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Searching for leptoquarks with the ATLAS detector

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Scalar leptoquarks (LQs) were sought using 36.1 fb^{-1} of pp-collision data at 13 TeV center-of-mass energy. The data was delivered by the LHC and recorded by the ATLAS experiment. No excess of data over the SM expectation is observed. First (second) generation LQs are excluded up to masses of 1400 (1560) GeV for $\beta = 1$. Third generation up- and down-type LQs are excluded up to masses of 1 TeV for the highest and the lowest branching ratio values.

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1. Introduction

This article presents results of the most recent ATLAS searches for a pair-production of scalar leptoquarks (LQs) [1, 2]. The dataset used corresponds to 36.1 fb^{-1}of proton-proton (pp) collisions data at a center-of-mass energy of 13 TeV. It was delivered by the LHC [3] in 2015 and 2016.

LQs are an important ingredient of many Beyond Standard Model (BSM) theories. They simultaneously couple to a lepton and a quark and they carry baryon and lepton numbers. LQs have a fractional electric charge as well as a colour charge. The spin of LQs can be either 0 or 1. Searches presented in this article use the minimal Buchmüller–Rückl–Wyler model (mBRW) [4] as a benchmark. This model assumes that there are three generations of LQs; each generation only couples to Standard Model (SM) fermions from the same generation. A LQ can have up to two decay modes–to a charged lepton and a quark, branching ratio (BR) B, and to the corresponding neutrino and the other quark, BR $1-B$. Depending on the electric charge, we distinguish up- and down-type LQs. The up-type LQs couple to the up-type SM fermions and/or to the down-type SM fermions. The down-type LQs couple to the up-type lepton and the down-type quark and/or vice versa. The Yukawa coupling of a LQ to the charged (neutral) lepton can be parametrized as $\beta\lambda$ ($(1-\beta)\lambda$). For the first and second generation LQs, the parameter β coincides with the BR to a charged lepton and a quark because the assumed LQ masses, m_{LQ}, are much higher than masses of the corresponding fermions. Pair production of LQs at the LHC proceeds mostly via the strong interaction. Therefore, the production cross-section is mostly independent of λ.

This article presents results of optimized searches for pair-produced scalar LQs conducted in $eejj$, $e\nu jj$, $\mu\mu jj$, $\mu\nu jj$ and $\tau\tau bb$ decay channels as well as reinterpretations of several searches for supersymmetry (SUSY) particles in terms of mBRW LQ scenarios. The reinterpreted searches are:

- Searches for stop pair production, with stop decaying to the top quark, in 1-lepton [5] and 0-lepton [6] channels.
- Search for sbottom pair production [7].
- Search for stop pair production with stop decaying via the tau slepton [8].

Information about the ATLAS detector [9] and Monte Carlo (MC) samples used for the background and signal event yields estimation can be found in Ref. [1, 2] and references therein.

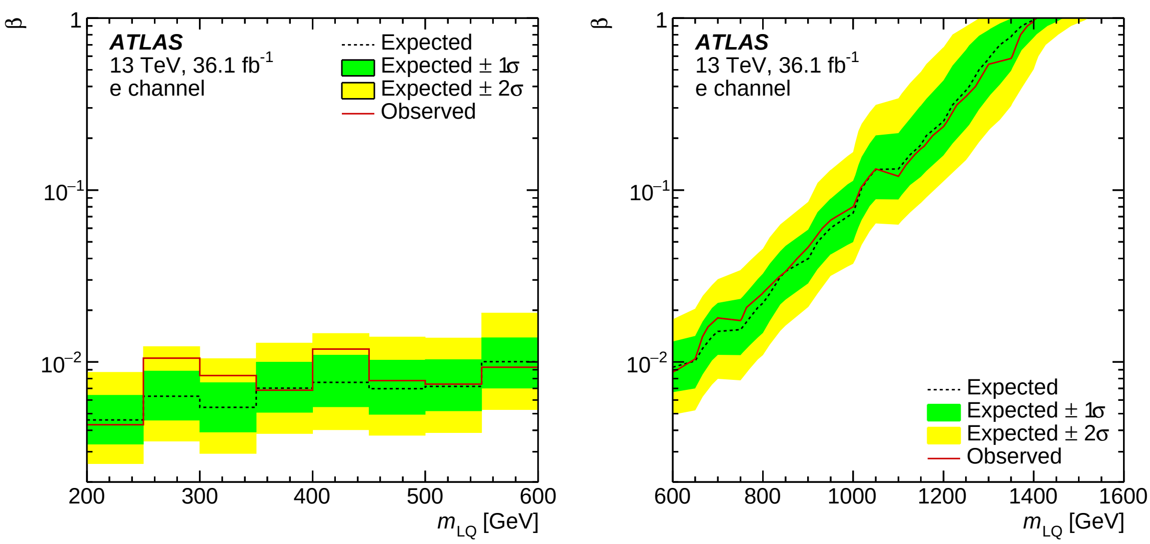
2. Searches for the first and second generation LQs

The first and second generation LQs were sought in events with at least two jets and either two same-flavour leptons (electrons or muons) or one lepton (electron or muon) and missing transverse energy, $E_{\mathrm{T}}^{\mathrm{miss}}$. Events with two leptons are most sensitive to high values of B whereas those with one lepton and $E_{\mathrm{T}}^{\mathrm{miss}}$ are most sensitive to $B \approx 0.5$.

All background sources are estimated with MC except for background due to detector objects misidentified as electrons, which background is determined in a data-driven way. The main backgrounds to the search are Z+jets, W+jets and $t\bar{t}$ events. Normalization of these three background sources is determined together with its uncertainty in a likelihood fit of a MC template to three single-bin control regions (CRs).

Signal MC was generated for LQ masses between 200 GeV and 1700 GeV. In the channels with two leptons, the most sensitive variables are invariant masses of lepton-jet pairs[1] $m_{\mathrm{LQ}}^{\mathrm{min}}$ and $m_{\mathrm{LQ}}^{\mathrm{max}}$, dilepton invariant mass $m_{\ell\ell}$, scalar sum of transverse momenta of the two leptons and the two highest-p_{T} jets, S_{T}, and transverse momenta of the individual leptons and jets. In the channels with one lepton and $E_{\mathrm{T}}^{\mathrm{miss}}$, the most sensitive variables are the invariant mass of the lepton-jet pair, m_{LQ}, the transverse invariant mass of the $\mathbf{E}_{\mathrm{T}}^{\mathrm{miss}}$-jet pair[2], $m_{\mathrm{LQ}}^{\mathrm{T}}$, S_{T} (defined with $E_{\mathrm{T}}^{\mathrm{miss}}$ instead of the second lepton p_{T}), $E_{\mathrm{T}}^{\mathrm{miss}}$, the transverse mass of the lepton-$\mathbf{E}_{\mathrm{T}}^{\mathrm{miss}}$ pair and transverse momenta of the individual jets and lepton. Using these variables, a dedicated BDT is trained for each of the four channels ($eejj$, $e\nu jj$, $\mu\mu jj$, $\mu\nu jj$) to maximize sensitivity to signal defined by the corresponding LQ decay mode. Also, a dedicated BDT is trained for each LQ mass for which there is a corresponding MC sample. For each such LQ mass and each channel, a single-bin signal region (SR) is defined by a cut on the BDT score, such that a significance function is maximal while keeping statistical uncertainties of MC samples below a certain threshold.

Since no excess of data over the background expectation is observed, limits are set on LQ production cross-section as a function of m_{LQ} for $\beta = 0.5$, as well as on signal scenarios determined by (β, m_{LQ}) values. The limits are evaluated with the profile likelihood ratio method [10]. Limits in the (β, m_{LQ}) plane are shown in Fig. 1 and 2 for the first and second generation LQs, respectively. First (second) generation LQs are excluded up to masses of 1400 (1560) GeV for $\beta = 1$.

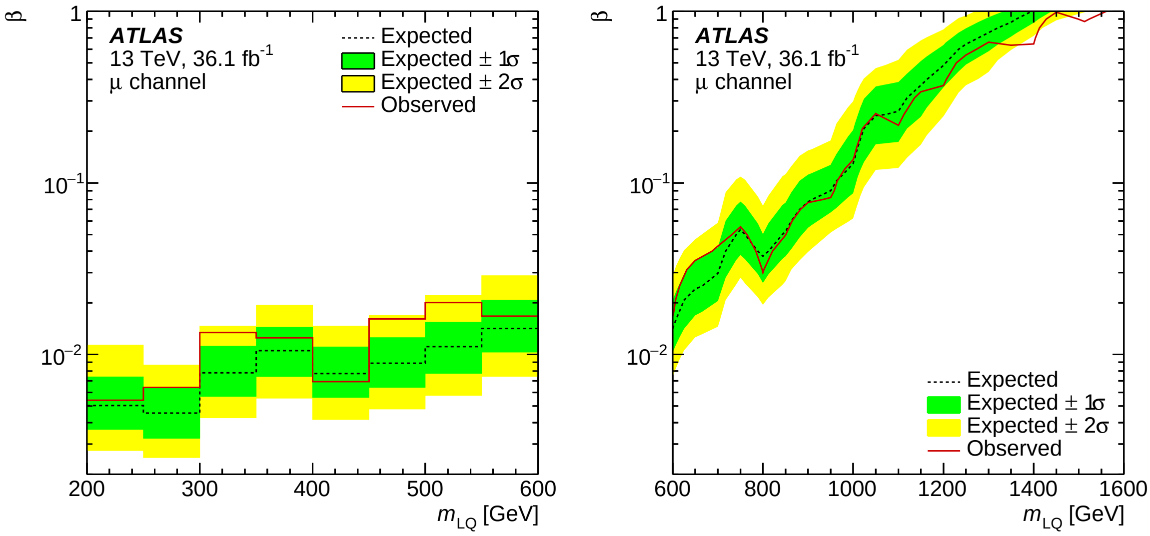


(a) (b)

Figure 1: Limits on first generation LQ scenarios determined by points in the (β, m_{LQ}) plane [1]. The solid red (dashed black) curve displays the observed (expected) limit. The green (yellow) band shows the $\pm 1\sigma$ ($\pm 2\sigma$) uncertainty on the expected limit.

[1] The pairing of leptons and jets is such that the absolute value of a difference between masses of the two pairs is minimal. Given this pairing, more sensitive variable is the lower mass out of the two, $m_{\mathrm{LQ}}^{\mathrm{min}}$.

[2] The pairing is such that the difference $|m_{\mathrm{LQ}} - m_{\mathrm{LQ}}^{\mathrm{T}}|$ is minimized.



(a) (b)

Figure 2: Limits on second generation LQ scenarios determined by points in the (β, m_{LQ}) plane [1]. The solid red (dashed black) curve displays the observed (expected) limit. The green (yellow) band shows the $\pm 1\sigma$ ($\pm 2\sigma$) uncertainty on the expected limit.

3. Searches for third generation LQs

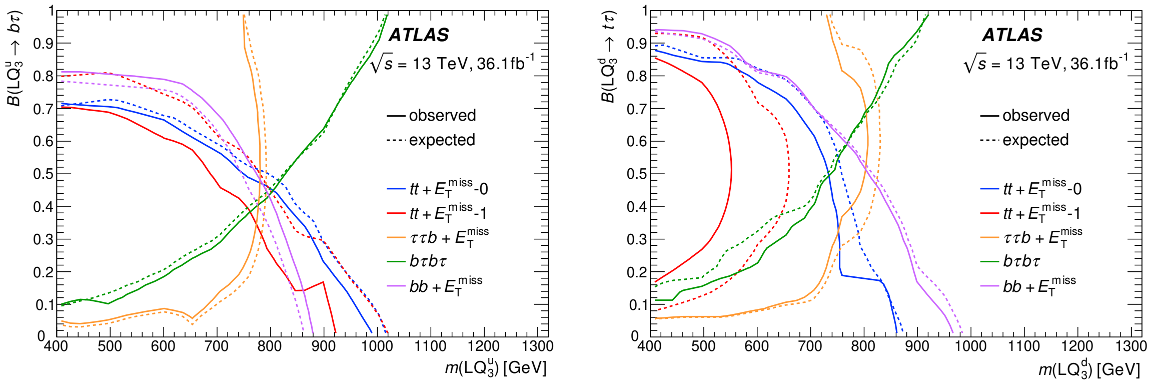
The optimized search for pair-produced third generation LQs decaying into $\tau\tau bb$ final state uses the same techniques as a search for production of two Higgs bosons decaying into bb and $\tau\tau$ pairs [11]. The search is based on four SRs, each requiring one hadronically decaying tau lepton and at least two jets, one of them b-tagged; the second tau lepton decay mode is either hadronic or leptonic and an additional b-tag of a jet is either required or vetoed. A dedicated BDT is trained for each SR and for each LQ mass for which there is a corresponding MC sample. BDT input variables are similar to those described in Sec. 2, for details see Ref. [2]. This search has the highest sensitivity to up-type LQs and to high B values. However, it has a quite good sensitivity to the down-type LQs, high B values as well due to the presence of b-jets from top quark decays.

Stop pair production searches exploit the same final state as up-type LQ searches at low B values. In the limit of a massless neutralino the searches are very similar. The same holds for the sbottom pair production search and a down-type LQ search at low B values. The stop pair production search where the top squarks decay to tau sleptons shows highest sensitivity to intermediate B values due to the exploited $\tau\tau b + E_{\mathrm{T}}^{\mathrm{miss}}$ final state.

Limits set in the (B, m_{LQ}) plane are shown in Fig. 3a for the up-type and in Fig. 3b for the down-type LQs. They reach masses of 1 TeV for the highest and the lowest B values.

4. Conclusion

Scalar LQs were sought using 36.1 fb^{-1} of pp-collision data at 13 TeV center-of-mass energy. The data was delivered by the LHC and recorded by the ATLAS experiment. No excess of data



(a) (b)

Figure 3: Limits on third generation (a) up-type and (b) down-type LQ scenarios determined by points in the (β, m_{LQ}) plane [2]. The solid (dashed) curves display the observed (expected) limits.

over the SM expectation is observed. First (second) generation LQs are excluded up to masses of 1400 (1560) GeV for $\beta = 1$. Third generation up- and down-type LQs are excluded up to masses of 1 TeV for the highest and the lowest B values.

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References

[1] ATLAS Collaboration, *Searches for scalar leptoquarks and differential cross-section measurements in dilepton-dijet events in proton-proton collisions at a centre-of-mass energy of $\sqrt{s}$ = 13 TeV with the ATLAS experiment*, arXiv:1902.00377 [hep-ex].

[2] ATLAS Collaboration, *Searches for third-generation scalar leptoquarks in $\sqrt{s}$ = 13 TeV pp collisions with the ATLAS detector*, arXiv:1902.08103 [hep-ex].

[3] L. Evans and P. Bryant, *LHC Machine*, JINST **3** (2008) S08001.

[4] W. Buchmüller, R. Rückl, and D. Wyler, *Leptoquarks in Lepton - Quark Collisions*, Phys. Lett. B **191** (1987) 442–448. Erratum: Phys. Lett. B **448** (1999) 320.

[5] ATLAS Collaboration, *Search for a scalar partner of the top quark in the jets plus missing transverse momentum final state at $\sqrt{s}$=13 TeV with the ATLAS detector*, JHEP **12** (2017) 085, arXiv:1709.04183 [hep-ex].

[6] ATLAS Collaboration, *Search for top-squark pair production in final states with one lepton, jets, and missing transverse momentum using 36fb^{-1} of $\sqrt{s} = 13$ TeV pp collision data with the ATLAS detector*, JHEP **06** (2018) 108, arXiv:1711.11520 [hep-ex].

[7] ATLAS Collaboration, *Search for supersymmetry in events with b-tagged jets and missing transverse momentum in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, JHEP **11** (2017) 195, arXiv:1708.09266 [hep-ex].

[8] ATLAS Collaboration, *Search for top squarks decaying to tau sleptons in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Phys. Rev. **D98** (2018) no.~3, 032008, arXiv:1803.10178 [hep-ex].

[9] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST **3** (2008) S08003.

[10] 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, arXiv:1007.1727 [physics.data-an]. *Erratum ibid.* 73 (2013) 2501.

[11] ATLAS Collaboration, *Search for resonant and non-resonant Higgs boson pair production in the $b\bar{b}\tau^+\tau^-$ decay channel in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Phys. Rev. Lett. **121** (2018) no.~19, 191801, arXiv:1808.00336 [hep-ex]. [Erratum: Phys. Rev. Lett.122,no.8,089901(2019)].