Possibility of a large electroweak penguin contribution in $B \to K\pi$ modes

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We discuss the possibility of a large electroweak penguin contribution in $B \to K\pi$ from recent experimental data. The several relations among the branching ratios which realize when the contributions from tree type and electroweak penguin contributions are small compared with the gluon penguin can be treated as the expansion parameters do not satisfy the data. The difference comes from the r^2 term which is the square of the ratio with the gluon penguin diagram and the main contribution comes from the electroweak penguin diagram. We find that the electroweak penguin contribution may be too large to explain the experimental data. If the magnitude estimated from experiment is quite large compared with the theoretical estimation, then it may be including some new physics effects.

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One of the main goals of the B factories is to determine all CP angles in the unitarity triangles of the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1]. ϕ_1 [2], as one of the angles, has already been measured and established the CP violation in the B meson system by Belle [3] and BaBar [4] Collaborations. The next step is to measure the remaining angles. The canonical decay modes for measuring ϕ_2 and ϕ_3 are $B_d^0 \to \pi^+\pi^-$ and $B^\pm \to DK^\pm$, respectively, but the methods have some difficulty extracting the angles clearly. To avoid this difficulty, the isospin relation [6] and SU(3) relation including $B \to K\pi$ modes [7–10] are being considered as a method to extract the weak phases.

$B \to K\pi$ modes have also been measured [5] and they will be useful information to understand CP violation through the KM phases. If we can directly solve these modes, it will be a very elegant way to determine the parameters and the weak phase. However we cannot do so because there are too many parameters in the $B \to K\pi$ modes to extract the weak phases. So we need to understand these modes step by step. To understand the weak phase through this mode, there are several approaches by diagram decomposition [7–13], QCD factorization [14] and perturbative QCD (PQCD) [15], and so on. The contributions including the weak phase ϕ_3 come from tree types of diagrams which have a CKM suppression factor and they usually deal with a small parameter compared with the gluon penguin contribution. If we can deal the contributions except for the gluon penguin contribution with the small parameters, then, there are several relations among the averaged branching ratios of $B \to K\pi$ modes. For example, $Br(K^+\pi^-)/2Br(K^0\pi^0) \approx 2Br(K^+\pi^0)/Br(K^0\pi^+)$ [14, *et al.*]. However, the recent experiment does not seem to satisfy them so well. When we reconsider these modes to compare with the data, we find that the role of a color favored electroweak penguin contribution may be important to explain the difference between the relations and the experimental data. The color favored electroweak penguin diagram is included in $B^0 \to K^0\pi^0$ and $B^0 \to K^+\pi^0$ and the data of the branching ratio are slightly larger than half of $B^0 \to K^+\pi^-$, where the 1/2 comes from the difference of π^0 and π^+ in the final state. So we need to know the information about the electroweak penguin contributions in $B \to K\pi$ decay modes to understand the effect from the weak phases. The role was pointed out and the magnitude was estimated in several works [14]. They said that the ratio between gluon and electroweak 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. If there is quite a large deviation in the contribution from the electroweak penguin contribution, it may suggest a possibility of new physics in these modes.

In $B^0 \to K_S\pi^0$, we can consider using the time-dependent CP asymmetry to extract the weak phase. However, the mode has the electroweak penguin diagram so that one must remove the contribution to extract ϕ_3. We have to check whether extracting ϕ_3 is possible or not. To do so, it is important to reconsider the electroweak penguin contribution.

In this work, we consider a large contribution from the electroweak penguin contribution from only experimental data.

The decay amplitudes of $B \to K\pi$ are

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

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

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

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

where T is a color favored tree amplitude, C is a color suppressed tree, A is an annihilation, $P_i(i=u,c,t)$ is a gluonic penguin, EP_i is a penguin exchange, P_{EWi} is a color favored electroweak penguin diagram, P_{EWi}^C is a color suppressed electroweak penguin diagram, and EP_{EWi}^C is a color suppressed electroweak penguin exchange diagram. After this, for simplicity, we neglect the u- and c- electroweak penguin diagram because of the smallness, and we redefine each term as the following:

$$T+P_u+EP_u-P_c-EP_c\to T, \quad (5)$$

$$C-P_u-EP_u+P_c+EP_c\to C, \quad (6)$$

$$A+P_u+EP_u-P_c-EP_c\to A, \quad (7)$$

$$P_t+EP_t-P_c-EP_c-\frac{1}{3}P_{EW}^C+\frac{2}{3}EP_{EW}^C\to P, \quad (8)$$

$$P_{EW}+EP_{EW}^C\to P_{EW}, \quad (9)$$

$$P_{EW}^C-EP_{EW}^C\to P_{EW}^C. \quad (10)$$

One can reduce the number of parameter up to 6 (or 12). Then, the amplitudes are, by using the unitarity relation of the KM matrix,

$$A^{0+}=[PV_{tb}^*V_{ts}+AV_{ub}^*V_{us}], \quad (11)$$

$$A^{00}=\frac{1}{\sqrt{2}}[(P-P_{EW})V_{tb}^*V_{ts}-CV_{ub}^*V_{us}], \quad (12)$$

$$A^{+-}=-[(P+P_{EW}^C)V_{tb}^*V_{ts}+TV_{ub}^*V_{us}], \quad (13)$$

$$A^{+0}=-\frac{1}{\sqrt{2}}[(P+P_{EW}+P_{EW}^C)V_{tb}^*V_{ts}+(T+C+A)V_{ub}^*V_{us}]. \quad (14)$$

By this diagram decomposition [8], one can easily find the isospin relation among the amplitudes,

$$\sqrt{2}A^{+0}+A^{0+}=\sqrt{2}A^{00}+A^{+-}. \quad (15)$$

They are rewritten as follows:

$$A^{0+}=-P|V_{tb}^*V_{ts}|[1-r_Ae^{i\delta^A}e^{i\phi_3}], \quad (16)$$

$$A^{00}=-\frac{1}{\sqrt{2}}P|V_{tb}^*V_{ts}|[1-r_{EW}e^{i\delta^{EW}}+r_Ce^{i\delta^C}e^{i\phi_3}], \quad (17)$$

$$A^{+-}=P|V_{tb}^*V_{ts}|[1+r_{EW}^Ce^{i\delta^{EWC}}-r_Te^{i\delta^T}e^{i\phi_3}], \quad (18)$$

$$A^{+0}=\frac{1}{\sqrt{2}}P|V_{tb}^*V_{ts}|[1+r_{EW}e^{i\delta^{EW}}+r_{EW}^Ce^{i\delta^{EWC}}-(r_Te^{i\delta^T}+r_Ce^{i\delta^C}+r_Ae^{i\delta^A})e^{i\phi_3}], \quad (19)$$

where ϕ_3 is the weak phase of $V_{ub}^*V_{us}$, δ^X is the strong phase difference between each diagram and gluon penguin, and

$$r_A=\frac{|AV_{ub}^*V_{us}|}{|PV_{tb}^*V_{ts}|}, \quad r_T=\frac{|TV_{ub}^*V_{us}|}{|PV_{tb}^*V_{ts}|}, \quad r_C=\frac{|CV_{ub}^*V_{us}|}{|PV_{tb}^*V_{ts}|}, \quad (20)$$

$$r_{EW}=\frac{|P_{EW}|}{|P|}, \quad r_{EW}^C=\frac{|P_{EW}^C|}{|P|}. \quad (21)$$

We assume as the hierarchy of the ratios that $1>r_T$, $r_{EW}>r_C$, $r_{EW}^C>r_A$ [8]. $|P/T|$ was estimated to be about 0.1 in [19][1] by considering the $B\to\pi\pi$ and it was also shown by the ratio of branchings of $B^+\to\pi^0\pi^+$ and $B^+\to K^0\pi^+$ [16–18]. In $B\to K\pi$ mode, the tree type diagram is suppressed by the KM factor $V_{ub}^*V_{us}$ and $r_T\sim|T/P|\times\lambda^2R_b\sim0.2$, where Cabibbo angle $\lambda=0.22$ and we used $R_b=\sqrt{\rho^2+\eta^2}\sim0.4$. r_C and r_{EW}^C are suppressed by color factor from r_T and r_{EW}. Comparing the Wilson coefficients which correspond to the diagrams under the factorization method, we assume that $r_C\sim0.1r_T$ and $r_{EW}^C\sim0.1r_{EW}$ [16,14]. Here we do not have any assumption about the magnitude of r_{EW}. r_A could be negligible because it should have a B meson decay constant and it works as a suppression factor f_B/M_B. According to this assumption, we will neglect the r^2 terms including r_C, r_A and r_{EW}^C. Then, the averaged branching ratios are

$$\overline{B}^{0+}\propto\frac{1}{2}[|A^{0+}|^2+|A^{0-}|^2]$$
$$=|P|^2|V_{tb}^*V_{ts}|^2[1-2r_A\cos\delta^A\cos\phi_3], \quad (22)$$

$$2\overline{B}^{00}\propto[|A^{00}|^2+|\overline{A}^{00}|^2]$$
$$=|P|^2|V_{tb}^*V_{ts}|^2[1+r_{EW}^2-2r_{EW}\cos\delta^{EW}+2r_C\cos\delta^C\cos\phi_3], \quad (23)$$

[1] Note that this ratio $|P/T|$ does not include CKM factors.

TABLE I. The experimental data and the average.

	CLEO [21]	Belle [5,22]	BaBar [23,24]	Average
$Br(B^+ \to K^0\pi^+)\times 10^6$	$18.8^{+3.7+2.1}_{-3.3-1.8}$	$22.0\pm 1.9\pm 1.1$	$17.5^{+1.8}_{-1.7}\pm 1.3$	19.6 ± 1.4
$Br(B^0 \to K^0\pi^0)\times 10^6$	$12.8^{+4.0+1.7}_{-3.3-1.4}$	$12.6\pm 2.4\pm 1.4$	$10.4\pm 1.5\pm 0.8$	11.2 ± 1.4
$Br(B^0 \to K^+\pi^-)\times 10^6$	$18.0^{+2.3+1.2}_{-2.1-0.9}$	$18.5\pm 1.0\pm 0.7$	$17.9\pm 0.9\pm 0.7$	18.2 ± 0.8
$Br(B^+ \to K^+\pi^0)\times 10^6$	$12.9^{+2.4+1.2}_{-2.2-1.1}$	$12.8\pm 1.4^{+1.4}_{-1.0}$	$12.8^{+1.2}_{-1.1}\pm 1.0$	12.8 ± 1.1

$$\overline{B}^{+-} \propto \frac{1}{2}[|A^{+-}|^2+|A^{-+}|^2] = |P|^2|V_{tb}^* V_{ts}|^2[1+r_T^2+2r_{EW}^C\cos\delta^{EWC} - 2r_T\cos\delta^T\cos\phi_3], \tag{24}$$

$$2\overline{B}^{+0} \propto [|A^{+0}|^2+|A^{-0}|^2] = |P|^2|V_{tb}^* V_{ts}|^2[1+r_{EW}^2+r_T^2+2r_{EW}\cos\delta^{EW} + 2r_{EW}^C\cos\delta^{EWC}-(2r_T\cos\delta^T+2r_C\cos\delta^C + 2r_A\cos\delta^A)\cos\phi_3-2r_{EW}r_T\cos(\delta^{EW} - \delta^T)\cos\phi_3]. \tag{25}$$

One can take several ratios between the branching ratios. If all modes are gluon penguin dominant, the ratios should be close to 1. The shift from 1 will depend on the magnitude of r's. From the averaged values of the recent experimental data in Table I,

$$\frac{\overline{B}^{+-}}{2\overline{B}^{00}} = 0.81\pm 0.11, \tag{26}$$

$$\frac{2\overline{B}^{+0}}{\overline{B}^{0+}} = 1.31\pm 0.15, \tag{27}$$

$$\frac{\tau^+}{\tau^0}\frac{\overline{B}^{+-}}{\overline{B}^{0+}} = 1.01\pm 0.09, \tag{28}$$

$$\frac{\tau^0}{\tau^+}\frac{\overline{B}^{+0}}{\overline{B}^{00}} = 1.05\pm 0.16, \tag{29}$$

$$\frac{\tau^+}{\tau^0}\frac{2\overline{B}^{00}}{\overline{B}^{0+}} = 1.24\pm 0.18, \tag{30}$$

$$\frac{\tau^0}{\tau^+}\frac{2\overline{B}^{+0}}{\overline{B}^{+-}} = 1.30\pm 0.13, \tag{31}$$

where τ^+/τ^0 is a lifetime ratio between the charged and the neutral B mesons and $\tau(B^\pm)/\tau(B^0)=1.083\pm 0.017$ [20]. While, from Eqs. (22)–(25) under the assumption that all r is smaller than 1 and the r^2 terms including r_C, r_A, and r_{EW}^C are neglected,

$$\frac{\overline{B}^{+-}}{2\overline{B}^{00}} = \{1+2r_{EW}\cos\delta^{EW}+2r_{EW}^C\cos\delta^{EWC} - 2(r_T\cos\delta^T+r_C\cos\delta^C)\cos\phi_3+r_T^2\}-r_{EW}^2 + 4r_{EW}^2\cos^2\delta^{EW}, \tag{32}$$

$$\frac{2\overline{B}^{+0}}{\overline{B}^{0+}} = \{1+2r_{EW}\cos\delta^{EW}+2r_{EW}^C\cos\delta^{EWC} - 2(r_T\cos\delta^T+r_C\cos\delta^C)\cos\phi_3+r_T^2\}+r_{EW}^2 - 2r_{EW}r_T\cos(\delta^{EW}-\delta^T)\cos\phi_3, \tag{33}$$

$$\frac{\tau^+}{\tau^0}\frac{\overline{B}^{+-}}{\overline{B}^{0+}} = 1+2r_{EW}^C\cos\delta^{EWC}-2(r_T\cos\delta^T - r_A\cos\delta^A)\cos\phi_3+r_T^2, \tag{34}$$

$$\frac{\tau^0}{\tau^+}\frac{\overline{B}^{+0}}{\overline{B}^{00}} = 1+2r_{EW}^C\cos\delta^{EWC}-2(r_T\cos\delta^T+2r_C\cos\delta^C + r_A\cos\delta^A)\cos\phi_3+r_T^2+4r_{EW}\cos\delta^{EW} - 2r_{EW}r_T\cos(\delta^{EW}-\delta^T)\cos\phi_3+4r_{EW}^2\cos^2\delta^{EW}, \tag{35}$$

$$\frac{\tau^+}{\tau^0}\frac{2\overline{B}^{00}}{\overline{B}^{0+}} = 1-2r_{EW}\cos\delta^{EW}-2(r_C\cos\delta^C+r_A\cos\delta^A) \times\cos\phi_3+r_{EW}^2. \tag{36}$$

$$\frac{\tau^0}{\tau^+}\frac{2\overline{B}^{+0}}{\overline{B}^{+-}} = 1+2r_{EW}\cos\delta^{EW}-2(r_C\cos\delta^C+r_A\cos\delta^A) \times\cos\phi_3+r_{EW}^2-2r_{EW}r_T\cos(\delta^{EW}-\delta^T) \times\cos\phi_3+4r_T^2\cos^2\delta^T\cos^2\phi_3. \tag{37}$$

If all modes are dominated by only the gluonic penguin contribution, namely, all r is much smaller than 1, then all ratios of branching ratios should be 1. But the data are not so. Equations (32), (33), (36), and (37) seem to differ from 1 so that there must be some sizable contributions except for the gluon penguin contribution.

If we can neglect all r^2 terms, then there are a few relations among Eqs. (32)–(37) as follows:

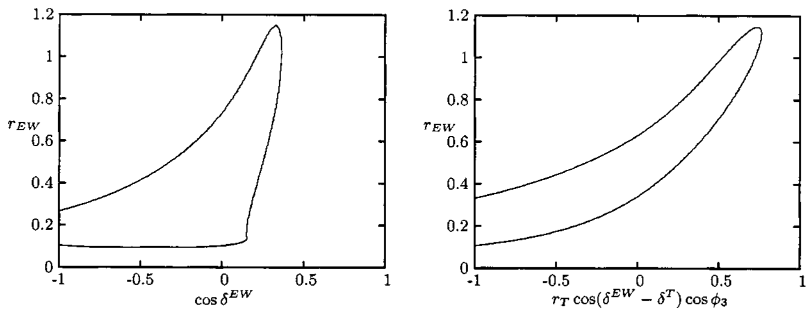

FIG. 1. The allowed region on the $(r_{EW}, \cos\delta^{EW})$ and $[r_{EW}, r_T\cos(\delta^{EW}-\delta^T)\cos\phi_3]$ plane at the 1σ level.

$$\frac{\overline{B}^{+-}}{2\overline{B}^{00}}=\frac{2\overline{B}^{+0}}{\overline{B}^{0+}}, \tag{38}$$

$$\frac{2\overline{B}^{+0}}{\overline{B}^{0+}}-\frac{\tau^+}{\tau^0}\frac{\overline{B}^{+-}}{\overline{B}^{0+}}+\frac{\tau^+}{\tau^0}\frac{2\overline{B}^{00}}{\overline{B}^{0+}}-1=0. \tag{39}$$

However, the experimental data listed in Eqs. (26)–(31) do not satisfy these relations so well. According to the experimental data, $\overline{B}^{+-}/2\overline{B}^{00}$ seems to be smaller than 1 but $2\overline{B}^{+0}/\overline{B}^{0+}$ seems to be larger than 1. So it shows that there is a discrepancy between them. The equations of $\overline{B}^{+-}/2\overline{B}^{00}$ and $2\overline{B}^{+0}/\overline{B}^{0+}$ are the same up to the r_T^2 term and the difference comes from the r^2 term including r_{EW}. The r_T^2 term does not seem to contribute to the ratios so strongly. The second relation corresponds to the isospin relation of Eq. (15) at the first order of r. The discrepancy of relation (39) from 0 also comes from the r^2 term including r_{EW}. The differences are

$$\begin{aligned}\frac{2\overline{B}^{+0}}{\overline{B}^{0+}}-\frac{\overline{B}^{+-}}{2\overline{B}^{00}}&=2r_{EW}^2-2r_{EW}r_T\cos(\delta^{EW}-\delta^T)\\&\quad\times\cos\phi_3-4r_{EW}^2\cos^2\delta^{EW}\\&=0.50\pm0.19,\end{aligned} \tag{40}$$

$$\begin{aligned}&\frac{2\overline{B}^{+0}}{\overline{B}^{0+}}-\frac{\tau^+}{\tau^0}\frac{\overline{B}^{+-}}{\overline{B}^{0+}}+\frac{\tau^+}{\tau^0}\frac{2\overline{B}^{00}}{\overline{B}^{0+}}-1\\&\quad=2r_{EW}^2-2r_{EW}r_T\cos(\delta^{EW}-\delta^T)\cos\phi_3\\&\quad=0.54\pm0.25,\end{aligned} \tag{41}$$

so that one can find the electroweak penguin contributions may be large. All terms are including r_{EW} and the deviation of the relation from 0 is finite. Here the errors are determined by adding quadratically all errors. Using the other relation as follows:

$$\begin{aligned}&\frac{\overline{B}^{+-}}{2\overline{B}^{00}}-\frac{\tau^0}{\tau^+}\frac{\overline{B}^{+0}}{\overline{B}^{00}}+\frac{\tau^+}{\tau^0}\frac{2\overline{B}^{00}}{\overline{B}^{0+}}-1\\&\quad=-4r_{EW}\cos\delta^{EW}+2r_{EW}r_T\cos(\delta^{EW}-\delta^T)\cos\phi_3\\&\quad=0.00\pm0.26,\end{aligned} \tag{42}$$

we can solve them about r_{EW}^2 and if we can respect the central values, the solutions are

$$\begin{aligned}&[r_{EW}, \cos\delta^{EW}, \ r_T\cos(\delta^{EW}-\delta^T)\cos\phi_3]\\&\quad=(0.26,-0.38,-0.75) \ \text{and} \ (0.69,0.21,0.41).\end{aligned} \tag{43}$$

This solution shows the large electroweak penguin contribution [but $r_T\cos(\delta^{EW}-\delta^T)\cos\phi_3$ is too large because r_T was estimated around 0.2 by the other methods]. The allowed region of r_{EW}, $\cos\delta^{EW}$, and $r_T\cos(\delta^{EW}-\delta^T)\cos\phi_3$ at the 1σ level for Eqs. (40)-(42) is shown in Fig. 1.

From this result, we find that the smaller r_{EW} will favor a larger $|r_T\cos(\delta^{EW}-\delta^T)\cos\phi_3|$ term with negative sign. However, such a large r_T is disfavored by the rough estimation that r_T should be around 0.2 which will satisfy that $|P/T|\sim0.1$ to explain the large CP violation in $B^0\to\pi^+\pi^-$. Even if $|r_T\cos(\delta^{EW}-\delta^T)\cos\phi_3|$ is within 0.2, then r_{EW} will also be larger than 0.2 and r_{EW} will be larger than r_T. This is showing that there is a possibility of a large electroweak penguin contribution. Note that in the case r_{EW} is quite large, the expansion by r_{EW} may not be good but Eq. (41) will be satisfied. Roughly speaking, the shift of Eqs. (26)–(31) from 1 seem to depend on the r_{EW}^2 term and the sign. To fix the solution or confirm the large electroweak penguin contribution, we need higher accurate data.

The contributions from the tree diagram are not so large except for the cross term with the electroweak penguin contribution because $(\tau^+/\tau^0)(\overline{B}^{+-}/\overline{B}^{0+})$ is quite near 1. When we consider the direct CP asymmetry, the experimental data in Table II do not also show so large a value. The CP asymmetries under the same assumption are

$$A_{CP}^{0+}\equiv\frac{|A^{0-}|^2-|A^{0+}|^2}{|A^{0-}|^2+|A^{0+}|^2}=-2r_A\sin\delta^A\sin\phi_3\sim0.0, \tag{44}$$

$$A_{CP}^{00}\equiv\frac{|\overline{A}^{00}|^2-|A^{00}|^2}{|\overline{A}^{00}|^2+|A^{00}|^2}=2r_C\sin\delta^C\sin\phi_3, \tag{45}$$

$$\begin{aligned}A_{CP}^{+-}&\equiv\frac{|A^{-+}|^2-|A^{+-}|^2}{|A^{-+}|^2+|A^{+-}|^2}\\&=-2r_T\sin\delta^T\sin\phi_3-r_T^2\sin2\delta^T\sin2\phi_3,\end{aligned} \tag{46}$$

TABLE II. The experimental data of the direct *CP* asymmetry and the average.

	Belle [5,25]	BaBar [23,24]	Average
$A_{CP}(B^+\to K^0\pi^+)$	$0.07^{+0.09+0.01}_{-0.08-0.03}$	$-0.17\pm0.10\pm0.02$	-0.03 ± 0.07
$A_{CP}(B^0\to K^0\pi^0)$		$0.03\pm0.036\pm0.09$	0.03 ± 0.37
$A_{CP}(B^0\to K^+\pi^-)$	$-0.07\pm0.06\pm0.01$	$-0.10\pm0.05\pm0.02$	-0.09 ± 0.04
$A_{CP}(B^+\to K^+\pi^0)$	$0.23\pm0.11^{+0.01}_{-0.04}$	$-0.09\pm0.09\pm0.01$	0.04 ± 0.07

$$\begin{aligned} A_{CP}^{+0} &\equiv \frac{|A^{-0}|^2-|A^{+0}|^2}{|A^{-0}|^2+|A^{+0}|^2} \\ &= -2(r_T\sin\delta^T+r_C\sin\delta^C+r_A\sin\delta^A) \\ &\quad\times\sin\phi_3-2r_{EW}r_T\sin(\delta^T-\delta^{EW}) \\ &\quad\times\sin\phi_3-r_T^2\sin 2\delta^T\sin 2\phi_3 \\ &\quad+2r_{EW}r_T\sin\delta^T\cos\delta^{EW}\sin\phi_3. \end{aligned} \tag{47}$$

A_{CP}^{0+} should be almost 0 because of the smallness of r_A and the data is also showing it. Up to the first order of r, there is a relation among the *CP* asymmetries as follows:

$$A_{CP}^{+0}=A_{CP}^{+-}-A_{CP}^{00}+A_{CP}^{0+}. \tag{48}$$

The discrepancy of this relation is also caused by the cross term of r_T and r_{EW}. If we can have more accurate data, this may also show useful information about r_{EW}. Because A_{CP}^{+-} is not so large, we can confirm that r_T will not become so large a value.

In $B\to\pi^0K_S$, we can also use some information about time dependent *CP* asymmetry [26]. The measurements for $B\to\pi^0K_S$ are

$$\Gamma(B^0\to\pi^0K_S)+\Gamma(\overline{B^0}\to\pi^0K_S)\propto(|A|^2+|\overline{A}|^2), \tag{49}$$

$$\begin{aligned} &\Gamma[B^0(t)\to\pi^0K_S]-\Gamma[\overline{B^0}(t)\to\pi^0K_S] \\ &\quad\propto(|A|^2-|\overline{A}|^2)\cos\Delta mt+2\,\mathrm{Im}(e^{-2i\phi_1}A^*\overline{A})\sin\Delta mt. \end{aligned} \tag{50}$$

We want to consider extracting a weak phase ϕ_3 but one cannot do so because the number of unknown parameters is more than the measurements. Hence we consider using the information from $B^+\to\pi^+K_S$ to reduce the number of parameters. Here we assume that we can neglect the effect from the color suppressed annihilation diagram because it should have a B meson decay constant which works as a suppression factor $f_B/M_B\sim0.03$ [8]. So in this discussion, as an ansatz, we assume that $r_A<0.1r_C$ and we can neglect it. However, we will have to confirm the magnitude by using A_{CP}^{0+} and others. After dividing the overall factor by $B^+\to\pi^+K_S$, the measurements under the same assumption with previous discussions are

$$\begin{aligned} &\frac{\tau^+}{\tau^0}\,\frac{\Gamma(B^0\to\pi^0K_S)+\Gamma(\overline{B^0}\to\pi^0K_S)}{\Gamma(B^+\to\pi^+K_S)} \\ &\quad\equiv X \\ &\quad=1-2r_{EW}\cos\delta^{EW}+r_{EW}^2+2r_C\cos\phi_3\cos\delta^C, \end{aligned} \tag{51}$$

$$\begin{aligned} &\frac{\tau^+}{\tau^0}\,\frac{\Gamma[B^0(t)\to\pi^0K_S]-\Gamma[\overline{B^0}(t)\to\pi^0K_S]}{\Gamma(B^+\to\pi^+K_S)} \\ &\quad\equiv Y\cos\Delta mt-Z\sin\Delta mt \\ &\quad=(-2r_C\sin\phi_3\sin\delta^C)\cos\Delta mt \\ &\qquad-\{\sin 2\phi_1(1-2r_{EW}\cos\delta^{EW}+r_{EW}^2) \\ &\qquad+2r_C\sin(\phi_3+2\phi_1)\cos\delta^C\}\sin\Delta mt. \end{aligned} \tag{52}$$

We define them as follows:

$$X=1-2r_{EW}\cos\delta^{EW}+r_{EW}^2+2r_C\cos\phi_3\cos\delta^C, \tag{53}$$

$$Y=-2r_C\sin\phi_3\sin\delta^C=-A_{CP}^{00}, \tag{54}$$

$$\begin{aligned} Z&=\sin 2\phi_1(1-2r_{EW}\cos\delta^{EW}+r_{EW}^2) \\ &\quad+2r_C\sin(\phi_3+2\phi_1)\cos\delta^C. \end{aligned} \tag{55}$$

If r_{EW} was negligible, then one can extract ϕ_3 by inputting ϕ_1 because there are just three parameters r_C, δ^C, and ϕ_3 for the three measurements X, Y, and Z. However, as we discussed before, r_{EW} is not negligible and should be kept. Eliminating $r_C\cos\delta^C$ in X and Z, we find $\tan\phi_3$ as a function of r_{EW},

$$\tan\phi_3 = \frac{\{Z - X\sin 2\phi_1\}}{\cos 2\phi_1\{X - (1 - 2r_{EW}\cos\delta^{EW} + r_{EW}^2)\}}. \quad (56)$$

If one can estimate r_{EW} at good accuracy, one can have information about ϕ_3 by inputting the value of ϕ_1 which is measured by $B \to J/\psi K_S$ at higher accurate experiment. It will be extracted from the quantity of $O(0.01)$ because $r_C \sim 0.02$ under the assumption in this work. Indeed, for the solution Eq. (43), $2r_C\cos\delta^C\cos\phi_3 \approx X - 1 + 2r_{EW}\cos\delta^{EW} - r_{EW}^2 \sim -0.03$. So to use this measurement one may need some corrections from $K-\bar{K}$ mixing and the width difference [27,28]. See the Appendix. We have to note that this method still includes a few theoretical uncertainties[2] for the estimations of r_{EW} and r_A. To extract ϕ_3 cleanly by this method may be slightly difficult. After extracting ϕ_3 by the other modes, we can use it to estimate or confirm how large the electroweak penguin contribution is.

In this paper, we discussed the possibility of a large electroweak penguin contribution in $B \to K\pi$ from recent experimental data. The several relations among the branching ratios which realize when the contributions from tree type and electroweak penguin contributions are small compared with the gluon penguin do not satisfy the data. The difference comes from the r^2 terms and the main contribution comes from the electroweak penguin contribution. We find that the contribution from the electroweak penguin contribution may be larger than from tree diagrams to explain the experimental data. If the magnitude estimated from experiment is quite large compared with the theoretical estimation which is usually smaller than tree contributions [12–14], then it may be including some new physics effects. In this analysis, we find that what can have some contribution from new physics is the color favored electroweak penguin type diagram which is the process π^0 goes out from $B-K$ current.

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[2]Indeed before the use of this method we have to note that it has several theoretical uncertainties. We have to extract some small quantities by removing several unknown parameters, which are r_{EW} and r_A, but we do not know the magnitudes so well. If r_A is not negligible, this will not work so well and we need get the information from the others. If r_{EW} will become so large by new physics as we discussed, then ϕ_1 may also include some effects from the new physics [29] so that the input parameter also has theoretical uncertainties.

APPENDIX: SOME CORRECTION TERMS FROM THE $K-\bar{K}$ MIXING AND THE WIDTH DIFFERENCE

In the discussion about the time dependent *CP* asymmetry of $B^0 \to K_S\pi^0$, we neglected the effects of *CP* violation in the K meson system and tiny width difference of B_d mesons because it is very small. The magnitude is $|\epsilon| = 2\times10^{-3}$ and $\Delta\Gamma_d/\Gamma_d$ is about 3×10^{-3} which was estimated in [28]. As the effects from them have been pointed out in several works [27,28], if r_C is the order, we must deal with the contributions. In the Kon system, we define the K_S and K_L mesons as follows:

$$|K^0\rangle = \frac{1-\epsilon}{\sqrt{2}}[|K_S\rangle + |K_L\rangle], \quad (A1)$$

$$|\bar{K^0}\rangle = \frac{1+\epsilon}{\sqrt{2}}[|K_S\rangle - |K_L\rangle], \quad (A2)$$

where ϵ is the parameter which shows the *CP* violation of K. Then one needs several correction terms including ϵ and $\Delta\Gamma_d$ as the expansion parameters [28] in X, Y, and Z (note that the definition of the sign of ϵ is different from that in [28]) as follows:

$$X(t) = 1 - 2r_{EW}\cos\delta^{EW} + r_{EW}^2 + 2r_C\cos\phi_3\cos\delta^C + \cos 2\phi_1 \sinh\frac{\Delta\Gamma_d t}{2} + \cdots, \quad (A3)$$

$$Y = 2r_C\sin\phi_3\sin\delta^C - 2\,\mathrm{Re}(\epsilon) + O(\epsilon r_C), \quad (A4)$$

$$Z = \sin 2\phi_1(1 - 2r_{EW}\cos\delta^{EW} + r_{EW}^2) + 2r_C\sin(\phi_3 + 2\phi_1)\cos\delta^C - 2\,\mathrm{Im}(\epsilon)\cos 2\phi_1 + \sin 2\phi_1\cos 2\phi_1 \sinh\frac{\Delta\Gamma_d t}{2} + O(\epsilon r_C). \quad (A5)$$

Here we neglected the terms of ϵr. In addition to these terms, there is also a constant term and a proportional term to $\sin^2(\Delta m t)$. X has also a correction term by ϵ but it is of order ϵr so that one can neglect it. However, indeed, the correction term has already been included in $\sin 2\phi_1$ determined by $B \to J/\psi K_S$ [28] and the value which subtracts from Z is effectively $[\sin 2\phi_1 - 2\,\mathrm{Im}(\epsilon)\cos 2\phi_1 + \cdots]$ so that one can neglect the effect in Z.

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