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Searches for Heavy Neutrinos with the ATLAS Detector

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Multiple theories beyond the Standard Model predict the existence of heavy Majorana or Dirac neutrinos. The ATLAS searches presented here focus on models in which these heavy neutral leptons are either produced together with a right-handed W gauge boson, via the Keung-Senjanović process, or with a heavy charged lepton from the same fermionic triplet, in the context of a type-III seesaw model. The searches focus on final states containing two leptons (of opposite signs or of same signs) and jets, using proton-proton collisions at $\sqrt{s} = 13$ TeV collected with the ATLAS detector at the LHC.

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1. Introduction

Experiments on neutrino flavour oscillations [1] provided evidence that neutrinos have non-zero masses, with tiny values at sub-eV scale. The smallness of neutrino masses compared to all other charged fermions suggests the existence of new BSM mechanisms acting at new mass scales. In fact, the simple introduction of a Standard Model (SM) singlet neutral fermion ("sterile") would lead to small Yukawa couplings of the order of $y = m_{\text{atm}}/v \simeq 10^{-13}$, where m_{atm} is the neutrino mass-scale indicated by atmospheric neutrino experiments and v is the SM Higgs vev. Such values would clash against naturalness principles and would make an experimental observation very difficult if not impossible.

Being neutrinos electrically neutral, an interesting workaround is provided by the seesaw mechanism, which introduces new massive states to generate explicit Majorana mass terms. There are three different realizations of this mechanism, depending on how the dimension-5 operator is implemented at tree level: i) through a SU(2) fermion singlet, identified as a right-handed (RH) Majorana neutrino N (type-I seesaw); ii) through a SU(2) scalar triplet $(\Delta^{++}, \Delta^{+}, \Delta^{0})$ (type-II seesaw); iii) through a SU(2) fermion triplet $(\Sigma^{+}, \Sigma^{0}, \Sigma^{-})$, where the neutral component is a Majorana RH neutrino (type-III seesaw). The common feature of these mechanisms is to provide light neutrino masses of the order of $m_\nu \sim M_D^2/M$, where M_D is a Dirac mass and M is the mass of the new states. For sufficiently large M (as those involved in Grand Unification Theories) small neutrino masses could be generated even with Yukawa coupling of the order of unity. On the other hand, small masses could be also obtained while keeping M at the TeV scale making these searches experimentally accessible at colliders [2, 3].

A natural implementation of the Type-I seesaw mechanism is within the Left-Right Symmetric Model (LRSM) in which a new high-scale SU(2)$_R$ symmetry group is introduced to restore parity symmetry in weak decays at high energy. In this case a new gauge sector $V_R = \{W_R, Z'\}$ is included together with a RH neutrino N as the counterpart of RH charged leptons. The golden channel at colliders is the Keung-Senjanović (KS) process [4], which can be considered a high energy analogous of the low energy $0\nu\beta\beta$ process. Its observation would provide the smoking gun for the Majorana nature of neutrinos. In Fig. 1 the process is shown in the $m_{W_R} > m_N$ hierarchy hypothesis, where opposite-sign (OS) and same-sign (SS) lepton pairs are produced in equal fractions. The inverse hierarchy case $m_{W_R} < m_N$ and the boosted $m_{W_R} \gg m_N$ topology can also be experimentally addressed, the latter by looking at substructures in "fat" jets.

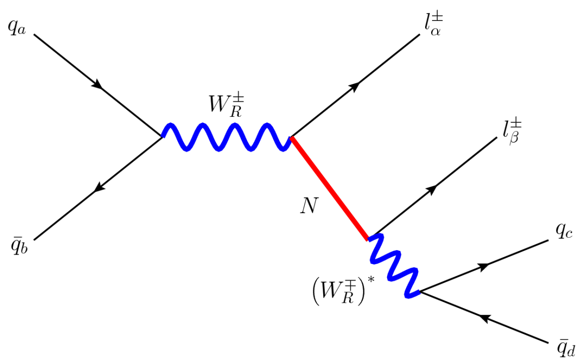

Figure 1: The KS process assuming the $m_{W_R} > m_N$ hierarchy, where a Majorana neutrino N produces a final state with two same-sign leptons and two jets violating the lepton number conservation ($\Delta L = 2$).

2. Results

A vast experimental program devoted to the quest for heavy neutrinos was carried out with the ATLAS detector [5] at LHC. All three types of seesaw mechanisms were addressed by looking at different final state topologies.

Type-I seesaw searches were performed by ATLAS at $\sqrt{s}$ = 7 TeV [6], 8 TeV [7] and, more recently, at $\sqrt{s}$ = 13 TeV [8]. Similar analyses were performed by the CMS experiment at $\sqrt{s}$ = 13 TeV [9, 10]. In [7] the analysis was set in the context of the minimal Type-I seesaw and in the LRSM. In the first case, the process is similar to the diagram shown in Fig. 1 where the W_R is replaced by an off-shell W boson. The free parameters of the model are the mixing between Majorana and ordinary neutrinos, V_{lN}, and the mass of the heavy neutrino m_N. The process is characterized by a very clean signature with two SS leptons and two high-p_T jets in the final state. The closed event kinematics allows the reconstruction of the resonant W boson mass from the measurement of two-jet invariant mass. The complementary $m_N < m_W$ scenario was not considered since it can be experimentally studied with dedicated analyses via displaced vertexes reconstruction. The dominant background common to most of these analyses comes from diboson production and $t\bar{t}$ events where one of the charged lepton undergoes a wrong charge reconstruction. The observed limits exclude mixing parameters above $|V_{lN}|^2 \simeq 0.003$ for $M_N \simeq 100$ GeV and above $|V_{lN}|^2 \simeq 0.4$ for $M_N \simeq 500$ GeV.

In the LRSM analysis, perfect symmetry is assumed at high scales so that right-handed gauge bosons are assumed to interact with SM particles as in the left sector ($g_R = g_L$). Exclusion contours were set in the (m_{V_R}, m_N) plane, as shown in the left panel of Fig. 2 for $V_R \equiv W_R$ and assuming $m_N < m_{W_R}$. The new analysis at $\sqrt{s}$ = 13 TeV [8] targets both Dirac and Majorana cases by looking at SS and OS lepton pairs. Also the inverted hierarchy $m_N > m_{W_R}$ is now explored for the first time.

Type-II seesaw does not contain explicit heavy neutrino production since the Majorana mass term is dynamically produced when the neutral component of the triplet acquires a vev v_Δ. Here we only mention a recent ATLAS result on the search for the doubly-charged component of the triplet

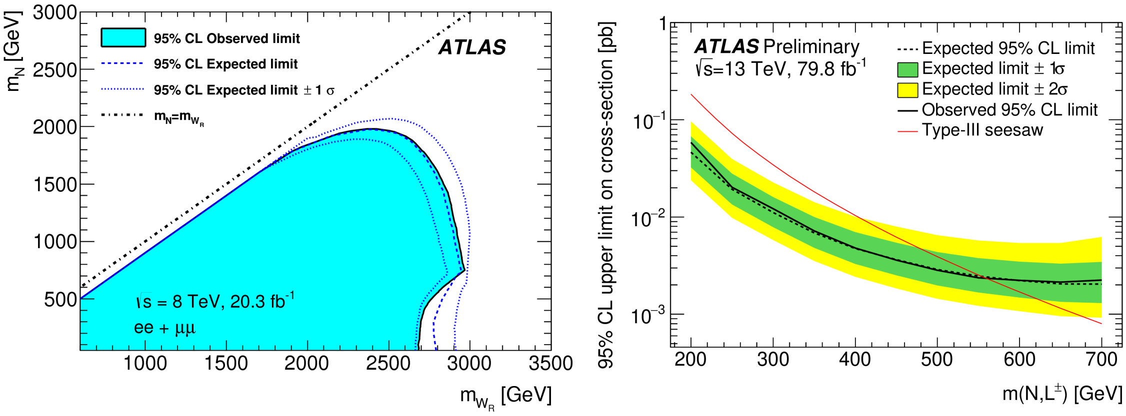

Figure 2: Left panel: observed and expected exclusion contour at 95% confidence level in the (m_{W_R}, m_N) plane within the LRSM [7]. Right panel: observed and expected exclusion limit at 95% confidence level for the production of Type-III seesaw heavy leptons [14], together with the cross section predicted by the model (red line).

at $\sqrt{s}$ = 13 TeV, setting lower limits on the their masses at about 800 GeV [11].

Type-III seesaw heavy lepton searches were performed by ATLAS at $\sqrt{s}$ = 8 TeV [12] looking at final states with two light leptons (electrons or muons) and at least two high-p_T jets and large transverse missing momentum. The analysis was updated at $\sqrt{s}$ = 13 TeV using final states containing two SS or OS light leptons [14] corresponding to 79.8 fb^{-1}. No significant excess above SM predictions was observed and a lower limit on the heavy lepton masses at 560 GeV was set. In Run 1 the analysis was complemented by Type-III seesaw heavy lepton search in the three-lepton final state [13], excluding heavy lepton masses below 470 GeV. Similar analyses were performed by CMS at $\sqrt{s}$ = 13 TeV both in the two-leptons [15] and in the three-lepton [16] final states.

3. Conclusions

The ATLAS experiment at LHC realised a vast research program for the quest of heavy neutrinos in the framework of the seesaw models. All the three model realizations were addressed, in particular in the context of LRSM where new Majorana states emerge naturally. Significant improvements are expected with the completion of the Run 2 data taking, when the luminosity will double with respect to the one used in these analyses. Most of these searches were performed by looking at light leptons (electrons and muons) in the final states, also considering leptonic tau decays. Sensible improvements are expected by the inclusion of hadronic tau decays and by a combination of the different final state results.

References

[1] M. Tanabashi *et al.* [Particle Data Group], Phys. Rev. D **98** (2018) 030001.

[2] T. Appelquist and R. Shrock, Phys. Lett. B **548** (2002) 204.

[3] F. del Aguila and J. A. Aguilar-Saavedra, Phys. Lett. B **672** (2009) 158.

[4] W. Y. Keung and G. Senjanovic, Phys. Rev. Lett. **50** (1983) 1427.

[5] ATLAS Collaboration, JINST **3** (2008) S08003.

[6] ATLAS Collaboration, Eur. Phys. J. C **72** (2012) 2056.

[7] ATLAS Collaboration, JHEP **1507** (2015) 162.

[8] ATLAS Collaboration, arXiv:1809.11105 [hep-ex].

[9] CMS Collaboration, Phys. Rev. Lett. **120** (2018) 221801.

[10] CMS Collaboration, CMS-PAS-EXO-17-028, `http://cds.cern.ch/record/2627097`.

[11] ATLAS Collaboration, Eur. Phys. J. C **78** (2018) 199.

[12] ATLAS Collaborations, Phys. Rev. D **92** (2015) 032001.

[13] ATLAS Collaboration, JHEP **1509** (2015) 108.

[14] ATLAS Collaboration, ATLAS-CONF-2018-020, `http://cds.cern.ch/record/2621484`.

[15] CMS Collaboration, JHEP **1805** (2018) 148.

[16] CMS Collaboration, Phys. Rev. Lett. **119** (2017) 221802.