Generalised Parton Distributions or GPDs) to include the difference of longitudinal momentum fractions of the two partons, ξ, and transverse momentum exchange at the proton vertex.

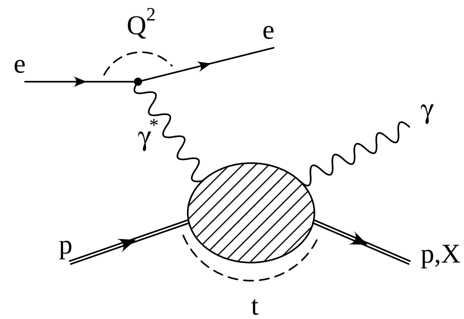

Figure 1: The DVCS process.

This paper reports the recent measurement, published in [3], of single and double differential DVCS cross sections as a function of Q^2 and the $\gamma^* p$ centre-of-mass energy W. The single differential cross section $d\sigma/dt$ is also extracted. The data were recorded between the years 2004 and 2007 with the H1 detector when HERA collided protons of 920 GeV energy with 27.6 GeV electrons and positrons. The total integrated luminosity of the data is 306 pb^{-1}. The data comprise 162 pb^{-1} recorded in e^+p and 144 pb^{-1} in e^-p collisions.

1. Cross Sections and t-dependence

The Q^2 and the W dependencies of the DVCS cross section are displayed in figure 2 and are in agreement within errors with the previous measurements [1, 2, 4, 5]. The data agree also with

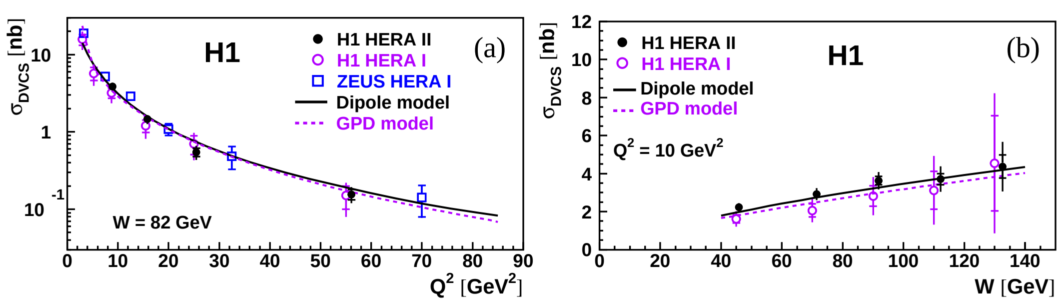

Figure 2: The DVCS cross section as a function of Q^2 at $W = 82$ GeV (a) and as a function of W at $Q^2 = 8$ GeV^2 (b).

models based on GPDs [7] or the dipole approach [8]. The steep rise of the cross section with W is an indication of the presence of a hard underlying process.

The W dependence of the DVCS cross section is determined for three separate ranges of Q^2, centered at 8, 15.5 and 25 GeV^2, and fitted with the form W^δ. The corresponding δ values are presented in Figure 3(a). It is observed that δ is independent of Q^2 within the errors. Using the complete analysis sample, the average δ value measured is $0.63 \pm 0.08 \pm 0.14$, where the first error is statistical and the second systematic.

The differential cross section as a function of t has been measured for three values of Q^2 and W. Fits of the form $d\sigma/dt \sim e^{-b|t|}$ are performed to extract possible dependence is of b in Q^2 and W. No significant variation of b with W is observed. The Q^2 dependence is presented in figure 3(b) together with values of the previous H1 measurement [1]. Using the complete analysis sample, the value of b expressed at $Q^2 = 10$ GeV^2 is found to be $5.41 \pm 0.14 \pm 0.31$ GeV^{-2}.

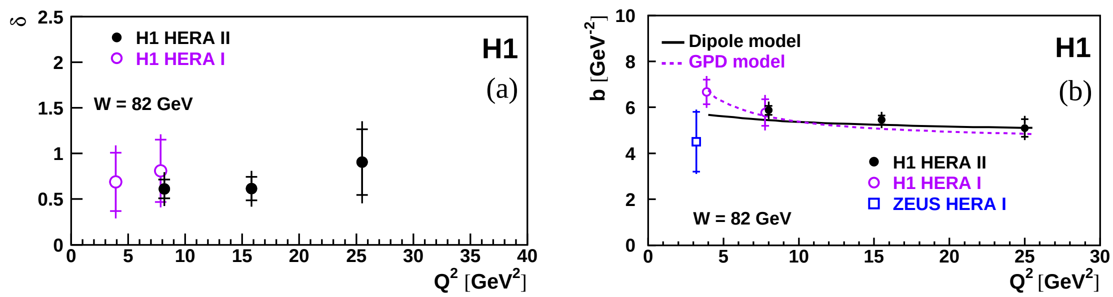

Figure 3: a) Results of fits of the form W^δ to the cross section for different values of Q^2. b) The fitted t-slope parameters $b(Q^2)$.

2. QCD Interpretation in Terms of GPDs

The measurement described above shows that the Q^2 dependence of the t-slope b is non-negligible. Therefore to study the Q^2 evolution of the GPDs themselves, we introduce the dimensionless observable S:

$$S = \sqrt{\frac{\sigma_{DVCS}\, Q^4\, b(Q^2)}{(1+\rho^2)}}\,,$$

where the Q^2 dependencies of the cross section are corrected for the photon propagator and the $b(Q^2)$. S is calculated for each Q^2 bin from the cross section measurements of [1, 2].

The results for S are presented in figure 4(a) together with the prediction of a GPD model [9], based on the PDFs parametrisation given in [10]. It is observed that the

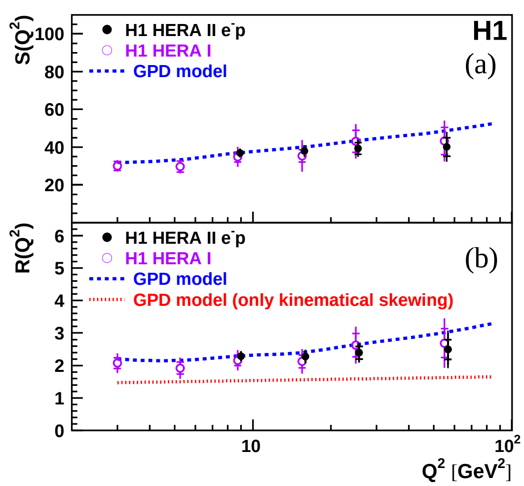

Figure 4: The observables S and R (see text), shown as a function of Q^2.

pQCD skewed evolution equations used in [9] provide a reasonable description of the measured weak rise of S with Q^2.

The magnitude of the skewing effects [11] present in the DVCS process can be extracted by constructing the ratio of the imaginary parts of the DVCS and DIS amplitudes:

$$R \equiv \frac{\mathscr{I}m A(\gamma^* p \to \gamma p)_{t=0}}{\mathscr{I}m A(\gamma^* p \to \gamma^* p)_{t=0}}$$

At leading order in α_s, as in the GPD formalism the DVCS amplitude is directly proportional to the GPDs, R is equal to the ratio of the GPDs to the PDFs. In the following, the virtual photon is assumed to be mainly transversely polarised in the case of the DVCS process due to the real photon in the final state and therefore has to be taken as transversely polarised in the DIS amplitude too. The expression for R as a function of the measured observables can be written as

$$R = \frac{4\sqrt{\pi\ \sigma_{DVCS}\ b(Q^2)}}{\sigma_T(\gamma^* p \to X)\sqrt{(1+\rho^2)}}\ . \qquad (2.1)$$

R is evaluated using the relation $\sigma_T(\gamma^* p \to X) = 4\pi^2\alpha_{EM}F_T(x,Q^2)/Q^2$ and taking $F_T = F_2 - F_L$ from the QCD analysis presented in [12] and ρ is determined from dispersion relations as in [13] The measured values of the ratio R for each Q^2 bin are shown in figure 4(b) and compared with the calculation based on the GPD model proposed in [9]. The typical values of R are around 2, whereas in a model without skewing R would be equal to unity. Therefore, the present measurement confirms the large effect of skewing. In GPD models, two different effects contribute to skewing: the kinematics of the DVCS process and the Q^2 evolution of the GPDs. In figure 4(b) the data are compared to a model which takes only the former effect into account (dotted line). The present measurements show that such an approximation is not sufficient to reproduce the total skewing effects observed in the data.

3. Beam Charge Asymmetry

The separate e^+p and e^-p data samples are used to measure the beam charge asymmetry as a function of ϕ:

$$A_C(\phi) = \frac{d\sigma^+/d\phi - d\sigma^-/d\phi}{d\sigma^+/d\phi + d\sigma^-/d\phi},$$

where ϕ is the angle between the plane containing the incoming and outgoing leptons and the plane formed by the virtual and real photons. The measured A_C integrated over the kinematic range of the analysis, presented in figure 5, is in good agreement with the model prediction [7].

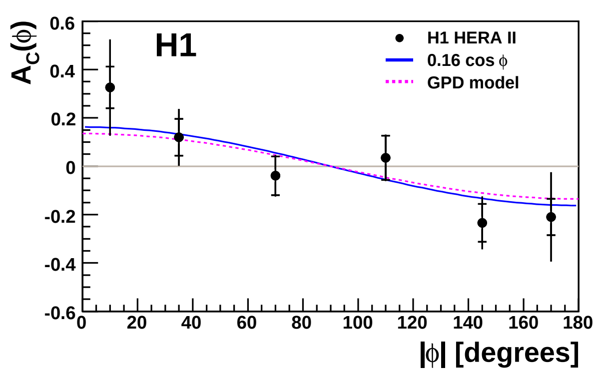

Figure 5: Beam charge asymmetry as a function of ϕ.

The beam charge asymmetry can be expressed as

$$A_C(\phi) = p_1 \cos\phi = 2A_{BH} \frac{\mathrm{Re}A_{DVCS}}{|A_{DVCS}|^2 + |A_{BH}|^2} \cos\phi.$$

The χ^2 minimisation procedure leads to a p_1 value of $p_1 = 0.16 \pm 0.04 \pm 0.06$. The term $|A_{DVCS}|^2$ can be derived directly from the DVCS cross section measurement $\sigma_{DVCS} = |A^2_{DVCS}|/(16\pi b)$. As the Bethe-Heitler (BH) amplitude is precisely known, the measured asymmetry is directly proportional to the real part of the DVCS amplitude and the ratio between real and imaginary parts of the DVCS amplitude, $\rho = \mathrm{Re}A_{DVCS}/\mathrm{Im}A_{DVCS}$, can be extracted. The first measurement of this ratio ever done in the low x region is found to be $\rho = 0.20 \pm 0.05 \pm 0.08$. The dispersion relation using our measurement of $\delta(Q^2)$ on the other hand leads to $\rho = 0.25 \pm 0.03 \pm 0.05$, in good agreement with the direct determination. While in the low x domain of the present measurement, the real part of the DVCS amplitude is positive, in contrast, at larger x ($x \sim 0.1$) and lower Q^2, a smaller and negative real part was measured by the HERMES Collaboration [14] (note that the convention used in [14] for the definition of the ϕ angle is different from ours). The GPD model considered here [7] correctly describes the measured A_C as well as ρ.

The measurements presented here show that a combined analysis of DVCS observables, including cross section and charge asymmetry, allows the extraction of the real part of the DVCS amplitude and subsequently a novel understanding of the correlations of parton momenta in the proton.

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