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Search for pair-production of vector-like quarks in final states
with at least one Z boson decaying into a pair of electrons or
muons in pp collision data collected with the ATLAS detector
at $\sqrt{s} = 13$ TeV

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A search for pair-produced vector-like quarks decaying into a Z boson and a third generation quark using 2015 and 2016 pp collision data at $\sqrt{s} = 13$ TeV collected by the ATLAS experiment at the Large Hadron Collider, corresponding to an integrated luminosity of 36.1 fb^{-1} , is presented. No significant excess over the Standard Model expectation was found so lower exclusion limits at 95% confidence level were set on the vector-like quark masses at 1030 (1210) GeV for singlet (doublet) T and 1010 (1140) GeV for singlet (doublet) B .

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1 Introduction

Vector-like quarks (VLQ) are color-triplet spin-1/2 fermions whose left- and right-hand component transform in the same way under $SU(2)_L \times U(1)_Y$ (from which they are given the name vector-like). The electric charge can be the SM-like with $+2/3e$ (T) and $-1/3e$ (B) or exotic with $+5/3e$ (X) and $-4/3e$ (Y), where e is the elementary charge. This search [1] only takes into account the SM-like electrically charged quarks. Given the assumption that these quarks can couple to the Higgs boson a limitation in their possible isospin quantum numbers is set. They can be singlets (T or B), doublets (XT , TB or BY) or triplets (XTB or TBY). They are predicted in many models that introduce fermionic top partners [2].

The present proceedings focus on events consistent with pair-produced VLQ with decays through a Z boson and a third generation quark, using data collected by the ATLAS experiment[3] in 2015 and 2016 corresponding to 36.1 fb^{-1} .

2 Analysis strategy

VLQ pair-production is expected to produce high multiplicity final states when compared to background processes. In Figure 1, unit normalized plots with the multiplicity of leptons on the left and large-R jets on the right are shown. In this figure the shape differences between signal and background are noticeable. Focusing on the lepton multiplicity it can be seen that the signal-to-background ratios in the first bin and the further ones are significantly different, thus a split is made: the dilepton channel (exactly two leptons) will benefit from an increase in statistics whereas the trilepton channel (at least three leptons) will have a much better signal-to-background ratio.

When the large-R jet multiplicity is considered a similar conclusion is reached. Therefore another split is made: the dilepton channel will focus separately in events with 0 or 1 large-R jet (with the label 2ℓ 0-1J) and events with at least 2 large-R jets ($2\ell \geq 2J$). The trilepton channel (3ℓ) will make no cuts in this category.

3 Signal regions

Events corresponding to VLQ with high masses are expected to be boosted with respect to background processes, which motivates a selection based on these differences. Therefore targeting the transverse momentum (p_T) of particles should allow to extrapolate these differences.

In all cases there will be a need to select events compatible with a VLQ decay through a Z boson and a third generation quark, so all channels will select at least two leptons with opposite-sign and same flavor with an invariant mass within 10 GeV of the Z boson mass. There will be a requirement of at least 1 b -tagged jet so that decays

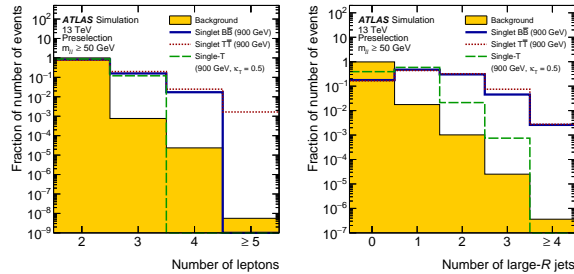


Figure 1: Distributions of the number of leptons (left) and the number of large-R jets (right). All background processes are added and all distributions are normalized to unit area. The last bin contains overflow.

to a b or a t quark are selected. In the dilepton channels the large-R jet multiplicity splitting follows. In both cases a cut in the Z candidate p_T at 250 GeV is applied to suppress background contributions. A cut in the scalar sum of jets p_T (H_T) is also applied, with 800 GeV being the threshold in the 2ℓ 0-1J channel and 1150 GeV in the $2\ell \geq 2J$ channel. In Figure 2(a) the H_T distributions after the aforementioned selection is applied are shown. Two signal regions are used in the fit, splitting events into 0 or 1 large-R jets, taking advantage of the different signal-to-background ratios in each case. Z +jets and $t\bar{t}$ are the main backgrounds and a control region for each of the backgrounds was designed.

Figure 2(b) shows the discriminant variable, m_{Zb} , of the $2\ell \geq 2J$ channel. It consists of the invariant mass of the Z boson candidate and the highest p_T b -tagged jet. This is a reconstruction of the vector-like B . In the vector-like T case it is not as good of a reconstruction due to the missing W boson but it is a reasonable compromise. Both dilepton channels have the same main backgrounds and the $2\ell \geq 2J$ channel also has two corresponding control regions.

In the 3ℓ channel after the requirement of a Z boson candidate and at least 1 b -tagged jet a cut on the Z candidate p_T is applied at 200 GeV. The discriminant variable is the S_T of jets and leptons and it can be seen in Figure 2(c). The main backgrounds for this channel are dibosons and $t\bar{t}+X$, both of which have its own control region.

All of the aforementioned thresholds were obtained by optimizing the expected VLQ lower mass limits. All the figures are shown after the fits of background prediction to data data in a background only hypothesis.

4 Results

The three optimized channels were used in a statistical combination in order to increasing the overall sensitivity. A profile likelihood fit using the CL_s method was

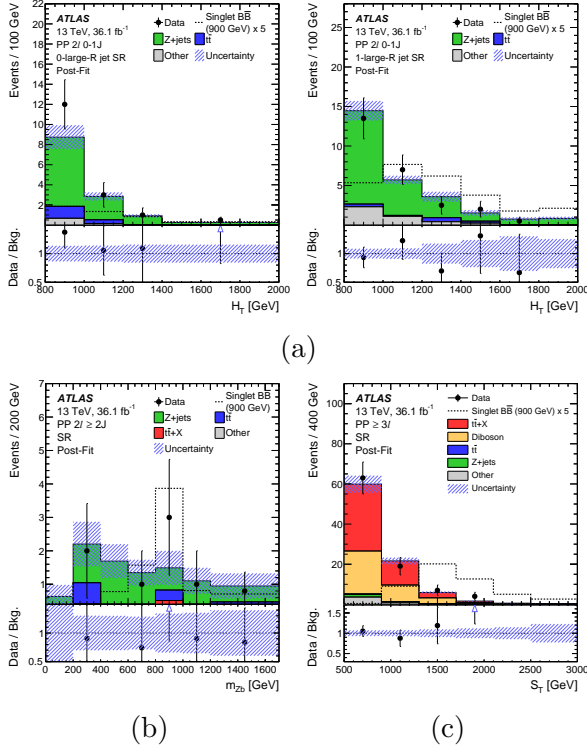


Figure 2: (a) Scalar sum of jets transverse momenta in the $2\ell 0 - 1J$ channel’s signal regions. (b) Invariant mass of the Z boson candidate and the jet with the highest traverse momentum in the $2\ell \geq 2J$ channel’s signal region. (c) Scalar sum of jets and leptons transverse momenta in the 3ℓ channel’s signal region. Background shown after the fit to the data under the background-only hypothesis. The last bin contains overflow.

performed to obtain 95% CL lower mass limits. The singlet and doublet hypothesis were tested for the vector-like B and T . These results can be seen in Figure 3. For the singlet hypothesis the observed (expected) limits are 1030 (1060) GeV for T and 1010 (1030) GeV for B . For the doublet hypothesis the observed (expected) limits are 1210 (1210) GeV for T and 1140 (1120) GeV for B . In Figure 3 the observed upper limits for VLQ pair-production cross-section are shown. The individual channel lines show their expected limits. It can be seen that the combination significantly improves the results with respect to the best channel in each scenario.

The results for each branching ratio possibility are shown in Figure 4(a), assuming that the branching ratios to Z , W and H add up to unity. It can be seen that the sensitivity increases in the Z corner, as expected.

The analysis described in this proceedings is integrated in a set of pair-production searches. Each targets a different final state with the goal of covering most of the

BR scenarios. The specific final states will present different challenges so each search is individually optimized and they are all statistically combined afterwards, resulting in what is shown in Figure 4(b)[4]. When comparing the combination to the analysis presented in this poster there is an improvement of 270 (160) GeV for the singlet (doublet) T and 200 (10) for the singlet (doublet) B .

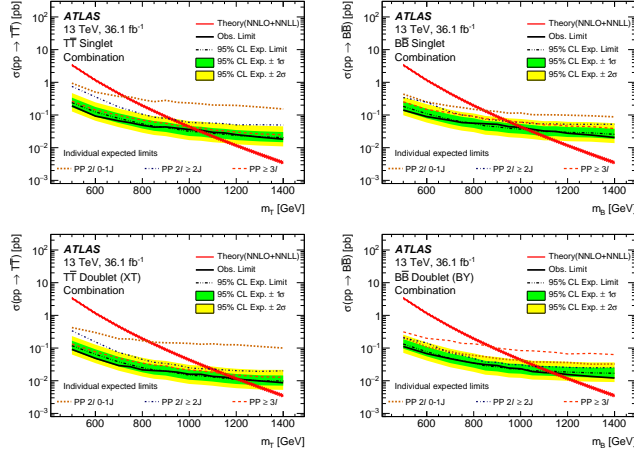


Figure 3: Upper limits at 95% CL on the vector-like quark pair-production cross-section. Expected limits shown for each individual channel and for the combination of all channels. Observed limits are shown for the combination. The expected cross-sections, with their uncertainties, are shown in the red lines.

References

- [1] ATLAS Collaboration, Search for pair- and single-production of vector-like quarks in final states with at least one Z boson decaying into a pair of electrons or muons in pp collision data collected with the ATLAS detector at $\sqrt{s}=13$ TeV, <https://arxiv.org/abs/1806.10555>
- [2] J. A. Aguilar-Saavedra, Identifying top partners at LHC, JHEP 11 (2009) 030
- [3] ATLAS Collaboration, The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3 (2008) S08003.
- [4] ATLAS Collaboration, Combination of the searches for pair-produced vector-like partners of the third-generation quarks at $\sqrt{s} = 13$ TeV with the ATLAS detector, <https://arxiv.org/abs/1808.02343>

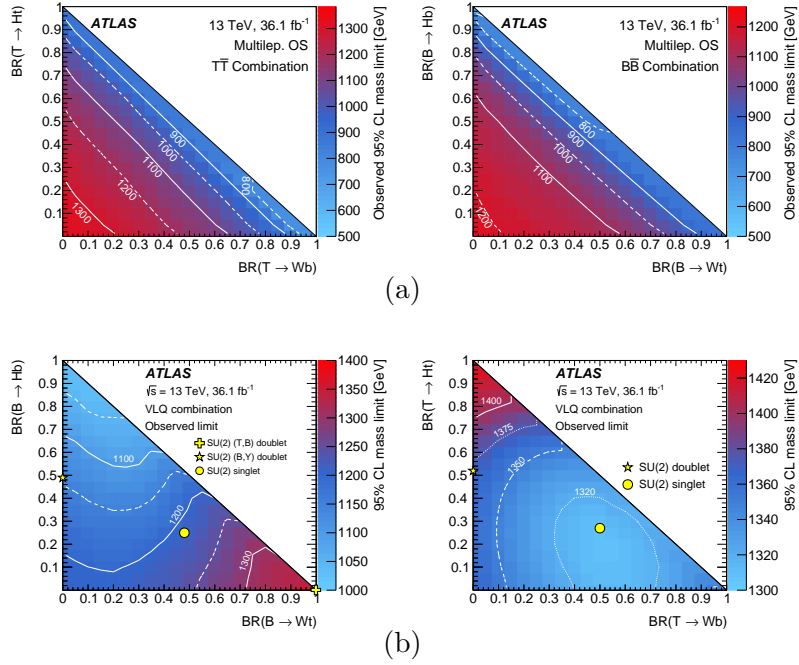


Figure 4: Observed 95% CL lower limits from the pair-production combination on the mass of vector-like quarks for all branching ratio combinations, adding up to unity for: (a) the analysis in presented in this document; (b) combination of all pair-production analysis. Fixed mass values are shown as contours with white lines.