$\mu \to e\gamma$ in the MSSM with Minimal Flavour Violation

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arXiv: 1102.1582 (hep-ph)

April 12, 2011

Sofia

Outline

The PMNS matrix

The charged current interaction Lagrangian:

$$\mathcal{L}_{CC} = -\frac{g_2}{\sqrt{2}} \sum_{i=1}^{3} \sum_{l=e,\mu,\tau} \bar{l}_L \gamma_\alpha U_{li} \nu_{i_L} W^{\alpha\dagger} + h.c.$$

PMNS matrix[a]:

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}, \qquad U \in \mathcal{C}^{3\times 3},\ U^\dagger = U^{-1}.$$

[a] Pontecorvo, Zh. Eksp. Teor. Fiz. 33, 549 (1957) and 34, 247 (1958).
Maki, Nakagawa, Sakata, Prog. Theor. Phys. 28, 870 (1962).

The PMNS matrix

Parametrisation:

$$U = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{i\delta} \\ -s_{12}c_{23} - c_{12}s_{13}s_{23}e^{i\delta} & c_{12}c_{23} - s_{12}s_{13}s_{23}e^{i\delta} & c_{13}s_{23} \\ s_{12}s_{23} - c_{12}s_{13}c_{23}e^{i\delta} & -c_{12}s_{23} - c_{23}s_{12}s_{13}e^{i\delta} & c_{13}c_{23} \end{pmatrix} T$$

where

$$T = \mathrm{diag}\left(1, e^{i\frac{\alpha_{21}}{2}}, e^{i\frac{\alpha_{31}}{2}}\right)$$

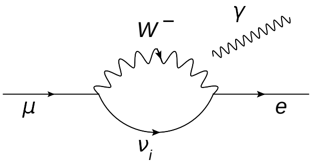
and

$c_{ij} \equiv \cos\theta_{ij}$, $s_{ij} \equiv \sin\theta_{ij}$, $\theta_{ij} \in \left[0, \frac{\pi}{2}\right]$

δ: Dirac CP violating phase

α_{21}, α_{31}: Majorana CP violating phases

$\mu \to e\gamma$ in the SM vs. experiments



SM branching ratio[b]

$$Br_{SM}(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\frac{\Delta m_{21}^2}{m_W^2} U_{e2} U_{\mu 2}^* + \frac{\Delta m_{31}^2}{m_W^2} U_{e3} U_{\mu 3}^*\right|^2 \approx 10^{-55}$$

[b]Bilenkii et al., Phys. Lett. B67 (1977) 309.
Marciano, Sanda, Phys. Lett. B67 (1977) 303.
Lee et al., Phys. Rev. Lett. 38 (1977) 937.

$\mu \to e\gamma$ in the SM vs. experiments

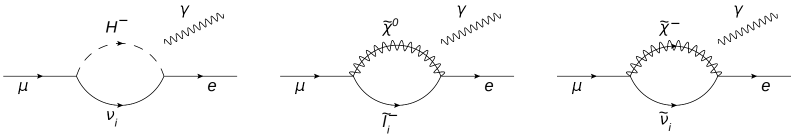
Experiments

At 90% C.L.:
MEGA[c]: $Br(\mu \to e\gamma) \leq 1.2 \cdot 10^{-11}$
MEG[d]: $Br(\mu \to e\gamma) \leq 2.8 \cdot 10^{-11}$

An experimental observation of the decay $\mu \to e\gamma$ would be a clear signal of new physics beyond the SM.

[c] Brooks et al., Phys. Rev. Lett. 83, 1521-1524 (1999).
[d] Adam et al., Nucl. Phys. B834, 1-12 (2010).

The SUSY contribution



The $\mu \to e\gamma$ decay rate

$$\Gamma(\mu \to e\gamma) = \frac{G_F^2 m_\mu^5 \alpha}{32\pi^4} \left| A_{W^\pm} + A_{H^\pm} + A_{\tilde{\chi}^0} + A_{\tilde{\chi}^\pm} \right|^2$$

The SUSY contribution

We consider mSUGRA with universal boundary conditions and minimal flavour violation.

At the GUT scale

- Universality: The soft SUSY breaking terms repeat the flavour structure of the original superpotential.
- 5 free parameters: m_0, $m_{1/2}$, A_0, $tan\beta$, $sgn(\mu)$.

Seesaw mechanism[e]

$$M_\nu = \begin{pmatrix} 0 & m_D \\ m_D^T & M_R \end{pmatrix}$$

$m_D \equiv v_2 Y_\nu \in \mathcal{C}^{3\times 3}$: Dirac mass matrix

$M_R \in \mathcal{C}^{3\times 3}$: Majorana mass matrix

Diagonalisation of M_ν in the L-R space:

$$M_{\nu_l} = m_D M_R^{-1} m_D^T, \quad M_{\nu_h} = M_R$$

Diagonalisation of M_{ν_l} in the flavour space with the PMNS matrix:

$$U^T M_{\nu_l} U = diag\left(m_{\nu_{l_1}}, m_{\nu_{l_2}}, m_{\nu_{l_3}}\right)$$

[e] Minkowski, Phys. Lett. B 67 (1977) 421.
Mohapatra, Senjanovic, Phys. Rev. Lett. 44 (1980) 912.
Glashow, in Quarks and Leptons, eds. M. Levy et al. (New York, 1980).

SUSY seesaw mechanism

At the GUT scale

Exact SUSY:

$$M^2_{\tilde{\nu}_l} = M^\dagger_{\nu_l} M_{\nu_l}, \quad M^2_{\tilde{\nu}_h} = M^\dagger_{\nu_h} M_{\nu_h}$$

SUSY braking with universal soft terms[f]:

$$M^2_{\tilde{\nu}_l} = \begin{pmatrix} (m_0^2 + \frac{1}{2} M_Z^2 \cos 2\beta) \mathbb{1}_{3\times 3} & 2(A_0 - \mu \cot\beta - B_0) M^*_{\nu_l} \\ 2(A_0 - \mu \cot\beta - B_0) M_{\nu_l} & (m_0^2 + \frac{1}{2} M_Z^2 \cos 2\beta) \mathbb{1}_{3\times 3} \end{pmatrix}$$

[f] Grossman, Haber, Phys. Rev. Lett. 78, 3438-3441 (1997).
Dedes et al., JHEP 0711, 059 (2007).

At the GUT scale

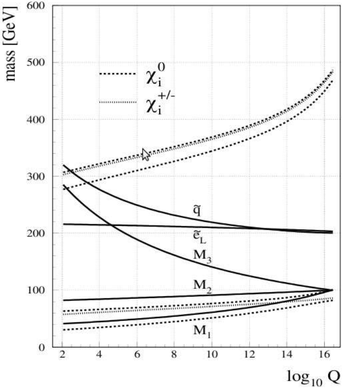
In the flavour space M_{ν_l} and $M^2_{\tilde{\nu}_l}$ are both diagonalised by the PMNS matrix.

$$\tilde{\nu}_{l_L} = \sum_{i=1}^{3} U^{\tilde{\nu}}_{li}\, \tilde{\nu}_{i_L},\ \ U^{\tilde{\nu}}_{li} = U_{li},\ \ l = e, \mu, \tau$$

The SUSY contribution

GUT scale → SUSY scale

RG evolution from the GUT scale down to the SUSY scale is model dependent[g], however, the parameters in the (s)lepton sector are hardly running.



[g] See i.e. Casas, Ibarra, Nucl. Phys. B618, 171-204 (2001), Pascoli et al., Phys. Lett. B564, 241-254 (2003), Branco et al., JHEP 0709, 004 (2007), Hisano et al., Phys. Rev. D53, 2442-2459 (1996) and refs. therein.

Figure from: de Boer, Ehret, Kazakov, Z. Phys. C67, 647-664 (1995).

The SUSY contribution

RG evolution

- Small mismatch between the neutrino and sneutrino mass matrices.
- FCNC contribution is suppressed.
- The contribution from heavy right-handed neutrinos and sneutrinos is suppressed by a very small mixing angle $\sim \frac{m_D}{M_R}$.

$\Rightarrow$ The LFV appears in FCCC processes described by the PMNS matrix.

The SUSY contribution

Contributions

- SM contribution: $A_{W^\pm} \sim \frac{m_\nu^2}{m_W^2} \Rightarrow$ negligible
- Charged Higgs contribution: $A_{H^\pm}$ involves neutrinos $\Rightarrow$ negligible
- Neutralino contribution: LFV through a FCNC $\Rightarrow$ suppressed
- Chargino contribution: LFV through a FCCC described by the PMNS matrix $\Rightarrow$ The most important contribution

The chargino contribution

The $\mu \to e\gamma$ branching ratio

$$Br(\mu \to e\gamma) \equiv \frac{\Gamma(\mu \to e\gamma)}{\Gamma(\mu \to e\bar{\nu}\nu)} = \frac{6\alpha}{\pi} \left|A_{\chi^\pm}\right|^2$$

The PMNS matrix is unitary $\Rightarrow A_{\tilde{\chi}^\pm} = 0$ for $m_{\tilde{\nu}_1} = m_{\tilde{\nu}_2} = m_{\tilde{\nu}_3}$.
For our considerations $m_{\tilde{\nu}_1} \approx m_{\tilde{\nu}_2}$

$$\Rightarrow A_{\tilde{\chi}^\pm} \sim U_{\mu 3} U^*_{e3} \left[f_{1,2}\left(\frac{m^2_{\tilde{\nu}_3}}{m^2_{\tilde{\chi}^\pm_j}}\right) - f_{1,2}\left(\frac{m^2_{\tilde{\nu}_1}}{m^2_{\tilde{\chi}^\pm_j}}\right) \right]$$

$$\sim \cos\theta_{13} \sin\theta_{13} \sin\theta_{23}$$

The chargino contribution

θ_{13} is poorly measured[h]:

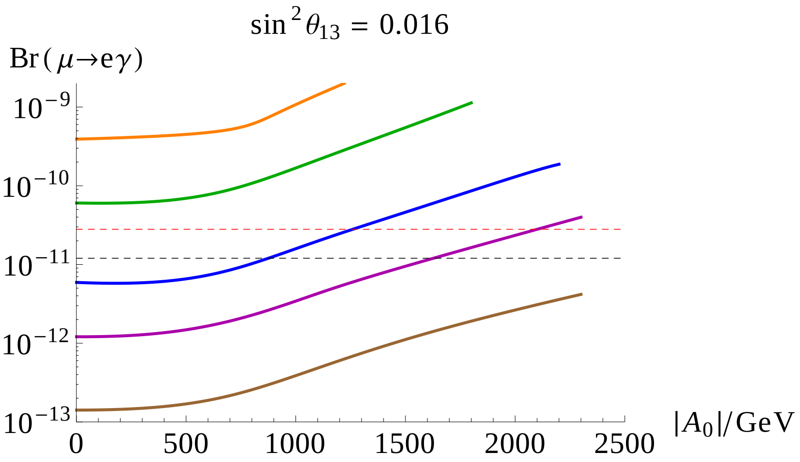
$$\sin^2\theta_{13} \leq 0.035\ (0.056)\ \textit{at}\ 90\%\ (99.73\%)\ \mathrm{C.L.}$$

Global analysis of all available neutrino oscillation data[i]:

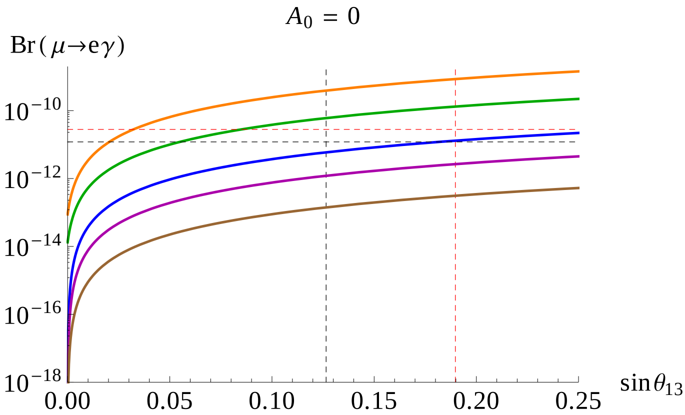
$$\sin^2\theta_{13} = 0.016 \pm 0.010$$

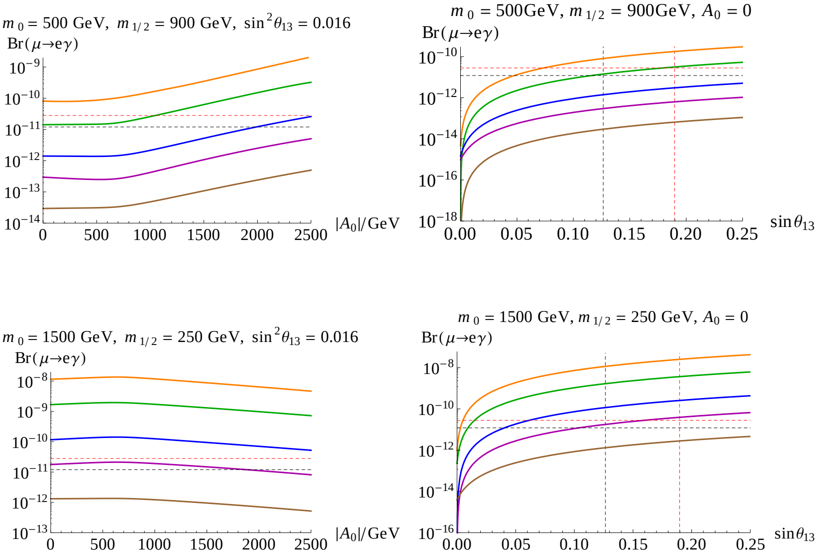
[h] Schwetz et al., New J. Phys. 10, 113011 (2008).
[i] Fogli et al., Phys. Rev. Lett. 101 (2008) 141801.

$m_0 = 500$ GeV, $m_{1/2} = 500$ GeV



$m_0 = 500$ GeV, $m_{1/2} = 500$ GeV




$m_0 = 500$ GeV, $m_{1/2} = 900$ GeV, $\sin^2\theta_{13} = 0.016$
Br($\mu\to e\gamma$)
$|A_0|$/GeV
$m_0 = 500$GeV, $m_{1/2} = 900$GeV, $A_0 = 0$
Br($\mu\to e\gamma$)
$\sin\theta_{13}$
$m_0 = 1500$ GeV, $m_{1/2} = 250$ GeV, $\sin^2\theta_{13} = 0.016$
Br($\mu\to e\gamma$)
$|A_0|$/GeV
$m_0 = 1500$ GeV, $m_{1/2} = 250$ GeV, $A_0 = 0$
Br($\mu\to e\gamma$)
$\sin\theta_{13}$

Conclusions

- The decay $\mu \to e\gamma$ might serve as a direct manifestation of physics beyond the SM, in particular, supersymmetry.
- The supersymmetric contribution to $\mu \to e\gamma$ decay crucially depends on the mixing angle θ_{13} which is not precisely measured.
- Global analyses of the SUSY parameter space prefer small values of θ_{13}. The experimental determination of this parameter is very important for placing stringent constraints on the MSSM parameter space.