PROCEEDINGS OF SCIENCE

SuperKEKB/Belle II

Kenkichi Miyabayashi*†
Department of Physics, Nara Women's University
E-mail: miyabaya@cc.nara-wu.ac.jp

Based on reviewing achievements in hadron spectroscopy at B-factories, the physics reach with the SuperKEKB e^+e^- collider and the Belle II spectrometer are discussed. Features and construction status of these experimental facilities are also described.

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*Speaker.
†for the Belle II collaboration

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1. Introduction

Motivated to study *CP* violation in *B* meson decays, two *B*-factory experiments, KEKB/Belle at KEK [1, 2] and PEP-II/BaBar at SLAC [3, 4], have been built and successfully operated for the first decade in 21st century. Comprehensive experimental test of the Kobayashi-Maskawa scheme [5] requires measurements of time-dependent *CP* violation in *B* meson system. It is very demanding measurement to require sophisticated detector and analysis methodology.

Both *B*-factory experiments equipped the 4π general purpose spectrometer with high momentum resolution $\sigma_{p_t}/p_t = 0.3\%$ for 1 GeV/c, ability to detect photons down to 30 MeV with an good energy resolution to realize $\sigma_{\gamma\gamma} = 5$ MeV/c^2 for π^0 decay, lepton identification with more than 90% efficiency and fake rate less than 1%, $K/\pi/p$ separation capability with more than 90% efficiency and fake rate less than 10% and excellent *B* decay vertex reconstruction with $\sigma_z = 80$ μm in the z-coordinate which is along with the incident beam toward the interaction point. The integrated luminosity recorded by Belle exceeds 1 ab^{-1} and BaBar accumulated 550 fb^{-1} thus in total more than 1.5 ab^{-1} including 1 G $B\overline{B}$ pairs are stored at *B*-factories. This high statistics data enabled us to have not only *CP* violation measurements but also many discoveries of new resonances, so-called XYZ states. It turned out that all the features of *B*-factory experiments are great benefits to perform hadron spectroscopy especially in charm and bottom sector.

Revealing the existence of the XYZ states opened a new era of hadron spectroscopy, however there are still many unresolved questions due to statistical limitation even with the available integrated luminosity mentioned above. Since *CP* violation and rare decay searches in bottom, charm and tau flavor sector need much higher statistics data to search for signatures of the physics beyond the Standard Model (SM), the upgrade project to realize SuperKEKB accelerator and Belle II detector [6] is going on. In this report, the prospect of the physics reach in hadron spectroscopy with SuperKEKB and Belle II as well as the design and construction status of the experimental facility are reviewed.

2. Discoveries and synergy among measurements at *B*-factories

Thanks to the excellent accelerator luminosity delivered by KEKB and PEP-II e^+e^- colliders, many new quarkonium(-like) states have been discovered in Belle and BaBar experiments. The most striking examples are; $X(3872)$ which is very narrow though its mass is above *D*-meson pair threshold and found in the $J/\psi\pi^+\pi^-$ final state [7], $Y(4260)$ found also in the $J/\psi\pi^+\pi^-$ final state in the e^+e^- annihilation with the initial state radiation (ISR) [8] and the bottomonium-like charged states, $Z(10610)^\pm$ and $Z(10650)^\pm$ [9] found in $\Upsilon(nS)\pi^\pm$ (n=1, 2, 3), $h_b(mP)\pi^\pm$ (m=1, 2) and $B\bar{B}^{(*)}$.

We have had not only these discoveries but also many synergy effect among measurements including the ones carried out by the experiments other than *B*-factories. Such synergy effects have been giving comprehensive understandings about the discovered states. For example, observation of $X(3872) \to J/\psi\gamma$ by both Belle and BaBar collaborations settled $X(3872)$ to be *C*-even [10, 11]. The decay products' angular distribution in $J/\psi\pi^+\pi^-$ mode by Belle [12] and CDF [13] as well as the 3π invariant mass spectrum in $J/\psi\pi^+\pi^-\pi^0$ mode by BaBar [14] restrict J^{PC} to be 1^{++} or

2^{-+} and LHCb finally determine $J^{PC} = 1^{++}$ [15]. This is a very good example to get a goal with various experiments' interplay.

There are still many other instances of synergetic effects among measurements. Anomalously large cross section of $\Upsilon(nS)\pi^+\pi^-$ (n=1, 2, 3) in the $\Upsilon(5S)$ data [16] inspired us to see the intermediate states of this reaction. This attempt lead to the discovery of the charged states of $Z_b(10610)^{\pm}$ and $Z_b(10650)^{\pm}$ [9] found in the $\Upsilon(nS)\pi^{\pm}$ final state. Motivated by this discovery, the charmonium-like resonance $Y(4260)$ which decays to $J/\psi\pi^+\pi^-$ is further investigated to look for the intermediate states. As a result, both Belle [17] and BES III [18] collaborations found a charged charmonium-like resonance, $Z(3895)^{\pm}$ in the $J/\psi\pi^{\pm}$ final state.

As for the resonance in the $J/\psi\eta$ final state, $\psi(4040)$ and $\psi(4160)$ are seen in the ISR at Belle [19], while no resonant structure was found in the $J/\psi\eta$ system in the $B^{\pm} \to J/\psi\eta K^{\pm}$ decays [20]. The observation in ISR implies a few % branching fraction to $J/\psi\eta$ for $\psi(4040)$ and $\psi(4160)$ and it is compatible with the fact they are unseen in B decay. These measurements give us a comprehensive understanding about those charmonia.

Study of the hyper nuclei attract a lot of attention in nuclear physics field. The ${}^{6}_{\Lambda\Lambda}$He candidate was identified in the event recorded by the emulsion in KEK-PS E373 experiment [21]. On the other hand, search for H-dybaryon in $\Upsilon(1S)$ and $\Upsilon(2S)$ decays in the $\Lambda\Lambda$ final state is carried out and stringent upper limit has been given [22].

We have not only the interplay with existent experiments but also B-factory results are providing important information to design future experiment. Many charmed baryons have been studied or newly observed in B-factory experiments, such as $\Xi_c(2980)^+$, $\Xi_c(3055)^+$, $\Xi_c(3080)^+$ in the $\Lambda_c^+ K^- \pi^+$ final states [23] and so on. On the other hand, charm baryons, especially series of exited states are expected to be a good probe to investigate the dynamics to form hadron from quarks and gluons to see whether the di-quark is behaving as a good degree of freedom. Fixed target experiment to reconstruct charmed baryon production with a missing mass technique is proposed as J-PARC P50 [24]. Since this method doesn't require knowledge about dominant decay modes, good sensitivity is expected for excited charmed baryon states. Here we see good complementarity between exclusive reconstruction at high intensity e^+e^- collider and missing mass technique performed by fixed target experiment at hadron beam facility.

All these interplay examples mentioned above are due to the variety of recorded reactions, B meson decay, ISR, $\gamma\gamma$ collision, bottomonium decays and so on at B-factory experiments. With this feature, the B-factory experiments have been functioning as the "hub" to develop comprehensive understanding about hadron spectroscopy.

3. Limitation with currently available statistics

In spite of the success Belle and BaBar have made, there are still unresolved questions. As already mentioned, $X(3872) \to J/\psi\gamma$ decay has been established, but BaBar reported an evidence of the similar decay mode $X(3872) \to \psi(2S)\gamma$ while Belle found no signature [10, 11]. Since this decay mode becomes quite small in the hypothesis that $X(3872)$ is purely the $D\overline{D}^*$ molecular state, it is important to determine this decay mode's branching fraction. Only larger integrated luminosity of e^+e^- collision at $\Upsilon(4S)$ can clarify this question. For the charged charmonium-like exotic resonance, $Z(4430)^{\pm}$ in its decay to $\psi(2S)\pi^{\pm}$ was reported by Belle but BaBar found only hint with statistical significance of 1.9 σ [25, 26]. Similarly, Belle reported $Z_1(4051)^\pm \to \chi_{c1}\pi^\pm$ and $Z_2(4248)^\pm \to \chi_{c1}\pi^\pm$ in B decays, but BaBar see no significant signal of those resonances in their data [27, 28]. In addition to those, there are still many states for which quantum numbers are not determined. As another issue, many exotic candidate states are observed in only one final state. If they are real particle, there should be several decay modes and relative strength of those branching fractions would give a good constraint to discuss its structure.

In order to solve these questions, higher statistics data are necessary. Belle II experiment at SuperKEKB e^+e^- collider will provide integrated luminosity up to 50 ab^{-1} with 8×10^{35} cm^{-2}s^{-1} at maximum.

4. SuperKEKB accelerator and Belle II spectrometer

In order to achieve high luminosity up to 8×10^{35} cm^{-2}s^{-1}, in SuperKEKB accelerator, the β-function at the interaction point (IP) is necessary to be squeezed down to $\beta_y^* = 0.3$ mm, 20 times smaller than the KEKB collider. In addition, maximum beam currents are to be doubled. These two points are keys to get 40 times as large luminosity as KEKB. Other parameters and components design are chosen to realize the two key points; large beam crossing angle of 83 mad at IP, beam energies are 4.0 GeV positron versus 7 GeV electron in order for reasonable dynamic aperture and new positron beam chambers equipping ante-chamber to take care of electron cloud induced beam instability.

Detector surrounding the IP is also upgraded to Belle II. Two layers DEPFET pixel detectors (PXD) and four layers double-sided silicon strip detectors (SVD) are to be assembled with the beam pipe to form particles' decay vertices detection system. Central Drift Chamber (CDC) is the drift chamber filled with He:C_2H_6=50:50 mixture gas to serve as the main charged particle tracking device. Charged particle identification is performed by the Time-Of-Propagation counter (TOP) and Aerogel radiator based Ring Image CHerenkov detector (A-RICH) in barrel and forward endcap regions, respectively. Electromagnetic CaLorimeter (ECL) is comprised by 8736 CsI(T$_l$) crystal with PIN-PD readout. The readout electronics is upgraded to the one with waveform sampling and digital signal processing to reduce fake hits as well as pileup noise. Since endcap region has higher beam background, replacing by Pure CsI crystals is planned in order for further pileup suppression. In the K_L^0 and μ-on detector system (KLM), resistive planer chambers (RPCs) in innermost two layers in barrel and whole endcaps are replaced by plastic scintillators with fiber and MPPC readout to cope with the higher counting rate.

Constructions of the accelerator and the detector are going on aiming to start accelerator commissioning starts from early 2015. Then the detector will roll in and physics run is to start in 2016. After a couple of years learning period, by gradually increasing machine luminosity toward the design value of 8×10^{35} cm^{-2}s^{-1}, we aim to accumulate 50 ab^{-1} by 2022.

5. Summary

Because of superb detector performance with excellent accelerator luminosity, B-factory experiments have provided many interesting discoveries and opened new era of the hadron spectroscopy especially in heavy flavor hadrons. Those physics results have caused many synergy effects among measurements to reach comprehensive understanding about the observed states. At the same time, we have still unsolved questions due to the limited statistics of currently available data.

With higher statistics unto 50 ab^{-1} in 2020's to be provided by SuperKEKB accelerator and Belle II spectrometer, we pursue to make high luminosity e^+e^- collider serving as the "hub" to give a comprehensive understanding in hadron spectroscopy. For this direction, accelerator and detector construction are going on toward machine commissioning starting from 2015.

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