

BFKL effects and central rapidity dependence in Mueller-Navelet jet production at 13 TeV LHC

Francesco Giovanni Celiberto*

*Dipartimento di Fisica, Università della Calabria and Istituto Nazionale di Fisica Nucleare,
Gruppo Collegato di Cosenza, Arcavacata di Rende, 87036 Cosenza, Italy*
E-mail: francescogiovanni.celiberto@fis.unical.it

Dmitry Yu. Ivanov

*Sobolev Institute of Mathematics, 630090 Novosibirsk, Russia
Novosibirsk State University, 630090 Novosibirsk, Russia*
E-mail: d-ivanov@math.nsc.ru

Beatrice Murdaca

*Istituto Nazionale di Fisica Nucleare,
Gruppo Collegato di Cosenza, Arcavacata di Rende, 87036 Cosenza, Italy*
E-mail: beatrice.murdaca@cs.infn.it

Alessandro Papa

*Dipartimento di Fisica, Università della Calabria and Istituto Nazionale di Fisica Nucleare,
Gruppo Collegato di Cosenza, Arcavacata di Rende, 87036 Cosenza, Italy*
E-mail: alessandro.papa@fis.unical.it

A study of the production of Mueller-Navelet jets at 13 TeV LHC is presented, including BFKL resummation effects and investigating three different variants of the BLM scale optimization method. It is shown how the cross section and the azimuthal observables are affected by the exclusion of the events where, for a given rapidity interval between the two jets, one of these is produced in the central region.

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*Speaker.

1. Introduction

The production at the LHC of Mueller-Navelet jets [1] represents a fundamental test of QCD at high energies. It is an inclusive process where two jets, characterized by large transverse momenta that are of the same order and much larger than Λ_{QCD} , are produced in proton-proton collisions, separated by a large rapidity gap Y and in association with an undetected hadronic system X . At the LHC energies the rapidity gap between the two jets can be large enough, that the emission of several undetected hard partons, having large transverse momenta, with rapidities intermediate to those of the two detected jets, becomes possible.

The BFKL approach [2] provides with a systematic framework for the resummation of the energy logarithms that accompany this undetected parton radiation, both in the leading logarithmic approximation (LLA) and in the next-to-leading logarithmic approximation (NLA). In this approach, the cross section for Mueller-Navelet jet production takes the form of a convolution between two impact factors for the transition from each colliding proton to the forward jet (the so-called “jet vertices”) and a process-independent Green’s function [3, 4, 5, 6, 7]. The jet vertex can be expressed, within collinear factorization at the leading twist, as the convolution of parton distribution functions (PDFs) of the colliding proton, obeying the standard DGLAP evolution [8], with the cross section of hard process describing the transition from the parton emitted by the proton to the forward jet in the final state. The Mueller-Navelet jet production process is, therefore, a unique venue, where the two main resummation mechanisms of perturbative QCD play their role at the same time. The expression for the “jet vertices” was first obtained with NLO accuracy in [9], a result later confirmed in [10]. A simpler expression, more practical for numerical purposes, was obtained in [11] within the so-called “small-cone” approximation (SCA) [12, 13]. A lot of papers have appeared, so far, about the Mueller-Navelet jet production process at LHC, both at a center-of-mass energy of 14 TeV [14, 15, 16] and 7 TeV [17, 18, 19, 20, 21]. Their main aim was the study of the Y -dependence of azimuthal angle correlations between the two measured jets and of ratios between them [22]. In order to improve the perturbative stability of the BFKL series, several possibilities were considered, such as collinear improvement [23], energy-momentum conservation [24], PMS [25], FAC [26], and BLM [27]. There is a clear evidence that theoretical results can nicely reproduce CMS data [28] at 7 TeV in the range $5 \lesssim Y \lesssim 9.4$ when the BLM optimization method is adopted.

The large rapidity gaps provided by the LHC definitely offer us a unique opportunity to disentangle the applicability region of the high-energy resummation. To this aim, new ways to probe BFKL have been recently investigated. On one side, one can study a process featuring a less inclusive final state, by allowing the detection of two charged light hadrons - instead of two jets - separated by a large interval of rapidity [29, 30]. On the other side, it was suggested to study azimuthal correlations where transverse momenta and azimuthal angles of extra particles introduce a new dependence. Therefore, the study of three and four-jet production processes has been proposed as a novel possibility to define new, generalized and suitable BFKL observables [31, 32, 33, 34, 35].

Returning back to Mueller-Navelet jets, there is another issue which has not been taken into account both in theoretical and experimental analyses so far. The rapidity of one of the two jets could be so small, say $|y_{J_i}| \lesssim 2$, that this jet is actually produced in the central region, rather than in one of the two forward regions. In this kinematic region PDF parametrizations extracted in NNLO

and in NLO approximations start to differ one from the other. Recently, in Ref. [36], results for NNLO corrections to the dijet production originated from the gluonic subprocesses were presented. In the region $|y_{J_{1,2}}| < 0.3$ and for jet transverse momenta ~ 100 GeV, the account of NNLO effects leads to an increase of the cross section by $\sim 25\%$. For our kinematics, featuring smaller jet transverse momenta and “less inclusive” coverage of jet rapidities, one could expect even larger NNLO corrections. In view of this statement, we propose to return to the original Mueller-Navelet idea, to study the inclusive production of two forward jets separated by a large rapidity gap, and to remove from the analysis those regions where jets are produced at central rapidities by imposing the constraint that the rapidity of a Mueller-Navelet jet cannot be smaller than a given value.

2. Theoretical setup

We consider the production of Mueller-Navelet jets [1] in proton-proton collisions

$$p(p_1) + p(p_2) \rightarrow \text{jet}(k_{J_1}) + \text{jet}(k_{J_2}) + X, \quad (2.1)$$

where the two jets are characterized by high transverse momenta, $\vec{k}_{J_1}^2 \sim \vec{k}_{J_2}^2 \gg \Lambda_{\text{QCD}}^2$ and large separation in rapidity, while p_1 and p_2 are taken as Sudakov vectors.

In QCD collinear factorization the cross section of the process (2.1) reads

$$\frac{d\sigma}{dx_{J_1} dx_{J_2} d^2k_{J_1} d^2k_{J_2}} = \sum_{i,j=q,\bar{q},g} \int_0^1 dx_1 \int_0^1 dx_2 f_i(x_1, \mu_F) f_j(x_2, \mu_F) \frac{d\hat{\sigma}_{i,j}(x_1 x_2 s, \mu_F)}{dx_{J_1} dx_{J_2} d^2k_{J_1} d^2k_{J_2}}, \quad (2.2)$$

where the i, j indices specify the parton types (quarks $q = u, d, s, c, b$; antiquarks $\bar{q} = \bar{u}, \bar{d}, \bar{s}, \bar{c}, \bar{b}$; or gluon g), $f_{i,j}(x, \mu_F)$ denotes the initial proton PDFs; $x_{1,2}$ are the longitudinal fractions of the partons involved in the hard subprocess, while $x_{J_{1,2}}$ are the jet momenta longitudinal fractions; μ_F is the factorization scale; $d\hat{\sigma}_{i,j}(x_1 x_2 s, \mu_F)$ is the partonic cross section for the production of jets and $x_1 x_2 s \equiv \hat{s}$ is the squared center-of-mass energy of the parton-parton collision subprocess (see Fig. 1 of Ref. [37]). The cross section of the process can be written as

$$\frac{d\sigma}{dy_{J_1} dy_{J_2} d|\vec{k}_{J_1}| d|\vec{k}_{J_2}| d\phi_{J_1} d\phi_{J_2}} = \frac{1}{(2\pi)^2} \left[\mathcal{C}_0 + \sum_{n=1}^{\infty} 2 \cos(n\phi) \mathcal{C}_n \right], \quad (2.3)$$

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. To fix (at a common value) the renormalization and factorization scales, μ_R and μ_F , we will make use of the “exact” and in some cases also of two approximate, semianalytic implementations of BLM method, labeled as (a) and (b), using the so called *exponentiated* representation to keep contact with previous works [38].

3. Numerical analysis

We present here 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 . Ratios of the form \mathcal{R}_{n0}

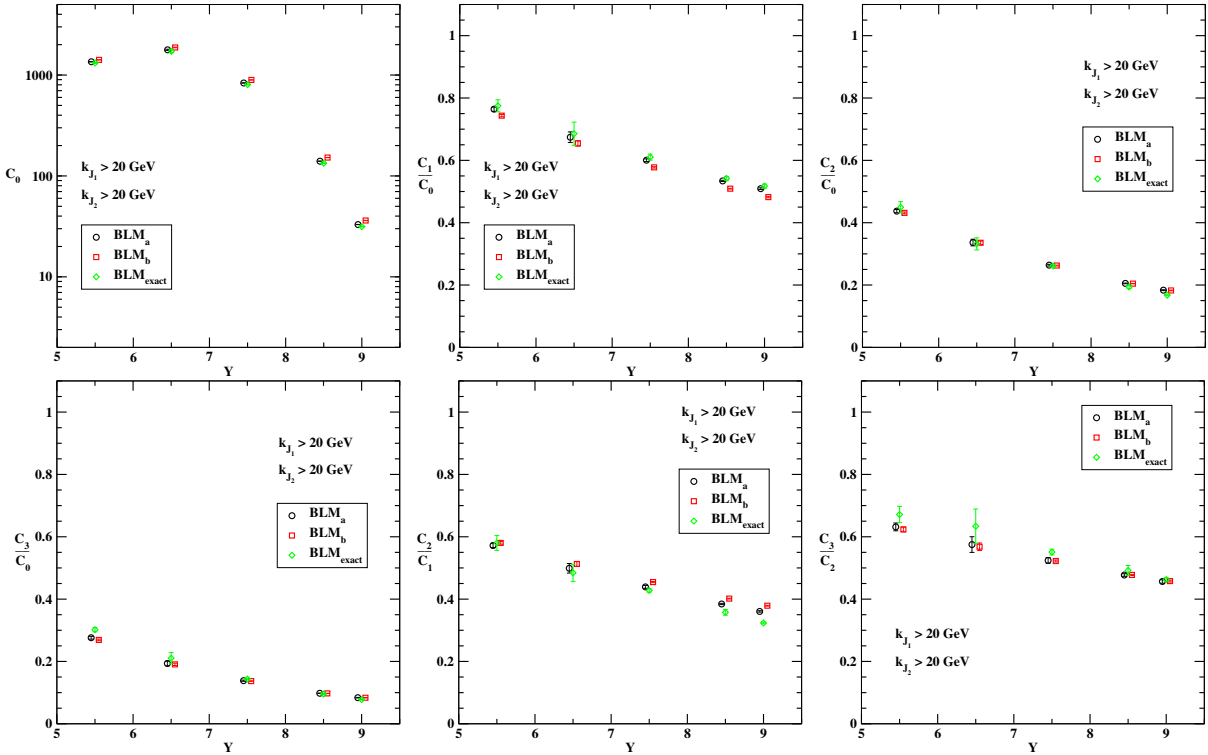


Figure 1: Y -dependence of C_0 and of several R_{nm} ratios for $k_{J_{1,\min}} = k_{J_{2,\min}} = 20$ GeV and for $|y_{J_i}| > 2.5$, from the three variants of the BLM method. For the numerical values, see Table 1 of Ref. [37].

have a simple physical interpretation, being the azimuthal correlations $\langle \cos(n\phi) \rangle$. To match the CMS kinematic cuts, we consider the *integrated coefficients* given by

$$C_n = \int_{y_{1,\min}}^{y_{1,\max}} dy_1 \int_{y_{2,\min}}^{y_{2,\max}} dy_2 \int_{k_{J_1,\min}}^{\infty} dk_{J_1} \int_{k_{J_2,\min}}^{\infty} dk_{J_2} \delta(y_1 - y_2 - Y) \theta(|y_1| - y_{\max}^C) \theta(|y_2| - y_{\max}^C) \mathcal{C}_n \quad (3.1)$$

and their ratios $R_{nm} \equiv C_n/C_m$. In Eq. (3.1), the two step-functions force the exclusion of jets with rapidity smaller than a cutoff value y_{\max}^C , which delimits the central rapidity region. We will take jet rapidities in the range delimited by $y_{1,\min} = y_{2,\min} = -4.7$ and $y_{1,\max} = y_{2,\max} = 4.7$, as in the CMS analyses at 7 TeV. As for the central rapidity exclusion, we will consider the three cases $y_{\max}^C = 0, 1.5, 2.5$. As for jet transverse momenta, differently from most previous analyses, we make five different choices which include *asymmetric* cuts. The center-of-mass energy is fixed at $\sqrt{s} = 13$ TeV. For details on kinematic setup, numerical tools used and uncertainties, see Ref. [37].

The main result we have found is that, except for the case of total cross section, \mathcal{C}_0 , R_{nm} remain unaffected by the cut on the central rapidity region, over the entire region of values of Y . This is obvious for the values of Y large enough to be insensitive to the very presence of a non-zero y_{\max}^C , but it is unexpectedly true also for the lower values of Y .

4. Summary

We have considered the Mueller-Navelet jet production process at LHC at the center-of-mass energy of 13 TeV and have given predictions for total cross sections and several moments of the jet

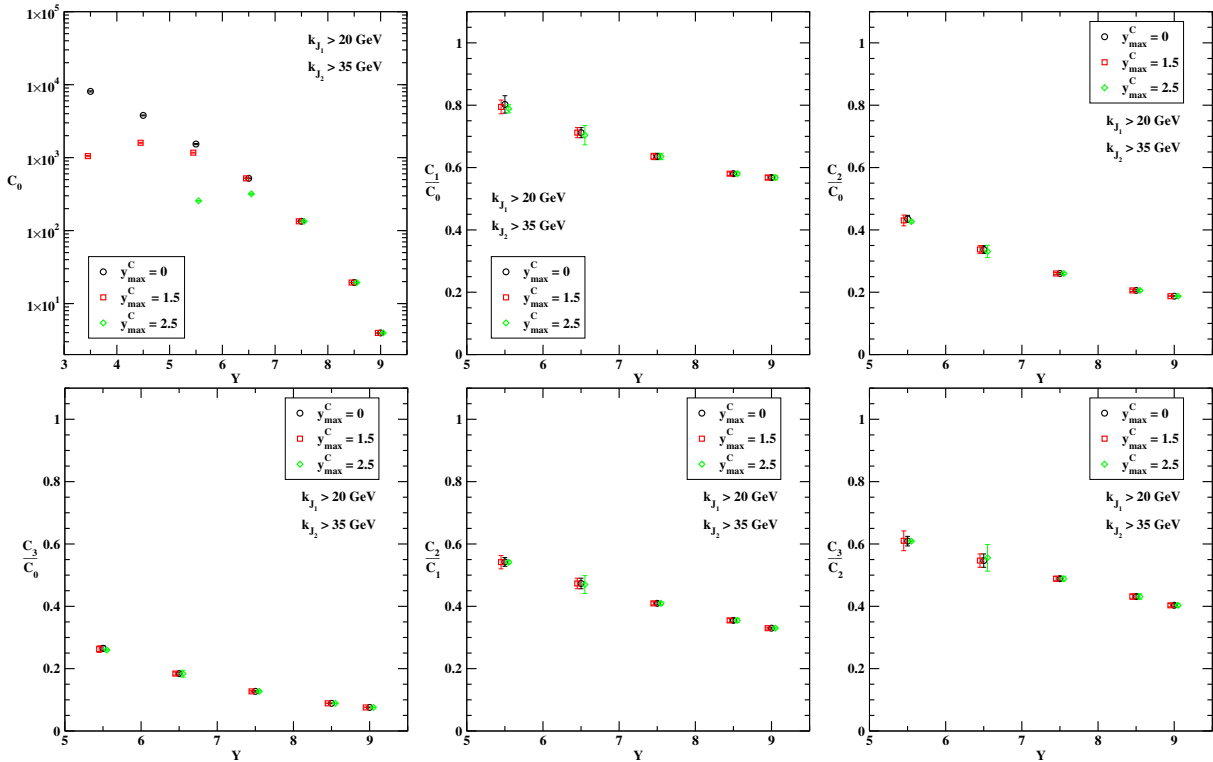


Figure 2: Y -dependence of C_0 and of several R_{nm} ratios from the “exact” BLM method, for $k_{J_1, \min} = 20$ GeV, $k_{J_2, \min} = 35$ GeV and for all choices of the cuts of the central rapidity region. For the numerical values, see Tables 2-7 of Ref. [37].

azimuthal angle distribution, using the BLM method to optimize the μ_R and μ_F scales. Differently from previous studies, we have considered the effect of excluding that one of the two detected jets be produced in the central rapidity region. Indeed, central jets originate from small- x partons and the collinear approach for the description of the Mueller-Navelet jet vertices may be not good at small x . It would be very interesting to confront our predictions with LHC data.

Acknowledgments

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