LFV constraints on M_R in mSUGRA

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LFV

Neutrino oscillations $\rightarrow$ Neutrino masses/mixings

Theoretical framework:

- SUSY see-saw mechanism (Majorana mass M_R ??)
- R-parity conserving mSUGRA scenarios
- Present/future neutrino data

Rare radiative decays:

- $\mathrm{Br}(\mu \rightarrow e\gamma) < 1.2 \times 10^{-11}$ (Future: $10^{-14}, 10^{-15}$)
- $\mathrm{Br}(\tau \rightarrow \mu\gamma) < 1.1 \times 10^{-6}$ (Future: 10^{-9})
- $Br\left(\mu^+ \rightarrow e^+e^+e^-\right) < 1.0 \times 10^{-12}$ (Future: 10^{-16})
- $R\left(\mu^- Ti \rightarrow e^- Ti\right) < 6.1 \times 10^{-13}$ (Future: $10^{-14}, 10^{-18}$)

High-energy processes:

- $e^+e^- \rightarrow \sum_{\alpha,\beta} \tilde{l}_\alpha^+ \tilde{l}_\beta^- \rightarrow l_i^- l_j^+ \tilde{\chi}_1^0 \tilde{\chi}_1^0$
- $e^-e^- \rightarrow \sum_{\alpha,\beta} \tilde{l}_\alpha^- \tilde{l}_\beta^- \rightarrow l_i^- l_j^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$

SUSY see-saw mechanism

Neutrinos

Neutrino mass terms:

$$-\left(\begin{array}{cc}\bar{\nu}_L & \bar{\nu}_R^{\,c}\end{array}\right)\left(\begin{array}{cc}0 & m_D/2 \\ m_D^T/2 & M_R\end{array}\right)\left(\begin{array}{c}\nu_L^{\,c} \\ \nu_R\end{array}\right)$$

$\rightarrow$ very heavy ν_R / very light ν_L

Diagonalization of left-handed neutrino mass matrix:

$$V^T M_\nu V = \text{diag}\ \underbrace{(m_1, m_2, m_3)}_{\text{Neutrino data}}$$

$$\text{Mixing matrix } V = V\overbrace{(\theta_{12}, \theta_{13}, \theta_{23}, \delta)}$$

Sleptons

RGE of Yukawa couplings and gauge couplings: $M_Z \rightarrow M_{GUT}$

New mSUGRA scenarios (with universality conditions at M_{GUT})

Charged slepton (mass)^2 matrix: $m_{\tilde{l}}^2 = \left(\begin{array}{cc}m_L^2 & (m_{LR}^2)^\dagger \\ m_{LR}^2 & m_R^2\end{array}\right)$

LFV terms in slepton mass matrix: RGE ($M_{GUT} \rightarrow M_R$)

$$\delta m_L^2 \simeq -\frac{1}{8\pi^2}(3m_0^2 + A_0^2) Y_\nu^\dagger Y_\nu \ln\left(\frac{M_{GUT}}{M_R}\right)$$

$$\delta m_R^2 \simeq 0$$

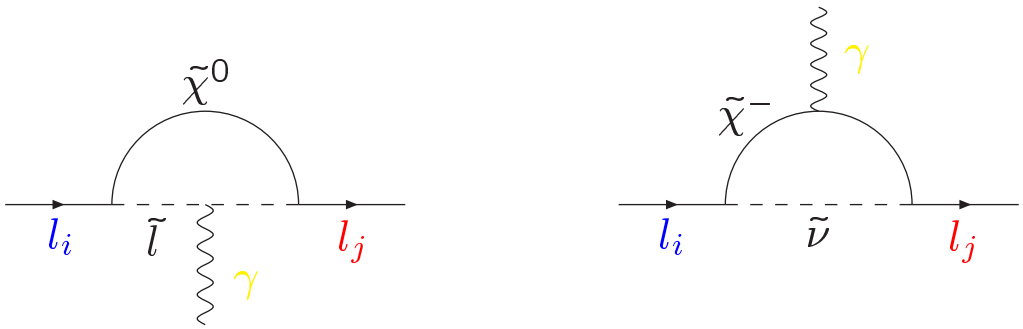
For degenerate M_R:

$$Y_\nu^\dagger Y_\nu = \frac{M_R}{v^2 \sin^2\beta} V \cdot \text{diag}(m_1, m_2, m_3) \cdot V^\dagger$$

Low-energy LFV

SM + massive $\nu's$: $l_i^- \to l_j^- \gamma$ unobservable

SUSY diagrams:



$$\Gamma\left(l_i^- \to l_j^- \gamma\right) \sim \alpha^3 m_{li}^5 \frac{\left|(\delta m_L)^2_{ij}\right|^2}{m_S^8} \tan^2\beta$$

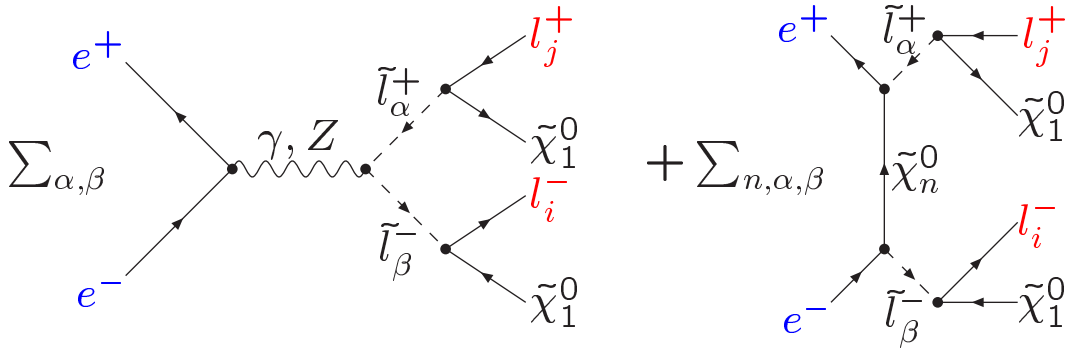
$\mu \to e\gamma$ penguin contributions dominant for

- $Br(\mu \to 3e)$:
  $Br(\mu \to 3e) \approx (6-7) \cdot 10^{-3} Br(\mu \to e\gamma)$

- $R(\mu^- N \to e^- N)$:
  $R(\mu^- Ti \to e^- Ti) \approx (5-7) \cdot 10^{-3} Br(\mu \to e\gamma)$

High-energy LFV

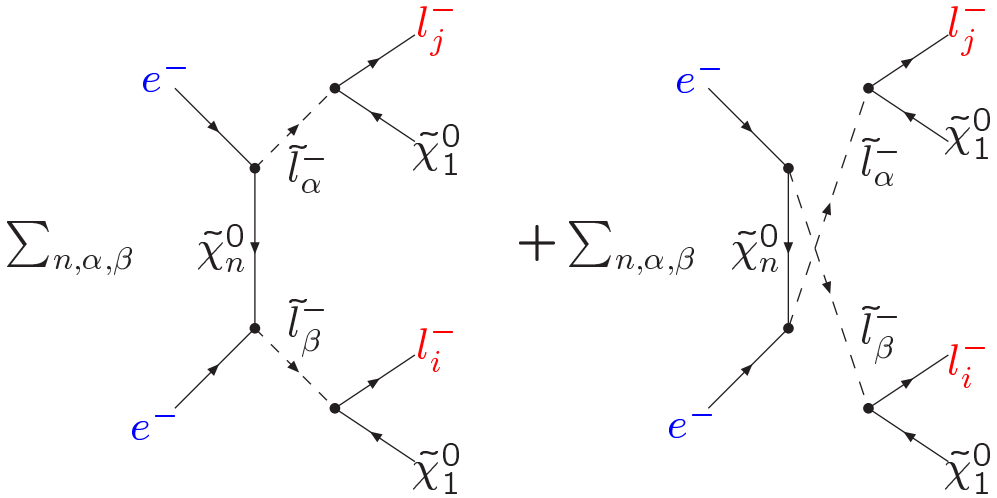
e^+e^- collisions:



- SM background:
  Double/single W-production: $e^+e^- \to l_i^- l_j^+ \bar{\nu}_i \nu_j$
  Cuts $\to \sigma_{SM} < 10$ fb at $\sqrt{s} = 800$ GeV

- MSSM background:
  Slepton/chargino production: $e^+e^- \to l_i^- l_j^+ + 2\tilde{\chi}_1^0 + 2(4)\nu$

e^-e^- collisions:



- SM background:
  Single W-production: $e^-e^- \to e^- l_i^- \nu_e \bar{\nu}_i$
  Cuts $\to \sigma_{SM} < 30$ fb at $\sqrt{s} = 800$ GeV

- MSSM background:
  Slepton production: $e^-e^- \to l_i^- l_j^- + 2\tilde{\chi}_1^0 + 2(4)\nu$

mSUGRA benchmark scenarios

- Proposed for Linear Collider studies (Battaglia et al.)
- Direct sparticle searches
- $b \to s\gamma$
- Cosmological bounds
- Higgs searches

mSUGRA parameter:

- m_0: Common scalar mass at M_{GUT}

$$90 \text{ GeV} \leq m_0 \leq 3450 \text{ GeV}$$

- $m_{1/2}$: Common gaugino mass at M_{GUT}

$$250 \text{ GeV} \leq m_{1/2} \leq 1900 \text{ GeV}$$

- A_0: Common trilinear coupling at M_{GUT}

$$A_0 = 0$$

- $\tan\beta$: Ratio of Higgs VEVs at EW scale $(\tan\beta = \frac{\langle H_2^0 \rangle}{\langle H_1^0 \rangle})$

$$5 \leq \tan\beta \leq 50$$

- sign(μ): Sign of Higgs mixing term

$$\text{sign}(\mu) = \pm 1$$

Neutrino data

LMA solution, present best fit

Oscillation parameters:

- $\nu_e - \nu_{\mu,\tau}$:
  $\delta\Delta m^2_{12}/\Delta m^2_{12} = 10\%$, $\delta \sin^2 2\theta_{12} = \pm 0.1$ (KAMLAND)

- $\nu_\mu - \nu_\tau$:
  $\delta\Delta m^2_{23} = \pm 10^{-3}$ eV^2, $\delta \sin^2 2\theta_{23} = \pm 0.1$ (MINOS)

- $\nu_e - \nu_\tau$:
  $\delta \sin^2 2\theta_{13} \sim 10^{-4}$ (Neutrino factory/ galactic supernova)

Absolute neutrino mass scale:

i) $m_{ee} < 10^{-2}$ eV $\rightarrow m_1 < 3 \cdot 10^{-2}$ eV
(GENIUSI/ MAJORANA/ EX0/ XMASS/ MOON)

ii) $m_1 \sim 0.3$ eV (KATRIN)

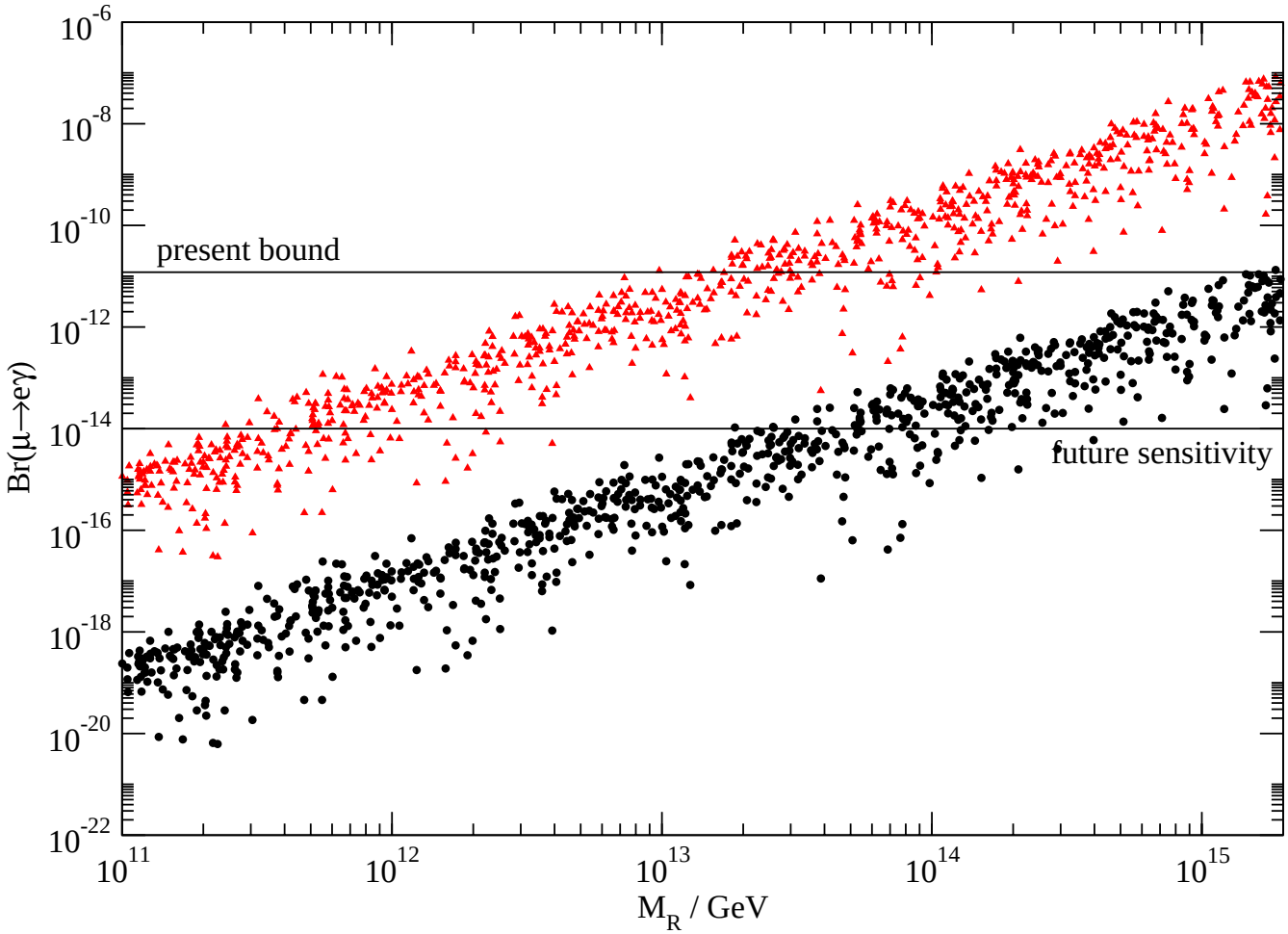
Neutrino mass schemes:

i) ν_L's hierarchical:
$$\left(Y_\nu^\dagger Y_\nu\right)_{ij} \approx \frac{M_R}{v^2 \sin^2\beta}\sqrt{\Delta m^2_{23}}\left(\sqrt{\frac{\Delta m^2_{12}}{\Delta m^2_{23}}}V^*_{i2}V_{j2} + V^*_{i3}V_{j3}\right)$$

ii) ν_L's degenerate:
$$\left(Y_\nu^\dagger Y_\nu\right)_{ij} \approx \frac{M_R}{v^2 \sin^2\beta}\left(m_1\delta_{ij} + \frac{\Delta m^2_{23}}{2m_1}\left(\frac{\Delta m^2_{12}}{\Delta m^2_{23}}V^*_{i2}V_{j2} + V^*_{i3}V_{j3}\right)\right)$$

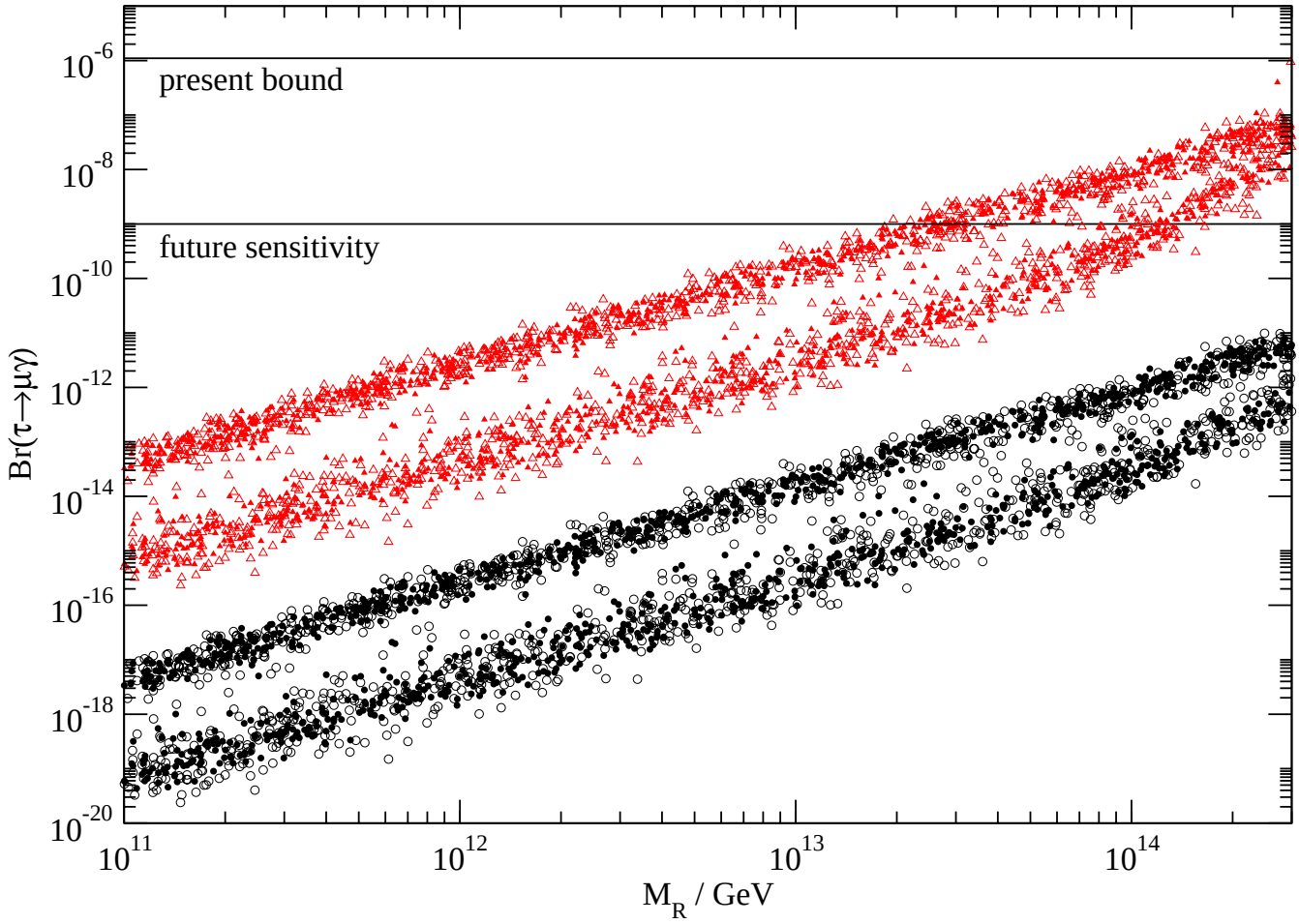
$\rightarrow Br(\text{degenerate}) \ll Br(\text{hierarchical})$

$Br(\mu \to e\gamma)$, hierar. ν_L's



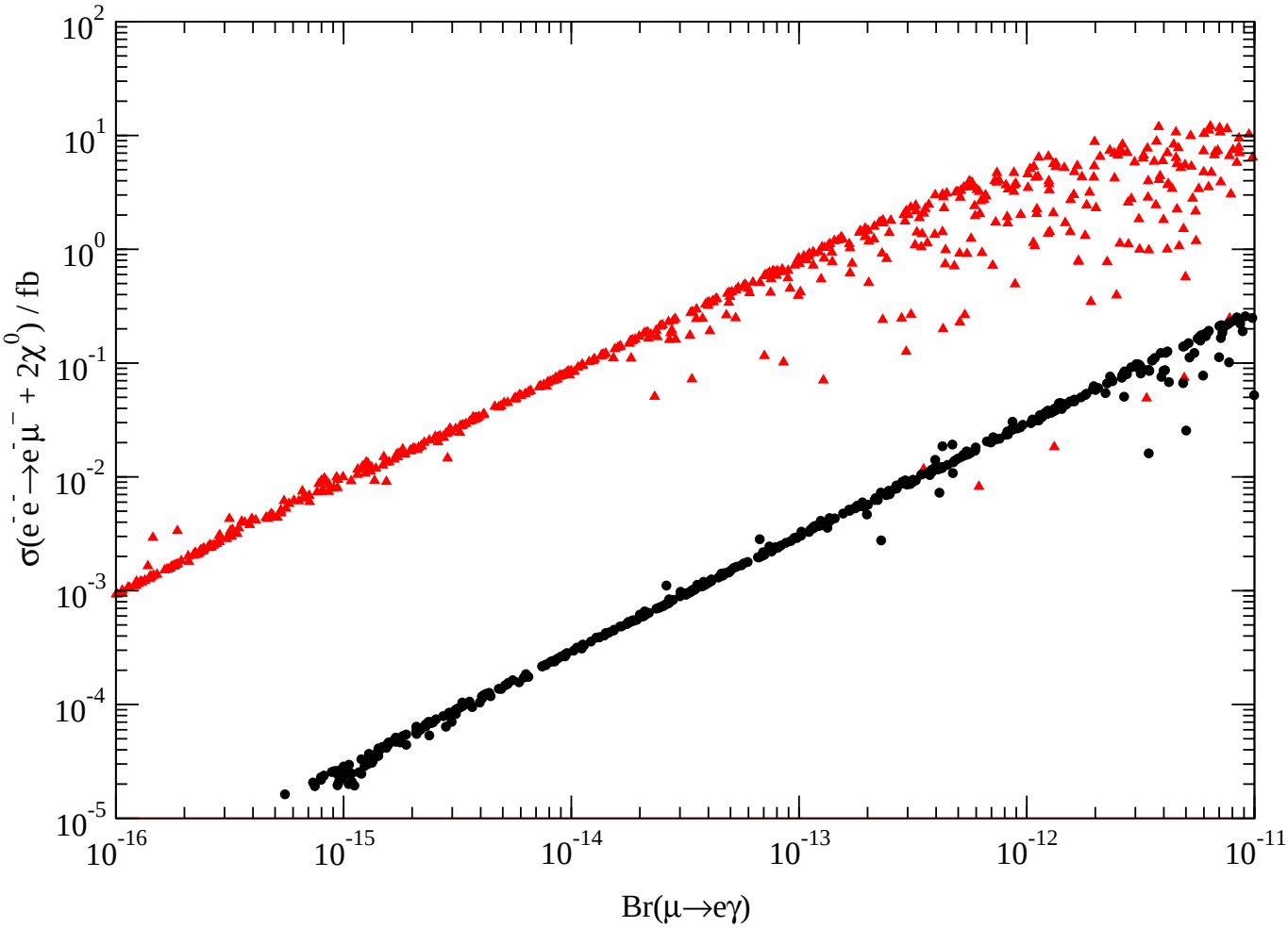
- Extreme scenarios L(red), H(black)
- Future neutrino uncertainties

$Br(\tau \to \mu\gamma)$



- Extreme scenarios L(red), H(black)
- Hierar.(straight)/ degenerate(bending) neutrino masses
- Future(filled symbols)/ present(open symbols) neutrino uncertainties

Correlation $\sigma(e^-e^- \to e^-\mu^- + 2\tilde{\chi}_1^0)$ and $Br(\mu \to e\gamma)$



- Scenarios C(red), I(black) hierarchical neutrino masses
- Future neutrino uncertainties
- $\sqrt{s} = 800$ GeV

Conclusions

SUSY see-saw mechanism can be tested by LFV processes

- $Br(\mu \to e\gamma) \approx 10^{-14}$
  - Hierarchical spectra:
    $M_R > 10^{11} - 10^{13}$ GeV (ν-data: Factor 10-100)
  - Degenerate spectra:
    $M_R > 10^{12} - 10^{14}$ GeV

- $Br(\tau \to \mu\gamma) \approx 10^{-9}$
  - Hierarchical masses:
    $M_R > 5 \cdot 10^{13}$ GeV (ν-data: Factor 2)

- Correlation: High/low-energy processes ($\sqrt{s} = 800$ GeV)
  - $Br(\mu \to e\gamma) < 10^{-11}$: Cross sections $\approx 0.1 - 10$ fb
  - $Br(\mu \to e\gamma) < 10^{-14}$: Cross sections $\approx 10^{-4} - 10^{-1}$ fb