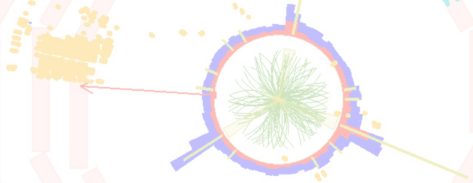
With support from Fondecyt 11220237, 1201673 and ANID – Millennium Science Initiative Program ICN2019_044

Long-lived heavy neutral leptons with a displaced shower signature



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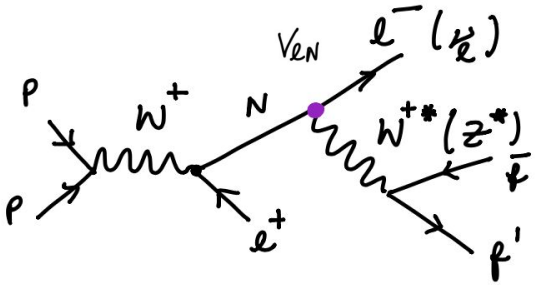
In collaboration with Juan Carlos Helo, Martin Hirsch, Cristián Peña, Christina Wang, Si Xie

Source background image
@CMS EXO-20-015

Heavy Neutral Leptons can be LLPs !

See reviews for HNL phenomenology
M. Drewes, Int.J.Mod.Phys.E 22 (2013) 1330019, arXiv:1303.6912
F. Deppisch, P. S. Bhupal Dev, Apostolos Pilaftsis, New J.Phys. 17 (2015) 7, 075019, arXiv:1502.06541
Y. Cai, T. Han, Tong Li, R. Ruiz, Front.in Phys. 6 (2018) 40, arXiv: :1711.02180
The Present and Future Status of Heavy Neutral Leptons, Snowmass, arXiv: 2203.08039

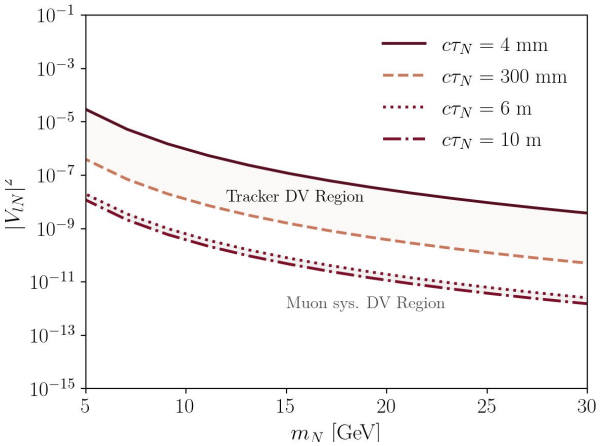
Neutrino mass mechanism involving HNL, specific BSM model, HNL mass and nature are unknowns. In the minimal HNL model we can have:



$$\Gamma \sim G_F^2 \, m_N^5 \, |V_{eN}|^2$$

Small mixings and ~ GeV scale HNL ⇒ LLP !

Adapted from G. Cottin, J.C. Helo and M. Hirsch, PRD 98 (2018)



Latest LHC LLP HNL searches (CMS PAS EXO-20-009 (arXiv:2201.05578) , EXOT-2019-29 (arXiv:2204.11988)) consider prompt lepton triggers (i.e. electron or muon) and the identification of a displaced vertex signature. They place constraints in the electron/muon mixing plane vs HNL mass.

Tau-mixing not covered yet at LHC, what can we do?

Starting point of our idea was presented as a Snowmass LoI https://www.snowmass21.org/loi

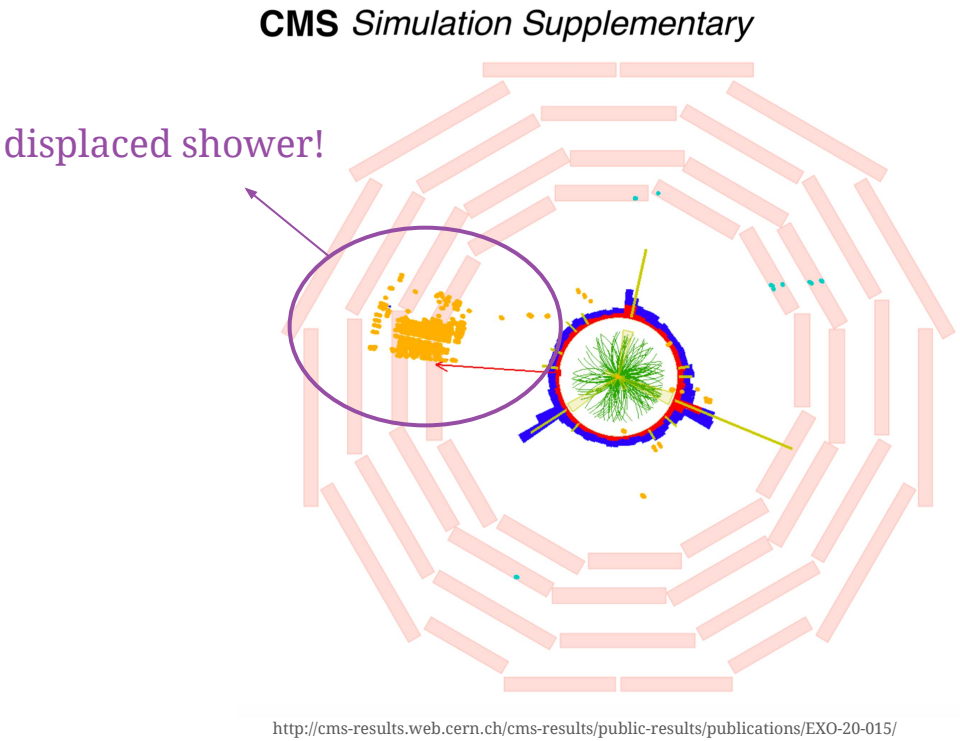
HNL reinterpretation of a CMS search for neutral LLPs with a displaced shower signature

- Original analysis in the context of a SM Higgs boson decaying to long-lived scalars (which can subsequently decay to taus), *Search for long-lived particles decaying in the CMS endcap muon detectors in proton-proton collisions at √s= 13 TeV , Phy. Rev. Lett. 127 (2021),* arXiv:2107.04838.

- Makes use of the CMS muon endcap detector to identify showers produced by LLPs decaying to final states including hadrons, *taus*, electrons, or photons.

- Search could be implemented for HNLs decaying to taus, taking advantage of the large CMS steel shielding, particularly useful to suppress backgrounds for a *single* HNL LLP decay

- The unique signature relies on large cluster of Cathode Strip Chamber (CSC) hits in the muon system (Nhits)



http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO-20-015/

- Reinterpretation relies on public instructions provided by CMS, as well as the implementation of a new Delphes module made specifically for muon system showers from LLP decays.

- Dedicated Delphes module presented by Christina Wang @ LLPX, see talk here.

http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO-20-015/

Instructions for Reinterpretation

We provide signal efficiency parameterization for the cluster-level selections that allows for reproduction of the full-simulation signal yield for various LLP masses (7-55 GeV), lifetimes (0.1 - 100 m) and decay modes ($d\bar{d}$ and $\tau^+\tau^-$). In order to recast this analysis, only the generator level LLP hadronic energy, EM energy, and decay position are needed. The following selection efficiencies are needed to account for all cluster-level selections mentioned in the paper:

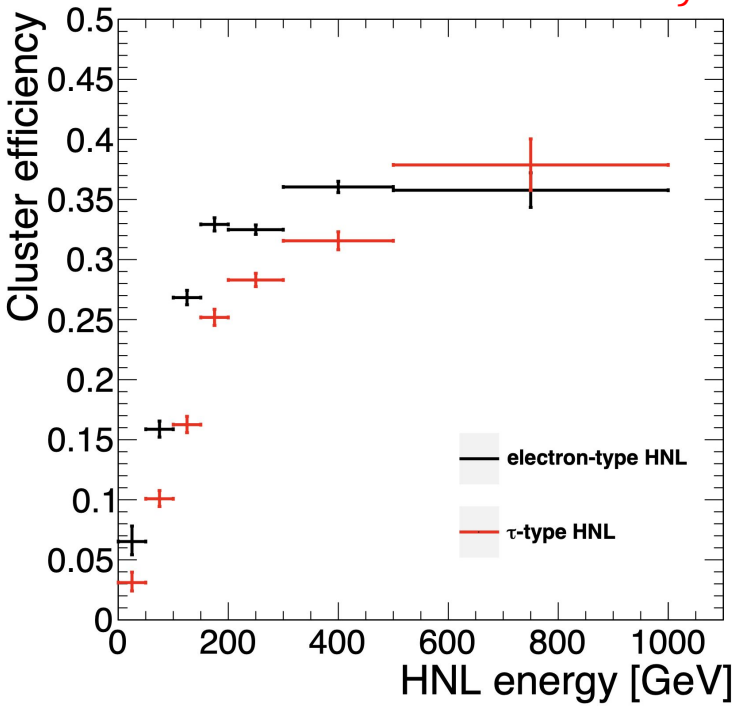
Recasted analysis and simulations

HeavyN model -> Madgraph+Pythia8 -> (tuned) Delphes (https://github.com/delphes/delphes/pull/103). Generator-level HNL energy and decay position are needed for signal yield prediction

Analysis selections:

- MET $\geq$ 200 GeV
- 1 CSC cluster that passes the CSCClusterEfficiency and CSCClusterID module (which includes Nhits> 130 and encodes parameterized functions depending on LLP energy and decay region provided by CMS)
- Jet veto, time cut and $|\Delta\varphi(\text{cluster, MET})|<0.75$

Preliminary !



FeynRules HNL implementation in
C. Degrande, O. Mattelaer, R. Ruiz, J. Turner, Phys. Rev. D 94, 053002 (2016), arXiv:1602.06957

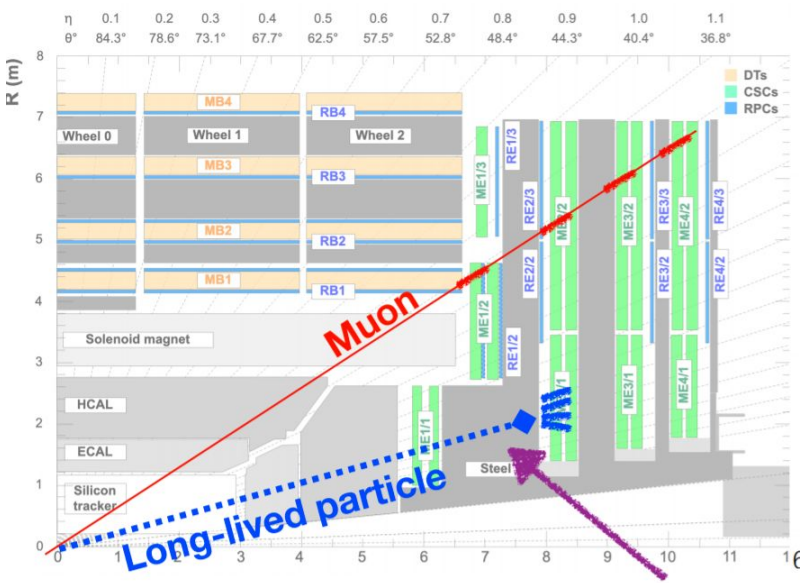
HNL optimized strategies

- Strategy 1 : Maintains high MET trigger but with a tighter Nhits cut.
  Nhits>210 suppresses background to 0.2 for 3/ab without rejecting too much signal (~20%)

- Strategy 2: Lower MET cut > 50 GeV and increased Nhits. Justified by the potential use of a new dedicated displaced trigger plan by CMS. See *Review of opportunities for new long-lived particle triggers in Run 3 of the Large Hadron Collider, CERN-LPCC-2021-01,* arXiv:2110.14675

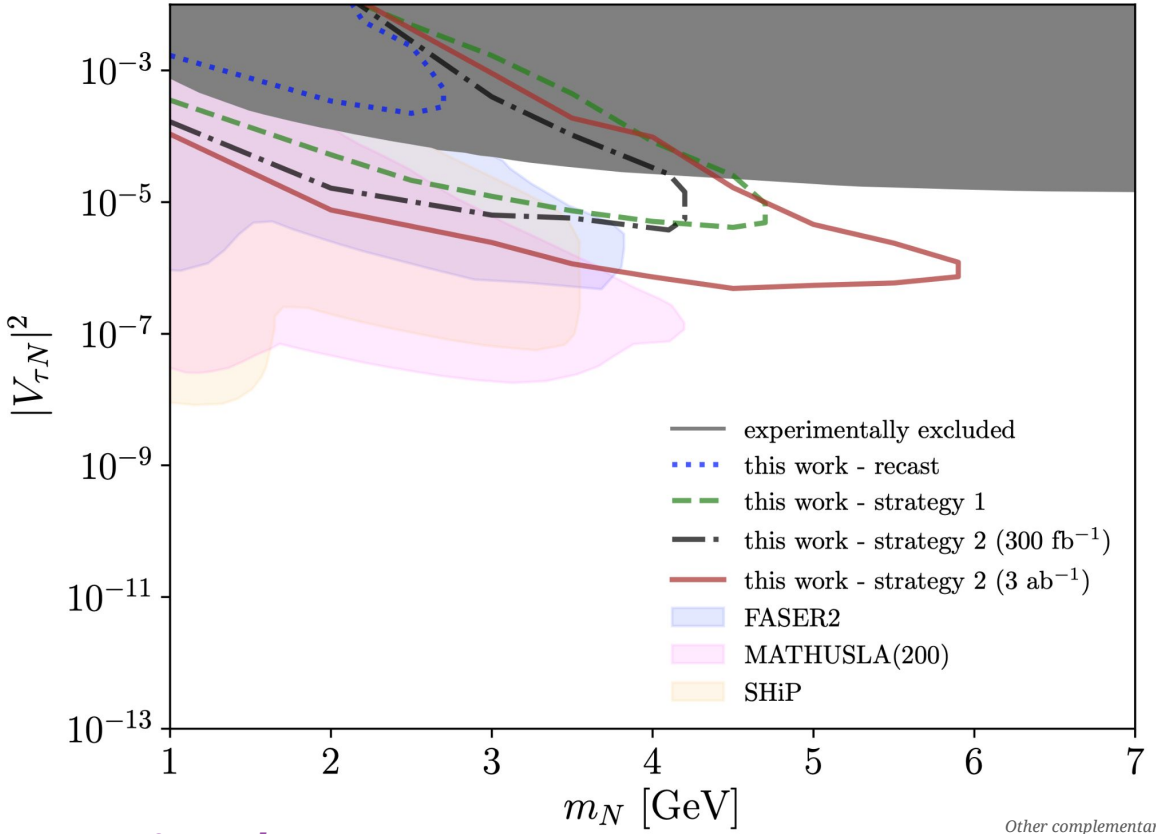
  Nhits>290 (for 300/fb) and Nhits>370 (for 3/ab), optimized to control background to neglectable levels and increase signal acceptance (by ~ 3 orders of magnitude with respect to nominal MET and Nhit cuts).

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



Results for tau-type HNL

Preliminary !



Mixings as low as ~5 x 10-7 and HNL masses between 1 and 6 GeV could de accessed!

Other complementary proposals with displaced vertices in tau-sector

G. Cottin, J.C. Helo and M. Hirsch, PRD 98 (2018), arXiv:1806.05191

M. Drewes, J. Hajer, JHEP 02 (2020) 070, arXiv:1903.06100

R. Beltrán, G. Cottin, J.C. Helo, M. Hirsch, A. Titov, Z.S. Wang, JHEP 01 (2022) 044 , arXiv:2110.15096

Summary

- We study the LHC discovery potential for long-lived heavy neutral leptons (HNL) with a new signature: a *displaced shower* in the CMS muon detector.

- A new Delphes module is used to model the CMS detector response for such displaced decays. With it we can reinterpret a dedicated CMS search for neutral LLPs decaying in the CMS muon endcaps for the minimal HNL scenario.

- We propose two strategies optimized for HNLs, one relies on a dedicated displaced trigger planned within CMS for Run 3 of the LHC.

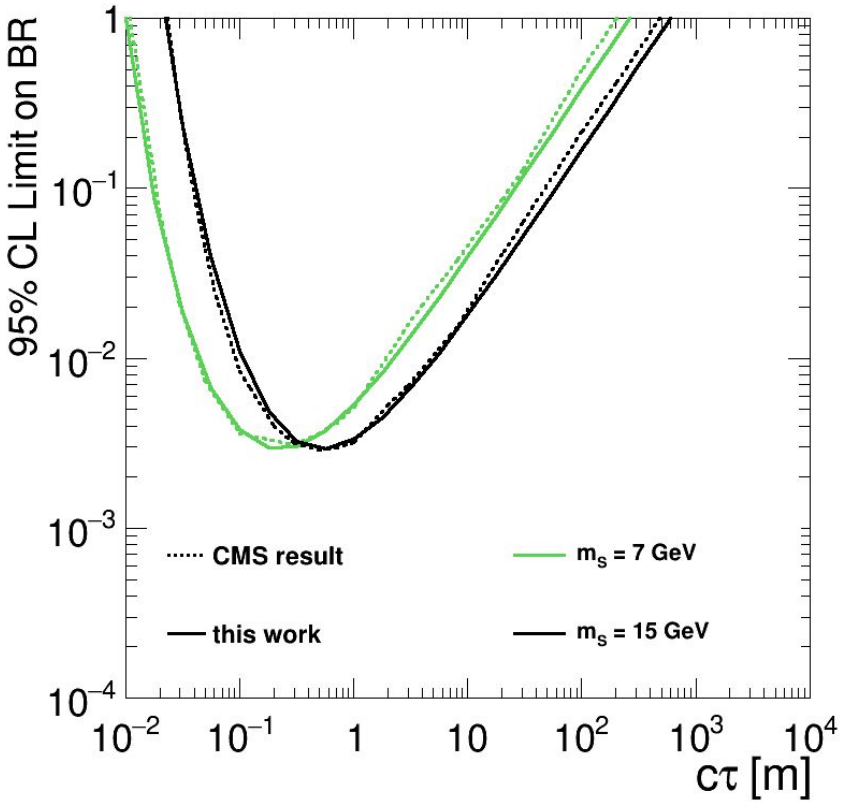
- We presented the estimated sensitivity focusing on HNL mixing with taus, taking advantage of the high cluster efficiency for hadronic showers of this search strategy. Unique regions of parameter space could be accessed, covering gaps between existing HNL searches and future dedicated LLP experiments !

Source background image
@CMS EXO-20-015

Backup

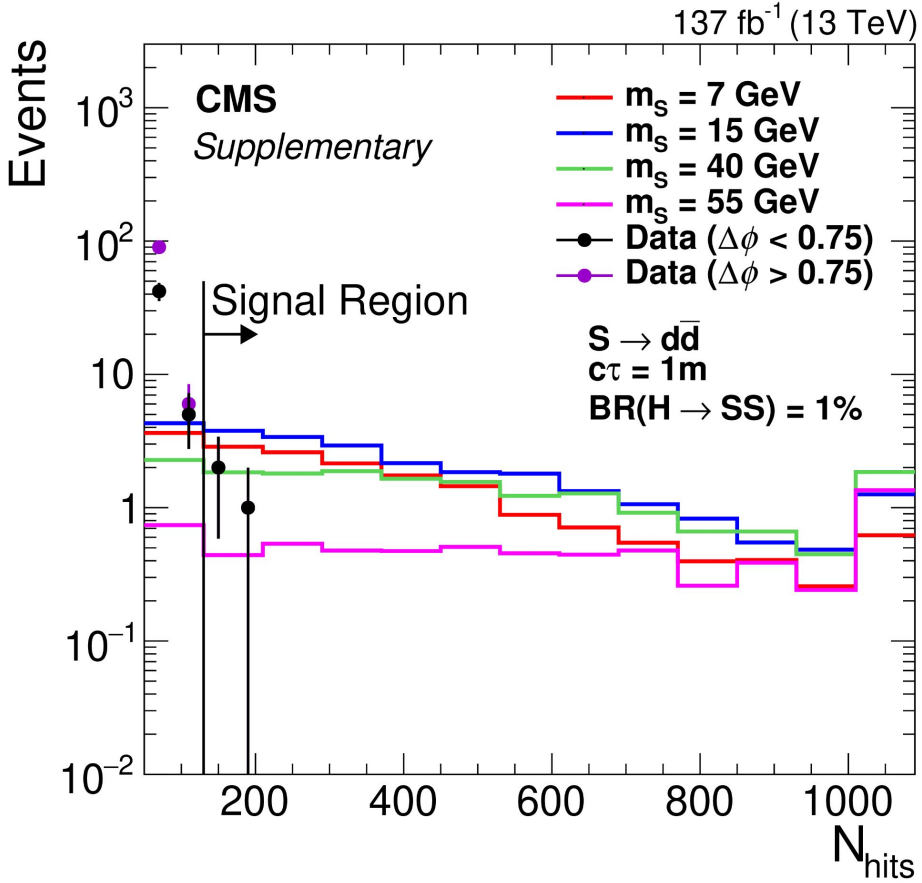
Validation of CMS reinterpretation

Preliminary !



Used for signal/background yield estimation

http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO-20-015/



Results for electron sector

Preliminary !