A Search for $t\bar{t}$ Resonances in Lepton Plus Jets Events with ATLAS using 14 fb$^{-1}$ of Proton-Proton Collisions at $\sqrt{s} = 8$ TeV

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Some Beyond the Standard Model (SM) theories predict new particles that decay predominantly into top-antitop quark pairs. A search for top-antitop quark resonances that decay into the lepton plus jets final state is carried out with the ATLAS experiment at the LHC using 14 fb$^{-1}$ of $\sqrt{s} = 8$ TeV proton-proton collisions. The search uses events in which the jets from hadronically decaying top quarks are resolved as well as events in which some or all of the jets from hadronically decaying top quarks are merged. Mass exclusion limits at a 95% CL are set for two benchmark models, one predicting leptophobic topcolor $Z'$ bosons and the other predicting Randall-Sundrum Kaluza-Klein gluons.

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1 Introduction

Some theories of beyond the SM physics predict the existence of new heavy bosons that decay primarily into $t\bar{t}$ pairs. Examples of these theories include topcolor models \cite{1}, chiral color models \cite{2} and Randall-Sundrum models with warped extra dimensions \cite{3}. The ATLAS experiment has searched for the production of top quark pair resonances produced in 14.3 fb$^{-1}$ of proton-proton (pp) collisions at a center-of-mass energy of 8 TeV \cite{4}. The search is carried out in the lepton plus jets decay channel where one $W$ boson from a top quark decays leptonically and the other decays hadronically. The $t\bar{t}$ invariant mass spectrum is then tested for any local excess of events. The data is tested against two particular theoretical models that differ in the width of the $t\bar{t}$ resonance with respect to detector mass resolution. A benchmark model that produces narrow width $t\bar{t}$ resonance is that of the topcolor, leptophobic $Z'$. A benchmark model that produces wide width $t\bar{t}$ resonance is the Kaluza Klein gluon that arise in Randall–Sundrum models with an extra dimension with a warped geometry and where the entire Standard Model fields and matter can propagate in all five dimensions (bulk).

2 Data and Monte Carlo Samples

The data sample used in this search was collected with single lepton triggers with exactly one lepton in the final state. The integrated luminosities for the electron and muon data sets collected during 2012 running are 14.3 ± 0.5 fb$^{-1}$ and 14.2 ± 0.5 fb$^{-1}$.

SM $t\bar{t}$ production is the primary irreducible background which is modeled using the MC@NLO \cite{8} generator, Herwig \cite{9} for parton showering and hadronization and Jimmy \cite{10} for modeling the multiple parton scattering. The CT10 \cite{11} parton distribution functions (PDFs) are used and the top quark mass is set to 172.5 GeV. Single top quark production in the s-channel and production with an associated $W$ ($Wt$) are modeled via MC@NLO/Herwig/Jimmy \cite{12} as above. Production in the t-channel is modeled using the AcerMC \cite{13} generator and Pythia \cite{14} for parton showering and hadronization. Samples for leptonic decays of $W$ and $Z$ bosons, including those to $\tau$, accompanied by jets are generated with Alpgen \cite{15} with up to five extra final state partons at leading order without virtual corrections. Specific $W$ boson plus heavy flavor processes are generated separately with Alpgen and double counting of the heavy flavor contributions is removed from the $W$ plus light quark jets samples. The $Z+$jets production is modeled using Alpgen and includes contributions from the interference between photon and $Z$ boson exchanges and events are required to have a dilepton invariant mass $40 < m_{ll} < 2000$ GeV. The overlap removal for heavy flavors is done as in the case of $W+$jets samples. The multijet background is estimated using data.

Signal samples of topcolor $Z'$ are modeled using the SSM $Z' \rightarrow t\bar{t}$ process as
implemented in Pythia with MSTW2008LO PDFs [16]. A K-factor of 1.3 [17] is applied to account for NLO effects. Signal samples of Randall-Sundrum KK gluons were generated via Madgraph [18] and then hadronized using Pythia.

3 Event Selection

Events are required to pass a high-$p_T$ single electron or muon lepton trigger with exactly one lepton in the final state. The events must have a reconstructed primary vertex with at least five tracks with $p_T > 0.4 \text{ GeV}$. In the $e+jets$ channel, $E_T^{\text{miss}}$ must be larger than 30 GeV and the transverse mass ($m_T$) larger than 30 GeV. Whereas In the $\mu+jets$ channel, $E_T^{\text{miss}}$ must be larger than 20 GeV and the $E_T^{\text{miss}}+m_T$ larger than 60 GeV.

The selected events are then classified as either originating from boosted or resolved hadronic top quark decays. The boosted sample consists of events with at least one small-radius ($\Delta R = 0.4$) jet and at least one large-radius ($\Delta R = 1.0$) jet. The small-radius jet is the highest-$p_T$ jet satisfying $\Delta R(l,j) < 1.5$ where $l$ is selected lepton. The large-radius jet must satisfy $m_{jet} > 100 \text{ GeV}$, first $k_T$ splitting scale $d_{12} > 40 \text{ GeV}$, $\Delta R(jet,j_{sel}) > 1.5$ and $\Delta \phi(jet,l) > 2.3$. Here $l$ is the selected lepton and $j_{sel}$ is the small-radius selected jet.

For the resolved selection, the event is required to have at least three small-radius jets. Furthermore it is required that one of those jets has mass $> 60 \text{ GeV}$ or there is another, fourth small-radius jet satisfying $p_T > 25 \text{ GeV}$, $|\eta| < 2.5$ and $|JVF| > 0.5$. Finally it is required that at least one of the selected small-radius jet should be b-tagged.

4 Event Reconstruction

The invariant mass of the top quark pairs is reconstructed using the four-momenta of the physics objects in the event. For the semi-leptonically decaying top quark, in both the resolved and the boosted selections, the $p_z$ is computed by imposing an on-shell $W$ boson mass constraint on the lepton plus $E_T^{\text{miss}}$ system. If only one real solution to $p_z$ exists, this is used. If two real solutions exist, the solution with the smallest $|p_z|$ is chosen. If no real solution is found, the $E_T^{\text{miss}}$ is rescaled and rotated by applying a minimum variation to find a real solution.

- For resolved reconstruction regime, a $\chi^2$ algorithm is used to select the best assignment of jets to the hadronically and semi-leptonically decaying top quarks. The algorithm uses the reconstructed top quark and $W$ boson masses as constraints. All possible permutations for four or more jets are tried and the permutation with the lowest $\chi^2$ is used to compute the $m_{tt}^{\text{reco}}$. 
• For the boosted reconstruction, there is no ambiguity in the assignment of jets. The hadronically decaying top quark four-momentum is taken to be that of the large-radius jet, while the semi-leptonically decaying top quark four-momentum is formed from the neutrino solution from the \( W \) boson mass constraint, the high \( p_T \) lepton and the selected small-radius jet.

The reconstructed spectra for \( t\bar{t} \) for each selection and channel is shown in Fig. 1. A good agreement is observed between data and the total background expectation.

Figure 1: The \( m_{\text{reco}} \) distribution for resolved selection (top row) and boosted selection (bottom row).

5 Limits

After the reconstruction of the \( t\bar{t} \) spectra, the data and expected background distributions are compared to search for hints of new physics using BumpHunter \(^{19}\), which is a hypothesis testing tool that searches for local excesses or deficits in the data compared to the expected background, taking the look-elsewhere effect into account over the full mass spectrum. The analysis considers various sources of systematics that affects the shape and normalization of the spectra. The dominant source of systematics arise from \( t\bar{t} \) normalization, jet energy scale for small-radius and large-radius jets, the b-tagging efficiency and PDF. After accounting for the systematic uncertainties, no significant deviation from the expected background is found. Hence upper limits are set on the cross section times branching ratio of the \( Z' \) and KKg benchmark models.
using a Bayesian technique. In the combination, the four statistically uncorrelated spectra are used, corresponding to boosted and resolved selections as well as $e + jets$ and $\mu + jets$ channel. Using the combined upper cross section limits, a leptophobic topcolor $Z'$ boson (KK gluon) with mass between 0.5 and 1.8 TeV (0.7 and 2.0 TeV) is excluded at 95% CL. The upper cross section limits with systematic and statistical uncertainties are given for the two benchmark models for the combination of the two selections (see Fig. 2).

Figure 2: Expected and observed upper cross section limits times the branching ratio on $Z'$ (left) and KKg(right).

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