PROCEEDINGS OF SCIENCE

Leptoquarks and other leptonic final states - ATLAS

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Searches for leptoquarks and other exotic processes in multi-lepton final states constitute a new probe to access new physics in the Standard Model flavour sector. The latest results from the ATLAS Collaboration are presented, covering a wide range of topologies. The analyses are performed exploiting the 139 fb^{-1} dataset, recorded at the LHC with a centre of mass energy of $\sqrt{s}$ = 13 TeV. No evidence of new physics is found, thus setting exclusion limits on the various models.

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After the measurement of flavour anomalies (R_D/R_{D^*}, R_K/R_{K^*}, ΔC_9, $g-2$, etc ...) interest has been raised in probing the flavour sector of the Standard Model looking for exotic processes which could generate lepton flavour violation. The ATLAS Collaboration [1] has performed a series of searches for leptoquarks, hypothetical particles coupling both to leptons and quarks, as well as other exotics objects (vector-like leptons, heavy Z' resonances, clockworks) involved in theory scenarios addressing the flavour anomalies.

This note presents analyses covering a wide range of signatures with a single or multi-lepton topology in the final state. Several leptoquarks models (vector and scalar, up/down type, Yang-Mills and minimal coupling scenario) are excluded, using the 139 fb^{-1} dataset recorded by ATLAS detector at the LHC [2], in p-p collisions at a centre-of-mass energy of $\sqrt{s}$ = 13 TeV.

1. Leptoquarks pair-production in multi-lepton final state

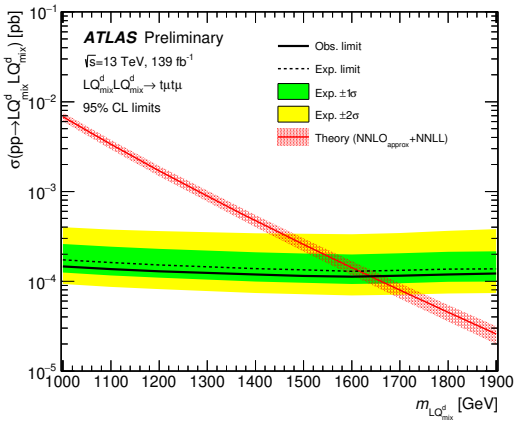

Figure 1: CL_S limit on σ as a function of m_{LQ} [3]

Leptoquark pair production has been searched looking for $t\ell\bar{t}\ell$ final states, where ℓ is an e or a μ. Since the top to bottom quark decay produces a W boson, a multi-lepton final state is generated [3]. Signal events with ≥ 2 light leptons and at least two jets are divided into 3ℓ and 4ℓ signal regions and a fit is done on the effective mass variable, $m_{\text{eff}} = \sum_{\ell,\text{jet}} p_T + p_T^{\text{miss}}$. Under the assumption of exclusive decays into te ($t\mu$), the corresponding lower limit on the scalar leptoquark mass is at 1.61(1.64) TeV, and on the vector leptoquark mass at 1.71(1.73) TeV in the minimal coupling scenario and at 2.0(2.0) TeV in the Yang-Mills scenario.

2. Leptoquarks pair-production in single lepton final state

This search targets pair-produced leptoquarks decaying into third generations quarks and first or second generation leptons [4]. The selected final state has a single lepton, produced either by the leptoquark decay or by top leptonic decay, together with missing transverse momentum and ≥ 4 hadronic jets. Lower limits are set on the LQ mass separately for the μ (e) final state: 1.47(1.44) TeV for the up scalar LQ, 1.37(1.39) TeV for the down scalar LQ, 1.71(1.62) TeV for the vector LQ in the minimal coupling scenario, 1.98(1.90) TeV for the vector LQ in the Yang-Mills scenario.

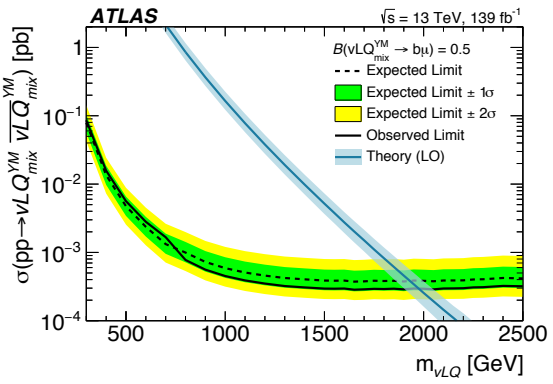

Figure 2: CL_S limit on σ as a function of m_{LQ} [4]

3. Leptoquarks pair-production in $\tau\tau c\bar{c}$ final state

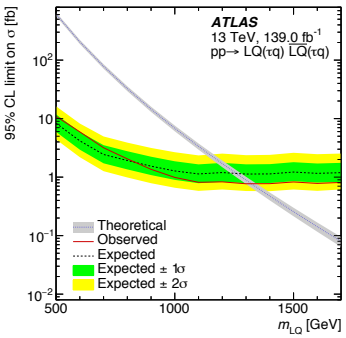

Figure 3: CL_S limit on σ as a function of m_{LQ} [5]

This search looks for leptoquarks pair produced via strong interaction and decaying into a tau lepton and a charm quark [5]. The analysis exploits the fully hadronic channel and targets a final state of $2\tau_{had}$ and $\geq$ 2 jets. The main analysis background, made of hadronic jets misidentified as hadronic taus, is estimated via a data-driven technique based on jet->tau fake factor rates. A same-sign validation region, is used to test the correctness of the fakes estimate. Finally, a lower limit on scalar leptoquarks mass is set at 1.3 TeV.

4. Leptoquarks pair-production in $\tau\tau b\bar{b}$ final state

In this analysis pair-produced leptoquarks are searched, decaying into τ-bjet couples [6]. Both semi-leptonic and fully hadronic channels are exploited. The scalar sum variable, $S_T = \sum_{\tau,\text{jet}} p_T + p_T^{\text{miss}} > 600$ GeV is used for signal selection, while multivariate discriminant scores are used to extract final exclusion limits. Masses below 1.49 TeV are excluded for scalar LQs, while for vector leptoquarks the corresponding limit is 1.69(1.96) TeV in the minimal coupling (Yang Mills) scenario.

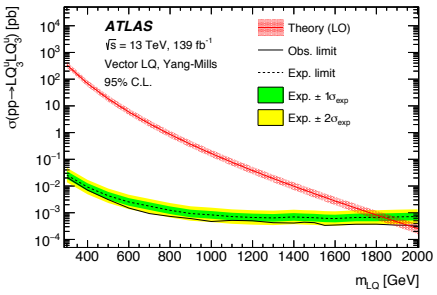

Figure 4: CL_S limit on σ as a function of m_{LQ} [6]

5. Search for vector-like leptons in multi-lepton final states

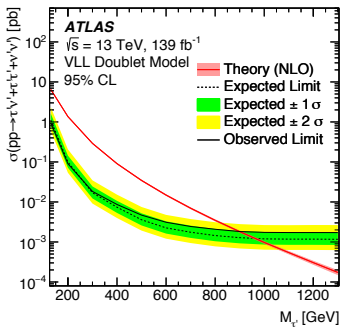

Figure 5: CL_S limit on σ as a function of $m_{\tau'}$ [7]

Vector-like leptons have also been searched exploiting multi-lepton final states [7]. A VLL is a doublet $L' = (\nu'_\tau, \tau')$ that comprises two fermions decaying into a tau-lepton and a SM gauge boson (which then decays into additional leptons). This analysis targets final states including $\geq$ 2 light leptons (e or μ) and $\geq$ 0 hadronically-decaying tau leptons. Seven distinct signal-regions are built and a BDT is trained to classify among the regions. Masses $m_{\tau'}$ in the interval 130 – 900 GeV are finally excluded.

6. Search for Z' heavy resonance in four-muon events

The Z' is vector gauge boson predicted in the context of lepton flavour universality violation theory scenarios [8]. The very clean channel with four muons in the final state is exploited, with muons divided in two pairs: two coming from a Z boson mediated Drell-Yan process, the other two coming from the decay of the Z' which is radiated in the final state. Mass pairing is used to reconstruct the two couples and a parametric DNN is exploited to parameterize all possible Z' masses. An exclusion contour is set in the coupling constant - mass plane, ruling out the intervals $5 < m_{Z'} < 81$ GeV and $0.003 < g_{Z'} < 0.2$ [9].

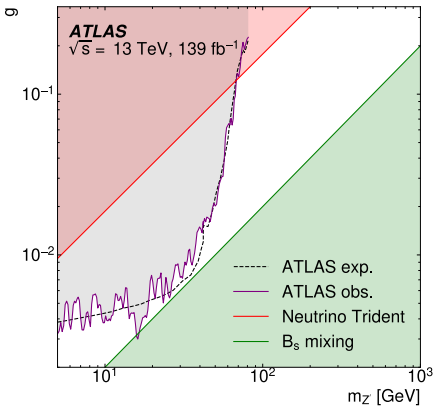

Figure 6: Exclusion contour in the g - m_Z plane. [9]

7. Search for clockworks in di-electron and di-photon mass spectra

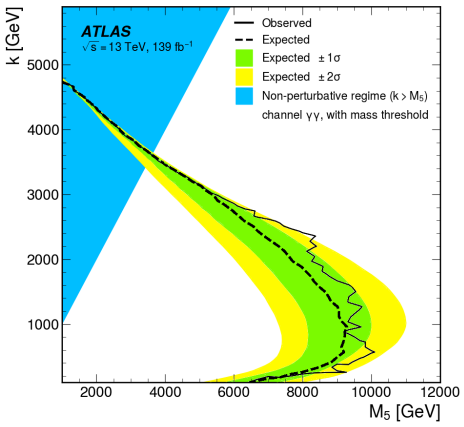

Figure 7: Exclusion contour in the k - m_5 plane. [11]

In the context of theories addressing the naturalness and hierarchy problem, the existence of exotic periodic signal in multi-lepton invariant mass spectrum (clockworks) has been hypothesized [10]. ATLAS has looked for clockworks in the di-electron and di-photon invariant mass spectrum [11]. Events are plot in the frequency domain via scalograms, i.e. diagrams in frequency - inv. mass space, in which a periodic signal corresponds to a local peak. Machine learning techniques are used to analyse the scalograms: auto-encoders for a model-independent search, while binary classifiers for a model-dependent search. An exclusion contour is set for two parameters of the spin-2 Kaluza-Klein periodic signal, ruling off the intervals $1 < M_5 < 11$ TeV and $0.1 < k < 5$ TeV.

Conclusions

This note summarised the most recent results searching for new physics in the Standard Model flavour sector via multi-leptons final states. ATLAS carried out a wide range of analyses considering complementary signatures to constrain as much as possible new physics models. No significant excess over the SM predictions has so far been observed and limits on several new physics mechanisms have been set, which provide the starting points for Run3 data-taking.

References

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