LFV and θ_{13} in SUSY Seesaw

Workshop 'Flavour in the Era of the LHC'

Talk by Stefan Antusch
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new results are work in progress with:
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María J. Herrero,
Ana M. Teixeira

CERN, May 2006

Motivation: LFV in SUSY Seesaw

even with high energy (M_{GUT}):

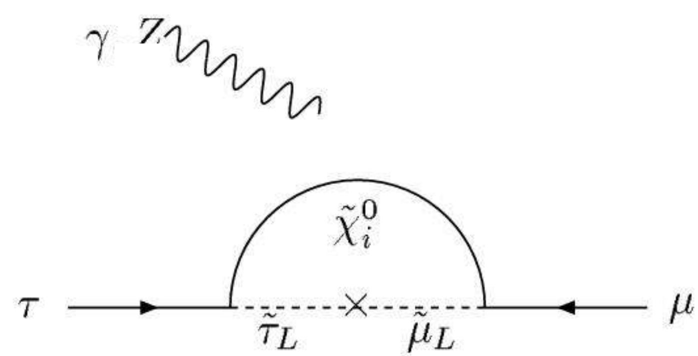
CMSSM + Seesaw

RG Running (Y_ν-effects)

in SUSY Seesaw scenario

non-diagonal

Slepton Mass Matrices



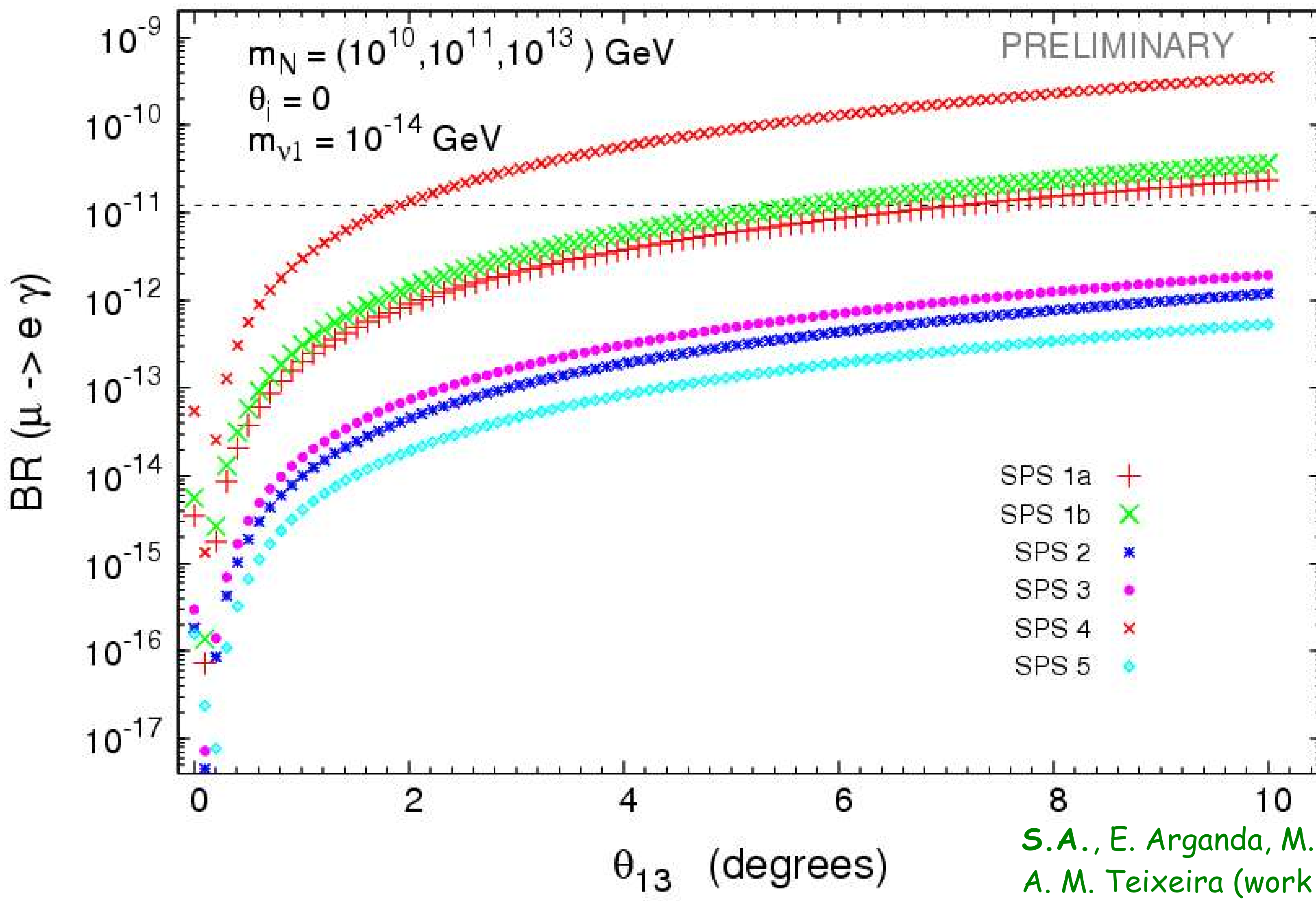
⇒ LFV decays

rates depend on neutrino parameters: Learn about SUSY / Seesaw

Motivation: Br ($\mu \to e \gamma$) and θ_{13} in an Example (R = 1)

CMSSM + Seesaw:

observed in E. Arganda, M. J. Herrero ('05)



S.A., E. Arganda, M. J. Herrero, A. M. Teixeira (work in preperation)

This study: Relation between θ_{13} and LFV decay rates

Content

Introduction

- Seesaw mechanism and parameterizing solutions to the seesaw equation
- LFV in our framework: CMSSM + Seesaw

LFV and the impact of θ_{13} (and other relevant parameters)

- The case of 'R = 1' (neutrino model type: 'heavy sequential dominance')
- Constraints from thermal leptogenesis and gravitinos (non-thermal LSP prod.)
- Discussion of the sensitivity to θ_{13} (and other relevant parameters)

Summary and Conclusions

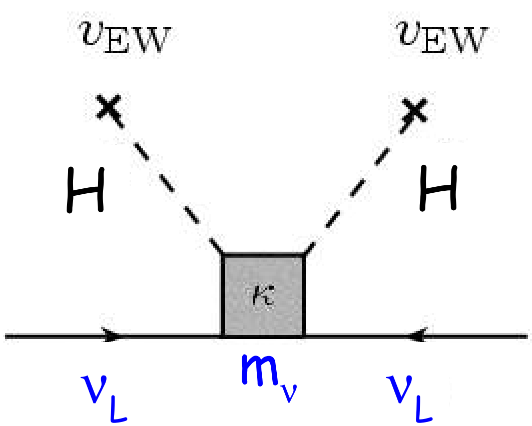
- main point: in the Seesaw parameter space favoured by thermal LG and gravitino problem (non-thermal LSP prod.): strong impact of θ_{13} on Br ($\mu \to e\,\gamma$)

The See-Saw Mechanism

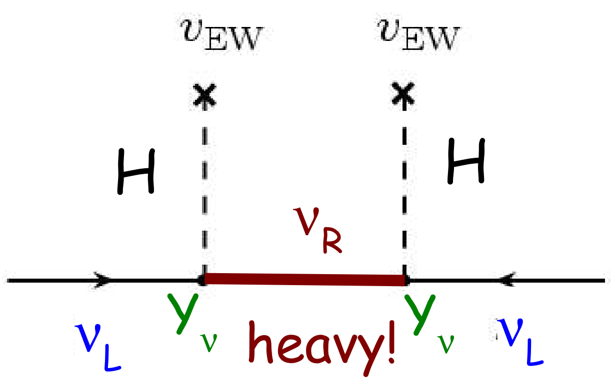
Small neutrino masses
from heavy ν_R!

close to the GUT scale (~ 10^{16} GeV)

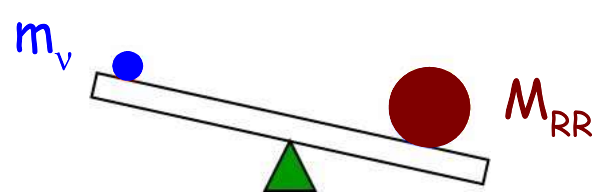
$m_\nu \sim v_u^2/M_{RR}$



Majorana masses



See-saw (type I)



Seesaw equation (type I):

$$m_\nu = -v_u^2 \, Y_\nu \, M_{RR}^{-1} \, Y_\nu^T$$

P. Minkowski (1977), Gell-Mann, Glashow, Mohapatra,
Ramond, Senjanovic, Slanski, Yanagida (1979/1980)

Solving the Seesaw Equation for Y_ν, M_{RR}: The R Matrix

Casas, Ibarra ('01)

Seesaw Equation: $$\boxed{m_\nu = -v_{\mathrm{u}}^2 \, Y_\nu \, M_{\mathrm{RR}}^{-1} \, Y_\nu^T}$$

low Energy:
12 parameters

high Energy:
21 parameters (lepton sector)

Find: $m_{\mathrm{D}} = v_{\mathrm{u}} Y_\nu$ for $(M_{\mathrm{RR}})_{ij} = (M_{\mathrm{RR}})_{ij}^{\mathrm{diag}}$, $Y_{\mathrm{e}} = Y_{\mathrm{e}}^{\mathrm{diag}}$

Solution: $$\boxed{m_{\mathrm{D}}^T = i\sqrt{M_{\mathrm{RR}}^{\mathrm{diag}}}\, R \sqrt{m_\nu^{\mathrm{diag}}}\, U_{\mathrm{MNS}}^\dagger}$$

where: $R = R^T$ (R orthogonal, complex)

$$R = \begin{pmatrix} c_2 c_3 & -c_1 s_3 - s_1 s_2 c_3 & s_1 s_3 - c_1 s_2 c_3 \\ c_2 s_3 & c_1 c_3 - s_1 s_2 s_3 & -s_1 c_3 - c_1 s_2 s_3 \\ s_2 & s_1 c_2 & c_1 c_2 \end{pmatrix}$$

with: $c_i = \cos\theta_i$, $s_i = \sin\theta_i$, $\theta_{1,2,3}$ complex

Low Energy Parameters in the Lepton Sector

Charged EW current: $\overline{e'_{\rm L}}^f \gamma^\mu \nu'^f_{\rm L} W^-_\mu \;\stackrel{!}{=}\; \overline{e_{\rm L}}^f \gamma^\mu U_{MNS}\, \nu^f_{\rm L} W^-_\mu \;\Rightarrow\; \boxed{U_{\rm MNS} = U_{e_{\rm L}} U^\dagger_{\nu_{\rm L}}}$

$$U_{MNS} = \mathrm{diag}(e^{i\delta_1}, e^{i\delta_2}, e^{i\delta_3}) \cdot U \cdot \mathrm{diag}(e^{i\frac{\varphi_1}{2}}, e^{i\frac{\varphi_2}{2}}, 1)$$

Lepton nixing matrix

$\theta_{12} \approx 30°$

$\theta_{23} \approx 45°$

$\theta_{13} < 13°$

atm. mass squared diff.: $\approx 2.5 \cdot 10^{-3}$ eV^2

solar mass squared diff.: $\approx 6.4 \cdot 10^{-5}$ eV^2

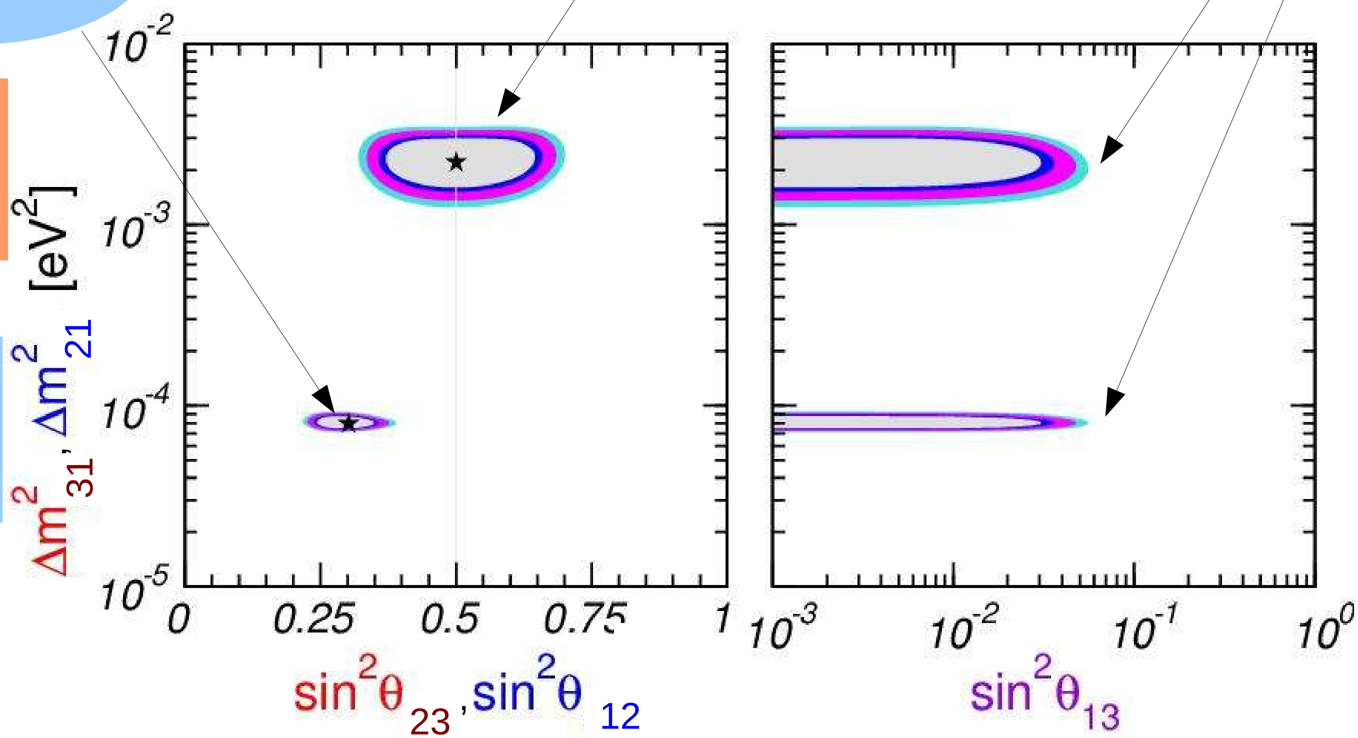


figure from: Maltoni, Schwetz, Tortola, Valle ('04)

Unknown:

- ν mass scale and mass scheme
- CP phases, value of θ_{13}, ...

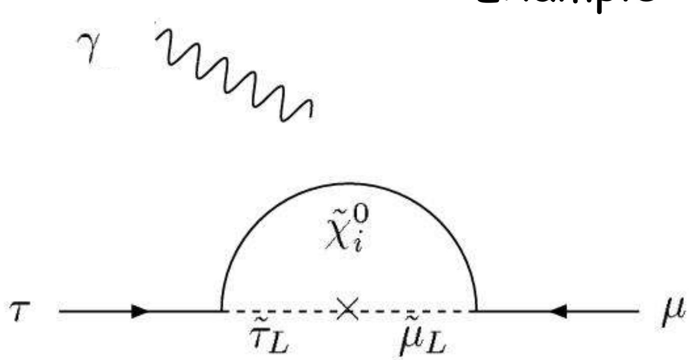
Lepton Flavour Violation (LFV)

Restrictive experimental bounds:

SM prediction: tiny (unobservable)

$$
\begin{aligned}
BR(\tau^- \to \mu^-\mu^-\mu^+) &< 1.9 \times 10^{-7} \quad \text{(BaBar 05)}\\
BR(\tau^- \to e^-e^-e^+) &< 2.0 \times 10^{-7} \quad \text{(BaBar 05)}\\
BR(\mu^- \to e^-e^-e^+) &< 1.0 \times 10^{-12} \quad \text{(SINDRUM 88)}\\
BR(\tau \to \mu\gamma) &< 6.8 \times 10^{-8} \quad \text{(BaBar 05)}\\
BR(\tau \to e\gamma) &< 1.1 \times 10^{-7} \quad \text{(BaBar 05)}\\
BR(\mu \to e\gamma) &< 1.2 \times 10^{-11} \quad \text{(MEGA 99)}
\end{aligned}
$$

Example:



LFV in SUSY See-Saw:

RG effects from neutrino Yukawa couplings induce Lepton Flavour Violating decays even for universal soft SUSY-breaking parameters at high energy (CMSSM).

Input Patrameters: CMSSM + See-Saw

CMSSM $+3\nu_R + 3\tilde{\nu}_R +$ seesaw

- MSSM with universal parameters at $M_X \sim M_{GUT} \sim 2 \times 10^{16}\, GeV$

$$\left\{ \begin{array}{l} M_0 = \text{universal scalar mass} \\ M_{1/2} = \text{universal gaugino mass} \\ A_0 = \text{universal trilinear coupling} \\ \tan\beta =< H_2 > / < H_1 > \text{ (at EW scale)} \\ \text{sign}(\mu) \ (\mu \text{ derived from EW breaking}) \end{array} \right\}$$

CMSSM parameters

- Seesaw parameters m_D (or Y_ν), m_M derived from $\left\{ \begin{array}{l} m_{\nu_{1,2,3}} \text{ (set by data)} \\ m_{N_{1,2,3}} \\ U_{MNS} \text{ (set by data)} \\ R(\theta_1, \theta_2, \theta_3) \end{array} \right.$

- For numerical estimates (examples: SPS points)

$$(\Delta m^2)_{12} = \Delta m^2_{sol} = 6.4 \times 10^{-5}\ \text{eV}^2$$
$$(\Delta m^2)_{23} = \Delta m^2_{atm} = 2.5 \times 10^{-3}\text{eV}^2$$
$$\theta_{12} = 30^o;\ \theta_{23} = 45^o;\ \delta = \alpha = \beta = 0$$

We study sensitivity to $0 < \theta_{13} < 10^o$

- We require: BAU $\in [10^{-9}, 10^{-10}]$ (via thermal leptogenesis)
  $\text{EDM}_{e\mu\tau} \lesssim (6.9 \times 10^{-28}, 3.7 \times 10^{-19}, 0.45 \times 10^{-16})$ e.cm
  $T_{RH} < 2\ 10^{10}$ GeV (Gravitino $\rightarrow$ nonthermal LSP prod., $m_{LSP} \sim 100$ GeV)

Minimal LFV in SUSY See-Saw

- misalignment slepton-lepton: generated by RGE-running and due to Y_ν

In the $(\tilde{e}_L, \tilde{e}_R, \tilde{\mu}_L, \tilde{\mu}_R, \tilde{\tau}_L, \tilde{\tau}_R)$ basis:

$$M_{\tilde{l}}^2 = \begin{pmatrix} M_{LL}^{ee\,2} & M_{LR}^{ee\,2} & M_{LL}^{e\mu\,2} & M_{LR}^{e\mu\,2} & M_{LL}^{e\tau\,2} & M_{LR}^{e\tau\,2} \\ M_{RL}^{ee\,2} & M_{RR}^{ee\,2} & M_{RL}^{e\mu\,2} & M_{RR}^{e\mu\,2} & M_{RL}^{e\tau\,2} & M_{RR}^{e\tau\,2} \\ M_{LL}^{\mu e\,2} & M_{LR}^{\mu e\,2} & M_{LL}^{\mu\mu\,2} & M_{LR}^{\mu\mu\,2} & M_{LL}^{\mu\tau\,2} & M_{LR}^{\mu\tau\,2} \\ M_{RL}^{\mu e\,2} & M_{RR}^{\mu e\,2} & M_{RL}^{\mu\mu\,2} & M_{RR}^{\mu\mu\,2} & M_{RL}^{\mu\tau\,2} & M_{RR}^{\mu\tau\,2} \\ M_{LL}^{\tau e\,2} & M_{LR}^{\tau e\,2} & M_{LL}^{\tau\mu\,2} & M_{LR}^{\tau\mu\,2} & M_{LL}^{\tau\tau\,2} & M_{LR}^{\tau\tau\,2} \\ M_{RL}^{\tau e\,2} & M_{RR}^{\tau e\,2} & M_{RL}^{\tau\mu\,2} & M_{RR}^{\tau\mu\,2} & M_{RL}^{\tau\tau\,2} & M_{RR}^{\tau\tau\,2} \end{pmatrix} \Rightarrow \delta_{LL,RR,LR}^{ij} \equiv \frac{M_{LL,RR,LR}^{ij2}}{\tilde{m}^2}$$

$$\tilde{m}^2 = \left(m_{\tilde{l}_1}^2 \ldots . m_{\tilde{l}_6}^2\right)^{1/6}$$

- CMSSM in the leading-log approximation

$$\begin{aligned} M_{LL}^{ij2} &= -\frac{1}{8\pi^2}(3M_0^2 + A_0^2)(Y_\nu^* L Y_\nu^T)_{ij} \\ M_{LR}^{ij2} &= -\frac{3}{16\pi^2} A_0 \frac{v_1}{\sqrt{2}} Y_{l_i} (Y_\nu^* L Y_\nu^T)_{ij} \\ M_{RR}^{ij2} &= 0 \ ; \ L_{kl} \equiv \log\left(\frac{M_X}{m_{M_k}}\right) \delta_{kl} \ ; \ (i \neq j) \end{aligned}$$

we take $M_x = M_{GUT}$

- We use instead SPheno program (Porod 03):

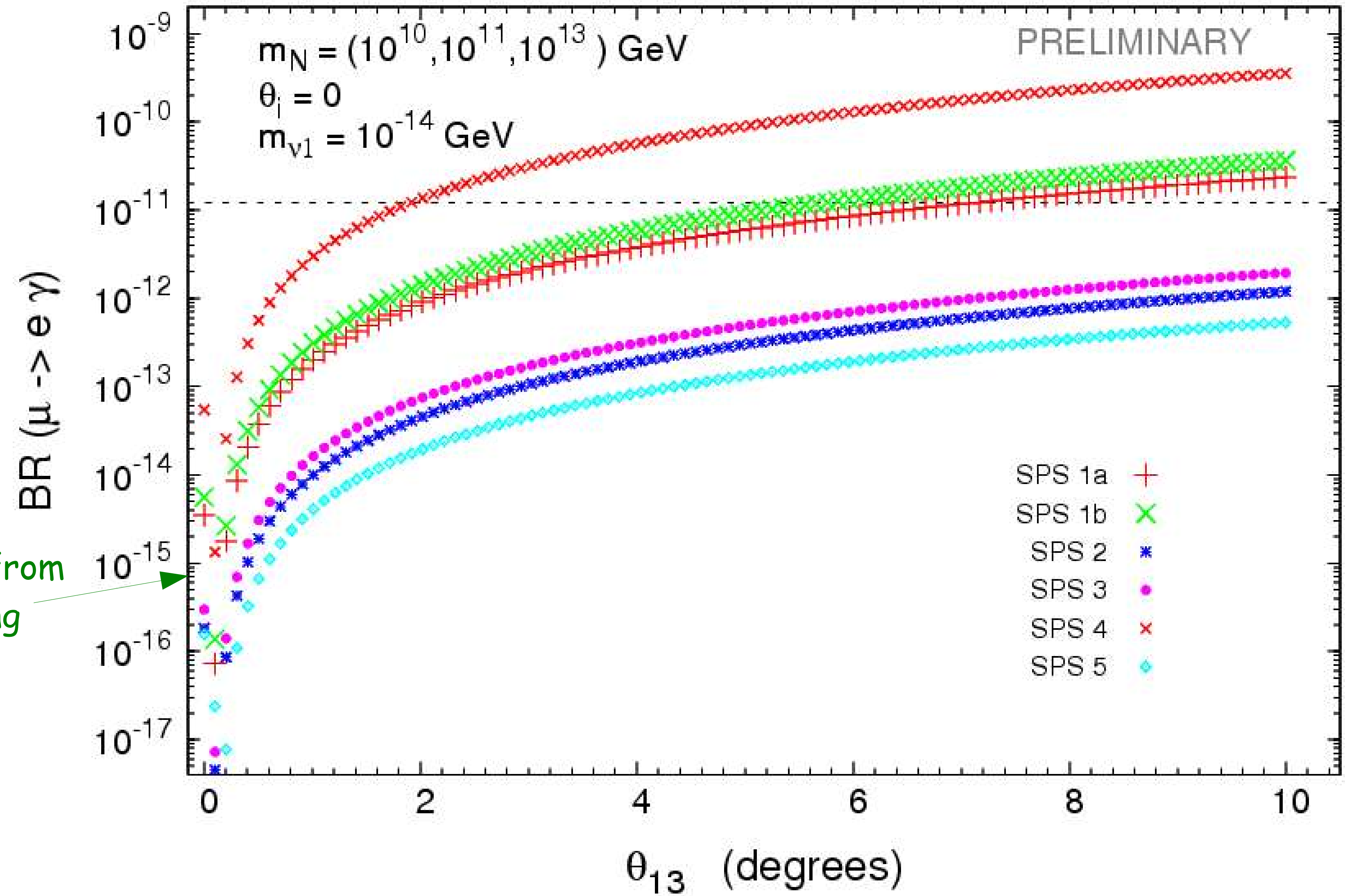
To integrate numerically two-loop RGEs from M_X down to M_Z

+ our Software: Routines for LFV decays*, Leptogenesis**, EDMs, Neutrino RGEs

*full 1-loop **using num. results for efficiency from hep-ph/0310123

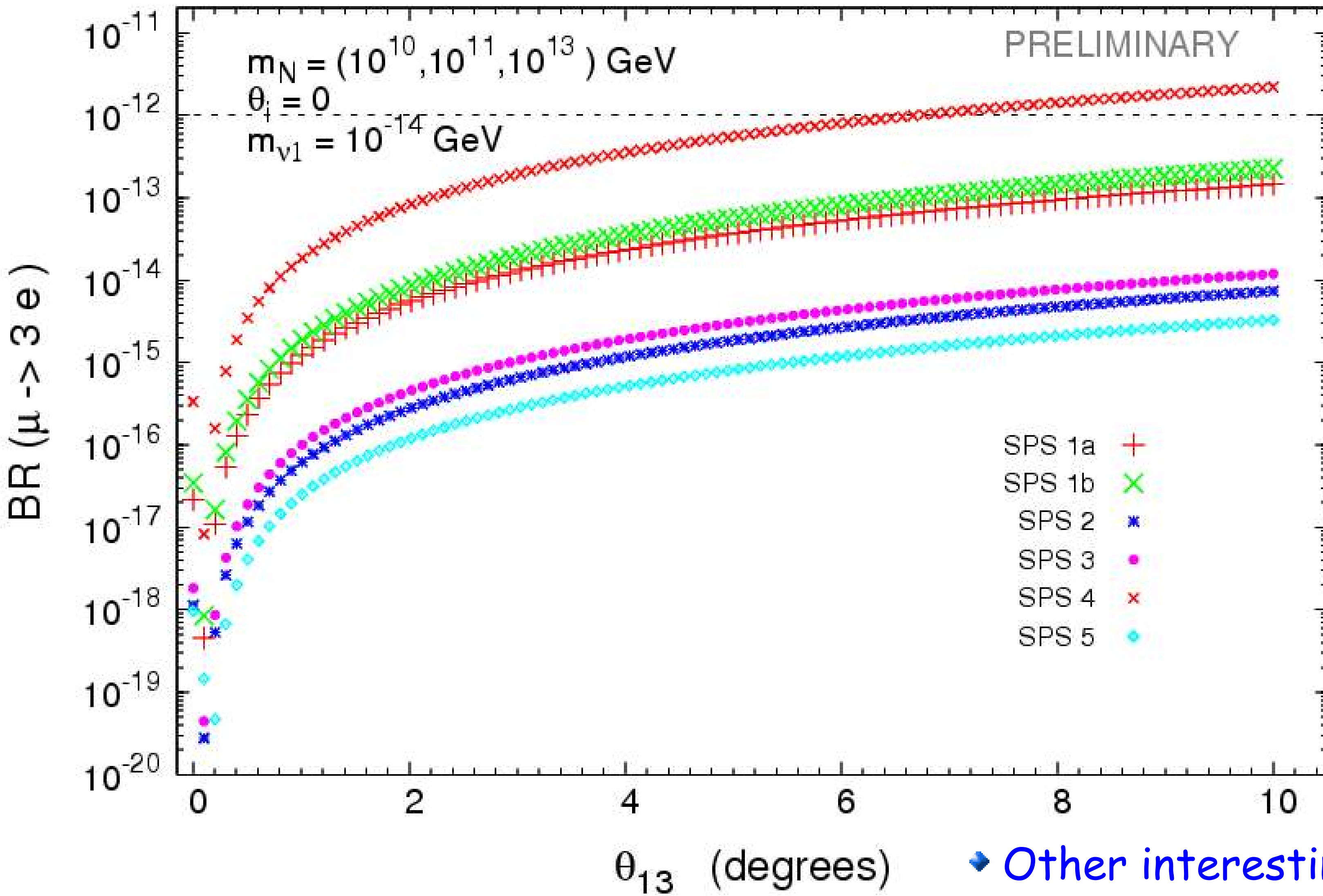
Br ($\mu \to e\,\gamma$) for R = 1 and Sensitivity to θ_{13}

Effects from RG running of θ_{13}



- Br ($\mu \to e\,\gamma$) depends dramatically on the value of the MNS mixing θ_{13} for R = 1 !

Also: Br ($\mu \to 3e$) for R = 1 and Sensitivity to θ_{13}



- Other interesting channels:

  Br ($\tau \to e \gamma$), ...

- Br ($\mu \to 3e$) ~ 10^{-2} Br ($\mu \to e \gamma$)

  (γ-dominance for Br ($\mu \to 3e$); analogous for all $\mu \to e \gamma$ plots in the talk)

Analytically

Leading-Log Approximation in the CMSSM: $Br(l_i \to l_j \gamma) \propto |Y_\nu^* L \; Y_\nu^T|_{ij}^2 \tan^2\beta$

$$
\begin{aligned}
v_u^2 \, (Y_\nu^* \, L \, Y_\nu^T)_{21} \overset{\theta_1=\theta_2=\theta_3=0}{=} \\
& L_3 \, M_3 \, e^{\mathrm{i}\,\delta} \, m_3 \, c_{13} \, s_{13} \, s_{23} \\
& + L_2 \, M_2 \, m_2 \, c_{13} \, s_{12} \, \left(c_{12} \, c_{23} - e^{\mathrm{i}\,\delta} \, s_{12} \, s_{13} \, s_{23} \right) \\
& + L_1 \, M_1 \, m_1 \, c_{12} \, c_{13} \, \left(- c_{23} \, s_{12} - e^{\mathrm{i}\,\delta} \, c_{12} \, s_{13} \, s_{23} \right)
\end{aligned}
$$

Neutrino Yukawa Matrix:

For $\theta_1 = 0$, $\theta_2 = 0$, $\theta_3 = 0$ ($R = 1$):

Neutrino mass model type:

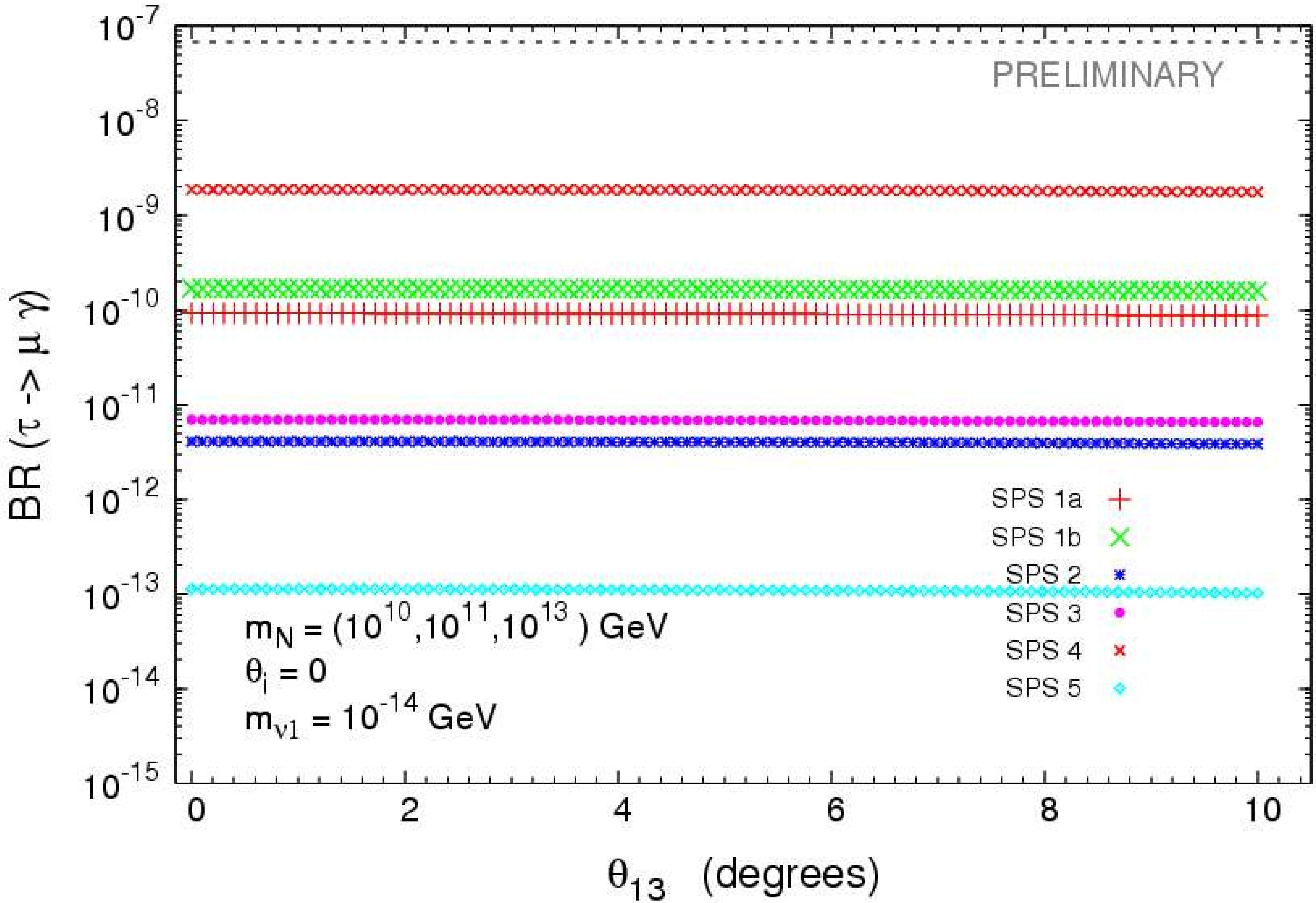
'Heavy Sequential Dominance' (S.F. King '98, '02)

$$
Y_\nu \, v_u = m_D \approx \begin{pmatrix}
\mathrm{i}\, e^{\frac{\mathrm{i}}{2}\phi_1} \sqrt{m_1} \sqrt{M_1} \, c_{12} & \mathrm{i}\, e^{\frac{\mathrm{i}}{2}\phi_2} \sqrt{m_2} \sqrt{M_2} \, s_{12} & \propto s_{13} \\
-\mathrm{i}\, e^{\frac{\mathrm{i}}{2}\phi_1} \sqrt{m_1} \sqrt{M_1} \, c_{23} \, s_{12} & \mathrm{i}\, e^{\frac{\mathrm{i}}{2}\phi_2} \sqrt{m_2} \sqrt{M_2} \, c_{12} \, c_{23} & \mathrm{i} \sqrt{m_3} \sqrt{M_3} \, s_{23} \\
\mathrm{i}\, e^{\frac{\mathrm{i}}{2}\phi_1} \sqrt{m_1} \sqrt{M_1} \, s_{12} \, s_{23} & -\mathrm{i}\, e^{\frac{\mathrm{i}}{2}\phi_2} \sqrt{m_2} \sqrt{M_2} \, c_{12} \, s_{23} & \mathrm{i} \sqrt{m_3} \sqrt{M_3} \, c_{23}
\end{pmatrix}
$$

couplings to N_1 couplings to N_2 couplings to N_3

Here and in the following: hierarchical m_ν and M_{RR}

In Comparison: Br ($\tau \to \mu\, \gamma$) well below bounds!



- Br($\tau \to \mu\, \gamma$) insensitive to θ_{13}
- yields weaker constraints than Br($\mu \to e\, \gamma$) if θ_{13} not very small!

Baryogenesis via Leptogenesis (decay of ν^1_R)

Baryon Asymmetry via the decay of lightest RH neutrino:

Fukugita, Yanagida ('86)

η: efficiency factor (solve Boltzmann equations)

n_{B-L}/s

ε_1: decay asymmetry of ν^1_R

Lepton asymmetry:

$$Y^{\mathrm{SM}}_{\mathrm{B-L}} \approx -\eta\,\varepsilon_1\,Y^{\mathrm{eq}}_{\nu^1_{\mathrm{R}}}$$

$$Y^{\mathrm{MSSM}}_{\mathrm{B-L}} \approx -\eta\left[\tfrac{1}{2}(\varepsilon_1+\widetilde{\varepsilon}_1)\,Y^{\mathrm{eq}}_{\nu^1_{\mathrm{R}}}+\tfrac{1}{2}(\varepsilon_{\widetilde{1}}+\widetilde{\varepsilon}_{\widetilde{1}})\,Y^{\mathrm{eq}}_{\widetilde{\nu}^1_{\mathrm{R}}}\right]$$

with:

$$Y^{\mathrm{eq}}_{\nu^1_{\mathrm{R}}} \approx \frac{45\,\zeta(3)}{\pi^4 g_* k}\frac{3}{4} \quad \text{and} \quad Y^{\mathrm{eq}}_{\widetilde{\nu}^1_{\mathrm{R}}} \approx \frac{45\,\zeta(3)}{\pi^4 g_* k}$$

$$\varepsilon_1 := \frac{\Gamma_{\nu^1_{\mathrm{R}}L}-\Gamma_{\nu^1_{\mathrm{R}}\overline{L}}}{\Gamma_{\nu^1_{\mathrm{R}}L}+\Gamma_{\nu^1_{\mathrm{R}}\overline{L}}}\,, \quad \widetilde{\varepsilon}_1 := \frac{\Gamma_{\nu^1_{\mathrm{R}}\widetilde{L}}-\Gamma_{\nu^1_{\mathrm{R}}\widetilde{L}^*}}{\Gamma_{\nu^1_{\mathrm{R}}\widetilde{L}}+\Gamma_{\nu^1_{\mathrm{R}}\widetilde{L}^*}}\,, \quad \varepsilon_{\widetilde{1}} := \frac{\Gamma_{\widetilde{\nu}^{1*}_{\mathrm{R}}L}-\Gamma_{\widetilde{\nu}^1_{\mathrm{R}}\overline{L}}}{\Gamma_{\widetilde{\nu}^{1*}_{\mathrm{R}}L}+\Gamma_{\widetilde{\nu}^1_{\mathrm{R}}\overline{L}}}\,, \quad \widetilde{\varepsilon}_{\widetilde{1}} := \frac{\Gamma_{\widetilde{\nu}^1_{\mathrm{R}}\widetilde{L}}-\Gamma_{\widetilde{\nu}^{1*}_{\mathrm{R}}\widetilde{L}^*}}{\Gamma_{\widetilde{\nu}^1_{\mathrm{R}}\widetilde{L}}+\Gamma_{\widetilde{\nu}^{1*}_{\mathrm{R}}\widetilde{L}^*}}$$

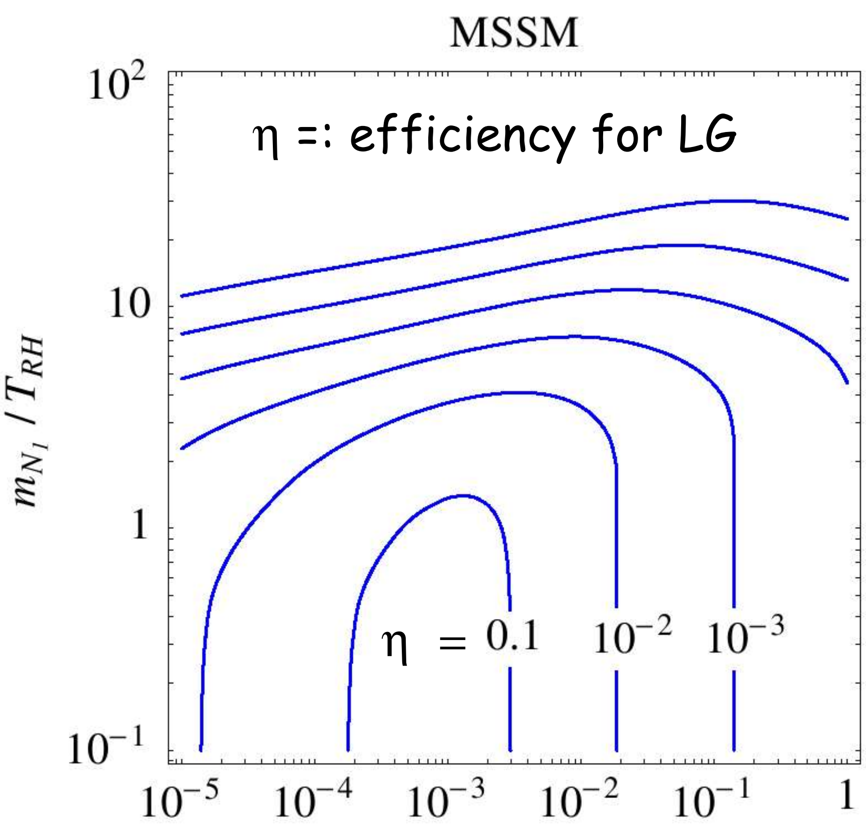
$$Y_{\mathrm{B}} = \alpha\,Y_{\mathrm{B-L}}\,, \quad \text{with} \quad \alpha \approx \frac{24+4N_H}{66+13N_H}$$

(Sphalerons partly convert lepton asymmetry into a baryon asymmetry)

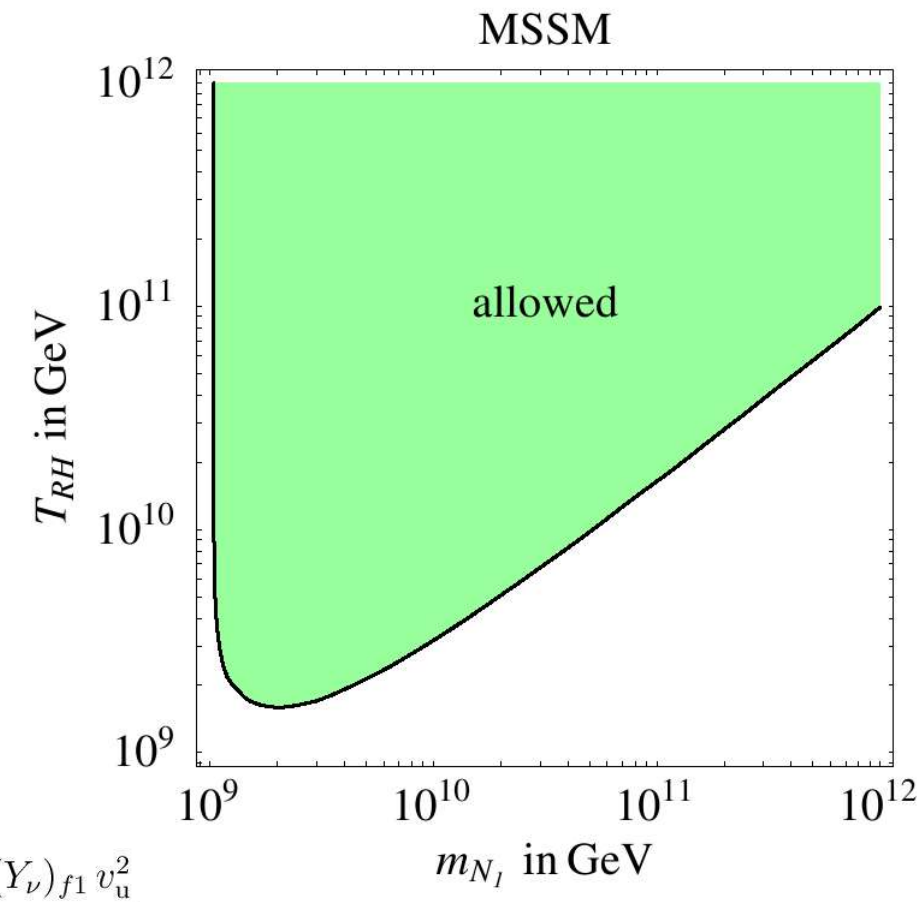
Kuzmin, Rubakov, Shaposhnikov ('85)

Observation: $n_B/n_\gamma \approx 6 \cdot 10^{-10}$ WMAP ('03)

Reheating after Inflation and Thermal Leptogenesis



$$\tilde{m}_1 := \frac{\sum_f (Y_\nu^\dagger)_{1f} (Y_\nu)_{f1}\, v_u^2}{m_{N1}}$$



$m_{N1} \gg T_{RH}$ (mass of lightest RH neutrino) leads to a dramatic loss in efficiency

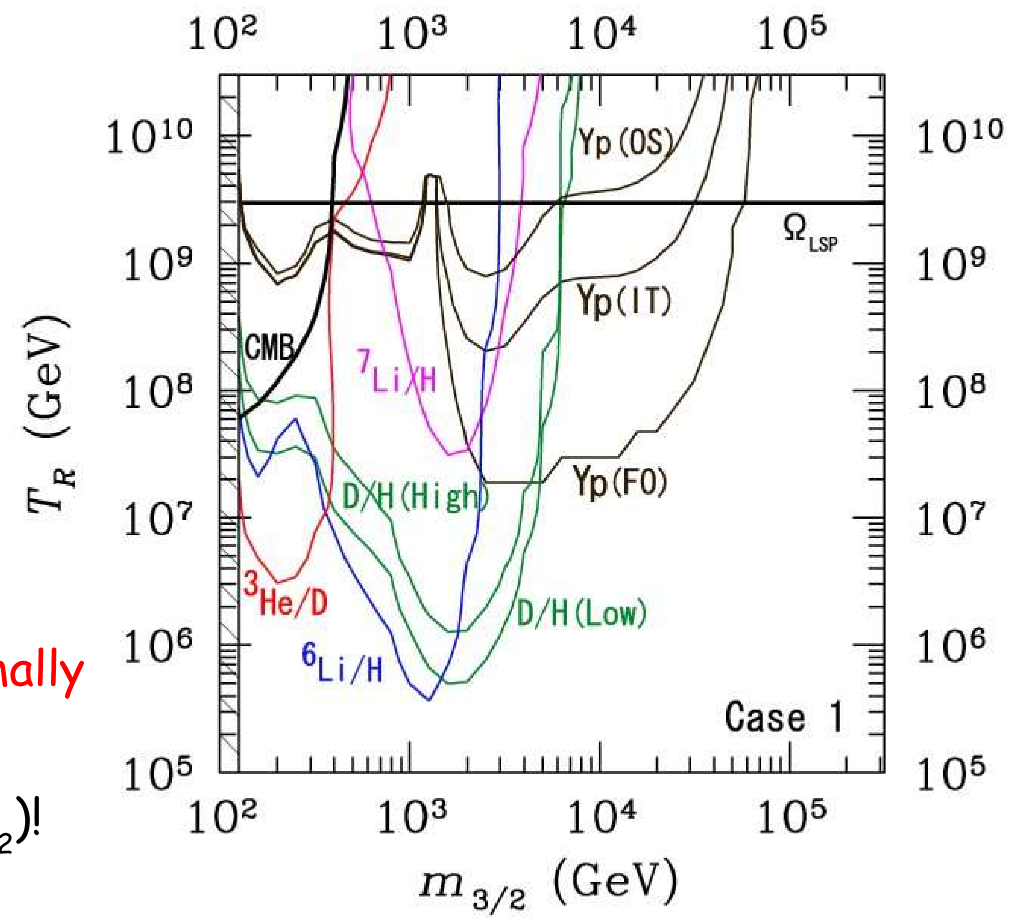
$\Rightarrow$ bound on m_{N1}

from G.F. Giudice, A. Notari, M. Raidal, A. Riotto, A. Strumina (hep-ph/0310123)

Thermal Leptogenesis in SUSY and Gravitino Problems

Two types of gravitino problems:
gravitinos produced thermally ...

- BBN gravitino problem:
  late gravitino decays ⇒ constraints on reheating T_{RH}, depending on $m_{3/2}$!
  Here: we assume CMSSM with $m_{3/2}$ being a free parameter



Example from: K. Kohri, T. Moroi, A. Yotsuyanagi (hep-ph/0507245)

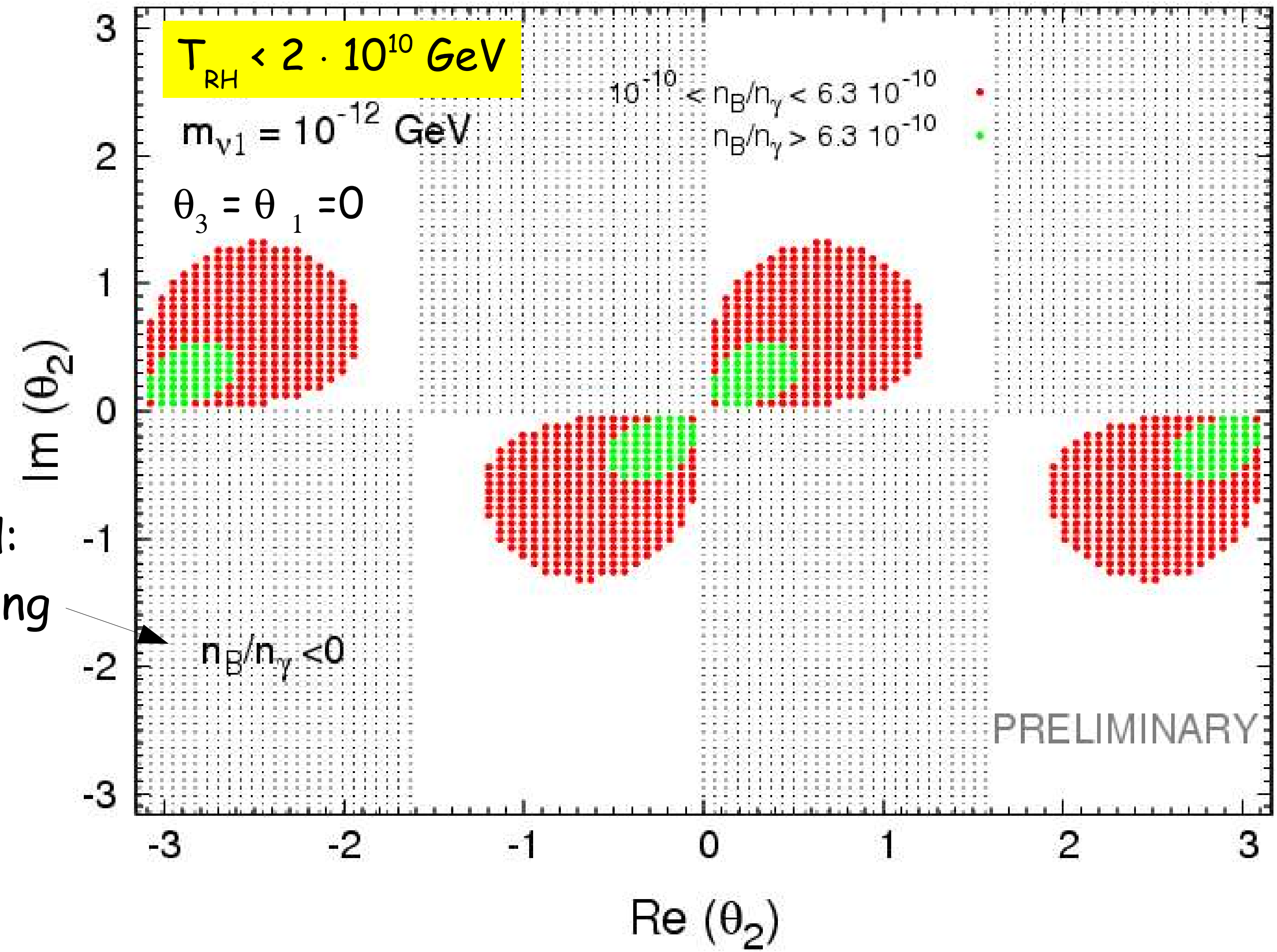
- Gravitino decay ⇒ LSP produced non-thermally
  ⇒ constraints on reheating T_{RH} in order not to overproduce DM (independent of $m_{3/2}$)!
  Here: we will consider this bound
  (assuming neutralino LSP as DM, $m_{3/2}$ large)

has to be $\lesssim$ 0.13 WMAP ('03)

nonth.:
$$\Delta\Omega_{\rm LSP}h^2 \simeq 0.054 \times \left(\frac{m_{\chi_1^0}}{100\ \mathrm{GeV}}\right)\left(\frac{T_{\rm R}}{10^{10}\ \mathrm{GeV}}\right)$$

neutralino mass ~ 100 GeV ⇒
$T_{RH} \lesssim 2 \cdot 10^{10}$ GeV (estimate)

Constraints on R-Matrix Angles from thermal LG: θ_2

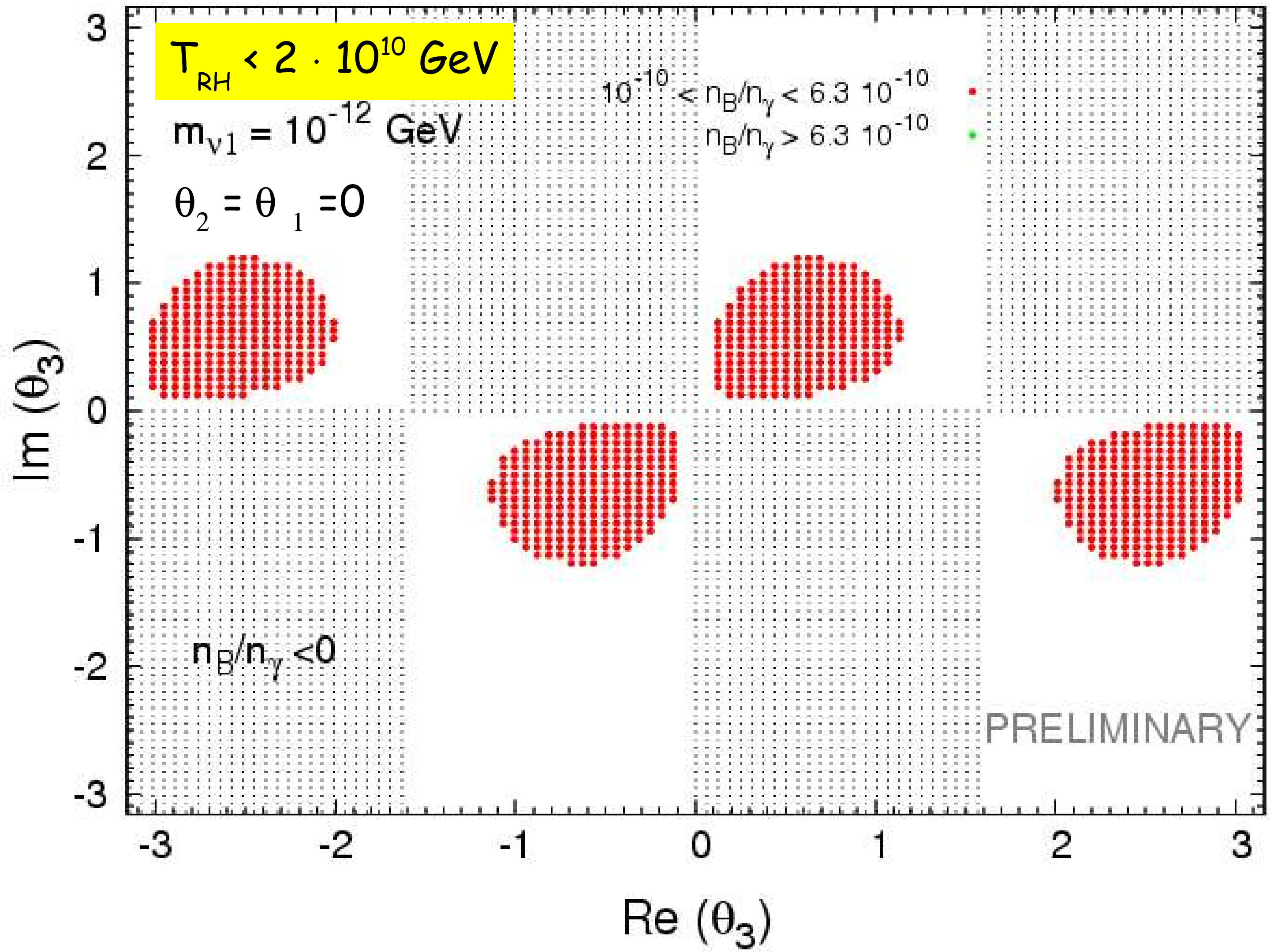


excluded: BAU wrong sign!

- Favoured by thermal LG and non-thermal LSP production via gravitino decays: $|\theta_2|$ (mod π) small, but non-zero (qualitatively similar for smaller $m_{\nu 1}$)
- θ_1 generically not constrained

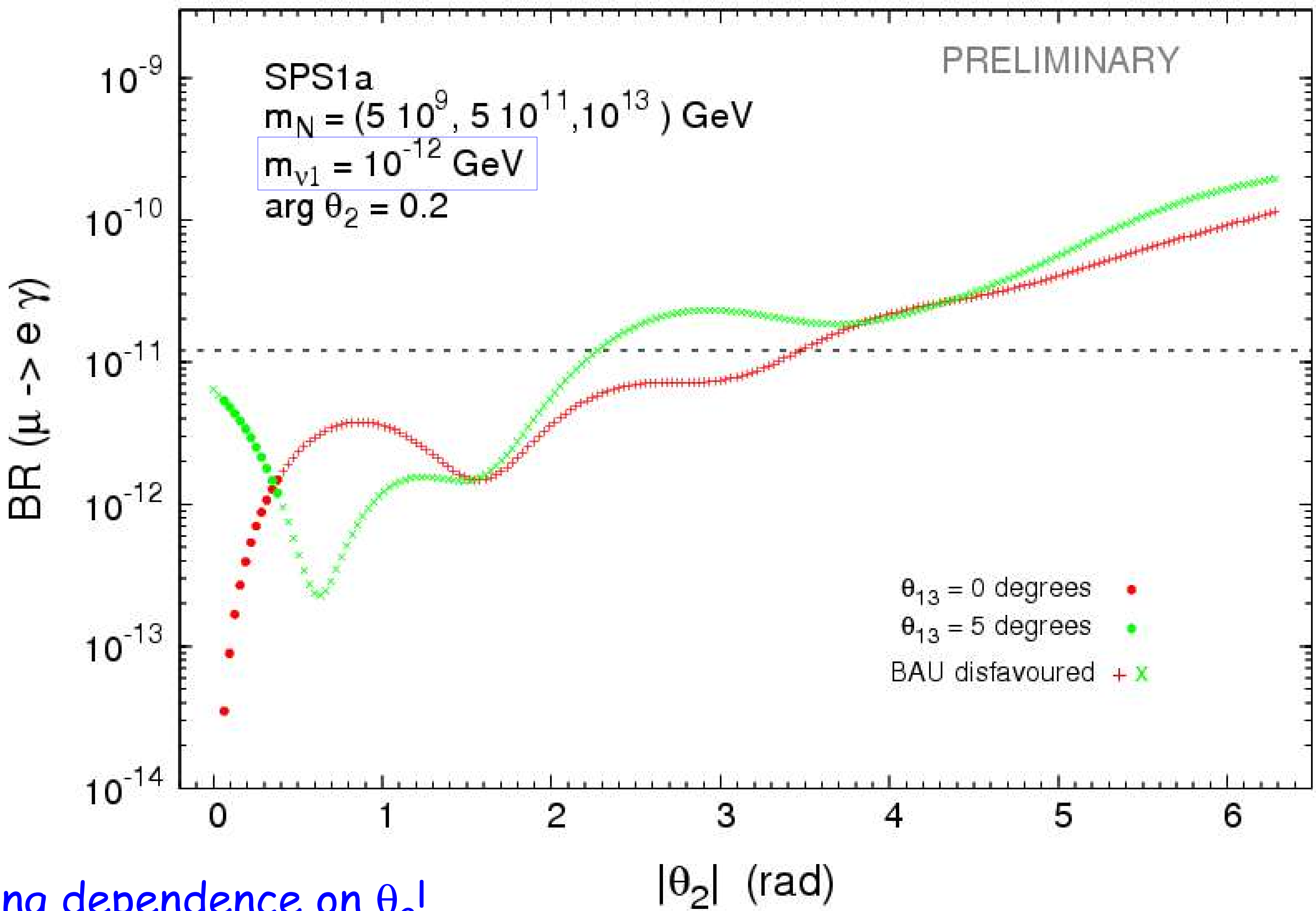
using num. results for the LG efficiencies (with T_{RH}) from hep-ph/0310123 for zero initial N_1 population

Constraints on R-Matrix Angles from thermal LG: θ_3



- Favoured by thermal LG and non-thermal LSP production via gravitino decays: $|\theta_3|$ (mod π) small, but non-zero (and/or $|\theta_2|$ (mod π) small, but non-zero)

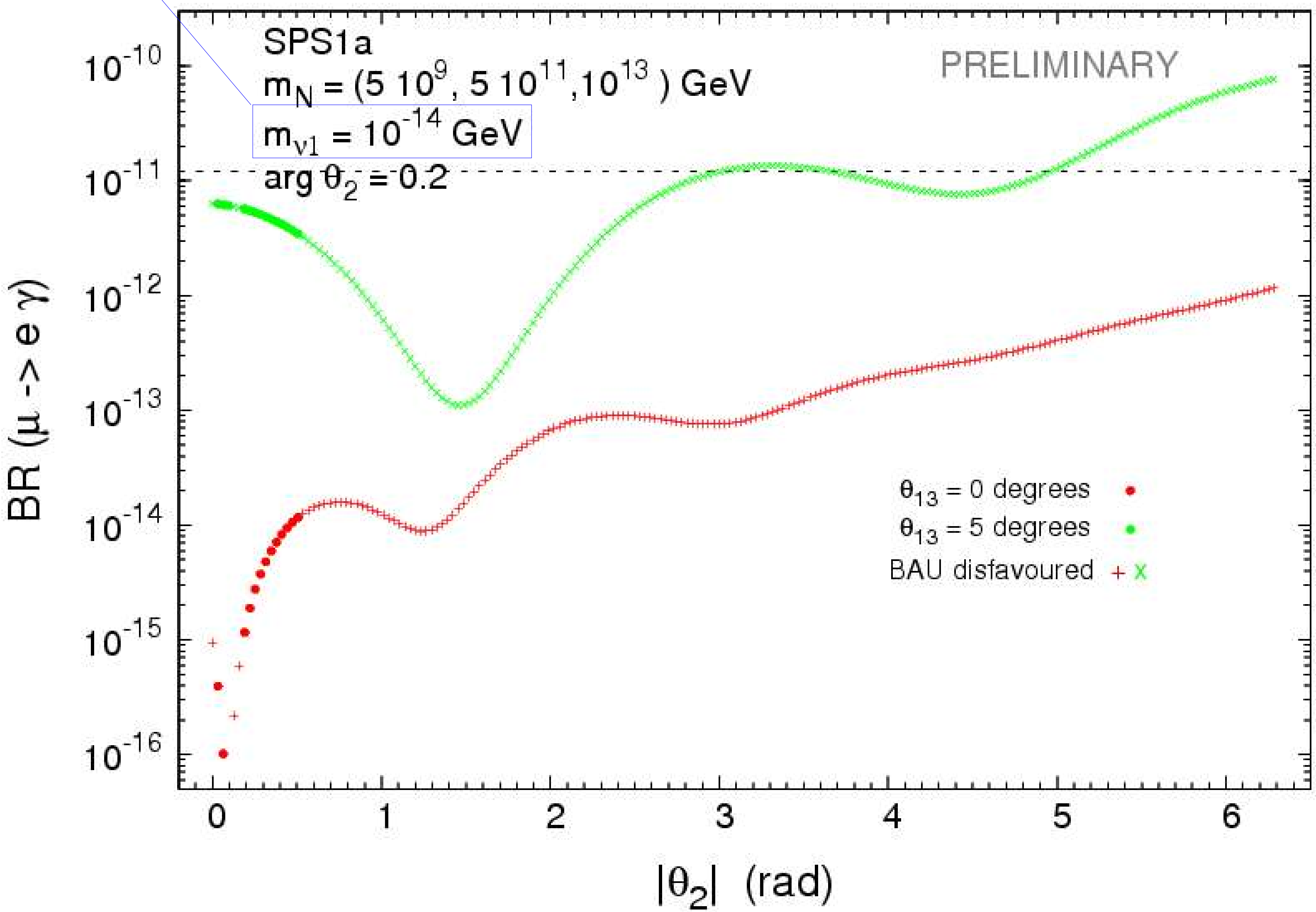
Dependence on the R-Matrix Angle θ_2 (RH 1-3 Rotation)



- Strong dependence on θ_2!
- In θ_2-regions favoured by thermal LG: θ_{13} particularly important!

Dependence on the R-Matrix Angle θ_2: depends on $m_{\nu 1}$

strong dependence on $m_{\nu 1}$



Leading-Log Approximation

Leading-Log Approximation in the CMSSM: $Br(l_i \to l_j \gamma) \sim |Y_\nu^* L \; Y_\nu^T|_{ij}^2 \tan^2\beta$

θ_2 contributes
proportional to $m_1 s_2^2$

$$v_u^2 \, (Y_\nu^* \, L \, Y_\nu^T)_{21} =$$

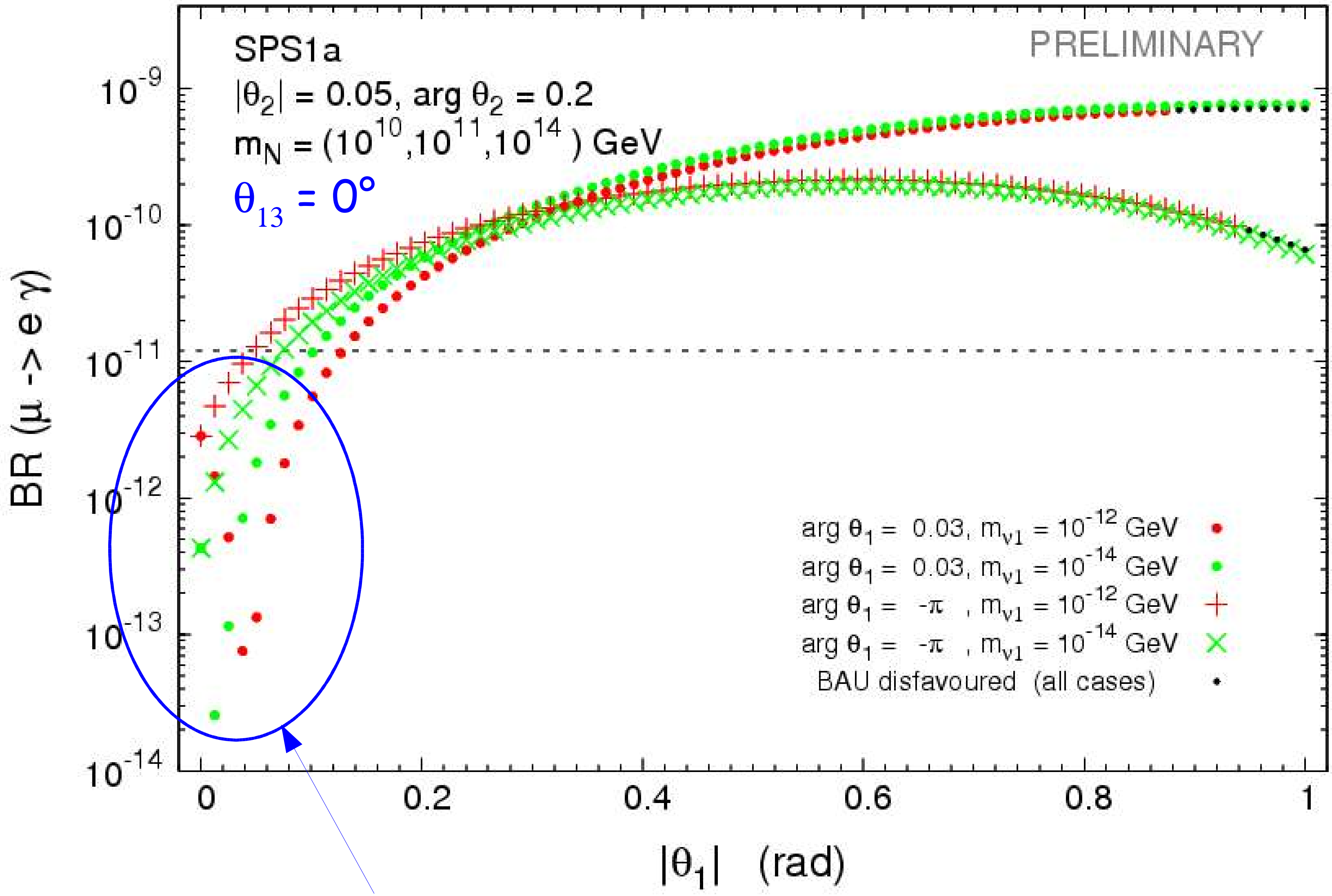
$$L_3 \, M_3 \, \Big(c_{13} \, \Big(e^{\frac{i}{2}\phi_1} \boxed{\sqrt{m_1} \, c_{12} \, s_2} + e^{\frac{i}{2}\phi_2} \sqrt{m_2} \, c_2 \, s_1 \, s_{12} \Big) + e^{i\delta} \sqrt{m_3} \, c_1 \, c_2 \, s_{13} \Big)$$

$$\Big(\sqrt{m_3} \, c_1 \, c_2 \, c_{13} \, s_{23} - e^{-\frac{i}{2}\phi_1} \sqrt{m_1} \, s_2 \, \left(c_{23} \, s_{12} + e^{i\delta} \, c_{12} \, s_{13} \, s_{23} \right)$$

$$+ e^{-\frac{i}{2}\phi_2} \sqrt{m_2} \, c_2 \, s_1 \, \left(c_{12} \, c_{23} - e^{i\delta} \, s_{12} \, s_{13} \, s_{23} \right) \Big)$$

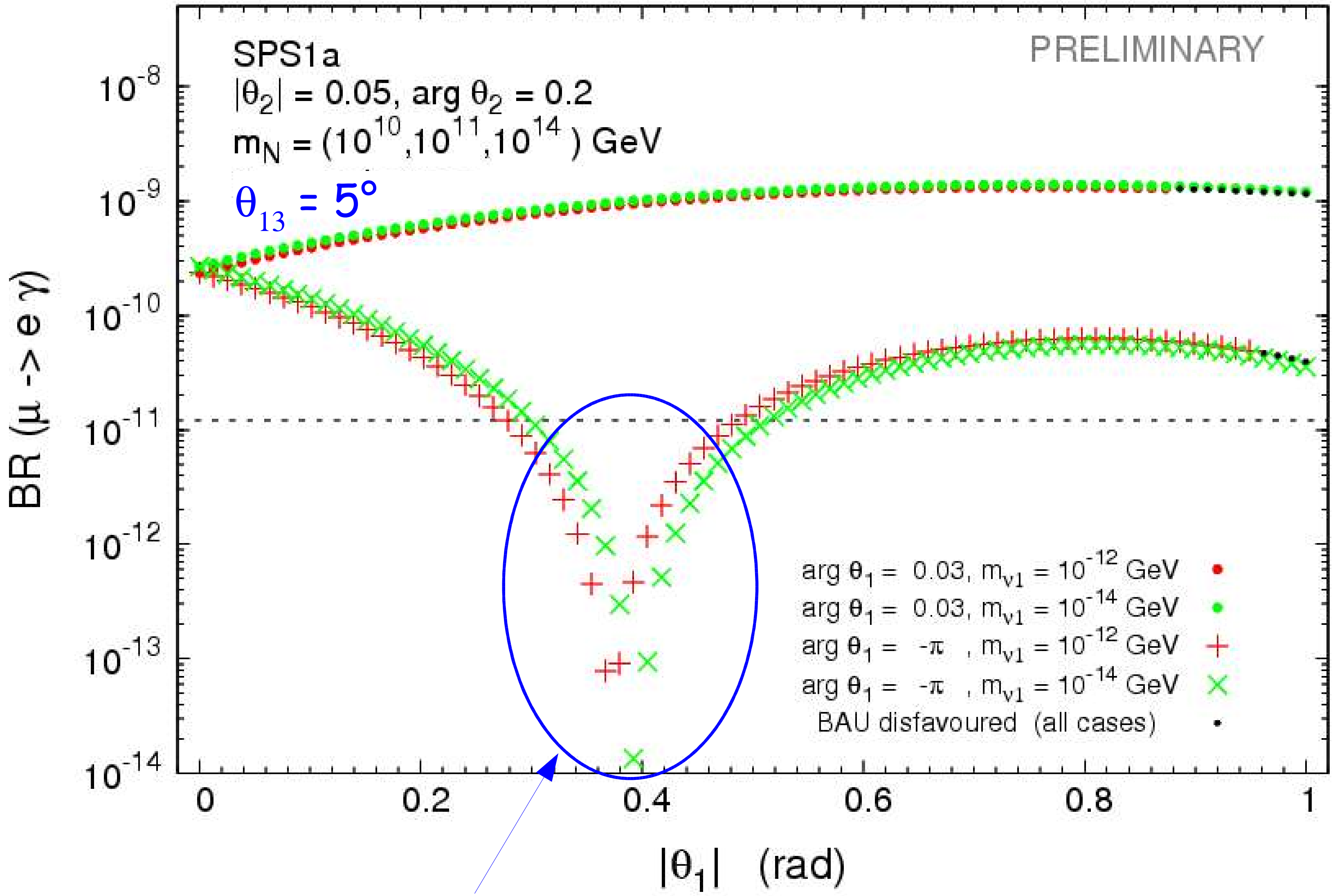
$$+ L_2 \, M_2 \text{-terms} + L_1 \, M_1 \text{-terms}$$

Dependence on the R-Matrix Angle θ_1 (RH 2-3 Rotation)



This example: consistency with Br ($\mu \to e\,\gamma$) favours small θ_1

Dependence on the R-Matrix Angle θ_1 (RH 2-3 Rotation)



Zero in 1-3 element of Y_ν @ scale M_3
and in the basis Y_e and M_R diagonal

Leading-Log Approximation

Leading-Log Approximation in the CMSSM: $Br(l_i \to l_j\, \gamma) \sim |Y_\nu^* L\ Y_\nu^T|_{ij}^2 \tan^2\beta$

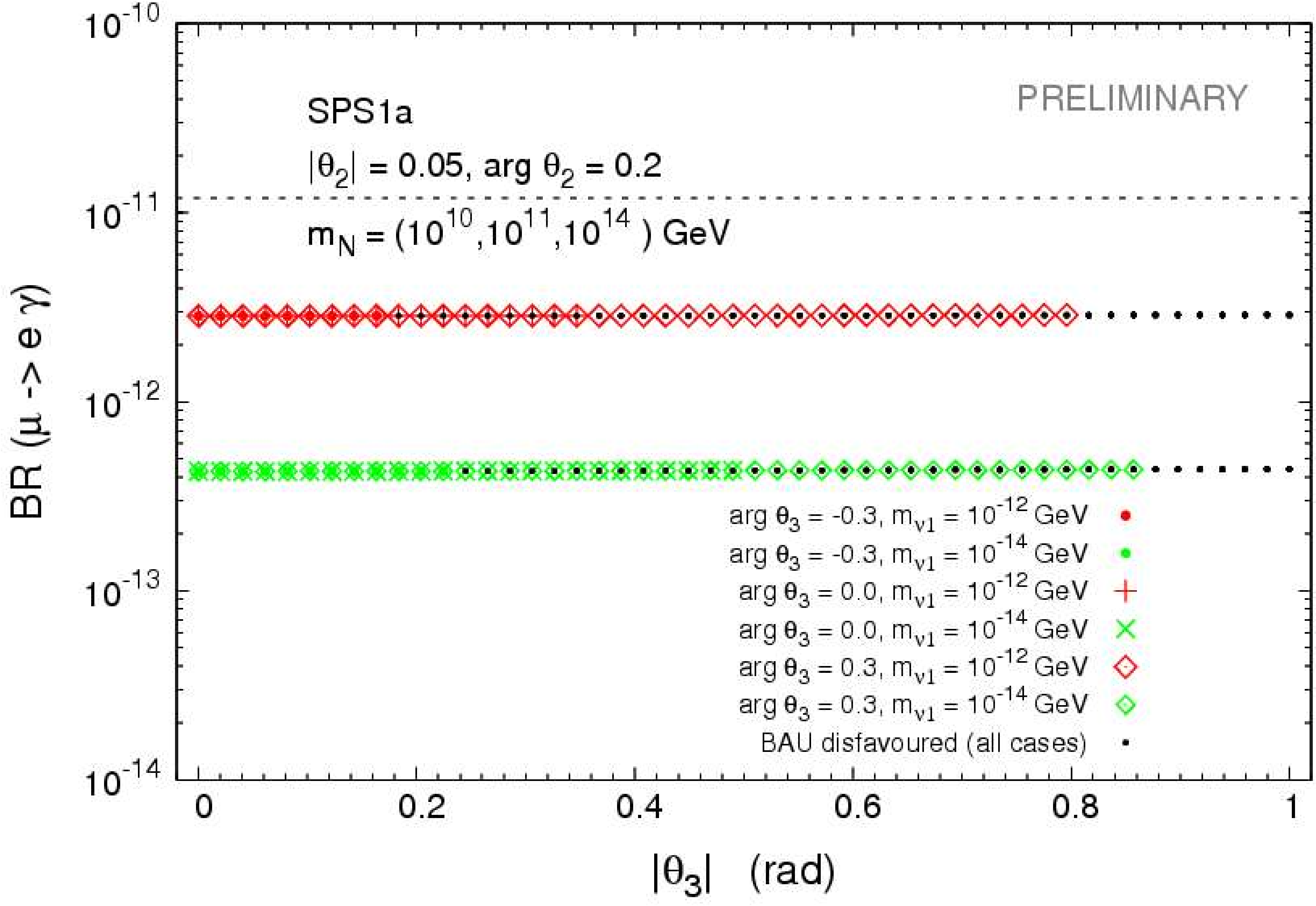
θ_{13} and θ_1: two contributions, which might interfere destructively

$(Y_\nu)_{13}$

$(Y_\nu^*)_{23}$

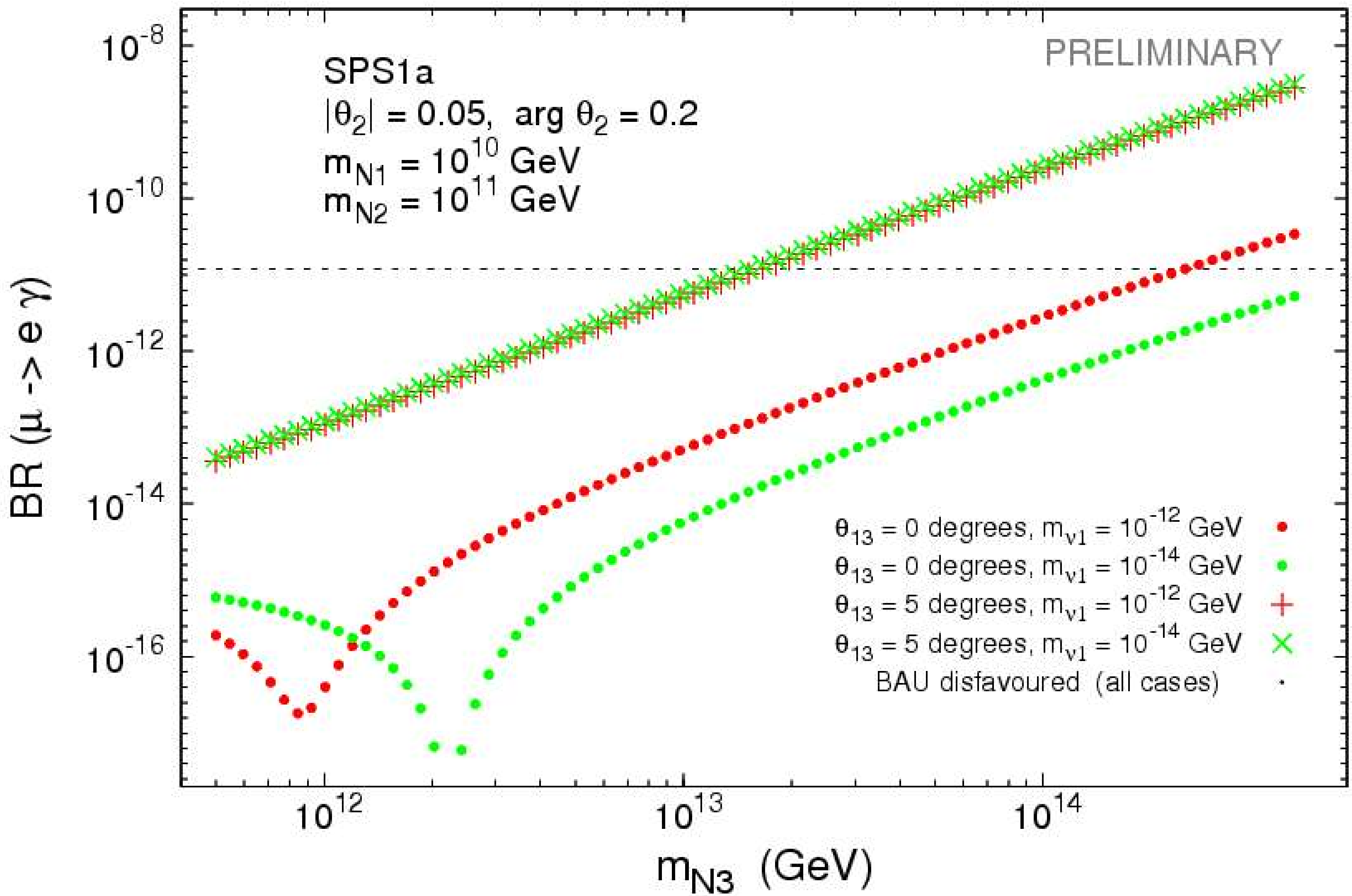
$$
\begin{aligned}
v_u^2\,(Y_\nu^*\,L\,Y_\nu^T)_{21} \stackrel{\theta_2\approx 0,\theta_3\approx 0}{\approx}\\
L_3\,M_3\,&\left(e^{\frac{i}{2}\phi_2}\sqrt{m_2}\,c_{13}\,s_1\,s_{12}+e^{i\,\delta}\sqrt{m_3}\,c_1\,s_{13}\right)\\
&\left(\sqrt{m_3}\,c_1\,c_{13}\,s_{23}+e^{-\frac{i}{2}\phi_2}\sqrt{m_2}\,s_1\,\left(c_{12}\,c_{23}-e^{i\,\delta}\,s_{12}\,s_{13}\,s_{23}\right)\right)\\
+L_2\,M_2\,&\left(e^{\frac{i}{2}\phi_2}\sqrt{m_2}\,c_1\,c_{13}\,s_{12}-e^{i\,\delta}\sqrt{m_3}\,s_1\,s_{13}\right)\\
&\left(-\left(\sqrt{m_3}\,c_{13}\,s_1\,s_{23}\right)+e^{-\frac{i}{2}\phi_2}\sqrt{m_2}\,c_1\,\left(c_{12}\,c_{23}-e^{i\,\delta}\,s_{12}\,s_{13}\,s_{23}\right)\right)\\
-L_1\,M_1\,m_1\,&c_{12}\,c_{13}\,\left(c_{23}\,s_{12}+e^{i\,\delta}\,c_{12}\,s_{13}\,s_{23}\right)
\end{aligned}
$$

Dependence on the R-Matrix Angle θ_3 (RH 1-2 Rotation)



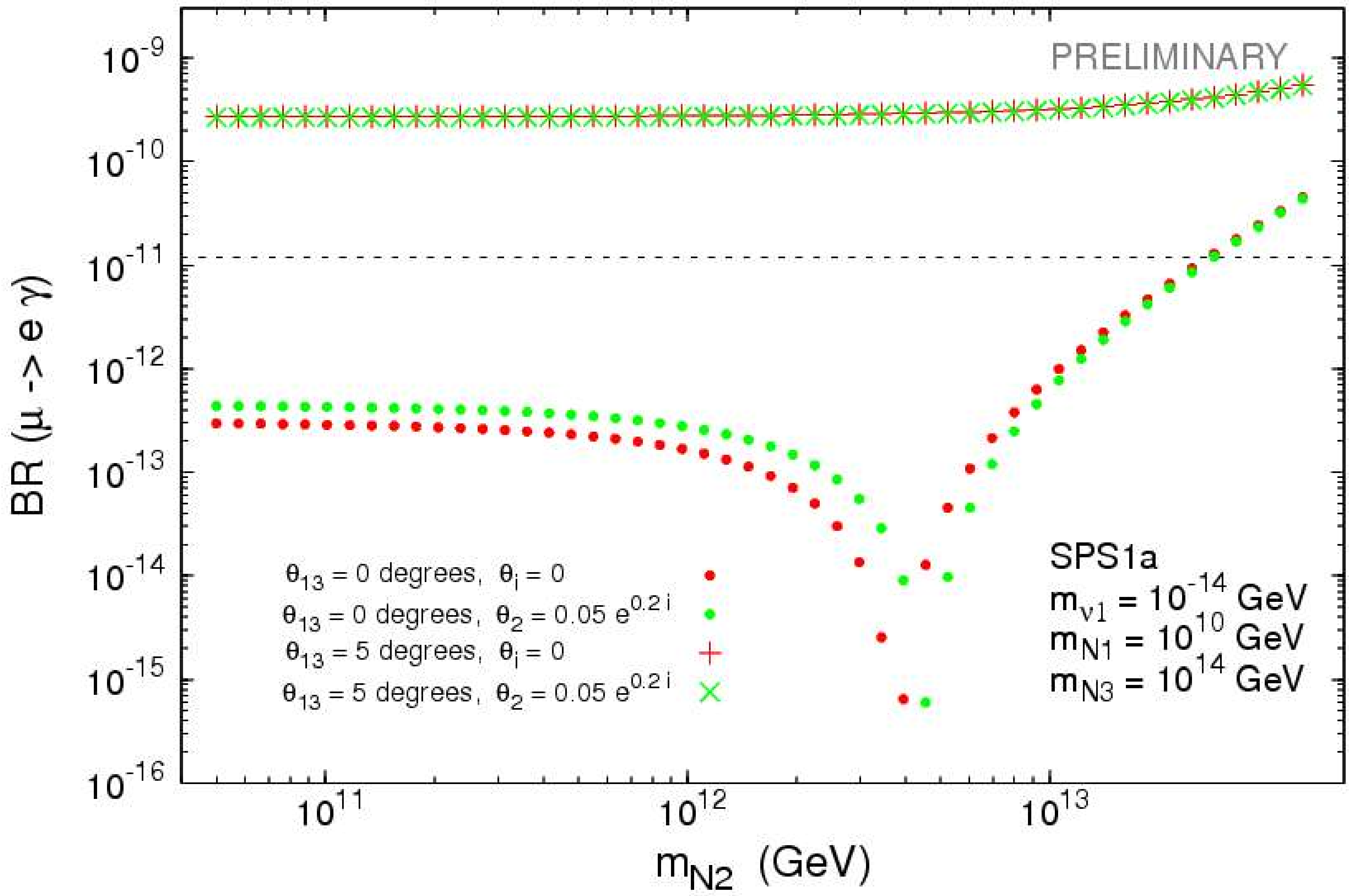
- θ_3 constrained by thermal Leptogenesis but does not affect Br ($\mu \to e\, \gamma$)

Dependence on the mass of the heaviest RH ν: m_{N3}



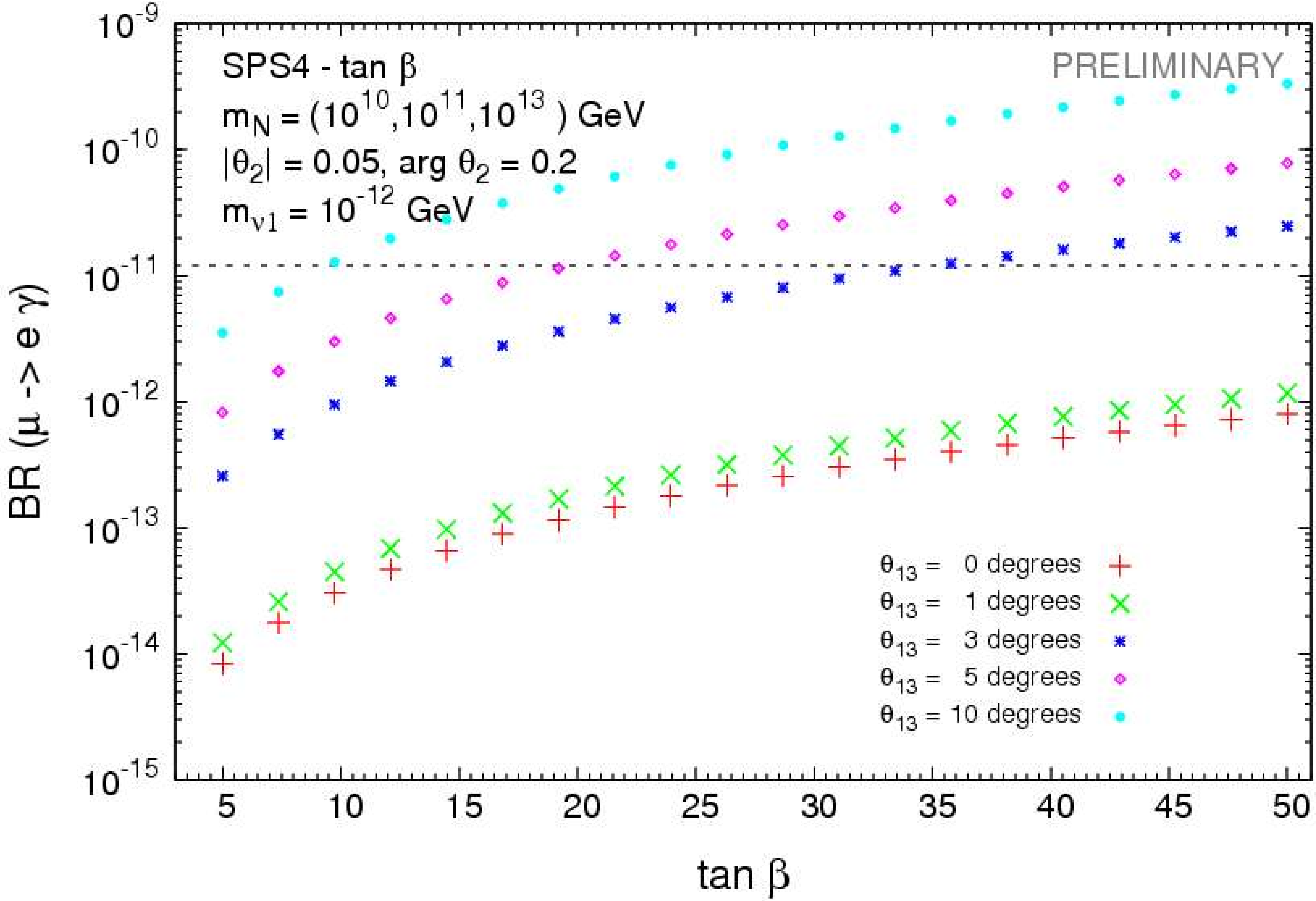
- As expected: Br ($\mu \to e\, \gamma$) approximately proportional to $(m_{N3} \log (m_{N3}/M_x))^2$

Dependence on the mass of the 2nd heaviest RH ν: m_{N2}



- As expected: only relevant when m_{N2} close to m_{N3} or when θ_{13} small

Dependence on tan β: SPS4 (with free tan β)



- As expected: $Br(\mu \to e\,\gamma)$ approximately proportional to $(\tan\beta)^2$

Summary and Conclusions

LFV and θ_{13} in SUSY Seesaw: Framework

- SUSY scenario: CMSSM + Seesaw (examples: SPS benchmark points)
- Seesaw compatible with low energy neutrino data: parameterized by R-Matrix
- Consistency with: low energy neutrino data, BAU via thermal leptogenesis (gravitino problem from non-thermal LSP prod. $T_{RH} < 2 \cdot 10^{10}$ GeV), charged lepton EDMs
- Study: impact of θ_{13} (and other relevant parameters) on LFV Muon and Tau decays

LFV and θ_{13} in SUSY Seesaw: Results

- Special example R = 1: Br ($\mu \rightarrow e\,\gamma$) can change with θ_{13} by 5 orders of magnitude!
  Stronger constraint than Br ($\tau \rightarrow \mu\,\gamma$) unless θ_{13} very small!
- General: many relevant parameters, θ_{13} particularly important if R close to 1: θ_i small
- BAU via thermal leptogenesis ($T_{RH} < 2 \cdot 10^{10}$ GeV): favours small θ_2 and/or θ_3, θ_1 'free'
- θ_1 can induce large rates for Br ($\mu \rightarrow e\,\gamma$): small θ_1 can avoid too large rates (θ_{13} small)
- Seesaw parameters favoured by thermal LG: strong impact of θ_{13} on Br ($\mu \rightarrow e\,\gamma$)
- Other relevant parameters we discussed: m_{N3}, m_{N2}, m_{N1}, tan β, $m_{\nu 1}$, θ_1 ,θ_2, θ_3

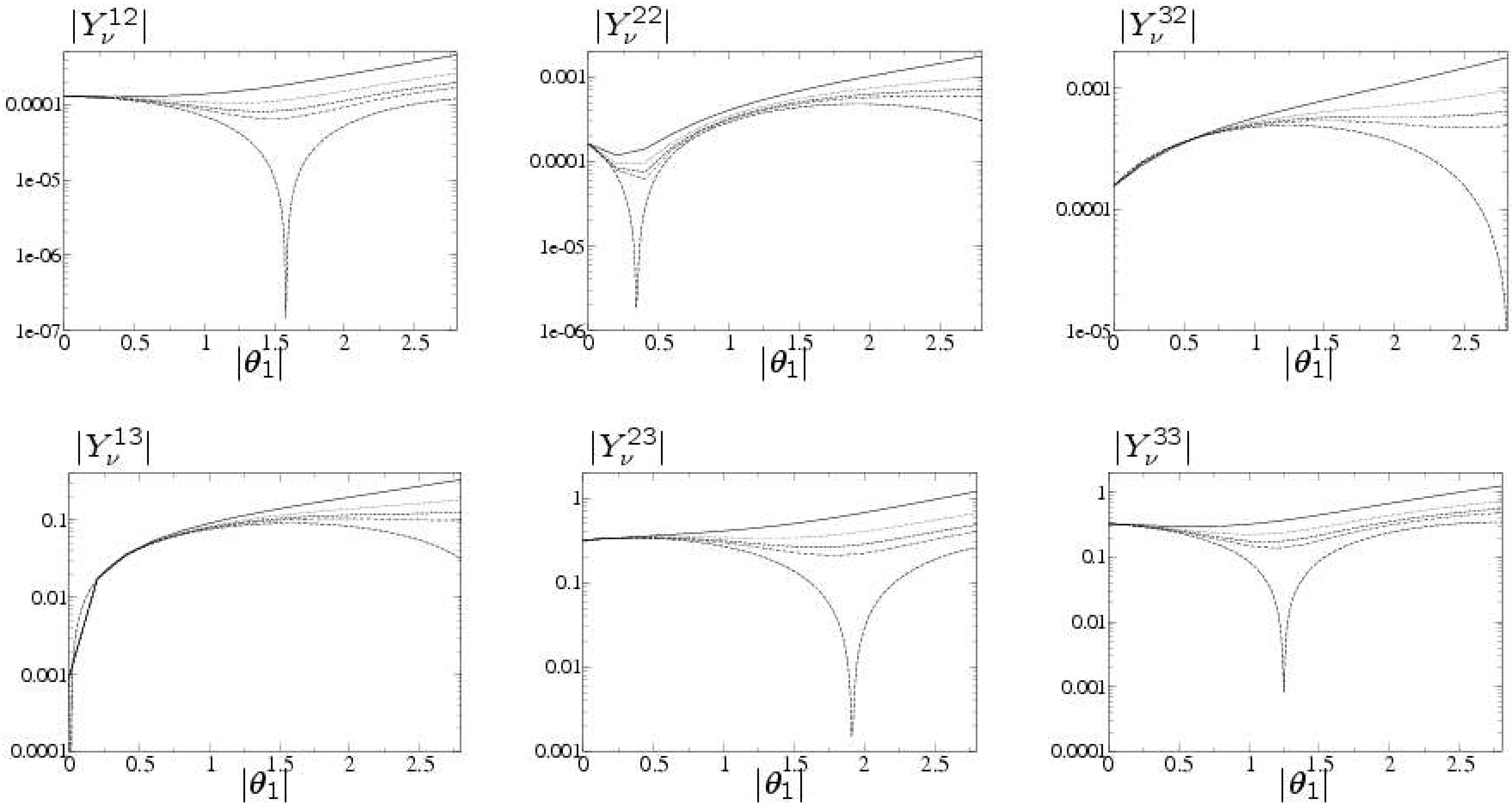
Additional Transparencies:

Neutrino Yukawa Couplings and the R-Matrix: θ_1

Example: Hierarchical m_{N_i} and complex $R(\theta_1, \theta_2, \theta_3)$

$(m_{N_1}, m_{N_2}, m_{N_3}) = (10^8, 2\times 10^8, 10^{14})$ GeV, $\arg(\theta_1) = 0, \pi/10, \pi/8, \pi/6, \pi/4 \, (\theta_2 = \theta_3 = 0)$

$\tan\beta = 50$

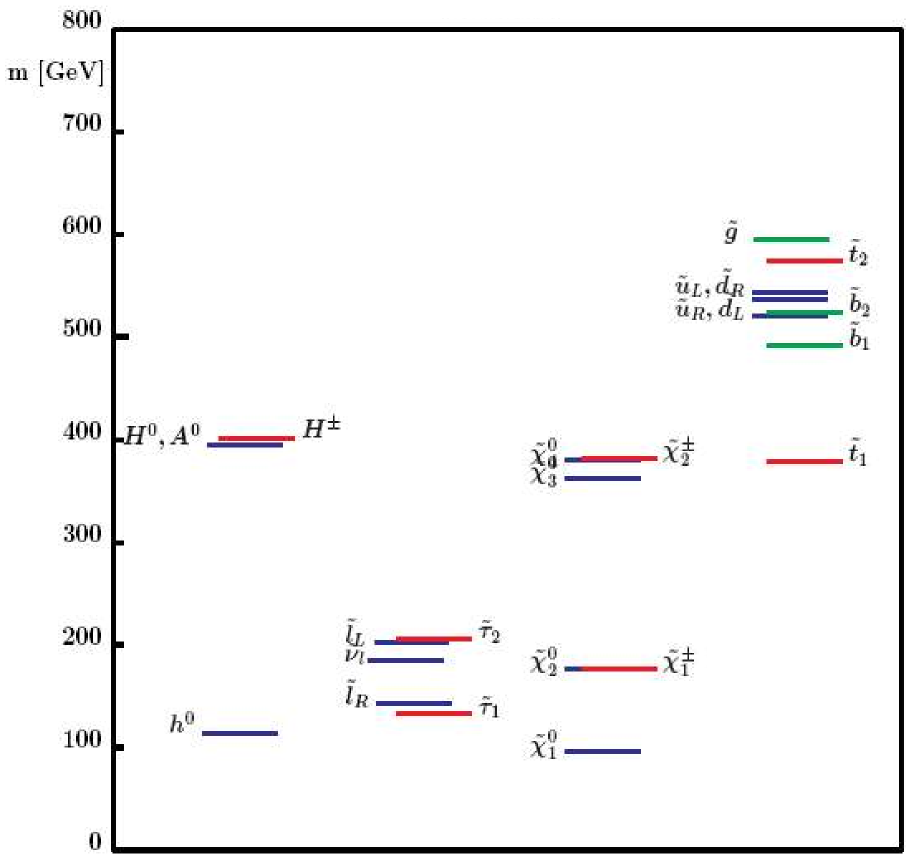


★ These results include also running effects on light neutrino masses and mixings

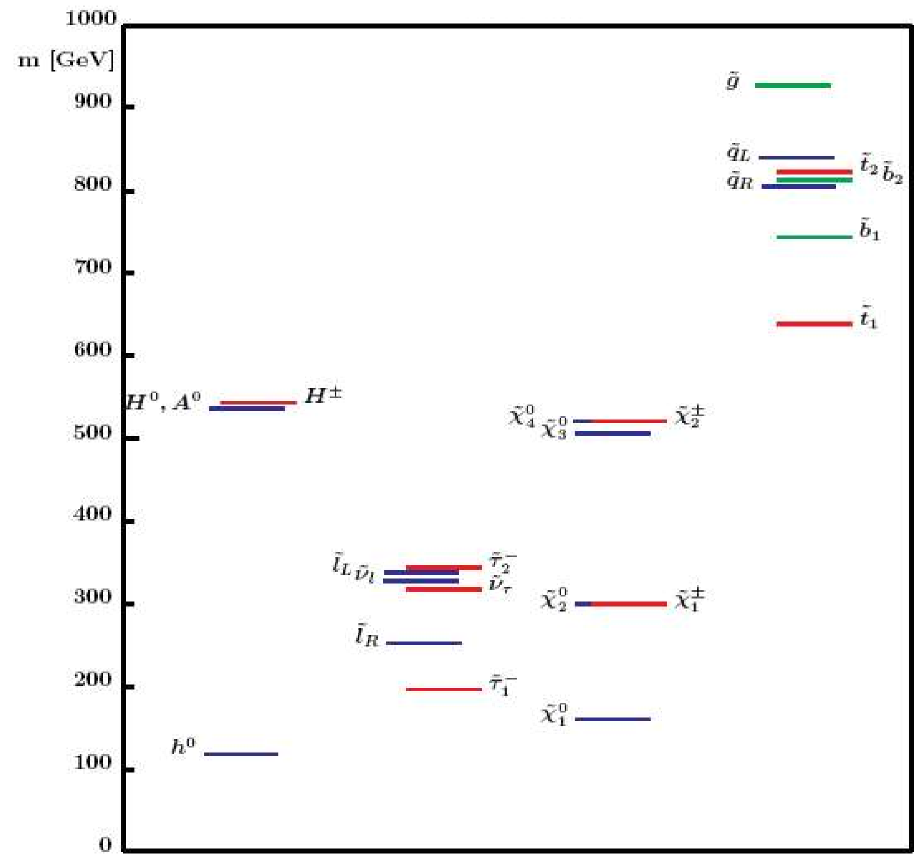
SPS Benchmark Points

SPS1a: $M_0 = 100$ GeV, $M_{1/2} = 250$ GeV, $A_0 = -100$ GeV, $\tan\beta = 10$, $\mu > 0$

SPS1b: $M_0 = 200$ GeV, $M_{1/2} = 400$ GeV, $A_0 = 0$ GeV, $\tan\beta = 30$, $\mu > 0$



SPS1a

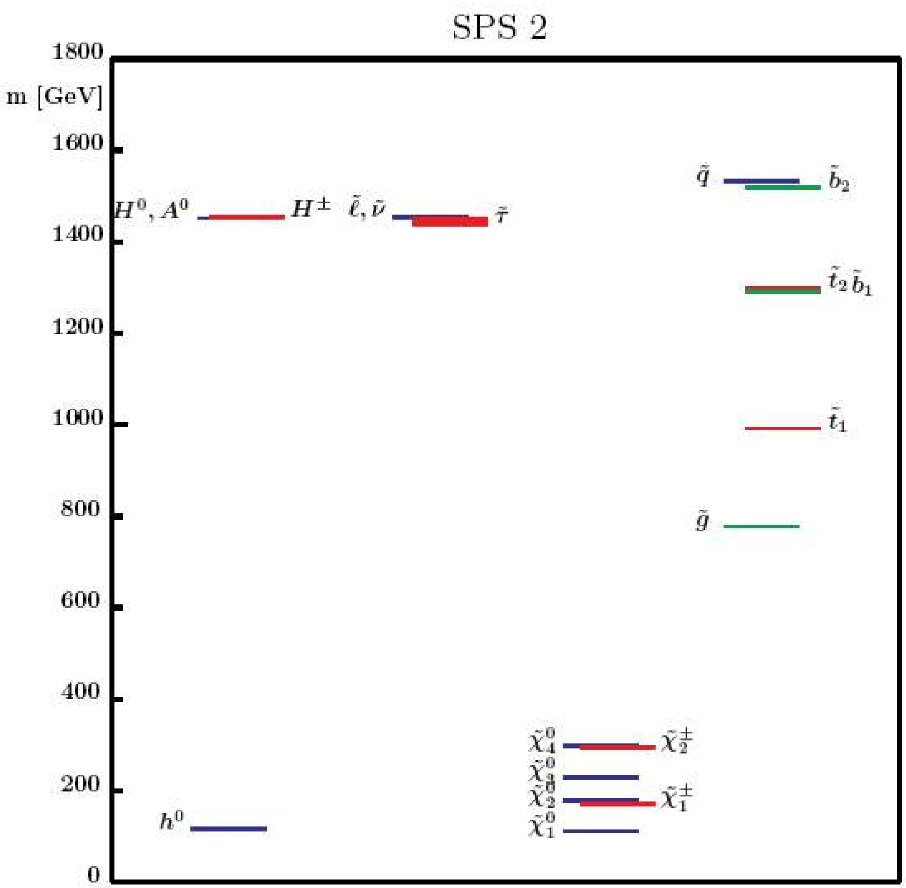


SPS1b

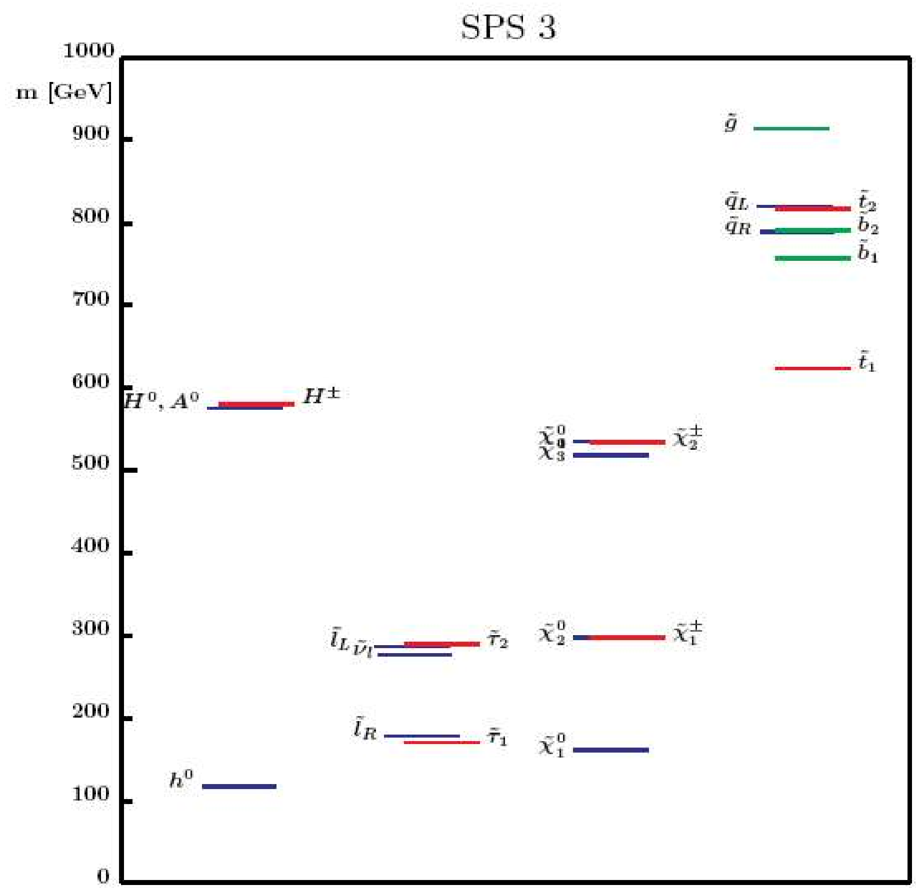
SPS Benchmark Points

SPS2: $m_0 = 1450\,\mathrm{GeV}, \quad m_{1/2} = 300\,\mathrm{GeV}, \quad A_0 = 0, \quad \tan\beta = 10, \quad \mu > 0$

SPS3: $m_0 = 90\,\mathrm{GeV}, \quad m_{1/2} = 400\,\mathrm{GeV}, \quad A_0 = 0, \quad \tan\beta = 10, \quad \mu > 0$



SPS2

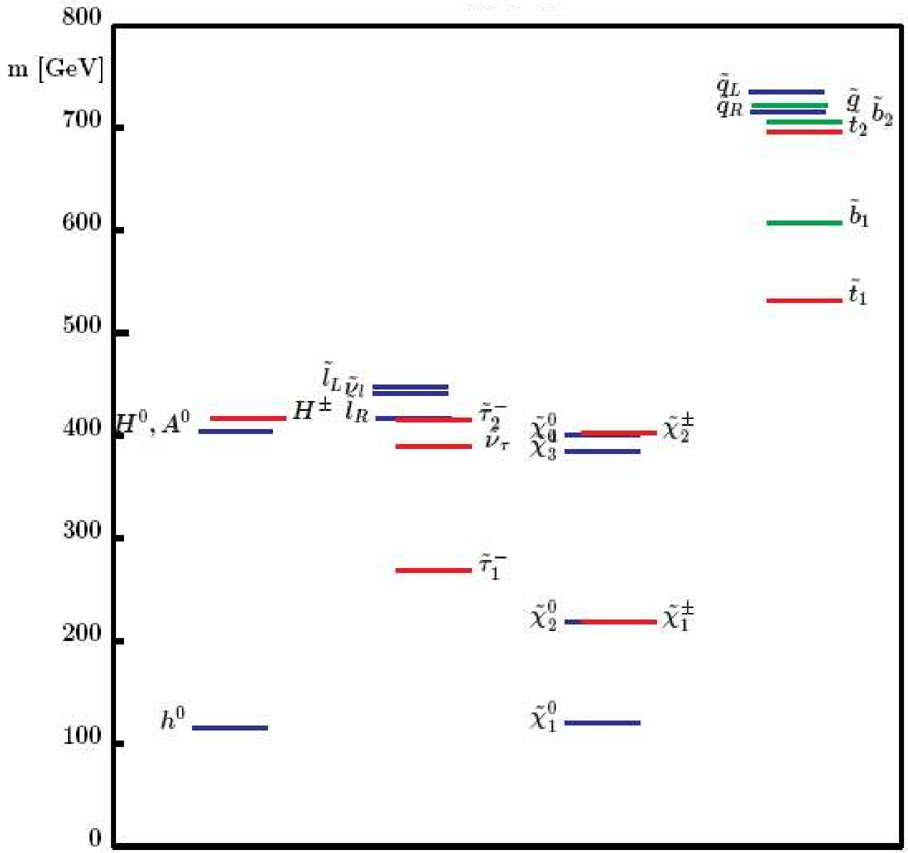


SPS3

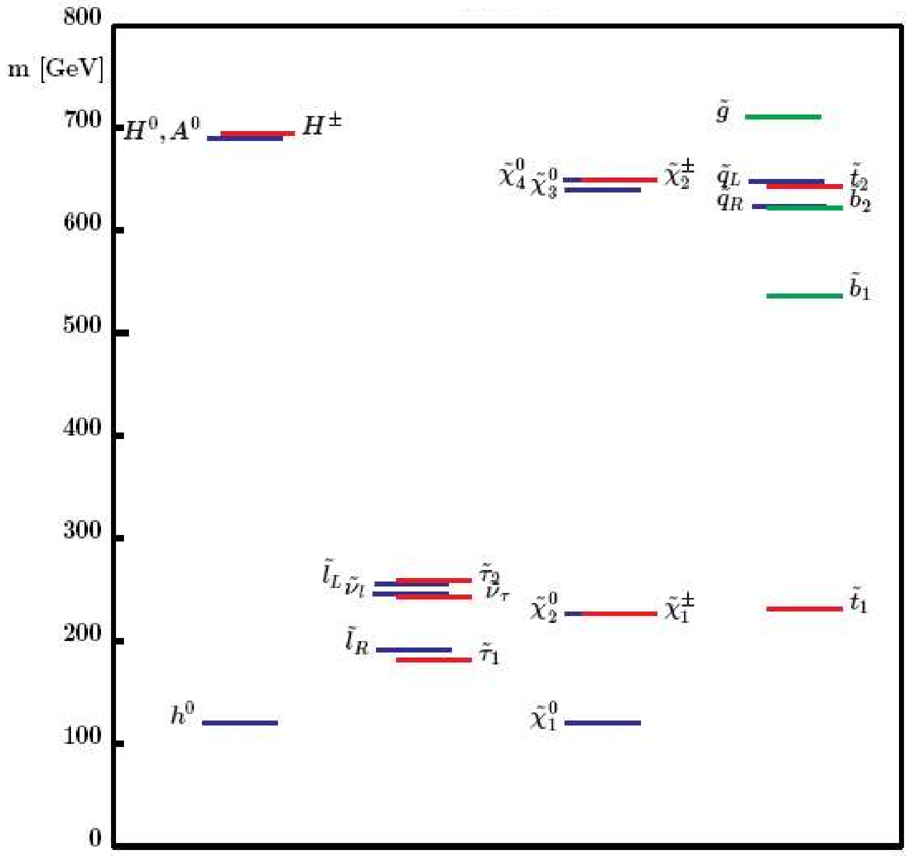
SPS Benchmark Points

SPS4: $M_0 = 400$ GeV, $M_{1/2} = 300$ GeV, $A_0 = 0$ GeV, $\tan\beta = 50$, $\mu > 0$

SPS5: $M_0 = 150$ GeV, $M_{1/2} = 300$ GeV, $A_0 = -1000$ GeV, $\tan\beta = 5$, $\mu > 0$



SPS4



SPS5