The DAFNE Main Rings are installed in the hall where ADONE has been running until April 1993.

*The DAFNE Main Rings during installation (December 1996).*
The DAFNE Main Rings at the end of the installation (July 1998).

Due to the peculiar geometry of the crossing in the horizontal plane, each Main Ring of the DAFNE collider consists of two 180 degrees bends of different length, the "short arc" and the "long arc".

Schematic layout of the two DAFNE Main Rings.
First assembly test of the short achromat with long vacuum vessel, dipoles, quadrupoles and wiggler.

The trajectories of the electron and positron beams cross at the two interaction points at an angle of 25 mrad with respect to each other. The separation between them increases along the interaction region (5 meters on each side of the interaction point), reaching ~12 cm at the entrance of a special septum magnet, called "splitter", which bends the two beams in opposite directions by means of opposite fields in the two gaps. In this magnet there is sufficient distance between the two beamlines to let the beams travel in two separate vacuum chambers: at its output the distance is large enough to accommodate the magnetic elements of the arcs. For this reason the vacuum chamber width increases from the interaction point to the splitter and large aperture focusing quadrupoles are needed to match the lattice functions.
The splitter magnet of the DAFNE Main Rings.

Front view of the large aperture quadrupole for the interaction region.
The short straight sections between the splitter and the first dipole in the arc are used to match the optical functions in the interaction region, where a low vertical beta value is required to reach high luminosity, to those in the arcs. Matching is realised by means of quadrupole triplets of the same kind of those installed in the Accumulator. A sextupole in each straight, where the dispersion is very low, is used to control high order aberrations introduced by the chromaticity correction sextupoles in the arcs. Also these sextupoles are of the same kind of those in the Accumulator. A special design of the vacuum chamber and large aperture quadrupoles and sextupoles allows the installation of tagging counters downstream the KLOE interaction region.

The original design of the Main Rings had vanishing dispersion at the crossing points and in all the four straight sections at 90 degrees with respect to the interaction regions. The arcs consisted therefore of two achromats, each composed of 2 dipoles, 3 quadrupoles, 2 sextupoles for chromaticity correction and one wiggler to increase the total radiation damping. In the long arc the dipoles bend the beam by 49.5 degrees each, in the short one by 40.5 degrees to compensate for the opposite deflection of the two arcs in the splitter. Further improvements in the lattice design have led to non-vanishing dispersion in the straight section of the long arc, where injection is performed. The short arc still preserves vanishing dispersion to avoid synchro-betatron coupling in the R.F. cavity. The definition of "achromat" in the long arc is therefore not correct, at least in principle. However, this name is still used, because the magnetic structure is flexible enough to make dispersion vanish also in the long straight.

The dipoles in the achromats are C-shaped with flat poles. In each achromat one of the two dipoles has parallel ends, while the other is a sector type one. The magnets have a rather large gap and pole width to provide a large acceptance for the relatively high beam emittance. The quadrupoles and sextupoles are also large, in order to cope with the peculiar design of the vacuum chamber in the achromat, described in the following.
"Parallel end short" dipole.
"Sector-like short" dipole.

Large quadrupole prototype.
Large sextupole prototype.

The wigglers used to double the synchrotron radiation power emitted by the beam are conventional electromagnets, each made of five central poles and two shorter end poles. The peak field in the poles is 1.85 T, to be compared to the 1.2 T in the bending magnet. Due to the strong power consumption of these magnets, it is foreseen to change them with superconducting ones in the future.

Front view of wiggler prototype.
The DAFNE wigglers after delivery.

In the long arc, the straight section between the achromats is used for injection. A first septum magnets, consisting of a thin copper sheet of 1.5 mm thickness, and carrying 2000 A direct current, separates the vacuum vessel of the ring from the injection channel coming from the Accumulator, and performs the final 2 degrees deflection of the injected beam. A system of 3 pulsed kickers provides a local single turn closed orbit deformation, which merges the injection pulses into the already stored beam. 8 quadrupoles in this section are used to control the betatron tunes of the ring and to optimise the phase advance between the kickers and the injection septum, while two sextupoles help in reducing high order aberrations. All the magnets in the straight are of the same type of the Accumulator ones.
The 2 degrees injection septa into the DAFNE Main Rings.

The 34 degrees injection septum into the DAFNE Main Rings.

The structure of the straight section in the short arc is similar to the long arc one, with 7 quadrupoles instead of 8: the R.F cavity of the ring is placed in this straight.

All the dipoles in the same ring (one short arc plus a long one) are connected in series, while all the other magnets have their independent power supply, in order to ensure the maximum flexibility in the operation of the machine.
There are 216 magnets in the Main Rings of 22 different kinds, including normal conducting electromagnets, superconducting solenoids and permanent magnet quadrupoles, powered by 290 independent power supplies. Their engineering design (excluding the superconducting and permanent magnet devices) has been done at LNF, while the construction has been committed to industry. The different prototypes are carefully measured at LNF to verify the mechanical, electric and magnetic properties foreseen in the design specifications for the acceptance tests. A smaller amount of measurements is performed on each magnet of the series production as well, in order to check normal operating behaviour, field quality and alignment parameters.

All the magnets for the DAY-ONE structure have been measured and installed on the rings.

All the power supplies have been delivered. They have been all connected to the corresponding magnets.

The pulsed systems under vacuum ("kickers") in the DAFNE Accumulator and Main Rings consists of a couple of coils fed by a pulsed power supply (completely designed and built at LNF) capable of delivering 200 ns pulses of 3 KA peak current at 35 KV at a maximum repetition rate of 50 Hz. The stability of the system is excellent: the peak current is stable within ±0.3% and jitters by less than 3 ns; the maximum reverse current is less than 2.5%. The injection test into the Accumulator have demonstrated the reliability of all the four systems installed. Six similar kickers are installed and fully operational, at a lower repetition rate, in the Main Rings.

Particular care has been taken in the design of the Main Rings vacuum system, to cope with the very high radiation power emitted by the beam. At the full design current (~5 A per beam), ~50 KW must be dissipated in each ring, under the constraint of keeping the average pressure in the chamber below 1 nTorr for beam lifetime reasons. In addition, the requirement of low beam generated background to the detectors in the interaction regions calls for lower pressure near the interaction points. In order to achieve this performance, a special vacuum chamber has been designed in the achromats, consisting of three parts, the central one around the beam separated from two "antechambers" by means of a narrow slot allowing the passage of photons radiated by the electron beam in the wiggler. The same arrangement, but with only one antechamber towards the outside of the ring has been adopted for the bending magnet.

All vacuum chambers of DAFNE have been assembled and connected to the pumping systems. The two rings are completely under vacuum since August 7, 1997.

The heart of the DAFNE pumping system is a special titanium sublimation pump. The necessity of making available a large amount of titanium has led to the design of a new type of source, composed of 12 titanium filaments, properly assembled and cabled on an ultravacuum compatible flanged support. The duration of such a source is between 12 and 8 months of continuous operation of the ring at full design current.

The requirement of keeping the pressure in the interaction region below 10^{-9} mbar with 5 A current in each ring together with the extremely poor availability of space in these regions resulted in the design of a high capacity non evaporable getter pump. Using a new type of syntherized getter, a prototype has been realized and tested with excellent results both in the pumping speed (2000 l/s) and in pumped gas amount (90 mbar.l) at each pump activation.

A new type of dilatation compensator for the long achromat vessels, with RF shield and without sliding contacts, has been realized as a collaboration of the accelerator physics, RF and vacuum groups, which allows 30 mm longitudinal and 10 mm horizontal displacements. In these bellows the internal shape of the vacuum chamber is reproduced by means of an elastic structure of copper-beryllium corrugated strips properly positioned and fixed on the compensator flanges. A prototype has been built and successfully tested through RF, thermal and structural analyses. The bellows are now installed in the rings.

The DAFNE electron ring is equipped with a system of clearing electrodes to sweep away the residual gas ions which may induce, under some circumstances, beam blow-up with strong reduction of luminosity, or even beam loss. They have been realized by means of an Al2O3 support covered by a special ultravacuum compatible resistive layer. After some preliminary tests on a prototype the final electrodes have been built and inserted into the long vacuum chamber of the electron ring achromats.
Vacuum vessel cross sections in the Main Ring achromats.

The achromats are the "hottest" region from the point of view of emitted synchrotron radiation power. The vacuum vessel in each achromat has been designed as a single piece ~10 m long aluminum chamber, including the two achromat dipoles and the straight section with the wiggler in between. The radiation from the dipoles and the wiggler travels through the slots to the antechamber, where it hits special water-cooled copper absorbers.

The first vacuum vessel of the Main Ring achromats.
Near each synchrotron radiation absorber, where the gas load is concentrated, there is a titanium sublimation pump with a pumping velocity of ~2000 litres per second, and a sputter ion pump to extract those kind of gases which are not efficiently pumped by the sublimators. Special NEG pumps are foreseen in the interaction regions, where a lower pressure is needed to avoid excessive backgrounds to the experiments.

The radiofrequency system of each ring consists of a normal conducting single cell cavity running at 368 MHz on the 120th harmonic of the revolution period. Each cavity is fed by a 150 KW/cw klystron, protected against the reflected cavity power by a ferrite circulator. In order to reduce the interaction of the beam with the high order modes of the cavity, the latter is equipped with long tapered beam tubes and three waveguides to couple out the parasitic modes that are then dissipated into external 50 Ohm loads by means of special broadband transitions between the waveguides and coaxial vacuum feedthroughs.
The R.F. cavity of the Main Rings.

The high order mode absorber with the broadband transition from the waveguide to coaxial external load.

The central body of the R.F. cavity is obtained from a single forged OFHC copper billet and the internal surface is fully manufactured with an automatic milling machine.

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 R.F. cavity. These instabilities have been identified as a potentially severe limit to the ultimate achievable luminosity. Even though the high order modes in the cavity are strongly damped by the waveguides absorbers, the probability for a damped
The required additional damping is provided by a longitudinal feedback system, based on digital signal processors (DSP), which acts on each bunch individually. The digital section is under construction at SLAC in the framework of a collaboration with the SLAC-LBL PEPII group on feedback systems for the next generation of "factories" with intense beams and a large number of bunches. The first realisation of this kind of feedback has been successfully tested at the synchrotron radiation source ALS in Berkeley.

The active element of the feedback chain for DAFNE is a special overdamped cavity running at 1.2 GHz (3.25 times the main R.F. frequency). The cavity has a diameter of 20 cm and is 7.2 cm long. To obtain the large required bandwidth (~180 MHz for operation with 120 bunches), the cavity is loaded with 6 ridged waveguides followed by broadband transitions.

CAD view of the longitudinal feedback kicker cavity.
Additional instrumentation for the Main Rings consists in a distributed orbit correction system made of button pick-ups, striplines and horizontal/vertical correctors, sensitive to the beam position also in a single-turn mode. Synchrotron radiation monitors and single bunch current detectors will also be available for beam diagnostics purposes. A system of skew quadrupoles is foreseen to control the beam coupling at the interaction point, as well as a beam deflection system to separate the beams during injection and to finely control the superposition of the beams at interaction.
The "Square" corrector for the Main Rings.
The "Rectangular" corrector for the Main Rings.
The double function corrector for the Main Rings: it is at the same time a horizontal/vertical dipole and a skew quadrupole

Special dipole correctors are needed near the splitter, due to the close proximity of the two rings. A couple of "Lambertson" correctors is placed between the solenoid compensator magnet and the splitter: they are used both to correct the closed orbit at the interaction point and to create vertical separation of the beams at injection. The "C" correctors, so called because of their unusual shape, correct, together with the field in the splitter, the orbit deviation occurring when the crossing angle of the beams at the interaction points is made different from the nominal one. This feature is particularly important in finding the optimum crossing angle to maximize the luminosity and keep the effect of parasitic crossings under control in the different bunch configurations foreseen for the operation of the collider.
The "Lambertson" corrector. A couple of these correctors is placed just before the splitter, where the vacuum chamber splits into the two separate rings. The yoke is of the "C" type with an iron shield towards the symmetry axis of the interaction section, to avoid interference with the other corrector.
The "C" corrector of the Main Rings: it is used when the crossing angle of the beams at the interaction point is changed from the nominal one (25 mrad total).

The luminosity is measured both by the experimental detectors through the rate of well-known electromagnetic reactions, and by a special system of counters placed right after the splitter magnets measuring the rate of single beam-beam bremsstrahlung produced at the interaction points.

**M. Preger 29 JUN 1998**