NEUTRINO TELESCOPES, VENICE, March 6-9,2007

PHYSICS OF NEUTRINO FLAVORS*

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*NEUTRINO FLAVORS AS A WINDOW TO

NEW PHYSICS AT THE ELECTROWEAK SCALE

WHY TO GO BEYOND THE SM

"OBSERVATIONAL" REASONS

- HIGH ENERGY PHYSICS

NO (but $A_{FB}^{Z \to bb}$......)

- FCNC, CP≠

NO (but $b \to s q \bar{q}$ penguin ...)

- HIGH PRECISION LOW-EN.

NO (but $(g-2)_{\mu}$ ...)

- NEUTRINO PHYSICS

YES $m_{\nu} \neq 0$, $\theta_{\nu} \neq 0$

- COSMO - PARTICLE PHYSICS

YES (DM, ΔB_{cosm}, INFLAT., DE)

THEORETICAL REASONS

- INTRINSIC INCONSISTENCY OF SM AS QFT

NO (spont. broken gauge theory without anomalies)

- NO ANSWER TO QUESTIONS THAT "WE" CONSIDER "FUNDAMENTAL" QUESTIONS TO BE ANSWERED BY "FUNDAMENTAL" THEORY

YES (hierarchy, unification, flavor)

Neutrinos are MASSIVE: New Physics IS there!

Is the above a TRIVIAL statement?

→ SM built to have massless neutrinos (no RH neutrino, no isospin triplet scalar higgs)

→ find that neutrinos are massive and claim that you have discovered New Physics!

- NO, NEUTRINO MASS IS “REAL” NP WITH A NEW ENERGY SCALE ASSOCIATED TO IT

THE FATE OF LEPTON NUMBER

L VIOLATED → ν Majorana ferm.

L CONSERVED → ν Dirac ferm. (dull option)

$h\,\bar{\nu}_L H\,\nu_R \rightarrow m_\nu = h\,\langle H\rangle$ $M_\nu < 1\,\text{eV} \rightarrow h < 10^{-11}$

EXTRA-DIM. ν_R in the bulk: small overlap?

SMALLNESS of m_ν

↓

PRESENCE OF A NEW PHYSICAL MASS SCALE

NEW HIGH SCALE / NEW LOW SCALE

SEE - SAW MECHAN.

Minkowski; Gell-Mann, Ramond, SlansKy, Vanagida

↓

ν_R ENLARGEMENT OF THE FERMIONIC SPECTRUM

$M\nu_R\nu_R + h\,\bar{\nu}_L\,\phi\,\nu_R$

	ν_L	ν_R
ν_L	~O	$h\,\langle\phi\rangle$
ν_R	$h\,\langle\phi\rangle$	M

LR Models?

MAJORON MODELS

Gelmini, Roncadelli

↓

Δ ENLARGEMENT OF THE HIGGS SCALAR SECTOR

$h\,\nu_L\nu_L\,\Delta$

$m_\nu = h\,\langle\Delta\rangle$

N.B.: EXCLUDED BY LEP!

The Energy Scale from the “Observational” New Physics

- neutrino masses
- dark matter
- baryogenesis
- inflation

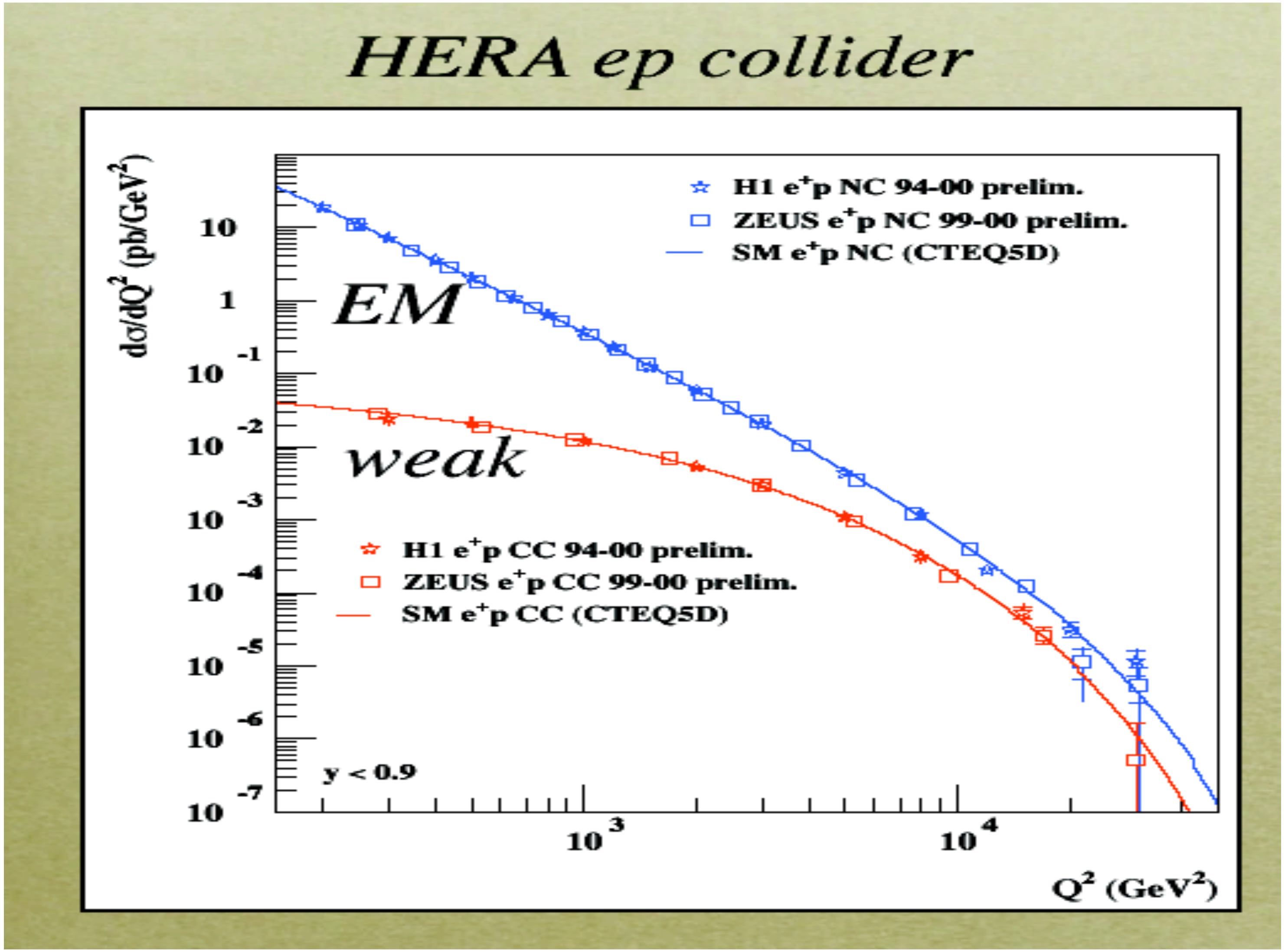
→ NO NEED FOR THE NP SCALE TO BE CLOSE TO THE ELW. SCALE

The Energy Scale from the “Theoretical” New Physics

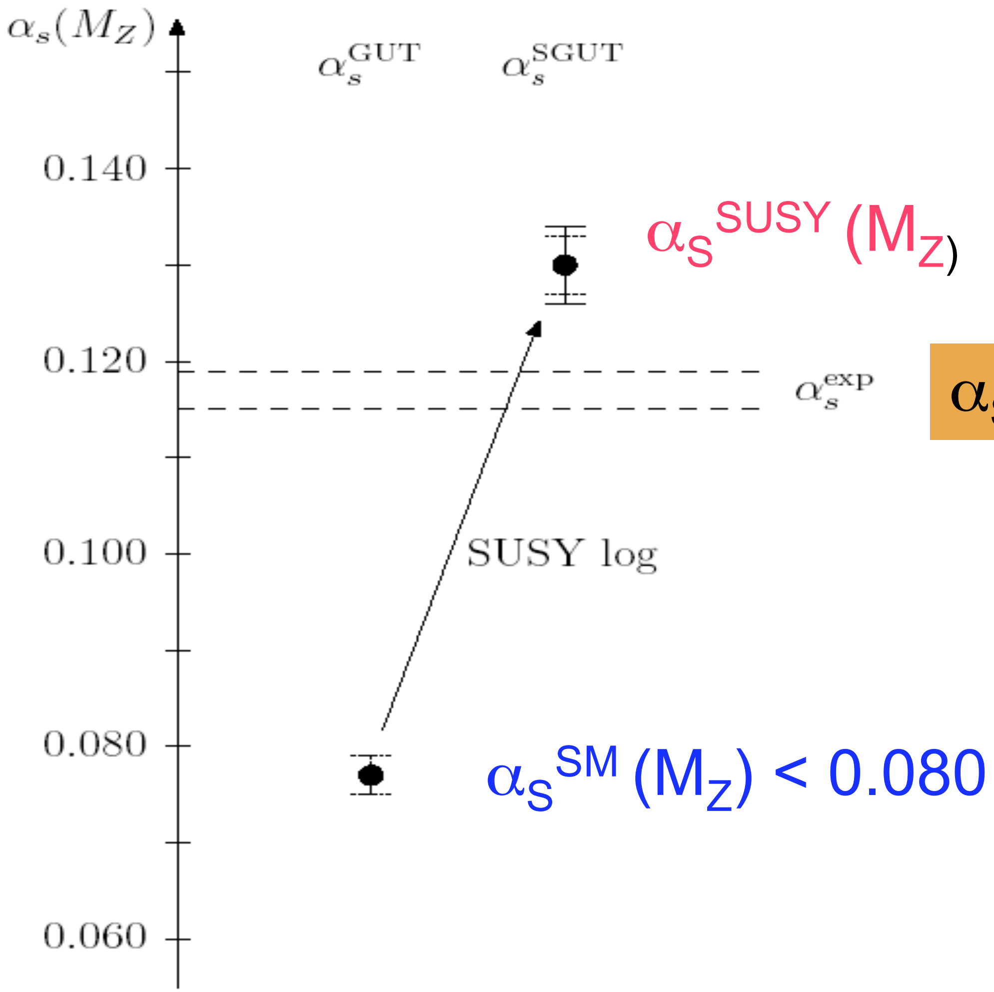
☆ ☆ ☆ Stabilization of the electroweak symmetry breaking at M_W calls for an ULTRAVIOLET COMPLETION of the SM already at the TeV scale +

☆ CORRECT GRAND UNIFICATION “CALLS” FOR NEW PARTICLES AT THE ELW. SCALE

Fundamental COUPLING CONSTANTS are NOT CONSTANT



Fundamental interactions unify



$\alpha_s^{exp}(M_Z)=0.117\pm0.002$

Hall, Nomura

STABLE ELW. SCALE WIMPs from PARTICLE PHYSICS

	SUSY	EXTRA DIM.	LITTLE HIGGS.
1) ENLARGEMENT OF THE SM	(x^{μ}, θ)	(x^{μ}, j^{i})	SM part + new part
	Anticomm. Coord.	New bosonic Coord.	to cancel Λ^2 at 1-Loop
2) SELECTION RULE	R-PARITY LSP	KK-PARITY LKP	T-PARITY LTP
→ DISCRETE SYMM.	Neutralino spin 1/2	spin1	spin0
→ STABLE NEW PART.	↓	↓	↓
3) FIND REGION (S) PARAM. SPACE WHERE THE "L" NEW PART. IS NEUTRAL + $\Omega_L h^2$ OK	m_{LSP} ~100 - 200 GeV *	m_{LKP} ~600 - 800 GeV	m_{LTP} ~400 - 800 GeV

* But abandoning gaugino-masss unif. → Possible to have m_{LSP} down to 7 GeV

Bottino, Donato, Fornengo, Scopel

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

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

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: $\Lambda_{UV} \sim O(1\ \mathrm{TeV})$

FROM DETERMINATION TO VERIFICATION OF THE CKM PATTERN FOR HADRONIC FLAVOR DESCRIPTION

$|V_{us}| \equiv \lambda, \qquad |V_{cb}|, \qquad R_b, \qquad \gamma,$ TREE LEVEL

$|V_{us}| \equiv \lambda, \qquad |V_{cb}|, \qquad R_t, \qquad \beta.$ ONE - LOOP

$$R_b \equiv \frac{|V_{ud}V_{ub}^*|}{|V_{cd}V_{cb}^*|} = \sqrt{\bar\varrho^2 + \bar\eta^2} = \left(1 - \frac{\lambda^2}{2}\right)\frac{1}{\lambda}\left|\frac{V_{ub}}{V_{cb}}\right|$$

$$R_t \equiv \frac{|V_{td}V_{tb}^*|}{|V_{cd}V_{cb}^*|} = \sqrt{(1-\bar\varrho)^2 + \bar\eta^2} = \frac{1}{\lambda}\left|\frac{V_{td}}{V_{cb}}\right|.$$

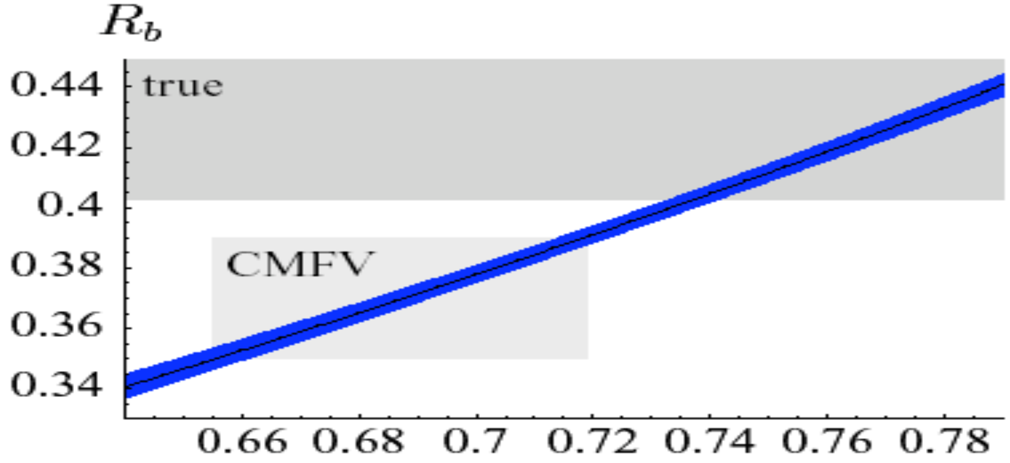
$$R_b = \sqrt{1 + R_t^2 - 2R_t\cos\beta}, \qquad \cot\gamma = \frac{1 - R_t\cos\beta}{R_t\sin\beta},$$

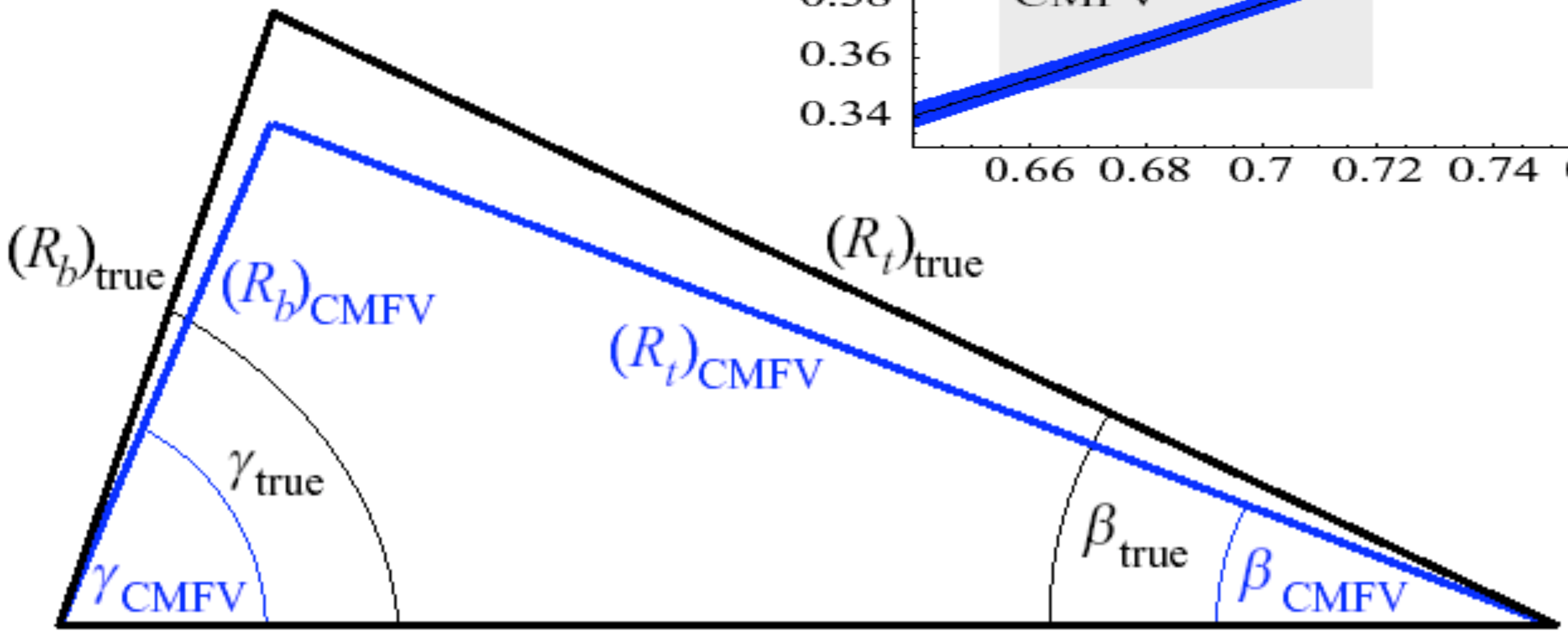
A. BURAS et al.

THE UT - UUT OVERLAP

$$(R_b)_{\rm CMFV} = 0.370 \pm 0.020, \qquad \gamma_{\rm CMFV} = (67.4 \pm 6.8)^\circ$$

$$(R_b)_{\rm true} = 0.440 \pm 0.037, \qquad \gamma_{\rm true} = (71 \pm 16)^\circ.$$





BLANKE, BURAS, GUADAGNOLI, TARANTINO

What to make of this triumph of the CKM pattern in 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!

THE FATE OF FLAVOR NUMBERS

HADRONIC FLAVOR NUMBERS: strangeness, charm, beauty.. ALL VIOLATED IN FLAVOR CHANGING CHARGED CURRENTS → mismatch in the simultaneous diagonalization of the up- and down- quark sectors allows for W intergenerational hadronic couplings

LEPTONIC FLAVOR NUMBERS: L_i i= e, μ, τ violated

in υ oscillations → massive neutrinos

→ mismatch in the simultaneous diagonalization of the up- (υ) and down- (l) sectors allows for W intergenerational leptonic couplings

LFV IN CHARGED LEPTONS FCNC

L_i - L_j transitions through W - neutrinos mediation

GIM suppression $(m_\nu / M_W)^2$ ⟶ 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,

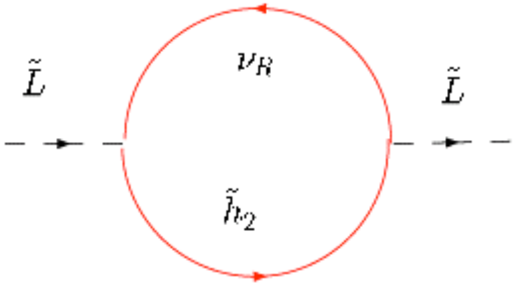
BUT in CMSSM (MSSM with flavor universality in the SUSY breaking sector) $\Delta M_{sleptons}$ is O($m_{leptons}$), hence GIM suppression is still too strong.

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)

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



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

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

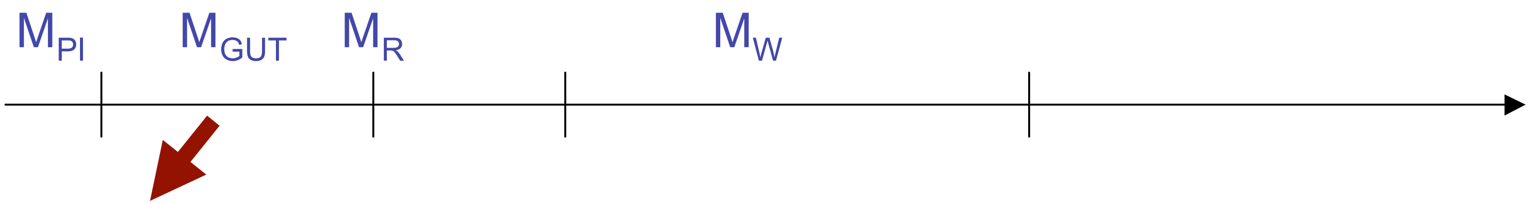
How Large LFV in SUSY SEESAW?

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

1) → in MSSM seesaw or in SUSY SU(5) (Moroi):
not possible to correlate the neutrino Yukawa couplings to known 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

2) 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

→ potentially large LFV

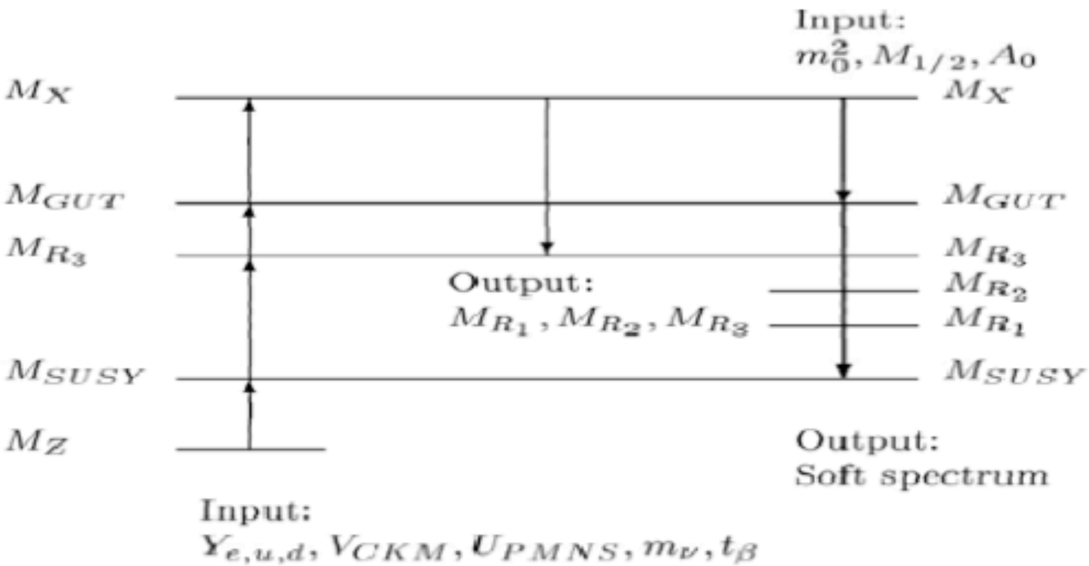
Barbieri, Hall; Barbieri, Hall, Strumia; Hisano, Nomura, Yanagida; Hisano, Moroi, Tobe Yamaguchi; Moroi;A.M.,, Vempati, Vives; Carvalho, Ellis, Gomez, Lola; Calibbi, Faccia, A.M, Vempati

LFV in MSSM seesaw: $\mu \to e\gamma$ 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 $M_X > M_{GUT}$

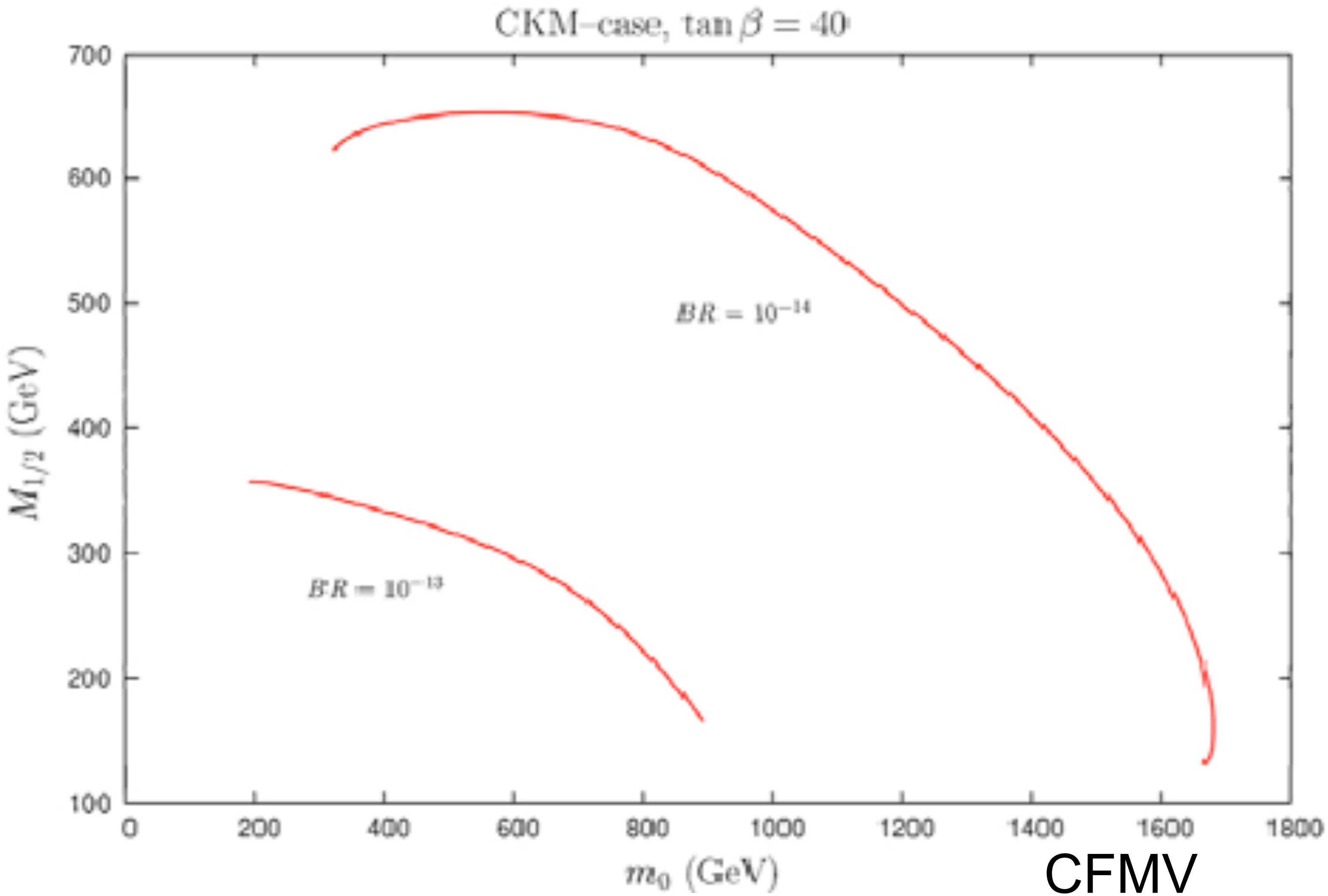
$$(\Delta_{RR})_{i\neq j} = -3 \cdot \frac{3m_0^2 + a_0^2}{16\pi^2} Y_t^2 V_{i3} V_{j3} \ln\left(\frac{M_X^2}{M_{GUT}^2}\right)$$

See-saw:

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

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

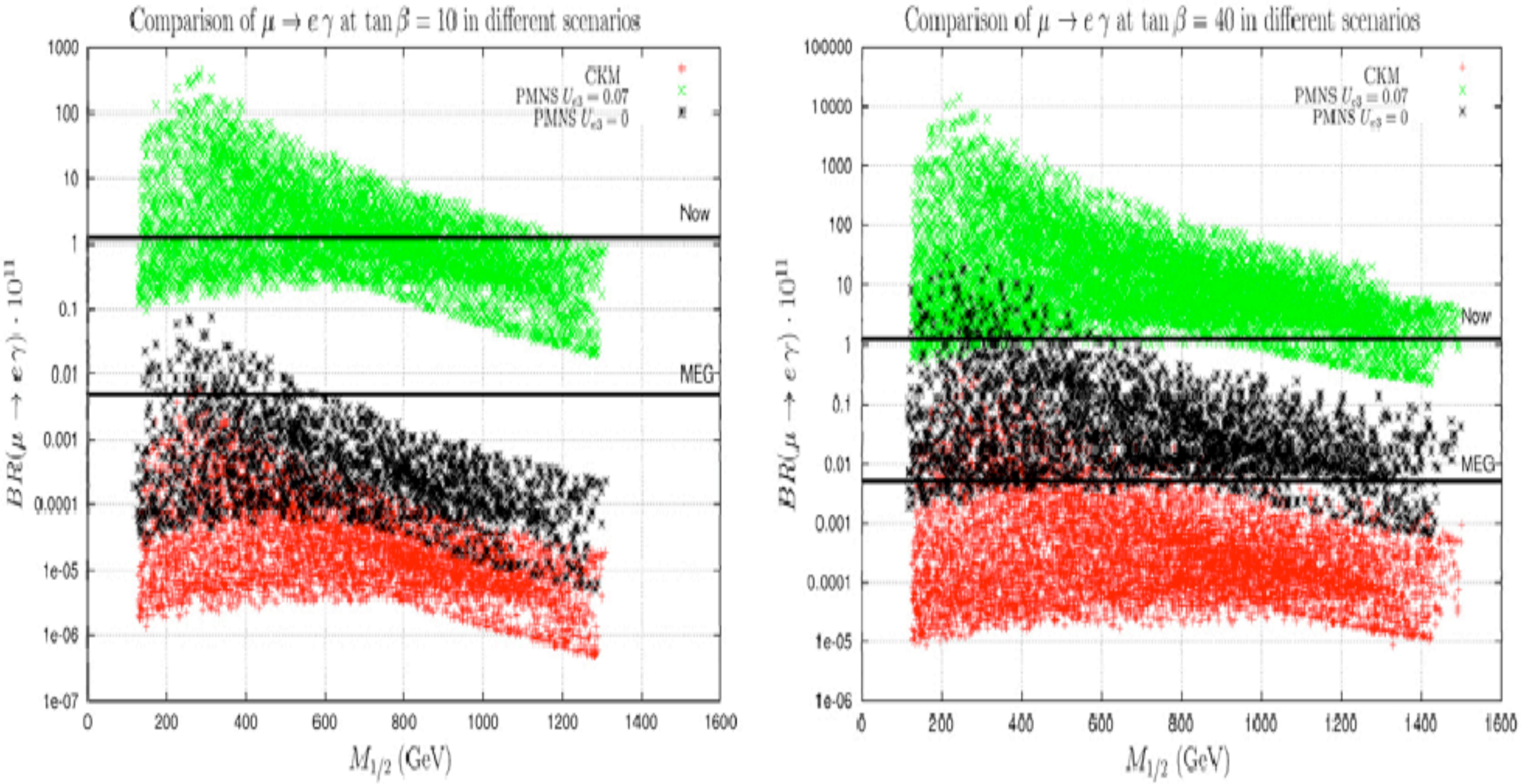
MEG POTENTIALITIES TO EXPLORE THE SUSY SEESAW PARAM. SPACE



CFMV

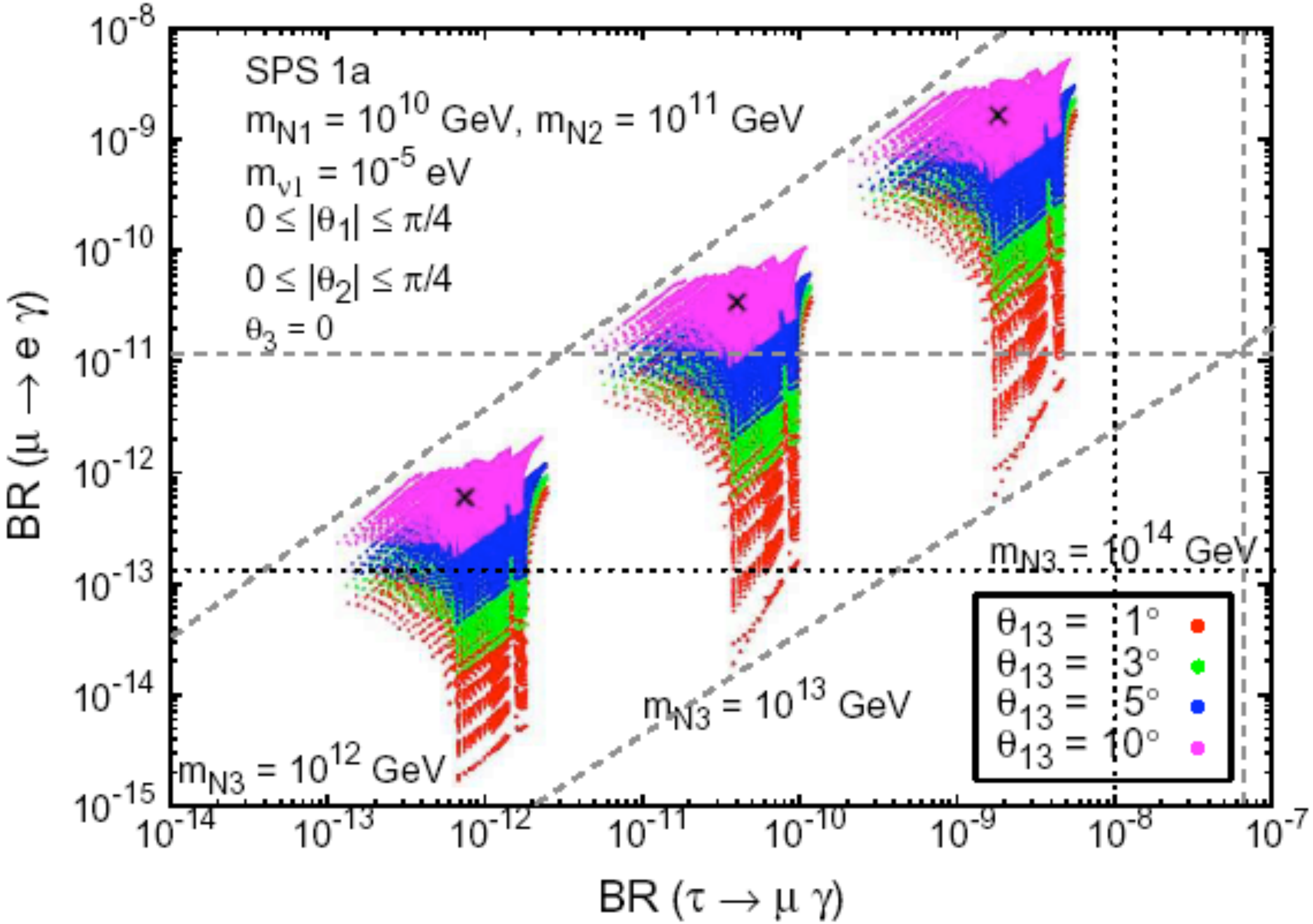
μ → e+γ in SUSYGUT: past and future

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

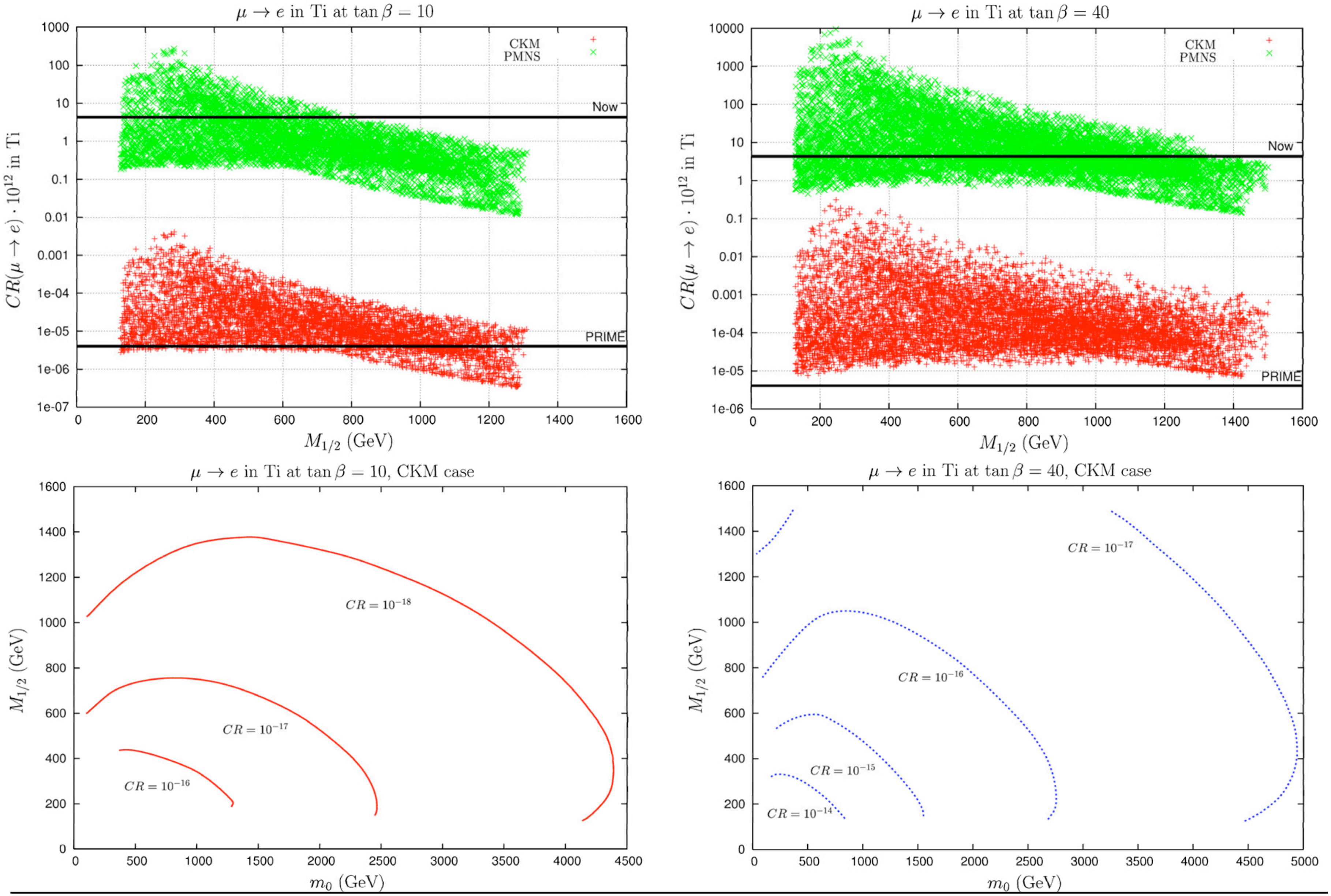


CFMV

Antusch, Arganda, Herrero, Teixeira



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



LFV ⟷ LHC SENSITIVITIES IN PROBING THE SUSY PARAM. SPACE

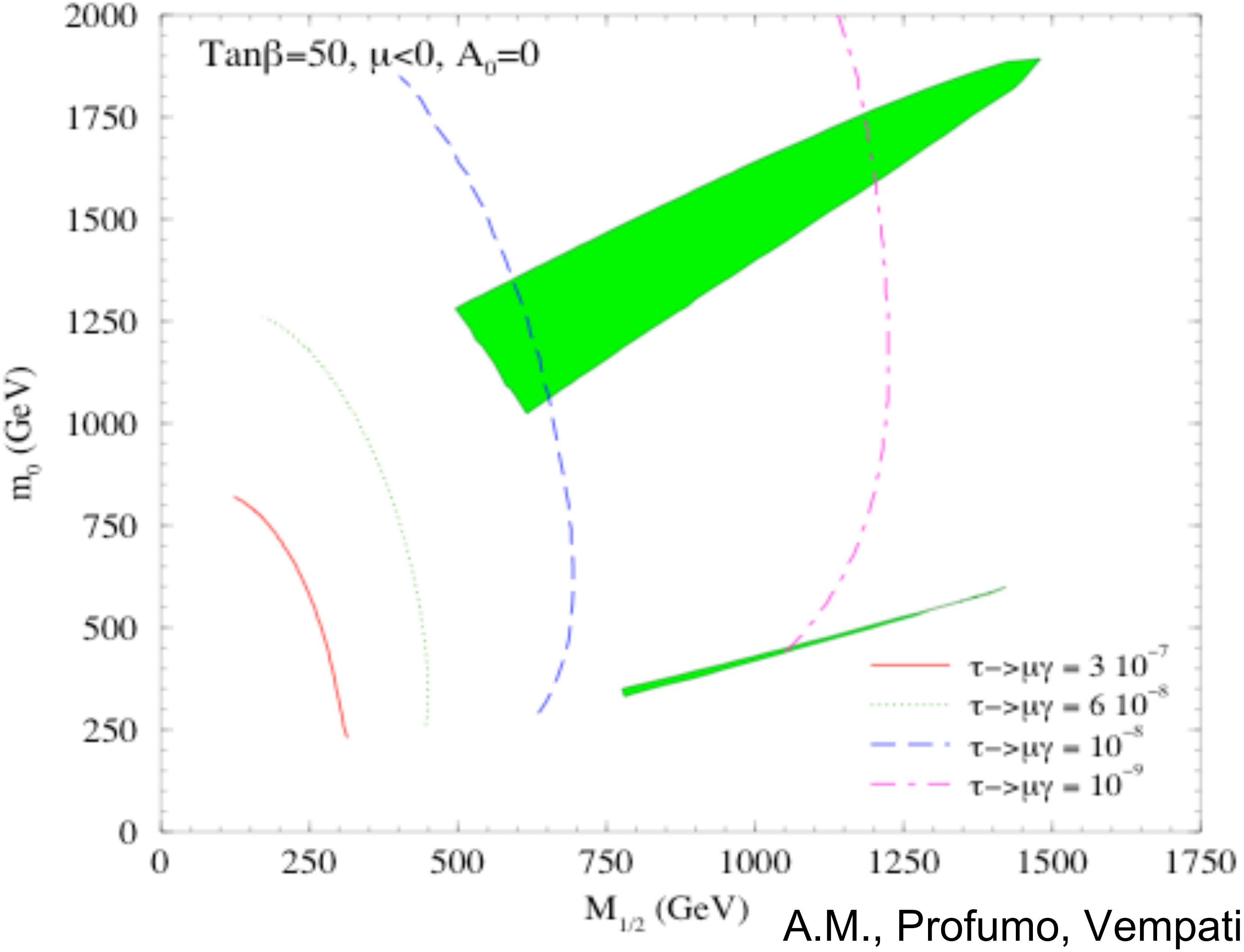
TABLE IX: Reach in $(m_0, m_{\tilde{g}})$ of the present and planned experiment from their $\tau \to \mu\gamma$ sensitivity.

	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

CFMV

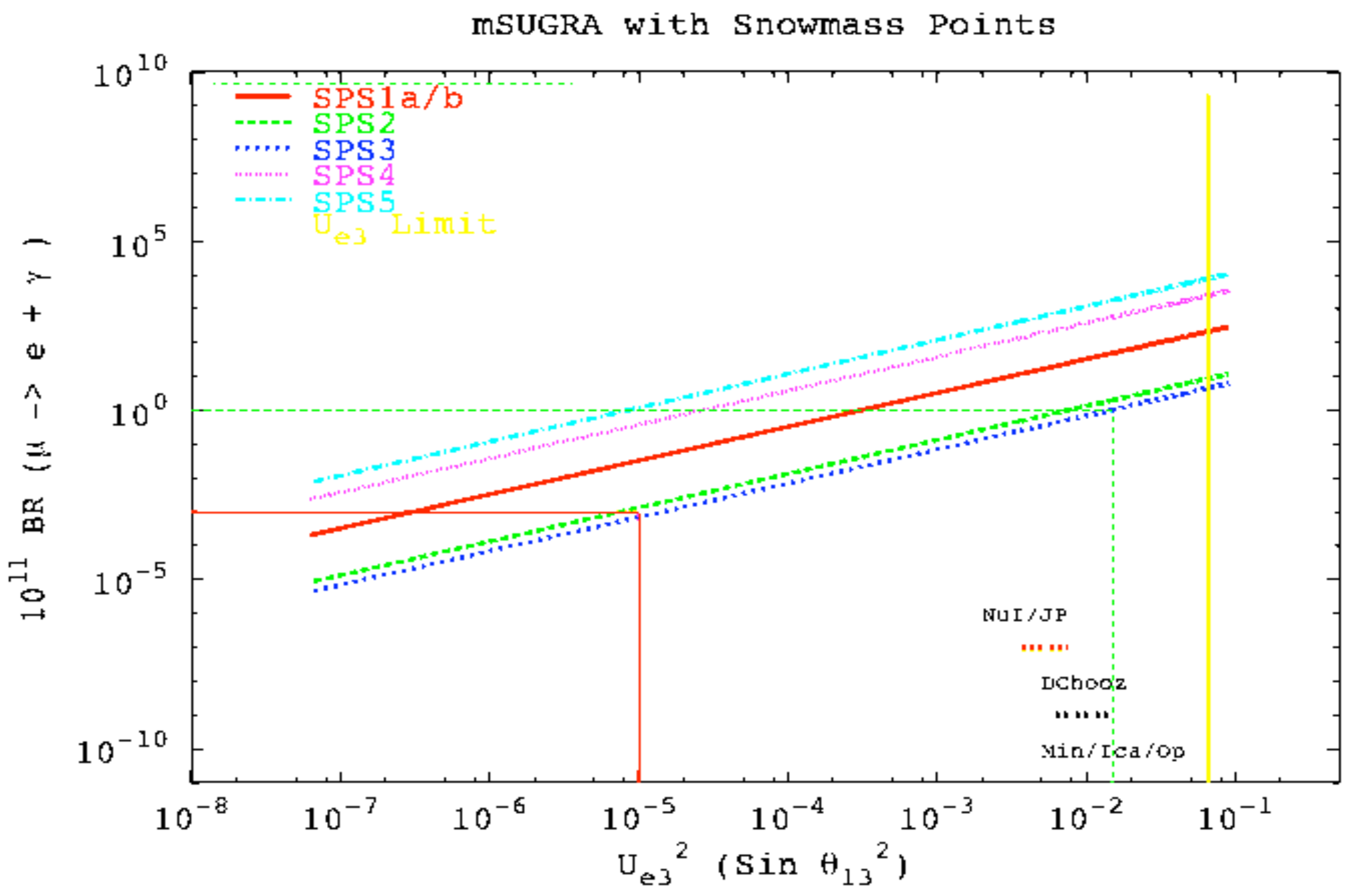
LFV - DM CONSTRAINTS IN MINIMAL SUPERGRAVITY



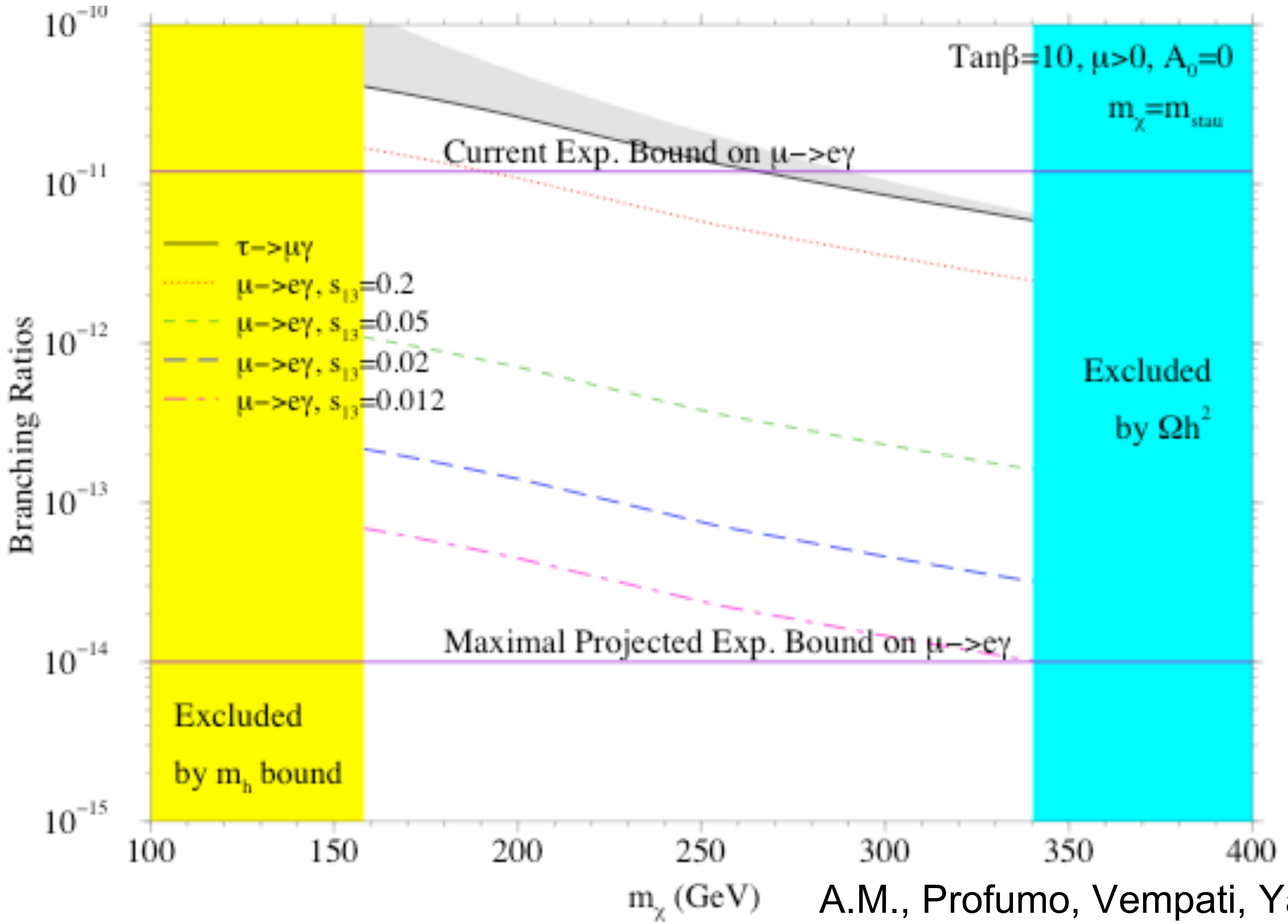
A.M., Profumo, Vempati, Yaguna

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

A.M.. Vempati. Vives



PROBING SUSY THROUGH LFV



A.M., Profumo, Vempati, Yaguna

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

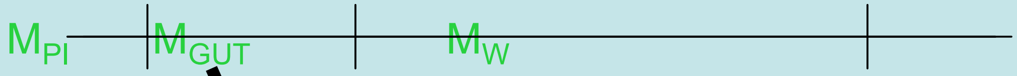
In SU(5) $d_R \longleftrightarrow l_L$ connection in the 5-plet
Large $(\Delta^l_{23})_{LL}$ induced by large f_ν of $O(f_{top})$
is accompanied by large $(\Delta^d_{23})_{RR}$

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



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

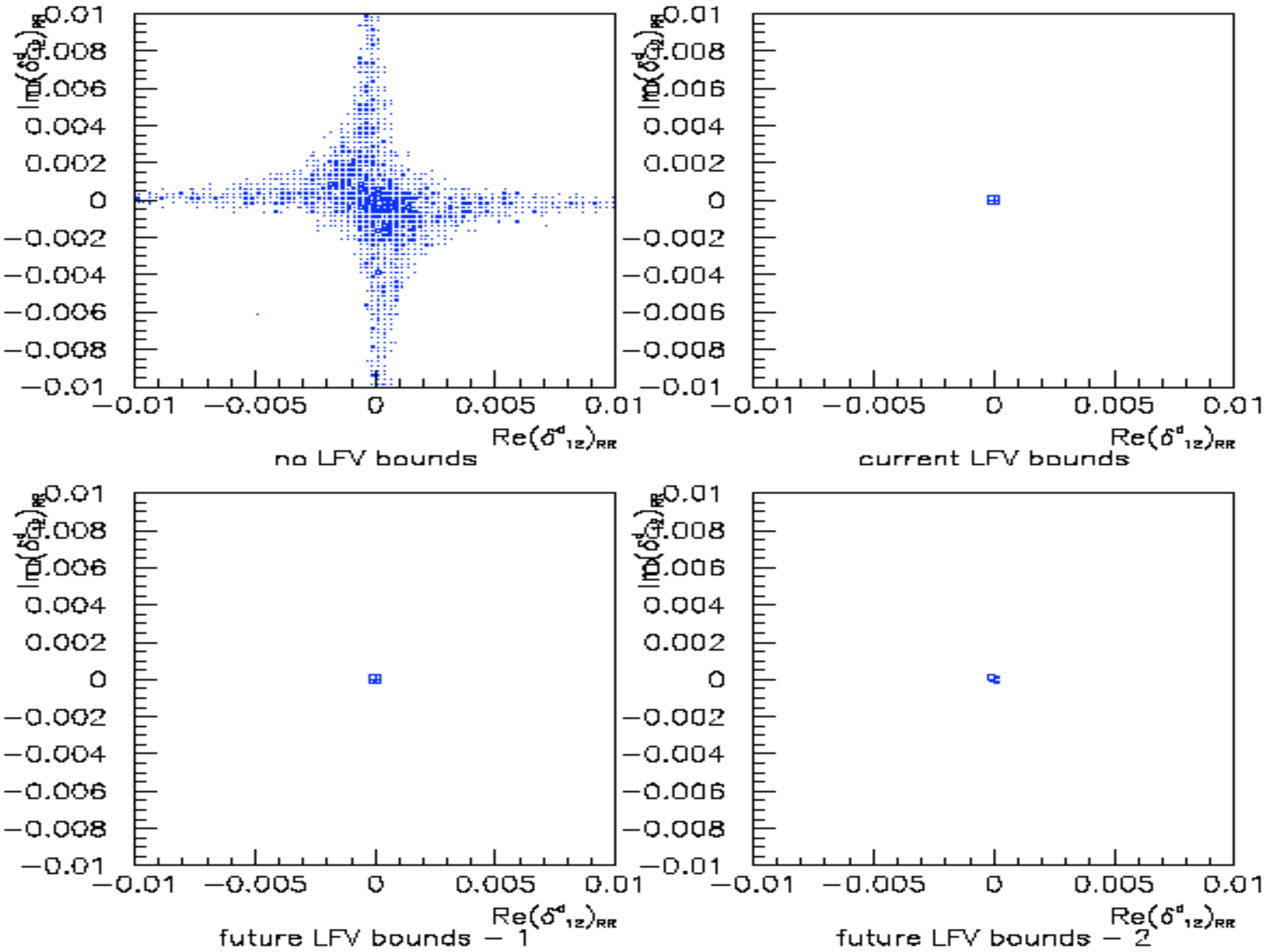
constraints on δ^{quark} from LFV and
constraints on δ^{lepton} from hadronic FCNC

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

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

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

CMPSVV



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:

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

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

HIGGS-MEDIATED LFV COUPLINGS

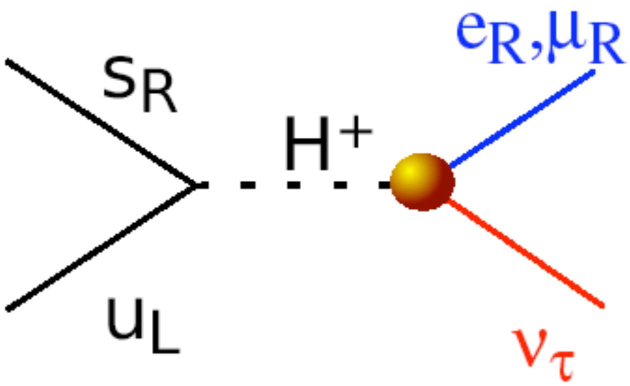
- When non-holomorphic terms are generated by loop effects (HRS corrections)
- And a source of LFV among the sleptons is present
- → Higgs-mediated (radiatively induced) H-lepton-lepton LFV couplings arise

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

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



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

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

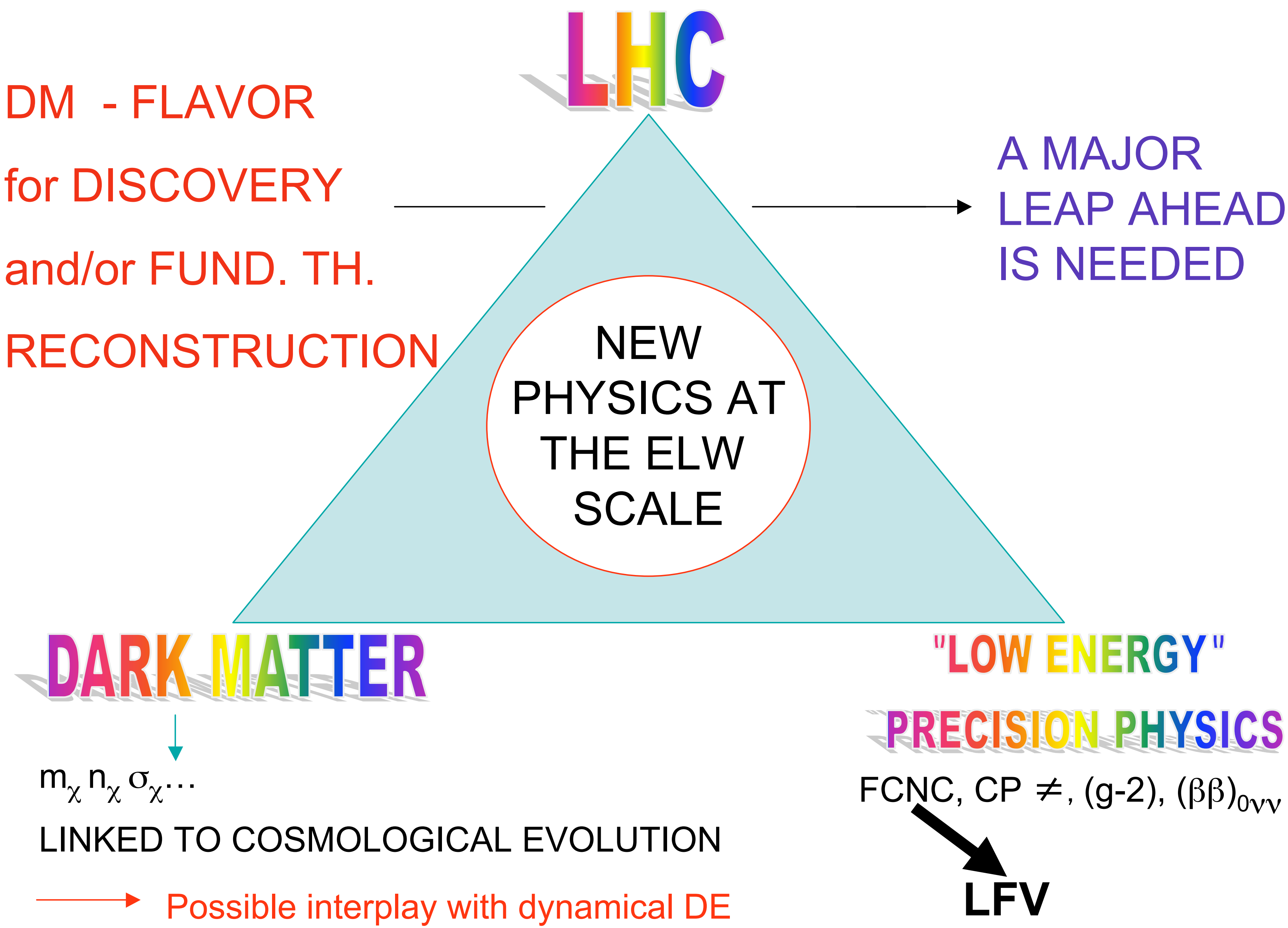
$$\Delta_R^{31} \sim 5 \cdot 10^{-4} \quad t_\beta = 40 \quad M_{H^\pm} = 500\mathrm{GeV}$$

$$\Downarrow$$

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

Extension to B ⟶ lν deviation from universality

Isidori, Paradisi


LHC
DM - FLAVOR
for DISCOVERY
and/or FUND. TH.
RECONSTRUCTION
A MAJOR
LEAP AHEAD
IS NEEDED
NEW
PHYSICS AT
THE ELW
SCALE
DARK MATTER
m_χ n_χ σ_χ…
LINKED TO COSMOLOGICAL EVOLUTION
Possible interplay with dynamical DE
"LOW ENERGY"
PRECISION PHYSICS
FCNC, CP $\neq$, (g-2), $(\beta\beta)_{0\nu\nu}$
LFV