Measurement of top-quark properties with the ATLAS experiment

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Abstract

Since the start of the LHC physics programme in 2009, a huge number of top quarks have been produced in collisions and recorded by the experiments. In 2011, 4.7 fb^{-1} of data has been collected by the ATLAS experiment [1] at $\sqrt{s} = 7$ TeV. This allows not only for searches of rare processes but for precision measurements of top quark properties. These measurements are especially important since they allow for tests of Standard Model predictions and for searches of new physics processes.

1 Introduction

The top quark decays almost exclusively into a W boson and a b quark. The decay modes of the W boson define three $t\bar{t}$ final states: lepton+jets, dilepton and all hadronic. The measurements summarised here have been performed in one or more of these decay channels using data sets of 1.04 – 4.7 fb^{-1} .

2 Measurements of top-quark properties

Measurement of the top quark mass The top quark mass is a fundamental parameter of the Standard Model that has been measured at the Tevatron to large precision: $\mathrm{m_{top}} = 173.2 \pm 0.6$ (stat.) $\pm$ 0.8 (syst.) GeV [2]. The ATLAS experiment has performed several measurements in the lepton+jets and in the fully hadronic channel.
In the lepton+jets channel, two analyses utilize 1.04 fb^{-1} of data each. The first uses a two-dimensional template fit to simultaneously extract the top quark mass and the Jet Scale Factor (JSF). The JSF is a global correction factor that accounts for the differences between the simulated and observed reconstructed W mass $\mathrm{m_W^{reco}}$ and is sensitive to the Jet Energy Scale (JES). The top mass obtained from this 2D fit yields: $\mathrm{m_{top}} = 174.5 \pm 0.6$ (stat.) $\pm$ 2.3 (syst.) GeV [3].

The second method performes a one dimensional template fit, using the R32 variable (defined as the ratio of the reconstructed top quark mass and the reconstructed W mass) as the observable. The result is in good agreement with the 2D fit:
m_{top} = 174.4 ± 0.9 (stat.) ± 2.5 (syst.) GeV [3].
The analysis in the all hadronic channel uses 2.04 fb^{-1} of data. Multijet production is the dominant source of background and is estimated from data. The events are reconstructed using a χ^2 fit. A one dimensional template fit is performed to the data. The systematic uncertainty is dominated by the JES and by the background modelling. The final result is: m_{top} = 174.9 ± 2.1 (stat.) ± 3.8 (syst.) GeV [4].

$t\bar{t}\gamma$ cross-section The electromagnetic coupling of the top quark is tested through a measurement of the cross-section for $t\bar{t}$-production in association with an additional photon using a data set of 1.04 fb^{-1} . In the analysis, prompt photons have to be distinguished from hadrons that are faking photons. Since prompt photons are in general isolated and those faked by hadrons are not, the photon isolation can be used as an observable in a template fit. Background templates are obtained using data driven techniques. Interference effects between radiative top quark production and decay are taken into account. The $t\bar{t}\gamma$ cross-section times branching ratio for photons with p_T > 8 GeV has been measured to:
σ = 2.0 ± 0.5 (stat) ± 0.7 (syst.) ± 0.08 (lumi) pb [5].

Charge asymmetry A small charge asymmetry in $t\bar{t}$-production is expected at NLO due to interferences between initial and final state radiation (ISR/FSR) as well as between Born- and box-diagrams. A deviation from the prediction could be a hint at the existence of new particles such as W' or Z' bosons. The Tevatron measurement of A_{FB} shows an excess as well as a mass dependence of the forward-backward asymmetry. Since the LHC is a pp collider, the charge asymmetry A_C (defined as $A_C = \frac{N(\Delta|y|>0)-N(\Delta|y|<0)}{N(\Delta|y|>0)+N(\Delta|y|<0)}$) is used instead of A_{FB}.
In the lepton+jets channel, the difference of the absolute rapidities between top- and antitop-quark $\Delta|y|$ is used to determine A_C in a data set of 1.04 fb^{-1} . A Bayesian unfolding method is applied. The result obtained for A_C is in good agreement with the SM prediction: A_C = -0.019 ± 0.028 (stat.) ± 0.024 (syst.) [6]. No mass dependence of the result is observed.
In the dilepton channel, the complete 2011 data set of 4.7 fb^{-1} is used [7]. In addition to the top quark-based asymmetry, the charge asymmetry of the two leptons is studied using the difference of the absolute pseudorapidities. No deviation from the SM prediction is found.

Spin correlation Since the top quark decays before it can hadronise, the spin information of the top quarks is transferred to its decay products. Therefore the spin correlation between the two top quarks in a top-quark pair event can be measured by studying the leptons and quarks from the decay. The spin correlation has been measured in the dilepton channel in 2.1 fb^{-1} of data [8], using the angular difference between the two charged leptons as observable. The measured spin correlation yields $A_{\text{helicity}} = 0.40^{+0.09}_{-0.08}$ (SM prediction: 0.31) and excludes the no spin correlation hypothesis with a significance of 5.1 σ. This result is the first observation of spin correlation in $t\bar{t}$-events.

W **boson polarization** *W* bosons from top-quark decays can either be longitudinally, left-handed or right-handed polarized where the right-handed contribution is strongly suppressed by the (V-A) structure of the Wtb vertex. This vertex structure can therefore be tested by comparing the measured W-helicity fractions with the SM predictions. Any deviation from the predicted values of F_0= 0.687(5), F_{L}= 0.311(5), F_{R} =0.0017(1) [9] could be a hint at non-SM physics processes. In ATLAS, the W-helicity fractions have been measured with two different approaches, both using the angular distribution of the charged lepton in the W boson rest frame. The first analysis performs a direct measurement using a template method while the second one measures angular asymmetries and uses them to determine the helicity fractions. Both analyses have been performed in the lepton+jets and in the dilepton channel, using 1.05 fb^{-1} of data. The four results are combined using the BLUE method [10, 11]. The combined result is in good agreement with the SM prediction and is the most precise measurement of the W-helicity fractions in top quark decays to date: F_0= 0.67 ± 0.07, F_{L}= 0.32 ± 0.04 and F_{R}= 0.01 ± 0.05 [12].

Searches for FCNC The large number of top quarks that are produced at the LHC allows for searches for rare processes such as searches for flavour changing neutral currents (FCNC). Two searches have been performed with one analysis looking for FCNC in single top production and one looking for FCNC in top decays.
In the SM, the decay $t \rightarrow qg$ is a rare process that is difficult to separate from the multijet background. Therefore, a search for FCNC in top production is performed ($qg \rightarrow t \rightarrow W(\rightarrow l\nu)b$) using 2.05 fb^{-1} of data. A neural network is used in the analysis [13]. No deviation from SM predictions has been found, therefore limits are set on the branching ratios at 95 % C.L.: BR($t \rightarrow ug$) $< 5.7 \cdot 10^{-5}$, BR($t \rightarrow cg$) $< 2.7 \cdot 10^{-4}$.
The second analysis searches for ttbar events where one of the top quarks decays into qZ. Only events with leptonically decaying Z and W bosons are considered. Since no signal is found, a limit is set on the branching ratio at 95 % C.L.: BR($t \rightarrow qZ$) < 0.73 % [14].

3 Conclusion and outlook

ATLAS has a wide-ranging programme of top-quark properties studies. Even though the full data set is not used in all the measurements, they already have a comparable or better precision than the corresponding results from the Tevatron. The highlights described here are the most precise measurement of the W-helicity fractions in top-quark decays and the observation of $t\bar{t}$ spin-correlation in the dilepton channel.

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