Higgs Exempt No-Scale Supersymmetry with a Neutrino Seesaw

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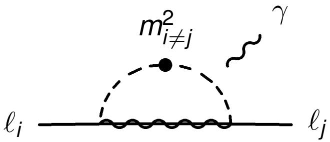
JLE, Morrissey, Wells PRD 75 (2007) 055017
Chun, JLE, Morrissey, Wells hep-ph/0804.3050

Supersymmetric Flavor Problem

- SUSY stabilization of hierarchy
- Parameters of softly broken SUSY

$$\mathcal{L}_{soft} = m_{ij}^2 \phi_i^* \phi_j + A_{ijk} \phi_i \phi_j \phi_k + M_a \lambda^a \lambda^a$$

- Flavor violation from non-universal scalar masses



No-Scale Approach to the Flavor Problem

- No-scale approach to flavor problem

$$M_{1/2} \quad \tan\beta \quad sgn(\mu) \quad m^2_{\tilde{f}} = 0 \quad A_{ijk} = 0$$

- RGE induced scalar masses

$$\beta(m^2_{(L,E)}) \sim \; -g_i^2|M_i|^2$$

- Charged Yukawa couplings diagonal
- Pure no-scale models have charged LSP

Higgs Exempt No-Scale Supersymmetry(HENS)

- HENS model parameters

$$M_{1/2} \quad \tan\beta \quad sgn(\mu) \quad m_{H_u}^2 \quad m_{H_d}^2$$

- $m_{H_{u,d}}^2 \neq 0$ gives non-zero S term

$$\beta(m_{(L,E)}^2) \sim \quad -g_i^2|M_i|^2 \mp g_1^2 S$$

- Higgs Exempt No-Scale(HENS) supersymmetry spectrum

$$M_1 = .41 M_{1/2}$$

$$m_E^2 = [(0.39)M_{1/2}]^2 - (0.055)S_{GUT}$$
$$m_L^2 = [(0.64)M_{1/2}]^2 + \frac{1}{2}(0.055)S_{GUT}$$

Experimental Constraints on Lepton Flavor Violation

- Lepton Flavor violating μ decays

$$B(\mu \to e\gamma) < 1.2 \times 10^{-11}$$
$$B(\mu \to 3e) < 1.0 \times 10^{-12}$$

- Lepton Flavor violating τ decays

$$B(\tau \to \mu\gamma) < 4.5 \times 10^{-8}$$
$$B(\tau \to e\gamma) < 1.1 \times 10^{-7}$$
$$B(\tau \to 3\ell) \lesssim 10^{-7}$$

- Generic prediction of SUSY lepton flavor violation

$$\frac{B(\ell_i \to \ell_j\gamma)}{B(\ell_i \to 3\ell)} \sim 10^2$$

$$B(\ell_i \to \ell_j\gamma) \sim B(\ell_k \to \ell_l\gamma)$$

Neutrino Sector

- Neutrino are massive $\rightarrow$ right-handed neutrinos
- Neutrino extended SUSY

$$W = W_{MSSM} + N Y_\nu L H_u + \frac{1}{2} N M_N N$$

- Y_ν cannot be diagonalized
- Give non-diagonal slepton mass matrix

$$m^2_{L_{i \neq j}} = -\frac{m^2_{H_u}}{8\pi^2} \sum_k Y^*_{kj} Y_{ki} \ln\left(\frac{M_{GUT}}{M_{N_k}}\right)$$

$$Y_{\nu ij} \sim \frac{\sqrt{M_{N_i} m_3}}{v_u}$$

νHENS predictions for LFV

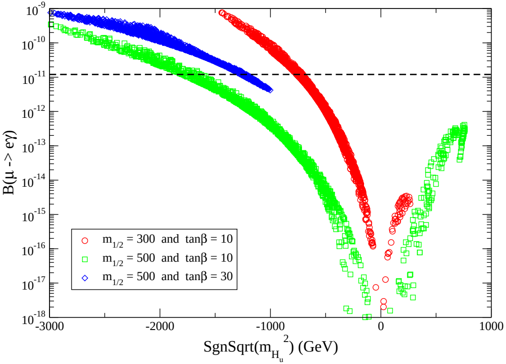
- LFV branching fraction in HENS model

$$B(\ell_i \to \ell_j \gamma) = |m^2_{L_{i\neq j}}|^2 |F_L^{ij}|^2 G(\mathbf{SM})$$

- Controlling LFV
  1. In the HENS model $m^2_{H_u} \sim 0$ will suppress LFV
  2. Suppression of Y_ν through $M_N \to 0$
  3. Tuning $Y_{\nu 32} Y_{\nu 31} \simeq -Y_{\nu 22} Y_{\nu 21}$

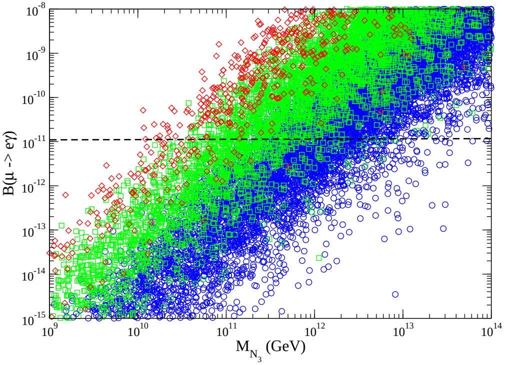
HENS Parameter Dependence of $B(\mu \to e\gamma)$

- Small Up Higgs mass suppresses LFV($m^2_{L_{i\neq j}} \propto m^2_{H_u}$)
- $M_{N_1} = 10^{10}\,\mathrm{GeV}$ $M_{N_2} = 10^{11}\,\mathrm{GeV}$ $M_{N_3} = 10^{12}\,\mathrm{GeV}$



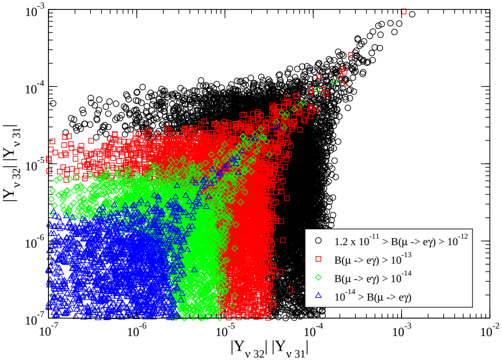
Suppression of LFV from Neutrino Masses

- LFV roughly scale as $M^2_{N_3}$
- $m^2_{H_u} = -(668)^2\,\mathrm{GeV}^2$ $m^2_{H_d} = -(511)^2\,\mathrm{GeV}^2$



Suppression of LFV from Yukawa Couplings

- Small/tuned Yukawa couplings suppress $B(\mu \to e\gamma)$
- $m^2_{H_u} = -(668)^2\,\mathrm{GeV}^2$ $m^2_{H_d} = -(511)^2\,\mathrm{GeV}^2$



Thermal Leptogenesis

- Sakharov conditions for baryogenesis
  1. Baryon violation: sphaleron violates $B + L$
  2. Y_ν complex $\rightarrow$ CP violation
  3. Cooling Universe $\rightarrow$ non-equilibrium
- Baryon asymmetry, CP violation, and washout parameter

$$Y_B \simeq \frac{10}{31 g^*} \sum_\ell \epsilon_\ell \eta(A_\ell m_\ell)$$

Leptogenesis and the Neutrino Sector

- *CP* violation and washout parameter

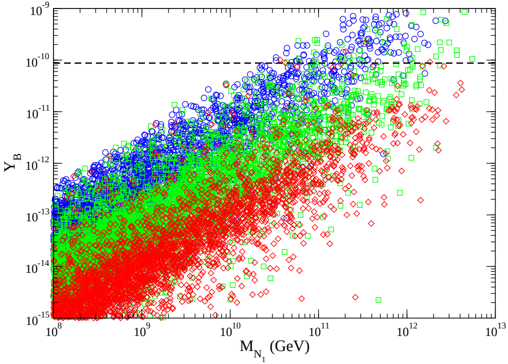
$$\epsilon_\alpha \sim -\frac{3M_{N_1} m_\nu}{16\pi v_u^2}$$

$$\widetilde{m}_\alpha = \left| \sum_k R_{1k} m_k^{1/2} U^*_{\alpha k} \right|^2$$

- Leptogenesis constraints on Neutrino Sector
  1. M_{N_1} large ($M_{N_1} \gtrsim 10^{10}\,\mathrm{GeV}$)
  2. R_{ij} small

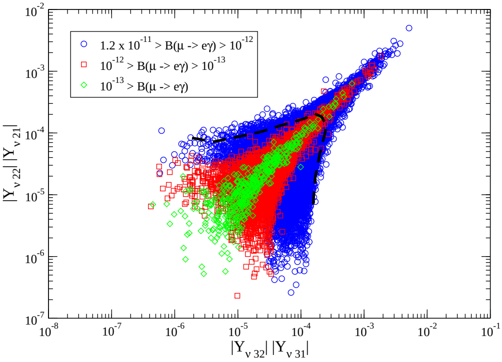
Lepton Flavor Violation and Leptogenesis

- Leptogenesis constraints require large right-handed neutrinos



Lepton Flavor Violation and Leptogenesis

- Leptogenesis constraints force large Y_ν



Summary

- HENS models have minimal lepton flavor violation
- Neutrino Yukawa couplings generically reintroduce LFV in SUSY models
- Simultaneously meeting LFV and leptogenesis bound is non-trivial for SUSY models – i.e., not just any couplings at the high scale will do
- Generically, even within this no-scale framework, neutrino masses imply LFV to be probed by experiment