DVCS and its t -dependence at HERA-II

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A measurement of elastic deeply virtual Compton scattering $\gamma^*p \rightarrow \gamma p$ using e^-p collision data recorded with the H1 detector at HERA is presented. The analysed data sample corresponds to an integrated luminosity of 145 pb^{-1} . 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 γ^*p system in the kinematic domain $6.5 < Q^2 < 80 \text{ GeV}^2$, $30 < W < 140 \text{ GeV}$ and $|t| < 1 \text{ GeV}^2$, 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. 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.

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 Chromodynamics (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 parton densities towards low x and to obtain information on their transverse distributions and dynamical correlations in the nucleon. DVCS cross section measurements [2, 3, 4] at HERA, similar to diffractive vector meson electroproduction [5] but with a real photon replacing the final state vector meson, become 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 γ^*p centre-of-mass energy W .

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The single differential cross section $d\sigma/dt$ is also extracted. The data were recorded in the years 2005 and 2006 with the H1 detector when HERA collided protons of 920 GeV energy with 27.6 GeV electrons. The sample of 2538 events corresponds to an integrated luminosity of 145 pb^{-1} , four times larger than the previous H1 measurement [2] of DVCS in positron-proton collisions.

1 Cross Sections and t -dependence

The Q^2 and the W dependences of the DVCS cross section are displayed in figure 2 and are in agreement within errors with the previous measurements [2, 4]. 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 value of δ expressed at $Q^2 = 8 \text{ GeV}^2$ is found to be $0.74 \pm 0.11 \pm 0.16$, 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 dependences 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 [2]. This Q^2 dependence can be parametrised [6] as $b(Q^2) = A(1 - B \log(Q^2/(2 \text{ GeV}^2)))$. A fit to the measured b values yields $A = 6.98 \pm 0.54 \text{ GeV}^{-2}$ and $B = 0.12 \pm 0.03$ and provides a good description over the whole Q^2 range. Using the complete analysis sample, the value of b expressed at $Q^2 = 8 \text{ GeV}^2$ is found to be $5.45 \pm 0.19 \pm 0.34 \text{ GeV}^{-2}$, where the first error is statistical and the second systematic.

Figure 2: The DVCS cross section as a function of Q^2 at $W = 82 \text{ GeV}$ (a) and as a function of W at $Q^2 = 8 \text{ GeV}^2$ (b). The results from the previous H1 and ZEUS publications [2, 4] based on HERA I data are also displayed. The inner error bars represent the statistical errors, the outer error bars the statistical and systematic errors added in quadrature.

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 $b(Q^2)$. The curve represents the result of the fit (see text).

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 :

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

where the Q^2 dependences 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 this analysis and from [2]. The results for S are presented in figure 4(a) together with the prediction of a GPD model [6], based on the PDFs parametrisation given in [7]. It is observed that the pQCD skewed evolution equations used in [6] provide a reasonable description of the measured weak rise of S with Q^2 .

The magnitude of the skewing effects [8] present in the DVCS process can be extracted by constructing the ratio of the imaginary parts of the DVCS and DIS amplitudes. At leading order in α_s , as in the GPD formalism the DVCS amplitude is directly proportional to the GPDs, this ratio

$$R \equiv \frac{\text{Im } A(\gamma^* p \rightarrow \gamma p)_{t=0}}{\text{Im } A(\gamma^* p \rightarrow \gamma^* p)_{t=0}}$$

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

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

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

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

R is evaluated using the relation $\sigma_T(\gamma^* p \rightarrow X) = 4\pi^2 \alpha_{EM} F_T(x, Q^2)/Q^2$ and taking $F_T = F_2 - F_L$ from the QCD analysis presented in [9] and ρ is determined from dispersion relations as in [10]. 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 [6]. 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 Geometric Scaling

The DVCS cross section can also be interpreted within the dipole model [10, 11]. In this picture the virtual photon fluctuates into a colour singlet $q\bar{q}$ pair (or dipole) of a transverse size $r \sim 1/Q$, which subsequently undergoes hard scattering with the gluons in the proton. At very small values of the Bjorken scaling variable x the saturation regime of QCD can be reached. In this domain, the gluon density in the proton is so large that non-linear effects like gluon recombination tame its growth. In [3] the present DVCS measurement combined with the previous H1 DVCS measurement [2] are compared to prediction of a dipole model [12] based on a transition to the saturation regime characterised by the so-called geometric scaling. In such an approach, the cross section can be approximated by a function of the single variable, $\tau = Q^2/Q_s^2(x)$ where $Q_s(x)$ is the saturation scale. The present measurement of the DVCS cross section is found to be compatible with such a geometric scaling using the same parameters as derived from inclusive DIS. For the first time, this scaling property is observed for different values of t .

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