Abstract

A triple vector correlation in the $\mu^+ \to e^+ e^+ e^-$ decay with polarized muons is investigated as a probe to CP violating coupling constants in supersymmetric models. A sizable triple correlation can be induced due to a complex phase in the supersymmetric soft-breaking terms in the SU(5) grand unified theory. Correlation with the electric dipole moments of electron and neutron are investigated and it is shown that these quantities give independent information on possible CP violating sources.

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Lepton flavor violating (LFV) processes such as $\mu^+ \to e^+ \gamma$, $\mu^+ \to e^+ e^+ e^-$ and $\mu^-e^-$ conversion in atoms have important implications in search for physics beyond the Standard Model (SM). Many extensions of the SM predict measurable rates for these LFV processes. In particular it has been pointed out that rates for these processes can be as large as or just below the present experimental upper bounds in supersymmetric (SUSY) grand unified theories (GUTs) \[1\]. Current experimental bounds for these processes are $B(\mu^+ \to e^+ \gamma) \leq 4.9 \times 10^{-11}$ \[2\], $B(\mu^+ \to e^+ e^+ e^-) \leq 1.0 \times 10^{-12}$ \[3\], $\sigma(\mu^- Ti \to e^- Ti)/\sigma(\mu^- Ti \to capture) \leq 4.3 \times 10^{-12}$ \[4\]. Further improvements of these bounds in two or three orders of magnitude will have a great impact on search for unified theories based on SUSY.

In this letter, we consider the $\mu^+ \to e^+ e^+ e^-$ process with polarized muons. If the initial muon is polarized we can define T-odd triple vector correlation,, $\vec{\sigma} \cdot (\vec{p}_1 \times \vec{p}_2)$ where $\vec{\sigma}$ is the muon spin and $\vec{p}_1$, $\vec{p}_2$ are two independent momenta of the final particles. In this way we can measure CP and T nonconserving effects in LFV interactions \[5\]. As possible sources of CP violation we consider SUSY soft-breaking terms in SUSY GUT. We show that it is possible to generate a measurable T-odd asymmetry in this model. We also consider the electron and the neutrion electric dipole moments (EDMs) which are sensitive to the same CP violating phase and show these observables give independent information on the possible CP violating sources.

Let us begin with the following effective lagrangian relevant for the $\mu^+ \to e^+ e^+ e^-$ decay.

$$
\mathcal{L} = m_\mu A_R \overline{\mu_R} \sigma^{\mu \nu} e_L F_{\mu \nu} + m_\mu A_L \overline{\mu_L} \sigma^{\mu \nu} e_R F_{\mu \nu} \\
+ g_1 \overline{\mu_R} e_L \overline{e_R} e_L + g_2 \overline{\mu_L} e_R \overline{e_L} e_R + g_3 \overline{\mu_R} \gamma^\mu e_R \overline{e_R} \gamma_{\mu} e_R \\
+ g_4 \overline{\mu_L} \gamma^\mu e_L \overline{e_L} \gamma_{\mu} e_L + g_5 \overline{\mu_R} \gamma^\mu e_R \overline{e_L} \gamma_{\mu} e_L + g_6 \overline{\mu_L} \gamma^\mu e_L \overline{e_R} \gamma_{\mu} e_R + \text{H.C.} \ (1)
$$

Here $A_R$, $A_L$ and $g_i$'s are in general complex coupling constants. In order to obtain the above expression we have used the Fiertz rearrangement for four-fermion terms and neglect terms suppressed by the electron mass compared to the muon mass.

Among the above terms the photon-penguin terms, $A_R$ and $A_L$, induce the $\mu^+ \to e^+ \gamma$ decay in addition to the $\mu^+ \to e^+ e^+ e^-$ decay. The branching ratio for $\mu^+ \to e^+ \gamma$ is given by

$$
B(\mu^+ \to e^+ \gamma) = \frac{48\pi^2}{G_F^2} \left(|A_R|^2 + |A_L|^2\right).
$$

On the other
hand the $\mu \rightarrow 3e$ branching ratio depends on four-fermion coupling constants $g_i$'s as well as $A_R$ and $A_L$. In order to present the differential branching ratio for this process we first discuss $\mu \rightarrow 3e$ kinematics with polarized muons which is specified by two energy valuables and two angle variables. We assign $p, p_1, p_2$ and $p_3$ to the momenta of $\mu^+$ and two $e^+$'s and $e^-$, then two energy variables are taken to be $x_1 = \frac{2E_1}{m_\mu}$ and $x_2 = \frac{2E_2}{m_\mu}$. Two angle variables are necessary to specify the relative position between the muon polarization direction ($\vec{n}$) and the decay plane. Defining $\vec{p}_1$ for the momentum of the positron which satisfies $(\vec{n} \times \vec{p}_3) \cdot \vec{p}_1 > 0$, angle variables $(\theta, \phi)$ can be identified as a polar coordinate of $\vec{n}$ ($0 \leq \theta \leq \pi, 0 \leq \phi \leq \pi$) in the coordinate system where $\vec{p}_3$ is taken as the $z$ direction and the decay plane is identified as $z$-$x$ plane with $(p_1)_x \geq 0$ (Fig. 1). Note that in this notation the T-odd asymmetry appears as an asymmetry in exchange of $x_1$ and $x_2$ in the Dalitz plot after integrating out the angle variables.

It is now straightforward to calculate the differential branching ratio from the effective lagrangian. A detail formula will be given elsewhere [6]. There are three types of terms in the differential decay branching ratio, i.e. square of photon-penguin terms, square of four-fermion terms and interference between the photon-penguin terms and four-fermion terms. T-odd terms arise as a part of the interference terms. These are given by

$$d\mathcal{B}_{T-odd} = \frac{3}{16\pi G_F^2} dx_1 dx_2 d\cos \theta d\phi P \sin \theta \sin \phi \ 8e(x_1 - x_2) \sqrt{\frac{(x_1 + x_2 - 1)}{(1 - x_1)(1 - x_2)}} \times [2(x_1 + x_2 - 1)\text{Im}(g_3A_L^* + g_4A_R^*) - (2 - x_1 - x_2)\text{Im}(g_5A_L^* + g_6A_R^*)], (2)$$

where $P$ is the polarization of muons and $e$ is the positron charge. As seen from the above expression the T-odd term is generated if the photon-penguin term $A_L$ (or $A_R$) has a different phase from the four-fermion terms $g_3, g_5$ (or $g_4, g_6$). These terms are in fact odd in exchange of $x_1$ and $x_2$.

In order to extract these T-odd terms from experiments we also need to know distribution of other terms in the $\mu \rightarrow 3e$ differential branching ratio. In particular, the $|A_L|^2$ and $|A_R|^2$ terms have the following form.

$$d\mathcal{B}_{\text{photon}} = \frac{3}{16\pi G_F^2} dx_1 dx_2 d\cos \theta d\phi$$
\[ \times 8e^2 \left[ \frac{2x_1^2 - 2x_1 + 1}{1 - x_2} + \frac{2x_2^2 - 2x_2 + 1}{1 - x_1} \right] \left( |A_R|^2 + |A_L|^2 \right), \] 

where we only keep terms independent of the muon polarization and neglect the electron mass. The above expression is singular for \( x_1 \to 1 \) and \( x_2 \to 1 \) if we neglect the electron mass, and therefore the integrated branching ratio is solely dominated by this kinematical region if \( eA_L \) and \( eA_R \) are similar in magnitude as \( g_i \)'s. In such a case the relation \( B(\mu \to 3e)/B(\mu \to e\gamma) \simeq 1/150 \) is known to hold \[7\]. Since our purpose is to look for the interference between the photon-penguin and the four-fermion terms we should exclude the region very close to \( x_1 = 1 \) and \( x_2 = 1 \). In the actual experiment T-odd asymmetry should be extracted from the investigation of distribution in the Dalitz plot. Here in order to present the T-odd effect we use the branching ratio and asymmetry integrated in the following way. Defining the regions \( R_1 = \{ x_1 + x_2 \geq 1, x_2 \leq 1 - \delta, x_2 \geq x_1 \} \) and \( R_2 = \{ x_1 + x_2 \geq 1, x_1 \leq 1 - \delta, x_1 \geq x_2 \} \), where \( \delta \) is introduced to cut off the region \( x_1, x_2 \simeq 1 \), the integrated branching ratio and the T-odd asymmetry are defined as

\[ B[\delta] = \int_{R_1 + R_2} d\cos \theta \int_0^\pi d\phi \frac{dB(\mu^+ \to e^+ e^+ e^-)}{dx_1 dx_2 d\cos \theta d\phi}, \]

\[ A[\delta] = \frac{1}{P B[\delta]} \left[ \int_{R_1} d\cos \theta \int_0^\pi d\phi \frac{dB(\mu^+ \to e^+ e^+ e^-)}{dx_1 dx_2 d\cos \theta d\phi} - \int_{R_2} d\cos \theta \int_0^\pi d\phi \frac{dB(\mu^+ \to e^+ e^+ e^-)}{dx_1 dx_2 d\cos \theta d\phi} \right]. \]

Let us consider the SU(5) SUSY GUT model. In this case the LFV occurs from the loop effect between the Planck scale and the GUT scale. Even if we assume that all scalar fields have a common SUSY breaking mass at the Planck scale, the large top Yukawa coupling constant becomes a source of the flavor mixing in the slepton sector since sleptons belong to the same GUT multiplet as squarks \[1, 8, 9\]. In the simplest SU(5) SUSY GUT the Yukawa couplings are given by the following superpotential.

\[ W = T_i (f_u)_{ij} T_j H + T_i (f_d)_{ij} \overline{T}_j \overline{H}, \]

where \( T_i \) are 10 dimensional representations and \( \overline{T}_i \) are the \( \overline{5} \) dimensional representations and \( H(\overline{H}) \) is \( 5(\overline{5}) \) dimensional Higgs superfield. Due to the loop effect of
$f_u$ the right-handed stau becomes lighter than other right-handed selectrons at the GUT scale and therefore slepton mass matrix is no longer simultaneously diagonalized with lepton mass matrix. In the approximation that the first two generation’s sleptons are degenerate every term in the LFV amplitude is proportional to $\lambda_\tau \equiv \V_R^*(\tau)\V_R(\tau)$, where $\V_R(e)$ is a right-handed lepton mixing matrix in the bases where the slepton mass matrix is diagonalized up to the left-right mixing terms \cite{8}. Therefore if there are no other source of complex coupling constants almost no asymmetry is generated because the photon-penguin and four-fermion terms have approximately the same phase. Situation will change if we allow complex phases for the SUSY breaking terms. Within the assumption of the universal soft-SUSY breaking terms we can introduce two independent phases which we take a phase of the trilinear coupling constant ($A$ term) and a phase of the higgsino mass term ($\mu$ term). These phases in general induce large EDMs of neutron and electron if the masses of squarks or sleptons are in the range of a few hundred GeV \cite{10}. In this respect an interesting observation was done in Ref.\cite{11} that unlike the $\mu$ phase, the constraint on the $A$ phase is much weaker so that even a $O(1)$ phase is allowed. In the followings we assume that the $\mu$ phase vanishes for simplicity and see effects of the $A$ phase to the electron and the neutron EDMs and the T-odd asymmetry in the $\mu \to 3e$ decay.

We calculate the branching ratio Eq.(4) and the T-odd asymmetry Eq.(5) and the electron and the neutron EDMs in the SUSY SU(5) GUT model with a complex $A$ parameter. For calculations of the electron and the neutron EDMs in SUSY models we follow Ref.\cite{12}. Assuming the universal soft-breaking terms at the Planck scale we solve the renormalization group equations for the coupling constants and SUSY soft-breaking terms from the Planck to the GUT scale, and then the GUT to the weak scale. We also require that the electroweak symmetry is broken properly due to the renormalization effect and take into account phenomenological constraints from various SUSY particle searches including the constraint from the $b \to s\gamma$ decay as discussed in Ref.\cite{13}. Once we obtain the SUSY breaking terms at the weak scale we can evaluate the coupling constants $A_R$, $A_L$ and $g_i$’s in Eq.(1) through one loop SUSY diagrams. $A_R$, $A_L$ are determined by photon-penguin diagrams and $g_i$’s get contributions from off-shell photon-penguin, Z-penguin and box diagrams. Formulas for these contributions can be found in Ref.\cite{14}.
In the calculation of the $\mu \to e\gamma$ and $\mu \to 3e$ branching ratios there is an important ambiguity associated with the Yukawa coupling constants at the GUT scale. As discussed before the branching ratios are proportional to $|\lambda_\tau|^2$. If the Yukawa coupling constants are given only by Eq.(6) the lepton mixing matrix can be related to the quark’s Cabibbo-Kobayashi-Maskawa (CKM) matrix element. It is known, however, that this assumption does not lead to a realistic mass spectrum for fermions. As discussed in Ref.[1] if other operators are relevant for generation of Yukawa coupling constants below the GUT scale the relationship between the lepton mixing matrix and the CKM matrix becomes quite model-dependent and $\lambda_\tau$ can be significantly different from the value obtained with the above assumption. In view of this ambiguity we treat $\lambda_\tau$ as a free parameter and calculate the $\mu \to e\gamma$ and $\mu \to 3e$ branching ratios normalized by $|\lambda_\tau|^2$. Note that the asymmetry and the EDM are essentially independent of $\lambda_\tau$.

In Fig.2.(a) we show the branching ratio for $\mu \to e\gamma$ and $\mu \to 3e$ normalized by $|\lambda_\tau|^2$ as a function of the right-handed selectron mass ($m_{\tilde{e}_R}$). The SUSY parameters in this model are taken as the SU(2) gaugino mass $M_2$, a complex $A$ parameter defined as $L_{soft} = -m_0 A_X (\tilde{T}_i (f_u)_{ij} \tilde{T}_j H + \tilde{T}_i (f_d)_{ij} \tilde{F}_j H)$ at the Planck scale, and the ratio of two Higgs vacuum expectation values ($\tan \beta$) and the universal scalar mass $m_0$ at the Planck scale and the sign of $\mu$. In this figure we fix $M_2 = 200$ GeV, $A_X = i$ and $\tan \beta = 3, 10, 30$, $\mu > 0$ and the branching ratio are shown as a function of $m_{\tilde{e}_R}$ instead of $m_0$. The cut off parameter $\delta$ is taken to be 0.02 for the $\mu \to 3e$ branching ratio. We fix the top quark mass as 175 GeV. If, for example, $|\lambda_\tau| = 1 \times 10^{-2}$ the $\mu \to e\gamma$ branching ratio is $10^{-10}$-$10^{-14}$ and the $\mu \to 3e$ branching ratio is $10^{-12}$-$10^{-16}$ for $\tan \beta = 10$. On the other hand if $\lambda_\tau$ is given by the corresponding CKM matrix elements $V_{td}^* V_{ts}$ then $|\lambda_\tau| = (3 - 5) \times 10^{-4}$ and therefore the branching ratio is smaller by three orders of magnitude. In Fig.2.(b) the T-odd asymmetry defined in Eq.(3) is shown for the same parameters as in Fig.2.(a). Also the electron and the neutron EDMs are shown in Fig.2.(c). We can see that the asymmetry becomes maximal around $m_{\tilde{e}_R} = 400$ GeV while the magnitude of the electron (neutron) EDM is a decreasing function of $m_{\tilde{e}_R}$ above 200 (400) GeV. The difference of these behaviors comes from the fact that for the asymmetry photon-penguin and four-fermion terms have similar magnitude for $m_{\tilde{e}_R} \approx 400$ GeV but for the EDMs only photon-penguin diagram is relevant. It is interesting to see
that when the asymmetry is large the ratio of the $B(\mu \rightarrow e\gamma)$ and $B(\mu \rightarrow 3e)$ is $1/50 - 1/100$. Fig.3(a) shows the correlation between the absolute value of the electron EDM and the T-odd asymmetry. In this figure, the SUSY parameters are scanned in the region $0 < m_0 < 2 \text{ TeV}, |A_X| < 5, 0 < M_X < 2 \text{ TeV}$ and fix $\text{arg}(A_X) = \pi/2, \mu > 0$. We find that the sign of the EDM and that of asymmetry are the same but here the absolute value of the EDM is shown. We can see that the electron EDM and the T-odd asymmetry do not show strong correlation. Within the current experimental upper bound of the EDM, which is $|d_e| < 4 \times 10^{-27}$ [15], the asymmetry can be as large as 18%. This means that the T-odd asymmetry in the $\mu \rightarrow 3e$ process gives independent information from the electron EDM on the possible complex parameters in the SUSY GUT model. Correlation between the neutron EDM and T-odd asymmetry is also calculated. As in Fig.3(a) we do not see any correlation and the $\pm 18\%$ asymmetry is possible within the experimental upper bound of the neutron EDM ($|d_n| < 1.1 \times 10^{-25}$ [16]). Fig.3(b) shows that the correlation between $B(\mu \rightarrow 3e)/|\lambda_{\tau}|^2$ and T-odd asymmetry. In this figure we take into account the experimental bounds of the electron and the neutron EDMs. We see that, for example, when $|\lambda| = 1 \times 10^{-2}$ 10% asymmetry is possible for $B(\mu \rightarrow 3e) \simeq 10^{-14}$. We also investigated the correlation between the asymmetry and the slepton mass and found that the slepton mass which corresponds to maximal asymmetry changes from 200 GeV to 2 TeV when we scanned the parameters in the above region, so that a large asymmetry does not necessarily mean a light slepton.

Let us discuss T-odd asymmetry in SUSY models other than SU(5) GUT. In the minimal SO(10) SUSY GUT model it is pointed out in Ref.[8] that the $\mu \rightarrow e\gamma$ branching ratio is enhanced by $(m_{\tau}/m_{\mu})^2$ compared to the SU(5) model. The $\mu \rightarrow 3e$ branching ratio is also enhanced by the same amount and in this case the photon-penguin and four-fermion terms can have different phases without the phases of the soft breaking terms. But unfortunately, the T-odd asymmetry cannot be large because only the photon-penguin term is enhanced in this decay. Another possibility to induce large LFV is the SUSY model with the right-handed neutrino supermultiplet [14, 17]. In this case the right-handed neutrino’s Yukawa coupling constants become new sources of LFV and CP violation. This model is also interesting in connection with the baryon number asymmetry of the Universe since the right-handed neutrino or right-handed sneutrino decays can be the origin
of the leptogenesis and CP violation in the Yukawa coupling constants is one of
the necessary ingredients. We have investigated the LFV branching ratio and the
T-odd asymmetry in this model. We take neutrino masses in the range of $10^{-3} - 10$
eV and adjust the right-handed neutrino Majorana mass to $10^{12} - 10^{16}$ GeV to get $O(1)$ Yukawa coupling constants. In this model using the freedom of right-handed
Yukawa coupling constants, it is possible to generate two independent phases in
the photon-penguin terms and the four-fermion terms without help of the complex
soft breaking terms. With real soft-breaking terms typical magnitude of asymmetry
turns out to be less than 0.1 % although it is possible to have an asymmetry up to
10 % by tuning the parameters in the right-handed Yukawa couplings.

We only consider the polarized muon decay here. Extension to the tau decay
is straightforward. For example the T-odd asymmetry in $\tau \rightarrow 3\mu$ is obtained by
replacing relevant generation indices in the $\mu \rightarrow 3e$ formula. It should be noticed, however, that there is essentially no difference between SU(5) and SO(10) models
in this case because there are no enhancement mechanism for the SO(10) model
compared to the SU(5) case in this decay mode.

In this letter we investigate a possibility to observe a sizable CP nonconserving
asymmetry in the $\mu \rightarrow 3e$ decay in SUSY models. In the SU(5) GUT model sizable
LFV arises from the GUT interactions and an asymmetry up to 18 % can be induced
by the complex phase of trilinear soft-breaking term. In order to measure the asym-
metry of this magnitude the the $\mu \rightarrow 3e$ branching ratio has to be large enough.
In the SU(5) model the magnitude of the branching ratio itself strongly depends
on the model-dependent parameter $\lambda_\tau$ so that practically the $\mu \rightarrow 3e$ branching
ratio is only constrained by the experimental bounds of the $\mu \rightarrow 3e$ and $\mu \rightarrow e\gamma$
processes. Therefore if the $\mu \rightarrow e\gamma$ process is observed at the level of $10^{-12}$-$10^{-11}$
in near future, the $\mu \rightarrow 3e$ branching ratio can be $O(10^{-13})$ and an experiment of
$\mu \rightarrow 3e$ with a sensitivity of the $10^{-15}$ level could reveal the T-odd asymmetry. Note
that stronger bounds on EDM or slepton mass do not mean that the asymmetry
cannot be measurable because due to ambiguity of $\lambda_\tau$ the branching ratio cannot be
strongly constrained by these bounds. Besides the EDMs for neutron and electron, the T-odd asymmetry therefore gives us a new possibility to search for CP violation
in SUSY models.

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References

[1] R. Barbieri and L.J. Hall, Phys. Lett. B 338, 212 (1994).

[2] R. Bolton et al., Phys. Rev. D38, 2077 (1988).

[3] SINDRUM Collaboration, U. Bellgardt et al., Nucl. Phys. B 299, 1 (1988).

[4] SINDRUM II Collaboration, C. Dohmen et al., Phys. Lett. B 317, 631 (1993).

[5] S.B. Treiman, F. Wilczek and A. Zee, Phys. Rev. D16, 152 (1977).

[6] Y. Okada, K. Okumura and Y. Shimizu, in preparation.

[7] N. Kroll and W. Wada, Phys. Rev. 98, 1355 (1955); G. Feinberg, Phys. Rev. 110, 1482 (1958).

[8] R. Barbieri, L.J. Hall and A. Strumia, Nucl. Phys. B 445, 219 (1995).

[9] J. Hisano, T. Moroi, K. Tobe and M. Yamaguchi, Phys. Lett. B 391, 341 (1997); Erratum, ibid. B 397, 357 (1997).

[10] J. Ellis, S. Ferrara and D.V. Nanopoulos, Phys. Lett. B 114, 231 (1982); W. Buchmüller and D. Wyler, Phys. Lett. B 121, 393 (1983); J. Polchinski and M. Wise, Phys. Lett. B 125, 393 (1983); F. del Aguila, M. Gavela, J. Grifols and A. Mendez, Phys. Lett. B 126, 71 (1983); D.V. Nanopoulos and M. Srednicki, Phys. Lett. B 128, 61 (1983); M. Dugan, B. Grinstein and L. Hall, Nucl. Phys. B 255, 413 (1985); Y. Kizukuri and N. Oshimo, Phys. Rev. D45, 1806 (1992); D46, 3025 (1992).

[11] T. Falk and K.A. Olive, Phys. Lett. B 375, 196 (1996); T. Nihei, KEK-TH-527, hep-ph/9707330.

[12] T. Ibrahim and P. Nath, Phys. Lett. B 418, 98 (1998); Phys. Rev. D 57, 478 (1998).
[13] T. Goto, Y. Okada, Y. Shimizu, and M. Tanaka, Phys. Rev. D55, 4273 (1997).

[14] J. Hisano, T. Moroi, K. Tobe and M. Yamaguchi, Phys. Rev. D53, 2442 (1996).
    The Z-penguin contribution from the neutralino diagram in Eq.(25) of this paper should be divided by 2.

[15] E.D. Commins et al., Phys. Rev. A50, 2960 (1994); K. Abdullah et al., Phys. Rev. Lett. 65, 2347 (1990).

[16] I.S. Altraev et al., Phys. Lett. B 276, 242 (1992); K.F. Smith et al., Phys. Lett. B 234, 191 (1990).

[17] F. Borzumati and A. Masiero, Phys. Rev. Lett. 57, 961 (1986); J. Hisano, T. Moroi, K. Tobe, M. Yamaguchi and T. Yanagida, Phys. Lett. B 357, 579 (1995).

[18] M. Fukugita and T. Yanagida, Phys. Rev. D42, 128 (1990); H. Murayama, H. Suzuki, T. Yanagida and J. Yokoyama, Phys. Rev. Lett. 70, 1912 (1993).
Figure Captions:

FIG. 1: Kinematics of $\mu \rightarrow 3e$ decay in the center-of-mass system of muon. The plane I represents the decay plane on which the momentum vectors $\vec{p}_1$, $\vec{p}_2$, $\vec{p}_3$ lie, where $\vec{p}_1$ and $\vec{p}_2$ are momenta of two $e^+$'s and $\vec{p}_3$ is momentum of $e^-$ respectively. The plane II is the plane which the muon polarization vector $\vec{n}$ and $\vec{p}_3$ make.

FIG. 2: (a). Branching ratios for $\mu \rightarrow e\gamma$ and $\mu \rightarrow 3e$ normalized by $|\lambda_\tau|^2 \equiv |V_{e\tau}^*(e)\tau e V_{e\tau}(e)\tau\mu|^2$ as a function of the right-handed selectron mass $m_{\tilde{e}_R}$. The cut-off parameter $\delta$ is taken to be 0.02. We fix the SUSY parameters as $M_2 = 200$ GeV, $A_X = i$, $\mu > 0$ and $\tan \beta = 3$ (dotted line), 10 (solid line), 30 (dashed line) and top quark mass as 175 GeV. (b). T-odd asymmetry $A$ as a function of $m_{\tilde{e}_R}$. Parameters are the same as in (a). (c). The electron and the neutron EDMs as a function of $m_{\tilde{e}_R}$.

FIG. 3: (a). A correlation between T-odd asymmetry $A$ and the absolute value of the electron EDM $|d_e|$. The SUSY parameters are scanned in the region $0 < m_0 < 2$ TeV, $|A_X| < 5$, $0 < M_X < 2$ TeV and fix arg($A_X$) = $\pi/2$, $\tan \beta = 5$ and $\mu > 0$. (b). A correlation between T-odd asymmetry $A$ and the branching ratio for $\mu \rightarrow 3e$ normalized by $|\lambda_\tau|^2$. The SUSY parameters are the same as in (a) and the experimental bounds of the electron and the neutron EDMs are imposed.
Fig. 1
Fig. 2.(a)
Fig. 2.(b)
Fig. 2. (c)

\[ d_n(10^{-26} \text{ e cm}), \quad d_e(10^{-27} \text{ e cm}) \]

\[ m_{e_R}^{\sim} \text{(GeV)} \]
Fig. 3.(a)
Fig. 3.(b)