FEASIBILITY STUDY FOR A VERY HIGH LUMINOSITY Φ-FACTORY

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Abstract

Particle factories are facing their future by looking at the possibility of upgrading the luminosity by orders of magnitude. The upgrade challenges are more stringent at lower energies. Double symmetric rings, enhanced radiation damping, negative momentum compaction and very short bunches at the collision point are the main features of a Φ-factory feasibility study presented in this paper. The bunch length of few millimetres at the crossing point of the beams is obtained by applying the Strong RF Focusing principle. The collider design fits the existing DAFNE infrastructures with completely rebuilt rings and upgraded injection system.

INTRODUCTION

DAΦNE, the Frascati Φ-factory, has reached a peak luminosity close to 10^{32} $cm^{-2}sec^{-1}$[1] at 1.02GeV E_{cm}. The design of a super Φ-factory, DAΦNE-II, with two order of magnitude higher luminosity, keeps the main DAΦNE characteristics (double symmetric ring collider in multibunch configuration and flat beams). It incorporates new ideas, feasible with completely rebuilt rings (see Fig.1), namely the Strong RF Focusing (SRFF) principle[2], enhanced radiation damping and negative α_c.

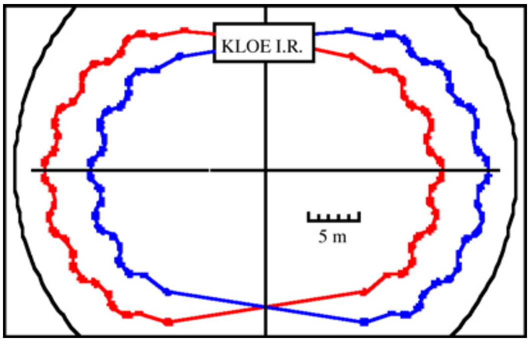

Figure 1: DAΦNE-II layout

Strong RF Focusing

Very small vertical beam sizes at the Interaction Point (IP) demand for very short bunches. Going to the millimetre range in the vertical β* is not conceivable for a low energy ring where the microwave instability appears at very low bunch charge. The SRFF overcomes this problem, by modulating the bunch length along the ring: bunches are very short at the IP, while the average bunch length is reasonably long and the bunch lengthening regime is not reached. High RF voltage and strong correlation between longitudinal position in the bunch and energy deviation produce the high synchrotron phase advance necessary to focus the beam longitudinally. An experiment in DAΦNE has been proposed [3] at low current to demonstrate the feasibility of such a regime.

High radiation damping

One of the limitations for reaching high beam-beam tune shifts at low energies is the naturally long radiation damping time. Any attempt to increase the single bunch luminosity must be based on enhancing the radiation emission, with the increase of the bending field along the ring, or, equivalently, of the synchrotron radiation integral I_2, by introducing wigglers or alternating field dipoles.

Negative momentum compaction

The shorter bunch length and the more regular longitudinal distribution in a lattice with negative α_c are beneficial to the luminosity. All present storage rings work in the positive α_c regime. Experiments done in different storage rings confirm simulations. Recently in DAΦNE a first test with a negative momentum compaction lattice has shown a very strong decrease of the bunch lengthening while keeping the same microwave instability threshold.

LATTICE CELL

The magnetic lattice of DAΦNE-II copes with the three principles above. The arc structure is a series of cells with negative and positive bending magnets.

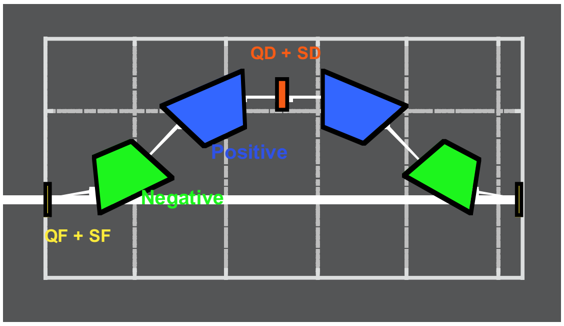

Figure 2: Schematic cell layout

The cell layout is sketched in Fig. 2 and the betatron functions and the dispersion in Fig. 3. The dipoles are sector combined function magnets, B = 1.8T, with field index equal to 0.5, which gives the same focusing in the vertical and horizontal planes. Furthermore it gives vanishing contribution to the synchrotron radiation integral I_4, thus minimizing the beam energy spread, which is enhanced by the high longitudinal phase advance and can be a limitation for the dynamic aperture [4].

The sign of the dispersion inside the dipoles is opposite to the bending radius' one: the contribution to the momentum compaction is negative from all the dipoles and large since the maximum of the absolute value of the dispersion function occurs inside the dipoles.

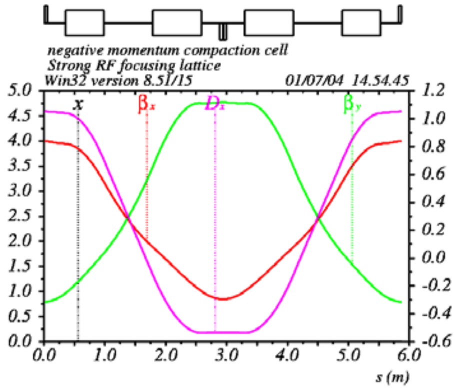

Figure 3: Betatron functions (left axis) and dispersion (right axis) in a cell (m)

The chromaticity is corrected by sextupole windings inside the quads, where the betatron functions are well separated. The phase advance per cell is similar in both planes and tunable by the quads.

STORAGE RING

The ring layout is similar to the DAFNE one, with a shorter inner arc composed of five cells and a longer outer one of seven (see Fig. 1). The rings cross in two points, one corresponding to the IP, the second one in the zone where RF cavities and injection will be placed. The minimum of the bunch length along the ring occurs at the position in which the longitudinal phase advance measured from the RF cavity is half the total one [4]: the R_{56} term of the first order transport matrix between the cavity position and the IP is equal on both sides of the ring. This is obtained by a slightly different behaviour of the dispersion in the short-arc and long-arc cells, as can be seen in Fig. 4 where the betatron and the dispersion functions along the whole ring are plotted. All high impedance elements (RF cavities, injection septa and kickers and feedback kickers) find their natural location in the long straight facing the IP, where the bunch is longer and the effect of impedances on beam dynamics less critical [2]. This zone is also used for the tuning of the betatron working point. In the second crossing point the beams are vertically separated, and so are the vacuum chambers, in order to eliminate any cross-talk between the two beams. The crossing angle is large enough (± 13°) to separate the two beam lines in a short distance, with space for the RF system. Dispersion suppressors are placed between the arcs and the straights.

The Interaction Region [5] is 10 m long, with two sets of four symmetric quadrupoles, with $\beta_x^* = 0.5$ m, and β_y^* tunable between 2 and 4 mm. The Interaction Region is compatible with the present KLOE detector with minor modifications.

The main parameters of the ring are listed in table I.

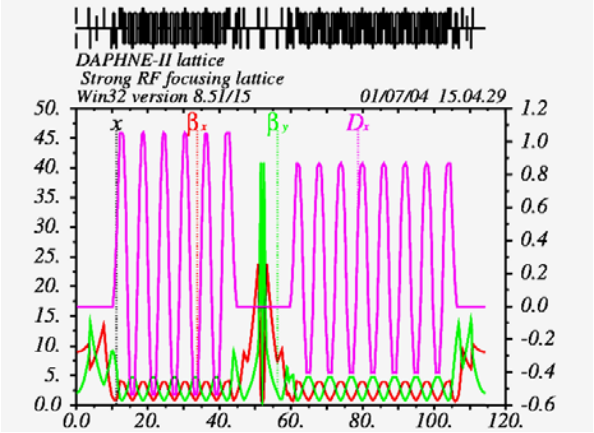

Figure 4: Betatron functions (left axis) and dispersion (right axis) in m of the whole ring (IP is in the ring center)

Table I: Main parameters

Parameters	
E (GeV)	**.51**
C (m)	**114.2**
L (10^{32} cm^{-2}s^{-1})	**100**
β^* (m) (h / v)	**0.5 / 0.0025**
ε (μ rad) (h / v)	**0.32 / 0.0013**
$Q_{x\,/}$ /Q_y	**8.120 / 8.102**
$Q'_{x\,/}$ /Q'_y	**-5. / -40.**
σ_z (cm)	**0.25-1.1**
σ_p	**1.1 10^{-3}**
N_b (10^{10})	**5**
ξ (h / v)	**0.067 / 0.075**
N bunches	**160**
I (A)	**3.5**
Uo (keV)	**37**
τ_x / τ_y / τ_s (msec)	**10 / 10 / 5**
f_{RF} (MHz)	**500**
V (MV)	**10.**
α_c	**-0.167**
μ_L (°)	**152**

SYNCHROTRON RADIATION AND STRONG RF FOCUSING PARAMETERS

The lattice can work with low RF voltage, or in SRFF regime. The choice of the best RF frequency is determined by the optimisation of the energy acceptance and the voltage level and 500 MHz fits the requirements.

By increasing the RF voltage, the ring enters in the SRFF regime. The longitudinal phase advance μ_L is:

$$\cos \mu_L = 1 - \pi \frac{\alpha_c C}{\lambda_{RF}} \frac{V_{RF}}{E} \tag{1}$$

The bunch length is shown in Fig. 5 for a weak focusing regime (V=1MV, μ_L=36º), and strong focusing one (V=10MV, μ_L = 152º). In the latter case σ_L = 2.5mm @ IP with a modulation factor ~ 4. The corresponding energy spread in the first case is almost equal to the natural one (4.5 10^{-4}) while it increases to 1.1 10^{-3} in the second.

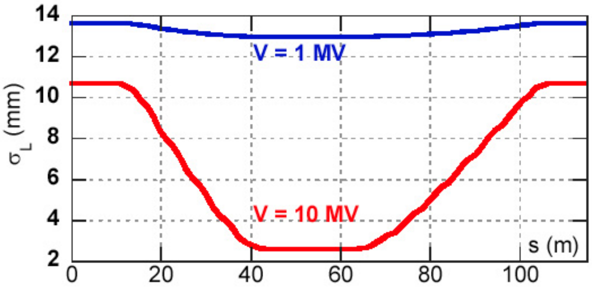

Figure 5: Bunch length along the ring for 1 and 10 MV.

LUMINOSITY

The design single bunch geometric luminosity is very high thanks to the very small β^*_y. The bunch spacing is 2 nsec and crossing angle is necessary. Since the Piwinski angle Φ is very small thanks to the very short bunch a crossing angle of up to ±30 mrad is still safe, giving a geometrical reduction of the luminosity of about 2%. The beam-beam blow-up should be reduced thanks to the strong radiation damping. Single bunch luminosity of the order of 6.5 10^{31} corresponds to 22 mA per bunch, σ_x=0.4mm, σ_y=1.8 m, σ_L =2.5mm, Φ = 0.19, κ = 0.4%.

With these parameters and 160 bunches (17% ion clearing gap), the luminosity is about 10^{34} cm^{-2}sec^{-1}. The total current per ring is 3.5 A (the maximum current stored up to now in DAΦNE has been 2.4A in the e-ring).

DYNAMIC APERTURE

The dynamic aperture (DA) is governed by the high vertical natural chromaticity of the ring: Q'_x~-5, Q'_y~-40, so the vertical DA is more sensitive to different kind of imperfections[6]. The on-energy DA is large enough (around $20\sigma_x$ and $350\sigma_y$) and the structure can be used with both high and low synchrotron tunes without special efforts. However, the 6D tracking shows the significant reduction of the vertical aperture even for zero amplitude of synchrotron oscillation. The reason is the large momentum compaction factor and hence the large path lengthening due to the betatron oscillation [7]. Increasing of the synchrotron oscillation amplitude provides further shrinking of the dynamic aperture. This can be explained by synchro-betatron satellites excited by the horizontal dispersion in sextupole magnets. According to [8] the following main satellites are located close to the chosen betatron tune region: $2\nu_{x,y} \pm \nu_s = n$, $\nu_x \pm 2\nu_s = n$.

However the 3D DA can be improved by a careful choice of the working point: moving it closer to the integer resonance and farther from the region of dangerous satellites, longitudinal aperture around $8\sigma_E$ has been obtained (see Fig. 6). A further increase can be obtained by the optimization of the lattice factors which define satellite band-with. For instance, in case of $2\nu_{x,y} \pm \nu_s = n$ this factor is [2] $\Delta Q_x \propto \hat{\delta} \left| \sum_k \left[(ml) \cdot \eta_x \cdot \beta_x \cdot e^{2i\psi_x} \right]_k \right|$, and can be minimized by usign several sextupole families.

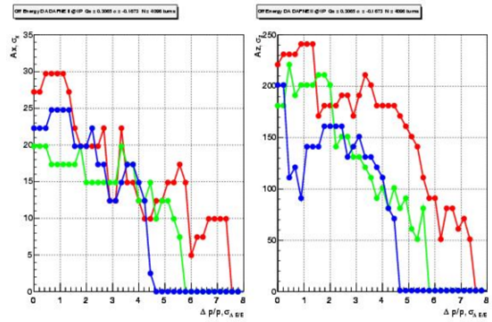

Figure 6: Horizontal and vertical DA in terms of σ_E

CONCLUSIONS

The increase by two orders of magnitude of the present performances of any accelerator is a very challenging task. In the case of a low energy collider this becomes really a very demanding process. A first analysis has shown that new concepts must be adopted to reach such a result. The idea of designing a collider on the strong rf focusing principle, together with the negative momentum compaction and the wiggling lattice covers in principle the required performances, but it needs experimental demonstrations. A first test of the negative α_c properties have been already done at DAΦNE and if the foreseen developments will be positive the configuration can be adopted in the normal operation. A SRFF experiment has been proposed at DAΦNE to demonstrate the regime feasibility. Many issues like for example the working point choice, the flexibility of the lattice, the background simulations, the continuous injection system due to the few minutes lifetime are still to be studied before this preliminary design becomes a real collider project.

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