Constraints on parameter space of BLMSSM from particle mass

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Abstract

To explain the matter-antimatter asymmetry, a supersymmetric extension of the standard model is proposed where baryon and lepton numbers are local gauged (BLMSSM), and exotic superfields are introduced when gauge group is enlarged to $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_B \otimes U(1)_L$. As signals of new physics have not been observed on Large Hadron Collider, the parameter space relevant to the masses of new particles is stringently constrained. By diagonalizing the mass squared matrices for neutral scalar sectors and the mass matrices for exotic quarks, we plot the masses of new particles varying with different parameters with some assumptions, so the constraints on model parameter is obtained with different lower limit on particle mass.

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I. INTRODUCTION

As an effective theory, the Standard Model (SM) is considered to be the most successful theory of particle physics. Though the discovery of Higgs boson makes SM seems complete [1, 2], it does not provide a candidate of dark matter. The explanation to hierarchy problem is another motivation for people to propose new physics beyond SM. By introducing the symmetry between fermions and bosons, supersymmetry (SUSY) solves the hierarchy problem naturally, and the Minimal Supersymmetric Standard Model (MSSM) is the simplest one [3–6]. With R-parity preserved, the lightest superparticle (LSP) of the MSSM is a good dark matter candidate. Since the asymmetry of matter-antimatter causes baryon number break, an extension with baryon and lepton numbers local gauged is proposed with enlarged gauge group $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_B \otimes U(1)_L$.

In this model, the baryon and the lepton numbers are local gauge symmetries spontaneously broken at the TeV scale [7–9], there is not dangerous baryon number violating operators. The generation of the heavy majorana neutrinos can understand the tiny mass of the neutrinos by the seesaw mechanism [10–17]. So BLMSSM is R-parity violating and can suppress the flavor violation in the quark and leptonic sectors [18–21]. One adds new quarks with $B=1$, and new leptons with $L=3$, to cancel fermionic family anomalies. In addition, the model ignores the coupling constants with Landau poles near the weak scale and there is no flavor changing neutral currents at tree level, and hence one does not need “desert region”. Furthermore, the model forbid proton decay [22] and ensure the stable dark matter candidate.

In this work, we study the masses of new particles in the framework of BLMSSM. As the gauge group is enlarged, many new parameters are introduced in this model. By extracting the mass matrices from superpotential and soft breaking terms, the masses can be expressed with model parameters. Therefore, it’s necessary to constrain the parameters space with the lower limits suggested by LHC observation. This paper has following structure. The BLMSSM model is introduced in Section 2, In section 3, we summarize the mass matrices. Section 4 shows the numerical analysis and discussions of parameter space. In section 5, the conclusion is given.
II. THE SUPERSYMMETRIC EXTENSION OF BLMSSM

When two new gauge symmetries are introduced, mean that baryon and lepton number are gauged, hence the local gauge group is extended to $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_B \otimes U(1)_L$. This model is called BLMSSM. New fields in the BLMSSM are collected here: the new quarks $\hat{Q}_4 \sim (3, 2, 1/6, B_4, 0)$, $\hat{U}_4^C \sim (3, 1, -2/3, -B_4, 0)$, $\hat{D}_4^C \sim (3, 1/3, -B_4, 0)$, $\hat{Q}_5^C \sim (3, 2, -1/6, -1 + B_4, 0)$, $\hat{U}_5 \sim (3, 1, 2/3, 1 + B_4, 0)$, $\hat{D}_5 \sim (3, 1, -1/3 + B_4, 0)$, and the new leptons $\hat{L}_4 \sim (1, 2, -1/2, 0, L_4)$, $\hat{E}_4^C \sim (1, 1, 1, 0, -L_4)$, $\hat{N}_5^C \sim (1, 1, 0, 0, -L_4)$, $\hat{L}_5 \sim (1, 2, 1/2, 0, -3 + L_4)$, $\hat{E}_5 \sim (1, 1, -1, 0, 3 + L_4)$, $\hat{N}_5 \sim (1, 1, 0, 0, 3 + L_4)$, to cancel the B and L anomalies, respectively. To avoid having a stable exotic quarks the model introduce the superfields $\hat{X} \sim (1, 1, 0, 2/3 + B_4, 0)$, and $\hat{X}' \sim (1, 1, 0, -(2/3 + B_4), 0)$.

Meanwhile, to break L and B spontaneously with nonzero vacuum expectation values (VEVs) and to provide masses for the exotic leptons and exotic quarks, the BLMSSM add the exotic Higgs superfields $\hat{\phi}_L$, $\hat{\varphi}_L$ and $\hat{\phi}_B$, $\hat{\varphi}_B$. In addition, using the right-handed neutrinos $N^C_R$, tiny masses related to neutrinos are acquired by see-saw mechanism.

The dark matter candidate corresponding to the lightest mass eigenstate, when $\hat{X}$ and $\hat{X}'$ mix together. In terms of the BLMSSM, the superpotential is written as

$$W_{BLMSSM} = W_{MSSM} + W_B + W_L + W_X,$$

with $W_{MSSM}$ denoting the superpotential of the MSSM. The superpotential of the baryon, lepton are denoted respectively

$$W_B = \lambda_Q \hat{Q}_4 \hat{Q}_5 \hat{\phi}_B + \lambda_U \hat{U}_4^C \hat{U}_5 \hat{\varphi}_B + \lambda_D \hat{D}_4^C \hat{D}_5 \hat{\varphi}_B + \mu_B \hat{\phi}_B \hat{\varphi}_B$$

$$+ Y_{u_4} \hat{Q}_4 \hat{H}_u \hat{U}_4^C + Y_{d_4} \hat{Q}_4 \hat{H}_d \hat{D}_4^C + Y_{u_5} \hat{Q}_5^C \hat{H}_u \hat{U}_5 + Y_{d_5} \hat{Q}_5^C \hat{H}_d \hat{D}_5,$$

$$W_L = Y_{e_4} \hat{L}_4 \hat{H}_d \hat{E}_4^C + Y_{e_5} \hat{L}_5 \hat{H}_u \hat{N}_5^C + Y_{e_4} \hat{L}_5 \hat{H}_d \hat{E}_5 + Y_{e_5} \hat{L}_5 \hat{H}_u \hat{N}_5^C$$

$$+ Y_{\nu} \hat{L}_u \hat{N}_5^C + \lambda_{N^C} \hat{N}_5^C \hat{N}_5^{C\dagger} \hat{\varphi}_L + \mu_L \hat{\phi}_L \hat{\varphi}_L,$$

$$W_X = \lambda_1 \hat{Q}_5 \hat{X}^C + \lambda_2 \hat{U}_4 \hat{U}_5 \hat{X}'^C + \lambda_3 \hat{D}_4 \hat{D}_5 \hat{X}' + \mu_X \hat{X} \hat{X}'$$

Correspondingly, the soft breaking terms of the MSSM are given as

$$\mathcal{L} = L_{soft}^{MSSM} - (m_\nu^2)_{ij} \hat{N}_i^{C\dagger} \hat{N}_j - m_{\hat{Q}_4}^2 \hat{Q}_4 \hat{Q}_4 - m_{\hat{U}_4^C}^2 \hat{U}_4^C \hat{U}_4^C$$

$$- m_{\hat{D}_4^C}^2 \hat{D}_4^C \hat{D}_4^C - m_{\hat{Q}_5}^2 \hat{Q}_5 \hat{Q}_5 - m_{\hat{U}_5}^2 \hat{U}_5 \hat{U}_5 - m_{\hat{D}_5}^2 \hat{D}_5 \hat{D}_5$$

$$- m_{\hat{L}_4}^2 \hat{L}_4 \hat{L}_4 - m_{\hat{N}_4}^2 \hat{N}_4 \hat{N}_4 - m_{\hat{E}_4^C}^2 \hat{E}_4^C \hat{E}_4^C - m_{\hat{L}_5}^2 \hat{L}_5 \hat{L}_5$$
\(-m_{\nu^2} \tilde{N}_u^* \tilde{N}_d - m_{\nu^2} \tilde{E}_u^* \tilde{E}_d - m_{\phi^2} \phi_B^* \phi_B - m_{\phi^2} \phi_B^* \varphi_B \phi_B^* \phi_B\)

\(-m_{\phi^2} \phi_B^* \phi_B - m_{\varphi^2} \phi_B^* \varphi_B - (m_B \lambda_B + m_L \lambda_L + h.c.)\)

\(+\{A_{u} Y_{u} \tilde{Q}_5 H_u \tilde{U}_5^c + A_{d} Y_{d} \tilde{Q}_5 H_d \tilde{D}_5^c + A_{u} Y_{u} \tilde{Q}_5 H_u \tilde{U}_5^c + A_{d} Y_{d} \tilde{Q}_5 H_d \tilde{D}_5^c\}

\(+A_{B Q} \lambda_Q \tilde{Q}_5 \phi_B + A_{B U} \lambda_U \tilde{U}_5^c \phi_B + h.c.\} + \{A_{1} \lambda_1 \tilde{Q}_5 \phi_B + A_{2} \lambda_2 \tilde{U}_5 \phi_B + h.c.\}\)

\(+A_{3} \lambda_3 \tilde{D}_5 \phi_B + B_{X \mu X XX' + h.c.}\),

(3)

with \(\lambda_B\) is gaugino of \(U(1)_B\), \(\lambda_L\) is gaugino of \(U(1)_L\), respectively.

The local gauge symmetry \(SU(2)_L \otimes U(1)_Y \otimes U(1)_B \otimes U(1)_L\) breaks down to the electromagnetic symmetry \(U(1)_e\) if the following conditions are satisfied[30]:

1. the Higgs field \(SU(2)_L\) doublets \((H_u, H_d)\) obtain nonzero VEVs \(\nu_u, \nu_d\).
2. the Higgs field \(SU(2)_L\) singlets \((\phi_L, \varphi_L, \phi_B, \varphi_B)\) obtain nonzero VEVs \(\nu_B, \nu_L, \nu, \nu_L\).

Where the \(SU(2)_L\) doublets \((H_u, H_d)\) and the \(SU(2)_L\) singlets \((\phi_B, \varphi_B, \phi_L, \varphi_L)\) are defined as

\[
H_u = \begin{pmatrix} H_u^+ \\ \sqrt{2} (\nu_u + H_u^0 + i P_u^0) \end{pmatrix},
\]

\[
H_d = \begin{pmatrix} H_d^- \\ \sqrt{2} (\nu_d + H_d^0 + i P_d^0) \end{pmatrix},
\]

\[
\phi_B = \frac{1}{\sqrt{2}} (\nu_B + \phi_B^0 + i P_B^0),
\]

\[
\varphi_B = \frac{1}{\sqrt{2}} (\bar{\nu}_B + \varphi_B^0 + i \bar{P}_B^0),
\]

\[
\phi_L = \frac{1}{\sqrt{2}} (\nu_L + \phi_L^0 + i P_L^0),
\]

\[
\varphi_L = \frac{1}{\sqrt{2}} (\bar{\nu}_L + \varphi_L^0 + i \bar{P}_L^0).
\]

Here, the values of VEVs \(\nu_u, \nu_d, \nu_B, \nu_L, \bar{\nu}_B, \bar{\nu}_L\) are nonzero, we adopt the shortcut notations \(\tan \beta_B = \bar{\nu}_B/\nu_B\) and \(\tilde{v}_B^2 + v_B^2 = v_B^2\).
III. THE MASS MATRICES FOR SOME NEW PARTICLES

From the soft breaking terms and superpotential of BLMSSM, we can extracted the mass matrices for following particles:

1. Two charged Higgs scalars denoted by \( H_1^\pm, H_2^\pm \) introduced in MSSM are related to the initial Higgs fields by the rotation matrix \( Z_H \) and that is defined as

\[
Z_H = \begin{pmatrix}
\sin \beta & -\cos \beta \\
\cos \beta & \sin \beta
\end{pmatrix}, \quad \text{with} \quad
H_1^* \begin{pmatrix}
H_1^+ \\
H_1^-
\end{pmatrix} = Z_H \begin{pmatrix}
H_1^x \\
H_1^y
\end{pmatrix}.
\]

2. The masses of four neutralinos \( \chi_i^0, (i = 1, \ldots, 4) \) can be obtained by diagonalizing the mass matrices with the rotation matrix \( Z_N \) as follow

\[
Z_N^T \begin{pmatrix}
M_1 & 0 & \frac{v_B}{2w_C} & \frac{v_B}{2w_C} \\
0 & M_2 & \frac{v_B}{2w_C} & -\frac{v_B}{2w_C} \\
\frac{v_B}{2w_C} & \frac{v_B}{2w_C} & 0 & \mu \\
-\frac{v_B}{2w_C} & \frac{v_B}{2w_C} & \mu & 0
\end{pmatrix} Z_N = \begin{pmatrix}
M_{\chi_i^0}^2 & 0 \\
0 & \ddots \\
0 & 0 & M_{\chi_4^0}
\end{pmatrix},
\]

where \( \chi_i^0, i = 1 \ldots 4 \) represent four Majorana fermions.

3. Compared with MSSM, the baryon neutralinos \( \chi_{Bj}^0 \) are the exotic particles in the BLMSSM. The new gaugino \( \lambda_B \) and the superpartner of the \( SU(2)_B \) singlets \( \phi_B \) and \( \varphi_B \) mix, which produce three baryon neutralinos in the base \((i\lambda_B, \psi_{\phi_B}, \psi_{\varphi_B})\)\[28–30\].

\[
\frac{1}{2} A \begin{pmatrix}
2M_B & -v_B g_B & \bar{v}_B g_B \\
-v_B g_B & 0 & -\mu_B \\
\bar{v}_B g_B & -\mu_B & 0
\end{pmatrix} A^T,
\]

with

\[
A = \begin{pmatrix}
i\lambda_B, \psi_{\phi_B}, \psi_{\varphi_B}
\end{pmatrix}.
\]

Using \( Z_{NB} \), one can diagonalize the mass matrix in Eq. (14) to obtain three lepton neutralino masses.

4. In BLMSSM, the mass squared matrix of the Down-squarks is different from that in MSSM, because of two exotic part \( \frac{g_B^2}{6}(v_B^2 - \bar{v}_B^2) \) and \( -\frac{g_B^2}{6}(v_B^2 - \bar{v}_B^2) \) from \( (\mathcal{M}_D^2)_{LL} \) and \( (\mathcal{M}_D^2)_{RR} \).

\[
Z_D^T \begin{pmatrix}
(\mathcal{M}_D^2)_{LL} & (\mathcal{M}_D^2)_{LR} \\
(\mathcal{M}_D^2)_{LR} & (\mathcal{M}_D^2)_{RR}
\end{pmatrix} Z_D = \begin{pmatrix}
M_{D_1}^2 & 0 \\
0 & \ddots \\
0 & 0 & M_{D_6}^2
\end{pmatrix}.
\]
The unitary matrix $Z_D$ is used to rotate Down-squarks mass squared matrix to mass eigenstates. And $(\mathcal{M}_D^2)_{LL}$, $(\mathcal{M}_D^2)_{RR}$, $(\mathcal{M}_D^2)_{LR}$ are read as

$$
(\mathcal{M}_D^2)_{LL} = -\frac{e^2(v_1^2 - v_2^2)(1 + 2c_W^2)}{24s_W^2c_W^2} + \frac{v_1^2Y_d^2}{2} + (m_Q^2)^T + \frac{g_B}{6}(v_B^2 - \bar{v}_B^2),
$$

$$
(\mathcal{M}_D^2)_{RR} = -\frac{e^2(v_1^2 - v_2^2)}{12c_W^2} + \frac{v_1^2Y_d^2}{2} + m_D^2 - \frac{g_B}{6}(v_B^2 - \bar{v}_B^2),
$$

$$
(\mathcal{M}_D^2)_{LR} = \frac{1}{\sqrt{2}}(v_2(-A_d' + Y_d\mu^*) + v_1A_d).
$$

we adopt the shortcut notations: $c_W = \cos \theta_W$, $s_W = \sin \theta_W$, with $\theta_W$ denoting the Weinberg angle.

5. In BLMSSM, the mass squared matrix of the Up-squarks is different from that in MSSM, because of two exotic part $\frac{g_B}{6}(v_B^2 - \bar{v}_B^2)$ and $-\frac{g_B}{6}(v_B^2 - \bar{v}_B^2)$ from $(\mathcal{M}_U^2)_{LL}$ and $(\mathcal{M}_U^2)_{RR}$,

$$
Z^T_U \begin{pmatrix} (\mathcal{M}_U^2)_{LL} & (\mathcal{M}_U^2)_{LR} \\ (\mathcal{M}_U^2)_{LR}^T & (\mathcal{M}_U^2)_{RR} \end{pmatrix} Z_U = \begin{pmatrix} M_{U_1}^2 & 0 \\ 0 & M_{U_0}^2 \end{pmatrix}.
$$

The unitary matrix $Z_U$ is used to rotate Up-squarks mass squared matrix to mass eigenstates. And $(\mathcal{M}_U^2)_{LL}$, $(\mathcal{M}_U^2)_{RR}$, $(\mathcal{M}_U^2)_{LR}$ are show here

$$
(\mathcal{M}_U^2)_{LL} = -\frac{e^2(v_1^2 - v_2^2)(1 - 4c_W^2)}{24s_W^2c_W^2} + \frac{v_1^2Y_u^2}{2} + (Km_Q^2K^T) + \frac{g_B}{6}(v_B^2 - \bar{v}_B^2),
$$

$$
(\mathcal{M}_U^2)_{RR} = \frac{e^2(v_1^2 - v_2^2)}{6c_W^2} + \frac{v_1^2Y_u^2}{2} + m_U^2 - \frac{g_B}{6}(v_B^2 - \bar{v}_B^2),
$$

$$
(\mathcal{M}_U^2)_{LR} = -\frac{1}{\sqrt{2}}(v_1(A_d' + Y_d\mu^*) - v_2A_u).
$$

6. Charginos mass matrix in BLMSSM is expressed as follow, and that existed in MSSM,

$$
Z^T_U \begin{pmatrix} M_{2} \frac{e\nu}{\sqrt{2} s_W} \\ \frac{e\nu}{\sqrt{2} s_W} \mu \end{pmatrix} Z_+ = \begin{pmatrix} M_{\chi_1^\pm} & 0 \\ 0 & M_{\chi_2^\pm} \end{pmatrix}.
$$

7. In BLMSSM, there are new exotic quarks $b'$,

$$
W_{b'} \begin{pmatrix} -\frac{1}{\sqrt{2}}Y_d\lambda_{Q} v_B - \frac{1}{\sqrt{2}} Y_d s_u & U_y = \begin{pmatrix} M_{b_4} & 0 \\ 0 & M_{b_5} \end{pmatrix} \end{pmatrix}
$$

8. In BLMSSM, there are new exotic scalar particles $X$, 

\begin{align}
Z_X^* \begin{pmatrix} |\mu_X|^2 + SS & -\mu_X^* B_X^* \\ -\mu_X B_X & |\mu_X|^2 - SS \end{pmatrix} Z_X &= \begin{pmatrix} m_{X1}^2 & 0 \\ 0 & m_{X2}^2 \end{pmatrix}, \quad (20)
\end{align}

\begin{align}
\begin{pmatrix} X_1 \\ X_2 \end{pmatrix} = Z_X^* \begin{pmatrix} X \\ X^* \end{pmatrix}. \quad (21)
\end{align}

The $Z_X$ is defined as unitary matrix to rotate rotate superfield mass squared matrix to mass eigenstates. Meanwhile, the mass matrix satisfy the following relation

$$SS = \frac{g_B^2}{2} \left( \frac{2}{3} + B_4 (v_B^2 - \bar{v}_B^2) \right). \quad (22)$$

9. In the basis $\bar{t}T = (\bar{\tilde{Q}}_4, \tilde{U}_4^*, \bar{\tilde{Q}}_5^{2*}, \bar{	ilde{U}}_5)$, $\bar{\nu}^T = (\bar{\tilde{Q}}_4^2, \bar{\tilde{D}}_4^*, \bar{\tilde{Q}}_5^{1*}, \bar{\tilde{D}}_5^*)$. The concrete forms for the exotic scalar quarks mass squared matrix are shown here,

\begin{align}
(\mathcal{M})_{11}^2(11) &= m_{Q4}^2 + \frac{1}{2} Y_{u_2} Y_u^2 + \frac{1}{2} Y_{d_2} Y_d^2 + \frac{1}{2} \lambda_{Q} v_B^2 - \frac{1}{2} \left( \frac{2}{3} s_w^2 \right) m_Z^2 \cos 2\beta + \frac{B_4}{2} m_{ZB}^2 \cos 2\beta_B,

(\mathcal{M})_{12}^2(22) &= m_{D4}^2 + \frac{1}{2} Y_{d_2} Y_d^2 + \frac{1}{2} \lambda_{d_2} v_B^2 - \frac{1}{2} s_w^2 m_Z^2 \cos 2\beta - \frac{B_4}{2} m_{ZB}^2 \cos 2\beta_B,

(\mathcal{M})_{20}^2(33) &= m_{Q5}^2 + \frac{1}{2} Y_{u_2} Y_u^2 + \frac{1}{2} Y_{d_2} Y_d^2 + \frac{1}{2} \lambda_{Q} v_B^2 - \frac{1}{2} \left( \frac{1}{3} s_w^2 \right) m_Z^2 \cos 2\beta - \frac{1}{2} m_{ZB}^2 \cos 2\beta_B,

(\mathcal{M})_{24}^2(44) &= m_{D5}^2 + \frac{1}{2} Y_{d_2} Y_d^2 + \frac{1}{2} \lambda_{d_2} v_B^2 + \frac{1}{2} s_w^2 m_Z^2 \cos 2\beta + \frac{1}{2} m_{ZB}^2 \cos 2\beta_B,

(\mathcal{M})_{22}^2(21) &= - \frac{1}{\sqrt{2}} Y_{d_4} v_d A_{d_4} + \frac{1}{\sqrt{2}} Y_{d_4} v_d \mu v_d,

(\mathcal{M})_{23}^2(31) &= - \frac{1}{\sqrt{2}} \lambda_Q v_B A_{BQ} + \sqrt{2} \lambda_Q v_B \bar{v}_B,

(\mathcal{M})_{24}^2(41) &= - \frac{1}{\sqrt{2}} Y_{d_4} \lambda_d v_d \bar{v}_B + \frac{1}{\sqrt{2}} Y_{d_4} \lambda_d v_u v_B,

(\mathcal{M})_{32}^2(32) &= \frac{1}{2} \lambda_d Y_{d_4} v_d v_B + \frac{1}{2} \lambda_d Y_{d_4} v_u \bar{v}_B,

(\mathcal{M})_{34}^2(42) &= - \frac{1}{\sqrt{2}} \lambda_d A_{BD} \bar{v}_B + \frac{1}{\sqrt{2}} \lambda_d \mu v_B,

(\mathcal{M})_{34}^2(43) &= - \frac{1}{\sqrt{2}} Y_{d_4} A_{d_4} v_u + \frac{1}{\sqrt{2}} Y_{d_4} \mu v_d. \quad (23)
\end{align}

IV. NUMERICAL RESULTS

As many supersymmetric extension, BLMSSM enlarged the gauge groups, and many parameters are introduced. The expression of mass matrices with these parameter are usually
complicated. So it is difficult to obtain the possible parameter space with mass limits suggested by LHC observation. For example, $v_{bt}$, $\tan \beta_B$, $g_B$ simultaneously appear in baryon neutralinos, down-squarks and up-squarks mass matrix. In addition, the baryon neutralinos mass matrix only the first diagonal elements is nonzero, so it’s hard to pick up the appropriate value of $g_B$, $v_B$, $\bar{v}_B$ through $v_{bt}$, $m_{Z\mu}$ in the process of diagonalization, makesure nonzero mass value of particle and meet mass limit.

In this section, we give the contour plot of mass vary with model parameters. By scanning the parameter space, we calculate the mass matrices numerically, then diagonalize them to get the masses of different particles. In our numerical analysis, we adopt the following parameters in Table I.

| $\alpha$ | $1/128$ | $M_u$ | 0.0023 | $A_{d4}$ | 100 | $m_{D_4}^2$ | 2500 |
| $\tan \beta$ | 5 | $M_d$ | 0.0048 | $A_{d5}$ | 100 | $m_{D_5}^2$ | 2500 |
| $\lambda_Q$ | 0.5 | $M_c$ | 1.275 | $\mu_X$ | 1500 | $\mu$ | -1000 |
| $\lambda_u$ | 0.5 | $M_s$ | 0.095 | $m_1$ | 1200 | $m_2$ | 1200 |
| $\lambda_d$ | 0.5 | $M_t$ | 173.5 | $B_X$ | 400 | $m_{Z_B}$ | 1000 |
| $\lambda_1$ | 0.4 | $M_b$ | 4.18 | $\tan \beta_B$ | 2.5 | $v_{bt}$ | 5000 |
| $\lambda_3$ | 0.4 | $M_W$ | 80.385 | $\mu_B$ | 1100 | $m_B$ | 2000 |
| $A_{BQ}$ | 100 | $M_Z$ | 91.188 | $A_{u_4}$ | 100 | $m_{U_4}^2$ | 2500 |
| $A_{BU}$ | 100 | $m_{Q_4}^2$ | 2500 | $A_{u_5}$ | 100 | $m_{U_5}^2$ | 2500 |
| $A_{BD}$ | 100 | $m_{Q_5}^2$ | 2500 |

**TABLE I**: parameters in the BLMSSM

The mass matrix of the baryon neutralinos includes $M_B$ and $\mu_B$. $\mu_B$ is a Non-diagonal element and $M_B$ is a diagonal element of this mass matrix. Therefore, the two parameters $M_B$ and $\mu_B$ can affect the contributions for the particle mass in some ways. We assume the value of parameters are same as above in Table I. In Fig. we show the contour for the mass of baryon neutralinos with respect to $M_B$ versus $\mu_B$. With the increase of $M_B$ and $\mu_B$, the mass value of the baryon neutralinos also increase. Here $M_B$ changes between 300 GeV and 3000 GeV and $\mu_B$ changes between 500 GeV and 2100 GeV.

$\mu$ and $M_2$ are not only the diagonal elements of the charginos mass matrix, but also constitute the mass matrix of neutralinos. Considerable influence to masses of charginos...
FIG. 1: The contour for the mass of baryon neutralinos with respect to $M_B$ versus $\mu_B$ with the parameters are same as above in table 1.

and neutralinos from $\mu$ and $M_2$ are hopeful. To see how $\mu$ and $M_2$ affect the numerical results, with $M_B = 1100$ GeV. We give out the allowed region in the plane of $M_2$ versus $\mu$. Figure 2 implies that when $\mu$ is near 0, the results are less than 200 GeV. The effects from $M_2$ are very weak, and can be neglected. The value of $\mu$ can vary from -2000 to 2000 GeV. The figure trend of the contour for the mass of neutralinos with respect to $M_2$ versus $\mu$ with $M_B = 1100$ GeV is same as the Fig. 2.

FIG. 2: The contour for the mass of charginos or neutralinos with respect to $M_2$ versus $\mu$ with $M_B = 1100$ GeV.
\( \lambda_Q \) and \( \lambda_d \) are not only the diagonal elements of the exotic -1/3 quark mass matrix, but also constitute the mass matrix of exotic -1/3 squark. Here we consider the elements of \( \lambda_Q \) and \( \lambda_d \), and suppose \( M_B = 1100 \) GeV. After the numerical calculation, the contour plot of \( \lambda_Q \) versus \( \lambda_d \) about the mass of exotic +2/3 quark and exotic -1/3 quark is shown in Fig. 3.

The mass of these particles will get values less than 1000 GeV when decrease the value of \( \lambda_Q \) and \( \lambda_d \). At this point, the exotic -1/3 quark and the exotic -1/3 squark is likely to be found in LHC.

![Contour plot](image)

**FIG. 3:** The contour for the mass of exotic -1/3 quark or exotic -1/3 squark with respect to \( \lambda_Q \) versus \( \lambda_d \) with \( M_B = 1100 \) GeV.

In the figure 4, we plot the values of the \( \mu_X \) and \( B_X \) that lead to the mass value of Superfields. We use \( A_{BQ} = A_{BU} = A_{BD} = A_{u_4} = A_{u_5} = A_{d_4} = A_{d_5} = 1000 \) GeV, \( \lambda_Q = 0.7 \) and \( \tan \beta = 3 \) for these plots. Figure 4 implies that from 0 to 6000 GeV of \( B_X \) and from 1000 to 6000 GeV of \( \mu_X \), the mass values of superfields are all increasing functions of the enlarging \( \mu_X \) and the diminishing \( B_X \). Moreover, there exist the value space that less than 1000 GeV, so this particle is likely to be found in LHC. In addition, there has an large empty area, so we choose one point to analyze. After the numerical analysis, as \( B_X = 5000 \) GeV, \( \mu_X = 2000 \) GeV, can lead to negative mass values of the superfields, so ones are unsuitable.

Compared with MSSM, \( V_{bt} \) and \( \mu_B \) are new parameters that have relation with mass matrices of the exotic squarks \( \tilde{b}' \) and \( \tilde{t}' \). Therefore, the effects to particles masses from \( V_{bt} \) and \( \mu_B \) are of interest. In the plane of \( V_{bt} \) versus \( \mu_B \), with \( A_{BQ} = A_{BU} = A_{BD} = A_{u_4} = A_{u_5} = A_{d_4} = A_{d_5} = 200 \) GeV, \( m_{Q_4}^2 = m_{Q_5}^2 = m_{U_4}^2 = m_{U_5}^2 = m_{D_4}^2 = m_{D_5}^2 = 4000 \) GeV and
FIG. 4: The contour for the mass of Superfields with respect to $\mu_X$ versus $B_X$ with $A_{BQ} = A_{BU} = A_{BD} = A_{u_4} = A_{u_5} = A_{d_4} = A_{d_5} = 1000$ GeV, $\lambda_Q = 0.7$ and $\tan \beta = 3$.

$\mu_X = 2000$ GeV, we show the allowed results denoted by the dots in Fig. 5. The values of the exotic squarks are less than 2500 GeV when $V_{bt}$ over the value of 5400 and $\mu_B$ over the value of 2000 GeV.

FIG. 5: The contour for the mass of the exotic squarks with respect to $V_{bt}$ versus $\mu_B$ with $A_{BQ} = A_{BU} = A_{BD} = A_{u_4} = A_{u_5} = A_{d_4} = A_{d_5} = 200$ GeV, $m_{Q_4}^2 = m_{Q_5}^2 = m_{U_4}^2 = m_{U_5}^2 = m_{D_4}^2 = m_{D_5}^2 = 4000$ GeV and $\mu_X = 2000$ GeV.

$\lambda_Q$ and $\tan \beta_B$ are important for the mass of the exotic quarks. Therefore, the numerical results maybe influenced obviously by varying $\lambda_Q$ and $\tan \beta_B$. For simplicity, we adopt
\( \tan \beta = 5, A_{BQ} = A_{BU} = A_{BD} = A_{u_4} = A_{u_5} = A_{d_4} = A_{d_5} = 600 \text{ GeV} \) and \( M_B = 1100 \text{ GeV} \), and plot \( \lambda_Q \) varying with \( \tan \beta_B \) in Fig.6 which \( \lambda_Q \) changes between \( 0 \sim 2.2 \) and \( \tan \beta_B \) changes between \( 0 \sim 13 \). It implies that in the region\((0 \sim 1)\) of \( \tan \beta_B \) the effect of \( \lambda_Q \) are small, but in the region\((1 \sim 13)\) of \( \tan \beta_B \) the effect of \( \lambda_Q \) are strong, when \( \tan \beta_B \) takes a certain value, the mass value of exotic quarks is decreasing with the decreasing value of \( \lambda_Q \). Most masses of the particles are smaller than \( 1000 \text{ GeV} \).

![Figure 6](image)

**FIG. 6:** The contour for the mass of the exotic quarks with respect to \( \lambda_Q \) versus \( \tan \beta_B \) with \( \tan \beta = 5, A_{BQ} = A_{BU} = A_{BD} = A_{u_4} = A_{u_5} = A_{d_4} = A_{d_5} = 600 \text{ GeV} \) and \( M_B = 1100 \text{ GeV} \).

Now, let us investigate the results for the mass of the exotic squarks where one takes into account the \( \lambda_Q \) and \( \tan \beta_B \). In order to illustrate the numerical solutions we choose \( \tan \beta = 5, A_{BQ} = A_{BU} = A_{BD} = A_{u_4} = A_{u_5} = A_{d_4} = A_{d_5} = 600 \text{ GeV} \) and \( M_B = 1100 \text{ GeV} \). In Fig.7 we show the values for the mass of the exotic squarks when \( \lambda_Q \) changes between \( 0.3 \sim 0.8 \) and \( \tan \beta_B \) changes between \( 1.5 \sim 6 \). The mass values of the exotic squarks decrease when increase the values of \( \lambda_Q \) and \( \tan \beta_B \), simultaneously.

\( M_2 \) and \( M_1 \) are diagonal elements of neutralinos mass matrix. They are sensitive parameters and affect the mass of neutralinos forcefully. Here we use the parameter \( M_B = 1100 \text{ GeV} \), in the plane of \( M_2 \) versus \( M_1 \), the contour plot is scanned, and the allowed results are shown in Fig.8. When \( M_2 \) and \( M_1 \) are greater than \( 600 \text{ GeV} \), the mass value of neutralinos is larger then \( 600 \text{ GeV} \). On the contrary, When \( M_2 \) and \( M_1 \) are less than \( 200 \text{ GeV} \), the mass value of neutralinos is smaller then \( 200 \text{ GeV} \). These are an acceptable kinematic range for discovery at the LHC.
FIG. 7: The contour for the mass of the exotic squarks with respect to $\lambda_Q$ versus $\tan \beta_B$ with
$tan \beta = 5, A_{BQ} = A_{BU} = A_{BD} = A_{u4} = A_{u5} = A_{d4} = A_{d5} = 600 \text{ GeV}$ and $M_B = 1100 \text{ GeV}$.

$\lambda_Q$ is related to the mass matrices of exotic quarks. Through scanning the contour plot
of $\lambda_Q$ versus $\lambda_u$ in Fig. 9 with the values of parameters are same as above in table 1, we
find that the most mass values of exotic quarks are less then 1000 GeV, when $\lambda_Q$ in the
region $0 \sim 1$ and $\lambda_u$ in the region $0 \sim 0.8$. Considering the experiment about LHC, one can
generate this particle.

Here, we consider $m^2_{D_4}$ versus $m^2_{D_5}$, ones are diagonal elements that included in the
FIG. 9: The contour for the mass of the exotic quarks with respect to $\lambda_Q$ versus $\lambda_u$ with the values of parameters are same as above in table 1.

mass matrix of the exotic -1/3 squark, which should produce considerable influence on the numerical results. Based on the supposition $\lambda_Q = 0.1$, $\lambda_d = 0.1$, we scan the contour of $m^2_{\tilde{D}_4}$ versus $m^2_{\tilde{D}_5}$ in Fig.10. From 300 to 2600 of $m^2_{\tilde{D}_4}$, the mass values of the exotic -1/3 squark are all increasing functions of the enlarging $m^2_{\tilde{D}_5}$. The values of $m^2_{\tilde{D}_5}$ vary from 1250 to 3000. The values of $m^2_{\tilde{D}_4}$ vary from 300 to 2600 GeV.

FIG. 10: The contour for the mass of the exotic -1/3 squark with respect to $m^2_{\tilde{D}_4}$ versus $m^2_{\tilde{D}_5}$ with $\lambda_Q = 0.1$, $\lambda_d = 0.1$.

In fig.11 we show the results of the $A_{BU}$ and $A_{BQ}$ values by changing the mass of the exotic
+2/3 squark and assuming $A_{BD} = A_{u_4} = A_{u_5} = A_{d_4} = A_{d_5} = 6000 \text{ GeV}$, $M_B = 1800 \text{ GeV}$ and $\lambda_Q = 0.7$. In this way, we can achieve a exotic +2/3 squark mass less then 1000 GeV for the region when $A_{BU}$ is almost over 5000 GeV and $A_{BQ}$ is almost over 12000 GeV.

![Image](figure11.png)

FIG. 11: The contour for the mass of the exotic +2/3 squark with respect to $A_{BU}$ versus $A_{BQ}$ with $A_{BD} = A_{u_4} = A_{u_5} = A_{d_4} = A_{d_5} = 6000 \text{ GeV}$, $M_B = 1800 \text{ GeV}$ and $\lambda_Q = 0.7$.

V. CONCLUSIONS

In this work, we study the relation between parameters of BLMSSM model and the masses of supersymmetric particles. With the model introduced firstly, we collected the mass matrices. To show the impact on masses, parameters such as $M_B$, $\mu_B$ contained in baryon neutralions, couplings of exotic quarks and new Higgs field $\lambda_Q$, $\lambda_d$, the $\tan\beta_B$ are scanned to give the masses numerically by diagonalizing the mass matrices. From the contour plots, we can intuitively obtain the parameter space for mass limits of baryon neutrinos, charginos, exotic quarks and squarks, and so on.

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