Radiative B meson decays into K pi gamma and K pi pi gamma final states

Nishida, S; Nakao, M; Abe, K; Abe, K; Abe, T; Ahn, BS; Aihara, H; ... Zhang, ZP; Zhilich, V; Zontar, D


2002-12-02

http://hdl.handle.net/2433/49942

Copyright 2002 American Physical Society
Radiative $B$ Meson Decays into $K\pi\gamma$ and $K\pi\pi\gamma$ Final States


(Belle Collaboration)

1Aomori University, Aomori 2Budker Institute of Nuclear Physics, Novosibirsk 3Chiba University, Chiba 4Chuo University, Tokyo 5University of Cincinnati, Cincinnati, Ohio 6Deutsches Elektronen–Synchrotron, Hamburg 7University of Frankfurt, Frankfurt 8Gyeongsang National University, Chinju 9University of Hawaii, Honolulu, Hawaii 10High Energy Accelerator Research Organization (KEK), Tsukuba 11Hiroshima Institute of Technology, Hiroshima 12Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 13Institute of High Energy Physics, Vienna 14Institute for Theoretical and Experimental Physics, Moscow 15J. Stefan Institute, Ljubljana 16Kangawa University, Yokohama 17Korea University, Seoul 18Kyoto University, Kyoto 19Kyungpook National University, Taegu 20Institut de Physique des Hautes Energies, Université de Lausanne, Lausanne 21University of Ljubljana, Ljubljana 22University of Maribor, Maribor 23University of Melbourne, Victoria 24Nagoya University, Nagoya 25Nara Women's University, Nara 26National Kaohsiung Normal University, Kaohsiung

VOLUME 89, NUMBER 23 PHYSICAL REVIEW LETTERS 2 DECEMBER 2002 231801-1
exclusive decays, such as the branching fractions of the exclusive decays can contribute to the final state. CLEO has reported evidence for resonant decays \[ B \rightarrow K^+ \pi^- \gamma \] and \[ B^+ \rightarrow K^+ \rho^0 \gamma \] channels dominate. The analysis is based on a data set of 29.4 fb\(^{-1}\) recorded by the Belle experiment at the KEKB collider.

DOI: 10.1103/PhysRevLett.89.231801

We select events that contain a high energy photon (\( \gamma \)) with an energy between 1.8 and 3.4 GeV in the \( K(4S) \) resonance. The Belle detector has a three-layer silicon vertex detector, 50-layer central drift chamber (CDC), an array of aerogel Cherenkov counters (ACC), time-of-flight (TOF) scintillation counters, and an electromagnetic calorimeter of CsI(Tl) crystals (ECL). We select events that contain a high energy photon (\( \gamma \)) with an energy between 1.8 and 3.4 GeV in the \( K(4S) \) resonance. The Belle detector has a three-layer silicon vertex detector, 50-layer central drift chamber (CDC), an array of aerogel Cherenkov counters (ACC), time-of-flight (TOF) scintillation counters, and an electromagnetic calorimeter of CsI(Tl) crystals (ECL).
excluded to remove $K^{*}$ contributions. Charged tracks are required to have CM momenta greater than 200 MeV/c, and to have impact parameters within ±5 cm of the interaction point along the positron beam axis and within 0.5 cm in the transverse plane. To identify kaon and pion candidates, we use a likelihood ratio that is calculated by combining information from the ACC, TOF, and $dE/dx$ (CDC) systems. We apply a tight selection with an efficiency (pion misidentification rate) of 83% (8%) for charged kaon candidates and a loose selection with an efficiency (kaon misidentification rate) of 97% (28%) for charged pion candidates.

We reconstruct $B$ meson candidates from a photon and a $K_{X}$ system by forming two independent kinematic variables: the beam constrained mass $M_{bc} = \sqrt{(E_{\text{beam}}/c^{2})^{2} - (|\vec{p}_{K_{X}} + \vec{p}_{\gamma}|/c)^{2}}$ and $\Delta E = E_{K_{X}} + E_{\gamma} - E_{\text{beam}}$, where $E_{\text{beam}}$ is the beam energy, and $\vec{p}_{K_{X}}$, $E_{K_{X}}$, $\vec{p}_{\gamma}$, $E_{\gamma}$ are the momenta and energies of the photon and the $K_{X}$ system, respectively, calculated in the CM frame. In order to improve the $M_{bc}$ resolution, the photon momentum is rescaled so that $|\vec{p}_{\gamma}| = (E_{\text{beam}} - E_{K_{X}})/c$ is satisfied.

The largest source of background originates from continuum $q\bar{q}$ (q = u, d, s, c) production. To suppress this background, we use a Fisher discriminant [9] formed from six modified Fox-Wolfram moments [10] and the cosine of the $B$ meson flight direction ($\cos\theta_{b}$). The moments are calculated in the rest frame of the $B$ candidate to avoid a correlation with $M_{bc}$ [11]. Signal and background events are classified according to a likelihood ratio $L_R = L_{\text{sig}}/(L_{\text{sig}} + L_{\text{bg}})$, where the likelihood $L_{\text{sig}}$ ($L_{\text{bg}}$) is the product of the probability density functions (PDF) of the Fisher discriminant and $\cos\theta_{b}$ for signal (background). The PDFs for the Fisher discriminant are determined from Monte Carlo (MC) simulations. For $\cos\theta_{b}$, we assume a $1 - \cos^{2}\theta_{b}$ behavior for signal events and a flat distribution for continuum background. The selection criteria on the likelihood ratio are chosen so that $S/\sqrt{S+N}$ is maximized, where $S$ and $N$ are (MC) signal and background yields, respectively. The optimized criteria retain 68% of the $B^{0} \rightarrow K^{+}\pi^{-}\gamma$ signal and 42% of the $B^{+} \rightarrow K^{+}\pi^{-}\pi^{+}\gamma$ signal.

The $B$ decay signal is separated from background, first by applying a requirement on $\Delta E$ and then by fitting the $M_{bc}$ spectrum. We find multiple candidates with $|\Delta E| < 0.5$ GeV and $M_{bc} > 5.2$ GeV/$c^{2}$ in the same event, we take the candidate which gives the highest confidence level when we fit the $K_{X}$ decay vertex (best candidate selection). We then select candidates with $-100$ MeV $\leq \Delta E < 75$ MeV, which removes 19% and 3% of signal on the lower and higher sides, respectively. We define a $\Delta E$ sideband to be $100$ MeV $\leq \Delta E < 500$ MeV at $M_{bc} > 5.2$ GeV/$c^{2}$, in which we expect negligible signal contribution.

In the $B^{0} \rightarrow K^{+}\pi^{-}\gamma$ analysis, we obtain the $M_{K\pi}$ distribution shown in Fig. 1(a). We observe an excess around $M_{K\pi} = 1.4$ GeV/$c^{2}$ [12]. The $M_{bc}$ distribution with $1.25$ GeV/$c^{2} < M_{K\pi} < 1.6$ GeV/$c^{2}$ is shown in Fig. 1(b). We fit the $M_{bc}$ distribution to extract the signal yield. The distribution for the $q\bar{q}$ background is modeled by an ARGUS function [13] in which the shape is determined from the $M_{bc}$ data sideband. The distribution for the signal component is modeled by a Gaussian determined from signal MC calibrated by $B^{0} \rightarrow D^{0}\pi^{-}$ data. The signal yield is found to be $27.0^{+1.1}_{-0.5}\text{(stat)}^{+3.2}_{-1.8}\text{(syst)}$ with a statistical significance of 5.0$\sigma$. Here the significance is defined as $\sqrt{-2\ln L(0)/L_{\text{max}}}$, where $L_{\text{max}}$ is the maximum of the likelihood and $L(0)$ is the likelihood for zero signal yield.

The observed signal may be explained as a mixture of three components: $B^{0} \rightarrow K^{*}_{S}(1430)\gamma$, $B^{0} \rightarrow K^{*}(1410)\gamma$, and nonresonant (NR) $B^{0} \rightarrow K^{+}\pi^{-}\gamma$. In order to separate these components, we apply an unbinned maximum likelihood (ML) fit to $M_{bc}$, the cosine of the decay helicity angle ($\cos\theta_{\text{hel}}$), and $M_{K\pi}$. The expected $\cos\theta_{\text{hel}}$ distributions are $\sin^{2}\theta_{\text{hel}}$, $\sin\theta_{\text{hel}}$, and uniform for these three components, respectively. The PDFs for $\cos\theta_{\text{hel}}$ and $M_{K\pi}$ are determined from the $\Delta E$ sideband data for $q\bar{q}$ background, from the corresponding MC samples for resonant components, and from an inclusive $b \rightarrow s\gamma$ MC sample [11] for the nonresonant component. The $\cos\theta_{\text{hel}}$ PDFs for signals are distorted up to 20% due to a nonuniform efficiency. The validity of the method is tested with $B^{-} \rightarrow D^{0}\pi^{-}$ data and MC.
The fit results for \(M_{K\pi}\) and \(\cos\theta_{\mathrm{hel}}\) are overlaid in Figs. 1(a) and 1(c), and summarized in Table I. We find evidence for radiative decays via an intermediate tensor state, \(B^0 \to K^*(1430)^0\). The \(K^*(1410)^0\) and nonresonant components are not significant, so we set upper limits. The 90\% confidence level upper limit \(N\) is calculated from the relation \(\int_0^N \mathcal{L}(n)dn = 0.9 \int_0^\infty \mathcal{L}(n)dn\), where \(\mathcal{L}(n)\) is the maximum likelihood with the signal yield fixed at \(n\).

We estimate the systematic error due to the fitting procedure as follows. For the signal shapes in the \(M_{bc}\) and \(M_{K\pi}\) distributions, we vary the mean and width parameters in the fit within their experimental errors. We also test the validity of the background PDFs by replacing them with those obtained from a \(q\bar{q}\) MC sample. We assign the largest deviation in these tests as the systematic error of the signal yield.

The event selection efficiency for \(B^0 \to K^*_2(1430)^0\) is (5.0 ± 0.3)% including the subdecay branching fractions. The error includes contributions from photon detection (2.8\%), tracking (2.3\% per track), kaon identification (0.6\%), pion identification (0.5\%), event selection including likelihood ratio, \(\pi^0/\pi^+\) veto and best candidate selection (2.0\%), and uncertainty of the subdecay branching fractions (2.4\%). Assuming an equal production rate for \(B^0\) and \(B^+\), this leads to a branching fraction of \(B^0 \to K^*_2(1430)^0\) of \([1.3 \pm 0.5(\text{stat}) \pm 0.1(\text{syst})] \times 10^{-5}\).

The result agrees with the predictions based on a relativistic form factor calculation [4]. Our result is also consistent with the CLEO measurement [3] when we neglect the nonresonant component and assume as they did that the \(K^*(1410)^0\) component is negligible.

In the \(B^+ \to K^+\pi^-\pi^+\gamma\) analysis, we find additional background sources from a MC study. Cross feed from \(B \to K^\gamma\) to \(B^+ \to K^+\pi^-\pi^+\gamma\) becomes negligible after removing positively identified \(B \to K\pi\gamma\) events. The size of the cross feed from other \(b \to s\gamma\) decays, especially from those with a \(\pi^0\) in the final state, is estimated by using the inclusive \(b \to s\gamma\) MC sample. The contribution from the \(b \to c\) background is estimated by using a corresponding MC sample.

To extract the signal yield, we fit the \(M_{bc}\) distribution shown in Fig. 2(a). In addition to a Gaussian and an ARGUS function to describe the signal and \(q\bar{q}\) background components obtained using the same method as in the \(B \to K\pi\gamma\) analysis, smooth MC histograms for the \(b \to s\gamma\) cross feed and other \(B\) meson decays are used to model the \(M_{bc}\) shape, where the normalizations are fixed assuming the luminosity and the measured \(b \to s\gamma\) branching fraction [11,15]. We find the signal yield of \(57 \pm 12(\text{stat}) \pm 5(\text{syst})\) with a 5.9\% statistical significance.

The \(M_{K\pi}\) distribution is shown in Fig. 2(b), where the distribution for \(q\bar{q}\) is obtained from the \(\Delta E\) sideband and is normalized using the fit result. We observe no signal excess above 1.8 GeV/c^2. The \(B^+ \to K^+\pi^-\pi^+\gamma\) signal may be explained as a sum of decays through kaonic resonances such as \(B^+ \to K_1(1400)^+\gamma\) and \(B^+ \to K^*(1680)^+\gamma\). The current statistics and the existence of a large number of resonances prevent us from decomposing the resonant substructure. However, it is still possible to measure the \(K^+\pi\gamma\) and \(K\rho\gamma\) components separately, as most of the resonances have sizable decay rates through the \(K^+\pi\gamma\) and \(K\rho\gamma\) channels.

To find the composition of the signal, we perform an unbinned ML fit to \(M_{bc}\), \(M_{K\pi}\), and \(M_{\pi\pi}\) with three signal components (\(K^+\pi\gamma\), \(K\rho\gamma\), and nonresonant \(K\pi\pi\gamma\)) and a \(q\bar{q}\) background component. In addition, the components from \(b \to s\gamma\) cross feed and from other \(B\) meson decays.

### Table I. Measured signal yields, statistical significances, reconstruction efficiencies, branching fractions (\(B\)), and 90\% confidence level upper limits (UL) including systematic errors. The first and second errors are statistical and systematic, respectively. Efficiencies include the subdecay branching fractions [14]. Efficiencies for \(K^+\pi^-\gamma\) and \(K^+\pi^-\pi^+\gamma\) are based on a mixture of the measured subcomponents.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Signal yield</th>
<th>UL (yield)</th>
<th>Significance</th>
<th>Efficiency(%)</th>
<th>(B) ((\times 10^{-5}))</th>
<th>UL ((\times 10^{-5}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(K^+\pi^-\gamma)</td>
<td>27 ± 8 ± 1</td>
<td>⋯</td>
<td>5.0(^c)</td>
<td>18 ± 2</td>
<td>0.46 ± 0.13 ± 0.05</td>
<td>⋯</td>
</tr>
<tr>
<td>(K^*_2(1430)^0)</td>
<td>21 ± 8 ± 1</td>
<td>⋯</td>
<td>3.2</td>
<td>5.0 ± 0.3</td>
<td>1.3 ± 0.5 ± 0.1</td>
<td>⋯</td>
</tr>
<tr>
<td>(K^*(1410)^0)</td>
<td>7.7 ± 1.0 ± 0.5</td>
<td>19</td>
<td>⋯</td>
<td>0.58 ± 0.12</td>
<td>⋯</td>
<td>13</td>
</tr>
<tr>
<td>(K^+\pi^-\gamma) (NR)(^b)</td>
<td>0.0 ± 0.0</td>
<td>15</td>
<td>⋯</td>
<td>19 ± 1</td>
<td>⋯</td>
<td>0.26</td>
</tr>
<tr>
<td>(K^+\pi^-\pi^+\gamma)</td>
<td>57 ± 12 ± 6</td>
<td>⋯</td>
<td>5.9(^c)</td>
<td>7.5 ± 0.7</td>
<td>2.4 ± 0.5 ± 0.4</td>
<td>⋯</td>
</tr>
<tr>
<td>(K^0\pi^+\gamma)</td>
<td>33 ± 10 ± 2</td>
<td>⋯</td>
<td>3.7</td>
<td>5.0 ± 0.5</td>
<td>2.0 ± 0.7 ± 0.2</td>
<td>⋯</td>
</tr>
<tr>
<td>(K^+\rho^0\gamma)</td>
<td>24 ± 12 ± 4</td>
<td>43</td>
<td>2.2</td>
<td>7.4 ± 0.7</td>
<td>1.0 ± 0.5 ± 0.3</td>
<td>2.0</td>
</tr>
<tr>
<td>(K^+\pi^-\pi^+\gamma) (NR)(^b)</td>
<td>0 ± 0</td>
<td>20</td>
<td>⋯</td>
<td>7.6 ± 0.7</td>
<td>⋯</td>
<td>0.92</td>
</tr>
<tr>
<td>(K_1(1270)^+)</td>
<td>4.0 ± 2.4 ± 0.6</td>
<td>10</td>
<td>⋯</td>
<td>0.40 ± 0.08</td>
<td>⋯</td>
<td>9.9</td>
</tr>
<tr>
<td>(K_1(1400)^+)</td>
<td>26 ± 6 ± 2</td>
<td>36</td>
<td>⋯</td>
<td>2.6 ± 0.3</td>
<td>⋯</td>
<td>5.0</td>
</tr>
</tbody>
</table>

\(^a\)1.25 GeV/c^2 < \(M_{K\pi}\) < 1.6 GeV/c^2.
\(^b\)\(M_{K\pi}\) < 2.4 GeV/c^2.
\(^c\)\(M_{bc}\) fit result.
are included in the fit with fixed normalizations. The $M_{K \pi}$ and $M_{\pi\pi}$ shapes for the $q \bar{q}$ background are determined from the $\Delta E$ sideband data, and those for the other components are determined from the corresponding MC samples.

In order to model the signal PDF for the $K^+ \pi^- \gamma$ component, we use a mixture of $B^+ \rightarrow K_1(1400)^+ \gamma \rightarrow K^{*0} \pi^+ \gamma$ and $B^+ \rightarrow K^*(1680)^+ \gamma \rightarrow K^{*0} \pi^+ \gamma$ MC. The $K_1(1400)^+ \gamma$ fraction of the mixture is determined to be 0.74 ± 0.14 by examining a background-subtracted $M_{K\pi\pi}$ distribution for candidates with $|M_{K\pi} - M_{K_1}| < 75$ MeV/c$^2$ ($K^*$ mass cut). Likewise for the $K \rho \gamma$ PDF, a mixture of $B^+ \rightarrow K_1(1270)^+ \gamma \rightarrow K^* \rho^0 \gamma$ and $B^+ \rightarrow K^*(1680)^+ \gamma \rightarrow K^* \rho^0 \gamma$ MC is used, where the $K_1(1270)^+ \gamma$ fraction is determined to be 0.68 ± 0.17 according to a background-subtracted $M_{K\pi\pi}$ distribution for candidates with $|M_{K\pi} - M_{K_1}| < 250$ MeV/c$^2$ and $|M_{K\pi} - M_{K^*}| > 125$ MeV/c$^2$ ($\rho$ mass cut).

Figures 2(c) and 2(d) show the distributions and fit results for $M_{K \pi}$ and $M_{\pi\pi}$. The selection efficiency is estimated from a MC sample with the mixture of resonances used for the PDF determination. We also consider other well-established resonances [16] which give slightly different efficiencies, and assign the difference in the result as a systematic error. The signal yields, the efficiencies, and the branching fractions are listed in Table I. The total $B^+ \rightarrow K^{*0} \pi^+ \gamma$ branching fraction is dominated by $B^+ \rightarrow K^{*0} \pi^+ \gamma$ and $B^+ \rightarrow K^{*0} \rho^0 \gamma$; the statistical significance for the sum of the two is calculated to be 6.2σ, and the nonresonant component is consistent with zero.
Republic of Slovenia; the National Science Council and the Ministry of Education of Taiwan; and the U.S. Department of Energy.

*On leave from Nova Gorica Polytechnic, Slovenia.


[2] Hereafter, $K^{*}(892)$ is denoted by $K^{*}$.


[8] The charge conjugated modes are implicitly included.


[12] We expect $3 \pm 1 \ B^{0} \rightarrow D^{0}\pi^{0}$ background which may account for the excess around $M_{K\pi} = 1.85 \text{ GeV}/c^{2}$.


[16] We consider $K_{1}(1270)$, $K_{1}(1400)$, $K^{*}(1410)$, $K_{2}^{*}(1430)$, $K_{1}(1650)$, and $K^{*}(1680)$.