The Belle II Experiment and SuperKEKB Upgrade

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Abstract: The Belle II / SuperKEKB experiment is an e^+e^- collider running at the $\Upsilon(4S)$ resonance energy to produce B meson pairs. As an upgrade of the Belle / KEKB experiment, it will start physics data taking from 2018 and with ~ 40 times luminosity, its goal is to accumulate 50 ab^{-1} of e^+e^- collision data. Now the upgrade of the sub-detector systems is on going in KEK. The physics programs have a wide range of areas, including searches for direct CPV, Lepton Flavour Violation and dark matter. In this proceedings, we will review the current upgrade status of Belle II and SuperKEKB and introduce some physics opportunities at this facility.

Key words: Belle II, SuperKEKB, e^+e^- collider, New Physics

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1 Introduction

The so-called B factory is an e^+e^- collider running at the $\Upsilon(4S)$ resonance energy to produce B meson pairs. The major B factories are Belle running at KEKB in Japan and BaBar running at PEP-II in US. The total data set collected by these two facilities is ~ 1.5 ab^{-1} of e^+e^- collision data. With that data sample, they've reached physics achievements in areas like the CKM angle measurement, $|V_{cb}|$ and $|V_{ub}|$ measurement, semileptonic and leptonic B decays, rare B decays, τ physics, D^0 mixing and CPV, B physics at the $\Upsilon(5S)$, two-photon physics and new resonances [1].

For searching the New Physics (NP), which is physics beyond the Standard Model (SM), the Belle / KEKB experiment will be upgraded to Belle II / SuperKEKB [2]. The upgraded detector is planning to take ~ 50 ab^{-1} of e^+e^- collision data. The SuperKEKB asymmetric electron positron collider can provide a clean environment for producing B meson pairs via $\Upsilon(4S)$ resonance decay. Its designed luminosity is $8 \times 10^{35} cm^{-2}s^{-1}$, which is about 40 times larger than the KEKB collider. The 50 ab^{-1} overall integrated luminosity corresponds to 55 billion of $B\overline{B}$ pairs, 47 billion of $\tau^+\tau^-$ pairs and 65 billion of $c\bar{c}$ states.

In this article, we will introduce the Belle II / SuperKEKB experiment, the current status and future plan of the experiment, and the opportunities for New Physics.

2 SuperKEKB

Many sub-systems of the SuperKEKB accelerator need to be upgraded for achieving the 40 times luminosity compared with KEKB. The most important part is the beam size. By using the so-called nano-beam technology, the beam bunches are significant squeezed as shown in Fig. 1. The beam energies of electron and position will be changed slightly to achieve a less boosted center-of-mass system.

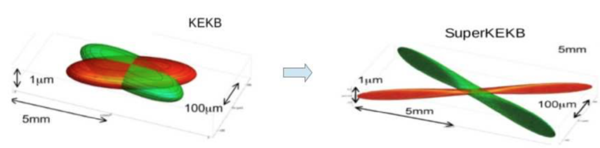

Fig. 1. The comparison of the beam size between KEKB (left) and SuperKEKB (right).

3 Belle II detector

As shown in Fig. 2, most sub-detectors of Belle will be upgraded for Belle II apparatus. This includes the newly designed vertex detection system (PXD and SVD), a drift chamber with longer arms and smaller cells, a completely new PID system which consists of TOP detector at the barrel and ARICH detector in the forward end, the electro-magnetic calorimeter (ECL) with upgraded crystals and electronics, and upgraded K_L-μ detection system (KLM). More details will be introduced in following sections.

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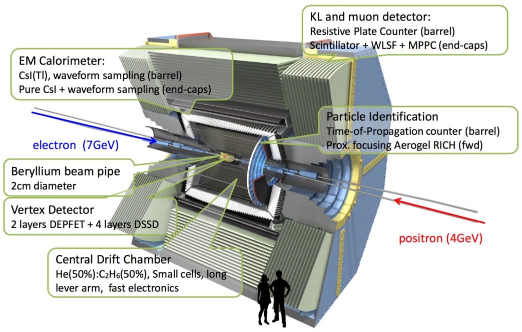

Fig. 2. Overview of the Belle II detector and its sub-detector systems.

3.1 VXD

The vertex detector consists of two parts: PXD in the inner part and SVD in the outer part. PXD consists of two layers of DEPFET (DEPleted p-channel Field Effect Transistor) and SVD consists of four layers of DSSD (Double Sided Strip Detectors), as shown in Fig. 3. These two sub-detectors combined could have a good vertex resolution for charged tracks. Now the system integration is on going, and a beam test for SVD just finished in the summer of 2015.

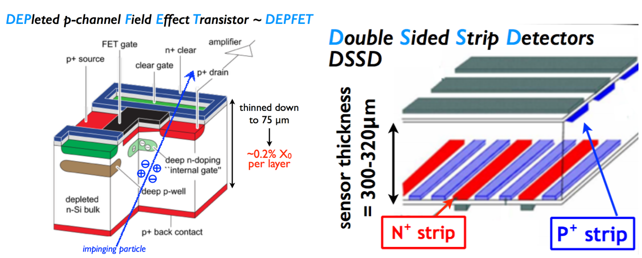

Fig. 3. The structure of the DEPFET (left) and DSSD (right).

3.2 CDC

As the main tracking device for charged tracks, the CDC in Belle II is larger than that in Belle and it has smaller cell size, as shown in Fig. 4. This could improve the momentum and dE/dx resolution. The stringing for CDC has finished in January of 2014 with 51456 wires and now it's commissioning with cosmic ray.

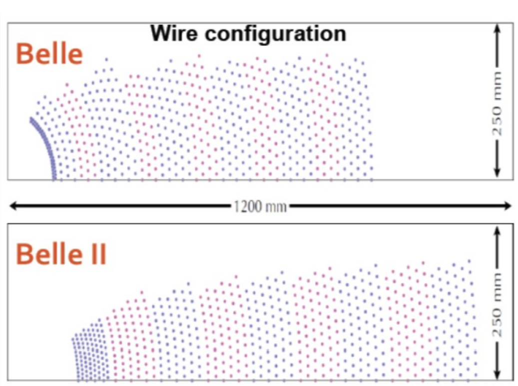

Fig. 4. The comparison of wire configuration between Belle (top) and Belle II (bottom).

3.3 TOP

The imaging Time of Propagation sub-detector (TOP or iTOP) will be used for particle identification in the barrel region of Belle II. There're totally 16 TOP modules, and each one consists of two quartz bars, one mirror, one prism, and an array of photo-detectors to collect Cerenkov photons generated by charged tracks going through the radiator, as shown in Fig. 5. To distinguish between kaons and pions, the photo-detectors should have excellent position and timing resolution. This is achieved by using MCP-PMTs and new waveform sampling electronics.

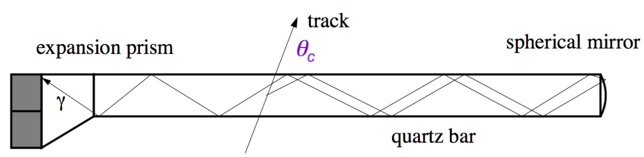

Fig. 5. The structure of the TOP detector.

TOP modules have been tested during the beam test at SPring-8 at LEPS in 2013, and good agreement between data and MC simulation has been obtained, with timing requirement $\sim$ O(100 ps) as shown in Fig. 6.

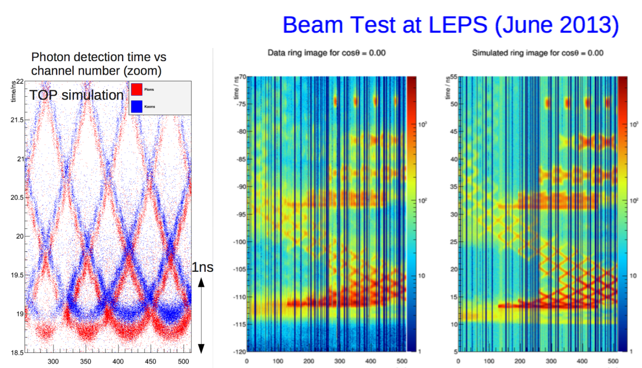

Fig. 6. The simulation of TOP beam test (left) and the data for different incident angles (middle and right).

The assembly of the TOP modules is on going in KEK, and all modules will be finished at the beginning of 2016. The commissioning with cosmic ray is under way.

3.4 ARICH

Aerogel Ring Imaging Cerenkov (ARICH) detector will be used for particle identification in the forward endcap. Two layers of aerogel will be used to obtain better photon yield, while not affecting resolution. For readout, 420 Hybrid Avalanche Photo Detectors (HAPD), each with 144 channels, will be used, as shown in Fig. 7.

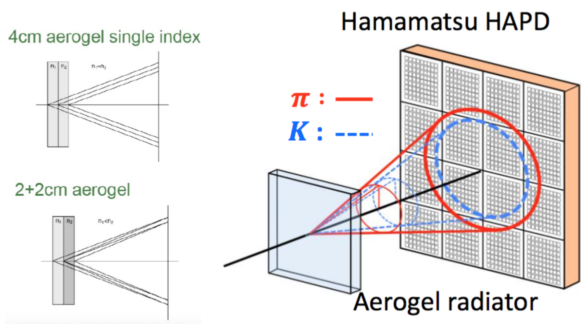

Fig. 7. The focusing mechanism (left) and the structure (right) of ARICH.

3.5 ECL

For the upgrade of the ECL detector, the crystals in barrel side will be reused and the crystals in end-cap will be refurbished. New electronics, such bias filter and waveform sampling will be used for the upgraded detector. Now the cosmic ray test is on going. The expected performance for ECL is shown in Fig. 8.

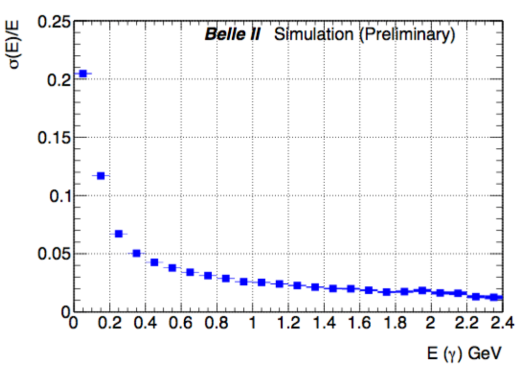

Fig. 8. The expected performance of the ECL detector.

3.6 KLM

Endcaps and the first two layers of the barrel RPCs of KLM will be replaced with scintillators due to increased backgrounds expected in Belle II, as shown in Fig. 9. Barrel KLM was the first sub-detector to be installed in Belle II.

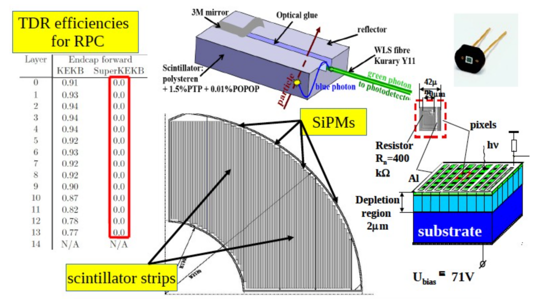

Fig. 9. The structure of the KLM detector.

4 Physics opportunities

There're lots of potential signals for new physics in Belle II, such as the flavor changing neutral currents, probing charged Higgs, new sources of CPV, Lepton Flavour Violation decays and search for dark photon. With the much larger data set compared with Belle and BaBar, Belle II will contribute to the search of the new physics, together with the upgraded LHCb. For example, the CKM Unitarity Triangle will be significantly improved, as shown in Fig. 10 [3].

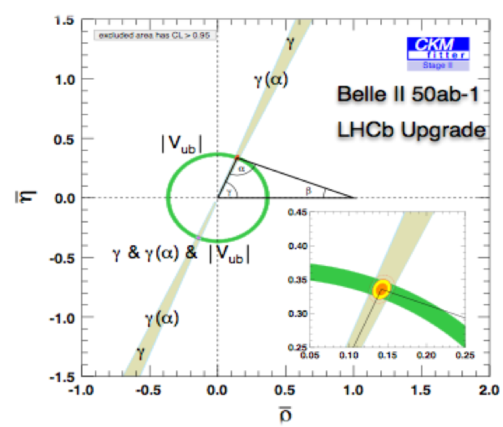

Fig. 10. The predicted accuracy of CKM UT with data taken by LHCb and Belle II.

4.1 Direct CPV in $D^0 \to \phi\gamma, \rho^0\gamma$

The direct CPV in radiative decays can be enhanced to exceed 1% [4]. The A_{CP} for $D^0 \to \phi\gamma$ could be up to 2%, and the A_{CP} for $D^0 \to \rho^0\gamma$ could be up to 10%. The decay for $D^0 \to \phi\gamma$ was first observed by Belle with 78 fb^{-1} of data, with the relative error on yield as about 25% [5]. With 50 ab^{-1} of data, the A_{CP} sensitivity will be reduced to 1%.

4.2 $D^0 \to \gamma\gamma$

The branching fraction of the decay $D^0 \to \gamma\gamma$ is predicted by SM as $\sim 10^{-8}$. The upper limit by BaBar with 470 fb^{-1} of data is 2.2×10^{-6} with 90% CL, as shown in Fig. 11.

With 50 ab^{-1} of data by Belle II, the upper limit could be improved to $\sim 2\times 10^{-8}$, if it scales with luminosity L, or $\sim 2\times 10^{-7}$, if it scales with $\sqrt{L}$.

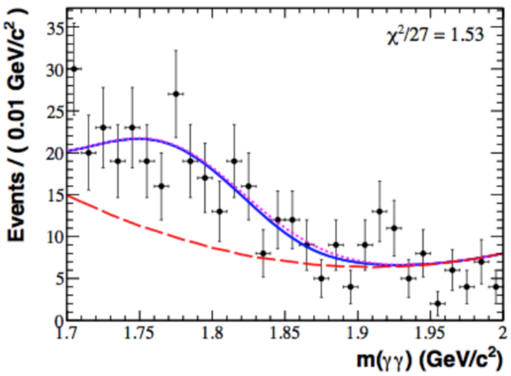

Fig. 11. The decay of $D^0 \to \gamma\gamma$.

4.3 τ Lepton Flavour Violation

The Lepton Flavour Violation decays are highly suppressed by SM, in a branching fraction as 10^{-25}. But they could be enhanced in certain New Physics scenarios. Belle has searched for LFV [7] [8], but no trace of NP has been found. As shown in Fig. 12, the red dots show the sensitivity for some LFV decays in Belle II [9]. The branching fraction of the decays is within the capability of the Belle II experiment.

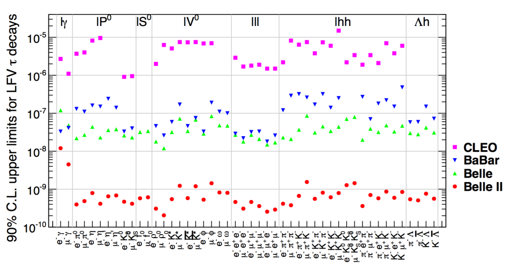

Fig. 12. The comparison of LFV upper limit by different experiments for different decay channels.

4.4 Dark sector

The dark photon A' is one candidate for dark matter which could be searched by accelerator. Its mass is predicted in the range of MeV to GeV. There're two ways to detect dark photon: probing leptonicaly decaying dark photons through mixing, or probing sub-GeV dark matter in invisible decays. The upper limits of dark photon measurement for different experiments are shown in Fig. 13 [10]. Belle II has an advantage to search dark photon A' with much higher integrated luminosity.

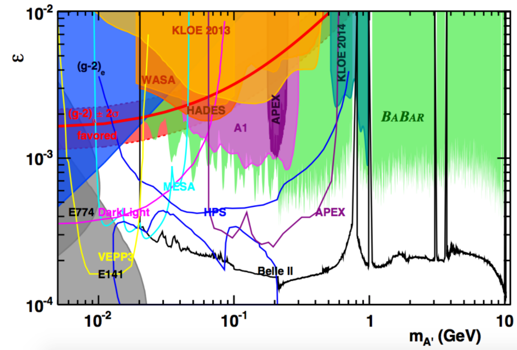

Fig. 13. The upper limit by different experiments for the searching of the dark photon.

5 Schedule

The SuperKEKB accelerator is now at the final stage of construction and the upgrade of the Belle II detector is on going. As shown in Fig. 14, there are three phases in commission and operation of Belle II. In phase 1 which begins at the early 2016, the commissioning of various components will start without rolling-in the detector. In phase 2 which begins in the middle of 2017, Belle II detector will be partly commissioned to take test physics data without the vertex detector. Finally, in phase 3, which is expected to start at the end of 2018, the Belle II detector with full apparatus is going to take physics data.

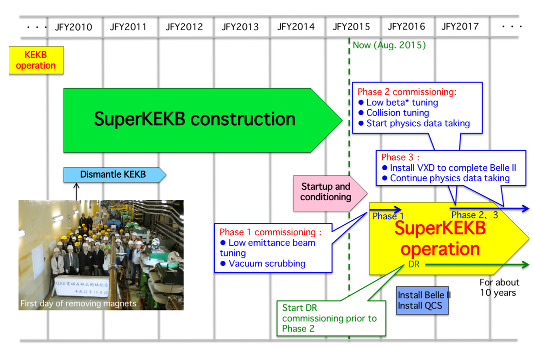

Fig. 14. The current schedule.

The plan for instantaneous and integrated luminosity is shown in Fig. 15. According to this plan, the target integrated luminosity of 50 ab^{-1} will be achieved by 2024.

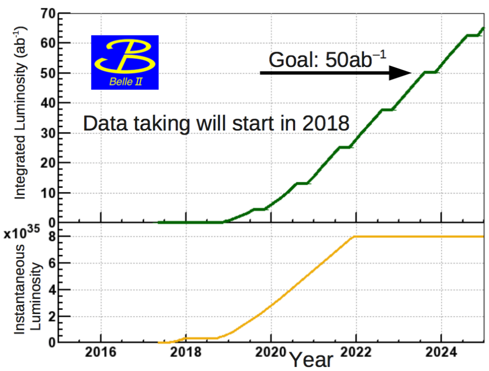

Fig. 15. The plan for data taking.

6 Summary

Belle and BaBar as B factories have made contribution for flavour physics. As an upgrade, the Belle II / SuperKEKB experiment could play an important role in the search for New Physics. With the upgraded accelerator and detector, the experiment will have much higher luminosity and much better performance for detecting final state particles.

With the much larger data set collected with the upgraded detector, Belle II has a rich physics program , which makes it possible to study the channels with missing energy and neutral particles in the final states. Now the accelerator and detector are under construction, and the physics data taking will start at the end of 2018.

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References

1 A. J. Bevan, et al, The Physics of the B Factories, Eur. Phys. J. C74 (2014) 3026
2 T. Abe et al, KEK Report 2010-1 (2010), arXiv: 1011.0352v1
3 CKM fitter, http://ckmfitter.in2p3.fr/
4 G. Isidori and J. F. Kamenik, PRL 109, 171801 (2012)
5 O. Tajima et al. (Belle Collaboration), PRL 92, 101803 (2004)
6 J. P. Lees et al. (The BABAR Collaboration) Phys. Rev. D 85, 091107(R)
7 K. Hayasaka, et al., Phys. Lett. B 666 16-22 (2008)
8 K. Hayasaka, K. Inami, Y. Miyazaki et al., Phys. Lett. B 687 139-143 (2010)
9 Belle II Flavour Prospects (B2TiP 2014)
10 Current and projected limits, radiative production of dark photon, decay to SM particles (C. Hearty, B2TIP 2014)