STATUS REPORT ON DAΦNE, THE FRASCATI Φ-FACTORY

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A high luminosity electron-positron collider, optimized at the Φ resonance energy (1.02 GeV in the center of mass), is presently under construction in the Frascati National Laboratory. It consists of two separate storage rings with two intersections where the beams cross at a small horizontal angle. Two large detectors, equipped with superconducting solenoids with the field parallel to the beam direction, are installed around the crossing point. The collider is designed to exceed the luminosity obtained at existing facilities at the same energy by two orders of magnitude. The design philosophy, the general layout of the collider with its injector and the status of the construction are presented.

Design philosophy

DAΦNE is a Φ-factory, namely a high luminosity electron-positron storage ring collider operating at the energy of the Φ resonance (1020 MeV in the center of mass). Its main physics goal is the measurement of the ratio ε'/ε in CP violating K decays [1], with an accuracy one order of magnitude better than what has been presently achieved at fixed target accelerators. The statistics required to reach this precision is of the order of 10^{10} K_S K_L pairs per year, which can be produced at the peak of the Φ resonance with an average luminosity of $5\text{x}10^{32}$ $\text{cm}^{-2}\text{s}^{-1}$ and an overall efficiency of $\approx 30\%$. This luminosity is about two orders of magnitude larger than that obtained at existing facilities in the same energy range [2].

It is clear that, in order to gain such a large factor in luminosity, a completely new approach must be followed. Let us remind that the luminosity L in a storage ring collider is given by:

$$L = h\, f_o \frac{N^+N^-}{4\pi\sigma_x\sigma_y} \qquad (1)$$

where h is the number of bunches stored in the ring, f_o the revolution frequency, N+ and N- the number of positrons and electrons stored in each bunch, σ_x and σ_y the standard deviations of the Gaussian horizontal and vertical distributions of the particles in the bunch at the interaction point (IP).

There is a limit to the number of particles which can be stored, due to the beam-beam interaction, namely the electromagnetic force seen by each particle when it crosses the counterrotating bunch of the other beam. This force has a linear behaviour near the bunch center, but it becomes strongly non-linear at a distance of the order of the bunch transverse size. The linear part of the force is characterized by a dimensionless parameter $\xi_{x,y}$ (called the "linear tune shift") related to the storage ring lattice parameters through the relation:

$$\xi_{x,y} = \frac{r_o N \beta_{x,y}}{2\pi\gamma\sigma_{x,y}\,[\sigma_x+\sigma_y]} \qquad (2)$$

Here r_o is the classical electron radius, γ the relativistic factor of the accelerated particles and $\beta_{x,y}$ the values of the horizontal and vertical betatron functions at the IP. The limit on the beam-beam interaction is set by the non linear part of the force, which tends to disrupt the particle distribution, leading either to beam blowup and luminosity reduction and/or to beam loss. However, it has been demonstrated through the experience on a large number of electron/positron colliders in operation in the world, that this limit is related to the value of the linear tune shift, which cannot exceed an "average" value of:

$$\xi_{max} = 0.038 \pm 0.013 \tag{3}$$

The optimum luminosity in a storage ring is reached when both ξ_x and ξ_y approach ξ_{max}, and this can be obtained when the ratios β_y/β_x and σ_y/σ_x at the IP are the same. Calling this ratio the coupling factor k and expressing the beam sizes in terms of the betatron functions and the beam emittance ε_o, the luminosity formula (1) takes the simple form:

$$L = h\, f_o\, \varepsilon_o\, \xi^2\, \frac{1+k}{\beta_y} \tag{4}$$

from which it is easy to see that, since the emittance is limited by the aperture of the machine, the luminosity can be improved by increasing the number of stored bunches or by reducing the value of the betatron function at the IP.

In a conventional electron/positron storage ring collider both beams are stored in a single ring and collide head-on at IP's, where low values of at least one of the betatron functions is realized by means of strong focusing doublets or triplets of quadrupoles, in order to keep the effect of the beam-beam non linear interaction within the stability limits. The optical functions at the IP are then matched to the periodic functions in the arcs by means of long matching sections. The strong focusing quadrupoles in the interaction regions enhance the chromaticity of the ring, which must be corrected in the arcs by means of distributed sextupole systems. For these reasons, it is not possible to reduce the betatron function at the IP below a practical limit and to have many IP's in a small storage ring at the Φ-resonance energy, because an excessive length of the ring circumference would lead to unacceptably long damping times. In practice, only one or two IP's can be realized.

The number of bunches which can be stored in each beam is half the number of IP's, unless the beams are separated by means of electric fields at the crossing points where the betatron functions are larger than the values required to avoid beam loss due to the beam-beam interaction. However, the number of points where the beams can be sufficiently separated depends on the total betatron tune of the ring, which is of the order of few units in a low energy collider, and therefore no more than two or three bunches can be stored in a single ring, thus limiting the attainable luminosity to less than 10^{31} $cm^{-2}s^{-1}$.

In DAΦNE the beams are stored in two separate rings, one for the electrons and one for the positrons. The two rings have two common interaction regions, where the trajectories of the two beams cross at a small angle in the horizontal plane (≈25 mrad). In this way it is possible to store a large number of bunches (up to 120) in each ring, which cross the other beam only at two IP's. A flat shape for the beam has been chosen, with a coupling factor of 1%, and in this case the optimum luminosity can be achieved with a small vertical betatron function (4.5 cm) and a rather large horizontal one (4.5 m). A small horizontal crossing angle at the IP between the trajectories of the beams provides the necessary separation where the vertical β is large. The product of this angle times the bunch length is much smaller than the beam width, and therefore the bunch crosses the bunch of the other beam almost head-on, reproducing the typical well-known crossing conditions of a conventional single ring collider.

The drawbacks of the double ring collider scheme are mainly related to the large stored current: there is a strong emission of synchrotron radiation (in DAΦNE ≈50 KW must be dissipated in each ring, requiring a special design for the vacuum vessel, where the circulating beam is separated from the region where the radiation hits the chamber surface by a narrow slot. Here ≈90% of the total radiation is concentrated on water cooled copper absorbers located near the pumping devices. The shape of the chamber must also be carefully studied, in order to avoid parasitic energy losses and improve instability thresholds. The large number of bunches introduces many longitudinal oscillation modes, a potential source of destructive instabilities. The remedies are a special design for the radiofrequency cavities, with waveguide absorbers to damp the higher order modes excited by the beam and a high efficiency bunch-to-bunch active feedback system.

There are points close to the IP at multiples of half the distance between the bunches where the two beams pass very near each other, their separation being the crossing angle times the distance from the IP. These points are called "parasitic crossings" and could, at least in principle, introduce additional limits to the beam-beam interaction. Designing the ring with a variable crossing angle is a good way of counteracting the possible harmful effects of these crossings.

Layout

In the DAΦNE collider the lifetime, due to the large bunch current and the low operating energy, is of the order of two hours, dominated by the Touschek effect. It is therefore necessary to refill the rings often, and rapidly, in order to maintain an average luminosity as close as possible to the maximum one. In addition, the bunch pattern in the Main Rings must be flexible, to cope with the different machine configurations (single bunch, 30 bunches, 120 bunches) and with the possible need of inserting trains of empty buckets to fight against ion trapping in the electron ring.

DAΦNE is therefore equipped with a full energy injector, so that the rings can be refilled without dumping the residual beam (this injection mode is called "topping up"). Fig.1 shows the overall accelerator complex inside the buildings where the former 3.0 GeV c.m. electron/positron collider, Adone, has been operating from 1969 to 1993.

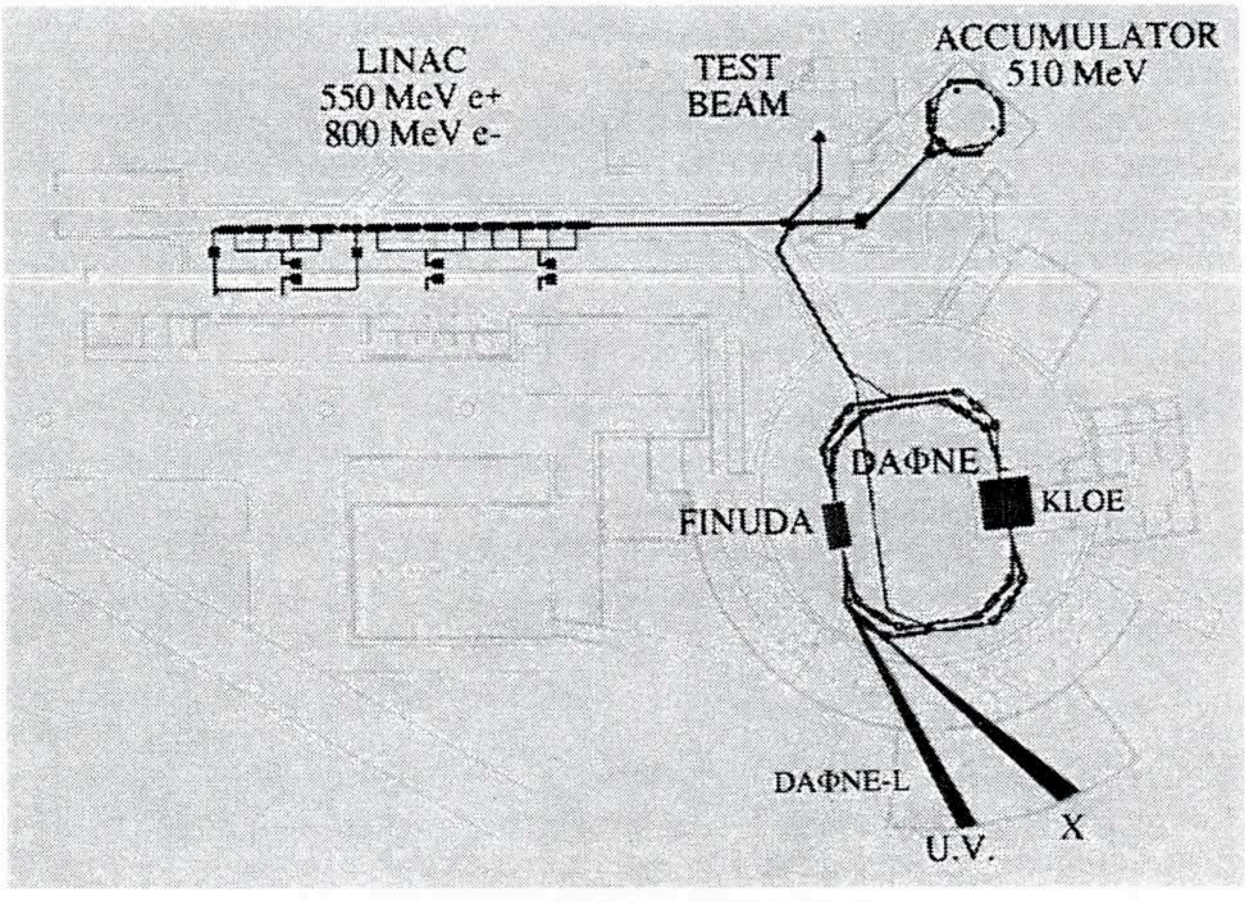

Figure 1. The DAΦNE collider with its injector

The injector is an S-band Linac, capable of delivering 10 ns bunches of 150 mA, 800 MeV electrons and 36 mA 550 MeV positrons at 50 pulses per second. Its accelerating structure consists of 16 constant gradient sections of 3 m length. The sections are powered by four 45 MW klystrons, equipped with SLED type energy doublers. In the positron acceleration mode, the first 6 sections are used to generate a 4 A, 250 MeV electron beam impinging on a tungsten target with a bright 1 mm radius spot. The positrons are collected by means of a flux concentrator, consisting of a high field (6 T) pulsed longitudinal solenoid and then accelerated to the required energy by the last 10 sections. In the electron mode the target is removed and the gun used at a lower emission current to keep beam loading in the sections under control.

The particles needed to fill a single Main Ring bunch are stored and damped in a small storage ring, called Accumulator. This is a 32 m long storage ring (one third of the Main Rings circumference), where electrons and positrons are stored alternatively in a single bunch. This bunch is then extracted, transported along the Transfer Lines and stored in the Main Rings. This ensures the maximum flexibility in the stored bunch pattern. The Accumulator is a symmetric machine where positrons are injected clockwise through the upper injection channel (see Fig.1) and extracted through the lower one. Electrons follow the opposite path without any need of changing the magnetic focusing. In this way the machine can be operated in a steady state with the best reliability. It is equipped with a radiofrequency cavity running at a frequency 5 times lower than the Main Rings one, with a corresponding gain by the same factor in the longitudinal acceptance. The particles, once reached the desired intensity, are damped before extraction, so that a high quality beam of small emittance and energy spread can be injected into the Main Rings, with substantial savings on its acceptance requirements, and, eventually, on the overall cost of the facility.

Due to the necessity of utilizing the existing buildings, the path followed by the particles during the whole injection procedure is rather complicated, requiring $\approx$180 m long Transfer Lines.

Each one of the DAΦNE Main Rings has an internal "short" arc and an external "long" one, in order to realize two crossing points where the beams collide at a small angle in the horizontal plane without any vertical bend, thus avoiding the excitation of vertical emittance, which could be harmful to its flat beam crossing geometry. The arcs are equipped with wigglers, to improve the synchrotron radiation emission, thus compensating for the low operating energy of the rings. As shown in Fig.2, there are four split field magnets, one on each side of the two interaction regions, where the vacuum chambers of the two rings merge into a common one. The final focus at the IP is obtained by means of permanent magnet quadrupoles, in order to leave the maximum free solid angle for the detectors. The straight sections at 90° with respect to the interaction regions are used for injection, R.F. and feedback equipment.

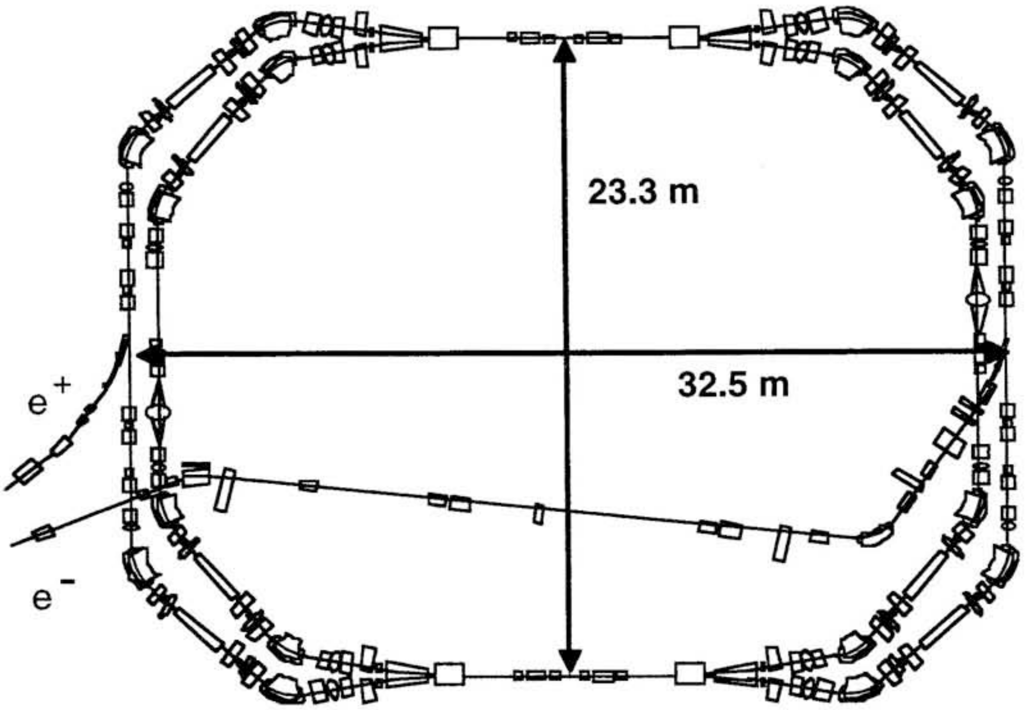

Figure 2 - Main Rings layout

Two large detectors, each equipped with a large superconducting solenoid with longitudinal magnetic field are placed around the interaction regions, as shown in Fig.1. They belong to the KLOE [3] and FINUDA [4] experiments. A third experiment without solenoidal field, DEAR [5], has also been approved and will be performed right after the first collider commissioning. Two synchrotron radiation outputs, one from a bending magnet and the second from a wiggler are also foreseen.

Status (June 1996)

The injector (Linac, Accumulator and Transfer Lines) is completely installed up to the Main Rings Hall (see Fig.1). The Linac has been fully commissioned with electrons, reaching its design performance. Commissioning with positrons is under way. All the hardware of the Transfer Line inside the Main Ring Hall has been delivered and will be installed together with the collider.

The electron beam has been transported through the Transfer Line and injected into the Accumulator for the first time on June 6, 1996. The first stored beam was achieved on June 21, and on June 30, a 75 mA stable single bunch was successfully accumulated under the design operating conditions. The machine will be commissioned with positrons as soon as the positron beam from the Linac will be available. The full performance operation of the injector is expected for the end of the year.

Most of the DAΦNE Main Rings magnets, the "small" quadrupoles and sextupoles for the straight sections, the wigglers, the superconducting compensator solenoids for the interaction regions, have been delivered and measured at Frascati. The prototypes of the dipoles, the "large" quadrupoles and sextupoles for the bending sections have been measured and approved. Series production is under way. Four out of ten permanent magnet quadrupoles for the interaction regions have been delivered and measured as well. The first RF cavity has been tested successfully at full power; the second one is under construction. All the large aluminium vessels for the arcs of the electron ring have been delivered and tested under vacuum. Those of the positron ring are under construction. The supports for the magnets are already installed.

The complete assembly of the Main Rings and of the Transfer Line inside the Main Rings Hall is scheduled for the end of the year, and the collider commissioning is foreseen to start in January 1997.

References

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4] The FINUDA Collaboration "FINUDA Technical Report" Frascati National Laboratory Internal Note LNF-95/024 (IR), 18/5/1995

5] The DEAR Collaboration "The DEAR Proposal" available from the Documentation Service of the Frascati National Laboratory