Non-universal Soft SUSY Breaking Effects on Dark Matter and on Physics at Colliders

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Abstract. Implications of the effects of non-universalities of the soft SUSY breaking parameters on dark matter and on physics at colliders is discussed.

1. Introduction

In this paper we review the effects of non-universalities of soft SUSY breaking parameters on low energy physics. Most of the existing analyses of SUSY phenomenology has been within the framework of minimal SUGRA unification\cite{1,2}, which is parametrized in terms of four parameters under the constraint of radiative breaking of the electro-weak symmetry. These can be taken to be the universal scalar mass $m_0$, the gluino mass $m_{\tilde{g}}$, the trilinear coupling $A_t$, and $\tan\beta = \frac{<v_2>}{<v_1>}$, where $v_2$ gives mass to the up quark and $<v_1>$ gives mass to the down quark. However, the framework of supergravity and string theory allows for non-universalities of the soft SUSY breaking parameters to appear\cite{3,4}. There are two main sources which can give rise to non-universalities of this type in supergravity unified models. One of these is the gauge kinetic energy function $f_{\alpha\beta}$ while the second is a non-flat generation dependent Kahler potential. A general gauge kinetic function introduces non-universalities in the gaugino masses while a non-flat Kahler potential leads to non-universal scalar masses at the scale where SUSY breaks. One of the purposes of the analysis discussed in this paper is to identify signatures of such non-universalities in low energy physics, such as in dark matter and in physics at colliders.
The outline of the paper is as follows. In Sec.2 we give a general discussion of non-universalities. In Sec.3 we discuss the implications of non-universalities on dark matter. In Sec.3 we discuss how non-universality effects can be discerned from precision analyses of the sfermion mass spectrum.

2. Non-universalities in Supergravity Unification

We discuss now the two main sources of non-universalities in supergravity unified models. One of the sources is the gauge kinetic energy function $f_{\alpha\beta}$ which in general can possess Planck scale corrections so that

$$f_{\alpha\beta} = \delta_{\alpha\beta} + \frac{c}{2M_{\text{Planck}}} f_{\alpha\beta\gamma} \Sigma^\gamma$$

where $\Sigma$ is the adjoint Higgs. The gauge kinetic energy function also enters in the gaugino masses and one gets

$$(m_{\tilde{\psi}})_{\alpha\beta} = \kappa^{-1} \langle G^a (K^{-1})^b_{\alpha\beta} Re f_{\alpha\beta\gamma} \rangle m_{\tilde{\psi}}$$

where $\kappa = 1/M_{\text{Planck}}$, $G = \kappa^2 K + \ell n |\kappa^6 | W G^2 |$, $K$ is the Kahler potential, $W$ is the superpotential, $G^a \equiv \partial G/\partial Q^a$ and $(K^{-1})^a_{\beta\gamma}$ is the matrix inverse of the Kahler metric $K^a_{\beta\gamma}$. After spontaneous breaking of the GUT symmetry one generates non-universalities of the gaugino masses of size $O(M/M_p)$ so that

$$M_i = \frac{\alpha_i(Q)}{\alpha_G} (1 + c' M_{\text{GUT}} n_i) m_{\tilde{\psi}}$$

where $\alpha_G$ is the GUT coupling constant, M is the GUT scale, $\alpha_i$ are the subgroup gauge coupling constants, and $n_i = (2, -3, -1)$ for the subgroups $(SU(3), SU(2), U(1))$, and $c'$ while proportional to $c$ is an independent parameter.

There may already be experimental evidence for the presence of the Planck scale correction of the type discussed above. Thus the renormalization group analyses of the gauge coupling constants within the minimal SU(5) SUSY/SUGRA unification show that $\alpha_s$ is about $2\sigma$ higher than the current world average. This situation can be corrected by an inclusion of the Planck scale correction with $c \sim 1$. Of course a non-vanishing $c$ term also generates a correction to the gaugino masses as seen above and such corrections affect scaling relations. Thus in the absence of the $c'$ term one finds that over most of the parameter space one has the scale relation.
arising because of the fact that over most of the parameter space of the
SUGRA unified models one has $\mu^2/M_Z^2 >> 1$. Some of these scaling laws
break down when non-universalities are included; e.g., one gets $2m_{\chi_1}^0 \neq m_{\chi_1}^\pm \neq m_{\chi_2}^0 \neq \frac{1}{3} m_3$. From Eq.(3) we see that for $M/M_{Pl} \approx 1/50$, $c' \sim 3$, one can get corrections to the gaugino masses of O(20%) generating
a splitting of O(30%) in the ratio of the gaugino masses from their $c' = 0$
values because $n_i$ do not have fixed sign for all $i$. Such effects could be seen
in accurate measurements of the mass spectra of charginos, neutralinos, and
gluinos (see Sec.4 for discussion of the accuracy with which mass spectra
can be measured in the future). Further, in the deep scaling region, i.e., if
$(|\mu/M_Z| > 5)$, scaling is expected to hold to a few % accuracy when $c' = 0$. Thus in this region significant contributions from $c'$, i.e., if $c' \sim 2-3$ could
be visible as deviations from scaling. Next we discuss non-universalities in
the scalar soft SUSY breaking sector. As pointed out earlier these arise
due to the presence of a general Kahler potential which can be expanded in
terms of the visible sector fields $(Q_a, Q^a)$ as follows

$$K = \kappa^2 K_0 + K_b^a Q_a Q^b + (K^{ab} Q_a Q_b + h.c.) + ..$$  \hspace{1cm} (5)

where $K_0, K_b^a, ..$ etc are in general functions of the fields in the hidden
sector. For the minimal supergravity unification case the assumption
$K_b^a = K(h,h^\dagger)\delta_b^a$, where $h$ are the fields in the hidden sector, which leads to universality when SUSY breaks. Non-universalities appear when one gives up this assumption. However, one cannot allow an arbitrary set of
non-universalities in the soft SUSY breaking sector because of the stringent experimental constraints on flavor changing neutral currents (FCNC).
One sector where the FCNC constraints are not so stringent is the Higgs
sector. Thus in this sector one may phenomenologically parametrize the non-universalities in the following way

$$m_{H_1}^2 = m_0^2(1 + \delta_1), \hspace{0.5cm} m_{H_2}^2 = m_0^2(1 + \delta_2)$$  \hspace{1cm} (6)

where one limits the $\delta_i$ so that $|\delta_i| \leq 1$ ($i=1,2$). However, it was pointed
out in ref.[12] that the non-universalities in the Higgs sector and in the
third generation sector are strongly coupled. Thus one should also include
non-universalities in the third generation, i.e.,

$$m_{Q_L}^2 = m_0^2(1 + \delta_3), \hspace{0.5cm} m_{U_R}^2 = m_0^2(1 + \delta_4)$$  \hspace{1cm} (7)
where as before one limits $|\delta_i| \leq 1$ (i=3,4).

One of the ways non-universalities can affect low energy physics is via their effects on $\mu^2$. One may in general write $\mu^2 = \mu^2_0 + \Delta \mu^2$, where $\mu^2_0$ is the part for universal soft SUSY breaking and $\Delta \mu^2$ is the correction that arises due to non-universalities. For $\tan \beta$ small enough one can neglect the b quark coupling and obtain the following analytic expression for $\Delta \mu^2$ \cite{12}

$$\Delta \mu^2 = m_0^2 \frac{1}{t^2 - 1} (\delta_1 - \delta_2 t^2 - \frac{D_0 - 1}{2} (\delta_2 + \delta_3 + \delta_4)t^2) + \frac{3 t^2 + 1}{5 t^2 - 1} S_0 p$$ (8)

where $t \equiv \tan \beta$, $D_0 = 1 - (m_f^2/m_t^2)^2$, $m_f \simeq 200 \sin \beta$ GeV, $S_0 = Tr(Y m^2)$, and $p=0.0446$. The $S_0$ term is the anomaly term which vanishes for the universal case because of anomaly cancellation, i.e., $Tr(Y m^2)=0$.

Part of the mass spectrum which is affected sensitively by non-universalities is the spectrum of the third generation masses, for example, the stop masses which are governed by the matrix

$$\begin{pmatrix} m^2_{\tilde{t}_L} & -m_t (A_t + \mu \cot \beta) \\ -m_t (A_t + \mu \cot \beta) & m^2_{\tilde{t}_R} \end{pmatrix}$$ (9)

Non-universalities enter via corrections to $\mu$ in the off-diagonal elements and corrections to the diagonal elements so that $m^2_{\tilde{t}_L} = m^2_{\tilde{t}_L} (0) + \Delta m^2_{\tilde{t}_L}$, where $m^2_{\tilde{t}_L} (0)$ is the part for universal soft SUSY breaking and $\Delta m^2_{\tilde{t}_L}$ is the non-universality correction \cite{12}

$$\Delta m^2_{\tilde{t}_L} = m_0^2 \frac{(D_0 - 1)}{6} (\delta_2 + \delta_3 + \delta_4)$$ (10)

Similarly $m^2_{\tilde{t}_R} = m^2_{\tilde{t}_R} (0) + \Delta m^2_{\tilde{t}_R}$, where $m^2_{\tilde{t}_R} (0)$ is the universal part and $\Delta m^2_{\tilde{t}_R}$ is given by \cite{12}

$$\Delta m^2_{\tilde{t}_R} = m_0^2 \frac{(D_0 - 1)}{3} (\delta_2 + \delta_3 + \delta_4)$$ (11)

The above analysis shows that $\delta_3$ and $\delta_4$ enter on an equal footing with $\delta_1$ and $\delta_2$ so the non-universalities in the Higgs sector and in the third generation are strongly coupled as stated earlier.

3. Effects of Non-universal Soft SUSY Breaking on Dark Matter

In this section we discuss the effects of non-universalities on dark matter. We review first the basic elements of the analysis. The analysis assumes R parity invariance, and it can be shown that over most of the parameter space of the model the lightest neutralino is also the lowest supersymmetric
particle (LSP) and hence a candidate for cold dark matter (CDM). For the purpose of the analysis here we shall impose the dark matter constraint

$$0.1 \leq \Omega_{\tilde{\chi}^0} h^2 \leq 0.4$$

(12)

where $\Omega_{\tilde{\chi}^0}$ in the ratio of the mass density of the LSP relic to the critical mass density needed to close the universe. The quantity that can be computed theoretically is $\Omega_{\tilde{\chi}^0} h^2$, where $h$ is the Hubble parameter in units of 100 km/sMpc, and is given by

$$\Omega_{\tilde{\chi}^0} h^2 \approx 2.48 \times 10^{-11} \left( \frac{T_{\tilde{\chi}^0}}{T_\gamma} \right)^3 \left( \frac{T_\gamma}{2.73} \right)^3 \frac{N_f^{1/2}}{J(x_f)}$$

(13)

Here $x_f = kT_f/m_{\tilde{\chi}^0}$, where $T_f$ is the freezeout temperature, $N_f$ is the number of degrees of freedom at freezeout, $(T_{\tilde{\chi}^0}/T_\gamma)^3$ is the reheating factor, $T_\gamma$ is the current micro-wave background temperature and $J(x_f)$ is given by

$$J(x_f) = \int_0^{x_f} dx \langle \sigma v \rangle (x) GeV^{-2}$$

(14)

where $\sigma$ is the annihilation cross-section for the neutralinos, $v$ is their relative velocity and $< \sigma v >$ is the thermal average. In the computation of the thermal average we have used the accurate method[14, 15].

There are many techniques discussed in the literature for the detection of dark matter. One interesting possibility is the direct detection via scattering of neutralinos off nuclei. This process is governed by the basic interaction

$$L_{eff} = (\bar{\chi}_1 \gamma^\mu \gamma_5 \chi_1)[\bar{q} \gamma_\mu (A_L P_L + A_R P_R) q] + (\bar{\chi}_1 \chi_1)(\bar{q} C m_q q)$$

(15)

which consists of a spin dependent interaction governed by $A_L$ and $A_R$ terms and a scalar interaction governed by the C term. The event rates are given by

$$R = [R_{SI} + R_{SD}] \left[ \frac{\rho_{\tilde{\chi}^0}}{0.3 GeV cm^{-3}} \right] \left[ \frac{v_{\tilde{\chi}^0}}{320 km/s} \right] \text{events/kg da}$$

(16)

where $R_{SD}$ is the spin dependent part, $R_{SD}$ is the spin independent part, $v_{\tilde{\chi}^0}$ is the velocity of relic neutralinos in our galaxy impinging on the target, and $\rho_{\tilde{\chi}^0}$ is the local density of the relic neutralinos. $R_{SD}$ is given by

$$R_{SD} = \frac{16 m_{\tilde{\chi}^0} M_N}{(M_N + m_{\tilde{\chi}^0})^2} \lambda^2 J(J + 1) |A_{SD}|^2$$

(17)
where $M_N$ is the mass and $J$ is the spin of the target nucleus, $\lambda$ is defined so that $\langle N | \sum \vec{S}_i | N \rangle = \lambda < J | N \rangle$, and $A_{SD}$ is the spin dependent amplitude. Similarly $R_{SI}$ is given by

$$R_{SI} = \frac{16 m_{\tilde{\chi}_1} M_N^2 M_Z^2}{|N_N + m_{\tilde{\chi}_1}|^2} |A_{SI}|^2$$

where $A_{SI}$ is the spin independent amplitude. For heavy targets one has $R_{SD} \sim 1/M_N$ and $R_{SI} \sim M_{N}$. Thus for heavy targets one expects that the scalar interaction will eventually dominate over the spin dependent interaction.

We discuss now the effect of the Higgs sector non-universalities when $\delta_3 = 0 = \delta_4$. We consider three cases for comparison (i) $\delta_1 = 0 = \delta_2$, (ii) $\delta_1 = -1 = \delta_2$, (iii) $\delta_1 = 1 = \delta_2$. The result of the analysis is exhibited in Fig.1. Here we find that for the $\delta_1 = -1 = -\delta_2$ case $\Delta \mu^2$ receives a negative contribution which tends to reduce $\mu^2$ which raises event rates. It also drives $\mu^2$ towards the tachyonic limit eliminating part of the parameter space. Typically the part of the parameter that gets eliminated for $m_{\chi_1} < 65$ GeV is the small $\tan \beta$ region. Elimination of small $\tan \beta$ tends to drive the minimum of the event rate higher which is what is seen in Fig.1. For the case $m_{\chi_1} > 65$ GeV Landau pole and $m_{\chi_1}^2/2$ term effects are the dominant terms so the effects of non-universalities here are somewhat suppressed. For the case $\delta_1 = 1 = -\delta_2$ the effect is opposite to that for the previous case. A similar analysis holds for the effects of non-universalities in the third generation sector with $\delta_3$ and $\delta_4$ acting opposite to $\delta_2$. From Fig.1 it is seen that the event rates lie in a wide range $O(1-10^{-5})$ event/kgd.

The sensitivity of current detectors is rather limited [21, 22], and one needs more sensitive detectors [23] to probe a majority of the parameter space of supergravity models.

Finally, we consider the effects more accurate determinations of the cosmological parameters by future satellite experiments, such as MAP and PLANCK, will have on dark matter analyses. It is expected that these experiments will determine the cosmological parameters to within (1-10%) accuracy [24, 25]. There are a variety of models which fit the current cosmological data, such as $\Lambda CDM, \nu CDM$, etc. For illustration we consider $\Lambda CDM$ with the parameters $\Omega_{CDM} = 0.4$, $\Omega_B = 0.05$, $\Omega_\Lambda = 0.55$, and $h=0.62$ which give a reasonable fit to the current astro-physical data. Assuming that PLANCK reaches its expected accuracy [24] one would find the constraint

$$\Omega_{CDM} h^2 = 0.154 \pm 0.017$$

The implications of this constraint on event rate analyses is exhibited in Fig.2. One finds two generic features valid for both the universal as well as for the non-universal case. The first is that the maximum and the minimum corridors appear to shrink giving a narrower range in which the event
Figure 1. Maximum and minimum of event rates/kg d for xenon for \( \mu > 0 \) for the case when \( \delta_3 = 0 = \delta_4 \) and (a)\( \delta_1 = 0 = \delta_2 \) (solid), (b)\( \delta_1 = 1 = -\delta_2 \) (dotted), and (c)\( \delta_1 = -1 = -\delta_2 \) (dashed) when \( 0.1 < \Omega h^2 < 0.4 \), and \( m_t = 175 \text{ GeV} \). (From Ref.[12]).

rates can lie. The second more potent result is that the new \( \Omega h^2 \) constraint implies that the gluino mass should lie below 520 GeV. An analysis analogous to Fig.2 using a 2\( \sigma \) error corridor increases the upper limit on the gluino mass to 560 GeV. Much of this gluino mass domain can be probed with an upgraded Tevatron which can probe a significant part of the above parameter space in the gluino mass, i.e., up to about 450 GeV, with an integrated luminosity of about 25 fb\(^{-1}\).[27, 28].

4. Sfermion Mass Spectrum as a Probe of Non-universalities

The use of sfermion spectrum as a probe of different patterns of GUT symmetry breaking has already been discussed in the literature[26]. We discuss here the interesting possibility that the non-universalities of the soft SUSY breaking can affect the sfermion masses and thus a precision measurement of such masses would act as a probe for the existence of non-universalities[4]. Thus assume, for example, the existence of non-universalities at the GUT scale in an SU(5) invariant theory. Then in this case one would find that the mass differences \( m_{\tilde{u}_L}^2 - m_{\tilde{u}_R}^2 \), \( m_{\tilde{d}_L}^2 - m_{\tilde{d}_R}^2 \), \( m_{\tilde{g}_L}^2 - m_{\tilde{g}_R}^2 \), at the electro-weak scale would still be independent of the non-universalities. Further, by evolving the sfermion masses beyond the GUT scale one can determine if the different scalar masses unify at a common scale. If they do then the unification would attest to the existence of a universal soft SUSY breaking at the SUSY breaking scale which could be the string scale and at the same time allow us to experimentally deduce the value of the string scale.
Figure 2. Same as Fig.1 except that the constraint $\Omega h^2 = 0.154 \pm 0.017$ is imposed. The isolated points are for the $\delta_1 = -1$, $\delta_2 = 1$ case.

These ideas can be easily extended to other choices of the GUT group, such as SO(10), SU(3)$^3$, $G_{SM}$, etc. We consider the SO(10) case and assume that SO(10) breaks in one step at the scale $M_{GUT}$ down to the Standard Model gauge group $G_{SM}$. Here because of rank reduction one has D term contributions to the matching conditions at $M_{GUT}$.

Assuming that the matter spectrum falls in the $16$-plets of SO(10) which decomposes into $16=10+\bar{5}+1$ of SU(5), and the $5+\bar{5}$ of Higgs lies in the $10$ of SO(10) one can define

$$m_5^2 = \tilde{m}_0^2(1 + \delta_5), \quad m_{H_1}^2 = \tilde{m}_0^2(1 + \delta_1), \quad m_{H_2}^2 = \tilde{m}_0^2(1 + \delta_2), \quad (20)$$

where we have absorbed $\delta_{10}$ into the definition of the mass of the $10$ of SU(5). In this case the matching conditions imply $\delta_5 = \delta_1 - \delta_2$. This constraint can be tested if one has accurate measurements of sfermion masses. One expects that measurements accurate to a few percent may be possible in future colliders, which would determine the non-universalities at the $\sim 10\%$ level allowing one to test physics in the post GUT region up to the string scale.

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References

[1] A.H. Chamseddine, R. Arnowitt and P. Nath, Phys. Rev. Lett. 49, 970 (1982).

[2] For reviews see P. Nath, R. Arnowitt and A.H. Chamseddine, “Applied N = 1 Supergravity” (World Scientific, Singapore, 1984); H.P. Nilles, Phys. Rep. 110, 1 (1984); R. Arnowitt and P. Nath, Proc. of VII J.A. Swieca Summer School ed. E. Eboli (World Scientific, Singapore, 1994).

[3] S. K. Soni and H. A. Weldon, Phys. Lett. B126, 215(1983); V. S. Kaplunovsky and J. Louis, Phys. Lett. B306, 268(1993).

[4] R. Arnowitt and P. Nath, CTP-TAMU-2/97; NUB-TH-3152/97; hep-ph/9701325 (to be pub. Phys. Rev. D).

[5] C.T. Hill, Phys. Lett. B135, 47(1984); Q. Shafi, C. Wetterich, Phys. Rev. Lett. 52, 875(1984); L. Hall and U. Sarid, Phys. Rev. Lett. 70, 2673(1993); P. Langacker and N. Polonsky, Phys. Rev. D47, 4028(1993).

[6] T. Dasgupta, P. Mamales, and P. Nath, Phys. Rev. D52, 5366(1995); D. Ring, S. Urano and R. Arnowitt, Phys. Rev. D52, 6623(1995); S. Urano, D. Ring and R. Arnowitt, Phys.Rev. Lett. 76, 3663(1996); P. Nath, Phys. Rev. Lett. 76, 2218(1996).

[7] R. Arnowitt and P. Nath, Phys. Rev. Lett. 69, 475(1992); P. Nath and R. Arnowitt, Phys. Lett.B289, 368(1992).

[8] D. Matalliotakis and H.P. Nilles, Nucl.Phys.B435, 115(1995).

[9] M. Olechowski and S. Pokorski, Phys.Lett. B344, 201(1995).

[10] N. Polonski and A. Pomarol,Phys.Rev.D51,6532(1995).

[11] V. Berezinsky, A. Bottino, J. Ellis, N. Forrengo, G. Mignola, and S. Scopel, Astropart. Phys. 5:1-26(1996);ibid, 5: 333 (1996).

[12] P. Nath and R. Arnowitt, [hep-ph/9701301]; Phys. Rev. D56, 2820(1997).

[13] For a review see G. Jungman, M. Kamionkowski and K. Greist, Phys. Rep. 267,195(1995); E.W. Kolb and M.S. Turner, “The Early Universe” (Addison-Wesley, Redwood City, 1989); P. Nath and R. Arnowitt, Proc. of the Workshop on Aspects of Dark Matter in Astrophysics and Particle Physics, Heidelberg, Germany 16-20 September, 1996.

[14] K. Greist and D. Seckel, Phys. Rev. D43, 3191 (1991); P. Gondolo and G. Gelmini, Nucl. Phys. B360, 145 (1991).

[15] R. Arnowitt and P. Nath, Phys. Lett. B299, 103(1993); Phys. Rev. Lett. 70, 3696(1993); Phys. Rev. D54, 2374(1996); M. Drees and A. Yamada, Phys. Rev. D53, 1586(1996); H. Baer and M. Brhlick, Phys. Rev. D53, 597(1996); V. Barger and C. Kao, [hep-ph/9704403].

[16] M.W. Goodman and E. Witten, Phys. Rev. D31, 3059(1983); K. Greist, Phys. Rev. D38, (1988)2357; D39,3802(1989)(E); J. Ellis and R. Flores, Phys. Lett. B300,175(1993); R. Barbieri, M. Frigeni and G.F. Giudice, Nucl. Phys. B313,725(1989); M. Srednicki and R.Watkins, Phys.
Lett. B225,140(1989); R. Flores, K. Olive and M. Srednicki, Phys. Lett. B237,72(1990).

[17] A. Bottino et.al., Astro. Part. Phys. 1, 61 (1992); 2, 77 (1994).

[18] V.A. Bednyakov, H. V. Klapdor-Kleingrothaus and S.G. Kovalenko, Phys. Rev. D50,7128(1994).

[19] R. Arnowitt and P. Nath, Mod. Phys. Lett. A 10,1257(1995).

[20] P. Nath and R. Arnowitt, Phys. Rev. Lett.74,4592(1995); R. Arnowitt and P. Nath, Phys. Rev. D54,2374(1996).

[21] R. Bernabei, et.al., Phys. Lett. B389, 757(1996).

[22] A.Bottino, F. Donato, G. Mignola, S. Scopel, P. Belli, A. Incicchitti, hep-ph/9612451.

[23] D. Cline, Nucl. Phys. B (Proc. Suppl.) 51B, 304 (1996); P. Benetti et al, Nucl. Inst. and Method for Particle Physics Research, A307,203 (1993).

[24] A. Kosowsky, M. Kamionskowski, G. Jungman and D. Spergel, Nucl. Phys. Proc. Suppl. 51B, 49(1996).

[25] S. Dodelson, E. Gates and A. Stebbins, Astroph. J. 467, 10 (1996).

[26] Y. Kawamura, H. Murayama and M. Yamaguchi, Phys. Lett. B304, 52(1994); H. Murayama, M. Olechowski and S. Pokorski, Phys. Lett. B371, 57 (1996); R. Arnowitt and P. Nath, hep-ex/9605011.

[27] T. Kamon, J. L. Lopez, P. McIntyre and J. T. White, Phys. Rev. D50, 5676(1994).

[28] Report of the tev-2000 Study Group, eds. D. Amidei and R. Brock, FERMILAB-Pub-961082.

[29] M. Drees, Phys. Lett. B181, 279 (1986); P. Nath and R. Arnowitt, Phys. Rev. D39, 2006(1989); J.S. Hagelin and S. Kelley, Nucl. Phys. B342, 95(1990).

[30] H. Baer, C. Chen, F. Paige, and X. Tata, Phys. Rev. DD52, 2746(1995).

[31] I. Hinchliffe, F.E. Paige, M.D. Shapiro, J. Soderqvist and W. Yao, Phys. Rev. D55, 5520(1997).

[32] T. Tsukamoto, K. Fujii, H. Murayama, M. Yamaguchi, and Y. Okada, Phys. Rev. D. 51, 3153(1995).

[33] J.L. Feng, M.E. Peskin, H. Murayama, and X. Tata, Phys. Rev. D52, 1418(1992).

[34] S. Kuhlman et. al., "Physics and Technology of the NLC: Snowmass 96", hep-ex/9605014.