Lepton flavour violation in supersymmetric seesaw III models

Florian Staub (University of Würzburg)

in collaboration with:
J. N. Esteves, M. Hirsch, W. Porod, J. Romao

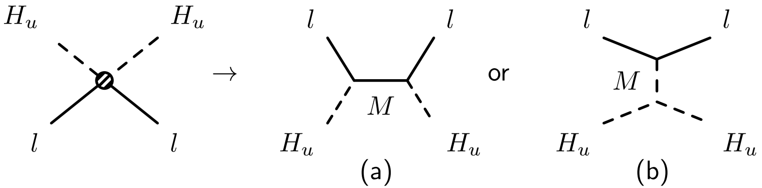
Reference: `arXiv:1010.6000`

4th Annual Helmholtz Alliance Workshop on "Physics at the Terascale"
03. December 2010

Outline

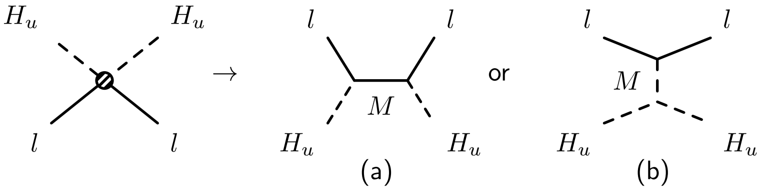
Seesaw mechanism

Neutrino masses can be generated by Dimension 5 operator.



Seesaw mechanism

Neutrino masses can be generated by Dimension 5 operator.



1. **Seesaw I**: (a) with a gauge singlet fermion: $m_\nu = \frac{Y^T Y}{M} v_u^2$
2. **Seesaw II**: (b) with scalar $SU(2)$ triplet. $m_\nu = \frac{Y\lambda}{M} v_u^2$
3. **Seesaw III**: (a) with fermionic $SU(2)$ triplet. $m_\nu = \frac{1}{2}\frac{Y^T Y}{M} v_u^2$

Embedding in $SU(5)$

- Adding only triplets spoils gauge unification

  $\rightarrow$ Embed model in $SU(5)$

Embedding in $SU(5)$

- Adding only triplets spoils gauge unification

  $\to$ Embed model in $SU(5)$

Superpotential of minimal $SU(5)$

$$W^{SU(5)} = \sqrt{2}\,\overline{5}_M\,Y^5\,10_M\,\overline{5}_H - \tfrac{1}{4}\,10_M\,Y^{10}\,10_M\,5_H + M_5\,5_H\,\overline{5}_H\ .$$

with

$$5_M = \left(\hat{d}, \hat{l}\right), 10_M = (\hat{q}, \hat{u}, \hat{e}), 5_H = \left(\hat{H}_u^C, \hat{H}_u\right), \overline{5}_H = \left(\hat{H}_d^C, \hat{H}_d\right)$$

Embedding in $SU(5)$

- Adding only triplets spoils gauge unification

  $\rightarrow$ Embed model in $SU(5)$

Superpotential of minimal $SU(5)$

$$W^{SU(5)} = \sqrt{2}\,\overline{5}_M\,Y^5\,10_M\,\overline{5}_H - \tfrac{1}{4}\,10_M\,Y^{10}\,10_M\,5_H + M_5\,5_H\,\overline{5}_H\,.$$

with

$$5_M = \left(\hat{d}, \hat{l}\right), 10_M = (\hat{q}, \hat{u}, \hat{e}), 5_H = \left(\hat{H}_u^C, \hat{H}_u\right), \bar{5}_H = \left(\hat{H}_d^C, \hat{H}_d\right)$$

- Integrating out $\hat{H}_d^C$, $\hat{H}_u^C$ reproduces superpotential of MSSM
- No assumptions about $SU(5)$ breaking or mechansim for doublet-triplet splitting

Seesaw I

Superpotential of Seesaw I

$$W^I = Y_\nu \, \hat{N} \, \overline{5}_M \, 5_H + \frac{1}{2} \hat{N} M_N \hat{N} \; .$$

$\hat{N}$ is gauge singlet. After $SU(5)$ breaking:

$$W^I \to Y_\nu \, \hat{N} \, \hat{l} \, \hat{H} + \frac{1}{2} \hat{N} M_N \hat{N} \; .$$

Seesaw II

Superpotential of Seesaw II

$$W^{II} = \frac{1}{\sqrt{2}} Y_{15}^{ab}\, \overline{5}_a\, 15\, \overline{5}_b + \frac{1}{\sqrt{2}} \lambda_1\, \overline{5}_H\, 15\, \overline{5}_H + \frac{1}{\sqrt{2}} \lambda_2\, 5_H\, \overline{15}\, 5_H + M_{15}\, 15\, \overline{15}\ .$$

The $\mathbf{15}$ splits after $SU(5)$ breaking in

$$\hat{S} : (\mathbf{6}, \mathbf{1})_{-2/3}\ , \qquad \hat{T} : (\mathbf{1}, \mathbf{3})_1\ , \qquad \hat{Z} : (\mathbf{3}, \mathbf{2})_{1/6}\ .$$

The superpotential reads

$$\begin{aligned} W^{II} \quad \rightarrow \quad & \frac{1}{\sqrt{2}} \left(Y_T\, \hat{l}\, \hat{T}\, \hat{l} + Y_S\, \hat{d}\, \hat{S}\, \hat{d} \right) + Y_Z\, \hat{d}\, \hat{Z}\, \hat{l} \\ & + \frac{1}{\sqrt{2}} \lambda_1 \hat{H}_d \hat{T} \hat{H}_d + \frac{1}{\sqrt{2}} \lambda_2 \hat{H}_u \hat{\bar{T}} \hat{H}_u \\ & + M_T \hat{T} \hat{\bar{T}} + M_Z \hat{Z} \hat{\bar{Z}} + M_S \hat{S} \hat{\bar{S}}\ . \end{aligned}$$

Seesaw III

Additional terms in superpotential

$$W^{III} = 5_H 24_M Y_{24} \bar{5}_M + \frac{1}{2} M_{24} 24_M 24_M$$

Seesaw III

Additional terms in superpotential

$$W^{III} = 5_H 24_M Y_{24} \bar{5}_M + \frac{1}{2} M_{24} 24_M 24_M$$

24-plet: quantum numbers of $SU(5)$-gauge bosons

$$24_M = \hat{G}_M + \hat{W}_M + \hat{B}_M + \hat{X}_M + \hat{\bar{X}}_M$$

$$\hat{G}_M : (8,1)_0 \,,\ \hat{W}_M : (1,3)_0 \,,\ \hat{B}_M : (1,1)_0 \,, \hat{X}_M : (3,2)_{-5/6} \,,\ \hat{\bar{X}}_M : (\bar{3},2)_{5/6}$$

Seesaw III

Additional terms in superpotential

$$W^{III} = 5_H 24_M Y_{24} \bar{5}_M + \frac{1}{2} M_{24} 24_M 24_M$$

24-plet: quantum numbers of $SU(5)$-gauge bosons

$$24_M = \hat{G}_M + \hat{W}_M + \hat{B}_M + \hat{X}_M + \hat{\bar{X}}_M$$

$$\hat{G}_M : (8,1)_0\,,\ \hat{W}_M : (1,3)_0\,,\ \hat{B}_M : (1,1)_0\,, \hat{X}_M : (3,2)_{-5/6}\,,\ \hat{\bar{X}}_M : (\bar{3},2)_{5/6}$$

After $SU(5)$-breaking

$$5_H\, 24_M\, Y_{24}\, \bar{5}_M \rightarrow Y_w \hat{H}_u \hat{W}_M \hat{l} - \sqrt{\frac{6}{5}} Y_b \hat{H}_u \hat{B}_M \hat{l} + Y_x \hat{H}_u \hat{\bar{X}}_M \hat{d}$$

$$\frac{1}{2} M_{24}\, 24_M\, 24_M \rightarrow \sum_{Y=B,G,W} \frac{1}{2} M_Y \hat{Y}_M \hat{Y}_M + M_X \hat{X}_M \hat{\bar{X}}_M$$

Neutrino masses generated by 24-plet(s)

One generation of 24-plet not sufficient to reproduce neutrino data

$\rightarrow$ 3 generations are added

Neutrino masses generated by 24-plet(s)

One generation of 24-plet not sufficient to reproduce neutrino data

$\rightarrow$ 3 generations are added

Effective mass term

Dimension 5 operator $l l^* H_u H_u^*$ with effective coupling

$$\kappa = \frac{1}{2} Y_w^T \frac{1}{M_W} Y_w + \frac{3}{10} Y_b^T \frac{1}{M_B} Y_b$$

$\rightarrow$ Seesaw I and III contributions

Analysis of Seesaw III

- Calculation of 2-loop RGEs with SARAH [FS (0909.2863)]

Analysis of Seesaw III

- Calculation of 2-loop RGEs with SARAH [FS (0909.2863)]
- Implementation in SPheno [Porod (hep-ph/0301101)]:
  - $SU(5)$ invariant boundary conditions at the GUT scale
  - Each generation is separately integrated out

    $\rightarrow$ 1-loop boundary conditions at each threshold scale
  - Large off-diagonal elements in $M_{G,W,B,X}$

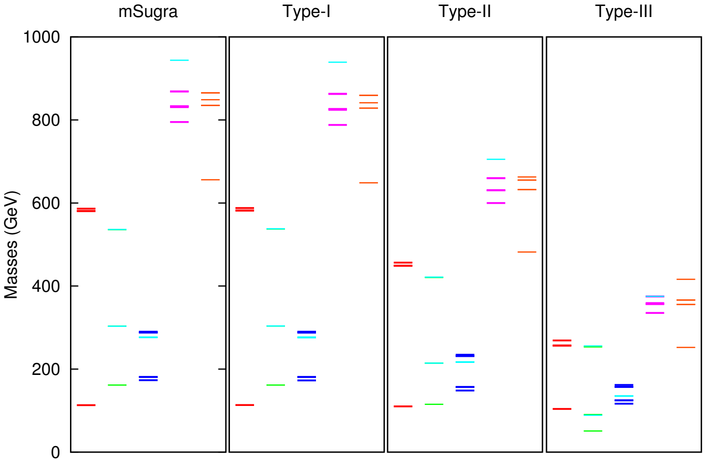
    $\rightarrow$ Rotate fields at each threshold to mass eigenstates

The mass spectrum

- The additional fields contribute to the β-functions of the gauge couplings ($b^{\mathrm{MSSM}} = (\frac{33}{5}, 1, -3)$)
- Change at 1-loop level:

$$\Delta b_i^{I} = 0, \qquad \Delta b_i^{II} = 7, \qquad \Delta b_i^{III} = 15$$

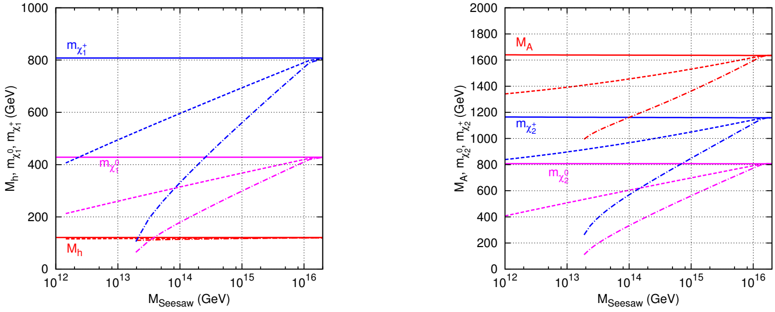
- Does not only change evolution of gauge couplings but also has large impact on mass spectrum
- Additional effects on the spectrum of the scalars can be present if some of the Yukawa couplings get large.



$$m_0 = 90\text{GeV}, M_{1/2} = 400\text{GeV}, \tan\beta = 10, A_0 = 0, \mu > 0, M_{\text{seesaw}} = 10^{14}\text{GeV}$$

left-to-right: h_i, A^0 - $\tilde{\chi}^0_i, \tilde{\chi}^+_i$ - $\tilde{e}_i, \tilde{\nu}_i$ - $\tilde{g}, \tilde{d}_i$ - $\tilde{u}_i$

Dependence on the seesaw scale



solid: seesaw I, dashed: seesaw II, dot-dashed: seesaw III

$$m_0 = M_{1/2} = 1\text{TeV}, \quad \tan\beta = 10, \quad A_0 = 0, \quad \mu > 0$$

Lepton flavor violation

- All models predict negligible flavour violation for the right-sleptons

$$m^2_{\tilde{e},ij} \simeq 0$$

- One-step integration of the RGEs: rough estimate for LFV entries

$$\begin{aligned} m^2_{\tilde{l},ij} &\simeq -a_k \frac{1}{8\pi^2}\left(3m_0^2 + A_0^2\right)\left(Y_\nu^\dagger L Y_\nu\right)_{ij} \ , \\ A_{e,ij} &\simeq -a_k \frac{3}{16\pi^2} A_0 \left(Y_e Y_\nu^\dagger L Y_\nu\right)_{ij} \ . \end{aligned}$$

Assumptation: Y_e diagonal, $L_{ij} = \log\left(\frac{M_{GUT}}{M_{N_i}}\right)\delta_{ij}$.

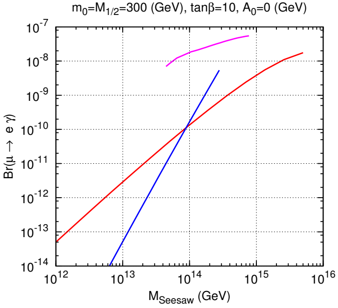
- The values for the different scenarios are

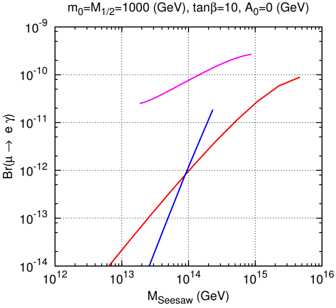
$$a_I = 1, \qquad a_{II} = 6, \qquad a_{III} = \frac{9}{5}$$

Validity of approximations

Gives only for type I a good estimation of LFV!

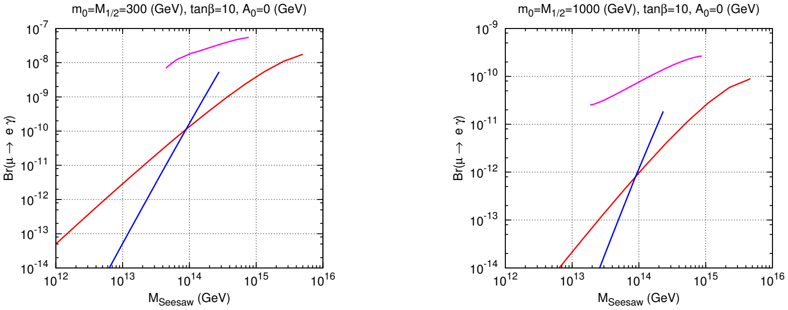
Comparison of $\mu \to e\gamma$





magenta: seesaw III, blue: seesaw II, red: seesaw I

Comparison of $\mu \to e\gamma$



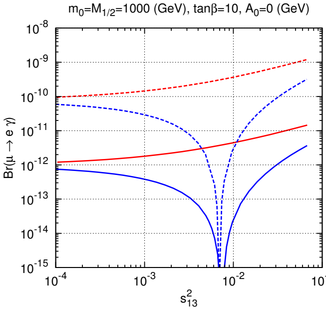
magenta: seesaw III, blue: seesaw II, red: seesaw I

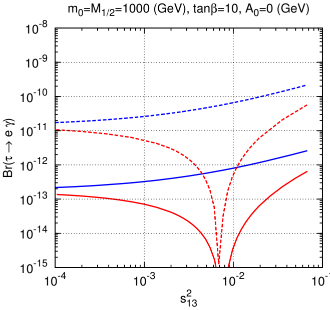
Experimental bounds

No 'low' seesaw scale possible in type III

$\to$ BR normally larger than the upper limit of $1.2 \cdot 10^{-11}$

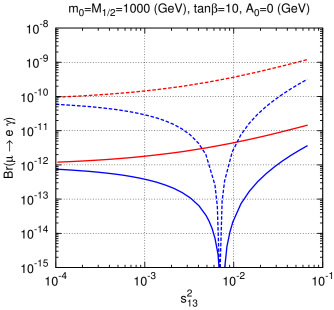
Cancellations in Seesaw III

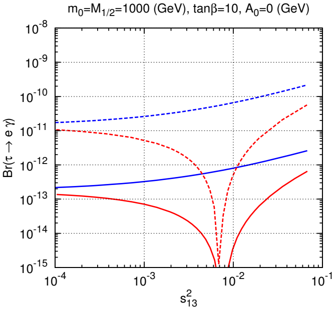




solid: seesaw I, dashed: seesaw III
red: $\delta_{\text{Dirac}} = 0$, blue: $\delta_{\text{Dirac}} = \pi$ (normal hierarchy)

Cancellations in Seesaw III





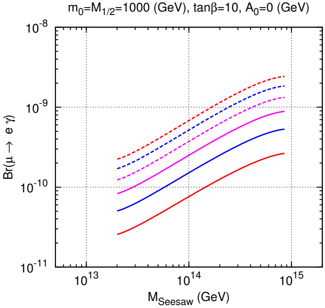
solid: seesaw I, dashed: seesaw III

red: $\delta_{\text{Dirac}} = 0$, blue: $\delta_{\text{Dirac}} = \pi$ (normal hierarchy)

Cancellations

Cancellations can reduce the BR to values consistent with data

Dependence on Θ_{13}



The curves are for:
$\Theta_{13} = 0$ (solid red), $\Theta_{13} = 2$ (solid blue), $\Theta_{13} = 4$ (solid magenta), $\Theta_{13} = 6$ (dashed magenta), $\Theta_{13} = 8$ (dashed blue), $\Theta_{13} = 10$ (dashed red).

Summary

- We performed a complete analysis using 2-loop RGEs and 1-loop boundary conditions
- The impact on the SUSY mass spectrum in type III is larger as in type II or I
- The contributions to LFV processes are often larger than the allowed upper limits
- The possibility of cancellations exists to suppress these contributions