45 Squark flavor mixing and CP violation of neutral B mesons at LHCb

K. Yamamoto

Abstract We study the contribution of the squark flavor mixing from the $LR(RL)$ component of the squark mass matrices to the direct CP violation of the $b \to s\gamma$ decay and the CP asymmetry of $B_d \to K^*\gamma$ decay and the non-leptonic decays of B mesons. The magnitude of the $LR(RL)$ component is constrained by the branching ratio and the direct CP violation of $b \to s\gamma$. We predict the time dependent CP asymmetries of the B decays.

45.1 Introduction

Recently LHCb has reported new data of the CP asymmetries of B_s mesons. They measured the time dependent CP asymmetry S_f of $B_s \to J/\psi\phi$ and $B_s \to J/\psi f_0(980)$ decays [1]. The CP violation in the K and B_d meson decays has been successfully explained within the framework of the standard model (SM), so called Kobayashi-Maskawa (KM) model [2]. However, there are a possibility of new sources of the CP violation if the SM is extended to the supersymmetric (SUSY) models. Therefore, we expect the SUSY contribution to the CP violation in the B meson decays.

The typical contribution of SUSY is the gluino-squark mediated flavor changing process [3]-[12]. We predict the time dependent CP asymmetries of $B_d^0 \to \phi K_S$ and $B_d^0 \to \eta' K^0$ decays which are deviated from the SM predictions in the framework of the SUSY. In this regard we consider constraints from the branching ratio and the direct CP violation of $b \to s\gamma$.

In that framework of the SUSY, the asymmetries of $B_d^0 \to \phi K_S$ and $B_d^0 \to \eta' K^0$ are deviated from the SM predictions [13, 14]. Then, these contributions of the new physics are correlated with the direct CP violation of the $b \to s\gamma$ decay. In this work, we present the numerical analyses in the case that LR and RL components of squark mass matrices dominate the penguin decays.

45.2 CP violation in B meson decays

Let us discuss the effect of the new physics in the non-leptonic decays of B mesons. The contribution of new physics to the dispersive part $M_{12}^q (q = d, s)$ is parameterized as

$$M_{12}^q = M_{12}^{q,\text{SM}} + M_{12}^{q,\text{SUSY}} = M_{12}^{q,\text{SM}}(1 + h_q e^{2i\sigma_q}) \,, \quad (q = d, s) \tag{45.1}$$

where $M_{12}^{q,\mathrm{SUSY}}$ is the SUSY contribution, and $M_{12}^{q,\mathrm{SM}}$ is the SM contribution [15].

The time dependent CP asymmetry S_f decaying into the final state f is defined as [16]

$$\mathcal{S}_f = \frac{2\mathrm{Im}\lambda_f}{|\lambda_f|^2+1}, \qquad \lambda_f = \frac{q}{p}\bar{\rho}\,, \qquad \frac{q}{p} = \sqrt{\frac{M_{12}^{q*}-\frac{i}{2}\Gamma_{12}^{q*}}{M_{12}^{q}-\frac{i}{2}\Gamma_{12}^{q}}}, \qquad \bar{\rho} \equiv \frac{\bar{A}(\bar{B}_q^0\to f)}{A(B_q^0\to f)}. \tag{45.2}$$

In the decay of $B_d^0 \to J/\psi K_S$, the new physics parameters h_d and σ_d appear in

$$\lambda_{J/\psi K_S} = -e^{-i\phi_d}, \quad \phi_d = 2\beta_d + \arg(1+h_d e^{2i\sigma_d}), \tag{45.3}$$

by putting $|\bar{\rho}|=1$ and $q/p \simeq \sqrt{M_{12}^{q*}/M_{12}^{q}}$, where the phase β_d is given in the SM.

The CKMfitter provided the allowed region of h_d and σ_d, where the central values are $h_d \simeq 0.3, \sigma_d \simeq 1.8$ rad[17, 18].

In the decay of $B_s^0 \to J/\psi\phi$, we have

$$\lambda_{J/\psi\phi} = e^{-i\phi_s}, \qquad \phi_s = -2\beta_s + \arg(1+h_s e^{2i\sigma_s}), \tag{45.4}$$

where β_s is given in the SM. Recently the LHCb has presented the observed CP-violating phase ϕ_s in $\bar{B}_s^0 \to J/\psi\pi^+\pi^-$ decay [1]. This result leads to $\phi_s = -0.019^{+0.173+0.04}_{-0.174-0.03}$ rad, which is consistent with the SM prediction $\phi_s^{J/\psi\phi,SM} = -2\beta_s = -0.0363\pm0.0017$ rad [17].

Taking account of these data, the CKMfitter has presented the allowed values of h_s and σ_s [17, 18]. We take the central values $h_s \simeq 0.1, \sigma_s \simeq 0.9-2.2$ rad as a typical parameter set.

Since the $B_d^0 \to J/\psi K_S$ process occurs at the tree level in SM, the CP-violating asymmetry originates from M_{12}^d. Although the $B_d^0 \to \phi K_S$ and $B_d^0 \to \eta' K^0$ decays are penguin dominant ones, their asymmetries also come from M_{12}^d. Then, asymmetries of $B_d^0 \to J/\psi K_S$, $B_d^0 \to \phi K_S$ and $B_d^0 \to \eta' K^0$ are expected to be same magnitude in SM.

On the other hand, if the squark flavor mixing contributes to the decay at the one-loop level, its magnitude could be comparable to the SM penguin one in $B_d^0 \to \phi K_S$ and $B_d^0 \to \eta' K^0$, but it is tiny in $B_d^0 \to J/\psi K_S$. Endo, Mishima and Yamaguchi proposed the possibility to find the SUSY contribution in these asymmetries [20].

The new physics contribute to the $b \to s\gamma$ process. The observed $b \to s\gamma$ branching ratio (BR) is $(3.60\pm0.23)\times10^{-4}$ [19], on the other hand the SM prediction is given as $(3.15\pm0.23)\times10^{-4}$ at $\mathcal{O}(\alpha_s^2)$ [21, 22]. Therefore, the contribution of the new physics should be suppressed compared with the experimental data. The new physics is also constrained by the direct CP violation

$$A_{\mathrm{CP}}^{b\to s\gamma} \equiv \frac{\Gamma(\bar{B}\to X_s\gamma)-\Gamma(B\to X_{\bar{s}}\gamma)}{\Gamma(\bar{B}\to X_s\gamma)+\Gamma(B\to X_{\bar{s}}\gamma)}. \tag{45.5}$$

Since the SM prediction $A_{\mathrm{CP}}^{b\to s\gamma} \simeq 0.005$ is tiny [23], the new physics may appear in this CP asymmetry. The present data $A_{\mathrm{CP}}^{b\to s\gamma} = -0.008\pm0.029$ [19] has large error bar, so the constraint of the new physics is not so severe. However improved data will provide the crucial test for the new physics. We also discuss the time dependent CP asymmetry of $B_d \to K^*\gamma$.

45.3 Squark flavor mixing in B meson decays

Let us consider the flavor structure of squarks in order to estimate the CP-violating asymmetries of B meson decays. We take the most popular anzatz, a degenerate SUSY breaking mass spectrum for down-type squarks. Then, in the super-CKM basis, we can parametrize the soft scalar masses squared $M^2_{\tilde{d}_{LL}}$, $M^2_{\tilde{d}_{RR}}$, $M^2_{\tilde{d}_{LR}}$, and $M^2_{\tilde{d}_{RL}}$ for the down-type squarks. For example,

$$M^2_{\tilde{d}_{LR}} = (M^2_{\tilde{d}_{RL}})^\dagger = m^2_{\tilde{q}} \begin{pmatrix} (\delta_d^{LR})_{11} & (\delta_d^{LR})_{12} & (\delta_d^{LR})_{13} \\ (\delta_d^{LR})_{21} & (\delta_d^{LR})_{22} & (\delta_d^{LR})_{23} \\ (\delta_d^{LR})_{31} & (\delta_d^{LR})_{32} & (\delta_d^{LR})_{33} \end{pmatrix}, \tag{45.6}$$

where $m_{\tilde{q}}$ is the average squark mass, and $(\delta_d^{LR})_{ij}$ and $(\delta_d^{RL})_{ij}$ are called as the mass insertion (MI) parameters. The MI parameters are supposed to be much smaller than 1.

The SUSY contribution by the gluino-squark box diagram to the dispersive part of the effective Hamiltonian for the B_q-$\bar{B}_q$ mixing is written as [13, 24, 25]

$$\begin{aligned} M_{12}^{q,SUSY} &= A_1^q \Big[A_2 \left\{ (\delta_d^{LL})^2_{ij} + (\delta_d^{RR})^2_{ij} \right\} + A_3^q (\delta_d^{LL})_{ij} (\delta_d^{RR})_{ij} \\ &\quad + A_4^q \left\{ (\delta_d^{LR})^2_{ij} + (\delta_d^{RL})^2_{ij} \right\} + A_5^q (\delta_d^{LR})_{ij} (\delta_d^{RL})_{ij} \Big], \end{aligned} \tag{45.7}$$

where A_i^q is a function of $x = m^2_{\tilde{g}}/m^2_{\tilde{q}}$.

The squark flavor mixing can be tested in the CP-violating asymmetries of B meson. Let us present our framework. The effective Hamiltonian for $\Delta B = 1$ process is defined as

$$H_{eff} = \frac{4G_F}{\sqrt{2}} \left[\sum_{q'=u,c} V_{q'b} V^*_{q's} \sum_{i=1,2} C_i O_i^{(q')} - V_{tb} V^*_{ts} \sum_{i=3-6,7\gamma,8G} \left(C_i O_i + \widetilde{C}_i \widetilde{O}_i \right) \right], \tag{45.8}$$

where O_i's are the local operators [13]. The Wilson coefficient C_i includes both SM contribution and gluino one, such as $C_i = C_i^{\rm SM} + C_i^{\tilde{g}}$, where $C_i^{\rm SM}$ and $C_{7\gamma}^{\tilde{g}}$ and $C_{8G}^{\tilde{g}}$ are given in Ref. [26, 27].

The CP-violating asymmetries $\mathcal{S}_f$ in Eq. (45.2) are calculated by using λ_f, which is given for $B_d^0 \to \phi K_S$ and $B_d^0 \to \eta' K^0$ as follows:

$$\lambda_{\phi K_S,\ \eta' K^0} = -e^{-i\phi_d} \frac{\sum_{i=3-6,7\gamma,8G} \left(C_i^{\rm SM} \langle O_i \rangle + C_i^{\tilde{g}} \langle O_i \rangle + \widetilde{C}_i^{\tilde{g}} \langle \widetilde{O}_i \rangle \right)}{\sum_{i=3-6,7\gamma,8G} \left(C_i^{\rm SM*} \langle O_i \rangle + C_i^{\tilde{g}*} \langle O_i \rangle + \widetilde{C}_i^{\tilde{g}*} \langle \widetilde{O}_i \rangle \right)} . \tag{45.9}$$

It is noticed that $\langle \phi K_S | O_i | B_d^0 \rangle = \langle \phi K_S | \widetilde{O}_i | B_d^0 \rangle$ and $\langle \eta' K^0 | O_i | B_d^0 \rangle = -\langle \eta' K^0 | \widetilde{O}_i | B_d^0 \rangle$ because of the parity of the final state. We estimate each hadronic matrix elements by using the factorization relations in Ref. [28].

The $b \to s\gamma$ decay is a typical process to investigate the new physics. We can discuss the direct CP violation $A_{\rm CP}^{b\to s\gamma}$ in the $b \to s\gamma$ decay, which is given as [23]:

$$A_{\rm CP}^{b\to s\gamma} = \frac{\alpha_s(m_b)}{|C_{7\gamma}|^2}\Big[\frac{40}{81}{\rm Im}[C_2 C_{7\gamma}^*] - \frac{8z}{9}[v(z)+b(z,\delta)]{\rm Im}\Big[\left(1+\frac{V_{us}^* V_{ub}}{V_{ts}^* V_{tb}}\right) C_2 C_{7\gamma}^*\Big]$$
$$- \frac{4}{9}{\rm Im}[C_{8G} C_{7\gamma}^*] + \frac{8z}{27} b(z,\delta){\rm Im}\Big[\left(1+\frac{V_{us}^* V_{ub}}{V_{ts}^* V_{tb}}\right) C_2 C_{8G}^*\Big]\Big],$$

where $v(z)$ and $b(z,\delta)$ are explicity given in [23].

We also discuss the time dependent CP asymmetry $S_{K^*\gamma}$ of $B_d \to K^*\gamma$ decay, which is given as [27]

$$S_{K^*\gamma} = \frac{2{\rm Im}(e^{2i\phi_1}\tilde{C}_{7\gamma}(m_b)/C_{7\gamma}(m_b))}{|\tilde{C}_{7\gamma}(m_b)/C_{7\gamma}(m_b)|^2+1}. \tag{45.10}$$

Let us set up the framework of our calculations. Suppose that $\mu\tan\beta$ is at most $O(1)$TeV. Then, magnitudes of $(\delta_d^{LL})_{23}$ and $(\delta_d^{RR})_{23}$ are constrained by M_{12}^s as seen in Eq.(45.7). Taking account of $h_s = 0.1$, we obtain $|(\delta_d^{LL})_{23}| \simeq |(\delta_d^{RR})_{23}| \simeq 0.02$ in our previous work [13]. Then, these contributions to $C_{7\gamma}^{\tilde{g}}$ and $C_{8G}^{\tilde{g}}$ are minor. On the other hand, $(\delta_d^{LR})_{23}$ and $(\delta_d^{RL})_{23}$ are severely constrained by $C_{7\gamma}^{\rm eff}$ and $C_{8G}^{\rm eff}$ independent of $\mu\tan\beta$. We show the constraint for $(\delta_d^{LR})_{23}$ and $(\delta_d^{RL})_{23}$ in our following calculations. In our convenience, we suppose $|(\delta_d^{LR})_{23}| = |(\delta_d^{RL})_{23}|$. Then, we can parametrize the MI parameters as follows:

$$(\delta_d^{LR})_{23} = |(\delta_d^{LR})_{23}| e^{2i\theta_{23}^{LR}}, \qquad (\delta_d^{RL})_{23} = |(\delta_d^{LR})_{23}| e^{2i\theta_{23}^{RL}}. \tag{45.11}$$

45.4 Numerical results

We show the numerical analyses of the CP violation in the B mesons. In our following numerical calculations, we fix the squark mass and the gluino mass as $m_{\tilde{q}} = 1000$ GeV and $m_{\tilde{g}} = 1500$ GeV, which are consistent with recent lower bound of these masses at LHC [29].

At first, we discuss the $b \to s\gamma$ decay. The observed $b \to s\gamma$ branching ratio is $(3.60 \pm 0.23) \times 10^{-4}$ [19], on the other hand the SM prediction is given as $(3.15 \pm 0.23) \times 10^{-4}$ at $\mathcal{O}(\alpha_s^2)$ [21, 22]. The branching ratio gives the constraint for the magnitude of $(\delta_d^{LR})_{23}$. The direct CP violation of the $b \to s\gamma$ is also useful to constraint $(\delta_d^{LR})_{23}$.

We show the $|(\delta_d^{LR})_{23}|$ dependence of the branching ratio taking accont of the constraint of $A_{\rm CP}^{b\to s\gamma}$ in Figure 1, where the upper and lower bounds of the experimental data with 90% C.L. are denoted red lines. As the magnitude of $(\delta_d^{LR})_{23}$ increases, the predicted region of the branching ratio splits into the larger region and smaller one. The excluded region around ${\rm BR} = 3 \times 10^{-4}$ is due to the constraint of $A_{\rm CP}^{b\to s\gamma}$. Then, the predicted branching ratio becomes inconsistent with the experimental data at $|(\delta_d^{LR})_{23}| \geq 5.5 \times 10^{-3}$.

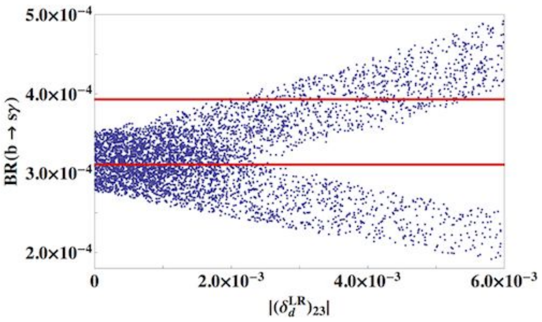

Figure 45.1: The predicted branching ratio of $b \to s\gamma$ versus $|(\delta_d^{LR})_{23}|$.

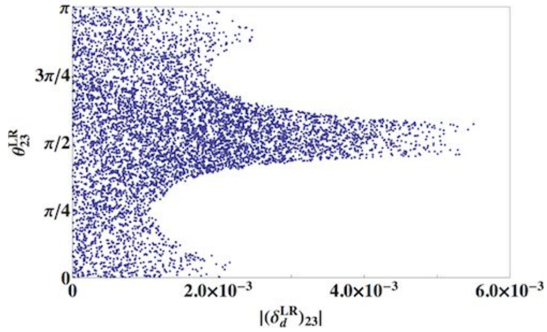

Figure 45.2: The allowed region of $\theta_{23}^{LR} - |(\delta_d^{LR})_{23}|$ plane.

In Figure 2, we plot the allowed region of the $\theta_{23}^{LR} - |(\delta_d^{LR})_{23}|$ plane by putting the experimental data at 90% C.L. of the branching ratio and the direct CP violation $A_{\rm CP}^{b\to s\gamma}$. The $|(\delta_d^{LR})_{23}|$ is cut at 5.5×10^{-3}, where θ_{23}^{LR} is tuned around $\pi/2$. Around $\pi/4$ and $3\pi/4$, $A_{\rm CP}^{b\to s\gamma}$ give the severe constraint. This CP-violating phase also contributes on the CP-violating asymmetry of the non-leptonic decays of B_d^0 and B_s^0 mesons.

In addition to the direct CP violation of $b \to s\gamma$, we predicted the time dependent CP asymmetry $S_{K^*\gamma}$ of $B_d \to K^*\gamma$ decay in Figure 3. The experimental upper and lower bounds with 90% C.L. are denoted by the red lines and the case of 1σ is denoted by the pink lines. We find that the constraint from $S_{K^*\gamma}$ is not severe at present.

Let us discuss $\mathcal{S}_f$, which is the measure of the CP-violating asymmetry, for $B_d^0 \to J/\psi K_S,\ \phi K_S$ and $\eta' K^0$. As discussed in Section 2, these $\mathcal{S}_f$'s are predicted to be same ones in the SM. On the other hand, if the squark flavor mixing contributes to the decay process at the one-loop level, these asymmetries are different from among as seen in Eq.(45.9). We present the predicted region of the $\mathcal{S}_{\eta' K^0}$-$\mathcal{S}_{\phi K_S}$ plane in Figure 4, the black line denotes the SM prediction $\mathcal{S}_{J/\psi K_S} = \mathcal{S}_{\phi K_S} = \mathcal{S}_{\eta' K}$, where the observed value $\mathcal{S}_{J/\psi K_S} = 0.671 \pm 0.023$ is put. The experimental data is denoted by red lines at 90% C.L. and we fix $|(\delta_d^{LR})_{23}| = 10^{-4}$(orange) and 10^{-3}(blue) for typical values. The reduction of the experimental error of $A_{\rm CP}^{b\to s\gamma}$ will give us severe predictions for $\mathcal{S}_{\phi K_S}$ and $\mathcal{S}_{\eta' K^0}$.

45.5 Conclusion

We have discussed the contribution of the squark flavor mixing from $(\delta_d^{LR})_{23}$ and $(\delta_d^{RL})_{23}$ on the direct CP violation of the $b \to s\gamma$ decay and the CP-violating asymmetry in the non-leptonic decays of B_d^0 meson. The magnitude of the $|(\delta_d^{LR})_{23}|$ is constrained by the branching ratio of $b \to s\gamma$ with the constraint of $A_{\rm CP}^{b\to s\gamma}$. The predicted branching ratio becomes inconsistent with the experimental data at $|(\delta_d^{LR})_{23}| \geq 5.5 \times 10^{-3}$. We have obtained the allowed region on the θ_{23}^{LR}-$|(\delta_d^{LR})_{23}|$ plane.

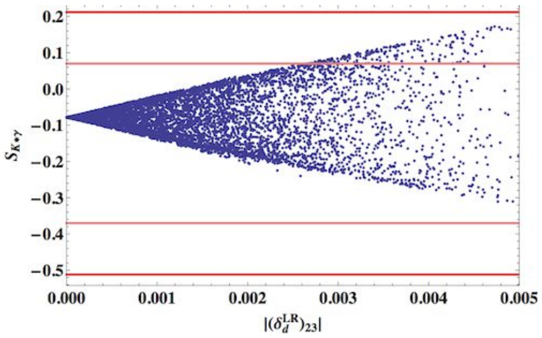

Figure 45.3: The allowed region of $S_{K^*\gamma}$ - $|(\delta_d^{LR})_{23}|$plane.

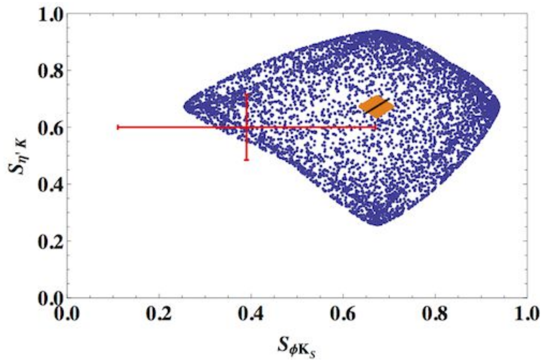

Figure 45.4: The predicted region of $\mathcal{S}_{\eta' K^0}$-$\mathcal{S}_{\phi K_S}$ plane.

Based on this result, we have predicted $\mathcal{S}_f$ of the B_d^0 and B_s^0 decays. These CP-violating asymmetries could deviate from the SM predictions.

In the near future, the precise data of the direct CP violation and CP-violating asymmetries in the non-leptonic decays of B_d^0 and B_s^0 mesons give us the crucial test for our framework of the squark flavor mixing.

Bibliography

[1] R. Aaij, *et al.* [LHCb collaboration], arXiv:1204.5675 [hep-ex].

[2] M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49** (1973) 652.

[3] S. F. King, JHEP **1009** (2010) 114 [arXiv:1006.5895 [hep-ph]].

[4] M. Endo, S. Shirai and T. T. Yanagida, Prog. Theor. Phys. **125** (2011) 921 [arXiv:1009.3366 [hep-ph]].

[5] M. Endo and N. Yokozaki, JHEP **1103** (2011) 130 [arXiv:1012.5501 [hep-ph]].

[6] J. Kubo and A. Lenz, Phys. Rev. D **82** (2010) 075001 [arXiv:1007.0680 [hep-ph]].

[7] Y. Kaburaki, K. Konya, J. Kubo and A. Lenz, Phys. Rev. D **84** (2011) 016007 [arXiv:1012.2435 [hep-ph]].

[8] J. K. Parry, Phys. Lett. B **694** (2011) 363 [arXiv:1006.5331 [hep-ph]].

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

[10] P. Ko and J. -h. Park, Phys. Rev. D **82** (2010) 117701 [arXiv:1006.5821 [hep-ph]].

[11] R. -M. Wang, Y. -G. Xu, Q. Chang and Y. -D. Yang, Phys. Rev. D **83** (2011) 095010 [arXiv:1102.2031 [hep-ph]].

[12] H. Ishimori, Y. Kajiyama, Y. Shimizu and M. Tanimoto, Prog. Theor. Phys. **126** (2012) 703 [arXiv:1103.5705 [hep-ph]].

[13] A. Hayakawa, Y. Shimizu, M. Tanimoto and K. Yamamoto, Phys. Lett. B **710** (2012) 446 [arXiv:1202.0486 [hep-ph]].

[14] Y. Shimizu, M. Tanimoto and K. Yamamoto, arXiv:1205.1705 [hep-ph].

[15] See I.I.Bigi and A.I.Sanda, “CP violation”, Cambridge University Press, 2000.

[16] T. Aushev, W. Bartel, A. Bondar, J. Brodzicka, T. E. Browder, P. Chang, Y. Chao and K. F. Chen *et al.*, arXiv:1002.5012 [hep-ex].

[17] J. Charles *et al.* [CKMfitter Group Collaboration], Eur. Phys. J. C **41** (2005) 1 [hep-ph/0406184], updated results and plots available at http://ckmfitter.in2p3.fr/ .

[18] Z. Ligeti, “Flavor physics in the LHC era,” The 1st KIAS Phenomenology workshop (2011).

[19] K. Nakamura *et al.* [Particle Data Group Collaboration], J. Phys. G **37** (2010) 075021.

[20] M. Endo, S. Mishima and M. Yamaguchi, Phys. Lett. B **609** (2005) 95 [hep-ph/0409245].

[21] A. J. Buras, Les Houches Lectures, arXiv:hep-ph/9806471.

[22] M. Misiak *et al.*, Phys. Rev. Lett. **98** (2007) 022002 [arXiv:hep-ph/0609232].

[23] A. L. Kagan and M. Neubert, Phys. Rev. D **58**, 094012 (1998) [hep-ph/9803368].

[24] F. Gabbiani, E. Gabrielli, A. Masiero and L. Silvestrini, Nucl. Phys. B **477** (1996) 321 [hep-ph/9604387].

[25] W. Altmannshofer, A. J. Buras, S. Gori, P. Paradisi and D. M. Straub, Nucl. Phys. B **830** (2010) 17 [arXiv:0909.1333 [hep-ph]].

[26] G. Buchalla, A. J. Buras and M. E. Lautenbacher, Rev. Mod. Phys. **68** (1996) 1125 [hep-ph/9512380].

[27] M. Endo and S. Mishima, hep-ph/0408138.

[28] R. Harnik, D. T. Larson, H. Murayama and A. Pierce, Phys. Rev. D **69** (2004) 094024 [hep-ph/0212180].

[29] G. Aad *et al.* [ATLAS Collaboration], Phys. Lett. B **710** (2012) 67 [arXiv:1109.6572 [hep-ex]].

[30] V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. D **82** (2010) 032001, Phys. Rev. Lett. **105** (2010) 081801, Phys. Rev. D **84** (2011) 052007 [arXiv:1005.2757 [hep-ex]] , [arXiv:1007.0395 [hep-ex]] , [arXiv:1106.6308 [hep-ex]].

[31] A. Lenz and U. Nierste, JHEP **0706** (2007) 072 [hep-ph/0612167],
A. Lenz, U. Nierste, J. Charles, S. Descotes-Genon, A. Jantsch,C. Kaufhold,Phys. Rev. D **83** (2011) 036004 [arXiv:1008.1593 [hep-ph]].

[32] Z. Ligeti, M. Papucci and G. Perez, Phys. Rev. Lett. **97** (2006) 101801 [hep-ph/0604112].

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

[34] R. Aaij *et al.* [The LHCb Collaboration], arXiv:1112.3056 [hep-ex].

[35] R. Aaij *et al.* [LHCb Collaboration], arXiv:1112.3183 [hep-ex].

[36] T. Aaltonen *et al.* [CDF Collaboration], arXiv:1112.1726 [hep-ex].

[37] W. Altmannshofer and M. Carena, arXiv:1110.0843 [hep-ph].

[38] J. Hisano and Y. Shimizu, Phys. Lett. B **581** (2004) 224 [hep-ph/0308255].

[39] J. Hisano and Y. Shimizu, Phys. Rev. D **70** (2004) 093001 [hep-ph/0406091].

[40] J. Hisano, M. Nagai and P. Paradisi, Phys. Rev. D **80** (2009) 095014 [arXiv:0812.4283 [hep-ph]].

[41] Y. Grossman, Y. Nir and G. Raz, Phys. Rev. Lett. **97** (2006) 151801 [hep-ph/0605028].

[42] For example, see the review; H. Ishimori, T. Kobayashi, H. Ohki, Y. Shimizu, H. Okada and M. Tanimoto, Prog. Theor. Phys. Suppl. **183** (2010) 1 [arXiv:1003.3552 [hep-th]].

[43] S. Bertolini, F. Borzumati, A. Masiero and G. Ridolfi, Nucl. Phys. B **353** (1991) 591.

[44] C. A. Baker, D. D. Doyle, P. Geltenbort, K. Green, M. G. D. van der Grinten, P. G. Harris, P. Iaydjiev and S. N. Ivanov *et al.*, Phys. Rev. Lett. **97** (2006) 131801 [hep-ex/0602020].