THE LEP PROJECT

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Introduction

We foresee that LEP operation will begin in July or August 1989 and it is hoped that first results may be obtained by the second half of 1989, with operation at full energy for physics beginning in 1990.

Octant 1-2 of LEP is completely installed (Fig. 1) and in July of this year the first beam of positrons will be injected in order to test the functioning of the principal elements of the machine. The installation of octant 1-8 will be completed at the end of June 1988.

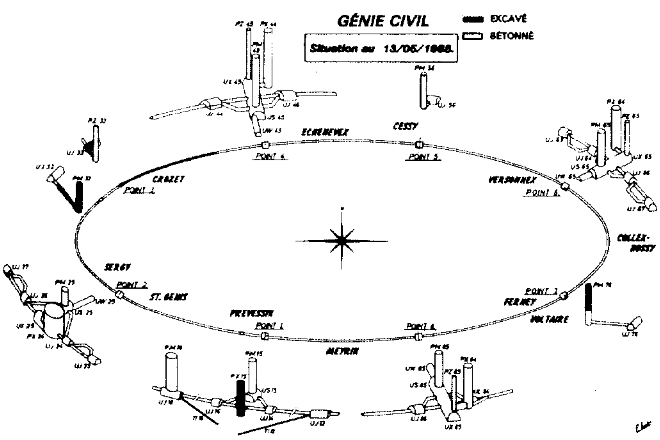

Fig. 1: Schematic View of the Present Status of the Underground Civil Engineering Work and the Location of the Different Points around the Machine

Excavation of the tunnel, of the experimental areas and the access points is completed as is the lining of the underground works, with however the exception of the part of the tunnel under the Jura where excavation is finished with only the lining remaining to be done.

The present state of installation of utilities (electricity, cooling, ventilation, access equipment, lifts, travelling cranes, emergency exits, etc.) and machine components, is advancing very well, closely following the installation schedule. The controls and the beam instrumentation systems of LEP are being mounted and tested. It is in fact foreseen that the installation of 7 out of 8 octants will be completed at the beginning of next year and the last octant (under the Jura) will require an accelerated installation programme in order to be ready in July 1989. The installation of the machine is under way simultaneously in at least three quarters of the ring.

Status of the Vacuum System

The installation of all vacuum equipment in octant 1-2 was carried out between 16 November, 1987 and 21 April, 1988 over a total length of 2.6 km. To give an idea of the status, the total number of joints is 2,229 and only 15 of them have leaked at installation, i.e. 0.6%. The joints damaged upon installation and repaired were 10 in number. Most of the vacuum sectors have been fully commissioned; this consists of bakeout of the vacuum chamber at 150°C for 24 hours (superheated water system), followed by activation of the getter (750°C for 45 minutes). Three leaks developed on one sector and obliged us to carry out these activities (bakeout and activation) once again. All sectors commissioned were in the low 10^{-11} Torr range after 24 h of pumping. Present vacuum readings range from 5.10^{-12} Torr to 1.10^{-11} Torr. Commissioning of the injection sector is scheduled for June.

Status of the RF System

The initial phase RF system consists of 128 accelerating cavities, each composed of 5 elementary cells. The cavities will be installed in areas 2 and 6, 32 cavities on either side of the interaction region. Each accelerating cavity is coupled to a spherical cavity, whose unloaded Q factor is higher than the Q factor of the accelerating cavity; the coupling of these two resonators reduces the electricity consumption by about 40%. All the cavities have been commissioned at CERN.

Installation of one side of point 2 is finished. The two RF units with 32 cavities and four klystrons are presently being commissioned. Both stations have been operated at their nominal power of 1 MW per klystron, giving a total accelerating voltage of 100 MV. Remote operation of both stations from the LEP Control Room has been demonstrated.

Status of the Magnet System

Practically all magnets and associated components have been delivered and measured, including the eight superconducting quadrupoles for the low-ß insertions.

In the steel-concrete cores of the main bending magnets it was found that the compressive stresses, which develop in the transverse plane of the laminations due to mortar shrinkage, impaired the magnetic properties of the steel and reduced the field strength by several parts in a thousand; in order to reduce this effect, each of the 3360 cores ordered has been subjected to a stress-relieving treatment in a hydraulic device, followed by a measurement of the excitation characteristics.

For all magnets, the results of magnetic measurements concerning both the systematic and random components are well within the tolerances imposed by beam optics requirements. For the large series of magnets, a further improvement is obtained by distributing the magnets in the ring according to their magnetic strengths.

In order to reduce the installation work in the tunnel, a pre-assembly of magnet units is performed at the surface; the steel-concrete cores are grouped in pairs equipped with their 13 m long vacuum chambers and excitation bars. Straight-section units are assembled, each with a quadrupole, a sextupole and an orbit corrector mounted on a common girder, with their vacuum chamber and beam pick-up electrodes. Out of a total of 1640 dipole pairs and 744 straight-section units, 280 and 250 units respectively have been assembled. Of these, 224 dipole pairs and 190 straight-section units have been installed in the tunnel.

In the first octant from the positron injection point to interaction point 2, all magnets have been electrically and hydraulically interconnected and are ready for the injection tests next July.

Status of the Injection System

The LEP injector chain consists of the LPI, the PS and the SPS. During one supercycle, lasting 14.4 s, the PS and the SPS will produce in sequence two e+ followed by two e- cycles (duration of each cycle 1.2 s). The production rate of LIL for e+ is about five times lower than for e- and EPA accumulates e+ during 10.8 s followed by an extraction of half of the accumulated intensity in two batches separated by 1.2 s. Two accumulation cycles of 1.2 s are used in EPA for the e-. The beams in LEP will be built up simultaneously with a rate of 0.25 mA min^{-1} per beam (Fig. 2).

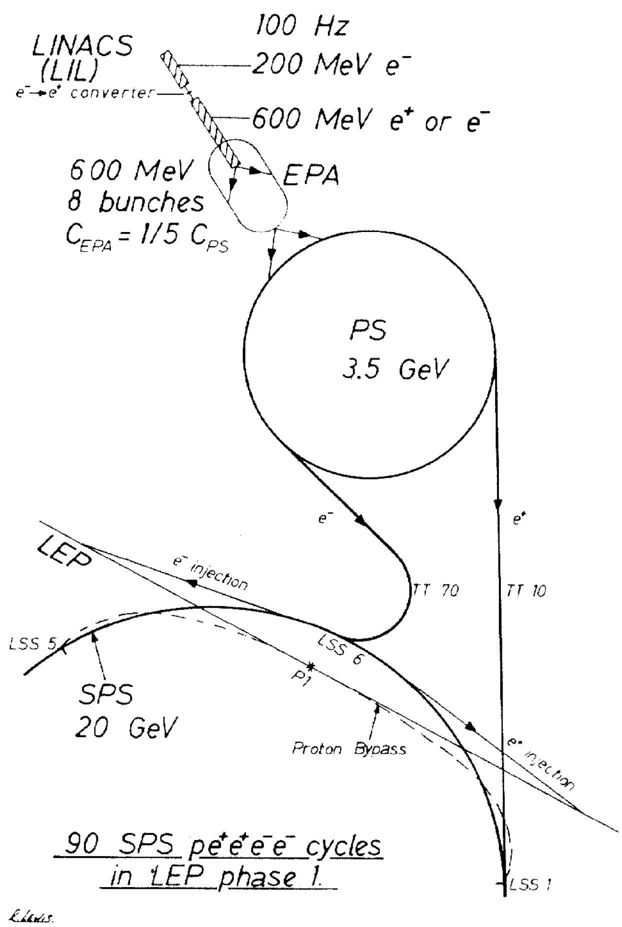

Fig. 2: View of the LEP Injection system

The poster presentation[2] giving a status report on the LEP Pre-Injector and the Proton-Synchrotron as an e+e- accelerator gives the following two tables.

	Operation	
Pulse current, gun	6	A
Pulse current, buncher	3.3	A
Pulse current, 200 MeV	2.6	A
Pulse length, 200 MeV	10 25	ns
Pulse shape, 200 MeV, rise	3	ns
Beam spot on converter	2 - 3	mm
Hor. ver. emitt./w. 200 MeV	not meas.	mm.mrad
Energy E	215	MeV
Energy spread E/E	10	%

Table 1 - LIL Performance

	Design	Obtained
Energy	600	500 MeV
Nb, the peak bunch intensity	$2.5.10^{10}$	7.10^{10}
The number of bunches	8	8
Accumulation rate, per bunch	$2.2.10^{3}s^{-1}$	5.10^{3}
Inject. plus acc. efficiency	30	max 65 %
Transfer efficiency to PS	80	90 %
Bunch length at r.f. 40 kV	25	30 cm
Hor. emittance/w	0.14	0.1 mm.mrad
Vert. emittance/w	0.03	0.04 mm.mrad

Table 2 - EPA Performance with Positrons

In order to prepare the SPS to inject leptons into LEP in the forthcoming years, lepton acceleration tests are made in parallel to the SPS physics programme. This is possible by operating the SPS in the so-called multicycling mode, where in a supercycle the cycle to accelerate protons is followed by three lepton cycles.

Each of the three lepton cycles is used in a different way. On the first cycle the acceleration system for leptons is being commissioned. This system using standing wave cavities will finally provide an accelerating voltage of 32 MV. So far 50% of the cavities have been brought into operation and with a voltage of about 16 MV the positrons have been accelerated up to 17.5 GeV.

On the second lepton cycle positrons are accelerated using the travelling wave cavities originally installed to accelerate protons. The beam is accelerated up to an energy of 14 GeV. On this cycle the extraction studies are well under way. The beam was successfully extracted and transported through the extraction channel into the first part of the beam transfer line to LEP. In this cycle the tune, the chromaticity and the closed orbit were carefully adjusted and a transmission of more than 90% was achieved between injection and extraction.

The third lepton cycle is used for acceleration of electrons. So far the electrons have been steered through the beam line between CPS and SPS and injected into the SPS. After injection the beam is observed at some monitors in the ring. The next objective is to establish a circulating beam.

For an extensive presentation of the SPS as an injector for LEP, see these proceedings "Commissioning of the SPS as LEP Injector", accepted for poster presentation at this conference[3].

Upgrading LEP

The scenarios of LEP upgrading, presented two years ago at the Aachen LEP 200 Workshop[4] are still considered valid but we have added a first intermediate step involving the installation of 32 superconducting cavities as soon as possible, probably coming into operation at the end of 1991. It is in fact foreseen to install 4 superconducting Nb cavities with their auxiliary equipment in LEP during the second half of 1989 after a short running-in period. With 4 cavities and a gradient of 5 $MV/_m$ a total acceleration voltage of 34 MV is obtained. This should allow storing and acceleration of LEP beams up to about 30 GeV using superconducting cavities only.

In the following, all LEP energies are calculated for an accelerating field of 5 or 7 $MV/_m$. High order mode (Hom) losses are sufficiently small to apply the simple extrapolation formula:

$$E = 12.63 \sqrt[4]{V_{rf}}\ , \quad E \lesssim 70 \text{ GeV, } 60^\circ \text{ lattice}$$

$$E = 13.23 \sqrt[4]{V_{rf}}\ , \quad E > 70 \text{ GeV, } 90^\circ \text{ lattice}$$

(E in GeV, V_{rf}: total (peak) RF voltage in MV).

An important question for LEP upgrading will be whether at high energies the concentration of the RF systems in two interaction regions only will be possible[5]. As this question may not be answerable through simulation methods alone, we present two scenarios, one providing acceleration in interaction regions 2 and 6 only, and one providing acceleration in regions 2, 4, 6 and 8.

The proposed first step of upgrading using 32 cavities and two 1-MW klystrons installed on either side of interaction region 2 could help to clarify this question. The 32 cavities alone will produce, at 5 or 7 $MV/_m$, a total accelerating voltage of 272 MV (381 MV) and one should be able to reach particle energies of 51 (56) GeV. Together with the Cu-cavities an energy of 64 (67) GeV can be reached. This is the limit where some machine components, as for instance the 24 concrete dipole cores in the injection regions and some quadrupoles (low ß quadrupoles), need not yet be upgraded.

Manufacture of the 32 superconducting cavities and their auxiliary equipment is scheduled to start in 1989. Cooling of the 16 cavities on one side of the interaction region will be by means of the existing (ISR) refrigerator, installed with the first 4 superconducting cavities.

Installation of an additional 32 cavities at interaction region 6 will bring the total number of superconducting cavities up to 64. It will require the addition of two 6 kW refrigerator cold boxes (with 2 KW compressors) and a total of 4 klystron systems. The system of Cu-cavities remains untouched and energies can be upgraded to 73 (77) GeV. A short shutdown will be sufficient for upgrading.

For the next step in upgrading, a decision should be taken on the final number of acceleration stations. If regions 2 and 6 only are used, Cu-cavities will need to be removed and a total of 192 superconducting cavities can be installed. Twelve klystron systems are needed and a rearrangement of klystrons, waveguide systems and beam elements will be necessary, involving a very long shutdown. Energies of 84 (91) GeV can be reached and $W^{\pm}$ production will be possible.

If installation in regions 2, 4, 6 and 8 is envisaged, then klystron galeries and access pits will have to be built. In this hypothesis, 64 superconducting cavities could be installed in the two regions 4 and 8 and energies up to 82 (88) GeV could be reached. In this scenario Cu-cavities could continue to operate. A large amount of preparatory work for the RF and cryogenic systems could be done without disturbing LEP operation.

For the next step in upgrading at least 50% of the Cu-cavities would have to be removed and another 128 RF superconducting cavities installed. Energies of 90 (98) GeV, corresponding to nearly the maximum crosssection for $W^{\pm}$ production, can be achieved.

It is worthwhile noting that the second scenario involving installation in 4 regions is more costly because of the additional civil engineering required in regions 4 and 8. It would however have the advantage of disturbing LEP operation much less and make possible, if required at a later stage, an additional upgrading of LEP energies up to 100 (108) GeV. Due to the $\sqrt[4]{V_{rf}}$ law these energies could only be achieved if 384 superconducting cavities were installed.

Table 3 shows a few possible scenarios. The construction, assembly and testing of many cavity cryostat units with all auxiliary facilities must be performed at a very high rate (about 2 cavities/week). This will imply very probably more than one production chain and several test facilities.

A period of about 2 years would be needed in order to reach these high production rates. In reference 4 a cost estimate for LEP upgrading with superconducting cavities is set out, and partly reproduced here in Table 3. Costs are divided into three parts:

(a) cost of the superconducting cavity cryostats with all auxiliaries and complete radio-frequency and cryogenic system;

(b) additional costs directly related to the installation of the above systems, for example, civil engineering work in regions 4 and 8, cooling plus ventilation, power supplies, surface buildings;

(c) additional costs for the upgrading of LEP components and power supplies from 65 to 100 GeV (magnets and vacuum chambers, low-ß systems, injection systems).

Regions with SC cavities	2	2+6	2+6	2+4+6+8	
Total number of SC cavities	32	64	192	128	256
Total number of klystron systems for SC cavities	2	4	12	8	16
Total number of refrigerator cold boxes	2	4	4	8	8
LEP energies (in GeV) E = 5-7 MV/m SC	51 56	64 70	84 92	82 88	90 98
SC + Cu	64 67	73 77			
Total cost of upgrading (MFS)	28	91	152	172	234

Table 3 - LEP Upgrading (in MSF)

It is our impression that with the present budgetary restrictions the W± production energy cannot be achieved before the end of 1994. If more means were available it would be conceivable to advance this schedule by one year (Fig. 3).

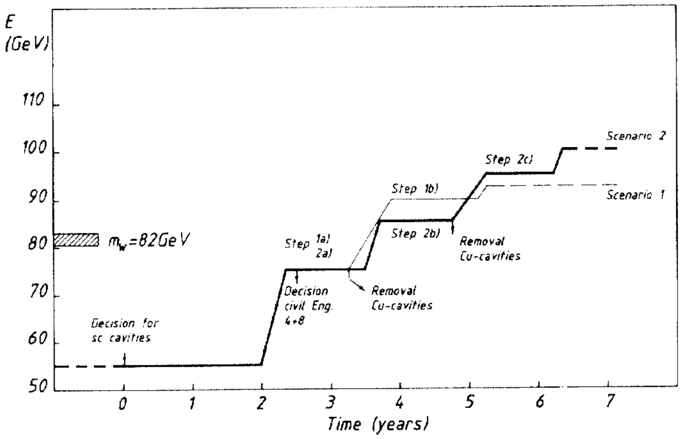

Fig. 3: A Possible Production and Installation Time Schedule to Upgrade the LEP Energies Reached at Each Step (for E_{acc} = 7 MV/m)

Polarization in LEP

Longitudinally polarized electron and positron beams in LEP would make possible the performance of high precision experiments and the study of phenomena of great interest. However, it is not easy to polarize the electron and positron beams in a short time, maintain the transverse polarization and flip the spin in a state of longitudinal polarization in the interaction region. Many studies have been carried out and the most recent calculations foresee a transverse polarization in LEP of 50 to 60%. Wigglers, with a choice of parameters so as to greatly reduce the time necessary to obtain transverse polarization and maintain a high level of transverse polarization without essentially reducing the luminosity, have been studied recently by A. Blondel and J. Jowett[6]. The strategy one would like to follow in LEP is to avoid depolarization effects due to machine imperfections, by design and by empirical correction procedures. Both problems are made considerably simpler by the location of photon emission and by the faster response of the machine to corrections. These assertions have been substantiated by first order simulations. Higher order effects have not been simulated as yet but tentative orders of magnitude are given in the paper by A. Blondel and J. Jowett.

The Experimental Programme

Four major experiments are under construction in LEP: Aleph, Delphi, L3 and Opal. Together the LEP experimental programme will involve more than 1000 experimental physicists.

The present state of the experimental programme is more than satisfactory and the installation of the experiments in the experimental areas is in some cases well advanced, and just beginning in others.

Acknowledgement

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References

(1) J. Billan et al., "Influence of Mortar-induced Stresses on the Magnetic Characteristic of the LEP Dipole Cores", LEP Divisional Report, CERN/LEP-MA/83-53.

(2) J.B. Madsen et al., "Status Report on the LEP Pre-Injector (LPI) and the Proton Synchrotron (PS) as a Lepton Accelerator", Proceedings of the EPAC Conference, 1988

(3) The SPS Lepton Commissioning Team, "Commissioning of the SPS as LEP Injector", Proceedings of the EPAC Conference, 1988

(4) Ph. Bernard et al., "Upgrading of LEP Energies by Superconducting Cavities", Proceedings of ECFA Workshop on LEP 200, Aachen, 19 September - 1 October, 1986

(5) M. Bassetti, Proceedings of the 11th Int. Conf. on High Energy Accelerators, Birkhäuser, Basel (1980)

E. Keil, "LEP at 200 GeV c.m. Energy", Proceedings of ECFA Workshop on LEP 200, Aachen, 19 September - 1 October, 1986

(6) A. Blondel and J. Jowett, "Dedicated Wigglers for Polarization", LEP NOTE 606, 1988