Rescattering effects in charmless $\bar{B}_{u,d,s} \to PP$ decays

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Final-state interaction effects in charmless $\bar{B}_{u,d,s} \to PP$ decays are studied. We investigate the $\bar{B}^0 \to \pi^+\pi^-$, $\pi^0\pi^0$ rates and the $K\pi$ direct CP violations, which lead to the so-called $K\pi$ puzzle in CP violation. Our main results are as follows: (i) Results are in agreement with data in the presence of FSI. (ii) For $\bar{B}^0$ decays, the $\pi^+\pi^-$ and $\pi^0\pi^0$ rates are suppressed and enhanced respectively by FSI. (iii) The FSI has a large impact on direct CP asymmetries $\langle A \rangle$ of many modes. (iv) The deviation $\langle \Delta A \rangle$ between $A(\bar{B}^0 \to K^-\pi^+) + A(B^- \to K^-\pi^+)$ can be understood in the FSI approach. (v) Sizeable and complex color-suppressed tree amplitudes, which are crucial for the large $\pi^0\pi^0$ rate and $\Delta A$, are generated through exchange rescattering. (vi) The $B^- \to K^-\pi^0$ direct CP violation is very small and is not affected by FSI. (vii) Several $\bar{B}$ decay rates are enhanced. In particular, the $\eta'\eta'$ branching ratio is enhanced to the level of $1.0 \times 10^{-4}$. (viii) Time-dependent CP asymmetries $S$ in $\bar{B}_{u,d,s}$ decays are studied. The $\Delta S(\bar{B}^0 \to K_S\eta')$ is very small ($\leq 1\%$). We found that the asymmetries $|S|$ for $\bar{B}^0 \to \eta\eta'$ and $\eta'\eta'$ decays are all below 0.06. CP asymmetries in these modes will be useful to test the SM.

1. Introduction

The study of $B$ decays provides many useful information of the flavor sector of the Standard Model (SM) and it also enables us to search for possible New Physics effects. Recently there are many interesting results: (a) The measurements of the time-dependent CP asymmetries in kaon and charmonium final states give a rather precise value of $\sin 2\beta = 0.681 \pm 0.025 \left[1\right]$, where $\beta/\phi_1 = \text{arg}(V_{tb}^*)$ with $V$ the Cabbibo-Kobayashi-Maskikawa (CKM) matrix. In the SM, time-dependent CP asymmetries in penguin dominated modes are expected to be close to the $\sin 2\beta$ value. Consequently, these asymmetries are promising places to search for new physics effects [2]. (b) Although $A(\bar{B}^- \to K^-\pi^0) \sim A(\bar{B}^0 \to K^-\pi^0)$ was expected in many early theoretical predictions [3, 4], the recent measurements show $A(K^-\pi^0) = (-9.8^{+1.2}_{-1.1})\%$ and $A(K^-\pi^0) = (5.0 \pm 2.5)\% [1]$, giving $A(K^-\pi^0) - A(K^-\pi^+) = (14.8^{+2.7}_{-2.8})\%$, which is more than 5 $\sigma$ from zero. This is the so-called $K\pi$ puzzle in direct CP violation. (d) The observed large $\bar{B}^0 \to \pi^0\pi^0$ rate [1] is puzzling and posing tension in many theoretical calculations. (e) Data for $\bar{B}_s$ decays are starting to emerge from the Tevatron [1] and from $B$ factories, and we anticipate more to come in the near future. Measurements of rates and CP asymmetries in $\bar{B}_s$ decays will be useful in testing the SM and in searching for new (physics) phases. In fact, recently, a claim on the evidence of new physics effect in the $\bar{B}_s$ mixing was put forward [3].

Before we can claim on New Physics effects in the above puzzles, it is important to investigate these processes within the SM carefully. As shown in Fig. 4, final state interaction (FSI) may affect $\bar{B} \to \pi^0\pi^0$ and $K^-\pi^0$ amplitudes and, hence, may help to resolve the the $\pi\pi$ and $K\pi$ puzzles at the same time [4]. In Fig. 5, we consider a FSI approach with both short- and long-distance contributions, where the former are from in-elastic channels and are contained in factorization amplitudes, while the latter are from the residual rescattering among $PP$ states. We have

$$A_i^{FSI} = \sum_{j=1}^{n} (S_{res}^{1/2})_{ij} A_j^{fac},$$

where $i, j = 1, \ldots, n$ denote all charmless $PP$ states, $A_j^{fac}$ is the factorization amplitude. The residual rescattering effect is encoded in the $S_{res}$ matrix. In factorization approaches, the above $S_{res}$ is taken to be unity. For the factorization amplitudes, we use those obtained in the QCD factorization approach [2]. Since strong interaction has (an approximate) SU(3) symmetry, which is expected to be a good one at the $m_B$ rescattering scale and, hence, can be used to constrain the form of $S_{res}$. From SU(3) symmetry and the Bose-Einstein statistics, we have

$$(S_{res})^{1/2} = \sum_{a=1}^{27} |27; a\rangle e^{i\delta_{27}} (27; a) + \sum_{b=1}^{8} \sum_{p,q=8,8'} |p; b\rangle U_{pq}^{1/2} (q; b) + \sum_{p,q=1,1'} |p; 1\rangle V_{pq}^{1/2} (q; 1),$$

where $\delta_{27}$ is the SU(3) phase.
main FSI source in this sector, can produce a color-suppressed tree amplitude for the $B$ amplitudes. The rescattering leads to the desired large and complex color-suppressed amplitude in the $K$ mode can be generated from the exchange rescattering of $\bar{B}$ DP, $P P$ rescatterings from SU(3) symmetry have been used in [8, 9].

After the residual FSI is turned on, some rates are enhanced remarkably. We see that impact on direct CP violations of many modes. We concentrate on the modes that lead to the results. The residual FSI has a more prominent effect on $\pi$ and $\delta$ rates are reduced and enhanced, respectively, as $\pi$ exchange rescattering. At the same time, the $K$ transitions receive large contributions from the residual FSI. In particular, through the residual FSI, $\bar{B}^0 \rightarrow \pi^0 \pi^0$, $B^- \rightarrow K^- \pi^0$ and $\bar{B}_s \rightarrow \eta^{(l)} \bar{\eta}^{(l)}$ decays.

2. Results

In Table 1, we show the CP-average rates and direct CP violations of $\bar{B}^0, B^-, \bar{B}_s \rightarrow PP$ decays [8]. In the table, Fac and FSI denote factorization and FSI results, respectively.

We discuss the rates in $\bar{B}^0$ and $B^-$ decays first. As shown in Table 1, the residual FSI results agree with data. After the residual FSI is turned on, some rates are enhanced remarkably. We see that $\bar{B}^0$ decays in the $\Delta S = 0$ transitions receive large contributions from the residual FSI. In particular, through the residual FSI, $\bar{B}^0 \rightarrow \pi^+ \pi^-$ and $\pi^0 \pi^0$ rates are reduced and enhanced roughly by factor 2, respectively, leading to a better agreement with data. In Fig. 2(a), we show the $\bar{B}^0 \rightarrow \pi^+ \pi^-$ and $\pi^0 \pi^0$ rates versus the FSI phase $\delta$. We see that $\bar{B}^0 \rightarrow \pi^+ \pi^-$ and $\pi^0 \pi^0$ rates are reduced and enhanced, respectively, as $\delta$ is increasing. Both rates reach the measured ones at $\delta \sim 0.3\pi$.

It is known that in order to have the $\pi^0 \pi^0$ rate as large as observed, we need a sizable color-suppressed tree amplitude [10]. In the residual FSI, a large color-suppressed tree contribution can be generated from the exchange rescattering. As shown in the upper part of Fig. 1, the color-allowed tree amplitude of the $\bar{B}^0 \rightarrow \pi^+ \pi^-$ decay, the main FSI source in this sector, can produce a color-suppressed tree amplitude for the $\bar{B}^0 \rightarrow \pi^0 \pi^0$ decay through the exchange rescattering. At the same time, the $\pi^+ \pi^-$ rate is reduced as it rescatters.

We turn to results for direct CP asymmetries in $\bar{B}^0, B^- \rightarrow PP$ decays. In general, the residual FSI has a large impact on direct CP violations of many modes. We concentrate on the modes that lead to the $K\pi$ puzzle. From Table 1, we see that before the residual FSI is turned on (i.e. taking $S_{res} = 1$), we have $A(\bar{B}^0 \rightarrow K^- \pi^+) \approx A(B^- \rightarrow K^- \pi^0) \approx -0.12$. After turning on the residual FSI ($S_{res} \neq 1$), the asymmetry $A(\bar{B}^0 \rightarrow K^+ \pi^-)$ changes from $\sim -0.12$ to $\sim -0.09$, while $A(B^- \rightarrow K^- \pi^0)$ changes from $\sim -0.12$ to $\sim +0.05$, reproducing the experimental results. The residual FSI has a more prominent effect on $A(B^- \rightarrow K^- \pi^0)$, and, hence, it is capable of lifting the degeneracy of $A(B^- \rightarrow K^- \pi^0)$ and $A(\bar{B}^0 \rightarrow K^+ \pi^-)$. It is known that a sizable and complex color-suppressed tree amplitude in the $B^- \rightarrow K^- \pi^0$ decay can solve the $K\pi$ puzzle [10]. As depicted in Fig. 1, a color-suppressed tree amplitude in the $K^- \pi^0$ mode can be generated from the exchange rescattering of $B^- \rightarrow K^- \eta^{(l)}$ color-allowed tree amplitudes. The rescattering leads to the desired large and complex color-suppressed amplitude in the $K^- \pi^0$ mode.

\[ \begin{align*}
\text{Fig. 1: Exchange rescattering in } & \bar{B}^0 \rightarrow \pi^0 \pi^0, \ B^- \rightarrow K^- \pi^0 \text{ and } \bar{B}_s \rightarrow \eta^{(l)} \bar{\eta}^{(l)} \text{ decays.}
\end{align*} \]
| Mode          | $B^{\exp}(10^{-6})$ | $B^{\text{Frac}}(10^{-6})$ | $B^{\text{FSI}}(10^{-6})$ | $A^{\exp}(\%)$ | $A^{\text{Frac}}(\%)$ | $A^{\text{FSI}}(\%)$ |
|--------------|---------------------|-----------------------------|---------------------------|----------------|------------------------|------------------------|
| $B^0 \to K^-\pi^+$ | 19.4 ± 0.6          | (16.0)                      | 20.1± 2.5                  | −9.8 ±0.1     | −11.8 ±0.2             | 9.0 ±2.2               |
| $B^0 \to \overline{K}^0\pi^0$ | 9.8 ± 0.6          | (7.2)                       | 9.3±0.7 ±1.3               | −1 ±0.3       | 3.3 ±1.7               | −12.8± 2.4             |
| $B^0 \to K^-\eta$  | 1.0 ± 0.3           | (0.9)                       | 1.4±0.4 ±0.5               | −0.1 ±0.1     | −10.7 ±0.1             | −19.9 ±1.9             |
| $B^0 \to K^-\eta'$ | 64.9 ± 3.1         | (66.4)                      | 65.9±0.9 ±9.2              | 10.6 ±0.3     | 4.8 ±5.9               | 1.7± 0.2               |
| $B^- \to K^-\pi^-$ | 23.1 ± 1.0         | (18.0)                      | 22.5±1.1 ±0.7              | 0.9 ±0.3      | 11.2 ± 1.2             | 0.3 ±1.1               |
| $B^- \to K^-\pi^0$ | 12.9 ± 0.6         | (10.1)                      | 12.4±1.5 ±1.6              | 5.0 ±0.5      | 11.8 ± 1.2             | 4.8±4.1                |
| $B^- \to K^-\eta$  | 2.7 ± 0.3           | (1.4)                       | 2.1±0.6 ±0.6               | −0.1 ±0.1     | −27 ±9.9               | 1.8±4.6                |
| $B^- \to K^-\eta'$ | 70.2 ± 2.5         | (70.1)                      | 70.5±1.6 ±1.3              | 1.6 ±1.9      | 19.7 ± 1.2             | 1.3±0.9                |
| $B^- \to \pi^-\pi^0$ | 5.59 ±0.4           | (5.18)                      | 5.18±0.5 ±0.0              | 6 ±5          | −0.06 ±0.00            | −0.06 ±0.00            |
| $B^- \to K^0\pi^-K^-$ | 1.36 ±0.29         | (1.22)                      | 1.4±0.3 ±0.15              | 12.2 ±3.5     | 16.0 ± 1.6             | 1.3±0.1                |
| $B^- \to \pi^-\eta$ | 4.4 ± 0.4           | (4.00)                      | 4.25±0.5 ±0.3              | −16 ±7        | 19.7 ± 1.2             | 12.3±3.3               |
| $B^- \to \pi^-\eta'$ | 2.7 ±0.6           | (3.00)                      | 3.3±0.4 ±0.6               | 21 ±15        | 22.8 ± 1.3             | 5.4±0.8                |
| $B^- \to \pi^+\pi^-$ | 5.16 ±0.22         | (6.65)                      | 5.3±0.1 ±0.3               | 38 ±15 ±0.5   | 22.3 ± 1.4             | 15.5±10.4              |
| $B^0 \to \pi^0\pi^0$ | 1.55 ±0.35         | (0.50)                      | 1.6±0.5 ±0.0               | 43 ±24        | 58 ±15 ±0.5            | 33.1 ±13.1             |
| $B^0 \to \eta\eta$ | 0.8 ±0.4 (<1.4)     | (0.21)                      | 0.4±0.2 ±0.1               | −11.7 ±0.5    | 0.3 ±0.5               | 0.1 ±0.0               |
| $B^0 \to \eta'\eta'$ | 0.5 ±0.4 (<1.2)     | (0.22)                      | 0.5±0.3 ±0.4               | −28.5 ±0.5    | 7.2 ±0.8               | 2.9±1.4                |
| $B^0 \to K^0\bar{K}^+K^-$ | 0.9 ±0.4           | (0.09)                      | 0.1±0.1 ±0.1               | 41 ±15 ±0.5   | 19 ±0.7               | 1.7±0.6                |
| $B^0 \to K^0\bar{K}^0\eta$ | 0.96 ±0.21         | (1.47)                      | 1.1±0.4 ±0.2               | −58 ±15 ±0.5  | 37 ±15 ±0.5            | 15 ±0.7               |
| $B^0 \to \pi^0\pi^0$ | 0.9 ±0.4 (<1.5)     | (0.26)                      | 0.3±0.1 ±0.1               | 19.7 ±0.7     | 13.5 ±0.5              | 5.4±0.8                |
| $B^0 \to \pi^0\eta'$ | 1.2 ±0.7           | (0.32)                      | 1.4±0.2 ±0.11              | 13 ±20 ±0.5   | 7.2 ±0.7               | 1.3±0.1               |
| $B^0 \to K^-\pi^+$ | 5.00 ±1.25         | (4.72)                      | 4.8±1.1 ±0.5               | 39 ±17        | 26 ±17 ±0.4            | 2.4±1.2               |
| $B^0 \to K^0\pi^0$ | 0.53 ±0.51         | (0.30)                      | 0.8±0.5 ±0.3               | (0)          | −6.1±0.9               | 7.5±6.4               |
| $B^0 \to \pi^0\pi^0$ | 0.53 ±0.51         | (0.30)                      | 0.8±0.5 ±0.3               | (0)          | −6.1±0.9               | 7.5±6.4               |
| $B^0 \to \pi^0\eta'$ | 17.5                | (20.2±7.5±5.9)              | 20.2±12.6 ±4.5             | 6.5±10±6.5   | 16±4.6                 | 1.6±1.4               |
| $B^0 \to \pi^0\eta'$ | 70.8                | (63.6±4.7±14.7)             | 63.6±19.7 ±9.2             | 0.4±0.2±1±1  | 0±1±0.1               | 0±0±0.1               |
| $B^0 \to \eta'\eta'$ | 81.9                | (99.1±6.9±15.2)             | 99.1±23.6 ±13.4            | 0.2±0±4     | 5.3±0.5                | 0±0±0.1               |
| $B^0 \to K^0\bar{K}^0$ | 24.4 ±4.8          | (24.7)                      | 24.2±2.1 ±3.0              | (−11.9 ±0.5) | −11.9±2.3              | 1.5±4.8               |
| $B^0 \to K^0\bar{K}^0\pi^0$ | 25.4                | (20.4±12.1±3.8)             | 20.4±18.1 ±1.3             | (0.3)        | 2.2±1.8±1.2            | 0.3±0.1               |
| $B^0 \to \pi^\pm\pi^\mp$ | 0.06                | (0.13)                      | 0.1±0.0±0.0                | (39)         | 8.2±5.5                | 4.2±0.7               |
| $B^0 \to \pi^\pm\pi^\mp$ | 0.09                | (0.09)                      | 0.1±0.0±0.0                | (37.5)       | 9.3±2.7                | 15.5±4.4              |

*S factors of $^a1.8, ^b1.7, ^c1.4 and $^d2.4 are included in the uncertainties, respectively.*

and resolves the $K\pi$ direct CP violation puzzle without the need of introducing any new physics contribution.

As noted before, the exchange rescattering is also responsible for the enhancement of the $T^\pi \to \pi^0\pi^0$ rate. In Fig. 2(d), we show a two-dimensional plot, exhibiting the correlation of the ratio $B(B^0 \to \pi^0\pi^0)/B(B^0 \to \pi^+\pi^-)$ with the difference $\Delta A \equiv A(T^0 \to K^-\pi^+) - A(B^- \to K^-\pi^0)$. The light shaded area corresponds to the restricted SU(3) case, the dark shaded area and the solid line correspond to the exchange-type U(3) case. We clearly see that the data can be easily reproduced and the exchange rescattering is responsible for generating sizable and complex color-suppressed tree amplitudes that account for the difference $\Delta A$ and the $B(B^0 \to \pi^0\pi^0)/B(B^0 \to \pi^+\pi^-)$ ratio at the same time.

We also note that the direct CP violation of $B^- \to \pi^-\pi^0$ is very small and does not receive any contribution from the residual rescattering, since it can only rescatter into itself. The $A(B^- \to \pi^-\pi^0)$ measurement remains as a clean
Figure 2: (a) $B^+ \to \pi^+ \pi^-$, $\pi^0 \pi^0$ rates, (b) $B_d^\pm \to \eta^(') \eta^(')$ rates and (c) direct CP violations of $\bar{B}^0 \to K^- \pi^+$ and $B^- \to K^- \pi^0$ versus the FSI phase $\delta$ are plotted. The solid (dashed) line corresponds to the SU(3) (exchange-type U(3)) case. Bands are 1-$\sigma$ ranges of data. Theoretical uncertainties are not shown. Note that the fitted $\delta/\pi$ is around 0.3. (d) Correlation of the ratio $B(\bar{B}^0 \to \pi^0 \pi^0)/B(\bar{B}^0 \to \pi^+ \pi^-)$ with the difference $\Delta A \equiv A(K^- \pi^+) - A(K^- \pi^0)$ is also plotted. The light shaded area corresponds to the restricted SU(3) case, the dark shaded area and the solid line correspond to the exchange-type U(3) case.

way to search for new physics effects [11].

We now turn to $B_s$ decays. Comparing to data, we see from Table II that the $B(\bar{B}_s \to K^- \pi^+)$, $B(\bar{B}_s \to K^+ K^-)$

Table II: Results on the time-dependent CP asymmetry $S$ of various $\bar{B}_{d,s} \to PP$ modes.

| Mode                  | $S^{Exp}(B_d)$  | $S^{Fac}(B_d)$ | $S^{FSI}(B_d)$ | $S^{Exp}(B_s)$  | $S^{Fac}(B_s)$ | $S^{FSI}(B_s)$ |
|-----------------------|-----------------|----------------|----------------|-----------------|----------------|----------------|
| $\bar{B}^0_{d,s} \to K_S \pi^0$ | $0.58 \pm 0.17$ | $(0.780)$  | $0.778^{+0.003+0.014+0.003}_{-0.037-0.015-0.002}$ | $-0.747^{+0.074}_{-0.057}$ | $(0.751)$  | $0.516^{+0.058+0.015+0.003}_{-0.095-0.034-0.074}$ |
| $\bar{B}^0_{d,s} \to K_S \eta$     | $-0.085$       | $(0.831)$  | $0.769^{+0.010+0.030+0.000}_{-0.040-0.030-0.001}$ | $-0.700^{+0.030+0.008+0.000}_{-0.039-0.005-0.000}$ | $(0.700)$  | $0.700^{+0.010+0.020+0.001}_{-0.016-0.005-0.001}$ |
| $\bar{B}^0_{d,s} \to K_S \eta^(')$ | $-0.095$       | $(0.845)$  | $0.845^{+0.010+0.020+0.001}_{-0.015-0.009-0.000}$ | $-0.700^{+0.010+0.020+0.001}_{-0.015-0.009-0.000}$ | $(0.700)$  | $0.700^{+0.010+0.020+0.001}_{-0.015-0.009-0.000}$ |
| $\bar{B}^0_{d,s} \to \pi^+ \pi^-$   | $-0.085$       | $(0.831)$  | $0.769^{+0.010+0.030+0.000}_{-0.040-0.030-0.001}$ | $-0.700^{+0.030+0.008+0.000}_{-0.039-0.005-0.000}$ | $(0.700)$  | $0.700^{+0.010+0.020+0.001}_{-0.016-0.005-0.001}$ |
| $\bar{B}^0_{d,s} \to \pi^0 \pi^0$  | $-0.085$       | $(0.831)$  | $0.769^{+0.010+0.030+0.000}_{-0.040-0.030-0.001}$ | $-0.700^{+0.030+0.008+0.000}_{-0.039-0.005-0.000}$ | $(0.700)$  | $0.700^{+0.010+0.020+0.001}_{-0.016-0.005-0.001}$ |
| $\bar{B}^0_{d,s} \to \eta^(') \eta^(')$ | $-0.095$       | $(0.845)$  | $0.845^{+0.010+0.020+0.001}_{-0.015-0.009-0.000}$ | $-0.700^{+0.010+0.020+0.001}_{-0.015-0.009-0.000}$ | $(0.700)$  | $0.700^{+0.010+0.020+0.001}_{-0.015-0.009-0.000}$ |
| $\bar{B}^0_{d,s} \to \eta \eta' $   | $-0.085$       | $(0.831)$  | $0.769^{+0.010+0.030+0.000}_{-0.040-0.030-0.001}$ | $-0.700^{+0.030+0.008+0.000}_{-0.039-0.005-0.000}$ | $(0.700)$  | $0.700^{+0.010+0.020+0.001}_{-0.016-0.005-0.001}$ |
| $\bar{B}^0_{d,s} \to \eta \eta' $   | $-0.085$       | $(0.831)$  | $0.769^{+0.010+0.030+0.000}_{-0.040-0.030-0.001}$ | $-0.700^{+0.030+0.008+0.000}_{-0.039-0.005-0.000}$ | $(0.700)$  | $0.700^{+0.010+0.020+0.001}_{-0.016-0.005-0.001}$ |
| $\bar{B}^0_{d,s} \to K^+ K^-$          | $-0.085$       | $(0.831)$  | $0.769^{+0.010+0.030+0.000}_{-0.040-0.030-0.001}$ | $-0.700^{+0.030+0.008+0.000}_{-0.039-0.005-0.000}$ | $(0.700)$  | $0.700^{+0.010+0.020+0.001}_{-0.016-0.005-0.001}$ |
| $\bar{B}^0_{d,s} \to \bar{K}^0 K^0$  | $-0.085$       | $(0.831)$  | $0.769^{+0.010+0.030+0.000}_{-0.040-0.030-0.001}$ | $-0.700^{+0.030+0.008+0.000}_{-0.039-0.005-0.000}$ | $(0.700)$  | $0.700^{+0.010+0.020+0.001}_{-0.016-0.005-0.001}$ |
| $\bar{B}^0_{d,s} \to \pi^0 \eta$     | $-0.085$       | $(0.831)$  | $0.769^{+0.010+0.030+0.000}_{-0.040-0.030-0.001}$ | $-0.700^{+0.030+0.008+0.000}_{-0.039-0.005-0.000}$ | $(0.700)$  | $0.700^{+0.010+0.020+0.001}_{-0.016-0.005-0.001}$ |
| $\bar{B}^0_{d,s} \to \pi^0 \eta'$    | $-0.085$       | $(0.831)$  | $0.769^{+0.010+0.030+0.000}_{-0.040-0.030-0.001}$ | $-0.700^{+0.030+0.008+0.000}_{-0.039-0.005-0.000}$ | $(0.700)$  | $0.700^{+0.010+0.020+0.001}_{-0.016-0.005-0.001}$ |
rates agree well with data, while the data on $B_s(\bar{B}_s \to \pi^+\pi^-)$ and $A(\bar{B}_s \to K^-\pi^+)$ can be reproduced, the results have large uncertainties. We expect the residual FSI to have sizable contributions to various $\bar{B}_s \to PP$ decay rates (see the lower diagram in Fig. 1). The plot of $\bar{B}_s \to \eta(\eta')$ rate versus $\delta$ is shown in Fig. 2(b). The $\bar{B}_s \to \eta(\eta')$ rate is enhanced and reaches 1.0 $\times 10^{-4}$, which can be checked soon. The $\bar{B}_s \to K^0\pi^0, K^0\eta$ modes are also quite sensitive to the residual rescattering. Similar to $\bar{B}_{u,d}$ cases, the residual FSI also has large impacts on many $A(\bar{B}_s \to PP)$.

Results on time-dependent CP-asymmetries $S$ are given in Table II (3). The last uncertainty comes from the variation of $\gamma/\phi_3 = (67.6^{+2.6}_{-4.5})^\circ$ (4). We fit to data on mixing induced CP asymmetries. For $\bar{B}_s^0$ decays, we define $\Delta S = \sin 2\delta_{eff} - \sin 2\beta_{c,K}$, where $\sin 2\beta_{c,K} = -\eta_f S(f)$ with $\eta_f$ the CP eigenvalue of the state $f$. Comparing with the recent value of $\sin 2\beta_{c,K} = 0.671 \pm 0.024$ (5) as measured in $B^0_s \to K +$ charmonium modes, we obtain:

$$\Delta S(K_S\pi^0) = 0.107^{+0.028}_{-0.046} , \quad \Delta S(K_S\eta) = 0.098^{+0.051}_{-0.068} , \quad \Delta S(K_S\eta') = 0.011^{+0.026}_{-0.024}. \quad (3)$$

The $\Delta S(K_S\eta')$, is a promising test of the SM. These $\Delta S(B_s)$ agrees with those found in (6, 7).

For $\bar{B}_s^0$ decays, the $S$ contributed from $\bar{B}_s^0-B_s^0$ mixing itself is around $-0.036$. Hence, for penguin dominated $b \to s$ transition, we do not expect the corresponding $|S|$ to be much larger than $O(0.05)$. Indeed, the predicted $|S|$ as shown in Table II for $\bar{B}_s^\pm \to \eta l^+\nu, \eta^0 l^+\nu$ and $\eta^0 l^+\nu$ decays are all below 0.06. Given the recent interesting preliminary results in the $B_s$ phase (10, 11, 12, 13), it will be very useful to search for $S$ in these $B_s$ charless decays.

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References

[1] C. Amsler et al. [Particle Data Group], Phys. Lett. B 667, 1 (2008); E. Barberio et al., [Heavy Flavor Averaging Group (HFAG)], arXiv:0808.1297 [hep-ex]; online update at http://www.slac.stanford.edu/xorg/hfag; B. Aubert et al. [BABAR Collaboration], arXiv:0804.2422 [hep-ex]; arXiv:0807.4226 [hep-ex]; W. T. Ford, arXiv:0810.0494 [hep-ex].

[2] For recent reviews, see, M. Artuso et al., arXiv:0801.1833 [hep-ph]; C. K. Chua, In the Proceedings of 4th Flavor Physics and CP Violation Conference (FPCP 2006), Vancouver, British Columbia, Canada, 9-12 Apr 2006, pp 008 [arXiv:hep-ph/0605301]; In the Proceedings of 6th Flavor Physics and CP Violation Conference (FPCP 2008), Taipei, Taiwan, 5-9 May 2008 [arXiv:0807.3596 [hep-ph]].

[3] Y. Y. Keum, H. n. Li and A. I. Sanda, Phys. Lett. B 504, 6 (2001); Phys. Rev. D 63, 054008 (2001).

[4] M. Beneke, G. Buchalla, M. Neubert and C. T. Sachrajda, Nucl. Phys. B 606, 245 (2001).

[5] M. Bona et al. [UTfit Collaboration], arXiv:0803.0659 [hep-ph]. D. Tonelli, talk given at ICHEP2008, July 29th. - Aug. 5th., 2008, Philadelphia; J. Ellison, talk given at ICHEP2008, July 29th. - Aug. 5th., 2008, Philadelphia.

[6] C. K. Chua, Phys. Rev. D 78, 076002 (2008).

[7] M. Beneke and M. Neubert, Nucl. Phys. B 675, 333 (2003); Nucl. Phys. B 651, 225 (2003).

[8] C. K. Chua, W. S. Hou and K.C. Yang, Phys. Rev. D 65, 096007 (2002); Mod. Phys. Lett. A 18, 1763 (2003); C. K. Chua and W. S. Hou, Phys. Rev. D 72, 036002 (2005); Phys. Rev. D 77, 116001 (2008).

[9] C. Smith, Eur. Phys. J. C 10, 639 (1999); Eur. Phys. J. C 33, 523 (2004).

[10] C. W. Chiang, M. Gronau, J. L. Rosner and D. A. Suprun, Phys. Rev. D 70, 034020 (2004); Y. Y. Charng and H. n. Li, Phys. Rev. D 71, 014036 (2005); C. W. Chiang and Y. F. Zhou, JHEP 0612, 027 (2006).

[11] H.Y. Cheng, C.K. Chua and A. Soni, Phys. Rev. D 71, 014030 (2005); Phys. Rev. D 72, 014006 (2005).

[12] M. Beneke, Phys. Lett. B 620, 143 (2005).

[13] M. Pierini, J. Phys. Conf. Ser. 110, 052045 (2008); M. Ciuchini et al., unpublished.

[14] J. Charles et al. [CKMfitter Group], Eur. Phys. J. C 41, 1 (2005); online update at http://ckmfitter.in2p3.fr/.