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CEDM constraints in $E_6 \times SU(2)_F \times U(1)_A$ SUSY GUT model

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We show chromo-electric dipole moment (CEDM) constraint in $E_6 \times SU(2)_F \times U(1)_A$ grand unified theory (GUT). In general, down quark CEDM decouples in large sfermion mass limit, while for up quark CEDM, there is non-decoupling effects caused by stop loop. Therefore, if up-quark and up-squark sectors are complex at GUT scale and stop mass is light in order to realize 125 GeV Higgs mass, up quark CEDM is enhanced and become one of the strong constraint for supersymmetric (SUSY) GUT model. However, in this model, although the mass of third generation SU(5) 10 representation sfermion is lighter than that of the other sfermions, up quark CEDM is suppressed because real up-quark and up-squark sectors at GUT scale can be also obtained. We saw that up and down quark CEDM satisfy current constraints and may be some signals in future experiments in E_6 SUSY GUT with $SU(2)_F$ flavor and anomalous $U(1)_A$ gauge symmetries.

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1. Introduction

Grand unified theory (GUT) can unify not only three Standard Model (SM) gauge couplings into a single one but also matter fields into a few multiplets. Furthermore, there are experimental supports for both unifications. One is for gauge coupling unification and the other is for matter unification. The former is quantitative consistency between experimental and theoretical couplings, and the latter is qualitative explanation of various hierarchies of matters and mixings.

If the E_6 supersymmetric (SUSY) GUT is considered with $SU(2)_F$ family symmetry[1] and the anomalous $U(1)_A$ gauge symmetry, we can obtain more attractive GUT model[2]. This model can solve doublet-triplet splitting problem in a natural assumption that all the interactions which are allowed by the symmetry are introduced with $O(1)$ coefficients. Moreover, in this model, we can obtain the natural SUSY-type sfermion mass spectrum which suppress the SUSY flavor-changing neutral current (FCNC) and stabilize the weak scale at the same time.

Because of this spectrum, stop can be light in order to realize 125 GeV Higgs mass. In that case, the SUSY contributions to the up quark chromo-electric dipole moment (CEDM) are not decoupled, and therefore, if up-quark and up-squark sectors are complex at GUT scale, the CEDM become one of the strong constraint for that model. However, in this model, real up-quark and up-squark sectors at GUT scale can be obtained. Hence, although these sectors are complex at low energy by the renormalization group equation (RGE), we expected that the CEDM of this model is suppressed enough for satisfying current bound.

In previous work[3], CEDM in this model was computed but the situation has changed because of 125 GeV Higgs observation. So, we compute the up and down quark CEDM in $E_6 \times SU(2)_F \times U(1)_A$ SUSY GUT model in the new situation. We will conclude that up and down quark CEDM satisfy current bound in this model and there may be some signals in future experiments.

2. $E_6 \times SU(2)_F \times U(1)_A$ SUSY GUT model

In this model, three **27** fundamental fields of E_6 are introduced as matters. This is decomposed in the $E_6 \supset SO(10) \times U(1)_{V'}$ notation (and in the $[SO(10) \supset SU(5) \times U(1)_V]$ notation) as

$$\mathbf{27} = \mathbf{16}_1[\mathbf{10}_1 + \bar{\mathbf{5}}_{-3} + \mathbf{1}_5] + \mathbf{10}_{-2}[\mathbf{5}_{-2} + \bar{\mathbf{5}}'_2] + \mathbf{1}'_4[\mathbf{1}'_0]. \tag{2.1}$$

This decomposition says that three generations of **27**s of E_6 contain six $\bar{\mathbf{5}}$s of $SU(5)$. Three of these $\bar{\mathbf{5}}$s become superheavy through the superpotential, and the remaining three of $\bar{\mathbf{5}}$s become the SM modes. These modes, denote $\bar{\mathbf{5}}^0_i$, mainly come from the first two generations of **27**, as like $(\bar{\mathbf{5}}^0_1, \bar{\mathbf{5}}^0_2, \bar{\mathbf{5}}^0_3) \sim (\bar{\mathbf{5}}_1, \bar{\mathbf{5}}'_1, \bar{\mathbf{5}}_2)$. Then, we can obtain the natural SUSY-type sfermion mass spectrum

$$\tilde{m}^2_{10} \sim \begin{pmatrix} m_0^2 & & \\ & m_0^2 & \\ & & m_3^2 \end{pmatrix}, \quad \tilde{m}^2_{\bar{5}^0} \sim \begin{pmatrix} m_0^2 & & \\ & m_0^2 & \\ & & m_0^2 \end{pmatrix} \tag{2.2}$$

from SUSY breaking potential $V_{SB} \ni m_0^2|\Psi_a|^2 + m_3^2|\Psi_3|^2$, where Ψ_a and Ψ_3 denote the matter fields of doublet and singlet of $SU(2)_F$, respectively.

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Also, specific Yukawa structure is obtained from superpotential in this model. Especially, up-type Yukawa matrix, Y_u in this model is real at GUT scale,

$$Y_u = \begin{pmatrix} 0 & \frac{1}{3}d_q\lambda^5 & 0 \\ -\frac{1}{3}d_q\lambda^5 & c\lambda^4 & b\lambda^2 \\ 0 & b\lambda^2 & a \end{pmatrix}, \tag{2.3}$$

where a, b, c and d_q are real $O(1)$ coefficients which are introduced by the natural assumption of this model, and $\lambda \sim 0.22$ is the Cabibbo angle. Note that $\Psi_1\Psi_1$ and $\Psi_1\Psi_3$ are forbidden by $SU(2)_F$ symmetry, therefore $(1,1), (1,3)$ and $(3,1)$ components of Y_u are 0. This structure is good not only for getting realistic up-type quark mass spectrum, but also for satisfying the CEDM constraint.

3. CEDM constraints and result

CEDM lagrangian is

$$\mathscr{L}_{\text{CEDM}} = -\sum_q d_q^C \frac{i}{2}\bar{q}g_s(\sigma \cdot G)\gamma_5 q, \tag{3.1}$$

where $\sigma \cdot G = \sigma^{\mu\nu}T^A G^A_{\mu\nu}$, $\sigma^{\mu\nu} = \frac{i}{2}[\gamma^\mu, \gamma^\nu]$, $T^A (A = 1, \cdots, 8)$ are generators of $SU(3)$ and $G^A_{\mu\nu}$ is field strength of gluon. SUSY contribution to CEDM is shown in Fig. 1. We can estimate this

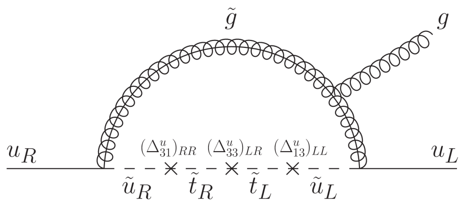

Figure 1: One example of SUSY contribution to up-type CEDM, d_u^C. $(\Delta^u_{ij})_{\Gamma\Gamma} (\Gamma\Gamma = LL, RR, LR)$ is off-diagonal element of 6×6 up-type squark mass matrix. This contribution doesn't decouple.

diagram roughly to be $\frac{\alpha_s}{4\pi}\frac{M_{\tilde{g}}}{m_{\tilde{t}}^2}$, where $M_{\tilde{g}}$ and $m_{\tilde{t}}$ is gluino and stop mass, respectively. Note that in the limit $m_0 \gg m_3$, this is not decoupled. Therefore, CEDM become strong constraints for SUSY GUT model if Y_u is complex at GUT scale. However, in this model, real Y_u at GUT scale is obtained, so we expect that CEDM constraint for this model is suppressed. Actually, at SUSY scale, Y_u becomes complex by the RGE effects even if Y_u is real at GUT scale, so that we must check whether the CEDM calculated in this model satisfy the current experimental bounds[4],

$$|d_u^C| < 6 \times 10^{-27} e \text{ cm}, \quad |d_d^C| < 6 \times 10^{-27} e \text{ cm}. \tag{3.2}$$

In this talk, we consider that m_3 is $\mathscr{O}(1)$ TeV in order to realize 125 GeV Higgs mass, so that m_0 is $\mathscr{O}(10)$ TeV. Also, we use one-loop RGEs for getting low energy parameters from input parameters. The result is shown in Fig. 2. In this figure, for comparison, we plot three type of inputs at GUT scale: imaginary Y_u (right four plots), real Y_u (middle four plots) and this model (left four plots). These Y_u has $\mathscr{O}(1)$ coefficients generated randomly within the interval 0.5 to 1.5 with

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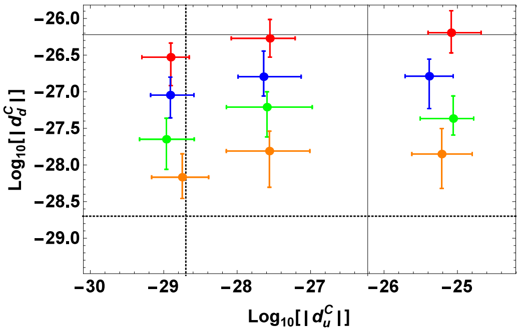

Figure 2: Up and down quark CEDM plots. We use $\tan\beta = 7$ at low energy scale and $M_{1/2} = 1$ TeV, $A_0 = -1$ TeV and $\mu = 500$ GeV at GUT scale. Right, middle and left four plots correspond to imaginary Y_u, real Y_u and Y_u of this model at GUT scale. We set m_0 value as 5 TeV (red), 10 TeV (blue), 20 TeV (green) and 40 TeV (orange). Black solid line is current bounds and dashed line is expected future bounds.

$+$ or $-$ signs. For each input, we use $\tan\beta = 7$ at low energy scale and $M_{1/2} = 1$ TeV, $A_0 = -1$ TeV and $\mu = 500$ GeV at GUT scale and we set m_0 value as 5 TeV (red), 10 TeV (blue), 20 TeV (green) and 40 TeV (orange). Black solid lines show the current bounds Eq. (3.2) and black dashed lines are the expected future bounds. From Fig. 2, CEDM values of this model is smaller than the other two situations because of specific structure of Y_u at GUT scale. So, we can conclude that up and down quark CEDM of this model satisfy the current bounds. And furthermore, these may be some signals in future experiments.

4. Summary and discussion

We have shown that in $E_6 \times SU(2)_F \times U(1)_A$ SUSY GUT model, up and down quark CEDM satisfy the current bounds. Moreover, we found that there may be some signals in future experiments. However, there are some considerations that we ignore here. Especially, it is non-trivial whether 125 GeV Higgs mass is really obtained. Of course, in order to obtain more precise value of CEDMs, we must consider two-loop RGE to get low energy parameters.

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