Evidence for the B_s meson in the $\Upsilon(5S)$ data

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Abstract. Employing exclusive and inclusive reconstruction techniques, evidence for the B_s meson is established in 0.42 fb^{-1} of data collected at the $\Upsilon(5S)$ resonance with the CLEO III detector. It is found that at the energy of the $\Upsilon(5S)$ resonance the B_s meson production proceeds predominantly through the creation of $B_s^*\bar{B}_s^*$ pairs and the ratio of the $B_s^{(*)}\bar{B}_s^{(*)}$ production to the total $b\bar{b}$ quark pair production is $(21\pm3\pm9)\%$ (model dependent). All results are preliminary.

1. Introduction

A physics case is being made for a Super B factory at an asymmetric e^+e^- collider with a design luminosity of 5×10^{35} cm^{-2}s^{-1}, for example, in [1]. While the rich physics accessible at the $\Upsilon(4S)$ resonance is in the focus of such a program, the option of additional running at the $\Upsilon(5S)$ resonance at the design luminosity promises a large sample of B_s mesons produced in a clean e^+e^- environment subject to kinematic constraints similar to those enjoyed in the B meson reconstruction at the $\Upsilon(4S)$ resonance. References [1] and [2] discuss measurements that such a sample could make possible. Knowledge of the B_s production rate and mechanism at the $\Upsilon(5S)$ energy is clearly essential for assessing the potential of the B_s physics at such an e^+e^- collider.

The $\Upsilon(5S)$ was discovered at the Cornell Electron Storage Ring (CESR) [3] (Figure 1). The $\Upsilon(5S)$ is massive enough to decay into a variety of $B^{(*)}\bar{B}^{(*)}(\pi)(\pi)$ channels, as well as the following three channels with B_s mesons: $B_s\bar{B}_s$, $B_s\bar{B}_s^*$ (or $B_s^*\bar{B}_s$) and $B_s^*\bar{B}_s^*$. Little is known about the B_s production at the $\Upsilon(5S)$ resonance at this moment. The CLEO I.V detector collected around 120 pb^{-1} of data at the $\Upsilon(5S)$ resonance, but no conclusive evidence for the B_s meson in this data sample was found. Theoretical models (*e.g.*, Unitarized Quark Model in [4]) predict that the $\Upsilon(5S)$ should decay predominantly to the $B_{(s)}^*\bar{B}_{(s)}^*$ states with the $B_s^*\bar{B}_s^*$ state produced about a third of the time. The $e^+e^- \to \Upsilon(5S)$ cross section is predicted to be about 0.35 nb, which is consistent with the early CLEO data.

In 2003, a data sample of 0.42 fb^{-1} of e^+e^- annihilation at the $\Upsilon(5S)$ energy provided by CESR was recorded by the CLEO III detector [5]. Two experimental approaches are employed in the searches for the B_s meson in this data sample: an exclusive approach and an inclusive one. Below, we will first overview basic selection criteria used in the reconstruction and, after that, the two approaches will be described and the preliminary results given.

2. Basic event selection requirements

All tracks and showers are required to satisfy a set of standard quality criteria. Charged pions or kaons are identified using the specific ionization information (dE/dx) in the drift chamber

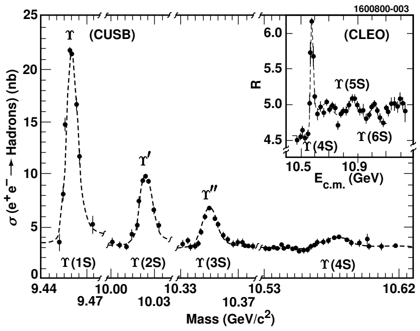

Figure 1. The e^+e^- hadronic cross section in the region of the Υ resonances. The insert plot shows the position of the $\Upsilon(5S)$ resonance.

and the information from the Ring Imaging Cherenkov Detector (RICH), if it is available. Identification of electrons is based on a likelihood function constructed from the ratio of the energy deposited in the calorimeter to the track momentum measured by the drift chamber, and the information from the dE/dx and RICH systems. Bremsstrahlung photons from electrons are recovered using showers in the crystal calorimeter that are not matched to the electron track but that line up with the track momentum. Muons are identified using the information from three layers of muon counters located behind layers of iron. Neutral pion candidates are formed from pairs of showers in the crystal calorimeter with the invariant mass within $[-3.5\sigma;+3.0\sigma]$ from the π^0 mass. K_S^0 candidates are built from pairs of oppositely charged pions constrained by a vertex fit and with the invariant mass within 12 MeV/c^2 from the K_S^0 mass. The basic reconstructed objects described in this section are used in the reconstruction of B_s decays in what follows.

3. Exclusive approach

Exclusive B meson reconstruction techniques used at the $\Upsilon(4S)$ resonance are employed to reconstruct B_s mesons at the $\Upsilon(5S)$ resonance. The search is performed on the plane of the following two variables: (1) $M_{\rm bc} \equiv \sqrt{E^2_{\rm beam} - \vec{p}^{\,2}_{\rm candidate}}$ and (2) $\Delta E \equiv E_{\rm beam} - E_{\rm candidate}$. Event shape variables, describing the distribution of track and shower momenta over the solid angle in the detector [6], are used to suppress the dominant continuum background in the same way as it is done at the $\Upsilon(4S)$.

The $\Upsilon(5S)$ resonance can decay into the following three channels with the B_s mesons: (1) $B_s\bar{B}_s$, (2) $B_s^*\bar{B}_s$ (or $B_s\bar{B}_s^*$) and (3) $B_s^*\bar{B}_s^*$. Case 1 is analogous to the B meson reconstruction at the $\Upsilon(4S)$ resonance, when $M_{\rm bc}$ peaks at the B meson mass and ΔE at zero. We assume that B_s^* decay to B_s via emission of a 47 MeV photon 100% of the time ($M(B_s^*) - M(B_s) = (47.0 \pm 2.6)$ MeV/c^2 [7]). In Cases 2 and 3, the photon from B_s^* is *not* reconstructed, which leads to a smearing of the B_s^* momentum, but not a significant one, as the photon carries only a small fraction of the total B_s^* momentum. In Case (3), because the soft photon is not reconstructed, E_{B_s} is approximately 47 MeV lower than $E_{\rm beam}$, therefore $M_{\rm bc}$ peaks approximately 47 MeV/c^2 higher than M_{B_s}, *i.e.*, at the mass of $M_{B_s^*}$, and ΔE peaks at $(M_{B_s^*} - M_{B_s}) \approx 47.0$ MeV. Similarly, in Case (2) the beam constrained mass peaks at $\frac{1}{2}(M_{B_s} + M_{B_s^*})$ and ΔE peaks at $\frac{1}{2}(M_{B_s^*} - M_{B_s})$. For these reasons, fully reconstructed B_s mesons populate different regions on the $M_{\rm bc} - \Delta E$ plane for the three cases, which allows the identification of the states in which $B_s^{(*)}$ mesons are produced.

Among experimental challenges in this analysis are backgrounds. The amount of the continuum background ($e^+e^- \to q\bar{q}$, where q is u, d, s or c quark) per a B_s meson in this search ($\sigma(B_s^{(*)}\bar{B}_s^{(*)})/\sigma(e^+e^- \to q\bar{q}) \approx 0.03$) is approximately 10 times or more larger than the amount of the continuum background per a B meson produced at the $\Upsilon(4S)$ ($\sigma(B\bar{B})/\sigma(e^+e^- \to q\bar{q}) \approx 0.3$). In addition, a variety of $B^{(*)}\bar{B}^{(*)}(\pi)(\pi)$ states are expected to be produced, any of which may produce a non-trivial structure on the search plane.

The B_s meson is reconstructed in two body modes with J/ψ or $D_s^{(*)}$ in the final state. J/ψ is reconstructed in the e^+e^- and $\mu^+\mu^-$ channels. Lepton identification requirements for the J/ψ daughter tracks make the B_s modes with J/ψ very clean. Modes with $D_s^{(*)}$ are not as clean, however, they have larger branching fractions.

The following B_s modes with J/ψ modes are reconstructed: $B_s \to J/\psi\phi$, $B_s \to J/\psi\eta$ and $B_s \to J/\psi\eta'$, where ϕ, η and η' are reconstructed in the channels: $\phi \to K^+K^-$, $\eta \to \gamma\gamma$ and $\eta' \to \eta\pi^+\pi^-$. Reconstruction of these decay sequences is so clean that requirements on the continuum suppression variables are not necessary. The plot on the left in Figure 2 shows the search plane in the data. We find three events consistent with $B_s \to J/\psi\phi$ and one event consistent with $B_s \to J/\psi\eta'$. All four events are in the region corresponding to $\Upsilon(5S) \to B_s^*\bar{B}_s^*$ peaking at $M_{\rm bc} = M_{B_s^*}$ and $\Delta E = M_{B_s^*} - M_{B_s}$. A preliminary estimate of the background in a 3σ box corresponding to $\Upsilon(5S) \to B_s^*\bar{B}_s^*$ is 0.1 events or less.

The following B_s modes with $D_s^{(*)}$ meson are reconstructed: $B_s \to D_s^{(*)}\pi^-$ and $B_s \to D_s^{(*)}\rho^-$, where D_s is reconstructed in $K^+K_S^0$, $K^+\bar{K}^{*0}(K^-\pi^+)$, $\phi(K^+K^-)\pi^+$ and $\phi(K^+K^-)\rho^+$, and $D_s^* \to D_s\gamma$. Tight continuum suppression criteria are applied for this set of modes. The plot on the right in Figure 2 shows the search plane in the data. Nine events are found in the signal region corresponding to $\Upsilon(5S) \to B_s^*\bar{B}_s^*$. A preliminary estimate of the background in a 3σ box for $\Upsilon(5S) \to B_s^*\bar{B}_s^*$ is 1.0 events or less.

Both sets of modes provide compelling evidence for the B_s meson at the $\Upsilon(5S)$ energy produced in the $B_s^*\bar{B}_s^*$ state as it is seen in Figure 2. The absolute beam energy scale is subject to systematic uncertainties and is being studied for a measurement of the B_s^* mass.

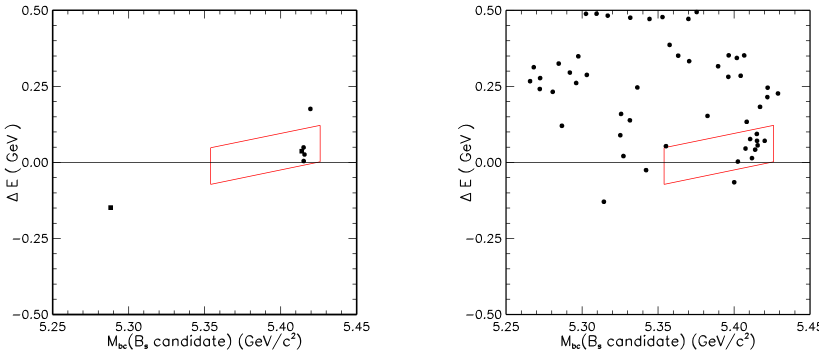

Figure 2. The signal $M_{\rm bc} - \Delta E$ plane in the data for B_s modes with J/ψ (left) and $D_s^{(*)}$ (right). The absolute $M_{\rm bc}$ and ΔE scales are subject to systematic uncertainties in the beam energy. Preliminary.

4. Inclusive approach [8]

The inclusive approach exploits the fact that D_s mesons are produced more copiously in the B_s decays compared to B decays: $\mathcal{B}(B_s \to D_sX) = (94{\pm}30)\%$ and $\mathcal{B}(B \to D_sX) = (10.5{\pm}2.6)\%$ [7]. Establishing higher production rate of D_s meson per an $\Upsilon(5S)$ decay compared to the same rate per an $\Upsilon(4S)$ decay would be evidence for B_s at the $\Upsilon(5S)$. The analysis involves three steps described below.

Firstly, D_s yields are measured in bins of $x \equiv |\vec{p}_{D_s}|/E_{\rm beam}$ in the continuum, $\Upsilon(4S)$ and $\Upsilon(5S)$ data. In this analysis, the D_s is reconstructed in the $\phi\pi^+$ mode with $\phi \to K^+K^-$. The D_s reconstruction efficiency in this mode is about 30% independent of the D_s momentum.

Secondly, $\mathcal{B}(\Upsilon(4S) \to D_sX)$ and $\mathcal{B}(\Upsilon(5S) \to D_sX)$ are measured by subtracting scaled and normalized D_s yields in the continuum data from the D_s yields in the $\Upsilon(4S)$ and $\Upsilon(5S)$ data. CLEO finds $\mathcal{B}(\Upsilon(4S) \to D_sX) = (22.3 \pm 0.7(\text{stat}) \pm 5.9(\text{syst}))\%$ (which is in good agreement with $\mathcal{B}(B \to D_sX) = (10.5 \pm 2.6)\%$ in [7]) and $\mathcal{B}(\Upsilon(5S) \to D_sX) = (55.0 \pm 5.2(\text{stat}) \pm 17.8(\text{syst}))\%$. Figure 3 shows excess in the D_s production at the $\Upsilon(5S)$ over that at the $\Upsilon(4S)$. This excess is interpreted as evidence for the B_s meson in the $\Upsilon(5S)$ data.

Finally, using $\mathcal{B}(B \to D_sX)$ and $\mathcal{B}(\Upsilon(5S) \to D_sX)$ and a model dependent estimate for $\mathcal{B}(B_s \to D_sX)$ in [8], CLEO measures: $\mathcal{B}(\Upsilon(5S) \to B_s^{(*)}\bar{B}_s^{(*)}) = (21 \pm 3(\text{stat}) \pm 9(\text{syst}))\%$, for the inclusive $B_s^{(*)}$ production rate, where the largest contributors to the systematic uncertainty are the uncertainty associated with the continuum subtraction and the uncertainty in $\mathcal{B}(D_s \to \phi\pi^+)$.

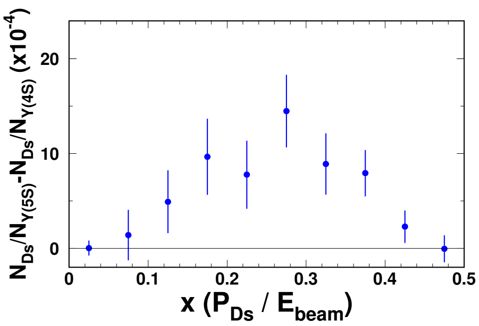

Figure 3. The enhancement of D_s yield at the $\Upsilon(5S)$ resonance compared to the $\Upsilon(4S)$ resonance. Preliminary.

5. Conclusion

Using 0.42 fb^{-1} of data collected with the CLEO III detector at the $\Upsilon(5S)$ resonance, we have established evidence for the B_s meson using exclusive and inclusive reconstruction techniques. It is found that at the $\Upsilon(5S)$ energy the production of the $B_s^*\bar{B}_s^*$ state is favored over the production of the $B_s\bar{B}_s$ or $B_s\bar{B}_s^*$ states, and the ratio of $B_s^{(*)}\bar{B}_s^{(*)}$ pair production to the total $b\bar{b}$ quark production is $(21 \pm 3(\text{stat}) \pm 9(\text{syst}))\%$. All results are preliminary.

Reference

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