Lepton-flavor violation in tau-lepton decay and the related topics

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I, Introduction

Lepton-flavor conservation is not exact in nature.

LFV in neutrino sector: Global fit to three neutrinos

- $\Delta m^2_{23} = 2,4(1^{+0.21}_{-0.15})\times 10^{-3}\text{eV}^2, \quad \sin^2\theta_{\mu 3} = 0.44(1^{+0.41}_{-0.22})$
- $\Delta m^2_{12} = 7.92(1\pm 0.09)\times 10^{-5}\text{eV}^2, \quad \sin^2\theta_{e2} = 0.314(1^{+0.18}_{-0.15})$
- $\sin^2\theta_{e3} = 0.9^{+2.3}_{-0.9}\times 10^{-2}$

(Fogli et al)

LFV in charged-lepton sector is not yet observed.

	2000PDG	current(Belle/Babar)	future
$\tau \to \mu(e)\gamma$	$< 1.1(2.7)\times 10^{-6}$	$< 0.5/0.7(1.2/1.1)\times 10^{-7}$	$\sim 10^{-(8-9)}$
$\tau \to \mu(e)\eta$	$< 9.6(8.2)\times 10^{-6}$	$< 1.5/1.3(2.3/1.9)\times 10^{-7}$	$10^{-(9-10)}$
$\tau \to lll$	$<\sim 10^{-6}$	$<\sim 10^{-7}$	$<\sim 10^{-(9-10)}$
$\mu \to e\gamma$	$< 1.2\times 10^{-11}$		$\sim 10^{-(13-14)}$
$\mu \to 3e$	$< 1.0\times 10^{-12}$		$\sim 10^{-14}(?)$
$\mu - e:\text{Ti}$	$< 4.3\times 10^{-12}$		$\sim 10^{-18}(?)$

MEG (mu->e gamma) will start this year.

Lepton-flavor conservation is not exact in nature. However, size of LFV depends on models beyond SM.

- Supersymmetric standard model (MSSM) and extensions
- Bulk fermions in flat or warped extra-dimensions
- Multi-Higgs models
- Seesaw models at weak scale
- Left-right symmetric model, etc, etc, ….

MSSM is the most well-motivated model, and it is also a good prototype of models beyond SM.

Flavor physics plays an important role in construction and establishment of MSSM. Introduction of SUSY breaking for squarks and sleptons leads to new flavor and CP violation.

$$\left(m^2_{\tilde{f}_{L/R}}\right)_{ij} = \left(m_f^\dagger m_f\right)_{ij} + \left(\tilde{m}^2_{\tilde{f}_{L/R}}\right)_{ij} \qquad (\tilde{m}_{\tilde{f}_{L/R}} \approx 100\text{GeV}\sim 1\text{TeV})$$

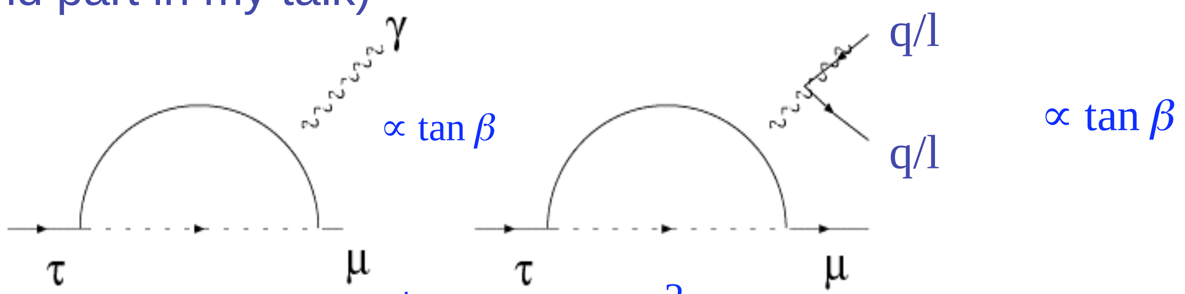
SUSY ~~SUSY~~

$K^0 - \bar{K}^0$ mixing and $\mu \to e\gamma$ give stringent constraints on structure of SUSY breaking. (SUSY flavor problem)

Ansatz for SUSY flavor problem and tau Lepton-flavor violation (I)

Universal scalar mass scenario

Slepton and squark masses are independent of the flavors at a high energy (messenger) scale $(m^2_{\tilde{q}/\tilde{l}} \propto 1 \text{ at } \Lambda >> m_{\rm Weak})$.
LFV slepton masses might be radiatively generated by the LFV interaction. (Ex, SUSY seesaw, SUSY GUTs).
(-> second part in my talk)



$$Br(\tau \to \mu(e)+e^+e^-) \approx 10^{-2} \times Br(\tau \to \mu(e)+\gamma),$$
$$Br(\tau \to \mu(e)+\mu^+\mu^-) \approx 2.2\times 10^{-3} \times Br(\tau \to \mu(e)+\gamma),$$
$$Br(\tau \to \mu(e)+\rho) \approx 2.5\times 10^{-3} \times Br(\tau \to \mu(e)+\gamma)$$
(Brignole and Rossi)

Strong correlation in the processes.
Competitor to them is mu->e gamma.
C.f. PRISM sensitivity is comparable to $\mathrm{Br}(\mu \to e\gamma) \sim 10^{-(15-16)}$

$$\mathrm{R}(\mu \to e;\mathrm{Ti}) \approx 5\times 10^{-3} \times \mathrm{Br}(\mu \to e\gamma)$$

Ansatz for SUSY flavor problem and tauLepton-flavor violation (II)

Decoupling scenarios

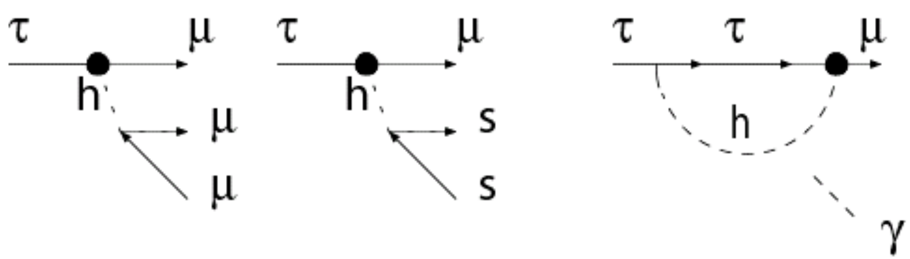
- .Case I: $m_{\tilde{q}/\tilde{l}}(1^{st}, 2^{nd} \text{gene.}) >> m_{\text{Weak}}$

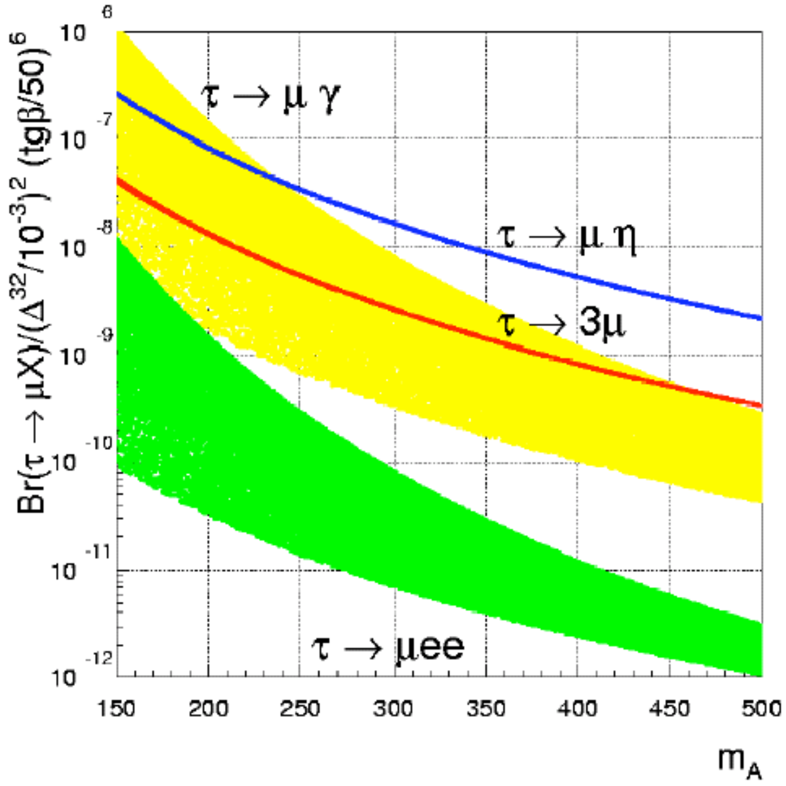
Tau LFV, $\tau \to \mu / e + \gamma$, is a window to probe flavor structure.

$$Br(\tau \to \mu(e)\gamma) \sim 10^{-6} \left(m_{\tilde{\tau}}/100\text{GeV}\right)^{-2} \tan^2\beta$$

- Case II: $m_{SUSY} >> m_{\text{Weak}}$

Anomalous LFV Higgs coupling appears (Babu&Kolda)





(Paradisi)

- Case III: $m_{\tilde{q}/\tilde{l}} >> m_{\text{Weak}}$ (Split SUSY)

Change subject.

2, Probe models beyond MSSM by tau lepton-flavor violation

Lepton-flavor symmetry is not exact in nature, and LFV Interaction is present beyond the MSSM. The radiative correction generates slepton mixing even in universal scalar mass scenario. (Hall, Kostelecky & Raby)

• SUSY Seesaw model (Introduction of right-handed neutrino)

Motivated from neutrino mass, SO(10) GUTs, and leptogenesis

ν Yukawa induces left-handed slepton mixing (Borzumati&Masiero)

• SUSY SU(5) model (Introduction of colored Higgs multiplet)

Colored Higgs is SU(5) partner of doublet Higgs in MSSM. CKM mixing induces right-handed slepton mixing. (Barbieri&Hall)

The radiative correction is not suppressed by power of LFV scale if it is smaller than the SUSY breaking messenger scale.

• SUSY Seesaw model (Introduction of right-handed neutrino)

$$L = f_l \, \overline{e}_R L h_1 + f_\nu \, \overline{\nu}_R L h_2 + M \, \nu_R \nu_R$$

Non-vanishing LFV slepton masses by radiative correction

$$\Delta\left(m_{\tilde{L}}^2\right)_{ij} \approx \frac{1}{8\pi^2}(3m_0^2 + A_0^2)\left(f_\nu^\dagger \log\frac{M}{M_G} f_\nu \right)_{ij}$$

And then, $Br(\tau \to l_j \gamma) \approx 3\times 10^{-6} \left(\frac{\Delta\left(m_{\tilde{L}}^2\right)_{3j}}{\overline{m_{\tilde{L}}^2}}\right)^2 \left(\frac{100\mathrm{GeV}}{m_{SUSY}}\right)^4 \tan^2\beta$

DOF in Seesaw model, M:6, ϕ:6, CP:4(mixing)+2(Majorana)=18

$$(m_\nu)_{ij} \equiv \left(f_\nu^T \frac{\langle h_2 \rangle^2}{M} f_\nu \right)_{ij}$$

$$H_{ij} \equiv \left(f_\nu^\dagger \log\frac{M}{M_G} f_\nu \right)_{ij}$$

In light ν mass matrix $(m_\nu)_{ij}$
M:3, ϕ:3, CP:1(mixing)+ 2(Majorana)
=9

In H_{ij} (Hermitian)
Real: 6, Phase:3
=9

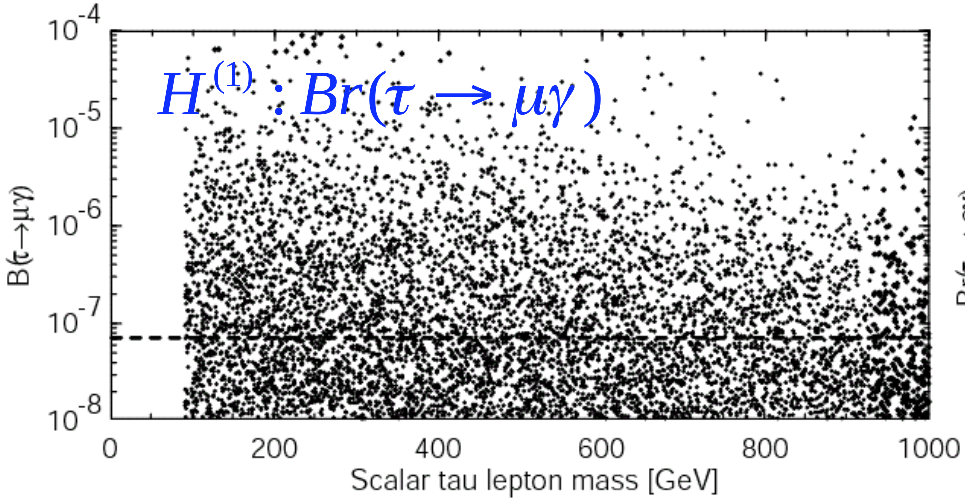
(Ibarra&Davidson)

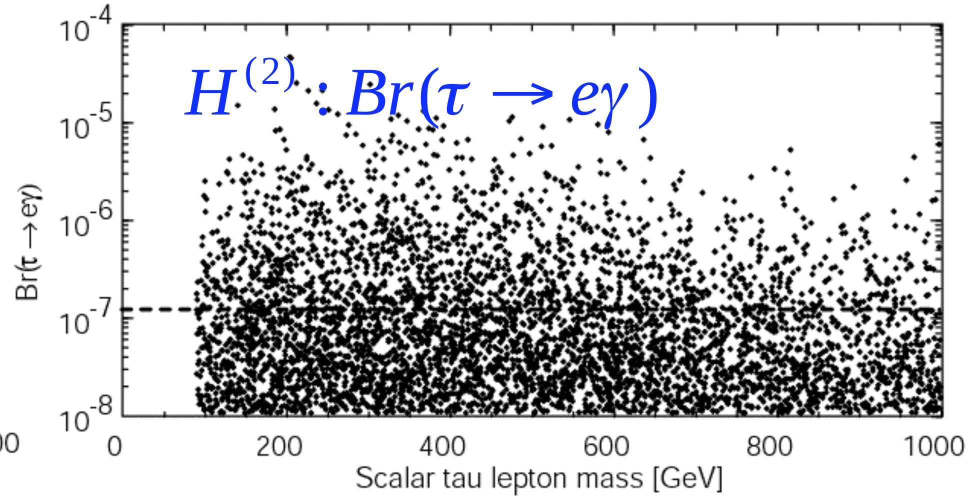
$Br(\tau \to \mu\gamma)$ comes from H_{23}, and $Br(\tau \to e\gamma)$ from H_{13}.
Question: How large they can be?

$\mu \to e\gamma$ is generated if $H_{12,}$ and/or $H_{13}H_{32} \neq 0$.

$$H^{(1)} = \begin{pmatrix} * & 0 & 0 \\ 0 & * & * \\ 0 & * & * \end{pmatrix} \qquad H^{(2)} = \begin{pmatrix} * & 0 & * \\ 0 & * & 0 \\ * & 0 & * \end{pmatrix}$$

Model-building favors with $H^{(1)}$, not $H^{(2)}$.





(mu->e gamma is suppressed below the exp. bound.)

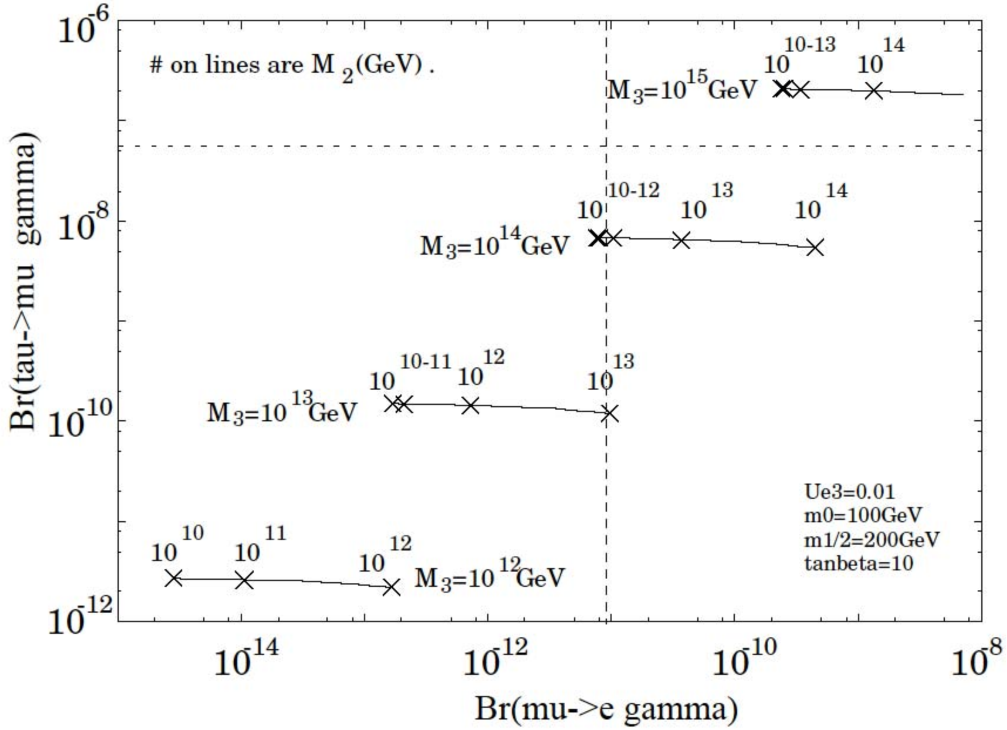
(Ellis,JH, Raidal, Shimizu)

$\tau \to \mu\gamma$ v.s. $\mu \to e\gamma$ (Bottom-up approach)

Working hypothesis: $(f_\nu)_{ij} \propto m_{\nu i} M_i U^\dagger_{ij}$ (U : MNS matrix)

$$\Delta\left(m^2_{\tilde{l}_L}\right)_{23} \propto U_{\mu 3} U^*_{\tau 3} m_{\nu 3} M_3 \quad (\tau \to \mu\gamma)$$

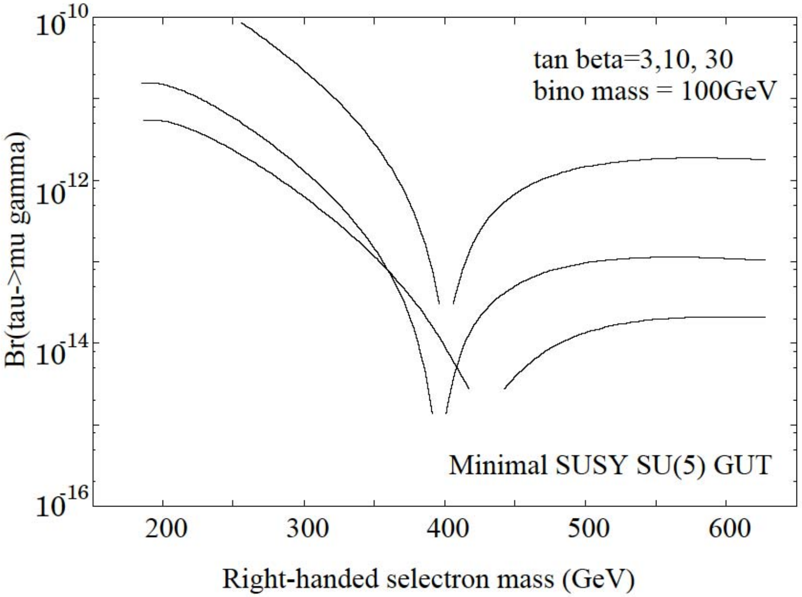
$$\Delta\left(m^2_{\tilde{l}_L}\right)_{12} \propto U_{e3} U^*_{\mu 3} m_{\nu 3} M_3 + U_{e2} U^*_{\mu 2} m_{\nu 2} M_2 \quad (\mu \to e\gamma)$$

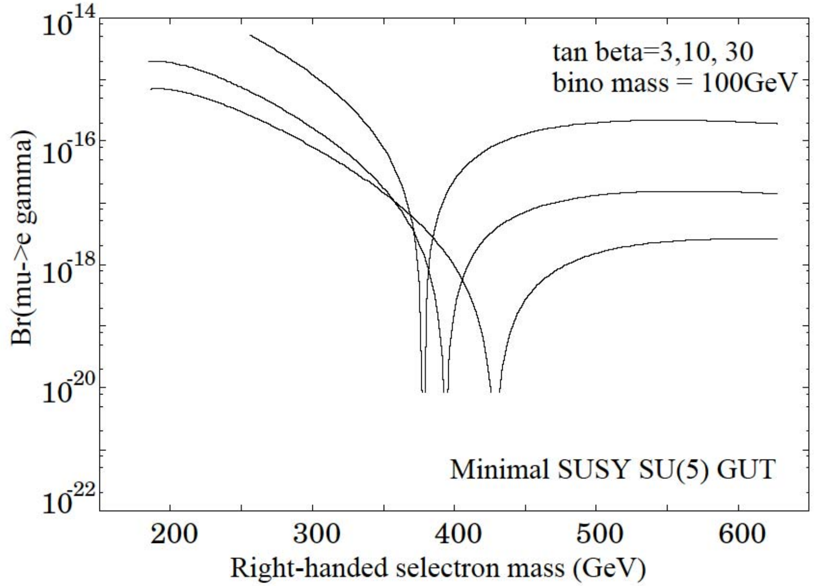


$$\frac{\mathrm{Br}(\mu \to e\gamma)}{\mathrm{Br}(\tau \to \mu\gamma)} \gtrsim \frac{|U_{e3}/U_{\tau 3}|^2}{0.17} \sim 10^{-3} \times |U_{e3}/0.01|^2$$

• SUSY SU(5) model (Introduction of colored Higgs multiplet)

Right-handed slepton mixings are induced by CKM mixing in the minimal model (without right-handed neutrinos), however, the branching ratios of charged LFV modes are smaller.





It is not end of the story since we have to care some illnesses (3-2 Higgs splitting, proton decay, fermion mass relation).

Ex, orbifold SU(5) GUT in 5 dim. space.

$$\mathrm{Br}(\tau \to \mu\gamma) \approx 5\times 10^{-8} \times \tan^2\beta \qquad \mathrm{Br}(\mu \to e\gamma) \approx 3\times 10^{-11} \times \tan^2\beta$$

$(m_{SUSY} \sim 100\mathrm{GeV})$ (Hall&Nomura)

(Universality of slepton mass is hardly broken.)

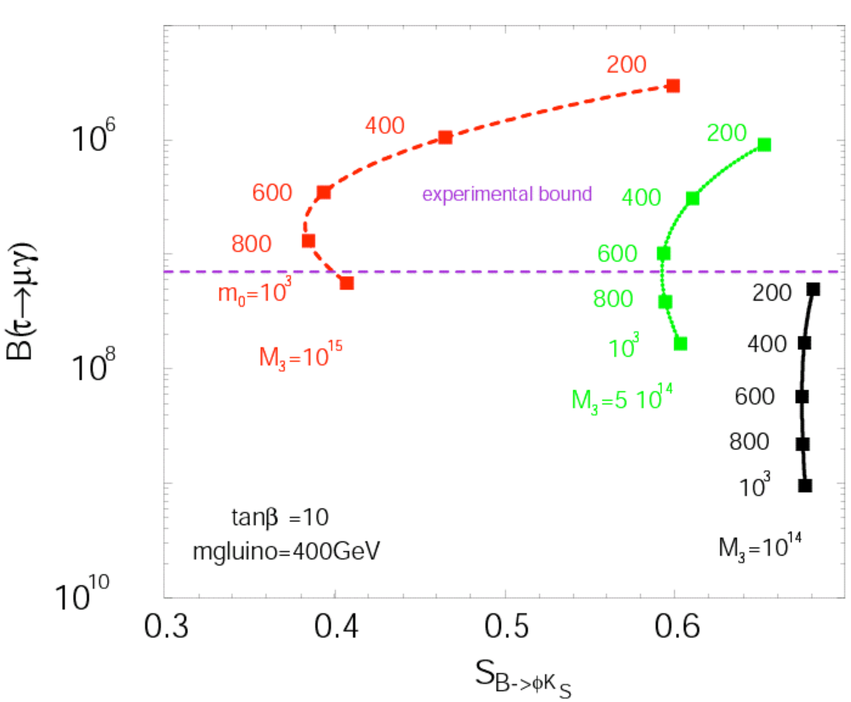
• SUSY SU(5) model with right-handed neutrinos

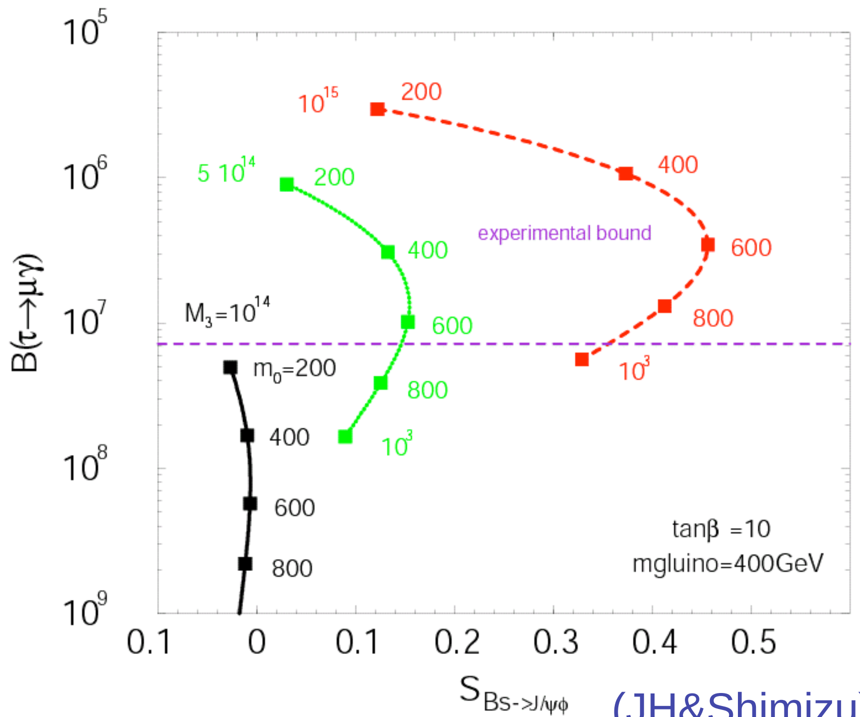
Leptonic and hadonic flavor violations are correlated to each other in SUSY GUTs.

$$\psi[10] = (u_L, d_L, u_R, e_R),\ \ \phi[5^*] = (d_R, \nu_L, e_L),\ \ \nu_R$$

GUT relation: $(m^2_{\tilde{l}_L})^*_{32} \approx (m^2_{\tilde{d}_R})_{23} e^{i\varphi_{23}}$ (Moroi)

$\tau \to \mu\gamma$ b-s quark transition





(JH&Shimizu)

3, Summary of my talk

• Lepton-flavor conservation is not exact in nature, and then, charged lepton-flavor violation is a good window to probe models beyond SM. In this talk, I reviewed tau lepton flavor violation in the SUSY models. Studies of LFV may give a clue for SUSY breaking mechanism and models beyond the MSSM.

• In conventional cases, tau->mu(e) gamma is the most sensitive to the SUSY models. However, other processes are also important in the cases of a decoupling scenario and R parity breaking.

• Current experimental bounds on LFV tau decay modes exclude a part of the SUSY seesaw models. Search for them gives information for the model, which is independent of mu->e gamma and neutrino oscillation.

3, Summary of my talk

• From model-building points of view, in SUSY seesaw model $\mathrm{Br}(\tau \to \mu\, \gamma) <\sim 10^{(2-3)} \times \mathrm{Br}(\mu \to e\gamma)$. In this case, MEG might be an important test for tau LFV searches.

• SUSY SU(5) GUT also provides other LFV interaction. Minimal model predicts a small branching ratio of LFV tau decay, $\mathrm{Br}(\tau \to \mu\, \gamma) < 10^{-10}$. But, non-minimal models may predict larger branching ratio.

• In SUSY GUTs, correlation between hadronic and leptonic flavor violation is a good test. If one of tau->mu gamma and b-s quark transition is observed, the other is promising in the model.