THE SuperB ACCELERATOR PROJECT


1 Introduction

SuperB [1] is an asymmetric (6.7 GeV HER, 4.2 GeV LER) $e^+e^-$ collider at the center of mass $\sqrt{s}$ $= 10.58$ GeV, to be built in Italy, with a design peak luminosity of $10^{36}$ cm$^{-2}$ s$^{-1}$. A collider like SuperB will open a unique window on this physics because it allows a high statistics study of the current hints of new aggregations of quarks and gluons. Besides the physics one can study in running at the $\Upsilon(4S)$ resonance, the following alternative energies are of interest: $\Upsilon(3S)$ (at least 0.3 ab$^{-1}$) and a high luminosity scan between 4-5 GeV (5 MeV steps of 0.2 fb$^{-1}$ each would require a total of 40 fb$^{-1}$). While this is not huge statistics, this scan is only feasible with SuperB. The only possible competitor, BES-III, is not planning to scan above 4 GeV, since their data sample would, in any case, be lower than that of the B Factories alone. Finally, the search for exotic particles among the decay products of the "bottomonia" can probe regions of the parameters space of non-minimal supersymmetric models that cannot be otherwise explored directly, for instance at LHC.

The superiority of SuperB with respect to the planned upgrade of KEKB lies both in the ten times higher statistics, which broadens the range of cross sections the experiment is sensitive to, but also in the flexibility to change center of mass energy, and the possibility to collide with a polarized electron beam. Moreover the SuperB design will also allow for running at the $\tau$/charm threshold with an expected luminosity of $10^{35}$ cm$^{-2}$ s$^{-1}$.

The SuperB project has been approved by the Italian Government as part of the National Research Plan. The design is based on a large Piwinski angle and Crab Waist scheme already successfully tested at the DAΦNE $\Phi$–Factory in Frascati, Italy. The project combines the challenges of high luminosity colliders and state-of-the-art synchrotron light sources, with two beams 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 tau/charm energy threshold with one tenth the luminosity. 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 users is the latest feature included in the design. The lattice has been recently modified to accommodate insertion devices for X-rays production.

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. In October 2011 for the construction and operation of the facility the "Nicola Cabibbo Laboratory" has been founded, as a consortium between INFN and the University of Rome II at Tor Vergata. Memorandum Of understanding (MOU) are in progress with France, SLAC and BINP (Russia).

Four general SuperB meetings have been organized in 2011: in March at LNF, in June at Elba (Italy), in September at Queen College (London, UK) and in December at LNF. A complete description of the work done is available from the meetings slides at:


In the following section the work performed at LNF on the design of the accelerator will be briefly described. This activity at LNF has been funded by the INFN NTA commission, and has received by INFN a special funding in 2010-2011.
2 Design strategy

SuperB consists of two rings of different energy (positrons in HER, 6.7 GeV, electrons in LER, 4.2 GeV) colliding in one IR at a large (60 mrad total) horizontal angle. Spin rotator sections in the LER will provide helicity of a polarized electron beam. With respect to the past years design an important change is to have polarized electrons in the LER instead of the HER. This was chosen for easier insertion of Spin Rotator (SR) sections in LER lattice. Also the beam energies have been changed in order to avoid spin resonances, with a consequent small reduction of the center-of-mass boost.

The two rings lay in the horizontal plane, each has two arcs and two long straight sections. The Final Focus (FF) in one straight is combined with the two Arcs in two half-rings (one inner, one outer) and a straight section on the opposite side. The straight section comes naturally to close the ring and readily accommodate the RF system and other necessities (e.g. injection). In this utility region crossing without collisions for the two rings will be provided.

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 FF. The accelerator lattice optics has been modified in 2011 to be able to install Insertion Devices in some of the straight sections, 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 dispersion 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 $\beta$ functions reach a maximum, which works very well in terms of dynamic aperture and off momentum behavior of $\beta$ functions 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 Year 2010 activity

3.1 Beam dynamics

During 2011 a lot of work has been done on the most relevant beam dynamics issues, such as e-cloud instability, intra-beam scattering (IBS), Touschek backgrounds, etc. 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 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 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 microns, 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.

IBS of particles inside a bunch can lead to an unwanted increase of the emittances and bunch length. 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. 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 instability in the positron ring 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 has been carried out successfully at the DAΦNE ring to check their effectiveness in suppressing the instability.

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 microrad) and very small spot size (1 micron) 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.
3.2 IP quadrupoles

The SuperB collision scheme requires a short focus final doublet to reduce the vertical $\beta$ function down to $\beta_y^*=0.2$ 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 values in parentheses) PM quadrupoles provide an integrated gradient of 23.1 T (11.2 T) over a magnetic length of 11 cm (7 cm). 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 about 200 W 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. A prototype has being constructed and results of test of a model of the superconducting quadrupole based on NbTi technology are very encouraging. The design is a collaboration among LNF, INFN-Pisa and INFN-Genova.

3.3 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. Both $e^+$ and $e^-$ 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, which is an essential component of the luminosity tuning for the high performances requested at SuperB, at present two approaches are being considered. One is an extension of the fast luminosity feedback already operating at PEP-II B-Factory. 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, 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. Studies of both systems will be carried out next year, probably both will be adopted.

3.4 Control System

SuperB is pushing us to study and implement new ideas in controls, to be up to date in integrating commercial web technologies and to overcome the primary issue coming from previous architectures: the limits due to the usage of specific hardware and software. The Frascati and Tor Vergata control groups have a long experience in design, development and implementation of innovative Control System. This experience and know-how is available today for a new challenging project. The idea is to design a new controls system based on the present software trends, dominated by web technologies and services, where large databases and the most robust available data bus, Ethernet, are used to match very high throughput. The large community of developers and users involved guarantees a good support and may give hints on the longevity of the product. The new CS, must be designed in such a way to accommodate any kind of devices to reduce the
hardware dependence and the development time by exploiting the availability of many devices with embedded programmable CPU. Furthermore, the CS has to be able to control and, where needed, to acquire data with performance limited only by the hardware capability. These requirements suggest inverting the typical CS device-client data flow from polling (the client polls) to pushing (the device push) information. A Control Library (CL) completely manages data and commands flow, the control processes and the devices configuration. The devices programmer is only asked to develop the driver for the specific controlled hardware. The plans have been to develop the core software of the Control Library and to explore its critical issues, if any, by the end of 2011. Some preliminary test started on the DAΦNE and SPARC accelerators at LNF, where is available a natural gym to understand any possible problem and rapidly solve it in a real operative contest. These preliminary tests have confirmed that the performance of a non-relational database resident on RAM is practically limited only by Ethernet bandwith. The systems load is very low, while redundancy and scalability allows being confident on the behaviour for a larger accelerator complex such as the SuperB.

3.5 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. The very low beam lifetime requires continuous injection at high repetition rate in order to keep the luminosity almost constant at the peak value. 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 Fig. 2. The main difference with respect to the previous scheme is the fact that only the positron beam is stored in the DR while the electron beam is directly accelerated and injected. In this way the positrons can be stored in the damping ring for the time between two injection pulses (before it was half this time) achieving the same emittance damping factor at twice the repetition frequency. Therefore it is possible with a 100 Hz linac to inject at 50 Hz in each ring using a single bunch per pulse to make the current per bunch very uniform along the ring. The $e^+$ conversion will be performed at low energy (0.6 GeV).

![Figure 2: Sketch of the SuperB injection system.](image-url)
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 about 30%. In the electron mode 12 out of 40 RF stations of the 6 GeV linac are switched off to accelerate the beam at 4.2 GeV. The positron converter is followed by a 1 GeV L-band linac that allows a large positron capture and transport efficiency. L-band, room temperature linacs are unusual in the field of particle accelerators: one is in operation at the University of Osaka, another one is foreseen for injection into the SuperKEKB collider. Both are based upon the use of 30-40 MW Klystrons and SW two meter length copper sections, with average gradient of 12 to 13 MV/m. R&D on these cavities is being carried out at LAL, Orsay. An S-band Linac at 100 Hz will be used for main rings injection at 50 Hz. Two electron 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 also under study.

3.6 Site studies

The chosen SuperB site is very convenient for its vicinity to the Frascati Labs (just 5 km away). Ground vibration measurements have been performed on site and have shown its very good ground stability, even with the highway only 100 m away. For the Final Focus vibrations a budget has been established, 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 micro-rad 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%.

4 Year 2012 activity

The organization chart for the Accelerator structure, including several groups for the different sub-systems, is being decided and will be in charge of the construction of the facility. The first half of 2012 will be devoted to a revision of the accelerator costs by the leaders of the accelerator sub-systems. This will allow to have a full endorsement by the Machine Review Committee in the Fall. In parallel we will proceed as much as possible with the technical drawings of the machine components and site and layout issues.

In the following is a list of the publications the Accelerator Division SuperB group has issued in the framework of the SuperB collaboration.

5 Publications in 2011


6 References