

Indication for Large Rescatterings in Charmless Rare B Decays

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The current wealth of charmless B decay data may suggest the presence of final state rescattering. In a factorized amplitude approach, better fits are found by incorporating two SU(3) rescattering phase differences, giving $\delta \sim 65^\circ$ and $\sigma \sim 90^\circ\text{--}100^\circ$. Fitting with unitarity phase ϕ_3 as a fit parameter gives $\phi_3 \sim 96^\circ$, the CP asymmetries $A_{\pi\pi}$, $S_{\pi\pi}$ agree better with BaBar, and the σ phase is slightly lower. Keeping $\phi_3 = 60^\circ$ fixed in fit gives $S_{\pi\pi} \sim -0.9$, which agrees better with Belle. With the sizable δ , σ rescattering phases as fitted, many direct CP asymmetries flip sign, and $B^0 \rightarrow \pi^0\pi^0$, K^-K^+ rates are of order 10^{-6} , which can be tested soon.

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I. INTRODUCTION

Based on data from the CLEO experiment, it was pointed out in 1999 [1] that the emerging $B \rightarrow K\pi$, $\pi\pi$ rates support factorization, *if the phase angle γ* (or $\phi_3 \equiv \arg V_{ub}^*$ [2]) of the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix *is large*. We now have some theoretical basis for factorization [3, 4] in charmless B decays, and it is common for B physics practitioners to take $\phi_3 \sim 80^\circ\text{--}90^\circ$, which is in contrast with the $\sim 60^\circ$ value indicated by CKM fits [5] to other data.

At the turn of the century, the dramatic ascent of the B factories brought the CLEO era to an end. CLEO did make an attempt [6] to measure direct CP violating rate asymmetries (A_{CP}) in a few modes, where for a $B \rightarrow f$ decay

$$A_{CP}(f) \equiv \frac{\mathcal{B}(\overline{B} \rightarrow \overline{f}) - \mathcal{B}(B \rightarrow f)}{\mathcal{B}(\overline{B} \rightarrow \overline{f}) + \mathcal{B}(B \rightarrow f)}. \quad (1)$$

The central values of the CLEO measurements differed from factorization expectations, but errors were large. Some other oddities lingered, such as the smallness of $\pi^-\pi^+$ rate compared with $\pi^-\pi^0$. It was thus suggested [7] that one *may need large rescattering, in addition to large ϕ_3* . Though speculative, this had implications beyond the shifted pattern in A_{CP} s: $\pi^0\pi^0$ would become prominent, and CP violation in $\overline{B}^0 \rightarrow \pi^-\pi^+$ could be sizable. A few years later, it is surprising that the speculated patterns seem to be really emerging!

Let us give a snapshot of the current landscape [8, 9, 10, 11, 12, 13] (as summarized in Tables I and II). All the $K\pi$, $\pi\pi$ modes have been measured by both Belle and BaBar experiments to some accuracy, and with good agreement. The A_{CP} in $K^-\pi^+$ mode is now significant, and seem *opposite in sign* to the factorization expectation [3]; the 3σ effect in $\overline{K}^0\pi^-$ mode reported by Belle is no more. The conflicting signs between Belle and BaBar on A_{CP} in $K^-\pi^0$ and $\overline{K}^0\pi^-$ modes keeps these asymmetries rather consistent with zero. Both experiments have hints for $\pi^0\pi^0 \sim 10^{-6}$, and have measured the mixing dependent CP asymmetries in $\pi^-\pi^+$ mode. For the latter,

the two experiments diverge. We thus scale the error-bars by an S factor following the Particle Data Group (PDG) [2] for these modes. Following Belle, we denote the two measurables as $A_{\pi\pi}$ ($\equiv -C_{\pi\pi}$), equivalent to A_{CP} in $\overline{B}^0 \rightarrow \pi^-\pi^+$, and $S_{\pi\pi}$, where

$$A_{CP}^{\pi\pi}(t) = \frac{\mathcal{B}(\overline{B}^0(t) \rightarrow \pi^+\pi^-) - \mathcal{B}(B^0(t) \rightarrow \pi^+\pi^-)}{\mathcal{B}(\overline{B}^0(t) \rightarrow \pi^+\pi^-) + \mathcal{B}(B^0(t) \rightarrow \pi^+\pi^-)} \\ = A_{\pi\pi} \cos(\Delta m_B t) + S_{\pi\pi} \sin(\Delta m_B t). \quad (2)$$

Belle finds $A_{\pi\pi} \simeq 1$ and $S_{\pi\pi} \simeq -1$ [11] (hence outside the physical domain), while BaBar finds [12] both $\simeq 0$. Note that Belle's updated numbers are consistent with earlier results, and the discrepancy with BaBar [12] remains. The two central values for $A_{\pi\pi}$ now do agree in sign, but are *opposite* to (QCD) factorization expectations [3].

Independent hint for rescattering [14] comes from the unexpected emergence of color-suppressed $\overline{B}^0 \rightarrow D^{(*)0}h^0$ decays [15], where $h^0 = \pi^0, \eta$ and ω ; the rates are all larger than expected. In this paper we extend the model of Ref. [7] and explore the implications of present data on both ϕ_3 and rescattering phases. The pattern change in rates, such as $\pi^0\pi^0$, $K^-K^{+,0}$, the sizable “*opposite sign*” A_{CP} s in various modes, and especially $A_{\pi\pi}$ and $S_{\pi\pi}$, can be tested in the near future.

II. FORMALISM

Our picture is that of factorized B decay amplitudes followed by *final state* rescattering (FSI), i.e.

$$\langle i; \text{out} | H_W | B \rangle = \sum_l \mathcal{S}_{il}^{1/2} \mathcal{A}_l^f, \quad (3)$$

where $|i; \text{out}\rangle$ is the out state, \mathcal{S} is the strong scattering matrix, and \mathcal{A}_l^f is a factorization amplitude. It was pointed out in Ref. [16] that elastic rescattering effects may not yet be greatly suppressed at m_B scale, while inelastic rescattering contributions may be important.

We would clearly lose control if the full structure of Eq. (3) is employed. It is clear that the subset of

TABLE I: Experimental data for CP-averaged $\overline{B} \rightarrow hh$ branching ratios in units of 10^{-6} [8, 9, 10, 11, 12, 13].

$\overline{B} \times 10^6$	CLEO	BaBar	Belle	Average
$K^- \pi^+$	$18.0^{+2.3+1.2}_{-2.1-0.9}$	$17.9 \pm 0.9 \pm 0.7$	$18.5 \pm 1.0 \pm 0.7$	18.2 ± 0.8
$K^- \pi^0$	$12.9^{+2.4+1.2}_{-2.2-1.1}$	$12.8^{+1.2}_{-1.1} \pm 1.0$	$12.8 \pm 1.4^{+1.4}_{-1.0}$	12.8 ± 1.1
$\overline{K}^0 \pi^-$	$18.8^{+3.7+2.1}_{-3.3-1.8}$	$20.0 \pm 1.6 \pm 1.0$	$22.0 \pm 1.9 \pm 1.1$	20.6 ± 1.3
$\overline{K}^0 \pi^0$	$12.8^{+4.0+1.7}_{-3.3-1.4}$	$10.4 \pm 1.5 \pm 0.8$	$12.6 \pm 2.4 \pm 1.4$	11.2 ± 1.4
$\pi^- \pi^0$	$4.6^{+1.8+0.6}_{-1.6-0.7}$	$5.5^{+1.0}_{-0.9} \pm 0.6$	$5.3 \pm 1.3 \pm 0.5$	5.3 ± 0.6
$\pi^+ \pi^-$	$4.5^{+1.4+0.5}_{-1.2-0.4}$	$4.7 \pm 0.6 \pm 0.2$	$4.4 \pm 0.6 \pm 0.3$	4.5 ± 0.4
$\pi^0 \pi^0$	$2.2^{+1.7}_{-1.3} \pm 0.7$	$1.6^{+0.7+0.6}_{-0.6-0.3}$	$1.8^{+1.4+0.5}_{-1.3-0.7}$	1.7 ± 0.6
$\eta \pi^-$	—	$4.2 \pm 1.0 \pm 0.3$	$5.4^{+2.0}_{-1.7} \pm 0.6$	3.9 ± 0.8
ηK^-	—	$2.8 \pm 0.8 \pm 0.2$	$5.3^{+1.8}_{-1.5} \pm 0.6$	3.2 ± 0.7
$\eta \overline{K}^0$	—	< 4.6	—	< 4.6
$K^- K^0$	< 3.3	< 2.2	$(1.7 \pm 1.2 \pm 0.1) < 3.4$	< 2.2
$K^- K^+$	< 0.8	< 0.6	< 0.7	< 0.6
$\overline{K}^0 K^0$	< 3.3	< 1.6	$(0.8 \pm 0.8 \pm 0.1) < 3.2$	< 1.6

TABLE II: Experimental data for direct CP asymmetries in $\overline{B} \rightarrow hh$ decays [6, 9, 11, 12, 13].

A_{CP} (%)	CLEO	BaBar	Belle	Average
$K^- \pi^+$	-4 ± 16	$-10.2 \pm 5 \pm 1.2$	$-7 \pm 6 \pm 1$	-9 ± 4
$K^- \pi^0$	-29 ± 23	$-9 \pm 9 \pm 1$	$23 \pm 11^{+1}_{-4}$	1 ± 12^a
$\overline{K}^0 \pi^-$	18 ± 24	$-5.3 \pm 7.9 \pm 1.3$	7^{+9+1}_{-8-3}	1 ± 6
$\overline{K}^0 \pi^0$	—	$3 \pm 36 \pm 9$	—	3 ± 36
$\pi^- \pi^0$	—	$-3 \pm 18 \pm 2$	$-14 \pm 24^{+5}_{-4}$	-7 ± 14
$A_{\pi\pi}$	—	$30 \pm 25 \pm 4$	$77 \pm 27 \pm 8$	51 ± 23^b
$S_{\pi\pi}$	—	$2 \pm 34 \pm 5$	$-123 \pm 41^{+8}_{-7}$	-49 ± 61^b
ηK^-	—	$-32 \pm 20 \pm 1$	—	-32 ± 20
$\eta \pi^-$	—	$-51 \pm 19 \pm 1$	—	-51 ± 19

^aError-bars of $A_{CP}^{\text{exp}t}(K^- \pi^0)$ is scaled by $S = 1.8$.^bError-bars of $A_{\pi\pi}$, $S_{\pi\pi}$ are scaled by $S = 1.2, 2.3$, respectively.

two body final states from elastic rescatterings stand out against inelastic channels. Furthermore, it has been shown from duality [17] as well as statistical arguments [18] that inelastic FSI amplitudes tend to cancel among themselves and lead to small FSI phases $\lesssim 20^\circ$. Thus, quasi-elastic scattering may well be still relevant in two-body B decays, and we should allow experiment as the final judge. For example, if the factorization amplitudes are already good enough, the data will force us to have $\mathcal{S}^{1/2} \sim 1$, and vice versa.

We extend from the quasi-elastic $\overline{B} \rightarrow DP$ [14] case to the $\overline{B} \rightarrow PP$ case, where D is the SU(3) D -meson triplet and P the pseudoscalar octet. That is, we extend the $\mathbf{3} \otimes \mathbf{8} \rightarrow \mathbf{3} \otimes \mathbf{8}$ FSI formalism developed for color-suppressed $D^0 h^0$ modes, to $\mathbf{8} \otimes \mathbf{8} \rightarrow \mathbf{8} \otimes \mathbf{8}$ rescattering in light PP final states. Bose symmetry then implies that the $\mathcal{S}^{1/2}$ matrix in Eq. (3) takes up the form

$$\mathcal{S}^{1/2} = e^{i\delta_{27}} |\mathbf{27}\rangle \langle \mathbf{27}| + e^{i\delta_8} |\mathbf{8}\rangle \langle \mathbf{8}| + e^{i\delta_1} |\mathbf{1}\rangle \langle \mathbf{1}|, \quad (4)$$

hence there are just two physical phase differences, which we take as $\delta \equiv \delta_{27} - \delta_8$ and $\sigma \equiv \delta_{27} - \delta_1$. These rescattering phases redistribute the factorized decay amplitudes

\mathcal{A}_i^f according to Eq. (3), but they also can be viewed as a *simple two parameter model extension* beyond the usual $B \rightarrow PP$ amplitudes. The detailed formalism is given elsewhere. There are also some similar works in the literature [19]. We shall see that $|\delta - \sigma| \lesssim 50^\circ$ turns out to be the case of interest. As in [14], we drop the SU(3) singlet $\mathbf{1}$, or η_1 , from the rescattering formulation. For the present case, one anyway has the difficulty in explaining the huge rate observed [2] for $B \rightarrow \eta' K$.

For \mathcal{A}_i^f , the present QCD [3] or PQCD [4] factorization approaches involve effects that are subleading in $1/m_b$, such as weak annihilation contributions. To avoid double counting hadronic effects, we shall use [20] naive factorization [21] amplitudes. In fact, for QCD factorization, which is close to naive factorization, removing all subleading effects but keeping the $1/m_s^{\text{eff}}$ chiral enhancement seems to give a better fit to $K\pi$, $\pi\pi$ rates [22].

We follow the χ^2 fit strategy of Ref. [23], but keeping the δ and σ phases of Eqs. (3) and (4) as additional parameters. As input, we take central values of $|V_{cb}|$ and $|V_{ub}|$ from Ref. [2]. We focus on $\overline{B} \rightarrow PP$ modes, since the VP , VV situation is not yet settled. We thus

TABLE III: World average inputs and fitted outputs; data in brackets are not used in fit, while $\eta_8 K(\pi)^-$ entries are for $\eta K(\pi)^-$. Horizontal lines separate rescattering subsets. Fit 1 or 2 stand for ϕ_3 free or fixed at 60° . Setting $\delta = \sigma = 0$ but keeping other parameters fixed give the results in parentheses; the fitted parameters and $\chi^2_{\min.}$ are given in Table IV.

Modes	$\mathcal{B}^{\text{expt}} \times 10^6$	$\mathcal{B}^{\text{Fit1}} \times 10^6$	$\mathcal{B}^{\text{Fit2}} \times 10^6$	$A_{\text{CP}}^{\text{expt}} (\%)$	$A_{\text{CP}}^{\text{Fit1}} (\%)$	$A_{\text{CP}}^{\text{Fit2}} (\%)$
$K^- \pi^+$	18.2 ± 0.8	$19.4^{+1.0}_{-1.2}$ (19.7)	18.5 ± 0.6 (18.1)	-9 ± 4	-6^{+2}_{-3} (9)	-4 ± 1 (7)
$\bar{K}^0 \pi^0$	11.2 ± 1.4	$8.3^{+1.3}_{-0.4}$ (7.3)	9.1 ± 0.3 (8.7)	[3 ± 37]	24^{+4}_{-30} (0)	16^{+2}_{-21} (0)
$\bar{K}^0 \eta_8$	[< 4.6 (90% CL)]	$3.4^{+0.8}_{-0.6}$ (4.1)	$3.9^{+1.0}_{-0.8}$ (4.6)	—	24^{+9}_{-4} (0)	15^{+3}_{-2} (0)
$K^0 \pi^-$	20.6 ± 1.3	$19.6^{+2.2}_{-1.4}$ (18.5)	21.6 ± 0.6 (20.9)	1 ± 6	8^{+2}_{-1} (0)	5 ± 0 (0)
$K^- \pi^0$	12.8 ± 1.1	$11.6^{+0.5}_{-1.0}$ (12.1)	11.0 ± 0.3 (10.9)	1 ± 12	-19^{+4}_{-7} (7)	-14^{+1}_{-2} (6)
$K^- \eta_8$	[3.2 ± 0.7]	$3.6^{+0.8}_{-0.7}$ (4.2)	$4.6^{+1.0}_{-0.8}$ (5.4)	[-32 ± 20]	33^{+15}_{-9} (-9)	19^{+6}_{-4} (-5)
$\pi^- \pi^0$	5.3 ± 0.6	$4.4^{+1.2}_{-0.6}$ (4.4)	$3.2^{+0.1}_{-0.2}$ (3.2)	[-7 ± 14]	0 (0)	0 (0)
$\pi^- \eta_8$	[3.9 ± 0.8]	$1.2^{+0.1}_{-0.3}$ (1.4)	$1.5^{+0.1}_{-0.1}$ (1.8)	[-51 ± 19]	75^{+25}_{-18} (-32)	42^{+9}_{-6} (-19)
$K^- K^0$	< 2.2 (90% CL)	$1.7^{+0.3}_{-0.2}$ (1.5)	1.3 ± 0.1 (1.0)	—	-84^{+9}_{-14} (-4)	-79 ± 3 (-3)
$\pi^- \pi^+$	4.5 ± 0.4	$4.7^{+0.7}_{-0.8}$ (7.4)	$5.1^{+0.3}_{-0.4}$ (8.7)	$[A_{\pi\pi} = 51 \pm 23]$ $[S_{\pi\pi} = -49 \pm 61]$	$A_{\pi\pi} = 12^{+14}_{-50}$ (-24) $S_{\pi\pi} = -15^{+69}_{-0}$ (-5)	$A_{\pi\pi} = 13 \pm 2$ (-17) $S_{\pi\pi} = -90^{+1}_{-0}$ (-88)
$\pi^0 \pi^0$	1.7 ± 0.6	$2.5^{+0.4}_{-0.9}$ (0.2)	$2.8^{+0.3}_{-0.7}$ (0.1)	—	-56^{+1}_{-16} (1)	-35^{+1}_{-6} (1)
$K^- K^+$	< 0.6 (90% CL)	$0.2^{+0.4}_{-0.2}$ (0.0)	$0.6^{+0.3}_{-0.1}$ (0.0)	—	-13^{+9}_{-76} (—)	-11^{+2}_{-1} (—)
$\bar{K}^0 K^0$	< 1.6 (90% CL)	$1.5^{+0.3}_{-0.6}$ (1.5)	1.1 ± 0.1 (1.0)	—	-63^{+141}_{-24} (-4)	-86^{+6}_{-1} (-3)
$\pi^0 \eta_8$	—	$0.4^{+0.2}_{-0}$ (0.3)	0.2 ± 0.0 (0.2)	—	-3 ± 0 (-4)	-3 ± 0 (-4)
$\eta_8 \eta_8$	—	0.2 ± 0.0 (0.1)	0.2 ± 0.1 (0.1)	—	-10^{+96}_{-75} (-6)	-91^{+14}_{-3} (-6)

take only the 7 $K\pi$ and $\pi\pi$ rates, the better measured A_{CPs} in $K^- \pi^{+,0}$ and $K^0 \pi^-$ modes, and average over the current values reported by BaBar, Belle and CLEO [6, 8, 9, 10, 11, 12, 13], as given in Table I and II. We also constrain $f_\pi F_0^{BK}/f_K F_0^{B\pi} = 0.9 \pm 0.1$ [3]. We use the stringent upper limit [13] of $2.2 (0.6) \times 10^{-6}$ for $K^- K^{0(+)}$ of BaBar. The limits are implemented as boundaries. We do not use $A_{\pi\pi}$ and $S_{\pi\pi}$ as input, since the experimental situation is still controversial. We do not use $\eta\pi^-(K^-)$ rates and A_{CPs} , but give $\eta_8 \pi^-(K^-)$ only.

The fit parameters are F_0^{BK} , the chiral enhancement parameter $1/m_s^{\text{eff}}$ [1], the FSI phases δ and σ , and possibly ϕ_3 . Because of the $S_{\pi\pi}$ controversy, we explore two cases: ϕ_3 free (Fit 1), or fixed (Fit 2) at 60° [5].

III. RESULTS

The fitted rates, A_{CPs} , and especially $A_{\pi\pi}$ and $S_{\pi\pi}$, together with inputs, are given in Table III. Setting δ and σ to zero but keeping all other parameters as determined by the fit, the results are given in parentheses to indicate FSI cross-feed. Note that σ appears only in the $\pi^- \pi^+$, $\pi^0 \pi^0$, $K^- K^+$, $K^0 \bar{K}^0$, $\pi^0 \eta_8$ and $\eta_8 \eta_8$ rescattering subset. The $\chi^2_{\min.}$ and fitted parameters are given in Table IV. The $\chi^2_{\min.}/\text{d.o.f.}$ for Fit 1 and 2 are 17/5 (giving $\phi_3 \cong 96^\circ$) vs. 25/6, and the former seems better. Both fits are much worse without FSI: $\chi^2_{\min.}/\text{d.o.f.}$ is 50/7 (65/8) for Fit 1 (2), as seen in the last column of Table IV. For illustration, we obtain output errors for both Tables by scanning the $\chi^2 \leq \chi^2_{\min.} + 1$ parameter space.

Let us illustrate the roles played by various inputs. The $K\pi$ rates are now measured with some precision. As before, together with the large $K^- \pi^+/\pi^- \pi^+$ ratio, these are the main driving force for large ϕ_3 [1, 23]. What

is new is the pull of A_{CPs} . With the 3σ effect from Belle gone, $A_{\text{CP}}(K^0 \pi^-)$ is consistent with zero and not very constraining. But the A_{CPs} in $K^- \pi^+$ now has some significance ($\sim 2\sigma$), with the central value *opposite in sign* with respect to factorization, which may call for [7] rescattering. We illustrate in Fig. 1 the δ dependence of $A_{\text{CP}}(K^- \pi^+,0)$. Indeed, we see that for both fits, a finite, positive $\sin \delta$ can turn the two A_{CPs} negative. Note that BaBar and CLEO give a negative $A_{\text{CP}}(K^- \pi^0)$, while the present Belle result flips sign from its previous result and prefers a positive asymmetry. Although $\sin \delta < 0$ is allowed by rate data, it is disfavored by $A_{\text{CP}}(K^- \pi^+)$. The two modes compete and settle on the fit output of $\delta \sim 65^\circ$, i.e. the $A_{\text{CP}}(K^- \pi^+)$ preference for larger δ is held back by $A_{\text{CP}}(K^- \pi^0)$. A similar tug of war is seen between the rates of $\bar{K}^0 \pi^0$ (and $\pi^- \pi^+$) vs. $K^- \pi^{+,0}$, $\bar{K}^0 \pi^-$.

As remarked earlier, the stringent bounds on $K^- K^{0,+}$ rates require special care. The limits are not Gaussian so should not enter the χ^2 fit, but were enforced as strict

TABLE IV: The $\chi^2_{\min.}$ and fitted parameters for Fits 1, 2. We constrain $f_\pi F_0^{BK}/f_K F_0^{B\pi} = 0.9 \pm 0.1$, and $1/m_s^{\text{eff}}$ gives the effective chiral enhancement for $\langle O_6 \rangle$ [21]. The last column is for ϕ_3 free (fixed) without FSI phases.

	Fit 1	Fit 2	No FSI
$\chi^2_{\min.}/\text{d.o.f.}$	17/5	25/6	50/7 (65/8)
ϕ_3	$(96^{+21}_{-10})^\circ$	[60°]	106° ([60°])
δ	$(67^{+21}_{-11})^\circ$	$(63^{+6}_{-0})^\circ$	—
σ	$(90^{+14}_{-59})^\circ$	$(103^{+0}_{-4})^\circ$	—
$F_0^{B\pi}$	$0.29^{+0.04}_{-0.02}$	$0.24^{+0.00}_{-0.01}$	0.25 (0.16)
F_0^{BK}	$0.33^{+0.05}_{-0.06}$	$0.27^{+0.00}_{-0.02}$	0.27 (0.18)
m_s^{eff} (MeV)	81^{+26}_{-14}	57^{+1}_{-3}	66 (35)

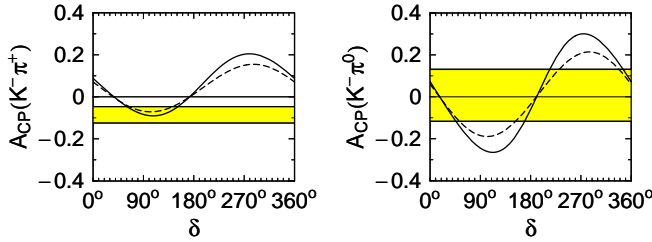


FIG. 1: $A_{CP}(K^-\pi^{+,0})$ vs. δ . Solid (dashed) line is for Fit 1 (Fit 2), and shaded bands are 1σ experimental ranges.

bounds. As can be seen from Table III, while the fitted K^-K^0 rate is below the bound, for K^-K^+ the Fit 2 output sits right at the bound. For Fit 1 it is also rather close. This implies sensitivity to the bounds and the way they are implemented. In Fig. 2 we give the δ (σ) dependence of $K^-K^{0(+)}$ and the bounds that we employ. Note that a vanishing K^+K^- rate is possible with finite σ . We stress that data is still fluctuating, as both BaBar and Belle have raised their bounds on K^-K^0 rates from the summer 2002 results.

Unlike K^0K^- mode which is already $\sim 10^{-6}$ under factorization, K^-K^+ is very suppressed hence sensitive to FSI. Fig. 2(b) illustrates some subtlety of our SU(3) FSI fit. From Eq. (4), if $\delta_{\mathbf{1}}$, $\delta_{\mathbf{8}}$, $\delta_{\mathbf{27}}$ are all randomly sizable, one would expect $K^-K^+ \sim \pi^-\pi^+ > 10^{-6}$, which is realized in Fig. 2(b) for $|\delta - \sigma| \gtrsim 60^\circ$. But this is ruled out by the absence of K^-K^+ so far. However, as also can be seen from Fig. 2(b), for $|\delta - \sigma| \lesssim 50^\circ$, the K^-K^+ rate can be comfortably below the present limit, *while* δ , σ *can be separately large*. The subtlety is traced to the SU(3) decomposition

$$\langle (\pi\pi)_{I=0} | \mathcal{S}^{\frac{1}{2}} | (\pi\pi)_{I=0} \rangle = \left(\frac{3}{8} e^{i\delta_{\mathbf{1}}} + \frac{3}{5} e^{i\delta_{\mathbf{8}}} + \frac{1}{40} e^{i\delta_{\mathbf{27}}} \right).$$

Thus, because of the small weight of $\mathbf{27} \rightarrow \mathbf{27}$ in the $I = 0$ $\pi\pi \rightarrow \pi\pi$ amplitude, when $\delta_{\mathbf{8}} \sim \delta_{\mathbf{1}}$, i.e. $\delta \sim \sigma$, one finds $|\langle (\pi\pi)_{I=0} | \mathcal{S}^{\frac{1}{2}} | (\pi\pi)_{I=0} \rangle| \simeq 1$, and “leakage” to $|(K\bar{K})_{I=0}\rangle$ is suppressed. Note that $K^0\bar{K}^0 \sim K^0K^-$ also remains little perturbed.

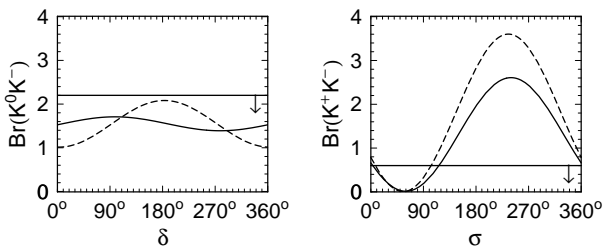


FIG. 2: Rates ($\times 10^6$) for (a) K^0K^- vs. δ and (b) K^+K^- vs. σ . Solid (dashed) line is for Fit 1 (Fit 2), with δ fixed at 55° (61°) in (b). See text for choice of experimental limits.

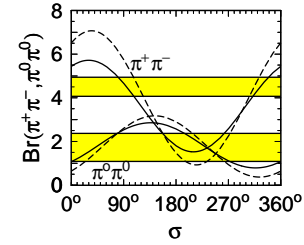


FIG. 3: $\pi^+\pi^-$ and $\pi^0\pi^0$ rates ($\times 10^6$) vs. σ . Solid (dashed) line is for Fit 1 (Fit 2) with δ fixed at 67° (63°). Horizontal bands are 1σ experimental ranges.

While $\sin \sigma < 0$ is strongly disfavored by K^-K^+ mode, the driving force for large σ rests in the $\pi\pi$ sector, where *all* measurables turn out to be volatile — *all* three rates and $A_{\pi\pi}$, $S_{\pi\pi}$. The $\pi^-\pi^+$ and $\pi^0\pi^0$ rates are sensitive to both δ and $\sigma = \delta_{\mathbf{27}} - \delta_{\mathbf{1}}$. To illustrate, we fix δ to the fit values of Table IV and plot in Fig. 3 the $\pi^-\pi^+$, $\pi^0\pi^0$ rates vs. σ . The two fits are similar and clearly favor large $\sigma \sim 90, 103^\circ$, as given in Table IV. The driving force for large σ is the smallness of $\pi^-\pi^+$ rate. For instance, if ϕ_3 went upward by 1σ in Fit 1, i.e. $\phi_3 \sim 117^\circ$, the stress from $\pi^-\pi^+$ rate would be greatly released and σ can come down to $\sim 31^\circ$. But for Fit 2 where ϕ_3 is held fixed at 60° , one needs more FSI to reduce $\pi^-\pi^+$ rate by shifting it partly to $\pi^0\pi^0$. It is therefore intriguing that *both Belle and BaBar have hints for the latter!*

At this point we note that the $\pi^-\pi^0$ rate in Fit 2 is $\sim 3\sigma$ below experiment, and accounts for most of the χ^2 difference between Fits 1 and 2. Unless both experiments are wrong, this makes Fit 2 less desirable; further symptoms are the need for larger $1/m_s^{\text{eff}}$ and lower $F_0^{B\pi(K)}$. The situation comes about because, with low ϕ_3 , it is hard to get low $\pi^-\pi^+$ rate, even with rescattering. The fit resorts to reducing $F_0^{B\pi}$ by 20% (vs. Fit 1), hence reducing $\pi\pi$ rates by 36%. Since $\pi^-\pi^0$ rate is independent of ϕ_3 and FSI, this makes $\pi^-\pi^0$ too small.

What is intriguing — and makes considering Fit 2 worthwhile — is $A_{\pi\pi}$ and $S_{\pi\pi}$. We plot these in Fig. 4 with δ fixed at fit values of Table IV. While we are aware that the two experiments are in conflict, we have forcefully “combined” the present Belle [11] and BaBar [12] results (with enlarged error bars) in the plots. The experiments do, however, agree on the *sign* of $A_{\pi\pi}$: Belle finds $0.77 \pm 0.27 \pm 0.08$, and BaBar finds $0.30 \pm 0.25 \pm 0.04$ ($\equiv -C_{\pi\pi}$). With $\sigma \simeq 100^\circ$, Fits 1 and 2 return $A_{\pi\pi} \simeq 0.12$, which agree with data in sign. Without the FSI phases, both fits would give opposite sign.

As a measure of direct CP violation, $A_{\pi\pi}$ is clearly sensitive to FSI phases, but it does not distinguish much between Fits 1 and 2; most results (except $\pi^-\pi^0$) are not that different. It is $S_{\pi\pi}$, which probes the CP phase of the combined mixing and decay amplitudes, that is sensitive to ϕ_3 , as is evident in Fig. 4(b). Various A_{CP} s and rates have constrained $\sin \delta > 0$ and $\sin \sigma > 0$. We

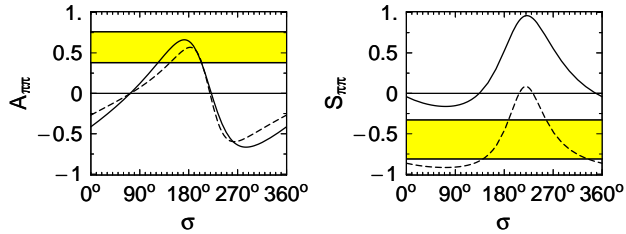


FIG. 4: (a) $A_{\pi\pi}$ and (b) $S_{\pi\pi}$ vs. σ , with notation as in Fig. 3.

have checked that $S_{\pi\pi}$ is not just flat in σ for $\sin \sigma > 0$ and $\delta \simeq 65^\circ$, as seen from Fig. 4(b), but is relatively flat for all δ , $\sigma \lesssim 180^\circ$. The sensitivity with ϕ_3 gives rise to intriguing results. *Fit 1* gives $\phi_3 \cong 96^\circ$, and $S_{\pi\pi} \sim -15\%$ is *consistent with BaBar*. However, sensitivity to ϕ_3 brings $S_{\pi\pi}$ up to 50% for $\phi_3 = 117^\circ$. For *Fit 2*, one fixes $\phi_3 = 60^\circ$ to the CKM fit value, and $S_{\pi\pi} \sim -0.9$ is *consistent with Belle*. We have included *Fit 2* in large part because of the present volatility in $S_{\pi\pi}$. Otherwise it has much poorer χ^2 .

It is useful to compare with the elastic (SU(2) or isospin) case given in Ref. [7]. For the whole range of δ and $|\delta - \sigma| \lesssim 70^\circ$, the summed rates in $K^-\pi^+ - \bar{K}^0\pi^0$ ($\bar{K}^0\pi^- - K^-\pi^0$) and $\pi^-\pi^+ - \pi^0\pi^0$ systems vary by no more than few% and 20%, respectively. We can reproduce the results of Ref. [7] for this parameter range by taking $\delta_{K\pi} \equiv \delta_{3/2} - \delta_{1/2} \sim \arg(1 + 9e^{i\delta})$ and $\delta_{\pi\pi} \equiv \delta_2 - \delta_0 \sim \arg(1 + 24e^{i\delta} + 15e^{i\sigma})$ [24]. We see from Fig. 4(a) that, to reach the Belle and BaBar “average” $A_{\pi\pi}$, a very large $\sigma \sim 180^\circ$ (hence large deviation from SU(2)) would be called for. This situation is not supported by the absence of K^-K^+ and the fact that $\pi^-\pi^+ > 4 \times 10^{-6}$.

IV. DISCUSSION AND CONCLUSION

Some remarks are now in order. First, the $S_{\pi\pi}$ sensitivity to ϕ_3 and its numerics are similar to other discussions [3, 5, 25], except we show that $S_{\pi\pi}$ is *insensitive* to FSI for $\sin \delta$, $\sin \sigma > 0$. Second, with current data, not

only $\pi^0\pi^0 \gtrsim 10^{-6}$, but also K^-K^0 , $K^-K^+ \sim 10^{-6}$ are inevitable for our rescattering model. Besides the rates of $\pi^-\pi^+$, $\pi^0\pi^0$, they are largely driven by $A_{CP}(K^-\pi^+)$ (otherwise sign would be wrong). It is also strongly suggested by the need to change sign for $A_{\pi\pi}$. With a factorization contribution at 10^{-6} level, K^-K^0 should be seen soon, but for K^-K^+ , it is possible to get vanishing rates at $\sigma \simeq \delta$, the “SU(2) limit”. Third, our $\pi^-\eta_8$ rate is quite low and the A_{CP} is opposite to the experimental result. This may be due to our inability to treat η_1 , or indicate an experimental problem, or both. Four, it has been pointed out that subleading, flavor exchange $PP \rightarrow PP$ scattering need not be small at m_B scale [16]. Note the present δ and σ phases are *effective* [7] parameters beyond factorization. Their link to the actual $PP \rightarrow PP$ phases are nontrivial and has to be studied further. Fifth, a fully SU(3) analysis also hints at large FSI phases [26].

Finally, let us compare with (P)QCD factorization approaches. For QCD factorization, removing all subleading effects (hence \sim naive factorization) gives better fit [22] to $K\pi$, $\pi\pi$ rates. To account for A_{CP} s, Ref. [3] resorts to a sizable *complex* $X_{H,A}$ hadronic parameter, which is a form of large strong phase. PQCD factorization fares better with A_{CP} s [27] by having a sizable absorptive part in some penguin annihilation diagrams. But it gives a larger $\pi^-\pi^+$ and a smaller $\pi^-\pi^0$ rate than data, the absence of $\pi^0\pi^0$, while K^-K^+ is always very small [28]. Our results can therefore be distinguished from QCD and PQCD factorization approaches.

In summary, we find that a minimal extension of two quasi-elastic SU(3) FSI phases, δ and σ , can suffice to account for current charmless B decay data. The observables to be tested in the near future are: sign of A_{CP} s, with $A_{CP}(K^-\pi^0) \simeq -20\%$; the rates of $\pi^0\pi^0 \gtrsim 10^{-6}$, $K^-K^+ \lesssim 10^{-6}$; $A_{\pi\pi} > 0$, and $S_{\pi\pi}$ could, depending on ϕ_3 , agree with either BaBar or Belle values. The $\pi^-\pi^0$ rate should be double checked. Many A_{CP} s are large and have sign flipped, but can only be checked later. More details of the present work would be given elsewhere.

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