Azimuthal-angle Observables in Inclusive Three-jet Production

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We discuss the impact of corrections beyond the leading-logarithmic accuracy on some recently proposed LHC observables that are based on azimuthal-angle ratios in a kinematical setup that is an extension to the usual one for Mueller-Navelet jets, after requiring an extra tagged jet in central regions of rapidity. The corrections tend to be mild which suggests that these observables are an excellent way to probe the onset of BFKL effects at hadronic colliders.

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1. Introduction

In high energy scattering in Quantum Chromodynamics (QCD) the Balitsky-Fadin-Kuraev-Lipatov (BFKL) framework in the leading logarithmic (LLA) [1–6] and next-to-leading logarithmic (NLLA) approximation [7,8] are used for the resummation of large logarithms in the center-of-mass energy squared s

An interesting case is Mueller-Navelet jets [9], configurations with two final state jets[1] with transverse momenta of similar sizes, $k_{A,B}$, and a rapidity distance $Y = \ln(x_1 x_2 s/(k_A k_B))$ large. A number of studies [13–28] focused on the azimuthal angle (θ) behaviour of the two jets regards that the presence of decisive minijet activity in the rapidity space between these two outermost jets can be accounted for by a BFKL gluon Green function connecting the two jets. Moreover, it was shown [29,30], that ratios of projections on azimuthal angle observables

$$\mathscr{R}_n^m = \langle \cos(m\,\theta) \rangle / \langle \cos(n\,\theta) \rangle\,, \tag{1.1}$$

(where m,n are integers) are much more favourable quantities in the search for a clear signal of BFKL effects. The comparison of different NLLA calculations for these ratios $\mathscr{R}_n^m$ [31–35] against LHC experimental data has been promising.

Along these lines, new observables were recently proposed for processes with three-jet [36,37] and four-jet final states [38,39] with the outermost jets having a large rapidity distance and any other tagged jet is to be found in more central regions of the detector. Here we will restrict the discussion to inclusive three-jet production assuming that the jets are connected in the t-channel via gluon Green's functions. The main idea presented in Refs. [36,37] was to produce theoretical estimates for the ratios

$$R_{PQ}^{MN} = \frac{\langle \cos(M\,\theta_1) \cos(N\,\theta_2) \rangle}{\langle \cos(P\,\theta_1) \cos(Q\,\theta_2) \rangle} = \frac{C_{MN}}{C_{PQ}}\,, \tag{1.2}$$

where θ_1 is the azimuthal angle difference between the first and the second (central) jet, while, θ_2 is the azimuthal angle difference between the second and the third jet. In this work, we show theoretical predictions for R_{33}^{22} at NLLA, originally presented in [40]. We are interested in seeing whether we have large corrections once we consider the NLLA gluon Green's functions instead of the leading-logarithmic accuracy ones. Large corrections of that origin is not a surprising outcome for many BFKL-based calculations and they could potentially have a strong impact on the ratios R_{PQ}^{MN}, hence they need to be addressed.

We assume for the outermost jet transverse momenta that $k_A^{\min} = 35$ GeV, $k_B^{\min} = 50$ GeV, $k_A^{\max} = k_B^{\max} = 60$ GeV, whereas the transverse momentum of the central jet, k_J, can live in three wide bins, that is, $20\,\text{GeV} < k_J < 35\,\text{GeV}$ (bin-1), $35\,\text{GeV} < k_J < 60\,\text{GeV}$ (bin-2) and $60\,\text{GeV} < k_J < 120\,\text{GeV}$ (bin-3). To quantify the difference between LLA and NLLA, we define

$$\delta x(\%) = \left(\text{res}^{(\text{LLA})} - \frac{\text{res}^{(\text{BLM}-1)} + \text{res}^{(\text{BLM}-2)}}{2} \right) \frac{1}{\text{res}^{(\text{LLA})}}\,, \tag{1.3}$$

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[1] Another interesting idea, suggested in [10] and investigated in [11,12], is the study of the production of two charged light hadrons, $\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$, with large transverse momenta and well separated in rapidity.

where res$^{\text{(LLA)}}$ is the LLA result while res$^{\text{(BLM-1)}}$ and res$^{\text{(BLM-2)}}$ are NLLA results in the BLM scheme [41] that differ in the renormalisation scale to give us a measure of the theoretical uncertainty.

2. Results

First we present results for R_{33}^{22} as a function of the rapidity difference after integrating over a central jet rapidity bin, that is, after allowing for the central jet rapidity to take values in the range $-0.5 < y_J < 0.5$, see Fig. 1. We use dashed lines to represent LLA results and a band for the NLLA results. The band is bounded by the res$^{\text{(BLM-1)}}$ and res$^{\text{(BLM-2)}}$ results in thin continuous lines. The red curve and band are representing the LLA and NLLA results respectively for the central jet belonging to bin-1 the green curve and band for the central jet belonging to bin-2 and the blue curve and band are representing the LLA and NLLA results respectively for the central jet belonging to bin-3. We see that the NLLA corrections are mild. Moreover, we note that the overall picture does not change considerably when we go from LLA to NLLA.
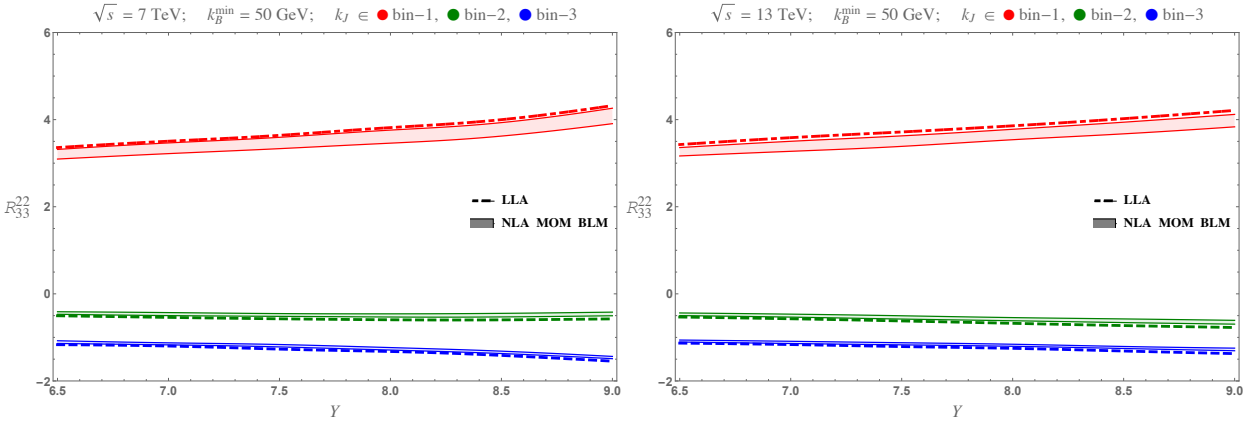

Figure 1: Y-dependence of the LLA (dashed lines) and NLLA (bands) results for R_{33}^{22} with y_J integrated over a central rapidity bin at $\sqrt{s} = 7$ TeV (left) and $\sqrt{s} = 13$ TeV (right).

Next, in Fig. 2, we allow for Y_A (rapidity of the forward jet) and Y_B (rapidity of the backward jet) to take values such that $(Y_A^{\min} = 3) < Y_A < (Y_A^{\max} = 4.7)$ and $(Y_B^{\min} = -4.7) < Y_B < (Y_B^{\max} = -3)$. Furthermore, the rapidity of the central jet can take values in five distinct rapidity bins of unit width, that is, $y_i - 0.5 < y_J < y_i + 0.5$, with $y_i = \{-1, -0.5, 0, 0.5, 1\}$. Obviously, the ratios now are functions of y_i, namely,

$$R_{PQ}^{MN}(y_i) = \frac{C_{MN}^{\text{integ}}(y_i)}{C_{PQ}^{\text{integ}}(y_i)}. \tag{2.1}$$

We see that the y_i-dependence of the three ratios is very weak. Moreover, the similarity between the $\sqrt{s} = 7$ TeV and $\sqrt{s} = 13$ TeV plots is more striking that in the Fig. 1 and the NLLA corrections seem even milder.
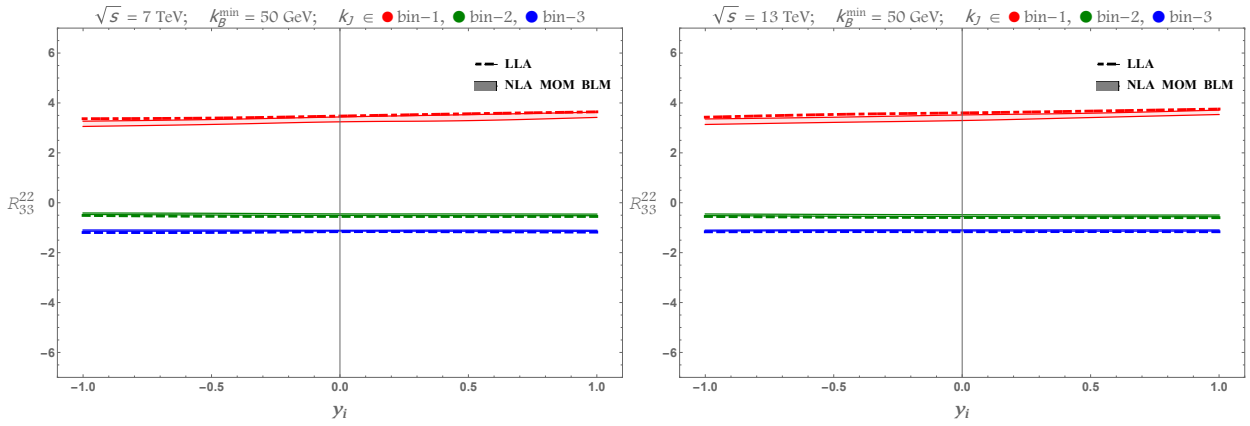
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Figure 2: y_i-dependence of the LLA (dashed lines) and NLLA (bands) results for R_{33}^{22} at $\sqrt{s} = 7$ TeV (left) and $\sqrt{s} = 13$ TeV (right).

3. Summary & Outlook

We have shown some results from a first beyond the leading logarithmic accuracy work on generalised azimuthal-angle observables in inclusive three-jet production at the LHC within the BFKL formalism. In addition, for a proper study of the total corrections beyond the LLA, the NLO jet vertices need to be included and the NLLA gluon Green functions.

Our most important conclusion in this work is that the corrections that come into play after considering NLLA gluon Green's functions are generally mild and the generalised ratio observables exhibit perturbative stability. Moreover, we note that the differences in the plots for 7 TeV to 13 TeV are small which suggests that these observables capture the crucial features of the BFKL dynamics with regard to the azimuthal behavior of the hard jets in hadronic inclusive three-jet production. We plan to compare our results here against theoretical estimates for these observables from fixed order calculations, the full BFKL Monte Carlo `BFKLex` [42–49] as well as from general-purpose Monte Carlos tools.

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