PROCEEDINGS OF SCIENCE

Searches for heavy neutral leptons with the CMS experiment

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In this note, recent results on searches for heavy neutral leptons (HNLs) with the CMS experiment at $\sqrt{s} = 13$ TeV are reviewed. Various phenomenological models predict HNLs as a compelling extension to the standard model. The HNL mass range from 1 GeV to several TeVs is investigated. In particular, searches for prompt and long-lived HNLs are performed.

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1. Introduction

Heavy neutral leptons (HNLs) are a compelling extension to the standard model (SM) of particle physics to explain various observed phenomena like the smallness of the neutrino masses, neutrino oscillations, and the baryon asymmetry of the universe. Phenomenological models introduce Majorana or Dirac HNLs N through a seesaw mechanism [1]. At the CERN LHC, searches for HNLs with masses m_N from $O(\mathrm{GeV})$ to several TeVs are performed exploiting a variety of signatures and models. A special case occurs for $1 < m_N < 20\,\mathrm{GeV}$, where HNLs can be long-lived and hence travel significant distances away from the interaction point before decaying. In this note, recent results on searches for prompt and long-lived HNLs with the CMS experiment [2] at $\sqrt{s} = 13\,\mathrm{TeV}$ are reported.

2. Prompt HNL searches

Various searches for prompt HNLs are performed that probe HNL masses up to several TeVs. A search for heavy composite Majorana neutrinos has been carried out. Events with two electrons or two muons together with one large radius jet are analyzed [3]. The resulting exclusion limits as a function of m_N and the composite scale Λ are presented in Fig. 1 with HNLs excluded up to 6.0 (6.1) TeV in the dielectron (dimuon) final state for $\Lambda = m_N$ at a confidence level (CL) of 95%.

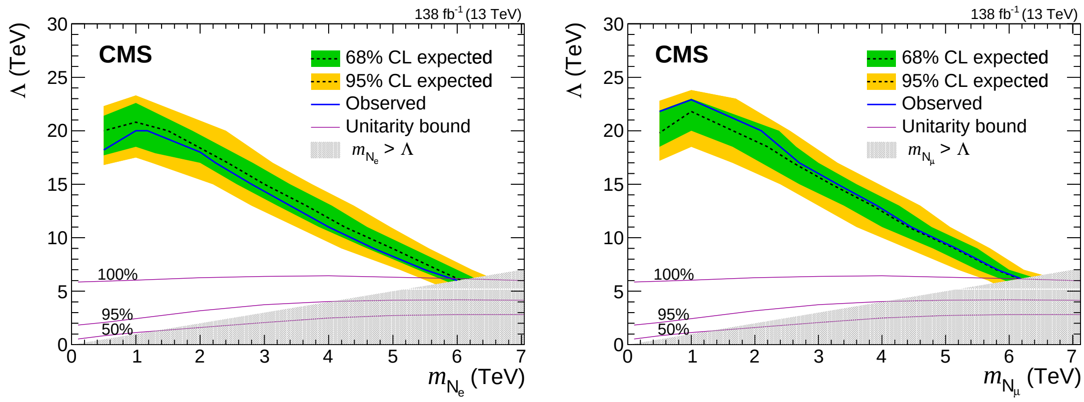

Figure 1: Exclusion limits on composite Majorana HNLs as a function of the mass and composite scale for (left) dielectron and (right) dimuon final states. Figures are taken from Ref. [3].

Vector boson fusion events, where HNLs are exchanged in t-channel, offer a complementary approach compared to searches for HNL s-channel production. In a corresponding analysis using events with two muons and two jets, exclusion limits on type I Majorana HNLs are determined beyond the LHC energy [4]. The corresponding Feynman diagram and the limits at 95% CL are shown in Fig. 2.

In left-right symmetric models (LRSM) new vector bosons (W_R and Z') and HNLs are postulated as right-handed partners to their left-handed SM counterparts. Searches are performed in dielectron or dimuon events including jets [5, 6]. The resulting exclusion limits as functions of the W_R and Z' masses are presented for dimuon events in Fig. 3. In dielectron (dimuon) events, vector boson masses of $m_{W_R} < 4.7$ (5.0) TeV and $m_{Z'} < 3.59$ (4.10) TeV are excluded for $m_N = m_{W_R}/2$ and $m_N = m_{Z'}/4$, respectively, at 95% CL.

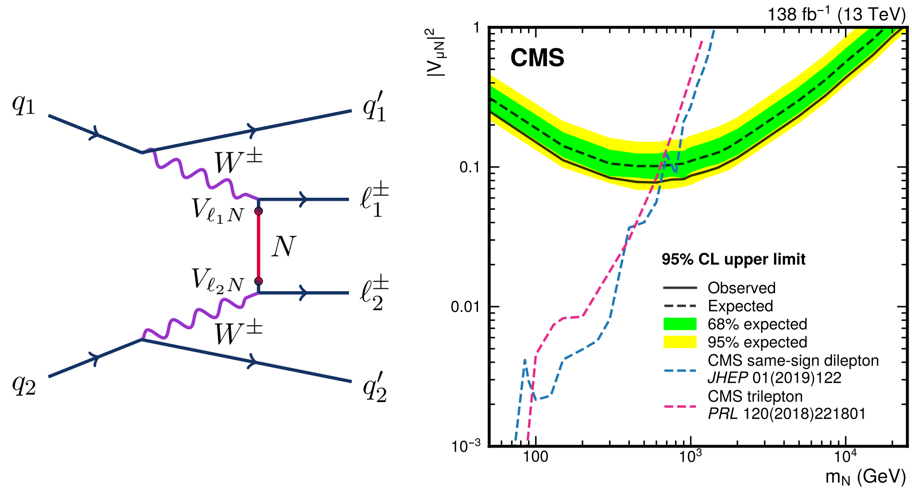

Figure 2: Type I Majorana HNL production through vector boson fusion: (left) Feynman diagram, (right) exclusion limits. Figures are taken from Ref. [4].

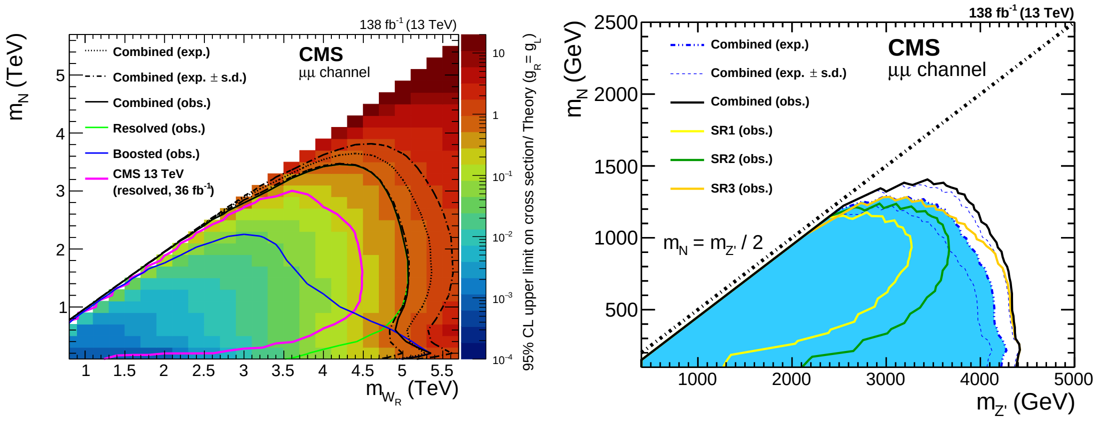

Figure 3: Exclusion limits on LRSM models for HNL production through (left) W_R and (right) Z' bosons in dimuon events. Figures are taken from Refs. [5, 6].

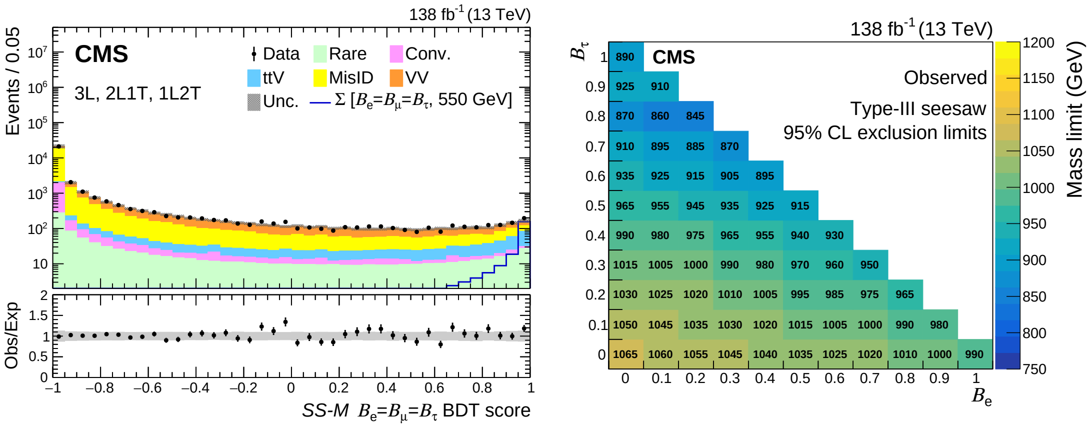

Figure 4: Multilepton analysis: (left) BDT classification score and (right) exclusion limits for type III HNLs. Figures are taken from Ref. [7].

A model-independent search for non-resonant multilepton events has also been conducted [7]. Events with a varying numbers of electrons, muons, hadronic τ leptons, and jets are analyzed. Boosted decision trees (BDTs) are used to enhance the sensitivity to specific scenarios. The BDT classification score and resulting limits at 95% CL for type III HNLs are shown in Fig. 4. For a flavour-democratic coupling scenario HNL masses of less than 980 GeV are excluded at 95% CL.

3. Long-lived HNL searches

The proper lifetime of type I HNLs is proportional to $m_\mathrm{N}^{-5}/\sum_\ell |\mathrm{V}_\ell|^2$ for $m_\mathrm{N} \gtrsim 1\mathrm{GeV}$, where three-body decays are dominant [1]. Primarily, the decay occurs via charged-currents resulting in leptonic ($\mathrm{N} \to \ell\ell'\nu$) and hadronic ($\mathrm{N} \to \ell\mathrm{q}\bar{\mathrm{q}}'$) final states with branching fractions of approximately 25% and 50%, respectively. Decays via neutral-currents or to final states involving neutrinos are subdominant. Two orthogonal searches have been performed targeting the leptonic and hadronic decay channels [8, 9]. Exclusion limits are derived for various coupling scenarios. The results for pure muon scenarios and for a fixed proper decay length of $c\tau = 1$ mm are presented in Fig. 5. For $m_\mathrm{N} = 10$ GeV the excluded muon coupling value squared is $|\mathrm{V}_\mu|^2 > 4.0\,(3.6) \times 10^{-7}$ for Majorana (Dirac) HNLs at 95% CL.

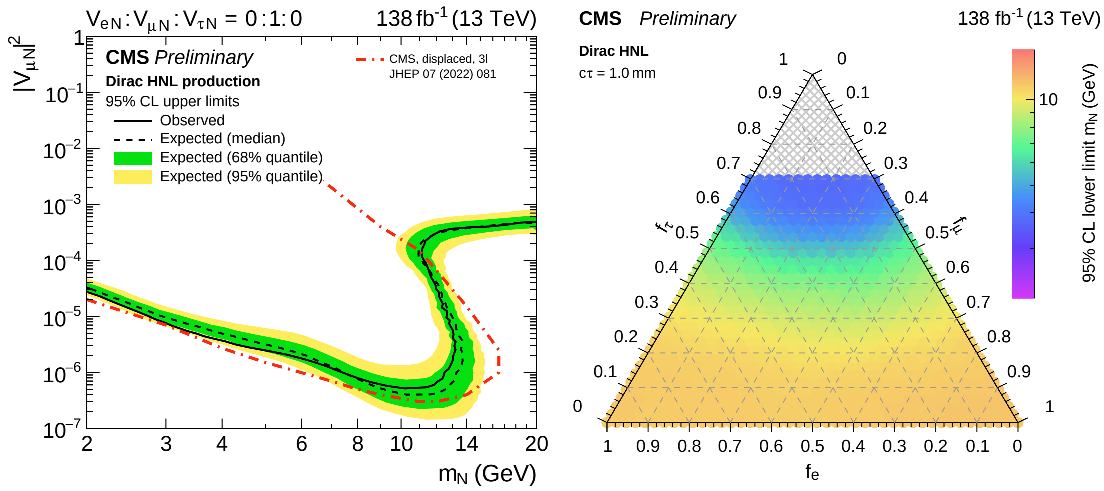

Figure 5: Exclusion limits on long-lived Dirac HNL production for (left) pure muon coupling scenarios and (right) for a fixed proper decay length as a function of the relative coupling strengths to each lepton generation. Figures are taken from Ref. [9] with limits from Ref. [8] overlaid on the left.

Decays of very displaced HNLs can be investigated by reconstructing hit clusters in the CMS muon system that is located 4 to 7 m away from the interaction point. A corresponding search selects events consisting of one lepton (electron or muon) and such a muon hit cluster [10]. The analysis is sensitive to all HNL decay modes that result in a reconstructable cluster. Exclusion limits are derived for various coupling scenarios with $1 < m_\mathrm{N} < 4$ GeV, where HNLs are sufficiently Lorentz-boosted to reach the muon system before decaying. In Fig. 6 limits for pure muon coupling scenarios and for a fixed mass of 1.5 GeV are shown. The most stringent limits are found for $m_\mathrm{N} = 2.6\,(2.8)$ GeV excluding $|\mathrm{V}|^2 > 8.6\,(4.6) \times 10^{-6}$ in the electron (muon) channel at 95% CL.

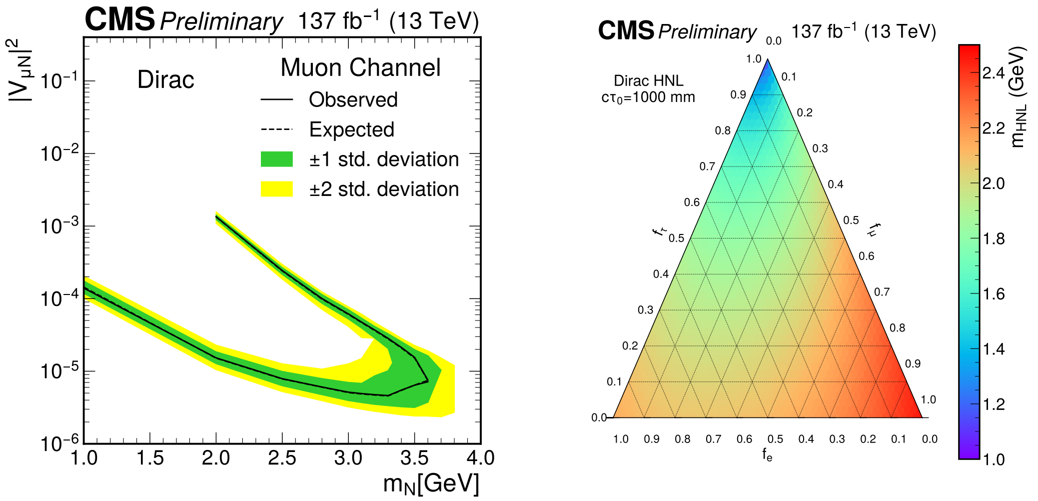

Figure 6: Exclusion limits on long-lived Dirac HNL production for (left) pure muon coupling scenarios and (right) for a fixed HNL mass as a function of the relative coupling strengths to each lepton generation. Figures are taken from Ref. [10].

4. Summary

In this note, recent results on searches for heavy neutral leptons (HNLs) production with the CMS experiment have been reviewed. Phenomenological models predicting Majorana or Dirac HNLs are composite lepton models, left-right symmetric models, effective field theory extensions, and those that are based on a seesaw mechanism to explain the smallness of the neutrino masses. Searches for HNLs from 1 GeV to several TeVs have been performed with the CMS experiment at $\sqrt{s}$ = 13 TeV. Typical signatures include one or two leptons and jets. A special case occurs for masses between 1–20 GeV where HNLs can be long-lived and decay spatially displaced with respect to the interaction point.

References

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