Top quark properties at ATLAS

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Discovered in 1995 by the CDF and D experiments at Tevatron, the top quark is the heaviest known elementary particle. Its properties might offer a hint of physics beyond the Standard Model. It is thus of interest to measure them as precisely as possible. We present a summary of property measurements of the top quarks which are produced in pp collisions with $\sqrt{s} = 7$ TeV at the LHC. Measurements of the top quark charge, the inclusive $t\bar{t}\gamma$ cross section, the W boson polarisation in top quark decays, the spin correlation in $t\bar{t}$ production and the charge asymmetry in $t\bar{t}$ production were performed with the ATLAS experiment. All measurements are in good agreement with the Standard Model predictions.

1 Introduction

The top quark was discovered in 1995 [1, 2], but many of its properties have been measured only with large uncertainties or not at all. Since a large number of top quarks from pp collisions with $\sqrt{s} = 7$ TeV at the LHC was already recorded by the ATLAS experiment, measurements with much higher precision can be performed to investigate the properties of the top quark. These precise measurements might give us a clue to catch physics beyond the Standard Model. Top quarks are produced mainly in pairs via the strong interaction and are predicted to decay via the electroweak interaction into a W boson and a bottom quark with nearly 100% branching ratio. Events are classified according to the decay of the W bosons. Each boson can either decay into a pair of quarks or into a charged lepton and a neutrino. Single lepton and dilepton topologies (one and two charged leptons in the final state respectively) were used in the analyses presented below. Only electrons and muons, including those from tau decays, were considered.

2 Top quark charge

The top quark charge was measured using 0.70 fb^{-1} of data. This measurement relies on the charge reconstruction of the top quark decay products. While the charge of the W boson can be determined through its leptonic decay, the b-quark charge is not directly measurable, as the b-quark hadronisation process results in a jet of hadronic particles (b-jet). It is possible however to establish a correlation between the charge of the b-quark and a weighted sum of the electric charges of the particles belonging to the b-jet. This weighted sum was used as the b-jet charge. The combined b-jet charge, $\mathcal{Q}_{comb}$ was defined as the product of the b-jet charge and the lepton charge for the b-jet associated with the leptonically decaying W. The measured average value of $\mathcal{Q}_{comb}$ was found to be in good agreement with the SM prediction. Also, the result was compared with the expectation for a "top-like" quark with an exotic charge of -4/3e. The exotic scenario is excluded at more than five standard deviations [3].

3 Inclusive $t\bar{t}\gamma$ cross section

Top quark pair events with additional photons in the final state are directly sensitive to the $t\bar{t}\gamma$ vertex. A first measurement of the $t\bar{t}\gamma$ cross section in pp collisions at $\sqrt{s}$ =7 TeV was performed using 1.04 fb^{-1} of data. Events are selected that contain a large transverse momentum electron or muon and a large transverse momentum photon. In the electron and muon samples, 52 and 70 candidate events were identified, respectively. The amount of the signal contribution was extracted using the template fitting method. The resulting cross section times branching ratio into the single and dilepton channel $t\bar{t}\gamma$ production with a photon with transverse momentum above 8 GeV is

$$\sigma_{t\bar{t}\gamma} \times \mathrm{BR} = 2.0 \pm 0.5(\mathrm{stat.}) \pm 0.7(\mathrm{syst.}) \pm 0.08(\mathrm{lumi.})\mathrm{pb}\ [4].$$

This result is consistent with the theoretical calculation which yields 2.1 ± 0.4 pb [5, 6] for the same phase space and decay channels.

4 W boson polarisation in top quark decays

A measurement of the helicity of W bosons and angular asymmetries in top quark decays was performed using final states with one or two charged leptons, missing transverse energy and at least four or two jets, respectively, with an integrated luminosity of 1.04 fb^{-1}. The fraction of each W boson helicity state (longitudinal, right- and left-handed. Each of them are called F_0, F_R and F_L, respectively) was extracted using the template fitting method for both single lepton and dilepton channel. The results obtained by fitting the three helicity fractions and from the asymmetry measurement are compatible with each other in all channels. Since F_R was found to be compatible with zero within uncertainty, the fit was repeated for a fixed F_R.

A combination of the measurements in the single lepton and dilepton channels with the right-handed fraction set to zero yields:

$$\begin{aligned} F_0 &= 0.66 \pm 0.03(\mathrm{stat.}) \pm 0.04(\mathrm{stat.}), \\ F_L &= 0.34 \pm 0.03(\mathrm{stat.}) \pm 0.04(\mathrm{stat.})\ [7]. \end{aligned}$$

This result is in agreement with the NNLO QCD prediction. As the polarisation of the W bosons in top quark decays is sensitive to the structure of the Wtb-vertex, the measurements were used to set limits on anomalous contributions to the Wtb-Lagrangian [8]. There are four couplings in the Lagrangian (V_L, V_R, g_L and g_R) and V_R, g_L and g_R are absent in the SM at the tree level. Figure 1 shows the allowed region of the anomalous couplings g_L and g_R with V_R set to zero.

5 Spin correlation in $t\bar{t}$ production

A measurement of the spin correlation in $t\bar{t}$ production was performed using data corresponding to an integrated luminosity of 2.1 fb^{-1}. The lifetime of the top quark is at least an order of magnitude shorter than the timescale for strong interactions, implying that the top quark decays before hadronisation. Therefore the spin of the top quark at production is transferred to its decay products and can be measured directly via their angular distributions. In this analysis, candidate events were selected in the dilepton topology with large missing transverse energy and at least two jets. The difference in azimuthal angle between the two charged leptons in the laboratory frame was used to extract the correlation between the top and antitop quark spins. In the helicity basis the measured degree of correlation corresponds to

$$A_{\text{helicity}} = 0.40 \pm 0.04(\text{stat.})^{+0.08}_{-0.07}(\text{syst.})\ [9],$$

in agreement with the NLO SM prediction. The hypothesis of zero spin correlation is excluded at 5.1 standard deviations.

6 Charge asymmetry in $t\bar{t}$ production

Due to the asymmetry in the production via $q\bar{q}$ and qg, QCD predicts at the LHC a small excess of centrally produced antitop quarks while top quarks are produced, on average, at higher absolute rapidities. Thus, a measurement of the top-antitop production charge asymmetry A_C was performed using data corresponding to an integrated luminosity of 1.04 fb^{-1}. A_C is defined as

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

where $\Delta|y| \equiv |y_t| - |y_{\bar{t}}|$ is the difference between the absolute values of the top and antitop rapidities ($|y_t|$ and $|y_{\bar{t}}$) and N is the number of events with $\Delta|y|$ positive or negative. Events were selected with exactly one isolated lepton, missing transverse momentum and at least four jets of which at least one identified as coming from a b-quark. A kinematic fit was used to reconstruct the $t\bar{t}$ event topology. After background subtraction, a Bayesian unfolding procedure was performed to correct for acceptance and detector effects. Measurement yields

$$A_C = -0.018 \pm 0.028(\text{stat.}) \pm 0.023(\text{syst.})\ [10],$$

consistent with the prediction from the MC@NLO [11] Monte Carlo generator $A_C = 0.006 \pm 0.002$. Also, Figure 2 summarises the measurements of A_C in two ranges of invariant mass of the top-antitop pair. These results are compatible with the prediction from the MC@NLO Monte Carlo generator, showing no evidence for an enhancement from physics beyond the Standard Model.

7 Summary

Several top properties measurements were performed with the ATLAS experiment. Spin correlations in $t\bar{t}$ production were observed with 5.1 sigma significance. All results are in good agreement with the SM predictions. Most of them will profit from the higher luminosity.

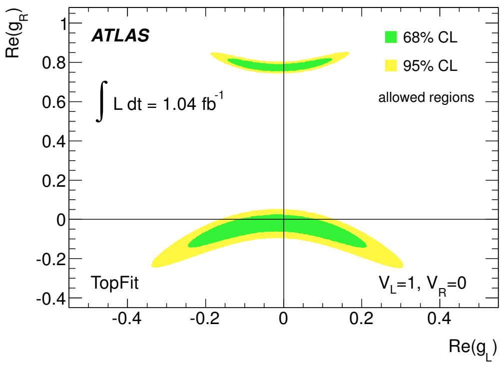

Figure 1: Allowed regions at 68% CL (green) and at 95% CL (green+yellow) for the Wtb anomalous couplings [7].

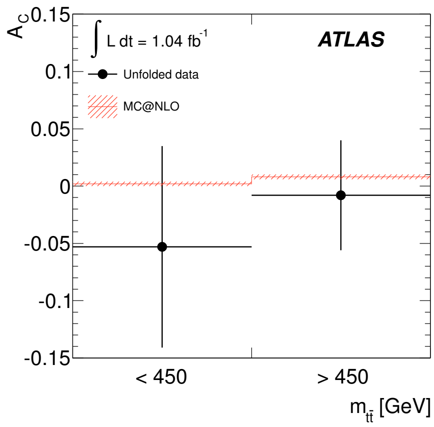

Figure 2: Unfolded asymmetries in two regions of $m_{t\bar{t}}$ compared to the prediction from MC@NLO. The error bands on the prediction include uncertainties from parton distribution functions and renormalisation and factorisation scales [10].

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