Flavour in the era of the LHC

Lepton Flavour Violation from SUSY GUTs

Lorenzo Calibbi
Università di Padova & INFN sez. di Padova

based on L.C., A. Faccia, A. Masiero, S.K. Vempati, arXiv: hep-ph/0605139

Why studying LFV in the era of the LHC?

•It exists in nature! (in the neutrinos sector...)

•It is (in general) a consequence of new physics at the TeV scale,

while in the SM is higly suppressed

•Model dependent

Experiments:

Running: **BaBar**, **Belle**

Upcoming: **MEG** (2006)

Future: **SuperKEKB** (2011)

PRISM/PRIME (next decade)

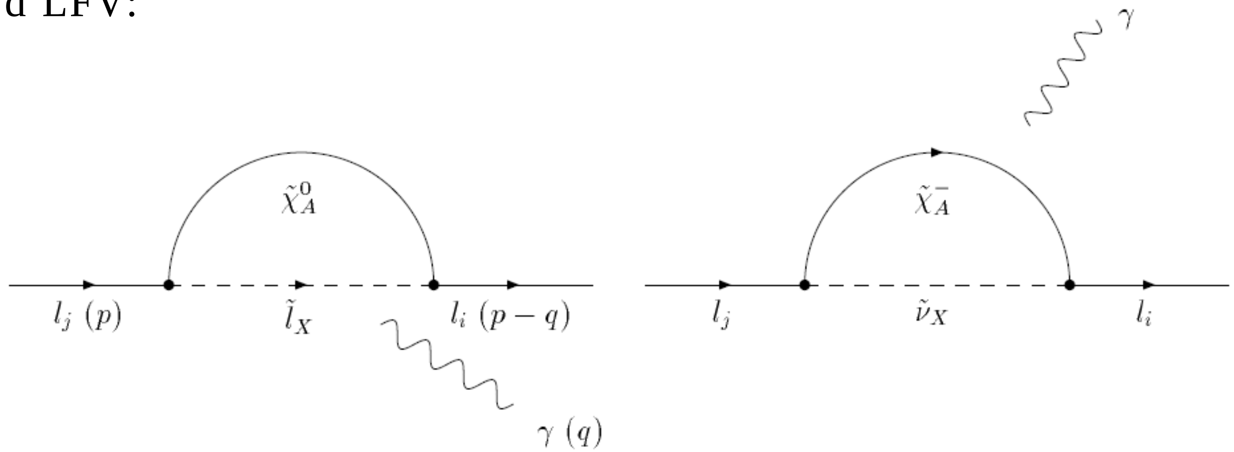
Super Flavour factory (?)

TABLE I: Present bounds and expected experimental sensitivities on LFV processes

Process	Present bound	Future sensitivity
$\mathrm{BR}(\mu \to e\,\gamma)$	1.2×10^{-11}	$\mathcal{O}(10^{-13} - 10^{-14})$
$\mathrm{BR}(\mu \to e\,e\,e\,)$	1.1×10^{-12}	$\mathcal{O}(10^{-13} - 10^{-14})$
$\mathrm{CR}(\mu \to e \text{ in Ti})$	4.3×10^{-12}	$\mathcal{O}(10^{-18})^{a}$
$\mathrm{BR}(\tau \to e\,\gamma)$	3.1×10^{-7}	$\mathcal{O}(10^{-8})$
$\mathrm{BR}(\tau \to e\,e\,e)$	2.7×10^{-7}	$\mathcal{O}(10^{-8})$
$\mathrm{BR}(\tau \to \mu\,\gamma)$	6.8×10^{-8}	$\mathcal{O}(10^{-8}) - \mathcal{O}(10^{-9})^{a}$
$\mathrm{BR}(\tau \to \mu\,\mu\,\mu)$	2×10^{-7}	$\mathcal{O}(10^{-8})$

[a] Planned or discussed experiment, not yet under construction

SUSY induced LFV:



$$\begin{pmatrix} \mathbf{m^2_{\tilde{L}}} + Y_e Y_e^\dagger v_d^2 + \mathcal{O}(g^2) & v_d(\mathbf{A_e^\dagger} - Y_e^\dagger \mu \tan\beta) \\ v_d(\mathbf{A_e} - Y_e \mu \tan\beta) & \mathbf{m^2_{\tilde{E}}} + Y_e^\dagger Y_e v_d^2 + \mathcal{O}(g^2) \end{pmatrix}$$

Two main sources of LFV have been studied for many years:

GUT effect, e.g. SU(5), if $\boldsymbol{M_X > M_{GUT}}$

$$(\Delta_{RR})_{i\neq j} = -3 \cdot \frac{3m_0^2 + a_0^2}{16\pi^2} Y_t^2\, V_{i3} V_{j3} \ln\left(\frac{M_X^2}{M_{GUT}^2}\right)$$

See-saw:

$$m_\nu = -Y_\nu \hat{M}_R^{-1} Y_\nu^T \langle H_u \rangle^2$$

$$(\Delta_{LL})_{i\neq j} = -\frac{3m_0^2 + A_0^2}{16\pi^2} Y_{\nu\ i3} Y_{\nu\ j3} \ln\left(\frac{M_X^2}{M_{R_3}^2}\right)$$

The most general renormalizable $SO(10)$ superpotential, relevant to fermion masses:

$$W_{SO(10)} = Y_{ij}^{10} 16_i 16_j 10 + Y_{ij}^{126} 16_i 16_j 126 + Y_{ij}^{120} 16_i 16_j 120$$

$$\Rightarrow \begin{cases} m_D^\nu = M_{10} - 3M_{126} + M_{120} \\ m_u = M_{10} + M_{126} + M_{120} \end{cases}$$

At least one of the *eigenvalues* of the neutrino Yukawa matrix in $Y_\nu = m_D^\nu / v_u$ has to be as large as the top Yukawa.

And what about the *mixing angles*? We consider two benchmark cases:

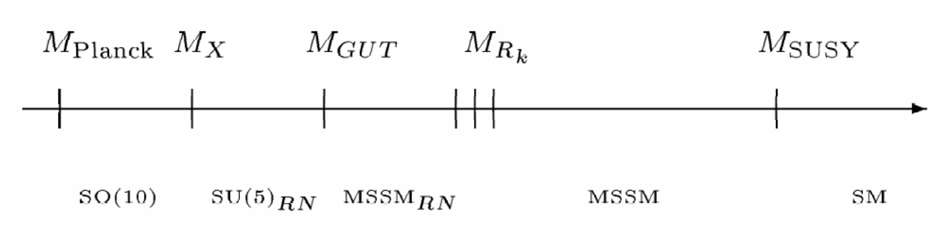
"Minimal" mixing (CKM):

$$Y^\nu = Y^u \Rightarrow Y^\nu = V_{\rm CKM}^T Y_{diag}^u V_{\rm CKM}$$

"Maximal" mixing (PMNS):

$$Y^\nu = U_{\rm PMNS} Y_{diag}^u$$

Scheme of the RG running and of the energy scales involved



How does the routine work:

•Running of the low energy fermion param.

•Definition of Y_ν

•M_R from see-saw

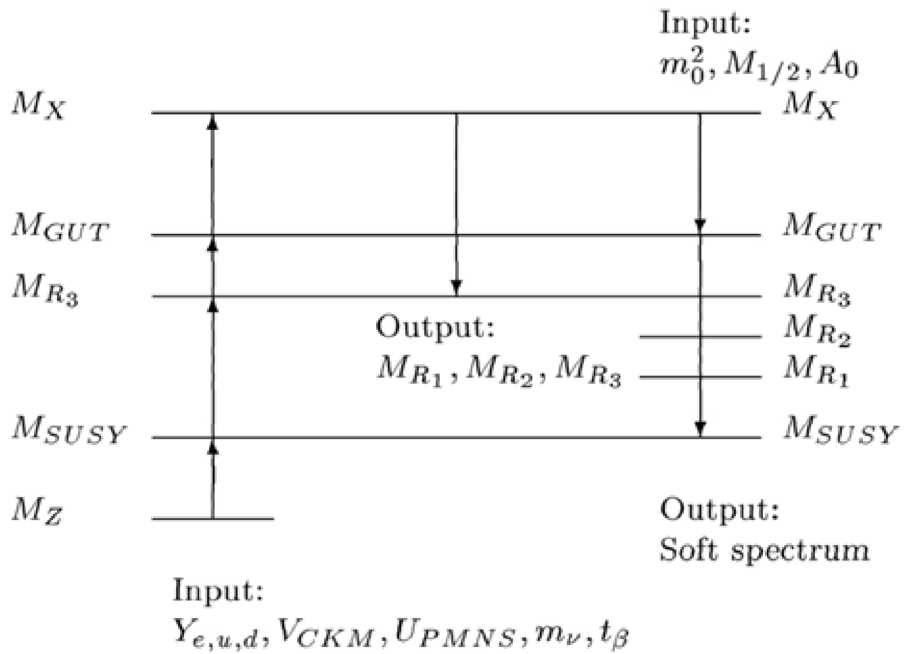
•RG evolution of the soft parameters

•SUSY spectrum

•Th. & Exp. checks

•Computation of the LFV processes rates through the exact SUSY masses and mixings

Sketch of the running routine



Scanning the mSUGRA parameter space:

$0 < m_0 < 5000$ GeV

$0 < M_{1/2} < 1500$ GeV

$-3\, m_0 < A_0 < +3\, m_0$

$\tan\beta = 10, 40$

μ and $B\mu$ fixed by EWB

Theoretical constraints:

- REWSB
- No tachyonic particles
- Neutral LSP

Experimental constraints:

- LEP limit on Higgs mass
- Limits on SUSY particles

→ The region where at least one squark has mass below 2.5 TeV is ‘our’ LHC accessible region.

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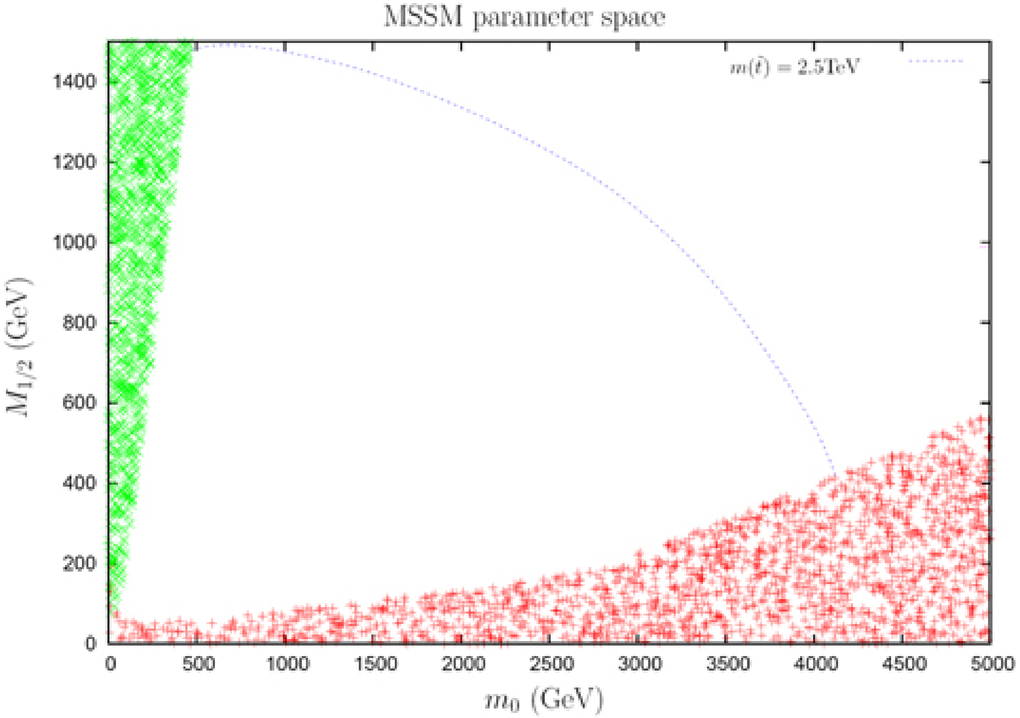

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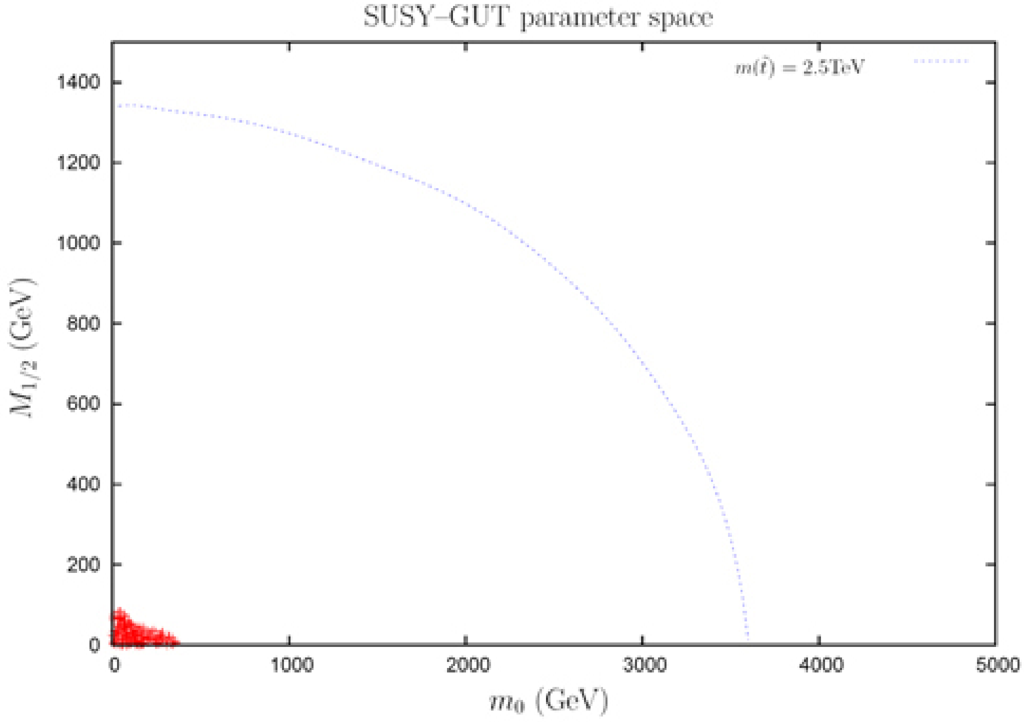

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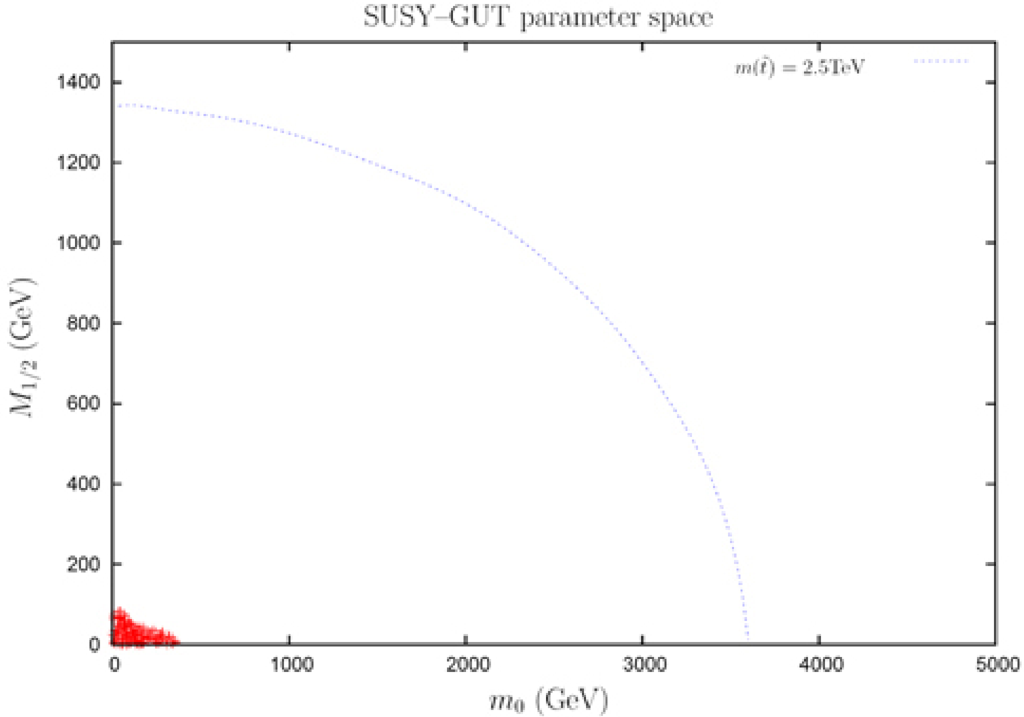

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$$\sin 2\beta = \frac{2B\mu}{m_{H_u}^2 + m_{H_d}^2 + 2\mu^2},$$

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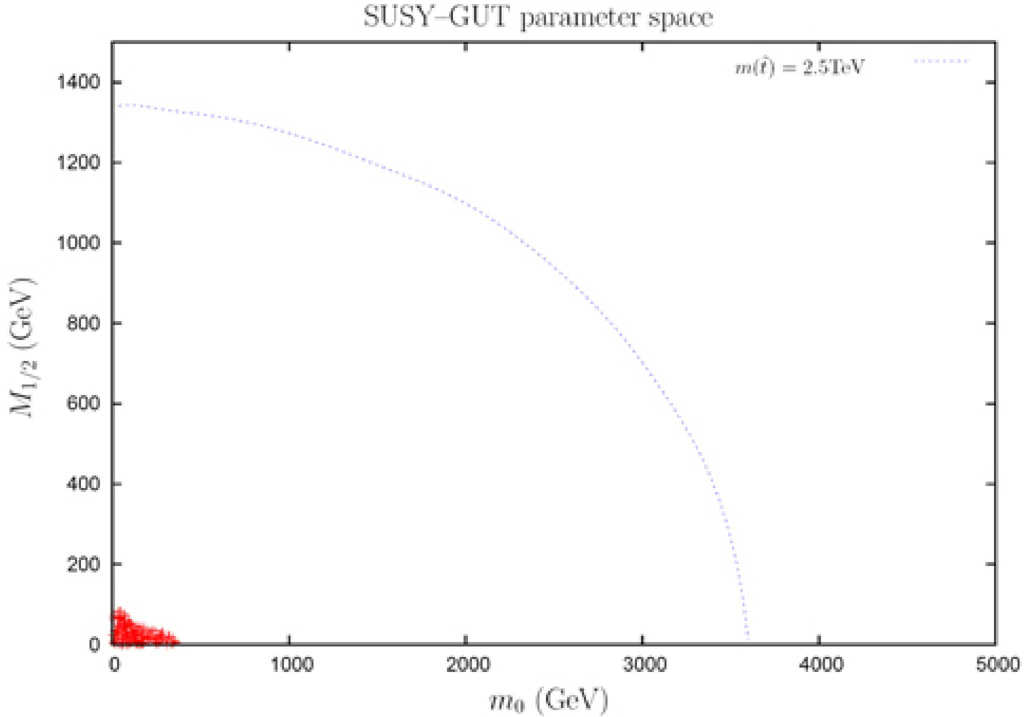

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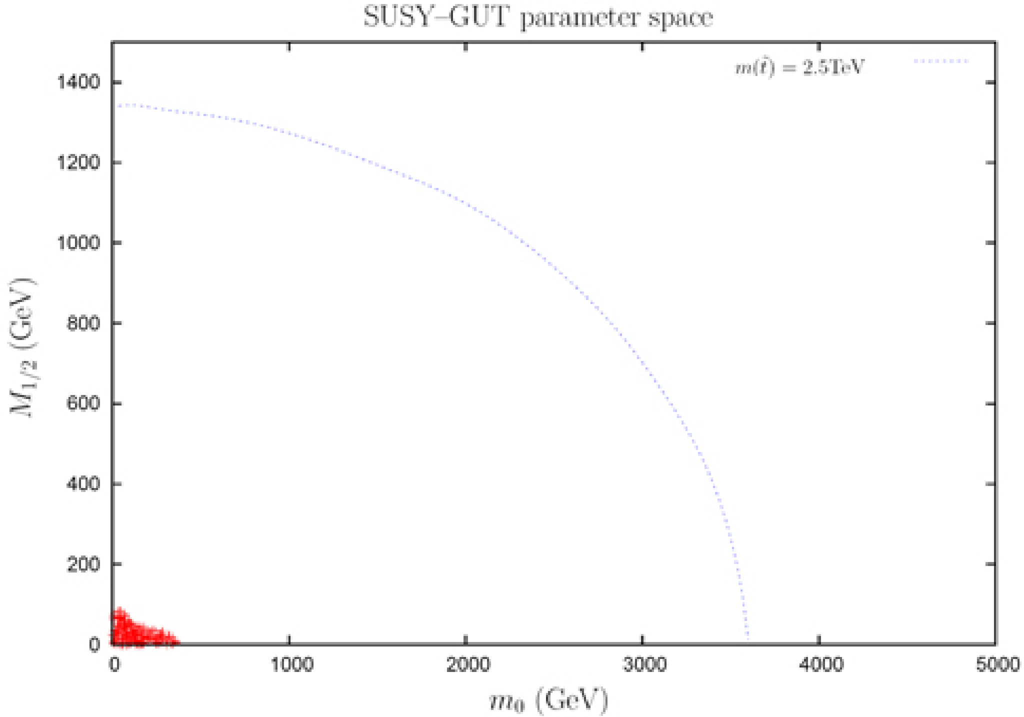
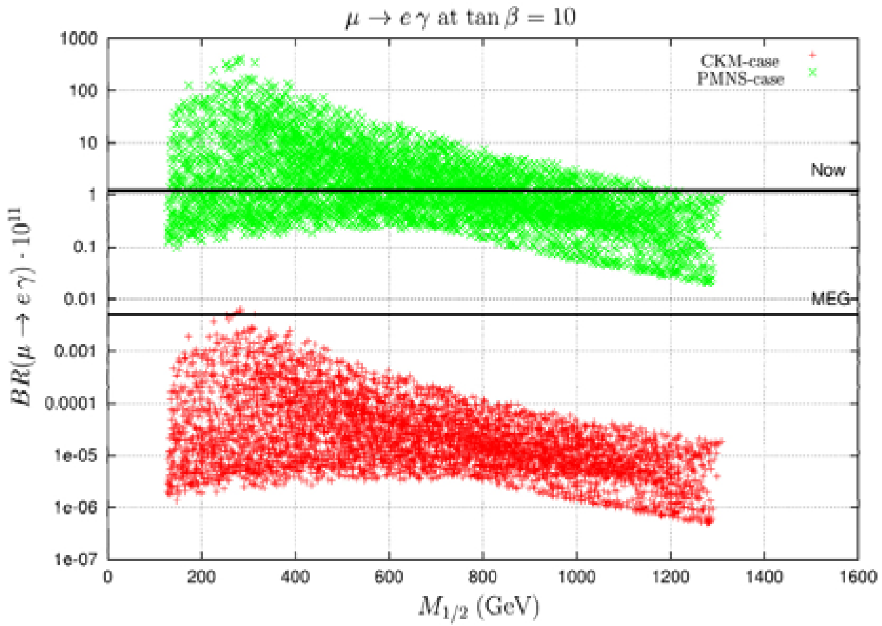


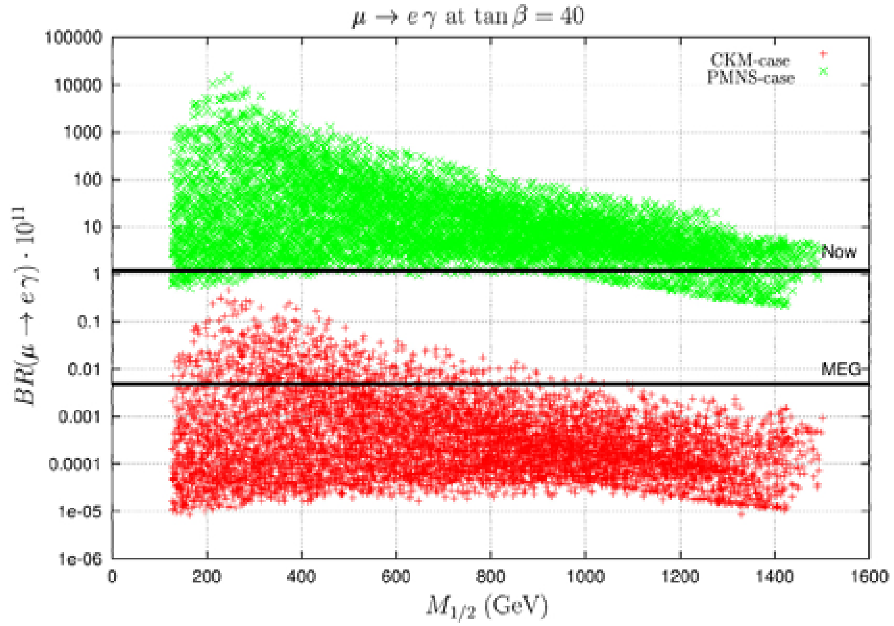
LSP:

$$m^2_{\tilde{\tau}_R}(M_{GUT}) = \frac{96}{80\pi^2} M^2_{1/2} \ln\left(\frac{M_X}{M_{GUT}}\right) \approx 0.4 M^2_{1/2}$$

(right stau mass for $m_0 = 0$)

$\mu \to e\,\gamma$ and **MEG** sensitivity reach



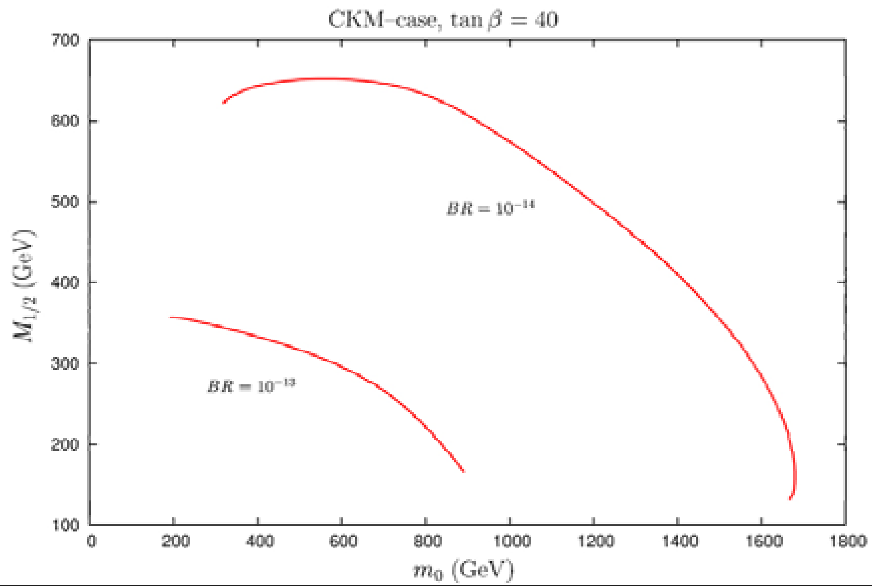


- Maximal mixing (PMNS), high $\tan\beta$ case, already ruled out in the LHC accessible region.

  MEG will test it well beyond the LHC.

- Minmal case (CKM) presently unconstrained.

  MEG will test, for high values of $\tan\beta$, the region $(m_0, m_{\tilde{g}}) \lesssim 1$ TeV



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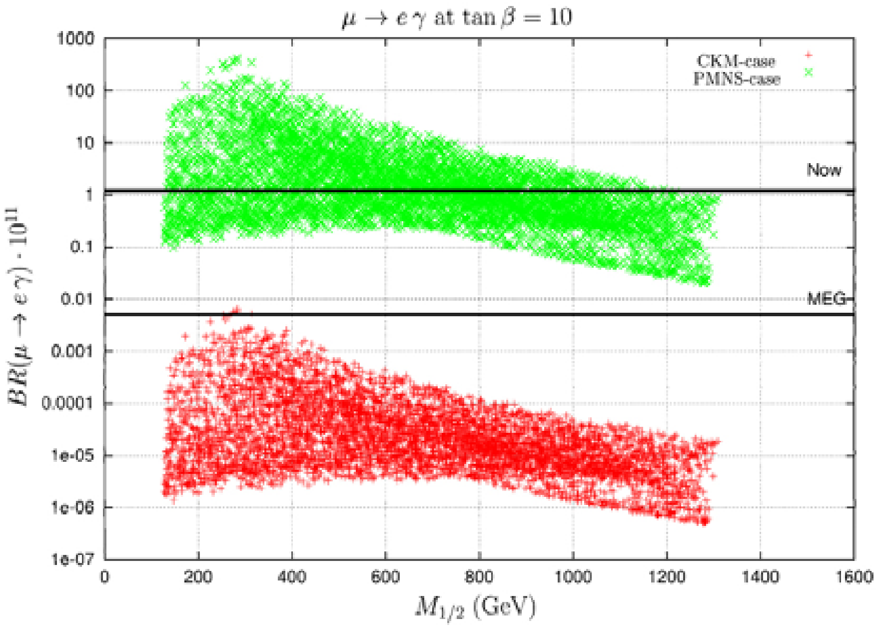
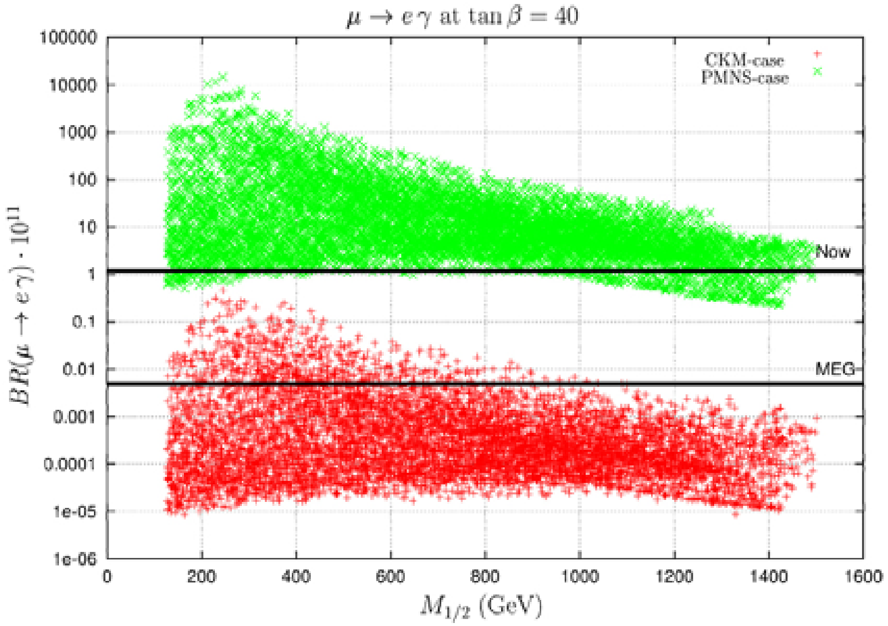
$\mu \to e\gamma$ and **MEG** sensitivity reach





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In fact:

$$(\delta_{LL})_{\mu e} = -\frac{3}{8\pi^2} Y_t^2 U_{e3} U_{\mu 3} \ln \frac{M_X}{M_{R_3}}$$

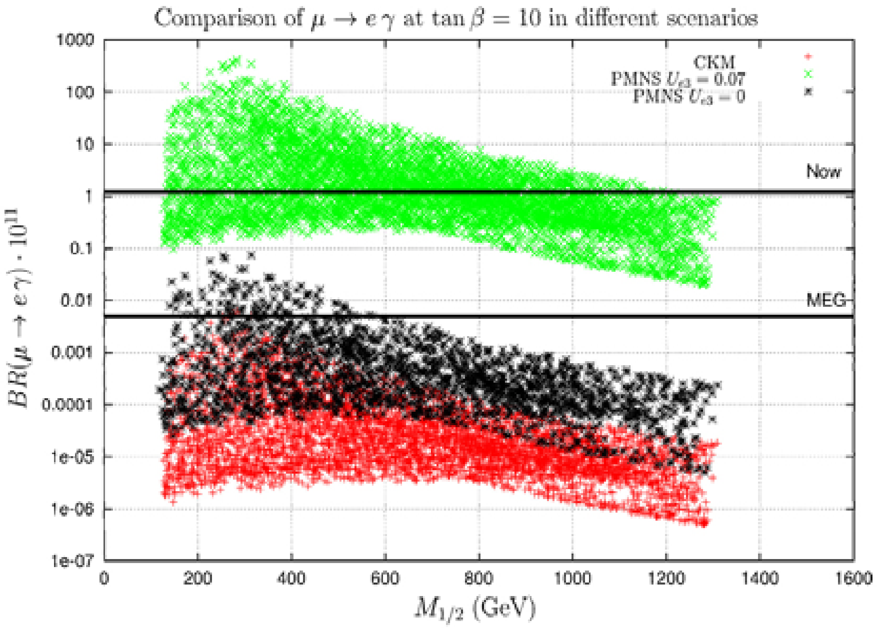
And if $U_{e3} = 0$:

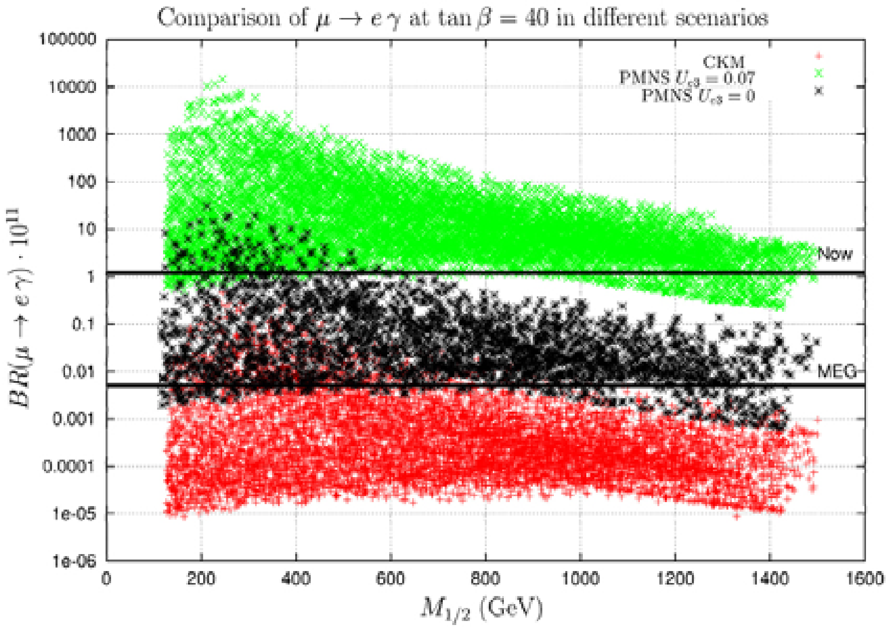
$$(\delta_{LL})_{\mu e} = -\frac{3}{8\pi^2} Y_c^2 U_{e2} U_{\mu 2} \ln \frac{M_X}{M_{R_2}}$$

But in the PMNS case, the rate depends on U_{e3} ...

$$\frac{Y_c^2\; U_{\mu 2}\; U_{e2} \ln(M_X/M_{R_2})}{Y_t^2\; V_{td}\; V_{ts} \ln(M_X/M_{R_3})} \sim \mathcal{O}(10^{-2})$$

$\mu \to e\gamma$ in the $U_{e3} = 0$ PMNS case



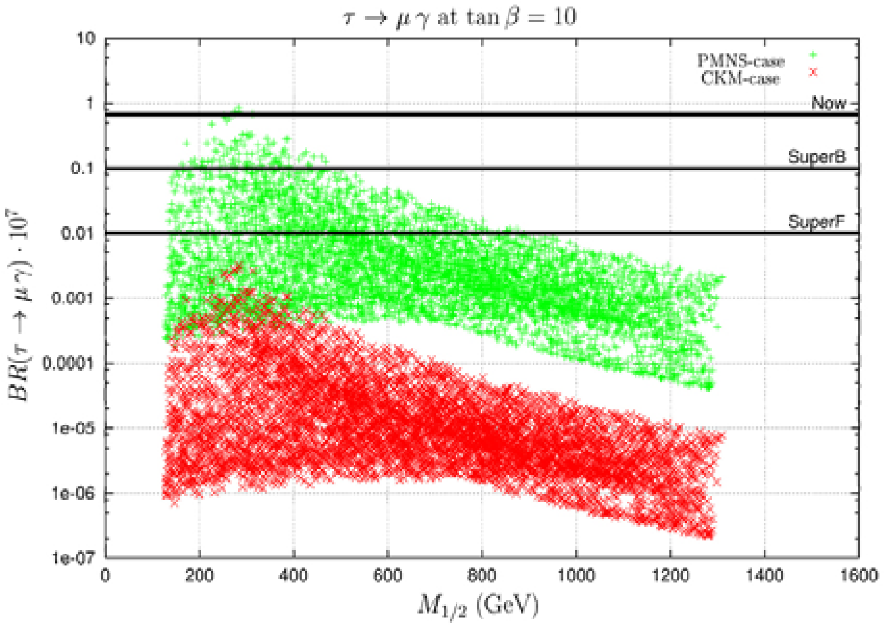


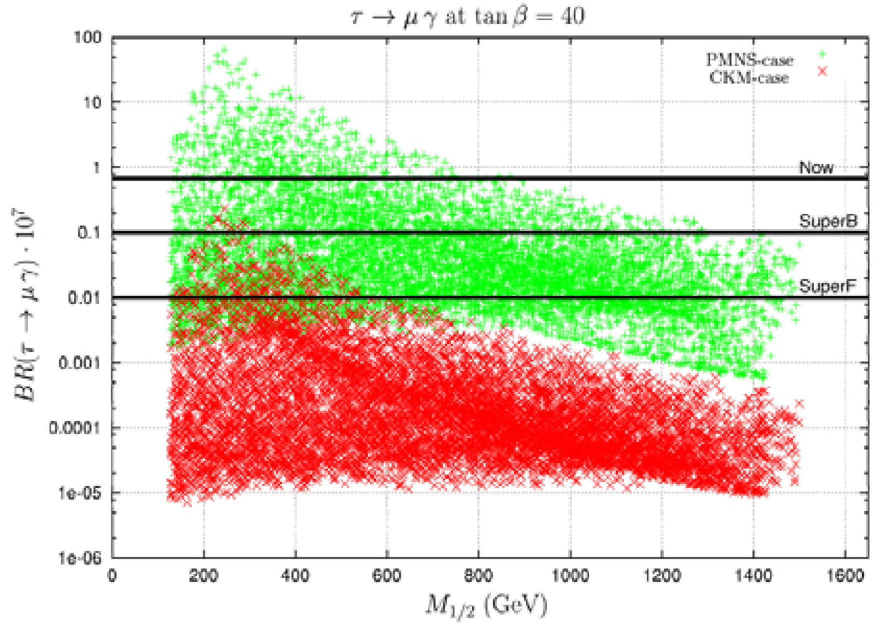
- The PMNS $U_{e3} = 0$ scenario is currently better costrained by $\tau \to \mu\gamma$ (see later)
- For high values of tanβ, **MEG** will probe almost all the LHC accessible parameter space
- In the case of small tanβ, MEG will test up to $(m_0, m_{\tilde{g}}) \lesssim 900$ GeV

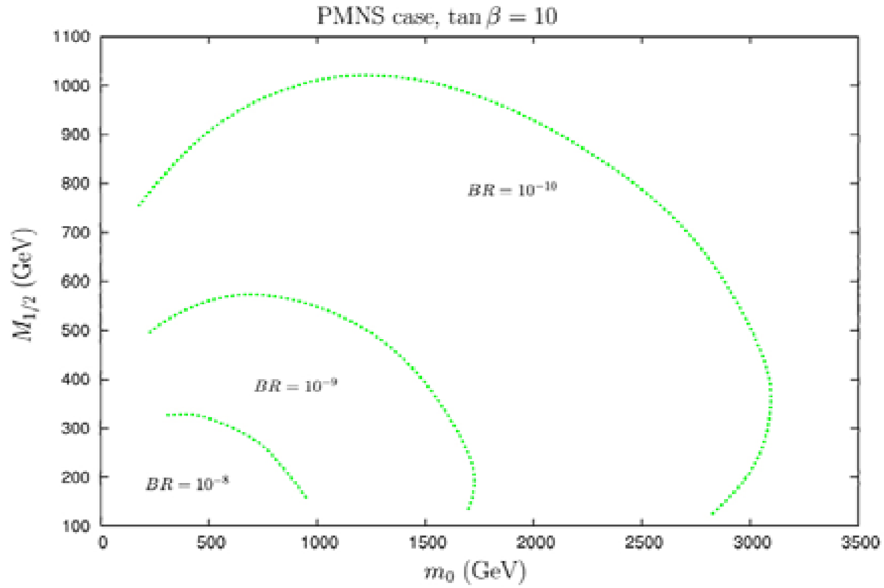
The observed enhancement is due to the interplay of different effects:

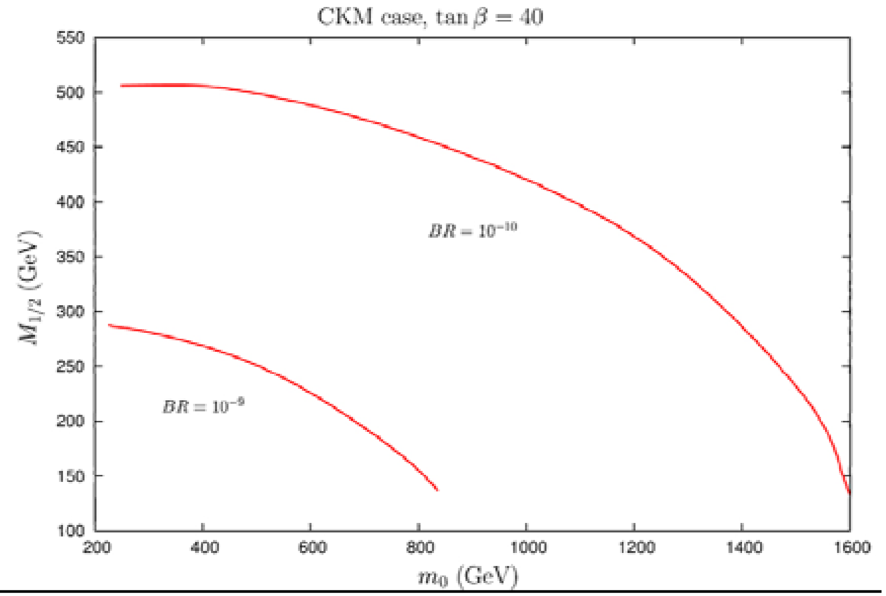
- The running of U_{e3} from low energy up to the high scale where the PMNS condition is imposed
- The dominance in some regions of the paramater space of SU(5) generated contributions, such as $(\delta_{LL})_{\mu\tau}(\delta_{RR})_{e\tau}$

$\tau \to \mu\gamma$ and the **Super B** (and **Flavour**) factories







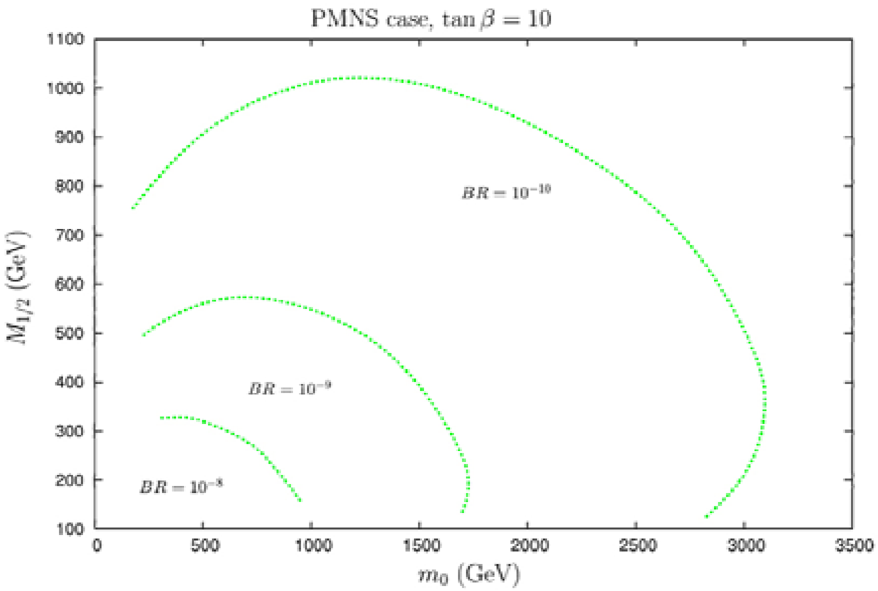


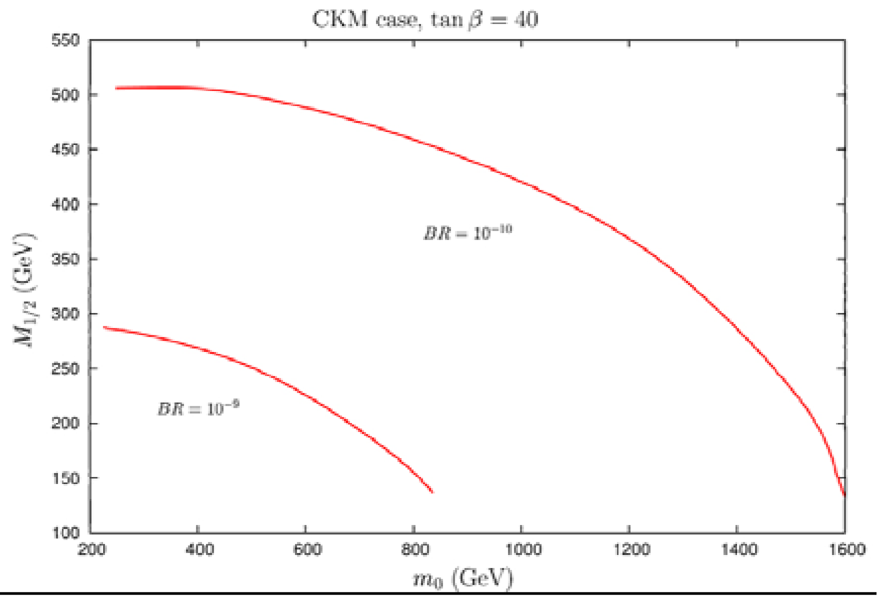
$\tau \to \mu\gamma$ and the **Super B** (and **Flavour**) factories

TABLE IX: Reach in $(m_0, m_{\tilde{g}})$ of the present and planned experiment from their $\tau \to \mu\gamma$ sensitivity.

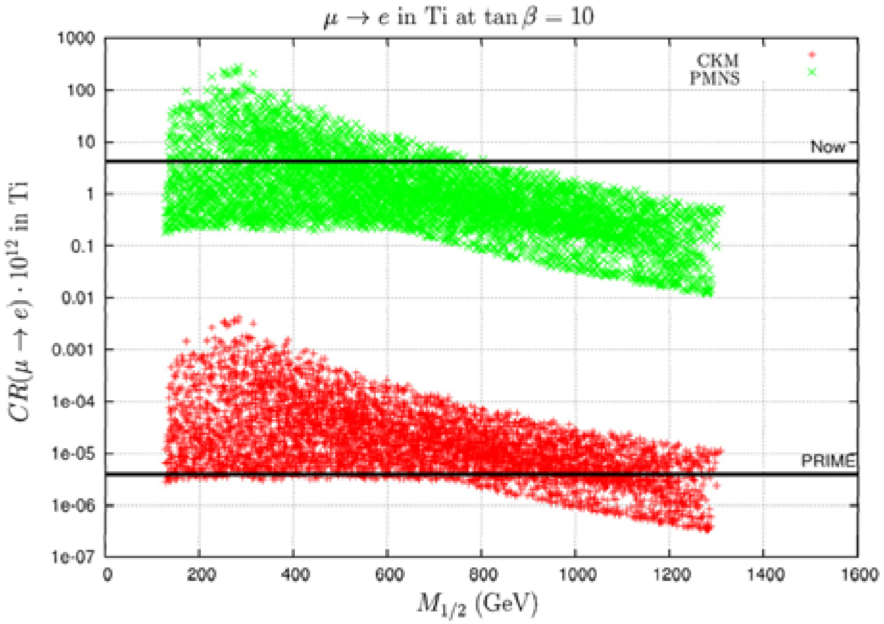
	PMNS		CKM	
Exp.	$t_\beta = 40$	$t_\beta = 10$	$t_\beta = 40$	$t_\beta = 10$
BaBar, Belle	1.2 TeV	no	no	no
SuperKEKB	2 TeV	0.9 TeV	no	no
Super Flavour [a]	2.8 TeV	1.5 TeV	0.9 TeV	no

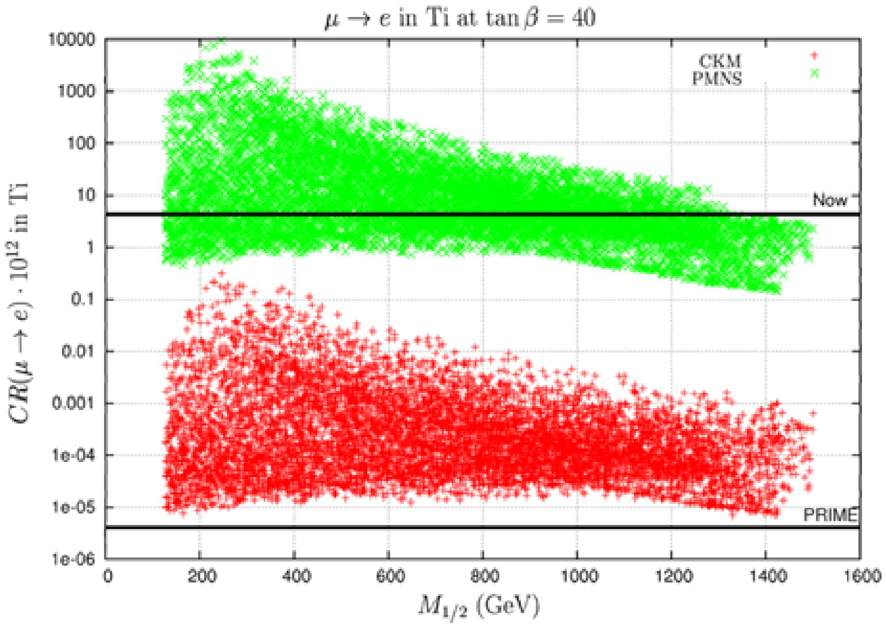
[a]Post–LHC era proposed/discussed experiment

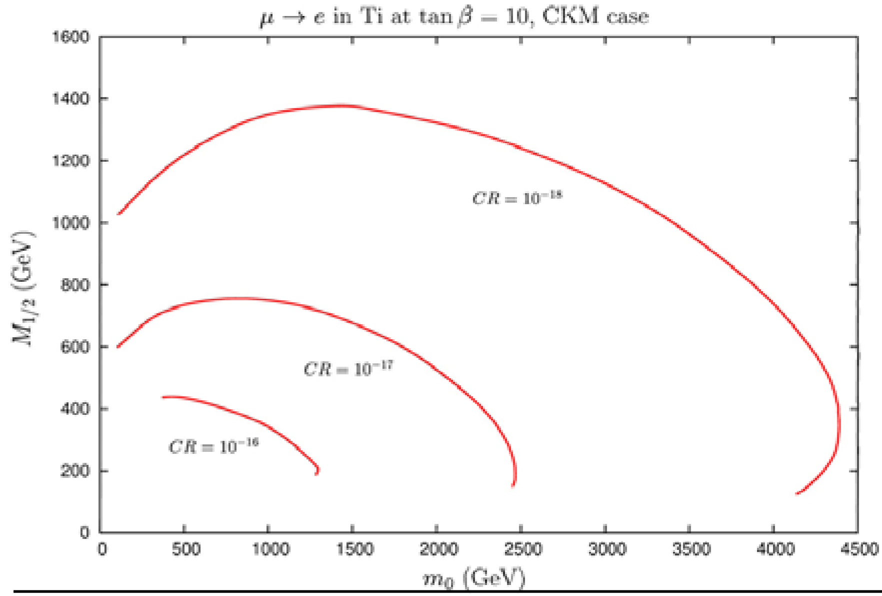


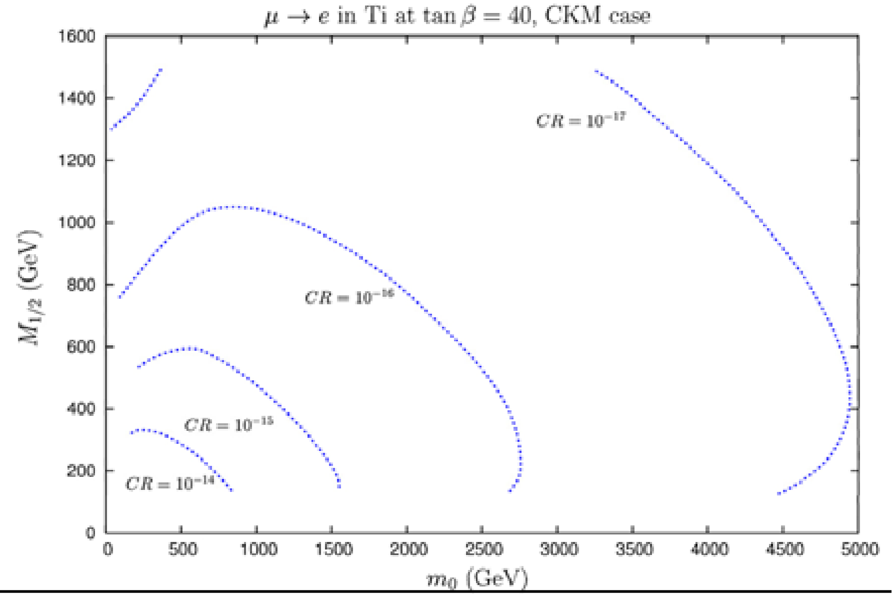


$\mu \to e$ in Ti and **PRISM/PRIME** conversion experiment









Conclusions

• LFV experiments are able to constrain much our SUSY-GUTs scenarios.

Supposing that LHC does find evidences of SUSY:

• If they detect LFV processes, by their rate and considering the interplay between different experiments (e.g. MEG and Super Flavour factory), we should be able to get a deep insight into the structure of Y_ν

• In this sense, the capability of a Super Flavour factory to discriminate between a minimal mixing case and the U_{e3} = 0 PMNS case is a very interesting feature

• If MEG (and Super Flavour) happens not to see LFV, only two possibilities should be left:
a) minimal mixing, low tanβ scenario
b) mSUGRA-SO(10) see-saw without fine-tuned Y_ν is not a viable framework of new physics.

•If the planned high sensitivity of PRISM/PRIME doesn't manage to find LFV evidences, the latter conclusion should be the most feasible one.

•LFV experiments will be able to test some scenarios even in the region of the mSUGRA parameter space beyond the LHC sensitivity reach

•LFV experiments result very useful in constraining/discriminating among different SUSY-GUTs models, and thus highly complementary to the LHC.