Lepton Flavour & CP Violations in Charged Lepton Transitions

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- Leptonic physical observables and limits on New Physics scales
- Limits on LFV & CPV in SUSY scalar masses
- Impact on Seesaw and GUT models

INTRODUCTION

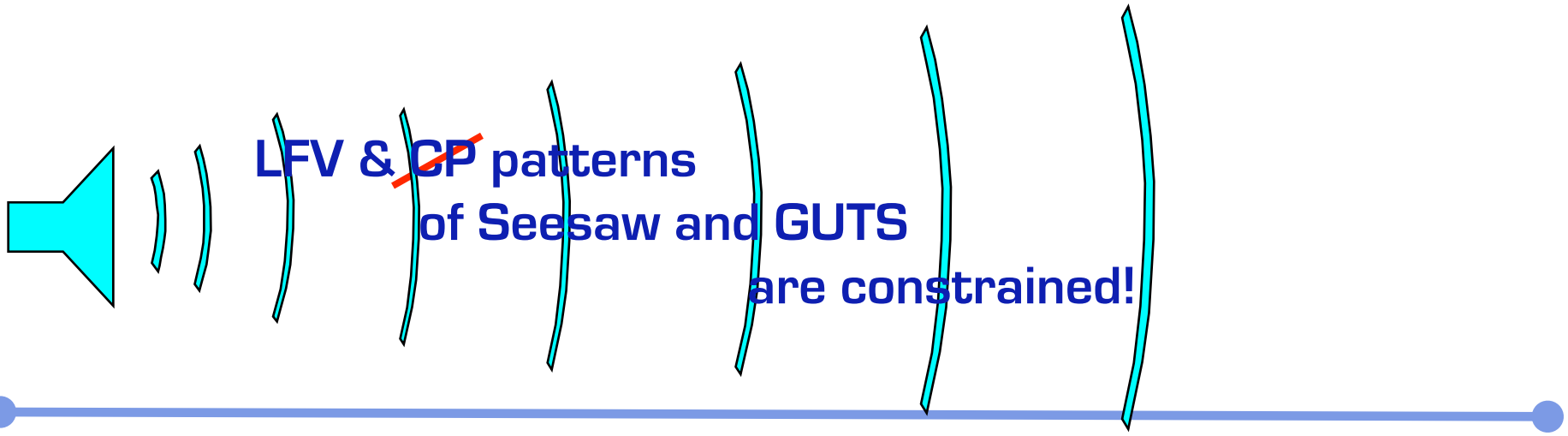
- Neutrino oscillations require LFV in the effective neutrino mass matrix
- Seesaw Leptogenesis requires phases in the couplings of the heavy neutrinos
- The impact of these important LFV&CPV in the charged lepton sector is experimentally irrelevant in the minimal framework: SM $\oplus$ Seesaw, because of GIM - like factors $(\Delta m_\nu^2 / M_W^2)$.
- The observation of LFV in $\mu \to e\gamma$, $\tau \to \mu\gamma$, or CPV in lepton electric dipole moments would be signals of New Physics beyond SM $\oplus$ Seesaw.
- Conversely, the present experiments constrain and will strongly constrain New Physics around and above the TeV region to produce LFV&CPV inhibition mechanisms. E.g., SUSY.
- Some tests provide already relevant constraints on radiative corrections involving new LFV&CPV couplings.

Planned improvements in **experimental limits** on **L**epton **F**lavour **V**iolating Decay and Lepton **E**lectric **D**ipole **M**oments constrain the Yukawa couplings and masses of **heavy states** of the

Seesaw Model and/or **GUT**s

from their **quantum corrections** to the Slepton mass matrix

$\propto$ ln (M_{PLANCK} / M_{HEAVY})

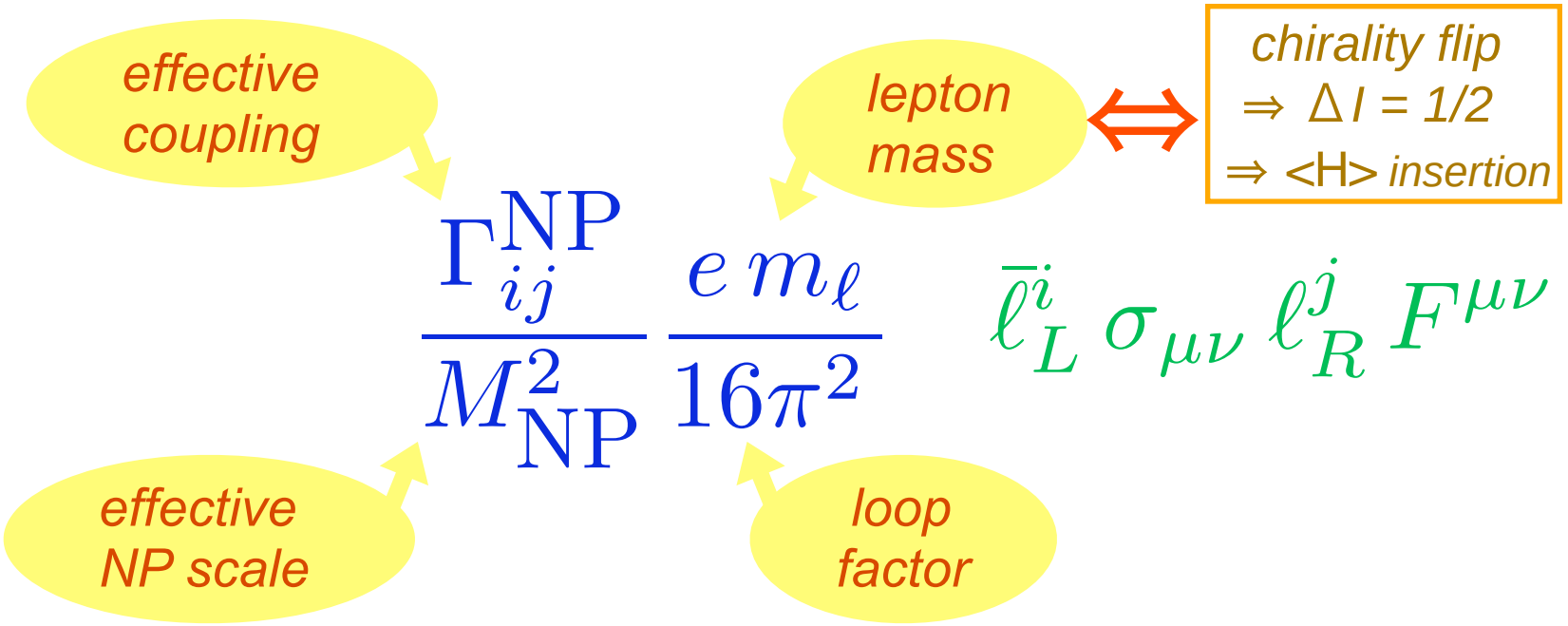


N.B. - These constraints are complementary to those from neutrino oscillations and leptogenesis (seesaw) and proton decays

OBSERVABLE	PRESENT LIMITS	PROSPECTS	S.M.PREDICTION
CLFV	*B.R.*		
$\tau \to \mu\,\gamma$	10^{-6}	10^{-8}(?)	$< 10^{-48}$
$\mu \to e\,\gamma$	10^{-11}	10^{-14} PSI	$< 10^{-48}$
EDM	*e.cm*		
d_e	10^{-27}	10^{-29}	$< 10^{-38}$
d_μ	10^{-18}	10^{-24} BNL 10^{-26} KEK	$<10^{-35}$

Experimental limits on LFV & CPV

MAGNETIC MOMENTS, LFV & CPV



flavour diagonal: i=j	$\Gamma^{\rm NP}_{ii}$	$(g-2)_e$	$(g-2)_\mu$
flavour violating: i≠j	$\Gamma^{\rm NP}_{i\neq j}$	μ → e γ	τ → μ γ
CP violating: i=j	$Im\,\Gamma^{\rm NP}_{ii}$	$\mathbf{d_e}$	$\mathbf{d}_\mu$

LIMITS ON NP CONTRIBUTIONS TO LFV AND CPV

Experiment	M^2_{NP} (TeV^2)	Prospects	Naive Scaling
$(g\text{-}2)_e$	$> \Gamma^{NP}_{ee} / 1000$		m_e^2 / m_μ^2
$(g\text{-}2)_\mu$	$> \Gamma^{NP}_{\mu\mu} / 20$		
$\mu \to e\,\gamma$	$> \Gamma^{NP}_{\mu e} \times 20$	$\times$ 30	m_μ / m_τ
$\tau \to \mu\,\gamma$	$> \Gamma^{NP}_{\tau\mu} / 40$	$\times$ 10 (?)	
d_e	$> \mathrm{Im}\,\Gamma^{NP}_{ee} \times 70$	$\times$ 100	m_e / m_μ
d_μ	$> \mathrm{Im}\,\Gamma^{NP}_{\mu\mu} \times 10^{-5}$	$\times 10^6$ (!)	

New Physics across the TeV barrier
⇒ new flavour and CP violations

Present (future) **experiments** constrain (will strongly constrain) contributions from NP around the TEV scale: **LFV & CPV** ones are much **more restricted** than the flavour and CP conserving ones.

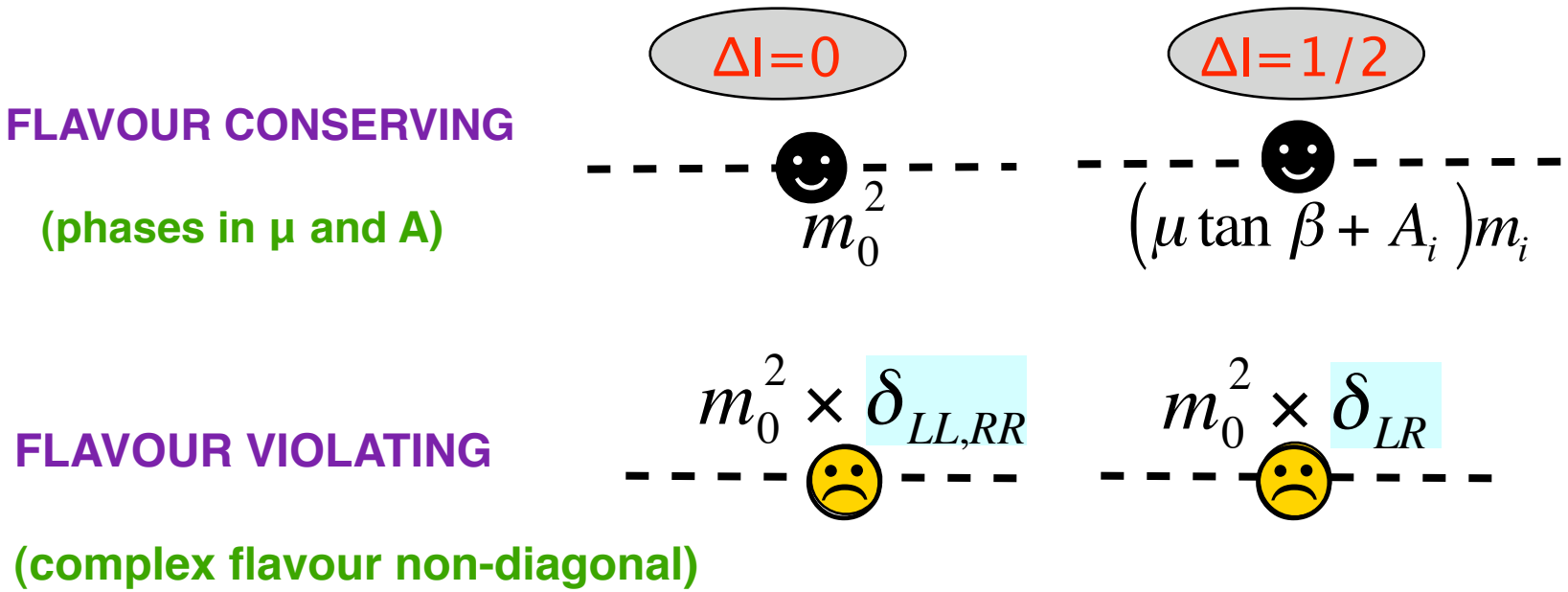
⇒ A generic NP flavour and CP problem to be controlled both at tree and quantum levels

SUSY is (one of) the best candidate(s) for a NP framework but it has many effective sources of low energy LFV & CPV, in particular in the **slepton/squark mass matrices** ⇒ contributions to LFV and EDM ⇒ strong constraints on SUSY breaking parameters (e.g., mSUGRA).

SEESAW theories and **GUT**'s contain **LFV & CPV in their couplings** that radiatively correct the low energy effective SUSY breaking parameters and are potentially measureable in LFV decays and EDMs.

SCALAR LEPTON MASS MATRICES

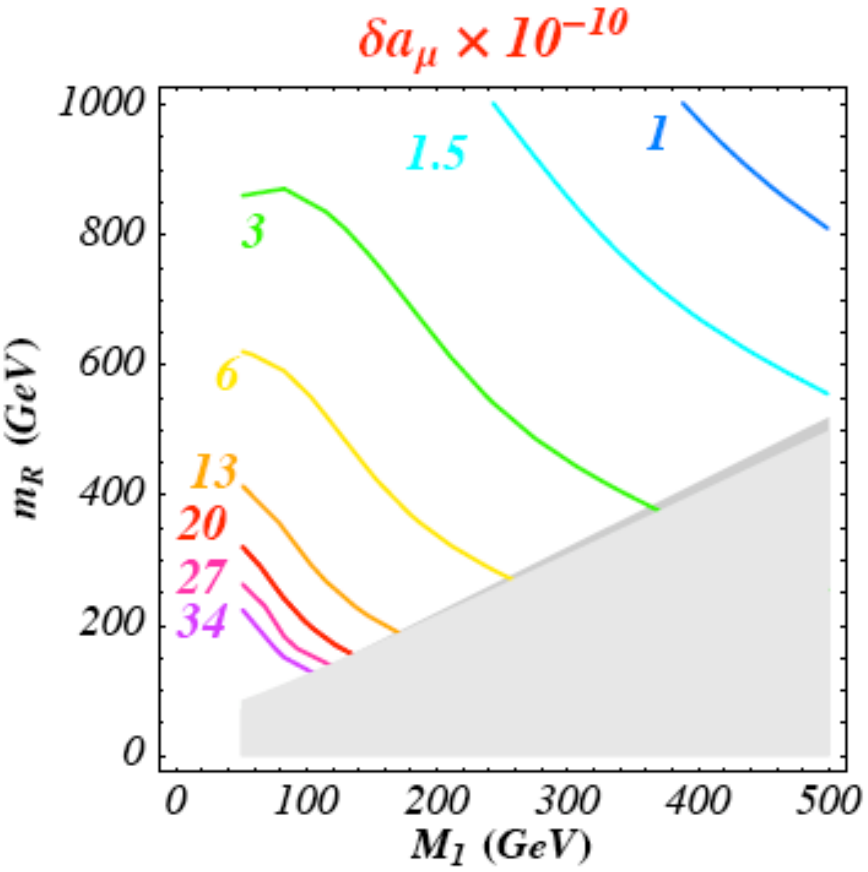
(standard notation)



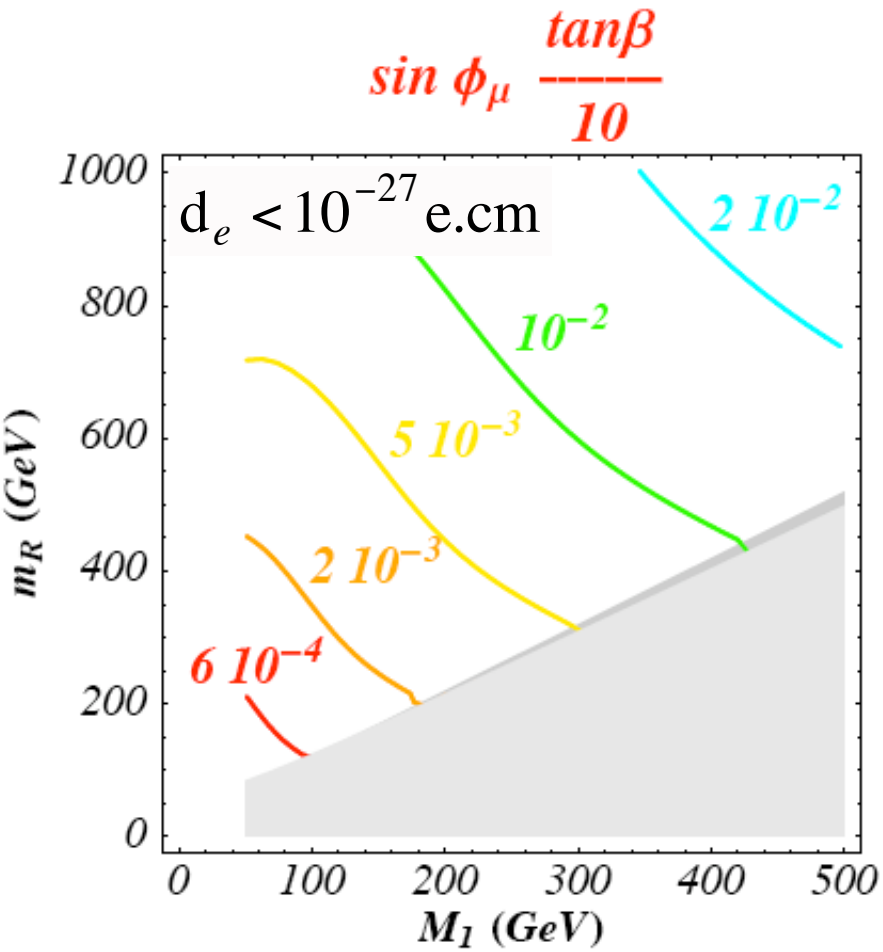
The limits on the δ matrix elements are obtained (not necessarily) by expanding the amplitudes in their products. E.g.:

$$\text{EDM} \in \text{Im}\left[\underbrace{(\mu \tan\beta + A_i)\, m_i}_{\text{lepton flavour conserving CP violation}} + \underbrace{(\delta_{RR})_{ik}\,(\mu \tan\beta + A_k)\, m_k (\delta_{LL})_{ki}}_{\text{lepton flavour violating CP violation}} + \ \ldots\ \right]$$

SUSY (MDM + "i"EDM) - flavour conserving



$\delta a_\mu \leq 20 \times 10^{-10}$

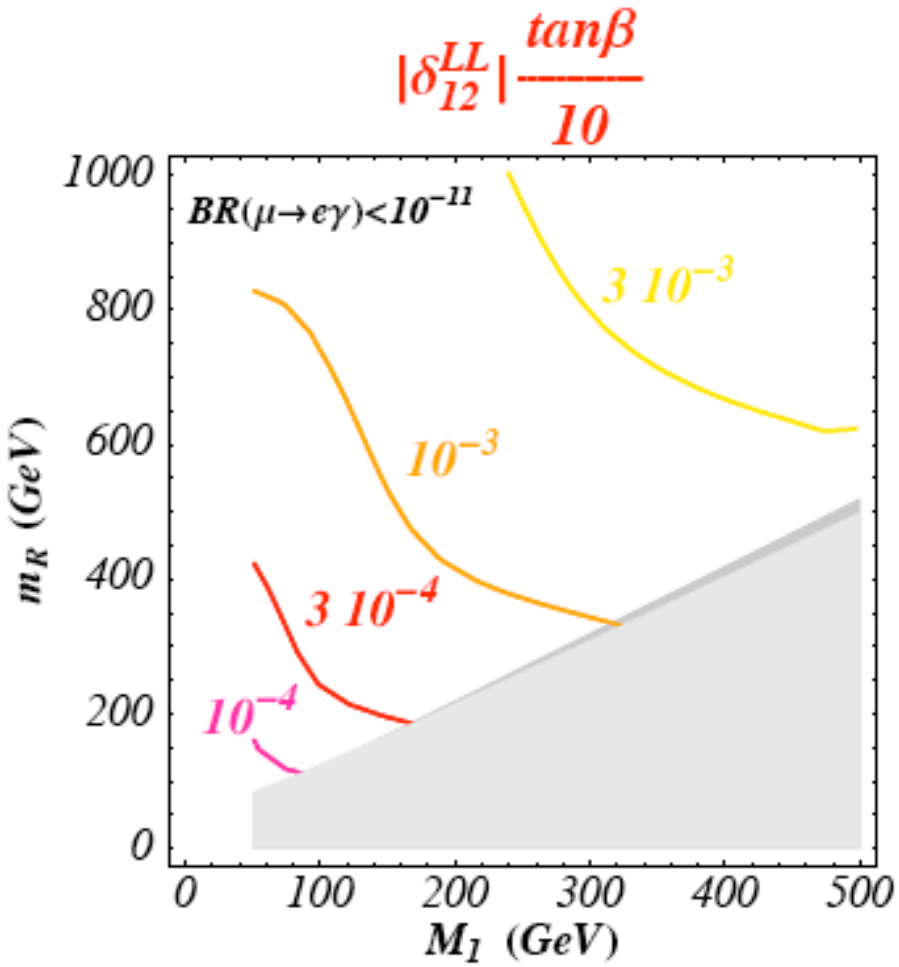


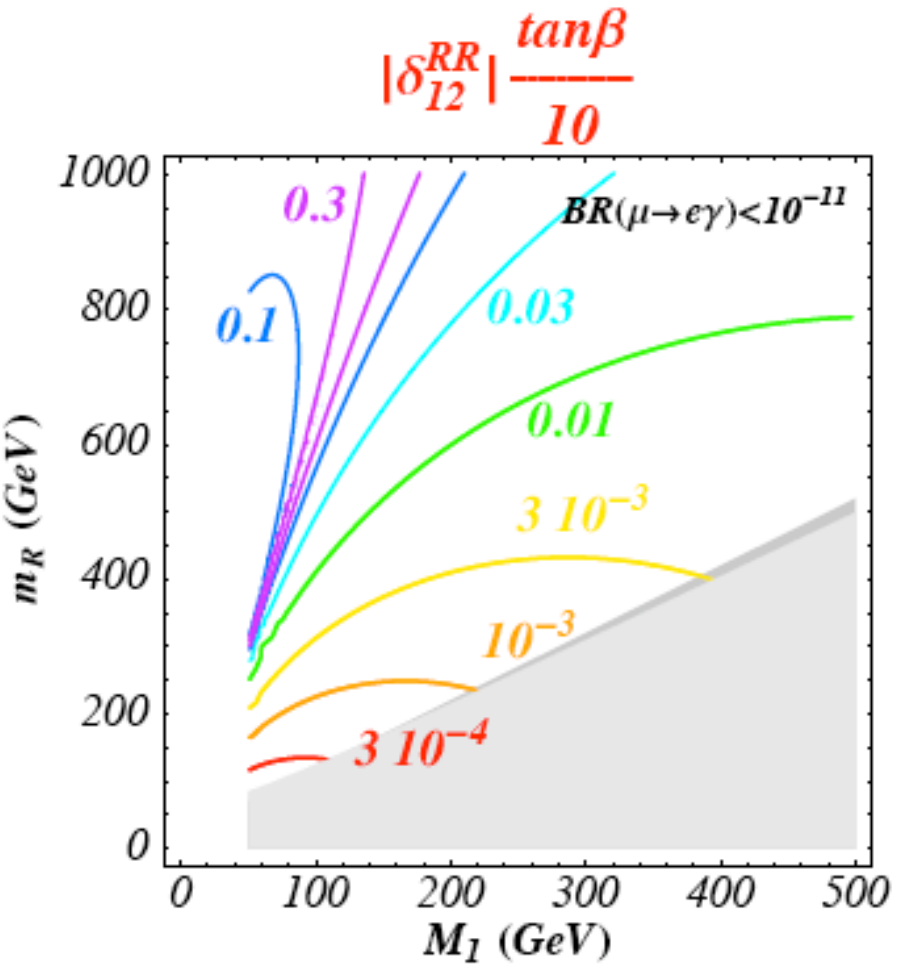
$\phi_\mu = ph[\mu]$

×1/100 for $d_e < 10^{-29}$ e.cm

limits on LFV slepton masses

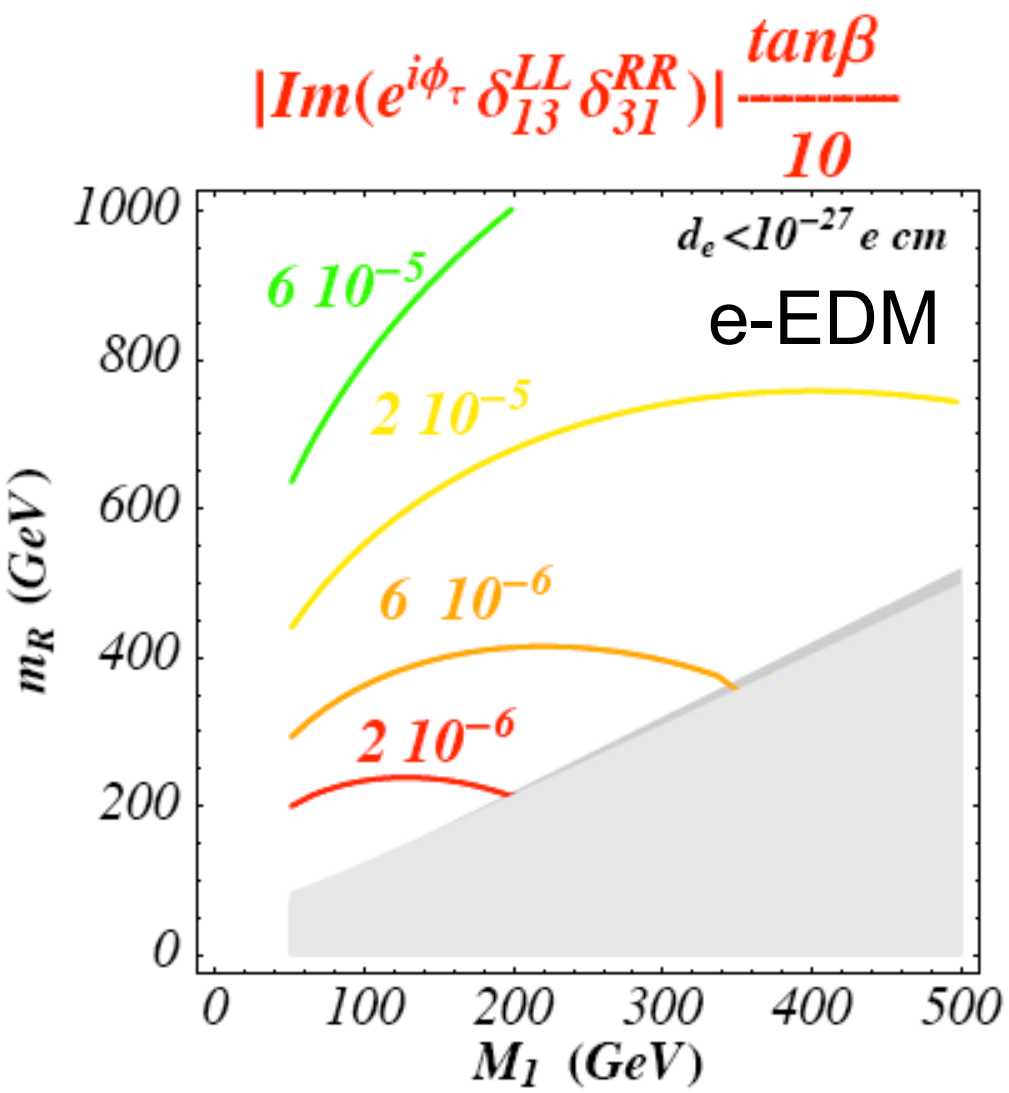
from B.R.(μ→eϒ)





Planned experiments are expected to improve these limits by a factor of 30

flavour violating CP violation



Therefore:
the LFV & CPV contributions from SUSY loops must be reduced by several orders of magnitude w.r.t. analogous radiative corrections to flavour & CP conserving processes

= SUSY FCNC & CP problems

LOOKING FOR FOOTPRINTS OF VERY HEAVY (DECOUPLED) STATES:

GUT COLOUR TRIPLETS

SEESAW MAJORANA NEUTRINOS

PATTERN OF FLAVOUR AND CP VIOLATIONS IN THE SLEPTON MASS MATRIX

INDUCING LFV AND CPV THRU SUSY RADIATIVE CORRECTIONS:

SUSY mediated LFV & CP

FOOTPRINTS OF SEESAW & GUT HEAVY STATES IN THE SLEPTON MASS MATRICES

LFV & CP phases are radiatively generated from **heavy state** contributions to the RGE running until their **decoupling**.
In 1st. order these loop contributions are like:

SEESAW HEAVY NEUTRINOS
decouple @ M_R

$$N = Y_\nu^\dagger \ln\left(\frac{M_{Pl}}{M_R}\right) Y_\nu$$

Text

GUT COLOUR TRIPETS
decouple @M_T

$$U = Y_u^\dagger \ln\left(\frac{M_{Pl}}{M_T}\right) Y_u$$

(in SO(10) GUT: $N \approx U$)

LFV e.m. decays: $\delta^{\mathrm{LL}}_{i\neq j} \propto N_{ij} \oplus \ldots$ $\delta^{\mathrm{RR}}_{i\neq j} \propto U_{ij} \oplus \ldots$

E.D.M (flavour conserving **A**-term) ≠ 0 iff strong hierarchy in M

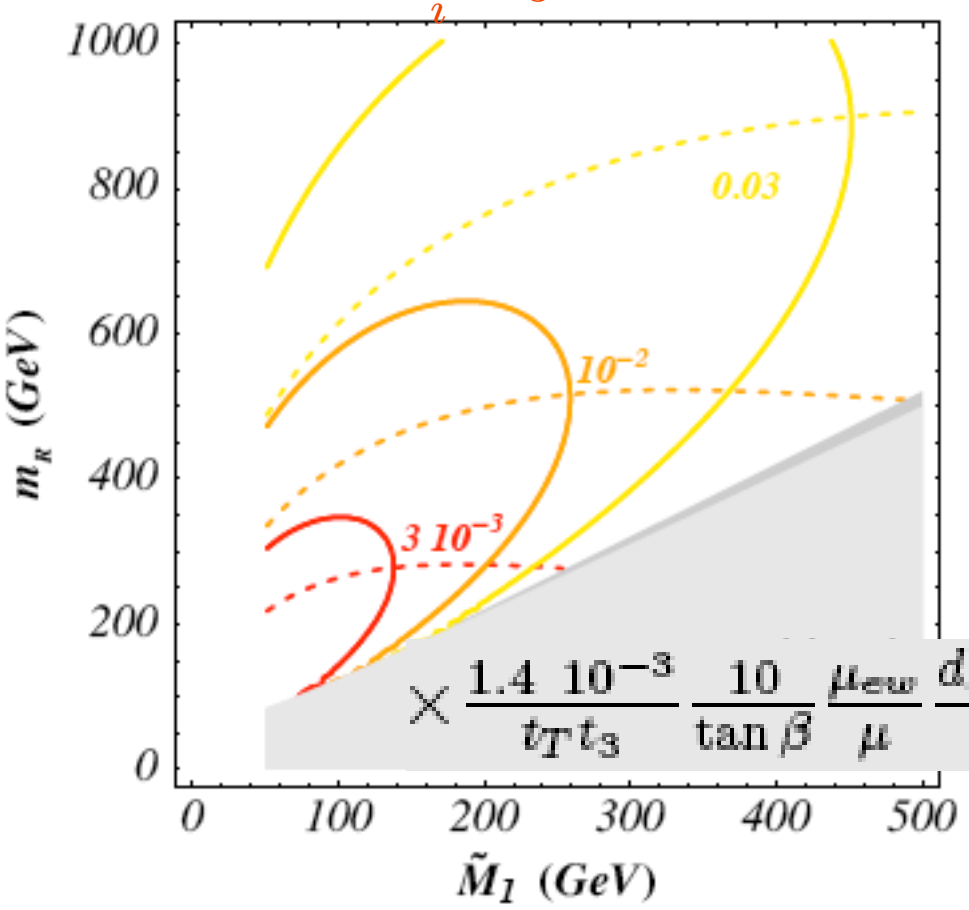
E.D.M (flavour violating): $\mathrm{Im}\left(\delta^{LL} m_\ell \delta^{RR}\right)_{ii} \sim \mathrm{O}(1)\mathrm{Im}(U^* m_\ell N)_{ii}$

limits on seesaw couplings in SU(5)

$$\mathrm{Im}\sum_i \frac{t_i}{t_3} Y^*_{\nu i1} Y_{\nu i3} e^{-i\beta}$$

$$t_i = \frac{1}{16\pi^2} \ln\left(\frac{M_{Pl}}{M_i}\right)$$

$$\beta = \mathrm{phase}(V_{td}) \approx .42$$

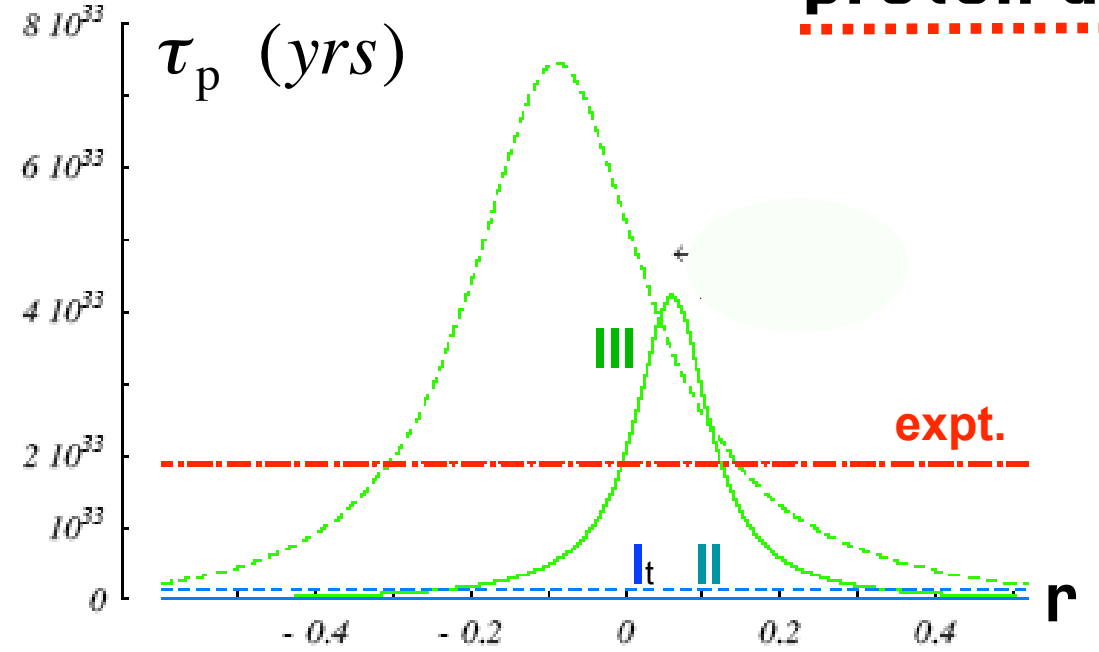


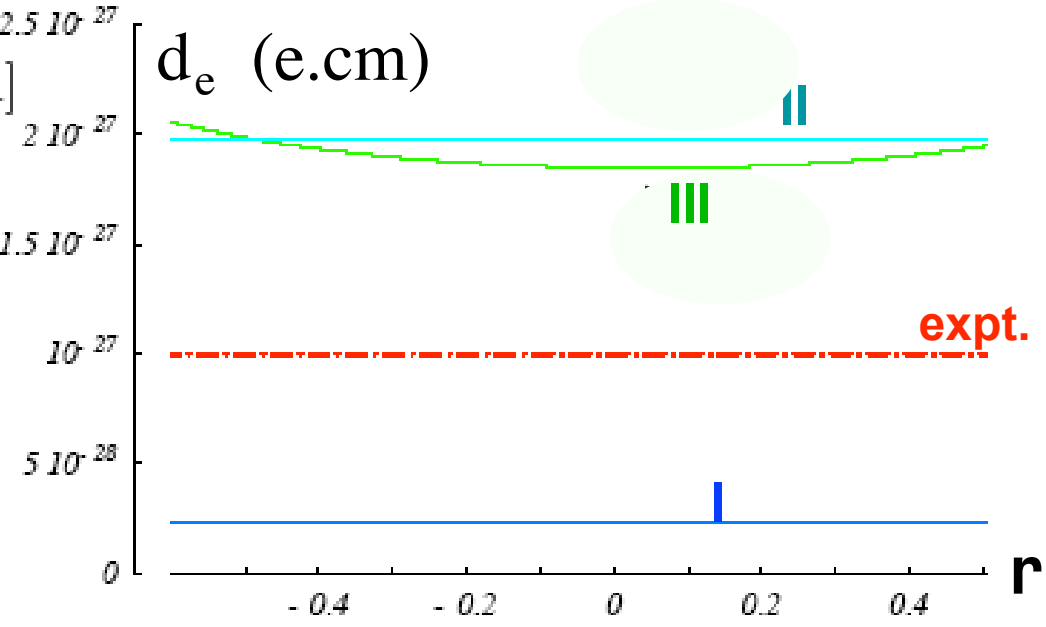
These limits will be multiplied by a 1/100 with the future limit:

$$d_e < 10^{-29}\ \mathrm{e.cm}$$

How relevant are these limits for GUT's?

limits on colour triplet masses: proton decay vs. electron EDM





Model I: SU(5) (minimal)
with $Y_\nu = Y_u$

Model II: SO(10) (minimal)
with $M_{T_1} = M_{T_2}$

Model III: SO(10) (pseudoDirac)
with $M_{T_1} / M_{T_2} = (r-1)/(r+1)$

$\tilde{M}_1 = 200\,\text{GeV} \quad m_{e_R} = 400\,\text{GeV}$

$\tan\beta = 3 \quad M_T = 10^{17}\,\text{GeV}$

- Conclusion -

d_e , d_μ, $\mu \to e\gamma$ experiments

- STRONGLY CONSTRAIN
- WILL SEVERELY CONSTRAIN SUSY GUT's and SEESAW's
- FROM LFV & CPV EFFECTS IN THE SCALAR LEPTON MASS MATRICES OF SUSY THEORIES

(ALTHOUGH ONE CANNOT EXCLUDE CONTRIBUTIONS BETWEEDIFFERENT PHASES)
LEPTON EDM WILL PROVIDE RELEVANT BOUNDS ON HEAVY TRIPLET MASSES IN GUT'S

$d_\mu > (m_\mu/m_e)d_e$ IS AN INTERESTING THEORETICAL CHALLENGE AND d_μ EXPERIMENTS ARE IMPROVING A LOT.