Matrix Elements with Vetoes in the CASCADE Monte Carlo Event Generator

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We illustrate a study based on a veto technique to match parton showers and matrix elements in the CASCADE Monte Carlo event generator, and present a numerical application to gluon matrix elements for jet production.

Baseline studies of final states containing multiple jets at the Large Hadron Collider use Monte Carlo event generators — see e.g. [1] for a recent review — based on collinear evolution of parton showers combined with hard matrix elements. These are either high-multiplicity tree-level matrix elements [2], or next-to-leading-order matrix elements [3] including virtual emission processes, or possibly, in the future, a combination of both [4, 5]. The parton showers take into account collinear small-angle QCD radiation, while the matrix elements take into account hard large-angle radiation.

When the longitudinal momentum fractions involved in the production of jets become small, however, new effects on jet final states arise from noncollinear corrections to parton branching processes [6], due to soft but finite-angle multi-gluon emission. An example of this occurs at the LHC when jets are produced at increasingly high rapidities [7]. In order to take these corrections into account one needs [8] transverse-momentum dependent showering algorithms coupled [9] to hard matrix elements at fixed transverse momentum.

The CASCADE Monte Carlo event generator [10] provides an implementation of this framework. Applications of this to hard production in the LHC forward region [11] have been investigated in [12], where studies of forward-central jet correlations have been proposed. First LHC measurements of jets at wide rapidity separations have appeared in [13, 14]. The approach of CASCADE is based on a small-x expansion, so that in order to apply it to the highest jet $p_\perp$ it is relevant to match it with perturbative fixed-order terms. In this article we describe a study based on a vetoing procedure to combine shower and matrix element contributions to jet production. The technique discussed is one of the elements needed to improve the accuracy of CASCADE at high transverse momenta.

To illustrate this, we focus on the partonic $q\bar{q}$ production process in the gg^* channel. This can occur by direct production from gluon-gluon annihilation or by decay $g \to q\bar{q}$ following elastic gluon scattering. When the quarks have small relative transverse momentum the two mechanisms are effectively of the same order in the strong coupling. The question of properly simulating these processes also arises in the case of collinear shower Monte Carlo; but the case of the transverse momentum dependent shower involves an additional (semi)hard scale set by the off-shellness of the incoming parton. Different behaviors may be expected depending on the ratio $|k^2|/\mu^2$, where $|k^2|$ is the off-shellness and μ^2 is the merging scale used for combining the different production processes. An approach to treat this is based on the subtractive method [15] (see [16] and [17] for further applications of the method). An analysis along these lines is reported in [18]. In this article we describe the result of another type of calculation [12], based on introducing a veto on $g \to q\bar{q}$ splitting above a given transverse momentum scale $\mu = \mathrm{p}_\perp^{(V)}$. In this calculation the gluonic matrix element is combined with the vetoed branching, and added to the hard production contribution.

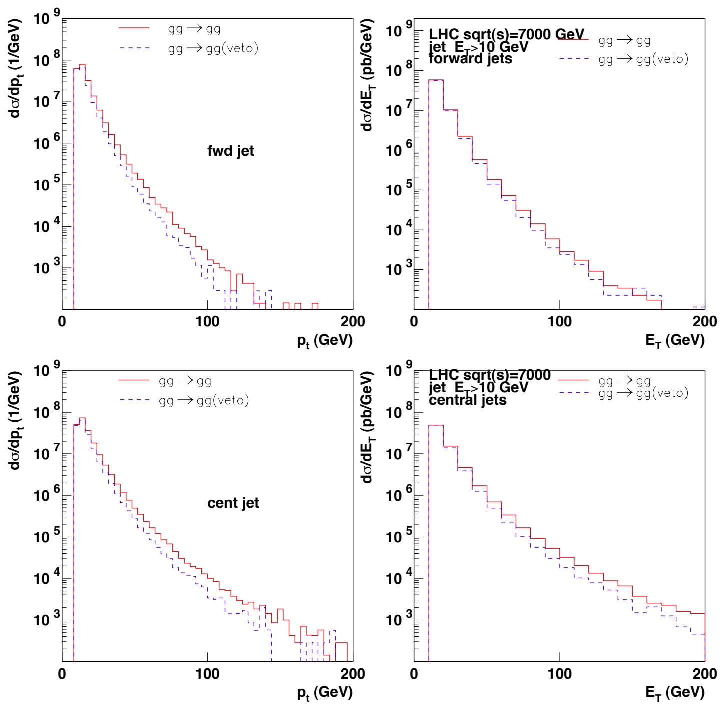

Figure 1: The effect of the veto at forward (top) and central (bottom) rapidities: (left) parton-level; (right) jet-level.

In Fig. 1 we consider the kinematic region [12] for production of jets at forward and central rapidities, and we examine numerically the effect of the veto on the gluon scattering contribution both at the level of final state partons and at the level of reconstructed jets. We see that in both cases the shape of transverse spectra is changed by the veto. In Fig. 2 we include all partonic channels, in the same kinematic region, combining the previous contribution with hard production. Then the shape of the transverse distribution is not changed much as an effect of the veto, while this results into a change in normalization. For reference we also include the result from the PYTHIA Monte Carlo generator [19] used in the LHC tune Z1 [20].

In summary, the study discussed in this contribution introduces vetoed decays coupled with finite-$\mathrm{k}_\perp$ matrix elements as an approach to matching in the case of transverse momentum

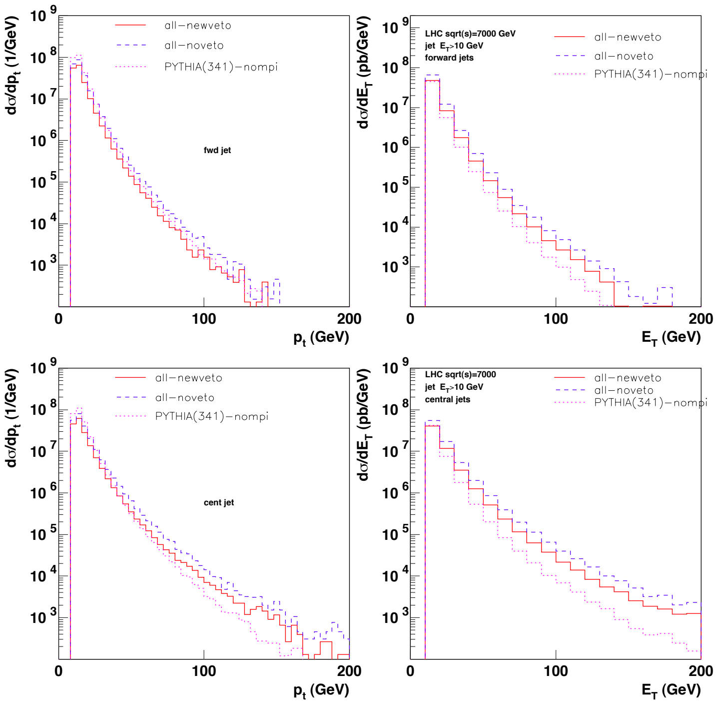

Figure 2: Comparison of transverse momentum spectra at forward (top) and central (bottom) rapidities: (left) parton-level; (right) jet-level.

dependent parton showers. This is one of the ingredients to extend results of the Cascade Monte Carlo generator toward higher $p_\perp$ jets. Other physical effects will also be important in this region. One is the behavior of the gluon distribution for large x at transverse momentum dependent level. At present this is not very well constrained in fits to experimental data [21]. Another is the inclusion of subleading quark contributions [22] to the evolution of the small-x parton shower. In the intermediate to low $p_\perp$ range, studies of the associated mini-jet energy flow [12, 23] as a function of rapidity and azimuthal distance will be helpful to investigate showering and possibly gluon rescattering [24] effects. We expect this to be relevant especially to analyze multiple parton interactions [25] and their role in multi-jet production at the LHC.

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