PROCEEDINGS OF SCIENCE

Super KEKB and Belle II: Status of the KEK Super B Factory

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The Belle detector at the KEKB electron-positron collider has collected approximately 800 million $\Upsilon(4S)$ events in its decade of operation. Many of the existing measurements have statistical uncertainties still higher than their systematics. More statistics would then bring a substantial improvement in the accuracy. However further increase of the luminosity at the same rate as now would not lead to significant reduction of uncertainties. The Japanese national accelerator laboratory KEK group has therefore started tu build Super-KEKB, an upgrade of KEKB to increase the luminosity by two orders of magnitude during a four-year shutdown, with an ultimate goal of $8 \times 10^{35}\text{cm}^{-2}\text{s}^{-1}$ luminosity. To exploit the increased luminosity, an upgrade of the Belle detector has to be built. A new international collaboration Belle II has being formed and started to design and construct a new detector in a full swing. The paper presents physics motivation, basic methods of the accelerator upgrade, as well as key improvements of the detector.

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PoS(HQL 2010)079

1. Introduction

The Standard Model (SM) – one of the most successful physics theories – describes elementary particles and their interactions. Studying processes with heavy quarks and leptons contributed significantly to the forming of SM, namely in the sector describing CP violation. Most of the experimental results from this area come from two B factories PEP-II at SLAC and KEKB at KEK. Here beams of e^+e^- collide with the unprecedented luminosity at the Υ resonance. 96 % of Υ created decay to $B\bar{B}$. Due to the asymmetry in the energy of electron and positron beams the $B\bar{B}$ system is boosted. This arrangement, in combination with precise vertex reconstruction, allows to register the decay time of the B's and to study time dependence of observed decays. Belle and BABAR, two detectors built at the KEKB and PEP-II, respectively, have accumulated 1500 fb^{-1}, corresponding to over 1 billion $B\bar{B}$ pairs. Some of the the principal achievements of the 2 experiments are listed here:

- discovery of CP violation in B system
- measurement of CKM matrix elements
- observation of new charmonium and charmonium-like states
- discovery of D^0 mixing
- many probes of New Physics

2. Prospects of the Super B Factory Physics Potential

Although the Standard Model has been very succesful in predictions and interpretations of current measurements, it has become clear that it cannot answer all questions posed. To resolve the remaining issues many new theories going beyond Standard Model (BSM) have been developped. These New Physics (NP) scenarios introduce new particles and processes. Tests of the NP processes in the existing data face the problem of still high statistical errors of crucial observables. Hence only new high statistics experiments would bring new insight into the field.

There are several complementary approaches to study the NP manifestation. Flavour experiments run at low energies have been always very instrumental in uncovering the phenomena of much higher energy scale. It is thus quite natural that 2 new B factories are planned, aiming at luminosity increased by almost 2 orders of magnitude. SuperB is planned to be built in Frascatti, while KEK started to construct SuperKEKB collider with Belle II detector. The status of the latter project will be described in this paper.

The SuperB factories will be able to perform a broad range of measurements: $B^{0(\pm)}$ meson decays to $B_s^{(*)}$ meson decays, charm physics, τ lepton physics, spectroscopy, and pure electroweak measurements. Let us detail here a few examples only.

$b \to s\bar{s}s$ **decays** There is a slight difference between $\sin 2\phi_1$ determined from the $B \to J/\psi K_S$ decays and the one measured in the $B^0 \to \phi K_S$. NP could explain some fraction of this difference, but it is impossible to draw any conclusions now, with the low precision achieved. However new vertex detectors and improved PID designed for the Belle II detector together with the higher beam instensity will bring substantial error reduction alowing us to find the matter of the difference.

$b \to s\gamma$ decays Radiative decays $b \to s\gamma$ are very sensitive to right-handed currents, not allowed by the SM. To study this, we will use the decay-time dependence of $B \to K_S\pi_0$ process. The improved Belle II vertex position resolution as well as increased K_S decay reconstruction efficiency will allow to detect potential NP contribution at 50 ab^{-1}.

$B \to \tau\nu_\tau$ decays While SM introduces a single neutral Higgs boson to explain the origin of masses, NP models propose several Higgs bosons, some of them charged. Existence of these additional particles would influence partial lepton decay width of B-mesons. The simulations indicate charged Higgs discovery potential above $\mathscr{L} > 50$ ab^{-1} at considerable part of the parameter space.

$B \to K\pi$ decays Although this process goes via the tree diagram, its probability is suppressed by the small value of the matrix element $|V_{ub}| \approx 4 \cdot 10^{-3}$. Hence NP contribution competes the SM one and could be determined from the CP asymmetries of individual $B \to K\pi$ combinations. $B \to K\pi$ measurements performed at $\mathscr{L} > 50$ ab^{-1} could sensitively test nature of these processes.

For further details the reader is referred to [1].

3. Accelerator Upgrade

The Super-B factory in Japan is designed as an upgrade of the existing KEKB collider operating since 1999 at the High Energy Accelerator Research Organization KEK in Tsukuba. It has been closed in 2010 after it reached world record luminosity of $\mathscr{L}_{\max} = 2.1 \times 10^{34}$cm^{-2}s^{-1} and brought an integrated luminosity of 1.014 ab^{-1}. The upgrade project has been approved and the upgrade is already on the way with the scheduled startup at 2014. The new machine dubbed SuperKEKB should eventually run at $\mathscr{L}_{\max} = 8 \times 10^{35}$cm^{-2}s^{-1} delivering 50 ab^{-1} by 2020 or 2021 (see Fig. 1)

The designed increase of the instanteneous luminosity by factor of 40 will be achieved by several crucial improvements, the key one being beam size reduction (*nano-beam scheme* based on the idea of P. Raimondi from Frascati [2]). Luminosity is linked to the machine parameters by the form

$$\mathscr{L} = \frac{\gamma_\pm}{2er_e}(1 + \frac{\sigma_y^*}{\sigma_x^*})\frac{I_\pm\xi_\pm R_L}{\beta_y^* R_y} \tag{3.1}$$

Here $\gamma_\pm$ are relativistic factors of electron and positron beam, r_e is the classical electron radius, σ_x^* and σ_y^* are beam dimensions at the interaction point (IP) in horizontal and vertical directions. $I_\pm$ are the currents of both beams, $\xi_{\pm y}$ is the beam-beam parameter, β_y^* is the vertical β function at the IP and (R_L/R_y) is a luminosity reduction factor (or tune shift) which reflects crossing at the finite (non-zero) angle.

The nano-beam scheme assumes squeezing the vertical beam dimension at the interaction point (IP) down to 48 nm (low-energy ring – LER) and 61 nm (high-energy ring – HER). The beam currents will be roughly doubled, while keeping the beam-beam parameter unchanged. The comparison of KEKB and preliminary SuperKEKB machine parameters can be found in Table 1.

4. Detector Upgrade

In order to exploit fully the luminosity increase at background levels increased by factor of 10-20, substantial upgrade of the Belle detector (called Belle II) is prepared. Large number of the

PoS(HQL 2010)079

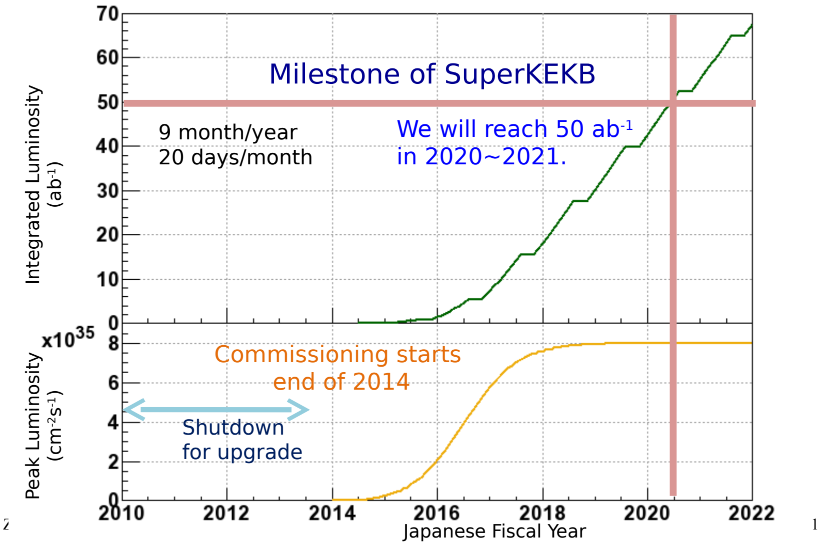

Figure 1: SuperKEKB luminosity prospects

Parameter	**KEKB**		**SuperKEKB**
LER/HER	design	achieved	preliminary
E [GeV]	3.6/8	3.6/8	4/7.007
β_y^* [mm]	10/10	5.9/5.9	0.27/0.30
σ_y^* [nm]	1900	1100	48/61
$\xi_{\pm y}$	0.052	0.101/0.096	0.089/0.08
$I_\pm$ [A]	2.6/1.1	1.62/1.15	3.6/2.6
L [10^{34}cm^{-2}s^{-1}]	1	2.1	80

Table 1: Machine parameters of KEKB and SuperKEKB (preliminary). For the notation see text

detector components will be reused, but many others (namely electronics) have to be replaced to prevent compromising the detector performance. The comparison of the Belle and Belle II detector is shown in Fig. 2.

The most chalenging experimental requirement is the detection of the decay point of the short-living B-mesons, relying on high-performance vertex detector. Therefore two inner layers of Belle II vertex detector will use pixels, followed by 4 double sided silicon strip layers and they will be able to determine vertex position with a precison $\sigma_{z_0} \approx 10\mu$m. The sketch of the vertex detector is in Fig. 3.

The DEPFET [3] active pixel technology will be utilized, with sensors thinned down to 75 μm and pixel pitch of 50×50 μm. Preliminary radii of the 2 pixel layers are 12 and 22 mm. 10 million readout channels pose chalenging task for the DAQ system (see later). The DEPFET pixel detectors have been developped for a long time as candidates for the ILC vertex detectors. They

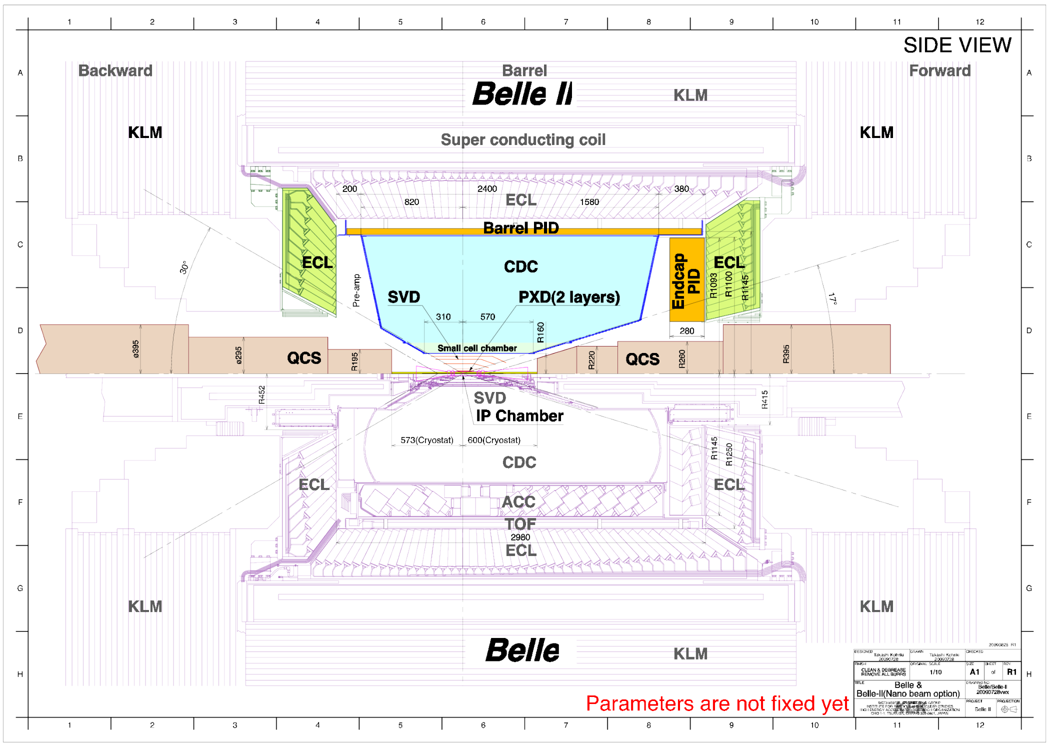

Figure 2: Upgraded Belle II spectrometer (top half) as compared to the present Belle detector (bottom half).

have shown an outstanding signal-to-noise ratio leading to submicron single point spatial resoution (at 450 μm thickness). The thinned sensors of Belle II are expected to provide about 4 μm single point spatial resoution. The strip sensors forming the four layers extended to 14 cm will be read out by fast APV25 chips, designed for the CMS experiment at the LHC.

Tracking and dE/dx measurement will be based on a new drift chamber with higher granularity, new gas - He/C_2H_6 and improved readout system. It will start immediately after SVD and cover $16 < r < 112$ cm.

Particle identification is another key requirement for detectors at Super B factories: it has to separate kaons from pions. This will be provided by Time-of-Propagation counter in the barrel region and proximity focusing Cherenkov ring imaging counter with aerogel radiators in the endcap. TOP will measure the time that the internally reflected light travels down the quartz bar and one spatial coordinate along the bar.

The electromagnetic calorimeter (ECL) will face the severe background increase. Hence the readout electronics will be replaced by a new verson equipped with pipeline and waveform sampling. CsI(Tl) crystals in the barrel will remain the same, but pure CsI will be used in the endcap.

The barrel part of the muon system of Belle will stay intact (resistive plate chambers). The harsh background conditions in the endcap region will force us to use a scintillator based solution, with the light detected by the Silicon photomultipliers.

A new readout system is under design. The main chalenge is to handle large data volumes from the pixel detector due to the high background rate and large number of cells. The expected

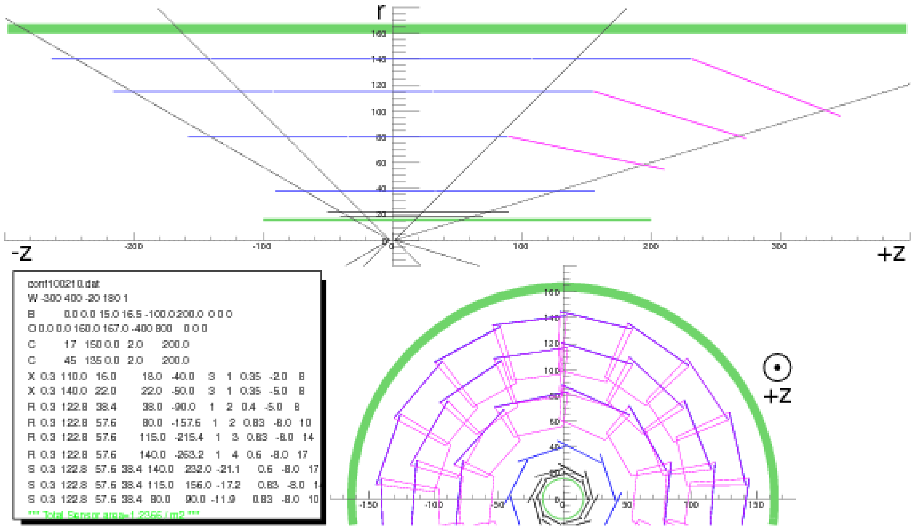

Figure 3: Configuration of the four strip layers, with slanted sensors in the forward region, and the two PXD layers. All dimensions are in mm.

data rate of 180 GBit/s from the pixel detectors is too large to be handled directly by the event builder. Thus, a reduction of the data by a factor 10 is required. A hardware platform capable of processing this amount of data is the ATCA based Compute Node. The solution based on this hardware is now under development.

Computing system of the new experiment will use the newly developped framework BASF2. It will have to handle an amount of data eventually corresponding to 50 times the Belle level by the end of 2020. This means an amount of raw data of the order of 10^{10} events per year. Therefore, a distributed computing model based on the grid will be adopted.

The detailed description of the detector upgrade can be found in the Technical Design Report published in 2010 [4].

The upgrade of Belle is pursued by a new collaboration called Belle II [5] consisting of more than 50 institutes.

5. Conclusions

As shown in the previous sections, exciting physics experiment is under preparation at KEK. The accelerator upgrade has been approved and the funding of the detector upgrade has been already secured in many countries. An open international collaboration has been created.

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PoS(HQL 2010)079

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