Results on a number of rare hadronic $B$ decays are presented. A data sample of 29.1 fb$^{-1}$ accumulated using the Belle detector at the KEKB asymmetric $e^+e^-$ collider operating at the $\Upsilon(4S)$ resonance is used. All results are preliminary unless indicated otherwise.

1 Introduction

Belle is an experiment designed to make measurements of time-dependent $CP$ asymmetries in $B$ physics. Important measurements of these phenomena have recently been reported. In addition, owing to the unparalleled performance of KEKB and the excellent performance of the Belle detector, numerous interesting rare $B$ decay modes can be studied.

The Belle detector is described in detail elsewhere. It consists of a silicon vertex detector, a central drift chamber (CDC), aerogel Cerenkov counters (ACC), time-of-flight scintillation counters (TOF) and an electromagnetic calorimeter made of CsI(Tl) crystals enclosed in alternating layers of resistive plate chambers and iron for $K_L/\mu$ detection and to return the flux of the 1.5 T magnetic field. The responses of the CDC, ACC and TOF are combined to provide clean identification of charged kaons, pions and protons, crucial for rare hadronic $B$ decays. Another important feature of rare decay analyses, is the suppression of background from $e^+e^- \rightarrow q\bar{q}$ (continuum) events. One commonly used tool is a likelihood ratio combining information from the reconstructed $B$ direction and a Fisher discriminant of modified Fox-Wolfram moments.

Signal candidates are identified using two kinematic variables: $m_{bc} = \sqrt{E_{\text{beam}}^2 - (\Sigma P_i)^2}$ and $\Delta E = \Sigma E_i - E_{\text{beam}}$. Signal yields are obtained by fitting the $\Delta E$ distributions, since this method allows separation of the continuum and $BB$ backgrounds from the signal.
Whilst 4φ-diagrams introduce significant theoretical uncertainty in the extraction. A cleaner method to be 0 would be a clear indication of new physics if confirmed.

Belle has previously published results on these modes using 10^-2 events/(0.05 GeV/c^2). These results include the first observation of a 6π^0 candidates with m_{KSπ^+} > 2.0 GeV/c^2; K_Sπ± invariant mass for B → K^0π^+π^- candidates with m_{π^±π^0} > 1.5 GeV/c^2; K^+K^- invariant mass for B → K^0K^+K^- candidates; K_SK^± invariant mass for B → K^0K^+K^- candidates with m_{K^+K^-} > 2.0 GeV/c^2. In each case the shaded histogram shows the background measured in a ΔE sideband.

Table 1: BFs and 90% confidence level (CL) upper limits, in units of 10^-6, for B → K_S h^+h^- and intermediate resonances.

| Mode                  | K^0π^+π^-               | K^0K^+K^-               | K^0K^±π^+               |
|-----------------------|-------------------------|-------------------------|-------------------------|
| B → K^0h^+h^-        | 53.2 ± 11.3 ± 9.7       | 34.8 ± 6.7 ± 6.5        | < 9.3                   |
| Resonance             | K*(892)^-π^+           | φ(1020)K^0             |                         |
|                       | K_X(1400)^-π^+         | f_X(1500)K^0           |                         |
|                       | 13.5^{+5.0}_{-4.4} ± 2.9| 22.9^{+8.7}_{-8.0} ± 6.0| 6.4^{+3.0}_{-2.6} ± 1.3 | 20.4^{+5.3}_{-4.9} ± 3.8 |

Figure 1: From left to right: π^+π^- invariant mass for B → K^0π^+π^- candidates with m_{KSπ^±} > 2.0 GeV/c^2; K_Sπ± invariant mass for B → K^0π^+π^- candidates with m_{π^±π^0} > 1.5 GeV/c^2; K^+K^- invariant mass for B → K^0K^+K^- candidates; K_SK^± invariant mass for B → K^0K^+K^- candidates with m_{K^+K^-} > 2.0 GeV/c^2.

2 Three Body Charmless Hadronic Decays

Belle has recently published results on three body charmless hadronic decays B^+ → K^+h^+h^- where h = K, π. These results include the first observation of a B decay to a scalar pseudoscalar final state, B^+ → f_0(980)K^+. It is of interest to look for similar phenomena in the neutral channel, to further investigate the b → s penguin transitions which mediate these decays. In addition, these modes may in future be used to measure direct CP violation.

The results are summarized in table 1. Branching fractions (BFs) for B^0 → K^0π^+π^- and B^0 → K^0K^+K^- have, without any assumptions about intermediate mechanisms, been measured for the first time. BFs for intermediate resonances are extracted in each mode using a simultaneous fit to the projections of the Dalitz plot, shown in figure 1. The results are consistent with those from charged B decays, albeit with larger statistical error (due to B(K^0 → π^+π^-)). The vector pseudoscalar decay B^0 → K^*- (892)π^+ is observed.

3 Two Body Charmless Hadronic Decays

Two body charmless decays provide a rich variety of B physics CP violation may be observed in the time-dependence of B → π^+π^- decays, whilst due to penguin pollution, isospin analysis of the ππ system will be required to extract the Unitary Triangle angle φ_2. The relative sizes of other B → hh modes provide information about the magnitudes of tree, penguin and other diagrams which contribute. Also, these modes may be used to search for direct CP violation, and to extract φ_3. Belle has previously published results on these modes using 10.4 fb^{-1}; updated results are shown in table 2. There is evidence of B^+ → π^+π^0 with a significance of 3.5σ, and a 2.2σ hint for B → π^0π^0. A possible CP asymmetry in B^+ → K^0π^+ is found. Such an effect would be a clear indication of new physics if confirmed. The ratio Γ(π^+π^-)/2Γ(π^+π^0) is found to be 0.40 ± 0.15 ± 0.05, indicating large tree-penguin interference.

4 φ_3 Program

Whilst φ_3 may be extracted from measurements of A_CP in B → hh decays, the contributing diagrams introduce significant theoretical uncertainty in the extraction. A cleaner method to
Further understanding of hadronic decay models and $s\bar{s}$ production can be gained by studying $B \to D^{(*)}K^-K^{(*)0}$ decays. BF$^*$s for these modes are presented in table 8. For the $D^{(*)}K^-K^{(*)0}$ modes, the $K^-K^{(*)0}$ invariant mass and angular distributions indicate a dominant component due to $D^{(*)}a_1^-$. $K^-K^{(*)0}$ pairs in the $D^{(*)}K^-K^{(*)0}$ modes appear to have $J^P = 1^-$.  

\footnote{The significance of the $\Sigma_c^0(2520)\bar{p}\pi^−/^+$ signal is 2.4$\sigma$; the other modes have significance greater than 5$\sigma$.}
Figure 2: From left to right: $\Delta E$ distributions for $B \to D^0p\bar{p}$ and for $B^0 \to D^{*0}p\bar{p}$ candidates, and the $p\bar{p}$ invariant mass distribution for $B \to D^0p\bar{p}$ candidates.

Table 3: BF s and 90% CL upper limits, in units of $10^{-4}$, for $B \to D^* K^- K^{(*)0}$ decays.

| Mode                        | $D^0 K^- K^{(*)0}$ | $D^+ K^- K^{(*)0}$ | $D^{*0} K^- K^{(*)0}$ | $D^{*+} K^- K^{(*)0}$ |
|-----------------------------|------------------|-----------------|----------------------|----------------------|
| $B(B \to D^* K^- K^{(*)0})$ | $7.5 \pm 1.3 \pm 1.1$ | $8.8 \pm 1.1 \pm 1.4$ | $14.0 \pm 3.1 \pm 2.6$ | $12.8 \pm 2.2 \pm 2.5$ |
| $B(B \to D^* K^- K^0)$     | $5.5 \pm 1.4 \pm 0.8$ | $< 3.1$         | $< 11.4$             | $< 4.9$              |

9 Conclusion

An overview of the rare hadronic $B$ decay program at Belle has been presented, including a large number of new results and first observations. Recent results from Belle on penguin mediated $B$ decays and $B \to \eta/\omega h^\pm$ have been presented elsewhere.\cite{ref17}

References

1. T. Higuchi, these proceedings; H. Sagawa, these proceedings.
2. The peak luminosity of KEKB has exceeded $7 \times 10^{33}$cm$^2$s$^{-1}$.
3. K. Abe et al., Nucl. Instr. and Meth. A479, 117 (2002).
4. G.C. Fox & S. Wolfram, Phys. Rev. Lett. 41, 1581 (1978).
5. Charge conjugate states are implied throughout.
6. K. Abe et al., Phys. Rev. D65, 092005 (2002).
7. M. Gronau & J.L. Rosner, Phys. Rev. D65 013004 (2002); M. Beneke et al., Nucl. Phys. B606 245 (2001); Y.-Y. Keum, H.-N. Li, & A.I. Sanda, Phys. Rev. D63 054008 (2001).
8. K. Abe et al., Phys. Rev. Lett. 87, 101801 (2001); K. Abe et al., Phys. Rev. D64, 071101 (2001).
9. M. Neubert, these proceedings.
10. M. Gronau & D. Wyler, Phys. Lett. B265 172 (1991); I. Dunitez, Phys. Lett. B270 75 (1991); D. Atwood, I. Dunitez & A. Soni, Phys. Rev. Lett 78 3257 (1997).
11. K. Abe et al., Phys. Rev. Lett. 88, 181803 (2002).
12. H.-Y. Cheng & K.-C. Yang, hep-ph/0112245; C.-K. Chua, W.-S. Hou & S.-Y. Tsai, Phys. Rev. D65 034003 (2002).
13. K. Abe et al., hep-ex/0203027 (to be published in Phys. Rev. D).
14. M. Jarfi et al., Phys. Rev. D43 1599 (1991); V. Chernyak & I. Zhitnisky, Nucl. Phys. B345 137 (1990).
15. X. Fu et al., Phys. Rev. Lett. 79, 3125 (1997).
16. K. Abe et al., Phys. Rev. Lett. 88, 052002 (2002); S. Pappas, these proceedings.
17. A. Ishikawa & H.C. Huang, in proceedings of XXXVII Rencontres de Moriond, Electroweak Interactions and Unified Theories.