EXPLORING THE MODEL 1-2-3

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INTRODUCTION

In this work we propose and study a scenario that accommodate eV sterile neutrino explaining, in this way, MiniBooNE and LSND results. The model involves an extension of the Standard Model with right-handed neutrinos (ν_R), triplet (Δ) and singlet (σ) of scalars. We obtain the Bounded From Below conditions of the potential and evaluate the RGE-evolution of the self coupling of the Higgs. We show that the interaction $\kappa(\Phi^T\Delta\Phi\sigma + h.c.)$, where Φ is the standard Higgs doublet, is responsible for the stability of the Electroweak Vacuum up to Planck scale. We also extract constraints over the parameters of the Potential by means of Lepton Flavor Violating(LFV) processes and from invisible decay of the standard-like Higgs.

SEESAW AND eV RHN

The leptonic sector of the model is composed by the standard content plus right-handed neutrinos in the singlet form,

$$L_i = \begin{pmatrix}\nu_i \\ \ell_i\end{pmatrix}_L \;;\quad \ell_{iR};\quad \nu_{iR}; \tag{1}$$

where $i = e\,,\mu\,,\tau$. The scalar content is composed by

$$\Delta = \begin{pmatrix}\Delta^0 & \frac{\Delta^+}{\sqrt{2}} \\ \frac{\Delta^+}{\sqrt{2}} & \Delta^{++}\end{pmatrix};\quad \Phi = \begin{pmatrix}\phi^+ \\ \phi^0\end{pmatrix};\quad \sigma. \tag{2}$$

With such lepton and scalar content, the Yukawa interactions that generate mass for all neutrinos of the model is given by

$$\mathcal{L}_Y^\nu = \frac{1}{2}Y^L_{ij}L_i^T\Delta L_j + Y^D_{ij}\overline{L_i}\tilde{\phi}\nu_{Rj} + \frac{1}{2}Y^R_{ij}\overline{\nu^C_{Ri}}\nu_{Rj}\sigma + H.c.. \tag{3}$$

For the following set of values for the VEV's,

$$v_1 = 10^5\text{ eV};\quad v_2 = 246\text{ GeV};\quad v_3 = 1\text{ eV}, \tag{4}$$

and an adequate choice of the Yukawa couplings, the model provides the following spectrum of neutrino masses

$$m_1 = 2\times10^{-4}\,eV;\; m_2 = 8,6\times10^{-3}\,eV;\; m_3 = 5\times10^{-2}\,eV;\; m_4 = 1,4\,eV;\; m_6 = 10^4\,eV;\; m_5 = 10^4\,eV, \tag{5}$$

the correct U_{PMNS} mixing matrix and the following value for the mixing among ν_1 and ν_4: $U_{14}\approx 0,045$. such value for masses and mixtures recover the $3+1$ scenario that accomodates MiniBooNE and LSND data.

SCALAR SECTOR

The most general potential that conserve lepton number is given by

$$\begin{aligned}V(\sigma,\Phi,\Delta) &= \mu_1^2\sigma^*\sigma + \mu_2^2\Phi^\dagger\Phi + \mu_3^2 tr(\Delta^\dagger\Delta)\\ &+\lambda_1(\Phi^\dagger\Phi)^2 + \lambda_2[tr(\Delta^\dagger\Delta)]^2\\ &+\lambda_3\Phi^\dagger\Phi tr(\Delta^\dagger\Delta) + \lambda_4 tr(\Delta^\dagger\Delta\Delta^\dagger\Delta)\\ &+\lambda_5(\Phi^\dagger\Delta^\dagger\Delta\Phi) + \beta_1(\sigma^*\sigma)^2 + \beta_2\Phi^\dagger\Phi\sigma^*\sigma\\ &+\beta_3 tr(\Delta^\dagger\Delta)\sigma^*\sigma - \kappa(\Phi^T\Delta\Phi\sigma + H.c.)\end{aligned} \tag{6}$$

Expanding the neutral scalars around their VEV's and looking at the minimum conditions, we obtain this interesting relation

$$v_1 \approx \frac{\mu_3}{\mu_1}v_3, \tag{7}$$

where v_3, v_2 and v_1 are the VEV's of Δ, Φ, σ respectively. Once v_3 is related to the masses of the left-handed neutrinos, it must be small when compared to the EW energy scale. The proportionality among v_1 and v_3 ties the value of v_1 to the required smallness of v_3. Then, we can use the following hierarchy:

$$v_3 << v_1 << v_2. \tag{8}$$

With this hierarchy, we can make an approximated diagonalization and we can find the mixing and masses of these scalars. Focusing on the CP-even scalars, we will have that the masses are given by,

$$m^2_{H_1} \approx \frac{2\beta_2^2 v_1^2}{\kappa}, m^2_{H_3} \approx \frac{\kappa v_1 v_2^2}{2v_3}, m^2_{H_2} \approx 2\lambda_1 v_2^2. \tag{9}$$

Observe that H_1 is a light salar. In regard to the CP-odd scalar, the model poses a Majoron, J.

SOME CONSTRAINTS

The light scalar, H_1, and the Majoron, J, both contribute to the invisible decay of the standard-like Higgs H_2 :

$$\Gamma_{H_2H_1H_1} \approx \frac{\beta_2^2 v_2}{128\sqrt{2}\pi} \quad,\quad \Gamma_{H_2JJ} \approx \frac{(\lambda_3+\lambda_5)^2 v_2}{128\sqrt{2}\pi} \tag{10}$$

The prediction for the total decay width of the H_2 is around 4 MeV with $BR(\text{inv}) = 0,26\pm0,17$. All this translate in the following constraint on the parameters β_2, λ_3, $\lambda_5 \leq 10^{-2}$.

In what concern LFV processes, the muon decay channel $\mu\to e\gamma$ may provide strong constraints on the parameters of the Potential. In one-loop order we have the following expression for the branching ratio of this process

$$BR_{(\mu\to\gamma e)} \approx \frac{27\alpha\mid(Y_L^\dagger Y_L)_{e\mu}\mid^2}{64\pi G_F^2 M^4_{\Delta^{++}}}. \tag{11}$$

On substituting the expression of the mass of the doubly charged scalar, using the fixed values of Y_L's given in the paper and of the VEVs given in the first section, the upper bound $BR(\mu\to\gamma e) < 5.7\times10^{-13}$ translates in the following lower bound over κ

$$\kappa > 1.1\times10^{-3}. \tag{12}$$

BOUNDED FROM BELOW

In what to concern the bounded from below, we make the following parametrization

$$\begin{aligned}r^2 &= \Phi^\dagger\Phi + tr(\Delta^\dagger\Delta) + \sigma^*\sigma;\\ \Phi^\dagger\Phi &= r^2cos^2\gamma sin^2\theta;\;\; \sigma^*\sigma = r^2cos^2\theta;\\ tr(\Delta^\dagger\Delta) &= r^2sin^2\gamma sin^2\theta;\end{aligned} \tag{13}$$

where $0\leq r\leq\infty$, $0\leq\gamma\leq\frac{\pi}{2}$ and $0\leq\theta\leq\frac{\pi}{2}$.

$$\zeta = \frac{tr(\Delta^\dagger\Delta\Delta^\dagger\Delta)}{[tr(\Delta^\dagger\Delta)]^2};\; \xi = \frac{\Phi^\dagger\Delta\Delta^\dagger\Phi}{\Phi^\dagger\Phi tr(\Delta^\dagger\Delta)}; \tag{14}$$

$$\alpha = \frac{Re(\Phi^T\Delta\Phi\sigma)}{tr(\Delta^\dagger\Delta)\sigma^*\sigma + \Phi^\dagger\Phi\sigma^*\sigma + tr(\Delta^\dagger\Delta)\Phi^\dagger\Phi}.$$

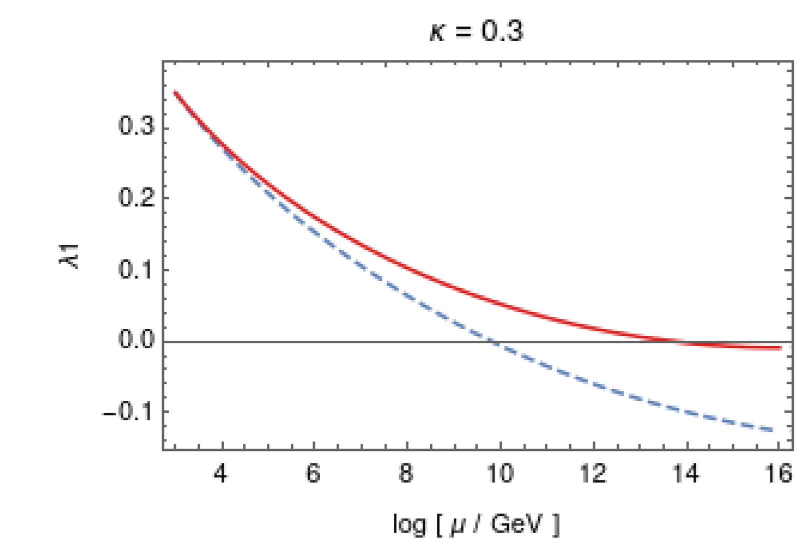
where $\frac{1}{2}\leq\zeta\leq1$, $0\leq\xi\leq1$ and $\mid\alpha\mid\leq1$.

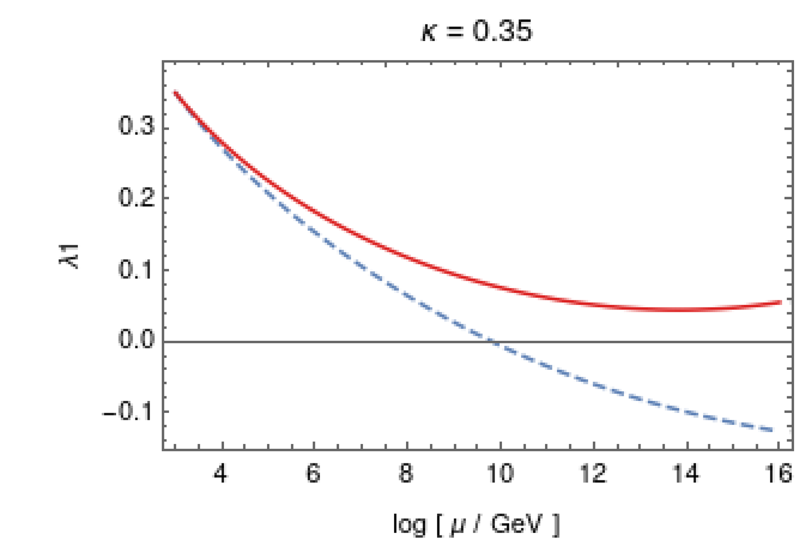
In the end we finded the conditions of BFB changing these real parameters in the potential. All the details are in the paper.

RGE evolution

The behavior of the Quartic coupling of the standard-like Higgs that guarantees stability of the vacuum up to Planck scale depends strongly on the coupling κ. We do our analysis by implementing the model in SARAH 4.13.0 and evaluating the β function for λ_1 at one-loop level. The main contributions for the beta function of λ_1 involve the following terms

$$\begin{aligned}\beta_{\lambda_1} &= \frac{27}{100}g_Y^4 + \frac{9}{4}g^4 + \frac{9}{20}g_Y^2(g^2 - 2\lambda_1)\\ &-\frac{9}{5}g^2\lambda_1 + 12\lambda_1^2 + 12\lambda_1 y_t^\dagger y_t - 6y_t^\dagger y_t y_t^\dagger y_t\\ &+\beta_2^2 + 3\lambda_3^2 + 3\lambda_3\lambda_5 + \frac{5}{4}\lambda_5^2 + 2\kappa^2.\end{aligned} \tag{15}$$





The couplings β_2, $\lambda_{3,5}$ and κ give positive contributions to the running of λ_1. However, the invisible Higgs decay requires β_2, $\lambda_{3,5}$ be minor then 10^{-2} which turns insignificant they contributions to the RGE-evolution. The, the predominant contribution is duo to κ. Above we show the plot of the running of λ_1 with energy scale for two possible values of κ. We see that the running of λ_1 may get positive up to Planck scale for $\kappa > 0.3$. Thus, the model may have the vacuum stable up to Planck scale thanks to the contribution of the parameter κ.

CONCLUSION

In this work we studied stability of the vacuum in the 1-2-3 model with right-handed neutrinos. Our investigation was restricted to a specific scenario characterized by spontaneous violation of the lepton number at low energy scale. This case yields to light sterile neutrinos and may explain MiniBooNE neutrino oscillation. We obtained the whole set of conditions that the model is Bounded From Below and studied the RGE-evolution of the self-coupling of the standard-like Higgs. As main result we have that the quartic coupling $\kappa\Phi^T\Delta\Phi\sigma$ plays a central role in the process and stability of the vacuum requires $\kappa > 0.3$.