

Leptons masses and the PMNS matrix in the minimal 3-3-1 model

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Abstract: We show how the mixing PMNS matrix in the charged current in the lepton sector arises in the minimal 3-3-1 model. The model implies necessarily flavour changing neutral currents but are appropriately suppressed by the parameters of the model.

The three lepton generations transform under the 3-3-1 symmetry as $\Psi_a = (v_a l_a l^c)^T \sim (1, 3, 0)$ and at this stage we do not introduce right-handed neutrinos. The scalar sector of the model is given by $\eta = (\eta^0, \eta^-, \eta^+)^T \sim (3, 0)$, $\rho = (\rho^+, \rho^0, \rho^{++})^T \sim (3, 1)$, $\chi = (\chi^-, \chi^{--}, \chi^0)^T \sim (3, -1)$ and a sextet:

$$S = \begin{pmatrix} \sigma^0 & \frac{h_2^+}{\sqrt{2}} & \frac{h^-}{\sqrt{2}} \\ \frac{h_2^+}{\sqrt{2}} & H^{++} & \frac{\sigma_2^0}{\sqrt{2}} \\ \frac{h^-}{\sqrt{2}} & \frac{\sigma_2^0}{\sqrt{2}} & H^{--} \end{pmatrix} \sim (1, \mathbf{6}, 0)$$

The Yukawa interactions in the lepton sector are:

$$-L_{YIH} = \epsilon_{ijk} \overline{(\Psi_{ia})^c} G_{ab}^{\eta} \Psi_{jb} \eta_k + \overline{(\Psi_{ia})^c} G_{ab}^S \Psi_{jb} S_{jk}^*$$

where a, b are generations indices, i, j, k are SU(3) indices, and G^{η} is an antisymmetric matrix and G^S symmetric ones. η is the same triplet which couples to quarks and S is the sextet, and it does not couple to quarks. Under $SU(2)_L \otimes U(1)_Y$ the sextet transform as $S = 1 + 2 + 3$, and we see that there is a doublet and a non-Hermitian triplet which gives mass to charged leptons and active left-handed neutrinos, respectively.

The mass matrices of the neutrinos and charge leptons, are:

$$M_{ab}^V = G_{ab}^S \frac{V_{\sigma 1}}{\sqrt{2}}, M_{ab}^l = G_{ab}^{\eta} \frac{V_{\eta}}{\sqrt{2}} + G_{ab}^S \frac{V_{\sigma 2}}{\sqrt{2}}$$

Notice that the matrix G^S appears in both mass matrices and in fact we can write

$$M_{ab}^l = G_{ab}^{\eta} \frac{V_{\eta}}{\sqrt{2}} + M_{ab}^V \frac{V_{\sigma 2}}{V_{\sigma 1}}$$

Without the contribution of the sextet the masses of charged leptons is $(0, m, -m)$ since $G\eta$ is an antisymmetric matrix. Moreover since $M^V/V_{\sigma 1} \sim O(1)$ we see that in order to have the correct masses either $V_{\sigma} \gg V_{\eta}$ or $G^{\eta} \ll G^S$. The first case is not interesting since V_{η} contribute to the quark masses we expect the opposite situation $V_{\eta} \gg V_{\sigma 2}$; and the second case implies a finetunning. Notice however, that if the interaction with η is avoided by the introduction of an appropriate discrete symmetry, it is still possible to give the appropriate mass to (Majorana) neutrinos and charged leptons, but it does not give the PMNS. We will consider two cases: i) $V_{\sigma 2} \approx 0$ and the sextet is heavy and generate an effective non-renormalizable interaction firs introduced: $(1/\Lambda)(\Psi_{ia})^c G^S \Psi_{jb} \chi_i^* \rho_j^*$ ii) We introduce right-handed neutrinos and the Yukawa interactions $\Psi_{aR} G^{\eta} v_{aR} \eta$ is now possible generating Dirac masses for neutrinos. In this case we have also the Majorana mass term for right-handed neutrinos $(v_{aR})^c M_{ab} v_{bR}$. We will assume, for the sake of simplicity, that M_R is diagonal, and $M^{-1} = (1/M) M^{-1}_R$ where $M^{-1} = \text{diag}(m_{R1}, m_{R2}, 1)$ and $M > m_{R1}, m_{R2}$.

The mass matrices are:

$$\begin{aligned} i) M_{ab}^V &= G_{ab}^S \frac{V_{\sigma 2}}{\sqrt{2}}, M_{ab}^l = G_{ab}^{\eta} \frac{V_{\eta}}{\sqrt{2}} + \frac{1}{\Lambda} \tilde{G}_{ab}^S v_{\rho} v_{\chi} \\ ii) M_{ab}^V &= -\frac{v_{\rho}^2}{2M} \tilde{G}_{ab}^S M_R^{-1} (\tilde{G}_{ab}^{\eta})^T, M_{ab}^l = G_{ab}^{\eta} \frac{V_{\eta}}{\sqrt{2}} + \frac{1}{\Lambda} \tilde{G}_{ab}^S v_{\rho} v_{\chi} \end{aligned}$$

for more details see arxiv:1406.xxxx

For the case i) we obtain:

$$U_L^r = \begin{pmatrix} -0.248 & -0.577 & 0.778 \\ 0.739 & -0.405 & 0.537 \\ -0.625 & -0.709 & 0.327 \end{pmatrix}; U_L' = \begin{pmatrix} -0.009 & 0.015 & -0.999 \\ -0.318 & -0.948 & -0.011 \\ 0.948 & -0.318 & -0.014 \end{pmatrix}; U_R^r = \begin{pmatrix} 0.005 & 0.007 & 0.999 \\ 0.003 & 0.991 & -0.007 \\ 0.999 & -0.003 & -0.005 \end{pmatrix}$$

$$|V_{PMNS}| = |(U_L')^T U_L^r| = \begin{pmatrix} 0.826 & 0.548 & 0.130 \\ 0.506 & 0.618 & 0.602 \\ 0.249 & 0.563 & 0.788 \end{pmatrix}$$

the interactions with the scalars are given by:

$$-L_{YIH} = \epsilon_{ijk} \overline{(\Psi_{ia})^c} G_{ab}^{\eta} \Psi_{jb} \eta_k + \overline{(\Psi_{ia})^c} G_{ab}^S \Psi_{jb} S_{jk}^* + \frac{1}{\Lambda} \overline{(\Psi_{ia})^c} \tilde{G}_{ab}^S \Psi_{jb} \chi_j \rho_k^*$$

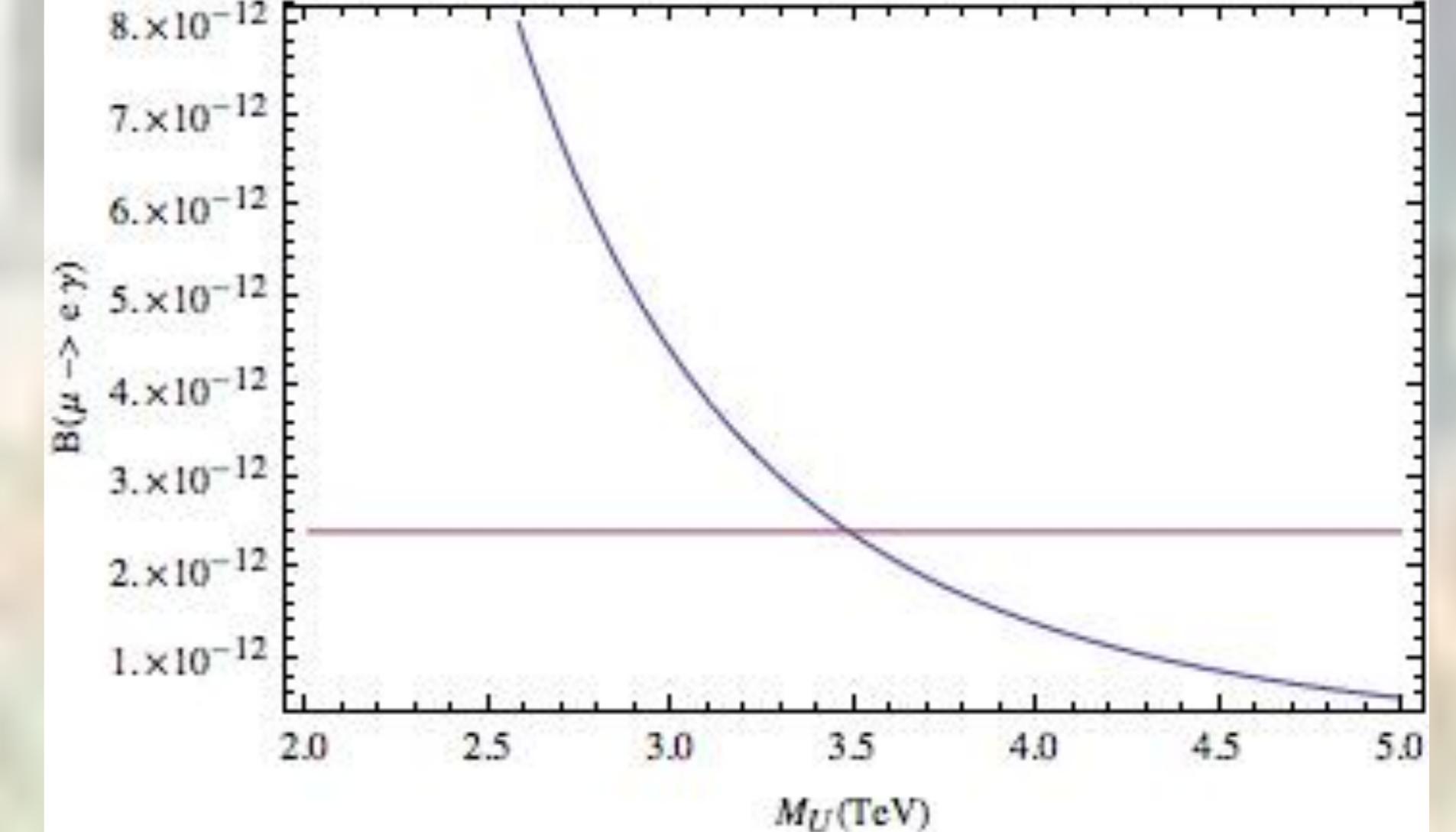
$$-L_{YIHC}^{NC} = \sum_{i,s=1,2,3} \overline{(v_{nl})^c} v_{nl} \frac{\sqrt{2} m_{\nu_s}}{v_{\sigma 1}} (U_{Si} h_i^0 - i V_{Si} A_i^0) + \sum_{i,l,r} \overline{l_L} U_L'^T \left\{ \left[G_{il}^n U_{nl} + \frac{v_{\chi}}{\Lambda} \tilde{G}_{ab}^S U_{nl} \right] h_i^0 + i \left[G_{il}^n V_{nl} + \frac{v_{\chi}}{\Lambda} \tilde{G}_{ab}^S V_{nl} \right] A_i^0 \right\} U_R^r l_R^r + H.c.$$

Using: $U_{\rho 1} = 0.42$ and $-0.2 \leq U_{\eta 1} \leq 0.2$

$$\text{We have: } U_R = \begin{pmatrix} -0.076 & -0.24 & -0.16 \\ -0.23 & -1.6 & 0.32 \\ -0.25 & -0.25 & -30 \end{pmatrix} \times 10^{-3}$$

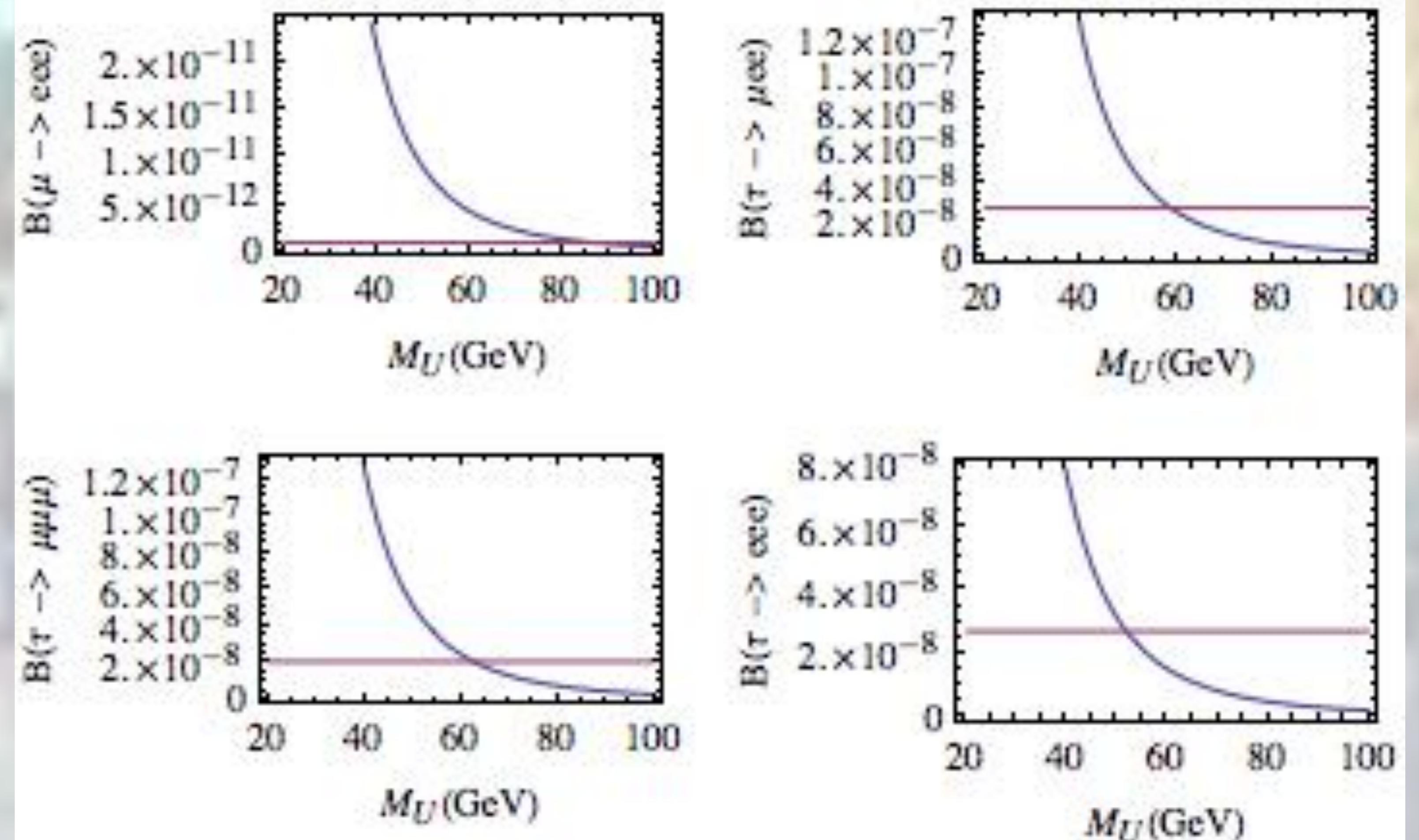
$$J_{U^{**}}^{\mu} = -\overline{e^c} \gamma^{\mu} \gamma_L [U_R^T U_L^r] e^r - -\overline{e^c} \gamma^{\mu} \gamma_L V_U e^r$$

$$B(\mu \rightarrow e\gamma) = \frac{54\alpha}{\pi} \left(\frac{M_w}{M_U} \right)^4 \left(\frac{M_\tau}{M_\mu} \right)^2 \left(|V_U^{13}|^2 |V_U^{32}|^2 + |V_U^{31}|^2 |V_U^{23}|^2 \right)$$



This decay do not impose restriction to the doubly charged vector boson

$$\Gamma(l_i^- \rightarrow l_j^+ l_k^- l_k^-) = \frac{g^4 m_i^5}{3 \times 2^{11} \pi^3 M_U^4} |V_{ik}^{**}|^2 (|V_U^0|^2 + |V_U^N|^2)$$



for case ii) it is possible obtain the same results in i) just adjusting the yukawas in the Equatiion ii).