

10th Workshop of the Long-Lived Particle Community  
November 10, 2021



# Displaced HNLs at CMS

CMS-PAS-EXO-20-009 [↗](#)

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on behalf of the CMS Collaboration



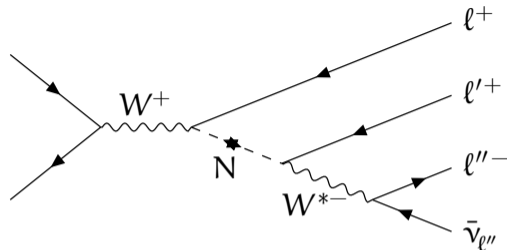
# Heavy Neutral Leptons (HNLs)

## Motivation

- ⚡ right-handed HNLs
  - ⇒ see-saw mechanism
  - ⇒ small mass of SM neutrinos
- ⚡ dark matter candidate
- ⚡ related to matter-antimatter asymmetry

## Phenomenology

- ⚡ mass  $m_N$
- ⚡ coupling to SM neutrino  $|V_{Ne\ell}|^2$
- ⚡ lifetime  $\tau_N \propto m_N^{-5} |V_{Ne\ell}|^{-2}$
- ⚡ Majorana or Dirac nature



## At the LHC

- ⚡ produced in  $W$  boson decays in association with prompt lepton
- ⚡ prompt or displaced decay to  $ll\nu$  or  $lqq$
- ⚡ previous CMS result: prompt  $3\ell$  final state with  $35.9 \text{ fb}^{-1}$  in mass range 1 GeV–1.2 TeV  
Phys. Rev. Lett. 120 (2018) 221801 [↗](#)

# Displaced HNL search: CMS-PAS-EXO-20-009

## Signature in mass range 1–20 GeV

- ⚡ one prompt lepton ( $e/\mu$ )
- ⚡ two displaced leptons ( $ee/\mu\mu/e\mu$ ), forming a secondary vertex (SV)

## Event selection

- ⚡ prompt lepton  $\ell_1$  compatible with PV
- ⚡ OS leptons  $\ell_2^\pm \ell_3^\mp$ , displaced w.r.t. PV
- ⚡ fit SV from tracks associated with  $\ell_2, \ell_3$

## Event categorization

- ⚡  $m(\ell_2\ell_3)$  – sensitive to  $m_N$
- ⚡  $\Delta_{2D}$  (transverse PV–SV distance) – sensitive to  $\tau_N$

## Selection criteria

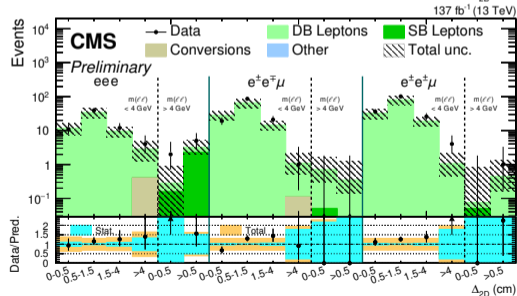
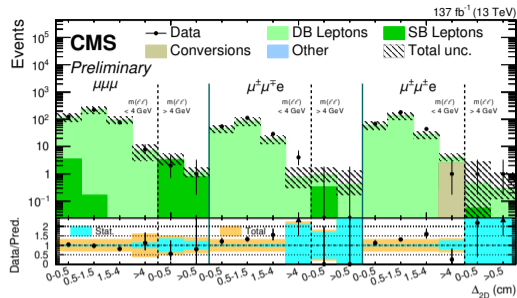
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- $\Delta R(\ell_2, \ell_3) < 1$
- $\min|\Delta\phi(\ell_1, \ell_{2/3})| > 1 \text{ rad}$
- $m(\ell_1\ell_2\ell_3) \in [50,80] \text{ GeV}$
- number of b jets = 0
- $p_T(\ell_2\ell_3) > 15 \text{ GeV}$
- $\cos\theta(\text{SV}, \ell_2\ell_3) > 0.99$
- $p_{\text{SV}} > 0.001$
- $S(\Delta_{2D}) > 20$
- $m(\ell_1\ell_{2/3}) \notin \text{vetoed ranges}$

# Background estimation

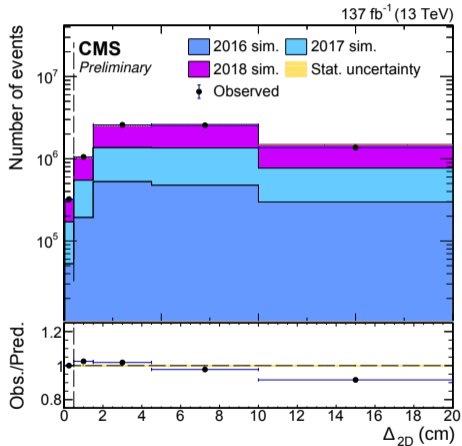
## Background leptons

- ⚡ displaced leptons are misidentified hadrons, from hadron decays, from conversions
- ⚡ Double-background (DB) leptons correlated, e.g.  $J/\Psi \rightarrow \ell\ell$  or B decay
- ⚡ Single-background (SB) leptons
- ⚡ estimated with “tight-to-loose” method
  - ⚡ from non-isolated sideband
  - ⚡ DB calibrated in sideband with b-jets
  - ⚡ SB calibrated in  $1\ell$ +jets selection
- ⚡ closure test: sideband events with  $m(\ell_1\ell_2\ell_3)$  inverted or with b-jets

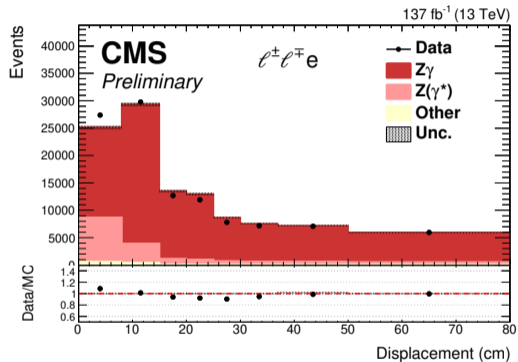


# Displaced lepton validation

## ⚡ Displaced tracking from $Z + K_S^0$

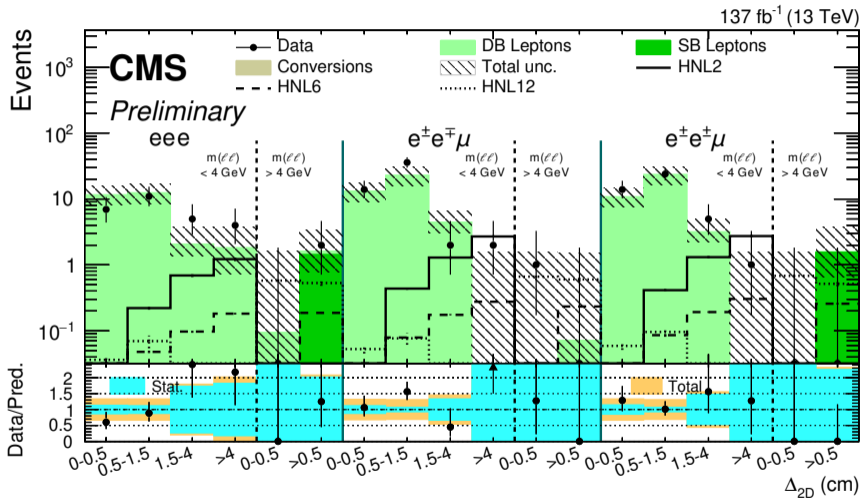


## ⚡ Displ. electrons from $Z\gamma$ conversions



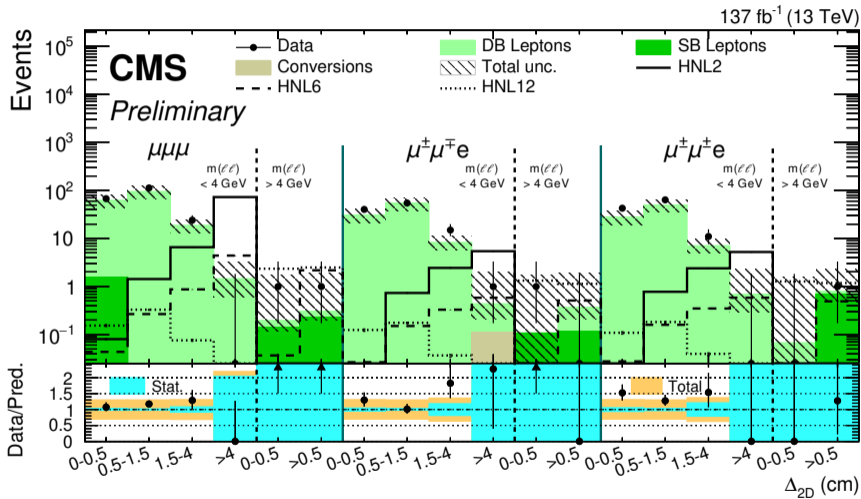
## ⚡ Displ. muons from $J/\psi$ in B decays

# Results: events with prompt electrons



- ⚡ observe good agreement with background prediction
- ⚡ no significant excess
- ⚡ HNL prediction for Majorana scenario shown

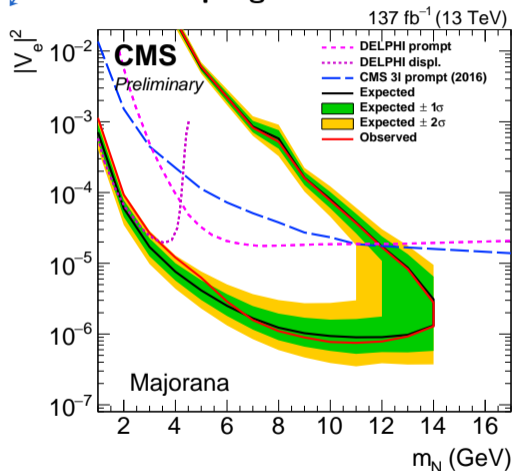
# Results: events with prompt muons



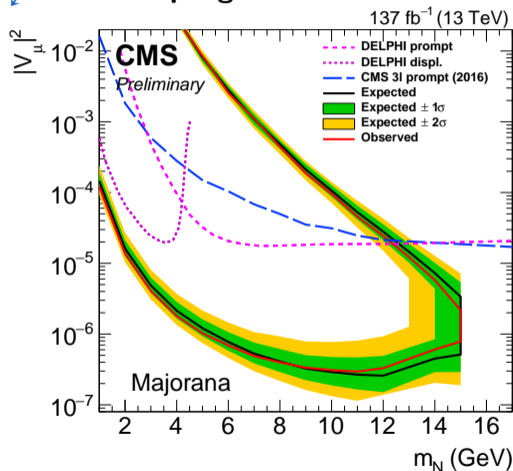
- ⚡ observe good agreement with background prediction
- ⚡ no significant excess
- ⚡ HNL prediction for Majorana scenario shown

# Limits on HNL couplings (Majorana scenario)

## ⚡ Electron coupling



## ⚡ Muon coupling





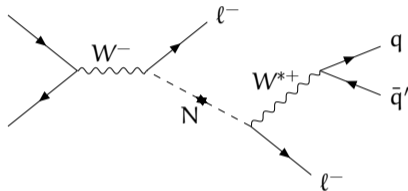
# Summary

## CMS-PAS-EXO-20-009 [↗](#)

- ⚡ displaced HNL search in trilepton final state with full Run-2 data
- ⚡ reconstruct secondary vertex from two displaced leptons
- ⚡ estimate backgrounds from control sample in data
- ⚡ validate displaced lepton selection
- ⚡ no excess observed
- ⚡ significantly improve over previous CMS limits on HNL couplings in probed mass range

## What's next? ⚡ *Work in progress* ⚡

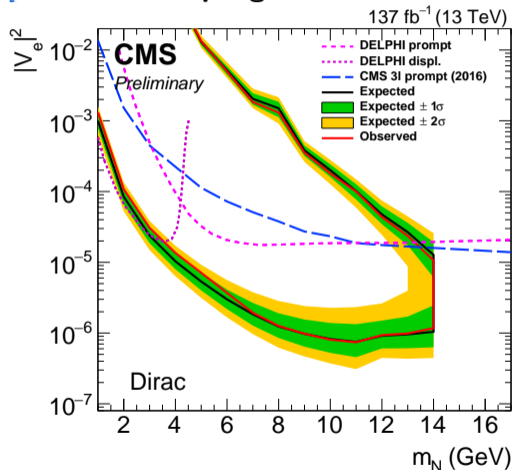
- ⚡ displaced HNL search with displaced jet



- ⚡ prompt HNL search in trilepton final state with full Run-2 data
- ⇒ Stay tuned!

# Backup: Limits on HNL couplings (Dirac scenario)

## ⚡ Electron coupling



## ⚡ Muon coupling

