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Addendum to: Implications of the measurements of B_s–$\overline{B_s}$ mixing on SUSY models

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This is an addendum to the previous publication, P. Ko and J.-h. Park, Phys. Rev. **D80**, 035019 (2009). The semileptonic charge asymmetry in B_s decays is discussed in the context of general MSSM with gluino-mediated flavor and CP violation in light of the recent measurements at the Tevatron.

In this addendum to Ref. [1], we discuss the semileptonic charge asymmetry in the B_s decays in general SUSY models with gluino-mediated flavor and CP violation, in light of the recent measurements of like-sign dimuon charge asymmetry by DØ 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–$\overline{B_s}$ mixing, the branching ratio of and CP asymmetry in $B \to X_s\gamma$, $B_d \to \phi K_S$ and CP asymmetry in $B_s \to J/\psi\phi$.

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

$$a_{\rm sl}^q \equiv \frac{\Gamma(\overline{B_q^0}(t) \to \mu^+ X) - \Gamma(B_q^0(t) \to \mu^- X)}{\Gamma(\overline{B_q^0}(t) \to \mu^+ X) + \Gamma(B_q^0(t) \to \mu^- X)}, \quad (1)$$

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

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

where $\phi_q \equiv \arg(-M_{12}^q/\Gamma_{12}^q)$. That is, this is another observable measuring CP violation in B_q–$\overline{B_q}$ mixing. We take the approximation, $\Gamma_{12}^q = \Gamma_{12}^{q,{\rm SM}}$, since the leading contribution comes from the absorptive part of the box diagrams for B_q–$\overline{B_q}$ mixing and there is no new common final state into which both B_q and $\overline{B_q}$ can decay in our scenario. The size of M_{12}^q is fixed by the ΔM_q data up to hadronic uncertainties. Then, $a_{\rm sl}^q$ 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 SM predictions [2],

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

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

Recently, the DØ 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,

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

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 $a_{\rm sl}^d$ coming from B_d decays as well as $a_{\rm sl}^s$ from B_s. One can extract the asymmetry relevant to the B_s meson using the measured value of $a_{\rm sl}^d$ and the result by DØ is

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

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

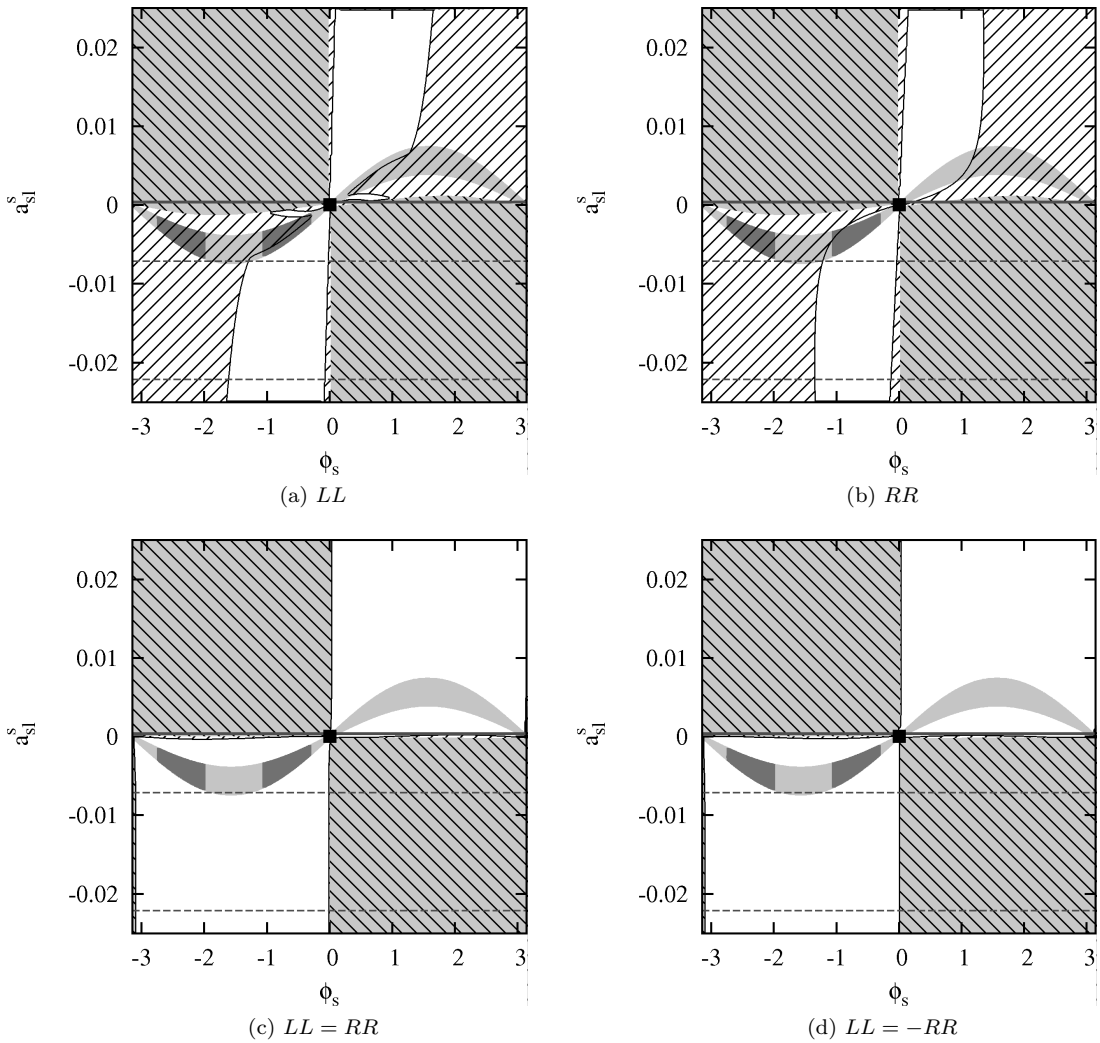
This DØ result has drawn interest in new physics explanations [4–8]. (For earlier works, see e.g. Refs. [9–11].) Some of the works consider extra contributions to Γ_{12}^q since the dimuon charge asymmetry depends on it as well as on M_{12}^q [5, 6]. This approach also has a possibility of altering $|\Delta\Gamma_s|$ even though its current experimental value is in agreement with the SM one, $2\,|\Gamma_{12}^{s,{\rm SM}}\cos\phi_s^{\rm SM}|$ [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}^s. 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 $a_{\rm sl}^s$ is the range of ϕ_s to be used. Following the latest reports from DØ [3] and CDF [14], there have been a couple of attempts to make a global fit of B_s–$\overline{B_s}$ 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 $\Gamma_{12}^{s,{\rm SM}}/M_{12}^{s,{\rm SM}}$, 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 $a_{\rm sl}^s$ band in the following figures.

We show $a_{\rm sl}^s$ 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



(a) LL (b) RR

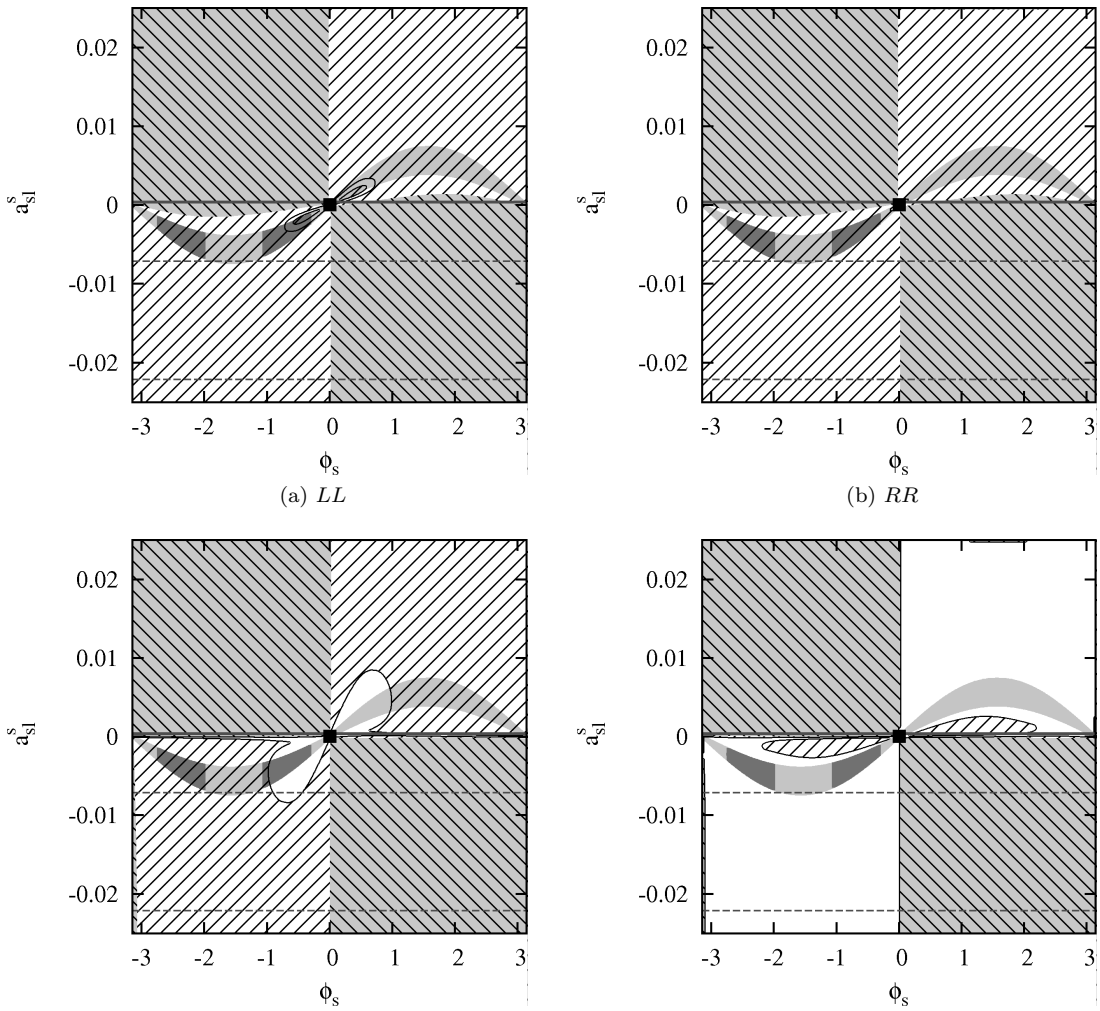
(c) $LL = RR$ (d) $LL = -RR$

FIG. 1. Plots of $a^s_{\rm sl}$ 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 $B \to X_s\gamma$ 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 $a^s_{\rm sl}$, respectively.

the $LL = -RR$ cases, respectively. One can immediately notice the aforementioned sinusoidal dependence of $a^s_{\rm sl}$ 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^s_{12}. The nonzero thickness of the band arises from the uncertainty in ΔM_s. The difference between $a^s_{\rm sl}$ 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 $B \to X_s\gamma$ 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 $a^s_{\rm sl} \simeq -0.006$ within the blue region does not change. In the lower two cases with two insertions, $B \to X_s\gamma$ does not play an important role since the supersymmetric effect on B_s–$\overline{B_s}$ mixing is enhanced.

Plots for $\tan\beta = 10$ are displayed in Figs. 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 $B \to X_s\gamma$ 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 $a^s_{\rm sl}$ is restricted closer to its SM value. In Fig. 2(a), ΔM_s, ϕ_s, and $B \to X_s\gamma$, together allow $a^s_{\rm sl}$ to be as low as -0.003. In Fig. 2(b), there is no solution satisfying all the three constraints. One could get $a^s_{\rm sl} \simeq -0.0006$ if ϕ_s were not limited. In the lower two cases, the lowest $a^s_{\rm sl}$, compatible with ΔM_s and ϕ_s, is almost the same as in Figs. 1.

We summarize. We have examined how $a^s_{\rm sl}$ is influenced by the LL and/or RR mass insertions. For $\tan\beta = 3$, one can reduce the discrepancy between $a^s_{\rm sl}$ and its SM expectation from 1.9σ down to 1.0σ in each



(a) LL (b) RR

(c) $LL = RR$ (d) $LL = -RR$

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

of the LL, RR, $LL = RR$, and $LL = -RR$ cases, obeying the ΔM_s, $B \to X_s\gamma$, and ϕ_s constraints. This amounts to reduction of the $A^b_{\rm sl}$ tension from 3.2σ down to 2.2σ if one assumes no new physics in the $b \to d$ transition. For $\tan\beta = 10$, it becomes difficult for the LL and RR cases whereas the $LL = RR$ and $LL = -RR$ cases are less limited by $B \to X_s\gamma$.

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NOTE ADDED

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 $(\delta^d_{23})_{RR}$ is a variable parameter and $(\delta^d_{23})_{LL}$ 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 $B \to X_s\gamma$ 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].)

[1] P. Ko and J.-h. Park, Phys. Rev. D **80**, 035019 (2009) [arXiv:0809.0705 [hep-ph]].

[2] A. Lenz and U. Nierste, JHEP **0706**, 072 (2007) [arXiv:hep-ph/0612167].

[3] V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. D **82**, 032001 (2010) [arXiv:1005.2757 [hep-ex]].

[4] Z. Ligeti, M. Papucci, G. Perez and J. Zupan, Phys. Rev. Lett. **105**, 131601 (2010) [arXiv:1006.0432 [hep-ph]].

[5] A. Dighe, A. Kundu and S. Nandi, Phys. Rev. D **82**, 031502 (2010) [arXiv:1005.4051 [hep-ph]].

[6] C. W. Bauer and N. D. Dunn, arXiv:1006.1629 [hep-ph].

[7] B. A. Dobrescu, P. J. Fox and A. Martin, Phys. Rev. Lett. **105**, 041801 (2010) [arXiv:1005.4238 [hep-ph]]; A. J. Buras, M. V. Carlucci, S. Gori and G. Isidori, JHEP **1010**, 009 (2010) [arXiv:1005.5310 [hep-ph]]; C. H. Chen and G. Faisel, arXiv:1005.4582 [hep-ph]; D. Choudhury and D. K. Ghosh, arXiv:1006.2171 [hep-ph]; N. G. Deshpande, X. G. He and G. Valencia, Phys. Rev. D **82**, 056013 (2010) [arXiv:1006.1682 [hep-ph]]; C. H. Chen, C. Q. Geng and W. Wang, JHEP **1011**, 089 (2010) [arXiv:1006.5216 [hep-ph]].

[8] J. K. Parry, arXiv:1006.5331 [hep-ph].

[9] G. L. Kane, P. Ko, H. b. Wang, C. Kolda, J.-h. Park and L. T. Wang, Phys. Rev. Lett. **90**, 141803 (2003) [arXiv:hep-ph/0304239]; Phys. Rev. D **70**, 035015 (2004) [arXiv:hep-ph/0212092].

[10] A. Lenz, Phys. Rev. D **76**, 065006 (2007) [arXiv:0707.1535 [hep-ph]].

[11] L. Randall and S. f. Su, Nucl. Phys. B **540**, 37 (1999) [arXiv:hep-ph/9807377]; K. Kawashima, J. Kubo and A. Lenz, Phys. Lett. B **681**, 60 (2009) [arXiv:0907.2302 [hep-ph]].

[12] E. Barberio *et al.* [Heavy Flavor Averaging Group], arXiv:0808.1297 [hep-ex].

[13] S. Esen *et al.*, Phys. Rev. Lett. **105**, 201802 (2010) [arXiv:1005.5177 [hep-ex]].

[14] L. Oakes (CDF Collaboration), talk at FPCP 2010, May 25–29, Torino, Italy, `http://agenda.infn.it/getFile.py/access?contribId=12&resId=0&materialId=slides&confId=2635`

[15] M. Bona *et al.* [UTfit Collaboration], PMC Phys. A **3**, 6 (2009) [arXiv:0803.0659 [hep-ph]].

[16] P. Ko, J.-h. Park and M. Yamaguchi, JHEP **0811**, 051 (2008) [arXiv:0809.2784 [hep-ph]].