Observation of Radiative $B$ Meson Decays into Higher Kaonic Resonances
(Penguin Mediated $B$ Decays at Belle)

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Abstract: We have studied radiative $B$ meson decays into higher kaonic resonances decaying into a two-body or three-body final state, using a data sample of $21.3 \, \text{fb}^{-1}$ recorded at the $\Upsilon(4S)$ resonance with the Belle detector at KEKB. For the two-body final state, we extract the $B \to K^{\ast}(1430)\gamma$ component from an analysis of the helicity angle distribution, and obtain $B(B^0 \to K^{\ast+}(1430)\pi^{-}) = (1.26 \pm 0.66 \pm 0.10) \times 10^{-5}$. For the three-body final state, we observe a $B \to K\pi\pi\gamma$ signal that is consistent with a mixture of $B \to K^\ast\pi\gamma$ and $B \to K\rho\gamma$ for the first time.

1. Introduction

Radiative $B$ meson decay through the $b \to s\gamma$ process has been one of the most sensitive probes of new physics beyond the Standard Model (SM). The inclusive picture of the $b \to s\gamma$ process is well established; however, our knowledge of the exclusive final states in radiative $B$ meson decays is rather limited. A relativistic form-factor model calculation [1] predicts that more than 20% of the $b \to s\gamma$ process should hadronize as kaonic resonances ($K_X$). CLEO has already reported an indication of the $B \to K^{\ast+}(1430)\gamma$ signal [2]. Precision measurement of the inclusive $b \to s\gamma$ branching fraction will require detailed knowledge of such resonances, for example to model the decay processes into multi-particle final states. In this analysis, we study radiative $B$ meson decay processes into higher kaonic resonances, which subsequently decay into two-body or three-body final states.

We have analyzed a data sample that contains $22.8 \times 10^6$ $BB$ events. The data sample corresponds to an integrated luminosity of $21.3 \, \text{fb}^{-1}$ collected at the $\Upsilon(4S)$ resonance with the Belle detector [3] at the KEKB $e^+e^-$ collider [4].

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2. Analysis of $B \to K_2^*(1430)\gamma$

In the $B \to K_2^*(1430)\gamma$ analysis, we reconstruct $K_2^*(1430)$ from $K^+\pi^-$ (charge conjugate modes are implicitly included) and require the $K\pi$ invariant mass to be within $\pm 125\text{ MeV}/c^2$ of the nominal $K_2^*(1430)$ value. Then, we combine the $K_2^*(1430)$ candidate with a high energy (1.8 to 3.4 GeV in the $\Upsilon(4S)$ rest frame) photon ($\gamma$) candidate inside the acceptance of the barrel calorimeter ($33^\circ < \theta_{\gamma} < 128^\circ$) to reconstruct a $B$ meson candidate, and form two independent variables: the beam constrained mass $M_{bc} \equiv \sqrt{(E_{\text{beam}})^2 - |p_{K}\pi + p_{\gamma}|^2}$, and the energy difference $\Delta E \equiv E_{K}\pi + E_{\gamma} - E_{\text{beam}}$. We apply a cut of $-100\text{ MeV} < \Delta E < 75\text{ MeV}$.

To suppress backgrounds from continuum light quark-pair ($q\bar{q}$) production, we apply a likelihood ratio cut where the likelihood ratio is calculated from the $B$ meson flight direction and an event shape variable which we call SFW \([5]\). We find that the contribution of the background from other $B$ meson decays is negligible from Monte Carlo (MC) study. Cross-feed from other $b \to s\gamma$ final states is estimated using an inclusive $b \to s\gamma$ MC sample, and subtracted from the signal yield.

The $M_{bc}$ distribution for $B^0 \to K_2^*(1430)^0\gamma$ is shown in Fig. 1. By the fit to the $M_{bc}$ distribution using a sum of a Gaussian function and a threshold-type function (ARGUS function \([6]\)), we obtain $29.1 \pm 6.7^{+2.4}_{-1.0}$ events, of which the contribution from other $b \to s\gamma$ decays is estimated to be $0.4 \pm 0.3$ events. The event selection efficiency is determined to be $(6.99 \pm 0.55)\%$ including the sub-decay branching fractions from a MC sample that is calibrated with high statistics control data samples.

In order to distinguish the $B \to K_2^*(1430)\gamma$ signal from $B \to K^*(1410)\gamma$ and non-resonant decays, we examine the helicity angle distribution for the signal candidates. All three modes have different helicity distributions: $\cos^2\theta_{\text{hel}} - \cos^4\theta_{\text{hel}}$ for $K_2^*(1430)$, $1 - \cos^2\theta_{\text{hel}}$ for $K^*(1410)$ and uniform for non-resonant decay. We divide $\cos\theta_{\text{hel}}$ into 5 bins, and extract the yield from fits to the $M_{bc}$ distribution for each bin (Fig. 2). This distribution clearly favors $B \to K_2^*(1430)\gamma$. We fit the $\cos\theta_{\text{hel}}$ distribution and obtain $20.1 \pm 10.5$ events for the $B \to K_2^*(1430)\gamma$ component. After subtracting other $b \to s\gamma$ contributions, this leads to a $B^0 \to K_2^*(1430)^0\gamma$ branching fraction of

$$B(B^0 \to K_2^*(1430)^0\gamma) = (1.26 \pm 0.66 \pm 0.10) \times 10^{-5}.$$

The background subtracted $K\pi$ invariant mass distribution for $B \to K\pi\gamma$ is obtained by a similar method. In Fig. 3, we see a clear enhancement around 1.4 GeV/$c^2$, which supports the conclusion that the $B \to K_2^*(1430)\gamma$ contribution dominates.
3. Analysis of $B \rightarrow K_X \gamma \rightarrow K\pi\pi\gamma$

The selection criteria used to reconstruct the $B \rightarrow K\pi\pi\gamma$ decay are similar to those used in the analysis of $B \rightarrow K_2^*(1430)\gamma$. The $K_X$ candidate is reconstructed from $K^+\pi^-\pi^+$, and required to have a mass between 1.0 GeV/c² and 2.0 GeV/c². The three charged tracks are required to form a vertex.

We select $B \rightarrow K_X\gamma \rightarrow K^*\pi\gamma$ candidates ($K^*$ denotes $K^*(892)$ for simplicity) by requiring the invariant mass of $K^+\pi^-$ to be within $\pm$75 MeV/c² of the nominal $K^*$ mass. We obtain $46.4 \pm 7.3^{+1.6}_{-2.7}$ events from the $M_{bc}$ distribution (Fig. 4). After subtracting $B^+ \rightarrow K^0\rho^0\gamma$ or non-resonant contribution using $M_{K\pi}$ sideband and other $b \rightarrow s\gamma$ contribution using MC, we obtain a $B^+ \rightarrow K^{*0}\pi^+\gamma$ yield of $39.7 \pm 7.4^{+1.7}_{-2.6}$ events.

From the $K_X$ invariant mass ($M_{K_X}$) distribution (Fig. 5), we observe a broad structure
below 2.0 GeV/c² that can be explained, for example, as a sum of two known resonances around 1.4 GeV/c² and 1.7 GeV/c², but cannot be explained by a single known resonance or phase space decay. We observe no excess above 2.0 GeV/c², indicating that the $M_{K_X} < 2.0$ GeV/c² cut does not introduce a significant inefficiency.

To estimate the efficiency of $B \rightarrow K^*\pi\gamma$, we analyze $B \rightarrow K_1(1400)\gamma$ and $B \rightarrow K^*(1680)\gamma$ MC samples, use the mean of the efficiencies as the central value, and assign the difference to the systematic error. As a result, the efficiency becomes $(3.13 \pm 0.47)\%$ including the other systematic errors. We determine the $B \rightarrow K^*\pi\gamma$ branching fraction,

$$B(B \rightarrow K^*\pi\gamma; M_{K^*\pi} < 2.0 \text{ GeV/c}^2) = (5.6 \pm 1.1 \pm 0.9) \times 10^{-5}.$$ 

There are four known resonances, $K_1(1270)$, $K_1(1400)$, $K^*(1410)$ and $K^*_2(1430)$, that can contribute to the signal around $M_{K_X} = 1.4$ GeV/c². In the region of 1.2 GeV/c² < $M_{K_X}$ < 1.6 GeV/c², we obtain 22.9 ± 5.1 +1.9 -1.7 events from the $M_{bc}$ distribution, where the $K^*_2(1430)$ contribution is estimated to be 2.6 ± 1.4 events from our branching fraction measurement. We interpret the signal yield as an upper limit on the weighted sum of the three resonances: $\frac{1}{2}B(B \rightarrow K_1(1270)\gamma) + B(B \rightarrow K_1(1400)\gamma) + B(B \rightarrow K^*(1410)\gamma) < 5.1 \times 10^{-5}$ (90% C.L.).

Next, we select $B \rightarrow K_X\gamma \rightarrow K\rho\gamma$ candidates by requiring the invariant mass of the $\pi^+\pi^-$ combination to be within ±250 MeV/c² of the nominal $\rho$ mass. To veto $B \rightarrow K_X\gamma \rightarrow K^*\pi\gamma$ events, we reject a candidate if the invariant $K^+\pi^-$ mass is within ±125 MeV/c² of the nominal $K^*$ mass. The $M_{bc}$ distribution and the $K_X$ invariant mass distribution are shown in Figs. 6 and 7, respectively. From the $M_{bc}$ distribution, we obtain a signal yield of 24.5 ± 6.4 ±1.2 +1.3 events. We subtract the contribution of 2.3 ± 1.2 events from other $b \rightarrow s\gamma$ decays.

The $M_{K_X}$ spectrum of these events (Fig. 7) shows a large peak around 1.7 GeV/c². Since there are quite a few resonances around 1.7 GeV/c², a detailed analysis will be required to disentangle the resonant structure. The reconstruction efficiency for $B \rightarrow K\rho\gamma$, which is $M_{K_X}$ dependent, is determined to be (1.51 ± 0.25)% by assuming a mixture of $K_1(1270)$ and $K^*(1680)$ with a ratio from the $M_{K_X}$ fit result. So far we find no signal outside the $\rho$ mass window; neglecting the non-resonant $K\pi\pi\gamma$ contribution, we determine the $B \rightarrow K\rho\gamma$ branching fraction,

$$B(B \rightarrow K\rho\gamma; M_{K\rho} < 2.0 \text{ GeV/c}^2) = (6.5 \pm 1.7^{+1.1}_{-1.2}) \times 10^{-5}.$$ 

The $K\rho\gamma$ final state in the mass range around 1.3 GeV/c² is effective for the search of $B \rightarrow K_1(1270)\gamma$. We find 4 candidates in the signal box with a background expectation of 1.19 events, when we require $|M_{K_X} - M_{K_1(1270)}| < 0.1$ GeV/c², and obtain an upper limit of $B(B \rightarrow K_1(1270)\gamma) < 9.6 \times 10^{-5}$ (90% C.L.).

### 4. Conclusion

We have searched for radiative $B$ meson decays into kaonic resonances that decay into a two-body or three-body final states together with a high energy photon. We observe sizable

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signals in $B \to K_2^*(1430)\gamma$, $B \to K^*\pi\gamma$ and $B \to K\rho\gamma$ decays and determine the branching fractions for these channels. The measured branching fractions respectively correspond to about 4%, 17% and 19% of the total $b \to s\gamma$ branching fraction [5,8–10]. Adding 15% from the $K^*(892)\gamma$ branching fractions, these decay modes sum up to about half of the entire $b \to s\gamma$ process.

For the $K\pi\gamma$ final state, the $K_2^*(1430)\gamma$ component is separated from a possible $K^*(1410)\gamma$ or non-resonant contribution using a helicity angle analysis.

For the three-body final states, we observe $B \to K^*\pi\gamma$ and $B \to K\rho\gamma$ signals separately for the first time; however, the possible contribution of many kaonic resonances prevents us from further identification of such resonances with the current statistics. We find no significant signal for $B \to K_1(1270)\gamma$ decay in the $K\rho\gamma$ final state.

References

[1] S.Veseli and M.G.Olsson, Phys. Lett. B 367, 309 (1996).
[2] CLEO Collaboration, T.E.Coan et al., Phys. Rev. Let. 84, 5283 (2000).
[3] Belle Collaboration, K. Abe et al., KEK Progress Report 2000-4 (2000), to be published in Nucl. Inst. and Meth. A.
[4] KEKB B Factory Design Report, KEK Report 95-7 (1995), unpublished; Y. Funakoshi et al., Proc. 2000 European Particle Accelerator Conference, Vienna (2000).
[5] Belle Collaboration, K.Abe et al., Phys. Lett. B 511, 151 (2001).
[6] ARGUS Collaboration, H. Albrecht et al., Phys. Lett. B 241, 278 (1990).
[7] Particle Data Group, D.E. Groom et al., Eur. Phys. J. C15, 1 (2000).
[8] K.Chetyrkin, M.Misiak, M.Münz, Phys. Lett. B 400, 206 (1997); Erratum ibid. B 425, 414 (1998)
[9] CLEO Collaboration, M.Alam et al., Phys. Rev. Lett. 74, 2885 (1995).
[10] ALEPH Collaboration, R.Barate et al., Phys. Lett. B 429, 196 (1998)