EVIDENCE FOR B_S PRODUCTION AT THE $\Upsilon(5S)$ FROM CLEO AND PROPERTIES OF THE $\Upsilon(4S)$ FROM BABAR

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BaBar experiment scan around the $\Upsilon(4S)$ resonance and measure its mass and full width. They also measure $\mathcal{B}(\Upsilon(4S) \to B^0\bar{B}^0) = 0.486 \pm 0.010 \pm 0.009$ from 81.7 fb^{-1} $\Upsilon(4S)$ data. CLEO collaboration took about 0.42 fb^{-1} $\Upsilon(5S)$ data. They search for B_s in both inclusive and exclusive modes and find evidence for B_s production at the $\Upsilon(5S)$ and $\mathcal{B}(\Upsilon(5S) \to B_s^{(*)}\bar{B}_s^{(*)}) = (21 \pm 3 \pm 9)\%$.

1 Introduction

The $\Upsilon(4S)$ is the lowest $b\bar{b}$ resonance above $B\bar{B}$ threshold. Its mass and total width had been measured in scans of the total e^+e^- cross-section at center of mass energy around 10.58 GeV. [1,2,3,4] The $\Upsilon(4S)$ decays into B^+B^- and $B^0\bar{B}^0$ modes allowing these particles to be carefully studied. Many B branching fractions had been measured from $\Upsilon(4S)$ data. Most of them, however, based on the assumption of equal production rates of the charged and neutral $B\bar{B}$ pairs. Previous measurements are consistent with this assumption. [5,6,7,8] More precise measurement may result in renormalization of B decay branching fractions.

The $\Upsilon(5S)$ was discovered by measuring the total hadronic cross-section above $\Upsilon(4S)$ as a function of energy at CESR. [1,2] It is massive enough to produce $B_s^{(*)}\bar{B}_s^{(*)}$ pairs. With limited data samples, experiments failed to clearly show the level of B_s production at the $\Upsilon(5S)$.

In this paper I summarize recent studies from BaBar and CLEO on these issues. The results on $\mathcal{B}(\Upsilon(4S) \to B^0\bar{B}^0)$ from BaBar and B_s from CLEO are preliminary.

2 Evidence of B_s in $\Upsilon(5S)$ at CLEO

The $\Upsilon(5S)$ was discovered at CESR. [1,2] Its mass was measured to be (10.865 ± 0.008) GeV. It can decay into $B^{(*)}\bar{B}^{(*)}(\pi)$ modes, more channels than the $\Upsilon(4S)$ due to its heavier mass. It is massive enough even to produce $B_s^{(*)}\bar{B}_s^{(*)}$ pairs. Potential models predict about 1/3 of $\Upsilon(5S)$ produces $B_s^{(*)}\bar{B}_s^{(*)}$ pair. [9] The $B_s^*\bar{B}_s^*$ mode is the largest. The experiments, however, failed to reveal if B_s mesons were produced in about 0.1 fb^{-1} data.

The CLEO III detector has recently recorded 0.42 fb^{-1} of e^+e^- annihilation data at the $\Upsilon(5S)$ resonance. Using this data sample they search for evidence of B_s in both inclusive and exclusive modes. [10]

Most of D_s production in B_s decay is analogous to D's in B decay. CLEO estimates $\mathcal{B}(\bar{B}_s \to D_sX) = (92 \pm 11)\%$, whereas the measurement of $\mathcal{B}(\bar{B} \to D_sX) = (10.5 \pm 2.6)\%$, which is the average of B^+ and B^0. The distinct D_s production rates can be used to unfold the production rate of B_s in $\Upsilon(5S)$ decays.

CLEO reconstructs D_s in the $D_s \to \phi\pi^+, \phi \to K^+K^-$ mode from $\Upsilon(5S)$, $\Upsilon(4S)$ and continuum data. The reconstruction efficiency is about 30%. The D_s yields as a function of x equal to the D_s momentum divided by the beam energy for $\Upsilon(4S)$ and $\Upsilon(5S)$ data are shown in Fig. 1. The contribution from $e^+e^- \to q\bar{q}$ events is subtracted, the reconstruction efficiency is applied, but there is no correction for D_s branching ratios. The production of D_s from $\Upsilon(5S)$ is significantly larger than that from $\Upsilon(4S)$.

Using $\mathcal{B}(D_s \to \phi\pi^+) = (3.6 \pm 0.9)\%$,

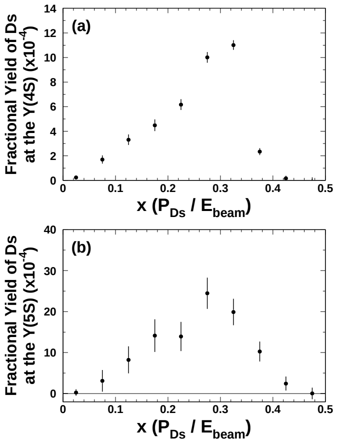

Figure 1. The D_s fractional yields vs x from (a)the $\Upsilon(4S)$ and (b)the $\Upsilon(5S)$ decays by CLEO, where the continuum contribution is subtracted.

CLEO finds

$$\begin{aligned}\mathcal{B}(\Upsilon(4S)\to D_sX)\ &= (22.3\pm0.7\pm5.7)\%,\\ \mathcal{B}(\Upsilon(5S)\to D_sX) &= (55.0\pm5.2\pm17.8)\%,\end{aligned}$$

where the systematic error is dominated by D_s decay branching ratio. From these numbers CLEO finds

$$\mathcal{B}(\Upsilon(5S)\to B_s^{(*)}\bar{B}_s^{(*)}) = (21\pm3\pm9)\%.$$

This is the first evidence of B_s production at $\Upsilon(5S)$. The rate agrees with theoretical expectations, which have a large range.

CLEO also looks for B_s in two groups of exclusive modes: $\bar{B}_s \to J/\psi\ \phi/\eta'/\eta$ and $\bar{B}_s \to D_s^{(*)}\ \pi^-/\rho^-$. The M_{bc} vs ΔE plots are shown in Fig. 2, where the beam energy constraint mass and energy difference are defined as

$$\begin{aligned}M_{bc} &= \sqrt{E_{beam}^2 - P_{candidate}^2},\\ \Delta E\ &= E_{beam} - E_{candidate}.\end{aligned}\qquad(1)$$

In the signal boxes 2 and 8 candidates for the two groups respectively are found.

The B_s from $\Upsilon(5S)$ decays can be produced via three different channels: $\Upsilon(5S)\to B_s\bar{B}_s, B_s\bar{B}_s^*, B_s^*\bar{B}_s^*$, and one expects that $\mathcal{B}(B_s^*\to B_s\gamma)\sim 100\%$. The energy of B_s candidates produced through these three modes are not the same due to available kinetic energy and Lorentz boost, resulting in 3 distinct signal regions as indicated in the plot. The rightmost box where the candidates are found corresponds to the $B_s^*\bar{B}_s^*$ mode. The large signal of $B_s^*\bar{B}_s^*$ with respect to the other modes is consistent with theoretical expectation.

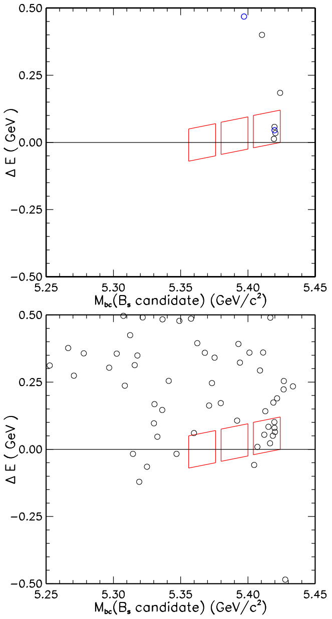

Figure 2. The M_{bc} vs ΔE distributions for (top) $\bar{B}_s \to J/\psi\ \phi/\eta'/\eta$ and (bottom) $\bar{B}_s \to D_s^{(*)}\ \pi^-/\rho^-$ modes. The three signal boxes from left to right correspond to $\Upsilon(5S)\to B_s\bar{B}_s, B_s\bar{B}_s^*, B_s^*\bar{B}_s^*$ channels.

3 Measurement of $\Upsilon(4S)$ parameters

The $\Upsilon(4S)$ is the lowest $b\bar{b}$ state above open bottom threshold. The full width of $\Upsilon(4S)$, Γ_{tot} is thus much larger than that of lower Υ states, which allows direct measurement of its value at e^+e^- collider. The mass, total width and e^+e^- partial width Γ_{ee} had been previously measured by CLEO, CUSB and ARGUS. [1,2,3,4] The values have relatively large uncertainty. Different measurements show substantial variation. Improved measurements are necessary.

The BaBar detector is designed to operate at the SLAC PEP-II asymmetric-energy B factory. The experiment scanned the e^+e^- system at center of mass energy $\sqrt{s}$ around the mass of $\Upsilon(4S)$, 10.58 GeV. [11]

The $\Upsilon(4S)$ resonance parameters can be determined from the fit of visible hadronic cross-section distribution to a so called line-shape function. To the first order, BaBar uses relativistic Breit-Wigner function for the production cross section of $e^+e^- \to \Upsilon(4S) \to B\bar{B}$

$$\sigma_0(s) = 12\pi \frac{\Gamma^0_{ee}\Gamma_{tot}(s)}{(s-M^2)^2 + M^2\Gamma^2_{tot}(s)}. \quad (2)$$

The electric partial width Γ^0_{ee} is taken as constant, and the total width $\Gamma_{tot}(s)$ is energy dependent. The function is further modified by radiative corrections calculable numerically, and the beam energy spread. BaBar did one scan around $\Upsilon(3S)$ to determine the energy spread as well as energy calibration. The visible hadronic cross-section also includes contributions from $e^+e^- \to q\bar{q}$ continuum events and other processes which are not totally eliminated but suppressed. This is modeled in the fit. The integrated luminosity is measured using $e^+e^- \to \mu^+\mu^-$ process.

BaBar fit three cross section distributions simultaneously. The parameters of $\Upsilon(4S)$ are measured to be:

$$\begin{aligned}\Gamma_{tot} &= (20.7 \pm 1.6 \pm 2.5)\ \text{MeV},\\ \Gamma_{ee} &= (0.321 \pm 0.017 \pm 0.029)\ \text{keV},\\ M &= (10579.3 \pm 0.4 \pm 1.2)\ \text{MeV}/c^2,\end{aligned}$$

where the uncertainty of energy spread, peak cross section, long term drift of energy scale, model uncertainty and other sources are accounted for in the systematic errors.

4 Measurement of $\mathcal{B}(\Upsilon(4S) \to B^0\bar{B}^0)$

The $\Upsilon(4S)$ decays into B^+B^- and $B^0\bar{B}^0$ modes. It is the most suitable environment to study B physics. Many B branching fractions had been measured from $\Upsilon(4S)$ data. Most of the measurements, however, based on the assumption of equal production rates of the charged and neutral $B\bar{B}$ pairs. Theoretic models predict that the ratio of the charged pair production over neutral one ranges from 1.03 to 1.25. [12] Previous measurements are consistent to 1 within error. [5,6,7,8] A non-unit value of the ratio results in renormalization of the B decay branching fractions and contributes to our understanding of isospin violation in B decays.

With a data sample of about 80 fb^{-1} collected at $\Upsilon(4S)$ BaBar measured $\mathcal{B}(\Upsilon(4S) \to B^0\bar{B}^0)$. [13] The neutral mode is tagged with $\bar{B}^0 \to D^{*+}l^-\nu$ decay. The sample of events in which at least one $\bar{B}^0 \to D^{*+}l^-\nu$ candidate is found is labeled as "single-tag sample", N_s. The subset of "single-tag sample" where two candidates are found on both B^0 and $\bar{B}^0$ sides is labeled as the "double-tag sample", N_d. We have

$$\begin{aligned}N_s &= 2N_{B\bar{B}}f_{00}\epsilon_s\mathcal{B}(\bar{B}^0 \to D^{*+}l^-\nu),\\ N_d &= N_{B\bar{B}}f_{00}\epsilon_d[\mathcal{B}(\bar{B}^0 \to D^{*+}l^-\nu)]^2, \quad (3)\end{aligned}$$

where total number of $B\bar{B}$ events $N_{B\bar{B}} = (88726 \pm 23) \times 10^3$, $f_{00} = \mathcal{B}(\Upsilon(4S) \to B^0\bar{B}^0)$, and ϵ_s and ϵ_d are the corresponding reconstruction efficiencies. The double-tag reconstruction efficiency $\epsilon_d = \epsilon_s^2$ because the efficiencies are not correlated. The ratio f_{00} is thus given by

$$f_{00} = \frac{N_s^2}{4N_dN_{B\bar{B}}}. \quad (4)$$

The measurement uses partial reconstruction of $\bar{B}^0 \to D^{*+}l^-\nu$, where only the lepton and the slow π^+ from $D^{*+} \to D^0\pi^+$ decay are observed. This technique was first proposed by ARGUS [14] and has been used in the CLEO measurement. [7] As there is very little kinematic energy released in D^{*+} decay, momenta of D^0 and π^+ are correlated in $\Upsilon(4S)$ rest frame. Thus D^{*+} momentum can be parameterized with the π^+ momentum. The neutrino invariant mass squared is

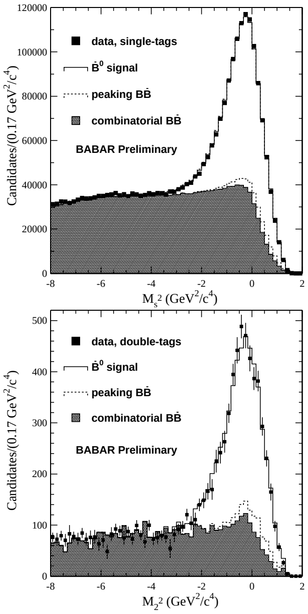

Figure 3. The $\mathcal{M}^2$ distributions of single-tag (top) and double-tag (bottom) samples by BaBar. Lines, and hatched area are fit to PDFs of various sources.

calculated as:

$$\mathcal{M}^2 \equiv (E_{beam} - E_{D^*} - E_l)^2 - (\vec{P}_{D^*} + \vec{P}_l)^2. \quad (5)$$

The $\mathcal{M}^2$ distributions for single and double tag samples are shown in Fig. 3, where contribution from $e^+e^- \to q\bar{q}$ is subtracted.

To determine N_s and N_d, binned χ^2 fits are performed to the two histograms. The probability density functions(PDF) of signal and backgrounds are determined from MC simulation. The number of signals are $N_s = 786300 \pm 2000$ and $N_d = 3560 \pm 80$. The neutral branching rate, $f_{00} = 0.486 \pm 0.010 \pm 0.09$, is still consistent with equal production rates of the charged and neutral pairs.

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