Lepton Flavor Violation in Supersymmetric Models

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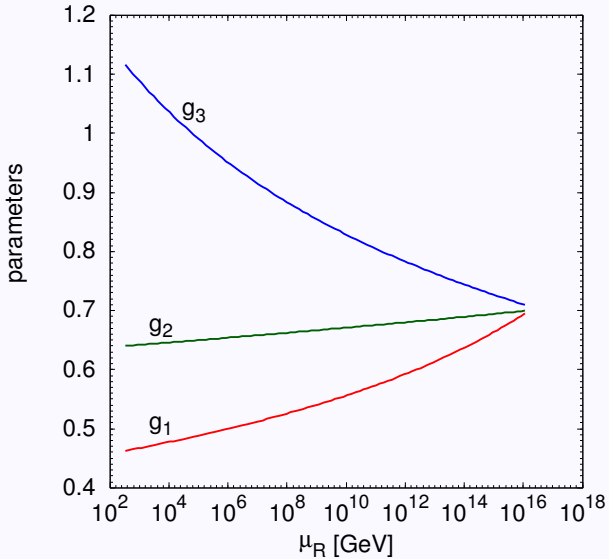
1. Introduction

1.1. Supersymmetry – the great theory

- no quadratic divergence
- gauge coupling unification
  [Dimopoulos,Georgi '81] [Sakai '81] [Dimopoulos,Raby,Wilczek '81]



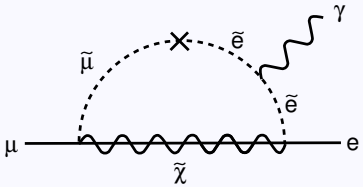
- Fermions
- Dark matter candidate
  ⋮

1.2. Lepton flavor is interesting

SUSY is broken ($m_e \neq m_{\tilde{e}}$)

$\Downarrow$

New source for flavor violation



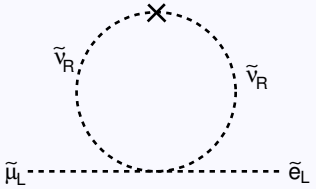
$$B(\mu \to e\gamma) < 1.2 \times 10^{-11} \text{ [MEGA, '99]} \tag{1}$$

$$B(\mu \to e\gamma) \simeq 10^{-5} \left[\frac{M_{\rm SUSY}}{100 \text{ GeV}}\right]^{-4} \left[\frac{\Delta m^2_{\tilde{e}\tilde{\mu}}}{\overline{m}^2_{\tilde{l}}}\right] \tan^2\beta \tag{2}$$

$$\Rightarrow \left[\frac{\Delta m^2_{\tilde{e}\tilde{\mu}}}{\overline{m}^2_{\tilde{l}}}\right] \lesssim 10^{-4} \left[\frac{\tan\beta}{10}\right]^{-1} \left[\frac{M_{\rm SUSY}}{200 \text{ GeV}}\right]^2 \tag{3}$$

Already severely constrained.

One the other hand, in seesaw model,



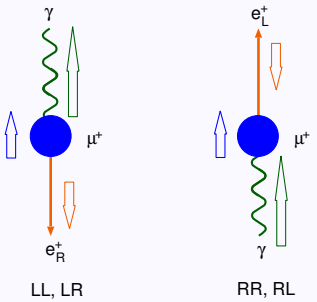
$$\Rightarrow \left[\frac{\Delta m^2_{\tilde{e}\tilde{\mu}}}{\overline{m}^2_{\tilde{l}}}\right] \simeq \frac{1}{8\pi^2}(f_\nu^\dagger f_\nu)_{e\mu} \log\frac{M_{\nu_R}}{M_{\rm Pl}} \simeq 0.1 \text{ for } O(1)\ f_\nu!!$$

1.3. What can we learn from LFV processes?

Sources of LFV (four different sources): [Gabbiani,Gabrielli,Masiero,Silvestrini'96]

$$\mathcal{L} \ni (\tilde{e}_L^*, \tilde{\mu}_L^*, \tilde{e}_R^*, \tilde{\mu}_R^*) \left(\begin{array}{cc|cc} m^2_{\tilde{e}_L} & \overline{m}_L \Delta_{LL} & -m_e \mu \tan\beta & m_\mu \Delta_{LR} \\ * & m^2_{\tilde{\mu}_L} & m_\mu \Delta_{RL} & -m_\mu \mu \tan\beta \\ \hline * & * & m^2_{\tilde{e}_R} & \overline{m}_R \Delta_{RR} \\ * & * & * & m^2_{\tilde{\mu}_R} \end{array} \right) \left(\begin{array}{c} \tilde{e}_L \\ \tilde{\mu}_L \\ \tilde{e}_R \\ \tilde{\mu}_R \end{array} \right) \qquad (4)$$

- $\mu \to e\gamma$ decay with polarized muon [Kuno,Okada'96][Okada,Okumura,Shimizu'99]



- target atom dependence of $\mu \to e$ conversion process in nuclei [Kitano,Koike,Okada'02]

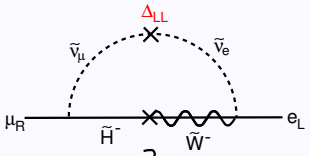
We find the ratio of the branching ratio $\dfrac{B(\mu \to e; \mathrm{Al})}{B(\mu \to e\gamma)}$ is also a useful quantity to extract information on underlying physics.

2. $\mu \to e\gamma$ in SUSY models

Effective Lagrangian:

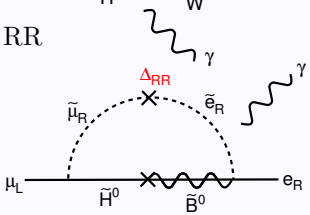
$$\mathcal{L}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} \left\{ m_\mu A_R \bar{\mu}\sigma^{\mu\nu} P_L e F_{\mu\nu} + m_\mu A_L \bar{\mu}\sigma^{\mu\nu} P_R e F_{\mu\nu} + \text{h.c.} \right\} \tag{5}$$

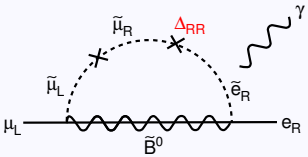
- LL



: $A_R \propto \tan\beta$

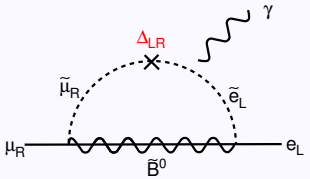
- RR





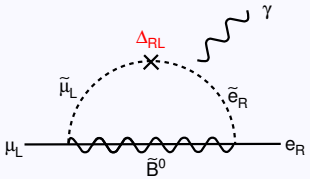
: $A_L \propto \tan\beta$

- LR

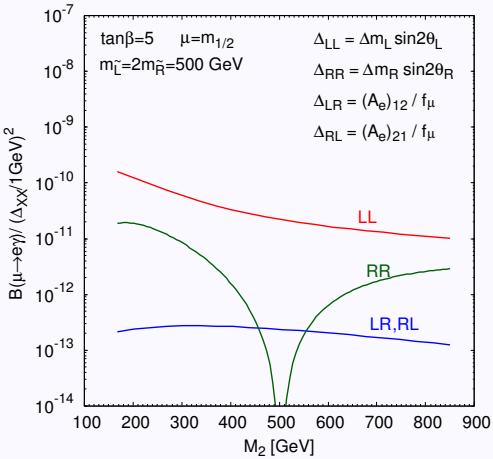


: $A_R \propto (\tan\beta)^0$

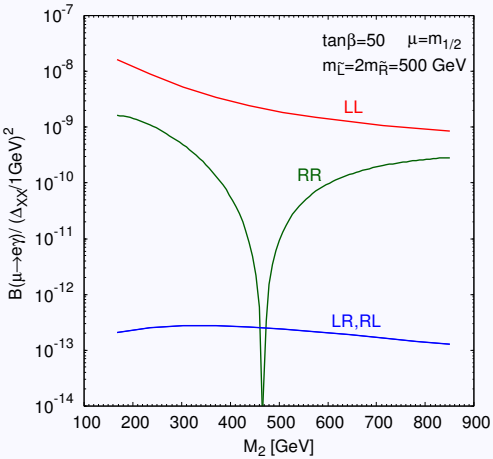
- RL



: $A_L \propto (\tan\beta)^0$



$\tan\beta = 5$



$\tan\beta = 50$

- cancellation between diagrams in RR case. [Hisano,Moroi,Tobe,Yamaguchi'96]
- no $\tan\beta$ enhancement in LR/RL case.

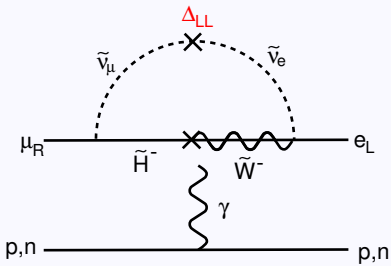
3. $\mu \to e$ conversion in nuclei in SUSY models

Effective Lagrangian:

$$\begin{aligned}
\mathcal{L}_{\rm eff} \;=\; & -\frac{4G_F}{\sqrt{2}}\left\{m_\mu A_R \bar{\mu}\sigma^{\mu\nu}P_L e F_{\mu\nu} + m_\mu A_L \bar{\mu}\sigma^{\mu\nu}P_R e F_{\mu\nu} + \text{h.c.}\right\} \qquad : \text{dipole} \\
& -\frac{G_F}{\sqrt{2}}\left\{\tilde{g}_{LS}\bar{e}P_R\mu\bar{\psi}\psi + \tilde{g}_{RS}\bar{e}P_L\mu\bar{\psi}\psi + \text{h.c.}\right\} \qquad : \text{scalar} \\
& -\frac{G_F}{\sqrt{2}}\left\{\tilde{g}_{LV}\bar{e}\gamma^\mu P_L\mu\bar{\psi}\gamma_\mu\psi + \tilde{g}_{RV}\bar{e}\gamma^\mu P_R\mu\bar{\psi}\gamma_\mu\psi + \text{h.c.}\right\} \qquad : \text{vector}
\end{aligned} \tag{6}$$

$$\psi = p,\ n \tag{7}$$

- dipole operator

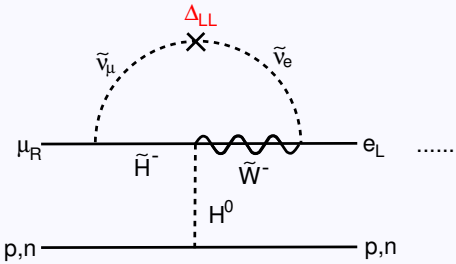


..... : $\propto \tan\beta$
: $\propto m_{\rm SUSY}^{-2}$

$O(\alpha)$ suppressed process compared to $\mu \to e\gamma$ decay.
Pure dipole operator prediction is:

$$\frac{B(\mu \to e; \text{Al})}{B(\mu \to e\gamma)} \simeq 0.002 \tag{8}$$

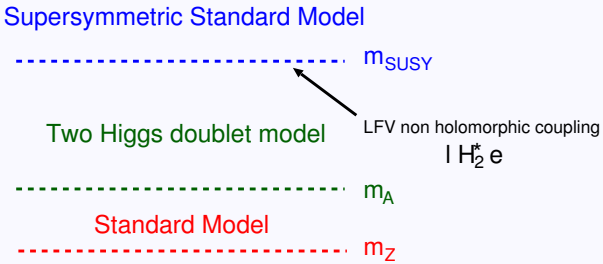
- scalar operator from Higgs exchange diagrams [Kitano,Koike,Komine,Okada'03]



: $\tilde{g}_{LS} \propto \tan^3\beta$
: $\propto m_{H^0}^{-2}$

it is NOT suppressed by up or down quark Yukawa coupling

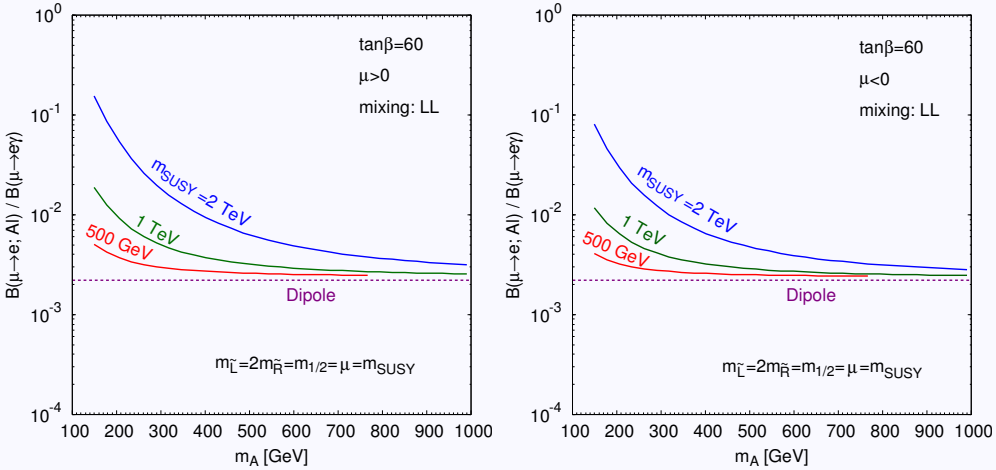
Those diagrams gives non-decoupling contribution in $m_{\rm SUSY} \to \infty$ limit.



$\Rightarrow$ **The Higgs mediated effect becomes important for $m_{H^0} \ll m_{\rm SUSY}$ and $\tan\beta \gg 1$.**

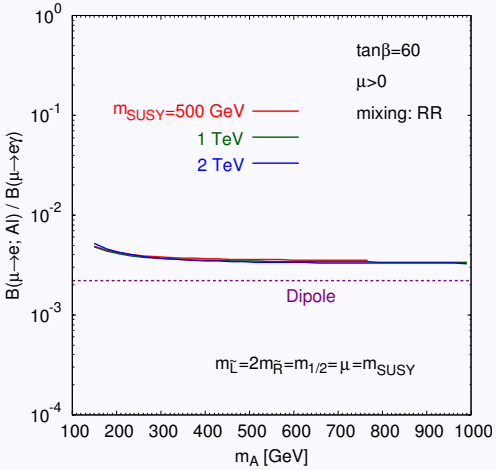
4. $B(\mu \to e; \mathrm{Al})/B(\mu \to e\gamma)$

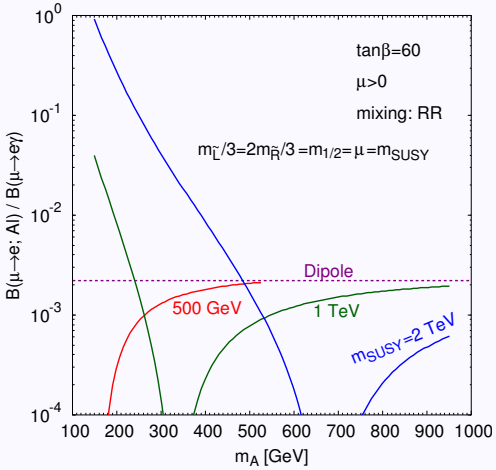
4.1. LL



- For $m_A (\simeq m_{H^0}) \ll m_{\mathrm{SUSY}}$, we can see the Higgs mediation effect.
- Always interfere constructively.

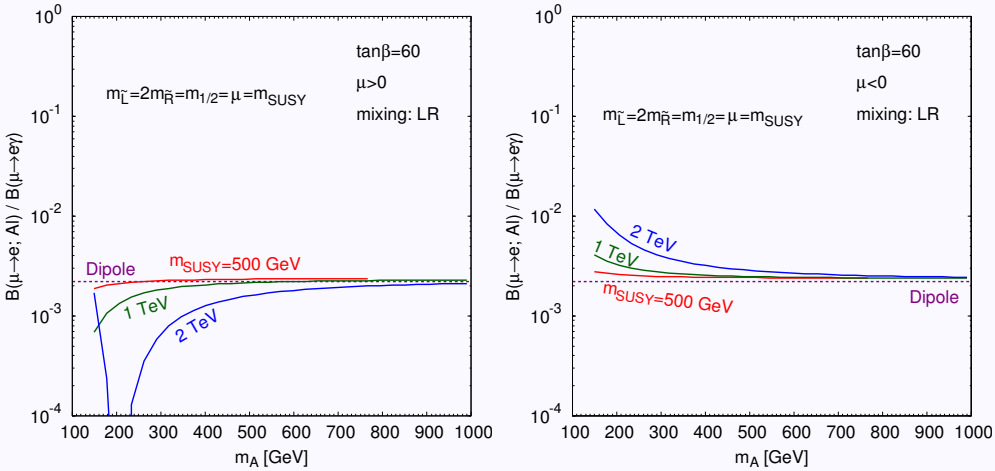
4.2. RR





Anything can happen due to cancellations among
two dipole diagrams + two Higgs exchange diagrams + ...

4.3. LR/RL



- dipole + Higgs exchange interefere constructively or destructively depending on the sign of μ.
- $\tan^3\beta$ enhancement is there in Higgs mediation whereas no $\tan\beta$ enhancement in dipole operator.

5. Summary

- LFV is very interesting in SUSY models.
- $B(\mu \to e; \mathrm{Al})/B(\mu \to e\gamma)$ is an interesting quantity.