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Transverse Momentum Distributions in Large-rapidity Dijet Production at the Tevatron[a]

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Abstract

In this contribution we examine the transverse momentum distributions in dijet production at large rapidity intervals at the Tevatron, using the BFKL resummation.

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The state-of-the-art in jet physics at hadron colliders is described by next-to-leading-order (NLO) QCD parton-level calculations[1]. They appear to be in very good agreement with the one- and two-jet inclusive distributions obtained from the data of the CDF experiment at the Fermilab Tevatron Collider. However, since data are being collected at the CDF and D0 detectors at larger and larger rapidities, it is possible to imagine kinematic configurations where this fixed-order analysis is inadequate. This could occur when the cross section contains large logarithms of the size of the rapidity interval in the scattering process. If the initial parton momentum fractions are large, then these logarithms factorize into the partonic subprocess cross section and can be resummed by using the techniques of Balitsky, Fadin, Kuraev, and Lipatov (BFKL)[2].

In analyzing dijet production experimentally so that it most closely resembles the configuration assumed in the BFKL theory, the jets are ordered first by their rapidity rather than by their energy[3]. Thus, we look at all the jets in the event that are above a transverse momentum cutoff $p_{\perp min}$, using some jet-definition algorithm, and rank them by their rapidity. We then tag the two jets with the largest and smallest rapidity $(\vec{p}_{1\perp}, y_1)$ and $(\vec{p}_{2\perp}, y_2)$, where we always take $y_1 > y_2$, and observe the distributions as a function of these two *tagging jets*. We reexpress the jet rapidities in terms of the rapidity interval $y = y_1 - y_2$ and the rapidity boost $\bar{y} = (y_1 + y_2)/2$. This is convenient since we are mainly interested in the behavior of the parton subprocess, which does not depend on $\bar{y}$. Then we sum inclusively the hadrons or jets produced in the rapidity interval y between the tagging jets, and refer to them as *minijets*. For large values of y the cross section for this process can be written

$$\frac{d\sigma_0}{dy\, d\bar{y}\, dp_{1\perp}^2 dp_{2\perp}^2 d\phi} = x_A^0 x_B^0\, f_{\rm eff}(x_A^0,\mu^2) f_{\rm eff}(x_B^0,\mu^2)\, \frac{d\hat{\sigma}_{gg}}{dp_{1\perp}^2 dp_{2\perp}^2 d\phi}\ , \tag{1}$$

where the parton momentum fractions are dominated by the contribution from the two tagging jets

$$\begin{aligned} x_A^0 &= \frac{p_{1\perp} e^{y_1}}{\sqrt{s}} \\ x_B^0 &= \frac{p_{2\perp} e^{-y_2}}{\sqrt{s}}, \end{aligned} \tag{2}$$

ϕ is the azimuthal angle in the transverse plane and μ is the factorization/renormalization scale. In this limit the amplitude is dominated by gg, qg, and qq scattering diagrams with gluon-exchange in the t-channel. The relative magnitude of the different subprocesses is fixed by the color strength of the respective jet-production vertices, so it suffices to consider only gg scattering and to include the other subprocesses by means of the effective parton distribution function $f_{\rm eff}(x,\mu^2)$[3].

The higher-order corrections to the gg subprocess cross section in (1) can be expressed via the solution of the BFKL equation[2], which is an all-order resummation in α_s of the leading powers of the rapidity interval

$$\frac{d\hat{\sigma}_{gg}}{dp_{1\perp}^2 dp_{2\perp}^2 d\phi} = \frac{C_A^2 \alpha_s^2}{4\pi p_{1\perp}^3\, p_{2\perp}^3} \sum_n e^{in(\phi-\pi)} \int_0^\infty d\nu e^{\omega(n,\nu)\, y} \cos\left(\nu\, \ln \frac{p_{1\perp}^2}{p_{2\perp}^2}\right) \tag{3}$$

with

$$\omega(n,\nu) = \frac{2C_A\alpha_s}{\pi}[\psi(1) - {\rm Re}\,\psi(\frac{|n|+1}{2} + i\nu)], \tag{4}$$

and ψ the logarithmic derivative of the Gamma function.

In ref. [4] we found that at Tevatron energies the transverse momentum $p_\perp$ distribution and the jet-jet correlations in $p_\perp$ and ϕ are significantly affected by the minijet resummation. For instance, the $p_\perp$ distribution was considerably enhanced at large $p_\perp$ and large y. However, in comparing the truncation of the BFKL resummation (3) to $\mathcal{O}(\alpha_s^3)$ with the exact $\mathcal{O}(\alpha_s^3)$ calculation of dijet production, computed through the $2\to 3$ parton amplitudes[5], we noticed that the large-rapidity approximation to the kinematics seriously overestimates the cross section and causes a serious error in the BFKL predictions when the two tagging jets are not back-to-back in $p_\perp$ and ϕ, even for rapidity intervals as large as $y = 6$. This occurs because the large-y cross section assumes that the third (minijet) parton can be produced anywhere within the rapidity interval $[y_2, y_1]$ with equal probability, whereas in the full $2 \to 3$ cross section the probability is highly suppressed by the structure functions when the third jet strays too far from the center of this interval. In order to account for this error we introduced in ref.[5] an effective rapidity $\hat{y}$ to take into account the fact that the range in rapidity spanned by the minijets is typically less than the kinematic rapidity interval y. $\hat{y}$ is defined so that if we replace $y \to \hat{y}$ in the BFKL solution the difference $y-\hat{y}$ is nonleading. Since the rapidity variable which is resummed by BFKL is only defined up to transformations $y \to y + X$ where X is subleading at large rapidities, we used $\hat{y}$ instead of y in the BFKL resummation in order to obtain quantitatively more reliable predictions of the transverse momentum distributions. We found that the effects on the $p_\perp$ distribution are not as dramatic as we had predicted in ref.[4] using the kinematic rapidity y. Because of the relatively small deviations of the BFKL resummation with the effective rapidity $\hat{y}$ from the Born-level calculation, and the sizeable renormalization/factorization scale ambiguities in the BFKL approximation, we concluded that a complete NLO calculation could probably give a more reliable estimate to the $p_\perp$ distributions.

However, much of the uncertainties due to the renormalization/factorization scale drop out in the ratios of cross sections, so the ratio of $p_\perp$ distributions should be a good observable to examine with the BFKL resummation.

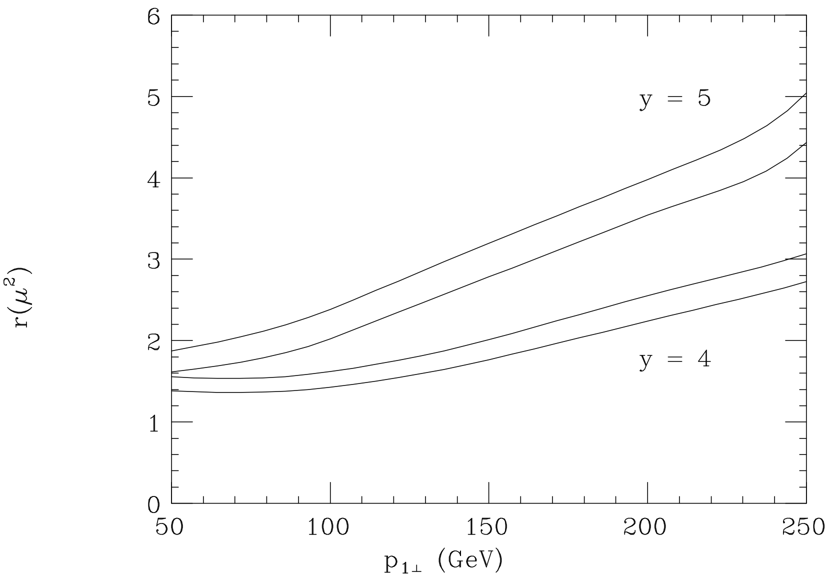

Figure 1: The ratios of transverse momentum distributions of jet 1 at $y = 4$ and 5, with two different cutoffs for jet 2 transverse momentum, $p_{2\perp min,a} = 20$ GeV in the numerator and $p_{2\perp min,b} = 30$ GeV in the denominator. The ren./fact. scale is set to $\mu^2 = 4max(p_{1\perp}^2, p_{2\perp}^2)$ for the lower curves and $\mu^2 = p_{1\perp}p_{2\perp}/4$ for the upper ones.

In Fig. 1 we plot the ratio of transverse momentum distributions of jet 1

$$r(\mu^2) = \frac{d\sigma(p_{2\perp min,a})/dyd\bar{y}dp_{1\perp}}{d\sigma(p_{2\perp min,b})/dyd\bar{y}dp_{1\perp}} \tag{5}$$

calculated using the effective rapidity $\hat{y}$ in the BFKL resummation, with two different cutoffs for jet 2 transverse momentum, $p_{2\perp min,a} = 20$ GeV and $p_{2\perp min,b} = 30$ GeV. The rapidity boost $\bar{y}$ is integrated over, subject to the constraint $|y_1|_{max} =$

$|y_2|_{max} = 3.2$. The rapidity interval is integrated in unit bins centered around $y = 4$ and $y = 5$. We use the LO CTEQ2 parton distribution functions[6] with two extreme choices for the ren./fact. scale $\mu^2 = 4max(p_{1\perp}^2, p_{2\perp}^2)$ for the lower curves and $\mu^2 = p_{1\perp}p_{2\perp}/4$ for the upper ones.

From the plot we see that lowering the $p_\perp$ cutoff for the second jet significantly increases the cross section, particularly for large y and $p_{1\perp}$. For example, for $y = 5$ and $p_{1\perp} = 300$ GeV, we gain more than a factor of six in lowering $p_{2\perp min}$ from 30 GeV to 20 GeV. This enhancement is entirely due to events in which the tagging jets are very unbalanced in $p_\perp$, thus requiring ≥ 3 final state jets. This suggests that a beyond-NLO calculation, such as the BFKL resummation, may be necessary for this configuration.

References

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