Enhanced Lepton Flavour Violation in the Inverse Seesaw Mechanism

Frank Deppisch
`frank.deppisch@desy.de`

DESY

in collaboration with
T. S. Kosmas (Ioannina), J.W.F. Valle (IFIC)
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Overview

- Inverse Seesaw Mechanism
  - Comparison to standard Seesaw
  - Heavy neutral leptons
  - SUSY contribution
- LFV decay $\mu \to e\gamma$
- μ-e conversion in nuclei
- Conclusion

Inverse Seesaw Mechanism

Particle Content

Standard Seesaw:

Add r.h. neutrinos to (MS)SM particle content

$$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}, e_i^c, \nu_i^c$$

Inverse Seesaw:

Additional singlet neutrinos S_i

e.g. Superstring inspired E(6) singlets

$$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}, e_i^c, \nu_i^c, S_i$$

Superpotential

$$W \ni \hat{\nu}^{cT} Y_\nu \hat{L} \cdot \hat{H}_u + \frac{1}{2} \hat{\nu}^{cT} M_R \hat{\nu}^c$$

6x6 mass matrix:

$$\begin{pmatrix} 0 & m_D^T \\ m_D & M_R \end{pmatrix}$$

$$W \ni \hat{\nu}^{cT} Y_\nu \hat{L} \cdot \hat{H}_u + \hat{\nu}^{cT} M \hat{S} + \frac{1}{2} \hat{S}^T \mu \hat{S}$$

9x9 mass matrix:

$$\begin{pmatrix} 0 & m_D^T & 0 \\ m_D & 0 & M^T \\ 0 & M & \mu \end{pmatrix}$$

Inverse Seesaw Mechanism

Light neutrino mass matrix

Standard Seesaw:

$$m_D \ll M_R \Rightarrow$$

$$m_\nu = m_D^T M^{-1} m_D$$

$$m_\nu = 0.1\mathrm{eV}\left(\frac{m_D}{100\,GeV}\right)^2\left(\frac{M_R}{10^{14}\,GeV}\right)^{-1}$$

$\Rightarrow$ 3 light neutrinos $\approx m_\nu$

3 heavy neutrinos $\approx M_R$

Inverse Seesaw:

$$\mu, m_D \ll M \Rightarrow$$

$$m_\nu = m_D^T M^{T-1} \mu M^{-1} m_D$$

$$m_\nu = 0.1\mathrm{eV}\left(\frac{m_D}{100\,GeV}\right)^2\left(\frac{\mu}{1\,keV}\right)\left(\frac{M}{10^{4}\,GeV}\right)^{-2}$$

$\Rightarrow$ 3 light neutrinos $\approx m_\nu$

6 heavy neutrinos $\approx M$

Inverse Seesaw:

- Low scale μ of lepton number violation
- Right-handed mass scale M can be much smaller, close to EW scale → enhanced left-right mixing → enhanced LFV
- Neutrino masses suppressed by smallness of μ

Inverse Seesaw Mechanism

Simplifications for Calculation

Too many parameters ⇒

- Use diagonal and degenerate *M*, μ
- Use best fit neutrino values (CP conserving)

$$\tan^2\theta_{23}=1.40, \tan^2\theta_{13}=0.005, \tan^2\theta_{12}=0.36,$$
$$\Delta m_{12}^2=3.30\cdot 10^{-5}\,\mathrm{eV}^2, \Delta m_{23}^2=3.10\cdot 10^{-3}\,\mathrm{eV}^2,$$
$$m_{\nu_1}=0\ldots 0.3\,\mathrm{eV}$$

- Use

$$m_D=M\,\mu^{-1/2}\,\mathrm{diag}(m_{\nu_i})\,U_\nu^+$$

corresponds to taking R = 1 in standard seesaw
⇒ correlating neutral and charged LFV:

$$(Y_\nu^+ Y_\nu)_{ij}\propto\frac{M^2}{\mu}(U_\nu\cdot\mathrm{diag}(m_{\nu_i})\cdot U_\nu^+)_{ij}=\frac{M^2}{\mu}(m_\nu)_{ij}$$

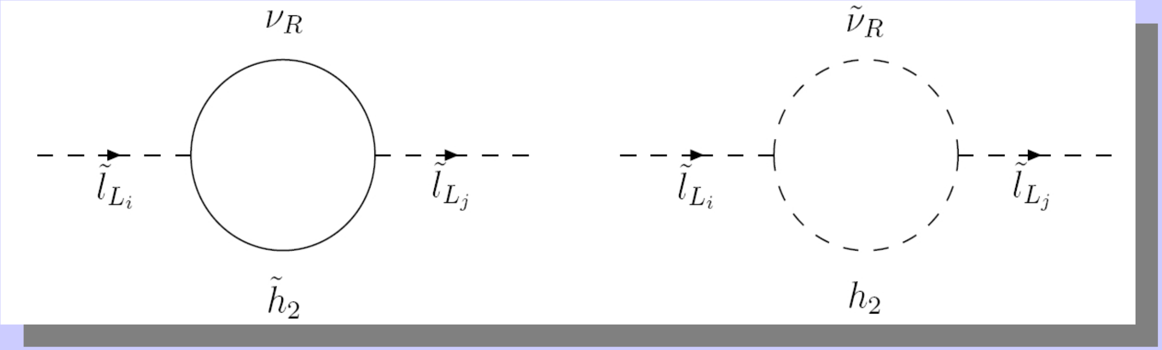
⇒ Two free model parameters: *M*, μ

Inverse Seesaw Mechanism

SUSY contributions

Qualitatively analogous to standard SUSY seesaw:

- R.h. neutrinos radiatively induce flavour off-diagonal slepton mass terms



- Assume mSUGRA conditions m_0, A_0

  ⇒ Slepton mass terms

  (Leading-Log)

$$\delta m_L^2 = \frac{-1}{8\pi^2}(3m_0^2 + A_0^2)(Y_\nu^+ L Y_\nu)$$

$$\delta A = \frac{-3A_0}{16\pi^2} Y_e \cdot (Y_\nu^+ L Y_\nu)$$

$$L = \mathrm{diag}\left(\ln \frac{M_{GUT}}{M}\right)$$

Inverse Seesaw Mechanism

SUSY contributions

BUT:

- Heavy neutrino scale *M* can be lower than M_R
- Yukawa coupling enhanced by small μ

$$\delta m_L^2 \propto (Y_\nu^+ L Y_\nu) \propto \frac{M^2}{\mu} \ln \frac{M_{GUT}}{M} \quad \left(M_R \ln \frac{M_{GUT}}{M_R} \text{ in standard seesaw} \right)$$

ALSO:

- More complicated sneutrino mass matrix,
  SUSY and heavy neutrino scales do not necessarily decouple

$$m_{\tilde{\nu}}^2 = \begin{pmatrix} m_D^+ m_D + m_{\tilde{L}}^2 + \frac{1}{2} m_Z^2 cos2\beta & \Box^+ & \Box^+ \\ A_\nu v \sin\beta - m_D \mu_{\text{Higgs}} \cot\beta & m_D^+ m_D + M^+ M + m_{\tilde{N}}^2 & \Box^+ \\ m_D^+ M & B_M^2 + M^+ \mu & \mu^+ \mu + M^+ M + m_{\tilde{S}}^2 + B_S^2 \end{pmatrix}$$

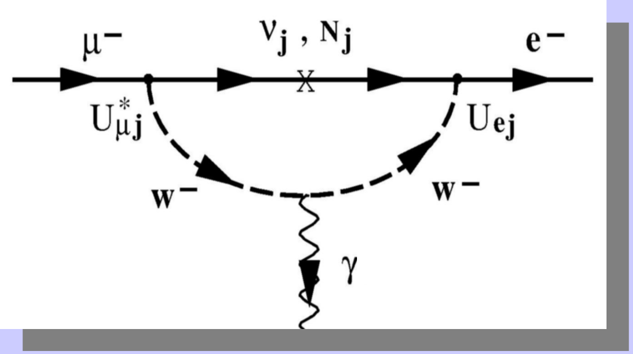
$\mu\rightarrow e\gamma$

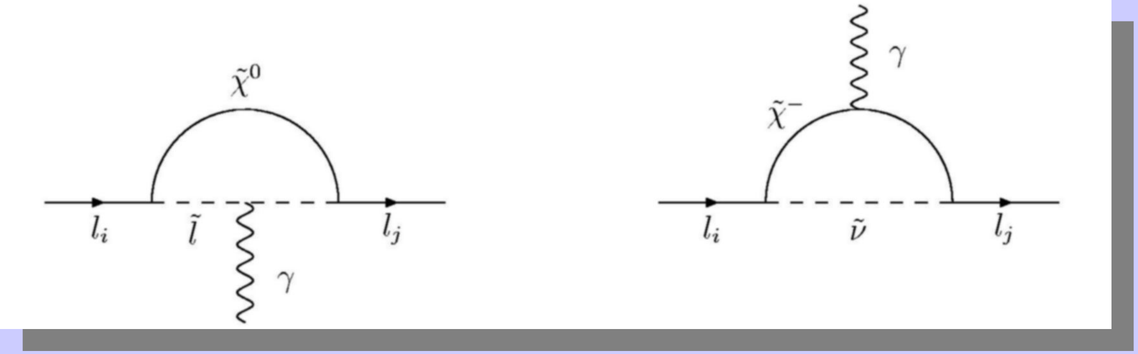
Current limit: $Br(\mu\rightarrow e\gamma) < 1.1\cdot 10^{-11}$ (MEGA, 1999)

Future: $Br(\mu\rightarrow e\gamma) = 10^{-13}$ (MEG, 2008?)

Inverse Seesaw:

- Neutral Heavy Lepton (NHL) contribution
- Supersymmetric contribution





μ–e Conversion in Nuclei

$$\mu^- + (A,Z) \to e^- + (A,Z)^*$$

Experiments:

$R^{Au}_{\mu e} \leqslant 5.0\cdot 10^{-13}$ (SINDRUM)

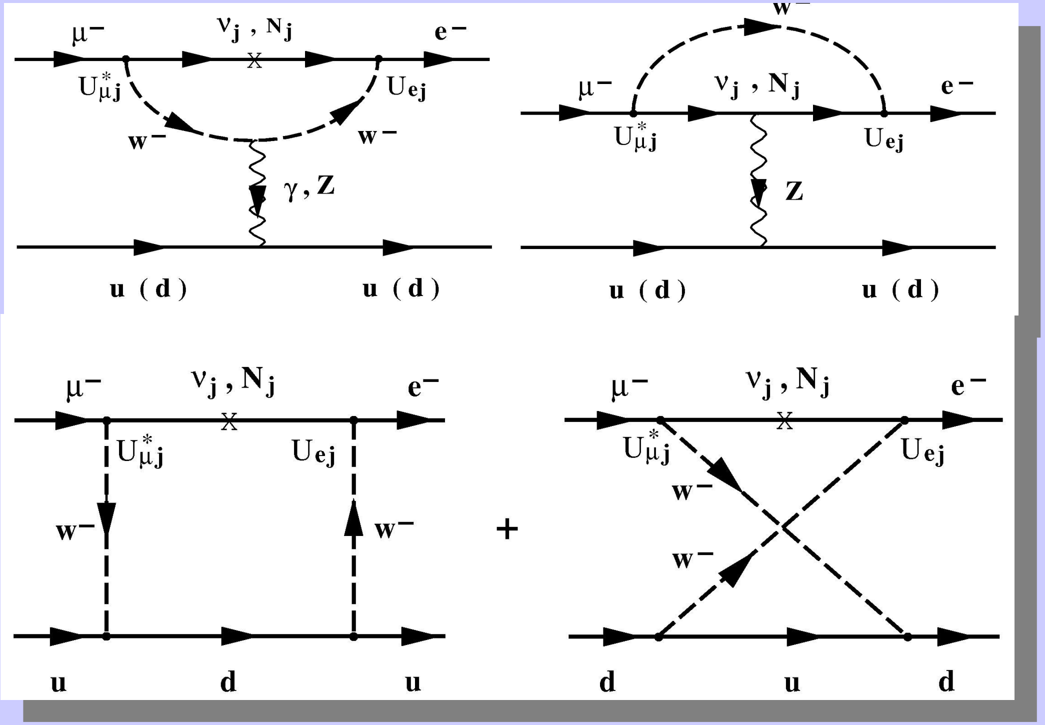
~~$R^{Al}_{\mu e} = 2\cdot 10^{-17}$ (MECO)~~

$R^{Ti}_{\mu e} = 10^{-18}$ (PRISM)

Elementary Particle Physics:

Quark-level effective Lagrangian

$$L^q_{eff} = \frac{G_F}{\sqrt{2}} \sum_{a,b,q}^{VA} \eta^{(q)}_{ab}\, j_\mu^{\ a} J^{b\mu}_{(q)} + \sum_{a,b,q}^{SP} \eta^{(q)}_{ab}\, j^a J^b_{(q)} + \sum_q \eta^{(q)}_T\, j_{\mu\nu}^{\ a} J^{\mu\nu}_{(q)}$$

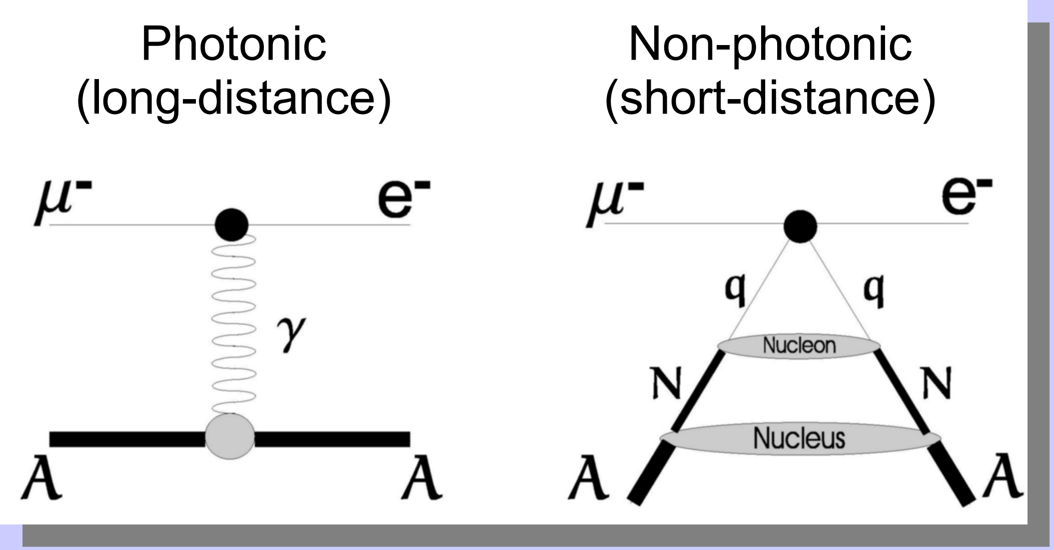


μ–e Conversion in Nuclei

Nuclear Physics:

Nucleon-level effective Lagrangian

$$L_{eff}^{N} = \frac{G_F}{\sqrt{2}} \sum_{a,b}^{VA} j_\mu^a (\alpha_{ab}^{(0)} J_{(0)}^{b\mu} + \alpha_{ab}^{(3)} J_{(3)}^{b\mu}) + \sum_{a,b}^{SP} j^a (\alpha_{ab}^{(0)} J_{(0)}^{b} + \alpha_{ab}^{(3)} J_{(3)}^{b}) + j_{\mu\nu}(\alpha_T^{(0)} J_{(0)}^{\mu\nu} + \alpha_T^{(3)} J_{(3)}^{\mu\nu})$$



Photonic (long-distance)

Non-photonic (short-distance)

Conversion Rate:

$$R_{\mu e} = Q_{ph/nph} G_F^2 \frac{p_e E_e}{2\pi} \frac{M_{ph/nph}^2}{\Gamma(\mu \rightarrow \text{capture})}$$

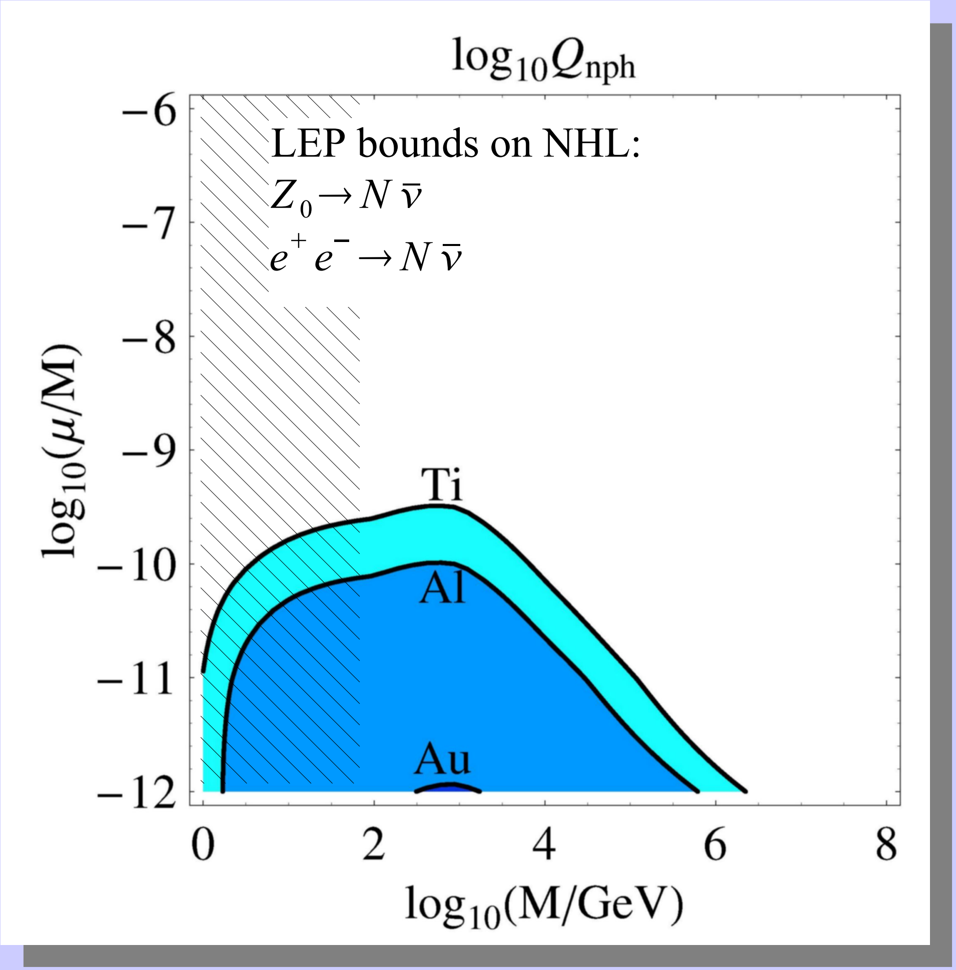
$Q \equiv Q(\alpha_{ab})$ → elementary particle physics, (negligible nuclear physics dependence)

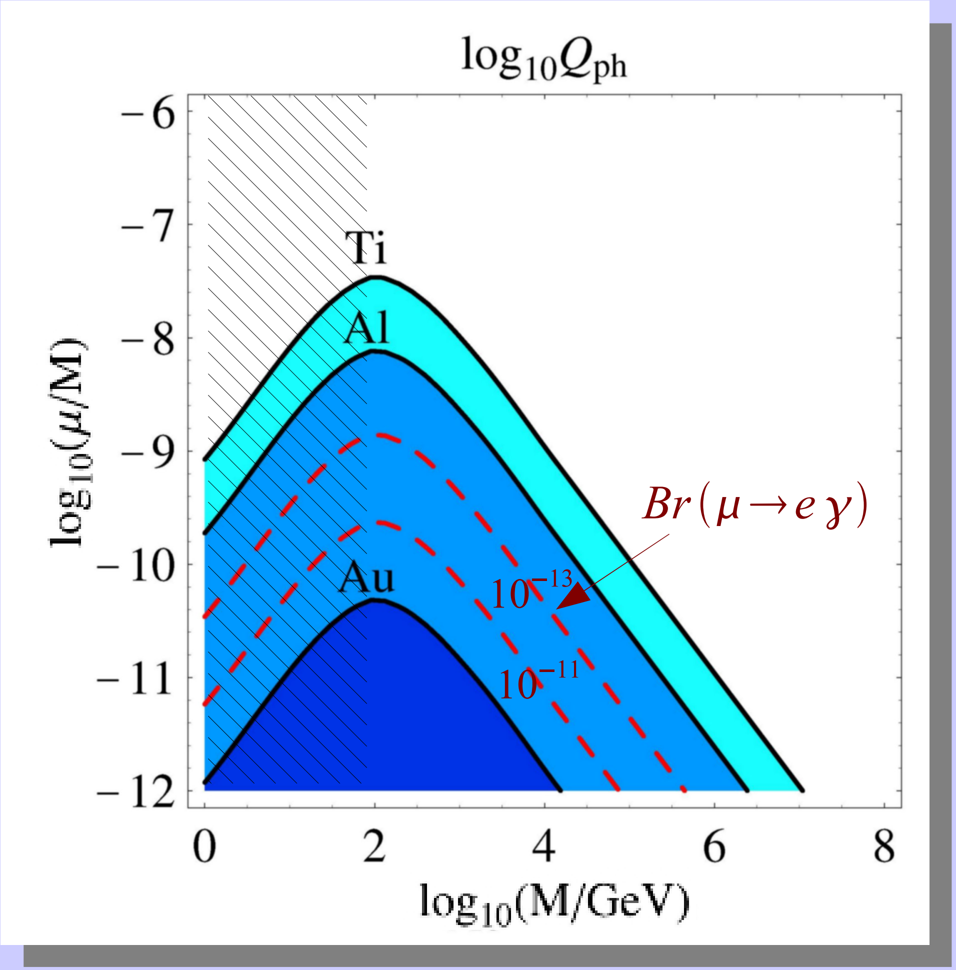
M^2 → nuclear matrix element, model independent

Neutral Heavy leptons only

Best fit neutrino parameters, hierarchical spectrum (m_1 = 0 eV)

Excluded areas (from Au, Al, Ti nucl. conv. and $\mu \to e\gamma$) in μ, M parameter space



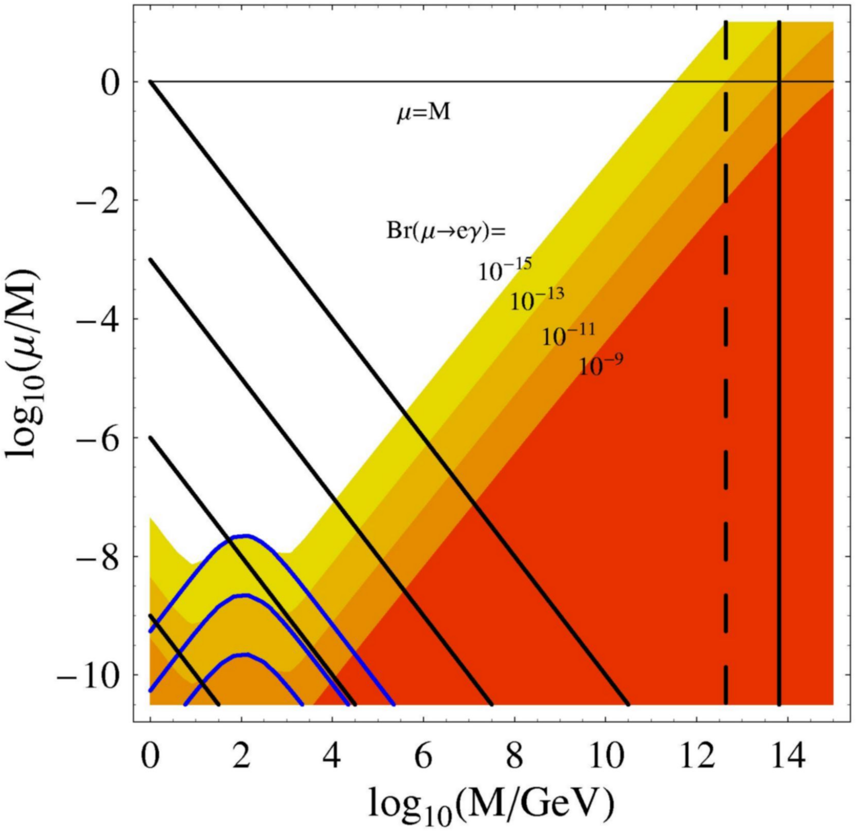


Including SUSY

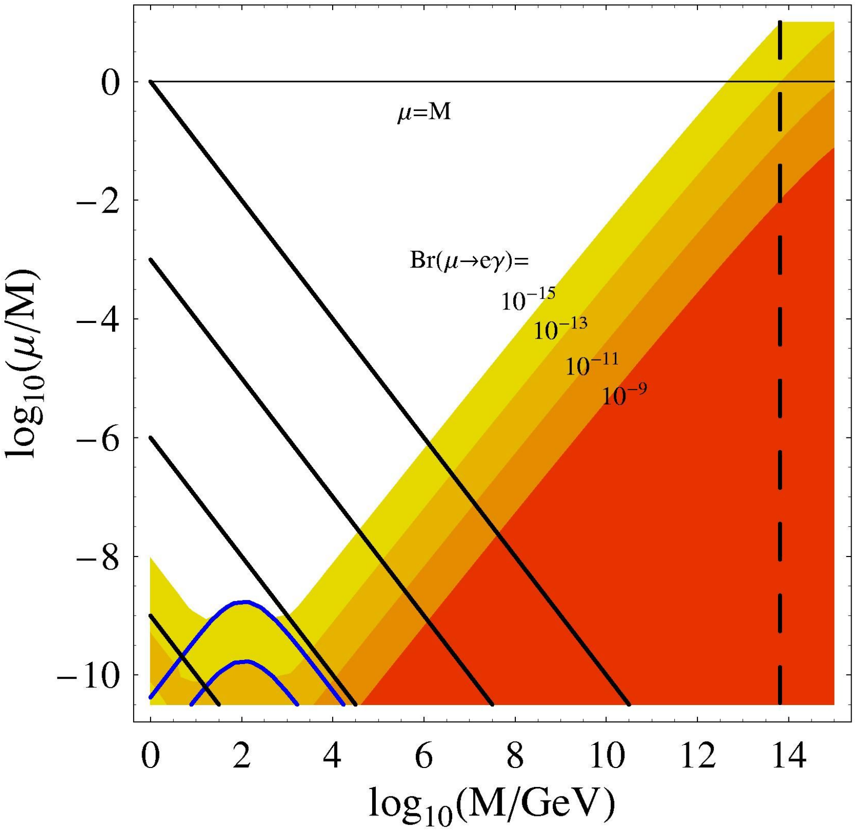
mSUGRA scenario SPS1a: m_0= 100 GeV, $m_{1/2}$= 250 GeV, A_0= -100 GeV, $\tan\beta$ = 10,μ > 0

Excluded areas (from $\mu \to e\gamma$) in μ, M parameter space

m_1 = 0 eV



m_1 = 0.3 eV



Conclusion

- Inverse Seesaw as alternative to standard seesaw
- Can be better testable due to accessible r.h. neutrino masses (NHLs can be as light as EW scale)
- Enhanced LFV in radiative decays and nuclear conversion
  - NHL contribution
  - SUSY contribution
- Explore:
  - Other flavour transitions
  - Collider bounds on NHLs
  - Neutrinoless Double-Beta-Decay
  - Leptogenesis