ONE–LOOP ANALYSIS OF THE ELECTROWEAK BREAKING IN SUPERSYMMETRIC MODELS AND THE FINE–TUNING PROBLEM

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Abstract

We examine the electroweak breaking mechanism in the minimal supersymmetric standard model (MSSM) using the complete one-loop effective potential $V_1$. First, we study what is the region of the whole MSSM parameter space (i.e. $M_{1/2}, m_0, \mu, ...$) that leads to a succesful $SU(2) \times U(1)$ breaking with an acceptable top quark mass. In doing this it is observed that all the one-loop corrections to $V_1$ (even the apparently small ones) must be taken into account in order to get reliable results. We find that the allowed region of parameters is considerably enhanced with respect to former "improved" tree level results. Next, we study the fine-tuning problem associated with the high sensitivity of $M_Z$ to $h_t$ (the top Yukawa coupling). Again, we find that this fine-tuning is appreciably smaller once the one-loop effects are considered than in previous tree level calculations. Finally, we explore the ambiguities and limitations of the ordinary criterion to estimate the degree of fine-tuning. As a result of all this, the upper bounds on the MSSM parameters, and hence on the supersymmetric masses, are substantially raised, thus increasing the consistency between supersymmetry and observation.
1 Introduction

Precision LEP measurements give a strong support [1] to the expectations of supersymmetric (SUSY) [2] grand unification [3]. Namely, the two loop calculation indicates that the gauge coupling constants of the standard model seem to be unified\(^1\) at \(M_X \sim 10^{16} \text{ GeV}\) with a value \(\alpha_X \sim 1/26\), provided the average mass of the new supersymmetric states lies in the range [100 GeV, 10 TeV].

This calculation has been refined in a recent paper by Ross and Roberts [5] in which the various supersymmetric thresholds were appropriately taken into account. This was done in the context of the minimal supersymmetric standard model (MSSM), which is characterised by the Lagrangian

\[
L = L_{\text{SUSY}} + L_{\text{soft}}. \tag{1}
\]

Here \(L_{\text{SUSY}}\) is the supersymmetric Lagrangian derived from the observable superpotential \(W_{\text{obs}}\), which includes the usual Yukawa terms \(W_Y\) and a mass coupling \(\mu H_1 H_2\) between the two Higgs doublets \(H_1, H_2\). \(L_{\text{soft}}\) at the unification scale \(M_X\) is given by

\[
L_{\text{soft}} = -m_o^2 \sum_\alpha |\phi_\alpha|^2 - \frac{1}{2} M_{1/2} \sum_{a=1}^3 \bar{\lambda}_a \lambda_a - (A m_o W_Y + B m_o \mu H_1 H_2 + \text{h.c.}) \tag{2}
\]

where \(m_o\) and \(M_{1/2}\) are the (common) supersymmetry soft breaking masses (at \(M_X\)) for all the scalars \(\phi_\alpha\) and gauginos \(\lambda_a\) of the theory, and \(A\) and \(B\) parametrize the (common) couplings of the trilinear and bilinear scalar terms. In this framework the physical spectrum of supersymmetric masses depend on the particular choice of the MSSM parameters

\[
m_o, M_{1/2}, \mu, A, B, h_t \tag{3}
\]

where \(h_t\) is the top Yukawa coupling\(^2\). Therefore, the requirement of gauge unification constrains their ranges of variation.

These parameters are also responsible of the form of the Higgs scalar potential and thus of the electroweak breaking process [6]. Requiring the electroweak scale (i.e. \(M_Z\)) to be the correct one, together with the presents bounds on \(m_{\text{top}}\), Ross and Roberts further

\(^1\)This unification does not necessarily require a GUT. In particular, in superstring theories all the gauge couplings are essentially the same at tree level [4] even in the absence of a grand unification group. This also avoids unwanted consequences of GUT theories.

\(^2\)These are the parameters, together with the gauge couplings, that enter in the renormalization group equations for the masses. The influence of the bottom and tau Yukawa couplings is negligible in most of the cases.
restricted the allowed space of these parameters. Finally, these authors imposed the absence of fine-tuning in the value of $h_t$ (the parameter to which $M_Z$ is more sensitive) for a successful electroweak breaking, by demanding $c \lesssim 10$ in the equation

$$\frac{\delta M_Z^2}{M_Z^2} = c \frac{\delta h_t^2}{h_t^2}$$

where the value of $c$ depends on the values of all the independent parameters listed in eq.(3) (which also determine the supersymmetric masses). As a consequence, they found $m_o, \mu, M_{1/2} \lesssim 200$ GeV (leading to typical supersymmetric masses $\lesssim 500$ GeV). In fact, this turns out to be the strongest constraint on the supersymmetric mass scale, stronger than the requirement of gauge unification.

The analysis of ref.[5] of the electroweak breaking process and the corresponding $h_t$-fine-tuning problem was performed by using the renormalization improved tree level potential $V_o(Q)$, i.e. the tree level potential in terms of the renormalized parameters at the scale $Q$. However, as was shown in ref.[8], one expects the effect of the one-loop contributions to be important. Consequently, the analysis should be re-done using the whole one-loop effective potential. This is the main goal of this paper.

In section 2 we study what is the region of the whole MSSM parameter space (eq.(3)) leading to a correct $SU(2) \times U(1)$ breaking (this means a correct value for $M_Z$ and $m_{top}$ without color and electric charge breakdown). The comparison with the results of the ”renormalization improved” tree level potential $V_o [5]$ shows that the one-loop corrections enhance (and also displace) this allowed region. As a by-product, we show that the (very common) approximation of considering only the top and stop contribution (disregarding the $\tilde{t}_L - \tilde{t}_R$ mixing) to the one-loop effective potential is not reliable for analyzing the electroweak breaking mechanism. In section 3 we analyze the above mentioned fine-tuning problem, showing that, once the one-loop contributions are taken into account, it becomes considerably softened. In addition to this, we study the limitations and ambiguities of the ordinary criterion (4) to estimate the fine-tuning problem. Although in the MSSM it turns out to be a sensible criterion (which is not a general fact), it should be considered as a rather qualitative one, thus the upper bound on $c$ should be conservatively relaxed, at least up to $c \lesssim 20$. As a consequence of all this, the upper bounds on the MSSM parameters and on the supersymmetric masses are pushed up from the ”renormalized improved” tree level results. This is relevant, of course, for the expectations of experimental detection of SUSY. Finally, we present our conclusions in section 4.

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3The sensitivity of $M_Z$ to other independent parameters has been analyzed in ref.[7].
2 Radiative electroweak breaking

In the MSSM the part of the tree-level potential along the neutral components of the Higgs fields at a scale $Q$ is given by

$$V_0(Q) = \frac{1}{8} (g^2 + g'^2) \left( |H_1|^2 - |H_2|^2 \right)^2 + m_1^2 |H_1|^2 + m_2^2 |H_2|^2 - m_3^2 (H_1 H_2 + \text{h.c.}) \right),$$

where

$$m_i^2 = m_{H_i}^2 + \mu^2, \quad m_3^2 = m_0 \mu B$$

with

$$m_{H_i}(M_X) = m_o^2$$

In the usual calculations with just the tree level potential $V_0(Q)$ (as in ref.[5]), this was minimized at the $M_Z$ (or $M_W$) scale.

The one-loop effective potential is given by [9]

$$V_1(Q) = V_0 + \Delta V_1$$

where

$$\Delta V_1(Q) = \frac{1}{64 \pi^2} \text{Str} \left[ \mathcal{M}^4 \left( \log \frac{\mathcal{M}^2}{Q^2} - \frac{3}{2} \right) \right]$$

depends on $H_1, H_2$ through the tree-level squared-mass matrix $\mathcal{M}^2$. In the expressions (5,6,8,9) all the parameters are understood to be running parameters evaluated at the scale $Q$. They can be computed by solving the standard renormalization group equations (RGE’s), whose form is well known [2], and taking into account all the supersymmetric thresholds. The supertrace of eq.(9) runs over all the states of the theory. This, in particular, amounts to determine the eigenvalues of the mass mixing matrices of stops, charginos and neutralinos. Incidentally, a simplification broadly used in the literature is to consider just the top ($t$) and stop ($\tilde{t}$) contributions to (9), disregarding also the $\tilde{t}_L - \tilde{t}_R$ mixing. This can be a good approximation for certain purposes (see e.g. ref.[10]), but, as will be shown shortly, it is not when one is interested in studying the $SU(2) \times U(1)$ breaking. To be in the safe side the whole spectrum contribution must be considered in eq.(9).
In order to exhibit the implications of considering the whole one-loop potential $V_1$ versus $V_o$, we have shown two examples (a) and (b) in fig.1. They are specified by the following initial values of the independent parameters

(a) \[ m_o = \mu = 120 \text{ GeV}, M_{1/2} = 230 \text{ GeV}, A = B = 0, h_t = 0.207 \]

(b) \[ m_o = \mu = 100 \text{ GeV}, M_{1/2} = 180 \text{ GeV}, A = B = 0, h_t = 0.250 \quad (10) \]

The case (a) corresponds to one of the two models explicitly expounded in ref.[5] (where it was called "X"). Although in the $V_o$ approximation this model works correctly, once the one-loop contributions are considered, we see that it does not even lead to electroweak breaking (the same happens with the model that was called "Z"). In the example (b) both $V_o$ and $V_1$ yield electroweak breaking, but for completely different values of $v_1 \equiv \langle H_1 \rangle$ and $v_2 \equiv \langle H_2 \rangle$. In this case, $V_1$ predicts electroweak breaking at the right scale, while $V_o$ does not. The above-mentioned approximation of considering just the top and stop contribution to $\Delta V_1$, which is also represented in the figure, works better than $V_o$, but not enough to produce acceptable results. Moreover, it is clear from the figure that only the whole one-loop contribution really helps to stabilize the values of $v_1, v_2$ versus variations of $Q$ (they are essentially constant up to $O(h^2)$ corrections). In fact, they should evolve only via the (very small) wave function renormalization effects, given by

\[
\frac{\partial \log v_1}{\partial \log Q} = \frac{1}{64\pi^2}(3g^2 + g'^2) \\
\frac{\partial \log v_2}{\partial \log Q} = \frac{1}{64\pi^2}(3g^2 + g'^2 - 12h_t^2) . \quad (11)
\]

There is a scale, that in ref.[8] was called $\hat{Q}$, at which the results from $V_o$ and $V_1$ approximately coincide. At this scale the one-loop contributions are quite small, in particular the logarithmic factors, so $\hat{Q}$ represents a certain average of all the masses. In the region around $\hat{Q}$ one expects, due to the smallness of the logarithms, that the evaluation of one-loop effects is more reliable (see also ref.[11]).

In the example depicted in fig.1b this consideration is not very relevant, for $v_1$ and $v_2$ are essentially constant. However, there are cases where $v_1(Q)$ and $v_2(Q)$ do not show such a remarkable stability. This happens when the averaged supersymmetric mass is much larger than $M_Z$, since this leads to the appearance of large logarithms at $Q = M_Z$ (this fact has been stressed in ref.[11]). However, in the region around $\hat{Q}$ (i.e. precisely where the calculation is more reliable) $v_1(Q)$ and $v_2(Q)$ are always stable. Thus we have used the following criterion: we evaluate $v_1$ and $v_2$ at the $\hat{Q}$ scale and then we calculate
$v_1(Q)$ and $v_2(Q)$ via eq.(11) at any other scale. This is relevant at the time of calculating physical masses. In particular $M_Z$ is given by

$$(M_Z^{\text{phys}})^2 \simeq \frac{1}{2} \left( g_2^2(Q) + g'^2(Q) \right) \left[ v_1^2(Q) + v_2^2(Q) \right] \bigg|_{Q=M_Z^{\text{phys}}}$$

and similar expressions can be written for all the particles of the theory.

Now we are ready to determine how the requirement of correct electroweak breaking (i.e. $M_Z^{\text{phys}} = M_Z^{\text{exp}}$) puts restrictions in the space of parameters. ”Correct electroweak breaking” of course means $M_Z^{\text{phys}} = M_Z^{\text{exp}}$, where $M_Z$ is given by (12). In addition, other physical requirements must be satisfied. Namely, the scalar potential must be bounded from below [2], color and electric charge must remain unbroken [2], and the top mass must lie within the LEP limits ($100 \text{ GeV} \lesssim \tilde{m}_{\text{top}} \lesssim 160 \text{ GeV}$). Following a similar presentation to that of ref.[5], the results of the analysis for $A = B = 0$ (at $M_X$) and for various initial values of $|\mu_o/m_o|$ are shown in fig.2. The value of $\alpha_3(M_Z)$ necessary to achieve unification of the couplings was calculated in ref.[5] at the two-loop order and is also represented in the figure. We have also evaluated the effect of varying the $A$ and $B$ parameters, as is illustrated in fig.3. The effect of the one loop contribution is to enhance and displace the region of allowed parameters appreciably. In order to facilitate the comparison we have reproduced in fig.4 the $V_o$ results [5] and the one-loop results for for the case of fig.2c (i.e. $m_o/\mu_o = 1$, $A = B = 0$), which is a representative one.

3 The fine-tuning problem

As was pointed out in ref.[5], $h_t$ is the parameter to which the value of $M_Z$ is more sensitive. This sensitivity is conveniently quantified by the $c$ parameter defined in eq.(4). We have represented the values $c$ for the representative case of fig.4. A good parameterization of the value of $c$ is

$$c \simeq \frac{1}{M_Z^2} \left[ 1.08 \ M_{1/2}^2 + 0.19 \ (m_o^2 + \mu_o^2) \right]$$

The high influence of $M_{1/2}$ on the value of $c$ compared to that of $m_o$ and $\mu_o$ comes from the fact that scalar masses can be very high, even if they are vanishing at tree level, due to the gaugino contribution in the RGE’s, but not the other way round. The tree level results [5] are also given to facilitate the comparison. The sensitivity of $M_Z$ to $h_t$ turns

\footnote{We reproduce here the values of $c$ for $V_o$ as given in ref.[5], though our calculation gives slightly different values.}
out to be substantially smaller with the complete one-loop effective potential than with the $V_o$ approximation. If, following ref.[5], we demand now $c \lesssim 10$ as the criterion to avoid the fine-tuning in $h_t$, this selects a region of acceptable SUSY parameters that can easily be read from fig.4. Notice that this region is noticeably larger than the corresponding one obtained from $V_o$. This is a consequence of the lower sensitivity of $M_Z$ to $h_t$ and the larger region of parameters giving a correct value of $M_Z$ (see section 2) when one uses the entire one-loop effective potential $V_1$. Accordingly, the one-loop contributions tend to make less "critical" the electroweak breaking process in supersymmetric models.

We would also like to make some comments on the criterion usually followed to parameterize the fine-tuning problem, i.e. $c \lesssim 10$ in eq.(4). First of all, to some extent this procedure is ambiguously defined, since it depends on our definition of the independent parameters and the physical magnitude to be fitted. For example, if we replace $M^2_Z$ by $M_Z$ in eq.(4), then the corresponding values of $c$ (represented in fig.3) are divided by two. Second, notice that if for a certain choice of the supersymmetric parameters $(m_o, M_{1/2}, \mu, A, B)$, the value of $c$ turned out to be high for most of the possible values of $h_t$ (or equivalently $M_Z$), then we would arrive to the bizarre conclusion that any value of $h_t$ leads to a fine-tuning. This is so because the "standard" criterion of eq.(4) measures the sensitivity of $M_Z$ to $h_t$ rather than the degree of fine-tuning. In order for eq.(4) to be a sensible quantification of the fine-tuning it should be required $c \sim 1$ for most of the $h_t$ values. To check this, we have represented in fig.5 $M_Z$ versus $h_t$ for a typical example ($m_o = \mu = M_{1/2} = 500 \, GeV, A = B = 0$). We see that, indeed, for most of the $h_t$ values the sensitivity of $M_Z$ to $h_t$ is small. Hence, the parameterization of the fine-tuning by the value of $c$ in eq.(4) is meaningful. A natural value for $M_Z$ under these conditions would be $M_Z \sim 1 \, TeV$. Nevertheless, this shows that it is dangerous to assume that $c$ is an exact measure of the degree of fine-tuning. It is rather a sensible, but qualitative one. In fact, a precise evaluation of the degree of fine-tuning would require a knowledge of what are the actual independent parameters of the theory and what is the supergravity breaking mechanism (for an example of this see ref.[12]).

All the previous considerations suggest that the upper limit $c \lesssim 10$ in the measure of the allowed fine-tuning should be conservatively relaxed, at least up to $c \lesssim 20$. We see

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5This would happen, for instance, if the hypothetic theoretical relation between $M_Z$ and $h_t$ were $M_Z \sim \exp\{Ch_t\}$ with $|Ch_t| > 10$.

6Notice, however, that if we restrict the range of variation of $h_t$ so that $100 \, GeV < m_{top} < 160 \, GeV$, then $c > 10$ in the entire "allowed" region of $h_t$. 

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from fig.4 that this implies

\[ m_0, \mu \lesssim 650 \text{ GeV}, \quad M_{1/2} \lesssim 400 \text{ GeV} \]

(14)

In order to see what are the corresponding upper limits on the supersymmetric masses, we have explicitly given the mass spectrum (including also the small contributions coming from the electroweak breaking) in Table 1 for the two ”extreme” cases labelled as \( X_1 \) and \( X_2 \) in fig.4. Note that these two cases are close to the \( c = 20 \) line and to the upper and lower limits on the top quark mass. From these extreme examples we see that, roughly speaking, the bounds on the most relevant supersymmetric particles are

\[
\begin{align*}
\text{Gluino} & \quad M_{\tilde{g}} \lesssim 1100 \text{ GeV} \\
\text{Lightest chargino} & \quad M_{\tilde{\chi}^\pm} \lesssim 250 \text{ GeV} \\
\text{Lightest neutralino} & \quad M_{\tilde{\chi}} \lesssim 200 \text{ GeV} \\
\text{Squarks} & \quad m_{\tilde{q}} \lesssim 900 \text{ GeV} \\
\text{Sleptons} & \quad m_{\tilde{l}} \lesssim 450 \text{ GeV}
\end{align*}
\]

(15)

These numbers are substantially higher than those obtained in ref.[5] from \( V_o \), and summarize the three main results obtained in this paper: i) The region of parameters giving a correct electroweak breaking is larger when one uses the entire one-loop effective potential \( V_1 \) than with \( V_o \) (see section 2), ii) The corresponding sensitivity of \( M_Z \) to the value of \( h_t \) is smaller and iii) The highest acceptable value of \( c \) (see eq.(11)) must be conservatively relaxed for the above explained reasons. The most important conclusion at this stage is that the supersymmetric spectrum is not necessarily close to the present experimental limits, though the future accelerators (LHC, SSC) should bring it to light. It is also remarkable that the \( \tilde{t}_L - \tilde{t}_R \) splitting can be very sizeable in many scenarios. Let us finally note that there are considerable radiative corrections to the lightest Higgs mass coming from the top-stop splitting [11], which have not been included in Table 1.

4 Conclusions

We have studied the electroweak breaking mechanism in the minimal supersymmetric standard model (MSSM) using the complete one-loop effective potential \( V_1 = V_o + \Delta V_1 \) (see eqs.(3,5,9)). We have focussed the attention on the allowed region of the parameter space leading to a correct electroweak breaking, the fine-tuning problem and the upper bounds on supersymmetric masses.
As a preliminary, we showed that some common approximations, such as considering only the top and stop contributions to $\Delta V_1$ and/or disregarding the $\tilde{t}_L - \tilde{t}_R$ mixing, though acceptable for other purposes, lead to wrong results for $SU(2) \times U(1)$ breaking. In consequence, we have worked with the exact one-loop effective potential $V_1$.

Next, we have examined what is the region of the whole MSSM parameter space (i.e. the soft breaking terms $M_{1/2}, m_o, A, B$ plus $\mu$ and $h_t$) that leads to a correct $SU(2) \times U(1)$ breaking, i.e. the correct value of $M_Z$, a value of $m_{top}$ consistent with the observations and no color or electric charge breakdown. A comparison with the results of the "renormalization improved" tree level potential $V_o$ [5] shows that the one-loop corrections enhance (and also displace) the allowed region of parameters. This, of course, are good news for the MSSM.

Our following step has been to analyze the top-fine-tuning problem. As it has been pointed out in ref.[5], $h_t$ (the top Yukawa coupling) is the parameter to which $M_Z$ is more sensitive. Using the ordinary criterion to avoid fine-tuning, i.e. $c < \sim 10$ in the relation

$$\frac{\delta M^2_Z}{M^2_Z} = c \frac{\delta h^2_t}{h^2_t},$$

(16)

strongly constraints the values of the MSSM parameters, leading to upper bounds on $M_{1/2}, m_o, \mu$, and thus on the masses of the new supersymmetric states (gluino, squarks, charginos, etc.). This analysis was performed in ref.[5] using the improved tree level potential $V_o$. We find that the one-loop corrections substantially soften the degree of fine-tuning. This, again, are good news for the MSSM.

Finally, we have explored what are the limitations of the ordinary criterion (16) to parameterize the degree of fine-tuning. We comment on its ambiguities and show a type of (hypothetical) scenarios in which this criterion would be completely meaningless. Fortunately, this is not the case for the MSSM and, thus, the $c$ parameter represents a sensible, but qualitative estimation of the degree of fine-tuning. A precise and non-ambiguous quantification of it can only be done once one knows the supergravity breaking mechanism. In view of all this, we have conservatively relaxed the acceptable upper bound for $c$ up to $c \sim 20$.

As a summary of the results the one-loop contributions

i) enhance (and displace) the allowed region of the MSSM parameters

ii) soften the fine-tuning associated with the top quark (for large values of the MSSM parameters). These two facts together with the fact that

iii) the upper bound on $c$ should be conservatively relaxed, push up the upper bounds on the MSSM parameters obtained from the former $V_o$ analysis and the corresponding upper bounds on supersymmetric masses. This is reflected in Table 1 for two "extreme"
cases and in eq. (13). Our final conclusion is that the supersymmetric spectrum is not necessarily close to the present experimental limits, though the future accelerators (LHC, SSC) should bring it to light.

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| Parameters (initial values) |
|-----------------------------|
| $M_{1/2}$ (GeV)             | 300  | 400  |
| $m_o$ (GeV)                 | 400  | 200  |
| $\mu$ (GeV)                | 400  | 200  |
| $h_t$                       | 0.618| 0.254|
| $A, B$                      | 0    | 0    |

| Masses of Gluino, Charginos and Neutralinos (in GeV) |
|------------------------------------------------------|
| $\tilde{g}$                                          | 837  | 1124 |
| $\chi^{\pm}_1$                                       | 407  | 376  |
| $\chi^{\pm}_2$                                       | 243  | 226  |
| $\lambda_1$                                          | 172  | 169  |
| $\lambda_2$                                          | 242  | 371  |
| $\lambda_3$                                          | 408  | 236  |
| $\lambda_4$                                          | 387  | 255  |

| Masses of Squarks (in GeV)                           |
|------------------------------------------------------|
| $\tilde{u}_L, \tilde{c}_L, \tilde{d}_L, \tilde{s}_L$| 785; 789| 922; 925|
| $\tilde{u}_R, \tilde{c}_R$                         | 766    | 888  |
| $\tilde{d}_R, \tilde{s}_R, \tilde{b}_R$           | 762    | 885  |
| $\tilde{t}_L, \tilde{b}_L$                         | 827, 698| 1055, 881|
| $\tilde{t}_R$                                       | 410    | 560  |

| Masses of Sleptons and Higgses (in GeV)             |
|------------------------------------------------------|
| $\tilde{l}_L, \tilde{l}_R$                          | 476, 431| 372, 256|
| $h^o, H^o$                                          | 91, 547| 91, 353|
| $H^\pm$                                             | 553    | 362  |
| $A^o$                                                | 547    | 353  |

Table 1: Masses of the supersymmetric states for the two solutions (called $X_1$ and $X_2$ in fig.4) with $m_{top} = 163, 109$ respectively. All the masses are given at the $M_Z$ scale.
**FIGURE CAPTIONS**

**Fig.1** $v_1 \equiv \langle H_1 \rangle$, $v_2 \equiv \langle H_2 \rangle$ versus the $Q$ scale between $M_Z$ and 2 TeV (in GeV) for the cases labelled as (a) and (b) in eq.(10). Solid lines: complete one-loop results; dashed lines: ”improved” tree level results; dotted lines: one-loop results in the top–stop approximation.

**Fig.2** Allowed values for the $M_{1/2}$, $m_o$ parameters (in GeV) for different vales of $\mu_o$: $|\mu_o/m_o| = 0.2, 0.4, 1, 3$ in (a), (b), (c), (d) respectively, and $A = B = 0$. The solid lines represent the value of $\alpha_3(M_Z)$ needed to achieved unification, as calculated in ref.[5]. Dotted lines correspond to the extreme values of $m_{top}$ (evaluated at the $M_Z$ scale): $m_{top} = 160, 100$ GeV.

**Fig.3** The same as fig.2, but for different values of $A, B$: $A = 0, 0, 1, -1$, $B = 0, 1, 0, 0$ in (a), (b), (c), (d) respectively, and $|\mu_o/m_o| = 1$. In case (c), the $m_{top} = 160$ GeV line coincides with the $M_{1/2} = 100$ GeV axis.

**Fig.4** The case $A = B = 0$, $|\mu_o/m_o| = 0.2, 0.4, 1, 3$ with the ”improved” tree level potential $V_o$ (a) and the whole one-loop effective potential $V_1$ (b). Diagonal lines correspond to the extreme values of $m_{top}$, as were calculated by Ross et al. in ref.[5]: $m_{top} = 160, 100$ GeV. Transverse lines indicate constant values of $c$, defined in eq.(4).

**Fig.5** $M_Z$ versus $h_t$ for $M_{1/2} = m_o = \mu_o = 500$ GeV, $A = B = 0$. The region of physical $M_Z$ amounts a fine-tuning in the value of $h_t$. 

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