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Search for pair-produced vector-like quarks with the ATLAS detector

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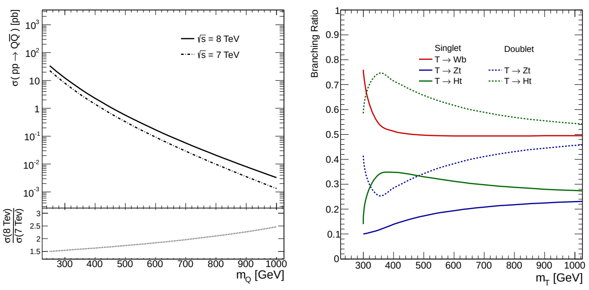
Abstract. The high energy frontier opened by the LHC is allowing us to explore physics scenarios where new physics might lay. The need to go beyond the Standard Model (SM) comes from various unanswered questions such as where does the matter-antimatter asymmetry comes from? What is the nature of Dark Matter? How can the hierarchy problem be solved? The recent discovery of an Higgs-like boson tends to disfavour the existence of a heavy 4th generation of quarks which would change the Higgs SM cross section and branching ratio in a way that is not experimentally observed. At the same time, vector-like quarks become a more compelling possibility due to their important role stabilizing the Higgs boson mass against radiative corrections. The purpose of this poster is to review the latest results in the searches for pair production of vector-like quarks at the ATLAS experiment.



(a) (b)

Figure 1. Pair production cross section of heavy quarks pairs in pp collisions (a) and B.R. of vector-like top partners as a function of the heavy quark mass m_T (b) [2].

Table 1. Allowed decay modes for vector-like singlets and doublets.

VLQ Singlets	Decay modes	VLQ Doublets	Decay modes
$T(+2/3)$	W^+b, Ht, Zt	$\begin{pmatrix} T \\ B \end{pmatrix}$	W^+b, Ht, Zt W^-t, Hb, Zb
$B(-1/3)$	W^-t, Hb, Zb		
$X(+5/3)$	W^+t	$\begin{pmatrix} T \\ X \end{pmatrix}$	Ht, Zt W^+t
$Y(-4/3)$	W^-b	$\begin{pmatrix} B \\ Y \end{pmatrix}$	Hb, Zb W^-b

1 Introduction

The ATLAS experiment [1] at CERN, Geneva, is a general purpose experiment operating at the Large Hadron Collider (LHC). The excellent performance of the detector provided a dataset of 4.7 fb^{-1} at a center-of-mass energy of 7 TeV in 2011 and more than 20 fb^{-1} at a center-of-mass energy of 8 TeV in 2012. As figure 1a shows, new exotics heavy quarks of mass m_Q can be pair-produced with significant cross section at these energies.

Many beyond-Standard Model (BSM) theories predict the extension of the quark families. A chiral fourth generation of quarks would not be compatible with the measured cross section of the new Higgs-like boson, hence heavy quarks searches are now focusing on vector-like quarks [3, 4]. Predicted in BSM models such as composite Higgs and extra dimensions, they are weak-isospin singlets, doublets or triplets with their left and right components transforming the same under $SU(2) \times U(1)$. In addition to the +2/3 and -1/3 charge partners of the top and bottom quark, T and B respectively (also called t' and b' before a uniform notation was chosen), two more exotic quarks with charges +5/3 and -4/3 are predicted, named X and Y respectively. Table 1 shows the possible decay modes for isosinglets and isodoublets. The Branching Ratios (BR) depend on the heavy quark mass, as shown in figure 1b.

Searches for vector-like quarks are performed at ATLAS in a model independent way. A two-dimensional plane is defined having the BR of two decay modes on the two axes, the third BR is then fixed by the requirement of unitarity. For each mass point of the available signal samples, a scan over the BRs with a 0.05 step is performed and for each point the analyses are repeated setting 95% CL exclusion using the CL_s technique [5, 6].

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2 Searches for vector-like top partners in the l+jets channel

Two analyses, focused on different decay channels, namely the $T \rightarrow Wb$ [7] and $T \rightarrow Ht$[2], have been performed selecting final states with only one lepton (e or μ) and multiple jets, respectively with 4.7 fb^{-1} of 2011 data and 14.3 fb^{-1} of 2012 data. The first one has been very recently updated with the same 2012 dataset [8].

2.1 $T\bar{T} \rightarrow WbWb$ analysis [7]

This analysis is optimized to reconstruct the invariant mass of the $T\bar{T}$ pair exploiting the ability to identify the hadronically decaying W boson thanks to the boosted configuration of the two jets. This allows the definition of very strict selection cuts that separate well the signal from the $t\bar{t}$ dominant background; the W from a pair-produced top quark will have low p_{T} and will be collimated to the associated $b-$jet, while the W from the heavy quark will have high transverse momentum and its decay products will be boosted. Two cases are considered: a single jet with $p_T > 250$ GeV and $m_j \in [60, 110]$ GeV is found (W_{had}^{typeI}); or two close-by jets with $\Delta R(j, j) < 0.8$, $p_T > 150$ GeV and $m_{jj} \in [60, 110]$ GeV are found (W_{had}^{typeII}). The selection applies the following cuts: ≥3 jets and one W_{had}^{typeI} or ≥4 jets and one W_{had}^{typeII} and no W_{had}^{typeI}; ≥ 1 btagged jet; $H_T > 750$ GeV (with H_T defined as the sum of the lepton p_{T}, the $E_{\mathrm{T}}^{\mathrm{miss}}$, and the p_{T} of the three or four hardest jets); $\Delta R(l, \nu) < 1.4$; $min(\Delta R(l, b_{1,2})) > 1.4$; $min(\Delta R(W_{had}, b_{1,2})) > 1.4$.

Figure 2a shows the 2-dimensional BR plane with observed and expected 95% CL exclusion.

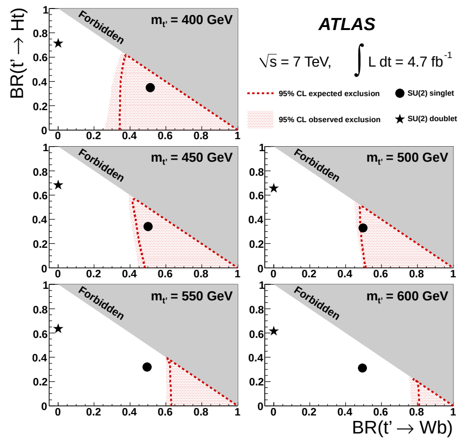
2.2 $T\bar{T} \rightarrow Ht + X$ analysis [2]

As this analysis focuses on final states where at least one heavy top decays into an Higgs and a top quark, with the Higgs decaying mainly into $b\bar{b}$, the signature has high jet and $b-$jet multiplicity. At least 6 jets with $p_T > 25$ GeV are required, and three channels with different $b-$jet multiplicities are defined: 2, 3, and ≥ 4 b-tagged jets. The signal enriched region is the third one, while the first two help to constrain the systematic uncertainties on the main background from $t\bar{t}$. The discriminant variable chosen is $H_T = \sum_j p_T(j) + p_T(l) + E_{\mathrm{T}}^{\mathrm{miss}}$.

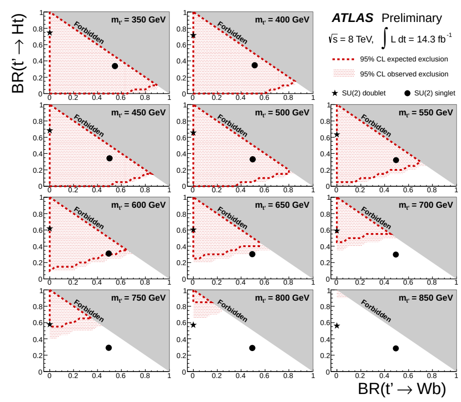
Figure 2b shows the 2-dimensional BR plane with observed and expected 95% CL exclusion, figure 3 shows the 95% CL exclusion limits on $T\bar{T}$ cross section times branching fraction as a function of the mass for the singlet model.

3 Searches for vector-like bottom partners in the same-sign dileptons channel [9]

A search for B in the same-sign dileptons channel was performed with 14.3 fb^{-1}of 2012 data. This channel has a very small contamination from SM backgrounds and is therefore sensitive to many possible new physics signals,



(a)



(b)

Figure 2. Observed (red filled area) and expected (red dashed line) 95% CL exclusion on the plane of BR($T \rightarrow Wb$) vs BR($T \rightarrow Ht$), for different values of the vector-like T quark mass for the $T\bar{T} \rightarrow WbWb$ (a) [7] and $T\bar{T} \rightarrow Ht + X$ (b) [2] analyses. The grey area corresponds to the unphysical region where the sum of branching ratios exceeds unity. The weak-isospin singlet and doublet points are shown as plain circle and star symbols, respectively.

e.g. chiral fourth generation bottom quark, vector-like B and T, four-top production. Exactly 2 leptons (e or μ) with same electric charge are selected, vetoing a Z in ee and $\mu\mu$ channels. Further selection cuts are: ≥ 2 jets with $p_T > 25$ GeV; ≥ 1 b-jet; $E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV; $H_T > 650$ GeV (with $H_T = \sum_j p_T(j) + p_T(l_1) + p_T(l_2)$).

The main sources of background leaking into the signal region come from charge misidentification and fakes, and are evaluated with data-driven techniques.

After selection, the events observed are 3, 10 and 2 in the ee, $e\mu$ and $\mu\mu$ channels respectively, all consistent with the expected background except for the $e\mu$ channel, where a small excess is observed. A Poisson likelihood is used to set 95% CL limits with the CL_s method. Figure 4 shows the 2-dimensional BR plane with observed and expected 95% CL exclusion, figure 5 shows the 95% CL exclusion limits on $B\bar{B}$ cross section times branching fraction as a function of the mass for the singlet model.

4 Conclusions

Searches for vector-like heavy quarks are being actively performed at the ATLAS experiment. Analyses are designed to be model independent and sensitive to different scenarios in a complementary way. 95% CL limits are set on T mass at 640 GeV, and on B mass at 590 GeV for weak-isospin singlets.

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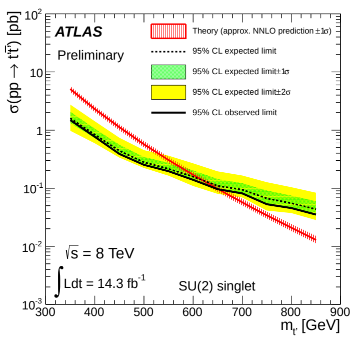

Figure 3. Observed (solid line) and expected (dashed line) 95% CL upper limits on the $T\overline{T}$ cross section times branching fraction for a weak-isospin singlet T quark as a function of its mass. The surrounding shaded bands correspond to the ±1 and ±2 standard deviations around the expected limit. The thin red line and band show the theoretical prediction and its ±1 standard deviation uncertainty [2].

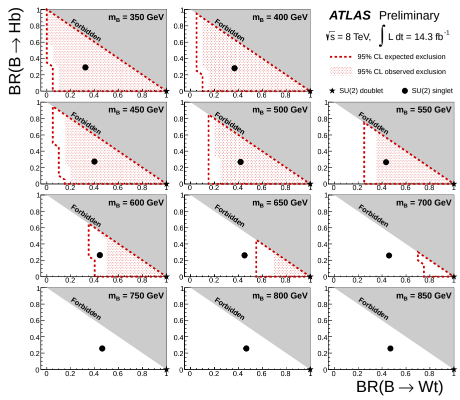

Figure 4. Observed (red filled area) and expected (red dashed line) 95% CL exclusion on the plane of BR($B \to Wt$) vs BR($B \to Hb$), for different values of the vector-like B quark mass. The grey area corresponds to the unphysical region where the sum of branching ratios exceeds unity. The weak-isospin singlet and doublet points are shown as plain circle and star symbols, respectively [9].

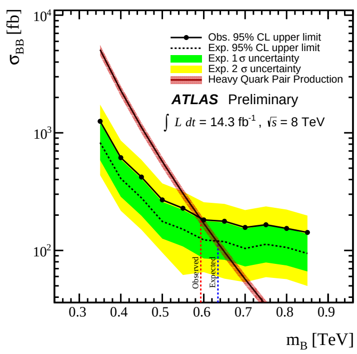

Figure 5. Observed (solid line) and expected (dashed line) 95% CL upper limits on the $B\overline{B}$ cross section times branching fraction for a weak-isospin singlet B quark as a function of its mass. The surrounding shaded bands correspond to the ±1 and ±2 standard deviations around the expected limit. The thin red line and band show the theoretical prediction and its ±1 standard deviation uncertainty [9].