Recent results on charmless hadronic $B$ decays at Belle

Bilas Pal$^{1}$ University of Cincinnati
On behalf of the Belle collaboration

Abstract
Two-body charmless hadronic decays of $B$ mesons are important for determining Standard Model parameters and for detecting the presence of new physics. We present recent results from the Belle experiment on the charmless hadronic decays $B \to \eta\pi^0$ and $B \to \pi^0\pi^0$.

PRESENTED AT

DPF 2015
The Meeting of the American Physical Society
Division of Particles and Fields
Ann Arbor, Michigan, August 4–8, 2015

$^1$palbs@ucmail.uc.edu
1 Introduction

Two-body charmless hadronic decays of B mesons are important for determining Standard Model parameters and for detecting the presence of new physics. We present recent results from the Belle experiment on the charmless hadronic decays $B \rightarrow \eta \pi^0$ and $B \rightarrow \pi^0 \pi^0$.

2 Evidence for the decay $B \rightarrow \eta \pi^0$

The decay $B \rightarrow \eta \pi^0$ proceeds mainly via a $b \rightarrow u$ Cabibbo- and color-suppressed “tree” diagram, and via a $b \rightarrow d$ “penguin” diagram, as shown in Fig. 1. The branching fraction can be used to constrain isospin-breaking effects on the value of $\sin 2 \phi_2$ ($\sin 2 \alpha$) measured in $B \rightarrow \pi \pi$ decays [1, 2]. It can also be used to constrain CP-violating parameters ($C_{\eta'K}$ and $S_{\eta'K}$) governing the time dependence of $B^0 \rightarrow \eta'K^0$ decays [3]. The branching fraction is estimated using QCD factorization [4], soft collinear effective field theory [5], and flavor SU(3) symmetry [6] and is found to be in the range $(2 - 12) \times 10^{-7}$.

Several experiments [7, 8, 9, 10, 11], including Belle, have searched for this decay mode. The current most stringent limit on the branching fraction is $\mathcal{B}(B^0 \rightarrow \eta \pi^0) < 1.5 \times 10^{-6}$ at 90% confidence level (C.L.) [11]. The analysis presented here uses the full data set of the Belle experiment running on the $\Upsilon(4S)$ resonance at the KEKB asymmetric-energy $e^+ e^-$ collider. This data set corresponds to $753 \times 10^6 B\bar B$ pairs, which is a factor of 5 larger than that used previously. Improved tracking, photon reconstruction, and continuum suppression algorithms are also used in this analysis.

We find the evidence of the decay $B \rightarrow \eta \pi^0$ [12], where the candidate $\eta$ mesons are reconstructed via $\eta \rightarrow \gamma \gamma$ ($\eta_{\gamma \gamma}$) and $\eta \rightarrow \pi^+ \pi^- \pi^0$ ($\eta_{\pi\pi\pi}$) decays and $\pi^0$ via $\pi^0 \rightarrow \gamma \gamma$. Results of the fit to the variables, beam-energy-constrained mass $M_{bc} = \sqrt{E_{\text{beam}}^2 - |p_B|^2 c^2/c^2}$, energy difference $\Delta E = E_B - E_{\text{beam}}$ and continuum suppression variable $C'_{NB} = \ln(C_{NB} - C_{\text{min}})$, are given in Table. 1. The combined branching fraction...
Table 1: Fitted signal yield $Y_{\text{sig}}$, reconstruction efficiency $\epsilon$, $\eta$ decay branching fraction $B_\eta$, signal significance, and $B^0$ branching fraction $B$ for the decay $B^0 \to \eta\pi^0$. The errors listed are statistical only. The significance includes both statistical and systematic uncertainties.

| Mode                  | $Y_{\text{sig}}$ | $\epsilon$ (%) | $B_\eta$ (%) | Significance | $B(10^{-7})$ |
|-----------------------|------------------|-----------------|--------------|--------------|--------------|
| $B^0 \to \eta\gamma\pi^0$ | $30.6^{+12.2}_{-10.8}$ | 18.4            | 39.41        | 3.1          | $5.6^{+2.2}_{-2.0}$ |
| $B^0 \to \eta_3\pi^0$  | $0.5^{+6.6}_{-5.4}$     | 14.2            | 22.92        | 0.1          | $0.2^{+2.8}_{-2.3}$ |
| Combined              |                  |                 |             | 3.0          | $4.1^{+1.7}_{-1.5}$ |

is determined by simultaneously fitting both $B^0 \to \eta\gamma\pi^0$ and $B^0 \to \eta_3\pi^0$ samples for a common $B(B^0 \to \eta\pi^0)$. Signal enhanced projections of the simultaneous fit are shown in Fig. 2. The branching fraction for $B \to \eta\pi^0$ decays is measured to be

$$B(B^0 \to \eta\pi^0) = (4.1^{+1.7+0.5}_{-1.5-0.7}) \times 10^{-7},$$
where the first uncertainty is statistical and the second is systematic. This corresponds to a 90% C.L. upper limit of $\mathcal{B}(B^0 \rightarrow \eta\pi^0) < 6.5 \times 10^{-7}$. The significance of this result is 3.0 standard deviations. The measured branching fraction is in good agreement with theoretical expectations [4, 5, 6]. Inserting our measured value into Eq. (19) of Ref. [1] gives the result that the isospin-breaking correction to the weak phase $\phi_2$ measured in $B \rightarrow \pi\pi$ decays due to $\pi^0$–$\eta$–$\eta'$ mixing is less than 0.97$^\circ$ at 90% C.L.

3 The decay $B^0 \rightarrow \pi^0\pi^0$ (preliminary results)

This decay is an important input for the isospin analysis in the $B \rightarrow \pi\pi$ system. A fit to the variables $\Delta E$, $M_{bc}$ and a fisher discriminant $T_C$ is performed. We measure a preliminary branching fraction of $\mathcal{B}(B^0 \rightarrow \pi^0\pi^0) = (0.9 \pm 0.12(\text{stat.}) \pm 0.10(\text{sys.})) \times 10^{-6}$, with a significance of 6.7 standard deviations and the direct $CP$ asymmetry of $A_{CP} = -0.054 \pm 0.086$. Signal enhanced projections are shown in Fig. 3. With this result, the constraint to the $\phi_2$ using the isospin relation in the $B \rightarrow \pi\pi$ system will be re-evaluated.

![Figure 3: Signal enhanced projections of the fit for the decay $B^0 \rightarrow \pi^0\pi^0$: (left) $\Delta E$, (middle) $M_{bc}$ and (right) $T_C$. Contributions from signal, continuum, $\rho\pi^+$ and other $B$ decays are shown by blue, green, red and cyan curves respectively.](image)

4 Summary

Using the full set of Belle data, recent and preliminary measurements of charmless hadronic $B$ decays are presented. Our measurement of $B^0 \rightarrow \eta\pi^0$ branching fraction constitutes the first evidence of the decay.
Acknowledgements

The author thanks the organizers of DPF 2015 for excellent hospitality and for assembling a nice scientific program. The author would also like to thank Alan Schwartz for reviewing and providing valuable feedback to the final manuscript. This work is supported by the U.S. Department of Energy.

References

[1] M. Gronau and J. Zupan, Phys. Rev. D 71, 074017 (2005).
[2] S. Gardner, Phys. Rev. D 72, 034015 (2005).
[3] M. Gronau, J. L. Rosner and J. Zupan, Phys. Lett. B 596, 107 (2004); Phys. Rev. D 74, 093003 (2006).
[4] M. Z. Yang and Y. D. Yang, Nucl. Phys. B609, 469 (2001); M. Beneke and M. Neubert, Nucl. Phys. B675, 333 (2003); J. f. Sun, G. h. Zhu and D. s. Du, Phys. Rev. D 68, 054003 (2003); Z. j. Xiao and W. j. Zou, Phys. Rev. D 70, 094008 (2004); H. s. Wang, X. Liu, Z. j. Xiao, L. b. Guo and C. D. Lu, Nucl. Phys. B738, 243 (2006); H. Y. Cheng and C. K. Chua, Phys. Rev. D 80, 114008 (2009); H. Y. Cheng and J. G. Smith, Annu. Rev. Nucl. Part. Sci. 59, 215 (2009).
[5] A. R. Williamson and J. Zupan, Phys. Rev. D 74, 014003 (2006); Phys. Rev. D 74, 039901 (2006).
[6] C. W. Chiang, M. Gronau and J. L. Rosner, Phys. Rev. D 68, 074012 (2003); H. K. Fu, X. G. He and Y. K. Hsiao, Phys. Rev. D 69, 074002 (2004); C. W. Chiang, M. Gronau, J. L. Rosner and D. A. Suprun, Phys. Rev. D 70, 034020 (2004); C. W. Chiang and Y. F. Zhou, J. High Energy Phys. 12 (2006) 027; H. Y. Cheng, C. W. Chiang and A. L. Kuo, Phys. Rev. D 91, 014011 (2015).
[7] H. Albrecht et al. (ARGUS Collaboration), Phys. Lett. B 241, 278 (1990).
[8] M. Acciarri et al. (L3 Collaboration), Phys. Lett. B 363, 127 (1995).
[9] S. J. Richichi et al. (CLEO Collaboration), Phys. Rev. Lett. 85, 520 (2000).
[10] P. Chang et al. (Belle Collaboration), Phys. Rev. D 71, 091106 (2005).
[11] B. Aubert et al. (BaBar Collaboration), Phys. Rev. D 78, 011107 (2008).
[12] B. Pal et al. (Belle Collaboration), Phys. Rev. D 92, 011101 (2015).