Large EW Penguin contribution in B decays

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We discuss a possibility of large electroweak penguin contribution in $B \to K\pi$ and $\pi\pi$. The recent experimental data may be still suggesting that there are some discrepancies between the data and theoretical estimations. In $B \to K\pi$ decays, to explain several theoretical relations among the branching ratios, a slightly large electroweak penguin contribution and large strong phase differences or quite large color suppressed tree contribution 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 $B \to \pi\pi$. It may be suggesting to need the 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.

$B \to K\pi$ modes have already been measured well (See the web page by Heavy Flavor Averaging Group [1]) and they will be useful informations to understand the CP violation through the Kobayashi-Maskawa (KM) phases. They may be telling us that it be slightly difficult to explain several relations among the branching ratios of $B \to K\pi$ and $B \to \pi\pi$ without a large electroweak penguin contribution with large phase[2–6]. After ICHEP04 conference, the data was slightly updated and the difficulty was quite relaxed. However the situation we need some larger contributions than the theoretical estimations did not change and furthermore a discrepancy among the direct CP asymmetries remained. To satisfy these data, we find that the role of a color-favored EW penguin (or color-suppressed tree) may be important. The role of the EW penguin was pointed out and their magnitude was estimated in several works [9–13]. They said that the ratio between gluonic and EW penguins is about 0.14, but the experimental data may suggest that the magnitude seems to be slightly larger than the estimation [3–6]. Furthermore, one of the most difficult points to explain them is that we will need quite large strong phase difference of EW penguin diagram compared with the other strong phases. It is difficult to produce the such large strong phase in the SM. If there is quite large deviation in the contribution from the EW penguin, it may suggest a possibility of new physics in these modes. We put the new physics contributions with weak phase into both gluonic and EW penguins to find the allowed regions for each parameters.

Using the diagram decomposition approach [7–10, 13] and redefinition of the parameters, the decay amplitudes of $B \to K^x\pi^y$ and $\pi^x\pi^y$, A_K^{xy} and A_π^{xy}, are written as follows:

$$A_K^{0+} = -P|V_{tb}^*V_{ts}|\left[1 - r_A e^{i\delta^A}e^{i\phi_3}\right], \quad (1)$$

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

$$A_K^{+-} = P|V_{tb}^*V_{ts}|\left[1 + r_{EW}^C e^{i\delta^{EWC}} - r_T e^{i\delta^T}e^{i\phi_3}\right], \quad (3)$$

$$A_K^{+0} = \frac{1}{\sqrt{2}}P|V_{tb}^*V_{ts}|\left[1 + r_{EW}e^{i\delta^{EW}} + r_{EW}^C e^{i\delta^{EWC}} - (r_T e^{i\delta^T} + r_C e^{i\delta^C} + r_A e^{i\delta^A})e^{i\phi_3}\right], \quad (4)$$

$$A_\pi^{+-} = -T|V_{ub}^*V_{ud}|\left[\tilde r_P e^{-i\delta^T}e^{-i\phi_1} + e^{i\phi_3}\right], \quad (5)$$

$$A_\pi^{00} = \frac{1}{\sqrt{2}}T|V_{ub}^*V_{ud}|\left[(\tilde r_P - \tilde r_{EW}e^{i\delta^{EW}})e^{-i\delta^T}e^{-i\phi_1} - \tilde r_C e^{i(\delta^C-\delta^T)}e^{i\phi_3}\right], \quad (6)$$

$$A_\pi^{+0} = -\frac{1}{\sqrt{2}}T|V_{ub}^*V_{ud}|\left[\tilde r_{EW}e^{i(\delta^{EW}-\delta^T)}e^{-i\phi_1} + (1 + \tilde r_C e^{i(\delta^C-\delta^T)})e^{i\phi_3}\right], \quad (7)$$

where ϕ_1 and ϕ_3 are the weak phases, δ^X's are the strong phase differences between each diagram and gluonic penguin, and $r_T = \frac{|TV_{ub}^*V_{us}|}{|PV_{tb}^*V_{ts}|}$, $r_C = \frac{|CV_{ub}^*V_{us}|}{|PV_{tb}^*V_{ts}|}$, $r_A = \frac{|AV_{ub}^*V_{us}|}{|PV_{tb}^*V_{ts}|}$, $r_{EW} = \frac{|P_{EW}|}{|P|}$, $r_{EW}^C = \frac{|P_{EW}^C|}{|P|}$, $\tilde r_P = \frac{|PV_{tb}^*V_{td}|}{|TV_{ub}^*V_{ud}|} = \frac{1}{r_T}\frac{|V_{td}V_{us}|}{|V_{ud}V_{ts}|}$, $\tilde r_C = \frac{|C|}{|T|} = \frac{r_C}{r_T}$, $\tilde r_{EW} = \frac{|P_{EW}V_{tb}^*V_{td}|}{|TV_{ub}^*V_{ud}|} = r_{EW}\tilde r_P$, where T is a color-favored tree amplitude, C is a color-suppressed tree, $A(E)$ is an annihilation (exchange), P is a gluonic penguin, P_{EW} is a color-favored EW penguin and P_{EW}^C is a color-suppressed EW penguin. To discuss the dependence of each diagram, we assume the hierarchy of the ratios as $1 > r_T, r_{EW} > r_C, r_{EW}^C > r_A$ and $1 > \tilde r_P > \tilde r_{EW}, \tilde r_C$ [7]. r_T can be estimated as $r_T \sim 0.2$ from the the ratio of $Br(B^+ \to \pi^0\pi^+)$ to $Br(B^+ \to K^0\pi^+)$. We can assume that $r_C \sim 0.1\,r_T$ and $r_{EW}^C \sim 0.1\,r_{EW}$. r_A could be negligible. While, by the similar way one can obtain $\tilde r_P \sim 0.3$, $\tilde r_C = 0.1$. Indeed, the estimations for each parameters in the PQCD approach are $r_T = 0.21$, $r_{EW} = 0.14$, $r_C = 0.018$, $r_{EW}^C = 0.012$ and $r_A = 0.0048$. 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 neglected $\tilde r_{EW}^C$ and $\tilde r_E$ for simplicity, but keep $\tilde r_{EW}$ to discuss its magnitude in the both modes.

Under the assumptions, one can find several relations among the branching ratios for $B \to K\pi$ decays up to $O(r)$. Here we list the 3 relations as follows:

$$R_c - R_n = \frac{2\bar B_K^{+0}}{\bar B_K^{0+}} - \frac{\bar B_K^{+-}}{2\bar B_K^{00}} = 0.21 \pm 0.11 = -2r_{EW}^2\cos 2\delta^{EW} + 2r_{EW}r_T\cos(\delta^{EW}+\delta^T)\cos\phi_3\ , \quad (8)$$

$$S = \frac{2\bar B_K^{+0}}{\bar B_K^{0+}} - \frac{\tau^+}{\tau^0}\frac{\bar B_K^{+-}}{\bar B_K^{0+}} + \frac{\tau^+}{\tau^0}\frac{2\bar B_K^{00}}{\bar B_K^{0+}} - 1 = 0.22 \pm 0.14 = 2r_{EW}^2 - 2r_{EW}r_T\cos(\delta^{EW}-\delta^T)\cos\phi_3\ , \quad (9)$$

$$R_+ - 2 \;= \frac{\tau^0}{\tau^+}\frac{2\bar{B}_K^{+0}}{\bar{B}_K^{+-}} + \frac{\tau^+}{\tau^0}\frac{2\bar{B}_K^{00}}{\bar{B}_K^{0+}} - 2 \;=\; 0.26 \pm 0.16$$
$$= 2r_{EW}^2 + 2r_{EW} r_T \cos(\delta^{EW} + \delta^T)\cos\phi_3 \;, \quad (10)$$

where $\bar{B}_K^{xy}$ shows the branching ratio for $B \to K^x \pi^y$ decay. If we can neglect all r^2 terms for the theoretical estimations $r \sim O(0.1)$, these relations should be close to zero but the experimental data do not seem to satisfy them. Thus it may show there is existing a discrepancy between theoretical estimations and experimental data. The difference comes from r^2 term including r_{EW} so that one can find these deviations may be an evidence that the EW penguin is larger than the estimation we expected within the SM.

What we can expect at present are roughly $40^\circ < \phi_3 < 80^\circ$ from CKM fitting and $r_T = 0.2$ from the ratio $\frac{B_\pi^{+0}}{B_K^{0+}}$. Hence from the old experimental data r_{EW} would 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 keep the positive $R_c - R_n$ [3]. Accordingly, to explain the data we may need some contribution from new physics in the EW-penguin-type contribution with a large phase. Under exact flavor SU(3) symmetry, the strong phase difference between the EW penguin and the color-favored tree, which is called as ω, ($\omega \equiv \delta^{EW} - \delta^T$), should be close to zero because the diagrams are topologically same [10] and effectively the difference is whether just only the exchanging weak gauge boson is W or Z. If it is correct, the constraint for δ^T has to influence on δ^{EW} due to $\delta^{EW} \sim \delta^T$. We consider the direct CP asymmetry to obtain the informations about strong phase.

The direct CP asymmetries of $B \to K\pi$ under the same assumption which we neglect the terms of $O(0.001)$ are

$$A_{CP}^{0+} = -2r_A \sin\delta^A \sin\phi_3 \;= -0.020 \pm 0.034, \quad (11)$$
$$A_{CP}^{00} = 2r_C \sin\delta^C \sin\phi_3 \;= 0.00 \pm 0.16, \quad (12)$$
$$A_{CP}^{+-} = -2r_T \sin\delta^T \sin\phi_3 - r_T^2 \sin 2\delta^T \sin 2\phi_3$$
$$= -0.109 \pm 0.018, \quad (13)$$
$$A_{CP}^{+0} = -2(r_T \sin\delta^T + r_C \sin\delta^C + r_A \sin\delta^A)\sin\phi_3$$
$$+ 2r_{EW} r_T \sin(\delta^T + \delta^{EW})\sin\phi_3 - r_T^2 \sin 2\delta^T \sin 2\phi_3$$
$$= 0.04 \pm 0.04. \quad (14)$$

Up to the order of r^2, there is a relation among the CP asymmetries as follows:

$$A_{CP}^{+0} - A_{CP}^{+-} + A_{CP}^{00} - A_{CP}^{0+}$$
$$= 2r_T r_{EW} \sin(\delta^T + \delta^{EW})\sin\phi_3 \;=\; 0.17 \pm 0.17 \,. \quad (15)$$

The discrepancy of this relation from zero is caused by the cross term of r_T and r_{EW}. This may also give us some useful informations about r_{EW} and the strong phases but the data of A_{CP}^{00} still has quite large error, so that one can not extract from it at present time. If we can neglect r_C and r_A according to the our hierarchy assumption, the relation will be $A_{CP}^{+0} - A_{CP}^{+-} = 2r_T r_{EW} \sin(\delta^T + \delta^{EW})\sin\phi_3 \;=\; 0.15 \pm 0.04$ so that it seems to say also r_{EW} should be larger value than the usual estimation. The difference between A_{CP}^{+-} and A_{CP}^{+0} is also an important information to understand whether the origin of the deviations is r_{EW} or r_C.

We use only A_{CP}^{+-} because it is an accurate measurement and will give a constraint to δ^T. Using both constraints from $A_{CP}^{+-} = -0.109 \pm 0.018$ and Fleischer-Mannel bound [8], $R \equiv \frac{\tau^+}{\tau^0}\frac{\bar{B}_K^{+-}}{\bar{B}_K^{0+}} = 1 - 2r_T \cos\delta^T \cos\phi_3 + r_T^2 = 0.82 \pm 0.06$, one can find the small δ^T is favored and δ^T should be around 15°. 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. 1, respectively. They show that at 1σ level r_{EW} should be larger than 0.2 which is slightly larger than theoretical estimation 0.14. Then the allowed regions for $\delta^{EW} - \delta^T$ around 0° and 180° disappear. $R_c - R_n$ seems to favor $45^\circ < |\delta^{EW}| < 135^\circ$, but the constraint from A_{CP}^{+-} is strongly suggesting that the strong phase, δ^T, should be around 15°. In consequence, $\delta^{EW} - \delta^T = 0$ as the theoretical prospect is disfavored. What the quite large strong phase difference is requested may be a serious problem in these modes. If SU(3) symmetry is good one, these properties should also appear in $B \to \pi\pi$.

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

$$\frac{2\bar{B}_\pi^{00}}{\bar{B}_\pi^{+-}} = \frac{\tilde{r}_C^2 + \tilde{r}_P^2(1 + r_{EW}^2 - 2r_{EW}\cos\delta^{EW}) - 2\tilde{r}_P\tilde{r}_C(\cos\delta^T - r_{EW}\cos\omega)\cos(\phi_1+\phi_3)}{1 + \tilde{r}_P^2 + 2\tilde{r}_P\cos\delta^T\cos(\phi_1+\phi_3)} \,, \quad (16)$$

$$\frac{\tau^0}{\tau^+}\frac{2\bar{B}_\pi^{+0}}{\bar{B}_\pi^{+-}} = \frac{1 + \tilde{r}_C^2 + 2\tilde{r}_C + \tilde{r}_P^2 r_{EW}^2 + 2\tilde{r}_P r_{EW}(\cos\omega + r_C\cos\omega)\cos(\phi_1+\phi_3)}{1 + \tilde{r}_P^2 + 2\tilde{r}_P\cos\delta^T\cos(\phi_1+\phi_3)} \,, \quad (17)$$

there are also discrepancies between theoretical expectation and experimental data. In above equations, δ^C is taken to be equal to δ^T. The theoretical rough estimations are $\frac{\tau^0}{\tau^+}\frac{2\bar{B}_\pi^{0+}}{\bar{B}_\pi^{+-}} \sim 1$ and $\frac{\bar{B}_\pi^{00}}{\bar{B}_\pi^{+-}} \sim 0.1$ for $\tilde{r}_P \sim 0.3$, but the experimental data are quite large values, $\frac{\tau^0}{\tau^+}\frac{2\bar{B}_\pi^{0+}}{\bar{B}_\pi^{+-}} = 2.20 \pm 0.31$ and $\frac{\bar{B}_\pi^{00}}{\bar{B}_\pi^{+-}} = 0.66 \pm 0.13$ and they are not consistent with the theoretical expectations. To explain the discrepancy, the denominator seems to have to be smaller value so that $\phi_1 + \phi_3$ should be larger than 90°. By the

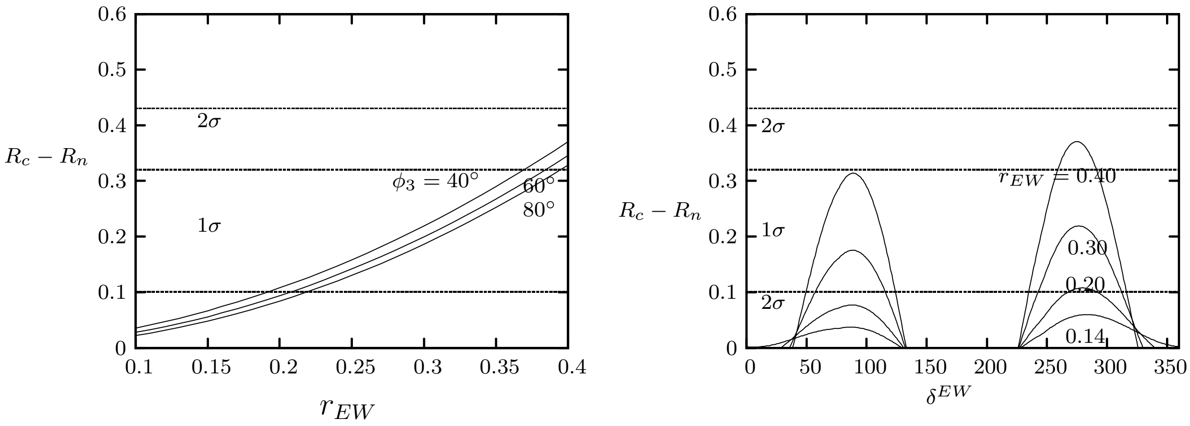

FIG. 1: The lines show the maximum bound of $R_c - R_n$ for r_{EW} and δ^{EW} at $r_T = 0.2$ and $40° < \phi_3 < 80°$ under constraint $-0.127 < A_{CP}^{+-} < -0.091$

constraint from CKM fitting, $|\phi_1+\phi_3|$ can not be so much larger than 90° that this may suggest some new phases is existing in these contributions. However it is not enough to explain the differences and we will also have to take account of SU(3) breaking effect. We can find that to explain the discrepancy, $b-d$ 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 help to enhance the ratios. Their 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 $1/N_c \sim 0.3$. Large $\tilde{r}_P$ is an evidence to explain the discrepancies but it also has some constraints from $B \to KK$ decays which are pure $b-d$ gluonic penguin processes. The constraint to P_π/P_K comes from $\frac{Br(B^0\to K^0\bar{K}^0)}{Br(B^+\to K^0\pi^+)} \sim \frac{|P_\pi \ V_{tb}^* V_{td}|^2}{|P_K \ V_{tb}^* V_{ts}|^2} < 7.3\times10^{-2}$ so that $\frac{P_\pi}{P_K} < 1.5$. Thus $\tilde{r}_P$ may be allowed up to $0.3\times1.5 = 0.45$.

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

When we keep the terms with r_C up to $O(r^2)$, To satisfy the relations about $R_c - R_n$, S and $R_+ - 2$, if r_{EW} can not be so large, at least, r_C should be large in spite of 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.2 in the cases δ^{EW}, δ^C are free parameters (left) and under constraint $\omega = \delta^{EW} - \delta^T = 0$ (right). On both figures, the line show the lower bound to satisfy the each relations at 1σ level. From the left figure, we find that in the small r_{EW} case, larger r_C is requested but it seems 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 0.08. If we put a constraint $\omega = \delta^{EW} - \delta^T = 0$ as we discussed before, still larger r_C will be favored. Thus there is also a possibility to explain by large r_C but the magnitude might be still large compared with the usual estimation. And it comes from tree diagram so that it may be slightly difficult to explain why r_C is so large even if we consider some new physics contribution. The 2 cases as the solutions by r_{EW} or r_C are summarized in Table 1. If so large r_C which mean the magnitude is almost same with r_T is allowed, it may help to explain the discrepancies for the branching ratios and direct CP asymmetries[4]. As a possibility, we discussed r_C contribution after relaxing the hierarchy assumption but we will discuss about new physics contribution including in the penguin type diagrams.

If the deviations come from new physics contribution, it has to be included in the penguin like contribution with new weak phases because it is very difficult to produce such 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 be including the new physics contribution with new weak phase in the EW penguin. Besides, the effect must appear also 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 check carefully these modes.

We consider a possibility of new physics in the penguin contributions. The ratios among the parameters with new phases are redefined as followes: $\frac{T\,V_{ub}^* V_{us}}{P\,V_{tb}^* V_{ts}} \equiv r_T\, e^{i\delta^T} e^{i(\phi_3+\theta^P)}$, $\frac{P_{EW}\,V_{tb}^* V_{ts}}{P\,V_{tb}^* V_{ts}} \equiv r_{EW}\, e^{i\delta^{EW}} e^{i(\theta^{EW}+\theta^P)}$, where θ^P and θ^{EW} are the weak phases coming from new physics. Using this parameterization,

$$\begin{aligned} R_c - R_n = {} & 2r_{EW}^2\left(1 - 2\cos^2\delta^{EW}\cos^2(\theta^{EW}+\theta^P)\right) \\ & -2r_{EW}\ r_T\cos(\delta^{EW}-\delta^T)\cos(\phi_3-\theta^{EW}) \\ & +4r_{EW}r_T\cos\delta^{EW}\cos\delta^T\cos(\phi_3+\theta^P)\cos(\theta^{EW}+\theta^P). \end{aligned} \tag{18}$$

Because of the new weak phase θ^{EW} and θ^P, the constraints for the strong phases is fairly relaxed. The constraint for r_{EW} is almost same but one for the strong phases is changed and almost region for the strong phase δ^{EW} will be allowed. Namely, 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 negligible value. To avoid the large strong phase difference, the EW penguin must have new weak phase.

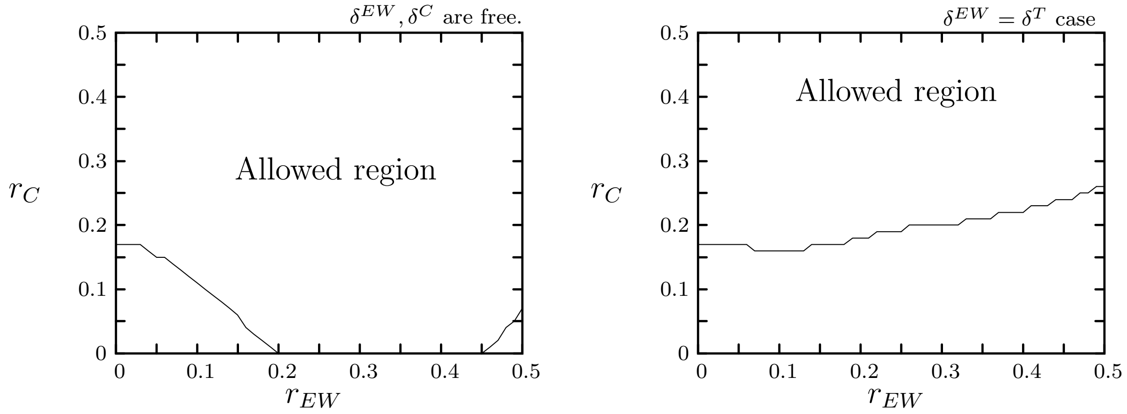

FIG. 2: The lower bound of r_C to satisfy $R_c - R_n, S$, and $R_+ - 2$ at 1σ at $r_T = 0.2$ and $40^\circ < \phi_3 < 80^\circ$ under constraint $-0.127 < A_{CP}^{+-} < -0.091$. The left figure shows that the case δ^{EW} and δ^C are free parameter and the right one is under constraint $\omega = \delta^{EW} - \delta^T = 0$ and δ^C is still free parameter.

parameter	theory	$K\pi$	$\pi\pi$	$K\pi$ and $\pi\pi$ with $\omega = 0$
r_{EW}	0.14	> 0.2	+ New Phases + SU(3) Breaking	> 0.2 + New Phases + SU(3) Breaking
r_C	0.02	> 0.08	> 0.14	> 0.18

TABLE I: Two solutions to solve the discrepancies in $B \to K\pi$ and $B \to \pi\pi$. The solution by r_C shows that the magnitude of r_C has to be quite large.

When we respect the allowed region for the parameters in $B \to K\pi$, then they could not satisfy $B \to \pi\pi$ modes under the SU(3) symmetry. To explain the both modes at once, SU(3) breaking effects in gluonic and EW penguin diagrams with new phase will be strongly requested. In consequence, the role of the EW penguin contribution will be more important even in $B \to \pi\pi$ modes. If there is 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 near future, we can use these modes to test the SM. For this purpose, the project the B factories are upgraded[14] is helpful and important.

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