PROCEEDINGS OF SCIENCE

Super B Factories

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Status of Super B factories, SuperKEKB in Japan and SuperB in Italy is briefly described. These Super B factories are motivated by the successful operations and physics achievements of the current generation of e^+e^- asymmetric B factories (KEKB and PEP-II). To clarify signals of New Physics beyond the Standard Model where some possible hints are seen in Belle and BaBar results, data from 50 (or 75) ab^{-1} of integreted luminosity are planned to be accumulated with the design luminosity of $\sim 10^{36}$ cm^{-2}s^{-1}.

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1. Introduction

It is about ten years since two asymmetric B factories and their experiments started the data taking; BaBar experiment at PEP-II asymmetric energy e^+e^- collider at SLAC in USA and Belle experiment at KEKB in Japan. The main goal of asymmetric B factories is studying the *CP* violation in *B* decays where the large *CP* violation is expected in the Standard Model (SM). When the B factories started, the scenario that we had in mind was following:
(step 1) Discovery of *CP* violation in *B* decays;
(step 2) Precise test of Kobayashi-Maskawa (KM) scheme of *CP* violation and the SM;
(step 3) Search for and finding evidence of New Physics beyond the SM.

The first step was achieved in 2001 using the decay modes B^0 to charmonium and K^0 [1]. In the following years, with much larger data samples thanks to improved accelerator performance, *CP* violation measurements have been made in various decay modes and the Cabibbo-Kobayashi-Maskawa (CKM) matrix elements were measured with improved precisions. These allow the test of the SM and the KM scheme for *CP* violation. The consistency of the sides and the angles of the Unitarity Triangle of the CKM matrix has confirmed the KM scheme [2]. The 2008 Physics Nobel Prize was awarded to Profs. Kobayashi and Maskawa and this tells us that the second step has been successfully achieved. The focus has been now moved to the third step with the measurements of further improved precisions to search for the deviations from the SM or new phenomena that are not expected from the SM. These are subjects of this conference. As mentioned in several talks, hints for New Physics have been seen in various processes. However, data of more than 50 (or 75) ab^{-1} are necessary to clarify these hints[3], which requires Super B factory with the luminosity of order of $10^{36}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Figure 1 show examples of the prospects with 50 at^{-1} data.

Since two *B* factories and experiments have had successful operations and provided fruitful results, it is natural for them to consider the upgrade of their accelerator and detectors for Super *B* factories. Currently two Super B factories are proposed and in progress; “SuperKEKB” [4] as an upgrade of KEKB with upgraded Belle detector and “SuperB” [5] at Frascati in Italy as a successor of PEP-II with upgraded BaBar detector.

2. Designs and Status of Accelerators

2.1 Two Accelerator Strategies

The luminosity of the e^+e^- collider is given by [4]

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm\xi_y}{\beta_y^*}\left(\frac{R_L}{R_y}\right) , \tag{2.1}$$

where $\gamma_\pm$ is a Lorentz boost factor of $e^\pm$ beam, e is the electronic charge unit, r_e is a classical electron radius, $\sigma^*_{y(x)}$ is a vertical (horizontal) beam size at the interaction point (IP), R_L/R_y is a geometrical reduction factors due to crossing angle (and hourglass effect mentioned later), β_y^* is a vertical beta function parameter at the IP, $I_\pm$ and ξ_y are beam current and beam-beam parameter (also called vertical tune shift) of the $e^\pm$ rings. In Eq. (2.1), the following transparency conditions are assumed: $\gamma_+I_+ = \gamma_-I_-$, and all other parameter values ($\sigma^*_{y(x)}$, β_y^* etc.) are same for $e^\pm$ beams. The three parameters, β_y^*, $I_\pm$ and ξ_y are the keys for the high luminosity. There are two approaches

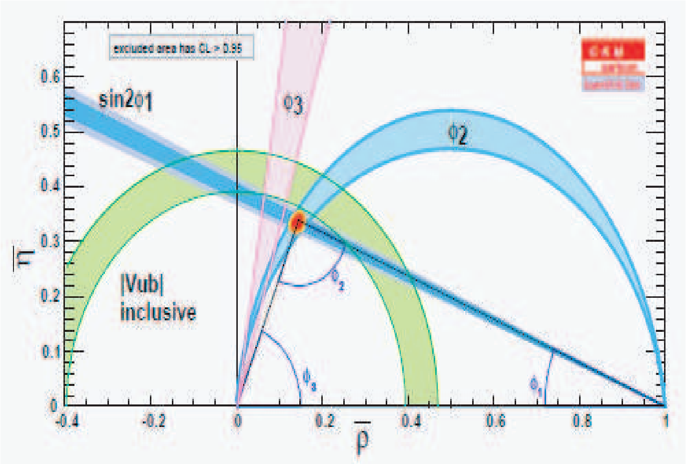

Figure 1: Expected constraints on the CKM Unitarity Triangle with data from 50 ab^{-1} of integrated luminosity.

to try to achieve new luminosity goals: one is try to get the gain mainly from the increase of the beam current ($I_\pm$) and the beam-beam parameter (ξ_y) with moderately reduced β_y^*; the other is to get much smaller β_y^* using a very low emittance beams. The former is called “high current scheme” and originally taken by SuperKEKB group. The latter is originally inspired by the linear collider technology and transfered to storage rings. It is called “nano-beam scheme”and taken by Italian SuperB group.

2.2 SuperKEKB High Current Design

The high current scheme is a natural extension of current KEKB accelerator toward higher luminosity. The design beam currents are 9.4 A for the low energy ring (LER) and 4.1 A for the high energy ring (HER) which is about five times higher than achieved currents by KEKB (1.8 A and 1.45 A). To cope with the high beam current, the whole beam pipe and all vacuum components will be replaced. To reduce the electron cloud effect, an ante-chamber with new design is developed. The number of RF stations will be increased to have more RF power. From the simulations, the high beam-beam parameters can be achieved, 0.3(0.51) for the LER (HER) utilizing crab cavities (more description is given later). With a new design of the optics around IP region, $\beta_y^* = 3$ mm is expected to be achieved which is half of current value (6 mm). With these improvements, the luminosity is expected to increase by about factor 40-50 from the current value ($2 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$).

One of the crucial components in the high current scheme is crab cavities which enable to have about factor two to four larger beam-beam parameter at high beam bunch current needed in the high current scheme. The crab cavity kicks the head and tail of each beam bunch to the opposite side when a bunch goes through the cavity so that the beam bunch is rotated in the horizontal plane by a half of the crossing angle and make two beam bunches collide with an effectively zero-crossing angle (a head-on collision). At high beam bunch current, a head-on collision helps significantly reduce instability due to the collisions and the high beam-beam parameter can be achieved. Crab cavities were installed in KEKB accelerator in February 2007 (one cavity in each beam) and intensive studies and tunings have been made since then. The specific luminosity (luminosity per bunch normalized by the bunch current product) has increased by about 30% with crab cavities compared to that without crab cavities. However, the amount of increase is not as large as expected, and the reason for a rapid decrease of the specific luminosity as a function of the bunch current product is not understood yet.

In early 2009, skew sextupole magnets were added and they allowed control of the behavior of off-energy beam particles. KEKB broke the world luminosity record and achieved a luminosity of 1.96×10^{34} cm^{-2}s^{-1} using the Crab cavities (the record was further renewed to 2.1×10^{34} cm^{-2}s^{-1} in June). This new record is a factor of two higher than the original design luminosity of KEKB. However, relative improvement and the rapid decrease of specific luminosity remain the same.

In the head-on collision case, the beam bunch length should be kept smaller than β_y^* in order to avoid the degradation of luminosity due to collisions outside of focal point (so called hourglass effect). Recent simulation study confirmed the coherent synchrotron radiation effect taking into account realistic conditions. For the short beam bunch, the synchrotron light emitted within a bunch with much longer wave length than bunch length behaves as coherent light and the bunch length becomes longer due to the enhanced disturbance by the synchrotron light; design beam bunch length of 3 mm becomes 5 mm and the luminosity deteriorates from 5 (design) to 3×10^{35} cm^{-2}s^{-1} due to the hourglass effect. This can be recovered by the traveling waste (focus) scheme which was already known in the linear collider.

In summary, the studies on high current scheme have progressed further with realistic conditions and some problems are encountered. Taking these into account, the baseline design luminosity of high current scheme is now 5×10^{35} cm^{-2}s^{-1}.

2.3 SuperB Nano-Beam Design

In nano-beam scheme, the transverse beam size is quite small ($\sigma_x \sim 10\mu$m and $\sigma_y \sim 40$ nm) and two bunches collide with a finite angle (ϕ). The hourglass condition becomes $\beta_y^* > \sigma_x/\phi$ and no constraint is imposed to the beam bunch length. The high luminosity (1×10^{36} cm^{-2}s^{-1}) is achieved by a very small vertical beam size and hence very small β_y^* with a moderate beam currents (~ 3 A) and ξ_y (~ 0.1). The design value of the beam length is 5 mm. The less asymmetric beam energies, 4 GeV for LER and 7 GeV for HER, are chosen, resulting in less boost factor compared to PEP-II and KEKB.

Like crab cavities in the high current scheme, in the nano-beam scheme, a “crab waist” technique provides about a factor two increase of luminosity, where the waist (focal position) of the beam is tilted so that it lies along the other beam. The crab waist is realized by the special sextupole magnets placed before and after the IP. This technique was tested at DAFNE. Successful results were obtained though the beam current and the luminosity were low.

It is planned that SuperB will reuse a number of components of the PEP-II accelerator complex, such as magnets. The site for SuperB was planned at Tor Vergata, University of Rome (recently, it was changed to use Frascati site).

This scheme allows to collision of longitudinally polarized beams. The polarization allows detection of T and CP violation in τ decays and reduces the background which benefits searches for lepton flavor violating τ decays [6]. Also it can operate at the energy of τ and charm threshold region with a luminosity of 10^{35} cm^{-2}s^{-1}, which provides an order of magnitude larger sample

	KEKB Design	KEKB achieved (): with crab	SuperKEKB High-current	SuperKEKB Nano-beam	SuperB
β_y^* LER/HER	10/10	6.5/5.9 (5.9/5.9)	3/6	0.26/0.26	0.21/0.37
ε_x (mm) LER/HER	18/18	18/24	24/18	2.8/2.0	2.8/1.6
σ_y (μm) LER/HER	1.9/1.9	1.9/1.9 (0.94/0.94)	0.85/0.73	0.073/0.097	0.038
ξ_y LER/HER	0.052/0.052	0.108/0.057 (0.129/0.090)	0.3/0.51	0.079/0.079	0.094/0.095
σ_z (μm) LER/HER	4/4	7/7	5/3	5/5	5/5
I_{beam} (A) LER/HER	2.6/1.1	1.8/1.45 (1.64/1.19)	9.4/4.1	3.84/2.21	2.7/2.7
N_{bunch}	5000	1387 (1585)	5000	2252	1740
Luminosity 10^{34} cm^{-2}s^{-1}	1	1.76 (2.11)	53	80	100

Table 1: Summary of parameters for current KEKB, SuperKEKB, and SuperB.

than CLEO-c and BESIII. The unique feature of $D\bar{D}$ pairs produced in quantum coherent state has been proven by CLEO-c [7].

2.4 SuperKEKB Nano-Beam Design

Recently, with a recommendation of the machine advisory committee, the study for nano-beam scheme has been started for SuperKEKB as an alternative option to high current scheme. The major components of the accelerator are kept common with those already designed for high current scheme. The change will be made for components at IP region and bending magnets at arc sections. Preliminary lattice design and optics parameters are made for the luminosity of 8×10^{35} cm^{-2}s^{-1}. The parameters of nano-beam option are similar to those of SuperB. The final design for the SuperKEKB machine in its nano-beam version is expected to be completed in the fall of 2009.

2.5 Luminosity Prospects

The main parameters of current KEKB, SuperKEKB and SuperB accelerators are summarized in Table 1.

The SuperKEKB was officially identified as a high priority project of the KEK in the KEK road map in 2008. The SuperKEKB expects to start operation in 2013 assuming three years construction starting 2010. It is expected to start with a luminosity of $\sim 2 \times 10^{35}$ cm^{-2}s^{-1} and accumulate about 10 ab^{-1} by 2016; expected to increase to the design luminosity 8×10^{35} cm^{-2}s^{-1} and accumulate about 50 ab^{-1} by 2020.

The TDR phase of the SuperB was approved by the INFN for three years (2009 – 2011). It expects to increase a luminosity step by step after starting operation and to reach the design goal of 10^{36} cm^{-2}s^{-1} in two years, which leads to more than 80 ab^{-1} after 6 years.

3. Status of Experiments

The detectors at Super B factories are required to cope with the much higher physics and background rates to keep performance at the level of current B factories and to further improve the overall physics performance.

Experimental groups of both Super B factories plan to use current B factory detectors, Belle and BaBar, upgrading various components for Super B factories.

For the upgraded Belle (Belle II) detector [4, 8], all sub-detectors inside the CsI(Tℓ) electromagnetic calorimeter (ECL) will be replaced with newly built detectors. The current 4 layers of Double-sided Silicon Strip Detectors (DSSD) will be replaced by the inner 2 layers of DEPFET Pixel Detectors (PXD) and outer 4 layers of DSSDs. The central drift chamber (CDC) will be replaced with the same small-cell type drift chamber with a larger inner radius to give a space to outer DSSD layers and avoid the too high hit rates due to beam background. A larger outer radius is possible due to reduced thickness of the particle identification (PID) detector. The larger outer radius results in an improved momentum resolution at high momentum. For PID, the current time-of-flight scintillators and aerogel Cherenkov counters will be replaced with a time-of-propagation (TOP) counter in the barrel region and a proximity-focusing Cherenkov ring imaging counter with aerogel radiators (ARICH) in the endcap region. The barrel ECL detector remains the same, but the readout electronics will be replaced by a waveform sampling scheme. The endcap part will be considered for replacement by pure CsI crystals which have faster signals to reduce the pile-up effect from the beam background. The endcap part of the K_L^0 and muon detector will be replaced by the scintillators tiles with Silicon PMT readout.

For the SuperB detector, the BaBar detector will be upgraded in the similar way [5]. The current five layer silicon vertex tracker (SVT) will be replaced by additional innermost pixel detectors and five layer SVT. The current drift chamber will be replaced by a newly built small-cell type drift chamber with about the same inner and outer radii; a carbon fiber structure is in consideration. It is considered as an option that the stand-off box of the DIRC (detector of internally reflected Cherenkov light) be replaced by a new photon detector system with a smaller size; with forward time-of-flight counters added. For the ECL, a forward detector will be added with new crystals; and backward veto counters are also added. The K_L^0 and muon detector will be replaced by the MINOS-type scintillators [9] for both barrel and endcap region.

A series of workshops have been held and documents produced [6]. The conceptual design report was produced in September 2007 with 320 signatures and about 85 institutes [5]. In June 2008, a MAC (Machine Advisory Committee) was formed with J.Dorfan the chair. Following the recommendation of the MAC, the TRD phase was approved by the INFN in December 2008 as mentioned above. Accordingly, the management structure has been formed with a director M.Georgi; deputies D.Hitlin, D.Leith, and G.Wormser; accelerator head J.Seeman; detector heads F.Forty and B.Ratcliff. The technical design report is expected to be ready by the end of 2010. The second MAC meeting was held in April 2009 and it made further recommendation on proceeding to the TDR phase, with confidence that the design parameters are achievable.

A letter of intent for SuperKEKB was submitted in June 2004 [4] and series of workshops have been held. In January 2008, the KEK Roadmap was issued which officially identified SuperKEKB as a high priority project of KEK. Following a few open proto-collaboration meetings, the new collaboration for a SuperKEKB experiment was officially formed in December 2008. Although the majority of the Belle II collaboration consists of current Belle institutes/members, it is constituted as a separate collaboration and has different organization from Belle. P.Krizan has been selected as the first spokesperson and M.Yamauchi serves as a project manager. About 300 physicists (including students) in 43 institutes from 13 countries and regions participate the Belle II.

4. Summary

The asymmetric energy e^+e^- *B* factories, KEKB and PEP-II, have achieved excellent performance and their experiments, Belle and BaBar, have successfully produced many valuable results. Particularly, the discovery of the *CP* violation in the *B* meson system and verifications of the KM anzats that the source of *CP* violation in weak decays is single irreducible phase in the CKM matrix. This led to the award of the 2008 Physics Nobel Prize to Profs. Kobayashi and Maskawa. Furthermore, various results on some decays which are sensitive to new physics provide hints of new physics. To clarify these hints are really due to new physics, much more data (50 – 75 ab^{-1}) are necessary. Although the SM describes almost all the experimental results in current accelerator experiments, new physics beyond the SM is required from various aspects. A Super B factory with a luminosity of $\sim 10^{36}$ $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ is expected to provide important results in exploring new physics.

A Super B factory experiment is complementary to LHC experiments in two aspects: energy frontier physics (ATLAS and CMC) and luminosity frontier of *B* physics (LHCb). Energy frontier experiments mainly explore the diagonal elements of the new physics flavor couplings, i.e. mass of new physics particles. Super B factory experiments explore the off-diagonal elements which are necessary to identify the model of new physics. Even if new physics particle masses are too heavy to find at the LHC, they can be probed via loop diagrams in *B* decays The LHCb experiment has advantages in the produced number of *B* mesons and capability of studying B_s, Λ_b and other *b*-flavored particles. On the other hand, Super *B* factory experiments can study *B* decays with neutrinos, photons, and π^0 with a clean environment.

Currently, two Super *B* factory projects, SuperKEKB in Japan and SuperB in Italy, are in progress, both in accelerators and detectors. Each group hopes to start construction of the accelerator and upgrade of the detector, and to start data taking as they plan.

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