Flavor Violation in SUSY GUT Scenario

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Work in Progress
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Talk Plan

- Flavor violation as a probe of new physics
- SUSY GUT Scenario and Flavor Violation
- Model-free Analysis of Flavor Violation in lepton and hadron sectors
- Numerical Results

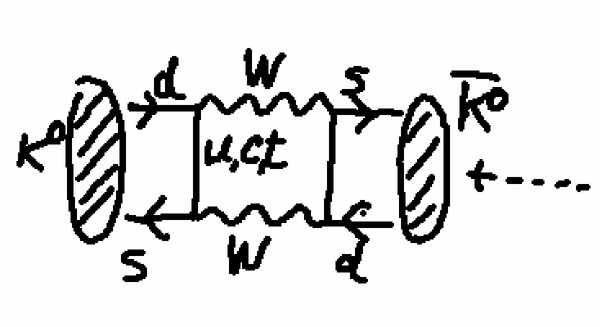
Flavor Violation as a probe of new physics

Standard Model

- Flavor Diagonal Part:
  - (spontaneously broken) gauge symmetry
- Flavor Off-Diagonal Part:
  - GIM mechanism   FCNC suppression
    - loop level
    - small quark masses

Examples

K^0-$\bar{K}^0$ mixing $\qquad \Delta m_K = 3.5 \times 10^{-12}\text{MeV}$



$$\propto \frac{g^4}{(4\pi)^2}\frac{m_c^2}{m_W^6}\sin^2\theta_c\cos^2\theta_c(\bar{d}_L\gamma^\mu s_L)(\bar{d}_L\gamma_\mu s_L)$$

$\mu \to e\gamma \qquad Br(\mu \to e\gamma)|_{\text{exp}} < 10^{-11}$

No lepton flavor violation in SM

One can freely rotate mass eigenbasis of massless neutrinos.

Beyond Standard Model

- New Particles and New Interactions at (sub-) TeV Scale
  - No GIM mechanism in general

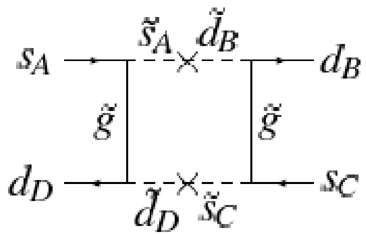
- Flavor Violation:

  good probe of new physics beyond SM

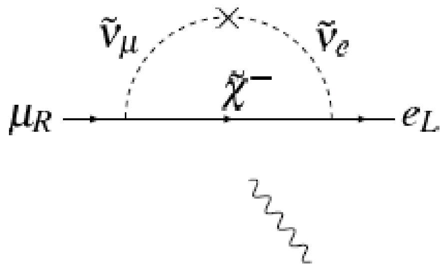
Example: Case of SUSY SM

- New particles: squarksand sleptons
- flavor mixing in squark/slepton masses
  →flavor violation

- K^0–$\overline{K^0}$ mixing



- $\mu \to e\gamma$



Present Status of Flavor Violation

Hadron Sector:

flavor mixing (&CP violation) in CKM framework works well

K, B-mesons

Recent News: Bs-mixing is remarkable agreement with SM prediction

(Charged) Lepton Sector

No Flavor Violation observed ($\mu \to e\,\gamma$, $\tau \to \mu\,\gamma$ …)

Only Exception:

Neutrino Oscillation: clear evidence of lepton flavor violation in neutrino sector

SUSY GUT Scenario

- Still most motivated candidate for NP beyond SM
  - low E SUSY: Sol. to gauge hierarchy problem
  - RG evolution in MSSM

    → gauge coupling unification
  - LSP: dark matter candidate

Flavor Violation in SUSY GUT Scenario

- Quarks and leptons are in the same multiplets.
- eg. SU(5)

$$\begin{aligned} \mathbf{10} &= (Q_L, U_R^C, E_R^C) \\ \bar{\mathbf{5}} &= (D_R^C, L_L) \end{aligned}$$

- "SUSY" GUT:

Squarks and sleptons are also in the same multiplets.

→ flavor mixing of squarks and that of slepons are related with each other.

→ flavor violaion in hadron sectors and flavor violation in lepton sectors are related.

Sources of Flavor Violation

Flavor Violation via RG evolution

- Top Yukawa & CKM above GUT scale
  → lepton flavor violation (&CPV)
- Neutrino Yukawas above GUT scale
  → hadronic flavor violaion (&CPV)

Flavor Violation via Flavor Symmetry

These are sensitive to the details of GUT model

Model-free Analysis

- Generic features of SUSY GUT (SU(5))
  - At the GUT scale, squark flavor mixing is related with slepton flavor mixing.

    d_R ←→l_L (5-plet)

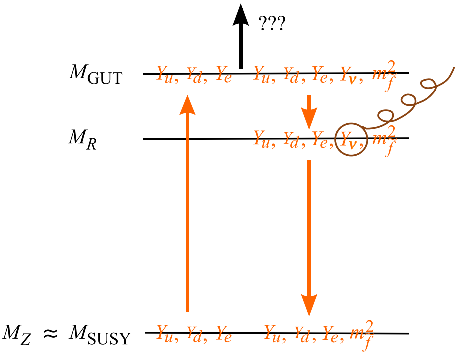
    d_L ←→ l_R (10-plet)

- Questions:
  - Which gives stronger constraint on squark/slepton mass mixing, hadron sector or lepton sector?
  - Given strong constraints from hadron sector, what is the prospect of lepton flavor violation?

Numerical Results

Procedure of numerical analysis

1. Run Y_u, Y_d, Y_e from M_Z to M_{GUT}
2. Go to the basis where Y_d and Y_e are diagonal
3. Set $Y_\nu, m^2_{\tilde{f}}$ at M_{GUT} **by hand**
   $A(M_{\text{GUT}}) = 0$
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 in consideration

- Consider $(\delta^d_{23})_{RR} \simeq (\delta^l_{23})_{LL}{}^*$ and $(\delta^d_{13})_{LL} \simeq (\delta^l_{13})_{RR}{}^*$; for the other mixings, see e.g.

  Cheung, Kang, Kim, Lee, hep-ph/0702050

  Ciuchini, Masiero, Paradisi, Silvestrini, Vempati, Vives, hep-ph/0702144

- 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%
$B(B \to X_s\gamma)$	$[2.0,\ 4.5] \times 10^{-4}$	
$B(B \to X_d\gamma)$	$[1,\ 10] \times 10^{-6}$	

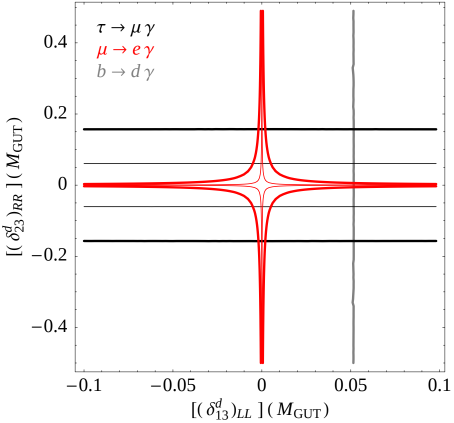
Constraints on $[(\delta^d_{23})_{RR}, (\delta^d_{13})_{LL}]$ plane

- Parameters

$$\mu > 0$$
$$\tan\beta = 3$$
$$m_0 = 210\ \text{GeV}$$
$$M_2 = 150\ \text{GeV}$$
$$\text{No } \nu_R \text{ below } M_{\text{GUT}}$$
$$\text{The other } \delta\text{'s} = 0$$

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

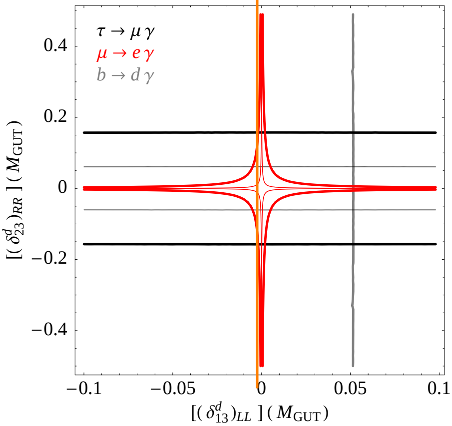
- Parameters

$$\mu > 0$$
$$\tan\beta = 3$$
$$m_0 = 210 \text{ GeV}$$
$$M_2 = 150 \text{ GeV}$$
No ν_R below M_{GUT}
The other δ's $= 0$

- Constraints

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

RGE from M_* to M_{GUT} ⟶



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

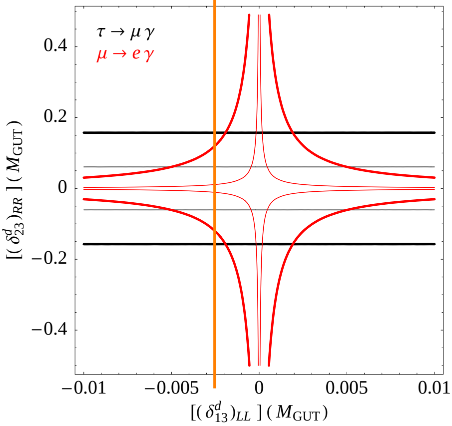
RGE from M_* to $M_{\rm GUT}$ $\longrightarrow$

- Parameters

$$\mu > 0$$
$$\tan\beta = 3$$
$$m_0 = 210 \text{ GeV}$$
$$M_2 = 150 \text{ GeV}$$
$$\text{No } \nu_R \text{ below } M_{\rm GUT}$$
$$\text{The other } \delta\text{'s} = 0$$

- 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

$$\mu > 0$$
$$\tan\beta = 3$$
$$m_0 = 210 \text{ GeV}$$
$$M_2 = 150 \text{ GeV}$$
No ν_R below M_{GUT}
$$(\delta^d_{13})_{LL} = 0.0025$$

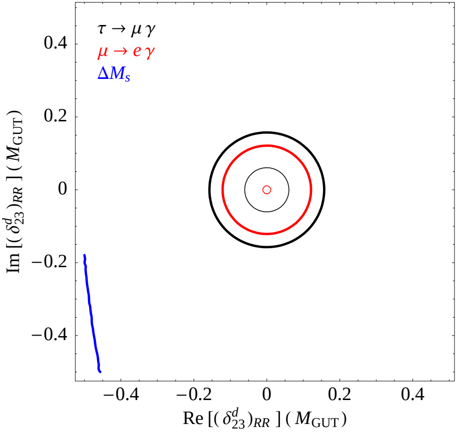
- Constraints

Present

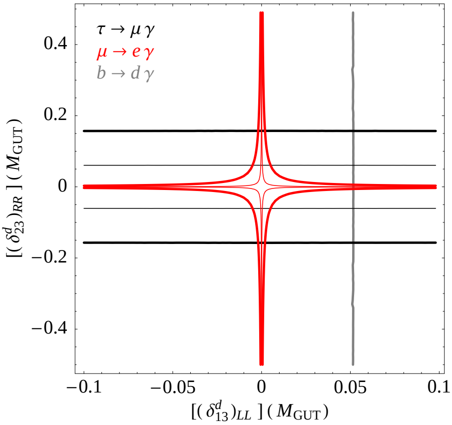
$\mu \to e\gamma$ comparable to $\tau \to \mu\gamma$

Future

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

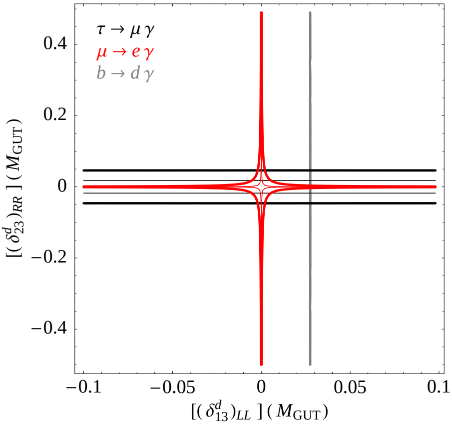


Results for higher $\tan\beta$

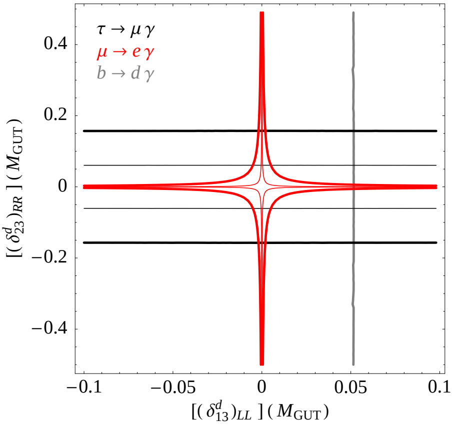


$\tan\beta = 3$

Results for higher $\tan\beta$



$\tan\beta = 10$



$\tan\beta = 3$

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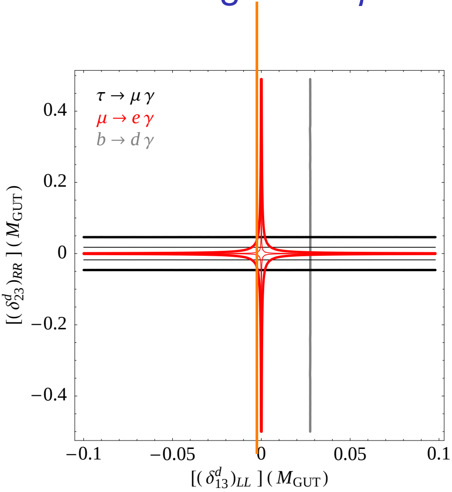

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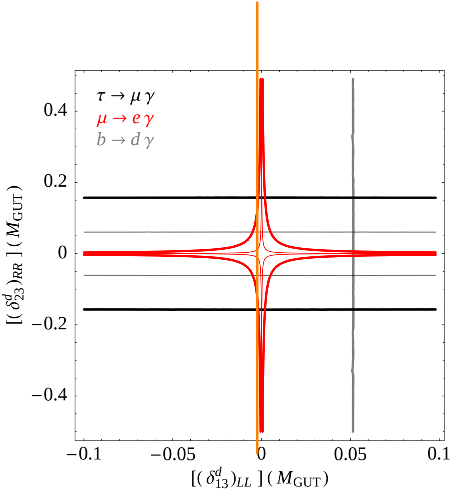

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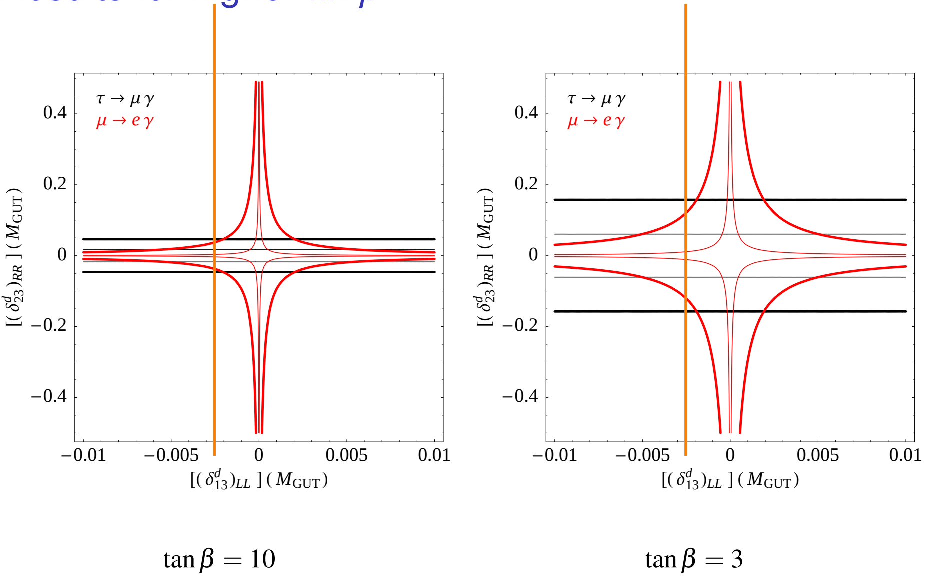
Results for higher $\tan\beta$



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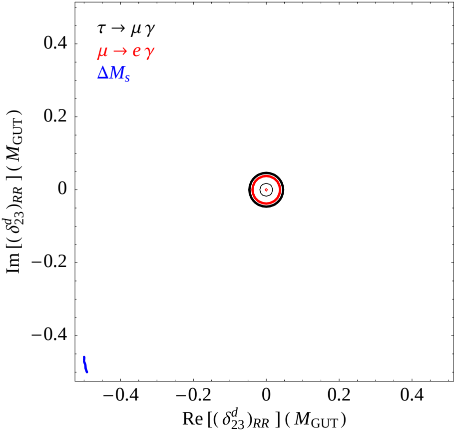

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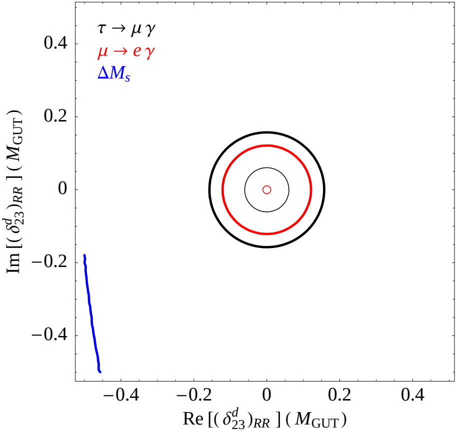

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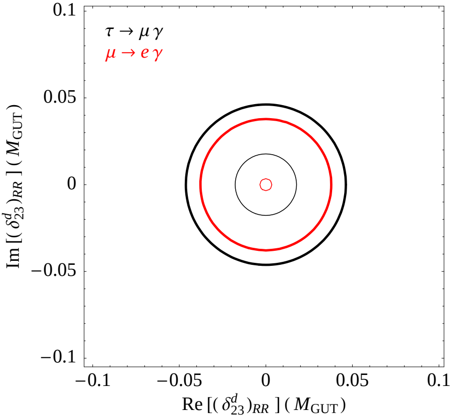

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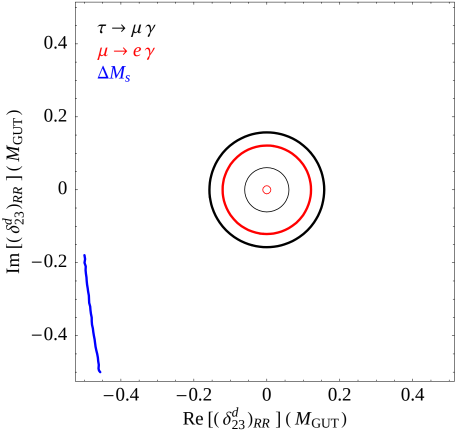
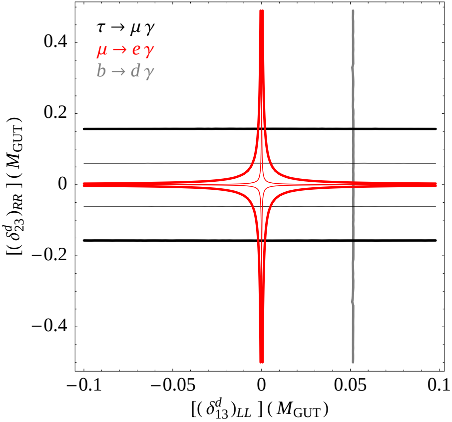


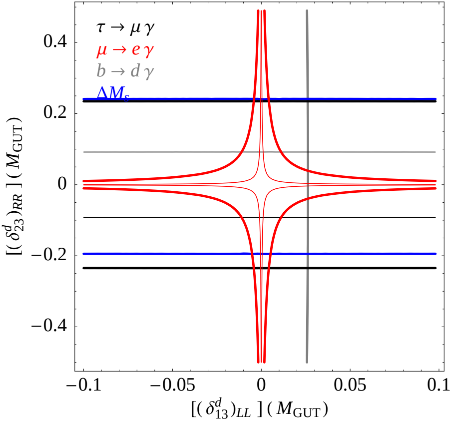
$\tan\beta = 3$

Gaugino/scalar mass dependence

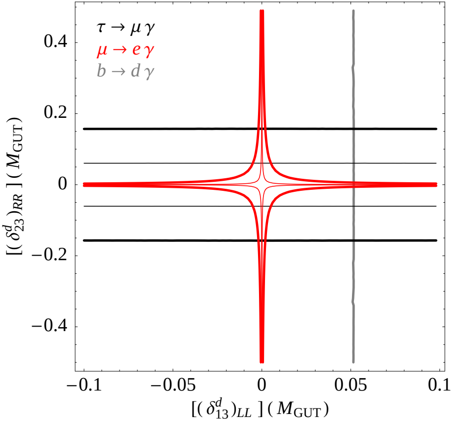


$m_0 = 210 \text{ GeV}$

Gaugino/scalar mass dependence

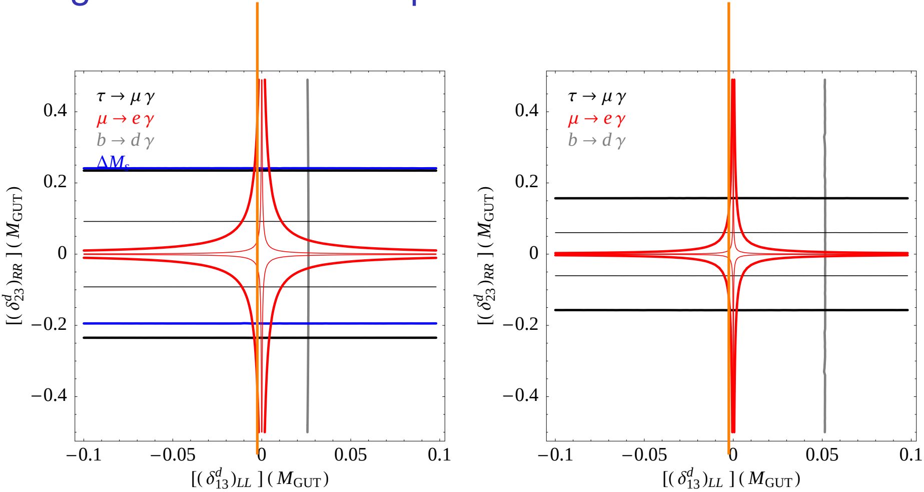


$m_0 = 400$ GeV



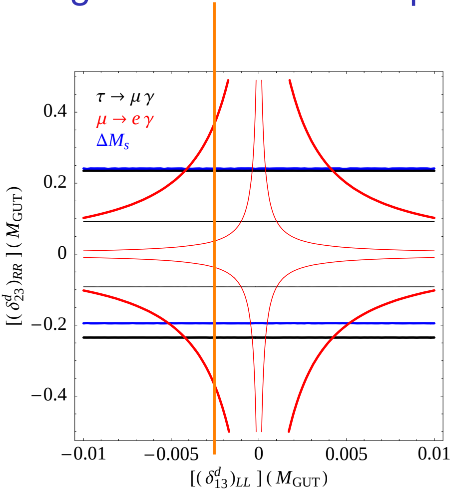
$m_0 = 210$ GeV

Gaugino/scalar mass dependence

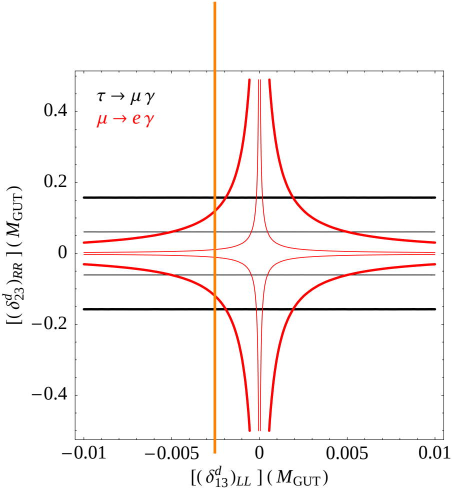


$m_0 = 400$ GeV $\qquad$ $m_0 = 210$ GeV

Gaugino/scalar mass dependence

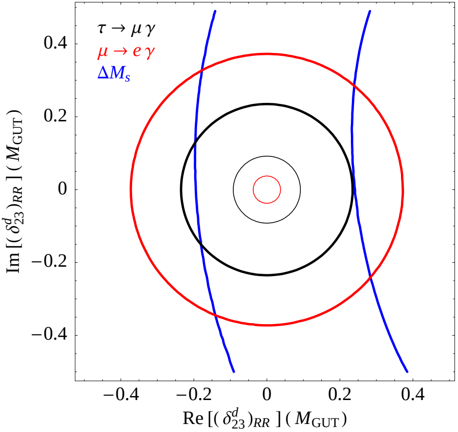


$m_0 = 400$ GeV



$m_0 = 210$ GeV

Gaugino/scalar mass dependence



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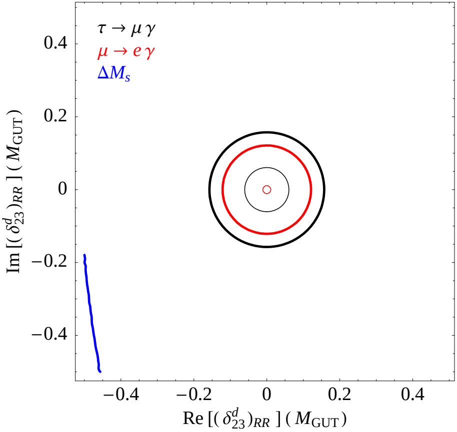

$m_0 = 210$ GeV

Summary of Numerical Results

- For smaller scalar mass (at GUT scale)
  Lepton sector constraint is stronger

- For larger scalar mass (at GUT scale)
  Hadron sector constraint becomes comparable.

- In both cases, future LFV experiments will explore yet unconstrained regions of parameter space.
  Discovery of LFV in charged lepton sector can be expected.