PROCEEDINGS OF SCIENCE

Searches for massive new states decaying to top anti-top quark pairs in proton proton collisions at 7 TeV with the ATLAS detector

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ATLAS presents three searches for resonances decaying to top anti-top quark pairs performed on 7 TeV proton - proton collisions collected by the ATLAS detector at the Large Hadron Collider (LHC). No significant excess of events is observed over the Standard Model expectations. Tight constraints are derived on the production rate of $t\bar{t}$ resonances, leading to exclusion at 95% credibility level of the mass range [0.5 TeV, 1.15 TeV] for a leptophobic Z' boson and [0.5 TeV, 1.5 TeV] for a Kaluza-Klein excitation of the gluon.

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1. Introduction

In this Contribution the ATLAS experiment [1] presents the results of three searches for massive new states that decay to top anti-top quark pairs. These analyses consider the di-lepton final state [2], where both W bosons decay to an electron or muon and a neutrino ($t\bar{t} \rightarrow b\bar{b}l^-\bar{\nu}l^+\nu$), and the lepton + jets final state [2, 3], where one of the W bosons decays to jets of hadrons ($t\bar{t} \rightarrow b\bar{b}q\bar{q}'l\nu$). For the latter topology ATLAS has adopted two strategies for selection and reconstruction of the $t\bar{t}$ system. The approach that is referred to as classical or resolved [2] in this Contribution assumes that all four final state partons give rise to jets that can be resolved experimentally. A second search [3] is performed using a novel selection and reconstruction algorithm specifically designed for events with highly boosted top quarks, where the hadronically decaying top quark is reconstructed as a single *fat* jet.

We interpret the result within two benchmark models:

- a leptophobic topcolor Z' boson (model IV in Ref. [4] with $f_1 = 1$ and $f_2 = 0$ and a width of 1.2% of the Z' boson mass)
- a Kaluza-Klein (KK) excitation of the gluon g_{KK} predicted by models with warped extra dimensions [5, 6].

The former represents an example of a narrow resonance, where the experimental resolution dominates the width of the reconstructed mass peak, while the latter model yields a relatively broad resonance ($\Gamma/m = 15.3\%$). Searches at the Tevatron have set a 95% confidence level (CL) limits on the mass of the leptophobic topcolor Z' boson [7] at $m_{Z'} > 900$ GeV [8].

The three search strategies are briefly outlined in Sections 2, 3 and 4. In Section 5 the construction of templates for the Standard Model contributions to the selected events is discussed. In Section 6 the results of searches on 2.04 fb^{-1} of data collected in 2011 are presented, followed by an interpretation in terms of the benchmark models in Section 7. The main results are summarized in Section 8.

2. Di-lepton final state

Candidate events are required to satisfy the following requirements: exactly tow isolated leptons of opposite charge must be present in the event, as well two or more anti-k_t jets [9] with transverse momentum $p_T > 25$ GeV. Neutrinos are expected to distort the p_T balance of the event, leading to $E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV. The mass of the di-electron or di-muon system is required to be greater than 10 GeV and to differ by more than 10 GeV from the Z boson mass. The scalar sum H_T of the p_T of the leptons and jets must be larger than 130 GeV for $e\mu$ events.

The total signal acceptance times branching ratio to $t\bar{t}$ is 1.3-1.5% for benchmark resonances with a mass around 1 TeV. With two neutrinos in the final state a complete reconstruction of the $t\bar{t}$ system is not attempted. Instead, the search is performend on the $H_T + E_{\mathrm{T}}^{\mathrm{miss}}$ distribution.

3. Lepton + jets final state

Selected events must contain exactly one isolated lepton with $p_{\mathrm{T}} > 25$ GeV and at least four jets with $p_T > 25$ GeV, one of them b-tagged. The jet multiplicity cut is relaxed to $N_{jets} \geq 3$ in events where one anti-k_t jet has an invariant mass greater than 60 GeV, to accomodate events with highly boosted top quarks. Events with an electron must satisfy: $E_{\mathrm{T}}^{\mathrm{miss}} > 35$ GeV and $m_T > 25$ GeV, those with a muon: $E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV and $E_{\mathrm{T}}^{\mathrm{miss}} + m_T > 60$ GeV.

The total signal acceptance times branching ratio to $t\bar{t}$ is approximately 7%. The special high-mass region contains only 1% of background events, but can have a relatively large signal contribution.

The neutrino transverse momentum is identified with the $E_{\mathrm{T}}^{\mathrm{miss}}$ of the event. The longitudinal component of the moment is determined by solving the quadratic equation that follows from the W-mass constraint. In case two solutions are found the solution that minimizes p_z^ν is chosen. The $t\bar{t}$ system is reconstructed by combining the charged lepton candidate, the reconstructed neutrino and the four leading jets. An ISR mitigation scheme is used to reduce the high-mass tail due to events where a jet due to initial state radiation (ISR) is mistaken for a jet from top quark decay.

4. Boosted top quarks

The third strategy is specifically designed for top quark pairs with an invariant mass beyond 1 TeV [10, 11, 12]. The highly energetic top quark decaying to three jets of hadrons ($t \rightarrow Wb \rightarrow bq\bar{q}'$) is reconstructed as a single fat jet. The selection of the $t\bar{t}$ sample is identical to that of the resolved analysis in Section 3, with the exception of the jet multiplicity and b-tag criteria. Instead we require one jet with standard radius parameter R of 0.4 in the vicinity of the charged lepton and an energetic fat jet with $R = 1$ at $\Delta R(lepton, jet) > 1.5$. The fat jet must have large momentum and significant jet substructure ($p_T > 250$ GeV, jet mass $m_j > 100$ GeV and k_t splitting scale [13] $\sqrt{d_{12}} > 40$ GeV). This approach yields an approximately flat signal acceptance of 5–6% for 1 TeV$< m_{t\bar{t}} < 2$ TeV.

The $t \rightarrow Wb \rightarrow l\nu b$ decay is reconstructed by combining the charged lepton, the neutrino reconstructed as in Section 3, and the jet with smallest ΔR to the charged lepton. The $t \rightarrow Wb \rightarrow jjb$ decay is identified with the *fat* jet. The $t\bar{t}$ mass resolution is approximately 10%.

5. Background templates

The backgrounds involving top quarks are modeled using Monte Carlo. Other backgrounds are estimated from data or with a mixture of Monte Carlo and control regions in data. The multi-jet background template for the single-lepton searches, for instance, is reconstructed from data with a poor lepton reconstruction. The W+jets shape is taken from MC, but is normalized by relating the number of events with negatively and positively charged leptons with the charge asymmetry of W boson production at the LHC. Similarly, the Z+jets background for the di-lepton analysis is measured in a data control sample orthogonal to the signal sample [14].

Over 30 sources of systematic uncertainties in the modeling of the background normalization and shape and the signal shape are taken into account. Uncertainties in the modelling of signal and background are evaluated using different generators, different prescriptions for initial state radiation, and different PDFs. Uncertainties in the scale and resolution of reconstructed objects are considered, those on non-standard jets following Reference [13]. The dominant uncertainties are those in the jet energy scale and resolution.

6. Results & Interpretation

The reconstructed $t\bar{t}$ mass spectra, combining electron and muon channels, are presented in Figure 1. No significant deviations from the SM template are observed in any of the spectra. The most significant excess according to the ranking by BUMPHUNTER [15] is 1.4 σ, found at $m =$ 2 TeV in the analysis aimed at boosted top quarks.

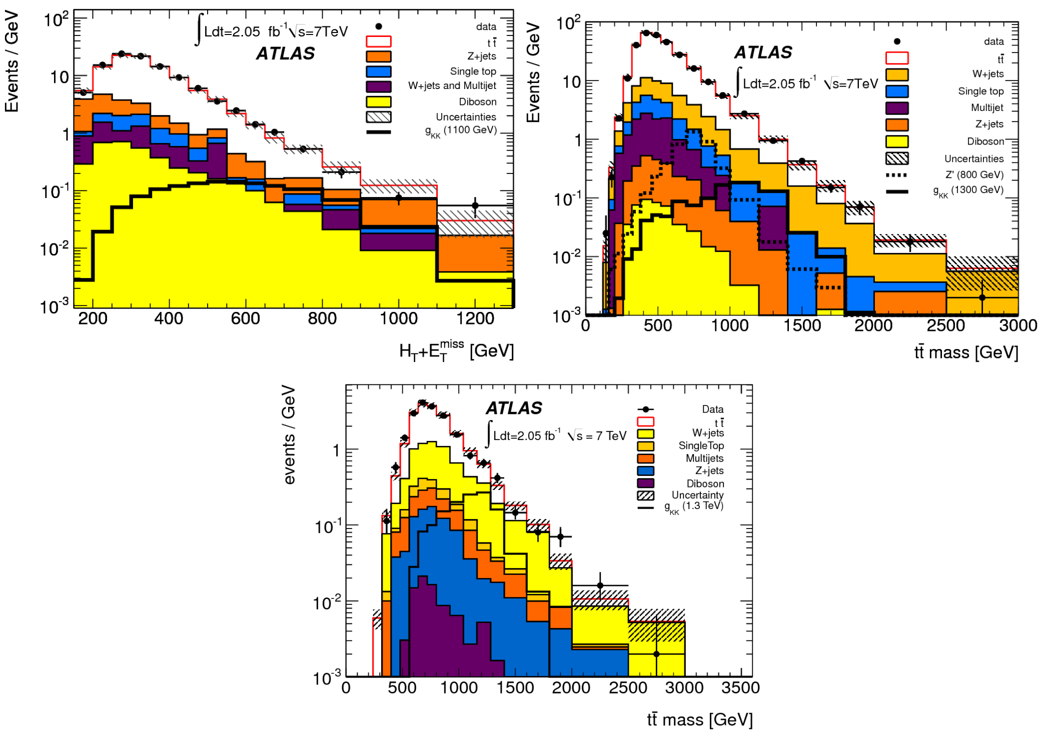

Figure 1: The reconstructed $t\bar{t}$ mass spectra for the di-lepton analysis (upper left panel), the lepton+jets analysis (upper right), both reported in Reference [2], and the lepton+jets analysis designed for boosted top quarks of Reference [3] (lower panel).

7. Interpretation

In the absence of a significant signal, upper limits are set on cross-section times branching ratio ($\sigma\times$ BR) as a function of $t\bar{t}$ resonance mass using a Bayesian approach [16]. The variable binning used in the Figures and limit setting procedure is suggested by the mass resolution The total signal acceptance as a function of mass is propagated into the expectation. The different channels (electron and muon) for the three analyses are combined. Systematic uncertainties, incorporated using nuisance parameters that smear the parameters of the Poisson probability in each bin, degrade the expected cross section limits by a factor of up to 3.

The sensitivity of the di-lepton channel is limited by the small branching fraction of this final state and its relatively poor mass resolution. The clean selection, however, is a useful asset. The two searches in the lepton+jets final state have complementary sensitivity in the low- and high-mass regions. For masses below approximately $m_{t\bar{t}} = 700$ GeV the more classical reconstruction scheme

Table 1: Excluded mass range at 95% credibility level for the two benchmark models discussed in the text from analyses in Reference [2, 3].

Final state & Reconstruction	di-lepton	l+jets resolved	l+jets boosted
$\int L$ [fb^{-1}]	2.04	2.04	2.04
Z' mass [TeV]	-	$0.5-0.88$	$0.6-1.15$
g_{KK} mass [TeV]	$0.5-1.08$	$0.5-1.13$	$0.6-1.5$

provides the tightest constraint. At high mass ($1-2$ TeV) the analysis geared towards boosted top quarks performs signficantly better, with upper limits on $\sigma\times$ BR decreasing by up to a factor two.

8. Summary

ATLAS has performed searches for new, resonant sources of $t\bar{t}$ production in the di-lepton and lepton+jets final state. No deviations from the Standard Model are observed and limits are derived on the production rate times branching fraction in two benchmark models. For a 1 TeV resonance with a width of $\Gamma = 0.15 \times M$ the observed limits range from 3.2 pb (di-lepton) to 1.4 pb (lepton+jets) and 0.7 pb (boosted lepton+jets), in good agreement with the expected sensitivity. The resulting constraints on the mass of a narrow, leptophobic Z' and a massive Kaluza-Klein excitation of the gluon are presented in Table 1. At the time of the Conference these were the most stringent constraint on the production on new massive states decaying to $t\bar{t}$ pairs.

Reference [3] constitutes the first ATLAS analysis where the selection and reconstruction scheme are specifically designed for the boosted topology that forms in the decay of highly energetic top quarks forms. The greater sensitivity at high mass establishes the potential of such specialized algorithms.

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