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Higgs Bosons In Nonlinearly Realized Supersymmetry

Bjong Ro Kim

III. Physikalisches Institut A

RWTH Aachen, D-52056 Aachen, Germany

Abstract

Using the formalism developed by Samuel and Wess a general form of the Higgs potential in nonlinearly realized supersymmetric extension of the Standard Model in curved space is constructed. In flat space limit we derive bounds for Higgs boson masses and mass relations. Comparisons to the linear supersymmetric models MSSM and NMSSM are made.

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1. Introduction

Supersymmetric extensions [1] of the Standard Model have been studied for almost twenty years. Almost all of these models are linear supersymmetric models, that is the supersymmetry is realized linearly. Linear Supersymmetric Models require a supersymmetric partner for every conventional particle of the Standard Model. Search for supersymmetric particles is one of the main goals of present and future collider experiments. So far no supersymmetric particles have been found [2].

It is not well known that SUSY can be realized nonlinearly [3] and the question, whether SUSY is realized in nature linearly or nonlinearly, is still open.

Samuel and Wess showed in their pioneering works [4,5,6], how to extend the Standard Model in a nonlinear supersymmetric way. A characteristic feature of the nonlinear realization is that no supersymmetric partner are required. In global nonlinear SUSY the only additional field which has to be introduced is the Akulov-Volkov field (AVfield [3]), a Goldstone fermion (Goldstino). Experimentally no Goldstino has been observed.

A possibility to avoid a massless physical Goldstino is to go to the curved space, to supergravity. In supergravity the Goldstino can be "gauged" away; the massless gravitino absorbs via the super Higgs mechanism [7] the Goldstino and becomes massive, whereas the graviton remains massless. In flat limit where the supergravity multiplet decouples from the ordinary matter the fermionic particle spectrum is the same as in the Standard Model without SUSY. The only reminiscence of SUSY manifests itself in the Higgs sector. The Higgs sector has to be extended. Now an extension of the Higgs sector is also necessary in linearly realized supersymmetric models. Both realizations need at least two Higgs doublets. This is a common aspect of the two realizations. There are however differences. A difference is that on the superfield level two Higgs doublets superfields suffice in the linear SUSY models, whereas in the nonlinear case an additional singlet Higgs field is required, either as auxiliary field or as dynamical one or as both. If the singlet field is an auxiliary one, the Physical Higgs boson spectrum of the nonlinear models are the same as that of the linear minimal SUSY model called the Minimal Supersymmetric Standard Model (MSSM). They differ, however, in general in the structure of the Higgs potentials in the component fields.

If the singlet Higgs field is both auxiliary and dynamical, the physical Higgs boson spectrum resembles to that of the linear model with one Higgs singlet, the Next to the Minimal

Supersymmetric Standard Model (NMSSM) [8], whereas there are typical differences in the structure of the Higgs potentials.

In ref. 6 Samuel and Wess considered an illustrative simple example for the Higgs sector assuming the Higgs doublets to be dynamical fields and the Higgs singlet to be auxiliary.

In this article we investigate the general case where the Higgs doublets and singlet fields are both dynamical and auxiliary. We derive upper bounds for the lightest Higgs scalar mass, mass relations between various Higgs bosons and discuss about decay patterns. Also different and similar aspects to the linear models MSSM [1] and NMSSM [8] are pointed out. The notations of Ref. 6 are, as far as possible, adopted.

2. The Model

The Lagrangian of the nonlinear supersymmetric extension of the Standard Model in curved space is given [6]

$$\mathbf{L} = \mathbf{L}_{\text{gravity}} + \mathbf{a}_V + \mathbf{L}_{\text{gauge}} + \mathbf{L}_{\text{gauge+matter}} + \mathbf{L}_{\text{Yukwa}} + \mathbf{L}_{\text{F-HP}} \quad (1)$$

$\mathbf{L}_{\text{gravity+av}}$ is the Lagrangian for the supergravity multiplet and the AV field. $\mathbf{L}_{\text{gauge}}$ is the gauge terms of $SU(3) \times SU(2) \times U(1)$ in curved space. $\mathbf{L}_{\text{gauge+matter}}$ contains among other things Higgs terms, which in flat limit reduce to the D-term of the Higgs potential. $\mathbf{L}_{\text{F-HP}}$ reduces to the F-part of the Higgs potential in the flat limit. As the main difference of our model from that of ref. 6 consists in $\mathbf{L}_{\text{F-HP}}$, we will concentrate on this term in the present note. The most general form of $\mathbf{L}_{\text{F-HP}}$ with two dynamical and two auxiliary Higgs doublets fields, one dynamical and one auxiliary Higgs singlet field and the assumption that in the low energy limit the model is renormalizable is given

$$\begin{aligned} \mathbf{L}_{\text{F-HP}} = \int d^2\vartheta \quad 2E \quad & \left[\lambda_0 N_F H_s^{1T} \varepsilon H_s^2 + \lambda_1 N_s H_s^{1T} \varepsilon H_F^2 + \lambda_2 N_s H_F^{1T} \varepsilon H_s^2 \right. \\ & + \mu_1 H_s^{1T} \varepsilon H_F^2 + \mu_2 H_F^{1T} \varepsilon H_s^2 \\ & \left. + \mu_0 N_F N_s + k N_F N_s N_s \right] + \text{h.c.} \end{aligned} \quad (2)$$

with

$$H_s^i = H_{sm}^i, \quad i = 1, 2$$

$$H_F^i = K^2 \Lambda^0 \Lambda^0 F_{sm}^i$$

$$N_S = N_{sm}$$

$$N_F = K^2 \Lambda^\sigma \Lambda^\sigma F_{sm}^\eta$$

H_{sm}^i : scalar chiral standard matter superfield of the Higgs doublet H^i in curved space

F_{sm}^i : scalar chiral standard matter superfield of the auxiliary Higgs doublet F^i in curved space

N_{sm} : scalar chiral standard matter superfield of the Higgs singlet N in curved space

N_F : scalar chiral standard matter superfield of the auxiliary Higgs singlet F^η in curved space

Λ : AV superfield in curved space (3)

$$\Lambda_o = -\frac{1}{4} (\overline{D}\overline{D} - 8R) K^2 \overline{\Lambda} \overline{\Lambda} \Lambda$$

$K^{-1} = M_{SB}^2$: Scale of SUSY Breaking

$(\overline{D}\overline{D} - 8R)$: chiral projection operator in curved space

R : scalar curvature field

$2E$: chiral density

λ_i ($i=0,1,2$): dimensionless parameter

k : dimensionless parameter

μ_i ($i=0,1,2$): mass parameter

For notations and detailed definition we refer the reader to ref. 6.

We have treated the dynamical and auxiliary fields independently. If one requires that they belong to one another and reduce in the flat limit to linear superfields, but without the fermionic components, then one would obtain $\lambda_o = \lambda_1 = \lambda_2$ and $\mu_1 = \mu_2$.

The main purpose of this note is to investigate the flat limit of the above Lagrangian. In this limit, where $\vartheta \rightarrow \theta$, $2E \rightarrow 1$ and the Planck mass $m_{pl} \rightarrow \infty$, LF-HP reduces to the F-part of the Higgs potential. Together with the D-part one obtains the following Higgs potential in low energy region

$$V = V_D + V_F \quad (4)$$

with

$$\begin{aligned} V_D &= \frac{1}{8} (g_1^2 + g_2^2) (|H^1|^2 - |H^2|^2)^2 + \frac{1}{2} g_2^2 |H_1^+ H_2|^2 \\ V_F &= \mu_1^2 |H^1|^2 + \mu_2^2 |H^2|^2 + \mu_o^2 |N|^2 \\ &\quad + \lambda_o^2 |H^{1T} \varepsilon H^2|^2 + k^2 |N^+ N|^2 + |N|^2 (\lambda_1^2 |H^1|^2 + \lambda_2^2 |H^2|^2) \\ &\quad + \lambda_o k [(H^{1T} \varepsilon H^2)^+ N^2 + \text{h.c.}] \\ &\quad + \left[\left\{ \lambda_1 \mu_1 |H^1|^2 + \lambda_2 \mu_2 |H^2|^2 + \lambda_o \mu_o (H^{1T} \varepsilon H^2)^+ \right\} N + \text{h.c.} \right] \\ &\quad + [k \mu_o N^+ N^2 + \text{h.c.}] \end{aligned}$$

where g_1 and g_2 are gauge coupling constant of U(1) and SU(2).

This potential has 9 parameters; $\lambda_o, \lambda_1, \lambda_2, \mu_o, \mu_1, \mu_2, k, \frac{x}{\sqrt{2}} = \langle N \rangle_o$ and $\tan \beta = v_2/v_1$, where x is the vacuum expectation value of the singlet Higgs field and $v_1(v_2)$ is that of $H^1(H^2)$.

Via the extremum conditions of the potential the number of the free parameters reduces to 6. Now we compare this model with the Higgs potential of the linear SUSY model NMSSM, which contains two Higgs doublets and one Higgs singlet and is a possible solution of the μ -parameter problem of MSSM.

First the particle contents of both models are the same; 3 physical Higgs scalars, 2 pseudoscalar and one charged Higgs boson.

Second the number of the parameters is the same, namely 6.

Third the quartic term of the Higgs doublets has the same form in both models: $\lambda |H^{1T} \varepsilon H^2|^2$.

As in the Standard Model, where the coupling constant of the quartic term in the Higgs potential determines the upper bound for the mass of the Higgs scalar boson, the coupling constant of $|H^{1T} \varepsilon H^2|^2$, in our model λ_o , determines the upperbound for the mass of the lightest Higgs scalar in both models.

The situation is different with MSSM, where the couplings constants of quartic terms are related to gauge coupling constants and model independent upper bound can be derived.

A difference between our model and NMSSM is with the cubic terms; in NMSSM the cubic terms with Higgs doublets is of the mixed form $(H^{1T} \varepsilon H^2)N$, whereas in our model both $(H^{1T} \varepsilon H^2)N$ and the "pure" form $|H^1|^2 N$ occur.

In the following we give the mass matrices and derive bounds for Higgs boson masses and relations between various Higgs boson masses.

3. Extremum conditions

We use the following notations

$$H^1 = \begin{pmatrix} \frac{1}{\sqrt{2}}(v_1 + \eta_1 + ia_1) \\ h_1 \end{pmatrix}$$

$$H^2 = \begin{pmatrix} h_2^* \\ \frac{1}{\sqrt{2}}(v_2 + \eta_2 + ia_2) \end{pmatrix} \quad (5)$$

$$N = \frac{1}{\sqrt{2}}(x + \eta_n + ia_n)$$

$$\frac{\partial V}{\partial \eta_i} = 0 \quad \text{yields the extremum conditions}$$

$$\overline{\mu_1^2} = - \left[\frac{1}{2} m_z^2 \cos 2\beta + 2\lambda_g^2 \sin^2 \beta + (\lambda_o k \frac{x^2}{2} + \lambda_o \mu_o \frac{x}{\sqrt{2}}) \tan \beta \right] \quad (6)$$

$$\overline{\mu_2^2} = - \left[-\frac{1}{2} m_z^2 \cos 2\beta + 2\lambda_s^2 \cos^2 \beta + (\lambda_o k \frac{x^2}{2} + \lambda_o \mu_o \frac{x}{\sqrt{2}}) \cot \beta \right]$$

$$\mu_o^2 + \mu_o \left(\frac{3}{\sqrt{2}} kx + \frac{1}{2\sqrt{2}} \lambda_o \frac{v^2}{x} \sin 2\beta \right) = - \left[k^2 x^2 + \frac{1}{2} v^2 \overline{\lambda^2} + \frac{1}{\sqrt{2}} \overline{\lambda \mu} \frac{v^2}{x} + \frac{1}{2} \lambda_o k v^2 \sin 2\beta \right]$$

with

$$\lambda_s^2 = \frac{\lambda_o^2}{g_1^2 + g_2^2}$$

$$\overline{\mu_1^2} = \left(\mu_1 + \frac{\lambda_1 x}{\sqrt{2}} \right)^2$$

$$\overline{\mu_2^2} = \left(\mu_2 + \frac{\lambda_2 x}{\sqrt{2}} \right)^2 \quad (7)$$

$$\overline{\lambda^2} = \lambda_1^2 \cos^2 \beta + \lambda_2^2 \sin^2 \beta$$

$$\overline{\lambda \mu} = \lambda_1 \mu_1 \cos^2 \beta + \lambda_2 \mu_2 \sin^2 \beta$$

Some useful relations which can be derived from eq.(6) are

$$\overline{\mu_1^2} + \overline{\mu_2^2} = -2\lambda_s^2 m_z^2 + \Delta$$

$$\overline{\mu_1^2} - \overline{\mu_2^2} = \cos 2\beta \left[-m_z^2 + 2\lambda_s^2 m_z^2 - \Delta \right] \quad (8)$$

$$\sin^2 \beta \overline{\mu_1^2} + \cos^2 \beta \overline{\mu_2^2} = \frac{1}{2} m_z^2 \cos^2 2\beta + \lambda_s^2 m_z^2 \sin^2 2\beta - 2\lambda_s^2 m_z^2 + \Delta + \sin 2\beta \Sigma$$

with

$$\Delta = \frac{-2\Sigma}{\sin^2 \beta}$$

$$\Sigma = \lambda_o \frac{x}{\sqrt{2}} \left(\mu_o + \frac{kx}{\sqrt{2}} \right)$$

4. The neutral Higgs scalars

The physical cp-even Higgs scalars are combinations of η_1, η_2 and η_n . In this basis the mass matrix $M^S = (m_{ij}^s)$ with $m_{ij}^s = m_{ji}^s$ is given

$$\begin{aligned} m_{11}^s &= m_Z^2 \left[\frac{3}{2} \cos^2 \beta - \frac{1}{2} \sin^2 \beta + 2\lambda_g^2 \sin^2 \beta \right] + \overline{\mu_1^2} \\ m_{22}^s &= m_Z^2 \left[\frac{3}{2} \sin^2 \beta - \frac{1}{2} \cos^2 \beta + 2\lambda_g^2 \cos^2 \beta \right] + \overline{\mu_2^2} \\ m_{12}^s &= m_Z^2 \sin 2\beta \left[-\frac{1}{2} + 2\lambda_g^2 \right] + \Sigma \\ m_{13}^s &= \lambda_o k x v_2 + \lambda_1^2 x v_1 + \sqrt{2} \lambda_1 \mu_1 v_1 + \lambda_o \mu_o \frac{v_2}{\sqrt{2}} \\ m_{23}^s &= \lambda_o k x v_1 + \lambda_2^2 x v_2 + \sqrt{2} \lambda_2 \mu_2 v_2 + \lambda_o \mu_o \frac{v_1}{\sqrt{2}} \\ m_{33}^s &= \mu_o^2 + 3\sqrt{2} \mu_o x + 3k^2 x^2 + \frac{3}{2} (\lambda_1^2 v_1^2 + \lambda_2^2 v_2^2) \end{aligned} \tag{9}$$

This matrix depends on 6 parameter. We denote the eigenvalues $m_{s1} \leq m_{s2} < m_{s3}$, which are the masses of the physical Higgs scalars. The masses can not in general be given analytically. However one can derive, using the same method as in NMSSM, an upper bound for m_{s1} , the mass of the lightest Higgs scalar,

$$m_{s1}^2 \leq m_Z^2 \left[\cos^2 2\beta + 2\lambda_g^2 \sin^2 2\beta \right] \tag{10}$$

We note that the same relation holds with NMSSM [8], λ_g replaced by the corresponding coupling constant. This is a remarkable relation. First it depends on just two parameters instead of on 6. Second it means that the scale of m_{s1} is set by the electroweak scale m_Z , and not by μ_i , $i = 0, 1, 2$ and x .

Dividing λ_g into two regions at the point $\lambda_g = \frac{1}{\sqrt{2}} (\lambda_o \approx 0.52)$ the relation can be cast in a more terse form:

$$\begin{aligned} m_{s1} &\leq m_Z & \text{for} & \quad \lambda_g \leq \frac{1}{\sqrt{2}} \\ m_{s1} &> \sqrt{2}\lambda_g m_Z & \text{for} & \quad \lambda_g > \frac{1}{\sqrt{2}} \end{aligned} \tag{11}$$

That is, in the region $\lambda_o \leq 0.52$ the upper bound for the mass of the lightest Higgs scalar is the same as in MSSM.

For $\tan \beta \rightarrow \infty$ $m_{s1} \leq m_Z$ holds for arbitrary λ_o .

Now the question is: what is the upper bound for λ_o ? An effective way to answer this question is to do RGE analysis for λ_o and related coupling constants. Assuming the absence of Landau Poles up to a certain scale, say GUT scale or Planck scale one can determine the upper bound at the electroweak scale. For NMSSM one obtains $\lambda \leq 0.9 \sim 0.86$ at m_Z with GUT scale as the upper scale and for $m_t > 175$ GeV [8,9]. It is most likely that the upper bound for λ_o is very close to that of λ , that is of order 1, which means that the absolute upper bound for m_{s1} is about $\sqrt{2}m_Z \approx 130$ GeV.

Assuming the contribution of higher order effects to be the same order as in NMSSM, that is about 10 GeV $\sim$ 30 GeV, the absolute upper bound is about $m_{s1} < 160$ GeV. A Higgs scalar of this mass is at least kinematically accessible at LEP200. It does not, however, mean that the Higgs boson is necessarily detectable. From the investigations with NMSSM [10] we know that a light Higgs scalar of $m_{s1} < 10$ GeV is still consistent with the present LEP data at z -peak, $\sqrt{s} = m_Z$. Generally it could happen that there are several kinematically accessible light Higgs scalars but they share the gauge-gauge-Higgs coupling in such a way that the coupling of the lightest Higgs scalar is too weak, but that of the next lightest one is strong enough to be detected. Or none have a large enough production rate.

The situation with our model is similar and detailed numerical calculations are under way.

For m_{s2} and m_{s3} no upper bounds can be derived. However a lower bound of m_{s3} is given

$$m_{s3}^2 \geq \frac{1}{2} m_z^2 \left[1 + \sqrt{\cos^2 2\beta + \sin^2 2\beta (4\lambda_s^2 - 1)^2} \right] \quad (12)$$

An absolute bound is

$$m_{s3}^2 \geq \frac{1}{2} m_z^2 \quad (13)$$

For $\tan \beta \rightarrow \infty$ eq. (12) reduces to $m_{s3} \geq m_z$.

5. The pseudoscalar and charged Higgs particles

The physical pseudoscalar Higgs bosons are combinations of a_1 , a_2 and a_n . In the unitary gauge where a degree of freedom is gauged away one can express the mass matrix as 2×2 matrix. In the basis of the fields orthogonal to the Goldstone boson the mass matrix M^P is given by

$$M^P = \begin{pmatrix} m_{11}^P & m_{12}^P \\ m_{21}^P & m_{22}^P \end{pmatrix} \quad (14)$$

with

$$m_{11}^P = \Delta$$

$$m_{12}^P = \frac{\lambda_o v}{\sqrt{2}} (\mu_o + \sqrt{2} kx)$$

$$m_{22}^P = \overline{\mu_o^2} + \frac{1}{2} k^2 x^2 + \frac{1}{2} v^2 (\overline{\lambda^2} - \lambda_o k \sin 2\beta)$$

$$m_{12}^P = m_{21}^P$$

$$\overline{\mu_o^2} = \left(\mu_o + \frac{kx}{\sqrt{2}} \right)^2$$

The eigenvalues $m_{p1}^2 < m_{p2}^2$, which are the masses of the physical pseudoscalars are given

$$m_{p1,p2}^2 = \frac{1}{2} \left[m_{11}^p + m_{22}^p \mp \sqrt{(m_{11}^p - m_{22}^p)^2 + 4(m_{12}^p)^2} \right] \quad (15)$$

No absolute bounds for m_{p1} and m_{p2} can be derived. One can however derive some useful relations from the condition that the mass m_{p1} is positive. From $m_{p1} \geq 0$ and $\Delta > 2\lambda_g^2 m_Z^2 > 0$, which follows from the extremum conditions, $m_{22}^p > 0$ follows. Putting together one obtains

$$m_{p1}^2 < m_{22}^p \quad \text{for } \Delta > m_{22}^p \quad (16)$$

$$m_{p2}^2 > \Delta$$

and

$$m_{p1}^2 < \Delta \quad \text{for } \Delta < m_{22}^p \quad (17)$$

$$m_{p2}^2 > m_{22}^p$$

As we will see below these relations are useful for deriving bounds for the difference between m_{p2} and other Higgs bosons.

The mass of the physical charged Higgs boson is given

$$m_c^2 = m_w^2 + \overline{\mu_1^2} + \overline{\mu_1^2} \quad (18)$$

Using the extremum conditions eq. (6) it can be written as

$$m_c^2 = m_w^2 + \Delta - 2\lambda_g^2 m_Z^2 \quad (19)$$

A lower bound for m_c^2 immediately follows:

$$m_c^2 > m_w^2 \quad (20)$$

This relation represents a manifestly different feature of our model from NMSSM, where $m_c^2 < m_w^2$ is not excluded.

6. Mass splitting between various Higgs bosons

As discussed in the preceding section there are no absolute upper bounds for m_{p1} , m_{p2} , m_c and m_{s3} . There are however such bounds for certain differences of the masses. Such differences may be of interest for testing models. For example they could allow or rule out certain decay modes.

It is straight-forward to derive from the eq. (15) and eq. (19) the following relations:

$$m_c^2 - m_{p2}^2 \leq m_w^2 [1 - 2\lambda_s^2] \quad (21A)$$

$$m_{p1}^2 - m_c^2 \leq m_w^2 [2\lambda_s^2 - 1] \quad (21B)$$

The relation (21A) implies that the decay mode $h^\pm \rightarrow p_2 + W^\mp$ is kinematically excluded. As in the case of m_{s1} definite predictions can be made for the two regions of λ_s :

$$\begin{aligned} m_c &> m_{p1} & \text{for} & \quad \lambda_s < \frac{1}{\sqrt{2}} \\ m_{p2} &> m_c & \text{for} & \quad \lambda_s > \frac{1}{\sqrt{2}} \end{aligned} \quad (22)$$

In a similar way we obtain

$$\begin{aligned} (m_{s3}^2 - m_c^2) &> (m_Z^2 - m_w^2) + m_Z^2 (2\lambda_s^2 - 1) \cos^2 2\beta \\ (m_{s3}^2 - m_{p1}^2) &> m_Z^2 (1 - 2\lambda_s^2) \sin^2 2\beta \end{aligned} \quad (23)$$

which yield

$$\begin{aligned} m_{s3} &> m_c & \text{for} & \quad \lambda_s > \frac{1}{\sqrt{2}} \\ m_{s3} &> m_{p1} & \text{for} & \quad \lambda_s < \frac{1}{\sqrt{2}} \end{aligned} \quad (24)$$

Finally we give a lower bound for $m_{s3}^2 - m_{s1}^2$

$$(m_{s3}^2 - m_{s1}^2) > m_Z^2 |(2\lambda_g^2 - 1)\sin 4\beta| \quad (25)$$

7. Model with two Higgs doublets

We consider a special case of the model of eq. (2). We require that there are no physical singlet Higgs bosons, but only Higgs doublets. A general model with this requirement emerges from the model, eq. (2) by setting $\lambda_1 = \lambda_2 = k = 0$ and $N_s = \frac{x}{\sqrt{2}}$. With the notation $M^2 = -\frac{\mu_o x}{\sqrt{2}}$ we obtain

$$\begin{aligned} L_{F-HP} = \int d^2\vartheta \quad 2E \quad & \left[\lambda_o N_F H_s^{1T} \varepsilon H_s^2 + \mu_1 H_s^{1T} \varepsilon H_F^2 + \mu_2 H_F^{1T} \varepsilon H_s^2 \right. \\ & \left. - M^2 N_F \right] + \text{h.c.} \end{aligned} \quad (26)$$

The Higgs potential in flat limit is

$$\begin{aligned} V = \frac{1}{8} (g_1^2 + g_2^2) & \left(|H_o^1|^2 - |H^2|^2 \right) + \frac{1}{2} g_2^2 |H_o^1 + H^2|^2 \\ & + \lambda_o^2 |H^{1T} \varepsilon H^2|^2 \\ & + \mu_1^2 |H^1|^2 + \mu_2^2 |H^2|^2 \end{aligned} \quad (27)$$

The masses of the two neutral physical Higgs scalars $m_{s1} < m_{s2}$, the pseudoscalar m_p and the charged Higgs boson m_c^2 are given

$$m_{s1,s2}^2 = \frac{1}{2} \left(m_Z^2 + m_p^2 \pm \sqrt{\cos^2 2\beta (m_Z^2 - m_p^2)^2 + \sin^2 2\beta [m_Z^2 (4\lambda_g^2 - 1) - m_p^2]^2} \right) \quad (28)$$

$$m_c^2 = m_w^2 + m_p^2 - 2\lambda_g^2 m_Z^2 = m_w^2 + \mu_1^2 + \mu_2^2 \quad (29)$$

$$\text{and} \quad m_p^2 = \frac{2\lambda_o M^2}{\sin 2\beta}$$

$$(30)$$

Following relations hold:

$$m_{s1}^2 \leq m_Z^2 [\cos^2 2\beta + 2\lambda_g^2 \sin^2 2\beta] \quad (31)$$

$$m_{s1}^2 + m_{s2}^2 = m_p^2 + m_Z^2 \quad (32)$$

$$m_c^2 + 2\lambda_g^2 m_Z^2 = m_w^2 + m_p^2 \quad (33)$$

Eq. (31) and (33) are different from those of MSSM, whereas eq. (32) is the same as in MSSM.

In the case of $\mu_1 = 0, \mu_2 = 0$ this model reduces to the model of ref. 6 and one obtains $m_c^2 = m_w^2, m_p^2 = 2\lambda_g^2 m_Z^2$ and $m_{s1}^2 = 2\lambda_g^2 m_Z^2$ and $m_{s2}^2 = m_Z^2$ for $\lambda_g \leq \frac{1}{\sqrt{2}}$ and $m_{s1}^2 = m_Z^2$ and $m_{s2}^2 = 2\lambda_g^2 m_Z^2$ for $\lambda_g > \frac{1}{\sqrt{2}}$.

8. Conclusion

We have presented a model-"independent" form of the Higgs sector of nonlinear supersymmetric extension of the Standard Model in curved space. The assumptions are that the doublet and singlet superfields are both dynamical and auxiliary. In the flat space limit we have derived bounds for Higgs boson masses, mass relations and compared the results to those of the linear supersymmetric models MSSM and NMSSM. We have shown that the model contains at least a Higgs boson, whose mass is not far away from m_Z and thus the model is very likely to be tested at LEP200.

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