

# Simulation of Top Quark Production for the ATLAS Experiment

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The Monte Carlo setups used by ATLAS to model the  $t\bar{t}$  and single-top production in 13 TeV pp collisions are described. The performance of different event generators is assessed by comparing measurements at 7 TeV, 8 TeV and 13 TeV to predictions from simulated data. The evaluation of systematic uncertainties and the dependence of generator predictions on the tuning parameters are also discussed.

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## 1. Introduction

Successful measurements and searches by the ATLAS experiment [1] rely on accurate models and predictions of high energy particle collisions. Monte Carlo event generators are used to simulate a hard-scatter process (typically between quarks and/or gluons) which will result in a specific final state. A range of event generators are used to model different physics processes and the focus of the work presented at this conference was to study the setups used to model  $t\bar{t}$  and single-top production in 13 TeV proton-proton collisions [2].

## 2. Event Generators and Parton Showers

Event generators use hard-scattering matrix elements (ME) to calculate cross-sections up to a fixed-order. Parton showers (PS) model the fragmentation and hadronisation of partons. Generators can differ on the procedure used for calculating real and virtual amplitudes and in the matching of next-to-leading order (NLO) radiation between ME and PS in order to preserve the total cross-section.

A range of samples are available for use in ATLAS analyses which use various combinations of event generators and parton showers. A summary of the samples is shown in Table 1 and further details on the setup with associated references can be found in [2–4]. The nominal  $t\bar{t}$  and single-top samples used in ATLAS analyses are generated with POWHEG+PYTHIA6. An alternative sample generated with MG5\_aMC@NLO provides a systematic uncertainty by varying the NLO matching scheme between POWHEG and MC@NLO. An alternative sample showered with HERWIG provides an additional systematic uncertainty by varying the hadronisation model.

Event Generator	Parton Shower	Accuracy	ME PDF	Scale
POWHEG	PYTHIA6	NLO	CT10	$\sqrt{m_t^2 + p_{T,t}^2}$
POWHEG	PYTHIA8	NLO	NNPDF3.0	$\sqrt{m_t^2 + p_{T,t}^2}$
POWHEG	HERWIG++	NLO	CT10	$\sqrt{m_t^2 + p_{T,t}^2}$
POWHEG	HERWIG7	NLO	CT10	$\sqrt{m_t^2 + p_{T,t}^2}$
MG5_aMC@NLO	PYTHIA8	NLO	NNPDF3.0	$H_T/2$
MG5_aMC@NLO	HERWIG++	NLO	CT10	$\sqrt{m_t^2 + (p_{T,t}^2 + p_{T,\bar{t}}^2)/2}$
MG5_aMC@NLO	HERWIG7	NLO	CT10	$\sqrt{m_t^2 + (p_{T,t}^2 + p_{T,\bar{t}}^2)/2}$
SHERPA 2.2	SHERPA	Multi-Leg NLO <sup>1</sup>	NNPDF3.0	$\sqrt{m_t^2 + (p_{T,t}^2 + p_{T,\bar{t}}^2)/2}$
MADGRAPH	PYTHIA8	Multi-Leg LO <sup>2</sup>	NNPDF3.0	$\sqrt{\sum m_T^2 \forall \text{ partons}}$

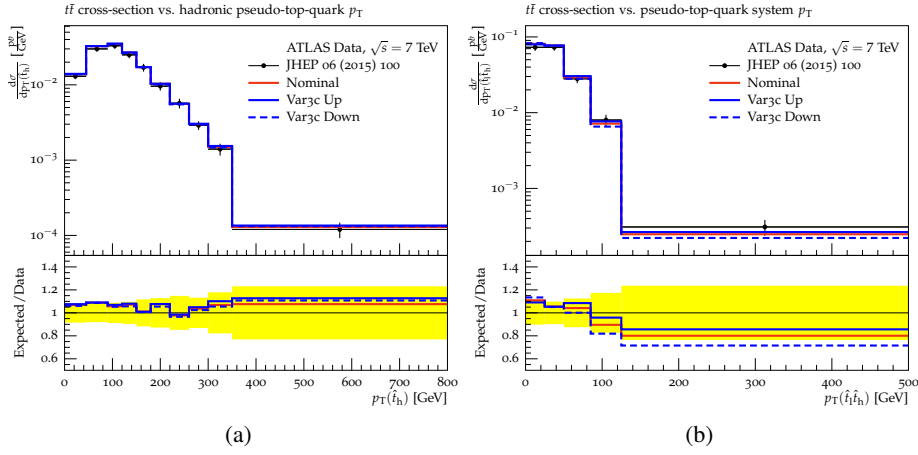
**Table 1:** Summary of  $t\bar{t}$  samples available in ATLAS.

<sup>1</sup> SHERPA generates  $t\bar{t}$  with up to 1 additional parton at NLO accuracy and up to 4 additional partons at LO accuracy.

<sup>2</sup> MADGRAPH generates  $t\bar{t}$  with up to two additional partons at LO accuracy.

## 2.1 POWHEG+PYTHIA8

For MC used by the ATLAS experiment, a transition has occurred moving from PYTHIA6 to PYTHIA8. This setup has been studied during the past year to improve the modelling of data by optimising the matching parameters in PYTHIA8. One topic which has an important consideration is the prescription for evaluating systematic uncertainties associated to varying the amount of QCD radiation in an event. A set of uncertainties have been determined for the A14 tuned set of parameters for the parton shower and underlying event [5]. These variations have been compared to 7 TeV measurements to establish the impact on top physics. Variation 3c which changes  $\alpha_s$  in the eigentune by  $\pm 10\%$  has been shown to have the largest impact and covers the size of the alternative variations. The coverage of this uncertainty is shown in Figure 1. Work is still ongoing to establish how to combine this uncertainty with scale variations to best cover measurements of additional radiation in  $t\bar{t}$  events at 13 TeV.



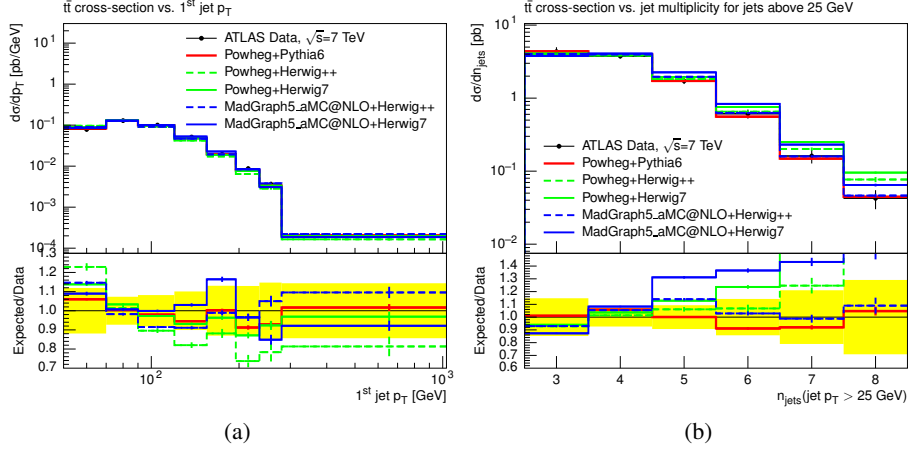
**Figure 1:** Comparison of A14 eigentune variation 3c as a function of the transverse momentum of the pseudo-top-quark (1a) and pseudo-top-quark pair system (1b) [3].

## 2.2 HERWIG7

The newest version of HERWIG, HERWIG7 [6], has been implemented in the ATLAS MC framework and has been tested when interfaced to POWHEG and to MG5\_aMC@NLO for  $t\bar{t}$  events. Some features of the HERWIG++ shower can be seen in Figure 2a where a slope in the leading jet  $p_T$  can be observed which does not agree within the uncertainties of the 7 TeV measurements. The use of HERWIG7 is seen to improve this distribution, but some shortcomings in the underlying event tune have lead to excessive jet activity which can be observed in Figure 2b and is being studied.

## 2.3 Multi-Leg Generators

Some analyses probe regions of extreme  $t\bar{t}$  phase-space. In these cases, it is sometimes more effective to make use of multi-leg event generators. These samples generate  $t\bar{t}$  with some given accuracy (LO or NLO) but then simulate an additional number of partons which have to be correctly

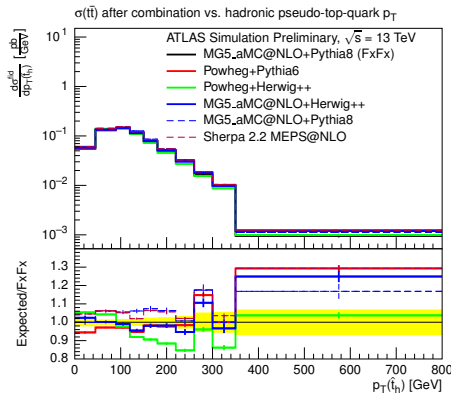


**Figure 2:** Comparison of HERWIG7 with other generators compared to  $\sqrt{s} = 7$  TeV measurements of leading jet  $p_T$  (2a) and number of jets (2b) in  $t\bar{t}$  events [2].

merged to prevent double-counting. These setups allow the matrix element generator to simulate additional radiation, rather than being dependent on the approximations applied by parton showers. There are three multi-leg samples in ATLAS which are being studied and used; a MADGRAPH sample which generates  $t\bar{t}$  plus up to two additional partons at LO using the CKKW-L merging scheme [7, 8], a MG5\_aMC@NLO sample which generates  $t\bar{t}$  plus up to two additional partons at NLO using the FxFx merging scheme [9], and a SHERPA sample which generates  $t\bar{t}$  plus up to one additional parton at NLO and up to four further partons at LO using the MEPS@NLO scheme [10].

### 3. Summary

A range of MC samples which model  $t\bar{t}$  production are available in ATLAS. A comparison of NLO samples are shown in Figure 3 as a function of the transverse momentum of a hadronic top quark at 13 TeV.



**Figure 3:** Summary of NLO  $t\bar{t}$  MC samples available in ATLAS. The MC have been produced at  $\sqrt{s} = 13$  TeV and the ratio is shown with respect to the FxFx sample [2].

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