Chapter 1

Motivation

$CP$ violation was discovered in 1964 in neutral kaon decays [1]. This phenomenon can be explained by a theory developed by Kobayashi and Maskawa [2]. According to this theory, the $CP$ violation can be explained if there are at least three generations of quarks. The bound states of $b\bar{b}$ quarks, the $\Upsilon(4S)$ was discovered [3] in 1977. After the discovery of bottom ($b$) quark, it was realized that the $CP$ violating asymmetries can be measured in certain decay modes of the $B$ meson [4]. $B$ meson decays are also an ideal place for extraction most of the Cabbibo-Kobayashi-Maskawa matrix elements. $B$ mesons can be produced through the process $e^+e^-\rightarrow \Upsilon(4S)\rightarrow B\bar{B}$.

There are many ways to measure $CP$ violation in $B$ meson system. The simple and easily accessible way is to measure time evolution asymmetry. Therefore precise measurement of the $B$ meson flight length is important. Successful experiments have been carried out for the study of $B$ meson, ARGUS at DORIS and CLEO at CESR. However their progress in $CP$ violation study was limited by two obstacles. First, most of the $CP$ channels have small branching ratios of about $10^{-4}$ $\sim$ $10^{-6}$, therefore, a very high luminosity $e^+e^-$ machine ($10^{33} - 10^{34} \text{ cm}^{-2}\text{s}^{-1}$) is needed. Furthermore, in the process $e^+e^-\rightarrow \Upsilon(4S)\rightarrow B\bar{B}$, $B\bar{B}$ pairs are produced almost at rest in the $\Upsilon(4S)$ rest frame because $\Upsilon(4S)$ mass is just above the $B\bar{B}$ threshold. Hence it is difficult to measure the $B$ meson flight length. Therefore asymmetric $e^+e^-$ collider with sufficient boost for $B$ meson is an ideal machine where $B$ mesons travel enough distance and the time evolution asymmetry can be measured.

The main motivation of Belle at KEKB is to study this interesting phenomenon. Recently, Belle observed $CP$ violation in the neutral $B$ meson system [5]. Besides $CP$ violation, there are also other interesting phenomena which can be studied at the high luminosity collider. One of them is the production mechanism of prompt charmonia (of non $B$ meson
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decay origin) which is not well understood.

Production of prompt charmonia provides an interesting ground to study the interplay between perturbative Quantum Chromodynamics (QCD) and non-perturbative effects. It has been the subject of considerable interest following results on $\psi(2S)$ production at the Tevatron [6] which revealed a dramatic discrepancy between the data and predictions of the existing quarkonium production models. In the theory, progress has been made on factorization between the short and long distance effects which has led to the formulation of a more consistent and rigorous calculation framework (NRQCD: non-relativistic QCD) [7] than the existing color-singlet model [8]. This effective field theory postulates an additional production mechanism of heavy quarkonia, color-octet mechanism [9]. Although NRQCD calculations successfully described charmonia production cross sections at the Tevatron, they fall short in predicting the observed polarization phenomena [10]. Other available data on charmonia production in $e^+e^-$ collisions at LEP [11] can be described by color-evaporation model, and particularly in $ep$ collisions at HERA [12] do not require the new color-octet mechanism.

Production of prompt charmonia in $e^+e^-$ collisions at energies around the $\Upsilon(4S)$ resonance is expected to be dominated by the color-singlet mechanism [13], although dramatic effects from the color-octet mechanism are also predicted to exist at the end-point of the charmonium momentum spectrum [13, 14, 15]. Predictions of charmonia production cross sections, momentum, polarizations and production angle distributions suffer from large uncertainties because their calculation involve non-perturbative factors which have to be determined from experimental data. Therefore measurements of prompt charmonia production in $e^+e^-$ collisions at low energies, besides being important tests of the models, can provide estimates of some of these uncertain factors. Studies of the production mechanism of charmonia are also important for understanding $B$ meson decays into final states involving these mesons.

Chapter 2 presents a theoretical overview of charmonium production, a brief description of NRQCD and its predictions for direct $J/\psi$ production in $e^+e^-$ collisions at $\sqrt{s} \approx 10.6$ GeV. Chapter 3 describes the detector and its performance as well as the accelerator. Chapter 4 describes the $K_L$ and muon detector's hardware and performance, with which I am heavily involved. Chapter 5 describes the analysis procedure and the results. In Chapter 6, we summarize the results and compare them to the theory predictions.