BEAM-BEAM SIMULATIONS FOR PARTICLE FACTORIES WITH CRABBED WAIST

P. Raimondi, M. Zobov, LNF-INFN, Frascati, Italy
D. Shatilov, BINP, Novosibirsk, Russia

Abstract

The recently proposed "crabbed waist" scheme for beam-beam collisions can substantially increase luminosity since it combines several potentially advantageous ideas. Large crossing angle together with small horizontal beam size allow having very small beta-functions at the interaction point (IP) and ordinary bunch length without incurring in the "hourglass" effect. The other main feature of such a collision scheme is the "crabbed waist" transformation, which is realized by two sextupoles placed in proper betatron phases around the IP. Such a transformation can strongly suppress the beam-beam betatron resonances induced in collisions with large Piwinski angle, thus providing significant luminosity increase and opening much more room for choices of the working point. In this paper we present the results of beam-beam simulations performed in order to optimize the parameters of two currently proposed projects with the crabbed waist: the DAΦNE upgrade and the Super B-factory project.

INTRODUCTION

In high luminosity colliders with standard collision schemes the key requirements to increase the luminosity are: the very small vertical beta function β_y at the interaction point (IP); the high beam intensity I; the small vertical emittance ε_y and large horizontal beam size σ_x and horizontal emittance ε_x required to minimize beam-beam effects. However, β_y can not be much smaller than the bunch length σ_z without incurring in the "hour-glass" effect. It is, unfortunately, very difficult to shorten the bunch in a high current ring without exciting instabilities. In turn, the beam current increase may result in high beam power losses, beam instabilities and a remarkable enhancement of the wall-plug power. These problems can be overcome with the recently proposed Crabbed Waist (CW) scheme of beam-beam collisions [1] where a substantial luminosity increase can be achieved without bunch length reduction and with moderate beam currents.

These advantages have triggered several collider projects exploiting the CW collision potential. In particular, the upgrade of the Φ-factory DAΦNE is aimed at increasing the collider luminosity up to 10^{33} cm^{-2}s^{-1} [2] to be compared with 1.6x10^{32} cm^{-2}s^{-1} obtained during the last DAΦNE run for the FINUDA experiment [3]. The first crabbed waist collisions are expected already by winter 2007/2008 [4], when the collider will run for the SIDDHARTA experiment. Besides, the physics and the accelerator communities are discussing a new project of a Super B-factory with luminosity as high as 10^{36} cm^{-2}s^{-1} [5], i.e. by about two orders of magnitude higher with respect to that achieved at the existing B-factories at SLAC [6] and KEK [7]. The decision on the Super B-factory construction will depend much on the results of the CW collision tests at DAΦNE.

In the following we briefly discuss the Crabbed Waist collision concept and present results of beam-beam simulations for the DAΦNE upgrade and for the Super B-factory project.

CRABBED WAIST CONCEPT

The Crabbed Waist scheme of beam-beam collisions can substantially increase collider luminosity since it combines several potentially advantageous ideas.

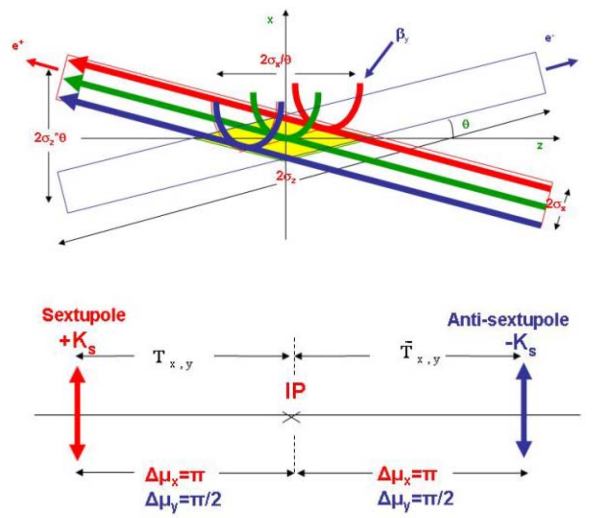

Figure 1: Collision scheme with large Piwinski angle and crabbing sextupoles.

The first one is large Piwinski angle. For collisions under a crossing angle θ the luminosity L and the horizontal ξ_x and vertical ξ_y tune shifts scale as (see, for example, [8]):

$$L \propto \frac{N\xi_y}{\beta_y} \propto \frac{1}{\sqrt{\beta_y}}; \quad \xi_y \propto \frac{N\sqrt{\beta_y}}{\sigma_z\theta}; \quad \xi_x \propto \frac{N}{(\sigma_z\theta)^2}$$

Here the Piwinski angle is defined as:

$$\phi = \frac{\sigma_z}{\sigma_x} tg\left(\frac{\theta}{2}\right) \approx \frac{\sigma_z}{\sigma_x}\frac{\theta}{2}$$

with N being the number of particles per bunch. Here we consider the case of flat beams, small horizontal crossing angle $\theta << 1$ and large Piwinski angle $\phi >> 1$.

1-4244-0917-9/07/$25.00

In the CW scheme described here, the Piwinski angle is increased by decreasing the horizontal beam size and increasing the crossing angle. In such a case, if it were possible to increase N proportionally to $\sigma_z\theta$, the vertical tune shift ξ_y would remain constant, while the luminosity would grow proportionally to $\sigma_z\theta$.. Moreover, the horizontal tune shift ξ_x drops like $1/\sigma_z\theta$.. However, the most important effect is that the overlap area of the colliding bunches is reduced, as it is proportional to σ_x/θ (see Fig. 1). Then, the vertical beta function β_y can be made comparable to the overlap area size (i.e. much smaller than the bunch length):

$$\beta_y \approx \frac{\sigma_x}{\theta} << \sigma_z$$

We get several advantages in this case:

- Small spot size at the IP, i.e. higher luminosity L.
- Reduction of the vertical tune shift ξ_y.
- Suppression of synchrobetatron resonances [9].

Besides, there are additional advantages in such a collision scheme: there is no need to decrease the bunch length to increase the luminosity as proposed in standard upgrade plans for B- and Φ-factories [10, 11, and 12]. This will certainly helps solving the problems of HOM heating, coherent synchrotron radiation of short bunches, excessive power consumption etc. Moreover, parasitic collisions (PC) become negligible since with higher crossing angle and smaller horizontal beam size the beam separation at the PC is large in terms of σ_x.

However, large Piwinski angle itself introduces new beam-beam resonances which may strongly limit the maximum achievable tune shifts (see [13], for example). At this point the crabbed waist transformation enters the game boosting the luminosity. This takes place mainly due to suppression of betatron (and synchrobetatron) resonances arising (in collisions without CW) through the vertical motion modulation by the horizontal oscillations [14]. The CW vertical beta function rotation is provided by sextupole magnets placed on both sides of the IP in phase with the IP in the horizontal plane and at $\pi/2$ in the vertical one (see Fig. 1). A numerical example of the resonance suppression is shown in Fig. 2.

DAΦNE UPGRADE SIMULATIONS

In order to estimate the achievable luminosity in DAΦNE with the crabbed waist scheme and to investigate distribution tails arising from beam-beam collisions, which may affect the beam lifetime, simulations with the code LIFETRAC [15] have been performed. The beam parameters used for the simulations are summarized in Table 1. For comparison, the parameters used during the last DAΦNE run with the KLOE detector (2005-2006) are also shown.

As discussed above, in order to realize the crabbed waist scheme in DAΦNE, the Piwinski angle $\phi=\theta\sigma_x/\sigma_z$ should be increased and the beam collision area reduced: this will be achieved by increasing the crossing angle θ by a factor 1.5 and reducing the horizontal beam size σ_x. In this scheme the horizontal emittance ε_x will be reduced by a factor 1.5, and the horizontal beta function β_x lowered from 1.5 to 0.2 m. Since the beam collision length decreases proportionally to σ_x/θ, the vertical beta function β_y can be also reduced by a factor 3, from 1.8 cm to 0.6 cm. All other parameters will be similar to those already achieved at DAΦNE.

Table 1: Comparison of beam parameters for KLOE run (2006) and for DAΦNE upgrade for SIDDHARTA run

Parameters	KLOE Run	Siddharta Run
L ($cm^{-2}\ s^{-1}$)	$1.5x10^{32}$	$>10^{33}$
N_{bunch}	110	110
N_{part}/bunch	$2.65*10^{10}$	$2.65*10^{10}$
I_{bunch} (mA)	13.	13.
ε_x (nm)	300.	200.
ε_y (nm)	1.5	1.
Coupling (%)	0.5	0.5
σ_x (μm)	700.	200.
σ_y (μm)	15 (blow up)	2.4
σ_z (mm)	25.	20
β_x (m)	1.5	0.2
β_y (mm)	18.	6.
θ (mrad)	2x16	2x25

Using the parameters of Table 1 and taking into account the finite crossing angle and the hourglass effect luminosity in excess of $1.0x10^{33}$ $cm^{-2}s^{-1}$ is predicted with the achieved beam currents during the KLOE run, about 6 times higher than the one obtained until now. The only parameter that seems to be critical for a low energy machine is the high vertical tune shift: ξ_y = 0.08, to be compared with the value of 0.03 so far obtained at DAΦNE. In order to check whether these tune shifts (and the luminosity) are achievable we have performed the luminosity tune scans. Figure 2 shows 2D luminosity contour plots in the tune plane for the crabbed waist collisions with the crabbing sextupoles on (left) and off (right), for comparison.

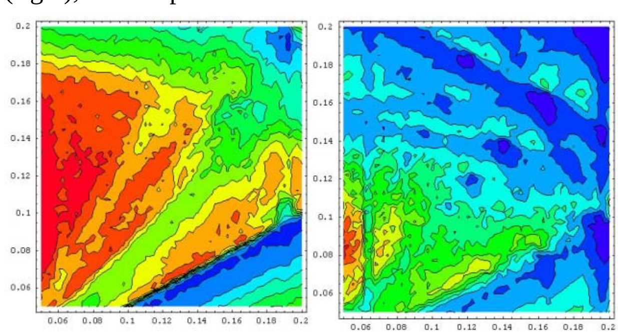

Figure 2: Luminosity tune scan (ν_x and ν_y from 0.05 to 0.20). W sextupoles on (left), CW sextupoles off (right).

"Geographic map" colors are used to produce the plots: the brighter red colors correspond to higher luminosities (mountains), while the blue colors are used for the lowest ones (rivers and oceans). For each plot 10 contour lines between the maximum and minimum luminosities are drawn. Comparing the two plots in Fig. 2 one can see that the good luminosity region with crabbing sextupoles on is much wider than with sextupoles off since many more betatron resonances arise without CW. The absolute luminosity values are higher in the crabbed waist collisions: a peak luminosity of 2.97x10^{33} cm^{-2} s^{-1} is foreseen against L_{max} = 1.74x10^{33} cm^{-2}s^{-1} in the case without CW. It should be noted that the worst luminosity value obtained with CW (2.5x10^{32} cm^{-2}s^{-1}) is still higher than the present luminosity record at DAΦNE. Without CW the lowest luminosity value drops by an order of magnitude, down to L_{min} = 2.78x10^{31} cm^{-2}s^{-1}.

SUPERB BEAM-BEAM SIMULATIONS

Beam-beam studies for SuperB started with a beam parameters set similar to that of the ILC damping ring (Table 2). Numerical simulations with LIFETRAC have shown that the design luminosity of 10^{36} cm^{-2}s^{-1} is achieved already with 2-2.5x10^{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 Fig.3, the luminosity grows quadratically with the bunch intensity till about 7.5x10^{10} particles per bunch. We have used this safety margin 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 maintaining the design luminosity of 10^{36} cm^{-2}s^{-1}. The optimized set of beam parameters is shown in the second column of Table 2.

Table 2: Parameters for early ILC-like design and current SuperB design. For the SuperB, the first entry is for LER and the bracketed numbers are for HER

Parameters	ILC-like	SuperB
ε_x (nm-rad)	0.8	1.6
ε_y (pm-rad)	2	4
β_x (mm)	9	20
β_y (mm)	0.08	0.30
σ_x (μm)	2.67	5.66
σ_y (nm)	12.6	35
σ_z (mm)	6	6
σ_e (x10^{-4})	10	8.4 (9.0)
θ (mrad)	2x25	2x17
N_{part}/bunch (x10^{10})	2.5	6.2 (3.5)
N_{bunch}	6000	1733
Circumference (m)	3000	2250
Damping time τ_s (ms)	10	16
RF frequency (MHz)	600	476

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 differ by 10% in luminosity. The maximum luminosity found inside the scanned area is 1.21x10^{36} cm^{-2}s^{-1}, while the minimum one is as low as 2.25x10^{34} cm^{-2}s^{-1}. We can conclude that the design luminosity can be obtained over a wide tune area. It has also been found numerically that for the best working points the distribution tails growth is negligible.

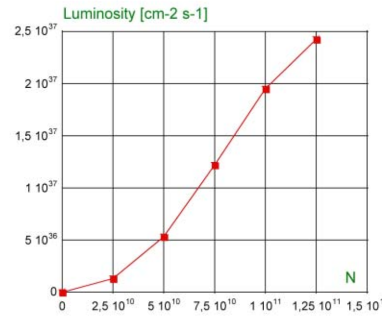

Figure 3: SuperB luminosity versus bunch intensity.

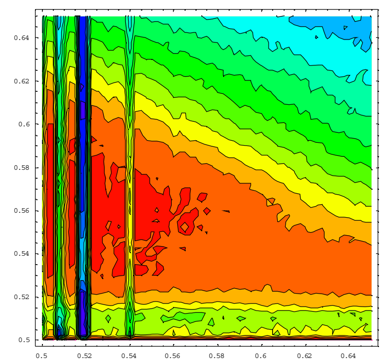

Figure 4: SuperB luminosity tune scan (horizontal axis - ν_x from 0.5 to 0.65; vertical axis – ν_y from 0.5 to 0.65).

CONCLUSIONS

The numerical simulations indicate that by exploiting the crabbed waist scheme of beam-beam collisions the luminosity of the Φ-factory DAΦNE can be pushed beyond 10^{33} cm^{-2}s^{-1} level, while the luminosity of the low emittance Super B-factory can be as high as 10^{36} cm^{-2}s^{-1}.

REFERENCES

[1] P. Raimondi, 2nd SuperB Workshop, Frascati, 2006.
[2] D. Alesini et al., LNF-06/33 (IR), 2006.
[3] C. Milardi et al., TUPAN033, this conference.
[4] M. Biagini et al., MOOBKI02, this conference.
[5] SuperB CDR, INFN/AE-07/2, SLAC-R-856, 2007.
[6] J. Seeman et al., EPAC06, p. 643.
[7] Y. Funakoshi et al., PAC05, p. 1045.
[8] D. Shatilov and M. Zobov, ICFA BDN 37, 99 (2005).
[9] D. Pestrikov, Nucl. Instrum. Meth. A336, 427 (1993).
[10] J. Seeman, PAC05, p. 2333.
[11] H. Koiso, PAC05, p. 64.
[12] DANAE Letter of Intent, see http://www.lnf.infn.it.
[13] K. Ohmi et al., PRSTAB 7, 104401 (2004).
[14] P. Raimondi et al., e-Print:physics/0702033, 2007.
[15] D. Shatilov, Particle Accelerators 52, 65 (1996).

1-4244-0917-9/07/$25.00 ©2007 IEEE