The SuperB project: accelerator status and R&D

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THE SUPERB PROJECT: ACCELERATOR STATUS AND R&D

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Abstract

The SuperB collider project [1] has been recently 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. 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 relatively low beam currents (about 2 A) will allow for low running (power) costs compared to similar machines. The insertion of beam lines for synchrotron radiation (SR) users is the latest feature included in the design [2]. The lattice has been recently modified to accommodate insertion devices for X-rays production.

INTRODUCTION

The SuperB collider has been approved by the Italian Research Minister as part of the Italian National Research Plan, with a 5 years construction budget. The next steps will be the formation of an international consortium in charge of the construction and operation of the collider, detector and SR beam lines.

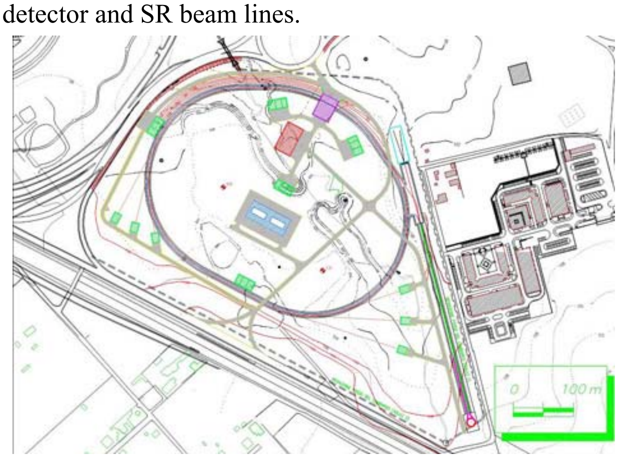

Figure 1: SuperB rings in the Tor Vergata University site.

Recently the construction site for SuperB has been selected in the campus of the Tor Vergata Rome II University, just 5 Km away from the Frascati Laboratories. Fig. 1 is a sketch of the rings in the new site. A Consortium agreement between INFN, Tor Vergata University and the Research Ministry is being signed, allowing for the constitution of the international "Cabibbo Laboratory", where the SuperB project will be hosted. A Memorandum Of Understanding is in preparation between INFN and SLAC for the use of many of the PEP-II rings components in SuperB.

THE ACCELERATOR

The SuperB collider is described in a revised edition of the Conceptual Design Report [1] where the design principles have been described in detail. Main parameters are summarized in Table 1.

Table 1: SuperB main parameters @ 10^{36} cm^{-2}s^{-1}

Parameter	**HER (e^+)**	**LER (e^-)**
C (m)	1260 m	1260 m
E (GeV)	6.7	4.18
I (mA)	1900	2440
$\varepsilon_{x/y}$ (nm/pm) (with IBS)	2/5	2.5/6.2
IP $\sigma_{x/y}$ (μm/nm)	7.2/36	8.9/36
σ_l (mm)	5	5
N. bunches	978	978
Part/bunch	$5.1\text{x}10^{10}$	$6.6\text{x}10^{10}$
σ_E/E	$6.4\text{x}10^{-4}$	$7.3\text{x}10^{-4}$
bb tune shift (x/y)	0.0026/0.107	0.004/0.107
Lifetime (s)	254	269
Polarization (%)	0	80
RF (MHz)	476	476

HER and LER rings have equal circumferences and will be hosted in the same tunnel. Their magnetic lattice is very similar, HER will use the PEP-II HER dipoles, while LER will have new ones. Most of the PEP-II hardware can be reused in SuperB, and at present work is in progress to establish the list of components that will be shipped from SLAC to Italy.

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SuperB 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 SuperB optics has been recently modified for the option to install Insertion Devices for future use as a Synchrotron Light Source. A separate chromaticity correction scheme has been developed for the two rings 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, where the β-functions reach a maximum, which works very well in terms of dynamic aperture and off-momentum behavior of α, β and tunes. It has to be noted that a "perfect" correction is preferable for the "crab-waist" sextupoles, located at both ends of the FF, to avoid reduction of the dynamic aperture. A coupling correction scheme with the detector solenoid ON has been also designed [3].

BEAM DYNAMICS

A lot of work has been done and is still in progress on the most relevant beam dynamics issues, such as e-cloud instability, intra-beam scattering (IBS), Touschek backgrounds, etc. More details can be found in the papers presented at this conference.

Touschek effect is the main source of lifetime reduction, even if the limiting effect for lifetime are the luminosity backgrounds. Touschek lifetime is computed with a tracking code [4] which takes into account the lattice design and nonlinear elements. Special care is needed to control Touschek particle losses and reduce possible showers in the detectors. A set of collimators that fulfils this requirement has been found, with 3 primary H collimators in the FF, intercepting most of the particles that would be lost in the IR. A secondary collimator at s=-21 m will stop the remaining Touschek scattered particles generated so close to the IR that primary collimators cannot be effective. With the insertion of collimators the computed lifetime is 6.6 min in LER and 33.2 min in HER. The rings lifetime in collision is however dominated by the luminosity beam lifetime, a few minutes for each ring.

A Low Emittance Tuning (LET) procedure has been developed [5] to correct magnet misalignments and BPM errors to achieve minimum coupling, β-beating and vertical emittance. Tables of error tolerances have been produced for both the LER and HER elements. The β-beating due to magnet misalignments after correction is between 3-5% in both planes for a rms misalignment error of 300 μm, the emittance coupling factor is always less than 0.1% (design is 0.25%). A comparison of performances with the LOCO tool, used for tuning in most SR rings, has been performed at the DIAMOND facility at RAL, showing that LET can indeed achieve comparable results in much less time.

Calculations based on a high energy approximation of the Bjorken-Mtingwa formalism show that IBS should be manageable in both SuperB rings. However some interesting aspects such as the impact of IBS during the damping process and its effect on beam distribution have been investigated using a newly developed multi-particle tracking code, based on the Zenkevich-Bolshakov algorithm [6]. Benchmarking with conventional IBS theories gave good results, and a new semi-analytical model fits simulation results very well, being thus able to predict IBS effect at various bunch currents.

The effect of electron cloud in SuperB has been also estimated. Build up and instability simulations show that e-cloud is a serious issue for the HER. An antechamber absorbing 99% of the synchrotron radiation and a maximum SEY of the surface below 1.2 could ensure stable operation because it would prevent e-cloud formation and its detrimental effect on the positron beam. A test of e-cloud clearing electrodes is being carried out at the DAΦNE ring to check their effectiveness in suppressing the instability.

IP QUADRUPOLES

The SuperB collision scheme requires a short focus final doublet to reduce the vertical beta function down to β_y*=0.2 mm at the IP. The final doublet will be composed by a set of permanent samarium cobalt magnets (PM) and superconducting (SC) quadrupoles. In the present design the HER (LER in parentheses) PM quadrupoles provide an integrated gradient of 23.1 T (11.2 T) over a magnetic length of 11 cm (7cm). The front pole face will be placed at 38 cm (30 cm) from the IP. The remaining vertical focusing strength will be provided by two (one) SC quadrupoles having an integrated gradient of 39.2 T (28.7 T) over a total magnetic length of 45 cm (30 cm). A cold bore design for the SC quadrupoles is not viable since the synchrotron radiation coming from the upstream dipoles will deposit a ~ 200W on the beam pipe section inside the SC. The requested horizontal beam stay clear fixes both the warm bore diameter to 24 mm and the maximum thickness allowed for the cryostat and the SC cold mass to 22 mm. This limited amount of available space together with the requested field purity and gradient strength poses very demanding constraints on the SC magnets design. An advanced design of the quadrupole has been developed, based on the double helical coil concept [7]. A prototype is being constructed and results of test of a model of the superconducting quadrupole based on NbTi technology will be available soon.

SITE AND VIBRATIONS

The chosen SuperB site is very convenient for its vicinity to the Frascati Labs (just 5 Km away). Ground vibration measurements [8] have been performed on site and have shown its very good ground stability, even with the highway only 100m away.

For the FF vibrations a budget has been established [9], including ground motion data, motion sensitivity of machine components and beam feedback system requirements. The small beam sizes at the IP pose stringent vibration requirements. Beam position at the IP is very sensitive to individual motion of IR components. However, the present IR design with shared elements in a common cryostat will cause coherent motion of these elements, greatly reducing the vibration sensitivity of the IR. The vertical displacement of IP and FF quadrupole should be kept below 300 nm rms while the rotation should be less than 2 μrad rms. The arc quadrupoles should be kept to less than 500 nm rms. The measured values during last vibration campaign at the IP, FF and Arcs are respectively 20-40 nm, 20-30 nm and 20-30 nm. A fast luminosity feedback system should have a bandwidth of at least 100 Hz, achieving at least 10x vibration reduction at low frequencies. With these requirements in the present lattice the vibration budget can be met even during the noisiest part of the day, with a vibration-induced luminosity loss of less than 1%.

FEEDBACKS

R&D on the longitudinal and transverse bunch-by-bunch feedbacks is continuing. The DAΦNE feedback systems have been upgraded last year also to test bunch-by-bunch feedback architectures proposed for SuperB [10]. Both e^+/e^- longitudinal feedback systems have been completely replaced with new hardware for increased reliability and better diagnostics. In the effort to reduce residual dipole beam motion, determined by the front-end and quantization noise floor, vertical feedback systems now feature a 12-bit ADC, in place of the old 8-bit design.

For the "luminosity" IP feedback at present two approaches are being considered. One is an extension of the fast luminosity feedback already operating at PEP-II B-Factory [11]. It uses fast dither coils to induce a fairly high dither rate for the x position, the y position and the y angle at the IP. The luminosity signal is read out with three independent lock-in amplifiers. An overall correction is computed, based on the lock-in signal strengths, and beam corrections for x and y position and y angle at the IP are simultaneously applied to the beam.

The other approach is based on the FONT5 intra-train feedback system developed for the ATF facility at KEK [12], aiming at stabilizing the beam orbit by correcting both the position and angle jitter in the vertical plane on a bunch-to-bunch timescale, providing micron-level stability at the entrance to FF system.

Work on a machine Control System of fairly new conception have also started at LNF (see details in [13]).

INJECTION SYSTEM

The injection complex has been updated to better exploit the necessity of high efficient e^+ production and top-up injection of polarized e- beam into the rings [14]. The present design features only one damping ring (DR) for e^+, lower energy e^+ production and polarized gun for the e^-. A sketch is shown in Figure 2.

The e^+ conversion will be performed at low energy (0.6 GeV) thanks to a newly designed high efficiency system, consisting of an adiabatic capture system after the conversion target, followed by a L-band section to inject at 1 GeV into the DR, allowing for an increase of the capture yield to ~ 30 %.

An S-band Linac at 100 Hz will be used for main rings injection at 50 Hz. Two e^- guns will be used: a "high current" for e^+ production and a "low emittance" polarized gun for e^- injection. This scheme reduces transfer lines and kickers for DR injection/extraction. The possibility to use C-band Linacs to reduce the Linac length is under study.

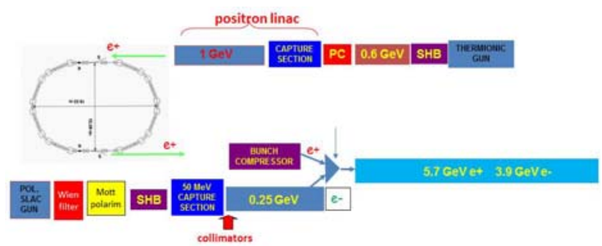

Figure 2: SuperB injection system.

SR BEAM LINES

The installation of SR beam lines (50-100m long for large demagnification) in the HER has been proposed. Several experiments can be carried out, such as X-ray diffraction, SAXS, imaging with phase contrast, all requiring photon energy between 4 and 15 keV. Low divergence (1 mrad to 1 μrad) and very small spot size (1 μm) are also required. For this purpose the lattice has been modified to have at least 6 straight sections where Insertion Devices (ID) can be installed. Particular care has been devoted to maintain the small horizontal emittance and at the same time obtain betatron functions suitable to the ID needs. Work is in progress to evaluate ID parameters, such as undulator gaps, to avoid narrow gap IDs and impedance issues with high current operation.

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