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STATUS OF DAΦNE PROJECT

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ABSTRACT

DAΦNE, the high luminosity e^+/e^- Φ-factory, built at LNF of INFN in Frascati is presently under commissioning. The collider commissioning started in September 1997, with a short term luminosity goal $L = 1.3\ 10^{32}\ cm^{-2}\ sec^{-1}$.
DAΦNE is the first of the new generation of very high luminosity colliders, called factories, to come in operation. In this paper we report about the status of the project and on the results of the first months of commissioning.

1. Introduction

The construction of the Φ-factory DAΦNE (including a completely new injector) was approved by the INFN Board of Directors in June 1990, while the engineering design started in spring 1991. This new facility is housed in the existing building of the ADONE accelerator, which has been shut down in April 1993. All the machine components have been installed and the commissioning started on September 1997.

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DAΦNE is optimized at the Φ energy (1.02 GeV c.m.) [1]. The major physics motivation is the observation of direct CP-violation in K_L decays, i.e. the measurement of ε'/ε with accuracy in 10^{-4} range by the KLOE [2] detector. A second, smaller detector, FINUDA [3], for the study of Lambda hyper nuclei levels and lifetimes has also been approved and will be installed at a later time.

The injector chain of DAΦNE consists of a full-energy high-intensity e^+/e^- Linac, injecting into an intermediate storage ring (Accumulator/Damping Ring), employed to accumulate the required single bunch e^+/e^- current and to damp the longitudinal and transverse emittances for subsequent single bunch injection in the DAΦNE main rings with no saturation of injection.

The collider consists of two symmetric rings, able to store up to 120 bunches of electrons and positrons, intersecting at a total horizontal angle of 25 mrad in two interaction regions (IR), equipped with superconducting solenoids and permanent magnet quadrupoles.

In September 1997 we began commissioning the facility without the experimental detectors in place. The IRs are equipped with two provisional (day-one) vacuum chambers accommodating conventional electromagnetic quadrupoles and additional diagnostics.

2. Injector

The injector consists of an e^-/e^+ Linac and an Accumulator/Damping Ring, connected to DAΦNE through ~160 m long Transfer-lines.

The Linac, 2.856 GHz, built by Titan Beta, has been already installed and commissioned with both electrons and positrons. All the design parameters for electrons and positrons have been achieved during the commissioning operation (Table I).

Table I: *DAΦNE LINAC parameter list*

	e^-	e^+
Max Energy (MeV)	800	550
Max. Rep. Rate (pps)	50	50
Peak current (mA)	150	36
Pulse width(ns)	10.0	10.0
Positron Production Energy(MeV)	250	
Emittance (mm-mrad)	1.0	10.0
Relative energy spread	±.005	±.01

The Accumulator is used to damp the transverse and longitudinal emittances of the Linac beam (e^- or e^+), thus relaxing the injection requirements in the design of DAΦNE. It has been built by Oxford Instruments and completely installed together with the transfer lines. The injection chain works as follows: LINAC beam is first injected at ~ 50 pps in one RF Accumulator bucket, damped in 100 ms, extracted at ≈1 Hz, and injected into a single DAΦNE bucket.

During the commissioning the accumulator has been fully characterized with several machine measurements: tunes, chromaticity, closed orbit distortion and correction, bunch-lengthening and machine impedance, lifetime, beam stability. Measurements have shown a very good agreement with the design predicted performances (Table II), in particular it was considered a noticeable result the stable and repeatable storage of up to 130 mA in a single electron bunch.

Injection and extraction to/from the Accumulator was also successfully tested in September ‘97. In Fig. 1 we show an example of stripline signals of the Linac e^+ beam (long and weak) and for the accumulator beam (short and intense).

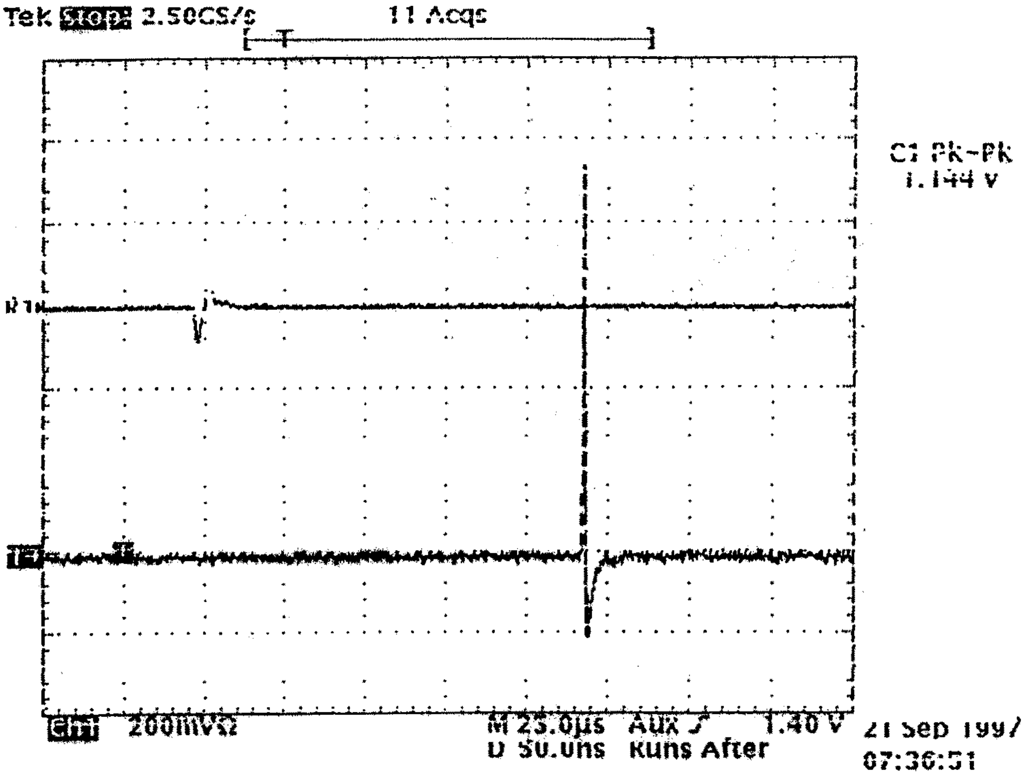

Figure 1: *Stripline response signal from the injected (top) and extracted (bottom) positron beam.*

Table II: *Accumulator Main parameters*

Max Energy (MeV)	550
Circumference (m)	32.56
Emittance (mm-mrad)	0.26
Betatron tune ν_x/ν_y	3.12/1.14
RF frequency (MHz)	73.65
RF peak voltage (kV)	200
Single bunch av. current (mA)	150
Bunch length (cm)	3.8
Synchrotron loss (keV/turn)	5.2
Damping time, τ_ε/τ_x (ms)	10.7/21.4

3. DAΦNE

In order to achieve a very high luminosity, mandatory target for a particle factory, the DAΦNE design is based on the high current, double ring approach, adopted also by PEP-II [4] and KEK-B [5]. This high current approach allows to use single bunch parameters rather conservative from an accelerator physics point of view, but it moves the difficulties to engineering challenges (vacuum, RF, multibunches).

Table III shows the DAΦNE design parameters compared to those of PEP-II and KEK-B.

3.1. Main features and optics

In DAΦNE electrons and positrons circulate in two separated storage rings laying in the same horizontal plane with horizontal crossing in 2×10 m long interaction regions (IR1 and IR2), at an angle of 25 mrad.

The regular lattice is a modified Chasman-Green type: it consists of 4 achromats, each housing a 2 m long, 1.8 T normal conducting wiggler to increase beam emittance and radiation damping. The straight sections orthogonal to the IR are used for injection, RF and feedback systems. Such a magnetic structure, with all the quadrupoles and sextupoles powered independently, has enough flexibility to cover a wide range of betatron tunes keeping good dynamic aperture. All the critical components of the project (injection, vacuum system, etc.) are dimensioned for a maximum current of 5 Amps.

Table III: *DAΦNE, KEK-B and PEP-II design parameters*

	DAΦNE	**KEK-B**		**PEP-II**	
		L.E.R.	H.E.R.	L.E.R.	H.E.R.
Energy (GeV)	0.51	3.5	8.0	3.1	9.0
Max. luminosity [$cm^{-2}s^{-1}$]	$5.3x10^{32}$	1010^{34}		$3x10^{33}$	
Trajectory length [m]	97.69	3016.26		2199.32	
Emittance, $\varepsilon_x/\varepsilon_y$ [mm·mrad]	1/0.01	0.018/0.00036		0.064/0.0026	0.048/0.0019
Beta function, $\beta^{*;x}$ /$\beta^{*;y}$ [cm]	450/4.5	33.0/1.0		37.5/1.5	50.0/2.0
Tranv. size, $\sigma^{*;x}$ /$\sigma^{*;y}$ [mm]	2/0.02	0.077/0.0019		0.16/.006	
Beam-beam tune shift, ξ_x/ξ_y	0.04/0.04	0.039/0.052		0.03/0.03	
Total crossing angle, θ_x [mrad]	25	22		0	
Betatron tune, ν_x/ν_y	5.09/6.07	45.52/45.08	47.52/43.08	36.57/34.64	24.57/23.64
RF frequency, f_{RF} [MHz]	368.25	508.9		476	
Number of bunches	120	5120		1658	
Min. bunch separation [cm]	81.4	58.9		126	
Particles/bunch [10^{10}]	8.9	3.3	1.4	5.9	2.7
RF voltage [MV]	0.250	5 ÷ 10	10 ÷ 20	5.5	14.0
Bunch length σ_z [cm]	3.0	0.4		1.0	1.1
Sync. rad. loss [keV/turn]	9.3	1500*	3500	700*	3570
Damping time, τ_ε/τ_x [ms]	17.8/36.0	23/46		26.4/52.8	19.8/39.6
Single bunch lum.[$cm^{-2}s^{-1}$]	$4.4x10^{30}$	$1.95x10^{30}$		$1.8x10^{30}$	

* Wiggler on.

Three different low-β optics designs have been developed, one without longitudinal field for commissioning purposes, the other two with permanent magnet quadrupoles, for KLOE and FINUDA experiments. The three IR insertions are completely equivalent and interchangeable from an optic point of view.

The KLOE's Be pipe has a bulb-like shape, with a very thin (50 μm Be) inner shield to prevent RF losses. This shape is needed to avoid K_S regeneration effects.

As far as the luminosity operation is concerned (let us remind that DAΦNE can operate with one or two interactions points), a careful study of the betatron tune working point with a beam-beam simulation code has been performed [6].

Simulations show that in order to keep a high luminosity and a reasonable lifetime the working point has to be close to integers. A relative luminosity contour plot (numerical scan) in the ν_x - ν_y tune plane is shown in Fig. 2. Here, the darker areas correspond to higher luminosities. The successive contour levels are at ~ 10% reduction in luminosity.

As it can be seen, the working point $\nu_x = 0.09$; $\nu_y = 0.07$, chosen for DAΦNE, can provide the maximum luminosity. At the same time the working point has a satisfactory dynamic aperture and acceptable growth of bunch distribution tails. According to the simulations, for the given working point the collisions at two interaction points simultaneously will only slightly reduce the luminosity per IP (from 96% (single IP collision) to 86% (two IP collisions)).

Table IV: *Working point (5.09, 6.07)*

	Short	Long	Total
ν_x	2.279	2.811	5.09
ν_y	3.035	3.035	6.07

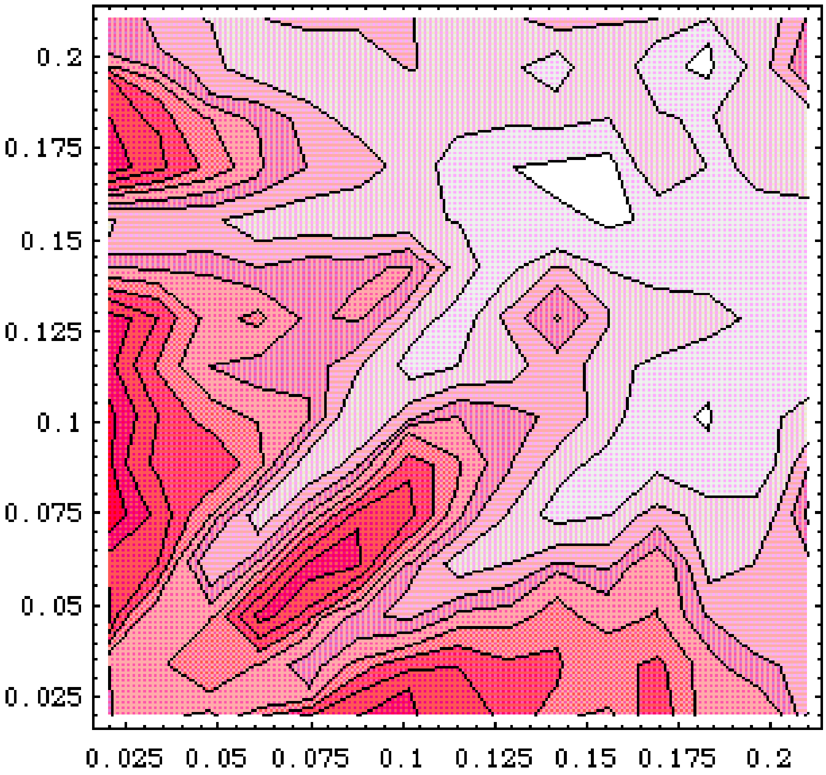

Figure 2: *Simulation scan of luminosity vs. working point. The abscissa and ordinate are the horizontal and vertical tunes, respectively.*

3.2 Vacuum system

The DAΦNE vacuum system is dimensioned for an operating pressure of 1 nTorr with 5 A circulating current. A design of the arc vacuum vessel, similar to ALS, has been adopted, consisting of 2 chambers connected through a narrow slot.

The beam circulates in the first chamber while the synchrotron radiation photons hit a system of water cooled copper absorbers located in the second one (antechamber). In this way more than 95% of the photon flux is collected in the antechamber. The achromat vessel (~10 m long) is made by two halves of Al alloy 5083-H321 plates which, after machining, are welded along the middle plane. The inner surface is mirror finished. The main inconvenient with this long vacuum chamber is the large expansion during bakeout (~35 mm in the longitudinal direction and ~10 mm in the transverse one). To cope with these large displacements a special shielded bellow [7] with no sliding contacts has been designed and a prototype tested both from mechanical and the HOM induced modes points of view.

3.3 RF System

The RF System of each ring consists of a normal conducting single cell cavity fed by a 150 kW/cw klystron. The RF cavity is equipped with three waveguides to damp the parasitic modes that are dissipated into external 50 Ω loads.

The first cavity has been successfully power tested up to 30 kW [8], corresponding to ~ 350 kV, and the HOM behavior (Fig. 3) found in agreement with expectation.

Figure 3: *HOM spectrum a)with couplers, b) without couplers*

3.4 Longitudinal feedback

Even though the HOMs in the RF cavity are heavily damped the probability for a damped HOM to cross a coupled bunch oscillation frequency is not negligible and, due to the large total current, the growth rate of unstable modes can be stronger than the radiation damping rate even by two orders of magnitude. For this reason the required additional damping is provided by a time domain, bunch to bunch feedback system [9] largely based on Digital Signal Processors (DSP). It has been developed and tested [10] with intense beams and a large number of bunches in the framework of a collaboration with SLAC/LBL PEP-II Group on feedback systems for the next generation of factories.

4. Commissioning

In April 1993, ADONE was shut down to permit the installation of DAΦNE. The upgrade and preparation of buildings went on until the beginning of 1996, when the installation of the main rings began. At that time most of the Linac, Accumulator and Transfer Lines installation work was already carried out. We started the systems check-out and commissioning from a temporary control center in the Linac area first and then in the Accumulator area, between May 1996 and March 1997, devoting short periods of one week to the commissioning work, interlaced with the continuing installation work.
In the Table below we summarize the principal commissioning milestones.

Table IV: *DAΦNE Commissioning Milestones*

Accumulator Ring Installation	December 95
First e- beam through the Tr. Line	27 May 96
First Turn in the Accumulator	1 June 96
Multiturn in the Accumulator	6-7 June 96
First Stored Beam in the Accumulator	21 June 96
120 mA in the Accumulator	30 January 97
LINAC e^+ beam to specifications	March 97
Main Rings Vacuum Connected	July 97
Extraction from the Accumulator	20 September 97
First e^- Beam in the Main Ring	28 September 97
Multiturn in the Main Ring	4 October 97
First Stored Beam in the Main Ring	25 October 97

The powerful Linac allowed us to commission the Accumulator in the short allocated time with no attempt made to optimize the Linac intensity nor the transfer lines transmission efficiency. In January 1997 we could store the nominal single bunch current of e^- in the Accumulator ring. By that time the following measurement were out in the Accumulator: Tunes and Chromaticity; Dispersion Function; Closed Orbit Distortion; Transverse Sizes; Beam Instability and RF HOMs; Bunch Lengthening and Machine Impedance; Injection Efficiency; Lifetime.

The complex timing system allowing to inject any single selected bucket was also tested and showed good performances.

The transfer line and Accumulator optics showed to be in a good agreement with the model based on the magnetic measurements (with only one important exception for a pair of vertical bending magnets in the transfer line) and a reliable model was tested for the Accumulator optics. Under all circumstances the diagnostics proved to be adequate.

The main ring vacuum chamber was entirely connected in July 1997 and in September we started its commissioning. The first electron beam was stored on October 25, just at the end of the workshop. In the following weeks the first positron beam was injected in the accumulator, extracted and stored in the main ring. The maximum current achieved was 80 mA in a single bunch, 300 mA in multibunch operation.

5. References

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