Radiation of Extra-Jets in Inclusive SUSY Samples

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Abstract. In order to simulate the multi-jets events in a reliable way, a matrix-element generator and a parton shower generator have to be used simultaneously. To avoid the problem of overlapping between their respective phase-spaces, various jet matching techniques can be used in the context of the Standard Model. Beyond the Standard Model, many models propose the existence of heavy particles for which the QCD radiation should be harder, justifying again the use of such technique. MADGRAPH/MADEVENT allows to apply the matching also beyond in this case. We present here the ongoing work in the context of the production of heavy particles in the MSSM.

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INTRODUCTION

Many models for physics beyond the Standard Model (notably SUSY, Little Higgs, extra dimension, technicolor) contain new strongly interacting particles with masses below or near the TeV scale. These particles, if they exist, will be copiously produced at the LHC, and could provide the first and most important sign of new physics. By analyzing their production and decay already after only a few years of data taking, many of the new physics properties could be determined.

The final state signatures that are characteristic of events where heavy colored particles are produced, typically include a large energy measured in the detector, often associated to the so-called H_t variable, missing transverse energy and several energetic jets coming from their decays. Such events can be simulated quite efficiently by using Monte Carlo generators that include new physics models, as well as showering and hadronization, such as PYTHIA [1], HERWIG [2]. However, an additional difficulty arises in the simulation of production of heavy particles at hadron colliders which is due to the presence of QCD radiation. This radiation, typically enhanced in the production of heavy and strongly interacting particles via gluon gluon initial state, can have important effects: for example on the event kinematics by giving a transverse boost to the heavy particle system. It can produce additional jets besides the jets originating from the decay of the heavy particles, making the reconstruction and the indentification of the event much complicated.

Traditionally, additional jet production has been simulated using Parton Shower (PS) Monte Carlo programs such as PYTHIA and HERWIG which describe parton radiation as successive parton emissions using the soft and collinear limit. This description is formally correct only in the limit of soft and collinear emissions, but has been shown to give a good description of much data also relatively far away from this limit. However, for the production of hard and widely separated extra jets, this description breaks down due to the lack of subleading terms and interference. For that case, it is necessary to use the full tree-level amplitudes for the heavy particle production plus additional partons.

The Matrix Element (ME) description diverges as partons become soft or collinear, while the parton shower description breaks down when partons become hard and widely separated. In order to describe both these areas in phase space, the two descriptions must be combined, without double counting or gaps between different multiplicities. An additional physical requirement is that such a procedure gives smooth distributions, and interpolates between the parton shower description in the soft and collinear limits and the matrix element description in the limit of hard and widely separated partons. Several such procedures have been proposed, and can be grouped into two familied differing by the philosophy. The CKKW scheme [3, 4] is based on the actual Sudakov reweighting whereas the Mangano techniques [5] use event rejection instead. These different procedures are in substantial agreement and give consistent results at hadron colliders [6, 7].

THE JET MATCHING IN MADGRAPH/MADEVENT: IN THE SM AND BEYOND

Our approach is completely general and therefore can be applied equally well to the SM as well as to any BSM construction. To be concrete we will focus on top pair production and on pair production of strongly interacting SUSY particles, such as squarks and gluinos. The MSSM model implementation used in this work has been presented in Refs. [8, 9, 10].

In this study we have employed the MADGRAPH/MADEVENT matrix element generator [11, 12, 10] interfaced to PYTHIA [1] for parton showering and hadronization.

The goal of jet matching is to merge samples of different multiplicity multiparton matrix element events, correctly accounting for showering effects and avoiding double counting. The matching algorithms used in this study can be viewed as hybrids between the approaches by SHERPA [13] and ALPGEN [14]. The phase space separation between the different multijet processes is achieved using the $k_{\perp}$-measure [15]. Instead of using analytic Sudakov reweighting of the events, showered events are rejected if they are not matched to the parton-level jets. .

The first matching scheme used in this study, the $k_{\perp}$-jet MLM scheme, is the one used for MADGRAPH/MADEVENT in [7].

In order to further study the systematics of the jet matching, a new matching scheme has been also implemented, called the "shower $k_{\perp}$ scheme". In this scheme, the events are generated by MADGRAPH/MADEVENT as described above, including the reweighting of α_s. The event is then passed to PYTHIA and showered using the $p_{\perp}$-ordered showers. For the $p_{\perp}$-ordered showers, PYTHIA reports the scale of the hardest emission, $Q^{PS}_{hardest}$, in the shower. For events from lower-multiplicity samples, the event is rejected if $Q^{PS}_{hardest}$ is above the matching scale Q_{match}, while events from the highest multiplicity sample are rejected if $Q^{PS}_{hardest}$ is bigger than the scale of the softest matrix element parton in the event. This matching scheme, although simple, effectively mimics the workings of the $k_{\perp}$-jet MLM scheme. However, it allows for the matching scale Q_{match} to be set equal to the matrix element cutoff scale Q^{ME}_{cut}, and it more directly samples the Sudakov form factor used in the shower.

Double counting from resonant diagrams

In the simulation of events where colored particles are produced that can possibly decay into one another by emitting partons, another type of double counting problem arises. Consider, for example, the contributions to $\tilde{g}\tilde{q}$ + 1 jet coming from various subprocesses. Among these, $gg \to \tilde{g}\tilde{q}q$ displays a peculiar behaviour.

When integrated over the phase space, the diagrams containing possibly resonant gluinos and squarks propagators give rise either to $gg \to \tilde{g}\tilde{g}$ with $\tilde{g} \to \tilde{q}q$ or to $gg \to \tilde{q}\tilde{q}^*$ with $\tilde{q} \to \tilde{g}q$, depending on the mass hierarchy. These contributions, are already taken into account by the Born level processes $gg \to \tilde{g}\tilde{g}$ or $gg \to \tilde{q}\tilde{q}^*$ plus the corresponding decays and have therefore to be properly subtracted to avoid double counting. In fact, this kind of issue appears every time a given final state can be reached through different decay cascades.

It is mandatory to have a proper way to get rid of this problem. There are two complementary solutions, one based on a automatic of the resonant diagrams, following the idea of [16], but in an automatic way directly by MadGraph. This approach has the virtue of being very simple, though it is not gauge invariant and neglects the interference between the diagrams. The impact of these approximations therefore has to be carefully case by case.

The second solution is an hybrid between a proper gauge-invariant subtraction and the diagram removal. It is based on a general algorithm implemented in MADGRAPH/MADEVENT to pass the information of the presence of intermediate resonant propagators on an event-by-event basis. We won't describe further this method here, this will be done in detail in the publication of this work [17].

An example of the good results given by the matching with resonances removing shown in the Fig. 1. The variable used if the differential jet rate DJR(N→N-1) and can be defined as the scale at which, when a clustering algorithm like $k_{\perp}$ is applied, an event pass from a N to a N-1 configuration. Therefore it is clear that this variable is very sensitive to the transition from one region of the phase-space, ruled for example by the PS to the other region ruled by the ME calculation. In this example, we show the DJR(2→1), where the 0-th and 1-th parton multiplicities are situated below the cutoff. This is due to the matching result, forbidding respectively 1 and 2 (or more) resolvable jets above the cutoff. On the contrary, the events with 2 jets are situated above the cutoff, thanks to the separation of at least the cutoff scale between the two jets. The smothness of the transition region indicates a good behaviour of the method. In addition, the global shape (only physical observable here) has to remain invariant when the cutoff is moved (in a reasonable range).

IMPACT OF THE MATCHING

As explained before, the control of extra-jet radiation appears to be crucial for reliable MonteCarlo simulations.

One of the main improvement brought by the use of matching techniques is the reduction of the sensitivity of the extra-jets to the shower parameterization, i.e. the shower type as well as the starting scale, from soft (wimpy) to hard (power) showers. This reduction is due to the fact that, as said before, above the matching cutoff the kinematics of initial state radiation is ruled by the

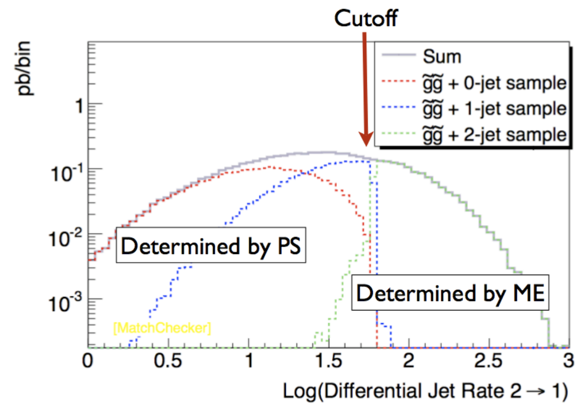

FIGURE 1. Differential jet rate showing the transition from 2→1 jets in the case of a production of $\tilde{g}\tilde{g}$+0,1,2 jets.

Matrix-Element calculation that does not depend on the shower characteristics. In the Fig. 2 an example of this reduction of sensitivity is shown for the leadind ISR in a $\tilde{g}\tilde{g}$ production, using a $k_\perp$ scale of 40 GeV as definition of the jet. The mass of the gluinos is 607 GeV.

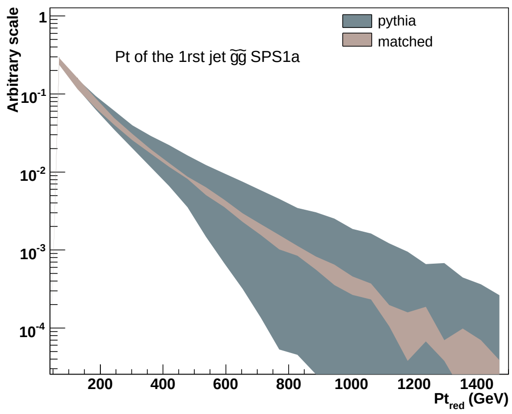

FIGURE 2. Variation of the P_T of the leading extra-jet in a production of $\tilde{g}\tilde{g}$ (607 GeV) when different parameterization of showers are applied with (light) or without matching (dark region)..

The result obtained with matching technique varies much less than if the ISRs kinematics are controlled by the PS generator used standalone. This can have an impact on the whole process, reducing a systematics uncertainty, at least when involved kinematics are above the matching cutoff (here 60 GeV).

This reduction of sensitivity also varies with the scale of the process, i.e. with the masses involved. In Fig. 3 we show the evolution of the H_t^{red} defined by the sum of the P_T of the extra-jets only (here defined with $k_\perp$=40 GeV)when the mass of the gluinos passes from 300 GeV to 1200 GeV.

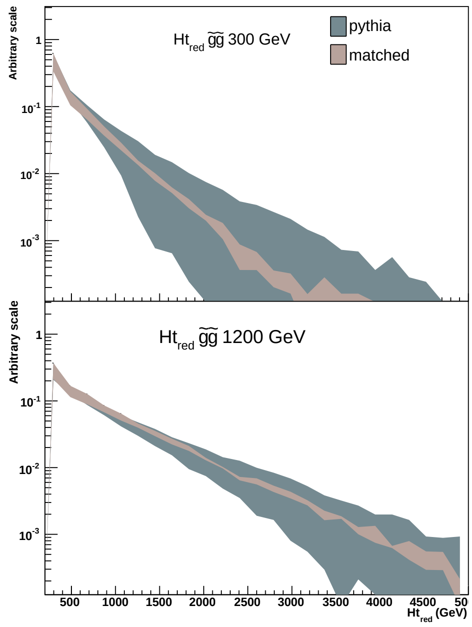

FIGURE 3. H_t^{red} for different mass of gluinos in a $\tilde{g}\tilde{g}$ process, with (light) and without (dark) matching when different shower parametrization are applied

However, it is not immediately obvious that a more predictive description of initial-state radiation, as given by the matching techniques, is important when using variables like H_t. Most relevant here is to know what fraction of the jet energy is coming from the decay of SUSY particles, and how much originates from initial state radiation.

Our preliminary estimates show that the percentage of energy coming from SUSY decays is very high in the bulk of the distribution and tends to decrease in the tails. This means that the matching impact is higher in the tails than in the bulk. This can be seen in Fig. 4 where we consider the production of two gluinos at 607 GeV decaying into squarks ar 550 GeV giving 2 hard jets and two soft jets from decays. Here we define $H_t^{jet}(4)$ as the scalar sum of the four leading jets, the missing ET is not included

Ongoing work

There are some other important points still in discussion, related to the impact of inital-state radiation. The first is purely a MonteCarlo issue: consider the case where the gluino is just slightly heavier than the squark. It is expected that out of the two jets coming from the gluino decay one will be soft, giving a typical final state signature two hard jets + two softer jets. For squarks production, we expect two hard jets + extra QCD radiation.

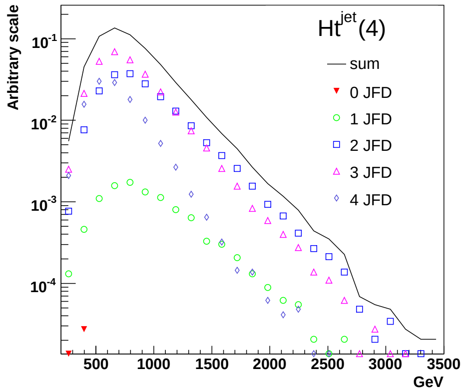

FIGURE 4. Contributions of jets from decay (JFD) to $H_t^{jet}(4)$. The jet definition used is $k_\perp$=40 GeV and the R=0.6.

If this radiation is modeled using too soft parton showers, then a harder spectrum seen in the data (corresponding to that obtained with ME+PS) could be erronously interpreted as a contribution from gluino pair production.

The second issue is more intimately related to a particular spectrum, where the neutralino would have a mass slightly lower than the mass of the gluino. In such a case, all jets coming from the decays would be soft and therefore mostly unseen. In this case the dominant visible contributions would come from configurations where the heavy pair recoils against one or more hard jets, producing missing transverse energy + jet(s). In this case also, the predictions by a PS based on the $2 \longrightarrow 2$ process would be completely unreliable.

The third point concerns a broader problem which is the visibility of the SUSY signals ($\tilde{g}\tilde{g}$, $\tilde{q}\tilde{q}(*)$ and $\tilde{g}\tilde{q}(*)$) above the Standard Model backgrounds. Typically, at middle mass scales (ex: SPS1a), the cross-section of the signal characterized by a large missing transverse energy and two or more hard jets is rather small compared to the cross-sections of W,Z,$t\bar{t}$+jets. The use of matching in this context is therefore important to avoid being sensitive to the shower approximations, especially in the tails

Work addressing the questions above is in progress [17]

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