1 Introduction

The Υ(4S) is the lowest $b\bar{b}$ resonance above $BB$ 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. 2,3,4 The Υ(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 Υ(4S) data. Most of them, however, based on the assumption of equal production rates of the charged and neutral $BB$ 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 Υ(5S) was discovered by measuring the total hadronic cross-section above Υ(4S) as a function of energy at CESR. 1,2 It is massive enough to produce $B^*_s(\ast)B_s(\ast)$ pairs. With limited data samples, experiments failed to clearly show the level of $B_s$ production at the Υ(5S).

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

2 Evidence of $B_s$ in Υ(5S) at CLEO

The Υ(5S) was discovered at CESR. 1,2 Its mass was measured to be $(10.865 \pm 0.008)$ GeV. It can decay into $B^*_s(\ast)B_s(\ast)(\pi)$ modes, more channels than the Υ(4S) due to its heavier mass. It is massive enough even to produce $B^*_s(\ast)B^*_s(\ast)$ pairs. Potential models predict about $1/3$ of Υ(5S) produces $B^*_s(\ast)B^*_s(\ast)$ pair. 9 The $B^*_sB^*_s$ 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 Υ(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 $B(\bar{B}_s \rightarrow D_sX) = (92 \pm 11)\%$, whereas the measurement of $B(B \rightarrow D_sX) = (10.5 \pm 2.6)\%$, 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 Υ(5S) decays.

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

Using $B(D_s \rightarrow \phi\pi^+) = (3.6 \pm 0.9)\%$,
CLEO finds

\[ B(\Upsilon(4S) \to D_s X) = (22.3 \pm 0.7 \pm 5.7)\%, \]
\[ B(\Upsilon(5S) \to D_s X) = (55.0 \pm 5.2 \pm 17.8)\%, \]

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

\[ B(\Upsilon(5S) \to B_s(\ast)\bar{B}_s(\ast)) = (21 \pm 3 \pm 9)\%. \]

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: \( B_s \to J/\psi \phi/\eta'/\eta \) and \( \bar{B}_s \to D_s^{(\ast)} \pi^-/\rho^- \). The \( M_{bc} \) vs \( \Delta E \) plots are shown in Fig. 2, where the beam energy constraint mass and energy difference are defined as

\[
M_{bc} = \sqrt{E^2_{\text{beam}} - P^2_{\text{candidate}}}, \\
\Delta E = E_{\text{beam}} - E_{\text{candidate}}. \tag{1}
\]

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 \( B(B_s^{(\ast)} \to B_s(\gamma)) \sim 100\% \). 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.

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

The \( \Upsilon(4S) \) is the lowest \( b\bar{b} \) state above open bottom threshold. The full width of \( \Upsilon(4S) \), \( \Gamma_{\text{tot}} \), is thus much larger than that of lower \( \Upsilon \) states, which allows direct measurement of its value at \( e^+e^- \) collider. The mass, total width and \( e^+e^- \) partial width \( \Gamma_{ee} \) 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 mea-

![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.](image1)

![Figure 2. The \( M_{bc} \) vs \( \Delta E \) distributions for (top) \( B_s \to J/\psi \phi/\eta'/\eta \) and (bottom) \( B_s \to D_s^{(\ast)} \pi^-/\rho^- \) 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.](image2)
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.  

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 $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$

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

The electric partial width $\Gamma^0_{ee}$ 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 $e^+e^- \rightarrow q\bar{q}$ continuum events and other processes which are not totally eliminated but suppressed. This is modeled in the fit. The integrated luminosity is measured using $e^+e^- \rightarrow \mu^+\mu^-$ process.

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

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

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 $B(\Upsilon(4S) \rightarrow B^0\bar{B}^0)$

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.  

Previous measurements are consistent to 1 within error. 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 $B(\Upsilon(4S) \rightarrow B^0\bar{B}^0)$. The neutral mode is tagged with $B^0 \rightarrow D^{*+}l^-\nu$ decay. The sample of events in which at least one $B^0 \rightarrow D^{*+}l^-\nu$ 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

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

where total number of $B\bar{B}$ events $N_{B\bar{B}} = (88726 \pm 23) \times 10^3$, $f_{00} = B(\Upsilon(4S) \rightarrow B^0\bar{B}^0)$, and $\epsilon_s$ and $\epsilon_d$ 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

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

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

\[ M^2 \equiv (E_{\text{beam}} - E_{D^*} - E_l)^2 - (\vec{P}_{D^*} + \vec{P}_l)^2. \]  

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

To determine \( N_s \) and \( N_d \), binned \( \chi^2 \) 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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References

1. D. Besson et al. [CLEO Collaboration], Phys. Rev. Lett. 54, 381 (1985).
2. D. M. J. Lovelock et al., Phys. Rev. Lett. 54, 377 (1985).
3. C. Bebek et al. [CLEO Collaboration], Phys. Rev. D 36, 1289 (1987).
4. H. Albrecht et al. [ARGUS Collaboration], Z. Phys. C 65, 619 (1995).
5. J. P. Alexander et al. [CLEO Collaboration], Phys. Rev. Lett. 86, 2737 (2001).
6. B. Aubert et al. [BABAR Collaboration], Phys. Rev. D 65, 032001 (2002).
7. S. B. Athar et al. [CLEO Collaboration], Phys. Rev. D 66, 052003 (2002).
8. B. Aubert et al. [BABAR Collaboration], Phys. Rev. D 69, 071101 (2004).
9. S. Ono, A. I. Sanda and N. A. Törnqvist, Phys. Rev. Lett 55, 2938 (1985); N. A. Törnqvist, Phys. Rev. Lett 53, 878 (1984); S. Ono and N. A. Törnqvist, Phys. Rev. D 34, 186 (1986).
10. D. Asner et al. [CLEO Collaboration], [arXiv:hep-ex/0408070].
11. B. Aubert et al. [BABAR Collaboration], [arXiv:hep-ex/0405025].
12. R. Kaiser, A. V. Manohar, and T. Mehen, Phys. Rev. Lett. 90, 142001 (2003); M. B. Voloshin, Mod. Phys. Lett. A 18, 1783 (2003); N. Byers and E. Eichten, Phys. Rev. D 42, 3885 (1990); G. P. Lepage, Phys. Rev. D 42, 3251 (1990); D. Atwood and W. J. Marciano, Phys. Rev. D 41, 1736 (1990); E. Eichten, K. Gottfried, T. Kinoshita, and K. D. Lane, Phys. Rev. D 21, 203 (1980).
13. B. Aubert et al. [BABAR Collaboration], [arXiv:hep-ex/0408022].
14. H. Albrecht et al. [ARGUS Collaboration], Phys. Lett. B 324, 249 (1994).