1995 International Europhysics Conference on High Energy Physics, Bruxelles, Belgium, July 1995

DAΦNE, THE ELECTRON POSITRON Φ-FACTORY AT INFN-FRASCATI

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The status of the $e^+ e^-$ Φ-factory DAΦNE, now under construction at LNF, and the main accelerator physics and technology issues are discussed. The construction of machine and detectors is proceeding steadily.

1 Introduction

The construction of a Φ-factory in Frascati was approved and funded in 1990 and the detailed engineering design started in 1991. The accelerator complex consists of a symmetric 510 MeV e^+e^- Two-Ring Collider, intersecting in two 10 m long Interaction Regions, where the beams are brought to collision at a horizontal angle; a full energy Linac and a Damping Ring for "topping-up" injection. The complex occupies the already existing LNF buildings where the long-lived ADONE was housed. One of the two IRs will accommodate the detector KLOE[2], designed mainly to study CP violation in neutral K decays. The other one is assigned to the detector FINUDA[3], designed to study Λ-hypernuclei formation and decay. The tender phase is complete and all the various components are under construction. The beginning of the collider commissioning, with a short term luminosity goal $L \approx 1.3\ 10^{32}\ cm^{-2}\ sec^{-1}$ with 30 bunches, is scheduled for the end of 1996, and the start of experimental runs for mid 1997.

2 Physics at DAΦNE

A high luminosity Φ-factory is a unique tool to produce a very large number of K_S K_L correlated pairs, suitable for studying CP and CPT violation in K decays. Briefly, we mention:

- the measurement of the ε'/ε parameter, describing CP violation beyond ε:

$$Re(\varepsilon'/\varepsilon\ ) \approx \frac{1}{6}\ [1 - \frac{N(K_L \to \pi^+\pi^-)/N(K_L \to \pi^o\pi^o)}{N(K_S \to \pi^+\pi^-)/N(K_S \to \pi^o\pi^o)}\ ]$$

  at the same statistical level expected by the next generation experiments at CERN and Fermilab, but with a different technique and with the advantage of having K_S and K_L decays detected in the same event. Furthermore, the measurement of Re(ε'/ε) and of any possible Im(ε'/ε) ≠ 0 (related to CPT violation) will be achieved with a very good accuracy looking at a unique feature: the correlation in the K_S, K_L decays;
- the detection for the first time of the expected CP violation in the $K_S \to 3\ \pi$ decay.

A high luminosity Φ-factory is also suitable to study Λ-hypernuclei formation and decay. In fact, it has been demonstrated that very low energy K^- are the best probe for these processes and DAΦNE will be the most intense source available of low energy, monochromatic K^-. Moreover, since K^- are produced in pairs with K^+, their detection will largely improve the measurements of hypernuclei decays.

Many other important physics topics will be studied in DAΦNE, for instance:

- radiative Φ decays;
- $\gamma\gamma \to \pi\pi$ at very low ππ invariant masses;
- precise measurement of the hadronic contribution to the anomalous magnetic moment of the muon by measuring the total hadronic cross section;
- nice tests of Quantum Mechanics on elementary particles at a macroscopic level.

Two first generation experiments, KLOE and FINUDA, are under construction at LNF.

KLOE is a general purpose detector whose principal components are:

- a huge drift chamber, 4 m diameter, filled with He and immersed in a .6 T magnetic field;
- a scintillating fibers calorimeter, very fast (≈ 100 ps) and with a good energy resolution ($\approx 4.5\% / \sqrt{E}$).

FINUDA is a smaller detector. Its main features are:

- a cylindrical target, a thin scintillator and a layer of silicon detectors all around the beam pipe;
- a set of cylindrical drift chambers filled with He in a 1.1 T magnetic field, to measure the momentum of the outgoing pion, - hence the binding energy of the Λ-hypernuclei - with a ≈ 500 KeV energy resolution;
- a layer of thick scintillators, suitable also for detecting neutrons from the hypernuclei decay.

3 Luminosity Strategies

To measure the ratio of the CP violating parameter ε'/ε down to 10^{-4}, a luminosity $L = 5\ 10^{32}\ cm^{-2}\ sec^{-1}$ integrated over an effective year of 10^7 seconds is required.

To get such a luminosity DAΦNE is designed as a high current double ring system with a high number of bunches.

The maximum single bunch luminosity L_o is determined by the beam-beam interaction, whose effect is described by the beam-beam linear tune shift parameter ξ:

$$\xi_{xy} = \frac{r_e N \beta_{x,y}}{2\pi\gamma\sigma_{x,y}(\sigma_x + \sigma_y}$$

with r_e the classical electron radius, $\beta_{x,y}$ the betatron functions at the IP, and γ the particle energy in units of rest mass. There is experimental evidence of a limit on the maximum value that ξ can reach, beyond which the beam-beam effect is so strong that instability and beam blow-up occur so that lifetime and luminosity are substantially reduced. Maximum luminosity can be reached with maximum and equal tune shifts in both planes ($\xi = \xi_x = \xi_y$). This condition is obtained when the ratio κ between beam emittances (ε_x, ε_y) is equal to the ratio of beam rms sizes at the IP. With $\varepsilon = \varepsilon_x + \varepsilon_y$, we can express the luminosity in terms of ξ :

$$L = h\,L_o = h\,f_{rev}\,\frac{\pi\gamma^2\xi^2}{r_e^2\,\beta_y}\,\varepsilon\,(1+\kappa)$$

The ξ value assumed for DAΦNE is obtained by a world average over most e^+e^- colliders: $\xi = .04$.

To gain the factor h in the luminosity, without a reduction of the maximum tune shift, the bunches have to be kept separated out of the interaction point, and this is the reason for the choice of two rings collider, so allowing multibunch operation (h=1,30,60,120). The multibunch instabilities, rising because of the high total current, are cured by specially designed feedback systems and new RF cavity design with strong suppression of high order modes (HOM). To avoid parasitic crossings the beams will cross in the horizontal plane at a small, tunable, angle ($\pm 10 \div \pm 15$ mrad).

A very small value of β_y at the IP has strong impact on the whole ring lattice design, leading to a high vertical chromaticity. Moreover due to the parabolic increase of β around the IP, the transverse size increases along the bunch length and to keep the advantage of having small dimensions at the IP, the bunch length σ_z must be shorter or at most of the same order of β_y, otherwise geometric reduction of the luminosity occurs. According to these considerations we have chosen $\beta_y = 4.5$ cm and $\sigma_z = 3$ cm.

A very flat beam scheme (κ=1%) has been adopted, with strong focusing only in the vertical plane. For flat beams the horizontal crossing angle θ, due to the design values of horizontal and longitudinal rms beam sizes at the IP, should not excite synchro-betatron resonances, which may limit the maximum achievable tune shift.

Large emittance is beneficial to luminosity in case of tune shift limited colliders, like Φ-factories, where wigglers are present to increase the emittance and to contribute additional damping, since beam-beam interaction experience suggests that the tune shift limit increases with the amount of radiated power. A relatively large value was chosen for DAΦNE: $\varepsilon = 10^{-6}$ m rad. For the single bunch luminosity a value of $\approx 4.3\ 10^{30}$ cm^{-2} sec^{-1} has been assumed comparable to that achieved in VEPP-2M[4].

In Table 1 the parameters relevant to the luminosity are summarized.

Table 1: DAΦNE luminosity parameters

E (MeV)	510.	θ (mrad)	10÷15
L_o (cm^{-2}s^{-1})	4.3 10^{30}	κ	.01
ξ	.04	σ_z (m)	.03
ε^{max} (m-rad)	10^{-6}	h^{max}	120
f_o (MHz)	3.17	β_y^* (m)	.045

4 The accelerator Complex

The accelerator complex layout is shown in Fig. 1. It consists of:
- e^+e^- LINAC;
- e^+e^- Damping Ring;
- twin ring collider.

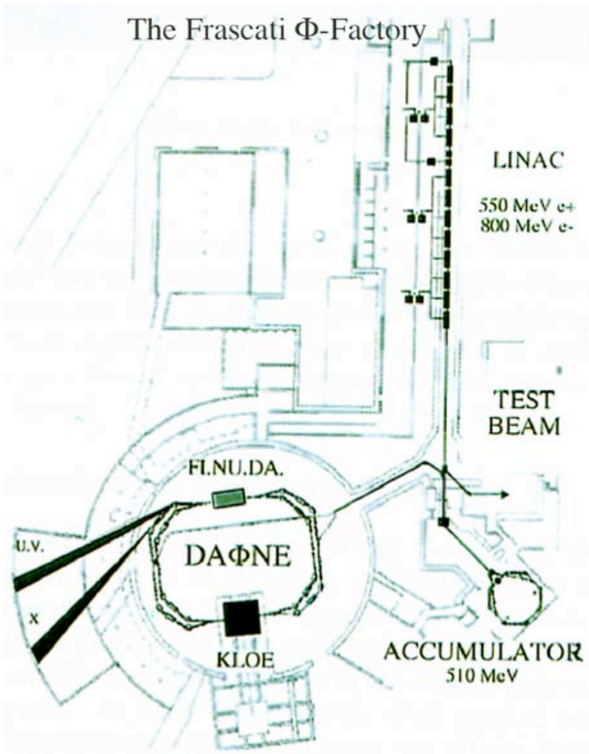

Figure 1: Layout of DAΦNE and its injector

4.1 LINAC and Damping Ring

The LINAC[5], manufactured by TITAN BETA, is capable of accelerating electrons up to 800 MeV at 50 pps. In the positron mode of operation the first part of the LINAC (from the gun to the positron converter) is used to accelerate a 4A-10ns electron pulse at 250 MeV. The LINAC has been installed at LNF and will be operational in December '95.

The Damping Ring, manufactured by OXFORD, has a compact 4 period structure, with a total length 1/3 of each ring and will be used to store at 50 pps the required number of electrons (positrons) in one RF bucket and to damp the transverse and longitudinal emittance of the LINAC beam. The damped beam is extracted at ~ 1 pps and injected into a single bucket in the main rings.

The series production of magnets (designed and measured by LNF), vacuum chambers and other components is complete. The installation of the Accumulator is scheduled for September '95, the beam tests will begin in January '96.

4.2 Main Rings

The regular lattice of each ring 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 interaction regions are used for injection, RF, feedbacks and a scrapers system optimized for reducing the lost particles background inside the detectors. The single ring parameters are shown in Table 2.

Table 2: DAΦNE Single Ring Parameters

Energy (MeV)	510.
Luminosity [cm^{-2} s^{-1}]	5.2×10^{32}
Trajectory length [m]	97.69
Emittance, ε_x,ε_y [mm mrad]	1, 0.01
Beta function at IP, β_x^* , β_y^* [m]	4.5, .045
Beam dimension at IP, σ_x^* , σ_y^* [mm]	2, .02
RF frequency, f_{RF} [MHz]	368.25
Max. number of bunches, h_{RF}	120
Minimum bunch separation [ns]	2.7
Bunch average current [mA]	43.7
RF voltage [kV]	250.
Bunch length σ_z [cm]	3.
Synchrotron radiation loss [keV/turn]	9.3
Damping time, τ_ε, τ_x [ms]	17.8, 36.
N^{max} /bunch	$8.9\ 10^{10}$

5 Vacuum System

The DAΦNE vacuum system[6] is dimensioned for an operating pressure of ~ 1 nTorr with ~ 5 A of circulating current. A design has been adopted for the vacuum vessel inside the achromat, consisting of two chambers connected through a narrow slot. The beam circulates in the first chamber, while the synchrotron radiation photons hit a system of copper absorbers located in the second one (antechamber) in such a way that more than 95% of the photon flux is intercepted in the antechamber. The first arc Al vacuum vessel has been already assembled and delivered at LNF (see Fig. 2).

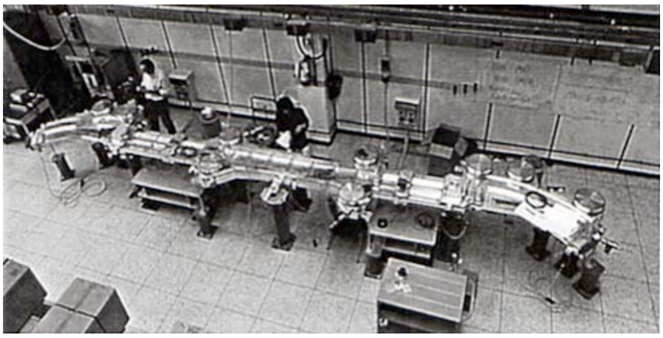

Figure 2: Arc Al vacuum vessel

6 RF System

The first main ring cavity is now under construction. Because of the large current and large number of bunches, the reduction of the beam-cavity spectra interaction is the most demanding feature of the RF system. For each ring it consists of a normal conducting single cell cavity, fed by a 150 kW/cw klystron. The design aimed at reducing significantly the impedance of the HOM[7] by a proper shape of the resonator and, more effectively, by coupling off the HOM electromagnetic fields with long tapered beam tubes and three waveguides (WG), which couple out the parasitic modes that are then dissipated into external 50 Ω loads. Low power tests, performed on a copper cavity prototype, have shown that a considerable reduction of the HOM Qs over a 2 GHz bandwidth is achieved.

7 Longitudinal Feedback System

The basic design choice of achieving the required luminosity with a large total current, distributed over a large number of bunches makes the operation very critical with respect to longitudinal coupled bunch instabilities caused by parasitic higher order modes in the ring, mainly in the RF cavity. An additional damping of all coupled modes and injection transients is provided via a time domain, bunch by bunch feedback system[8] based on digital signal processors (DSP). A prototype system with a single-board digital section has been running at ALS[9]. The complete modular system has been installed in July in ALS and went into operation smoothly, providing damping of all coupled modes at the design current of 400 mA.

References

1. The DAΦNE Project Team: M. Bassetti, M.E. Biagini, C. Biscari, R. Boni, A. Cattoni, V. Chimenti, A. Clozza, S. De Simone, G. Di Pirro, H. Dong, A. Drago, S. Faini, A. Gallo, A. Ghigo, S. Guiducci, Y. He, H. Hsieh, F. Marcellini, C. Marchetti, M.R. Masullo, M. Migliorati, C. Milardi, M. Modena, L. Palumbo, L. Pellegrino, M.A. Preger, H. Qu, G. Raffone, C. Sanelli, F. Sannibale, M. Serio, F. Sgamma, B. Spataro, A. Stecchi, L. Trasatti, C. Vaccarezza, M. Verola, M. Vescovi, S. Vescovi, G. Vignola, D. Yao, M. Zobov.
2. The KLOE Collaboration, *KLOE, a General Purpose Detector for DAΦNE*, Frascati Internal Note LNF-92/019 (IR), April 1992.
3. The FINUDA Collaboration, *FINUDA, a Detector for Nuclear Physics at DAΦNE*, Frascati Internal Note LNF 93/021 (IR), May 1993.
4. P.M. Ivanov et al., Proc. of the Third Advanced ICFA Beam Dynamics Workshop, Novosibirsk, May 1989, p.26.
5. K. Whitham et al., *Design of the e^+ e^- Frascati Linear Accelerator for DAΦNE*, PAC 93, Washington, p.611.
6. V. Chimenti et al., *The DAΦNE Main Ring Vacuum System*, PAC 93, Washington, p. 3906.
7. S. Bartalucci et al., *Analysis of Methods for Controlling Multibunch Instabilities in DAΦNE*, Particle Accelerator, Vol. 48, 4 (1995), p. 213.
8. G. Oxoby et al., *Bunch by Bunch Longitudinal Feedback System for PEP-II*, EPAC 94 , London , p.1616.
9. J.D. Fox et al., *Operation and Performance of the PEP-II Prototype Longitudinal Damping System at the ALS*, Proceedings of PAC and ICHEA, May 1995, Dallas.