

Search for exotic same-sign dilepton signatures (b' quark, $T_{5/3}$ and four top quarks production) in 4.7 fb^{-1} of pp collisions at $\sqrt{s} = 7 \text{ TeV}$ with the ATLAS detector

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Abstract. We present a search for pair production of down-type heavy quarks ($b'\bar{b}'$), single and pair production of heavy top quark partners ($T_{5/3}q\bar{q}'$ and $T_{5/3}\bar{T}_{5/3}$, respectively), and production of events containing four top quarks ($t\bar{t}t\bar{t}$) in pp collisions at $\sqrt{s} = 7 \text{ TeV}$ recorded with the ATLAS detector at the LHC. For an integrated luminosity of 4.7 fb^{-1} , the corresponding lower limit on both the b' and $T_{5/3}$ mass is 0.67 TeV at 95% confidence level, when produced in pairs. When including the single production mechanism, limits on $T_{5/3}$ production are 0.68 TeV and 0.70 TeV for a coupling constant of the $tWT_{5/3}$ vertex equal to 1 and 3, respectively. The upper limit on the four top quarks production cross section is 61 fb at 95% confidence level.

1. Introduction

The Standard Model (SM) is extremely successful in explaining experimental measurements in particle physics, however it possesses some theoretical problems such as the Higgs boson mass fine-tuning [2] which have motivated a large number of extensions to the theory. Due to the large variety of models proposed, searches based on the signature of same-sign lepton pairs are often useful since they have a low background rate in the SM and potentially large contributions from new phenomena. In this note, three specific signal processes are considered: pair production of down-type heavy quarks, single and pair production of heavy top quark partners and production of events containing four top quarks, produced via a four-top-quark contact interaction. This note presents the first ATLAS [1] results on the experimental search on four-top-quarks production and the first search for both single and pair-production of $T_{5/3}$ [3].

2. Processes

2.1. Pair production of down-type heavy quarks (b')

A fourth generation of heavy chiral quarks is a natural extension to the SM [4]. This model is based on a new chiral generation: a $SU(2)_L$ doublet $(t', b')_L$ with the corresponding right-handed singlets t'_R, b'_R . It remains consistent with precision electroweak measurements if one assumes small mass splitting between the heavy up-type quark (t') and the heavy down-type quark (b') [4]. This model is disfavoured, however, by $m_H \sim 126 \text{ GeV}$ [5]. In the scenario studied in this note, the b' decays into the final states $u/c + W^-$ as well as $t + W^-$, as long as



$m_{b'} - m_t > m_W$. If one assumes $V_{u(c)b'} \ll V_{tb'}$ the dominant decay is $b' \rightarrow t + W^-$.

2.2. Single and pair production of heavy top quark partners ($T_{5/3}$)

This natural, non-supersymmetric solution to the hierarchy problem requires fermionic partners of the top quark [6]. These heavy fermions are coupled to SM quarks through a W boson preferentially to the third generation. We study here the pair and single production of the top-quark partner with electric charge $Q = 5/3$, denoted $T_{5/3}$. For single production, the cross section depends on the coupling constant λ of the $tWT_{5/3}$ vertex. In this analysis, we study the cases $\lambda = 1$, $\lambda = 3$ and $\lambda \ll 1$. In the latter case, the single production vanishes and the study corresponds to the pair production of b' quarks (same final state and acceptance).

2.3. Production of events containing four top quarks

Many new physics models couple strongly to the top quark, including a new interaction related to electroweak symmetry breaking that couples uniquely to the top quark, models where only the top quark is composite, or new coloured heavy particles that decay preferentially to top quarks. Many of these new physics models predict an enhanced rate of events containing four top quarks with respect to the SM production. In this analysis, only the contact interaction operator with right-handed top quarks is considered, as left-handed top operators are already strongly constrained by electroweak precision.

3. Background

3.1. Data-driven background

This background includes top-quark pair production, W +jets and single-top-quark production. It is divided into:

- charge mis-identification: the sign of the electric charge of the electron can be mis-reconstructed due to incorrect measurement of the sign of the track curvature or hard bremsstrahlung producing trident electrons ($e^\pm \rightarrow e^\pm \gamma^* \rightarrow e^\pm e^+ e^-$). The charge mis-identification of the muon is negligible. The rate of charge mis-identification for electrons is derived as a function of the electron pseudorapidity ($|\eta|$) from the rate of same-sign and opposite-sign electron pairs in data events from Z bosons. The dependence of this rate as a function of the transverse momentum (p_T) is much smaller than the variation with η and so is neglected in the parametrization of the rate.
- mis-reconstructed leptons: at least one of the two leptons in the selected same-sign pair is not a real isolated lepton. The leptons may come from the semi-leptonic decay of a b or a c hadron, π^0 's or photons mis-reconstructed as leptons. To estimate this background, two sets of lepton selection criteria are defined, named *tight* [3] (same as standard selection) and *loose* (*tight* without isolation requirement). The probabilities r and f that a real or a fake loose lepton, respectively, passes the tight criteria are measured in dedicated control regions. The matrix method [7] is then used to estimate the number of events in the signal region with at least one fake lepton.

3.2. Monte Carlo background

Additional background estimates are derived using simulated Monte Carlo samples:

- di-boson production: WZ and ZZ take into account hard emission of up to three partons, the soft emission, showering and hadronization. Cross sections are normalised to next-to-leading order (NLO) theoretical calculations. $W\gamma$, with hard emission of up to five partons, are also considered and $W^\pm W^\pm + 2$ jets is generated taken into account showering and hadronization.
- $t\bar{t}W(+\text{jets})$, $t\bar{t}Z(+\text{jets})$ and $t\bar{t}W^\pm W^\pm$ take into account showering and hadronization and

the $t\bar{t}W/Z(+\text{jet})$ are rescaled to NLO calculations.

4. Event selection

Jets are reconstructed using the anti- k_t [8] algorithm with a distance parameter of 0.4 and are required to satisfy $p_T > 25$ GeV and $|\eta| < 2.5$. In order to avoid reconstructing electrons as jets, the latter are required to have an angular separation $\Delta R(\text{jet}, e)$ of at least 0.2. Jets from the decay of heavy flavour hadrons are selected by a multivariate b -tagging algorithm [9] at an operating point of 70% efficiency, which corresponds to a mis-tag rate of less than 1%. Electrons are required to have a transverse energy $E_T > 25$ GeV and $|\eta_{\text{cluster}}| < 2.47$ excluding $1.37 < |\eta_{\text{cluster}}| < 1.52$). Electrons are also required to be well isolated from jets ($\Delta R(e, \text{jet}) > 0.4$). Muons are required to have transverse momentum $p_T > 20$ GeV and to fall within $|\eta| < 2.5$. Muons are also required to be well isolated from jets ($\Delta R(\mu, \text{jet}) > 0.4$). Events that contain two muons which could originate from a cosmic muon are rejected, when the angle between them in the transverse plane is larger than 3.1 rad.

Events must contain at least two isolated leptons of the same charge with $p_T > 25$ GeV for the leading lepton. In events with more than one same-sign pair, the pairs are sorted according to the leading lepton p_T , then by the sub-leading lepton p_T . At least one of the selected leptons must match the one that triggered the readout of the event. Events should also contain at least two jets, including at least one b -tagged jet and in the ee or $\mu\mu$ channel, the invariant mass of the two selected leptons must exceed 15 GeV and be out of the Z boson mass window, meaning $|m_{ll} - m_Z| > 10$ GeV. The transverse missing energy E_T^{miss} must be greater than 40 GeV and the total transverse energy H_T , defined as the scalar sum of the p_T of all leptons and jets, must exceed 550 GeV. This cut optimization is done with the extraction of the expected limit by taking into account the systematic uncertainties described in the following section.

5. Systematics

Several systematic uncertainties have been considered:

- Uncertainties affecting the Monte Carlo samples: uncertainties in the jet and lepton efficiency, energy or momentum calibration, and resolution lead to systematic uncertainties on the signal and background acceptance. Their effect is evaluated by varying each parameter independently within its uncertainty and recomputing the yield of each sample. The uncertainty on the luminosity has been estimated from van der Meer scans and is 3.9% [10]. Uncertainties on Monte Carlo background cross sections depend on the process.
- Uncertainties affecting the data-driven backgrounds: The uncertainty on the overall scale of the charge mis-identification background in the signal region is derived from a comparison of the mis-id rate extracted by three different methods. The uncertainties on the estimate of background coming from fake electrons was estimated by using different loose electron definitions while, for the muon case, it was estimated by changing the definition of the multi-jet enriched region.

6. Results

For each model, upper limits at 95% Confidence Level (CL) on the cross sections of the hypothetical processes are derived using the CL_s method [11]. We use single-bin counting experiments to extract the most likely signal cross section. Systematic uncertainties are included as variations in the expected signal and background yields, which are allowed to vary in the ensembles used to generate the CL_s distributions. Correlations of the systematic uncertainties across samples and channels are taken into account.

The expected and observed limits on the masses of the b' and $T_{5/3}$ and on the four top quark events production cross-section are shown in Table 1.

Table 1. Expected and observed limits on the masses of the b' and $T_{5/3}$ and on the four-top-quark events production cross-section.

Constrained parameter	Expected	Observed
b' mass or $T_{5/3}$ mass for $\lambda \ll 1$	> 0.64 TeV	> 0.67 TeV
$T_{5/3}$ mass for $\lambda = 1$	> 0.64 TeV	> 0.68 TeV
$T_{5/3}$ mass for $\lambda = 3$	> 0.66 TeV	> 0.70 TeV
Four top quark production cross-section	< 90 fb	< 61 fb

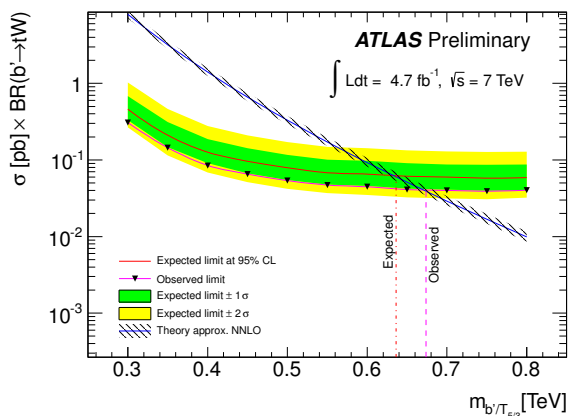


Figure 1. Expected and observed upper limits on the pair production cross section of the b' and $T_{5/3}$, as a function of their mass [3].

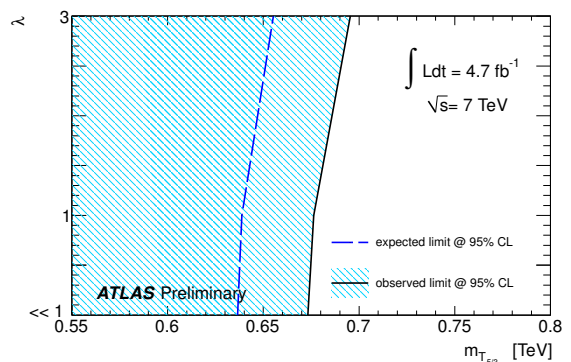


Figure 2. Expected and observed lower limits on the $T_{5/3}$ signal, as a function of the $T_{5/3}$ mass and the coupling constant λ . The shaded area is excluded at 95% CL [3].

7. Conclusion

A search for exotic processes in the same-sign dilepton plus jets signature with the ATLAS detector for an integrated luminosity of 4.7 fb^{-1} at $\sqrt{s} = 7 \text{ TeV}$ has been presented. The obtained limit on the b' and $T_{5/3}$ mass in the pair production is the most stringent limit to date in the same-sign dilepton channel. The limits obtained on the $T_{5/3}$ including the single production, and on four top quark event production are the first to date.

References

- [1] ATLAS Collaboration, (2008) *JINST* **3** S08003
- [2] E. Gildener, *Phys. Rev D* **14** (1976) 1667
- [3] ATLAS Collaboration, ATLAS-CONF-2012-130 (2012)
- [4] B. Holdom, *J. High Energy Phys* JHEP0608(2006)076
- [5] ATLAS Collaboration, *Phys. Rev. D* **86** (2012) 074014
- [6] R. Contino and G. Servant, *J. High Energy Phys* JHEP0806(2008)026
- [7] ATLAS Collaboration, *Eur. Phys. J.* **C71** (2011) 1577
- [8] M. Cacciari, G. P. Salam, and G. Soyez, *J. High Energy Phys* JHEP0804(2008)063
- [9] ATLAS Collaboration, ATLAS-CONF-2012-043 (2012)
- [10] ATLAS Collaboration, *Eur. Phys. J.* **C71** (2011) 1630
- [11] T. Junk, *Nucl.Instrum.Meth.* **A434** (1999) 435443