Inclusive Dijet Cross Sections in Neutral Current Deep Inelastic Scattering and Photoproduction at HERA

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Abstract. Recent results from the ep collider HERA are presented. Inclusive dijet cross sections have been measured in neutral current deep inelastic scattering, for virtualities of the exchanged boson in the range $125 < Q^2 < 20000$ GeV$^2$ and in photoproduction, $Q^2 \sim 0$ GeV$^2$. The measurements are compared to perturbative QCD calculations at next-to-leading order.

Keywords: dijet production, deep inelastic scattering, photoproduction
PACS: 13.87.-a, 13.87.Ce, 12.38.Qk

INTRODUCTION

At HERA, two kinematic regions can be distinguished: in deep inelastic scattering (DIS) the electron interacts with a parton from the proton via the exchange of a virtual boson with large virtuality, $Q^2$. In contrast, in photoproduction the exchanged photon is quasi-real and the electron escapes the detector through the beam pipe. The virtuality of the exchanged boson in DIS is $Q^2 \gtrsim 1$ GeV$^2$, whereas in photoproduction the exchanged boson is almost on its mass shell, and $Q^2 \lesssim 1$ GeV$^2$ holds.

The measurements of jet production are a well established tool for stringent tests of quantum chromodynamics (QCD) and have been performed at HERA for many jet observables. The production of jets allows a direct measurement of the strong coupling constant, $\alpha_s$, and photon (in photoproduction) and proton parton density functions (PDFs) can be extracted.

In DIS, two processes contribute to the production of two jets in leading-order (LO) $\alpha_s$: boson-gluon fusion (Fig. 1, left) and QCD Compton scattering (Fig. 1, middle). For the dijet measurement in DIS, the Breit reference frame was used, since it provides a maximal separation between the hard jets and the beam fragmentation products. In this frame the exchanged boson collides head-on with the parton. Therefore, transverse energies are an indicator for the occurrence of strong processes. Dijet measurements in DIS have been performed at large virtualities $Q^2$, where both the theoretical and experimental uncertainties are relatively small. Jet data have been included in the ZEUS-JETS [1] fit of the proton PDFs, which significantly reduced the uncertainty on the gluon density in the regions of medium and high $x$.

In the photoproduction regime two types of processes contribute to dijet production in LO $\alpha_s$: in direct photon processes the photon interacts with a parton as a point-like
object whereas in resolved photon processes (Fig. 1, right) the photon acts as a source of partons, one of which interacts with the parton from the proton. Thereby, in addition, in photoproduction the measurement is sensitive to the photon PDFs.

In both DIS and photoproduction, jets were reconstructed with the $k_T$ cluster algorithm [2] in the longitudinally invariant inclusive mode [3] using the smallest calorimeter units called cells. The jet search in DIS was performed in the Breit reference frame, whereas in photoproduction it was performed in the laboratory frame. In order to take into account detector effects, LO Monte Carlo (MC) samples were used, which utilise different approaches for the parton cascade. The next-to-leading order (NLO) QCD predictions were corrected using these MCs to take into account hadronisation and electroweak effects.

In this report, recent measurements of inclusive dijet production in neutral current (NC) DIS [4] and photoproduction [5] performed with the ZEUS detector are presented.

The measurements presented here correspond to integrated luminosities of 189 pb$^{-1}$ for the photoproduction and of 374 pb$^{-1}$ for the NC DIS analysis, respectively.

**INCLUSIVE DIJETS IN NEUTRAL CURRENT DIS**

The phase space of the measurement was defined by $125 < Q^2 < 20000$ GeV$^2$ and $0.2 < y < 0.6$, where $y$ is the inelasticity determined using the relation $y = Q^2/x_{Bj}s$. In this formula, $x_{Bj}$ is the Bjorken scaling variable and $s$ is the square of the centre-of-mass energy. The selected events were required to have a well reconstructed and isolated scattered electron. The pseudorapidities of the jets in the laboratory frame, $\eta_{LAB}^{jet}$, were required to satisfy $-1 < \eta_{LAB}^{jet} < 2.5$. For the measurement of the jet cross sections events with at least two jets with transverse energies in the Breit frame, $E_{T,B}^{jet}$, greater than 8 GeV were selected. Additionally, the invariant mass of the dijet system had to be greater than 20 GeV. The latter cut was introduced to suppress infrared sensitive regions in the fixed-order calculations.

Cross sections were compared to NLO QCD calculations as implemented in the NLO-JET++ program [6]. The calculations were obtained using the CTEQ6.6 parameterisations for the proton PDFs with the factorisation and renormalisation scales set to $\mu_F = Q$ and $\mu_R^2 = Q^2 + E_{T,B}^{jet^2}$, respectively. Here, $E_{T,B}^{jet}$ is the mean jet transverse energy of the dijet system in the Breit frame. The uncertainty on the NLO predictions due to missing higher orders was estimated by varying $\mu_R$ by a factor 2 up and down and was found to be below $\pm 6\%$ at low $Q^2$ and low $E_{T,B}^{jet}$ and below $\pm 3\%$ in the highest $Q^2$ region.
FIGURE 2. The differential cross sections as functions of the exchanged boson virtuality, $Q^2$ (left), and the mean energy of the jets of the dijet system in the Breit frame, $E_{T,B}$ (right).

The calculations provide a good description of the measured cross sections, as demonstrated in Fig. 2, where the differential cross sections as functions of $Q^2$ and $E_{T,B}$ are compared with the NLO QCD predictions. The data and the theory agree very well in shape and normalisation. The theoretical uncertainty in the lower $Q^2$ region, which amounts to about $\pm 7\%$, is larger than the uncertainty of the data, which is $\approx \pm 1\%$. The fraction of gluon induced events as predicted by CTEQ6.6 ranges from about 75% at $125 < Q^2 < 250$ GeV$^2$ to about 5% in the highest $Q^2$ region investigated. The PDF uncertainty in the medium $Q^2$ region is larger than the theoretical uncertainty due to the choice of $\mu_R$. Therefore precise input for the determination of the gluon distribution function is expected.

INCLUSIVE DIJETS IN PHOTOPRODUCTION

In photoproduction the electron escapes undetected through the beam pipe. Thus, the jets of the dijet system are approximately balancing each other in the transverse plane. The phase space of the measurement was defined by $Q^2 < 1$ GeV$^2$ with the centre-of-mass energy of the photon-proton system, $W_{\gamma p}$, in the range $142 < W_{\gamma p} < 293$ GeV. Selected events were required to lack an identified scattered electron. For the cross sections presented here, only events with at least two jets with transverse energies $E_{T,1} > 21$ GeV and $E_{T,2} > 17$ GeV were considered. The latter cuts, which are asymmetric, were applied to make the theory infrared insensitive. The pseudorapidities of the jets had to satisfy $-1 < \eta_{\text{jet}} < 2.5$ to ensure that jets were contained within a section of the detector in which the acceptance is well understood.

In order to distinguish direct and resolved photoproduction events, the variable $x_\gamma$ was used, which is the fraction of the photon momentum participating in the production of the two most energetic jets. This variable can be determined according to $x_\gamma^{\text{obs}} =$
(E_{\text{jet}1} e^{-\eta_{\text{jet}1}} + E_{\text{jet}2} e^{-\eta_{\text{jet}2}}) / 2yE_e$, where $E_e = 27.5$ GeV is the energy of the electron beam. For direct photon events, $x_\gamma$ is close to one, whereas for events with resolved photons characteristic $x_\gamma$ values are smaller.

Cross sections were compared to NLO QCD calculations obtained using the program from Klasen, Kleinwort and Kramer [7]. The ZEUS-S proton PDFs and the GRV-HO photon PDFs were used. The scales $\mu_R$ and $\mu_F$ were set to $\mu_R = \mu_F = (E_{\text{jet}})_{\text{max}}$. The renormalisation scale uncertainty was evaluated by scaling $\mu_R$ by a factor 2 up and down and amounts to 20%. As shown in Fig. 3, where the cross sections as functions of $x_{\text{obs}}^{\gamma}$ and $E_{\text{jet}}$ are compared with NLO QCD predictions, the NLO calculations provide a good description of the data. The cross section measured as a function of $x_{\text{obs}}^{\gamma}$ is sensitive to the photon PDFs, due to the large spread observed between the predictions using different parameterisations of the photon PDFs. This sensitivity is especially pronounced in the low-$x_{\text{obs}}^{\gamma}$ region, in which resolved photon events are dominating. In all investigated cross section bins, the theoretical uncertainties are larger than the experimental uncertainties.

The measured differential cross sections of inclusive dijet production in both neutral current DIS and photoproduction have small statistical and systematic uncertainties. The description of the data by NLO QCD is good. These jet data have the potential to significantly reduce PDF uncertainties and provide information for the determination of the strong coupling constant.

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