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New results on top-quark mass, including new methods, in ATLAS

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Recent results on top-quark mass measurements with the ATLAS detector using proton-proton collisions at the Large Hadron Collider are presented. These results correspond to the measurements in the $t\bar{t}$ all-hadronic and dilepton channels at $\sqrt{s} = 8$ TeV collisions and an integrated luminosity of 20 fb^{-1}.

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1 Introduction

The top quark is the heaviest elementary particle in the Standard Model (SM) and its mass is a fundamental parameter that needs to be determined experimentally. The top-quark mass has an important effect in electroweak radiative corrections and a precise measurement is relevant, in particular, for theories of physics beyond the SM. Furthermore, its value is an important test for the consistency of the SM.

The ATLAS detector [1] is a general purpose detector located at the Large Hadron Collider (LHC). Two top-quark mass measurements were performed in the last year using data from the ATLAS detector at a center-of-mass energy of $\sqrt{s} = 8$ TeV:

- the top-quark mass measurement in the dilepton channel [2] and
- the top-quark mass measurement in the all-hadronic channel [3].

Both measurements use the template method to extract the top-quark mass, where the templates are derived using Monte-Carlo simulations.

2 Top-quark measurement in the dilepton channel

This analysis [2] uses the full $\sqrt{s} = 8$ TeV ATLAS data, which gives an integrated luminosity of 20 fb^{-1}.

Although the $t\bar{t}$ dilepton channel has a small branching ratio (6%), this is compensated by an extremely high purity, of the order of 99%. The main disadvantage is the presence of two neutrinos which makes the full reconstruction of the event difficult, since the missing transverse momentum ($\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$) and the missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$) can only be associated to the combined effects of two particles. The use of the template method circumvents this problem, since it exploits the expected distribution of the $m_{\ell b}$ variable to extract the top-quark mass.

The $m_{\ell b}$ variable is defined as the invariant mass of the two lepton−b-jet pairs. Since the correct pairing between each lepton and their corresponding b jet is not known a priori, both combinations are computed and the combination giving the smallest value of $m_{\ell b}$ is taken as the correct pairing.

In order to select signal events and reject background, the events are required to have exactly two reconstructed leptons with opposite-sign charges, at least two reconstructed jets and at least one reconstructed jet must be b-tagged (tagger efficiency: 70%). All the reconstructed leptons and jets must have a transverse momentum (p_{T}) larger than 25 GeV. For the ee and $\mu\mu$ channels, it is also required that $E_{\mathrm{T}}^{\mathrm{miss}} > 60$ GeV and the invariant mass of the two reconstructed leptons ($m_{\ell\ell}$) must satisfy $m_{\ell\ell} > 15$ GeV and $|m_{\ell\ell} - m_{\mathrm{Z}}| > 10$ GeV, where m_{Z} is the mass of the Z boson. For the $e\mu$ channel, the scalar sum of the p_{T} of all reconstructed jets and leptons must be larger than 130 GeV.

In order to increase the pairing efficiency of the lepton−b-jet pairs, events are also required to satisfy 30 GeV $< m_{\ell b} <$ 170 GeV and the average transverse momentum of the two lepton−b-jet pairs ($p_{\mathrm{T},\ell b}$) must be larger than 120 GeV. The distribution of $m_{\ell b}$ after applying all the cuts is shown in Figure 1 (left).

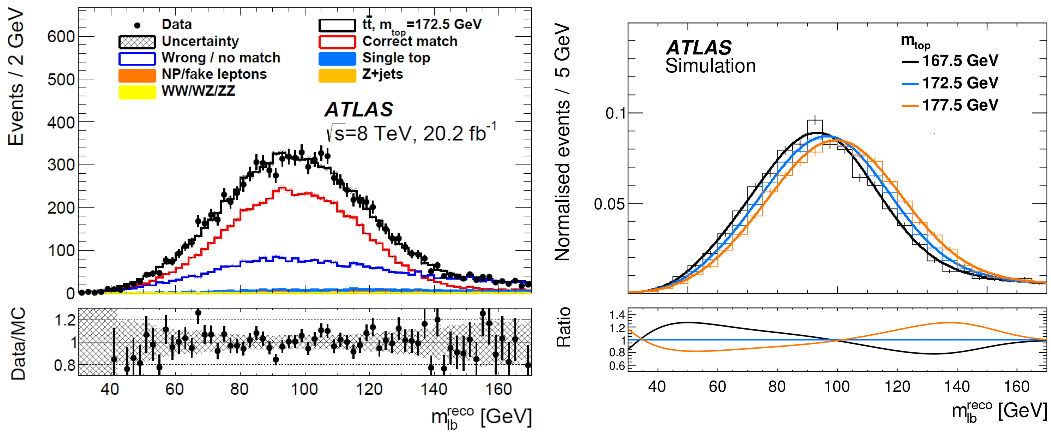

Figure 1: Left: comparison between data and simulation of the $m_{\ell b}$ distribution after applying all cuts. Right: template used to measure the top-quark mass using the $m_{\ell b}$ variable. The histograms show the distribution generated by the Monte-Carlo simulations while the solid lines show the respective template distribution [2].

After applying the final selection, 10100 ± 770 events are expected, of which 10030 ± 770 are predicted to be signal events. The expected matching efficiency for the lepton−b-jet pairing is (95.3 ± 0.4)%. Applying this selection to the data, 9426 events are found.

In order to measure the top-quark mass, the template shown in Figure 1 (right) is used. This template is created by modelling the signal as the sum of a Gaussian and a Landau distribution, while the background is modelled with a Landau distribution. The final template depends only on the top-quark mass.

Fitting this template to the data, a measurement of:

$$m_{\mathrm{top}} = 172.99 \ \pm \ 0.41(\mathrm{stat.}) \ \pm \ 0.74(\mathrm{syst.}) \ \mathrm{GeV}$$

is obtained, where the systematic uncertainty is dominated by the jet energy scale (0.54 GeV).

This result is combined with the ATLAS top-quark mass measurements in the single-lepton and dilepton channels performed at $\sqrt{s} = 7$ TeV [4] using the Best Linear Unbiased Estimate method [5]. The combined measurement gives a combined top-quark mass value of:

$$m_{\mathrm{top}} = 172.84 \ \pm \ 0.34(\mathrm{stat.}) \ \pm \ 0.61(\mathrm{syst.}) \ \mathrm{GeV}.$$

3 Top-quark mass measurement in the all-hadronic channel

This mass measurement [3] also uses the full $\sqrt{s} = 8$ TeV ATLAS data, which gives an integrated luminosity of 20 fb^{-1}.

In the all-hadronic channel, both W bosons decay hadronically, giving a signature of four light jets and two b jets. Unlike the dilepton channel, the all-hadronic channel has the advantage of having the largest branching ratio of all channels, no neutrinos and, hence, the ability to perform a full kinematic reconstruction of the event. The main disadvantage of the all-hadronic channel is the large amount of jets, which poses a complex combinatorics problem to properly identify and reconstruct events. Furthermore, the kinematic reconstruction of an event depends heavily on the jet energy scale. Finally, the multijet background is significant.

The $R_{3/2}$ variable is used for the template method. It is defined, in a top quark hadronic decay, as the ratio between the invariant mass of the three jets (one b jet and two coming from the decay of the W boson) and the invariant mass of the two jets that are the product of the W-boson decay. Since there are two top-quark decays per $t\bar{t}$ event, two $R_{3/2}$ values can be computed per event. The correlation between the two values of $R_{3/2}$ per event is 0.59 and such correlation is considered in the estimation of the uncertainties.

The events are required to have no reconstructed leptons, at least six reconstructed jets with $p_{\mathrm{T}} > 25$ GeV, of which at least five reconstructed jets must have $p_{\mathrm{T}} > 60$ GeV and at least two of the six leading-p_{T} jets must be b-tagged (tagger efficiency: 57%). It is also required that $E_{\mathrm{T}}^{\mathrm{miss}} < 60$ GeV and that the azimuthal separation between the two b jets with the highest b-tagging weights must be larger than 1.5. Furthermore, after performing the $t\bar{t}$ kinematic fit explained in the next paragraph, the average azimuthal separation between the corresponding b jets and W bosons of both decay chains must be smaller than 2 and the smallest value of χ^2 must be less than 11. The final selection gives an expected purity of 34%.

In order to fully reconstruct the $t\bar{t}$ event, a kinematic fit is performed by minimizing the value of:

$$\chi^2 = \frac{\left(m_{b_1 j_1 j_2} - m_{b_2 j_3 j_4}\right)^2}{\sigma^2_{\Delta m_{bjj}}} + \frac{\left(m_{j_1 j_2} - m_W^{\mathrm{MC}}\right)^2}{\sigma^2_{m_W^{\mathrm{MC}}}} + \frac{\left(m_{j_3 j_4} - m_W^{\mathrm{MC}}\right)^2}{\sigma^2_{m_W^{\mathrm{MC}}}},$$

where b_1 is the b jet originating from the top quark decay, b_2 is the b jet originating from the antitop quark decay, j_1 and j_2 are the jets originating from the W^+ decay, while j_3 and j_4 are the jets originating from the W^- decay. The values of $m_W^{\mathrm{MC}} = 81.18 \pm 0.04(\mathrm{stat.})$ GeV, $\sigma_{\Delta m_{bjj}} = 21.60 \pm 0.16(\mathrm{stat.})$ GeV and $\sigma_{m_W^{\mathrm{MC}}} = 7.89 \pm 0.05(\mathrm{stat.})$ GeV are determined from Monte-Carlo simulations using the correct combination of jets, which is obtained from the event generator.

During the $t\bar{t}$ event reconstruction, all the possible jet combinations are tried, and the combination giving the smallest value of χ^2 is considered the correct jet combination of the event.

The QCD multijet background is the largest background contribution and it is estimated using data-driven methods. Its uncertainty is expected to have an impact of 0.16 GeV in the final top-quark mass measurement.

In order to measure the top-quark mass, the template shown in Figure 2 (left) is used. This template is created by modelling the signal distribution with a Novosibirsk distribution, while the background distribution is modelled with a Landau distribution. The final template depends on the top-quark mass and the background fraction parameter (F_{bkgd}).

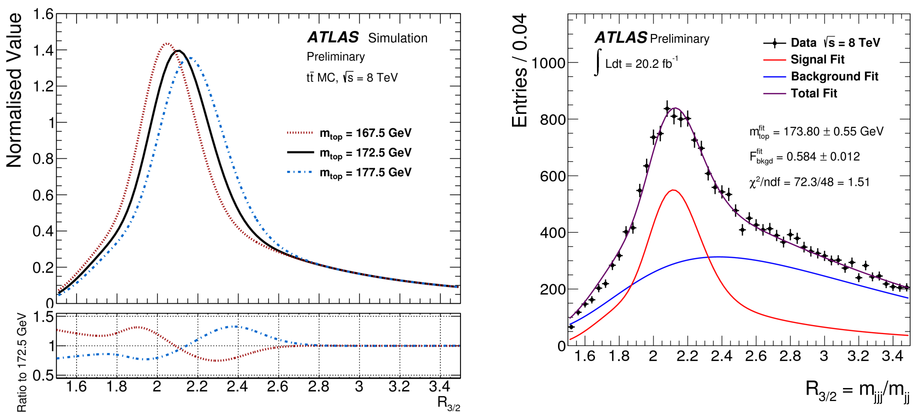

Figure 2: Left: template used to measure the top-quark mass using the $R_{3/2}$ variable. Right: result of the template fit to the distribution of the $R_{3/2}$ variable in data [3].

Fitting the template to the data, as shown in Figure 2 (right), a top-quark mass of

$$m_{\mathrm{top}} = 173.80 \ \pm\ 0.55(\mathrm{stat.}) \ \pm\ 1.01(\mathrm{syst.}) \ \mathrm{GeV}$$

is measured, where the systematic uncertainty is dominated by the hadronization modelling (0.64 GeV) and the jet energy scale (0.60 GeV).

ACKNOWLEDGEMENTS

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