High-E_T dijet photoproduction at HERA

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Measurements of cross sections for high-E_T dijet production in photoproduction are presented. The data samples used were collected with the ZEUS detector at HERA and correspond to an integrated luminosity of $81.8\,\mathrm{pb}^{-1}$. The measured cross sections show sensitivity to the parton distributions in the photon and proton and to QCD effects beyond next-to-leading order. The data are therefore well-suited to further constrain the proton and photon parton distribution functions when used in global QCD fits.

1 Introduction

In photoproduction at HERA, a quasi-real photon, emitted from the incoming electron, collides with a parton from the incoming proton. The photoproduction of jets can be classified into two types of process in leading-order (LO) Quantum Chromodynamics (QCD). In direct processes, the photon participates in the hard scatter via either boson-gluon fusion or QCD Compton scattering. The second class, resolved processes, involves the photon acting as a source of quarks and gluons, with only a fraction of its momentum, x_γ^{obs}, participating in the hard scatter. Measurements of jet cross sections in photoproduction are sensitive to both the structure of the proton and photon and thus provide input to global fits of their parton densities. The objective of the measurement presented in this paper is threefold.

Firstly, the analysis was designed to provide constraints on the parton density functions (PDFs) of the photon. The effectiveness of available photon PDFs at describing HERA photoproduction data is tested by comparing the measured cross sections with next-to-leading order (NLO) predictions using different parameterizations of the photon structure, including the most up-to-date ones. The present analysis was conducted at higher transverse jet energy relative to previous publications.

Secondly, the present analysis was designed to provide constraints on the proton PDFs. A common feature of global fits to determine the proton structure is a large uncertainty in the gluon PDF for high values of x_p^{obs}, the fractional momentum at which partons inside the proton are probed. At such high values of x_p^{obs} the gluon PDF is poorly constrained and so attempts were made for the present investigation to measure cross sections which show particular sensitivity to these uncertainties. The cross sections in the following represent the best effort that can be made using HERA-I photoproduction data at high x_p .

Finally, the difference in azimuthal angle of two jets was considered. The cross sections defined in terms of this variable are directly sensitive to higher-order topologies and therefore provide a test of NLO QCD and of Monte Carlo (MC) models.

2 Data sample and event selection

The data were collected during the 1998–2000 running periods, when HERA operated with protons of energy $E_p = 920\,\mathrm{GeV}$ and electrons or positrons of energy $E_e = 27.5\,\mathrm{GeV}$. The results presented here are based on a total integrated luminosity of $81.8 \pm 1.8\,\mathrm{pb}^{-1}$.

*On behalf of the ZEUS collaboration.

The events were required to have a virtuality of the incoming photon Q^2 of less than $1\,\mathrm{GeV}^2$ and a photon-proton center-of-mass energy in the range $142 < W_{\gamma p} < 293\,\mathrm{GeV}$. Jets were reconstructed with a k_T-clustering algorithm using calorimeter information. Events were selected in which at least two jets were found with transverse jet energies of $E_T^{\mathrm{jet1}} > 20\,\mathrm{GeV}$, $E_T^{\mathrm{jet2}} > 15\,\mathrm{GeV}$ and a pseudorapidity in the range $-1 < \eta^{\mathrm{jet1,2}} < 3$, with at least one of the jets satisfying $-1 < \eta^{\mathrm{jet}} < 2.5$. This corresponds to an extension of 0.6 units in forward η direction compared to previous studies.

3 Monte Carlo models and NLO QCD calculations

The acceptance and the effects of detector response were determined using samples of simulated events. The programs Herwig 6.505 and Pythia 6.221, which implement the leading-order matrix elements, followed by parton showers and hadronization, were used. For both MC programs, the CTEQ5L and GRV-LO proton and photon PDFs, respectively, were used. The p_T^{min} for the outgoing partons from the hard scatter was set to 4 GeV. For the generation of resolved photon events, the default multi-parton interaction models were used.

For the NLO predictions, the calculation of Frixione and Ridolfi is used, which employs the subtraction method for dealing with the collinear and infra-red divergencies. The following parametrizations of the photon PDFs were used: Cornet et al. (CJK) [2], Aurenche et al. (AFG04) [3], Slominski et al. (SAL) [4], Glück et al. (GRV-HO) [5] and a previous set of PDFs from Aurenche et al. (AFG-HO) [6]. All PDFs were obtained in fits to data on the photon structure function F_2^γ from the LEP experiments, with only SAL additionally using previous dijet photoproduction data from ZEUS. The parametrization from CJK uses a more careful treatment of heavy quarks. The most striking difference between the resulting PDFs is the more rapid rise of the gluon density to low x_γ for CJK.

4 Theoretical and experimental uncertainties

The uncertainties on the pertubative QCD calculations are dominated by the effect of higher orders omitted in the pertubative expansion. These were assessed by a variation of the renormalization scale μ_R which lead to an uncertainty of $\pm$10–20% on the cross sections. Uncertainties arising from the hadronization correction and the choice of factorization scale and α_s gave much smaller contributions. All theoretical uncertainties were added in quadrature and are shown in the plots as shaded band around the central theoretical prediction.

The systematic uncertainties on the measurement are dominated by the uncertainty in the jet energy scale which is assumed to be $\pm$1%. As this uncertainty is correlated between bins, it is shown separately as shaded band in the figures. The next-largest uncertainty arises from the model dependence in the unfolding of the measured cross sections to hadron-level. Other sources of uncertainty such as variations of the cleaning cuts were also considered but are usually much smaller.

5 Dijet differential cross sections and sensitivity to photon PDFs

Dijet differential cross sections have been measured as functions of the mean transverse energy of the two leading jets $\bar{E}_T$. The measurement has been performed in two regions of

$x_\gamma^{\rm obs}$, namely a region enriched in direct photoproduction processes with $x_\gamma^{\rm obs} > 0.75$ and a resolved enriched region with $x_\gamma^{\rm obs} \leq 0.75$.

The cross sections $d\sigma/d\bar{E}_T$ are shown in Figure 1. For $x_\gamma^{\rm obs} > 0.75$, the NLO QCD predictions describe the data well, although some difference in shape is observed when using the AFG04 photon PDF. In the resolved enriched region, the prediction using CJK is much higher than the data in the first bin, but then agrees with the data for all subsequent bins. All photon PDFs have a similar shape and none can reproduce the shape of the measured distribution. In addition, apart from CJK, all are too low in the region $22.5 < \bar{E}_T < 37.5$ GeV.

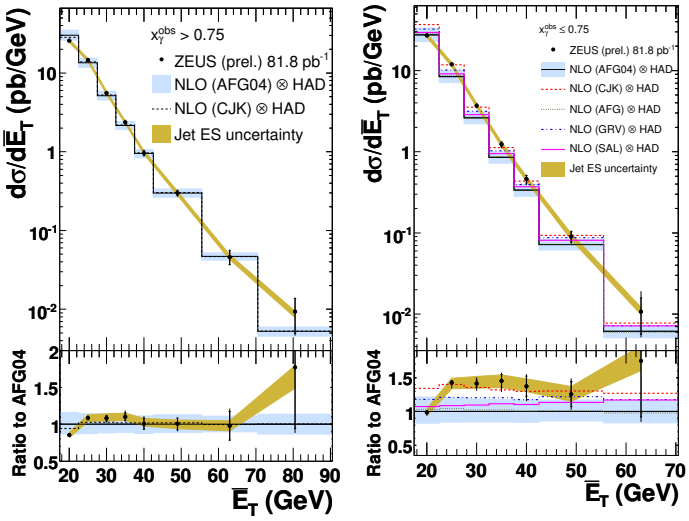

Figure 1: Cross sections $d\sigma/d\bar{E}_T$ in two regions of $x_\gamma^{\rm obs}$.

Also measured were cross sections as functions of $x_\gamma^{\rm obs}$, $x_p^{\rm obs}$, and the mean pseudorapidity of the two leading jets $\bar{\eta}$ (none shown here). For $x_\gamma^{\rm obs} > 0.75$ the data are usually well described by NLO QCD predictions, while for $x_\gamma^{\rm obs} \leq 0.75$ large deviations between predictions using different photon PDFs are observed with no PDF giving an adequate description of the data in all variables studied.

6 Measurement of $d\sigma/d|\Delta\phi|$

In LO QCD, the cross section as a function of the azimuthal difference would simply be a delta function located at π radians. However, the presence of higher-order effects results in the emission of additional partons in the final state and in values less than π radians. The cross section is therefore directly sensitive to higher-order topologies and provides a test of NLO QCD and of MC models. The cross sections measured as functions of the difference in azimuthal angle of two jets $|\Delta\phi|$ are shown in Figure 2 for $x_\gamma^{\rm obs}$ above and below 0.75.

The data are compared to predictions from NLO QCD and also the Herwig and Pythia MC programs. At high $x_\gamma^{\rm obs}$, NLO QCD agrees with the data at highest $|\Delta\phi|$, but it has a somewhat steeper fall off. The prediction from the Pythia MC program is similar to that for NLO QCD, whereas the prediction from the Herwig program describes the data well. For low $x_\gamma^{\rm obs}$, the distribution for NLO QCD is much too steep and is significantly below the data for all values of $|\Delta\phi|$ except the highest bin. The prediction from the Pythia program is less steep, but still gives a poor description. The prediction from the Herwig program is in remarkable agreement with the data.

7 Optimized cross sections

Cross-sections $d\sigma/dx_p^{\rm obs}$ optimized to be most sensitive to the uncertainty on the gluon PDF in the proton were also measured for $x_\gamma^{\rm obs}$ above and below 0.75. At high $x_\gamma^{\rm obs}$ the data are very well described by NLO QCD predictions. At low $x_\gamma^{\rm obs}$ the description by NLO QCD is less good, particularly when using the AFG04 photon PDF. Generally the predictions with CJK describe the data better. Inclusion of these data in future fits should be able to constrain the proton PDFs further, in particular that of the gluon. However, to fully exploit these data and include the cross section for low $x_\gamma^{\rm obs}$ a systematic treatment of the photon PDFs and their uncertainty is needed.

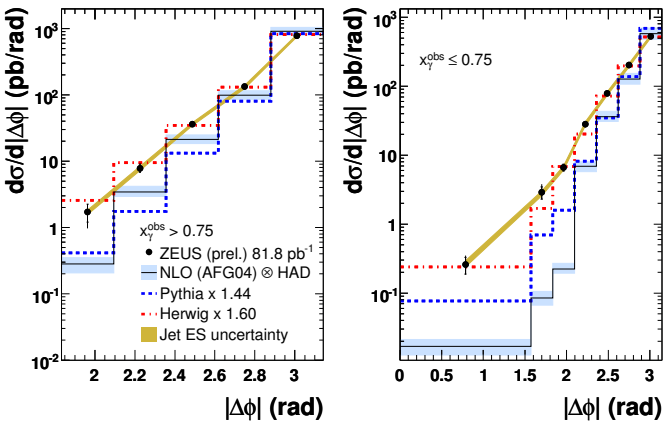

Figure 2: Cross sections $d\sigma/d|\Delta\phi|$ in two regions of $x_\gamma^{\rm obs}$.

8 Conclusions

The measured dijet cross sections in HERA 1998–2000 photoproduction data were generally found to agree well with NLO QCD predictions in the case of direct enriched cross sections with $x_\gamma^{\rm obs}$ above 0.75. For the resolved enriched cross sections at low $x_\gamma^{\rm obs} \leq 0.75$, the data are less well described by NLO. In the phase-space considered in this analysis, the different photon parameterizations give a large spread with no parton density function giving an adequate description of the data in all variables studied. Therefore the data have the potential to further constrain the PDFs in the proton and photon and should be used in future fits. The cross sections as function of $|\Delta\phi|$ are intrinsically sensitive to high-order QCD processes and are therefore a good testing ground for new calculations of higher orders or simulations thereof.

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