Three-body charmless $B \to Khh$ decays at Belle

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Study of three-body B decays can significantly broaden the understanding of B meson decay mechanisms and provide additional possibilities for CP violation searches. The decays of B mesons to charmless three-body Khh final states can be described by a $b \to u$ tree-level spectator diagram and a $b \to s(d)g$ one-loop penguin diagram. (Although $b \to u$ W-exchange, annihilation, or vertical W loop diagrams can also contribute to these final states, they are expected to be smaller and we neglect them for simplicity.) Three-body decays of B mesons to final states with odd numbers of kaons (s-quarks) are expected to proceed dominantly via the $b \to sg$ penguin transition since the $b \to u$ contribution in these cases has an additional CKM suppression. In contrast, decays with two kaons in final state proceed via $b \to u$ tree transition (with possible contribution from $b \to dg$ penguin), and have no contribution from $b \to sg$ penguin. From this simple consideration we can naively expect that the $K\pi\pi$ and KKK final states have the largest signal among other three-body Khh final states. The observation of $K^{+(0)}\pi^+\pi^-$ and $K^{+(0)}K^+K^-$ final states has been reported recently by the Belle Collaboration [1, 2]. Here, we report the results of a study of B mesons decays to three-body $K\pi\pi$, $KK\pi$, and KKK final states, where no prior assumptions are made about intermediate hadronic resonances. The inclusion of charge conjugate states is implicit throughout this report.

The data sample used for this analysis was collected with the Belle detector [3] operating at the KEKB asymmetric energy e^+e^- collider. It consists of 43 fb^{-1} taken at the $\Upsilon(4S)$ resonance, corresponding to 45.3×10^6 produced $B\overline{B}$ pairs.

Charged tracks are selected with a set of track quality requirements based on the average hit residual and on the distances of closest approach to the interaction point. We also require that the transverse track momenta be greater than 0.1 GeV/c to reduce the low momentum combinatoric background. Charged kaons and pions are identified basing on dE/dx measurements by the central drift chamber, information from threshold Čerenkov counters and time-of-flight scintillation counters. Tracks that identified as protons or electrons are rejected. Neutral kaons are reconstructed via their decay chain $K^0(\overline{K}^0) \to K_S \to \pi^+\pi^-$. The invariant mass of the two pions is required to satisfy $|M(\pi^+\pi^-) - M_{K^0}| < 10$ MeV/c^2 and the displacement of the $\pi^+\pi^-$ vertex from the interaction point in the transverse (r-ϕ) plane is required to be greater than 0.1 cm and less than 20 cm. The K_S flight direction and combined pion pair momentum direction in the r-ϕ plane must agree within 0.2 radians. Photons are

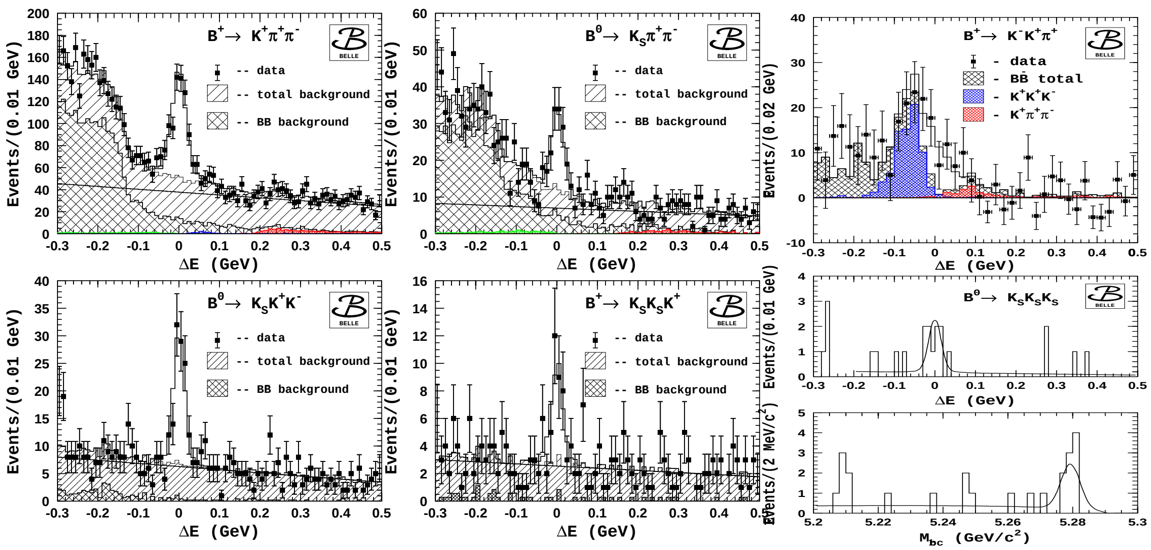

Figure 1: The ΔE distributions for three-body final states.

identified as isolated clusters in the electromagnetic calorimeter with energy greater than 50 MeV. Pairs of photons with an invariant mass within 15 MeV of the π^0 nominal mass are considered as π^0 candidates. The reconstructed π^0 momentum is required to be more than 0.2 GeV/c.

We reconstruct B mesons in three-body $K\pi\pi$, $KK\pi$, and KKK final states with charged or neutral (not more than one) pions and charged or neutral kaons. The candidate events are identified by their center of mass (CM) energy difference, $\Delta E = (\sum_i E_i) - E_{\rm b}$, and the beam constrained mass, $M_{\rm bc} = \sqrt{E_{\rm b}^2 - (\sum_i \vec{p}_i)^2}$, where $E_{\rm b} = \sqrt{s}/2$ is the beam energy in the CM frame, and $\vec{p}_i$ and E_i are the CM three-momenta and energies of the candidate B meson decay products. We select events with $M_{\rm bc} > 5.20$ GeV/c^2 and $-0.30 < \Delta E < 0.50$ GeV, and define a *signal* region of $|M_{\rm bc} - M_B| < 9$ MeV/c^2 and $|\Delta E| < 0.04$ GeV and two ΔE *sideband* regions defined as -0.08 GeV $< \Delta E < -0.05$ GeV and 0.05 GeV $< \Delta E <$ 0.15 GeV.

To suppress the large combinatorial background which is dominated by two-jet-like $e^+e^- \to q\bar{q}$ continuum events, variables that characterize the event topology are used. The procedure is described in detail in Ref. [1]. The potentially dangerous sources of background from other B decays were studied with a large sample of $B\overline{B}$ Monte Carlo (MC) events. As a result of this study we found that $B \to Dh$, where h stands for a charged pion or kaon, produce the dominant background to the most of the three-body final states. To suppress this background we introduce D veto cut: we reject candidates if any two-particle invariant mass is consistent with a $D \to K\pi$ hypothesis, independently of the PID information. In the analysis of $K^{+(0)}\pi^+\pi^-$ final states we also apply a charmonium veto: candidates, with a two-pion invariant mass

Mode	Eff., %	Yield, events	$\mathcal{B}, 10^{-6}$ (43$\texttt{fb}^{-1}$)	$\mathcal{B}, 10^{-6}$ (29$\texttt{fb}^{-1}$), Ref.[1]
$K^+\pi^-\pi^+$	21.1	463 ± 32	59.3 ± 4.1	$55.6 \pm 5.8 \pm 7.7$
$K^0\pi^-\pi^+$	5.23	94.7 ± 14.4	41.7 ± 7.2	$53.2 \pm 11.3 \pm 9.7$
$K^+\pi^-\pi^0$	11.6	$173^{+30.5}_{-29.6}$	–	$47.1 \pm 8.2 \pm 6.3$
$K^+K^+K^-$	22.2	289 ± 20	35.8 ± 2.5	$35.3 \pm 3.7 \pm 4.3$
$K^0K^+K^-$	7.10	88.8 ± 11.8	32.3 ± 4.8	$34.8 \pm 6.7 \pm 6.5$
$K_SK_SK^+$	5.76	27.5 ± 6.7	13.1 ± 3.2	–
$K_SK_SK_S$	3.86	$8.2^{+3.5}_{-2.9}$	$5.5^{+2.3}_{-1.9}$	–
$K^+K^-\pi^+$	13.8	49 ± 15	$9.1 \pm 2.8 (< 14)$	< 12
$K^+K^+\pi^-$	14.2	-4.7 ± 9	< 2.0	< 3.2
$K^-\pi^+\pi^+$	17.0	14 ± 12	< 5.4	< 7.0
$K^0K^\pm\pi^\mp$	4.53	1 ± 11	< 9.2	< 13.4
$K_SK_S\pi^+$	5.31	-6.4 ± 8.1	< 3.3	–

Table 1: Summary table of three-body results.

consistent with $J/\psi(\psi(2S)) \to \mu^+\mu^-$ are rejected.

The ΔE distributions for some of the three-body final states are shown in Fig. 1, where the points with errors represent the experimental data, and histograms show the expected background distributions. To extract the signal yield in the $K\pi\pi$ and KKK final states, we fit the ΔE distributions to the sum of signal and background components. The signal shape is parameterized by a double Gaussian function with the same mean. There are two sources of background: $q\overline{q}$ continuum background that is approximated by the linear function and $B\overline{B}$ background which is final state dependent. The shape of the $B\overline{B}$ background for each particular three-body final state was determined using a large set (~3.5 times the data set) of MC events. The $q\overline{q}$ and $B\overline{B}$ component are also shown in Fig. 1. The $B\overline{B}$ is found to be substantial in $K\pi\pi$ final states, while it gives very small contribution in three-kaon final states. For other final states, a different technique is used for signal yield extraction. We subdivide the ΔE region into 20 MeV bins and determine the signal yield in each bin from the fit to the corresponding $M_{\rm bc}$ spectrum. The signal yield from the $M_{\rm bc}$ fit is then plotted as a function of ΔE. The results for the $K^+K^-\pi^+$ final state is shown in Fig. 1 as points with errors, where the $B\overline{B}$ contribution is also shown. The more detailed description can be found in Ref. [1].

The results of the fit are summarized in Table 1. Statistically significant signals are observed in $K^{+(0)}\pi^+\pi^-$, $K^+\pi^-\pi^0$ and all three-kaon final states. The resulting branching fractions for the three-body final states are presented in Table 1, where the results of Ref. [1] are also included for comparison.

To examine possible intermediate quasi-two-body states, we analyze two-particle mass spectra. The $K^+\pi^-$ and $\pi^+\pi^-$ invariant mass spectra for the $B^+ \to K^+\pi^+\pi^-$

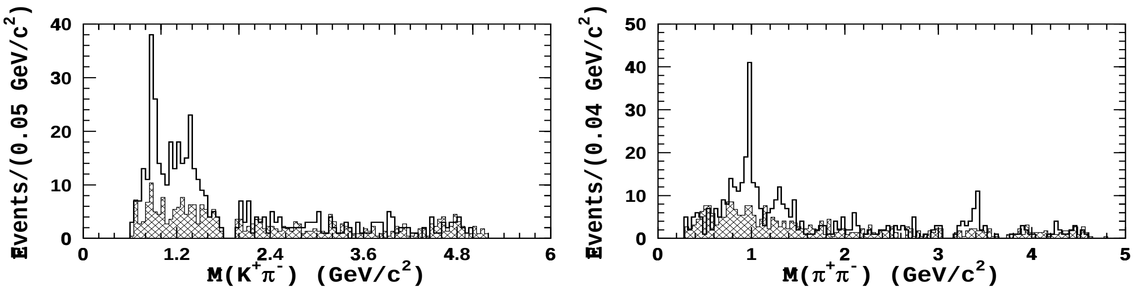

Figure 2: The $K^+\pi^-$ and $\pi^+\pi^-$ invariant mass spectra for the $K^+\pi^+\pi^-$ final state.

signal are shown in Fig. 2. To suppress the feed-across between the $\pi^+\pi^-$ and $K^+\pi^-$ states, we require the $K^+\pi^-$ ($\pi^+\pi^-$) invariant mass to be larger than 2.0 (1.5) GeV/c^2 when making the $\pi^+\pi^-$ ($K^+\pi^-$) projection. The hatched histograms shown in Fig. 2 are the corresponding two-particle invariant mass spectra for the background events in the ΔE sidebands with proper normalization. The Dalitz plot analysis procedure is described in Ref. [1] in detail.

In conclusion, the results of the branching ratio measurement for the B decays to three-body $K\pi\pi$, $KK\pi$, and KKK final states are presented, where the $K_SK_SK^+$ and $K_SK_SK_S$ final states are observed for the first time. We also report 3σ evidence for the signal in $K^+K^-\pi^-$ final state. The analysis of quasi-two-body final states reveals large signals of $B^+\to f_0(980)K^+$, $B^+\to K^*(892)^0\pi^+$ in $K^+\pi^+\pi^-$ final state and $B^+\to\phi K^+$ in $K^+K^+K^-$ final state. The measured branching fraction product for the $f_0(980)K^+$ final state is $\mathcal{B}(B^+\to f_0(980)K^+)\times\mathcal{B}(f_0(980)\to\pi^+\pi^-) = (9.6^{+2.5+1.5+3.4}_{-2.3-1.5-0.8})\times 10^{-6}$. This is the first observation of a B meson decay to a charmless scalar-pseudoscalar final state. We find that effects of interference between different quasi-two-body intermediate states can have significant influence on the observed two-particle mass spectra and a full amplitude analysis of three-body B meson decays is required for a more complete understanding. This will be possible with increased statistics.

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