Measurements of the top quark mass with the ATLAS Experiment

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Three measurements of the mass of the top quark performed with the ATLAS detector in proton-proton collision at the LHC are presented. Two of them employ the decay mode where one of the pair-produced top quarks decays in either an electron or a muon and the other one into jets while the third measurement is performed in the decay mode where both top quarks decay into jets. Finally a combination of the two channels of the most precise measurement is presented which leads to the result of $m_{\text{top}} = 174.5 \pm 0.6_{\text{stat.}} \pm 2.3_{\text{syst.}}$ GeV.

1 Introduction

A precise measurement of the top quark mass is an important part of the LHC physics program. Because of its high mass the top quark plays an important role in precision fits of the standard model as well as in several models of physics beyond the standard model [1].

The most precise measurement to date is the combination of measurements of the two Tevatron experiments CDF and D0 with a result of $m_{\text{top}} = 173.2 \pm 0.6_{\text{stat.}} \pm 0.8_{\text{syst.}}$ GeV[2] yielding a total uncertainty of 0.9 GeV.

In the following, three measurements of the top quark mass using ATLAS data are presented:

- A 1D template method which uses the lepton + jets decay channel
- A 2D template method using the same events as the 1D analysis
- A measurement using the fully hadronic top decay channel

2 1D Template Method

Candidate events are required to contain exactly one isolated lepton (electron or muon) with transverse momentum of more than 25 GeV, at least four jets with transverse momentum larger than 25 GeV and different cuts on missing energy and transverse mass of the lepton and the missing energy. Additionally, at least one of the selected jets has to be tagged by a high-performance b-tagger.

As all three methods presented use the three-jet invariant mass in the measurement, one of the dominating systematic uncertainties is the knowledge of the jet energy scale. In order to lessen the size of the jet energy scale systematic uncertainty it is possible to refine the approach

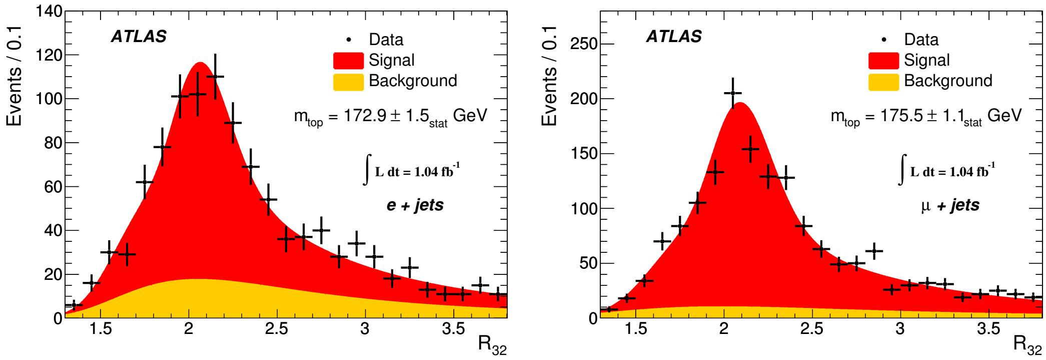

Figure 1: The R_{32} variable in data together with the fit result for the 1D template analysis in the e+jets channel (left) and the μ+jets channel (right). [3]

a bit. One possibility is to fit the so-called R_{32} variable which is the ratio of the three-jet-mass and the two-jet-mass of the two light jets from the W boson decay. Since numerator and denominator are both affected by the same jet energy scale the effect on the fitted top mass is dampened.

A kinematic fit using the full event topology is performed to assign jets to partons. To ensure the convergence of the fit only events with a certain likelihood value are kept. Also all jets used in the fit are required to have a transverse momentum of more then 40 GeV. Finally the reconstructed W boson mass must be in the range between $60 - 100$ GeV. From the two jets assigned as originating from the W decay and the hadronic b-jet the invariant masses of the W boson and the top quark are reconstructed and from the ratio of these the R_{32} variable is built. A likelihood fit to the data using templates of the R_{32} distribution for different generated top quark masses is performed to extract the top quark mass. Figure 1 shows the distribution of R_{32} in data together with the fitted signal and background contributions.

3 2D Template Method

Another approach for mitigating the effect of the jet energy scale uncertainty is to do a multidimensional analysis. This analysis measures the top mass together with a Jet Scale Factor (JSF) which is a correction factor to the jet energies. In addition to the top candidate invariant mass distribution it fits the W candidate invariant mass distribution to gain information on the JSF.

The candidate events are selected in the same way as in the 1D analysis. The assignment of the jets to partons is done combining each pair of untagged jets which fulfill $50\,\text{GeV} < M_{12} < 110\,\text{GeV}$ with the b-tagged jet. Events which do not fulfill this requirement are discarded. As these cuts are less stringent than the additional cuts performed in the 1D analysis this analysis has a higher number of candidates. The combination with the highest transverse momentum is chosen. Similarly to the 1D analysis templates of the reconstructed W boson and the top quark masses for different configurations of top quark mass and JSF are produced. The measured values in data are then used in a two-dimensional likelihood fit to extract the top quark mass and the JSF.

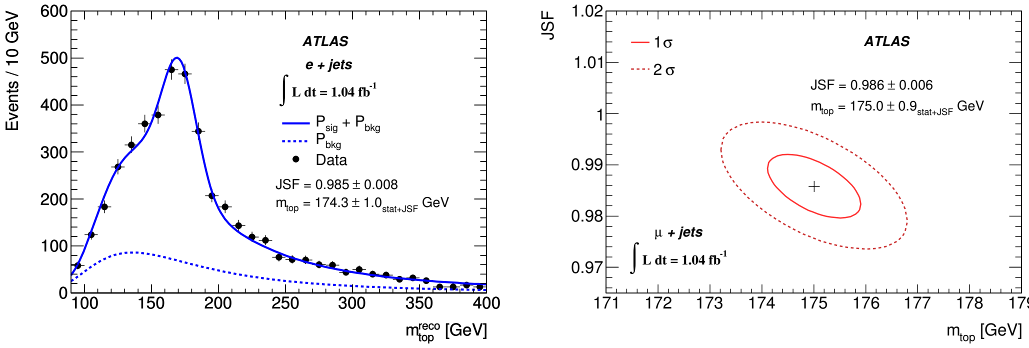

Figure 2: The invariant mass of the top candidates in data together with the fit result for the 2D template analysis in the e+jets channel (left) and correlation between the top mass and the JSF in the muon channel (right). [3]

In figure 2 the reconstructed top mass and the fit result of the template analysis is shown for the electron channel. It also shows the correlation between the top quark mass and the JSF in the muon channel.

4 Measurement in the All-hadronic Channel

In this channel, the main challenge for a top mass measurement is the reduction and the estimate of the multijet background. The reduction of the background is performed by choosing higher transverse momentum cuts on the jets and by requiring two b-tagged jets. The background template is obtained by selecting QCD multijet events which contain 5 jets, two of which must be b-tagged. Then, from a different event a jet with a lower transverse momentum than any of the five jets is added. To validate this approach, several validations have been made for example modeling six-jet events with five-jet event-mixed data but using no b-tagging requirement. Figure 3 shows the three-jet invariant mass for this crosscheck together with the estimate from this technique.

A χ^2-fit is performed to assign the jets to W boson and top quark decays. Additionally events with a $\chi^2 > 8$ are discarded from the analysis.

Figure 3 shows the obtained invariant mass of the top candidates. For the background fit only the normalization has been fitted as the shape was obtained with the data-driven technique.

5 Results

Table 1 shows the results for the three analyses. All measurements agree within statistical errors and are limited by the systematic uncertainties. For all three analyses, the dominating systematic uncertainties are the light jet energy scale, the b-jet energy scale and the uncertainty on additional initial or final state radiation. The all-hadronic analysis also has an additional contribution from the uncertainty of the background shape estimation technique.

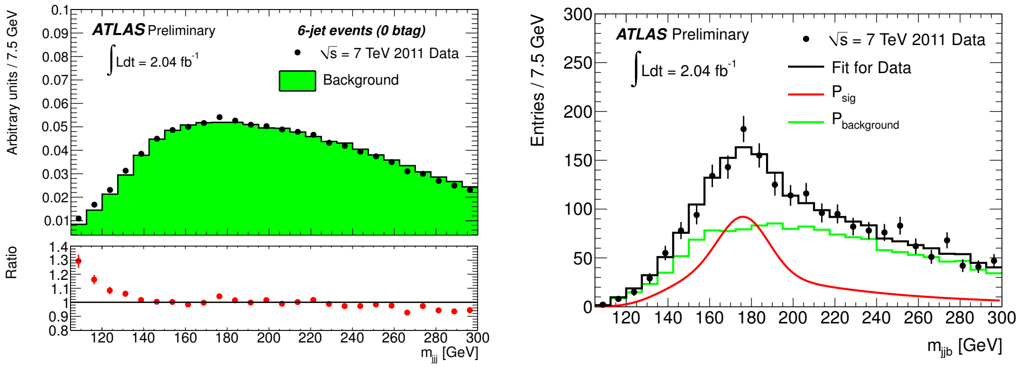

Figure 3: The three-jet invariant mass of the six-jet background with no b-tagging requirement. The green area represents five-jet event-mixed background (left) and the invariant mass of the top candidates in data together with the fit result for the analysis in the all-hadronic channel (right).[4]

The 2D method also measures the JSF, with values equal to 0.985 ± 0.008 (electron channel) and 0.986 ± 0.006 (muon channel) suggesting that the jet energies are described with an accuracy of about 1%. The correlation between the top mass and the JSF is estimated to be -0.6 for both channels.

All results are compatible with the current world average. Finally, the two channels of the lepton+jets 2D analysis are combined to give the following result for the top mass: $m_{\text{top}} = 174.5 \pm 0.6_{\text{stat.}} \pm 2.3_{\text{syst.}}$ GeV.

Method	m_{top}[GeV]
1D electron	$172.9 \pm 1.5_{\text{stat.}} \pm 2.5_{\text{syst.}}$
1D muon	$175.5 \pm 1.1_{\text{stat.}} \pm 2.6_{\text{syst.}}$
2D electron	$174.3 \pm 1.0_{\text{stat.}} \pm 2.2_{\text{syst.}}$
2D muon	$175.0 \pm 0.9_{\text{stat.}} \pm 2.5_{\text{syst.}}$
1D All Hadronic	$174.9 \pm 2.1_{\text{stat.}} \pm 3.8_{\text{syst.}}$
World average [2]	$173.2 \pm 0.6_{\text{stat.}} \pm 0.8_{\text{syst.}}$

Table 1: The fitted top mass for all 5 measurements together with the current world average top mass.

6 Acknowledgments

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