THE SUPERB-FACTORY ACCELERATOR PROJECT

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Abstract

An international collaboration on the design of a Super B-Factory aiming at a 10^{36} cm^{-2} s^{-1} luminosity is in progress. The design relies on a new collision scheme with large Piwinski's angle and very small IP beam sizes, where possible harmful resonances will be cancelled by the newly proposed "crab waist" method.

A Conceptual Design Report has been published in April this year. A review of the design principles and of the project status will be given.

INTRODUCTION

A Super B-Factory like *SuperB*, an asymmetric energy $e^{+}e^{-}$ collider with a luminosity of the order 10^{36} cm^{-2}s^{-1}, can provide a uniquely sensitive probe of New Physics in the flavour sector of the Standard Model.

The PEP-II and KEKB [1,2] asymmetric colliders have produced unprecedented luminosities, above 10^{34} cm^{-2}s^{-1}, taking our understanding of the accelerator physics and engineering demands of asymmetric $e^{+}e^{-}$ colliders to a new parameter regime.

Furthermore, the success of the SLAC Linear Collider and FFTB [3], and the subsequent work on the ILC [4] allow a new Super collider to incorporate linear collider techniques.

The implementation of a new colliding scheme with the combination of "large Piwinski angle", low β*, and "*crab waist*" will enable the design of a Super B-Factory with a target luminosity two orders of magnitude higher than presently achieved, by overcoming some of the issues that have plagued earlier super $e+e^{-}$ collider designs, such as very high beam currents and very short bunches.

An international *SuperB* study group has been formed in the past year to work on the physics case, the accelerator, and the detector. An International Steering Committee has been established, with members from Canada, France, Germany, Italy, Russia, Spain, UK, US, and close collaboration with Japan. Five workshops have been held at Frascati, SLAC and Paris, to focus on the physics case and the detector and accelerator feasibility. As a result, a Conceptual Design Report [5] was published in March 2007, describing the project and including costs estimates. About 85 Institutions worlwide have partecipated to this document, with the contribution of 320 scientists.

An International Review Committee, with experts in the fields, has also been appointed to review the whole project before spring 2008. More detailed informations on this project can be found at: www.pi.infn.it/SuperB.

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B-FACTORIES OUTLOOK

The construction and operation of multi-bunch $e^{+}e^{-}$ colliders have brought about many advances in accelerator physics in the area of high currents, complex interaction regions, high beam-beam tune shifts, high power RF systems, controlled beam instabilities, rapid injection rates, and reliable uptimes (~95%). The present B-Factories have proven that their design concepts are valid, since asymmetric energies work well, the beam-beam energy transparency conditions are weak, high currents can be stored and the electron cloud instability (ECI) can be managed. On the detector-machine side the IR backgrounds can be handled successfully and Interaction Regions with two energies can work. Moreover unprecedented values of beam-beam parameters have been reached (0.06 up to 0.09), and continuous injection in production has helped increasing the integrated luminosity. Remarkably, SuperB would produce this very large improvement in luminosity with circulating currents and wall plug power similar to those of the current B-Factories.

On the other hand lessons learned from SLC and subsequent studies for the International Linear Collider (ILC) Damping Ring (DR) as well as experiments (FFTB, ATF, ATF2) have also shown new successful concepts: small beam emittances can be produced in a DR with a short damping time and very small beam spot sizes and β-functions can be achieved at the Interaction Region. All of the above techniques can be incorporated in the design of a future *SuperB* collider. There is clear synergy with ILC R&D; design efforts have already influenced one another, and many aspects of the ILC-R and Final Focus would be operationally tested at *SuperB*.

A NEW COLLISION SCHEME

Past approaches of collider optimization - the so called "brute force" methods followed over several decades, - have now run into a dead end. These approaches were mainly based on an increase of beam currents and a decrease of β_{y}* at the Interaction Point. However, β_{y}* cannot be made much smaller than the bunch length σ_{z} without incurring an "hourglass" effect, since particles in the head and tail of bunches would experience a larger β_{y}*. So, the bunch must be shortened accordingly with an increase in RF voltage, beam pipe overheating, instabilities and power costs. Other side effects related to the high currents are raising HOM instabilities and detector backgrounds increase.

The novel collision scheme [6, 7] uses frozen variables in parameter space to ascend to a new luminosity scale, by effectively exchanging the roles of the longitudinal and

transverse dimensions. The design is based on a new collision scheme, with "large Piwinski angle" and small beam sizes with "*crab waist*".

In the new scheme, the Piwinski angle ϕ defined as:

$$\phi = \frac{\sigma_z}{\sigma_x} \tan\frac{\theta}{2} \approx \frac{\sigma_z}{\sigma_x}\frac{\theta}{2}$$

(σ_x being the horizontal rms bunch size, σ_z the rms bunch length and θ the horizontal crossing angle) is increased by decreasing the horizontal beam size and increasing the crossing angle. In this way, the luminosity is increased, and the horizontal tune shift due to the crossing angle decreases. The most important effect is that the overlap area of colliding bunches is reduced, as it is proportional to σ_x/θ. Thus, if β_y^* can be made comparable to the overlap area size several advantages are gained, as small spot size at the IP, i.e. higher luminosity, a reduction of the vertical tune shift, and suppression of vertical synchro-betatron resonances. Moreover the problem of parasitic collisions (PC) is automatically solved by the higher crossing angle and smaller horizontal beam size, which makes the beam separation at the PC larger in terms of σ_x.

However, a large Piwinski angle itself introduces new beam-beam resonances and may strongly limit the maximum achievable tune shifts. This is where the "*crab waist*" innovation is required, boosting the luminosity mainly by suppression of betatron and synchro-betatron resonances that usually arise, through vertical motion modulation by horizontal beam oscillations [8]. A sketch of the new collision scheme is shown in Fig.1. The "*crab waist*" correction can easily be realized in practice with two sextupoles magnets in phase with the IP in the x plane and at $\pi/2$ in the y plane, on both sides of the IP.
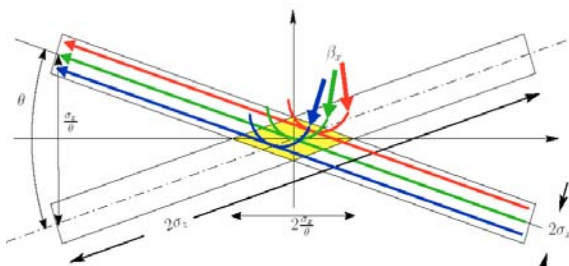

Figure 1: Large Piwinsky angle and crab waist scheme. The collision area is shown in yellow.

In summary, the main advantages of this new scheme are:
- manageable HOM heating;
- no coherent synchrotron radiation of short bunches;
- less power consumption;
- higher luminosity with same currents and bunch length;
- less severe beam instabilities;

- lower beam-beam tune shifts;
- negligible parasitic collisions due to higher crossing angle and smaller σ_x.

BEAM PARAMETERS AND LATTICE

Two beams will circulate in two separate rings at 4 and 7 GeV, colliding in only one Interaction Region, where the Super-BaBar detector will be installed. The Final Focus section design is similar to that designed for FFTB/ILC. The rings design is based on recycling all PEP-II hardware, magnets, and RF system, with a total RF power needed of 17 MW, lower than the PEP-II one. Fig. 2 shows a sketch of the layout with expanded arc cell and Final Focus section.
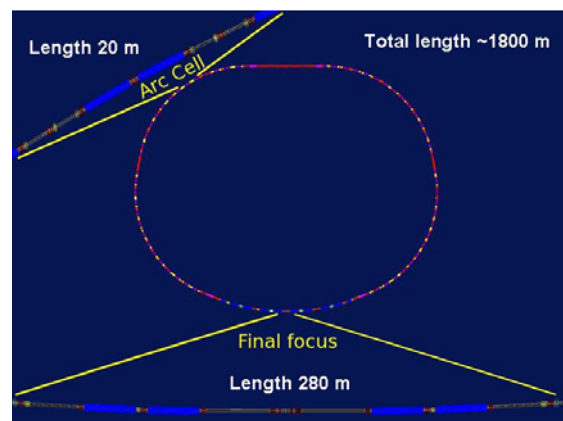

Figure 2: Layout of one ring with close up of one arc cell and Final Focus

The *SuperB* parameters have been optimized based on several constraints. The most significant are:
- maintaining wall plug power, beam currents, bunch lengths, and RF requirements comparable to present B-Factories;
- planning for the reuse as much as possible of the PEP-II hardware;
- requiring ring parameters as close as possible to those already achieved in the B-Factories, or under study for the ILC-DR or achieved at the ATF ILC-DR test facility [9];
- simplifying the IR design as much as possible. In particular, reduce the synchrotron radiation in the IR, reduce the HOM power and increase the beam stay-clear. In addition, eliminate the effects of the parasitic beam crossings;
- relaxing as much as possible the requirements on the beam demagnification at the IP;
- designing a Final Focus system to follow as closely as possible already tested systems, and integrating the system as much as possible into the ring design.

Table 1 shows the main parameter set that closely matches these criteria.

Table 1: *SuperB* Main parameters list

C (m)	1800	ε_y (pm-rad)	7/4
E (GeV)	4/7	β_y^* (mm))	0.22/0.39
I (A)	2	β_x^* (mm)	35/20
N_{bunch}	1342	σ_y^* (mm)	0.039
N_{part}/bunch	5.5×10^{10}	σ_x^* (mm)	10/6
θ (rad)	2x24	σ_z (mm)	5
ε_x (nm-rad)	2.8/1.6	RF Power (MW)	17
Peak luminosity (cm^{-2}s^{-1})		$1. \times 10^{36}$	

Many of the nominal *SuperB* design parameters could, in principle, be pushed further to increase performance. This provides an excellent upgrade path after experience is gained with the nominal design. The upgrade parameters can be based on the following assumptions:

- the beam currents could be raised to the levels that PEP-II should deliver in 2008;
- the vertical emittance at high current could be reduced to the ATF values;
- the lattice supports a further reduction in β_x^* and β_y^*;
- the beam-beam effects are still far from saturating the luminosity.

In principle, the design supports these improvements, so luminosity higher than nominal may well be feasible. In addition, it should be pointed out that, since the nominal design parameters are not pushed to maximum values, there is flexibility in obtaining the design luminosity by relaxing certain parameters, if they prove more difficult to achieve, and pushing others.

BEAM-BEAM STUDIES

Beam-beam studies have been performed in order to verify the validity of the new scheme. Numerical simulations performed with LIFETRAC [10] have shown that the design luminosity of 10^{36} cm^{-2}s^{-1} is achieved already with $2-2.5 \times 10^{10}$ particles per bunch.

According to the simulations, for this bunch population the beam-beam tune shift is well below the maximum achievable value. Indeed, as one can see in the left plot of Fig. 3, the luminosity grows quadratically with the bunch intensity till about 7.5×10^{10} particles per bunch. This safety margin has been used to significantly relax and optimize many critical parameters, including damping time, crossing angle, number of bunches, bunch length, bunch currents, emittances, beta functions and coupling, while main-taining the design luminosity of 10^{36} cm^{-2}s^{-1}.
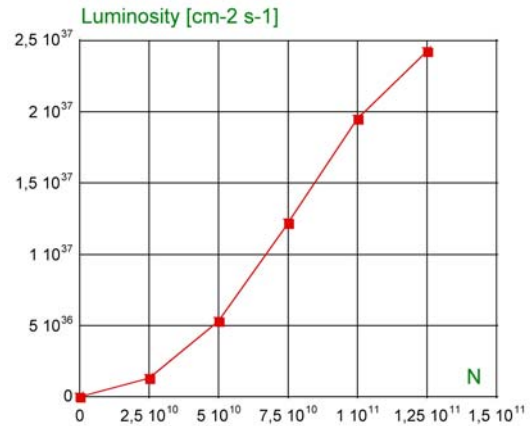

Figure 3: *SuperB* luminosity versus bunch intensity.

In order to define how large is the "safe" area with the design luminosity, a luminosity tune scan has been performed for tunes above the half integers, which is typical for the operating B-factories. The resulting 2D contour plot is shown in Fig.4, individual contours differing by 10% in luminosity, where the effect of the betatron resonances suppression by the "*crab waist*" becomes obvious. It is clear that the design luminosity can be obtained over a wide tune area, allowing for large operation freedom. It has also been found numerically that for the best working points the distribution tails growth is negligible.
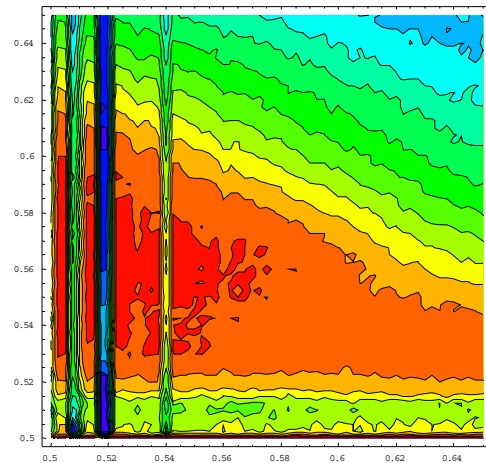

Figure 4: *SuperB* luminosity tune scan (horizontal axis: ν_x from 0.5 to 0.65; vertical axis: ν_y from 0.5 to 0.65).

CONCLUSIONS

The new large Piwinski angle collision scheme will allow for peak luminosity well beyond the current state-of-the-art, without a significant increase in beam currents or shorter bunch lengths. The use of the "*crab waist*" sextupoles will add a bonus for suppression of dangerous resonances. This scheme will be first tested at the DAΦNE Φ-Factory in Frascati, so helping in discovering

possible issues. There is a growing international interest and participation to the *SuperB*, with R&D proceeding on various items. A Conceptual Design Report (CDR) was published and is being reviewed by an International Review Committee.

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