DAΦNE COMMISSIONING

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Abstract

We report the main results of DAΦNE commissioning, which is underway and is expected to be completed by next autumn, when the KLOE detector will be rolled in to begin physics run.

1 INTRODUCTION

The construction and installation phase of DAΦNE [1], the Frascati Φ-factory, have been completed in autumn 1997 (see Fig. 1).

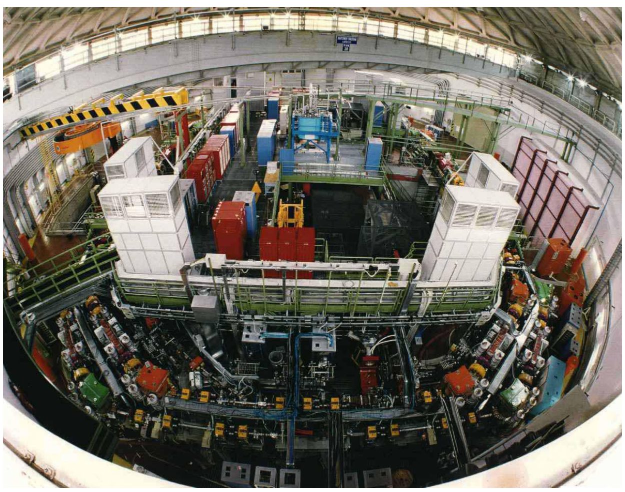

Figure 1: DAΦNE hall (June 1998)

The approach of DAΦNE to high luminosity, multi-bunch flat beams with a very high current stored in two separate rings, is common to the other two factories presently under construction, KEK-B [2] and PEP-II [3].

The electron and positron beams collide in two Interaction Points (IP). The crossing at a horizontal angle of 25 mrad minimizes the effect of parasitic collisions and it allows to store up to 120 bunches per ring, corresponding to a colliding frequency of 368.26 MHz. The high rate of bunch collisions relaxes the single bunch luminosity parameters.

The magnetic layout of DAΦNE is shown in Fig. 2, while the main design parameters are reported in Table 1.

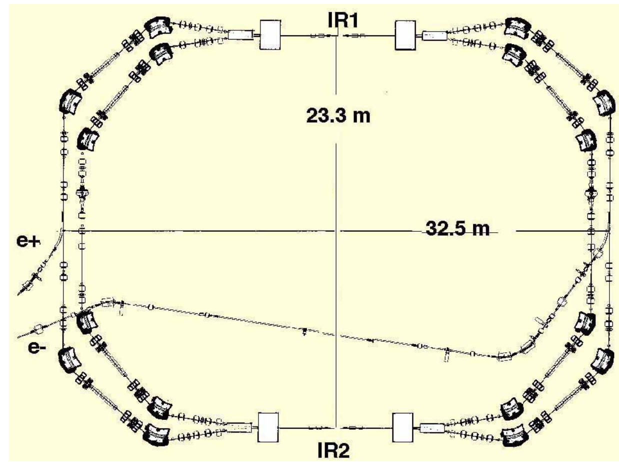

Figure 2: DAΦNE magnetic layout

Table 1: DAΦNE Design Parameters

Energy [GeV]	0.51
Maximum luminosity [$cm^{-2}s^{-1}$]	5.3×10^{32}
Single bunch luminosity [$cm^{-2}s^{-1}$]	4.4×10^{30}
Trajectory length (each ring) [m]	97.69
Emittance, $\varepsilon_x/\varepsilon_y$ [mm·mrad]	1/0.01
Beta function, $\beta^{*,x}/\beta^{*,y}$ [m]	4.5/0.045
Transverse size $\sigma^{*,x}/\sigma^{*,y}$ [mm]	2/0.02
Beam-beam tune shift, ξ_x/ξ_y	0.04/0.04
Crossing angle, θ_x [mrad]	25
Betatron tune, ν_x/ν_y	5.09/5.07
RF frequency, f_{RF} [MHz]	368.26
Number of bunches	120
Minimum bunch separation [cm]	81.4
Particles/bunch [10^{10}]	8.9
RF voltage [MV]	0.250
Bunch length σ_L [cm]	3.0
Synchrotron radiation loss [keV/turn]	9.3
Damping time, τ_ε/τ_x [ms]	17.8/36.0

The collider commissioning without experiments (*day-one* configuration) is well advanced. The roll in of KLOE [4] detector on the first IP is scheduled by next fall and starts of physics run by the end of the year. FINUDA [5] roll-in will come later and in the meantime the DEAR [6] experiment will take data on the second IP.

The injector system, consisting of a full energy LINAC and a damping ring (Accumulator), is described in detail in this conference [7, 8].

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The injector commissioning has been carried out in parallel with the main rings installation, for a total period of two months spread along two years. The LINAC and Accumulator performance have exceeded the design values and both operate in a reliable way.

2 MAIN RING OVERVIEW

Electrons and positrons are stored in two symmetric rings, intersecting in two points and sharing two Interaction Regions (IR), where beams travel in the same vacuum chamber, passing off-axis in the low beta quadrupoles. At the end of each IR the beams are separated by 12 cm and a splitter magnet, with two independent vacuum chambers, drives the two beams in the corresponding rings.

The ring periodic structure consists of four arcs. The straight sections orthogonal to the IRs are used for injection, RF and feedback kickers. The arc cell, named BWB (Bending-Wiggler-Bending) [9], is quasi-achromatic, its special feature being the presence of a 1.8 T wiggler, 2 m long, in the region of maximum dispersion, which doubles up the synchrotron radiation emitted in the dipoles. The damping times are shortened and instabilities thresholds are raised. The wiggler allows also emittance tuning at constant field by appropriate control of the dispersion function. Moreover, the resulting increase of the natural energy fluctuation should raise the beam-beam tune shift limit [10].

To make optics flexible all quadrupoles and sextupoles are independently powered. There are 480 power supplies [11], ranging from 100 VA to 1500 kVA. The very different output currents (10÷2300 A) and output voltages (8÷1300 V) have led to different technical solution realized by various industries (Danfysik - Denmark, Hazemeyer - France, Inverpower - Canada, OCEM - Italy).

Special RF cavities, with low impedances parasitic high order modes (HOM) content, have been developed [12] to allow stable high current-multibunch operation. The cavities, one per ring, are normal conducting copper single cells, with a system of HOM damping waveguides which couple out and dissipate the HOM energy induced by the beam on external 50 Ω loads. The HOM shunt impedances have been reduced by orders of magnitude. The operation of the damped cavities has been until now very successful, without any evidence of arcing or multipacting effects due to the loading waveguides.

A longitudinal bunch-by-bunch feedback system [13] has been implemented in collaboration with the SLAC/LBL PEP II group to damp beam residual oscillations. It consists of a scalable time domain system employing digital techniques. A wideband kicker cavity has been developed at LNF [14].

A timing system [15] provides the synchronization of the Main Ring (MR) RF cavities, the Accumulator RF phase, the firing instant of the Linac, the injection/extraction kickers in the accumulator ring and the MR injection kickers in order to fill the selected bucket, with a precision down to a few picoseconds.

The Control System [16] is completely based on personal computers. The commercial software LabVIEW has been chosen at any level and the hardware interface is based on specially developed MacIntosh boards in a VME environment. The machine devices are driven by several distributed CPUs. A shared memory instead of a network permits fast, easy, and high bandwidth communications. The Control System has allowed the step by step commissioning of the major DAΦNE subsystems as they were installed, proving to be modular and extensible.

3 SINGLE RING COMMISSIONING

The initial commissioning phase of the collider has been dedicated to optimize the single bunch luminosity. Single ring commissioning has therefore been focused on full characterization and equalization of the single bunch luminosity parameters of both rings. The start up has been done directly on design IP parameters, i.e., nominal betatron functions (β^*) at the IP and nominal crossing angle.

Being DAΦNE a low energy machine the IR optics is highly influenced by the experimental detector solenoidal fields. The KLOE detector, for example, (0.6 T x 4 m magnetic field) will introduce focusing effects plus a rotation of ~ 45° in the transverse plane which will be cancelled by external compensating solenoids.

For the collider commissioning in the absence of experiments, two *day-one* IRs with conventional quadrupoles and no solenoids, have been installed in the experimental pits. From the optics point of view the IR first order matrix is equal to the IR experimental matrix, while the chromatic contribution is weaker, since quadrupole arrangements had no space constraints. Figure 3 shows the IR betatron functions.

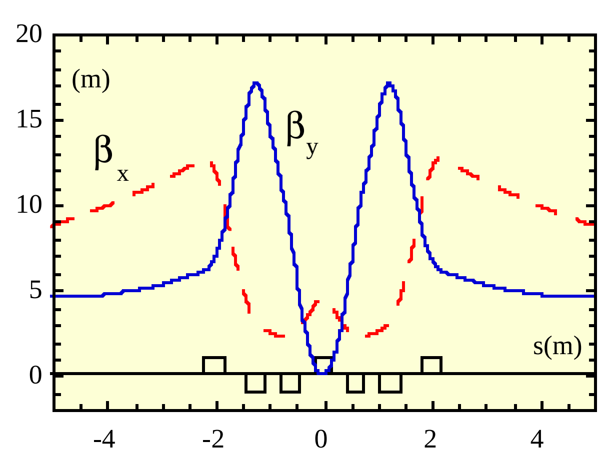

Figure 3: *Day-one* IR betatron functions

The closed orbit has been corrected in both rings to rms values of 1 ~ 2 mm.

Since the two rings are close to each other (see Figs. 1, 2) the magnetic cross-talk is not negligible, as was already estimated from magnetic measurements. Fringing fields of dipoles, wigglers, splitters and elements of the transfer lines produce orbit and tune shifts on the near ring mainly in the horizontal plane. Measurement and correction of these effects have been successfully carried out. The horizontal closed orbit is also influenced by the compensation of the trajectory in the wigglers ($\int B\,dl = 0$ on the trajectory), by the splitter magnet set point as a function of the crossing angle at the IP and by the balance between the splitter and the dipole field. The vertical closed orbit with no correction is stable in both machines: this is a cross-check of the goodness of the alignment [17].

The Beam Position Monitor (BPM) system includes striplines for single pass measurements and button monitors for accurate measurements on the stored beam. The electronics for the BPM detectors has been developed by BERGOZ Beam Instrumentation System. An example of the corrected orbit on the electron ring is given in Fig. 4.

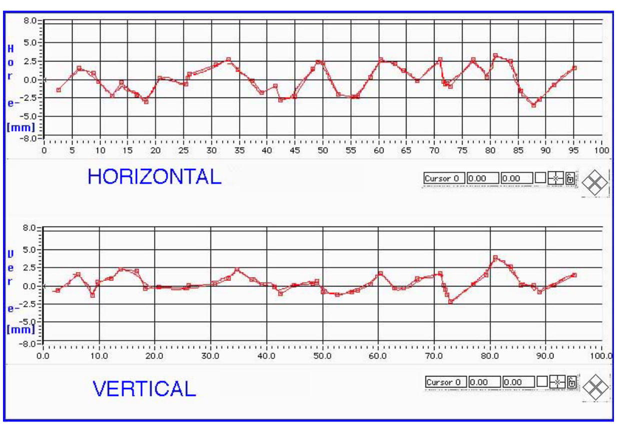

Figure 4: Corrected closed orbit in e^- ring

Extensive measurements of optical functions and chromaticity have been done. A quite satisfactory agreement has been reached between measurements and a machine modeling which includes fringing effects of wigglers, small curvature radius dipoles, quadrupoles and off-axis effects of low-beta quadrupoles. No evidence of dynamic aperture limits has been found.

Coupling has been measured and corrected by powering few of the installed skew quadrupoles. The bunch dimensions were measured with the synchrotron light monitors. Since the vertical resolution was not sufficient, beam lifetime measurements have been used to minimize the coupling: in fact the beam lifetime τ is Touschek dominated, and for a given bunch current, minimum coupling corresponds to maximum bunch density and to minimum τ. The estimated coupling is around the nominal 1% for the positron beam, which is again a check of the good magnet alignment. In the e^- ring the ratio of the vertical emittance to the horizontal one is also ~ 1% at low current; as the current increases the emittance blow-up due to ion trapping leads to vertical dimension increase.

Special care has been put on the minimisation of the coupling impedance. The contribution of every vacuum system element to the impedance budget has been accurately assessed.

The bunch length as a function of the bunch current has been measured in the positron ring. Figure 5 shows a comparison of the measured bunch length with the results of numerical simulations which were carried out much before the measurements [18]. The agreement is really satisfactory. The normalised longitudinal coupling impedance $|Z/n|$ estimated from both the measurement and the simulation results is equal to 0.6 Ω.

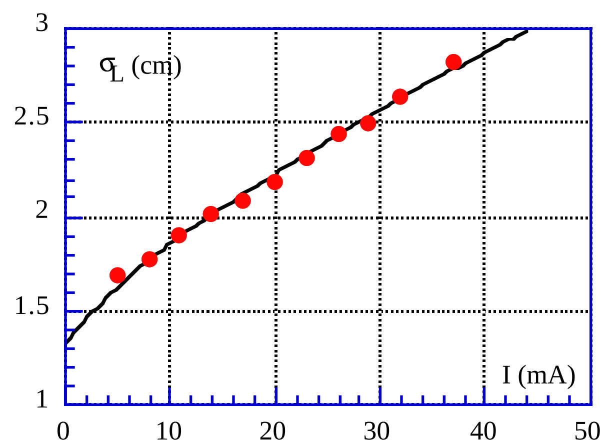

Figure 5: Bunch length simulations (solid line) and measurements (dots) in the e^+ ring

Most components of the vacuum chamber have been baked out before the installation. No bake-out has been done in-situ so far. The vacuum has been improved by beam-conditioning: several night shifts have been dedicated to clean the vacuum walls by waving vertically the beam at the maximum available current. Titanium sublimation pumps have been activated few times. The present static average pressure in the rings is ≤ 1 nanotorr. The pressure rise due to the beam is still high and evidence of ion trapping in the electron ring has been found even in the single bunch mode. Tune spread and shift have been measured. The ion clearing system has been preliminarily tested, partially powered, with several bunch filling configurations. No evidence of photo-electron instabilities in the positron ring has been so far detected.

The nominal single bunch current of 44 mA has been exceeded in both positron and electron rings: 90 mA of positrons and 110 mA of electrons have been stored with no active feedback and with no evidence of harmful instabilities. In particular, the transverse mode coupling threshold has not been reached.

The threshold of head-tail instability with no sextupoles is of the order of 10 mA in both rings with the present chromaticities.

A few hundreds of mA have been stored in both rings with different multibunch configurations.

In spite of no dedicated machine time spent in studying and optimising multibunch injection and operation, the longitudinal bunch by bunch feedback systems have been set-up [13] and are operational in both rings. In particular, damping times in the millisecond region are routinely obtained and consistently measured. A damping time faster than ~ 200 μsec has been demonstrated in the positron ring with 30 bunches. Figure 6 shows the beam spectrum with feedback off and on in the positron ring.

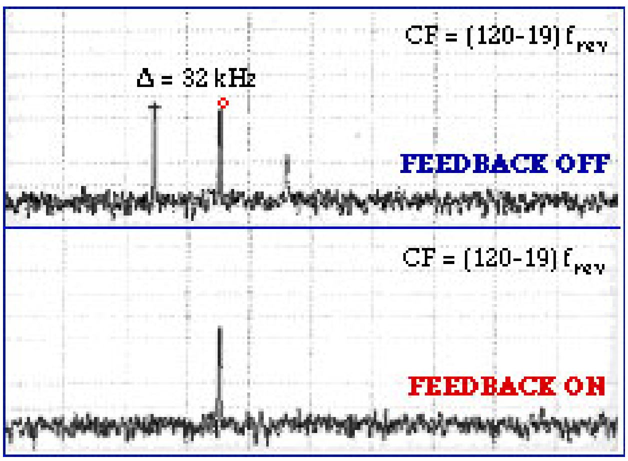

Figure 6: Beam spectrum without and with feedback in the positron ring, 30 bunches, 70 mA

4 SINGLE BUNCH LUMINOSITY

The design value of the beam-beam tune shift is 0.04. The design betatron working point has been chosen on the basis of beam-beam simulations [19] which include crossing angle, finite bunch length, variation of β along the bunch during collisions and energy loss due to longitudinal effects. The optimum operating point is of course near the integer.

Since in the first runs of single ring operation the rings were tuned on working points far from the integer, we have decided to make the first collisions in the tune zone already explored. According to simulations the chosen working point in this tune region is (5.15, 5.21) which provides a reasonable beam-beam tune shift parameters of $\xi = 0.02$. The corresponding current is 20 mA per bunch. Tail growth and beam blow up at larger currents are predicted.

The two rings have been separately tuned on the collision configuration, checking the symmetry of the two distinct β_y; the two beam trajectories in the IR were aligned (see Fig. 7), especially benefiting of one BPM at the IP installed in the *day-one* vacuum chamber.

The longitudinal overlap of collisions at the nominal IP has been timed by monitoring the distance between the combined signals left on two sets of symmetric BPMs around the IP by the incoming beam toward the IP and the outcoming one.

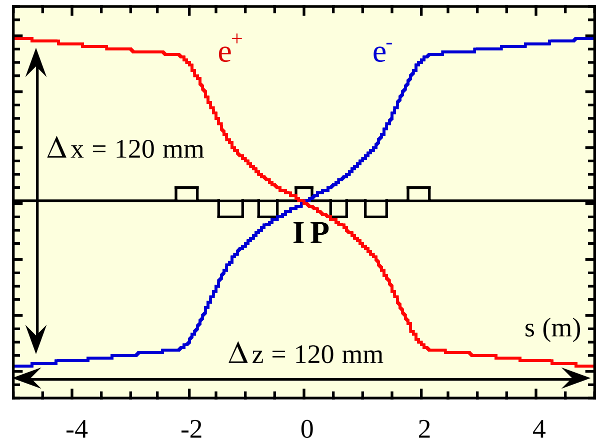

Figure 7: Beam trajectories in the IR.

The collisions have been done on one IP with the beams kept vertically separated at the other one.

A luminosity monitor [20] based on the measurement of the photons from the single bremsstrahlung (SB) reaction is used. The SB high counting rate allows fast monitoring, which is very useful during machine tune-up. The contribution of the gas bremsstrahlung reaction is subtracted by measuring the counting rate with two non interacting bunches. The estimated error on the measurements is of the order of 20%.

The luminosity has been also evaluated from beam-beam tune shift measurements and results are in good agreement with the luminosity monitor ones.

Sets of luminosity measurements have been executed during two different shifts. The results are summarized in Fig. 8. All the measurements correspond to good beam-lifetime in both beams and stable conditions. First runs dedicated to luminosity parameter tuning were done with bunch currents limited to few mA.

The design luminosity is $4.4 \cdot 10^{30}$ cm^{-2} sec^{-1} with 44 mA per bunch. Scaling it by the two beam currents, the design geometrical luminosity for nominal emittance, coupling and β* is $2.2 \cdot 10^{27}$ cm^{-2} sec^{-1} mA^{-2}.

The maximum measured luminosity so far is:

$$4 \cdot 10^{29} \text{ cm}^{-2} \text{ sec}^{-1}.$$

Values of 60% the design geometrical luminosity have been consistently obtained. The maximum current per beam was about 20 mA, well in agreement with the $\xi = 0.02$ beam-beam simulations. Larger currents showed as expected emittance blow-up in the weaker beam and poor lifetime. Considering that the e^- emittance is enhanced by ion trapping, we can conclude that the basic single bunch luminosity parameters are in agreement with the design ones.

Next shifts will be done at the design working point for luminosity optimisation.

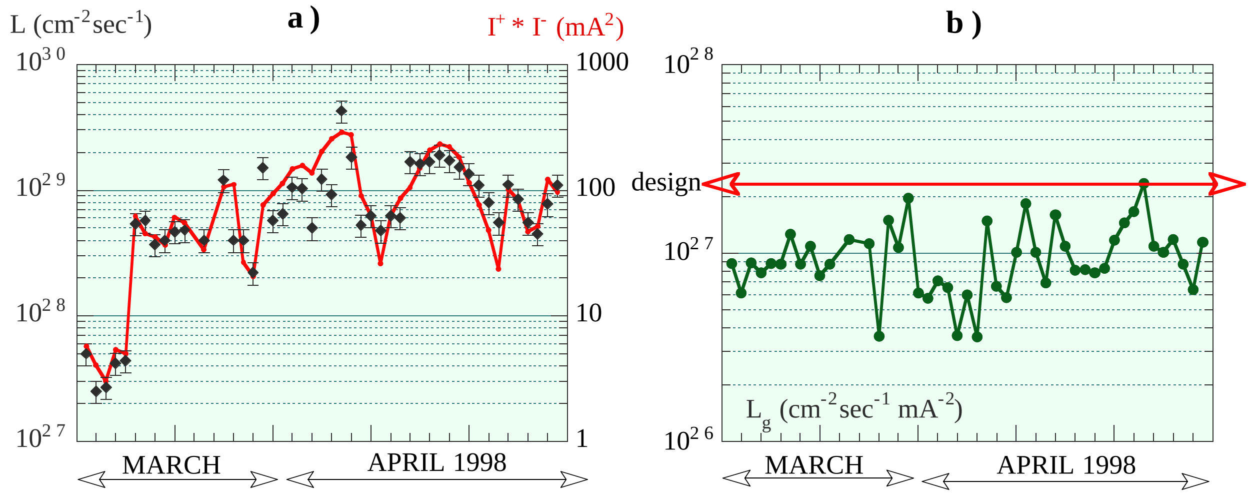

Figure 8: a) Luminosity (circles with error bars) and product of bunch currents (solid line); b) Geometrical luminosity

5 CONCLUSIONS

The results so far obtained during the first period of DAΦNE commissioning are in agreement with all the design parameters and there is no evidence of new accelerator physics.

The DAΦNE commissioning will continue to achieve the design luminosity, together with high current and multibunch operation optimization.

The commissioning with the KLOE detector, coinciding with the first physics data taking, is foreseen for the end of 1998.

6 ACKNOWLEDGMENTS

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