

Top quark mass measurements in ATLAS

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Abstract. The top quark is a fundamental constituent of the Standard Model (SM). The properties of this quark are accurately predicted by this theory, except for its mass, which remains a fundamental parameter of the SM. With the advent of the Large Hadron Collider (LHC), many million of top-antitop quark pairs are available for study. With such statistics, the physics of the top quark has entered the precision era. In this note, the most recent experimental results by ATLAS concerning the top quark mass are reported.

1. Introduction

The top quark is the heaviest elementary particle known up to date. It was discovered at Tevatron in 1995 by the CDF [1] and DØ [2] experiments. It is an up-type quark, therefore it is expected to have the same quantum numbers as the u and c quarks. Only its mass is a free parameter. Thus, within the SM all production and decay properties of the top quark are fully defined. As the value of the top quark mass is close the electroweak symmetry breaking scale, it has inspired speculations about the top quark having a special role in the symmetry breaking mechanism. For this reason, it is important to confirm experimentally at LHC [3] that the top quark has the properties predicted by the Standard Model. Any deviation from the expectations may be a hint to new physics. This is one of the reasons why the physics of the top quark is a major topic of the ATLAS [4] and CMS [5] experiments at LHC.

In the SM, the Higgs boson mass is related to the top quark and W boson masses through the radiative corrections. The most up to date electroweak fit uses NNLO theoretical predictions and compares the constraints from the electroweak fit on the Higgs with direct LHC measurements [6]. Current experimental results show this set of masses to be in agreement (Fig. 1).

The quark masses are fundamental parameters of the SM lagrangian which are not predicted by the theory. However, the definition of the quark mass is not unique as quarks are not observed as free particles. Therefore, the use of dynamical expressions is mandatory in order to determine unequivocally the masses of the quarks. The perturbative pole mass and the running mass in the \overline{MS} scheme are two definitions among the most frequently used in theoretical QCD calculations. However, for the top quark, the Monte Carlo (MC) mass is also frequently used (as a kind of kinematic mass). According to references [7] [8] the difference between the kinematic mass and the pole mass is estimated to be ≤ 1 GeV.

1.1. Top quark production and decay

At LHC, top quarks are predominantly produced in quark-antiquark ($t\bar{t}$) pairs, although it is possible that a single (anti-)quark is being produced. The analysis reported in this note deal

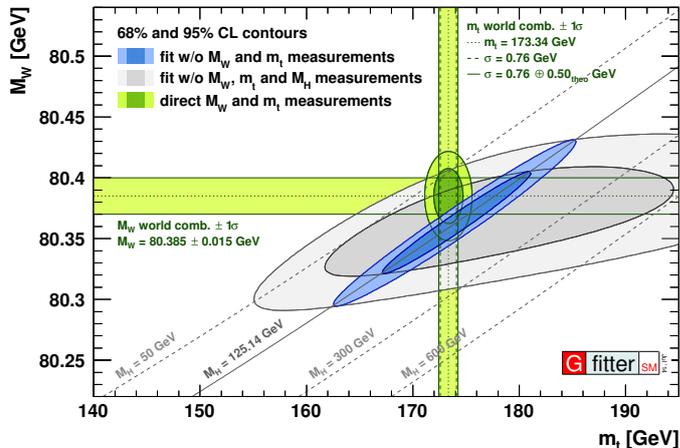


Figure 1. Contours of 68% and 95% confidence level of the experimental W boson mass versus the top quark mass including the Higgs boson mass (blue) and excluding it (grey). The values are in agreement as expected in the SM. Figure extracted from [6].

38 only with the $t\bar{t}$ production.

39 Once produced the top quark decays almost exclusively via the $t \rightarrow Wb$ vertex. Obviously
 40 a jet emanates from the b hadronization. In turn, the W boson decays either into leptons or
 41 into quarks. The W decay mode defines the topology of the event. When leptons are produced
 42 ($W \rightarrow \ell\nu$), the neutrinos escape detection and their transverse energy appears afterwards during
 43 reconstruction as an unbalance of the event transverse energy. When quarks stem from the
 44 $W \rightarrow q\bar{q}'$ decay, they hadronize giving rise to jets.

45 The usual classification of the events is: all-hadronic (when both W s decay hadronically),
 46 lepton plus jets (ℓ +jets in short, when each W decays in either mode) and dilepton channel
 47 (both W decaying leptonically). The branching ratios are well established in the SM. The
 48 ℓ +jets channel has a large branching ratio¹. Moreover the presence of the charged lepton and
 49 missing transverse energy carried away by the neutrino help to keep the SM physics background
 50 under control. The all-hadronic is the most probable channel (44% branching ratio) but the
 51 background is high. Besides, the reconstruction of many jets in the event is very challenging.
 52 The dilepton channel has a low background but its branching fraction is quite small. On the other
 53 hand, the presence of two neutrinos makes the event kinematic reconstruction more arduous.

54 2. Top quark mass measurements in ATLAS

55 There exists ATLAS measurements of the top quark mass (MC mass) in all event topologies
 56 [9, 10, 11] using the 7 TeV proton-proton collisions at LHC. The analysis use template methods
 57 to extract the top quark mass. They consist in characterizing the distribution of selected
 58 observables which are sensitive to the top quark mass. The shape of the distribution is
 59 parametrized as a function of the top quark MC mass in the simulations. Then a likelihood
 60 fit figures out which top quark mass better describes the real data distribution of those same
 61 observables. In the fit, the estimated physics background is also included.

62 In the case of the most recent ATLAS 7 TeV data analysis in the ℓ +jets, the template
 63 considers 3 variables (3D template) (Fig. 2). The first is the reconstructed invariant mass of
 64 the top quark (from a kinematic fit to the event data). Then comes the reconstructed invariant
 65 mass of the W boson from the hadronic decay part. This observable allows to calibrate the
 66 relative reconstructed jet energy scale factor (JSF) between real data and MC. Even a tiny
 67 difference in the JSF may bias irremediably the extracted value of the top quark mass. The
 68 third observable may control/detect/avoid possible (small) differences in the b -jet energy scale

¹ Its actual value depends to the treatment given to the $W \rightarrow \tau\nu$ decays. As the τ will decay later, some of the ATLAS analysis only consider as genuine signal the W decays into e or μ .

69 factor (b JSF) between real data and MC that may rise due to the different fragmentation of the
70 b quark compared with respect to the light quarks.

71 The analysis uses either events with one or two b -tagged jets. Of course the templates of the
72 observables are parametrized independently. Despite of the two b -tagged jets sample being more
73 sensitive to the top quark mass, that with one b -tagged jet sample gets more statistics, resulting
in a similar resolution power.

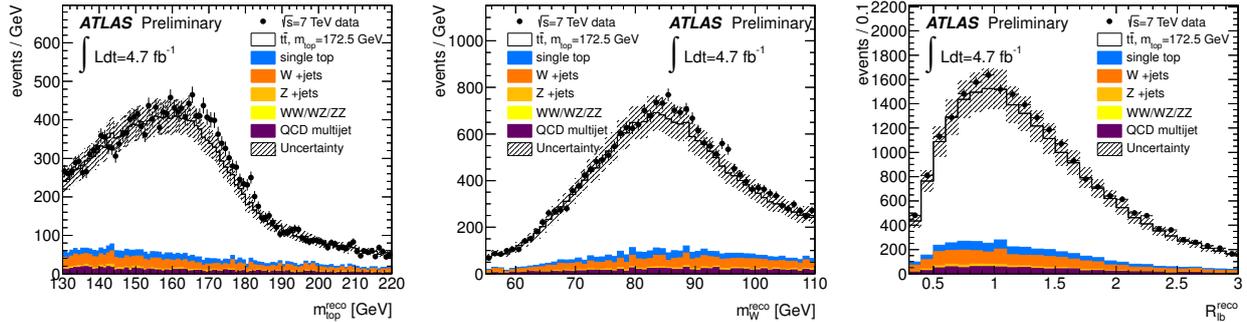


Figure 2. Distributions of the three observables used in the ℓ +jets channel top mass analysis with a 3D template. Real data (dots) are compared with MC expectation (using MC mass of 172.5 GeV, solid line). The contribution from different physics backgrounds is also presented. The sample includes events either with 1 b -tagged jet or 2 b -tagged jets. Taken from [9].

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75 In the dilepton channel, the presence of two neutrinos in the final state is a challenge for
76 the event reconstruction. The observable used is the invariant mass between the reconstructed
77 charged lepton (ℓ) and the b -jet ($m_{\ell b}$). As there are two leptons and two b -jets, for each possible
78 lepton-to- b -jet assignment, the average of the two invariant masses is calculated. Then the lowest
79 average mass is taken as the $m_{\ell b}$ estimator for the event. Finally the top quark mass is extracted
80 using also a template method.

81 Concerning the systematic uncertainties, both analysis are dominated by the Jet Energy
82 Scale uncertainty (representing about 0.8 and 0.9 GeV in the ℓ +jets and dilepton analysis
83 respectively). Of course the hadronization modeling and the ISR/FSR effects play a major
84 role. The uncertainty arising from these effects is about 0.6 GeV for both analysis. The latests
85 ATLAS results in all analysis are reported in Table 1.

Table 1. Summary of top mass (MC mass) values from ATLAS.

decay channel	reference	m_t (GeV)
ℓ + jets	[9]	$172.31 \pm 0.75(\text{stat.} + \text{JSF} + b\text{JSF}) \pm 1.35(\text{syst.})$
dilepton	[10]	$173.09 \pm 0.64(\text{stat.}) \pm 1.50(\text{syst.})$
all-hadronic	[11]	$174.9 \pm 2.1(\text{stat.}) \pm 3.8(\text{syst.})$

86

Another mass measurement comes from the $t\bar{t}$ cross section ($\sigma_{t\bar{t}}$). The $\sigma_{t\bar{t}}$ has been calculated
87 at NNLO accuracy in α_s including the resummation of next-to-next-to-leading logarithmic
88 (NNLL) soft gluon terms [12, 13]. These calculations are performed in a well defined scheme
89 using the pole mass. ATLAS has already performed the measurements using the 7 and 8 TeV
90 LHC data [14] and obtained: $m_t^{\text{pole}} = 172.9 \pm_{2.6}^{2.5}$ GeV. Unfortunately, the dependence of $\sigma_{t\bar{t}}$ on
91 the mass is quite mild (Fig. 2). This is why the measurement of m_t^{pole} gets such a big uncertainty.

92 Finally, it is worth to mention that there are underway certain efforts to define a new
 93 observable sensitive to the m_t^{pole} that may provide a better accuracy than the $\sigma_{t\bar{t}}$ result. These
 94 studies consider the mass effects in the gluon radiation in $t\bar{t}$ events using NLO calculations [15].

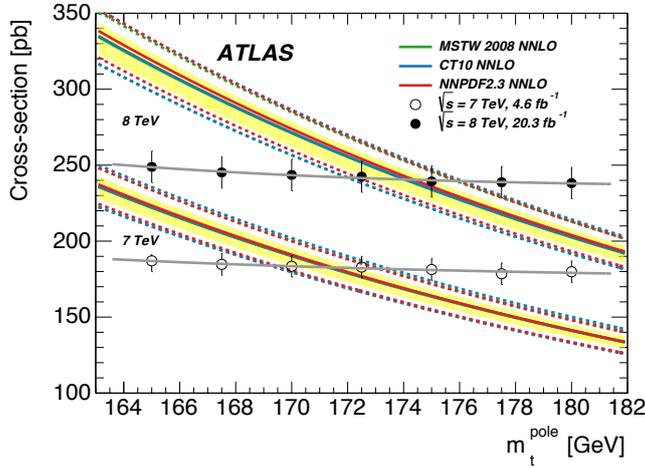


Figure 3. Predicted NNLO $\sigma_{t\bar{t}}$ at 7 and 8 TeV as a function of m_t^{pole} , showing the central values and total uncertainty bands with several PDF sets. The yellow band shows the QCD scale uncertainty. The measurements of $\sigma_{t\bar{t}}$ are also shown, with their dependence on the assumed value of m_t . Figure taken from [14].

95 3. Summary

96 The most up to date measurements of the top quark mass using ATLAS data have been reported.
 97 ATLAS, CMS, CDF and DØ measurement have been used to get a m_t world combination [16].

$$98 \quad m_t = 173.34 \pm 0.27(\text{stat.}) + 0.71(\text{syst.}) \text{ GeV.}$$

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