Hybrid high-energy/collinear factorization in a heavy-light dijets system reaction

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Abstract

We propose the inclusive hadroproduction of a heavy-light dijet system, as a new channel for the investigation of high-energy QCD. We build up a hybrid factorization that incorporates a partial next-to-leading BFKL resummation inside the standard collinear description of observables. We present a detailed analysis of different distributions: cross-section summed over azimuthal angles and differential in rapidity and azimuthal distribution. The stability that these distributions show under higher-order corrections motivates our interest in future studies, doable at new generation colliding machines.

1 Introduction

Semihard processes ($s \gg Q^2 \gg \Lambda^2_{\text{QCD}}$, with s the squared center-of-mass energy, Q^2 the process hard scale and Λ^2_{QCD} the QCD mass scale) represent a challenge for high-energy QCD. Fixed-order perturbative calculations miss the effect of large energy logarithms, which must be resummed to all orders. The most general framework to perform this resummation is the BFKL approach [1–3]. This procedure allows us to resum all terms proportional to $(\alpha_s \ln(s))^n$

(the so called leading logarithmic approximation or LLA) and also of those proportional to $\alpha_s(\alpha_s \ln(s))^n$ (the so called next-to-leading logarithmic approximation or NLA).

Within the BFKL approach, the imaginary part of an elastic amplitude (which can be related to a inelastic total cross-section by the *optical theorem*), can be presented as a convolution of a process-independent object, the BFKL *Green's function*, and of two process-dependent *impact factors* (depending on the type of colliding particles). Being the Green's function universal (and known with NLA accuracy), to investigate new processes within the framework, all that remains is to compute impact factors.

A detailed list of impact factors known to the leading order (LO) and to the next-to-leading order (NLO) can be found in Ref. [4]. In the present work the LO impact factor for the production of a forward jet (see e.g. [5] and references therein) and the one for the production of a heavy quark-antiquark pair starting from a gluon will come into play [6]. Here, the semi-hard reaction under investigation is:

$$P(k_1) + P(k_2) \rightarrow Q\text{-jet}(k_Q, y_Q) + X + \text{jet}(k_J, y_J) \,, \tag{1}$$

where P labels the colliding protons with momenta k_i ($i = 1, 2$), Q the heavy-jet carrying (a large) transverse momenta k_Q and emitted at rapidity y_Q and, lastly, J is the light-jet carrying (a large) transverse momenta k_J and emitted at rapidity y_J. X contains all the undetected products of the reaction.

2 Theoretical set-up

For the process under consideration we plan to construct a cross section, differential in some of the kinematic variables of the tagged jets. We will be able to build up all considered observables from the master formula for this cross-section.

At LO and in the x-range relevant for this process at LHC ($x \sim 10^{-2}$ to 10^{-4}), the dominant mechanism of production of an heavy-quark pair is the splitting of a partonic gluon (with the Q-jet generated either from the quark or from the antiquark); the LO *heavy-quark pair* impact factor (upper vertex of our hybrid-factorized cross section) and its projection onto the BFKL eigenfunctions have been evaluated in Ref. [6].
Conversely, a light jet directly stems from a partonic light quark or from a gluon; the LO expression for the *forward-jet* impact factor (lower-vertex of our hybrid-factorized cross section) and its projection, can be found, for instance, in Ref. [7]. At this level of accuracy, the jet selection functions are obviously set to one, while impact factors are convoluted with the parton distribution functions (PDFs) to obtain the hadronic cross section. The differential proton cross section is then

$$\frac{d\sigma_{pp}}{dy_Q dy_J d|\vec{k}_Q| d|\vec{k}_J| d\phi_Q d\phi_J} = \frac{1}{(2\pi)^2} \left[\mathcal{C}_0 + 2 \sum_{n=1}^{\infty} \cos(n\varphi) \mathcal{C}_n \right], \tag{2}$$

where $\varphi = \phi_J - \phi_Q - \pi$ and $\mathcal{C}_n$'s are the *azimuthal coefficients*. $\mathcal{C}_n$'s embody in their definition the parton distribution function, impact factors and the BFKL Green function (projected on the (n, ν)-space). Their analytic expression can be found in Ref. [8].

3 Phenomenology

Observables under investigation are:
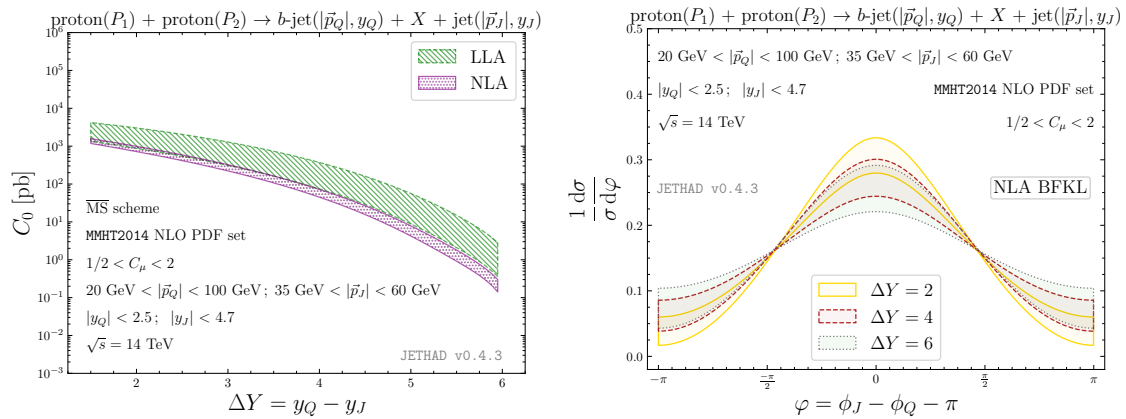
Figure 1: φ-summed cross section, C_0, as a function of ΔY (left). NLA azimuthal distribution for different ΔY (right).

- *Azimuthal coefficients*

$$C_n(\Delta Y, s) = \int_{k_Q^{\min}}^{k_Q^{\max}} d|\vec{k}_Q| \int_{k_J^{\min}}^{k_J^{\max}} d|\vec{k}_J| \int_{y_Q^{\min}}^{y_Q^{\max}} dy_Q \int_{y_J^{\min}}^{y_J^{\max}} dy_J \, \delta\left(y_Q - y_J - \Delta Y\right) \mathcal{C}_n. \quad (3)$$

We investigate the ΔY-behavior of the φ-summed cross section (or ΔY-distribution), $C_0(\Delta Y, s)$.

- *Azimuthal distribution*

$$\frac{d\sigma_{pp}(\varphi, \Delta Y, s)}{\sigma_{pp}d\varphi} \equiv \frac{1}{\pi}\left\{\frac{1}{2} + \sum_{n=1}^{\infty}\cos(n\varphi)\frac{C_n}{C_0}\right\} = \frac{1}{\pi}\left\{\frac{1}{2} + \sum_{n=1}^{\infty}\cos(n\varphi)\langle\cos(n\varphi)\rangle\right\}. \quad (4)$$

In the following, we focus our attention on bottom-jet (b-jets) emissions fixing the center-of-mass energy at $\sqrt{s} = 14$ TeV. Rapidity intervals, $|y_Q| < 2.5$ and $|y_J| < 4.7$, are choosen in order to fit a realistic CMS analysis. We work in the $\overline{\text{MS}}$ scheme.

An extensive analysis, which includes other distributions (*e.g.* the heavy-jet transverse momentum distribution) as well as the charm-jet production case, can be found in [8].

In the left panel of Fig. 1 we present predictions for the φ-summed cross section, C_0, as a function of the rapidity interval, ΔY. The downtrend of the cross section comes out as the net result of two competing effects. On one side BFKL predicts an increase in the partonic cross section as the rapidity grows. On the other side, in our hybrid approach the BFKL-resummed partonic cross section is convoluted with PDFs. In particular, the gluon one plays a dominant role and it decreases as the rapidity difference grows. We note that the inclusion of NLA corrections to the BFKL Green's function reduces the value of the cross section, due to the fact that these terms have opposite sign with respect to pure LLA. Nevertheless, the emission of a heavy-flavored jet provides with a partial stabilization, that allows us to perform studies around small multiples of natural scales.

In the right panel of Fig. 1 we present predictions for the azimuthal distribution, $d\sigma_{pp}/d\varphi$ at different values of ΔY. High-energy behavior clearly emerges from these distributions. In fact, all distributions have a peak when the two tagged objects are back-to-back ($\varphi = 0$), but, distributions associated to higher rapidity difference are wider and with a smaller peak height, indicating a clear loss of correlation when ΔY increases.

4 Conclusions and outlook

We have proposed a new type of inclusive semi-hard reaction in which a heavy-flavored jet and a light-flavored jet are emitted with a large separation in rapidity. The following phenomenological analysis not only enriches the class of useful processes for testing the high-energy dynamics of QCD (see *e.g.* [9–15]), but also allows for a stabilization of the BFKL series. Thanks to these stabilizing effects, it has been possible, in contrast with the case of inclusive light-dijet production [5, 7, 16–28] (Mueller-Navelet channel [29]), to perform studies around natural values of energy scales. This result is very promising when considering the perspective of performing high-precision calculations in our hybrid collinear/high-energy framework, as well as gauging the weight of high-energy effects in wider kinematical ranges, like the ones typical of new generation colliding machines [30–36].

This work is part of our current program on heavy-flavored emissions, which has started from the analytic calculation of heavy-quark pair impact factors [6, 37, 38]. From the phenomenological point of view, our next step is the extension of these analyses to bound states of quarks, such as heavy-light mesons and quarkonia. From the theoretical side a very interesting and challenging development is the calculation of the NLO heavy-quark pair impact factor.

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