Vol. 33 (2002) *ACTA PHYSICA POLONICA B* No 10

REAL PHOTON STRUCTURE via DIJET PHOTOPRODUCTION*

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(Received June 21, 2002)

The dijet cross section in photoproduction has been measured with the ZEUS detector at HERA using an integrated luminosity of 38.6 pb^{-1}. The events were required to have a virtuality of the incoming photon, Q^2, of less than 1 GeV^2 and a photon-proton centre-of-mass energy in the range $134 < W_{\gamma p} < 277$ GeV. Each event contains at least two jets satisfying transverse-energy requirements of $E_{\rm T}^{\rm jet1} > 14$ GeV and $E_{\rm T}^{\rm jet2} > 11$ GeV and pseudorapidity requirements of $-1 < \eta^{\rm jet1,2} <2.4$. The measurements are compared to next-to-leading-order QCD predictions. The data show particular sensitivity to the density of partons in the photon, allowing the validity of the current parameterisations to be tested.

PACS numbers: 13.60.Le

1. Introduction

In dijet photoproduction at HERA, a quasi-real photon interacts with a parton from the proton, producing two or more jets. The dynamics of the hard subprocess are reconstructed from the jets found in the hadronic final state using the $k_{\rm T}$-clustering algorithm [1]. The hard scale, μ, necessary for perturbative QCD (pQCD) calculations, is provided by the transverse energy, $E_{\rm T}$, of the jets. When $E_{\rm T}^2$ is much larger than the negative four-momentum squared of the photon, Q^2, the structure of the photon is probed by the hard dijet system. In order to provide precise measurements that can be used to constrain the parton densities of the photon, high-$E_{\rm T}$ jets are

* Presented at the X International Workshop on Deep Inelastic Scattering (DIS2002) Cracow, Poland, 30 April–4 May, 2002.

required. In this kinematic region, where the effects of soft physics are suppressed and the parton densities in the proton are well known, the data can be specifically used to test the validity of the current parametrisations of the parton densities in the photon.

Two types of subprocess contribute to the cross section: resolved and direct. In a direct, leading-order (LO) event, the photon participates in the hard scatter via either boson-gluon fusion or QCD Compton scattering. In a resolved event, the photon acts as a source of quarks and gluons, one of which scatters off the parton from the proton. The observable $x_\gamma^{\rm obs}$ is the fraction of the photon's momentum that contributes to the production of the two highest-$E_{\rm T}$ jets. It is defined in QCD to all orders. The variable provides a means of separating the dijet cross section into a photon structure sensitive region (low $x_\gamma^{\rm obs}$) dominated by resolved-like events, and a less sensitive region (high $x_\gamma^{\rm obs}$) dominated by direct-like events.

The photon structure function, F_2^γ, has been measured in deep inelastic electron photon scattering (γ^*-DIS) at e^+e^- experiments [2]. Using this method F_2^γ and hence photon parton distribution funcions (PDFs) are not well constraint at $\mu^2 > 100$ GeV^2 and for $x_\gamma^{\rm obs}$ values above 0.5. The gluon density, in particular, is poorly known since LO γ^*-DIS is only sensitive to the quak densities in the photon. Jet photoproduction at HERA, however, is already sensitive to the gluon content of the photon at LO and cross sections can be measured accurately up to high $x_\gamma^{\rm obs}$ values and with $\mu^2 > 190$ GeV^2.

2. Results

The analysis [3] used 38.6 pb^{-1} of data collected by the ZEUS detector during 1996–97. The events were required to have a virtuality of the incoming photon, Q^2, of less than 1 GeV^2 and a photon–proton centre-of-mass energy in the range $134 < W_{\gamma p} < 277$ GeV. Each event contains at least two jets satisfying transverse-energy requirements of $E_{\rm T}^{\rm jet1} > 14$ GeV and $E_{\rm T}^{\rm jet2} >$ 11 GeV and pseudorapidity requirements of -1< $\eta^{\rm jet1,2}$ <2.4.

2.1. Probing the matrix elements

The dijet cross section as a function of $|\cos\theta^*|$ is shown in Fig. 1. The angle θ^* is that between the jet and the beam axes in the dijet centre-of-mass system. The cross section is defined in the above kinematic region but with additional restrictions to remove the bias from η^{jet} and $E_{\rm T}^{jet}$ cuts: $0.1 < (\eta^{\rm jet1} + \eta^{\rm jet2})/2 < 1.3$, $|\cos\theta^*| < 0.8$ and $M_{jj} > 42$ GeV, where M_{jj} is the dijet invariant mass. The data are shown separately for $x_\gamma^{\rm obs} < 0.75$ (Fig. 1(a)) and $x_\gamma^{\rm obs} > 0.75$ (Fig. 1(b)) and compared to NLO predictions. For $x_\gamma^{\rm obs} < 0.75$, the measured cross section lies above the NLO predictions, using GRV–HO [4] for the photon PDF, by an average of (10–15)%. Considering the theoretical and experimental uncertainties, both of (5–10)%, the NLO prediction gives a reasonable description of the data. The predictions using AFG–HO [5] parameterisation for the photon give a lower cross section than that of GRV–HO, and are thus around (20–25)% lower than the data. For $x_\gamma^{\rm obs} > 0.75$, the NLO prediction is in agreement with the measured cross section.

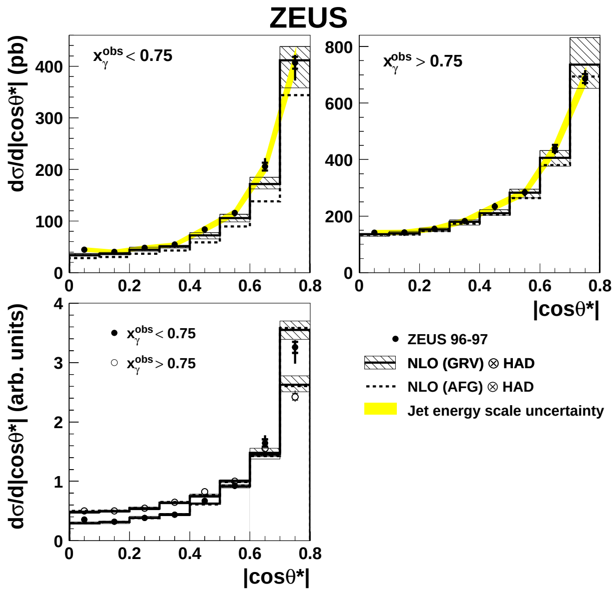

Fig. 1.

In Fig. 1(c), the shapes of the data and NLO distributions are compared. The predictions give a generally good description of the data; the shapes of the predictions when using the GRV-HO and AFG-HO are similar. The data at low $x_\gamma^{\rm obs}$ rise more rapidly at high $|\cos\theta^*|$ than those at high $x_\gamma^{\rm obs}$. This is consistent with a difference in the spin of the dominant propagators. In LO direct events, the propagator is a quark, whereas resolved events are dominated by gluon exchange. The agreement in shape of these distributions, which are sensitive to the matrix elements, demonstrates that also in this high-mass region the dynamics of the short-distance process is understood.

2.2. Testing the current parametrisations of the photon PDF

The cross sections and ratios of data and theory as a function of $x_\gamma^{\rm obs}$ in regions of increasing transverse energy are shown in Figs. 2–3. The predictions lie significantly above the data using the GRV–HO parameterisation at

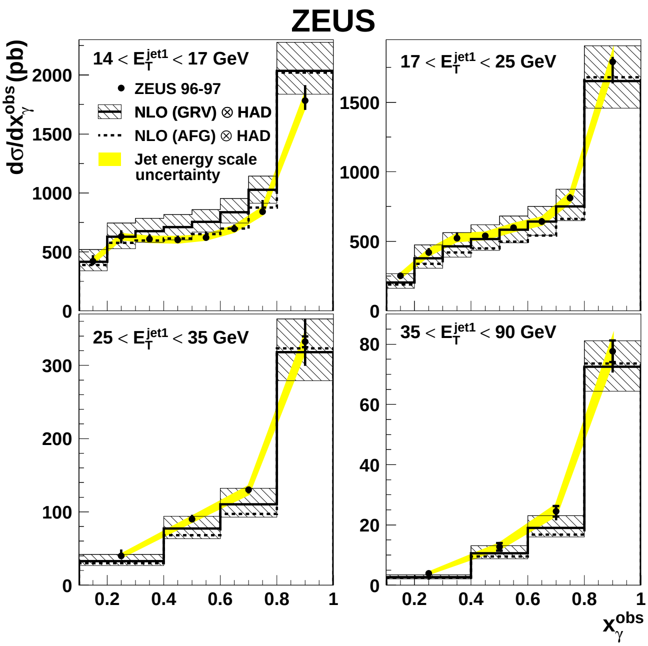
ZEUS
14 < E_T^jet1 < 17 GeV
17 < E_T^jet1 < 25 GeV
25 < E_T^jet1 < 35 GeV
35 < E_T^jet1 < 90 GeV
ZEUS 96-97
NLO (GRV) ⊗ HAD
NLO (AFG) ⊗ HAD
Jet energy scale uncertainty
dσ/dx_γ^obs (pb)
x_γ^obs

Fig. 2.

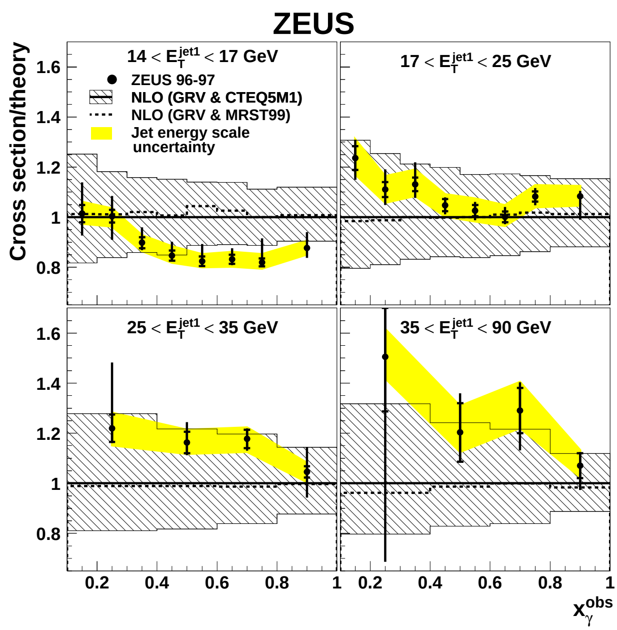
ZEUS
14 < E_T^jet1 < 17 GeV
17 < E_T^jet1 < 25 GeV
25 < E_T^jet1 < 35 GeV
35 < E_T^jet1 < 90 GeV
ZEUS 96-97
NLO (GRV & CTEQ5M1)
NLO (GRV & MRST99)
Jet energy scale uncertainty
Cross section/theory
x_γ^obs

Fig. 3.

the lowest values of transverse energy for $x_\gamma^{\rm obs} > 0.5$, but are increasingly below the data for values larger than 17 GeV. This trend with transverse energy is stronger for $x_\gamma^{\rm obs} < 0.8$. Given the uncertainties, the data and predictions are consistent except in the region of lowest transverse energy for $x_\gamma^{\rm obs} > 0.5$. The dominant theoretical uncertainty arises from the higher-order contributions beyond these present in an NLO calculation. The inclusion of higher order contributions would have to result in a significant change of shape of the distribution as a function of both the transverse energy and $x_\gamma^{\rm obs}$ if it were to describe the data. Fig. 2 also show the differences between the predictions with CTEQ5M1 and MRST99 as proton's PDF which are everywhere less than 5%. The predictions using AFG–HO as photon parameterisation are similar in shape to those using GRV–HO but are (10–14)% lower.

2.3. Importance of the cut on the second jet

To improve the understanding of the features of the cross section in different regions of transverse energy, the sensitivity of the above comparisons to the value of the cut on the second jet has been studied.

Starting at a minimum of 11 GeV, the cut on the second jet was raised in both data and theory for the region $25 < E_{\rm T}^{\rm jet1} < 35$ GeV; the results are shown in Fig. 4. With increasing $E_{\rm T}^{\rm jet2,cut}$, the data fall, as expected.

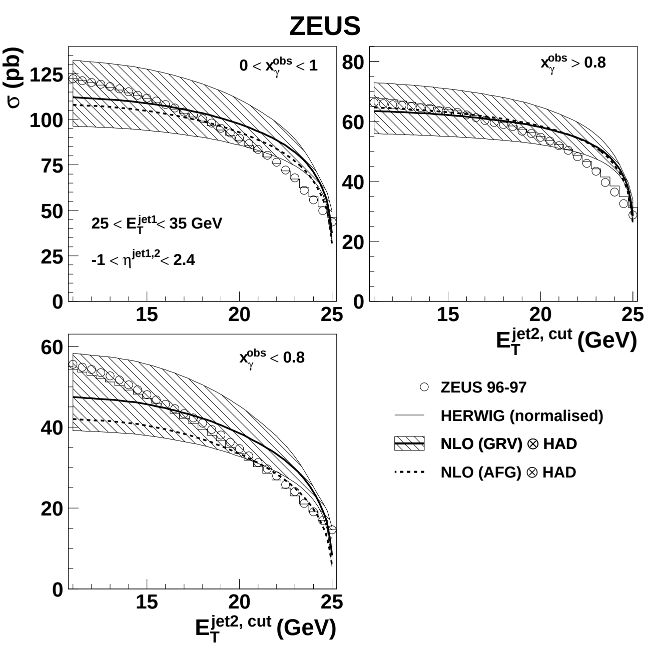

Fig. 4.

From Fig. 4 it can be seen that there is a significant dependence on $E_{\mathrm{T}}^{\mathrm{jet2,cut}}$ in the comparisons between the measurements and NLO QCD. By adjusting $E_{\mathrm{T}}^{\mathrm{jet2,cut}}$ separately in each $E_{\mathrm{T}}^{\mathrm{jet1}}$ range, it would be possible to achieve agreement between the NLO prediction and the data.

Fig. 4 shows that for a cut on the first jet of $25 < E_{\mathrm{T}}^{\mathrm{jet1}} < 35$ GeV, the cut on the jet of lower transverse energy has to be below 21 GeV for the NLO predictions to agree with the data. However, this is a somewhat arbitrary procedure: theoretical work on improving dijet calculations is needed.

3. Conclusions

The dijet cross section in photoproduction has been measured in the kinematic reagion $Q^2 < 1$ GeV^2, $0.2 < y < 0.85$, $E_{\mathrm{T}}^{\mathrm{jet1}} > 14$ GeV, $E_{\mathrm{T}}^{\mathrm{jet2}} > 11$ GeV and $-1 < \eta^{\mathrm{jet1,2}} < 2.4$. In the high-mass region defined by $M^{jj} > 42$ GeV and $0.1 < \eta < 1.3$, the dijet angular distribution of the data is well reproduced by the NLO predictions, indicating that the dynamics of the short-distance process is understood. Over a wider region, the measurements are compared with NLO predictions using different parameterisations for the parton densities of the photon. Neither the AFG-HO nor the GRV-HO parameterisation, convoluted with the NLO matix elements, fully describes all features of the data. There is agreement with the theory at high $x_{\gamma}^{\mathrm{obs}}$ and high transverse energy, where the dependence on the photon structures is small. The data at low $x_{\gamma}^{\mathrm{obs}}$ significantly constrain the parton densities in the photon; future parameterisations of the photon PDFs should take them into account. These constraints would be made more strigent where improved higher-order or resummed calculations available.

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