

BOTTOMONIUM AND BOTTOMONIUM-LIKE STATES AND DECAYS AT BELLE

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Recent results from the Belle experiment are presented. We report the results of the first observation of P-wave spin-singlet Bottomonium states, observation of two charged Bottomonium-like resonances and the first observation of the radiative transition $h_b(1P) \rightarrow \eta_b(1S)\gamma$ at the $\Upsilon(5S)$ resonance region.

We report the results of the first observation of P-wave spin-singlet Bottomonium states $h_b(1P)$ and $h_b(2P)$ produced in the $\Upsilon(5S)$ region. We used a 121.4 fb^{-1} data sample collected near the peak of the $\Upsilon(5S)$ resonance with the Belle detector at the KEKB asymmetric-energy e^+e^- collider. The Belle detector is a large-solid-angle magnetic spectrometer consisting of a central drift chamber, an array of aerogel threshold Cherenkov counters, electromagnetic calorimeter composed of CsI(Tl) crystals located inside a superconducting solenoid with 1.5 T magnetic field. The detector is described in detail elsewhere ¹.

The $h_b(nP)$ states were produced via $e^+e^- \rightarrow h_b(nP)\pi^+\pi^-$ and observed in the $\pi^+\pi^-$ missing mass spectrum of hadronic events ². The $\pi^+\pi^-$ missing mass was calculated by formula $M_{\text{miss}}^2 = (P_{\Upsilon(5S)} - P_{\pi^+\pi^-})^2$, where $P_{\Upsilon(5S)}$ (4-momentum of the $\Upsilon(5S)$) was determined from the beam momenta. $P_{\pi^+\pi^-}$ is the 4-momentum of the $\pi^+\pi^-$ system. The background subtracted inclusive M_{miss} spectrum is presented in Fig.1. To determine the number of produced resonant decays the M_{miss} spectrum was fitted separately into three adjacent regions. The measured masses of $h_b(1P)$ and $h_b(2P)$ states are $M = (9898.2_{-1.0-1.1}^{+1.1+1.0}) \text{ MeV}/c^2$ and $M = (10259.8 \pm 0.6_{-1.0}^{+1.4}) \text{ MeV}/c^2$, respectively. Using the measured h_b and world average masses of $\chi_{bJ}(nP)$ states we determine the hyperfine

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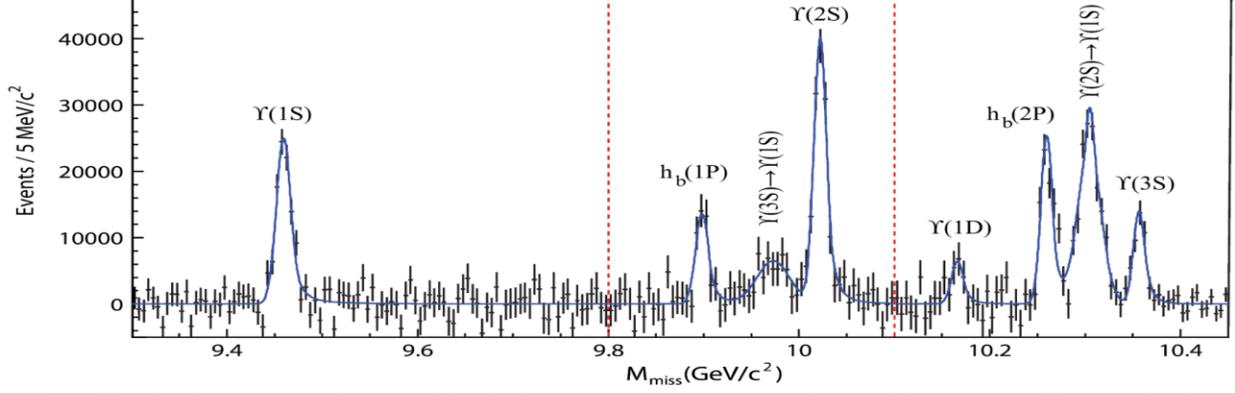


FIG. 1 The background subtracted inclusive M_{miss} spectrum (points with errors). The vertical lines indicate boundaries of the fit regions. Overlaid smooth curve is the resulting fit function.

splittings to be $\Delta M_{\text{HF}} = (+1.7 \pm 1.5)$ and $(+0.5^{+1.6}_{-1.2})$ MeV/c^2 for $h_b(1P)$ and $h_b(2P)$, respectively which are consistent with zero. We measured the ratio of cross sections $R = \sigma(h_b(nP)\pi^+\pi^-) / \sigma(\Upsilon(2S)\pi^+\pi^-)$ to be $0.45 \pm 0.08^{+0.07}_{-0.12}$ for the $h_b(1P)$ and $0.77 \pm 0.08^{+0.22}_{-0.17}$ for the $h_b(2P)$, which indicates that $h_b(nP)\pi^+\pi^-$ and $\Upsilon(2S)\pi^+\pi^-$ proceed at similar rates despite the fact that the production of $h_b(nP)$ requires a spin flip of a b quark. The angular analysis of the $\Upsilon(5S) \rightarrow h_b(1P)\pi^+\pi^-$ transition indicates spin parity of $J^P=1^+$ for the $h_b(1P)$ state. We also analyzed 711fb^{-1} data at the $\Upsilon(4S)$ resonance to search for $h_b(1P)\pi^+\pi^-$ transition and set an upper limit on the ratio of $\sigma(e^+e^- \rightarrow h_b(1P)\pi^+\pi^-)$ at the $\Upsilon(4S)$ to that at the $\Upsilon(5S)$ of 0.27 at 90% C.L.

The analysis of di-pion transition of $\Upsilon(5S)$ resonance shows a high rates of $\Upsilon(5S) \rightarrow \Upsilon(nS)\pi^+\pi^-$ ($n=1,2,3$) and $\Upsilon(5S) \rightarrow h_b(mP)\pi^+\pi^-$ ($m=1,2$) which indicates contribution of exotic mechanisms in the $\Upsilon(5S)$ decays. We report results of study of resonant substructure in the decays of $\Upsilon(5S) \rightarrow \Upsilon(nS)\pi^+\pi^-$ ($n=1,2,3$) and $\Upsilon(5S) \rightarrow h_b(mP)\pi^+\pi^-$ ($m=1,2$)³. Fig.2 (a) and 2(b) show Dalitz distributions – the maximum value of the two $M^2[\Upsilon(2S)\pi^\pm]$ versus $M^2(\pi^+\pi^-)$ for $\Upsilon(2S)$ sideband and signal regions, respectively. Two horizontal bands in Fig. 2(b) indicate existence of structures in $\Upsilon(nS)\pi$ system near $10.61 \text{ GeV}/c^2$ ($Z_b(10610)$) and $10.65 \text{ GeV}/c^2$ ($Z_b(10650)$). Fig.3 show the yield of $\Upsilon(5S) \rightarrow h_b(mP)\pi^+\pi^-$ ($m=1,2$) as a function of pion missing mass. A clear two-peak structure indicates the production of $Z_b(10610)$ and $Z_b(10650)$. In total we observed two $Z_b(10610)$ and $Z_b(10650)$ Bottomonium-like resonances in five different decay channels $\Upsilon(nS)\pi^\pm$ ($n=1,2,3$) and $h_b(mP)\pi^\pm$ ($m=1,2$). The minimal quark content of the $Z_b(10610)$

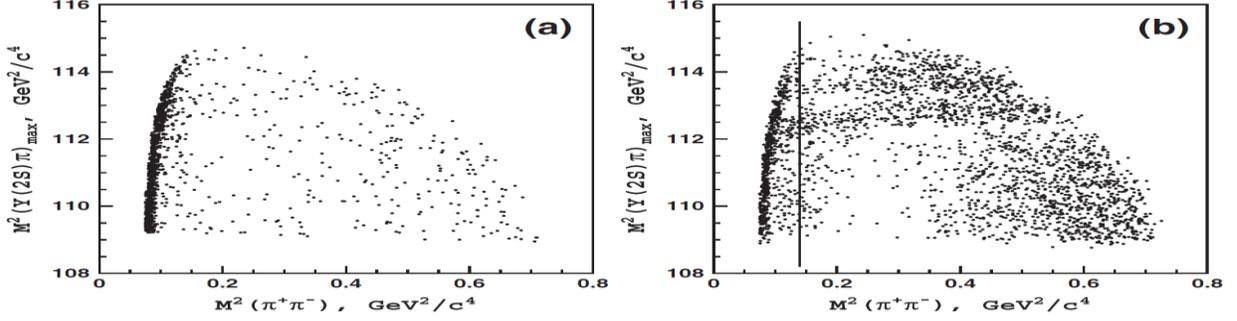


FIG. 2 Dalitz plots for the $\Upsilon(2S)$ sideband (a) and $\Upsilon(2S)$ signal (b) regions. Vertical line shows the cut which allows to remove a background from photon conversions in the detector elements.

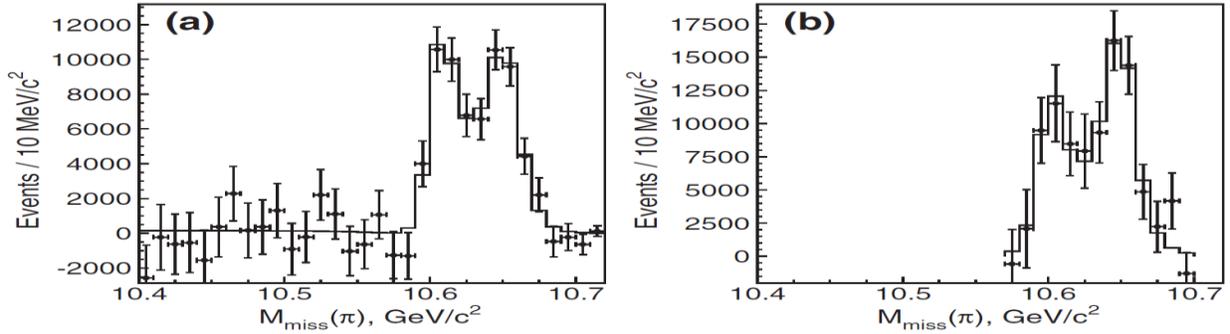


FIG. 3. The $h_b(1P)$ (a) and $h_b(2P)$ (b) yields as a function of the missing mass recoiling against the pion. Fit results are presented as a histograms.

and $Z_b(10650)$ requires a four quark combination. Weighted average values of masses and widths over all five channels are $M=10607.2\pm 2.0$ MeV/ c^2 , $\Gamma=18.4\pm 2.4$ MeV for the $Z_b(10610)$ and $M=10652.2\pm 1.5$ MeV/ c^2 , $\Gamma=11.5\pm 2.2$ MeV for the $Z_b(10650)$. The measured masses of these states are a few MeV/ c^2 above the thresholds for the open beauty channels which suggests that their internal dynamics is dominated by the coupling to B meson pairs⁴.

The radiative transition to the $\eta_b(1S)$ is expected to be one of the dominant decay modes of the $h_b(1P)$. We report the first observation of the radiative transition $h_b(1P) \rightarrow \eta_b(1S)\gamma$ ⁵. In the decay chain $\Upsilon(5S) \rightarrow Z_b^+ \pi^-$, $Z_b^+ \rightarrow h_b(1P)\pi^+$, $h_b(1P) \rightarrow \eta_b(1S)\gamma$ we reconstruct only the π^- , π^+ and γ . We search for the $\eta_b(1S)$ signal in the distribution of $\Delta M_{\text{miss}}(\pi^+ \pi^- \gamma) - M_{\text{miss}}(\pi^+ \pi^-) + m[h_b(1P)]$ (see Fig.4). Observed signal parameterized by a non-relativistic Breit-Wigner function, the combinatorial background – by an exponential function.

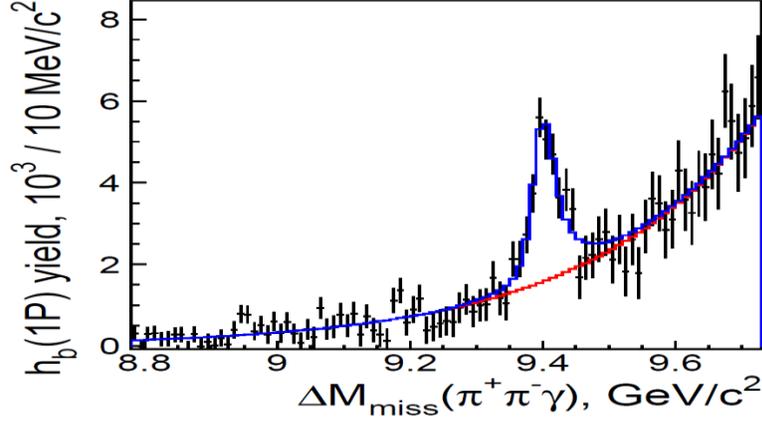


FIG. 4 $\Delta M_{\text{miss}}(\pi^+\pi^-\gamma)$ distribution of the $h_b(1P)$ yield with fit result superimposed.

We obtained the single most precise measurement of the $\eta_b(1S)$ mass, $(9401.0 \pm 1.9_{-2.4}^{+1.4}) \text{ MeV}/c^2$, which corresponds to the hyperfine splitting $\Delta M_{\text{HF}}[\eta_b(1S)] = (59.3 \pm 1.9_{-1.4}^{+2.4}) \text{ MeV}/c^2$. We report the first measurement of the $\eta_b(1S)$ width $(12.4_{-4.6-3.4}^{+5.5+11.5}) \text{ MeV}$. For the branching fraction we find $B[h_b(1P) \rightarrow \eta_b(1S)\gamma] = (49.8 \pm 6.8_{-5.2}^{+10.9}) \%$ which agrees with the theoretical expectations⁶.

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