Measurement of the top quark mass in dileptonic top quark pair decays with $\sqrt{\mathrm{s}} = 7$ TeV ATLAS data

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The top quark mass in dileptonic top quark pair decays is measured using 4.7 fb^{-1} of proton-proton collision data recorded at the centre of mass energy $\sqrt{s} = 7$ TeV by the ATLAS experiment at the LHC in 2011. The event topology is characterised by the presence of two charged leptons, at least two neutrinos, and several jets, two of which originate from bottom quarks. Using the template method and the $\mathrm{m}_{\ell b}$ observable, defined as the average invariant mass of the two lepton plus b-jet pairs in each event, the top quark mass is measured to be $173.09 \pm 0.64_{\mathrm{stat}} \pm 1.50_{\mathrm{syst}}$ GeV.

1 Introduction

The mass of the top quark (m_{top}) is a fundamental parameter of the Standard Model of particle physics. The most recent combination of the measurements performed at the LHC [1], based on data luminosities of up to 4.9 fb^{-1}, yields $m_{\mathrm{top}} = 173.29 \pm 0.95$ GeV. The LHC at CERN serves as a top quark factory, and thanks to the large sample of top anti-top quark ($t\bar{t}$) pairs collected by the ATLAS experiment analyses exploiting the $t\bar{t}$ dileptonic final state $t\bar{t} \to W^+bW^-\bar{b} \to \ell^+\nu b\ell'^-\bar{\nu}'\bar{b}$ can also provide precision measurements of m_{top}, as presented in the following [2].

2 Event reconstruction, modeling and selection

The data used in this analysis correspond to 4.7 fb^{-1} of proton-proton (pp) collision data at $\sqrt{s} = 7$ TeV recorded by the ATLAS detector [3] during 2011.

The final state considered in this analysis is $t\bar{t} \to W^+bW^-\bar{b} \to \ell^+\nu b\ell'^-\bar{\nu}'\bar{b}$, with ℓ being either electron (e) or muon (μ). This results in three different decay channels, which are all considered in this analysis. The decay channels involving tau leptons are not taken into account due to the difficulties in tau lepton reconstruction. To identify jets originating from the hadronisation of b-quarks an algorithm based on a neural-net, relying on topological properties such as the vertex decay length significance, is applied [4]. The chosen working point of this "MV1" algorithm corresponds to a b-tag efficiency of 70% for jets originating from b-quarks in simulated $t\bar{t}$ events and a light quark jet rejection factor of about 130. The selection of events consists of a series of requirements on the general event quality and on the reconstructed objects, that are designed to select events consistent with this topology. It is characterised by the presence of two isolated leptons with relatively high p_{T}, missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) arising from the two neutrinos from the leptonic W-boson decays, and two b-jets. Consequently exactly two b-tagged jets with $p_{\mathrm{T}} > 25$ GeV and exactly two opposite sign leptons with $p_{\mathrm{T,e}} > 25$ GeV, $p_{\mathrm{T},\mu} > 20$ GeV are required. In the same flavour channels events have to satisfy $E_{\mathrm{T}}^{\mathrm{miss}} > 60$ GeV.

Monte Carlo (MC) simulated events are used to model the $t\bar{t}$ signal events and most of the physics background processes, consisting mostly of single top quark production in the Wt-channel and the small contributions from Drell-Yan processes and diboson production with additional jets. Events may also be wrongly reconstructed as dileptonic $t\bar{t}$ decays due to the presence of misidentified, or "fake", leptons together with b-tagged jets and $E_{\mathrm{T}}^{\mathrm{miss}}$. This contribution is estimated using a data-driven method [5], found to be consistent with zero and, consequently, neglected in the m_{top} measurement. Additional information on the sample production and the samples used for background and systematics evaluation can be found in [2].

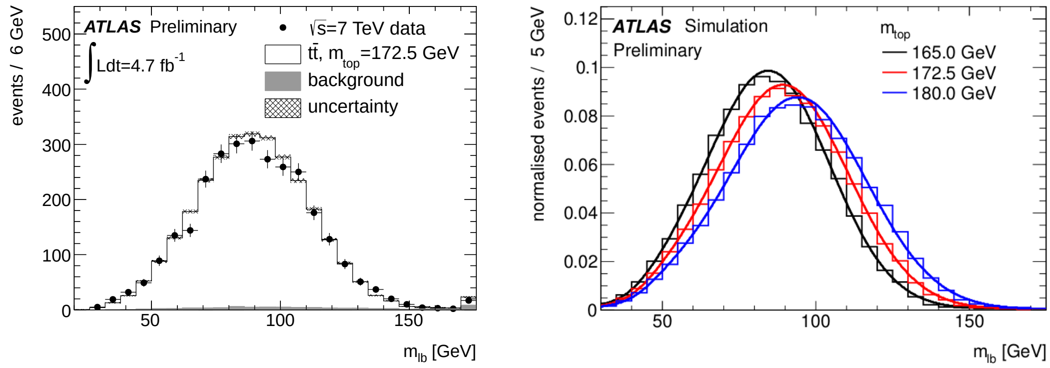
The observed numbers of events in data after the event selection, together with the expected numbers of signal and background events corresponding to the integrated luminosity of 4.7 fb^{-1}, are given in Table 1. The relative fractions of events in data for the ee, $e\mu$ and $\mu\mu$ channels respectively are 9%, 67% and 24%. Assuming a top quark mass of $m_{\mathrm{top}} = 172.5$ GeV, the number of events observed in data is about 16% higher than the prediction, but still consistent within uncertainties. This does not affect the analysis, because the template method implemented here depends on the shape of the distributions only, and does not rely on the normalisation of the signal plus background prediction. In all kinematic distributions the shape of data can be properly accounted for by the sum of signal and background predictions.

	All channels
$t\bar{t}$ signal	2400 $\pm$ 400
Fake leptons	-4 $\pm$ 7
Single top quark	73 $\pm$ 15
Drell-Yan	3.1 $\pm$ 1.3
Diboson	0.75 $\pm$ 0.29
Total expected	2500 $\pm$ 400
Total observed	2913

Table 1: The observed and expected numbers of events after the final event selection.

3 The template method

In the template method, simulated distributions are constructed for a chosen quantity sensitive to the parameter under study, known as the "physics parameter", using a number of discrete values of that parameter. These templates are then fitted to functions that interpolate between different input values of the physics parameter, fixing all other parameters of the functions. In the final step a likelihood fit of these functions to the observed data distribution is used to obtain the value for the physics parameter that best describes data. The $m_{\ell b}$ estimator is defined as the average invariant mass of the lepton b-jet systems, leading to two possible assignments of the two b-jets to the two charged leptons. The assignment corresponding to the



(a) (b)

Figure 1: **(a)** Estimator distribution after applying all selection requirements for data (points), the sum of signal and background (black line) and for background alone (grey histogram). The signal plus background prediction is normalised to the number of events observed in data. The uncertainties shown for data are statistical only. The hatched band indicates the shape uncertainty of the signal and background contributions due to the leading jet uncertainties. The rightmost bin contains the overflow. **(b)** Dependence of the distribution on $m_{\rm top}$ for signal samples for different input top quark masses and the signal probability density functions.

lowest $m_{\ell b}$ estimator is chosen, which yields the correct matching in 77% of the cases. The $m_{\ell b}$ distribution for data and the prediction for $m_{\rm top} = 172.5$ GeV are shown in Figure 1(a). Figure 1(b) shows the sensitivity of the $m_{\ell b}$ observable to the input value of the top quark mass by the superposition of the signal templates and their fits for three input $m_{\rm top}$ values. The parameters of the fitting functions of $m_{\ell b}$ depend linearly on $m_{\rm top}$ for both the signal and background templates, the latter being introduced by the single top quark contribution. This allows to build signal and background probability density functions for the $m_{\ell b}$ estimator that depend only on $m_{\rm top}$. These functions are then used in an unbinned likelihood fit to data for all events, $i = 1, \ldots, N$. The likelihood function maximised is:

$$\mathcal{L}(m_{\ell b}|m_{\rm top}, r) = \prod_{i=1}^{N} \left[(1-r) \cdot P_{\rm sig}(m_{\ell b}|m_{\rm top}) + r \cdot P_{\rm bkg}(m_{\ell b}|m_{\rm top})\right],$$

where $P_{\rm sig}$ and $P_{\rm bkg}$ are the signal and background probability density functions and r is the relative normalisation of the background contribution. The value of r is small, $r = 0.03 \pm 0.01$, and is fixed to its nominal value in the likelihood fit.

Using pseudo-experiments on large Monte Carlo samples, a good linearity is found between the input top quark mass and the results of the fits. Within their statistical uncertainties, the mean values and widths of the pull distributions are consistent with the expectations of zero and one, respectively. This shows that the method is unbiased and the statistical uncertainty is evaluated correctly. The expected statistical uncertainty on $m_{\rm top}$ obtained from pseudo-experiments for an input top quark mass of $m_{\rm top} = 172.5$ GeV and for a luminosity of 4.7 fb^{-1} is 0.64 GeV.

Description	Value [GeV]
Measured value	173.09
Statistical uncertainty	0.64
Detector modeling	1.25
MC modeling	0.80
Background	0.14
Method calibration	0.07
Total systematic uncertainty	1.50
Total uncertainty	1.63

Table 2: The measured value of m_{top} and the statistical and systematic uncertainties.

4 Systematic uncertainties

The systematic uncertainties are estimated by varying the respective uncertainty source and determining the impact on the mass measurement via pseudo-experiments. Wherever applicable the uncertainty sources are varied by one standard deviation ($\pm 1\sigma$) with respect to the default value. The resulting average value of the fitted m_{top} in the pseudo-experiments is compared to the corresponding value without variation and the difference is used to determine the systematic uncertainty. The total uncertainty is calculated as the quadratic sum of the individual contributions, i.e. neglecting possible correlations. The sources and systematic uncertainties investigated are summarised in Table 2 and explained below.

Detector modeling: This category summarises object-related uncertainties, comprising e.g. jet and lepton energy scale, reconstruction efficiency or pile-up. As expected from an analysis without in-situ calibration of the jet energy scale, the dominant systematic uncertainties on m_{top} stem from the imperfect knowledge of the jet and b-jet energy calibration, contributing with $O(0.8)$ GeV each.

MC modeling: This category summarises uncertainties related to the signal simulation, such as the choice of the event generator, hadronisation model, choice of proton PDF, modeling of colour reconnection, underlying event or initial and final state radiation. The dominant contributions of $O(0.4)$ GeV come from the hadronisation model and the modeling of the underlying event.

Background: The impact of the uncertainty of the background contribution on the final result is obtained by varying the background normalisation within its uncertainty and re-evaluating the top quark mass using the template fit.

Method calibration: The good linearity found between the input top quark mass used in the simulation and the results of the fit described in Section 3 shows that the method is unbiased at the level of statistical precision of the MC samples. The maximum between the average absolute mass deviation and its statistical uncertainty observed in the m_{top} variation samples is assigned as an uncertainty.

5 Results

The result of the fit to 2011 ATLAS data in the dileptonic $t\bar{t}$ decay channel is

$$m_{\text{top}} = 173.09 \pm 0.64_{\text{stat}} \pm 1.50_{\text{syst}} \text{ GeV}.$$

Figure 2 shows the $m_{\ell b}$ distribution in data together with the corresponding fitted probability density functions for signal plus background and for the background contribution alone. The inset shows the $-2\ln\mathcal{L}$ profile as a function of the fitted top quark mass. The vertical lines correspond to $\pm 1\sigma$ of the statistical uncertainty. The result has a total uncertainty similar to that of the ATLAS m_{top} measurement obtained in the lepton+jets channel [6].

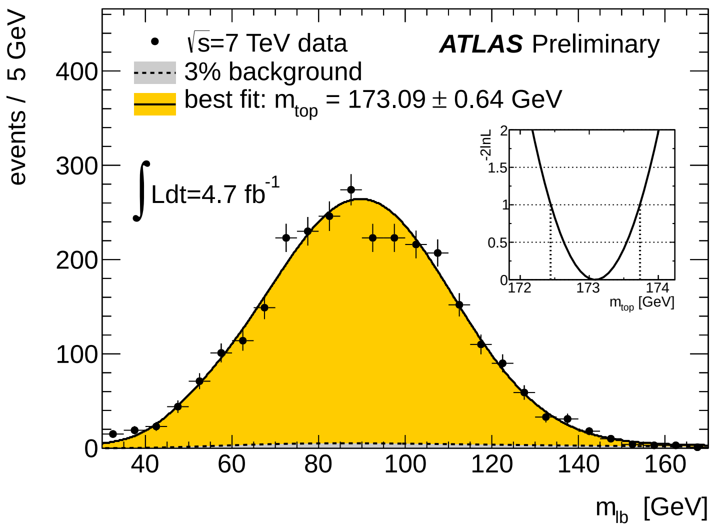


Figure 2: Fitted $m_{\ell b}$ distribution in data. The fitted probability density functions for the signal plus background and for the background contribution alone are also shown. The inset shows the $-2\ln\mathcal{L}$ profile as a function of the fitted top quark mass.

References

[1] ATLAS and CMS Collaborations, ATLAS-CONF-2012-095.

[2] ATLAS Collaboration, ATLAS-CONF-2013-077.

[3] G. Aad *et al.* [ATLAS Collaboration], JINST **3** (2008) S08003.

[4] ATLAS Collaboration, ATLAS-CONF-2012-040.

[5] G. Aad *et al.* [ATLAS Collaboration], Eur. Phys. J. C **71** (2011) 1577, arXiv:1012.1792 [hep-ex].

[6] ATLAS collaboration, ATLAS-CONF-2013-046.