Pontecorvo100, Pisa, Sept. 18 – 20, 2013

LEPTON FLAVOR VIOLATION

Antonio Masiero

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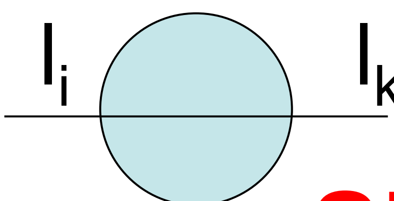
LFV

- Lepton Flavor numbers, i.e. L_e, L_μ, L_τ, are largely violated in ν oscillations (large ν mixing angles)
- But charged LFV (cLFV) has never been observed (BR(μ → eγ) < 5.7×10^{-13})
- Extreme smallness of LFV in the charged lepton sector of the SM with massive neutrinos:



l_i l_k suppressed by $(m_{\nu_i}^2 - m_{\nu_k}^2) / M_W^2$

SM → cLFV never to be seen

Present “Observational” Evidence for New Physics Beyond the SM

- **NEUTRINO MASSES** ☆☆☆
- **DARK MATTER** ☆☆☆
- **MATTER-ANTIMATTER ASYMMETRY** ☆☆
- **INFLATION** ☆
- **DARK ENERGY (?)**

Aesthetical reasons to go BSM

NATURALNESS :

- Electroweak scale (M_H) stabilization ($M_P - M_W$ energy scale hierarchy)
- Cosmological constant problem ($M_P^4 - \Lambda^4$ energy scale hierarchy with $\Lambda = 10^{-3}$ eV)
- θ – QCD problem (smallness of CPV in strong interactions

UNIFICATION of strong and electroweak interactions; inclusion of gravity?

FLAVOR number of fermion generations; fermionic masses and mixing angles

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**

LFV ⟺ PHYSICS BSM

- LFV ⟺ NEUTRINO MASSES
- LFV ⟺ MATTER-ANTIMATTER ASYMMETRY
- LFV ⟺ GAUGE UNIFICATION
- LFV ⟺ GAUGE HIERARCHY PROBLEM

THE FATE OF LEPTON NUMBER

L VIOLATED → υ Majorana ferm.

L CONSERVED → υ Dirac ferm. (dull option)

$h\,\bar{\upsilon}_L H\,\upsilon_R \rightarrow m_\upsilon = h\,\langle H\rangle$ $\quad M_\upsilon < 5$ eV $\rightarrow h < 10^{-11}$

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

SMALLNESS of m_υ

↓

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

$M\upsilon_R\,\upsilon_R + h\,\bar{\upsilon}_L\,\bar{\phi}\,\upsilon_R$

	υ_L	υ_R
υ_L	~O	$h\,\langle\phi\rangle$
υ_R	$h\,\langle\phi\rangle$	M

LR Models?

MAJORON MODELS

Gelmini, Roncadelli

↓

Δ ENLARGEMENT OF THE HIGGS SCALAR SECTOR

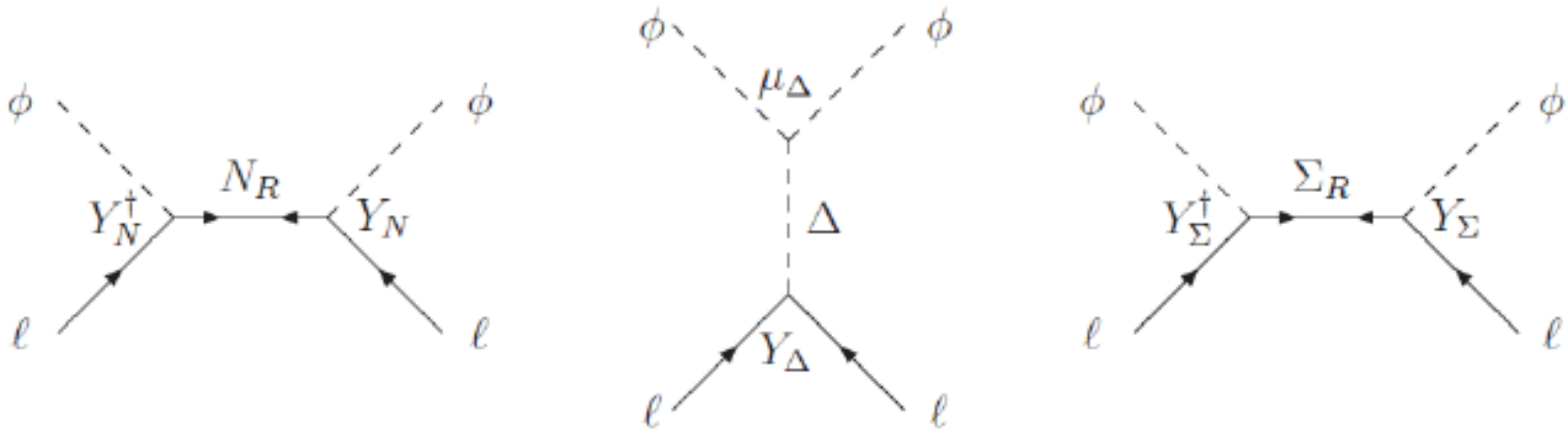
$h\,\upsilon_L\,\upsilon_L\,\Delta$

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

N.B.: EXCLUDED BY LEP!

ν MASSES THROUGH A SEESAW MECHAMISM

Tree level generation of the neutrino mass operator $\frac{1}{2} c^{d=5}_{\alpha\beta} \left(\overline{\ell^c_{L\alpha}} \tilde{\phi}^*\right) \left(\tilde{\phi}^\dagger \ell_{L\beta}\right)$:



Type I	Type II	Type III
Heavy fermionic singlets (RH neutrinos)	Heavy scalar triplet	Heavy fermionic triplets
Minkowski, Gell-Mann, Ramond, Slansky, Yanagida, Glashow, Mohapatra, Senjanovic, ...	Magg, Wetterich, Lazarides, Shafi, Mohapatra, Senjanovic, Schecter, Valle, ...	Foot, Lew, He, Joshi, Ma, Roy, Hambye et al., Bajc et al., Dorsner, Fileviez-Perez, ...

L. CALIBBI, NuFact 2012

SM FAILS TO GIVE RISE TO A SUITABLE COSMIC MATTER-ANTIMATTER ASYMMETRY

:

- **NOT ENOUGH CP VIOLATION IN THE SM**

NEED FOR ***NEW SOURCES OF CPV IN ADDITION TO THE PHASE PRESENT IN THE CKM MIXING MATRIX***

- FOR M_{HIGGS} > 80 GeV THE ELW. PHASE TRANSITION OF THE SM IS A SMOOTH CROSSOVER

NEED *NEW PHYSICS BEYOND SM*. IN PARTICULAR, FASCINATING POSSIBILITY: THE ENTIRE MATTER IN THE UNIVERSE ORIGINATES FROM THE SAME MECHANISM RESPONSIBLE FOR THE EXTREME SMALLNESS OF NEUTRINO MASSES

MATTER-ANTIMATTER ASYMMETRY ⟷ NEUTRINO MASSES CONNECTION: BARYOGENESIS THROUGH LEPTOGENESIS

- Key-ingredient of the SEE-SAW mechanism for neutrino masses: **large Majorana mass for RIGHT-HANDED neutrino**
- In the early Universe the heavy RH neutrino decays with Lepton Number violatiion; if these decays are accompanied by a new source of CP violation in the leptonic sector, then

→ it is possible to create a lepton-antilepton asymmetry at the moment RH neutrinos decay. Since SM interactions preserve Baryon and Lepton numbers at all orders in perturbation theory, but violate them at the quantum level, such **LEPTON ASYMMETRY** can be converted by these purely quantum effects into a BARYON-ANTIBARYON ASYMMETRY (**Fukugita-Yanagida mechanism for leptogenesis**)

LFV and GAUGE UNIF.

- **B**, **L** (possibly also B – L) violating operators → new sorces of LFV
- **Hadronic – Leptonic "unification"** (quarks and leptons sit in the same gauge group representations) → possible **link between hadronic and leptonic flavor patterns**
- **New particles carrying Lepton (Flavor) numbers**

LFV and the Gauge Hierarchy Problem

- **New particles at the electroweak scale** (to guarantee a "natural" UV completion of the SM)
- Some of these **new particles can carry LF** numbers
- **New TeV particles** (in addition to the light neutrinos) **in the LFV loops**

LFV IN SUSY SEE-SAW

SEE- SAW (type 1)

New source of (leptonic) flavor:

YUKAWA COUPLINGS OF THE NEUTRINO DIRAC MASS CONTRIBUTIONS, i.e. **THE YUKAWAs** of the **HIGGS couplings to the LETF- and RIGHT – HANDED NEUTRINOS**

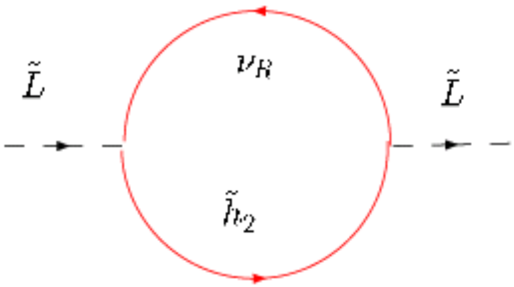
LOW-ENERGY SUSY

The scalar lepton masses through their running bring memory of those new sources of leptonic flavor at the TeV scale, i.e. at energies much below the (Majorana) mass of the RH neutrinos

<u>SUSY SEESAW</u>: *Flavor universal SUSY breaking and yet* ***large lepton flavor violation***

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

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



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

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

LFV in SUSY seesaw

L. Calibbi, NuFact 2012

In SUSY, new fields interacting with the MSSM fields enter the radiative corrections of the sfermion masses

Hall Kostelecky Raby '86

⇨ This applies to the new seesaw interactions: generically induce LFV in the slepton mass matrix!

Borzumati Masiero '86

Type I

$$(\tilde{m}_L^2)_{ij} \propto m_0^2 \sum_k (\mathbf{Y}_N^*)_{ki} (\mathbf{Y}_N)_{kj} \ln\left(\frac{M_X}{M_{R_K}}\right)$$

Borzumati Masiero '86

Type II

$$(\tilde{m}_L^2)_{ij} \propto m_0^2 (\mathbf{Y}_\Delta{}^\dagger \mathbf{Y}_\Delta)_{ij} \ln\left(\frac{M_X}{M_\Delta}\right) \propto m_0^2 (\mathbf{m}_\nu{}^\dagger \mathbf{m}_\nu)_{ij} \ln\left(\frac{M_X}{M_\Delta}\right)$$

$$U \hat{\mathbf{m}}_\nu^2 U^\dagger$$

A. Rossi '02; Rossi Joaquim '06

Type III

Similar to type I

Biggio LC '10; Esteves et al. '10

Thorough analysis of LFV in these 3 kinds of Seesaw in the SUSY context

M. HIRSCH, F. JOAQUIM, A. VICENTE arXiv: 1207.6635 [hep-ph]

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

THE STRONG ENHANCEMENT OF LFV IN SUSY SEESAW MODELS CAN OCCUR

EVEN IF THE MECHANISM RESPONSIBLE FOR SUSY BREAKING IS ABSOLUTELY FLAVOR BLIND

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 <u>LFV</u>

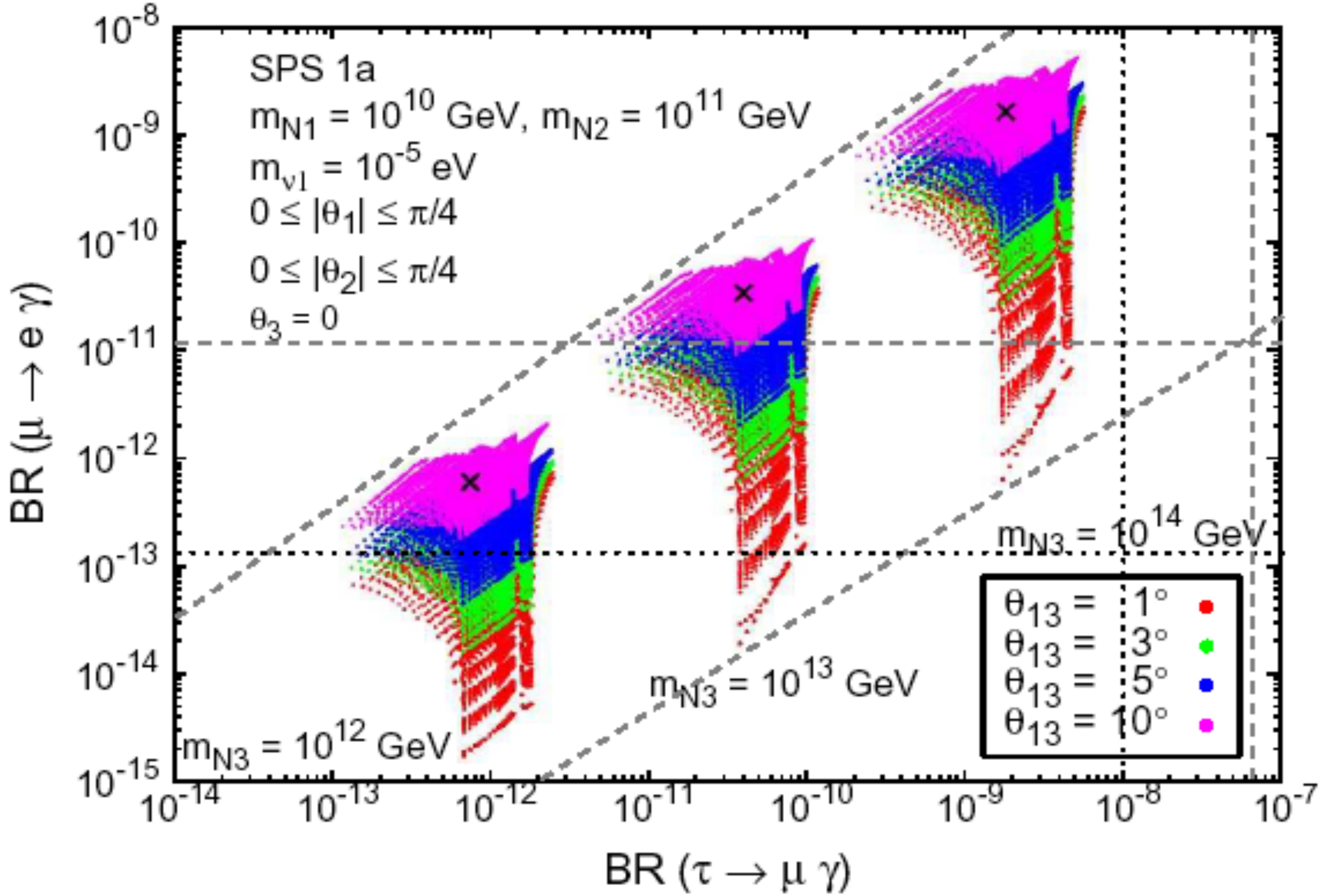
Barbieri, Hall; Barbieri, Hall, Strumia; Hisano, Nomura, Yanagida; Hisano, Moroi, Tobe Yamaguchi; Moroi;A.M.,, Vempati, Vives; Carvalho, Ellis, Gomez, Lola; Calibbi, Faccia, A.M, Vempati

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

τ $\mu\gamma$ 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

Antusch, Arganda, Herrero, Teixeira



IMPACT OF

HIGGS $124.5 \text{ GeV} \lesssim m_h \lesssim 126.5 \text{ GeV}$

LFV LIMITS $\mathrm{BR}(\mu \to e + \gamma) < 2.4 \times 10^{-12} \ (90\% \ \mathrm{CL})$.

θ_{13}

$$\sin^2 2\theta_{13} = 0.092 \pm 0.016(\text{stat.}) \pm 0.005(\text{syst.})$$

$$\sin^2 2\theta_{13} = 0.113 \pm 0.013(\text{stat.}) \pm 0.019(\text{syst.})$$

on SUSY GUTs where neutrinos get mass through the SEE-SAW MECHANISM

L. Calibbi, D. Chowdhury,A.M., K.M. Patel and S.K. Vempati arXiv:1207.7227v1 [hep-ph]

PARAMETER SPACE and CONSTRAINTS

$$m_0 \in [0,\ 5]\ \mathrm{TeV}$$

$$\Delta m_H \in \begin{cases} 0 & \text{for mSUGRA} \\ [0,\ 5] & \text{for NUHM1} \end{cases}$$

$$m_{1/2} \in [0.1,\ 2]\ \mathrm{TeV}$$

$$A_0 \in [-3m_0,\ +3m_0]$$

$$\mathrm{sgn}(\mu) \in \{-,+\}$$

$$121.5\ \mathrm{GeV} \leq m_h \ \leq\ 129.5\ \mathrm{GeV}$$

$$m_{\tilde{\chi}^\pm}\ (\text{lightest Chargino mass})\ \geq\ 103.5\ \mathrm{GeV}$$

$$\mathrm{BR}(B_s \to \mu^+\mu^-)\ <\ 4.5 \times 10^{-9}$$

$$2.85 \times 10^{-4} \leq \mathrm{BR}(b \to s\gamma) \leq\ 4.24 \times 10^{-4}$$

cLFV Searches: Current Situation

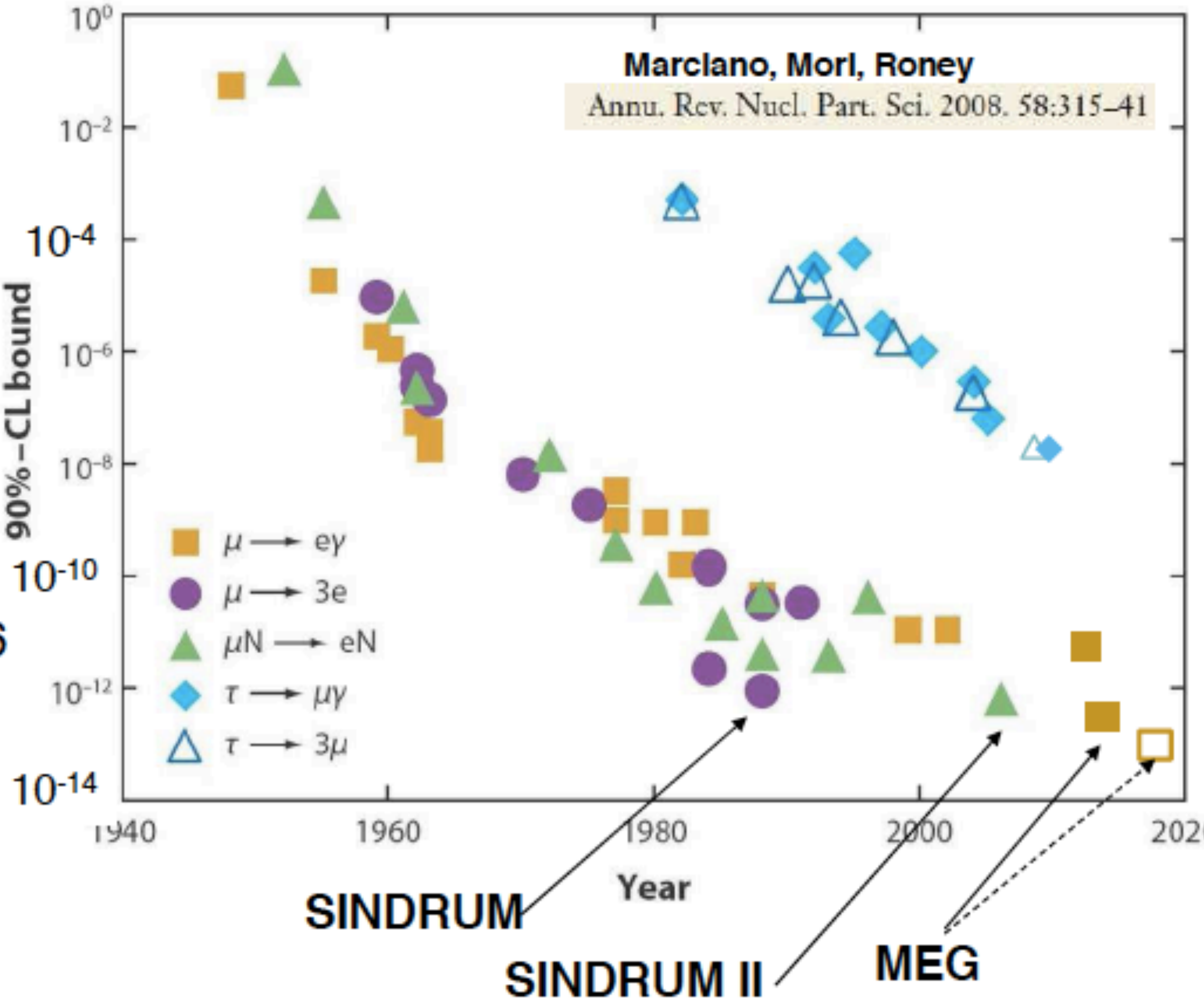
The present best limits on LFV come from PSI muon experiments

$\mu^+ \rightarrow e^+ee$
BR $< 1 \times 10^{-12}$
SINDRUM 1988

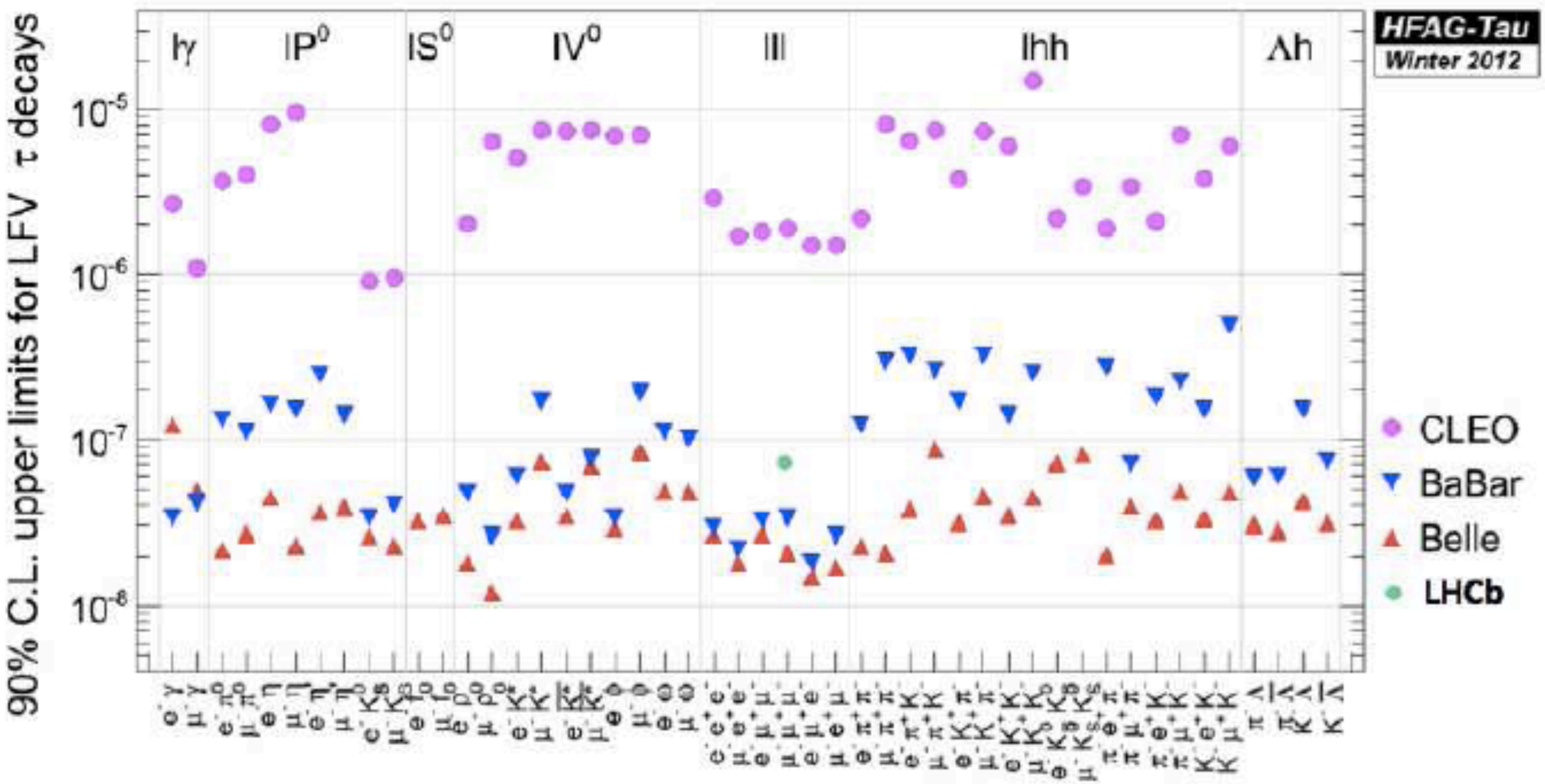
$\mu^- + Au \rightarrow e^- + Au$
BR $< 7 \times 10^{-13}$
SINDRUM II 2006

$\mu^+ \rightarrow e^+ + \gamma$
BR $< 5.7 \times 10^{-13}$
MEG 2013

[90 % C.L.]



Summary Belle τ LFV results

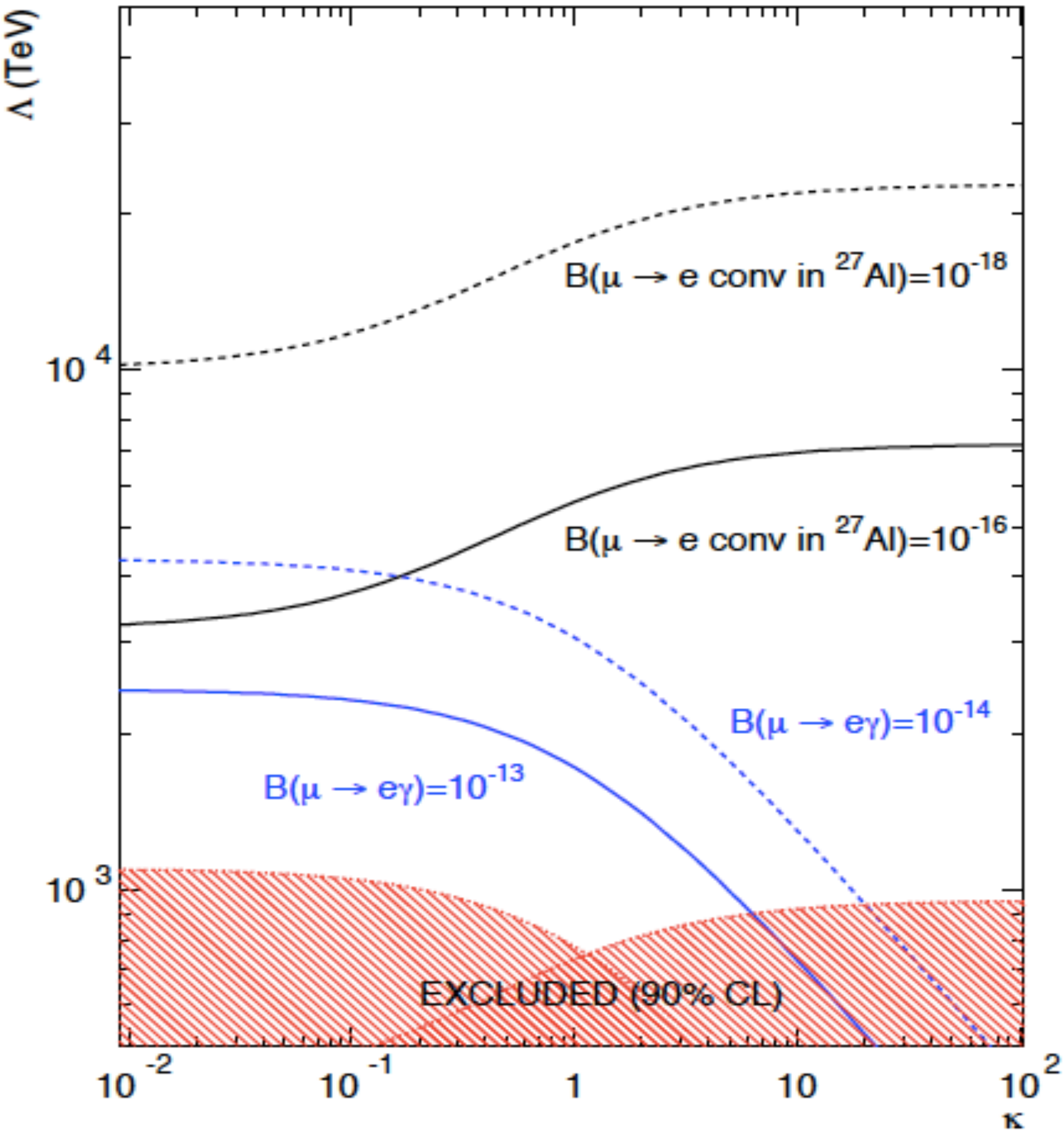


48 modes searched for, U.L.s around ~10^{-8}

Schwanda, Lecce, 2013

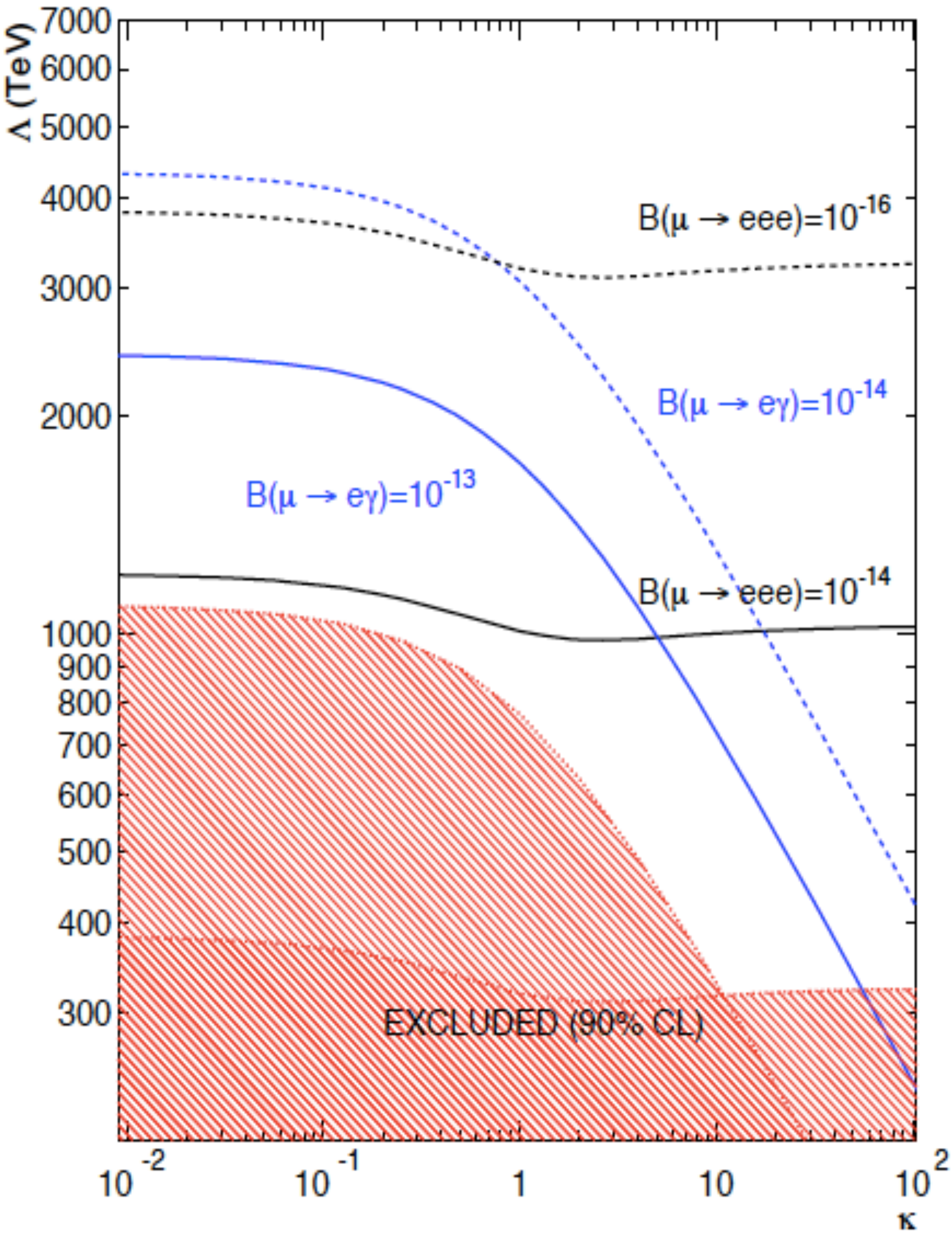
$$\mathcal{L}_{\rm CLFV} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R \sigma_{\mu\nu} e_L F^{\mu\nu} + h.c.$$

$$\frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L \gamma_\mu e_L \left(\bar{u}_L \gamma^\mu u_L + \bar{d}_L \gamma^\mu d_L\right) + h.c.\,.$$



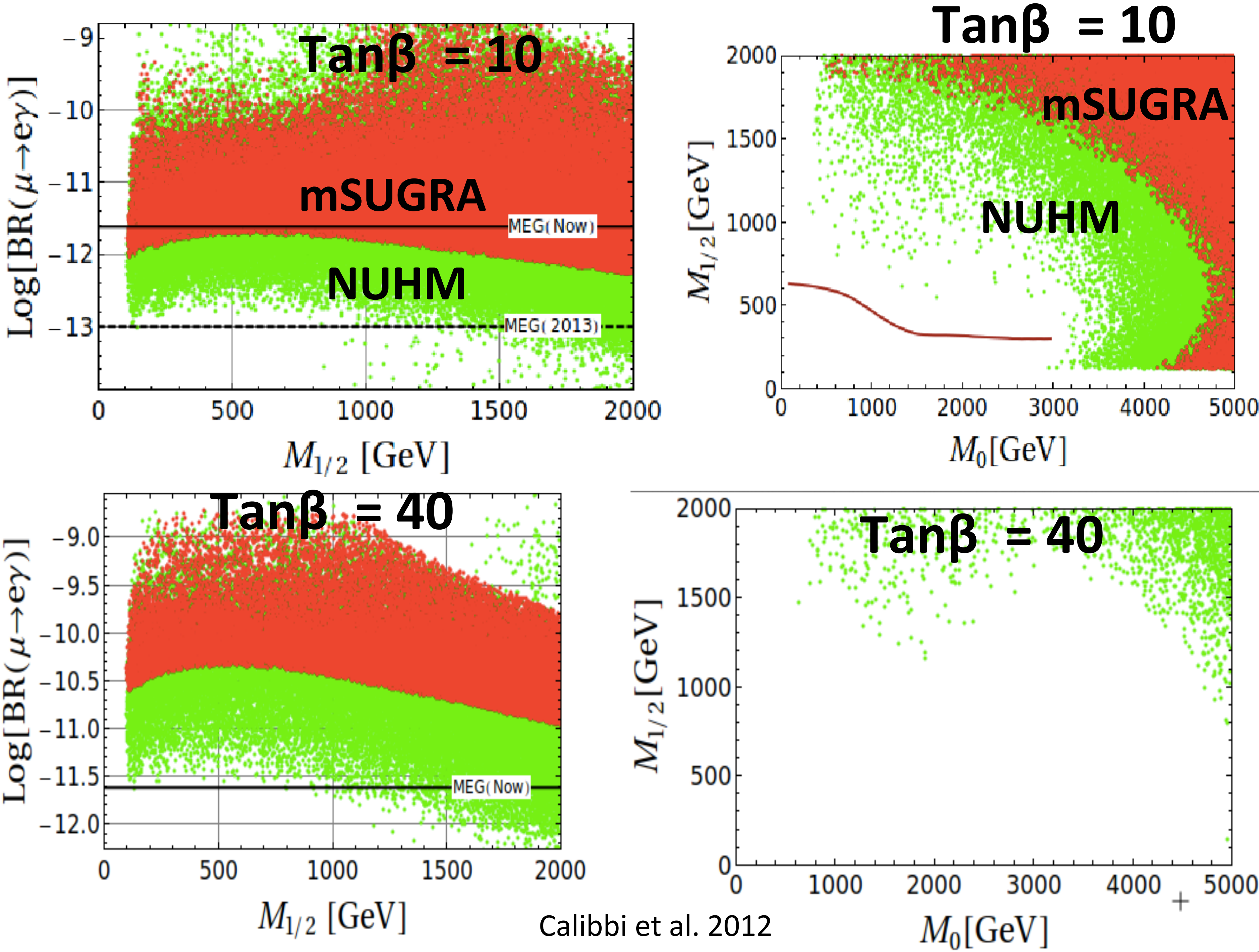
Sensitivity of μ – e conversion and μ → eγ to the New Physics scale Λ

de Gouvea, Vogel
arXIv:1303.4097



Sensitivity of $\mu - eee$ and $\mu \rightarrow e\gamma$ to the New Physics scale Λ

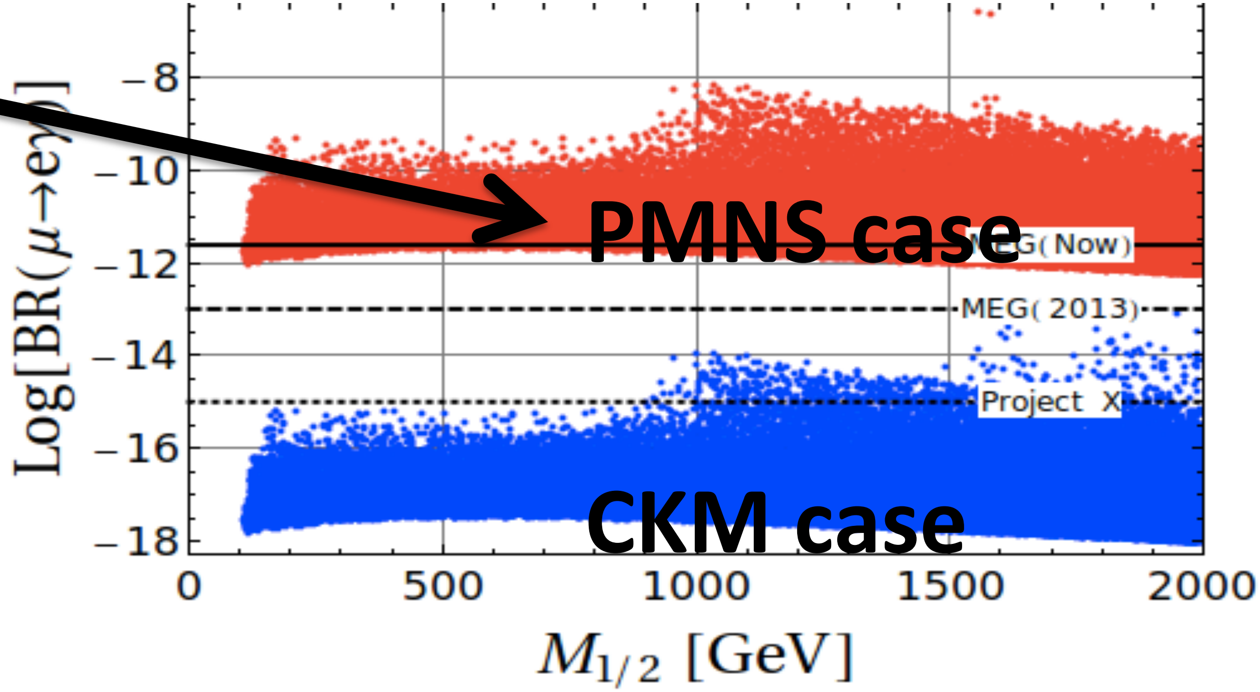
de Gouvea, Vogel
arXiv:1303.4097

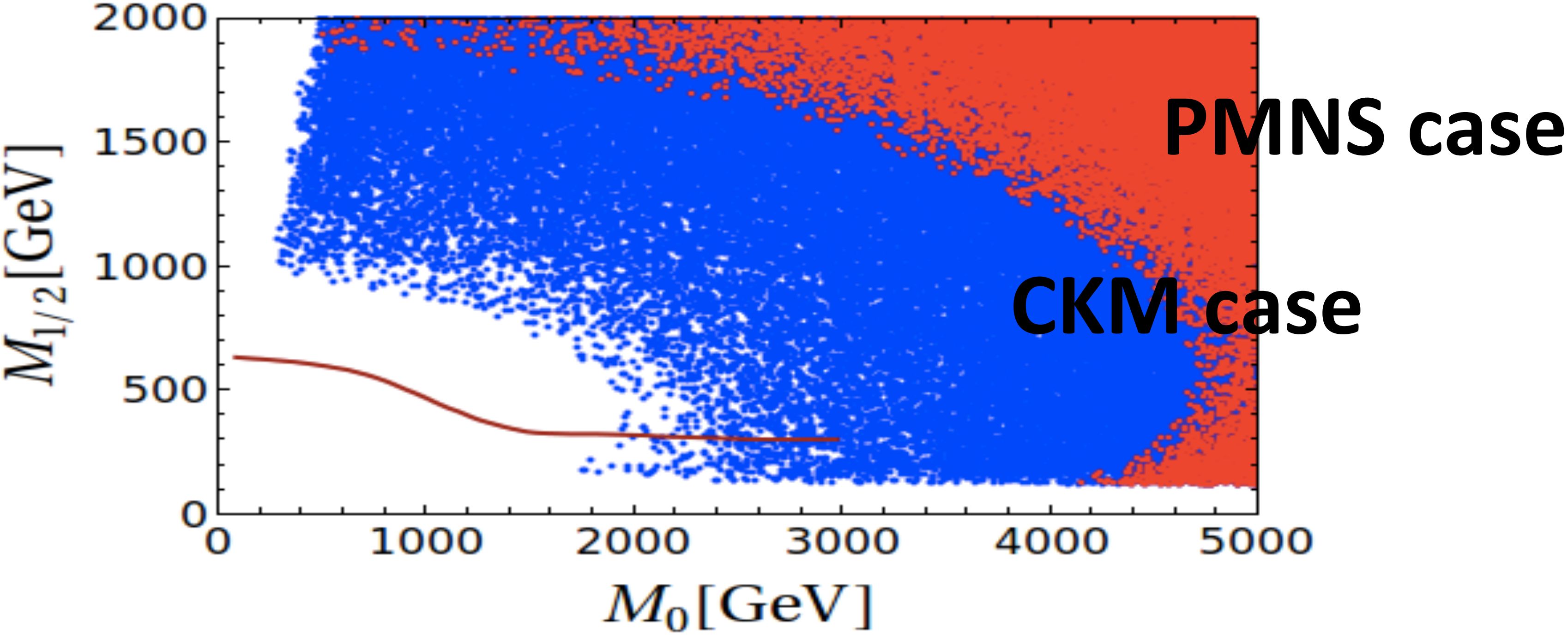


Calibbi et al. 2012

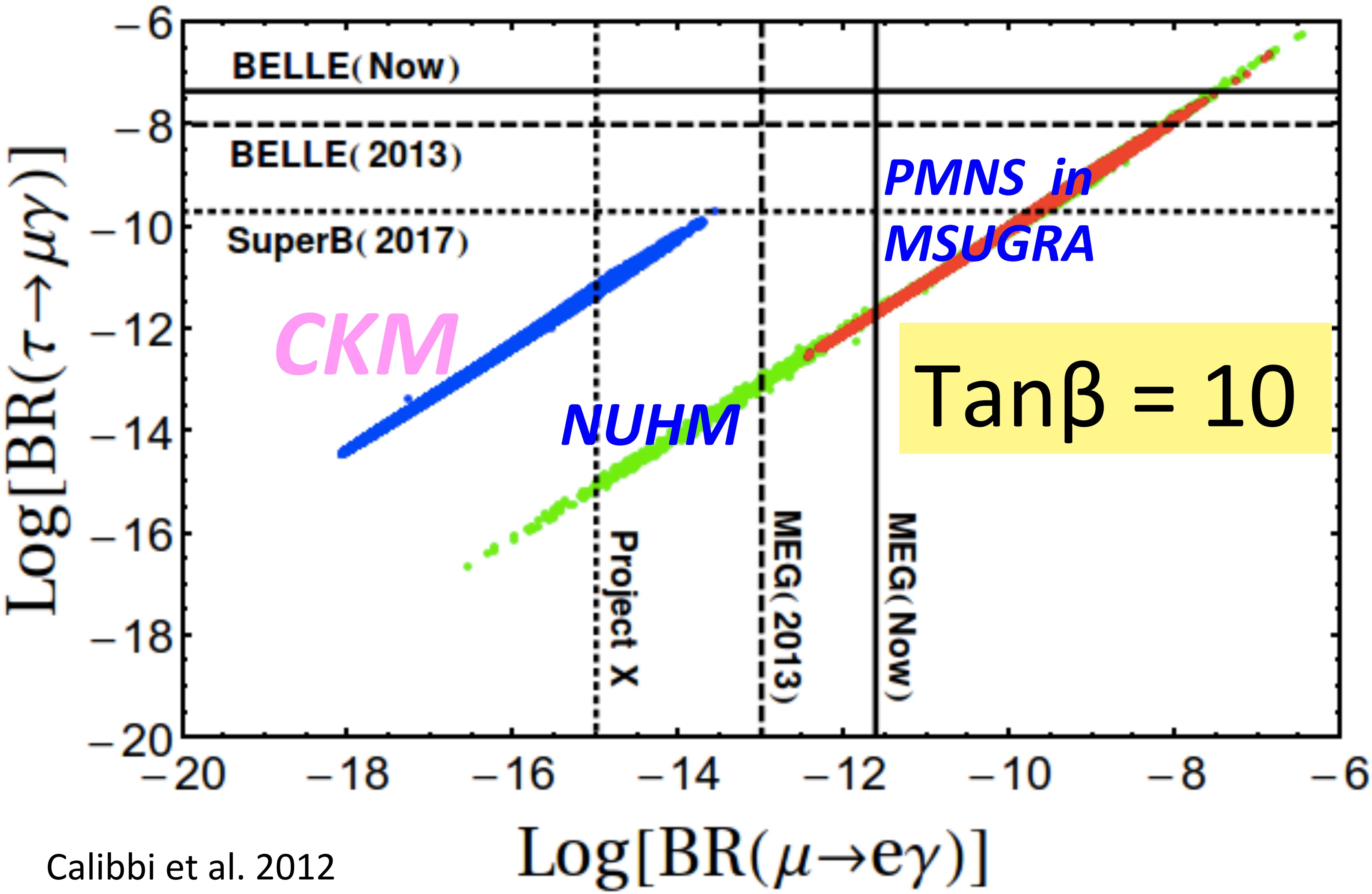
PMNS case in mSUGRA with tanβ = 10

Calibbi et al. 2012



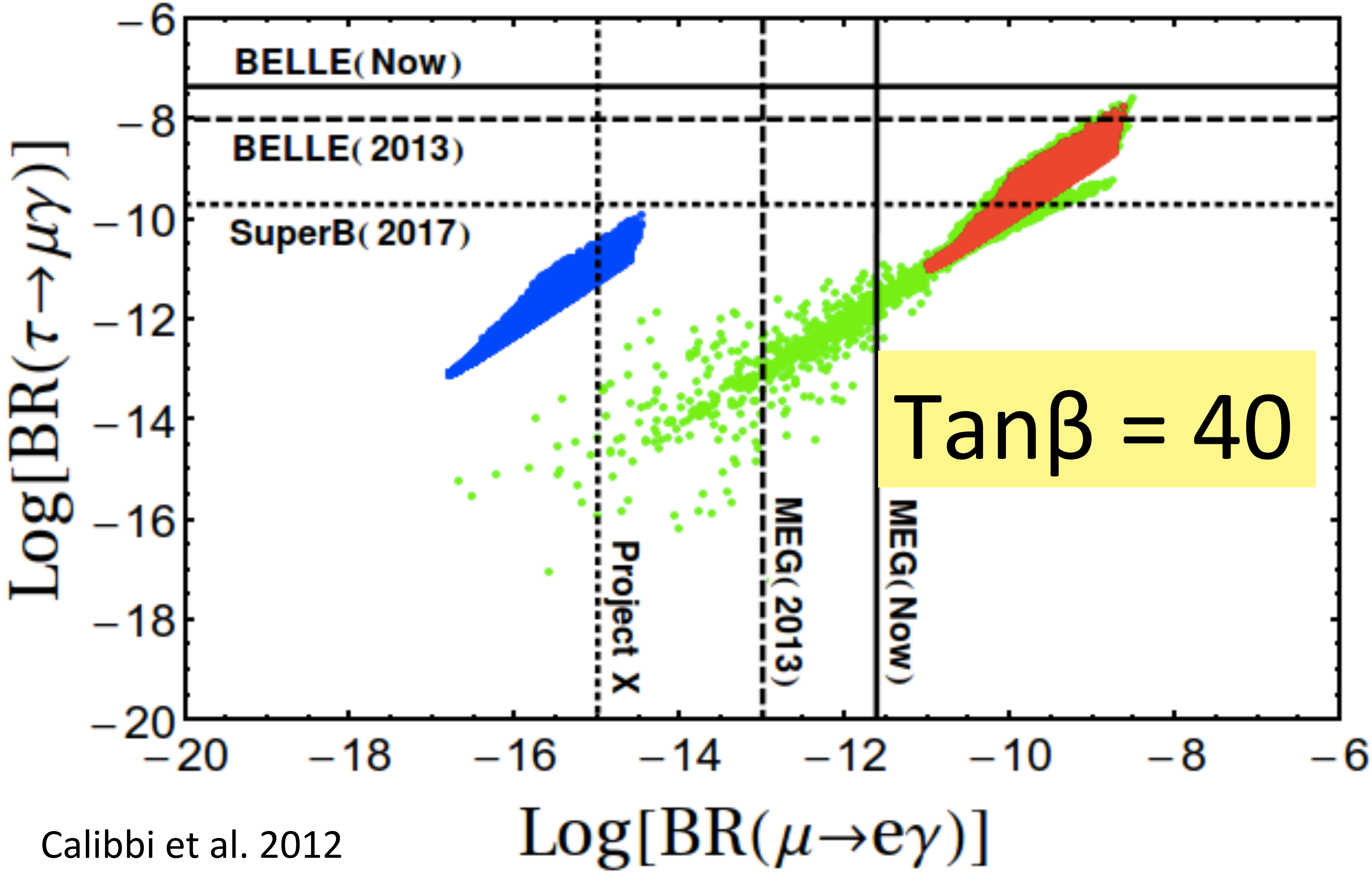


τ → μγ vs. μ → eγ sensitivities



Calibbi et al. 2012

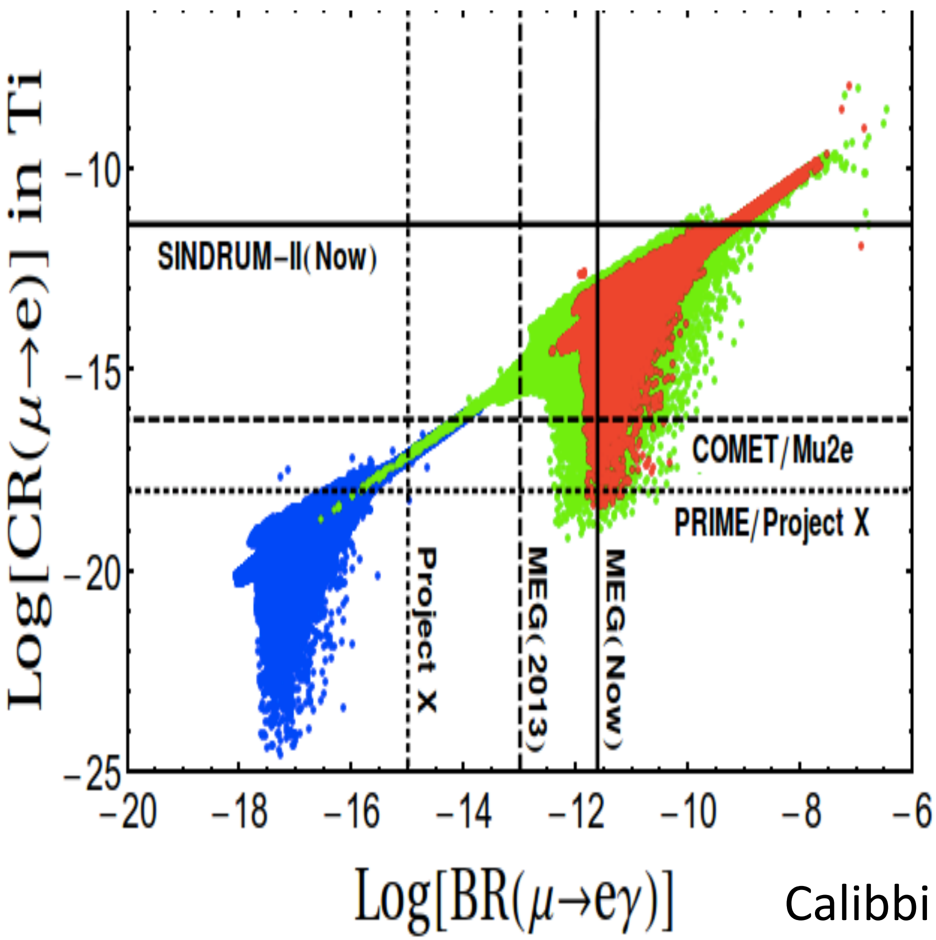
$\tau \to \mu\gamma$ vs. $\mu \to e\gamma$ sensitivities



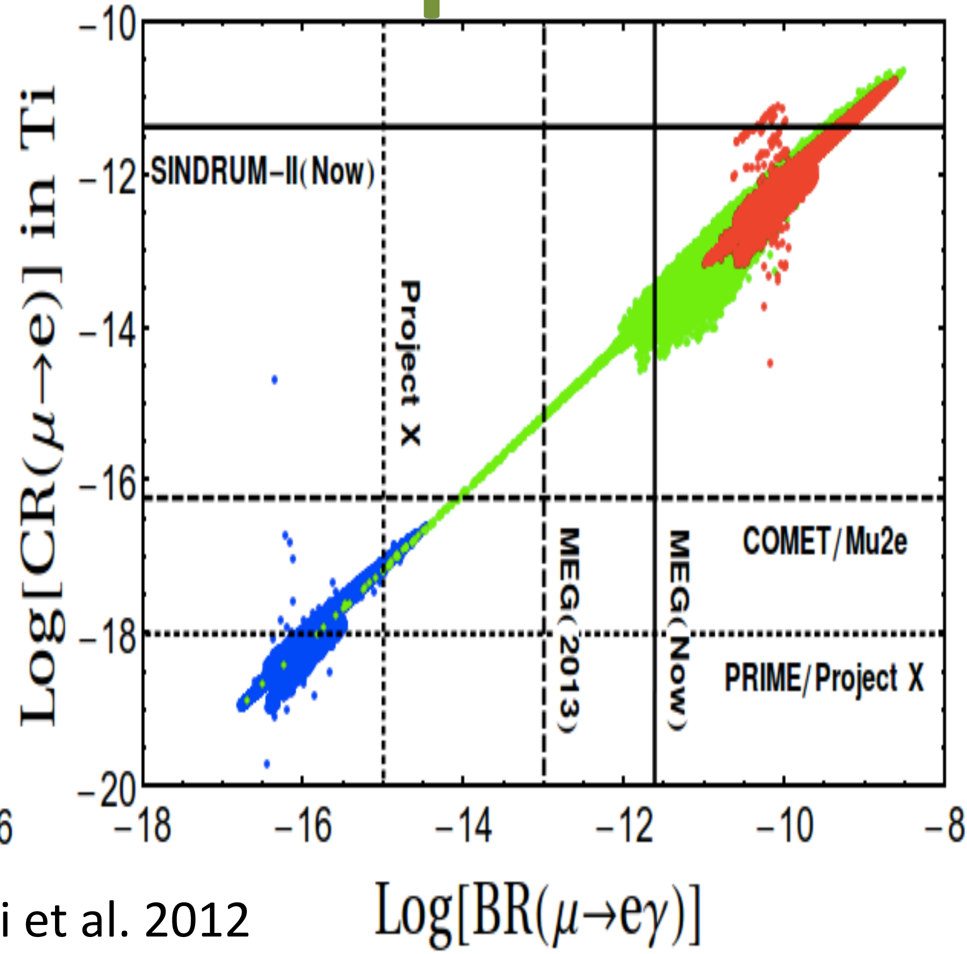
Calibbi et al. 2012

μ – e conversion vs μ → eγ

Tanβ = 10

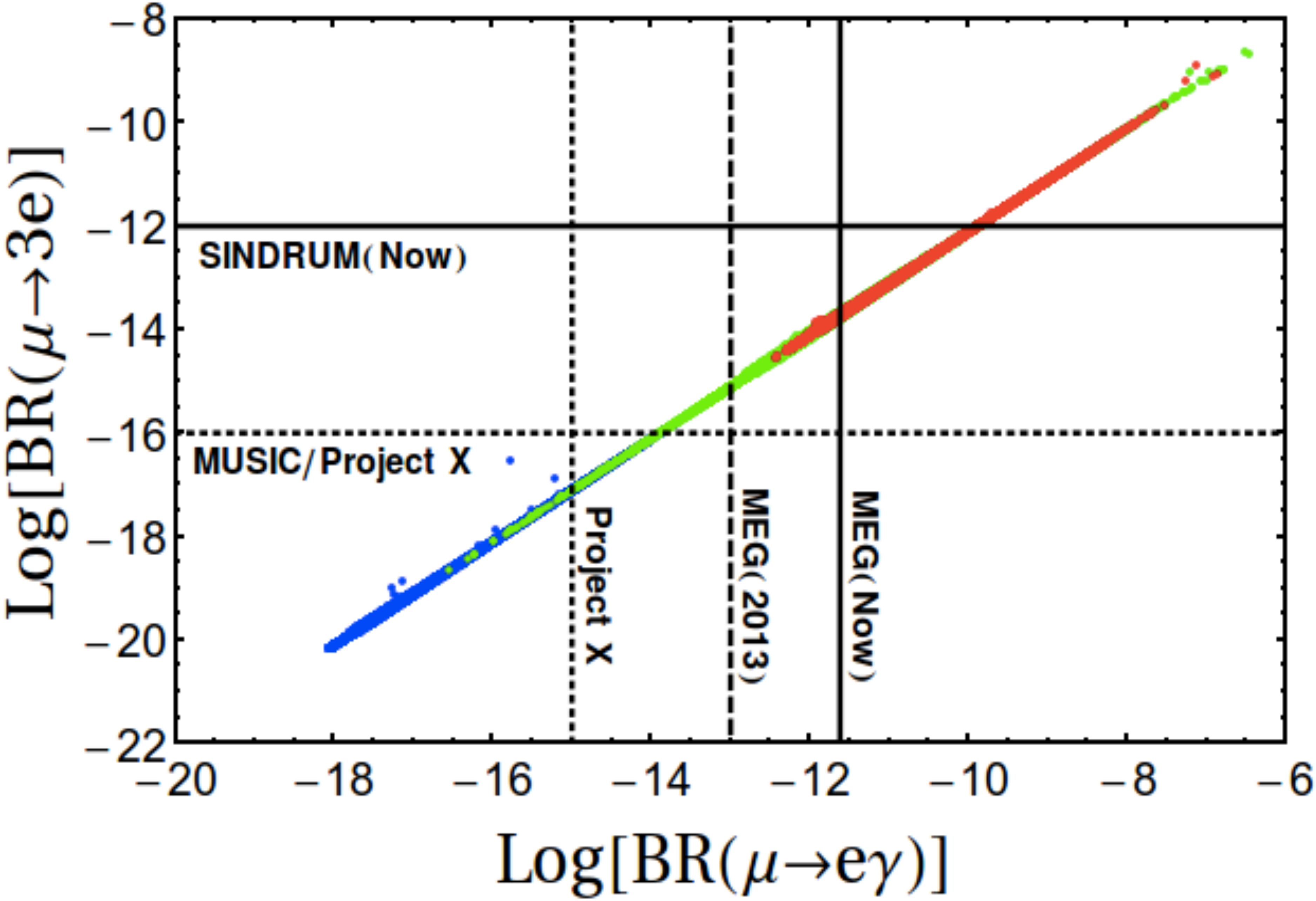


Tanβ = 40

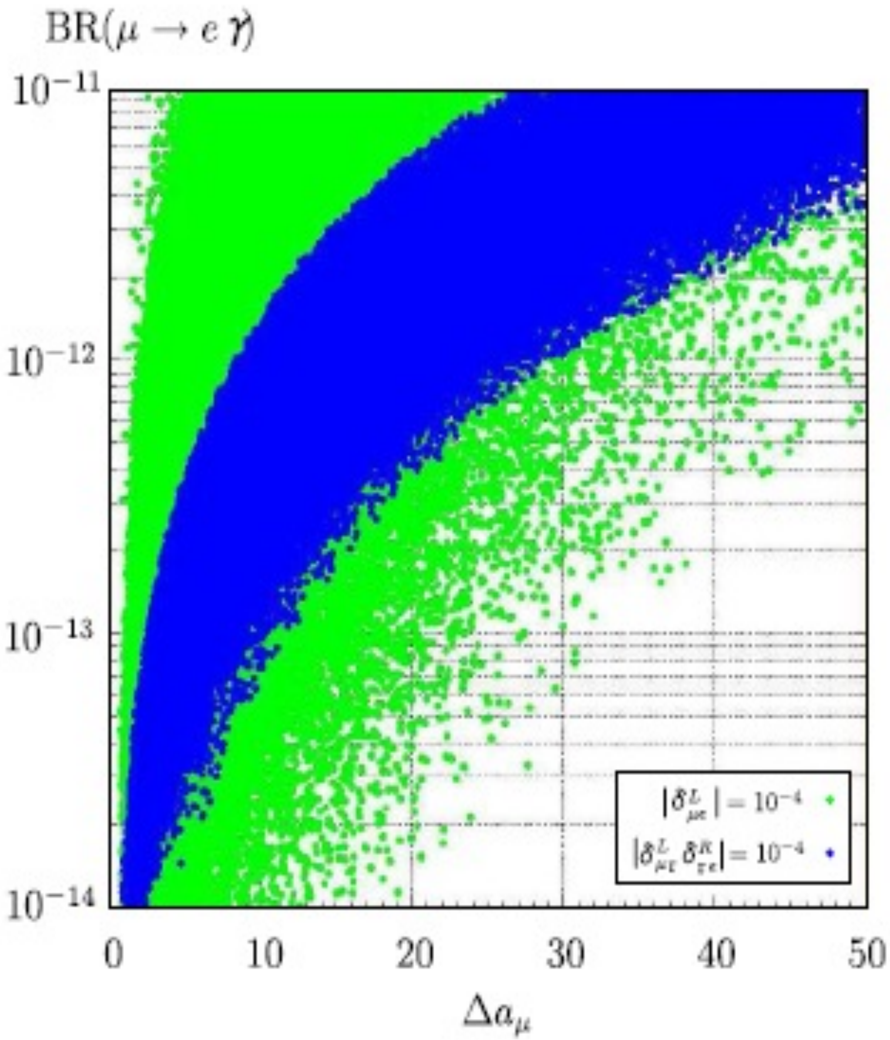


Calibbi et al. 2012

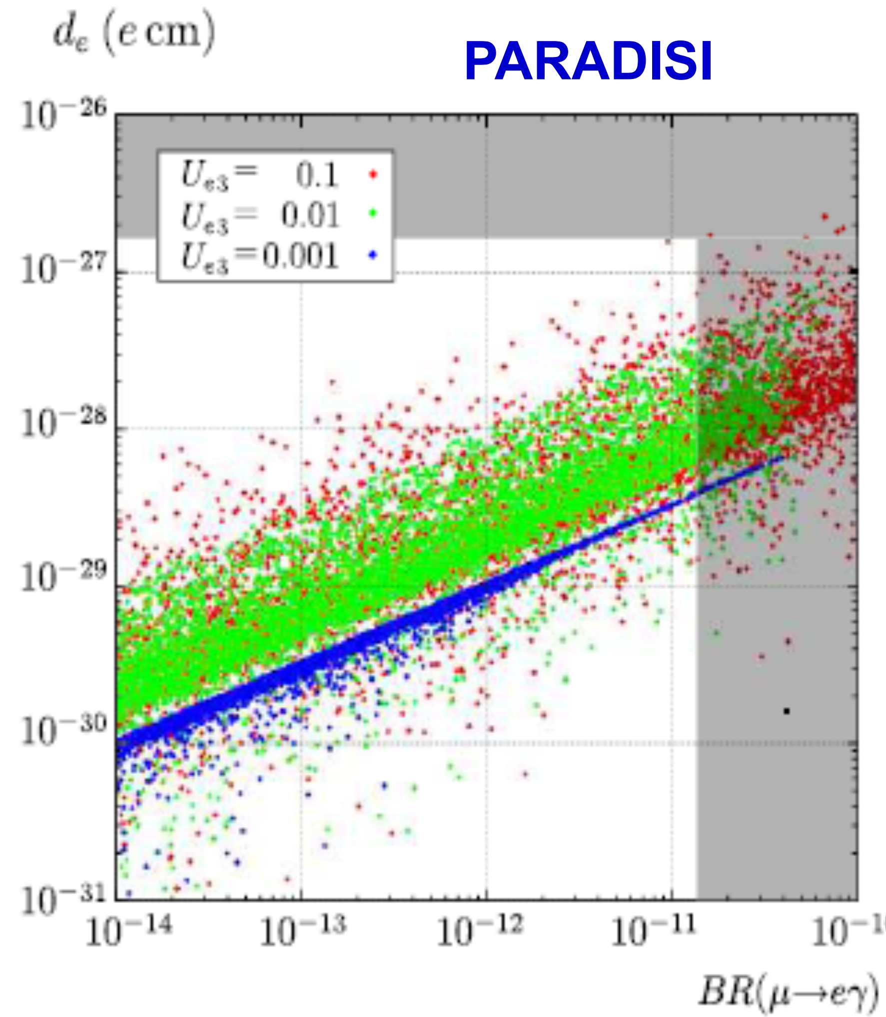
Calibbi et al. 2012



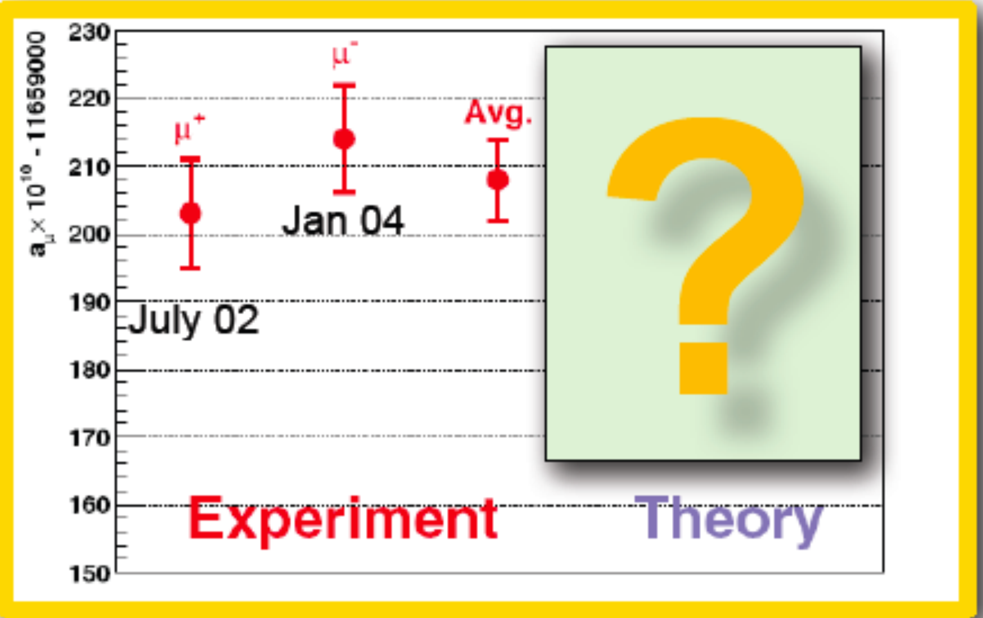
LFV, g – 2, EDM: a promising correlation in SUSY SEESAW



PARADISI



The muon g-2: the experimental result



- **Today:** $a_\mu^{EXP} = (116592089 \pm 54_{stat} \pm 33_{sys}) \times 10^{-11}$ [0.5ppm].
- **Future:** new muon g-2 experiments proposed at:
  - Fermilab (E989), aiming at 0.14ppm → Has now Stage 1 Approval!
  - J-PARC aiming at 0.1 ppm

  [D. Hertzog & N. Saito, U.Paris, Feb 2010; B.Lee Roberts & T. Mibe, Tau2010]
- **Are theorists ready for this (amazing) precision?** No(t yet)

M. PASSERA 2012

The muon g-2: Standard Model vs. Experiment

Adding up all contributions, we get the following SM predictions and comparisons with the measured value:

$a_\mu^{EXP} = 116592089\ (63) \times 10^{-11}$

E821 – Final Report: PRD73 (2006) 072 with latest value of $\lambda = \mu_\mu/\mu_p$ (CODATA'06)

	$a_\mu^{SM} \times 10^{11}$	$(\Delta a_\mu = a_\mu^{EXP} - a_\mu^{SM}) \times 10^{11}$	σ
[1]	116 591 782 (59)	307 (86)	3.6
[2]	116 591 802 (49)	287 (80)	3.6
[3]	116 591 828 (50)	261 (80)	3.2
[4]	116 591 894 (54)	195 (83)	2.4

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with $a_\mu^{HHO}(lbl) = 105\ (26) \times 10^{-11}$

[1] F. Jegerlehner, A. Nyffeler, Phys. Rept. 477 (2009) 1
[2] Davier et al, EPJ C71 (2011) 1515 (includes BaBar and KLOE10 2π)
[3] HLMNT11: Hagiwara et al, JPG38 (2011) 085003 (incl BaBar and KLOE10 2π)
[4] Davier et al, Eur.PJ C71 (2011) 1515, τ data.

Note that the th. error is now about the same as the exp. one

THE EDM CHALLENGE

FOR **ANY** **NEW PHYSICS AT THE TEV SCALE** WITH **NEW SOURCES OF CP VIOLATION** → NEED FOR **FINE-TUNING** TO PASS THE EDM TESTS OR SOME **DYNAMICS TO SUPPRESS THE CPV** IN FLAVOR CONSERVING EDMS

$$|d_{\rm n}| < 2.9 \times 10^{-26} e \text{ cm (90\%C.L.)},$$
$$|d_{\rm Tl}| < 9.0 \times 10^{-25} e \text{ cm (90\%C.L.)},$$
$$|d_{\rm Hg}| < 3.1 \times 10^{-29} e \text{ cm (95\%C.L.)}.$$

HIGGS-MEDIATED LFV COUPLINGS

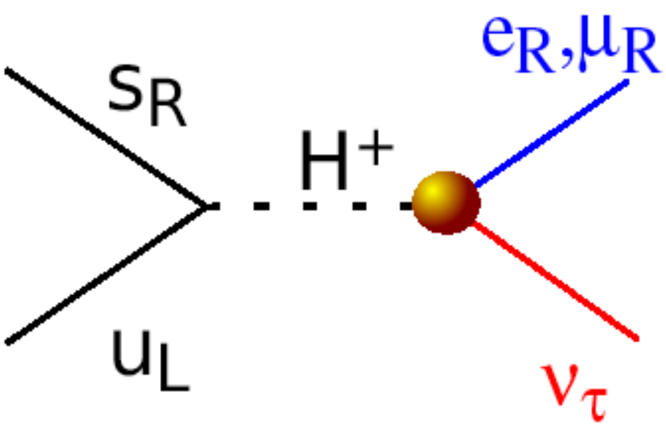
- When non-holomorphic terms are generated by loop effects (HRS corrections)
- And a source of LFV among the sleptons is present
- $\longrightarrow$ Higgs-mediated (radiatively induced) H-lepton-lepton LFV couplings arise

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

A.M, PARADISI, PETRONZIO

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



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

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

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

$$\Downarrow$$

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

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

A.M., PARADISI. PETRONZIO

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

LFU breaking occurs with LFV

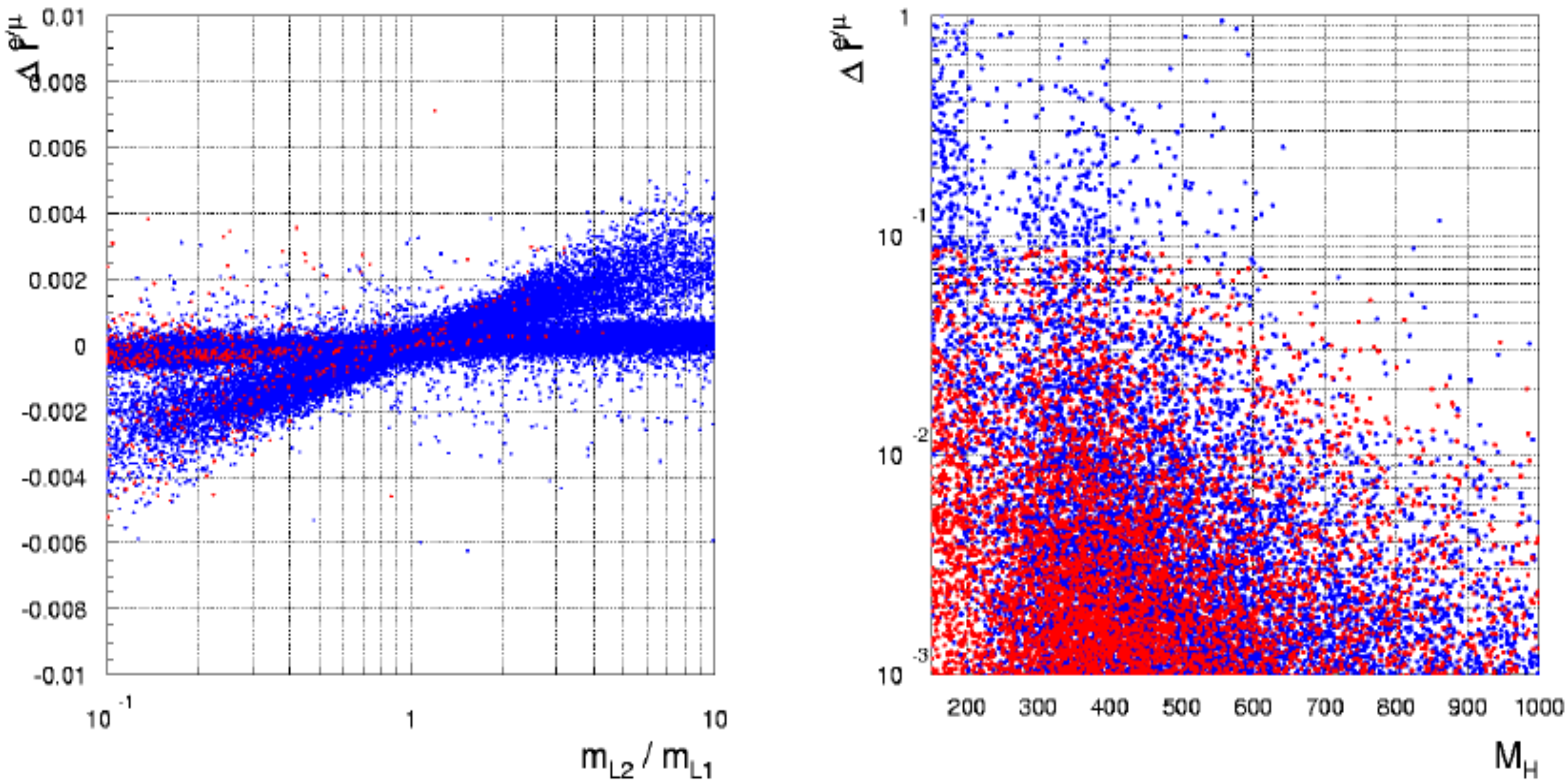


Figure 2: Left:$\Delta r_K^{e/\mu}$ as a function of the mass splitting between the second and the first (left-handed) slepton generations. Red dots can saturate the $(g-2)_\mu$ discrepancy at the 95% C.L., i.e. $1 \times 10^{-9} < (g-2)_\mu < 5 \times 10^{-9}$. Right: $\Delta r_K^{e/\mu}$ as a function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

In SU(5) d_R ⟷ 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

GUT -RELATED SUSY SOFT BREAKING TERMS

$$m^2_Q = m^2_{\tilde{e}^c} = m^2_{\tilde{u}^c} = m^2_{\mathbf{10}}$$

$$m^2_{\tilde{d}^c} = m^2_{L} = m^2_{\bar{\mathbf{5}}}$$

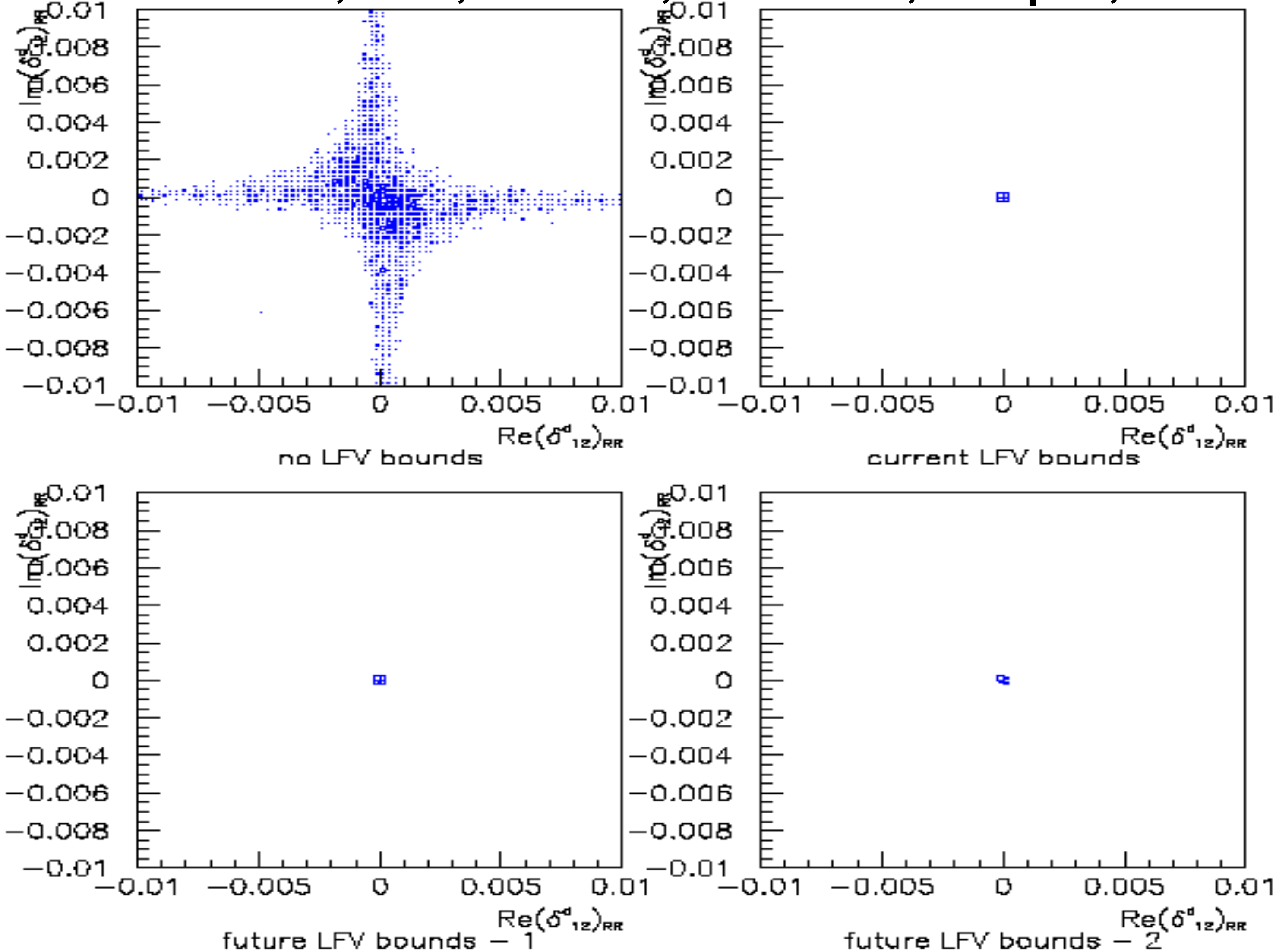
$$A^e_{ij} = A^d_{ji} \, .$$

SU(5) RELATIONS

	Relations at weak-scale	Relationss at $M_{\rm GUT}$
(1)	$(\delta^u_{ij})_{\rm RR} \approx (m^2_{e^c}/m^2_{u^c})\ (\delta^l_{ij})_{\rm RR}$	$m^2_{u^c{}_0} = m^2_{e^c{}_0}$
(2)	$(\delta^q_{ij})_{\rm LL} \approx (m^2_{e^c}/m^2_{Q})\ (\delta^l_{ij})_{\rm RR}$	$m^2_{Q_0} = m^2_{e^c{}_0}$
(3)	$(\delta^d_{ij})_{\rm RR} \approx (m^2_{L}/m^2_{d^c})\ (\delta^l_{ij})_{\rm LL}$	$m^2_{d^c{}_0} = m^2_{L_0}$
(4)	$(\delta^d_{ij})_{\rm LR} \approx (m^2_{L_{avg}}/m^2_{Q_{avg}})\ (m_b/m_\tau)\ (\delta^l_{ij})^\star_{\rm LR}$	$A^e_{ij_0} = A^d_{ji_0}$

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

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



Final thoughts on LFV and New Physics BSM

- Complementarity of the **3 roads to go BSM**: high energy (LHC), high intensity (flavor), astroparticle (DM etc.)
- In the HI road, **LFV plays a major role** – high sensitivity to TeV new particles/interactions related to Lepton Flavor numbers
- The **complementarity** between **LHC physics** and **LFV searches** is already **now** providing relevant results (for instance, exclusion of the PMNS models in type I SUSY seesaw) and is promising **much more** with the 14 TeV LHC run and the new experiments looking for LFV