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MUELLER–NAVELET JETS AT THE LHC: DISCRIMINATING BFKL FROM DGLAP BY ASYMMETRIC CUTS*

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The Mueller–Navelet di-jet production process represents an ultimate test field of pQCD in the high-energy limit. Several experimental analyses carried out so far are in a good agreement with theoretical predictions, based on collinear factorization and BFKL resummation of energy logarithms in the next-to-leading approximation, with the CMS experimental data at center-of-mass energy equal to 7 TeV. However, the question if the same data can be described also by fixed-order perturbative approaches has not yet been fully answered. We discuss how the use of partially asymmetric cuts in the transverse momenta of the detected jets allows to discriminate between BFKL-resummed and fixed-order predictions (the latter in the high-energy limit) in observables related with this process at the LHC.

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1. Introduction

The inclusive hadro-production of two jets featuring transverse momenta of the same order and much larger than the typical hadronic masses and being separated by a large rapidity gap Y, the so-called Mueller–Navelet jets [1], is a fundamental testfield for perturbative QCD in the high-energy limit. At the LHC energies, the theoretical description of this process lies between two distinct approaches: collinear factorization and BFKL [2] resummation. On the one hand, at leading twist, the process can be seen

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as the hard scattering of two partons, each emitted by one of the colliding hadrons according to the appropriate parton distribution function (PDF), see Fig. 1 of [3]. Collinear factorization takes care to resum the logarithms of the hard scale, through the standard DGLAP evolution [4] of the PDFs and the fixed-order radiative corrections to the parton scattering cross section. The other approach is the BFKL resummation of energy logarithms, which are so large to compensate the small QCD coupling and must, therefore, be accounted for to all orders. These logarithms are related with the emission of undetected partons between the two jets (the larger s, the larger the number of partons), which lead to a reduced azimuthal correlation between the two detected forward jets, in comparison to the fixed-order DGLAP calculation, where jets are emitted almost back-to-back. In the BFKL approach, energy logarithms are systematically resummed in the leading logarithmic approximation (LLA) and in the next-to-leading logarithmic approximation (NLA). To get the cross section, the BFKL Green's function must be convoluted with two impact factors for the transition from the colliding parton to the forward jet. They were first calculated with NLO accuracy in [5] and the result was later confirmed in [6]. A simpler expression, more practical for numerical purposes, was obtained in [7] adopting the so-called "small-cone" approximation (SCA) [8, 9]. Unfortunately, the NLO BFKL corrections for the $n = 0$ conformal spin are with the opposite sign with respect to the leading order (LO) result and large in absolute value [10]. This calls for some optimization procedure. Common optimization methods are those inspired by the *principle of minimum sensitivity* (PMS) [11], the *fast apparent convergence* (FAC) [12] and the *Brodsky–LePage–Mackenzie method* (BLM) [13]. This variety of options reflects in the large number of numerical studies of the Mueller–Navelet jet-production process at the LHC, both at a center-of-mass energy of 14 TeV [14–16] and 7 TeV [17–20]. In the case of *asymmetric* cuts, the Born term, present only for back-to-back jets, is suppressed and the effects of the additional undetected hard gluon radiation is enhanced, thus making more visible the BFKL resummation, with respect to DGLAP calculations, in all observables involving C_0 [20]. So, we compare predictions for several azimuthal correlations and their ratios obtained, on the one hand, by a fixed-order high-energy DGLAP calculation at the NLO and, on the other hand, by BFKL resummation in the NLA. To single out the only effect of transverse momentum cuts, we consider just one optimization procedure (the BLM one, in the two variants discussed in [21]).

2. Theoretical setup

The process under exam is the production of Mueller–Navelet jets [1] in proton–proton collisions

$$p(p_1) + p(p_2) \to \mathrm{jet}(k_{J_1}) + \mathrm{jet}(k_{J_2}) + X\,, \tag{1}$$

where the two jets are characterized by high transverse momenta, $\vec{k}_{J_1}^2 \sim \vec{k}_{J_2}^2 \gg \Lambda_{\mathrm{QCD}}^2$ and large separation in rapidity, while p_1 and p_2 are taken as Sudakov vectors. The cross section of the process can be presented as

$$\frac{d\sigma}{dy_{J_1}dy_{J_2}\,d\left|\vec{k}_{J_1}\right|\,d\left|\vec{k}_{J_2}\right|d\phi_{J_1}d\phi_{J_2}} = \frac{1}{(2\pi)^2}\left[\mathcal{C}_0 + \sum_{n=1}^{\infty} 2\cos(n\phi)\,\mathcal{C}_n\right]\,, \tag{2}$$

where $\phi = \phi_{J_1} - \phi_{J_2} - \pi$, while $\mathcal{C}_0$ gives the total cross section and the other coefficients $\mathcal{C}_n$ determine the distribution of the azimuthal angle of the two jets. We concentrate on the so-called *exponentiated* representation, and use the BLM optimization procedure, *i.e.* we choose the scale μ_{R} such that it makes vanish completely the β_0-dependence of a given observable. As discussed in [20], we implement two variants of the BLM method, dubbed (a) and (b) [21]. A common optimal value for the renormalization scale μ_{R} and for the factorization scale μ_{F} is used. In [20], it was shown that this setup allows a nice agreement with the CMS data for several azimuthal correlations and their ratios in the large Y regime. The BFKL and DGLAP expressions for the coefficients $\mathcal{C}_n$, in the two variants of BLM setting, are given in Eqs. (4), (6), (12) and (13) of Ref. [3]. We note that, in our way to implement the BLM procedure (see [21]), the final expressions are given in terms of α_{s} in the $\overline{\mathrm{MS}}$ scheme, although in one intermediate step the MOM scheme was used.

3. Numerical analysis

We present our results for the dependence on the rapidity separation between the detected jets, $Y = y_{J_1} - y_{J_2}$, of ratios $\mathcal{R}_{nm} \equiv \mathcal{C}_n/\mathcal{C}_m$ between the coefficients $\mathcal{C}_n$. Among them, the ratios of the form of R_{n0} have a simple physical interpretation, being the azimuthal correlations $\langle\cos(n\phi)\rangle$. In order to match the kinematic cuts used by the CMS Collaboration, we will consider the *integrated coefficients* given in Eq. (13) of Ref. [20] and their ratios $R_{nm} \equiv C_n/C_m$. We will take jet rapidities in the range delimited by $y_{1,\mathrm{min}} = y_{2,\mathrm{min}} = -4.7$ and $y_{1,\mathrm{max}} = y_{2,\mathrm{max}} = 4.7$ and consider $Y = 3$, 6 and 9. As for the jet transverse momenta, we make two *asymmetric* choices: (1) $k_{J_1,\mathrm{min}} = 35$ GeV, $k_{J_2,\mathrm{min}} = 45$ GeV (Fig. 1) and (2) $k_{J_1,\mathrm{min}} = 35$ GeV, $k_{J_2,\mathrm{min}} = 50$ GeV (Fig. 3 of Ref. [3]). The center-of-mass energy is fixed at

$\sqrt{s} = 7$ TeV. We can clearly see that, at $Y = 9$, BFKL and DGLAP, in both variants (a) and (b) of the BLM setting, give quite different predictions for the all considered ratios except C_1/C_0; at $Y = 6$, this happens in fewer cases,

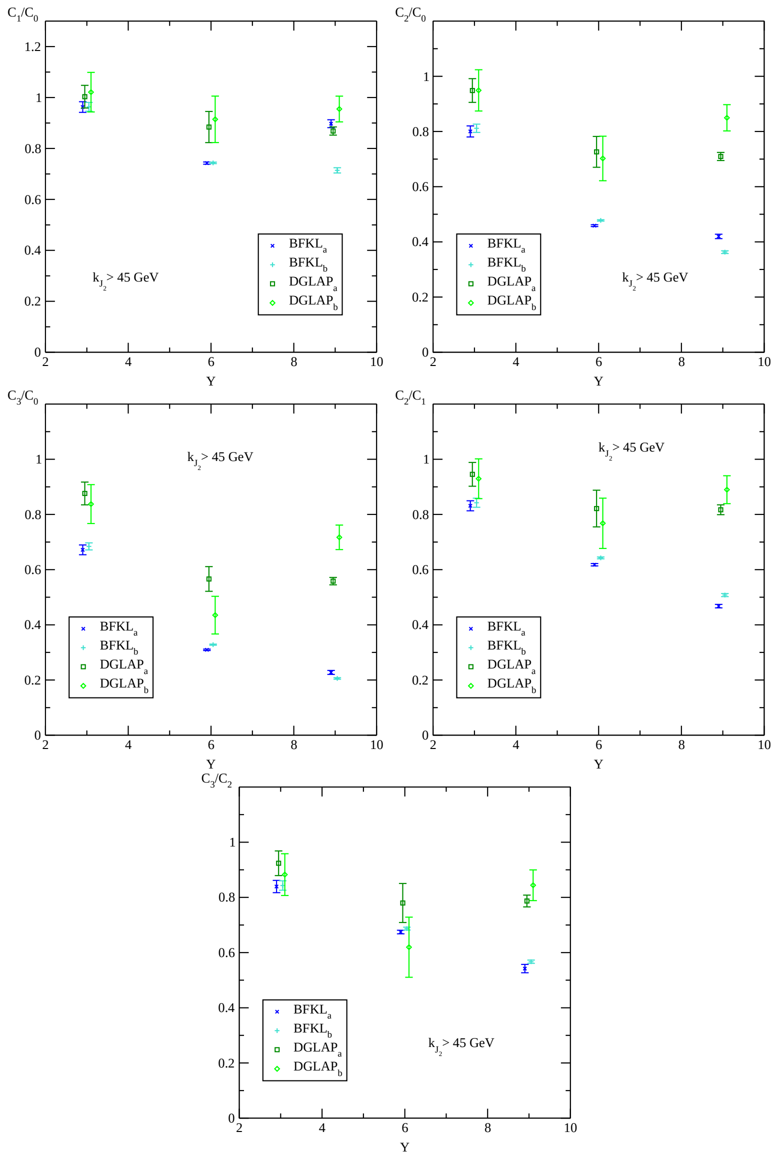

Fig. 1. Y-dependence of several ratios C_m/C_n for $k_{J_1,\min} = 35$ GeV and $k_{J_2,\min} = 45$ GeV, for BFKL and DGLAP in the two variants of the BLM method (data points have been slightly shifted along the horizontal axis for the sake of readability). For the numerical values, see Table 1 of Ref. [3].

while at $Y = 3$, BFKL and DGLAP cannot be distinguished with the given uncertainties. This scenario is similar in the two choices of the transverse momentum cuts. For a detailed discussion of the numerical tools used and of the uncertainty estimation in our analysis, see Sections 3.2 and 3.3 of Ref. [3].

4. Conclusions

In this paper, we considered the Mueller–Navelet jet-production process at the LHC at the center-of-mass energy of 7 TeV and compared predictions for several azimuthal correlations and ratios between them, both in full NLA BFKL approach and in fixed-order NLO DGLAP. Differently from current experimental analyses of the same process, we have used *asymmetric* cuts for the transverse momenta of the detected jets. The use of *symmetric* cuts for jet transverse momenta maximizes the contribution of the Born term, which is present for back-to-back jets only and is expected to be large, making therefore the effect of the BFKL resummation less visible. This phenomenon could be at the origin of the instabilities observed in the NLO fixed-order calculations of [22, 23]. Another important benefit from the use of asymmetric cuts, pointed out in [19], is that the effect of violation of the energy-momentum conservation in the NLA is strongly suppressed with respect to what happens in the LLA. In view of all these considerations, we strongly suggest experimental collaborations to consider also asymmetric cuts in jet transverse momenta in all future analyses of the Mueller–Navelet jet production process.

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