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Slepton Flavor Nonuniversality, the Muon EDM and its Proposed Sensitive Search at Brookhaven

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Abstract

We analyze the electric dipole moment of the electron (d_e), of the neutron (d_n) and of the muon (d_μ) using the cancellation mechanism in the presence of nonuniversalities of the soft breaking parameters. It is shown that the nonuniversalities in the slepton sector produce a strong violation of the scaling relation $d_\mu/d_e \simeq m_\mu/m_e$ in the cancellation region. An analysis of d_e, d_n and d_μ under the constraints of the current experimental limits on d_e and d_n and under the constraints of the recent Brookhaven result on $g_\mu - 2$ shows that in the non-scaling region d_μ can be as large as $(10^{-24} - 10^{-23})$ecm and thus within reach of the recently proposed Brookhaven experiment for a sensitive search for d_μ at the level of 10^{-24} ecm.

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1 Introduction

Recently a proposal has been made to carry out a dedicated search for the electric dipole moment of the muon at the level of $10^{-24} ecm$[1, 2]. The current experimental limit on the muon edm from the previous CERN experiment is $d_\mu < 1.05 \times 10^{-18}$ecm[3] and thus the proposed experiment will improve the sensitivity for d_μ by a factor of 10^5 to 10^6 over its previous measurement. As is well known the electric dipole moment is an important probe of new physics beyond the Standard Model. Thus the Standard Model predicts very small values for the edms[4], e.g., $d_e < 10^{-38} ecm$, $d_\mu < 10^{-35} ecm$ and $d_n < 10^{-31} ecm$. However, many models of new physics predict much larger edms[5] and thus an increased sensitivity of edm measurements is a probe of new physics. Supersymmetric (SUSY) models with softly broken supersymmetry are an example of this class of models as they provide abundant new sources of CP violation since the soft breaking parameters can be complex with CP phases O(1). In fact, with CP phases of O(1) an order of magnitude estimate shows that the edm of the electron and of the neutron are already in excess of the experimental limits which are[6]

$$d_e < 4.3 \times 10^{-27} ecm, \quad d_n < 6.3 \times 10^{-26} ecm \tag{1}$$

Several possible solutions have been offered to resolve this problem. One possibility is to assume that the phases are small which, however, requires a fine tuning[7]. A second possibility is to assume that the sparticles circulating in the loops are heavy, of masses in the range of several TeV, which, however, puts the sparticle spectrum beyond the reach of even the Large Hadron Collider (LHC)[8]. Another alternative discussed more recently is the possibility of cancellations[9, 10] allowing for a satisfaction of the experimental limits on the electron and on the neutron edms with CP phases $O(1)$ and the sparticle spectrum within reach of accelerators. In addition to the above in certain specific unified models, such as in left-right symmetric models, the troublesome phases may automatically be small[11]. Now the normal expectation is that the edms scale by the fermion mass and thus the muon edm should be related to the electron edm by the scaling relation $d_\mu \simeq (m_\mu/m_e)d_e$. Using the experimental limit on the electron edm of Eq.(1) this leads to $d_\mu < 10^{-25} ecm$ which is below the sensitivity of the BNL experiment. However, we will show in this paper that the scaling relation $d_\mu \simeq (m_\mu/m_e)d_e$ can be violated strongly in the presence of nonuniversalities. The breakdown of scaling allows significant enhancement of the muon edm, by as much as a factor of 100, over the scaling result and $d_\mu \sim O(10^{-23}) ecm$ can be gotten which is well within reach of the proposed Brookhaven experiment.

The analysis presented here is within the framework of MSSM. Thus we do not assume any symmetries between the squark and the slepton sector and consequently there are no constraints on the slepton sector arising from limits on flavor changing neutral currents in the quark sector. Further, we do not impose the constraints from $\mu \to e\gamma$. This sector of the theory involves additional parameters in MSSM and thus no stringent constraints from this sector are expected on the edm analysis. However, a similar analysis within a specific unified model will require inclusion of such constraints. In addition to the mechanism discussed here, there exist previous analyses where a muon edm much larger than what is implied by scaling can be generated. These consist of analyses in left-right symmetric models[12], in a two Higgs doublet model[13], and in models with certain assumed patterns of textures in the flavor space[14, 15]. The mechanism we propose in this paper is different. Our technique is a natural extension of the cancellation mechanism using nonuniversalities which are already present within MSSM.

The outline of the rest of the paper is as follows: In Sec.2 we review the basic formula for a charged lepton EDM in MSSM. In the analysis we impose the constraints on a_μ^{SUSY} from the BNL experiment[16] as a recent analysis has shown that the BNL result provides stringent constraints on the phases[17]. In Sec.3 we give a discussion of the analysis and give results. Conclusions are given in Sec.4.

2 Slepton nonuniversalities, d_e and d_μ

The basic idea we use is that the cancellations arise between the chargino and the neutralino exchange contributions to the edm of the electron but such cancellations occur only partially or negligibly for the case of the edm of the muon. The mechanism which brings this about arises from nonuniversality between the electron and the muon sector. We give now the details of the analysis. First we review some basic formula that will be relevant in our discussion. The chargino exchange contribution to the charged lepton edm is given by[10]

$$d_l(chargino) = \frac{e\alpha_{EM}}{4\pi\sin^2\theta_W}\frac{\kappa_l}{m^2_{\tilde{\nu}_l}}\sum_{1=1}^{2}\tilde{m}_{\chi_i^+}Im(U^*_{i2}V^*_{i1})A(\frac{\tilde{m}^2_{\chi_i^+}}{m^2_{\tilde{\nu}_l}}) \tag{2}$$

where κ_l is given by $\kappa_l = m_l/(\sqrt{2}m_W\cos\beta)$, $A(x) = 2(1-x)^{-2}(3-x+2lnx(1-x)^{-1})$, and U and V in Eq.(2) are unitary transformations which diagonalize the chargino mass matrix

$$M_C = \begin{pmatrix} |\tilde{m}_2|e^{i\xi_2} & \sqrt{2}m_W \sin\beta \\ \sqrt{2}m_W \cos\beta & |\mu|e^{i\theta_\mu} \end{pmatrix} \tag{3}$$

so that $U^* M_C V^{-1} = diag(\tilde{m}_{\chi_1^+}, \tilde{m}_{\chi_2^+})$, where θ_μ is the phase of the Higgs mixing parameter μ and ξ_2 is the phase of the SU(2) gaugino mass $\tilde{m}_2$. It is easily seen that the chargino exchange contribution to the edm of the charged lepton depends on just one combination of the phases, i.e., $\theta_\mu + \xi_2$. The neutralino exchange contribution is given by[10]

$$d_l(neutralino) = \frac{e\alpha_{EM}}{4\pi \sin^2\theta_W} \sum_{k=1}^{2} \sum_{i=1}^{4} Im(\eta_{ik}^l) \frac{\tilde{m}_{\chi_i^0}}{M_{\tilde{l}_k}^2} Q_{\tilde{l}} B(\frac{\tilde{m}_{\chi_i^0}^2}{M_{\tilde{l}_k}^2}) \tag{4}$$

where $B(x) = (2(x-1)^2)^{-1}(1 + x + 2xlnx(1-x)^{-1})$ and where $Q_{\tilde{l}}$ is the charge of the lepton and η_{ik}^l is given by

$$\eta_{ik}^l = [-\sqrt{2}\{\tan\theta_W(Q_l - T_{3l})X_{1i} + T_{3l}X_{2i}\}D_{l1k}^* - \kappa_l X_{3i} D_{l2k}^*]$$
$$(\sqrt{2}\tan\theta_W Q_l X_{1i} D_{l2k} - \kappa_l X_{3i} D_{l1k}) \tag{5}$$

Here X diagonalizes the neutralino matrix M_{χ^0} so that

$$X^T M_{\chi^0} X = diag(\tilde{m}_{\chi_1^0}, \tilde{m}_{\chi_2^0}, \tilde{m}_{\chi_3^0}, \tilde{m}_{\chi_4^0}) \tag{6}$$

where the matrix D_l diagonalizes the slepton (mass)^2 matrix so that $D_l^\dagger M_{\tilde{l}}^2 D_l = diag(M_{\tilde{l}_1}^2, M_{\tilde{l}_2}^2)$ where

$$M_{\tilde{l}}^2 = \begin{pmatrix} M_{\tilde{L}_l}^2 + m_\mu^2 - M_Z^2(\frac{1}{2} - \sin^2\theta_W)\cos 2\beta & m_\mu(A_\mu^* m_0 - \mu\tan\beta) \\ m_\mu(A_\mu m_0 - \mu^*\tan\beta) & M_{\tilde{R}_l}^2 + m_\mu^2 - M_Z^2 \sin^2\theta_W \cos 2\beta \end{pmatrix} \tag{7}$$

The neutralino exchange contribution depends additionally on the phase combinations $\theta_\mu + \xi_1$, and $\theta_\mu + \alpha_{A_{\tilde{l}}}$. There are several ways in which the nonuniversality between the selectron and the smuon channels can appear. For instance, the sneutrino mass with the e flavor, i.e., $\tilde{\nu}_e$ may be different from the sneutrino mass for the μ flavor, i.e., $\tilde{\nu}_\mu$. In this case if one arranges cancellations between the chargino and the neutralino contributions to occur for d_e so that d_e is in accord with the current experimental limits, then such exact cancellations would not occur for the muon channel due to different chargino contributions in this case because of the disparity between the masses $m_{\tilde{\nu}_e}$ and $m_{\tilde{\nu}_\mu}$. A similar situation arises because of the nonuniversality in $M^2_{L\tilde{e}}$ and $M^2_{L\tilde{\mu}}$ and between $M^2_{R\tilde{e}}$ and $M^2_{R\tilde{\mu}}$. In this case if the cancellation is arranged between the chargino and the neutralino for d_e it would be upset for d_μ due to neutralino contributions being different between the two cases. There is yet a third possibility in which one may achieve a large cancellation between the chargino and the neutralino contributions for d_e but only a partial or no cancellation for d_μ. This consists in introducing nonuniversality only in the trilinear soft parameters in the selectron and the smuon channels, i.e., nonuniversalities between A_e and A_μ. In the following analysis we focus on this type of nonuniversality. In the analysis we impose the constraints from the recent results from Brookhaven[16] on the size of new physics contributions to $a_\mu = (g_\mu - 2)/2$. This experiment finds a deviation from the Standard Model result[18] at the 2.6σ level so that[16]

$$a_\mu^{exp} - a_\mu^{SM} = 43(16) \times 10^{-10} \tag{8}$$

It has been known for some time that the supersymmetric electro-weak contributions can make a significant correction to the muon g-2 and the size of this contribution can be as large or larger than the Standard Model electro-weak correction[19, 20, 21]. It is also known that contributions to $g-2$ from models with large extra dimensions are not significant and thus do not produce a strong background for supersymmetric contributions[22] (see, however, Ref.[23]). Assuming then that all of the effect of Eq.(8) comes from supersymmetry, one finds that the sparticle spectrum is severely constrained by the BNL result and further that the sign of μ in the standard convention[24] with CP invariance is determined to be positive[25] (Similar conclusions are drawn in Refs.[26, 27, 28]. See also Ref.[29]). A positive μ sign is also the one favored by the $b \to s + \gamma$ constraint[30]. Another important phenomenon is the effect of CP violating phases on a_μ. It was shown in Ref.[31] that a_μ is a very sensitive function of the CP phases[31] and that the CP phases can change both the magnitude and the sign of a_μ. In the analysis of Ref.[17] this sensitivity was used to constrain the CP phases that enter a_μ by using the constraint of Eq.(8). It was found that as much as (60-90)% of the parameter space of CP phases may be eliminated by the BNL constraint[17]. The total contribution to a_μ arises from the chargino and neutralino exchanges where the dominant contribution is from the chargino exchange and in the presence of phases is given by[31]

$$a_\mu^{\chi^+} = \frac{m_\mu \alpha_{EM}}{4\pi \sin^2\theta_W} \sum_{i=1}^{2} \frac{1}{M_{\chi_i^+}} Re(\kappa_\mu U_{i2}^* V_{i1}^*) F_3\Big(\frac{M_{\tilde{\nu}_\mu}^2}{M_{\chi_i^+}^2}\Big)$$
$$+\frac{m_\mu^2 \alpha_{EM}}{24\pi \sin^2\theta_W} \sum_{i=1}^{2} \frac{1}{M_{\chi_i^+}^2} (|\kappa_\mu U_{i2}^*|^2 + |V_{i1}|^2) F_4\Big(\frac{M_{\tilde{\nu}_\mu}^2}{M_{\chi_i^+}^2}\Big). \tag{9}$$

Here $F_3(x)$=$(x-1)^{-3}(3x^2-4x+1-2x^2 lnx)$, $F_4(x)$=$(x-1)^{-4}$ $(2x^3+3x^2-6x+1-6x^2 lnx)$ and κ_μ is defined as in Eq.(2). As in the case of the edm analysis, it is easily seen that the chargino exchange depends on the single phase combination $\theta_\mu + \xi_2$, while the neutralino contribution depends on several phase combinations, i.e., $\theta_\mu + \xi_i$ (i=1.2) and on $\theta_\mu + \alpha_{A_\mu}$. In carrying out the analysis we use the CP dependent formulae for a_μ and impose the constraints of Eqs.(1) and (8) on the phases.

3 Analysis and Results

The general framework of our analysis is MSSM. However, since the parameter space of this model is rather large we restrict our numerical analysis to a subset of parameters. This subset consists of m_0 (the universal scalar mass at the GUT scale), $m_{\frac{1}{2}}$ (magnitude of the universal gaugino mass at the GUT scale), $|A_0|$ (the magnitude of the trilinear coupling of the soft parameters at the GUT scale for all sectors except the smuon sector), and $\tan\beta = < H_2 > / < H_1 >$ where H_2 gives mass to the up quarks and H_1 gives mass to the down quarks and the leptons. The magnitude of the Higgs mixing parameter μ is determined by the radiative breaking of the electro-weak symmetry. We choose as independent the set of phases θ_μ, ξ_i (i=1,2,3) (the phases of the U(1), SU(2) and SU(3) gauginos) and α_{A_0}, the phase of A_0. The trilinear soft parameters A_t, A_b, A_e etc are all evolved from A_0 using renormalization group (RG) equations. Additionally in the smuon sector we choose $|A_\mu|$ and α_{A_μ} to be independent parameters to generate the desired nonuniversalities in the smuon sector. The model described above is essentially a supergravity unified model[32] with nonuniversalities[33] in the gaugino sector and in the slepton sector. Our technique consists in first finding a set of soft parameters with large phases which give a simultaneous cancellation for the case of the edm of the electron and of the neutron. Nonuniversalities are then used to generate violations of scaling and a large edm for the muon. In the analysis we include sbottom contribution to the gluonic dimension six operator in the case of the neutron and include two loop Higgs mediated contributions of the type discussed in Ref.[34]. Regarding the g-2 constraint we use a 2 sigma error corridor on Eq.(8) to constraint the sparticle spectrum and the phases, i.e., we use $10.6 \times 10^{-10} < a_{\mu}^{SUSY} < 76.2 \times 10^{-10}$.

In Table 1 we exhibit five cases each of which leads to a cancellation in the electron and in the neutron channel producing d_e and d_n in conformity with the current data as shown in column 3 of Table 1. For the muon case we then use all the same parameters except A_{μ}. We consider three different cases here: (1) universal case where $A_{\mu} = A_e$, (2) $|A_{\mu}| = |A_e|$, $\alpha_{A_{\mu}} \neq \alpha_{A_e}$, and (3) $|A_{\mu}| \neq |A_e|$ and $\alpha_{A_{\mu}} \neq \alpha_{A_e}$. Results of the analysis using these three cases are shown in Table 2, Table 3 and Table 4 respectively. Thus for case(1) one finds that the cancellations between the chargino and the neutralino contributions for d_{μ} parallel the cancellations of these contributions for d_e. Thus here a rough scaling results, i.e., $d_{\mu} \sim (m_{\mu}/m_e) d_e$ as can be seen by comparing d_e of Table 1 with d_{μ} of Table 2 (a detailed discussion of this phenomenon is given in the Appendix). In this case the predicted values of d_{μ} are smaller that than what the proposed Brookhaven experiment can probe.

Next we discuss the other two cases which are more promising because they contain nonuniversality of the soft parameter A which leads to a breakdown of scaling and allows an enhancement of d_{μ} over what is allowed by scaling. (a detailed discussion of the breakdown of scaling is given in the Appendix). For case (2) the nonuniversality effects arise from $\alpha_{A_{\mu}} \neq \alpha_{A_e}$ and the cancellation between the chargino and the neutralino contributions to d_{μ} do not parallel the cancellation in d_e. Because of this one has only a partial cancellation in d_{μ} in the region of the parameter space where one has a large cancellation for d_e. This phenomenon leads to a violation of scaling and one obtains here values of d_μ much larger than expected from scaling. The results are exhibited in Table 3 and one finds that for entries (a)-(e) d_μ is typically larger than its corresponding value in Table 2 by a factor of 2-3. Further, all d_μ values listed in Table 3 fall in the range $O(10^{-24})$ecm which is within reach of the proposed Brookhaven experiment[1, 2]. Finally we consider case(3) where both the magnitude and the phase of A_μ differ from A_e. In this case one can manage a much larger value for d_μ over the value expected from scaling. The results are shown in Table 4. In computing d_μ in this case we have used all the same parameters as in Table 1 except that the magnitude and the phase of A_μ are treated as independent. As can be seen from Table 4 one finds that d_μ can be as large as O(10^{-23})ecm in this case. For the above three cases the a_μ listed in Tables (2), (3) and (4) is consistent with the 2 sigma error corridor constraint as discussed at the end of the first paragraph in this section.

A plot of d_e, d_n as a function of $|A_0|$ with the other parameters fixed by Table 1 is given in Figs. 1-5. Thus Fig.1 contains case (a) of Table 1, Fig.2 contains case (b) of Table 1 etc. The three cases, (1), (2) and (3) for d_μ given by Tables 2, 3 and 4 are also plotted. These figures thus illustrate graphically the results discussed above. The analysis of Figs.1-5 shows that the effect of nonuniversality is to shift the point of maximum cancellation between the chargino and the neutralino contributions for d_μ relative to what happens in d_e. This shift creates a much larger value for d_μ in the region where d_e is compatible with the current experimental limits.

Table 1: **EDMs of electron and of neutron for large phases**

case	$\tan\beta$,m_0, $m_{\frac{1}{2}}$,$\lvert A_e\rvert$, ξ_1, ξ_2, ξ_3,θ_μ, α_{A_e}	d_e, d_n (ecm)
(a)	$10, 150, 281, 0.78,\ .5, -.45, .42, .2, 4.1$	1.28×10^{-27}, -2.04×10^{-26}
(b)	$15, 120, 316, 0.77,\ -.6, -.15, -.64, .3, 1.33$	3.15×10^{-27}, -4.8×10^{-27}
(c)	$20, 200, 246, 0.93,\ .28, -.51, -.11, .4, 1.02$	-1.33×10^{-27}, -1.52×10^{-27}
(d)	$20, 180, 298, 0.76,\ -.6, -.07, -.49, .2, 2.6$	3.45×10^{-27}, -2.24×10^{-27}
(e)	$6, 100, 246, 1.31,\ .4, -.77, .55, .4, 1.15$	-3.8×10^{-27}, -3.9×10^{-26}

4 Conclusion

In this paper we have investigated the effect of nonuniversality in the trilinear soft parameter in the slepton sector on the scaling relation $d_\mu/d_e \simeq m_\mu/m_e$. We have shown that large violations of this relation can occur in the region of the parameter space where the cancellation mechanism operates in the presence of nonuniversalities. Using this mechanism it is then shown that values of d_μ as much as a factor of 100 larger than implied by the scaling relation can be obtained. Two branches of solutions were found. In the first solution the magnitudes $|A_\mu|$ and $|A_e|$ were assumed to be universal and the nonuniversalities arose only in the phases of A_e and A_μ, i.e.,$\alpha_{A_\mu} \neq \alpha_{A_e}$. In this case violations of scaling were generally modest but still sufficient to give d_μ of size $10^{-24}ecm$

Table 2: **Muon edm for universal soft parameters**

case	$\lvert A_\mu\rvert$,α_{A_μ}	d_μ (ecm), a_μ
(a)	$.78, 4.1$	2.5×10^{-25}, 16.14×10^{-10}
(b)	$.77, 1.33$	6.47×10^{-25}, 24.30×10^{-10}
(c)	$.93, 1.02$	-2.92×10^{-25}, 34.85×10^{-10}
(d)	$.76, 2.6$	7.21×10^{-25}, 28.50×10^{-10}
(e)	$1.31, 1.15$	-7.92×10^{-25}, 13.04×10^{-10}

consistent with Eqs.(1) and (8) and within reach of the sensitivity of the proposed BNL experiment[1]. In the second solution nonuniversalities both in the magnitude and in the phase of the trilinear soft parameter were assumed, i.e., $|A_\mu| \neq |A_e|$ and $\alpha_{A_e} \neq \alpha_{A_\mu}$. In this case violations of the scaling formula were as much as a factor of 100 and one can get $d_\mu \sim O(10^{-23})ecm$ consistent with Eqs.(1) and (8). Both of these possibilities are very encouraging for the observation of the muon edm in the proposed Brookhaven experiment which can explore the muon edm at the level of 10^{-24}ecm. Thus one may construe that the proposed Brookhaven experiment is an important probe of both CP violation and of nonuniversalities in the muon sector.

Table 3: **Muon edm when $|A_\mu| = |A_e|$ and $\alpha_{A_\mu} \neq \alpha_{A_e}$**

case	$\lvert A_\mu \rvert$,α_{A_μ}	d_μ (ecm), a_μ
(a)	$.78, -1.5$	1.07×10^{-24}, 16.05×10^{-10}
(b)	$.77, 0.0$	1.17×10^{-24}, 24.12×10^{-10}
(c)	$.93, 0.0$	1.51×10^{-24}, 34.80×10^{-10}
(d)	$.76, -2.0$	2.04×10^{-24}, 28.30×10^{-10}
(e)	$1.31, 1.8$	-1.94×10^{-24}, 13.27×10^{-10}

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6 Appendix: The edm scaling relation and its violation from nonuniversalities

In this Appendix we explain the phenomenon seen in Tables 1-4 and in figs.1-5 where one finds that for the universal values of A the edm of the muon and of the electron satisfy a scaling relation, i.e., $d_\mu/d_e \simeq m_\mu/m_e$, in the cancellation region, while violations of scaling occur due to nonuniversalities in A. We exhibit this phenomenon for both chargino and neutralino contributions. Now the chargino exchange contribution is strictly linear in the lepton mass as can be seen from Eq.(2) and we write $d_l(chargino) = m_l \bar{d}_l^C$ where $\bar{d}_l^C$ is

Table 4: **Muon edm when $A_\mu \neq A_e$**

case	$\lvert A_\mu\rvert$,α_{A_μ}	d_μ (ecm), a_μ
(a)	$7.0, 1.5$	-1.33×10^{-23}, 15.10×10^{-10}
(b)	$8.0, 1.0$	-1.27×10^{-23}, 24.28×10^{-10}
(c)	$6.0, -2.0$	-1.05×10^{-23}, 35.80×10^{-10}
(d)	$10.0, -2.5$	1.79×10^{-23}, 29.02×10^{-10}
(e)	$7.0, 2.5$	-1.57×10^{-23}, 14.40×10^{-10}

now independent of the charged lepton mass. For the neutralino exchange contribution to d_l there are many types of terms that contribute. The leading dependence of the lepton mass arises from n^l_{ik} while subleading dependence arises from the outside smuon mass factors in Eq.(4). Thus to understand the scaling phenomenon and its breakdown we focus on n^l_{ik} which can be expanded as follows using Eq.(5):

$$\eta^l_{ik} = a_0c_0X^2_{1i}D^*_{l1k}D_{l2k} + b_0c_0X_{1i}X_{2i}D^*_{l1k}D_{l2k} - \kappa_l a_0X_{1i}X_{3i}|D_{l1k}|^2$$
$$-\kappa_l b_0X_{2i}X_{3i}|D_{l1k}|^2 - \kappa_l c_0X_{1i}X_{3i}|D_{l2k}|^2 + \kappa^2_l X^2_{3i}D_{l1k}D^*_{l2k} \tag{10}$$

where a_0, b_0 and c_0 are independent of the lepton mass. The first two terms on the right hand side of Eq.(10) are linear in lepton mass through the relation

$$Im(D^*_{l11}D_{l21}) = -Im(D^*_{l12}D_{l22}) =$$
$$\frac{m_l}{M^2_{\tilde{l}1} - M^2_{\tilde{l}2}}(m_0|A_l|\sin\alpha_f + |\mu|\sin\theta_\mu\tan\beta). \tag{11}$$

The third, fourth and fifth terms on the right hand side of Eq.(10) have a leading linear dependence on the lepton mass through the parameter κ_l and have additional weaker dependence on the lepton mass through the diagonalizing matrix elements D_{ij}. The last term in Eq.(10) is cubic in the lepton mass. However, in most of the parameter space cosidered, the first term in Eq.(10) is the dominant one and controls the scaling behavior. Thus for the case when all the soft SUSY breaking parameters including A are universal (i.e., $A_l = A$) in Eq. (11)), one finds from Eqs.(2), (4), (10) and (11), that scaling results, i.e., $d_\mu/d_e \simeq m_\mu/m_e$. This is borne out by the detailed numerical analysis as can be seen by comparing d_μ in Table 2 with d_e in Table 1, and also by comparing d_μ for the universal case (dotted line) with d_e (solid line with squares) in Figs.1-5. However, for the nonuniversal case since the contribution from the A parameter is flavor dependent we have a breakdown of scaling here. This breakdown can be seen by comparing d_μ in Tables 3 and 4 with d_e in Table 1, and also by comparing d_μ for the nonuniversal cases (dashed line with triangles pointed down and dashed line with triangles pointed up) with d_e (solid line with squares) in Figs.1-5.

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S. P. Martin, James D. Wells, hep-ph/0103067; K. Cheung, C-H Chou, O.C.W. Kong, hep-ph/0103183; S.Baek, P. Ko, H. S. Lee, hep-ph/0103218; D.F. Carvalho, J. Ellis, M.E. Gomez, S. Lola, hep-ph/0103256; A. Bartl, T. Gajdosik, E. Lunghi, A. Masiero, W. Porod, H. Stremnitzer, O. Vives, hep-ph/0103324; Y.-L. Wu and Y.-F. Zhou, hep-ph/0104056; B. Baek. T. Goto, Y. Okada and K. Okumura, hep-ph/0104146; C.-H. Chen and C.Q. Geng, hep-ph/0104151; K. Enqvist, E. Gabrielli, K. Huitu, hep-ph/0104174; D.-G. Cerdeno, E. Gabrielli, S. Khalil, C. Munoz and E. Torrente-Lujan, hep-ph/0104242; Y.G.Kim and M.M. Nojiri, hep-ph/0104258; Z. Chacko and G.D. Kribs, hep-ph/0104317; T. Blazek and S.F. King, hep-ph/0105005.

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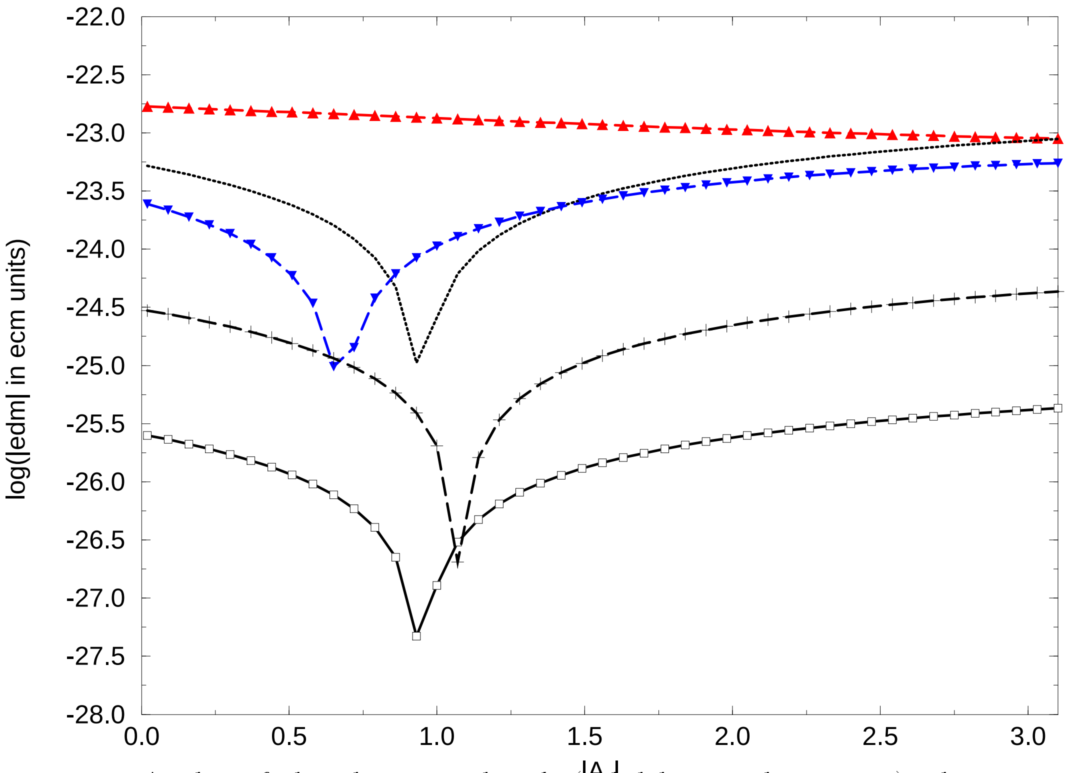

Figure 1: A plot of the electron edm d_e (solid line with squares), the neutron edm d_n (dashed line with plus signs), and the muon edm d_μ (dotted line) as a function of $|A_0|$ for the case when $\tan\beta = 10$, $m_0 = 150$, $m_{\frac{1}{2}} = 281$, $\xi_1 = .5$, $\xi_2 = -.45$, $\xi_3 = .42$, $\theta_\mu = .2$ and $\alpha_{A_e} = 4.1$ where all masses are in GeV corresponding to case (a) in Table 1. The curve with dashed line with triangles pointed down is a plot of the muon edm d_μ which have all the same parameters as for d_e and d_n except that $\alpha_{A_\mu} = -1.5$ (corresponding to case(a) of Table 3) and the curve with dashed line with triangles pointed up is a plot of the muon edm d_μ which have all the same parameters as for d_e and d_n except that $|A_\mu| = 7.0$, and $\alpha_{A_\mu} = -1.5$ (corresponding to case(a) of Table 4).

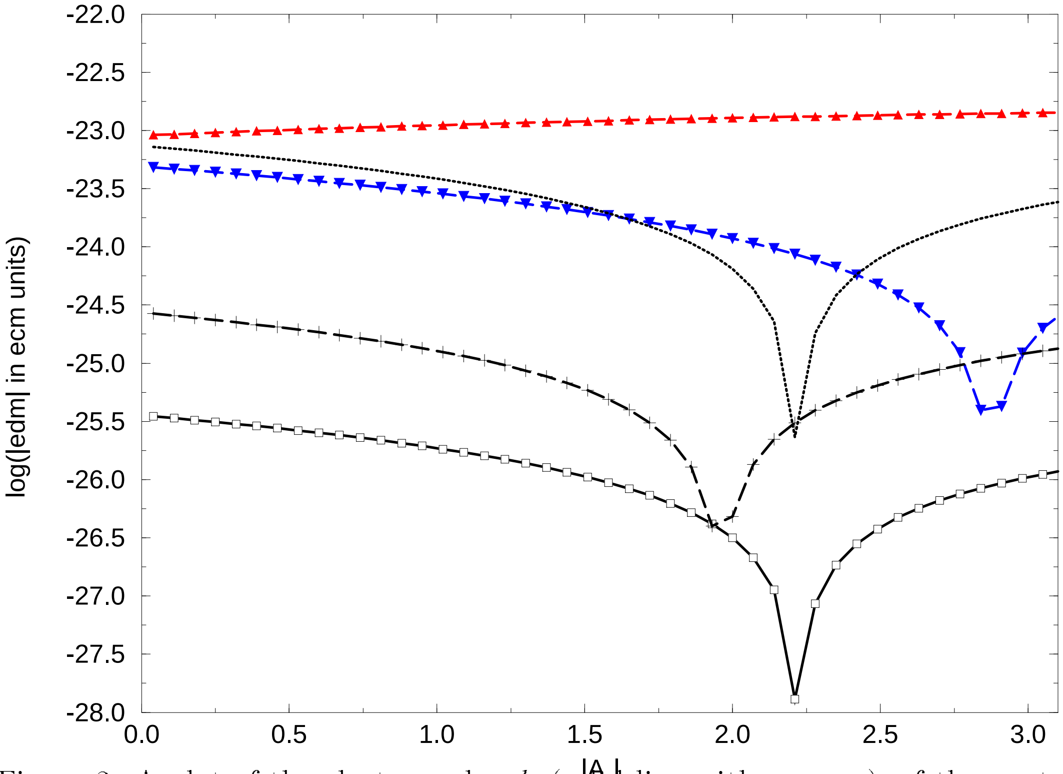

Figure 2: A plot of the electron edm d_e (solid line with squares), of the neutron edm d_n (dashed line with plus signs), and the muon edm d_μ (dotted line) as a function of $|A_0|$ for the case when $\tan\beta = 15$, $m_0 = 120$, $m_{\frac{1}{2}} = 316$, $\xi_1 = -.6$, $\xi_2 = -.15$, $\xi_3 = -.64$, $\theta_\mu = .3$ and $\alpha_{A_e} = 1.33$ where all masses are in GeV corresponding to case (b) in Table 1. The curve with dashed line with triangles pointed down is a plot of the muon edm d_μ which have all the same parameters as for d_e and d_n except that $\alpha_{A_\mu} = 0.0$ (corresponding to case(b) of Table 3)and the curve with dashed line with triangles pointed up is a plot of the muon edm d_μ which have all the same parameters as for d_e and d_n except that $|A_\mu| = 8.0$, and $\alpha_{A_\mu} = 1.0$ (corresponding to case(b) of Table 4).

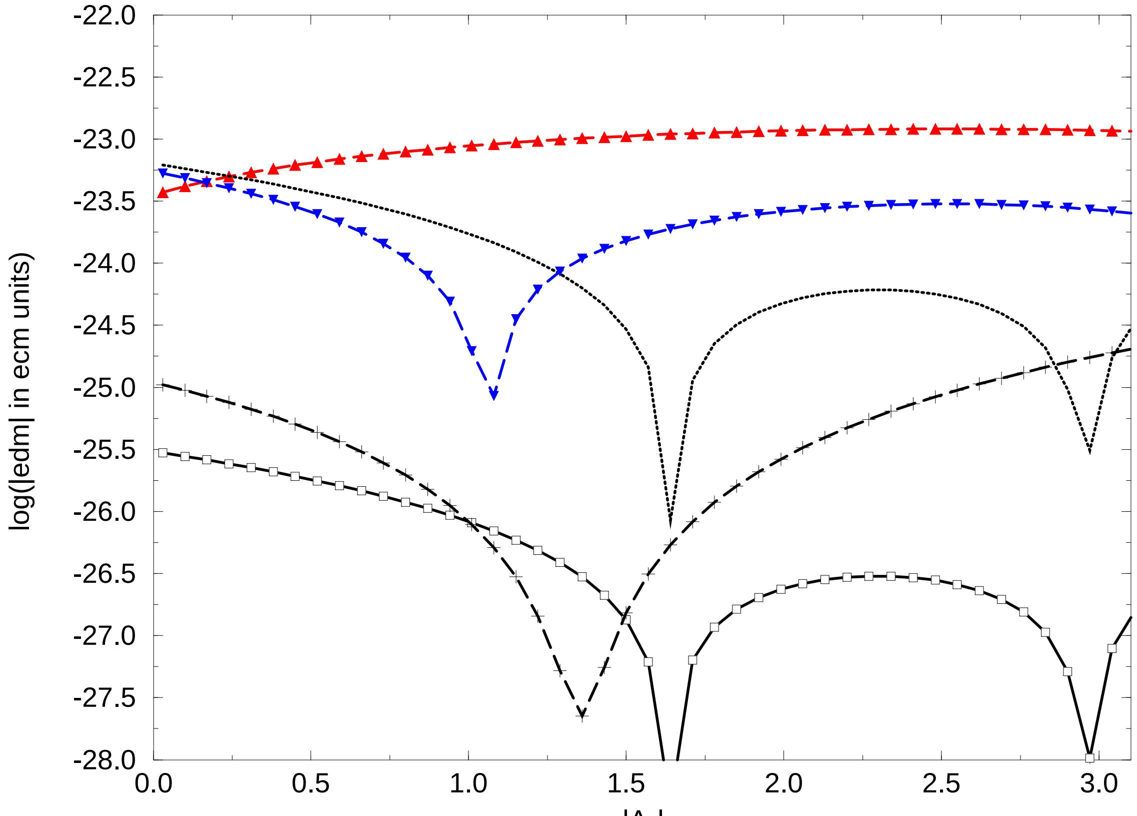

Figure 3: A plot of the electron edm d_e (solid line with squares), of the neutron edm d_n (dashed line with plus signs), and of the muon edm d_μ as a function of $|A_0|$ for the case when $\tan\beta = 20$, $m_0 = 200$, $m_{\frac{1}{2}} = 246$, $\xi_1 = .28$, $\xi_2 = -.51$, $\xi_3 = -.11$, $\theta_\mu = .4$ and $\alpha_{A_e} = 1.02$ where all masses are in GeV corresponding to case (c) in Table 1. The curve with dashed line with triangles pointed down is a plot of the muon edm d_μ which have all the same parameters as for d_e and d_n except that $\alpha_{A_\mu} = 0.0$ (corresponding to case(c) of Table 3)and the curve with dashed line with triangles pointed up is a plot of the muon edm d_μ which have all the same parameters as for d_e and d_n except that $|A_\mu| = 6.0$, and $\alpha_{A_\mu} = -2.0$ (corresponding to case(c) of Table 4).

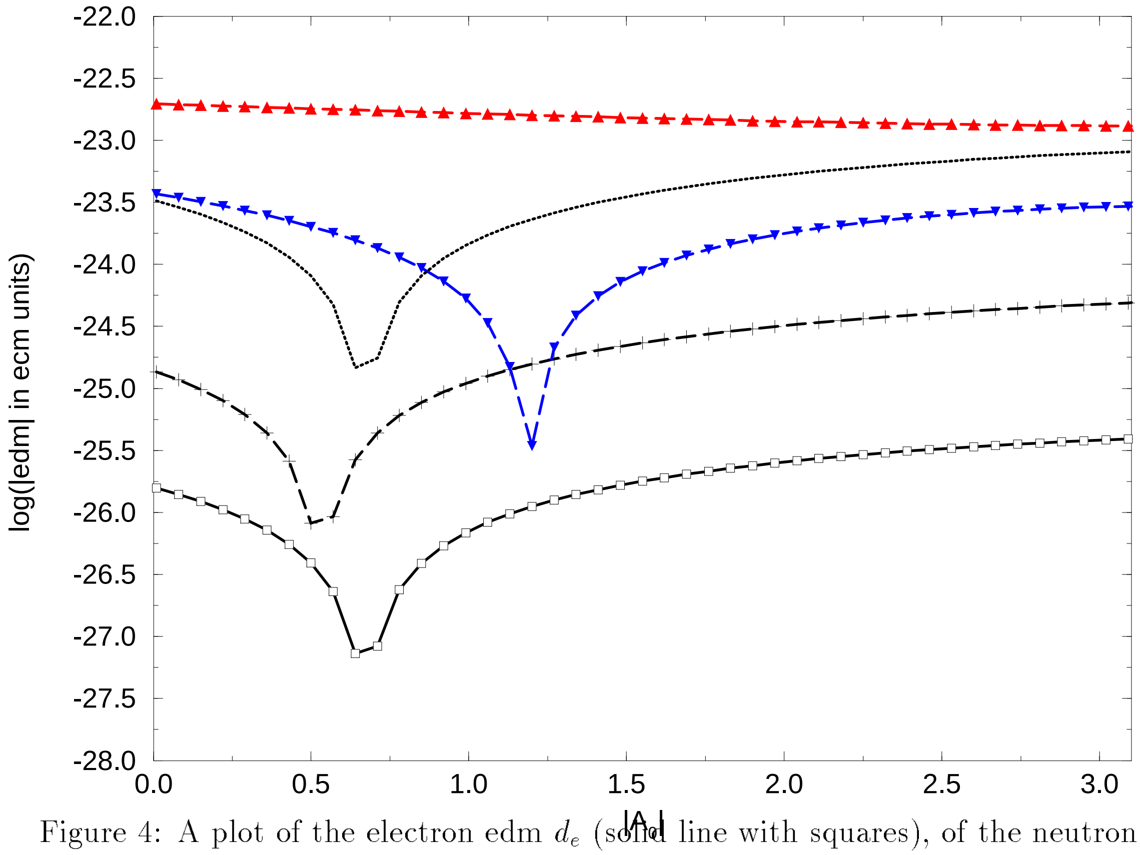

Figure 4: A plot of the electron edm d_e (solid line with squares), of the neutron edm d_n (dashed line with plus signs),and the muon edm d_μ as a function of $|A_0|$ for the case when $\tan\beta = 20$, $m_0 = 180$, $m_{\frac{1}{2}} = 298$, $\xi_1 = -.6$, $\xi_2 = -.07$, $\xi_3 = -.49$, $\theta_\mu = .2$ and $\alpha_{A_e} = 2.6$ where all masses are in GeV corresponding to case (d) in Table 1. The curve with dashed line with triangles pointed down is a plot of the muon edm d_μ which have all the same parameters as for d_e and d_n except that $\alpha_{A_\mu} = -2.0$ (corresponding to (d) of Table 3)and the curve with dashed line with triangles pointed up is a plot of the muon edm d_μ which have all the same parameters as for d_e and d_n except that $|A_\mu| = 10.0$, and $\alpha_{A_\mu} = -2.5$ (corresponding to case (d) of Table 4).

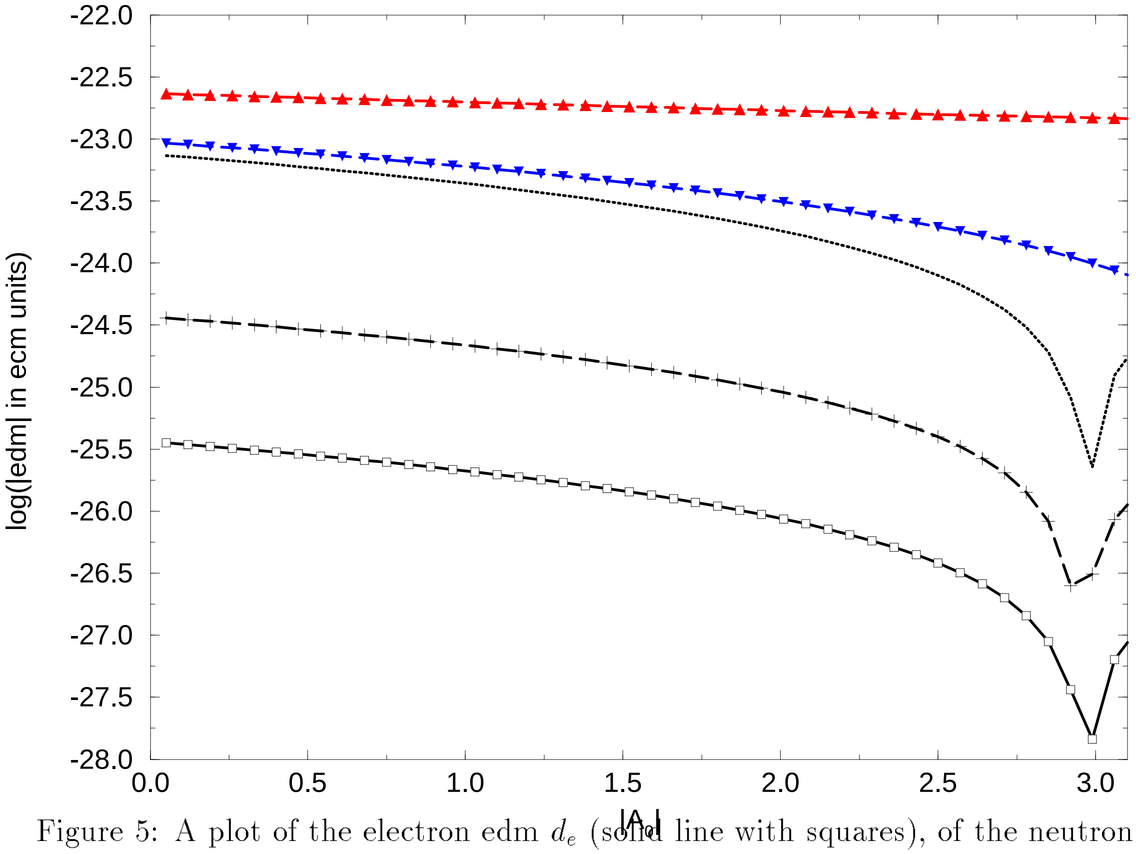

Figure 5: A plot of the electron edm d_e (solid line with squares), of the neutron edm d_n (dashed line with plus signs), and of the muon edm d_μ (dotted line) as a function of $|A_0|$ for the case when $\tan\beta = 6$, $m_0 = 100$, $m_{\frac{1}{2}} = 246$, $\xi_1 = .4$, $\xi_2 = -.77$, $\xi_3 = .55$, $\theta_\mu = .4$ and $\alpha_{A_e} = 1.15$ where all masses are in GeV corresponding to case (e) in Table 1. The curve with dashed line with triangles pointed down is a plot of the muon edm d_μ which have all the same parameters as for d_e and d_n except that $\alpha_{A_\mu} = 1.8$ (corresponding to (e) of Table 3)and the curve with dashed line with triangles pointed up is a plot of the muon edm d_μ which have all the same parameters as for d_e and d_n except that $|A_\mu| = 7.0$, and $\alpha_{A_\mu} = 2.5$ (corresponding to case (e) of Table 4).