Abstract

We show that the recent measurements of $B_s - \overline{B}_s$ mass difference, $\Delta m_s$, by DO and CDF collaborations give very strong constraints on MSSM scenario with large flavor mixing in the LL and/or RR sector of down-type squark mass squared matrix. In particular, the region with large mixing angle and large mass difference between scalar strange and scalar bottom is ruled out by giving too large $\Delta m_s$. The allowed region is sensitive to the CP violating phases $\delta_{L(R)}$. The $\Delta m_s$ constraint is most stringent on the scenario with both LL and RR mixing. We also predict the time-dependent CP asymmetry in $B_s \rightarrow \psi\phi$ decay and semileptonic asymmetry in $B_s \rightarrow \ell X$ decay.
1 Introduction

The flavor changing processes in the \( s - b \) sector are sensitive probe of new physics (NP) beyond the standard model (SM) because they are experimentally the least constrained. In the minimal supersymmetric standard model (MSSM), however, the flavor mixing in the chirality flipping down-type squarks, \( \tilde{s}_{L(R)} - \tilde{b}_{R(L)} \), is already strongly constrained by the measurement of \( BR(B \rightarrow X_s\gamma) \). On the other hand, large flavor mixing in the chirality conserving \( \tilde{s}_{L(R)} - \tilde{b}_{L(R)} \) has been largely allowed. Especially the large mixing scenario in the \( \tilde{s}_R - \tilde{b}_R \) sector has been drawing much interest because it is well motivated by the measurement large neutrino mixing and the idea of grand unification [1].

Recently DØ and CDF collaborations at Fermilab Tevatron reported the results on the measurements of \( B_s - \bar{B}_s \) mass difference [2, 3]

\[
17 \text{ ps}^{-1} < \Delta m_s < 21 \text{ ps}^{-1} \quad (90\% \text{ CL}),
\]

\[
\Delta m_s = 17.33^{+0.42}_{-0.21} \pm 0.07 \text{ ps}^{-1},
\]

respectively. These measured values are consistent with the SM predictions [4, 5]

\[
\Delta m_s^{\text{SM}} (\text{UTfit}) = 21.5 \pm 2.6 \text{ ps}^{-1}, \quad \Delta m_s^{\text{SM}} (\text{CKMfit}) = 21.7^{+5.9}_{-4.2} \text{ ps}^{-1}
\]

which are obtained from global fits, although the experimental measurements in (1) are slightly lower. The implications of \( \Delta m_s \) measurements have already been considered in model independent approach [6, 7, 8], MSSM models [9, 10], \( Z' \)-models [11], etc.

In this paper, we consider the implications of (1) on an MSSM scenario with large mixing in the LL and/or RR sector. We do not consider flavor mixing in the LR(RL) sector because they are i) are already strongly constrained by \( BR(B \rightarrow X_s\gamma) \) [12] and ii) therefore relatively insensitive to \( B_s - \bar{B}_s \) mixing. We neglect mixing between the 1st and 2nd generations which are tightly constrained by \( K \) meson decays and \( K - \bar{K} \) mixing, and mixing between the 1st and 3rd generations which is also known to be small by the measurement of \( B_d - \bar{B}_d \) mixing.

The paper is organized as follows. In Section 2, the relevant formulas for \( B_s - \bar{B}_s \) mixing are presented. In Section 3 we perform numerical analysis and show the constraints imposed
on our scenario. With these constraints, in Section 4, we predict the time-dependent CP asymmetry in $B_s \to \psi \phi$ decay and the semileptonic asymmetry in $B_s \to \ell X$ decay. We conclude in Section 5.

## 2 $B_s - \overline{B}_s$ mixing in the MSSM scenario with large LL/RR mixing

According to the description of our model in Section 1, the scalar down-type mass squared matrix in the basis where down quark mass matrix is diagonal is given by [13, 14]

$$
M^2_{d,LL} = 
\begin{pmatrix}
\tilde{m}^d_{L11} & 0 & 0 \\
0 & \tilde{m}^d_{L22} & \tilde{m}^d_{L23} \\
0 & \tilde{m}^d_{L32} & \tilde{m}^d_{L33}
\end{pmatrix},
M^2_{d,LR(RL)} \equiv 0_{3 \times 3}.
$$

The $M^2_{d,RR}$ can be obtained from $M^2_{d,LL}$ by exchanging $L \leftrightarrow R$. We note that this kind of scenario is orthogonal to the one with flavor violation controlled only by CKM matrix (minimal flavor violation model [15, 8] or the effective SUSY model considered in [16]), where large flavor violation in $s - b$ is impossible a priori.

The mass matrix $M^2_{d,LL}$ can be diagonalized by

$$
\Gamma_L M^2_{d,LL} \Gamma^\dagger_L = \text{diag}(m^2_{d_L}, m^2_{s_L}, m^2_{b_L}),
$$

with

$$
\Gamma_L =
\begin{pmatrix}
1 & 0 & 0 \\
0 & \cos \theta_L & \sin \theta_L e^{i\delta_L} \\
0 & -\sin \theta_L e^{-i\delta_L} & \cos \theta_L
\end{pmatrix}.
$$

Similarly, the exchange $L \leftrightarrow R$ in (5) gives $\Gamma_R$. We restrict $-45^\circ < \theta_{L(R)} < 45^\circ$ so that the mass eigenstate $\tilde{s}(\tilde{b})$ has more strange (beauty) flavor than beauty (strange) flavor.

The most general effective Hamiltonian for $B_s - \overline{B}_s$ mixing

$$
H_{\text{eff}} = \sum_{i=1}^{5} C_i O_i + \sum_{i=1}^{3} \tilde{C}_i \tilde{O}_i
$$

(6)
has 8 independent operators

\[ O_1 = (\bar{s}_L \gamma_\mu b_L) (\bar{s}_L \gamma^\mu b_L), \]
\[ O_2 = (\bar{s}_R b_L) (\bar{s}_R b_L), \]
\[ O_3 = (\bar{s}_R^\alpha b_L^\beta) (\bar{s}_R^\beta b_L^\alpha), \]
\[ O_4 = (\bar{s}_R b_L) (\bar{s}_R b_R), \]
\[ O_5 = (\bar{s}_R^\alpha b_L^\beta) (\bar{s}_R^\beta b_L^\alpha), \]
\[ \tilde{O}_{i=1, 3} = O_{i=1, 3} \mid_{L \leftrightarrow R}. \]  

(7)

The Wilson coefficients for these \( \Delta B = \Delta S = 2 \) operators can be obtained by calculating the gluino mediated box diagrams. Since the chargino and neutralino exchanged box diagrams are suppressed by the small gauge coupling constants, we neglect them. In the scenario we are considering, when we consider only LL (RR) mixing, the SUSY box diagram contributes only to \( C_1 (\tilde{C}_1) \). When both LL and RR mixing exist simultaneously, there are also contributions to \( C_4 \) and \( C_5 \). However, \( \tilde{C}_2 \) or \( \tilde{C}_3 \) are not generated at all. Note that the induced LR (RL) mixing [17] does not occur, either, because we set \( M^2_{\tilde{d}_{LR}(RL)} \equiv 0_{3 \times 3} \). Otherwise, the SUSY parameter space is further constrained depending on \( \tan \beta \) [17]. The analytic formulas for the Wilson coefficients at the MSSM scale are given by

\[ C_{1\text{MSSM}} = \frac{\alpha_s^2}{4m_{\tilde{g}}^2} \sin^2 2\theta_L e^{i\delta_L} \left( f_1(x_{\tilde{b}_L,\tilde{g}}, x_{\tilde{b}_L,\tilde{g}}) - 2f_1(x_{\tilde{s}_L,\tilde{g}}, x_{\tilde{b}_L,\tilde{g}}) + f_1(x_{\tilde{s}_L,\tilde{g}}, x_{\tilde{s}_L,\tilde{g}}) \right), \]
\[ C_{4(5)\text{MSSM}} = \frac{\alpha_s^2}{4m_{\tilde{g}}^2} \sin 2\theta_R e^{i(\delta_L + \delta_R)} \left( f_4(5)(x_{\tilde{b}_R,\tilde{g}}, x_{\tilde{b}_L,\tilde{g}}) - f_4(5)(x_{\tilde{b}_R,\tilde{g}}, x_{\tilde{s}_L,\tilde{g}}) \right. \\
\left. - f_4(5)(x_{\tilde{s}_R,\tilde{g}}, x_{\tilde{b}_L,\tilde{g}}) + f_4(5)(x_{\tilde{s}_R,\tilde{g}}, x_{\tilde{s}_L,\tilde{g}}) \right), \]
\[ \tilde{C}_{1\text{MSSM}} = C_{1\text{MSSM}} \mid_{L \leftrightarrow R}, \]  

(8)

where the loop functions are defined as

\[ f_1(x, y) \equiv \frac{1}{9} j(1, x, y) + \frac{11}{36} k(1, x, y), \]
\[ f_4(x, y) \equiv \frac{7}{3} j(1, x, y) - \frac{1}{3} k(1, x, y), \]
\[ f_5(x, y) \equiv \frac{1}{9} j(1, x, y) + \frac{5}{9} k(1, x, y), \]  

(9)
and the \(j\) and \(k\) are defined in [18]. The RG running of the Wilson coefficients down to \(m_b\) scale can be found, for example, in [19].

We can calculate the \(B_s - \bar{B}_s\) mixing matrix element, which is in the form

\[
M_{12}^s = M_{12}^{s, \text{SM}} (1 + R).
\] (10)

The mass difference of \(B_s - \bar{B}_s\) system is then given by

\[
\Delta m_s = 2|M_{12}^s| = \Delta m_s^{\text{SM}} |1 + R|.
\] (11)

In the SM contribution [20] to the mass matrix element

\[
M_{12}^{s, \text{SM}} = \frac{G_F^2 M_B^2}{12\pi^2} M_{B_s} \left( f_{B_s} \hat{B}_{B_s} \right)^2 \eta_B S_0(x_t) (V_{tb} V_{ts}^*)^2,
\] (12)

the non-perturbative parameters \(f_{B_s}\) and \(\hat{B}_{B_s}\) give main contribution to the theoretical uncertainty. Using the combined lattice result [21] from JLQCD [22] and HPQCD [23],

\[
f_{B_s} \hat{B}_{B_s} \bigg|_{(\text{HP+JL)QCD}} = (0.295 \pm 0.036) \text{ GeV},
\] (13)

the SM predicts

\[
\Delta m_s^{\text{SM}} = (22.5 \pm 5.5) \text{ ps}^{-1},
\] (14)

which is consistent with the values in (2) obtained from global fits. For the prediction in (14), we used \(\eta_B = 0.551\), \(m_t^{\text{MS}}(m_t) = 162.3\) GeV and \(V_{ts} = 0.04113\) [24].

Now, inserting the CDF data in (1) and the SM prediction in (14) into (11), we obtain

\[
|1 + R| = 0.77^{+0.02}_{-0.01}(\text{exp}) \pm 0.19(\text{th}),
\] (15)

where the experimental and theoretical errors were explicitly written. The expression for \(R\) in our scenario is given by \(^2\)

\[
R(\mu_b) = \xi_1(\mu_b) + \tilde{\xi}_1(\mu_b) + \frac{3}{4} \frac{B_1(\mu_b)}{B_1(\mu_b)} \left( \frac{M_{B_s}}{m_b(\mu_b) + m_s(\mu_b)} \right)^2 \xi_4
\]

\(^2\)The \(\hat{B}_{B_s}\) in (12) is related to \(B_1(\mu_b)\) as [20]

\[
\hat{B}_{B_s} = B_1(\mu_b) [\alpha_s^{(5)}(\mu_b)]^{-\alpha_s^{(5)}(\mu_b)/4/23} \left[ 1 + \frac{\alpha_s^{(5)}(\mu_b)}{4\pi} J_5 \right].
\] (16)
\[ + \frac{1}{4} \frac{B_5(\mu_b)}{B_1(\mu_b)} \left( \frac{M_{B_s}}{m_b(\mu_b) + m_s(\mu_b)} \right)^2 \xi_5, \]  

where we defined \((i = 1, \ldots, 5)\)

\[ \xi_i(\mu_b) \equiv \frac{C_{i}^{\text{SUSY}}(\mu_b)}{C_{i}^{\text{SM}}(\mu_b)}, \]

\[ \tilde{\xi}_i(\mu_b) \equiv \frac{\tilde{C}_{i}^{\text{SUSY}}(\mu_b)}{C_{i}^{\text{SM}}(\mu_b)}. \]  

The relevant B-parameters are given in [25] by

\[ B_1(\mu_b) = 0.86(2) \left( \frac{\tau}{\Delta} \right), \quad B_4(\mu_b) = 1.17(2) \left( \frac{\tau}{\Delta} \right), \quad B_5(\mu_b) = 1.94(3) \left( \frac{\tau}{\Delta} \right). \]  

Now we briefly discuss \(B \to X_s \gamma\) constraint. The SUSY parameters we consider are also directly constrained by the measured branching ratio of inclusive radiative \(B\)-meson decay, \(B \to X_s \gamma\). We take this constraint into account, although it is not expected to be so severe as in a scenario with LR or RL mixing. In the operator basis given in [26], the SUSY contributions to the Wilson coefficients of magnetic operators in our scenario are

\[ C_{7\gamma}^{\text{SUSY}} = \frac{4}{9} \lambda_t \frac{\pi \alpha_s \sin 2 \theta_L e^{i \delta_L}}{\sqrt{2} G_F m_g^2} \left[ J_1(x_{bLg}) - J_1(x_{sLg}) \right], \]

\[ C_{8g}^{\text{SUSY}} = \frac{1}{\lambda_t} \frac{\pi \alpha_s \sin 2 \theta_L e^{i \delta_L}}{\sqrt{2} G_F m_g^2} \left[ \left( - \frac{3}{2} J_1(x_{bLg}) - \frac{1}{6} J_1(x_{sLg}) \right) - (b_L \leftrightarrow s_L) \right], \]  

where \(\lambda_t = V_{tb}^* V_{tb}\) and

\[ I_1(x) = \frac{1 - 6x + 3x^2 + 2x^3 - 6x^2 \log x}{12(1 - x)^4}, \]

\[ J_1(x) = \frac{2 + 3x - 6x^2 + x^3 + 6x \log x}{12(1 - x)^4}. \]  

There are also chirality flipped \(\tilde{C}_{7\gamma,8g}\) with \(L\) replaced by \(R\). Therefore, we can see that in principle \(\theta_{L(R)}, \delta_{L(R)}\) and \(m_s - m_b\) can be constrained. Compared to the LR(RL) mixing case where large SUSY contribution \(O(m_{\tilde{g}}/m_b)\) is possible due to the chirality flipping inside the loop, our scenario allows only a small SUSY correction to the SM contributions. In addition, although LL mixing gives a linear correction \(O(C_{7\gamma,8g}^{\text{SUSY}} / C_{7\gamma,8g}^{\text{SM}})\) due to the interference term, RR mixing generates only a quadratic correction \(O(|C_{7\gamma,8g}^{\text{SUSY}} / C_{7\gamma,8g}^{\text{SM}}|^2)\) because it is added incoherently to the SM contribution.
3 Numerical analysis

In this Section, we perform numerical analysis and show the constraints imposed by $\Delta m_s^{\text{exp}}$. We also consider the $\text{BR}(B \to X_s \gamma)$ constraint.

![Contour plots](image)

Figure 1: Contour plots for $|1+R|$ in $(m_s^L, \theta_L)$ plane. Sky blue region represents $2\sigma$ allowed region ($0.39 \leq |1+R| \leq 1.15$), blue $1\sigma$ allowed region ($0.58 \leq |1+R| \leq 0.96$), and white (grey) region is excluded at 95% CL by giving too small (large) $\Delta m_s$. The labeled thick lines represent the constant $(BR^{\text{tot}}(B \to X_s \gamma) - BR^{\text{SM}}(B \to X_s \gamma)) / BR^{\text{SM}}(B \to X_s \gamma)$ contours. Only LL mixing is assumed to exist. The fixed parameters are $m_{\tilde{g}} = 0.5$ (TeV), $m_{\tilde{b}_L} = 0.5$ (TeV), (a) $\delta_L = 0$, (b) $\delta_L = \pi/2$.

From (8) it is obvious that the larger the mass splitting between $\tilde{s}$ and $\tilde{b}$, the larger the SUSY contributions are. Therefore we expect that (15) constrains the mass splitting when the mixing angle $\theta_{L(R)}$ is large. This can be seen in Figure 1 where we show filled contour plots for $|1+R|$ in $(m_s^L, \theta_L)$ plane: sky blue region represents $2\sigma$ allowed region ($0.39 \leq |1+R| \leq 1.15$), blue $1\sigma$ allowed region ($0.58 \leq |1+R| \leq 0.96$), and white (grey) region is excluded at 95% CL by giving too small (large) $\Delta m_s$. For these plots we assumed...
that only LL mixing exists and fixed $m_{\tilde{g}} = 0.5$ TeV, $m_{\tilde{b}_L} = 0.5$ TeV. In Figure 1(a), we fixed $\delta_L = 0$. We can see that the SUSY interferes with the SM contribution constructively (i.e. the SUSY contribution has the same sign with the SM), and when the mixing angle is maximal, i.e. $\theta_L = \pm \pi/4$, $m_{\tilde{s}_L} - m_{\tilde{b}_L}$ cannot be greater than about 150 GeV. In Figure 1(b), we set $\delta_L = \pi/2$. The SUSY contribution can interfere destructively (i.e. in opposite sign) with the SM and much larger mass splitting is allowed. Therefore we can see that the allowed parameters are sensitive to the CPV phase.

Also the constant $\left( BR^{tot}(B \rightarrow X_s\gamma) - BR^{SM}(B \rightarrow X_s\gamma) \right)/BR^{SM}(B \rightarrow X_s\gamma)$ lines are shown. For fixed $\theta_L$, larger mass splitting $m_{\tilde{s}_L} - m_{\tilde{b}_L}$ gives larger deviation for the branching ratio. This can be understood from (20). However, for very large mass splitting the SUSY contribution decouples and the deviation eventually saturates. We can see that $BR^{tot}(B \rightarrow X_s\gamma)$ deviates from the SM predictions at most about 5% in the region allowed by $\Delta m_s$. Since

$$BR^{exp}(B \rightarrow X_s\gamma)/BR^{SM}(B \rightarrow X_s\gamma) = 1.06 \pm 0.13$$

for $E_\gamma > 1.6$ GeV [27], it is clear that the $BR(B \rightarrow X_s\gamma)$ constraint is completely irrelevant in Figure 1.

The plots for the scenario with RR mixing only are the same with Figure 1 because the expression for $B_s - \overline{B}_s$ is completely symmetric under $L \leftrightarrow R$. As mentioned above, the contribution to $BR(B \rightarrow X_s\gamma)$ is much smaller than LL case.

In Figure 2, contour plots for constant $|1 + R|$ in $(\theta_L, \delta_L)$ plane are shown. For Figure 2(a)(2(b)), we fixed $m_{\tilde{s}_L} = 0.8(1.0)$ TeV. The other parameters used are the same with those in Figure 1. We can again see the strong dependence on the CPV phase $\delta_L$. It can also be seen that the parameter space with large mixing angle $\theta_L$ can be made consistent with the experiments by cancellation with the SM contributions in the destructive interference region (i.e. $\delta_L \approx \pi/2$).

Now we consider a scenario with both LL and RR mixing at the same time. Then the operators $O_4$ and $O_5$ are additionally generated as mentioned above. They dominate $O_1$ or $\tilde{O}_1$ for sizable mixing angles. As a consequence, the constraint on the SUSY parameter
Figure 2: Contour plots for $|1 + R|$ in $(\theta_L, \delta_L)$ plane. (a) $m_{\tilde{s}_L} = 0.8$ (TeV), (b) $m_{\tilde{s}_L} = 1.0$ (TeV). The rest is the same with Figure 1.

space is very stringent as can be seen in Figure 3. In Figure 3 we set $m_{\tilde{g}} = 0.5$ TeV, $m_{\tilde{b}_L} = m_{\tilde{b}_R} = 0.5$ TeV, $m_{\tilde{s}_L} = m_{\tilde{s}_R} = 0.6$ TeV, and (a) $\delta_L = \delta_R = 0$ (b) $\delta_L = 0, \delta_R = \pi/2$.

Even for small mass splitting most region of the parameter space is ruled out by giving too large $\Delta m_s$. We can see that $BR(B \to X_s \gamma)$ is almost insensitive to the change of $\theta_R$ as mentioned before.

4 The predictions of $S_{\psi\phi}$ and $A_{SL}^s$

The CPV phase in the $B_s - \bar{B}_s$ mixing amplitude will be measured at the LHC in the near future through the time-dependent CP asymmetry

$$\frac{\Gamma(B_s(t) \to \psi\phi) - \Gamma(B_s(t) \to \psi\phi)}{\Gamma(B_s(t) \to \psi\phi) + \Gamma(B_s(t) \to \psi\phi)} \equiv S_{\psi\phi} \sin(\Delta m_s t).$$

(23)
Figure 3: Contour plots for $|1 + R|$ in $(\theta_L, \theta_R)$ plane. $m_{\tilde{s}_L} = m_{\tilde{s}_R} = 0.6$ (TeV). (a) $\delta_L = \delta_R = 0$ (b) $\delta_L = 0, \delta_R = \pi/2$. We assume both LL and RR mixing exist. The rest is the same with Figure 1.

In the SM, $S_{\psi\phi}$ is predicted to be very small, $S_{\psi\phi}^{SM} = -\sin 2\beta_s = 0.038 \pm 0.003$ ($\beta_s \equiv \arg[(V_{ts}^*V_{tb})/(V_{cs}^*V_{cb})]$) [7]. If the NP has additional CPV phases, however, the prediction

$$S_{\psi\phi} = -\sin(2\beta_s + \arg(1 + R))$$

can be significantly different from the SM prediction.

In Figure 4, we show $|1 + R|$ constraint and the prediction of $S_{\psi\phi}$ in $(m_{\tilde{s}_L}, \delta_L)$ plane. However, the $B \to X_s\gamma$ prediction is not shown from now on because it is irrelevant as mentioned above. For Figure 4(a), we assumed the scenario with LL mixing only and maximal mixing $\theta_L = \pi/4$. We fixed $m_{\tilde{g}} = 0.5$ TeV, $m_{\tilde{b}_L} = 0.5$ TeV. For Figure 4(b), we allowed both LL and RR mixing simultaneously, while fixing $m_{\tilde{g}} = 2$ TeV, $m_{\tilde{b}_L} = m_{\tilde{b}_R} = 1$ TeV, $m_{\tilde{s}_R} = 1.1$ TeV, $\theta_R = \pi/4$, $\delta_L = \pi/4$, and $\delta_R = \pi/2$. In both cases we can see that large $S_{\psi\phi}$ is allowed for large mass splitting between $m_{\tilde{b}_L}$ and $m_{\tilde{s}_L}$. At the moment, $S_{\psi\phi}$ can take any value in the range $[-1, 1]$ even after imposing the current $\Delta m_s^{\exp}$ constraint.
Figure 4: Contour plots for $|1 + R|$ in $(m_{\tilde{s}_L}, \delta_L)$ plane. The $S_{\psi \phi}$ predictions are also shown as thick contour lines. The thin red lines are constant $A_{SL}^s[10^{-3}]$ contours assuming $\text{Re}(\Gamma_{12}/M_{12}^s)^{\text{SM}} = -0.0040$. (a) Only LL mixing is assumed to exist. We fixed $m_{\tilde{g}} = m_{\tilde{b}_L} = 0.5$ TeV, $\delta_L = \pi/4$. (b) Both LL and RR mixing are assumed to exist simultaneously. We fixed $m_{\tilde{g}} = 2$ TeV, $m_{\tilde{b}_L} = m_{\tilde{b}_R} = 1$ TeV, $m_{\tilde{s}_R} = 1.1$ TeV, $\theta_R = \pi/4$, $\delta_L = \pi/4$, and $\delta_R = \pi/2$. The rest is the same with Figure 1.

Finally we consider the semileptonic CP asymmetry [28, 16, 7]

$$A_{SL}^s \equiv \frac{\Gamma(B_s \to \ell^+ X) - \Gamma(B_s \to \ell^- X)}{\Gamma(B_s \to \ell^+ X) + \Gamma(B_s \to \ell^- X)} = \text{Im} \left( \frac{\Gamma_{12}^s}{M_{12}^s} \right).$$  \hspace{1cm} (25)$$

It is approximated to be [7]

$$A_{SL}^s \approx \text{Re} \left( \frac{\Gamma_{12}^s}{M_{12}^s} \right) \text{Im} \left( \frac{1}{1 + R} \right),$$  \hspace{1cm} (26)$$

where $\text{Re}(\Gamma_{12}^s/M_{12}^s)^{\text{SM}} = -0.0040 \pm 0.0016$ [29]. The SM prediction is $A_{SL}^s(\text{SM}) = (2.1 \pm 0.4) \times 10^{-5}$ [29, 30].

In Figure 4, the thin red lines are constant $A_{SL}^s[10^{-3}]$ contours taking $\text{Re}(\Gamma_{12}^s/M_{12}^s)^{\text{SM}} = -0.0040$. We can readily see that the strong correlation between $S_{\psi \phi}$ and $A_{SL}^s$. This can
Figure 5: The correlation between $A_{SL}^s$ and $S_{\psi \phi}$. The red line is 1-\sigma upper bound.

be seen from the relation

$$A_{SL}^s = -\left| \text{Re} \left( \frac{\Gamma_{12}^s}{M_{12}^s} \right) \right| \frac{S_{\psi \phi}}{|1 + R|}. \quad (27)$$

For small $R$ the two observables are linearly correlated as can be seen in Figure 4.

In Figure 5, we show the correlation between $A_{SL}^s$ and $S_{\psi \phi}$. We scanned $0.5 \leq m_{\tilde{g}} \leq 4.0$ TeV, $0.5 < m_{\tilde{b}_L}, m_{\tilde{s}_L} < 2.0$ TeV, $-\pi/4 < \theta_L < \pi/4$ and $0 < \delta_L < 2\pi$, while fixing $m_{\tilde{g}} = m_{\tilde{b}_L} = 0.5$ TeV. The $\Delta m_s$ constraint is imposed with $0.39 \leq |1 + R| \leq 1.15$. We have checked that in the scenario with only LL (RR) mixing, we get the similar correlations. The red line is experimental 1-\sigma upper bound from $A_{SL}^s = -0.013 \pm 0.015$ [7]. Now several comments are in order: i) The values for $S_{\psi \phi}$ and $A_{SL}^s$ can be significantly different from the SM predictions. ii) The two observables are strongly correlated. These two facts were already noted in [7]. It has been checked that in the $(\text{Re}R, \text{Im}R)$ plane the above scanned points can completely fill the region allowed by $\Delta m_s$. This explains why the correlation in Figure 5 is basically the same with model-independent prediction in [7]. iii) Although it looks like that large negative $S_{\psi \phi}$ value is disfavored, due to large error in $\text{Re}(\Gamma_{12}^s/M_{12}^s)^{\text{SM}}$ we cannot definitely rule out the region at the moment.
5 Conclusions

We considered the MSSM scenario with large LL and/or RR mixing in the down-type mass squared matrix. This scenario is strongly constrained by the recent measurements of $B_s - \bar{B}_s$ mass difference, $\Delta m_s$, in contrast with the MSSM scenario where the flavor mixing is controlled only by the CKM matrix [16, 8]. The constraint is most stringent when both LL and RR mixing exist simultaneously. It is also shown that the allowed region is quite sensitive to the CP violating phase.

We also considered the time-dependent CP asymmetry, $S_{\psi\phi}$, and the semileptonic CP asymmetry, $A_{SL}^s$. It was shown that the $S_{\psi\phi}$ and $A_{SL}^s$ can take values significantly different from the SM predictions. There is also strong correlation between $S_{\psi\phi}$ and $A_{SL}^s$.

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