# Precision Physics at DAΦNE

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**In addition to a complementary programme in particle and nuclear physics, the DAΦNE meson factory, by promising precision studies aimed at understanding the crucial problem of charge-parity violation, will provide powerful insights into the theory of fundamental particles.**

The discrete symmetries connected with charge conjugation (*C*), parity (*P*) and time reversal (*T*) are fundamental in quantum mechanics (see insert). Their study has been central to particle physics for many years. The experiment of Wu *et al.* in 1957 [1] which proved for the first time that parity is not conserved was motivated by a proposal of Lee and Yang that *P* is violated in weak decays. This proposal followed from an analysis by Dalitz in 1954 of the pionic decays of K mesons.

K mesons, along with hyperons and hypernuclei, contain a strange quark (s) in combination with the normal up (u) and down (d) light quarks. The neutral K mesons contain the d quarks $K_o(\bar{d}s)$ and $K_o(d\bar{s})$, while the charged ones contain the u quarks $K^+(u\bar{s})$ and $K^-(\bar{u}s)$. $K^o$ and $K^+$ have strangeness $S = +1$ while $\bar{K}^o$ and $K^-$ have strangeness $S = -1$. For some years after the discovery that *C* and *P* were violated in the weak interactions, it was thought that the combined *CP* operation might still be conserved. As a consequence of *C* violation, the eigenstates of the strong interactions $K^o$ and $\bar{K}^o$ can transform into each other, *i.e.*, $K^o \leftrightarrow \bar{K}^o$. However, *CP* invariance requires that the physically observable states are eigenstates of *CP*. Thus we have the new observable states $K_1$ and $K_2$, which are the symmetric linear combination of $K^o$ and $\bar{K}^o$ (*CP*-even), and the asymmetric combination (*CP*-odd), respectively. Owing to the different decay channels available to *CP*-even and *CP*-odd neutral kaons, specifically two and three pions, respectively, one expects the width of the $K_1$ to be much larger than that of the $K_2$, or, equivalently, the $K_2$ to be much longer lived. Neutral K mesons with two very different lifetimes were indeed observed in 1956 [2].

However, the observation in 1964 [3] that the $K^o$ with a long lifetime decays a minute fraction of the time into two pions proved unambiguously that *CP* is also violated. In other words, the physical states are not anymore *CP* eigenstates: instead of $K_1$ and $K_2$, the physical states are now $K_S$ and $K_L$, where $K_S$ is $K_1$ with a small admixture of $K_2$, and $K_L$ is $K_2$ with a small admixture of $K_1$. The amount of this admixture is parametrized by the *CP*-violation parameter $\varepsilon$, which has the measured value $|\varepsilon| = (2.259 \pm 0.018) \times 10^{-3}$.

Physicists have been trying since 1964 to understand the source of this *CP* violation. Is it due to the mixing of the *CP*-odd initial state with the *CP*-even eigenstate, *i.e.*, a small impurity of $K_1$ is introduced in the $K_L$ state, *via* $K^o \leftrightarrow \bar{K}^o$, $|\Delta S| = 2$ transitions ? Alternatively, is *CP* due to direct violation in $K^o$ decays owing to the presence of a *CP*-odd component in the transition amplitude. In other words, is the $|\Delta S| = 1$ amplitude $\langle|\pi\pi|K_2\rangle \neq 0$ ?

Experimentally, the direct decay implies a difference in *CP* violation in the neutral and charged pion decay channels. To be more explicit, we can use the now standard definitions for expressing the ratios of the transition amplitudes $\eta$ of the $K_L$ and $K_S$ into charged and neutral pions ($\eta_{+-}$ and $\eta_{oo}$) in terms of $\varepsilon$ and a new *CP*-violation parameter $\varepsilon'$ to give:

$$\frac{\langle\pi^+\pi^-|H_W|K_L\rangle}{\langle\pi^+\pi^-|H_W|K_L\rangle} = \eta_{+-} = \varepsilon - \varepsilon'$$
$$\frac{\langle\pi^o\pi^o|H_W|K_L\rangle}{\langle\pi^o\pi^o|H_W|K_L\rangle} = \eta_{oo} = \varepsilon + \varepsilon'$$

where $H_W$ is the transition Hamiltonian. The question now becomes: is $\varepsilon' = 0$ ?

Experimental progress over the last 30 years can thus be summarized as follows: it was discovered in 1964 that $\varepsilon$ is nonzero; three decades later, we know that the real part of $\varepsilon'/\varepsilon$ is in the range of zero to three parts per thousand [4].

Mixing could be due to the existence of a super-weak interaction [5] which would result in $\varepsilon'$ being identical to zero. The Standard Model has a natural place for *CP* violation because a phase can be introduced in the Cabibbo-Kobayashi-Maskawa quark-mixing matrix, but the theory does not predict the magnitude of the effect. However, if the violation of *CP* which results in $\varepsilon \neq 0$ is explained in this way then, in general, we expect $\varepsilon' \neq 0$. Given the well-measured value of $\varepsilon$, $\varepsilon'$ can in principle be calculated in the Standard Model. However, for technical reasons, this is difficult. The predicted value for $\varepsilon'/\varepsilon$ is $\approx 10^{-4}$ because cancellations can occur, depending on the mass of the top quark and the values of appropriate matrix elements, mostly connected with understanding the structure of the light hadron [6].

## The Experimental Problem

One can define the ratio of the partial widths $\Gamma$ of the decay of the K meson to charged and neutral pions as:

$$R_S = \Gamma(K_S \Rightarrow \pi^+\pi^-)/\Gamma(K_S \Rightarrow \pi^o\pi^o)$$
$$R_L = \Gamma(K_L \Rightarrow \pi^+\pi^-)/\Gamma(K_L \Rightarrow \pi^o\pi^o)$$

From the definitions of $\varepsilon$ and $\varepsilon'$, we obtain:

$$\Delta R/R = (R_L - R_S)/R_{L\,or\,S} = R_L/R_{L\,or\,S} - 1 = 6 \times Re(\varepsilon'/\varepsilon).$$

## Discrete Symmetries

**Charge Conjugation**
Charge congugation (*C*)hanges the sign of all the additive quantum numbers (*e.g.*, charge and baryon number) while leaving momentum and spin unchanged, *i.e.*, turns particles into their antiparticles. *C* is known to be a valid symmetry for the strong and electromagnetic interactions, but is not valid for the weak interaction.

**Parity**
Rarity (*P*) is the symmetry relating a physical system and its mirror image. A particle with left-handed spin transforms into one with right-handed spin under *P*. The neutrino is a striking illustration of *P*-violation: while neutrinos are apparently always left-handed, left-handed antineutrinos do not seem to exist. Parity, like charge conjugation, is only violated in weak interactions.

**Charge-Parity**
Under the combined charge-parity (*CP*) symmetry a left-handed neutrino, for example, transforms into a right-handed antineutrino. *CP* is observed to be a valid symmetry of almost all interactions: the only known exception is that observed in the K system, as discussed in the text.

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where *Re* is the real part of the $\varepsilon'/\varepsilon$ ratio. So the question whether *CP* is violated in the decay of K mesons now becomes: is $\varepsilon'$ non-zero ? This is equivalent to asking whether $R_S$ is equal to $R_L$. Data from CERN and the Fermi National Accelerator Laboratory (FNAL) in the USA give $\Delta R/R \approx 6 \times (0\text{-}3) \times 10^{-3}$ based on the study of of the decay of a large number $N$ ($\approx 250\,000$) of $K_L$ to two pions [4]. Since the error $\delta(\Delta R/R) \approx \Delta R/R = 1/\sqrt{N}$, new experiments, able to reach statistical errors of about $6 \times 10^{-4}$ require the observation of some $5 \times 10^6$ $K_L \Rightarrow 2\pi$ decays among $5 \times 10^9$ $K_L$ decays.

## Particle Factories

The history of particle physics in the last decades indicates that it advances through the interplay of theory and experiment, and that the latter makes breakthroughs by pursuing the energy frontier and by seeking increasingly precise measurements performed at lower energies. As pure and luminous beams of particles are prerequisites for obtaining experimental accuracy, towards the end of the 1980s many physicists became interested in using electron-positron colliders as particle factories. These factories generally operate at relatively low energies, compared to other machines such as CERN's Large Hadron Collider (LHC) and the upgrades and successors to CERN's Large Electron Positron (LEP) collider.

The various types of machines form a very complementary, three-way thrust for particle physics: the proton machines concentrate on the highest energy frontier, with the highest luminosities, energies (several TeV), and backgrounds; the LEP-type machines concentrate on precision physics at relatively high energies (hundreds of GeV); the $e^+e^-$ particle factories generally concentrate on producing, with very low background, a copious supply of a single, known particle/resonance of a few GeV mass, such as the $\varphi$, $J/\psi$ or B meson. The factories will generate several orders of magnitude more resonances than have so far been collected around the world, and the subsequent detailed study of the decay of the resonances will provide valuable insights in the study of discrete symmetries.

The first particle factory to study *CP* and charge-parity-time reversal (*CPT*) violation at sensitivities of the order of $10^{-4}$ was approved in June 1990 [7]. Funded by Italy's Istituto Nazionale di Fisica Nucleare (INFN), DAΦNE (Double Annular Φ-factory for Nice Experiments) has as its main mission the understanding of the source of charge-parity (*CP*)-violation in the K-meson system.

DAΦNE consists of an $e^+e^-$ collider optimized for operation at a total energy of 1019.4 MeV, the mass of the $\phi$ meson. It is now under construction at the INFN's Laboratori Nazionali di Frascati (LNF). Two other $e^+e^-$ colliders designed to operate as B-meson factories were approved in 1994. One will be constructed in the USA at the Stanford Linear Accelerator Center and the other in Japan at the National Institute for High-Energy Research (KEK). Their mission is to search for *CP*-violation in the B-meson system.

## K Mesons at DAΦNE

DAΦNE possesses several unique advantages for the study of discrete symmetries. The first relates to the types of particles it will produce. Neutral K-meson pairs from Φ decays are produced in a pure *C*-odd quantum state. It turns out that the two kaon states have the antisymmetric form $|K^0,\boldsymbol{p}\rangle|\bar{K}^0,-\boldsymbol{p}\rangle - |\bar{K}^0,\boldsymbol{p}\rangle|K^0,-\boldsymbol{p}\rangle$, which means that:

a) The observation of a $K^0$ ($\bar{K}^0$) at any given time signals at the same time the presence of a $\bar{K}^0$ ($K^0$) of opposite momentum $\boldsymbol{p}$. This state can also be written as $|K_S,\boldsymbol{p}\rangle|K_L,-\boldsymbol{p}\rangle - |K_L,\boldsymbol{p}\rangle|K_S,-\boldsymbol{p}\rangle$, which implies that:

b) The observation of a $K_S$ ($K_L$) also signals the presence of a $K_L$ ($K_S$) of opposite momentum.

This second feature is very important since it implies that we shall never have a decay with two $K_S$ or two $K_L$; the identification of one type of K meson guarantees the presence of the other type. Thus DAΦNE is a source of pure, backgroundless beams of $K^0$, $\bar{K}^0$, $K_S$ and $K_L$. Pure $K_S$ beams can only be produced at a $\phi$-factory. In addition, owing to the presence of an initial two-kaon state which is coherent:

c) Interference phenomena can be observed without requiring the identification of either $K_S$ or $K_L$.

It should be noted out that these three characteristics also apply to the $B\bar{B}$ system which is used to study CP-violation.

## Interferometry

The second advantage concerns the possibility of carrying out high-precision "kaon interferometry". Consider the process $\varphi \Rightarrow KK \Rightarrow f_1, t_1 + f_2, t_2$ where one K meson decays into a state $f_1$ at time $t_1$ and the other into a state $f_2$ at time $t_2$, as illustrated in Fig. 1. The intensity $I$ of the decay to $f_1, f_2$ as a function of $\Delta t = t_1 - t_2$ and for $\Delta t > 0$ is:

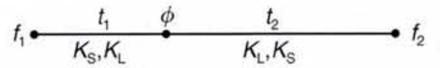


**Fig. 1.** The decay of a K meson into a state $f_1$ at a time $t_1$ and into another state $f_2$ at a time $t_1$, where the physical states $K_S$ and $K_L$ are mixtures of $K_1$ and $K_2$, the pure *CP*-states.

$$I(f_1, f_2; \Delta t) = |\langle f_1|K_S\rangle\langle f_2|K_S\rangle|^2(|\eta_1|^2\exp\{-\Gamma_L\Delta t\} + |\eta_2|^2\exp\{-\Gamma_S\Delta t\} - 2|\eta_1||\eta_2|\exp\{-\Gamma\Delta t/2\}\cos[\Delta m\Delta t + \phi_1 - \phi_2])/2\Gamma$$

where $\Gamma = \Gamma_L + \Gamma_S$, $\Delta m = m_L - m_S$ and $\eta_i = |\eta_i|\exp(i\phi_i)$, with a similar expression for $\Delta t < 0$. We note that the interference term, the third term, is sensitive to $\Delta m$, to the magnitude of the amplitude ratios $\eta_1$ and $\eta_2$ and their phase difference $\phi_1 - \phi_2$, while the complete distribution also depends on the $K_S$ and $K_L$ lifetimes.

One can thus perform a wide spectrum of highly precise kaon interferometry experiments at DAΦNE by measuring the decay intensity distributions for appropriate pairs of the final states $f_1$ and $f_2$. For example, with $f_1 = f_2$ one measures $\Gamma_L$, $\Gamma_S$ and $\Delta m$, since all phases cancel. Rates with a ten-fold improvement in accuracy compared to existing facilities, and mass differences $\Delta m$ with a two-fold improvement, can be determined. Examples of interference patterns for three other pairs of final states are illustrated in Fig. 2.

In the Standard Model, without assuming *CPT* invariance the neutral K system is completely determined by measuring 13 parameters. By choosing appropriate $f_1$ and $f_2$ channels, one can perform a total of 16 independent measurements of these parameters. Experiments at DAΦNE can therefore test *CPT* invariance, in addition to studying *CP* violation.

We can also use the classical method based on the double ratio $R^{\pm}/R^0 = 1 + 6 \times R'(\varepsilon'/\varepsilon)$ – see above – as well as other methods of quantifying $R'(\varepsilon'/\varepsilon)$ from selected final states. Very different systematics are involved, thus allowing a self-checking of the results.

## Other Techniques

*CP* violation has so far only been detected in $K_L$ decays ($K_L \Rightarrow \pi\pi$ and semi-leptonic decays). DAΦNE can look for $K_S \Rightarrow \pi^0\pi^0\pi^0$, the counterpart to $K_L \Rightarrow \pi\pi$. The branching ratio for this process is proportional to $\varepsilon + \varepsilon'_{000}$, where $\varepsilon'_{000}$ is a quantity similar to $\varepsilon'$ signalling direct *CP* violation; it is suppressed by a factor of perhaps 20-times less than $\varepsilon'$. Nonetheless, as the expected branching ratio is $2 \times 10^{-9}$, the signal will be at the 30-event level. So one has the possibility to detect the *CP* impurity of $K_S$, as opposed to direct *CP* violation, which has not been observed so far.

Another possibility is to look at the difference in the rates of $K_S \to \pi^+ l^- \nu$ and $K_S \to \pi^- l^+ \upsilon$, which is expected to be approximately $1.6 \times 10^{-3}$. Again this would only measure $\varepsilon$ and not $\varepsilon'$, but the observation for the first time of *CP* violation in two new channels of $K_S$ decay should nonetheless be of considerable interest.

Evidence for direct *CP* violation can be also be obtained from the decays of charged kaons which are copiously produced at DAΦNE. *CP* requires equality of the partial rates for $K^\pm \Rightarrow \pi^\pm\pi^+\pi^-(\tau^\pm)$ and for $K^\pm \Rightarrow \pi^\pm\pi^\circ\pi^\circ(\tau'^\pm)$. One can improve the present rate asymmetry by two orders of magnitude. One can also examine the energy distribution of the final states (so-called Dalitz plots) for $K^+$ and $K^-$ decays in both the $\tau$ and $\tau'$ modes (sensitivities of about $10^{-4}$ can be reached at DAΦNE). Finally, differences in rates in the radiative two-pion decays of $K^\pm, K^\pm \Rightarrow \pi^\pm\pi^\circ\gamma$ would also constitute proof of direct *CP* violation (the sensitivity that can be reached at DAΦNE) is about $1.4 \times 10^{-3}$).

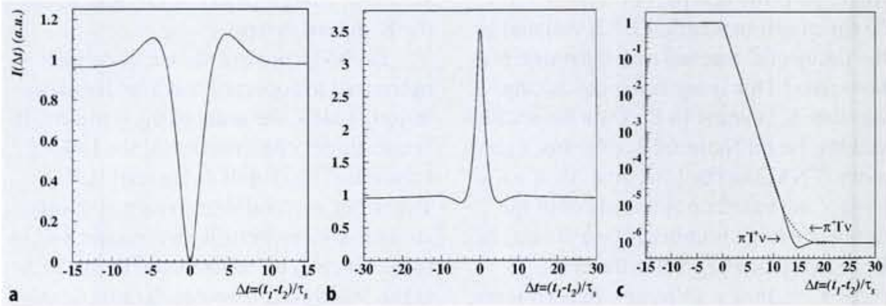

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**Fig. 2.** Kaon interferometry: calculated interference patterns for the decay of K mesons, The decay intensity $I$ is plotted as a function of the time difference $\Delta t$ between the times $t_1$ and $t_2$ to decay into states $f_1$ and $f_2$, normalised with respect to $\tau_s$, the lifetime of the $K_s$ state.
**a:** Interference pattern for $f_1 = \pi^+\pi^-, f_2 = \pi^0\pi^0$. The destructive interference at the origin is due to the asymmetric initial state decaying to almost identical final states. One measures the real part of $\varepsilon/\varepsilon'$ at large $\Delta t$ and the imaginary part at $|\Delta t| < 5\tau_s$.
**b:** Interference pattern for $f_1 = \pi^+ l^- \upsilon, f_2 = \pi^- l^+ \upsilon$. The pattern is constructive at the origin since the final-state amplitudes have almost equal sign. One measures the magnitude of one of the *CPT*-violation parameters, where the real part is for large $\Delta t$ and the imaginary part for $|\Delta t| < 5\tau_s$.
**c:** Interference pattern for $f_1 = 2\pi, f_2 = Kl_3$. For $\Delta t < 0$, one measures the lepton asymmetry parameter which provides tests of *CP* and *CPT* while $|\Delta t| \approx$ (0-20) $\tau_s$ gives $\Delta m$ and other parameters.

## e⁺e⁻ Colliders as Factories

Quarks heavier than the up and down quarks form bound, narrow quark-antiquark states ($q\bar{q}$) with, among other possibilities, quantum numbers $J^{PC} = 1^{--}$ equal to those of the photon. These vector states are copiously produced by resonance in $e^+e^-$ annihilations at energies equal to the meson mass. The physical process consists of the annihilation of the $e^+e^-$ pair into a virtual photon with a mass equal to the total available energy. The photon then creates a $q\bar{q}$ pair, which is bound by the colour force resulting in the final-state vector meson. Vector mesons are produced in $e^+e^-$ annihilations with a large signal-to-noise ratio compared to hadronic collisions. Table 1 gives the production cross-section $\delta$ and signal-to-noise ratio for two important cases of current interest.

**Table 1.** A comparison of the production cross-section and signal-to-noise ratio S/N for vector mesons produced in $e^+e^-$ collisions.

| Quark-antiquark state, $q\bar{q}$ | Meson | Production cross-section | S/N ratio |
|---|---|---|---|
| $s\bar{s}$ | φ | 5 μb | 30:1 |
| $b\bar{b}$ | Y‴ | 1 nb | 1:4 |

The vector mesons decay in turn into stable particles with the flavour of the initial pair, namely the φ meson into kaons and the Y‴ meson into B mesons. By stable particle we mean here particles that decay only through the weak interaction, therefore having lifetimes of 1 ps or larger. High-luminosity electron-positron colliders can thus produce very large numbers of K and B mesons.

A simple analysis of the requirements for studying *CP* violation at a new level of accuracy indicates that an $e^+e^-$ collider delivering a luminosity $L$ of $10^{33}$ cm$^{-2}$s$^{-1}$ is needed. One also requires a suitable detector. DAΦNE's KLOE detector [8] will provide a very efficient large tracking device for detecting charged K° decay products, as well as an electromagnetic calorimeter with an exceptional timing ability.

The luminosity of $10^{33}$ cm$^{-2}$s$^{-1}$ is some 100-times larger than those which have been achieved so far. Two main lines of approach for obtaining these high luminosities have been proposed. The more innovative way would be to try to invent an improved collider which allows the specific luminosity, *i.e.*, the single-bunch luminosity $L_o$, to be increased. The more conservative approach accepts the present empirical and theoretical limits for $L_o$ and stores in the collider a large number $N$ of bunches, thus arriving at a luminosity $NL_o$.

Since the specific luminosity limit is essentially determined by beam-beam interaction, the latter approach immediately imposes the need for two independent storage rings, with the associated complications of intersecting two stored beams and bringing the stored bunches into collision with high accuracy and stability. Each electron bunch would collide with a positron bunch from the other ring only once per turn to give, in principle, the required increase in luminosity. Attention must thus be given to the beam-line vacuum (to ensure adequate beam lifetimes) and to the radio-frequency accelerating cavities; dynamic control of beam instabilities using active feedback is essential. Fortunately, these accelerator issues are relatively easy to address using modern technology (see insert).

## Other Physics at DAΦNE

Many other physics topics can be studied at DAΦNE, especially during the start-up phase, when the number of beam bunches will be approximately one-quarter that of the final design value. We summmarise below three typical examples of topics that will be addressed, the first two using the KLOE detector [8] which is presently under construction, and the third using a special purpose detector called FI.NU.DA.

• K-mesons and the chiral Lagrangian: recent extensions of chiral perturbation theory – the theory of low-energy K-meson physics – has shown that DAΦNE is well-suited for testing many new predictions about semileptonic decays [9]and radiative non-leptonic K decays[10]. The two-photon production of pions is also of great interest.

• Radiative φ decays: the unique and lightest scalar meson state $f_o(975)$ is poorly described by current models. At DAΦNE

## DAΦNE

DAΦNE consists of two co-planar storage rings fed by a linac with an accumulator ring for fast topping up. It will be installed in the buildings that used to house the INFN's ADONE collider. The detectors FI.UN.DA and KLOE are situated at DAΦNE's two colliding regions. The operating energy range is 0.3 - 1.5 GeV, and the luminosity at the φ peak is expected to be about $10^{32}$ cm$^{-2}$s$^{-1}$ initially, increasing to planned luminosity of about $10^{33}$ cm$^{-2}$s$^{-1}$. The size of the storage rings allows operation with up to 120 bunches in each ring, with the filling of every RF bucket at the operating frequency of 370 MHz. A conservative estimate for the DAΦNE luminosity is obtained by scaling performance data for the VEPP-2M collider in Novosibirsk, assuming flat beams and two interactions per turn at the φ peak. The single-bunch luminosity $L_o$ for DAΦNE is $7.2 \times 10^{30}$ cm$^{-2}$s$^{-1}$ and the luminosity $L$ for 120 bunches is about $9 \times 10^{32}$ cm$^{-2}$s$^{-1}$. The final expected luminosity can thus be obtained using a conservative single-bunch value, noting however that the circulating current in the storage rings is very large (about 5 A). This results in two main problems:

- high outgassing rates of the vacuum chamber walls owing to bombardment by synchrotron radiation;
- bunch-bunch interactions *via* excitations of higher modes of the accelerating RF cavity leading to instability and reduced specific luminosity.

The vacuum problem is solved in DAΦNE using vacuum chambers having a complicated profile with slots in the median plane. The synchrotron radiation is transferred to auxiliary regions where cooled synchrotron light absorbers can be inserted and high efficiency pumping can be provided. The problem of higher modes is alleviated considerably by strong damping of modes other than the accelerating mode. This leads to cavities with shapes reminiscent of some metal sculptures, or even a sea urchin. The cavities have many ports to extract power at appropriate frequencies, and they couple the power *via* wave-guide transformers into external loads. The unwanted modes can also be tuned away from the unsuitable frequencies. Finally, active feedback based on digital signal processors will dampen out excitation of bunch instabilities. A total of 240 channels are required for the 120 positron and 120 electron bunches; the system is, however, highly modular and quite effective. Prototypes developed at SLAC in the USA, in collaboration with LNF personnel, have performed satisfactorily.

DAΦNE's two beams cross at a relatively shallow angle of 12.5 + 12.5 mrad in order to reduce the effects of parasitic bunch-bunch interactions. The dimensions of the beam have been chosen to ensure that synchrobetatron oscillations are not excited, as would be the case if the beams were to cross in the vertical plane. Numerical simulations show almost no effect (< 10%) on the size of the beam envelope for crossing angles up to 50 + 50 mrad. Crab crossing can be implemented if necessary, which for crossing in the horizontal plane requires a field that is 10-times smaller than for crossing in the vertical plane.

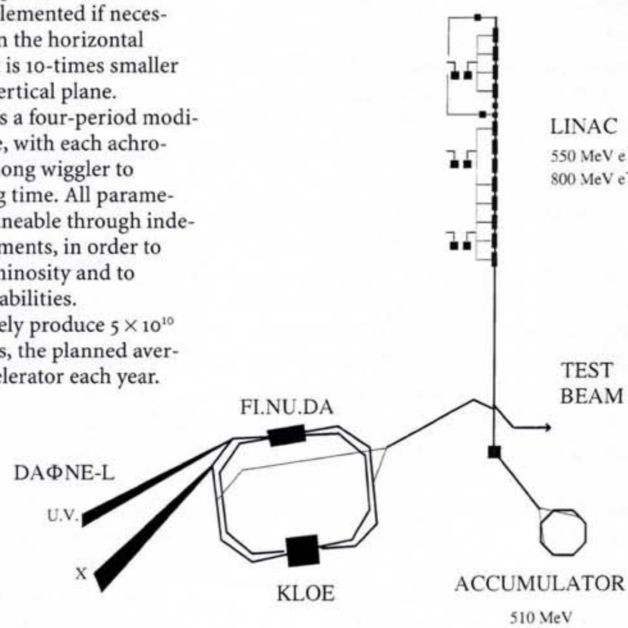
The DAΦNE lattice is a four-period modified Chasman-Green type, with each achromat incorporating a 2 m long wiggler to reduce the beam damping time. All parameters of the machine are tuneable through independent control of all elements, in order to maximize the specific luminosity and to suppress multibunch instabilities.

DAΦNE will ultimately produce $5 \times 10^{10}$ kaon pairs in four months, the planned average duty time for the accelerator each year.

### DAΦNE Parameters

| | |
|---|---|
| Beam energy | 0.510 GeV |
| Luminosity | up to $10^{33}$ cm$^{2}$s$^{-1}$ |
| Crossing angle | 10 - 15 mrad |
| Energy spread | $0.4 \times 10^{-3}$, rms |
| Bunch length | 30 mm |
| Beam size at interaction point | 2.1 mm horiz.; 21 μm vert. |
| Luminosity lifetime | 3.0 h |
| Topping-up time | < 2 mins |
| Injection energy | 0.510 GeV |
| Transverse emittance | $1000 \times \pi . 10^{-9}$ mrad, horiz.; $10 \times \pi . 10^{-9}$ mrad., vert. |
| RF frequency | 368.25 MHz |
| Particles/bunch | $8.9 \times 10^{10}$ |
| Bunches per ring | up to 120 |
| Average beam current | up to 5 A |
| Orbit length | 97.7 m |

This yield is adequate for the physics programme described in the text. Assembly of all components of DAΦNE is scheduled for start-up at the end of 1996, followed by commissioning without the detectors in place.




The DAΦNE machine complex showing the two coplanar rings and an accumulator for fast topping-up. There are two interaction regions where the detectors FI.NU.DA and KLOE will be installed.

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one will be able to measure the interference between the charged decay signal and the background signal as well as the charged and neutral decay energy spectra and angular distributions. A full determination of the nature and interaction of this particle is therefore expected [11].

- Physics of hypernuclei: DAΦNE is a unique source of low-energy, monochromatic charged kaons, offering the possibility of a unique programme to study hypernuclei. Decays of hypernuclei, the spectroscopy of Λ-hypernuclei, and the question of whether Σ-hypernuclei exist will be investigated. The FI.NU.DA Collaboration is designing and building the FI.NU.DA detector [12], sited in DAΦNE's second interaction region, to address these issues.

The DAΦNE facility, which has as its main mission the search for charge-parity violation in the K-meson system, promises not only an era of precision and varied *CP* and *CPT* violation studies when it begins operation in 1997, but also a rich complementary programme in nuclear and particle physics. It is anticipated that the study of K mesons will continue to provide powerful insights into the construction of the present theory of elementary particles and their interactions.

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