The effective theory of the see-saw portal at future lepton colliders

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Abstract

Heavy Neutral Leptons (HNL) with masses around the electroweak scale are an interesting phenomenological possibility, since they can not only generate neutrino masses and the matter-antimatter asymmetry of the universe, but they are testable at colliders and fixed target experiments via active-sterile mixing. Such HNL can be part of a larger sector, with the other states much heavier than the electroweak scale. In this case the physics is captured by the higher dimensional operators of the so-called νSMEFT. Interestingly, the effective operators can drastically modify the phenomenology of HNL, introducing new production and decay modes that can dominate over the ones induced by mixing. Given the important role played by HNL, we consider important to include a discussion about the reach of future lepton colliders in bounding the operators of the νSMEFT.

Electroweak scale Heavy Neutral Leptons (HNL, also called right-handed or sterile neutrinos) are an interesting possibility to explain some of the shortcomings of the Standard Model (SM) such as neutrino masses [1] and the matter-antimatter asymmetry of the universe [2]. If such HNL have masses of the order of the electroweak scale, their presence can be tested at colliders and fixed-target experiments [3, 4, 5]. In this case, production and decay of HNL proceed through mixing with active neutrinos, and depending on the region in parameter space we can have either prompt, displaced or outside the detector decays. There are however well motivated situations (like in TeV left-right symmetric models [6] or

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in GUTs [7]) in which the HNL are part of an extended sector, with the masses of the additional states above the TeV scale. This possibility is accounted for in a model independent way by the so-called νSMEFT, *i.e.* the effective field theory constructed out of SM and HNL fields [3, 8]. Interestingly, the effective operators added to the Lagrangian may drastically modify HNL physics, with contact interactions introducing new production modes (for instance, additional exotic Higgs decays into a pair of HNL) and new decay channels. Remarkably, these new decay channels can easily dominate over those mediated by active-sterile mixing, making the HNL decays prompt even in regions in which displaced decays are expected. Whether this is the case or not depends crucially on whether the additional contact interactions are generated at tree of loop level, and whether flavor symmetries impose additional selection rules on the size of the Wilson coefficients [9]. Several works have explored the phenomenology of the νSMEFT. A useful classification is based on whether the processes involved in HNL production and decays are driven by mixing or contact interactions. Most studies have focussed the possibility of production via new contact interactions with decays occurring via active-sterile mixing (see for instance [5] for a study considering displaced HNL decays generated via mixing), but there are regions in parameter space in which potentially both production and decays can be mediated by the higher dimensional operators (see for instance [10] for studies considering displaced HNL decays generated by contact interactions).

It is in this context that we think important to have a detailed look at the reach of future lepton colliders. The reason is two-fold: on one hand the clean environment can allow for improved bounds on the Wilson coefficients of contact interactions, especially for sufficiently high luminosity. In addition, since the νSMEFT operators introduce new exotic Higgs and Z decays, there is an important interplay with the precise measurement of the Higgs and Z decay widths that may also allow to probe interesting regions of parameter space. Preliminary results regarding the dimension 5 operator $c_{NH}NN(H^\dagger H)/\Lambda$ (where N represents the HNL and H the Higgs field) show that at the FCC-ee with a luminosity of 5 ab^{-1} can probe Λ/c_{NH} in the $(150 \div 500)$ TeV region using parton level events [11].

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