LFV theory

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Open questions

- **The origin of flavour is still, to a large extent, a mystery. The most important open questions can be summarized as follow:**
  - **Which is the organizing principle behind the observed pattern of fermion masses and mixing angles?**
  - **Are there extra sources of flavour symmetry breaking beside the SM Yukawa couplings which are relevant at the TeV scale?**
- **Related important questions are:**
  - **Which is the role of flavor physics in the LHC era?**
  - **Do we expect to understand the (SM and NP) flavor puzzles through the synergy and interplay of flavor physics and the LHC?**

NP search strategies

- **High-energy frontier: A unique effort to determine the NP scale**

- **High-intensity frontier (flavor physics): A collective effort to determine the flavor structure of NP**

Where to look for New Physics at the low energy?

- **Processes very suppressed or even forbidden in the SM**
  - FCNC processes ($\mu \to e\gamma$, $\mu \to eee$, $\mu \to e$ in N, $\tau \to \mu\gamma$, $B^0_{s,d} \to \mu^+\mu^-$...)
  - CPV effects in the electron/neutron EDMs, $d_{e,n}$...
  - FCNC & CPV in $B_{s,d}$ & D decay/mixing amplitudes

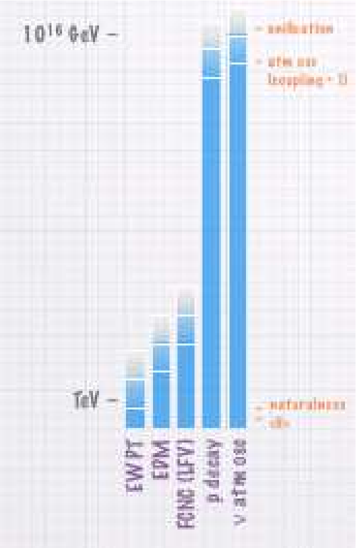
- **Processes predicted with high precision in the SM**
  - EWPO as $(g-2)_{\mu,e}$: $a_\mu^{exp} - a_\mu^{SM} \approx (3 \pm 1) \times 10^{-9}$, a discrepancy at 3σ!
  - LU in $R_M^{e/\mu} = \Gamma(M \to e\nu)/\Gamma(M \to \mu\nu)$ with $M = \pi, K$

Experimental status

LFV process	Experiment	Future limits	Year (expected)
BR($\mu \to e\gamma$)	MEG	$\mathcal{O}(10^{-13})$	~ 2013
	Project X	$\mathcal{O}(10^{-15})$	> 2021
BR($\mu \to eee$)	Mu3e	$\mathcal{O}(10^{-15})$	~ 2017
	Mu3e	$\mathcal{O}(10^{-16})$	> 2017
	MUSIC	$\mathcal{O}(10^{-16})$	~ 2017
	Project X	$\mathcal{O}(10^{-17})$	> 2021
CR($\mu \to e$)	COMET	$\mathcal{O}(10^{-17})$	~ 2017
	Mu2e	$\mathcal{O}(10^{-17})$	~ 2020
	PRISM/PRIME	$\mathcal{O}(10^{-18})$	~ 2020
	Project X	$\mathcal{O}(10^{-19})$	> 2021
BR($\tau \to \mu\gamma$)	Belle II	$\mathcal{O}(10^{-8})$	> 2020
BR($\tau \to \mu\mu\mu$)	Belle II	$\mathcal{O}(10^{-10})$	> 2020
BR($\tau \to e\gamma$)	Belle II	$\mathcal{O}(10^{-9})$	> 2020
BR($\tau \to \mu\mu\mu$)	Belle II	$\mathcal{O}(10^{-10})$	> 2020

Table: Future sensitivities of next-generation experiments.

- **Gravity** $\Longrightarrow$ $\Lambda_{\text{Planck}} \sim 10^{18-19}$ GeV
- **Neutrino masses** $\Longrightarrow$ $\Lambda_{\text{see-saw}} \lesssim 10^{15}$ GeV
- **BAU**: evidence of CPV beyond SM
  - Electroweak Baryogenesis $\Longrightarrow$ $\Lambda_{NP} \lesssim$ TeV
  - Leptogenesis $\Longrightarrow$ $\Lambda_{\text{see-saw}} \lesssim 10^{15}$ GeV
- **Hierarchy problem**: $\Longrightarrow$ $\Lambda_{NP} \lesssim$ TeV
- **Dark Matter** $\Longrightarrow$ $\Lambda_{NP} \lesssim$ TeV



SM = effective theory at the EW scale

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \sum_{d\geq 5} \frac{c_{ij}^{(d)}}{\Lambda_{NP}^{d-4}}\, O_{ij}^{(d)}$$

$$\mathbf{BR}(\ell_i \to \ell_j \gamma) \sim \frac{1}{\Lambda_{NP}^4}$$

- $\mathcal{L}_{\rm eff}^{d=5} = \frac{y_\nu^{ij}}{\Lambda_{\rm see-saw}} L_i L_j \phi\phi$,
- $\mathcal{L}_{\rm eff}^{d=6}$ generates FCNC operators

The NP "scale" vs. LFV

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \sum_{d\geq 5} \frac{C_{ij}^{(d)}}{\Lambda_{NP}^{d-4}} O_{ij}^{(d)}$$

$\mathrm{BR}(\mu \to e\gamma) < 5 \times 10^{-14}$

Process	Relevant operators	Present Bound on Λ (TeV) $C = 1/16\pi^2$	Present Bound on Λ (TeV) $C = 1$	Future Bound on Λ (TeV) $C = 1/16\pi^2$	Future Bound on Λ (TeV) $C = 1$
$\mu \to e\gamma$	$\frac{C}{\Lambda^2}\frac{m_\mu}{16\pi^2}\overline{\mu}_L\sigma^{\mu\nu}e_R F_{\mu\nu}$	50	—	90	—
$\mu \to eee$	$\frac{C}{\Lambda^2}(\overline{\mu}_L\gamma^\mu e_L)(\overline{e}_L\gamma^\mu e_L)$	17	210	170	2100
	$\frac{C}{\Lambda^2}(\overline{\mu}_L e_R)(\overline{e}_R e_L)$	10	120	100	1200
$\mu \to e$ in Ti	$\frac{C}{\Lambda^2}(\overline{\mu}_L\gamma^\mu e_L)(\overline{d}_L\gamma^\mu d_L)$	30	420	580	7300
	$\frac{C}{\Lambda^2}(\overline{\mu}_L e_R)(\overline{d}_R d_L)$	60	750	1000	13000

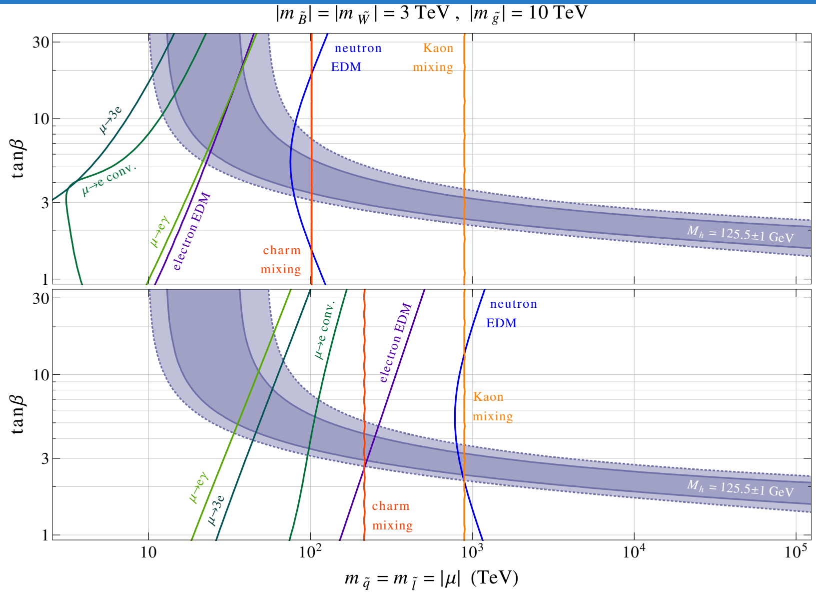
updated from LC Lalak Pokorski Ziegler '12

$\mathrm{BR}(\mu \to eee) < 10^{-16}$

$\mathrm{CR}(\mu \to e \text{ in Ti}) < 5 \times 10^{-17}$

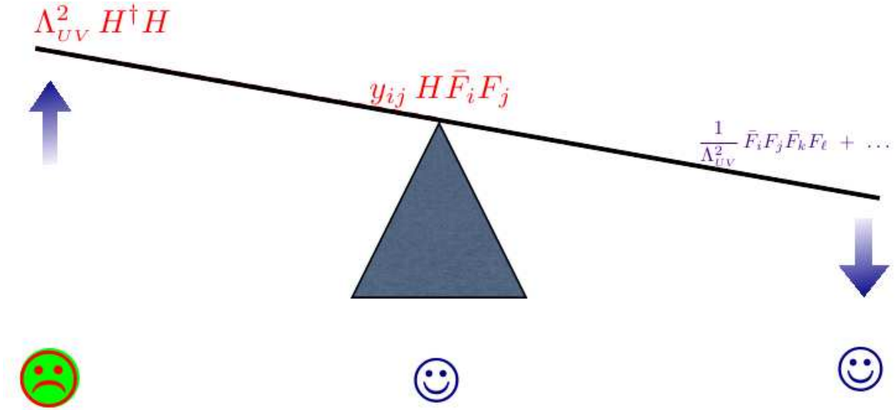
Calibbi @ IFAE2014

SUSY Flavour after the Higgs discovery



Low energy constraints fixing $(\delta_A)_{ij} = 0.3$. The upper (lower) plot gives the reach of current (projected future) experimental results [Altmannshofer, Harnik, & Zupan, '13]

Hierarchy see-saw



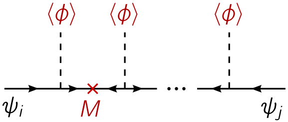
Rattazzi @ ppLHCb2013, Genova

SM vs. NP flavor problems

- Can the SM and NP flavour problems have a common explanation?

- **Froggat-Nielsen '79: Hierarchies from SSB of a Flavour Symmetry**

$$\epsilon = \frac{\langle \phi \rangle}{M} \ll 1 \Rightarrow Y_{ij} \propto \epsilon^{(a_i+b_j)}$$



- **Flavor protection from flavor models:** [Lalak, Pokorski & Ross '10]

Operator	$U(1)$	$U(1)^2$	$SU(3)$	MFV
$(\overline{Q}_L X^Q_{LL} Q_L)_{12}$	λ	λ^5	λ^3	λ^5
$(\overline{D}_R X^D_{RR} D_R)_{12}$	λ	λ^{11}	λ^3	$(y_d y_s) \times \lambda^5$
$(\overline{Q}_L X^D_{LR} D_R)_{12}$	λ^4	λ^9	λ^3	$y_s \times \lambda^5$

- Is the this flavor protection enough?

- Is it possible to disentangle among different flavour models by means of their predicted pattern of deviation w.r.t. the SM predictions in flavour physics?

LFV frameworks

- **Neutrino Oscillation** $\Rightarrow m_{\nu_i} \neq m_{\nu_j} \Rightarrow$ **LFV**

- **see-saw**: $m_\nu = \frac{(m_\nu^D)^2}{M_R} \sim eV$, $M_R \sim 10^{14-16} \Rightarrow m_\nu^D \sim m_{top}$

- LFV transitions like $\mu \to e\gamma$ @ 1 loop with exchange of

  - W and ν in the SM framework (GIM) with $\Lambda_{NP} \equiv M_R$

$$Br(\mu \to e\gamma) \sim \frac{m_\nu^{D\,4}}{M_R^4} \leq 10^{-50}$$

  - $\tilde{W}$ and $\tilde{\nu}$ in the MSSM framework (SUPER-GIM) with $\Lambda_{NP} \equiv \tilde{m}$

$$Br(\mu \to e\gamma) \sim \frac{m_\nu^{D\,4}}{\tilde{m}^4}$$ [Borzumati & Masiero '86]

$$\Downarrow$$

- LFV signals are undetectable (detectable) in the SM (MSSM)

- **NP effects are encoded in the effective Lagrangian**

$$\mathcal{L} = e\frac{m_\ell}{2}\left(\bar{\ell}_R\sigma_{\mu\nu}A_{\ell\ell'}\ell'_L + \bar{\ell}'_L\sigma_{\mu\nu}A^{\star}_{\ell\ell'}\ell_R\right)F^{\mu\nu} \qquad \ell,\ell' = e,\mu,\tau\,,$$

$$A_{\ell\ell'} = \frac{1}{(4\pi\,\Lambda_{\rm NP})^2}\left[\left(g^L_{\ell k}\,g^{L*}_{\ell' k} + g^R_{\ell k}\,g^{R*}_{\ell' k}\right)f_1(x_k) + \frac{v}{m_\ell}\left(g^L_{\ell k}\,g^{R*}_{\ell' k}\right)f_2(x_k)\right]\,,$$

  - Δa_ℓ **and leptonic EDMs are given by**

$$\Delta a_\ell = 2m^2_\ell\,\mathrm{Re}(A_{\ell\ell}), \qquad \frac{d_\ell}{e} = m_\ell\,\mathrm{Im}(A_{\ell\ell})\,.$$

  - **The branching ratios of** $\ell \to \ell'\gamma$ **are given by**

$$\frac{\mathrm{BR}(\ell \to \ell'\gamma)}{\mathrm{BR}(\ell \to \ell'\nu_\ell\bar{\nu}_{\ell'})} = \frac{48\pi^3\alpha}{G_F^2}\left(|A_{\ell\ell'}|^2 + |A_{\ell'\ell}|^2\right)\,.$$

- **“Naive scaling”:**

$$\Delta a_{\ell_i}/\Delta a_{\ell_j} = m^2_{\ell_i}/m^2_{\ell_j}, \qquad d_{\ell_i}/d_{\ell_j} = m_{\ell_i}/m_{\ell_j}\,.$$

(for instance, if the new particles have an underlying SU(3) flavor symmetry in their mass spectrum and in their couplings to leptons, which is the case for gauge interactions).

[Giudice, P.P., & Passera, '12]

Model-independent predictions

- $(g-2)_\ell$ **assuming "Naive scaling"** $\Delta a_{\ell_i}/\Delta a_{\ell_j} = m^2_{\ell_i}/m^2_{\ell_j}$

$$\Delta a_e = \left(\frac{\Delta a_\mu}{3\times 10^{-9}}\right) 0.7\times 10^{-13}\,, \qquad \Delta a_\tau = \left(\frac{\Delta a_\mu}{3\times 10^{-9}}\right) 0.8\times 10^{-6}.$$

- **EDMs assuming "Naive scaling"** $d_{\ell_i}/d_{\ell_j} = m_{\ell_i}/m_{\ell_j}$

$$d_e \simeq \left(\frac{\Delta a_e}{7\times 10^{-14}}\right) 10^{-24} \tan\phi_e \; e\,\mathrm{cm}\,,$$
$$d_\mu \simeq \left(\frac{\Delta a_\mu}{3\times 10^{-9}}\right) 2\times 10^{-22} \tan\phi_\mu \; e\,\mathrm{cm}\,,$$
$$d_\tau \simeq \left(\frac{\Delta a_\tau}{8\times 10^{-7}}\right) 4\times 10^{-21} \tan\phi_\tau \; e\,\mathrm{cm}\,,$$

- $\mathrm{BR}(\ell_i \to \ell_j\gamma)$ **vs.** $(g-2)_\mu$

$$\mathrm{BR}(\mu\to e\gamma) \approx 3\times 10^{-13}\left(\frac{\Delta a_\mu}{3\times 10^{-9}}\right)^2 \left(\frac{\theta_{e\mu}}{10^{-5}}\right)^2\,,$$
$$\mathrm{BR}(\tau\to \mu\gamma) \approx 4\times 10^{-8}\left(\frac{\Delta a_\mu}{3\times 10^{-9}}\right)^2 \left(\frac{\theta_{\ell\tau}}{10^{-2}}\right)^2\,.$$

[Giudice, P.P., & Passera, '12]

Not only $\mu \to e\gamma$...

- LFV operators up to dimension-six

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda^2_{\rm LFV}}\,\mathcal{O}^{\rm dim-6} + \ldots\,.$$

$$\mathcal{O}^{\rm dim-6} \ni \;\; \bar{\mu}_R\,\sigma^{\mu\nu}\,H\,e_L\,F_{\mu\nu}\,,\;\; (\bar{\mu}_L\gamma^{\mu}e_L)\left(\bar{f}_L\gamma^{\mu}f_L\right)\,,\;\; (\bar{\mu}_R e_L)\left(\bar{f}_R f_L\right)\,,\;\; f = e,u,d$$

- the dipole-operator leads to $\ell \to \ell'\gamma$ while 4-fermion operators generate processes like $\ell_i \to \ell_j\bar{\ell}_k\ell_k$ and $\mu \to e$ conversion in Nuclei.
- When the dipole-operator is dominant:

$$\frac{{\rm BR}(\ell_i \to \ell_j\ell_k\bar{\ell}_k)}{{\rm BR}(\ell_i \to \ell_j\bar{\nu}_j\nu_i)} \simeq \frac{\alpha_{el}}{3\pi}\left(\log\frac{m^2_{\ell_i}}{m^2_{\ell_k}} - 3\right)\frac{{\rm BR}(\ell_i \to \ell_j\gamma)}{{\rm BR}(\ell_i \to \ell_j\bar{\nu}_j\nu_i)}\,,$$

$$\mathrm{CR}(\mu \to e \text{ in N}) \simeq \alpha_{\rm em} \times {\rm BR}(\mu \to e\gamma)\,.$$

- ${\rm BR}(\mu \to e\gamma) \sim 10^{-12}$ implies ${\rm BR}(\mu \to eee) \leq 0.5 \times 10^{-14}$ and $\mathrm{CR}(\mu \to e \text{ in N}) \leq 0.5 \times 10^{-14}$.
- A combined analysis of $\mu \to e$ conversion on different target nuclei can discriminate among the underlying operators since the sensitivity of different processes to these operators is not the same [Okada et al. 2004].
- For three body LFV decays as $\mu \to eee$, an angular analysis of the signal would be crucial to shed light on the operator which is at work.

Pattern of LFV in NP models

- **Ratios like** $Br(\mu \to e\gamma)/Br(\tau \to \mu\gamma)$ **probe the NP flavor structure**
- **Ratios like** $Br(\mu \to e\gamma)/Br(\mu \to eee)$ **probe the NP operator at work**

ratio	LHT	MSSM	SM4
$\frac{Br(\mu \to eee)}{Br(\mu \to e\gamma)}$	$0.02 \ldots 1$	$\sim 2 \cdot 10^{-3}$	$0.06 \ldots 2.2$
$\frac{Br(\tau \to eee)}{Br(\tau \to e\gamma)}$	$0.04 \ldots 0.4$	$\sim 1 \cdot 10^{-2}$	$0.07 \ldots 2.2$
$\frac{Br(\tau \to \mu\mu\mu)}{Br(\tau \to \mu\gamma)}$	$0.04 \ldots 0.4$	$\sim 2 \cdot 10^{-3}$	$0.06 \ldots 2.2$
$\frac{Br(\tau \to e\mu\mu)}{Br(\tau \to e\gamma)}$	$0.04 \ldots 0.3$	$\sim 2 \cdot 10^{-3}$	$0.03 \ldots 1.3$
$\frac{Br(\tau \to \mu ee)}{Br(\tau \to \mu\gamma)}$	$0.04 \ldots 0.3$	$\sim 1 \cdot 10^{-2}$	$0.04 \ldots 1.4$
$\frac{Br(\tau \to eee)}{Br(\tau \to e\mu\mu)}$	$0.8 \ldots 2$	~ 5	$1.5 \ldots 2.3$
$\frac{Br(\tau \to \mu\mu\mu)}{Br(\tau \to \mu ee)}$	$0.7 \ldots 1.6$	~ 0.2	$1.4 \ldots 1.7$
$\frac{\mathrm{R}(\mu \mathrm{Ti} \to e \mathrm{Ti})}{Br(\mu \to e\gamma)}$	$10^{-3} \ldots 10^{2}$	$\sim 5 \cdot 10^{-3}$	$10^{-12} \ldots 26$

[Buras et al., '07, '10]

Testing new physics with the electron $g-2$

- **Longstanding muon $g-2$ anomaly**

$$\Delta a_\mu = a_\mu^{\rm EXP} - a_\mu^{\rm SM} = 2.90(90)\times 10^{-9}\,, \qquad \mathbf{3.5\sigma\ \ discrepancy}$$

- **NP effects are expected to be of order $a_\ell^{\rm NP} \sim a_\ell^{\rm EW}$**

$$a_\mu^{\rm EW} = \frac{m_\mu^2}{(4\pi v)^2}\left(1 - \frac{4}{3}\sin^2\theta_{\rm W} + \frac{8}{3}\sin^4\theta_{\rm W}\right) \approx 2\times 10^{-9}.$$

- **Main question: how could we check if the a_μ discrepancy is due to NP?**
- **Answer: testing new-physics effects in a_e** [Giudice, P.P, & Passera, '12]
- **"Naive scaling":** $\Delta a_{\ell_i}/\Delta a_{\ell_j} = m_{\ell_i}^2/m_{\ell_j}^2$

$$\Delta a_e = \left(\frac{\Delta a_\mu}{3\times 10^{-9}}\right) 0.7\times 10^{-13}\,.$$

  - a_e has never played a role in testing beyond SM effects. From $a_e^{\rm SM}(\alpha) = a_e^{\rm EXP}$, we extract α which is is the most precise value of α available today!
  - The situation has now changed thanks to progresses both on the th. and exp. sides.

The Standard Model prediction of the electron $g-2$ [Giudice, P.P, & Passera, '12]

- **Using the second best determination of α from atomic physics $\alpha(^{87}\mathrm{Rb})$**

$$\Delta a_e = a_e^{\mathrm{EXP}} - a_e^{\mathrm{SM}} = -10.6\,(8.1) \times 10^{-13},$$

  - Beautiful test of QED at four-loop level!
  - $\delta\Delta a_e = 8.1 \times 10^{-13}$ is dominated by δa_e^{SM} through $\delta\alpha(^{87}\mathrm{Rb})$.

- **Future improvements in the determination of Δa_e**

$$\underbrace{(0.6)_{\mathrm{QED4}},\ \ (0.4)_{\mathrm{QED5}},\ \ \ \ (0.2)_{\mathrm{HAD}},}_{(0.7)_{\mathrm{TH}}}\ \ (7.6)_{\delta\alpha},\ \ (2.8)_{\delta a_e^{\mathrm{EXP}}}.$$

  - The first error, 0.6×10^{-13}, stems from numerical uncertainties in the four-loop QED. It can be reduced to 0.1×10^{-13} with a large scale numerical recalculation [Kinoshita]
  - The second error, from five-loop QED term may soon drop to 0.1×10^{-13}.
  - Experimental uncertainties 2.8×10^{-13} ($\delta a_e^{\mathrm{EXP}}$) and 7.6×10^{-13} ($\delta\alpha$) dominate. We expect a reduction of the former error to a part in 10^{-13} (or better) [Gabrielse]. Work is also in progress for a significant reduction of the latter error [Nez].

- **Δa_e at the 10^{-13} (or below) is not too far! This will bring a_e to play a pivotal role in probing new physics in the leptonic sector.**

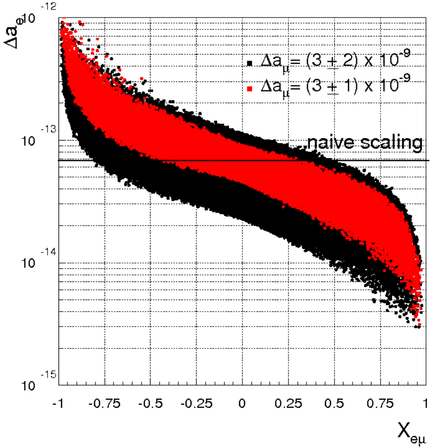
Supersymmetry and a_e [Giudice, P.P, & Passera, '12]

- SUSY contributions to a_ℓ comes from loops with exchange of chargino/sneutrino or neutralino/charged slepton.

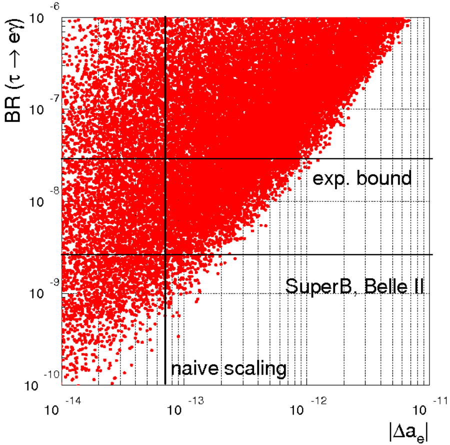
- **Violations of "naive scaling"** can arise through sources of non-universalities in the slepton mass matrices in two possible ways

  - **Lepton flavor conserving (LFC) case**. The charged slepton mass matrix violates the global non-abelian flavor symmetry, but preserves $U(1)^3$. This case is characterized by non-degenerate sleptons ($m_{\tilde{e}} \neq m_{\tilde{\mu}} \neq m_{\tilde{\tau}}$) but vanishing mixing angles because of an exact alignment.
    - Interesting interplay with collider physics: slepton mass splittings from kinematic edges [Allanach, Colon, Lester, '08, Buras, Calibbi, P.P., '09]

  - **Lepton flavor violating (LFV) case**. The slepton mass matrix fully breaks flavor symmetry up to U(1) lepton number, generating mixing angles that allow for flavor transitions. Lepton flavor violating processes, such as $\mu \to e\gamma$, provide stringent constraints on this case. However, because of flavor transitions, a_e and a_μ can receive new large contributions proportional to m_τ (from a chiral flip in the internal line of the loop diagram) [Girrbach, Nierste, '09], giving a new source of non-naive scaling.



Δa_e vs. $X_{e\mu} = (m^2_{\tilde{e}} - m^2_{\tilde{\mu}})/(m^2_{\tilde{e}} + m^2_{\tilde{\mu}})$



$\mathrm{BR}(\tau \to e\gamma)$ vs. $|\Delta a_e|$

A concrete SUSY scenario: "Disoriented A-terms"

- **Challenge**: Large effects for $g-2$ keeping under control $\mu \to e\gamma$ and d_e
- **"Disoriented A-terms"** [Giudice, Isidori & P.P., '12]:

$$(\delta_{LR}^{ij})_f \sim \frac{A_f \theta_{ij}^f m_{f_j}}{m_{\tilde{f}}} \qquad f = u, d, \ell \,,$$

  - Flavor and CP violation is restricted to the trilinear scalar terms.
  - Flavor bounds of the down-sector are naturally satisfied thanks to the smallness of down-type quark/lepton masses.
  - This ansatz arises in scenarios with partial compositeness (where a natural prediction is $\theta_{ij}^\ell \sim \sqrt{m_i/m_j}$ [Rattazzi et al.,'12]) or, as shown in [Calibbi, P.P. and Ziegler,'13], in Flavored Gauge Mediation models [Shadmi and collaborators].

- $\mu \to e\gamma$ and d_e are generated only by $U(1)$ interactions

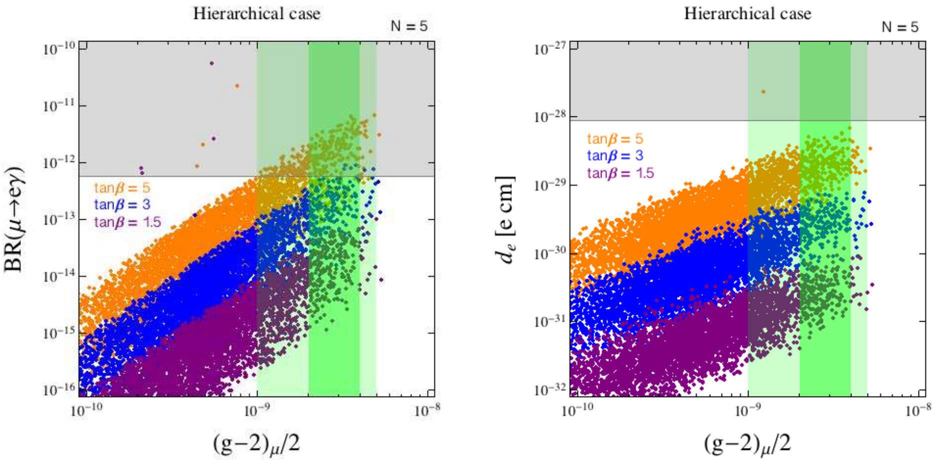
$$\mathrm{BR}(\mu \to e\gamma) \sim \left(\frac{\alpha}{\cos^2\theta_W}\right)^2 \left|\delta_{LR}^{\mu e}\right|^2 \,, \qquad \frac{d_e}{e} \sim \frac{\alpha}{\cos^2\theta_W}\, \mathrm{Im}\delta_{LR}^{ee} \,.$$

- $(g-2)_\mu$ is generated by $SU(2)$ interactions and is $\tan\beta$ enhanced

$$\Delta a_\ell \sim \frac{\alpha}{\sin^2\theta_W}\, \tan\beta$$

- $(g-2)_\mu$ is enhanced by $\approx 100 \times (\tan\beta/30)$ w.r.t. $\mu \to e\gamma$ and d_e amplitudes

A concrete SUSY scenario: “Flavored Gauge Mediation”



- LFV processes with an undelying $\tau - \mu$ and $\tau - e$ are unobservable

[Calibbi, P.P., & Ziegler, to appear]

Conclusions and future prospects

- **Important questions in view of ongoing/future experiments are**:
  - What are the expected deviations from the SM predictions induced by TeV NP?
  - Which observables are not limited by theoretical uncertainties?
  - In which case we can expect a substantial improvement on the experimental side?
  - What will the measurements teach us if deviations from the SM are [not] seen?
- **(Personal) answers**:
  - The expected deviations from the SM predictions induced by NP at the TeV scale with generic flavor structure are already ruled out by many orders of magnitudes.
  - On general grounds, we can expect any size of deviation below the current bounds.
  - cLFV processes, leptonic EDMs and LFU observables $R^{e/\mu}_{K,\pi}$ do not suffer from theoretical limitations (clean th. observables).
  - On the experimental side there are still excellent prospects of improvements in several clean channels especially in the leptonic sector: $\mu \to e\gamma$, $\mu N \to eN$, $\mu \to eee$, τ-LFV, EDMs and leptonic $(g-2)$ and also $R^{e/\mu}_{K,\pi}$.
  - The the origin of the $(g-2)_\mu$ discrepancy can be understood testing new-physics effects in the electron $(g-2)_e$. This would require improved measurements of $(g-2)_e$ and more refined determinations of α in atomic-physics experiments.

The origin of flavour is still, to a large extent, a mystery. The most important open questions can be summarized as follow:

- **Which is the organizing principle behind the observed pattern of fermion masses and mixing angles?**
- **Are there extra sources of flavour symmetry breaking beside the SM Yukawa couplings which are relevant at the TeV scale?**

Irrespectively of whether the LHC will discover or not new particles, flavor physics in the leptonic sector (especially cLFV, leptonic $g-2$ and EDMs) will teach us a lot...