LEP The Large Electron-Positron Project

Herwig Schopper

CERN
1211 Geneva 23, Switzerland

1. Introduction

The definition of LEP is that it is an e^+e^- ring optimized for about 100 GeV per beam. One will start with 50 GeV per beam, but the dipole magnets can take beams up to 125 GeV. With 100 GeV as the optimum energy one obtains a circumference of about 26.7 kilometres. The ring will be 80 to 125 metres deep underground. The present accelerators, both the PS and the SPS, will be used as injectors. Initially four interaction regions will be equipped with experiments; four more could be opened up later. Note that both the radius of the ring and the cross-section of the tunnel were chosen to be as large as possible in order to have other options open for the use of the tunnel in the future.

The cost of LEP is 910 million Swiss francs, at 1981 prices. The project was approved unanimously by the Member States in December 1981, on the condition of a constant budget and constant staff during the construction period. Fig. 1 shows a map of LEP in relation to the present CERN site. It is quasi-tangential to the SPS so that the latter can serve as an injector with short transfer tunnels. There will be eight access areas, most of them with three access shafts (one for the machine, one for experiments and one for personnel) as indicated by the numbers, and the first four experiments will be installed at the even-numbered places. The rf accelerating cavities will be installed at points 2 and 6. Later it would be easy to open up interaction regions at points 1 and 5 whereas this would be a little more difficult at points 3 and 7 because, for various reasons, short access tunnels have to be built.

Fig. 2 shows an aerial photograph of the LEP site and Fig. 3 a simplified geological section across a diameter of the ring from the Jura to Geneva airport. Most of the LEP tunnel will be excavated in the molasse sandstone which is very good for tunnelling and in which the SPS was built. Unfortunately, the roof of this rock goes down towards the airport and there is moraine and gravel and sand above, which is bad for tunnelling. Hence in order to stay in the molasse the tunnel has to be rather deep underground. At the opposite end the limestone of the Jura rises, which could contain cracks filled with water with much rock above. There could be rather high water pressures which would be a nuisance when tunnelling, so that the aim was to have not more than 150 metres of rock above the tunnel. In order to achieve these different requirements LEP is designed to be built on an inclined plane, probably the first accelerator to be built in such a way. The slope is about 1.5% which seems negligible but is not. For example, the water pressure difference from one side to the other of the ring would be 15 atmospheres which has to be taken into account as well as the fact that some of the experiments will be on an inclined plane.

The injection system is shown in Fig. 4. There are two linacs; one is a 200 MeV high-curret linac to produce electrons which will then produce positrons from a target; the second linac will accelerate both electrons and positrons to 600 MeV, and this is followed by an electron-positron accumulator (EPA). The electrons and positrons are then accelerated in the PS to 3.5 GeV and then transferred to the SPS to be accelerated to 20 GeV before finally being injected into LEP. The two linacs are being built in collaboration with LAL, Orsay, in France.

For the injection system the idea is that LEP will be able to operate simultaneously while the SPS is doing fixed-target physics. Nevertheless when LEP comes into operation the $p\bar{p}$ collider will continue, probably for about 40% of the time as at present, since in any case in the first few years there will be technical changes, upgrading and completion of LEP which is planned to be operated for about 4000 hours per year. Fig 5 shows the details of the injection sequence where the upper graph gives the magnetic field of the SPS as a function of time, and the lower graph the electron and positron currents in the accumulator ring, also as a function of time. Of course, this applies only when injection is taking place into LEP; while LEP beams are circulating the SPS does not need to have such a complicated supercycle.

2. Present Status of the LEP Machine

The ordering of components is within the scheduled timescale and budget envelope and contracts amounting to some 500 million Swiss francs (about half of the total cost of the project) have been adjudicated.

Injector System

The building to house the preinjector LIL (Linear Injector for LEP) is completed. Most of the components, including new pulsed klystrons, have been ordered, as have those for the electron-positron accumulator (EPA). Installation work will start in the autumn of 1984. The various modifications to the PS and SPS (kickers, septa, RF, wiggler, vacuum, transfer lines) are advancing well.

Magnets

The bending magnets cover three-quarters of the machine circumference. There are 3328 dipole cores, each about 5.76 m long, powered by sets of excitation bars, which are mounted on their poles. The vacuum chamber is mounted in the gap between the poles as shown in Fig. 6. The space between the magnet laminations is filled with a fine-grain sand and cement mortar which acts as a bonding agent. Because of the large radius of curvature of the LEP ring the main dipole field at 50 GeV is only 0.054 T. Because of this low field the dipoles are equipped with simple aluminium excitation bars instead of the traditional coils. These bars will be produced by continuous extrusion and installed in elements about 12 metres long insulated by fibre-glass and epoxy impregnated profiles. They will carry a current of about 2250 A at 50 GeV and will be cooled by circulation of demineralized water. Delivery of the dipoles will start in the autumn of 1984, while the excitation bars, which in total amount to about 1000 tons of aluminium, have been ordered.

Concerning the supply of the other magnets of the main ring lattice, four contracts have been placed - two for the two types of quadrupoles, one for the sextupoles, and one for the correctors. Whereas the sextupoles and the quadrupoles in the arcs will have coils made out of conventional hollow conductor, the coils of the quadrupoles for the dispersion suppressor and acceleration regions will be wound with anodized aluminium strip. Tenders have been invited for the dipoles in the injection regions, the busbar modules in the arcs, and the girders of the straight-section groups. Widespread interest has been raised by a preliminary enquiry for the supply of the super-conducting quadrupoles for the low-beta insertions.

The construction of the instrumentation for systematic magnetic measurements upon delivery of the different magnets is well advanced. Based on the satisfactory performance of the prototype, the components of the automated benches for quadrupole and sextupole measurements have been ordered. One of the sets of proximity detectors, which have been developed to allow the determination of the magnetic field pattern in the dipole core gaps without requiring their excitation, has already helped to define the profile of the laminations for the production prototypes.

Accelerating System

To reach an energy of 50 GeV per beam 128 accelerating cavity storage units are required (see Figs. 7 and 8). The storage cavities on top of the acceleration cavities will reduce losses during the periods when no particle bunches are in the accelerating cavities. These cavities will be driven by 16 MW of RF power via a power distribution system. The RF sources will be large klystrons which will feed a number of cavities simultaneously (see Fig. 9). Almost all of these various components have now been ordered and prototypes have been delivered. Preparations are under way for the assembly and testing of one complete RF unit consisting of 16 cavities, 2 klystrons and the corresponding waveguides and low-power drive and control systems.

Experimental Areas

Fig. 11 shows the detail of an interaction region which is one of the more complicated ones since it has a large experiment and one rf station. There is an underground hall for the experiments and a shaft for lowering the apparatus for assembly in the so-called garage position, before being moved into the beam. There is a second shaft for the machine services and a small shaft for personnel access to the experiments. The galleries for the rf klystrons are also shown.

3. Present Status of the Civil Engineering Work

Two international consortia are responsible for the civil engineering work for the excavation of the tunnel for the main ring. One is working in the "plain" using two tunnelling machines to bore through the sandstone and molasse. The starting point will be point 8 (see Fig. 1) and one machine would work clockwise towards point 3 and the other anti-clockwise towards point 4. The second consortium is working in the Jura using conventional techniques (explosives). A reconnaissance gallery excavated earlier has been converted into an access tunnel and a large cavern has been provided for the tunnelling installations (see Fig. 12).

Pits are now being dug at the eight points around the circumference. Fig. 13 shows the state of the work at point 8 as of October 1983. Digging the pits often presents more difficulties than tunnelling in the sandstone. For example, for the pits on the airport side of the ring, which will be 80 metres deep, it will be necessary to pass through two ground-water levels. To avoid interfering with the water tables two methods have been employed, viz. 1) a special system of screen walls - a concrete wall built around the pit before digging it to keep the water out - and 2) freezing the ground to be dug to prevent water from entering (see Fig. 14).

The overall status of the civil engineering work as of May 1984 is illustrated in Fig. 15.

Vacuum

Many tests have been carried out on 12 m long model vacuum chambers. The main aspects covered were the detection and repair of leaks; the systematic introduction of aluminium gaskets; bakeouts with superheated water; and full vacuum tests with prototype getter systems. The latter test included pumpdowns before and after the process of soldering the lead shielding to the chambers. All dipole chambers eventually attained a pressure in the low 10^{-11} Torr range, which proved the satisfactory state of leak-tightness and cleanliness.

Development work has been carried out on the application of lead shielding to the aluminium vacuum chamber and a press suitable for treating full-length dipole chambers has been constructed. Most of the model chambers mentioned above have been successfully clad in this way.

Contracts have been awarded recently for both the dipole and quadrupole type vacuum chambers.

Other Items

Many other items are in various stages of advancement, for example, beam instrumentation, injection insertions, electrostatic separators, power converters and electrical distribution, controls, cooling and ventilation etc.

One major difficulty will be the infrastructure; there are only eight access shafts with 3.5 kilometres of tunnel between each of them. The solution adopted for the transport of both components and people is a monorail suspended from the ceiling of the tunnel (see Fig. 10). In order to speed up the installation in the tunnel, there will be various devices for transporting long items which will be preassembled at the surface as much as possible; for example, one unit of 14 metres length would be two bending dipoles with a common vacuum chamber.

It is planned to complete all the access shafts and the tunnel by the summer of 1987; during the intervening time there are 21 fixed contractual dates to be met by the consortia. Installation of services in the tunnel (power, light, etc) should start in spring 1986 and the installation of machine components in the autumn of 1986. First injection tests into an octant are planned for autumn 1987 and the first beam all around LEP for the end of 1988.

4. Upgrading of the RF System

Initially 128 copper accelerating cavities operating at 352 MHz will be installed at two straight sections at points 2 and 6. This will enable a beam energy of 55 GeV (max. luminosity) to be attained. For the upgrading of LEP in due course it is envisaged to use superconducting cavities which should yield accelerating fields of at least 5 MV per metre. If one added 64 such cavities in the space still available at points 2 and 6 an energy of ~ 70 GeV could be reached. If in addition a further 192 superconducting cavities were placed in straight sections at points 4 and 8 then 90 GeV could be attained. Finally, if all the copper cavities were replaced by superconducting cavities then the energy per beam would be 96 GeV. In fact, all of these numbers may be on the low side as recently accelerating fields of 8 MV per metre have been obtained. Fig. 16 shows a four cell 500 MHz cavity made of Niobium which has been built at CERN.

5. LEP Experiments

The four detectors, which have been approved by a LEP Experiments Committee chaired by G. Wolf of DESY, have the following features.

Two of them are universal detectors which differ in the following respects: OPAL is more or less an upgrading of the JADE detector at PETRA, has a warm coil and uses well proven techniques. ALEPH is also a universal detector but uses some novel techniques; in particular, it has a very large TPC. Then there are two specialized detectors. One is L3 which is specialized in calorimetry. It is planned to have a very powerful electromagntic calorimeter using the new material BGO, bismuth-germaniumoxide, a very fine-grain hadron calorimeter, and it can also measure very precisely the momenta of muons. DELPHI is specialized in the identification of hadrons and uses the new technology of so-called Ring Imaging Cherenkov Counters. The largest detector will be that of L3. Because of its size it cannot be moved, but the magnet is installed permanently in the experimental cave (Fig. 17).

Between 200-300 physicists are in each experiment. In view of the new technologies involved in making the components, teams had been requested first to build prototypes and the LEP Experiments Committee had laid down milestones that had to be passed before the experiment teams could go ahead with the construction of the whole detector. The Committee had conducted a survey of the experiments earlier in 1984 and most of the difficulties had been overcome and the preparations for all the experiments and hardware developments were on schedule. Experiment L3 will be installed at point 2 on the LEP ring since it requires a wide shaft and it was therefore more appropriate and cheaper to locate it in the experimental area closest to the surface. OPAL will be located at point 6. The other two experiments have yet to be assigned their locations.

New negotiations are under way concerning the civil engineering work in order to ensure that all experimental halls are ready for installation at about the same time.

One question raised by the experiments is the computing capacity required at CERN to deal with the enormous quantity of data that will be produced and the distribution of analysis between the experiments using microprocessors and emulators and CERN central computers. The computing requirements of the experiments were now being evaluated but it was already clear that CERN would have difficulty in finding the necessary resources. Collaboration with outside institutes would therefore be needed in order to apportion tasks and prevent duplication.

In the spring of 1985 the LEP Experiments Committee will organize a workshop to discuss the latest developments in LEP physics.

Fig. 1 Map of LEP in relation to present CERN site.

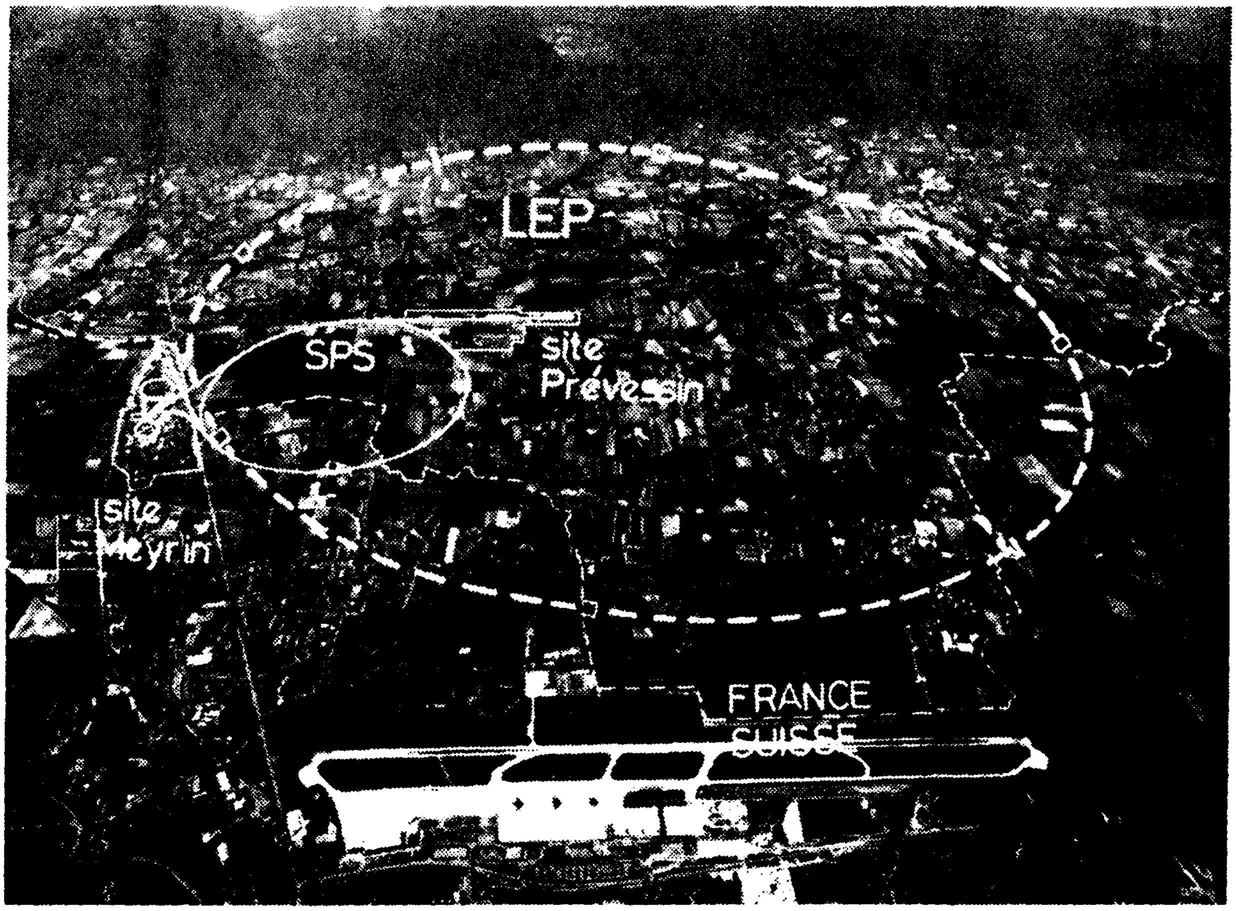


Fig. 2 Aerial photograph of the LEP site.

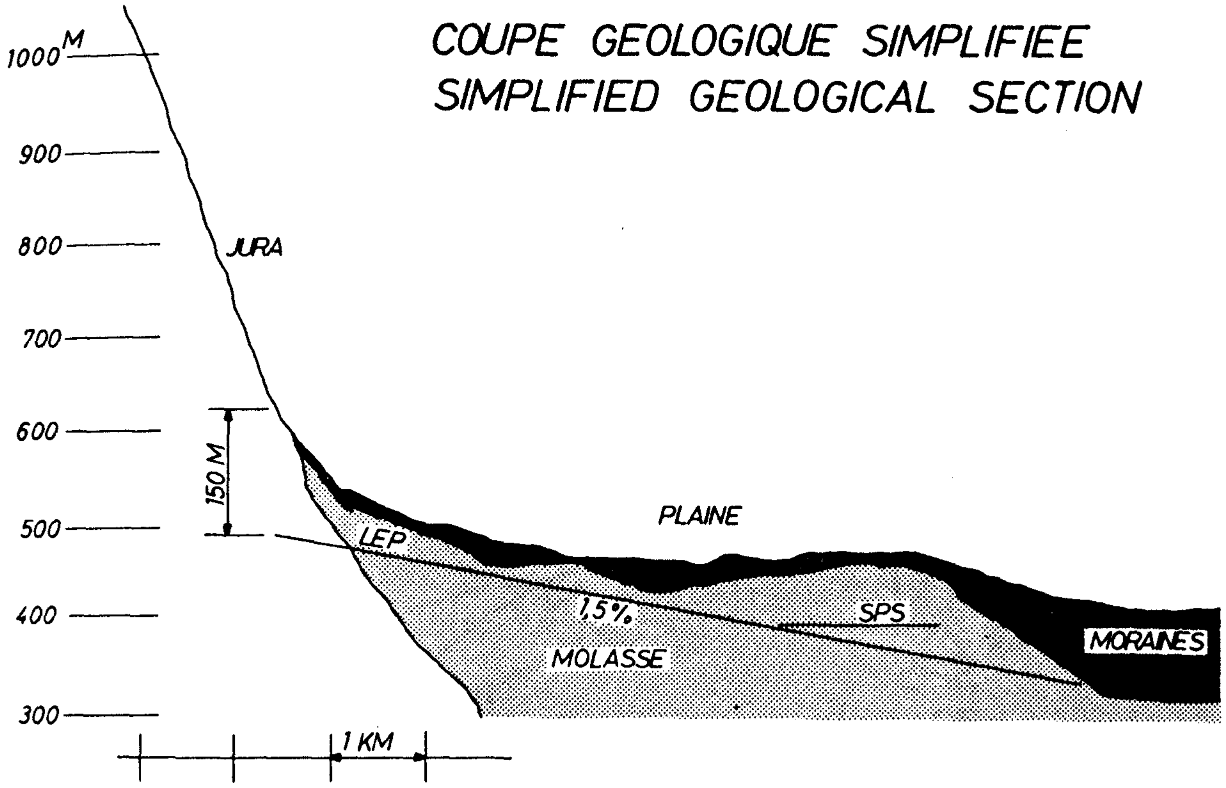


Fig. 3 Simplified geological section across a diameter of the LEP ring.

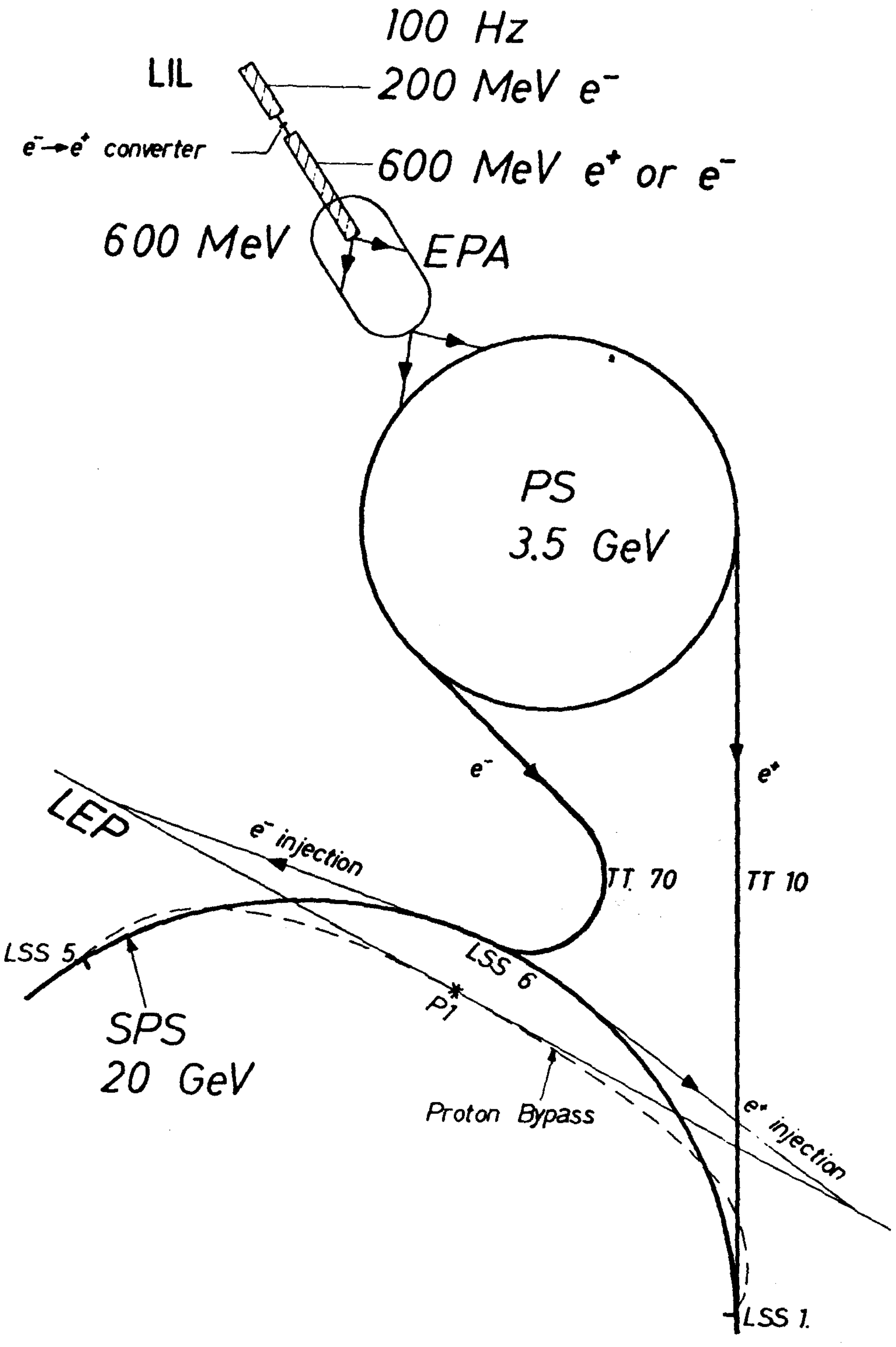
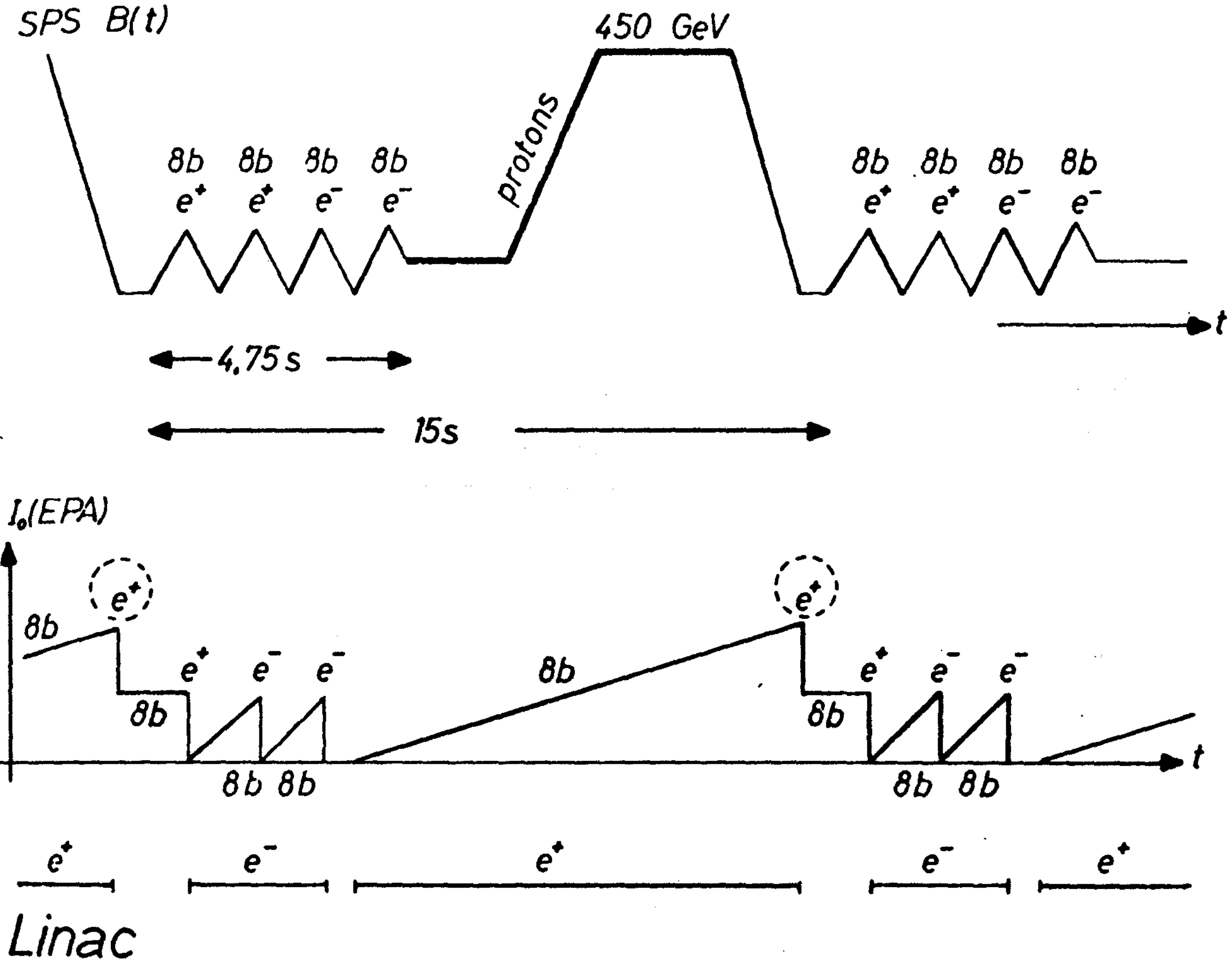
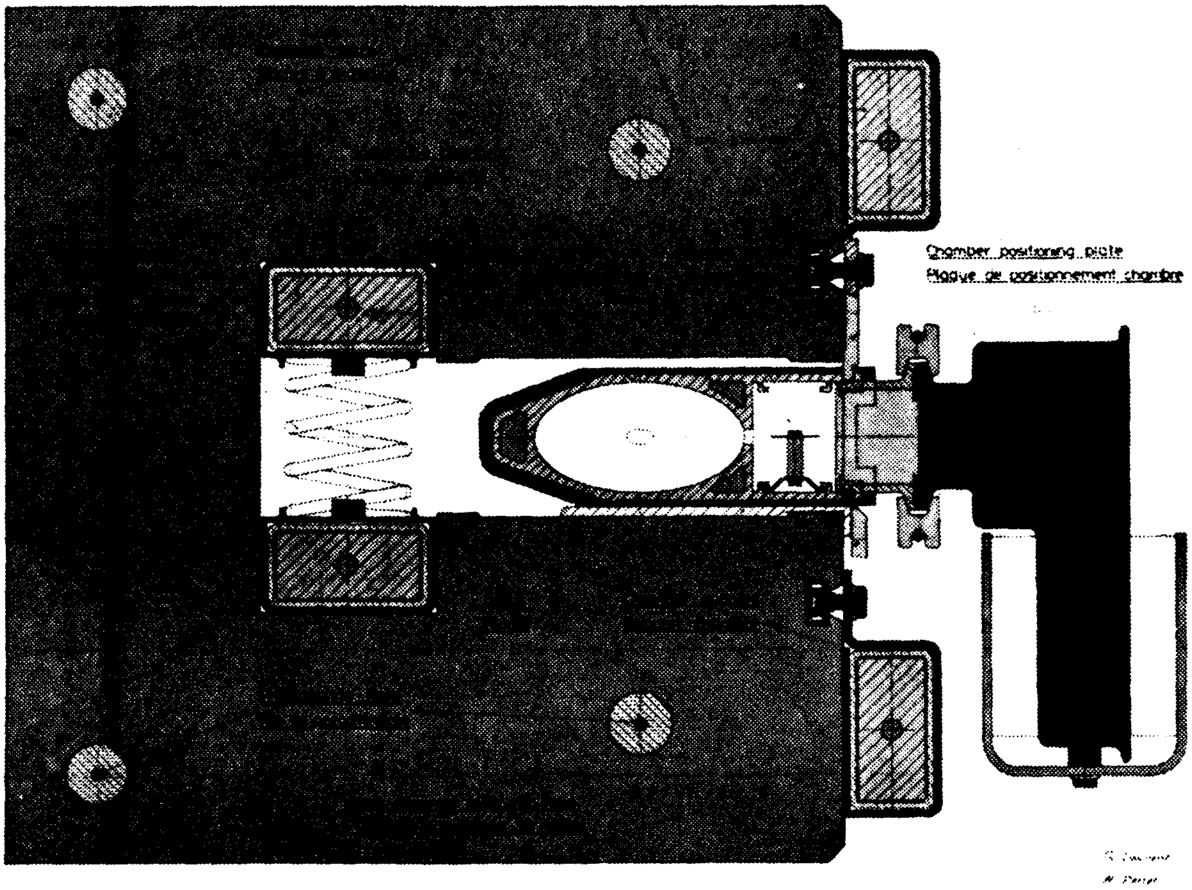


Fig. 4 Injection system for LEP.



<u>Fig. 5</u> Details of the injection system.



Cross section of the dipole magnet with the vacuum chamber

Section de l'aimant dipole avec la chambre à vide

Fig. 6 LEP vacuum chamber and magnet arrangement.

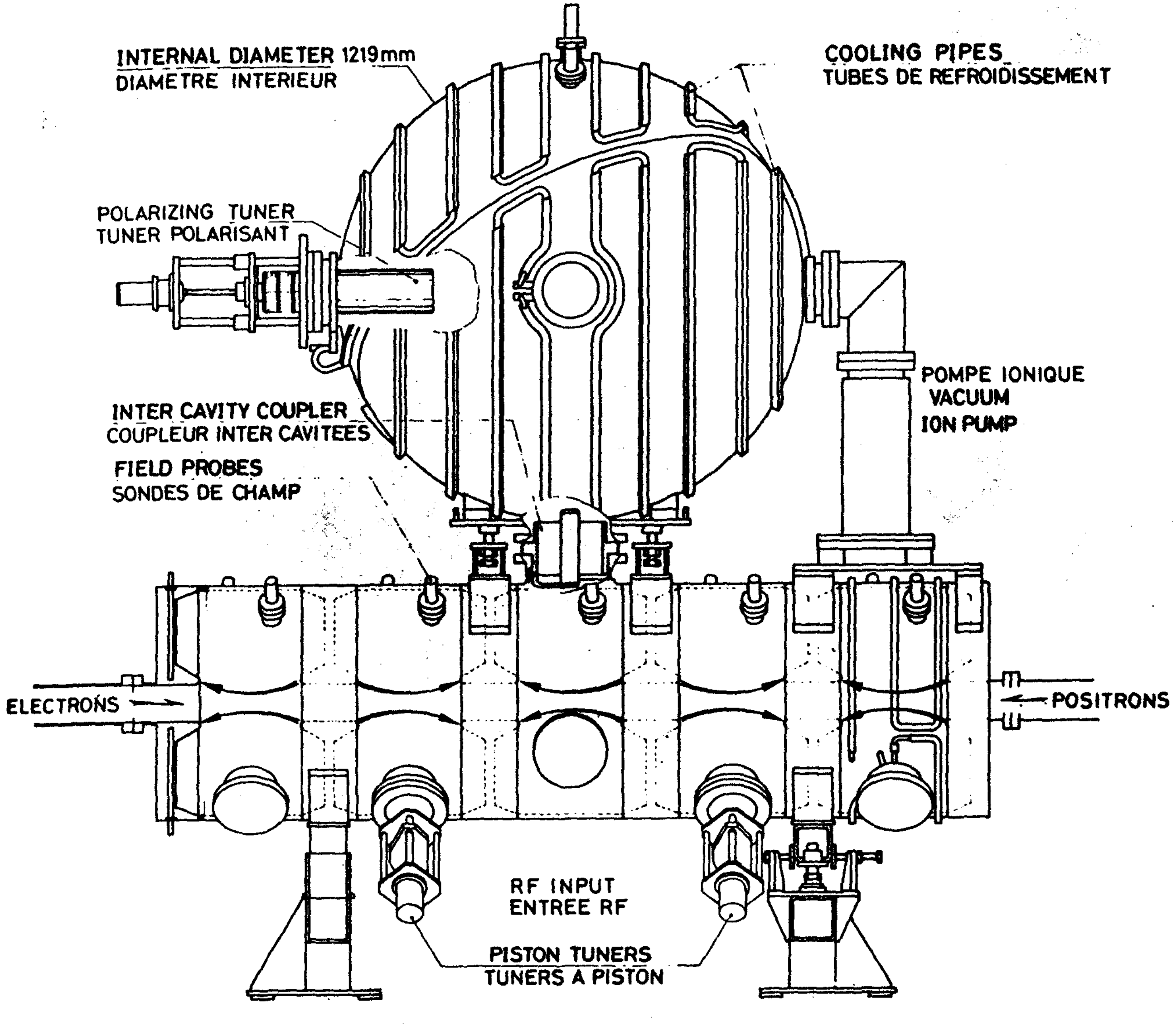


Fig. 7 Diagram of an accelerating cavity plus storage cavity.

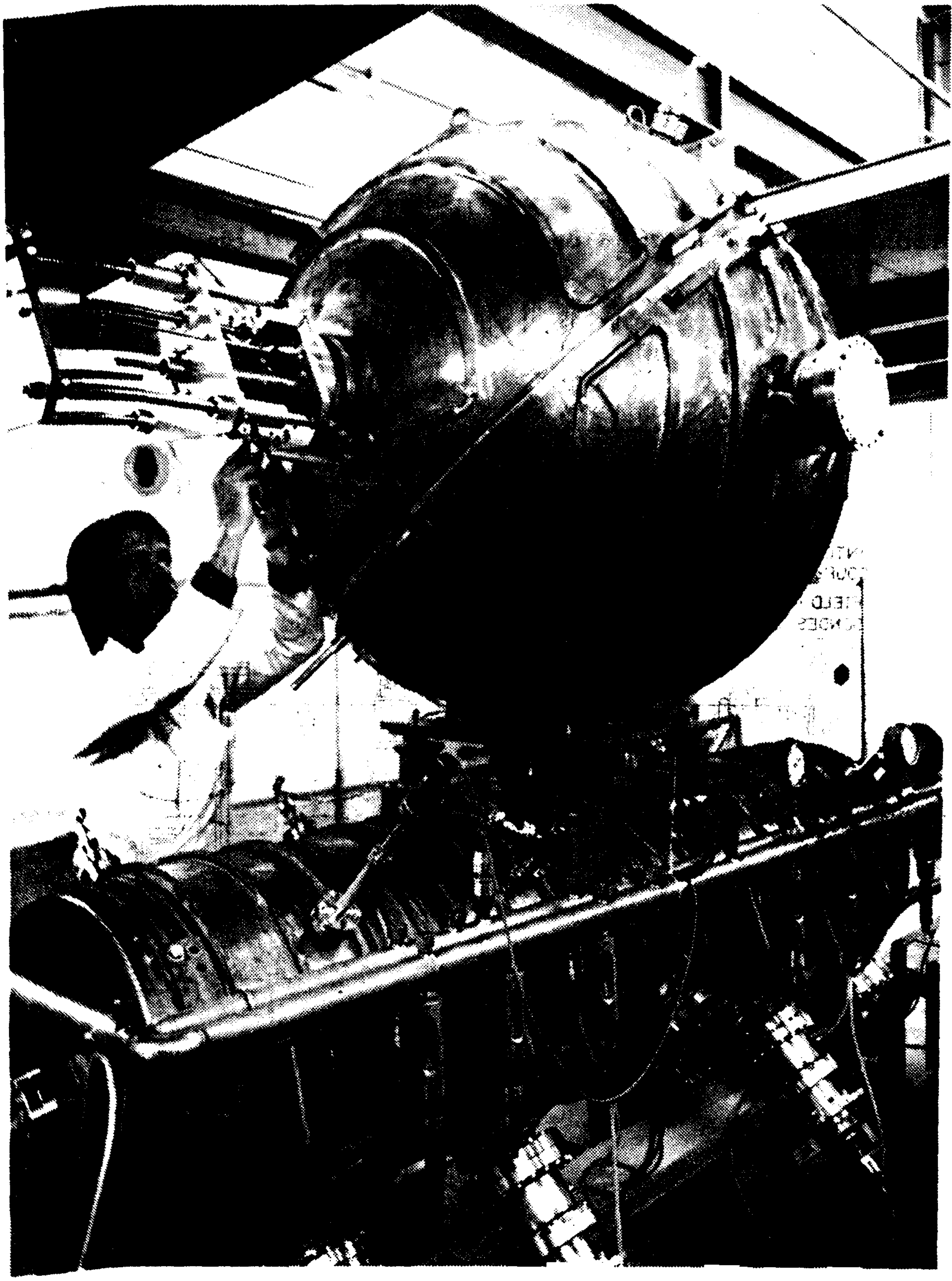


Fig. 8 Photograph of an accelerating cavity and its storage cavity.

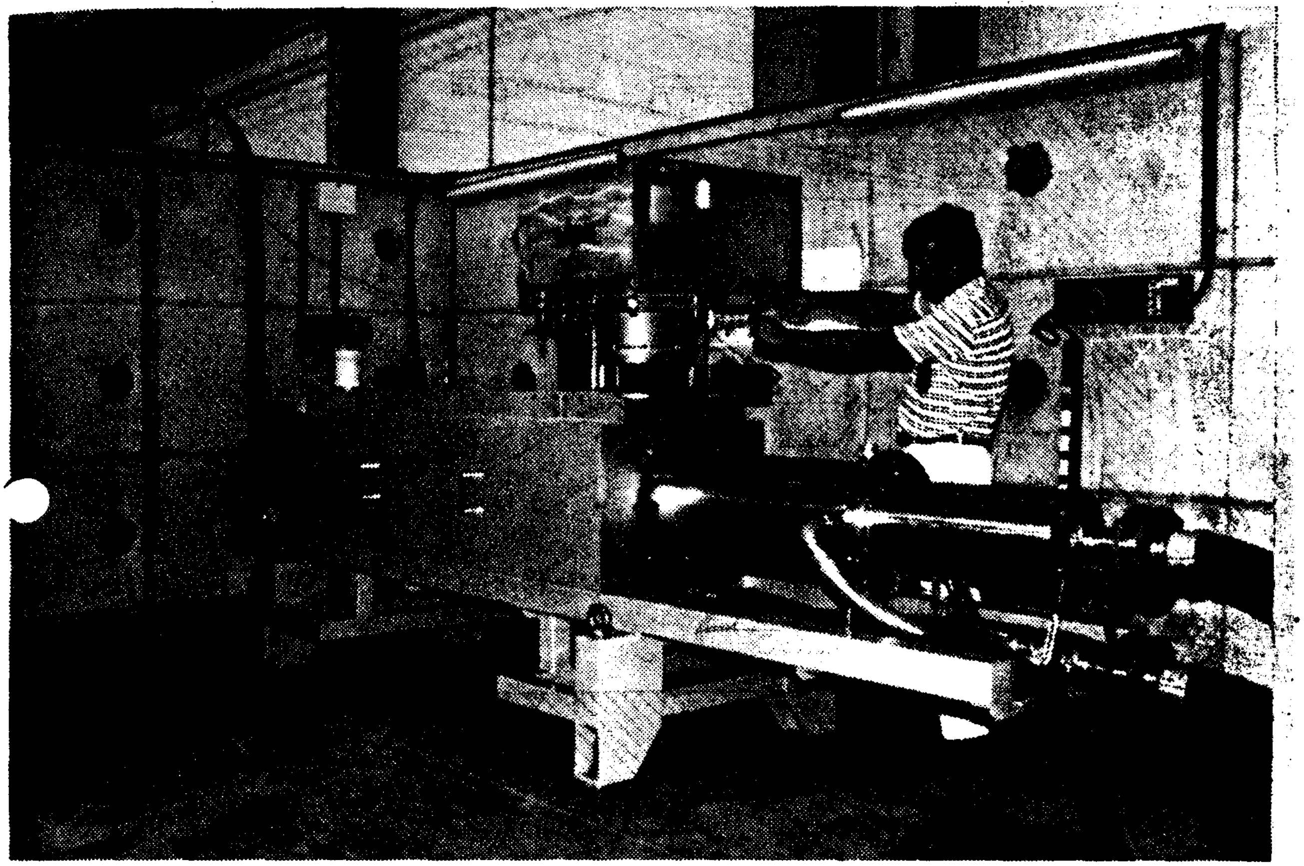


Fig. 9 Production prototype of an RF klystron.

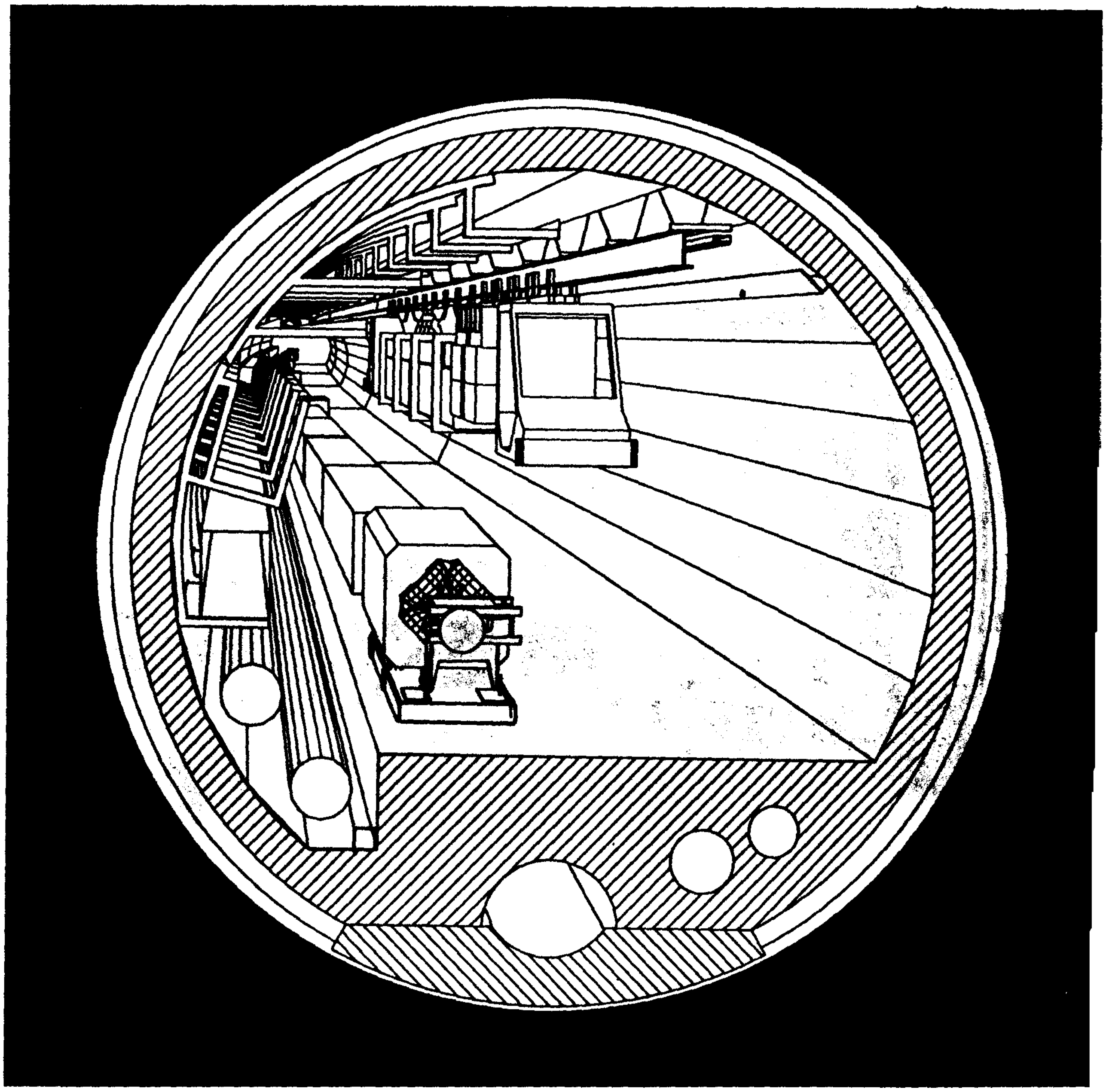


Fig. 10 Planned monorail system for the LEP tunnel.

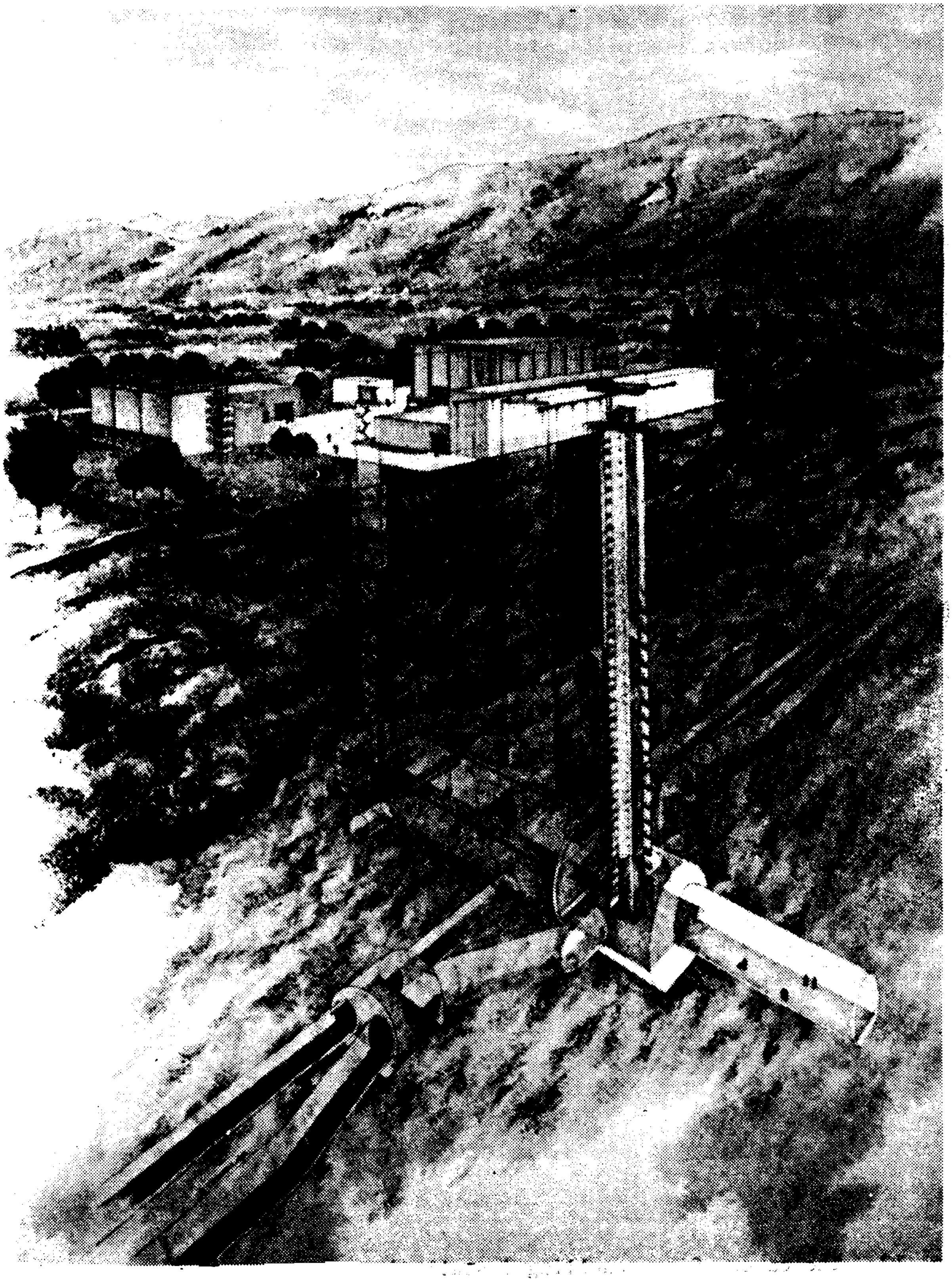


Fig. 11 Detail of an interaction region.

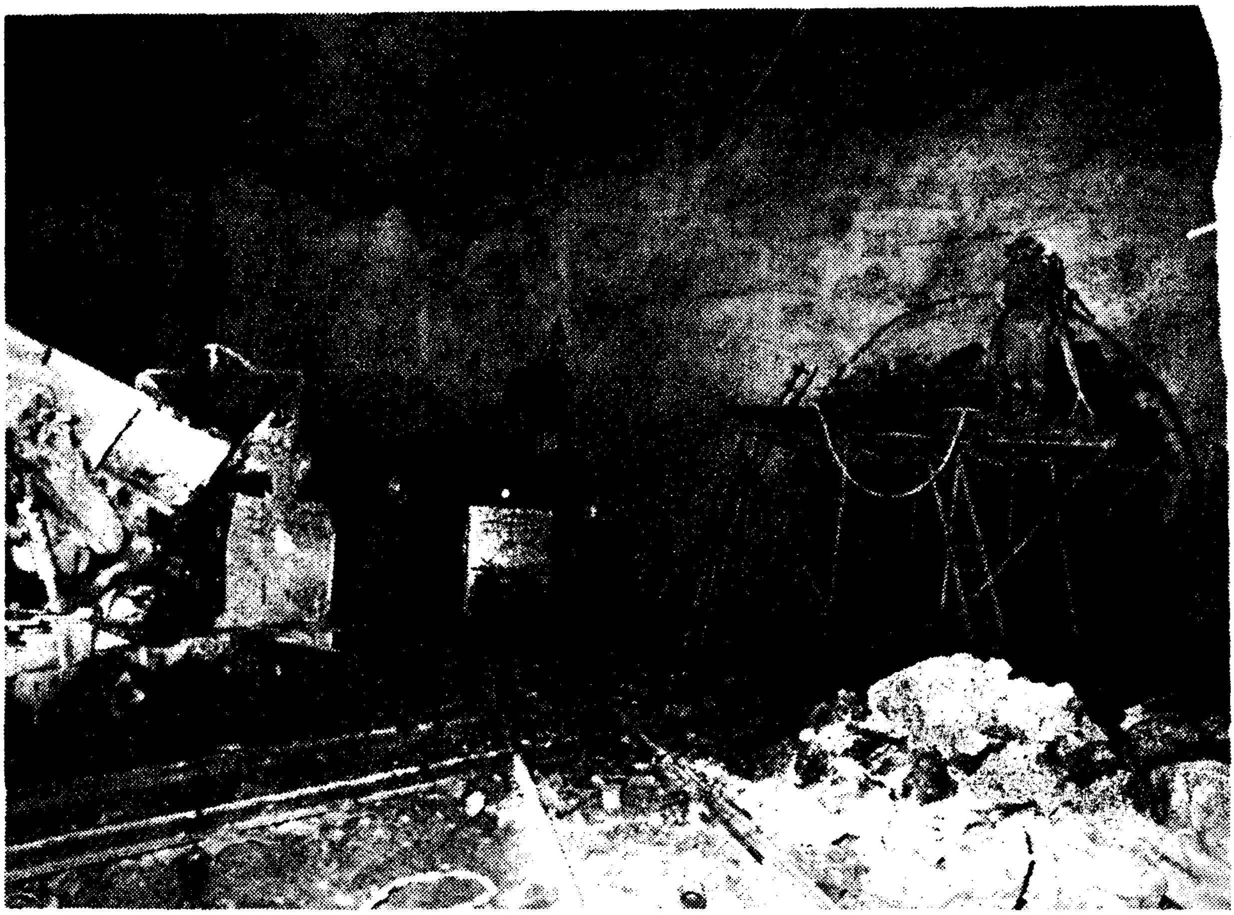


Fig. 12 The cavern for tunnelling installations at the end of the previous reconnaissance gallery now converted into an access tunnel.

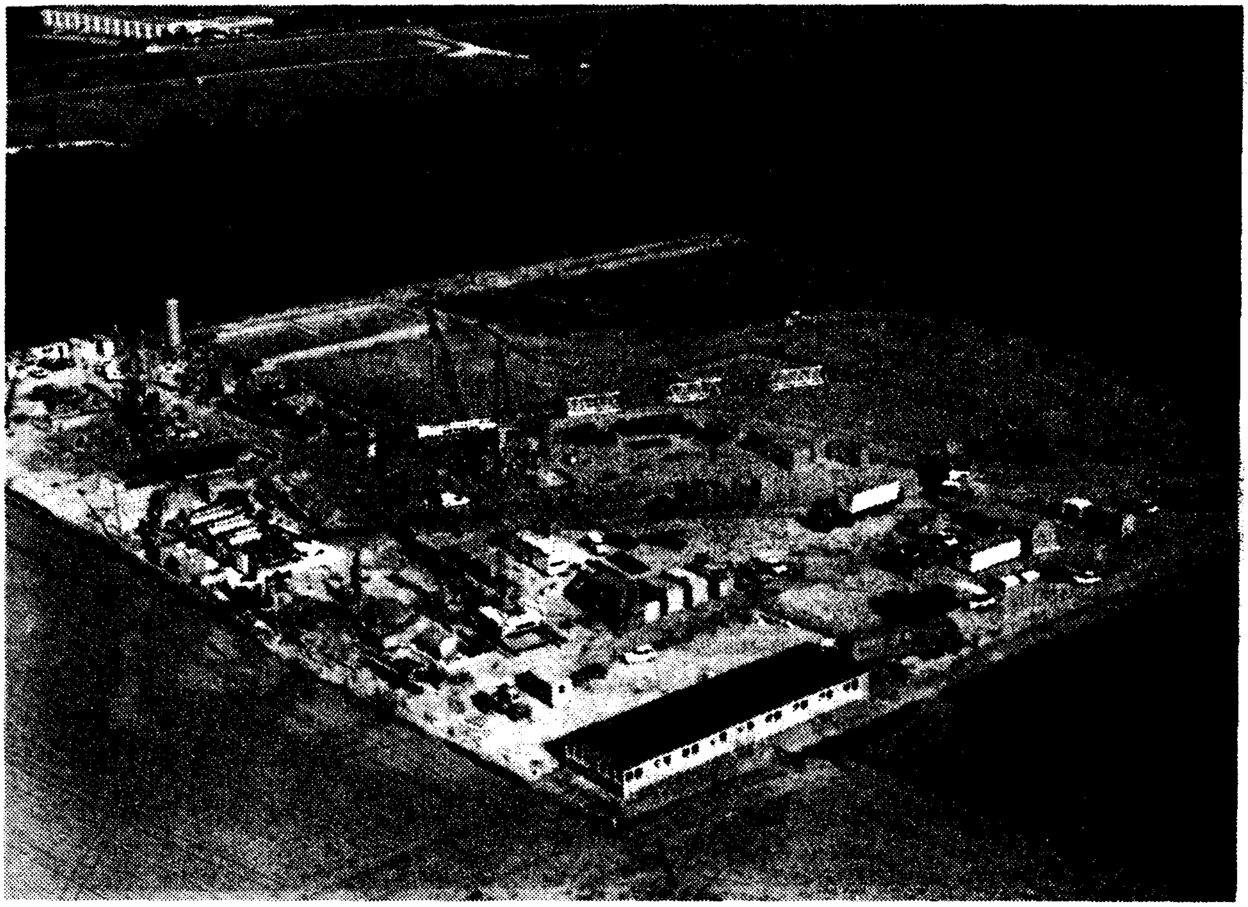
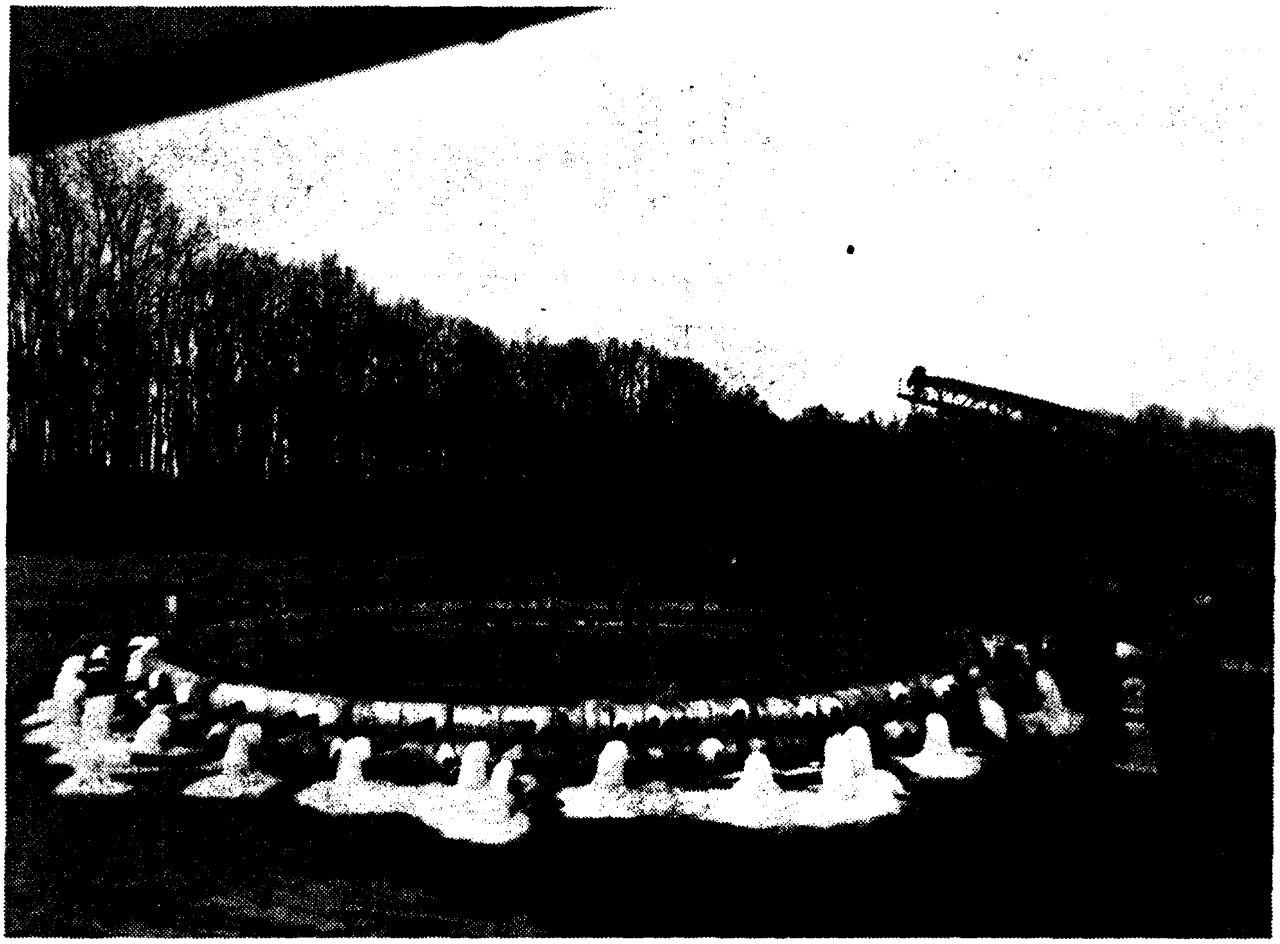


Fig. 13 Photograph of pit 8 taken in October 1983.



<u>Fig. 14</u> Photograph of the use of the "freezing of the ground" technique for the excavation of the shafts for LEP.

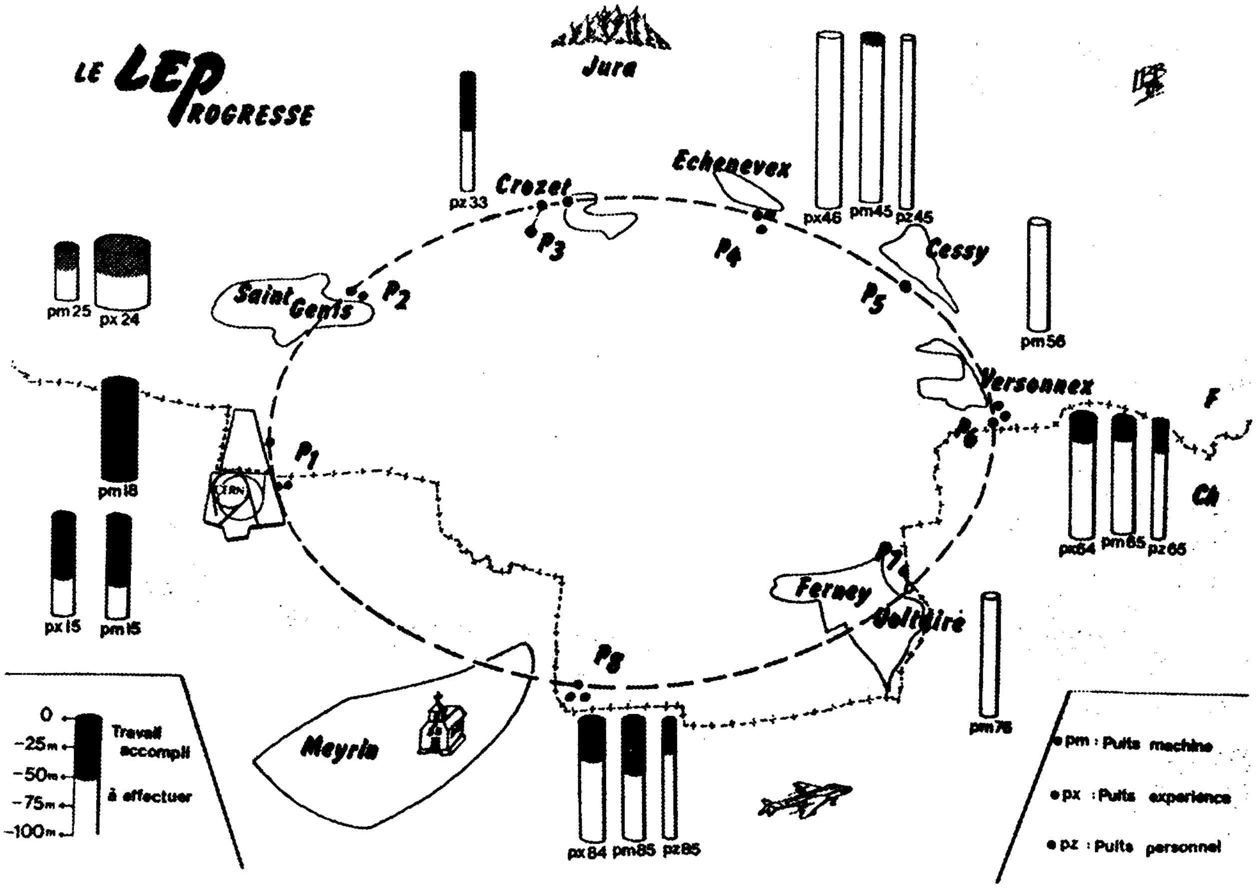


Fig. 15 Overall status of the civil engineering work for LEP as of May 1984.

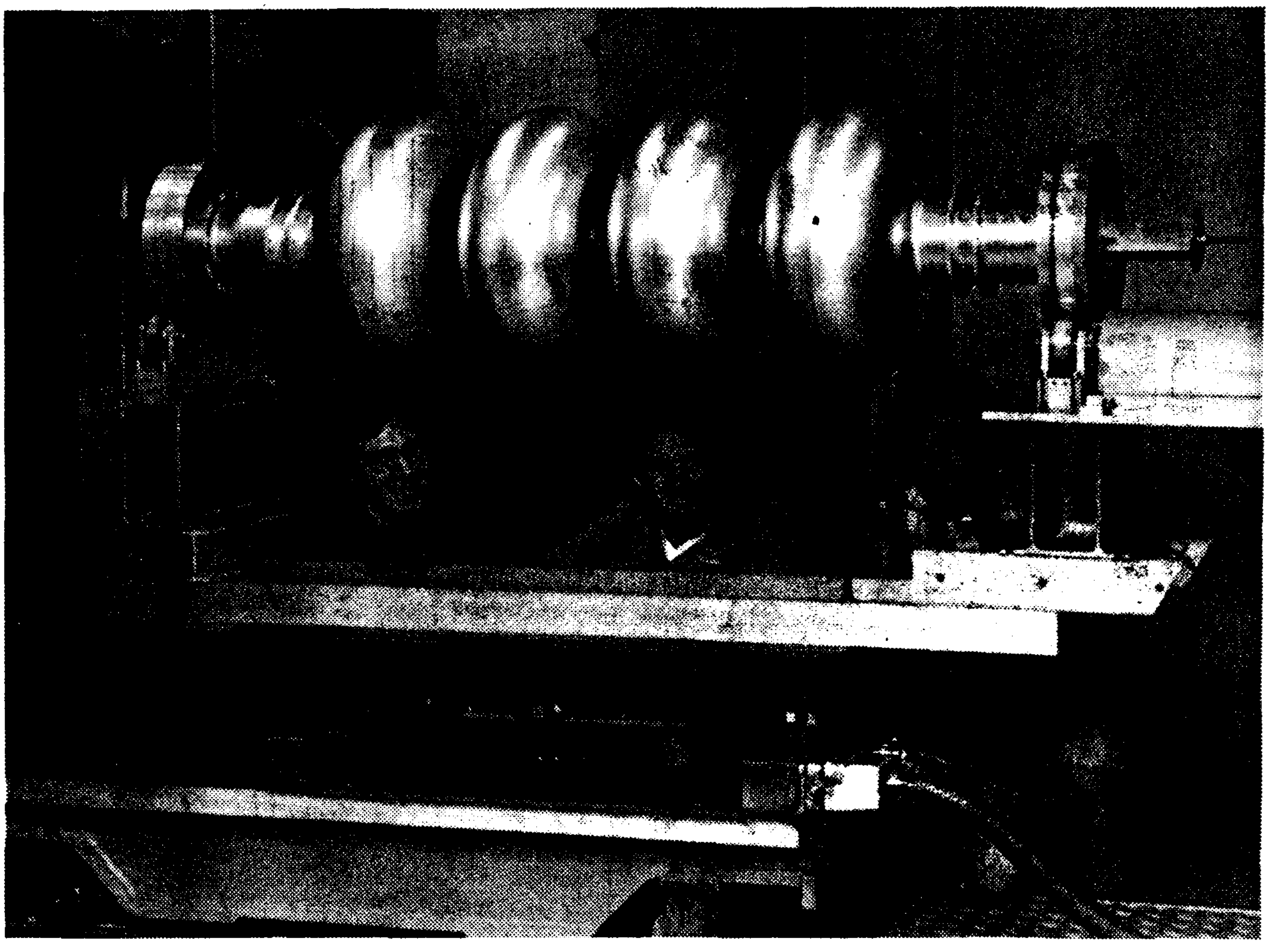


Fig. 16 A four cell 500 MHz superconducting RF cavity made of Niobium. built at CERN.

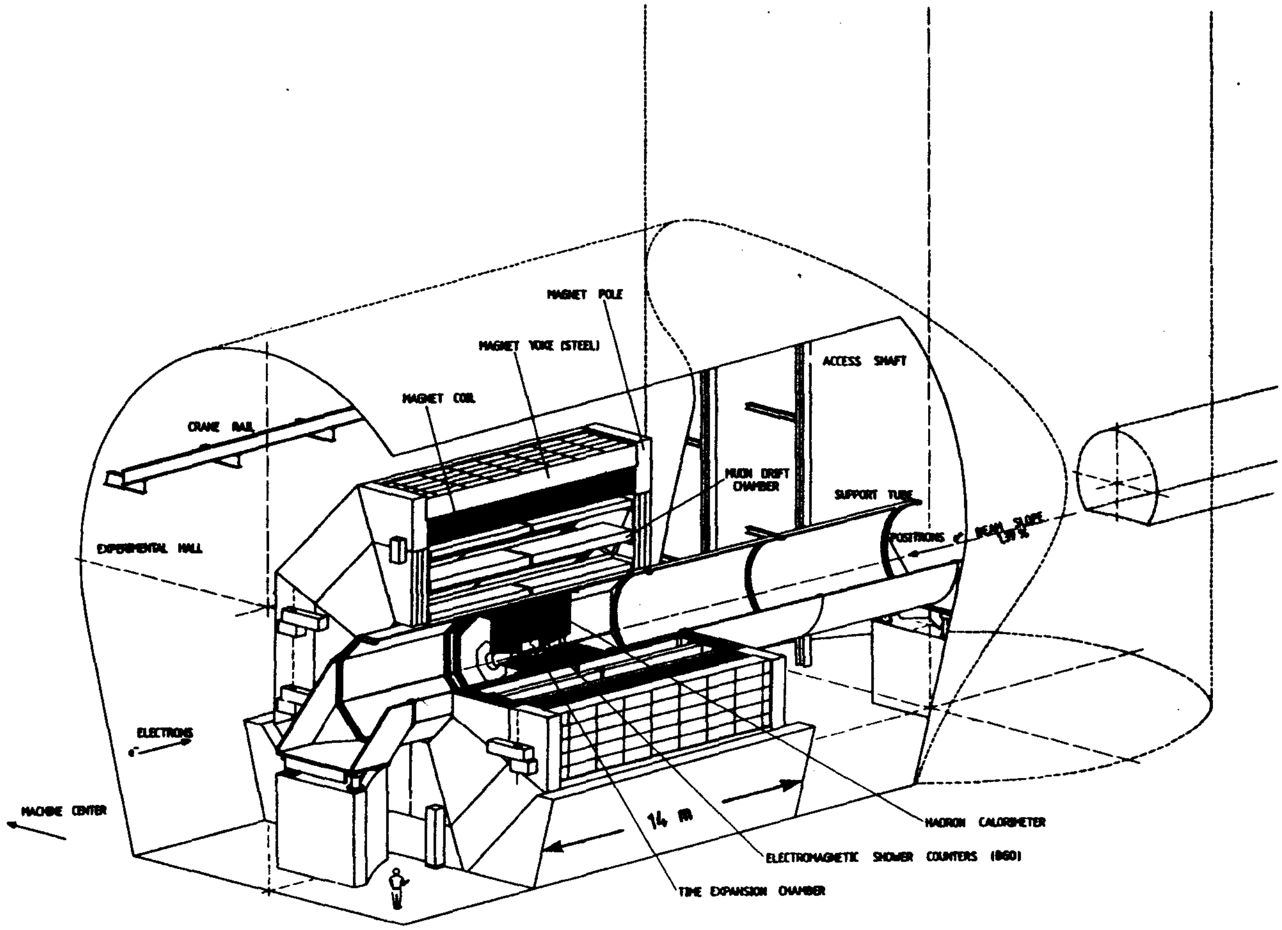


Fig. 17 Diagram of the L3 detector facility.