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

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I discuss about a possibility of large electroweak penguin contribution in $B \to K\pi$. To satisfy several relations among the branching ratios, we need large electroweak penguin contribution. The magnitude is larger than the theoretical estimation in the SM so that it may be including some new physics effects.

$B \to K\pi$ modes has been measured\(^2\) and they will be useful informations to understand the CP violation through the KM phases and check the standard model(SM). If we can directory solve about these modes, it is very elegant way to determine the parameters and the weak phase within (or without) the SM. However we can not do so because there are too many parameters in $B \to K\pi$ modes. So we need understand these modes step by step. To understand this modes, there are several approaches by diagram decomposition\(^4\)-\(^{12}\), QCD factorization\(^13\) and pQCD\(^14\) and so on. The largest contribution comes from the gluon penguin. If we can deal the contributions from the other diagrams as the small parameters, then, there are several relations among the averaged branching ratios of $B \to K\pi$ modes. For example, $Br(K^+\pi^-)/2Br(K^0\pi^0) \approx 2Br(K^+\pi^0)/Br(K^0\pi^+) \parallel \parallel \parallel 10$.

However, the recent experiment does not seem to satisfy them so well\(^11,\,\, 12,\,\, 13\). When we reconsider these modes to compare with the data, we find that the role of a color favored electroweak penguin may be important to explain the discrepancy between the relations and the experimental data\(^11,\,\, 12,\,\, 13,\,\, 16,\,\, 17,\,\, 18\). So we need to know the informations about the electroweak penguin contributions in $B \to K\pi$ decay modes to understand and check the SM. The ratio between gluon and electroweak penguins is estimated in several works\(^11,\,\, 12,\,\, 13\) and it is about 0.14 as the central value but the experimental data suggest that the magnitude should be larger than the estimation. If there is quite large deviation in the contribution from the electroweak penguin, it may be an evidence of new physics.

In this talk, I consider how large contribution from the electroweak penguins we need in $B \to K\pi$ modes and whether it is including some new physics effects.

Using diagram decomposition and redefinition of the parameters\(^1\), the decay amplitudes $A^{XY}$ for $B \to K^X\pi^Y$ decays are written as follows:

\[
A^{0+} = -P[V_{tb}^*V_{ts}][1 - r_A e^{i\phi^A} e^{i\phi_3}],
\]

\[
\sqrt{2} A^{00} = -P[V_{tb}^*V_{ts}][1 - r_{EW} e^{i\phi^{EW}} + r_C e^{i\phi^C} e^{i\phi_3}],
\]

\[
A^{+-} = P[V_{tb}^*V_{ts}][1 + r_{EW} e^{i\phi^{EW}} - r_T e^{i\phi^T} e^{i\phi_3}],
\]

\[
2 A^{+0} = P[V_{tb}^*V_{ts}][1 + r_{EW} e^{i\phi^{EW}} + r_C e^{i\phi^C} - (r_T e^{i\phi^T} + r_C e^{i\phi^C} + r_A e^{i\phi^A}) e^{i\phi_3}],
\]

where $\phi_3$ is the weak phase of $V_{ub}^*V_{us}$, $\delta^X$ is the strong phase difference between each diagram and gluon penguin and

\[
r_T = \frac{|TV_{ub}^*V_{us}|}{|PV_{tb}^*V_{ts}|},
\]

\[
r_C = \frac{|CV_{ub}^*V_{us}|}{|PV_{tb}^*V_{ts}|},
\]

\[
r_{EW} = \frac{|P_{EW}|}{|P|},
\]

\[
r_{EW}^C = \frac{|PC_{EW}|}{|P|},
\]

\[
r_A = \frac{|AV_{ub}^*V_{us}|}{|PV_{tb}^*V_{ts}|}.
\]

$T$ is a color favored tree amplitude, $C$ is a Color suppressed tree, $A$ is an annihilation, $P$ is a gluonic penguin, $P_{EW}$ is a color favored electroweak penguin, and $P_{EW}^C$ is a color suppressed electroweak penguin. We assume as the hierarchy of the ratios that $1 > r_T, r_{EW} > r_C, r_{EW}^C > r_A \parallel \parallel \parallel 16,\,\, 17,\,\, 18$. \parallel \parallel \parallel 22$. $|P/T|$ was estimated about 0.1 in \parallel \parallel \parallel 22$ 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 $B^+ \to K^0\pi^+ \parallel \parallel \parallel 19,\,\, 20,\,\, 21$. In $B \to K\pi$ mode, the tree type diagram is suppressed by KM factor $V_{ub}^*V_{us}$ and $r_T \sim |T/P| \times \lambda^2 R_0 \sim 0.2$, where cabibbo angle $\lambda = 0.22$ and we used $R_0 = \sqrt{\rho^2 + \eta^2} \sim 0.4$. $r_C$ 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 $r_C \sim 0.1 r_T$.

\(^1\) Note that this ratio $|P/T|$ does not include CKM factors.

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and $r_{EW}^C \sim 0.1 r_{EW}$ [13, 19]. We can also assume that the magnitude of $r_{EW}$ is $O(0.1)$ by considering the estimation by factorization method. $r_A$ could be negligible because it should have B meson decay constant and it works as a suppression factor $f_B/M_B$. So in this talk, I assume that $r_T, r_{EW} \sim O(0.1)$ and $r_C, r_{EW} \sim O(0.01)$ and 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

$$
\bar{B}^{0+} = |P|^2 |V_{tb} V_{ts}|^2 \left[ 1 - 2r_A \cos \delta \cos \phi_3 \right],
$$

(5)

$$
2\bar{B}^{00} = |P|^2 |V_{tb} V_{ts}|^2 \left[ 1 + 2r_{EW} \cos \delta_{EW} \right.
+ 2r_C \cos \delta_{EW} \cos \phi_3, \right.

(6)

$$
\bar{B}^{+-} = |P|^2 |V_{tb} V_{ts}|^2 \left[ 1 + r_{EW}^2 - 2r_{EW} \cos \delta_{EW} \right.
+ 2r_C \cos \delta_{EW} \cos \phi_3, \right.

(7)

$$
2\bar{B}^{++} = |P|^2 |V_{tb} V_{ts}|^2 \left[ 1 + r_{EW}^2 + 2r_{EW} \cos \delta_{EW} \right.
+ 2r_C \cos \delta_{EW} \cos \phi_3
\left. - 2r_{EW} r_T \cos (\delta_{EW} - \delta_T) \cos \phi_3 \right].
$$

(8)

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 $rs$. From the averaged values of the recent experimental data in Table 1,

$$\frac{\bar{B}^{+-}}{2\bar{B}^{00}} = 0.81 \pm 0.11, \quad \frac{2\bar{B}^{++}}{\bar{B}^{00}} = 1.31 \pm 0.15, \quad \frac{\tau^+ \bar{B}^{+-}}{\tau^0 \bar{B}^{00}} = 1.01 \pm 0.09, \quad \frac{\tau^0 \bar{B}^{++}}{\tau^+ \bar{B}^{00}} = 1.05 \pm 0.16, $$

(9)

(10)

(11)

(12)

(13)

(14)

where $\tau^+$ is a lifetime ratio between the charged and the neutral $B$ mesons and $\tau(B^+)/\tau(B^0) = 1.083 \pm 0.017$ [23]. As an example, we can find two ratios from eqs. [13, 14] 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,

$$\frac{\bar{B}^{+-}}{2\bar{B}^{00}} = \left\{ 1 + 2r_{EW} \cos \delta_{EW} + 2r_C \cos \delta_{EW} \right\}
- 2r_{EW} r_T \cos (\delta_{EW} - \delta_T) \cos \phi_3 + 4r_{EW}^2 \cos^2 \delta_{EW}, \quad \frac{2\bar{B}^{++}}{\bar{B}^{00}} = \left\{ 1 + 2r_{EW} \cos \delta_{EW} + 2r_C \cos \delta_{EW} \right\}
- 2r_{EW} r_T \cos (\delta_{EW} - \delta_T) \cos \phi_3 + 4r_{EW}^2 \cos^2 \delta_{EW}, \quad \frac{\tau^+ \bar{B}^{+-}}{\tau^0 \bar{B}^{00}} = \left\{ 1 + 2r_{EW} \cos \delta_{EW} + 2r_C \cos \delta_{EW} \right\}
- 2r_{EW} r_T \cos (\delta_{EW} - \delta_T) \cos \phi_3 + 4r_{EW}^2 \cos^2 \delta_{EW}, $$

(15)

(16)

The equations are same up to $r_T^2$ term and the difference seems to come from $r_{EW}^2$ term. The difference of experimental data from 1 seems to depend on the sign of $r_{EW}^2$ term. If we can neglect all $r^2$ terms, then there are a few relations among the ratios as following

$$\frac{\bar{B}^{+-}}{2\bar{B}^{00}} - \frac{2\bar{B}^{++}}{\bar{B}^{00}} = 0, \quad \frac{2\bar{B}^{++}}{\bar{B}^{00}} - \frac{\tau^+ \bar{B}^{+-}}{\tau^0 \bar{B}^{00}} = \frac{\tau^+ \bar{B}^{00}}{\tau^0 \bar{B}^{00}} - 1 = 0. $$

(17)

(18)

However, the experimental data listed in eqs. [19-21] do not satisfy these relations so well. According to the experimental data, $\frac{\bar{B}^{+-}}{2\bar{B}^{00}}$ seems to be smaller than 1 but $\frac{2\bar{B}^{++}}{\bar{B}^{00}}$ be larger than 1. So it shows there is a discrepancy between them. $r_T^2$ term does not seem to contribute to the ratios so strongly. The second relation corresponds to the isospin relation at the first order of $r$. The discrepancy of relation [18] from 0 also comes from $r_{EW}^2$ term. The differences are

$$\frac{2\bar{B}^{++}}{\bar{B}^{00}} - \frac{\bar{B}^{+-}}{2\bar{B}^{00}} = 2r^2_{EW} - 2r_{EW} r_T \cos (\delta_{EW} - \delta_T) \cos \phi_3 - 4r_{EW}^2 \cos^2 \delta_{EW} = 0.50 \pm 0.19, $$

(19)

$$\frac{2\bar{B}^{++}}{\bar{B}^{00}} - \frac{\tau^+ \bar{B}^{+-}}{\tau^0 \bar{B}^{00}} - \frac{\tau^+ \bar{B}^{00}}{\tau^0 \bar{B}^{00}} - 1 = 2r^2_{EW} - 2r_{EW} r_T \cos (\delta_{EW} - \delta_T) \cos \phi_3 = 0.54 \pm 0.25, $$

(20)
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 error are determined by adding quadratically all errors. Using the other relation as following

$\frac{B^{+} - \tau^{0} B^{0} + \tau^{+} 2B^{00} - 1}{2B^{00} - \tau^{0} B^{0} + \tau^{+} 2B^{00}} = -4r_{EW} \cos \delta_{EW} + 2r_{EW} \tau_{T} \cos(\delta_{EW} - \delta_{T}) \cos \phi_{3}$

$= 0.00 \pm 0.26,$  \hspace{1cm} (21)

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

$(r_{EW}, \cos \delta_{EW}, \tau_{T} \cos(\delta_{EW} - \delta_{T}) \cos \phi_{3})$

$= (0.26, -0.38, -0.75)$ and $(0.69, 0.21, 0.41)$. \hspace{1cm} (22)

This solution show that 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 $r_{EW}$ and $\tau_{T} \cos(\delta_{EW} - \delta_{T}) \cos \phi_{3}$ at 1σ level for eqs. (19)-(21) is shown in Fig. 1.

From this result, we find that the smaller $r_{EW}$ will favored a larger $|r_{T} \cos(\delta_{EW} - \delta_{T}) \cos \phi_{3}| term with negative sign. However such large $r_{T}$ is disfavored by the rough estimation of $r_{T}$ which is around 0.2. Even if $|r_{T} \cos(\delta_{EW} - \delta_{T}) \cos \phi_{3}| is within 0.2, then $r_{EW}$ will also be larger than 0.3 and $r_{EW}$ will be larger than $r_{T}$. This is showing that there is a possibility of large electroweak penguin contribution and it may be an evidence of new physics effects. Roughly speaking, the shift of eqs. (22) from 1 seem to depend on the $r_{EW}$ term and the sign. The contributions from tree diagram are not so large except for the cross term with the electroweak penguin because $\frac{r_{T} \cos(\delta_{EW} - \delta_{T}) \cos \phi_{3}}{\frac{r_{T} \cos(\delta_{EW} - \delta_{T}) \cos \phi_{3}}{\tau_{T} \cos(\delta_{EW} - \delta_{T}) \cos \phi_{3}}}$ is quite near 1. To fix the solution or confirm the large electroweak penguin contribution, we need higher accurate data.

In this talk, I discussed about a possibility of large electro-weak penguin contribution in $B \rightarrow K \pi$ from recent experimental data. The several relations among the branching ratios which realize when the contributions from tree type and electroweak penguin are small compared with the gluon penguin do not satisfy the data. The difference comes from the $r_{T}^{2}$ terms and the main contribution comes from electroweak penguin. We find that the contribution from electroweak penguin 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, then it may be including some new physics effects. In this analysis, we find that who can have some contribution from new physics is the color favored Z penguin type diagram (ZFCNC) which is the process $\pi^{0}$ goes out from $B - K$ current.

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| $Br(B^{+} \rightarrow K^{0} \pi^{+}) \times 10^{6}$ | CLEO[24] | Belle[2, 25] | BaBar[26, 27] | Average |
|-----------------|----------|----------|----------|---------|
| 18.8 $^{+3.7+2.1}_{-3.3-1.8}$ | 22.0 $\pm 1.9$ $\pm 1.1$ | 17.5 $^{+1.8}_{-1.7}$ $+1.3$ | 19.6 $\pm 1.4$ |
| 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 $\pm 1.4$ |
| 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 $\pm 0.8$ |
| 12.9 $^{+2.4+1.2}_{-2.2-1.1}$ | 12.8 $\pm 1.4$ $^{+1.4}_{-1.0}$ | 12.8 $^{+1.2}_{-1.1}$ $^{+1.0}$ | 12.8 $\pm 1.1$ |

TABLE I: The experimental data and the average.

FIG. 1: The allowed region at 1σ level on $(r_{EW}, \tau_{T} \cos(\delta_{EW} - \delta_{T}) \cos \phi_{3})$ plane.

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