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Large electroweak penguin contribution in $B \to K\pi$ and $\pi\pi$ decay modes

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We discuss a possibility of large electroweak penguin contribution in $B \to K\pi$ and $\pi\pi$ from recent experimental data. The experimental data may be suggesting that there are some discrepancies between the data and theoretical estimation in the branching ratios of them. In $B \to K\pi$ decays, to explain it, a large electroweak penguin contribution and large strong phase differences seem to be needed. The contributions should appear also in $B \to \pi\pi$. We show, as an example, a solution to solve the discrepancies in both $B \to K\pi$ and $B \to \pi\pi$. However the magnitude of the parameters and the strong phase estimated from experimental data are quite large compared with the theoretical estimations. It may be suggesting some new physics effects are included in these processes. We will have to discuss about the dependence of the new physics. To explain both modes at once, we may need large electroweak penguin contribution with new weak phases and some SU(3) breaking effects by new physics in both QCD and electroweak penguin-type processes.

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I. INTRODUCTION

One of the main targets at the B factories is to determine all the CP angles in the unitarity triangles of the Cabbibo-Kobayashi-Maskawa (CKM) matrix [1]. ϕ_1 [2], which is one of the CP angles, has already been measured and the CP violation in B meson system was established by Belle [3] and *BABAR* [4] collaborations. The next step is to determine the remaining angles and to confirm the unitarity of the CKM matrix. The good decay modes for measuring ϕ_2 and ϕ_3 are $B^0 \to \pi^+\pi^-$ and $B^\pm \to DK^\pm$, respectively, but their methods have some difficulties to extract the angles cleanly. To avoid the difficulties, isospin relation [5] and SU(3) relation including $B \to K\pi$ modes [6–16] are being considered as a method to extract the weak phases. However there seems to be anomalies in the recent experimental data of $B \to K\pi$ and $\pi\pi$ [17–19]. To explain the discrepancies in $B \to K\pi$ modes[11], a large electroweak (EW) penguin contribution will be requested [20][1] [21–23]. In addition, the magnitude of the branching ratios for $B \to \pi\pi$ also do not agree with the theoretical estimations [22,23]. In other words, without solving the problems, we cannot extract any information from these B decays.

$B \to K\pi$ modes have already been measured [17–19] (and see also the web page by Heavy Flavor Averaging Group [24]) and they will be useful in understanding the CP violation through the Kobayashi-Maskawa (KM) phases. If we can directly solve these modes, it is a very elegant way to determine the parameters and the weak phases. In order to extract the weak phases through this mode, there are several approaches: diagram decomposition [6–10,12,13,16], QCD factorization [25], PQCD [26,27], and so on. The contributions including the weak phase ϕ_3 come from tree-type diagrams which have a CKM suppression factor and they are usually dealt with small parameters compared with the gluonic penguin diagram. If we can deal with the contributions as small parameters, except for the gluonic penguin with the small parameters, then there are several relations among the averaged branching ratios of $B \to K\pi$ modes: $Br(K^+\pi^-)/2Br(K^0\pi^0) \approx 2Br(K^+\pi^0)/Br(K^0\pi^+)$ [20,25] et al. However, the recent data do not seem to satisfy them so well. To satisfy the data, we find that the role of a color-favored EW-penguin may be important. The color-favored EW-penguin diagram is included in $B^0 \to K^0\pi^0$ and $B^0 \to K^+\pi^0$ and the data of their branching ratio are slightly larger than half of that for $B^0 \to K^+\pi^-$, where the $1/2$ comes from the difference between π^0 and π^+ in final state. Thus we need to know the EW-penguin contributions in $B \to K\pi$ decay modes to extract the weak phases. The role of the EW-penguin was pointed out and their magnitude was estimated in several works [11–16,25–27]. These works said that the ratio between gluonic and EW penguins is about 0.14 as the central value, but the experimental data may suggest that the magnitude seems to be slightly larger than the estimation [20–23]. Furthermore, one of the most difficult points to explain is that we will need quite a large strong phase difference of EW-penguin diagram compared with the other strong phases. To produce such a large strong phase is difficult in the SM. If there is quite a large deviation in the contribution from the EW-penguin, it may suggest a possibility of new physics in these modes.

Under the flavor SU(3) symmetry, these discussions in $B \to K\pi$ have to relate to $B \to \pi\pi$ modes too. If the

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[1]In the previous work [20], one of authors showed several relations for $B \to K\pi$. Some of these relations did not include a cross term. In this work, it is corrected but the discussion is almost the same and it did not make any large changes.

contributions from EW-penguin are so large, then they also have to appear in $B \to \pi\pi$. However it is slightly difficult to explain the discrepancies between theoretical estimations and experimental data of the branching ratios by only the EW-penguin contribution because in these modes the leading contribution comes from tree-type diagram and the EW-penguin is the subleading contribution. It seems to need other contributions such as the SU(3) breaking effects. Perhaps they are induced from some new physics effects. In the usual sense, new physics contributions should appear loop effects such as the penguin-type diagram so that there should not be any discrepancies in tree-type diagrams. We put the new physics contributions with weak phase into both gluonic and EW penguins to find the allowed regions for each parameter.

This paper is organized as follows. In Section II, we review the diagram decomposition approach in $B \to K\pi$ and $\pi\pi$. In Section III, the large EW-penguin contribution in $B \to K\pi$ decay modes is discussed. We find that we do not only need the large magnitude but also the large strong phase differences. In Sections IV and V, the SU(3) breaking effect and the large EW-penguin contributions in $B \to \pi\pi$ is discussed. Section VI shows what is needed to explain both modes at once if the new physics contributions are exiting in these modes. Section VII summarizes our discussions.

II. $B \to K\pi$ AND $\pi\pi$ UNDER FLAVOR SU(3) SYMMETRY

Using the diagram decomposition approach [6–10,12,13,16], the decay amplitudes of $B \to K\pi$ and $\pi\pi$ are

$$A_K^{0+} \equiv A(B^+ \to K^0\pi^+) = \Big[AV_{ub}^*V_{us} + \sum_{i=u,c,t}\Big(P_i + EP_i - \frac{1}{3}P_{EWi}^C + \frac{2}{3}EP_{EWi}^C\Big)V_{ib}^*V_{is}\Big], \tag{1}$$

$$A_K^{00} \equiv A(B^0 \to K^0\pi^0) = -\frac{1}{\sqrt{2}}\Big[CV_{ub}^*V_{us} - \sum_{i=u,c,t}(P_i + EP_i - P_{EWi} - \frac{1}{3}P_{EWi}^C - \frac{1}{3}EP_{EWi}^C)V_{ib}^*V_{is}\Big], \tag{2}$$

$$A_K^{+-} \equiv A(B^0 \to K^+\pi^-) = -\Big[TV_{ub}^*V_{us} + \sum_{i=u,c,t}\Big(P_i + EP_i + \frac{2}{3}P_{EWi}^C - \frac{1}{3}EP_{EWi}^C\Big)V_{ib}^*V_{is}\Big], \tag{3}$$

$$A_K^{+0} \equiv A(B^+ \to K^+\pi^0) = -\frac{1}{\sqrt{2}}\Big[(T + C + A)V_{ub}^*V_{us} + \sum_{i=u,c,t}\Big(P_i + EP_i + P_{EWi} + \frac{2}{3}P_{EWi}^C + \frac{2}{3}EP_{EWi}^C\Big)V_{ib}^*V_{is}\Big], \tag{4}$$

$$A_\pi^{00} \equiv A(B^0 \to \pi^0\pi^0) = \frac{1}{\sqrt{2}}\Big[(-C + E)V_{ub}^*V_{ud} + \sum_{i=u,c,t}\Big(P_i + EP_i - P_{EWi} - \frac{1}{3}P_{EWi}^C - \frac{1}{3}EP_{EWi}^C\Big)V_{ib}^*V_{id}\Big], \tag{5}$$

$$A_\pi^{+-} \equiv A(B^0 \to \pi^+\pi^-) = -\Big[(T + E)V_{ub}^*V_{ud} + \sum_{i=u,c,t}\Big(P_i + EP_i + \frac{2}{3}P_{EWi}^C - \frac{1}{3}EP_{EWi}^C\Big)V_{ib}^*V_{id}\Big], \tag{6}$$

$$A_\pi^{+0} \equiv A(B^+ \to \pi^+\pi^0) = -\frac{1}{\sqrt{2}}\Big[(T + C)V_{ub}^*V_{ud} + \sum_{i=u,c,t}(P_{EWi} + P_{EWi}^C)V_{ib}^*V_{id}\Big], \tag{7}$$

where T is a color-favored tree amplitude, C is a color-suppressed tree, $A(E)$ is an annihilation (exchange), P_i ($i = u, c, t$) is a gluonic penguin, EP_i is a penguin exchange, P_{EWi} is a color-favored EW-penguin, P_{EWi}^C is a color-suppressed EW-penguin and EP_{EWi}^C is a color-suppressed EW-penguin exchange. In the following study, for simplicity, we neglect the u- and c- EW penguins because of their smallness, Here we redefine the each terms as follows:

$$T + P_u + EP_u - P_c - EP_c \to T, \tag{8}$$

$$C - P_u - EP_u + P_c + EP_c \to C, \tag{9}$$

$$A + P_u + EP_u - P_c - EP_c \to A, \tag{10}$$

$$E \to E, \tag{11}$$

$$P_t + EP_t - P_c - EP_c - \frac{1}{3}P_{EW}^C + \frac{2}{3}EP_{EW}^C \to P, \tag{12}$$

$$P_{EW} + EP_{EW}^C \to P_{EW}, \tag{13}$$

$$P_{EW}^C - EP_{EW}^C \to P_{EW}^C. \tag{14}$$

One can reduce the number of complex parameters up to seven. By using the unitarity relation of the CKM matrix, the amplitudes are written as

$$A_K^{0+} = [PV_{tb}^* V_{ts} + AV_{ub}^* V_{us}], \tag{15}$$

$$A_K^{00} = \frac{1}{\sqrt{2}}[(P - P_{EW})V_{tb}^* V_{ts} - CV_{ub}^* V_{us}], \tag{16}$$

$$A_K^{+-} = -[(P + P_{EW}^C)V_{tb}^* V_{ts} + TV_{ub}^* V_{us}], \tag{17}$$

$$A_K^{+0} = -\frac{1}{\sqrt{2}}[(P + P_{EW} + P_{EW}^C)V_{tb}^* V_{ts} + (T + C + A)V_{ub}^* V_{us}], \tag{18}$$

$$A_\pi^{00} = \frac{1}{\sqrt{2}}[(P - P_{EW})V_{tb}^* V_{td} - (C - E)V_{ub}^* V_{ud}], \tag{19}$$

$$A_\pi^{+-} = -[(P + P_{EW}^C)V_{tb}^* V_{td} + (T + E)V_{ub}^* V_{ud}], \tag{20}$$

$$A_\pi^{+0} = -\frac{1}{\sqrt{2}}[(P_{EW} + P_{EW}^C)V_{tb}^* V_{td} + (T + C)V_{ub}^* V_{ud}]. \tag{21}$$

By this diagram decomposition [7], one can easily find the isospin relation among the amplitudes,

$$\sqrt{2}A_K^{+0} + A_K^{0+} = \sqrt{2}A_K^{00} + A_K^{+-}, \tag{22}$$

$$\sqrt{2}A_\pi^{+0} = \sqrt{2}A_\pi^{00} + A_\pi^{+-}. \tag{23}$$

The largest contribution in $B \to K\pi$ is the gluonic penguin, which in $B \to \pi\pi$ is the color-favored tree so that by factoring them out the amplitudes are rewritten as follows:

$$A_K^{0+} = -P|V_{tb}^* V_{ts}|[1 - r_A e^{i\delta^A} e^{i\phi_3}], \tag{24}$$

$$A_K^{00} = -\frac{1}{\sqrt{2}}P|V_{tb}^* V_{ts}|[1 - r_{EW}e^{i\delta^{EW}} + r_C e^{i\delta^C} e^{i\phi_3}], \tag{25}$$

$$A_K^{+-} = P|V_{tb}^* V_{ts}|[1 + r_{EW}^C e^{i\delta^{EWC}} - r_T e^{i\delta^T} e^{i\phi_3}], \tag{26}$$

$$A_K^{+0} = \frac{1}{\sqrt{2}}P|V_{tb}^* V_{ts}|[1 + r_{EW}e^{i\delta^{EW}} + r_{EW}^C e^{i\delta^{EWC}} - (r_T e^{i\delta^T} + r_C e^{i\delta^C} + r_A e^{i\delta^A})e^{i\phi_3}], \tag{27}$$

$$A_\pi^{00} = \frac{1}{\sqrt{2}}T|V_{ub}^* V_{ud}|[(\tilde{r}_P e^{-i\delta^T} - \tilde{r}_{EW}e^{i(\delta^{EW}-\delta^T)})e^{-i\phi_1} - (\tilde{r}_C e^{i(\delta^C-\delta^T)} - \tilde{r}_E e^{i(\delta^E-\delta^T)})e^{i\phi_3}], \tag{28}$$

$$A_\pi^{+-} = -T|V_{ub}^* V_{ud}|[(\tilde{r}_P e^{-i\delta^T} + \tilde{r}_{EW}^C e^{i(\delta^{EWC}-\delta^T)})e^{-i\phi_1} + (1 + \tilde{r}_E e^{i(\delta^E-\delta^T)})e^{i\phi_3}], \tag{29}$$

$$A_\pi^{+0} = -\frac{1}{\sqrt{2}}T|V_{ub}^* V_{ud}|[(\tilde{r}_{EW}e^{i(\delta^{EW}-\delta^T)} + \tilde{r}_{EW}^C e^{i(\delta^{EWC}-\delta^T)})e^{-i\phi_1} + (1 + \tilde{r}_C e^{i(\delta^C-\delta^T)})e^{i\phi_3}], \tag{30}$$

where ϕ_1 and ϕ_3 are the weak phases in $V_{tb}^* V_{td}$ and $V_{ub}^* V_{us}$, respectively; δ^X's are the strong phase differences between each diagram and gluonic penguin, and

$$r_A = \frac{|AV_{ub}^* V_{us}|}{|PV_{tb}^* V_{ts}|}, \qquad r_T = \frac{|TV_{ub}^* V_{us}|}{|PV_{tb}^* V_{ts}|}, \qquad r_C = \frac{|CV_{ub}^* V_{us}|}{|PV_{tb}^* V_{ts}|}, \tag{31}$$

$$r_{EW} = \frac{|P_{EW}|}{|P|}, \qquad r_{EW}^C = \frac{|P_{EW}^C|}{|P|}, \tag{32}$$

$$\tilde{r}_C = \frac{|C|}{|T|} = \frac{r_C}{r_T}, \qquad \tilde{r}_E = \frac{|E|}{|T|}, \tag{33}$$

$$\tilde{r}_P = \frac{|PV_{tb}^* V_{td}|}{|TV_{ub}^* V_{ud}|} = \frac{1}{r_T}\frac{|V_{td}V_{us}|}{|V_{ud}V_{ts}|}, \tag{34}$$

$$\tilde{r}_{EW} = \frac{|P_{EW}V_{tb}^* V_{td}|}{|TV_{ub}^* V_{ud}|} = r_{EW}\tilde{r}_P, \qquad \tilde{r}_{EW}^C = \frac{|P_{EW}^C V_{tb}^* V_{td}|}{|TV_{ub}^* V_{ud}|} = r_{EW}^C \tilde{r}_P. \tag{35}$$

We assume the hierarchy of the ratios as $1 > r_T, r_{EW} > r_C, r_{EW}^C > r_A$ and $1 > \tilde{r}_P > \tilde{r}_{EW}, \tilde{r}_C > \tilde{r}_{EW}^C, \tilde{r}_E$ [7]. r_T can be estimated from the ratio of $Br(B^+ \to \pi^0\pi^+)$ to $Br(B^+ \to K^0\pi^+)$ [28–32], which is almost a pure gluonic penguin and a pure tree process, respectively. Under the naive factorization approach, the ratio should be proportional to r_T^2:

$$\frac{2Br(B \to \pi^0\pi^+)}{Br(B \to K^0\pi^+)} = \frac{|T|^2}{|P|^2}\frac{f_\pi^2|V_{ub}^* V_{ud}|^2}{f_K^2|V_{tb}^* V_{ts}|^2} \sim r_T^2\frac{f_\pi^2}{\lambda^2 f_K^2}, \tag{36}$$

where the difference between the tree diagrams in $B \to \pi\pi$ and $B \to K\pi$ decays come from the decay constants, $T_\pi \sim T_K\frac{f_\pi}{f_K}$, and λ is the Cabbibo angle, so that $r_T \sim 0.2$ with 10% error from recent experimental data. r_C and r_{EW}^C must be suppressed by color factor from r_T and r_{EW}. Comparing the Wilson coefficients, which correspond to the diagrams under the factorization method, we can assume that $r_C \sim 0.1r_T$ and $r_{EW}^C \sim 0.1r_{EW}$ [25,28]. Here we do not put any assumption for the magnitude of r_{EW}. r_A could be negligible because it should have B meson decay constant and it works as a suppression factor f_B/M_B. While, by the similar way one obtains $\tilde{r}_P \sim 0.3$, $\tilde{r}_C = 0.1$. Indeed, the assumption is consistent with the estimations for each parameters in the PQCD approach:

$$r_T = 0.21, \qquad r_{EW} = 0.14 \qquad : O(0.1) \tag{37}$$

$$r_C = 0.018, \quad r_{EW}^C = 0.012, \quad r_A = 0.0048 \quad : O(0.01) \tag{38}$$

According to this assumption, we neglect the r^2 terms including r_C, r_A and r_{EW}^C in $B \to K\pi$. In $B \to \pi\pi$ we will neglect $\tilde{r}_{EW}^C$ and $\tilde{r}_E$ for simplicity, but keep $\tilde{r}_{EW}$ to discuss its magnitude in the both modes. Consequently, the averaged branching ratios are

$$\bar{B}_K^{0+} \propto \frac{1}{2}[|A^{0+}|^2 + |A^{0-}|^2] = |P|^2|V_{tb}^*V_{ts}|^2[1 - 2r_A\cos\delta^A\cos\phi_3], \tag{39}$$

$$2\bar{B}_K^{00} \propto [|A^{00}|^2 + |\bar{A}^{00}|^2] = |P|^2|V_{tb}^*V_{ts}|^2[1 + r_{EW}^2 - 2r_{EW}\cos\delta^{EW} + 2r_C\cos\delta^C\cos\phi_3], \tag{40}$$

$$\bar{B}_K^{+-} \propto \frac{1}{2}[|A^{+-}|^2 + |A^{-+}|^2] = |P|^2|V_{tb}^*V_{ts}|^2[1 + r_T^2 + 2r_{EW}^C\cos\delta^{EWC} - 2r_T\cos\delta^T\cos\phi_3], \tag{41}$$

$$\begin{aligned}2\bar{B}_K^{+0} \propto{}& [|A^{+0}|^2 + |A^{-0}|^2] \\ ={}& |P|^2|V_{tb}^*V_{ts}|^2[1 + r_{EW}^2 + r_T^2 + 2r_{EW}\cos\delta^{EW} \\ &+2r_{EW}^C\cos\delta^{EWC} \\ &-(2r_T\cos\delta^T + 2r_C\cos\delta^C + 2r_A\cos\delta^A)\cos\phi_3 \\ &-2r_{EW}r_T\cos(\delta^{EW} - \delta^T)\cos\phi_3],\end{aligned} \tag{42}$$

$$\begin{aligned}2\bar{B}_\pi^{00} \propto{}& [|A_\pi^{00}|^2 + |\bar{A}_\pi{}^{00}|^2] \\ ={}& |T|^2|V_{ub}^*V_{ud}|^2\{\tilde{r}_C^2 + \tilde{r}_P{}^2 + \tilde{r}_{EW}{}^2 - 2\tilde{r}_P\tilde{r}_{EW}\cos\delta^{EW} \\ &-2\tilde{r}_C[\tilde{r}_P\cos\delta^C - \tilde{r}_{EW}\cos(\delta^{EW} - \delta^C)] \\ &\times\cos(\phi_1 + \phi_3)\},\end{aligned} \tag{43}$$

$$\bar{B}_\pi^{+-} \propto \frac{1}{2}[|A_\pi^{+-}|^2 + |A_\pi^{-+}|^2] = |T|^2|V_{ub}^*V_{ud}|^2[1 + \tilde{r}_P^2 + 2\tilde{r}_P\cos\delta^T \times\cos(\phi_1 + \phi_3)], \tag{44}$$

$$\begin{aligned}2\bar{B}_\pi^{+0} \propto{}& [|A_\pi^{+0}|^2 + |A_\pi^{-0}|^2] \\ ={}& |T|^2|V_{ub}^*V_{ud}|^2[1 + \tilde{r}_C^2 + \tilde{r}_{EW}^2 + 2\tilde{r}_C \\ &\times\cos(\delta^C - \delta^T) + 2\tilde{r}_{EW}\{\cos(\delta^{EW} - \delta^T) \\ &+\tilde{r}_C\cos(\delta^{EW} - \delta^C)\}\cos(\phi_1 + \phi_3)].\end{aligned} \tag{45}$$

When we compare the theoretical predictions with the experimental data, the ratios among the branching ratios are very useful to reduce uncertainties in hadronic parts. One can take several ratios among the branching ratios. From the averaged values of the recent experimental data in Table I,

$$\frac{\bar{B}_K^{+-}}{2\bar{B}_K^{00}} = 0.78 \pm 0.10, \qquad \frac{2\bar{B}_K^{+0}}{\bar{B}_K^{0+}} = 1.15 \pm 0.12, \tag{46}$$

$$\frac{\tau^+}{\tau^0}\frac{\bar{B}_K^{+-}}{\bar{B}_K^{0+}} = 0.90 \pm 0.07, \qquad \frac{\tau^0}{\tau^+}\frac{\bar{B}_K^{+0}}{\bar{B}_K^{00}} = 0.98 \pm 0.15, \tag{47}$$

$$\frac{\tau^+}{\tau^0}\frac{2\bar{B}_K^{00}}{\bar{B}_K^{0+}} = 1.17 \pm 0.16, \qquad \frac{\tau^0}{\tau^+}\frac{2\bar{B}_K^{+0}}{\bar{B}_K^{+-}} = 1.26 \pm 0.13, \tag{48}$$

$$\frac{\tau^0}{\tau^+}\frac{2\bar{B}_\pi^{+0}}{\bar{B}_\pi^{+-}} = 2.08 \pm 0.37, \qquad \frac{2\bar{B}_\pi^{00}}{\bar{B}_\pi^{+-}} = 0.83 \pm 0.23, \tag{49}$$

where $\frac{\tau^+}{\tau^0}$ is a lifetime ratio between the charged and the neutral B mesons and $\tau(B^\pm)/\tau(B^0) = 1.086 \pm 0.017$ [33].

III. EW-PENGUIN CONTRIBUTION IN $B \to K\pi$

Under the assumption that all r are smaller than 1 and the r^2 terms including r_C, r_A and r_{EW}^C are neglected, the ratios among the decay rates of $B \to K\pi$ are

TABLE I. The experimental data [17–19] and the average [24].

	CLEO	Belle	*BABAR*	Average
$Br(B^0 \to K^+\pi^-) \times 10^6$	$18.0^{+2.3+1.2}_{-2.1-0.9}$	$18.5 \pm 1.0 \pm 0.7$	$17.9 \pm 0.9 \pm 0.7$	18.2 ± 0.8
$Br(B^0 \to K^0\pi^0) \times 10^6$	$12.8^{+4.0+1.7}_{-3.3-1.4}$	$11.7 \pm 2.3^{+1.2}_{-1.3}$	$11.4 \pm 1.7 \pm 0.8$	11.7 ± 1.4
$Br(B^+ \to K^+\pi^0) \times 10^6$	$12.9^{+2.4+1.2}_{-2.2-1.1}$	$12.0 \pm 1.3^{+1.3}_{-0.9}$	$12.8^{+1.2}_{-1.1} \pm 1.0$	12.5 ± 1.1
$Br(B^+ \to K^0\pi^+) \times 10^6$	$18.8^{+3.7+2.1}_{-3.3-1.8}$	$22.0 \pm 1.7 \pm 1.1$	$22.3 \pm 1.9 \pm 1.1$	21.8 ± 1.4
$Br(B^0 \to \pi^+\pi^-) \times 10^6$	$4.5^{1.4+0.5}_{-1.2-0.4}$	$4.4 \pm 0.6 \pm 0.3$	$4.7 \pm 0.6 \pm 0.2$	4.6 ± 0.4
$Br(B^0 \to \pi^0\pi^0) \times 10^6$	···	$1.7 \pm 0.6 \pm 0.2$	$2.1 \pm 0.6 \pm 0.3$	1.9 ± 0.5
$Br(B^+ \to \pi^+\pi^0) \times 10^6$	$4.6^{+1.8+0.6}_{-1.6-0.7}$	$5.0 \pm 1.2 \pm 0.5$	$5.5^{+1.0}_{-0.9} \pm 0.6$	5.2 ± 0.8

$$\frac{\bar{B}_K^{+-}}{2\bar{B}_K^{00}} = \{1 + 2r_{EW}\cos\delta^{EW} + 2r_{EW}^C\cos\delta^{EWC} - 2(r_T\cos\delta^T + r_C\cos\delta^C)\cos\phi_3 + r_T^2\} - r_{EW}^2 + 4r_{EW}^2\cos^2\delta^{EW} - 4r_{EW}r_T\cos\delta^{EW}\cos\delta^T\cos\phi_3, \tag{50}$$

$$\frac{2\bar{B}_K^{+0}}{\bar{B}_K^{0+}} = \{1 + 2r_{EW}\cos\delta^{EW} + 2r_{EW}^C\cos\delta^{EWC} - 2(r_T\cos\delta^T + r_C\cos\delta^C)\cos\phi_3 + r_T^2\} + r_{EW}^2 - 2r_{EW}r_T\cos(\delta^{EW} - \delta^T)\cos\phi_3, \tag{51}$$

$$\frac{\tau^+}{\tau^0}\frac{\bar{B}_K^{+-}}{\bar{B}_K^{0+}} = 1 + 2r_{EW}^C\cos\delta^{EWC} - 2(r_T\cos\delta^T - r_A\cos\delta^A)\times\cos\phi_3 + r_T^2, \tag{52}$$

$$\frac{\tau^0}{\tau^+}\frac{\bar{B}_K^{+0}}{\bar{B}_K^{00}} = 1 + 2r_{EW}^C\cos\delta^{EWC} - 2(r_T\cos\delta^T + 2r_C\cos\delta^C + r_A\cos\delta^A)\cos\phi_3 + r_T^2 + 4r_{EW}\cos\delta^{EW} + 8r_{EW}^2\cos^2\delta^{EW} - 2r_{EW}r_T\cos(\delta^{EW} - \delta^T)\times\cos\phi_3 - 4r_{EW}r_T\cos\delta^{EW}\cos\delta^T\cos\phi_3, \tag{53}$$

$$\frac{\tau^+}{\tau^0}\frac{2\bar{B}_K^{00}}{\bar{B}_K^{0+}} = 1 - 2r_{EW}\cos\delta^{EW} + 2(r_C\cos\delta^C + r_A\cos\delta^A)\times\cos\phi_3 + r_{EW}^2, \tag{54}$$

$$\frac{\tau^0}{\tau^+}\frac{2\bar{B}_K^{+0}}{\bar{B}_K^{+-}} = 1 + 2r_{EW}\cos\delta^{EW} - 2(r_C\cos\delta^C + r_A\cos\delta^A)\times\cos\phi_3 + r_{EW}^2 + 2r_{EW}r_T\cos(\delta^{EW} + \delta^T)\cos\phi_3. \tag{55}$$

If we neglect all r^2 terms, then there are a few relations[20] among Eqs. (50)–(55) as following

$$R_c - R_n \equiv \frac{2\bar{B}_K^{+0}}{\bar{B}_K^{0+}} - \frac{\bar{B}_K^{+-}}{2\bar{B}_K^{00}} = 0, \tag{56}$$

$$S \equiv \frac{2\bar{B}_K^{+0}}{\bar{B}_K^{0+}} - \frac{\tau^+}{\tau^0}\frac{\bar{B}_K^{+-}}{\bar{B}_K^{0+}} + \frac{\tau^+}{\tau^0}\frac{2\bar{B}_K^{00}}{\bar{B}_K^{0+}} - 1 = 0, \tag{57}$$

$$R_+ - 2 \equiv \frac{\tau^0}{\tau^+}\frac{2\bar{B}_K^{+0}}{\bar{B}_K^{+-}} + \frac{\tau^+}{\tau^0}\frac{2\bar{B}_K^{00}}{\bar{B}_K^{0+}} - 2 = 0, \tag{58}$$

where S is a kind of relation called Lipkin sum rule [11] and based on the isospin relation among the amplitudes. However, the experimental data listed in Eqs. (46)–(48) do not satisfy these relations so well. According to the experimental data, $\frac{\bar{B}_K^{+-}}{2\bar{B}_K^{00}}$ seems to be smaller than 1 but $\frac{2\bar{B}_K^{+0}}{\bar{B}_K^{0+}}$ seems to be larger than 1. Thus it shows there is a discrepancy between them. The equations of $\frac{\bar{B}_K^{+-}}{2\bar{B}_K^{00}}$ and $\frac{2\bar{B}_K^{+0}}{\bar{B}_K^{0+}}$ are the same up to the r_T^2 term and the difference comes from the r^2 term including r_{EW}. The second relation corresponds to the isospin relation of Eq. (22) at the first order of r. The discrepancy of relation (57) from 0 also comes from the r^2 term including r_{EW}. The differences are

$$R_c - R_n = \frac{2\bar{B}_K^{+0}}{\bar{B}_K^{0+}} - \frac{\bar{B}_K^{+-}}{2\bar{B}_K^{00}} = 2r_{EW}^2 + 2r_{EW}r_T\cos(\delta^{EW} + \delta^T)\cos\phi_3 - 4r_{EW}^2\cos^2\delta^{EW} = 0.37 \pm 0.16, \tag{59}$$

$$S = \frac{2\bar{B}_K^{+0}}{\bar{B}_K^{0+}} - \frac{\tau^+}{\tau^0}\frac{\bar{B}_K^{+-}}{\bar{B}_K^{0+}} + \frac{\tau^+}{\tau^0}\frac{2\bar{B}_K^{00}}{\bar{B}_K^{0+}} - 1 = 2r_{EW}^2 - 2r_{EW}r_T\cos(\delta^{EW} - \delta^T)\cos\phi_3 = 0.43 \pm 0.20, \tag{60}$$

$$R_+ - 2 = \frac{\tau^0}{\tau^+}\frac{2\bar{B}_K^{+0}}{\bar{B}_K^{+-}} + \frac{\tau^+}{\tau^0}\frac{2\bar{B}_K^{00}}{\bar{B}_K^{0+}} - 2 = 2r_{EW}^2 + 2r_{EW}r_T\cos(\delta^{EW} + \delta^T)\cos\phi_3 = 0.43 \pm 0.21, \tag{61}$$

so one can find that the EW-penguin contributions may be large. All terms are including r_{EW} and the deviation of the relation from zero is finite. These deviations may be an evidence that the EW-penguin is larger than the estimation we expected within the SM. Here the errors are determined by adding all errors quadratically. We want to solve from these three relations but there are too many parameters. To estimate the magnitude of the EW-penguin contribution, satisfying the experimental data roughly, we use Eq. (54),

$$\frac{\tau^+}{\tau^0}\frac{2\bar{B}_K^{00}}{\bar{B}_K^{0+}} - 1 \simeq -2r_{EW}\cos\delta^{EW} + r_{EW}^2 \simeq 0.17 \pm 0.16, \tag{62}$$

where the r_C and r_A terms were neglected to reduce the number of parameters, because the r_{EW} in Eqs. (59) and (60) should be larger than the usual prediction, therefore, r_C and r_A must be quite smaller than r_{EW}. Using Eqs. (59)–(62), we can solve them in terms of r_{EW} and if we can respect the central values of experimental data, the solution is

$$[r_{EW}, \cos\delta^{EW}, r_T\cos(\delta^{EW} + \delta^T)\cos\phi_3] = (0.64, 0.19, -0.30). \tag{63}$$

This solution shows that the EW-penguin contribution is too large compared with the rough theoretical estimation and the strong phase may not be close to zero. The allowed region of r_{EW}, $\cos\delta^{EW}$ and $r_T\cos(\delta^{EW} + \delta^T)\times\cos\phi_3$ at 1σ level from the three relations, Eqs. (59)–(62) is shown in Fig. 1. The "×" in these figures shows the central values of the solution, Eq. (63), and the dotted

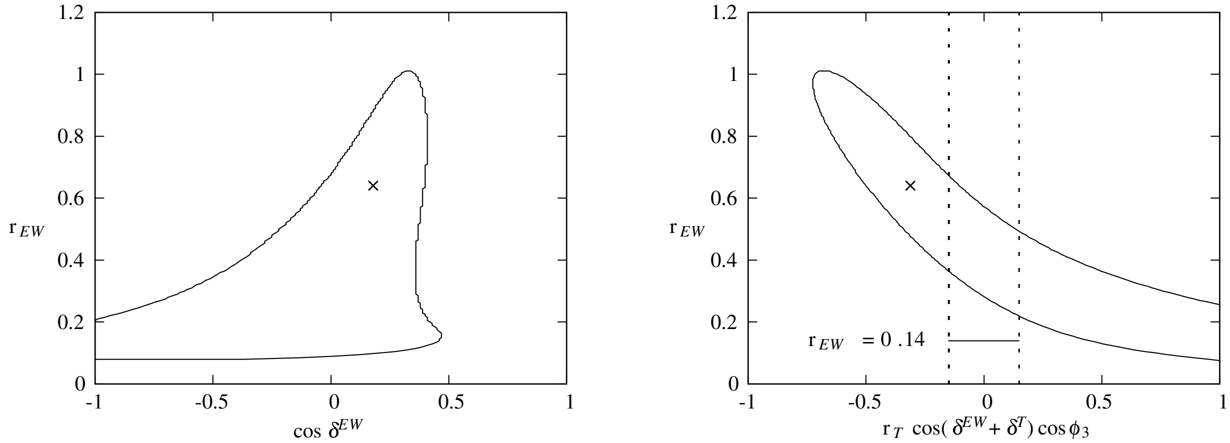

FIG. 1. The allowed region on $(r_{EW}, \cos\delta^{EW})$ and $[r_{EW}, r_T\cos(\delta^{EW}+\delta^T)\cos\phi_3]$ plane at 1σ level varying the magnitude of $r_T\cos(\delta^{EW}+\delta^T)\cos\phi_3$ up to 1. The dashed line shows the bound of $r_T\cos(\delta^{EW}+\delta^T)\cos\phi_3$ for $r_T = 0.2$ and $\phi_3 = 40°$.

lines in the right figure show the bound of $r_T\cos(\delta^{EW}+\delta^T)\cos\phi_3$ for $r_T = 0.2$ and $\phi_3 = 40°$. The theoretical prediction should be in the bound at $r_{EW} = 0.14$ but there is no overlap region with the allowed one at 1σ level.

What we can expect at present are roughly $40° < \phi_3 < 80°$ from CKM fitting and $r_T = 0.2$ with 10% error from the estimation of the ratio $\frac{B_\pi^{+0}}{B_K^{0+}}$. Hence the figure shows that r_{EW} will be larger than 0.2 while the theoretical prediction of r_{EW} is 0.14, and a large strong phase difference between gluonic and EW penguins will be requested due to $\cos\delta^{EW} < 0.5$ [20]. Accordingly, to explain the data we may need some contribution from new physics in the EW-penguin-type contribution with a large phase. We have to also consider the possibility of large strong phases. From Eq. (59) one can extract more information about strong phases to satisfy the experimental data. Equation (59) is

$$\begin{aligned} R_c - R_n &= -2r_{EW}^2\cos2\delta^{EW} + 2r_{EW}r_T\cos(\delta^{EW}+\delta^T) \\ &\quad\times\cos\phi_3 \\ &= 0.37 \pm 0.16 > 0. \end{aligned} \tag{64}$$

The first term has a negative sign but $R_c - R_n$ should be a positive value. For this reason, negative $\cos2\delta^{EW}$, that is, $45° < |\delta^{EW}| < 135°$ will be favored. Namely, it seems to show the strong phase difference should be large. Furthermore, considering S in Eq. (60), we can obtain stronger constraint for the parameters because the second term has a negative sign which is different from the case of Eq. (59). If $\cos(\delta^{EW}-\delta^T)\cos\phi_3$ was positive value, r_{EW} must be larger values in order to satisfy the condition for S. In Fig. 2, the allowed regions for r_{EW}, δ^T and δ^{EW} from three constraints, Eqs. (59)–(61), are plotted. Here we did not use Eq. (62) because it is including an assumption which r_C can be neglected. One can find that to satisfy the experimental data at 1σ level, r_{EW} should be larger than about 0.3. Under exact flavor SU(3) symmetry, the strong phase difference between the EW-penguin and the color-favored tree, which is called to as ω,

$$\omega \equiv \delta^{EW} - \delta^T, \tag{65}$$

should be close to zero because the diagrams are topologically same [13] and, effectively, the difference is only whether the exchanging weak gauge boson is W or Z. If it is correct, the constraint for δ^T has to influence δ^{EW} due to $\delta^{EW} \sim \delta^T$. We consider the direct CP asymmetry to obtain the information about strong phase.

The direct CP asymmetries under the same assumption, neglecting the terms of $O(0.001)$, are

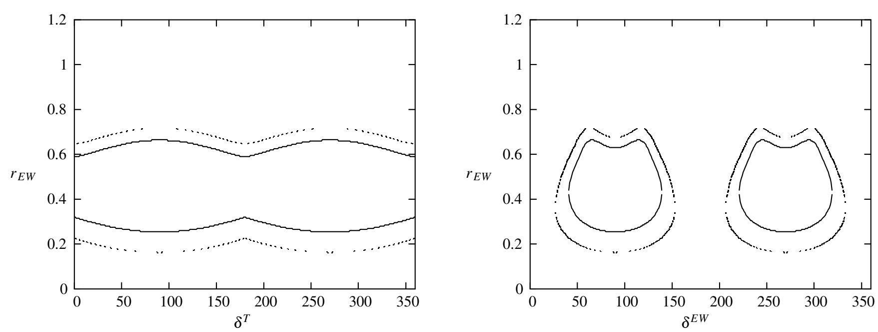

FIG. 2. From Eqs. (59)–(61), the allowed regions for r_{EW}, δ^T and δ^{EW} at $r_T = 0.2$ and $40° < \phi_3 < 80°$. The solid (dashed) line shows the 1σ (2σ) bound.

$$A_{CP}^{0+} \equiv \frac{|A_K^{0-}|^2 - |A_K^{0+}|^2}{|A_K^{0-}|^2 + |A_K^{0+}|^2} = -2r_A \sin\delta^A \sin\phi_3 \sim 0.0, \tag{66}$$

$$A_{CP}^{00} \equiv \frac{|\bar{A}_K^{00}|^2 - |A_K^{00}|^2}{|\bar{A}_K^{00}|^2 + |A_K^{00}|^2} = 2r_C \sin\delta^C \sin\phi_3 \sim O(0.01), \tag{67}$$

$$A_{CP}^{+-} \equiv \frac{|A_K^{-+}|^2 - |A_K^{+-}|^2}{|A_K^{-+}|^2 + |A_K^{+-}|^2} = -2r_T \sin\delta^T \sin\phi_3 - r_T^2 \sin2\delta^T \sin2\phi_3, \tag{68}$$

$$A_{CP}^{+0} \equiv \frac{|A_K^{-0}|^2 - |A_K^{+0}|^2}{|A_K^{-0}|^2 + |A_K^{+0}|^2} = -2(r_T \sin\delta^T + r_C \sin\delta^C + r_A \sin\delta^A)\sin\phi_3 + 2r_{EW} r_T \sin(\delta^T + \delta^{EW})\sin\phi_3 - r_T^2 \sin2\delta^T \sin2\phi_3. \tag{69}$$

Up to the first order of r, there is a relation among the CP asymmetries as follows:

$$A_{CP}^{+0} - A_{CP}^{+-} + A_{CP}^{00} - A_{CP}^{0+} = 0. \tag{70}$$

The discrepancy of this relation is caused from the cross term of r_T and r_{EW}:

$$A_{CP}^{+0} - A_{CP}^{+-} + A_{CP}^{00} - A_{CP}^{0+} = 2r_T r_{EW} \sin(\delta^T + \delta^{EW}) \times \sin\phi_3 = 0.18 \pm 0.24. \tag{71}$$

This may also give us some useful information about r_{EW} and the strong phases but the data of A_{CP}^{00} still has quite large error, as shown in Table II, so that one cannot extract from it at present time. We need more accurate data to use this relation. For this reason, we only use A_{CP}^{+-} because it is an accurate measurement and will give some constraint to δ^T. In Fig. 3, we plot A_{CP}^{+-} as a function of δ^T. From this figure, we can find the constraint for δ^T at $-0.123 < A_{CP}^{+-} < -0.067$. It tells us that the small δ^T is favored and δ^T should be around 15° or 160°.

In Eq. (52), which leads to Fleischer-Mannel bound [10], if r_{EW}^C and r_A are negligible, then

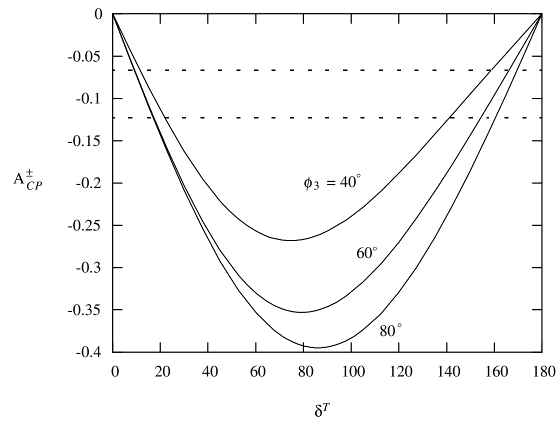

FIG. 3. A_{CP}^{+-} as a function of δ^T.

$$R \equiv \frac{\tau^+}{\tau^0} \frac{\bar{B}_K^{+-}}{\bar{B}_K^{0+}} = 1 - 2r_T \cos\delta^T \cos\phi_3 + r_T^2 = 0.90 \pm 0.07, \tag{72}$$

To satisfy $R = 0.90 \pm 0.07 < 1$ we need positive $\cos\delta^T$ so that the range $\delta^T \sim 10° - 20°$ is favored. Taking account of these constraints for δ^T from A_{CP}^{+-}, we plot the maximum bound of $R_c - R_n$ as the functions of δ^{EW} and r_{EW} in Fig. 4, respectively. Then the allowed regions for $\delta^{EW} - \delta^T$ around 0° and 180° disappear. $R_c - R_n$ seems to favor $45° < |\delta^{EW}| < 135°$, but the constraint from A_{CP}^{+-} strongly suggests that the strong phase, δ^T, should be around 15°. As a consequence, $\delta^{EW} - \delta^T = 0$ as the theoretical prospect is disfavored.

What we found from $B \to K\pi$ decays is that we need larger $r_{EW} > 0.3$ and large strong phase differences, $\delta^{EW} - \delta^T$. The constraint, $\delta^T \sim 10° - 20°$, from direct CP asymmetry is different from the favored range of the strong phase of EW-penguin $\delta^{EW} > 45°$ so that $\omega = \delta^{EW} - \delta^T \simeq 0$, which is favored in theory, will not be satisfied. What the large strong phase difference requests may be a serious problem in these modes. If SU(3) symmetry is good one, these properties should also appear in $B \to \pi\pi$.

IV. SU(3) BREAKING EFFECT IN GLUONIC PENGUIN

When we consider the ratios among the branching ratios for $B \to \pi\pi$ decays,

TABLE II. The experimental data of the direct CP asymmetry [17,19,42] and the averaged values [24].

	CLEO	Belle	*BABAR*	Average
A_{CP}^{0+}	$0.18 \pm 0.24 \pm 0.02$	$0.05 \pm 0.05 \pm 0.01$	$-0.05 \pm 0.08 \pm 0.01$	0.03 ± 0.04
A_{CP}^{00}	···	$0.16 \pm 0.29 \pm 0.05$	$0.03 \pm 0.36 \pm 0.11$	0.11 ± 0.23
A_{CP}^{+-}	$-0.04 \pm 0.16 \pm 0.02$	$-0.088 \pm 0.035 \pm 0.018$	$-0.107 \pm 0.041 \pm 0.013$	-0.095 ± 0.028
A_{CP}^{+0}	$-0.29 \pm 0.24 \pm 0.02$	$0.06 \pm 0.06 \pm 0.02$	$-0.09 \pm 0.09 \pm 0.01$	0.00 ± 0.05

$$\frac{2\bar{B}_{\pi}^{00}}{\bar{B}_{\pi}^{+-}} = \frac{\tilde{r}_C^2 + \tilde{r}_P^2(1 + r_{EW}^2 - 2r_{EW}\cos\delta^{EW}) - 2\tilde{r}_P\tilde{r}_C(\cos\delta^T - r_{EW}\cos\omega)\cos(\phi_1 + \phi_3)}{1 + \tilde{r}_P^2 + 2\tilde{r}_P\cos\delta^T\cos(\phi_1 + \phi_3)}, \tag{73}$$

$$\frac{\tau^0}{\tau^+}\frac{2\bar{B}_{\pi}^{+0}}{\bar{B}_{\pi}^{+-}} = \frac{1 + \tilde{r}_C^2 + 2\tilde{r}_C + \tilde{r}_P^2 r_{EW}^2 + 2\tilde{r}_P r_{EW}(\cos\omega + r_C\cos\omega)\cos(\phi_1 + \phi_3)}{1 + \tilde{r}_P^2 + 2\tilde{r}_P\cos\delta^T\cos(\phi_1 + \phi_3)}, \tag{74}$$

there is also a discrepancy between theoretical expectation and experimental data. In the above equations, δ^C is taken to be equal to δ^T. From a rough estimation, $\tilde{r}_P \sim 0.3$, $\frac{\tau^0}{\tau^+}\frac{2\bar{B}_{\pi}^{0+}}{\bar{B}_{\pi}^{+-}} \sim 1$, $\frac{\bar{B}_{\pi}^{00}}{\bar{B}_{\pi}^{+-}} \sim 0.1$, but the experimental data (49) are quite large values and are not consistent with them. To explain the discrepancy, the denominator seems to be a smaller value so that $\cos\delta^T$ should be negative or $\phi_1 + \phi_3$ should be larger than 90° to reduce the denominator. The negative $\cos\delta^T$ case is inconsistent with the condition $R = \frac{\tau^+}{\tau^-}\frac{\bar{B}^{+-}}{\bar{B}^{00}} = 0.90 \pm 0.07 < 1$. As the result, negative $\cos(\phi_1 + \phi_3)$ is favored. However it is not enough to explain the differences and we will also have to take account of SU(3) breaking effect.

The ratio of the direct CP asymmetries may show the SU(3) breaking effect. We consider the following ratio between $B \to K^+\pi^-$ and $B \to \pi^+\pi^-$:

$$\frac{|\bar{A}_{\pi}^{+-}|^2 - |A_{\pi}^{+-}|^2}{|\bar{A}_{K}^{+-}|^2 - |A_{K}^{+-}|^2} = -\frac{|T + E||P + P_{EW}^C|\sin\delta^T}{|T||P + P_{EW}^C|\sin\delta^T} \sim -\frac{f_\pi}{f_K}\frac{|P_\pi|\sin\delta_\pi^T}{|P_K|\sin\delta_K^T}$$
$$= \frac{Br^{\pi^+\pi^-}A_{CP}^{\pi^+\pi^-}}{Br^{K^+\pi^-}A_{CP}^{K^+\pi^-}} = \begin{cases} -f_\pi^2/f_K^2 = -0.66 & \text{(factorization)} \\ -1.54 \pm 0.66 & \text{(Belle)} \\ -0.50 \pm 0.55 & (BABAR) \\ -1.12 \pm 0.49 & \text{(Average)} \end{cases} \tag{75}$$

[24,34,35], where each value in Eq. (75) corresponds to the each experimental data of the direct CP asymmetry $A_{CP}^{\pi^+\pi^-}$ and the other data used are the averaged values. The factors of the CKM matrix elements are completely canceled. If SU(3) is exact symmetry, the ratio must be -1. From the experimental data in Eq. (75), one can find that a possibility of large SU(3) breaking in gluonic penguin contribution is remaining. When we assume there is no SU(3) breaking effect in tree-type diagram except for the difference of decay constants in the sense of factorization because it is good agreement in $\frac{B\to D\pi}{B\to DK}$, the gluonic penguin contribution might have the SU(3) breaking effect like $P_\pi/P_K \sim 2$.

V. LARGE EW-PENGUIN CONTRIBUTION IN $B \to \pi\pi$

We discuss the role of r_{EW} in $B \to \pi\pi$ decays. To explain the $B \to \pi\pi$ modes, we may need SU(3) breaking effect in gluonic penguin as discussed in previous section. In this section, we assume that the strong phases almost satisfy the SU(3) symmetry as an anzatz. To enhance both ratios, $\frac{2B_{\pi}^{00}}{B_{\pi}^{+-}}$ and $\frac{2B_{\pi}^{+0}}{B_{\pi}^{+-}}$, the smaller denominator will be favored so that the cross term $2\tilde{r}_P\cos\delta^T\cos(\phi_1 + \phi_3)$ should have a negative sign. Since $\cos\delta^T$ should be positive from the data of A_{CP}^{+-}, $\cos(\phi_1 + \phi_3)$ has to be a negative value. As an example, we plot the ratios as the

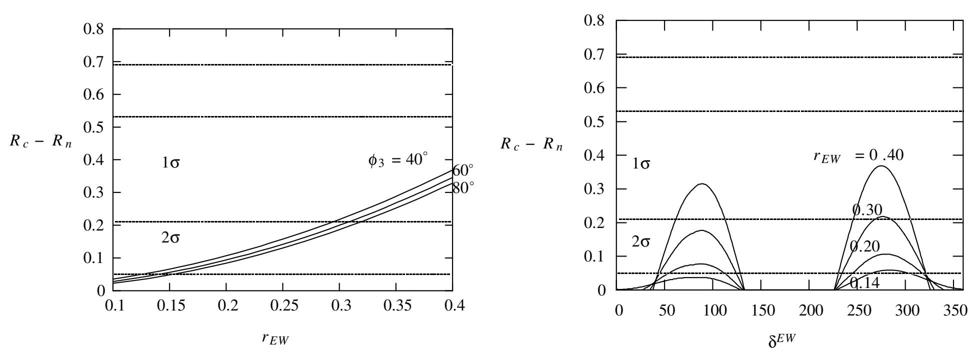

FIG. 4. The lines show the maximum bound of $R_c - R_n$ for r_{EW} and δ^{EW} at $r_T = 0.2$ and $40° < \phi_3 < 80°$ under constraint $-0.123 < A_{CP}^{+-} < -0.067$

function of $\tilde{r}_P$ and r_{EW} in a case with $\delta^{EW} = 110°$, $\delta^C = \delta^T = 10°$ and $\phi_1 + \phi_3 = 110°$ for $\tilde{r}_C = 0.1, 0.2$ and 0.3 in Figs. 5. $\phi_1 + \phi_3 = 110°$ is almost maximum value of allowed region and $\delta^T = 10°$ to satisfy $A_{CP}^{K^+\pi^-}$. From the figures, we can find that in order to explain the discrepancy between the theoretical estimation and the experimental data, $b - d$ gluonic penguin contribution P_π should be larger than $b - s$ gluonic penguin P_K without the CKM factor. It shows SU(3) breaking effect must appear in these decay modes. In addition, large EW-penguin contribution also helps to enhance the ratios.

From these figures, we find that the ratios are enhanced by $\tilde{r}_P$, $\tilde{r}_C$ and r_{EW}. However $\tilde{r}_C = C/T$ is 0.1 for the naive estimation by factorization and it will be at largest up to $1/N_c \sim 0.3$ because it is the simple ratio of two tree diagrams between color-allowed and color-suppressed types. Large $\tilde{r}_P$ is evidence that explains the discrepancies but it also has some constraints from $B \to KK$ decays, which are pure $b - d$ gluonic penguin ($\sim P_\pi$) processes. The upper bounds of $B \to KK$ decays [24] are

$$Br(B^+ \to K^+ \bar{K}^0) \propto |PV_{tb}^* V_{td}|^2 < 2.5 \times 10^{-6}, \quad (76)$$

$$Br(B^0 \to K^0 \bar{K}^0) \propto |PV_{tb}^* V_{td}|^2 < 1.5 \times 10^{-6}, \quad (77)$$

where P is the gluonic penguin contribution without the CKM factor and $P \sim P_\pi$ under SU(3) symmetry. The constraint to P_π/P_K comes from

$$\frac{Br(B^0 \to K^0 \bar{K}^0)}{Br(B^+ \to K^0 \pi^+)} \sim \frac{|P_\pi V_{tb}^* V_{td}|^2}{|P_K V_{tb}^* V_{ts}|^2} < 7.3 \times 10^{-2}, \quad (78)$$

$$\frac{P_\pi}{P_K} < 1.5. \quad (79)$$

Thus $\tilde{r}_P$ may be allowed up to $0.3 \times 1.5 = 0.45$. In addition, we will also need the help from $r_{EW} = P_{EW}/P$ to enhance B_π^{00}.

It is slightly difficult to get the values within the 1σ region unless larger r_C is allowed. However we feel that it may be unnatural that such tree diagram obtains the

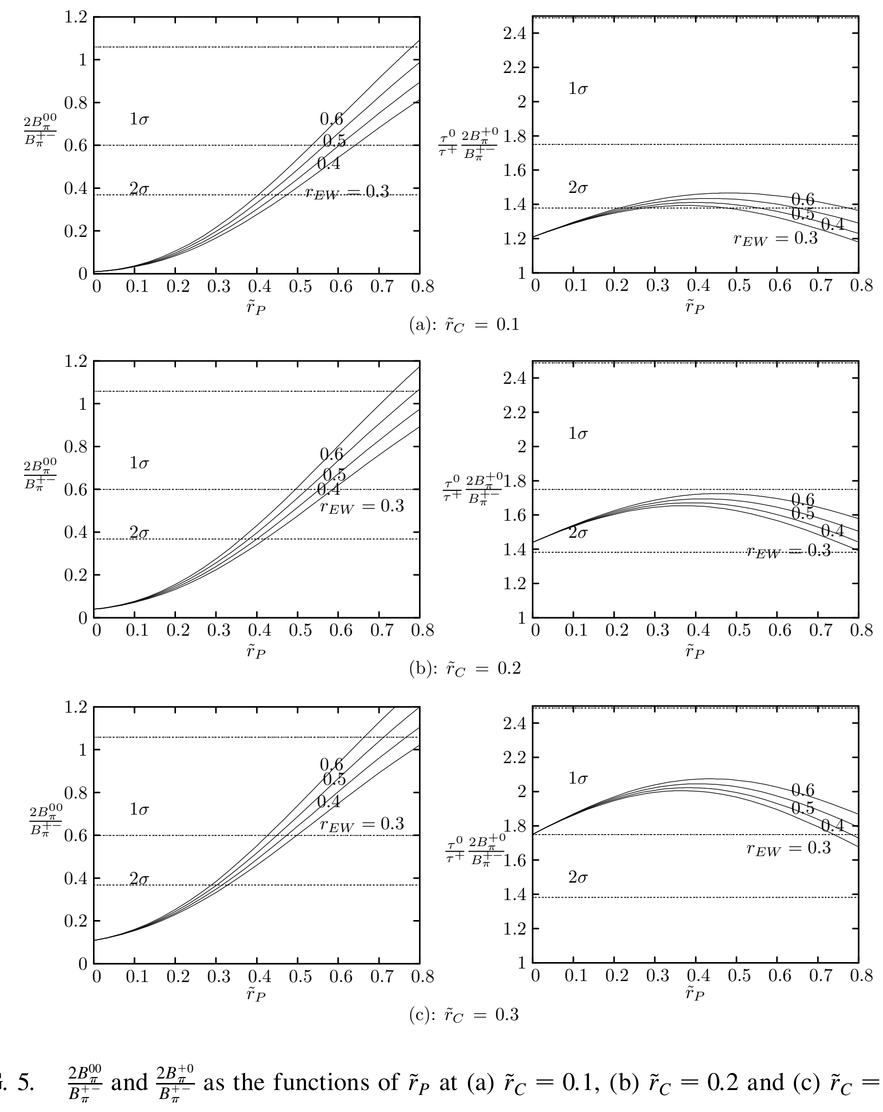

FIG. 5. $\frac{2B_\pi^{00}}{B_\pi^{+-}}$ and $\frac{2B_\pi^{+0}}{B_\pi^{+-}}$ as the functions of $\tilde{r}_P$ at (a) $\tilde{r}_C = 0.1$, (b) $\tilde{r}_C = 0.2$ and (c) $\tilde{r}_C = 0.3$.

larger contribution than usual estimation. Therefore we consider the case keeping small r_C and including some new effects in penguin contribution.

VI. DEPENDENCE OF COLOR-SUPPRESSED TREE CONTRIBUTION

In previous sections, we discussed about large EW-penguin contribution under the assumption of hierarchy among the parameters for each diagram, which is $1 > r_T, r_{EW} > r_C, r_{EW}^C > r_A$. This is based on the hierarchy assumption in Ref. [7] and indeed they are consistent with the estimations by PQCD approach. On the other hand, the experimental data tell us that some contributions should be larger to explain the discrepancies. Hence, we should consider the other possibility also. From the experimental data, the branching ratios of $B^0 \to K^0\pi^0$ and $B^+ \to K^+\pi^0$ seem to be larger compared with the expected values. They are not only including r_{EW} but also r_C so that the remaining possibility is the case that the contribution from the color-suppressed tree diagrams is slightly larger [21]. For the branching ratios of $B \to \pi\pi$, the large r_C helped to explain them.

When we keep the terms up to $O(r^2)$, Eqs. (59)–(61) are

$$\begin{aligned} R_c - R_n = {}& 2r_{EW}^2 + 2r_{EW}r_T\cos(\delta^{EW}+\delta^T)\cos\phi_3 \\ & -4r_{EW}^2\cos^2\delta^{EW} + 2r_C^2(1-2\cos^2\delta^C\cos^2\phi_3) \\ & -2r_Cr_T[\cos(\delta^T+\delta^C) - 2\cos\delta^T\cos\delta^C\sin^2\phi_3] \\ & +4r_Cr_{EW}\cos(\delta^C+\delta^{EW})\cos\phi_3 \end{aligned} \tag{80}$$

$$\begin{aligned} S = {}& 2r_{EW}^2 - 2r_{EW}r_T\cos(\delta^{EW}-\delta^T)\cos\phi_3 + 2r_C^2 \\ & +2r_Tr_C\cos(\delta^T-\delta^C) - 4r_{EW}r_C\cos(\delta^{EW}-\delta^C) \\ & \times\cos\phi_3 \end{aligned} \tag{81}$$

$$\begin{aligned} R_+ - 2 = {}& 2r_{EW}^2 + 2r_{EW}r_T\cos(\delta^{EW}+\delta^T)\cos\phi_3 + 2r_C^2 \\ & +2r_Tr_C[\cos(\delta^T-\delta^C) - 2\cos\delta^T\cos\delta^C\cos^2\phi_3] \\ & -4r_{EW}r_C\cos(\delta^{EW}-\delta^C)\cos\phi_3. \end{aligned} \tag{82}$$

To satisfy these relations, if r_{EW} cannot be so large, at least, r_C should be large in spite of r_{EW}. From the difference between the equations,

$$\begin{aligned} R_+ - 2 - S &= -\frac{2\bar{B}_K^{+0}}{\bar{B}_K^{0+}} + \frac{\tau^+}{\tau^0}\frac{\bar{B}_K^{+-}}{\bar{B}_K^{0+}} + \frac{\tau^0}{\tau^+}\frac{2\bar{B}_K^{+0}}{\bar{B}_K^{+-}} - 1 \\ &= 4r_{EW}r_T\cos\delta^{EW}\cos\delta^T\cos\phi_3 \\ &\quad -4r_Cr_T\cos\delta^T\cos\delta^C\cos^2\phi_3 \\ &= 0.00 \pm 0.29. \end{aligned} \tag{83}$$

When we respect the central value, in this case $\cos\delta^{EW} \neq 0$, r_C may be same order quantity with r_{EW}. Using the experimental bounds for $R_c - R_n$, S and $R_+ - 2$, the lower bound of r_C for r_{EW} are plotted in Fig. 6 in the cases δ^{EW}, δ^C are free parameters (left) and under constraint $\omega = \delta^{EW} - \delta^T = 0$ (right). In both figures, the solid lines show the lower bound to satisfy each of the relations at 1σ level and the dashed lines are 2σ bound. From the left figure, we find that in the small r_{EW} case, larger r_C is requested but it seems to be too large because the usual theoretical estimation is $r_C \simeq 0.02$. For $r_{EW} = 0.14$, r_C should be larger than about 0.2. If we put a constraint $\omega = \delta^{EW} - \delta^T = 0$ as we discussed before, still larger r_C will be favored. It agrees with our result in Fig. 4.

Thus there is also a possibility to explain by large r_C but the magnitude might still be large compared with the usual estimation. It also comes from a tree diagram so it may be slightly difficult to explain why r_C is so large even if we consider some new physics contribution. If such a large r_C, which means the magnitude is almost same as the color-allowed tree, r_T, is allowed, it may help to explain the discrepancies in the branching ratios and direct CP asymmetries [21]. As a possibility, we discussed r_C contribution after relaxing the hierarchy assumption but in next section we will discuss new physics contribution including the penguin-type diagrams.

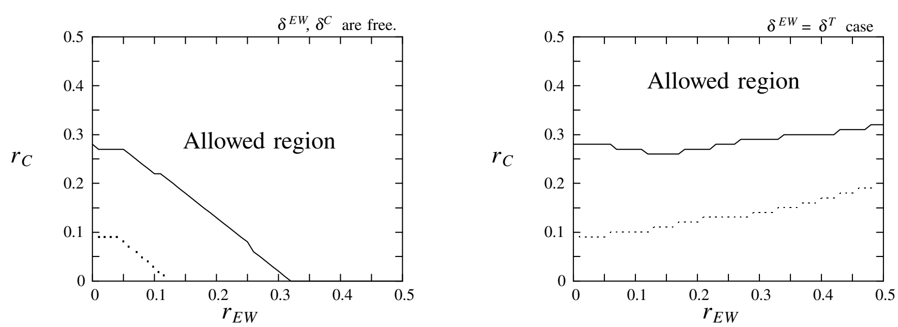

FIG. 6. The lower bound of r_C to satisfy $R_c - R_n$, S, and $R_+ - 2$ at 1σ (solid line) and 2σ (dashed line) at $r_T = 0.2$ and $40° < \phi_3 < 80°$ under constraint $-0.123 < A_{CP}^{+-} < -0.067$. The left figure shows that the case δ^{EW} and δ^C are free parameter and the right one is under constraint $\omega = \delta^{EW} - \delta^T = 0$ and δ^C is still free parameter.

VII. NEW PHYSICS CONTRIBUTION

If the deviations come from new physics contribution, it has to be included in the penguinlike contribution with new weak phases because it is very difficult to produce such a large strong phase difference as $\omega = \delta^{EW} - \delta^T \sim 100°$ within the SM. $B \to K\pi$ decays need large EW-penguin contributions so that it may include the new physics contribution with new weak phase in the EW-penguin. Besides, the effect must also appear in the direct CP asymmetries. For example, $A_{CP}^{K^0\pi^0} \propto 2r_{EW}\sin\delta^{EW}\sin\theta^{New}$, so that we will have to carefully check these modes.

We consider a possibility of new physics in the penguin contributions as follows:

$$P = P^{SM} + P^{New}, \qquad P_{EW} = P_{EW}^{SM} + P_{EW}^{New}, \tag{84}$$

where P^{New} and P_{EW}^{New} are gluonic and EW-penguin-type contributions coming from new physics, respectively. For simplicity, we assume that the strong phase of the penguin diagram within the SM is the same with one from new physics. Here we parametrize the phases as follows:

$$PV_{tb}^*V_{ts} \equiv -|PV_{tb}^*V_{ts}|e^{-i\theta^P}, \tag{85}$$

$$P_{EW}V_{tb}^*V_{ts} \equiv -|P_{EW}V_{tb}^*V_{ts}|e^{i\delta^{EW}}e^{i\theta^{EW}}, \tag{86}$$

where θ^P and θ^{EW} are the weak phases coming from new physics contributions. The ratios among the parameters are

$$\frac{TV_{ub}^*V_{us}}{PV_{tb}^*V_{ts}} = r_Te^{i\delta^T}e^{i(\phi_3+\theta^P)}, \tag{87}$$

$$\frac{P_{EW}V_{tb}^*V_{ts}}{PV_{tb}^*V_{ts}} = r_{EW}e^{i\delta^{EW}}e^{i(\theta^{EW}+\theta^P)}. \tag{88}$$

Using this parametrization,

$$\begin{aligned} R_c - R_n = {} & 2r_{EW}^2[1 - 2\cos^2\delta^{EW}\cos^2(\theta^{EW} + \theta^P)] \\ & -2r_{EW}r_T\cos(\delta^{EW} - \delta^T)\cos(\phi_3 - \theta^{EW}) \\ & +4r_{EW}r_T\cos\delta^{EW}\cos\delta^T\cos(\phi_3 + \theta^P) \\ & \times\cos(\theta^{EW} + \theta^P), \end{aligned} \tag{89}$$

$$S = 2r_{EW}^2 - 2r_{EW}r_T\cos(\delta^{EW} - \delta^T)\cos(\phi_3 - \theta^{EW}). \tag{90}$$

Because of the new weak phase θ^{EW} and θ^P, the constraints for the strong phases is fairly relaxed. To keep the first term a positive value, $\cos^2\delta^{EW}\cos^2(\theta^{EW} + \theta^P)$ must be less than 1/2 so that smaller $|\cos(\theta^{EW} + \theta^P)|$ will be favored. In the second term, if $\cos(\phi_3 - \theta^{EW})$ was negative, small $\omega = \delta^{EW} - \delta^T$ was not excluded in contrast with the SM case. The constraint for r_{EW} is almost the same but one for the strong phases is changed and all region for the strong phase δ^{EW} is allowed. Furthermore, small ω is also allowed in this case. In other words, the constraint for δ^{EW} is replaced to one for the new weak phase and their magnitude is not a negligible value. Therefore, to investigate the direct CP asymmetries for $B \to K\pi$ it will become more important to know the information about the new CP phases. A_{CP}^{00} will be an especially important mode. The CP asymmetries for $B \to K\pi$ decays are

$$A_{CP}^{+-} \propto -2r_T\sin\delta^T\sin(\phi_3 + \theta^P) - r_T^2\sin2\delta^T\sin2(\phi_3 + \theta^P), \tag{91}$$

$$\begin{aligned} A_{CP}^{00} \propto {} & -2r_{EW}\sin\delta^{EW}\sin(\theta^{EW} + \theta^P) \\ & -r_{EW}^2\sin2\delta^{EW}\sin2(\theta^{EW} + \theta^P) \\ & +2r_C\sin\delta^C\sin(\phi_3 + \theta^P), \end{aligned} \tag{92}$$

$$\begin{aligned} A_{CP}^{+0} \propto {} & 2r_{EW}\sin\delta^{EW}\sin(\theta^{EW} + \theta^P) \\ & -2r_T\sin\delta^T\sin(\phi_3 + \theta^P) + 2r_Tr_{EW}\sin(\delta^{EW} + \delta^T) \\ & \times\sin(\theta^{EW} + \phi_3 + 2\theta^P) - r_{EW}^2\sin2\delta^{EW} \\ & \times\sin2(\theta^{EW} + \theta^P) - r_T^2\sin2\delta^T\sin2(\phi_3 + \theta^P). \end{aligned} \tag{93}$$

To explain the deviation of $R_c - R_n$, large r_{EW} and large $\sin\delta^{EW}\sin(\theta^{EW} + \theta^P)$ are favored so that if there are new physics contributions in $B \to K\pi$, sizable $A_{CP}^{K^0\pi^0}$ will appear in the B factory experiment in the near future. At present time, these experimental data still have large uncertainties.

As we used A_{CP}^{+-} before, it seems accurate that it is a good example to plot the maximum bound of $R_c - R_n$ and S as the function of θ^{EW} for each r_{EW} at $\omega = 0°$ and $r_T = 0.2$ under constraint of A_{CP}^{+-}. Here we take $\theta^P = 0$, for simplicity. Figure 7 shows that the allowed region for both constraints of $R_c - R_n$ and S exists even if $\omega = \delta^{EW} - \delta^T = 0°$ and it is about $240° < \theta^{EW} < 300°$. If the θ^P is a nonzero value, the allowed region should be wider. In Fig. 8, the allowed region on the plane of θ^{EW} and θ^P is plotted.

As in $K\pi$, we have to reconsider $B \to \pi\pi$ modes in the case with new physics contributions. Under the same conditions which are $\omega = 0°$ and $\theta^P = 0°$ but $\tilde{r}_C = 0.2$, which is slightly larger than usual estimation, the ratios among the branching fractions are plotted in Fig. 9. The allowed region for θ^{EW}, however, seems to be slightly different between $K\pi$ and $\pi\pi$. Moreover, $\tilde{r}_P = 0.45$, which is almost 1.5 times as large as the SM expectation, and larger r_{EW} will be requested to satisfy $\frac{B_\pi^{00}}{B_\pi^{+-}}$. In the allowed region of θ^{EW} for $B \to K\pi$, there is no region satisfying the data of $B \to \pi\pi$ at 1σ level even if $\tilde{r}_C = 0.2$. It may suggest other angles as the parameters of new physics are needed. Hence to find the allowed region to explain both discrepancies between $B \to K\pi$ and $B \to \pi\pi$ may be slightly difficult without considering the SU(3) breaking effects and assuming that these parame-

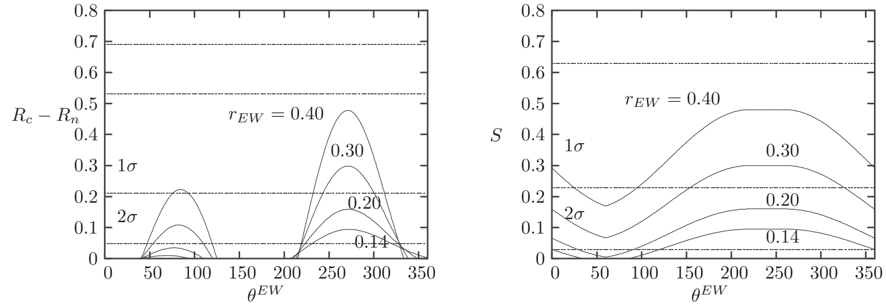

FIG. 7. The lines show the maximum bound of $R_c - R_n$ and S for θ^{EW} at $\omega = 0°$ and $r_T = 0.2$ under constraint $-0.123 < A_{CP}^{+-} < -0.067$, $\theta^P = 0°$ and $40° < \phi_3 < 80°$.

ters should be independent each other between $K\pi$ and $\pi\pi$ even if θ^P is nonzero value.

In order to solve them, we introduce one more parameter as a phase difference of the new weak phases between $K\pi$ and $\pi\pi$. The phase difference is defined as

$$\theta_X \equiv \theta_\pi^P - \theta^P = \theta^{EW} - \theta_\pi^{EW}, \tag{94}$$

which is a phase difference of penguin diagrams between $B \to K\pi$ and $B \to \pi\pi$ modes except for the KM phase, where

$$\begin{aligned} P_\pi V_{tb}^* V_{td} &\equiv |P_\pi V_{tb}^* V_{td}| e^{-i\phi_1} e^{-i\theta_\pi^P}, \\ P_{EW\pi} V_{tb}^* V_{td} &\equiv |P_{EW\pi} V_{tb}^* V_{td}| e^{-i\phi_1} e^{i\delta^{EW}} e^{i\theta_\pi^{EW}}. \end{aligned} \tag{95}$$

We assume that the SU(3) breaking effect in the strong phase is not large because the final state is the same even if the modes are including some new physics effects. Using this parametrization, the branching ratios are

$$\begin{aligned} 2\bar{B}_\pi^{00} \propto\ & \tilde{r}_C^2 + \tilde{r}_P^2[1 + r_{EW}^2 - 2r_{EW}\cos\delta^{EW}\cos(\theta^{EW} + \theta^P)] \\ & -2\tilde{r}_C\tilde{r}_P[\cos\delta^T\cos(\phi_1 + \phi_3 + \theta^P + \theta_X) \\ & -r_{EW}\cos\omega\cos(\phi_1 + \phi_3 - \theta^{EW} + \theta_X)], \end{aligned} \tag{96}$$

$$\bar{B}_\pi^{+-} \propto 1 + \tilde{r}_P^2 + 2\tilde{r}_P\cos\delta^T\cos(\phi_1 + \phi_3 + \theta^P + \theta_X), \tag{97}$$

$$\begin{aligned} 2\bar{B}_\pi^{+0} \propto\ & 1 + \tilde{r}_C^2 + \tilde{r}_P^2 r_{EW}^2 + 2\tilde{r}_C + 2\tilde{r}_P r_{EW}(1 + \tilde{r}_C) \\ & \times \cos\omega\cos(\phi_1 + \phi_3 - \theta^{EW} + \theta_X). \end{aligned} \tag{98}$$

Considering several constraints from the experimental values, $R_c - R_n = 0.37 \pm 0.16$, $A_{CP}^{+-} = -0.095 \pm 0.028$, $A_{CP}^{00} = 0.11 \pm 0.23$, $R = 0.90 \pm 0.14$, $\frac{2B_\pi^{00}}{B_\pi^{+-}} = 0.83 \pm 0.23$ and $\frac{\tau^0}{\tau^+}\frac{2B_\pi^{+0}}{B_\pi^{+-}} = 2.08 \pm 0.37$, the allowed region for the three new phases, θ^P, θ^{EW} and θ_X at $\omega = 0°$, $r_T = 0.2$, $\tilde{r}_C = 0.1$ and $\tilde{r}_P = 0.45$ in Fig. 10, where $\tilde{r}_P$ with some new physics contribution may be taken to be almost maximum value from constraints by $B \to KK$ and $\tilde{r}_C$, which are used in usual estimation. To enhance the ratios, the denominator, $\bar{B}_\pi^{+-}$, should be reduced so that the cross term is important and negative $\cos\delta^T\cos(\phi_1 + \phi_3 + \theta^P - \theta_X)$ will be favored. $\phi_1 + \phi_3$ is about $60° \sim 100°$ so that they will be strongly enhanced around $\theta^P - \theta_X \sim 100°$. However, if θ^P is a large angle, we have to note that the region for δ^T is also changed since the constraint from $A_{CP}^{K^+\pi^-}$ will be relaxed by θ^P. Here $A_{CP}^{K^0\pi^0}$ was taken into account and it gives a constraint to θ^{EW}. Hence it may be slightly complicated to understand the allowed region.

From Fig. 10, we can find that satisfying the several experimental data for $B \to \pi\pi$ and $B \to K\pi$ at once does not only require the large r_{EW} but also large new weak phases, θ^{EW} and a phase difference $\theta_X = \theta^{EW} - \theta_\pi^{EW}$, which may suggest SU(3) breaking effects for the penguin diagrams. The right figure shows that there is no solution for $\theta_X = 0°$ if we take the current experimental data seriously.

In this analysis, we assumed that the tree processes do not have any new physics contributions and there are not such large strong phase differences that satisfy also SU(3) symmetry. If some new physics exists, it is included in the

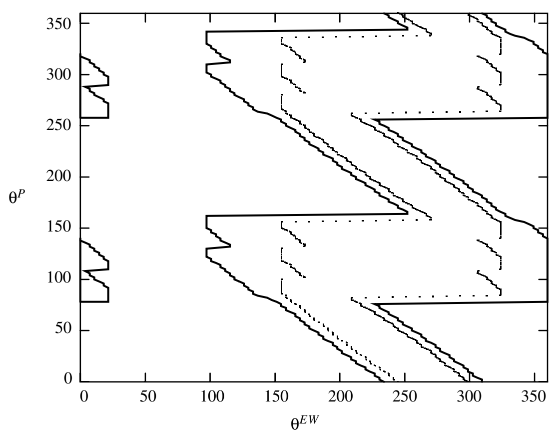

FIG. 8. The lines show the allowed region for θ^{EW} and θ^P satisfying the data of $R_c - R_n$ and S a 1σ level. The solid line shows that the case of $r_{EW} = 0.40$ and the dashed lines is $r_{EW} = 0.30$ at $\omega = 0°$ and $r_T = 0.2$ under constraint $-0.123 < A_{CP}^{+-} < -0.067$ and $40° < \phi_3 < 80°$.

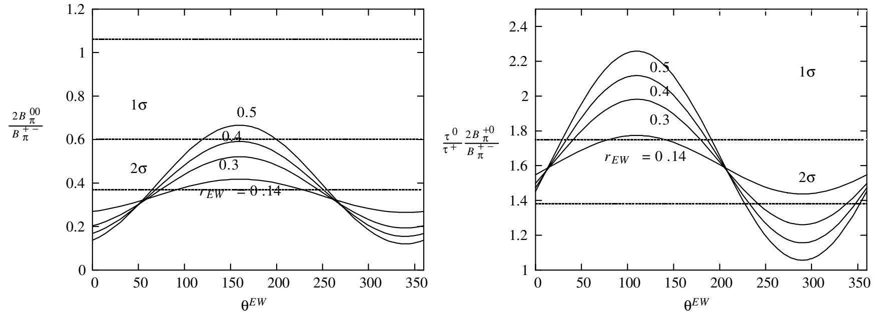

FIG. 9. $\frac{2B_{\pi}^{00}}{B_{\pi}^{+-}}$ and $\frac{\tau^0}{\tau^+}\frac{2B_{\pi}^{+0}}{B_{\pi}^{+-}}$ as the function of θ^{EW} at $\tilde{r}_C = 0.2$, $\omega = 0°$ and $\theta^P = 0°$. The gluonic penguin contribution $\tilde{r}_P$ is 0.45, which is almost 1.5 times as large as the usual estimation in the SM.

penguin-type diagrams and they should appear as the large EW-penguin contribution with large new weak phase and it may cause some SU(3) breaking effects. As a result we can find several allowed regions, such as Fig. 10, for the new weak phases of penguin contributions. In $B \to \pi\pi$ mode, the role of EW-penguin is not as important within the SM because its magnitude is much smaller than that of the tree. However if we consider some new physics contribution to explain both $B \to K\pi$ and $B \to \pi\pi$, then the role of EW-penguin contribution with the new weak phase will be more important so that it should not be neglected even if we consider new physics effects in $\pi\pi$.

VIII. CONCLUSION

In this paper, we discussed a possibility of large EW-penguin contribution in $B \to K\pi$ and $B \to \pi\pi$ from recent experimental data. To satisfy several relations among the branching ratios of $B \to K\pi$, the larger EW-penguin contribution with non-negligible strong phase differences is needed. It seems to be difficult to explain them in the SM. If the EW-penguin estimated from experimental data is quite large compared with the theoretical estimation, which is usually smaller than tree contributions [13,16,25], then it may include some new physics effects. In addition, to avoid the large strong phase difference, the EW-penguin must have new weak phase.

When we respect the allowed region for the parameters in $B \to K\pi$, then they cannot satisfy $B \to \pi\pi$ modes under the SU(3) symmetry. To explain both modes at once, SU(3) breaking effects in gluonic and EW-penguin diagrams with new phase will be strongly requested. As a consequence, the role of the EW-penguin contribution will be more important even in $B \to \pi\pi$ modes. In several recent works discussing the branching ratios in the $B \to \pi\pi$ modes, EW-penguin contribution is usually neglected because of the smallness and it suggests the other large contribution such as color-suppressed tree for explaining the deviations from experimental data. However, it is unnatural that the color-suppressed tree diagram includes such large new contributions. Therefore, in this

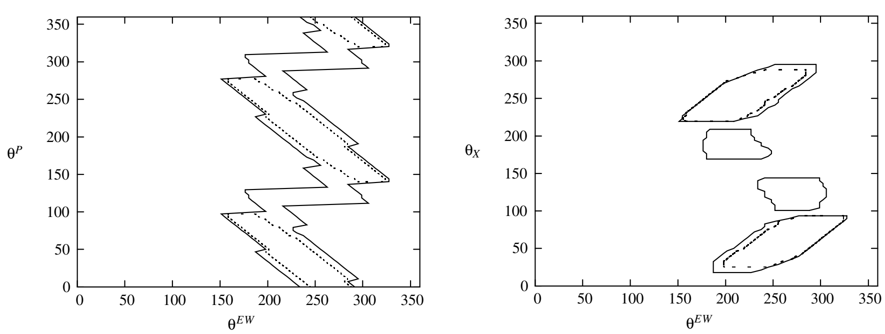

FIG. 10. The allowed region for the new weak phases θ^{EW}, θ^P of each penguin diagrams and θ_X which is the phase difference between $\pi\pi$ and $K\pi$ final state modes, under a assumption that the tree diagrams do not include any new physics and $\tilde{r}_C = 0.1$ and the all strong phase differences do not also so that $\omega = \delta^{EW} - \delta^T = 0°$. The regions are satisfying $R_c - R_n = 0.37 \pm 0.16$, $S = 0.43 \pm 0.20$, $A_{CP}^{K^+\pi^-} = -0.095 \pm 0.028$, $A_{CP}^{K^0\pi^0} = 0.11 \pm 0.23$, $\frac{2B_{\pi}^{00}}{B_{\pi}^{+-}} = 0.83 \pm 0.23$ and $\frac{\tau^0}{\tau^+}\frac{2B_{\pi}^{+0}}{B_{\pi}^{+-}} = 2.08 \pm 0.37$. And at 2σ level R is used to put a constraint because we neglected some small terms to get the bound. Here the KM weak phases are used $\phi_1 = 23.7°$ and $40° < \phi_3 < 80°$. The gluonic penguin contribution in $B \to \pi\pi$, $\tilde{r}_P$ is 0.45 which is almost 1.5 times of the usual estimation. In both figures, the solid line show the case of $r_{EW} = 0.4$ and the dashed line is $r_{EW} = 0.3$.

paper we discussed the explanation using the penguin-type diagrams.

If there are any new physics and the effects appear through the loop effect in these modes, $B \to K\pi$ and $B \to \pi\pi$ will be helpful modes to examine and search for the evidence of new physics. At the present situation, the deviation from the SM in $B \to K\pi$ is still within the 2σ level if large strong phase difference is allowed. Thus we need more accurate experimental data. In the near future, we can use these modes to test the SM [27] or the several new models [36–40]. For this purpose, the super B factory projects [41] are helpful and important.

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