Generator comparison for top-pair production at CMS

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Abstract
This work presents a throughout comparison of some of the most popular generators for top-pair production at the LHC in the frame of the CMS software. The aim is to validate the physics contents after their integration in the experimental software and to give indications for the best possible choices of the generator set-up.

1 Introduction

The description of top-pair production at the LHC can be handled by different kind of generation tools. The most traditional approach, via leading order (LO) calculations (examples are generators like PYTHIA [1], TopRex [2]), is now accompanied by more modern tools allowing the inclusion of higher leading order (HLO) QCD terms, via the so-called matrix elements (ME) - parton shower (PS) matching [3] (examples are ALPGEN [4] or the recent version of MadGraph [5]). Also available are now next-to-leading-order (NLO) QCD generators like MC@NLO [6].

The aim of this work is to test the physics contents of the different generators in the domain of top physics and in the framework of the CMS software. This also allows a common environment for the comparisons. Studies at pure generator level are documented by several articles already [7]. This work should not be intended as a generator review.

2 Set-up and event reconstruction

In the following comparisons of event generators, performed for pp collisions at a centre-of-mass energy of 14 TeV, the pure PS part is described in a uniform way by the use of PYTHIA, with care to have the same input parameter settings in all conditions. Exception is MC@NLO, currently only interfaced to HERWIG. The scales and PDFs are also chosen to be as much as possible the same: exception to this is a slight difference in the scale definition in ALPGEN and MadGraph. The details of the input settings, as well as the numbers of events generated for this study, are reported in table 1. The validity of the choice of the tuning with new approaches for the description of the radiation goes beyond the scope of the present note; it is, on the contrary, relevant to maintain the input settings as uniform as possible.

The comparisons are made at the generator level, after radiation from PS. The variables are reconstructed from the quarks and leptons before their final state radiation, the shown variables are therefore sensitive to the description of initial or intermediate (from top) state radiation (ISR). All the plots shown in the following are normalised to unity for the sake of clarity.

Parameter	TopRex	MadGraph	ALPGEN	MC@NLO
PDFs	CTEQ5L	CTEQ5L	CTEQ5L	CTEQ5L
Renormalization scale	m_T	m_t	m_T	m_T
Factorization scale	m_T	m_t	m_T	m_T
Λ_{QCD} in PYTHIA (PARP(61), PARP(62)) (GeV)	0.25	0.25	0.25	-
Q^2_{max} PYTHIA switch (PARP(67))	2.5	2.5	2.5	-
Generated events	$1,5 \times 10^6$	3×10^6	2×10^5	1×10^6

Table 1: Main generator input parameter settings, and total number of generated events for this study. The transverse mass m_T is defined as $\sum_{tops}(m^2+p_T^2)$. The MC@NLO generator is only interfaced with the HERWIG hadronisation, so no direct comparison in the parameter settings can be made.

3 The importance of ME-PS matching

At the energy scale of the LHC the description of gluon radiation becomes crucial. Recent techniques for PS-ME matching allow to describe much better the hard gluon radiation, maintaining the parton shower approximation for low p_T emissions. In the following we have used TopReX as the LO reference, ALPGEN and MadGraph as examples of matched $t\bar{t}$ event generations and MC@NLO as a NLO QCD description of the $t\bar{t}$ process.

Differences in gluon radiation may manifest themselves in distortions of the top quark angular distributions and transverse variables. The most spectacular effect can be appreciated in the transverse momentum of the radiation itself, which equals the transverse momentum of the $t\bar{t}$ system.

This is what is shown in figure 1 for two standard generations in comparison to the newly available matching scheme [8] of MadGraph: all the different contributions to a fixed ME order, ie tt+0jets, tt+1jets, tt+2jets and tt+3jets, are explicitly indicated. The matching scheme is such that there is no phase space double counting in the different samples: no matching is performed for the last sample to let the PS predict configurations at higher jet multiplicities. The samples are mixed together according to the respective cross-sections. In the same figure also the azimuthal difference between the two tops is shown.

From the picture it is evident that gluon production via ME predicts a much harder transverse spectrum. The difference in shape is impressive, reaching orders of magnitude in the ratio at very high p_T. The increased activity in hard gluon emission for the matched case also explains a decreased azimuthal distance between the two tops, as shown in the right-hand plot. The predicted average p_T of the radiation by MadGraph is 62 GeV/c (72 GeV/c with ALPGEN), with a 40% probability of having more than 50 GeV/c as gluon p_T in $t\bar{t}$ events. This large gluon activity will have an impact in the capability of correctly reconstructing top quark events at the LHC, and in correctly interpreting radiation as a background for new physics searches.

Difference in differential distributions are visible not only in the transverse plane: having more radiation tends to increase the event transverse activity. Moreover, the two top quarks and the resulting decay products are more central and generally closer to each other. We believe the difference we see are important enough to motivate the choice of a matching generation for

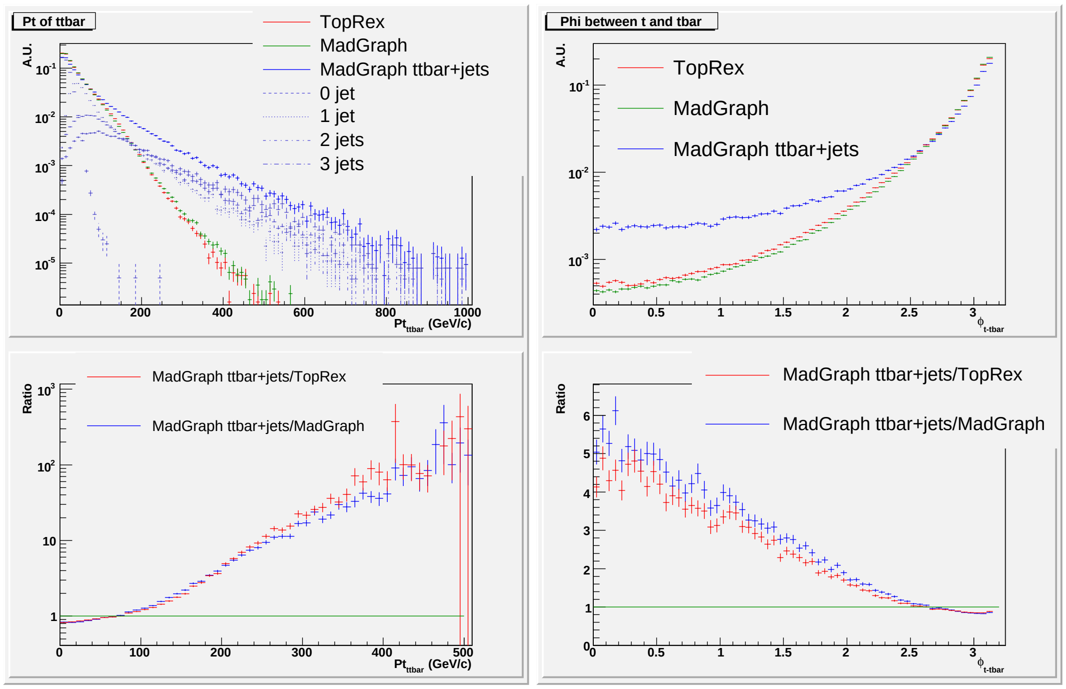

Fig. 1: Transverse momentum of the $t\bar{t}$ system (left) and azimuthal difference between the top quarks (right) for TopRex, standard MadGraph and MadGraph with matching. The individual components tt+njets are explicitly plotted in the left plot. The lower plots show the ratios of the histograms.

the description of any sufficiently hard SM process: this is particularly important when such processes are background to higher jet multiplicity configurations.

One important step in the validation of the physics contents of the matching in CMSSW is to compare two different approaches in the top sector. In figure 2 we present the ALPGEN predictions compared to MadGraph with ME-PS matching.

The blue and red curves represent the distributions for the matched samples of ALPGEN and MadGraph, respectively. For the p_T of the $t\bar{t}$ system also the individual components are shown. The agreement is more than acceptable for the p_T and remarkable for the azimuthal difference between the top quarks. Especially in the tails of the distributions, corresponding to high radiation conditions, the disagreement reduces to a maximum discrepancy of 50%. To properly appreciate the difference between the two predictions we should, however, account for the theory errors as well. These errors come, mainly, from scale definitions, PDFs, PS tunings; a detailed study on the dependence of the results on these effects is desirable before any conclusion on residual discrepancies between the generators can be drawn.

The comparison showed very good agreement in many other distributions that are not shown here. We observed a slight difference in shape for the transverse momentum and an excellent agreement for angular variables, with difference typically below 5%. We believe that the two generators can equally well be used to describe environments with hard gluon emission

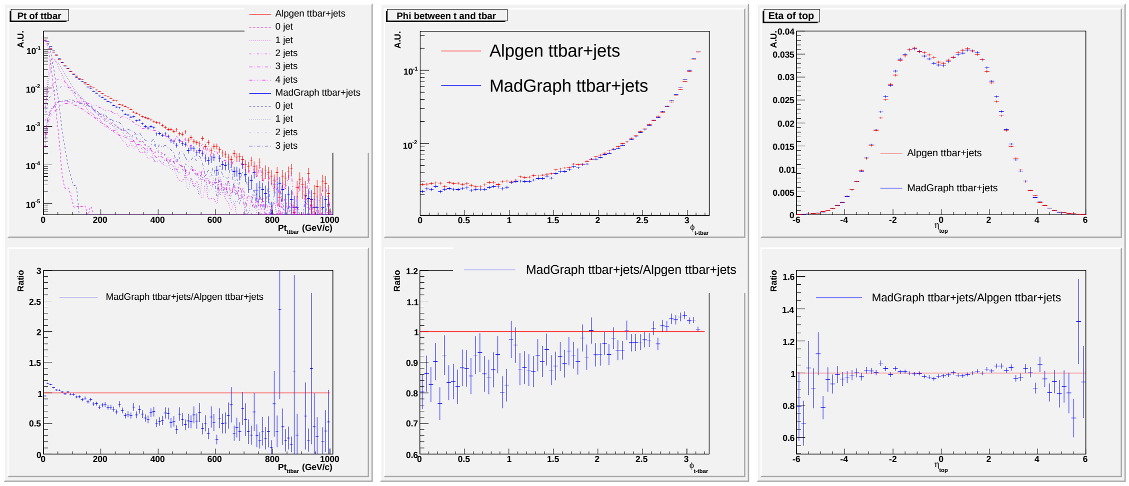

Fig. 2: Transverse momentum of the $t\bar{t}$ system (left), azimuthal difference between the tops (center) and pseudorapidity of the tops (right) for ALPGEN matched and MadGraph matched. The individual components tt+njets are explicitly plotted in the left plot. The lower plots show the ratios of the histograms.

in the final state.

4 Matched calculations versus NLO predictions

Another extremely important test comes by comparing ME-PS matched calculations with NLO QCD tools, especially for what concerns transverse variables. With the availability of MC@NLO as event generator this is now possible. Such comparison must be looked at with a grain of salt, since the hadronisation is performed with different tools and since inclusive NLO variables are compared with matched HLO quantities, typically at orders greater than the first. Nonetheless, in a throughout comparison of the kinematics of final state fermions and intermediate tops, a very good agreement was always found. Figure 3 shows the transverse momentum of the system, and excellent agreement in the high radiation tails is visible.

In this case discrepancies appear in the soft regime, where indeed the hadronisation with the PS plays an important role. There, a complete tuning of the PS models (with the respective externals MEs) needs to be made before performing a trustable comparison.

5 Summary and outlook

We presented a throughout comparison, at parton level, of generator predictions in the top sector at the LHC energy. The tests were performed in the framework of the CMS software. A generation with matching PS-ME gives important differences in the description of the radiation and should be chosen as currently the best way to describe SM processes where the description of QCD radiation is important. This is even more relevant when such process is background to something else (SM or new physics). Matched calculations have also been tested versus NLO generators, with very good agreement in the prediction of transverse variables.

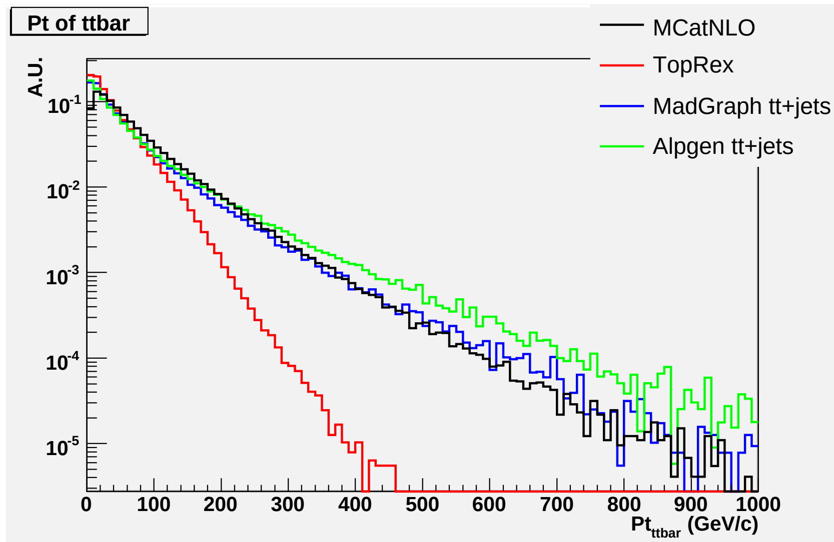

Fig. 3: Transverse momentum of the $t\bar{t}$ system for ME-PS matched predictions and MC@NLO.

References

[1] T. Sjöstrand et al., Comput. Phys. Commun. 135 (2001) 238.

[2] S.R. Slabospitsky, Comput. Phys. Commun. 148 (2002) 87.

[3] S.Hoche et al., hep-ph/0602031.

[4] M.L. Mangano et al., Journal of High Energy Physics **0307** (2003) 001.

[5] F. Maltoni and T. Stelzer, hep-ph/0208156.

[6] S. Frixione and B.R. Webber, Journal of High Energy Physics JHEP06 (2002) 029.

[7] M. Mangano et al., CERN-PH-TH-2006-232
J.Alwall et al., CERN-PH-TH-2007-066.

[8] J.Alwall et al., CERN-PH-TH-2007-066.