BEAM-BEAM SIMULATIONS FOR A SINGLE PASS SUPERB-FACTORY

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Abstract

A study of beam-beam collisions for an asymmetric single pass SuperB-Factory is presented [1]. In this scheme an e^- and an e^+ beam are first stored and damped in two Damping Rings (DR), then extracted, compressed and focused to the IP. After collision the two beams are re-injected in the DR to be damped and extracted for collision again. The explored beam parameters are similar to those used in the design of the International Linear Collider, except for the beam energies. Flat beams and round beams were compared in the simulations in order to optimize both luminosity performances and beam blow-up after collision. With such approach a luminosity of the order of 10^{36} cm^{-2} s^{-1} can be achieved.

SINGLE-PASS SUPERB-FACTORY

The concept of combining linear and circular collider ideas to make a linear-circular B-Factory was discussed in the late 1980's, although only circular B-Factories were built in the 1990's. Recent advances in B-Factory performance and solid linear collider design progress has reopened this design avenue.

The design presented here is based on the work done at the First SuperB Workshop held in November 2005 in Frascati [2]. Schematic drawings of a first Linear Super-B Factory design are shown in Fig. 1. An e^+ bunch from a 2 GeV damping ring is extracted and accelerated to 7 GeV in a SC linac. Simultaneously, an e^- bunch is accelerated in a separate SC linac to 4 GeV. The two bunches are transported to the IP through bunch compressors, then focused to a small spot and made to collide. The spent beams are returned to their respective linac with transport lines where they return their energies to the SC accelerator. The 2 GeV e^+ are returned to the damping ring to restore the low emittances. The spent e^- beam is discarded. Each bunch collides at 120Hz, there will be about 10000 bunches. Thus, the collision rate is about 1.2 MHz. A small electron linac and positron source is used to replenish lost positrons in the colliding process and natural beam lifetime. This scheme would reduce the demands on the electron gun but increase the site AC power.

These schemes present several complexities and challenging requirements for several subsystems. Moreover several technical solutions proposed have never been tested and proven before, a lot of R&D and extremely detailed studies, in order to ensure the success of the machine, is henceforth required.

BEAM-BEAM SIMULATIONS

The beam parameters are listed in Table 1.

Table 1: Preliminary Super-B Factory collision parameters.

Parameter	**LEB**	**HEB**
Beam Energy (GeV)	4	7
Number of bunches	10000	10000
Collision freq/bunch (Hz)	120	120
IP energy spread (MeV)	5	7
N_{part} /bunch x 10^{10}	10	10
β_x* /β_y* (mm)	22/0.5	22/0.5
Emittance (x/y) (nm)	0.7/0.0016	0.7/0.0016
σ_z (mm)	0.35	0.35
Lumi enchancement H_d	1.07	1.07
IPx/y size (μm)	4/0.028	4/0.028
x/y Disruption	1.7/244	0.9/127
Luminosity (x10^{34}/cm^2/s)	100	100

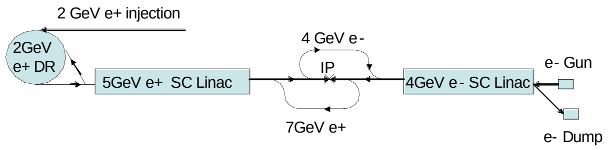

Figure 1: Linearly colliding Super-B Factory layouts.

The beam-beam interaction in a linear collider is basically the same Coulomb interaction as in a storage ring, with extremely high charge densities at IP, leading to very intense fields; since in this case quantum behaviour becomes important it is necessary to use a beam-beam code to predict luminosities and related backgrounds. The "classical" effects of the beam-beam interaction are characterized by a parameter called "disruption", which can be seen as the equivalent to what the linear beam-beam tune shift is in storage rings. Typical values for D in the vertical plane are less than 30 in ILC, and more than 50 in a "linearly colliding" SuperB-Factory. The horizontal D is kept near or below 1 to reduce energy spread in the beam. The beam-beam interaction in such a regime can be highly non linear and unstable, leading to loss of luminosity, rather than gain, and to emittance blow-up. Since the beams must be recovered in this scheme, emittance blow-up should be kept at minimum in order to decrease the number of damping time necessary before the beams can collide again. Let's now recall some of the scaling laws that have to be considered in the choice of the collision parameters.

The beam-beam disruption is defined as:

$$D^{\pm}_{x,y} = \frac{N^{\mp}\sigma_z^{\mp}}{\gamma^{\pm}\sigma_{x,y}^{\mp}(\sigma_x^{\mp}+\sigma_y^{\mp})} \tag{1}$$

where N is the number of particles in one bunch, σ_z is the bunch length, γ is the beam energy in terms of electron mass, σ_x and σ_y are the beam spot sizes at collision. All the quantities refer to the opposite beam, except for the beam energy factor. On the other hand the luminosity is proportional to:

$$L_B \propto \frac{N^{+}N^{-}}{\sigma_x\sigma_y} \tag{2}$$

and the center of mass (cm) energy spread during collision can be defined as:

$$\sigma_E^{cm} \propto \frac{N^2}{(\sigma_x^2\sigma_z)} \propto \frac{D_x N}{\sigma_z^2} \propto \frac{L\sigma_y}{(\sigma_x\sigma_z)} \tag{3}$$

For "linearly colliding" beams a large contribution to the energy spread comes from the beam-beam interaction via the "beamstrahlung", synchrotron radiation produced during collision. Due to the high fields at the interaction the beams lose more energy and the cm energy spread increases. This is an unwanted effect, since the Y(4S) is relatively narrow (10 MeV), so the cm energy spread should be as small as possible. As it can be seen from the previous formulas there are conflicting requirements for the collision parameters; for example increasing the number of particles gives higher luminosity but also higher energy spread. Also, a short bunch gives less disruption and more luminosity, since β_y^* can be decreased, but this produces larger cm energy spread.

The strong-strong collision regime requires a simulation, since analytical treatment is limited. Preliminary beam-beam studies have been performed with the "GuineaPig" code by D. Schulte (CERN) [3], which includes backgrounds calculations, pinch effect, kink instability, quantum effects, energy loss, and luminosity spectrum. This code has been used for ILC studies of beam-beam performances and backgrounds. An intensive study of the luminosity as a function of N, σ_z, $\sigma_{x,y}$, $\varepsilon_{x,y}$ and energy asymmetry has been performed, while trying to keep small the cm σ_E and the outgoing beam emittances. Some preliminary conclusions can be drawn from the large number of runs performed with different collision parameters:

- σ_z should be as short as possible, this allows to decrease β_y^* and disruption;
- given the maximum storable beam current in the DR the number of bunches should be as big as possible, i.e. the number of particles/bunch should be as low as possible (see for example Fig. 2), compatibly with the increase of the cm σ_E;
- increasing the beam aspect ratio, i.e. having flat beams, helps to overcome the kink instability. As a result the spent beam emittances are less disrupted, D_y is smaller and the cm σ_E is weakly affected by the interaction.

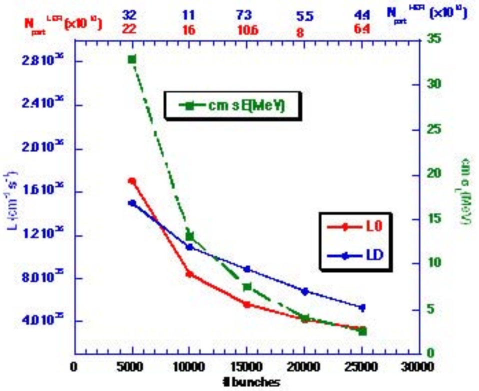

Figure 2: L and cm σ_E *vs* $N_{bunches}$ for a fixed current in the DR. Red: geometric L, Blue: disrupted L, Green: cm σ_E.

As an example of spent beams emittances, in Fig. 3 the (x,x') and (y,y') space phase plots after collision for the Low Energy Beam are shown. The different colours refer to different longitudinal bunch slices, from the bunch head to the bunch tail, the vertical emittance growth in a single collision being about 300.

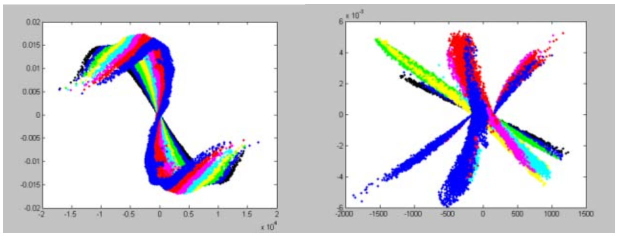

Figure 3: LEB (x,x') (left) and (y,y') (right) phase spaces.

INTERFACE WITH MATHEMATICA

The study of beam-beam parameters requires a huge number of simulations. In particular both round and flat beams and collision with 2 and 4 beams were studied. To speed up this process an interface among Mathematica [4] and GuineaPig has been developed. It is then possible to make subsequent runs by varying the parameters in a multi-dimensional space and find the optimum set for the Luminosity.

The best parameters set is obtained by maximizing the figure of merit Q defined as *Q=L/T*, being L the luminosity and T = Log $(\varepsilon_i^{out}/\varepsilon_i^{in})$. T is directly proportional to the time spent by the beams in the rings to recover their emittances after the collision (subscript i ranges over x,y,z for each beam). Both L and T are predicted by GuineaPig.

This procedure was effective in finding the optimal parameter set for a round case scenario. The beam parameters are listed in Table 2. As an example of this optimization procedure Fig. 4 shows Luminosity scan in the (σ_x,σ_y) plane and the figure of merit Q in the (β_x, σ_x) plane, with the blue region corresponding to the maximum.

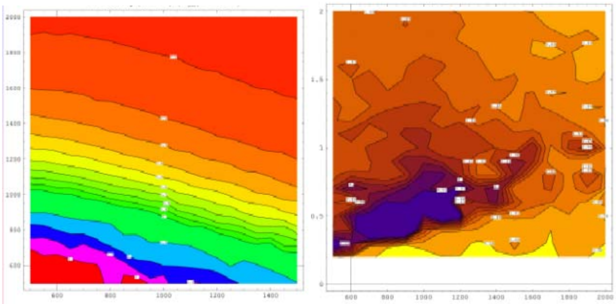

Figure 4: (a) Scan of L in the the (σ_x,σ_y) plane, (b) Scan of L in the the (β_x,σ_x) plane

In order to understand the behaviour of intense and low-size beams in collisions the previous studies were performed with symmetric energies (5 GeV). However the final SuperB asymmetric energies are required to allow tracking particle vertices in the collisions. A study of the flat beams case blow-up, with the parameters listed in Table 1 has been performed with a 4 GeV beam colliding with a 7 GeV beam. The vertical emittance blow-up is the same for the 2 beams if we use the "transparency condition" of having current inversely proportional to the beam energies. Another option to have the same blow-up in the 2 beams is to keep same currents but have different bunch lengths: 3 mm LEB colliding with a 5.3 mm HEB.

Table 2 Round beams collision parameters

Parameter	LEB	HEB
Beam Energy (GeV)	4	7
Number of bunches	10000	10000
Collision freq/bunch (Hz)	120	120
N_{part} /bunch x 10^{10}	7	7
β_x* /β_y* (mm)	0.55/0.55	0.55/0.55
Emittance (x/y) (nm)	1.54/1.54	1.54/1.54
σ_z (mm)	0.8	0.8
IPx/y size (μm)	0.92/0.92	0.92/0.92
x/y Disruption	24/24	14/14
Luminosity (x10^{34}/cm^2/s)	120	120

FOUR BEAMS SIMULATIONS

The four-beam DCI-like [6] beam charge compensation scheme (allowing the beams to collide again before being sent back into the Linac), was also studied. In principle this scheme could reduce the disruption, allowing much smaller IP sizes, together with very little emittance growth, relaxing the requirements on beam current and damping time. However the 4 beams scheme turned out to be more unstable than the 2 beams, being highly disrupted, with larger emittance blow-ups and with a resulting lower luminosity. This is mainly due to the kink-instability that is now much larger due to the defocusing forces of the same-charges colliding beams. The analysis performed was not exhaustive and a better working parameter set could be found in the future. From the present results it seems that in this scheme shorter beams, with larger horizontal beam size, could work better. Fig.5 shows a comparison of the (x,x'), (y,y'), (z,ΔE/E) phase spaces after collision for 4 (upper) and 2 (lower) beam case.

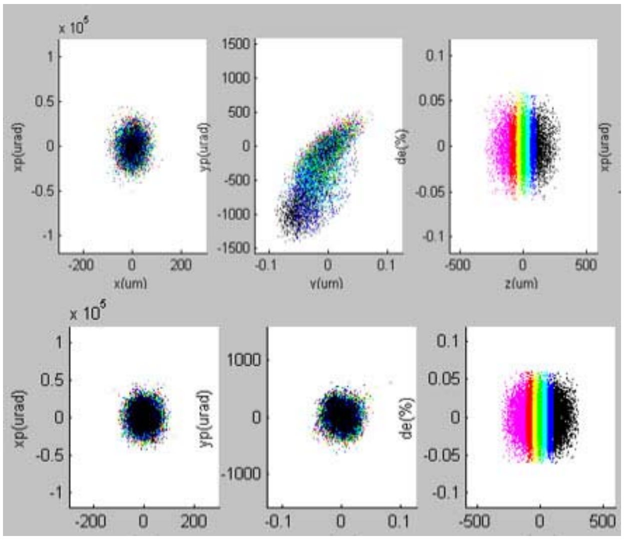

Figure 5: (x,x'), (y,y'), (z,ΔE/E) phase spaces after collision for the 4 beams (upper) and the 2 beams (lower).

CONCLUSIONS

Beam-beam studies have been performed for the design of a linearly colliding, single pass SuperB-factory. Both round and flat beams have been considered. The required luminosity of 10^{36} cm^{-2}s^{-1} can be achieved, but the required parameters for the damping rings are very challenging.

A solution with a novel collision regime, called "crabbed waist", that will allow to collide in two conventional rings with the ILCDR characteristics was proposed at the Second SuperB Workshop in Frascati [5,6] and is being intensively studied [7] and beam-beam simulations with weak-strong and strong-strong codes are being performed.

REFERENCES

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