Search for new physics effects involving top quarks and studies of jet shape and substructure at ATLAS

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Abstract. In this paper we present some selected results of search for new physics effects beyond the Standard Model (SM) involving top quarks, as well as several studies of jet shape and substructure by the ATLAS collaboration. The results are based on data samples recorded with the ATLAS detector from proton-proton collisions at a center-of-mass energy of $\sqrt{s} = 7$ TeV at the Large Hadron Collider at CERN.

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INTRODUCTION

In this paper we present some selected results of search for new physics (NP) effects beyond the Standard Model (SM) involving top quarks, as well as several studies of jet shape and substructure by the ATLAS collaboration. The results are based on data samples recorded with the ATLAS detector [1] from proton-proton collisions at a center-of-mass energy of $\sqrt{s} = 7$ TeV at the Large Hadron Collider at CERN.

SEARCH FOR TOP PAIR RESONANCES

Many models of physics beyond the SM predict the existence of new resonances that decay predominantly into top quark pairs. The ATLAS experiment performed a search for such resonance using two different final states: dilepton final state and lepton plus jets final state, as described below.

In the dilepton final state, the W bosons from the top quark decay into either an electron and electron-neutrino or a muon and muon-neutrino [2]. The analysis is based on the studies of the possible excess in the $H_T + E_T^{miss}$ spectrum, where H_T is defined as the scalar sum of the transverse momenta of the two identified leptons and all the jets in the event above a given momentum threshold, E_T^{miss} is the missing transverse momentum from the escaping neutrinos from the leptonic W boson decay and is constructed from the vector sum of all calorimeter cells contained in topological clusters. The data used in the analysis were recorded by the ATLAS experiment during 2011 and correspond to a total integrated luminosity of $\mathcal{L} = 1.04 \text{ fb}^{-1}$. As shown in Fig. 1, no statistically significant excess above the SM expectation is observed. Upper limits at the 95% Confidence Level

are set on the cross section times branching ratio of the resonance decaying to $t\bar{t}$ pairs as a function of the resonance mass. A lower mass limit of 0.84 TeV is set for the case of a Kaluza-Klein gluon in the Randall-Sundrum Model.

FIGURE 1. Left: Data-Monte Carlo comparison for the $H_T + E_T^{\text{miss}}$ distribution together with a KK-gluon signal with a mass of 700 GeV for illustration. The statistical and systematic uncertainty on the Monte Carlo is represented by the hashed band. Right: Expected and observed limits on cross section times branching ratio at 95% C.L. and expected cross section for a Randall-Sundrum KK-gluon g_{KK} . Cross sections were calculated using the MRST 2007 LO* PDF. The results shown here are from reference [2].

As for the lepton plus jets final state [3], one of the W boson from top quark decays leptonically, and the other W boson from the other top quark decays hadronically. The search exploits the shape of the $t\bar{t}$ invariant mass distribution compared to the expected SM backgrounds using a data sample corresponding to an integrated luminosity of 2.05 fb^{-1} . No evidence of NP effects were observed. Limits are set on the production cross-section times branching ratio to top quark pairs of such resonances for several NP models, as shown in Fig. 2. For a leptophobic topcolour Z' boson, the excluded range of its mass is $500 < m(Z') < 860 \text{ GeV}$ at 95% C.L. In Randall-Sundrum models, Kaluza-Klein gluons with masses between 500 and 1025 GeV are excluded at 95% C.L.

FIGURE 2. Left plot: Reconstructed $t\bar{t}$ mass for all events on the logarithmic scale. The electron and muon channels have been added together and all events beyond the range of the histogram have been added to the last bin. The grey hashed area shows the background normalization uncertainties. Middle and Right plots: Expected (dashed line) and observed (solid line) upper limits on $\sigma \times \text{BR}(Z' \rightarrow t\bar{t})$ (middle) and $\sigma \times \text{BR}(g_{KK} \rightarrow t\bar{t})$ (right). The green and yellow 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 topcolour and RS models. The bands around the signal cross-section curves represent the effect of the PDF uncertainty on the prediction. The results shown here are from reference [3].

SEARCH FOR RESONANCE DECAY TO TOP AND B QUARKS

Several NP models, such as universal extra dimensions and little Higgs models, predict a new heavy gauge bosons W' that can decay to a tb final state. Using 1.04 fb^{-1} of proton-proton collision data, the ATLAS experiment performed a search for tb resonances [4]. Events with a lepton, missing transverse momentum, and two jets are selected and the invariant mass of the corresponding final state is reconstructed. The search exploits the shape of the tb invariant mass distribution compared to the expected SM backgrounds. The model of a right-handed W'_R with the SM-like couplings is chosen as the benchmark model for this search. As shown in Fig. 3, no statistically significant excess of events is observed in data, and upper limits on the cross section times the branching ratio of W'_R resonances at 95% CL lie in the range $6.1 - 1.0 \text{ pb}$ for W'_R masses ranging from 0.5 to 2.0 TeV. These limits are translated into a lower bound on the allowed right-handed W'_R mass, giving $m(W'_R) > 1.13 \text{ TeV}$ at 95% CL.

FIGURE 3. The left and middle plots are the distribution of m_{tb} for single-tagged (left) and double-tagged (middle) events in data compared to Standard Model expectations. The expected W'_R signal, normalized to the theoretical cross section times the $\text{B}(W'_R \rightarrow tb)$, has been scaled by a factor of 10. The effect of the jet energy scale (JES) uncertainty on the predicted background is shown, as are the data statistical uncertainties. The bin width is constant in $\log(m_{tb})$. The highest bin in each plot includes overflows. The right plot is the 95% CL limit on the cross section, $\sigma(pp \rightarrow W'_R)$, times branching ratio for $W'_R \rightarrow tb$ as a function of the W' boson mass. The theory curve is also shown. The results shown here are from reference [4].

SEARCH FOR FCNC SINGLE TOP PRODUCTION

According to the SM of particle physics, flavour-changing neutral-current (FCNC) processes are forbidden at tree level and suppressed at higher orders. Extensions of the SM with new sources of flavor predict higher rates for FCNCs involving the top quark; these extensions include new exotic quarks, new scalars, supersymmetry, or technicolour. The ATLAS experiment performed a search for FCNC single top production with 2.05 fb^{-1} of proton-proton collision data [5]. Candidate events with a semileptonic top-quark decay signature are classified as signal or background-like events by using several kinematic variables as input to a neural network. No signal is observed in the neural network output distribution, as shown in Fig. 4, and a Bayesian upper limit is placed on the production cross-section. The observed upper limit at 95% confidence level on the cross-section multiplied by the $t \rightarrow Wb$ branching fraction is measured to be $\sigma_{qg \rightarrow t} \times \text{Br}(t \rightarrow Wb) < 3.9 \text{ pb}$. This upper limit is converted using a model-independent approach into upper limits on the coupling strengths $\kappa_{ugt}/\Lambda < 6.9 \times 10^{-3} \text{ TeV}^{-1}$ and

65 $\kappa_{cgt}/\Lambda < 1.6 \times 10^{-2} \text{TeV}^{-1}$, where Λ is the new physics scale, and on the branching
 fractions $\text{Br}(t \rightarrow ug) < 5.7 \times 10^{-5}$ and $\text{Br}(t \rightarrow ug) < 2.7 \times 10^{-4}$.

FIGURE 4. Left: Neural network output distribution scaled to the number of observed events in the b-tagged sample. In this distribution, the signal contribution is shown stacked on top of the backgrounds normalized to 100 pb. The hatched band indicates the statistical uncertainty from the sizes of the simulated samples and the uncertainty in the background normalization. Right: Distributions of the neural network output: Observed signal and simulated background output distribution normalized to the mean value of the marginalized nuisance parameters, zoomed into the signal region. The FCNC single top quark process is normalized to the observed limit of 3.9 pb. The hatched band indicates the statistical uncertainty from the sizes of the simulated samples and the uncertainty in the background normalization. The results shown here are from reference [5].

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SEARCH FOR SAME-SIGN TOP PRODUCTION

67 In the SM, the production of same sign top quark pair is strictly forbidden. However,
 68 such a final state is allowed in many NP scenarios, such as new flavor-changing Z' bosons
 69 or new heavy quarks. Using 1.04fb^{-1} of proton-proton collision data, the ATLAS
 70 experiment performed a search for same sign top quark pair production in events with
 71 two isolated leptons (e or μ) that have the same electric charge, at least two jets and large
 72 missing transverse momentum [6]. The analysis is based on the studies of the possible
 73 excess in the H_T and E_T^{miss} spectrums. The observed data are consistent with expectations
 74 from the SM processes, as shown in Fig. 5. Upper limits are set at 95% confidence
 75 level on the cross section of new sources of same-sign top-quark pair production of
 76 $1.4 - 2.0 \text{pb}$ depending on the assumed mediator mass.

JET SHAPE AND SUBSTRUCTURE

77 Many recent studies have highlighted the potential of jet substructure techniques to
 78 identify the hadronic decays of boosted heavy particles in searches for NP effects. Us-
 79 ing 35pb^{-1} of proton-proton collision data collected in 2010, the ATLAS experiment
 80 performed several studies of the substructure properties of high transverse momentum
 81 jets [7, 8], such as jet mass as shown in Fig. 6, and width, eccentricity, planar flow, angu-
 82 larity, k_t splitting scales and N-subjettiness variables. The measurements are compared
 83 to the expectations of Monte Carlo generators that match leading-logarithmic parton
 84 showers to leading, or next-to-leading, order matrix elements. The generators are able to

85 describe the general features of the jets, though discrepancies are observed in the details
 86 of some distributions.

FIGURE 5. Missing energy distribution: comparison of observed data and expected SM backgrounds for events with a pair of same-sign leptons, at least two reconstructed jets, missing energy greater than 40 GeV, H_T greater than 150 GeV and $m_{\ell\ell}$ greater than 100 GeV. Shown are negatively-charged lepton (left) and positively-charged lepton (right) pairs. Uncertainties (hatched) are systematic and statistical. The last bin includes overflow events. For comparison, we also plot the expected distributions that include the SM background and a signal distribution (times 10) from a light flavor-changing Z' boson with right-handed couplings and 100 GeV mass. The results shown here are from reference [6].

FIGURE 6. The jet mass distributions for leading p_T , anti- k_t $R = 0.6$ (left) and $R = 1.0$ (right) jets in the full 2010 data set, corrected for pileup and corrected to particle level. The data are compared to various tunes of PYTHIA 6 and PYTHIA 8. The shaded bands indicate the sum of statistical and systematic uncertainties. The results shown here are from reference [7].

CONCLUSION

87 In this paper we present some selected results of search for new physics effects and
 88 studies of jet shape and substructure by the ATLAS collaboration. With more data
 89 delivered by LHC, we expect to update our measurements soon.

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