# DESIGN CRITERIA AND LATTICE STUDY FOR THE LNF Φ-FACTORY

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## Abstract

We present here a Φ-factory machine design with a luminosity of $10^{32}$ $cm^{-2}sec^{-1}$ at 510 MeV. The machine consists of two vertically separated storage rings with head-on collision in a single interaction point. Conventional wiggler magnets are inserted to increase the radiation damping and therefore the luminosity. A crab-crossing scheme is also presented.

## Introduction

A Φ-factory proposal for the Frascati LNF-INFN laboratory has recently been submitted[1] to the INFN board of trustees.

The project consists of a two-ring colliding beam Φ-factory with a conventional Linac as an injector. The accelerator complex will be placed inside existing LNF buildings (fig. 1).

A two stage project is foreseen: the PHASE I Factory will be entirely based on very conventional technology and its design luminosity is $10^{32}$ $cm^{-2}sec^{-1}$ at 510 MeV. The design affords enough flexibility so that any further modification that may prove necessary or desirable to upgrade the machine performance can be incorporated during PHASE II, dedicated to the upgrade of luminosity (increase of radiation damping and fluctuations by additional wigglers, crab-crossing, smaller $\beta_y$ etc.).

The design presented here has two distinctive features:

- electrons and positrons circulate in two vertically separated storage rings and collide head-on in a single interaction point (IP);
- the ring magnetic lattice is a modified Chasman-Green type with a 1.9 Tesla conventional wiggler magnet inside each achromat. This choice allows ample emittance tunability and, at the same time, stronger radiation damping.

## Design criteria

The single bunch luminosity for an electron-positron storage ring collider can be written, in the case of equal tune shifts and equal number N of e⁻ and e⁺, as:

$$L = \pi\,(\gamma/r_e)^2\ \xi^2\ f\ \varepsilon\ (1+\kappa)/\beta_y \qquad (1)$$

where f is the collision frequency, $\gamma$ is the electron energy in units of its rest mass, $r_e$ the classical electron radius, $\beta_y$ the value of the vertical betatron function at the IP, $\xi$ the linear tune shift, $\kappa$ the coupling coefficient and $\varepsilon$ the emittance.

A complete parameter list is reported in Table 1, while the discussion of parameter optimization can be found in ref.[1]. Let us mention here two "phenomenological prescriptions" that we have followed in our design.

The first one is Seeman's best fit[2] for $\xi$

$$(\xi/\gamma)^{max} \sim 1.4\ 10^{-5}\ (\,I_{2\,(m^{-1})}/n_i\,)^{1/2} \qquad (2)$$

where $I_2$ is the synchrotron radiation integral as defined in[3] and $n_i$ the number of crossings/turn.

The design value of $I_2$ (see Table 1) satisfies (2) for $\xi \sim .04$ and $n_i = 1$.

The second prescription, described in a recent study of M. Bassetti[4], implies, independently from $\xi$, a limitation on the maximum number N of particles per bunch due to the perturbation of radiative phenomena.

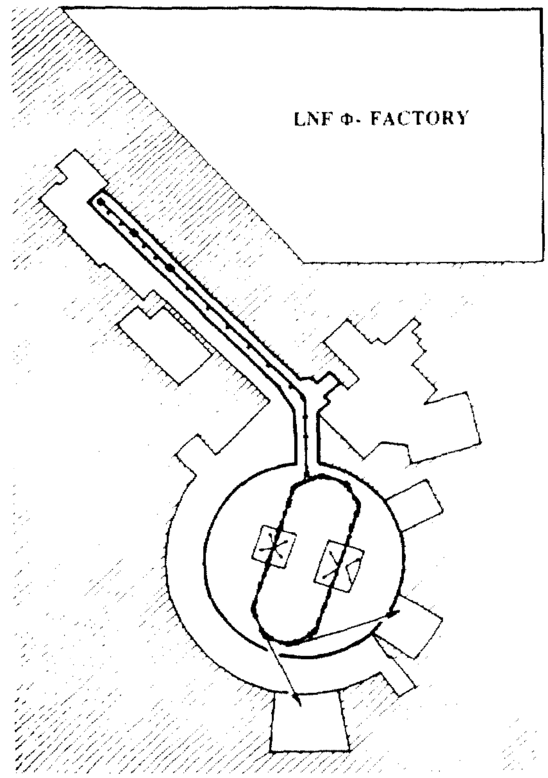


*Fig. 1 - LNF Φ-Factory Complex.*

The relevant quantities, in Bassetti's theory, are the average energy deviation $\Delta E_{bb}$ of a particle working against the electric field of the opposite beam and the rms quantum energy fluctuation $\sigma_R$ between two consecutive interactions. $\Delta E_{bb}$ and $\sigma_R$ can be written as[5]:

$$\Delta E_{bb\ (KeV)} \sim 280\ r_e\ (\sigma_y/\sigma_x)\ N/\beta_y \qquad (3)$$

$$\sigma_{R\ (KeV)} \sim 6.5\ \ E^{3.5}{}_{(GeV)}\ (I_{3\ (m^{-2})}/n_i\,)^{1/2} \qquad (4)$$

where $\sigma_x$ and $\sigma_y$ are the rms horizontal and vertical beam sizes and $I_3$ is the synchrotron radiation integral as defined in ref. [3].

For a given set of beam parameters, above a certain threshold, in order to accumulate more particles one has to increase $I_3$ in such a way to satisfy the relation:

$$\sigma_R/\Delta E_{bb} = C >> 1 \qquad (5)$$

The coefficient C can be derived by fitting the experimental data from operating storage rings. As a preliminary evaluation from available data we obtained $C \sim 150$ which gives $I_3 \sim 11$. The corresponding wiggler characteristics are given in Table I. However it must be noted that $I_3$, and therefore the wiggler length, is strongly dependent on the value of the constant C. Studies are in progress in order to get a more accurate estimate.

Let us point out that, by incorporating Seeman's and Bassetti's criteria in our design we are making a conservative luminosity estimate.

*Table I - Parameter List.*

| | | | |
|---|---|---|---|
| Energy (MeV) | 510. | Luminosity ($cm^{-2}$ $sec^{-1}$) | $10^{32}$ |
| Circumference (m) | 100.73 | | |
| Dipole bending radius (m) | 1.464 | | |
| Wiggler bending radius(m) | 0.9 | $N^{er}$ of particles/bunch | 8.9 $10^{10}$ |
| Wiggler length (m) | 1.5 | $N^{er}$ of bunches | 24 |
| Wiggler period (m) | 0.5 | Collision frequency (MHz) | 71.4 |
| Rings separation (m) | 1.391 | Coupling coefficient $\kappa$ | .01 |
| Horizontal β-tune | 6.12 | $\xi_y = \xi_x$ | .04 |
| Vertical β-tune | 6.1 | $\beta_y$ at I.P. (cm) | 4.5 |
| Momentum compaction | .0086 | $\beta_x$ at I.P. (m) | 4.5 |
| Energy loss/turn (KeV): bending magnets | 4.08 | $\sigma_y$ at I.P. (μm) | 21.1 |
| wigglers | 7.06 | $\sigma_x$ at I.P. (mm) | 2.11 |
| $I_2$ ($m^{-1}$) | 11.7 | RF freq. (MHz) | 357.14 |
| $I_3$ ($m^{-2}$) | 11.2 | Harmonic number | 120 |
| $\sigma_R$ (KeV) | 2.1 | RF voltage (kV) at Z/n = 2 Ω | 273. |
| $\Delta E_{bb}$(KeV) | .015 | at Z/n = 1 Ω | 131. |
| Betatron damping time (msec) | 30.4 | Parasitic losses/Ω (keV) | 4.0 |
| Relative r.m.s. energy spread | 4.25 $10^{-4}$ | Bunch length $\sigma_z$ (cm) | 3.0 |
| Natural emittance (m-rad) | $10^{-6}$ | Bunch peak current (Amp) | 57. |
| Natural chromaticity: horizontal | -10.3 | Total average curr. (Amp) | 1.02 |
| vertical | -16.4 | Synch. Rad. Power/beam (kW) | 11.5 |

## The storage ring lattice

In Fig. 2 we plot the optical functions for half the ring starting from the IP.

The low-β insertion is the most crucial part of the design because it has to fullfill the following constraints:

- low $\beta_y$ value;
- vertical separation;
- vertical dispersion suppressor;
- experimental apparatus: the low β section is confined within a cone of half aperture angle $\theta = 8.5°$ over a length of ± 5 m from IP.

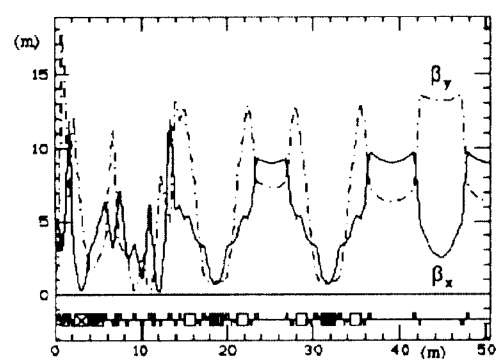


*Fig. 2 - β-functions for half ring.*

The resulting structure satisfying all the requirements is rather long, as shown in fig. 3, but guarantees flexibility and tunability. The vertical half-separation and the horizontal beam size from IP to the second parasitic crossing point are shown in fig. 4. For the electrostatic separator we assumed a voltage of 100 KV and a plate separation of 4 cm.

The storage rings main arcs structure is a 4-period modified Chasman-Green lattice. In order to increase the radiated energy per turn we also decided to include, inside each achromat, 1.5 m of 1.9 Tesla normal conducting wiggler. In this way we also obtain an emittance of $10^{-6}$ m-rad because the wiggler is in a high dispersion region. To tune the emittance, it will be necessary to change the dispersion function in the wiggler region; this is why we decided to introduce also a D Q-pole inside the achromat.

In the straight section opposite to the low-β one there is enough free space to insert the RF cavity, the injection system and more wigglers.

The fully periodic Chasman-Green lattice has large dynamic aperture with only two families of chromaticity correcting sextupoles. When the low-β insertion is included, the dynamic aperture shrinks because of the larger chromaticity and lower symmetry. However in the horizontal plane the maximum aperture is of the order of 10 $\sigma_x$ , enough for beam lifetime, while in the vertical plane, as we have chosen $\kappa$ =.01, the dynamic aperture is much larger than the beam size (~ 50 $\sigma_y$). A preliminary dynamic aperture calculation at the IP is shown in Fig. 5. Optimization of the working point in the tune diagram and a more elaborate chromaticity correction scheme are under study.

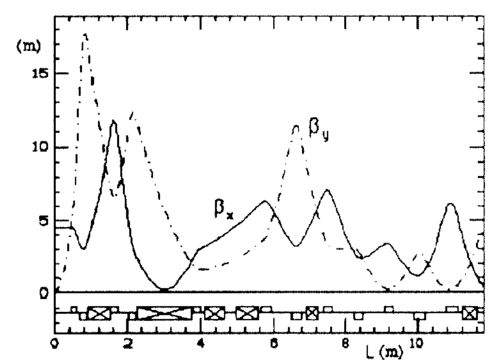


*Fig.3 - β -functions from the IP to the last vertical bending magnet.*

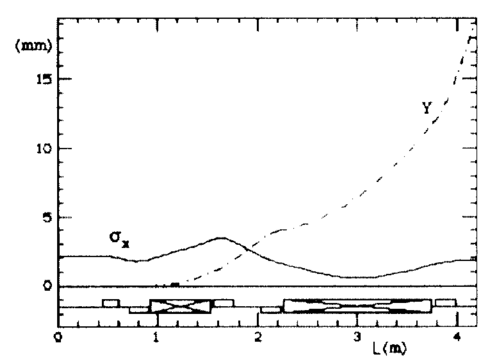


*Fig.4 - Vertical separation Y and horizontal beam size from IP to the second parasitic crossing point.*

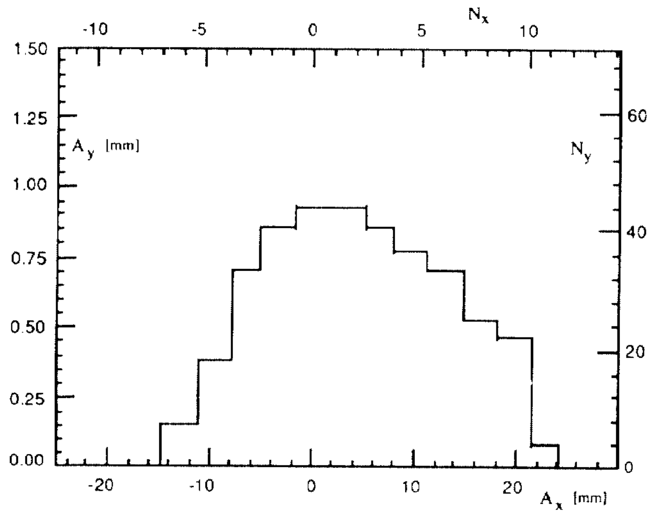


*Fig. 5 - On-momentum dynamic aperture at the IP. $N_x$ and $N_y$ are the maximum stable amplitudes in unit of σ's.*

## Beam stability and lifetime

High current in single and multibunch operation, short bunch length, long lifetime and the stablest possible beams are all required at the same time, thereby putting severe constraints on the design of the overall system.

A self consistent computation has therefore to be carried out and an optimum seeked. The main phenomena considered in this analysis are: single bunch instabilies with turbulent bunch-lengthening, lifetimes (Touschek, gas scattering, single beam-beam bremsstrahlung), coupled bunch instabilities, emittance growth (intrabeam scattering).

Fig. 6 shows the curves (dashed lines) relating the peak voltage, necessary to obtain the nominal bunch length of 3 cm, to the RF frequency for different machine impedances. The solid line is the limiting curve for transverse instabilities. The dots are the calculated Touschek lifetimes for two different RF frequencies, 357 and 500 MHz.

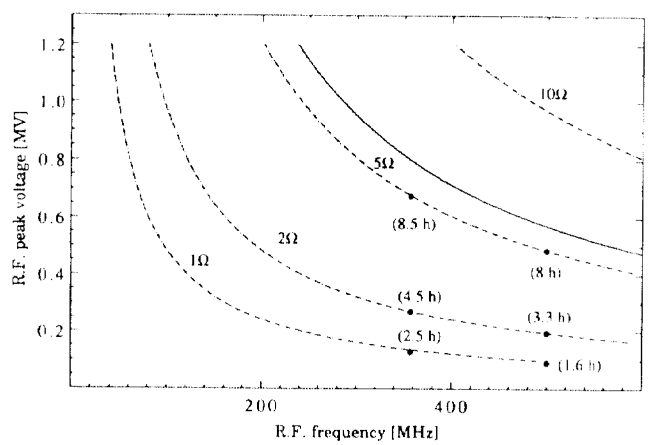


*Fig. 6 - RF peak voltage necessary to obtain 3 cm bunch length as a function of RF frequency.*

Finally we mention that for this machine multibunch instabilities are very important and must be carefully studied foreseeing the combined use of HOM frequencies detuning and feedback systems.

## The crab-crossing option

In a crab-crossing scheme[6] the centers of the colliding beams travel along two separate trajectories intersecting with an angle θ at the IP. A first RF cavity gives an angular kick θ/2 to the head of the bunch and a kick of opposite sign to the tail. If the cavity is located π/2 from the IP in β-phase angle, the crossing beam geometry is changed into a head-on collision. A second crab cavity, π away from the first one, restores the original bunch orientation.

Due to this crossing geometry a bunch spacing closer than in the head-on collision scheme is allowed and, consequently, a higher collision frequency **f**. This increase implies a luminosity enhancement, if one can store large average beam currents and if the experiments can tolerate high collision rate.

We are investigating several crab-crossing schemes[7].

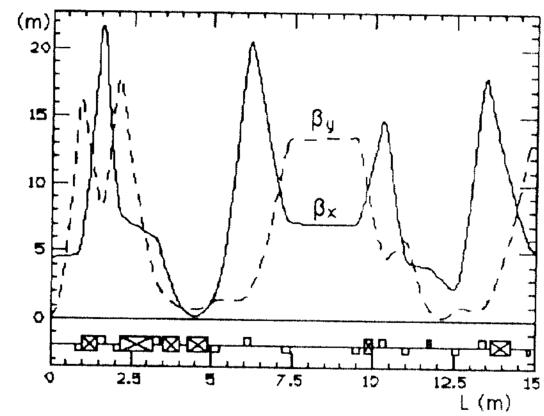


*Fig.7 - β-functions from IP to the first dipole of the arcs for the crab-crossig lattice.*

We present here a first scheme of a transverse crab that should give, in principle, a luminosity enhancement factor of the order of 5. To incorporate this option in the previous design we mantain the same separation between the two rings, the same structure of the arcs and the same values for $\beta_{x,y}$ at the IP.

The RF crab-cavities (two for each beam) are put at a distance of 3π/2 (instead of π) in β-phase angle from the IP, at 8.61 m (fig.7). The peak voltage required is then $V_T$ = 860 KV and the phase and amplitude stability requirements are:

$$\Delta\phi < 0.9^o \ , \quad \Delta V/V < 2.3\times10^{-4}$$

We point out that, due to the bunch frequency of 357 MHz, the scheme has been designed with a reasonable beam vertical separation at a distance as short as .42 m from the IP.

The vertical crab crossing geometry implies a second crossing point on the opposite side of the ring. To avoid a second IP the crossing can be set between two parasitic interaction points.

## References


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