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Searches for new phenomena in final states involving leptons and jets using the ATLAS detector

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Many theories beyond the Standard Model predict new particles which decay to final states containing both leptons and jets. Searches for these kinds of signatures, predicted by new physics models, are performed using the ATLAS experiment at the LHC. The results of recent searches using 13 TeV proton-proton collision data are presented.

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1. Introduction

In searches with data from the ATLAS experiment [1] at the Large Hadron Collider (LHC), final states including jets and leptons are used to investigate a wide range of phenomena. For the results presented here, data from LHC Run 2 proton-proton collisions were used. The selected analyses include 2015, 2016, and 2017 data, corresponding to integrated luminosities ranging from $36-80$ fb^{-1} collected at a center-of-mass-energy of $\sqrt{s}=13$ TeV.

2. Search for excited electrons

The search for excited electrons [2] is motivated due to their appearance in various compositeness models. This analysis uses the model presented in Reference [3] as a benchmark. It introduces particles called *preons* that bind at a high scale Λ to form SM fermions and their excited states. Excited fermions form vector-like states that acquire masses on the order of Λ.

The search in this analysis is divided into two channels as shown in Figure 1. Decays of the excited electron are searched for in final states including

- two electrons and two hadronic jets ($eejj$ channel)
- an electron, missing transverse momentum, and a large-radius jet ($e\nu J$ channel).

For the $eejj$ channel the main background contribution comes from Drell-Yan events. For the $e\nu J$ channel, events including a W boson and jets constitute the main background. In addition to these, $t\bar{t}$, single-top events, and events including two bosons contribute to the backgrounds.

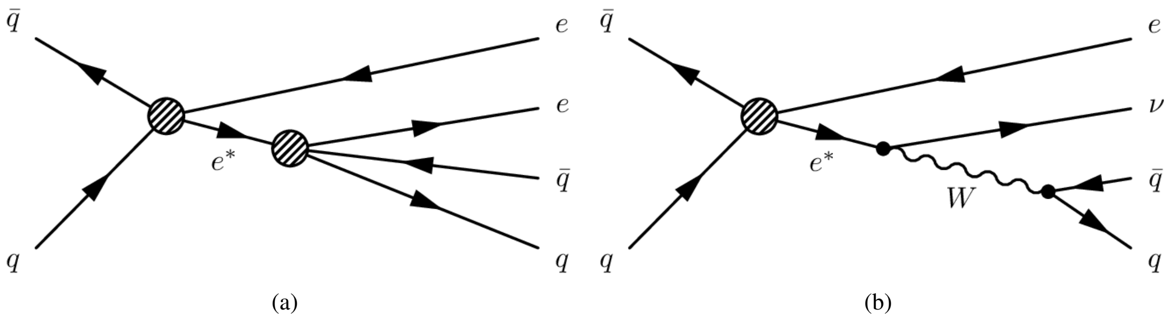
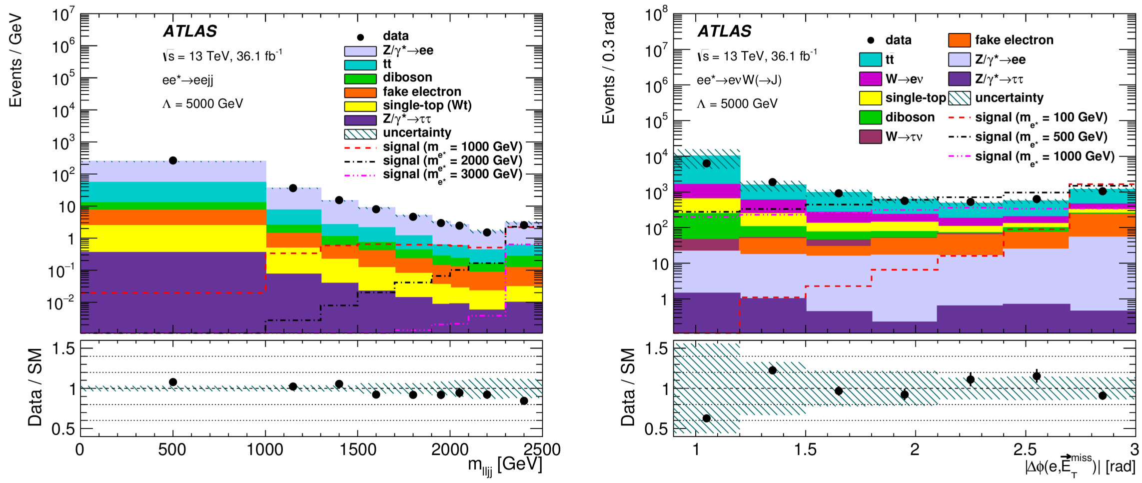


Figure 1: An excited electron decaying via a contact interaction into an electron and a pair of quarks $eq\bar{q}$ in (a), and via a gauge interaction into a neutrino ν, a W boson, and a large jet, J, formed by the quark-antiquark pair in (b).

For the $eejj$ channel the signal region was defined using the invariant mass m_{ll} of the electron pair, the scalar sum S_{T} of the transverse momenta of the two electrons and the two jets with the highest p_{T}, and the invariant mass m_{lljj} of these two electrons and jets.

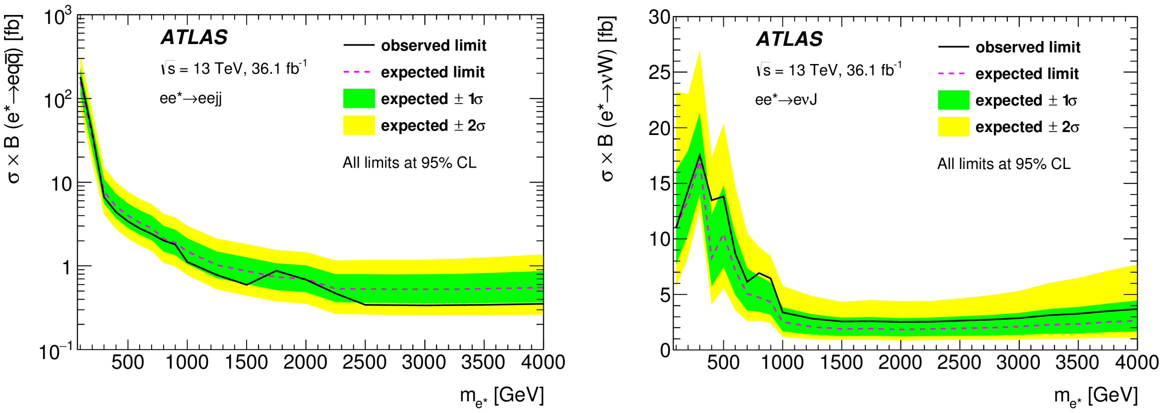
For the $e\nu J$ channel, the transverse mass $m_{\mathrm{T}}^{\nu W}$, and the azimuthal angle $|\Delta\phi(e, E_{\mathrm{T}}^{\mathrm{miss}})|$ between the electron and missing transverse energy were used. Example distributions of these variables are shown in Figure 2. The normalization for the main backgrounds was taken from control regions.



(a) (b)

Figure 2: The invariant mass distribution m_{lljj} of two electrons and two jets in the $eejj$ signal region in (a), and the distribution of the azimuthal angle $|\Delta\phi(e, E_{\mathrm{T}}^{\mathrm{miss}})|$ between the electron and missing transverse energy term in (b) for the $e\nu J$ channel [2].

A binned likelihood fit was performed on the yields in the two control regions and the signal region. Since no significant excess was observed over the expected backgrounds, limits, as shown in Figure 3, were set on the cross-section, σ, times the branching ratio, B, as a function of the excited electron mass m_e^*.



(a) (b)

Figure 3: Limits on the cross-section, σ, times the branching ratio, B, as a function of the excited electron mass m_e^* for the $eejj$ channel in (a) and for the $e\nu J$ channel in (b) [2].

In order to set a combined limit on the compositeness scale Λ, as shown in Figure 4, a unified likelihood function for both channels was constructed.

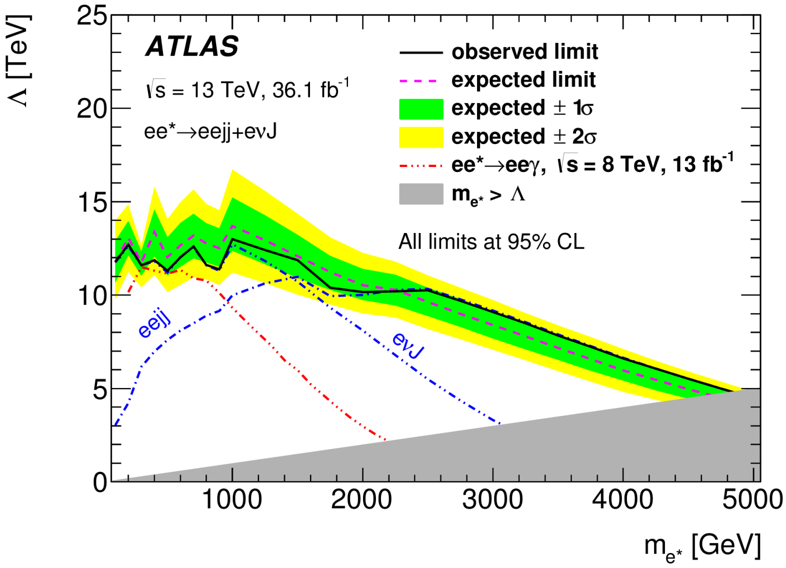


Figure 4: A combined limit on the compositeness scale Λ is shown. For the low mass region Λ is excluded up to 13 TeV. The limit for $m_e^* > 4$ TeV is the result of extrapolation [2].

3. Search for third generation scalar leptoquarks

The second result [4] presented is a combination of various analyses of pair production of scalar leptoquarks (LQs), decaying into third generation quarks (i.e. top or bottom quark), and a τ or a neutrino ν. The search is carried out for up- and down-type LQs which decay as shown in Figure 5. The benchmark model used in this search is the Buchmüller-Rückl-Wyler model [5], that assumes that LQs can only interact with leptons and quarks of the same generation. The LQs couple to the lepton-quark pair via a Yukawa interaction. The strength of these couplings is determined by two parameters; the model parameter β, and the coupling parameter Λ. For $\beta = 0.5$, the LQ mass dependency on the branching ratio B is shown in Figure 6.

The search was split into the following event categories:

- two b-jets and two τs
- a $t\bar{t}$ pair, and missing transverse energy
- a $t\bar{t}$ pair, missing transverse energy, and a lepton
- one b-jet, two τs, and missing transverse energy
- two b-jets, and missing transverse energy.

For each of these channels upper limits are set on the cross-section for a fixed value of B that is expected to have the highest sensitivity for the respective analysis. Based on theoretical predictions for the LQ pair production cross-section, these limits are converted to lower limits on the LQ mass (Figure 7), and LQ masses below 800 GeV are excluded, independent of B.

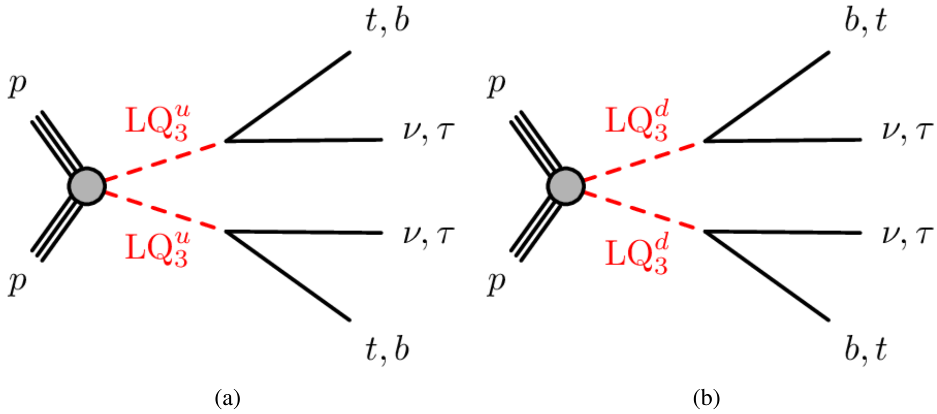


Figure 5: The decay of an up-type leptoquark $\mathrm{LQ}_3^u \to \tau\nu/b\tau$ is shown in (a), and for a down-type leptoquark $\mathrm{LQ}_3^d \to b\nu/t\tau$ in (b).

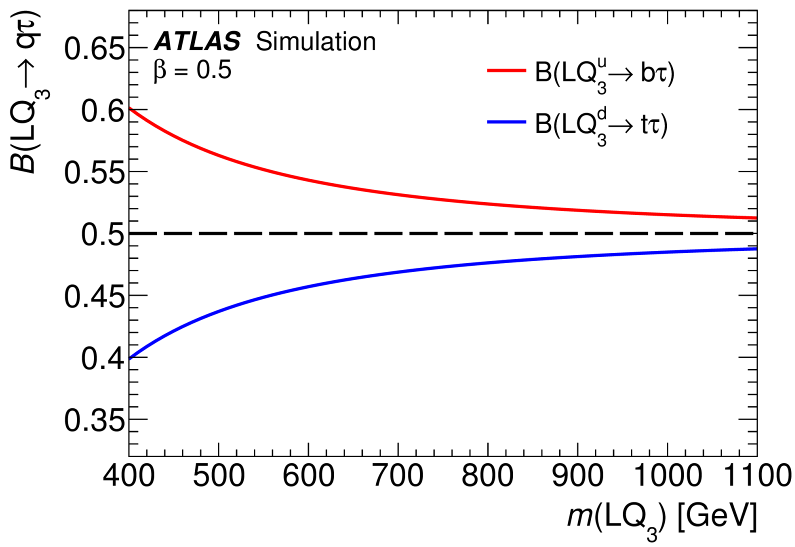


Figure 6: For a model parameter $\beta = 0.5$, the branching ratio B is shown as a function of the LQ mass for the LQ_3^u and LQ_3^d LQ [4].

4. Search for a right-handed gauge boson

This analysis [6] presents a search for a right-handed gauge boson W_R that decays into a boosted, right-handed heavy neutrino N_R, and a lepton l. The lepton and large-R jet in the final state are back-to-back due to the W_R being heavy and produced nearly at rest. The signature for this decay is as shown in Figure 8. The process being tested here is predicted by the so-called Keung-Senjanović model [7]. The analysis was performed in the electron and the muon channel.

The dominant backgrounds are events with a Z boson and jets (Z+jets), and $t\bar{t}$ events which are both estimated using simulation. The signal, control, and validation regions are as defined in Table 1. The Z+jets background was fitted in the full range as shown in Figure 9.

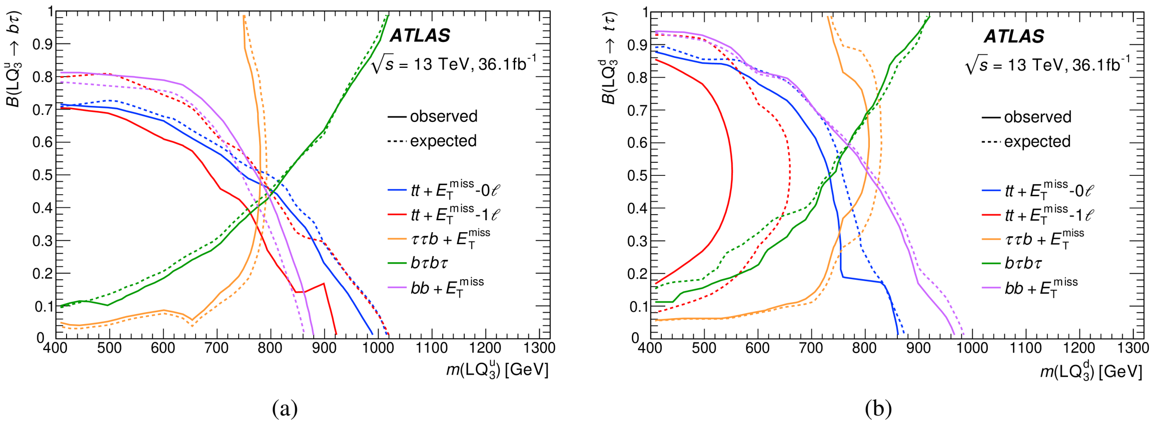


Figure 7: Lower limits on the LQ mass for the up-type (a) and down-type (b) LQs. For both LQ types, masses below 800 GeV are excluded, independent of B. For the values of $B = 0$ and $B = 1$, the LQ mass was excluded up to 1000 GeV LQs [4].

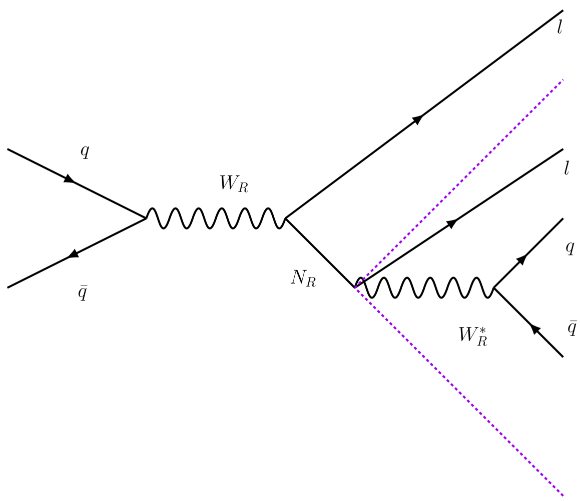


Figure 8: A right-handed gauge boson W_R is produced and decays into a boosted, right-handed heavy neutrino N_R and a lepton l. The N_R decays into a lepton and another right-handed gauge boson $W_{R'}$ that decays hadronically. The decay products of the N_R are considered as one "large-R jet".

The validation region was used to asses the electron identification performance for the sub-leading electron that is inside the jet.

In order to obtain limits on the masses of the N_R and W_R, a one-binned likelihood fit was performed. The limits are presented in Figure 10, showing that the W_R boson is excluded for masses below 5 TeV.

Region	Range of $m_{W_R}^{\text{reco}}$	Lepton flavour
SR	> 2 TeV	Same flavour
CR	< 2 TeV	Same flavour
Validation region (VR)	All	Mixed flavour (leading: muon, subleading: electron)

Table 1: Definition of signal, control, and validation regions for the search for a right-handed W_R boson [6].

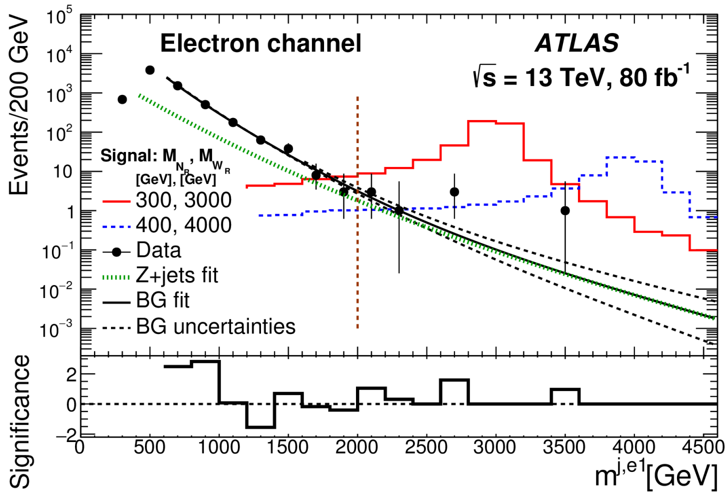
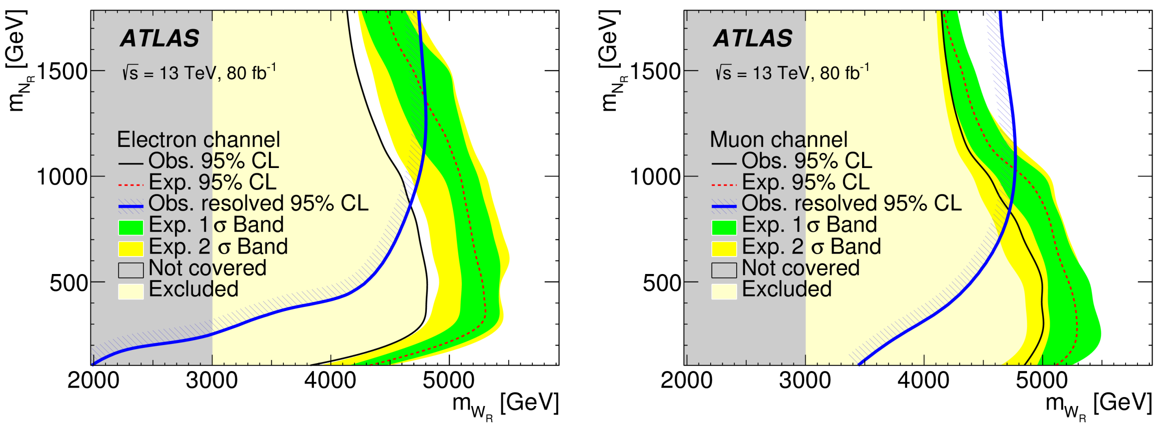


Figure 9: Signal and control regions are shown with Z+jets fitted in the CR ($m^{j,e1} < 2$ TeV) and extrapolated to the SR ($m^{j,e1} > 2$ TeV). The normalization of the $t\bar{t}$ background was obtained by setting the value of the Z+jets normalization to a fixed value and taking the difference between that background and data to compute the $t\bar{t}$ normalization factor [6].



(a) (b)

Figure 10: Limits on the masses of the N_R and W_R for the (a) electron and (b) muon channels [6].

5. Summary

In this document, results are presented for phenomena with final states including jets and leptons, measured in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS experiment at the LHC. The first search for excited electrons that was presented set stronger limits on the excited electron masses than those set previously. The second result, including searches for third generation scalar LQs and considering many decay channels, set higher limits on the LQ masses for up- and down-type LQs. The last analysis presented here is a search for a right-handed gauge boson, setting limits on the mass of a heavy neutrino and a heavy gauge boson in the electron and muon channel.

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