Lepton Flavor Violation in New Physics Models

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Search for Baryon and Lepton Number Violations International Workshop
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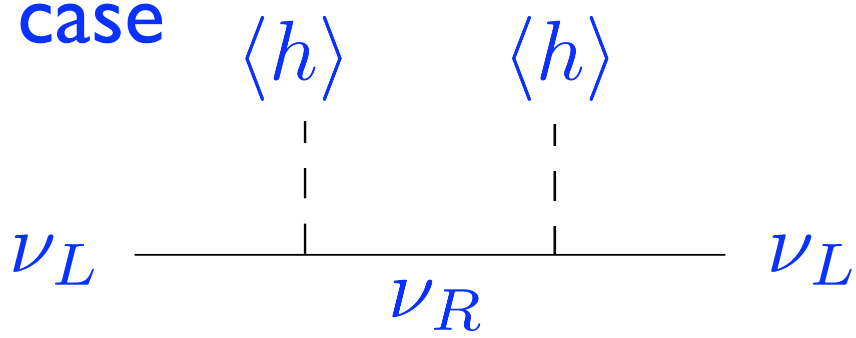
✳ We have seen large "flavor violations" in neutrino sector

$$\text{e.g.} \quad \nu_\mu \to \nu_\tau , \quad \nu_e \to \nu_\mu$$

Lepton "flavor" number violation (LFV)!

Seesaw case



$$m_\nu \simeq \frac{(y_\nu \langle h \rangle)^2}{M_{\nu_R}}$$

neutrino Yukawa interaction can have large lepton flavor violation (LFV) for large neutrino mixings

Since there is no symmetry to forbid the LFV, there may be many LFV interactions.

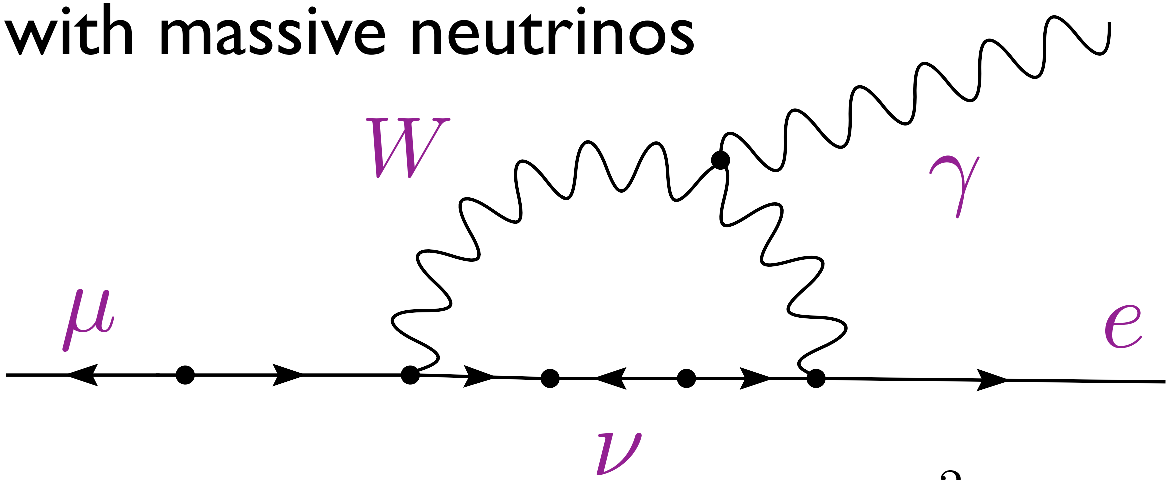
LFV in charged lepton sector?

$$\mu \to e\gamma, \ \mu - e \text{ conversion } etc.$$

Experimental limits on lepton flavor violation

process	current limit	future
$\mu \to e\gamma$	1.2×10^{-11}	$10^{-13} - 10^{-14}$
$\tau \to \mu\gamma$	4.5×10^{-8}	$10^{-8} - 10^{-9}$
$\mu^+ \to e^+e^-e^+$	1×10^{-12}	$-$
$\mu \to e\ (\mathrm{Ti})$	6.1×10^{-13}	$10^{-16} - 10^{-18}$

In SM with massive neutrinos



$$\mathrm{BR}(\mu \to e\gamma) = \frac{3\alpha}{32\pi} \sum_i \left| V^*_{\mu i} V_{ei} \frac{m^2_{\nu_i}}{M^2_W} \right|^2 < 10^{-54}$$

extremely small!

Effective Lagrangian for $\mu \to e\gamma$

$$\mathcal{L}_{\rm LFV} = y \frac{e m_\mu}{\Lambda^2} \bar{\mu}_R \sigma^{\mu\nu} e_L F_{\mu\nu} + \text{h.c.} + \cdots$$

$$\text{BR}(\mu \to e\gamma) = y^2 \frac{3(4\pi)^3 \alpha}{G_F^2 \Lambda^4}$$

$\Lambda :$ new physics scale

- If $y \simeq 1$, (the operator is induced at tree level)

$$\text{BR}(\mu \to e\gamma) = 1 \times 10^{-11} \times \left(\frac{400\text{TeV}}{\Lambda} \right)^4 \left(\frac{y}{1} \right)^2$$

- If $y = \frac{g^2}{16\pi^2} \theta_{\mu e}$, (the operator is induced at one loop level)

$$\text{BR}(\mu \to e\gamma) = 1 \times 10^{-11} \times \left(\frac{2\text{TeV}}{\Lambda} \right)^4 \left(\frac{\theta_{\mu e}}{10^{-2}} \right)^2$$

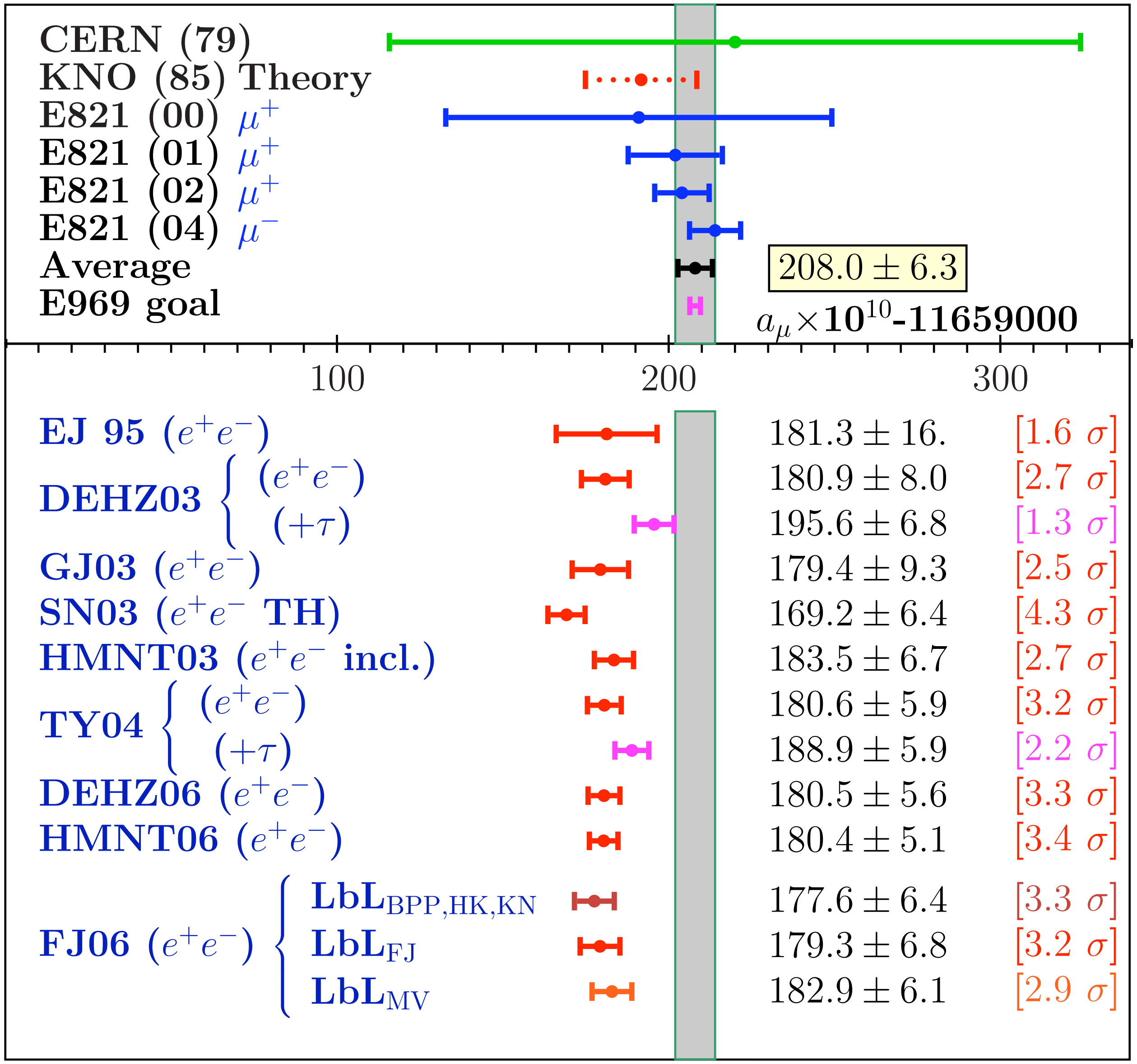
example: SUSY

It's sensitive to the flavor violating TeV scale physics!

neutrino → flavor violation + TeV scale physics ← LHC

✴ anomaly in muon g-2 (?)

F. Jegerlehner
hep-ph/0703125



"06" results include the recent $\pi^+\pi^-$ data from SND, CMD-2, and Babar (and KLOE)

The discrepancy between the experimental result and the SM prediction is 3σ level

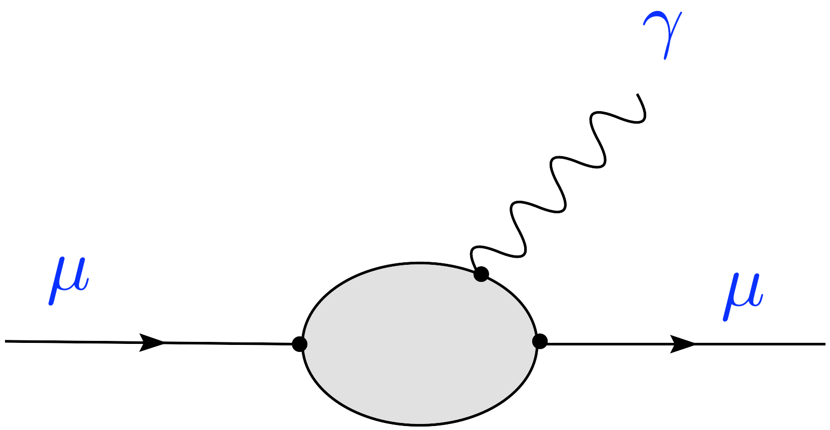
$$\delta a_\mu (\equiv a_\mu^{\rm exp} - a_\mu^{\rm SM}) = (27.6 \pm 8.1) \times 10^{-10} \quad \text{(HMNT06)}$$

Hagiwara et al: hep-ph/0611102

$(3.4\sigma$ discrepancy$)$

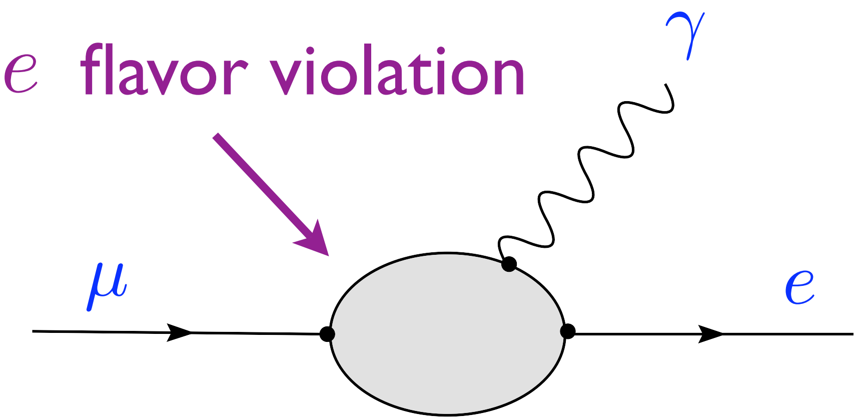
Note: $a_\mu(\mathrm{EW}) \sim O(10^{-9})$

new physics with a scale of O(100 GeV - 1 TeV)
may be responsible for this discrepancy



muon g-2

$\mu \to e$ flavor violation



$\mu \to e\gamma$

neutrino → flavor violation + anomaly of muon g-2

⬇

$\mu \to e\gamma$ LFV in charged lepton sector

muon g-2 vs. $\mu \to e\gamma$

$$e \frac{m_\mu}{2} \frac{y}{\Lambda^2} \bar{\mu} \sigma_{\mu\nu} \mu F^{\mu\nu} \qquad\qquad e m_\mu \frac{y_{\mathrm{LFV}}}{\Lambda^2} \bar{\mu}_R \sigma_{\mu\nu} e_L F^{\mu\nu}$$

$$\delta a_\mu = y \frac{2 m_\mu^2}{\Lambda^2} \qquad\qquad \mathrm{BR}(\mu \to e\gamma) = \frac{3(4\pi)^3 \alpha}{G_F^2 \Lambda^4} y_{\mathrm{LFV}}^2$$

If $y_{\mathrm{LFV}} = y \theta_{\mu e}$

$$\mathrm{BR}(\mu \to e\gamma) = \frac{3(4\pi)^3 \alpha}{4 G_F^2 m_\mu^4} (\delta a_\mu)^2 \, \theta_{\mu e}^2$$

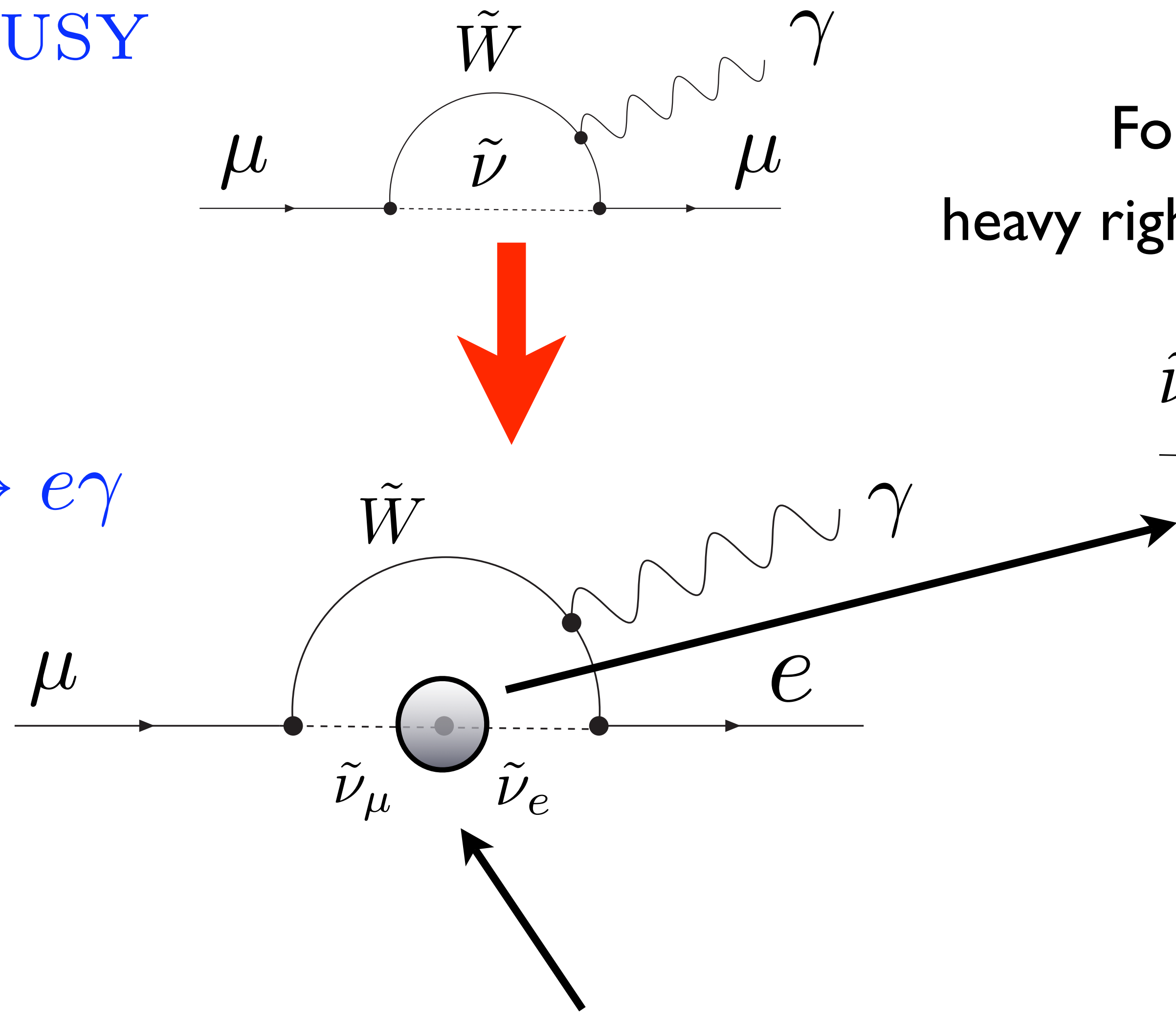
$$\simeq 0.6 \times 10^{-11} \left(\frac{\delta a_\mu}{10^{-9}} \right)^2 \left(\frac{\theta_{\mu e}}{10^{-4}} \right)^2$$

If the muon g-2 anomaly is true, the current and future experiments on lepton flavor violation can probe the small flavor violation!

★ LFV in SUSY models

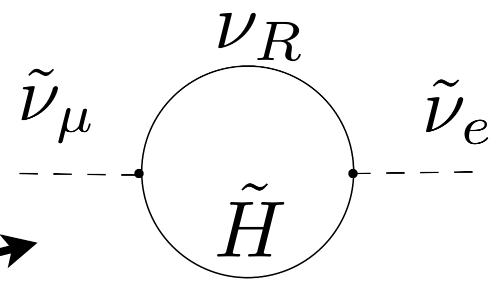
$\delta a_\mu^{\mathrm{SUSY}}$

$\mu \to e\gamma$



For example,

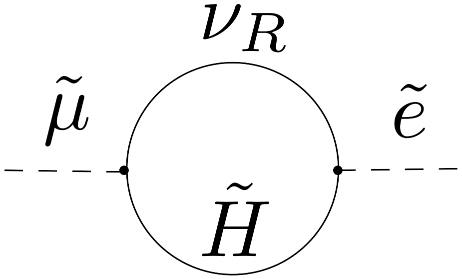
heavy right-handed neutrinos



The LFV slepton masses can be induced by high energy flavor violating interactions

Hall, Kostelecky, Raby, 1985

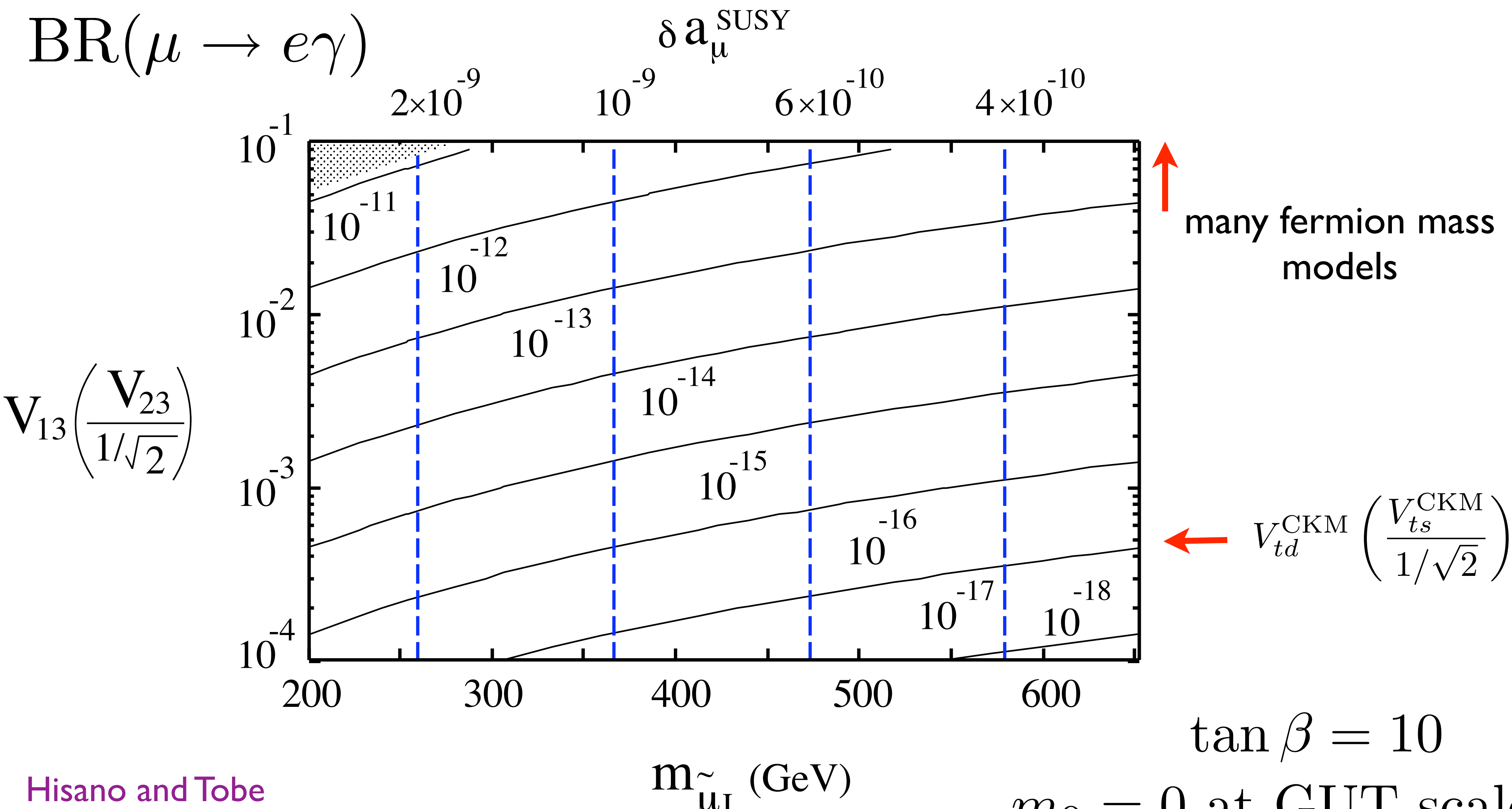
e.g. Right-handed neutrino Yukawa interaction



$$\frac{(m^2_{\tilde{L}})_{\mu e}}{m_0^2} \sim (y_\nu^\dagger y_\nu)_{21} \sim y^2_{\nu_\tau} V_{23} V_{13} \text{ for } y_{\nu_\tau} \gg y_{\nu_e},\ y_{\nu_\mu}$$

and if SO(10)-like Yukawa unification is realized.....

$$y_{\nu_\tau}(M_{\rm GUT}) = y_{\rm top}(M_{\rm GUT})$$

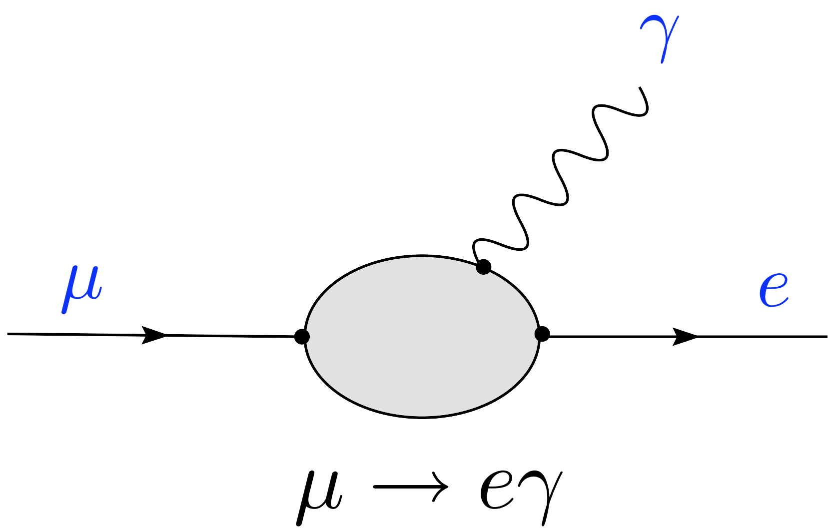


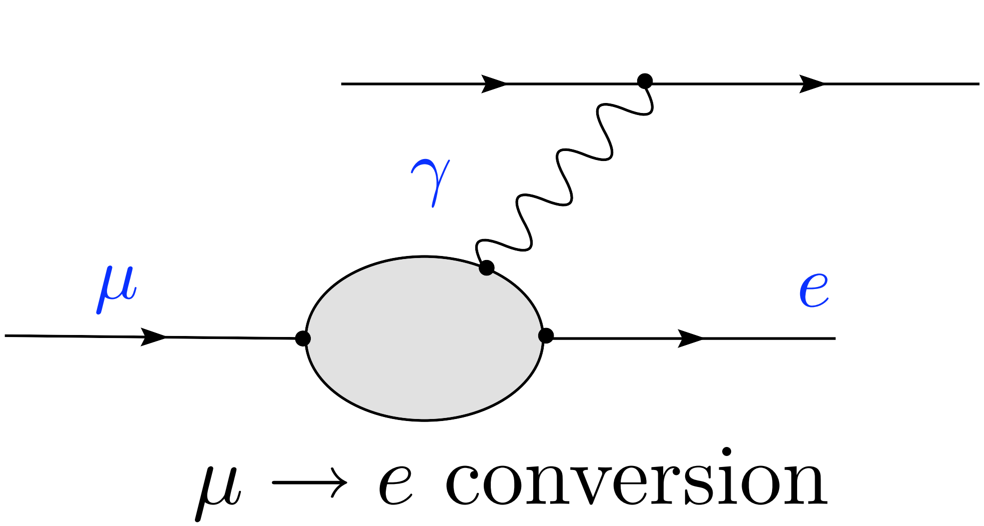
$\tan\beta = 10$

$m_0 = 0$ at GUT scale

Hisano and Tobe

Note: If the photon penguin diagram is dominant in $\mu \to e$ conversion ,





$$\mathrm{R}(\mu^- \mathrm{T_i} \to e^- \mathrm{T_i})/\mathrm{BR}(\mu \to e\gamma) \simeq 5 \times 10^{-3}$$

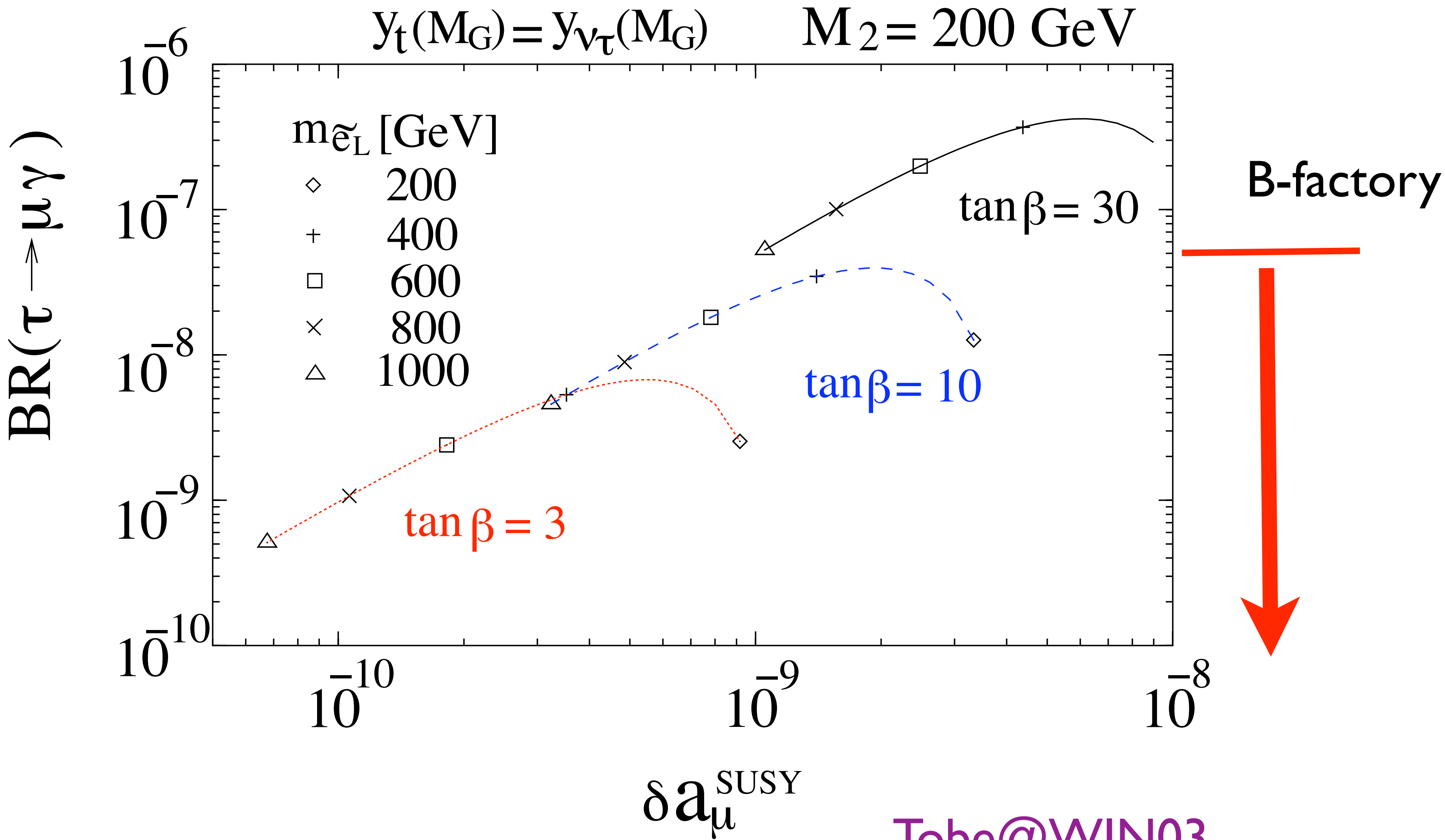
(In SUSY, the photon penguin has the $\tan\beta$ enhancement.)

$$\mathrm{BR}(\mu \to e\gamma) \sim 10^{-11} \longrightarrow \mathrm{R}(\mu^- \mathrm{T_i} \to e^- \mathrm{T_i}) \sim 5 \times 10^{-14}$$

$$\mathrm{BR}(\mu \to e\gamma) \sim 10^{-13} \longrightarrow \mathrm{R}(\mu^- \mathrm{T_i} \to e^- \mathrm{T_i}) \sim 5 \times 10^{-16}$$

$$\mathrm{BR}(\mu \to e\gamma) \sim 10^{-16} \longrightarrow \mathrm{R}(\mu^- \mathrm{Ti} \to e^- \mathrm{Ti}) \sim 10^{-18}$$

$\tau \to \mu\gamma$ is also interesting!



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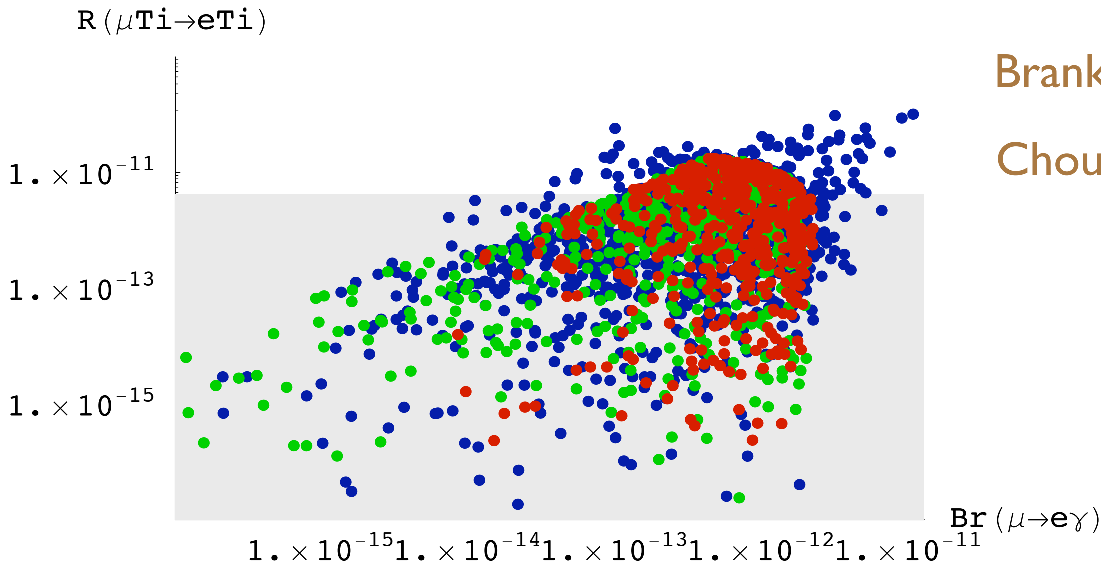
★ LFV in other models

Littlest Higgs model with T-parity (LHT model)

- Higgs boson is a pseudo Nambu-Goldstone boson which is light because of approximate global symmetries.
- quadratic divergence in Higgs mass parameter is cancelled by new particle contribution at one-loop level

→ solve the naturalness problem



Branke et al, hep-ph/0702136

Choudhury et al, hep-ph/0612327

Figure 10: *$\mu - e$ conversion rate in $^{48}_{22}Ti$ as a function of $Br(\mu \to e\gamma)$, after imposing the existing constraints on $\mu \to e\gamma$ and $\mu^- \to e^-e^+e^-$. The shaded area represents the current experimental upper bound on $R(\mu Ti \to e Ti)$.*

Comparison of various ratios of event rates

	MSSM	MSSM (Higgs mediated)	LHT
$\frac{\mathrm{R}(\mu\mathrm{Ti}\to e\mathrm{Ti})}{\mathrm{BR}(\mu\to e\gamma)}$	$\sim 5\times 10^{-3}$	$\sim 0.1-0.2$	$\sim 10^{-2}-10^{2}$
$\frac{\mathrm{BR}(\mu\to eee)}{\mathrm{BR}(\mu\to e\gamma)}$	$\sim 6\times 10^{-3}$	$\sim 6\times 10^{-3}$	$\sim 0.4-2.5$

(Higgs mediated contribution is important when $\tan\beta$ is large, Higgs bosons are light and SUSY scale is large.)

These kind of ratios will be important to distinguish the different models

- SUSY seesaw model (Borzumati, Masiero 1986; Hisano et al 1995...)
- SUSY GUT (Barbieri, Hall 1994,....)
- R-parity violationg SUSY (A.de Gauvea et al 2000,......)
- neutrinos in extra dimensions (Ioannisian, Pilaftsis 1999; Kitano 2000,......)
- many other models...........

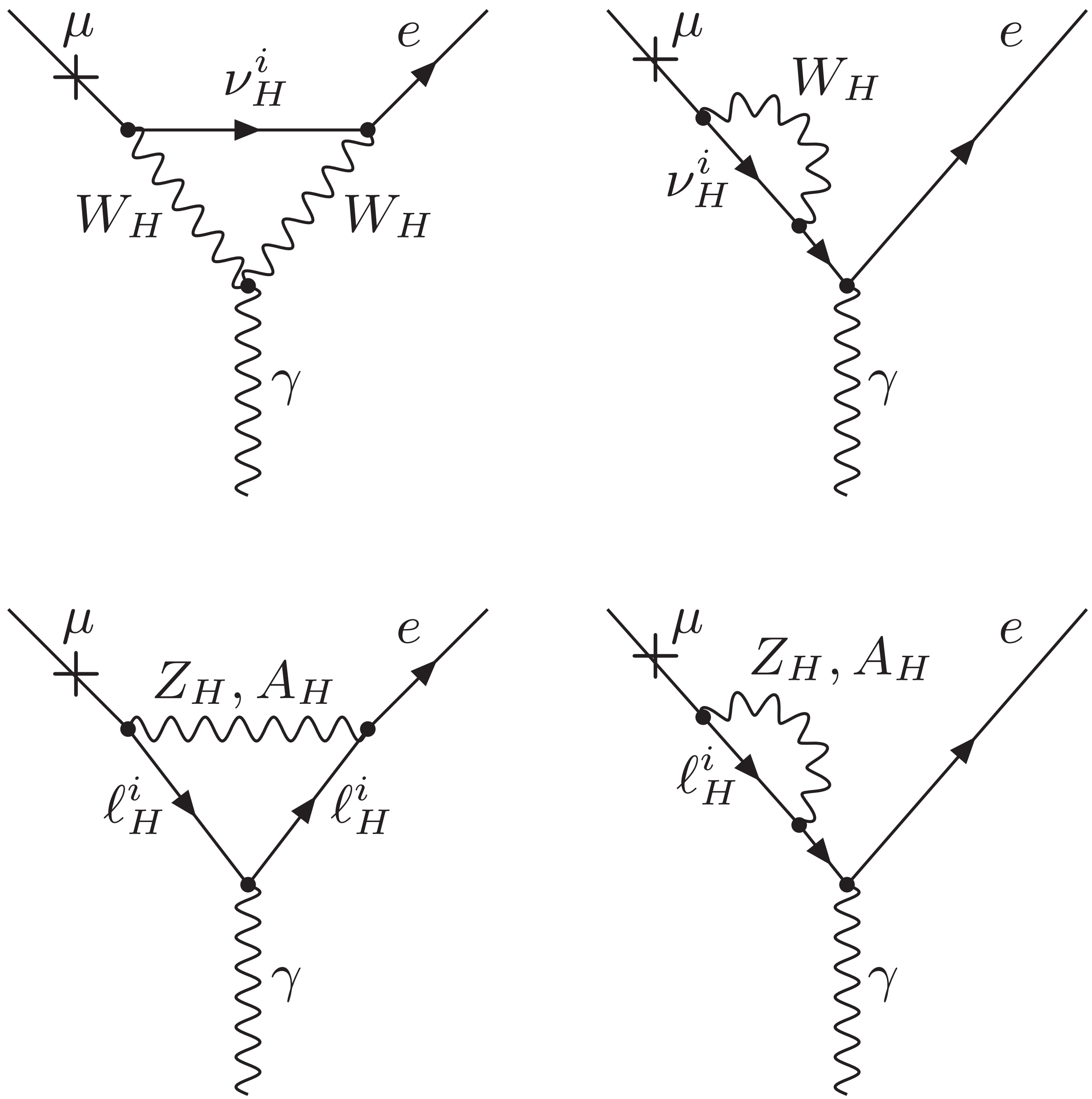
Summary

✴ The current and future LFV search can be sensitive to the flavor violating TeV scale physics.

✴ The search for the LFV can be important to probe the high-energy LFV interactions (e.g. origin of neutrino mixing, GUT interactions etc.), which can not be reached by the collider experiments.

✴ The search for the LFV is complementary to the direct search for TeV scale new physics at LHC/Tevatron/ILC.

Backup slides



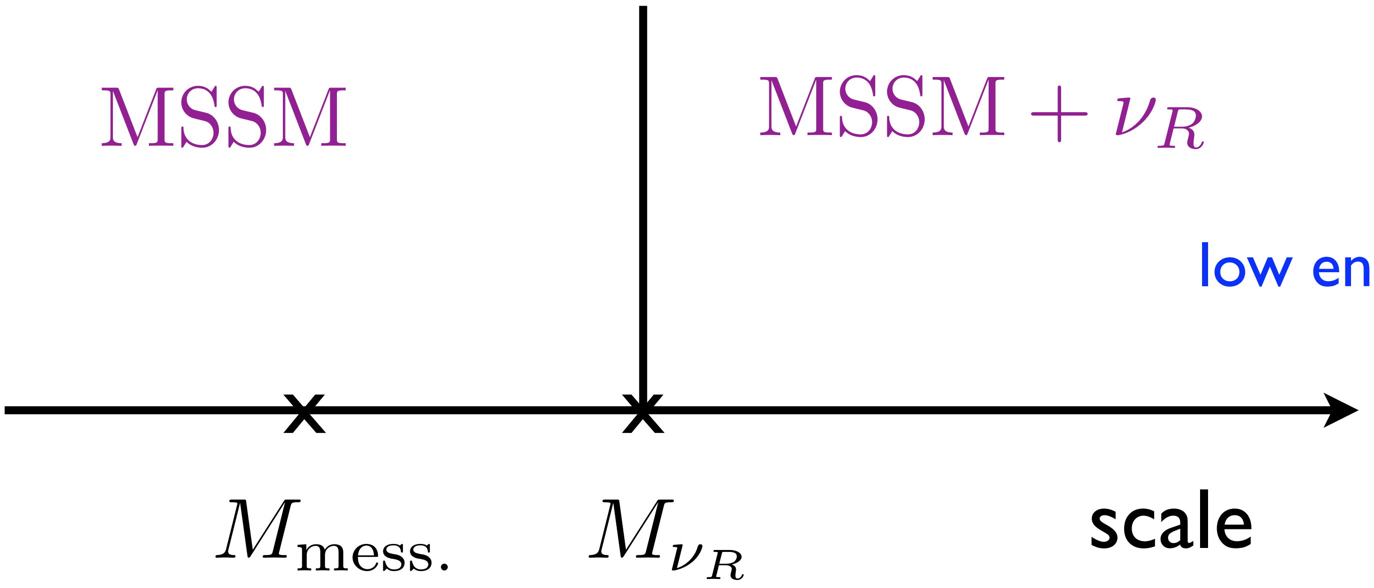
μ
e
ν_H^i
W_H
W_H
γ
μ
e
W_H
ν_H^i
γ
μ
e
Z_H, A_H
ℓ_H^i
ℓ_H^i
γ
μ
e
Z_H, A_H
ℓ_H^i
γ

Models	V_{23}	V_{13}
Albright *et al.* [25]	0.9	0.06
Altarelli *et al.* [25]	0.5	0.09
Bando *et al.* [25]	~ 0.7	~ 0.1
Hagiwara *et al.* [25]	0.7	0.06
Nomura *et al.* [25]	0.7	~ 0.1
Sato *et al.* and Buchmüller *et al.* [23, 24]	0.7	~ 0.05

Table 1: Typical predicted values for V_{23} and V_{13} in various models [23, 24, 25].

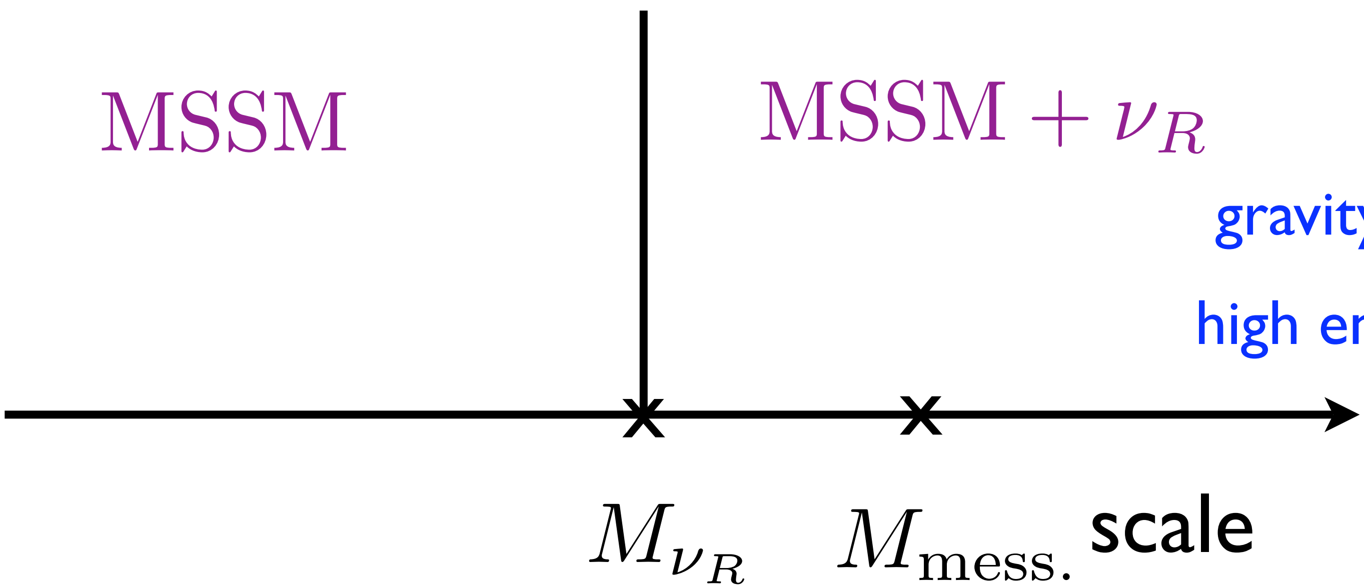
✳Constraint on SUSY breaking messenger scale from LFV

$M_{\mathrm{mess.}}$: scale where SUSY breaking terms are generated



No LFV

low energy gauge mediation



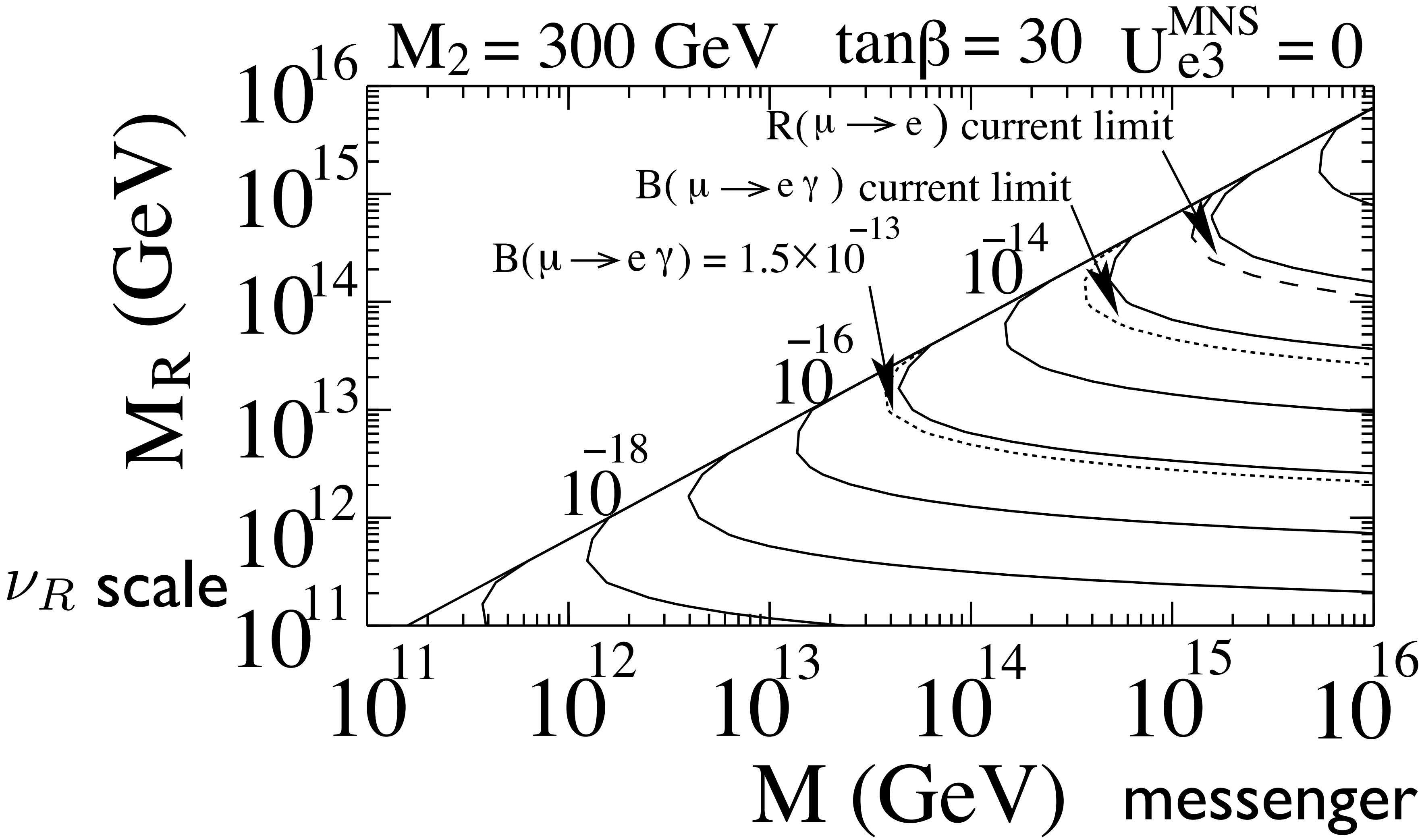
LFV

gravity mediation

high energy gauge mediation

$R(\mu \to e \text{ in Ti})$

Tobe, Wells, Yanagida



If we observe the LFV, low energy gauge mediation will be strongly disfavored

Combining LHC and LFV data, we may have some information on messenger scale and right-handed neutrino masses