Snowmass2021 - Letter of Interest

Heavy Neutrino search in Lepton-Rich Higgs Boson Rare Decays

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

□ (EF01) EW Physics: Higgs Boson properties and couplings
■ (EF02) EW Physics: Higgs Boson as a portal to new physics
□ (EF03) EW Physics: Heavy flavor and top quark physics
□ (EF04) EW Precision Physics and constraining new physics
□ (EF05) QCD and strong interactions: Precision QCD
□ (EF06) QCD and strong interactions: Hadronic structure and forward QCD
□ (EF07) QCD and strong interactions: Heavy Ions
□ (EF08) BSM: Model specific explorations
□ (EF09) BSM: More general explorations
□ (EF10) BSM: Dark Matter at colliders
□ (Other) *[Please specify frontier/topical group]*

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Abstract: The Higgs boson can mix with Beyond the Standard Model scalars which give mass to neutrinos. This mixing opens rare Higgs decay channels into heavy neutrinos, and subsequently a multi-lepton final state at the collider. Searching for heavy neutrinos via rare Higgs decay can test a small mixing between the Higgs boson and BSM 'seesaw' scalars, and it is complementary to $|V_{lN}|^2$-based heavy neutrino search channels. Performing the study for future lepton collider, like CEPC and FCC-ee, etc. will help learning the prospective of testing such mixings.

In BSM theories, 'the Higgs' can mix with extra scalars that generate neutrino masses. The Higgs boson thus acquire a coupling to heavy neutrinos proportional to the scalar mixing θ_S, and this mixing governs the Higgs decay branching fraction into the heavy neutrinos whenever kinematically allowed. Noticeably this scalar mixing angle is generally independent from $|V_{lN}|^2$, or the effective heavy neutrino's coupling to the active neutrino and the SM's gauge bosons, thus serves as an a complementary search channel to $|V_{lN}|^2$-based Drell-Yan channels.

Higgs-mediated heavy neutrino seach involves efficient Higgs production at collider and the Higgs boson's prompt decay into one or two heavy neutrinos. The heavy neutrinos subsequently decay into a final state containing leptons and missing momentum. This search channel depends on θ_S, it applies to seesaw scenarios with tiny $|V_{lN}|$, such as Type-I like models where $|V_{lN}|^2$ can be suppressed. The Higgs mixing to extra seesaw scalar(s) is often a crucial part of a neutrino mass model as it connects the model to the electroweak sector. A model independent, high sensitivity search limit of θ_S will be an important check for studying these seesaw scenarios.

The Higgs boson can decay to heavy neutrinos (N) less massive than $m_h/2$ and $N \to l(W^*)$ decay yields leptons in the final state. The 'traditional' $h \to NN \to l^{\pm}l^{\pm} + j(s)$ features lepton number violation and is well-studied. We are interested in further optimizing signal-background ratio, by choosing final states with a larger multiplicity in leptons: such as two pairs of same-sign, same-flavor dileptons[1], which can be almost background-free and has very good prospective sensitivity on small θ_S values.

	pp	ee @ 240, 350, 500 GeV
Signal	$l^+l^+l'^-l'^-$ + MET	$(Z) + l^+l^+l'^-l'^-$ + MET
Background	$4\tau, WWZ$, fake leptons	$4\tau, 2\tau 2W, 4\tau + Z/2W$

Table 1: Signal and major SM background channels in 4^+ lepton Higgs rare decay channel $h \to NN \to 4l$ + MET.

We find it of interest to extend the existing θ_S study[1;2] to future lepton collider projects, such as the CEPC, FCC-ee, where different (from pp-collision) signal and background channels (listed in Table 1) will need to be studied.

References

[1] Y. Gao, M. Jin and K. Wang, JHEP **02**, 101 (2020) doi:10.1007/JHEP02(2020)101 [arXiv:1904.12325 [hep-ph]].

[2] A. Das, Y. Gao and T. Kamon, Eur. Phys. J. C **79**, no.5, 424 (2019) doi:10.1140/epjc/s10052-019-6937-7 [arXiv:1704.00881 [hep-ph]].