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Measurements of top quark decay properties in ATLAS

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A summary on the most recent results of the ATLAS Collaboration on top quark properties is presented. Most of the analyses use 2010 data, corresponding to an integrated luminosity of 35 pb^{-1}, while some higher statistics of data was taken in 2011. Many interesting results that constrain several new physics models can already be obtained.

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1. Introduction

The top quark completes the three generation structure of the Standard Model (SM). After QCD jets, W and Z bosons, the production of top quarks is the dominant process in pp collisions at multi-TeV energies: at $\sqrt{s}$=7 TeV with an instantaneous luminosity of $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, 10 $t\bar{t}$ pairs are produced per minute. Therefore studying the top quark properties at the LHC is of great interest since it can lead to precise tests of the Standard Model (SM), predictions in terms of charge, spin and the Wtb vertex. It also allows one to look for new physics, which is likely to show up in the top sector, by searching for rare decays, anomalous couplings, anomalous production of missing energy, $t\bar{t}$ charge asymmetry, Flavour Changing Neutral Currents (FCNC) or resonances that would decay into $t\bar{t}$. A short summary of the most recent results by the ATLAS Collaboration is presented here.

2. Selection of top events

The top properties analyses presented here mainly use single-lepton final states, where one of the W's from the top decays hadronically and the other leptonically. The main selection cuts are common to most analyses: where necessary differences will be emphasized. The selection requires exactly one high p_T isolated muon or electron (typically with p_T>20 GeV), 4 high p_T jets (p_T>25 GeV), one of which should be b-tagged. Missing Transverse Energy (MET) is required to be >35 and 20 GeV for the electron and muon channel, respectively. In addition the reconstructed transverse mass of the leptonically decaying W ($m_T(W)$) should satisfy: $m_T(W)$>25 GeV (MET+$m_T(W)$>60 GeV) for the electron (muon) channel.

3. W boson polarization

The polarisation of W bosons in top-quark decays is sensitive to the Wtb vertex structure from which limits on new physics can be extracted. In this analysis the W-boson helicity fractions and angular asymmetries are measured using single-lepton final states. The information on the z component of the neutrino momentum ($p_z(\nu)$) is obtained from a kinematic fit or from a χ^2 minimisation [1]. The QCD multi-jet shape and normalisation are obtained from data-driven methods, namely the matrix method. Two different methods are used to determine the polarisation: the first extracts the helicity fractions from a likelihood fit of the $\cos\theta^*$ distribution using MC templates corresponding to different pure helicity states. The second method extracts the angular asymmetries by counting events in 2 bins of $\cos\theta^*$ distribution:

$$A_Z = \frac{N(\cos\theta^* > z) - N(\cos\theta^* < z)}{N(\cos\theta^* > z) + N(\cos\theta^* < z)}. \tag{3.1}$$

Three different z values are used to extract the W helicity fractions F_0, F_L, F_R and a detector correction function is used to recover the undistorted parton level distributions.

The results obtained with an integrated luminosity of 35 pb^{-1} are shown in table 1. The measurement is dominated by the statistical error which is about 16%, while the main systematics are due to initial and final state radiation (ISR/FSR) and jet energy scale (JES) which are about 7%

Table 1: The W helicity fractions F_0, F_L, F_R extracted with the template method and with the asymmetry method, together with the SM predictions. Errors include both statistics and systematics.

	Template method	Asymmetry method	V-A
F_L	0.42±0.12	0.36±0.10	0.3
F_0	0.59±0.12	0.65±0.15	0.7
F_R	Fixed 0	0.01±0.07	∼0

and 5%, respectively. Good agreement has been found with SM expectations and limits have been extracted on Wtb anomalous couplings, resulting in a value compatible with 0 (the SM expectation). New physics above the electroweak symmetry breaking scale could be parametrised in terms of an effective Lagrangian with three additional anomalous couplings generated by dimension six-operators that are absent in the SM: V_R, g_L, g_R. Those would cause the W-boson helicity fractions to depart from their SM values [2]. Since no excess has been observed with respect to the SM, limits have been derived on such couplings: Re$(V_R) \in$ [-0.44,0.48], Re$(g_L) \in$ [-2.83,2.46] and Re$(g_R) \in$ [-5.59,1.81].

4. FCNC in top decays

In the SM, FCNC are forbidden at tree level in the SM, and are expected to be much smaller than the $t \rightarrow Wb$ Branching Ration (BR) at 1 loop. On the other hand several SM extensions among which 2 Higgs doublet models, the MSSM and SUSY R-Parity violation, predict higher BRs [3]. The search for FCNC selects events with one top decaying via the SM decay and the other decaying via FCNC into qZ. The SM prediction for the latter is at the level of 10^{-12}%, while new physics would predict this BR to be between $10^{-2} - 10^{-8}$%. The selection requires 3 leptons in the final state, 2 out of which should have the same flavour and opposite charge with $p_T \geq 25$, 20 and 15 GeV respectively. Additionally exactly 2 jets with $p_T \geq$ 35 and 20 GeV, respectively, and MET$\geq$ 20 GeV are asked for. The information on $p_z(\nu)$ is obtained from a χ^2 minimisation [4]. No evidence for such decays has been observed and limits has been obtained: BR$(t \rightarrow qZ) < 17\%$ at 95% confidence level (CL). Similarly, a search has been performed for the production of single top-quark events via FCNC, e.g. by looking for the $qg \rightarrow t$ vertex. The selection in this case is the standard single lepton one, where the $p_z(\nu)$ is obtained by imposing the m_W mass constraint. A neural network is used to better separate signal and background and uses 13 kinematic variables as input. Analysing 35 pb^{-1} of data, no excess is observed with respect to the SM expectations and the observed 95% CL cross-section times branching fraction limit is $\sigma(qg \rightarrow t)BR(t \rightarrow bW) <$ 17.3 pb [4].

5. Event with anomalous MET

Events with an anomalous amount of MET have been selected by using the standard single-lepton selection with no b-tagged jet, MET$>$ 80 GeV and the invariant transverse mass $m_T > 120$ GeV, where m_T is obtained from the lepton and MET [5]. Several models would predict such event topologies, e.g. little Higgs [6], stop quark production in SUSY and UED models with KK-parity [7]. They would lead to a pair-produced exotic quark-like top partner T that would decay into a tA_0 final state, with A_0 being a stable neutral scalar (which is a Dark Matter candidate) that escapes undetected. The main backgrounds are estimated via data-driven techniques. For the QCD background, the matrix method is used. The W+jets and single-lepton $t\bar{t}$ are treated together and estimated from the data: no evidence of a shape correction to be applied to the MC has been found and the distribution of m_T near to the m_W peak (60-90 GeV) is used for the MC normalisation. When analysing 35 pb^{-1} of data, no evidence of anomalous MET production has been found and 95% CL limits on the mass of the top partner T have been obtained: $m(T) < 275$ (300) GeV for $m_{A_0} < 50$ (10) GeV.

6. $t\bar{t}$ resonances

Various resonances might decay into $t\bar{t}$ pairs, in particular two models are studied: a Kaluza Klein gluon g_{KK} (coloured) in the Randall Sundrum model [8] that predicts the existence of a narrow $t\bar{t}$ resonance and a leptophobic $Z^{'}$ (colourless) in a Topcolor model that predicts a narrow resonance. The analysis has been performed using 200 pb^{-1} of ATLAS data [10], the standard single-lepton selection has been applied and the main backgrounds (QCD and W+jets) have been estimated from data-driven techniques: the shape and normalization of the QCD background uses the matrix method. A data sample enriched in W+jets is used to normalise and extract the shape of this same background: the sample has been selected by requiring exactly one isolated lepton, 30<MET<80 GeV, 40< M_T <80 GeV and no b-tag. The $p_z(\nu)$ is obtained by imposing the m_W mass constraint. The jet multiplicity distribution is then fitted to extract the scale factors in each jet bin. The main systematics arise from the b-tagging efficiency and JES (11%, 9%, respectively). No evidence of an excess with respect to the SM expectations is observed. For the $Z^{'}$ the observation cannot exclude a mass range yet, but the analysis probes already cross sections of a few pb at $m_{Z'} \sim$1 TeV. A Kaluza Klein gluon with mass larger than 650 GeV is excluded at 95% CL. The obtained limits are also shown in figure 1.

7. Charge asymmetry in $t\bar{t}$ events

At NLO, QCD predicts an asymmetry for $t\bar{t}$ events produced via the $q\bar{q}$ initial state, mainly through interference of the box/s-channel and ISR/FSR diagrams. As a consequence the top quark is predicted to be emitted preferably in the direction of the incoming quark, while the antitop in the direction of the antiquark. New physics models can alter this asymmetry and a measurement at Tevatron shows a 2σ excess over the SM [11]. At LHC, $t\bar{t}$ events are mainly produced via gluon gluon fusion which is symmetric: although a small asymmetry is predicted from the $q\bar{q}$ initial state (0.6% from the MC@NLO Monte Carlo generator [12]). The asymmetry can be observed in the lab frame where the top quarks are preferentially emitted in forward/backward directions while antitop quarks are more centrally produced. The standard selection for single-lepton events is applied [13] and the asymmetry is measured as

$$A_C = \frac{N(\Delta|Y| > 0) - N(\Delta|Y| < 0)}{N(\Delta|Y| > 0) + N(\Delta|Y| < 0)}, \tag{7.1}$$

where $\Delta|Y|$ represents the difference of the absolute values of top and antitop quark rapidities, $\Delta|Y| = |Y_t| - |Y_{\bar{t}}|$. The analysis is performed on 0.7 fb^{-1} of data; the main backgrounds are data-

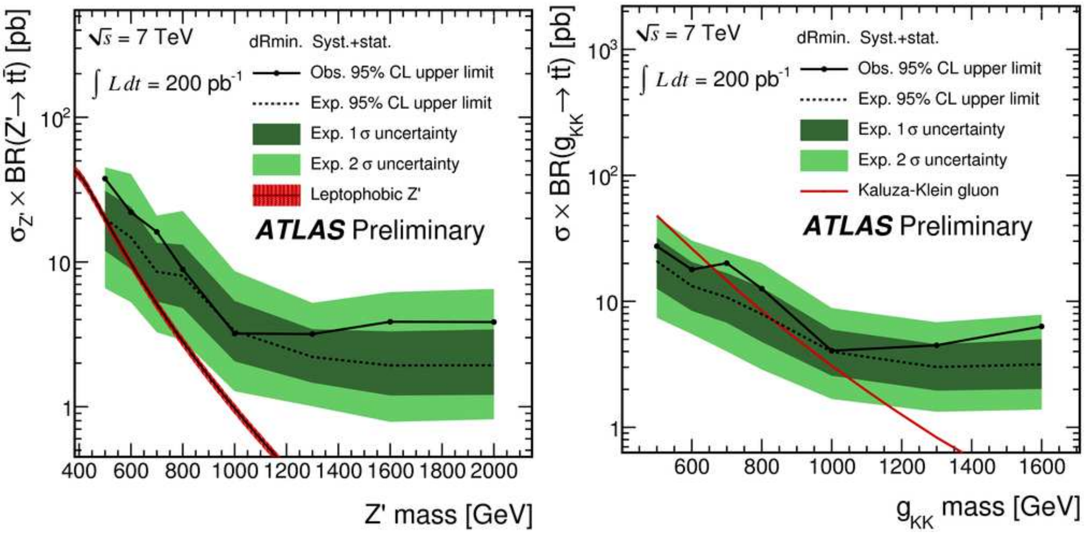

Figure 1: Expected (dashed line) and observed (black points connected by a line) upper limits on $\sigma \times BR(Z^{'} \to t\bar{t})$ (a) and $\sigma \times BR(g_{KK} \to t\bar{t})$ (b). The dark and light green bands show the range in which the limit is expected to lie in 68% and 95% of experiments, respectively, and the red lines correspond to the predicted cross-section times branching ratio in the leptophobic Topcolor and RS models. The error bars on the Topcolor cross-section curve represent the effect of the PDF uncertainty on the prediction.

driven: the QCD background uses the matrix method and the W+jets the W^+ and W^- production asymmetry in the data for its normalisation. The uncertainty on the W+jets background was estimated to be 48% in the four jet bin, increasing with the jet multiplicity. The $t\bar{t}$ system is reconstructed using a kinematic likelihood method which assigns a probability for the kinematics of an observed event to be compatible with a top quark pair decay. The correct event topology in the $t\bar{t}$ Monte Carlo simulation is found in 62% (74%) of the cases without (with) b-tagging applied. An unfolding method is used to retrieve the true asymmetry from the reconstructed one: both the reconstruction and selection efficiencies and the acceptance effects are accounted for. The results show no significant beyond the Standard Model asymmetry. The present result combining both the electron and the muon channel is $A_C = -0.024 \pm 0.016(stat.) \pm 0.023(syst.)$ in agreement with the Standard Model prediction of A_C = 0.006. The largest systematic errors come from the uncertainty due the $t\bar{t}$ Monte Carlo generator and parton shower and the jet energy scale resolution. Figure 2 shows the measured $\Delta|Y|$ distribution before unfolding and after b-tagging for the muon and electron channel.

8. Summary

Top properties have been investigated with the data collected in 2010, corresponding to an integrated luminosity of 35 pb^{-1}, but also with higher statistics using data taken in 2011. Many interesting results that constrain several models have been produced. In many cases even with little integrated luminosity, ATLAS is already able to push the reach to the TeV scale, to reach Tevatron or to set world's best limits.

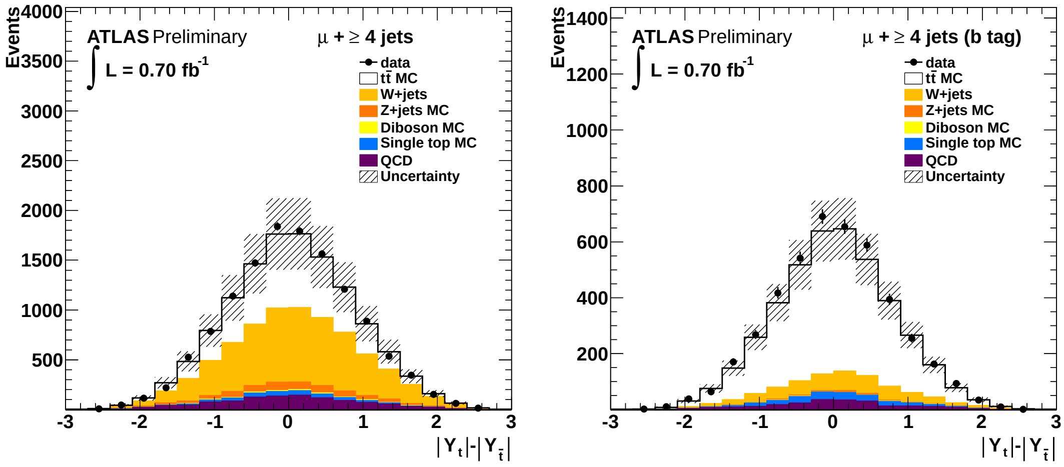

Figure 2: The unfolded $\Delta|Y|$ distribution for the electron channel (left) and the muon channel (right) after b-tagging and before unfolding. Data (points) and Monte Carlo estimates (solid lines) are represented. The QCD background and the normalisation of the W+jets background are obtained using data-driven methods.

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