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Physics of SuperKEKB/Belle II

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The SuperKEKB/Belle II experiment, the next generation electron-positron B-factory experiment at KEK, aims to find evidence of New Physics by precision measurement of rare decay processes of B and D mesons, and also by searching for decays prohibited by the Standard Model, such as the Lepton-Flavor-Violating (LFV) decays of the τ lepton. In this talk, we present physics topics and status of the SuperKEKB/Belle II experiment, with emphasis on activities of the Nagoya team.

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1. Introduction

Progress of particle physics in this century is remarkable. In 2001, the two *B*-factory experiments at KEK(KEKB/Belle) and SLAC(PEP II/BaBar) succeeded to observe *CP* violation in *B*-meson decays, and confirmed that the symmetry is violated as predicted by the theory proposed by Kobayashi and Maskawa in 1973 [1]. In 2012, the ATLAS and CMS experiments at the CERN Large Hadron Collider (LHC) found the Higgs boson, the last missing piece of the Standard Model, and by now, they confirmed the measured properties are consistent with the SM [2]. While the SM has succseeded to explain almost all particle phenomena, it does not provide reasonable explanation for the hierarchy problem, the grand unification of interactions, the matter-dominated universe and the dark matter problem. Hence a variety of models for physics beyond the SM (BSM), such as SUper SYmmetry (SUSY) and Extra Dimensions(ED), have been proposed, and many of them predict existence of new particles in the TeV region. Hence, the next target of particle physics is to search for New Physics (NP) and elucidate their properties.

There are two approaches to search for New Physics; one is a direct search using energy-frontier machines, like LHC, and the other is an indirect seacrh using a luminosity frontier machines. The Super *B*-factory experiment at KEK, SuperKEKB/Belle II, described in this paper, takes the latter approach, and tries to find evidence of New Physics in decays of heavy flavor particles, such as B and D mesons and the τ lepton [3].

2. SuperKEKB/ Belle II Experiment

The SuperKEKB accelerator (Figure 1) is a collider of 7GeV e^- and 4GeV e^+, designed to provide the peak luminosity of $8 \times 10^{35}\text{cm}^{-2}\cdot\text{s}^{-1}$, approximately 40 times higher than the former KEKB accelerator. Such dramatic improvement in the luminosity will be achieved by decreasing size of the two colliding beams ($\times 20$) as well as by increasing their currents ($\times 2$). This enables us to produce about 10^{10} B, τ and charm mesons every year.

In order to cope with the increased background due to higher luminosity as well as beam currents, and also to impove the performance, we are upgrading the detector. The Belle II detector is a large-solid-angle general purpose detector, which surround the interaction point of the two beams (Figure 2). The detector consists of a 2-layer pixel detector (PXD) and a 4-layer silicon vertex detector (SVD) for particle decay vertex measurement, a central drift chamber (CDC) for the momentum measurement, a Time-Of-Propagation (TOP) counter and Aerogel Ring-Imaging Cherenkov Counter (A-RICH) for hadron identification, electromagnetic calorimeter (ECL) to measure energy of $e^{\pm}$ and γ, and an iron-flux return instrumented with devices to detect K_L^0 mesons and muons (KLM). The ultimate goal of the experiment is to reach the integrated luminosity of 50 ab^{-1} by early 2000's.

3. Physics at Belle II

There are variety of channels in B, D and τ decays to search for effects of NP [4]. In particular, Nagoya group focuses on the τ lepton, the heaviest charged lepton in the third generation. Because of the large mass, the τ-lepton is expected to have high sensitivity to NP. In particular, Lepton

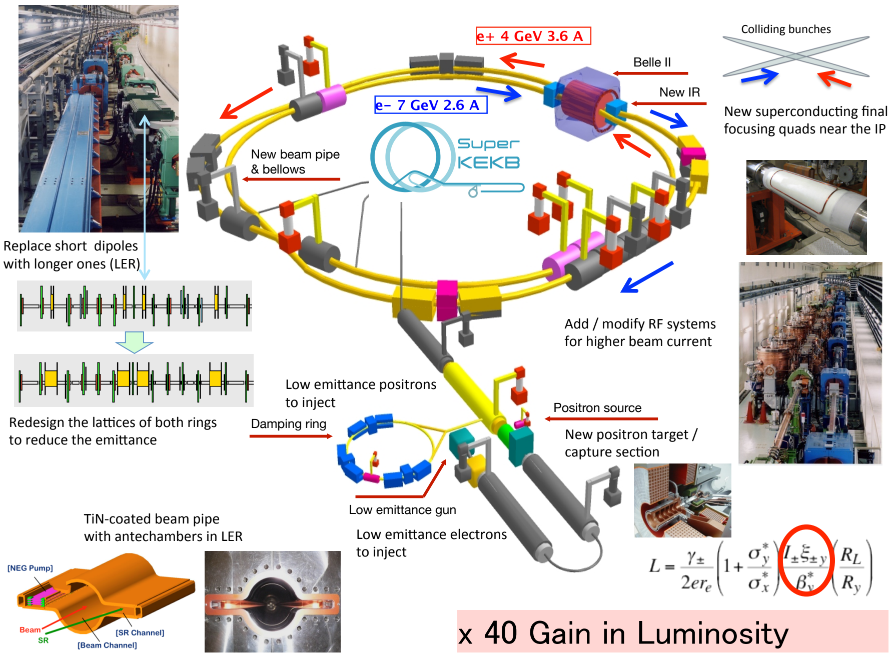

Figure 1: Layout of the SuperKEKB accelerator.

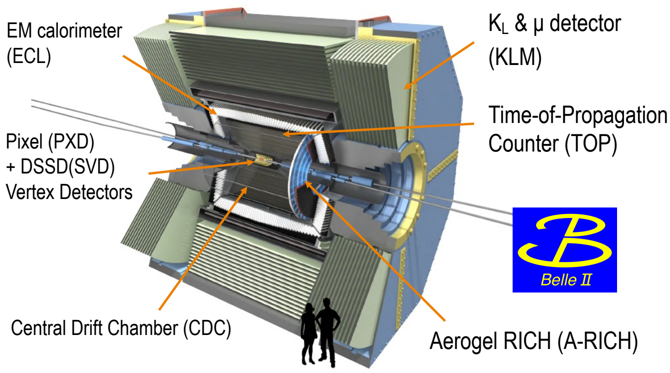

Figure 2: Belle II detector.

Flavor Violation (LFV) in τ decays is one of the most important physics targets. Since the LFV decays are strongly suppressed to the level of $10^{-53} \sim 10^{-49}$ in the SM, observation of LFV decays would be a clear evidence of NP. Figure 3 shows the projected sensitivity for three LFV decays, $\tau \to \mu\gamma, \tau \to \mu\mu\mu, \tau \to \eta\mu$. As shown in the figure, we can search these decays down to the order of $O(10^-9)$ in branching fractions, which are comparable to predictions by many NP models.

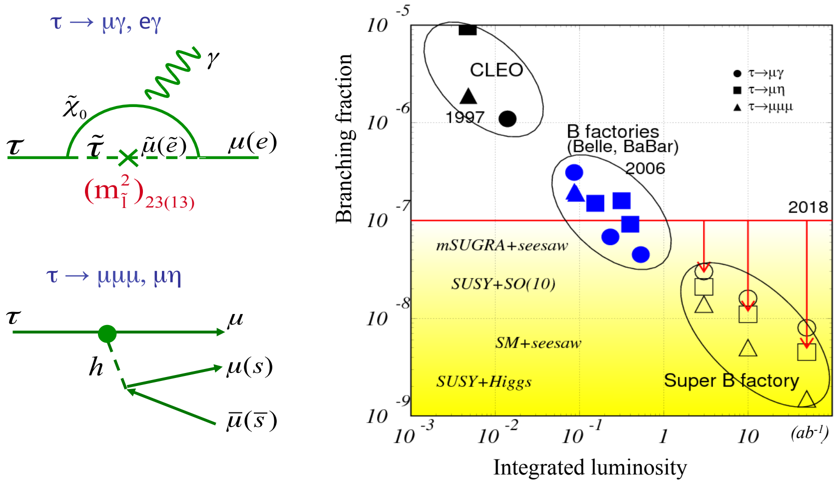

Figure 3: Feynman diagram of LFV τ decays, and projected sensitivity for them as a function of the integrated luminosity.

The τ lepton is also a useful probe to possible NP effects in B decays, such as $B \to \tau\nu$ and $B \to D^{(*)}\tau\nu$. These decays proceed via exchange of the $W^{\pm}$ bosons in the SM. On the other hand, if the charged Higgs boson ($H^{\pm}$) exists, as predicted by SUSY models, the two amplitudes interfere to change the decay amplitudes significantly. We have measured these decays at the KEKB/Belle experiment The measured branching fraction for $B \to \tau\nu$ is consistent with the SM, which constrains the $H^{\pm}$ mass, as shown in Figure 4 (left). The branching fractions of $B \to D^{(*)}\tau\nu$ reported by the Belle and BaBar experiments point to larger values than the SM, with significance of more than 3σ. At the Belle II experiment, we aim at measuring these decays with precision of about $2-3\%$. Then, the region of search will expand as shown in Figure 4 (right).

We also expect to have improved search for the electric dipole moment (EDM) of the τ lepton, *CP* violation in τ decays and precision measurement of τ decay parameters (Michel parameters), which are sensitive to NP.

4. TOP counter and Computing

For precision measurements, as discussed in the previous section, one of the critical components is the particle identification. In the Belle II experiment, we install novel ring-imaging

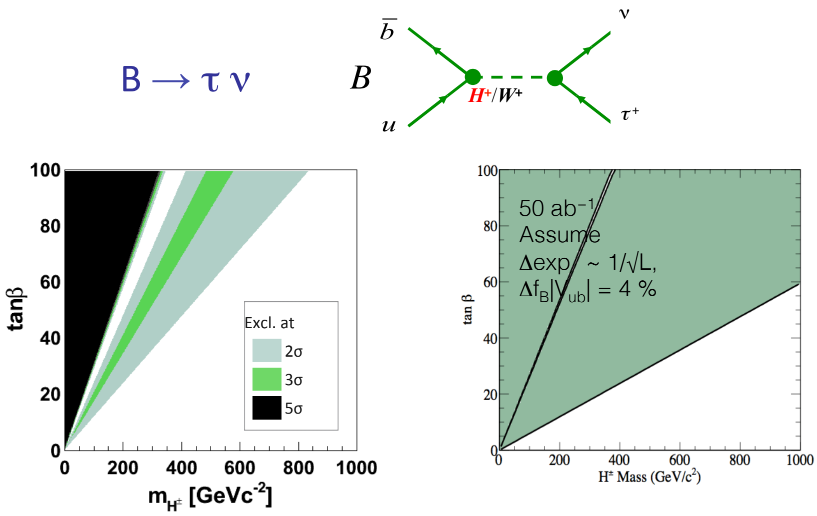

Figure 4: Feynman diagram of $B \to \tau\nu$, and constraint on the charged Higgs boson from the branching fraction of $B \to \tau\nu$ (Type-II HDM); (left) constraint from the present result and (right) constraint expected with 50 ab^{-1} data at Belle II.

Cherenkov detectors; TOP (Time-Of-Propagation) counter in the barrel, and a proximity focusing RICH with aerogel radiator (A-RICH) to identify K and π mesons with more than 4σ separation up to 4GeV/c.

The TOP counter is a new type of RICH, developed originally by Nagoya group, based on precision timing [5]. As shown in Figure 5 (top), Cherenkov photons produced in a quartz bar are transported by total internal reflection, and then detected by an array of photomultiplier tubes. The key technologies are precise quartz optics, accurately polished down to 5 Åfor the surface roughness, and Micro-Channel-Plate PhotoMutiplier Tubes (MCP-PMT) to detect position and arrival time of each Cherenkov photon with precision less than 50 ps. We have developed a new MCP-PMT with 4×4 anode, each having size of approximately $5mm \times 5mm$, by collaboration with Hamamatsu Photonics K.K. Then, ring images are obtained in the coordinate of time (T) and position (X), instead of two positions (X-Y) as in conventional RICH. This approach allows us to perform the precise particle identification with a very compact detector, advantageous in a collider experiment. Figure 5 (bottom) shows the ring image obtained in a beam test carried out at SPring-8 in June 2013. Clear ring images are obtained as expected from a Monte Carlo (MC) simulation.

In order to perform precision measurements, we need use detectors with finer segmentation with more number of readout channels, and also accumulate more statistics, that require us to handle huge size of data. Therefore, not only accelerators and detectors, but also computing is critical component in modern collider experiments like Belle II. In case of Belle II, we need store and process $O(10-100)PB$ data, which cannot be handled only by computers at KEK, and hence we are developing a grid computing system, as described in [6].

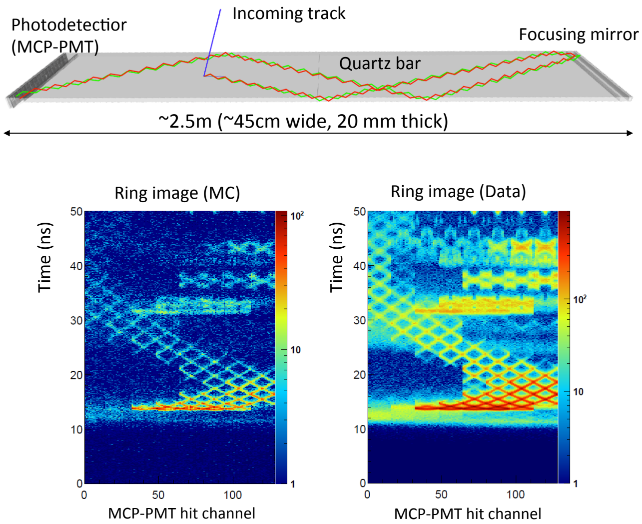

Figure 5: Top: Concept of the TOP counter. Bottom: TOP ring image obtained by a Monte Carlo simulation (left) and beam test data (right). Particle species can be identified by correlation of hits between the MCP-PMT channel (horizontal axis) and detected time (vertical axis) for each penetrating track.

5. Prospect and Summary

The upgrade of the accelerator from KEKB to SuperKEKB is in progress; a new positron damping ring has been build, all magnet components have been installed and positioned in the main ring tunnel, and new beam pipes are being installed. The detector upgarde is also in progress by the Belle II international collaboration formed by approximately 600 scientists from 95 institues distributed in 23 countries and regions. Our group at Nagoya, together from graduate school of science and KMI, make significant contribution to the development and construction of the TOP counter and also for the grid computing. Commissioning of the experiment will start in fiscal year 2015. Together with the data from LHC, data from the Belle II experiment will shed light on New Physics in the last half of this decade.

References

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