Trilinear Selfinteraction of Neutral Higgs Bosons in MSSM

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Abstract

Some results of the leading one-loop analysis of the trilinear Higgs selfcouplings in MSSM are presented. The role of leading one-loop contribution is shown, especially for the trilinear coupling of the lightest Higgs boson.

Introduction

The Standard Model with minimal supersymmetric extension (MSSM) [1] is developed and checked today very actively. The MSSM – theory with soft supersymmetry breaking – contains Standard Model (SM) particles and their supersymmetric partners. The scalar sector includes two Higgs doublets necessary for the generation of fermion masses and the cancellation of anomalies.

In the low energy limit the MSSM predictions are the same as in the SM. But MSSM has some remarkable features. First of all it predicts masses of Higgs bosons from loop corrections and also the cancellation of quadratic divergences (Table 1).

Table 1: Higgs boson mass in SM and MSSM.

SM	**MSSM**
indirect prediction on mass	direct prediction on lightest Higgs **exists**
perturbative corrections more than tree mass value	**stability** to corrections $95\text{GeV} \leq M_h \leq 130\text{Gev}$ [2, 3]

In 1991 the Higgs sector of MSSM attracted much attention after the discovery that the top and stop loops are sources of rather large corrections to the neutral CP-even Higgs boson masses [2]. Previously the top quark contribution had been neglected or only corrections to the sum rule had been considered.

The one-loop contributions to self-energies and Higgs boson masses are presented in [4]. The leading two-loop corrections in the Feynman diagram approach are presented in [3]. On the basis of [3, 5] the programs *FeynHiggs* and *FeynHiggsFast* for calculation of Higgs masses and mixing angle were created by S. Heinemeyer, W. Hollik and G. Weiglein [6].

The discovery of light Higgs boson could be the evidence in favor of the supersymmetry. Precise predictions of Higgs masses and selfcouplings are necessary for Higgs bosons discovery, investigation of their propeties and more precise definition of physics posibilities with modern colliders LEP, SLC, LEP2 and Tevatron, future colliders LHC, TESLA, NLC, FMC, and also laser photon collider. The expected precision of LHC mass measurement $\Delta m_h \approx 0.2\text{GeV}$ [7], at NLC it will be improved up to $\Delta m_h \approx 0.05\text{GeV}$ [8], at FMC it is supposed to be $\Delta m_h \approx 0.1$ [9]. With the next e^+e^- collider of high luminosity it will be possible to measure the trilinear Higgs selfcouplings [10].

Spontaneous symmetry breaking is the principal element of the electroweak sector in SM and MSSM. However, it is not confirmed experimentally. In order to do this, it is necessary to carry out the following: 1) first of all Higgs particle(s) must be discovered, 2) Higgs couplings to fermions and gauge bosons must be determined from the data on decay widths and production cross sections 3) trilinear and quartic selfcouplings of the Higgs potential must be measured.

Thus, the experimental discovery and the investigation of Higgs boson properties is an important task of collider physics.

Trilinear Higgs selfcouplings

MSSM Higgs sector [1] contains two Higgs doublets H_1 $(Y_1 = -1)$ and H_2 $(Y_2 = +1)$:

$$H_1 = \begin{pmatrix} H_1^1 \\ H_1^2 \end{pmatrix} \equiv \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix} = \begin{pmatrix} v_1 + \frac{1}{\sqrt{2}}(H^0\cos\alpha - h^0\sin\alpha + iA^0\sin\beta + iG^0\cos\beta) \\ H^-\sin\beta - G^-\cos\beta \end{pmatrix}, \tag{1}$$

$$H_2 = \begin{pmatrix} H_2^1 \\ H_2^2 \end{pmatrix} \equiv \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix} = \begin{pmatrix} H^+\cos\beta + G^+\sin\beta \\ v_2 + \frac{1}{\sqrt{2}}(H^0\sin\alpha + h^0\cos\alpha + iA^0\cos\beta - iG^0\sin\beta) \end{pmatrix}, \tag{2}$$

where v_1 v_2 are the vacuum expectation values (real and positive). Physical Higgs particles are the neutral CP even h^0 and H^0, the neutral CP odd A^0 and charged $H^\pm$ bosons. G^0, $G^\pm$ are the Goldstone bosons, α is the mixing angle in the CP-even sector $(-\frac{\pi}{2} \le \alpha \le 0)$, β in the CP-odd and charged $(0 \le \beta \le \frac{\pi}{2})$ sectors.

The Higgs potential for the case of soft breaking of supersymmetry and spontaneous breaking of electroweak symmetry [1]has the form

$$V = m_1^2|H_1| + m_2^2|H_2| - m_{12}^2(\epsilon_{ab}H_1^aH_2^b + .c.) + \frac{g'^2+g^2}{8}(|H_1| - |H_2|)^2 + \frac{g^2}{2}|\bar{H}_1H_2|^2, \tag{3}$$

where $m_i^2 \equiv |\mu|^2 + \tilde{m}_i^2$; $\tilde{m}_1, \tilde{m}_2$, m_{12} are the real mass parameters of soft supersymmetry breaking, $(m_{12}^2 \equiv \mu B < 0)$; $\epsilon_{12} = -1$ $(\epsilon_{21} = 1)$; μ characterizes H_1 and H_2 mixing.

The input parameters are, as usual, electroweak parameters and

$$tg\beta \equiv \frac{v_2}{v_1} \qquad \text{and} \qquad M_A^2 = -m_{12}^2(tg\beta + ctg\beta). \tag{4}$$

The Higgs masses and mixing angle α in the one-loop leading m_t^4 approximation (at tree level $\epsilon \equiv 0$):

$$M_{H^\pm}^2 = M_A^2 + M_W^2, \tag{5}$$

$$M_{h,H}^2 = \frac{1}{2}\left[M_A^2 + M_Z^2 + \epsilon \mp \right.$$

$$\left. \mp\sqrt{(M_A^2 + M_Z^2 + \epsilon)^2 - 4M_A^2M_Z^2\cos^2 2\beta - 4\epsilon(M_A^2\sin^2\beta + M_Z^2\cos^2\beta)}\right], \tag{6}$$

$$\tan 2\alpha = \tan 2\beta \frac{M_A^2 + M_Z^2}{M_A^2 - M_Z^2 + \epsilon/\cos 2\beta}, \tag{7}$$

$$\epsilon \approx \frac{3G_F m_t^4}{\sqrt{2}\pi^2\sin^2\beta}\ln\frac{\tilde{M}^2}{m_t^2} \equiv \frac{2N_C e^2 m_t^4}{(4\pi)^2 s_W^2 M_W^2\sin^2\beta}\ln\frac{m_{\tilde{t}_L}m_{\tilde{t}_R}}{m_t^2}. \tag{8}$$

From the potential (3) we can get six (in the case of CP invariance) trilinear selfcouplings (in units of $\lambda_0 = M_Z^2/v$, $v = \sqrt{2(v_1^2 + v_2^2)}$) [11]:

$$\lambda_{hhh} = 3\cos 2\alpha\sin(\beta+\alpha) + 3\frac{\epsilon}{M_Z^2}\frac{\cos\alpha}{\sin\beta}\cos^2\alpha, \tag{9}$$

$$\lambda_{Hhh} = 2\sin 2\alpha\sin(\beta+\alpha) - \cos 2\alpha\cos(\beta+\alpha) + 3\frac{\epsilon}{M_Z^2}\frac{\sin\alpha}{\sin\beta}\cos^2\alpha, \tag{10}$$

$$\lambda_{HHh} = -2\sin 2\alpha\cos(\beta+\alpha) - \cos 2\alpha\sin(\beta+\alpha) + 3\frac{\epsilon}{M_Z^2}\frac{\cos\alpha}{\sin\beta}\sin^2\alpha, \tag{11}$$

$$\lambda_{HHH} = 3\cos 2\alpha\cos(\beta+\alpha) + 3\frac{\epsilon}{M_Z^2}\frac{\sin\alpha}{\sin\beta}\sin^2\alpha, \tag{12}$$

$$\lambda_{hAA} = \cos 2\beta\sin(\beta+\alpha) + \frac{\epsilon}{M_Z^2}\frac{\cos\alpha}{\sin\beta}\cos^2\beta, \tag{13}$$

$$\lambda_{HAA} = -\cos 2\beta\cos(\beta+\alpha) + \frac{\epsilon}{M_Z^2}\frac{\sin\alpha}{\sin\beta}\cos^2\beta. \tag{14}$$

In figure 1 we present the dependence of Higgs selfcouplings on MSSM parameters: $\tan\beta$, M_A and fixed $m_t = 175$GeV, $M_{SUSY} = 1000$Gev, $M_Z = 91.187$GeV, $M_W = 80.39$GeV, $v = 246$GeV, $\alpha = 1/137$.

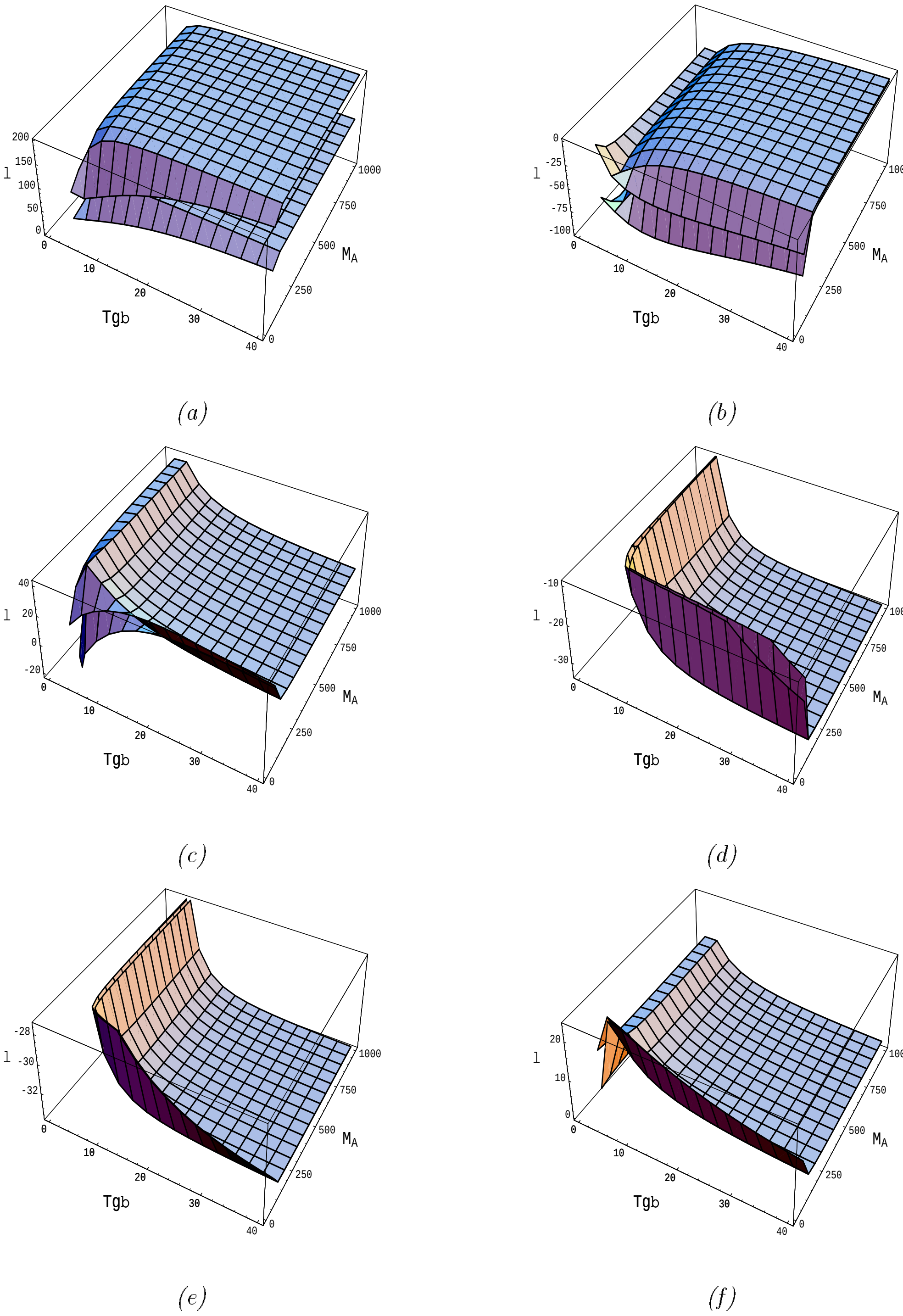
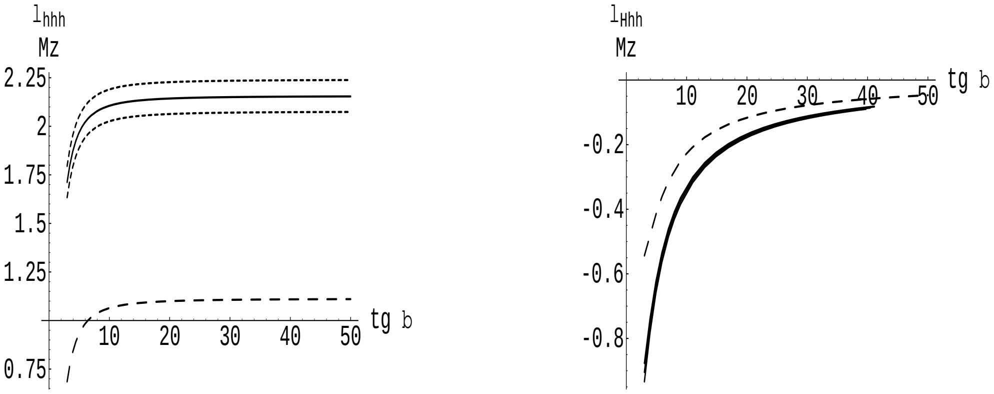


Figure 1: Trilinear Higgs selfcouplings in the one-loop approximation (a) λ_{hhh}, (b) λ_{Hhh}, (c) λ_{HHh}, (d) λ_{HHH}, (e) λ_{hAA}, (f) λ_{HAA}, GeV.

In figure 2 we present the dependence of λ_{hhh} and λ_{Hhh} on the same parameters, but $m_t = 174.3 \pm$

4GeV and fixed $M_A = 500$GeV. Dotted line corresponds to the tree level and solid line to the leading one-loop aproximation.



(a) *(b)*

Figure 2: Couplings (a) λ_{hhh}/M_Z and (b) λ_{Hhh}/M_Z.

In the limit $M_A^2 \sim M_H^2 \sim M_{H^\pm}^2 \gg v^2/2$ we have $\sin(\beta-\alpha) \to 1$, $\cos(\beta-\alpha) \to 0$, $M_h^2 = M_Z^2 \cos^2 2\beta + \epsilon \sin^2\beta$ and [12]:

$$\lambda_{hhh} \longrightarrow 3M_h^2/M_Z^2, \tag{15}$$

$$\lambda_{Hhh} \longrightarrow -3\sqrt{\left(\frac{M_h^2}{M_Z^2} - \frac{\epsilon}{M_Z^2}\sin^2\beta\right)\left(1 - \frac{M_h^2}{M_Z^2} + \frac{\epsilon}{M_Z^2}\sin^2\beta\right)} - \frac{3\epsilon}{M_Z^2}\sin\beta\cos\beta, \tag{16}$$

$$\lambda_{HHh} \longrightarrow 2 - \frac{3M_h^2}{M_Z^2} + \frac{3\epsilon}{M_Z^2}, \tag{17}$$

$$\lambda_{HHH} \longrightarrow 3\sqrt{\left(\frac{M_h^2}{M_Z^2} - \frac{\epsilon}{M_Z^2}\sin^2\beta\right)\left(1 - \frac{M_h^2}{M_Z^2} + \frac{\epsilon}{M_Z^2}\sin^2\beta\right)} - \frac{3\epsilon}{M_Z^2}\frac{\cos^3\beta}{\sin\beta}, \tag{18}$$

$$\lambda_{hAA} \longrightarrow -\frac{M_h^2}{M_Z^2} + \frac{\epsilon}{M_Z^2}, \tag{19}$$

$$\lambda_{HAA} \longrightarrow \sqrt{\left(\frac{M_h^2}{M_Z^2} - \frac{\epsilon}{M_Z^2}\sin^2\beta\right)\left(1 - \frac{M_h^2}{M_Z^2} + \frac{\epsilon}{M_Z^2}\sin^2\beta\right)} - \frac{\epsilon}{M_Z^2}\frac{\cos^3\beta}{\sin\beta}. \tag{20}$$

Conclusion

On the basis of fermion and sfermion loop contributions calculated in the leading one-loop approximation, the MSSM trilinear selfcouplings were considered. Our results are compared with previous results. The analysis shows that λ_{hhh} is the largest selfcoupling of Higgs bosons and the one-loop contribution increases it approximately by a factor of 2. This estimate may be important for future data analysis of a collider with high luminosity.

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