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THE LEP PROJECT - STATUS AND PLANS

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Introduction

Reports on the LEP Project have been presented at all accelerator conferences in recent years. The reports to the 1979 Conference in San Francisco[1] and to the 1980 International Conference at CERN[2] were based on the design published in the well-known "Pink Book"[3], whereas in 1981 in Washington[4] the first important modifications were reported. The outstanding event in the meantime was the approval by the CERN Council at the end of 1981 of the Project, albeit in a reduced version known as Phase 1[4]. As the project has thus entered the stage of realization, we are now in the position to describe its final design[5]. In this paper, aspects of the design will be presented, with particular reference to the departures from the earlier publications. The status of the current transactions as well as the construction programme will be commented.

It was only after the Council vote and the final siting of the tunnel that the necessary administrative procedures in the Host States (France and Switzerland) could be initiated in order to obtain the construction permits which, we are confident, will lead to tunnel construction starting by mid-1983. In parallel, tenders were launched for civil engineering and some of the main components which in several cases have already resulted in firm contracts.

In the recent years, the design goals and the volume of civil engineering work were adjusted so as to fit the available budget envelope. The general layout was modified so as to ascertain as far as possible feasibility within the planned time span, the machine infrastructure systems, i.e. transport, cooling, ventilation, power distribution, were redesigned, and the design of machine components was advanced. Also during this time we became aware of the consequences of one major departure from the established ways: The CERN Laboratory is being extended beyond its fenced limits, into residential areas. Although the tunnel is dug deep underground, inhabitants and authorities rightly want answers to many questions. Shafts and surface buildings are needed in a number of places and there necessarily the problem of integration in the local environment is raised.

In order to reduce the initial expenditure to the minimum compatible with the definition of Phase 1, a modular approach will be used where possible, later extension being possible by adding modules. Furthermore, equipment from the ISR which will be closed early in 1984, will be re-used where possible. Many dipole and quadrupole magnets, vacuum equipment, parts of the cooling plant, the main power supply, and other components, have already been earmarked.

General Description

Layout

Early in 1981, it was decided to reduce the circumference of LEP from 30.6 to 26.6 km and to increase the betatron phase advance of the machine at high energy from 60° to 90° per lattice period. While the asymptotic beam energy was only reduced by about 4%, substantially less than the resulting cost saving, the main advantage of this shrinkage of the ring size was to move the tunnel out from under the Jura mountains. A second displacement taking the tunnel still further away from below the nearly 1000 m overburden of the Jura crest was decided in fall 1981. After a campaign of test borings along the final machine circumference, the depth of the machine was determined so that it would be located in the molasse or Jura rock everywhere, while keeping the total shaft length to a minimum. As a result, the machine is now lying in a plane which is inclined by 1.5% with respect to the horizontal.

After these changes, nearly 90% of the machine tunnel will be in the molasse rock, whose favorable properties for tunnelling operations are well known to us from the construction of the SPS. The remaining 3 km of tunnel in Jurassic rock are located such that the overburden is no more than 160 m. In Jura rock the danger is always present of encountering caverns or faults which can carry large amounts of water. Under a low overburden, the water pressure is naturally limited, and borings for the purposes of exploration or of curing bad ground are possible at moderate cost.

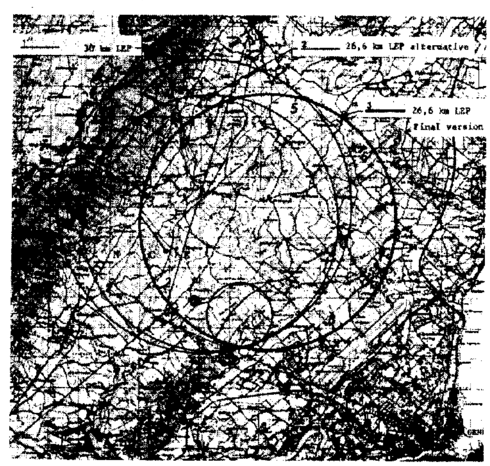

Fig. 1 : Previous and final positions of LEP

Main Parameters

The new set of main parameters is given in Table 1.

Many of the chosen parameters were commented earlier[4]. In the context of considering the impact of LEP on the environment, it was decided to ask at present for the construction permission for a machine with a maximum power consumption of 150 MW. The maximum beam energy that can be achieved within this limit is about 100 GeV if superconducting cavities with an average gradient approaching 5 MW/m are installed along the full length available near 4 crossing points.

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Table 1, Parameters of LEP (Version 12)

Circumference	26.659	km
Number of crossing points	8	
Number of bunches	4	
Length of lattice cell	79	m
Beam-beam tune shift	0.03	
Vertical ß value at crossing	0.07	

	Phase 1	Final	
Peak beam energy (top luminosity)	51.5	95	GeV
Peak beam energy (zero luminosity)	60	100	GeV
Power consumption	70	150	MW
Acc. gradient	1.47	5	MV/m
Beam current (per beam)	3	5	mA
Max. luminosity	10^{31}	2×10^{31}	$cm^{-2}s^{-1}$
Horiz. betatron wave no.	58.35±2	90.35±2	
Vert. betatron wave no.	66.2 ±2	94.2 ±2	
Number of exp. areas	4	6	

Lattice

The design of the regular arc lattice cell has not been changed significantly since the San Francisco Conference, but the number of cells was reduced in accordance with the reduction of the machine circumference. The phase advance per cell will be maintained at 60° in Phase 1, and be changed to 90° when the peak energy will be approached.

The ratio of the horizontal and vertical beta values in the experimental intersections was modified[6] (table 2) so as to minimize the aperture of the low beta quadrupoles, reducing at the same time the beta value in the RF insertions. As a consequence of that, a new dispersion suppressor insertion had to be designed.

Extensive simulation calculations[7] showed that electrostatic beam separators are necessary during accummulation and ramping to avoid blow-up, as well as at the flat top. The luminosity can be raised significantly in the initial LEP configuration with 4 experimental areas and 4 bunches if the beams in the other crossing points are separated[8]. A vertical separation by 2σ is specified as the design criterion, which leads to required field strengths of about 20 kV/cm.

Injection System

The new injection system, using the existing 25 GeV and 400 GeV proton synchrotrons suitably turned into $e^{\pm}$ synchrotrons for the purpose, was described earlier[4] and is the subject of a companion paper to this conference[9]. Much more than by straight-forward budget considerations, this move was motivated by the possibility to avoid the building of yet another machine and in particular the setting up of a group of experts to run it and to maintain it in running condition.

Experimental Areas

The parameters of the interaction regions are given in Table 2.

It was one of the recommendations of the Villars General Meeting on LEP, to suppress the "push-pull" option for the experimental areas. Consequently, the caverns are now located at the outside periphery of the machine tunnel (Fig. 2), with substantial concomittant reductions of volume and cost for the excavations on the "machine" side.

Table 2, Interaction region parameters, Phase 1

Overall insertion length	± 77.819	m
Free space between quadrupoles	± 3.5	m
Crossing angle	0	degree
Horiz. ß function at I.P.	1.75	m
Vert. ß function at I.P.	0.07	m
Dispersion	0	m
Horiz. rms beam radius at I.P. (design coupling)	310	μm
Vert. rms beam radius at I.P. (design coupling)	12.6	μm
Assumed beam-beam tune shift	0.03	
Luminosity at 51.5 GeV	10^{31}	$cm^{-2}s^{-1}$
Assumed current per beam	3	mA
Assumed particles per bunch	4.17×10^{11}	

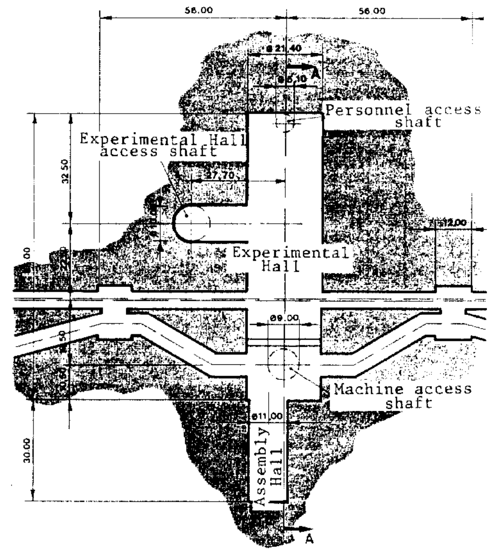

Fig. 2 : Layout of a typical interaction region

Due to the shift of the machine away from the Jura, all four experimental areas planned in Phase 1 will have direct accesses by vertical shafts from the surface. This is essential in view of the size of the experiments now envisaged. Each "standard" cavern will have one personnel access shaft and one drop-through shaft for experimental equipment, which has been located at the side of the cavern mainly for safety considerations. Three of these standard experimental areas will be built in points 4, 6 and 8. The experimental area in point 2 will have its axis parallel to the beam axis and be fitted as a "magnetic cave" as required by one of the experiments selected[10].

Contrary to previous expectations, the molasse lies too deep to permit the creation of experimental areas near the surface.

The Proton Bypass[11]

The precise circumference and the position of LEP in relation to the SPS were chosen in such a way that a bypass bringing the SPS proton beam into collision with the LEP beam can be built at a later date. In the final geometry the bypass extends over two sextants of the SPS and the necessary vertical deflection is about 40 m. By a careful adjustment of the relative position of the two machines, it was possible to design a by-pass for up to 300 GeV (the peak energy at which the SPS might run in storage mode) with normal iron magnets.

Machine Components and Systems

Magnet and RF Systems

Details of these systems which are still fully valid have been given at the previous conferences. Nevertheless, great progress has been made in the past years in the preparation of series production. Fig. 3 shows a full scale prototype dipole[12] of which 14 have been made to date, partly in-house and partly by industry. The requirements for the other regular magnets have been specified (Table 3) and prototypes tested. For the quadrupoles and sextupoles, a technique for making the coils out of anodized aluminium strip[13] has been developed.

In Fig. 4 the prototype acceleration[14] and storage cavity assembly which has been run at full power, is shown. Prototypes of 1 MW klystrons have been received from two potential manufacturers and been tested at full power. Preparations are now being made for setting up a string of 16 cavities with their power sources and the necessary waveguide and power splitter systems.

Table 3

	Max. B (T)	Para. Values dB/dx (T/m)	d^2B/dx^2 (T/m²)	Gap dimension (mm)	Length (mm)	Steel mass (kg)	Cond. mass (kg)	Number required
Normal quads		9.7		125	1.55	2500	275	504
Insertion quads		11		122	1.85	2500	320	256
F sextupoles			180	150	0.37	420	75	264
D sextupoles			256	150	0.73	500	123	256
Corr. magnets V	0.04			200	0.4	65	43	176
H	0.06			102	0.4	88	33	168
(insert.) V	0.06			200	0.4	65	50	80
(insert.) H	0.08			102	0.4	88	33	64

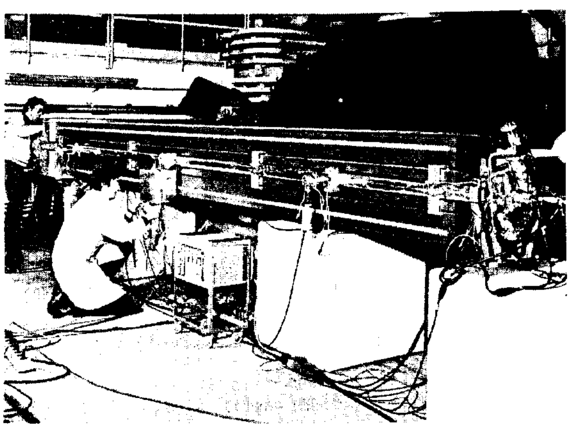

Fig. 3 : Dipole prototype with vacuum chamber

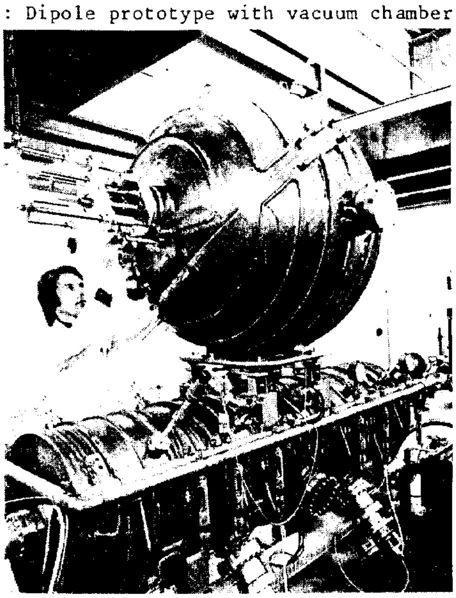

Fig. 4 : Prototype assembly of accelerating and storage cavity

Vacuum System

Further development work has led to major changes to the vacuum system. First, the concept of a distributed ion pump system has been abandoned in favour of a non-evaporable getter (NEG) pump[15] because of the inherent simplicity of the latter and due to the difficulty to ignite the ion pump in the low magnetic field present at injection. A constantan strip covered with getter material is suspended in the volume initially provided for the ion pump which is activated and reconditioned by passing a large current through the strip. Full-scale NEG pumps have in fact been tested in PETRA and DCI and have given excellent results, which lead to the prediction of a life-time in LEP of ten years or more.

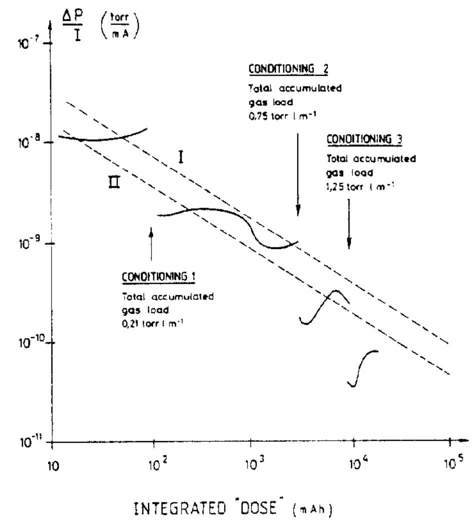

Fig. 5 : A typical pump-down curve

Secondly, a reliable technique for providing the necessary lead shielding[16] around the Al vacuum chamber (Fig. 6) has been developed. It consists in tin-soldering of pre-cast lead shells onto the chamber, the fusion temperature being achieved by passing hot liquid through the cooling channels.

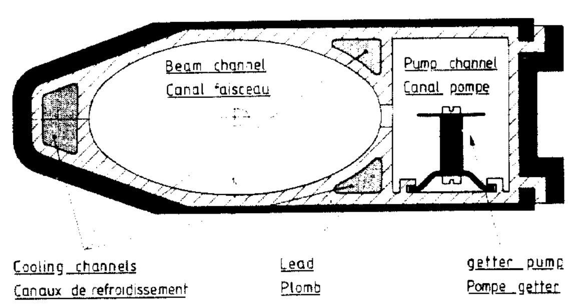

Fig. 6 : Cross-section of the dipole vacuum chamber

Thirdly, the glow-discharge cleaning of the vacuum chamber envisaged earlier has been abandoned. As in other machines, a combination will be used of chemical pre-cleaning and bake-out at 150°, relying for final cleaning on the beam synchrotron radiation.

Orbit Observation System

Fig. 7 shows the cross-section of the pick-ups for beam position measurement, of which nearly 800, 2 per lattice cell, will be installed. The buttons are placed at 45° in order to avoid the synchrotron radiation in the median plane. The body will be welded into the vacuum chamber and should be manufactured to high precision so that one can rely on mechanical positioning of the buttons without electrical calibration.

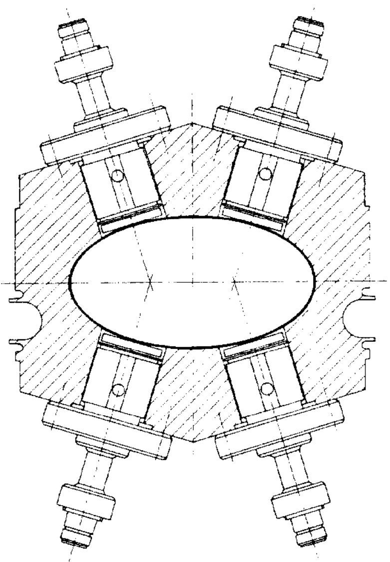

Fig. 7 : Cross-section of the pick-ups

Controls[17]

The guidelines concerning this system have been announced recently. It will be an updated extension of the SPS controls system, both machines being operated from the enlarged SPS Control Room. The access control system for the remote sites, buildings and tunnels will be part of a new integrated access control system for the whole of CERN.

Cooling[18]

The cooling system will be arranged by octants, the refrigeration stations being located in the service areas at points 2, 4, 6 and 8. For the raw water supply, water will be taken which has already been used to cool the SPS. It will be distributed through the machine tunnel to the service areas. Fig. 8 should show some of the complications of a machine built deep underground and on a slope.

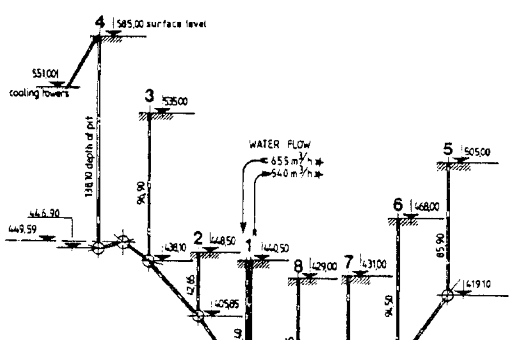

Fig. 8 : Raw water supply circuit

Ventilation[18]

The octants of the machine tunnel will each be ventilated longitudinally, which is the only way possible without excessive cost. Air will be injected at even-numbered and extracted at odd-numbered points. At the even-numbered points will be situated the experimental caverns and most of the machine systems; hence, three separate ventilation circuits will be provided. Safety regulations call for a fourth independent circuit pressurizing the personnel lifts and stairwells (Fig. 9).

Questions of general safety and fire hazard are being actively pursued. As a first step, the amount of combustible material installed in the machine will be carefully scrutinized and fire retarding chlorine free cables will be installed where possible, since industry has responded very positively to CERN's request for the production of such cables for power and low-level purposes. For the experimental areas, strict limits have been announced for the amount of flammable gas allowed in any of the experiments.

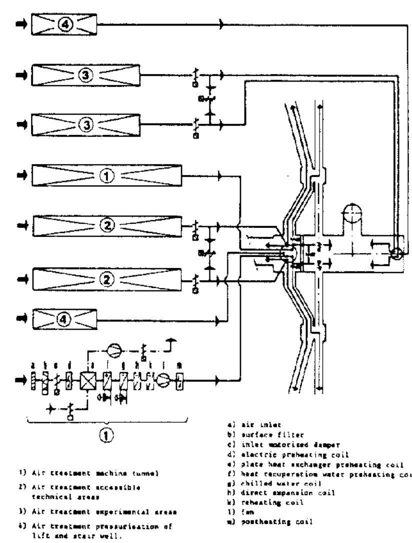

Fig. 9 : Air treatment underground areas points 2, 4, 6, 8

Power Network[21] and Power Converters

LEP will be powered from the French network. As the feeder line for the SPS has a large reserve capacity, LEP will be fed from the SPS power station, which will be extended by an additional 400/66 kV transformer. There will be an 18 keV loop fed from one of the SPS transformers running along the ring tunnel and special 38 MW feeders at 66 kV in surface trenches to points 2 and 6 where RF and experiments with conventional coils are installed. The power converters[19] for the major consumers will be of conventional design, but for those in the range below 100 kVA use of the novel "switch mode" technique is being investigated.

Transportation system

An efficient transport system is essential for smooth installation of a project of the size of LEP. A monorail system suspended from the tunnel ceiling was chosen in view of the rather narrow passage left on the tunnel floor. Similar systems are being used in mines, so that standard equipment is available for many items. Special vehicles must, however, be developed for the transport of our machine components, viz. the 12 m long dipole units, the straight sections, vehicles for unrolling cables, etc.

Survey[20]

The topology of the LEP site is far from flat. The survey reference system of the machine is therefore based on a set of monuments set up on nearby hills, from which the relative positions of the octogonal points can be determined by trilateration. This network involves distances of up to 15 km. The precision of optical distance measurements over such distances is limited by the knowledge of the optical properties of the air. Therefore, a two-colour measuring instrument using the combination of a blue and a red laser beam in order to obtain a measurement independent of the refraction index of the air, has been acquired. It is expected to obtain a precision of a few times 10^{-7} in the distance measurement.

For checking the guidance of the tunnel boring machine, the gyro-theodolite used already for the SPS tunnel will again be employed.

Status

Authorization was granted by CERN Council at the end of 1981 to start the Project on 1 January, 1982. Among the first steps to be taken were those concerning the building permits to be obtained from the Host State authorities and for this purpose, in particular to satisfy French law, a study on the impact of the project on the environment had to be made, and discussed with local authorities. The 170-page study, backed up by several kilos of background material was submitted in final form in August, 1982. It was presented to the public for comments for two months in the autumn. At the time of writing, the final green light has been obtained from the Swiss authorities and the procedures within the French administration have reached a very advanced stage.

In parallel, the work on preparing tender documents for construction and the main components was speeded up. Many calls for tender were issued and contracts have been placed which amount to more than one third of the project budget which is 970 MSF in 1983 money.

Plans

The contract for the "Civil Engineering in the Plain" which covers 90% of the machine tunnel and all shafts but one, was signed at the end of February. It provides for starting the work by mid-1983 and for a duration of 48 months. As it constitutes the basis for the project planning, a series of 21 contractual dates has been defined which should provide a basis for smooth installation progress.

As far as tunnel installation is concerned, civil engineering will be far enough advanced to begin the installation of machine services, starting from point 1, after 32 months, i.e. in Spring 1986. About 8 months later, early in 1987, the first machine components will be introduced. Installation will proceed on two fronts, following the finishing of the tunnel octants. We expect that in month 66 the last of the installation teams will meet in point 4, machine installation then being completed.

As installation proceeds starting from point 1, tests of beam transfer, injection and of the beam passing octant by octant will be possible from month 52 (autumn 1987) onwards. This should be a good preparation for starting up LEP at the end of 1988.

Advancement of the surface service buildings is conditioned by the liberation of the required surfaces near the pits by the civil engineering firm. The first building in point 1 will be ready for installation work after 18 months and the other buildings will become available gradually. Installation of the last building is expected after 60 months.

Although LEP construction activities will be spread widely over the CERN site, the main activity of preparation of the machine components will be concentrated in the ISR tunnel building and an assembly building to be built near a shaft of 14 m diameter. Dipole units of 12 m in length with the vacuum chamber installed will be lowered down through this shaft suspended on the monorail transport carriage, as will be complete short straight sections on their cradles, thus reducing the installation work in the tunnel to the strict minimum.

We have, of course, ideas, though not yet defined plans, going beyond the 66 months mentioned above : we hope for the success of the on-going development of superconducting RF cavities, which will allow us to pass the threshold of W-pair production. There is still a long way to go from the present successful laboratory models to industrial series production, but we hope sincerely that these cavities will be available for the energy improvement of LEP at the beginning of the next decade.

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