τs and Bs versus μs and Ks where to look for new physics?

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Theory view

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- Flavour physics and new physics flavour-dependent generically strongly linked with 3^{rd} generation.
- Flavoured CP violation also associated to mixing and 3^{rd} generation.

$\Longrightarrow$ **Expect large FCNC and CP violation in Bs and τs**

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- Flavour physics and new physics flavour-dependent generically strongly linked with 3^{rd} generation.
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$\Rightarrow$ **Expect large FCNC and CP violation in Bs and τs**

Mixings and couplings much smaller in K and μ systems.

$\Rightarrow$ **Assuming "similar" experimental sensitivity 3^{rd} generation generically better**

Experimental View

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Kaon and μ physics

In the "SM", **small** mixings and suppressed CP phases. But new physics has to compete with "small" SM contributions

$\Longrightarrow$ **Complicate measurements, but possible...**
Small NP reachable in a small background.

Experimental View

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$\Rightarrow$ **Complicate measurements, but possible... Small NP reachable in a small background.**

B and τ physics

In the SM, larger FCNC and CP transitions. But NP has to compete with this large contribution.

$\Rightarrow$ **Is it more difficult to find NP here?**

Example I: ε_K and B_s mixing in SUSY

- Large contributions possible on $d \longrightarrow s$ transitions (ε_k):

$\mathrm{Re}\{(\delta^d_R)_{12}\} \leq 4 \times 10^{-2}$, $\mathrm{Im}\{(\delta^d_R)_{12}\} \leq 3.2 \times 10^{-3}$

However, things are difficult in B system...

- SM phase in B_s small: $\beta_S = 0.035$, where the SM contribution to mixing:

$$M_{12}^{\mathrm{SM}} \simeq \frac{\alpha_{em}^2}{8 M_W^2 \sin^2\theta_W} \frac{m_t^2}{M_W^2} \tfrac{1}{3} f_B^2 B_B \left(V_{tb}^* V_{ts}\right)^2$$

while SUSY contribution:

$$M_{12}^{\mathrm{SUSY}} \simeq \frac{\alpha_s^2}{216 M_{\mathrm{SUSY}}^2} f(x) \tfrac{1}{3} f_B^2 B_B \left(\delta^d_{LL}\right)^2_{12}$$

- To have a large phase in mixing $M_{12}^{B_s} = M_{12}^{\mathrm{SM}} + M_{12}^{\mathrm{SUSY}}$, we need,

$$1 \simeq \frac{M_{12}^{\mathrm{SUSY}}}{M_{12}^{\mathrm{SM}}} = \frac{\alpha_s^2 \sin^2\theta_W}{\alpha_{em}^2} \frac{M_W^2}{m_t^2 M_{\mathrm{SUSY}}^2} \frac{8 f(x)}{216} \frac{\left(\delta^d_{LL}\right)^2_{12}}{\left(V_{tb}^* V_{ts}\right)^2} = 12.5 \times 0.005 \times 0.04 \times \frac{\left(\delta^d_{LL}\right)^2_{12}}{(0.008)^2}$$

Thus, to have a large phase in B_s $\Longrightarrow$ $\left(\delta^d_{LL}\right)_{12} \geq 0.16$

Example II: μ versus τ

- Present experimental sensitivity in μ LFV decays:

$$\propto \text{BR}(\mu \to e\gamma) = 10^{-11}\ (10^{-13})$$

while in τ LFV decays:

$$\propto \text{BR}(\tau \to \mu\gamma) = 10^{-8}\ (10^{-9})$$

- Generically we can write $l_i \to l_j\gamma$ transitions:

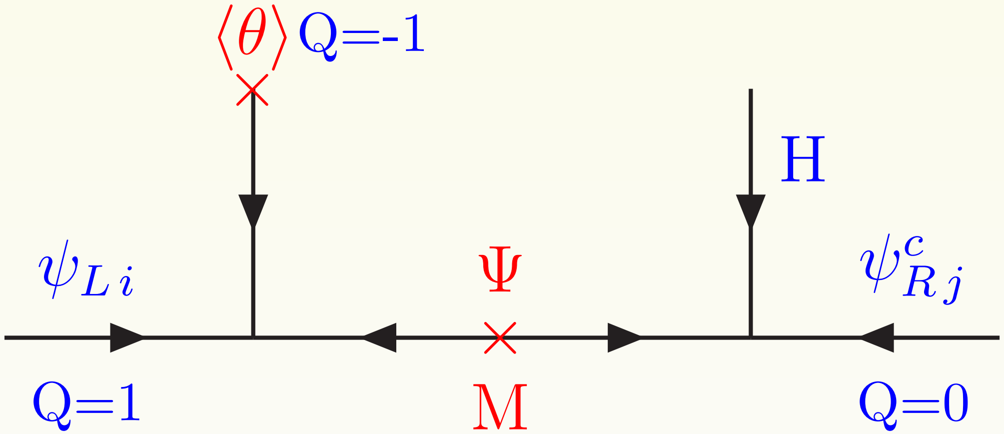
$$\text{BR}(l_i \to l_j\gamma) \simeq \left(\frac{M_W}{M_{NP}}\right)^4 \times |\left(\delta^l\right)_{ij}|^2 \times f(\tan\beta, \mu \ldots),$$

$\Rightarrow$ **Interesting models determined by flavour structure:**

$$|\left(\delta^l\right)_{i3} / \left(\delta^l\right)_{12}| \gtrsim 30\ (100)$$

Flavour symmetries in SUSY

- Very different elements in Yukawa matrices: $y_t \simeq 1$, $y_u \simeq 10^{-5}$
- Expect couplings in a "fundamental" theory $\mathcal{O}(1)$
- Small couplings generated at higher order or function of small vevs.
- Froggatt-Nielsen mechanism and flavour symmetry to understand small Yukawa elements. Example: $U(1)_{fl}$



$$\Rightarrow Y_{ij} = \left(\frac{\langle\theta\rangle}{M}\right) \ll 1$$

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$\Downarrow$

We can relate the structure in Yukawa matrices to the nonuniversality in Soft Breaking masses !!!

Symmetric texture

- Non-Abelian flavour symmetries.

$$Y^d = \begin{pmatrix} 0 & 1.5\ \varepsilon^3 & 0.4\ \varepsilon^3 \\ 1.5\ \varepsilon^3 & \varepsilon^2 & 1.3\ \varepsilon^2 \\ 0.4\ \varepsilon^3 & 1.3\ \varepsilon^2 & 1 \end{pmatrix} y_b$$

- Universal sfermion masses in in unbroken limit:

$$\mathcal{L}_{m^2} = m_0^2 \Phi^\dagger \Phi = m_0^2 \left(\phi_1\ \phi_2\ \phi_3\right)^* \begin{pmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \end{pmatrix}$$

- After symmetry breaking:

$$M^2_{\tilde{D}_R} \simeq \begin{pmatrix} 1+\bar{\varepsilon}^3 & \bar{\varepsilon}^3 & 0 \\ \bar{\varepsilon}^3 & 1+\bar{\varepsilon}^2 & \bar{\varepsilon}^2 \\ 0 & \bar{\varepsilon}^2 & 1+\bar{\varepsilon} \end{pmatrix} m_0^2$$

Asymmetric texture

- Abelian flavour symmetries.

$$Y^d = \begin{pmatrix} \varepsilon^4 & \varepsilon^3 & \varepsilon^3 \\ \varepsilon^3 & \varepsilon^2 & \varepsilon^2 \\ \varepsilon & 1 & 1 \end{pmatrix} y_b$$

- In principle nonuniversal masses in unbroken symmetry:

$$\mathcal{L}_{m^2} = m_1^2\ \phi_1^* \phi_1 + m_2^2\ \phi_2^* \phi_2 + m_3^2\ \phi_3^* \phi_3$$

- After symmetry breaking:

$$M^2_{\tilde{D}_R} \simeq \begin{pmatrix} 1 & \bar{\varepsilon} & \bar{\varepsilon} \\ \bar{\varepsilon} & c & b \\ \bar{\varepsilon} & b & a \end{pmatrix} m_0^2$$

FCNC constraints

- Large offdiagonal entries in sfermion mass matrices generally overproduce FCNC and CP Violation transitions

$\Rightarrow$ SUSY flavour problem

- Strong phenomenological bounds on Mass Insertions

$$\left(\delta^f_A\right)_{ij} = \frac{(m^2_{\tilde{f}_A})_{ij}}{m^2_{\tilde{f}}}$$

- Very stringent bounds on $d \to s$ transitions from ΔM_k and ε_k:

$$\mathrm{Re}\{\left(\delta^d_R\right)_{12}\} \leq 4 \times 10^{-2}, \qquad \mathrm{Im}\{\left(\delta^d_R\right)_{12}\} \leq 3.2 \times 10^{-3}$$

- Less stringent bounds from $b \to d$ and $b \to s$ transitions

$$\mathrm{Re}\{\left(\delta^d_R\right)_{13}\},\ \mathrm{Im}\{\left(\delta^d_R\right)_{13}\} \ \leq \ 0.1$$

($\Rightarrow$ Simple abelian models not allowed by ΔM_k and ε_k)

Abelian Flavour symmetry

- "Realistic" model with two Abelian groups $U(1)_1 \times U(1)_2$
- Charges under $(U(1)_1, U(1)_2)$:

$$Q_1 \sim (0,1),\quad Q_2 \sim (1,0),\quad Q_3 \sim (0,0),\qquad \phi_1 \sim (-1,0) \text{ with } \langle\phi_1\rangle/M = \lambda_c^2$$
$$d_1^c \sim (3,-1),\quad d_2^c \sim (1,0),\quad d_3^c \sim (1,0),\qquad \text{(flavons)}$$
$$u_1^c \sim (0,1),\quad u_2^c \sim (-1,1),\quad u_3^c \sim (0,0)\qquad \phi_2 \sim (0,-1) \text{ with } \langle\phi_2\rangle/M = \lambda_c^3$$

- Yukawa couplings proportional to: $Y_{ij} = \left(\frac{\langle\phi_1\rangle}{M}\right)^{(q_1^i+q_1^j)} \left(\frac{\langle\phi_2\rangle}{M}\right)^{(q_2^i+q_2^j)}$

$$M^{d,e} = \langle H_1\rangle\, \lambda^2 \begin{pmatrix} \lambda^4 & \lambda^3 & \lambda^3 \\ 0 & \lambda^2 & \lambda^2 \\ 0 & 1 & 1 \end{pmatrix}, \qquad M^u = \langle H_2\rangle \begin{pmatrix} \lambda^6 & 0 & \lambda^3 \\ \lambda^5 & \lambda^3 & \lambda^2 \\ \lambda^3 & 0 & 1 \end{pmatrix}.$$

- Soft mass coupling $\phi_i^\dagger \phi_i$ invariant under all symmetries
  $\Longrightarrow$ flavour diagonal soft masses allowed by flavour symmetry
- Diagonal masses required to be equal by phenomenology
- After symmetry breaking offdiagonal entries proportional to flavon vevs

$$M_{ij}^2 = m_0^2 \left(\frac{\langle\phi_1\rangle}{M}\right)^{|q_1^i - q_1^j|} \left(\frac{\langle\phi_2\rangle}{M}\right)^{|q_2^i - q_2^j|}$$

$$M^2_{\tilde{D}_R,\tilde{E}_L} \sim m_0^2 \begin{pmatrix} 1 & \lambda^7 & \lambda^7 \\ \lambda^7 & 1 & 1 \\ \lambda^7 & 1 & 1 \end{pmatrix}, \qquad M^2_{\tilde{U}_R} \sim m_0^2 \begin{pmatrix} 1 & \lambda^2 & \lambda^3 \\ \lambda^2 & 1 & \lambda^5 \\ \lambda^3 & \lambda^5 & 1 \end{pmatrix},$$

$$M^2_{\tilde{D}_L} = M^2_{\tilde{U}_L} \sim m_0^2 \begin{pmatrix} 1 & \lambda^5 & \lambda^3 \\ \lambda^5 & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}.$$

$SU(3)$ Flavour model

- $Q, L \sim \mathbf{3}$ and $d^c, u^c, e^c \sim \mathbf{3}$; flavon fields: $\theta_3, \theta_{23} \sim \overline{\mathbf{3}}$, $\overline{\theta}_3, \overline{\theta}_{23} \sim \mathbf{3}$
- Family Symmetry breaking: $SU(3) \xrightarrow{\langle\theta_3\rangle} SU(2) \xrightarrow{\langle\theta_{23}\rangle} \emptyset$

$$\theta_3, \overline{\theta}_3 = \begin{pmatrix} 0 \\ 0 \\ a_3 \end{pmatrix}, \quad \theta_{23}, \overline{\theta}_{23} = \begin{pmatrix} 0 \\ b \\ b \end{pmatrix} \text{with} \quad \left(\frac{a_3}{M}\right) \sim \mathcal{O}(1), \left(\frac{b}{M_u}\right) \simeq \left(\frac{b}{M_d}\right)^2 = \varepsilon \sim 0.05.$$

- Yukawa superpotential: $W_Y = H\psi_i\psi_j^c\left[\theta_3^i\theta_3^j + \theta_{23}^i\theta_{23}^j\left(\theta_3\overline{\theta_3}\right) + \epsilon^{ikl}\overline{\theta}_{23,k}\overline{\theta}_{3,l}\theta_{23}^j\left(\theta_{23}\overline{\theta_3}\right)\right]$

$$Y^f = \begin{pmatrix} 0 & a\ \varepsilon^3 & b\ \varepsilon^3 \\ a\ \varepsilon^3 & \varepsilon^2 & c\ \varepsilon^2 \\ b\ \varepsilon^3 & c\ \varepsilon^2 & 1 \end{pmatrix} \frac{|a_3|^2}{M^2},$$

- Soft mass coupling $\Phi^\dagger\Phi$ invariant $\Longrightarrow$ common soft mass for the triplet
- Universality guaranteed in the exact symmetry limit.
- After symmetry breaking offdiagonal entries proportional to (complex) flavon vevs

$$M^2_{ij} = m_0^2 \Big(\delta^{ij} + \frac{1}{M^2}[\theta_3^{i\dagger}\theta_3^j + \overline{\theta}_3^{i\dagger}\overline{\theta}_3^j + \theta_{23}^{i\dagger}\theta_{23}^j + \overline{\theta}_{23}^{i\dagger}\overline{\theta}_{23}^j] + \frac{1}{M^4}[(\epsilon^{ikl}\overline{\theta}_{3,k}\overline{\theta}_{23,l})^\dagger(\epsilon^{jmn}\overline{\theta}_{3,m}\overline{\theta}_{23,n}) + (\epsilon_{ikl}\theta_3^k\theta_{23}^l)^\dagger(\epsilon_{jmn}\theta_3^m\theta_{23}^n)] + \ldots \Big)$$

$$M^2_{\tilde{D}_R}{}^{\rm SCKM} \simeq 6\, M^2_{1/2}\, \mathbb{1} + \begin{pmatrix} 1+\bar\varepsilon^3 & \bar\varepsilon^3 & \bar\varepsilon^3 \\ \bar\varepsilon^3 & 1+\bar\varepsilon^2 & \bar\varepsilon^2 \\ \bar\varepsilon^3 & \bar\varepsilon^2 & 1+\bar\varepsilon \end{pmatrix} m_0^2$$

(with $\bar\varepsilon \simeq 0.15$, $\varepsilon \simeq 0.05$)

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$$M^2_{\tilde{D}_R}{}^{\rm SCKM} \simeq 6\, M^2_{1/2}\, \mathbb{1} + \begin{pmatrix} 1 & 0.003 & 0.003 \\ 0.003 & 1 & 0.02 \\ 0.003 & 0.02 & 1 \end{pmatrix} m_0^2$$

(with $\bar{\varepsilon} \simeq 0.15, \varepsilon \simeq 0.05$)

At M_W in the SCKM basis:

$$M^2_{\tilde{D}_L} \simeq 6\, M^2_{1/2}\, \mathbb{1} + \begin{pmatrix} 1+\varepsilon^3 & \varepsilon^2\bar{\varepsilon} & \varepsilon^2\bar{\varepsilon} + c_{\rm run}\ \bar{\varepsilon}^3 \\ \varepsilon^2\bar{\varepsilon} & 1+\varepsilon^2 & \varepsilon^2 + c_{\rm run}\ \bar{\varepsilon}^2 \\ \varepsilon^2\bar{\varepsilon} + c_{\rm run}\ \bar{\varepsilon}^3 & \varepsilon^2 + c_{\rm run}\ \bar{\varepsilon}^2 & 1+\bar{\varepsilon} \end{pmatrix} m_0^2$$

$$M^2_{\tilde{E}_R} \simeq 0.15\, M^2_{1/2}\, \mathbb{1} + \begin{pmatrix} 1+\bar{\varepsilon}^3 & \frac{\bar{\varepsilon}^3}{3} & \bar{\varepsilon}^3 \\ \frac{\bar{\varepsilon}^3}{3} & 1+\bar{\varepsilon}^2 & \bar{\varepsilon}^2 \\ \bar{\varepsilon}^3 & \bar{\varepsilon}^2 & 1+\bar{\varepsilon} \end{pmatrix} m_0^2$$

$$M^2_{\tilde{E}_L} \simeq 0.5\, M^2_{1/2}\, \mathbb{1} + \begin{pmatrix} 1+\varepsilon^3 & \frac{\varepsilon^2\bar{\varepsilon}}{3} & \varepsilon^2\bar{\varepsilon} + c_{\rm run}\ \bar{\varepsilon}^3 \\ \frac{\varepsilon^2\bar{\varepsilon}}{3} & 1+\varepsilon^2 & \varepsilon^2 + 3\ c_{\rm run}\ \bar{\varepsilon}^2 \\ \varepsilon^2\bar{\varepsilon} + c_{\rm run}\ \bar{\varepsilon}^3 & \varepsilon^2 + 3\ c_{\rm run}\ \bar{\varepsilon}^2 & 1+\varepsilon \end{pmatrix} m_0^2$$

At M_W in the SCKM basis:

$$M^2_{\tilde{D}_L} \simeq 6\, M^2_{1/2}\, \mathbb{1} + \begin{pmatrix} 1 & 4\times 10^{-4} & 7\times 10^{-4} \\ 4\times 10^{-4} & 1 & 4\times 10^{-3} \\ 7\times 10^{-4} & 4\times 10^{-3} & 1 \end{pmatrix} m_0^2$$

$$M^2_{\tilde{E}_R} \simeq 0.15\, M^2_{1/2}\, \mathbb{1} + \begin{pmatrix} 1 & 0.001 & 0.003 \\ 0.001 & 1 & 0.02 \\ 0.003 & 0.02 & 1 \end{pmatrix} m_0^2$$

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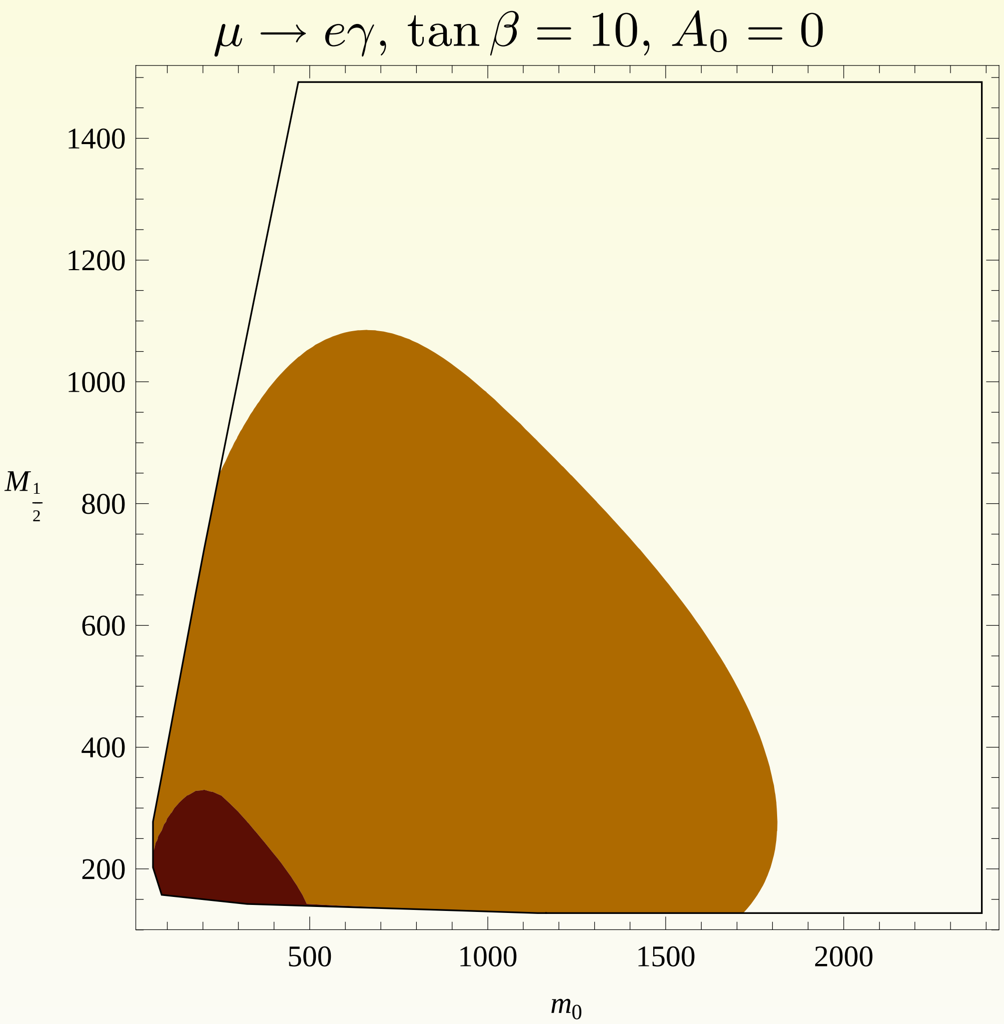
WARNING!!!

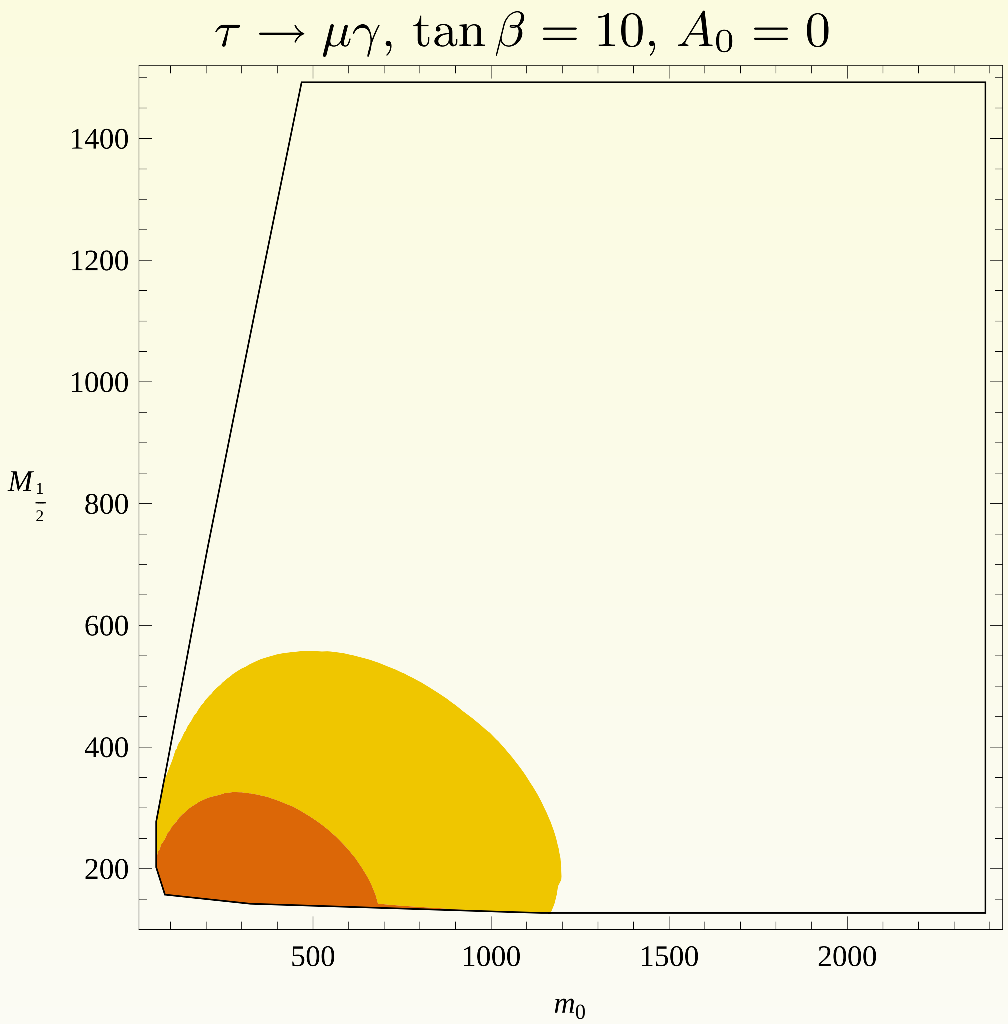
$O(1)$ coefficients in soft breaking terms completelly unknown.

Following plots are only true in order of magnitude !!

Predictions may easily vary by factors of 2, 3 . . .

Lepton Flavour Violation





Brown (clear): Present (fut.) $\mu \to e\gamma$ bounds, Orange: Present (fut.) $\tau \to \mu\gamma$ bounds.

Type I seesaw in MFV SUSY

- Offdiagonal Mass Insertions generated through RGE running proportional to neutrino Yukawas :

$$[m^2_{\tilde{L}}]_{21} \approx -\frac{1}{8\pi^2}(3m_0^2 + A_0^2)\; h_{23}h^*_{13} \log(\frac{M_{GUT}}{M_R})$$

$\Longrightarrow$ **LFV depends on the neutrino Yukawa structure**

- PMNS-like Yukawas with $U_{e3} = 0$

$$\text{BR}(\mu \to e\gamma) \propto |U_{e3}|^2 + O((m_c/m_t)^2)$$

$\Longrightarrow$ **$\tau \to \mu\gamma$ large in these models!!!**

$\tau \to l_i l_k l_k$ versus $\mu \to eee$

- SuperB better sensitivity for $\tau \to 3l$:

$$\propto \mathrm{BR}(\tau \to l_i l_k l_k) \sim 2 \times 10^{-10}$$

- Typically in SUSY models, $\tau \to 3l$ is penguin dominated, then:

$$\frac{\mathrm{BR}(\tau \to l_j l_k l_k)}{\mathrm{BR}(\tau \to l_j \gamma)} \sim \alpha_{em},$$

$\Rightarrow$ **$\tau \to \mu\gamma$ is usually better here.**

- However other models have large boxes or other contributions and $\tau \to 3l$ can be larger: Example: LHT, type II sesaw, type III seesaw

LHT$\Rightarrow$ Talk by B. Duling

Type II seesaw (Abada et al. 0707.4058)

- Tree level contributions mediated by triplet Higgs $\tau \to 3l$.

$$BR(\tau \to 3l) \simeq 10 \left(\frac{M_W}{M_\Delta}\right)^4 \times \left|Y_{\Delta_{\tau i}}\right|^2 \left|Y_{\Delta_{jj}}\right|^2$$

Type III seesaw (Abada et al. 0707.4058)

- Tree level LFV mediated by Z!! $\propto (NN^\dagger)_{i\tau}$

$$BR(\tau \to l_i l_j l_j) \simeq 0.15 \left|(NN^\dagger)^2_{i\tau}\right|^2$$