# Snowmass EOI: Heavy Neutral Leptons at HL-LHC with the CMS Muon Spectrometer

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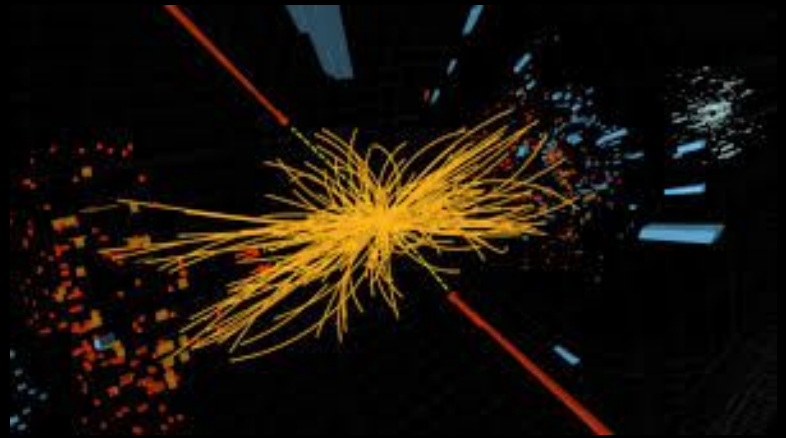
EOI with Juan Carlos Helo, Cristián Peña, Artur Apresyan, and Si Xie

*Dark Sectors and Light Long-Lived Particles*
SNOWMASS Cross Frontier Meeting
July 2020



CMS @ CERN

Heavy Neutrino

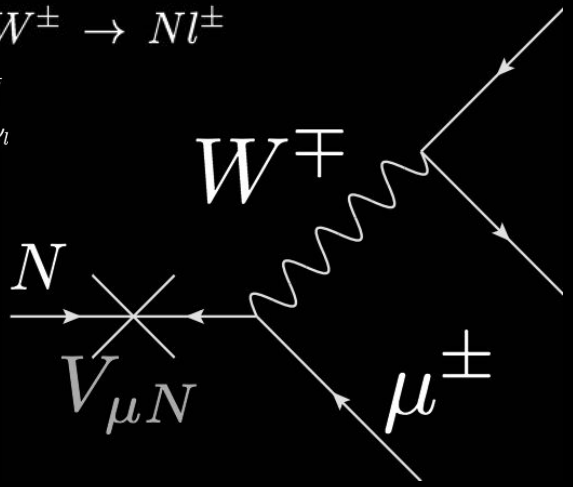
# An answer for Neutrino Mass generation Mechanism. HNLs can be long-lived particles !

See-saw:
P. Minkowski, Phys. Lett. 67B (1977)
R. N. Mohapatra and G. Senjanovic, Phys. Rev. Lett. 44 (1980)
J. Schechter and J. W. F. Valle, Phys. Rev. D22, 2227 (1980)

$$|V_{\mu N}|^2 \sim \frac{m_\nu}{m_N}$$

$$pp \to W^\pm \to N l^\pm$$

$N \to l^\pm q\bar{q}$
$N \to l'^\mp l^\pm \nu_l$
$N \to \nu_l q\bar{q}$



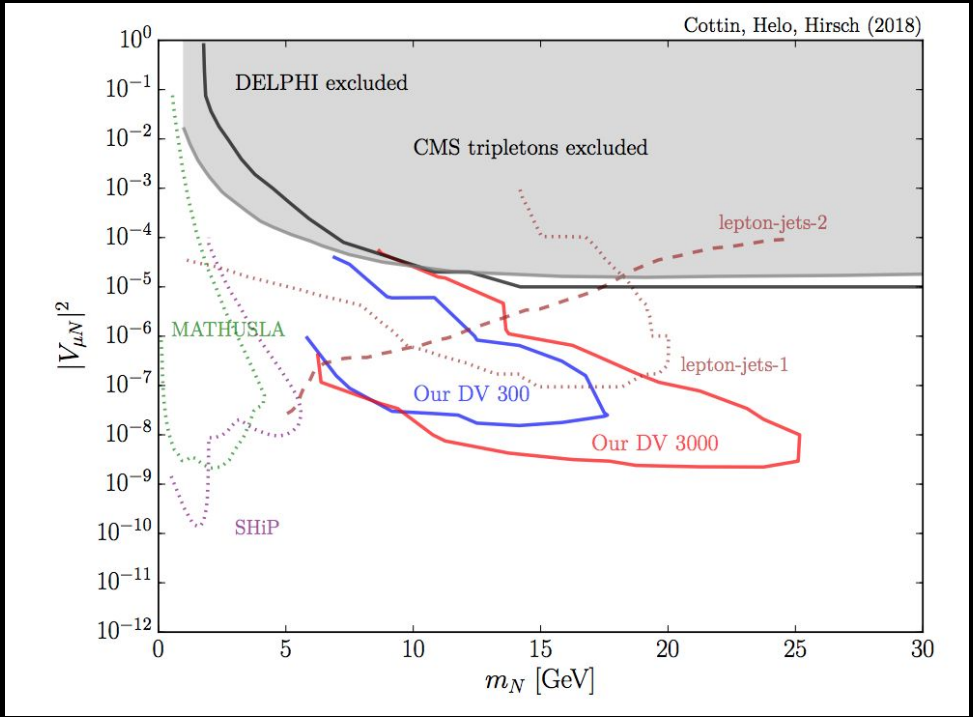

$$c\tau_N \sim 3.7 \left(\frac{1\,\text{GeV}}{m_N}\right)^5 \left(\frac{0.1}{|V_{lN}|^2}\right) \text{ [mm]}$$

Sterile N mixes with SM neutrino.
Large lifetime due to off-shell decay

Some displaced N studies in:
**G. Cottin**, J.C. Helo, M. Hirsch, D. Silva, Phys. Rev. D.99 (2019)
**G. Cottin**, J.C. Helo and M. Hirsch, Phys. Rev. D97 (2018)
**G. Cottin**, J.C. Helo and M. Hirsch, Phys. Rev. D98 (2018)
E. Izaguirre and B. Shuve, Phys. Rev. D91 (2015)
S. Dube, D. Gadkari, and A. M. Thalapillil, Phys. Rev. D96 (2017)
J. C. Helo, M. Hirsch, and S. Kovalenko, Phys. Rev. D89 (2014)

The off-shell $W$ boson can decay to a lepton and neutrino or (displaced) quarks which, depending on the experimental search strategy, can lead to displaced tracks or displaced jets from the N decay.

## Back in 2018... G. Cottin, J.C. Helo and M. Hirsch, Phys. Rev. D97 (2018)

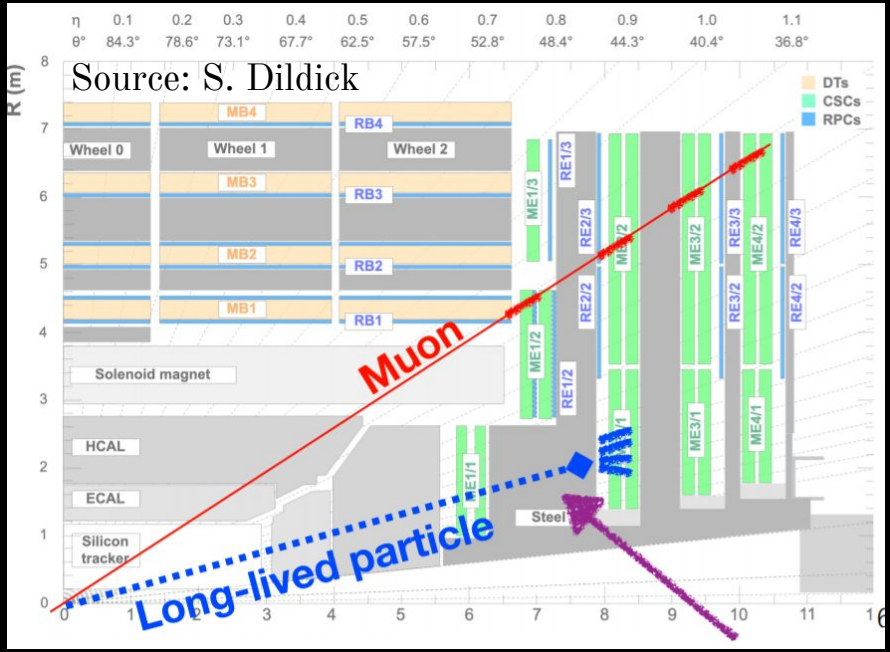



Could access efficiently the lower mass (and low mixing or larger displacement) region with a dedicated displaced trigger. Our focus will be the CMS μ L1 Trigger Proposal in Run 3 !!!

# CMS High multiplicity showers in the Muon System (MS) L1 Trigger Proposal in Run 3

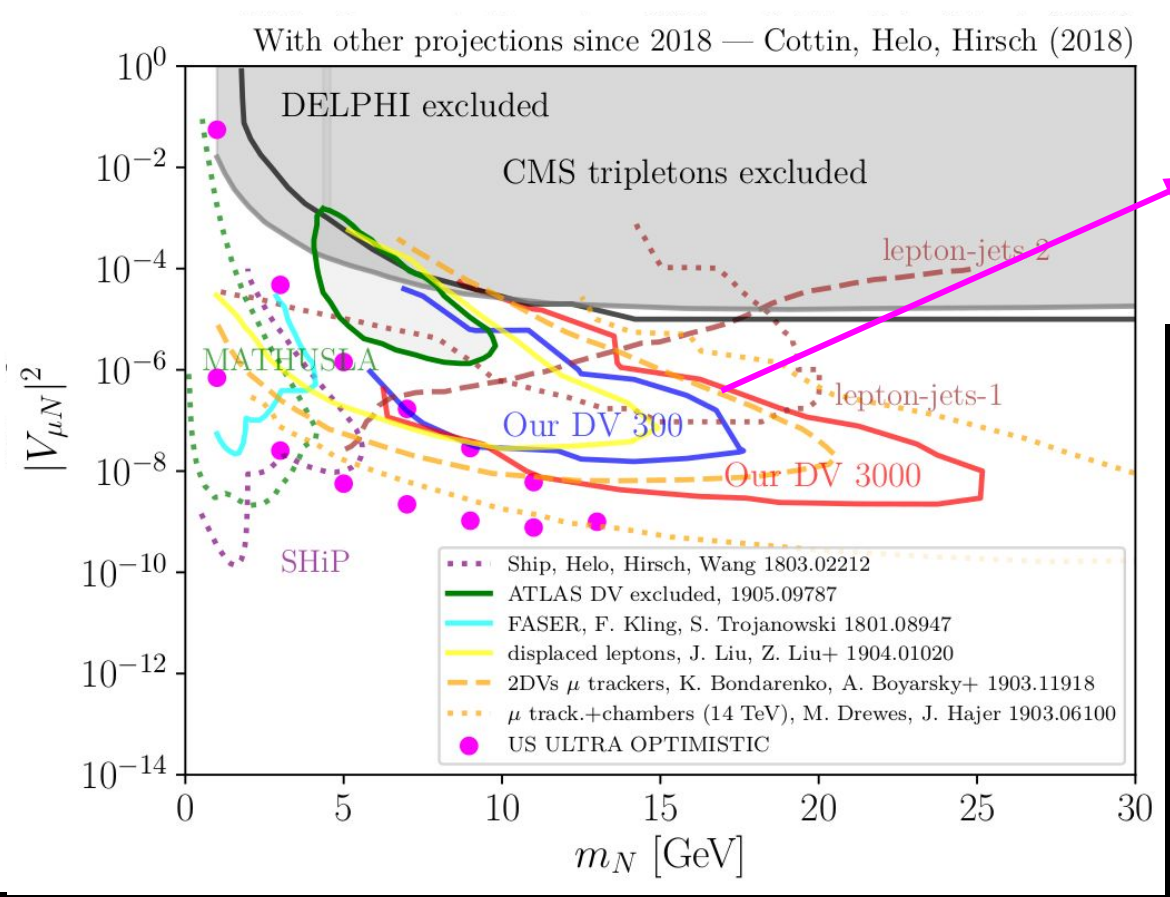
CMS presented a plan for a dedicated L1 trigger for Run3 @ 7th LHC LLP Workshop, see talk by Sven Dildick

- Trigger on displaced jets (10x gains in trigger efficiency), see also C. Peña's Talk at BSM EFT9 Meeting
- Sensitivity to light LLP produced through $W$ bosons !
- Sensitivity to larger displacements (LLP decays 6-10 m from IP)




Our proposal is to study the LLP potential of the CMS Muon System for Run3 and HL-LHC to HNLs !

# HNL landscape (apologies if I missed your work !)



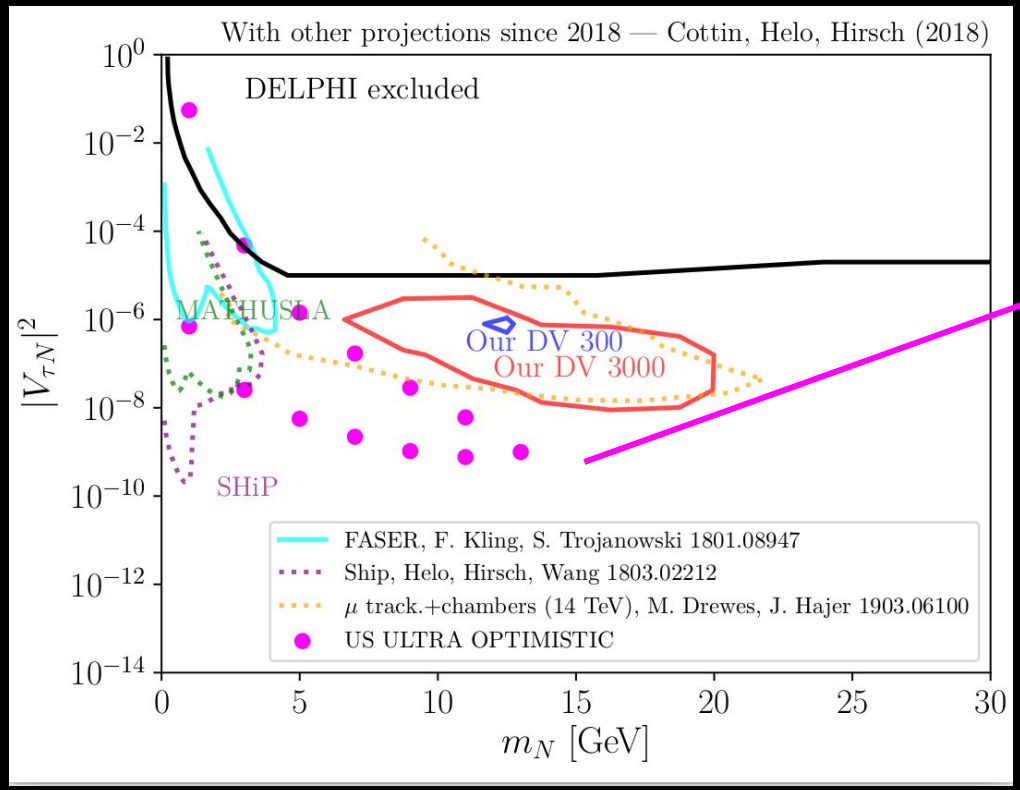

| $\mathcal{L}[fb^{-1}]$ | $d_1[m]$ | $m_N$[GeV] | $\lvert V_{lN}\rvert^2$ |
|---|---|---|---|
| 300 | 6 | $[1-9]$ | $[2\times10^{-6}-1\times10^{-8}]$ |
| 300 | 1 | $[1-13]$ | $[1\times10^{-6}-5\times10^{-9}]$ |
| 300 | 0.1 | $[1-20]$ | $[1\times10^{-6}-2\times10^{-9}]$ |
| 3000 | 6 | $[1-13]$ | $[7\times10^{-7}-1\times10^{-9}]$ |
| 3000 | 1 | $[1-20]$ | $[5\times10^{-7}-4\times10^{-10}]$ |
| 3000 | 0.1 | $[1-30]$ | $[5\times10^{-7}-3\times10^{-10}]$ |

Our VERY Optimistic estimates with CMS

All past studies trigger on either one or two prompt leptons !

Can foresee particular potential for mixing in the tau sector !

Fully hadronic decays of $N$ with CMS L1 trigger can be detected




Optimistic Reach with CMS trigger can lie HERE

# Summary

We note the following advantages with respect to the previous works that will help to extend the reach to HNLs :

- New L1 trigger capabilities for Run3 will allow to trigger directly on the HNL signature.
- CMS large shielding in the MS allows for large background suppression — critical for HNL due to single LLP decay.
- The possibility to best access the $\tau$ sector, with the $N$ decaying to a $\tau$ which decays to hadrons.

Looking forward to perform this study !

# Backup

From M. Drewes and J. Hajer
https://arxiv.org/pdf/1903.06100.pdf

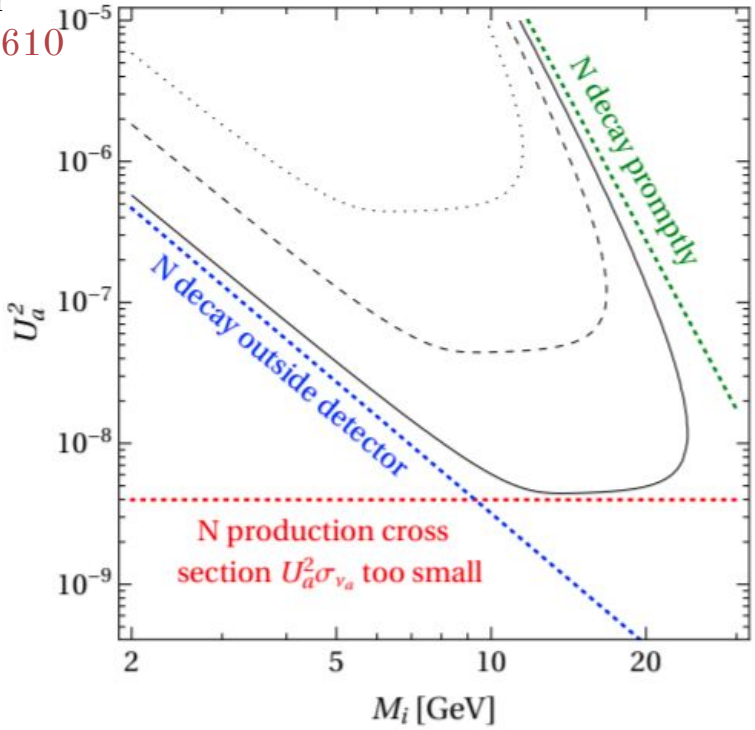



Figure 4: A simplified sensitivity estimate based on the analytic approximation (2) using $l_0 = 5\,\text{mm}$ and $l_1 = 3\,\text{m}$ illustrates the three main obstacles in improving the sensitivity (colored dotted lines). The three black sensitivity curves correspond to nine expected events for integrated luminosities of 3, 30, $300\,\text{fb}^{-1}$, and we have assumed that all efficiencies are 100 %.