Charged Lepton Flavour Violation

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Outline

$\mathcal{I}$. Introduction

$\mathcal{II}$. SUSY LFV and Seesaw

$\mathcal{III}$. Discrete symmetries and LFV

$\mathcal{IV}$. Exotic decay $\mu \to eJ$

$\mathcal{I}.$

Introduction

Motivation

Lepton flavor is violated:

Parameter	Best fit	3 σ c.l.
$\Delta m^2_\odot$ (10^{-5} eV^2)	$7.59^{+0.23}_{-0.18}$	7.03 - 8.27
$\Delta m^2_{\rm Atm}$ (10^{-3} eV^2)	$2.40^{+0.12}_{-0.11}$	2.07 - 2.75
$\sin^2\theta_\odot$	$0.318^{+0.019}_{-0.016}$	0.27 - 0.38
$\sin^2\theta_{\rm Atm}$	$0.50^{+0.07}_{-0.06}$	0.36 - 0.67
$\sin^2\theta_{13}$	$0.013^{+0.013}_{-0.009}$	$\leq$ 0.053

Data from updated global fit:
Schwetz, Tórtola & Valle, New J Phys 10:113011, 2008;
arXiv:0808.2016 (hep-ph) updated V3: 11 Feb 2010

Hint for no-zero θ_{13} at 1.5 σ? - Fogli et al., 2008

Experimental status: LFV

Decay	Current Limit
$\tau \to \mu\gamma$	$4.4 \cdot 10^{-8}$
$\tau \to e\gamma$	$3.3 \cdot 10^{-8}$
$\mu \to e\gamma$	$1.2 \cdot 10^{-11}$
$\tau \to 3\mu$	$3.2 \cdot 10^{-8}$
$\tau^- \to e^-\mu^+\mu^-$	$3.7 \cdot 10^{-8}$
$\tau^- \to e^+\mu^-\mu^-$	$2.3 \cdot 10^{-8}$
$\tau^- \to \mu^-e^+e^-$	$2.7 \cdot 10^{-8}$
$\tau^- \to \mu^+e^-e^-$	$2.0 \cdot 10^{-8}$
$\tau \to 3e$	$3.6 \cdot 10^{-8}$
$\mu \to 3e$	$1 \cdot 10^{-12}$

Particle Data Group
2010

Sensitivity MEG:
Br($\mu \to e\gamma$)$\sim 10^{-13}$
see talk by:
G. Cavoto

Experimental status: LFV

Capture	Current Limit
$\mu^- \ {}^{32}S \to e^- \ {}^{32}S$	$7 \cdot 10^{-11}$
$\mu^- \ {}^{32}S \to e^+ \ {}^{32}Si$	$9 \cdot 10^{-10}$
$\mu^- Ti \to e^- Ti$	$4.3 \cdot 10^{-12}$
$\mu^- Ti \to e^+ Ca$	$3.6 \cdot 10^{-11}$
$\mu^- Pb \to e^- Pb$	$4.6 \cdot 10^{-11}$
$\mu^- Au \to e^- Au$	$7 \cdot 10^{-13}$

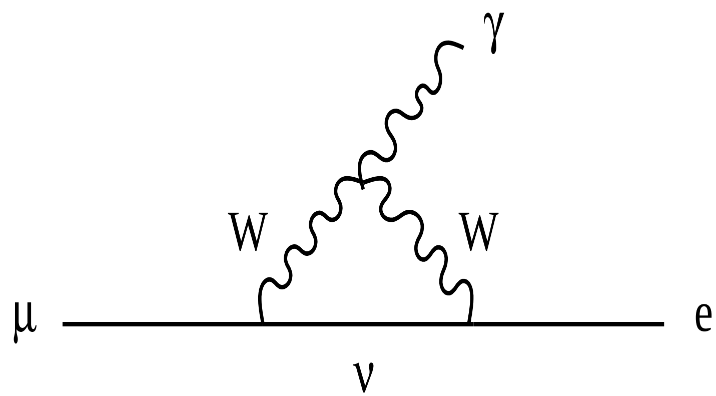
Particle Data Group
2010

Future sensitivity:
$\sim 10^{-16}$
see talk by:
Y. Kuno

Simplest LFV by m_ν

⇒ Extend the minimal SM by neutrino masses

⇒ LFV appears, such as $\mu \to e\gamma$:



$$\mathrm{Br}(\mu \to e\gamma) \sim \frac{3\alpha}{32\pi} \sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{i1}}{m^2_W} \leq 10^{-54}$$

⇒ GIM suppressed by small neutrino masses

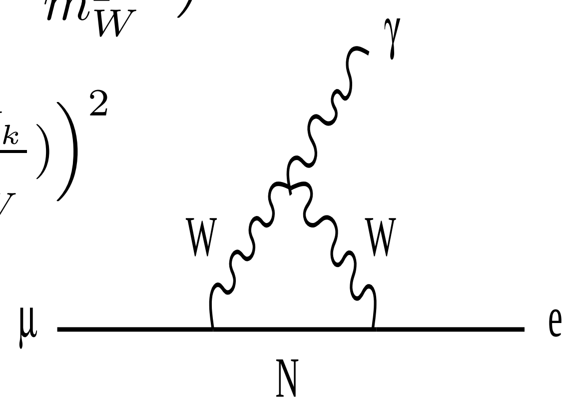
⇒ any observation of charged LFV points to physics beyond (neutrino mass extended) SM

LFV beyond m_ν

Simple example: Heavy neutrinos (N) with masses order $\mathcal{O}(TeV)$ exist:

$$\mathrm{Br}(\mu \to e\gamma) \sim \frac{\alpha^3 s_W^2}{256\pi^2}\frac{m_\mu^5}{m_W^4\Gamma_\mu}\Big(\sum_i K_{\mu i}^* K_{ei} G(\frac{m_{N_k}^2}{m_W^2})\Big)^2$$

$$\leq 7\times 10^{-6}\Big(\sum_i K_{\mu i}^* K_{ei} G(\frac{m_{N_k}^2}{m_W^2})\Big)^2$$



$\Rightarrow$ K_{ik} heavy neutrino - lepton mixing

$\Rightarrow$ G(x) loop function, $G(1) = 1/8$

(C)LFV - Models

⇒ Many models produce sizeable CLFV

- RPC Supersymmetry
- RPV Supersymmetry
- Practically any extended Higgs sector:
  Little Higgs models, additional Higgs doublets, triplets, etc...
- Extra generations
- Extra (large) dimensions
- etc ...

⇒ "Flavour problem" of BSM

Theoretical description

see, for example review:
Kuno & Okada, 2001

General Lagrangian:

$$\mathcal{L} = -\frac{4G_F}{\sqrt{2}} \quad (\quad m_\mu A_R \bar{\mu} \sigma^{\mu\nu} P_L e F_{\mu\nu} + m_\mu A_L \bar{\mu} \sigma^{\mu\nu} P_R e F_{\mu\nu})$$

photonic diagrams

$$-\frac{G_F}{\sqrt{2}} \sum_f \quad (\quad g_{L,\alpha,f} \bar{e} \mathcal{O}^\alpha P_L \mu + g_{R,\alpha,f} \bar{e} \mathcal{O}^\alpha P_R \mu)(\bar{f} \mathcal{O}_\alpha f) + h.c$$

contact interaction

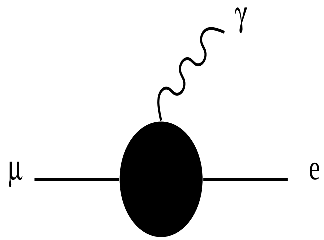
where $\alpha = S, P, V, A, T$ and $f = l_i, q_i$

$\Rightarrow$ A_L, A_R and $g_{L/R,\alpha,q}$ depend on model

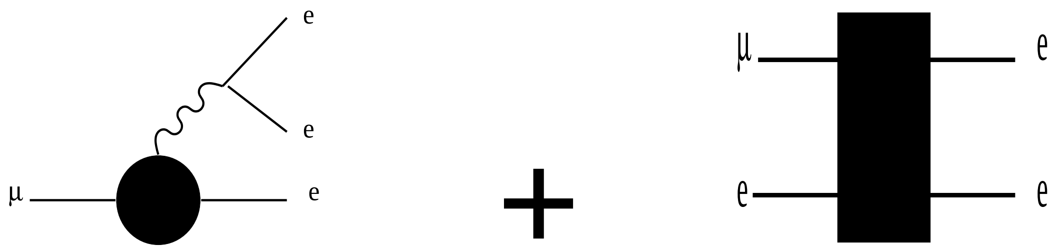
$\Rightarrow$ τ lepton same structure, A and g matrices

Diagramatically

$\mu \rightarrow e\gamma$:



$\mu \rightarrow 3e$:



$\Rightarrow$ If photonic diagram dominates:

$$Br(l_i \rightarrow l_j l_k l_k) \sim \alpha \times Br(e \rightarrow l_j + \gamma)$$

$$Cr(\mu \rightarrow eN) \sim \alpha \times Br(\mu \rightarrow e + \gamma)$$

Photon dominance?

From Buras et al., 2010: Different particle models predict different ratios for ...

ratio	LHT	MSSM (dipole)	MSSM (Higgs)	SM4
$\frac{Br(\mu^- \to e^- e^+ e^-)}{Br(\mu \to e\gamma)}$	0.02...1	$\sim 6 \cdot 10^{-3}$	$\sim 6 \cdot 10^{-3}$	$0.06 \ldots 2.2$
$\frac{Br(\tau^- \to e^- e^+ e^-)}{Br(\tau \to e\gamma)}$	0.04...0.4	$\sim 1 \cdot 10^{-2}$	$\sim 1 \cdot 10^{-2}$	$0.07 \ldots 2.2$
$\frac{Br(\tau^- \to \mu^- \mu^+ \mu^-)}{Br(\tau \to \mu\gamma)}$	0.04...0.4	$\sim 2 \cdot 10^{-3}$	$0.06 \ldots 0.1$	$0.06 \ldots 2.2$
$\frac{Br(\tau^- \to e^- \mu^+ \mu^-)}{Br(\tau \to e\gamma)}$	0.04...0.3	$\sim 2 \cdot 10^{-3}$	$0.02 \ldots 0.04$	$0.03 \ldots 1.3$
$\frac{Br(\tau^- \to \mu^- e^+ e^-)}{Br(\tau \to \mu\gamma)}$	0.04...0.3	$\sim 1 \cdot 10^{-2}$	$\sim 1 \cdot 10^{-2}$	$0.04 \ldots 1.4$
$\frac{Br(\tau^- \to e^- e^+ e^-)}{Br(\tau^- \to e^- \mu^+ \mu^-)}$	0.8...2	~ 5	0.3...0.5	$1.5 \ldots 2.3$
$\frac{Br(\tau^- \to \mu^- \mu^+ \mu^-)}{Br(\tau^- \to \mu^- e^+ e^-)}$	0.7...1.6	~ 0.2	5...10	$1.4 \ldots 1.7$
$\frac{R(\mu \mathrm{Ti} \to e \mathrm{Ti})}{Br(\mu \to e\gamma)}$	$10^{-3} \ldots 10^{2}$	$\sim 5 \cdot 10^{-3}$	$0.08 \ldots 0.15$	$10^{-12} \ldots 26$

LHT: Little Higgs model with T-parity

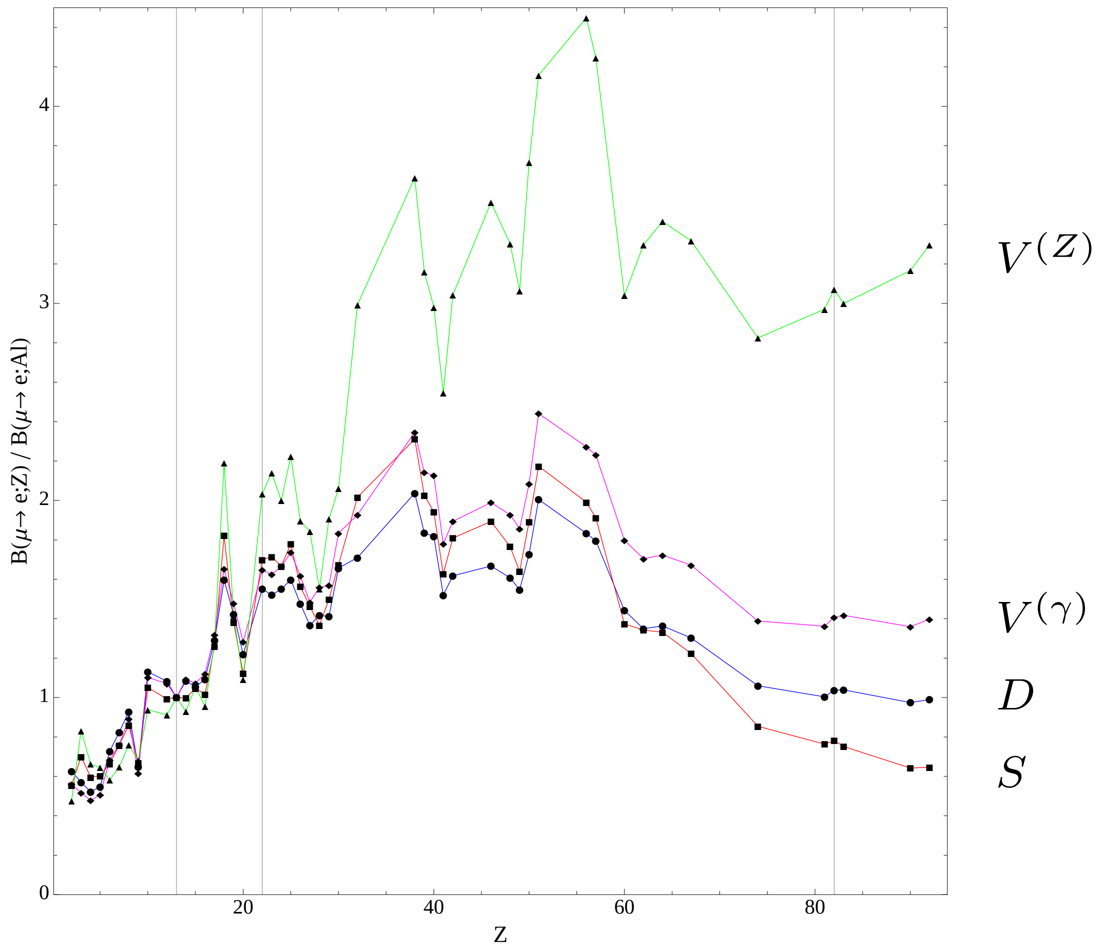
MSSM: Minimal supersymmetric model (with R_P)

SM4: Standard model with 4th generation

Target dependence

Fig. from Cirigliano et al., 2009

Kitano et al., 2002



$\Rightarrow$ use different nuclear targets to distinguish different operators

$\mathcal{I}.$

SUSY LFV and Seesaw

The MSSM: Superfields

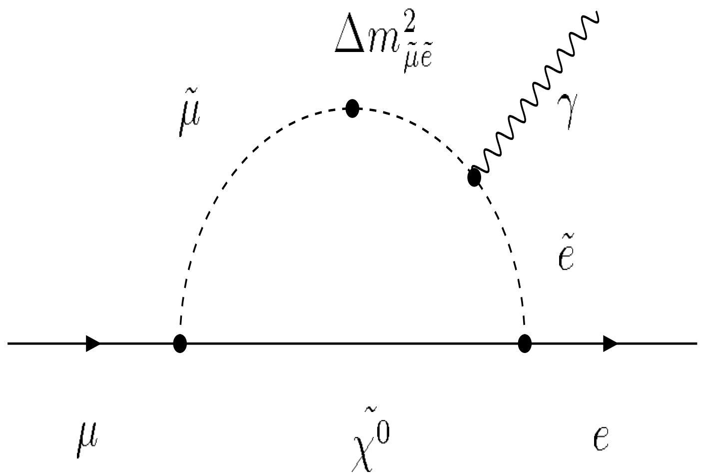
Superfield	Bosons	Fermions	SU(3)$_C$	SU(2)$_L$	U(1)$_Y$
Gauge Multiplets					
$\widehat{G}$	g	$\widetilde{g}$	8	0	0
$\widehat{V}$	W^a	$\widetilde{W}^a$	1	3	0
$\widehat{V}'$	B	$\widetilde{B}$	1	1	0
Matter Multiplets					
$\widehat{L}$	$(\tilde{\nu}, \tilde{e}^-_L)$	(ν, e^-_L)	1	2	-1
$\widehat{E}^C$	$\tilde{e}^+_R$	e^+_L	1	1	2
$\widehat{Q}$	$(\tilde{u}_L, \tilde{d}_L)$	(u_L, d_L)	3	2	1/3
$\widehat{U}^C$	$\tilde{u}^*_R$	u^c_L	3^*	1	-4/3
$\widehat{D}^C$	$\tilde{d}^*_R$	d^c_L	3^*	1	2/3
Higgs Multiplets					
$\widehat{H}_d$	(H^0_d, H^-_d)	$(\tilde{H}^0_d, \tilde{H}^-_d)$	1	2	-1
$\widehat{H}_u$	(H^+_u, H^0_u)	$(\tilde{H}^+_u, \tilde{H}^0_u)$	1	2	1

LFV soft terms

Soft SUSY breaking terms:

$$-\mathcal{L}_{soft} = (M^2_{\tilde{L}})_{ij}(\tilde{e}^*_{L,i}\tilde{e}_{L,j} + \tilde{\nu}^*_{L,i}\tilde{\nu}_{L,j}) + \cdots$$

Off-diagonal elements lead to:



$\Rightarrow$ In general MSSM much too big: SUSY flavour problem

mSugra = CMSSM

At the GUT scale:

$$(m^2_{\tilde{L}})_{ij} = (m^2_{\tilde{E}})_{ij} \quad = \quad \cdots = m_0^2 \delta_{ij}$$
$$(A_l)_{ij} = A_0 (Y_l)_{ij} \quad , \quad (A_\nu)_{ij} = A_0 (Y_\nu)_{ij}$$
$$\cdots \qquad \cdots$$

Imposing unification on all soft terms, one is left with only 5 parameters @ M_X:

$$m_0, M_{1/2}, A_0, t_\beta, \mathrm{sgn}(\mu)$$

$\Rightarrow$ Essential assumptions: (i) SUSY breaking flavour blind

(ii) $\Lambda_{seesaw} < \Lambda_{SUSY}$

'Classical' Seesaw

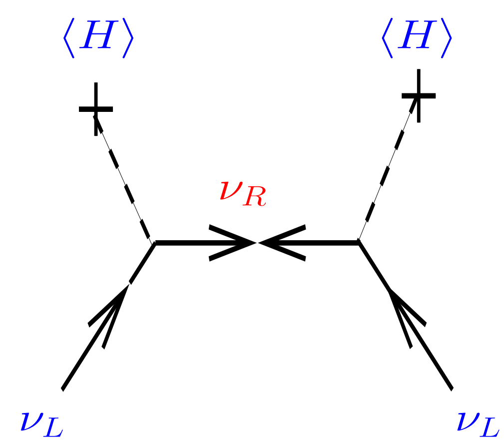
In the basis (ν_L, ν_R) write mass matrix:

Minkowski, 1977
Yanagida, 1979
Gell-Mann, Ramond & Slansky, 1979
Mohapatra & Senjanovic, 1980
... ...

$$\mathcal{M}_\nu = \begin{pmatrix} 0 & m_D \\ m_D & M_M \end{pmatrix}.$$

If $m_D \ll M_M$:

$$m_{1/2} \simeq (-\frac{m_D^2}{M_M}, M_M)$$



Santamaria, 1993

⇒ For 3 ν_R 21 parameters

⇒ At low energy 12 parameters measurable:

3 m_{l_i}, 3 m_{ν_i}, 3 angles & 3 phases

⇒ Predictive power: -9

mSugra and RGEs

Seesaw type-I: Borzumati & Masiero, 1986

$$(\Delta M^2_{\tilde{L}})_{ij} \sim -\frac{1}{8\pi^2} f(m_0, A_0, ...)(Y_\nu^\dagger L Y_\nu)_{ij}$$

$$(\Delta M^2_{\tilde{E}})_{ij} \simeq 0$$

Note: $L_i = \log[M_G/M_i]$.

$\Rightarrow$ 9 independent parameters

$\Rightarrow$ 9+12=21! Ellis et al., 2002

$\Rightarrow$ Rewrite Y_ν Casas & Ibarra, 2001

$$Y_\nu = \sqrt{2}\frac{i}{v_U}\sqrt{\hat{M}_R} R \sqrt{\hat{m}_\nu} U^\dagger .$$

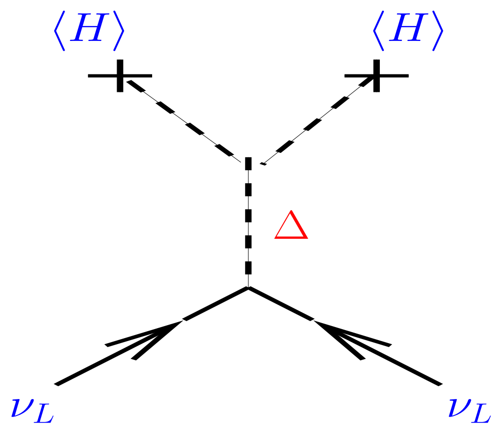
$\Rightarrow$ Measure $\hat{m}_\nu$ & U at low-energy

$\Rightarrow$ Learn about $\hat{M}_R$ and R from $(\Delta M^2_{\tilde{L}})_{ij}$ ... ?

Seesaw: Type II

Schechter & Valle, 1980, 1982
Cheng & Li, 1980
Mohapatra, Senjanovic, 1981
...

$$m_M \simeq Y^\nu \langle \Delta_L^0 \rangle$$



Example:

$SU(5)$ with $\mathbf{15}$:

$$\langle \Delta_L^0 \rangle \sim \frac{\langle h^0 \rangle^2}{m_{\mathbf{15}}}$$

RGEs type-II:

Rossi, 2002

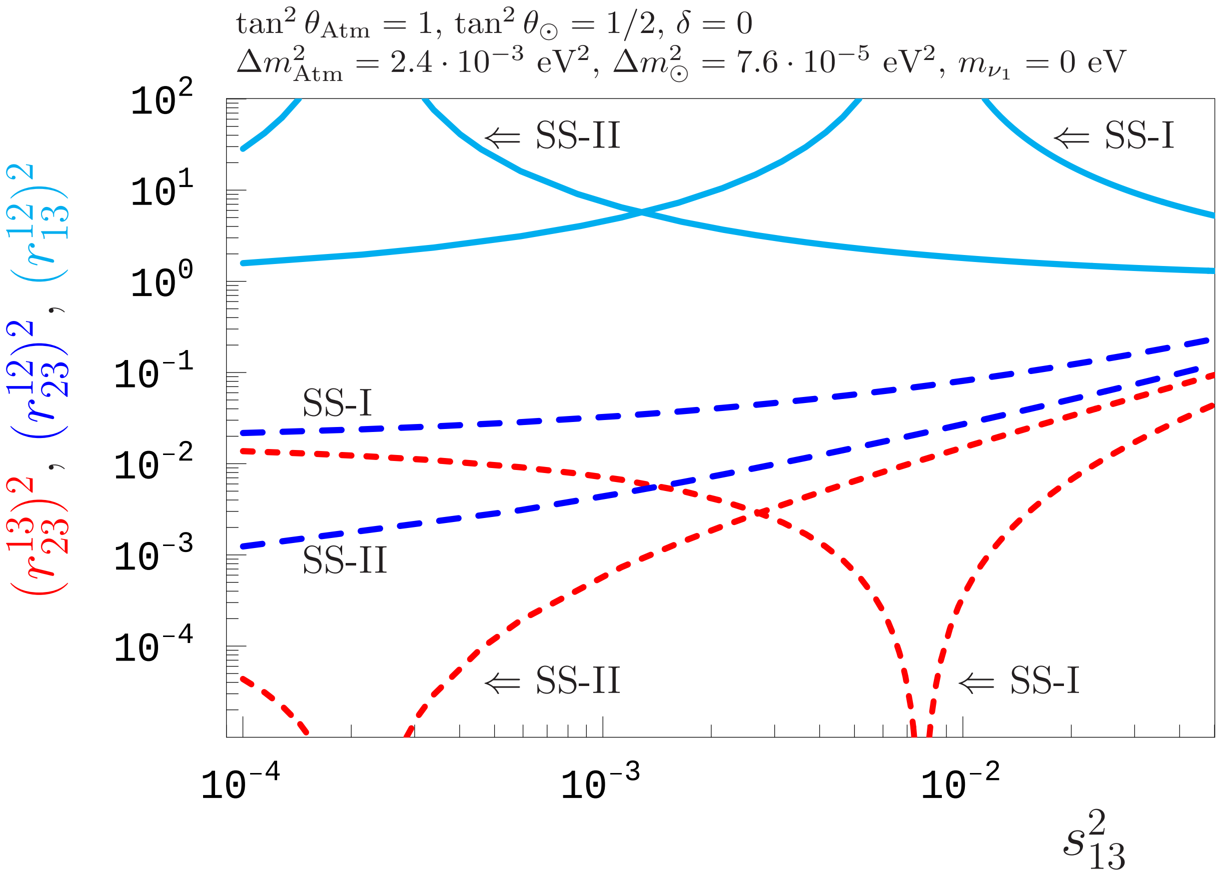
$$(\Delta M^2_{\tilde{L}})_{ij} \sim -\frac{1}{8\pi^2} g(m_0, A_0, M_{1/2}, ...)(Y_T^\dagger Y_T)_{ij} \log(M_G/M_T)$$

$$(\Delta M^2_{\tilde{E}})_{ij} = 0$$

$\Rightarrow$ 9+12=21, but only 15 parameters

$\Rightarrow$ Measuring all entries in $(\Delta M^2_{\tilde{L}})_{ij}$
"over-constrains" triplet seesaw ???

Analytical results



Def:

$$r^{ij}_{kl} = \frac{(\Delta M^2_{\tilde{L}})_{ij}}{(\Delta M^2_{\tilde{L}})_{kl}}$$

Ratios

"independent"

of mSugra

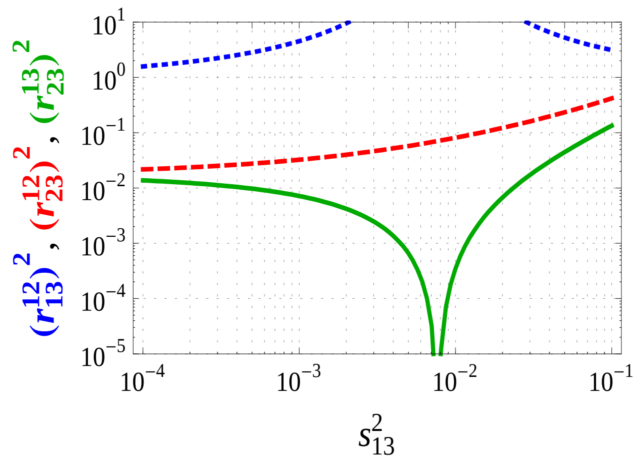
parameters!

WARNING:

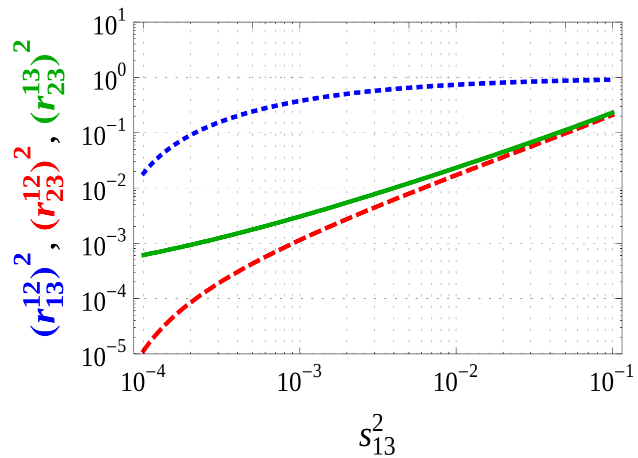
- Plot assumes right-handed neutrinos are degenerate
- Hierarchical right-handed neutrinos lead to very different results

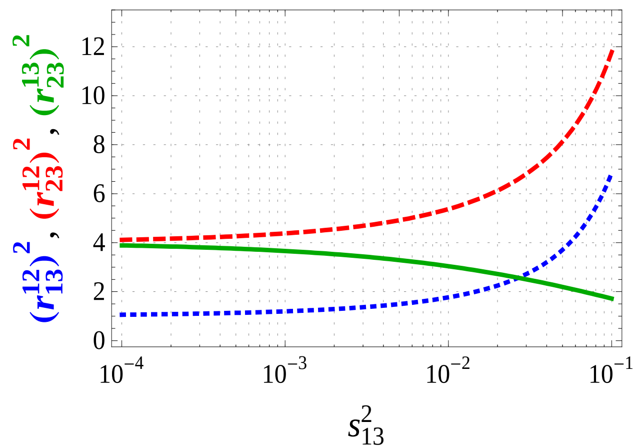
Analytical results

Degenerate N^c, SNH

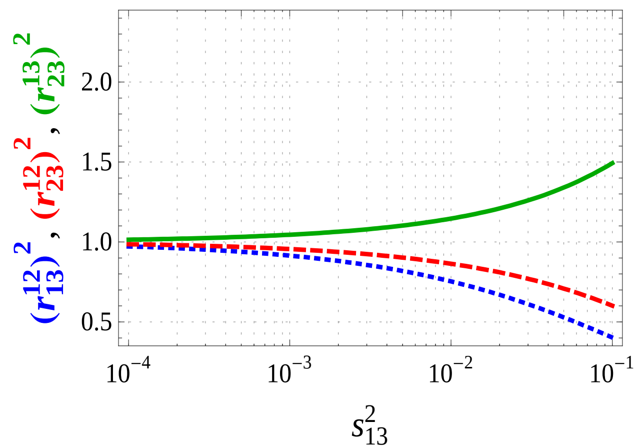


Degenerate N^c, SIH





Hierarchical N^c, N_1



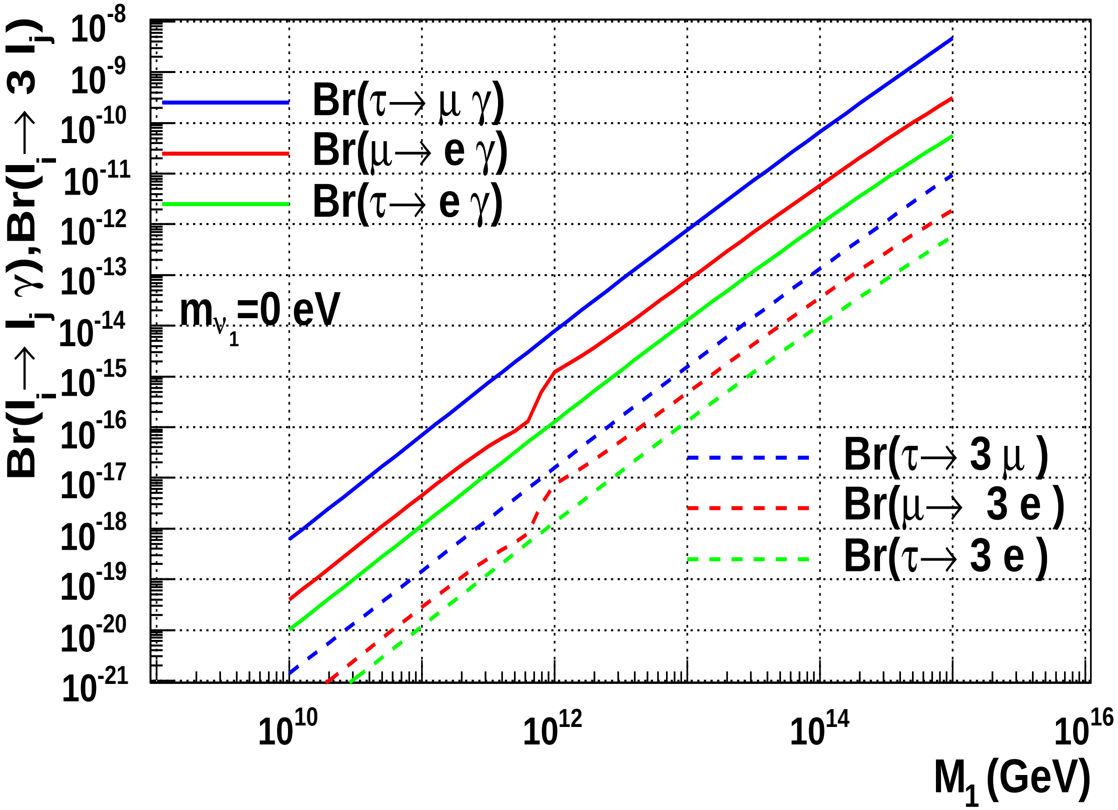
Hierarchical N^c, N_2

$\Rightarrow$ Learn about N^c once s_{13} (and m_{ν_1}) known?

Numerical results: SPheno3

Example: Seesaw-I, SPS3

Calculated assuming: (i) Degenerate N^c, (ii) TBM angles, (iii) best fit $\Delta m^2_{\rm A}$ and $\Delta m^2_\odot$, (iv) $m_{\nu_1} \equiv 0$:

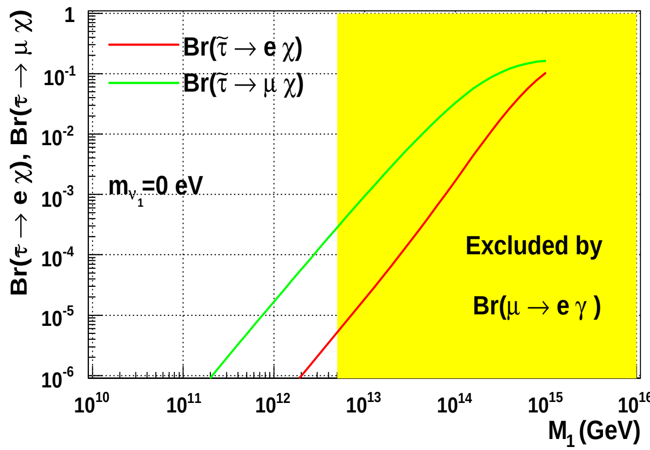


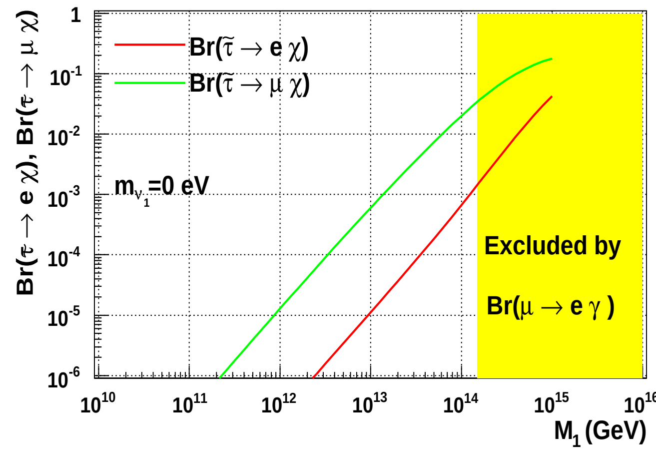
$\Rightarrow$ Ratios determined by seesaw parameters!

Numerical results: LHC

Seesaw-I:

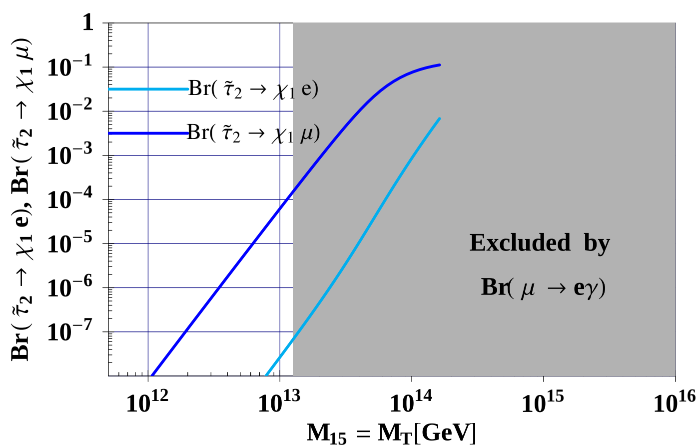
Left: SPS1a′ Right: SPS3

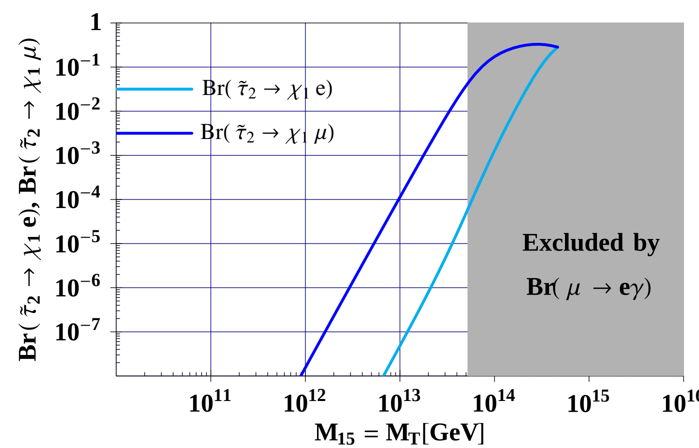




Seesaw-II:

Left: SPS1a′ Right: SPS3





$\Rightarrow$ LHC can see LFV (if SPS3-like ...)

$\mathcal{III}.$

Discrete symmetries and LFV

Discrete flavour symmetries

A very partial list:

S_3: Kubo et al., 2003; Chen et al., 2004; Grimus and Lavoura, 2005; Lavoura and Ma, 2005; Teshima, 2006; Koide, 2006; Mohapatra et al., 2006; $\cdots$, $\cdots$

Many Refs in: E. Ma, arXiv:0705.0327

S_4: Ma, 2006; Hagedorn et al., 2006; Cai & Yu, 2006; Zhang, 2006; Koide, 2007; $\cdots$, $\cdots$

Review: Altarelli & Feruglio, 2010

A_4: Ma & Rajasekaran, 2001; Ma, 2002; Babu et al., 2003; Hirsch et al., 2003; Altarelli and Feruglio, 2005; Babu and He, 2005; Koide, 2007; $\cdots$, $\cdots$

Q_4: Frigerio et al. 2005, $\cdots$

See also talks by: S Morisi, C Hagedorn

D_4: Grimus & Lavoura, 2003; Grimus et al., 2004; $\cdots$, $\cdots$

$\cdots$

A_4: linear & inverse seesaw

Inverse seesaw, basis (ν, ν^c, S):

Mohapatra & Valle, 1986

$$M_\nu = \begin{pmatrix} 0 & m_D & 0 \\ m_D^T & 0 & M \\ 0 & M^T & \mu \end{pmatrix},$$

After EWSB the effective light neutrino mass matrix is given by

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

Linear seesaw:

Akhmedov et al., 1995

$$M_\nu = \begin{pmatrix} 0 & m_D & M_L \\ m_D^T & 0 & M \\ M_L^T & M^T & 0 \end{pmatrix}.$$

Light neutrino mass:

$$M_\nu = m_D (M_L M^{-1})^T + (M_L M^{-1}) m_D{}^T$$

TBM in A_4

If M_l is diagonalized on the left by the magic matrix U_ω

$$U_\omega = \frac{1}{\sqrt{3}} \begin{pmatrix} 1 & 1 & 1 \\ 1 & \omega & \omega^2 \\ 1 & \omega^2 & \omega \end{pmatrix},$$

(with $\omega \equiv \exp i\pi/3$) and

$$m_\nu = \begin{pmatrix} c & 0 & 0 \\ 0 & a & b \\ 0 & b & a \end{pmatrix}.$$

$\Rightarrow$ Lepton mixing is exactly TBM
$\Rightarrow$ If in addition: $c = a$, neutrino spectrum fixed

Linear and inverse SS in A_4

Mixing between light and heavy neutrinos is generically:

$$K = m_D . M^{-1}$$

Use A_4 to fix charged lepton matrix and:

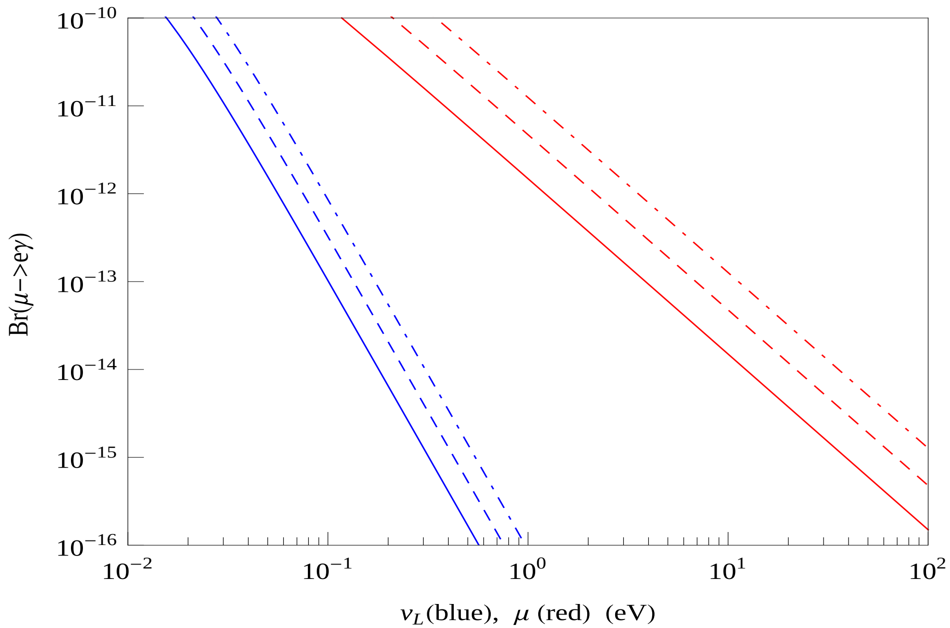
Hirsch, Morisi & Valle, 2009

$$m_D = \begin{pmatrix} a & 0 & 0 \\ 0 & a & b \\ 0 & b & a \end{pmatrix}.$$

Then, $\sum_j K^*_{ik} K_{jk}$ fixed, example inverse seesaw:

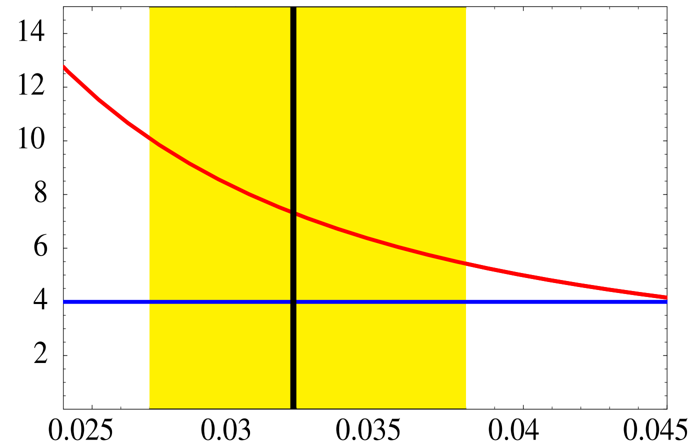
$$\sum_j K^*_{ik} K_{jk} = \begin{pmatrix} a^2 + \frac{4ab}{3} + \frac{2b^2}{3} & -\frac{1}{3}b(2a+b) & -\frac{1}{3}b(2a+b) \\ -\frac{1}{3}b(2a+b) & \frac{1}{3}b(4a-b) & a^2 - \frac{2ab}{3} + \frac{2b^2}{3} \\ -\frac{1}{3}b(2a+b) & a^2 - \frac{2ab}{3} + \frac{2b^2}{3} & \frac{1}{3}b(4a-b) \end{pmatrix}$$

Linear and inverse SS in A_4



$\mathrm{Br}(\mu \to e\gamma)$ for 3 different values of m_N for inverse and linear seesaw

Ratio:
$\mathrm{Br}(\tau \to \mu\gamma)/\mathrm{Br}(\tau \to e\gamma)$ for inverse and linear seesaw assuming exact TBM mixing as function of
$\alpha = \frac{\Delta m^2_{\odot}}{\Delta m^2_{\mathrm{Atm}}}$



$\mathcal{IV}.$

Exotic decay $\mu \to eJ$

Experimental status

Limits on Majoron emission both **very old and very weak**. PDG 2010 gives ($X^0 =$ "familon"):

$$Br(\mu \to eX^0) \leq 2.6 \times 10^{-6}$$

A. Jodidio et al.
PRD34 (1986)

⇒ Not a valid limit for Majoron, since experimental cuts to minimize backgrounds *eliminated* interesting (angular) region. Estimated limit from fig.(7) of this paper, very roughly: $Br(\mu \to eJ) \sim \ \mathrm{(few)}\ 10^{-5}$

$$Br(\tau \to \mu + J) \leq 2.3\%$$
$$Br(\tau \to e + J) \leq 0.73\%$$

MARK-III Collaboration
PRL 55 (1985)

Theoretical status?

(i) Classical "Singlet" Majoron

Chikashige, Mohapatra and Peccei, 1981

(ii) "Doublet" Majoron

Aulakh & Mohapatra, 1982

(iii) Triplet Majoron

Gelmini & Roncadelli, 1981

(iv) "Singlet-doublet" (?) Majoron

Masiero & Valle, 1990

(v) $\cdots$

Theoretical status?

(i) Classical "Singlet" Majoron — Alive, but Experimentally hopeless

Chikashige, Mohapatra and Peccei, 1981

(ii) "Doublet" Majoron — DEAD - LEP

Aulakh & Mohapatra, 1982

(iii) Triplet Majoron — DEAD - LEP

Gelmini & Roncadelli, 1981

(iv) "Singlet-doublet" (?) Majoron — ALIVE

Masiero & Valle, 1990

(v) · · ·

Spontaneous $R\!\!\!/_P$

$$\begin{aligned}\mathcal{W} = h_U^{ij}\widehat{Q}_i\widehat{U}_j\widehat{H}_u &+ h_D^{ij}\widehat{Q}_i\widehat{D}_j\widehat{H}_d + h_E^{ij}\widehat{L}_i\widehat{E}_j\widehat{H}_d \\ &+ \mu\widehat{H}_d\widehat{H}_u\end{aligned}$$

Spontaneous $R\!\!\!/_P$

$$\mathcal{W} = h_U^{ij}\widehat{Q}_i\widehat{U}_j\widehat{H}_u + h_D^{ij}\widehat{Q}_i\widehat{D}_j\widehat{H}_d + h_E^{ij}\widehat{L}_i\widehat{E}_j\widehat{H}_d$$
$$+h_\nu^{ij}\widehat{L}_i\widehat{\nu}^c_j\widehat{H}_u + \mu\widehat{H}_d\widehat{H}_u$$

⇒ Conserves L at level of $\mathcal{W}$

⇒ If scalar singlet gets vacuum expectation value:

$$\epsilon_i = h_i^\nu \langle\tilde{\nu}^c\rangle$$

⇒ Spontaneous breaking of lepton number, Goldstone boson: Majoron

⇒ "Mostly" singlet Majoron of $\langle\tilde{\nu}\rangle \ll \langle\tilde{\nu}^c\rangle$

⇒ Neutrino data easily fitted

Spontaneous $R\!\!\!/_P$

$$\mathcal{W} = h_U^{ij}\widehat{Q}_i\widehat{U}_j\widehat{H}_u + h_D^{ij}\widehat{Q}_i\widehat{D}_j\widehat{H}_d + h_E^{ij}\widehat{L}_i\widehat{E}_j\widehat{H}_d$$
$$+h_\nu^{ij}\widehat{L}_i\widehat{\nu}^c_j\widehat{H}_u - h_0\widehat{H}_d\widehat{H}_u\widehat{\Phi} + h^{ij}\widehat{\Phi}\widehat{\nu}^c_i\widehat{S}_j$$

As before, plus:

Masiero & Valle, 1990

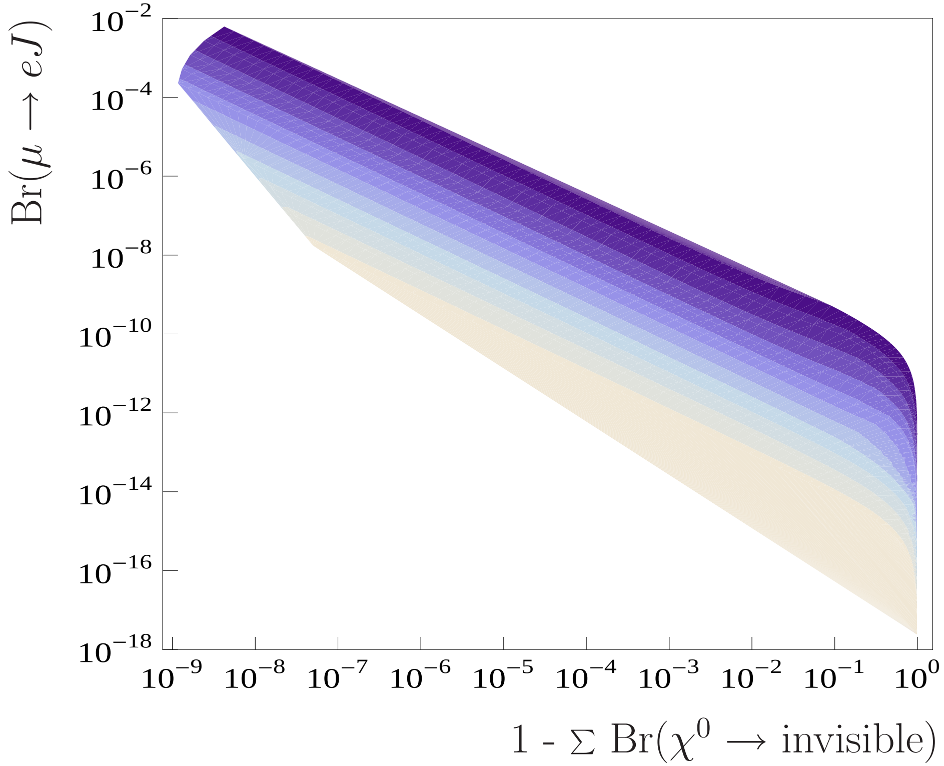
$\Rightarrow$ $\widehat{\Phi}$ potentially solves μ-problem á la NMSSM

$\Rightarrow$ Dirac mass term for $\widehat{\nu}^c$ through v_Φ

$\Rightarrow$ ν^c light a la "inverse seesaw"

$\Rightarrow$ Many variants possible ...

Invisible neutralino decay



Lightest χ^0 decays to $J + \nu$

Decay channel large if $\mu- > eJ$ large

Hirsch et al., 2009

⇒ Large statistics necessary to improve limit

⇒ MEG experiment not sensitive, must search for $\mu- > eJ + \gamma$ instead

Conclusions

- ⇒ observation of CLFV points to BSM - beyond neutrino masses
- ⇒ distinguish between models by different operators (with same generation of leptons)
- ⇒ probe models of neutrino angles by comparing CLFV (using different generations of leptons)
- ⇒ If signs of SUSY at LHC, indirect insight into high energy world: Seesaw parameters (?)

Backup Slides

Neutrino angles

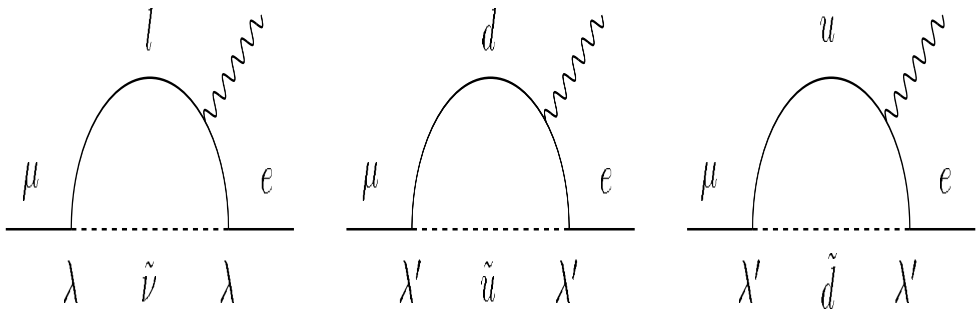
Very good first approximation:
tri-bimaximal ansatz of
Harrison, Perkins & Scott, 2002:

$$\mathcal{U}_\nu^{\mathrm{HPS}} = \begin{pmatrix} \sqrt{\frac{2}{3}} & \frac{1}{\sqrt{3}} & 0 \\ -\frac{1}{\sqrt{6}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{6}} & -\frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \end{pmatrix}$$

Corresponding to

$$\tan^2\theta_{\mathrm{Atm}} = 1 \quad , \quad \tan^2\theta_\odot = \frac{1}{2} \quad , \quad \sin^2\theta_{\mathrm{R}} = 0$$

Trilinear RPV SUSY



Contrary to RPC SUSY
photon diagram
not dominant