Measurements of \( B \) Decays to Two Kaons


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Unlike completing the list of penguin dominated B mesons, these modes arise only from annihilation diagrams, unless there are contributions from new physics. What is still missing are standing of CP violation in B0 → K0K− transitions. No signal is observed in the decay B0 → K−K+, and we set an upper limit of 3.7 × 10−5 at 90% confidence level.

We report measurements of B meson decays to two kaons using 253 fb−1 of data collected with the Belle detector at the KEKB energy-asymmetric e+e− collider. We find evidence for signals in B+ → K0K+ and B0 → K0K0 with significances of 3.0σ and 3.5σ, respectively. (Charge-conjugate modes are included.) The corresponding branching fractions are measured to be B(B+ → K0K+) = (1.0 ± 0.4 ± 0.1) × 10−6 and B(B0 → K0K0) = (0.8 ± 0.3 ± 0.1) × 10−6. These decay modes are examples of hadronic b → d transitions. No signal is observed in the decay B0 → K−K+, and we set an upper limit of 3.7 × 10−7 at 90% confidence level.

All B → Kπ, ππ decay branching fractions have now been measured [1–4], and direct CP violation in B0 → K+π− decay has been established [5,6]. These measurements constrain the hadronic b → s and b → u amplitudes and have provided essential information for our understanding of B decay mechanisms. They also probe possible contributions from new physics. What is still missing are the B → KK modes, which are hadronic b → d transitions. In this Letter, we report results on B0 → K0K0 and B+ → K0K+ decays, which are dominated by the loop-induced b → dūs process (so-called b → d penguin diagrams). These modes are expected to be suppressed by a factor of roughly 20 with respect to the b → s penguin-dominated B → Kπ decays and, hence, are expected at the 10−6 level [7,8]. We also report a search for B0 → K+K−, which can arise only from annihilation diagrams, unless there are final-state interactions (FSI) [9].

Establishing B → KK modes is of interest not just for completing the list of B → Kπ, ππ and KK decays. Unlike b → s penguin dominated modes such as B+ → K0π+, direct CP violation is expected to be sizable in B0 → K0π0 and B+ → K0K+ decays [7], while mixing-dependent CP violation can be measured in B0 → K0K0 (and K+K−) [8]. Since b → d penguin diagrams contribute to the B → ππ amplitudes, measurements of b → d penguin dominated B → KK rates and CP violation will shed light on CP violation in B0 → π+π− decay [10,11], where currently some disagreement exists. It could also shed light on the strength of B0 → π0π0 [3,4], which is not yet understood.

The results are based on a sample of 275 × 106 B̅B pairs collected with the Belle detector at the KEKB e+e− asymmetric-energy (3.5 on 8 GeV) collider [12] operating at the Y(4S) resonance. The Belle detector is a large-solid-angle magnetic spectrometer that consists of a silicon vertex detector (SVD), a 50-layer central drift chamber (CDC), an array of aerogel threshold Cherenkov counters (ACC), a barrel-like arrangement of time-of-flight scintillation counters, and an electromagnetic calorimeter (ECL) comprised of CsI(Tl) crystals located inside a superconducting solenoid coil that provides a 1.5 T magnetic field. An iron flux-return located outside the coil is instrumented to detect K0L mesons and to identify muons (KLM). The detector is described in detail elsewhere [13]. Two different inner detector configurations were used. For the first sample of 152 × 106 B̅B pairs (set I), a 2.0 cm radius beampipe and a 3-layer silicon vertex detector were used; for the latter 123 × 106 B̅B pairs (set II), a 1.5 cm radius beampipe, a 4-layer silicon detector, and a small-cell inner drift chamber were used [14].

Charged kaons are required to have a distance of closest approach to the interaction point (IP) in the beam direction...
of the tagging $B$ meson, and a quality $r$, a continuous variable ranging from zero for no flavor tagging information to unity for unambiguous flavor assignment. An event with a high value of $r$ (typically containing a high-momentum lepton) is more likely to be a $B\bar{B}$ event, and a looser $R$ requirement can be applied. We divide the data into $r > 0.5$ and $r \leq 0.5$ regions. A selection requirement on $R$ for events in each $r$ region of set I and set II is applied according to a figure of merit defined as $N_{\text{sig}}/\sqrt{N_{\text{exp}}+N_{\text{q\bar{q}}}}$, where $N_{\text{exp}}$ denotes the expected signal yields based on MC simulation and the assumed branching fractions, $1.0 \times 10^{-6}$, and $N_{\text{q\bar{q}}}$ denotes the expected $q\bar{q}$ yields from sideband data ($M_{bc} < 5.26$ GeV/$c^2$).

Background contributions from $\Upsilon(4S) \to B\bar{B}$ events are investigated using a large MC sample, which includes events from $b \to c$ transitions and charmless decays. After all the selection requirements, no $B\bar{B}$ background is found for the $B^0 \to K^0\bar{K}^0$ mode. Owing to $K-\pi$ misidentification, large $B^0 \to K^+\pi^- \bar{K}^0\pi^+$ and $B^+ \to K^0\pi^+$ feed-across backgrounds appear in the $B^+ \to K^+\pi^-$ and $B^0 \to K^0\bar{K}^0$ modes, respectively. A small charmless three-body contribution is found at low $\Delta E$ values for these two modes.

The signal yields are extracted by performing unbinned two-dimensional maximum likelihood fits to the $(M_{bc}, \Delta E)$ distributions. The likelihood for each mode is defined as

$$L = \exp\left(-\sum_{s,k,j} N_{s,k,j}\right) \prod_i \left(\sum_{s,k,j} P_{s,k,j} \mathcal{P}_{s,k,j} \right),$$

where $s$ indicates set I or set II, $k$ distinguishes between events in the $r < 0.5$ and $r > 0.5$ regions, $i$ is the identifier of the $i$th event, $P(M_{bc}, \Delta E)$ is the two-dimensional PDF of $M_{bc}$ and $\Delta E$, and $N_j$ is the number of events for the category $j$, which corresponds to either signal, $q\bar{q}$ continuum, a feed-across due to $K-\pi$ misidentification, or background from other charmless three-body $B$ decays.

All the signal PDFs $[P_{s,k,j \to \text{signal}}(M_{bc}, \Delta E)]$ are parametrized by a product of a single Gaussian for $M_{bc}$ and a double Gaussian for $\Delta E$ using MC simulations based on the set I and set II detector configurations. The same signal PDFs are used for events in the two different $r$ regions. Since the $M_{bc}$ signal distribution is dominated by the beam energy spread, we use the signal peak positions and resolutions obtained from $B^+ \to D^-\pi^+\pi^+$ (data) $(\bar{D}^0 \to K^0_S\pi^+\pi^-)$ subdecay is used for the $K^0\bar{K}^0$ mode, while $D^0 \to K^+\pi^-$ is used for the other two modes) with small mode dependent correlations obtained from MC. The MC-predicted $\Delta E$ resolutions are corrected using the ratio of widths (data/MC) of invariant mass distributions of high-momentum $D$ mesons. The decay mode $D^0 \to K^-\pi^-$ is used for $B^0 \to K^-\bar{K}^0$, $D^+ \to K^0\pi^+$ for $B^+ \to K^0\pi^+$, and $\bar{D}^0 \to K^0\pi^-\bar{K}^0$ for $B^0 \to K^0\bar{K}^0$. The parameters that describe the shapes of the PDFs are fixed in all of the fits.
The continuum background in $\Delta E$ is described by a linear function, while the $M_{bc}$ distribution is parametrized by an ARGUS function $f(x) = x\sqrt{1-x^2}\exp[-\xi(1-x^2)]$, where $x$ is $M_{bc}$ divided by half of the total center-of-mass energy [18]. Therefore, the continuum PDF is the product of this ARGUS function and the linear function, where the overall normalization, $\xi$, and the slope of the linear function are free parameters for each $r$ region in the fit. These free parameters are $r$-dependent and allowed to be different in set I and set II. The background PDFs for charmless three-body $B$ decays for the $K^+K^-$ and $K^0\pi^+$ modes are each modeled by a smoothed two-dimensional histogram, obtained from a large MC sample. The feed-across backgrounds for these two modes from the $K^+\pi^-$ and $K^0\pi^+$ events have $M_{bc} - \Delta E$ shapes similar to the signals with the $\Delta E$ peak positions shifted by $\approx \pm 45$ MeV. The methods to model the $K^+K^-$ and $K^0\pi^+$ signal PDFs are also applied to describe the feed-across background.

When likelihood fits are performed, the yield for each background component ($N_{s,k,j}$, where $j = q\bar{q}$, feed-across, charmless) is allowed to float independently for each $s$ (set I or set II) and $k$ bin (low or high $r$ region). For the signal component, the same branching fraction is required by constraining the number of signal events in each $(s,k)$ bin using the measured efficiency in the corresponding $(s,k)$ bin. Table I summarizes the fit results for each mode. The statistical significance for $K^+K^-$, $K^0\pi^+$, and $K^0\pi^+$ modes are $0.5\sigma$, $3.1\sigma$, and $3.6\sigma$, respectively. Including systematic uncertainty, we observe $13.3 \pm 5.6 \pm 0.6$ $K^+K^-$ and $15.6 \pm 5.8^{+0.1}_{-0.6}$ $K^0\pi^+$ signal events with significances of $3.0\sigma$ and $3.5\sigma$, respectively. The second errors in the yields are the systematic errors from fitting, estimated from the deviations after varying each parameter of the signal PDFs by 1 standard deviation, and from modeling the three-body background, studied by excluding the low $\Delta E$ region ($\Delta E < -0.15$ GeV) and repeating the fit. At each step, the yield deviation is added in quadrature to provide the fitting systematic errors, and the statistical significance is computed by taking the square root of the difference between the value of $-2\ln L$ for the best fit value and zero signal yield. The smallest value obtained when varying all the parameters simultaneously by 1 standard deviation is chosen to estimate the significance including the systematic uncertainty.

Figure 1 shows the $M_{bc}$ and $\Delta E$ projections of the fits after requiring events to have $|\Delta E| < 0.06$ GeV and $5.271 \text{ GeV}/c^2 < M_{bc} < 5.289 \text{ GeV}/c^2$, respectively. The feed-across yields are $47.1 \pm 8.7$ in the $K^+K^-$ mode and $16.4 \pm 6.1$ in the $K^0\pi^+$ mode. The amounts of the feed-across background are consistent with the expectations of $49.1$ $K^+\pi^-$ and $18.8$ $K^0\pi^+$ events, based on MC simulation and measured branching fractions [19]. The MC modeling of the requirement on the likelihood ratio $R$ is investigated using the $B^+ \rightarrow D^0\pi^+$ ($D^0 \rightarrow K_S^0\pi^+\pi^-$ for $K^0\pi^+$ and $D^0 \rightarrow K^+\pi^-$ for the others) samples. The obtained systematic errors are $\pm 2.9\%$ for $B^0 \rightarrow K^0\bar{K}^0$ and $\pm 6.8\%$ for the other two modes. The systematic error on the charged track reconstruction efficiency is estimated to be around 1% per track using partially reconstructed $D^*$

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![Figure 1](color online). $M_{bc}$ (left) and $\Delta E$ (right) distributions for $B^0 \rightarrow K^+K^-$ (top), $B^+ \rightarrow K^0K^+$ (middle), and $B^0 \rightarrow K^0\bar{K}^0$ candidates. The points with error bars show the data, while the curves represent the various components from the fit: signal (open solid line), continuum (dotted line), three-body $B$ decays (hatched line), background from misidentification (dashed-dotted line), and sum of all components (solid line). In the $K^+K^-$ mode, there is a large contribution from misidentified $K^+\pi^-$ but no significant signal excess. In the $K^0\pi^+$ mode, the signal and misidentified $K^0\pi^+$ contributions are comparable in size. In the $K^0\bar{K}^0$ mode, there is a signal excess but no misidentification background.

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**Table I.** Fitted signal yields, reconstruction efficiencies, product of efficiencies and subdecay branching fractions ($B_i$), branching fractions with upper limits at 90% confidence level, and significances for individual modes.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Sig. yield</th>
<th>Bkg. yield</th>
<th>Eff. (%)</th>
<th>Eff. $\times B_i$ (%)</th>
<th>$B(10^{-6})$</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^+K^-$</td>
<td>2.5$^{+1}_{-1}$</td>
<td>1508.1 $\pm$ 39.9</td>
<td>15.5</td>
<td>15.5</td>
<td>0.06 $\pm$ 0.1 ($&lt;0.37$)</td>
<td>0.5</td>
</tr>
<tr>
<td>$K^0\pi^+$</td>
<td>13.3 $\pm$ 5.6</td>
<td>893.5 $\pm$ 30.7</td>
<td>14.5</td>
<td>5.0</td>
<td>1.0 $\pm$ 0.4 ($&lt;1.5$)</td>
<td>3.0</td>
</tr>
<tr>
<td>$K^0\bar{K}^0$</td>
<td>15.6 $\pm$ 5.8</td>
<td>1136.6 $\pm$ 34.8</td>
<td>28.7</td>
<td>6.8</td>
<td>0.8 $\pm$ 0.3 ($&lt;2.1$)</td>
<td>3.5</td>
</tr>
</tbody>
</table>
events. The resulting $K_S^0$ reconstruction is verified by comparing the ratio of $D^+ \rightarrow K_S^0 \pi^+$ and $D^+ \rightarrow K^- \pi^+ \pi^+$ yields with the MC expectation. The resulting $K_S^0$ detection systematic error is $\pm 4.5\%$. The final systematic errors are then obtained by quadratically summing the errors due to the reconstruction efficiency and the fitting systematics.

With $275 \times 10^6$ $B\bar{B}$ pairs, we find evidence of $B^+ \rightarrow \bar{K}^0 K^+$ and $B^0 \rightarrow \bar{K}^0 K^0$ with branching fractions $\mathcal{B}(B^+ \rightarrow \bar{K}^0 K^+) = (1.0 \pm 0.4 \pm 0.1) \times 10^{-6}$ and $\mathcal{B}(B^0 \rightarrow \bar{K}^0 K^0) = (0.8 \pm 0.3 \pm 0.1) \times 10^{-6}$. These are examples of $b \rightarrow d$ penguin dominated hadronic transitions. Our measurements are consistent with preliminary results reported by the BABAR Collaboration [20]. They are also in general agreement with theoretical expectations [7–9,21–24]. It has been suggested that the branching fraction and CP asymmetry of the mode $B^0 \rightarrow \bar{K}^0 K^0$ may be sensitive to physics beyond the standard model [23]. Measurements with larger statistics are needed for this purpose. No signal is observed in $B^0 \rightarrow K^+ K^-$, and we set the upper limit of $3.7 \times 10^{-7}$ at the 90% confidence level, using the Feldman-Cousins approach [25], taking into account both the statistical and systematic errors [26]. The result is consistent with a preliminary result reported by the BABAR Collaboration [27], and constrains the FSI rescattering picture [9].

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