Probing BFKL dynamics in Mueller-Navelet jet production at the LHC

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Abstract

We review the results of our studies on the production of two jets with a large interval of rapidity at hadron colliders, which was proposed by Mueller and Navelet as a possible test of the high energy dynamics of QCD, within the next-to-leading logarithm framework. The application of the Brodsky-Lepage-Mackenzie procedure to fix the renormalization scale leads to a very good description of the available CMS data at the LHC for the azimuthal correlations of the jets. We show that the inclusion of next-to-leading order corrections to the jet vertex significantly reduces the importance of energy-momentum non-conservation which is inherent to the BFKL approach, for an asymmetric jet configuration.

One of the most famous testing grounds for BFKL physics [1] are the Mueller Navelet jets [2], illustrated in Fig. 1. Besides the cross section also a more exclusive observable within this process drew the attention, namely the azimuthal correlation between these jets. Considering hadron-hadron scattering in the common parton model to describe two jet production at LO, one deals with a back-to-back reaction and expects the azimuthal angles of the two jets always to be π and hence completely correlated. This corresponds in Fig. 1 to $\phi_{J,1} = \phi_{J,2} - \pi$. But when we increase the rapidity difference between these jets, the phase space allows for more and more emissions leading to an angular decorrelation between the jets.

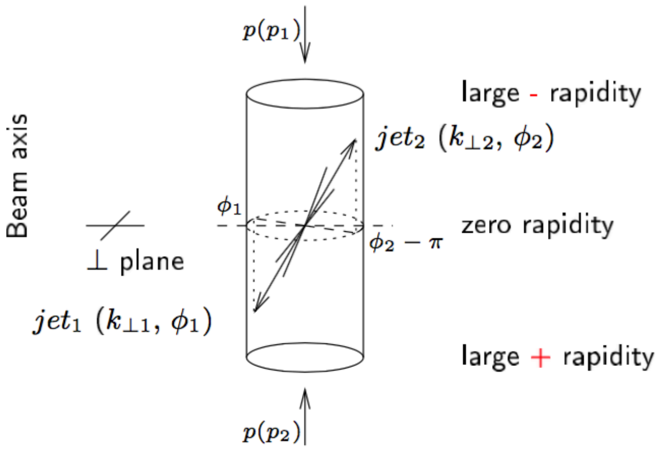

Figure 1: Mueller Navelet jets production.

The production of two jets of transverse momenta $\mathbf{k}_{J,1}$, $\mathbf{k}_{J,2}$ and rapidities $y_{J,1}$, $y_{J,2}$ is described by the differential cross-section

$$\frac{\mathrm{d}\sigma}{\mathrm{d}|\mathbf{k}_{J,1}|\,\mathrm{d}|\mathbf{k}_{J,2}|\,\mathrm{d}y_{J,1}\,\mathrm{d}y_{J,2}} = \sum_{\mathrm{a,b}} \int_0^1 \mathrm{d}x_1 \int_0^1 \mathrm{d}x_2\, f_{\mathrm{a}}(x_1) f_{\mathrm{b}}(x_2) \frac{\mathrm{d}\hat{\sigma}_{\mathrm{ab}}}{\mathrm{d}|\mathbf{k}_{J,1}|\,\mathrm{d}|\mathbf{k}_{J,2}|\,\mathrm{d}y_{J,1}\,\mathrm{d}y_{J,2}}, \tag{1}$$

where $f_{\mathrm{a,b}}$ are the usual collinear partonic distributions (PDF). In the BFKL framework, the partonic cross-section reads

$$\frac{\mathrm{d}\hat{\sigma}_{\mathrm{ab}}}{\mathrm{d}|\mathbf{k}_{J,1}|\,\mathrm{d}|\mathbf{k}_{J,2}|\,\mathrm{d}y_{J,1}\,\mathrm{d}y_{J,2}} = \int \mathrm{d}\phi_{J,1}\,\mathrm{d}\phi_{J,2} \int \mathrm{d}^2\mathbf{k}_1\,\mathrm{d}^2\mathbf{k}_2\, V_{\mathrm{a}}(-\mathbf{k}_1, x_1)\, G(\mathbf{k}_1, \mathbf{k}_2, \hat{s})\, V_{\mathrm{b}}(\mathbf{k}_2, x_2), \tag{2}$$

where $V_{\mathrm{a,b}}$ and G are respectively the jet vertices and the BFKL Green's function. At present, they are known with the next-to-leading logarithm accuracy [3, 4, 5, 6, 7]. The cross sections (1, 2) are the basic blocks of the calculations presented in [9, 10, 11] of the decorrelation coefficients $\langle \cos m(\pi - \Delta\phi)\rangle$, $\Delta\phi = \phi_{J,1} - \phi_{J,2}$, $m \in N$, which are observables which can be measured at experiments performed at the LHC. At present the measurements of the CMS collaboration are done for the so called the symmetric configuration of produced jets, i.e. jets in which the lower limit on transverse momentum is the same for both jets.The theoretical estimates obtained in this case for $\langle \cos m(\pi - \Delta\phi) \rangle$ with the use of the Brodsky-Lepage-Mackenzie method to fix the renormalization scale [12], turns out to be in good agreement with the measurement reported recently by the CMS collaboration [8]. This fact is

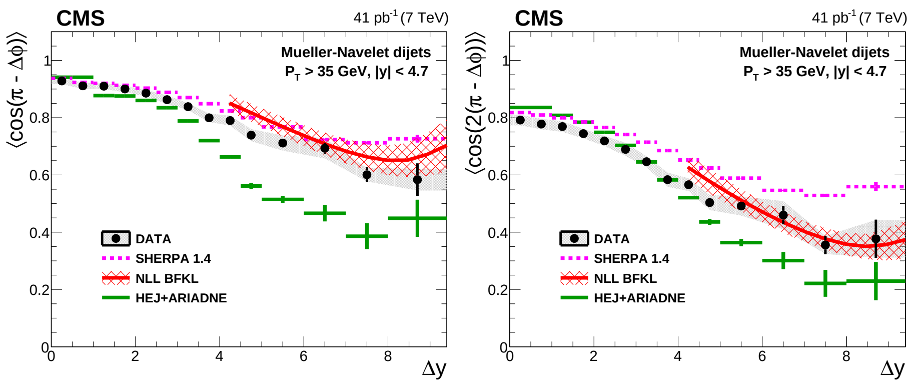

Figure 2: The comparison of the results of the theoretical calculation of Ref. [11] for $\langle \cos(\pi - \Delta\phi) \rangle$ (left panel) and $\langle \cos 2(\pi - \Delta\phi) \rangle$ (right panel), with the measurements by CMS@LHC presented in [8].

clearly illustrated in Fig. 2 and the left panel of Fig. 3 shown in Ref. [8], which also shows the comparison of measurements with various Monte Carlo simulations. The observables which are more robust against theoretical uncertainties, in particular which are more stable against a choice of renormalization and factorization scales, are the ratios of decorrelation coefficients. Fig. 4 shows a good agreeement of results of calculation with the CMS data. The CMS collaboration also measured

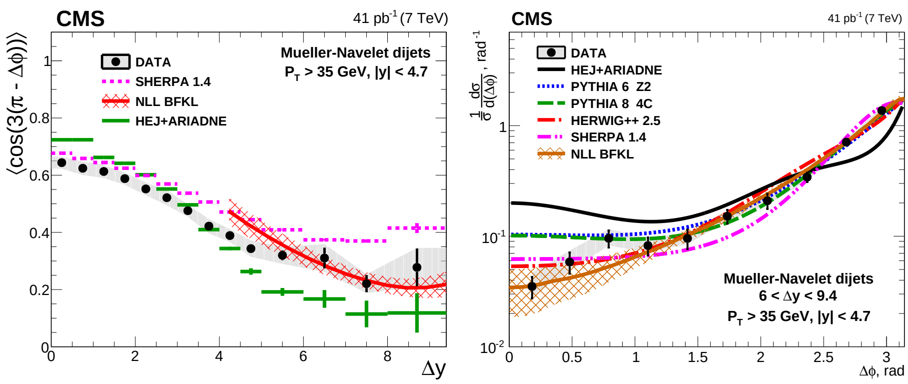

Figure 3: The comparison of theoretical calculation of Ref. [11] for $\langle \cos 3(\pi - \Delta\phi) \rangle$ (left panel) and $\frac{1}{\sigma}\frac{d\sigma}{d\varphi}$ (right panel), with the measurements by CMS@LHC presented in [8].

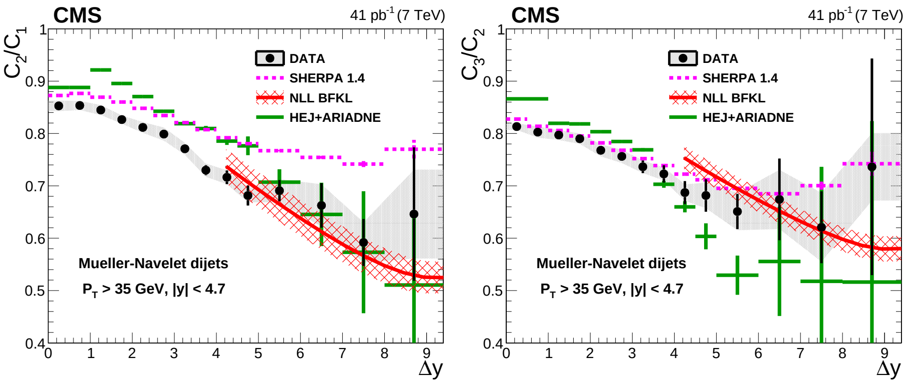

Figure 4: The comparison of theoretical predictions of Ref. [11] for the ratio $\frac{\cos 2\varphi}{\cos\varphi}$ (left panel) and the ratio $\frac{\cos 3\varphi}{\cos 2\varphi}$ (right panel), with the measurements by CMS@LHC presented in [8].

the azimuthal distribution of the jets, defined as

$$\frac{1}{\sigma}\frac{d\sigma}{d\varphi} = \frac{1}{2\pi}\left\{1 + 2\sum_{n=1}^{\infty}\cos(n\varphi)\,\langle\cos(n\varphi)\rangle\right\}, \quad \varphi = \Delta\phi - \pi\,. \tag{3}$$

The good agreement between theoretical estimates of [11] and measurements of this observable is shown in the right panel of Fig. 3.

Up to now we discussed production of jets in the symmetric configuration. From theoretical point of view the Monte Carlo simulations suffer in this case from instabilities which makes difficult the comparison of theoretical results based on BFKL method with the fixed order calculation. Such comparison of different theoretical predictions can be made in the case of jet production in the asymmetric configuration, in which two jets have very different transverse momenta. In the Fig. 5 and

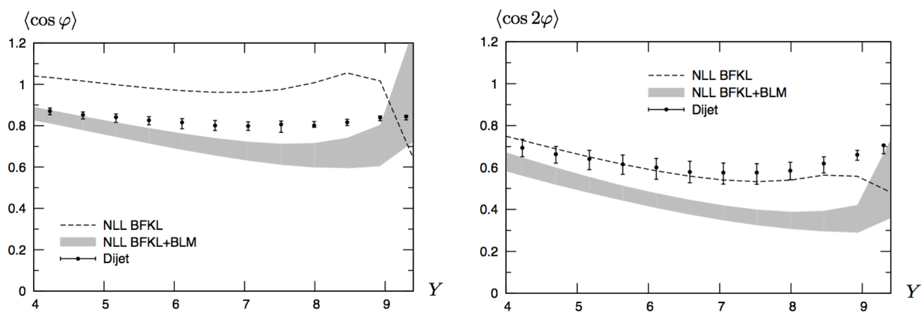

Figure 5: Asymmetric configuration. Variation of $\langle\cos\varphi\rangle$ and $\langle\cos 2\varphi\rangle$ as a function of rapidity difference Y at NLL accuracy compared with a fixed order treatment.

in the left panel of Fig. 6 we present our theoretical predictions for decorrelation coefficients and their ratio confronted with the result of the fixed order calculation of Ref. [13]. It seems that specially in the case of the ratio $\frac{\cos 2\varphi}{\cos\varphi}$ a measurement of this observable could discriminate between two different mechanisms. Unfortunately, for now experimental measurements in such asymmetric configurations, although very desirable, are not available.

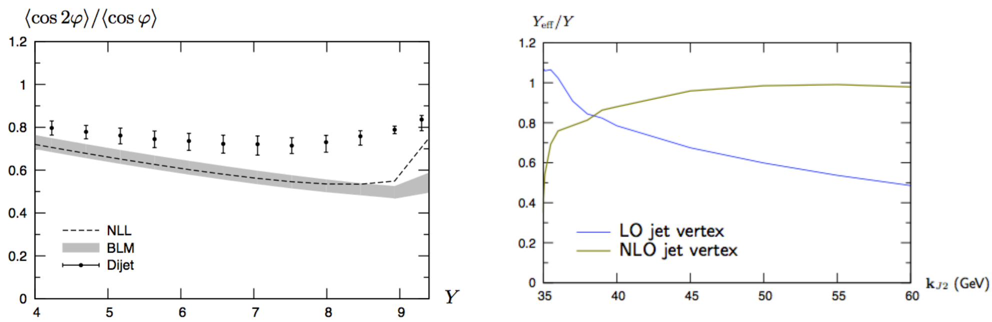

Figure 6: Left panel: Asymmetric configuration. Variation of the ratio $\frac{\langle\cos 2\varphi\rangle}{\langle\cos\varphi\rangle}$ as a function of rapidity difference Y at NLL accuracy compared with a fixed order treatment. Right panel: Variation of the ratio $\frac{Y_{eff}}{Y}$ as a function of jet momentum $\mathbf{k}_{J,2}$ for fixed $\mathbf{k}_{J,1} = 35\,\mathrm{GeV}$ for $Y = 8$ and $s = 7\,\mathrm{TeV}$ at leading logarithmic (blue) and next-to-leading logarithmic (brown) accuracy

The important drawback of the BFKL method is the fact that it does not respect exact energy-momentum conservation. This fact can lead to sizable numerically effects, although formally it represents a non-leading correction. In the Ref. [14] we studied the violation of energy-momentum conservation for asymmetric configuration using the method proposed by Del Duca nd Schmidt in [15]. In consist in introduction of the effective rapidity $Y_{\rm eff}$ defined as

$$Y_{\rm eff} \equiv Y \frac{\mathcal{C}_0^{2\to 3}}{\mathcal{C}_0^{\rm BFKL, \mathcal{O}(\alpha_s^3)}} \tag{4}$$

in [14], where $\mathcal{C}_0^{2\to 3}$ is the amplitude for $2 \to 3$ partonic process (contributing to the cross section) calculated up to $\mathcal{O}(\alpha_s^3)$ accuracy without any approximations and $\mathcal{C}_0^{\rm BFKL, \mathcal{O}(\alpha_s^3)}$ is the amplitude of the same process obtained within BFKL method. If the violation of energy-momentum conservation is not numerically important the ratio $\frac{Y_{\rm eff}}{Y}$ should take values close to one. In the right panel of Fig. 6 we show our result for the ratio $\frac{Y_{\rm eff}}{Y}$ estimated by taking into account NLO BFKL corrections to the jet production vertex . We see that for very asymmetric jet momenta this ratio takes values close to 1, which justifies our conclusion that the predictions obtained for production of jets in asymmetric configuration should not be affected by violation of energy-momentum conservation.

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