Top quark mass and properties at ATLAS

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Abstract. The measurements of the top quark mass and other top quark properties in the lepton+jets and dilepton channels at ATLAS are presented in this paper, with emphasis on the current understanding of the systematic uncertainties. All results were obtained using the data taken during 2010 at a proton-proton center-of-mass energy of $\sqrt{s} = 7$ TeV and correspond to an integrated luminosity of about 35 pb^{-1}.

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INTRODUCTION

Discovered in 1995 by the CDF and D0 experiments [2], the top quark is the heaviest known fundamental particle with a mass of $m_{\mathrm{top}} = 173.3 \pm 1.1$ GeV [4]. In contrast to the Tevatron, at the LHC [3] top quark pair production takes place through QCD interactions dominantly by gluon fusion ($\sim 85\%$) and to a less extent by quark-antiquark annihilation ($\sim 15\%$). Within the Standard Model (SM) the $t\bar{t}$ production cross section in proton-proton collisions at a center-of-mass energy $\sqrt{s} = 7$ TeV is predicted to be 165^{+11}_{-16} pb at approximate NNLO [5]. Recently, the CMS collaboration has presented a cross-section measurement, $\sigma_{t\bar{t}} = 158 \pm 19$ pb using 36 pb^{-1} of data [6] and ATLAS reported a measurement of $\sigma_{t\bar{t}} = 180 \pm 18$ pb for an integrated luminosity of 35 pb^{-1} [7]. Due to its short lifetime ($\sim 10^{-25}$s), smaller than the typical hadronization time scale ($\sim 10^{-24}$s), top quarks decay before hadronization can take place. The top quark spin information is then preserved in the decay products before hadronization can dilute it.

In this paper, the measurements of the top quark mass and several top quark properties are discussed. Top quarks are predicted to decay almost exclusively to a W boson and a b-quark ($t \to Wb$). Events from $t\bar{t}$ decays are classified as 'lepton+jets' or 'dilepton'. The 'lepton+jets' topology is characterized by an isolated charged lepton (electron or muon), missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$) corresponding to the undetected neutrino, two b quark jets and two light jets. The 'dilepton' final state is characterized by two isolated leptons, missing transverse energy corresponding to the undetected neutrinos, and two b quark jets.

TOP QUARK MASS

In ATLAS three complementary methods to measure m_{top} have been developed. They address the jet energy scale (JES) uncertainty in different ways. The first method is a 2-dimensional template analysis that simultaneously determines m_{top} and a global Jet

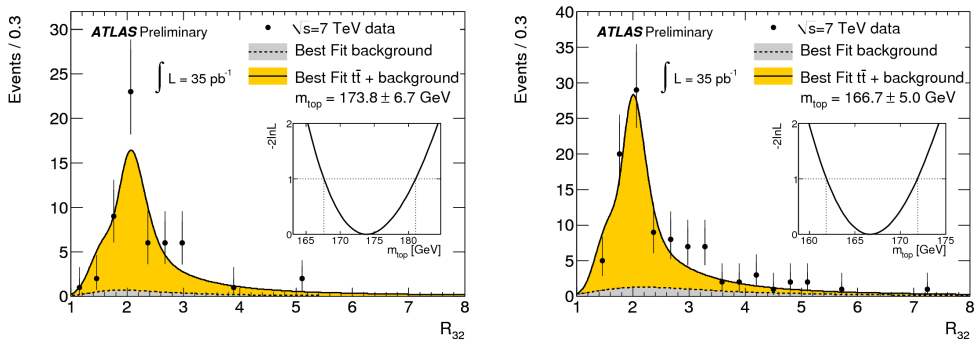

FIGURE 1. The measured R_{32} distributions for the electron (left) and muon (right) channels.

energy Scale Factor between data and predictions. The second method is a 1-dimensional template analysis exploiting a kinematical likelihood fit to all decay products of the $t\bar{t}$ system. Finally, the baseline analysis presented here is a 1-dimensional template analysis based on the measurement of the ratio of the reconstructed top-quark and W boson masses associated to the hadronically decaying top-quark candidate: $R_{32} = \frac{m_{\rm top}^{\rm reco}}{m_{\rm W}^{\rm reco}}$ [8]. The lepton+jets channel with lepton = e, μ was used.

Signal templates of the R_{32} distribution generated for different mass values $m_{\rm top} = 160$, 170, 172.5, 180, 190 GeV are compared to reconstructed data. The measured R_{32} distributions are shown in Figure 1 together with the signal template which best fits the data for the electron (left) and muon (right) channels. Combining both channels, the measured top-quark mass is $m_{\rm top} = 169.3 \pm 4.0$ (stat.) ± 4.9 (syst.) GeV. The main sources of systematic uncertainty stem from the initial and final state radiation (2.2 and 2.6 GeV for the e and μ channels respectively) and JES. For light-jets (b-jets) an uncertainty of 2.3 and 1.9 GeV for the e and μ channels respectively (2.5 GeV for both channels) was estimated taking into account the current light-jets JES uncertainty of 4% plus additional corrections from neighbor jets. An additional constant variation due to the b-tagged JES uncertainty (2.5%) was also applied. During the next year, the precision of this measurement is expected to be limited by the systematic uncertainty, for which the JES makes a significant contribution.

ATLAS has also measured the top quark pole mass ($m_{\rm top}^{\rm pole}$) indirectly from the measured $t\bar{t}$ cross-section using the lepton+jets channel [9]. The result, $m_{\rm top} = 166.4^{+7.8}_{-7.3}$ GeV, is in good agreement with the previous one.

W BOSON POLARIZATION

The helicity fractions (F_0,$F_{\rm L}$,$F_{\rm R}$) of the W-bosons produced in top quark decays can be extracted by measuring the angle θ^* (in the W-boson rest frame) between the charged lepton momentum from the W-boson decay and the reversed b-quark momentum from top quark decay ($t \to bW \to b\ell\nu_\ell$). The normalized decay rate for top quarks is:

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{8}(1+\cos\theta^*)^2 F_{\rm R} + \frac{3}{8}(1-\cos\theta^*)^2 F_{\rm L} + \frac{3}{4}\sin^2\theta^* F_0 . \qquad (1)$$

TABLE 1. Asymmetries and helicity fractions results

	$e+$jets	$\mu+$jets	combined
	Templates Method		
F_0	0.60 ± 0.20	0.56 ± 0.18	0.59 ± 0.12
F_L	0.40 ± 0.20	0.44 ± 0.18	0.41 ± 0.12
F_R	fixed to 0	fixed to 0	fixed to 0
	Correction Function Method		
A_{FB}	-0.30 ± 0.13	-0.29 ± 0.10	-0.29 ± 0.08
A_+	0.50 ± 0.12	0.50 ± 0.09	0.50 ± 0.07
A_-	-0.85 ± 0.09	-0.87 ± 0.05	-0.86 ± 0.04
F_0	0.64 ± 0.27	0.66 ± 0.19	0.65 ± 0.15
F_L	0.36 ± 0.17	0.36 ± 0.12	0.36 ± 0.10
F_R	0.00 ± 0.13	-0.02 ± 0.08	-0.01 ± 0.07

Within the Standard Model and assuming $m_b = 5.0$ GeV, the expected polarization fractions are $F_0 = 0.698$, $F_L = 0.301$, $F_R = 4.1 \times 10^{-4}$ at LO [10]. Angular asymmetries can be defined using this angular distribution. The advantage of using asymmetries is the possibility of canceling systematic uncertainties that may affect the angular distribution [11]. For any fixed value of z in the interval $[-1,1]$, one can define the asymmetry:

$$A_z = \frac{N(\cos\theta^* > z) - N(\cos\theta^* < z)}{N(\cos\theta^* > z) + N(\cos\theta^* < z)}. \tag{2}$$

Three asymmetries are defined involving F_0, F_L and F_R: $A_{FB} = \frac{3}{4}[F_R - F_L]$ $(z = 0)$, $A_+ = 3\beta[F_0 + (1+\beta)F_R]$ $(z = (2^{2/3} - 1))$ and $A_- = -3\beta[F_0 + (1+\beta)F_L]$ $(z = -(2^{2/3} - 1))$, where $\beta = 2^{1/3} - 1$.

The CDF and D0 experiments at the Tevatron have measured the helicity fractions to be $F_0 = 0.669 \pm 0.078$ (stat.) ± 0.065 (syst.) and $F_R = 0.023 \pm 0.041$ (stat.) $\pm$ 0.034 (syst.) [12]. ATLAS obtained the helicity fractions from the direct fit of the angular distribution and from the asymmetries measurements. Results are presented in Table 1 [13]. The measurements are in good agreement with the SM and are still dominated by the statistical uncertainty. Assuming $F_R = 0$, the main sources of systematic uncertainties for F_L and F_0 come from the background model (0.03), the modeling of initial and final state radiation (0.04) and the JES (0.03). The precision of these measurements will be dominated by the systematic uncertainty during the next year.

$t\bar{t}$ + ANOMALOUS E_T^{miss}

A search for anomalous missing transverse energy in the lepton+jets $t\bar{t}$ final state was performed [14]. Such decays can arise from several Standard Model extensions but the analysis is focused on a search for a pair-produced top partner (T) decaying to a top quark and a long lived neutral particle which escapes undetected. No evidence for signal was found in the data. The first limits from the LHC were set on the mass of such a particle, excluding $m(\mathrm{T}) < 300$ GeV for a neutral particle mass of 10 GeV and $m(\mathrm{T}) < 275$ GeV for a neutral particle mass of 50 GeV with 95% confidence level. The background modeling is the dominant systematic error in the E_T^{miss} signal

region. Although still limited by the statistical uncertainty, the understanding of $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution is of crucial importance to reduce the global systematic error during the next year.

FCNC

The $t \to qZ$ decay channel is searched for by looking for top quark pair production with one top quark decaying through Flavor Changing Neutral Current ($t \to qZ$) and the other through the Standard Model dominant mode ($t \to bW$). Only the leptonic decays of the Z and W bosons were considered as signal. Events with three leptons, two jets and $E_{\mathrm{T}}^{\mathrm{miss}}$ were selected. Additionally a search for anomalous single top quark production, through the FCNC ($qg \to t \to bW$) was also performed. No evidence for any FCNC signal is found. The upper limit on the $t \to qZ$ FCNC top quark decay branching ratio is $BR(t \to qZ) < 17\%$ at 95% confidence level (CL). For the single top quark production through FCNC, the observed 95% CL cross-section times branching fraction limit is $\sigma_{qg\to t} \times BR(t \to bW) < 17.3$ pb [15]. For the single top analysis the b-tagging, the JES and the lepton identification are the dominant systematic uncertainties. For the $t \to qZ$ channel, the dominant systematic uncertainties are the ISR/FSR and the background modeling, in particular the Z+jets background.

CONCLUSIONS

Several precision top quark measurements were already performed at ATLAS with a total luminosity of about 35 pb^{-1}. With the expected increase of luminosity during the next year, the statistical uncertainty will be very much improved and the results will be dominated by the systematical uncertainty. The understanding of ISR/FSR, JES and background modeling are particularly relevant for all the measurements discussed and should also profit from the expected increase of luminosity.

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