Top Quark Mass and Top Properties at ATLAS

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Abstract. The measurement of the top quark mass and other top quark properties, such as the W boson polarization, flavor changing neutral currents (FCNC), anomalous production with large missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$) and charge asymmetry in top quark pair ($t\bar{t}$) production, at ATLAS are presented in this paper. The results were obtained using the data collected during the 2010 proton-proton run of the LHC at a center-of-mass energy of 7 TeV, which corresponds to an integrated luminosity of 35 pb^{-1}. The charge asymmetry was measured with data taken during 2011 which corresponds to an integrated luminosity of 700 pb^{-1}.

Keywords: top quark mass, W boson polarization, anormalous $E_{\mathrm{T}}^{\mathrm{miss}}$, FCNC, charge asymmetry
PACS: 10

INTRODUCTION

The top quark is the heaviest known fundamental particle, with a mass of 173.3 ± 1.1 GeV [1]. It was discovered in 1995 by the Tevatron experiments CDF and D0 [2, 3]. At the LHC the main production mechanism for top quark pairs is gluon fusion ($\sim$ 85%) while the quark-quark annihilation was dominant at the Tevatron. The standard model (SM) pair production cross section for proton-proton collisions at 7 TeV is predicted to be 165^{+11}_{-16} pb [4, 5] (at approx. next-to-next-to-leading order calculation) which is also in agreement with the latest cross section measurements at the LHC experiments ATLAS [6] and CMS [7]. A description of the ATLAS detector can be found in [8, 9]. The abundant production of top quarks enables studies of the top properties that were statistically limited at the Tevatron. The electroweak production of top quarks results in single observable top quarks. This is ideal to probe the top quark production and decay vertices in isolation.

The top quark decays in the SM almost exclusively to a W boson and a b quark ($t \to Wb$). Events are classified according to the decay modes of the W bosons as lepton+jets or dilepton. The lepton+jets final state topology consists of an isolated charged lepton (electron or muon), large $E_{\mathrm{T}}^{\mathrm{miss}}$ from the neutrino, two b-jets and two light quark jets. Jets from b quarks are identified with the SV0 b-tagging algorithm [10] with an efficiency of $\sim$ 50%. At least one jet needs to be tagged. Another signal discriminant is the W-boson transverse mass calculated from the lepton and the $E_{\mathrm{T}}^{\mathrm{miss}}$ vector[2]. The $t\bar{t}$ kinematics can be reconstructed in a kinematic fit from the final state particles in which the decay kinematics and the top/W boson masses enter as constraints. Single top decay signatures are very similar to $t\bar{t}$ signatures with typically fewer jets. Most single top analyses suffer from $t\bar{t}$ and W+heavy flavor background, but with advanced analysis techniques this production mode has been observed at Tevatron and LHC [11, 12, 13].

TOP QUARK MASS

The main measurement of the top quark mass at ATLAS has been performed with a template method. The 1-D templates are made of the reconstructed top quark/W boson mass ratio distribution R_{23} [14]. This ratio was chosen to reduce the jet energy scale (JES) uncertainty. Lepton+jets $t\bar{t}$ events are selected from data sample corresponding to an integrated luminosity of 35.0 ± 1.2 pb^{-1}, and the top mass is calculated from the three jets with the highest vector-p_{T} sum. The W boson mass is calculated from the invariant mass of the two (of the three) jets that are not b-tagged. Events with two or more b-tagged jets in the jet triplet are rejected and the event selection is further restricted

[2] The $E_{\mathrm{T}}^{\mathrm{miss}}$ calculation begins with the vector sum of transverse momenta of all jets with $p_{\mathrm{T}} > 20$ GeV and $|\eta| < 4.5$. The calibrated transverse energies of electron candidates are added. The contributions from all well-identified muon candidates and calorimeter clusters not belonging to a reconstructed object are also included.

to events with a reconstructed W boson mass between 60 and 100 GeV. The top mass is extracted from an unbinned likelihood fit to R_{23} distributions generated at different top masses. The data distribution and the best fit template for the electron and muon channel can be seen in Figure 1. Combining the electron and muon channel yields a top mass of $m_t = 169.3 \pm 4.0\,(\text{stat.}) \pm 4.9\,(\text{syst.})$ GeV. The largest systematic uncertainties stem from initial and final state radiation (ISR/FSR) modeling, light jet and b-jet energy scale.

Cross checks have been performed with three methods: A template method where the reconstructed top mass distribution is taken from a kinematic fit on the event [14], a 2-D template method where simultaneously a global JES factor and the top mass is extracted [14], and an indirect top mass determination from the $t\bar{t}$ cross section exploiting the theoretical correlation between these two quantities [15]. The top masses determined with the different methods are compatible with the main result.

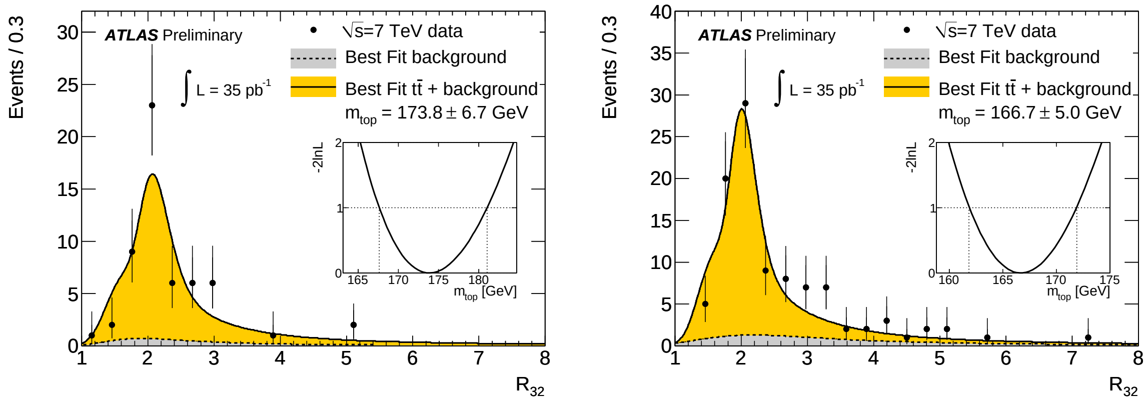

FIGURE 1. R_{23} distribution for data and the best fit template for the top mass in the electron (left) and muon (right) channel.

FCNC

Flavor changing neutral currents (FCNC) in top quark decays, in which the top quark produces a Z boson instead of a W boson, occur in the SM only through loop effects. The SM branching ratio (BR) is in the order of 10^{-12} [16]. This BR can be modified in new physics models and hence is interesting to measure. For this search the fully leptonic (three leptons) signature is chosen in order to suppress QCD multi-jet background [17]. The three leptons are required to pass different p_{T} thresholds and two of them must have the same flavor and opposite charge. After this stringent selection only one candidate event is found in the data sample and a limit of BR $< 17\%$ (observed limit at 95% CL) was calculated.

FCNC at production can be observed in single top production where the top quark originates from a $qg \to t$ (q=u,c quarks) vertex. In certain models this cross section can reach 10 pb. With a tighter requirement of exactly one jet, b-tagged, in the event and a neural network with 13 input variables, no excess over the SM background was found [17]. The 95% CL limit on the cross section, $\sigma_{qg\to t}$, was calculated to be $\sigma_{qg\to t} \times \mathrm{BR}_{t\to Wb} < 17.3$ pb. The largest systematic uncertainties stem from initial state radiation (ISR) modeling, JES and the fraction of heavy flavor in the W+jets background.

ANOMALOUS $E_{\mathrm{T}}^{\mathrm{miss}}$

$t\bar{t}$ are usually found with $E_{\mathrm{T}}^{\mathrm{miss}}$ arising from the escaping neutrinos. In SM extensions, anomalous large $E_{\mathrm{T}}^{\mathrm{miss}}$ can arise from additional non-SM neutral particles that are created along with the $t\bar{t}$ pair. This search focuses on a vector top partner (T) pair decaying into two long-lived, neutral scalars (A^0) and a $t\bar{t}$ pair [18]. There is no requirement on the b-tagged jet in the lepton+jets events, but the requirement on $E_{\mathrm{T}}^{\mathrm{miss}}$ and the transverse mass are stricter. The veto against dilepton events is also more restrictive. It uses a lower p_{T} threshold for any extra lepton, a looser selection for any extra electron and checks for isolated tracks. So far no excess has been found in data and limits at 95% CL on the mass of the T (m_{T}) for two mass ranges of A^0 have been derived: $m_{\mathrm{T}} < 275$ GeV and $m_{\mathrm{T}} < 300$ GeV for $m_{A^0} < 50$ GeV and $m_{A^0} < 10$ GeV, respectively. The background modeling of the $E_{\mathrm{T}}^{\mathrm{miss}}$ signal is the largest systematic uncertainty.

W-BOSON POLARIZATION

The helicity fraction (F_0, F_{L}, F_{R}) of the W boson produced in top quark decays can be calculated in the SM to be $F_0 = 0.698$, $F_{\mathrm{L}} = 0.301$, and $F_{\mathrm{R}} = 4.1 \times 10^{-4}$ [19]. The fractions can be measured from the angle θ^* between the charged lepton and the b-quark momentum vector in the W-boson rest frame. Two methods have been used at ATLAS to measure the helicity fractions [20]. The asymmetry method determines the asymmetry of the $\cos\theta^*$ distribution at three intervals and relates these measurements to the helicity fractions. The template method uses simulated pure helicity states and determines the fractions in a binned likelihood fit. The two analyses reconstruct fully the $t\bar{t}$ lepton+jets events with a χ^2 method and a kinematic fit, respectively. Both results are compatible with SM expectations, but they are still statistically limited. The largest systematic uncertainties are due to ISR/FSR modeling, JES and background shapes.

CHARGE ASYMMETRY

The measurement of the charge asymmetry in $t\bar{t}$ production [21] has been performed on data corresponding to an integrated luminosity of 700 ± 26 pb^{-1} [22]. The charge asymmetry that has been observed at the Tevatron is mainly caused by the interference of the production diagrams involving quark-anti-quark and quark-gluons in the initial state. This results in a forward-backward (FB) asymmetry between top and anti-top quarks and a deviation from the SM expectation was observed [23, 24, 25]. At the LHC the gluon-gluon initiated state is dominating and symmetric under charge exchange. Thus the $t\bar{t}$ system is not expected to exhibit a FB asymmetry. Measurable instead is the feature that the distribution of anti-top quarks is more central, while top quarks are produced at slightly higher η. The asymmetry (A_C) is expressed as the difference ($\Delta|Y| = |Y_t| - |Y_{\bar{t}}|$) between the reconstructed top (Y_t) and anti-top ($Y_{\bar{t}}$) rapidity:

$$A_C = \frac{N(\Delta|Y| > 0) - N(\Delta|Y| < 0)}{N(\Delta|Y| > 0) + N(\Delta|Y| < 0)}$$

The top quarks are reconstructed from the lepton+jets final state particles with a kinematic fit and the result is unfolded to parton level. The $\Delta|Y|$ distributions for data and Monte Carlo can be seen in Figure 2. The result of $A_C = -0.024 \pm 0.016\,(\mathrm{stat.}) \pm 0.034\,(\mathrm{syst.})$ is in agreement with the expected asymmetry of $A_C = 0.006$ (MC@NLO simulation). The main systematic uncertainties are due to the theoretical modeling (generator choice, parton shower and fragmentation model, top mass uncertainty), JES and jet energy resolution.

CONCLUSIONS

Several precision top quark measurements have been performed at ATLAS with data corresponding to integrated luminosities of 35 pb^{-1} and 700 pb^{-1}. So far no deviations from the SM expectation have been seen in FCNC in the $t\bar{t}$ and single top channels, W-boson helicity fractions and charge asymmetry in the $t\bar{t}$ production. No excess in the production with anomalous $E_{\mathrm{T}}^{\mathrm{miss}}$ has been observed. The top quark mass has been determined to be $m_t = 169.3 \pm 4.0\,(\mathrm{stat.}) \pm 4.9\,(\mathrm{syst.})$ GeV.

Most analyses are not statistically limited and it is expected that with the already available data collected in 2011 the largest systematic effects will be much better under control. This will improve the analyses results.

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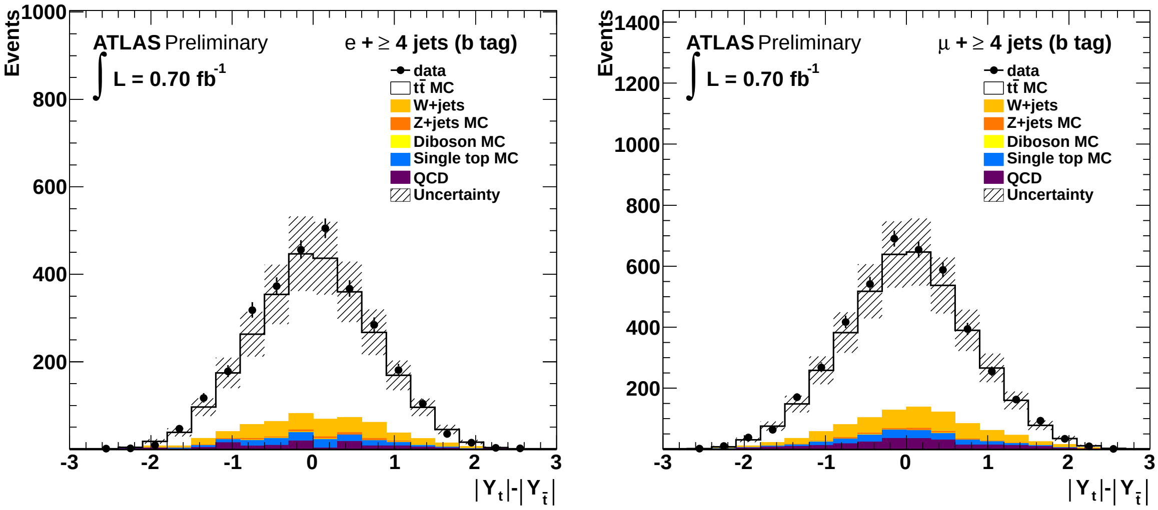

FIGURE 2. $\Delta|Y| = |Y_t| - |Y_{\bar{t}}|$ distributions for electron (left) and muon (right) channel in data (points with statistical uncertainties) and MC simulations (solid lines with total uncertainty bands).

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