NEW LOW EMITTANCE LATTICE FOR THE SUPER-B ACCELERATOR

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Abstract

New low emittance lattices have been designed for the asymmetric SuperB accelerator, aiming at a luminosity of 10^{36} cm^{-2} s^{-1}. Main optics features are two alternating arc cells with different horizontal phase advance, decreasing beam emittance and allowing at the same time for easy chromaticity correction in the arcs. Emittance can be further reduced by a factor of two for luminosity upgrade. Spin rotation schemes for the e^- beam have been studied to provide longitudinal polarization at the IP, and implementation into the lattice is in progress.

INTRODUCTION

The SuperB project [1] aims at the construction of a very high luminosity (10^{36} cm^{-2} s^{-1}) asymmetric (4 on 7 GeV) e^+e^- Flavour Factory with possible location at the campus of the University of Rome Tor Vergata near the INFN Frascati National Laboratory.

The design is based on a novel collision scheme, the “large Piwinski angle and crab waist” [2, 3], which will allow to reach unprecedented luminosity with low beam currents and reduced background at affordable operating costs. A polarized electron beam will allow for producing polarized τ leptons, opening an entirely new realm of exploration in lepton flavor physics. The principle of operation of this scheme is under test at the DAΦNE Frascati Φ-Factory [2,4].

A Conceptual Design Report (CDR) [5] was issued in May 2007, with about 200 pages dedicated to the accelerator design.

Several accelerator issues such as site requirements, crab waist compensation, parameter optimization in order to save power consumption and costs, first IP quadrupole design, Touschek backgrounds and spin rotators have been addressed after completion of CDR, and the rings lattice has been modified accordingly.

BEAM PARAMETERS

The SuperB accelerator consists of two rings of different energy colliding in one Interaction Region (IR) at a large horizontal angle. The crab waist scheme, with a couple of sextupoles per ring at appropriate phase with respect to the IP, will provide suppression of betatron and synchrobetatron resonances arising from the crossing angle geometry. Spin rotator sections in the HER will provide helicity of a polarized electron beam.

The three operation scenarios (Nominal, upgrade and ultimate) have different peak luminosity goals: the upgrade one will use emittances 50% smaller than the nominal, while the ultimate will push up the beam currents and number of bunches.

SuperB beam parameters are summarized in Table 1.

Table 1: SuperB main parameters

Parameter (LER/HER)	Nominal	Upgrade	Ultimate
Energy (GeV)	4/7	4/7	4/7
Luminosity ($cm^{-2}s^{-1}$)	$1x10^{36}$	$2x10^{36}$	$4x10^{36}$
C (m)	1800	1800	1800
N. of bunches	1251	1251	2502
F_{RF} (MHz)	476	476	476
N. part/bunch	$5.5x10^{10}$	$5.5x10^{10}$	$5.5x10^{10}$
I_{beam} (A)	1.85/1.85	1.85/1.85	3.7/3.7
β_x* (mm)	35/20	35/20	35/20
β_y* (mm)	0.22/0.39	0.16/0.27	0.16/0.27
ε_x* (nm rad)	2.8/1.6	1.4/0.8	1.4/0.8
ε_y* (pm rad)	7/4	3.5/2	3.5/2
σ_x* (μm)	10/5.7	7/4	7/4
σ_y* (μm)	0.039	0.023	0.023
σ_z (mm)	5.	4.3	4.3
α_c ($x10^{-4}$)	3.2/3.8	3.2/3.8	3.2/3.8
θ_{cross}(mr)	48	48	48
$\tau_{x,y}/\tau_s$ (ms)	40/20	28/14	28/14

RINGS LATTICE

The optimization of the ring lattices, performed after the CDR completion, aimed to minimize the intrinsic emittance so that nominal values can be obtained even without wigglers and the ring circumference is shortened, better fitting the proposed construction site.

When increasing the horizontal phase advance μ_x in the SuperB arc cell, the intrinsic emittance naturally decreases. The damping time increases by 30% but the RF power decreases, with a net operational costs saving. Beam-beam simulations (see for example in [5], page 211) have studied the degree to which an increase in the damping time affects the luminosity and beam-beam induced tails: an increase by a factor of 2.5 does not lead to any substantial luminosity degradation. In the new lattice the longitudinal damping times are of the order of 20 msec in both rings, about 1.3 times larger than the CDR values and still below the threshold of beam tail growth.

LER and HER lattices are very similar, and based on the reuse of most PEP-II (SLAC) hardware. The arcs have an alternating sequence of two different cells: a $\mu_x = \pi$ cell, that provides the best dynamic aperture, and a $\mu_x = 0.72$ cell that has a much smaller intrinsic emittance and provides a phase slippage for the sextupoles pairs, in such a way that one arc corrects all the phases of the chromaticity. As a consequence, the chromatic functions W_x and W_y are lower than 20 and the second order dispersion is almost zero everywhere except in the Interaction Region (IR). With this arrangement, the number of arcs can be reduced to 4, with two 40 m long “empty” wiggler sections for the upgrade scenario. The increase of the phase advance, together with future wigglers installation, will provide the required emittance and damping time for the upgrade parameters. With 14 cells in each arc a horizontal emittance of 1.6 nm in HER and 2.8 nm in LER are obtained, the LER lattice having still room for further reduction. The LER optical functions are shown in Fig. 1 (HER’s are very similar), while the 2 different phase arc cells for HER (top) and LER (bottom) are shown in Fig. 2.

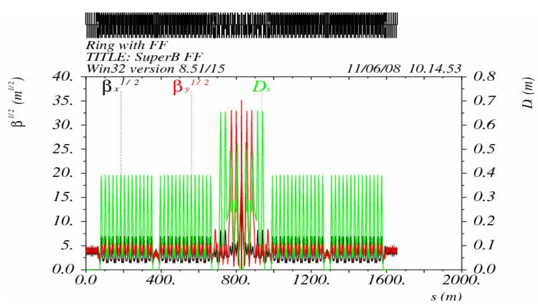

Figure 1: LER optical functions.

INTERACTION REGION

The design of the IR [6] has also been optimized. The new design provides better bandwidth and smaller emittance growth as well as reduced geometric aberrations. The peak dispersion is decreased, thus reducing the Touschek particles’ amplitude across the IP. The crab sextupoles have also been included. The optical functions of half the IR ($\sqrt{\beta}$) are in Fig. 3: in each half IR two couples of non interleaved sextupoles (H,V), at –I phase, provide correction of first order horizontal and vertical chromaticity. Two more sextupoles (H, V) at low-β locations are used to have a larger bandwidth for off-energy particles, and a horizontal sextupole has been added to cancel residual geometric aberrations from off-phase sextupoles. Two octupoles on each side of the IP are used to correct third order aberrations.

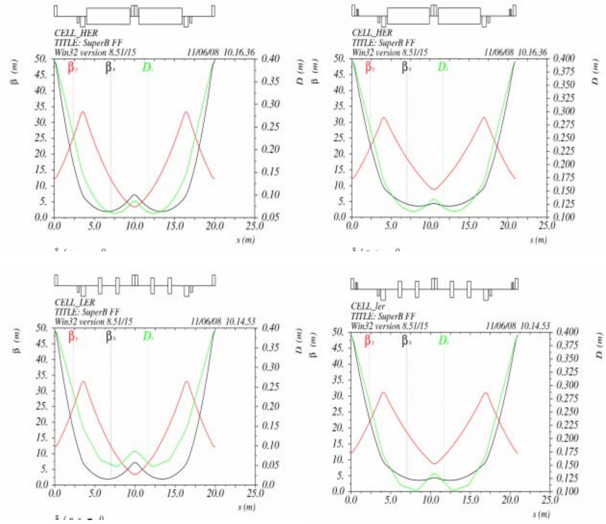

Figure 2: HER (top) and LER (bottom) arc cells: $\mu_x = 0.72$ (left), $\mu_x = 0.5$ (right).

The first drift length is L* = 0.4 m. The large crossing angle geometry allows then for having two separate QD0 for HER and LER. The horizontal separation of the beam lines at the QD0 entrance (2 cm ~ 180 σ_x) is enough to accommodate four layers of super-conducting windings and two cold beam pipe walls, still leaving a reasonable aperture. The mechanical constraints are too tight for a conventional septum magnet, a novel concept to compensate the cross-talk among the two QD0’s core and fringe fields has then been studied [7], and 3D finite-elements simulations show field errors well under ten parts per million. This design strongly reduces the rate of off-energy particle losses near the IP, thus reducing the background rates seen in the detector with respect to a conventional design with a shared QD0. An additional small D-quadrupole will provide the necessary focusing to the HER beam.

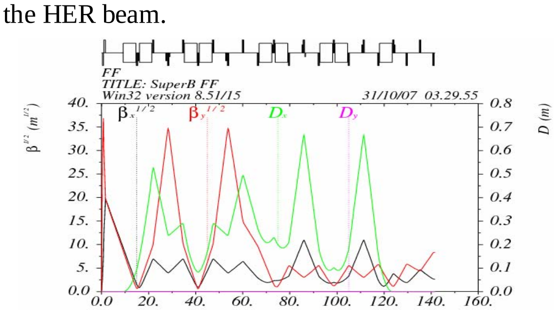

Figure 3: Optical functions in half IR, IP is at s=0, crab sextupole at s = 140.

DYNAMIC APERTURE

Dynamic aperture (DA) studies are presently carried out with the Acceleraticum code [8] which allows for optimization of DA and machine working point (WP) at the same time. The code uses the “best sextupole pair” method to find the optimal sextupoles configuration. Figs.

4 and 5 show preliminary calculations of LER and HER DA for on and off-energy particles (green curve is with synchrotron oscillations) with just two sextupole families. Units are number of $\sigma_{x,y}$ at the straight section opposite to the IP. DA reduction comes mainly from the strong FF, LER having higher chromaticity, however tuning the IR octupoles helps (black curve in the top plot). An example of sextupoles optimization and scan of the DA as a function of tunes for the HER is shown in Fig. 6, where in red are "good" DA regions, with a different WP (black dot) preferred to the nominal one (cross). A further DA reduction comes from the strong crab sextupoles, not included in these examples. Optimization of HER and LER DA is in progress, cross-checking good DA WP with good beam-beam WP.

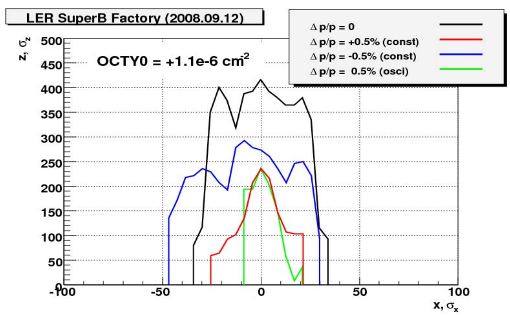

Figure 4: LER dynamic aperture (preliminary).

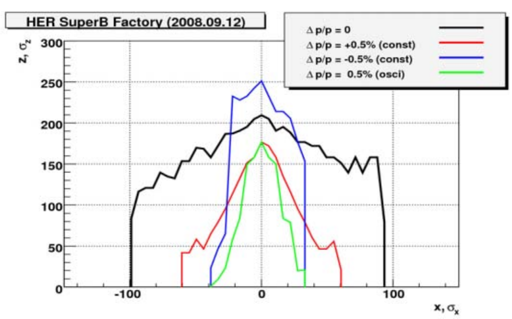

Figure 5: HER dynamic aperture (preliminary).

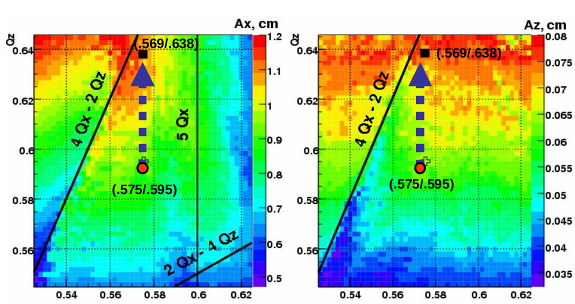

Figure 6: Example of HER DA vs tune scan.

SPIN ROTATOR

At SuperB energies, Sokolov-Ternov polarization takes too long and polarized electrons will be injected. The injector will have the necessary spin handling, and polarized sources with the required intensity exist (e.g. the SLC gun). At the IP, the desired polarization is longitudinal; this can be provided in principle either by 90° spin rotators up and downstream of the IP or by a Siberian Snake (180° rotator) diametrically opposite in the ring, thus avoiding the need for spin rotators matched to the critical IR optics. The rotators or Snake(s) can be designed either using solenoids or vertical dipoles together with horizontal dipoles. The overall spin matching in SuperB will be less critical than in facilities like HERA or LEP because of the short beam lifetime. This causes frequent injection of freshly polarized beam, thus reducing the effect of depolarization in the ring, so that maintaining above 90% of the injecting polarization is an achievable goal, provided rotators are spin-matched across the whole energy spread of the beam. It is still important to avoid integer spin tunes (and their synchrotron sidebands) as the spin orientation will move away from longitudinal at the IP for such values. Solenoid spin rotators tend to be more compact than pure dipole rotators, however for first-order spin matching they need to be anti-symmetric about the IP, leading to a horizontal "dog leg" in the IR layout causing a distortion of the ring geometry. The orbital coupling introduced by the solenoids is compensated by inserting a plane twister between two half-solenoids [9]. A pure dipole spin rotator has been designed that avoids this, i.e. its dipoles become part of the overall 360° bending, however, the vertical bends will raise the minimum vertical emittance achievable [10]. A novel scheme investigated would use 7 Siberian Snakes to maintain longitudinal polarization at the IP without local rotators, while at the same time maintaining sufficiently long (de-)polarization time to have good polarization at high luminosity [11].

CONCLUSIONS

The SuperB lattice, based on the reuse of PEP-II hardware, fits in the Tor Vergata University campus site near Frascati. The new cell layout is more flexible in terms of emittance, and wigglers are no longer needed for the nominal operation scenario, with a net gain in wall plug power and costs. The rings are shorter and less costly, since the total number of magnets has been reduced. The upgrade parameters are achievable with the installation of two, 40 m long, wigglers in each ring. Spin rotator sections are being studied and matched into the HER lattice. Dynamic aperture calculation is in progress.

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