FORWARD JETS AND BFKL AT HADRON COLLIDERS*

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We present results on dijet and $W+$dijet production at hadron colliders obtained by supplementing the leading log BFKL resummation with energy and momentum conservation. For pure dijet production, the inclusion of the BFKL radiation in the energy conservation leads to a decrease in the parton flux sufficient to counter-act the expected exponential increase in the cross section obtained for the partonic cross section. Other BFKL signatures such as the dijet azimuthal angle decorrelation do still survive.

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1. Introduction

When confronting BFKL with data, it must be remembered that the analytic Leading Log (LL) BFKL resummation [1] makes some approximations which, even though formally subleading, can be numerically important at present collider energies. These approximations include:

(a) The BFKL resummation is performed at fixed coupling constant.

(b) Because of the strong rapidity ordering any two-parton invariant mass is large. Thus there are no collinear divergences in the LL resummation in the BFKL ladder; jets are determined only at tree-level and accordingly have no non-trivial structure.

(c) Finally, energy and longitudinal momentum are not conserved, since the momentum fraction x of the incoming parton is reconstructed without the contribution to the total energy from the radiation of the BFKL ladder.

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Therefore, the analytic BFKL approach systematically underestimate the exact value of the x's, and can thus grossly overestimate the parton luminosities. In fact, for dijet production (at a hadron collider) with a BFKL gluon exchange in the t-channel we have

$$x_{a(b)} = \frac{P_{a\perp}}{\sqrt{s}}\mathrm{e}^{(-)y_a} + \frac{P_{b\perp}}{\sqrt{s}}\mathrm{e}^{(-)y_b} + \sum_{i=1}^{n}\frac{k_{i\perp}}{\sqrt{s}}\mathrm{e}^{(-)y_i}\,, \tag{1}$$

where the minus sign in the exponentials of the right-hand side applies to the subscript b on the left-hand side. x_a, x_b is the Bjorken x of the incoming partons, and $(P_{a\perp}, y_a), (P_{b\perp}, y_b)$ is the transverse momentum and rapidity of the two leading dijets. The sum is over the number n of gluons emitted from the BFKL chain, each with transverse momentum $k_{i\perp}$ and rapidity y_i. It is this last contribution to the energy and longitudinal momentum conservation that is inaccessible in the standard analytic approach to LL BFKL, since the BFKL equation is solved by summing over any number of gluons radiated and integrating over the full allowed rapidity ordered gluon phase space. Considering Mueller–Navelet dijet production [2], a comparison of three-parton production to the truncation of the BFKL ladder to $\mathcal{O}(\alpha_\mathrm{s}^3)$ shows that the LL approximation leads to sizable violations of energy-momentum conservation [3].

We will, in the following, report on studies of the effects of including energy and momentum conservation in the LL BFKL evolution.

2. Monte Carlo approach to studying the BFKL chain

A Monte Carlo approach to studying the BFKL gluon exchange was first reported in Ref. [4, 5] and the details of the formalism will not be repeated here. The basic idea of the Monte Carlo BFKL model is to solve the BFKL equation while maintaining information on each radiated gluon. This is done by unfolding the integration over the rapidity ordered BFKL gluon phase space by introducing a resolution scale μ discriminating between resolved and unresolved radiation. The latter combines with virtual corrections to form an IR safe integral. Thereby the solution to the BFKL equation is recast in terms of phase space integrals for resolved gluon emissions, with form factors representing the net effect of unresolved and virtual emissions. Besides being necessary for calculating the impact on the parton flux by including energy and momentum conservation, this approach also allows for further studies of the details of the BFKL radiation, and for the effects of the running of the coupling to be added to the LL evolution.

3. BFKL signatures in dijet production

The main result of the study [6] is that the contribution of the BFKL gluon radiation to the parton momentum fractions (at LHC energies) lowers the parton flux in such a way as to approximately cancel the rise in the subprocess cross section with increasing dijet rapidity separation ($\hat{\sigma}_{jj} \sim \exp(\lambda\Delta y)$) predicted from the standard BFKL approach (see figure 1).

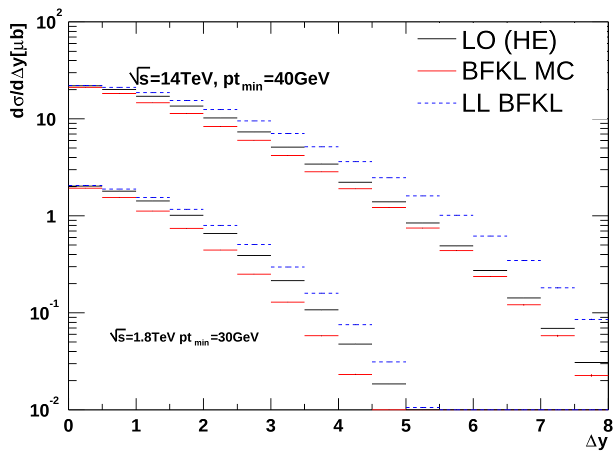

Fig. 1. Mueller–Navelet dijet cross sections calculated for the high-energy limit of leading order QCD and for LL BFKL, both in the standard LL approach and this supplemented with energy-momentum conservation (BFKL MC).

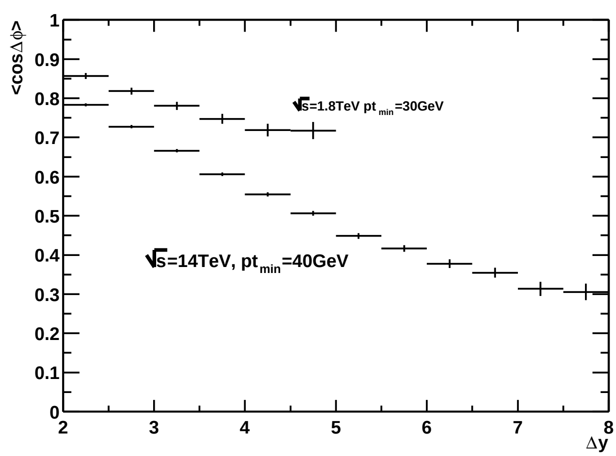

Fig. 2. Dijet angular decorrelation of Mueller–Navelet dijets calculated for energy-momentum conserving LL BFKL. The levelling out of the decorrelation at higher values of the rapidity separation is a result of the available phase space restricting further radiation from the BFKL chain.

This strong pdf suppression is due to the dijet production being driven by the gluon pdf, which is very steeply falling in x for the region in x of interest. This means that even the slightest change in x has a dramatic impact on the parton flux. The leading-order QCD prediction for the hadronic dijet cross section is therefore only slightly modified when including BFKL evolution of the t-channel gluon to an almost no-change situation. However, other BFKL signatures such as the dijet azimuthal angle decorrelation do still survive (see figure 2).

4. BFKL signatures in $W + 2$jet production

Although at hadron colliders the simplest process for studying BFKL effects is the production of dijets with large rapidity separation, the formalism also applies to the production of more complicated forward final states. One of the forward Mueller–Navelet jets can be replaced by a W-jet pair, which also provides a testing ground for BFKL signatures [7]. In fact, the suppressing effect of the BFKL gluon radiation on the pdfs is less pronounced in this case, since requiring a W in the final state at means (at leading order) that at least one of the initial state partons must be a *quark*, with a less steeply falling pdf. This means that the BFKL rise in the partonic cross section is not compensated to the same extent as in the dijet case. In fact, we find that in this case the cross section for the process including a BFKL gluon exchange is higher than the leading order cross section, thanks to the relative flatness of the quark pdf in the relevant region in x (see figure 3).

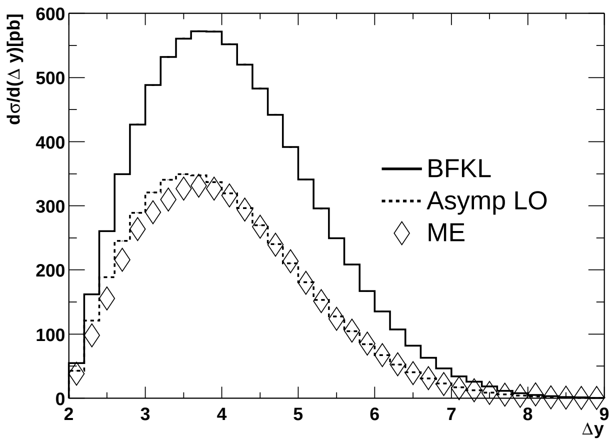

Fig. 3. The $W + 2$-jet production rate as a function of the rapidity interval between the jets Δy with the following cuts $y_W, y_{j_2} \geq 1, y_{j_1} \leq -1$ or $y_W, y_{j_2} \leq -1, y_{j_1} \geq 1$. The diamonds are the leading order production rate; the dashed curve is the production rate in the high-energy limit; the solid curve includes the BFKL corrections taking energy/momentum conservation into account.

In the case of W+2jet production, there will be some decorrelation in azimuthal angle between the two jets already at leading order because of the radiation of the W. However, a BFKL gluon exchange will increase this decorrelation [7] significantly (see figure 4).

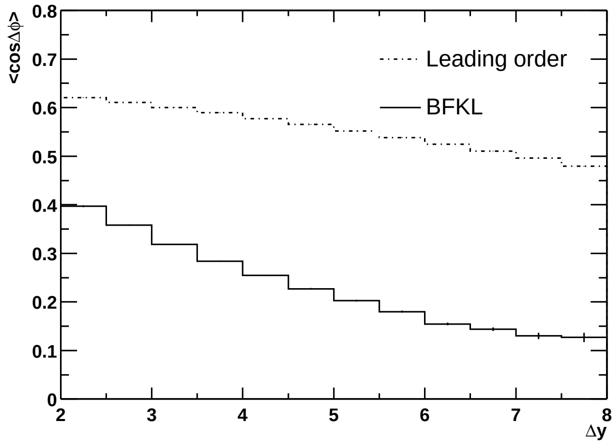

Fig. 4. The average azimuthal angle between the two jets in W+2jet production as a function of the rapidity interval between them. Same cuts applied as in Fig. 3.

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