$\Upsilon(5S)$ Results from CLEO

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Abstract. 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 have fully reconstructed 14 candidates consistent with B_s decays into final states with a J/ψ or a $D_s^{(*)-}$. The probability that this is a background fluctuation is less than 8×10^{-10}. We have established that B_s production proceeds predominantly through the creation of $B_s^*\bar{B}_s^*$ pairs with $\sigma(e^+e^- \to B_s^*\bar{B}_s^*) = [0.11^{+0.04}_{-0.03}(\mathrm{stat}) \pm 0.02(\mathrm{syst})]$ nb. The following limits are set: $\sigma(e^+e^- \to B_s\bar{B}_s)/\sigma(e^+e^- \to B_s^*\bar{B}_s^*) < 0.16$ 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% CL). In a separate analysis, by comparing production rates of D_s^+ mesons in $\Upsilon(5S)$ and $\Upsilon(4S)$ decays, an estimate of the ratio of $B_s^{(*)}\bar{B}_s^{(*)}$ to the total $b\bar{b}$ quark pair production at the $\Upsilon(5S)$ energy of $(16 \pm 3 \pm 6)\%$ is obtained.

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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, 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. In this contribution, we report on results from two studies of B_s production at the $\Upsilon(5S)$ [3][4] using a 0.42 fb^{-1} data sample of e^+e^- annihilation at the $\Upsilon(5S)$ recorded by the CLEO III detector [5] in 2003.

In the first study, an extension of the exclusive B meson reconstruction technique used at the $\Upsilon(4S)$ resonance is employed to reconstruct B_s mesons at the $\Upsilon(5S)$ [3]. Signal events are identified in the search plane of two variables: $M_{\mathrm{bc}} \equiv \sqrt{E_{\mathrm{beam}}^2/c^4 - |\vec{p}_{B_s}|^2/c^2}$ and $\Delta E \equiv E_{B_s} - E_{\mathrm{beam}}$. 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, $M_{\mathrm{bc}} = M_{B_s}$ 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. (It is assumed that the

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B_s^* meson decays to a B_s meson via the emission of a 47 MeV photon with a branching fraction equal to unity [6].) 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} ($M_{\rm bc} = M_{B_s^*}$). For the case of $B_s\bar{B}_s^*$ 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.

Signal B_s mesons are reconstructed in modes with a J/ψ or a $D_s^{(*)-}$ meson. 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 $\eta' \to \eta(\gamma\gamma)\pi^+\pi^-$. The J/ψ is reconstructed in the e^+e^- and $\mu^+\mu^-$ channels. The $\bar{B}_s$ modes with a $D_s^{(*)+}$ used in the analysis include $D_s^{(*)+}\pi^-$ and $D_s^{(*)+}\rho^-$, where the D_s^+ meson is reconstructed in $K^+K^0_S(\pi^+\pi^-)$, $K^+K^{*0}(K^-\pi^+)$, $\phi(K^-K^+)\pi^+$ and $\phi(K^-K^+)\rho^+(\pi^+\pi^0)$, and the D_s^{*+} is reconstructed in the $D_s^+\gamma$ channel. Data collected at the $\Upsilon(4S)$ resonance and just below it as well as the data from the Λ_b^0 scan [7] are used to study background. For all modes the background shows no tendency to peak in the signal region and is similar in shape. It decreases in ΔE, and is approximately uniformly distributed throughout most of the $M_{\rm bc}$ range, tending to zero at the phase space limit $M_{\rm bc} = \frac{1}{2}E_{\rm CM}$.

Figure 1 shows the search plane in the data for $\bar{B}_s$ modes with a J/ψ and a $D_s^{(*)+}$, and its projection on $M_{\rm bc}$ for events in the signal band. There are 4 and 10 events in the signal region all corresponding to $B_s^*\bar{B}_s^*$ production for modes with a J/ψ and a $D_s^{(*)+}$, respectively. The number of non-B_s background events in the $B_s^*\bar{B}_s^*$ signal region is estimated from the background study for modes with a J/ψ and from sidebands in the search plane in the $\Upsilon(5S)$ data for modes with a $D_s^{(*)+}$ to be less than 0.08 and 1.8 events at 68% Confidence Level (CL), respectively. The Poisson probability for 0.08 (1.8) background events to fluctuate to 4 (10) or more events in the signal region is $P_{\rm I} = 1.6\times10^{-6}$ ($P_{\rm II} = 1.9\times10^{-5}$). The probabilities $P_{\rm I}$ and $P_{\rm II}$ are combined using $P = (P_{\rm I}P_{\rm II})[1-\ln(P_{\rm I}P_{\rm II})]$ [9]. We find $P = 7.7\times10^{-10}$, which corresponds to a significance above 6.1σ.

We calculate $\sigma(e^+e^- \to B_s^*\bar{B}_s^*)$ as $\frac{N_{\rm observed} - N_{\rm background}}{2\mathcal{L}\epsilon^*}$, where ϵ^* is the combined reconstruction efficiency including the B_s and subsidiary branching fractions. The B_s branching fractions are unknown and estimated from B branching fractions that have contributions from the same quark-level diagrams under the assumption of $SU(3)$ symmetry. We find $\sigma(e^+e^- \to B_s^*\bar{B}_s^*) = [0.11^{+0.04}_{-0.03}({\rm stat}) \pm 0.02({\rm syst})]$ nb for $E_{\rm CM} = 10.859 \pm 0.006$ GeV. Accounting for the background in the signal region, the following limits are set: $\sigma(e^+e^- \to B_s\bar{B}_s)/\sigma(e^+e^- \to B_s^*\bar{B}_s^*) < 0.16$ 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% CL. The mass of the B_s^* meson is measured to be $M_{B_s^*} = [5.414 \pm 0.001({\rm stat}) \pm 0.003({\rm syst})]$ GeV/c^2.

In the second study, CLEO exploits the fact that D_s^+ mesons are produced more copiously in B_s decays compared to B decays. In this analysis, D_s^+ yields are measured in the $\phi(K^+K^-)\pi^+$ mode in bins of $x \equiv |\vec{p}_{D_s}|/E_{\rm beam}$ in the continuum, $\Upsilon(4S)$ and $\Upsilon(5S)$ data. The branching fractions $\mathcal{B}(\Upsilon(4S) \to D_s^+X)$ and $\mathcal{B}(\Upsilon(5S) \to D_s^+X)$ are measured by subtracting appropriately scaled and normalized D_s^+ yields in the continuum data

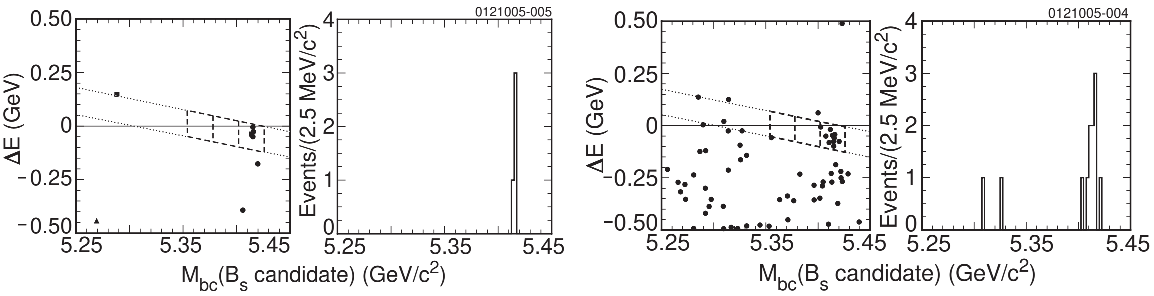

FIGURE 1. The search plane and its projection on $M_{\rm bc}$ for events in the signal band for B_s modes with a J/ψ (two plots on the left) and a $D_s^{(*)-}$ (two plots on the right) in the $\Upsilon(5S)$ data. In the signal band (dotted lines), assuming $M_{B_s^*} - M_{B_s} = 47$ MeV/c^2 [6] and $M_{B_s} = (5.3660 \pm 0.0008)$ GeV/c^2 [8], 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.

from the D_s^+ yields in the $\Upsilon(4S)$ and $\Upsilon(5S)$ data. CLEO finds $\mathcal{B}(\Upsilon(4S) \to D_s^+ X) = (18.1 \pm 0.5(\mathrm{stat}) \pm 2.8(\mathrm{syst}))\%$, which is in good agreement with $\mathcal{B}(\bar{B} \to D_s^+ X) = (10.5 \pm 2.6)\%$ in Ref. [6], and $\mathcal{B}(\Upsilon(5S) \to D_s^+ X) = (44.7 \pm 4.2(\mathrm{stat}) \pm 9.9(\mathrm{syst}))\%$. A statistically significant excess (5.6σ) in the production rate of D_s^+ mesons per an $\Upsilon(5S)$ decay compared to that per an $\Upsilon(4S)$ decay is observed. The excess is interpreted as evidence for B_s production at the energy of the $\Upsilon(5S)$ resonance. Using the measurements of $\mathcal{B}(\Upsilon(4S) \to D_s^+ X)$ and $\mathcal{B}(\Upsilon(5S) \to D_s^+ X)$ and a model dependent estimate for $\mathcal{B}(\bar{B}_s \to D_s^+ X)$ [4], CLEO finds: $\mathcal{B}(\Upsilon(5S) \to B_s^{(*)}\bar{B}_s^{(*)}) = (16 \pm 3(\mathrm{stat}) \pm 6(\mathrm{syst}))\%$, where the largest contribution to the systematic uncertainty comes from the uncertainty in the relative luminosities of the continuum and $\Upsilon(5S)$ data sets used in the analysis.

In this contribution, we have reported on results from two studies of B_s production at the $\Upsilon(5S)$ resonance [3][4]. We gratefully acknowledge the effort of the CESR staff in providing us with excellent luminosity and running conditions. This work was supported by the National Science Foundation and the U.S. Department of Energy.

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