

A search for $t\bar{t}$ resonance in the lepton plus jets channel with ATLAS using 14 fb^{-1} of proton-proton collisions at $\sqrt{s} = 8 \text{ TeV}$

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Abstract. The search for $t\bar{t}$ resonances allows the investigation of a wide range of physics beyond the Standard Model. For a high mass resonance, the top quark is produced with a transverse momentum that is large, compared to its mass, and the decay of such a highly boosted top often leads to a topology that differs in several respects from that encountered when the top quarks are produced approximately at rest. The search is performed with the ATLAS experiment at the LHC using an integrated luminosity of 14 fb^{-1} of proton-proton collisions data collected at center-of-mass energy $\sqrt{s} = 8 \text{ TeV}$. No evidence for a $t\bar{t}$ resonance is found and 95% CL limits on the production rate are determined for massive states in two benchmark models. A narrow leptophobic topcolor Z' boson with a mass below 1.8 TeV is excluded and a Kaluza-Klein excitation of the gluon in a Randall-Sundrum model is excluded for masses below 2.0 TeV.

1 Introduction

This note reports on an ATLAS experiment [1] search for the production of top quark pair resonances, such as a leptophobic Z' or a Kaluza-Klein gluon, produced in proton-proton collisions at a center-of-mass energy of 8 TeV using data collected in 2012 with an integrated luminosity of 14.3 fb^{-1} [2]. This search is carried out in the lepton plus jets decay channel, where one of the W bosons from a top quark decays leptonically (to an electron or a muon and a neutrino) and the other decays hadronically. The $t\bar{t}$ invariant mass spectrum is tested for any local excess of events that may stem from a resonance decaying into $t\bar{t}$. The events are reconstructed using a combination of *resolved* and *boosted* reconstruction methods. In the former, the hadronically decaying top quark is identified by two or three distinct small-radius jets. In the latter, the hadronically decaying top quark is identified by reconstructing one large-radius jet with a substructure consistent with the decay products of a W boson and a b quark. High momentum top quark decays are indeed reconstructed more efficiently using boosted reconstruction techniques. For both reconstruction methods, the semileptonically decaying top quark is identified by a lepton, one small-radius jet and missing transverse momentum.

Both ATLAS [2] and CMS [3] have used two specific theoretical models as benchmarks to test the production of narrow and broad resonances as compared to the detector resolution, which is of the order of 7%. The narrow resonance benchmark is a topcolor, leptophobic Z' given by model IV of Harris et al. [4] with a width of

$\Gamma_{Z'}/m_{Z'} = 1.2\%$. The broad resonance benchmark is related to Kaluza-Klein (KK) excitation states of the gluon as predicted in Randall-Sundrum models with a warped extra-dimension and where all the standard model fields can propagate in the five dimensions. A resonance width of $\Gamma_{g_{KK}}/m_{g_{KK}} = 15.3\%$ is used. Details on the tested models can be found in previous ATLAS studies [5].

2 Data and Monte Carlo samples

Only data recorded under stable beam conditions and operational ATLAS subdetector systems are considered. The data sample is collected using a logical OR of two single-muon triggers with transverse momentum thresholds of 24 and 36 GeV and a logical OR of two single-electron triggers with transverse momentum thresholds of 24 and 60 GeV. In both electron and muon triggers, an isolation criteria is used for the lower threshold.

Samples of Monte Carlo simulated events are used to predict the contribution from various SM processes to the expected background and also to model possible $t\bar{t}$ resonance signal. After event generation, all samples are passed through a GEANT4 [6] based simulation of the ATLAS detector and reconstructed using the same reconstruction software used for data.

The primary irreducible background is SM $t\bar{t}$ production, characterized by a smoothly falling invariant mass spectrum. It is modelled using the MC@NLO v4.01 generator [7] with the CT10 PDFs set [8], HERWIG v6.520 [9] for parton showering and hadronization and JIMMY v4.31 [10] to model multiple parton scattering.

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Standard model single top quark production is modeled using multiple generators. Production in the s -channel and associated production with a W boson are modeled on the same basis as for SM $t\bar{t}$ production. Production in the t -channel is modeled using the ACERMC v3.8 [11] generator and PYTHIA v6.426 [12] for parton showering and hadronization.

The leptonic decay of W and Z bosons in association with jets is an important background. The samples are generated with ALPGEN v2.13 [13] and include up to five extra final state partons at leading order without virtual corrections. The modeling of parton showering, hadronization and underlying events is based on PYTHIA and the matching of the matrix element to the parton shower is done using the MLM method [14]. Specific W boson plus heavy flavor processes ($Wb\bar{b}$, $Wc\bar{c}$ and Wc) are generated with ALPGEN. The W +jets samples are normalized to the inclusive NNLO cross sections and are then corrected with the observed charge asymmetry observed in data [2].

Background due to massive diboson processes is modeled using HERWIG v6.520 and JIMMY v4.31 with CTEQ6L1 PDFs [15].

Finally, the normalization and shape for the multi-jet background is determined directly from data using the matrix method [16] for both resolved and boosted selections. This method makes use of samples of events that possess similar kinematic characteristics but are enriched in multi-jet events, obtained by relaxing lepton identification criteria such as isolation requirement.

3 Object selection and reconstruction

3.1 Object selection

Jets are reconstructed by the use of an anti- k_T [17] algorithm with radius parameter of $R = 0.4$ and $R = 1.0$. Large-radius jets have *trimming* [18] applied. Trimming allows the mitigation of pile-up in large-radius jets. It is based on the formation of subjets, obtained by applying to the original jet an inclusive k_T algorithm, with radius R_{sub} . Soft subjets with less than a certain fraction f_{cut} of the original jet p_T are removed. The trimming parameters used in this search are $f_{\text{cut}} = 0.05$ and $R_{\text{sub}} = 0.3$.

The tagging of small-radius jets associated with the decay of b -quarks is used in both the resolved and boosted reconstructions. A neural network based b -tagging algorithm is employed [19]. The operating point is chosen to correspond to an average of 70% b -tagging efficiency in simulated $t\bar{t}$ events.

Electrons and muons are both identified by a set of tracks in the inner detector associated to a dedicated sub-detector (electromagnetic calorimeter for electrons and muon spectrometer for muons). Their p_T must be greater than 25 GeV to ensure fully efficient triggering conditions. Finally, they are considered isolated if their *mini-isolation* [20] I_{mini} satisfies $I_{\text{mini}} < 0.05 E_T$. The variable I_{mini} is defined as the sum of the p_T of tracks not associated to the lepton within an $\eta - \phi$ cone of size inversely proportional to the lepton transverse energy: $R = 10/E_T$, where E_T is

in GeV. This E_T dependence is well suited to semileptonic decays of high p_T top quarks, where the lepton and b -jet tend to be closer together at higher top quark p_T .

3.2 Event selection

The event selection is designed to have a high efficiency for events with high p_T top quarks, while minimizing non $t\bar{t}$ backgrounds. Suppression of the multijet background is achieved by a missing energy requirement. In the e +jets channel, both E_T^{miss} and the transverse mass $m_T = \sqrt{2p_T E_T^{\text{miss}}(1 - \cos \Delta\phi)}$ must be larger than 30 GeV, where p_T is the transverse momentum of the lepton and $\Delta\phi$ is the azimuthal angle between the lepton and the missing transverse momenta. In the μ +jets channel, the selection is $E_T^{\text{miss}} > 20$ GeV and $E_T^{\text{miss}} + m_T > 60$ GeV. Events can then be categorized as either "boosted" or "resolved" samples.

The boosted sample consists of events with at least one small-radius jet and at least one large-radius jet, identified as the hadronic top candidate. The selected small-radius jet is taken as the highest p_T jet satisfying $\Delta R(l, \text{jet}) < 1.5$, where l is the selected lepton. The large radius-jet should be corresponding to a top candidate and therefore must have a mass $m > 100$ GeV and must fulfill jet substructure requirement: the large-radius jet is reclustered with an exclusive k_T jet algorithm. Then, the first k_T splitting scale $\sqrt{d_{12}}$ must satisfy $\sqrt{d_{12}} > 40$ GeV, in order to match with the decay of the hadronically decaying W boson. Furthermore, the large-radius jet must be well separated from the lepton and selected small-radius jet: $\Delta R(\text{jet}_{R=1.0}, \text{jet}_{R=0.4}) > 1.5$ and $\Delta\phi(\text{jet}_{R=1.0}, l) > 2.3$. Finally, there must be at least one small-radius jet b -tagged in the event.

Events that fail the boosted selection are subsequently examined using the resolved selection criteria. In the resolved selection, the event must have at least four small-radius jets with $p_T > 25$ GeV or at least three small-radius jets if one of those jets has mass greater than 60 GeV. As in the boosted selection, there must be at least one b -tagged jet in the event.

Thus, events are placed in four categories corresponding to the e +jets and μ +jets decay channels for boosted and resolved reconstruction criteria.

3.3 Event reconstruction

The $t\bar{t}$ candidate invariant mass $m_{t\bar{t}}^{\text{reco}}$ is computed from the four-momenta of the selected physics objects in the event. For the semileptonically decaying top quark, the longitudinal component p_z of the neutrino momentum is computed in both resolved and boosted selections by imposing an on-shell W boson mass constraint on the lepton plus E_T^{miss} system [2].

For the resolved construction, the best assignment of jets to the hadronically and leptonically decaying top quarks is made by the use of a χ^2 algorithm, based on physical constraint that the jets must fulfill [2]. All possible permutations for four or more jets are tried and the permutation with lowest χ^2 is used to calculate $m_{t\bar{t}}^{\text{reco}}$. In

the case where one jet has a mass larger than 60 GeV, a slightly modified χ^2 is used.

For the boosted selection, there is no ambiguity in the assignment of jets. The hadronically decaying top quark four-momentum is then taken to be that of the large-radius jet, while the semileptonically decaying top quark four-momentum is formed from the neutrino, high p_T lepton and small-radius jet.

Figure 1 shows the $t\bar{t}$ invariant mass obtained after summing over the spectra for the two channels and the two selection methods.

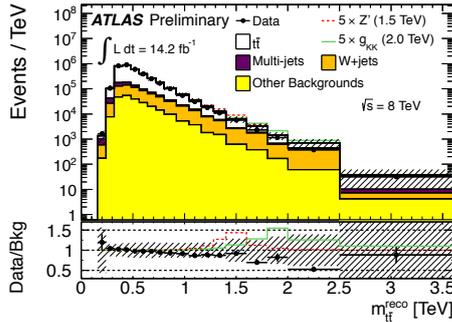


Figure 1. The $t\bar{t}$ invariant mass spectrum, summing the spectra for the two channels and the two selection methods [2]. The shaded area indicates the total systematic uncertainties. Two benchmark signals are indicated on top of the background, a Z' with $m = 1.5$ TeV in red and a g_{KK} with $m = 2$ TeV in green.

4 Results

After the reconstruction of the $t\bar{t}$ mass spectra in each of the four categories, the data and expected background distributions are compared using the BUMPHUNTER [2, 21] hypothesis testing toolkit, searching in data for local excesses or deficits as compared to the expected background. After accounting for systematic uncertainties, no significant deviation is found. Hence, upper limits are set on the production cross sections times branching ratio of the Z' and Kaluza-Klein gluon benchmark models using a Bayesian approach as shown in Figs 2 and 3.

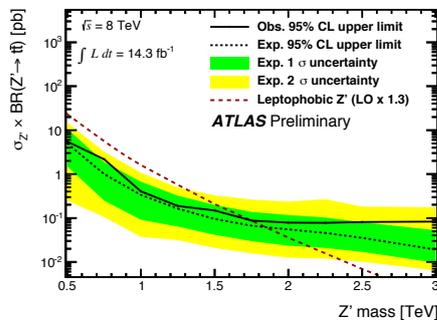


Figure 2. Observed and expected upper cross section limits on leptophobic Z' bosons [2].

Using these combined upper cross section limits, a leptophobic topcolor Z' boson (KK gluon of width 15.3 %) with mass between 0.5 and 1.8 TeV (0.5 and 2.0 TeV) is excluded at 95% CL, while the expected exclusion range is between 0.5 and 1.9 TeV (0.5 and 2.1 TeV).

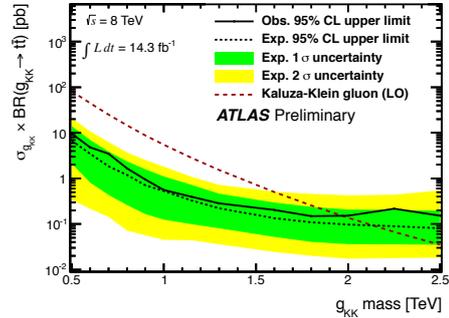


Figure 3. Observed and expected upper cross section limits on Kaluza-Klein gluon [2].

References

- [1] ATLAS collaboration, JINST **3** S08003 (2008).
- [2] ATLAS collaboration, ATLAS-CONF-2013-052 (2013) <https://cds.cern.ch/record/1547568>.
- [3] CMS collaboration, CMS-PAS-B2G-12-006 (2013).
- [4] R.M. Harris, C.T. Hill and S.J. Parke, arXiv:9911288 [hep-ph].
- [5] ATLAS collaboration, ATLAS-PHYS-PUB-2010-008 (2010) <https://cds.cern.ch/record/1278454>.
- [6] S. Agostinelli et al., Nucl. Instrum. Meth. **A506** 250-303 (2003).
- [7] S. Frixione and B.R. Webber, JHEP **0206** 029 (2002).
- [8] H. L. Lai et al., Phys. Rev. D **82** 0074024 (2010).
- [9] G. Corcella et al., JHEP **0101** 010 (2001).
- [10] J.M. Butterworth, J.R. Forshaw and M. H. Seymour, Z. Phys. **C72** 637-646 (1996).
- [11] B.P. Kersevan and R.-W. Elzbieta, Comput. Phys. Commun. **184** 919-985 (2013).
- [12] T. Sjöstrand, S. Mrenna and P.Z. Skands, JHEP **0605** 026 (2006).
- [13] M.L. Mangano et al., JHEP **0307** 001 (2003).
- [14] J. Alwall et al., Eur. Phys. J. **C53** 473-500 (2008).
- [15] J. Pumplin et al., JHEP **0207** 012 (2002).
- [16] ATLAS collaboration, Phys. Lett. **B711** 244-263 (2012).
- [17] M. Cacciari et al JHEP **04** 063 (2008)
- [18] D. Krohn, J. Thaler and L.T. Wang, JHEP **1002** 084 (2010).
- [19] ATLAS collaboration, ATLAS-CONF-2012-043 (2012) <https://cds.cern.ch/record/1435197>.
- [20] K. Rehermann and B. Twedie, JHEP **1103** 059 (2011).
- [21] G. Choudalakis, arXiv:1101.0390 [physics.data-an].