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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 fb^{-1} recorded at the $\Upsilon(4S)$ resonance with the Belle detector at KEKB. For the two-body final state, we extract the $B \to K_2^*(1430)\gamma$ component from an analysis of the helicity angle distribution, and obtain $\mathcal{B}(B^0 \to K_2^*(1430)^0\gamma) = (1.26 \pm 0.66 \pm 0.10) \times 10^{-5}$. For the three-body final state, we observe a $B \to K\pi\pi\gamma$ signal that is consistent with a mixture of $B \to K^*\pi\gamma$ 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 $B \to K_2^*(1430)\gamma$ 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 22.8×10^6 $B\bar{B}$ events. The data sample corresponds to an integrated luminosity of 21.3 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 ± 125 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 (γ) 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 $M_{\rm bc} \equiv \sqrt{(E_{\rm beam})^2 - |\vec{p}_{K_X} + \vec{p}_\gamma|^2}$, and the energy difference $\Delta E \equiv E_{K_X} + E_\gamma - E_{\rm beam}$. We apply a cut of -100 MeV $< \Delta E <$ 75 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 $M_{\rm bc}$ distribution for $B^0 \to K_2^*(1430)^0\gamma$ is shown in Fig. 1. By the fit to the $M_{\rm bc}$ distribution using a sum of a Gaussian function and a threshold-type function (ARGUS function [6]), we obtain $29.1 \pm 6.7\,^{+2.4}_{-1.9}$ events, of which the contribution from other $b \to s\gamma$ decays is estimated to be 0.4 ± 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.

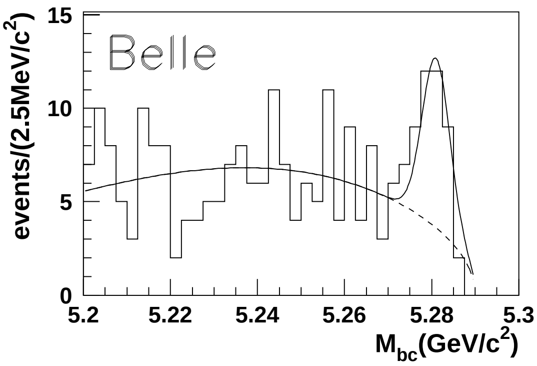

Figure 1: The $M_{\rm bc}$ distributions for $B^0 \to K_2^*(1430)^0\gamma$. The solid line is the fitting result. The background component is shown as the dashed line.

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: $\cos^2\theta_{\rm hel} - \cos^4\theta_{\rm hel}$ for $K_2^*(1430)$, $1 - \cos^2\theta_{\rm hel}$ for $K^*(1410)$ and uniform for non-resonant decay. We divide $\cos\theta_{\rm hel}$ into 5 bins, and extract the yield from fits to the $M_{\rm bc}$ distribution for each bin (Fig. 2). This distribution clearly favors $B \to K_2^*(1430)\gamma$. We fit the $\cos\theta_{\rm hel}$ distribution and obtain 20.1 ± 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

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

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.

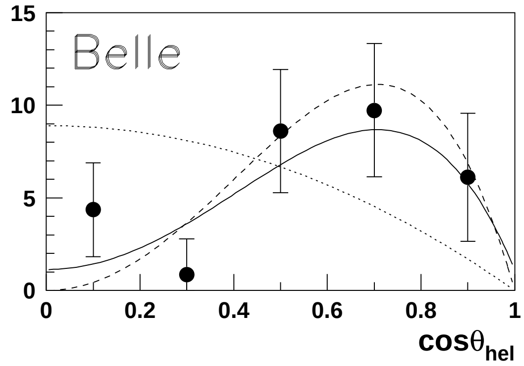

Figure 2: The background subtracted $K_2^*(1430)$ helicity angle distribution. The solid curve is the fitting result. The curve for $B \to K_2^*(1430)\gamma$ ($B \to K^*(1410)\gamma$) is shown as the dashed (dotted) line.

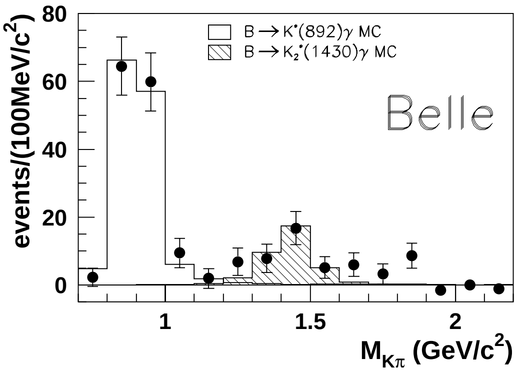

Figure 3: The background subtracted $K\pi$ invariant mass distribution.

3. Analysis of $B \to K_X\gamma \to K\pi\pi\gamma$

The selection criteria used to reconstruct the $B \to K\pi\pi\gamma$ decay are similar to those used in the analysis of $B \to K_2^*(1430)\gamma$. The K_X candidate is reconstructed from $K^+\pi^-\pi^+$, and required to have a mass between 1.0 GeV/c^2 and 2.0 GeV/c^2. The three charged tracks are required to form a vertex.

We select $B \to K_X\gamma \to K^*\pi\gamma$ candidates (K^* denotes $K^*(892)$ for simplicity) by requiring the invariant mass of $K^+\pi^-$ to be within ± 75 MeV/c^2 of the nominal K^* mass. We obtain $46.4 \pm 7.3\,^{+1.6}_{-2.7}$ events from the $M_{\rm bc}$ distribution (Fig. 4). After subtracting $B^+ \to K^+\rho^0\gamma$ or non-resonant contribution using $M_{K\pi}$ sideband and other $b \to s\gamma$ contribution using MC, we obtain a $B^+ \to K^{*0}\pi^+\gamma$ yield of $39.7 \pm 7.4\,^{+1.7}_{-2.6}$ events.

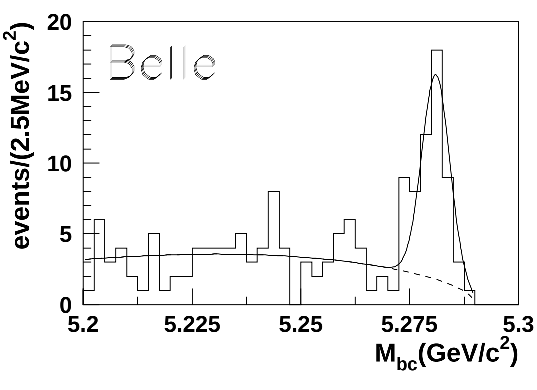

Figure 4: The $M_{\rm bc}$ distribution for $B \to K^*\pi\gamma$ candidates.

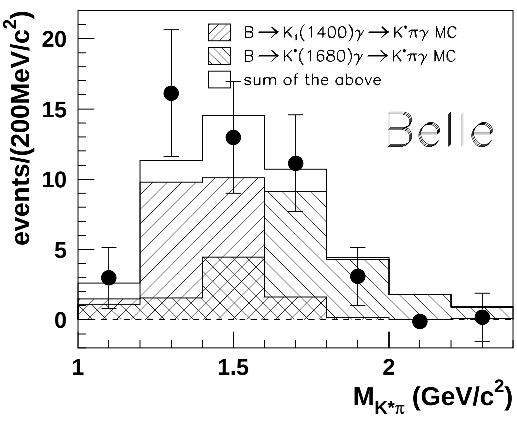

Figure 5: The background subtracted $K\pi\pi$ invariant mass distribution for the $B \to K^*\pi\gamma$ analysis.

From the K_X invariant mass (M_{K_X}) distribution (Fig. 5), we observe a broad structure below 2.0 GeV/c^2 that can be explained, for example, as a sum of two known resonances around 1.4 GeV/c^2 and 1.7 GeV/c^2, but cannot be explained by a single known resonance or phase space decay. We observe no excess above 2.0 GeV/c^2, indicating that the $M_{K_X} <$ 2.0 GeV/c^2 cut does not introduce a significant inefficiency.

To estimate the efficiency of $B \to K^*\pi\gamma$, we analyze $B \to K_1(1400)\gamma$ and $B \to K^*(1680)\gamma$ 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 $B \to K^*\pi\gamma$ branching fraction,

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

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/c^2. In the region of 1.2 GeV/$c^2 < M_{K_X} <$ 1.6 GeV/c^2, we obtain $22.9 \pm 5.1\,^{+1.0}_{-1.7}$ events from the $M_{\rm bc}$ 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: $\frac{1}{2}\mathcal{B}(B \to K_1(1270)\gamma) + \mathcal{B}(B \to K_1(1400)\gamma) + \mathcal{B}(B \to K^*(1410)\gamma) < 5.1 \times 10^{-5}$ (90% C.L.).

Next, we select $B \to K_X\gamma \to K\rho\gamma$ candidates by requiring the invariant mass of the $\pi^+\pi^-$ combination to be within ± 250 MeV/c^2 of the nominal ρ mass. To veto $B \to K_X\gamma \to K^*\pi\gamma$ events, we reject a candidate if the invariant $K^+\pi^-$ mass is within ± 125 MeV/c^2 of the nominal K^* mass. The $M_{\rm bc}$ distribution and the K_X invariant mass distribution are shown in Figs. 6 and 7, respectively. From the $M_{\rm bc}$ distribution, we obtain a signal yield of $24.5 \pm 6.4\,^{+1.2}_{-2.3}$ events. We subtract the contribution of 2.3 ± 1.2 events from other $b \to s\gamma$ decays.

The M_{K_X} spectrum of these events (Fig. 7) shows a large peak around 1.7 GeV/c^2. Since there are quite a few resonances around 1.7 GeV/c^2, a detailed analysis will be required to disentangle the resonant substructure. The reconstruction efficiency for $B \to K\rho\gamma$, which is M_{K_X} dependent, is determined to be $(1.51 \pm 0.25)\%$ 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 ρ mass window; neglecting the non-resonant $K\pi\pi\gamma$ contribution, we determine the $B \to K\rho\gamma$ branching fraction,

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

The $K\rho\gamma$ final state in the mass range around 1.3 GeV/c^2 is effective for the search of $B \to K_1(1270)\gamma$. 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/c^2, and obtain an upper limit of $\mathcal{B}(B \to K_1(1270)\gamma) < 9.6 \times 10^{-5}$ (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

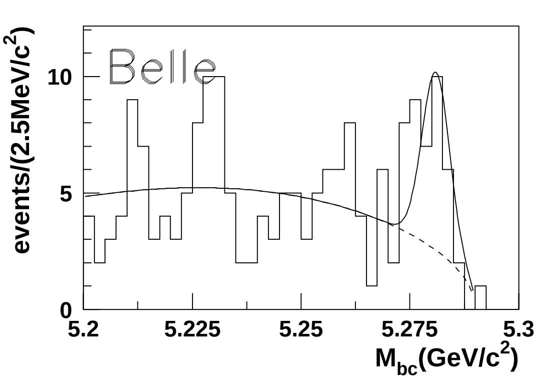

Figure 6: The $M_{\rm bc}$ distribution for $B \to K\rho\gamma$ candidates.

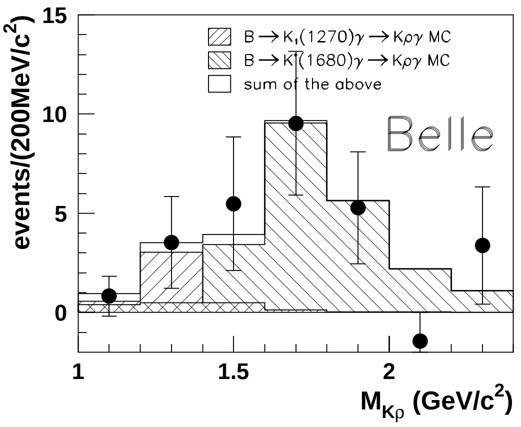

Figure 7: The $K\pi\pi$ invariant mass distribution in the $B \to K\rho\gamma$ analysis. Background is subtracted in each bin.

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.

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