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Time-dependent CP violation in $B^0 \to K_s^0\phi$, $K_s^0\eta'$ and $K_s^0K^+K^-$ in the Belle and BaBar experiments

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Abstract. Both the Belle and BaBar collaborations have recently measured time-dependent CP violation in B^0 decays to $ss\bar{s}$ states and compared the results to those for $sc\bar{c}$ states for which quite precise results were previously available. Within the framework of the standard model the same results should be expected for both cases. The decays to $ss\bar{s}$ states are dominated by penguin diagrams and may be sensitive to physics beyond the standard model. For these states, compared to the results for $sc\bar{c}$ states, a discrepancy in the mixing-induced CP violation of 2.7 standard deviations was found, and may be interpreted as an indication for physics beyond the standard model.

PACS. 11.30.Er Charge conjugation, parity, time reversal, and other discrete symmetries – 12.15.Hh Determination of Kobayashi-Maskawa matrix elements – 13.25.Hw Decays of bottom mesons

1 Introduction

In the standard model sizable CP violation in B-decay arising from an irreducible complex phase in the Kobayashi-Maskawa quark mixing matrix [1] has been predicted in the time-dependent decay rates for B and $\overline{B}$ decays into a common CP eigenstate [2]. In particular it has been clearly established in the decay of neutral B mesons to charmonium such as $B^0 \to J/\psi K_s^0$ [3] at a rate which is consistent with other information available on the values of the relevant KM matrix elements. These decays are dominated by the tree $b \to c$ amplitudes. However it is desirable to make other tests of the standard model, in particular using final states where penguin $b \to s$ diagrams are expected to dominate such as $ss\bar{s}$ final states of the type $K_s^0\phi$, $K_s^0K^+K^-$ and $K_s^0\eta'$. (The latter also has contributions from $sd\bar{d}$ and $su\bar{u}$.) The standard model predicts that to a good approximation all of the above channels should lead to the same value of $\sin 2\phi_1$. If deviations are found, it could be a clear indication of physics beyond the standard model. The $K_s^0\phi$ and $K_s^0\eta'$ final states have CP eigenvalues $\xi_f = -1$, whereas $K_s^0K^+K^-$ is a mixture of +1 and -1 eigenstates, but Belle has shown that CP +1 dominates [4].

Events of the type where one B^0 decays into a CP eigenstate and the other decays into a final state potentially distinguishing B^0 from $\overline{B^0}$ (tagging side) are used for this analysis. The time dependence of the B decays is given by [2]

$$\mathcal{P}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\Big\{1 + q \cdot \Big[\mathcal{S}\sin(\Delta m_d \Delta t) + \mathcal{A}\cos(\Delta m_d \Delta t)\Big]\Big\}, \quad (1)$$

where τ_{B^0} is the B^0 lifetime, Δm_d is the mass difference between the two B^0 mass eigenstates, $\Delta t = t_{CP} - t_{\rm tag}$, and the b-flavor charge $q = +1$ (-1) when the tagging B meson is a B^0 $(\overline{B}^0)$. The results contained in this talk have been presented by the BaBar [5] and Belle [6] collaborations based on data taken 1999-2002. The critical parts of the analysis are precision measurements of the B^0 decay vertices using information about their resolution function, identification of the decay on the tagging side as B or $\overline{B}$, taking into account the performance of the methods used, and identification of candidates for the CP eigenstates used in the analysis.

2 Experimental procedure

The vertices of the CP eigenstates are reconstructed by combining a K_s^0 candidate with charged tracks coming from ϕ decay to K^+K^-, η' decaying to ρ^0 $(\to \pi^+\pi^-)$ γ or $\pi^+\pi^-\eta$ ($\to \gamma\gamma$) (both Belle and BaBar) or K_s^0 with K^+K^- for the $K_S^0K^+K^-$ final state (Belle). The "tagging" vertex is reconstructed by using all the tracks which would reasonably be expected to be connected to that vertex. Studies of the B lifetime were made to check

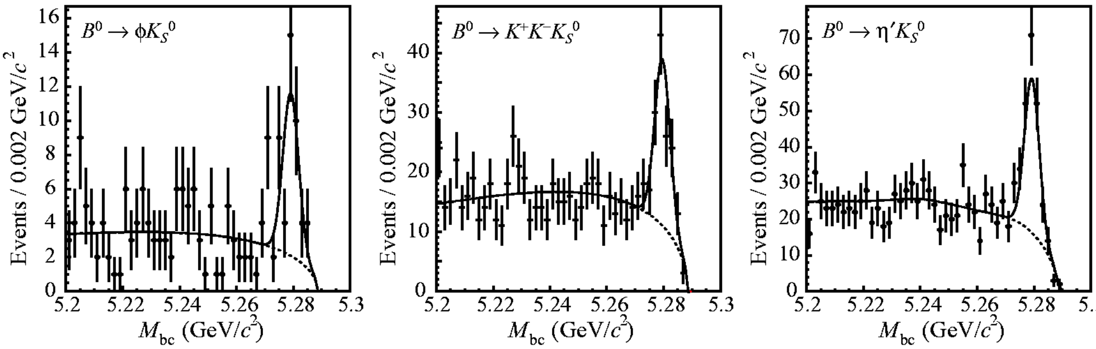

Fig. 1. The beam-energy constrained mass distributions for $B^0 \to \phi K_S^0$ (*left*), $B^0 \to K^+K^-K_S^0$ (*center*), and $B^0 \to \eta' K_S^0$ (*right*) within the ΔE signal region. *Solid curves* show the fit to signal plus background distributions, and *dotted curves* show the background contributions. The background for $B^0 \to \eta' K_S^0$ decay includes an MC-estimated $B\overline{B}$ background component (from Belle)

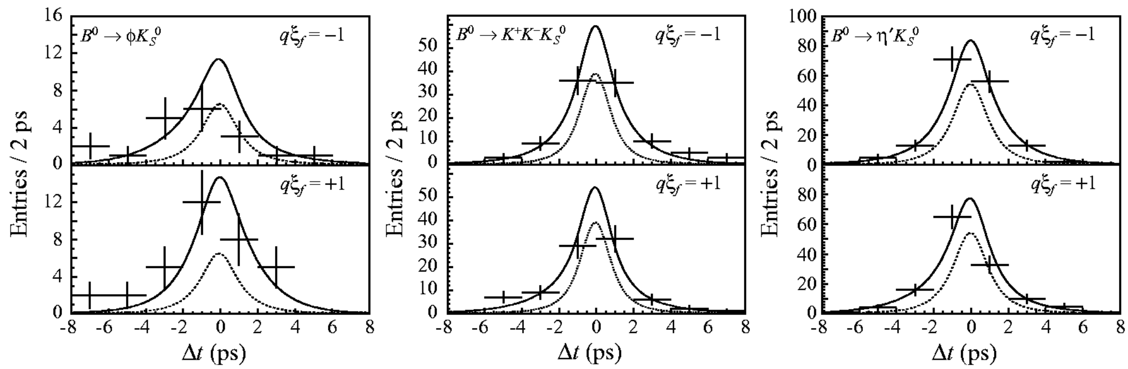

Fig. 2. The Δt distributions for $B^0 \to \phi K_S^0$ (*left*), $B^0 \to K^+K^-K_S^0$ (*center*), and $B^0 \to \eta' K_S^0$ (*right*) decays. The upper and lower plots are for $q\xi_f = -1$ and $q\xi_f = +1$ candidates, respectively. The *solid curves* show the results of the global fits, and the *dashed curves* show the background distributions (from Belle)

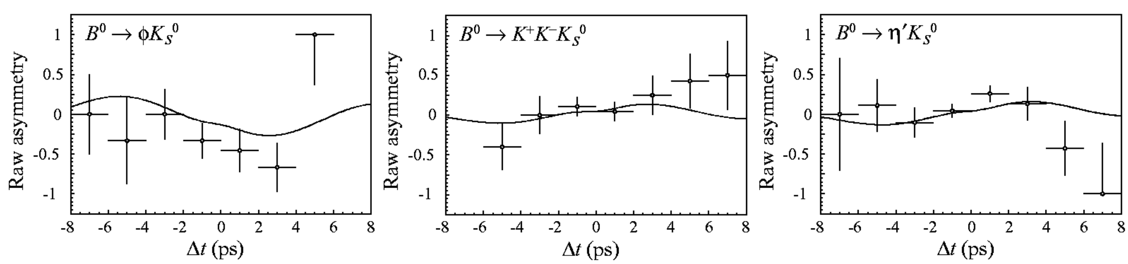

Fig. 3. The Δt asymmetry, A, in each bin for $B^0 \to \phi K_S^0$ (*left*), $B^0 \to K^+K^-K_S^0$ (*center*), and $B^0 \to \eta' K_S^0$ (*right*) respectively. The *curves*, which originate from time-dependent asymmetries given by $-\xi_f S \sin(\Delta m_d \Delta t) - \xi_f A \cos(\Delta m_d \Delta t)$, show the results of the unbinned-maximum likelihood fit (from Belle)

the understanding of the resolution function of vertex reconstruction.

For flavor tagging identified leptons, charged kaons and pions are used, where depending on particle identity and momentum they arise preferentially from B^0 or $\overline{B}^0$ decays. Mistagging probability is calculated using the real data. The effective tagging efficiency is 28-29% for both Belle and BaBar. BaBar used a neural network for the tagging analysis, and Belle used a likelihood method.

The combinatorial background from continuum events is the main source of background. Events coming from B decays and from continuum have different shapes in general, with the B decay events being spherical in shape, and the continuum events being more elongated. Both experiments make selections based on the shapes of the events, as well as the production angular distribution, to reduce the continuum background.

In the Belle experiment candidates of CP-eigenstates are identified by using the energy difference $\Delta E \equiv E_B^{\rm cms} - E_{\rm beam}^{\rm cms}$ and the beam-energy constrained mass $M_{\rm bc} \equiv \sqrt{(E_{\rm beam}^{\rm cms})^2 - (p_B^{\rm cms})^2}$, where $E_{\rm beam}^{\rm cms}$ is the beam energy in the cms, and $E_B^{\rm cms}$ and $p_B^{\rm cms}$ are the cms energy and momentum of the reconstructed B candidate, respectively.

Table 1. Results of the fits to the Δt distributions. The first errors are statistical, and the second errors are systematic. The third error for the $K^+K^-K_S^0$ channel in the BELLE experiment arises from the uncertainty in the fraction of the CP odd component

Exp.	Mode	$-\xi_f S(=\sin 2\phi_1$ in SM)	$A(=0$ in SM)
Belle	ϕK_S^0	-0.73 ± 0.64 ± 0.22	-0.56 ± 0.41 ± 0.16
Belle	$K^+K^-K_S^0$	+0.49 ± 0.43 ± 0.11 $^{+0.33}_{-0.00}$	-0.40 ± 0.33 ± 0.10
Belle	$\eta' K_S^0$	+0.71 ± 0.37 $^{+0.05}_{-0.06}$	+0.26 ± 0.22 ± 0.03
BaBar	ϕK_S^0	-0.18 ± 0.51 ± 0.07	+0.80 ± 0.38 ± 0.12
BaBar	$\eta' K_S^0$	+0.02 ± 0.34 ± 0.03	+0.10 ± 0.22 ± 0.03

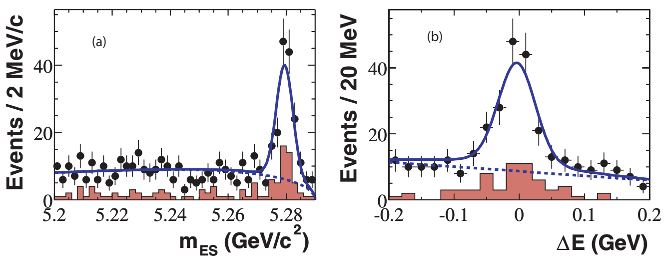

Fig. 4. The B candidate m_{ES} (m_{ES} is almost the same as M_{bc}) and ΔE projections for $B^0 \to \eta' K_S^0$ (a,b). Points with errors represent the data, *solid curves* the full fit functions, and *dashed curves* the background functions; the *shaded histogram* represents the $\eta'_{\eta\pi\pi}K$ subset (from BaBar)

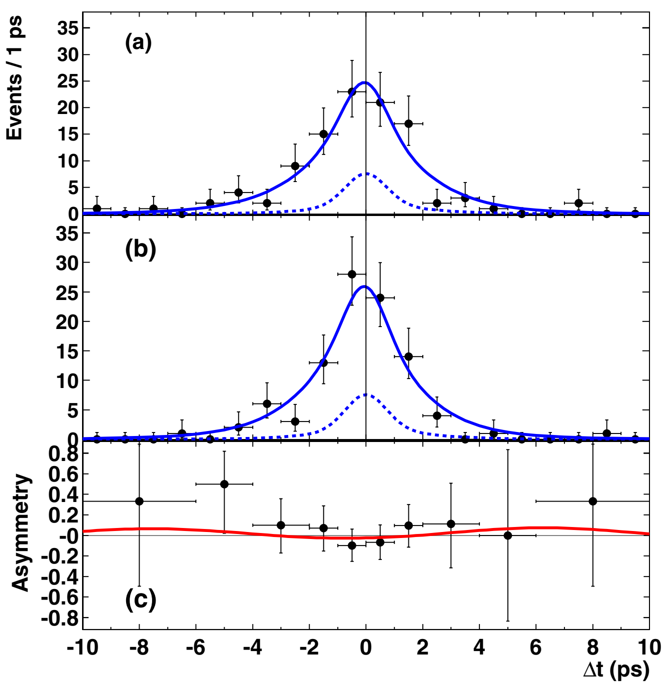

Fig. 5. Projections onto Δt for $B^0 \to \eta' K_S^0$ data (*points with errors*), the fit function (*solid line*) and background function (*dashed line*), for **a** B^0 and **b** $\overline{B^0}$ tagged events, and **c** the asymmetry between B^0 and $\overline{B^0}$ tags (from BaBar)

The B meson signal region is defined as 5.27 GeV/c^2 < $M_{\rm bc}$ < 5.29 GeV/c^2 and $|\Delta E| < 0.051$ GeV for $B^0 \to \phi K_S^0$ or $|\Delta E| < 0.040$ GeV for $B^0 \to K^+K^-K_S^0$ (Fig. 1). The BaBar experiment uses a similar procedure with the results for the $K_S^0\eta'$ final state shown in Fig. 4.

3 Results

Figure 2 shows the observed Δt distribution for $q\xi_f = -1$ (upper figure) and for $q\xi_f = +1$ (lower figure).

The differences in the Δt distributions in the Belle experiment are shown in Fig. 3. The Δt distribution for the $K_S^0\eta'$ final state in the BaBar experiment is shown in Fig. 5. Fits were made to the experimental Δt distributions taking into account the backgrounds and experimental resolutions. The results of the fits for the CP violating parameters are shown in Table 1.

From the table one sees that for the $ss\bar{s}$ states listed in the table, the values of $-\xi_f S$ tend to lie systematically below the value of $\sin 2\phi_1$ determined from the $sc\bar{c}$ states, 0.73±0.06. In particular this is especially true for the state ϕK_S^0. Considering all such states listed in the table, this is a 2.7 standard deviation discrepancy with the standard model and is an indication for new physics.

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