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Recent diffractive results from HERA

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Abstract. The diffractive dijet cross sections for photoproduction and deep inelastic scattering were studied and compared with theoretical NLO QCD predictions. The results of exclusive dijet production were compared to predictions from models which are based on different assumptions about the nature of diffractive exchange. Isolated prompt photons in diffractive photoproduction produced inclusively or together with a jet were studied for the first time.

1 Introduction

The first observation of diffractive electron-proton deep-inelastic scattering (DIS) at HERA in 1993 has renewed the interest in understanding such processes. Indeed at HERA a substantial part of the ep cross section (up to 10%) is represented by diffractive scattering processes initiated by a virtual photon. The diffractive deep inelastic scattering process $ep \to eXY$ factorises in QCD and it was proven to hold for inclusive and dijet diffractive processes, assuming high enough photon virtuality such that higher twist effects can be neglected. Diffractive parton distribution functions (DPDFs) have to be determined from QCD fits to the measured inclusive DIS diffractive cross sections. The concept of DPDFs plays an important role in the study of diffractive reactions in DIS and can be an essential input to calculations of hard diffractive processes at the LHC.

Experimentally, diffractive $ep \to eXY$ scattering is characterised by the presence of a leading proton in the final state, retaining most of the initial state proton energy, and by a lack of any other hadronic activity in the outgoing proton direction. System X is cleanly separated from a system Y which is an outgoing intact proton or its low mass excitation. In many analyses diffractive events have been selected on the basis of a large rapidity gap (LRG) between these two systems. The main advantage of this method is its high acceptance. A complementary way to select diffractive events is by direct measurements of the outgoing proton in forward proton spectrometers. This method has a disadvantage of lower acceptance but gives an opportunity to distinguish between the case where the scattered proton remains intact or dissociates into a system of low mass M_Y. These two methods of selection differ partially in the accessible kinematic ranges and substantially in their dominant sources of systematic uncertainties.

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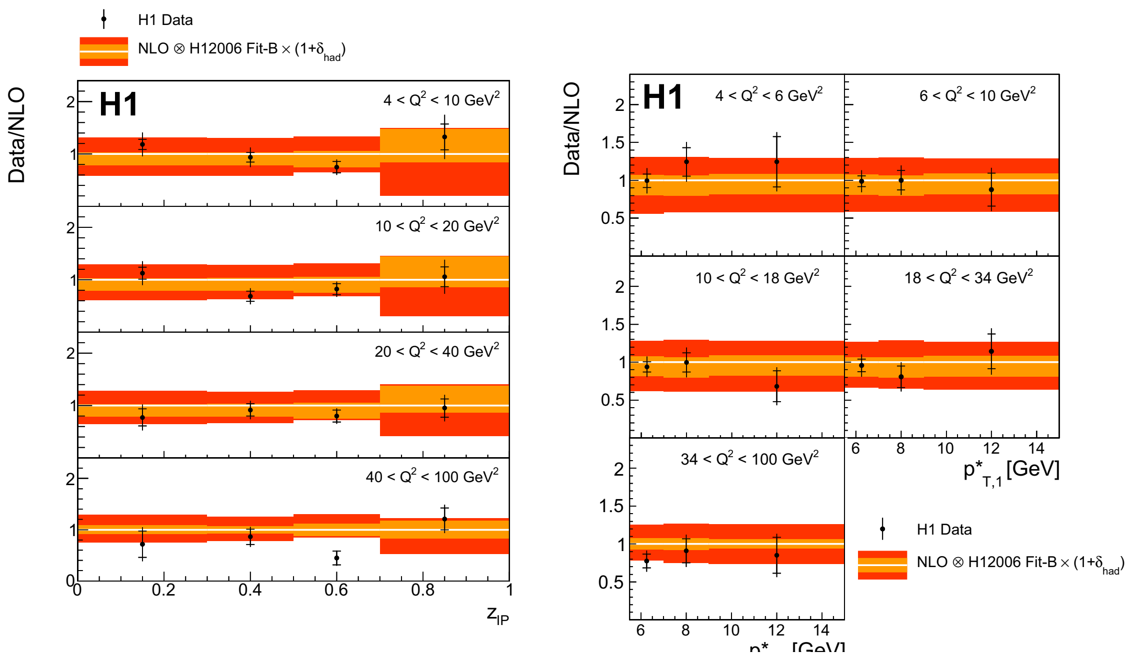

Figure 1. a) Ratio of the double-differential cross section to the NLO QCD predictions as a function of $z_{\mathbb{P}}$ and Q^2 and b) $p^*_{T,1}$ and Q^2. The inner error bars on the data points represent the statistical uncertainties, outer error bars with systematic uncertainties added in quadrature.

2 Diffractive dijets in DIS and photoproduction

A new measurement with about six times higher statistics than previous measurements was provided by H1 using the data of HERA II and LRG method of selection of diffractive events. The measurement was performed for $x_{\mathbb{P}} < 0.03$, $4 < Q^2 < 80$ GeV^2 and events with jets with transverse momenta $p^*_{\mathrm{T},1} > 5.5$ GeV and $p^*_{\mathrm{T},2} > 4$ GeV [1]. The cross sections are determined using a regularised unfolding procedure which fully accounts for efficiencies, migrations and correlations among the measurements. The integrated diffractive dijet cross section is found to be well described by the NLO QCD predictions using the H1 2006 Fit-B DPDF set. Both shapes and normalisation of the single-differential cross sections are reproduced by the theory within the experimental and theory uncertainties, as shown in Fig. 1. The measured dijet cross sections are used to extract the strong coupling constant in diffractive DIS processes for the first time. The result $\alpha_s = 0.119 \pm 0.004(exp) \pm 0.012(DPDF, theo)$ is consistent within the uncertainties with the world average.

Models based on QCD collinear and proton vertex factorisation work well to describe all diffractive processes in DIS, they however fail spectacularly when DPDFs extracted from HERA data are applied to diffractive scattering at the Tevatron [2]. For example, predictions for diffractive dijet production at the Tevatron exceed the data by about one order of magnitude. These results were also recently confirmed at the LHC [3]. This breaking of factorisation was theoretically predicted to be present also in *ep* diffractive dijet photoproduction due to contributions of a resolved component to photoproduction in LO QCD which resemble hadron-hadron collisions [4]. A variable which is commonly used to separate direct and resolved processes in LO is x_γ, measuring the fraction of the photon

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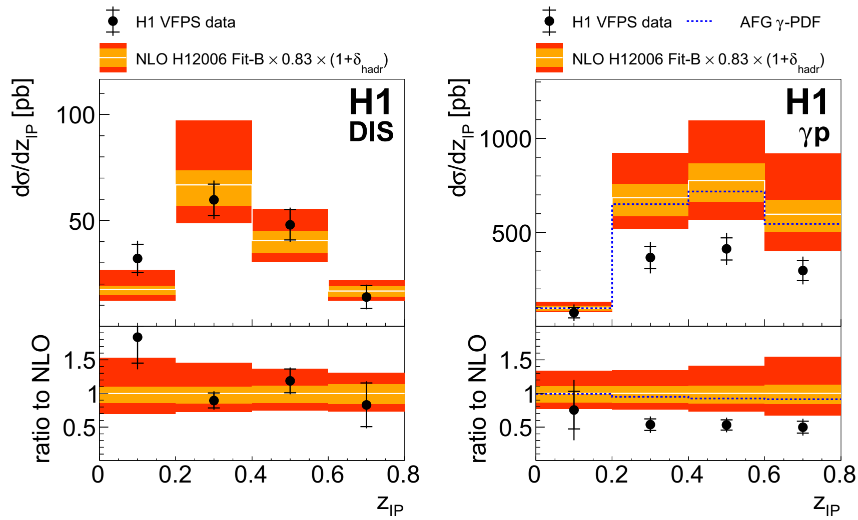

Figure 2. Diffractive dijet a) DIS and b) photoproduction cross sections differential in $z_{\mathbb{P}}$ compared to NLO QCD predictions. The inner error bars represent the statistical errors, outer error bars statistical and systematic uncertainties added in quadrature.

momentum participating in the production of the dijet system. The resolved (direct) processes dominate at low (high) x_γ values, respectively. Due to hadronisation, detector resolution and acceptances the unambiguous separation between direct and resolved components of photoproduction is one of the limiting factors in studies of possible factorisation breaking in photoproduction.

Previous H1 measurements [5, 6] suggested a suppression of the dijet photoproduction cross section by a factor of around 0.5-0.6 relative to NLO QCD predictions. ZEUS results [7] correspond to a smaller suppression and are within uncertainties consistent with no suppression whatsoever. Neither collaboration sees any evidence for the expected x_γ dependence of the survival probability.

To clarify the situation a new measurement is provided by H1 for both DIS diffractive dijets and dijets produced in photoproduction. In contrast to the previous measurements where the LRG method was used, diffractive events were selected using a leading proton spectrometer VFPS [9] placed at a distance of 220 m from the central detector. The VFPS spectrometer covered the kinematic region $0.010 < x_{\mathbb{P}} < 0.024$ and $|t| < 0.6$ GeV^2. The phase space of DIS and photoproduction differs only in momentum transfer Q^2 between the incoming and outcoming electron which is defined as $Q^2 < 2$ GeV^2 for photoproduction and $4 < Q^2 < 80$ GeV^2 for DIS events. Jets were required to have the transverse energy of leading (subleading) jet $E_{T1} > 5.5$ GeV and $E_{T2} > 4$ GeV, respectively. The dijet cross sections were evaluated at the level of stable hadrons using a matrix unfolding method. The measured differential cross sections as a function of $z_{\mathbb{P}}$ are for DIS and photoproduction dijets shown and compared to NLO QCD predictions in Fig. 2. It is seen that theoretical predictions describe properly the DIS data but for photoproduction the measurements are suppressed in comparison with NLO QCD by a factor about 0.5. In Fig. 3a) the differential cross section is shown and compared to NLO QCD as a function of x_γ for dijet photoproduction. Within uncertainties there is clearly no indication of the resolved-part ($x_\gamma < 0.8$) being more suppressed than the direct part ($x_\gamma > 0.8$), which confirms previous measurements at HERA. In a refined method for studying deviations of the NLO QCD predictions from photoproduction data the cross sections measured in this regime are divided

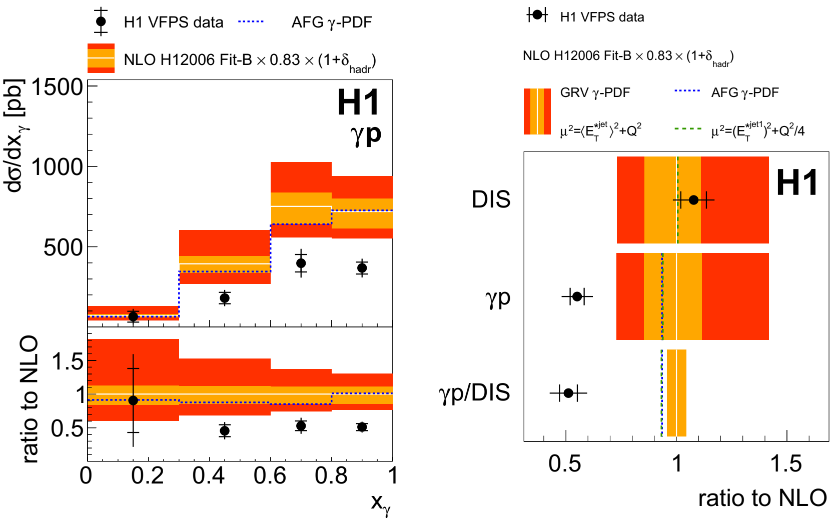

Figure 3. a) Diffractive dijet ep cross section in photoproduction differential in x_γ compared to NLO QCD predictions. b) Diffractive dijet DIS and photoproduction cross sections normalised to NLO QCD calculation and double ratio of photoproduction to DIS cross sections, normalised to the corresponding ratio of NLO QCD predictions.

by the corresponding cross sections in DIS. In such ratios most of the data and theoretical systematic uncertainties are reduced. The double-ratio of photoproduction to DIS, data to NLO QCD, is shown in Figure 3 b). The observation of factorisation breaking by factor of about 0.5 is in agreement with previous H1 measurements [5, 6], where complementary experimental methods of diffraction selection were used.

The production of exclusive dijets $e + p \rightarrow e + p + jet_1 + jet_2$ in DIS has been measured with the ZEUS detector [10]. The production of exclusive dijets is sensitive to the nature of the object exchanged between the virtual photon and the proton. The two models - Resolved–Pomeron model [11] and Two–Gluon–exchange model [12] - predict different shapes in the distribution of Φ, the azimuthal angle between lepton and jet planes (definition see Fig. 4 a)). It was pointed out for the first time in [13] that the parameter A in the function $1 + A cos\Phi$ is positive if the quark - antiquark pair is produced via the interaction of a single gluon with the virtual photon and negative if a system of two gluons takes part in the interaction. The measurement was performed in the range of $90 < W < 250$ GeV and for photon virtualities $Q^2 > 25$ GeV^2 . The shapes of the Φ distributions were parameterised in different intervals of β (momentum fraction of the struck parton with respect to the pomeron) with the function $1 + A cos\Phi$. The dependence of the parameter A in intervals of β is compared with predictions of two versions of MC predictions for the Resolved–Pomeron model and Two–Gluon–Exchange model as implemented in Rapgap [14] in Fig. 4b). The Two-Gluon-Exchange model predicts reasonably well the measured value of A for $\beta > 0.3$, whereas the Resolved–Pomeron model exhibits a very different trend. In terms of absolute normalisation, both models are below the data and thus fail to describe the measurement [10]. It could indicate that the NLO QCD corrections are large or the cross-section enhancement arising from the evolution of the off-diagonal gluon distribution is significant.

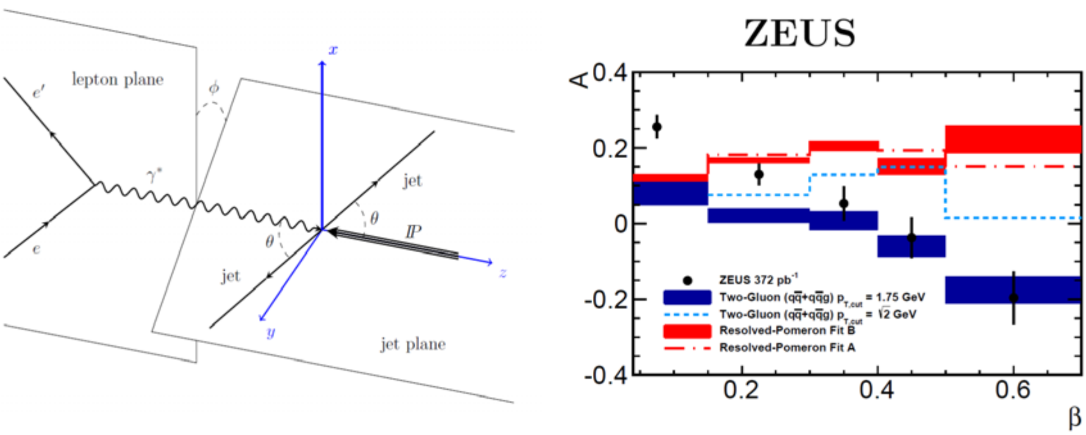

Figure 4. a) Definition of lepton and jet planes, angle Φ is the angle between these two planes. b) The shape parameter A as a function of β in comparison with two models, the bands in model predictions represent statistical uncertainties. The normalisation uncertainty originating from the proton-dissociation background ($\sim 27\%$) is not shown.

3 Hard photons in diffraction

Prompt photon emission in hadronic interactions is a sensitive probe of QCD dynamics and partonic structure, providing additional information to the study of jet production. Although cross sections are small in this case, an isolated photon at large transvers energy can be related directly to the partonic event structure. This is in contrast with jet measurements, where the partonic structure is obscured by hadronization effects.

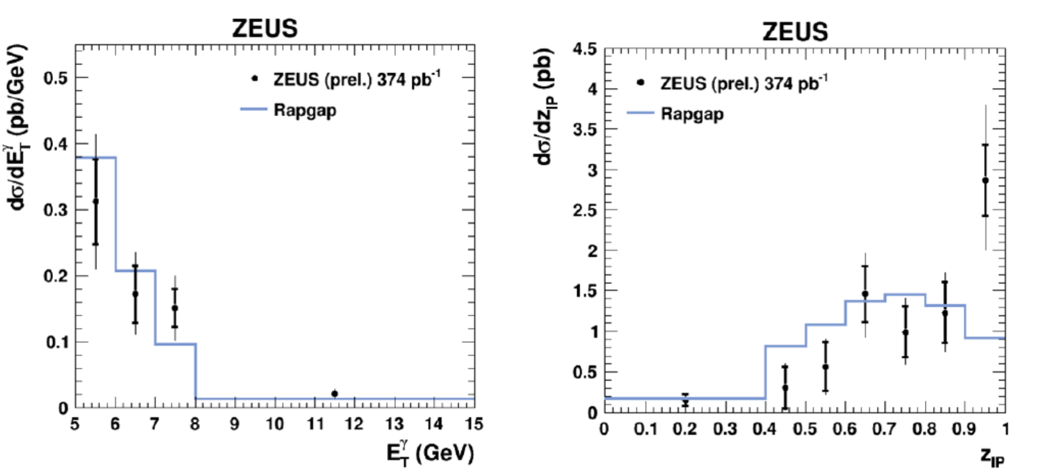

Figure 5. Differential cross sections as functions of a) E_T^{γ} and b) $z_{I\!P}$ for events with isolated photon accompanied by a jet compared to normalised prediction of RAPGAP.

A new measurement was provided by ZEUS collaboration for diffractive photoproduction ep events in which a hard isolated prompt photon is detected in the central region of the ZEUS detector and may be accompanied by a jet [15]. Cross sections are evaluated in the photon transverse energy range $5 < E_T^\gamma < 15$ GeV, inclusively and with a jet with transverse-energy in the range $4 < E_T^{jet} < 35$ GeV. In Fig. 5a) differential cross sections are shown as a function of the photon transverse energy E_T^γ for the photon+jet configuration. The shape of this distribution and also other distributions of inclusive and photon+jet configurations, see [15], are satisfactorily described by the Rapgap Monte Carlo model, normalised to the data. The shape of the $z_{\mathbb{P}}$ distribution, see Fig. 5b), however is not well described. In particular, a prominent peak near $z_{\mathbb{P}} = 1$ is seen and requires further study. In future, comparison with NLO QCD calculations would give another handle on factorisation in ep diffractive photoproduction.

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