STATUS OF LEP AND ITS EXPERIMENTAL PROGRAMME

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Abstract and Introduction

LEP is an electron-positron collider designed for 2x100 GeV. For an initial phase the RF power will be sufficient to produce collisions at 2 x 50 GeV at a luminosity of about 1.6 x 10^{31} cm^{-2} s^{-1}. The circumference of the ring is 26.7 km and will be installed 80 - 125 m underground. Electrons and positrons will first be accelerated in a linear accelerator LIL and accumulated in a new storage ring EPA. Subsequently, the existing machines, the PS and the SPS, will be used as pre-accelerators.

The LEP project was approved unanimously by the CERN Member States in December 1981 on the condition of a constant budget and constant staff during the construction period. The investment cost of LEP is 910 million SF (1981 prices). The series production of most components is under way and intensive acceptance tests are going on. A flexible planning has been introduced to cope with some minor difficulties in civil engineering. About three quarters of the total investment have been adjudicated, and so far the project is within the foreseen budget and time schedule. Completion of the initial construction phase is foreseen for the end of 1988.

Four experiments have been approved, which will be installed in 4 of the 8 available interaction regions. More than 1000 physicists are very actively engaged in the development and construction of these detectors. The progress of the detector construction is monitored by an Experiments Committee and by Finance Committees. The preparations of these experiments advance very impressively and within the foreseen schedule.

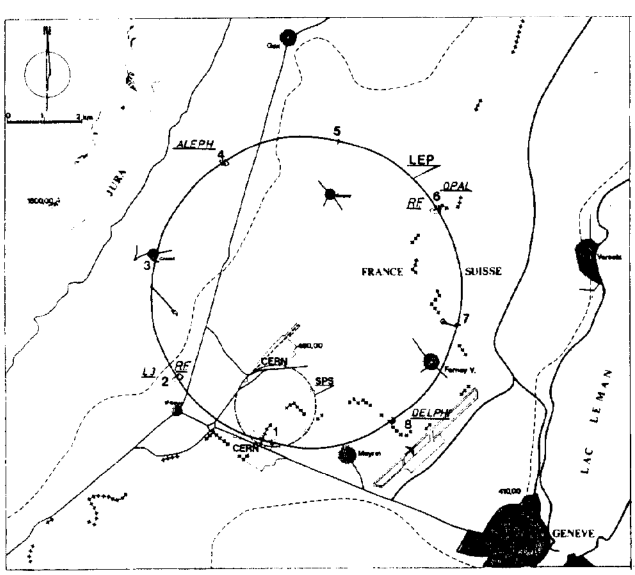

Fig. 1 Plan of LEP indicating the position of the RF stations and the four experiments

Injector system.

The existing machines, the PS and the SPS, will be used in the injection system (Fig. 2). The injection chain will start, however, with two linear accelerators: a high current accelerator to produce the positrons and a 600 MeV linac to accelerate both electrons and positrons. These two linacs are built in collaboration with LAL at Orsay. They are followed by a new storage ring EPA in which high density bunches will be formed. Because of space limitations, the injection into EPA has to be performed from the inside of the ring. Electrons and positrons are then further accelerated in the PS to 3.5 GeV and, after transfer to the SPS, to 20 GeV before finally being injected into LEP. A number of modifications have to be made to the PS and SPS in order to allow acceleration of electrons in these machines. A new RF system, consisting of 32 single cell standing wave cavities will be added to the SPS. The vacuum system and the shielding has to be improved for these machines in order to cope with the synchrotron radiation.

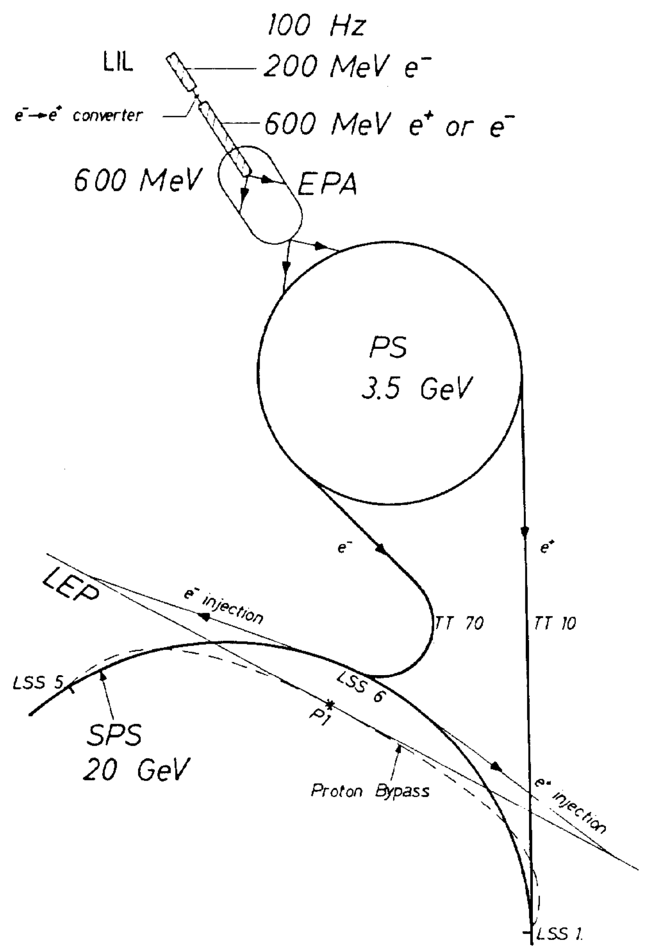

Fig. 2 The injection system using existing machines (PS, SPS) and transfer tunnels

The buildings for LIL and EPA are ready and the installation of the linac is far advanced (Fig. 3). Not only is a large fraction of the accelerating structure already in place, but most of the modulators

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and other modular subsystems have been installed. A new type of high power klystron is being manufactured. Commissioning of the linacs is planned for the end of 1985 and of the EPA in spring 1986.

The design and construction of ejection, injection and transfer elements is well advanced. About 90 % of the 100 magnets needed for the transfer lines are recuperated from the ISR.

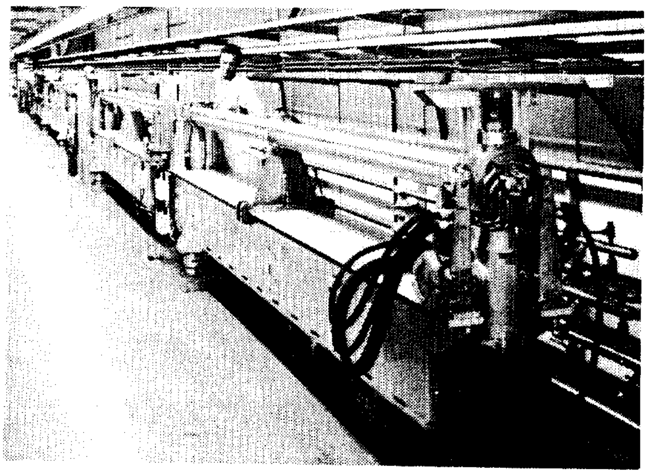

Fig. 3 The injector linac LIL

Main LEP Ring

As far as the main components for the ring itself are concerned, a new phase has been entered. Most of the components are in series production and elements start to arrive in large quantities at the CERN site. Tests are becoming a major activity. In order to avoid delays during the installation in the LEP tunnel, it has been decided to set up full size sub-units of the machine lattice and of the accelerator system to be able to conduct detailed tests.

Magnets. The magnetic field of the dipoles, even at the design energy of 100 GeV, is only about 0.1 T. So-called "concrete magnets" have therefore been developed which allow an essential saving. The magnets consist of spaced iron laminations where the spacing is filled with fine grained sand and mortar which gives the magnets the necessary mechanical stability but reduces the amount of iron needed. 3328 dipoles, each about 5.67 m long, are required to fill about three quarters of the machine circumference.

The development of these new types of magnets required extensive development work, during which the magnetic and mechanical properties were investigated as a function of different compositions of the mortar.

The series production of the dipole cores is under way at two manufacturing firms and about 200 cores have been delivered to CERN (Fig. 4). Since the dipoles will be equipped with simple aluminium excitation bars instead of individual coils, special measuring devices have been developed in order to verify the magnetic geometry of the cores and they are now in regular use.

Prototypes for the lattice quadrupoles and the correcting sextupoles have been received and tested. Contracts for these and almost all other major components of the magnet system (bus bars, watercooled cables, supporting jacks, superconducting quadrupoles for the low β insertions etc.) have been adjudicated.

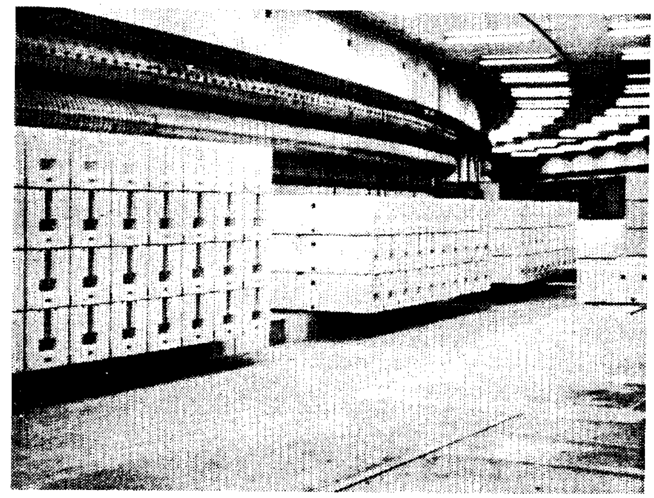

Fig. 4 A part of the 200 dipole cores delivered to CERN (stored in the former ISR tunnel)

Accelerating System. To reach an energy of about 50 GeV per beam, 128 copper cavities are foreseen. In order to save power during the long intervals between bunches, a low loss storage cavity has been added to each accelerating cavity. These cavities will be driven by 16 newly developed klystrons, each delivering one MW average power.

One complete RF unit consisting of 16 cavities driven by two klystrons with the necessary wave guides, low power drive and control systems has been set up in a mock-up LEP gallery (Fig. 5) where they are now being extensively tested.

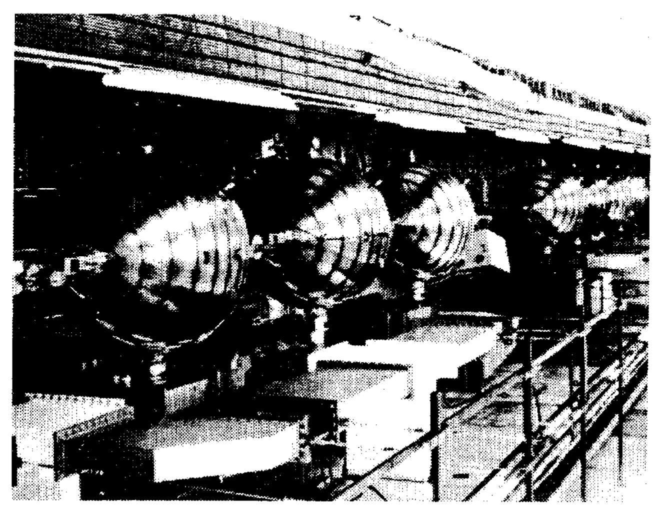

Fig. 5 Accelerating sub-unit consisting of 16 cavities (8 visible) fed by two 1 MW klystrons

The Vacuum System. The essential part of the vacuum system is a newly developed non-evaporation getter pump which will be installed in a side chamber adjacent to the beam chamber of the vacuum tube. About three kilometers of this getter strip have been received, and tests have shown that the performance is better than required in the specifications.

In order to gain experience with a complete vacuum system, a full length half cell of the standard LEP lattice (40 m long) has been set up where many problems, like the fixation of the vacuum chambers in the magnet yokes, thermal insulation during bake-out, interconnection of the chambers etc., are being studied.

Other Components. Many other components are in various stages of advancement. The majority of the contracts which still have to be adjudicated concern beam instrumentation, power supplies, ventilation and cooling, and electrical distribution.

One major problem will be the transportation in the tunnel where access shafts are 3.5 km apart. In total about 60 000 tons of material have to be installed in the tunnel. The main transport system will be electric trains, suspended from a monorail on the ceiling of the tunnel. A test circuit has been installed at the surface which has already provided valuable information.

Civil Engineering

The excavation of the access shafts and the underground caverns turned out to be more difficult than expected due to bad rock quality and several water levels which had to be traversed. By now, most of the access shafts and underground caverns are finished. On the other hand, the excavation of the tunnel itself turned out to be less problematic than expected. Under the foot-hills of the Jura more than 1300 m have been excavated in difficult limestone which corresponds to about 40 % of the total length to be tunnelled in difficult rock. No major incidents happened so far. The tunnelling in the favourable molasse rock of the plain will be performed by three full face tunnelling machines. One of these machines with its very complicated auxiliary equipment behind it has been installed in March and was run-in much faster than expected. After a few weeks it has already achieved the design speed of about 36 m per day. Two more tunnelling machines will come into operation during the coming months. A flexible planning has been introduced in order to be able to cope with some minor difficulties and delays. It is expected that the original schedule can be kept which foresaw that the underground civil engineering will be completed by summer 1987.

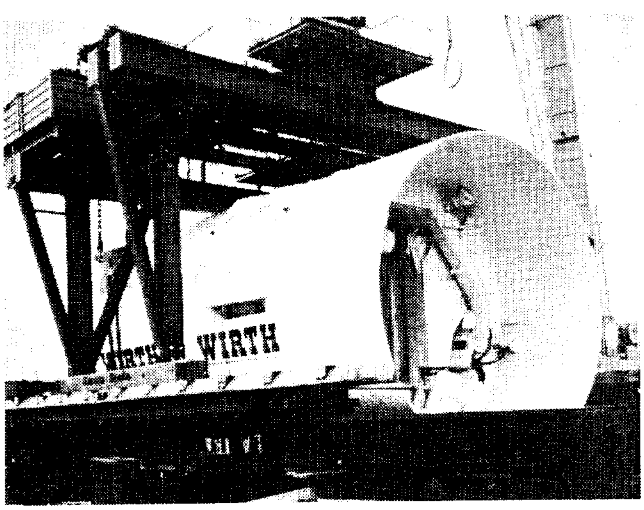

Fig. 6 Head of the full face tunnelling machine before installation

Upgrading of LEP

It is foreseen to use superconducting cavities to raise the LEP energy from the initial phase of 50 GeV per beam to about 100 GeV per beam. This can be done in different steps which will be determined by the physics needs and by the financial resources available. In the initial phase eight half cells of the machine lattice in the straight sections 2 and 6 will be filled with copper cavities. In each of these two straight sections four half-cells are free and could be used for superconducting cavities, and two more half-cells are reserved for a third harmonic system. No accelerating cavities will be installed in the initial phase in the straight sections 4 and 8 which will be used at a later stage. Some civil engineering will be necessary for this purpose in order to provide klystron galleries.

Progress in the development of superconducting cavities has been very encouraging in recent years. Accelerating gradients of more than 10 MV/m had been achieved in single cells at CERN and in other laboratories, and one might hope that gradients of about 7 MV/m could be obtained in a realistic accelerating system in several years from now. With this assumption the steps shown in Table 1 could be envisaged. The simplest step would be to fill the empty half cells in straight sections 2 and 6 with superconducting cavities. This would lead to beam energies of 74 GeV. By filling two complete straight sections with superconducting cavities, one could go beyond the threshold for W pair production and achieve energies of about 87 GeV. This could be obtained by either replacing the copper cavities in sections 2 and 6 or by installing superconducting cavities in the straight sections 4 and 8. If four intersections would be installed completely with superconducting cavities, beam energies somewhat above 100 GeV could be obtained.

It has been decided to use the same frequency of 352 MHz for the superconducting cavities as for the copper cavities. In this way not only the klystrons, but the wave guides and other equipment can be used for both systems.

Physics Requests

A workshop on LEP physics was organized in March 1985. There it was confirmed that a very rich research programme will be opened up both by the initial phase of LEP and at higher energies. It is not the purpose of this report to go into the physics questions, but a few requests from the physicists concerning machine performance will be mentioned.

A unique feature of the LEP machine will be its high energy resolution of about 3.10^{-4}. This will allow a precision determination of the mass of the Z^0 with an error of about 30 MeV. If it were possible to measure the dipolarisation resonances, the energy resolution could be improved to about 10^{-5} giving a mass resolution of the order of 1 MeV. In order to measure the width of the Z-particle with high accuracy, it will be necessary to maintain a relative stability of the magnetic field of the ring with a tolerance of about 2×10^{-4}, yielding an error of the width of about 10 MeV. In order to study the physics of the toponium state which will not be too far from the Z^0, it is essential to produce the highest possible energy resolution even at the expense of a loss of luminosity by an order of magnitude. This is a challenge for the imagination of accelerator people. The advantage of having longitudinal polarisations in order to measure asymmetries was again stressed.

LEP Experiments

Four large detecting facilities have been approved, which involve the collaboration of more than 1000 physicists of whom about one quarter come from non-Member States of CERN. ALEPH and OPAL can be

Table 1. Possible stages of upgrading LEP with superconducting cavities (7MV/m)

Straight Section	Number of cavities	Total length m	Number of Klystrons **)	Energy per beam GeV
Cu 2+6*)	128	272	16	56.5
Fill up 2+6 with s.c. cavities	64	109	+ 4	74
SC in 4+8 (or 2+6)	192	326	12	87
SC in 2+6 and 4+8	384	657	24	104

*) Initial phase using Cu cavities
**) Each klystron gives 1 MW average power

considered as two universal detectors, but using different techniques. ALEPH will have a large time projection chamber (TPC), a lead calorimeter for gamma rays and a superconducting magnet coil, whereas OPAL will use a "Jet chamber", a lead glass gamma calorimeter and a warm coil. DELPHI is specialized for hadron identification by using the newly developed ring imaging Cherenkov counters (RICH). The detector L3 is specialized in calorimetry by using a very powerful electromagnetic calorimeter of bismuth-germanium-crystals and a fine-grain hadron calorimeter. This experiment will also be able to measure muon momenta very precisely. The progress in the preparation of these experiments is very impressive. It is closely monitored by the LEP Experiments Committee which has defined various technical milestones which experiments have to pass in order to get approval for the mass production of the elements. Practically all of these milestones have been passed.

The total cost of these experiments will be about 320 M Swiss Francs. Only 60 millions will be contributed by CERN, whereas the rest will be provided by the collaborating groups, mostly in kind. Such a financing structure requires new ways of organizing and controlling the collaborations. A Finance Committee consisting of representatives of the various funding agencies has been set up for each experiment.

Since the time for the installation of the experiments will be very short, as many components as possible of the experiments are tested on the surface and the installation of complete modules is foreseen wherever possible. In that way it is hoped that all four experiments will be installed in time for the first beam.