Dijet Production Associated with a Leading Neutron at HERA

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Dijet differential cross sections for the reaction $e^+p \to e^+ + jet + jet + n + X$ in the photoproduction regime have been measured with the ZEUS detector at HERA using an integrated luminosity of 6.4 pb^{-1}. The cross sections are given for jet transverse energies $E_T^{jet} > 6$ GeV, neutron energy $E_n > 400$ GeV, and neutron angle $\theta_n < 0.8$ mrad with respect to the proton direction. The fraction of events with a leading neutron in the final state is shown. The predictions of the one pion exchange model are found to be in reasonable agreement with the measurements presented, namely the dijet cross section as a function of the jet transverse energies, the jet pseudorapidities, and the fraction of the momentum of a postulated exchanged pion participating in the production of the dijet system.

1. INTRODUCTION

The electron-proton collider at HERA provides new opportunities to study physics processes in a new kinematic range. From dijet production in deep inelastic scattering (DIS) processes a hard scale is provided either by a large momentum transfer at the photon vertex, Q^2, or by high transverse energy, E_T^{jet}, of the produced jets. A small momentum transfer at the nucleon vertex has been taken as evidence for a peripheral collision and the presence of a soft, colour singlet interaction. The observation and measurement of dual scale (hard-soft) events at HERA has elicited much experimental and theoretical interest. At ZEUS such events are tagged either indirectly through the presence of a large rapidity gap or directly through the measurement of a scattered proton in the Leading Proton Spectrometer (LPS), or by a scattered neutron in the Forward Neutron Calorimeter (FNC) [1]. The ZEUS FNC is a Pb-scintillator sandwich calorimeter located in the HERA tunnel at $\theta = 0°$, Z = 105 m downstream of the interaction point.

We present the observation of dijet photoproduction cross sections as a function of the jet transverse energy (E_T^{jet}) and pseudorapidity (η^{jet}) of the two highest E_T^{jet} jets. Cross sections are also presented as a function of x_π, the fraction of the momentum of a hypothetical exchanged particle participating in the production of the dijet system when a neutron is detected. x_π can be expressed in terms of the E_T^{jet} and η^{jet} of the dijet system via

$$x_\pi^{OBS} = \frac{\sum_{jets} E_T^{jet} e^{\eta^{jet}}}{2(E_p - E_n)} \qquad (1)$$

where E_p and E_n are the energies of proton and neutron and the sum runs over two jets with the highest E_T^{jet}. Similarly x_γ, where x_γ is the fraction of photon's momentum into the photon-proton interaction, is defined as

$$x_\gamma^{OBS} = \frac{\sum_{jets} E_T^{jet} e^{-\eta^{jet}}}{2E_\gamma} \qquad (2)$$

where E_γ is the energy of the exchanged photon. In the previous FNC measurement [2], we have shown the uncorrected ratio of highly energetic neutrons in DIS to all DIS events, as a function of Q^2, was flat. These are the first result in the photoproduction regime ($Q^2 \approx 0$), where we have studied the ratio as a function of a different hard scale, E_T^{jet}. The rate of neutron production as a function of E_T^{jet} is thus a test of factorization of the photon vertex from the proton vertex.

2. EVENT SELECTION

Photoproduction events containing at least two jets are selected with photon virtuality $Q^2 < 1$

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GeV^2 and photon-proton center of mass energies $W_{\gamma p}$ in the range 134 GeV $< W_{\gamma p} <$ 269 GeV. Jets are identified with the k_T algorithm [3]. The jets are required to have pseudorapidities $\mid \eta^{jet} \mid <$ 2, and transverse energies $E_T^{jet} > 6$ GeV. This is referred to as an untagged sample. In addition, neutron tagged events are selected requiring the presence of an energetic neutron tagged by the FNC, $E_n > 400$ GeV, with a neutron scattering angle $\theta_n < 0.8$ mrad with respect to the proton direction.

3. RESULTS

Figure 1(a) shows the ratio of dijet photoproduction events with a leading neutron to all dijet photoproduction events as a function of E_T^{jet}. The shaded band shows the uncertainty on the ratio due to the ZEUS main calorimeter (CAL) energy scale (3-5%). The statistical errors are indicated by the thick error bars. The systematic uncertainties not associated with the absolute energy scale of the CAL have been added in quadrature to the statistical errors and are shown as thin error bars where the data has been corrected for the FNC acceptance (36%). The ratio is nearly flat with an average value of $R \sim 4\%$. The flatness of this ratio supports the factorization hypothesis.
Figure 1(b) shows the neutron energy spectrum in different x_γ ranges. As can be seen, the neutron energy spectrum is fairly independent of x_γ again, in support of factorization.
Figures 2(a,b) show the differential cross sections for the untagged sample as a function of E_T^{jet} and η^{jet}. This is compared with predictions from two leading order plus parton shower Monte Carlo programs, PYTHIA 5.7 [4] for which multi-parton scatterings have not been included and HERWIG 5.8 [5] for which they have. The Monte Carlo predictions have been normalized to the measured cross sections at high E_T^{jet} and negative η^{jet}, in order to facilitate the comparison of the shapes. The HERWIG 5.8 prediction including multi-parton scattering describes the shape of the data better in the forward region. However (although not shown here), note that the normalization does not fit the data. The measured cross sections $d\sigma/dE_T^{jet}$ and $d\sigma/d\eta^{jet}$ for neutron tagged events are shown in Figures 2(c,d). The data are compared with the predictions of the one pion exchange models RAPGAP [6] and POMPYT [7], for the SMRS-P3 [8] pion parton densities and two different options for the pion flux, Holtmann [9] and Monopole (M-pole) [10]. Within the large theoretical uncertainties the one pion exchange model is able to describe the data, as shown by the POMPYT prediction using the M-pole pion flux factor.

Figures 3(a,b) show the differential cross section as a function of x_π. In Fig. 3(a) the cross section is compared to prediction of the two Monte Carlo models using the SMRS-P3 pion parton density and two different pion flux factors (Holtmann, and M-pole) in POMPYT and RAPGAP. Due to uncertainties in the Monte Carlo simulations, it is not possible to discriminate between the available options for the pion flux factor. Although the correction factors are independent of the MC models, it is seen that within a model (POMPYT or RAPGAP), Holtmann and M-pole pion fluxes are different by a factor of two. There exits a large uncertainty in our measurement, therefore it is currently not possible to distinguish between two models.

Fig. 3(b) shows $d\sigma/dlogx_\pi$ for data compared to various pion structure functions with POMPYT using the M-Pole pion flux. In this kinematic region, there is only mild sensitivity to the variation of the pion structure function.

4. CONCLUSIONS

The differential dijet cross sections as a function of the jet transverse energy, E_T^{jet}, and pseudorapidity, η^{jet}, have been measured in photoproduction for both untagged and neutron tagged samples. The ratio of tagged to untagged dijet photoproduction as well as the neutron spectrum in different x_γ ranges, support the factorization hypothesis. The neutron tagged cross section has also been measured as a function of the fraction of the momentum of a postulated exchanged pion participating in the production of the dijet system. One pion exchange models can reproduce the shape but due to sensitivity to the pion flux

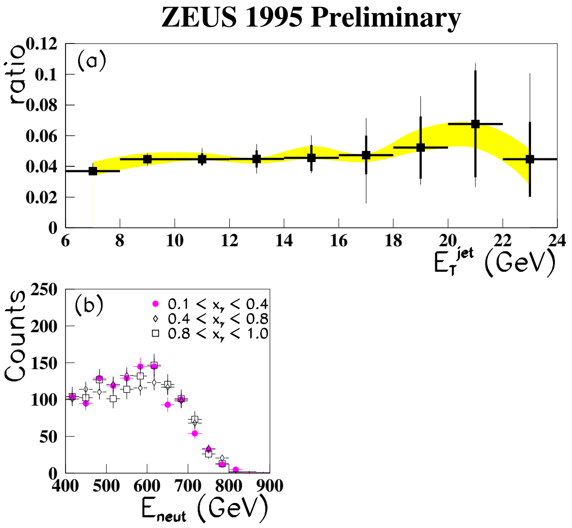

Figure 1. (a) ratio of tagged to untagged events. (b) observed neutron energy spectrum for different ranges of x_γ.

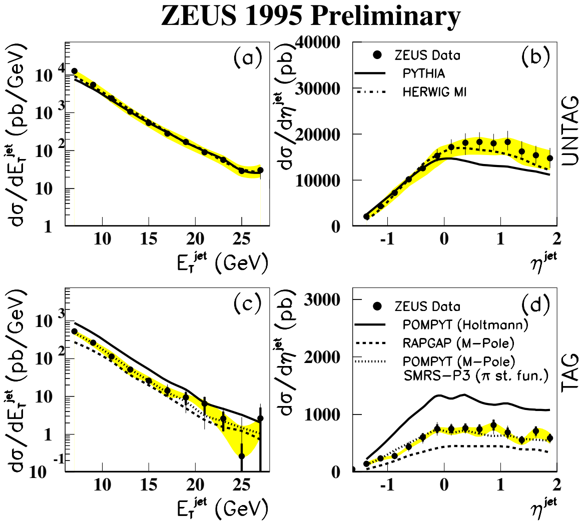

Figure 2. The differential dijet cross sections as a function of E_T^{jet} and η^{jet} for both untagged (a,b) and neutron tagged (c,d) samples.

factor, it is unable to describe the magnitude of the cross sections. In this kinematic region, the measurement has only a mild sensitivity to the variation of the pion structure function.

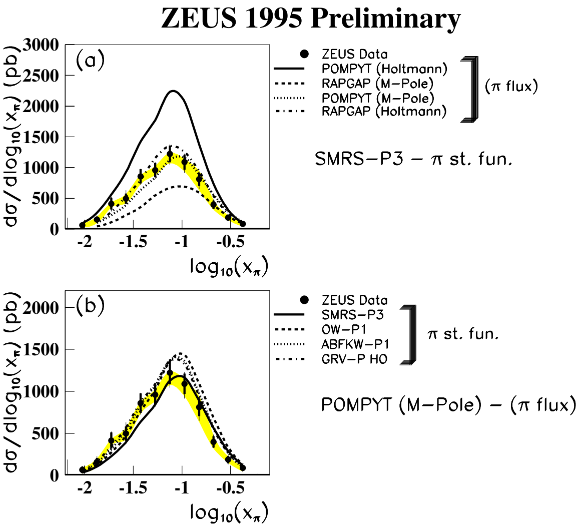

Figure 3. Measured differential cross section as a function of the fraction of the exchanged pion's momentum participating in the production of the two jets.

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