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# DEEPLY VIRTUAL COMPTON SCATTERING AT HERA*

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Results on Deeply Virtual Compton Scattering in electron proton interactions by the H1 and ZEUS experiments are reviewed. Measured cross sections as a function of the photon virtuality $Q^2$ and the photon–proton center of mass energy $W$ are presented and compared to different theoretical predictions based on the colour dipole model and Generalised Parton Distributions.

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## 1. Introduction

Deeply Virtual Compton Scattering (DVCS) is the elastic scattering of a virtual photon off a hadron. In electron proton collisions the incident electron emits a photon with virtuality $Q^2$, which subsequently interacts with the proton (figure 1). The final state contains a real photon together with the elastically scattered proton and the electron. The final state proton also might break up which is not considered further.

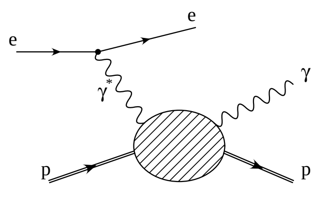


Fig. 1. DVCS diagram.

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The process is similar to the elastic production of vector mesons with the real photon replacing the vector meson. The process is diffractive and leads to the possibility of extracting the so called Generalised Parton Distributions (GPD's). These are well defined objects which appear in calculations of several exclusive reactions. They unify information from different data containing information about the proton structure (*e.g.* elastic proton form factors and parton density functions). However, they contain additional information (*e.g.* on the orbital angular momentum of the partons in the proton) which is so far unexplored.

The Bethe–Heitler (BH) process where a real photon is emitted by the incoming or outgoing electron and the interaction with the proton is mediated by photon exchange, also ontributes to the reaction $ep \longrightarrow e\gamma p$, The interference term between the DVCS and BH processes leads to azimuthal asymmetries. The BH process is purely electromagnetic and can be calculated to high precision in the framework of QED. Future HERA collider measurements might access the interference term which has already been observed in low energy $ep$ scattering experiments [1,2]. The aim of the present measurements is the determination of the direct contribution of the DVCS process to the cross section.

The existing models for the description of DVCS can be grouped in two classes, the colour dipole models [3,4] and the models based on QCD calculations using Generalised Parton Distributions [5–7]. In some colour dipole models effects due to GPDs are also modelled.

In the colour dipole picture, which is applied in the proton rest frame, the photon fluctuates into a quark–antiquark dipole well before the interaction with the proton. After the interaction the quark–antiquark system recombines to a real photon. The fluctuation of the photon into the quark antiquark system and the recombination to a real photon can be calculated in perturbation theory. The interaction with the proton is parametrised by a dipole cross section which has to be extracted from data. Although the colour dipole models differ in detail, the predictions for DVCS are quite similar. The models only calculate the direct contribution of the DVCS process to the cross section. The interference term with the BH process is neglected.

In a leading order QCD expansion the virtual photon interacts with a quark from the proton which emits the real photon before recombining with the proton. At next to leading order, diagrams have to be considered where two gluons are exchanged. These are modelled using the Generalised Parton Distributions. A leading order calculation has been performed by Frankfurt, Freund and Strikman [5] which calculate the influence of GPD's by the comparison of evolution effects in ordinary parton density functions w.r.t. GPD's. A complete LO and NLO calculation was carried out by

Freund and McDermott [6] using different types of GPD's as input. An analysis up to twist three accuracy has been performed by Belitsky, Müller and Kirchner [7].

## 2. Analysis strategy

Since the total cross section for the reaction $ep \longrightarrow e\gamma p$ is dominated by the Bethe–Heitler process, the data analysis is restricted to a region in phase space where the BH process is suppressed and the DVCS process is sizable. In addition a sample of events dominated by the Bethe–Heitler process is selected to demonstrate the understanding of the detector.

In both analyses by H1 [8] and ZEUS [9] events are selected with one electromagnetic energy deposition in the central region of the detector and a second one in the backward region, defined by the direction of the incoming lepton beam. If a track is reconstructed it is required to match with one of the two clusters which then defines the scattered electron. If no track is reconstructed the backward cluster is assumed to be the electron since there is not full coverage of tracking devices in the backward direction.

It is then required that the detector shows no additional signal above the noise level since the scattered proton leaves the main detector through the forward beam pipe. In the H1 analysis additional detectors placed in the forward direction close to the beam pipe are used to further suppress the background from proton dissociation events.

The sample is divided into two subsamples where a control sample consists of events with the electron candidate identified in the central region of the detector. In this sample the DVCS contribution is kinematically suppressed to a negligible level. Since the control sample is dominated by the BH process which is precisely calculable in the framework of QED it is used to control the detector performance.

The DVCS enriched sample consists of events where the electron is scattered in the backward direction and the photon is identified in the central part of the detector. In this sample a large excess of events above the BH process is observed which can be attributed to the DVCS process.

## 3. Results

Cross sections for the reactions $ep \longrightarrow e\gamma p$ and $\gamma^* p \longrightarrow \gamma p$ have been extracted using the DVCS enriched data sample. Figure 2 shows the differential cross sections resulting from the ZEUS analysis. The measurements are made as a function of $Q^2$ and $W$ in the kinematic range $Q^2 > 5\,\mathrm{GeV}^2$, $40 < W < 140\,\mathrm{GeV}$, $E_{\mathrm{T}}^{\gamma} > 3\,\mathrm{GeV}$ and $-0.6 < \eta_\gamma < 1.0$ where $E_{\mathrm{T}}^{\gamma}$ and $\eta_\gamma$ are the transverse energy and the pseudorapidity of the real photon. The

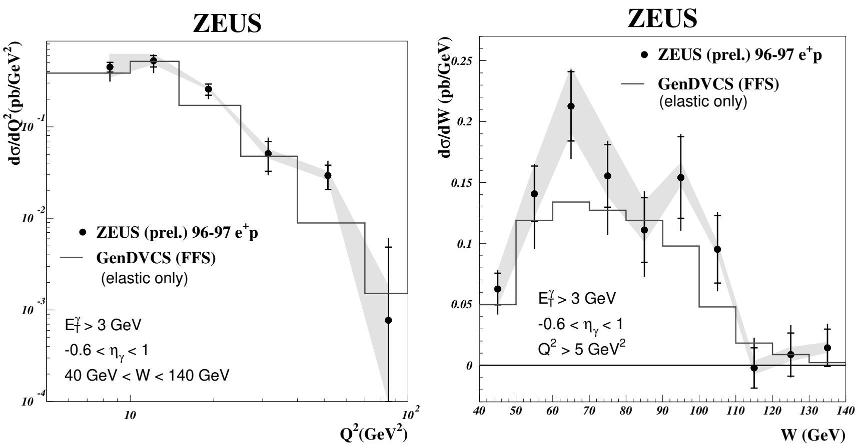


Fig. 2. Differential cross sections for the reaction $ep \longrightarrow e\gamma p$ as a function of $Q^2$ and $W$ after subtraction of the BH contribution. The histogram indicates the FFS prediction [5]. The band indicates the electromagnetic energy scale uncertainty.

Bethe–Heitler contribution has been subtracted. The data is compared to the calculation by Frankfurt, Freund and Strikman(FFS) based on GPD's which is able to describe the data assuming a $t$ dependence of $\sim e^{-b|t|}$ with $b = 4.5\,\mathrm{GeV}^{-2}$. Here $t$ is the squared momentum transfer at the proton vertex. The remaining contribution from proton dissociation is expected to be about 20 % and has not been subtracted.

Figure 3 shows the cross section for the reaction $\gamma^* p \longrightarrow \gamma p$ resulting from the H1 analysis The cross section measurement is shown as a function of $Q^2$ and $W$ for fixed values of $W = 75\,\mathrm{GeV}$ and $Q^2 = 4.5\,\mathrm{GeV}^2$ for $|t| < 1\,\mathrm{GeV}^2$. The data are compared with the predictions by Frankfurt,

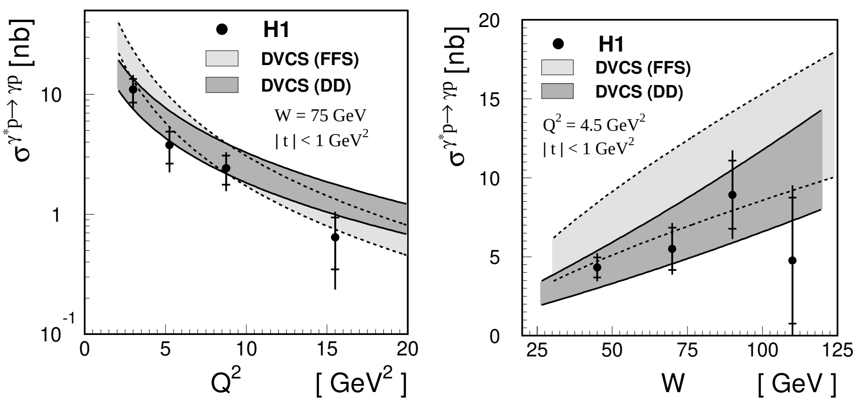


Fig. 3. Cross sections for the reaction $\gamma^* p \longrightarrow \gamma p$ as a function of $Q^2$ and $W$. The measurement is compared to the predictions by DD [4] and FFS [5].

Freund and Strikman and by Donnachie and Dosch(DD), based on the colour dipole model assuming a $t$–dependence with slope parameter $b$ in the range $b = 5$–$9\,\mathrm{GeV}^{-2}$ represented by the bands for the theoretical predictions. Within the present accuracy of the data, both assumptions model the data.

## 4. Prospects for the future

After the HERA upgrade a large increase of luminosity is expected, allowing more precise measurements. The H1 experiment installed an upgraded silicon detector in the backward region to ensure precise tracking for scattered electrons and to determine their azimuthal and polar scattering angle which will lead to a better resolution of the kinematic variables and smaller systematic errors.

The interference term of the DVCS and BH processes which contains additional information about the GPD's can be accessed by the measurement of angular asymmetries [6, 7]. Resolution studies have shown that such asymmetry measurements are feasible when exploiting the newly built detectors. Furthermore polarised electrons and positrons will be provided which will enable the measurement of spin and charge asymmetries, allowing a separation of the real and imaginary part of the QCD amplitude.

## 5. Summary

The first generation measurements of DVCS at the HERA collider have been presented. Cross sections have been measured as a function of $Q^2$ and $W$. Models based on colour dipoles as well as models based on Generalised Parton Distribution describe the data within the present accuracy. A large increase of data is expected after the HERA upgrade which enables more precise measurements and a direct access to the interference term.

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