Long-Lived Neutrinos with CMS high multiplicity shower L1 Trigger Proposal in the Muon System in Run 3 of the LHC

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A letter of intent with the proposal to search for long-lived heavy neutrinos with the future CMS μ shower L1 Trigger for Run 3 of the LHC. This falls under the scope of Snowmass 2021. A presentation of this proposal was given at the Snowmass Dark Sectors and Light Long-Lived Particles Cross Frontier Meeting [1].

I. DISCUSSION

Long-Lived particles are nowadays highly motivated from the theoretical and experimental points of view [2]. In the context of theories that address the mechanism for the generation of light neutrino masses in the Standard Model (SM), a new sterile or right-handed neutrino that can be long-lived - and decay with characteristic signatures inside the LHC detectors - is predicted in several models. This heavy neutrino or generally, Heavy Neutral Lepton (HNL) states are currently being looked for by the LHC experiments in various mass ranges, from the GeV to the TeV scale, with several prompt and displaced search strategies. The most up-to-date exclusion comes from ATLAS for a long-lived sterile neutrino decaying to $l = e, \mu$ [3]. No dedicated experimental search targeting a long-lived sterile neutrino mixing in the τ sector has been performed yet at the LHC.

The simplest model, the type-I see-saw model of neutrino mass generation [4] introduces the existence of a heavy sterile neutrinos that mix with the neutrinos in the Standard Model. For low enough mixing angles and sterile neutrino masses below the electroweak scale, the sterile neutrino N can be long-lived, and may decay with a characteristic (displaced) signature inside particle detectors. In ref. [5] we considered a long-lived state N that couples to the SM leptons via a small mixing in the electroweak currents. N can be produced in W boson decays in association with the respective lepton flavour: $W^{\pm} \to N l^{\pm}$. The N decays proceed via $N \to l^{\pm} q\bar{q}$, $N \to l'^{\mp} l^{\pm} \nu_l$ and $N \to \nu_l q\bar{q}$. The relevant parameters are the sterile neutrino mass m_N and active-sterile neutrino mixing $|V_{lN}|^2$, which we treat as independent. In general, small neutrino masses and mixing lead to macroscopic lifetimes.

Several long-lived particle analysis have been proposed to access different ranges in the mixing-mass plane, for mixing with different flavours. These include lepton-jets [6] (prompt μ trigger), displaced vertices in the inner-trackers [5, 7] (prompt lepton trigger, either e, μ or a τ), two displaced vertices in the μ trackers [8] (prompt lepton, e or μ), μ chambers [9] (trigger on a prompt lepton or pairs of leptons), displaced leptons [10] (double lepton trigger). Constraints in the μ sector were also recently performed by the authors in [11] where they take account displacement in searches for semileptonic decays with pions (with a different production mechanism). Also, for completeness, the authors in [12] recently explored constraints in the τ sector for GeV-scale N masses decaying to pions with a dedicated prompt search strategy (two prompt muons as trigger). We note that all these search strategies trigger on either one or two prompt leptons. Figure 1 shows projected exclusions in the μ and τ sector of the studies mentioned above.

Motivated by the critical need for dedicated displaced triggers to access efficiently the lower mass (and low mixing or larger displacement) region, is why we believe a study of the sensitivity that can be obtained with the CMS μ shower L1 Trigger [13] in Run 3 is worthwhile. We note the following advantages with respect to previous works that will help to extend the reach:

- New L1 trigger capabilities for Run 3 will allow to trigger directly on the HNL signature.
- CMS large shielding in the MS allows for large background suppresion - critical for HNL due to single LLP decay.

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- The possibility to best access the τ sector, with the N decaying to a τ which decays to hadrons.
- A suppressed background analysis across the (long-lived) mass range of m_N between $1-50$ GeV (not limited by the displaced vertex invariant mass as in [5]), due to the large amount of CMS's iron to reject it.

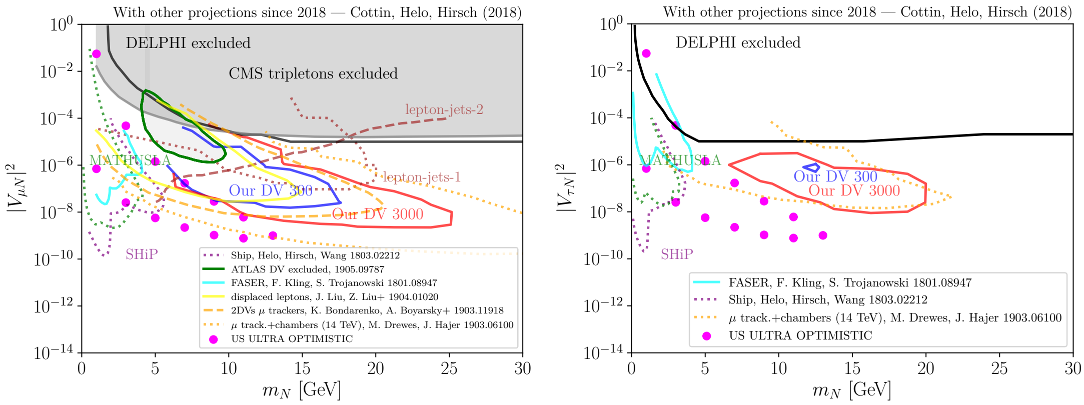

FIG. 1: HNL landscape. The magenta points shows an estimated optimistic region where exclusion should be possible with CMS for $\mathcal{L} = 300 fb^{-1}$.

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