R_p violating decays of the sneutrinos

Diego Restrepo

Consejo Superior de Investigaciones Científicas
Universitat de València

IFIC - INSTITUTO DE FISICA CORPUSCULAR

Outline

- Supersymmetry with minimal content of fields: Supersymmetric Standard Model (SSM)

Outline

- Supersymmetry with minimal content of fields: Supersymmetric Standard Model (SSM)
- Majorana neutrino masses in SSM with minimal content of couplings:
  - Minimal Lepton number violation (SSSM)

CSIC

Outline

- Supersymmetry with minimal content of fields:
  Supersymmetric Standard Model (SSM)
- Majorana neutrino masses in SSM with minimal content of couplings:
  - Minimal Lepton number violation (SSSM)
- Correlations between neutrino oscillation experiments and collider physics → Sneutrino decays

Quarks	Squarks
$\begin{pmatrix} u_L \\ d_L \end{pmatrix}$	
$u_R^\dagger$	
$d_R^\dagger$	

Leptons	Sleptons
$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	
$\bar{e}_R^\dagger$	

Higgsinos	Higgs
	$\begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}$

Gauginos	Gauge P.
	$W^\pm$ W^0
	B^0

Quarks	Squarks
$\begin{pmatrix} u_L \\ d_L \end{pmatrix}$	$\begin{pmatrix} \tilde{u}_L \\ \tilde{d}_L \end{pmatrix}$
$u_R^\dagger$	$\tilde{u}_R^*$
$d_R^\dagger$	$\tilde{d}_R^*$

Leptons	Sleptons
$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	$\begin{pmatrix} \tilde{\nu}_L \\ \tilde{e}_L \end{pmatrix}$
$\bar{e}_R^\dagger$	$\tilde{e}_R^*$

Higgsinos	Higgs
$\begin{pmatrix} \tilde{H}_u^+ \\ \tilde{H}_u^0 \end{pmatrix}$	$\begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}$
$\begin{pmatrix} \tilde{H}_d^0 \\ \tilde{H}_d^- \end{pmatrix}$	$\begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$

Gauginos	Gauge P.
$\begin{matrix} \tilde{W}^\pm \\ \tilde{W}_u^0 \end{matrix}$	$\begin{matrix} W^\pm \\ W^0 \end{matrix}$
$\tilde{B}^0$	B^0

SUSY particles SM particles

Quarks	Squarks
$\begin{pmatrix} u_L \\ d_L \end{pmatrix}$	$\begin{pmatrix} \tilde{u}_L \\ \tilde{d}_L \end{pmatrix}$
$u_R^\dagger$	$\tilde{u}_R^*$
$d_R^\dagger$	$\tilde{d}_R^*$

Leptons	Sleptons
$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	$\begin{pmatrix} \tilde{\nu}_L \\ \tilde{e}_L \end{pmatrix}$
$\bar{e}_R^\dagger$	$\tilde{e}_R^*$

Higgsinos	Higgs
$\begin{pmatrix} \tilde{H}_u^+ \\ \tilde{H}_u^0 \end{pmatrix}$	$\begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}$
$\begin{pmatrix} \tilde{H}_d^0 \\ \tilde{H}_d^- \end{pmatrix}$	$\begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$

Gauginos	Gauge P.
$\tilde{W}^\pm$ $\tilde{W}_u^0$	$W^\pm$ W^0
$\tilde{B}^0$	B^0

Fermions Bosons

SSM Superpotential

- $W = h_U \widehat{Q}\widehat{U}\widehat{H}_u + h_D \widehat{Q}\widehat{D}\widehat{L}_0 + h_E \widehat{L}_0 \widehat{L}_i \widehat{E}$
- $-\mu_0 \widehat{L}_0 \widehat{H}_u$

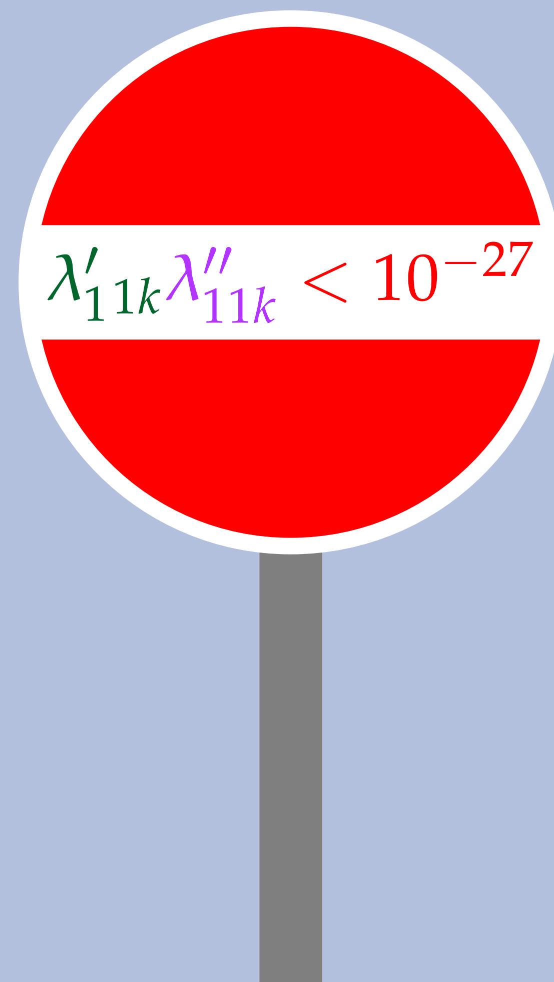
SSM Superpotential

- $W = h_U \widehat{Q}\widehat{U}\widehat{H}_u + h_D \widehat{Q}\widehat{D}\widehat{L}_0 + h_E \widehat{L}_0 \widehat{L}_i \widehat{E}$
- $\qquad -\mu_0 \widehat{L}_0 \widehat{H}_u$
- $\qquad -\mu_i \widehat{L}_i \widehat{H}_u$
- $\qquad +\lambda_{ijk} \widehat{L}_i \widehat{L}_j \widehat{E}_k + \lambda'_{ijk} \widehat{L}_i \widehat{Q}_j \widehat{D}_k$

CSIC

SSM Superpotential

- $W = h_U \widehat{Q}\widehat{U}\widehat{H}_u + h_D \widehat{Q}\widehat{D}\widehat{L}_0 + h_E \widehat{L}_0 \widehat{L}_i \widehat{E}$
- $-\mu_0 \widehat{L}_0 \widehat{H}_u$
- $-\mu_i \widehat{L}_i \widehat{H}_u$
- $+\lambda_{ijk} \widehat{L}_i \widehat{L}_j \widehat{E}_k + \lambda'_{ijk} \widehat{L}_i \widehat{Q}_j \widehat{D}_k$
- $+\lambda''_{ijk} \widehat{U}_i \widehat{D}_j \widehat{D}_k$



Dim. ≤ 5 L or B	Name
	R_pSSM
	SSSM
	L_pSSM
	–
	–
$\lambda_{ijk}\widehat{L}_i\widehat{L}_j\widehat{E}_k + \lambda'_{ijk}\widehat{L}_i\widehat{Q}_j\widehat{D}_k + \mu_i\widehat{L}_i\widehat{H}_u$	B_pSSM
3,9,12,30,39	

Dim. ≤ 5 L or B	Name
	R_pSSM
$\mu_i \widehat{L}_i \widehat{H}_u$	SSSM
	L_pSSM
	–
	–
$\lambda_{ijk} \widehat{L}_i \widehat{L}_j \widehat{E}_k + \lambda'_{ijk} \widehat{L}_i \widehat{Q}_j \widehat{D}_k + \mu_i \widehat{L}_i \widehat{H}_u$	B_pSSM
3,9,12,30,39	

Dim. ≤ 5 L or B	Name
	R_pSSM
$\mu_i \widehat{L}_i \widehat{H}_u$	SSSM
$\lambda''_{ijk} \widehat{U}_i \widehat{D}_j \widehat{D}_k$	L_pSSM
	–
	–
$\lambda_{ijk} \widehat{L}_i \widehat{L}_j \widehat{E}_k + \lambda'_{ijk} \widehat{L}_i \widehat{Q}_j \widehat{D}_k + \mu_i \widehat{L}_i \widehat{H}_u$	B_pSSM
3,9,12,30,39	

Dim. ≤ 5 L or B	Name
	R_pSSM
$\mu_i \widehat{L}_i \widehat{H}_u$	SSSM
$\lambda''_{ijk} \widehat{U}_i \widehat{D}_j \widehat{D}_k$	L_pSSM
$\lambda_{ijk} \widehat{L}_i \widehat{L}_j \widehat{E}_k + \mu_i \widehat{L}_i \widehat{H}_u$	–
	–
$\lambda_{ijk} \widehat{L}_i \widehat{L}_j \widehat{E}_k + \lambda'_{ijk} \widehat{L}_i \widehat{Q}_j \widehat{D}_k + \mu_i \widehat{L}_i \widehat{H}_u$	B_pSSM

3,9,12,30,39

Dim. ≤ 5 L or B	Name
	R_pSSM
$\mu_i \widehat{L}_i \widehat{H}_u$	SSSM
$\lambda''_{ijk} \widehat{U}_i \widehat{D}_j \widehat{D}_k$	L_pSSM
$\lambda_{ijk} \widehat{L}_i \widehat{L}_j \widehat{E}_k + \mu_i \widehat{L}_i \widehat{H}_u$	–
$\lambda'_{ijk} \widehat{L}_i \widehat{Q}_j \widehat{D}_k + \mu_i \widehat{L}_i \widehat{H}_u$	–
$\lambda_{ijk} \widehat{L}_i \widehat{L}_j \widehat{E}_k + \lambda'_{ijk} \widehat{L}_i \widehat{Q}_j \widehat{D}_k + \mu_i \widehat{L}_i \widehat{H}_u$	B_pSSM
3,9,12,30,39	

Dim. ≤ 5 L or B	Name
	R_pSSM
$\mu_i \widehat{L}_i \widehat{H}_u$	SSSM
$\lambda''_{ijk} \widehat{U}_i \widehat{D}_j \widehat{D}_k$	L_pSSM
$\lambda_{ijk} \widehat{L}_i \widehat{L}_j \widehat{E}_k + \mu_i \widehat{L}_i \widehat{H}_u$	–
$\lambda'_{ijk} \widehat{L}_i \widehat{Q}_j \widehat{D}_k + \mu_i \widehat{L}_i \widehat{H}_u$	–
$\lambda_{ijk} \widehat{L}_i \widehat{L}_j \widehat{E}_k + \lambda'_{ijk} \widehat{L}_i \widehat{Q}_j \widehat{D}_k + \mu_i \widehat{L}_i \widehat{H}_u$	B_pSSM
3,9,12,30,39	

mass eigenstates

For the third generation the squark and stau mixing can be large:

- $\tilde{t}_L,\ \tilde{t}_R \longrightarrow \quad \tilde{t}_1, \quad \tilde{t}_2,\ \cos\theta_{\tilde{t}}$
- $\tilde{b}_L,\ \tilde{b}_R \longrightarrow \tilde{b}_1,\ \tilde{b}_2,\ \cos\theta_{\tilde{b}}$
- $\tilde{\tau}_L,\ \tilde{\tau}_R \longrightarrow \tilde{\tau}_1,\ \tilde{\tau}_2,\ \cos\theta_{\tilde{\tau}}$
- $\tilde{W}^+,\ \tilde{H}_u^+ \longrightarrow \tilde{\chi}_1^+, \tilde{\chi}_2^+$
- $\tilde{W}^0, \tilde{B}^0, \tilde{H}_u^0, \tilde{H}_d^0 \longrightarrow \quad \tilde{\chi}_1^0, \quad \dots, \tilde{\chi}_4^0$
- $\longrightarrow \quad \tilde{\nu}_i$

mass eigenstates

For the third generation the squark and stau mixing can be large:

- $\tilde{t}_L,\ \tilde{t}_R \longrightarrow \tilde{t}_1,\ \tilde{t}_2,\ \cos\theta_{\tilde{t}}$
- $\tilde{b}_L,\ \tilde{b}_R \longrightarrow \tilde{b}_1,\ \tilde{b}_2,\ \cos\theta_{\tilde{b}}$
- $\tilde{\tau}_L,\ \tilde{\tau}_R \longrightarrow \tilde{\tau}_1,\ \tilde{\tau}_2,\ \cos\theta_{\tilde{\tau}} \longrightarrow S_i^{\pm}$
- $\tilde{W}^+,\ \tilde{H}_u^+ \longrightarrow \tilde{\chi}_1^+, \tilde{\chi}_2^+ \longrightarrow \tilde{\chi}_i^+, \tau^+$
- $\tilde{W}^0, \tilde{B}^0, \tilde{H}_u^0, \tilde{H}_d^0 \longrightarrow \tilde{\chi}_1^0, \ \ldots, \tilde{\chi}_4^0 \longrightarrow \tilde{\chi}_i^0, \nu_i$
- $\longrightarrow \tilde{\nu}_i \longrightarrow S_i^0, P_i^0$

mass eigenstates

For the third generation the squark and stau mixing can be large:

- $\tilde{t}_L, \ \tilde{t}_R \longrightarrow \ \tilde{t}_1, \ \ \tilde{t}_2, \ \cos\theta_{\tilde{t}}$
- $\tilde{b}_L, \ \tilde{b}_R \longrightarrow \tilde{b}_1, \ \tilde{b}_2, \ \cos\theta_{\tilde{b}}$
- $\tilde{\tau}_L, \ \tilde{\tau}_R \longrightarrow \tilde{\tau}_1, \ \tilde{\tau}_2, \ \cos\theta_{\tilde{\tau}} \qquad \longrightarrow S_i^{\pm}$
- $\tilde{W}^+, \ \tilde{H}_u^+ \longrightarrow \tilde{\chi}_1^+, \tilde{\chi}_2^+ \longrightarrow \tilde{\chi}_i^+, \tau^+$
- $\tilde{W}^0, \tilde{B}^0, \tilde{H}_u^0, \tilde{H}_d^0 \longrightarrow \ \tilde{\chi}_1^0, \ \ldots, \tilde{\chi}_4^0 \longrightarrow \tilde{\chi}_i^0, \nu_i$
- $\longrightarrow \tilde{\nu}_i \qquad \longrightarrow S_i^0, P_i^0$

Neutrino mass

The mixing $\tilde{\chi}_1^0$–ν induce the mass

$$m_\nu \approx 2\frac{m_W^2}{M_2}\frac{\sin^2\xi}{1+\tan^2\beta}$$

Neutrino mass

The mixing $\tilde{\chi}_1^0$–ν induce the mass

$$m_\nu \approx 2\frac{m_W^2}{M_2}\frac{\sin^2\xi}{1+\tan^2\beta}$$

$$\sin^2\xi = \frac{\sum_i \Lambda_i^2}{\mu^2+v_d^2} = \frac{\sum_i(\mu_0 v_i - \mu_i v_0)^2}{(\mu_0^2+\sum_i \mu_i^2)(v_0^2+\sum_i v_i^2)}$$

where $v_0 = \langle L_0\rangle = \langle H_d\rangle,\ v_i = \langle L_i\rangle,\ \epsilon_i = -\mu_i$

Neutrino mass

The mixing $\tilde{\chi}_1^0$–ν induce the mass

$$m_\nu \approx 2\frac{m_W^2}{M_2}\frac{\sin^2\xi}{1+\tan^2\beta}$$

For $m_\nu = 1\,\text{eV}$ and $1 \leq \tan\beta \leq 60 \longrightarrow$

Neutrino mass

The mixing $\tilde{\chi}_1^0$–ν induce the mass

$$m_\nu \approx 2\frac{m_W^2}{M_2}\frac{\sin^2\xi}{1+\tan^2\beta}$$

For $\quad m_\nu = 1\,\text{eV} \quad$ and $1 \le \tan\beta \le 60 \longrightarrow$

$$10^{-5} \lesssim \sin\xi \lesssim 10^{-4}$$

CSIC

Neutrino mass

The mixing $\tilde{\chi}_1^0$–ν induce the mass

$$m_\nu \approx 2\frac{m_W^2}{M_2}\frac{\sin^2\xi}{1+\tan^2\beta}$$

For $m_\nu = 1\,\mathrm{eV}$ and $1 \leq \tan\beta \leq 60 \longrightarrow$

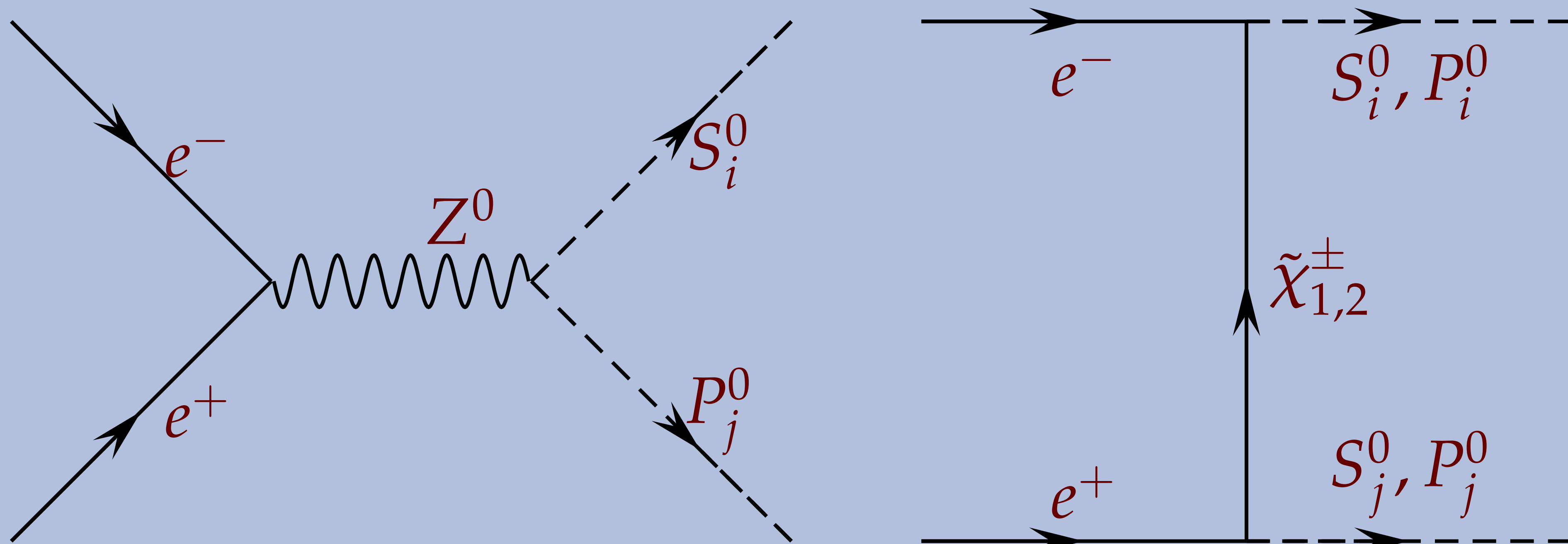
$$10^{-5} \lesssim \sin\xi \lesssim 10^{-4}$$

Radiative Generated Misalignment (RGM)

$$\sin^2\xi \sim \frac{\sum_i \mu_i^2}{\mu^2}\frac{4g^4 m_b^4}{m_W^4}\left(1+\tan^2\beta\right)^2 \sim 10^{-3}\frac{\sum_i \mu_i^2}{\mu^2}\left(1+\tan^2\beta\right)^2$$

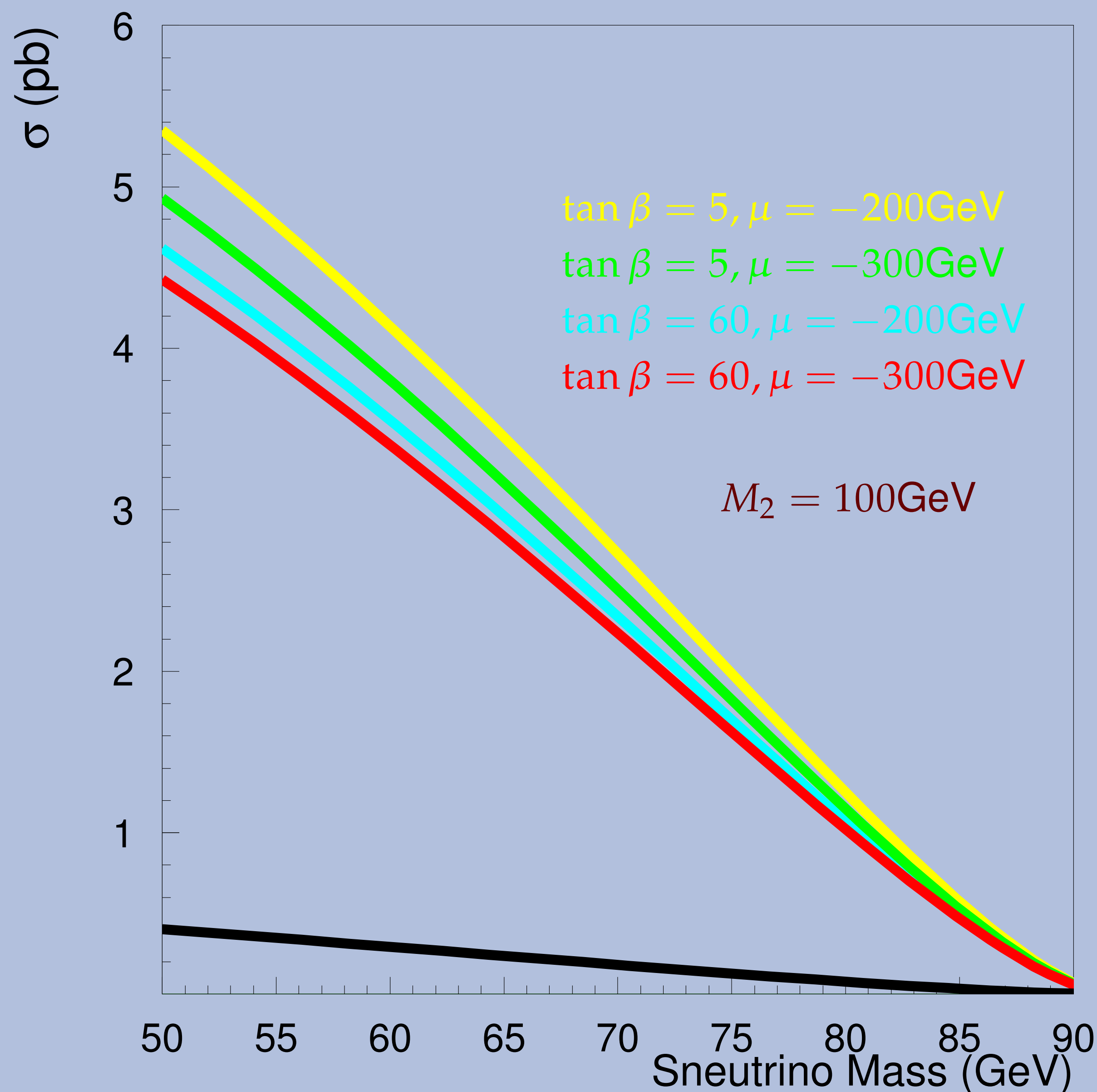
RGM: $\mu_i \sim 1\,\mathrm{GeV}$

Sneutrino Production

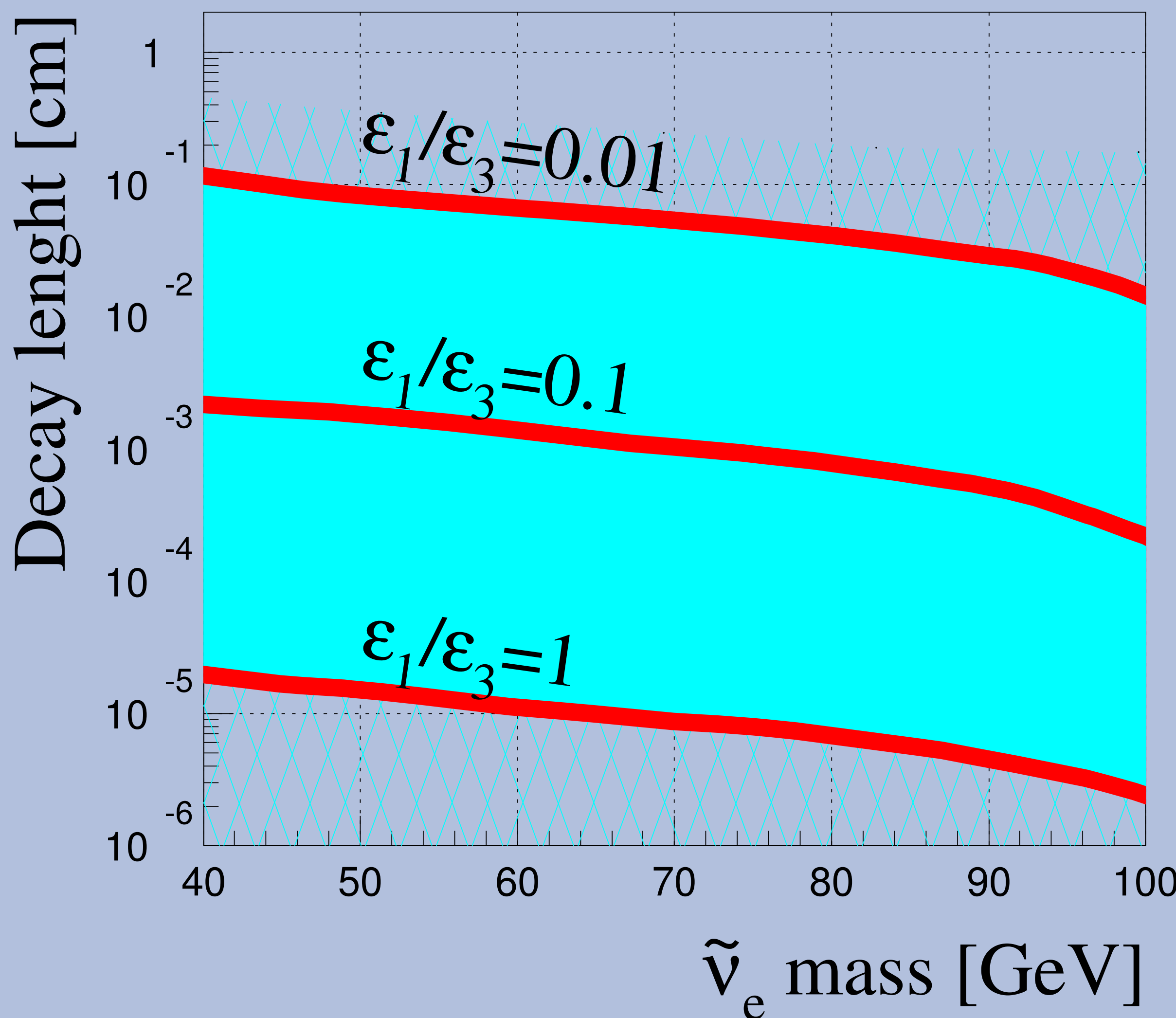


Mainly $\tilde{\nu}_e$

Sneutrino Production



Decay Lenght



$m_{\nu_3} \approx 0.06\,\mathrm{eV}$,

$2 < \tan\beta < 50$,

$200 < \mu < 500\,\mathrm{GeV}$,

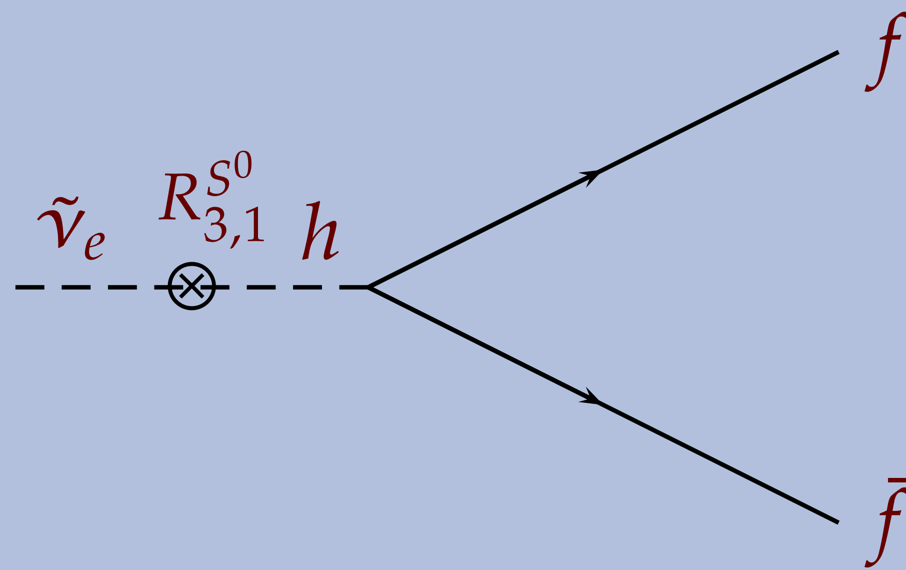
$100 < m_A < 500\,\mathrm{GeV}$,

$65 < m_{L_i} < 100\,\mathrm{GeV}$,

$M_2 = 140\,\mathrm{GeV}$,

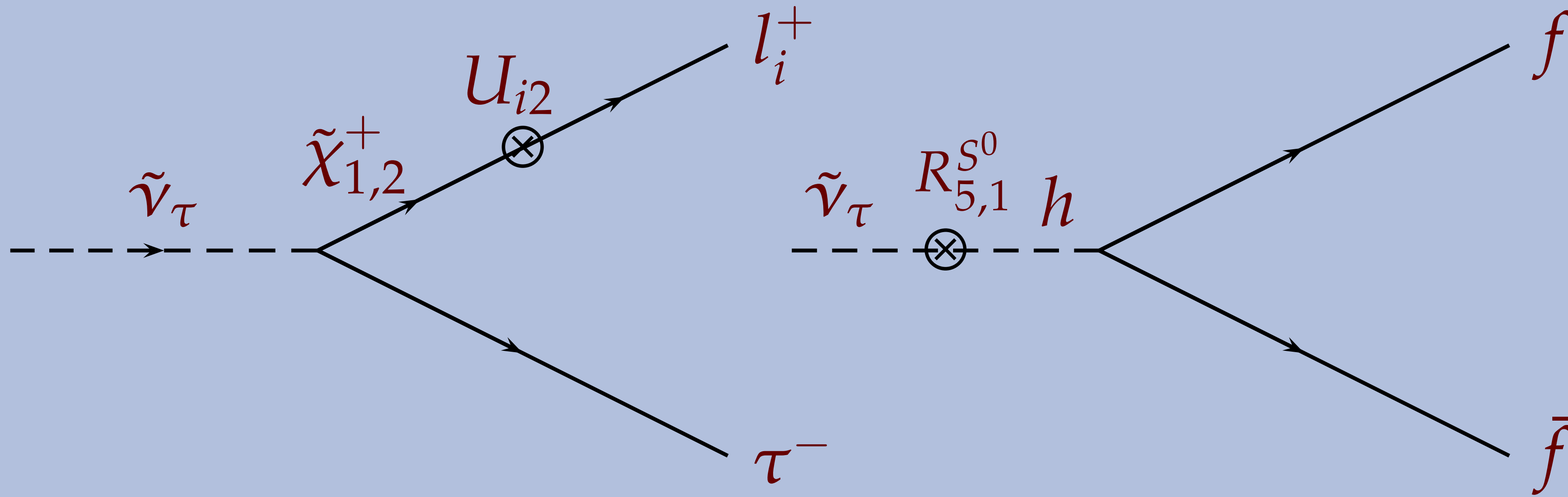
$-2 < \epsilon_{1,2}/\epsilon_3 < 2$,

Sneutrino decay



$$\frac{\sum_{i,j}\Gamma(\tilde{\nu}_e^R \longrightarrow l_i^+ l_j^-)}{\Gamma(\tilde{\nu}_e^R \longrightarrow b\bar{b})} \approx \frac{\Gamma\left(\tilde{\nu}_e^R \longrightarrow \tau^+\tau^-\right)}{\Gamma(\tilde{\nu}_e^R \longrightarrow b\bar{b})} \approx \frac{m_\tau^2}{3m_b^2}$$

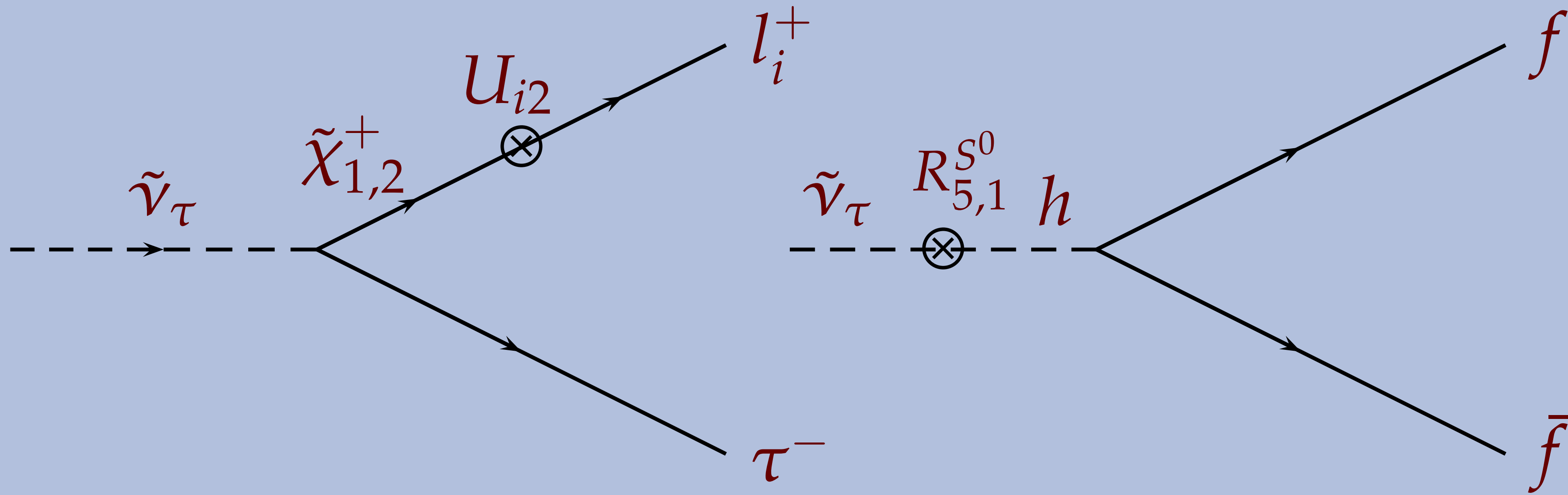
Sneutrino decay



$$\frac{\sum_{i,j}\Gamma(\tilde{\nu}^R_\tau \to l_i^\pm l_j^\mp)}{\Gamma(\tilde{\nu}^R_\tau \to b\bar{b})} \approx \frac{\sum_i \Gamma(\tilde{\nu}^R_\tau \to \tau^\pm l_i^\mp)}{\Gamma(\tilde{\nu}^R_\tau \to b\bar{b})}$$

$$\approx \frac{m_\tau^2}{3m_b^2}\frac{m^4_{A\tilde{\nu}_\tau}}{\mu^4}\left[\left(1-\frac{\mu^2}{m^2_{A\tilde{\nu}_\tau}}\right)^2+\frac{\epsilon_2^2}{\epsilon_3^2}+\frac{\epsilon_1^2}{\epsilon_3^2}\right]$$

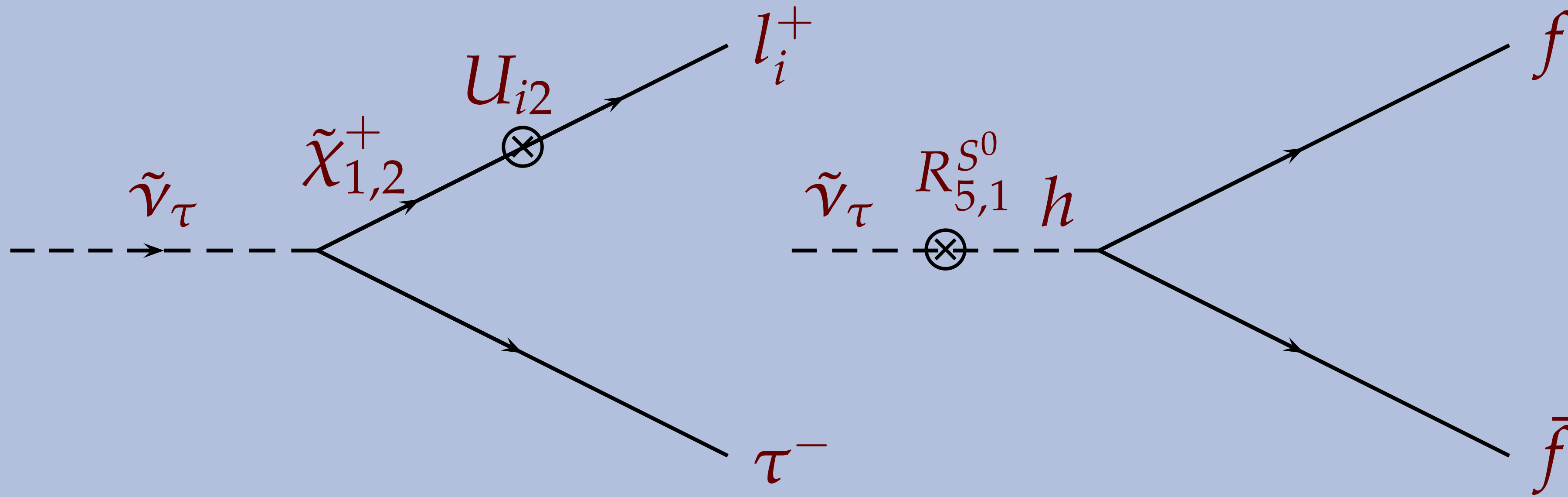
Sneutrino decay



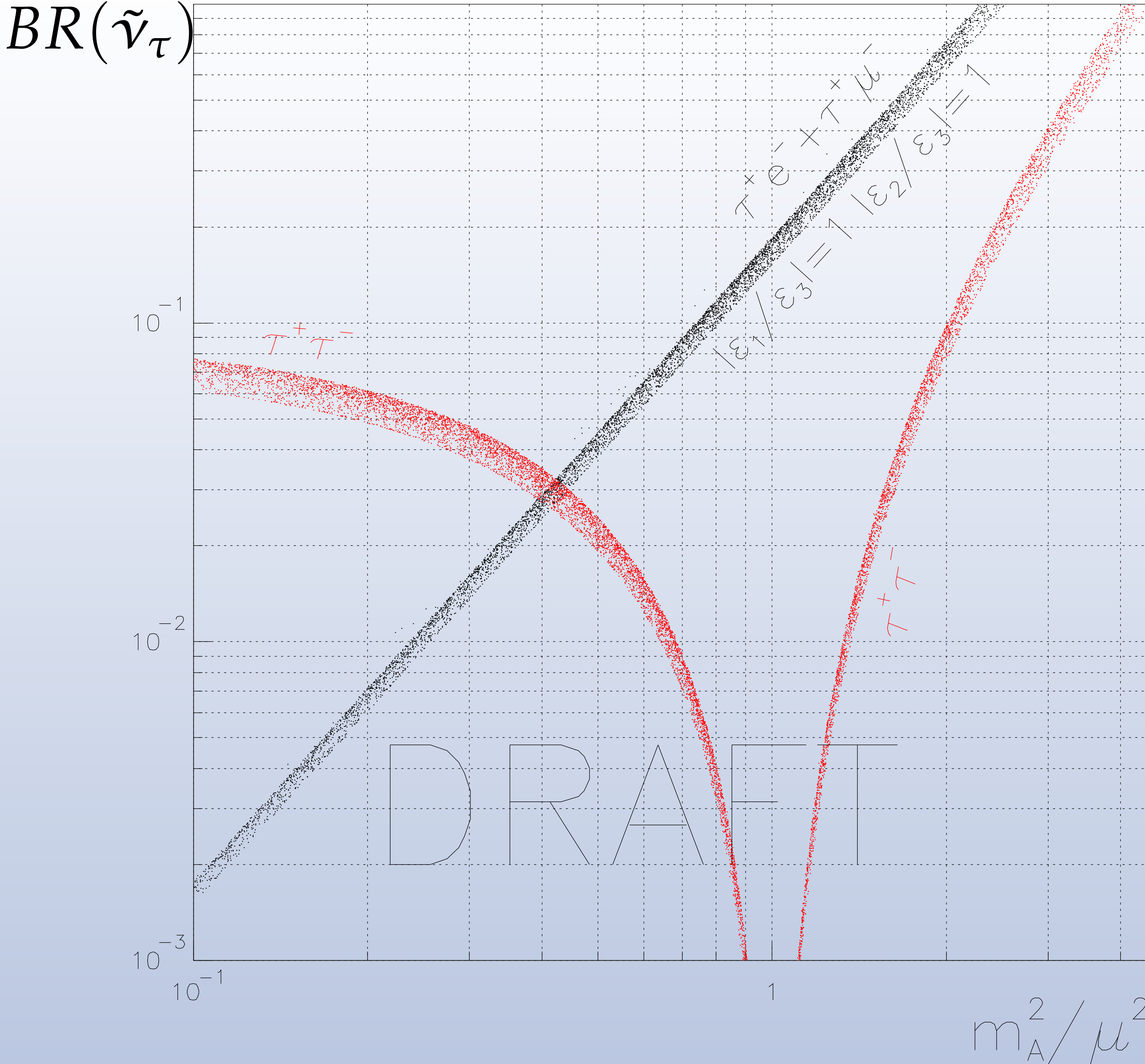
$$\frac{\Gamma(\tilde{\nu}_\tau \to \tau^\pm l_i^\mp)}{\Gamma(\tilde{\nu}_\tau \to \tau^\pm l_j^\mp)} \approx \frac{\epsilon_i^2}{\epsilon_j^2} \frac{[1-(\mu^2/m^2_{A\tilde{\nu}_\tau})\delta_{i3}]^2}{[1-(\mu^2/m^2_{A\tilde{\nu}_\tau})\delta_{j3}]^2}$$

$$\frac{\Gamma(\tilde{\nu}_e \to \tau^\pm \tau^\mp)}{\Gamma(\tilde{\nu}_\tau \to \tau^\pm l_j^\mp)} \approx \frac{\epsilon_1^2}{\epsilon_j^2} \frac{(\mu^4/m^4_{A\tilde{\nu}_e})}{[1-(\mu^2/m^2_{A\tilde{\nu}_\tau})\delta_{j3}]^2}$$

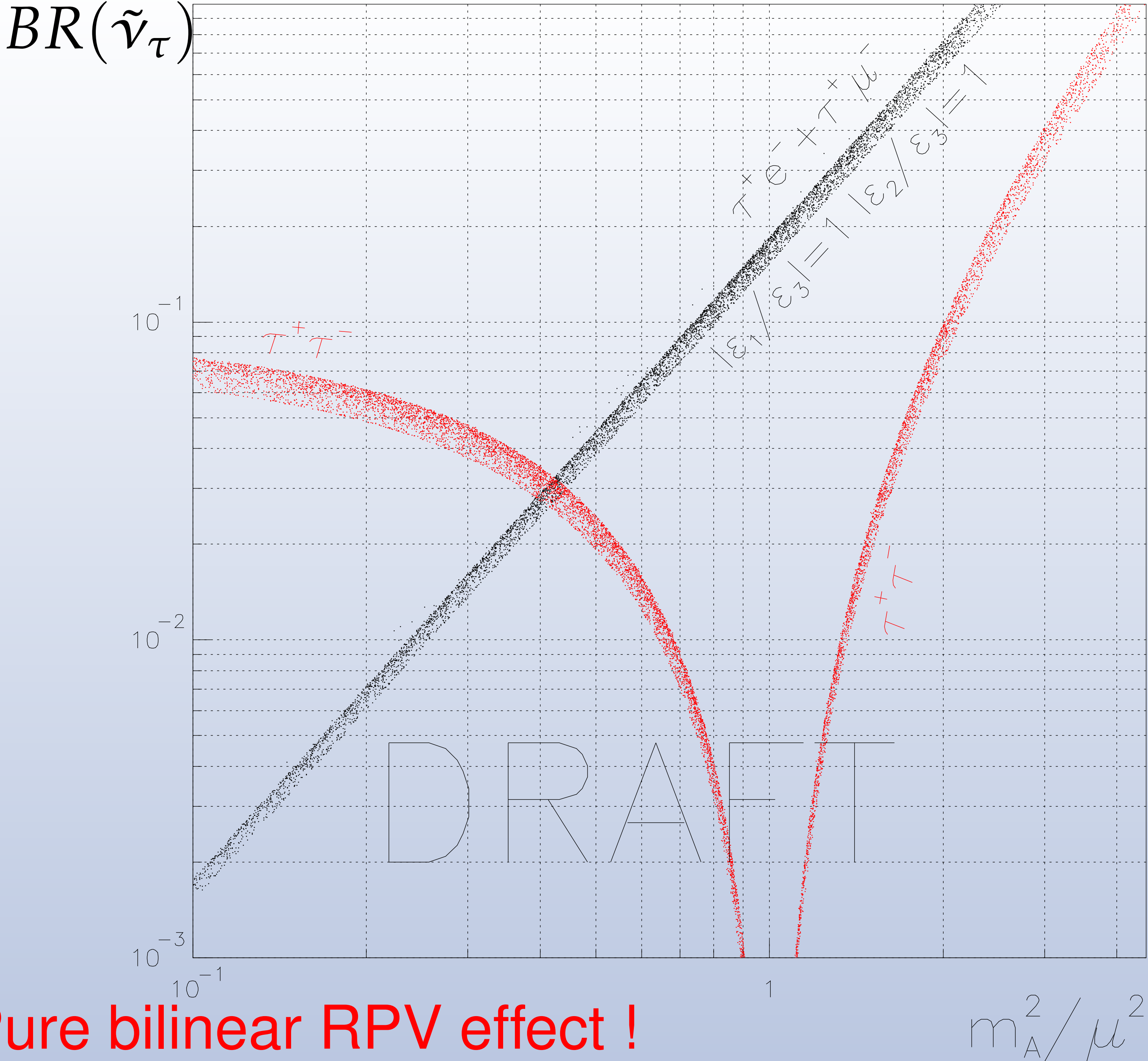
Sneutrino decay



$$\frac{\Gamma(\tilde{\nu}_\tau \longrightarrow \tau^\pm e^\mp)}{\Gamma(\tilde{\nu}_\tau \longrightarrow \tau^\pm \mu^\mp)} \approx \frac{\epsilon_1^2}{\epsilon_2^2} \approx \tan^2\theta_{\rm sol}$$



$BR(\tilde{\nu}_\tau)$
$\tau^+\tau^-$
$\tau^+ e^- + \tau^+ \mu^-$
$|\varepsilon_1/\varepsilon_3| = 1$ $|\varepsilon_2/\varepsilon_3| = 1$
$\tau^+\tau^-$
DRAFT
10^{-1}
10^{-2}
10^{-3}
10^{-1}
1
m_A^2/μ^2



Pure bilinear RPV effect !

Conclusions

- Enhanced $\tilde{\nu}_e$ production
- $\tilde{\nu}_e \longrightarrow b\bar{b}$ like a Higgs
- Bilinear R-parity Violation
  - Correlations of $\tilde{\nu}_\tau$ decays with neutrino physics
  - $\tilde{\nu}_\tau \longrightarrow \tau\tau \neq 0$
  - Measurable invisible decays