PROGRESS IN SUPER B-FACTORIES

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Abstract

The upgrade of B-Factories to Super B-Factories, which will search for new physics beyond the Standard Model, opens the way for a new luminosity frontier. The status of Super B-Factories is reported.

INTRODUCTION

Two asymmetric energy electron-positron colliders, KEKB and PEP-II, have continued to push the luminosity frontier, opening up a new era with luminosity on the order of 10^{34} $cm^{-2}s^{-1}$. With the success of the two B-factories, the search for "new physics" beyond the Standard Model utilizing further challenging colliders with the design luminosity of about 10^{36} $cm^{-2}s^{-1}$, two orders higher than the B-factories, has become an urgent program in particle physics. Two Super B-factories, SuperKEKB [1] at KEK, and SuperB/INFN [2] located at Tor Vergata near Frascati, have been proposed [3].

The designs of both Super B-factories are based on the Nano Beam Scheme [4], which was first proposed for SuperB. In this scheme, a large horizontal crossing angle between the beams at the interaction point (IP) is introduced to shorten the longitudinal crossing region, which reduces the hourglass effect and makes it possible to reduce the vertical beta function at the IP, β^*_y.

SuperKEKB was approved by the Japanese government as an upgrade of KEKB partially in 2010, and fully in 2011. The construction of SuperKEKB is currently under way. Commissioning of the accelerator will start early 2015, and the Belle II detector roll-in is scheduled for the summer of 2015.

In 2012, after a costing review of the SuperB project [5] a decision was taken by INFN to cancel it, due to budget issues. A study for a dedicated high luminosity τ/charm factory based on the design of SuperB has started, keeping costs in the allocated budget.

The status of SuperKEKB is described in this paper. The study for the Italian τ/charm factory is also reported.

STATUS OF SUPERKEKB

The main parameters of SuperKEKB are shown in Table 1. The intra-beam scattering is included in the calculation. The extremely small β^*_y together with low horizontal emittance and small *x-y* emittance ratio reduces the vertical beam size at the IP to 50 – 60 nm, one-twentieth of that of KEKB. At the same time, the stored beam current in both rings will be approximately double that of KEKB. The beam-beam parameters are chosen at the modest values that were achieved at KEKB. The design luminosity is 8×10^{35} $cm^{-2}s^{-1}$, which is 40 times higher than that achieved at KEKB, and the goal is to accumulate an integrated luminosity of 50 ab^{-1}.

Table 1: Main Machine Parameters of SuperKEKB.

	LER(e^+)	HER(e^-)	units
Beam energy	4	7.007	GeV
Circumference	3016.315		m
Crossing angle: full	83		mrad
Horizontal emittance	3.2	4.6	nm
Vertical emittance	8.64	11.5	pm
Coupling	0.27	0.28	%
β^*_x / β^*_y	32 / 0.27	25 / 0.30	mm
Vert. beam size at IP	48	62	nm
Energy spread	8.10	6.37	10^{-4}
Beam current	3.60	2.60	A
Number of bunches	2500		
Energy loss/turn	1.86	2.43	MeV
RF frequency	508.9		MHz
RF voltage	9.4	15.0	MV
Bunch length	6.0	5.0	mm
Vert. b-b param.	0.088	0.081	
Luminosity	8×10^{35}		$cm^{-2}s^{-1}$

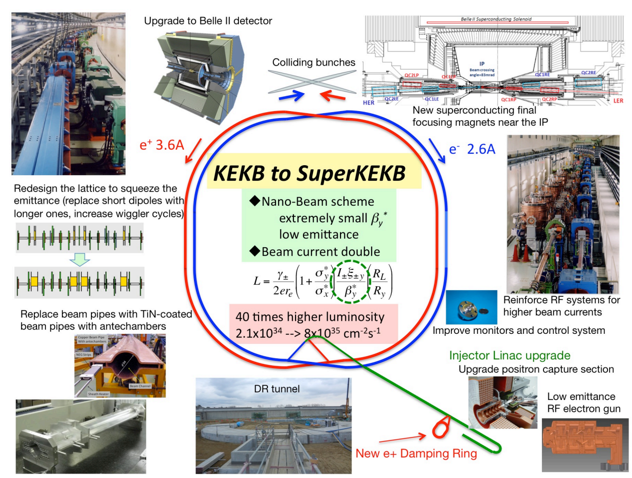

Figure 1: Layout and scheme for SuperKEKB.

As schematically shown in Fig. 1, the upgrade of KEKB to SuperKEKB addresses the following new, rebuilt, modified, and reinforced items:

- The horizontal emittances in both rings are reduced by redesigning the lattices. The optics design is also optimized to ensure small *x-y* emittance coupling ratio and a sufficiently large dynamic aperture.
- To realize the extremely low beta optics, the beam lines of about 300 m length around the IP are completely rebuilt. A new superconducting final-focus magnet system as well as local chromaticity correction sections for both the vertical and horizontal planes will be employed.
- To cope with the electron cloud issues and heating problems, antechamber-type beam pipes are adopted

with a combination of other measures such as TiN coatings, grooved shape surfaces, and clearing electrodes.
- To store twice as large beam currents and to provide beams with 2.5 times the power of KEKB, the RF system needs rearrangement and reinforcement. The cooling system is also reinforced.
- The beam monitor and control systems are improved for the small beam size and more accurate control of the beams.
- The injection beams into the rings are required to have low emittance and high charge. The injector Linac will be upgraded with a new low-emittance electron gun, an improved positron source, and good emittance preservation. A new damping ring reduces the emittance of the positron beam from the Linac.

Design Improvements

While construction proceeds, the design work continues to finalize the most critical region, including the interaction region (IR). The overall optimization of the IR design is in progress, considering various viewpoints:
- Optics design to obtain a sufficiently large dynamic aperture and long beam lifetime.
- Evaluation of the beam background (BG) at the Belle II detector and various measures to reduce the BG such as collimation and shielding.
- Design optimization of magnets, beam pipes, and other hardware components.
- Mechanical support and assembly procedure in very tight spaces.
- Beam motion due to ground motion and measures.

The final focusing magnet system is crucial for the extremely low-beta optics. The performance is very sensitive to various machine errors, in particular in the IR. Modeling of the IR optics is being refined by using three-dimensional calculation of the magnetic field.

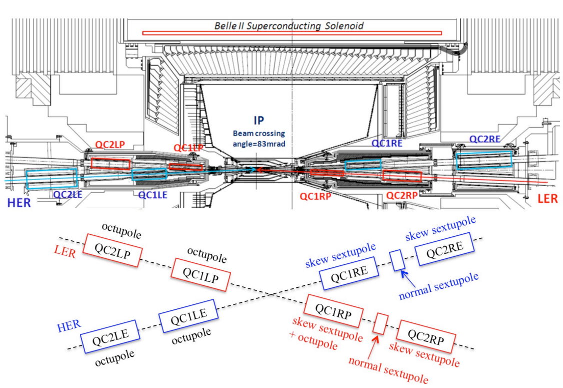

Figure 2: Schematic drawing of the final focus system of SuperKEKB (upper) and layout of sextupole and octupole corrector coils (lower).

Figure 2 shows a schematic drawing of the final focus system. Eight superconducting main quadrupole magnets are utilized as doublets for vertical (QC1's) and horizontal (QC2's) focus. In order to correct the leakage field from QC1RP and QC1LP, which are located closest to the IP and have no return yokes, a cancel corrector coil is located in the HER beam line. Compensation solenoid magnets are installed in the cryostats to compensate for the Belle II solenoid fields. Each main quadrupole magnet has correction coil windings: horizontal and vertical dipoles to correct horizontal and vertical misalignments, a skew quadrupole to correct rotation error, and multipoles to optimize the dynamic aperture. The design and fabrication of the correction coils are in progress through the BNL/KEK collaboration [6].

Recent design improvements are described below. First, it was found by a three-dimensional magnetic field calculation with the Belle II solenoid field that the magnetic field in the iron yokes of the main quadrupole magnets could easily go over 1T when the compensation is not perfect, which generates an unacceptably large leakage field in the other beam line. In order to suppress the leakage field, Permendur is adopted for yokes on QC1E and QC2P and for shielding [7].

Second, it was also found that a possible sextupole error field in QC1 seriously deteriorates the dynamic aperture. The original design did not include sextupole correction coils. Since fabrication of the left side magnets already had started, possible ideas for changing the right side magnet design have been studied. The result showed that by adopting normal and skew-sextupole correction coils as shown in Fig. 2 (lower), the dynamic aperture recovers to the level obtained without sextupole errors [8]. This scheme will be adopted for the fabrication of the right side magnets that starts in JFY2013.

Collision control is also crucial for the very small beam size at the IP. To prevent single beam vertical emittance growth, the final focus magnets movement should be less than 200 nm [9]. However, to prevent emittance growth due to a beam-beam effect, the relative displacement of final focus magnets between both rings should be kept much less, about ±0.1~0.2 σ_y (5~10 nm) [10]. The ground motion at the floor level in the IR has been measured, and the response of the QCS cryostats to this ground motion is being analyzed [11]. The specifications for a feedback system to control collision are under discussion.

Beam loss and collimation scheme are being evaluated to estimate and effectively reduce BG at the Belle II detector and to meet requirements from radiation safety. The very small beam size and small aperture at the IR beam pipes shorten the Touschek lifetime, approximately 10 minutes. The very high luminosity shortens the lifetime owing to radiative Bhabha process to about 30 minutes. Lifetime due to beam-gas Coulomb scattering is also about 30 minutes, and total lifetime is only 6 minutes in both rings.

Optimization of the horizontal and vertical movable collimators was carried out to minimize the BG at the Belle II detector from the Touschek and beam-gas

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scattering, while keeping as long lifetime. In particular the nearest horizontal collimators just before the IP play an important role to effectively reduce the BG. Figure 3 shows the optimized layout of the collimators [12].

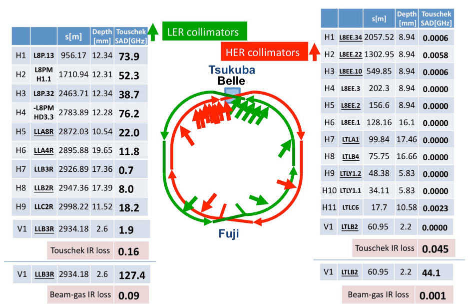

Figure 3: Optimized layout of the collimators [12].

The BG due to the radiative Bhabha process remains a big concern to Belle II. Sufficient neutron shielding is required to protect the outermost detectors. Furthermore, it was found that electromagnetic showers generated by particles with very large energy loss inside the detector area could unacceptably shorten the lifetime of the cathodes of photomultipliers in the TOP detector [13]. In order to mitigate the problem, tungsten shields are added inside the QCS cryostats wherever possible.

Construction Status

The overall schedule of the SuperKEKB construction and commissioning is shown in Fig. 4. The construction plan is optimized considering various boundary conditions such as budgetary profile, contract process, design progress, technical issues and civil engineering.

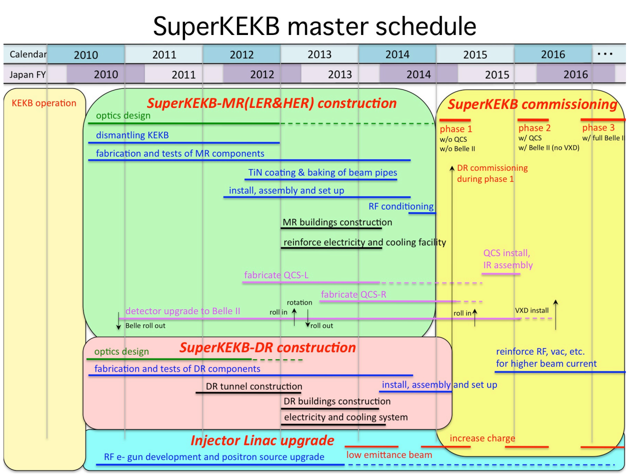

Figure 4: Schedule of SuperKEKB construction and commissioning.

Vacuum system Mass production, surface treatments including TiN coating and baking, and installation of beam pipes and other vacuum components in the tunnel are under way. The experimental decks at the KEKB Oho laboratory were reconstructed to build TiN coating stations, baking stations, and a clean room for assembly (Fig. 5, lower left). Approximately 1000 beam pipes will be TiN coated and 1200 baked in two years. Five vertical-type coating facilities and four baking facilities have been established, and steadily operating to treat about 15 beam pipes per week. Thus far, approximately 460 and 550 beam pipes have been coated and baked, respectively. The operation will continue through next year with the aid of three new horizontal-type coating facilities made especially for the bent beam pipes.

Figure 5: Copper and aluminum antechamber-type beam pipes (upper). Vacuum work deck, and TiN coating and baking facilities (lower).

Magnet system The mass production, assembly, field measurements, and installation of new magnets as well as power supplies for magnets are ongoing. The replacement of dipole magnets in the LER arc sections with new 4 m length ones have been completed. The rearrangement of the LER wiggler sections to have twice as many wiggle pitches for the same length by adding new half pole and single pole wiggler magnets as well as installation of wiggler sections in the HER is also completed (Fig. 6). The Tsukuba straight section of 300 m length has been dismantled for a complete rebuild.

Surveying of the tunnel and the alignment of magnets around the ring is ongoing. The rough alignment has been done, and more fine alignment continues.

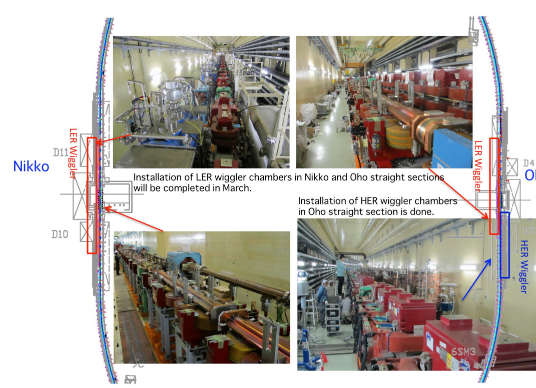

Figure 6: Wiggler magnets and antechamber-type beam pipes installed in the Nikko and Oho straight sections.

RF system In order to increase the power delivered to beam, the RF system needs to be rearranged and reinforced, as shown in Fig. 7. The rearrangement of the ARES cavities has already been done. Adding nine RF sources will be carried out in two phases; five stations are being added before, and the additional four will be after, the commissioning. Eight LLRF stations will be replaced with new ones, which are equipped with μTCA-based digital boards with EPICS-IOC embedded FPGA [14].

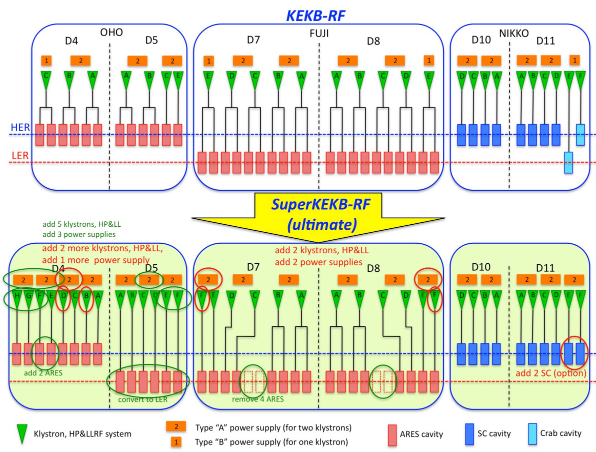

Figure 7: Rearrangement and reinforcement of the RF system.

Monitors and control Beam instrumentations including beam position monitors and bunch-by-bunch feedback system are under fabrication. To measure very small vertical beam size, an X-ray beam size detector based on coded aperture imaging is being developed [15].

Damping ring (DR) The DR tunnel construction has been completed, and the construction of buildings for the DR started. The fabrication and test of magnets and power supplies is ongoing. Antechamber-type of beam pipes is used to avoid the electron cloud issues. Mass-production of the chambers is ongoing. A prototype of new accelerating cavity for the DR was fabricated and successfully high-power tested. Two cavities will be installed in the DR.

Injector Linac The upgrade of the injector Linac is schematically shown in Fig. 8. The development of a low emittance, high charge RF gun is in progress. A 4.4 nC charge was demonstrated using a cathode of Ir5Ce and a DAW cavity [16]. A quasi-travelling wave side-couple structure is also being developed as an alternative [17].

The improvement of the positron source to increase charge is ongoing. A SLAC-type flux concentrator is being developed. Large aperture S-band (LAS) accelerating structures will be installed for the capture section. The issue of a satellite bunch addressed for the S-band structures has been solved by adopting high gradient deceleration by a few LAS just after the target [18].

The alignment of the Linac components should be improved to prevent emittance dilution. Errors of 0.1 mm and 0.3 mm are required locally and globally, respectively. The present alignment system using laser photo detectors with necessary improvements as well as a laser tracker system is considered. Beam-based alignment will also be introduced later [19].

		KEKB e^+ / e^-	SuperKEKB required e^+ / e^-
Beam energy	GeV	3.5 / 8.0	4.0 / 7.0
Bunch charge	nC	1 / 1	4 / 5
Beam emittance (γε)	μm	~2100 / ~100	10 / 20
Repetition rate	Hz	50	50

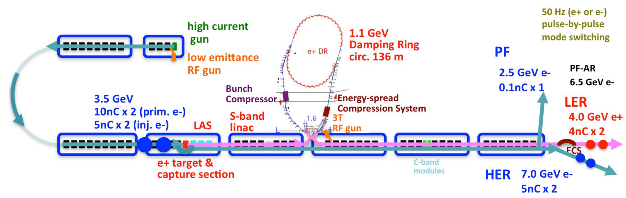

Figure 8: Upgrade of the injector Linac and a new positron damping ring.

Commissioning Scenario

The commissioning scenario has been discussed between the accelerator group and the Belle II group, and a baseline scenario was determined. The SuperKEKB rings commissioning will be performed in three phases.

- Phase 1: Beam operation without QCS and Belle II. Basic machine tuning, low emittance beam tuning, and vacuum scrubbing with beam currents up to about 0.5~1.0 A will be performed. In the latter half of this period, commissioning of the DR will start.
- Phase 2: Beam operation with QCS and Belle II, but no vertex detectors. The β^*_y will be gradually squeezed to avoid risks to Belle II. Small *x*-*y* coupling tuning, collision tuning, and background studies will be performed.
- Phase 3: Physics runs starts with the full Belle II detector. Beam currents will be increased by adding more RF stations. Beam tuning will continue to increase the luminosity. The operation period each year depends on budget and cost, mostly determined by electricity. Figure 9 shows the expected luminosity projection, assuming nine months of operation.

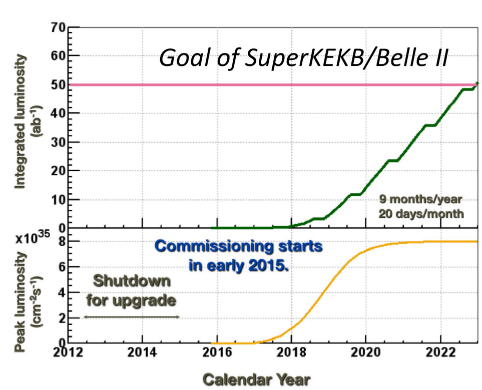

Figure 9: Luminosity projection of SuperKEKB.

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FROM SUPERB TO TAU/CHARM

After the decision on the SuperB project in 2012, a study for a dedicated high luminosity τ/charm factory has started. It has to be noted that this program was already planned as a second phase of SuperB, so most of the work done in the past years can be used for the new project. Main features of the Italian τ/charm project are:

- Energy tunable in the range E_{cm}=1 – 4.6 GeV
- 10^{35} $cm^{-2}s^{-1}$ peak luminosity at the τ/charm threshold and upper
- Symmetric beam energies
- Longitudinal polarization in the e^- beam (60-70%)
- Possibility of e^-e^- collisions (to be studied)

Design features are similar to those of SuperB: "large Piwinski angle and crab waist sextupoles" collision scheme, low H-emittance lattice, small H-V coupling for ultra low V-emittance, small IP β functions and beam sizes, beam-beam tune shifts < 0.1, low beam currents to keep low power costs. Beam parameters to reach a baseline luminosity of 10^{35} $cm^{-2}s^{-1}$ at 4 GeV c.m. energy have been chosen, an upgrade to 2×10^{35} $cm^{-2}s^{-1}$ being possible by increasing the beam currents. The main beam parameters for the baseline at 2 GeV/beam are listed in Table 2. Intra-beam scattering (IBS) and hourglass effects are included [20].

Table 2: Tau/charm Beam Parameters@2GeV/beam

Parameter	Value	Units
Luminosity	10^{35}	$cm^{-2}s^{-1}$
Circumference	~330	m
X-crossing angle (full)	60	mrad
Tune shifts (X/Y)	0.005 / 0.1	
IP betas (X/Y)	6 / 0.06	cm
IP sigmas (X/Y)	17.7 / 0.09	μm
Emittances (X/Y) with IBS	5.22 / 13	nm/pm
Bunch length with IBS	5.6	mm
Beam current	1570	mA
RF frequency	476	MHz
Number of bunches	506	
Damping times (X/Y)	33 / 47	msec

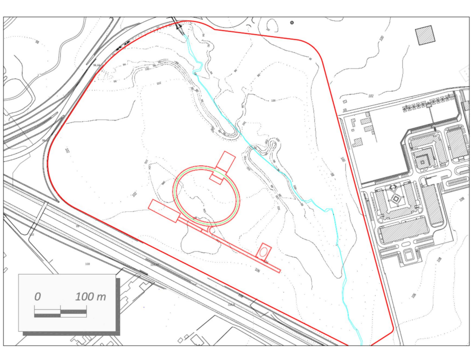

Figure 10: Layout of Tau/charm complex at Tor Vergata.

The layout of the project is shown in Fig. 10. The equal beam energies simplify the design with respect to SuperB and result in a more compact and cheaper complex. One Siberian Snake in the electron ring will rotate the spin to have longitudinal polarization at the IP. The lattice design for the low emittances has almost been completed. The final focus system has been optimized for the lower energy and different IP functions.

The τ/charm injection system delivers full energy, low emittance beams to the main rings at a maximum energy of 2.3 GeV/beam. The injection has been designed to be continuous in order to keep nearly constant beam current and luminosity. The layout of the injection system is based on the design of the SuperB injection system [21], in order to use the same linac and DR. The main difference with respect to the SuperB design is the fact that only positrons will be stored in the DR.

CONCLUSIONS

Construction of SuperKEKB is underway, and the commissioning is scheduled early 2015. Finalizing the design is also in progress for the most critical region, in particular for the IR.

SuperB has been cancelled due to budget issues, but a design for a τ/charm factory has started, based on the previous work done for the SuperB.

ACKNOWLEDGMENT

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REFERENCES

[1] Belle II Technical Design Report, http://xxx.lanl.gov/abs/1011.0352.
[2] SuperB Progress Report: Accelerator, arXiv:1009.6178v3.
[3] M. Masuzawa, proceedings of IPAC'10, p. 4764. H. Koiso, proceedings of IPAC2011, p. 1931. M. E. Biagini, proceedings of IPAC2012, p. 2086.
[4] P. Raimondi, 2nd SuperB Meeting, Frascati (2006).
[5] M. E. Biagini, P. Raimondi, and J. Seeman editors, "SuperB Progress Report – Accelerator", http://arxiv.org/abs/1009.6178v3.
[6] B. Parker et al., proceedings of IPAC2012, p. 2191.
[7] N. Ohuchi, private communication.
[8] H. Sugimoto, private communication.
[9] Y. Ohnishi, private communication.
[10] K. Ohmi, private communication.
[11] H. Yamaoka, private communication.
[12] Y. Funakoshi, Y. Ohnishi, private communication.
[13] H. Nakayama, private communication.
[14] T. Kobayashi et al., WEPME014, these proceedings.
[15] J.W. Flanagan et al., proceedings of IPAC'10, p. 966.
[16] D. Satoh et al., MOPFI023, these proceedings.
[17] T. Natsui et al., TUOCB103, these proceedings.
[18] T. Kamitani, private communication.
[19] K. Furukawa et al., TUPME010, these proceedings.
[20] M. E. Biagini, private communication.
[21] S. Guiducci et al., proceedings of IPAC'12, p. 2032.