Addendum to: Implications of the measurements of B_s - $\bar{B}_s$ mixing on SUSY models

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(Received 7 July 2010; published 1 December 2010)

This is an addendum to the previous publication, [P. Ko and J.-h. Park, *Phys. Rev. D* **80**, 035019 (2009)]. The semileptonic charge asymmetry in B_s decays is discussed in the context of the general minimal supersymmetric standard model with gluino-mediated flavor and CP violation in light of the recent measurements at the Tevatron.

DOI: 10.1103/PhysRevD.82.117701

PACS numbers: 12.60.Jv, 11.30.Er, 13.25.Hw

In this addendum to Ref. [1], we discuss the semileptonic charge asymmetry in the B_s decays in general supersymmetric models with gluino-mediated flavor and CP violation, in light of the recent measurements of like-sign dimuon charge asymmetry by D0 Collaboration at the Tevatron. The model is described in Ref. [1], to which we refer for the details of the model and other phenomenological aspects related with B_s - $\bar{B}_s$ mixing, the branching ratio of and CP asymmetry in $B \rightarrow X_s \gamma$, $B_d \rightarrow \phi K_S$ and CP asymmetry in $B_s \rightarrow J/\psi \phi$.

One can define the semileptonic charge asymmetry in the decay of B_q mesons as

$$a_{\text{sl}}^q \equiv \frac{\Gamma(\bar{B}_q^0(t) \rightarrow \mu^+ X) - \Gamma(B_q^0(t) \rightarrow \mu^- X)}{\Gamma(\bar{B}_q^0(t) \rightarrow \mu^+ X) + \Gamma(B_q^0(t) \rightarrow \mu^- X)}, \quad (1)$$

for $q = d, s$. In terms of the matrix elements of the effective Hamiltonian describing the damped oscillation between B_q^0 and $\bar{B}_q^0$, the asymmetry a_{sl}^q is given by

$$a_{\text{sl}}^q = \text{Im} \frac{\Gamma_{12}^q}{M_{12}^q} = \frac{|\Gamma_{12}^q|}{|M_{12}^q|} \sin \phi_q, \quad (2)$$

where $\phi_q \equiv \arg(-M_{12}^q/\Gamma_{12}^q)$. That is, this is another observable measuring CP violation in B_q - $\bar{B}_q$ mixing. We take the approximation, $\Gamma_{12}^q = \Gamma_{12}^{q, \text{SM}}$, since the leading contribution comes from the absorptive part of the box diagrams for B_q - $\bar{B}_q$ mixing and there is no new common final state into which both B_q and $\bar{B}_q$ can decay in our scenario. The size of M_{12}^q is fixed by the ΔM_q data up to hadronic uncertainties. Then, a_{sl}^q can be regarded as a sine function of ϕ_q , multiplied by the factor $|\Gamma_{12}^q|/|M_{12}^q|$. This curve is traversed as one allows for arbitrary supersymmetric contributions to M_{12}^q obeying the ΔM_q constraint. Combining the standard model (SM) predictions [2],

$$\begin{aligned} |\Gamma_{12}^{s, \text{SM}}|/|M_{12}^{s, \text{SM}}| &= (49.7 \pm 9.4) \times 10^{-4}, \\ \phi_s^{\text{SM}} &= (4.2 \pm 1.4) \times 10^{-3}, \end{aligned} \quad (3)$$

one finds the vanishingly small asymmetry $a_{\text{sl}}^{s, \text{SM}} \sim 2 \times 10^{-5}$.

Recently, the D0 Collaboration reported a measurement of like-sign dimuon charge asymmetry [3]. They interpreted the result as coming from the mixing of neutral B mesons and have found an evidence for an anomaly in the asymmetry,

$$A_{\text{sl}}^b \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}, \quad (4)$$

where N_b^{++} and N_b^{--} are the number of events where decays of two b hadrons yield two positive and two negative muons, respectively. Their result shows a discrepancy of 3.2σ from the SM expectation. This asymmetry consists of a_{sl}^d coming from B_d decays as well as a_{sl}^s from B_s . One can extract the asymmetry relevant to the B_s meson using the measured value of a_{sl}^d and the result by D0 is

$$a_{\text{sl}}^s = -0.0146 \pm 0.0075. \quad (5)$$

This is 1.9σ away from the SM prediction. We shall use this data in the following discussion.

This D0 result has drawn interest in new physics explanations [4–8]. (For earlier works, see e.g. Refs. [9–11].) Some of the works consider extra contributions to Γ_{12}^q since the dimuon charge asymmetry depends on it as well as on M_{12}^q [5,6]. This approach also has a possibility of altering $|\Delta\Gamma_s|$ even though its current experimental value is in agreement with the SM one, $2|\Gamma_{12}^{s, \text{SM}} \cos \phi_s^{\text{SM}}|$ [2,12,13]. As we said, Γ_{12}^q is fixed in the present work and we are left only with the option of modifying M_{12}^q . Therefore, $|\Delta\Gamma_s|$ shall become smaller than its SM prediction as $|\phi_s|$ grows up to $\mathcal{O}(1)$.

We perform the numerical analysis in the same way as in the main article [1]. The crucial ingredient for evaluating a_{sl}^s is the range of ϕ_s to be used. Following the latest reports from D0 [3] and CDF [14], there have been a couple of attempts to make a global fit of B_s - $\bar{B}_s$ mixing parameters including ϕ_s [4,6]. However, the official combination is not available yet. Partly because of this reason and partly for the sake of coherent presentation, we keep using the range used in Refs. [1,15],

$$\phi_s \in [-1.10, -0.36] \cup [-2.77, -2.07]. \quad (6)$$

As a matter of fact, this range is not very different from the 2σ interval found in Ref. [6]. As for $\Gamma_{12}^{s,SM}/M_{12}^{s,SM}$, we take its central value from Eqs. (3). Considering the error in this ratio could add 20% more of uncertainty to the thickness of the a_{sl}^s band in the following figures.

We show a_{sl}^s as a function of ϕ_s for $\tan\beta = 3$ in Figs. 1. The four plots are for the LL , the RR , the $LL = RR$, and the $LL = -RR$ cases, respectively. One can immediately notice the aforementioned sinusoidal dependence of a_{sl}^s on ϕ_s , coming from Eq. (2) and the ΔM_s constraint. This feature is not only true of all the cases shown here but also of any new physics model that does not affect Γ_{12}^s . The nonzero thickness of the band arises from the uncertainty in ΔM_s . The difference between a_{sl}^s and its central value is at least about 1.0σ . This discrepancy becomes worse but only slightly after ϕ_s is restricted inside its preferred ranges (colored in blue). If one incorporates the $B \rightarrow X_s \gamma$ constraint, substantial part of the blue regions is excluded, in particular, in the upper two cases with one insertion. Even then, however, the lowest possible value of $a_{sl}^s \simeq -0.006$ within the blue region does not change. In the lower two cases with two insertions, $B \rightarrow X_s \gamma$ does

not play an important role since the supersymmetric effect on $B_s - \bar{B}_s$ mixing is enhanced.

Plots for $\tan\beta = 10$ are displayed in Fig. 2. The model-independent characteristics dictated by Eq. (2) remain exactly the same as in the previous set of figures. The only difference is the stronger $B \rightarrow X_s \gamma$ constraint due to higher $\tan\beta$. Here, it excludes more part of the blue regions. Again, this is particularly true of the upper two cases in which a_{sl}^s is restricted closer to its SM value. In Fig. 2(a), ΔM_s , ϕ_s , and $B \rightarrow X_s \gamma$, together allow a_{sl}^s to be as low as -0.003 . In Fig. 2(b), there is no solution satisfying all the three constraints. One could get $a_{sl}^s \simeq -0.0006$ if ϕ_s were not limited. In the lower two cases, the lowest a_{sl}^s , compatible with ΔM_s and ϕ_s , is almost the same as in Figs. 1.

We summarize. We have examined how a_{sl}^s is influenced by the LL and/or RR mass insertions. For $\tan\beta = 3$, one can reduce the discrepancy between a_{sl}^s and its SM expectation from 1.9σ down to 1.0σ in each of the LL , RR , $LL = RR$, and $LL = -RR$ cases, obeying the ΔM_s , $B \rightarrow X_s \gamma$, and ϕ_s constraints. This amounts to reduction of the A_{sl}^b tension from 3.2σ down to 2.2σ if one assumes no new physics in the $b \rightarrow d$ transition. For $\tan\beta = 10$,

FIG. 1 (color online). Plots of a_{sl}^s as a function of ϕ_s for the four different cases with $\tan\beta = 3$. The hatched gray region leads to the lightest squark mass < 100 GeV. The hatched region is excluded by the $B \rightarrow X_s \gamma$ constraint. The light gray region (cyan online) is allowed by ΔM_s . The dark gray region (blue online) is allowed both by ΔM_s and ϕ_s . The black square is the SM point. The dashed and solid lines (both red online) mark the 1σ and 2σ ranges of a_{sl}^s , respectively.

FIG. 2 (color online). Plots with $\tan\beta = 10$. The meaning of each region is the same as in Figs. 1.

it becomes difficult for the LL and RR cases whereas the $LL = RR$ and $LL = -RR$ cases are less limited by $B \rightarrow X_s \gamma$.

We thank A. Ali, A. Lenz, and S. Mishima for useful comments.

Note added in proof.—While we were waiting for the approval for submission, a paper by J. K. Parry appeared on the e-print archive that employs a related model [8].

However, the flavor structure of the squark mass matrix therein is different from any of those here. As far as squarks are concerned, he considers only one case where $(\delta_{23}^d)_{RR}$ is a variable parameter and $(\delta_{23}^d)_{LL}$ is fixed to a value that comes from renormalization group running. This way of parameter scan is not covered in this work. He does not display the $B \rightarrow X_s \gamma$ constraint on his plots, but it may not be very restrictive in his case depending on μ and $\tan\beta$. (See e.g. Fig. 4 in Ref. [16].)

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