Signal of New Physics and Test of Isospin-SU(3) Relations and CP Violation in Charmless B Decays

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Abstract

A model-independent analytical analysis for charmless B decays is presented. It is demonstrated that the CP-averaging branching ratio difference $\Delta R = R_c - R_n$ in $B \to \pi K$ decays with $R_c = 2Br(\pi^0K^-)/Br(\pi^-\bar{K}^0)$ and $R_n = Br(\pi^+K^-)/2Br(\pi^0\bar{K}^0)$ defines a sensitive quantity for probing new physics as $\Delta R$ is dominated by the second order of electroweak penguin contributions. A large discrepancy between experimental data and standard model (SM) prediction $\Delta R_{\text{exp}}/\Delta R_{\text{SM}} > 9.0 \pm 5.0$ strongly indicates a signal of new physics in the electroweak penguin sector. Within the SM, the current $\pi K$ data favor a very large color-suppressed tree amplitude $|C'/T'| \sim 2$, large CP violations ($A_{CP}(\pi^0\bar{K}^0) \sim 0.69$ and $A_{CP}(\pi^+\bar{K}^-) \sim 0.56$), which is connected to $\Delta R$ and be solved simultaneously with extra electroweak penguin contributions. More accurate measurements on the ratio difference $\Delta R$ and CP violation in $B \to \pi\pi, \pi K$ decays may provide a window for probing new physics and testing the isospin and SU(3) symmetries.

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I. INTRODUCTION

The measurements of hadronic charmless $B$ decays at the two $B$-factories become more and more accurate. Currently, all the branching ratios of $B \to \pi\pi$ and $\pi K$ modes have been measured with good accuracy\cite{1} and a large direct CP violation has been established in $\pi^+K^-$ mode \cite{2,3}. The current data show some puzzling patterns: big relative enhancements of $\pi^0\pi^0$ and $\pi^0\bar{K}^0$ modes, and a large direct CP asymmetry in $\pi^+K^-$ relative to that of $\pi^0K^-$. These are usually referred to as $\pi\pi$ and $\pi K$ puzzles. Their implications have been investigated by many groups\cite{4,5,6,7,8,9,10,11,12,13,14,15}. In our recent paper\cite{16}, it has been shown that the weak phase $\gamma$ can well be determined to be consistent with the standard model, a large electroweak penguin relative to tree type diagrams with a large strong phase is preferred and an enhanced color-suppressed tree diagram is needed. A comprehensive $\chi^2$ analysis has been carried out including subleading diagrams, their implications to $KK$ modes as well as the SU(3) broken effects\cite{17}. In the present note, we shall present a model-independent analytical analysis on the origins of these puzzles in the relevant decay modes, how a signal of new physics can be singled out from the experimental observables, and how more precise measurements can provide a window for exploring new physics and testing isospin and SU(3) relations from the charmless B decays.

As the experiments have already shown the possibility of large CP asymmetries, the final state interactions (FSIs) can not be simply neglected. It is natural to rise a question that whether the current puzzles especially the $\pi K$ puzzle is linked to new physics beyond the SM or just from some complicate strong interaction effects. The widely used quark flavor diagrams are however not eigenstates of strong interaction which makes it difficult to get general conclusions. Furthermore, it is not clear whether the usually neglected subleading diagrams of annihilation type are indeed tiny and whether the FSIs will spoil the diagrammatic decomposition by change the hierarchy among the diagrams\cite{18} or introducing new diagrams like charming penguins\cite{19}. For these reasons, in the present work, we shall begin with a general isospin analysis.

The effective Hamiltonian for $\Delta S = 0(1)$ nonleptonic B decays is given by

$$H_{\text{eff}} = \frac{G_F}{\sqrt{2}} \sum_{q=u,c} \lambda_q^{(s)} \left( C_1 O_1^q + C_2 O_2^q + \sum_{i=3}^{10} C_i O_i \right),$$

with $\lambda_q^{(s)} = |V_{qb}^* V_{qd}|$ is the products of CKM matrix elements. where $O_{1,2}^u$, $O_{3,4,5}$ and $O_{7,10}$ are related to tree, QCD penguin and electroweak penguin sectors respectively.

The general isospin decomposition of the decay amplitudes for $B \to \pi\pi(\pi K)$ decays can be expressed as\cite{20}:

$$A^{\pi\pi(\pi K)} = \lambda_u^{(s)} A_u^{\pi\pi(\pi K)} + \lambda_c^{(s)} A_c^{\pi\pi(\pi K)},$$
where $\lambda_u^{(s)} = V_{ub} V_{us}^*$, $\lambda_c^{(s)} = V_{cb} V_{cd}^*$ and

$$A_{q^+}^{\pi^-\pi^+} = \sqrt{\frac{2}{3}} a_u^q e^{i\delta_u^q} + \sqrt{\frac{1}{3}} a_c^q e^{i\delta_c^q},$$

$$A_{q^0}^{\pi^0\pi^0} = \sqrt{\frac{1}{3}} a_u^q e^{i\delta_u^q} - \sqrt{\frac{2}{3}} a_c^q e^{i\delta_c^q},$$

$$A_{q^-}^{\pi^-\pi^0} = -\sqrt{\frac{3}{2}} a_c^q e^{i\delta_c^q},$$

and

$$A_{q^+}^{\pi^+K^-} = \sqrt{\frac{2}{3}} a_u^{q_{1/2}} e^{i\delta_u^{q_{1/2}}} + \sqrt{\frac{1}{3}} a_c^{q_{3/2}} e^{i\delta_c^{q_{3/2}}},$$

$$A_{q^0}^{\pi^0K^0} = \sqrt{\frac{1}{3}} a_u^{q_{1/2}} e^{i\delta_u^{q_{1/2}}} - \sqrt{\frac{2}{3}} a_c^{q_{3/2}} e^{i\delta_c^{q_{3/2}}},$$

$$A_{q^-}^{\pi^-K^-} = -\sqrt{\frac{1}{3}} b_u^{q_{1/2}} e^{i\delta_u^{q_{1/2}}} - \sqrt{\frac{2}{3}} b_c^{q_{3/2}} e^{i\delta_c^{q_{3/2}}},$$

$$A_{q^-}^{\pi^-K^0} = \sqrt{\frac{2}{3}} b_u^{q_{1/2}} e^{i\delta_u^{q_{1/2}}} - \sqrt{\frac{1}{3}} b_c^{q_{3/2}} e^{i\delta_c^{q_{3/2}}},$$

(3)

with $a_{1/2}^q(b_{3/2}^q)$ and $\delta_{1/2}^q(\delta_{3/2}^q),(q = u, c$ and $I = 0, 2$ or $I = 1/2, 3/2)$ the isospin amplitudes and strong phases.

In the $B \to \pi\pi$ processes, as the effective operator with $\Delta I = 3/2$ isospin component is unique in the effective Hamiltonian, the hadronic matrix elements drop out in the ratio between two isospin $I = 2$ amplitudes, leading to the following relations [20, 21]:

$$\frac{a_u^c}{a_u^u} \equiv R_{EW} = \frac{2}{3} \frac{C_9 + C_{10}}{C_1 + C_2 + C_9 + C_{10}} = (-1.25 \pm 0.125) \times 10^{-2}$$

(5)

$$\delta_{2}^u = \delta_{2}^c \equiv \delta_2$$

(6)

Note that the above relation is model independent and free from hadronic uncertainties. A direct consequence from this relation is that no direct CP violation occurs in the $B \to \pi^-\pi^0$ decay, namely

$$A_{CP}(B \to \pi^-\pi^0) \simeq 0, \quad \text{SM}$$

$$A_{CP}(B \to \pi^-\pi^0) \gg 0.1, \quad \text{new physics}$$

(7)

(8)

as long as isospin symmetry holds at a few percent level. A similar observation was also made within SU(3) symmetry [22]. Obviously, the conclusion based on isospin symmetry is more reliable as SU(3) breaking effects can not be neglected. In $B \to \pi K$ decays, the effective operators for the highest $\Delta I = 1$ isospin components are not unique. However, one can still define a similar ratio

$$R'_{EW} \equiv \frac{a_{3/2}^c}{a_{3/2}^u}.$$ 

(9)
In SU(3) limit $R'_{EW} = R_{EW}$ and $\delta_{3/2}^u = \delta_{3/2}^c$. Due to SU(3) breaking in the isospin amplitudes from operators $O^u_1 - O^u_2 = (\bar{u}u)(\bar{s}b) - (\bar{s}u)(\bar{u}b)$, the value of $R'_{EW}$ become slightly model dependent. However, in the factorization approach, it has been demonstrated that the SU(3) symmetry breaking effects are small either because of the cancellation between two combining factors of the decay constants and form factors, namely $f_K f_B^{B\rightarrow\pi} \approx f_{\pi} f_B^{B\rightarrow K}$, or the suppression by the heavy bottom meson mass $(m_K^2 - m_\pi^2)/m_B^2 \ll 1$. The typical corrections are less than 10%. Thus, in such an approximation, one has in the standard model

$$R'_{EW} \simeq R_{EW}, \quad \delta_{3/2}^u \simeq \delta_{3/2}^c \equiv \delta_{3/2}$$

II. $\pi K$ PUZZLE AND NEW PHYSICS

The relative sizes of the isospin amplitudes has been calculated in Ref.[20] based on factorization. From those results and considering the most conservative uncertainties we have:

$$\varepsilon'_{P} = \frac{a_{3/2}^c}{a_{1/2}^c} = O(10^{-1} \sim 10^{-2})$$

$$\varepsilon''_{P} = \frac{a_{3/2}^c}{b_{1/2}^c} = O(10^{-1} \sim 10^{-2})$$

$$R'_P = \frac{a_{1/2}^c}{a_{1/2}^u} = -O(10^{-1} \sim 1)$$

$$R''_P = \frac{b_{1/2}^c}{b_{1/2}^u} = -O(10^{-1} \sim 1)$$

In the whole discussions bellow, we shall assume that above order of magnitude estimate for the isospin amplitudes remain unchanged under FSI. With the smallness of $|\lambda_u^u|/|\lambda_c^e| \simeq 0.02$, the branching ratios of $\pi K$ modes can be expanded around small quantities $\varepsilon'_{P}$ and $\varepsilon''_{P}$.

$$R_n = \frac{Br(\pi^+K^-)}{2Br(\pi^0K^0)} = \frac{1 + \alpha'_1 \varepsilon'_P + \alpha'_2 \varepsilon''_P}{1 - \alpha'_1 \varepsilon'_P + 4\alpha'_2 \varepsilon''_P}$$

$$R_c = \frac{2Br(\pi^0K^-)}{Br(\pi^-K^0)} = \frac{1 + \alpha''_1 \varepsilon''_P + 4\alpha'_2 \varepsilon''_P}{1 - \alpha''_1 \varepsilon''_P + \alpha'_2 \varepsilon''_P}$$

The coefficients have the following structure

$$\alpha'_1 = \sqrt{2} \frac{\xi}{R_{EW}} \left( \varepsilon'_1 + \varepsilon'_2/R'_P \right)$$

$$\alpha''_1 = \sqrt{2} \frac{\xi}{R_{EW}} \left( \varepsilon''_1 + \varepsilon''_2/R''_P \right)$$

$$\alpha'_2 = \frac{1}{2} \frac{\xi}{R_{EW}} \left( \varepsilon'_1 + \varepsilon'_2/R'_P \right)$$

$$\alpha''_2 = \frac{1}{2} \frac{\xi}{R_{EW}} \left( \varepsilon''_1 + \varepsilon''_2/R''_P \right)$$
where $\xi_s = |\lambda_u^s/\lambda_c^s|$. The coefficient $\alpha'_1(\alpha''_1)$ for the linear expansion is dominated by $\varepsilon'_1(\varepsilon''_1)$ which are unstable under small variations of $R'_{\text{EW}}$ and $\cos \gamma$. The expressions for $\varepsilon$ quantities are given by

$$
\varepsilon'_1 = \frac{1}{\xi_s} R'_{\text{EW}} \cos (\delta^c_{1/2} - \delta^c_{3/2}) + \cos \gamma \cos (\delta^c_{1/2} - \delta^u_{3/2})
$$

$$
\varepsilon''_1 = \frac{1}{\xi_s} R'_{\text{EW}} \cos (\delta^c_{1/2} - \delta^c_{3/2}) + \cos \gamma \cos (\delta^c_{1/2} - \delta^u_{3/2})
$$

$$
\varepsilon'_2 = \xi_s \cos (\delta^u_{1/2} - \delta^u_{3/2}) + R'_{\text{EW}} \cos \gamma \cos (\delta^u_{1/2} - \delta^c_{3/2})
$$

$$
\varepsilon''_2 = \xi_s \cos (\delta^u_{1/2} - \delta^u_{3/2}) + R'_{\text{EW}} \cos \gamma \cos (\delta^u_{1/2} - \delta^c_{3/2})
$$

$$
\varepsilon'_1 = \frac{1}{\xi_s} R'_{\text{EW}} + \cos \gamma \cos (\delta^u_{3/2} - \delta^c_{3/2})
$$

$$
\varepsilon''_2 = \xi_s + R'_{\text{EW}} \cos \gamma \cos (\delta^u_{3/2} - \delta^c_{3/2})
$$

(15)

To the next leading order of $\varepsilon'_p$ and $\varepsilon''_p$, we have

$$
R_c \simeq 1 + 2 \alpha'_1 \varepsilon'_p + (3 \alpha'_2 - 2 \alpha''_2) \varepsilon''_p
$$

$$
R_n \simeq 1 + 2 \alpha'_1 \varepsilon''_p - (3 \alpha'_2 - 2 \alpha''_2) \varepsilon''_p
$$

(16)

Applying Eq. (10), we arrive at the following expressions

$$
\varepsilon''_1 = \varepsilon'_1 = \left( \frac{1}{\xi_s} R'_{\text{EW}} + \cos \gamma \right) \cos (\delta^c_{1/2} - \delta^c_{3/2})
$$

$$
\varepsilon'_2 = (\xi_s + R'_{\text{EW}} \cos \gamma) \cos (\delta^u_{1/2} - \delta^c_{3/2})
$$

$$
\varepsilon''_2 = (\xi_s + R'_{\text{EW}} \cos \gamma) \cos (\delta^u_{1/2} - \delta^c_{3/2})
$$

$$
\varepsilon'_1 = \frac{1}{\xi_s} R'_{\text{EW}} + \cos \gamma
$$

$$
\varepsilon''_2 = \xi_s + R'_{\text{EW}} \cos \gamma
$$

(17)

Taking $\xi_s \simeq 0.02$ and $\cos \gamma \simeq 60^\circ$

$$
\frac{1}{\xi_s} R'_{\text{EW}} + \cos \gamma \simeq -0.125, \quad \xi_s + R'_{\text{EW}} \cos \gamma \simeq 0.014
$$

(18)

Note that a model-independent cancelation takes place in the first factor which greatly suppresses the coefficients $\alpha'_1$ and $\alpha''_1$. As a consequence, large deviations of $R_n$ and $R_c$ at $\sim 10\%$ from unity becomes unlikely. For in SM, with the most conservative estimation, we can get:

$$
\alpha'_1 \simeq 0.28 \cos (\delta^c_{1/2} - \delta^c_{3/2}),
$$

$$
\alpha''_1 \simeq 1.0
$$

$$
\varepsilon'_p \simeq \varepsilon''_p \simeq 0.04 \sim 0.06
$$

(19)

As a consequence, we obtain the following correlated numerical predictions for the ratios

$$
0.97 < R_c < 1.05, \quad 0.96 < R_n < 1.04
$$

(20)
\[ \Delta R^{SM} \simeq 2(3\alpha_2' - 2\alpha_1'^2)\epsilon_P^2 \simeq 0.01 \sim 0.02 \]  

which do not agree well with the current data

\[ R^e_x = 1.0 \pm 0.06, \quad R^h_x = 0.82 \pm 0.08, \quad \text{or} \quad \Delta R^{ex} = 0.18 \pm 0.10 \]  

The ratio \( R^e_x \) or the ratio difference \( \Delta R \) is about 2\( \sigma \) away from the standard model predictions. This may be regarded as an indication for new physics beyond the standard model.

The above observations are obtained from flavor symmetries and depend mostly on isospin. It is expected that it is more robust comparing with diagrammatic method which based on short distance pictures. To see the implications in terms of quark flavor flow diagrams, one may rewrite the isospin amplitudes as follows:

\[
\begin{align*}
    a_0^u e^{i\delta_0} &= -\frac{1}{\sqrt{6}}[\hat{T} - 3\hat{P} + (\hat{T} - 3\hat{C}) + (\hat{P}_{EW} - 3\hat{P}_{EW}')], \\
    a_0^c e^{i\delta_0} &= \frac{1}{\sqrt{6}}[3\hat{P} - (\hat{P}_{EW} - 3\hat{P}_{EW}')], \\
    a_2^u e^{i\delta_2} &= -\frac{1}{\sqrt{3}}[\hat{T} - \hat{P}_{EW}], \\
    a_2^c e^{i\delta_2} &= \frac{1}{\sqrt{3}}\hat{P}_{EW},
\end{align*}
\]

and similarly

\[
\begin{align*}
    a_{1/2}^u e^{i\delta_{1/2}} &= -\frac{1}{\sqrt{6}}[\hat{T'} - 3\hat{P}' + (\hat{T'} - 3\hat{C'}) + (\hat{P}'_{EW} - 3\hat{P}'_{EW}')], \\
    a_{1/2}^c e^{i\delta_{1/2}} &= \frac{1}{\sqrt{6}}[3\hat{P}' - (\hat{P}'_{EW} - 3\hat{P}'_{EW}')], \\
    a_{3/2}^u e^{i\delta_{3/2}} &= -\frac{1}{\sqrt{3}}[\hat{T'} - \hat{P}'_{EW}], \\
    a_{3/2}^c e^{i\delta_{3/2}} &= \frac{1}{\sqrt{3}}\hat{P}'_{EW},
\end{align*}
\]

\[
\begin{align*}
    b_{1/2}^u e^{i\delta_{1/2}} &= -\frac{1}{\sqrt{6}}[\hat{T'} - (3\hat{P}' + \hat{P}'_{EW}) - 3A'], \\
    b_{1/2}^c e^{i\delta_{1/2}} &= \frac{1}{\sqrt{6}}(3\hat{P}' + \hat{P}'_{EW})
\end{align*}
\]

Where \( \hat{T} = T + C = \hat{T} + \hat{C} \), \( \hat{T} = T + E \), \( \hat{C} = C - E \), \( \hat{P} = P - P_{EW}/3 + P_A \), \( \hat{P}_{EW} = P_{EW} + P_{EW}' \), and similarly \( \hat{T'} = T' + C' \), \( \hat{P}' = P' - P_{EW}/3 + P_A' \), \( \hat{P}'_{EW} = P_{EW}' + P_{EW}' \).

Here \( T, C, P, P_{EW}, P_{EW}' \) represent the tree diagram, color-suppressed tree diagram, QCD penguin diagram, electroweak penguin diagram and color suppressed electroweak penguin diagram, and \( E, A \) and \( P_A \) denote the exchange diagram, annihilation diagram and penguin annihilation diagram respectively.
In the diagrammatic language, the counterpart of Eq. (10) is given by

\[
P^{(c)}_{\text{EW}} \simeq \frac{\hat{P}^{(c)}_{\text{EW}}}{\hat{T}^{(c)}}
\]

and

\[
\begin{align*}
R_n & \simeq 1 + (r_{\text{EW}C})^2 + (r_{\text{EW}})^2 (4 \cos \delta_{\text{EW}}^2 - 1) - 2 (r_{\text{EW}C} \cos \delta_{\text{EW}}^C + r_{\text{EW}} \cos \delta_{\text{EW}}^C) \\
& \quad - 2 \zeta \alpha r_T \cos \gamma \cos \delta_T^C + 2 \zeta \alpha r_T r_{\text{EW}C} \cos \gamma \cos (\delta_T^C - \delta_{\text{EW}}^C) \\
& \quad - 2 \zeta \alpha r_C \cos \gamma \cos \delta_C^C - 2 \zeta \alpha r_C r_{\text{EW}} \cos \gamma \cos (\delta_C^C - \delta_{\text{EW}}^C) \\
& \quad + 4 \zeta \alpha r_T r_{\text{EW}} \cos \gamma \cos \delta_T^C \cos \delta_{\text{EW}}^C + 4 \zeta \alpha r_C r_{\text{EW}C} \cos \gamma \cos \delta_C^C \cos \delta_{\text{EW}}^C \\
& \quad + 4 r_{\text{EW}C} r_{\text{EW}} \cos \delta_{\text{EW}}^C \cos \delta_{\text{EW}}', \\
R_c & \simeq 1 + (r_{\text{EW}C})^2 + (r_{\text{EW}})^2 - 2 (r_{\text{EW}C} \cos \delta_{\text{EW}}^C + r_{\text{EW}} \cos \delta_{\text{EW}}) \\
& \quad - 2 \zeta \alpha r_T \cos \gamma \cos \delta_T^C + 2 \zeta \alpha r_T r_{\text{EW}C} \cos \gamma \cos (\delta_T^C - \delta_{\text{EW}}^C) \\
& \quad - 2 \zeta \alpha r_C \cos \gamma \cos \delta_C^C + 2 \zeta \alpha r_C r_{\text{EW}} \cos \gamma \cos (\delta_C^C - \delta_{\text{EW}}^C) \\
& \quad + 2 \zeta \alpha \cos \gamma \left[ r_{\text{EW}C} r_C \cos \delta_{\text{EW}}^C \cos \delta_{\text{EW}}' + r_{\text{EW}} \cos \delta_{\text{EW}}' \right] \\
& \quad + 2 r_{\text{EW}C} r_{\text{EW}} \cos (\delta_{\text{EW}}' - \delta_{\text{EW}}^C),
\end{align*}
\]

To get the above expressions, we have neglected the terms proportional to \( \xi_s^2 \). Here \( r_F = |F'| |\hat{P}'| \) with F denote Feynman diagrams (\( F' = T', C', P_{\text{EW}}' \) etc). We define \( F' = |F'| e^{i\delta_F} \) except for the E-W penguin \( P_{\text{EW}}^{(c)} = - |P_{\text{EW}}^{(C')}| e^{i\delta_{\text{EW}C}} \) in the rest of this paper. The difference between \( R_n \) and \( R_c \) is of the second order

\[
\Delta R \simeq -2 (r_{\text{EW}})^2 \cos (2 \delta_{\text{EW}}) - 2 r_{\text{EW}C} r_{\text{EW}} \cos (\delta_{\text{EW}}^C + \delta_{\text{EW}}^C) \\
& \quad - 2 \zeta \alpha r_C r_{\text{EW}} \cos \gamma \cos (\delta_C^C + \delta_{\text{EW}}^C) \\
& \quad - 2 \zeta \alpha r_T r_{\text{EW}} \cos \gamma \cos (\delta_T^C + \delta_{\text{EW}}^C) \\
& \quad - 4 \zeta \alpha r_C r_{\text{EW}} \cos \gamma \cos (\delta_C^C + \delta_{\text{EW}}^C)
\]

The third to fifth terms are all \( \xi_s \) suppressed and \( \Delta R \) is dominated by electroweak penguin and very sensitive to any new physics in electroweak penguin sector. It is not difficult to check that in order to simultaneously explain the experimental data, it requires that

\[
\alpha_1' \varepsilon_p' \simeq -0.05, \quad \alpha_2' \simeq 14 \alpha_1'^2
\]

which leads to the following solution

\[
\begin{align*}
\delta_{3/2}^C - \delta_{3/2}^C & \simeq -\pi/3, \quad \delta_{1/2}^C - \delta_{3/2}^u \simeq 0.40 \\
\alpha_1' & \simeq 0.68, \quad \alpha_1 \simeq -0.22 \\
\varepsilon_p' & \simeq 0.20, \quad \text{i.e.} \quad |\hat{P}_{\text{EW}}'/\hat{P}'| \simeq 0.42
\end{align*}
\]

For the typical values of \( |\hat{P}'/\hat{T}'| = 0.10 \sim 0.15 \), we find

\[
\begin{align*}
R_{\text{EW}}|_{\text{exp}} & = -(0.04 \sim 0.06) \\
(\delta_{3/2}^C - \delta_{3/2}^C)|_{\text{exp}} & \simeq -\pi/3
\end{align*}
\]
which shows that a large enhancement by a factor 3.5 to 5 for the effective electroweak penguin contributions is needed and also a large strong phase difference is required. This may imply the existence of new physics with a significant contribution to the effective electroweak penguin operator.

With the above analytical analysis, we can arrive at the following conclusions:

\[
\begin{align*}
\Delta R &= R_c - R_n \leq 0.02, \quad \text{isospin & SU(3) relations in SM} \\
\Delta R &= R_c - R_n > 0.02, \quad \text{SU(3) symmetry breaking/new physics} \\
\Delta R &= R_c - R_n \gg 0.02, \quad \text{signal of new physics}
\end{align*}
\]

The present experimental data for \(\Delta R\) is much larger than the standard model prediction with using isospin and SU(3) relations, i.e.,

\[
(\Delta R)^{exp}/(\Delta R)^{SM} > 9.0 \pm 5.0
\]

which indicates a signal of new physics. It is clear that more precise measurements on the difference between two ratios will provide an effective way to probe new physics beyond the standard model.

An alternative possibility is to introduce a new CP phase \(\phi_{NP}\) in EW penguin diagram, which was discussed recently in ref.\[23\]. Taking the isospin relation for the amplitude \(R'_{EW} = R_{EW} = -0.0125\), but with introducing a new weak phase \(\phi_{NP}\) for the EW penguin. As a consequence, the expressions in Eq(15) will be modified as:

\[
\begin{align*}
\varepsilon'_1 &= \frac{1}{\xi_s} R'_E W \cos \phi_{NP} \cos (\delta^c_{1/2} - \delta^c_{3/2}) + \cos \gamma \cos (\delta^c_{1/2} - \delta^u_{3/2}) \\
\varepsilon''_1 &= \frac{1}{\xi_s} R'_E W \cos \phi_{NP} \cos (\delta^c_{1/2} - \delta^c_{3/2}) + \cos \gamma \cos (\delta^c_{1/2} - \delta^u_{3/2}) \\
\varepsilon'_2 &= \xi_s \cos (\delta^u_{1/2} - \delta^u_{3/2}) + R'_E W \cos (\gamma + \phi_{NP}) \cos (\delta^u_{1/2} - \delta^c_{3/2}) \\
\varepsilon''_2 &= \xi_s \cos (\delta^u_{1/2} - \delta^u_{3/2}) + R'_E W \cos (\gamma + \phi_{NP}) \cos (\delta^u_{1/2} - \delta^c_{3/2}) \\
\varepsilon'_1 &= \frac{1}{\xi_s} R'_E W + \cos (\gamma + \phi_{NP}) \cos (\delta^u_{3/2} - \delta^c_{3/2}) \\
\varepsilon''_1 &= \xi_s + R'_E W \cos (\gamma + \phi_{NP}) \cos (\delta^u_{3/2} - \delta^c_{3/2})
\end{align*}
\]

As \(\phi_{NP}\) is a free parameter, thus \(\cos (\gamma + \phi_{NP})\) can be \([-1, 1]\). We then obtain the following solution in order to explain the experimental data within 1\(\sigma\) error:

\[
\begin{align*}
\delta^u_{3/2} &= \delta^c_{3/2}, \quad \delta^c_{1/2} - \delta^c_{3/2} \simeq \pm 1.3, \\
\alpha'_2 &\leq 3.4, \quad \alpha'_1 \leq -0.5, \\
\varepsilon'_P &\geq 0.06
\end{align*}
\]

where the smallest \(\varepsilon'_P\) occurs at \(\cos (\gamma + \phi_{NP}) = -1\). It shows that a new CP phase can truly bring the results closer to the present data without a large enhanced E-W penguin.

From the above discussions, the \(R_n\) and \(R_c\) puzzle can be solved through new physics in the EW penguin sector with an enhanced amplitude and/or a new CP-violating phase. In general, both effects can improve the discrepancy between the present data and the SM predictions.
III. ENHANCED COLOR-SUPPRESSED AMPLITUDES FROM $B \to \pi\pi$

We now consider the $B \to \pi\pi$ decays using the diagrammatic method, the CP-averaging branching ratios have the following forms:

$$
\frac{1}{\tau_{B^0}} Br(\pi^+\pi^-) = |\lambda_u|^2|\bar{T}|^2 + (|\lambda_u|^2 + |\lambda_c|^2 - 2\cos\gamma|\lambda_u||\lambda_c|)|\bar{P}|^2 + 2|\lambda_u||\bar{P}||\bar{T}| \cos\delta_T(|\lambda_c|\cos\gamma - |\lambda_u|),
$$

$$
\frac{1}{\tau_{B^0}} Br(\pi^0\pi^0) = \frac{1}{2}([\lambda_u]^2|\bar{C}|^2 + (|\lambda_u|^2 + |\lambda_c|^2 - 2\cos\gamma|\lambda_u||\lambda_c|)|\bar{P} - \hat{P}_{EW}|^2]
$$

$$
\frac{1}{\tau_{B^-}} Br(\pi^-\pi^0) = \frac{1}{2}[|\lambda_u|^2|\bar{T} + C|^2 + (|\lambda_u|^2 + |\lambda_c|^2 - 2\cos\gamma|\lambda_u||\lambda_c|)|\bar{P}_{EW}|^2
$$

where $\bar{P} = \hat{P} + \hat{P}_{EW}$ and $\delta_C, \delta_T, \delta_{EW}, \delta_{T+C}$ are the strong phases of $C, T, \hat{P}_{EW}$ and $T + C$. We fix the strong phase of $\hat{P}(\delta_\hat{P})$ to be zero as an overall phase. Noticing the fact that $|\hat{P}| \ll |\bar{T}|$ and $2|\lambda_u|^2(|\lambda_u|^2\cos\gamma - |\lambda_c|^2) \approx 0.4|\lambda_u|^2$, we obtain in a good approximation the following relations

$$
\frac{R_-}{(1 - R_0)} \approx 1 + \frac{|\bar{C}/\bar{T}|^2 + 2|\bar{C}/\bar{T}| \cos(\delta_T - \delta_C)}{1 - |\bar{C}/\bar{T}|^2}
$$

with $R_- \equiv 2Br(\pi^-\pi^0)/\tau Br(\pi^+\pi^-)$ and $R_0 \equiv 2Br(\pi^0\pi^0)/Br(\pi^+\pi^-)$. where $\tau = \tau_{B^-}/\tau_{B^0} = 1.086$ reflects the life-time difference. Taking the experimental data for the three branching ratios and considering the possible range for $\cos(\delta_T - \delta_C) \in [1, -1]$, we arrive at the following constraint for the ratio $|\bar{C}|/|\bar{T}|$

$$
0.68 \leq \frac{|\bar{C}|}{|\bar{T}|} \leq 0.98
$$

Noticing the positivity of the quantity

$$
(|\lambda_u|^2 + |\lambda_c|^2 - 2\cos\gamma|\lambda_u||\lambda_c|)|\bar{P}|^2 + 2|\lambda_u||\bar{P}||\bar{T}| \cos\delta_T(|\lambda_c|\cos\gamma - |\lambda_u|) > 0
$$

namely, $Br(\pi^+\pi^-)/\tau_B > |\lambda_u|^2|\bar{T}|^2$, we yield a more strong constraint for the ratio

$$
\frac{|\bar{C}|}{|\bar{T}|} \leq \sqrt{R_0} \equiv \sqrt{\frac{2Br(\pi^0\pi^0)}{Br(\pi^+\pi^-)}} \simeq 0.76
$$

Combining the above two constraints,

$$
0.68 \leq |\bar{C}|/|\bar{T}| \leq 0.76, \quad \text{or} \quad |\bar{C}|/|\bar{T}| = 0.72 \pm 0.04,
$$

we obtain from eq.(38) the following allowed ranges for two amplitudes $\bar{T}$ and $\bar{C}$ and the difference of their strong phases

$$
|\bar{T}| \simeq 0.58 \pm 0.02, \\
|\bar{C}| \simeq 0.41 \pm 0.03, \\
\cos(\delta_T - \delta_C) \simeq 0.70 \mp 0.30
$$
Note that the above numerical values are obtained for simplicity by only taking the central values of the experimental data. When taking into account the experimental errors, the allowed range could be enlarged by (10 $\sim$ 20)$\%$. While the above results are almost not affected by the enhanced electro-weak penguin contributions as long as $|\hat{P}_{EW}| \ll |\hat{T}|$ remains a good approximation. Obviously, the resulting ratio $|\hat{C}|/|\hat{T}| \simeq 0.72$ is much larger than the result $|\hat{C}|/|\hat{T}| \simeq 0.1 \sim 0.2$ calculated from both the QCD factorization approach[24] and perturbative QCD approach[27]. Although the recent next to leading order QCD factorization calculations show some enhancement of $C$, it is still difficult to meet the current data[25], and a large color suppressed tree diagram is also independently favored by $\pi K$ and $K\eta(0)$ data[12, 17, 26].

IV. LARGE $|C'/T'|$ AND LARGE ELECTROWEAK PENGUIN

Let us now discuss the so-called large $|C'/T'|$ puzzle in the $B \rightarrow \pi K$ decays. Firstly, considering the case with the SU(3) relations $P'_{EW} \simeq R'_{EW} T'$, $P'_{EW} = R'_{EW} C'$ and $R'_{EW} \simeq R_{EW} \simeq -0.0125$(refer to Case I). With this consideration, the numbers of parameters in the $B \rightarrow \pi K$ decays are reduced to be five, i.e., $|T'|$, $|C'|$, $|\hat{P}'|$, $\delta_{T'}$ and $\delta_{C'}$ (The strong phase of $\hat{P}'(\delta_{P'} = 0)$ as an overall phase). They can be solved by five experimental data, namely four branching ratios and one direct CP violation of $B \rightarrow \pi^+ K^-$. For simplicity, taking the central values of experimental data, we found in this case it’s impossible to find a solution to meet all the five data points. If we only use four data points of branching ratios in $\pi K$ system in Case I analysis, numerical results are then found with SU(3) relations and $\gamma \simeq \pi/3$ to be

$$
|T'| \simeq 1.20, \quad \delta_{T'} \simeq 0.30 \\
|C'/T'| \simeq (2.0 \sim 3.0), \quad \delta_{C'} \simeq 2.2 \\
|\hat{P}'| \simeq 0.12, \quad \text{(Case I)}
$$

The resulting ratio $|C'/T'|$ is unexpected large compared with QCD factorization and perturbative QCD approaches. It is also larger by a factor of three than that extracted from $\pi\pi$ modes $|\hat{C}/\hat{T}| \simeq 0.72$. This confirms the previous observations in Ref.[12, 17].

It is natural to ask whether the above puzzle is related to the ratio difference $\Delta R = R_c - R_n$, and can simultaneously be solved by new contributions from electroweak penguin. To check that, first taking an enhanced ratio $R'_{EW} \simeq -0.04$, but with the strong phase $\delta_{P'_{EW}}$ as a free parameter and also neglecting $P'_{EW}^{C'}$ (refer to Case II), we find the following results which can meet all the five data points in 1σ error:

$$
|T'| \simeq 1.07, \quad \delta_{T'} \simeq 0.31, \quad |\hat{P}'| \simeq 0.12, \\
|C'/T'| \simeq 0.60 \sim 0.80, \quad \delta_{C'} \simeq \pm (2.0 \sim 2.5), \\
\text{for} \quad \delta'_{EW} \simeq \pm (1.4 \sim 1.5), \quad \text{(Case II)}
$$

The ratio $|C'/T'|$ is found to be sensitive to the strong phase $\delta'_{EW}$ of electroweak penguin. It is seen that a large value of electroweak penguin can reduce the color-suppressed tree amplitude $C'$. While the resulting value for the tree amplitude $T'$ remains somehow larger than $\hat{T}$ extracted from $B \rightarrow \pi\pi$ decays, which may indicate that the contribution from the
color-suppressed electroweak penguin $P_{EW}^{C'}$, may not be neglected and it could be enhanced in a similar way. To see that, further taking the following relation (refer to Case III)

$$ \left| \frac{P_{EW}^{C'}}{P_{EW}} \right| \simeq \left| \frac{C'}{T'} \right| \simeq 0.70 $$

(46)

it is then not difficult to find that when appropriately taking the strong phases, the tree amplitude $T'$ can truly be largely reduced to a low value with the following typical solution

$$ |T'| \simeq 0.60, \quad \delta_{T'} \simeq 0.5, \quad |C'/T'| \simeq 0.60 \sim 0.80, \quad |P'| \simeq 0.12 $$

$$ \delta_{C'} \simeq \pm(2.0 \sim 2.4), \quad \delta_{EW}' \simeq \pm(1.4 \sim 1.6), \quad \delta_{EW}^{C'} \simeq 1.3 \sim 1.5, \quad \text{(Case III)} \quad (47) $$

It is noticed that the solution is sensitive to the strong phases $\delta_{EW}'$ and $\delta_{EW}^{C'}$. The reason is simple that the tree amplitude $T'$ and the color-suppressed electroweak penguin amplitude $P_{EW}^{C'}$ are associated with the small and large CKM factors $\lambda_u$ and $\lambda_c$ respectively, here $|\lambda_u^s/\lambda_c^s| \simeq 0.02$. Thus as long as $|P_{EW}^{C'}/T'| > 0.02$ and $|P_{EW}^{C'}/C'| > 0.02$, the contributions from the amplitudes $P_{EW}^{C'}$ and $P_{EW}'$ become sizable and more significant than the ones from the amplitudes $T'$ and $C'$ respectively.

Similar to the analysis of $R_n$ and $R_c$, we consider the fourth case with an additional weak phase $\phi_{NP}$ in the electroweak penguin, but keeping the amplitude obtained from the isospin relation $P_{EW}^{C'} = R_{EW} T', P_{EW}^{C} = R_{EW} C'$ (refer to Case IV). If we take a typical value $\phi_{NP} = \pi/2$ and only use four data points of branching ratios, we get the following solution:

$$ |T'| \simeq 1.4, \quad |C'/T'| \simeq 1.0, \quad \delta_{T'} = \delta_{EW}' \simeq 1.0, \quad |P'| \simeq 0.12 $$

$$ \delta_{C'} = \delta_{EW}^{C'} \simeq 2.0, \quad \text{(Case IV)} \quad (48) $$

It is found that this new weak phase $\phi_{NP}$ in E-W penguin sector can't reduce much larger $|T'| \simeq 1.4$ and larger ratio $|C'/T'| \simeq 1.0$ than $|\bar{T}| \simeq 0.58$ and $|\bar{C}/\bar{T}| \simeq 0.7$ we got in $\pi\pi$ system if SU(3) symmetry is not broken strongly. So it is not enough to solve the large $|C'/T'|$ puzzle by merely introducing the weak phase though it helps to solve the large $R_n - R_c$ puzzle.

It has recently been shown\textsuperscript{[7]} by using perturbative QCD approach that the next-to-leading-order contributions from the vertex corrections of the quark loops and the magnetic penguins may also provide a solution for the puzzle of very large $|C'/T'|$. While the resulting ratio difference $\Delta R$ remains much smaller than the experimental data, which is actually expected from our above analyzes for a conclusion that all the standard model predictions lead to a small $\Delta R$. This is attributed to the smaller PQCD results for the $B^0 \rightarrow \pi^0 K^0$ branching ratio and hence for a large ratio $R_n$.

V. IMPLICATIONS OF CP VIOLATION

To be consistent with the experimental results and keeping the isospin and SU(3) relations for the electroweak penguin amplitudes and phases, i.e., Case I, besides the puzzle for the very large ratio $|C'/T'| \sim 2$ and the discrepancy with the experimental data for the branching ratio difference $\Delta R^{exp}$, the resulting CP asymmetries in $B \rightarrow \pi^0 K^0$ and
$B^- \to \pi^0\bar{K}^-$ are also much larger than the experimental data. The CP asymmetry can be expressed as follows

$$\frac{1}{\tau_{B^-}} A_{CP}(B \to \pi^+K^-) \cdot Br(B \to \pi^+K^-)$$

$$= -2|\lambda_u\lambda_s| \sin \gamma |T'| \left[ |\hat{P}'| \sin \delta_{T'} - |P'_{EW}| \sin (\delta_{T'} - \delta_{EW}') \right],$$

$$\frac{1}{\tau_{B^0}} A_{CP}(B \to \pi^0\bar{K}^0) \cdot Br(B \to \pi^0\bar{K}^0)$$

$$= |\lambda_u\lambda_s^*| \sin \gamma |C''||\hat{P}'| \sin \delta_{C'} + |P'_{EW}| \sin (\delta_{C'} - \delta_{EW}'),$$

$$\frac{1}{\tau_{B^-}} A_{CP}(B \to \pi^0K^-) \cdot Br(B \to \pi^0K^-) = -|\lambda_u\lambda_s^*| \sin \gamma$$

$$\cdot \left[ |T'|(|\hat{P}'| \sin \delta_{T'} - |P'_{EW}| \sin (\delta_{T'} - \delta_{EW}')) - |P'_{EW}| \sin (\delta_{C'} - \delta_{EW}') \right] + |C''||\hat{P}'| \sin \delta_{C'} - |P'_{EW}| \sin (\delta_{C'} - \delta_{EW}') - |P'_{EW}| \sin (\delta_{C'} - \delta_{EW}'),$$

and the time-dependent CP asymmetry for $B^0 \to K_S\pi^0$ is defined as:

$$A_{K_S\pi^0}(t) \equiv \frac{\Gamma(\bar{B}^0(t) \to K_S\pi^0) - \Gamma(B^0(t) \to K_S\pi^0)}{\Gamma(B^0(t) \to K_S\pi^0) + \Gamma(B^0(t) \to K_S\pi^0)}$$

$$\equiv S_{K_S\pi^0} \sin (\Delta m_{Bt}) - C_{K_S\pi^0} \sin (\Delta m_{Bt}),$$

(50)

The $S_{K_S\pi^0}$ and $C_{K_S\pi^0} = -A_{CP}(K_S\pi^0)$ are mixing-induced and direct CP-violating parameters respectively. The expression for $S_{K_S\pi^0}$ is given by:

$$S_{K_S\pi^0} \simeq \sin (2\beta) + 2r'_C \cos (2\beta) \cos \delta_{C'} \sin \gamma - 2r'^2_C \sin (2\beta) \sin^2 \gamma$$

$$- r'^2_C \cos (2\beta) \cos (2\gamma) \sin (2\gamma) - 2r'_C r_{EW} \cos (2\beta) \cos (\delta_{C'} + \delta_{EW}') \sin \gamma,$$

(51)

Here $r'_C \simeq \xi_s|C''/|\hat{P}'|$, and $r_{EW} = |P'_{EW}/|\hat{P}'|$. In our numerical calculations, we will use the latest experimental result for $\sin (2\beta) = 0.687 \pm 0.032$ as an input parameter. It is known that the experimental result for $S_{K_S\pi^0}$ has a significant deviation from $\sin (2\beta)$, it should be attributed to the subleading terms relevant to $r'_C$ and $r_{EW}$. Numerically, it is found that in Case I the CP asymmetries are given by

$$A_{CP}(\pi^0\bar{K}^0) \sim 0.69, \quad A_{CP}(\pi^0K^-) \sim 0.56$$

(52)

which are too large in comparison with the latest experimental results $A_{CP}(\pi^0\bar{K}^0) = 0.02 \pm 0.13$(BABAR and Belle’s results have opposite sign: $-0.06 \pm 0.18 \pm 0.03$(BABAR);0.11 $\pm 0.18 \pm 0.08$(Belle)) and $A_{CP}(\pi^0K^-) = 0.04 \pm 0.04$. It is then natural to ask whether the enhanced electroweak penguin amplitude can simultaneously solve the above puzzle. Firstly, consider the Case II, namely $R'_{EW} \simeq -0.04$ but with the strong phase $\delta_{EW}'$ as a free parameter and also neglecting the color-suppressed electroweak penguin contribution $P'_{EW}$. The resulting CP violation in this case has two possible solutions for $\delta_{EW}' > 0$

$$A_{CP}(\pi^0\bar{K}^0) \simeq -0.12, \quad \delta_{C'} < 0; \quad -0.25, \quad \delta_{C'} > 0$$

$$A_{CP}(\pi^0K^-) \simeq 0.02, \quad \delta_{C'} < 0; \quad 0.12, \quad \delta_{C'} > 0$$

(53)  (54)
the $\delta_C' < 0$ solution is consistent with the experimental data at $1\sigma$ level. The other two solutions for $\delta_{EW}' < 0$ are not consistent with the data.

We now consider the Case III, i.e., including $P^C_{EW}$ with $|P^C_{EW}/P_{EW}'| \simeq |C'/T'| \simeq 0.70$. In this case, it is interesting to notice that only one solution with $\delta_{EW}' > 0$ and $\delta_C' < 0$ is consistent with the experimental data and the corresponding CP asymmetry is:

$$A_{CP}(\pi^0\bar{K}^0) \simeq -0.08, \quad A_{CP}(\pi^0\bar{K}^-) \simeq -0.02$$ (55)

It is seen that including the constraint of CP violation not only helps to reduce the ambiguities for the signs of strong phases, but also provides a consistent check for a signal of new physics. All of the puzzles likely indicate new physics in the electroweak penguin sector.

To check the SU(3) relations with symmetry breaking effects only for the amplitudes $T, P, C$, we further evaluate the CP violation in $B \to \pi\pi$ decays. Neglecting the contributions from the annihilation amplitudes $E$ and $P_A$ which are found to be small from the analysis of $B \to KK$ decays, we then have in the Case III that:

$$A_{CP}(B \to \pi^+\pi^-) \simeq 0.41,$$

$$A_{CP}(B \to \pi^0\pi^0) \simeq 0.57,$$ (56)

which are consistent with experimental data at $1\sigma$ level\cite{1}: $A_{CP}^{exp}(B \to \pi^+\pi^-) = 0.37 \pm 0.10$ and $A_{CP}^{exp}(B \to \pi^0\pi^0) = 0.28 \pm 0.40$.

Considering Case IV with a new CP phase ($\phi_{NP} = \pi/2$) of EW penguin without changing the isospin relation. For in this case, $|C'/T'|$ are still large from analysis of branching ratios of $B \to \pi K$, which leads to a bigger $|P^C_{EW}'|$ and there will be new terms in the expressions of $A_{CP}$ such as $|P^C_{EW}'|\sin \phi_{NP} \sin \delta_{EW}'$ term, our calculation shows that in this case the direct CP violations are not consistent with the data.

Finally, we also check the mixing induced CP asymmetries in $B \to \pi^0\pi^0, \pi^+\pi^-, \pi^0K_S$ decays. The results are shown in Table I. It is seen that in Case I (the first column), $S_{KS\pi^0}$ coincides with the measured value as in this case $|C'/T'|$ is large enough to give a comparable cancelation to $\sin (2\beta)$. And in Case IV, a new CP phase $\phi_{NP} = \pi/2$ can also take the $S_{KS\pi}$ closer to the experimental data. In other cases with new electroweak penguin contributions, larger mixing-induced CP violation occur, but it is still consistent with the data at $1.5\sigma$ level. For only the results of $|C'|, |T'|$ in Case III that extracted from the $\pi K$ decays are consistent with the results in $\pi\pi$ system within the SU(3) symmetry or even considering a little breaking effects, we just calculate the mixing-induce CPV of $\pi\pi$ system in Case III.

### Table I: Mixing induced CP violation (The four columns refer to I-IV cases mentioned above)

| Case | I   | II  | III | IV  | Exp.\cite{1} |
|------|-----|-----|-----|-----|--------------|
| $S_{\pi^0K_S}$ | 0.32 | 0.62 | 0.68 | 0.50 | 0.31 $\pm$ 0.26 |
| $S_{\pi^0\pi^0}$ | -    | -    | -0.70 | -   | -            |
| $S_{\pi^+\pi^-}$ | -    | -    | -0.63 | -   | -0.50 $\pm$ 0.12 |
VI. CONCLUSIONS

In summary, we have presented a model-independent analytical analysis for charmless B decays. The quantity \( \Delta R = R_c - R_n \) defined by four CP-averaging branching ratios in \( B \to \pi K \) decays with 
\[
R_c = 2Br(\pi^0 K^-)/Br(\pi^- \bar{K}^0) \quad \text{and} \quad R_n = Br(\pi^+ K^-)/2Br(\pi^0 \bar{K}^0)
\]
provides a promise way for probing new physics beyond the standard model. This is because the ratio difference \( \Delta R \) has been found to be at the second order of electroweak penguin amplitude in the precision of order \( 10^{-3} \) and it is sensitive to new physics associating with electroweak penguin. Of particular, the ratio difference can well be evaluated in the standard model with isospin and SU(3) relations. Its numerical values \( \Delta R^{SM} \approx 0.01 \sim 0.02 \) is found to be much smaller than the current experimental data \( \Delta R^{exp} = 0.18 \pm 0.10 \), which strongly indicates a signal of new physics in the electroweak penguin sector. The possible new physics effects requires an additional electroweak penguin contribution with an enhanced amplitude and/or a large CP phase. In \( B \to \pi\pi \) decays, we have demonstrated that the tree and color-suppressed tree amplitudes \( \bar{T} \) and \( \bar{C} \) as well as their relative strong phase can independently be extracted from their three CP-averaging branching ratios, which are almost not affected by the enhanced electroweak penguin contributions. The resulting large ratio \( |\bar{C}/\bar{T}| \approx 0.72 \) has strongly indicated an enhanced color-suppressed tree contributions. It has also been shown that the puzzle of a very large color-suppressed tree amplitude \( |C'/T'| \sim 2 \) in \( B \to \pi K \) decays may originate from the same reason as the large ratio difference \( \Delta R^{exp}/\Delta R^{SM} > 9.0 \pm 5.0 \), thus the puzzle can be solved simultaneously by the same new electroweak penguin contributions. The large CP violation \( A_{CP}(\pi^0 \bar{K}^0) \approx 0.69 \) and \( A_{CP}(\pi^0 \bar{K}^-) \approx 0.56 \) have also been found to be solved simultaneously with the new electroweak penguin contributions.

The mixing induced CP violation in \( B \to \pi K, \pi\pi \) decays has also been checked. It has been found that a very large \( |C'/P'| \) is helpful to explain \( S_{\pi K_s} \) puzzle, but inconsistent with the direct CP-violating measurements. And Case III’s results are also consistent with the latest experimental results in \( 1.5\sigma \) error level. More accurate measurements on the ratio difference \( \Delta R \) and direct/mixing-induced CP violation in \( B \to \pi\pi, \pi K \) decays are very important for probing the signal of new physics in the electroweak penguin sector and testing the isospin and SU(3) symmetries in the standard model.

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