Snowmass2021 - Letter of Interest

Scrutinising Left Right Symmetric Extensions at LHC and Beyond

Richard Ruiz*[1], Manimala Mitra†[2,3], and Michael Spannowsky‡[4]

[1]Centre for Cosmology, Particle Physics and Phenomenology (CP3),Universite Catholique de Louvain, Chemin du Cyclotron, Louvain la Neuve, B-1348, Belgium
[2]Institute of Physics, Sachivalaya Marg, Bhubaneswar 751005, India
[3] Homi Bhabha National Institute, BARC Training School Complex, Anushakti Nagar, Mumbai 400094, India
[4]Institute for Particle Physics Phenomenology, Department of Physics, Durham University, Durham DH1 3LE, U.K

August 30, 2020

Abstract

Left-Right Symmetric Extensions of the Standard Model are considered among of the most well-motivated theoretical frameworks for generating neutrino masses. Conventional LHC searchs for right-handed (RH) neutrinos mostly probe the same-sign dilepton and dijet signature. For multiple, nearly degenerate RH neutrinos, however, a strong interference among RH neutrinos can sizably influence signal rates. Furthermore, for hierarchical masses, fat-jet descriptions of the signal become more optimal. As a part of the Snowmass 2021 exercises, we plan to explore such non-conventional signals in detail, thereby updating the sensitivity at the LHC and potential successors.

Frontiers: Primary: EF09, NF03. Secondary: TF11, NF05

1 Left Right Symmetric Model and the Collider Signatures

Measurements of neutrinos' squared mass differences and mixing angles [1, 2] by a number of neutrino oscillation experiments clearly indicate the necessity of new, underlying physics behind neutrino mass generation. Furthermore, recent measurements from T2K provide an indication towards CP violation in the Standard Model's (SM) lepton sector. Over the past decades, several different theoretical frameworks have been constructed to explain the neutrino masses and mixings. Most of these extensions contain right handed (RH) neutrinos that generate SM neutrino masses via a seesaw mechanism. At low energies, this manifests as the lepton number-violating (LNV) dimension-5 Weinberg operator, which generates light Majorana masses for neutrino after electroweak symmetry breaking (EWSB).

Among these frameworks, one very well-motivated, ultraviolet completions of the SM that contain RH neutrinos is the Left Right Symmetric Model (LRSM) [3–7], based on gauge symmetry $\mathcal{G}_{LRSM} = SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$. The model encompasses various novel features, including parity restoration at a high scale, and generation of light neutrino masses and mixings. RH Majorana neutrino masses are generated due to breaking of $SU(2)_R \times U(1)_{B-L}$ symmetry, and likewise LH Majorana neutrino masses by EWSB. The model contains additional BSM states, including three heavy Majorana neutrinos (N_k), an exotic Higgs sector, charged gauge bosons $W_R^\pm$, and a neutral gauge boson Z'.

A number of searches have been proposed so far to test the model at LHC. The proposed golden channel [8], which contains same-sign dilepton pair in association with two resolves jets, has been investigated by experiments at both the Tevatron and LHC [9–11]. The non-observation of any signal in this channel has severely constrained the mass of N_k and the mass of the gauge boson W_R. On the other hand, this signal only works as a suitable description if the leptons and jets are well-isolated. In [12], it was shown that if a hierarchy exists between the masses of N_k and W_R, with $M_{W_R} \gg m_{N_k}$, the decay products of the N_k would rather be collimated, leading to a single jet with a three-pronged substructure. This channel has further been investigated by the ATLAS collaboration [13]. The LHC searches so far have looked for different resolved final state, and a lepton-fat jet signature. However, few of the many possibilities have yet to be throughly explored.

Like many other beyond the SM (BSM) theories, present searches at ATLAS and CMS focus on benchmark scenario of the LRSM. This includes considering only a single mass eigenstate N and real-valued mixing. As such, present

*richard.ruiz@uclouvain.be
†manimala@iopb.res.in
‡michael.spannowsky@durham.ac.uk

experimental constraints from direct searches would be different if degenerate N participate in the LNV signal process and subsequently interfere [14–17]. Non-trivial, complex-valued heavy neutrino mixing would further offer possible CP violation in the RH neutrino sector. For nearly degenerate heavy neutrinos, interference effects between different heavy neutrino contributions in the dilepton+dijet signal and lepton+fat jet signal categories can change the signal rates significantly [17]. Moreover, the LNV and lepton number conserving (LNC) rates can also be different, independent of helicity arguments [18, 19]. The observation of a difference in these rates would suggest a large interference effect, and a non-trivial mixing present in the RH neutrino sector.

2 Scope

As a part of the Snowmass 2021 exercises, we plan to explore non-conventional signatures, such as the lepton+fat jet signal as well as the dilepton+dijet signal for nearly degenerate heavy neutrinos. We plan to perform a detailed analysis taking into account interference effect between different neutrino contributions, and in doing so update the sensitivity to the LRSM at the LHC and potential successors.

References

[1] I. Esteban, M. Gonzalez-Garcia, M. Maltoni, T. Schwetz, and A. Zhou, "The fate of hints: updated global analysis of three-flavor neutrino oscillations," arXiv:2007.14792 [hep-ph].

[2] P. de Salas, D. Forero, S. Gariazzo, P. Martínez-Miravé, O. Mena, C. Ternes, M. Tórtola, and J. Valle, "2020 Global reassessment of the neutrino oscillation picture," arXiv:2006.11237 [hep-ph].

[3] J. C. Pati and A. Salam, "Lepton Number as the Fourth Color," *Phys. Rev. D* **10** (1974) 275–289. [Erratum: Phys.Rev.D 11, 703–703 (1975)].

[4] R. N. Mohapatra and J. C. Pati, "Left-Right Gauge Symmetry and an Isoconjugate Model of CP Violation," *Phys. Rev. D* **11** (1975) 566–571.

[5] R. Mohapatra and J. C. Pati, "A Natural Left-Right Symmetry," *Phys. Rev. D* **11** (1975) 2558.

[6] G. Senjanovic and R. N. Mohapatra, "Exact Left-Right Symmetry and Spontaneous Violation of Parity," *Phys. Rev. D* **12** (1975) 1502.

[7] G. Senjanovic, "Spontaneous Breakdown of Parity in a Class of Gauge Theories," other thesis, 1979.

[8] W.-Y. Keung and G. Senjanovic, "Majorana Neutrinos and the Production of the Right-handed Charged Gauge Boson," *Phys. Rev. Lett.* **50** (1983) 1427.

[9] **D0** Collaboration, S. Abachi *et al.*, "Search for Right-Handed W Bosons and Heavy W' in $p\bar{p}$ Collisions at $\sqrt{s}$ =1.8 TeV," *Phys. Rev. Lett.* **76** (1996) 3271–3276, arXiv:hep-ex/9512007.

[10] **CMS** Collaboration, A. M. Sirunyan *et al.*, "Search for a heavy right-handed W boson and a heavy neutrino in events with two same-flavor leptons and two jets at $\sqrt{s} = 13$ TeV," *JHEP* **05** (2018) 148, arXiv:1803.11116 [hep-ex].

[11] **ATLAS** Collaboration, M. Aaboud *et al.*, "Search for heavy Majorana or Dirac neutrinos and right-handed W gauge bosons in final states with two charged leptons and two jets at $\sqrt{s} = 13$ TeV with the ATLAS detector," *JHEP* **01** (2019) 016, arXiv:1809.11105 [hep-ex].

[12] M. Mitra, R. Ruiz, D. J. Scott, and M. Spannowsky, "Neutrino Jets from High-Mass W_R Gauge Bosons in TeV-Scale Left-Right Symmetric Models," *Phys. Rev. D* **94** no. 9, (2016) 095016, arXiv:1607.03504 [hep-ph].

[13] **ATLAS** Collaboration, M. Aaboud *et al.*, "Search for a right-handed gauge boson decaying into a high-momentum heavy neutrino and a charged lepton in pp collisions with the ATLAS detector at $\sqrt{s} = 13$ TeV," *Phys. Lett. B* **798** (2019) 134942, arXiv:1904.12679 [hep-ex].

[14] P. Bhupal Dev, R. N. Mohapatra, and Y. Zhang, "CP Violating Effects in Heavy Neutrino Oscillations: Implications for Colliders and Leptogenesis," *JHEP* **11** (2019) 137, arXiv:1904.04787 [hep-ph].

[15] J. Gluza and T. Jeliński, "Heavy neutrinos and the pp→lljj CMS data," *Phys. Lett. B* **748** (2015) 125–131, arXiv:1504.05568 [hep-ph].

[16] S. Bray, J. S. Lee, and A. Pilaftsis, "Resonant CP violation due to heavy neutrinos at the LHC," *Nucl. Phys. B* **786** (2007) 95–118, arXiv:hep-ph/0702294.

[17] R. M. Godbole, S. P. Maharathy, S. Mandal, M. Mitra, and N. Sinha, "Interference Effect in LNV and LNC Meson Decays for Left Right Symmetric Model," arXiv:2008.05467 [hep-ph].

[18] T. Han, I. Lewis, R. Ruiz, and Z.-g. Si, "Lepton Number Violation and W' Chiral Couplings at the LHC," *Phys. Rev. D* **87** no. 3, (2013) 035011, arXiv:1211.6447 [hep-ph]. [Erratum: Phys.Rev.D 87, 039906 (2013)].

[19] R. Ruiz, "A quantitative study on helicity inversion in Majorana neutrino decays at the LHC," arXiv:2008.01092 [hep-ph].