PROCEEDINGS OF SCIENCE

Belle II Early Bottomonia Physics Program

Dave Besson[*†]
MEPhI, Moscow, 115409, Russia, & KU, Lawrence, KS 66045, USA
E-mail: zedlam@ku.edu

The Belle-II experiment will begin ramping up data collection at the SuperKEKB accelerator facility in Tsukuba, Japan, within the next 1-2 years. Projecting peak luminosities approximately 40 times higher than KEKB, Belle-II is expected to accumulate 50 ab^{-1} by 2024, or a roughly 50-fold increase over Belle-I, enabling higher statistics investigation of a wide range of physics, including bottomonium spectroscopy. Additional scientific reach is afforded by the improved charged particle tracking and refined particle ID capabilities of Belle-II over Belle-I.

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[*]Speaker.
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1. Introduction

The Belle detector[1] has accumulated the world's largest data sample of electron-positron annihilations in the $\sim$10 GeV center-of-mass range. Although the bulk of the Belle data sample is collected at the Υ(4S) center-of-mass energy in order to study weak decays of B-mesons, and, in particular, make precision measurements of CP-violation in the bottom sector, there has also been considerable data accumulated on the narrow Υ(1S) and Υ(2S) resonances, corresponding to 5.7 fb^{-1} and 24.7 fb^{-1} of luminosity on these lowest two J(PC)=1(- -) resonances, respectively, and 1.8 fb^{-1} and 1.7 fb^{-1} on the continua just below the Υ(1S) and Υ(2S) resonances, respectively. These data samples correspond to approximately $(101.5 \pm 1.6) \times 10^6$ resonant Υ(1S) and $(157.8 \pm 3.6) \times 10^6$ resonant Υ(2S) decays, offering enormous statistical improvements over the previous CLEO-III data sample, by factors of approximately 5 and 15, respectively.

2. Belle-II accelerator and beam

The KEKB accelerator will, relative to KEK, have higher beam currents, mostly by compressing the beam to a width of O(several hundred atomic layers). This will result in an enormous increase in luminosity; currently a 40-fold increase in $\mathscr{L}$ $(2.11 \times 10^{34}/cm^2s \to 80 \times 10^{34}/cm^2s)$ is anticipated, such that after reaching the design luminosity in $\sim$2022, we expect 50/ab delivered in the space of two years. The accelerator will also have slightly more energy reach than KEK, reaching ECM^{max}=11.24 GeV ($\Lambda_b\overline{\Lambda}_b$ threshold)

3. Physics Interest

3.1 The XYZ affair

Among the most interesting results to emerge from both the Babar and Belle experiments within the last 10-15 years has been the discovery of a rich, and unexpected spectroscopy of "charmonium-like" states, with masses in the range 3-4.5 GeV[2, 3, 4, 5]. These states, labeled "X", "Y", or "Z" are observed typically in one of four ways (charge conjugates are implicit): a) direct production in B-decay, e.g., $B \to XK$, analogous to $B \to J/\psi K$, b) direct two-photon production, which selects parity and charge conjugation (++) states, c) correlated production, in association with a charmonium state: $e^+e^- \to J/\psi(D\overline{D})$, where the D$\bar{\text{D}}$ invariant mass distribution near threshold often shows a signficant excess above background, or d) direct observation in e^+e^- production, in association with an initial state radiation (ISR) photon, e.g., $e^+e^-\gamma_{ISR} \to Y(4660)$; $Y \to \Lambda_c\overline{\Lambda}_c$. Processes a), c) and d) also permit an inference of (PC) quantum numbers based on either the associated produced particle, or the decay products (D$\bar{\text{D}}$ vs. D$\bar{\text{D}}$*, e.g.). The spectroscopy of these charmonium-like states, which may have a parallel hierarchy of bottomonium-like states (the Z_b states are now well-established[6]) is shown in Figure 1.

Running Plan Proposal

Since the existing Υ(4S) and Υ(5S) Belle-I samples are already satisfactorily large, the biggest science gains are likely to be obtained by running at the Υ(3S) resonance, for which Belle-I has a sample of only 3fb^{-1}) and the Υ(6S) resonance (M=11020 MeV; Belle-I sample of 6fb^{-1}). Given

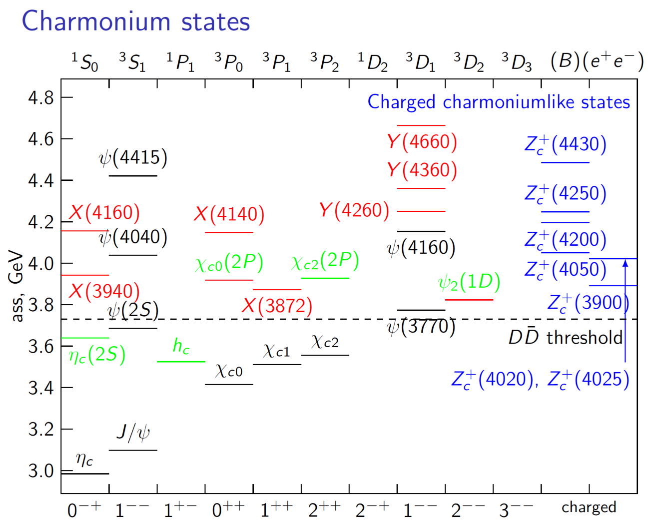

Figure 1: Spectroscopy of particles in the charmonium mass regime. Black represents 'conventional' known charmonium states; green are 'conventional' states which have not yet conclusively been identified, but may have already been observed (e.g., the X(3915) may be the χ_{c0}(2P) and the X(3823) may be the ψ_2(1D)). X, Y, and Z states are as shown.

that BaBar has 30fb^{-1} Υ(3S) "in the can", we would like to quickly obtain $\sim$200fb^{-1} samples on both these resonances.

In addition to WXZ, 'conventional' Υ(6S) spectroscopic studies follow patterns observed already in Υ(4S) and Υ(5S) transitions, including likely final states:

- $\pi\pi\Upsilon(\mathrm{n}^3D_J)$, $\pi\pi h_b$(3P) & $\pi\pi\Upsilon$(2D) (discovery)
- $\eta\Upsilon$(mS) & $\eta\Upsilon(\mathrm{n}^3D_J)$; $\eta\Upsilon$(2D) (discovery)
- $KK\Upsilon$(mS)
- $\omega\chi_b$(1P)

Also at ECM=11020 MeV, we can access the physics of excited $B(^*)$ and $B_s(^*)$ states, make precision measurements of the color factor $R = \frac{\sigma(e^+e^-\to q\bar{q})}{\sigma(e^+e^-\to\mu^+\mu^-)}$, and also measure the B_s decay constant, f_{Bs} from the annihilation channel: $B_s \to \mu^+\mu^-$. The latter represents a stringent test of lattice gauge calculations, as it depends critically on the wave-function overlap between the bottom and strange quarks.

Υ(3S) physics

Running on the Υ(3S), below open B$\bar{\mathrm{B}}$ threshold, will hopefully not only resolve the D-states (which are also accessible in four-photon transitions in which there is one unit of ΔJ at each step: $S \to P \to D \to P' \to S'$), but is, of course, one of the preferred modes for finding either vector or scalar exotica: Υ(3S)$\to$ $\pi\pi\Upsilon$(1S); Υ(1S)$\to$"nothing" (V), or Υ(1S)$\to$ γ+"nothing" (Axial Vector coupling). Of course, dark photon (A') exotica, e.g., may be probed at any center-of-mass energy: $e^+e^- \to \gamma A'$; $A' \to$"invisible", which is possible via mixing with SM γ. Depending on the nature of the mixing, we may also fortuitously observe $A' \to e^+e^-$. One caution, however - high efficiency for exotica sensitivity often requires **loose** trigger configurations, as they may result in either single-photon and/or low-momentum charged track final states.

We can guesstimate some expected $\Upsilon(3S)$ final state yields:

- $\gamma\eta_b$(1S,2S): if $\mathscr{B}\varepsilon$=2×10^{-4} $\Rightarrow$800/fb^{-1}
- $\pi^0 h_b$(1P); $h_b \to \gamma\eta_b$(1S): $\Rightarrow$400/fb^{-1}
- $\gamma\chi_{b0}$; $\chi_{b0} \to \eta\eta_b(1S)$(1S): assume latter $\mathscr{B} \sim 10^{-3}$; $\Rightarrow$10/fb^{-1}

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