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Studies of DVCS and photoproduction of photons at high t with the H1 detector

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Abstract. The diffractive scattering of photons off protons $\gamma^{(*)}p \to \gamma Y$ (where Y denotes the proton dissociative system or the elastically scattered proton) is measured in two different kinematic regimes at high energy with the H1 detector at HERA. i) the process is studied for the first time at large transverse photon momentum $p_t^\gamma > 2$ GeV in photoproduction regime ($Q^2 < 0.01$ GeV^2) and photon-proton c.m.s. energy $175 < W < 247$ GeV. The cross section is measured differentially in t and in $x_{I\!P}$. The measurement is compared to a LL BFKL prediction of QCD. ii) in electroproduction, the Deeply Virtual Compton Scattering (DVCS) $\gamma^* p \to \gamma p$ cross section has been measured more precisely and in an extended kinematic domain: at photon virtualities $4 < Q^2 < 80$ GeV^2 and $30 < W < 140$ GeV. The measurement is compared to NLO QCD calculations using the DGLAP approximation and to Colour Dipole model predictions.

PACS. 12.38.Qk Experimental tests – 12.38.Aw General properties of QCD

1 Introduction

The hard diffractive scattering of a photon off a proton: $\gamma^{(*)}p \to \gamma Y$ (where Y denotes the proton dissociative system or the elastically scattered proton) is an important process for the understanding of high energy diffraction. Its study allows to investigate the applicability and the relevance of perturbative Quantum Chromo Dynamics (QCD) and provides unique information on the proton structure. It gives access to new class of parton distribution functions, the Generalised Parton Distributions (GPD) that can be interpreted as parton correlation functions in the proton. Compared to vector meson production, the photon scattering is theoretically simpler because the theoretical predictions avoid uncertainties due to unknown meson wave functions.

In the present report, the process is studied in two different kinematic regimes.
i) the photoproduction of photons at high t (also called high t Virtual Compton Scattering)
ii) the Deeply Virtual Compton Scattering (DVCS).
In the first case, the hard scale needed for perturbative QCD predictions is provided by the large t value, where t is the squared 4-momentum transfer at the proton vertex, in the second, by the large Q^2 value. In the first case due to large t values, the cross section is largely dominated by the proton dissociation, while in the second, the measurement is performed in the elastic case ($Y = p$). The measurements can be compared to QCD predictions, respectively, in the two asymptotic limits BFKL and DGLAP.

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2 Photoproduction of photons at high t

The data for this analysis were collected with the H1 detector during the 1999-2000 running period, when HERA collided 27.6 GeV positrons with 920 GeV protons. An integrated luminosity of 47.6 pb^{-1} is used.
Photoproduction events were selected by detecting the scattered positron in the electron tagger of the luminosity system restricting the virtuality of the photon to $Q^2 < 0.01$ GeV^2 and the photon-proton centre of mass energy to $175 < W < 247$ GeV.
Photons with an energy of at least 8 GeV were identified in the electromagnetic part of the SPACAL calorimeter (covering the polar region $153^\circ < \theta < 177.8^\circ$ [1]). The hadronic final state, if visible, is measured in a liquid argon (LAr) calorimeter covering the range in polar angle $4^\circ < \theta < 153^\circ$. Diffractive events were selected by requiring that $y_{I\!P} < 0.018$, where

$$y_{I\!P} = \frac{p.(q-q')}{q.p} \simeq \frac{\sum_Y (E-P_z)}{2E_\gamma}. \qquad (1)$$

p and q being the 4-vectors of the incoming proton and photon respectively and q' the 4-vector of the scattered photon. The quantity is calculated experimentally by summing the $E - P_z$ of all hadronic final state objects in the event (i.e. all measured particles except the scattered electron and high p_t photon), and dividing by twice the incoming photon energy E_γ. As $y_{I\!P} \simeq e^{-\Delta\eta}$, this cut ensures

[1] θ is measured relative to the outgoing proton beam direction.

that there is a large rapidity gap between the photon and the proton dissociative system [2]. However, no proton dissociative system is required to be seen in the detector.
In addition to the kinematic variables defined above, the variable $x_{I\!P}$ is defined as

$$x_{I\!P} = \frac{q.(p-Y)}{q.p} \simeq \frac{(E+P_z)_\gamma}{2E_p}, \qquad (2)$$

where Y is the 4-vector of the proton dissociative system, $(E+P_z)_\gamma$ is the $E+P_z$ of the photon candidate and E_p is the energy of the incident proton.

The γp cross section differential in $x_{I\!P}$, in the range $175 < W < 247$ GeV, $p_{t(\gamma)} > 2$ GeV, $y_{I\!P} < 0.018$, is shown in Fig. 1 (upper). The largest systematic error is due to the uncertainty on the noise subtracted from the LAr calorimeter. The total systematic uncertainty is small compared to the statistical error. Also shown are the Monte Carlo prediction based on the leading logarithmic approximation (LL) of BFKL [1]. The data are sensitive to the choice of the $\overline{\alpha_s}$ parameter in the prediction through the slope in $x_{I\!P}$ related to the BFKL pomeron intercept and the normalisation. A choice of $\overline{\alpha_s} = 0.17$ gives a reasonable description of the data in both normalisation and shape. This is in comparison to the value $\overline{\alpha_s} = 0.18$ as used for recent H1 measurements on J/Ψ production [2, 3].
The γp cross section differential in the squared 4 momentum transfer t between proton and the incoming photon (where in photoproduction $-t \sim p^2_{t(\gamma)}$), in the range $175 < W < 247$ GeV, $0.0001 < x_{I\!P} < 0.0007$, $y_{I\!P} < 0.018$, is shown in Fig. 1 (lower). In this case, the agreement in the shape of the cross section between the Monte Carlo predictions and the data is perhaps more questionable, for all values of $\overline{\alpha_s}$ chosen here.

It is worth bearing in mind that there may be important contributions from higher order effects beyond the LL, so strong statements about the agreement may be premature. However, the fact that the measured cross section exhibits such a dramatic rise with energy ($W \sim 1/x_{I\!P}$) is a striking result, and there is an reasonable overall agreement with the LL BFKL predictions.

3 Deeply virtual compton scattering

First cross section measurements of the DVCS process were published by H1 [4] and ZEUS [5]. Here, the new H1 measurement is reported, in an extended kinematic range: $4 < Q^2 < 80$ GeV^2, $30 < W < 140$ GeV and $|t| < 1$ GeV^2, using integrated luminosity of 26 pb^{-1} of data taken during the year 2000 (i.e. 3.5 times larger than the previously published by H1 [4]).

At these small values of t the reaction $ep \to e\gamma p$ is dominated by the purely electromagnetic Bethe-Heitler (BH) process the cross section of which cross section,

[2] To ensure efficient background rejection, a minimum rapidity gap of $\Delta\eta = 2$ is required between the photon candidate and the edge of the proton dissociative system.

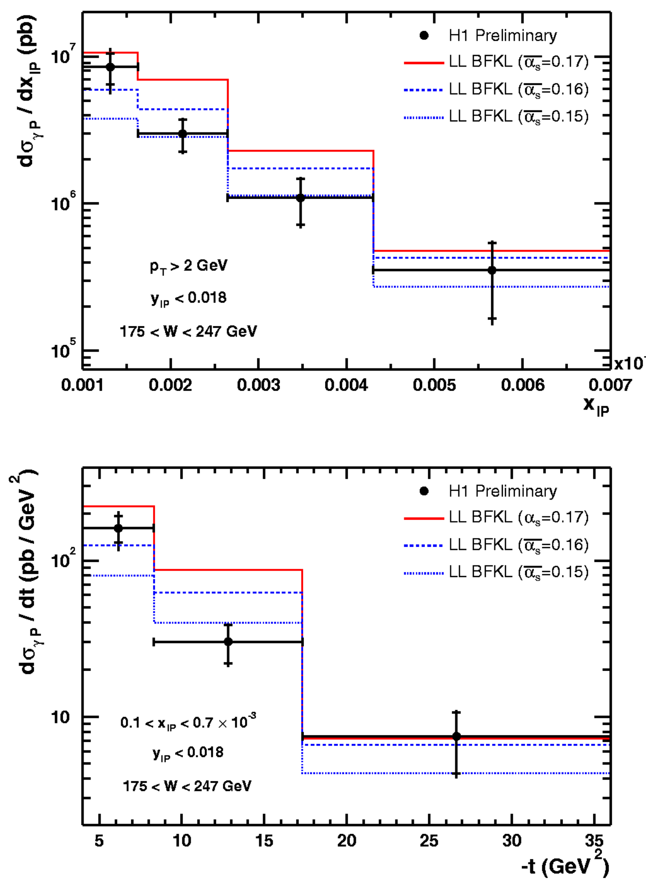

Fig. 1. The γp cross section differential in $x_{I\!P}$ (*upper*) and in t (*lower*). The *inner error bars* show the statistical error and the *outer error bars* show the statistical and systematic errors added in quadrature. The *dotted line* shows the LL BFKL prediction, for different choices of $\overline{\alpha_s}$

depending only on QED calculations and proton elastic form factors, is precisely known and therefore can be subtracted. To enhance the ratio of selected DVCS events to BH events the outgoing photon is selected in the forward, or outgoing proton, region with transverse momentum larger than 2 GeV. Large values of the incoming photon virtuality Q^2 are selected by detecting the scattered electron in the SPACAL calorimeter with energy larger than 15 GeV. The outgoing proton escapes down the beam-pipe in the forward direction.

The $\gamma^* p$ cross section for the DVCS process is shown in Fig. 2 as a function of Q^2 for $W = 82$ GeV, and in Fig. 3 as a function of W for $Q^2 = 8$ GeV^2. In the upper plot of Fig. 2 the measurement is compared to the NLO QCD prediction [6,7] using two different GPD parametrisations [8]. The t dependence is parametrised as $e^{-b|t|}$, with $b = b_0(1 - 0.15\log(Q^2/2))$ GeV^{-2}. The classic PDF $q(x,\mu^2)$ of MRST2001 and CTEQ6 are used in the DGLAP region ($x > \xi$) such that $\mathcal{H}$, which is the only important GPD at small x is given at the scale μ by: $\mathcal{H}^q(x,\xi,t;\mu^2) = q(x;\mu^2)\,e^{-b|t|}$ for quark singlet and $\mathcal{H}^g(x,\xi,t;\mu^2) = x\ g(x;\mu^2)\,e^{-b|t|}$ for gluons, i.e. independent of the skewing parameter ξ. Keeping this parametri-

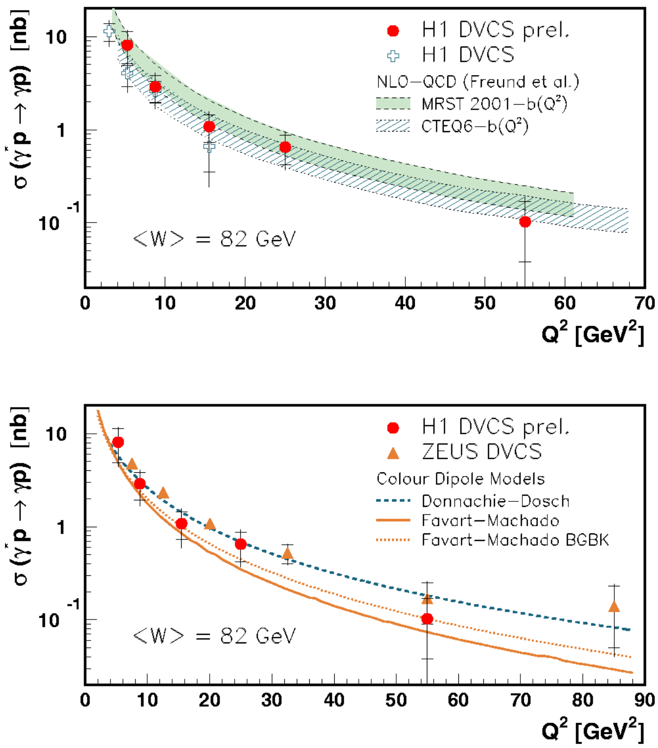

Fig. 2. $\gamma^* p \rightarrow \gamma p$ cross section as a function of Q^2 for $< W >= 82$ GeV. The *inner error bars* are statistical and the *full error bars* include the systematic errors added in quadrature. The measurement is compared (*upper plot*) to the NLO QCD prediction [6,7] using GPD parametrisations based on MRST2001 and CTEQ6 [8] The *bands* correspond to b_0 values between 5 and 9 GeV^{-2}. On the *lower plot*, the measurement is compared to two different Colour Dipole models predictions, by Donnachie and Dosch [9] and by Favart, Machado [10] at the fixed value $b = 7$ GeV^{-2}. The BGBK notation indicates the additional DGLAP evolution of the dipole cross section added to the basic prediction

sation in the ERBL region ($|x| < \xi$) would lead to a prediction overshooting the data by a factor 4-5. Therefore, a parametrisation is proposed by the authors to suppress the region of very small x (for details see [8]). This emphasises the interesting sensitivity to the ERBL region. The NLO QCD predictions are in good agreement with the data, for both GPD parametrisations. Since the main difference between the two parametrisations resulting in the normalisation, it emphasizes the need for a direct t dependence measurement.

In the lower plots of Fig. 2 the measurement is compared to two different Colour Dipole models predictions, by Donnachie and Dosch [9] and by Favart and Machado [10]. They are based on a factorisation into the incoming photon wave function, a $q\bar{q}$-p cross section and the outgoing photon wave function. The models differ in the way the quark dipole cross section is parametrised. Donnachie and Dosch [9] basically connect a soft Pomeron with large dipole size and a hard Pomeron with small dipole size. Favart and Machado [10] apply the saturation

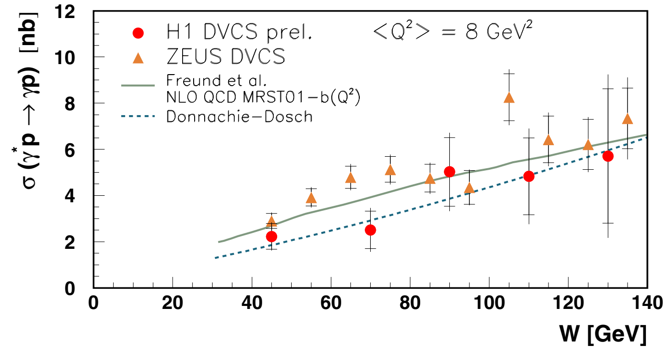

Fig. 3. $\gamma^* p \rightarrow \gamma p$ cross section as a function of W for $< Q^2 >= 8$ GeV^2. The measurement is compared to the NLO QCD prediction [6,7] using GPD parametrisation based on MRST2001 [8] and to the Colour Dipole models prediction of Donnachie and Dosch [9]

model of Golec-Biernat et al. [11] to the DVCS process, withl a possible DGLAP evolution [12] quoted BGBK on the plot. In both cases an exponential t-dependence, $e^{-b|t|}$, is assumed. All presented Colour Dipole model predictions describe well the data in shape and in normalisation for the same value of $b = 7$ GeV^{-2}.

The new measurement is also compared to the previous measurement by H1 [4] and to the ZEUS measurement [5]. The two H1 measurements are in good agreement. The new H1 measurement is in fair agreement with ZEUS results except for $W \sim 70$ GeV, where H1 points are lower by about two standard deviations.

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