Snowmass2021 - Letter of Interest

Low Mass Right Handed Neutrino at LHC and HL-LHC

Thematic Areas: (check all that apply □/■)

■ (TF07) Collider physics
■ (EF09) BSM: More general explorations
■ (TF11) Theory of Neutrino Physics

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Abstract

We plan to explore the detection prospect of a low mass right handed (RH) neutrino, arising from a $B-L$ gauge symmetric extension at LHC and at its future upgrades. The RH neutrinos of masses in the few GeV range can have macroscopic decay lengths. Moreover, a lighter RH neutrino state can be sufficiently boosted. We plan to investigate the displaced decays of the RH neutrinos, along with fat-jet signatures.

Motivation:

The experimental probe of the underlying theory of neutrino mass generation is one of the major research activities in the worldwide particle physics research program. The observation of neutrino oscillation by solar, atmospheric, long-baseline and reactor neutrino experiments have conclusively proven, that the Standard Model (SM) neutrinos have tiny eV masses [1]. Cosmological observations [2] impose further constraints on the absolute mass scale of the light neutrinos, $m_0 < 0.1$ eV. Over the past few decades, several appealing theories have been postulated to explain neutrino masses. The gauged $U(1)_{B-L}$ model is one of the well-motivated and simplest extensions among them. The model contains three generations of right handed (RH) neutrinos N_R, one extra gauge singlet scalar field, and an extra $B-L$ gauge field Z'. The vacuum expectation value of the scalar field breaks the $B-L$ symmetry, and generates the Majorana masses of the RH neutrinos. The RH neutrinos in-turn generate light Majorana neutrino masses via the profound *seesaw* mechanism [3–6]. The RH neutrinos N_{R_i} interact with the Z' gauge boson, as well as, the SM and BSM Higgs h and H, respectively. This facilitates the production of the RH-neutrinos at colliders, and in-turn offers enhancement in their detection prospects.

A handful of searches have been proposed so far to test the $B-L$ model at LHC [7–10]. The RH neutrinos can be pair produced, with a subsequent decay to lepton and quarks. This results in a di-lepton+4 *jet* final state. The other very interesting mode, mostly relevant for a relatively lighter RH neutrino state is the displaced decay mode of N_R. It has been shown [11], that for RH neutrino mass $M_{N_R} \sim \mathcal{O}(10)$ GeV, pair-production of N_R from SM Higgs decay at LHC can be significant, while its decay can have displaced decay characteristics. Depending upon the mixing between active and RH neutrinos, the decay length can be considerably large $l \sim$ mm-cm range. For lower masses, the RH neutrino can further be boosted, with decay products being collimated, leading to a large radius jet. In addition to the production from SM Higgs decay, the Z', and BSM Higgs decay can also contribute to the pair-production of these low mass RH neutrinos [12]. These different channels enhance the detection prospect of a low mass RH neutrino state at LHC, and at its future upgrades.

Objective:

We plan to focus on the detection prospects of a low mass RH neutrino with mass $M_{N_R} \sim 100\,\text{MeV} - 50\,\text{GeV}$ at LHC and its future upgrades. In particular, we would explore the pair-production mode of the RH neutrino, and its displaced decays. For the above mentioned mass range, the RH neutrino can have a wide variation in its macroscopic decay length $l \sim mm -$ km. Furthermore, a light RH neutrino state can be sufficiently boosted, leading to collimated decay products. Therefore, our proposed signature would contain displaced fat jets. In particular, we plan to focus on a dedicated simulation of the displaced fat jet signal at the LHC, and it's High Luminosity upgrades. For a very large decay length $l \sim$ km, the RH neutrino can be probed at MATHUSLA. A study on the detection prospect of low mass RH neutrino for a very high energy pp machine, operating with c.m.energy 100 TeV will also be pursued.

Summary:

The low mass region of the RH neutrino is one of the challenging corners of the parameter space, that is yet to be explored. For masses of the RH neutrinos in the few GeV range, its decay can be displaced. This encompasses few different possibilities, such as, RH neutrino can decay within the inner tracker, or even outside the inner tracker and in other different components of the detector. We plan to investigate the displaced decays of RH neutrinos in detail, along with the fat jet signature.

References

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