PROCEEDINGS OF SCIENCE

Belle II at SuperKEKB

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The Belle II experiment will search for Physics beyond the Standard Model at the KEK laboratory in Japan by exploiting the substantial upgrade of the of the KEKB asymmetric $e^+ - e^-$ collider to SuperKEKB. The instantaneous design luminosity of SuperKEKB is $8 \times 10^{34} cm^2 s^{-1}$ which is a factor of 40 larger than the KEKB. The Belle II detector also represents substantial upgrade of the Belle experiment to cope with this substantial increase in luminosity. The status of the collider and the detector is presented in this article.

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1. Introduction

The discovery of the Higgs-like resonance at 126 GeV by the ATLAS [1] and CMS experiments[2] announced at this conference brings new urgency to the questions posed by the Standard model (SM). In particular, how does Nature solve the Heirachy problem? What is the origin of Dark Matter? What is the origin of the Universal Matter-Antimatter asymmetry? Consequently it is vital that Physicists continue the search for New Physics (NP) processes. The effects of NP can be manifest through the effects of Quantum Loops which enable otherwise forbidden particle decays and/or alter the expected rate of well-predicted processes. Measurements of CP-violating processes are a particularly sensitive probe since these arise from the interference of competing amplitudes.

The B factory experiments Belle[3] at the KEKB accelerator in Tsukuba, Japan, and BaBar [4] at the PEP-II accelerator in Stanford, USA, have successfully confirmed the Kobayashi-Maskawa mechanism of CP violation in the standard model (SM) [5] and in addition have carried carried out a rich physics program covering B mesons, charm hadrons, and τ leptons. This abundance of high-profile results was facilitated by the excellent performance of the asymmetric e^+e^- colliders. A world-record luminosity of $2.1 \times 10^{34} cm^2 s^1$, more than twice the design luminosity, was achieved for the KEKB accelerator. This enabled the Belle experiment to collect more than 1 ab^1 of data. Although there are some hints of discrepancies with the SM in flavor physics measurements, so far most are in good agreement with predictions. Nevertheless, the unresolved issues in the SM require NP processes and the search for NP effects is the mission of the Belle II experiment.

It will be located at the upgraded KEKB accelerator, SuperKEKB, and record $e^+ - e^-$ collision data with an upgraded Belle detector. The aim is to accumulate 50 ab^1, corresponding to about 55 billion BB pairs and about 47 billion τ pair events, by the year 2023. The Physics of Belle II has been presented by M. Danilov elsewhere at the conference. A more detailed review is provided by Aushev et al. [6]. This article will concentrate on describing the upgrades to the accelerator and detector.

2. Accelerator

The heart of the project is the substantial upgrade of the KEKB asymmetric KEKB asymmetric $e^+ - e^-$ collider to SuperKEKB with a design luminosity of $8 \times 10^{35} cm^2 s^{-1}$.

The luminosity of the SuperKEKB colliding beam accelerator is given by formula 2.1.

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)_\pm \left(\frac{R_L}{R_{\Xi_y}}\right) \tag{2.1}$$

Where L is Luminosity, $\gamma_\pm$ is the relativistic gamma factor of the positron (electron) beams, e is the electron charge, r$_e$ is the classical electron radius, $\frac{\sigma_y^*}{\sigma_x^*}$ is the ratio of the vertical and horizontal beam profiles, $I_\pm$ is the current in the positron (electron) beams, $\xi_{\pm y}$ is the beam-beam tune shift, $\beta_{y\pm}^*$ is the vertical beta function of the positron (electron) bunches and $\frac{R_L}{R_{\Xi_y}}$ is a geometric factor.

Most of the luminosity increase in SuperKEKB compared to KEKB is due to the factor two increase the beam currents ($I_\pm$) and a factor of 20 decrease in the vertical beta-function $\beta_{y\pm}^*$. This parameterizes the vertical size of the electron and positron bunches. The effect is to significantly

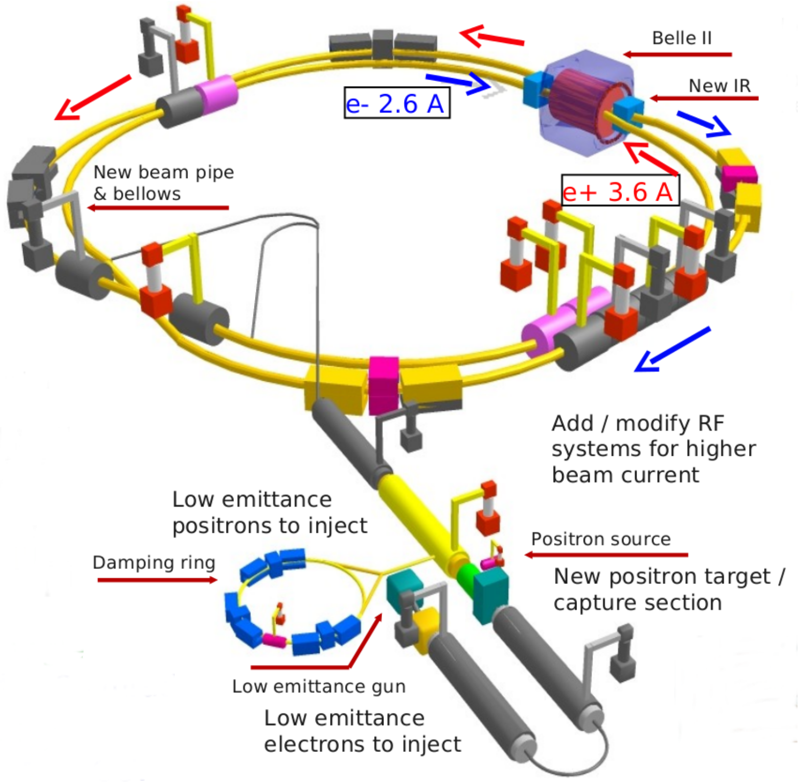

Figure 1: A schematic view of the SuperKEKB accelerator. The details are described in the text.

reduce the vertical size of the bunches such that they are contained within a 60 nm aperture. This is the nanobeam scheme invented by P. Raimondi[7] for the SuperB accelerator.

A diagram showing the layout of SuperKEKB is shown in figure 1. SuperKEKB will reuse the tunnel and much of the infrastructure from KEKB. The significantly smaller beam size requires a corresponding reduction in the beam emittance. This is accomplished through an improved electron gun for electron source and damping ring for the positron source. The highly concentrated bunches leads to a significant increase in intra-bunch scattering due to the Toushek effect [9]. This places a severe limitation on the lifetime of low energy beam. Since beam-lifetime is proportional to γ^3 the effect is mitigated by raising the energy of the positron beam from its nominal 3.5 GeV to 4.0 GeV compared to KEKB. The energy of the electron beam was corresponding lowered from 8.0 GeV to 7.002 GeV.

By operating at the nominal 7.002/4.0 GeV energies, the lifetime of positron beam is expected to be 10 minutes. Consequently SuperKEKB will operated in the "continuous injection" mode developed for KEKB.

Lowering the electron beam energy has the positive effect of reducing synchrotron radiation. Overall changing the beam energies lowers boost of the $\Upsilon(4S)$ in the lab frame. However the reduced boost is more than compensated by the addition of a high resolution pixel detector very close to the interaction point. Overall the Belle II detector is expected to have significantly better indirect CPV performance compared to KEKB.

The electron cloud instability is mitigated by a TiN coated beam pipe with an integrated

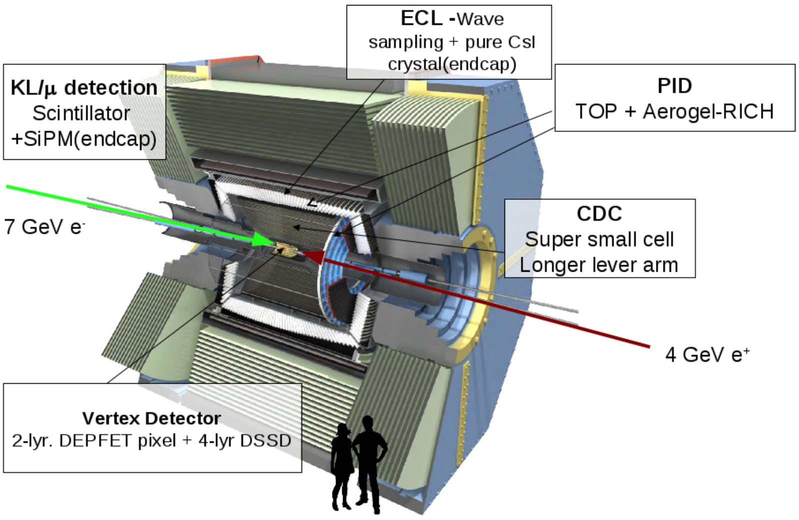

Figure 2: A schematic view of the Belle II detector.

ante-chamber. The TiN coating reduces electron emission from synchrotron radiation. The ante-chamber draws the electron cloud away from the positron beam. The higher energy of the positron beam requires new dipole bending magnets, while the HER will reuse the dipole magnets from KEKB. Additional klystrons and accelerating cavities will be installed to accelerate the higher current beams. Overall the power required for SuperKEKB is 70 MW compared to 45 MW for KEKB.

Construction of SuperKEKB is well underway. As of November 2012, initial operations of the accelerator are on-track to commence in January, 2015.

3. Detector

The Belle II detector is shown in figure 2. The main components of the detector are (in order from the interaction point), the DEPFET Pixel detector (PXD), the silicon vertetx detector (SVD), the Central Drift Chamber (CDC), the barrel particle identification system (TOP), the end-cap particle identification (ARICH), the electromagnetic calorimeter (ECL) and the K-long and muon detector (KLM). The details of each are briefly described in the following subsections. A much more detailed description is available in the Belle II Technical Design Report[8].

The substantial increase in luminosity is accompanied by a comensurate increase in both background and radiation damage. The background is calculated to be up to a factor of 20 times higher than Belle. The effects of the background are mitigated with increased grainularity in both space and time.

The PXD consists of two layers of DEPleted Field Effect Transistor (DEPFET) active pixel detectors. These combine a first amplification stage with a fully depleted sensor in one single device. This inherit amplification enables the sensors to achieve good signal to noise ratio even with extremely thin devices. In the case of the Belle II design, the sensors are 75 μm thick. The inner layer is located just outside the beam-pipe at 14 mm radius and has pixel dimensions of 50μm $\times$ 50 μm. The outer pixel layer is located at 22 mm radius with pitch 50μm $\times$ 75 μm.

The next tracking detector is the SVD consisting of 4 layers of double-sided silicon strip detectors at radii 38mm, 80mm, 115mm and 140mm. The larger outer radius of the SVD compared to Belle provides a 30% increase in efficiency for $K_S \rightarrow \pi^+\pi^-$ reconstruction inside the SVD. The PXD + SVD combination is expected to provide a factor 2 improvement in Δz resolution compared to Belle. This more than compensates for the smaller boost at SuperKEKB.

The central drift chamber (CDC) provides precise measurement of the momentum of charged particles and particle identification via dE/dx measurements. To compensate for the higher backgrounds, the drift cell size has been reduced from 18mm × 20mm to 10mm × 8 mm. Further background discrimination is provided by waveform sampling. Improved momentum resolution is obtained by increasing the outer radius and new electronics reduces the deadtime from 1 μs to 200 ns.

Charged particle identification (PID)is accomplished via different detector systems in the barrel and end-cap regions. PID is the barrel region is provided via the Time of Propagation (TOP) detector. This device consist of quartz-bar radiators coupled to micro-channel plate (MCP) photon detectors. Sufficiently fast charged particles traversing the quartz-bar emit cherenkov light in a cone characteristic of their velocity. Light photons are captured via total internal reflection within the bar where they propagate until detection with the MCP's. These provide excellent resolution in position and time. The pattern of photon hits in time and space on the MCP provides excellent PID. The system is expected to provide 5 σ resolution between high-momentum pions and kaons. Furthermore the timing of the device provides the common start to the inner tracking detector and the compact nature of the detector allows the CDC to be extended to a larger radius, as mentioned previously.

PID in the end-cap is provide by the Aerogel Ring Imaging Detector (ARICH). Here two layers of aerogel with different refractive indicies are read-out via position sensitive avalanche photodiode arrays. The double layer aerogel provides proximity focusing to different radii for pions and kaons of the same momentum. The ARICH also provides 5σ separation between high momentum pions and kaons.

The baseline design of the ECL is for the reuse of CsI(Tl) from Belle experiment and to replace the endcap with pure CsI crystals. This is more radiation tolerant and has a much shorter decay constant. However pure CsI provides less photon output and so will be readout with photopentode photomultipliers. These can be operated in the large magnetic field within the detector. Additional background suppression will be provided via a waveform sampling readout which can resolve otherwise over lapping signals.

The K-long and muon-detection systems will reuse the resistive plate chambers above layer 2 in the barrel region of the detector. The sensitive detector in the endcap and inner layers will be provided by strips of scintillation counters with embedded wavelength shifting optical fibres. Photons from the fibres will be registered with Silicon Photomultipliers. The substantial increase in readout speed will enable the system to cope with the higher background of the Belle II experiment.

4. Computing and Software

Since we intend to record every interesting collision within Belle II, the Data Acquisition system of Belle II will be upgraded to enable data taking with a trigger rate of 6000 Hz and a total data rateof 1800 MegaBytes/Sec. This is a factor 6 times higher than the original design of the LHC experiments.

All components of the Belle II data handling system will employ the same ROOT-based persistancy layer and software framework. The framework is designed to efficiently allow the dynamic loading of C++ object modules driven via a python steering file. Accordingly the data processing at every layer can be scaled to provided just the resources needed for the task. It is also designed from the beginning to efficiently utilize multicore machines.

The LHC-scale size of the computing effort required by Belle II requires a distributed computing solution. The raw data stream of the Belle II experiment will be recorded at the local KEK computing center and a complete copy will be sent to the Pacific North-West National Laboratory in Washington State, USA. Data analysis and MC generation will be provided at grid sites, local clusters and cloud resources around the world. Our distributed computing solution is based on the DIRAC middleware originally developed for the LHCb experiment. We have developed our own extensions to this enable users to easily and efficiently utilize computing resources where ever they're located.

5. Summary

The SuperKEKB and Belle II experiment will search for New Physics via precision measurements and rare decays of B and D mesons and τ leptons in a data sample 50 times larger than the Belle experiment. This will be accomplished through substantial accelerator and detector upgrades. Construction of both is well underway and on track for first physics runs in September, 2016. We expect to have accumulated our target data set of 50 ab^{-1} by 2023.

References

[1] G. Aad et al. (The ATLAS collaboration), *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, Phys.Lett. **B716** (2012) 1-29

[2] C. Chatrchyan et al. (The CMS collaboration)*Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC,* Phys.Lett. **B716** (2012) 30-61

[3] A. Abashian, K. Gotow, N. Morgan, L. Piilonen, S. Schrenk, et al., The Belle Detector, Nucl.Instrum.Meth. A479 (2002) 117 - 232.

[4] B. Aubert, et al., The BaBar detector, Nucl.Instrum.Meth. A479 (2002) 1 - 116.

[5] M. Kobayashi, T. Maskawa, CP Violation in the Renormalizable Theory of Weak Interaction, Prog.Theor.Phys. 49 (1973) 652 - 657.

[6] T. Aushev, W. Bartel, A. Bondar, J. Brodzicka, T. Browder, et al., Physics at Super B Factory arXiv:1002.5012.

[7] P. Raimondi, *Status of the SuperB Effort*. URL http://www.lnf.infn.it/conference/superb06/talks/raimondi1.ppt

[8] T. Abe et al.., Belle II Technical Design Report arXiv:1011.0352.

[9] A. Piwinski, *The Touschek Effect in Strong Focusing Storage Rings.* arXiv:physics/9903034 [physics.acc-ph]

[10] S. Agostinelli, et al., GEANT4: A Simulation toolkit, Nucl.Instrum.Meth. A506 (2003) 250âĂŞ303.