The Higgs boson masses and Higgs decays in the B-LSSM with explicit CP violation

Wen-Hui Zhang, Tai-Fu Feng, Hai-Bin Zhang, Jin-Lei Yang

Department of Physics , Hebei University, Baoding, 071002, China

Introduction

We study the B-LSSM where gauge symmetry group $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_{B-L}$ is introduced with B representing baryon number and L standing for lepton number. Besides, the invariance under $U(1)_{B-L}$ gauge group imposes the R-parity conservation which is assumed in the MSSM to avoid proton decay. In the B-LSSM, right-handed neutrinos can naturally be implemented due to the introduction of the right-handed neutrino superfields, which can realize type I seesaw mechanism, thus provide an elegant solution for the existence and smallness of the light left-handed neutrino masses. Furthermore, additional parameter space in the B-LSSM is released from the LEP, Tevatron and LHC constraints through the additional singlet Higgs state and right-handed(s) neutrinos . It alleviates the hierarchy problem of the MSSM. Other than this, the model can also provide much more DM candidates comparing that in the MSSM.

Abstract

We calculate one-loop radiation corretions to the mass matrix of the neutral Higgs bosons in the B-L Supersymmetric Standard Model (B-LSSM) with explicit CP violation. Within the effective potential methods, the masses of the neutral Higgs bosons are calculated at the one-loop level by taking into account the contributions of the following loops of ordinary particles and superparticles: the top quarks, the bottom quarks, the scalar top quarks and the scalar bottom quarks. At the same time, we also calculate the lightest Higgs decays $h_0 \rightarrow \gamma\gamma$,$h_0 \rightarrow \bar{f}f$,$h_0 \rightarrow VV^*(V=W,Z)$, $h_0 \rightarrow gg$ in the B-LSSM with explicit CP violation.

CP-violating one-loop effective potential

In the $\overline{MS}$ scheme, the one-loop CP-violating effective potential is determined by

$$-\mathcal{L}_V = -\mathcal{L}_V^0 + \frac{3}{32\pi^2}\sum_{q=t,b}\Big[\sum_{i=1,2}\tilde{m}_{q_i}^4\Big(\ln\frac{\tilde{m}_{q_i}^2}{\Lambda^2}-\frac{3}{2}\Big) - 2\bar{m}_q^4\Big(\ln\frac{\bar{m}_q^2}{\Lambda^2}-\frac{3}{2}\Big)\Big]$$

$\mathcal{L}_V^0$ is the tree-level Lagrangian of the B-LSSM Higgs potential. Meanwhile, at the tree level , CP-even Higgs and CP-odd Higgs satisfy the following relation:

$$\sum_{i=1}^{4} m_{H_i^0}^2 = m_{A_1}^2 + m_{A_2}^2 + m_z^2 + m_{z'}^2$$

$$\prod_{i=1}^{4} m_{H_i^0}^2 = \cos^2 2\beta\cos^2 2\beta' m_z^2 m_{z'}^2 m_{A_1}^2 m_{A_2}^2$$

Further, $\bar{m}_i^2\ (i=t,b)$ and $\tilde{m}_{q_k}^2\ (q_k = t_1, b_1, t_2, b_2)$ denote the result of taking the vacuum expectative values of the eigenvalues of the mass matrices of quarks and squarks, respectively.

We now derive the minimization conditions for controlling the B-LSSM one-loop effective potential and determine the Higgs boson mass matrix. The minimization conditions are as follows:

$$\begin{aligned}T_{\phi_{d(u)}} = & \Big\langle\frac{\partial\mathcal{L}_V}{\partial\phi_{d(u)}}\Big\rangle = v_{d(u)}\Big[\frac{1}{8}\Big(g_1^2+g_2^2+g_{YB}^2\Big)\Big(v_{d(u)}^2-v_{u(d)}^2\Big)+\frac{1}{4}g_Bg_{YB}\Big(v_{\eta(\bar\eta)}^2-v_{\bar\eta(\eta)}^2\Big)\\ & +\Big(m_{H_{d(u)}}^2+|\mu|^2\Big)\Big]-v_{u(d)}\Re\Big(B_\mu e^{i\xi_1}\Big)-\frac{3}{16\pi^2}\sum_{q=t,b}\Big[\sum_{k=1,2}2\Big\langle\frac{\partial\bar{m}_q^2}{\partial\phi_{d(u)}}\Big\rangle m_q^2\\ & \times\Big(\ln\frac{m_q^2}{\Lambda^2}-1\Big)-\Big\langle\frac{\partial\tilde{m}_{q_k}^2}{\partial\phi_{d(u)}}\Big\rangle m_{\tilde{q}_k}^2\Big(\ln\frac{m_{\tilde{q}_k}^2}{\Lambda^2}-1\Big)\Big]\end{aligned}$$

$$\begin{aligned}T_{\phi_{\eta(\bar\eta)}} = \Big\langle\frac{\partial\mathcal{L}_V}{\partial\phi_{\eta(\bar\eta)}}\Big\rangle = & \ v_{\eta(\bar\eta)}\Big[\frac{1}{2}g_B^2\Big(v_{\eta(\bar\eta)}^2-v_{\bar\eta(\eta)}^2\Big)+\frac{1}{4}g_Bg_{YB}\Big(v_{d(u)}^2-v_{u(d)}^2\Big)+\Big(m_{\eta(\bar\eta)}^2+|\mu_\eta|^2\Big)\Big]\\ & -v_{\bar\eta(\eta)}\Re\Big(B_\eta e^{i\xi_2}\Big)-\frac{3}{16\pi^2}\sum_{q=t,b}\Big[\sum_{k=1,2}2\Big\langle\frac{\partial\bar{m}_q^2}{\partial\phi_{\eta(\bar\eta)}}\Big\rangle m_q^2\Big(\ln\frac{m_q^2}{\Lambda^2}-1\Big)\\ & -\Big\langle\frac{\partial\tilde{m}_{q_k}^2}{\partial\phi_{\eta(\bar\eta)}}\Big\rangle m_{\tilde{q}_k}^2\Big(\ln\frac{m_{\tilde{q}_k}^2}{\Lambda^2}-1\Big)\Big]\end{aligned}$$

$$T_{\sigma_{d(u)}} = \Big\langle\frac{\partial\mathcal{L}_V}{\partial\sigma_{d(u)}}\Big\rangle = -v_{u(d)}\Im\Big(B_\mu e^{i\xi_1}\Big)+\frac{3}{16\pi^2}\sum_{q=t,b}\sum_{k=1,2}\Big\langle\frac{\partial\tilde{m}_{q_k}^2}{\partial\sigma_{d(u)}}\Big\rangle m_{\tilde{q}_k}^2\Big(\ln\frac{m_{\tilde{q}_k}^2}{\Lambda^2}-1\Big)$$

$$T_{\sigma_{\eta(\bar\eta)}} = \Big\langle\frac{\partial\mathcal{L}_V}{\partial\sigma_{\eta(\bar\eta)}}\Big\rangle = -v_{\bar\eta(\eta)}\Im\Big(B_\eta e^{i\xi_2}\Big)$$

where $\Big\langle\tilde{m}_{q_k}^2\Big\rangle = m_{\tilde{q}_k}^2$nd in order to save space, the tadpole derivatives $\Big\langle\partial\tilde{m}_{q_k}^2/\partial\phi_{d(u)}\Big\rangle$, $\Big\langle\partial\tilde{m}_{q_k}^2/\partial\phi_{\eta(\bar\eta)}\Big\rangle$, $\Big\langle\partial\bar{m}_q^2/\partial\phi_{d(u)}\Big\rangle$ $\Big\langle\partial\bar{m}_q^2/\partial\phi_{\eta(\bar\eta)}\Big\rangle$ and $\Big\langle\partial\tilde{m}_{q_k}^2/\partial\sigma_{d(u)}\Big\rangle$are not feasible to list them all here.

Then, the neutral-Higgs-boson mass matrix takes on the form:

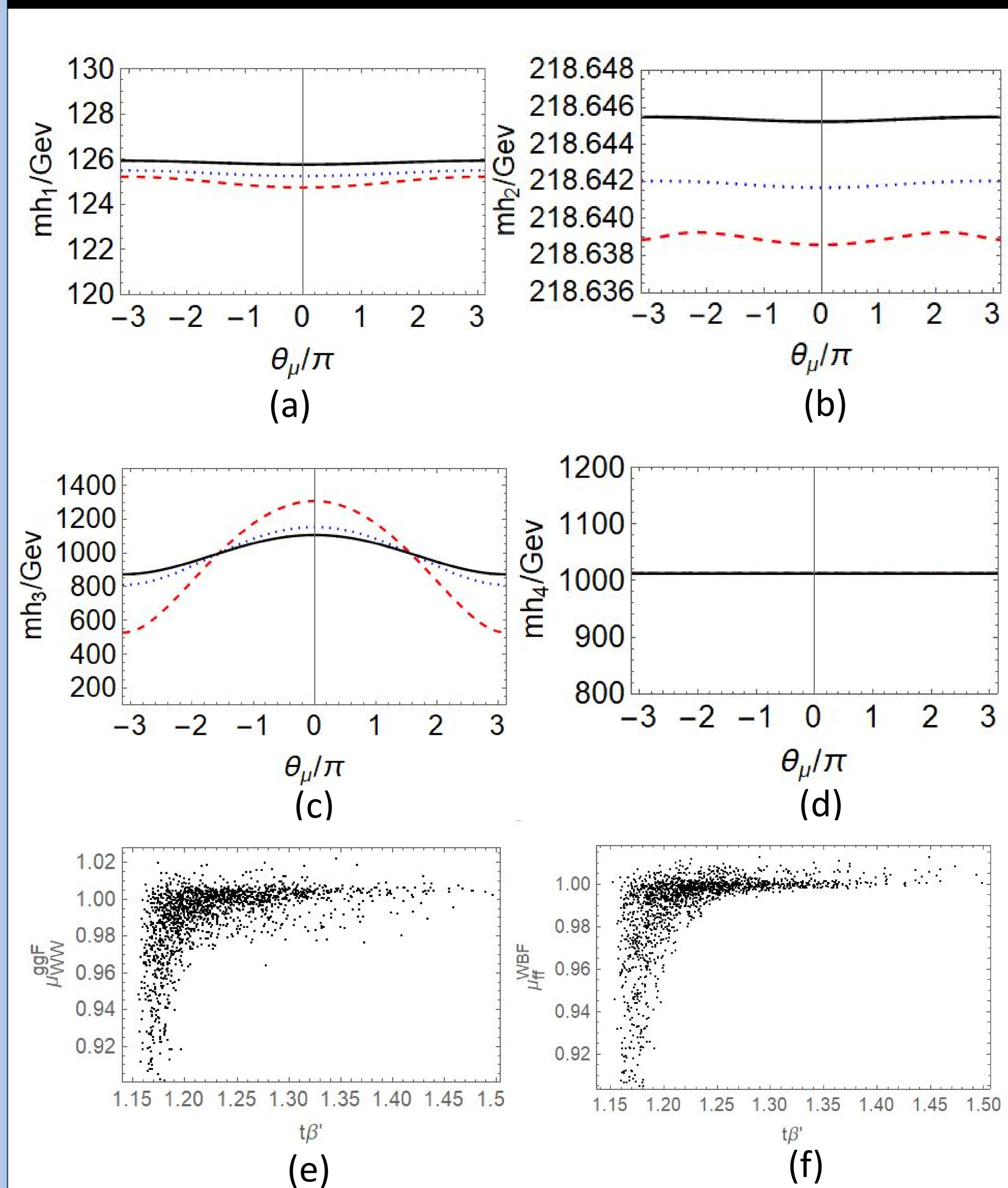
$$\mathcal{M}_0^2 = \begin{pmatrix} \mathcal{M}_S^2 & \mathcal{M}_{SY}^2 & \mathcal{M}_{SP}^2 & \mathcal{M}_{SR}^2 \\ (\mathcal{M}_{SY}^2)^T & \mathcal{M}_Y^2 & \mathcal{M}_{YP}^2 & \mathcal{M}_{YR}^2 \\ (\mathcal{M}_{SP}^2)^T & (\mathcal{M}_{YP}^2)^T & \mathcal{M}_P^2 & \mathcal{M}_{PR}^2 \\ (\mathcal{M}_{SR}^2)^T & (\mathcal{M}_{YR}^2)^T & (\mathcal{M}_{PR}^2)^T & \mathcal{M}_R^2 \end{pmatrix}$$

where $\mathcal{M}_S^2$,$\mathcal{M}_{SY}^2$, $\mathcal{M}_Y^2$ and $\mathcal{M}_P^2$, $\mathcal{M}_{PR}^2$, $\mathcal{M}_R^2$ and $\mathcal{M}_{SP}^2$, $\mathcal{M}_{SR}^2$, $\mathcal{M}_{YP}^2$, $\mathcal{M}_{YR}^2$ denote the two-by-two matrices of the scalar, pseudoscalar and scalar-pseudoscalar squared mass terms of the neutral Higgs bosons, respectively.

Since Goldstone does not mix with the other neutral field, the (8×8) matrix $\mathcal{M}_0^2$ reduces to a (6×6) matrix, which we denote by $\mathcal{M}_N^2$.

$$\mathcal{M}_N^2 = \begin{pmatrix} (\mathcal{M}_S^2)_{11} & (\mathcal{M}_S^2)_{12} & (\mathcal{M}_{SY}^2)_{13} & (\mathcal{M}_{SY}^2)_{14} & \frac{(\mathcal{M}_{SP}^2)_{12}}{c_\beta} & 0 \\ (\mathcal{M}_S^2)_{21} & (\mathcal{M}_S^2)_{22} & (\mathcal{M}_{SY}^2)_{23} & (\mathcal{M}_{SY}^2)_{24} & -\frac{(\mathcal{M}_{SP}^2)_{21}}{s_\beta} & 0 \\ (\mathcal{M}_{SY}^2)_{31} & (\mathcal{M}_{SY}^2)_{32} & (\mathcal{M}_Y^2)_{33} & (\mathcal{M}_Y^2)_{34} & -\frac{(\mathcal{M}_{YP}^2)_{31}}{s_\beta} & 0 \\ (\mathcal{M}_{SY}^2)_{41} & (\mathcal{M}_{SY}^2)_{42} & (\mathcal{M}_Y^2)_{43} & (\mathcal{M}_Y^2)_{44} & \frac{(\mathcal{M}_{YP}^2)_{42}}{c_\beta} & 0 \\ \frac{(\mathcal{M}_{SP}^2)_{12}}{c_\beta} & -\frac{(\mathcal{M}_{SP}^2)_{21}}{s_\beta} & -\frac{(\mathcal{M}_{YP}^2)_{31}}{s_\beta} & \frac{(\mathcal{M}_{YP}^2)_{42}}{c_\beta} & -\frac{2(\mathcal{M}_P^2)_{12}}{s_{2\beta}} & 0 \\ 0 & 0 & 0 & 0 & 0 & -\frac{2(\mathcal{M}_R^2)_{34}}{s_{2\beta'}} \end{pmatrix}$$

Results and discussion



Figs.(a),(b),(c) and (d) show the curves of the four eigenvalues of the neutral Higgs mass-squared matrix as a function of the mass parameter μ for varying phase angles. Figs.(e) and (f) represent the variation of the signal strength for Higgs decay to WW^* and $\bar{f}f$, as a function of the newly introduced parameter tan β′ in the B-LSSM. It can be observed from the above figure that the eigenvalues of the neutral Higgs bosons exhibit different behaviors with respect to the variation of the CP-violating phase angle. Some show only a small change, while others exhibit a significant change, and there are also those that remain unchanged.

Summary

The impact of CP-violating phase angles varies for Higgs bosons of different masses. The B-LSSM, which features explicit radiative breaking of CP invariance, constitutes a highly rich theoretical framework and will have an impact on the search for dark matter.

For any suggestion : zwh_0218@163.com