PROCEEDINGS OF SCIENCE

Search for heavy resonances decaying to top quarks

Saverio D'Auria*,
University of Glasgow
on behalf of the ATLAS *collaboration*
E-mail: saverio.dauria@cern.ch

Searches for new resonances that decay either to pairs of top quarks or a top and a b-quark are presented. The searches are performed with the ATLAS experiment at the LHC using 3.2 fb^{-1} proton-proton collision data at $\sqrt{s} = 13$ TeV and 20.3 fb^{-1} of 8 TeV collision data. The invariant mass spectrum of hypothetical resonances are examined for local excesses or deficits that are inconsistent with the Standard Model prediction. No significant deviation from the prediction is found so far.

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1. Introduction

Many models of new physics beyond the standard model predict the production of new heavy bosons at the LHC. If the mass of this new particle is larger than twice the mass of the top quark, they can decay to a top-anti top pair. In addition, several models make this decay mode preferential, with larger couplings to top than to other quarks. An obvious example of this is a second Higgs boson, in one of the two Higgs doublet models (2HDM) [1]. Also a leptophobic Z' of a topcolour-assisted-technicolour model [2, 3] would decay preferentially to $t\bar{t}$. A corresponding charged boson would decay into a tb pair. This contribution presents the searches for resonances decaying into $t\bar{t}$ and $t\bar{b}$ which have been conducted by the ATLAS collaboration in a model-independent way. The ATLAS detector is described in [4]. The main physics processes which constitute a background are: the production of $W^{\pm}$+jets and Z+jets, the single top plus jets production, and, clearly the non resonant $t\bar{t}$ production, which has a well defined mass spectrum shape. By the nature of the resonance we need to distinguish two cases. The signal of a vector resonance, like a Z', is a localised excess over a continuum $t\bar{t}$ invariant mass spectrum. There is very little interference between the standard $t\bar{t}$ production processes and the sought signal. This is not the case for scalar or pseudoscalar resonances: as the initial state is the same (gluon-gluon), the interference term is so important that the signal shape is strongly distorted from a standard Breit-Wigner distribution. The model independent searches are then translated into limits for specific models. The signal of the new particle is simulated using a monte carlo generator with a grid of masses and natural widths, to cover different coupling strengths. Most of these analyses use the $t\bar{t}$ decay channels, where one electron or one muon are present in the final state, together with jets and jets containing B-mesons; results from all-hadronic top decays are also included.

2. Resonances decaying to $t\bar{t}$

The search for vector resonances has been performed [5] using 3.2 fb^{-1} of 13 TeV collision data collected in 2015 in the lepton+jet channel, using a single muon or electron (indicated with ℓ) as a trigger. The reconstruction of the event is based on three types of jets, all using the anti-k_t algorithm: the *small-R jets* are the standard, calorimeter-based jets, reconstructed with a radius parameter $R = 0.4$; they have a minimum $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.5$. The *large-R jets* are reconstructed with $R = 1$, but also have a *"trimming"* process, to discard low-energy sub-jet components, which are due to event pile-up. The large-R jets have a minimum $p_{\mathrm{T}} > 300$ GeV and $|\eta| < 2.0$. The *track jets* are reconstructed from charged tracks, with $R = 0.2$. Their minimum $p_{\mathrm{T}} > 10$ GeV and $|\eta| < 2.5$. The lepton is required to be unique in the event and have a $p_{\mathrm{T}} > 25$ GeV. A p_{T}-dependent isolation cut is also used. A small-R jet (J_{sel}), with no specific b-tagging is required to be near to the lepton, at $\Delta R(\text{jet-}\ell) < 1.5$ ($\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$). The large-$R$ jet is required to be at a large azimuthal angle from both the lepton ($\Delta\phi_1 > 2.3$ rad) and from J_{sel} ($\Delta\phi_2 > 1.5$ rad). Cuts on missing transverse energy from the neutrino are also required: $E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV, $E_{\mathrm{T}}^{\mathrm{miss}} + m_{\mathrm{T}}^{W} > 60$ GeV. The invariant mass distribution of the large-R jets is shown in Figure 1 (a).

2.1 Vector resonances

The simulation agrees well with the data, within the systematic uncertainties. A high purity

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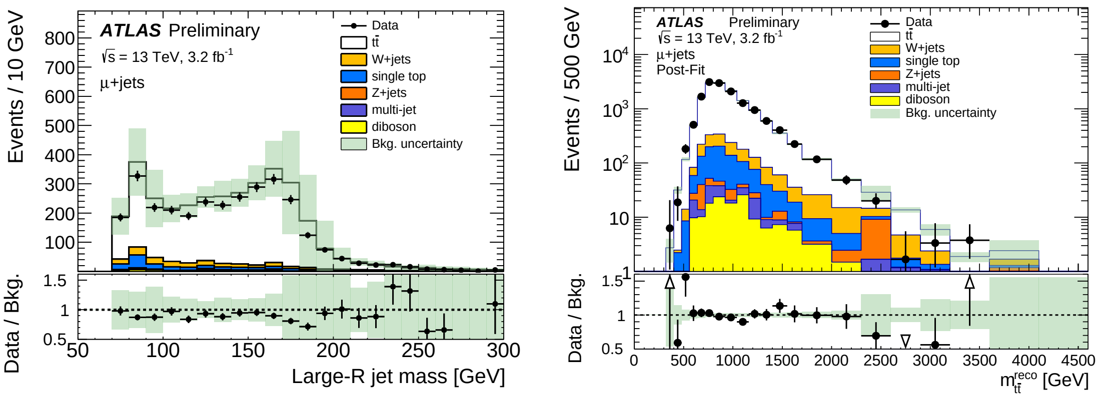

Figure 1: (a) Left: distribution of the mass of the large-R jet in the selected events containing muons. (b) Right: distribution of the invariant mass, after the likelihood fit, assuming no signal is present. [5].

$t\bar{t}$ sample is selected (85%), and a statistical fit is performed to the invariant mass distribution (Figure 1 (b)) using the BumpHunter algorithm, with nuisance parameter profile fit. No evidence

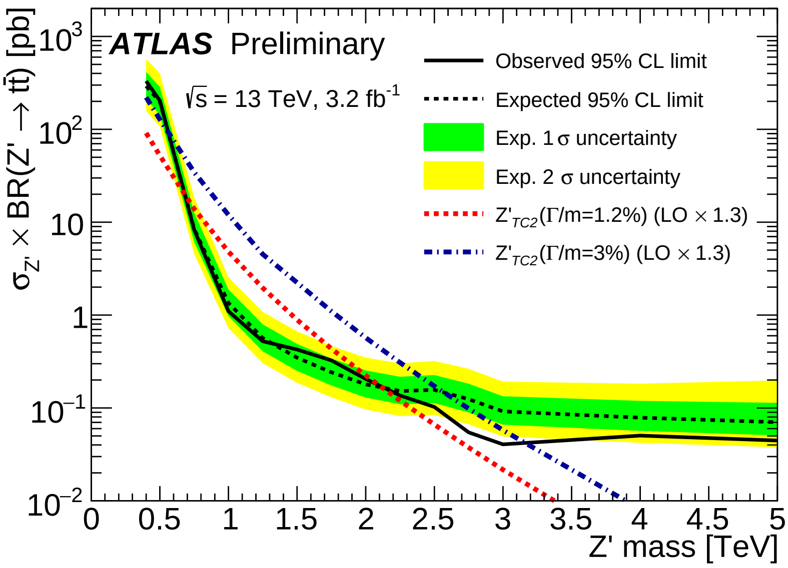

Figure 2: The experimental upper limit of the production cross section times branching fraction of a weakly coupled vector boson, as a function of its mass, is indicated by the solid black line. The expected signal for a leptophobic Z' is shown in the red and black dashed curves, for two different hypotheses on the width (Ref. [5]). The existence of a Z' resonance is excluded in the mass regions where these lines are above the upper limit.

is found for a deviation from non-resonant m_{tt} distribution. The main systematic uncertainties are related to the large-R jet energy scale. From the fit, using various hypotheses for the mass and width, it is possible to establish limits on the cross section times the branching ratio to top quark pairs. For a leptophobic Z' (topcolour-assisted) with a width of 1.2% of the mass value this analysis has excluded $0.7 < m_{Z'} < 2.0$ TeV at 95% C.L., as shown in Figure 2. The corresponding ATLAS analysis [6] of 8 TeV data has excluded $m_{Z'} < 1.8$ TeV

2.2 Scalar resonances

Gluon–initiated processes interfere with non–resonant $t\bar{t}$ production [7, 8]. This makes it slightly more difficult to simulate the signal for a grid of masses and widths. A common non resonant $t\bar{t}$ sample for the continuum background has been generated with Powheg [9] and Pythia6 [10]. The resonant signal and the interference have been generated for various mass values and both parities using a slightly modified version of Madgraph_aMC@NLO, with negative weights. This way the correct peak-dip shape could be generated with the same computing intensive background sample. The analysis [11] used the *resolved* jet configuration in the ℓ+jets channel, requiring at least

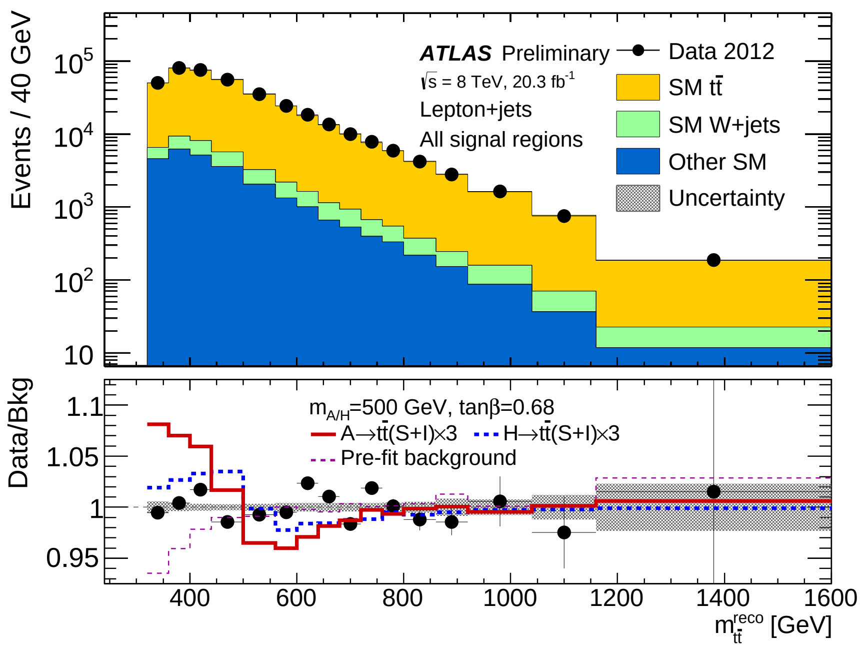

Figure 3: Distribution of the reconstructed $t\bar{t}$ invariant mass in for events selected as candidates in the ℓ+ jets analysis of 8 TeV collisions. The observed deviation from the non resonant spectrum is shown in the lower plot, together with the expected deviations in case of presence of a scalar and a pseudoscalar particle. From ref. [11].

four small-R jets, each with $p_T > 25$ GeV, and at least one b-tagged jet with 70% efficiency, with the same requirements on leptons and missing E_T as in the boosted analysis. The invariant mass distribution obtained with 20.3 fb^{-1} at $\sqrt{s} = 8$ TeV shows no sign of deviation from the shape expected from SM processes (Figure 3). The results are interpreted in terms of a CP-conserving 2HDM of type II, with a softly broken Z_2 symmetry [12]. The lighter of the two neutral CP-even states, h, is assumed to be the Higgs boson, with a mass of $m_h = 125$ GeV [13, 14] and couplings as predicted by the SM. This corresponds to the condition $\sin(\alpha - \beta) = 1$. The parameter $\tan\beta$ is the ratio between the vacuum expectation values of the two doublets and α is the mixing angle between the two scalar states. The exclusion limits are derived separately for each signal hypothesis from a profile-likelihood fit [15]. The upper limits on signal strength at 95% confidence level (CL)

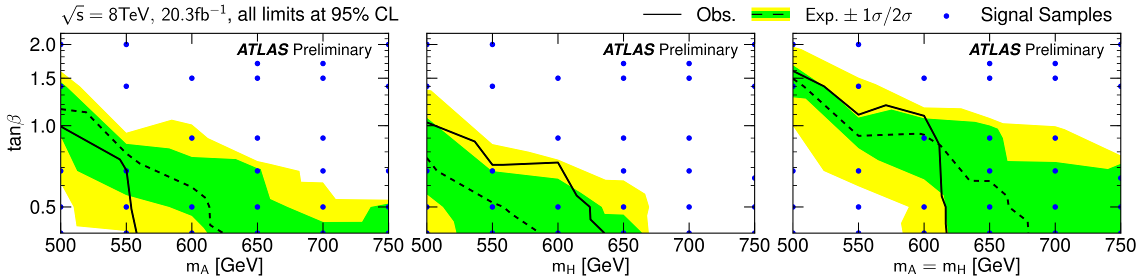

Figure 4: Exclusion limits in the $\tan\beta$-mass plane for the scalar and pseudoscalar hypotheses. The blue points correspond the parameters used in Monte Carlo samples [11].

are obtained with the CLs method [16] for a grid of values in the $(m_{A/H}, \tan\beta)$ plane, as shown in Figure 4.

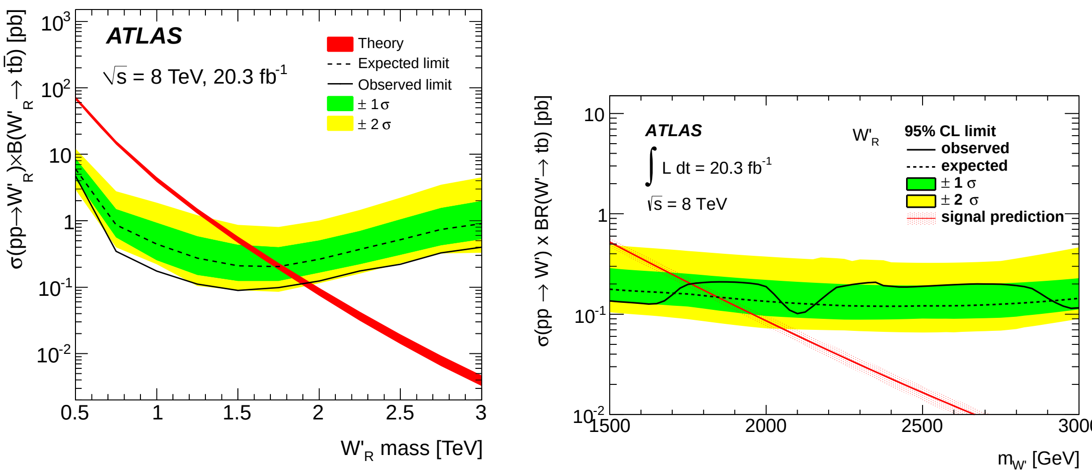

Figure 5: Exclusion limits in terms of cross section times branching ratio for the ℓ+jets channel ((a), left [17]) and for the all hadronic channel ((b), right [18]), as a function of the resonance mass. The W'_R expected signal is shown in red.

3. Vector resonances decaying to $t\bar{b}$

A leptophobic W' decaying to tb has the same final state as the s-channel single top production, at a high invariant mass. It has been sought by the ATLAS collaboration with 20.3 fb^{-1} collision data at $\sqrt{s} = 8$ TeV in the ℓ+jets [17] and in the hadronic decay channel, requiring 4 jets, of which 2 b-jets [18]. Various theoretical models have a different coupling for right and left-handed W', which corresponds to slightly different exclusion limits. With the hypothesis of a standard model coupling $g' = g_{SM}$, the exclusion limits are: $m_{W'_L} < 1.68$ TeV and $m_{W'_R} < 1.76$ TeV from the analysis of the 4-jet final state (Figure 5(b)); $m_{W'_L} < 1.70$ TeV and $m_{W'_R} < 1.92$ TeV for the $\ell\nu bb$ final state, as shown in Figure 5(a). The limits on $\sigma\times$BR are 0.10 pb to 0.21 pb for W' bosons with purely right-handed couplings. More accurate exclusion curves have been drawn in the g'/g_{SM} vs. mass plane. The search for a scalar particle $H^+ \to t\bar{b}$ has been described elsewhere in these proceedings [19].

4. Conclusions

No sign of new resonances to $t\bar{t}$ or $t\bar{b}$ has been found so far by the ATLAS collaboration. The 13 TeV data exclude leptophobic Z' with $m_{Z'} < 2.0$ TeV. The 8 TeV ATLAS analysis excludes also the presence of scalar or pseudo scalar resonances. The parameter space of the 2HDM-II model has been explored and has exclusion for $M_{A/H} < 600$ GeV. The 8 TeV data exclude leptophobic W' with $m_{W'} < 1.92$ TeV. New analyses on these channels are being finalised using the 13 TeV data collected in 2015 and 2016.

References

[1] G. C. Branco et al., *Theory and phenomenology of two-Higgs-doublet models*, Physics Reports, vol. 516 n.1, p.1 (2012).

[2] C. T. Hill and S. J. Parke, *Top production: Sensitivity to new physics*, Phys. Rev. D 49 (1994) 4454.

[3] C. T. Hill, *Topcolor assisted technicolor*, Phys. Lett. B 345 (1995) 483.

[4] ATLAS collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST 3 (2008) S08003

[5] ATLAS collaboration, *Search for heavy particles decaying to pairs of highly-boosted top quarks using lepton-plus-jets events in proton–proton collisions at* $\sqrt{s} = 13$ *TeV with the ATLAS detector*, ATLAS-CONF-2016-014, http://cds.cern.ch/record/2141001/files/ATLAS-CONF-2016-014.pdf

[6] ATLAS collaboration, *A search for ttbar resonances using lepton plus jets events in proton-proton collisions at* $\sqrt{s} = 8$ *TeV with the ATLAS detector*, JHEP 08 (2015) 148.

[7] A. Djouadi, J. Ellis, J. Quevillon, *Interference Effects in the Decays of Spin-Zero Resonances into* $\gamma\gamma$ *and* $t\bar{t}$, CERN-TH/2016-095, arXiv:1605.00542v2 [hep-ph].

[8] B. Hespel, F. Maltoni et al., *Signal background interference effects in heavy scalar production and decay to a top-anti-top pair* , JHEP 1610 (2016) 016.

[9] S. Frixione, P. Nason and G. Ridolfi, *A Positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction*, JHEP 0709 (2007) 126.

[10] T. Sjostrand, S. Mrenna and P. Z. Skands, *PYTHIA 6.4 Physics and Manual*, JHEP 0605 (2006) 026.

[11] ATLAS collaboration, *Search for a heavy pseudo-scalar/scalar particle decaying to a top quark pair in pp collisions at* $\sqrt{s} = 8$ *TeV with the ATLAS detector*, arXiv: 1707.06025 [hep-ex], to be published in Phys. Rev. Letters.

[12] J. F. Gunion and H. E. Haber, *The CP conserving two Higgs doublet model: The Approach to the decoupling limit*, Phys. Rev. D 67 (2003) 075019.

[13] ATLAS collaboration, *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, Physics Letters B, vol. 716 n. 1 p. 1 (2012).

[14] CMS collaboration, *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC*, Physics Letters B, vol. 716 n. 1 p. 30 (2012).

[15] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, *Asymptotic formulae for likelihood-based tests of new physics*, Eur. Phys. J. C 71 (2011) 1554, Erratum: Eur. Phys. J. C 73 (2013) 2501.

[16] A. L. Read, *Presentation of search results: The CL(s) technique*, J. Phys. G 28 (2002) 2693.

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[17] ATLAS collaboration, *Search for $W' \to tb$ in the lepton plus jets final state in proton–proton collisions at a centre-of-mass energy of $\sqrt{s} = 8$ TeV with the ATLAS detector*, Phys. Lett. B743 (2015) 235

[18] ATLAS collaboration, *Search for $W' \to tb \to qq'bb$ decays in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector*, Eur. Phys. J. C75 (2015) 165.

[19] E. Bergeas Kuutmann, *Charged Higgs boson searches with the ATLAS detector*, these proceedings.