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BEAM-BEAM INTERACTION STUDY FOR DAΦNE

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ABSTRACT

By using a weak-strong simulation code BBC 1) which is fully symplectic in 6D phase space, suitable working points for DAΦNE were found. Despite a large crossing angle in DAΦNE of 12.5 - 15 mrad, the performed tune scan has shown reasonably large "safe" areas around working points (0.09;0.07) and (0.53;0.06) with the luminosity close to the design value.

The beam tails were simulated by the dedicated code LIFETRAC 2). It has been found that the Parasitic Crossings (PC) near the interaction point substantially reduce the lifetime in case of maximum design number of bunches (120). In order to avoid PC problems, we propose a slight changes in working point and some modifications in machine lattice, which result in increasing of the separation in PC normalized on the transverse beam size.

1 Introduction

In order to find a suitable working point for DAΦNE we perform a scan in the tune areas close (above) to the integer (half-integer) tunes by using a recently developed beam-beam code BBC 1), which is capable to simulate equilibrium beam size and luminosity. The simulation algorithm is fully symplectic in the 6D phase space, and includes all the known effects as crossing angle, finite bunch length, variation of β

along the bunch during collision, energy loss due to the longitudinal electric fields, etc.

Besides a beam core blow up (luminosity reduction), long beam tails can be induced by beam-beam interaction, causing lifetime and background problems. It appears that this may represent a serious problem due to the small values of the DAΦNE damping decrements. In order to save CPU time (up to several orders of magnitude) when simulating beam tails, we use a dedicated code LIFETRAC 2). A recently performed comparison 3) between the two codes showed good agreement.

In this report we briefly present the obtained results. More detailed information can be found in 4) and 5).

2 Collisions at a single interaction point (tune scan)

Table 1 summarizes the main DAΦNE parameters used in the beam-beam simulations.

Table 1: *DAΦNE parameters relevant for simulations.*

Energy: E	510	MeV
Circumference: C	97,69	m
Beta functions at IP: β_x^*, β_y^*	450, 4.5	cm
Emittances: ε_x, ε_y	$1 \cdot 10^{-4}$, $1 \cdot 10^{-6}$	cm · rad
Bunch length: σ_z	3.0	cm
Energy spread: σ_ε	$5 \cdot 10^{-4}$	
Synchrotron tune: ν_z	0.012	
Damping times: τ_x, τ_y, τ_z	110540, 109650, 54620	turns
Crossing angle: ϕ_x	± 12.5	mrad
Tune shifts: ξ_x, ξ_y	0.041, 0.041	
Particles/bunch: N	$9 \cdot 10^{10}$	

We find the dependence of beam sizes and the luminosity on the tunes by scanning $\nu_x - \nu_y$ plane in two regions: $0.01 < \nu_{x,y} < 0.21$ and $0.51 < \nu_x < 0.6$; $0.01 < \nu_y < 0.1$, with a step of $\Delta\nu_{x,y} = 0.01$. The beam-beam collisions and revolutions through the ring are simulated for 10 radiation damping times (about 10^6 turns). The strong bunch is longitudinally devided into 5 slices, and the weak one is represented by 50 superparticles. The luminosity is estimated by a convolution of the distribution function of the two beams.

Figure 1 shows a luminosity contour plots in the $\nu_x - \nu_y$ plane. The darker areas correspond to the higher luminosities with the design luminosity being the

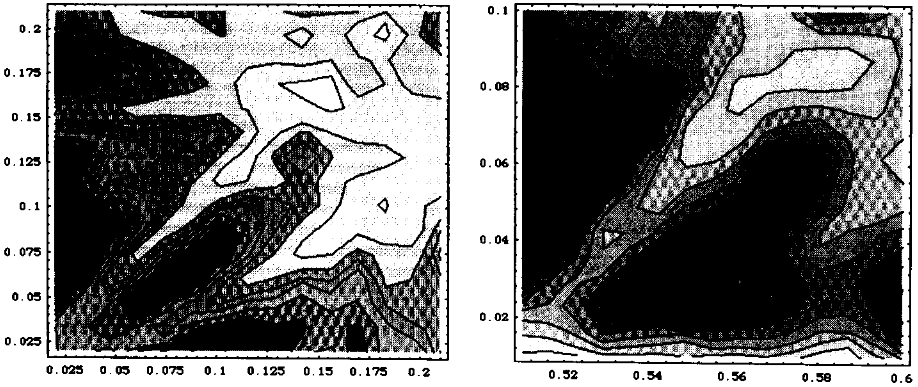

Figure 1: *Luminosity contour plots (scan). The abscissa and ordinate are the horizontal and vertical tunes, respectively.*

maximum value. The contour spacing is 10% in luminosity reduction. On the contour plots we can clearly see the reduction of luminosity due to various resonances: $\nu_x = \nu_y$, $\nu_x = 2\nu_y$, $6\nu_y = 1$ and others. The absolute minimum of the luminosity in the given tune regions is near the intersection of the beam-beam resonances of the sixth order and the resonance $\nu_x = \nu_y$.

Numerical simulations have shown that the areas close to the integer tunes have a very small dynamic aperture, so that we choose two remaining "good" regions. Namely, we consider two possible candidates for the DAΦNE working point: $\nu_x = 0.09$; $\nu_y = 0.07$ and $\nu_x = 0.53$; $\nu_y = 0.06$. For these working points the luminosity reaches 95% and 98% of the nominal value, respectively. For the chosen working points we repeat simulation with 500 particles in the weak beam and 10 slices in the strong one. The results do not differ substantially from those with 5 slices and 50 particles. The finer tune scan with a step of $\Delta\nu_{x,y} = 0.0025$ has been done in the vicinity of the working points which confirms that the tune area with an acceptable beam-beam performance is reasonably large.

3 Collisions at the two IP

The DAΦNE main rings consist of two rather different arcs ("Short" and "Long") having different horizontal phase advances between the two IPs. It is known that phase advance differences between IPs break the symmetry of a collider, i. e. introduce new, low order resonances thus deteriorating the collider performance. In order to investigate a possibility to employ both IPs for the experimental study in

DAΦNE we have simulated beam-beam collisions at these two IPs.

Despite the differences in the horizontal tunes between IPs the weak-strong simulation for the nominal working point (0.09; 0.07) shows only a slight reduction in luminosity to 86% of the design luminosity value per each IP. For the other working point (0.14; 0.10), chosen for a comparison, luminosity drops from 61% with a single IP to 21% per each IP in the two IP collisions.

4 Simulations with Parasitic Crossings

We used the parameters of PCs in KLOE interaction region, and studied only the working point (0.09; 0.07) and small area around it. The strong bunch is longitudinally devided into 3 slices. Only the case of one IP on the ring was considered. Table 2 summarises the relevant PC data, taken from $^{6)}$.

Table 2: *Parasitic crossings in KLOE interaction region.*

PC	s(m)	d(m) 12.5 mrad	d/σ_x 12.5 mrad	d/σ_x 15.0 mrad	Number of bunches 30	40	60	120
1	0.4	0.0100	4.70	5.64	-	-	-	+
2	0.8	0.0175	9.81	11.77	-	-	+	+
3	1.2	0.0301	16.91	20.29	-	+	-	+
4	1.6	0.0510	20.91	25.10	+	-	+	+

As it is seen, in spite of the crossing angle at the IP, the design separation between bunches at the PC in the case of 120 stored bunches is approximately equal to $5\sigma_x$. It turns out that such a separation is absolutely not enough, since PCs induce very long tails, with the lifetime dropping to few seconds. The problem arises from the high value of β_y at the PC, resulting in a very strong normalized vertical kick experienced by a test particle when it drifts horizontally near a PC, and emphasized by the small values of the DAΦNE damping decrements.

Fig. 2 shows the equilibrium distributions obtained in the cases of 120, 60 and 40 bunches (KLOE lattice). It can be noticed that long tails grow beyond the PC's horizontal position ($5\sigma_x$ for 120 bunches, $9.9\sigma_x$ for 60 bunches). In the other words, the horizontal dynamic aperture becomes equal to the separation between the bunches at the PC, and the lifetime is determined by the probability of overlapping the PC in the horizontal direction.

In order to operate the collider with the maximum design number of bunches, we need to undertake some additional efforts, which could be summarized as follows:

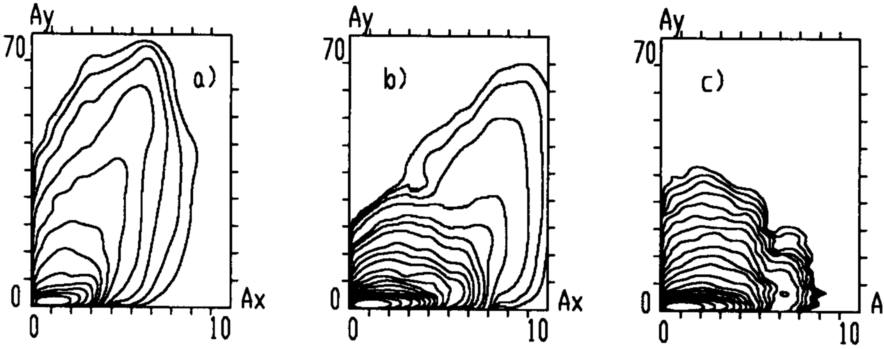

Figure 2: *Equilibrium density in the space of normalized betatron amplitudes for DAΦNE working point (0.09;0.07) with Parasitic Crossings, KLOE lattice. The successive contour levels are at a constant ratio e below each other. The lifetime (the vertical aperture is assumed to be 70 σ_y) strongly depends on the separation value.*

Bunches	*Separation*	σ_x/σ_{xo}	σ_{Px}/σ_{Pxo}	σ_y/σ_{yo}	σ_{Py}/σ_{Pyo}	*lifetime (sec)*
a) 120	$5\sigma_x$	*0.97*	*1.13*	*3.40*	*3.46*	*1*
b) 60	$9.9\sigma_x$	*0.93*	*1.13*	*1.24*	*1.14*	10^4
c) 40	$17\sigma_x$	*0.97*	*1.17*	*1.24*	*1.11*	$> 10^7$

1) Increase the crossing angle up to ±15 mrad., namely the maximum value which does not require hardware layout modifications.

2) Change the betatron tunes in order to avoid resonances which provide the horizontal drift of the particles.

3) Decrease β_x by a factor of 2, increasing at the same time the vertical emittance ε_y by the same factor. The separation at the PC would increase by a factor of $\sqrt{2}$, while the tune shifts ξ_x, ξ_y and the luminosity are kept unchanged.

As shown in Fig. 3(a,b), the lifetime improves significantly when getting closer to integer betatron tunes, thus avoiding synchro-betatron resonances. Nevertheless, a separation of $6\sigma_x$ at the PC seems to be insufficient in any case. On the other hand, only increasing the separation up to $8.5\sigma_x$ by using both 1) and 3) is also not enough (see Fig. 3c). We need therefore to realize all the improvements together to obtain acceptable lifetime and luminosity, as shown in Fig. 3d.

At the end of our study we repeated the last simulation with an increased number of slices (up to 7) in the longitudinal distribution. The results do not differ substantially from those with 3 slices.

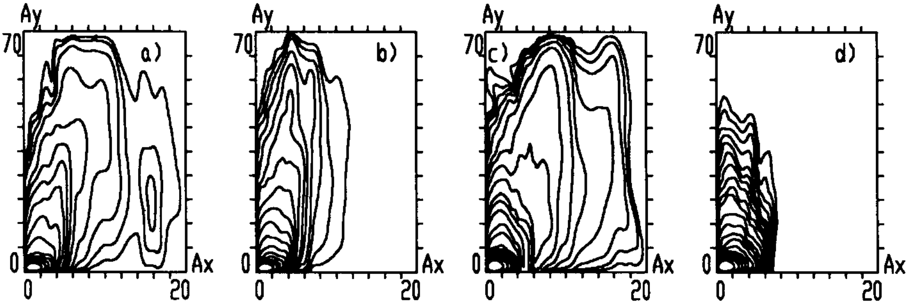

Figure 3: *Equilibrium density in the space of normalized betatron amplitudes,* $\phi_x = \pm 15$ *mrad, 120 bunches. Cases c) and d) present a new lattice with the changed* β_x *and* ε_y*. The successive contour levels are at a constant ratio e below each other.*

Working point	d/σ_x	σ_x/σ_{xo}	σ_{Px}/σ_{Pxo}	σ_y/σ_{yo}	σ_{Py}/σ_{Pyo}	*lifetime (sec)*
a) (0.09;0.07)	*6.0*	*0.96*	*1.12*	*1.83*	*1.78*	*4*
b) (0.08;0.06)	*6.0*	*0.93*	*1.11*	*1.58*	*1.48*	*70*
c) (0.09;0.07)	*8.5*	*0.95*	*1.13*	*1.37*	*1.26*	$3 \cdot 10^2$
d) (0.08;0.06)	*8.5*	*0.93*	*1.13*	*1.25*	*1.11*	10^6

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