<table>
<thead>
<tr>
<th>Title</th>
<th>Radiative B meson decays into K pi gamma and K pi pi gamma final states</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author(s)</td>
<td>Nishida, S; Nakao, M; Abe, K; Abe, K; Abe, T; Ahn, BS; Aihara, H; Akatsu, M; Asano, Y; Aushev, T; Bakich, AM; Ban, Y; Banas, E; Bartel, W; Bay, A; Bedny, I; Bondar, A; Bozek, A; Bracko, M; Brodzicka, J; Browder, TE; Casey, BCK; Chang, P; Chao, Y; Cheon, BG; Chistov, R; Choi, SK; Choi, Y; Danilov, M; Dong, LY; Drutskoy, A; Eidelman, S; Eiges, V; Enari, Y; Fukunaga, C; Gabyshev, N; Gershon, T; Gordon, A; Gotow, K; Guo, R; Haba, J; Hara, T; Hayashii, H; Hazumi, M; Heenan, EM; Higuchi, I; Higuchi, T; Hojo, T; Hokuue, T; Hoshi, Y; Hou, SR; Hou, WS; Hsu, SC; Huang, HC; Igaki, T; Iijima, T; Inami, K; Ishikawa, A; Ishino, H; Itoh, R; Iwamoto, M; Iwasaki, H; Iwasaki, Y; Jalocha, P; Jang, HK; Kang, JH; Kapusta, P; Kataoka, SU; Katayama, N; Kawai, H; Kawakami, Y; Kawamura, N; Kawasaki, T; Kichimi, H; Kim, DW; Kim, H; Kim, HJ; Kim, HO; Kim, H; Kim, TH; Kinoshita, K; Krizan, P; Krokovny, P; Kulasiri, R; Kumar, S; Kwon, YJ; Lange, JS; Leder, G; Lee, SH; Li, J; Lu, RS; MacNaughton, J; Majumder, G; Mandl, F; Matsumoto, S; Matsumoto, T; Mikami, Y; Mitaroff, W; Miyabayashi, K; Miyake, H; Miyata, H; Moloney, GR; Mori, S; Nagamine, T; Nagasaka, Y; Nakadaira, T; Nakano, E; Nam, JW; Natkaniec, Z; Neichi, K; Nitoh, O; Noguchi, S; Nozaki, T; Ogawa, S; Ohno, F; Ohshima, T; Okabe, T; Okuno, S; Olsen, SL; Ostrowicz, W; Ozaki, H; Pakhlov, P; Palka, H; Park, CW; Park, H; Park, KS; Peak, LS; Perroud, JP; Peters, M; Piilonen, LE; Rozanska, M; Rybicki, K; Sagawa, H; Saitoh, S; Sakai, Y; Sakamoto, H; Satapathy, M; Satpathy, A; Schneider, O; Schrenk, S; Schwanda, C; Semenov, S; Senyo, K; Seuster, R; Sevior, ME; Shibuya, H; Shwartz, B; Sidorov, V; Singh, JB; Stanic, S; Sugi, A; Sugiyama, A; Sumisawa, K; Sumiyoshi, T; Suzuki, K; Suzuki, S; Takahashi, T; Takasaki, F; Tamai, K; Tamura, N; Tanaka, M; Taylor, GN; Teramoto, Y; Tokuda, S; Tomoto, M; Tomura, T; Tovey, SN; Trabelsi, K; Tsuboyama, T; Tsukamoto, T; Uehara, S; Ueno, K; Uno, S; Ushiroda, Y; Varner, G; Varvell, KE; Wang, CC; Wang, CH; Wang, JG; Wang, MZ; Watanabe, Y; Won, E; Yabsley, BD; Yamada, Y; Yamaguchi, A; Yamamoto, H; Yamashita, Y; Yamauchi, M; Yuan, Y; Yusa, Y; Zhang, J; Zhang, ZP; Zhilich, V; Zontar, D</td>
</tr>
<tr>
<td>Citation</td>
<td>PHYSICAL REVIEW LETTERS (2002), 89(23)</td>
</tr>
<tr>
<td>Issue Date</td>
<td>2002-12-02</td>
</tr>
<tr>
<td>Copyright</td>
<td>Copyright 2002 American Physical Society</td>
</tr>
<tr>
<td>項目</td>
<td>内容</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>コメント</td>
<td>表記せずに記載</td>
</tr>
<tr>
<td>その他</td>
<td>表記せずに記載</td>
</tr>
</tbody>
</table>
Radiative B Meson Decays into $K\pi\gamma$ and $K\pi\gamma\gamma$ 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
16Kanagawa 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
the branching fractions of the exclusive decays can be found in Ref. [3]. Some theoretical predictions for branching fractions of the exclusive decays can be found in Ref. [3]. Exclusive decays, such as $B \rightarrow K^+_S(1430)\gamma$, can also be used to measure the photon helicity, which may differ from the SM prediction in some new physics models [5].

In this Letter, we report on a search for resonant structures $K_X$ above the $K^+$ mass in radiative $B$ meson decays. The analysis is based on a data sample of 29.4 fb$^{-1}$ (31.9 $\times$ 10$^6$ $B\bar{B}$ events) recorded by the Belle detector at KEKB [6]. KEKB is an asymmetric energy $e^+e^-$ collider (3.5 GeV on 8 GeV) operated at the Y(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 $Y(4S)$ center-of-mass frame and within the acceptance of the barrel ECL ($33^\circ < \theta_\gamma < 128^\circ$). In order to reduce the background from $\pi^0, \eta \rightarrow \gamma\gamma$ decays, we combine the photon candidate with all other photon clusters in the event and reject the candidate if the invariant mass of any pair is within 18 MeV/c$^2$ (32 MeV/c$^2$) of the nominal $\pi^0$ ($\eta$) mass (this condition is referred to as the $\pi^0/\eta$ veto).

We search for $K_X$ resonances decaying into two-body ($K^+\pi^-$) and three-body ($K^+\pi^-\pi^+$) final states [8] in the invariant mass ($M_{K_X}$) range up to 2.4 GeV/c$^2$. For the $K^+\pi^-$ final state, the range $M_{K_X} < 1.2$ GeV/c$^2$ is

$$\frac{B(B^0 \rightarrow K^+\pi^-\gamma)}{B(B^0 \rightarrow K^+\pi^-\pi^+\gamma)} \approx \frac{1}{2} \pm 0.5\% \text{ (stat)} \pm 1\% \text{ (syst)} \times 10^{-3}.$$
excluded to remove $K^*$ contributions. Charged tracks are required to have CM momenta greater than 200 MeV/c, and to have impact parameters within $\pm 5$ 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 $\vec{p}_{K_X}$, $\vec{E}_{K_X}$, $\vec{p}_\gamma$, $\vec{E}_\gamma$ 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 momenta 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$h_{B}$). 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$h_{B}$ for signal (background). The PDFs for the Fisher discriminant are determined from Monte Carlo (MC) simulations. For cos$h_{B}$, we assume a $1 - \cos^2\theta^{h}_{B}$ 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. If 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 < $\Delta E$ < 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 < $\Delta E$ < 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 $\Delta E$ data sideband. The distribution for the signal component is modeled by a Gaussian determined from signal MC calibrated by $B^- \rightarrow D^0 \pi^-$ data. The signal yield is found to be $27^{+7}_{-5}\text{(stat)}^{+8}_{-8}\text{(syst)}$ with a statistical significance of 5.0$s$. 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: $B^0 \rightarrow K^*_D(1430)^0 \gamma$, $B^0 \rightarrow K^*(1410)^0 \gamma$, 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$h_{hel}$), and $M_{K\pi}$. The expected cos$h_{hel}$ distributions are $\sin^2\theta_{hel}$, $\sin^2\theta_{hel}$, and uniform for these three components, respectively. The PDFs for cos$h_{hel}$ 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$h_{hel}$ 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$\theta_{hel}$ 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, $B^0 \rightarrow K^0_s(1430)^0\gamma$. The $K^*(1410)^0\gamma$ and nonresonant components are not significant, so we set upper limits. The 90% confidence level upper limit $N$ is calculated from the relation $\int_0^N L(n)dn = 0.9 \int_0^\infty L(n)dn$, where $L(n)$ 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 $B^0 \rightarrow K^0_s(1430)^0\gamma$ 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, $\pi^0/\gamma$ veto and best candidate selection (2.0%), and uncertainty of the subdecay branching fractions (2.4%). Assuming an equal production rate for $B^0\bar{B}^0$ and $B^+B^-$, this leads to a branching fraction of $B^0 \rightarrow K^0_s(1430)^0\gamma$ 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 $K^*(1410)^0\gamma$ component is negligible.

In the $B^+ \rightarrow K^+\pi^-\pi^+\gamma$ analysis, we find additional background sources from a MC study. Cross feed from $B \rightarrow K^+\gamma$ to $B^+ \rightarrow K^+\pi^-\pi^+\gamma$ becomes negligible after removing positively identified $B \rightarrow K^*\pi\gamma$ events. The size of the cross feed from other $b \rightarrow s\gamma$ decays, especially from those with a $\pi^0$ in the final state, is estimated by using the inclusive $b \rightarrow s\gamma$ MC sample. The contribution from the $b \rightarrow c$ 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 $B \rightarrow K\pi\gamma$ analysis, smoothed MC histograms for the $b \rightarrow s\gamma$ 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 $b \rightarrow s\gamma$ branching fraction [11,15]. We find the signal yield of $57_{-12}^{+11}(\text{stat})_{-2}^{+2}(\text{syst})$ with a 5.9σ 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 $B^+ \rightarrow K^+\pi^-\pi^+\gamma$ signal may be explained as a sum of decays through kaonic resonances such as $B^+ \rightarrow K_1(1400)^+\gamma$ and $B^+ \rightarrow K^*(1680)^+\gamma$. 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 $K^\pi$ and $K\rho$ 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 $b \rightarrow s\gamma$ cross feed and from other $B$ meson decays

<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 (×10^{-5})</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^+\pi^-\pi^+\gamma^a$</td>
<td>$27_{-1}^{+1}$</td>
<td>5.0$^c$</td>
<td>18 ± 2</td>
<td>0.46 ±0.13</td>
<td>0.05 ±0.07</td>
<td>...</td>
</tr>
<tr>
<td>$K_2^*(1430)^0\gamma$</td>
<td>$21_{-1}^{+1}$</td>
<td>3.2</td>
<td>5.0 ± 0.3</td>
<td>1.3 ±0.5</td>
<td>0.03 ±0.01</td>
<td>...</td>
</tr>
<tr>
<td>$K^*(1410)^0\gamma$</td>
<td>$7.7_{-1}^{+3}$</td>
<td>0.58 ±0.12</td>
<td>...</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K^\pi^-\pi^+\gamma^\text{NR}^b$</td>
<td>$0.0_{-0.0}^{+0.0}$</td>
<td>19</td>
<td>19 ± 1</td>
<td>0.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K^+\pi^-\pi^+\gamma^b$</td>
<td>$57_{-11}^{+12}$</td>
<td>5.9$^c$</td>
<td>7.5 ± 0.7</td>
<td>2.4 ±0.5</td>
<td>0.04 ±0.02</td>
<td>...</td>
</tr>
<tr>
<td>$K^0\pi^+\gamma^b$</td>
<td>$33_{-2}^{+1}$</td>
<td>3.7</td>
<td>5.0 ± 0.5</td>
<td>2.0 ±0.7</td>
<td>0.02 ±0.02</td>
<td>...</td>
</tr>
<tr>
<td>$K^+\rho^0\gamma^b$</td>
<td>$24_{-2}^{+1}$</td>
<td>2.2</td>
<td>7.4 ± 0.7</td>
<td>1.0 ±0.5</td>
<td>0.02 ±0.03</td>
<td>2.0</td>
</tr>
<tr>
<td>$K^+\pi^-\pi^+\gamma^\text{NR}^b$</td>
<td>$0_{-0.0}^{+0.0}$</td>
<td>7.6 ± 0.7</td>
<td>...</td>
<td>...</td>
<td></td>
<td>0.92</td>
</tr>
<tr>
<td>$K_1(1270)^+\gamma$</td>
<td>$4.0_{-0.6}^{+0.6}$</td>
<td>0.40 ±0.08</td>
<td>...</td>
<td>9.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K_1(1400)^+\gamma$</td>
<td>$26_{-0.0}^{+0.0}$</td>
<td>2.6 ± 0.3</td>
<td>...</td>
<td>5.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^a$1.25 GeV/$c^2 < M_{K\pi} < 1.6$ GeV/$c^2$.

$^b$ $M_{K\pi\pi} < 2.4$ 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 $K_1(1400)\pi^-\gamma$ 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 $B^+ \rightarrow K_1(1270)^+\gamma \rightarrow K^+\rho^-\gamma$ and $B^+ \rightarrow K^*(1680)^+\gamma \rightarrow K^+\rho^-\gamma$ MC is used, where the $K_1(1270)\rho^-\gamma$ 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 $|M_{K\pi} - M_{K_1}| > 125$ MeV/$c^2$ (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 $B^+ \rightarrow K^+\pi^-\pi^+\gamma$ branching fraction is dominated by $B^+ \rightarrow K^{*0}\pi^+\gamma$ and $B^+ \rightarrow K^+\rho^-\gamma$; the statistical significance for the sum of the two is calculated to be 6.2$\sigma$, and the nonresonant component is consistent with zero.

We find evidence for the decay $B^+ \rightarrow K^{*0}\pi^+\gamma$ with a 3.7$\sigma$ significance, while the $B^+ \rightarrow K^+\rho^-\gamma$ channel alone yields only 2.2$\sigma$. Systematic errors are evaluated using the same procedures as in the $B \rightarrow K^+\pi^-\gamma$ analysis.

We also search for resonant decays by applying further kinematical requirements. We search for $B^+ \rightarrow K_1(1720)^+\gamma$ in the $K^{*0}\rho^-\gamma$ final state by applying the $\rho$ mass cut and $|M_{K\pi} - M_{K_1}| < 100$ MeV/$c^2$. We find six candidates with a background expectation of 2.0 ± 0.6 events. To find $B^+ \rightarrow K_1(1400)^+\gamma$ in the $K^{*0}\pi^+\gamma$ final state, we apply the $K^*$ mass cut and $|M_{K\pi} - M_{K_1}| < 200$ MeV/$c^2$. We obtain a sizable signal; however, we provide only upper limits due to a lack of ability to distinguish these resonances. The results are also listed in Table I.

In conclusion, we have studied radiative $B$ decays with the $K^+\pi^-\gamma$ and $K^+\pi^+\pi^-\gamma$ final states. For $K^+\pi^-\gamma$, we consider $B^0 \rightarrow K_2^*(1430)^0\gamma$, $B^0 \rightarrow K^*(1410)^0\gamma$, and nonresonant components, and find that only the first one is significant. For $B^+ \rightarrow K^+\pi^-\pi^+\gamma$, we observe the decay mode and measure the branching fraction. The branching fractions for $B \rightarrow K^+\pi^-\gamma$ and $K^{*0}\rho^-\gamma$ are consistent with the sum of predicted rates of resonant decays [4]. As listed in Table II, we find (35 ± 8)% of the total $B \rightarrow Xs\gamma$ decay is accounted for by the $B \rightarrow K^+\gamma$, $B \rightarrow K_2^*(1430)\gamma$, and $B \rightarrow K^*\pi^-\gamma$ final states.

We thank the KEKB accelerator group for the excellent operation of the KEKB accelerator. We acknowledge support from the Ministry of Education, Culture, Sports, Science, and Technology of Japan and the Japan Society for the Promotion of Science; the Australian Research Council and the Australian Department of Industry, Science and Resources; the National Science Foundation of China under Contract No. 10175071; the Department of Science and Technology of India; the BK21 program of the Ministry of Education of Korea and the CHEP SRC program of the Korea Science and Engineering Foundation; the Polish State Committee for Scientific Research under Contract No. 2P03B 17017; the Ministry of Science and Technology of the Russian Federation; the Ministry of Education, Science and Sport of the

Table II. Exclusive and inclusive branching fractions for the $b \rightarrow s\gamma$ process. Equal branching fractions are assumed for neutral and charged $B$ decays. Using isospin, the branching fraction of $B^+ \rightarrow K^{*0}\pi^+\gamma$ ($K^0\rho^-\gamma$) is assumed to be half (twice) that of $B^+ \rightarrow K^{*0}\pi^+\gamma$ ($K^0\rho^-\gamma$).

<table>
<thead>
<tr>
<th>Mode</th>
<th>$\mathcal{B} \times 10^{-5}$</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B \rightarrow K^+\gamma$</td>
<td>4.2 ± 0.4</td>
<td>[3,17]</td>
</tr>
<tr>
<td>$B \rightarrow K_1'(1430)\gamma$ (excluding $K^+\pi^-\gamma$, $K^0\gamma$)</td>
<td>0.9 ± 0.3</td>
<td></td>
</tr>
<tr>
<td>$B \rightarrow K^*\pi^-\gamma$</td>
<td>3.1 ± 1.0</td>
<td></td>
</tr>
<tr>
<td>$B \rightarrow K^0\rho^-\gamma$</td>
<td>3.0 ± 1.6</td>
<td></td>
</tr>
<tr>
<td>Sum of exclusive modes</td>
<td>11.2 ± 2.1</td>
<td></td>
</tr>
<tr>
<td>$B \rightarrow Xs\gamma$ (inclusive)</td>
<td>32.2 ± 4.0</td>
<td>[11,15]</td>
</tr>
</tbody>
</table>
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 $3 \pm 1$ $B^0 \to D^0 \pi^0$ background which may account for the excess around $M_{K\pi} = 1.85$ GeV/$c^2$.


[16] We consider $K_1(1270)$, $K_1(1400)$, $K^{*}(1410)$, $K_2^*(1430)$, $K_1(1650)$, and $K^{*}(1680)$.