Lepton flavor violation at the LHC in supersymmetric type I seesaw

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(Work in progress)

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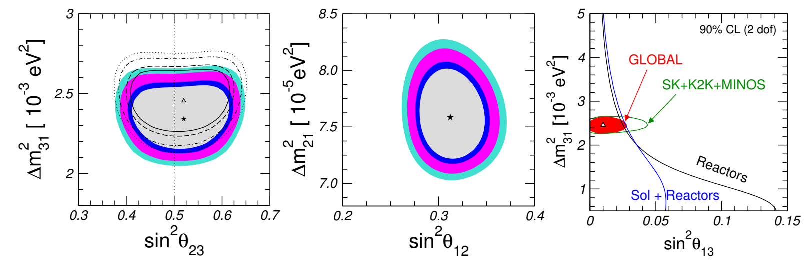
Outline

Outline

Experimental neutrino data

Neutrino oscillations



[T. Schwetz, M. Tortola and J. W. F. Valle, arXiv:1103.0734v2 [hep-ph]]

Neutrino masses

$$m < 2 \quad \text{eV}$$

[K. Nakamura *et al.* [Particle Data Group], J. Phys. G **37**, 075021 (2010)]

Seesaw mechanism

- $\hat{\nu}_L$ mix with very heavy states ($M_{\rm SS} \sim 10^{14}$ GeV)
- After integrating out the heavy states,

$$W_{\rm eff} \supset -\frac{1}{4}\frac{c^{ij}}{M_{\rm SS}}(\hat{L}_i\hat{H}_u)(\hat{L}_j\hat{H}_u)$$

light neutrino masses are supressed by $M_{\rm SS}^{-1}$

Canonical SUSY type I seesaw

- Particle content

$$\text{MSSM} \quad + \quad 3\,\hat{\nu}_i^c$$

Canonical SUSY type I seesaw

- Superpotential

$$W = W_{\mathrm{MSSM}} + Y_\nu^{ji} \hat{L}_i \hat{\nu}_j^c \hat{H}_u + \frac{1}{2} M_R^{ij} \hat{\nu}_i^c \hat{\nu}_j^c$$

where

$$Y_\nu = \begin{pmatrix} Y_\nu^{11} & Y_\nu^{12} & Y_\nu^{13} \\ Y_\nu^{21} & Y_\nu^{22} & Y_\nu^{23} \\ Y_\nu^{31} & Y_\nu^{32} & Y_\nu^{33} \end{pmatrix} \qquad M_R = \begin{pmatrix} M_1 & 0 & 0 \\ 0 & M_2 & 0 \\ 0 & 0 & M_3 \end{pmatrix}$$

Inconvenients of *canonical* SUSY type I seesaw

Testability

- Impossible direct tests: $M_R \sim 10^{14}$ GeV
- Only indirect tests: LFV and SUSY particle masses

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- Possible solutions
  - Simplifying assumptions about neutrino scenarios
  - Additional flavor symmetries
  - 2RHN

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2RHN SUSY type I seesaw

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  - rank$(m_\nu^{\text{eff}}) = 2$
  - 1 zero-eigenvalue
  - SNH $(m_1 = 0)$ or SIH $(m_3 = 0)$

Parametrization of 2RHN SUSY type I seesaw

High energy

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$$R = \begin{pmatrix} 0 & \cos(\theta_R) & \sigma_R \sin(\theta_R) \\ 0 & -\sin(\theta_R) & \sigma_R \cos(\theta_R) \end{pmatrix} \quad \text{where } \sigma_R = \pm 1 \qquad \text{SNH}$$

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$$Y_\nu = i\frac{\sqrt{2}}{v_u}\mathrm{diag}(\sqrt{M}) \cdot R \cdot \mathrm{diag}(\sqrt{m}) \cdot U^\dagger$$

Lepton flavor violation

- Small mixing angle approximation
- Neglecting L-R mixing
- mSugra boundary conditions

$$\mathrm{BR}_{ij} \propto |(Y_\nu^\dagger \cdot L \cdot Y_\nu)_{ij}|^2$$

$$\mathrm{BR}_{ij} \propto \left| U^*_{i\alpha} U_{j\beta} \sqrt{m_\alpha} \sqrt{m_\beta} R^*_{k\alpha} R_{k\beta} M_k \log\left(\frac{M_X}{M_k}\right) \right|^2$$

- Trick: Ratio of BR's

$$\frac{\mathrm{BR}_{i_1 j_1}}{\mathrm{BR}_{i_2 j_2}} \simeq \frac{\left| U^*_{i_1\alpha_1} U_{j_1\beta_1} \sqrt{m_{\alpha_1}} \sqrt{m_{\beta_1}} R^*_{k_1\alpha_1} R_{k_1\beta_1} M_{k_1} \log\left(\frac{M_X}{M_{k_1}}\right) \right|^2}{\left| U^*_{i_2\alpha_2} U_{j_2\beta_2} \sqrt{m_{\alpha_2}} \sqrt{m_{\beta_2}} R^*_{k_2\alpha_2} R_{k_2\beta_2} M_{k_2} \log\left(\frac{M_X}{M_{k_2}}\right) \right|^2}$$
$$\equiv (r^{i_1 j_1}_{i_2 j_2})^2$$

Case-1: TBM + Degenerate ν_R + Real θ_R

The same dependence as is 3RHN: m

SNH

$$(r_{31}^{21})^2 = 1$$

$$(r_{32}^{21})^2 = (r_{32}^{31})^2 = \left(\frac{2\sqrt{\frac{\Delta_S}{|\Delta_A|}}}{3 - 2\sqrt{\frac{\Delta_S}{|\Delta_A|}}}\right)^2 = 0.018 = [0.015,\ 0.022]$$

SIH

$$(r_{31}^{21})^2 = 1$$

$$(r_{32}^{21})^2 = (r_{32}^{31})^2 = \left(\frac{2\sqrt{1+\frac{\Delta_S}{|\Delta_A|}} - 2}{2\sqrt{1+\frac{\Delta_S}{|\Delta_A|}} + 1}\right)^2 = 1.1 \times 10^{-4} = [0.78,\ 1.6] \times 10^{-4}$$

Case-2: TBM + Degenerate ν_R + Complex θ_R

More constrained than in 3RHN: m and $\mathrm{Im}(\theta_R)$

$$R^\dagger \cdot R \supset \begin{pmatrix} \cosh(2\,\mathrm{Im}(\theta_R)) & i\sigma_R \sinh(2\,\mathrm{Im}(\theta_R)) \\ -i\sigma_R \sinh(2\,\mathrm{Im}(\theta_R)) & \cosh(2\,\mathrm{Im}(\theta_R)) \end{pmatrix}$$

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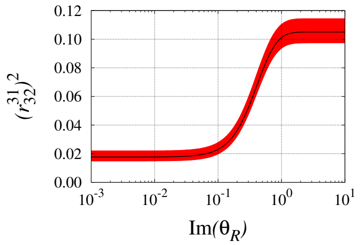
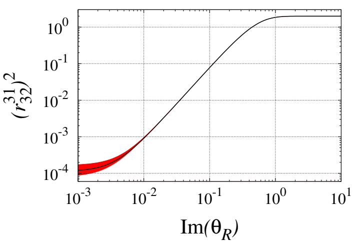
SNH

$$(r_{31}^{21})^2 = 1$$
$$(r_{32}^{21})^2 = (r_{32}^{31})^2 = [0.018, 0.105] = [0.014, 0.114]$$



SIH

$$(r_{31}^{21})^2 = 1$$
$$(r_{32}^{21})^2 = (r_{32}^{31})^2 = [1.13 \times 10^{-4}\ 2] = [7.8 \times 10^{-5}, 2]$$



Other cases

- Departure from TBM: dependence on θ_{ij}, δ
- Departure from degenerate ν_R: dependence on M_i
- Dependence on R

Outline

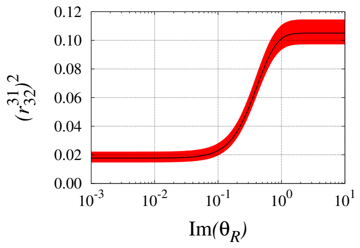
Software

- Implementation of 2RHN in SPheno3.1.2
- mSugra boundary conditions
- Iteratively fit of light neutrino masses

Case-2: TBM + Degenerate ν_R + Complex θ_R

- mSugra point:
  $(m_0,\ m_{1/2}) = (350,\ 700)$ GeV, $A_0 = 0$ GeV, $\tan\beta = 10$, $\mu > 0$
- $M = 10^{10}$ GeV
- $\max(\mathrm{Im}(\theta_R)) \Rightarrow$ renormalizable Y_ν

Neutrino sector



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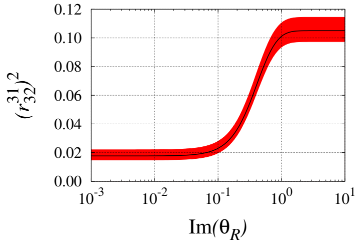
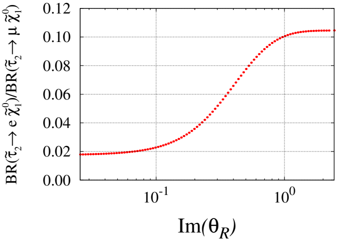


Slepton sector



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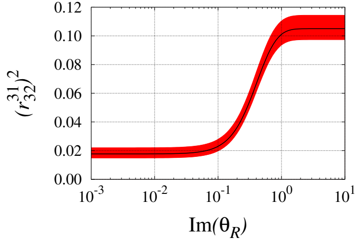
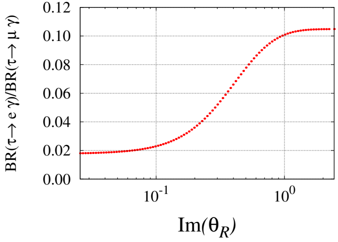


Lepton sector



Outline

Summary

- Neutrino data
  - Neutrinos have little masses
  - Neutrinos mix
- Neutrino mass generation:
  2RHN SUSY type I seesaw $\subset$ 3RHN
- mSUGRA: LFV decays are related to neutrino parameters
- Study falsifiability of 2RHN SUSY type I seesaw