OVERVIEW OF B-FACTORIES

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Abstract

An overview of the status of two recently approved high luminosity B-Factories, the SuperB in Italy and the SuperKEKB in Japan, will be presented. These colliders will profit of the successful experience of the PEP-II (SLAC) and KEKB (Tsukuba) B-Factories, boosting up the target luminosity with a new collision scheme. The main design features of both projects to reach the very high luminosity requested and the status of progresses in design and construction will be given.

INTRODUCTION

The SuperB collider project [1] has been approved by the Italian Government as part of the National Research Plan. SuperB is a high luminosity (10^{36} cm^{-2} s^{-1}) asymmetric e^+e^- collider at the Y(4S) energy. The design is based on a "large Piwinski angle and Crab Waist" scheme already successfully tested at the DAΦNE Φ-Factory in Frascati, Italy. The project combines the challenges of high luminosity colliders and state-of-the-art synchrotron light sources, such as two beams (e^+ at 6.7, HER, and e^- at 4.2 GeV, LER) with extremely low emittances and small beam sizes at the Interaction Point (IP). As unique features, the electron beam will be longitudinally polarized at the IP and the rings will be able to ramp down to collide at the τ/charm energy threshold with a luminosity of 10^{35} cm^{-2} s^{-1}.

The SuperKEKB collider [2] is an upgrade of KEKB in the same tunnel, also based on the scheme with large Piwinski angle and small emittances, but the use of crab sextupoles is not planned at the moment. The HER and LER rings (with energies scaled down to 4 and 7 GeV with respect to KEKB) will be renewed to meet the emittance requirements, a new positron ring damping ring and an upgrade of the injection lines are also part of the construction plans. Polarization of the electron beam is not part of the design.

A summary of the main parameters for both colliders is presented in Table 1.

Table 1: SuperB and SuperKEKB Main Parameters

Parameter	SuperB		SuperKEKB	
	HER (e^+)	LER (e^-)	HER (e^-)	LER (e^+)
Luminosity (cm^{-2}s^{-1})	10^{36}		8x10^{35}	
C (m)	1200 m	1200 m	3016	3016
E (GeV)	6.7	4.18	7.007	4
Crossing angle (mrad)	60		83	
Piwinski angle	20.8	16.9	19.3	24.6
I (mA)	1900	2440	2600	3600
$\varepsilon_{x/y}$ (nm/pm) (with IBS)	2/5	2.5/6.2	4.6/11.5	3.2/8.6
IP $\sigma_{x/y}$ (μm/nm)	7.2/36	8.9/36	10.7/62	10.1/48
σ_l (mm)	5	5	5	6
N. bunches	978		2500	
Part/bunch (x10^{10})	5.1	6.6	6.5	9.04
σ_E/E (x10^{-4})	6.4	7.3	6.5	8.14
bb tune shift (x/y)	0.0026/0.107	0.004/0.107	0.0012/0.081	0.0028/0.088
Beam losses (MeV)	2.1	0.86	2.4	1.9
Total beam lifetime (s)	254	269	332	346
Polarization (%)	0	80	0	0
RF (MHz)	476		508.9	

SUPERKEKB STATUS

With respect to KEKB the design of SuperKEKB, with the so-called "nano-beam" scheme, requires double beam currents, reduced IP beta functions, higher energy for LER (from 3.5 to 4 GeV to suppress the emittance growth due to IBS and have longer Touschek beam lifetime), and lower HER energy (from 8 to 7 GeV to reduce the beam emittance and the power losses). The collider will be hosted in the KEKB tunnel, and to meet the beam parameters requested by the collision scheme as many as possible KEKB accelerator components will be reused.

Lattice

In order to decrease the horizontal emittance in HER about 60% of the available KEKB-LER wigglers will be installed in HER, with the possibility to increase their number if necessary. Fig. 1 shows a detail of the Oho straight section with the position of the wigglers.

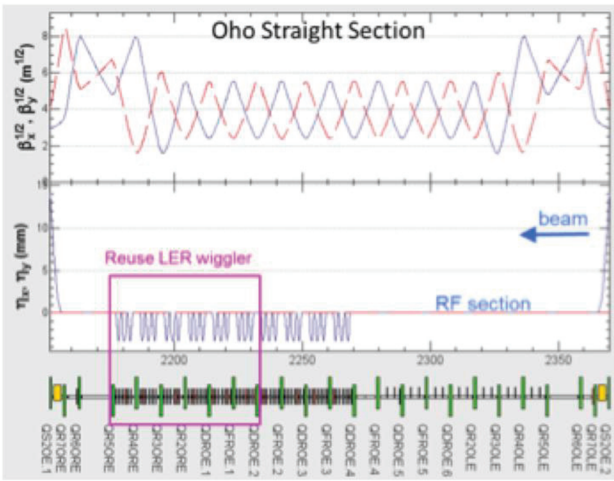

Figure 1: HER lattice in the Oho straight with wigglers.

The lattice model includes:

- the 3D detector solenoid field;[3]
- the higher order multipoles (sextupole, octupole, decapole, dodecapole normal & skew) in the IR;
- the H-V dispersion and X-Y coupling correction by normal dipoles, skew dipoles, and skew quadrupoles;[4]
- the local chromaticity correction scheme (Y first, with π phase advance from IP, and X later, with 2π).

The dynamic aperture (DA) has been optimized by using both sextupoles (normal or skew) and octupoles. HER has a smaller horizontal acceptance ($\pm 10\ \sigma_x$) with respect to LER ($\pm 20\ \sigma_x$).

The computed Touscheck lifetime so far is 480 s for LER and 580 s for HER, with still room for optimization.

The injection scheme still needs some work, since a synchrotron injection scheme is necessary in HER.

Estimation of error tolerances and development of optics correction system are in progress. Error tolerances of Interaction Region (IR) magnets (in terms of vibrations, ripple of power supplies, etc) are very small. Requirement for BPM detectors (characteristics and number) are still to be decided. Realistic solution to maintain good conditions of optics and collision should be developed. Sufficient correction and tuning knobs for optics correction and luminosity tuning, such as correction winding of each quadrupole (0.5%), skew quadrupole windings of each sextupole, rotated sextupoles or skew sextupoles to correct chromatic couplings, should also be provided.

Interaction Region

The design of the IR in terms of magnets, vacuum chamber, beam backgrounds estimation, collimation system, has been improved. The 3D magnet designs of the SC-QCs (see Fig. 2) have been completed.

Figure 2: Schematic layout of near IP quadrupoles.

Iron yokes for the IP Super Conducting quadrupoles, and magnetic shields on the beam pipes have been introduced. Calculation of 3D solenoid field is on-going, and all coils needed for correctors and leak field cancellation will be manufactured by BNL. A QC1P magnet prototype was constructed and cold tested at 4 K with the vertical cryostat in January, showing no quench up to the nominal current (1512.6A and G=74.56T/m). The test results are acceptable for the production of the real ones, Fig. 3 shows the QC1P magnet prototype. Magnetic field measurements were performed in February. Error multipole fields in the magnet straight section were measured and resulted less than 1.5×10^{-4} w.r.t. the quadrupole field at the radius of 9.77 mm.

Figure 3: SuperKEKB QC1P magnet prototype.

In order to force the integrated solenoid field to zero from the IP, additional SC solenoids are designed inside the QC2RE iron yoke on both beam lines.

Some critical issues need still to be solved, such as Beam-Gas backgrounds, collimation system, and radiation shield. A collision feedback still needs to be studied. The production IR (300m Tsukuba straight) vacuum components and magnets is scheduled in 2012 and 2013.

Vacuum System

The Al ante-chamber beam pipes for LER arc sections (700 pieces, 2km length) is on-going. Bellows and gate-valves for arc and wiggler sections will be completed soon, as well as the Cu beam pipes for wiggler sections in LER and HER. Sets of baking and TiN coating system are being built. Movable masks, SR and X-ray monitor

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chambers will be made in 2013 and 2014, since R&D is still going on. The replacement of some HER components for higher beam current before or after the commissioning start will depend on the budget.

Magnet System

Fabrication and field measurement of LER 4m dipole magnets have been done. These will be installed in the tunnel in the first half of 2012. Half-pole and single-pole wiggler magnets, LER V-steering magnets, and some of Q magnets are being made. The power supplies for the main dipole magnets and wiggler magnets are also in progress, while those of medium and small power will be ordered in late 2012 or later.

For what concerns the alignment and tunnel, some measurement after the earthquake of March 2011 showed a significant movement of tunnel. A GPS system has been installed and investigation of the ground (boring, etc.) is going on.

RF System

Some upgrades are needed to cope with the higher beam current, such as a change to 1 klystron to 1 ARES cavity scheme and the re-arrangement of the ARES cavities. Change of the input coupler of the ARES cavities to increase coupling "b" from 3 to 6 is also in progress. Klystrons, power supplies, and new LLRF are being added. A cure for increasing HOM power has to be studied.

Injection System

The KEKB injection system is being upgraded [5] to obtain: a higher (4~8-times) injection beam current to meet the need for larger stored beam current and the shorter beam lifetime in the ring; a lower injected beam emittance to meet the nano-beam scheme requirements in the ring (this is achieved with a positron Damping Ring (DR), an electron photo-cathode RF gun and emittance preservation by better alignment and beam instrument-tation); the quasi simultaneous positron and electron injection, with improvement of the beam instrumentation, Low-level RF, controls, etc.

For the positron source the new L-band structure is ready to be tested, and large aperture S-band structures are in fabrication. The new positron DR (1.1 GeV), as well as the electron and positron compression systems are in construction. The DR optics design is almost fixed. The beam pipe cross section has been decided from the view point of CSR and beam acceptance. Fabricating magnets and power supplies are on-going as scheduled. Test beam pipes (Al, ante-chamber) are being made. Mass production will be conducted in 2012. The R&D of DR cavity is also going on. A prototype cavity has been completed in 2011, and will be high-power tested soon. Tunnel construction has started and buildings will be completed in 2013.

Since tunnel construction was delayed for six months due to the earthquake, the installation of components will start only one year before the commissioning start, and the original schedule in 2014 will be then very tight for installation, cabling and piping, system checks, etc.

SUPERB STATUS

The SuperB site has been chosen to be the campus of the Tor Vergata University, just 5 Km away from the INFN Frascati National Laboratories. The layout of the SuperB accelerator is shown in Figure 4 below.

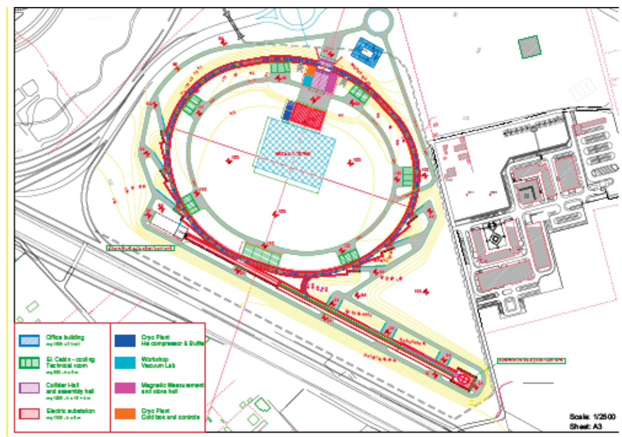

Figure 4: SuperB layout on the Tor Vergata University site.

The project has been approved by the Italian Research Minister as part of the Italian National Research Plan, with a 5 years construction budget. An international consortium, the "Nicola Cabibbo Laboratory", in charge of the construction and operation of the collider and detector, has been created in October 2011. A detailed cost review of the accelerator is in progress at the moment in order to meet Government approval for further funds in October 2012.

The SuperB collider is described in detail in a revised edition of the Conceptual Design Report [1], but the original design has been lately reviewed in order to meet the requirements of the new site. In particular the location of the injection complex and the length of the rings have been modified. Some Synchrotron Radiation (SR) beam lines were also foreseen for a future use of SuperB as a SL source, and the lattice has been modified accordingly to be able to meet the user requests in terms of beam spot. However at the moment this option is not foreseen for the phase 1.

A recent development is the option to use the HER Linac for a SASE-X-FEL in parasitic mode to the collisions. Work is in progress to exploit the design and evaluate possible issues.

Lattice and Errors

The baseline lattice design is almost frozen, requiring just few fixes in the geometry of the IR. The design is based on very low H-V emittances, low emittance coupling and very small beam sizes at the IP. Moreover the crab-waist sextupoles demand for particular care in designing the chromaticity correction in the Final Focus (FF). The two HER and LER rings have equal circumference and very similar small emittance lattices, inspired to those of modern SR sources.

A vertical beam tilt of 2.6 mrad between the LER and HER median planes was introduced in the IR. As a result, the first horizontal dipole now declines the beam vertically also providing a 0.9m rings separation in the vertical plane at the IP counter point. This separation will allow, if required, SR beam lines output from both LER and HER. A separate chromaticity correction scheme has been developed for the Arc-cells and for the FF. In the Arcs a scheme, where all sextupoles are paired with a (-I) transfer matrix, provides optimum correction and very small chromatic W functions and second order η function in both planes. In the FF a special scheme has been designed with separate YCCS and XCCS sections (H-V chromaticity correction sextupoles) in phase with the IP.

Dynamic aperture studies, with tracking codes and Frequency Map Analysis [6] are in progress in order to minimize the crab sextupoles influence.

A procedure to obtain and maintain the reference emittances is mandatory for SuperB. For this purpose the LET (Low Emittance Tuning [7]) tool for the correction of the effects of magnet errors has been implemented. LET is a modified response matrix method that extends the Dispersion Free Steering (DFS) technique with correction of Orbit, Dispersion and Coupling at the same time. The method, very efficient and fast, has been tested both at Diamond Light Source (RAL) [8], where a vertical emittance of 1.7 pm rad was achieved, and at the Swiss Light Source (PSI) with a resulting vertical emittance of 1.3 pm rad. The application of the LET tuning at DAΦNE is also in progress. First tests gave very promising results, showing the influence of the BPM roll errors in the LET correction. This test is of crucial importance for SuperB, since it will allow to test the technique in a collider with a very low-β insertion. The production of tables of error tolerances for both the SuperB LER and HER elements is in progress.

Interaction Region

The IR was designed to have a total crossing angle at the IP of 60 mrad, the lowest value allowing for enough beams separation, at the same time avoiding SR backgrounds from large transverse orbits which can cause too much backgrounds on the detector beam pipe.

The two beams will be focused by two independent magnetics systems. No quadrupole will be shared among the LER and the HER. The advantage of this design choice with respect to most conventional ones is the smaller dispersion attainable inside the QD0. This is a bonus for both the machine (smaller equilibrium emittance) and the detector (lower background rates). In the present design the HER (LER) permanent magnets (PM) quadrupoles will provide the first IP vertical focusing. The remaining vertical focusing strength will be provided by two (one) SCQ, with warm bore cryostat. Extra focusing for the HER is provided by other two quadrupoles (QD0H, QF1H). Soft upstream bend magnets are used to reduce the SR power in the IP area as much as possible. This applies especially to the inside walls of the cryostats.

IP Quadrupoles

The design of the SCQ is particularly challenging. The thermal load by synchrotron radiation on the beam pipe inside the SCQ will be ~200W, so a cold bore design is not suitable. The horizontal beam stay-clear and the crossing angle at the IP fix both the warm bore diameter to 24 mm and the maximum thickness allowed for the cryostat and the SC cold mass to 22 mm.

The SCQ will be build using a double helical winding scheme [9] and a novel compensation technique [10] to cancel out the cross talk among adjacent quadrupoles (i.e. LER QD0 upstream and HER QD0 downstream, see sketch in Figure 5).

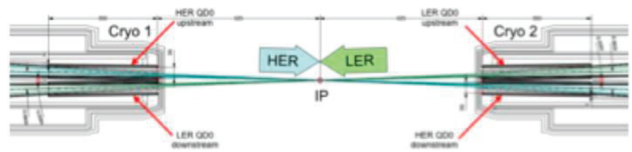

Figure 5: Schematic layout of the near IP quads.

The critical aspect of these SCQ is the limited amount of space available for the SC wires and for their thermal stabilization and protection. A double helical quadrupole prototype has been built and its quench behaviour has been studied. The prototype generates a gradient of 50 T/m on a cold bore diameter of 50mm operating at 2650 A. The first tests demonstrated the capability of the magnet to operate at the design current in steady state, and survive very well to quenches also for currents higher than the design one.

Injection System

For the injection system baseline [11], to be used in the cost estimate, simple and well tested solutions have been chosen, so that no further R&D is requested and components available on the market are preferred. The scheme (see sketch in Fig. 6) is flexible enough to allow for the introduction of alternative solutions that can improve performances or reduce costs once their feasibility is proven.

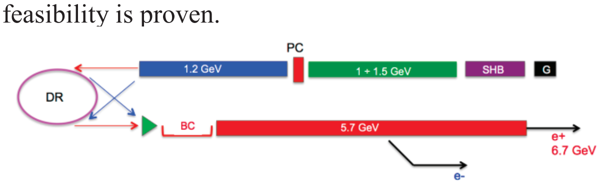

Figure 6: SuperB Injection system sketch.

Electrons will be produced using a polarized gun like the one used by the SLC collider at SLAC, where a polarization of 80% has been routinely achieved. A single electron bunch (or a short train of up to 5 bunches), with up to 10 nC charge will be produced and passed through a sub-harmonic bunching system to reduce the bunch length from 1 ns FWHM down to 10 psec. The charge required

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for injection into main rings is 300 pC/bunch in 5 bunches. All the 3 linac sections are based on S-band SLAC type accelerating sections with SLED systems.

Positrons will be produced by electrons accelerated in Linac1 impinging on a positron converter target. Linac 2 will be used to capture and accelerate positrons up to 1 GeV before DR injection. The electron energy at the positron converter will be evaluated to get the required charge with 5 bunches per pulse. A preliminary estimate gives ~ 1-1.5 GeV. Both beams will be stored in a Damping Ring (DR) for emittance damping. Electrons are accelerated up to 1 GeV in Linac 1 and injected into the DR. Simulation of Coherent Synchrotron Radiation in the DR showed that no instability should arise, since radiation is well suppressed by the chamber shielding [12].

Simulations of the injected beam together with beam-beam interactions have been carried out [13], showing that the effect of the crab sextupoles is beneficial. In Fig. 7 contour plots of the injected beam distribution in the plane of normalized betatron amplitudes are shown. 10^5 particles were tracked, and their coordinates over 100 consecutive turns were collected to build the distribution. Top plots refer to the undamped injected beam (first 100 turns), bottom plot to the beam after 30000 turns. Left plots show the case without bb interactions, center plots same with bb interactions and crab sextupoles OFF, right ones with bb interactions and crab sextupoles ON.

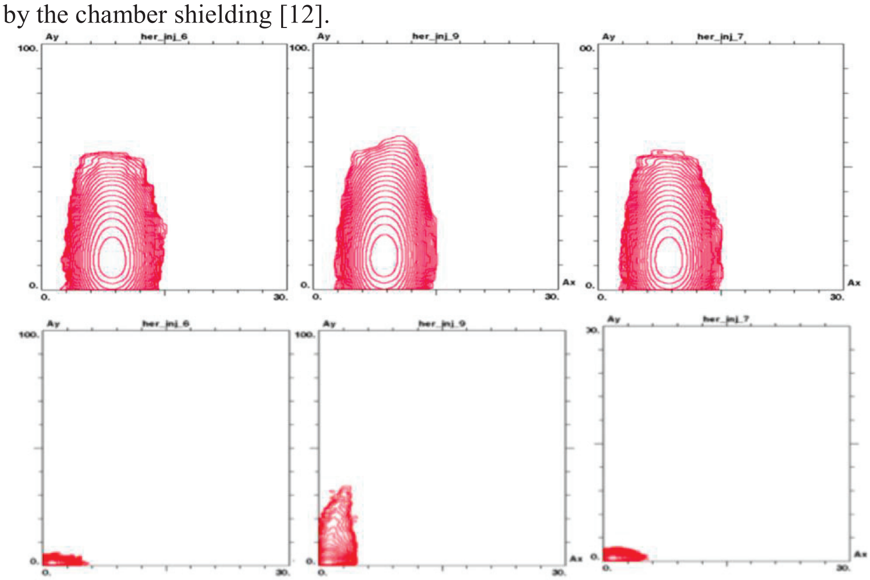

Figure 7: Effect of crab sextupoles on injected beam. Top: injected beam, bottom damped beam. Left: no bb interactions, center: bb interactions + crab sextupoles OFF, right: bb interactions + crab sextupoles ON.

CONCLUSIONS

SuperB and SuperKEKB will allow to study high precision B Physics with unprecedented high luminosity. The construction of SuperKEKB is proceeding fast, profiting of the KEKB tunnel and rings components, in parallel with recovery work from the March 2011 earthquake. Design work still remains, in particular for very difficult parts including the IR. The commissioning is foreseen for end of 2014. SuperB has to face the challenge of the construction from scratch of a big accelerator complex. However the design is almost completed and most of the crucial decisions have been taken. A detailed cost review will be completed before the summer, in order to proceed with the acquisition of components and the TDR of some parts.

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