Production of Forward Jets at HERA

J. Bartels[1], A. De Roeck[2], M. Wüsthoff[3,a]

[1] II. Institut für Theoretische Physik, Universität Hamburg, D-22761 Hamburg, Germany.
[2] Deutsches Elektronen Synchrotron DESY, D-22603 Hamburg, Germany.
[3] Argonne National Laboratory, 9700 South Cass Avenue, IL 60439, USA.
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Abstract: We study predictions for the associated production of forward jets at HERA using the high energy asymptotic expressions derived from the BFKL equation, and compare it with calculations made in the Born approximation. The cuts have been varied to optimize the detection of the BFKL signal. For typical detector cuts we find that the slope of the cross section as a function of x can strongly increase if jets with smaller angles (more forward jets) can be detected.

1 Introduction

A proposed clean footprint of BFKL dynamics [1] at HERA is the measurement of inclusive jet production in the forward direction, in deep inelastic scattering interactions. Jets have to be selected with longitudinal momentum close to the one of the proton (i.e. the fractional momentum of the jet is much larger than the Bjorken-x : $x_{\rm jet} \gg x$), and transverse momentum, $p_{T{\rm jet}}$, of the order of the virtual photon mass $\sqrt{Q^2}$. These measurements have been proposed in[2] and analytical calculations were performed in[3]. The cross section formula for the process $\gamma^* + g \to g + (n\, g) + q\bar{q}$ or $\gamma^* + q \to q + (n\, g) + q\bar{q}$ has been derived from the BFKL equation which resums the leading logarithms. Details are given in [4]. The results of the BFKL calculations have been compared with the Born diagram calculations, i.e. interactions where no gluons are emitted along the ladder (n=0). Data from the H1 experiment at HERA [5] have shown encouraging agreement with the BFKL parton level calculations presented in [4]. Moreover, recently fixed-order NLO calculations [4, 6] demonstrate that the expected jet cross sections are lower and may have a different x dependence. The BFKL prediction — which, as a result of gluon production between the forward jet and the current jet, rises as a function of $1/x$ — is found to lie above the matrix element calculation. We also find that the Born calculation and matrix element calculation are very similar. In our previous publication we compared the results of the calculation with the H1 data, for exactly the same cuts. In this paper we use the BFKL cross section program to investigate the dependence of the cross section on these cuts.

2 Experimental cuts

In a recent analysis forward jets have been studied by the H1 collaboration[7] for a sample of DIS events with a scattered electron satisfying $E_e > 11$ GeV, $160^0 < \theta_e < 173^0$ and the kinematical conditions $y > 0.1$ and $0.0005 < x < 0.0035$. A cone algorithm is used to find jets in the H1 calorimeter, requiring an E_T larger than 3.5 GeV in a cone of radius $R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 1.0$ in the space of pseudo-rapidity η and azimuthal angle ϕ in the HERA frame of reference. Preliminary cross sections are measured for events which have a "forward" jet defined by $x_{\rm jet} > 0.035$, $0.5 < {p_{T\rm jet}}^2/Q^2 < 2$, $7^0 < \theta_{\rm jet} < 20^0$ and $p_{T\rm jet} > 3.5$ GeV, where $p_{T\rm jet}$ is the transverse momentum of the jet, and $\theta_{\rm jet}$ the angle of the jet with respect to the proton beam direction. The variable $x_{\rm jet}$ is approximated as $E_{\rm jet}/E_{\rm beam}$ with $E_{\rm jet}$ the energy of the jet and $E_{\rm beam} = 820$ GeV. The data are presented as function of Bjorken-x. The prediction for this experimental cuts is shown in Fig.1 for incident electron and proton beam energies of 27.5 and 820 GeV respectively. Shown is the jet cross section per bin in x. The bins of the histogram are matched to the preliminary bining of the data as they were presented in [7].

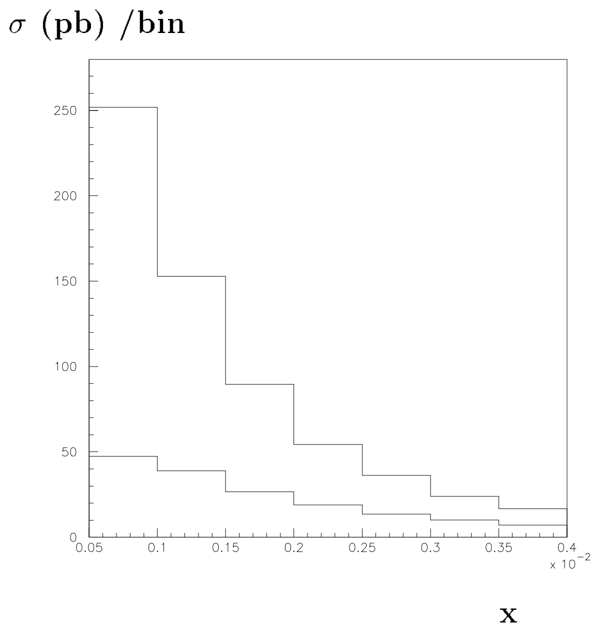

Figure 1: *Cross section per bin from the BFKL calculation (upper curve) and Born calculation (lower curve), for the jet and event selection given in section 2.*

3 Modified cuts

We have varied the cuts described in the section above and studied the behaviour of the Born and BFKL cross sections. We modify the forward jet quantities ${p_{T\rm jet}}^2/Q^2$, $p_{T\rm jet}$, and $\theta_{\rm jet}$ The variables defining the selection of the deep inelastic events have not been varied. It was checked that selecting predominately events with lower x by either changing the minimum scattered electron energy to a few GeV, or by increasing the cut on minimum y from 0.1 to 0.4 does not

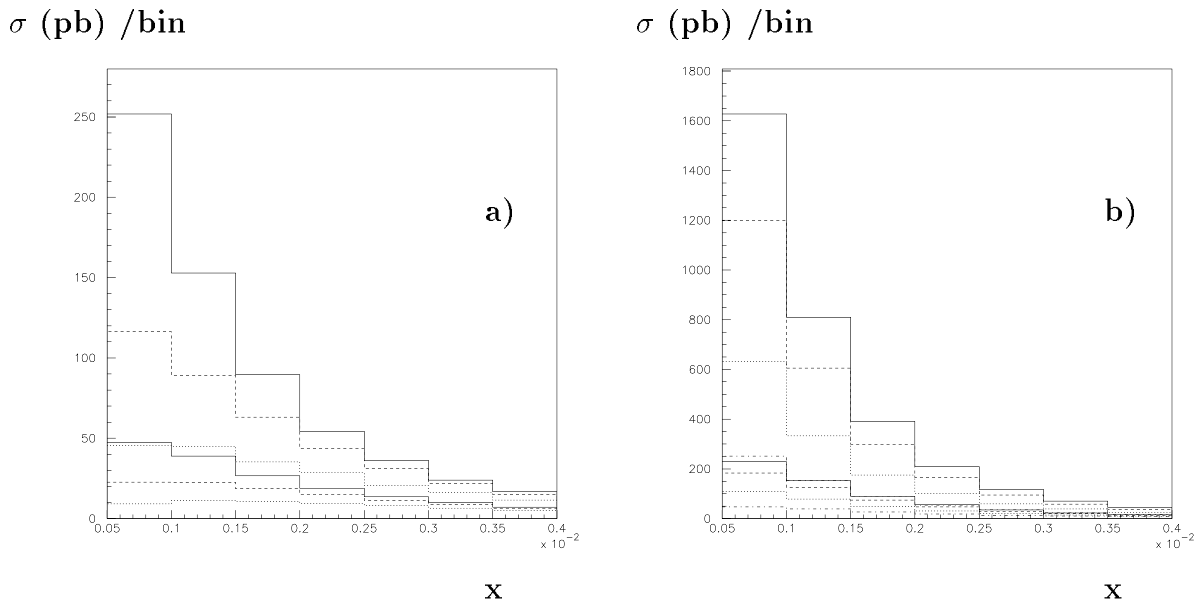

Figure 2: **a)** *Cross section per bin from the BFKL and Born calculations with $p_{T\mathrm{jet}}$ = 3.5 GeV (solid line), 5 GeV (dashed line) and 6 GeV (dotted line); upper curves are BFKL, lower are Born calculations.* **b)** *Cross section per bin from the BFKL and Born calculations with θ_{jet} = 2 (solid line), 3 (dashed line) 5 (dotted line) and 7 degrees (dash-dotted line); upper curves are BFKL, lower are Born calculations. All other cuts for both figures are as given in Section 2.*

have a large effect. Beam energies of 27.5 and 820 GeV were assumed for the electrons and protons respectively.

A priori one could imagine that tightening the cut $0.5 < {p_{T\mathrm{jet}}}^2/Q^2 < 2$ would result in a more visible difference as one approaches more the 'BFKL' condition. In practice the slope for both the BFKL and Born cross sections do not change much. Reducing the cut to $0.8 < {p_{T\mathrm{jet}}}^2/Q^2 < 1.2$, however reduces the cross section by approximately a factor of 4. It would be of interest to see the effect in a NLO calculation, but the results basically indicate that this cut as used in the experiment at present is sufficiently narrow.

The minimum jet transverse energy required by the set of standard cuts is 3.5 GeV. This could be considered too low to be safe against hadronization effects. Also the predictions of NLO calculations, to be considered as a background to this process, become more reliable at large $p_{T\mathrm{jet}}$. Therefor predictions were calculated for higher $p_{T\mathrm{jet}}$ cuts. In Fig. 2a results are shown for cuts $p_{T\mathrm{jet}} = 3.5, 5$ and 6 GeV. It shows that the slope of the BFKL calculation becomes less steep with increasing $p_{T\mathrm{jet}}$. This is in accord with the expectations as presented in [4]. It can understood as being due to the decrease in phase space: the requirement of $p_{T\mathrm{jet}}$ to be similar to $\sqrt{Q^2}$ results, for an increase in $p_{T\mathrm{jet}}$, to an increase in $\sqrt{Q^2}$, and correspondingly an increase in x. Hence the x_{jet}/x lever arm becomes smaller and the BFKL gluon emission is reduced. Note also that the cross sections are strongly reduced as the cut increases. Hence such an increase reduces the BFKL effect and makes it harder to detect.

The most substantial effect comes from reducing the minimum angle for the jet detection θ_{jet}. In Fig.2b the cross section is shown for $\theta_{\mathrm{jet}} = 7, 5, 3$ and 2 degrees. The slope of the BFKL calculation increases strongly at small angles. It would be interesting to see if the

NLO calculations are still in agreement with the Born calculations for these small angles. If so, instrumenting the detectors to cover low angles for jet measurements would be clearly advantageous for these BFKL studies.

The effect of an increased $p_{T\mathrm{jet}}$ cut on a data sample selected with $\theta_{\mathrm{jet}} = 3$ degrees is similar to the one discussed above: the slope gets smaller. However the slope and cross section for a selection with $p_{T\mathrm{jet}} = 5$ GeV and $\theta_{\mathrm{jet}} = 3$ degrees is about the same as for the present selection with $p_{T\mathrm{jet}} = 3.5$ GeV and $\theta_{\mathrm{jet}} = 7$ degrees. Hence detecting jets towards smaller angles allows to put more stringent cuts on the jet energies. It also allows to increase the x_{jet} cut to enlarge the x_{jet}/x lever arm.

4 Conclusions

The dependence of the forward jet cross section as function of x was studied for different jet selections. Increasing the jet energy reduces the sensitivity to the BFKL effect. A substantial gain to observe the BFKL pomeron can be made if the detectors can get upgraded to detect and measure jets at smaller angles.

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