Observation of Two Charged Bottomoniumlike Resonances in $\Upsilon(5S)$ Decays

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We report the observation of two narrow structures in the mass spectra of the $\pi^\pm\Upsilon(nS)$ ($n = 1, 2, 3$) and $\pi^\pm h_b(mP)$ ($m = 1, 2$) pairs that are produced in association with a single charged pion in $\Upsilon(5S)$ decays. The measured masses and widths of the two structures averaged over the five final states are $M_1 = (10\,607.2 \pm 2.0)\ \mathrm{MeV}/c^2$, $\Gamma_1 = (18.4 \pm 2.4)$ MeV, and $M_2 = (10\,652.2 \pm 1.5)\ \mathrm{MeV}/c^2$, $\Gamma_2 = (11.5 \pm 2.2)$ MeV. The results are obtained with a 121.4 fb^{-1} data sample collected with the Belle detector in the vicinity of the $\Upsilon(5S)$ resonance at the KEKB asymmetric-energy e^+e^- collider.

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Recent studies of heavy quarkonium have produced a number of surprises and puzzles [1], including some associated with $\Upsilon(5S)$ decays to non-$B\bar{B}$ final states. The Belle Collaboration reported the observation of anomalously high rates for $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$ ($n = 1, 2, 3$) [2] and $\Upsilon(5S) \to h_b(mP)\pi^+\pi^-$ ($m = 1, 2$) [3] transitions. If the $\Upsilon(nS)$ signals are attributed entirely to $\Upsilon(5S)$ decays, the measured partial decay widths $\Gamma[\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-] \sim 0.5$ MeV are about 2 orders of magnitude larger than typical widths for dipion transitions among the four lower $\Upsilon(nS)$ states. Furthermore, the processes $\Upsilon(5S) \to h_b(mP)\pi^+\pi^-$, which require a heavy-quark spin flip, are found to have rates that are comparable to those for the heavy-quark spin conserving transitions $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$ [3]. These observations differ from *a priori* theoretical expectations and strongly suggest that exotic mechanisms are contributing to $\Upsilon(5S)$ decays. We report results of resonant substructure studies of $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$ ($n = 1, 2, 3$) and $\Upsilon(5S) \to h_b(mP)\pi^+\pi^-$ ($m = 1, 2$) decays [4]. We use a 121.4 fb^{-1} data sample collected on or near the peak of the $\Upsilon(5S)$ resonance ($\sqrt{s} \sim 10.865$ GeV) with the Belle detector at the KEKB asymmetric-energy e^+e^- collider [5].

The Belle detector is a large-solid-angle magnetic spectrometer that consists of a silicon vertex detector, a central drift chamber, an array of aerogel threshold Cherenkov counters, a barrel-like arrangement of time-of-flight scintillation counters, and an electromagnetic calorimeter comprised of CsI(Tl) crystals located inside a superconducting solenoid that provides a 1.5 T magnetic field. An iron flux-return located outside the coil is instrumented to detect K_L^0 mesons and to identify muons. The detector is described in detail elsewhere [6].

To reconstruct $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$, $\Upsilon(nS) \to \mu^+\mu^-$ candidates we select events with four charged tracks with zero net charge that are consistent with coming from the interaction point. Charged pion and muon candidates are required to be positively identified. Exclusively reconstructed events are selected by the requirement $|M_{\mathrm{miss}}(\pi^+\pi^-) - M(\mu^+\mu^-)| < 0.2\ \mathrm{GeV}/c^2$, where $M_{\rm miss}(\pi^+\pi^-)$ is the missing mass recoiling against the $\pi^+\pi^-$ system calculated as $M_{\rm miss}(\pi^+\pi^-) = \sqrt{(E_{\rm c.m.} - E^*_{\pi^+\pi^-})^2 - p^{*2}_{\pi^+\pi^-}}$, $E_{\rm c.m.}$ is the center-of-mass (c.m.) energy, and $E^*_{\pi^+\pi^-}$ and $p^*_{\pi^+\pi^-}$ are the energy and momentum of the $\pi^+\pi^-$ system measured in the c.m. frame. Candidate $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$ events are selected by requiring $|M_{\rm miss}(\pi^+\pi^-) - m_{\Upsilon(nS)}| < 0.05$ GeV$/c^2$, where $m_{\Upsilon(nS)}$ is the mass of an $\Upsilon(nS)$ state [7]. Sideband regions are defined as $0.05\ {\rm GeV}/c^2 < |M_{\rm miss}(\pi^+\pi^-) - m_{\Upsilon(nS)}| < 0.10\ {\rm GeV}/c^2$. To remove background due to photon conversions in the innermost parts of the Belle detector we require $M^2(\pi^+\pi^-) > 0.20, 0.14, 0.10$ GeV$/c^2$ for a final state with an $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$, respectively.

Amplitude analyses of the three-body $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$ decays reported here are performed by means of unbinned maximum likelihood fits to two-dimensional $M^2[\Upsilon(nS)\pi^+]$ vs $M^2[\Upsilon(nS)\pi^-]$ Dalitz distributions. The fractions of signal events in the signal region are determined from fits to the corresponding $M_{\rm miss}(\pi^+\pi^-)$ spectrum and are found to be $0.937 \pm 0.015({\rm stat})$, $0.940 \pm 0.007({\rm stat})$, $0.918 \pm 0.010({\rm stat})$ for final states with $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$, respectively. The variation of reconstruction efficiency across the Dalitz plot is determined from a GEANT-based MC simulation [8] and is found to be small except for the higher $M[\Upsilon(nS)\pi^\pm]$ region. The distribution of background events is determined using events from the $\Upsilon(nS)$ sidebands and found to be uniform (after efficiency correction) across the Dalitz plot.

Dalitz distributions of events in the $\Upsilon(2S)$ sidebands and signal regions are shown in Figs. 1(a) and 1(b), respectively, where $M[\Upsilon(nS)\pi]_{\rm max}$ is the maximum invariant mass of the two $\Upsilon(nS)\pi$ combinations. This is used to combine $\Upsilon(nS)\pi^+$ and $\Upsilon(nS)\pi^-$ events for visualization only. Two horizontal bands are evident in the $\Upsilon(2S)\pi$ system near 112.6 GeV2$/c^4$ and 113.3 GeV$^2/c^4$, where the distortion from straight lines is due to interference with other intermediate states, as demonstrated below. One-dimensional invariant mass projections for events in the $\Upsilon(nS)$ signal regions are shown in Fig. 2, where two peaks are observed in the $\Upsilon(nS)\pi$ system near 10.61 GeV$/c^2$ and 10.65 GeV$/c^2$. In the following we refer to these structures as $Z_b(10\,610)$ and $Z_b(10\,650)$, respectively.

We parametrize the $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$ three-body decay amplitude by

$$M = A_{Z_1} + A_{Z_2} + A_{f_0} + A_{f_2} + A_{\rm nr}, \qquad (1)$$

where A_{Z_1} and A_{Z_2} are amplitudes to account for contributions from the $Z_b(10\,610)$ and $Z_b(10\,650)$, respectively. Here we assume that the dominant contributions come from amplitudes that preserve the orientation of the spin of the heavy quarkonium state and, thus, both pions in the cascade decay $\Upsilon(5S) \to Z_b\pi \to \Upsilon(nS)\pi^+\pi^-$ are emitted in an S wave with respect to the heavy quarkonium system. As demonstrated in Ref. [9], angular analyses support this assumption. Consequently, we parametrize the observed $Z_b(10\,610)$ and $Z_b(10\,650)$ peaks with an S-wave Breit-Wigner function ${\rm BW}(s, M, \Gamma) = \frac{\sqrt{M\Gamma}}{M^2 - s - iM\Gamma}$, where we do not consider possible s dependence of the resonance width. To account for the possibility of $\Upsilon(5S)$ decay to both $Z_b^+\pi^-$ and $Z_b^-\pi^+$, the amplitudes A_{Z_1} and A_{Z_2} are symmetrized with respect to π^+ and π^- transposition. Using isospin symmetry, the resulting amplitude is written as

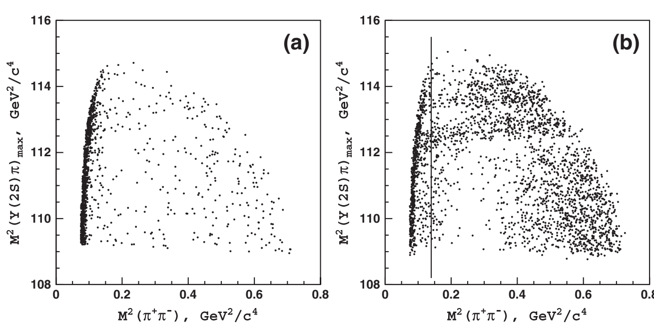

FIG. 1. Dalitz plots for $\Upsilon(2S)\pi^+\pi^-$ events in the (a) $\Upsilon(2S)$ sidebands; (b) $\Upsilon(2S)$ signal region. Events to the left of the vertical line are excluded.

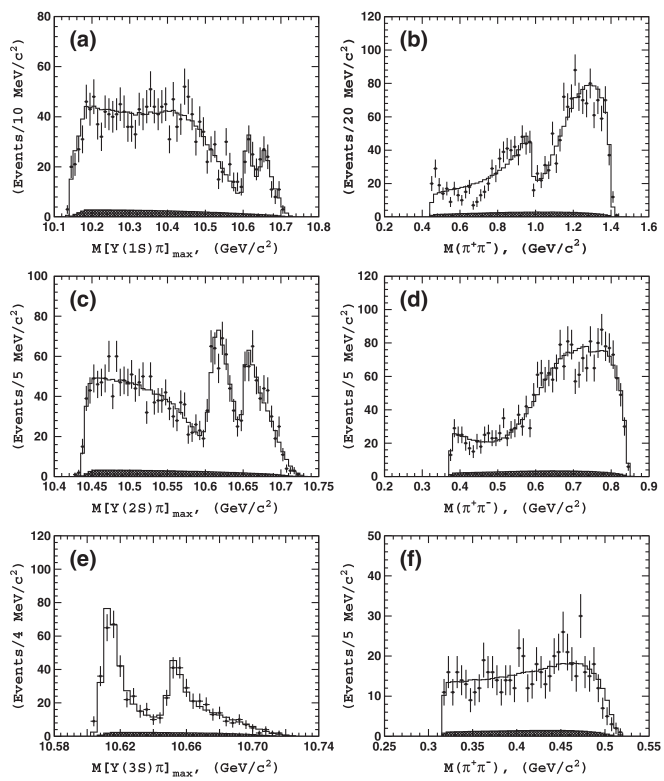

FIG. 2. Comparison of fit results (open histogram) with experimental data (points with error bars) for events in the $\Upsilon(1S)$ (a),(b), $\Upsilon(2S)$ (c),(d), and $\Upsilon(3S)$ (e),(f) signal regions. The hatched histogram shows the background component.

$$A_{Z_k} = a_{Z_k} e^{i\delta_{Z_k}} [\mathrm{BW}(s_1, M_k, \Gamma_k) + \mathrm{BW}(s_2, M_k, \Gamma_k)], \quad (2)$$

where $s_1 = M^2[\Upsilon(nS)\pi^+]$, $s_2 = M^2[\Upsilon(nS)\pi^-]$. The relative amplitudes a_{Z_k}, phases δ_{Z_k}, masses M_k, and widths Γ_k ($k = 1, 2$) are free parameters. We also include the A_{f_0} and A_{f_2} amplitudes to account for possible contributions in the $\pi^+\pi^-$ channel from the $f_0(980)$ scalar and $f_2(1270)$ tensor states, respectively. The inclusion of these two states is needed to describe the shape of the $M(\pi^+\pi^-)$ spectrum around and above $M(\pi^+\pi^-) = 1.0\ \mathrm{GeV}/c^2$ for the $\Upsilon(1S)\pi^+\pi^-$ final state (see Fig. 2). We use a Breit-Wigner function to parametrize the $f_2(1270)$ and a coupled-channel Breit-Wigner function [10] for the $f_0(980)$. The mass and width of the $f_2(1270)$ state are fixed at their world average values [7]; the mass and the coupling constants of the $f_0(980)$ state are fixed at values determined from the analysis of $B^+ \to K^+\pi^+\pi^-$: $M[f_0(980)] = 950\ \mathrm{MeV}/c^2$, $g_{\pi\pi} = 0.23$, $g_{KK} = 0.73$ [11].

Following suggestions in Ref. [12], the nonresonant amplitude A_{nr} is parametrized as $A_{\mathrm{nr}} = a_1^{\mathrm{nr}} e^{i\delta_1^{\mathrm{nr}}} + a_2^{\mathrm{nr}} e^{i\delta_2^{\mathrm{nr}}} s_3$, where $s_3 = M^2(\pi^+\pi^-)$ (s_3 is not an independent variable and can be expressed via s_1 and s_2 but we use it here for clarity), a_1^{nr}, a_2^{nr}, δ_1^{nr}, and δ_2^{nr} are free parameters of the fit.

The logarithmic likelihood function $\mathcal{L}$ is then constructed as

$$\mathcal{L} = -2 \sum \log[f_{\mathrm{sig}} S(s_1, s_2) + (1 - f_{\mathrm{sig}}) B(s_1, s_2)], \qquad (3)$$

where $S(s_1, s_2)$ is the density of signal events $|M(s_1, s_2)|^2$ convolved with the detector resolution function, $B(s_1, s_2)$ describes the combinatorial background that is considered to be constant, and f_{sig} is the fraction of signal events in the data sample. Both $S(s_1, s_2)$ and $B(s_1, s_2)$ are efficiency corrected.

In the fit to the $\Upsilon(1S)\pi^+\pi^-$ and $\Upsilon(2S)\pi^+\pi^-$ samples, the amplitudes and phases of all of the components are allowed to float. However, in the $\Upsilon(3S)\pi^+\pi^-$ samples the available phase space is significantly smaller and contributions from the $f_0(980)$ and $f_2(1270)$ channels are not well constrained. Since the fit to the $\Upsilon(3S)\pi^+\pi^-$ signal is insensitive to the presence of these two components, we fix their amplitudes at zero. Because of the very limited phase space available in the $\Upsilon(5S) \to \Upsilon(3S)\pi^+\pi^-$ decay, there is a significant overlap between the two processes $\Upsilon(5S) \to Z_b^+\pi^-$ and $\Upsilon(5S) \to Z_b^-\pi^+$.

Results of the fits to $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$ signal events are shown in Fig. 2, where one-dimensional projections of the data and fits are compared. Numerical results are summarized in Table I, where the relative normalization is defined as a_{Z_2}/a_{Z_1} and the relative phase as $\delta_{Z_2} - \delta_{Z_1}$. The combined statistical significance of the two peaks exceeds 10σ for all tested models and for all $\Upsilon(nS)\pi^+\pi^-$ channels.

The main source of systematic uncertainties in the analysis of $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$ channels is due to uncertainties in the parametrization of the decay amplitude. We fit the data with modifications of the nominal model [described in Eq. (1)]. In particular, we vary the $M(\pi^+\pi^-)$ dependence of the nonresonant amplitude A_{nr}, include a D-wave component into A_{nr}, include the $f_0(600)$ state, etc. The variations in the extracted Z_b parameters determined from fits with modified models are taken as estimates of the model uncertainties. Other major sources of systematic error include variation of the reconstruction efficiency over the Dalitz plot and uncertainty in the c.m. energy. Systematic effects associated with uncertainties in the description of the combinatorial background are found to be negligible. The overall systematic errors are quoted in Table I.

To study the resonant substructure of the $\Upsilon(5S) \to h_b(mP)\pi^+\pi^-$ ($m = 1, 2$) decays we measure their yield as a function of the $h_b(1P)\pi^\pm$ invariant mass. The decays are reconstructed inclusively using the missing mass of the $\pi^+\pi^-$ pair, $M_{\mathrm{miss}}(\pi^+\pi^-)$. We fit the $M_{\mathrm{miss}}(\pi^+\pi^-)$ spectra in bins of $h_b(1P)\pi^\pm$ invariant mass, defined as the missing mass of the opposite sign pion, $M_{\mathrm{miss}}(\pi^\mp)$. We combine the $M_{\mathrm{miss}}(\pi^+\pi^-)$ spectra for the corresponding $M_{\mathrm{miss}}(\pi^+)$ and $M_{\mathrm{miss}}(\pi^-)$ bins and we use half of the available $M_{\mathrm{miss}}(\pi)$ range to avoid double counting.

Selection requirements and the $M_{\mathrm{miss}}(\pi^+\pi^-)$ fit procedure are described in detail in Ref. [3]. We consider all well reconstructed and positively identified $\pi^+\pi^-$ pairs in the event. Continuum $e^+e^- \to q\bar{q}$ ($q = u, d, s$) background is

TABLE I. Comparison of results on $Z_b(10\,610)$ and $Z_b(10\,650)$ parameters obtained from $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$ ($n = 1, 2, 3$) and $\Upsilon(5S) \to h_b(mP)\pi^+\pi^-$ ($m = 1, 2$) analyses.

Final state	$\Upsilon(1S)\pi^+\pi^-$	$\Upsilon(2S)\pi^+\pi^-$	$\Upsilon(3S)\pi^+\pi^-$	$h_b(1P)\pi^+\pi^-$	$h_b(2P)\pi^+\pi^-$
$M[Z_b(10\,610)]$ (MeV$/c^2$)	$10\,611 \pm 4 \pm 3$	$10\,609 \pm 2 \pm 3$	$10\,608 \pm 2 \pm 3$	$10\,605 \pm 2^{+3}_{-1}$	$10\,599^{+6+5}_{-3-4}$
$\Gamma[Z_b(10\,610)]$ (MeV)	$22.3 \pm 7.7^{+3.0}_{-4.0}$	$24.2 \pm 3.1^{+2.0}_{-3.0}$	$17.6 \pm 3.0 \pm 3.0$	$11.4^{+4.5+2.1}_{-3.9-1.2}$	13^{+10+9}_{-8-7}
$M[Z_b(10\,650)]$ (MeV$/c^2$)	$10\,657 \pm 6 \pm 3$	$10\,651 \pm 2 \pm 3$	$10\,652 \pm 1 \pm 2$	$10\,654 \pm 3^{+1}_{-2}$	$10\,651^{+2+3}_{-3-2}$
$\Gamma[Z_b(10\,650)]$ (MeV)	$16.3 \pm 9.8^{+6.0}_{-2.0}$	$13.3 \pm 3.3^{+4.0}_{-3.0}$	$8.4 \pm 2.0 \pm 2.0$	$20.9^{+5.4+2.1}_{-4.7-5.7}$	$19 \pm 7^{+11}_{-7}$
Relative normalization	$0.57 \pm 0.21^{+0.19}_{-0.04}$	$0.86 \pm 0.11^{+0.04}_{-0.10}$	$0.96 \pm 0.14^{+0.08}_{-0.05}$	$1.39 \pm 0.37^{+0.05}_{-0.15}$	$1.6^{+0.6+0.4}_{-0.4-0.6}$
Relative phase (deg)	$58 \pm 43^{+4}_{-9}$	$-13 \pm 13^{+17}_{-8}$	$-9 \pm 19^{+11}_{-26}$	187^{+44+3}_{-57-12}	$181^{+65+74}_{-105-109}$

suppressed by a requirement on the ratio of the second to zeroth Fox-Wolfram moments $R_2 < 0.3$ [13]. The fit function is a sum of peaking components due to dipion transitions and combinatorial background. The positions of all peaking components are fixed to the values measured in Ref. [3]. In the case of the $h_b(1P)$ the peaking components include signals from $\Upsilon(5S) \to h_b(1P)$ and $\Upsilon(5S) \to \Upsilon(2S)$ transitions, and a reflection from the $\Upsilon(3S) \to \Upsilon(1S)$ transition, where the $\Upsilon(3S)$ is produced inclusively or via initial state radiation. Since the $\Upsilon(3S) \to \Upsilon(1S)$ reflection is not well constrained by the fits, we determine its normalization relative to the $\Upsilon(5S) \to \Upsilon(2S)$ signal from the exclusive $\mu^+\mu^-\pi^+\pi^-$ data for every $M_{\rm miss}(\pi)$ bin. In case of the $h_b(2P)$ we use a smaller $M_{\rm miss}(\pi^+\pi^-)$ range than in Ref. [3], $M_{\rm miss}(\pi^+\pi^-) < 10.34\ {\rm GeV}/c^2$, to exclude the region of the $K_S^0 \to \pi^+\pi^-$ reflection. The peaking components include the $\Upsilon(5S) \to h_b(2P)$ signal and a $\Upsilon(2S) \to \Upsilon(1S)$ reflection. To constrain the normalization of the $\Upsilon(2S) \to \Upsilon(1S)$ reflection we use exclusive $\mu^+\mu^-\pi^+\pi^-$ data normalized to the total yield of the reflection in the inclusive data. Systematic uncertainty in the latter number is included in the error propagation. The combinatorial background is parametrized by a Chebyshev polynomial. We use orders between 6 and 10 for the $h_b(1P)$ [the order decreases monotonically with the $M_{\rm miss}(\pi)$] and orders between 6 and 8 for the $h_b(2P)$.

The results for the yield of $\Upsilon(5S) \to h_b(mP)\pi^+\pi^-$ ($m = 1, 2$) decays as a function of the $M_{\rm miss}(\pi)$ are shown in Fig. 3. The distribution for the $h_b(1P)$ exhibits a clear two-peak structure without a significant nonresonant contribution. The distribution for the $h_b(2P)$ is consistent with the above picture, though the available phase space is smaller and uncertainties are larger. We associate the two peaks with the production of the $Z_b(10\,610)$ and $Z_b(10\,650)$. To fit the $M_{\rm miss}(\pi)$ distributions we use the expression

$$|{\rm BW}_1(s, M_1, \Gamma_1) + ae^{i\phi}{\rm BW}_1(s, M_2, \Gamma_2) + be^{i\psi}|^2 \frac{qp}{\sqrt{s}}. \quad (4)$$

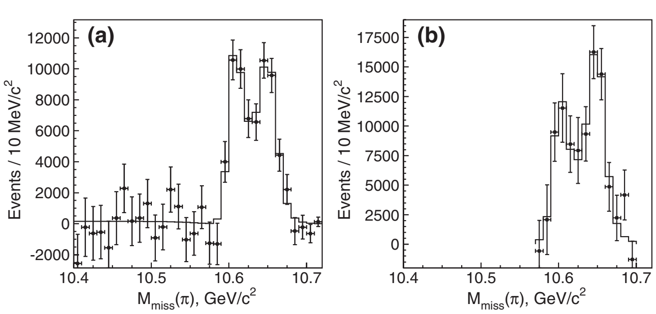

FIG. 3. The (a) $h_b(1P)$ and (b) $h_b(2P)$ yields as a function of $M_{\rm miss}(\pi)$ (points with error bars) and results of the fit (histogram).

Here $\sqrt{s} \equiv M_{\rm miss}(\pi)$; the variables M_k, Γ_k ($k = 1, 2$), a, ϕ, b, and ψ are free parameters; $\frac{qp}{\sqrt{s}}$ is a phase-space factor, where p (q) is the momentum of the pion originating from the $\Upsilon(5S)$ (Z_b) decay measured in the rest frame of the corresponding mother particle. The P-wave Breit-Wigner amplitude is expressed as ${\rm BW}_1(s, M, \Gamma) = \frac{\sqrt{M\Gamma}F(q/q_0)}{M^2 - s - iM\Gamma}$.

Here F is the P-wave Blatt-Weisskopf form factor $F = \sqrt{\frac{1+(q_0R)^2}{1+(qR)^2}}$ [14], q_0 is a daughter momentum calculated with pole mass of its mother, $R = 1.6\ {\rm GeV}^{-1}$. The function [Eq. (4)] is convolved with the detector resolution function ($\sigma = 5.2\ {\rm MeV}/c^2$), integrated over the 10 MeV$/c^2$ histogram bin and corrected for the reconstruction efficiency. The fit results are shown as solid histograms in Fig. 3 and are summarized in Table I. We find that the nonresonant contribution is consistent with zero [significance is 0.3σ both for the $h_b(1P)$ and $h_b(2P)$] in accord with the expectation that it is suppressed due to heavy-quark spin flip. In case of the $h_b(2P)$ we improve the stability of the fit by fixing the nonresonant amplitude to zero. The C.L. of the fit is 81% (61%) for the $h_b(1P)$ [$h_b(2P)$]. The default fit hypothesis is favored over the phase-space fit hypothesis at the 18σ [6.7σ] level for the $h_b(1P)$ [$h_b(2P)$].

To estimate the systematic uncertainty we vary the order of the Chebyshev polynomial in the fits to the $M_{\rm miss}(\pi^+\pi^-)$ spectra; to study the effect of finite $M_{\rm miss}(\pi)$ binning we shift the binning by half bin size; to study the model uncertainty in the fits to the $M_{\rm miss}(\pi)$ distributions we remove [add] the nonresonant contribution in the $h_b(1P)$ [$h_b(2P)$] case; we increase the width of the resolution function by 10% to account for possible difference between data and MC simulation. The maximum change of parameters for each source is used as an estimate of its associated systematic error. We estimate an additional 1 MeV$/c^2$ uncertainty in mass measurements based on the difference between the observed $\Upsilon(nS)$ peak positions and their world averages [3]. The total systematic uncertainty presented in Table I is the sum in quadrature of contributions from all sources. The significance of the $Z_b(10\,610)$ and $Z_b(10\,650)$ including systematic uncertainties is 16.0σ [5.6σ] for the $h_b(1P)$ [$h_b(2P)$].

In conclusion, we have observed two charged bottomoniumlike resonances, the $Z_b(10\,610)$ and $Z_b(10\,650)$, with signals in five different decay channels, $\Upsilon(nS)\pi^\pm$ ($n = 1, 2, 3$) and $h_b(mP)\pi^\pm$ ($m = 1, 2$). The parameters of the resonances are given in Table I. All channels yield consistent results. Weighted averages over all five channels give $M = 10\,607.2 \pm 2.0\ {\rm MeV}/c^2$, $\Gamma = 18.4 \pm 2.4$ MeV for the $Z_b(10\,610)$ and $M = 10\,652.2 \pm 1.5\ {\rm MeV}/c^2$, $\Gamma = 11.5 \pm 2.2$ MeV for the $Z_b(10\,650)$, where statistical and systematic errors are added in quadrature. The $Z_b(10\,610)$ production rate is similar to that of the

$Z_b(10\,650)$ for each of the five decay channels. Their relative phase is consistent with zero for the final states with the $\Upsilon(nS)$ and consistent with 180° for the final states with $h_b(mP)$. Production of the Z_b's saturates the $\Upsilon(5S) \to h_b(mP)\pi^+\pi^-$ transitions and accounts for the high inclusive $h_b(mS)$ production rate reported in Ref. [3]. Analyses of charged pion angular distributions [9] favor the $J^P = 1^+$ spin-parity assignment for both the $Z_b(10\,610)$ and $Z_b(10\,650)$. Since the $\Upsilon(5S)$ has negative G parity, the Z_b states have positive G parity due to the emission of the pion.

The minimal quark content of the $Z_b(10\,610)$ and $Z_b(10\,650)$ is a four quark combination. The measured masses of these new states are a few MeV$/c^2$ above the thresholds for the open beauty channels $B^*\bar{B}$ (10 604.6 MeV$/c^2$) and $B^*\bar{B}^*$ (10 650.2 MeV$/c^2$). This suggests a ''molecular'' nature of these new states, which might explain most of their observed properties [15]. The preliminary announcement of these results triggered intensive discussion of other possible interpretations [16–19].

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