PROCEEDINGS OF SCIENCE

Search for heavy neutrinos at CMS

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The smallness of neutrino masses provides a tantalizing allusion to physics beyond the standard model. Heavy neutral leptons (HNL), such as hypothetical sterile neutrinos, accommodate a way to explain this observation, through the see-saw mechanism. If they exist, HNL could also provide answers about the dark matter nature, and baryon asymmetry of the universe. Searches for the production of HNL at the LHC, in final states with three leptons or two leptons and jets, are presented. The sample of pp collisions collected by the CMS detector throughout 2016 is used, amounting to a volume of $35.6\,\mathrm{fb}^{-1}$.

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1. Introduction

The discovery of neutrino oscillations established that the Standard Model (SM) neutrinos have mass. Among proposed extensions of the SM that explain neutrino masses, models that are based on the seesaw mechanism are favoured. The seesaw mechanism introduces new heavy particles that couple to the SM leptons and can account for the smallness of neutrino masses. This paper discusses searches by CMS for the evidence of type-I and type-III seesaw models via the observation of new heavy fermions (N, $\Sigma^{\pm}$), in which N is a Majorana type particle.

In this paper we present searches for heavy fermions decaying to leptons, based on the 13 TeV dataset collected in 2016. Even though the branching fractions are relatively small for the leptonic channels compared to the hadronic channel, with the Majorana nature of N the leptonic channels provide cleaner signatures with lower backgrounds when compared to the hadronic channel. The channels considered are those that contain electrons (e) or muons (μ) (and any combination of the two). The integrated luminosity used in the results corresponds to around $35.6\,\mathrm{fb}^{-1}$.

2. Searches for N in type-I seesaw models

Searches for a heavy neutrino in the type-I seesaw model have been performed using cut-and-count based analyses. The analyses look for a heavy neutrino in the process $\mathrm{pp} \to \mathrm{W}^{*} \to \mathrm{N}\ell \to \mathrm{W}\ell\ell'$. Analyses in both the same-sign (SS) dilepton plus jets [2] and trilepton plus missing transverse energy (MET) [3] channels have been performed. The MET in the trilepton channel comes from the fact SM neutrinos leave the CMS detector [1] without interaction.

Both analyses select events using standard CMS muon, electron and jet identifications, with tight requirements on the isolation and impact parameters of the leptons. The dominant irreducible backgrounds are from diboson events (WZ, ZZ, Wγ, Zγ), which are estimated using simulation and normalised in data control regions. The dominant reducible backgrounds contain events where one or more jets are misidentified as leptons i.e., from W+jets, Z+jets or $\mathrm{t\bar{t}}$+jets events. The two analyses split the signal into low-mass ($\mathrm{m_N} \le \mathrm{m_W}$) and high-mass ($\mathrm{m_N} > \mathrm{m_W}$) regions. The SS analysis further split the low- and high-mass regions depending on the number of wide-cone and non wide-cone jets in the event. The trilepton channel is more sensitive in the low-mass region and the SS channel is more sensitive in the high-mass region.

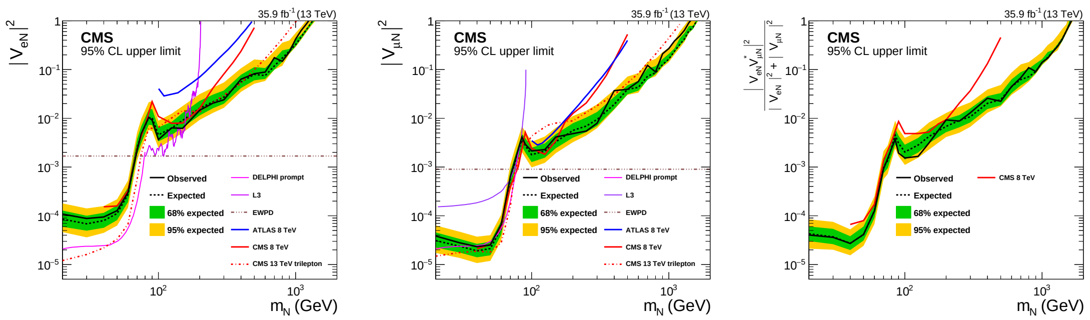

Figure 1: Exclusion region at 95% CL in the $|V_{e\mathrm{N}}|^2$ (left), $|V_{\mu\mathrm{N}}|^2$ (middle) and $|V_{e\mathrm{N}}V^{*}_{\mu\mathrm{N}}|^2/(|V_{e\mathrm{N}}|^2+|V_{\mu\mathrm{N}}|^2)$ (right) vs $\mathrm{m_N}$ planes [2].

The SS analysis optimised the signal for each mass hypothesis, applying selection requirements on several variables such as the lepton p_{T} ($p_{\mathrm{T}}{}^{\ell}$) and the masses of the reconstructed N and W. No excess beyond the SM background predictions are observed. Exclusion limits at 95% confidence level (CL) are set on the heavy Majorana neutrino mixing matrix elements, $|V_{\ell\mathrm{N}}|^2$, as a function of $\mathrm{m_N}$. Figure 1 shows the results of the limit calculations, where the limits on the mixing matrix elements are placed up to 1240 GeV for $|V_{e\mathrm{N}}|^2$, 1430 GeV for $|V_{\mu\mathrm{N}}|^2$, and 1600 GeV for $|V_{e\mathrm{N}}V^*_{\mu\mathrm{N}}|^2/(|V_{e\mathrm{N}}|^2+|V_{\mu\mathrm{N}}|^2)$.

The trilepton analysis selects events with various lepton triggers and requires exactly three leptons, using all combinations of muons and electrons. At the baseline selection events are required to contain an opposite-sign lepton pair (2ℓOS) and contain no jet originating from a bottom quark. The events are split into 33 orthogonal search regions (8 low-mass and 25 high-mass) for each lepton channel. These search regions depend on the number of opposite-sign same-flavour (OSSF) pairs, $p_{\mathrm{T}}{}^{\ell}$, the transverse invariant mass ($\mathrm{M_T}$), $\mathrm{M}_{2\ell\mathrm{OS}}$ and $\mathrm{M}_{\ell\ell\ell}$, where we define $\mathrm{M_T}=\sqrt{2p_{\mathrm{T}}{}^{\ell}p_{\mathrm{T}}^{\mathrm{miss}}[1-\cos(\Delta\phi_{\ell,\vec{p}_{\mathrm{T}}^{\mathrm{miss}}})]}$, with $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$equal to -$\Sigma\vec{p}_{\mathrm{T}}$ of all reconstructed particles in the event, with magnitude $p_{\mathrm{T}}^{\mathrm{miss}}$.

No evidence of a significant excess beyond the SM background is observed. Limits are set on $|V_{e\mathrm{N}}|^2$ and $|V_{\mu\mathrm{N}}|^2$ separately, while assuming other matrix elements to be 0, as shown in Figure 2 to range between 1.2×10^{-5} and 1.0 for N masses in the range $1\,\mathrm{GeV}<\mathrm{m_N}<1.2\,\mathrm{TeV}$. Since the N lifetime is inversely proportional to the square of $\mathrm{m_N}$, it is significant at low masses, resulting in displaced N decays, and low signal efficiency.

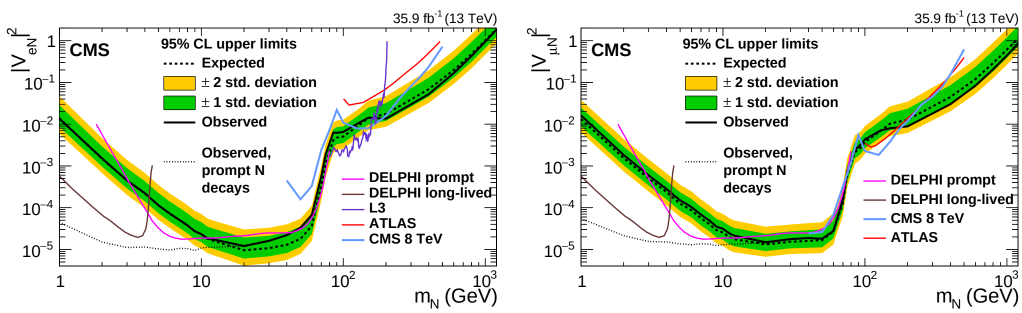

Figure 2: Exclusion region at 95% CL in the $|V_{e\mathrm{N}}|^2$ (left), $|V_{\mu\mathrm{N}}|^2$ (right) vs $\mathrm{m_N}$ planes [3].

3. Searches for N in type-III seesaw models

We present a search for three new massive fermions, expected in the type-III seesaw model, by examining final states with at least three electrons or muons [4]. The search considers all 27 different processes resulting from the different production modes of two heavy fermions ($\Sigma^{\pm}$ or N) and their decays to the nine different pairs of W, Z and H bosons. In the model considered in this search the fermions are considered prompt and their masses are degenerate. The branching fraction (B_ℓ) of a heavy fermion to a lepton of flavour ℓ is mass dependent and is proportional to $|V_{\ell\mathrm{N}}|^2/(|V_{e\mathrm{N}}|^2+|V_{\mu\mathrm{N}}|^2+|V_{\tau\mathrm{N}}|^2)$. Since the search looks for final states with three or more leptons the main backgrounds are the same as in the type-I analyses.

Events are selected only if they pass an online dilepton trigger requirement and have three or more offline reconstructed leptons that satisfy a standard set of CMS identification requirements. To reduce backgrounds from low mass resonances any event with an OSSF lepton pair with mass below 12 GeV are removed. In addition, trilepton events with an OSSF pair with mass less than the Z boson mass are vetoed in order to reduce backgrounds from conversions.

The multilepton events are classified into independent search channels using the number of leptons and OSSF pairs, and depending on the mass of the OSSF pair relevant to the Z boson mass (using a window of 81-101 GeV), events are split into "on-Z", "below-Z" and "above-Z". The discriminating variables used are M_T and the sum of L_T and p_T^{miss}, where L_T is defined as the scalar sum of all charged lepton p_T's in the event.

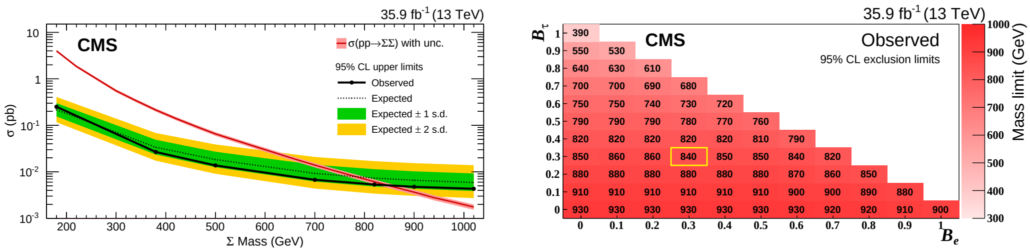

Figure 3: The 95% confidence level upper limits on the cross section for production of heavy fermion pairs in flavour-democratic scenario (left) and the 95% confidence level observed limits for each combination of branching fractions (right) [4].

No statistically significant excess is observed in the various signal regions that are probed. Figure 3 (left) shows the limits on the cross section for a flavour-democratic scenario, with upper observed (expected) limits on masses of heavy fermions set as 840 (780) GeV. The upper observed limits in the B_e-B_τ plane are shown in Figure 3 (right), where we note that $B_\mu = 1 - [B_e + B_\tau]$.

4. Summary

In summary, we have discussed the latest CMS results of searches for heavy neutrinos in type-I and type-III seesaw models in mulitilepton channels at 13 TeV in proton-proton collisions delivered by the LHC in 2016. No significant deviation from the Standard Model prediction is observed and therefore limits are set at 95% CL with various benchmark models.

References

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[2] CMS Collaboration, CMS-PAS-EXO-17-028 (2018), https://cds.cern.ch/record/2308273.

[3] CMS Collaboration, Phys. Rev. Lett. **120** (2018) 221801.

[4] CMS Collaboration, Phys. Rev. Lett. **119** (2017) 221802.