$B^0 - \overline{B^0}$ mixing, $B \to J/\psi K_s$, and $B \to X_d\ \gamma$ in general MSSM

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Abstract

We consider the gluino-mediated SUSY contributions to $B^0 - \overline{B^0}$ mixing, $B \to J/\psi K_s$ and $B \to X_d \gamma$ in the mass insertion approximation. We find the (LL) mixing parameter can be as large as $|(\delta^d_{13})_{LL}| \lesssim 2 \times 10^{-1}$, but the (LR) mixing is strongly constrained by the $B \to X_d \gamma$ branching ratio and we find $|(\delta^d_{13})_{LR}| \lesssim 10^{-2}$. The implications for the direct CP asymmetry in $B \to X_d \gamma$ and the dilepton charge asymmetry (A_{ll}) are also discussed, where substantial deviations from the standard model (SM) predictions are possible.

Recent observations of large CP violation in $B \to J/\psi K_s$ [1, 2] giving

$$\sin 2\beta = (0.79 \pm 0.10) \tag{1}$$

confirm the SM prediction and begin to put a strong constraint on new physics contributions to $B^0 - \overline{B^0}$ mixing and $B \to J/\psi K_s$, when combined with $\Delta m_{B_d} = (0.472 \pm 0.017)\ \mathrm{ps}^{-1}$ [3]. Since the decay $B \to J/\psi K_s$ is dominated by the tree level SM process $b \to c\bar{c}s$, we expect the new physics contribution may affect significantly only the $B^0 - \overline{B^0}$ mixing and not the decay $B \to J/\psi K_s$. However, in the presence of new physics contributions to $B^0 - \overline{B^0}$ mixing, the same new physics would generically affect the $B \to X_d \gamma$ process. In this talk, we present our recent work on $B^0 - \overline{B^0}$ mixing, $B \to J/\psi K_s$ and $B_d \to X_d \gamma$ in general SUSY models where flavor and CP violation due to the gluino mediation can be important [5], where more detailed references can be found. We use the mass insertion approximation (MIA) for this purpose. Comprehensive work has been done for the first two observables in the MIA considering Δm_{B_d} and $\sin 2\beta$ constraints only (see Ref. [2] for the most recent studies with such an approach). In our work, we also include the dilepton charge asymmetry A_{ll} and the $B_d \to X_d \gamma$ branching ratio constraint extracted from the recent experimental upper limit on the $B \to \rho\gamma$ branching ratio [4] $B(B \to \rho\gamma) < 2.3 \times 10^{-6}$, and rederive the upper limits on the $(\delta^d_{13})_{LL}$ and $(\delta^d_{13})_{LR}$ mixing parameters assuming that only one of these gives a dominant SUSY contribution in addition to the standard model (SM) contribution. In addition we study the direct CP asymmetry in $B_d \to X_d \gamma$ on the basis of our result for the SUSY contribution, and discuss how much deviations from the SM predictions are expected. Although we confine ourselves here to the gluino-mediated SUSY constributions only, our strategy can be extended to any new physics scenario with a substantial constribution to $B^0 - \overline{B^0}$ mixing and $B \to X_d\gamma$.

The effective Hamiltonian for $B^0 - \overline{B^0}$ mixing ($\Delta B = 2$) and $B \to X_d\gamma$ including the gluino loop contributions can be found in Ref. [2] and Ref. [5], respectively. The $\Delta B = 2$ effective Hamiltonian will contribute to Δm_B, the dilepton charge asymmetry and the time dependent CP asymmetry in the decay $B \to J/\psi K_s$ via the phase of the $B^0 - \overline{B^0}$ mixing. Defining the mixing matrix element by

$$M_{12}(B^0) \equiv \frac{1}{2m_B}\ \langle B^0 | H_{\rm eff}^{\Delta B=2} | \overline{B^0} \rangle \tag{2}$$

one has $\Delta m_{B_d} = 2|M_{12}(B_d^0)|$. On the other hand, the phase of the $B^0 - \overline{B^0}$ mixing amplitude $M_{12}(B^0) \equiv \exp(2i\beta')\ |M_{12}(B^0)|$ appears in the time dependent asymmetry : $A_{\rm CP}^{\rm mix}(B^0 \to J/\psi K_s) = \sin 2\beta'\ \sin \Delta m_{B_d} t$. Finally, the dilepton charge asymmetry A_{ll} is also determined by $M_{12}(B^0)$, albeit a possible long distance contribution to $\Gamma_{SM}(B^0)$:

$$A_{ll} \equiv \frac{N(BB) - N(\bar{B}\bar{B})}{N(BB) + N(\bar{B}\bar{B})} \approx {\rm Im}\,(\Gamma_{12}/M_{12}) \approx {\rm Im}\left(\frac{\Gamma_{12}^{\rm SM}}{M_{12}^{\rm SM} + M_{12}^{\rm SUSY}} \right). \tag{3}$$

Here M_{12}, Γ_{12} are the matrix elements of the Hamiltonian in the $(B^0, \overline{B^0})$ basis:

$$\frac{1}{2m_B}\ \langle \overline{B} | H_{\rm full} | B \rangle = M_{12} - \frac{i}{2}\Gamma_{12}.$$

We have used the fact $\Gamma_{12}^{\rm FULL} \approx \Gamma_{12}^{\rm SM}$. The SM prediction is $-1.54 \times 10^{-3} \leq A_{ll}^{\rm SM} \leq -0.16 \times 10^{-3}$, whereas the current world average is [6] $A_{ll}^{\rm exp} \approx (0.2 \pm 1.4) \times 10^{-2}$.

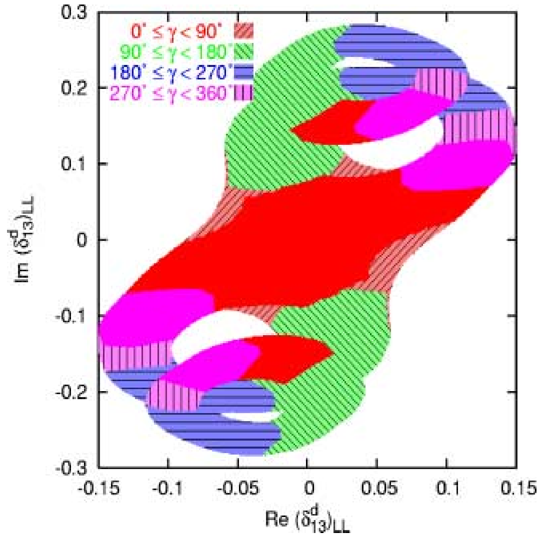
The effective Hamiltonian relevant to $\Delta B = 1$ processes involves four quark operators and $b \to d\gamma$ and $b \to dg$ penguin operators. Since we are not going to discuss $\Delta B = 1$ nonleptonic decays due to theoretical uncertainties related with factorization, we shall consider the inclusive radiative decay $B \to X_d\gamma$ only. The relevant effective Hamiltonian for this process is given by [7]. Varying f_{B_d}, $|V_{ub}|$, and $|V_{cb}|$ in the uncertainty range, and γ between $(54.8 \pm 6.2)^\circ$ [8], we get the branching ratio for this decay in the SM to be $8.9 \times 10^{-6} - 1.1 \times 10^{-5}$. The direct CP asymmetry in the SM is about $-15\% - -10\%$ [7]. We have updated the previous predictions by Ali et al. [7] using the present values of CKM parameters.

In the numerical analysis, we impose the following quantities as constraints :

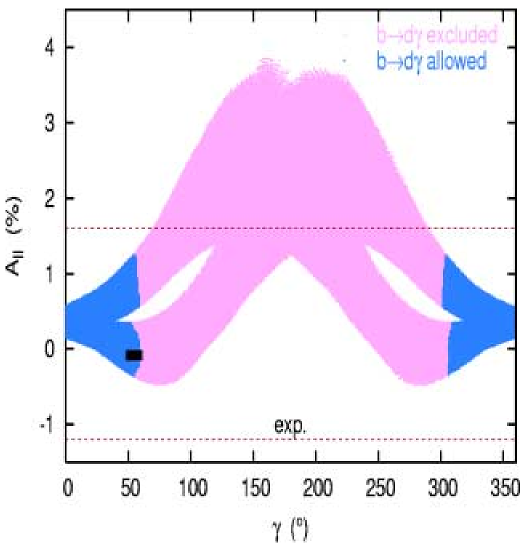
$$\Delta m_{B_d} = (0.472 \pm 0.017)\ {\rm ps}^{-1}, \quad A_{\rm CP}^{\rm mix} = (0.79 \pm 0.10), \quad {\rm Br}(B \to X_d\gamma) < 1 \times 10^{-5}$$

For the dilepton charge asymmetry, we do not use this constraint to restrict the allowed parameter space, since it is weaker than the other constraints. We indicate the parameter space where the resulting A_{ll} falls out of the 1σ range. We impose these constraints at 68 % C.L. (1σ) as we vary the KM angle γ between 0 and 2π. In all cases, we set the common squark mass $\tilde{m} = 500$ GeV and $x = 1$ ($m_{\tilde{g}} = \tilde{m}$). Finally for the mass insertion parameters $(\delta_{13}^d)_{AB}$, we consider two cases.

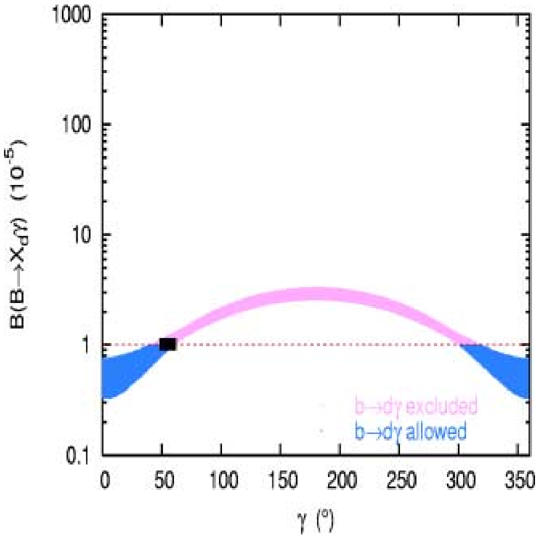
In Figs. 1 (a), we show the allowed parameter space in the $({\rm Re}(\delta_{13}^d)_{LL}, {\rm Im}(\delta_{13}^d)_{LL})$ plane for different values of the KM angle γ with different color codes: dark (red) for



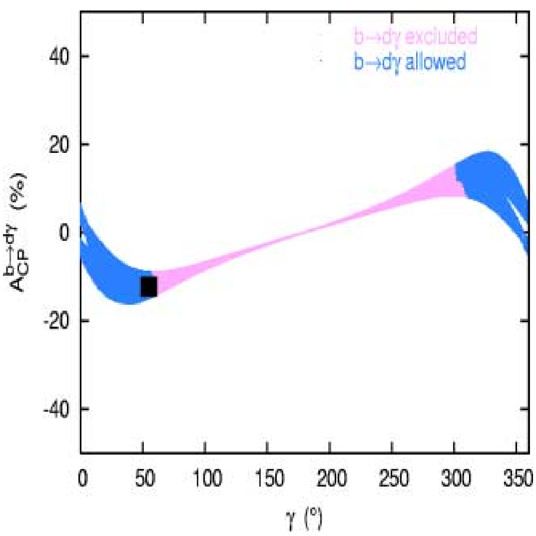
(a) LL mixing only



(b) A_{ll}

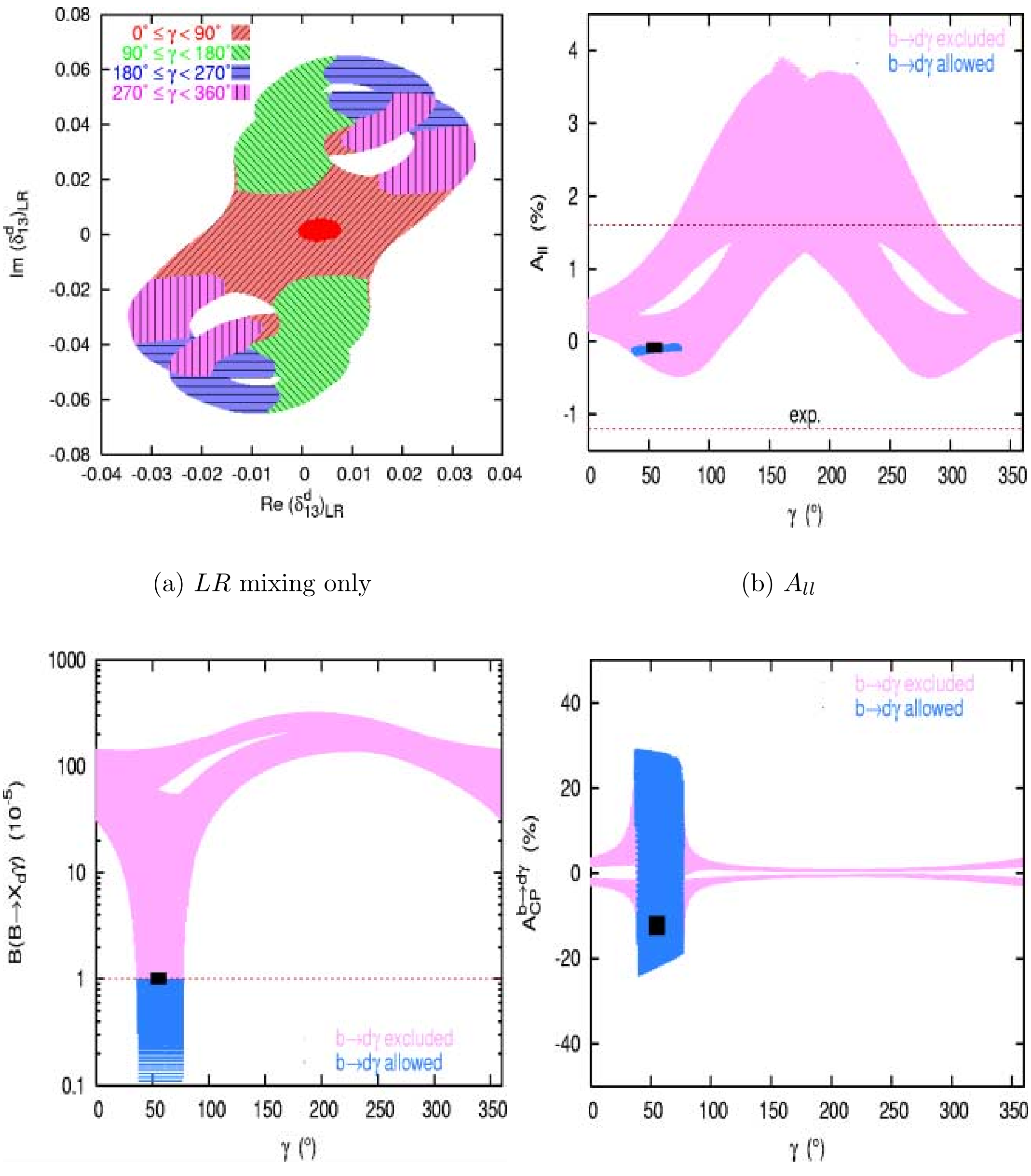


(c) B ($B \to X_d\gamma$)



(d) $A_{\rm CP}^{b\to d\gamma}$

Figure 1: (a) The allowed range in the LL insertion case for the parameters $(\mathrm{Re}(\delta^d_{13})_{AB}, \mathrm{Im}(\delta^d_{13})_{AB})$ for different values of the KM angle γ with different color codes: dark (red) for $0^\circ \leq \gamma \leq 90^\circ$, light gray (green) for $90^\circ \leq \gamma \leq 180^\circ$, very dark (blue) for $180^\circ \leq \gamma \leq 270^\circ$ and gray (magenta) for $270^\circ \leq \gamma \leq 360^\circ$. The region leading to a too large branching ratio for $B_d \to X_d\gamma$ is colored lightly and covered by parallel lines. (b), (c) and (d) are A_{ll}, B ($B \to X_d\gamma$) and direct CP asymmetry therein as functions of KM angle γ.



(a) LR mixing only (b) A_{ll}

(c) B $(B \to X_d\gamma)$ (d) $A_{\rm CP}^{b\to d\gamma}$

Figure 2: (a) The allowed range in the LR insertion case for the parameters $({\rm Re}(\delta^d_{13})_{AB}, {\rm Im}(\delta^d_{13})_{AB})$ for different values of the KM angle γ with different color codes: dark (red) for $0° \leq \gamma \leq 90°$, light gray (green) for $90° \leq \gamma \leq 180°$, very dark (blue) for $180° \leq \gamma \leq 270°$ and gray (magenta) for $270° \leq \gamma \leq 360°$. The region leading to a too large branching ratio for $B_d \to X_d\gamma$ is colored lightly and covered by parallel lines. (b), (c) and (d) are A_{ll}, B $(B \to X_d\gamma)$ and direct CP asymmetry therein as functions of KM angle γ.

$0^\circ \leq \gamma \leq 90^\circ$, light gray (green) for $90^\circ \leq \gamma \leq 180^\circ$, very dark (blue) for $180^\circ \leq \gamma \leq 270^\circ$ and gray (magenta) for $270^\circ \leq \gamma \leq 360^\circ$. The region leading to a too large branching ratio for $B_d \to X_d\gamma$ is covered by slanted lines. And the region where A_{ll} falls out of the data within 1σ range is already excluded by the $B \to X_d\gamma$ branching ratio constraint [Fig. 1 (b)]. Note that the KM angle γ should be in the range between $\sim -60^\circ$ and $\sim +60^\circ$, and A_{ll} can have the opposite sign compared to the SM prediction, even if the KM angle is the same as its SM value $\gamma \simeq 55^\circ$ due to the SUSY contributions to $B^0 - \overline{B^0}$ mixing. This is entirely different from Ref. [2], where the KM angle γ is not constrained at all. $B \to X_d\gamma$ plays an important role here. In Figs. 1 (c) and (d), we show the branching ratio of $B_d \to X_d\gamma$ and the direct CP asymmetry therein, respectively, as functions of the KM angles γ for the LL insertion only. The SM predictions

$$B(B_d \to X_d\gamma) = (0.9 - 1.1) \times 10^{-5}, \quad A_{\rm CP}^{b\to d\gamma} = (-15 \sim -10)\%$$

are indicated by the black boxes. In this case, the KM angle γ is constrained in the range $\sim -60^\circ$ and $\sim +60^\circ$. The direct CP asymmetry is predicted to be between $\sim -15\%$ and $\sim +20\%$. In the LL mixing case, the SM gives the dominant contribution to $B_d \to X_d\gamma$, but the KM angle can be different from the SM case, because SUSY contributions to the $B^0 - \overline{B^0}$ mixing can be significant and the preferred value of γ can change from the SM KM fitting. This is the same in the rare kaon decays and the results obtained in Ref. [9] apply without modifications. If the KM angle γ is substantially different from the SM value (say, $\gamma = 0$), we could anticipate large deviations in the $B_d \to X_d\gamma$ branching ratio and the direct CP violation thereof.

For the LR mixing [Fig. 2 (a)], the $B(B_d \to X_d\gamma)$ puts an even stronger constraint on the LR insertion, whereas the A_{ll} does not play any role. In particular, the KM angle γ can not be too much different from the SM value in the LR mixing case, once the $B(B_d \to X_d\gamma)$ constraint is included. Only $30^\circ \lesssim \gamma \lesssim 80^\circ$ is compatible with all the data from the B system, even if we do not consider the ϵ_K constraint. The resulting parameter space is significantly reduced compared to the result obtained in Ref. [2]. The limit on the LR insertion parameter will become even stronger as the experimental limit on $B_d \to X_d\gamma$ will be improved in the future. In Fig. 2 (b), we show the predictions for A_{ll} as a function of the KM angle γ for the LR insertion only. On the other hand, for the LR insertion case, the $B \to X_d\gamma$ constraint rules out essentially almost all the parameter space region, and the resulting A_{ll} is essentially the same as for the SM case. In Figs. 2 (c) and (d), we show the branching ratio of $B_d \to X_d\gamma$ and the direct CP asymmetry therein, respectively, as functions of the KM angles γ for the LR insertion only. As before, the black boxes represent the SM predictions for $B(B_d \to X_d\gamma)$ and the direct CP asymmetry therein. In the LR insertion case, there could be substantial deviations in both the branching ratio and the CP asymmetry from the SM predictions, even if the Δm_B and $\sin 2\beta$ is the same as the SM predictions as well as the data. For the LL insertion, such a large deviation is possible, since the KM angle γ can be substantially different from the SM value. On the other hand, for the LR mixing, the large deviation comes from the complex $(\delta_{13}^d)_{LR}$ even if the KM angle is set to the same value as in the SM. The size of $(\delta_{13}^d)_{LR}$ is too small to affect the $B^0 - \overline{B^0}$ mixing, but is still large enough too affect $B \to X_d\gamma$. Our model independent study indicates that the current data on the Δm_B, $\sin 2\beta$ and A_{ll} do still allow a possibility for large deviations in $B \to X_d\gamma$, both in the branching ratio and the direct CP asymmetry thereof. The latter variables are indispensable to test completely the KM paradigm for CP violation and get ideas on possible new physics with new flavor/CP violation in $b \to d$ transition.

In conclusion, we considered the gluino-mediated SUSY contributions to $B^0 - \overline{B^0}$ mixing, $B \to J/\psi K_s$ and $B \to X_d \gamma$ in the mass insertion approximation. We find that the (LL) mixing parameter can be as large as $|(\delta_{13}^d)_{LL}| \lesssim 2 \times 10^{-1}$, but the (LR) mixing is strongly constrained by the $B \to X_d \gamma$ branching ratio: $|(\delta_{13}^d)_{LR}| \lesssim 10^{-2}$. The implications for the direct CP asymmetry in $B \to X_d \gamma$ are also discussed, where substantial deviations from the SM predictions are possible both in the LL and LR insertion cases for different reasons, as discussed in the previous paragraphs. Our analysis demonstrates that all the observables, A_{ll}, the branching ratio of $B \to X_d \gamma$ and the direct CP violation thereof are very important, since they could provide informations on new flavor and CP violation from $(\delta_{13}^d)_{LL,LR}$ (or any other new physics scenarios with new flavor/CP violations). Also they are indispensable in order that we can ultimately test the KM paradigm for CP vioaltion in the SM.

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