# Forward Jets Cross Sections

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**Abstract**

We investigate the prospects for a precise measurement of differential forward jet cross sections with the ZEUS detector in order to discriminate between the QCD evolution schemes of DGLAP and BFKL.

At low $x$-Bjorken ($x$) and in leading order of $\alpha_S$ the parton evolution is dominated by the Boson-Gluon Fusion process. Higher order terms are usually described by the Altarelli-Parisi equation [1], which sums up leading powers of $\ln Q^2$ and neglects terms with $\ln\frac{1}{x}$ alone. This leads to an emission of partons strongly ordered both in longitudinal ($x_i$) and transverse momentum ($k_T^2$) (see fig.1):

$$x \ll x_1 \ll \cdots \ll x_{JET}, \qquad Q^2 \gg k_{T,1}^2 \gg \cdots \gg k_{T,Jet}^2.$$

The resulting gluon distribution is proportional to: $xg(x) \propto exp((2(\frac{3\alpha_S}{\pi} lnQ^2 ln\frac{1}{x}))^{\frac{1}{2}})$.

The BFKL approach [2] resums the $\ln\frac{1}{x}$ terms and leads to parton emissions which are not ordered in transverse momentum. The resulting gluon density grows as a power of $x$ (the *Lipatov* growth): $xg(x) \propto x^{-\alpha_P+1}$ with $\alpha_P - 1 = \frac{12\alpha_S}{\pi} ln2$.

The effects predicted by the BFKL evolution equation are expected to become important at low $x$. As a signature of a BFKL-like parton evolution, it has been suggested [4] to study high-$E_T$ jets ($k_{T,Jet}^2 \sim Q^2$) emitted in the forward direction. This relies on the idea that, in the BFKL picture, because of the absence of strong ordering in transverse momentum, the struck quark and the high $x_{Jet}$ parton can be separated by a large rapidity interval, in which the parton emissions are enhanced. In this picture, the cross section for parton emission is dominated by powers of $\alpha_S ln\frac{x_{Jet}}{x}$, while these processes are suppressed in the DGLAP picture.

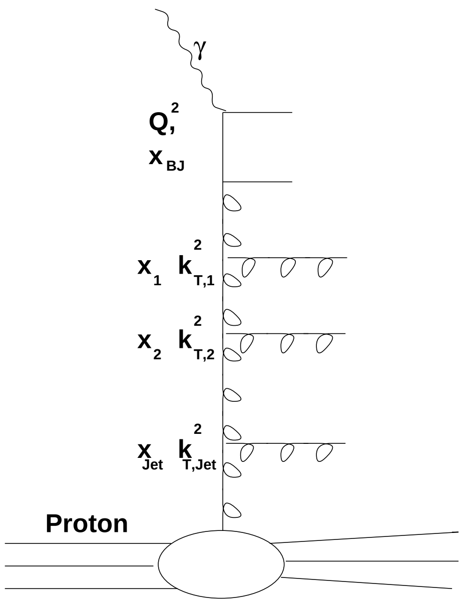


Figure 1: *Gluon ladder in the Boson-Gluon Fusion process.*

In contrast to measurements of the inclusive proton structure function or transverse energy flow, measurements of forward jet cross sections have the advantage that they are sensitive to the explicit details of QCD evolution and have smaller sensitivity to hadronization effects.

However some difficulties still remain. First, because of the kinematics, NLO corrections are large in this region [6]; therefore it is necessary to evaluate the perturbative background to BFKL using NLO calculations of DGLAP. Then the experimental problems are more difficult to handle in the forward region than elsewhere: the purity of the jet sample (i.e. the ratio of the number of jets seen in the detector which also match a jet from the generator level to the total number of jets in the detector) and the jet resolution (i.e. the difference between jet detected and jet generated as a function of various kinematical variables) drop in this region.

Here, as an example, we use the ZEUS detector to show the possibilities and the limits of a forward jet analysis as well as to discuss some luminosity requirements for such an analysis.

In order to reconstruct the jets, the cone algorithm was used, because it leads to small higher order corrections and recombination schemes dependences [6].

In order not to lose energy in the beam pipe, a cut on the pseudorapidity $\eta < 3$ units has been used where $\eta$ is a function of the polar angle $\theta$ ($\eta = -ln(tan(\theta/2))$). A cut on the transverse energy of the jets of 7 GeV has been imposed for better energy resolution and small hadronization effects (for this value of $E_T$, studies show that the hadronization effects are less than 10%). The present study has been performed for events with $Q^2 > 6$ GeV$^2$.

In order to evaluate the size of the expected effect of a BFKL type process, the cross section for inclusive one-jet production, where one jet is constrained in the forward region, is calculated with the ARIADNE Monte Carlo [5]. ARIADNE is often used as an approximation to the BFKL effect, although it does not have the exact BFKL evolution process implemented. This cross section is compared to the one found in the LEPTO Monte Carlo [5]. LEPTO implements the DGLAP evolution process.

The results of the comparison are shown in fig.2, where the inclusive one-jet cross section (one jet being constrained in the forward region) is plotted as a function of $x$. The forward jet has been selected with $2 < \eta_{jet} < 3$ and the transverse energy of the jets is larger than 7 GeV. For this value of $E_T$, the hadronization effects are within 10%, as determined with the present generators. The plots show a significantly larger cross section in ARIADNE compared to LEPTO at low $x$ and low $Q^2$, as expected. This is taken as a sign of the difference between the two parton evolution schemes. Recent comparisons of theoretical calculations using fixed-order NLO QCD calculations [8] and calculation based on a BFKL ladder in the initial state [9] show similar strong differences in the rate of forward jet cross sections. These cross sections have also been evaluated using with other cuts using MEPJET [8] at leading and next-to-leading order. The numerical results of the comparison between LEPTO and ARIADNE are:

| $Q^2$ | 6-10 GeV$^2$ | | | 10-20 GeV$^2$ | | | 20-100 GeV$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|
| $x$ ($\times 10^{-4}$) | 1-3 | 3-7 | 6-20 | 1.5-5 | 5-15 | 15-40 | 6-15 | 15-30 | 30-80 |
| LEPTO [pb] | 120 | 149 | 128 | 136 | 214 | 135 | 177 | 204 | 262 |
| ARIADNE [pb] | 243 | 214 | 196 | 173 | 286 | 140 | 191 | 145 | 229 |

Table 1: Comparison of cross sections

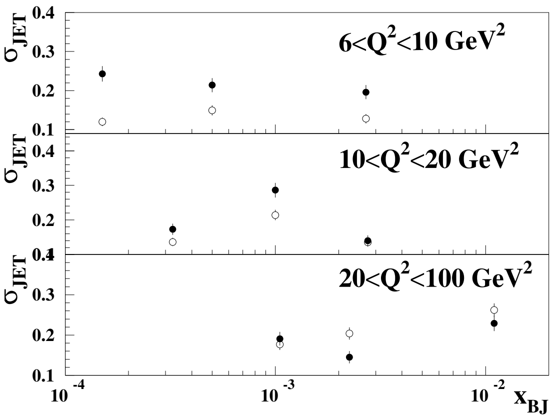


Figure 2: *Comparison of the 1 jet inclusive cross section (in nb) for LEPTO 6.3(○) and ARIADNE 4.08(●) in different* $Q^2$ *bins.*

This study is experimentally challenging, as can be inferred from fig.3. There, the purity (defined above) and efficiency (i.e. the ratio of the generated jets which actually match a jet observed at detector level over the total number of generated jets) on a one-to-one jet basis, as well as the correction factors (i.e. the factors needed to get the hadron jet cross section from the detector level value) are shown for an $E_T$ cut of 7 GeV. There is a clear drop in purity at high $\eta$, obviously due to the difficulty of reconstructing the jet in this region: Monte Carlo studies show that the angular resolution gets worse in the forward region. As a matter of fact, the granularity of the ZEUS calorimeter sets the limits on the angular resolution of the jet in this region.

In fig.4 the luminosity needed in order to get to 5% for the statistical error as a function of $x$ (for $x$ bins of $2 \cdot 10^{-4}$) is shown for two different sets of cuts.

The first one has requirements only for the jets (a forward jet with $2 < \eta < 3$, $E_{T,Jet} > 7$ $GeV$). The second one requires additionally a cut on $p_T^2/Q^2$ on the forward jet in order to be in the phase space region of interest ($0.5 < p_T^2/Q^2 < 6$). No detector effect has been taken into account. As can be seen from the figures, the constraint on the momentum of the jet to be within some range around $Q^2$ severly decreases the statistics and increases the luminosity requirements by a factor between 2 and 5.

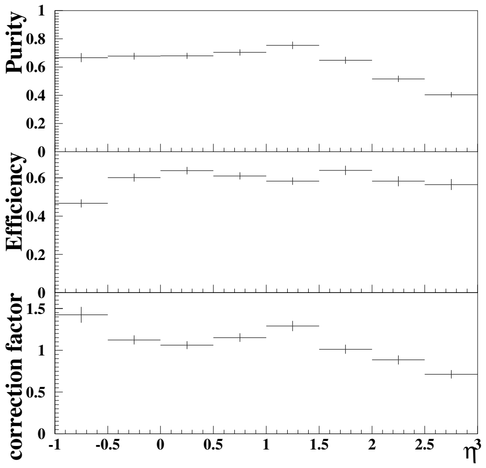


Figure 3: *Purity, efficiency and correction factors as a function of* $\eta_{Jet}$ *in a jet by jet basis with* $E_{T,Jet} > 7$ $GeV$.

## Summary and future

Forward jets are expected to be a clear signature to distinguish between BFKL and DGLAP parton evolution. These jets are a challenge to measure, but a sufficient accuracy can be reached with the set of cuts that has been worked out here. The difference predicted for the cross sections in BFKL and DGLAP evolutions are expected to be larger than 10%. A comparison with the NLO calculation seems to be necessary to evaluate the standard QCD background. This could be done by using the MEPJET package.

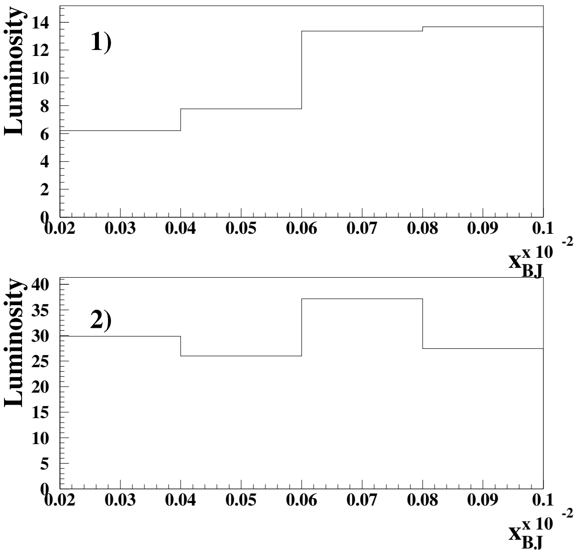


Figure 4: *Luminosity (in $pb^{-1}$) needed to have a statistical error of 5% in each x bin for two sets of cuts: 1) cuts on rapidity and transverse energy of the jets and 2) same cuts plus constaint on $p_T^2/Q^2$ on the forward jet.*

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