Implications of new data in charmless B decays

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Abstract

Based on the latest experimental data of $B \to \pi\pi$ and $\pi K$ modes, a model-independent analytical analysis is presented. The CP-averaged branching ratio difference $\Delta R = R_c - R_n$ in $B \to \pi K$ decays with $R_c = 2Br(\pi^0K^-)/Br(\pi^-K^0)$ and $R_n = Br(\pi^+K^-)/2Br(\pi^0K^0)$ is reduced though it remains larger than the prediction from the standard model (SM) as both measured $R_n$ and $R_c$ are enhanced, which indicates that a room for new physics becomes smaller. The present data of $\pi\pi$ decay reduce the ratio $|C/T|$ from the previous value of $|C/T| \simeq 0.8$ to $|C/T| \simeq 0.65$, which is still larger than the theoretical estimations based on QCD factorization and pQCD. Within SM and flavor SU(3) symmetry, the current $\pi K$ data also diminish the ratio $|C'/T'|$ from the previous value $|C'/T'| \simeq 2$ to $|C'/T'| \simeq 1.16$ with a large strong phase $\delta_{C'} \simeq -2.65$, while its value remains much larger than the one extracted from the $\pi\pi$ modes. The direct CP violation $A_{CP}(\pi^0\bar{K}^0)$ is predicted to be $A_{CP}(\pi^0\bar{K}^0) = -0.15 \pm 0.03$, which is consistent with the present data. Two kinds of new effects in both strong and weak phases of the electroweak penguin diagram are considered. It is found that both cases can reduce the ratio to $|C'/T'| = 0.40 \sim 0.80$ and lead to roughly the same predictions for CP violation in $\pi^0K^0$.

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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, 2}, and a large direct CP violation has well been established in $\pi^+ K^-$ mode \cite{3, 4}. Recently, the BaBar and Belle collaborations have reported their updated results which show a better agreement with the Standard Model\cite{2}. The new world average is summarized in Table I. In $\pi\pi$ and $\pi K$ decay modes, one can define the following ratios:

$$R_{00} = \frac{2Br(\pi^0\pi^0)}{Br(\pi^+\pi^-)},$$

and

$$R_c = \frac{2Br(\pi^0K^-)}{Br(\pi^-K^0)}, \quad R_n = \frac{Br(\pi^+K^-)}{2Br(\pi^0K^0)}.$$  \hspace{1cm} (2)

A relatively large $R_{00}$ and $R_n$ or $R_c$ deviating significantly from unity are usually referred to $\pi\pi$ and $\pi K$ puzzles respectively. Their implications have been investigated by many groups\cite{5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19}. Compared to the old data which give $R_{00} = 0.67 \pm 0.14$, $R_n = 0.82 \pm 0.08$ and $R_c = 1.00 \pm 0.06$, the latest data indicate a reduction of $R_{00}$ and enhancement of $R_n$ and $R_c$, i.e., $R_{00} = 0.50 \pm 0.08$, $R_n = 1.00 \pm 0.07$ and $R_c = 1.11 \pm 0.08$. Namely $R_{00}$ and $R_n$ are moving closer to the SM estimation. On the contrary, $R_c$ deviates from unity now. The ratio difference $\Delta R = R_c - R_n$ is reduced in comparison with the previous result, but it is still puzzling since the ratio difference in the SM is of the order $O(|P_{EW}/P|^2) \approx O(10^{-2})$. Within the SM, both the $\pi\pi$ and $\pi K$ puzzles can be accounted for by large color suppressed tree diagrams $C$ and $C'$. However, the previous analysis showed that $|C/T| \approx 0.7$ in $\pi\pi$ decays, while in $\pi K$ decays, $|C'/T'| \approx 2.0$. Such a large $|C'/T'|$ may either indicate a breakdown of SU(3) symmetry or new physics from electroweak penguin sector\cite{19}.

In light of the latest data, it is interesting to make an updated analysis within the framework of quark flavor topology. Our results show that in both $\pi\pi$ and $\pi K$ modes, the values of $|C/T|$ and $|C'/T'|$ are reduced and closer to the theoretical estimations. Numerically, it is found that $|C/T| \approx 0.65$ and $|C'/T'| \approx 1.16$ respectively. We also make predictions for the direct CP asymmetry and mixing induced CP asymmetry of $B \to \pi^0 K^0$ and compare them with the preliminary data of Babar and Belle. In our previous paper\cite{8}, it has been shown that the weak phase $\gamma$ can well be determined to be remarkably consistent with the global standard model fit, which gives $\gamma = 1.08^{+0.17}_{-0.21}$\cite{20}. In the present paper, we shall take the CKM phase $\gamma$ as an input parameter in analytical analysis.
\[ A(\pi^+\pi^-) = -\left[ \lambda_u(T + E - P - P_A - \frac{2}{3}P_{EW}^C) - \lambda_c(P + P_A + \frac{2}{3}P_{EW}^C) \right], \]
\[ A(\pi^0\pi^0) = -\frac{1}{\sqrt{2}} \left[ \lambda_u(C - E + P + P_A - P_{EW} - \frac{1}{3}P_{EW}^C) - \lambda_c(-P - P_A + P_{EW} + \frac{1}{3}P_{EW}^C) \right], \]
\[ A(\pi^0\pi^-) = -\frac{1}{\sqrt{2}} \left[ \lambda_u(T + C - P_{EW} - P_{EW}^C) - \lambda_c(P_{EW} + P_{EW}^C) \right], \]

with \( \lambda_u = V_{ub}V_{ud}^* = A\lambda^3(\rho - i\eta)(1 - \lambda^2/2) \), \( \lambda_c = V_{cb}V_{cd}^* = -A\lambda^3 \) and:
\[ A(\pi^+K^-) = -\left[ \lambda_u^s(T' - P' - \frac{2}{3}P'_{EW}^C) - \lambda_c^s(P' + \frac{2}{3}P'_{EW}^C) \right], \]
\[ A(\pi^0K^0) = -\frac{1}{\sqrt{2}} \left[ \lambda_u^s(C' + P' - P'_{EW} - \frac{1}{3}P'_{EW}^C) - \lambda_c^s(-P' + P'_{EW} + \frac{1}{3}P'_{EW}^C) \right], \]
\[ A(\pi^0K^-) = \lambda_u^s(A' - P' + \frac{1}{3}P'_{EW}^C) - \lambda_c^s(P' - \frac{1}{3}P'_{EW}^C), \]
\[ A(\pi^0\bar{K}^0) = -\frac{1}{\sqrt{2}} \left[ \lambda_u^s(T' + C' + A' - P' - P'_{EW} - \frac{2}{3}P'_{EW}^C) - \lambda_c^s(P' + P'_{EW} + \frac{2}{3}P'_{EW}^C) \right], \]

with \( \lambda_u^s = V_{ub}V_{us}^* = A\lambda^4(\rho - i\eta) \), and \( \lambda_c^s = V_{cb}V_{cs}^* = A\lambda^2(1 - \lambda^2/2) \). Note that in the \( \pi K \) modes \( |\lambda_u^s| \) is much smaller than \( |\lambda_c^s| \). Taking \( V_{ub} = (3.82 \pm 0.15) \times 10^{-3} \) and \( V_{cb} = (41.79 \pm 0.63) \times 10^{-3} \) [21], we have \( |\lambda_u^s/\lambda_c^s| = 0.021 \pm 0.001 \).

The effective Hamiltonian for \( \Delta S = 0(1) \) non-leptonic B decays is given by
\[ H_{eff} = \frac{G_F}{\sqrt{2}} \sum_{q=u,c} \lambda_q^{(s)} \left( C_1O_1^q + C_2O_2^q + \sum_{i=3}^{10} C_iO_i \right), \]

where \( O_{1,2}^{(c)} \), \( O_{3,6} \) and \( O_{7,10} \) are related to tree, QCD penguin and electro-weak penguin sectors respectively and \( C_i^q \)s are the corresponding short distance Wilson coefficients.
In the SM, from the isospin structure of the effective Hamiltonian, the ratio between electroweak penguin and tree diagrams are fixed through\cite{22}

\[ R_{EW} = \frac{P_{EW} + P'_{EW}}{T + C} = \frac{3}{2} \cdot \frac{C_9 + C_{10}}{C_1 + C_2} = -(1.25 \pm 0.12) \times 10^{-2}, \tag{6} \]

for $\pi\pi$ modes. Where $T$, $C$, $P_{EW}$ and $P'_{EW}$ are diagrams with CKM matrix elements factorized out. $C_i$s stand for the short distance Wilson coefficients at the scale of $\mu \simeq m_b$.

A direct consequence from this relation is that no direct CP violation occurs in the $B \to \pi^-\pi^0$ decay, namely

\[ A_{CP}(B \to \pi^-\pi^0) \approx 0, \quad \text{SM} \]

\[ A_{CP}(B \to \pi^-\pi^0) \gg 0.1, \quad \text{new physics} \tag{8} \]

as long as isospin symmetry holds at a few percent level. The latest average data is $A_{CP}(B \to \pi^-\pi^0) = 0.04 \pm 0.05$ which is not precise enough to draw a robust conclusion. 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 $f_K f_0^{B-K}/f_\pi f_0^{B-K}$, or the suppression by the heavy bottom meson mass $(m_K^2 - m_\pi^2)/m_B^2 \ll 1$\cite{22}. The typical corrections are less than 10%. Thus in flavor SU(3) limit, the relation of eq.(6) should still hold in a good approximation in $\pi K$ system, i.e., $R'_{EW} \approx R_{EW}$\cite{23}. This relation is free from hadronic uncertainties and survives under elastic final state interactions (FSIs) and inelastic FSIs through low isospin states such as $B \to DD_s \to \pi\pi(K)$. It can directly confront the experiments and allows us to explore new physics in hadronic charmless $B$ decays.

The current average data give the following results for the ratios $R_c$ and $R_n$ in $\pi K$ system:

\[ R_c = 1.11 \pm 0.08, \quad R_n = 1.00 \pm 0.07, \tag{9} \]

which shows that $R_c$ and $R_n$ are all enhanced in comparison with the previous values, the difference of two ratios is $\Delta R = R_c - R_n = 0.11 \pm 0.10$ which is diminished in comparison with the previous result $\Delta R = 0.18 \pm 0.10$. As shown in ref.\cite{19} that $\Delta R$ is dominated by $|P'_{EW}/P''|^2$, a large deviation from the small value $\Delta R \simeq 0.02$ may indicate signal of new physics beyond SM. In general, the ratio difference $\Delta R$ is a sensitive probe for new physics. Note that the Belle collaboration reported almost the same $R_n$ and $R_c$:

\[ R_c = 1.08 \pm 0.06 \pm 0.08, \quad R_n = 1.08 \pm 0.08^{+0.09}_{-0.08}, \quad \text{(Belle)} \tag{10} \]

the central values are consistent with the SM estimation but the uncertainty is still large. Meanwhile the BaBar collaboration reported the following results,

\[ R_c = 1.11 \pm 0.07 \pm 0.07, \quad R_n = 0.94 \pm 0.07 \pm 0.05, \quad \text{(BaBar)} \tag{11} \]

From the present experiments, one can not yet rule out the possibility of new physics.
III. ENHANCED COLOR-SUPPRESSED AMPLITUDES FROM B → ππ

We now discuss B → ππ decays. Using the diagrammatic method, the CP-averaging branching ratios have the following forms:

\[
Br(\pi^+\pi^-) \simeq |\lambda_u|^2 |T|^2 + (|\lambda_u|^2 + |\lambda_c|^2 - 2 \cos \gamma |\lambda_u||\lambda_c|)|P|^2 \\
+ 2|\lambda_u||P||T| \cos \delta_T (|\lambda_c| \cos \gamma - |\lambda_u|),
\]

\[
Br(\pi^0\pi^0) \simeq \frac{1}{2} [|\lambda_u|^2 |C|^2 + (|\lambda_u|^2 + |\lambda_c|^2 - 2 \cos \gamma |\lambda_u||\lambda_c|)|P - P_{EW}|^2] \\
- 2|\lambda_u||P - P_{EW}| |C| \cos \delta_C (|\lambda_c| \cos \gamma - |\lambda_u|),
\]

\[
\frac{1}{\tau} Br(\pi^-\pi^0) \simeq \frac{1}{2} |\lambda_u|^2 |T + C|^2,
\]

where \( \tau = \tau_B/\tau_B = 1.086 \) reflecting the life-time difference. Here we have neglected the subleading diagrams \( P_{EW}^C, E \) and \( P_A \) for simplicity. \( \delta_C, \delta_T \) and \( \delta_{EW} \) are the strong phases of \( C, T \) and \( P_{EW} \) respectively. The strong phase of \( P \) is fixed to be zero as an overall phase. The CP violation parameters \( S \) and \( C \) in \( B \rightarrow \pi^+\pi^- \) decays are introduced through the time-dependent decay rate difference:

\[
A_{CP}(t) = \frac{\Gamma(\bar{B} \rightarrow \pi^+\pi^-) - \Gamma(B \rightarrow \pi^+\pi^-)}{\Gamma(B \rightarrow \pi^+\pi^-) + \Gamma(\bar{B} \rightarrow \pi^+\pi^-)} \\
\simeq -a_\epsilon + (a_\epsilon + a_\epsilon') \cos (\Delta m_B \cdot t) + a_{\epsilon' + \epsilon'} \sin (\Delta m_B \cdot t),
\]

\[
\simeq S \cdot \sin (\Delta m_B \cdot t) - C \cdot \cos (\Delta m_B \cdot t),
\]

(13)

\( \Delta m_B \) is the neutral B meson mass difference. The CP-violating quantities are defined as:

\[
S = \frac{\text{Im} \lambda}{1 + |\lambda|^2} = a_{\epsilon + \epsilon'}, \quad \text{and} \quad C = \frac{1 - |\lambda|^2}{1 + |\lambda|^2} = -A_{CP} = -(a_\epsilon + a_\epsilon')
\]

(14)

with \( \lambda = e^{-2i\beta} (\bar{A}/A) \). Where the rephase-invariant quantities \( a_\epsilon, a_\epsilon' \) and \( a_{\epsilon + \epsilon'} \) \([24]\) represent indirect, direct and mixing-induced CP violations respectively. As \( a_\epsilon \ll 1 \) for neutral B system, we have \( A_{CP} \simeq a_\epsilon \) which characterizes direct CP violation.

With the above equations, we can get the explicit expressions of \( A_{CP}(\pi^+\pi^-) \cdot Br(B \rightarrow \pi^+\pi^-) \) and \( S_{\pi^+\pi^-} \) as:

\[
A_{CP}(B \rightarrow \pi^+\pi^-) \cdot Br(B \rightarrow \pi^+\pi^-) \simeq 2|\lambda_u\lambda_c| \sin \gamma |T||P| \sin \delta_T, \\
S_{\pi^+\pi^-} \simeq \frac{2\kappa \cos 2(\beta + \gamma) \cos \delta_T \sin \gamma - \sin 2(\beta + \gamma)(1 + 2\kappa \sin \delta_T \sin \gamma)}{1 + 2\kappa \sin \delta_T \sin \gamma + 2\kappa^2 \sin^2 \gamma},
\]

(15)

with \( \kappa = |\lambda_c P|/|\lambda_u T| \). Noticing the fact that \( |P| \ll |T| \) and \( 2|\lambda_u^d|(|\lambda_u^d| \cos \gamma - |\lambda_u^d|) \simeq 0.4|\lambda_u^d|^2 \) and considering the error of data, we can safely ignore the cross term in branching ratio of \( B \rightarrow \pi^+\pi^- \). Similarly, we can also ignore the cross term in the branching ratio of \( \pi^0\pi^0 \) and obtain in a good approximation the following relations:

\[
\frac{R_{-0}}{1 - R_{00}} \simeq \frac{1 + |C/T|^2 + 2|C/T| \cos (\delta_T - \delta_C)}{1 - |C/T|^2}
\]

(16)
with \( R_0 \equiv 2Br(\pi^-\pi^0)/Br(\pi^+\pi^-) \). 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 \(|C|/|T|\):

\[
0.60 \leq \frac{|C|}{|T|} \leq 0.97. \tag{17}
\]

Using the three precise observed data points of \( Br(\pi^+\pi^-), A_{CP}(\pi^+\pi^-), S_{\pi^+\pi^-} \) and taking the latest experimental result for \( \sin(2\beta) \) as an input parameter\(^1\), we get:

\[
|P| = 0.10 \pm 0.03, \quad |T| = 0.58 \pm 0.05, \quad \delta_T = 0.60 \pm 0.10 \tag{18}
\]

Noticing the positivity of the quantity:

\[
(|\lambda_u|^2 + |\lambda_c|^2 - 2 \cos \gamma |\lambda_u||\lambda_c|)|P|^2 + 2|\lambda_u||P||T| \cos \delta_T (|\lambda_c| \cos \gamma - |\lambda_u|) > 0. \tag{19}
\]

The above inequality holds for \( |P/T| \geq 0.1 \) which is true from the above analysis, i.e., \( Br(\pi^+\pi^-)/\tau_B > |\lambda_u|^2|T|^2 \). We then yield a more strong constraint for the ratio:

\[
\frac{|C|}{|T|} \leq \sqrt{R_0} \equiv \sqrt{\frac{2Br(\pi^0\pi^0)}{Br(\pi^+\pi^-)}} \approx 0.70 \tag{20}
\]

Combining the above two constraints, we have

\[
0.6 \leq \frac{|C|}{|T|} \leq 0.7 \tag{21}
\]

Note that the above numerical bounds are obtained by simply taking the central values of the experimental data. When taking into account the experimental errors, the allowed range could be enlarged by (10 ~ 20)%\(^\text{21}\). The result is still larger than the theoretical estimations \(|C/T| \approx 0.1 \sim 0.2\) calculated from both the QCD factorization approach\(^2\) and perturbative QCD approach\(^3\). Although the next to leading order contributions calculated recently in QCD factorization show some enhancement of \(C\), it is still difficult to meet the current data\(^2\). Also a large color suppressed tree diagram is independently favored by \(\pi K\) and \(K\eta(0)\) data\(^\text{3, 15, 28}\).

IV. IMPLICATIONS FROM NEW EXPERIMENTAL RESULTS OF \(B \rightarrow K\pi\) DECAYS

The latest averaged data give \( A_{CP}(\pi^+K^-) = -0.098 \pm 0.015, A_{CP}(\pi^0\bar{K}^0) = -0.12 \pm 0.11\) and \( A_{CP}(\pi^0K^-) = 0.05 \pm 0.03\). All these preliminary measurements are more precise. However, there still exists significant differences between two experiments. We shall make, basing on the new data, a model-independent analysis to determine the hadronic amplitudes and see whether there is any implication for new physics beyond the SM.

In the \(\pi K\) system, there are now five established experimental observables, including four branching ratios and one direct CP as of \(B \rightarrow \pi^+K^-\). Using the diagrammatic language and neglecting the small contributions from \(P_{EW}', A', E'\), there are seven free parameters, four magnitudes and three relative strong phases. Keeping isospin relation in Eq.(6) within the SM, only five free parameters are left, namely three magnitudes.
FIG. 1: Allowed range for $|C'/T'|$ with $\delta_{C'}$ by using five measured $\pi K$ data.

$|T'|, |C'|, |P'|$ and two relative strong phases $\delta_{T'}$ and $\delta_{C'}$, where we take the strong phase of $P'$ as an overall phase. In this case, the data are enough to extract all these parameters. In fact, by taking three data points of $Br(B \to \pi^- K^0)$, $Br(B \to K^+ \pi^-)$ and $A_{CP}(K^+ \pi^-)$, one can extract $|T'|, |P'|$ and $\delta_{T'}$. The numerical results are found to be

$$|T'| = 0.87 \pm 0.18, \quad \delta_{T'} = 0.33 \pm 0.07, \quad |P'| = 0.12 \pm 0.02. \quad (22)$$

The other two data points are used to determine the color suppressed tree amplitude and it’s strong phase.

In the first step, we shall work within SM. Neglecting the color suppressed EW penguin, and taking $Br(B \to \pi^0 \bar{K}^0)$ and $Br(B \to \pi^0 K^-)$ within $1\sigma$ error, we find the allowed region for $\delta_{C'}$ and $|C'/T'|$. The results are plotted in Fig.1. In obtaining the figure, we let $\delta_C$ vary in the range $[-\pi, \pi]$ and $|C'/T'|$ in $[0, 10]$. The result indicates that a large strong

FIG. 2: Allowed range for $A_{cp}(\pi^0 \bar{K}^0)$ and $A_{cp}(\pi^0 K^-)$ as function of $\delta_{C'}$ by using five measured $\pi K$ data.
phase of the color suppressed tree diagram is necessary to explain the experiments and there exists two allowed regions with opposite signs of $\delta_{C'}$ but similar size of $|C'|$ around $2.0 \sim 3.0$. As for the ratio $|C'/T'|$, the minimal value is about $|C'/T'| \simeq 1$ with $\delta_{C'} \approx \pm \pi$, the whole allowed range is from 1.0 to 2.4. So the large $C'$ puzzle is still there though the minimal value can be reduced to about unity. When only taking the latest data from the Belle collaboration, the ratio $|C'/T'|$ can be further reduced and the minimal size can reach $|C'/T'| \simeq 0.74$ which is still large.

The CP asymmetry in $\pi K$ decays can be expressed as follows

$$A_{CP}(B \to \pi^+ K^-) \cdot Br(B \to \pi^+ K^-) \simeq -2|\lambda_u^s \lambda_c^s| \sin \gamma |T'| |P'| \sin \delta_{T'},$$

$$A_{CP}(B \to \pi^0 \bar{K}^0) \cdot Br(B \to \pi^0 \bar{K}^0) \simeq |\lambda_u^s \lambda_c^s| \sin \gamma |C'| |P'| \sin \delta_{C'} + |P'_{EW}^L| \sin (\delta_{C'} - \delta_{EW'})],$$

$$\frac{1}{\tau} A_{CP}(B \to \pi^0 K^-) \cdot Br(B \to \pi^0 K^-) \simeq -|\lambda_u^s \lambda_c^s| \sin \gamma \cdot \left[|T'| |P'| \sin \delta_{T'} - |P'_{EW}^L| \sin (\delta_{T'} - \delta_{EW'})\right] \left[|C'| |P'_{EW}^L| \sin (\delta_{C'} - \delta_{EW'})\right].$$

(23)

The expression of mixing-induced CP-violating parameter $S_{\pi K_S}$ is

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

(24)

where $r'_C \simeq |\lambda_u^s / \lambda_c^s||C'/P'|$ and $r'_{EW} = |P'_{EW}/P'|$. The corresponding predictions for $A_{CP}(\pi^0 \bar{K}^0)$ and $A_{CP}(\pi^0 K^-)$ are given in Fig.2. It shows that there are two solutions corresponding to the sign of $\delta_{C'}$

for $\delta_{C'} < 0$ :

$$-0.08 < A_{CP}(\pi^0 K^-) < 0.39,$$

$$-0.50 < A_{CP}(\pi^0 \bar{K}^0) < 0,$$

for $\delta_{C'} > 0$ :

$$-0.34 < A_{CP}(\pi^0 K^-) < -0.10,$$

$$0 < A_{CP}(\pi^0 \bar{K}^0) < 0.35,$$

(25)

where $A_{CP}(\pi^0 \bar{K}^0)$ and $A_{CP}(\pi^0 K^-)$ almost have opposite signs. In Fig.3, the mixing induced CP asymmetry $S_{\pi K_S}$ as function of strong phase $\delta_{C'}$ is given. One finds that for both positive or negative $\delta_{C'}$, the resulting mixing CP violation $S_{\pi K_S}$ is the same, because it depends only on $\cos \delta_{C'}$

$$S_{\pi^0 K_S} = 0.55 \pm 0.07$$

(26)

From the above discussions, we see that from the measured five data, there is still significant uncertainties in determining the magnitude of $|C'/T'|$ and predicting for the direct CP violation. In order to tighten the constraints, we try to add another data point of $A_{CP}(\pi^0 K^-)$. Note that the preliminary result show that the Babar and Belle’s results are consistent with each other, $A_{CP}(\pi^0 K^-) = 0.016 \pm 0.041 \pm 0.010$(Babar) and
\[ A_{CP}(\pi^0 K^-) = 0.07 \pm 0.03 \pm 0.01 \text{(Belle)}. \]

With this extra data point included, a very strong constraint on \( |C'/T'| \) is found. The allowed region for \( \delta_{C'} \) and \( |C'/T'| \) are given in Fig. 4, where we scan all the possible solutions to meet six data points within the region of \( \delta_{C'} \in [-\pi, \pi] \) and \( |C'/T'| \in [0, 10] \). average data within 1σ error. The figure shows that \( |C'/T'| \) and \( \delta_{C'} \) can be well determined with \( |C'/T'| = 1.16 \pm 0.08, \delta_{C'} = -2.65 \pm 0.10 \). The positive \( \delta_{C'} \) solution is excluded completely, and there is no two-fold ambiguity in the prediction of CP asymmetry for \( \pi^0 \bar{K}^0 \)

\[
A_{CP}(\pi^0 \bar{K}^0) = -0.15 \pm 0.03, \\
S_{\pi^0 K_S} = 0.55 \pm 0.03. \quad (27)
\]

The prediction coincides with the preliminary data at 1σ error and also the results obtained by using the sum rules in \( \pi K \) system [29]. Although \( |C'/T'| \) is moving towards the SM value, a large value around unity with a large negative strong phase \( \delta_{C'} \simeq -2.65 \) is still inevitable. Obviously, the obtained ratio \( |C'/T'| \simeq 1.2 \) is much larger than the theoretical estimation using QCD factorization or pQCD method [24, 26, 27]. It is almost twice as large as \( |C/T| \) extracted from \( \pi \pi \) system, which may indicate a breakdown of flavor SU(3) symmetry. Unlike in the pQCD and QCD factorization calculations, the soft collinear effective theory (SCET) shows that the color suppressed amplitudes can be of similar size to the tree amplitudes in [30, 31], which may provide a dynamic QCD explanation for large \( C \sim T \), but it depends on two unknown parameters \( \zeta_J \) and \( \zeta \), and the predicted strong phase is smaller than the one obtained directly from the data, as shown in ref. [17], it also overshoots the bound of the \( B \to \rho^0 \rho^0 \) branch ratio and deteriorates the predictions for \( B \to \pi K \) direct CP violations.
FIG. 4: The allowed range for $|C'/T'|$ and $\delta_{C'}$ by using five measured $\pi K$ data and the preliminary data of $A_{cp}(\pi^0K^-)$

V. NEW PHYSICS EFFECTS

In this section, we consider two kinds of phase effects in the presence of new physics, i.e., there is a new CP phase or a new strong phase in electroweak penguin sector, but the magnitude of $P_{EW}'$ remains to be unchanged $|P_{EW}'| = |R_{EW}'||T' + C'|$. For the case with an enhanced electroweak penguin amplitude has widely been discussed, we shall not discuss its effects here, it is referred to the recent papers in refs. [5, 6, 8, 9, 19]. For the scenario with a new CP violating phase, we add $\phi_{NP}$ to $P_{EW}'$, i.e., $P_{EW}' = |P_{EW}'|^e^{i(\delta_{EW'} + \phi_{NP})}$, the corresponding expressions of branching ratios and CP asymmetries are changed accordingly. For example, in $\pi^0\bar{K}^0$ mode:

$$A_{CP}(B \to \pi^0\bar{K}^0) \cdot Br(B \to \pi^0\bar{K}^0) \simeq |\lambda_u^s \lambda_c^s|^2 |\sin \gamma| |C'| |P'| |\sin \delta_{C'} + \sin (\gamma + \phi_{NP})| |C'| |P'| |\sin (\delta_{C'} - \delta_{EW'})|$$

$$- [\lambda_u^s|^2 + \lambda_c^s|^2 + 2|\lambda_u^s \lambda_c^s|^2] \sin \phi_{NP} \sin \delta_{EW'}|P'| |P_{EW}'|.$$  \hspace{1cm} (28)

We use the whole six data points and scan all the allowed values of $\phi_{NP}$ and $\delta_{C'}$ which meet the data within 1σ error. The allowed region of $|C'/T'|$ is found to be $[0.40, 2.40]$ with $\delta_{C'} = -1.5 \pm 0.7$. For a large weak phase $\phi_{NP} \approx \pm (2.6 \pm 0.4)$, the ratio $|C'/T'|$ can be strongly reduced to the range $0.40 \sim 0.80$ which is similar to the result of $|C/T|$ obtained in the $\pi\pi$ system. The corresponding CP asymmetries in this case are:

$$A_{CP}(\pi^0\bar{K}) = -0.22 \pm 0.12,$$

$$S_{\pi^0K_S} = 0.60 \pm 0.20.$$  \hspace{1cm} (29)

In ref. [32], the authors introduced such a new CP phase as a new physics scenario in electroweak penguin sector, and found that $\phi_{NP} \approx \pm \pi/2$ is needed to meet the $B \to \pi K$ data. Here we adopt the latest experimental data and find that a much larger $\phi_{NP} \approx \pm (2.6 \pm 0.4)$ is required to give a consistent explanation for the data when keeping SU(3) symmetry.
In the other scenario, we add a new strong phase $\delta_{NP}$ to $P_{EW}'$, namely the isospin relation will be broken by an extra phase factor, $P_{EW}' = R_{EW}'(T' + C') e^{i\delta_{NP}}$. By redefining it as $P_{EW}' = |R_{EW}'(T' + C')| e^{i\delta_{EW'}}$, similar results can be obtained as introducing a new CP phase in $P_{EW}'$. It is interesting to find that a new strong phase $\delta_{EW'} = -2.70 \pm 0.30$ can also reduce $|C'/T'|$ to 0.40 $\sim$ 0.80. As a consequence, the CP asymmetries are predicted to be

$$A_{CP}(\pi^0 \bar{K}^0) = -0.10 \pm 0.10,$$
$$S_{\pi^0 K_S} = 0.57 \pm 0.12.$$  \hspace{1cm} (30)

Thus we find that either a new weak phase or a new isospin relation broken strong phase in electroweak penguin diagrams can significantly reduce the ratio $|C'/T'|$ to be close to the ratio $|C/T|$ in $\pi\pi$ system and meet all the present experimental data well within 1\(\sigma\) error. While $|C'/T'| \approx 0.40 \sim 0.80$ is still 2 $\sim$ 3 times larger than the theoretical evaluation calculated by using QCD factorization and PQCD methods, also a large weak phase or strong phase around $\pm(2 \sim 3)$ is necessary. Nevertheless, the predictions for the direct CP asymmetry of $B \to \pi^0 \bar{K}^0$ is consistent with the averaged data though BaBar and Belle did not give very consistent values and the errors are still large $A_{CP}(\pi^0 \bar{K}^0) = -0.20 \pm 0.16 \pm 0.03$(BaBar) and $A_{CP}(\pi^0 \bar{K}^0) = -0.05 \pm 0.14 \pm 0.05$(Belle) \(\mathbb{Z}_3\). As for $S_{\pi K_S}$, in both cases, a large value around 0.6 is obtained in comparison with the experimental result 0.33 $\pm$ 0.21, they are consistent within 1.5\(\sigma\) error. It is noted that both cases can bring out similar effects: a) reducing the ratio $|C'/T'|$ to a reasonable value where SU(3) symmetry holds; b) leading to almost the same prediction for $S_{\pi^0 K_S} \approx 0.60$ and a consistent prediction for $A_{CP}(\pi^0 \bar{K}^0)$. However, adding a new strong phase in $P_{EW}$ will lead to a nonzero $A_{CP}(\pi^- \pi^0)$ at a few percent level, which can be used to distinguish the two type of scenarios in the future.

VI. CONCLUSIONS

In summary, we have presented a model-independent analytical analysis for $B \to \pi\pi$ and $\pi\bar{K}$ decays based on the latest data. We obtained the ratio between color-suppressed tree diagram and tree diagram 0.6 $\leq |C/T| \leq 0.7$ in $\pi\pi$ system through model-independent analysis and found that the latest data makes it move closer to the SM estimation, but was still large. We made an similar analysis in $\pi K$ system and found $|C'/T'| \approx 1.16$ in comparison with the previous value $|C'/T'| \approx 2.0$ and a large negative strong phase $\delta_{C'} \approx -2.65$. The predictions for CP asymmetries in $\pi^0 K^0$ are $A_{CP}(\pi^0 \bar{K}^0) = -0.15 \pm 0.03$ and $S_{\pi^0 K_S} = 0.55 \pm 0.03$, which are consistent with the present data within 1\(\sigma\) and 1.5\(\sigma\) respectively. We also considered two kinds of new physics scenarios with a new CP phase and a new strong phase in electroweak penguin sector. In our present analysis with the latest experiment data, we found that with a new CP phase $\phi_{NP} = \pm(2.2 \sim 3.0)$, the ratio $|C'/T'|$ could be reduced to 0.40 $\sim$ 0.80 that was similar to that in $\pi\pi$ system, and the strong phase $\delta_{C'}$ could also be reduced to about $-1.5$. Alternatively, an extra strong phase in electroweak penguin sector which breaks the isospin symmetry in phase could also reduce the ratio $|C'/T'|$ to about 0.40 $\sim$ 0.80 and coincided with the data well. Thus, new physics may help to explain the discrepancy between $|C/T|$ and $|C'/T'|$ in $\pi\pi$ and $\pi\bar{K}$ systems. Recently, it has been shown that new
physics effects in $P'_{EW}$ can be effectively reparameterized into $C'[33]$, thus a large $|C'/T'|$ may also be a consequence of new physics. The two kinds of scenarios lead to a consistent prediction for $A_{CP}(\pi^0\bar{K}^0)$ and similar for $S_{\pi K_S} \simeq 0.60$ which is consistent with the data within 1.5σ error. A more precise measurement of $A_{CP}(\pi^-\pi^0)$ may not only help us to signal out new physics but also distinguish these two kinds of new scenarios in the near future.

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