Flavour mixing and EDMs in the SUSY models

J. Hisano (Univ. of Tokyo, ICRR)

“FLAVOUR IN THE ERA OF THE LHC ”
3rd meeting (WGs): CERN, May 15-17 2006

Contents of my talk

1, Introduction

Electric Dipole Moment (EDM) : T-odd observable.

$$H_{eff} = -d_f \vec{S} \bullet \vec{E}$$

EDMs for electron, neutron and atoms are measured. CP phase in CKM matrix does not generate sizable EDMs, and EDMs are sensitive to beyond the standard model.

$$d_e < 10^{-40} e\,cm \quad \text{(no contribution up to 3 loop)}$$
$$d_q \approx 10^{-(33-34)} e\,cm \quad (O(\alpha_s G_F^2))$$
$$d_n \approx 10^{-(31-32)} e\,cm \quad \text{(long distance effects)}$$

SUSY SM provides new ~~CP~~ sources in ~~SUSY~~ terms.

Phases in F-term ~~SUSY~~ terms:

$$\phi_B = \arg(M_{1/2} B^*), \quad \phi_A = \arg(M_{1/2} A^*)$$

SUSY CP problem: from current EDM bounds,

$$|\sin\phi_B| <\sim \left(\frac{m_{SUSY}}{\text{TeV}}\right)^2 \tan^{-1}\beta, \quad |\sin\phi_A| <\sim \left(\frac{m_{SUSY}}{\text{TeV}}\right)^2$$

Some mechanism should suppress F-term phases.

Sfermion mass terms are also sources of ~~flavor~~ and/or ~~CP~~.

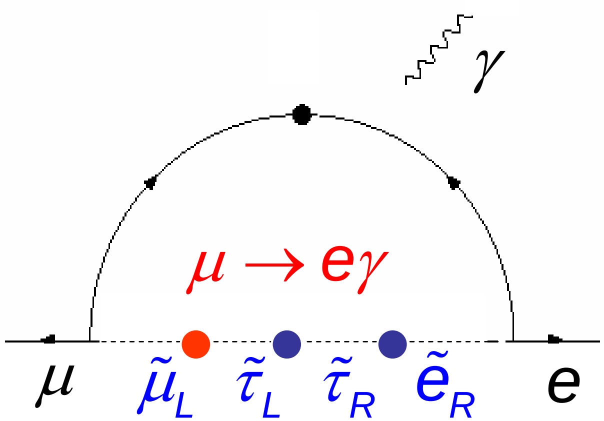
$$\delta_{ij}^{LL} \equiv \frac{\left(m^2_{\tilde{f}_L \tilde{f}_L}\right)_{ij}}{\bar{m}^2_{\tilde{f}}}, \quad \delta_{ij}^{RR} \equiv \frac{\left(m^2_{\tilde{f}_R \tilde{f}_R}\right)_{ij}}{\bar{m}^2_{\tilde{f}}}, \quad \delta_{ij}^{LR} \equiv \frac{\left(m^2_{\tilde{f}_L \tilde{f}_R}\right)_{ij}}{\bar{m}^2_{\tilde{f}}}$$

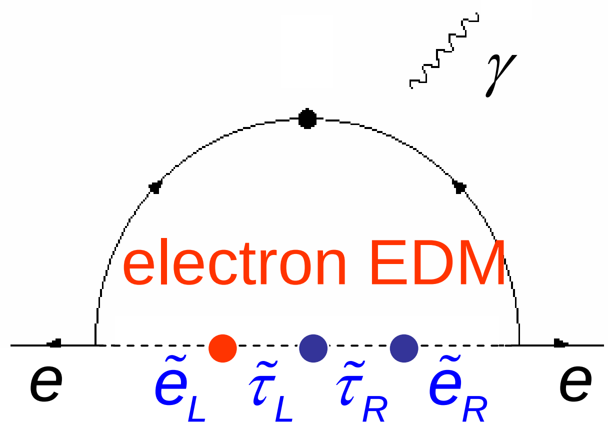
When left- and right-handed sfermions have mixing,

$$\delta_{ee}^{LR(\mathrm{eff})} \approx (m_\tau / m_e) \times \delta_{e\tau}^{LL} \delta_{e\tau}^{RR*} \delta_{ee}^{LR}, \qquad \delta_{dd}^{LR(\mathrm{eff})} \approx (m_b / m_d) \times \delta_{db}^{LL} \delta_{db}^{RR*} \delta_{dd}^{LR}.$$

And, if $\mathrm{Im}[\delta_{ij}^{LL} \delta_{ij}^{RR*}] \neq 0$, it contributes to EDMs even if $\phi_{B/A} = 0$.

FCNC processes and EDMs may be correlated to each others.





FCNC processes and EDMs probe flavor structure in ~~SUSY~~ terms.

Supersymmetric SU(5) Ground Unification

Flavor-violating SUSY breaking mass terms for sfermion are induced by GUT interaction even if the flavor universality is imposed at the cutoff scale. (Hall, Kostelecky & Raby)

In MSSM with right-handed neutrinos,

CKM mixing ⇒ Left-handed sdown mixing
Neutrino mixing ⇒ Left-handed slepton mixing

In SUSY SU(5) GUT with right-handed neutrinos, quarks and leptons are unified, and then

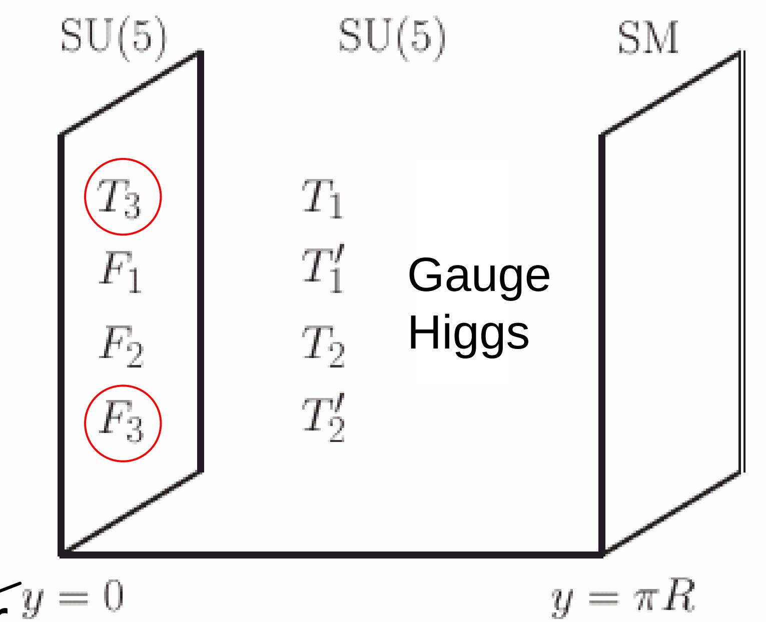
CKM mixing ⇒ Right-handed slepton mixing
Neutrino mixing ⇒ Right-handed sdown mixing

We can check consistency among FCNCs and EDMs due to the GUT relation in flavor violation.

Generation structure comes from simple repetation?

Orbifold SU(5) SUSY GUT in 5 dimensional space (Hall&Nomura)

Solution for Triplet-doublet Higgs mass splitting problem and dim-5 proton decay problem. Unparallel generation structure is favored from matter fermion masses and p-decay. 3rd generation in 10 dim has different configuration from others.



Sherk-Shwartz ~~SUSY~~ mechanism:
at tree-level.

$$m^2_{\tilde{T}} \propto \mathrm{diag}(1,1,0)$$
$$m^2_{\tilde{F}} \propto \mathrm{diag}(0,0,0)$$

Matter sfermions in 10 dim have ~~flavor~~ mass terms. (Left and right-handed mixing in up squark.)

10 dim matter, $T(=(Q_L, u_R, e_R))$
5^* dim matter, $F(=(d_R, L_L))$

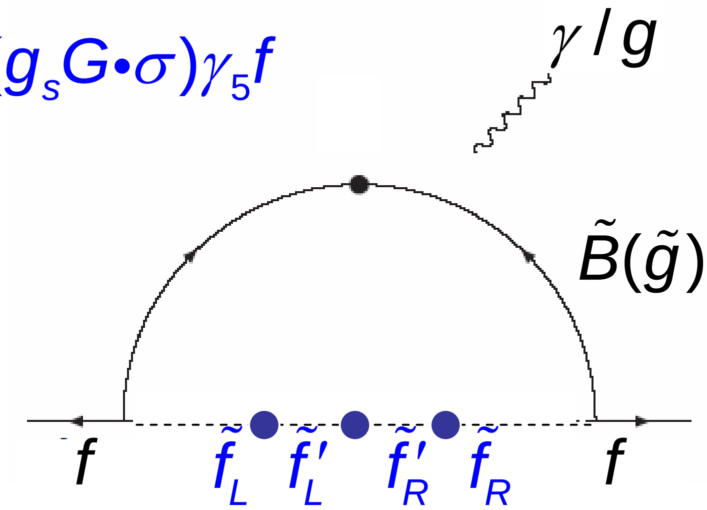
2, EDMs vs FCNC processes

Effective ~~CP~~ operators at parton-level

- $L_{\rm eff}^{\rm dim5} = -\sum_{f=e,u,d,s} i\frac{d_f}{2}\bar{f}(F\bullet\sigma)\gamma_5 f - \sum_{f=u,d,s} i\frac{d_f^C}{2}\bar{f}(g_s G\bullet\sigma)\gamma_5 f$

$$\frac{d_e}{e} \sim \frac{\alpha_Y m_e}{4\pi m_{SUSY}^2}{\rm Im}[\delta_{ee}^{LR(eff)}],$$

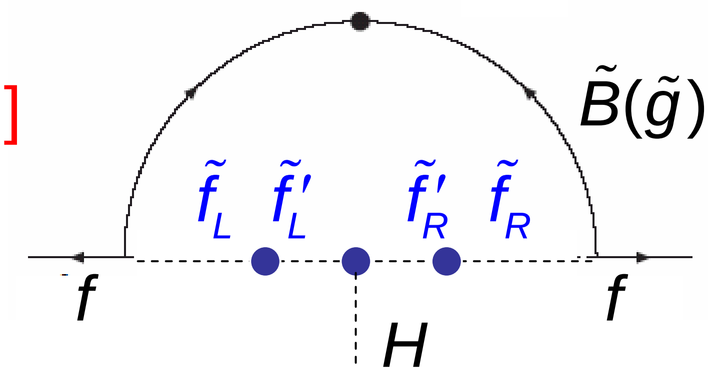
$$\frac{d_q}{e}, d_q^C \sim \frac{\alpha_s m_q}{4\pi m_{SUSY}^2}{\rm Im}[\delta_{qq}^{LR(eff)}]$$



- $L_{\rm eff}^{\rm dim6} = -\sum_{f,f'=e,u,d,s} C_{ff'}\bar{f}f\bar{f}'i\gamma_5 f'$ (Higgs mediation contribution (HMC))

$$C_{ed} \sim \frac{\alpha_s f_e^{SM} f_d^{SM}}{4\pi m_A^2}\tan^2\beta \times {\rm Im}[\delta_{dd}^{LR(eff)} - \frac{\alpha_Y}{\alpha_s}\delta_{ee}^{LR(eff)}]$$

$$C_{ds} \sim \frac{\alpha_s f_d^{SM} f_s^{SM}}{4\pi m_A^2}\tan^2\beta \times {\rm Im}[\delta_{dd}^{LR(eff)} - \delta_{ss}^{LR(eff)}]$$

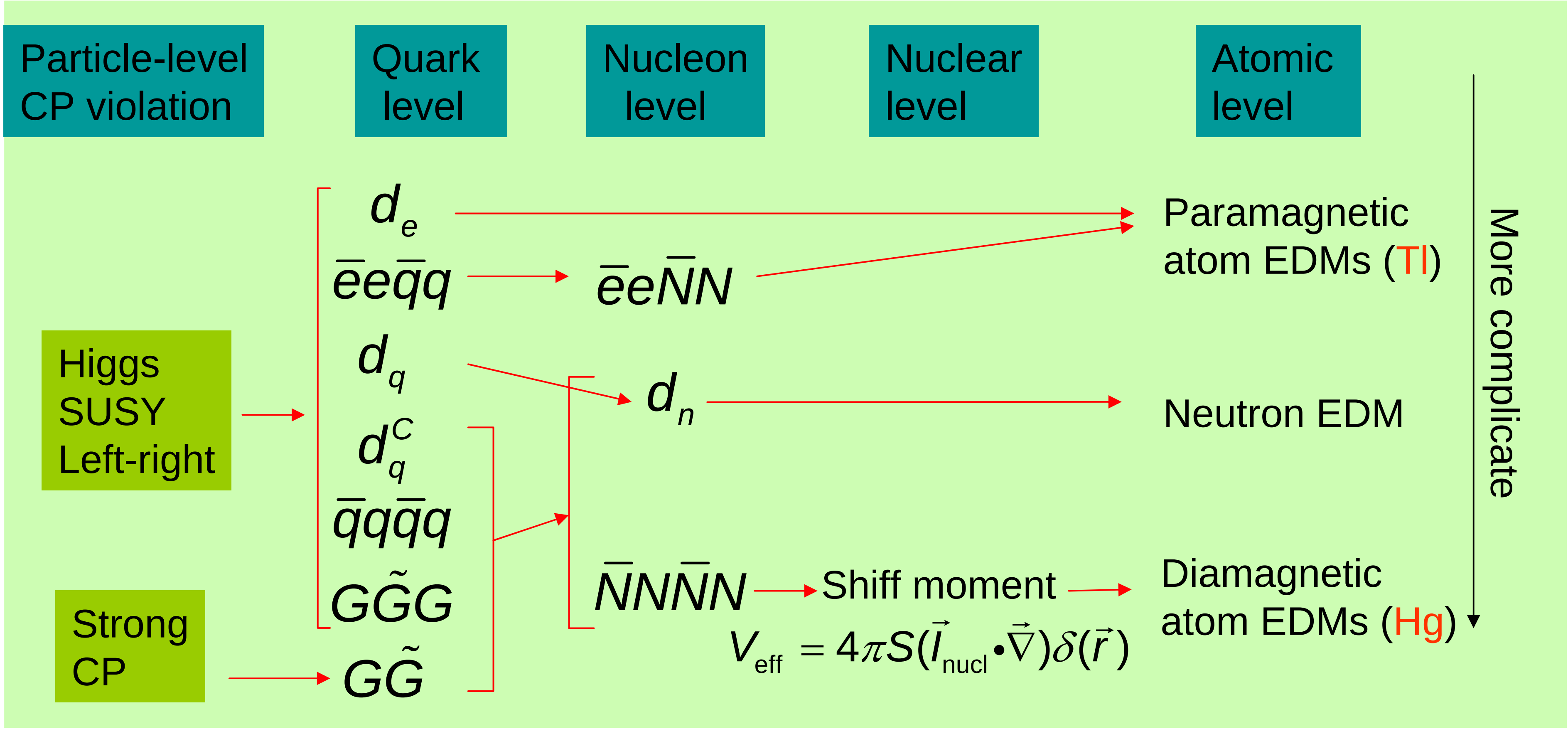


HMC becomes dominant when $\tan\beta$ is larger than $\sim 10^3 (m_A / m_{SUSY})$.

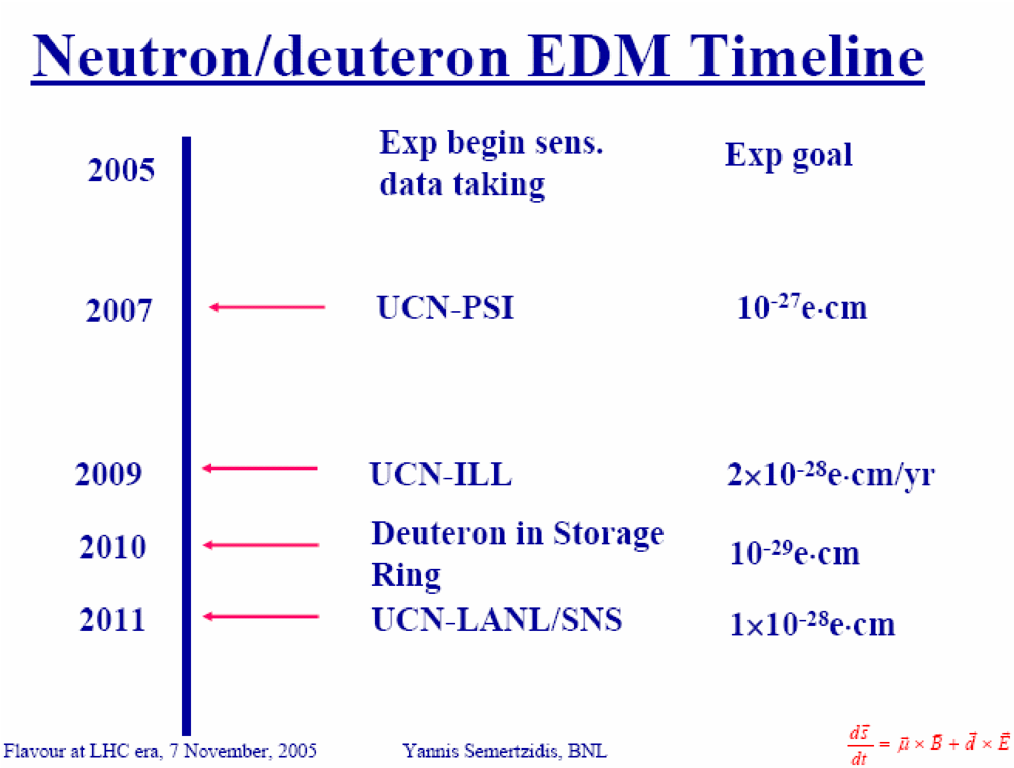
Current bounds on EDMs and the evaluation.

- paramagnetic atom (Tl) : $|d_{\mathrm{Tl}}| < 9 \times 10^{-25}\, e\,cm$

  $\rightarrow$ electron : $|d_{\mathrm{e}}| < 1.7 \times 10^{-27}\, e\,cm$
- diamagnetic atom (Hg) : $|d_{\mathrm{Hg}}| < 2 \times 10^{-28}\, e\,cm$
- neutron (n) : $|d_{\mathrm{n}}| < 6 \times 10^{-26}\, e\,cm$



Future prospects on EDMs



- PbO, YbF molecule EDMs

$$d_e \to 10^{-29}\, e\, cm$$

- muon EDMs

$$d_\mu \to 10^{-24}\, e\, cm$$

(from Semertzidis's presentation)

Strange quark CEDM

Strange quark component in necleon is not negligible. From baryon mass and sigma term in chiral perturbation theory,

$$\langle p|\bar{u}u|p\rangle \simeq 4.8,\ \langle p|\bar{d}d|p\rangle \simeq 4.1,\ \langle p|\bar{s}s|p\rangle \simeq 2.8$$ (Zhitnitsky)

Thus, hadronic EDMs depend on the strange quark CEDM via K or eta meson interaction. Using the QCD sum rule, ex,

$$g_{pp\eta}^{CP} \approx -\frac{2}{3\sqrt{3}f_\pi}\langle p|\bar{s}s|p\rangle m_0^2 d_s^C, \quad (m_0^2 \approx 0.8\mathrm{GeV}^2).$$ (Falk et al)

$$\Rightarrow \quad d_{\mathrm{Hg}} = -8.7\times 10^{-3} e\,(d_u^C - d_d^C - 0.005 d_s^C)$$

$$d_{\mathrm{n}} = -1.6 e\,(d_u^C + 0.81 d_d^C + 0.16 d_s^C)$$ (JH, Shimizu)

This is close to an order of magnitude discussion, and then, further investigation ,such as by lattice, should be important.

Hadronic EDM vs FCNC processes

For $\tan\beta = 10, m_{SUSY} = 500\text{GeV}$,

Hg (neutron) EDM	$\Delta M_{K/Bd/Bs/D}$ (Box)
$\lvert \mathrm{Im}[\delta^{LL}_{ds}\delta^{RR*}_{ds}] \rvert < 0.6(1) \times 10^{-3}$	$\lvert \mathrm{Re}[\delta^{LL}_{ds}\delta^{RR}_{ds}] \rvert < 7 \times 10^{-6}$
$\lvert \mathrm{Im}[\delta^{LL}_{db}\delta^{RR*}_{db}] \rvert < 2(4) \times 10^{-5}$	$\lvert \mathrm{Re}[\delta^{LL}_{db}\delta^{RR}_{db}] \rvert < 3 \times 10^{-4}$
$\lvert \mathrm{Im}[\delta^{LL}_{sb}\delta^{RR*}_{sb}] \rvert < 3(0.2) \times 10^{-3}$	$\lvert \mathrm{Re}[\delta^{LL}_{sb}\delta^{RR}_{sb}] \rvert < 9 \times 10^{-3}$
$\lvert \mathrm{Im}[\delta^{LL}_{uc}\delta^{RR*}_{uc}] \rvert < 0.8(1) \times 10^{-3}$	$\lvert \mathrm{Re}[\delta^{LL}_{uc}\delta^{RR}_{uc}] \rvert < 3 \times 10^{-4}$
$\lvert \mathrm{Im}[\delta^{LL}_{ut}\delta^{RR*}_{ut}] \rvert < 3(5) \times 10^{-6}$	

Future neutron and deuteron EDM measurements may improve up and down (C)EDM by 10^{2-4} and strange CEDM by 10^{2-3}.

Hadronic EDM vs FCNC processes (Higgs mediation)

For $\tan\beta = 50, m_A = 500\text{GeV},$

Tl EDM	$\Delta M_{Bd/Bs}$ (Box)
$\|\text{Im}[\delta_{db}^{LL}\delta_{db}^{RR*}]\| <\sim 10^{-2}$	$\|\text{Re}[\delta_{db}^{LL}\delta_{db}^{RR}]\| <\sim 10^{-4}$
$\|\text{Im}[\delta_{sb}^{LL}\delta_{sb}^{RR*}]\| <\sim 10^{-1}$	$\|\text{Re}[\delta_{sb}^{LL}\delta_{sb}^{RR}]\| <\sim 10^{-3}$
$\|\text{Im}[\delta_{e\tau}^{LL}\delta_{e\tau}^{RR*}]\| <\sim 10^{-2}$	

When left- and right-handed down squarks have mixing, Bd and Bs (and K) mixing gives stringent constraints on Higgs mediation. (Hamzaoui et al)

Neutron and Hg EDMs gives looser constraints at present.

Leptonic EDM vs LFV processes

MEG experiment will start soon and cover $Br(\mu \to e\gamma) \approx 10^{-(13-14)}$, and improvement of $10^{(2-3)}$ may be achieved.

$$Br(\mu \to e\gamma) \propto \left(\left| \delta^{LL}_{\mu e} + 1.8 \delta^{RR}_{\mu\tau} \delta^{LL}_{\tau e} \right|^2 + \left| 0.05 \delta^{RR}_{\mu e} + 1.8 \delta^{LL}_{\mu\tau} \delta^{RR}_{\tau e} \right|^2 \right)$$

Seesaw GUT w.ν_R SU(5) GUT GUT w.ν_R

Current bound implies that for $\tan\beta = 10$ and $m_{SUSY} = 200\mathrm{GeV}$.

$$|\delta^{LL}_{e\mu}| < 2 \times 10^{-4}, \quad |\delta^{RR}_{e\mu}| < 3 \times 10^{-3}, \quad |\delta^{LL}_{e\tau} \delta^{RR}_{\tau\mu}|, |\delta^{RR}_{e\tau} \delta^{LL}_{\tau\mu}| < 1 \times 10^{-4}$$

Electron EDM bound is competitive to it:

$$\mathrm{Im}[\delta^{LL}_{e\tau} \delta^{RR}_{\tau e}] < 2 \times 10^{-5}.$$

The future EDM measurement is useful to discriminate models even when $\mu \to e\gamma$ is discovered. When left- and right-handed sleptons have mixing and they dominate in the process,

$$d_e \approx 2.5 \times 10^{-26} e\,cm \times \left(\left| \delta^{LL}_{\mu\tau} / \delta^{LL}_{e\tau} \right|^2 + \left| \delta^{RR}_{\mu\tau} / \delta^{RR}_{e\tau} \right|^2 \right)^{-1/2} \sqrt{\frac{Br(\mu \to e\gamma)}{1.2 \times 10^{-11}}}$$

Search for $\tau \to \mu\gamma$ improve bounds on $\delta^{LL}_{\mu\tau} \delta^{RR}_{\tau\mu}$. It implies $d_\mu <\sim 10^{-24} e\,cm$.

3, Models

- SUSY SU(5) GUT w. right-handed neutrinos

$$\delta^{LL}_{e\mu}, \delta^{RR}_{ds} \propto U_{e3} U^*_{\mu 3} m_{\nu\tau} M_N$$

$$\delta^{RR}_{e\mu}, \delta^{LL}_{ds} \propto V_{td} V^*_{ts}$$

(U :MNS, V :CKM)

- Orbifold SU(5) SUSY GUT

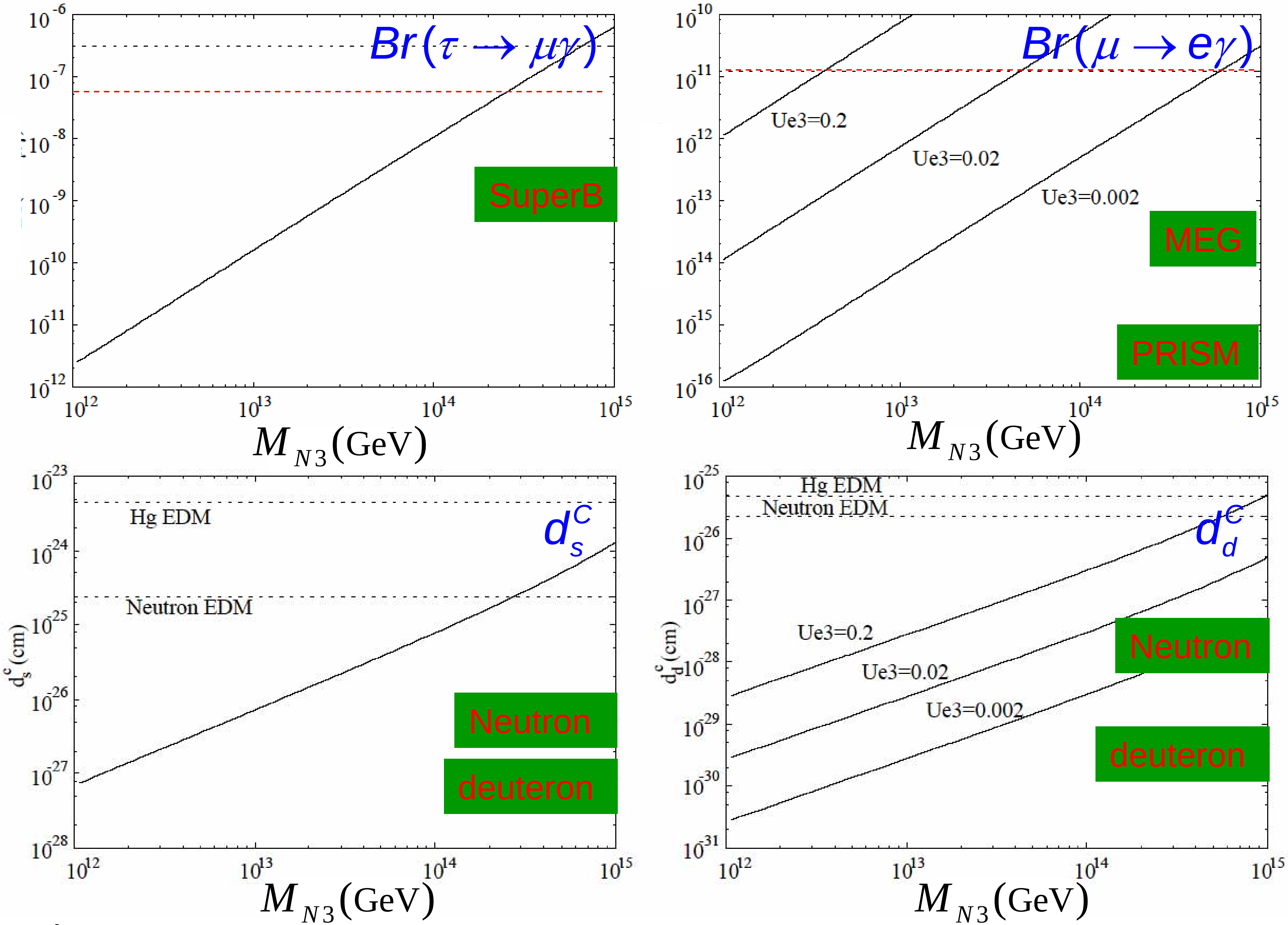
Sfermions in 10-dim have ~~flavor~~ mass terms.

$$\delta^{RR}_{\mu\tau}, \delta^{RR}_{ct}, \delta^{LL}_{ct} \sim \lambda^2$$

$$\delta^{RR}_{e\tau}, \delta^{RR}_{ut}, \delta^{LL}_{ut} \sim \lambda^3$$

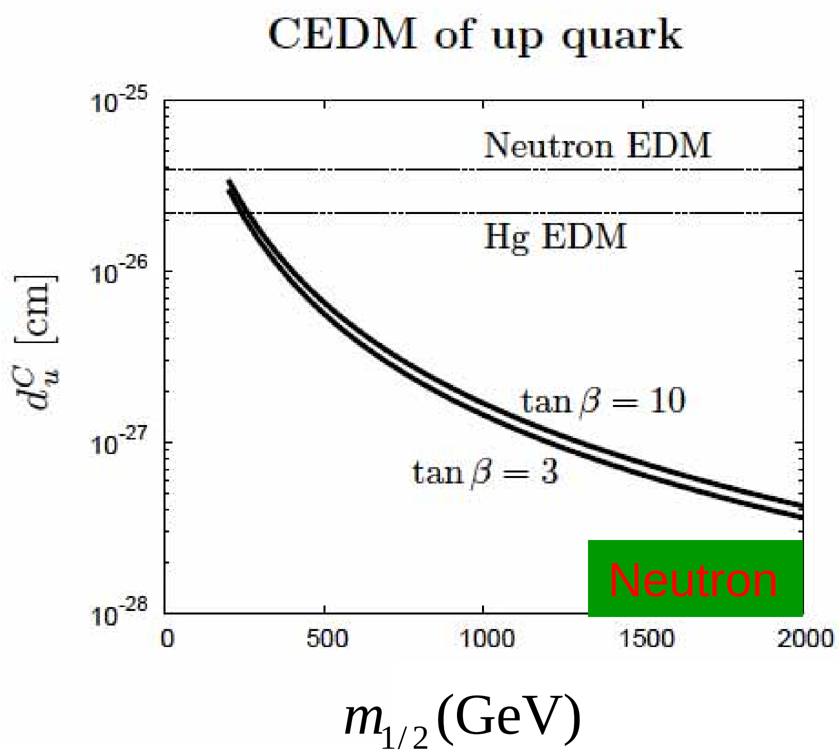
($\lambda \sim 0.2$)

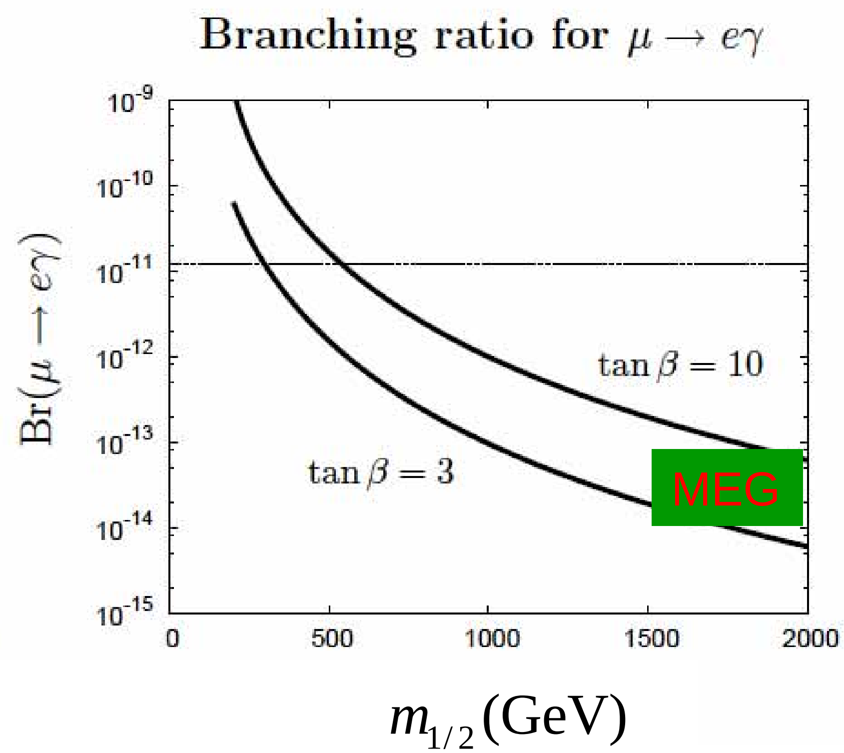
SUSY SU(5) GUT w. right-handed neutrinos



$(m_{\nu\tau} = 0.05\text{eV},\ m_0 = 500\text{GeV},\ m_{\tilde{g}} = 500\text{GeV})$ (JH, Kakizaki, Nagai, Shimizu)

Orbifold SU(5) SUSY GUT





(JH, Kakizaki, Nagai)

4 Summary

In this talk, I review EDMs induced by flavor violation in SUSYSM. When both left- and right-handed sfermions have flavor mass terms, sizable EDMs may be generated from the relative phases even if F-term SUSY breaking, such as A and B parameters, are close to real. This mechanism is applicable in other models with flavor left- and right-handed currents.

I show constraints on flavor mass insertion parameters from experimental bounds on EDMs, and some of them are comparable to or stronger than FCNC bounds. The bounds will be furthermore improved in the future experiments by $10^{(2-3)}$.

When non-zero values of EDMs are observed in the future experiments , the interpretation would be still difficult.

• Hadronic EDMs have various contribution, EDM, CEDM of up, down, strange, theta, etc.
• EDMs come from ~~CP~~ in (flavor conserving) F-terms or those in ~~flavor~~ D-terms?

Further studies are needed.