Constraining sterile neutrinos using decay width measurements of SM bosons

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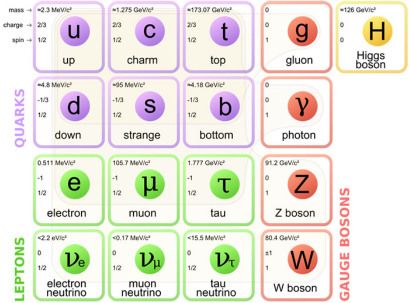
Introduction

- The Standard model describes all the fundamental particles of nature and their dynamics.
- After beeing tested experimentally, it becomes a successful renormalizable chiral gauge theory and is based on the gauge symmetry $SU(3)_C \times SU(2)_L \times U(1)_Y$.
- All the SM particles except neutrinos acquire masses through the Higgs mechanism with the discovery of Higgs boson.
- The observed neutrino oscillations in solar, reactor and accelerator experiments provides information about the massive nature of neutrinos.
- To explain the tiny neutrino mass, one must go beyond the SM physics.

The Standard Model

- The SM explains how the subatomic particles interact among themselves.
- The SM consists of 12 matter particles and 4 force carrier particles.
- All the matter particles are fermions (spin $\frac{1}{2}$ particles) and are classified as quarks and leptons.
- The force carriers are bosons, which possess integral spins.



Seesaw Mechanism

- It is one of the BSM physics, which gives idea about the neutrino mass as well as its tiny nature.
- It predicts there are 2 types of neutrinos.
  - the light left handed neutrino ν
  - the heavy right handed neutrino N
- Basically, seesaw represents a ratio: the heavier the right handed neutrino, the lighter the left handed (SM) neutrino.
- There are various types of seesaw. However, the widely accepted version of seesaw is Type-I seesaw.
- Type-I seesaw can be explained only with the introduction of right handed neutrinos.
- This right handed neutrinos are known as the sterile neutrinos as they can not actively participate in the SM interactions.

Seesaw mechanism

- $M_\nu = -M_D \frac{1}{M_N} M_D^T$
- $V_{lN} \sim M_D M_N^{-1}$

The two important aspects of seesaw mechanism are

- The Majorana mass of the sterile neutrinos.
- Mixing of the sterile neutrinos with the active (SM) neutrinos.

The Left-right Symmetric Model

- The left-right symmetric model is an extension of the SM gauge group and can be represented as $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_Y$.
- It requires that all left handed fermions must have a right handed partner and hence the existence of right handed neutrino.
- The electric charge formula for this model is

$$Q = T_{3L} + T_{3R} + \frac{B-L}{2}$$

where $T_i = \frac{1}{2}\tau_i$, τ_i are the Pauli matrices.
- It introduces some new gauge bosons and scalar particles, which are massive than the SM particles and opens up the possibility of detecting these particles in the experimental collider Physics.

- It removes the left-right asymmetry of the SM.
- Parity symmetry is spontaneously broken, which is not achieved in the SM.
- The LRSM gauge group can spontaneously broken down to the observed $U(1)_{EM}$ group in 2 steps.

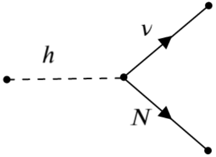
$$SU(2)_L \times SU(2)_R \times U(1)_{B-L} \xrightarrow{<\Delta_R^0>} SU(2)_L \times U(1)_Y$$

$$SU(2)_L \times U(1)_Y \xrightarrow{<\Phi>} U(1)_Q$$

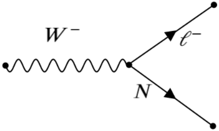
Numerical Analysis

We consider the following decay modes for the sterile neutrino production from Higgs, W and Z bosons and the corresponding decay widths are as follows.

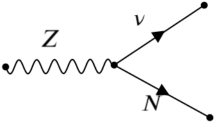
- $\Gamma_{h \longrightarrow N\nu} = |V_{lN}|^2 \frac{g^2 M_h M_N^2}{32\pi M_W^2} \left(1 - \frac{M_N^2}{M_h^2}\right)^2$



- $\Gamma_{W \longrightarrow Nl} = |V_{lN}|^2 \frac{g^2 M_W^3}{96\pi M_W^2} \left(1 - \frac{M_N^2}{M_W^2}\right)^2 \left(2 + \frac{M_N^2}{M_W^2}\right)$



- $\Gamma_{Z \longrightarrow N\nu} = |V_{lN}|^2 \frac{g^2 M_Z^3}{48\pi M_W^2} \left(1 - \frac{M_N^2}{M_Z^2}\right)^2 \left(2 + \frac{M_N^2}{M_Z^2}\right)$



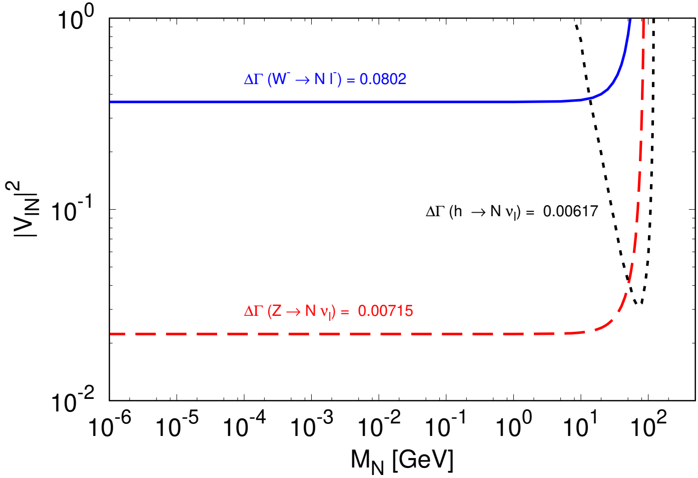
Numerical Analysis

- The new Yukawa interaction of the LRSM enhances the total decay widths of the SM particles in comparison with its SM predicted value.
- Considering both the theoretical and experimental uncertainties in the decay widths, the maximum possible errors are listed as follows.

$$\Delta\Gamma_h = 0.00617 \; GeV$$
$$\Delta\Gamma_W = 0.0802 \; GeV$$
$$\Delta\Gamma_Z = 0.00715 \; GeV$$

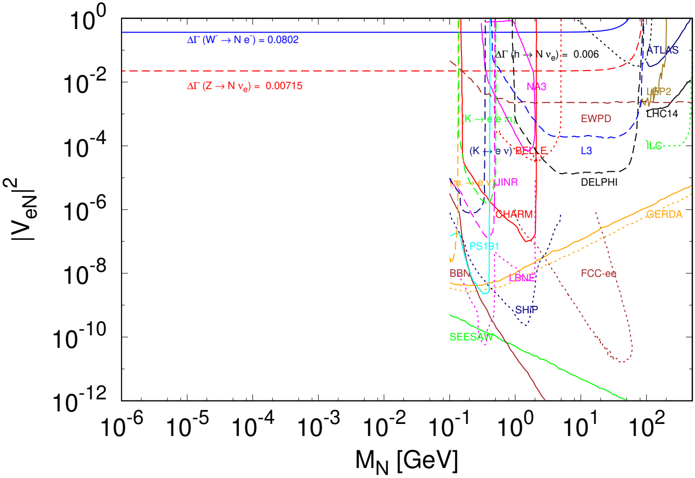
- Here, we obtain the upper bounds on the active-sterile neutrino mixing from the decay widths of the SM Higgs, W and Z bosons in the wide mass range of sterile neutrinos.
- We made a comparative study of our active-sterile neutrino mixing constraints as a function of sterile neutrino mass with other existing constraints from experimental searches.

Figure: Upper limits of the active-sterile neutrino mixing as a function of sterile neutrino mass.



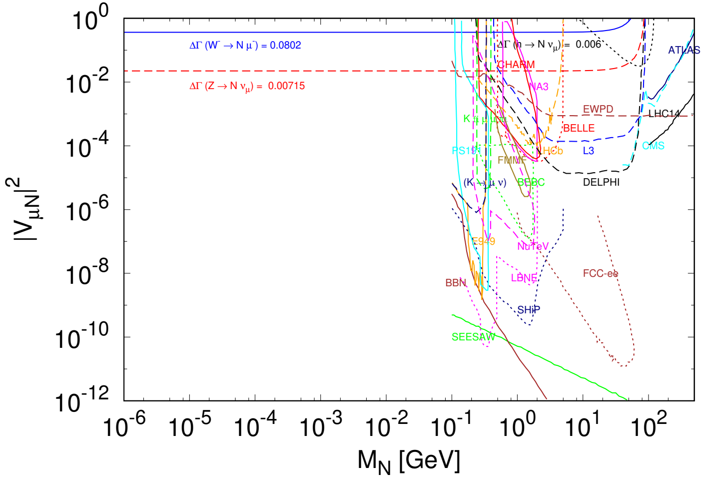
Results

Figure: Constraints on the active-sterile neutrino mixing as a function of the sterile electron neutrino mass in the range 1 MeV-500 GeV.



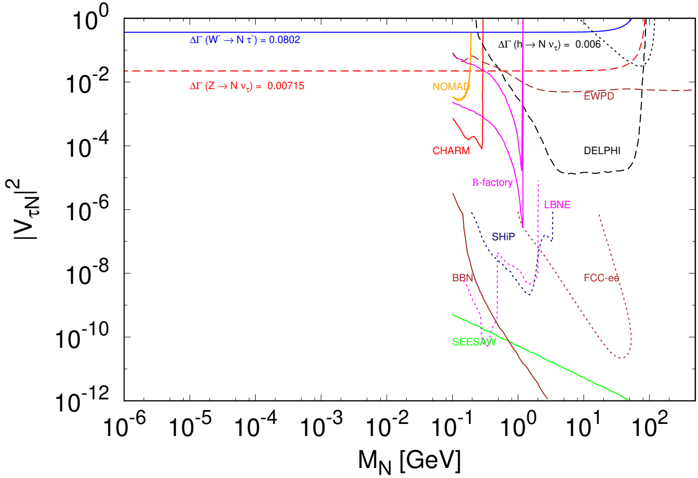
Results

Figure: Constraints on the active-sterile neutrino mixing as a function of the sterile muon neutrino mass in the range 1 MeV-500 GeV.



Results

Figure: Constraints on the active-sterile neutrino mixing as a function of the sterile tau neutrino mass in the range 1 MeV-500 GeV.



Summary

- Though we studied the neutrino mass mechanism through various theoretical models, it is necessary to probe the experimental signatures of these models for the better understanding of the underlying neutrino Physics.
- We obtained the sensitivity of the measured decay widths to constrain the active-sterile neutrino mixing as a function of the sterile neutrino mass.
- We also made a comparative study of these constraints with other existing constraints.
- We conclude that the measured decay widths of the Higgs, W and Z bosons could impose stringent constraints on the active-sterile neutrino mixing and mass.

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THANK YOU