General Super B Meeting, Perugia, June 16-18, 2009

FLAVOR and NEW PHYSICS: FRUSTRATION and HOPE

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The Energy Scale from the "Observational" New Physics

neutrino masses
dark matter
baryogenesis
inflation

→ NO NEED FOR THE NP SCALE TO BE CLOSE TO THE ELW. SCALE

The Energy Scale from the "Theoretical" New Physics

☆ ☆ ☆ Stabilization of the electroweak symmetry breaking at M_W calls for an ULTRAVIOLET COMPLETION of the SM already at the TeV scale +

☆ CORRECT GRAND UNIFICATION "CALLS" FOR NEW PARTICLES AT THE ELW. SCALE (in particular few hundred GeV SUSY particles)

ELW. SYMM. BREAKING STABILIZATION VS. FLAVOR PROTECTION: THE SCALE TENSION

$$M(B_d\text{-}\bar{B}_d) \sim \quad c_{SM} \frac{(y_t V_{tb}{}^* V_{td})^2}{16\,\pi^2 M_W{}^2} + c_{new} \frac{1}{\Lambda^2}$$

If $c_{new} \sim c_{SM} \sim 1$

Isidori

$\Lambda > 10^4$ TeV for $O^{(6)} \sim (\bar{s}\, d)^2$

[K^0-$\bar{K}^0$ mixing]

$\Lambda > 10^3$ TeV for $O^{(6)} \sim (\bar{b}\, d)^2$

[B^0-$\bar{B}^0$ mixing]

UV SM COMPLETION TO STABILIZE THE ELW. SYMM. BREAKING: Λ_{UV} ~ O(1 TeV)

How large Λ NP and/or how small the "angles" of the Λ = 1 TeV NP couplings have to be to cope with the FCNC ?

Mixing	$\Lambda_{NP}^{CPC} \gtrsim$	$\Lambda_{NP}^{CPV} \gtrsim$
$K-\overline{K}$	1000 TeV	20000 TeV
$D-\overline{D}$	1000 TeV	3000 TeV
$B-\overline{B}$	400 TeV	800 TeV
$B_s-\overline{B}_s$	70 TeV	70 TeV

$K-\overline{K}$	8×10^{-7}	6×10^{-9}
$D-\overline{D}$	5×10^{-7}	1×10^{-7}
$B-\overline{B}$	5×10^{-6}	1×10^{-6}
$B_s-\overline{B}_s$	2×10^{-4}	2×10^{-4}

Y. NIR et al.

$K-\overline{K}$	8×10^{-7}	6×10^{-9}
$D-\overline{D}$	5×10^{-7}	1×10^{-7}
$B-\overline{B}$	5×10^{-6}	1×10^{-6}
$B_s-\overline{B_s}$	2×10^{-4}	2×10^{-4}

$\rightarrow$ **SMALLNESS OF THE NP COUPLINGS IF THE NP SCALE IS 1 TEV**

$$Y_t \sim 1,\quad Y_c \sim 10^{-2},\quad Y_u \sim 10^{-5}$$

$$Y_b \sim 10^{-2},\quad Y_s \sim 10^{-3},\quad Y_d \sim 10^{-4}$$

$$Y_\tau \sim 10^{-2},\quad Y_\mu \sim 10^{-3},\quad Y_e \sim 10^{-6}$$

$$|V_{us}| \sim 0.2,\quad |V_{cb}| \sim 0.04,\quad |V_{ub}| \sim 0.004,\quad \delta_{\rm KM} \sim 1$$

$\rightarrow$ **SMALLNESS OF THE SM COUPLINGS**

THE FLAVOUR PROBLEMS

FERMION MASSES

What is the rationale hiding behind the spectrum of fermion masses and mixing angles (our "**Balmer lines**" problem)

LACK OF A FLAVOUR "THEORY"

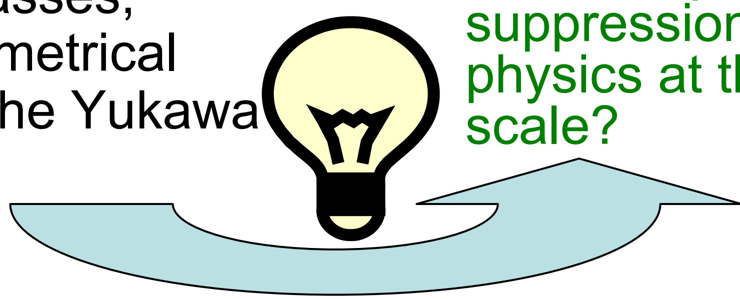
(new flavour – horizontal symmetry, radiatively induced lighter fermion masses, dynamical or geometrical determination of the Yukawa couplings, …?)

FCNC

Flavour changing neutral current (FCNC) processes are suppressed.

In the SM two nice mechanisms are at work: the **GIM mechanism** and the structure of the **CKM mixing matrix.**

How to cope with such delicate suppression if the there is new physics at the electroweak scale?

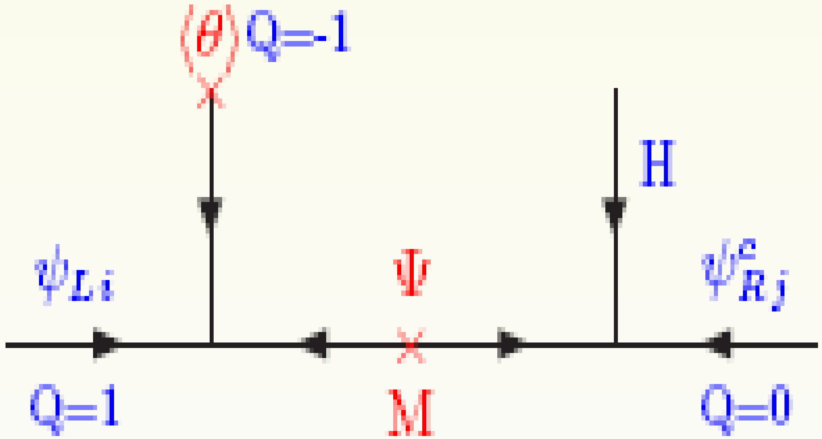


MSSM X FAMILY SYMM.

- **AMBITION**: **simultaneously** accounting for the "correct" SM fermion masses and mixings (***SM Flavor Puzzle***) **and** a structure of the SUSY soft breaking masses allowing for adequate FCNC suppression + possible "explanation" of the alleged SM FCNC difficulties (***SUSY Flavor Puzzle***)

- Mechanism a la Frogatt – Nielsen with **abelian or non-abelian family symmetry**

- Froggatt-Nielsen mechanism and flavour symmetry to understand small Yukawa elements. Example: $U(1)_{fl}$



$$\Rightarrow Y_{ij} = \left(\frac{\langle\theta\rangle}{M}\right) \ll 1$$

Yukawa Textures

What we want:

$$Y_u \propto \begin{pmatrix} 0 & \varepsilon^3 & \varepsilon^3 \\ \varepsilon^3 & \varepsilon^2 & \varepsilon^2 \\ \varepsilon^3 & \varepsilon^2 & 1 \end{pmatrix} \qquad Y_d \propto \begin{pmatrix} 0 & \bar{\varepsilon}^3 & \bar{\varepsilon}^3 \\ \bar{\varepsilon}^3 & \bar{\varepsilon}^2 & \bar{\varepsilon}^2 \\ \bar{\varepsilon}^3 & \bar{\varepsilon}^2 & 1 \end{pmatrix}$$

$$\varepsilon = 0.05 \qquad \bar{\varepsilon} = 0.15$$

R. G. Roberts, A. Romanino, G. G. Ross, L. Velasco-Sevilla (hep-ph/0104088)

$SU(3)$ Flavour model

ROBERTS, ROMANINO, ROSS, VELASCO-SEVILLA;
ROSS, VELASCO-SEVILLA, VIVES

- $Q, L \sim \mathbf{3}$ and $d^c, u^c, e^c \sim \mathbf{3}$; flavon fields: $\theta_3, \theta_{23} \sim \overline{\mathbf{3}}$, $\overline{\theta}_3, \overline{\theta}_{23} \sim \mathbf{3}$

- Family Symmetry breaking: $SU(3) \xrightarrow{\langle\theta_3\rangle} SU(2) \xrightarrow{\langle\theta_{23}\rangle} \emptyset$

$$\theta_3, \overline{\theta}_3 = \begin{pmatrix} 0 \\ 0 \\ a_3 \end{pmatrix}, \quad \theta_{23}, \overline{\theta}_{23} = \begin{pmatrix} 0 \\ b \\ b \end{pmatrix} \text{ with } \left(\frac{a_3}{M}\right) \sim \mathcal{O}(1), \left(\frac{b}{M_u}\right) \simeq \left(\frac{b}{M_d}\right)^2 = \varepsilon \sim 0.05.$$

- Yukawa superpotential: $W_Y = H\psi_i\psi_j^c\left[\theta_3^i\theta_3^j + \theta_{23}^i\theta_{23}^j\left(\theta_3\overline{\theta_3}\right) + \epsilon^{ikl}\overline{\theta}_{23,k}\overline{\theta}_{3,l}\theta_{23}^j\left(\theta_{23}\overline{\theta_3}\right)\right]$

$$Y^f = \begin{pmatrix} 0 & a\,\varepsilon^3 & b\,\varepsilon^3 \\ a\,\varepsilon^3 & \varepsilon^2 & c\,\varepsilon^2 \\ b\,\varepsilon^3 & c\,\varepsilon^2 & 1 \end{pmatrix} \frac{|a_3|^2}{M^2},$$

O. VIVES

THE SFERMION MASS PATTERN

$$(M^2_{\tilde f})^{ij} = m_0^2\Bigg(\delta^{ij} + \frac{1}{M_f^2}\Big[\theta^\dagger_{3,i}\theta_{3,j} + \overline{\theta}^i_3\overline{\theta}^{j\dagger}_3 + \theta^\dagger_{23,i}\theta_{23,j} + \overline{\theta}^i_{23}\overline{\theta}^{j\dagger}_{23} + \theta^i_{123}\theta^{j\dagger}_{123} + \overline{\theta}^i_{123}\overline{\theta}^{j\dagger}_{123}\Big]$$

$$+ \frac{1}{M_f^4}(\epsilon^{ikl}\overline{\theta}_{3,k}\overline{\theta}_{23,l})^\dagger(\epsilon^{jmn}\overline{\theta}_{3,m}\overline{\theta}_{23,n}) + \quad \dots \quad \Bigg),$$

UNIVERSAL SFERMION MASSES

AFTER SYMMETRY BREAKING → OFF-DIAGONAL ENTRIES IN THE SFERMION MASSES PROPORTIONAL TO THE COMPLEX FLAVON VEV's (also SPONTANEOUS CP VIOLATION)

Field	ψ	ψ^c	H	Σ	θ_3	θ_{23}	$\bar{\theta}_3$	$\bar{\theta}_{23}$
SU(3)	3	3	1	1	$\bar{3}$	$\bar{3}$	3	3
U(1)	0	0	0	1	0	-1	1	0
U′(1)	-1	-1	0	2	1	0	-1	4
U″(1)	1	1	0	-3	-1	1	0	-4

Field	ψ	ψ^c	H	Σ	θ_3	θ_{23}	$\bar{\theta}_3$	$\bar{\theta}_{23}$
SU(3)	3	3	1	1	$\bar{3}$	$\bar{3}$	3	3
U(1)	-2	-2	0	-4	2	3	0	-2
U′(1)	0	0	0	1	0	-1	1	0

$$M^2_{\tilde{u}^c_R} = \begin{pmatrix} 1+\varepsilon^2 y_t & -\varepsilon^3 e^{-i\omega'} & -\varepsilon^3 e^{-i(\omega'-2\chi)} \\ -\varepsilon^3 e^{i\omega'} & 1+\varepsilon^2 & \varepsilon^2 e^{2i\chi} \\ -\varepsilon^3 e^{i(\omega'-2\chi)} & \varepsilon^2 e^{-2i\chi} & 1+y_t \end{pmatrix} m_0^2$$

$$M^2_{\tilde{u}^c_R} = \begin{pmatrix} 1+\varepsilon^2 y_t & -\varepsilon^3 e^{-i\omega'} & -\varepsilon^2 y_t^{0.5} e^{-i(\omega'-2\chi+\beta_3-\beta_2')} \\ -\varepsilon^3 e^{i\omega'} & 1+\varepsilon^2 & \varepsilon\, y_t^{0.5} e^{i(2\chi-\beta_3+\beta_2')} \\ -\varepsilon^2 y_t^{0.5} e^{i(\omega'-2\chi+\beta_3-\beta_2')} & \varepsilon\, y_t^{0.5} e^{-i(2\chi-\beta_3+\beta_2')} & 1+y_t \end{pmatrix} m_0^2$$

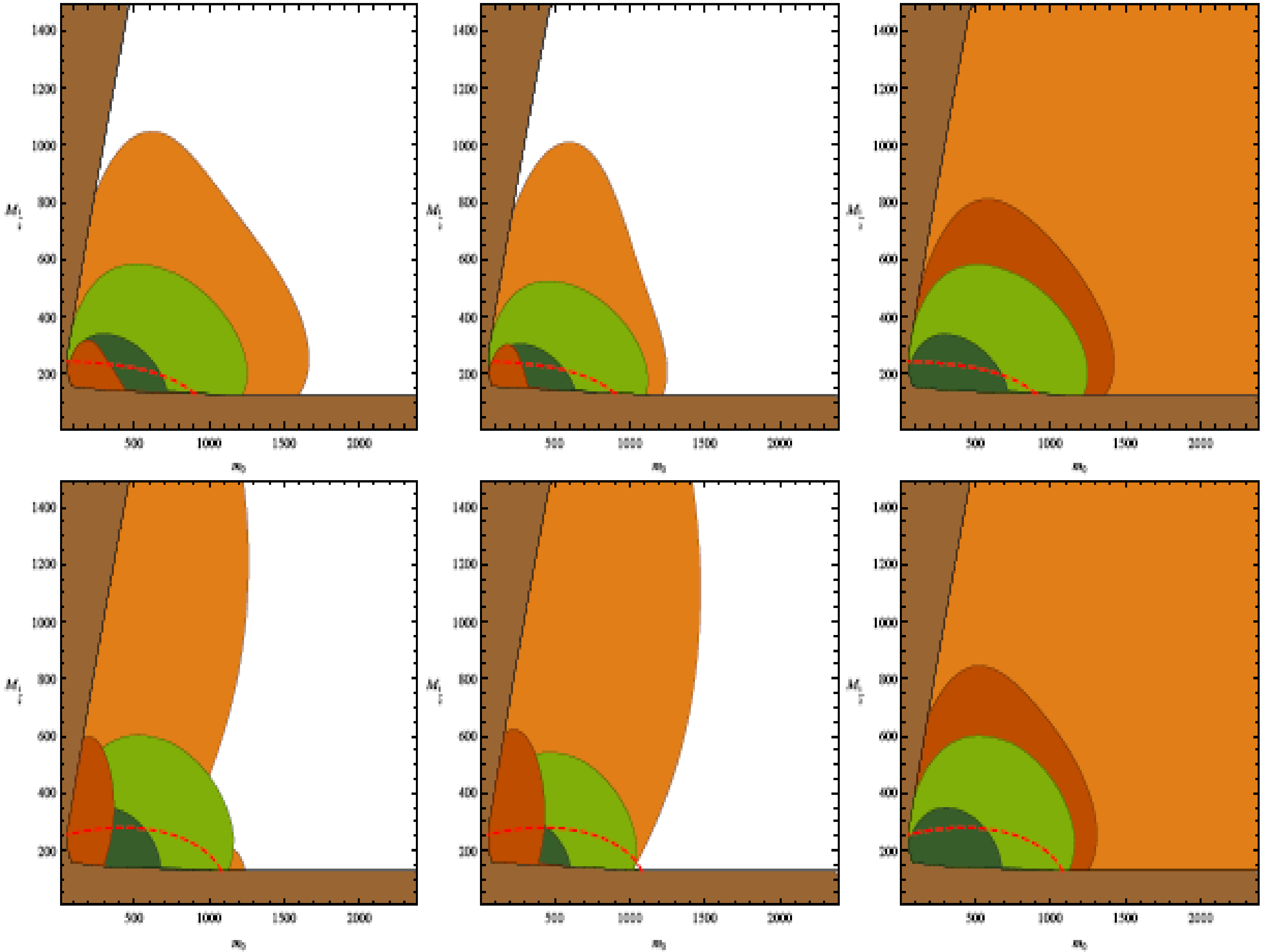
$$M^2_{\tilde{d}^c_R} = \begin{pmatrix} 1+\bar{\varepsilon}^2 y_b & -\bar{\varepsilon}^3 e^{-i\omega_{us}} & -\bar{\varepsilon}^3 e^{-i\omega_{us}} \\ -\bar{\varepsilon}^3 e^{i\omega_{us}} & 1+\bar{\varepsilon}^2 & \bar{\varepsilon}^2 \\ -\bar{\varepsilon}^3 e^{i\omega_{us}} & \bar{\varepsilon}^2 & 1+y_b \end{pmatrix} m_0^2$$

$$M^2_{\tilde{d}^c_R} = \begin{pmatrix} 1+\bar{\varepsilon}^2 y_b & -\bar{\varepsilon}^3 e^{-i\omega_{us}} & -\bar{\varepsilon}^2 y_b^{0.5} e^{-i(\omega_{us}-\chi+\beta_3-\beta_2')} \\ -\bar{\varepsilon}^3 e^{i\omega_{us}} & 1+\bar{\varepsilon}^2 & \bar{\varepsilon}\, y_b^{0.5} e^{i(\chi-\beta_3+\beta_2')} \\ -\bar{\varepsilon}^2 y_b^{0.5} e^{i(\omega_{us}-\chi+\beta_3-\beta_2')} & \bar{\varepsilon}\, y_b^{0.5} e^{-i(\chi-\beta_3+\beta_2')} & 1+y_b \end{pmatrix} m_0^2$$

$$M^2_{\tilde{Q}} = \begin{pmatrix} 1+\varepsilon^2 y_t & -\varepsilon^2\bar{\varepsilon}\, e^{i\omega_{us}} & -\bar{\varepsilon}^3 y_t e^{i\omega_{us}} \\ -\varepsilon^2\bar{\varepsilon}\, e^{-i\omega_{us}} & 1+\varepsilon^2 & \bar{\varepsilon}^2 y_t \\ -\bar{\varepsilon}^3 y_t e^{-i\omega_{us}} & \bar{\varepsilon}^2 y_t & 1+y_t \end{pmatrix} m_0^2$$

$$M^2_{\tilde{Q}} = \begin{pmatrix} 1+\varepsilon^2 y_t & -\varepsilon^2\bar{\varepsilon}\, e^{i\omega_{us}} & \varepsilon\bar{\varepsilon}\, y_t^{0.5} e^{i(\omega_{us}-2\chi+\beta_3+\beta_2')} \\ -\varepsilon^2\bar{\varepsilon}\, e^{-i\omega_{us}} & 1+\varepsilon^2 & \varepsilon\, y_t^{0.5} e^{-i(2\chi-\beta_3-\beta_2')} \\ \varepsilon\bar{\varepsilon}\, y_t^{0.5} e^{-i(\omega_{us}-2\chi+\beta_3+\beta_2')} & \varepsilon\, y_t^{0.5} e^{i(2\chi-\beta_3-\beta_2')} & 1+y_t \end{pmatrix} m_0^2$$

	$\|(\delta^e_{LL})_{12}\|$	$\|(\delta^e_{LL})_{13}\|$	$\|(\delta^e_{LL})_{23}\|$	$\|(\delta^e_{RR})_{12}\|$	$\|(\delta^e_{RR})_{13}\|$	$\|(\delta^e_{RR})_{23}\|$
RVV1	$\frac{1}{3}\varepsilon^2\bar{\varepsilon}$	$y_t\bar{\varepsilon}^3$	$3y_t\bar{\varepsilon}^2$	$\frac{1}{3}\bar{\varepsilon}^3$	$\frac{1}{3}\bar{\varepsilon}^3$	$\bar{\varepsilon}^2$
RVV2	$\frac{1}{3}\varepsilon^2\bar{\varepsilon}$	$\frac{1}{3}\sqrt{y_t}\varepsilon\bar{\varepsilon}$	$\sqrt{y_t}\varepsilon$	$\frac{1}{3}\bar{\varepsilon}^3$	$\frac{1}{3}\sqrt{y_b}\bar{\varepsilon}^2$	$\sqrt{y_b}\bar{\varepsilon}$
RVV3	$3y_t\varepsilon\bar{\varepsilon}^2$	$y_t\varepsilon$	$3y_t\bar{\varepsilon}^2$	$\frac{1}{3}\bar{\varepsilon}^3$	$y_b\bar{\varepsilon}$	$\bar{\varepsilon}^2$


1400
1200
1000
800
600
400
200
500
1000
1500
2000

ELECTRIC DIPOLE MOMENT OF THE ELECTRON

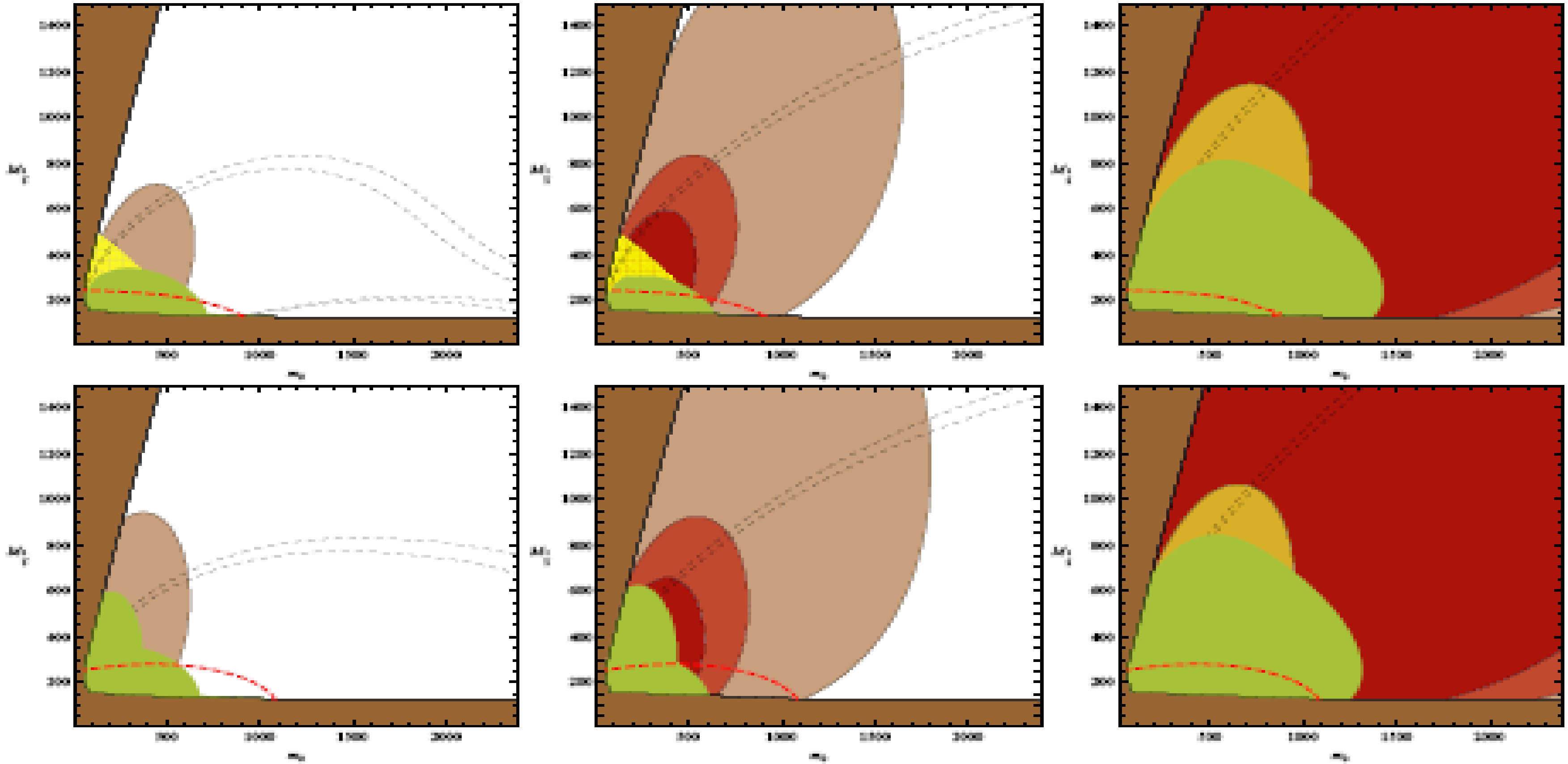
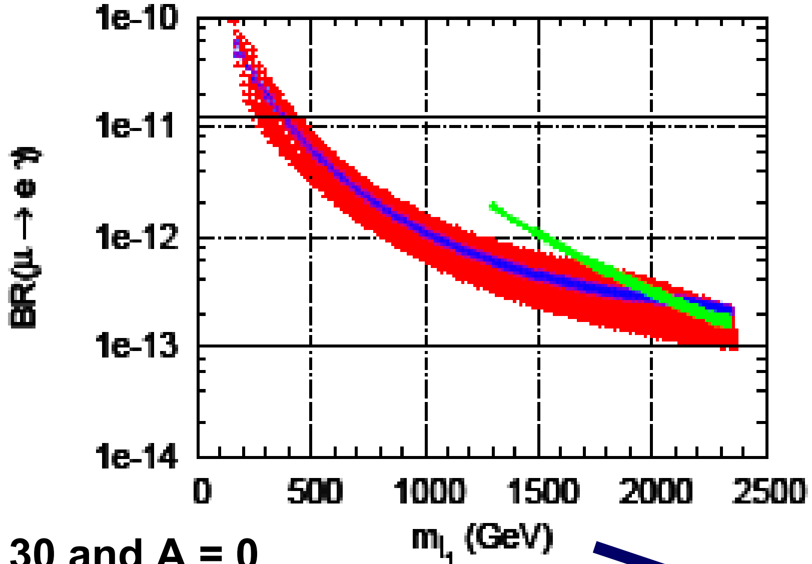
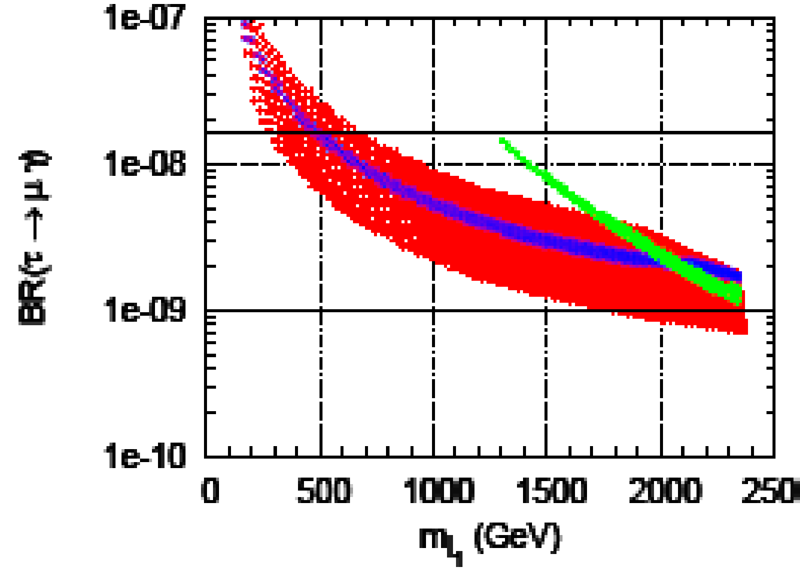


FIG. 4: Contours of $|d_e| = 1 \times 10^{-28}$ e cm (dark red), $|d_e| = 5 \times 10^{-29}$ e cm (light red) and $|d_e| = 1 \times 10^{-29}$ e cm (grey) in the m_0-$M_{1/2}$ plane for $\tan\beta = 10$ and $A_0 = 0$ (top), $A_0 = m_0$ (bottom). We show predictions for RVV1 (left), RVV2 (center) and RVV3 (right). Current EDM bound (1.4×10^{-27}) is shown in gold. Current LFV bounds are also shown in green, and the $g-2$ favoured region is shown hatched in yellow. The area between the dashed black lines solve the ε_K tension, and the dark brown region show areas excluded by having a charged LSP or by LEP, excepting the Higgs mass bound, which is shown in thick dashed red lines.

EX.: SU(3) – FLAVORED SUSY

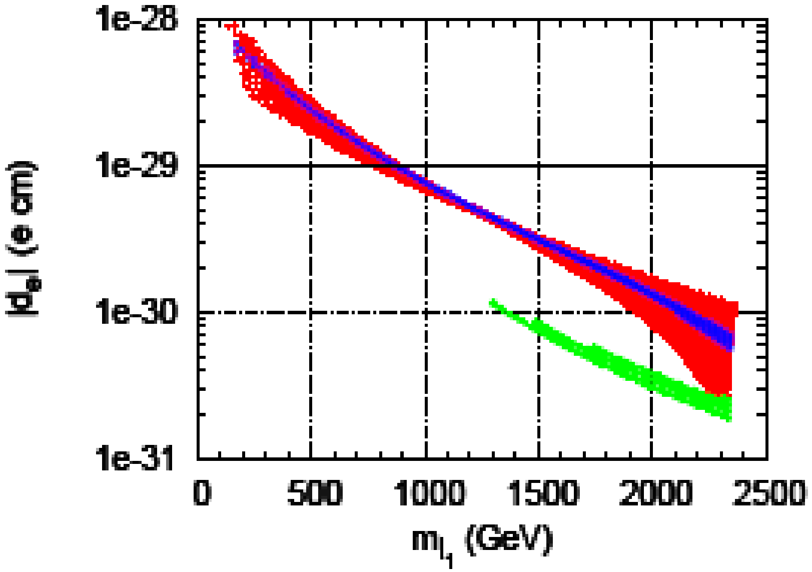
CALIBBI, JONES PEREZ, A.M., J.-h.PARK, POROD and VIVES, in preparation

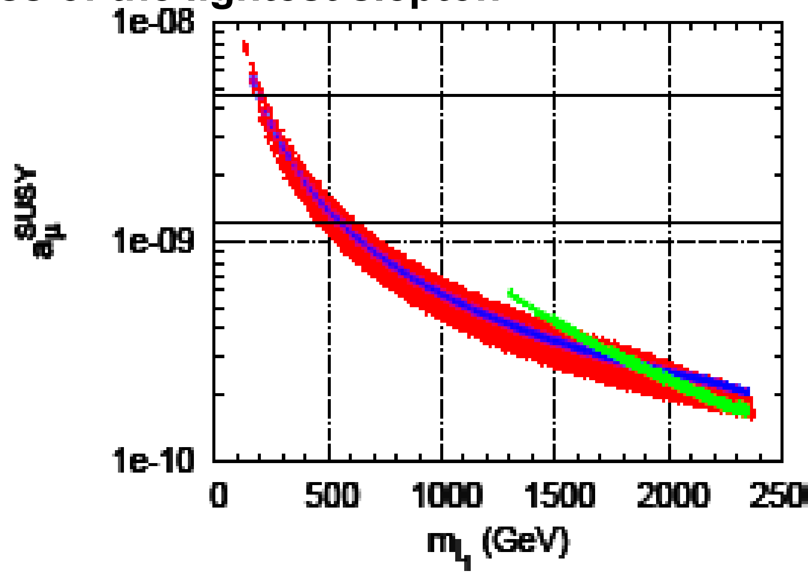




tan β = 30 and A = 0

Mass of the lightest slepton





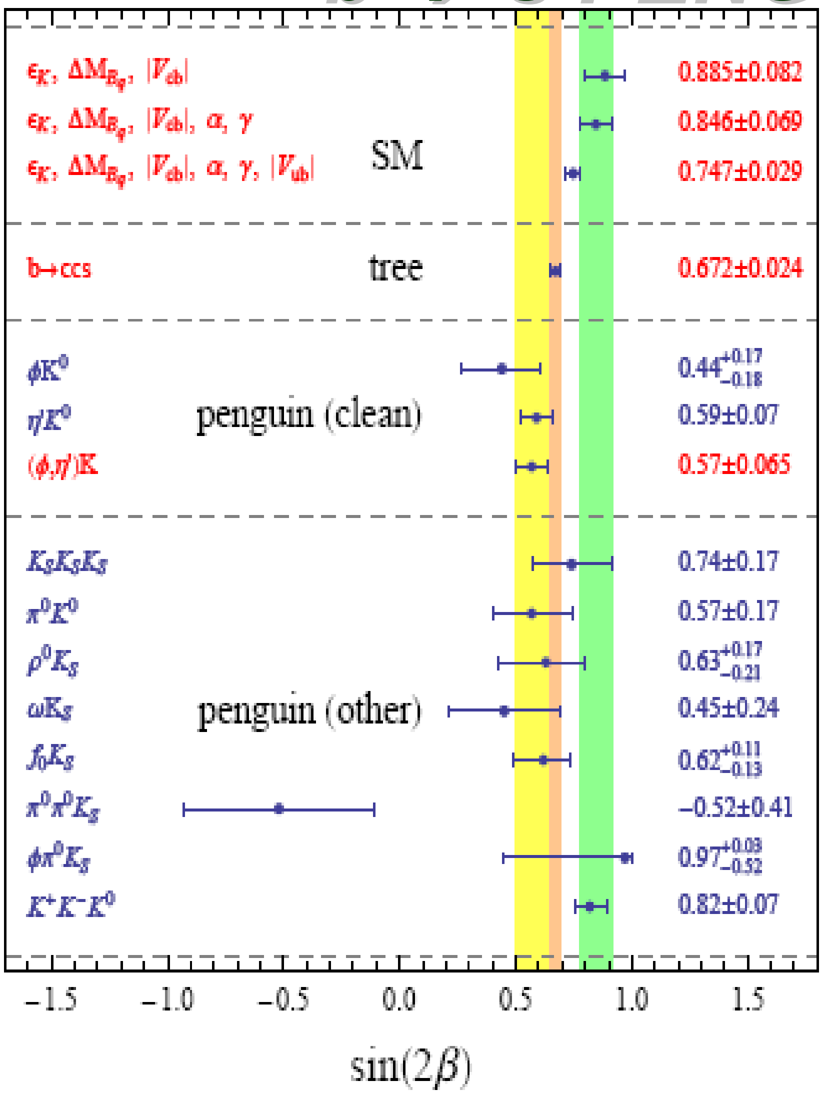
FLAVOR BLINDNESS OF THE NP AT THE ELW. SCALE?

- **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 (flavor violating) 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

Possible hints for NP in B and K

- sin2β can be measured directly or inferred from the UT ~ 2σ discrepancy
- sin2β can be measured directly also through penguin-mediated B decays ~ 1.5 σ discrep.
- Comparison of partial rate asymmetries in charged and neutral B decays into Kπ
- Deviation of the time dependent CP asymmetry in $B_s \rightarrow J/\Psi\varphi$ as measured bv CDF and D0 from the SM ~ 2—3 σ (FIRST EVIDENCE OF NEW PHYSICS IN $b \leftrightarrow s$ TRANSITIONS (UT*fit* Collaboration))
- The prediction of the SM for ε_K is ~ 18% below its exp. Value (BURAS et al.)

sin 2β FROM FITTING THE UT AND ITS DIRECT DETERMINATIONS IN b → ccs and b → s PENGUIN MODES



mode	w/out V_{ub}	with V_{ub}
$S_{\psi K_S}$	2.4 σ	2.0 σ
$S_{\phi K_S}$	2.2 σ	1.8 σ
$S_{\eta' K_S}$	2.6 σ	2.1 σ
$S_{(\phi+\eta')K_S}$	2.9 σ	2.5 σ

LUNGHI and SONI

Kπ Puzzle: hint for NP?

$$A_{CP}(\bar{B}^0 \to K^-\pi^+) \equiv \frac{N(\bar{B}^0 \to K^-\pi^+) - N(B^0 \to K^+\pi^-)}{N(\bar{B}^0 \to K^-\pi^+) + N(B^0 \to K^+\pi^-)}$$

$$A_{CP}(B^0 \to K^+\pi^-) = -9.7 \pm 1.2\%,$$
$$A_{CP}(B^+ \to K^+\pi^0) = +5.0 \pm 2.5\%,$$

$$(\Delta A_{CP})_{\rm exp} = (14.7 \pm 2.8)\% \qquad (\Delta A_{CP})_{\rm th} = (2.1 \pm 1.6)\%$$

NON-VANISHING DIFFERENCE AT MORE THAN 5σ – possible strategy: to get a large effect without affecting other penguin-driven contributions to B decays, call for NP to modify the Im part of the ELW. Penguins through the presence of large phases in the A trilinear scalar couplings of the 3rd generation work in progress with S. Khalil

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!

Is there a hope to see **NP with MFV** in **HIGH INTENSITY Physics**?

- In hadronic **FCNC** experiments the best chance is:

Measurement of Br $(B_{s,d} \to \mu^+\mu^-)$

SM:

$$Br\left(B_s \to \mu^+\mu^-\right)_{SM} = (3.37 \pm 0.31) \cdot 10^{-9}$$
$$Br\left(B_d \to \mu^+\mu^-\right)_{SM} = (1.02 \pm 0.09) \cdot 10^{-10}$$

$$< 6 \cdot 10^{-8}$$
$$< 2 \cdot 10^{-8}$$

CDF (95% C.L.)
DØ

- In rare processes where the flavor does **not** change: **magnetic and electric dipole moments** (es. Muon magnetic moment, electric dipole moments of electron and nucleon)

What a SuperB can do in testing CMFV

L. Silvestrini at SuperB IV

Minimal Flavour Violation

In **MFV models** with **one Higgs doublet** or **low/moderate tanβ** the NP contribution is a shift of the Inami-Lim function associated to top box diagrams

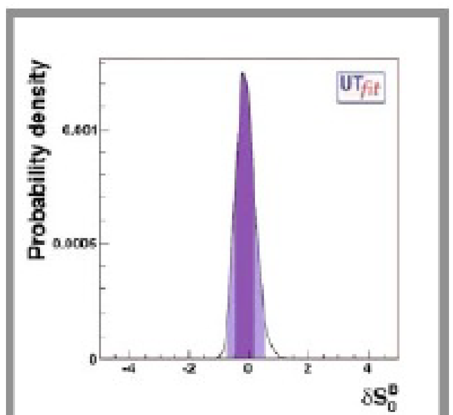
$$S_0(x_t) \to S_0(x_t) + \delta S_0(x_t)$$

$$\delta S_0(x_t) = 4a\left(\frac{\Lambda_0}{\Lambda}\right)^2$$

$$\Lambda_0 = \frac{\lambda_t \sin^2\vartheta_W M_W}{\alpha} \simeq 2.4 \text{ TeV}$$

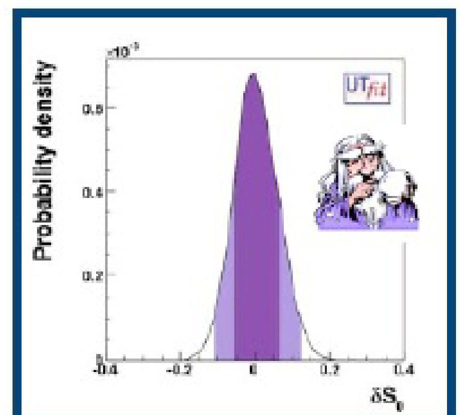
(D'Ambrosio et al., hep-ph/0207036)

$$\delta S_0^B = \delta S_0^K$$



$\delta S_0 = -0.16 \pm 0.32$

$\Lambda > 5.5$ TeV @95%



$\delta S_0 = 0.004 \pm 0.059$

$\Lambda > 28$ TeV @95%

The "worst" case: we still probe virtual particles with masses up to ~12 M_W ~1 TeV

SuperB vs. LHC Sensitivity Reach in testing Λ_{SUSY}

	superB	general MSSM	high-scale MFV
$\left\vert\left(\delta^d_{13}\right)_{LL}\right\vert$ $(LL \gg RR)$	$1.8 \cdot 10^{-2} \frac{m_{\tilde{q}}}{(350\mathrm{GeV})}$	1	$\sim 10^{-3} \frac{(350\mathrm{GeV})^2}{m_{\tilde{q}}^2}$
$\left\vert\left(\delta^d_{13}\right)_{LL}\right\vert$ $(LL \sim RR)$	$1.3 \cdot 10^{-3} \frac{m_{\tilde{q}}}{(350\mathrm{GeV})}$	1	$-$
$\left\vert\left(\delta^d_{13}\right)_{LR}\right\vert$	$3.3 \cdot 10^{-3} \frac{m_{\tilde{q}}}{(350\mathrm{GeV})}$	$\sim 10^{-1} \tan\beta \frac{(350\mathrm{GeV})}{m_{\tilde{q}}}$	$\sim 10^{-4} \tan\beta \frac{(350\mathrm{GeV})^3}{m_{\tilde{q}}^3}$
$\left\vert\left(\delta^d_{23}\right)_{LR}\right\vert$	$1.0 \cdot 10^{-3} \frac{m_{\tilde{q}}}{(350\mathrm{GeV})}$	$\sim 10^{-1} \tan\beta \frac{(350\mathrm{GeV})}{m_{\tilde{q}}}$	$\sim 10^{-3} \tan\beta \frac{(350\mathrm{GeV})^3}{m_{\tilde{q}}^3}$

SuperB can probe MFV (with small-moderate tanβ) for TeV squarks; for a generic non-MFV MSSM → sensitivity to squark masses > 100 TeV !

Ciuchini, Isidori, Silvestrini

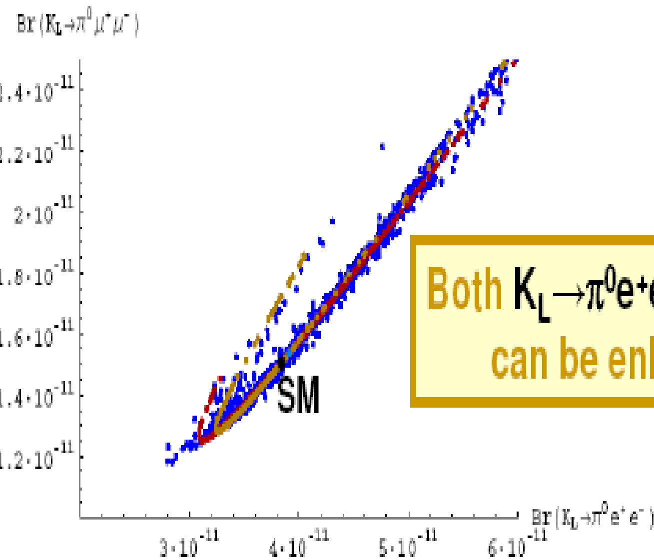
SLOW-DECOUPLING OF NP IN FCNC

FCNC SL K DECAYS

Decay	SM	Exp	TH
$K^+ \to \pi^+ \nu\bar{\nu}$	$(8.1\pm1.1)\cdot10^{-11}$	$(14.7^{+13.0}_{-8.9})\cdot10^{-11}$ (BNL)	±2-3%
$K_L \to \pi^0 \nu\bar{\nu}$	$(2.6\pm0.3)\cdot10^{-11}$	$< 2.1\cdot10^{-7}$ (KTeV,KEK)	±1-2%
$K_L \to \pi^0 e^+e^-$	$(3.5\pm1.0)\cdot10^{-11}$	$< 28\cdot10^{-11}$ (KTeV)	$\pm15\%$
$K_L \to \pi^0 \mu^+\mu^-$	$(1.4\pm0.3)\cdot10^{-11}$	$< 38\cdot10^{-11}$ (KTeV)	$\pm15\%$

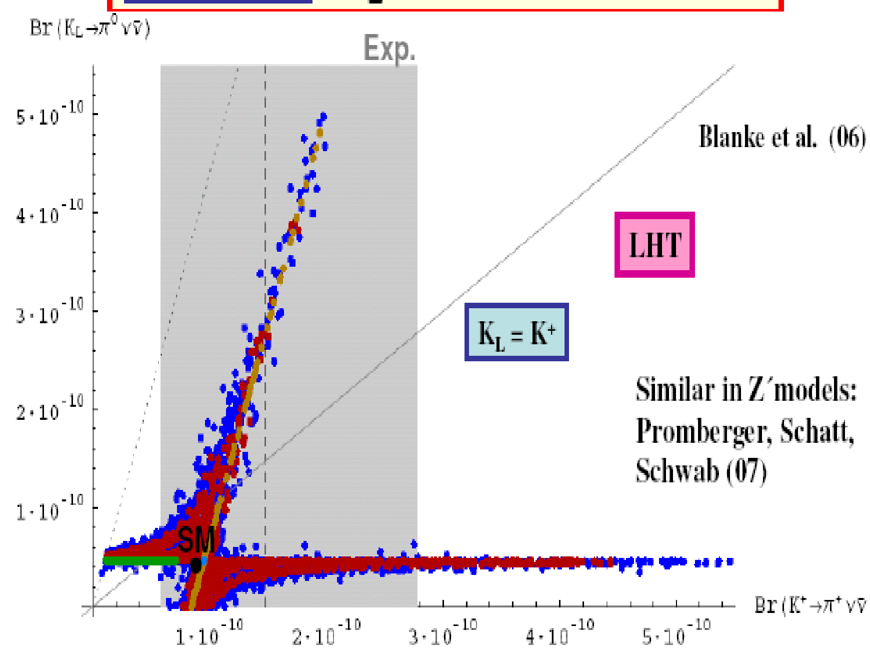
K-system: $K_L\to\pi^0\nu\bar{\nu}$ vs $K^+\to\pi^+\nu\bar{\nu}$

K-system: $K_L\to\pi^0e^+e^-$ and $K_L\to\pi^0\mu^+\mu^-$



Friot, Greynat, de Rafael (04)
General correlation:
Isidori, Smith, Unterdorfer (04)
Mescia, Smith, Trine (06)

Both $K_L\to\pi^0e^+e^-$ and $K_L\to\pi^0\mu^+\mu^-$ can be enhanced by ~2



Two distinguished branches appear!
~10 times enhancement in $K_L\to\pi^0\nu\bar{\nu}$
~5 times enhancement in $K^+\to\pi^+\nu\bar{\nu}$

SUSY SEE-SAW

- **UV COMPLETION OF THE SM TO STABILIZE THE ELW. SCALE:**

LOW-ENERGY SUSY

- **COMPLETION OF THE SM FERMIONIC SPECTRUM TO ALLOW FOR NEUTRINO MASSES**: NATURALLY SMALL PHYSICAL NEUTRINO MASSES WITH RIGHT-HANDED NEUTRINO WITH A LARGE MAJORANA MASS

SEE-SAW

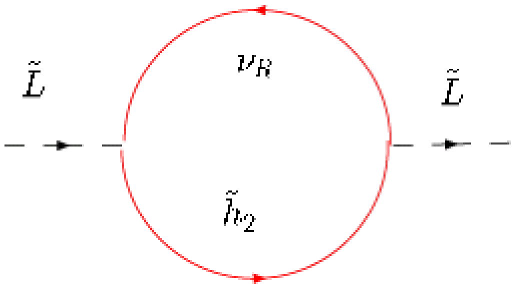
SUSY

GUT SEE-SAW

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

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

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



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

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**

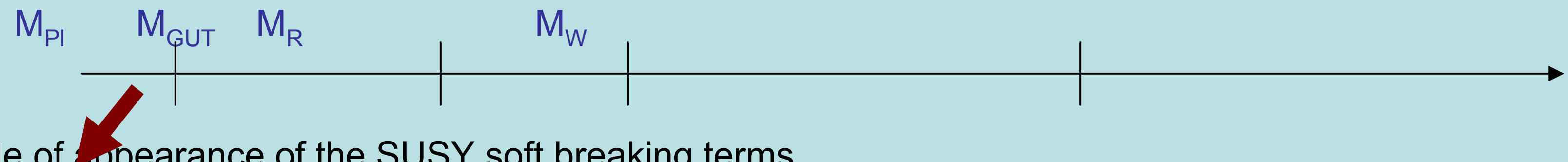
In **MSSM seesaw** or in **SUSY SU(5)** (Moroi): not possible to correlate the neutrino Yukawa couplings to know Yukawas;

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** $\longrightarrow$ one large of O(1) f_ν

U $\longrightarrow$ two "extreme" cases:

a) **U with "small" entries** $\longrightarrow$ **U = CKM**;
b) **U with "large" entries** with the exception of the 13 entry
$\longrightarrow$ **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

potentially large LFV

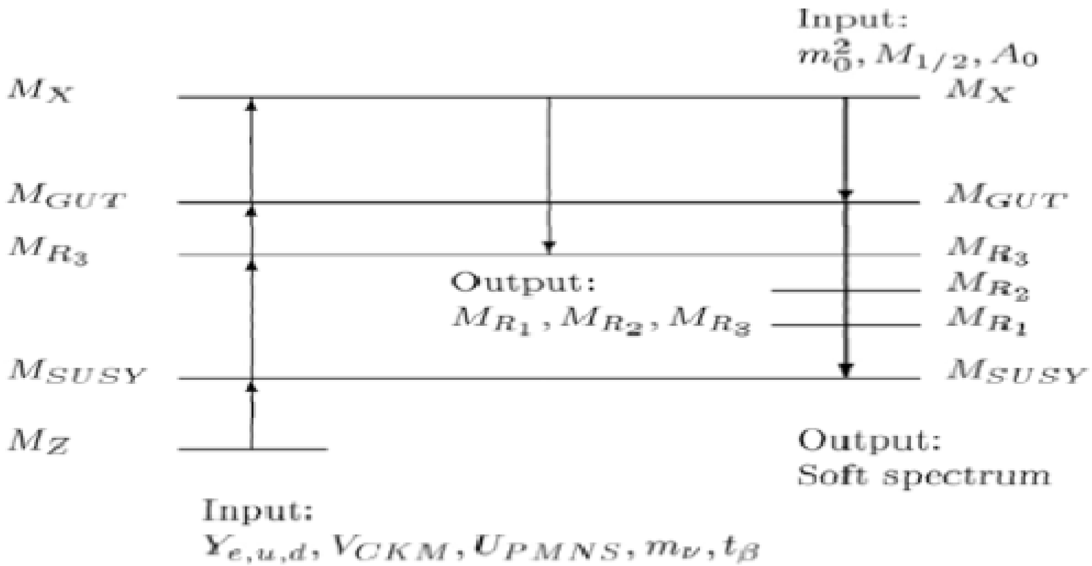
Barbieri, Hall; Barbieri, Hall, Strumia; Hisano, Nomura, Yanagida; Hisano, Moroi, Tobe Yamaguchi; Moroi;A.M.,, Vempati, Vives; Carvalho, Ellis, Gomez, Lola; Calibbi, Faccia, A.M, Vempati

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

$\tau \quad \mu\gamma$ 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 $M_X > M_{GUT}$

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

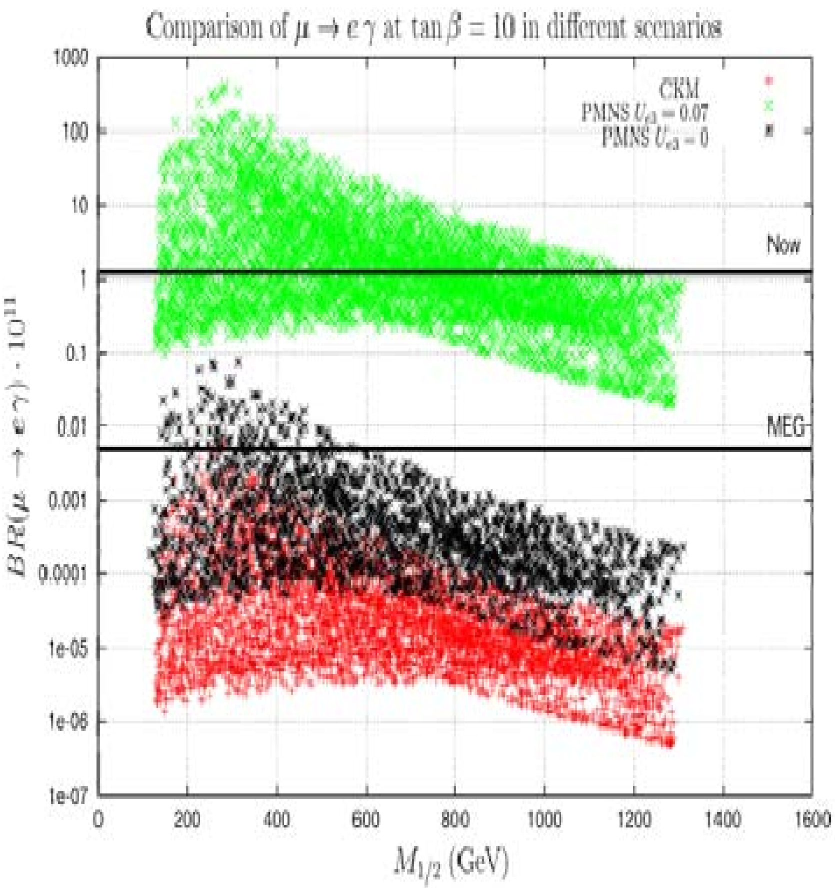
See-saw:

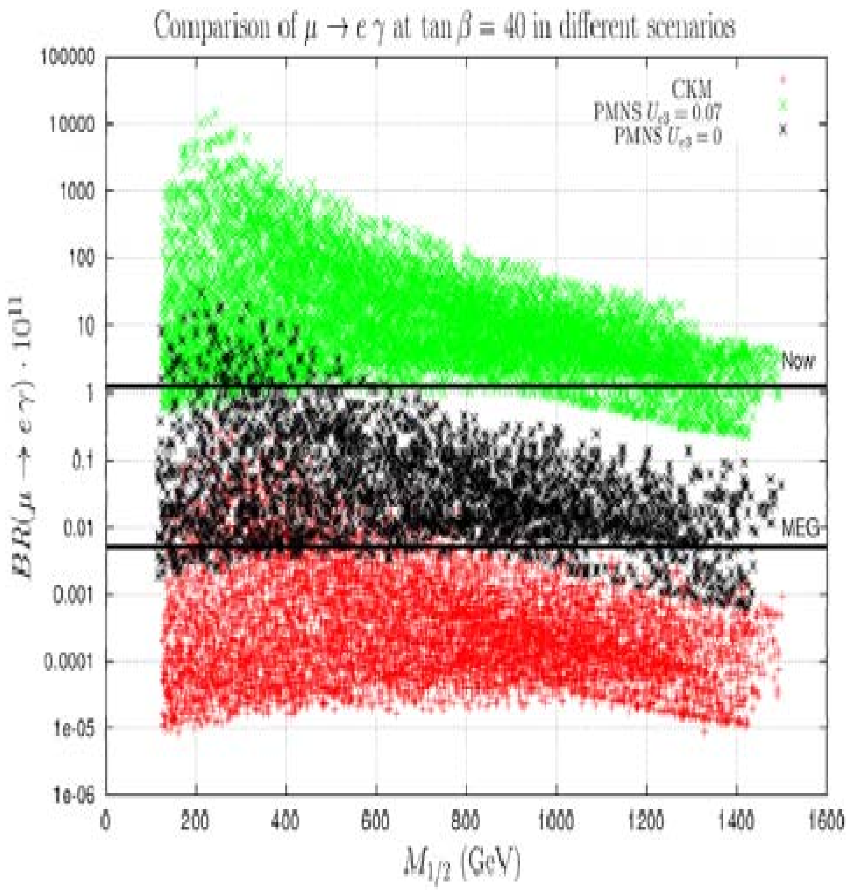
$$m_\nu = -Y_\nu \hat{M}_R^{-1} Y_\nu^T \langle H_u \rangle^2$$

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

μ ➞ e+γ in SUSYGUT: past and future

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





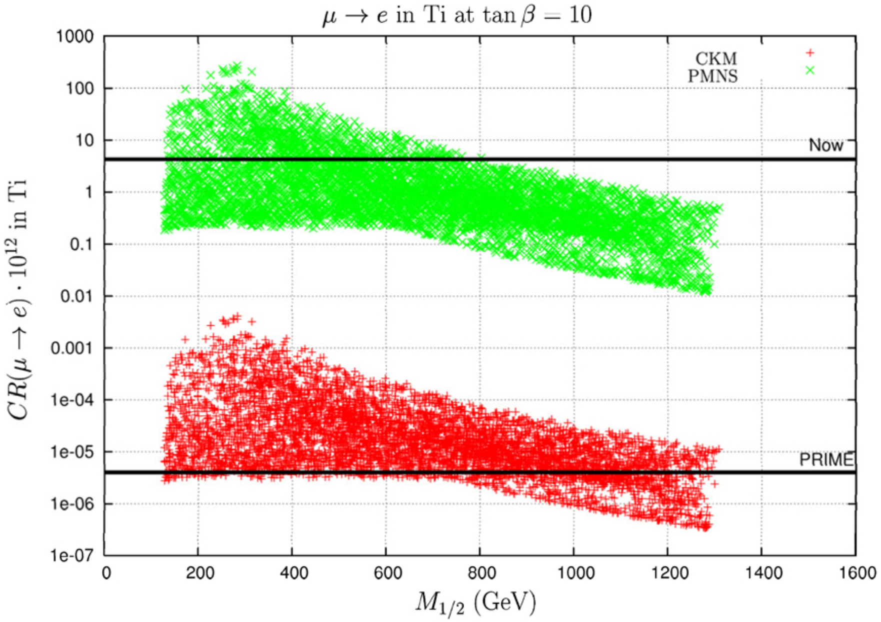
Calibbi, Faccia, A.M., Vempati

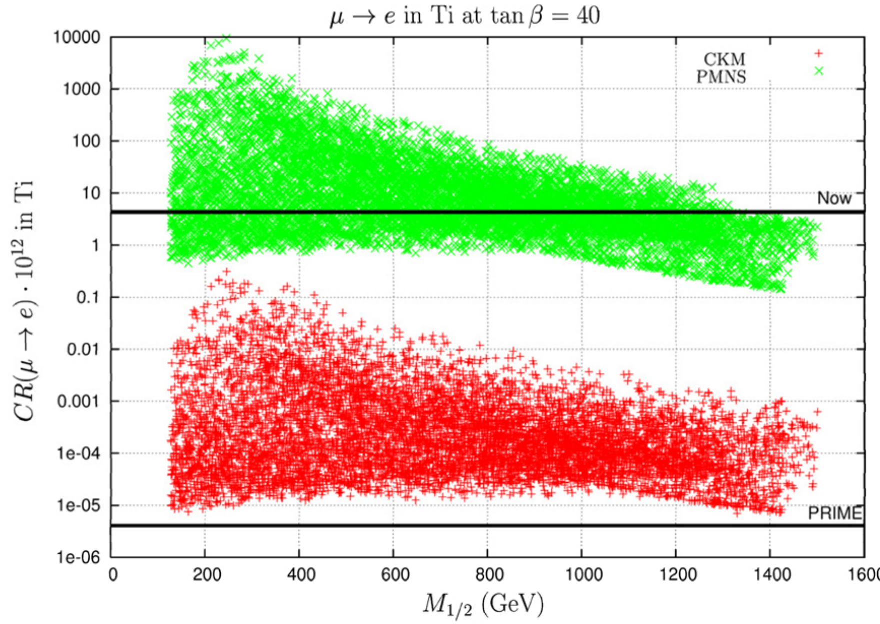
Sensitivity of $\mu \longrightarrow e\gamma$ to U_{e3} for various Snowmass points in mSUGRA with seesaw

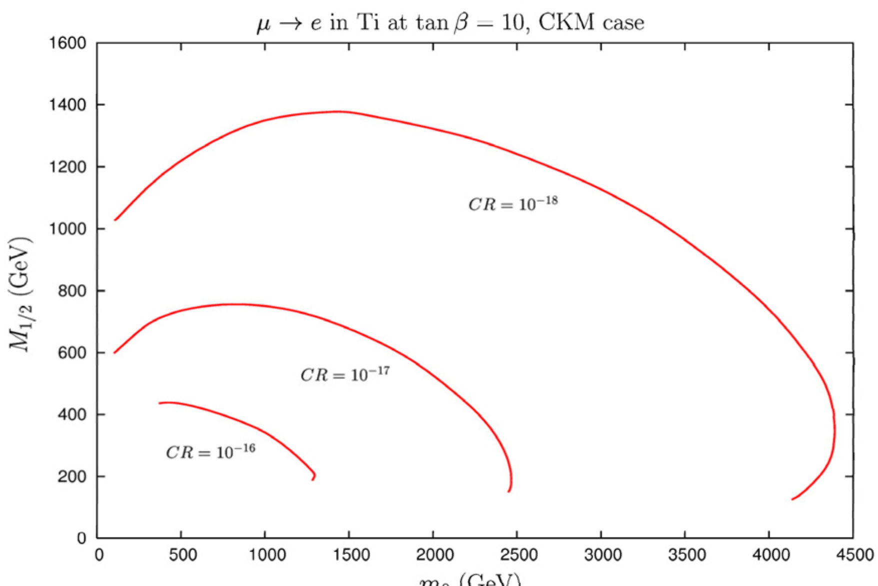
A.M., Vempati, Vives

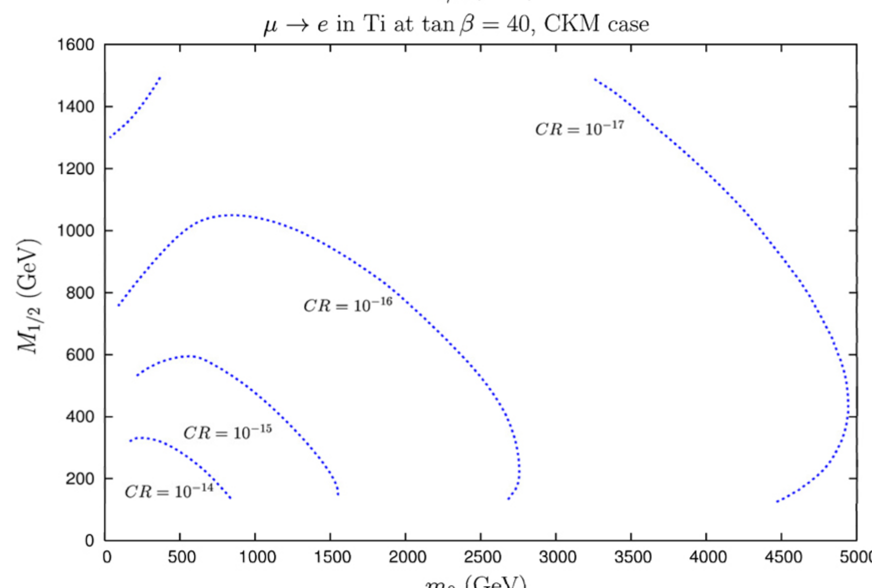
QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

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

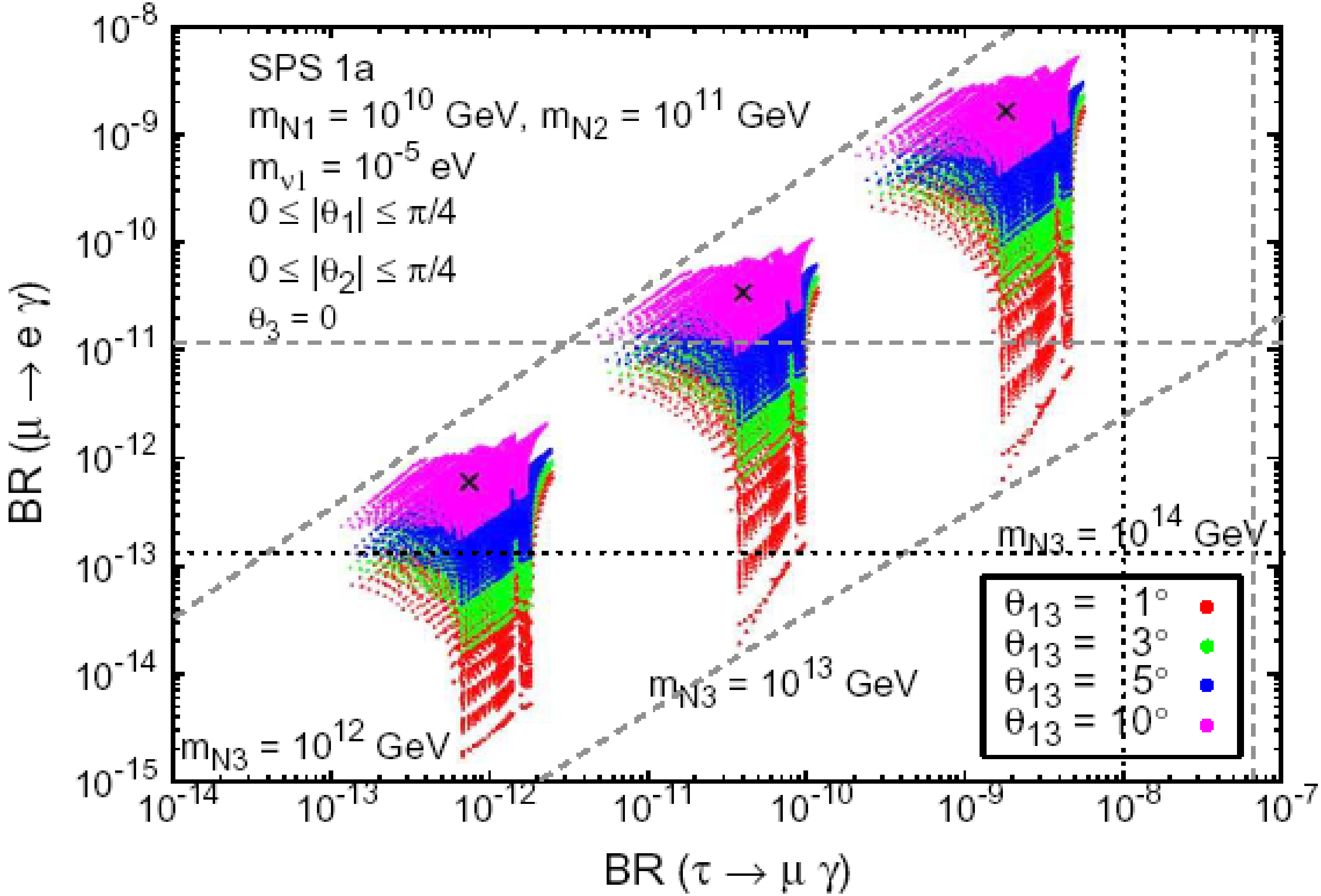






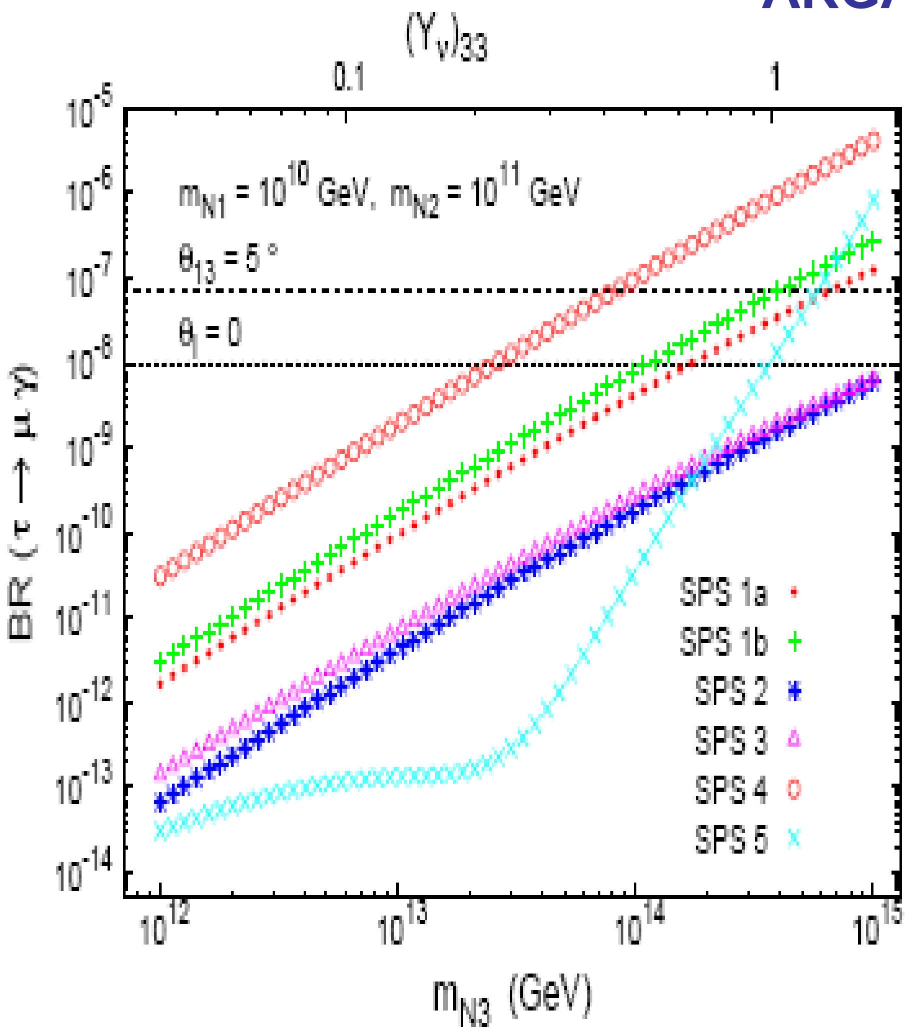


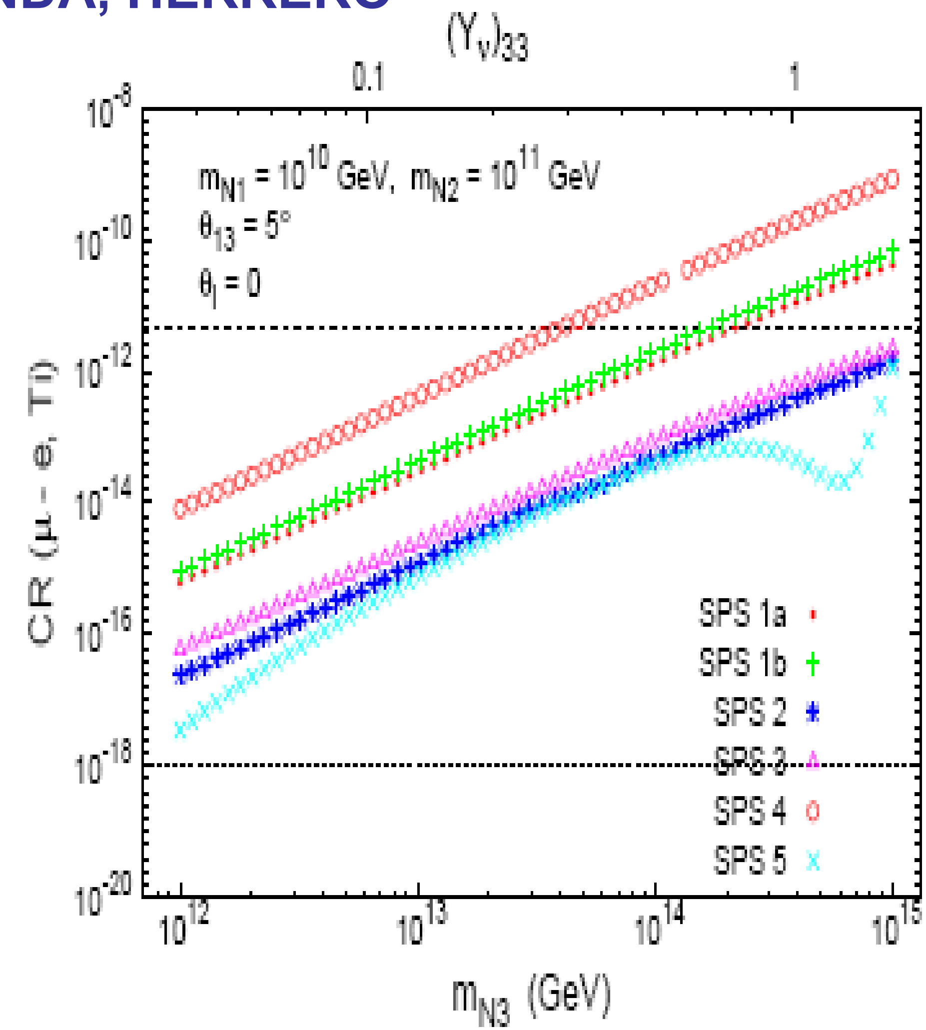
Antusch, Arganda, Herrero, Teixeira



LFV IN THE CONSTRAINED MSSS

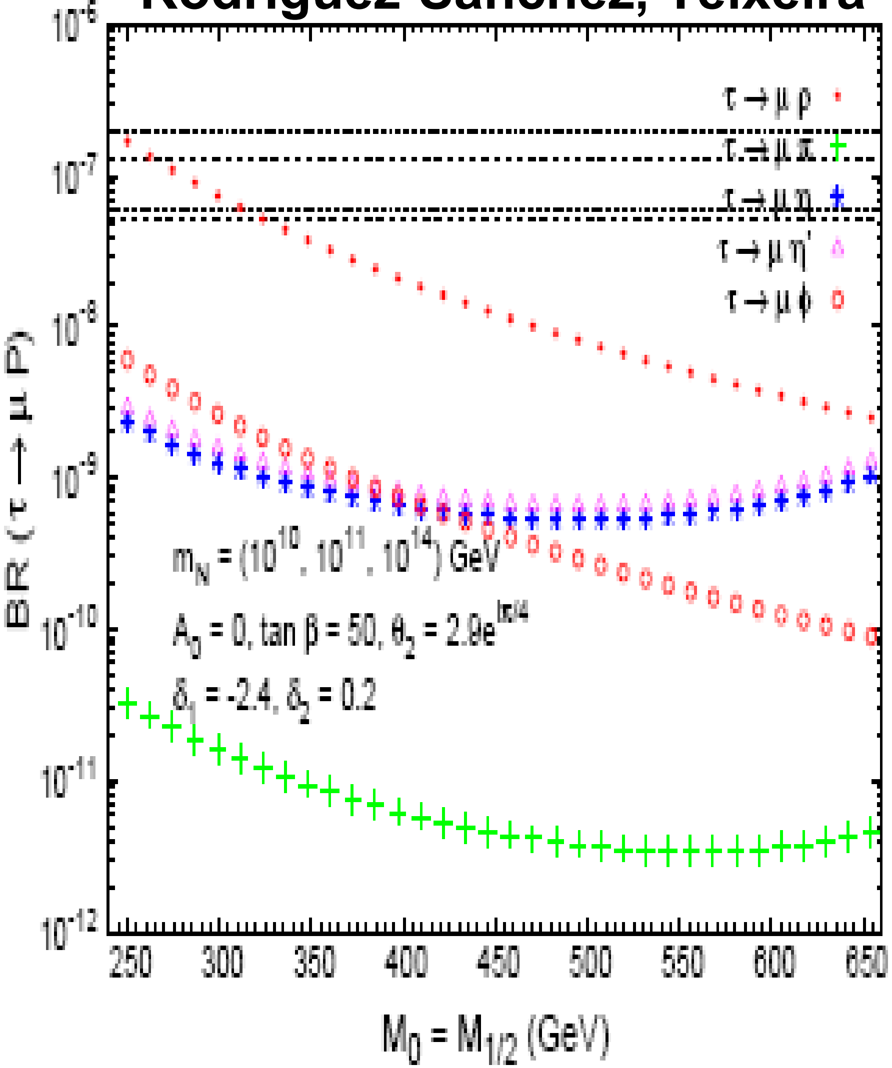
ARGANDA, HERRERO



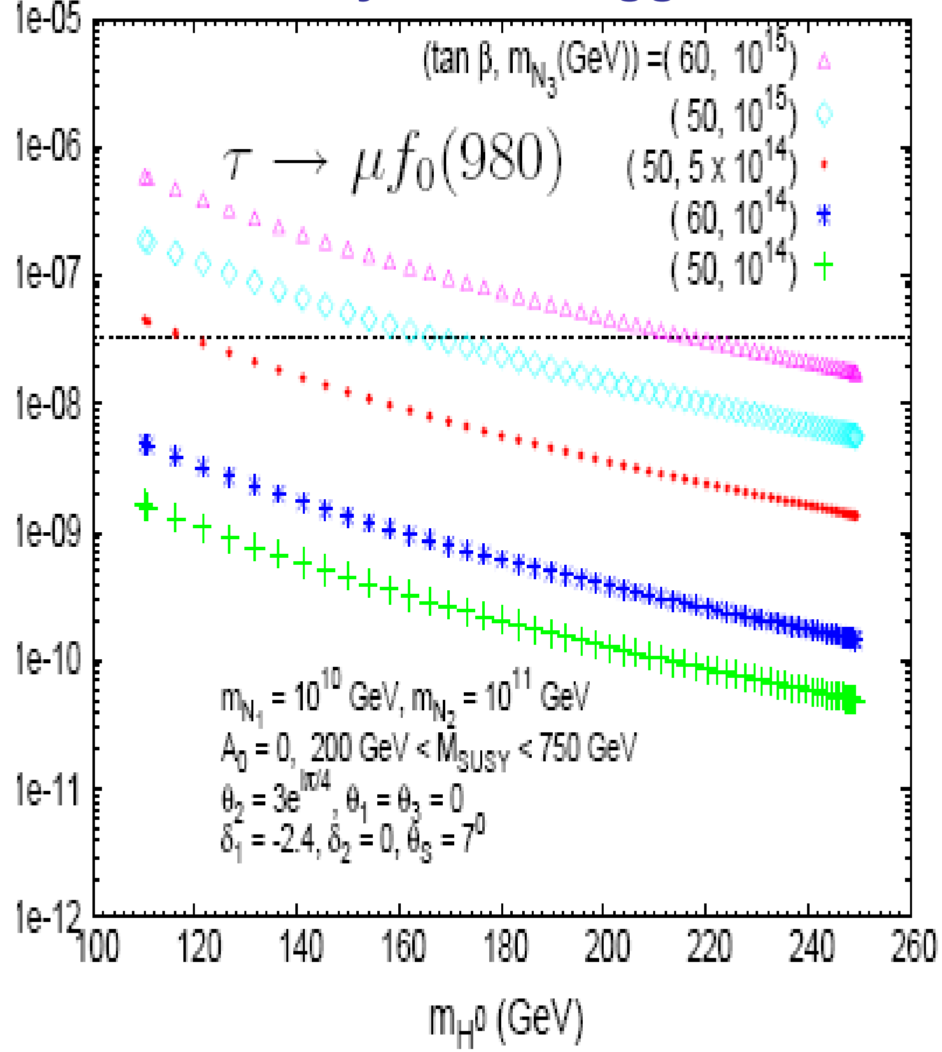


LFV SEMILEPTONIC TAU DECAYS

Arganda, Herrero, Portoles, Rodriguez-Sanchez, Teixeira



Sensitivity to the Higgs sector



Herrero, Portoles, Rodriguez-Sanchez

LFV vs. MUON (g – 2) in MSSM

Isidori, Mescia, Paradisi, Temes

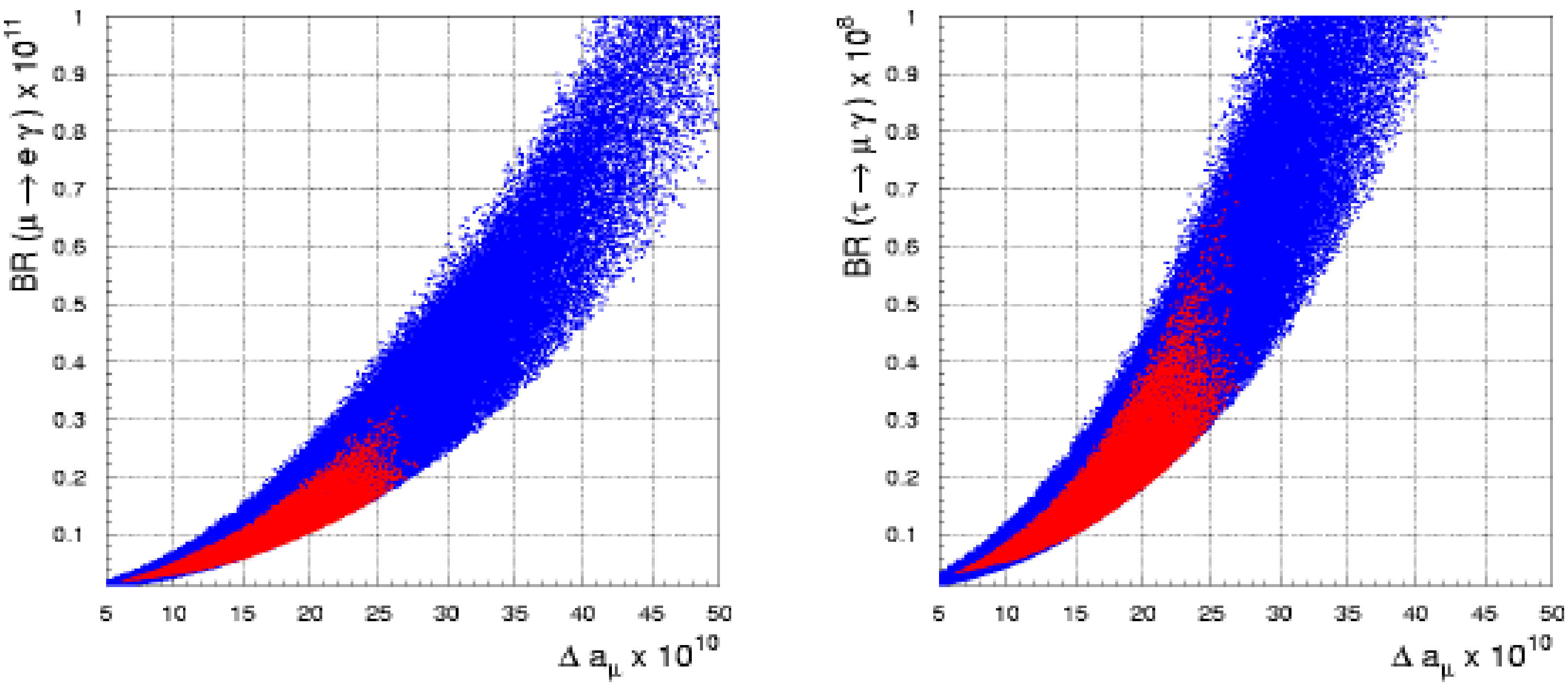


Figure 6: Expectations for $\mathcal{B}(\mu \to e\gamma)$ and $\mathcal{B}(\tau \to \mu\gamma)$ vs. $\Delta a_\mu = (g_\mu - g_\mu^{\rm SM})/2$, assuming $|\delta_{LL}^{12}| = 10^{-4}$ and $|\delta_{LL}^{23}| = 10^{-2}$. The plots have been obtained employing the following ranges: 300 GeV $\leq M_{\tilde\ell} \leq$ 600 GeV, 200 GeV $\leq M_2 \leq$ 1000 GeV, 500 GeV $\leq \mu \leq$ 1000 GeV, $10 \leq \tan\beta \leq 50$, and setting $A_U = -1$ TeV, $M_{\tilde q} = 1.5$ TeV. Moreover, the GUT relations $M_2 \approx 2M_1$ and $M_3 \approx 6M_1$ are assumed. The red areas correspond to points within the funnel region which satisfy the B-physics constraints listed in Section 3.2 [$\mathcal{B}(B_s \to \mu^+\mu^-) < 8 \times 10^{-8}$, $1.01 < R_{Bs\gamma} < 1.24$, $0.8 < R_{B\tau\nu} < 0.9$,

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:

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

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

Presently: error on R_K down to the **1% level** (KLOE (09) and NA48 (07 data);using 40% of the data collected in 08, NA62 is now decreasing the uncertainty at the **0.7% level**
Prospects: Summer conf. we'll have the result concerning the 40% data analysis by NA62 and when the analysis of the whole sample of data is accomplished **the stat. uncertainty will be < 0.3%**

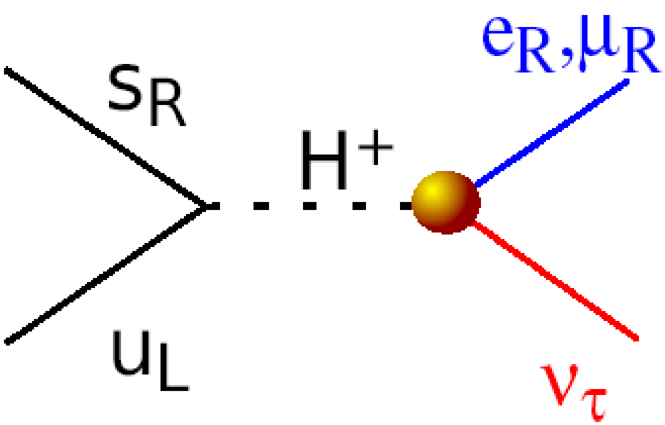
HIGGS-MEDIATED LFV COUPLINGS

- 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

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



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

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

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

$$\Downarrow$$

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

Extension to B $\longrightarrow$ lν deviation from universality
Isidori, Paradisi

LFU breaking occurs in a **LF conserving** case because of the splitting in slepton masses

A.M., PARADISI. PETRONZIO

LFU breaking occurs with LFV

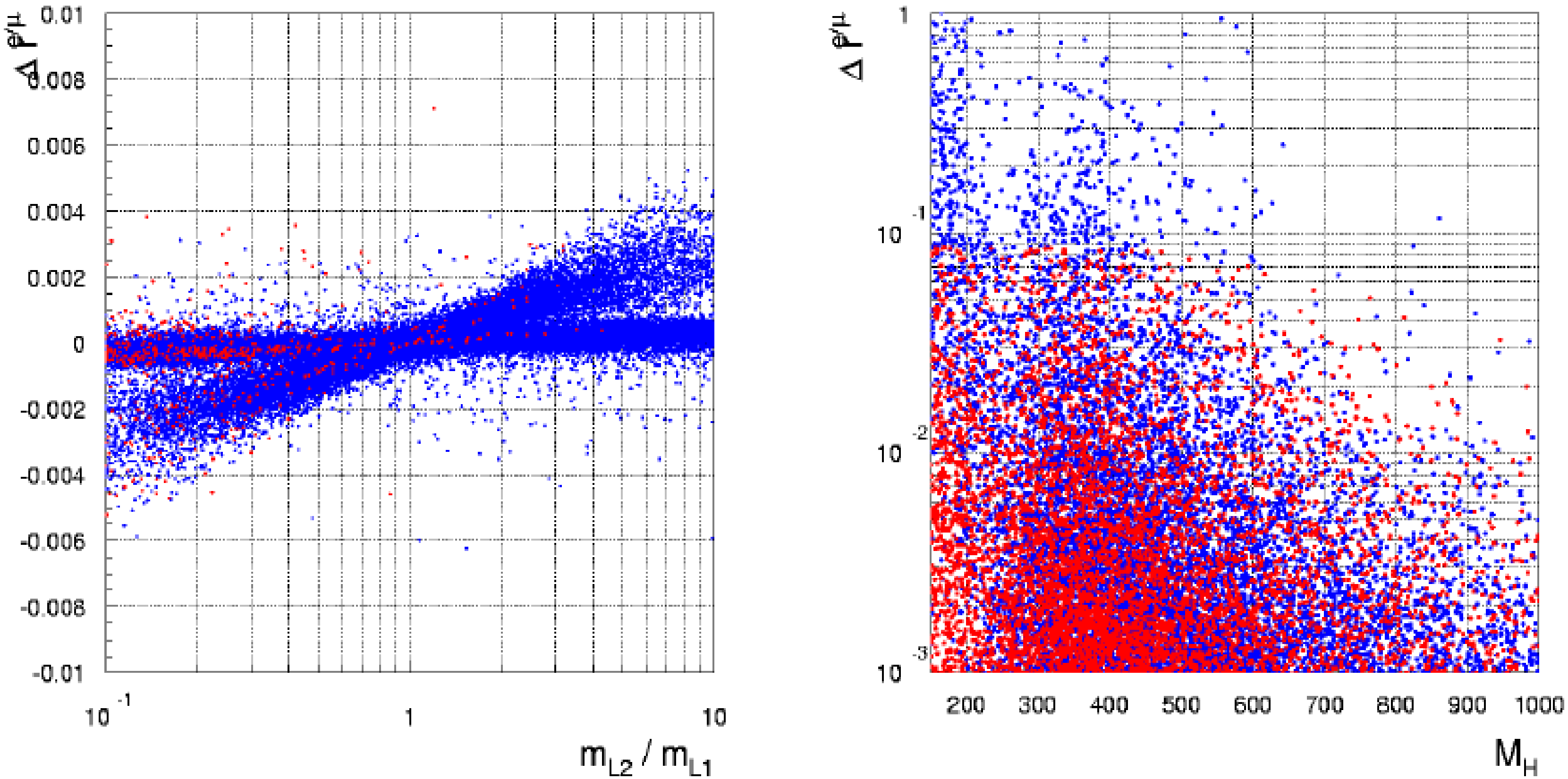


Figure 2: Left:$\Delta r_K^{e/\mu}$ as a function of the mass splitting between the second and the first (left-handed) slepton generations. Red dots can saturate the $(g-2)_\mu$ discrepancy at the 95% C.L., i.e. $1 \times 10^{-9} < (g-2)_\mu < 5 \times 10^{-9}$. Right: $\Delta r_K^{e/\mu}$ as a function of M_{H+}.

SUSY GUTs

- UV COMPLETION OF THE SM TO STABILIZE THE ELW. SCALE:

LOW-ENERGY SUSY

TREND OF UNIFICATION OF THE SM GAUGE COUPLINGS AT HIGH SCALE:

GUTs

Large ν mixing $\leftrightarrow$ 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

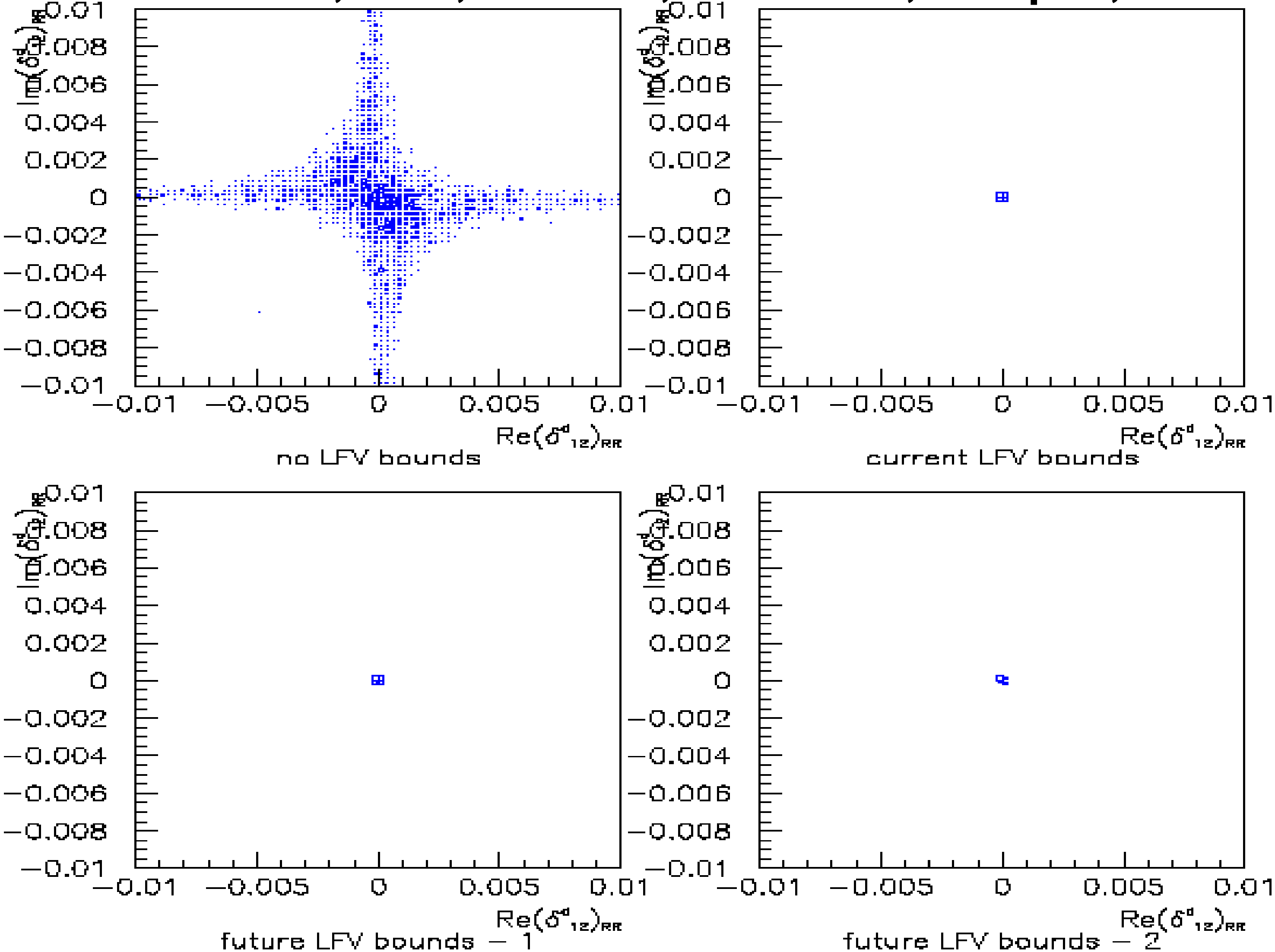
soft **SUSY breaking terms** arise
at a scale > M_{GUT}, they have to **respect the underlying quark-lepton GU symmetry**

constraints on δ^{quark} **from LFV** and
constraints on δ^{lepton} **from hadronic FCNC**

Ciuchini, A.M., Silvestrini, Vempati, Vives PRL 2004
general analysis **Ciuchini, A.M., Paradisi, Silvestrini, Vempati, Vives** NPB 2007
For previous works: Baek, Goto, Okada, Okumura PRD 2001;
Hisano, Shimizu, PLB 2003;
Cheung, Kang, Kim, Lee PLB 2007
Borzumati, Mishima, Yamashita hep-ph 0705:2664
For recent works: Goto, Okada, Shindou, Tanaka PRD 2008;
Ko, J-h. Park, Yamaguchi arXiv:0809:2784

Bounds on the hadronic $(\delta_{12})_{RR}$ as modified by the inclusion of the LFV correlated bound

Ciuchini, A.M., Paradisi, Silvestrini, Vempati, Vives



A FUTURE FOR FLAVOR PHYSICS IN OUR SEARCH BEYOND THE SM?

- The traditional **competition** between direct and indirect (FCNC, CPV) searches to establish who is going **to see the new physics first** is no longer the priority, rather

- **COMPLEMENTARITY** between direct and indirect searches for New Physics is the key-word

- Twofold meaning of such complementarity:

i) synergy in "reconstructing" the "fundamental theory" staying behind the signatures of NP;

ii) **coverage of complementary areas of the NP parameter space** (ex.: multi-TeV SUSY physics)

THE MULTI-MESSENGER APPROACH TO TEV NEW PHYSICS

- **High-Energy** (Tevatron, LHC, ILC) + **High-Intensity** (SuperFlavour machines) + **Astro-Particle Physics** (DM searches) : we need a deep and efficient synergy of these three roads to be able to accomplish the **DISCOVERY+IDENTIFICATION (UNDERSTANDING?) of the TeV NP**

- **(KAON + BEAUTY + CHARM + LEPTON) FV + RARE FLAVOR CONSERVING (EDMs, g – 2) ROADS**: important to have an efficient interplay of these different approaches to i) achieve an **understanding/discovery of the NP flavor structure**; ii) explore the existence of **lepton – hadron connections** like in SUSYGUTs (possibility to access not only TeV NP, but also some “progenitor” of it at very high energy scales)