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Search for vector-like quarks with the ATLAS Detector

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Vector-like quarks appear in many theories beyond the Standard Model as a way to cancel the mass divergence for the Higgs boson. The current status of the ATLAS searches for the production of vector-like quarks is reviewed for proton-proton collisions with $\sqrt{s} = 13$ TeV produced by the Large Hadron Collider. The results and the complementarity of the various searches are discussed.

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1. Introduction

Vector-like quarks (VLQs) are predicted by many theories beyond the Standard Model, e.g. composite Higgs, which are designed to address the divergence of the Higgs boson mass. VLQs are spin-1/2 particles, but are 'vector-like' in the sense that they have left- and right-handed components with the same color and electroweak quantum numbers. VLQs can arise in singlets, doublets, or triplets, and can have a charge of 2/3, -1/3, 5/3 or -4/3 [2]. For this summary of current ATLAS results, only VLQs in singlets or doublets with a charge of 2/3 (T) or -1/3 (B) are considered, and only decay modes to a top or bottom quark and a boson, under the assumption that BR($T \to Ht$) + BR($T \to Zt$) + BR($T \to Wb$) = 1 and BR($B \to Hb$) + BR($B \to Zb$) + BR($B \to Wt$) = 1.

VLQs can be produced in pairs or singly. The search for pair-produced VLQs is relatively model independent, since the production cross section depends only on the VLQ mass. On the other hand, singly-produced VLQs can have higher production cross sections at larger VLQ mass for some models. The status of searches with the ATLAS detector [1] at the LHC for pair-production of VLQs is described in Sec. 2, and the status for single-production is described in Sec. 3.

2. Pair production of vector-like quarks

The ATLAS Collaboration has searched for pair-produced VLQs through analyses targeting particular final states, and has then combined the results of these channels. All of the current results for pair-production use 36 fb^{-1} of pp collision data at $\sqrt{s}$ = 13 TeV recorded by the ATLAS detector.

Earlier searches for VLQ published in 2017-2018 include searches for $TT \to Ht + X$ [3], $TT \to Wb + X$ [4], $BB \to Wt + X$ [5] and $TT \to Zt + X$ with Z decaying to neutrinos [6]. where X refers to any possible considered VLQ decay mode. Multiple new searches for pair production were shown for the first time at this conference, and they include $TT/BB \to Zt/b + Z$ with Z decaying to leptons [7], the search for TT or BB in same-sign dilepton or trilepton final states [8], the search for TT or BB in fully hadronic states [9], and the combination of all listed ATLAS results [10].

This is the first full combination for VLQ results at the ATLAS collaboration, and it required all participating channels to carefully maintain orthogonality in their signal selections. The combination benefits from the complementarity of the various searches. Each search is evaluated for the entire plane of possible branching ratios, but each is particularly strong in the branching ratios that correspond most closely to their targeted final state. For instance, the case where BR($B \to Hb$) is near 100% is strengthened by the fully-hadronic search, since it is difficult to probe with leptonic final states. The combined limit on the pair-production of VLQs is significantly stronger than any analysis alone, and it extends the mass exclusion to 1.31 (1.03) TeV for T (B) VLQs with any considered combination of branching ratios, as seen in Fig. 1. In terms of specific models, the branching ratios for SU(2) singlets and doublets are indicated on each plane.

3. Single production of vector-like quarks

The searches for singly-produced VLQs in pp collision data with $\sqrt{s}$=13 TeV recorded by the ATLAS detector include $T \to Wb$ (using 3.2 fb^{-1} of data), $T/B \to Zt/b$ (using 36 fb^{-1} of

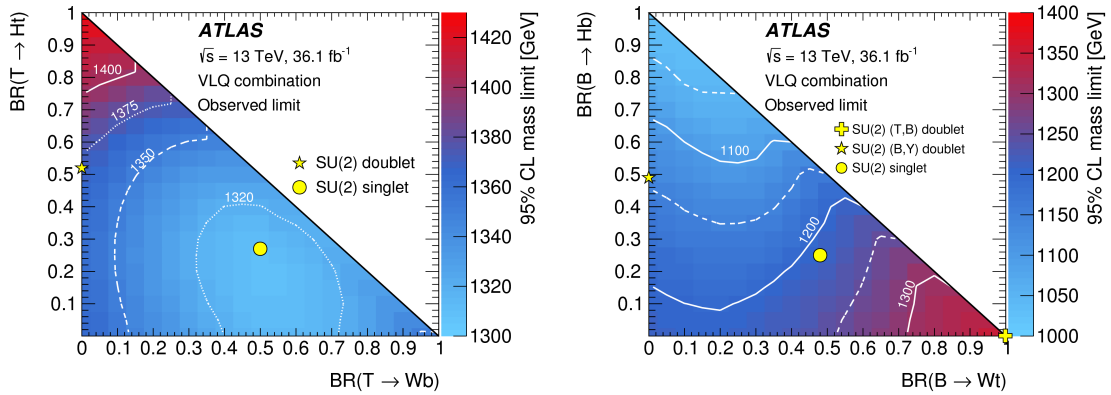

Figure 1: Observed lower limits at 95% Confidence Level on the mass of the (left) T and (right) B as a function of branching ratio, for the combination of all ATLAS searches for pair-produced vector-like quarks that are included in this presentation. These limits assume BR($T \to Ht$) + BR($T \to Zt$) + BR($T \to Wb$) = 1 and BR($B \to Hb$) + BR($B \to Zb$) + BR($B \to Wt$) = 1. The yellow markers indicate the branching ratios for the SU(2) singlet and doublet scenarios with masses above 800 GeV for which they are approximately independent of the VLQ mass. Figures are from Ref. [10].

data), and $B \to Hb$ with H decaying to two photons (using 80 fb^{-1} of data). The production cross sections for these searches are model-dependent, so assumptions must be made in order to interpret the upper limits in terms of a physical model. The latest results, shown in Fig. 2, consider the case of a generalized coupling κ_T or κ_B, which is set to a value of 0.5 [13, 14].

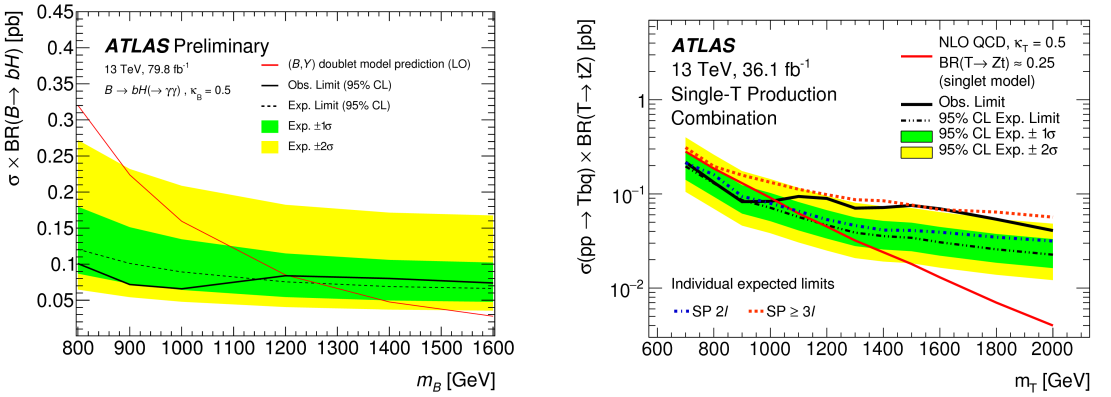

Figure 2: Upper limits at 95% CL on the cross section times branching ratio for single production of (left) B quarks decaying to bH with branching ratios taken from the doublet scenario, and (right) T quarks decaying to Zt with branching ratios taken from the singlet scenario. Figures are from (left) Ref. [12] and (right) Ref. [7].

4. Conclusions

The ATLAS Collaboration has an active and broad VLQ search program. The combination of searches for pair-production with 36 fb^{-1} of pp LHC collision data at $\sqrt{s}$= 13 TeV recorded by

the ATLAS detector have now set exclusions at 1.03 (1.31) TeV for any considered decay of B (T) VLQs. Searches for singly-produced VLQs have also been performed with $\sqrt{s}$= 13 TeV data, and have set competitive exclusions on the production cross section. No evidence for VLQs has yet been seen, but the addition of data from 2017-2018 will extend the reach of the VLQ search.

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