Observation of B-s production at the Upsilon(5S) resonance

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Using the CLEO detector at the Cornell Electron Storage Ring, we have observed the B_s meson in e^+e^- annihilation at the $\Upsilon(5S)$ resonance. We find 14 candidates consistent with B_s decays into final states with a J/ψ or a $D_s^{(*)-}$. The probability that we have observed a background fluctuation is less than 8×10^{-10}. We have established that at the energy of the $\Upsilon(5S)$ resonance B_s production proceeds predominantly through the creation of $B_s^* \bar{B}_s^*$ pairs. We find $\sigma(e^+e^- \to B_s^* \bar{B}_s^*) = [0.11^{+0.04}_{-0.03}(\text{stat}) \pm 0.02(\text{syst})]$ nb, and set the following limits: $\sigma(e^+e^- \to B_s \bar{B}_s)/\sigma(e^+e^- \to B_s^* \bar{B}_s^*) < 0.16$ and $[\sigma(e^+e^- \to B_s \bar{B}_s^*) + \sigma(e^+e^- \to B_s^* \bar{B}_s)]/\sigma(e^+e^- \to B_s^* \bar{B}_s^*) < 0.16$ (90% C.L.). The mass of the B_s^* meson is measured to be $M_{B_s^*} = [5.414 \pm 0.001(\text{stat}) \pm 0.003(\text{syst})]\ \text{GeV}/c^2$.

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The $\Upsilon(5S)$ resonance was discovered by the CLEO and CUSB Collaborations [1]. It lies about 40 MeV above the $B_s^*\bar{B}_s^*$ production threshold. At this energy $B_{(s)}$ mesons can be produced in a variety of states $B_{(s)}^{(*)}\bar{B}_{(s)}^{(*)}(\pi)(\pi)$. The cross section in this energy region is well described by the unitarized quark model [2], which predicts that the total $b\bar{b}$ cross section, measured to be about 0.35 nb [1], is dominated by $B_{(s)}^*\bar{B}_{(s)}^*$ production with $B_s^*\bar{B}_s^*$ constituting one-third of it. Knowledge of the B_s production mechanism and rate at the $\Upsilon(5S)$ resonance is essential for evaluating the physics potential of the B_s program at a future e^+e^- Super-B Factory [3].

In this Letter, we report the first observation of fully reconstructed B_s mesons produced in e^+e^- annihilation at the energy of the $\Upsilon(5S)$ resonance. We demonstrate for the first time that the dominant B_s production mechanism at this energy is $B_s^*\bar{B}_s^*$, measure the cross section for this process, set upper limits on the competing mechanisms, and thereby test theoretical predictions. A companion Letter using the same data set reported first evidence for $B_s^{(*)}\bar{B}_s^{(*)}$ production from a measurement of the D_s^+ inclusive yield [4].

An extension of the exclusive B meson reconstruction technique used at the $\Upsilon(4S)$ resonance is employed to reconstruct B_s mesons at the $\Upsilon(5S)$ [5]. Signal events are identified in the search plane of two variables: $M_{\rm bc} \equiv \sqrt{E_{\rm beam}^2/c^4 - |\vec{p}_{B_s}|^2/c^2}$ and $\Delta E \equiv E_{B_s} - E_{\rm beam}$. The signal regions in the search plane are chosen using $M_{B_s} = (5.3660 \pm 0.0008)~{\rm GeV}/c^2$ [6] and $M_{B_s^*} - M_{B_s} = (47.0 \pm 2.6)~{\rm MeV}/c^2$ [7]. We assume that the B_s^* meson decays to a B_s meson via the emission of a 47 MeV photon with a branching fraction equal to unity.

At the energy of the $\Upsilon(5S)$ resonance, the following states containing a $b\bar{s}$ quark pair are possible: $B_s\bar{B}_s$, $B_s\bar{B}_s^*$ (or $B_s^*\bar{B}_s$), and $B_s^*\bar{B}_s^*$. If the production of B_s mesons occurs through the creation of $B_s\bar{B}_s$ pairs, $M_{\rm bc} = M_{B_s}$ and $\Delta E = 0$ MeV. In the two cases involving B_s^* production, to increase the reconstruction efficiency, the soft photon from the B_s^* meson is not reconstructed. This leads to a shift from zero in ΔE but negligible smearing of the B_s momentum, as the photon carries a small fraction of the total B_s^* momentum. For $B_s^*\bar{B}_s^*$, E_{B_s} tends to be 47 MeV smaller than $E_{\rm beam}$ ($\Delta E = M_{B_s} - M_{B_s^*}$), and $M_{\rm bc}$ is 47 MeV$/c^2$ higher than M_{B_s} ($M_{\rm bc} = M_{B_s^*}$), because the 47 MeV photon is not reconstructed. If B_s mesons are produced via $B_s\bar{B}_s^*$ or $B_s^*\bar{B}_s$ pair creation, $M_{\rm bc}$ and ΔE, to a good approximation, peak at $\frac{1}{2}(M_{B_s} + M_{B_s^*})$ and $\frac{1}{2}(M_{B_s} - M_{B_s^*})$, respectively. We define a signal band in the search plane as $-60~{\rm MeV} \leq \Delta E + [M_{\rm bc} - M_{B_s}]c^2 \leq +60~{\rm MeV}$. Within the signal band, there are three signal regions, each about 24 MeV$/c^2$ wide and centered at $M_{\rm bc} = 5.366$, 5.390, and 5.413 GeV$/c^2$ corresponding to $B_s\bar{B}_s$, $B_s\bar{B}_s^*$, and $B_s^*\bar{B}_s^*$ production, respectively. Identical signal regions are used for all B_s modes, each corresponding to about 3 standard deviations (3σ) in $M_{\rm bc}$ and 2σ to 4σ in ΔE, depending on the mode.

The data used in this analysis were recorded by the CLEO III detector at Cornell Electron Storage Ring (CESR). CLEO III is a general multipurpose solenoidal detector designed to provide excellent charged and neutral particle reconstruction efficiency and resolution. It has been described in detail in Ref. [8]. The integrated luminosity of the data sample collected in the vicinity of the $\Upsilon(5S)$ peak is 0.42 fb^{-1}, most of which was taken at a center-of-mass energy $E_{\rm c.m.} = (10.859 \pm 0.006)$ GeV. A data sample of 7.6 fb^{-1} collected at, and just below, the $\Upsilon(4S)$ resonance and a data sample of 0.7 fb^{-1} collected at $11.2 < E_{\rm c.m.} < 11.4$ GeV (Λ_b^0-scan data) [9] is used to study background from B mesons and continuum events of the type $e^+e^- \to q\bar{q}$, where q is u, d, s, or c quark.

Tracks and showers used in reconstruction must satisfy a set of quality criteria. Primary tracks must be in the fiducial volume of the detector, come from the interaction point, and have momenta above 50 MeV$/c$. Identification of hadrons utilizes measurements of dE/dx and information from a ring imaging Cherenkov detector (RICH). Pion or kaon candidates are required to have dE/dx measurements within 3.0σ of the expected value, and for tracks with momenta greater than 700 MeV$/c$, RICH information, if available, is combined with dE/dx information. Electrons are identified above 700 MeV$/c$ using the ratio of the energy deposited in the calorimeter to the track momentum, and dE/dx information. Muon identification is efficient above 1.0 GeV$/c$ and is based on the information from the muon chambers and the energy associated with the track in the calorimeter.

Each shower must not be matched to a track or be consistent with a hadronic fragment. The shower cannot be associated with noisy crystals in the calorimeter, and its energy must be greater than 30 MeV. Neutral pion candidates are selected from pairs of photons with invariant mass within 2.5σ ($\sigma \sim 6.0~{\rm MeV}/c^2$) of the π^0 mass. A mass constraint is used for π^0 candidates to improve their energy resolution in further reconstruction.

B_s mesons are reconstructed in modes with a J/ψ or a $D_s^{(*)-}$ meson. (Charge-conjugate modes are implied throughout this Letter.) We describe each of these in turn. The following modes with a J/ψ are reconstructed: $J/\psi\phi$, $J/\psi\eta$, and $J/\psi\eta'$, where ϕ, η, and η' mesons are reconstructed using $\phi \to K^+K^-$, $\eta \to \gamma\gamma$, and $\eta' \to \eta(\gamma\gamma)\pi^+\pi^-$.

Two oppositely charged electron or muon candidates are combined to form a J/ψ candidate. In the reconstruction of $J/\psi \to e^+e^-$, bremsstrahlung photons are recovered by using showers that are not matched to a track, but that line up with one or the other electron momentum vector within a 0.10 rad angle. The $J/\psi \to \mu^+\mu^-$ candidates are required to be within 35 MeV/c^2 (3.0σ) of the J/ψ mass. The invariant mass window for $J/\psi \to e^+e^-$ is wider and asymmetric due to bremsstrahlung. Combinations satisfying $[M(e^+e^-) - M_{J/\psi}] \in [-150; 50]$ MeV/c^2 are accepted for further analysis.

We form ϕ candidates from pairs of oppositely charged tracks that do not satisfy stringent particle identification criteria for pions. The ϕ candidates within 10 MeV/c^2 of the known ϕ mass are accepted. The η candidates are formed from pairs of photons, each having an energy of at least 50 MeV, with an invariant mass within 2.5σ of the known η mass. A mass constraint is used for η candidates in further reconstruction. To reduce background from low energy photons and noise in the calorimeter, we require $\cos\theta_\gamma > -0.95$, where θ_γ is the angle between the η momentum vector in the laboratory frame and the momentum vector of the lower energy photon in the η rest frame. The reconstruction of η' candidates is achieved by combining an η candidate with any two oppositely charged tracks interpreted as pions and requiring the invariant mass of the combination to be within 12 MeV/c^2 of the known η' mass. The J/ψ is combined with a ϕ, η, or η' candidate to form a B_s candidate. If there are multiple B_s candidates in an event, the candidate having the smallest distance to the center of the signal band along the ΔE axis is selected for each B_s mode.

These selection criteria allow B_s reconstruction with a very large signal-to-background ratio. We use data collected in the vicinity of the $\Upsilon(4S)$ resonance and the Λ_b^0-scan data to study background. To correct for the difference in the beam energy between these data and the $\Upsilon(5S)$ data, M_{bc} is obtained using $\frac{E_{\Upsilon(5S)}}{E_{\mathrm{beam}}} \times \sqrt{E_{\mathrm{beam}}^2/c^4 - |\vec{p}_{B_s}|^2/c^2}$. The background shows no tendency to peak in the signal band. It decreases with increasing ΔE, and is approximately uniformly distributed throughout most of the M_{bc} range, tending to zero at the phase space limit $M_{\mathrm{bc}} = E_{\mathrm{c.m.}}/2$. The total number of non-B_s background events in the entire search plane in the $\Upsilon(5S)$ data is estimated to be $2.4 \pm 0.4(\mathrm{stat})$. Backgrounds are well determined as the integrated luminosity of the background samples is a factor of 20 greater than that of the $\Upsilon(5S)$ data sample.

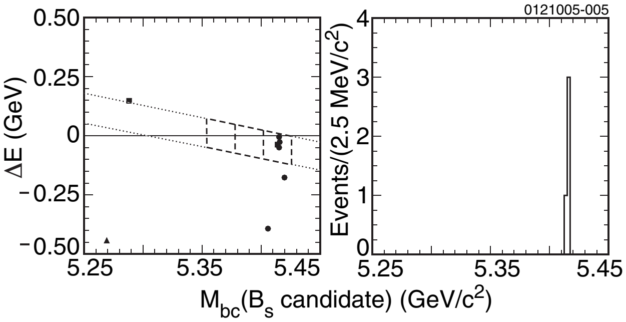

FIG. 1. The search plane (left) and its projection on M_{bc} (right) for events in the signal band for B_s modes with a J/ψ in the $\Upsilon(5S)$ data. The circles, triangles, and squares represent $B_s \to J/\psi\phi$, $J/\psi\eta$, and $J/\psi\eta'$ candidates, respectively. In the signal band (dotted lines), assuming $M_{B_s^*} - M_{B_s} = 47$ MeV/c^2 [7], B_s mesons are expected to cluster within the signal boxes (dashed lines) at (5.366, 0.000), (5.390, −0.024), and (5.413, −0.047) for $B_s\bar{B}_s$, $B_s\bar{B}_s^*$, and $B_s^*\bar{B}_s^*$ production, respectively.

Figure 1 shows the search plane in the data (left) and its projection on M_{bc} (right) for events in the signal band. There are 4 events in the signal region all corresponding to $B_s^*\bar{B}_s^*$ production: 2 events in the $B_s \to J/\psi(\mu^+\mu^-)\phi$ mode, 1 event in the $B_s \to J/\psi(e^+e^-)\phi$ mode, and 1 event in the $B_s \to J/\psi(\mu^+\mu^-)\eta'$ mode. The rest of the search plane contains 4 background events: 2 events in the $B_s \to J/\psi\phi$ mode, 1 event in the $B_s \to J/\psi\eta$ mode, and 1 event in the $B_s \to J/\psi\eta'$ mode.

To calculate the probability, P_{I}, for the background to account for all events in the $B_s^*\bar{B}_s^*$ signal region requires assumptions about the background shape in the search plane. To obtain a conservative estimate, we assume that the background density is uniform over the lower half of the search plane. The number of non-B_s background events in the $B_s^*\bar{B}_s^*$ signal region is estimated from the background study to be less than 0.08 events at 68% confidence level (C.L.). The Poisson probability for 0.08 background events to fluctuate to 4 or more events in the signal region is $P_{\mathrm{I}} = 1.6 \times 10^{-6}$.

We now describe the analysis of B_s modes with a $D_s^{(*)-}$ meson in the final state. As the B_s is expected to decay almost 100% of the time to a D_s^-, these modes provide access to a large fraction of B_s decays. However, background from continuum production is significant and consequently stringent background suppression criteria must be applied. We reconstruct the modes $\bar{B}_s \to D_s^{(*)+}\pi^-$ and $\bar{B}_s \to D_s^{(*)+}\rho^-$, where the D_s^+ meson is reconstructed in the final states $K^+K_S^0(\pi^+\pi^-)$, $K^+K^{0*}(K^-\pi^+)$, $\phi(K^-K^+)\pi^+$, and $\phi(K^-K^+)\rho^+(\pi^+\pi^0)$, and the D_s^{*+} meson is reconstructed in the $D_s^+\gamma$ channel.

Hadron identification information is used only for kaons. The $\phi/K^{*0}/\rho^+$ candidates are constructed from (K^- and K^+)/(K^- and π^+)/(π^0 and π^+) candidates within 8/75/100 MeV/c^2 of their known mean masses, respectively. The K_S^0 candidates are formed from pairs of oppositely charged and vertex-constrained tracks, if the invariant mass is within 8 MeV/c^2 of the known K_S^0 mass, and the vertex is displaced from the beam interaction point by at least 3.0 mm. All D_s^+ candidates with an invariant mass within 3.0σ of the known D_s^+ mass are used in further reconstruction.

The D_s^{*+} candidates are reconstructed by combining the D_s^+ candidates with photons. The photon candidates are required to have energies, E_γ, in the kinematically allowed range: $60 < E_\gamma < 400$ MeV. The mass difference

$(M_{D_s^{*+}} - M_{D_s^+})$ is required to be within 2.0σ ($\sigma \sim 6$ MeV$/c^2$) of the known value in order to suppress a large background from random photons.

The $D_s^{(*)+}$ candidates are combined with a π^- or a ρ^-. The ρ^- candidates are required to have invariant mass within 100 MeV of the known mean value. We also require that the momentum of π^0 mesons from the ρ^- candidates be above 200 MeV$/c$ to remove a large background in π^0 reconstruction at lower momenta.

In reconstruction of the decay sequences $P_i \to V_f P_f$ with $V_f \to p_1 p_2$, where P or p is a pseudoscalar and V is a vector, the distribution of $\cos\theta_V$, where θ_V is the angle between the p_1 momentum in the V_f rest frame and the V_f momentum in the P_i rest frame, is proportional to $\cos^2\theta_V$, while the background tends to be uniform in this variable. Accordingly, we require $|\cos\theta_V| > 0.60$ in the reconstruction of $D_s^+ \to \bar{K}^{*0}(K^-\pi^+)K^+$, $D_s^+ \to \phi(K^-K^+)\pi^+$, and $\bar{B}_s \to D_s^+\rho^-(\pi^-\pi^0)$. Similarly, in the reconstruction of $\bar{B}_s \to D_s^{*+}\pi^-$, we require $|\cos\theta_\gamma| < 0.70$, where θ_γ is the angle between the photon momentum in the D_s^{*+} frame and the D_s^{*+} momentum in the $\bar{B}_s$ frame. The distribution of $\cos\theta_\gamma$ is proportional to $(1 - \cos^2\theta_\gamma)$ for signal decays, while the background gradually increases towards $\cos\theta_\gamma = -1$.

To suppress the continuum background, the ratio of Fox-Wolfram moments H_2 and H_0 [10] is required to be less than 0.30. The continuum background is suppressed further using a requirement of $|\cos\theta_{\text{thrust}}| < 0.70$, where θ_{thrust} is the angle between the thrust axis of the B_s candidate and the thrust axis of the rest of the event.

If there are multiple candidates in an event satisfying all selection criteria, we select one candidate for $\bar{B}_s \to D_s^+\pi^-/\rho^-$ modes and one candidate for $\bar{B}_s \to D_s^{*+}\pi^-/\rho^-$ modes. In each case the candidate with the smallest $|\Delta E|^{\text{signal band}}/\sigma(\Delta E)$ is selected, where $|\Delta E|^{\text{signal band}}$ is the distance to the center of the signal band along the ΔE axis and $\sigma(\Delta E)$ is mode dependent.

The same data samples as those in the analysis of B_s modes with a J/ψ are used in a background study. Again, the background shows no tendency to peak in the signal band, and is similar in shape to the background in $B_s \to J/\psi\phi/\eta/\eta'$. The total number of non-B_s background events in the entire search plane in the $\Upsilon(5S)$ data is estimated to be 47 ± 2(stat).

Events satisfying the selection criteria in the $\Upsilon(5S)$ data are shown in Fig. 2 (left). There are 63 events in the search plane, 10 events are in the signal region corresponding to $B_s^*\bar{B}_s^*$. Figure 2 (right) is a projection of the search plane on M_{bc} for events in the signal band. Table I shows the signal events by the $\bar{B}_s$ and D_s^+ mode of reconstruction.

The probability, P_{II}, for the background to fluctuate upwards and account for all events in the signal region for $B_s^*\bar{B}_s^*$ is estimated using the $\Upsilon(5S)$ data in the sidebands of the signal region. To obtain a conservative estimate, we assume that the background is distributed uniformly over the lower half of the search plane. The number of background events in the signal region is less than 1.8 at 68% C.L. The Poisson probability for 1.8 events to fluctuate to 10 or more events in the signal region is $P_{\text{II}} = 1.9 \times 10^{-5}$.

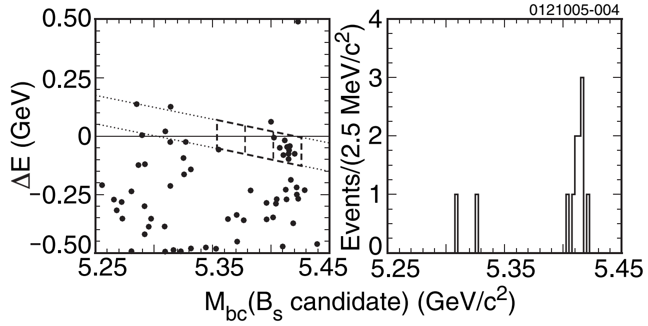

FIG. 2. The search plane (left) and its projection on M_{bc} (right) for events in the signal band for B_s modes with a $D_s^{(*)-}$ in the $\Upsilon(5S)$ data. The signal band (dotted lines) and signal boxes (dashed lines) are the same as in Fig. 1.

The probabilities P_{I} and P_{II} for the background to account for all events in the signal region for the two analyses are independent. A combined probability P is obtained as $P = (P_{\text{I}}P_{\text{II}})[1 - \ln(P_{\text{I}}P_{\text{II}})]$ [11]. We find $P = 7.7 \times 10^{-10}$, which corresponds to a significance above 6.1σ [12].

We calculate $\sigma(e^+e^- \to B_s^*\bar{B}_s^*)$ using $\sigma(e^+e^- \to B_s^*\bar{B}_s^*) = \frac{N_{\text{observed}} - N_{\text{background}}}{2\mathcal{L}\epsilon^*}$, where ϵ^* is the combined reconstruction efficiency obtained using a GEANT-based Monte Carlo simulation [13] for all modes including the B_s and subsidiary branching fractions. The absolute reconstruction efficiencies range from a few percent for $\bar{B}_s \to D_s^{*+}\rho^-$ to about 30% for $B_s \to J/\psi\phi$. All B_s branching fractions are unknown or poorly measured. We estimate the B_s branching fractions by relating them to B branching fractions that have contributions from the same quark-level diagrams, and assuming SU(3) symmetry. For the $B_s \to J/\psi\phi$, $B_s \to J/\psi\eta$, and $B_s \to J/\psi\eta'$ modes, the following branching fractions are used: $\mathcal{B}(B \to J/\psi K^*) = (1.32 \pm 0.06) \times 10^{-3}$, $\frac{1}{3}\mathcal{B}(B \to J/\psi K) = (0.31 \pm 0.01) \times 10^{-3}$, and $\frac{2}{3}\mathcal{B}(B \to J/\psi K) = (0.63 \pm 0.02) \times 10^{-3}$, respectively. For the $\bar{B}_s \to D_s^{(*)+}\pi^-/\rho^-$ modes, only the corresponding $\bar{B}^0$ branching fractions, i.e., $\mathcal{B}(\bar{B}^0 \to D^{(*)+}\pi^-/\rho^-)$, are used, as they proceed predominantly through an external spectator diagram. For $\mathcal{B}(D_s^+ \to \phi\pi^+)$ a weighted average of the PDG average [7] and a recent measurement [14] is used. The D_s^+ branching frac-

TABLE I. The B_s candidates tabulated by the $\bar{B}_s$ and D_s^+ mode.

	$D_s^+ \to K^+K_S^0$	$K^+\bar{K}^{0*}$	$\phi\pi^+$	$\phi\rho^+$
$\bar{B}_s \to D_s^+\pi^-/\rho^-$	0/0	1/1	1/3	1/1
$\bar{B}_s \to D_s^{*+}\pi^-/\rho^-$	0/1	1/0	0/0	0/0

tions for the other three modes are updated accordingly, as they are all measured with respect to $D_s^+ \to \phi\pi^+$. Other subsidiary branching fractions are well known [7].

Most of the data was taken at $E_{\mathrm{c.m.}} = 10.859$ GeV; however, a small subset, which contains one signal event, was taken at an energy about 56 MeV higher. In order to quote the cross section at the $\Upsilon(5S)$ peak, we exclude this event from the signal yield. Using the remaining 13 B_s candidates, we find $\sigma(e^+e^- \to B_s^*\bar{B}_s^*) = [0.11^{+0.04}_{-0.03}(\mathrm{stat}) \pm 0.02(\mathrm{syst})]$ nb. The systematic uncertainty has large contributions from the uncertainties in B and D_s^+ branching fractions, and the assumption of SU(3) symmetry. Other uncertainties in track, π^0, and K_S^0 finding efficiencies, particle identification efficiencies, the background estimates, and the integrated luminosity of the $\Upsilon(5S)$ data sample are small.

The number of events consistent with $B_s^*\bar{B}_s^*$ production at $E_{\mathrm{c.m.}} = 10.859$ GeV is 13, while the number of events consistent with either of the other two B_s production mechanisms is 0. Accounting for the background in the signal region, we find $\sigma(e^+e^- \to B_s\bar{B}_s)/\sigma(e^+e^- \to B_s^*\bar{B}_s^*) < 0.16$ and $[\sigma(e^+e^- \to B_s\bar{B}_s^*) + \sigma(e^+e^- \to B_s^*\bar{B}_s)]/\sigma(e^+e^- \to B_s^*\bar{B}_s^*) < 0.16$ at 90% C.L.

Using all 14 signal B_s candidates, the mass of the B_s^* meson is measured to be $M_{B_s^*} = [5.414 \pm 0.001(\mathrm{stat}) \pm 0.003(\mathrm{syst})]\ \mathrm{GeV}/c^2$. The dominant systematic uncertainty arises from imperfect knowledge of the absolute beam energy scale ($2.9\ \mathrm{MeV}/c^2$), which was calibrated using data collected at the narrow $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ resonances, as well as data collected at the $\Upsilon(4S)$ resonance. Using the B_s mass measurement in Ref. [6], we also find $M_{B_s^*} - M_{B_s} = [48 \pm 1(\mathrm{stat}) \pm 3(\mathrm{syst})]\ \mathrm{MeV}/c^2$, which is consistent with an earlier measurement of $M_{B_s^*} - M_{B_s} = (47.0 \pm 2.6)\ \mathrm{MeV}/c^2$ [7].

In summary, using the CLEO detector at CESR, we have observed the B_s meson in e^+e^- annihilation at the $\Upsilon(5S)$ resonance. We have established that B_s meson production proceeds predominantly through the creation of $B_s^*\bar{B}_s^*$ pairs. We find $\sigma(e^+e^- \to B_s^*\bar{B}_s^*) = [0.11^{+0.04}_{-0.03}(\mathrm{stat}) \pm 0.02(\mathrm{syst})]$ nb and set the following limits: $\sigma(e^+e^- \to B_s\bar{B}_s)/\sigma(e^+e^- \to B_s^*\bar{B}_s^*) < 0.16$ and $[\sigma(e^+e^- \to B_s\bar{B}_s^*) + \sigma(e^+e^- \to B_s^*\bar{B}_s)]/\sigma(e^+e^- \to B_s^*\bar{B}_s^*) < 0.16$ at 90% C.L. The observation that B_s pairs are produced predominantly in the $B_s^*\bar{B}_s^*$ configuration is in agreement with the prediction of the unitarized quark model [2] and predictions in Ref. [15]. The mass of the B_s^* meson is measured to be $M_{B_s^*} = [5.414 \pm 0.001(\mathrm{stat}) \pm 0.003(\mathrm{syst})]\ \mathrm{GeV}/c^2$.

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