Signal modelling systematics at ATLAS

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Abstract. For the analysis of various properties of the top quark, parameters like selection efficiency are taken from simulated event samples. These samples need several input parameters, like the top quark mass, the strength of initial and final state radiation or parton distribution functions. The presented results will depend on the choice of these input parameters. Therefore it is mandatory to determine a range of parameters which is consistent with current measurements and is able to determine the systematic uncertainty on the measurement result due to the input of certain parameters in the signal generation. In these proceedings the procedures used by the ATLAS experiment at the LHC are given.

1. Introduction
At the ATLAS experiment [1] at the LHC several modelling parameters were studied and their influence on the results of various measurements for top quarks were evaluated. The signal modelling uncertainties that are covered in this article are the following:

- Monte Carlo generator
- parton shower model
- parton distribution function
- initial and final state radiation
- top quark mass
- colour reconnection

2. Event generators
In ATLAS the default generator for events with top quarks is MC@NLO 4.0x\(^1\) [2] with HERWIG 6.520 [3] for the parton shower and JIMMY 4.31 [4] for the underlying event. As the name suggests this generator simulates events at next-to-leading order in perturbation theory.

Two more generators, POWHEG-hlvq-patch4(BOX 1.0.x) [5] and ALPGEN 2.1x [6] with the same settings, are also used to generate events within the ATLAS event generation environment.

For any analysis the largest discrepancy observed for these three generators is taken as a systematic uncertainty. Typical discrepancies are 5 % [7] for MC@NLO compared to POWHEG and up to 10 % for MC@NLO compared to ALPGEN. Even though ALPGEN is a leading order generator, in some parts of the phase space the data are better described by ALPGEN than by the other generators which are next-to-leading order generators.

\(^1\) Version numbers greater or equal to 4.01 are currently used while older analyses were using MC@NLO 3.41.
In general one cannot say that one generator describes the data better than any of the other generators as for each generator there is some phase space where it agrees better with the data than the other generators. The largest discrepancies are observed in the acceptance. For the future it is therefore foreseen to reduce this acceptance dependency by applying looser cuts or to use variables that depend less on the boost of objects.

Data from the jet veto [8] analysis is compared to the prediction from the Monte Carlo generators mentioned above and is shown in Fig. 1. In this analysis events are vetoed if they contain in addition to the jets from the top quark pair production decay an additional jet with transverse momentum above a threshold $Q_0$ in a central rapidity interval. The fraction of events surviving the jet veto is presented as a function of $Q_0$. For the central rapidity region $|y| < 0.8$ the result is shown in Fig. 1. Discrepancies of several percent are observed between the different generators but all are in agreement with the data within the measurement uncertainties.

![Figure 1](image1.png)

**Figure 1.** Gap fraction, i.e. the fraction of the number of top quark pair production events with no jet above the threshold $Q_0$ and the total number of top quark pair production events as a function of $Q_0$ for ATLAS data and several generators [8]. This plots shows the gap fraction for the central detector region with rapidity $|y| < 0.8$. It can be seen that the data and the Monte Carlo predictions agree within the uncertainty of the data.

![Figure 2](image2.png)

**Figure 2.** Gap fraction. i.e. the fraction of the number of top quark pair production events with no jet above the threshold $Q_0$ and the total number of top quark pair production events as a function of $Q_0$ for ATLAS data and several generators [8]. This plots shows the gap fraction for the central detector region with rapidity $|y| < 0.8$. It can be seen that the Monte Carlo predictions for different values of ISR parameters vary stronger than the uncertainty from this measurement.

3. Parton shower
Parameters in Pythia [9] for parton shower (PS) and underlying event (UE) are tuned to match data from the LHC [10]. There exist separate tunes for minimum bias (MB) and underlying event parameters. The tuning is done in several steps, beginning with flavour parameters, then using final state radiation (FSR) and hadronisation, followed by initial state radiation (ISR)
and multiple-parton interactions (MPI). For HERWIG and JIMMY the UE parameters are also
tuned. Tuning is done using Rivet [11] and the professor tool [12].

Tunes for PYTHIA6 were done using ATLAS data taken at a centre-of-mass energy of
$\sqrt{s} = 7$ TeV using several sets of PDFs. Theses tunes are called AUET2B (ATLAS underlying
event tune) and AMBT2B (ATLAS minimum bias tune). Tunes for PYTHIA8 are already
available but are not yet extensively used for top quark production process simulation.

For HERWIG and JIMMY a tune is done only for MPI parameters of JIMMY, as HERWIG does
not have MPI model. The minimum bias data cannot be used is this case and consequently only
a UE event tune using several PDFs exists.

For the determination of the systematic uncertainties due to the modelling of the parton
shower the following two models are using in combination with the POWHEG event generator:
- HERWIG with JIMMY and AUET2B
- PYTHIA with AUET2B

In Fig. 3 ATLAS data is compared to the event tune AUET2B for PYTHIA, using three
different parton distribution functions. Within the uncertainty of the data there is good
agreement between data and the simulated events.

The comparison between the different tunes results in an uncertainty of 2% in the
measurement of the top quark pair-production cross section [7] or an uncertainty of 0.15 GeV
in the measurement of the top quark mass [13].

![Figure 3](image_url)

**Figure 3.** Mean number of selected tracks ($N_{chg}$) per unit of rapidity ($\eta$) and polar angle
($\phi$) as a function of the transverse momentum ($p_{\perp}$) of the track with the largest transverse
momentum [10]. Shown are data and simulated events with PYTHIA and the ATLAS tune
AUET2B for three different parton distribution functions.
4. Initial and final state radiation

At hadron colliders ISR and FSR of gluons is the most common process. This results in additional jets in the event except those from of the hard scattering. As this process is so common it can be rather well measured in data. ATLAS has performed a study of such events. When using the gap fraction analysis [8] the data can be compared with different settings for initial state radiation. This is shown in Fig. 2 for the central detector region with a rapidity $|y| < 0.8$. As can be seen the parameter variation used gives larger variations than is compatible with the measured data and its uncertainties. Consequently the ISR variations in future analyses will be smaller than the ones used so far and will reduce the dependency of results on the parameters for ISR.

Taking into account the uncertainties on the ISR and FSR parameters in the simulation of events, results in uncertainties for the top quark pair production cross section in the range of $2 - 5\%$ and in an uncertainty of $0.5 - 1.1$ GeV for the top quark mass [13].

5. Parton distribution functions

For the evaluation of uncertainties due to the use of a certain parton distribution function (PDF) a recommendation of the PDF4LHC group [14] exists. In ATLAS these recommendations are used comparing results for three different PDFs, i.e. MRSTW08 [15], CTEQ6.6 (or CT10) [16] and NNPDF2.2 [17]. All available sets for each PDF and the strong coupling constant $\alpha_s$ uncertainty are used. For all results using the different inputs an envelope is calculated and taken as the systematic uncertainty. This corresponds to an uncertainty on the top quark pair production cross section of less than $3\%$ [7] and of $0.1$ GeV for the top quark mass [13].

6. Top quark mass

The top quark mass is known with a precision of $0.9$ GeV from the Tevatron experiments [18]. Consequently this uncertainty is used in the variation of the top quark mass in the analyses. Event samples are produced with a value for the top quark mass of $172.5$ GeV. Additional samples with $\pm 2.5$ GeV and $\pm 5$ GeV are also produced. From these samples results for a variation of the top quark mass by the world average uncertainty value of $0.9$ GeV are derived. For the cross section measurement for top quark pair production this results in an uncertainty of less than $1\%$ [19].

7. Colour reconnection

In recent analyses, especially in the top quark mass measurements, colour reconnection effects are also taken into account. In ATLAS the MC generator ACERMC [20] with PYTHIA and the Perugia2011 [21] tune with and without colour reconnection with the new PS/MI model in PYTHIA6.4 are used. In addition also the Tevatron tune A-Pro [22] and A-Pro with colour reconnection (ACR-Pro) with the old PS/MI model in previous versions of PYTHIA are used.

Depending on the analysis, uncertainties due to colour reconnection of up to $1.2$ GeV [23] on the top quark mass are calculated.

8. Conclusions

Signal modelling is still one of the major systematic uncertainties for many analyses related to top quarks. The main contributions are the Monte Carlo generator and parton shower model uncertainties. By using the large amount of data that the LHC has delivered and the ATLAS experiment has recorded these uncertainties will be reduced in the near future.

In the case of initial and final state radiation the measurements have already constrained the uncertainties stronger than the uncertainties assumed so far. This will lead to strongly reduced uncertainties for future analyses.
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