High energy effects in multi-jet production at LHC

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Abstract

We study differential cross sections for the production of three and four jets in multi-Regge kinematics, the main interest lying on azimuthal angle dependences. The theoretical setup is the jet production from a single BFKL ladder with a convolution of two/three BFKL Green functions, where two forward/backward jets are always tagged in the final state. Furthermore, we require the tagging of one/two further jets in more central regions of the detectors with a relative separation in rapidity. We found, as result, that the dependence on transverse momenta and rapidities of the central jets can be considered as a distinct signal of the onset of BFKL dynamics.

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1 Introduction

The study of semi-hard processes in the high-energy (Regge) limit represents an ultimate research field for perturbative QCD, the Large Hadron Collider (LHC) providing with an abundance of data. Multi-Regge kinematics (MRK), which prescribes final state objects strong ordered in rapidity, is the key point for the study of multi-jet production at LHC energies. In this kinematical regime, the Balitsky-Fadin-Kuraev-Lipatov (BFKL) approach, at leading (LL) [1, 2, 3, 4, 5, 6] and next-to-leading (NLL) [7, 8] accuracy, is the most powerful tool to perform the resummation of large logarithms in the colliding energy to all orders of the perturbative expansion. This formalism was successfully applied to lepton-hadron Deep Inelastic Scattering at HERA (see, *e.g.* [9, 10]) in order to study quite inclusive processes which are not that suitable though to discriminate between BFKL dynamics and other resummations. The high energies reachable at the LHC, however, allow us to investigate processes with much more exclusive final states which could, in principle, be only described by the BFKL framework, making it possible to disentangle the applicability region of the approach. So far, Mueller–Navelet jet production [11] has been the most studied process. Interesting observables associated to this reaction are the azimuthal correlation momenta which, however, are strongly affected by collinear contaminations. Therefore, new observables independent from the conformal contribution were proposed in [12, 13] and calculated at NLL in [14, 15, 16, 17, 18, 19, 20, 21], showing a very good agreement with experimental data at the LHC. Nevertheless, Mueller-Navelet configurations are still too inclusive to perform MRK precision studies. Pursuing the goal to further and deeply probe the BFKL dynamics by studying azimuthal decorrelations where the transverse momenta of extra particles introduces a new dependence, we proposed new observables for semi-hard processes which can be thought as a generalization of Mueller-Navelet jets[1]. These processes are inclusive three-jet [24, 25] and four-jet production [26, 27].

2 Multi-jet production

The class of processes under exam is the inclusive hadroproduction of n jets in the final state, well separated in rapidity so that $y_i > y_{i+1}$ according to MRK, and with their transverse momenta $\{k_i\}$ lying above the experimental resolution scale, together with an undetected gluon radiaton emission. With the aim to generalize the azimuthal ratios R_{nm} defined in the Mueller–Navelet jet configuration, we propose new, generalized azimuthal observables by taking the projection of the differential cross section $d\sigma^{n-\text{jet}}$ on all angles, so having the general expression given in Eq. (3) of [28]:

$$\mathcal{C}_{M_1 \cdots M_{n-1}} = \left\langle \prod_{i=1}^{n-1} \cos\left(M_i\,\phi_{i,i+1}\right) \right\rangle = \int_0^{2\pi} d\theta_1 \cdots \int_0^{2\pi} d\theta_n \prod_{i=1}^{n-1} \cos\left(M_i\,\phi_{i,i+1}\right) d\sigma^{n-\text{jet}} \tag{1}$$

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[1] Another interesting and novel possibility, the detection of two charged light hadrons: $\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$ having high transverse momenta and separated by a large interval of rapidity, together with an undetected soft-gluon radiaton emission, was suggested in [22] and studied in [23].

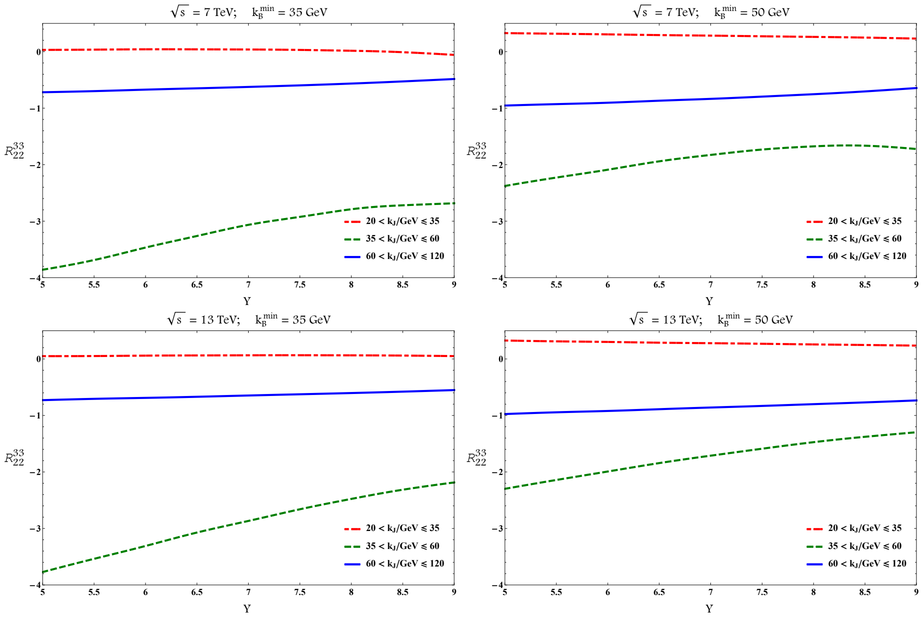

Figure 1: Y-dependence of R^{33}_{12} for $\sqrt{s} = 7, 13$ TeV and $k_{B,\text{min}} = 35$ GeV (left column) and $k_{B,\text{min}} = 50$ GeV (right column). $k_{A,\text{min}}$ is equal to 35 GeV, while the rapidity of the central jet is fixed to $y_J = (y_A + y_B)/2$.

where $\phi_{i,i+1} = \theta_i - \theta_{i+1} - \pi$, and θ_i is the azimuthal angle of the jet i. From a phenomenological perspective, we want to provide predictions compatible with the current and future experimental data. To this purpose, we introduce the kinematical cuts already in place at the LHC by integrating $\mathcal{C}_{M_1 \cdots M_{n-1}}$ over the momenta of all tagged jets in the form

$$C_{M_1 \cdots M_{n-1}} = \int_{y_{1,\text{min}}}^{y_{1,\text{max}}} dy_1 \int_{y_{n,\text{min}}}^{y_{n,\text{max}}} dy_n \int_{k_{1,\text{min}}}^{\infty} dk_1 \cdots \int_{k_{n,\text{min}}}^{\infty} dk_n \delta\left(y_1 - y_n - Y\right) \mathcal{C}_n \quad (2)$$

where the most forward and the most backward jet rapidities are taken in the range delimited by $y_1^{\text{min}} = y_n^{\text{min}} = -4.7$ and $y_1^{\text{max}} = y_n^{\text{max}} = 4.7$, keeping their difference $Y = y_1 - y_n$ fixed. From a theoretical point of view, it is important to improve the stability of our predictions (see [29] for a related discussion). This can be done by removing the zeroth conformal spin contribution responsible for any collinear. For this reason, we introduce the ratios

$$R^{M_1 \cdots M_{n-1}}_{N_1 \cdots N_{n-1}} \equiv \frac{C_{M_1 \cdots M_{n-1}}}{C_{N_1 \cdots N_{n-1}}} \quad (3)$$

where $\{M_i\}$ and $\{N_i\}$ are positive integers.

We performed the numerical computation of the ratios $\mathcal{R}^{MN}_{PQ}$ both in FORTRAN and in MATHEMATICA (mainly for cross-checks). The NLO MSTW 2008 PDF sets [30] were used and for the strong coupling α_s we chose a two-loop running coupling setup with $\alpha_s\left(M_Z\right) = 0.11707$. We made extensive use of the integration routine `Vegas` [31] as implemented in the `Cuba` library [32, 33]. Furthermore, we used the `Quadpack` library [34] and a slightly modified version of the `Psi` [35] routine.

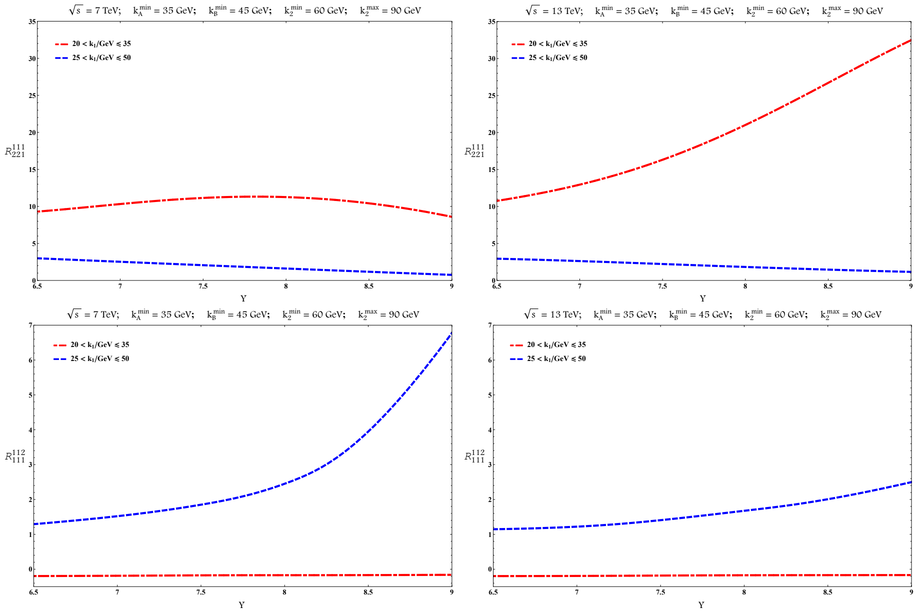

Figure 2: Y-dependence of R_{221}^{111} and R_{111}^{112} for $\sqrt{s} = 7$ TeV (left column) and for $\sqrt{s} = 13$ TeV (right column). The rapidity interval between a jet and the closest one is fixed to $Y/3$.

In Fig. 1 we show the dependence on Y of the R_{22}^{33} ratio, characteristic of the 3-jet process, for $\sqrt{s} = 7$ and 13 TeV, for two different kinematical cuts on the transverse momenta $k_{A,B}$ of the external jets and for three different ranges of the transverse momentum k_J of the central jet.

In Fig. 2 we show the dependence on Y of R_{221}^{111} and R_{111}^{112} ratios, characteristic of the 4-jet process, for $\sqrt{s} = 7$ and 13 TeV, for asymmetrical cuts on the transverse momenta $k_{A,B}$ of the external jets and for two different configurations of the central jet transverse momenta $k_{1,2}$.

A comparison with predictions for these observables from fixed order analyses as well as from the BFKL inspired Monte Carlo `BFKLex` [36, 37, 38, 39, 40, 41, 42] is underway.

3 Conclusions & Outlook

We studied ratios of correlation functions of products of azimuthal angle difference cosines in order to study three- and four-jet production at hadron colliders. The dependence on the transverse momenta and rapidities of the central jet(s) represent a clear signal of the BFKL dynamics. For future works, more accurate analyses are needed: higher order effects and study of different configurations for the rapidity range of the two central jets, together with the analysis of the effect of using different PDF parametrizations. It would be also interesting to calculate our observables using other approaches not based on the BFKL approach and to test how they differ from our predictions. The comparison with experimental data will help to disentangle the region of applicability of the BFKL approach, therefore we strongly encourage experimental collaborations to study these observables in the next LHC analyses.

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