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Recent results on charmless B^0 and B_s^0 decays from Belle

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We report the recent results on charmless B^0 and B_s^0 decays from Belle. The results are based on the data collected by the Belle detector at e^+ and e^- collision at KEKB, Japan. These include the studies of $B_s^0 \to K^0\bar{K}^0$ and $B^0 \to \eta\eta$.

38th International Conference on High Energy Physics
3-10 August 2016
Chicago, USA

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PoS(ICHEP2016)535

1. Introduction

Charmless hadronic B decays are good probe to search for new physics beyond the Standard Model (SM) because these decays are suppressed in the SM compared to other hadronic B decays. Observation of any deviation from the SM background will provide a clear signal for new physics beyond SM. Here we present the recent results of charmless hadronic B_s^0 and B^0 decays, namely, $B_s^0 \to K^0\bar{K}^0$ and $B^0 \to \eta\eta$ from the Belle experiment.

2. The decay $B_s^0 \to K^0\bar{K}^0$

The two body decays $B_s^0 \to h^+h'^-$, where $h^{(\prime)}$ is either a pion or kaon, have now all been observed [1]. On the other hand the decays $B_s^0 \to h^0h'^0$, where h^0 or h'^0 are neutral hadrons, are yet to be observed. The predicted branching fraction for the decay $B_s^0 \to K_0\bar{K}_0$ is large [2]. According to the SM, this decay is dominated by $b \to s$ penguin process as shown in Figure 1. SM based calculation predicts the branching fraction for this decay to be in the range $(16-27)\times 10^{-6}$ [3], but beyond the SM, new particles (non-SM) may appear in the loop that can enhance the branching fraction [4]. Studies also shows that CP asymmetries in the in $B_s^0 \to K_0\bar{K}_0$ decays is a promising probe to search for new physics [5].

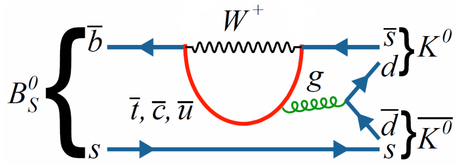

Figure 1: Feynman diagram for $B_s^0 \to K^0\bar{K}^0$ decay.

The previous 90% confidence level (C.L.) upper limit on the branching fraction of $B_s^0 \to K_0\bar{K}_0$ was set at 6.6×10^{-5} by the Belle experiment using $23.6 fb^{-1}$ of data collected at the $\Upsilon(5S)$ resonance [6]. This updated analysis uses the full data set of $121.4 fb^{-1}$ collected at the $\Upsilon(5S)$ resonance, which corresponds to $(6.53\pm 0.66)\times 10^6$ $B_S^0\bar{B}_S^0$ pairs [7]. The tracking, K^0 reconstruction and continuum $e^+e^- \to q\bar{q}$ $(q = u,d,s,c)$ background suppression algorithms are also improved in this analysis.

Candidate K^0 mesons are reconstructed from the decay $K_S^0 \to \pi^+\pi^-$. The $\pi^+\pi^-$ invariant mass require to be within $12 MeV/c^2$ of the nominal K_S^0 mass [1]. To suppress the large background arsing from $e^+e^- \to q\bar{q}$ $(q = u,d,s,c)$ continuum background, we use a multivariate analyzer based on a neural network. To discriminate the continuum background, the neural network uses event shape variables. The output of the neural network is modified to a variable $C'_{NN} = ln(\frac{C_{NN}-C_{NN}^{min}}{C_{NN}^{max}-C_{NN}})$ where C_{NN}^{min} and C_{NN}^{max} are the minimum and maximum values of the neural network output respectively. Signal B_s^0 candidates are identified by two kinematic variables: the energy difference $\Delta E = E_B - E_{beam}$ and the beam constrained mass $M_{bc} = \sqrt{(E_{beam})^2 - (P_B)^2}$, where E_{beam} is the

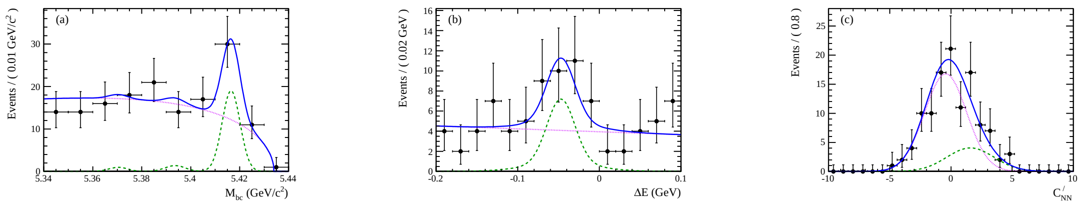

Figure 2: Projections of the 3D fit to the real data: (a) M_{bc} in $-0.11GeV < \Delta E < 0.02GeV$ and $C'_{NN} > 0.5$; (b) ΔE in $5.405GeV/c^2 < M_{bc} < 5.427GeV/c^2$ and $C'_{NN} > 0.5$; and (c) C'_{NN} in $5.405GeV/c^2 < M_{bc} < 5.427GeV/c^2$ and $-0.11GeV < \Delta E < 0.02GeV$. The points with error bars are data, the (green) dashed curves show the signal, (magenta) dotted curves show the continuum background, and (blue) solid curves show the total.

beam energy and $E_B(P_B)$ are energy and momentum of the reconstructed B_S^0 meson candidates.

We perform a three dimensional (3D) unbinned maximum likelihood fit to the variables M_{bc}, ΔE and C'_{NN} to extract the signal yield. We extract $29.0^{+8.5}_{-7.6}$ signal events and $1095.0^{+33.9}_{-33.4}$ continuum background events. Projections of the 3D fit in the signal regions are shown in Figure 2. The branching fraction of the decay $B_s^0 \to K^0\bar{K}^0$ is measured to be [8]

$$B(B_s^0 \to K^0\bar{K}^0) = (19.6^{+5.8}_{-5.1} \pm 1.0 \pm 2.0) \times 10^{-6},$$

where the first uncertainty is statistical, the second is systematic and the third reflects the uncertainty due to the total number of $B_S^0\bar{B}_S^0$ pairs. The significance of this result is 5.1σ, thus, our measurement constitutes the first observation of this decay. The result is in good agreement with the SM predictions [3].

3. Evidence of the decay $B^0 \to \eta\eta$

The CP violation measurements using charmless hadronic decays of B^0 mesons are primarily important for testing of SM and searching for physics beyond the SM. The $B^0 \to \eta\eta$ decay mode mainly proceeds via $b \to u$ Cabibbo-color suppressed tree diagram and $b \to d$ penguin diagram as shown in Figure 3. The expected branching fraction of this decay mode is $(0.3-3.1)\times 10^{-6}$ estimated based on QCD factorization [9], soft collider effective theory [10], SU(3) flavor symmetry [11]and flavor U(3) symmetry [12].

This decay plays an important role to improve the flavor SU(3) based calculations of $|S_{ccs} - S_f|$ where f is $\eta' K$ and ϕK and the $S_f = sin2\phi_1$ is the $CP-$ violating parameter measured in the time-dependent analysis [13], and the S_{ccs} is the $CP-$ violation parameter measured in the CKM favored $b \to c\bar{c}s$ transitions, if penguin $b \to s$ transitions are dominant. The $sin2\phi_1$ deviation bound may be improved by the precise measurement of the branching fraction of this decay [14, 15].

Both Belle and BABAR experiments have studied this decay. The upper limit on the branching fraction given by Belle experiment was $B(B^0 \to \eta\eta) < 2.0 \times 10^{-6}$ at 90% C.L. which was based on 152 M $B\bar{B}$ pairs [16] and by BABAR experiment was $B(B^0 \to \eta\eta) < 1.0 \times 10^{-6}$ at 90% C.L. based

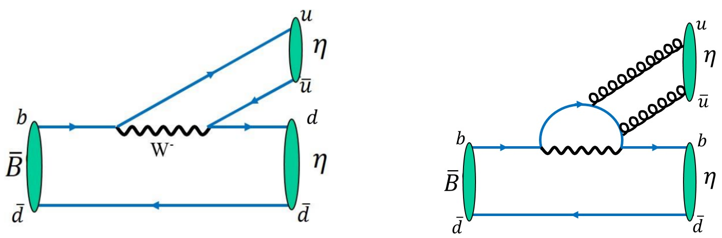

Figure 3: Feynman diagrams for $B^0 \to \eta\eta$ decay.

on the 467 M $B\bar{B}$ pairs [17]. We update the previous Belle result using the full data set collected at the $\Upsilon(4S)$ resonance at the KEKB asymmetric energy e^-e^+ collider. This data set corresponds to 753×10^6 $B\bar{B}$ pairs, which is a factor of five larger than the previous Belle study.

Candidate η mesons are reconstructed from the sub-decay modes: $\eta \to \gamma\gamma(\eta_{\gamma\gamma})$ and $\eta \to \pi^+\pi^-\pi^0(\eta_{3\pi})$. For $\eta_{\gamma\gamma}$ candidates selection, we require the invariant mass of $\eta_{\gamma\gamma}$ in the range of $476-579MeV/c^2$, which corresponds to $\pm2.5\sigma$ around the nominal η mass [18]. π^0 candidates are reconstructed from two γ's by requiring the $\gamma\gamma$ invariant mass to be within $117-155MeV/c^2$, which corresponds to $\pm3\sigma$ around the nominal π^0 mass [18]. Candidates $\eta_{3\pi}$ are reconstructed by combining two selected oppositely charged pion candidates and a π^0 candidate. To select $\eta_{3\pi}$, candidates we require the invariant mass of $\eta_{3\pi}$ in the range of $527-568MeV/c^2$, which corresponds to $\pm3.0\sigma$ around the nominal η mass [18]. For selection of B^0 candidates, we define two kinematic variables in the form of the energy difference $\Delta E = E_B - E_{beam}$ and the beam constrained mass $M_{bc} = \sqrt{(E_{beam})^2-(P_B)^2}$, where E_{beam} is the beam energy and $E_B(P_B)$ are energy and momentum of the reconstructed B meson candidates. We require the B meson candidates to satisfy $-0.3GeV < \Delta E < 0.2GeV$ and $M_{bc} > 5.25GeV/c^2$.

To suppress the dominant $e^+e^- \to q\bar{q}$ $(q = u,d,s,c)$ continuum background we use the neural network. We define modified neural network output variable $C'_{NB} = ln(\frac{C_{NB}-C_{NB}^{min}}{C_{NB}^{max}-C_{NB}})$, where $C_{NB}^{min} = -0.8$ and C_{NB}^{max} is the maximum value of the neural network output. This variable is also used to extract signal events during the maximum likelihood (ML) analysis.

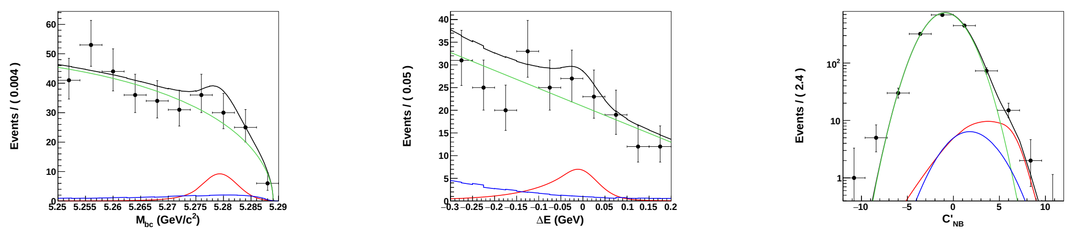

Figure 4: Signal-enhanced projections of the simultaneous fit: The points with the error bars are the real data, the black line is the total PDF, the red line show the signal, the green line is $b \to u,d,s$ and the blue line is $b \to c$ background.

Table 1: Summary of the ML fit

sub-decay mode	$\eta_{\gamma\gamma}\eta_{\gamma\gamma}$	$\eta_{\gamma\gamma}\eta_{3\pi}$	$\eta_{3\pi}\eta_{3\pi}$
Yields			
Signal	$23.6^{+8.1}_{-6.9}$	$9.2^{+3.2}_{-2.7}$	$2.7^{+0.9}_{-0.8}$
Continuum	$3860.5^{+63.1}_{-62.4}$	$3779.7^{+62.0}_{-61.5}$	$621.4^{+25.4}_{-24.8}$
Charmed B (fixed)	5.9	5.9	2.2
rare B (fixed)	27.4	17.8	4.5
$B^0 \to \eta\pi^0$ (fixed)	1.4	0.1	-

We perform a three-dimensional (3D) unbinned extended ML fit to the variable M_{bc}, ΔE and C'_{NB}. The results of the ML fit are summarized in Table 1. Fit projections are shown in Figure 4. We measure the branching fraction to be

$$B(B^0 \to \eta\eta) = (7.6^{+2.7+1.4}_{-2.3-1.6}) \times 10^{-7},$$

where the first uncertainty is statistical and and the second is systematic. The significance of this result is 3.3σ, which provides the first evidence for this decay.

4. Conclusions

Recent results of charmless B^0 and B_s^0 decays are presented using the full data set collected by the Belle detector at $\Upsilon(4S)$ and $\Upsilon(5S)$ resonances. Our measurement of the branching fraction of $B_s^0 \to K^0\bar{K}^0$ constitutes the first observation of the decay. For the decay $B^0 \to \eta\eta$, the first evidence for this decay is presented on this paper which is consistent with the SM prediction.

Acknowledgments

The author is thankful to the organizers of 38th International Conference on High Energy Physics for assembling a nice scientific event. The author is also thankful to the KEKB group, all institutes and agencies that have support the work of the members of the Belle Collaboration.

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