

## $b \rightarrow s$ Hadronic Decays at Belle

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We report measurements of charmless hadronic  $B^0$  decays into the  $\pi^+\pi^-K^+\pi^-$  final state from Belle. This study includes the first observation of  $B^0 \rightarrow \rho^0 K^+ \pi^-$ , which is measured to have the branching fraction  $\mathcal{B}[B^0 \rightarrow \rho^0 K^+ \pi^-; M_{K\pi} \in (0.75, 1.20) \text{ GeV}/c^2] = [2.8 \pm 0.5(\text{stat}) \pm 0.5(\text{syst})] \times 10^{-6}$  and the first evidence of the decays  $B^0 \rightarrow f_0(980)K^+\pi^-$  and  $B^0 \rightarrow \pi^+\pi^-K^{*0}$  with significances of  $3.5\sigma$  and  $4.5\sigma$ , respectively. For the two-body decays  $B^0 \rightarrow \rho^0 K^{*0}$  and  $B^0 \rightarrow f_0(980)K^{*0}$ , the significances are  $2.7\sigma$  and  $2.5\sigma$ , respectively, and the upper limits on the branching fractions are  $3.4 \times 10^{-6}$  and  $2.2 \times 10^{-6}$  at 90% confidence level. These measurements are obtained from a data sample of 657 million  $B\bar{B}$  pair events collected with the Belle detector at the KEKB asymmetric-energy  $e^+e^-$  collider.

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## 1. Introduction

In the Standard Model (SM), charmless hadronic  $B$  decays occur mainly via two processes (i)  $b \rightarrow s$  penguin and (ii)  $b \rightarrow u$  tree decay. These charmless hadronic  $B$  decays therefore give us plenty of information. Search for new physics effect, for example, can be done by studying loop processes because  $b \rightarrow s$  quark transitions are very sensitive to physics beyond SM. In addition, measuring the branching fraction ( $\mathcal{B}$ ) and angular correlations could advance the phenomenological test and/or development of the theoretical models.

In particular, the measurements of the longitudinal polarization fraction ( $f_L$ ) in rare  $B$  decays to vector-vector (VV) state, such as  $B \rightarrow \phi K^*$  [1–3], have revealed an unexpectedly large fraction of transverse polarization. This implies that non-factorizable contributions to the decays amplitude play a significant role. Therefore, further information about these effects can be obtained with  $\mathcal{B}$  and  $f_L$  in the decay  $B^0 \rightarrow \rho^0 K^{*0}$ , this occurring mostly via the  $b \rightarrow s$  penguin process [1–5].

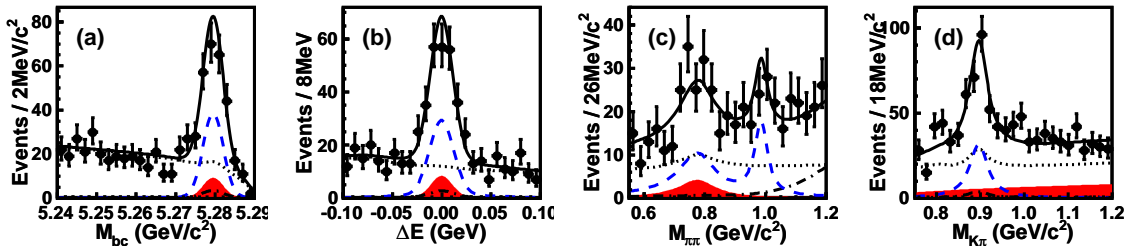
The results are based on a sample of 657 million  $B\bar{B}$  pair events, collected with the Belle [6] detector at the KEKB [7] asymmetric-energy  $e^+e^-$  collider (3.5 on 8 GeV) operating at the  $\Upsilon(4S)$ .

## 2. Measurements of $B^0 \rightarrow \rho^0 K^{*0}$ and $B^0 \rightarrow \pi^+ \pi^- K^+ \pi^-$

We reconstruct the signal  $B$  candidates using the kinematic variables such as the beam-energy constrained mass,  $M_{bc} \equiv \sqrt{E_{\text{beam}}^2 - p_B^2}$ ; the energy difference,  $\Delta E \equiv E_B - E_{\text{beam}}$ ; the invariant masses of  $\pi\pi$  and  $K\pi$  ( $M_{\pi\pi}$  and  $M_{K\pi}$ ), where  $E_{\text{beam}}$  is the beam energy and  $E_B$  and  $p_B$  are the reconstructed energy and momentum, respectively, of  $B$  candidates in the center-of-mass frame.

The dominant background arises from the continuum process. The continuum suppression is achieved by applying a requirement on a likelihood ratio, based on a GEANT-based [8] Monte Carlo (MC) simulation and sideband data, together with the  $B$  flavour tagging information [9]. Background contribution from  $b \rightarrow c$  events is investigated using a large MC sample. We veto the decays  $B \rightarrow D^{*\pm} X$ ,  $B \rightarrow D^\pm X$  and  $B \rightarrow D^0 X$  by applying the invariant mass cuts.

After the optimization of selection cuts, events that remain in the fitting regions of the observables  $M_{bc}$ ,  $\Delta E$ ,  $M_{\pi\pi}$  and  $M_{K\pi}$  are used for the yield extraction. This process is done by performing the four-dimensional unbinned maximum likelihood fit (4D fit).



**Figure 1:** Projection of the 4D fit results onto (a)  $M_{bc}$ , (b)  $\Delta E$ , (c)  $M_{\pi\pi}$ , (d)  $M_{K\pi}$ , with the other variables required to satisfy (except for the variable plotted)  $M_{bc} \in (5.27, 5.29)$  GeV/ $c^2$ ,  $\Delta E \in (-0.045, 0.045)$  GeV,  $M_{\pi\pi} \in (0.62, 1.04)$  GeV/ $c^2$  and  $M_{K\pi} \in (0.84, 0.94)$  GeV/ $c^2$ . The curves are for the  $\rho^0 K^{*0}$  (solid-shaded), the sum of  $\rho^0 K^{*0}$  and  $f_0(980) K^{*0}$  (dashed),  $f_2(1270) K^{*0}$  and the sum of feed-down modes (dot-dashed), the sum of the backgrounds (dotted), and the total (solid).

**Table 1:** The signal yield  $Y$  and its statistical uncertainty, corrected MC efficiency  $\varepsilon$  (assuming  $f_L = 0.5$  for  $B^0 \rightarrow \rho^0 K^{*0}$ ), significance  $\mathcal{S}$  including the systematic uncertainties, measured branching fraction  $\mathcal{B}$  and the upper limit (UL) at the 90% confidence level  $\mathcal{B}_{\text{UL}}$ . For non-resonant decay components,  $\varepsilon$ ,  $\mathcal{B}$  and  $\mathcal{B}_{\text{UL}}$  are obtained for  $M_{K\pi} \in (0.75, 1.20)$  GeV/ $c^2$  and  $M_{\pi\pi} \in (0.55, 1.20)$  GeV/ $c^2$  assuming phase space distributions. For the branching fraction, the first (second) uncertainty is statistical (systematic).

Mode	$Y$ (events)	$\varepsilon$ (%)	$\mathcal{S}$ ( $\sigma$ )	$\mathcal{B}$ ( $10^{-6}$ )	$\mathcal{B}_{\text{UL}}$ ( $10^{-6}$ )
$B^0 \rightarrow \rho^0 K^{*0}$	$77.6^{+28.6}_{-27.9}$	5.73	2.7	$2.1^{+0.8+0.9}_{-0.7-0.5}$	$< 3.4$
$B^0 \rightarrow f_0(980)K^{*0}$	$51.2^{+20.4}_{-19.3}$	5.56	2.5	$1.4^{+0.6+0.6}_{-0.5-0.4}$	$< 2.2$
$B^0 \rightarrow \rho^0 K^+ \pi^-$	$207.8^{+39.8}_{-39.2}$	11.15	5.0	$2.8 \pm 0.5 \pm 0.5$	-
$B^0 \rightarrow f_0(980)K^+ \pi^-$	$106.9^{+31.6}_{-29.9}$	11.43	3.5	$1.4 \pm 0.4^{+0.3}_{-0.4}$	$< 2.1$
$B^0 \rightarrow \pi^+ \pi^- K^{*0}$	$200.7^{+46.7}_{-44.9}$	6.74	4.5	$4.5^{+1.1+0.9}_{-1.0-1.6}$	-
$B^0 \rightarrow \pi^+ \pi^- K^+ \pi^-$	$-5.4^{+54.9}_{-44.9}$	6.84	0.0	$-0.1^{+1.2+1.4}_{-1.1-0.8}$	$< 2.1$

The fit projections are shown in Figure 1, and the results are summarized in Table 1. The fit yields the first observation for  $B^0 \rightarrow \rho^0 K^+ \pi^-$  with a significance of  $5.0\sigma$  (including systematic uncertainty). We also find evidence for  $B^0 \rightarrow f_0(980)K^+ \pi^-$  with a significance of  $3.5\sigma$ , and evidence for  $B^0 \rightarrow \pi^+ \pi^- K^{*0}$  with a significance of  $4.5\sigma$ . For  $B^0 \rightarrow \rho^0 K^{*0}$  and  $B^0 \rightarrow f_0(980)K^{*0}$ , we observe excesses of events with significances of  $2.7\sigma$  and  $2.5\sigma$ , respectively. Our results for these two-body decays are approximately  $2\sigma$  and  $1\sigma$  lower, respectively, than in the previous measurement [4]. We have also searched for the fully non-resonant four-body decays  $B^0 \rightarrow \pi^+ \pi^- K^+ \pi^-$  and calculated a 90% confidence level upper limit on its partial branching fraction. Our results [10] for the non-resonant modes are the first and can advance our understanding of the polarization puzzle in  $\rho K^*$  decays.

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