Top studies for the ATLAS Detector Commissioning

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Abstract — The LHC collider plans to start in 2007, after which millions of top quarks will be produced at the collision points. During the first period of data taking these events will provide an essential calibration tool for ATLAS, playing a key role in the detector commissioning phase. Beyond that, the top mass peak will be one of the first physics signal which will be detected in ATLAS, and the top cross section one of the first relevant measurement which we will be able to extract from our detector.

1 Introduction

There are many motivations to study top quark physics at the LHC. It is by far the heaviest fundamental particle, with a mass close to the Electro-Weak Breaking Scale. Precise determination of its mass allows stringent tests on the Standard Model (SM) and constrains via radiative corrections the mass of the Higgs boson [1]. In many scenarios beyond the SM heavier particles decay into top quarks. Hence studying in detail properties of top quarks can provide handles on new physics.

In addition, the top pair production process is very valuable for the in-situ calibration of the ATLAS detector at the commissioning stage. The large cross section and the large S/B ratio for the lepton + jets $t\bar{t}$ channel, allow to produce high purity samples with large statistics in a short time period. The understanding of the experimental signatures for top events involves most parts of the ATLAS detector and is essential for claiming potential discoveries of new physics.

The commissioning period has basically already started and will continue until after data taking with proton-proton collisions. It may be divided in several phases, including sub-detector level calibrations and noise studies, recording of cosmic ray events, studies with single proton beam in the LHC machine and very first collisions to commission the trigger. At that stage the detectors and trigger are debugged to a level where first physics analysis can be performed in order to feed back to the detector performance. Data samples for calibration and control will be collected, like Z+jets, $Z \rightarrow$ll, electrons with $P_T > 10$ GeV, muons with $P_T > 6$ GeV etc. Surely, $t\bar{t}$ events will also play a major role. These first collected top data samples will be used to refine the calibration and alignment, to understand some main performance issues like: triggering, detector uniformity, absolute energy scale calibration, missing E_T, b-tagging and τ-tagging, to learn about particle identification (e/jet, γ/jet separation), etc. In addition with this top sample the Monte Carlos can be tested and tuned, the main backgrounds can be understood and the cross sections and mass be measured.

Given this scenario, we started to think which basic measurements can be performed during these early days. In particular, we concentrate on the top quark physics case and investigate in several scenarios how well we can estimate the top mass and cross section. This paper gives some preliminary comments to these issues. In Section 2 we briefly summarize the characteristics of top physics at the LHC, and the conventional methods to determine its mass. In Section 3 we discuss various Monte Carlo (MC) predictions of top-quark production, including the new NLO QCD event generator MC@NLO. We then focus in Section 4 on the performance with reduced b-tagging performance, including estimations of the background events. In Section 5 we study the effect of a possible initial jet scale mis-calibration and in Section 6 we show the preliminary signal as expected with a fully functional detector. Finally, in Section 7, we show some effects of the underlying event.

2 Top quark physics at the LHC

The cross section for $t\bar{t}$ production has been calculated up to NLO order, and results in 830 ± 100 pb^{-1}, where the uncertainty reflects the theoretical error obtained from varying the renormalisation scale by a factor of two. Already with a luminosity of 10 fb^{-1}, expected in a first full year of LHC running, top physics will hardly be limited by statistics.

The top quark decays for nearly 100% to $W + b$. The inclusive lepton plus jet channel, $t\bar{t} \rightarrow WWb\bar{b} \rightarrow (l\nu)(jj)(b\bar{b})$, provides a large and clean sample of top quarks and is the most promising channel for an accurate determination of the top quark mass [2],[3]. Considering only electrons and muons, the branching ratio of this channel is 29.6%. These events can relatively easily be triggered by the isolated lepton.

Various methods have been exploited to measure the top quark mass at the LHC. In the most straightforward and conventional one, the hadronic part of the decay is used, and the top mass is obtained from the invariant mass of the three jets coming from the same top: $M_t = M_{jjb}$. The typical selection of single lepton top events is based on the presence of an isolated high P_T lepton with $P_T > 20$ GeV and missing energy $E_T^{miss} > 20$ GeV. At least four jets, typically reconstructed with a cone size of $\Delta R = 0.4$, with $P_T > 40$ GeV and $|\eta| < 2.5$ are required. One or two jets are required to be b-jets. The reconstruction of the decay $W \rightarrow jj$ is performed by selecting the pair of non b-tagged jets with invariant mass closest to M_W. Events are retained only if $|M_{jj} - M_W| < 20$ GeV. The combination of the jet pair jj with the b-tagged jet yields a combinatoric ambiguity. For events with only one tagged b-jet the events are kept for which the opening angle of the b-jet with the W is smaller than with the lepton of the event. For events with two b-tagged jets, the b-jet which results in the highest P_T of the system is combined with the jet pair jj.

Using this selection (with the requirements of at least two b-tagged jets), it is possible to have a first evaluation of the statistical uncertainty on the top cross section and top mass. Assuming the initial luminosity (L = 10^{33} cm^{-2}s^{-1}), Table 2 shows that one will get a small uncertainty after a very short time of LHC running. After only

Period	Events	δM$_{top}$ (stat)	$\delta\sigma/\sigma$ (stat)
1 year	3x10^5	0.1 GeV	0.2%
1 month	7x10^4	0.2 GeV	0.4%
1 week	2x10^3	0.4 GeV	2.5%

Table 1: *Expected number of top events and corresponding statistical uncertainty on the top mass and cross section measurements, for different integrated periods of data taking. The selection effi ciency is of about 3.5%.*

one week of data taking at the initial luminosity phase, about 2000 top events will be collected, resulting in a statistical error of only 0.4 GeV. The statistical uncertainty on the cross section can be reduced to approximately 2.5% with this sample.

From previous studies, we know that the largest source of uncertainty in the top mass determination is due to the b-jet energy scale. The shift on the top mass due to an uncertainty of 1% in the b-jet scale is 0.7 GeV, hence with an uncertainty of 10%, the mass shift goes up to 7 GeV.

3 Comparison between event generators

Up to now, for the top event generation, ATLAS used the Pythia [4] and Herwig [5] MC generators. These MC's describe the top-anti-top production in leading order QCD, and include full parton shower and hadronization. The TopRex [6] Monte Carlo, interfaced to the Pythia shower and hadronization, has been used for studies which include the polarization of the top-quarks, in order to describe e.g. spin correlations. All these generators are interfaced with the ATLAS offline software suite, allowing e.g. to simulate the response of the detector using the fast simulation code (ATLFAST [7]).

Recently, the NLO QCD calculations of top-anti-top production has been implemented in the so-called MC@NLO Monte Carlo [8]. This MC is interfaced to the Herwig shower and fragmentation, allowing to study effects of NLO QCD calculations on an event-by-event basis. The NLO calculations of MC@NLO are ingeniously matched to the parton shower of Herwig in order to avoid 'double counting' of gluon radiation[1]. As this is relevant theoretical improvement, we studied its effect on the determination of the top mass, and adopted MC@NLO for

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[1] The events in MC@NLO are produced un-weighted up-to a sign. Effectively each event acquires a weight +1 or −1, and in the top-anti-top sample a fraction of 13.5% has negative weight. The distributions of all observables are positive.

top commissioning studies. In this section we show a few characteristic distributions to indicate the differences between the various MC's. All distributions have been generated with a top mass of $M_{top} = 175$ GeV and standard settings.

One of the most characteristic features of the NLO QCD calculations is the presence of additional radiation of hard gluons, a part of phase space that is not well described by the shower evolution. An observable for this effect is the total transverse momentum of the top-anti-top system, as it recoils against the total of the gluon emission. Figure 1 shows this P_T of the $t\bar{t}$ system as obtained by MC@NLO (solid line), Pythia (dotted line) and Herwig (dashed line), after the initial state shower has been simulated. The left plot shows the P_T distribution in linear scale, while the right plot shows the same distribution in logarithmic scale. The distributions are normalised to unity. As expected, Herwig and MC@NLO agree in the low P_T region which is dominated by the shower evolution, while at large P_T the MC@NLO prediction is harder with respect to the leading order calculations. In [8] it is explicitly demonstrated that in this part of the phase space the NLO calculations are exactly reproduced. The P_T obtained from the Pythia generator is too soft[2].
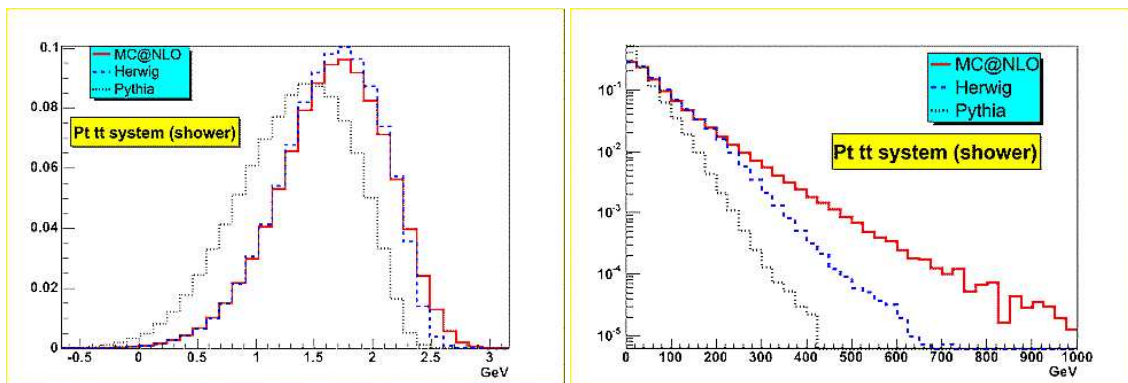

Figure 1: P_T distribution of the $t\bar{t}$ system on the left in a linear scale and on the right in logarithmic scale. The distributions are normalised to unity.

Another way of visualising the additional gluon radiation is the azimuthal opening angle between the top and anti-top quark. The distribution is shown in Figure 2 (left). The azimuthal opening angle between the top and anti-top quarks reaches small values more often in MC@NLO compared to the LO MC's, when recoiling against hard gluons. At the right side of Figure 2 the distribution of the pseudorapidy of the top and anti-top quarks is shown. Each event contribute to two entries in this plot. The distributions are rather similar for the three generators and show the characteristic plateau for $|\eta| < 2$.

After hadronization, the events are passed through a parameterized simulation of the detector response. A cone jet-finder is used to identify the jets in the event, with radius $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2} = 0.4$. In Figure 3 the P_T distribution of the jets with highest (left) and second highest (right) P_T is shown. Whereas the distributions for the jet with highest P_T show a clear difference between the various MC's, this effect is diminished for the jets with second highest value of P_T.

With this simulation of the detector response, the reconstructed mass of the top-quarks can be performed, as explained in Section 2. The distributions in Figure 4 show the reconstructed mass of the hadronic top quark for events with one identified b-jet (left) as well as for two identified b-tags (right). The algorithms to reconstruct the top mass are described in the previous section. The differences between the various MC predictions are of the order of a few GeV, much larger than the accuracy with which ATLAS aims to ultimately determine the mass of the top quark.

4   A pessimistic scenario: no b-tagging

As the top quarks are abundantly produced at the LHC, the question we like to pose is 'how well can we observe the top-quark with a not-yet optimal detector performance?'. In order to answer to this question, first we investigate

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[2] Various options exists in Pythia to harden the shower radiation. For example, one can raise the maximum scale of the initial shower, which is by default set to Q^2, to the value s. In this way the phase space of the initial shower is increased considerably and the P_T of the $t\bar{t}$ system increases. As it turns out, its distribution actually becomes harder than the NLO predictions. No settings were found were the spectrum of MC@NLO was reproduced.
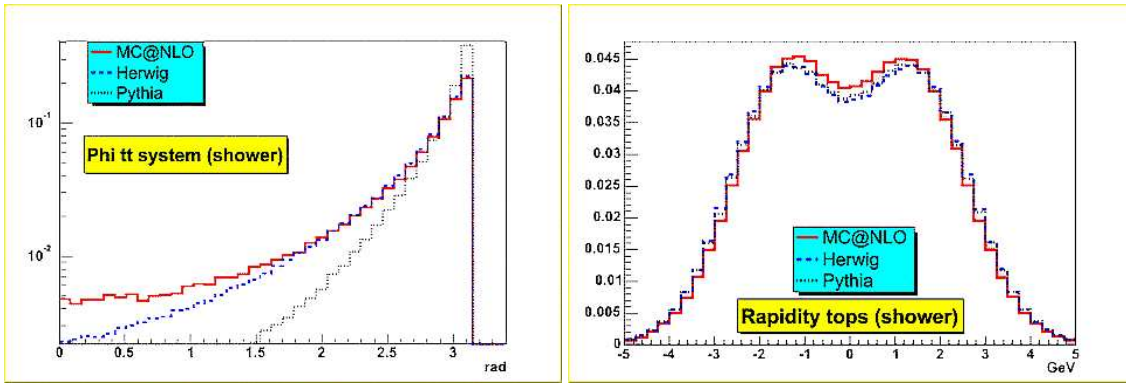
Figure 2: *On the left side: azimuthal opening angle between the top and anti-top quark. On the right side: distribution of the pseudo-rapidity of the top and anti-top quarks (two entries per event). Both distributions are normalised to unity.*
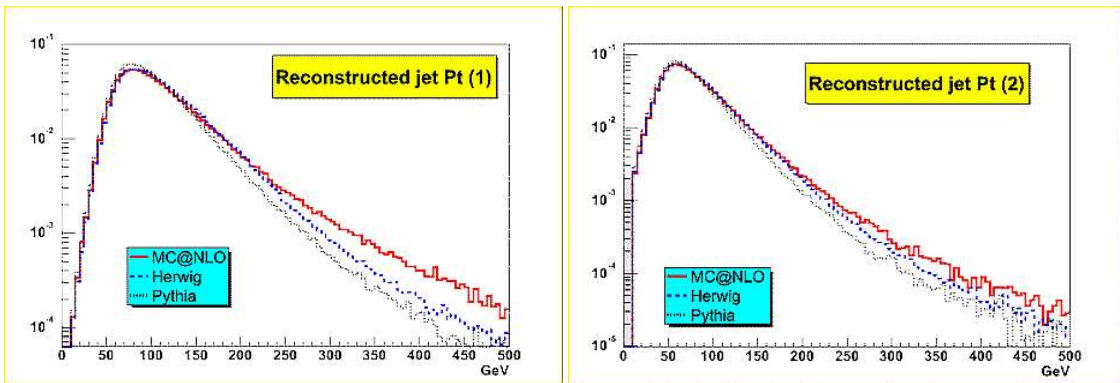

Figure 3: *On the left side: P_T distribution of the jet with the highest P_T in the event. On the right side: distribution for the jet with the second highest P_T. A cone size of 0.4 was used, and the distributions are normalised to unity.*
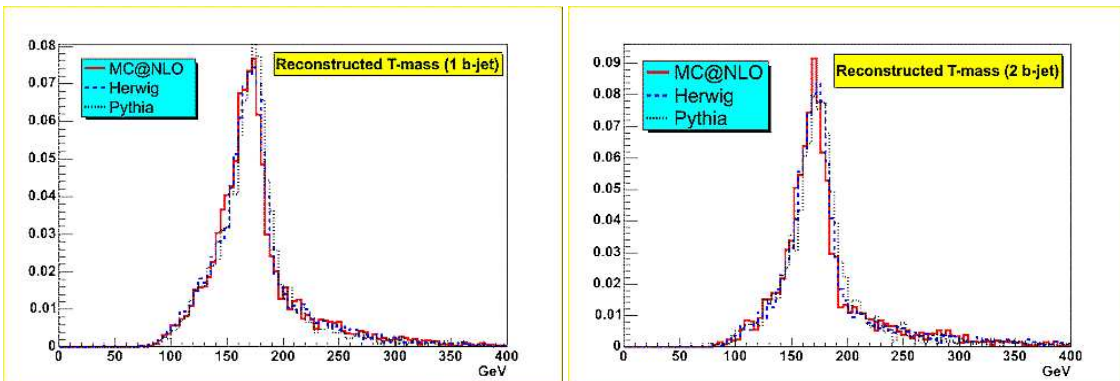

Figure 4: *Distributions of the reconstructed top mass. On the left side: for events with one identified b-jet, on the right side: for events with two identified b-jets. Both distributions are normalised to unity.*

whether we can do any top physics without b-jet tagging.

The experimental signature for top events include one or more b-tagged jets, originating from the decay of the top-quark. Thus, the b-tagging performance of the ATLAS detector has an important role for top analysis. An efficient b-tagging needs precise alignment of the trackers of the Inner Detector, which will be reached only after few months of data taking. It has been already shown that the impact of misalignment can be much larger than having two instead of three Pixel layers [12]. The top events themselves can be used to evaluate the b-tagging efficiencies from the data. This is important, as it is not guaranteed that the the efficiency as determined using data coinsides with the Monte Carlo expectations. It can be done, for example, by selecting a pure $t\bar{t}$ sample with tight kinematical cuts and counting then the number of events with at least one tagged jet. The number of events with 0, 1 and 2 b-tagged jets can then be compared and the tagging efficiency be evaluated.

But at the very beginning, in the commissioning stage, will it be possible to perform top physics? This study has explored the possibility of reconstructing top events in $t\bar{t}$ production by assuming the absence of b-tagging.

In this scenario, without b-tagging, we aim to reconstruct the top using extremely simple and robust selection criteria. We select the events by requiring:

- One isolated lepton (electron or muon) with $P_T > 20$ GeV.

- Missing energy $E_T^{miss} > 20$ GeV.

- Exactly 4 reconstructed jets, with a cone size $\Delta R = 0.4$, each with $|\eta| < 2.5$ and $P_T > 40$ GeV.

The efficiency for these cuts is approximately 4.5%.

The (hadronic) top mass is reconstructed as follows: All four permutations of three jets (out of the four selected jets) are considered. For each permutation the jets are added together and the P_T of the system is determined. The permutation which results in the highest value of P_T is taken as the set of jets that correspond to the decay of the top quark. The top mass itself is then simply reconstructed as the invariant mass of the three selected jets. Figure 5 shows the reconstructed top mass both for the inclusive sample (left) and for a sample of events for which the total P_T of the system of three jets exceeds 250 GeV right). In both cases the top-peak is clearly visible above a combinatorial background. In the latter case the boost of the top quarks is large, and hence the probability that the correct three jets are selected has increased. Indeed, it can be seen from Figure 5 that the shoulder at masses larger than M_{top} due to the combinatoric background is diminished.
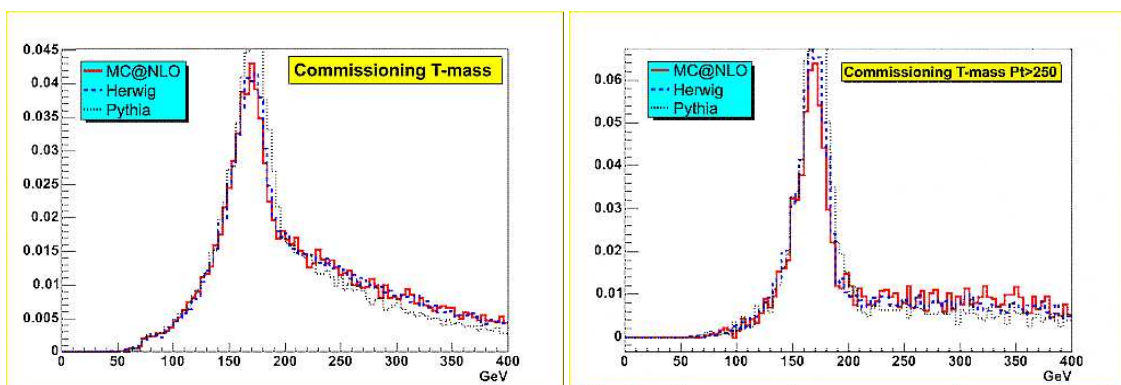

Figure 5: *Reconstructed top mass in the absence of b-tagging. On the left side for the inclusive top samples, on the right side for events with large transverse momentum of the top quark, $P_T^{top} > 250$ GeV. All distributions are normalised to unity.*

The threshold for the P_T of the four jets is set to 40 GeV. This is quite a hard cut and removes most of the jets originating from initial- and final state radiation. It furthermore tends to favour configurations where the top and anti-top recoil against each other with large transverse momentum. In Figure 6 (left) the P_T distribution of the sum of the selected three jets is presented, and shows that the P_T is larger than around 100 GeV. As a net result of these effects, the combinatorial background in the reconstruction of the top-quark is well under control.

The Herwig and MC@NLO predictions are very similar if the top quark mass is reconstructed in this way, indicating that the NLO effects are not dominant. The difference with Pythia, mainly due to a different shower and hadronization model, is larger.
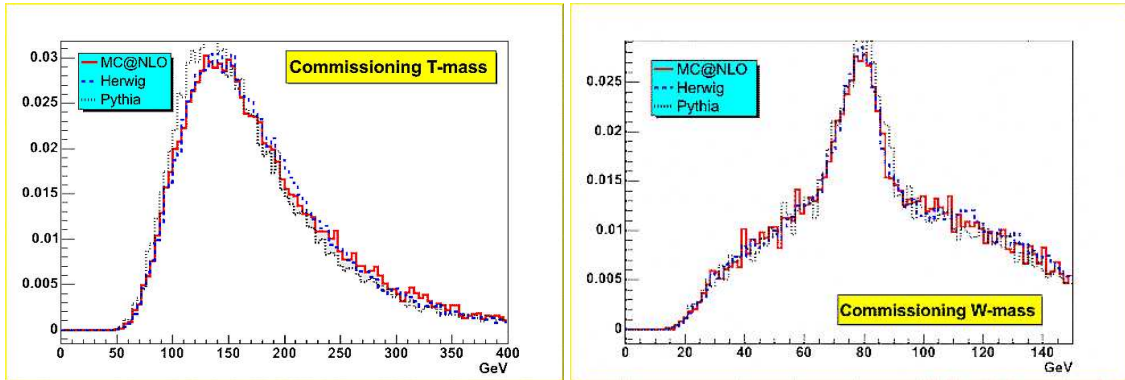
Figure 6: *On the left side: P_T distribution of the hadronic top-quark. On the right side: reconstructed mass of the W boson, in the absence of b-tagging. All distributions are normalised to unity.*

Using this sample, it is possible to also reconstruct the W-boson of the top-quark decay, that itself decay hadronically into two jets. For this we take the three jets that constitute the top quark, and select two jets that originated from the W-decay. All three permutations of selecting two jets out of three are considered, and again the combination is taken that results in the highest value of P_T of the summed two jets. The W-boson mass is then the invariant mass of the two jet system. In Figure 6 (right) this mass distribution is shown, and the W-boson peak around 80 GeV is clearly visible. As we will discuss in the next section, this reconstructed W-boson mass is very valuable for jet-energy calibration.

Note that with these reconstruction methods the top-quark peak is actually reconstructed with less ambiguity than the hadronic W-boson mass. Nevertheless the top sample may provide a very nice sample of hadronic W-decays, and can be used in jet energy corrections. Its now essential to see if these conclusions still hold after adding background events.

4.1 W+jets background evaluation

In previous notes [3] the main sources for background to top-production have been identified and evaluated in the case of one or two b-tagged jets. In the absence of b-tagging the largest irreducible contribution to the background originates from W+4 jet events, where the W-boson decays leptonically and produces the isolated lepton and missing E_T, and the four jets survive the selection criteria as given in the previous section. This background is not well described by shower MC like Pythia and Herwig, which have as matrix elements $qq' \rightarrow W + q(g)$ at most, i.e. three or four extra jets need to be generated by the parton shower, detector effects or reconstruction. The shower MC therefore seriously underestimate this background.

Several matrix element generators are on the market that do implement the matrix element for $W + 4$ partons, like Vecbos or Alpgen [11]. For this study, we used the Alpgen generator to generate a sample of events with a leptonically decaying W-boson and four additional partons which are required to have

- $P_T(\text{parton}) > 10$ GeV

- $|\eta(\text{parton})| < 2.5$, $\Delta R(\text{parton-parton}) > 0.4$

- no lepton cuts

The effective cross section of this sample is $\sigma = 2430$ pb. We have generated (through the NIKHEF grid) a sample of approximately 1.5×10^{10} (weighted) W+4 jets events, using the Alpgen MC. After the unweighting procedure 380740 events remained, with an efficiency of 2.6×10^{-6}, corresponding to a luminosity of approximately 150 pb^{-1}. These events were passed through the Pythia shower and hadronization algorithms in order to obtain full events. No attempt was made to include events with more or with less partons in the final state [3]. Approximately 2.5% of the events passed the selection criteria as listed in the previous section and enter as background events in the top mass distribution.

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[3] After shower and hadronization, events with three or less partons in the matrix element may end up as four jets events, as well as events with five or more partons in the matrix element may end up as four jet events. These samples with various number of partons in the final state have to be added, avoiding double counting as described by the CKKW or MLM prescriptions.

There is a large uncertainty in the predicted rate of this background. Ultimately the rate can be obtained from the data itself. For example, the ratio (Z+4 jets)/(W+4 jets) has a much reduced theoretical uncertainty and is much better described by Monte Carlo. One will be able to measure the Z+4 jets rate in the data using the leptonic decay of the Z and hence the W+4 jets can be determined by a measurement of this Z+4 jets rate.

4.2 Reducible backgrounds

A completely different type of background and much harder to evaluate is the reducible background, originating from non-perfect detector performance. For example, sometimes π and K particles can be wrongly identified in the detector as leptons. Due to fluctuations in the jet fragmentation process and in the detector response, we can get events which seem to contain a high P_T isolated lepton and missing energy, but do not. The probability that this happens in any given event is very low, but the jet production cross section is much larger than the W production cross section. In addition, there will be electrons from non-identified photon conversions and leptons from beauty decays which are wrongly taken as coming from a W decay. One refers to all of these processes as non-W QCD background. The non-W QCD multijet background can't be realistically generated through a Monte Carlo. Its effect depends crucially on the capability of the ATLAS experiment to minimize the misidentification and increase the e/π separation. It is essential to obtain this background from the data itself.

We will not discuss this type of background any further here. It will be a challenge during the commissioning phase of ATLAS to keep these backgrounds under control, and to develop more handles to estimate their exact size. Any further development requires the use of a full detailed Geant4 simulation of ATLAS, beyond the scope of this note.

4.3 Top mass and top cross section

Figure 7 shows the expected top signal for a luminosity of 150 pb^{-1}, i.e. after a few days of LHC running. The most important background, production of $W + 4$ jets, is determined using the Alpgen event generator as discussed in Section 4.1 and is added to the top signal, as obtained from the NLO Monte Carlo generator MC@NLO.
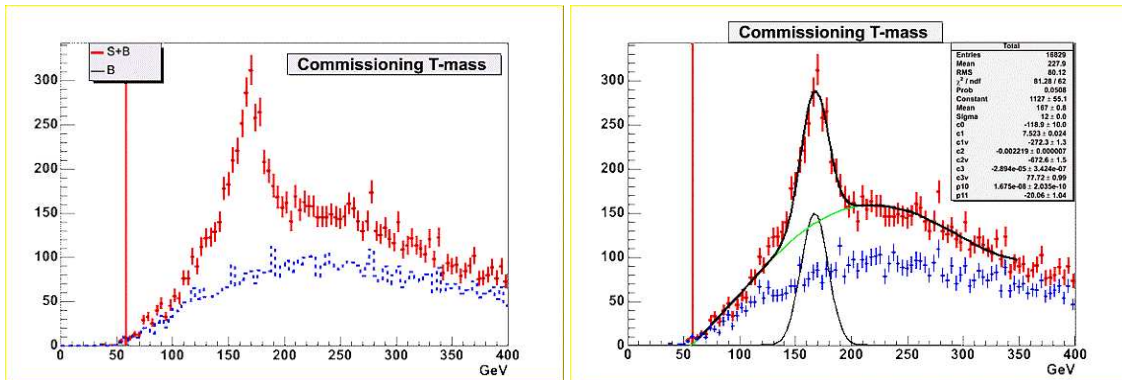

Figure 7: *On the left side: Reconstructed top mass, without b-jet tagging, for 150 pb^{-1} of data. The W+4 jet background is added to the signal events, and is shown by the dashed line. On the right side: Fit to the signal and background is made.*

The top-peak is clearly visible above the combinatorial background and the very smooth distribution of the $W + 4$ jet events. This very nice behaviour allows to perform a sideband subtraction or a fit of the continuous background. On the right side of Figure 7, a Gaussian fit for the signal together with a 4th order Chebechev polynomial for the background is performed. In order to increase the stability of the fit, the width of the Gaussian is fixed to 12 GeV which gives a good description of the signal width. The result of the Gaussian fit is redrawn in the figure, the mean value (i.e. top mass) being fitted to 167 ± 0.8 GeV. A total of 1127 ± 55 events enter the Gaussian distribution, which corresponds to a overall efficiency of 0.9%.

The fact that the top-peak is clearly visible, and can be fitted separately from the background, allows to perform the top-mass measurement and cross section determination without b-tagging. Even if the normalisation and shape of the background is rather different (but still smooth) these parameters can be determined. It is this behaviour that gives confidence we can perform this measurement using the first ATLAS data already after a 2-3 days of data taking.

5 Hadronic W mass and jet energy miscalibration

When one or two b jets are identified in the event, the combinatorics of selecting two jets to obtain the hadronic decays of the W-boson is small. In the case of no b-tagging however, this combinatorics increases, as well as the fraction of background events. If we select the W by requiring two jets with invariant mass closest to M_W (80.4 GeV), as is done with b-tagged events, we obtain the result as given in Figure 8 (left). With this reconstruction method, a peak is visible in the background and an important bias is clearly present. Uncertainty in the yield of the background translates in this case in an uncertainty of the bias, and therefore this method is not usable.

However, if the two jets with the highest resulting P_T are selected, a W peak is clearly visible if we look at top candidate events, as shown in Figure 8 (right). No peak appears in the background, which indicates there is very little bias from the background.
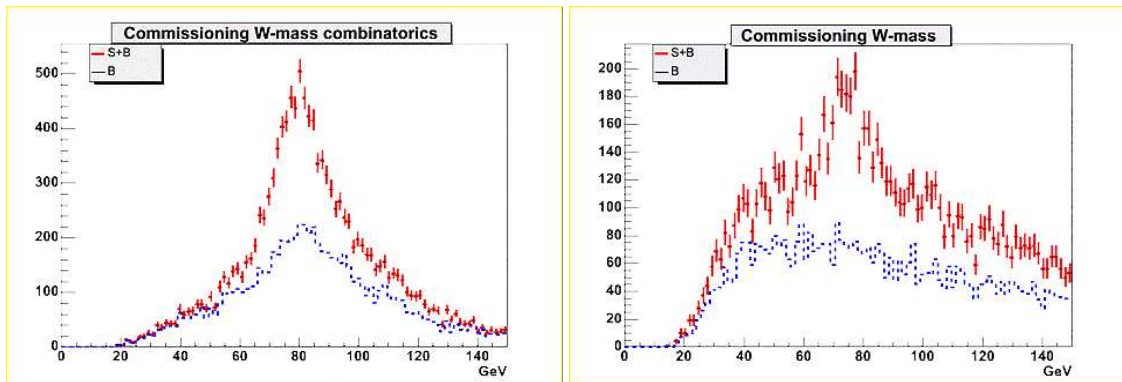

Figure 8: *On the left side: Reconstructed W-mass peak, without b-jet tagging, for 150 pb^{-1} of data, obtained selecting the two jets with the highest P_T. The background corresponds to W+4 jet events. On the right side: Reconstructed W-mass peak, without b-jet tagging, for 150 pb^{-1} of data, obtained as the mass of the two jets with invariant mass closest to M_W.*

150 pb^{-1}	Mean	σ (stat)
ϵ in peak	0.9%	5%
M_{top}	167.0	0.8
M_W	78.0	0.7 GeV

Table 2: *Selection efficiency in the peak, estimated top and W-mass and corresponding statistical uncertainties.*

We apply a fit to the signal and the background events, as shown in Figure 9. This fit has a somewhat more difficult convergence than in the previous top signal case and the W width is fixed to 8 GeV. The results are listed in Table 5 and, within the statistical uncertainties, are consistent with earlier studies.
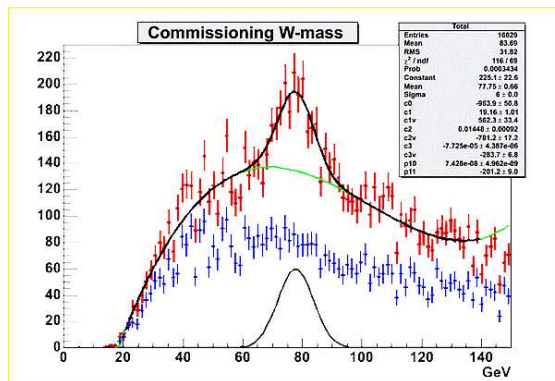

Figure 9: *Fitted W mass peak, without b-tagging, for 150 pb^{-1} of data. The background corresponds to W+4 jet events.*

Both the top mass and the W mass are somewhat lower than the generated values, 175 and 80.4 GeV respectively.

If we naively scale the the measured W mass to its simulated value, and then scale the top mass by the same factor, we end up with a top mass of 171.6 GeV.

5.1   Jet energy scale

The fact that the mass of the hadronically decaying W-boson can be reconstructed in the top sample is important for absolute jet-scale calibration. After all, we know the W-boson mass with an uncertainty (approximately 40 MeV) much better than the accuracy of the jet scale in ATLAS. The mass of the W can therefore be utilized to calibrate the jet energies, again in the absence of b-jet tagging.

To estimate the effect of an absolute jet energy scale uncertainty, we undertook a very simple exercise and rescaled the jet energies (by hand) by various fractions. With these rescaled energies we performed the same analysis again in order to find the top mass and cross section without b-tagging. We shifted the absolute jet energy scales by fractions of 0.96, 0.98, 1.00, 1.02, 1.04 for the light (u, d, s, c) jets, and a fraction of 0.92, 0.96, 1.00, 1.04, 1.08 for b-quark induced jets respectively. The change in the reconstructed top mass is indicated in the first five (light colored) points of Figure 10 (left), the third point being the nominal one without jet mis-calibration. On the right side of Figure 10 the variation in the measured cross section is shown and again the first five points correspond to the variation of the jet-energy scales.

The second series of five (light colored) points in the Figure corresponds to the same variation of jet-scales, but now using the Herwig LO MC for the signal. The third series of five (light colored) points the same but with the Pythia MC and in the last series of light colored points the $W + 4$ jet background was doubled, i.e. the cross section of the background was assumed to be twice as large.

All these studies show that the jet-miscalibration has a large effect on the reconstructed top mass, which varies between 158 to 179 GeV. The Pythia MC shows generally some larger values of M_{top}, and the size of the background does not influence the mass of the top nor the size of the cross section very much.

In the same figure (left) the dark colored points correspond instead to M_{top} which are rescaled. The size of the rescaling is the same as the size of rescaling needed to project the mass of the observed, raw W mass to 80.4 GeV. No jet-energies were re-scaled in this exercise, only the final top mass. As is clearly visible, the variation in the top masses is much reduced. This method can however not be applied to the determination of the cross section.
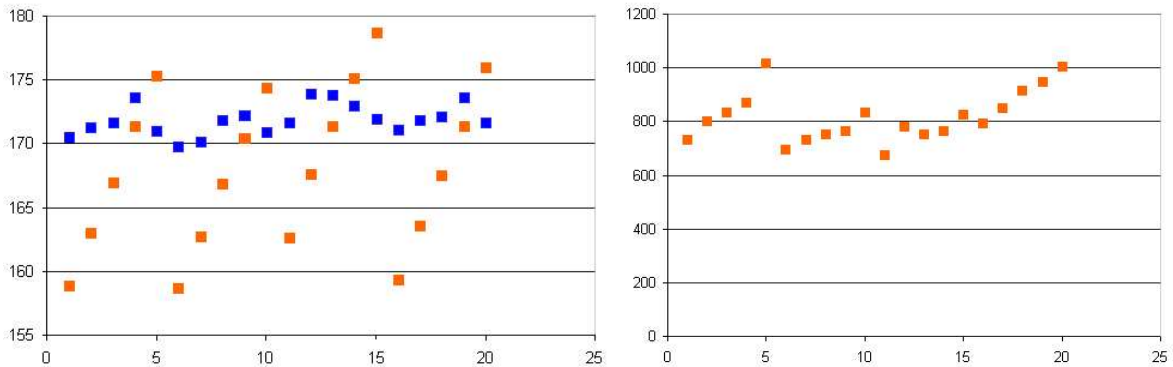

Figure 10: *Left: Top mass shifts, for various jet miscalibrations and predictions, as explained in the text. The vertical scale is the top mass in units of GeV. Right: Shifts in the measured cross sections for different coefficients of the jet energy scale miscalibration. The vertical scale is the cross section in units of pb.*

One way to quantify the difference between the 'raw' and 'rescaled' top masses is to calculate the standard deviation (rms) on the distribution of the masses, as it is a measure of their spread. The rms of the 'raw' top masses is 6.2 GeV and goes to 1.2 GeV for the 'rescaled' top masses. Figure 10 (on the right) shows that there is a large dependance of the cross section on the jet energy scale. Table 5.1 summarizes these results and indicate that the statistical uncertainty will be already smaller than these systematics variation.

The quoted numbers are very preliminary. For the determination of the cross section one should add the uncertainty on the determination of the luminosity as well, which is expected at the beginning to be of the order of 15%-20%. On the one hand, the systematics may be overestimated here, since we simply used all available generators for this study, with pessimistic energy miscalibration. In addition the $W+4$ jets rate can be measured from data. On the

		mean	stat	rms	percent
M_{top}	'raw'	168,1	0,8	6,2	3,7%
	'rescaled'	171,9	0,8	1,2	0,7%
σ_{top}	raw	817,2	5%	94,8	11,6%

Table 3: *Estimated top mass and cross section with their statistical and (partial) systematic errors.*

other hand there are still many effects which are not taken into account here. For example, the systematics due to variations in the modelling of the final state radiation has not been studied, and no other backgrounds (like WW or QCD) have been added to the $W + 4$ jets. In addition, we did not take into account the trigger effect as well as the calorimeter non-uniformities. Therefore more detailed studies are needed, and all the results presented here have to be confirmed by the full simulation.

5.2 What after a few hours of data taking?

It is perhaps illuminating to illustrate what we may observe in ATLAS after only a few hours of data taking. With an instantanuous luminosity of 10^{33} cm^{-2}s^{-1}, ATLAS will collect a total luminosity of approximately 30 pb^{-1} in 9 hours of data taking. And with this amount of collected data, both the W and top peaks will be already visible, as shown in Figure 11. Table 5.2 shows the mean value and σ for the efficiency in peak and the top and W mass.

30 pb^{-1}	Mean	σ (stat)
ϵ in peak	0.8%%	17%
M_{top}	170.0	3.2
M_W	78.3	1.0

Table 4: *Mean value and σ for the efficiency in peak and for the estimated top and W mass, for 30 pb^{-1} of integrated luminosity.*
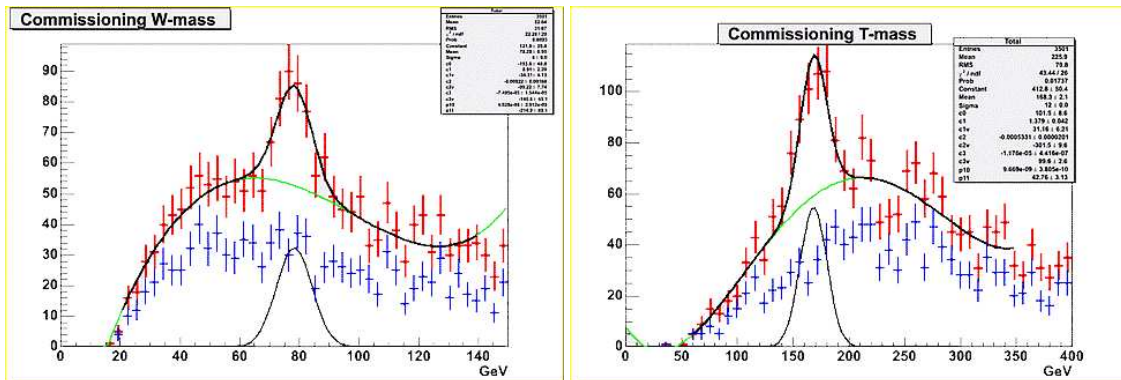

Figure 11: *Reconstructed W and top masses, without b-jet tagging, for 30 pb^{-1} of data. The background corresponds to $W+4$ jet events.*

6 W and Top mass peaks with b-tagging

The scenario with absolutely no available b-tagging is pessimistic, certainly after some initial running period. Therefore we also investigate the behavior of the top mass reconstruction if we assume a b-tagging efficiency like the one expected in ATLAS (b tagging efficiency of 60%, with a 1% of mistags). The background in our $t\bar{t}$ candidate sample is rapidly decreasing in this case. Now, to improve the efficiency, we no longer require to select exactly four jets, but instead require a minimum of four selected jets. We reconstruct the W mass as the mass of the di-jet combination which minimize the quantity $|M_{jj} - 80.4|$ (for light jets), and we obtain the W-mass peaks as shown in Figure 12, requiring one b-tagged jet (left plot) or two b-tagged jets (right plot). Here the combinatorics are too small to create a peak around the W-mass in the background sample.

For top-mass reconstruction, we use only the events for which $|M_{jj} - 80.4| < 20$ GeV. A clear peak is obtained
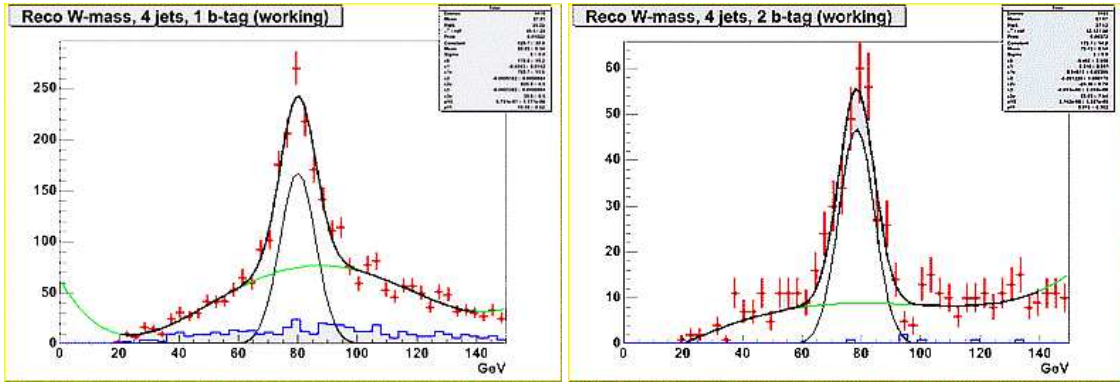
Figure 12: *Left plot: W mass peak reconstructed as the di-jet mass closest to the value of 80.4 GeV, after requiring one b-tagged jet in the event. Right plot: W mass peak, reconstructed as before, but requiring two b-tagged jets in the event. The statistics corresponds to 150 pb^{-1}.*

with very little background, as shown in Figure 13. These distributions correspond to requiring one b-tagged jet in the event (left plot) or two-b-tagged jets (right plot). Clearly, the W+4 jets background is efficiently removed by the b-tag requirement. However, it has to be underlined that these results are very sensitive to the b-mistag rate.
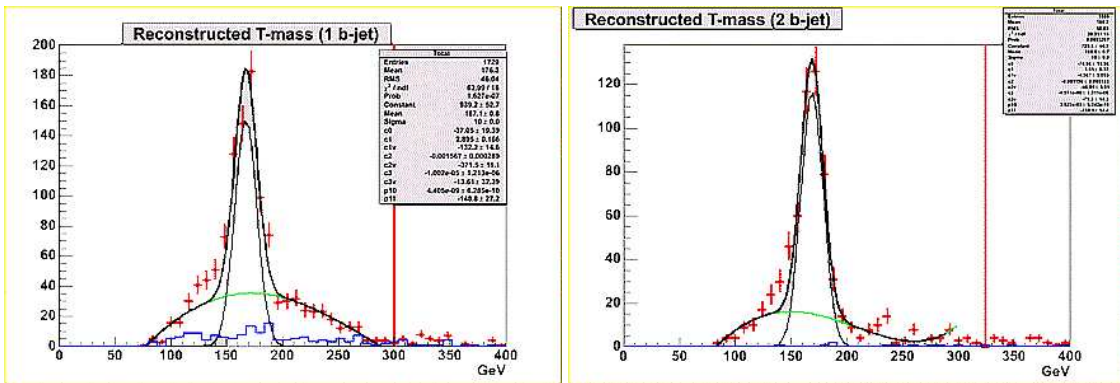

Figure 13: *Left plot: Reconstructed top mass peak, requiring one b-tagged jet in the event. Right plot: Reconstructed top mass peak, requiring two b-tagged jets in the event. The statistics correspond to 150 pb^{-1}.*

7 Underlying events

A complete analysis of systematics involved in the top mass determination has been done in [2]. Here we like to show the effect of one of them, involving the underlying event (UE).

It will be extremely difficult to predict the magnitude of the UE at the LHC, and much more will have to be learned from the Tevatron before startup. Presently, various models exist.

The Herwig's UE and minimum bias shows much less activity compared to Pythia. There is an alternative model for UE originally developed for e-p collisions, and is known as Jimmy [9]. The Jimmy UE model is interfaced with the Herwig MC. Various "tunings" of Jimmy exist, and they lead to wildly different sizes of the UE. In Figure 14 we show as an example the density of tracks as function of the pseudorapidity, for top-anti-top events [10]. No detector simulation is performed in this plot: these tracks are as produced by the MC generator. The difference in track densities of the various models is impressive. Given the status of the subject, it is clear that more work is mandatory in this field.

For this preliminary study we just investigated the effect as predicted by two models. In order to get a feeling on the importance of the UE at detector level, we show as an example the comparison between Jimmy (standard tune) and Herwig's underlying event in Figure 15. The three plots on the left show the different predictions of the two models in terms of cell multiplicity, cluster multiplicity and jet multiplicity respectively. The three plots on the right present the predictions for the cell, cluster and jet energies. One notices that at jet level the differences are
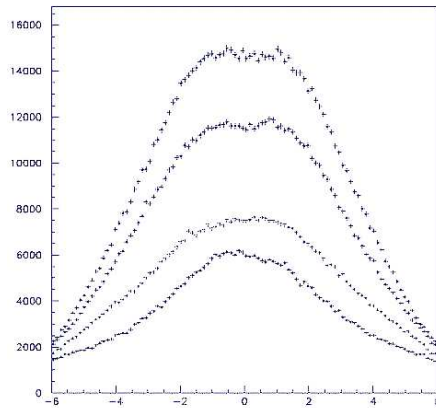
Figure 14: *Pseudorapidity distribution of tracks as produced by top-anti-top events. The lowest curve, with the smallest number of tracks, correspond to the standard Herwig MC. The next curve correspond to the standard Pythia MC. The next one is using the Jimmy UE model in Herwig, with the standard settings. The top curve, with the highest number of tracks, is Jimmy UE in Herwig, with a special tuning of parameters.*

reduced, and the UE shifts the energy of the jets.

Figure 16 shows the reconstructed top mass distribution using the two different models for the underlying event and comparing with the MC@NLO prediction, which is also interfaced to the standard Herwig UE. As is clear, a large activity of the UE shifts the reconstructed mass of the top-quark, as more energy is collected in the cones of the jets. Hence for a precise determination of the top quark mass the effect of the UE is important. But this preliminary analysis shows that the reconstruction of the top-peak itself is not diminished by a large activity of the UE.

8 Conclusions

During the commissioning phase of the ATLAS detector it will be crucial to understand the interplay between the top signal as tool to improve the understanding of the detector (b-tagging, jet E scale, ID etc..) and the top signal to perform precision measurements.

A preliminary study using the ATLFAST simulation shows that at the LHC the top-quark mass can be quite easily reconstructed, even using a very simple selection and without making any requirements in terms of b-tagging, afetr few weeks of data taking. The hadronically decaying W boson can be reconstructed as well, giving an excellent handle on light jet energy calibration.

If we limit our analysis to the first few days of data taking (collecting about 150 pb^{-1}), we can give a preliminary estimate of the accuracy with which we can measure the cross section (about 10% plus the luminosity uncertainty). Utilizing the W-mass to calibrate the jet energy scale looks promising, albeit more work has to be done to isolate a very pure top sample without b-tagging.

This study needs certainly more work in terms of background estimation, for example from W+jets and non-W QCD events, e/π separation, trigger, lepton identification and all the other sources of systematics. And clearly, all the presented results have to be verified with fully simulated data.

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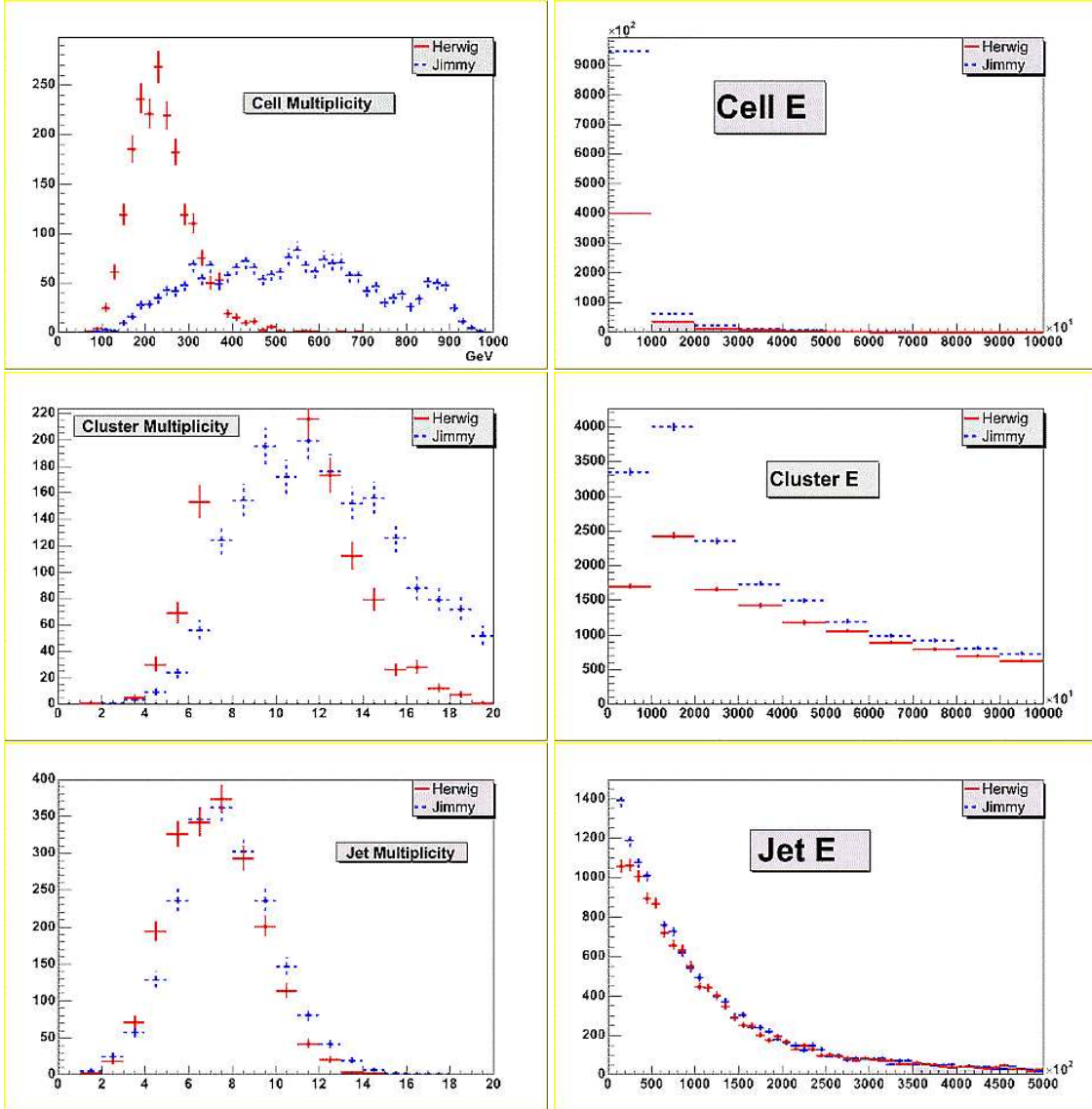
Figure 15: *Different predictions of Herwig and Jimmy models. On the left side the plots show the multiplicity of the cells, the clusters and jets respectively. On the right side the corresponding energy per cell, per cluster and per jet. The scale is given in units of MeV, hence the first plot ends at 10 GeV, the second at 100 GeV and the third at 500 GeV.*
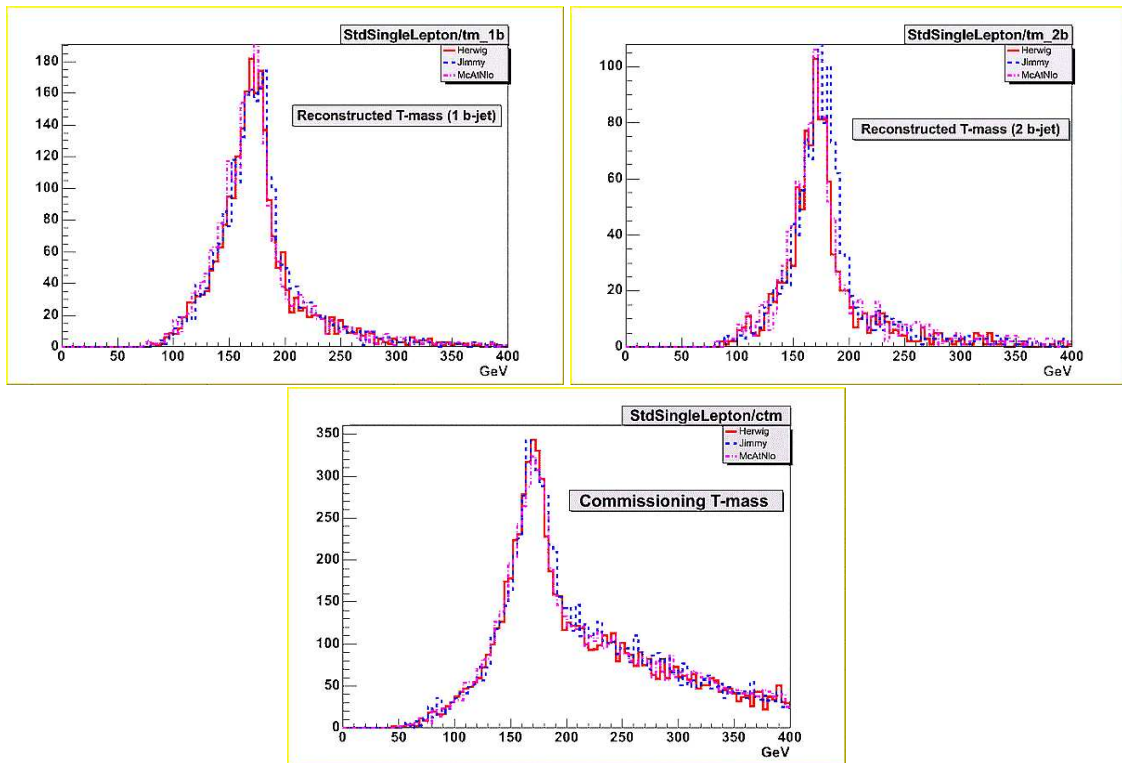
Figure 16: *Predictions of the Herwig and Jimmy models for the reconstructed top mass. For comparison the MC@NLO prediction is added, which is interfaced to the standard Herwig UE. No background is added to these distributions.*

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