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SUSY and SEESAW

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SUSY: still most “realistic” new physics at the Elw. Scale: prob. P1

SEESAW: most appealing way to provide neutrino masses: prob. P2

SUSY SEESAW: prob. (P1XP2), i.e. most promising new physics with massive neutrinos!

FLAVOR BLINDNESS OF THE NP AT THE ELW. SCALE?

- THREE DECADES OF FLAVOR TESTS (Redundant determination of the UT triangle $\longrightarrow$ verification of the SM, theoretically and experimentally "high precision" FCNC tests, ex. b $\rightarrow$ s + γ, CP violating flavor conserving and flavor changing tests, lepton flavor violating (LFV) processes, …) clearly state that:
- A) in the **HADRONIC SECTOR** the CKM flavor pattern of the SM represents the main bulk of the flavor structure and of CP violation;
- B) in the **LEPTONIC SECTOR**: although neutrino flavors exhibit large admixtures, LFV, i.e. non – conservation of individual lepton flavor numbers in FCNC transitions among charged leptons is extremely small: once again the SM is right (to first approximation) predicting negligibly small LFV

What to make of this triumph of the CKM pattern in hadronic **flavor tests**?

New Physics at the Elw. Scale is Flavor Blind
CKM exhausts the flavor changing pattern at the elw. Scale →

MINIMAL FLAVOR VIOLATION

MFV : Flavor originates only from the SM Yukawa coupl.

New Physics introduces

NEW FLAVOR SOURCES in addition to the CKM pattern. They give rise to contributions which are <20% in the “flavor observables” which have already been observed!

LFV IN CHARGED LEPTONS FCNC

L_i - L_j transitions through W - neutrinos mediation

GIM suppression $(m_\nu / M_W)^2$ $\longrightarrow$ forever invisible

New mechanism: replace SM GIM suppression with a new GIM suppression where m_ν is replaced by some $\Delta M >> m_\nu$.

Ex.: in SUSY L_i - L_j transitions can be mediated by photino - SLEPTONS exchanges,

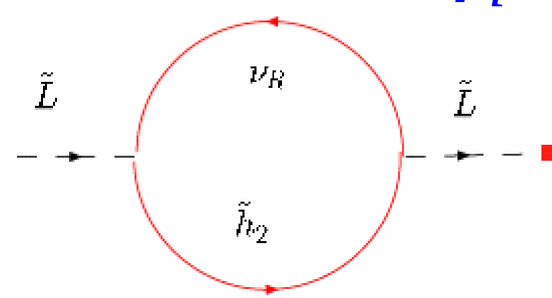
BUT in CMSSM (MSSM with flavor universality in the SUSY breaking sector) $\Delta M_{\text{sleptons}}$ is O(m_{leptons}), hence GIM suppression is still too strong.

How to further decrease the SUSY GIM suppression power in LFV through slepton exchange?

SUSY SEESAW: Flavor universal SUSY breaking and yet large lepton flavor violation

Borzumati, A. M. 1986 (after discussions with W. Marciano and A. Sanda)

$$L = f_l\, \bar{e}_R L h_1 + f_\nu\, \bar{\nu}_R L h_2 + M\ \nu_R \nu_R$$



$$\left(m^2_{\tilde{L}}\right)_{ij} \sim \frac{1}{8\pi^2}\left(3m_0^2 + A_0^2\right)\left(f_\nu^\dagger f_\nu\right)_{ij} \log\frac{M}{M_G}$$

Non-diagonality of the slepton mass matrix in the basis of diagonal lepton mass matrix depends on the unitary matrix U which diagonalizes ($f_\nu^+ f_\nu$)

How Large LFV in SUSY SEESAW?

- 1) Size of the **Dirac neutrino couplings f_ν**
- 2) Size of the **diagonalizing matrix U**

In **MSSM seesaw** or in **SUSY SU(5)** (Moroi): not possible to correlate the neutrino Yukawa couplings to know Yukawas;

In **SUSY SO(10)** (A.M., Vempati, Vives) at least one neutrino Dirac Yukawa coupling has to be of the **order of the top Yukawa coupling** → one large of O(1) f_ν

U → two "extreme" cases:

a) **U with "small" entries** → **U = CKM**;
b) **U with "large" entries** with the exception of the 13 entry → **U = PMNS** matrix responsible for the diagonalization of the neutrino mass matrix

LFV in SUSYGUTs with SEESAW

Scale of appearance of the SUSY soft breaking terms
resulting from the spontaneous breaking of supergravity

Low-energy SUSY has "memory" of all the multi-step RG occurring from such superlarge scale down to M_W

$\longrightarrow$ **potentially large LFV**

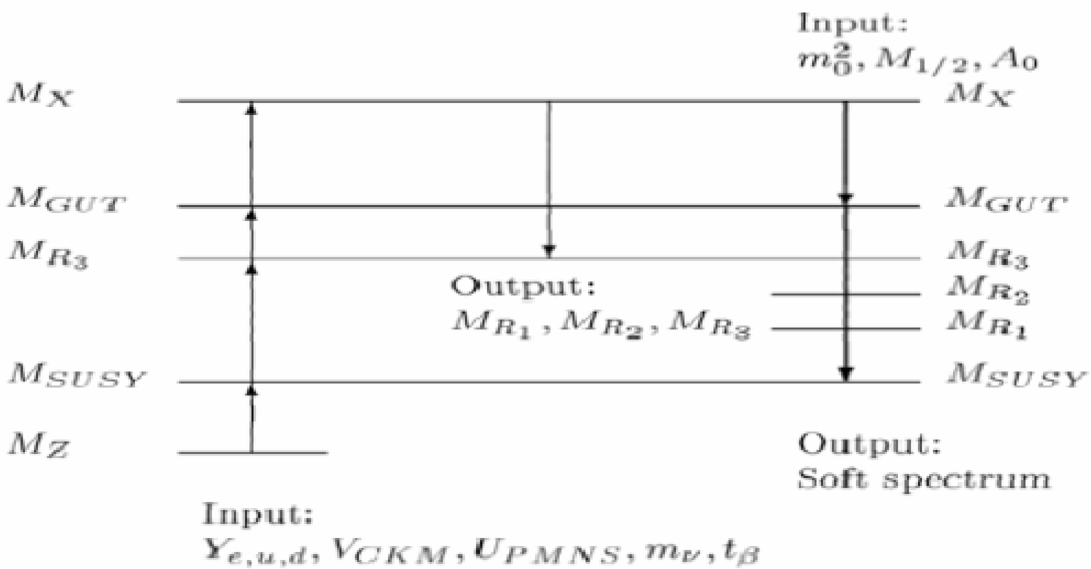
Barbieri, Hall; Barbieri, Hall, Strumia; Hisano, Nomura, Yanagida; Hisano, Moroi, Tobe Yamaguchi; Moroi;A.M.,, Vempati, Vives; Carvalho, Ellis, Gomez, Lola; Calibbi, Faccia, A.M, Vempati

LFV in MSSMseesaw: $\mu \to e\gamma$ Borzumati, A.M.

$\tau \to \mu\gamma$ Blazek, King;

General analysis: Casas Ibarra; Lavignac, Masina,Savoy; Hisano, Moroi, Tobe, Yamaguchi; Ellis, Hisano, Raidal, Shimizu; Fukuyama, Kikuchi, Okada; Petcov, Rodejohann, Shindou, Takanishi; Arganda, Herrero; Deppish, Pas, Redelbach, Rueckl; Petcov, Shindou

LFV with MULTIPLE RUNNING THRESHOLDS



CALIBBI, FACCIA, A.M., VEMPATI ;

For previous related work, see, in particular, HISANO et al.

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

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

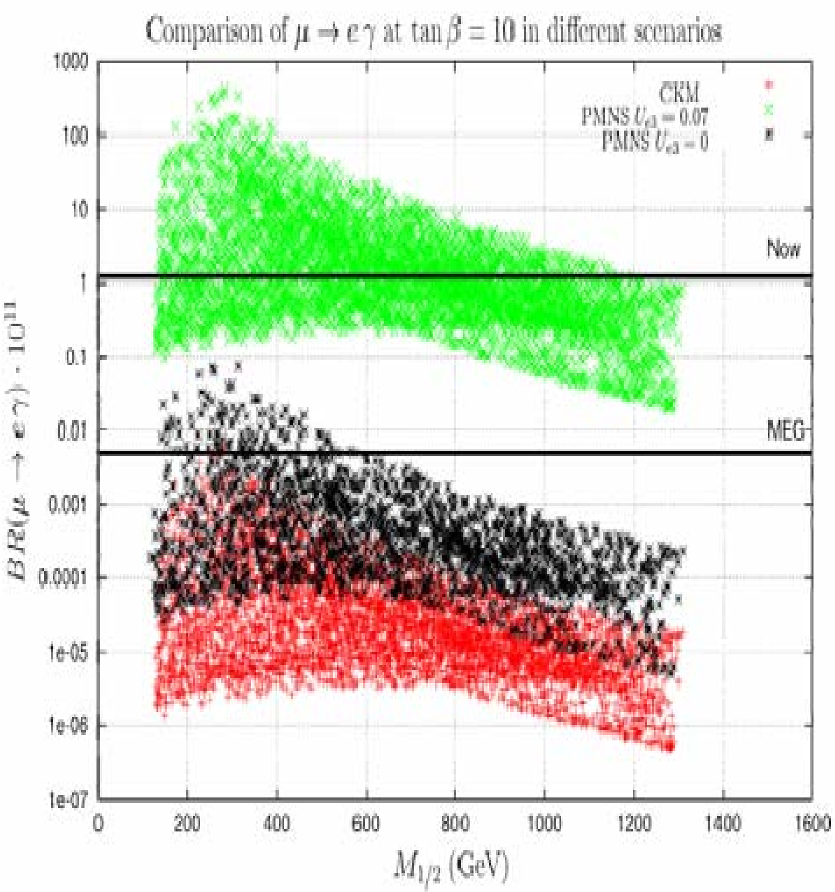
See-saw:

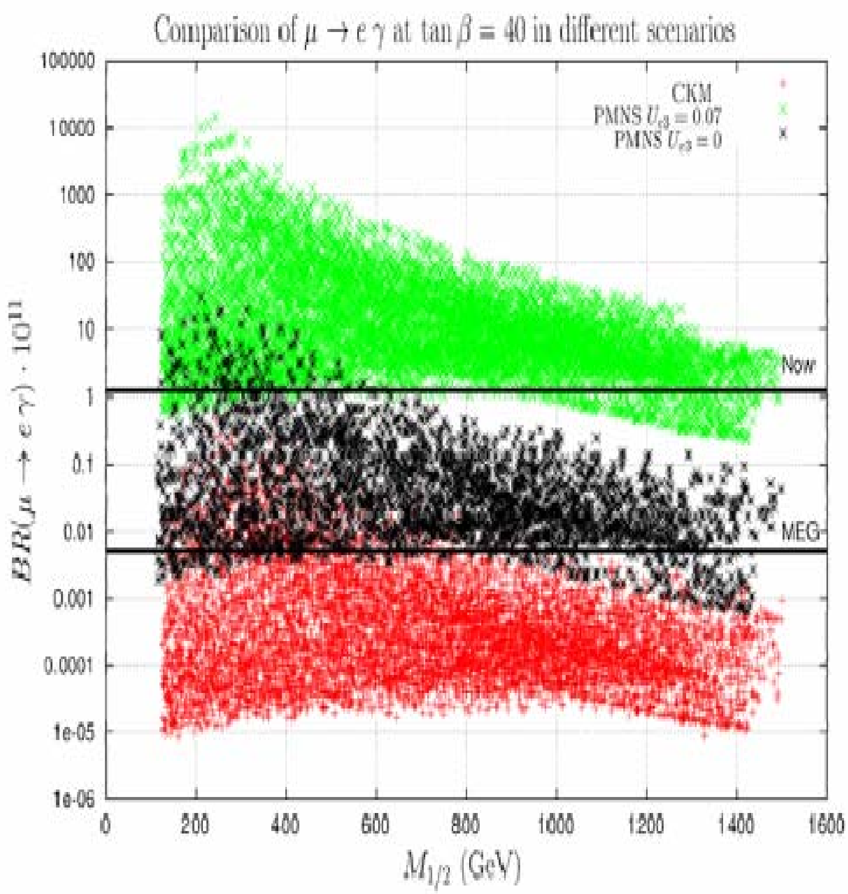
$$m_\nu = -Y_\nu \hat{M}_R^{-1} Y_\nu^T \langle H_u \rangle^2$$

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

$\mu \rightarrow e+\gamma$ in SUSYGUT: past and future

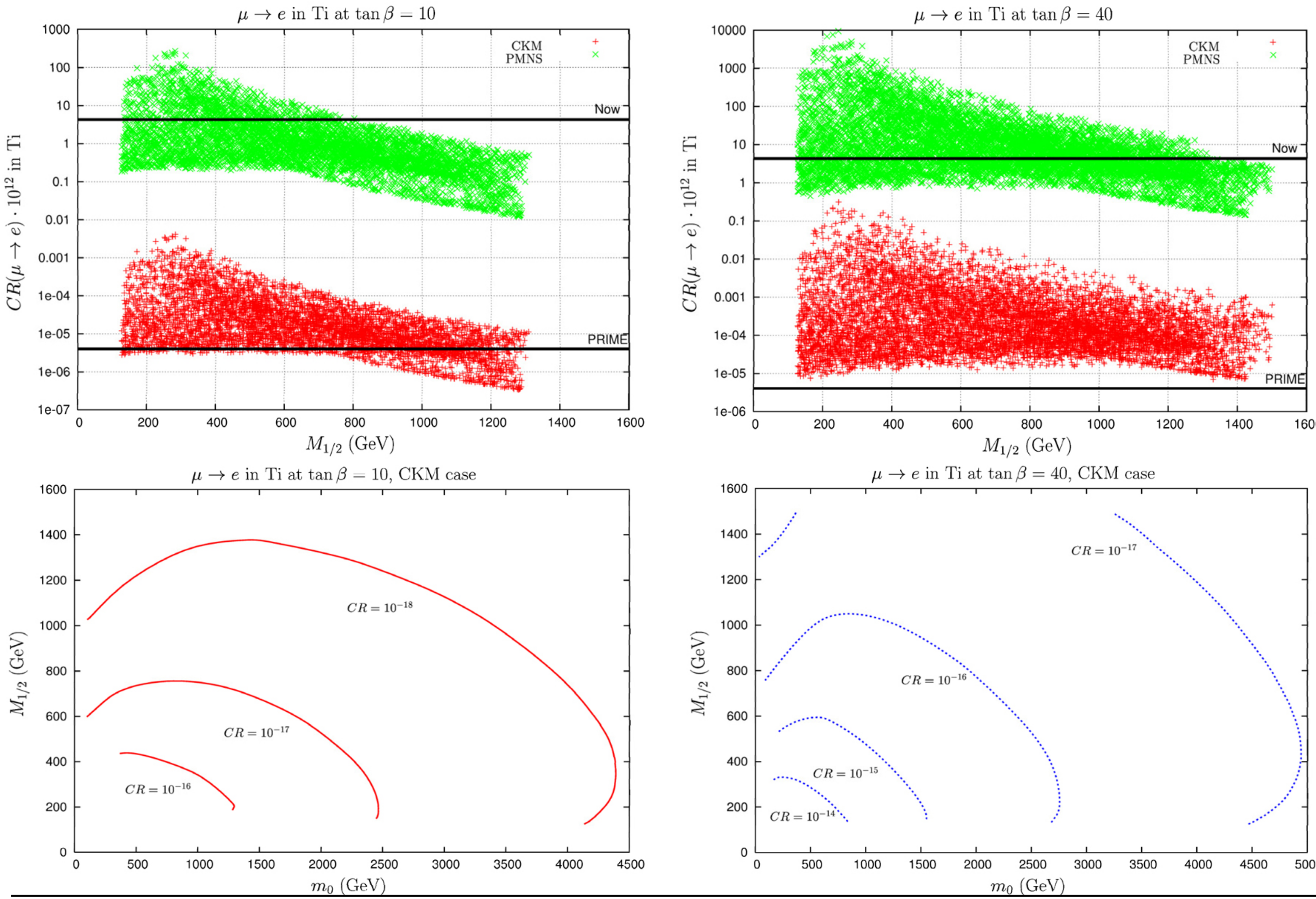
$\mu \rightarrow e\,\gamma$ in the $U_{e3} = 0$ PMNS case



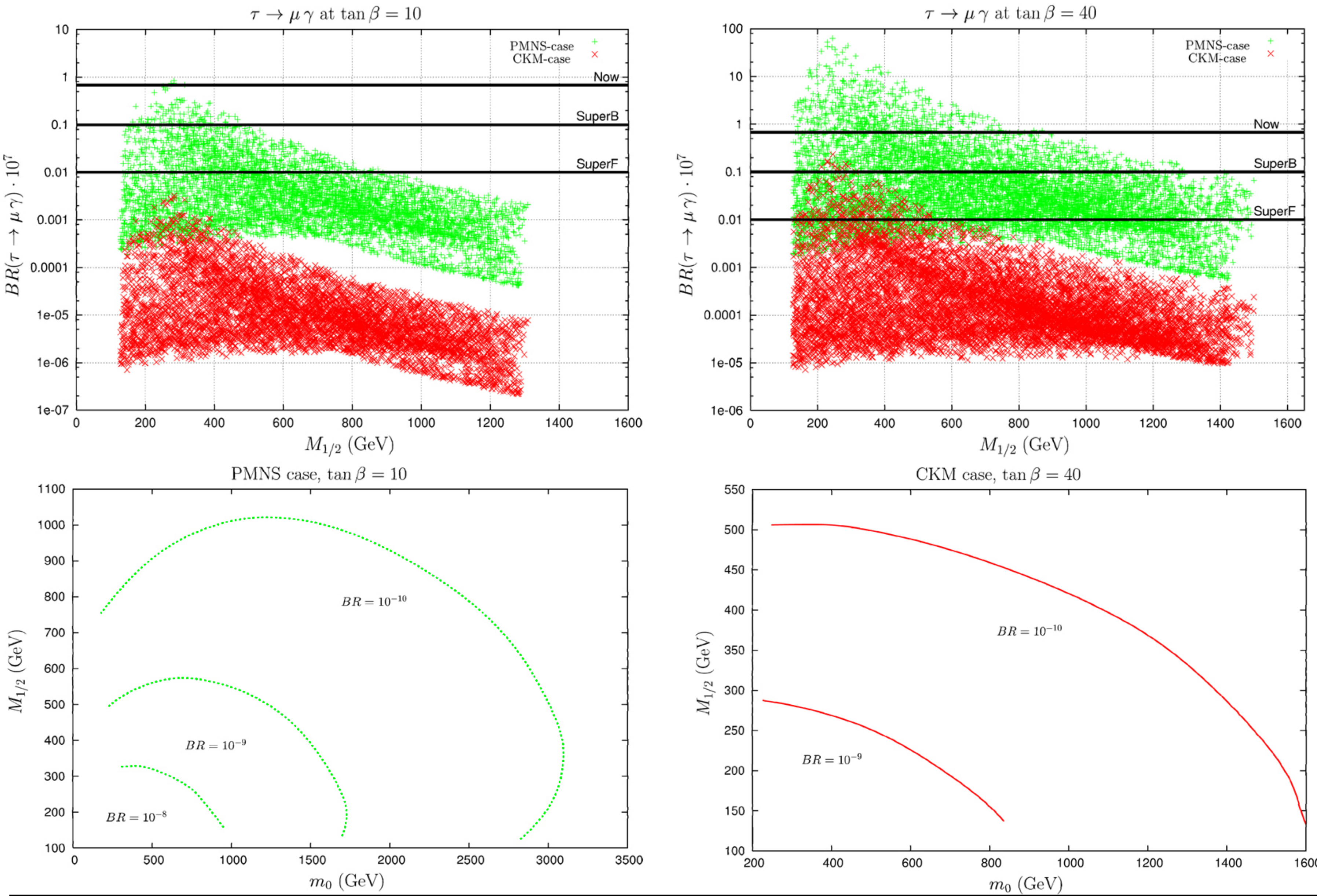


CFMV

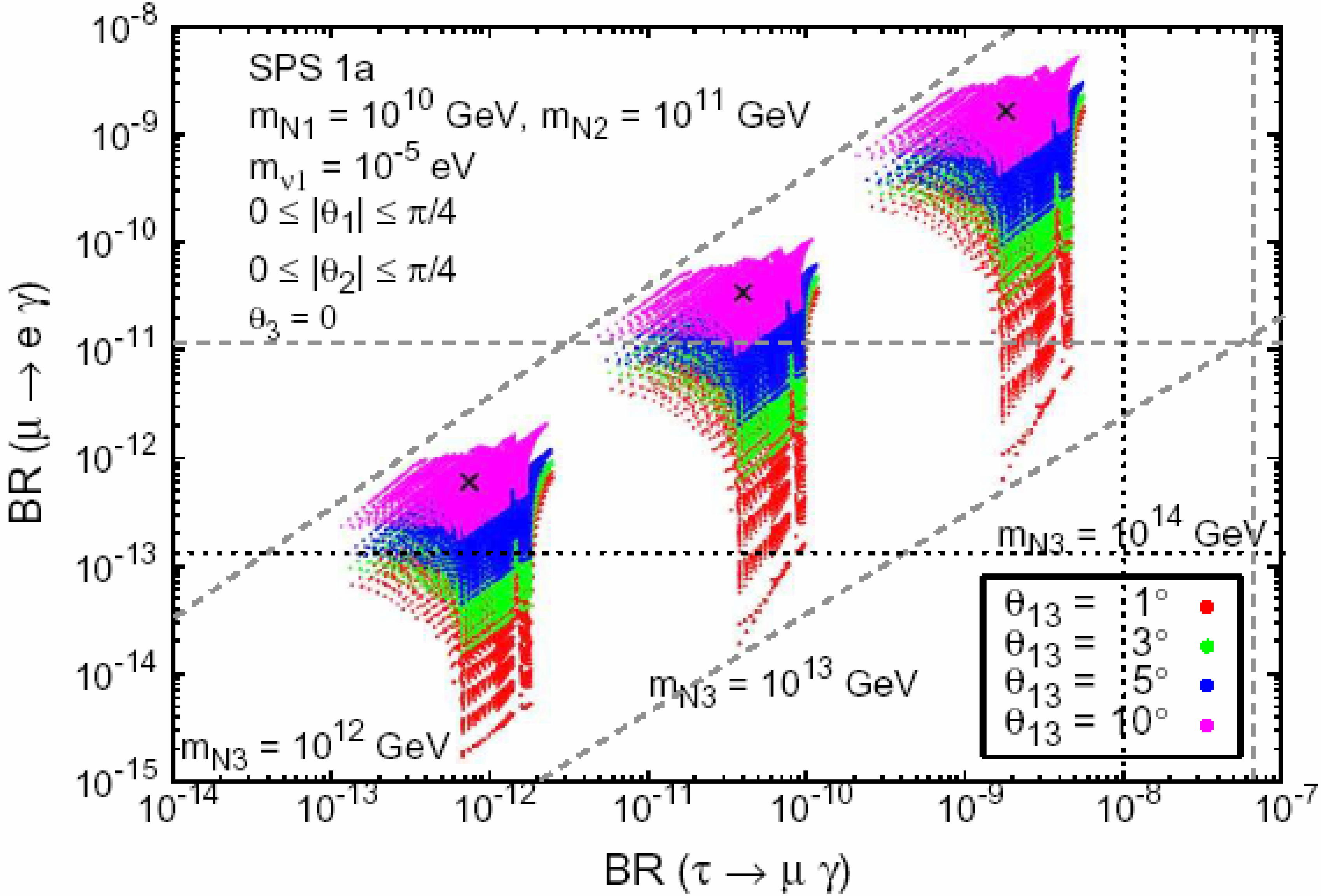
$\mu \to e$ in Ti and **PRISM/PRIME** conversion experiment



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



Antusch, Arganda, Herrero, Teixeira



LFV ⟷ LHC SENSITIVITIES IN PROBING THE SUSY PARAM. SPACE

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

Calibbi, Faccia, A.M., Vempati

DEVIATION from μ - e UNIVERSALITY

A.M., Paradisi, Petronzio

- Denoting by $\Delta r_{NP}^{e-\mu}$ the deviation from $\mu - e$ universality in $R_{K,\pi}$ due to new physics, i.e.:

$$R_{K,\pi} = R_{K,\pi}^{SM}\left(1 + \Delta r_{K,\pi\,NP}^{e-\mu}\right),$$

- we get at the 2σ level:

$$-0.063 \leq \Delta r_{K\,NP}^{e-\mu} \leq 0.017 \quad \mathrm{NA48/2}$$

$$-0.0107 \leq \Delta r_{\pi\,NP}^{e-\mu} \leq 0.0022 \quad \mathrm{PDG}$$

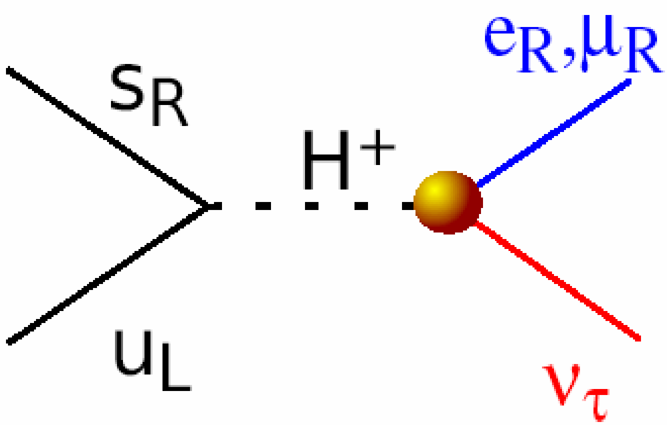
HIGGS-MEDIATED LFV COUPLINGS

- When non-holomorphic terms are generated by loop effects (HRS corrections)
- And a source of LFV among the sleptons is present
- $\longrightarrow$ Higgs-mediated (radiatively induced) H-lepton-lepton LFV couplings arise

Babu, Kolda; Sher; Kitano,Koike,Komine, Okada; Dedes, Ellis, Raidal; Brignole,Rossi; Arganda,Curiel,Herrero,Temes; Paradisi; Brignole,Rossi

H mediated LFV SUSY contributions to R_K

$$R_K^{LFV} = \frac{\sum_i K \to e\nu_i}{\sum_i K \to \mu\nu_i} \simeq \frac{\Gamma_{SM}(K \to e\nu_e) + \Gamma(K \to e\nu_\tau)}{\Gamma_{SM}(K \to \mu\nu_\mu)} \;, \quad i = e, \mu, \tau$$



$$eH^\pm\nu_\tau \to \frac{g_2}{\sqrt{2}}\frac{m_\tau}{M_W}\Delta_R^{31}\tan^2\beta$$

$$\Delta_R^{31} \sim \frac{\alpha_2}{4\pi}\delta_{RR}^{31}$$

$$\Delta_R^{31} \sim 5\cdot 10^{-4} \;\; t_\beta = 40 \;\; M_{H^\pm} = 500\mathrm{GeV}$$

$$\Downarrow$$

$$\Delta r_{K\,SUSY}^{e-\mu} \simeq \left(\frac{m_K^4}{M_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{m_e^2}\right)|\Delta_R^{31}|^2 \tan^6\beta \approx 10^{-2}$$

Extension to B $\longrightarrow$ lν deviation from universality

Isidori, Paradisi

Large ν mixing $\longleftrightarrow$ large b-s transitions in SUSY GUTs

In SU(5) $d_R \longleftrightarrow l_L$ connection in the 5-plet

Large $(\Delta^l_{23})_{LL}$ induced by large f_ν of $O(f_{top})$ is accompanied by large $(\Delta^d_{23})_{RR}$

In SU(5) assume large f_ν (Moroi)

In SO(10) f_ν large because of an underlying Pati-Salam symmetry

(**Darwin Chang**, A.M., Murayama)

See also: Akama, Kiyo, Komine, Moroi; Hisano, Moroi, Tobe, Yamaguchi, Yanagida; Hisano, Nomura; Kitano,Koike, Komine, Okada

FCNC HADRON-LEPTON CONNECTION IN SUSYGUT

If

M_{Pl} M_{GUT} M_W

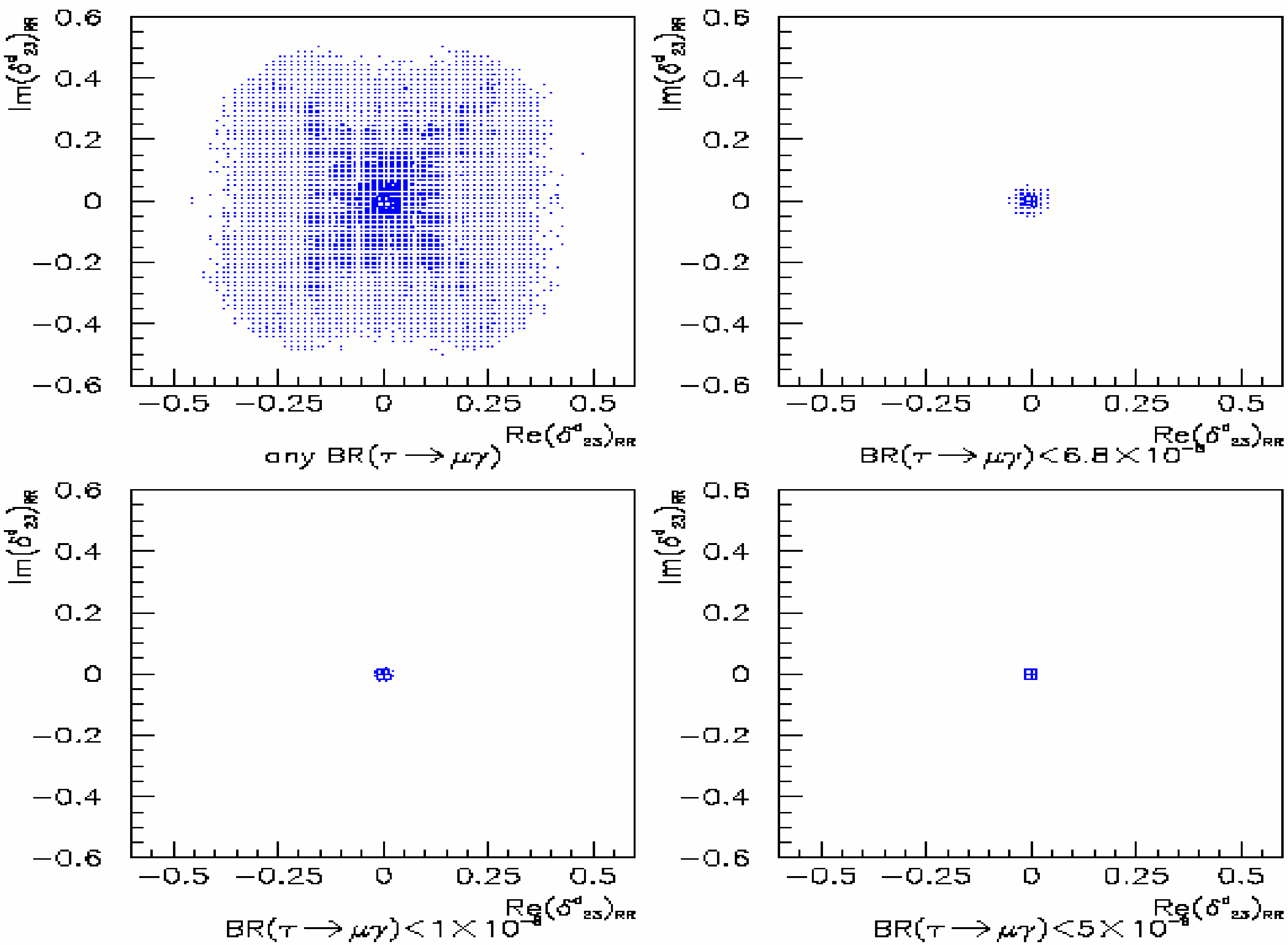
soft **SUSY breaking terms** arise
at a scale > M_{GUT}, they have to **respect the underlying quark-lepton GU symmetry**

constraints on $\delta^{\mathbf{quark}}$ **from LFV** and
constraints on $\delta^{\mathbf{lepton}}$ **from hadronic FCNC**
Ciuchini, A.M., Silvestrini, Vempati, Vives PRL
general analysis Ciuchini, A.M., Paradisi, Silvestrini, Vempati, Vives

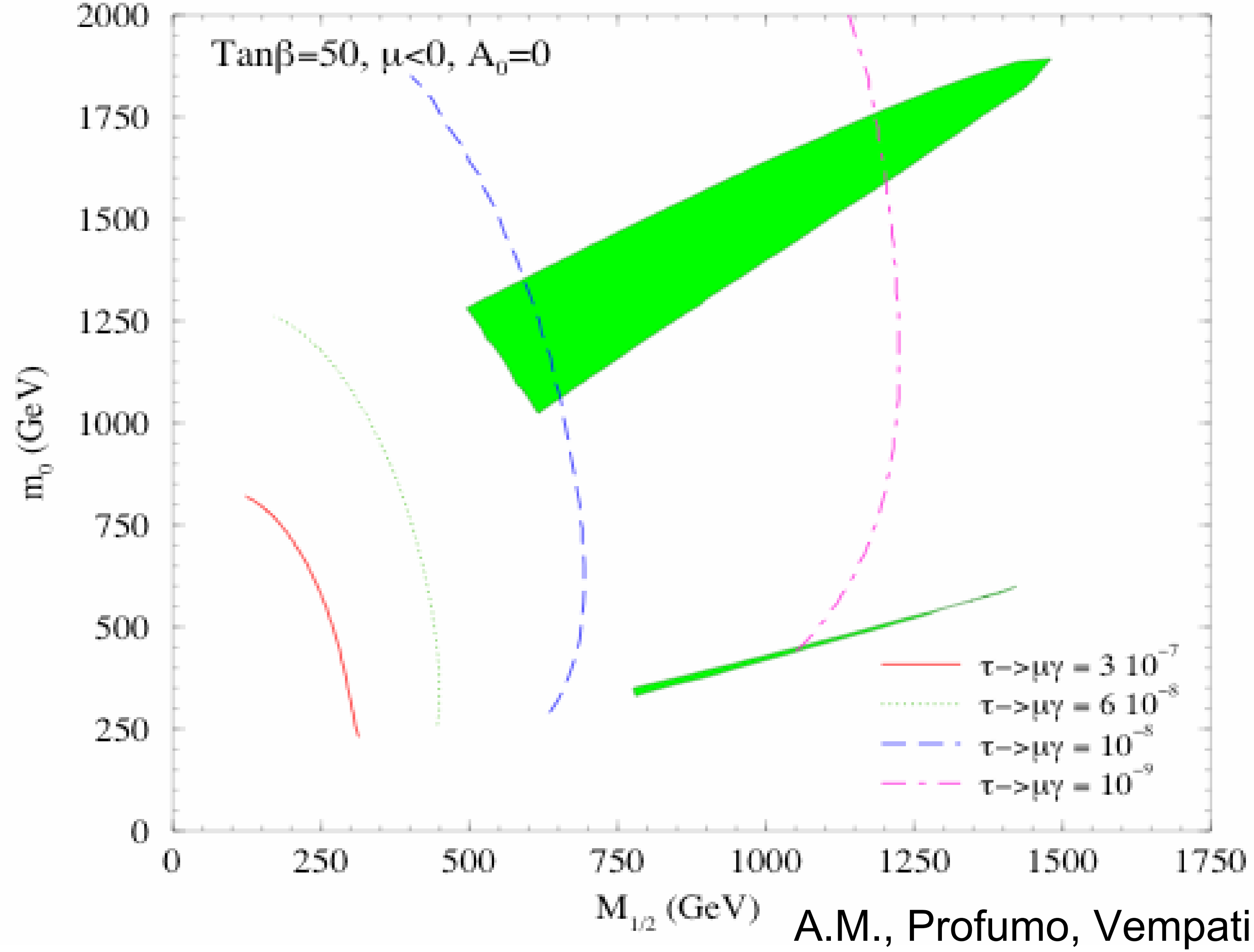
See also Jae-hyeon Park's talk in the Flavor parallel session for multiple mass insertion

Bounds on the hadronic $(\delta_{23})_{RR}$ as modified by the inclusion of the LFV correlated bound

CMPSVV

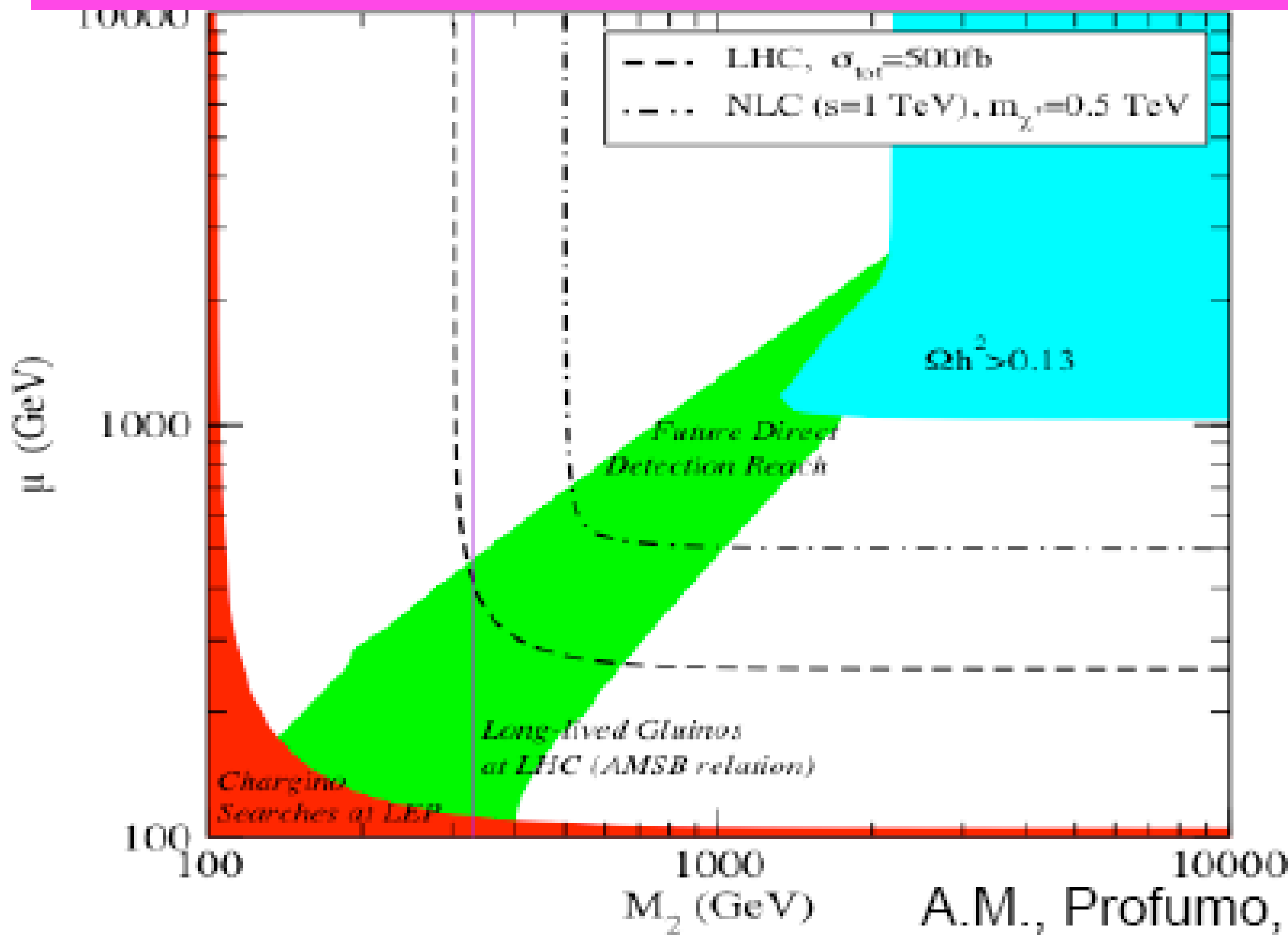


LFV - DM CONSTRAINTS IN MINIMAL SUPERGRAVITY



A.M., Profumo, Vempati, Yaguna

LHC, ILC, DM SEARCHES SENSITIVITIES



A.M., Profumo, Ullio

Final thoughts on the "complementarity" of flavor physics in our search for NP

- **"Slow" decoupling** of FCNC SUSY contributions: it is possible, through low-energy FCNC effects induced by the running, to **get access to some large scale** (SUSY SeeSaw scale , Supergravity breaking scale)

- If the SUSY breaking mechanism is completely **flavor blind**, large **LFV in SUSY SEESAW is one of the very few hopes to observe significant deviations from the SM in FCNC phenomena**: **MEG, LFV at B and SuperB factories, PRISM,… probe SUSY (with a seesaw) in a way complementary to the direct searches of SUSY particles at LHC.**

- Possible correlation of **hadronic and leptonic FCNC** in SUGRAGUTs

TEVATRON → LHC → ILC

DM - FLAVOR

for DISCOVERY

and/or FUND. TH.

RECONSTRUCTION

NEW PHYSICS AT THE ELW SCALE

A MAJOR LEAP AHEAD IS NEEDED

DARK MATTER

$m_\chi \; n_\chi \; \sigma_\chi \ldots$

LINKED TO COSMOLOGICAL EVOLUTION

→ Possible interplay with dynamical DE

BARYO- LEPTO- GENESIS

"LOW ENERGY"

PRECISION PHYSICS

FCNC, CP ≠, (g-2), $(\beta\beta)_{0\nu\nu}$

LFV