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Multi-jet Cross Sections in Deep Inelastic Scattering at HERA

H1 Collaboration

Abstract

Differential two jet cross sections have been measured in deep inelastic scattering covering the kinematic domain 5 GeV$^2 \lesssim Q^2 \lesssim 100$ GeV^2 and $10^{-4} \lesssim x_{Bj} \lesssim 10^{-2}$. The analysis is based on data collected with the H1 detector at HERA in 1994 corresponding to an integrated luminosity of about 2 pb^{-1}. The results have been corrected for detector effects. Jets are defined using a cone type algorithm in the photon-proton center of mass system requiring jet transverse momenta of 5 GeV. Jet rates are shown as a function of Q^2 and x_{Bj} and compared to several QCD models.

1 Introduction

The study of deep inelastic lepton proton scattering (DIS) provides a testing ground for perturbative QCD. Partons emerging from the scattering process manifest themselves in jets which are observable in the experiment.

In lowest order process, i.e. the quark parton model, the virtual photon is absorbed by a single quark (antiquark) of the proton resulting in two jets, one from the struck quark and one from the proton remnant. Both jets have small transverse momentum in the photon-proton center of mass frame (cms). To first order in α_s 2 jets are produced either by gluon emission from the scattering quark or by the photon gluon fusion process ($\gamma g \rightarrow q\bar{q}$), both leading to two jets with balanced transverse momenta in the cms.

The rate of 2-jet events is the basic observable for more sophisticated analyses, e.g. the measurement of the strong coupling constant α_s [1] or the determination of the gluon density within the proton [2].

In this analysis we present a measurement of the dependence of the fraction R_2 of 2-jet events in all DIS events on the scaling variable x_{Bj} integrated over Q^2 and the dependence on the virtuality of the exchanged photon Q^2 integrated over x_{Bj}. Jets are defined using a cone type algorithm in the photon-proton center of mass system requiring jet transverse momenta of 5 GeV. The measured jet rates are corrected for detector effects.

Previous measurements of jet production at HERA [3] used the JADE jet algorithm which restricts the phase space to high values ($\lesssim$0.02) of the fractional momentum of the parton entering the hard subprocess. The cone algorithm with a 5 GeV p_t threshold, on the other hand, covers fractional parton momenta above 0.001.

The measurement has been performed with the H1 detector at the HERA storage ring where 27.5 GeV positrons collide with 820 GeV protons.

2 The H1 Detector

A detailed description of the H1 apparatus is given elsewhere [4]. The parts of the detector which were essential for this measurement are the liquid argon calorimeter (LAr) and the backward lead-scintillator calorimeter (BEMC).

The energy of the scattered positrons is measured in the BEMC which has a depth of 21.7 radiation lengths and covers the polar angle range from 151° to 176°. Its position is determined with the backward tracking system located in front of the BEMC covering polar angles from 155.5° to 174.5°.

The hadronic energy flow is detected in the LAr which extends over a polar angle from 4° to 153°. The depth of the LAr varies between 4.5 and 8 hadronic interaction lengths.

3 Data Selection

The data sample used for the present analysis corresponds to an integrated luminosity of 1.97 pb^{-1} taken during the 1994 run period. DIS events are selected applying the following cuts:

- polar angle of the scattered positron $156° < \theta_{e^+} < 173°$

- electron energy $E' > 11$ GeV
- scaling variable $y > 0.05$

The kinematic variables x_{Bj}, Q^2, and y are measured from the scattered electron. Additional cuts are applied to suppress the influence of QED radiation and photoproduction background.

4 Jet Selection

Jets are defined by the algorithm used. There is no unambiguous a priori definition available. This analysis is based on the cone algorithm [5] which defines jets in the photon-proton center of mass system (cms) requiring a minimum transverse momentum p_t in a circular area of given radius R in the $\eta^* - \phi^*$ space. Here η^* and ϕ^* are pseudorapidity and azimuthal angle in the cms where the positive z direction is the incident proton direction. The four vector of the resulting jet is calculated as the sum of four vectors of the massless calorimeter objects which are associated into the jet. This recombination scheme is usually called the "E"-scheme.

In this analysis a cone radius of R=1 and a minimum p_t of 5 GeV has been chosen. Exactly two jets are required. In addition a difference in pseudorapidity of the two jets of less than 2 units is demanded to suppress events from parton showering and the proton remnant. For 2 jet events, this cut is equivalent to requiring $z_p > 0.12$ where $z_p = \frac{1}{2}(1 - \cos\theta')$ is given by the polar angle θ' of the emerging partons in the gamma-parton center of mass frame.

5 Corrections for detector effects

The correction of data for detector effects is performed using the MEPS model of the LEPTO 6.4 generator [6] with the MRS-H parton density parametrization [7]. It incorporates the QCD matrix element up to first order, with additional soft emissions generated by leading log parton showers. The generated events have been fed into the detector simulation and reconstruction chain. The corrected jet rates are then obtained using the formula:

$$R_2^{corr} = c \cdot R_2^{data}; \; c = \frac{R_2^{MC,hadrons}}{R_2^{MC,recon.}}$$

This treatment of data is justified if the observables of the jet events which are sensitive to detector effects are reasonably well described by the Monte Carlo simulation. Critical observables in this sense are the energy flow within and around the jets and the η^* and p_t^* distribution of jets. In figure 1 the excellent agreement between data and simulated events is demonstrated for these quantities.

The correction factor c amounts to 1.5, independent of Q^2 for $R_2(Q^2)$. For $R_2(x_{Bj})$ it varies between 1.9 in the lowest x_{Bj} bin and 1.3 in the highest bin.

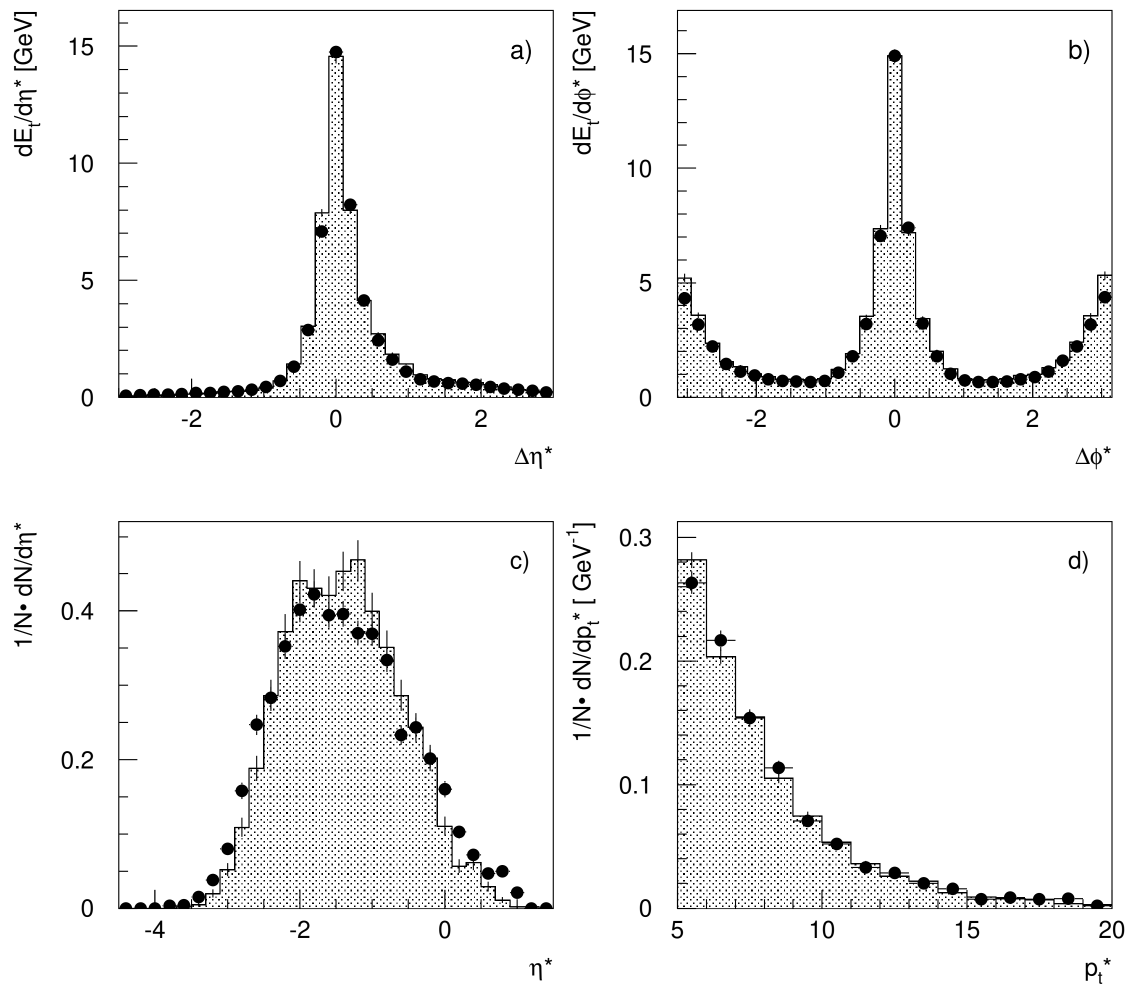

Figure 1: Transversal energy flow with respect to the jet axis, a) in a slice of $\Delta\phi^* < 1$, b) in a slice of $\Delta\eta^* < 1$, c) η^* and d) p_t^* spectrum of the jets. • denote data and shaded histograms the MEPS model of LEPTO 6.4.

Systematic Checks

Several sources of systematic uncertainties were investigated. A change in the hadronic energy scale of the LAr calorimeter by its estimated precision of $\pm 5\%$ results in a change of jet rates by 13%. Changing the energy scale of the electron measurement in the BEMC has a negligible effect on jet rates. Residual photoproduction background has been estimated from a Monte Carlo simulation which was checked against data [8]. It amounts up to 9% in the lowest x_{Bj} bin but has been proven to cancel for the fractional jet rate.

We repeated the correction procedure with the Django 6.0 Monte Carlo model [9] with the GRV parton density parametrization [10]. It contains an implementation of the colour dipole model [11] (Ariadne 4.03 [12]) together with a simulation of electroweak effects [13]. The description of the hadronic final state observables is of similar quality as for Lepto 6.4 discussed above. However, besides including QED radiation, Django predicts a

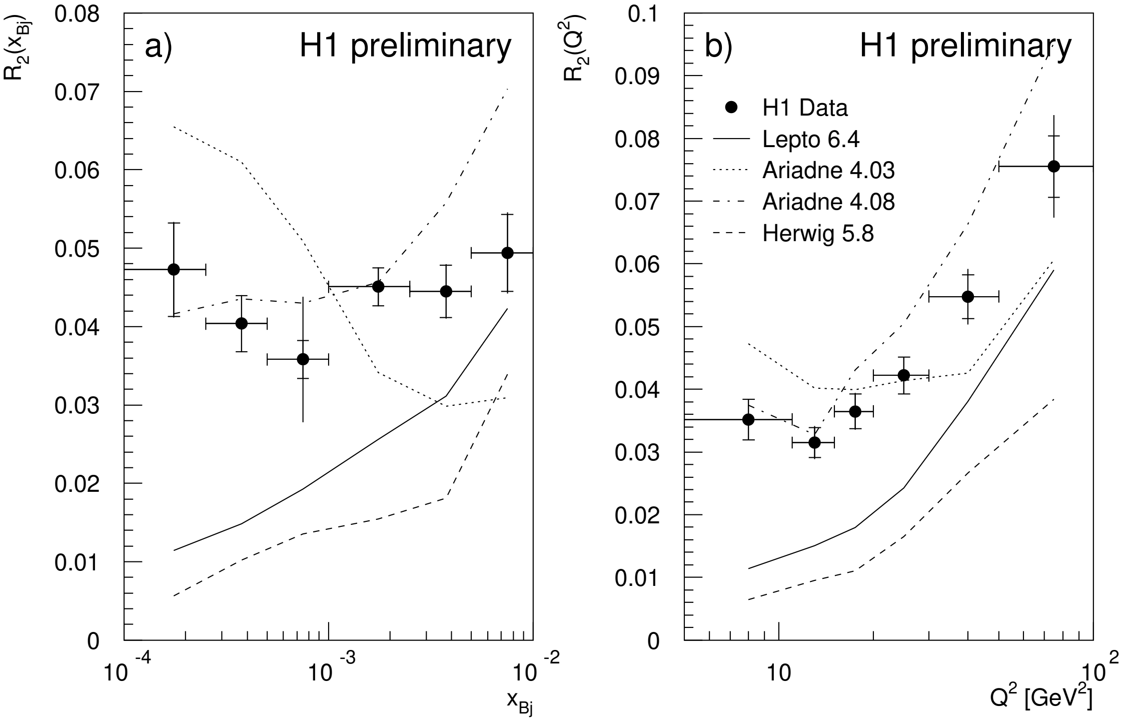

Figure 2: Fractional rate of 2 jet events as function of x_{Bj} integrated over Q^2 (a) and as a function of Q^2 integrated over x_{Bj} (b). The inner error bars are statistical, the full error bars include the model dependence of the detector correction. Not shown is a global uncertainty of 13 % due to the hadronic energy scale of the calorimeter. Also indicated are the predictions of several QCD Monte Carlo models. Their statistical errors are of the same order as the statistical error of data.

substantially different Q^2 and x_{Bj} dependence. Nevertheless, it yields a correction function consistent within 10% with the one from Lepto 6.4. This indicates that the correction procedure is independent of the Monte Carlo model used and that the results are not affected by QED radiation. Residual differences in the correction factors are reflected in the systematic errors.

Results

Figures 2a and 2b show the fractional 2 jet rate in all DIS events as function of $x_{Bj}$and Q^2 respectively. Data are corrected for detector effects. The data show a jet rate consistent with being flat in $x_{Bj}$and rising strongly in Q^2.

The Results are compared to the predictions of various Monte Carlo models: Lepto 6.4 [6], Ariadne 4.03 [12] Herwig 5.8 [14]. We also show the more recent Ariadne version 4.08 [15] which differs from 4.03, among others, in the treatment of the QCD matrix element. In all models we use the MRS-H parton density parametrization [7], except for Ariadne 4.03 which was used in its Django implementation with the GRV [10] parametrization.

Both MRS-H and GRV give a good description of HERA low x_{Bj}structure function measurements.

The investigated QCD models vary widely in their prediction of jet rates. This is surprising because, for a given set of parton densities, the production of jets with transverse momenta above 5 GeV is expected to be described by perturbative QCD, which forms the basis for all these models.

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