Hadronic EDMs in SUSY GUTs [1]

Mitsuru Kakizaki

ICRR, University of Tokyo, Kashiwa 277-8582, Japan

Abstract

We investigate constraints from null results of hadronic electric dipole moments (EDMs) searches on supersymmetric grand unified theories (SUSY GUTs). Especially we focus on (i) SUSY SU(5) GUTs with right-handed neutrinos and (ii) Kaluza-Klein GUTs in which both the GUT symmetry and SUSY are broken by boundary conditions in compactified extra dimensions. We demonstrate that hadronic EDM experiments severely constrain SUSY GUT models and are promising for probing the structure of GUT and SUSY breaking mediation mechanism.

1 Introduction

After the discovery of successful agreement of the three extrapolated gauge couplings at a higher energy scale, supersymmetric grand unified theories (SUSY GUTs) have been considered as ones of the most predominant candidates for a theory beyond the standard model (SM). The measured ratio of the bottom quark mass to tau lepton mass seems to support the idea of GUTs which also predict Yukawa coupling unification. There have been extensive experimental researches to detect another implications for SUSY GUTs.

Crucial hints for SUSY GUTs are obtained by investigating flavor and CP violation originated from the SUSY breaking scalar mass terms. Because SUSY GUTs also provide some relations between squark and slepton mass matrices [3], we can probe the structure of SUSY GUT by combining results of low energy experiments, such as K and B physics, lepton flavor violating (LFV) decays and electric dipole moment (EDM) searches.

Recently Hisano and Shimizu pointed out that null results of hadronic EDM experiments severely constrain CP-violating squark generation mixings in SUSY models [4, 5]. When off-diagonal elements in squark mass matrices have sizable imaginary parts, unacceptably large chromo-electric dipole moments (CEDMs) would be induced and conflict with hadronic EDM data. Since chirality flip effect involved in dipole diagrams is enhanced by heavier quark masses, imaginary parts of products of left- and right-handed squark flavor mixings are stringently constrained. It is also interesting to notice that flavor conserving moments severely constrain flavor changing parameters. In particular the bound on down-type squark mixings between the second and third generation plays a crucial role in discussing the SUSY contribution to the CP asymmetry in the B meson system. If sizable deviation from the SM prediction of the CP asymmetry in $B_d^0 \to \phi K_S$ is attribute to the right-handed down-type squark mixings arising from radiative correction by the right-handed neutrino Yukawa coupling in SUSY GUTs, the CEDM of the strange quark would exceed the experimental bound. We emphasize that the hadronic EDM constraints are important criteria for distinguishing various scenarios and for building models.

In this talk we discuss the hadronic EDM in SUSY GUTs. For definiteness we consider (i) SUSY SU(5) GUTs with right-handed neutrinos under the minimal supergravity (mSUGRA) boundary condition, and (ii) the Hall–Nomura model where nontrivial boundary conditions in a fifth dimension break SUSY and SU(5) gauge symmetry and produce rich fermion and sfermion flavor structure [6].

2 Chromo-electric dipole moments

First let us recall the CEDM of the light quarks and their experimental upper limit constrained by hadronic EDM experiments. The contributions from the CEDM d_q^C of the light quark $q(=u,d,s)$ to the EDMs of the neutron and ^{199}Hg atom are evaluated as [5] $d_n = -1.6 \times e(d_u^C + 0.81 \times d_d^C + 0.16 \times$

[1] This talk is based on collaboration with Junji Hisano, Minoru Nagai and Yasuhiro Shimizu [1, 2]

d_s^C), $\quad d_{\rm Hg} = -8.7\times10^{-3}\times e(d_u^C - d_d^C + 0.005\times d_s^C)$ when the Peccei–Quinn mechanism works. Here d_n is generated by the charged meson loops and $d_{\rm Hg}$ comes from the nuclear force by the pion exchange in the chiral perturbation theory. The current upper bounds on the EDMs are $|d_n| < 6.3\times10^{-26}\,e$cm, $\quad |d_{\rm Hg}| < 1.9\times10^{-26}\,e$cm at 90 % confidence level. In the absence of accidental cancellation among various contributions we obtain $e|d_u^C| < 3.9(2.2)\times10^{-26}\,e$cm, $\quad e|d_d^C| < 4.8(2.2)\times10^{-26}\,e$cm, $\quad e|d_s^C| < 2.4(44)\times10^{-25}\,e$cm from the EDM of the neutron (^{199}Hg atom).

In discussing effects caused by sfermion mixings, it is convenient to introduce the following mass insertion parameters:

$$(\delta^f_{ij})_{L/R} \equiv \frac{(m^2_{\tilde{f}_{L/R}})_{ij}}{(\overline{m}^2_{\tilde{f}})}, \quad (\delta^d_i)_{LR} \equiv \frac{m_{d_i}(A_i^{(d)} - \mu\tan\beta)}{\overline{m}^2_{\tilde{d}}}, \quad (\delta^u_i)_{LR} \equiv \frac{m_{u_i}(A_i^{(u)} - \mu\cot\beta)}{\overline{m}^2_{\tilde{u}}}. \tag{1}$$

Here these quantities are defined in the so-called super-CKM basis, where the corresponding quark masses are diagonal. When both the left-handed and right-handed squarks have off-diagonal components in their mass matrices, the CEDMs of the light quarks are significantly enhanced by the heavier quark mass as

$$d^C_{q_i} \sim \frac{\alpha_s}{4\pi}\frac{m_{\tilde{g}}}{\overline{m}^2_{\tilde{q}}} f\left(\frac{m^2_{\tilde{g}}}{\overline{m}^2_{\tilde{q}}}\right) {\rm Im}\left[(\delta^q_{ij})_L(\delta^q_j)_{LR}(\delta^q_{ji})_R\right], \tag{2}$$

where $m_{\tilde{g}}$ and $\overline{m}_{\tilde{q}}$ are the gluino and averaged squark masses.

3 SUSY SU(5) GUTs with right-handed neutrinos

Here we discuss hadronic EDM constraints on the neutrino sector in the SUSY SU(5) GUT with the right-handed neutrinos.

In high energy SUSY breaking scenarios the left-handed down-type squark mixings inevitably arise due to renormalization group (RG) effects of the large top Yukawa coupling and quark generation mixing. Thus the hadronic EDMs are sensitive to the right-handed down-type squark mixings, especially between the second and third generations and between the first and third ones compared with the other low-energy hadronic observables.

In SUSY GUTs radiative corrections by the right-handed neutrino Yukawa coupling induces the flavor-violating mass terms for the right-handed down-type squarks as well as for the left-handed sleptons. These mass matrices are related as $(\delta^d_{ij})_R \simeq (\overline{m}^2_{\tilde{l}}/\overline{m}^2_{\tilde{d}})(\delta^l_{ij})^*_L$ [3].

In Fig. 1 we show the CEDMs for the down and strange quarks in the SUSY SU(5) GUT with the right-handed neutrinos. We assume the minimal supergravity scenario and take the colored Higgs mass to be $M_{H_c} = 2\times10^{16}$ GeV. The CP violating phases are taken to be maximal. In Fig. 1(a) we show the strange quark CEDM as a function of the right-handed tau neutrino mass. We take $m_{\nu_\tau} = 0.05$ eV and $U_{\mu3} = 1/\sqrt{2}$ and use the the well-known seesaw formula in order to fix the tau neutrino Yukawa coupling constant. For the SUSY breaking parameters, we take $m_0 = 500$ GeV, $A_0 = 0$, $m_{\tilde{g}} = 500$ GeV and $\tan\beta = 10$, which lead to $\overline{m}_{\tilde{q}} \simeq 640$ GeV. We ignore the contribution from the electron and muon neutrino Yukawa interactions to the flavor violation in the right-handed down-type squark mass matrix. The contribution is bounded by the constraints from the K^0–$\overline{K}^0$ mixing and ${\rm Br}(\mu\to e\gamma)$ when $|U_{e2}| \sim 1/\sqrt{2}$. From this figure, the right-handed tau neutrino mass should be smaller than $\sim 3\times10^{14}$ GeV. In Fig. 1(b) we show the down quark CEDM as a function of the right-handed tau neutrino mass. This comes from non-vanishing U_{e3} in our assumption that the right-handed neutrino mass matrix is diagonal. The current bound is not significant even when $U_{e3} = 0.2$.

The new technique for the measurement of the deuteron EDM has a great impact on the quark CEDMs if it is realized. If they establish the sensitivity of $d_D \sim 10^{-27}\,e$cm, we may probe the new physics to the level of $ed_s^C \sim 10^{-26}\,e$cm and $ed_d^C \sim ed_u^C \sim 10^{-28}\,e$cm, which are much stronger than the bounds from the neutron and ^{199}Hg atom EDMs [5]. This may imply that we can probe the structure in the neutrino sector even if $M_{N_3} \sim 10^{13}$ GeV and $U_{e3} \sim 0.02$.

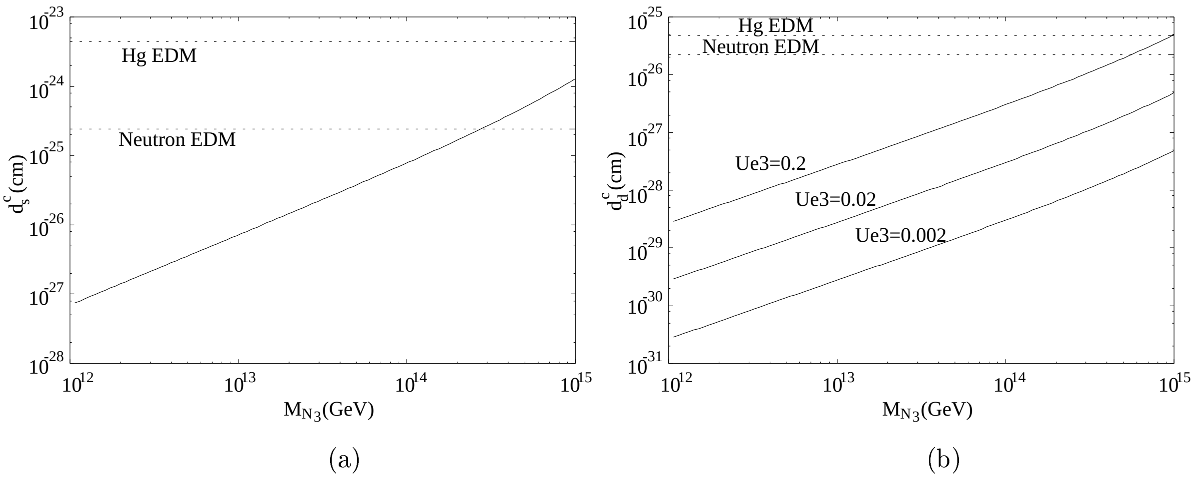

Figure 1: The CEDMs of the strange quark (a) and the down quark (b) as a function of the right-handed tau neutrino mass, M_{N_3}. Here, $M_{H_c} = 2 \times 10^{16}$ GeV, $m_{\nu_\tau} = 0.05$ eV, $U_{\mu 3} = 1/\sqrt{2}$, and $U_{e3} = 0.2$, 0.02, and 0.002. For the MSSM parameters, we take $m_0 = 500$ GeV, $A_0 = 0$, $m_{\tilde{g}} = 500$ GeV and $\tan\beta = 10$.

4 Kaluza-Klein GUTs

Here we point out that the null results of the hadronic EDM searches severely constrain Kaluza-Klein GUTs where both the GUT symmetry and SUSY are broken by boundary conditions in extra dimensions. Especially we consider one construction of a SUSY SU(5) GUT in five dimensions proposed by Hall and Nomura [6].

The extra spatial dimension is compactified on an S^1/Z_2 orbifold, a line interval $0 < y < \pi R$. The SU(5) symmetry is preserved in the bulk and on the brane at $y = 0$, while only the standard model gauge symmetry survives on the brane at $y = \pi R$. The gauge and Higgs fields live in the bulk. The decuplets of the first two generations reside in the bulk, while the other matter fields are located on the SU(5) preserving brane. Given this matter configuration the hierarchical fermion masses are reproduced and the SUSY flavor problems are ameliorated. The Yukawa interactions between the decuplets and the fundamental Higgs multiplet leading to the up-type quark masses are allowed only on the SU(5) brane. Since the zero mode left-handed quark doublets and the zero mode right-handed up-type quarks have to be derived from different bulk decuplets due to the SU(5) breaking boundary condition, the resulting up-type quark mass matrix M_u is not symmetric ($M_u \neq M_u^T$). For the SUSY breaking sector, the Scherk–Schwarz mechanism generates the soft breaking mass $\widetilde{m}$ for bulk fields with no soft masses for brane fields, and so non-universal mass spectra are realized for both left- and right-handed up-type squarks. Thus in the super-CKM basis the CP violating phases of off-diagonal components in the left-handed up-type squark mass matrix do not coincide with the right-handed counterparts, leading to the CEDM of the up quark enhanced by the large top quark mass.

We have performed numerical analysis of the CEDM of the up quark. In Fig. 2(a) we show the CEDM of the up quark originated from squark flavor mixing in the Hall–Nomura model as a function of the SUSY breaking parameter $\widetilde{m}$. We take the compactification scale as $M_c = 1 \times 10^{15}$ GeV and $\tan\beta = 3, 10$. We postulate flavor mixing parameter between the first and third generation of $U_{13} = 0.01$ at the compactification scale and maximal CP violation. We find that the predicted up CEDM is marginal to the current experimental limit. This situation is to be contrasted with the conventional SUSY GUTs in four dimensions, where the up CEDM arises only from RG effects and is estimated as $d_u^C \sim 10^{-28}$ cm even for large $\tan\beta$. The non-trivial configuration of the decuplets also induce flavor mixing in the right-handed slepton sector. The LFV branching ratios for the $\mu \to e\gamma$ decay coming from the right-handed slepton mixing is depicted in Fig. 2(b). It is demonstrated that the up CEDM

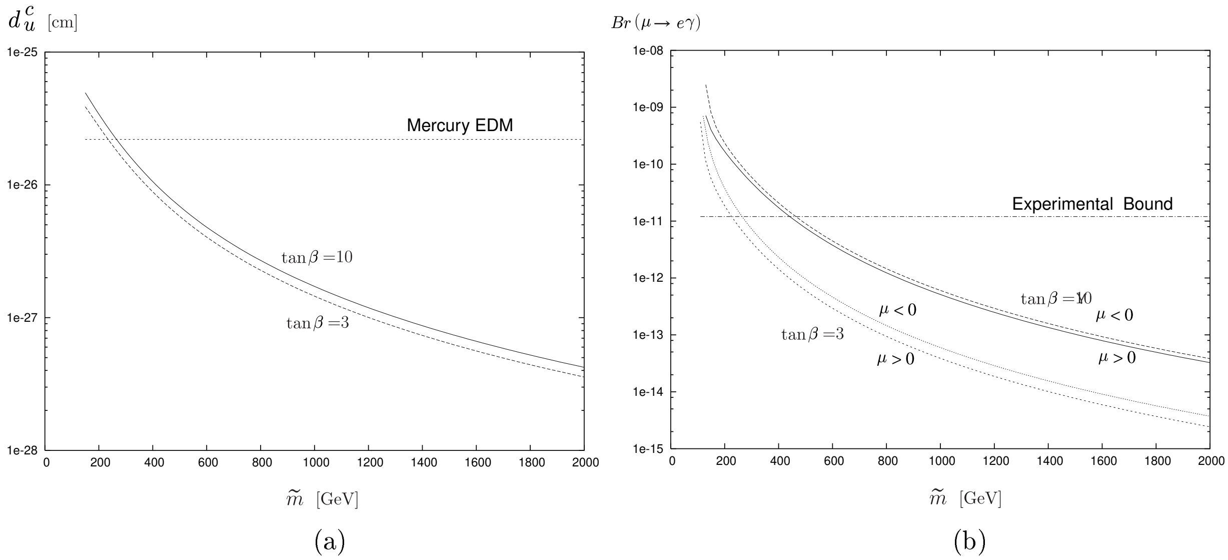

Figure 2: The predictions of the CEDM of the up quark (a) and the branching ratio of the $\mu \to e\gamma$ decay (b) as a function of the SUSY breaking parameter $\widetilde{m}$. Here μ denotes the Higgs mixing parameter. We take $M_c = 1 \times 10^{15}$ GeV, $U_{13} = 0.01$ and $\tan\beta = 3, 10$.

constraint on the orbifold GUT is as strong as that from the lepton flavor violating decay.

5 Conclusion

We have investigated the hadronic EDM constraints on SUSY GUT models. Although EDMs are flavor conserving processes, they also constrain flavor mixing of squarks. We find that in SUSY SU(5) GUTs with right-handed neutrinos the current experimental bound of the neutron EDM may imply that the right-handed tau neutrino mass is smaller than about 10^{14} GeV in the minimal supergravity scenario. In the light of the CEDM of the up quark orbifold GUTs are found to be marginally allowed when both fermion and sfermion mass structure are attributed to the nature of extra dimensions. The sensitivity to CP violating squark generation mixings may be improved furthermore in future experiments, such as the deuteron EDM measurement.

References

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