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Long-Distance contribution to $\Delta\Gamma_s$ in the B_s–$\bar{B}_s$ System

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We estimate the long-distance contribution to the width difference of the B_s–$\bar{B}_s$ system, based mainly on two-body $D_s^{(*)}\bar{D}_s^{(*)}$ modes and three-body $D_s^{(*)}\bar{D}^{(*)}\bar{K}^{(*)}$ modes (and their CP conjugates). Some higher $c\bar{s}$ resonances are also considered. The contribution to $\Delta\Gamma_s/\Gamma_s$ by two-body modes is $(10.2\pm3.0)\%$, slightly smaller than the short-distance result of $(13.3\pm3.2)\%$. The contribution to $\Delta\Gamma_s/\Gamma_s$ by $D^*_{s0}(2317)$, $D_{s1}(2460)$, and $D_{s1}(2536)$ resonances is negligible. For the three-body $D_s^{(*)}\bar{D}^{(*)}\bar{K}^{(*)}$ modes, we adopt the factorization formalism and model the form factors with off-shell $D_s^{(*)}$ poles, the $D_{sJ}(2700)$ resonance, and nonresonant contributions. These three-body modes can arise through current-produced or transition diagrams, but only SU(3)-related $D_{u,d}^{(*)}\bar{D}^{(*)}\bar{K}$ modes from the current diagram have been measured so far. The pole model results for $D^*_{u,d}\bar{D}^{(*)}\bar{K}$ agree well with the data, while $D_{u,d}\bar{D}^{(*)}\bar{K}$ rates agree with the data only within a factor of 2 to 3. All measured $D_{u,d}^{(*)}\bar{D}^{(*)}\bar{K}$ rates can be reproduced by including nonresonant contributions. The total $\Delta\Gamma_s/\Gamma_s$ obtained is $(16.7\pm8.5)\%$, which agrees with the short-distance result within uncertainties. For illustration, we also demonstrate the effect of $D_{sJ}(2700)$ in modes with $D^{(*)}K^*$. In all scenarios, the total $\Delta\Gamma_s/\Gamma_s$ remain consistent with the short-distance result. Our results indicate that (a) the operator product expansion in the short-distance picture is a valid assumption, (b) approximating the $B_s \to D_s^{(*)}\bar{D}_s^{(*)}$ decays to saturate $\Delta\Gamma_s$ has a large correction, (c) the effect of three-body modes cannot be neglected, and (d) in addition to the D_s and D_s^* poles, the $D_{sJ}(2700)$ resonance also plays an important role in three-body modes. Future experiments are necessary to improve the estimation of $\Delta\Gamma_s$ from the long-distance point of view.

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The B_s–$\bar{B}_s$ system received a lot of attention recently. Motivated by the dimuon anomaly [1], we estimate the long-distance contribution to the width difference of the B_s–$\bar{B}_s$ system, based mainly on two-body $D_s^{(*)}\bar{D}_s^{(*)}$ modes (updating [2]) and three-body $D_s^{(*)}\bar{D}^{(*)}\bar{K}^{(*)}$ modes (and their CP conjugates) in [3] using the following formulas:

$$\Delta\Gamma_f \equiv -2\times \mathrm{Re}[\Gamma_{12,f}], \quad \Gamma_{12,f} \equiv \frac{1}{2M_B}\int d\Phi \mathscr{A}^*_{B\to f}(\Phi)\mathscr{A}_{\bar{B}\to f}(\Phi), \tag{1}$$

where $\mathscr{A}_{\bar{B}\to f}$ is the color-allowed $\bar{B}\to f$ decay amplitude [see Fig. 1(a) for diagrams of three-body modes]. The factorization approach, which is known to work rather well for color allowed decays, is used to calculate these amplitudes. For three body modes, pole model is employed with nonresonant (NR) contributions included if needed [see Fig. 1(b)].

There has been no measurement on three body $B_s(\bar{B}_s)\to D_s^{(*)}\bar{D}^{(*)}\bar{K}^{(*)}$ modes, so far. However, rates of some SU(3) related modes are measured. Table 1 shows our efforts with different scenarios to reproduce these data, before we turn to $\Delta\Gamma_s$. In Scenario I, $D_s^{(*)}$ and D_{sJ} poles are used, while in Scenario I′, only $D_s^{(*)}$ poles are considered. In Scenario II, NR contributions in $\bar{D}\bar{K}$ time-like form factors are included to demonstrate that the inconsistency with experiments in Scenario I can be resolved. We find that in most cases the experimental results can be reasonably reproduced.

Our main results for $\Delta\Gamma_s$ in scenarios I, II and III (with estimated contributions from $\bar{D}_{sJ}(2700)$–$\bar{D}^{(*)}\bar{K}^*$ coupling included for illustration) are summarized in Table 2. These results can be compared to the short-distance calculation in SM [4], $\Delta\Gamma_{s,\mathrm{SM}}/\Gamma_{s,\mathrm{SM}} = (13.3\pm 3.2)\%$. Although the three scenarios have different theoretical assumptions, it is of interest to note that the resulting $\Delta\Gamma_s$ values are similar. Thus, we give the following concluding remarks. First, the total $\Delta\Gamma_s$ agrees with the short-distance calculation. This demonstrates that the short-distance result and the assumption of OPE are reliable (see also [5]). Second, we find that the effect of three-body modes ($\sim 8\%$) is comparable to two-body modes ($\sim 10\%$). The assumption that two-body decays saturate $\Delta\Gamma_s$ receives a considerable correction. This correction comes from both $D_{sJ}(2700)$ and off-shell $D_s^{(*)}$ poles. We conclude by pointing out some experimental issues where progress can be made in the near future. Two-body modes in B_s decays need to be measured with better precision. For three-body modes, up to now, there has been no measurement of transition modes, nor on modes with K^* in the $B_{u,d}$ system. Even the available measurements in current-produced modes with K contain inconsistencies. In particular, the 2.2σ difference between Belle and BaBar in the $B^-\to D^0\bar{D}^0K^-$ mode has to be resolved. Although the measurements of two and three-body decay rates are useful for refining the theoretical prediction and to set a bound on $\Delta\Gamma_s$, these modes are of interest in their

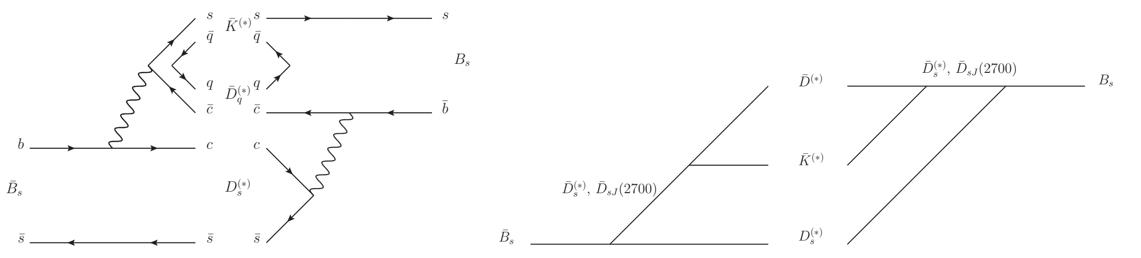

Figure 1: (a) The current and transition diagrams. Left: $\bar{B}_s\to D_s^{(*)}\bar{D}^{(*)}\bar{K}^{(*)}$, current-produced diagram. Right: $B_s\to D_s^{(*)}\bar{D}^{(*)}\bar{K}^{(*)}$, transition diagram. (b) Pole diagrams correspond to (a).

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Measurement	BaBar (%)	Belle (%)	Our Results (%) Scenario I (I′) Pole model w. D_{sJ} (without D_{sJ})	Scenario II Pole model+NR	Remarks
			Category 1: current-produced $\bar{D}\bar{K}$ with $\bar{B} \to D$ transition		
$\mathscr{B}(\bar{B}_u \to D_u \bar{D}_{sJ}(2700)^-)\times$ $\mathscr{B}(\bar{D}_{sJ}(2700)^- \to \bar{D}^0 K^-)$	$\dots$	$0.113^{+0.026}_{-0.040}$	$0.12 \pm 0.08 \pm 0.03$ (0)	$0.12 \pm 0.08 \pm 0.03$	Input for Scenario I
$\mathscr{B}(\bar{B}_u \to D_u \bar{D}^0 K^-)$	0.131 ± 0.014	0.222 ± 0.033	~ 0.23 (~ 0.07)	~ 0.11	Color-suppressed diagram neglected
$\mathscr{B}(\bar{B}_d \to D_d \bar{D}^0 K^-)$	0.107 ± 0.011	$\dots$	$0.22 \pm 0.14 \pm 0.05$ $(0.06 \pm 0.03 \pm 0.01)$	$0.10^{+0.23}_{-0.02} \pm 0.02$	Input for Scenario II
$\mathscr{B}(\bar{B}_d \to D_d \bar{D}_{sJ}(2700)^-)\times$ $\mathscr{B}(\bar{D}_{sJ}(2700)^- \to \bar{D}^0 K^-)$	$\dots$	$\dots$	$0.11 \pm 0.07 \pm 0.02$ (0)	$0.11 \pm 0.07 \pm 0.02$	
			Category 2: current-produced $\bar{D}\bar{K}$ with $\bar{B} \to D^*$ transition		
$\mathscr{B}(\bar{B}_d \to D_d^* \bar{D}^0 K^-)$	0.247 ± 0.021	$\dots$	$0.67 \pm 0.45 \pm 0.14$ $(0.07 \pm 0.03 \pm 0.01)$	$0.32^{+0.75}_{-0.13} \pm 0.07$	Input for Scenario II
$\mathscr{B}(\bar{B}_d \to D_d^* \bar{D}_{sJ}(2700)^-)\times$ $\mathscr{B}(\bar{D}_{sJ}(2700)^- \to \bar{D}^0 K^-)$	$\dots$	$\dots$	$0.50 \pm 0.33 \pm 0.11$ (0)	$0.50 \pm 0.33 \pm 0.11$	
			Category 3: current-produced $\bar{D}^*\bar{K}$ with $\bar{B} \to D$ transition		
$\mathscr{B}(\bar{B}_d \to D_d \bar{D}^{*0} K^-)$	0.346 ± 0.041	$\dots$	$0.35 \pm 0.21 \pm 0.07$ $(0.20 \pm 0.10 \pm 0.04)$	$0.35 \pm 0.21 \pm 0.07$	
$\mathscr{B}(\bar{B}_d \to D_d \bar{D}_{sJ}(2700)^-)\times$ $\mathscr{B}(\bar{D}_{sJ}(2700)^- \to \bar{D}^{*0} K^-)$	$\dots$	$\dots$	$0.11 \pm 0.07 \pm 0.02$ (0)	$0.11 \pm 0.07 \pm 0.02$	
			Category 4: current-produced $\bar{D}^*\bar{K}$ with $\bar{B} \to D^*$ transition		
$\mathscr{B}(\bar{B}_d \to D_d^* \bar{D}^{*0} K^-)$	1.060 ± 0.092	$\dots$	$0.94 \pm 0.62 \pm 0.20$ $(0.15 \pm 0.08 \pm 0.03)$	$0.94 \pm 0.62 \pm 0.20$	
$\mathscr{B}(\bar{B}_d \to D_d^* \bar{D}_{sJ}(2700)^-)\times$ $\mathscr{B}(\bar{D}_{sJ}(2700)^- \to D^{*0} K^-)$	$\dots$	$\dots$	$0.52 \pm 0.33 \pm 0.11$ (0)	$0.52 \pm 0.33 \pm 0.11$	
$\mathscr{B}(\bar{B}_d \to D_d^* \bar{D}^{*+} \bar{K}^0)$	0.826 ± 0.080	$\dots$	~ 0.91 (~ 0.15)	~ 0.91	Color-suppressed diagram neglected
$\mathscr{B}(\bar{B}_d \to D_d^* \bar{D}^{*+} K_S^0)$	0.44 ± 0.08	0.34 ± 0.08	~ 0.46 (~ 0.07)	~ 0.46	Color-suppressed diagram neglected

Table 1: Comparison between experimental results from BaBar and Belle collaborations and our results in Scenario I, II, and I′. See [3] for references and details.

Mode	$\Delta\Gamma_s/\Gamma_s$(%) (Scenario I)	$\Delta\Gamma_s/\Gamma_s$(%) (Scenario II)	$\Delta\Gamma_s/\Gamma_s$(%) (Scenario III)
$D_s^{(*,**)}\bar{D}_s^{(*,**)}$	$10.4 \pm 2.5 \pm 2.2$	$10.4 \pm 2.5 \pm 2.2$	$10.4 \pm 2.5 \pm 2.2$
$D_s^{(*)}\bar{D}^{(*)}\bar{K} + \bar{D}_s^{(*)}D^{(*)}K$	$5.9 \pm 3.6 \pm 1.2$	$4.5 \pm 4.4 \pm 0.9$	$4.5 \pm 4.4 \pm 0.9$
$D_s^{(*)}\bar{D}^{(*)}\bar{K}^* + \bar{D}_s^{(*)}D^{(*)}K^*$	$1.9 \pm 0.9 \pm 0.4$	$1.9 \pm 0.9 \pm 0.4$	$3.4 \pm 1.6 \pm 0.7$
Total	$18.2 \pm 7.0 \pm 3.8$	$16.7 \pm 7.8 \pm 3.5$	$18.2 \pm 8.5 \pm 3.8$

Table 2: Results on $\Delta\Gamma_s/\Gamma_s$ from various contributions and scenarios.

own right. We hope that (Super-) B factories and LHCb can complete the measurements of these missing modes.

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