UPPER BOUNDS ON SUSY CONTRIBUTIONS TO $b \rightarrow s$ TRANSITIONS FROM $B_s - \bar{B}_s$ MIXING

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We study the constraints on supersymmetric contributions to $b \rightarrow s$ transitions from the recent allowed range and measurement of $B_s - \bar{B}_s$ mixing obtained by the D0 and CDF collaborations at the Tevatron. We compute the upper bounds on the relevant off-diagonal squark mass terms and compare them with the bounds coming from $\Delta F = 1$ decays. We find that the constraints on chirality-flipping mass insertions are unaffected. Conversely, the measurement of $B_s - \bar{B}_s$ mixing is effective in constraining chirality-conserving mass insertions, and it has striking effects in the case in which left- and right-handed insertions have similar size. Finally, we discuss the phase of the $B_s - \bar{B}_s$ mixing amplitude in the presence of SUSY contributions.

The study of Flavour Changing Neutral Currents (FCNC) and CP violation at low energies is a very powerful probe of New Physics (NP). In particular, the Unitarity Triangle (UT) analysis $^{1,2}$ and the study of rare $K$ and $B$ decays $^3$ provide stringent constraints on additional sources of flavour and CP violation beyond the SM. The impact of these constraints on supersymmetry (SUSY) is impressive $^4$. Indeed, the Minimal Supersymmetric Standard Model (MSSM) contains about a hundred new sources of flavour and CP violation, mainly given by the sfermion mass matrices $^5$. A closer look at the data from $K$ and $B_d$ physics reveals that, while new sources of flavour violation in $s \rightarrow d$ and $b \rightarrow d$ transitions are strongly constrained, the possibility of large NP contributions to $b \rightarrow s$ transitions remains open $^2$.

Interestingly, CP violation in nonleptonic $b \rightarrow s$ penguin decays, such as $B \rightarrow \phi K_S$, exhibits some hint of a departure from SM expectations $^6$. SUSY can account for such deviations while respecting all other available constraints from $B$ physics $^7$. In addition, in SUSY Grand Unified Theories (GUTs) the large mixing angle observed in the neutrino sector can be connected to a large mixing between right-handed $b$- and $s$-type squarks $^8$. Therefore, SUSY models with large contributions to $b \rightarrow s$ transitions have received a lot of interest recently $^4$.

A crucial piece of information which has been missing until now is the amplitude and phase of $B_s - \bar{B}_s$ mixing. Clearly, this would provide an independent source of information on $b \rightarrow s$ transitions. While the $B_s - \bar{B}_s$ mixing phase remains unknown, a preliminary measurement of the mixing amplitude has been presented very recently $^9$. The aim of this paper is to assess the impact of this measurement on SUSY sources of $b \rightarrow s$ transitions.

To fulfill our task in a model-independent way we use the mass-insertion approximation. Treating off-diagonal sfermion mass terms as interactions, we perform a perturbative expansion of FCNC amplitudes in terms of mass insertions. The lowest nonvanishing order of this expansion gives an excellent approximation to the full result, given the tight experimental constraints on flavour changing mass insertions. It is most convenient to work in the super-CKM basis, in which all gauge interactions carry the same flavour dependence as SM ones. In this basis, we define the mass insertions $(\delta_{ij}^R)^{AB}$ as the off-diagonal mass terms connecting down-type squarks of flavour $i$ and $j$ and helicity $A$ and $B$, divided by the average squark mass.

The constraints on $(\delta_{ij}^R)^{AB}$ have been studied in detail in ref. $^1$, using as experimental input the branching ratios and CP asymmetries of $b \rightarrow s\gamma$ and $b \rightarrow s\ell^+\ell^-$ decays, and the lower bound on $B_s - \bar{B}_s$ mixing previously available. An update using the summer 2005 data has been presented in ref. $^2$. We perform the same analysis using, instead of the previously available lower bound, the following result for $B_s - \bar{B}_s$ mixing:

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

and refer the reader to $^2$ for the details of the procedure $^{13}$.

For definitiveness, we choose an average squark mass of 350 GeV, a gluino mass of 350 GeV, $\mu = -350$ GeV and $\tan \beta = 3$ $^{14}$. In Fig. $^1$ we present the allowed range in the $\text{Re}(\delta_{23}^R)^{LL}$-$\text{Im}(\delta_{23}^R)^{LL}$ plane, using the previous lower bound (upper left) or the present measurement (upper right) of $\Delta m_s$. We see that the effect of the measurement is to suppress the regions $|\text{Im}(\delta_{23}^R)^{LL}| \gtrsim 0.2$. For higher values of $\tan \beta$, the effect of $\Delta m_s$ becomes less important, since the constraints from $\Delta F = 1$ processes become comparable for $\tan \beta \sim 10$ and then dominate, as can be seen looking at the lower part of Fig. $^1$ where the same analysis has been performed with $\tan \beta = 10$.

In Fig. $^2$ we present the allowed range in the $\text{Re}(\delta_{23}^R)^{RR}$-$\text{Im}(\delta_{23}^R)^{RR}$ plane, using the previous lower bound (left) or the present value (right) of $\Delta m_s$ (the plots correspond to $\tan \beta = 3$, but the dependence on $\tan \beta$ is negligible here and in the following). The effect of the constraint from $\Delta m_s$ can clearly be seen, leading
to an upper bound on $|\text{Re}(\delta_{23})_{RR}|$ around 0.4. The effect of the bound from $\Delta m_s$ is much more striking in the case of $(\delta_{23})_{LL} = (\delta_{23})_{RR}$, as can be seen in Fig. 3. In this case, the upper bound obtained on $|\text{Re}(\delta_{23})_{LL=RR}|$ is around $10^{-1}$. For the other mass insertions $(\delta_{23})_{LR,RL}$, the constraint from $\Delta m_s$ is irrelevant since the main effect comes from $\Delta F = 1$ processes. This leaves open the possibility of sizable deviation from the SM prediction in the CP asymmetries in $b \to s$ penguin decays.

Finally, in Fig. 4 we present the p.d.f. for $\sin 2\beta_s$, where $2\beta_s$ is the phase of the $B_s - \bar{B}_s$ mixing amplitude, relevant for measurements of CP violation in $B_s$ physics. Comparing these results with the SM value $\sin 2\beta_s^{SM} = -(3.65 \pm 0.30) \times 10^{-2}$, it is evident that there is still plenty of room to observe non-standard CP violation in the $B_s$ system.

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FIG. 2: Allowed range in the $\text{Re}(\delta_{23}^{d})_{RR} - \text{Im}(\delta_{23}^{d})_{RR}$ plane. In the plots on the left (right), the lower bound (measurement) on $\Delta m$ is used. See the text for details.

FIG. 3: Allowed range in the $\text{Re}(\delta_{23}^{d})_{LL} - \text{Im}(\delta_{23}^{d})_{LL}$ plane. In the plots on the left (right), the lower bound (measurement) on $\Delta m$ is used. See the text for details.

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FIG. 4: P.d.f. for \( \sin 2\beta_s \) in the presence of \((\delta_{23}^d)_{RR}\) (left) or \((\delta_{23}^d)_{LL}=RR\) (right). See the text for details.

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[13] In a previous version of this Letter, we used the milder two-sided 90% C.L. bound from the D0 collaboration [11].

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