Flavor violation in a SUSY GUT

Jae-hyeon Park

Tohoku University

Work in progress

in collaboration with

Pyungwon Ko and Masahiro Yamaguchi

SUSY 2007, University of Karlsruhe, 2007–07–28

Supersymmetrizing the Standard Model

attractively

- offers a natural candidate of dark matter
- stabilizes hierarchy between distant scales
- helps gauge coupling unification

$\Longrightarrow$ has an intimate relation with grand unification

Supersymmetrizing the Standard Model

attractively

- offers a natural candidate of dark matter
- stabilizes hierarchy between distant scales
- helps gauge coupling unification

  $\Longrightarrow$ has an intimate relation with grand unification

however

- may cause cosmological problems (gravitino, moduli)
- introduces many potential sources of flavor and CP violations in the soft SUSY breaking terms

  $\Longrightarrow$ may serve as a probe of SUSY

Flavor violation as a probe of SUSY

- Down-type scalar quark mass term:

$$-\mathscr{L}_{\text{soft}} \ni \widetilde{d}^*_{Ai}\, (M^2_{d,AB})_{ij}\, \widetilde{d}_{Bj}$$

$A, B = L, R$ and $i, j = 1, 2, 3$

- may lead to an interaction

$$\tilde{d}_{B\,j} \text{ - - - }\times\text{ - - - } \tilde{d}_{A\,i} \quad = -i\,(M^2_{d,AB})_{ij}$$

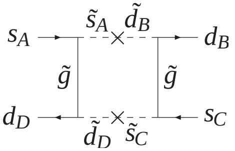
if M^2_d is non-diagonal in the basis where m_d is diagonal and a d–$\widetilde{d}$–$\widetilde{g}$ vertex preserves flavor

- For almost diagonal $M^2_{\tilde{d}}$, use a mass insertion parameter

$$(\delta^d_{ij})_{AB} \equiv (\Delta^d_{ij})_{AB}/m^2_{\tilde{d}}$$
$$(M^2_{d,AB})_{ij} = m^2_{\tilde{d}}\,\delta_{ij} + (\Delta^d_{ij})_{AB}$$

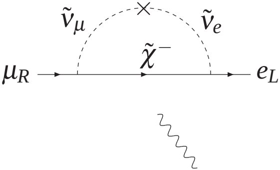
Hadronic and leptonic flavor violations

- K^0–$\overline{K^0}$ mixing



$$\propto \quad (\delta^d_{12})_{BA} \times (\delta^d_{12})_{DC}$$

- $\mu \to e\gamma$



$$\propto \quad (\delta^l_{12})_{LL}$$

SUSY GUT and flavor physics

- Superpotential of SUSY SU(5) model

$$W_{\rm GUT} = (1/8)\, T^T \lambda_U T H + T^T \lambda_D \overline{F}\overline{H} + \nu_R^T \lambda_\nu \overline{F} H + (1/2)\, \nu_R^T M_R \nu_R$$

$$T\ [\mathbf{10}] = \{Q, V_Q^\dagger \Theta_Q^\dagger \overline{U}, \Theta_L \overline{E}\}, \quad \overline{F}\ [\bar{\mathbf{5}}] = \{\overline{D}, \Theta_L^\dagger L\}$$

- Part of $W_{\rm GUT}$ in terms of MSSM fields, in a particular basis

$$W_{\rm SSM} = Q^T [V_Q^T \widehat{Y}_U] \overline{U} H_u + Q^T [\widehat{Y}_D] \overline{D} H_d + \overline{E}^T [\widehat{Y}_D] L H_d + \nu_R^T [\widehat{Y}_\nu V_L] L H_u + (1/2)\, \nu_R^T M_R \nu_R$$

- Soft scalar mass terms

$$-\mathscr{L}_{\rm soft} \supset \widetilde{Q}^\dagger m_{\mathbf{10}}^2 \widetilde{Q} + \widetilde{\overline{E}}^\dagger \Theta_L^\dagger m_{\mathbf{10}}^2 \Theta_L \widetilde{\overline{E}} + \widetilde{\overline{U}}^\dagger \Theta_Q V_Q m_{\mathbf{10}}^2 V_Q^\dagger \Theta_Q^\dagger \widetilde{\overline{U}} + \widetilde{\overline{D}}^\dagger m_{\bar{\mathbf{5}}}^2 \widetilde{\overline{D}} + \widetilde{L}^\dagger \Theta_L m_{\bar{\mathbf{5}}}^2 \Theta_L^\dagger \widetilde{L}$$

- Ignore phase factor Θ_L not relevant to $B(l_i \to l_j \gamma)$; then,

$$(\delta_{ij}^d)_{LL} = (\delta_{ij}^l)_{RR}^*, \quad (\delta_{ij}^d)_{RR} = (\delta_{ij}^l)_{LL}^* \qquad \text{at } M_{\rm GUT}$$

Grand unification of flavor violations

Ciuchini, Masiero, Silvestrini, Vempati, Vives, PRL(2004)

- Off-diagonal entries of scalar mass matrix are not renormalized very much if between M_{GUT} and M_{SUSY} is a desert

$$(\delta^d_{ij})_{RR} = (\delta^l_{ij})^*_{LL} \quad \text{at } M_{\mathrm{GUT}} \quad \Longrightarrow \quad (\delta^d_{ij})_{RR} \approx \frac{m^2_{\tilde{L}}}{m^2_{\tilde{d}}} (\delta^l_{ij})^*_{LL} \quad \text{at } M_{\mathrm{SUSY}}$$

- Large couplings and large mixing in Y_ν may modify the relation at M_{SUSY}; still, a footprint of the GUT relation remains
- Naturally expected correlations among flavor transitions

Transitions of L		Transitions of $\overline{D}$
$\mu \to e$	$\leftrightarrow$	$s \to d$
$\tau \to e$	$\leftrightarrow$	$b \to d$
$\tau \to \mu$	$\leftrightarrow$	$b \to s$

Caveat: $Y_D \neq Y_E^T$ at $M_{\rm GUT}$

- Fermion mass relations from $W_{\rm GUT}$,

$$\overline{m}_e = \overline{m}_d, \quad \overline{m}_\mu = \overline{m}_s, \quad \overline{m}_\tau = \overline{m}_b \qquad \text{at } M_{\rm GUT},$$

  are inconsistent with data
- Solutions: add non-renormalizable terms or $\mathbf{45}$ Higgs
- In the basis where Y_D is diagonal,

$$Y_U = V_Q^T \widehat{Y}_U U_Q^*, \quad Y_D = \widehat{Y}_D, \quad Y_E = U_L^T \widehat{Y}_E U_R^*, \quad Y_N = U_L^T V_L^T \widehat{Y}_N$$

- GUT relations are modified to

$$\delta^l_{LL} = U_L\, \delta^{d*}_{RR}\, U_L^\dagger, \quad \delta^l_{RR} = U_R\, \delta^{d*}_{LL}\, U_R^\dagger$$

- Suppose $U_L = U_R = \mathbf{1}$ for numerical analysis
  (a general case is discussed later)

A natural question

A natural question

- Which constraint is stronger, hadronic or leptonic?

A natural question

- Which constraint is stronger, hadronic or leptonic?
- Or, how do they interplay?

For recent analyses, see e.g.
Cheung, Kang, Kim, Lee, hep-ph/0702050
Ciuchini, Masiero, Paradisi, Silvestrini, Vempati, Vives, hep-ph/0702144

A natural question

- Which constraint is stronger, hadronic or leptonic?
- Or, how do they interplay?

For recent analyses, see e.g.
Cheung, Kang, Kim, Lee, hep-ph/0702050
Ciuchini, Masiero, Paradisi, Silvestrini, Vempati, Vives, hep-ph/0702144

- This talk deals with cases with more than one mass insertions.

Consider $(\delta^d_{23})_{RR}$ $[= (\delta^l_{23})^*_{LL}$ at $M_{\rm GUT}]$

- Well motivated from large neutrino mixing within SUSY GUT + ν_R with O(1) neutrino Yukawa coupings
  $\Longleftarrow$ GUT partner of $(\delta^l_{23})^*_{LL}$

  Moroi, JHEP(2000)

  Baek, Goto, Okada, Okumura, PRD(2001)

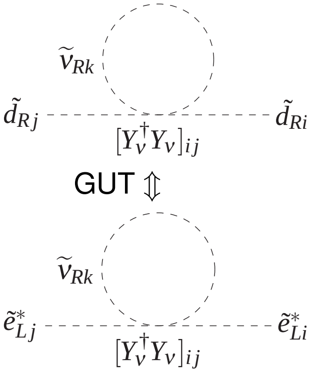
- Recently has attracted interests regarding $b \to s$ transitions such as $B \to \phi K$ and B_s mixing

  With Kane, Ko, Kolda, Wang×2

  Hisano, Shimizu

  With Ko, Masiero, PRD(2005)

  Endo, Mishima, PLB(2006)



Constraints on $(\delta^d_{23})_{RR}$ in SUSY GUT

- Linked to $\tau \to \mu\gamma$

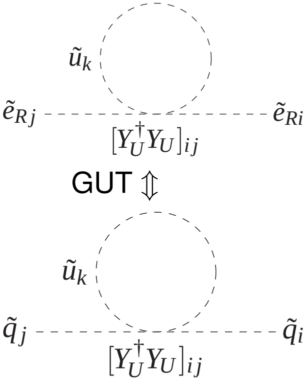
Hisano, Shimizu, PLB(2003)

Constraints on $(\delta^d_{23})_{RR}$ in SUSY GUT

- Linked to $\tau \to \mu\gamma$

Hisano, Shimizu, PLB(2003)

- Radiatively generated $(\delta^l_{13})_{RR}$ included,

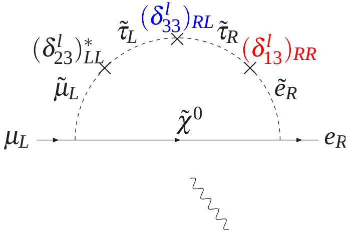


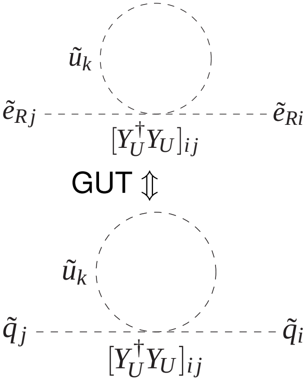
Constraints on $(\delta^d_{23})_{RR}$ in SUSY GUT

- Linked to $\tau \to \mu\gamma$

Hisano, Shimizu, PLB(2003)

- Radiatively generated $(\delta^l_{13})_{RR}$ included, also related to $\mu \to e\gamma$





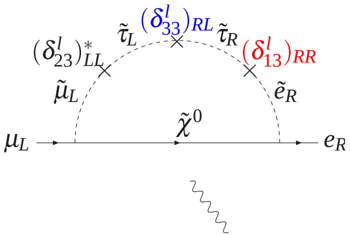
Constraints on $(\delta^d_{23})_{RR}$ in SUSY GUT

- Linked to $\tau \to \mu\gamma$

Hisano, Shimizu, PLB(2003)

- Radiatively generated $(\delta^l_{13})_{RR}$ included,

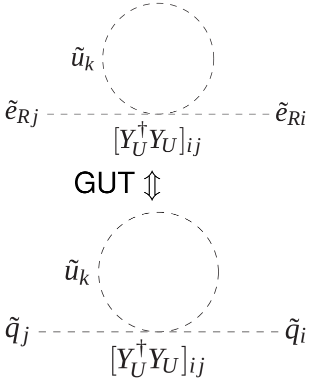
also related to $\mu \to e\gamma$



Enhanced by a factor m_τ/m_μ

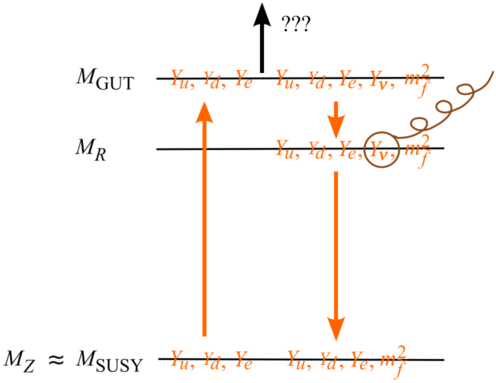
Hisano, Moroi, Tobe, Yamaguchi, PRD(1996)

Baek, Goto, Okada, Okumura, PRD(2001)



Procedure of numerical analysis

1. Run Y_u, Y_d, Y_e from M_Z to $M_{\rm GUT}$
2. Go to the basis where Y_d and Y_e are diagonal
3. Set $Y_\nu, m^2_{\tilde{f}}$ at $M_{\rm GUT}$ **by hand** regarding $(\delta^d_{23})_{RR}$ and $(\delta^d_{13})_{LL}$ as free parameters
   $A(M_{\rm GUT}) = 0$
4. Run down to M_R
5. Remove ν_R
6. Run down to M_Z
7. Calculate μ from EWSB condition
8. Compute flavor violations



Mixings and constraints

- Scan over $(\delta^d_{23})_{RR} = (\delta^l_{23})^*_{LL}$ and $(\delta^d_{13})_{LL} = (\delta^l_{13})^*_{RR}$
- Leptonic constraints

Process	Present upper bound	Future upper bound
$B(\mu \to e\gamma)$	1.2×10^{-11}	1×10^{-13}
$B(\tau \to e\gamma)$	3.1×10^{-7}	1×10^{-8}
$B(\tau \to \mu\gamma)$	6.8×10^{-8}	1×10^{-8}

- Hadronic constraints

Observable	Range	Note
ΔM_s	$[12.5,\ 23]\ \mathrm{ps}^{-1}$	CDF central value $\pm$ 30%
$B(B \to X_s\gamma)$	$[2.0,\ 4.5] \times 10^{-4}$	NLO uncertainty
$B(B \to X_d\gamma)$	$[1,\ 10] \times 10^{-6}$	

Also, ΔM_d, $\sin 2\beta$, $\cos 2\beta$, ϕ_s, $S_{\phi K}$, ε_K, $\varepsilon'/\varepsilon_K$, d_n

Constraints on $[(\delta^d_{13})_{LL}, (\delta^d_{23})_{RR}]$ plane

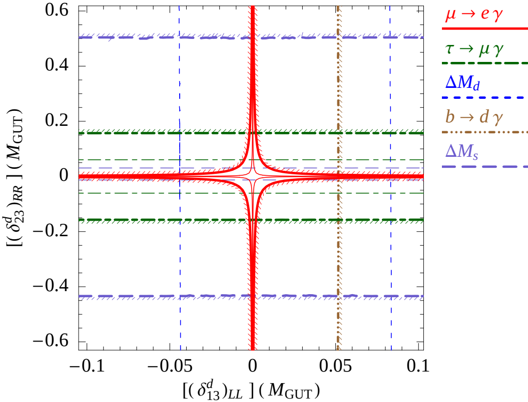
- Parameters

$$\mu > 0, \quad \tan\beta = 3$$
$$m_0(M_{\rm GUT}) = 210 \text{ GeV}$$
$$M_2(M_Z) = 150 \text{ GeV}$$
$$[\ m_{\tilde{d}}(M_Z) = M_3(M_Z) = 500 \text{ GeV}\ ]$$
$$[(\delta^d_{23})_{LL}](M_{\rm GUT}) = 0.014$$

No ν_R below $M_{\rm GUT}$

- Effective constraints

$$(\delta^d_{13})_{LL} : B \to X_d\gamma$$
$$(\delta^d_{23})_{RR} : \Delta M_s, \tau \to \mu\gamma$$
$$(\delta^d_{13})_{LL} \times (\delta^d_{23})_{RR} : \mu \to e\gamma$$



Constraints on $[(\delta^d_{13})_{LL}, (\delta^d_{23})_{RR}]$ plane

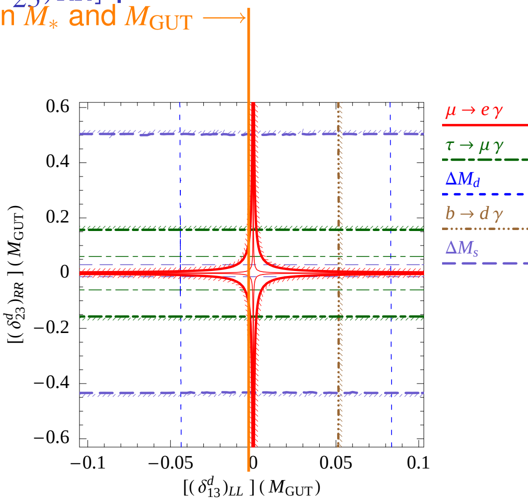
- Parameters

$$\mu > 0, \quad \tan\beta = 3$$
$$m_0(M_{\mathrm{GUT}}) = 210 \text{ GeV}$$
$$M_2(M_Z) = 150 \text{ GeV}$$
$$[\ m_{\tilde{d}}(M_Z) = M_3(M_Z) = 500 \text{ GeV}\ ]$$
$$[(\delta^d_{23})_{LL}](M_{\mathrm{GUT}}) = 0.014$$

No ν_R below M_{GUT}

- Effective constraints

$$(\delta^d_{13})_{LL} : B \to X_d\gamma$$
$$(\delta^d_{23})_{RR} : \Delta M_s, \tau \to \mu\gamma$$
$$(\delta^d_{13})_{LL} \times (\delta^d_{23})_{RR} : \mu \to e\gamma$$



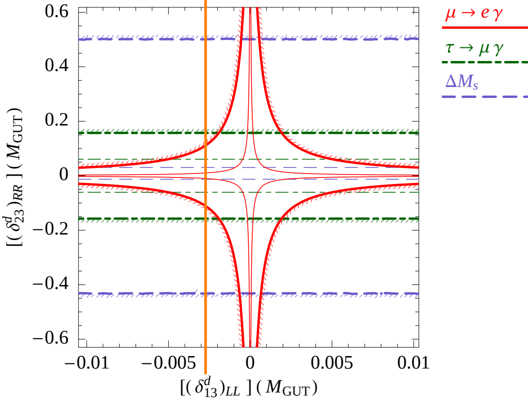
Constraints on $[(\delta^d_{13})_{LL}, (\delta^d_{23})_{RR}]$ plane

$(\delta^d_{13})_{LL}$ from RGE between M_* and $M_{\rm GUT}$ $\longrightarrow$

- Parameters

$$\mu > 0, \quad \tan\beta = 3$$
$$m_0(M_{\rm GUT}) = 210 \text{ GeV}$$
$$M_2(M_Z) = 150 \text{ GeV}$$
$$[\ m_{\tilde{d}}(M_Z) = M_3(M_Z) = 500 \text{ GeV}\ ]$$
$$[(\delta^d_{23})_{LL}](M_{\rm GUT}) = 0.014$$

No ν_R below $M_{\rm GUT}$



- Effective constraints

$$(\delta^d_{13})_{LL} : B \to X_d\gamma$$
$$(\delta^d_{23})_{RR} : \Delta M_s, \tau \to \mu\gamma$$
$$(\delta^d_{13})_{LL} \times (\delta^d_{23})_{RR} : \mu \to e\gamma$$

Constraints on $[\mathrm{Re}(\delta^d_{23})_{RR}, \mathrm{Im}(\delta^d_{23})_{RR}]$ plane

- Parameters

$$\mu > 0, \quad \tan\beta = 3$$
$$m_0(M_{\rm GUT}) = 210 \text{ GeV}$$
$$M_2(M_Z) = 150 \text{ GeV}$$
$$[(\delta^d_{13})_{LL}](M_{\rm GUT}) = 0.0028$$
$$[(\delta^d_{23})_{LL}](M_{\rm GUT}) = 0.014$$

No ν_R below $M_{\rm GUT}$

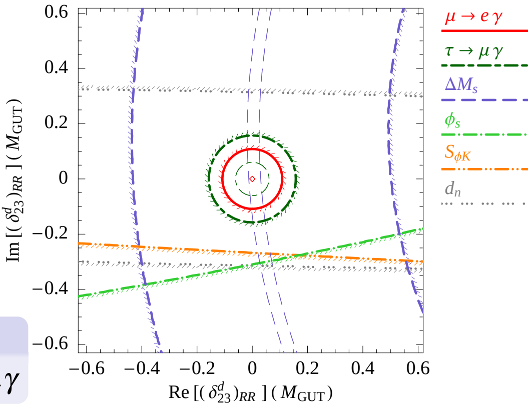
- Constraints

Present

$\mu \to e\gamma$ comparable to $\tau \to \mu\gamma$

Future

$\mu \to e\gamma$ stronger than $\tau \to \mu\gamma$



Constraints on $[\mathrm{Re}(\delta^d_{23})_{RR}, \mathrm{Im}(\delta^d_{23})_{RR}]$ plane

- Parameters

$$\mu > 0, \quad \tan\beta = 3$$
$$m_0(M_{\mathrm{GUT}}) = 400\ \mathrm{GeV}$$
$$M_2(M_Z) = 150\ \mathrm{GeV}$$
$$[(\delta^d_{13})_{LL}](M_{\mathrm{GUT}}) = 0.0028$$
$$[(\delta^d_{23})_{LL}](M_{\mathrm{GUT}}) = 0.014$$

No ν_R below M_{GUT}

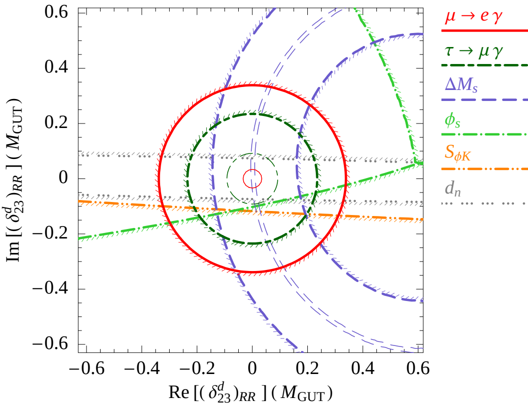
- Constraints

LFV

got weaker

ΔM_s

got stronger

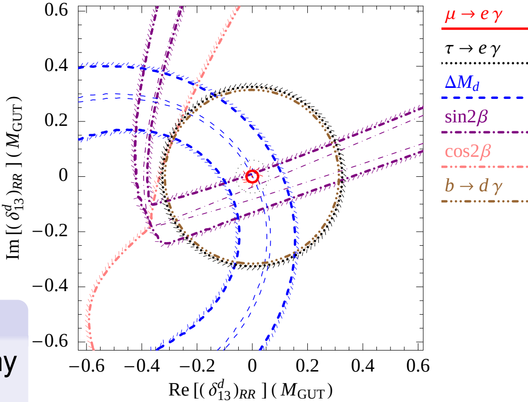


Same exercise on $[\mathrm{Re}(\delta^d_{13})_{RR}, \mathrm{Im}(\delta^d_{13})_{RR}]$ plane

- Parameters

$$\mu > 0, \quad \tan\beta = 3$$
$$m_0(M_{\mathrm{GUT}}) = 210\ \mathrm{GeV}$$
$$M_2(M_Z) = 150\ \mathrm{GeV}$$
$$[(\delta^d_{13})_{LL}](M_{\mathrm{GUT}}) = 0.0028$$
$$[(\delta^d_{23})_{LL}](M_{\mathrm{GUT}}) = 0.014$$

No ν_R below M_{GUT}



- Constraints

Present

$\mu \to e\gamma$ stronger than any other constraint

Future

$\mu \to e\gamma$ even stronger

Same exercise on $[\mathrm{Re}(\delta^d_{13})_{RR}, \mathrm{Im}(\delta^d_{13})_{RR}]$ plane

- Parameters

$$\mu > 0, \quad \tan\beta = 3$$
$$m_0(M_{\mathrm{GUT}}) = 400\ \mathrm{GeV}$$
$$M_2(M_Z) = 150\ \mathrm{GeV}$$
$$[(\delta^d_{13})_{LL}](M_{\mathrm{GUT}}) = 0.0028$$
$$[(\delta^d_{23})_{LL}](M_{\mathrm{GUT}}) = 0.014$$

No ν_R below M_{GUT}

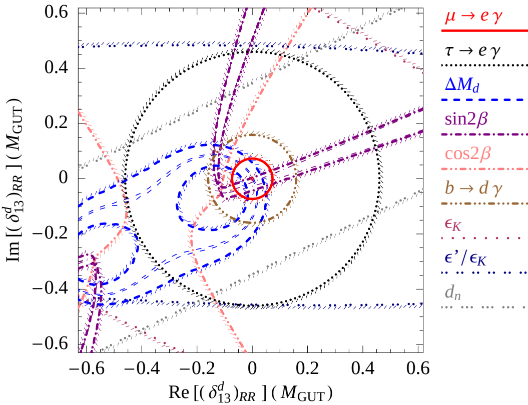
- Constraints

LFV

got weaker

hadronic

got stronger



Effects of non-renormalizable terms on an RR mixing

- Key equation

$$(\delta^l_{a3})_{LL} = [U_L]_{ab}\,(\delta^d_{b3})^*_{RR}\,[U_L]^*_{33} + \mathcal{O}(\cos^2\beta\,\delta^d_{RR}), \quad a,b = 1,2$$

- A tau decay is dominated by chargino loop

$$\begin{aligned} B(\tau \to (e+\mu)\gamma) &\propto |(\delta^l_{13})_{LL}|^2 + |(\delta^l_{23})_{LL}|^2 \\ &\approx |(\delta^d_{13})_{RR}|^2 + |(\delta^d_{23})_{RR}|^2 + \mathcal{O}[\cos^2\beta\,(\delta^d_{RR})^2] \end{aligned}$$

$\Longrightarrow$ Constraint on δ^d_{RR} roughly independent of U_L

- $\mu \to e\gamma$ is dominated by neutralino loop

$$\begin{aligned} B(\mu \to e\gamma) \propto &|(\delta^l_{13})_{RR}(\delta^l_{32})_{LL}|^2 + |(\delta^l_{13})_{LL}(\delta^l_{32})_{RR}|^2 \\ \approx &|(\delta^l_{13})_{RR}|^2 \times |[U_L]_{21}(\delta^d_{13})^*_{RR} + [U_L]_{22}(\delta^d_{23})^*_{RR}|^2 \\ &+|(\delta^l_{23})_{RR}|^2 \times |[U_L]_{11}(\delta^d_{13})^*_{RR} + [U_L]_{12}(\delta^d_{23})^*_{RR}|^2 \\ &+\mathcal{O}[\cos^2\beta\,(\delta^l_{RR})^2(\delta^d_{RR})^2] \end{aligned}$$

$\Longrightarrow$ Constraint on δ^d_{RR} generically remains strong

Summary

[δ's at $M_{\rm GUT}$; $\tan\beta = 3$, $m_0 = 210$ GeV, $M_2 = 150$ GeV by default]

Constraints on $(\delta^d_{23})_{RR}$, with fixed $(\delta^d_{13})_{LL} = 0.0028$

- At present, $\mu \to e\gamma \sim \tau \to \mu\gamma$ stronger than ΔM_s
- In future, $\mu \to e\gamma$ stronger than $\tau \to \mu\gamma$ stronger than ΔM_s, unless hadronic uncertainty is reduced

Constraints on $(\delta^d_{13})_{RR}$, with fixed $(\delta^d_{23})_{LL} = 0.014$

- At present, $\mu \to e\gamma$ very strong
- In future, $\mu \to e\gamma$ will be stronger

In either case

- For higher $\tan\beta$, LFV constraints become stronger
- For $m_0 = 400$ GeV, LFV constraints become weaker, hadronic constraints become stronger

Summary

[δ's at M_{GUT}; $\tan\beta = 3$, $m_0 = 210$ GeV, $M_2 = 150$ GeV by default]

Constraints on $(\delta^d_{23})_{RR}$, with fixed $(\delta^d_{13})_{LL} = 0.0028$

- At present, $\mu \to e\gamma \sim \tau \to \mu\gamma$ stronger than ΔM_s
- In future, $\mu \to e\gamma$ stronger than $\tau \to \mu\gamma$ stronger than ΔM_s, unless hadronic uncertainty is reduced

Constraints on $(\delta^d_{13})_{RR}$, with fixed $(\delta^d_{23})_{LL} = 0.014$

- At present, $\mu \to e\gamma$ very strong
- In future, $\mu \to e\gamma$ will be stronger

In either case

- For higher $\tan\beta$, LFV constraints become stronger
- For $m_0 = 400$ GeV, LFV constraints become weaker, hadronic constraints become stronger
- **Wait for MEG result!**

Summary

[δ's at M_{GUT}; $\tan\beta = 3$, $m_0 = 210$ GeV, $M_2 = 150$ GeV by default]

Constraints on $(\delta^d_{23})_{RR}$, with fixed $(\delta^d_{13})_{LL} = 0.0028$

- At present, $\mu \to e\gamma \sim \tau \to \mu\gamma$ stronger than ΔM_s
- In future, $\mu \to e\gamma$ stronger than $\tau \to \mu\gamma$ stronger than ΔM_s, unless hadronic uncertainty is reduced

Constraints on $(\delta^d_{13})_{RR}$, with fixed $(\delta^d_{23})_{LL} = 0.014$

- At present, $\mu \to e\gamma$ very strong
- In future, $\mu \to e\gamma$ will be stronger

In either case

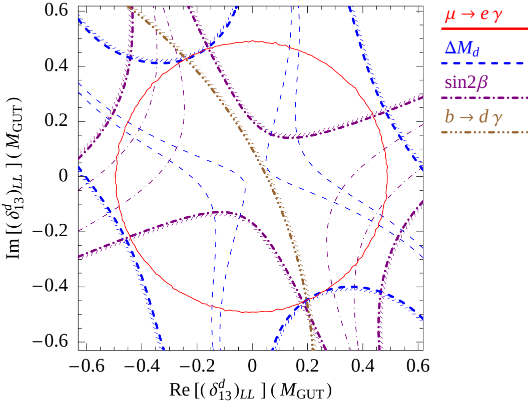
- For higher $\tan\beta$, LFV constraints become stronger
- For $m_0 = 400$ GeV, LFV constraints become weaker, hadronic constraints become stronger
- **Wait for MEG result! (and SuperB)**

Constraints on $[\mathrm{Re}(\delta^d_{13})_{LL}, \mathrm{Im}(\delta^d_{13})_{LL}]$ plane

- Parameters

$$\mu > 0, \quad \tan\beta = 3$$
$$m_0(M_{\rm GUT}) = 210 \text{ GeV}$$
$$M_2(M_Z) = 150 \text{ GeV}$$
$$[(\delta^d_{23})_{LL}](M_{\rm GUT}) = 0.014$$

No ν_R below $M_{\rm GUT}$

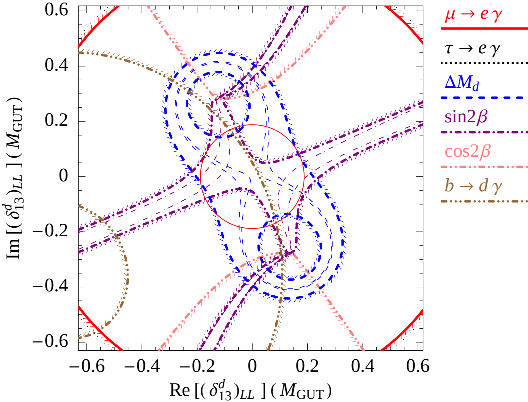


Constraints on $[\mathrm{Re}(\delta^d_{13})_{LL}, \mathrm{Im}(\delta^d_{13})_{LL}]$ plane

- Parameters

$$\mu > 0, \quad \tan\beta = 3$$
$$m_0(M_{\mathrm{GUT}}) = 400 \text{ GeV}$$
$$M_2(M_Z) = 150 \text{ GeV}$$
$$[(\delta^d_{23})_{LL}](M_{\mathrm{GUT}}) = 0.014$$

No ν_R below M_{GUT}

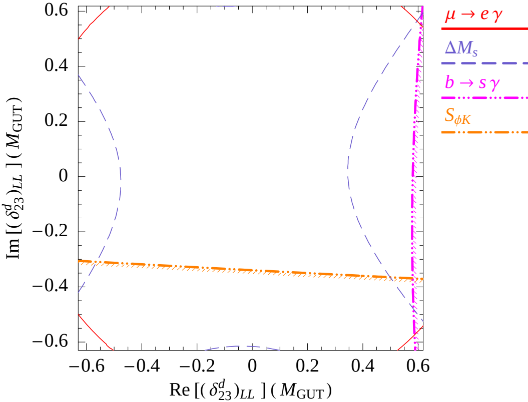


Constraints on $[\mathrm{Re}(\delta^d_{23})_{LL}, \mathrm{Im}(\delta^d_{23})_{LL}]$ plane

- Parameters

$$\mu > 0, \quad \tan\beta = 3$$
$$m_0(M_{\mathrm{GUT}}) = 210 \text{ GeV}$$
$$M_2(M_Z) = 150 \text{ GeV}$$
$$[(\delta^d_{13})_{LL}](M_{\mathrm{GUT}}) = 0.0028$$

No ν_R below M_{GUT}

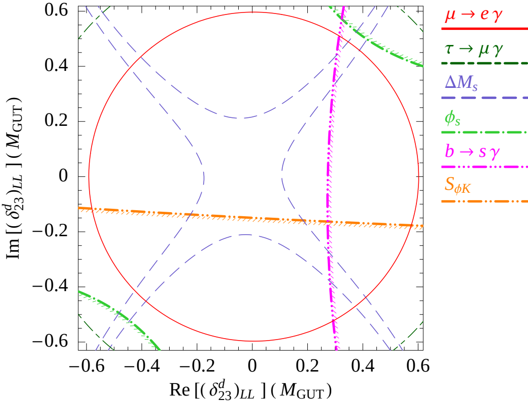


Constraints on $[\mathrm{Re}(\delta^d_{23})_{LL}, \mathrm{Im}(\delta^d_{23})_{LL}]$ plane

- Parameters

$$\mu > 0, \quad \tan\beta = 3$$
$$m_0(M_{\mathrm{GUT}}) = 400\ \mathrm{GeV}$$
$$M_2(M_Z) = 150\ \mathrm{GeV}$$
$$[(\delta^d_{13})_{LL}](M_{\mathrm{GUT}}) = 0.0028$$

No ν_R below M_{GUT}



‘Mass insertion’ parameter at M_{GUT}

- An off-diagonal entry of a soft scalar mass matrix divided by a diagonal entry

$$m_q^2 = m_0^2 \begin{pmatrix} 1 & 0 & (\delta^d_{13})_{LL} \\ 0 & 1 & (\delta^d_{23})_{LL} \\ (\delta^d_{13})^*_{LL} & (\delta^d_{23})^*_{LL} & 1 \end{pmatrix},$$

$$m_d^2 = m_0^2 \begin{pmatrix} 1 & 0 & (\delta^d_{13})_{RR} \\ 0 & 1 & (\delta^d_{23})_{RR} \\ (\delta^d_{13})^*_{RR} & (\delta^d_{23})^*_{RR} & 1 \end{pmatrix}$$

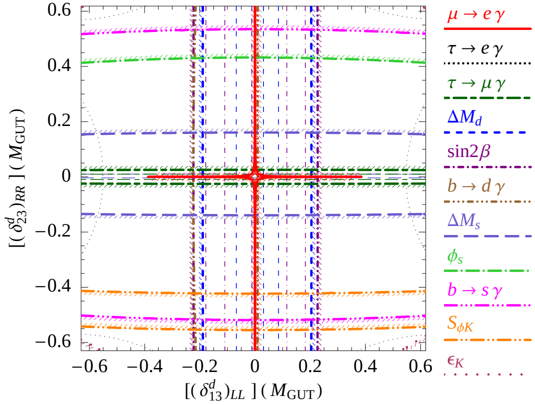
List of hadronic constraints

Observable	Measured value	Imposed constraint
ΔM_{B_d}	0.507 ± 0.004 ps^{-1}	$[0.355, 0.659]$ ps^{-1}
$\sin 2\beta$	0.678 ± 0.025	$2\ \sigma$
$\cos 2\beta$	> -0.4	
$B(B \to X_d \gamma)$		$[10^{-6}, 10^{-5}]$
ΔM_{B_s}	17.77 ± 0.12 ps^{-1}	$[12.5, 23]$ ps^{-1}
ϕ_{B_s}	$-0.70^{+0.47}_{-0.39}$	$[-1.48, 0.24]$
$B(B \to X_s \gamma)$	$(355 \pm 24^{+9}_{-10} \pm 3) \times 10^{-6}$	$[2.0, 4.5] \times 10^{-4}$
$S_{\phi K}$	0.39 ± 0.18	$2\ \sigma$
$\lvert\varepsilon_K\rvert$	$(2.232 \pm 0.007) \times 10^{-3}$	$\lvert\varepsilon_K^{\mathrm{SUSY}}\rvert < \lvert\varepsilon_K^{\mathrm{exp}}\rvert$
$\varepsilon'/\varepsilon_K$	$(1.66 \pm 0.26) \times 10^{-3}$	$\lvert(\varepsilon'/\varepsilon_K)^{\mathrm{SUSY}}\rvert < \lvert(\varepsilon'/\varepsilon_K)^{\mathrm{exp}}\rvert$
$\lvert d_n\rvert$	$< 6.3 \times 10^{-26}\ e\,$cm	

$B \to X_s\gamma$?

- Parameters

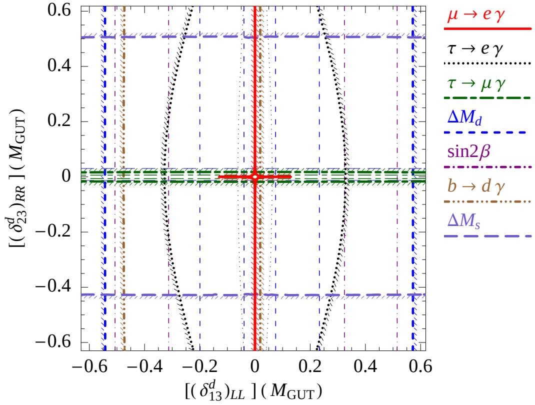
$$\mu > 0$$
$$\tan\beta = 25$$
$$m_0 = 400 \text{ GeV}$$
$$M_2 = 150 \text{ GeV}$$
No ν_R below M_{GUT}
$$[(\delta^d_{23})_{LL}](M_{\text{GUT}}) = 0.014$$



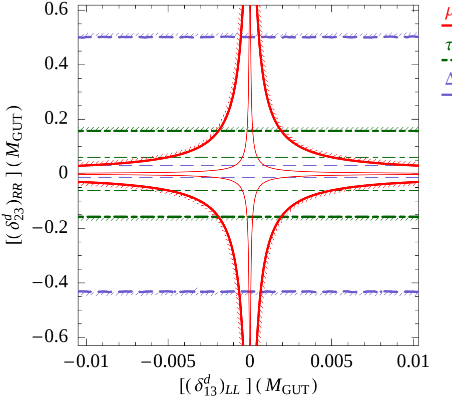
$\tau \to e\gamma$?

- Parameters

$$\mu > 0$$
$$\tan\beta = 25$$
$$m_0 = 210 \text{ GeV}$$
$$M_2 = 150 \text{ GeV}$$
No ν_R below M_{GUT}
$$[(\delta^d_{23})_{LL}](M_{\text{GUT}}) = 0.014$$

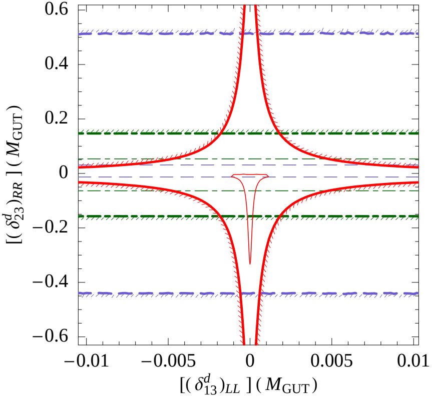


Large neutrino Yukawa couplings

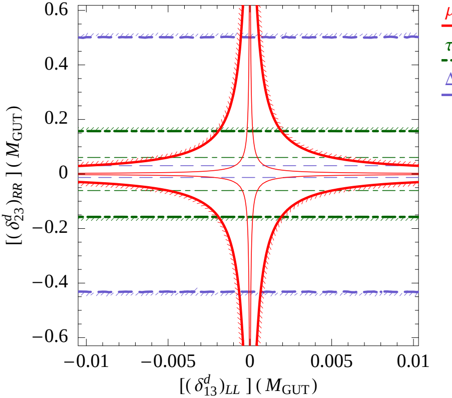


No ν_R below M_{GUT}

Large neutrino Yukawa couplings

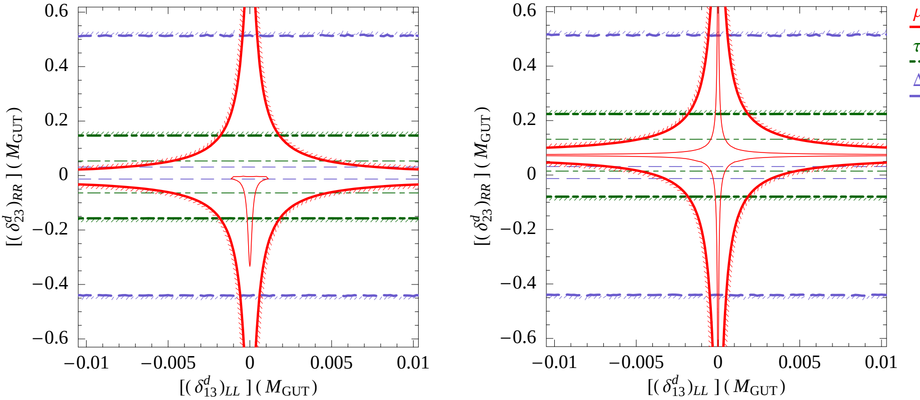


$Y_\nu = Y_u$ at $M_{\rm GUT}$ (CKM-like mixing)



No ν_R below $M_{\rm GUT}$

Large neutrino Yukawa couplings



$Y_\nu = Y_u$ at $M_{\rm GUT}$ (CKM-like mixing) $Y_\nu = U^*_{\rm PMNS} Y^{\rm diag}_u$ at $M_{\rm GUT}$ (large mixing