Reconstructing the Right-Handed neutrino masses in Left-Right symmetric theories

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Introduction

Aim of this work : introducing a method of reconstruction for the RH neutrino mass matrix from the type I + type II seesaw formula, and applying it to SUSY $SO(10)$ GUTs.

Type I seesaw : ν_L couples to heavy N_R

$$Y_\nu \overline{N_R} H \nu_L + \frac{1}{2} M_R N_R N_R \qquad \Rightarrow \qquad m_\nu = -v^2 Y_\nu^T M_R^{-1} Y_\nu$$

Type II seesaw : ν_L couples to heavy scalar triplet of $SU(2)_L$, Δ_L

$$\frac{1}{2} f_L l_L^T \Delta_L C l_L \qquad \Rightarrow \qquad m_\nu = v_L f_L$$

We will consider both types of seesaw without assuming any dominance :

$$m_\nu = v_L f_L - v^2 Y_\nu^T M_R^{-1} Y_\nu$$

Reconstruction Procedure

In order to reconstruct M_R from the seesaw formula we will consider more specific models, namely Left-Right symmetric models :

- M_R comes from an $SU(2)_R$ triplet vev $v_R \Rightarrow M_R = v_R f_R$
- LR symmetry $\Rightarrow$ $f_L = f_R = f$ and Y_ν is symmetric

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Now supposing Y_ν known, we can rewrite the seesaw formula :

$$m_\nu = v_L f - \frac{v^2}{v_R} Y_\nu f^{-1} Y_\nu \qquad \Rightarrow \qquad Z = \alpha X - \beta X^{-1}$$

$$\alpha = v_L \qquad \beta = \frac{v^2}{v_R} \qquad Z = Y_\nu^{-\frac{1}{2}} m_\nu (Y_\nu^{-\frac{1}{2}})^T \qquad X = Y_\nu^{-\frac{1}{2}} f (Y_\nu^{-\frac{1}{2}})^T$$

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Z and X are complex symmetric, hence diagonalisable by a complex orthogonal transformation : $Z = O_Z^T D_Z O_Z$ and $O_Z = O_X$.
The eigenvalues z_i and x_i are complex and unphysical.

The matrix equation transposes to the eigenvalues :

$$x_i^{\pm} = \frac{z_i \pm \sqrt{z_i^2 + 4\alpha\beta}}{2\alpha}$$

$\Rightarrow$ 2 solutions for each eigenvalue : 8 possible spectra (Akhmedov-Frigerio)
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When $\alpha\beta$ is small enough (large v_R) we can identify some known limits :

$$f^{(---)} \longrightarrow -\frac{v^2}{v_R} Y_\nu m_\nu^{-1} Y_\nu \qquad \text{(Type I limit)}$$

$$f^{(+++)} \longrightarrow \frac{m_\nu}{v_L} \qquad \text{(Type II limit)}$$

which will allow us to compare with known results from type I or type II dominance.

SO(10) Setup

In order to illustrate these results we will apply the procedure to SUSY SO(10) theories with a Higgs sector containing :

- two **10**s containing the H_u and H_d of the MSSM
- a $\overline{\mathbf{126}}$ containing the triplets Δ_L and Δ_R
- a **54** containing a bitriplet needed to generate v_L

The yukawa part of the superpotential is :

$$W \supset Y_{uij} 16_i 16_j 10_u + Y_{dij} 16_i 16_j 10_d + f_{ij} 16_i 16_j \overline{126}$$

$$W \supset Y_u l_L N_R^c H_u + Y_d l_L e_R^c H_d + \frac{1}{2} f\, l_L \Delta_L l_L + \frac{1}{2} f\, l_R^c \Delta_R l_R^c$$

with : $\langle \Delta_R^0 \rangle = v_R \sim 10^{12}\text{–}10^{17}$ GeV, $\langle \Delta_L^0 \rangle = v_L = h \dfrac{v_2^2}{v_R}$

and we know Y_ν from the relations : $Y_\nu = Y_u$ and $Y_e = Y_d$

Mass Spectra

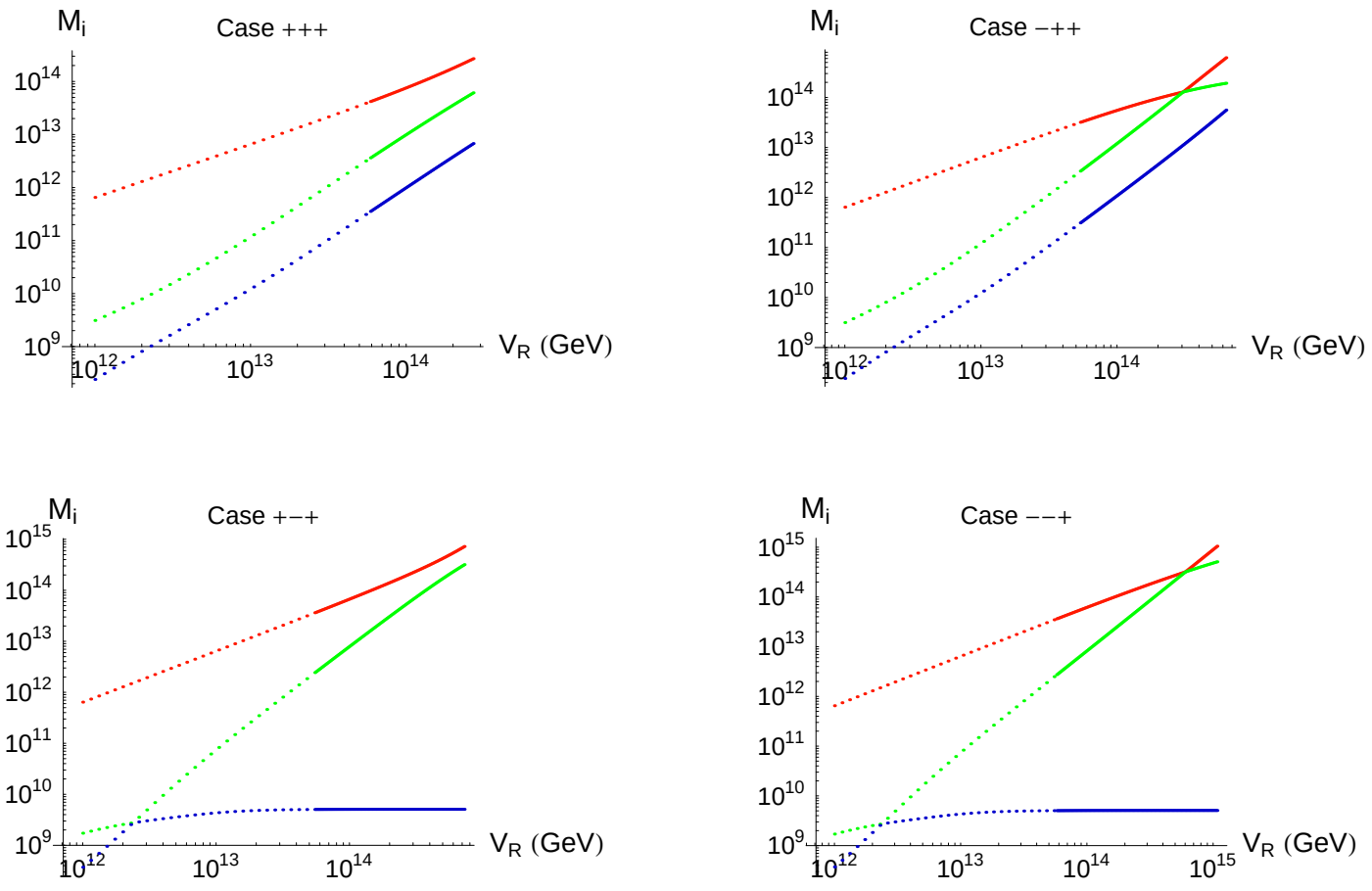

Figure: 4 different mass spectra of heavy neutrinos as function of v_R (dotted region is fine-tuned)

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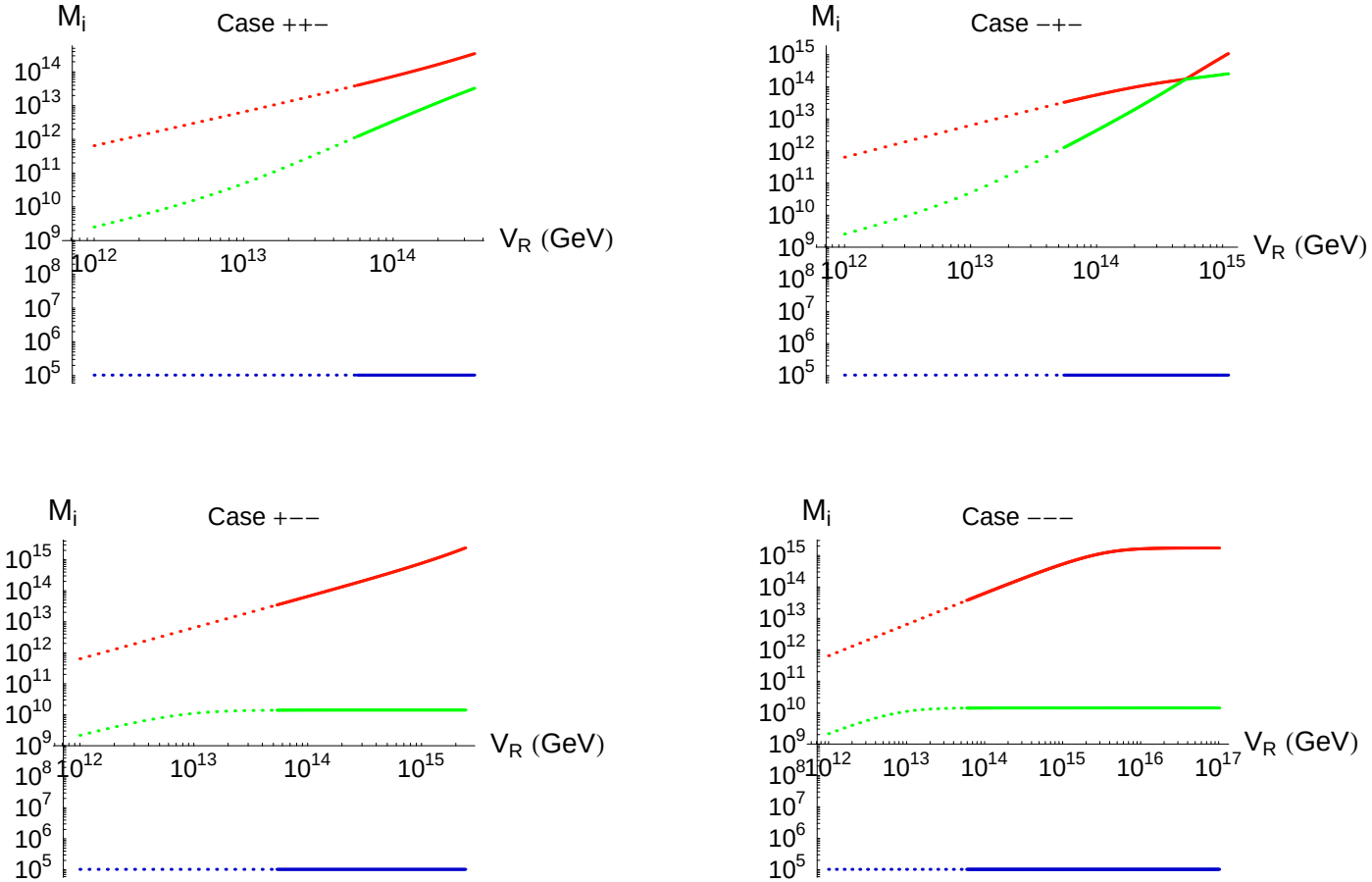

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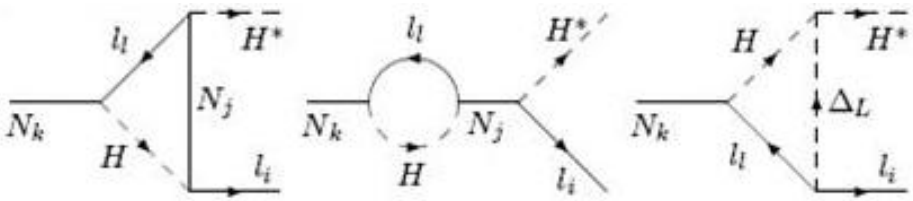
Leptogenesis

Having determined M_R we can check wether leptogenesis can accomodate a good baryon asymmetry of the universe.

Δ_L being always heavier than N_1 we consider only decays of the latter :



Using supersymmetric formulae (Hambye-Senjanovic,Antusch-King) :

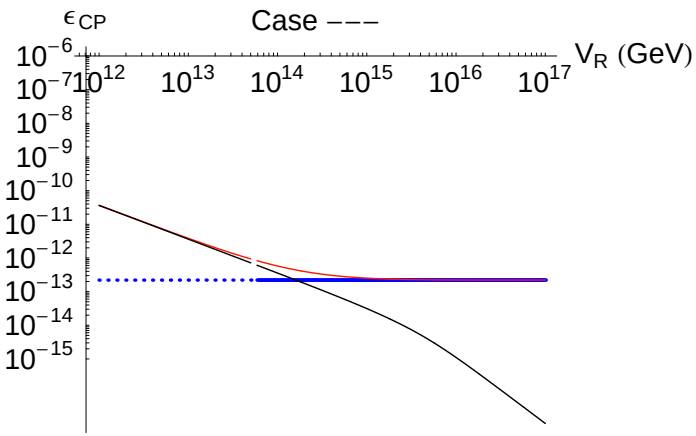
$$\varepsilon_{\mathrm{CP}} \simeq \frac{3}{8\pi} \frac{\mathrm{Im}[Y m_\nu^* Y^T]_{11}}{(YY^\dagger)_{11}} \frac{M_1}{v^2}$$

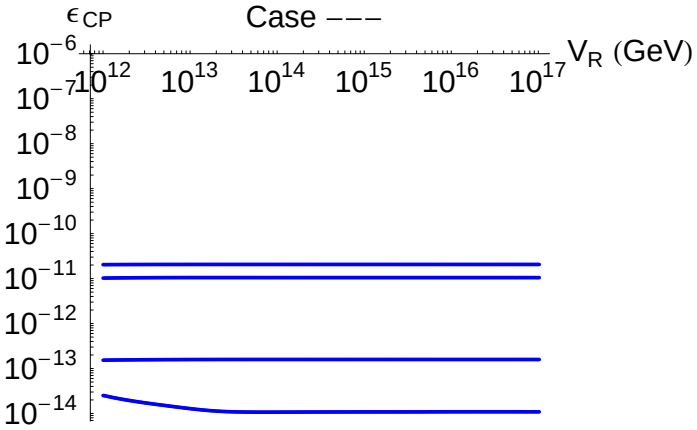
we will calculate $\varepsilon_{\mathrm{CP}}$ and try to find $\varepsilon_{\mathrm{CP}} \gtrsim 10^{-6}$ (we do not study washout effects in detail).

There are three generic behaviours :

Leptogenesis

Cases with $M_1 \sim 10^5$GeV :

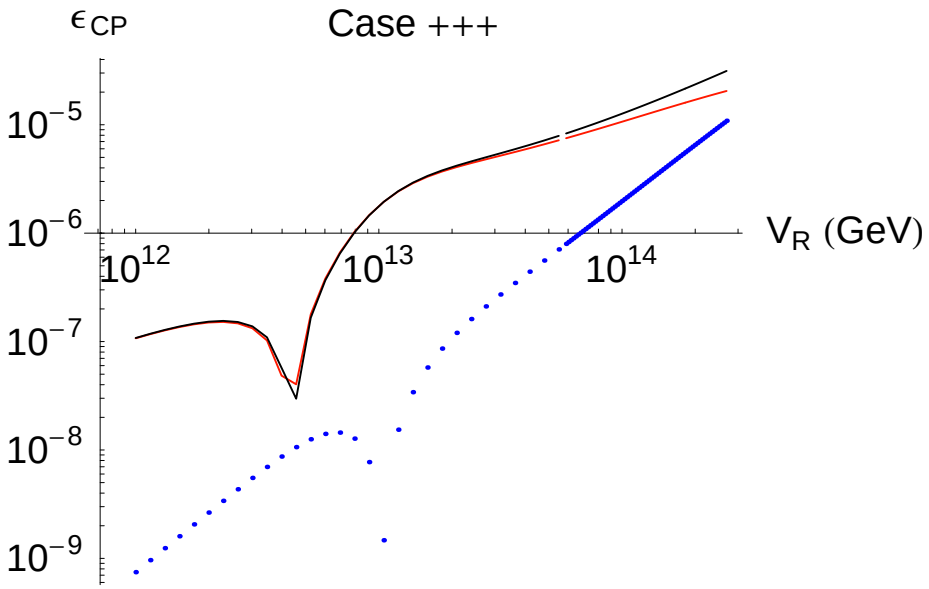




By the same reason why type I doesn't work in SO(10) (M_1 too small) leptogenesis doesn't work for these 4 cases, even including recently studied flavour effects (Vives).

Leptogenesis

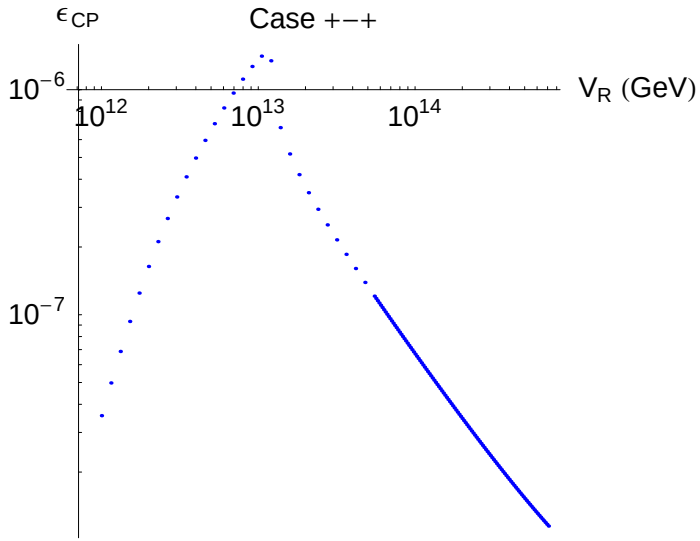
Cases with M_1 heavy ($\gtrsim 10^{10}$GeV) :

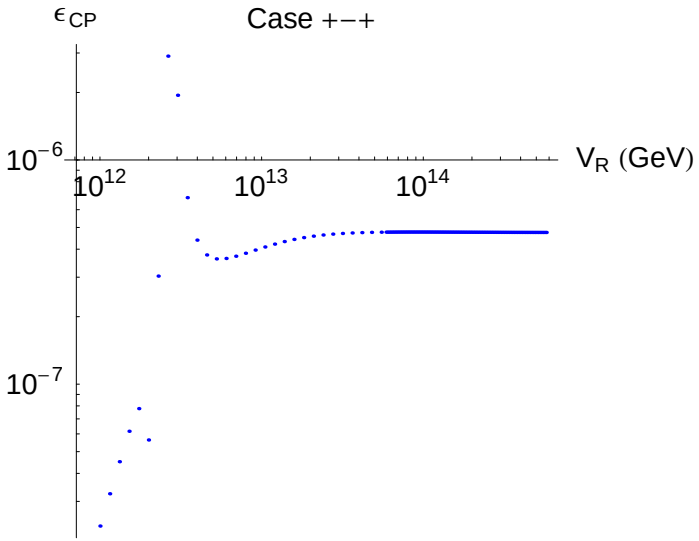


Leptogenesis easily accomodated, but often in the fine-tuned region.

Leptogenesis

Cases with $M_1 \sim$ few10^9GeV :





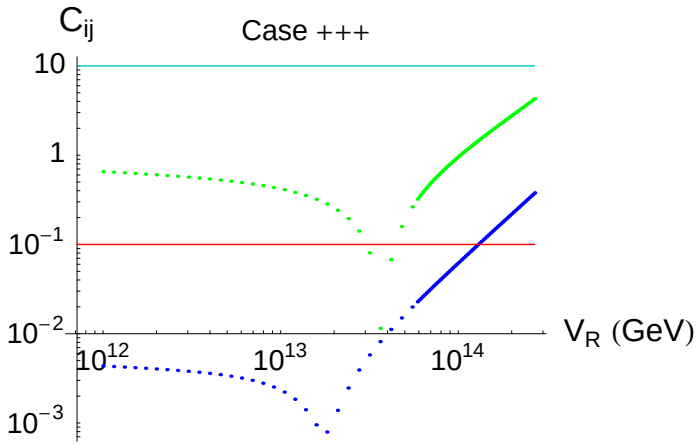
Cases allowed for some specific choices of the phases.

Lepton Flavour Violation

In addition we can study $\mu \to e\gamma$ and $\tau \to \mu\gamma$ processes (Borzumati, Masiero, Rossi) parametrised by the quantities :

$$C_{ij} = (Y^\dagger \ln(M_U/M_R) Y)_{ij} + 2(f^\dagger \ln(M_U/M_\Delta) f)_{ij}$$

$$BR(\mu \to e\gamma) < 1.2 \times 10^{-11} \quad \Rightarrow \quad |C_{e\mu}| < 0.1$$
$$BR(\tau \to \mu\gamma) < 6.8 \times 10^{-8} \quad \Rightarrow \quad |C_{\mu\tau}| < 10$$



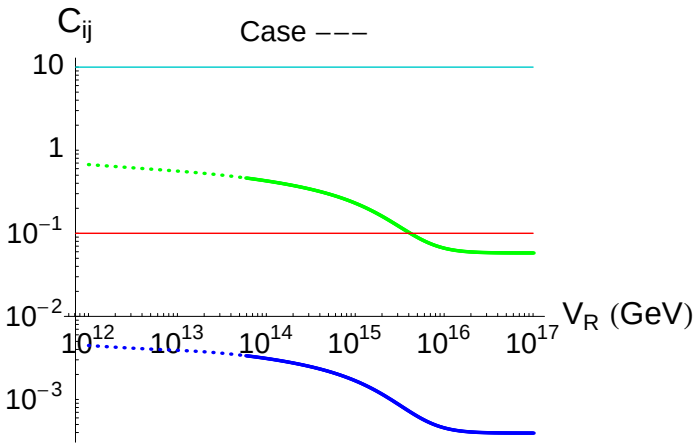


Figure: $\mu \to e\gamma$ (blue curve) and $\tau \to \mu\gamma$ (green curve) with present experimental limits (red and light blue)

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  $\Rightarrow$ It can point towards an embedding of SO(10) in an E_6 GUT where the 10_1, the $\overline{126}$ and the 54 are unified into the $351'$ dimensional representation, giving $f \propto Y_\nu$.

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- A realistic model of fermion masses requires contributions to the $\overline{126}$ to M_u, M_d and M_e, but we expect our results to be qualitatively the same.