On the interrelationship among leptonic $g-2$, EDMs and LFV

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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 $M = \pi, K$

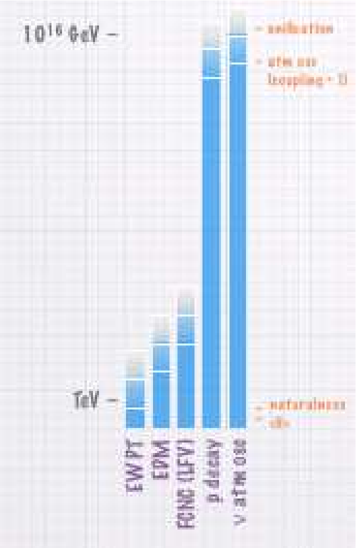
Experimental status

Process	Present	Experiment	Future	Experiment
$\mu \to e\gamma$	5.7×10^{-13}	MEG	$\approx 6 \times 10^{-14}$	MEG
$\mu \to 3e$	1.0×10^{-12}	SINDRUM	$\approx 10^{-16}$	Mu3e
μ^- Au $\to e^-$ Au	7.0×10^{-13}	SINDRUM II	?	
μ^- Ti $\to e^-$ Ti	4.3×10^{-12}	SINDRUM II	?	
μ^- Al $\to e^-$ Al	–		$\approx 10^{-16}$	COMET, MU2e
$\tau \to e\gamma$	3.3×10^{-8}	Belle & BaBar	$\sim 10^{-9}$	Belle II
$\tau \to \mu\gamma$	4.4×10^{-8}	Belle & BaBar	$\sim 10^{-9}$	Belle II
$\tau \to 3e$	2.7×10^{-8}	Belle & BaBar	$\sim 10^{-10}$	Belle II
$\tau \to 3\mu$	2.1×10^{-8}	Belle & BaBar	$\sim 10^{-10}$	Belle II
$d_e(\mathrm{e\ cm})$	8.7×10^{-29}	ACNE	?	
$d_\mu(\mathrm{e\ cm})$	1.9×10^{-19}	Muon (g-2)	?	

Table: Present and future experimental sensitivities for relevant low-energy observables.

The NP "scale"

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



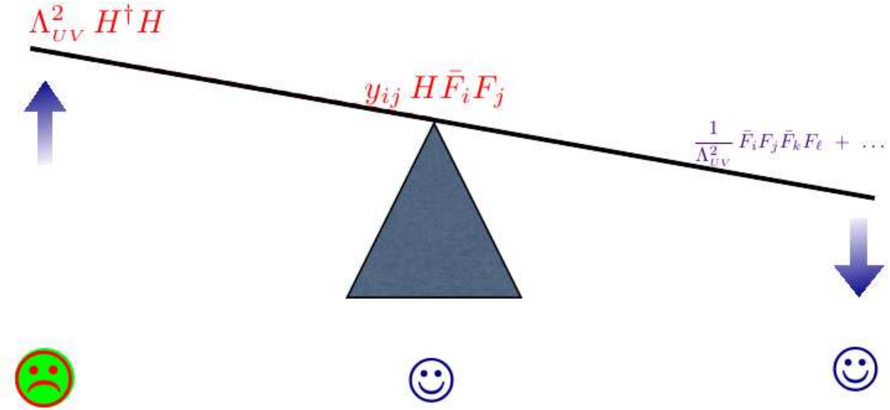
SM = effective theory at the EW scale

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

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

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

Hierarchy see-saw



- **Hierarchy problem**: $\Lambda_{\text{NP}} \lesssim \text{TeV}$
- **SM Yukawas**: $M_W \lesssim \Lambda_{\text{NP}} \lesssim M_P$
- **Flavor problem**: $\Lambda_{\text{NP}} \gg \text{TeV}$

Why LFV is interesting?

- **Neutrino Oscillation** $\Rightarrow m_{\nu_i} \neq m_{\nu_j} \Rightarrow$ **LFV**
- **see-saw**: $m_\nu \sim \frac{v^2}{M_R} \sim eV \Rightarrow M_R \sim 10^{14-16}$
- LFV transitions like $\mu \to e\gamma$ @ 1 loop with exchange of
  - W and ν in the SM with $\Lambda_{NP} \equiv M_R \equiv \Lambda_{see-saw}$

$$Br(\mu \to e\gamma) \sim \frac{v^4}{M_R^4} \leq 10^{-50} \qquad \textbf{GIM}$$

  - If $\Lambda_{NP} \ll \Lambda_{see-saw}$ ($\Lambda_{NP} \equiv m_{susy}$ in the MSSM)

$$Br(\mu \to e\gamma) \sim \frac{v^4}{\Lambda_{NP}^4}$$

$$\Downarrow$$

- LFV generally detectable in (multi) TeV scale NP scenarios like the MSSM, ...

Why CPV is interesting?

- **Why CP violation? Motivation:**
  - Baryogenesis requires extra sources of CPV
  - The QCD $\overline{\theta}$-term $\mathcal{L}_{CP} = \overline{\theta}\frac{\alpha_s}{8\pi}G\tilde{G}$ is a CPV source beyond the CKM
  - Most UV completion of the SM, e.g. the MSSM, have many CPV sources
  - However, TeV scale NP with $\mathcal{O}(1)$ CPV phases generally leads to EDMs many orders of magnitude above the current limits $\Rightarrow$ the New Physics CP problem.

- **How to solve the New Physics CP problem?**
  - Decoupling some NP particles in the loop generating the EDMs (e.g. hierarchical sfermions, split SUSY, 2HDM limit...)
  - Generating CPV phases radiatively $\phi^f_{CP} \sim \alpha_w/4\pi \sim 10^{-3}$
  - Generating CPV phases via small flavour mixing angles $\phi^f_{CP} \sim \delta_{fj}\delta_{fj}$ with $f = e, u, d$: maybe the suppression of FCNC processes and EDMs have a common origin?

- **LFV** operators **@ dim-6**

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

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

- 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:

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

$${\rm CR}(\mu \to e \text{ in N}) \simeq \frac{\alpha_{\rm em}}{2} \times {\rm BR}(\mu \to e\gamma) .$$

- ${\rm BR}(\mu \to \mathbf{e}\gamma) \sim \mathbf{5 \times 10^{-13}}$ implies

$$\frac{{\rm BR}(\mu \to \mathbf{3e})}{\mathbf{3 \times 10^{-15}}} \approx \frac{{\rm BR}(\mu \to \mathbf{e}\gamma)}{\mathbf{5 \times 10^{-13}}} \approx \frac{{\rm CR}(\mu \to \mathbf{e} \text{ in N})}{\mathbf{2 \times 10^{-15}}}$$

- $\mu + N \to e + N$ on different N discriminates the operator at work [Okada et al. 2004].
- An angular analysis for $\mu \to eee$ can test 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...1	$\sim 2\cdot 10^{-3}$	0.06...2.2
$\frac{Br(\tau\to eee)}{Br(\tau\to e\gamma)}$	0.04...0.4	$\sim 1\cdot 10^{-2}$	0.07...2.2
$\frac{Br(\tau\to \mu\mu\mu)}{Br(\tau\to \mu\gamma)}$	0.04...0.4	$\sim 2\cdot 10^{-3}$	0.06...2.2
$\frac{Br(\tau\to e\mu\mu)}{Br(\tau\to e\gamma)}$	0.04...0.3	$\sim 2\cdot 10^{-3}$	0.03...1.3
$\frac{Br(\tau\to \mu ee)}{Br(\tau\to \mu\gamma)}$	0.04...0.3	$\sim 1\cdot 10^{-2}$	0.04...1.4
$\frac{Br(\tau\to eee)}{Br(\tau\to e\mu\mu)}$	0.8...2	~ 5	1.5...2.3
$\frac{Br(\tau\to \mu\mu\mu)}{Br(\tau\to \mu ee)}$	0.7...1.6	~ 0.2	1.4...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]

- **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**

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

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

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

- **“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

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

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

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

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

$$d_e \simeq \left(\frac{\Delta a_\mu}{3 \times 10^{-9}} \right) 10^{-24} \tan\phi_e \ e\,\mathrm{cm} ,$$

$$d_\mu \simeq \left(\frac{\Delta a_\mu}{3 \times 10^{-9}} \right) 2 \times 10^{-22} \tan\phi_\mu \ e\,\mathrm{cm} ,$$

$$d_\tau \simeq \left(\frac{\Delta a_\mu}{3 \times 10^{-9}} \right) 4 \times 10^{-21} \tan\phi_\tau \ e\,\mathrm{cm} ,$$

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

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

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

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]:

$$(\delta^{ij}_{LR})_f \sim \frac{A_f \theta^f_{ij} m_{f_j}}{m_{\tilde{f}}} \quad f = u, d, \ell\,,$$

  - 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 $\theta^\ell_{ij} \sim \sqrt{m_i/m_j}$ [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

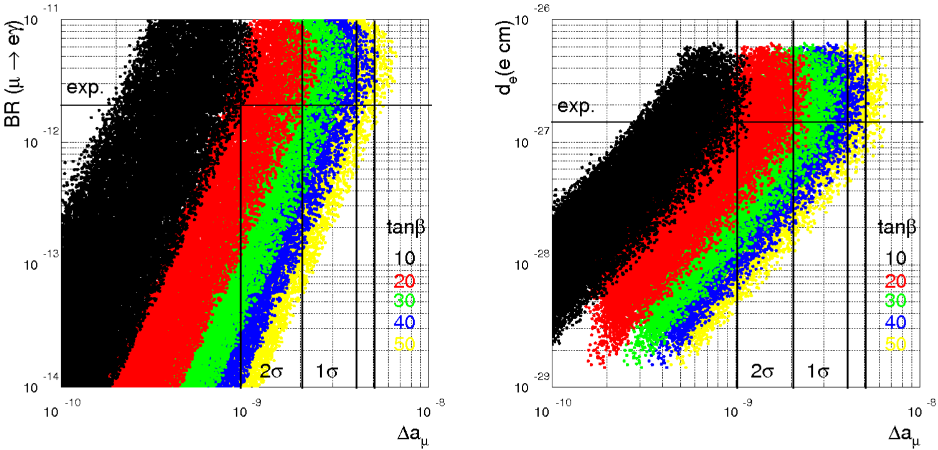
$$\mathrm{BR}(\mu \to e\gamma) \sim \left(\frac{\alpha}{\cos^2\theta_W}\right)^2 \left|\delta^{\mu e}_{LR}\right|^2 , \qquad \frac{d_e}{e} \sim \frac{\alpha}{\cos^2\theta_W}\,\mathrm{Im}\delta^{ee}_{LR}\,.$$

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

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

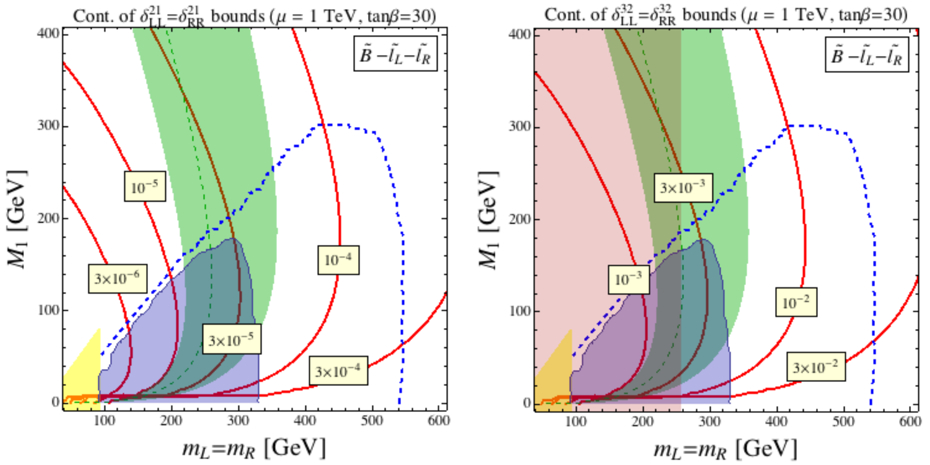
- $(g-2)_\mu$ is enhanced by $\approx 100 \times (\tan\beta/30)$ w.r.t. $\mu \to e\gamma$ and d_e amplitudes

A concrete SUSY scenario: “Disoriented A-terms”



Predictions for $\mu \to e\gamma$, Δa_μ and d_e in the disoriented A-term scenario with $\theta^\ell_{ij} = \sqrt{m_i/m_j}$. Left: $\mu \to e\gamma$ vs. Δa_μ. Right: d_e vs. Δa_μ [Giudice, P.P., & Passera, '12]

LFV and $(g-2)_\mu$ vs. LHC



- The light-blue (yellow) area is excluded by ATLAS (LEP) and the dashed line refers to the limits by LHC14 with $\mathcal{L} = 100\ \mathrm{fb}^{-1}$. The green band explains the $(g-2)_\mu$ anomaly at 2σ. The red-shaded area is excluded by a stau LSP.

[Calibbi, Galon, Masiero, P.P., & Shadmi, '15]

Testing new physics with the electron $g-2$

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

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

- **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":** $\Delta a_{\ell_i}/\Delta a_{\ell_j} = m^2_{\ell_i}/m^2_{\ell_j}$

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

  - 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 $g-2$

- **Standard Model vs. measurement**

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

  - 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**

$$\underbrace{(0.6)_{\mathrm{QED4}},\ \ (0.4)_{\mathrm{QED5}},\ \ (0.2)_{\mathrm{HAD}}}_{(0.7)_{\mathrm{TH}}},\ \ (7.6)_{\delta\alpha},\ \ (2.8)_{\delta a_e^{\mathrm{EXP}}} \qquad (1)$$

  - 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

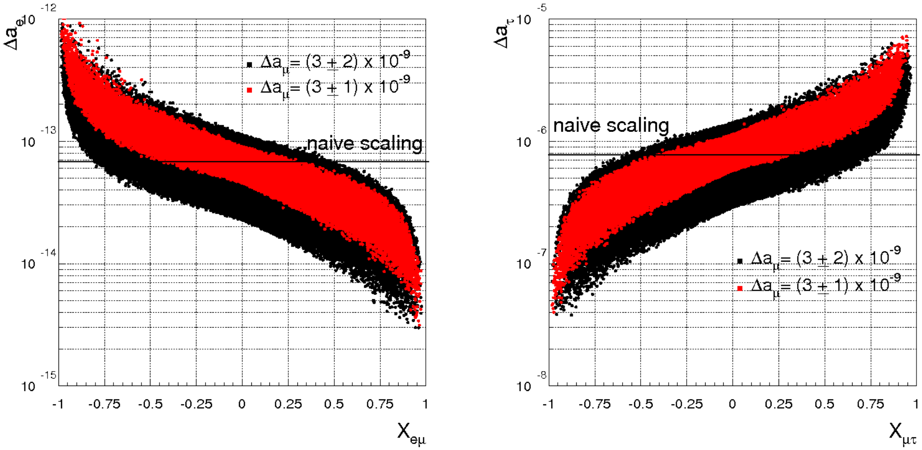
  - **Lepton flavor conserving (LFC) case:** the charged slepton mass matrix violates the global non-abelian flavor symmetry, but preserves $U(1)^3$. This case is characterized by non-degenerate sleptons ($m_{\tilde{e}} \neq m_{\tilde{\mu}} \neq m_{\tilde{\tau}}$) but vanishing mixing angles because of an exact alignment.

$$\Delta a_e \approx \Delta a_\mu \frac{m_e^2}{m_\mu^2} \frac{m_{\tilde{\mu}}^2}{m_{\tilde{e}}^2} \approx \frac{m_{\tilde{\mu}}^2}{m_{\tilde{e}}^2} \left(\frac{\Delta a_\mu}{3 \times 10^{-9}} \right) 10^{-13}$$

$$\Delta a_\tau \approx \Delta a_\mu \frac{m_\tau^2}{m_\mu^2} \frac{m_{\tilde{\mu}}^2}{m_{\tilde{\tau}}^2} \approx \frac{m_{\tilde{\mu}}^2}{m_{\tilde{\tau}}^2} \left(\frac{\Delta a_\mu}{3 \times 10^{-9}} \right) 10^{-6}$$

  - **Lepton flavor violating (LFV) case:** the slepton mass matrix fully breaks the flavor symmetry up to $U(1)$ lepton number. Now a_e and a_μ can receive new large contributions proportional to m_τ giving a new source of non-naive scaling.

“Naive scaling” violations



Left: Δa_e as a function of $X_{e\mu} = (m^2_{\tilde{e}} - m^2_{\tilde{\mu}})/(m^2_{\tilde{e}} + m^2_{\tilde{\mu}})$. Right: Δa_τ as a function of $X_{\mu\tau} = (m^2_{\tilde{\mu}} - m^2_{\tilde{\tau}})/(m^2_{\tilde{\mu}} + m^2_{\tilde{\tau}})$. Black points satisfy the condition $1 \leq \Delta a_\mu \times 10^9 \leq 5$, while red points correspond to $2 \leq \Delta a_\mu \times 10^9 \leq 4$.

[Giudice, P.P., & Passera, ’12]

“Naive scaling” vs. lepton flavor universality (LFU) violations

- In SUSY, “naive scaling” violations for $(g-2)_\ell$ can arise through sources of non-universalities in the slepton masses.

$$\Delta a_e \approx \Delta a_\mu \, \frac{m_e^2}{m_\mu^2} \frac{m_{\tilde{\mu}}^2}{m_{\tilde{e}}^2} \approx \frac{m_{\tilde{\mu}}^2}{m_{\tilde{e}}^2} \left(\frac{\Delta a_\mu}{3 \times 10^{-9}} \right) 10^{-13}$$

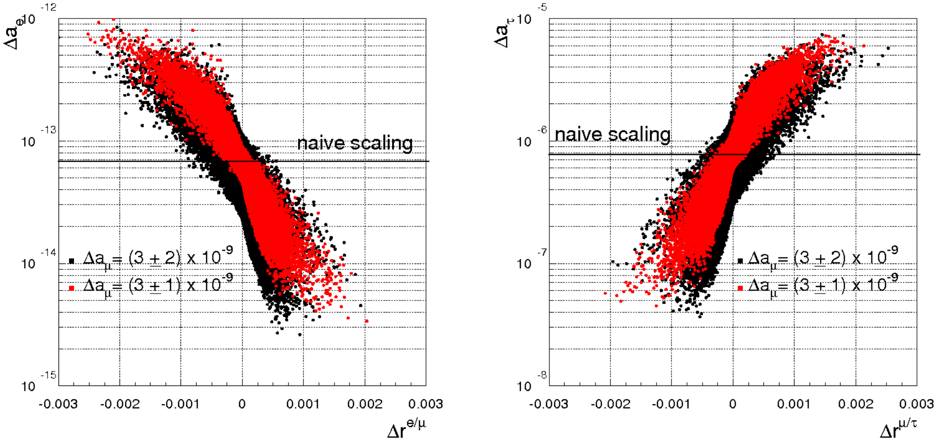
- Slepton non-universalities induce violations of LFU in $P \to \ell\nu$, $\tau \to P\nu$ (where $P = \pi, K$), $\ell_i \to \ell_j \bar{\nu}\nu$, $Z \to \ell\ell$ and $W \to \ell\nu$ through loop effects. Taking for example $R_P^{e/\mu} = \Gamma(P \to e\nu)/\Gamma(P \to \mu\nu)$

$$\frac{(R_P^{e/\mu})_{\rm EXP}}{(R_P^{e/\mu})_{\rm SM}} = 1 + \Delta r_P^{e/\mu}$$

- $\Delta r_P^{e/\mu} \neq 0$ signals the presence of new physics violating LFU.

$$\Delta r_{\rm P}^{e/\mu} \sim \frac{\alpha}{4\pi} \left(\frac{m_{\tilde{e}}^2 - m_{\tilde{\mu}}^2}{m_{\tilde{e}}^2 + m_{\tilde{\mu}}^2} \right) \frac{v^2}{\min(m_{\tilde{e},\tilde{\mu}}^2)}$$

“Naive scaling” vs. LFU violations



Left: $\Delta r_{\rm P}^{e/\mu}$ vs. Δa_e, where $\Delta r_{\rm P}^{e/\mu}$ measures violations of lepton universality in $\Gamma(P \to e\nu)/\Gamma(P \to \mu\nu)$ with $P = K, \pi$. Right: $\Delta r_{\rm P}^{\mu/\tau}$ vs. Δa_τ where $\Delta r_{\rm P}^{\mu/\tau}$ measures violations of lepton universality in $\Gamma(P \to \mu\nu)/\Gamma(\tau \to P\nu)$.

[Giudice, P.P., & Passera, ’12]

Light (pseudo)scalars and a_e

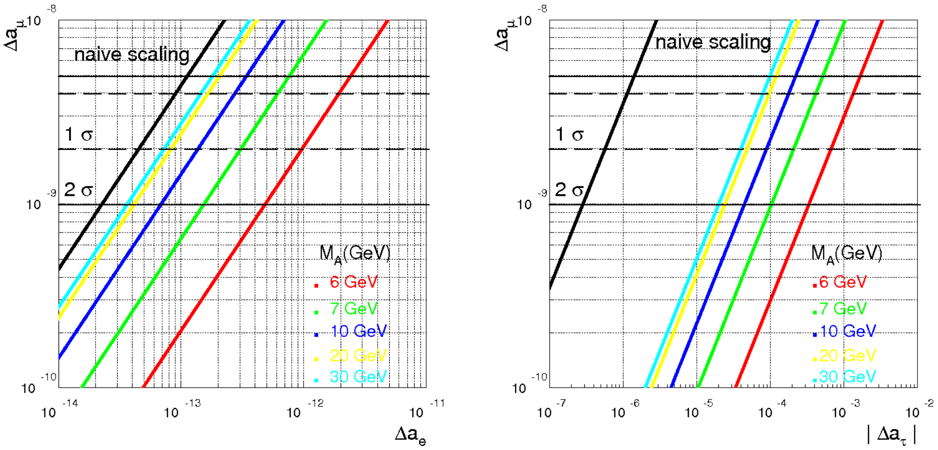
- **Lepton Yukawa interactions of a light scalar (pseudoscalar) ϕ (A)**

$$\mathcal{L} = \left(\frac{g m_\ell}{2M_W}\right) C_\phi^\ell \, \bar{\ell}\ell\phi + i \left(\frac{g m_\ell}{2M_W}\right) C_A^\ell \, \bar{\ell}\gamma_5 \ell A$$

  - A could be a pseudo-Goldstone boson of an extended Higgs sector and ϕ a light gauge singlet coupled through a dimension-five interaction to the Yukawa terms.
  - Very light ϕ and A are constrained by low-energy data (meson decays) as well as reactor experiments (most of these bounds disappear for $M_A > 10$ GeV).

- **For $m_\ell \ll M_A$, where the Δa_μ anomaly can be explained, we have**
  - Δa_e is always dominated by two-loop effects
  - Δa_μ receives comparable one- and two-loop contributions
  - Δa_τ is always dominated by one-loop effects.
  - As a result, we expect significant “naive scaling” violations

Light (pseudo)scalars and a_ℓ



- In the regions where the Δa_μ anomaly is accommodated, Δa_e typically exceeds the 10^{-13} level, providing a splendid opportunity to test the $(g-2)_\mu$ anomaly.
- $\Delta a_\tau \sim 10^{-3}$ is well within the experimental resolutions of Belle II.

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

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 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 $(g-2)$.
  - 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.

Conclusions

Irrespectively of whether the LHC will discover or not new particles, leptonic dipoles (leptonic $g-2$, $\mu \to e\gamma$ and the electron EDM) will teach us a lot...