Forward Jet Production in DIS

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Forward jet cross sections have been measured in neutral current deep inelastic scattering at low Bjorken-x with the ZEUS detector at HERA using an integrated luminosity of 81.8 pb^{-1}. Measurements are presented for inclusive forward jet as well as for forward jet accompanied by a dijet system. The explored phase space with jet pseudorapidity up to 4.3 is expected to be particularly sensitive to the dynamics of QCD parton evolution at low x. The measurements are compared to fixed order QCD calculations and to leading-order parton-shower Monte Carlo models.

1 Introduction

Forward jets in DIS, i.e. jets at rapidity close to the initial proton, measured at small x_{Bj}, are expected to be a valuable means for discerning the BFKL dynamics of the perturbative QCD. The BFKL evolution proceeds over x and a large space for evolution over x between the corresponding parton in the beginning of the evolution and the parton interacting with the photon appears. An additional condition that the transverse momentum of the forward jet be of the order of the virtuality of the photon diminishes the space for the DGLAP evolution over virtuality. Consequently, BFKL should provide larger cross sections for the forward jet production than DGLAP. Even further discriminative power could be achieved by studying a dijet supplementing the forward jet.

Inclusion in the analysis of the data from the forward plug calorimeter (FPC) of ZEUS allowed an essential increase in the pseudorapidity of forward jets to be attained. Here, results are presented on the study of the forward jet and dijet+forward jet production up to the pseudorapidity $\eta = 4.3$.

2 Theoretical approaches

NLO calculations and Monte Carlo simulations are compared with data. NLO code DISENT is used for inclusive forward jets (shown in [1]) and NLOJET++ for forward jet+dijets, both with the factorisation and renormalisation scales $\mu_{\mathrm{R}} = \mu_{\mathrm{F}} = Q$. Three MC programs are used, representing different approaches to the QCD evolution. The Lepto MC represents the DGLAP approach. The Cascade MC represents the CCFM approach and is used with two sets of unintegrated parton (gluon) density function (uPDF), J2003 set-1 and set-2. The Ariadne MC is an implementation of the Colour Dipole Model (CDM), which provides non-ordered in transverse momentum parton cascade, i.e. BFKL-like evolution. Results with two tunings of Ariadne are presented, the default tuning and the new tuning as introduced in [2].

3 Results

The analysis is based on the data collected with the ZEUS detector in 1998-2000 years, corresponding to an integrated luminosity of $81.8 \pm 1.5\,\mathrm{pb}^{-1}$. A description of the ZEUS

detector and of the FPC can be found elsewhere [3, 4]. Electrons or positrons with energy of $E_e = 27.5$ GeV collided with protons of energy $E_p = 920$ GeV. The neutral current DIS events were selected with the energy of the scattered electron $E_e^{'} > 10$ GeV, inelasticity $0.04 < y < 0.7$ and $20 < Q^2 < 100$ GeV^2. Only small $x_{\rm Bj}$ events were analysed,
$0.0004 < x_{\rm Bj} < 0.005$. Jets were reconstructed with inclusive k_T-algorithm in the Breit frame and thereafter boosted to the laboratory frame. Forward jets within the pseudorapidity range $2 < \eta^{\rm jet} < 4.3$ were selected with the transverse energy in the laboratory frame $E_T^{\rm jet} > 5$ GeV. Two additional requirements were imposed to enhance the BFKL evolution and to suppress the DGLAP evolution: the jet should have a large fraction of the proton momentum $x^{\rm jet} = p_Z^{\rm jet}/p > 0.036$ and the transverse energy of the order of the virtuality of the photon $0.5 < (E_T^{\rm jet})^2/Q^2 < 2$. For the "forward jet+dijet" study, the events were required to have one forward jet, satisfying above conditions except the $(E_T^{\rm jet})^2/Q^2$ cut, and at least two additional jets with $E_T^{\rm jet} > 5$ GeV in the pseudorapidity range $-1.5 < \eta^{\rm jet} < 4.3$. From these additional jets, the two with the highest transverse energy were chosen. The three selected jets were ordered in pseudorapidity such that $\eta^{\rm jet_1} < \eta^{\rm jet_2} < \eta^{\rm fjet}$.

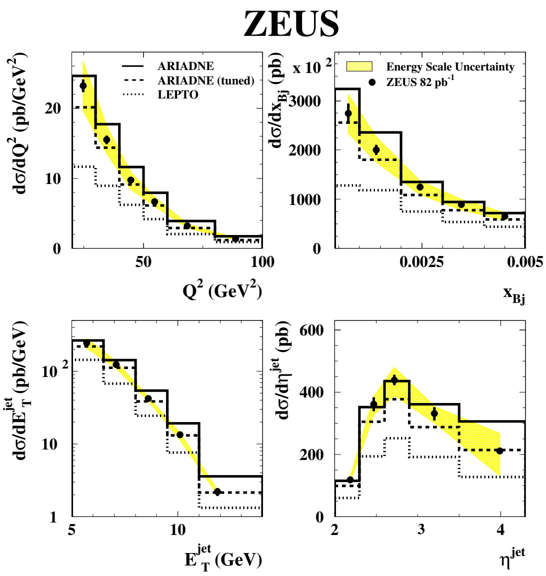

Figure 1: Inclusive forward jet cross sections. Data are compared with LEPTO, default ARIADNE and newly tuned ARIADNE. The shaded area shows the cumulative uncertainty of the CAL and FPC energy scales.

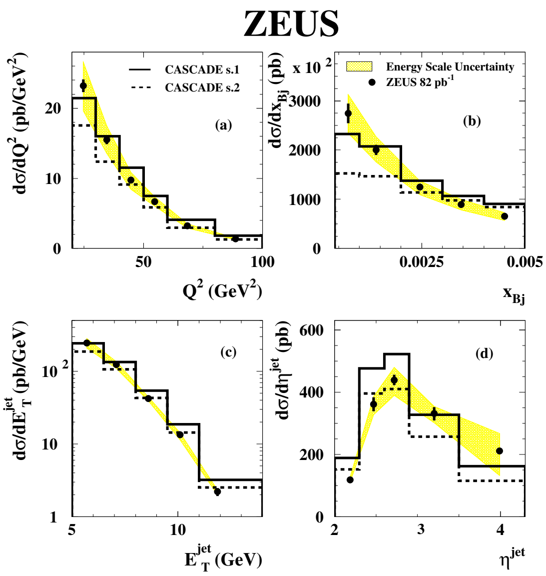

Figure 2: Inclusive forward jet cross sections. Data are compared with CASCADE with two sets of uPDF.

The measured differential forward jet cross sections are compared with the ARIADNE and LEPTO MC in Figure 1. ARIADNE default is in fair agreement with the data with the exception of high $E_T^{\rm jet}$ and high $\eta^{\rm jet}$. The newly tuned ARIADNE yields lower cross section, in particular at high $E_T^{\rm jet}$ and high $\eta^{\rm jet}$, and provides a better description of the data. The predictions of the LEPTO MC are in agreement with data in shape for all distributions, however the absolute normalisation is below the measurements by about a factor of two.

In Figure 2, data are compared with CASCADE. Set-2 results in lower cross sections than set-1. Neither of two uPDF sets provides overall satisfactory agreement with the measurements.

Forward jet+dijet study was performed through measuring cross sections as functions of two pseudorapidity separation $\Delta\eta_1 = \eta^{\rm jet_2} - \eta^{\rm jet_1}$ and $\Delta\eta_2 = \eta^{\rm fjet} - \eta^{\rm jet_2}$. Additionally, the cross section as a function of $\Delta\eta_2$ was plotted for two intervals of $\Delta\eta_1$, $\Delta\eta_1 < 1$ and $\Delta\eta_1 > 1$.

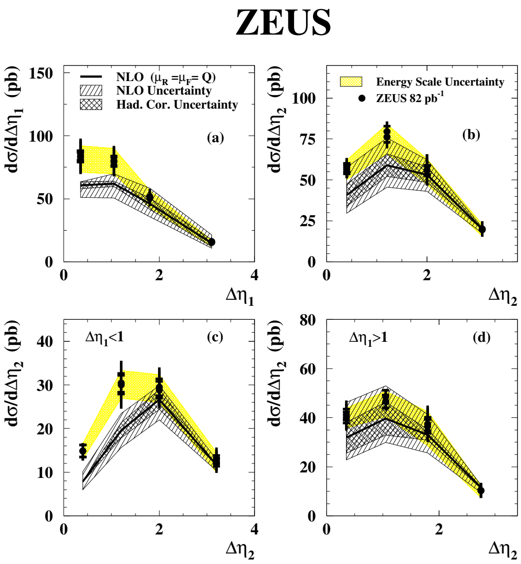

Figure 3: The forward jet+dijet cross sections. Data are compared with the NLO QCD calculations (solid line). The hatched area shows the theoretical uncertainities. The shaded area shows the uncertainty after varying the CAL and FPC energy scales.

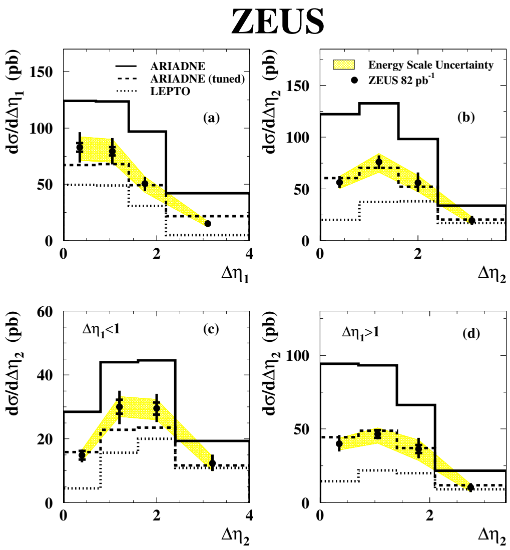

Figure 4: The forward jet+dijet cross sections. Data are compared with LEPTO, default ARIADNE and newly tuned ARIADNE.

Figure 3 shows the comparison of the data with the calculations of NLOJET++. The NLO calculations agree with data at large $\Delta\eta_2$, while does not describe the data at small $\Delta\eta_2$, especially when $\Delta\eta_1$ is small. The large $\Delta\eta_2$ kinematics at low $x_{\rm Bj}$ favours dijets originating from the photon-gluon fusion, with an additional gluon responsible for the forward jet. This case is well treated by NLOJET++. The small $\Delta\eta_1$ and $\Delta\eta_2$ region corresponds to the event configuration in which all the three jets tend to go forward, away from the hard interaction. This configuration favours multigluon emission, which lacks in NLOJET++. Figure 4 shows the comparison of the data with LEPTO and ARIADNE. As before, the LEPTO predictions are generally significantly below the data. ARIADNE with default tuning overestimates the cross sections, which implies that energetic multiple jets are too often produced. The new tuning of the ARIADNE parameters brings this model into very good agreement with data for all distributions.

4 Conclusions

Forward jets study is performed both by measuring inclusive forward jet cross sections and forward jet+dijet cross sections. Good overall description of the inclusive forward jet cross sections is obtained by the newly tuned ARIADNE MC, representing CDM, i.e. non-ordered in the transverse momentum evolution. The LEPTO MC, representing the DGLAP approach, i.e. strongly ordered in the transverse momentum evolution, significantly underestimates the cross sections. The CASCADE MC, representing the CCFM approach, with J2003 set-1 and J2003 set-2 for unintegrated gluon density, fails to satisfactorily describe the data. These measurements can be used for further adjusting the uPDF.

For the forward jet+dijet cross sections, NLO calculations describe the data at large $\Delta\eta_2$ but underestimate the cross sections at small $\Delta\eta_2$, especially for small values of $\Delta\eta_1$, where in the case of small x_{Bj} the contribution of multiple gluon emission is expected to be large. The predictions of LEPTO, like in the inclusive case, are significantly below the data. ARIADNE with default parameters significantly overestimates the cross sections whereas the new tuning provides good description of the data.

References

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