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The SuperBelle Project

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Abstract

To search for deviations from the Standard Model in flavour physics and to distinguish between different new physics models by a close examination of the flavour structure, we plan a major upgrade of the KEKB electron-positron collider (SuperKEKB). The design luminosity of 8x10^{35} $cm^{-2}s^{-1}$, which is 50 times larger than the peak luminosity achieved with KEKB, will allow studies of rare processes in B, D and tau decays to be performed with unprecedented precision. The current Belle detector will be upgraded to take full advantage of the high luminosity of SuperKEKB. Despite substantial beam backgrounds, the SuperBelle detector should, at the end, perform at least as well as the present Belle detector.

Key words: B factory, luminosity frontier, Standard Model, rare B decays
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1. Introduction

Comprehensive studies of B meson decays in the clean e^+e^- environment provide an ideal tool to distinguish between different new physics models by a close examination of the flavor structure. Such studies are complementary to the experiments at the Large Hadron Collider (LHC) or the future linear collider [1–3]. If, e.g., supersymmetric partners of elementary particles are found at LHC, the pattern of supersymmetry breaking can be investigated at a Super B factory.

The past experiments at asymmetric e^+e^- B factories KEKB and PEPII have yielded important results. The main task of B factories was to measure CP violation in the system of B mesons, i.e. perform various measurements of complex elements of the CKM matrix. The obtained results are in good agreement with the Kobayashi Maskawa model of CP violation. The other important results are the observation of direct CP violation in

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B decays, measurements of rare decay modes (e.g., $B \to \tau\nu$, $B \to D\tau\nu$), and observation of D meson mixing. In addition, many new hadronic states have been observed. The Belle experiment, operating at the KEKB e^+e^- collider, proved its ability to measure a number of decay modes of the B meson and to extract many interesting observables. By the 2008 summer shutdown, Belle had accumulated data with an integrated luminosity of 800 fb^{-1} at the $\Upsilon(4S)$ resonance, corresponding to 840 million $B\bar{B}$ pairs.

However, many questions still remain unanswered. Are there new CP-violating phases? Are there new right handed currents? Are there effects from new Higgs fields? Are there new flavor violations? Is there a new flavor symmetry to explain the CKM hierarchy? The answers are only possible with precision measurements, for which a much larger sample of B mesons is required. A factor of 50 improvement would greatly enhance the possibility to discover new physics or at least to constrain new physics models. The physics motivation does not dependent on the LHC results. If LHC finds physics outside the Standard Model, precision measurements in flavour physics are compulsory. If no deviations from the Standard Model are found, a high statistics sample of B and τ decays would be a unique way to search for the TeV scale physics.

This paper presents one possible scenario of enlarging the existing sample of B mesons by upgrading the KEKB collider and the Belle spectrometer. Since the Letter of Intent [2], many R&D studies have been performed on the fundamental performance of the sensors, material structure and geometry of the collider and the detector. In what follows, the design of both will be summarized [4].

2. The collider

The SuperKEKB collider will replace the current KEKB collider. The luminosity will be increased by increasing the number of bunches and the beam currents, and by optimizing the beam optics in the interaction region. In the first phase the luminosity will be increased by a factor of 10. This will be realized by installing the crab cavities in front and behind the interaction region, by a redesign of the interaction region, by increasing the beam currents in the machine and by installing new beam pipes with an ante-chamber. A further increase of the luminosity to 8 $\times 10^{35}$ $\text{cm}^{-2}\text{s}^{-1}$ is planned by installing a damping ring for positrons and by increasing the beam currents. A total integrated luminosity of 50 ab^{-1} in 8 years of operation will enable us to collect a 50 times larger sample of $B\bar{B}$ and $\tau\bar{\tau}$ pairs as compared to the present Belle data.

3. The Detector

Some of the accelerator changes will increase the level of the beam-induced background (scattering of the beam on residual gas, Touschek scattering, synchrotron radiation, back scattering of synchrotron radiation and the electron-positron interactions at the interaction point) by about a factor of 20. The current Belle detector [5] will be upgraded to operate in such an environment that will result in much higher occupancies of the detectors. Due to up to ten times higher event rate, also the trigger, the data acquisition and the computing facilities will have to be be redesigned.

The detector performance should be at least as good as the performance of the current Belle spectrometer. In addition, it should provide low momentum μ identification to

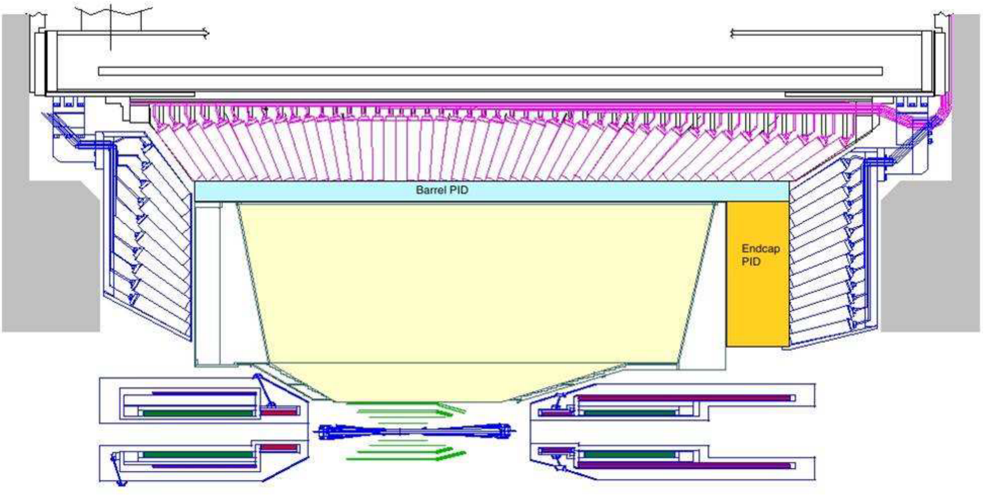

Fig. 1. Cross section of the inner part of the SuperBelle spectrometer.

increase the $s \to \mu\mu$ reconstruction efficiency. To allow for neutrino reconstruction from the missing energy and momentum, the detector should be hermetic. The SuperBelle detector will be a general purpose spectrometer inside a solenoid with 1.5 T magnetic field. It will consist of a vertex detector that measures the decay-vertex positions of long-lived beauty, charmed and strange hadrons, a central tracker that measures the momentum and dE/dx of charged tracks, a super conducting solenoid that provides a strong and uniform magnetic field, barrel and end-cap calorimeters that measure the energy and direction of photons, electrons and neutral pions, barrel and end-cap particle identification devices that distinguish kaons from pions and muons, and, a K_L/μ detector that is instrumented in the flux return yoke. A fast and reliable trigger and data acquisition system will record the signals from detectors. The computing and data storage will be distributed globally.

3.1. *Vertex detector*

The vertex detector is indispensable for precise determination of the vertex position of the interaction products. It plays an important role in reducing the track reconstruction errors, which is beneficial in many analyses. The foreseen detector will be built around a 1.5 cm beam pipe and and will consist of 6 layers of double-sided silicon strip sensors. This will enable a more robust particle tracking and higher K_S reconstruction efficiency compared to the present 4 layer design of the Belle vertex detector. To reduce the occupancy coming from the beam background, the VA1TA readout chips will be replaced with APV25 [2]. A pipeline chip readout will be implemented. To increase the vertex resolution, the sensors of the innermost layer might be later replaced with pixel sensors and moved closer to a distance of 1 cm from the beam-pipe.

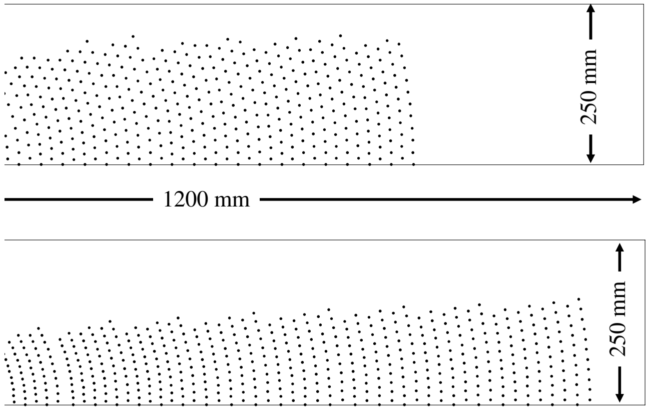

Fig. 2. Configurations of CDC sense wires in the present (top) and the upgraded (bottom) CDC.

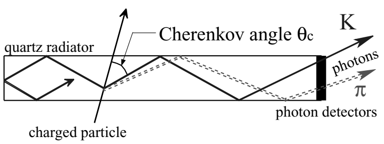

Fig. 3. Principle of measurement in the Time-Of-Propagation counter.

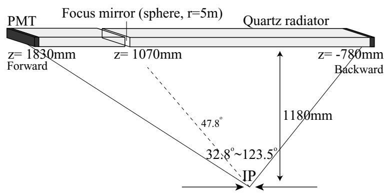

Fig. 4. TOP counter quartz bar.

3.2. *Central Drift Chamber*

The present Central Drift Chamber (CDC) has been working well since the beginning of the experiment. It is used to reconstruct charged tracks with good momentum resolution due to its low mass, and hence reduced multiple scattering. It also provides particle identification based on the characteristic energy loss (dE/dx). In addition, it provides a powerful trigger signal with a latency of a few μs.

To avoid the severe beam background, the inner radius of the central drift chamber will be increased and the volume replaced by two layers of the vertex detector (Fig. 2). The outer radius of the chamber will be larger because the barrel part of the particle identification device will be thinner. The cell size of the inner layers will be smaller (change from 12 mm to 8 mm) to reduce the occupancy. As a result, by using more stereo layers three-dimensional track reconstruction will be improved.

New readout electronics will be used to reduce the dead time. ASIC chips with a shorter shaping time will be used for signal amplification, shaping, and discrimination. The drift time and the pulse height will be measured separately by using pipelined TDCs and slow FADCs.

3.3. *Particle identification system*

To extend the K/π separation capability up to momenta of 4 GeV/c, to cope with the higher background, to make the system more homogenious and to reduce the amount of material in front of the calorimeter, the currently installed Aerogel threshold Cherenkov counters and the time-of-flight system will be replaced by two Cherenkov ring imaging detectors: a time-of-propagation (TOP) counter in the barrel region, and a proximity focusing Cherenkov ring imaging counter with aerogel radiators (ARICH) in the forward end-cap region.

In the Time-Of-Propagation (TOP) counter (Fig. 4) the time of propagation of the Cherenkov photons internally reflected inside a quartz radiator is measured (Fig. 3). The Cherenkov image is reconstructed from the two-dimensional information provided by measuring one of the coordinates (x) and precise timing, which is determined by position sensitive micro-channel plate (MCP) photomultipliers at the end surfaces of the quartz bar. The array of 18, 2 cm thick quartz bars of 40 cm width will surround the outer wall of the Central Drift Chamber. In order to reduce the possible degradation of resolution due to chromatic dispersion, each radiator bar in one module is subdivided into one 185 cm and one 75 cm long piece.

Due to limited space in the Belle end-cap, a proximity focusing RICH counter with aerogel radiator and expansion distance of 20 cm is foreseen [6]. To increase the separation capabilities, 3 layers of silica aerogels [7], each 10 mm thick, with different refractive indices between 1.045 and 1.055 will be used as Cherenkov radiators. Cherenkov photons will produce overlaping images on the photon detector surface, as shown in Fig. 5. The photon detector, sensitive to single photons and working in the high magnetic field of 1.5 T, will be chosen among three candidates, a hybrid avalanche photon detector (HAPD), MCP PMT or Geiger mode avalanche photo-diode. The excellent timing resolution of $\tilde{5}0$ ps of the MCP-PMT allows an additional time-of-flight measurement by using the Cherenkov photons from the entrance window of the MCP-PMT [7]. With this additional information one can positively identify kaons with momenta below the Cherenkov threshold in aerogel ($\approx$ 1.5 GeV/c).

3.4. *Electromagnetic Calorimeter*

The performance of the present electromagnetic calorimeter would be degraded due to an order of magnitude larger background resulting in fake clusters and pile-up of noise. The shaping time of the new front-end electronics will be shortened from 1 μs to 0.5 μs. In addition, waveform sampling with 2 MHz sampling frequency will be implemented. The signal amplitude and timing will be extracted in the on-board FPGA. Because of expected radiation damage in the most exposed parts of the end-caps, the present Thallium doped CsI crystals, with scintillation decay time constant of about 1 μs, will be replaced with pure CsI crystals with a fast time constant of 30 ns. The signal output will be read by fine-mesh photomultipliers with a small number of multiplication stages.

3.5. *K_L and μ detector*

The performance of the currently installed resistive plate counters (RPCs) will be degraded due to neutrons, which are the dominant background in the K_L and μ detectors.

In the barrel, the degradation of performance will be reduced by changing the gas mixture of the RPC's to Ar/C_4H_{10}/HFC134a/SF6 in proportion of 50/8/37/5 and by replacing the innermost RPC layer with a 4 cm thick passive polyethylene absorber.

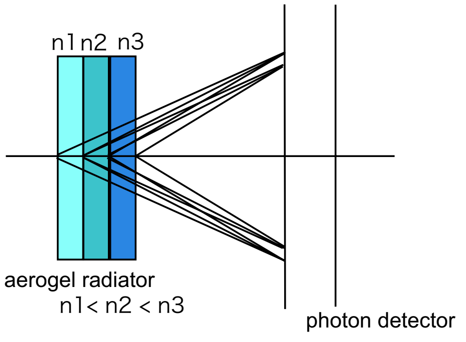

Fig. 5. Proximity focusing RICH with multiple layer of aerogel radiators.

In the end-caps, where the beam background effects are most disturbing, the RPCs will be replaced with scintillation counters with wave-length-shifting (WLS) fiber readout. Each super-layer consists of two independent and orthogonal planes of scintillator strips extruded from granulated polystyrene. The light will be read out by Geiger mode avalanche photo diodes at one edge of the strip.

4. Conclusions

B factories have proven to be an excellent tool for flavour physics. They have shown a reliable long term operation and were constantly improving their performance. With a major upgrade of the KEKB accelerator between 2009 and 2012, we plan to build a Super B factory, with luminosity up to 40 times higher than the current KEKB machine. Although the new spectrometer will be built by using parts of the Belle spectrometer, the SuperBelle is essentially a new project. Due to much larger backgrounds, most of the components of the existing spectrometer will have to be replaced. To perform the upgrade and for later operation of the spectrometer, a new collaboration has been formed. The first open meeting of the new collaboration has been held in KEK, Tsukuba, in December 2008; further meetings are planned in March and July 2009. By using the proposed spectrometer, we expect a new, exciting era of discoveries, complementary to LHC.

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