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Lepton flavour violation and θ_{13}

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OUTLINE

- Introduction
- The framework: SUSY and see-saw
- Different parameterizations: a paradox
- Solution
- Conclusion

INTRODUCTION

Neutrino mixing is expressed in terms of the standard MNS parameterization

$$U = V \,.\, \mathrm{diag}(e^{i\Phi_1}, e^{i\Phi_2}, 1)$$

$$V = \begin{pmatrix} c_{13}c_{12} & c_{13}s_{12} & s_{13}e^{-i\delta} \\ -c_{23}s_{12} - s_{23}s_{13}c_{12}e^{i\delta} & c_{23}c_{12} - s_{23}s_{13}s_{12}e^{i\delta} & s_{23}c_{13} \\ s_{23}s_{12} - c_{23}s_{13}c_{12}e^{i\delta} & -s_{23}c_{12} - c_{23}s_{13}s_{12}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

- 3 angles + 3 phases
- θ_{13} is the less constraint angle: $0^\circ \leq \theta_{13} \lesssim 10^\circ$

framework: See-saw + SUSY

- See-saw: provides a natural mechanism to generate small masses

- SUSY: new sources for flavour mixing (sleptons) that are sensitive to the (high energy) details of neutrino mixing.

Borzumati, Masiero

SUSY + See-saw

At high energy:

$$W = W_0 - \frac{1}{2}\nu_R^c{}^T \mathcal{M} \nu_R^c + \nu_R^c{}^T \mathbf{Y}_\nu L \,.\, H_2$$

RGE's

Below the Majorana scale

$$W_{\rm eff} = W_0 + \frac{1}{2}(\mathbf{Y}_\nu L \,.\, H_2)^T \mathcal{M}^{-1} (\mathbf{Y}_\nu L \,.\, H_2)$$

RGE's

At the EW scale

$$\delta\mathcal{L} = -\frac{1}{2}\nu^T \mathcal{M}_\nu \nu + h.c.$$

$$\delta\mathcal{M}_\nu = \mathbf{Y}_\nu^T \mathcal{M}^{-1} \mathbf{Y}_\nu \left\langle H_2^0 \right\rangle^2$$

NOTICE: Since we are integrating out heavy degrees of freedom we cannot reconstruct the full lagrangian from "low energy" data

In particular, neutrino data only determine the matrix:

$$\kappa_\nu = \mathbf{Y}_\nu^T \mathcal{M}^{-1} \mathbf{Y}_\nu$$

that, when diagonalized, provides the neutrino masses and mixings:

$$U^T \kappa U = D_\kappa \equiv \mathrm{diag}(\kappa_1, \kappa_2, \kappa_3), \quad \kappa_i = m_{\nu_i} / \langle H_0^2 \rangle$$

Two different parameterizations can be adopted to describe Y_{ij}

Casas, Ibarra

$$\kappa = \mathbf{Y}^T \mathcal{M}^{-1} \mathbf{Y}$$

- R-parameterization

$$Y = D_{\sqrt{M}} R D_{\sqrt{\kappa}} U^\dagger$$

$R^T R = 1$ — 3 ang + 3 phases

$D_{\sqrt{M}} \equiv (\sqrt{M}_1, \sqrt{M}_2, \sqrt{M}_3)$ — 3 real

- V_L-parameterization

$$Y = V_R D_Y V_L^\dagger$$

V_L — 3 ang + 3 phases

$D_Y \equiv (y_1, y_2, y_3)$ — 3 real

V_R — fixed by ν-data (idem M_1, M_2, M_3)

Lepton flavour violation

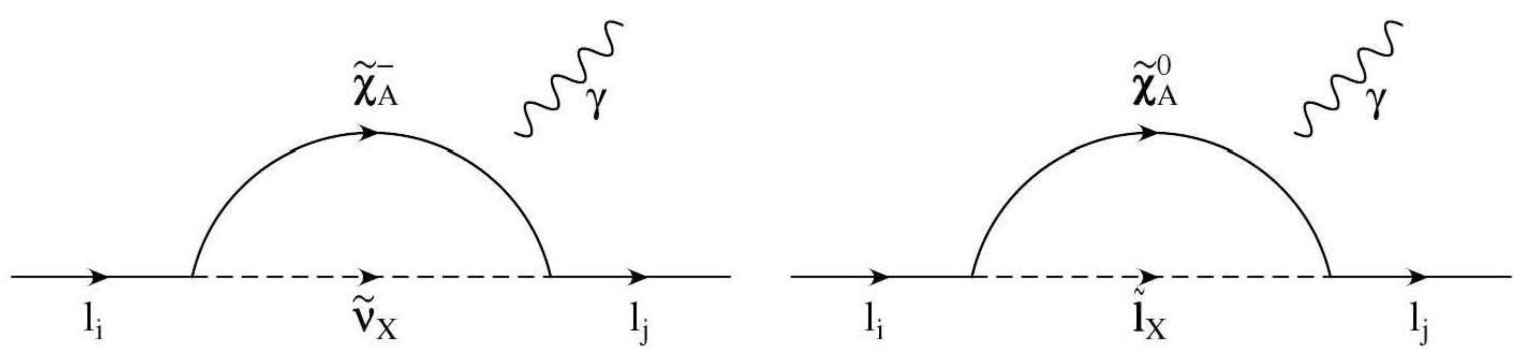
Borzumati, Masiero
....

Y_{ij} generate non-diagonal slepton entries:

$$(m^2_{\tilde{L}})_{ij} \simeq -\frac{3m_0^2 + A_0^2}{8\pi^2} \, Y_{ik} Y^*_{jk} \, \ln\left(\frac{M_X}{M_k}\right)$$

RGE's

that trigger lepton flavour violation processes $l_i \to l_j \, \gamma$

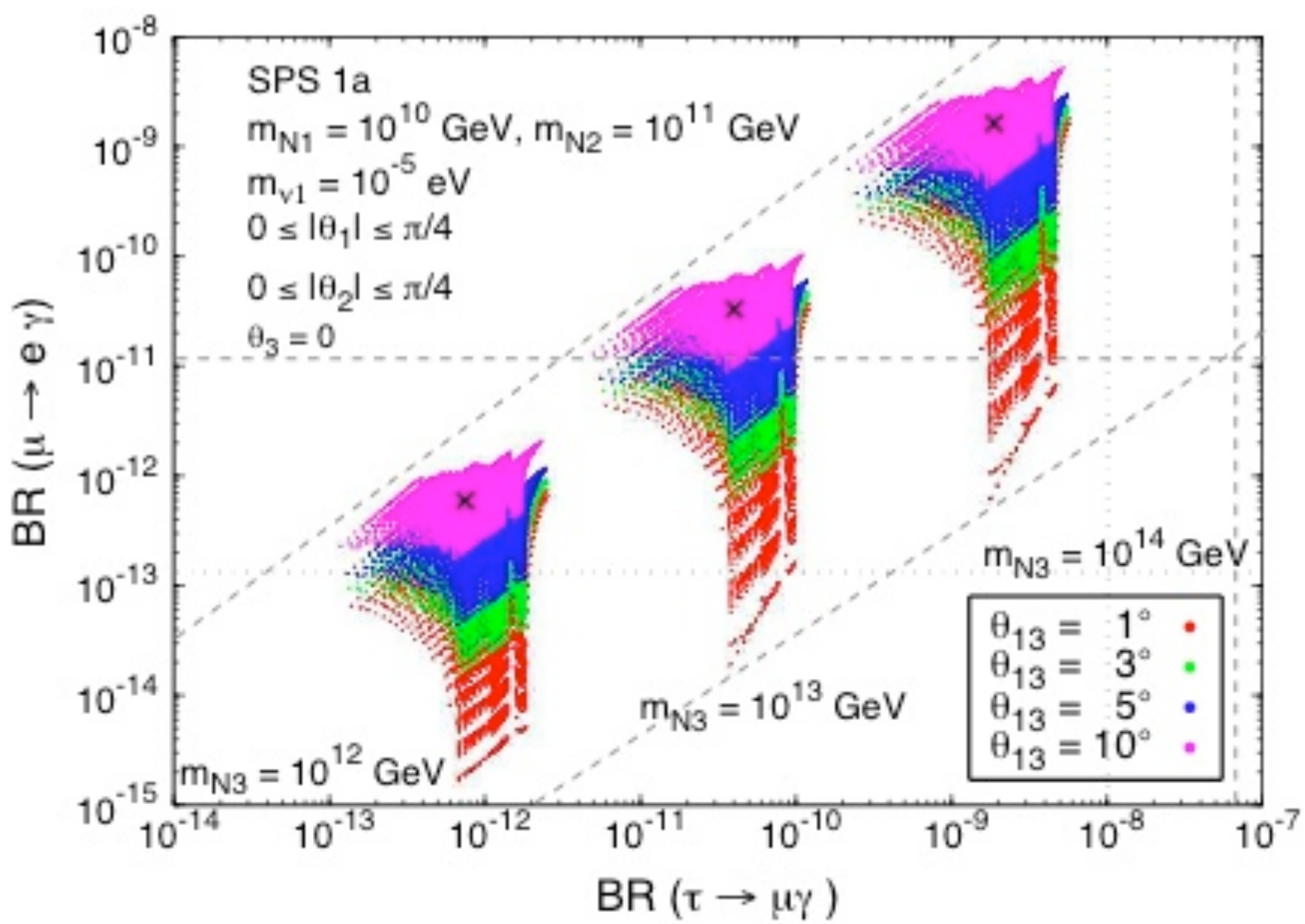


Notice, e.g.

$$BR(\mu \to e\gamma) \sim |(Y^\dagger Y)_{12}|^2$$

APROX

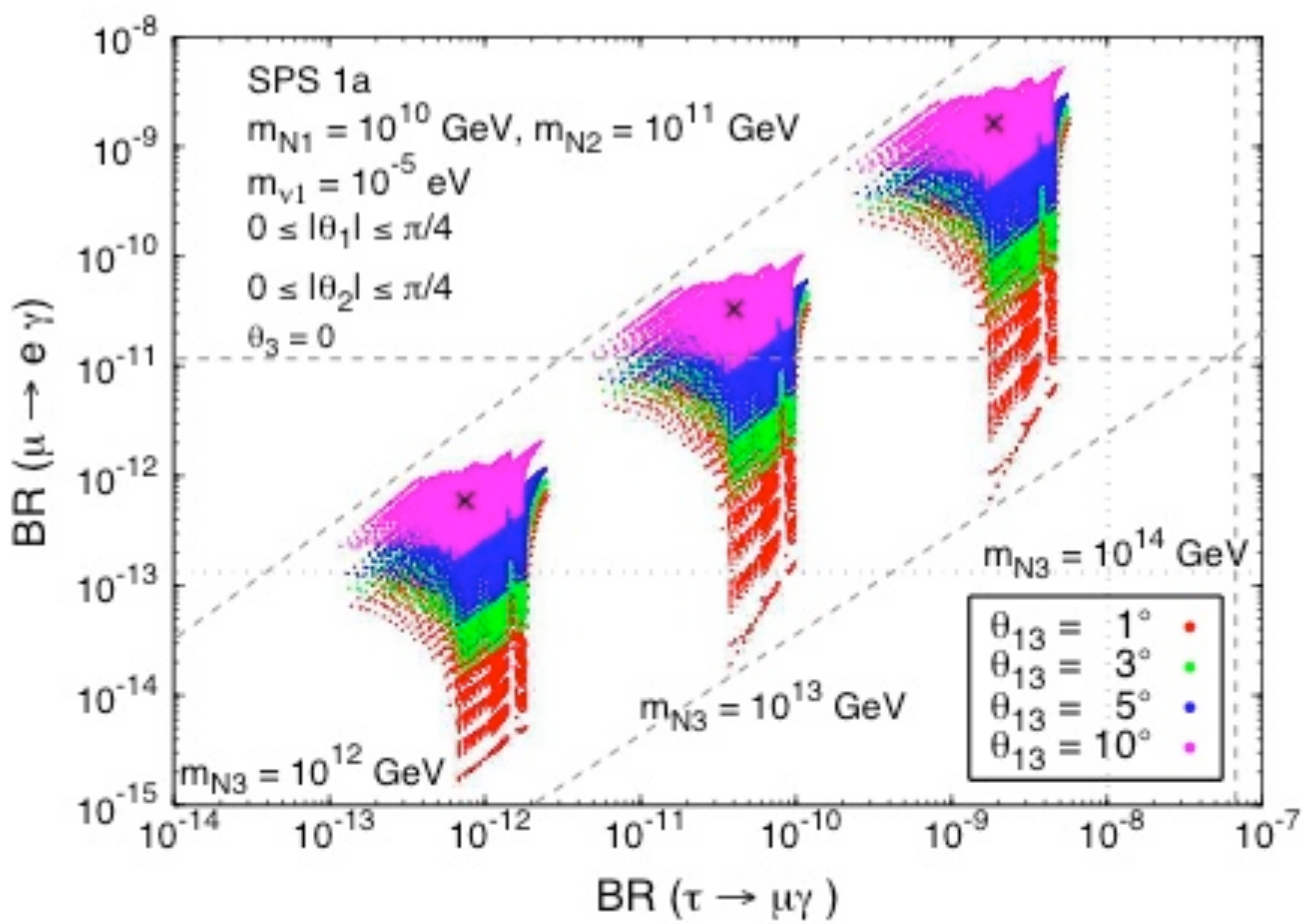
Dependence of BR(μ→eγ) on Θ_{13}



Antusch Arganda, Herrero, Teixeira

Correlation between BR(μ→eγ) and BR(τ→μγ) as a function the mass m_{N3} of the heaviest right handed neutrino (SPS1a) Scan over the R-matrix angles θi.

Dependence of BR(μ→eγ) on Θ13



Antusch Arganda, Herrero, Teixeira

Correlation between BR($\mu \to e\gamma$) and BR($\tau \to \mu\gamma$) as a function the mass m_{N3} of the heaviest right handed neutrino (SPS1a) Scan over the R-matrix angles θi.

BUT .....

A PARADOX

- V_L-parameterization

$$Y = V_R D_Y V_L^\dagger$$

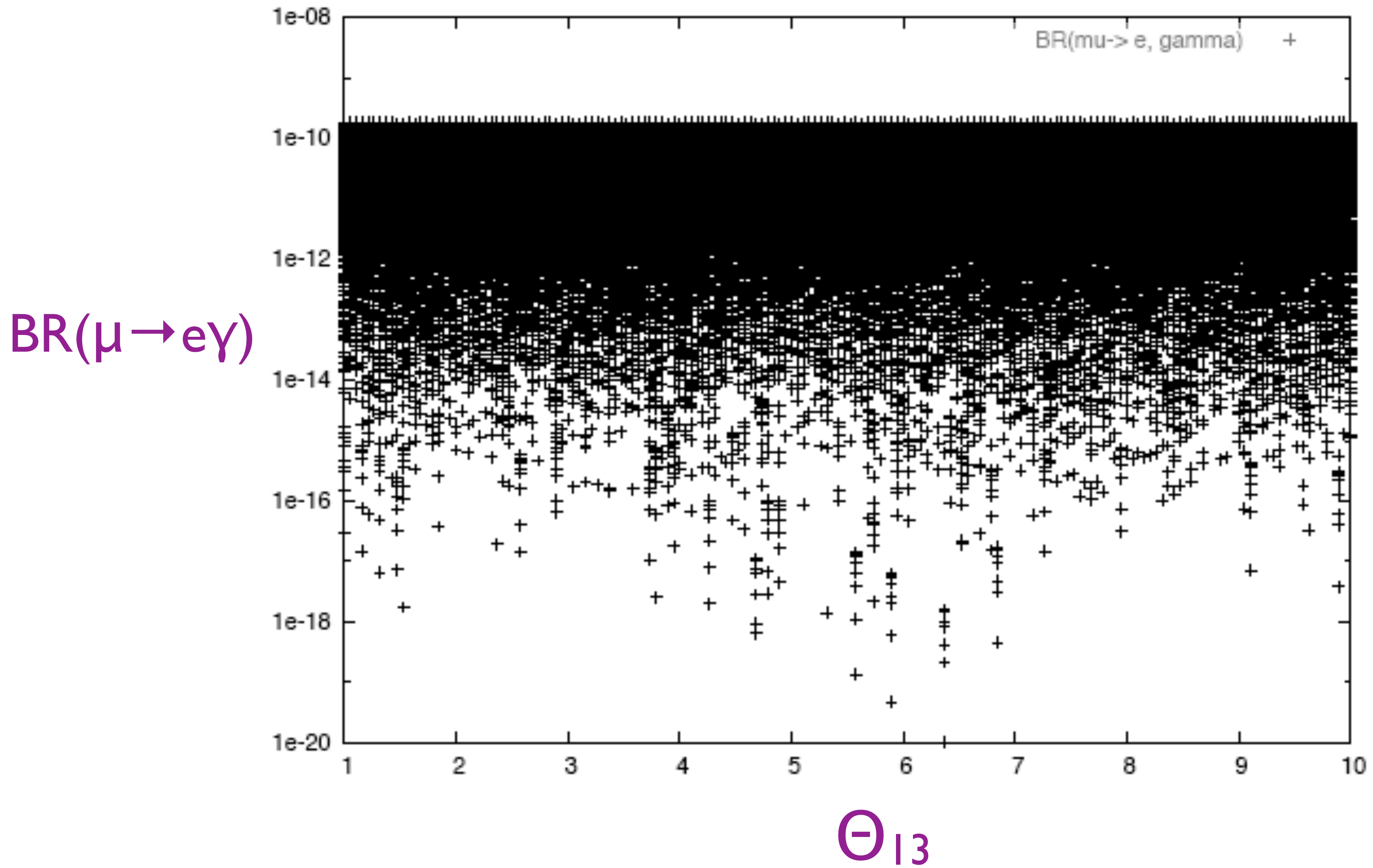
$$(Y^\dagger Y)_{12} = (V_L D_Y^2 V_L^\dagger)_{12}$$

does not depend on U !!

(and then neither on s_{13})

A numerical test:

- V_L-parameterization



Scatter plot for BR($\mu \to e\gamma$) as a function of the MNS angle Θ_{13} The scan is made over the angles of V_L ,in the full region. The phases of MNS and V_L have been fixed to zero. For the matrix MNS, Θ_{12} =30°, Θ_{12} =45°. We have considered the SPS-1a.

Let us revise the dependence of $BR(\mu \to e\gamma)$ on Θ_{13} in the R-parameterization

✷ R-parameterization

Let us try to analyze the BR(μ→eγ) dependence on the MNS angle Θ_{13}

$$Y = D_{\sqrt{M}}\, R\, D_{\sqrt{\kappa}} U^\dagger$$
$$(Y^\dagger Y)_{12} = (U D_{\sqrt{\kappa}} R^\dagger D_M R D_{\sqrt{\kappa}} U^\dagger)_{12}$$

$$= U_{13}\sqrt{\kappa}_3 \left[R^\dagger D_M R\right]_{33} \sqrt{\kappa}_3 U^*_{23} + U_{12}\sqrt{\kappa}_2 \left[R^\dagger D_M R\right]_{23} \sqrt{\kappa}_3 U^*_{23} + \ldots$$

assuming hierarchical neutrinos ($\kappa_3 > \kappa_{2,1}$) and "democratic" R entries

$$\left[R^\dagger D_M R\right]_{33} \sim \left[R^\dagger D_M R\right]_{23} \sim \ldots$$

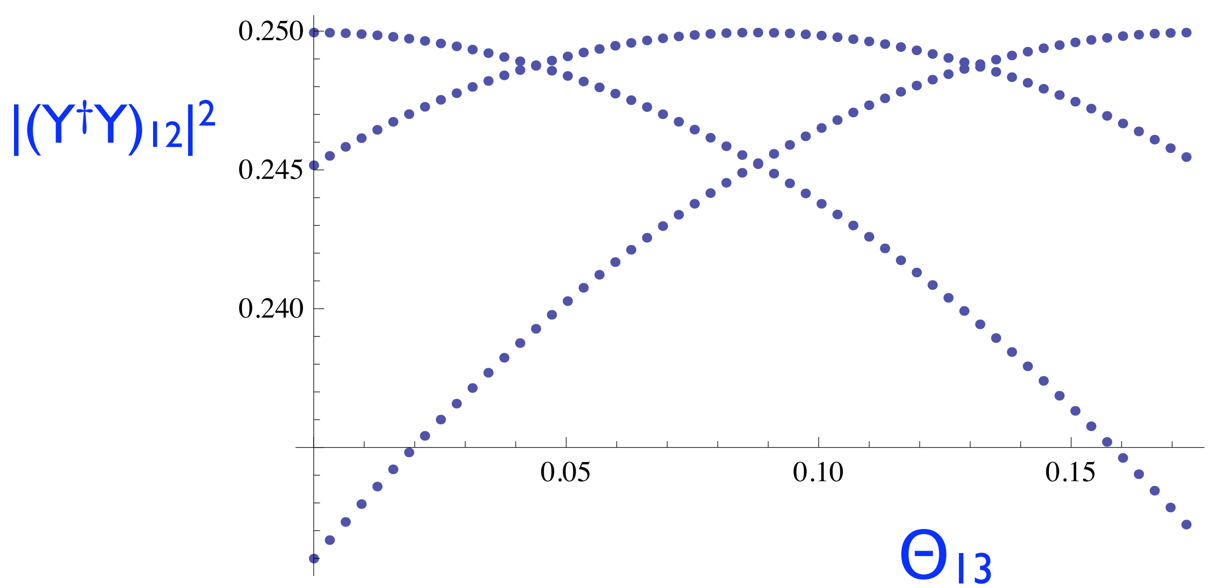
one concludes

$$(Y^\dagger Y)_{12} \propto s_{13}$$

Is this also valid for generic R-matrices ?

An exhaustive numerical analysis shows:

- $BR(\mu \to e\gamma)$ as a function of Θ_{13} shows <u>different profiles</u> depending on the particular R matrix chosen value.



- This suggest that the influence of Θ_{13} on $BR(\mu \to e\gamma)$ depends crucially on the explored subset of R-matrices

Is there any physical constraint on R?

YES

PERTURBATIVITY of Yukawa couplings

A criterion:

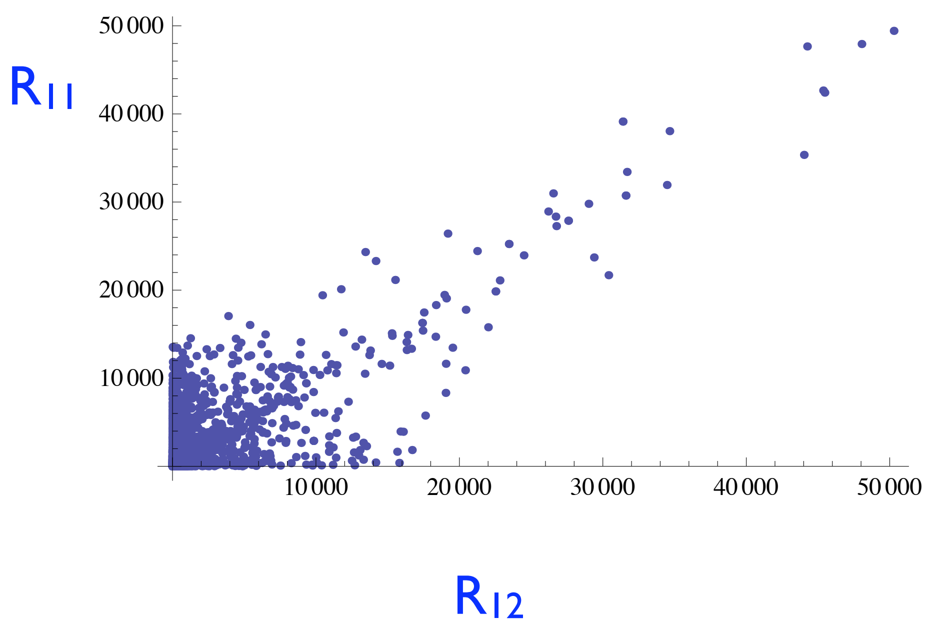
$$Tr(Y^\dagger Y) \lesssim 3 \qquad Y^\dagger Y = U D_{\sqrt{\kappa}} R^\dagger D_{\mathcal{M}} R D_{\sqrt{\kappa}} U^\dagger$$

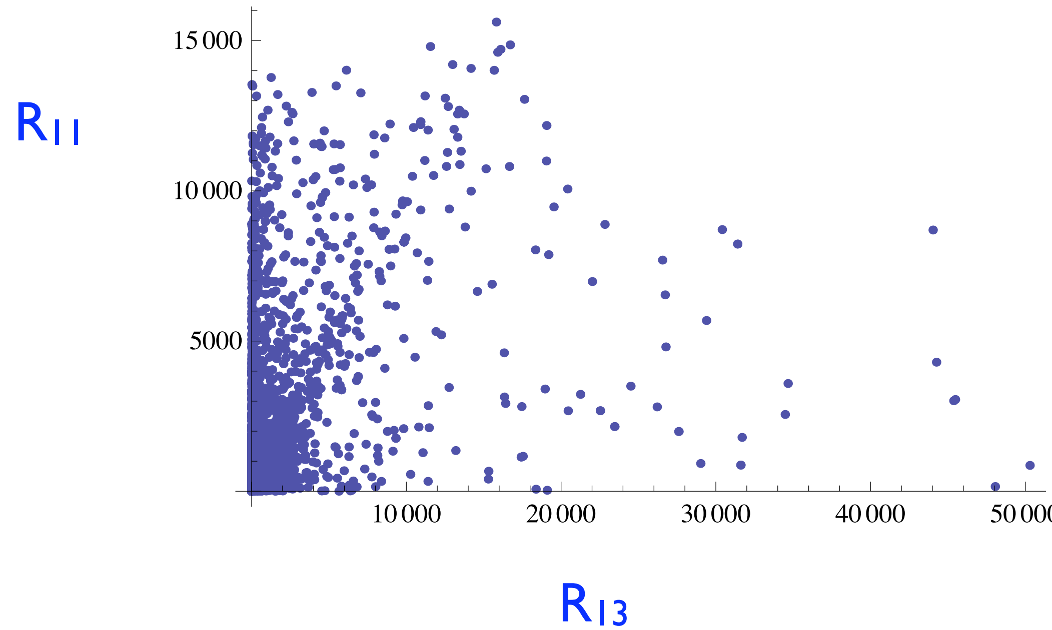
The U dependence cancels:

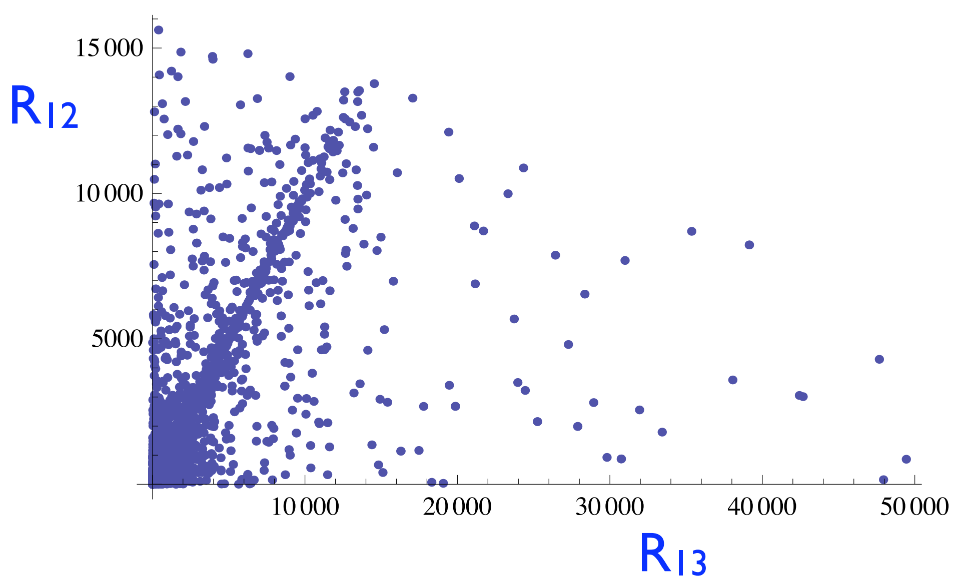
$$\sum_{j=1,2,3} \kappa_j \left[R^\dagger D_M R\right]_{jj} \lesssim 3 \qquad \Rightarrow \qquad |R_{ij}|^2 \lesssim \frac{1}{M_i \kappa_j}$$

R entries ARE NOT DEMOCRATIC:
different perturbativity bounds apply to different R entries

✷ Scan of R matrices







REMEMBER

$$Y = D_{\sqrt{M}}\, R\, D_{\sqrt{\kappa}} U^\dagger$$

$$(Y^\dagger Y)_{12} = (U D_{\sqrt{\kappa}} R^\dagger D_M R D_{\sqrt{\kappa}} U^\dagger)_{12}$$

$$= U_{13}\sqrt{\kappa}_3 \left[R^\dagger D_M R\right]_{33} \sqrt{\kappa}_3 U_{23}^* + U_{12}\sqrt{\kappa}_2 \left[R^\dagger D_M R\right]_{23} \sqrt{\kappa}_3 U_{23}^* + \ldots$$

assuming hierarchical neutrinos ($\kappa_3 > \kappa_{2,1}$) and "democratic" R entries

$$\left[R^\dagger D_M R\right]_{33} \sim \left[R^\dagger D_M R\right]_{23} \sim \ldots$$

one concludes

$$(Y^\dagger Y)_{12} \propto s_{13}$$

.... BUT

$$Y = D_{\sqrt{M}} \, R \, D_{\sqrt{\kappa}} U^\dagger$$

$$(Y^\dagger Y)_{12} = (U D_{\sqrt{\kappa}} R^\dagger D_M R D_{\sqrt{\kappa}} U^\dagger)_{12}$$

$$= U_{13}\sqrt{\kappa}_3 \left[R^\dagger D_M R\right]_{33} \sqrt{\kappa}_3 U^*_{23} + U_{12}\sqrt{\kappa}_2 \left[R^\dagger D_M R\right]_{23} \sqrt{\kappa}_3 U^*_{23} + \ldots$$

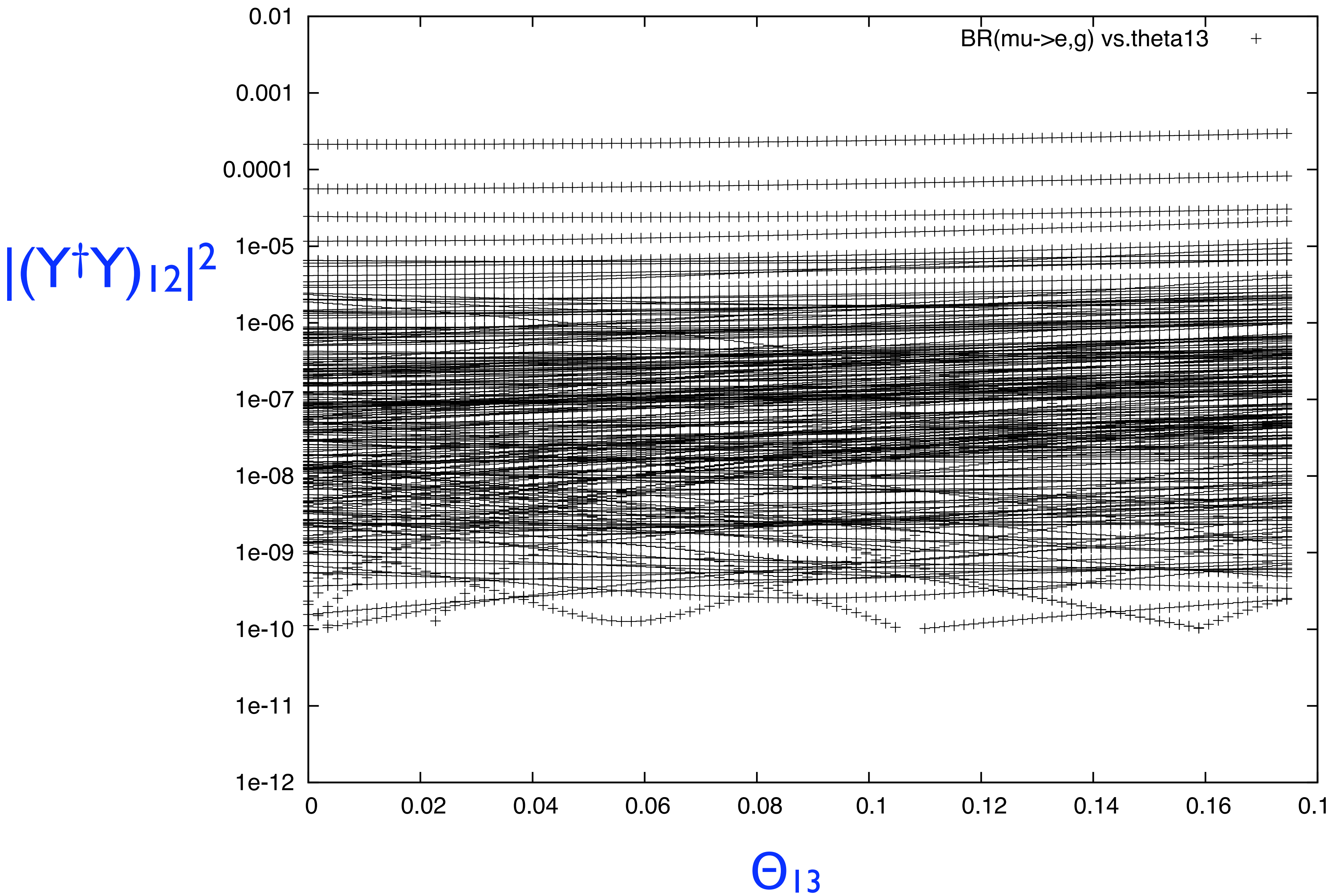
assuming hierarchical neutrinos ($\kappa_3 > \kappa_{2,1}$) and "~~democratic~~" R entries

$$\left[R^\dagger D_M R\right]_{33} \not\sim \left[R^\dagger D_M R\right]_{23} \not\sim \ldots$$

⇒ The dependence on Θ_{13} is much softer !!!

Besides on can consider additional physical requirements : Leptogenesis

PERTURBATIVITY + LEPTOGENESIS



Scatter plot (scanning R, M= (10^{10}, 10^{11}, 10^{12}) GeV) imposing consistent values for unflavored leptogenesis.

CONCLUSION

- Results in the literature on the BR($\mu \to e\gamma$) show a strong dependence on the MNS angle Θ_{13}

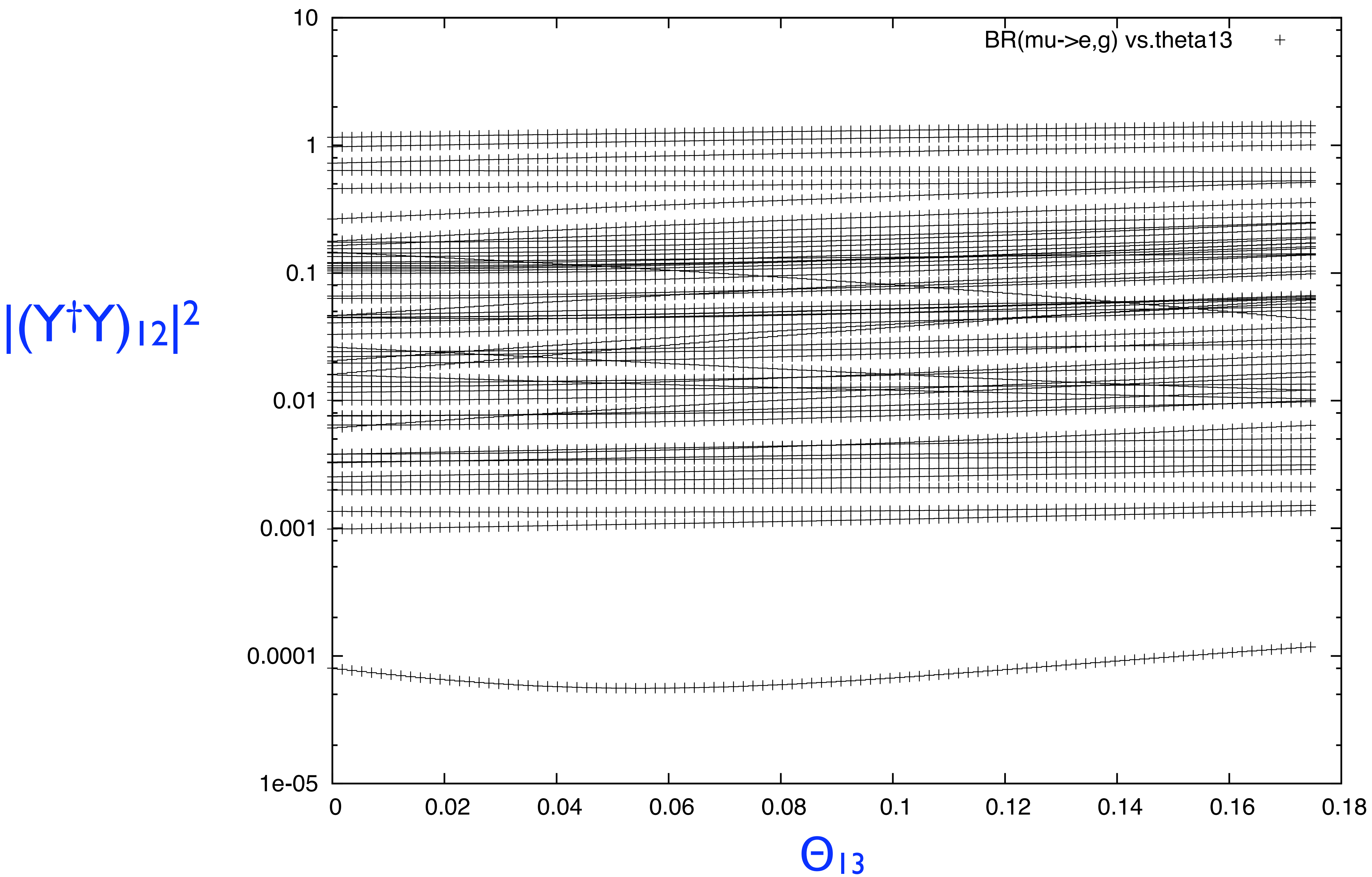
- These studies indirectly assume a particular subset of R-matrices (democratic)

- We have performed a detailed, analytical and numerical, analysis of BR($\mu \to e\gamma$) varying R in the full range allowed by physical constraints:

  - perturbativity of yukawa couplings
  - leptogenesis

- The dependence of BR($\mu \to e\gamma$) on Θ_{13} is much softer than claimed in the literature

PERTURBATIVITY + flavoured LEPTOGENESIS



Scatter plot (scanning R, M= (10^{10}, 10^{11}, 10^{12}) GeV) imposing consistent values for flavored leptogenesis.