$A_{CP}$ Puzzle : Possible Evidence for Large Strong Phase in 
$B \to K\pi$ Color-Suppressed Tree Amplitude

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In QCD Factorization(QCDF), the suppression of the color-suppressed tree amplitude relative to 
the color-allowed one in $B \to K\pi$ decay implies a direct CP asymmetry in $B^- \to K^-\pi^0$ 
to be of the same sign and comparable in magnitude to that in $B^0 \to K^+\pi^-$, in contradiction with experiment. 
This is the $A_{CP}$ $B \to K\pi$ puzzle. One of the current proposal to solve this puzzle is the existence of 
a large color-suppressed amplitude with large strong phase which implies also a large negative 
$B^0 \to \bar{K}^0\pi^0$ CP asymmetry. In this paper, by an essentially model-independent calculation, we 
show clearly that the large negative direct CP asymmetry in $B^0 \to K^0\pi^0$ implies a large $C/T$, 
the ratio of the color-suppressed to the color-allowed tree amplitude and a large negative strong 
phase for $C$. By adding to the QCDF amplitude an additional color-suppressed term to generate 
a large $C/T$ and a large strong phase for $C$ and an additional penguin-like contribution, we obtain 
branching ratios for all $B \to K\pi$ modes and CP asymmetry for $B^0 \to K^+\pi^-$ and $B^- \to K^-\pi^0$ in 
agreement with experiment, and a large and negative CP asymmetry in $B^0 \to \bar{K}^0\pi^0$ which could 
be checked with more precise measurements.

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I. INTRODUCTION

In the penguin-dominated $B \to K\pi$ decays, the color-suppressed tree contribution(C) is suppressed relative 
to the color-allowed tree contribution(T) because of the small Wilson coefficient $a_2$ relative to $a_1$. One would then 
expect the direct CP asymmetries in $B \to K^-\pi^0$ and $B^0 \to K^-\pi^+$ to be essentially given by the color-allowed 
tree and strong penguin interference terms(TP). The 
CP asymmetry($A_{CP}$) in $B^- \to K^-\pi^0$ would be of the 
same sign and comparable in magnitude to that in $B^0 \to K^+\pi^-$. The current measurements[1], though with large 
errors, seem to indicate a positive CP asymmetry for $B^- \to K^-\pi^0$, in opposite sign to the negative $B^0 \to K^+\pi^+$ 
CP asymmetry measured with greater accuracy. This is the $A_{CP}$ puzzle[2, 3, 4, 6, 7, 8, 10, 11, 12].

To reverse the sign of the predicted $B^- \to K^-\pi^0$ CP asymmetry, one would need a large color-suppressed tree 
terms, i.e a large $C/T$ ratio, and also a large strong phase for $C$, as will be shown in the following. Since 
the color-suppressed tree-penguin interference term in $B^- \to K^-\pi^0$ is opposite in sign to that in $B^0 \to \bar{K}^0\pi^0$, 
the $B^0 \to \bar{K}^0\pi^0$ CP asymmetry would become large and 
negative. If the positive asymmetry for $B^- \to K^-\pi^0$ and a large negative $B^0 \to \bar{K}^0\pi^0$ CP asymmetry are 
confirmed by new measurements, this would be a clear 
evidence for the enhanced color-suppressed tree contribution to CP asymmetries in $B \to K\pi$ decays. Apart 
from the possibility of new physics[8, 13] to solve the $A_{CP}$ $B \to K\pi$ puzzle, recent calculations in the standard 
model(SM), as done in perturbative QCD (pQCD)[2, 3], in QCD Factorization(QCDF) with large hard scattering 
corrections[14] seem to obtain a large color-suppressed enhancement in $B \to \pi\pi$ and $B \to K\pi$ decays. The calculation in [5] also shows that the color-suppressed 
tree contribution has to be large to solve the $B \to K\pi$ $A_{CP}$ puzzle within the standard model. Various 
phenomenological analyses[15] using $SU(3)$ symmetry obtain also a large $C/T$ ratio. Final state interaction 
(FSI) rescattering term with a large absorptive part, like the charmed meson rescattering charming penguin 
contribution(16, 17, 18, 19, 20, 21, 22), could also produce a large $C/T$ with a strong phase[3, 22, 23, 24], for example, through the CKM-suppressed, color-allowed 
tree rescattering $B \to K^*\rho \to K\pi$ process, which produces a tree-penguin interference term responsible for 
CP asymmetry, similar to the process $B \to \rho\rho \to \pi\pi$ in $B \to \pi\pi$ decays. Before going further in analyzing these 
possibilities, one would like to have a model-independent calculation to show that, apart from the possibility of new 
physics, the solution to the $A_{CP}$ puzzle is an enhanced color-suppressed contribution to CP asymmetry in 
$B \to K\pi$ decays. In the next section we will show in an essentially model-independent calculation that the large 
negative $B^0 \to \bar{K}^0\pi^0$ CP asymmetry requires a large ratio $C/T$ with $C$ mainly absorptive. We then show that 
with this additional contribution to the color-suppressed tree term and a penguin-like additional term as given in 
25, QCDF could predict all the branching ratios and CP asymmetries for $B \to K\pi$ decays consistent with 
experiment.

II. MODEL-INDEPENDENT DETERMINATION 
OF STRONG PHASES IN $B \to K\pi$

As our analysis is based on QCD Factorization, for convenience, we reproduce here the QCDF $B \to \bar{K}\pi$ decay
amplitudes given in \[25\]. We have \[26, 27, 28, 29\]:

\[
A(B^- \to K^- \pi^0) = -i \frac{G_F}{2} f_K F_0^{B*}(m_K^2)(m_B^2 - m_\pi^2) \\
(V_{ub} V_{us}^* a_1 + (V_{ub} V_{us}^* + V_{cb} V_{cs}^*) [a_4 + a_{10} + (a_6 + a_8) r_\chi]) \\
-i \frac{G_F}{2} f_P F_0^{B*K}(m_\pi^2)(m_B^2 - m_K^2) \\
\times (V_{ub} V_{us} a_2 + (V_{ub} V_{us}^* + V_{cb} V_{cs}^*) \times \frac{3}{2} (a_9 - a_7)) \\
-i \frac{G_F}{2} f_B f_J f_\pi \\
\times [V_{ub} V_{us}^* b_2 + (V_{ub} V_{us}^* + V_{cb} V_{cs}^*) \times (b_3 + b_3^{cw})] \\
\times \left( \frac{1}{2} \bar{\Gamma}(A) + \frac{1}{2} \bar{\Gamma}(P) \right)
\]

\[
A(B^- \to K^0 \pi^-) = -i \frac{G_F}{\sqrt{2}} f_K F_0^{B*}(m_K^2)(m_B^2 - m_\pi^2) \\
(V_{us} V_{ub}^* [a_4 + a_{10} + (a_6 + a_8) r_\chi]) \\
-i \frac{G_F}{\sqrt{2}} f_B f_J f_\pi \\
\times [V_{ub} V_{us}^* b_2 + (V_{ub} V_{us}^* + V_{cb} V_{cs}^*) \times (b_3 + b_3^{cw})] \\
\times \left( \frac{1}{2} \bar{\Gamma}(A) + \frac{1}{2} \bar{\Gamma}(P) \right)
\]

and for \(B^0\):

\[
A(B^0 \to K^- \pi^+) = -i \frac{G_F}{\sqrt{2}} f_K F_0^{B*}(m_K^2)(m_B^2 - m_\pi^2) \\
(V_{ub} V_{us}^* a_1 + (V_{ub} V_{us}^* + V_{cb} V_{cs}^*) [a_4 + a_{10} + (a_6 + a_8) r_\chi]) \\
-i \frac{G_F}{\sqrt{2}} f_B f_J f_\pi \\
\times (V_{ub} V_{us}^* V_{cs}^* a_2 + (V_{ub} V_{us}^* + V_{cb} V_{cs}^*) \times \frac{3}{2} (a_9 - a_7)) \\
+i \frac{G_F}{2} f_B f_J f_\pi \\
\times (V_{ub} V_{us}^* V_{cs}^* a_2 + (V_{ub} V_{us}^* + V_{cb} V_{cs}^*) \times (b_3 - b_3^{cw})/2)
\]

where \(r_\chi = \frac{2 m_\pi^2}{(m_b - m_d)(m_b + m_s)}\) is the chirally-enhanced term in the penguin \(O_6\) matrix element. The annihilation term \(b_1\) is evaluated with the factor \(f_B f_J f_M\) included and normalized relative to the factor \(f_K F_0^{B*}(m_\pi^2)(m_\pi^2 - m_\pi^2)\) in the factorisable terms. For the \(B^- \to \pi^- \pi^0\) amplitude, we have:

\[
A(B^- \to \pi^- \pi^0) = -i \frac{G_F}{2} f_P F_0^{B*}(m_\pi^2)(m_B^2 - m_\pi^2) \\
(V_{ud} V_{us}^* (a_1 + a_2) + (V_{ud} V_{us}^* + V_{cd} V_{cs}^*) \times \frac{3}{2} (a_9 - a_7)) \\
\times \left( a_9 - a_7 + a_{10} + a_{sr_\chi} \right)
\]

We see that the \(B \to K\pi\) decay amplitudes consist of a QCD penguin(P) \(a_4 + a_6 r_\chi\), a color-allowed tree(T) \(a_1\), a color-suppressed tree(C) \(a_2\), a color-allowed electroweak penguin(EW) \(a_9 - a_7\), a color-suppressed electroweak penguin(EWC) \(a_1 + a_{sr_\chi}\) terms. (There are also the penguin contribution given by \(a_3^{ew} + a_3^{ew} r_\chi\) term not shown in the above expressions, for simplicity). Because of the relative large Wilson coefficients, the QCD penguin, the color-allowed tree and the color-allowed electroweak contribution are the major contributions in \(B \to K\pi\) decays. The \(B \to K\pi\) amplitude in Eqs. \(1\)–\(4\) are then given as the sum of the allowed-tree \(T\), the color-suppressed tree \(C\), the color-allowed electroweak penguin \(P_W\), the color-suppressed electroweak penguin, \(P_{WC}\), tree-annihilation \(A\) (the \(b_2\) terms in Eq.\(1\)–\(2\)) the penguin-induced weak annihilation \(P_A\). One can further simplify the expressions, by grouping together the penguin and penguin weak annihilation as an effective penguin \(P_{eff}\) as usually done\[28\], furthermore, since the CKM-suppressed, color-suppressed \(b_2\) terms are much smaller than the color-allowed tree term, we could also neglect \(A\), and put the tree terms and the CKM-suppressed part of \(P\) and \(P_A\) into an effective \(T_{eff}\) and \(C_{eff}\). The \(B \to K\pi\) amplitudes in terms of the effective penguin and tree amplitude are then (putting \(P_{eff} = P_{T}, T_{eff} = T, C_{eff} = C\), we have (in the notations of Ref.\[14\]):

\[
A(B^- \to K^- \pi^0) = \frac{1}{\sqrt{2}} (P_{e^{i\delta_P}} + T e^{i\delta_T} e^{i\gamma} + C e^{i\delta_C} e^{-i\gamma}) \\
+ P_W + \frac{2}{3} P_{WC},
\]

\[
A(B^- \to K^0 \pi^-) = P e^{i\delta_P} - \frac{1}{3} P_{WC},
\]

\[
A(B^0 \to K^- \pi^+) = P e^{i\delta_P} + T e^{i\delta_T} e^{-i\gamma} + \frac{2}{3} P_{WC},
\]

\[
A(B^0 \to K^0 \pi^0) = -\frac{1}{\sqrt{2}} (P_{e^{i\delta_P}} - C e^{i\delta_C} e^{-i\gamma}) \\
- P_W - \frac{1}{3} P_{WC}. \tag{6}
\]

with the strong phase \(\delta_P, \delta_T, \delta_C\) for the penguin, color-allowed and color-suppressed tree, respectively and the weak phase \(\gamma\) of the CKM matrix element \(V_{ub}\) is written explicitly in the color-allowed \(T\) and color-suppressed \(C\) terms. In terms of the relative strong phase \(\delta_P, \delta_T, \delta_C\), and to take into account of the fact that the real part of the penguin amplitude \(P\) is negative in QCDF, we have \(\delta_P = \delta_P + \pi + \delta_T\), and \(\delta_C = \delta_C + \delta_T\).

Consider now the CP-averaged \(\Gamma_{as}\) and CP-difference \(\Gamma_{as}\) for \(B \to K\pi\) decay rates are then, with \(\Gamma_{as} = (\Gamma(B \to K\pi) + \Gamma(B \to K\pi))/2, \Gamma_{as} = (\Gamma(B \to K\pi) - \Gamma(B \to K\pi)) \) and \(\Gamma(B \to K\pi)\) and \(\Gamma(B \to K\pi)\) denotes the decay rate for the corresponding charge-conjugate
mode. We have
\begin{align}
\Gamma_{av}(B^- \rightarrow K^- \pi^0) = \frac{P^2}{2} - PT \cos(\delta_{PT}) \cos(\gamma), \\
-PC \cos(\delta_{PT} - \delta_{CT}) \cos(\gamma) + TC \cos(\delta_{CT}), \\
-PPW \cos(\delta_{PT} + \delta_T) \cos(\gamma) + TPW \cos(\delta_{PT}) \cos(\gamma), \\
+CPW \cos(\delta_{CT} + \delta_T) \cos(\gamma) + \frac{T^2}{2} + \frac{C^2}{2} + \frac{P^2_W}{2}, \tag{7}
\end{align}
\begin{align}
\Gamma_{av}(B^- \rightarrow \bar{K}^0 \pi^-) = P^2 + PC \cos(\delta_{PT} - \delta_{CT}) \cos(\gamma), \\
+PPW \cos(\delta_{PT} + \delta_T) \cos(\gamma), \\
+CPW \cos(\delta_{CT} + \delta_T) \cos(\gamma) + \frac{C^2}{2} + \frac{P^2_W}{2}, \tag{8}
\end{align}
\begin{align}
\Gamma_{av}(\bar{B}^0 \rightarrow K^- \pi^+) = P^2 - 2PT \cos(\delta_{PT}) \cos(\gamma) + T^2, \tag{9}
\end{align}
\begin{align}
\Gamma_{av}(\bar{B}^0 \rightarrow \bar{K}^0 \pi^0) = \frac{P^2}{2} + PC \cos(\delta_{PT} - \delta_{CT}) \cos(\gamma), \\
+PPW \cos(\delta_{PT} + \delta_T) \cos(\gamma), \\
+CPW \cos(\delta_{CT} + \delta_T) \cos(\gamma) + \frac{C^2}{2} + \frac{P^2_W}{2}, \tag{10}
\end{align}

where \( P, T, C \) and \( PW \) are positive and the negative real part of the penguin term has been taken into account in the phase \( \delta_P = \pi + \delta_{PT} + \delta_T \) as mentioned above. To simplify the analysis, we have neglected the color-suppressed electroweak penguin \( PW \) contribution which is smaller than the color-allowed electroweak penguin \( PW \) by an order of magnitude as can be seen from the \( a_8 \) and \( a_{10} \) terms in Eqs. [11, 12]. For the CP-difference decay rates, we obtain:
\begin{align}
\Gamma_{as}(B^- \rightarrow K^- \pi^0) = 2PT \sin(\delta_{PT}) \sin(\gamma), \\
+2PC \sin(\delta_{PT} - \delta_{CT}) \sin(\gamma) + 2TPW \sin(\delta_T) \sin(\gamma), \\
+2CPPW \sin(\delta_{CT} + \delta_T) \sin(\gamma), \tag{11}
\end{align}
\begin{align}
\Gamma_{as}(B^- \rightarrow \bar{K}^0 \pi^-) = 0, \tag{12}
\end{align}
\begin{align}
\Gamma_{as}(\bar{B}^0 \rightarrow K^- \pi^+) = 4PT \sin(\delta_{PT}) \sin(\gamma), \tag{13}
\end{align}
\begin{align}
\Gamma_{as}(\bar{B}^0 \rightarrow \bar{K}^0 \pi^0) = -2PC \sin(\delta_{PT} - \delta_{CT}) \sin(\gamma), \\
+2CPPW \sin(\delta_{CT} + \delta_T) \sin(\gamma). \tag{14}
\end{align}

and the CP asymmetries are then given by:
\begin{align}
A_{CP}(B \rightarrow K\pi) = \frac{\Gamma_{as}(B \rightarrow K\pi)}{2\Gamma_{av}(B \rightarrow K\pi) \cos(\gamma)} \tag{15}
\end{align}

As the \( B \rightarrow K\pi \) branching ratios have been measured with an accuracy at the 10^{-6} level, it is possible to use the differences in the measured branching ratios and CP asymmetry to determine the relative \( T/P, C/T \) and the strong phase \( \delta_{PT}, \delta_{CT} \), as done for \( B \rightarrow \pi\pi \) decays\[^{24, 30}\] in which the relative strong phase \( \delta_{PT} \) can be extracted from the measured mixing-induced and direct CP asymmetry parameters \( S_{\pi^+\pi^-} \) and \( C_{\pi^+\pi^-} \). For example, by neglecting the \( (P/T)^2 \) term in \( S_{\pi^+\pi^-} \), one would obtain:
\begin{align}
tan(\delta_{PT}) \approx -C_{\pi^+\pi^-}/S_{\pi^+\pi^-} \tag{16}
\end{align}

which gives, for \( \bar{B}^0 \rightarrow \pi^-\pi^+ \), \( \delta_{PT} = -36.5^\circ \) close to the value \( -41.3^\circ \) in a more precise determination\[^{24}\]. Similar determination of the strong phase could be done for \( B \rightarrow K\pi \) decays by using the quantity
\begin{align}
D = 2(\Gamma_{av}(\bar{B}^0 \rightarrow K^- \pi^+) - \Gamma_{as}(B^- \rightarrow \bar{K}^0 \pi^-) - T^2) \tag{17}
\end{align}

which is given by:
\begin{align}
D = -4PT \cos(\delta_{PT}) \cos(\gamma)
\end{align}

The ratio \( R_{K^-\pi^+} = \frac{\Gamma_{as}(\bar{B}^0 \rightarrow K^- \pi^+)/D}{\Gamma_{as}(B^- \rightarrow \bar{K}^0 \pi^-)/D} \) is then:
\begin{align}
R_{K^-\pi^+} = -\tan(\delta_{PT}) \tan(\gamma)
\end{align}

from which we obtain:
\begin{align}
\tan(\delta_{PT}) = \frac{-R_{K^-\pi^+}}{\tan(\gamma)}, \\
\sin(\delta_{PT}) = -\frac{R_{K^-\pi^+}}{\sqrt{(\tan^2(\gamma) + R_{K^-\pi^+}^2)}} \tag{19}
\end{align}

From the measured \( B \rightarrow K\pi \) branching ratios and the QCDF expression for \( T^2 \), we obtain \( D = -5.35 \), \( R_{K^-\pi^+} = 0.71 \) (in terms of the branching ratios and in unit of 10^{-6}) which give,
\begin{align}
\tan(\delta_{PT}) = -0.30, \quad \delta_{PT} = -17^\circ. \tag{20}
\end{align}

within an error of \( 20 - 30\% \), including a small theoretical uncertainty in the use of QCDF for \( T^2 \) which makes only a small contribution to \( D \) relative to the main tree-penguin interference term. This value is smaller than the value \( -36.5^\circ \) for \( \delta_{PT} \) in \( \bar{B}^0 \rightarrow \pi^-\pi^+ \) mentioned above, but the small value of the strong phase \( \delta_{PT} \) we obtained here from \( B^0 \rightarrow K^- \pi^+ \) could be due to the cancellation between the factorisable term, penguin-induced weak annihilation and FSI charmed meson intermediate states contribution to produce a negative CP asymmetry in \( B^0 \rightarrow K^- \pi^+ \) decay\[^{25}\].

We now come to the \( A_{CP} \) puzzle. As mentioned earlier, the solution of the puzzle requires a moderate \( C/T \) ratio, but with a strong phase \( \delta_{CT} \) sufficiently large to keep the real part of the color-suppressed tree contribution close to QCDF prediction, like those computed for \( B \rightarrow \pi\pi \) decays\[^{31}\]. Then the large absorptive part could find an explanation from FSI effects as mentioned earlier. Indeed, as shown in the following, such a large strong phase for \( C \) is required to produce a large \( C \) asymmetry for \( \bar{B}^0 \rightarrow \bar{K}^0 \pi^0 \). Defining \( R_{K^0\pi^0} = \frac{\Gamma_{as}(\bar{B}^0 \rightarrow \bar{K}^0 \pi^0)}{\Gamma_{av}(\bar{B}^0 \rightarrow \bar{K}^0 \pi^0)} \), we have:
\begin{align}
R_{K^0\pi^0} = -\frac{1}{2T} \frac{C}{ \frac{3}{2} F_{\bar{B}^0 K} \left( \frac{1}{2} \right) / \left| a_6 - a_7 \right| } \left( \sin(\delta_{CT}) \tan(\gamma) + \cos(\delta_{CT}) R_{K^-\pi^+} + RW \sin(\delta_{CT} + \delta_T) \sqrt{(R_{K^-\pi^+}^2 + \tan^2(\gamma))} \right) \tag{21}
\end{align}

where \( RW = P_{W}/P \) which is given approximately by QCDF\[^{28}\]:
\begin{align}
RW = \frac{3 f_{\pi} F_{\bar{B}^0 \pi\pi}}{2 f_{K} F_{\bar{B}^0 \pi}} \frac{|a_6 - a_7|}{|a_4 + a_6 f_{\chi}|} \approx 0.13 \tag{22}
\end{align}

The CP asymmetry for \( \bar{B}^0 \rightarrow \bar{K}^0 \pi^0 \) is then
\begin{align}
A_{CP}(\bar{B}^0 \rightarrow \bar{K}^0 \pi^0) = \frac{D R_{K^0\pi^0}}{2 |B(\bar{B}^0 \rightarrow \bar{K}^0 \pi^0)|} \tag{23}
\end{align}
with $D$ given in terms of the CP-averaged $B \to K\pi$ branching ratios, experimentally, $D = -5.35$, as mentioned above (in unit of $10^{-6}$).

A nice feature of the above expression for $R_{K^0\pi^0}$ is that it gives the CP asymmetry for $B^0 \to \bar{K}^0\pi^0$ in terms of the strong phase $\delta_{CT}$, the measured $B^+ \to K^-\pi^+$ CP asymmetry and the weak phase $\gamma$. For a large strong phase $\delta_{CT}$, the $\cos(\delta_{CT})R_{K^-\pi^+}$ term is suppressed so that the dependence of $R_{K^0\pi^0}$ on $R_{K^-\pi^+}$ is weak. There is also some dependence on $\delta_T$ in the electroweak contribution to $R_{K^0\pi^0}$ which could produce a small uncertainty on the CP asymmetry, about $10 - 15\%$, roughly the size of the electroweak penguin contribution. Thus the CP asymmetry for $B^0 \to \bar{K}^0\pi^0$ depends essentially on the strong phase of the color-suppressed tree contribution $\delta_{CT}$.

Numerically, from the measured $B(B^0 \to K^-\pi^+)$, the CP asymmetry $A_{CP}(\bar{B}^0 \to K^-\pi^+) \approx 76^\circ$, and taking $\delta_T = 30^\circ$, we obtain:

$$A_{CP}(\bar{B}^0 \to \bar{K}^0\pi^0) = 0.27 \frac{C}{T} [1.31 \sin(\delta_{CT}) + 0.44 \cos(\delta_{CT})]$$

Thus a large negative value for $\delta_{CT}$ could produce a large negative $A_{CP}(\bar{B}^0 \to \bar{K}^0\pi^0)$, which is needed to accommodate the measured positive asymmetry for $(B^- \to K^-\pi^0)^4$. For example, with $\delta_{CT} = -72^\circ$, one would get $A_{CP}(\bar{B}^0 \to \bar{K}^0\pi^0) = -0.30(C/T)$ which implies $C/T = 1/2$ for $A_{CP}(\bar{B}^0 \to \bar{K}^0\pi^0) = -0.15$. If we neglect the electroweak penguin $P_W$ term, we would have:

$$A_{CP}(\bar{B}^0 \to \bar{K}^0\pi^0) = 0.27 \frac{C}{T} [1.17 \sin(\delta_{CT}) + 0.35 \cos(\delta_{CT})]$$

independent of $\delta_T$. The same value for the CP asymmetry would imply $\delta_{CT} = -75^\circ$, close to the value obtained with electroweak penguin. Thus the determination of $C/T$ will not be greatly affected by the electroweak penguin contribution. In general from QCDF one expects a small $\delta_T$, in our calculation we will put $\delta_T = 30^\circ$. In terms of the measured $A_{CP}(\bar{B}^0 \to \bar{K}^0\pi^0)$, from Eq. (23), $C/T$ is then:

$$C/T = \frac{A_{CP}(\bar{B}^0 \to \bar{K}^0\pi^0)}{0.27 [1.31 \sin(\delta_{CT}) + 0.44 \cos(\delta_{CT})]}$$

As shown in Fig. 1, for the strong phase in the range $-(50^\circ - 70^\circ)$, $C/T$ is of the order $0.3 - 0.4$ for an asymmetry of $-0.10$, with a larger asymmetry of $-0.15$, $C/T$ become larger, of the order $0.5 - 0.6$. Thus in an essentially model-independent calculation, we have shown that a large and negative $\bar{B}^0 \to \bar{K}^0\pi^0$ CP asymmetry, which is required to produce a sizable positive CP asymmetries in $B^- \to K^-\pi^0$, implies a large color-suppressed tree $C$ term and its strong phase in $B \to K\pi$ decay, with a ratio $C/T$ of the order $0.4 - 0.6$ and the strong phase $\delta_{CT}$ in the range $-(50 - 70)^\circ$. Indeed, a recent analysis in QCDF shows that the $A_{CP} B \to K\pi$ puzzle could be solved with a color-suppressed tree $a_2$ term large and having a large negative strong phase $\gamma$. In the next section, we will show that, by adding to the QCDF amplitude, an additional color-suppressed tree contribution with this size to reverse the sign of the $B^- \to K^-\pi^0$ asymmetry, together with the additional penguin terms (charming penguin etc.), indeed good agreement with experiment is obtained for all the $B \to K\pi$ branching ratios and CP asymmetries.

### III. $B \to K\pi$ DECAYS IN QCDF WITH ADDITIONAL PENGUIN AND COLOR-SUPPRESSED CONTRIBUTIONS

In a previous paper, we have shown that the $B \to K\pi$ branching ratios and the $B^0 \to K^+\pi^-\bar{\nu}$ CP asymmetry could be described by QCDF with a mainly absorptive additional penguin terms (charming penguin etc.), with a strength $30\%$ of the penguin term. However the predicted CP asymmetry for $B^- \to K^-\pi^0$ is of the same sign and magnitude to that for $B^0 \to K^-\pi^+$, in disagreement with the measured value. Therefore, to reverse the sign of the predicted asymmetry, we need a large negative $B^0 \to K^0\pi^0$ CP asymmetry and hence a color-suppressed tree term with large magnitude and large negative strong phase. By adding this term to the QCDF $B \to K\pi$ amplitudes given in our previous work, one would obtain correct predictions for $B \to K\pi$ branching ratios and CP asymmetries as will be shown below.

With the same hadronic, CKM parameters and the additional penguin term $\delta P$ given in Eq. (25), and writing the color-suppressed additional term as $\delta C = ra_2(k_1 + i k_2)$ where $ra_2$ is the real part of $a_2$, and taking $k_1 = 0$, $k_2 = -1.7$, the computed branching ratios and direct CP asymmetries, with $\rho_H = 1$, $\phi_H = 0$ and $\phi_A = -55^\circ$ as in scenario S4 of (28) are shown in Fig. 2 and Fig. 3 as function of $\rho_A$. For convenience we also give in Table II and Table III the computed values at $\rho_A = 1$ as in S4 with and without the additional penguin-like $\delta P$ and color-suppressed $\delta C$ contribution. We see that with these additional contributions, all the branching ratios and CP asymmetries are in good agreement with the measured values. In particular, the $B^0 \to K^0\pi^0$ branching ratio is slightly larger than the previous predicted value of $8.9 \times 10^{-6}$ due to the additional $\delta C$ contribution and is closer to experiment, while other predicted branching ratios remain practically unchanged.

In our previous work, we give predictions for the $B^0 \to K^0\pi^0$, $B^- \to K^-\pi^0$ and $B^0 \to K^-\pi^+$ branching ratios in terms of the computed differences $2B(B^0 \to K^0\pi^0) - r_\pi B(B^- \to K^-\pi^+)$, $2r_\pi B(B^- \to K^-\pi^+) - B(B^0 \to K^-\pi^+)$, $B(B^0 \to K^-\pi^+) - r_\pi B(B^- \to K^0\pi^-)$ and the measured $B^0 \to K^-\pi^+$ and $B^- \to K^0\pi^-$ branching ratios. The good agreement with experiment
FIG. 1: The ratio $C/T$ plotted against $\Delta_{\text{CT}}$, the strong phase of the color-suppressed tree contribution $C$. (a1,a2) are the curves for $\mathcal{A}_{\text{CP}}(\bar{B}^0 \to \bar{K}^0\pi^0) = -0.10$ with $\delta_T$ taken to be 0.0 and 30°, respectively, (b1,b2) are similar curves for $\mathcal{A}_{\text{CP}}(\bar{B}^0 \to \bar{K}^0\pi^0) = -0.15$.

FIG. 2: The computed and measured CP-averaged branching ratios. The horizontal line are the measured values [1] with the unit of $10^{-6}$, the gray areas represent the experimental errors. (a), (b), (c), (d) in the left and right figure represent the values for $B^- \to K^-\pi^0$, $B^- \to K^0\pi^-$, $\bar{B}^0 \to K^-\pi^+$ and $\bar{B}^0 \to K^0\pi^0$ respectively. The curves (a1)-(d1) and (a2)-(d2) are the corresponding QCDF predicted values for $\phi_A = -55^\circ$, without and with additional penguin-like $\delta P$ and color-suppressed $\delta C$ contribution respectively.

| Decay Modes | $\delta P = 0$ | $\delta P \neq 0$ | $\delta C = 0$ | $\delta C \neq 0$ | Exp [1] |
|-------------|---------------|----------------|---------------|----------------|---------|
| $B^- \to \pi^-\pi^0$ | 5.7 | 5.7 | 5.59 ± 0.4 |
| $B^- \to K^-\pi^0$ | 10.3 | 12.6 | 12.9 ± 0.6 |
| $B^- \to \bar{K}^0\pi^-$ | 18.1 | 22.9 | 23.1 ± 1.0 |
| $\bar{B}^0 \to K^+\pi^0$ | 15.5 | 19.9 | 19.4 ± 0.6 |
| $\bar{B}^0 \to \bar{K}^0\pi^0$ | 6.8 | 9.2 | 9.8 ± 0.6 |

TABLE I: The CP-averaged $B \to K\pi$ Branching ratios in unit of $10^{-6}$ in QCDF with and without additional penguin-like $\delta P$ and color-suppressed $\delta C$ contribution and with $\rho_A = 1.0$, $\phi_A = -55^\circ$.

shows that QCDF could describe rather well the electroweak penguin contribution. We give here similar predictions with the additional color-suppressed term included (in unit of $10^{-6}$):

$\mathcal{B}(\bar{B}^0 \to \bar{K}^0\pi^0) = 9.3 \pm 0.3$, \hspace{1cm} (27)

$\mathcal{B}(B^- \to K^-\pi^0) = 12.4 \pm 0.3$, \hspace{1cm} (28)

$\mathcal{B}(\bar{B}^0 \to K^-\pi^+) = 20.1 \pm 0.6$, \hspace{1cm} (29)

| Decay Modes | $\delta P = 0$ | $\delta P \neq 0$ | $\delta C = 0$ | $\delta C \neq 0$ | Exp [1] |
|-------------|---------------|----------------|---------------|----------------|---------|
| $B^- \to \pi^-\pi^0$ | 0.0 | 0.0 | 0.06 ± 0.05 |
| $B^- \to K^-\pi^0$ | 0.01 | 0.06 | 0.05 ± 0.025 |
| $B^- \to \bar{K}^0\pi^-$ | 0.004 | 0.01 | -0.009 ± 0.025 |
| $\bar{B}^0 \to K^-\pi^+$ | -0.02 | -0.08 | -0.098 ± 0.012 |
| $\bar{B}^0 \to \bar{K}^0\pi^0$ | -0.02 | -0.11 | -0.01 ± 0.10 |

TABLE II: The direct $B \to K\pi$ CP asymmetries in QCDF with and without additional penguin-like contribution $\delta P$ and color-suppressed $\delta C$ contribution and with $\rho_A = 1.0$, $\phi_A = -55^\circ$.

We see that because of the large color-suppressed contribution, the $\bar{B}^0 \to \bar{K}^0\pi^0$ predicted branching ratio is larger than the previous predicted value $(9.0 \pm 0.3) \times 10^{-6}$ and is closer to experiment, the other two predicted branching ratios are almost unchanged and are in good agreement with experiment within the current accuracy.
FIG. 3: The same as in Fig. 2 but for the computed CP asymmetries.

IV. CONCLUSION

By adding mainly absorptive additional penguin-like and color-suppressed tree terms to the QCDF $B \to K\pi$ decay amplitudes, we show that QCDF could successfully predict the $B \to K\pi$ branching ratios and CP asymmetries. In particular, with a large negative strong phase for the color-suppressed tree contribution, we obtain the correct magnitude and sign for the $\bar{B}_0 \to K^-\pi^+$ and $B^- \to K^-\pi^0$ CP asymmetry, and a large negative asymmetry for $\bar{B}_0 \to \bar{B}_0 \pi^0\pi^0$. Confirmation of these CP asymmetries by new measurements and the measurement of $B_0 \to \pi^0\pi^0$ CP asymmetry would be an evidence for a large $C/T$ ratio and a large strong phase in $B \to \pi\pi$ and $B \to K\pi$ decays.

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