STATUS OF THE LEP $e^{\pm}$ INJECTOR LINACS

F. Dupont for the CERN-LAL Collaboration

Summary

The LEP Injector Linacs are the first part of the LEP injection chain, and consist of a 200 MeV high current electron linac, followed by a 600 MeV low current electron/positron linac.

A progress report on the prototype work will be given as well as status of the major components of the machine : accelerating sections, klystrons and modulators, front-end, optics, positron production and instrumentation.

This machine is the result of a technical collaboration between LAL (Orsay) and CERN. The commissioning of the linac is expected to take place before the end of 1986, well before LEP, in order to test all the parameters of the LEP injection process.

Introduction

Previous comprehensive reports of the LEP injector Linacs (LIL) have covered the preparatory work leading to the main design decisions[1], and described the linacs, then having a coherent set of design parameters, within the framework of the LEP Injector chain[2,3]. This present paper gives the up-to-date status now that manufacturing is fully underway and that the start of installation is imminent.

Description of the LEP Injector Linacs

LIL is the first part of the LEP injector chain (Fig.1). It consists essentially of two linacs in tandem : a high current electron linac (V) of nominal energy 200 MeV, used for positron production, followed by a lower current linac (W) accelerating either positrons or electrons to 600 MeV before injection into accumulation ring (EPA).

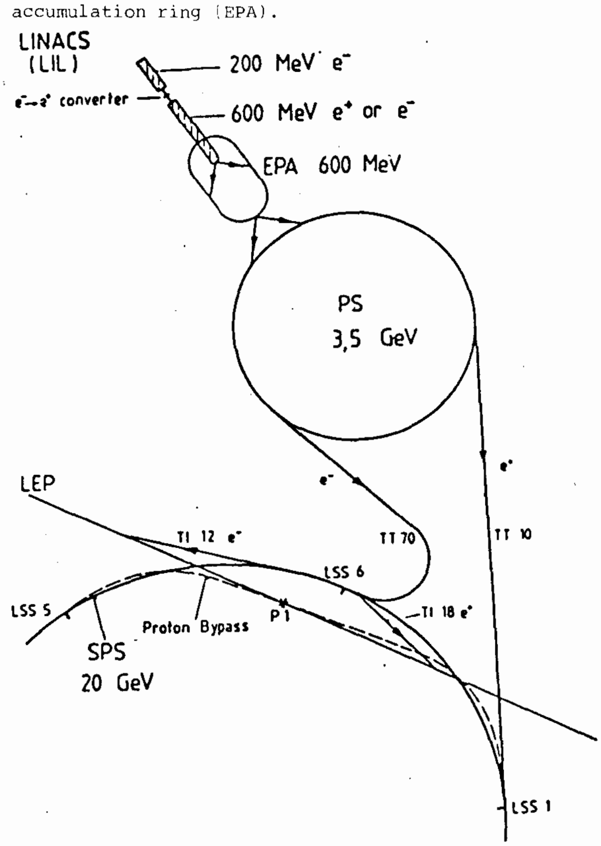

Fig. 1 : Schematic layout of the LEP injector chain. The dashed line indicates the possible future SPS bypass of the ep option. Of LEP, only the part around the crossing point 1 (P1) is shown.

The latter matches the linac repetition frequency of 100 Hz to the LEP injection chain cycle, which for its basic mode of operation accelerates positrons and electrons in the dead-time of the SPS proton cycles to 3.5 GeV (PS) and then to 20 GeV (SPS). This fact plus the necessity not to exceed a maximum charge per bunch lead to a specific operation of the linac which injects positrons into EPA during 11.2 sec, then commutes to electrons, injects electrons during 2.4 sec, then commutes to positrons in 0.15 sec. This feature leads to some constraints in the design, for example two electron guns are necessary, one for each linac to ensure high quality e^+ and e^- beams matched to EPA acceptance with good reproducibility despite the frequent commutation. In particular, linac V is used only for positron production and its settings are kept constant during all the injection time. However, the relative phase of the beam versus the RF is one of the few parameters which it is necessary to adjust when switching between e^+ and e^- acceleration in linac W. Another constraint is, in the design of the optical system of linac W, which must work either for e^+ or e^- beams with minimum changes in focussing element settings.

After their initial S.W. bunching sections, both linacs are composed of travelling wave sections of length 4.8 m, operating at 2998.55 MHz. Their RF power systems are based on 35 MW klystrons feeding two sections in the basic configuration (15 MW per section) and when used in the LIPS (LEP Injector Power Saver) energy storage configuration, giving sufficient peak power output to feed four sections. Waveguides, LIPS storage cavities, and other high power RF circuit elements are under vacuum.

High peak current in linac V is required for positron production and this leads to a transient beam-loading and energy decrease during the pulse and hence to a variation of spot size on the converter. For given beam emittance this effect can be tolerated if the stored energy in the accelerating section is sufficiently large. This was an important criterion for choice of section length.

Accelerating Section

This consists of a disc-loaded waveguide operating in the $2\pi/3$ travelling wave mode with quasi-constant field gradient. The RF structure including input and output coupling cavities is 4.605 m long and provides an energy gain of 60 MeV for an input power of 15 MW. The sections are composed of 135 elementary cells, each consisting of an iris between two half resonant cavities, an input coupler assembly and an output coupler assembly. To reduce the number of cells types required, the section is divided into nine constant impedance landings of eleven cells plus four transition cells between the landings, in which the iris diameter decreases by 0.175 mm from one cell to another. To avoid problems of beam break up in the linac V, the four sections differ by 0.175 mm on all corresponding iris diameters. This gives 44 types of cells for the two linacs. The Fig. 2 and 3 give the overall aspect of a LIL cell and the resulting electric field with the parameters of Table I.

Table I

MAIN CHARACTERISTICS OF ACCELERATING SECTIONS

Frequency	2998.55 MHz
Accelerating mode	$2\pi/3$, TW
Range of iris diameter (2a)	25 to 18 mm
Theoretical Quality Factor Q	15200
Shunt impedance per unit length (Beginning/end of section)	64/74 MΩ/m
Input power	15 MW
Energy gain (non-LIPS)	60.2 MeV

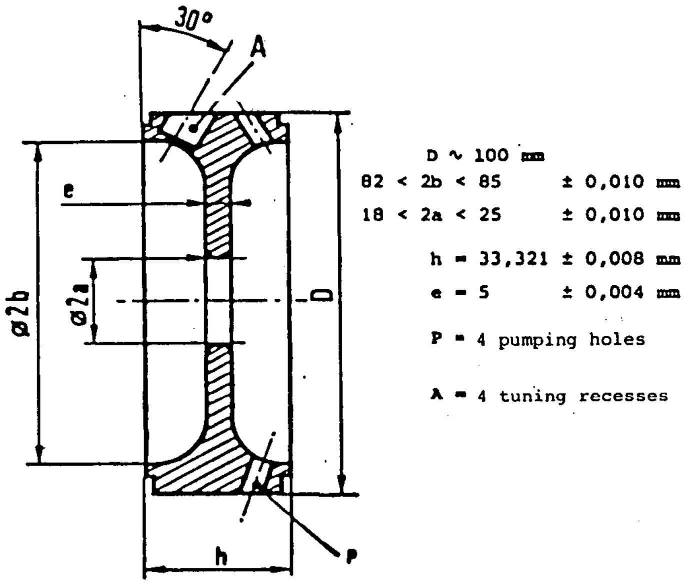

Fig.2: Mechanical features of LIL unit cell.

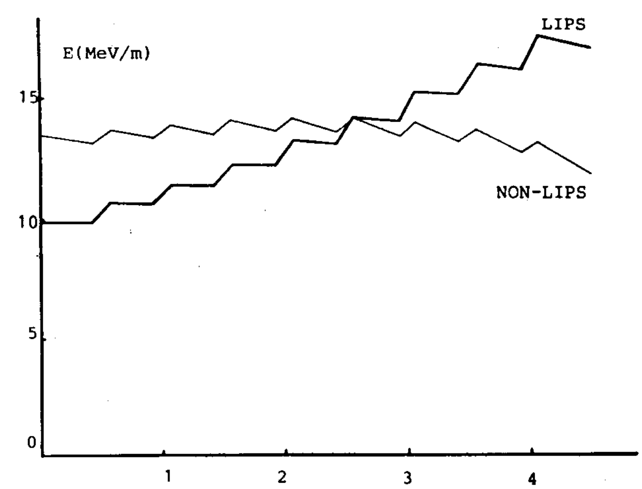

Fig. 3 - Computed acceleration rate versus longitudinal particle position in the LIL TW accelerating section for LIPS and non-LIPS. Main parameters : for non-LIPS as in Table I ; for LIPS Q(spheres) = 150 000, τ_p (RF pulse legth) = 3,9 μs, π phase-switch at τ_p minus 1.2 μs.

To allow simple and fast RF tuning, cells are machined very precisely, to tolerances of better than .01 mm for most dimensions. RF tuning of the individual cell is obtained by deformation of the cell wall which has dictated a reproducible RMS grain size of .2 mm and required a special forging of the cell copper blanks.

After individual tuning and silver plating of the mating surfaces, cells are mounted on a special bench, assembled with input and output couplers to allow matching of couplers and global tuning. The section is then brazed by silver diffusion and mounted in a thick walled vacuum envelope which is machined from long bars of high purity stainless steel.

The sections are supported by structural steel girders (stainless steel for the two solenoid sections). The girder stiffness is sufficient to give an overall misalignment of no more than .2 mm which is the aim fixed initially to minimize beam break up problems.

In order to cut the manufacturing costs, the different parts of the sections are made by a variety of European firms, most of them having no experience in accelerator or RF engineering.

Thus, it has been necessary to design and make all the apparatus and tools, e.g. to tune, braze, clean cells and sections, which has led to a large design effort within the collaboration, and careful preparation inside the contracting firms.

Injection Systems and Positron Production

As mentioned above, each linac has its own injection system to satisfy operational requirements when switching between e^+ and e^- beams. The gun-buncher ensemble for linac V has been built by industry and installed at LAL for tests since 1981[5]. It comprises a triode electron gun operating up to 100 keV and delivering up to 10 A in pulses ranging from 8 to 25 ns at 100 Hz. The nominal performance required for the buncher for LEP injection is 2.5 A peak current (30 nC) at W > 25 MeV with good emittance and phase bunching. Measurements on the buncher V, with accelerated beams of 100 nC (6.5 A peak current) give emittances at the output between 8.5 π and 12.2 π mm.mrad for 80% of particles at 29 MeV, which is acceptable for positron production purposes.

The triode electron gun for linac W has been ordered from industry. It operates at 60 keV and must deliver 250 mA peak current in pulses ranging from 8 to 25 ns. This gun is off axis and the injection system, shown on Fig. 4, includes 3 short lenses, a 255° achromatic magnet based on the SLAC α-magnet, a pre-buncher and buncher (4 MeV) and a "telescope" lens used in conjunction with the pulsed converter solenoid to match the emittance of the 4 MeV electron beam to the solenoid focussed sections of linac W. This part of the beam transport is not yet frozen.

The high current electron beam from linac V is focussed to a small diameter spot on to a target made of tungsten, two radiation lengths thick. The field of the λ/4 solenoid is set to focus the positrons which are produced around a mean energy of 8 MeV with small radius of approximately 1 mm and large divergence of about 200 mrad. To allow easy commutation of the beam, the converter target has been designed to be removed and put in place with the necessary tolerance within the commutation time (0.15 s). Both the target (with its mechanism) and the λ/4 coil are mounted from vacuum flanges which facilitates their removal, in case of a fault, from the high radiation area around the converter. A prototype high field coil and power supply are under test.

Beam optics and magnets

The LIL beam optics comprises five main parts :

- The focussing system for the linac V uses quadrupoles with gradients less than 2.5 Tm^{-1} arranged in triplets between the sections. However for the quadruplet which is used to obtain a minimum diameter beam on the converter, gradients of about 5 Tm^{-1} are required which involves a special high current coil design.

- Two further points concerning the optics in W-injection region (see previous section) must be mentioned. As the 60 keV beam just penetrates the α-magnet fringe field of a few hundred gauss, it is necessary to minimize the stray field to ensure proper operation. This is not easy when taking into account the magnetic elements nearby and implies detailed field measurements in this region. Another point is that it has to accommodate both the 200 MeV high intensity electron beam and the 60 keV/4 MeV low intensity one. It will

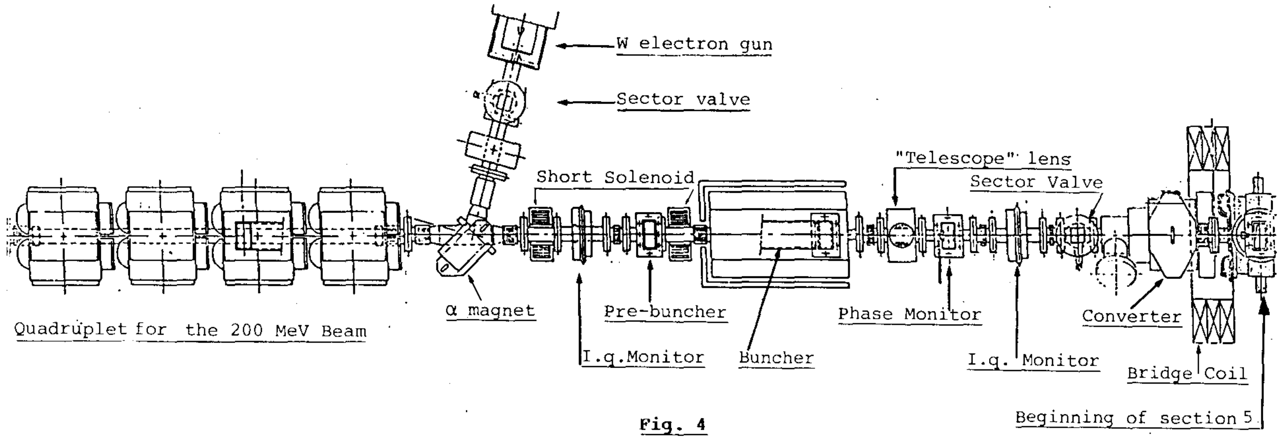

Fig. 4

Injection system of linac W

probably be necessary to switch off the telescope solenoid during positron cycles.

- Matching of the positron beam emerging from the converter into the acceptance of the accelerating section is made with a quarter wave transformer system. This consists of a short pulsed solenoid (1.5 T) based on the DESY type[6], mounted just after the converter and followed by a long solenoid mounted on the first two accelerating sections of linac W. These magnetic fields and the iris diameter of the sections define the maximum transverse acceptance of the system.

- The FODO channel for linac W is preceded by a matching system which consists of a quadrupole doublet and three quadrupoles mounted on the third accelerating section of linac W just after the two sections with solenoid coils. The final design for the FODO system proper consists of 32 quadrupoles mounted around the section and two quadrupoles between sections. The positron beam envelopes are shown on Fig. 5.

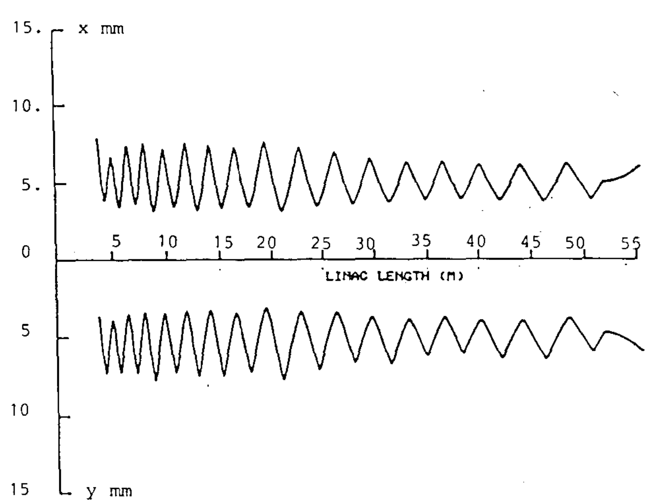

Fig. 5 : Beam envelopes for positrons in Linac W for an emittance of 4.8 π mm.mrad. at 600 MeV.

- Beam steering is necessary to guide the beam through accelerating sections (minimum iris diameter of 18 mm) over 100 m, taking into account the effects of the earth's magnetic field, transverse forces acting on the beam at each RF coupler (input and output of sections), and focussing element misalignments. This is particularly acute for the positron beam which needs nearly all the available aperture. The studies to determine suitable disposition of correcting elements and position measurers in linac W are still not finalized. However it is proposed to fit all FODO quadrupoles with correction windings designed to give dipole fields.

<u>High power modulators, klystrons and LIPS</u>

The RF power sources at 3 GHz are 35 MW klystrons amplifiers fed by high power modulators (90 MW peak). Six such ensembles are necessary for the two linacs, one for the two bunchers, one for the two critical sections following the converter in which the design electric field is lower than in other sections and one for the last two sections of linac W. The three other modulator ensembles are used with LIPS, an energy storage configuration based on the SLAC SLED arrangement[7]. This more than doubles the effective peak power given by the klystron and it is thus possible to use one modulator and klystron to feed four linac sections if the ensemble is operated with an RF pulse length of 4.5 μs instead of 2.5 μs without LIPS. A prototype LIPS system which included two high Q spherical resonators, their associated 3 dB coupler and a 180° phase switch at the klystron input circuit was tested successfully in 1982[8]. Three LIPS systems using improved cylindrical resonators are currently under construction.

The modulator consists essentially of a lumped element pulse forming network (PFN) charged resonantly by a thyristor controlled 23 kV power supply and discharged by a thyratron switching circuit which is protected by an end-of-line clipper. The high voltage mains transformer, filter choke, bridge rectifier and voltage doubling choke are housed in a silicon-oil-filled tank. For 5.5 μs (3 μs) pulses the PFN has 25 (15) capacitors respectively and the output pulse is applied via a 1:13 pulse transformer to the klystron cathode.

Many auxiliary supplies are under development e.g. a solid state trigger, pulse transformer premagnetisation and cathode heater supplies for klystron and thyratron.

Table II gives the main parameters of the LIL modulator.

Table II

MAIN PARAMETERS OF THE LIL MODULATORS

Peak output values	
power	90 MW
forward voltage (maximum)	300 kV
current (maximum)	300 A
Average output power	50 kW
Repetition frequency	100 Hz
Output pulse (voltage)	
rise time	0,8 μs
flat top	4,8 μs
Ripple and droop of flat top	± 0.5 %
Flat top reproducibility (10mn)	± 0.05%

A first modulator prototype was successfully tested at Orsay during 1983 up to the nominal values of 280 kV, 290 A at 100 Hz on the klystron cathode. Computations of the PFN, the switching circuit and the end of line clipper using the program ECAP have been confirmed by the extensive tests on this modulator.

Prototype klystrons and their tanks have been under development by two European firms and were tested successfuly by the end of 1983 to their nominal output values of 35 MW with 45 % efficiency and 53 dB gain.

RF Distribution

The "low power RF distribution" consists of a crystal controlled RF source (200 mW) followed by a pulsed 24 kW amplifier (klystron + modulator) and a rigid coaxial reference line distributing this power along the linacs with directional couplers feeding power to each klystron via a level and phase control network e.g. a phase comparator, phase shifter, attenuator and pulse shaper [9]. One important function concerns the energy control of the e^+ and e^- beams by means of klystron input phase adjustment. The phases of the electron beams as measured by means of phase detectors located just after buncher V or W are locked to the reference line phase. Half the energy correction is then made with a positive phase shift of the first ten sections of linac W and the other half with a negative shift of the last two sections of linac W. This method avoids unnecessary energy dispersion in the 600 MeV beam (e^+ and e^-).

The "high power RF distribution" includes the waveguides, flanges, 3 dB couplers, high power windows and RF loads. It will operate with a vacuum of $<10^{-7}$ Torr to cope with the high electric field in the waveguide and at the RF windows. As the accelerating sections and the high power RF distribution have a common vacuum system, a gas lock and a high power RF window are located just after the klystron to allow its replacement.

Vacuum System

Fig. 6 gives a schema of the vacuum system for one part of the linac. Although the electron guns, accelerating sections and high power RF distribution form one extended vacuum system, these parts are nearly independent as far as pumping is concerned due to low conduction paths between them, e.g. 20 $\ell s^{-1} m^{-1}$ for the waveguide and less than that between sections.

The major problems are to ensure pressures less than 5.10^{-8} Torr at the RF windows in the high power network and about 10^{-7} Torr inside the accelerating sections. Two important constraints on the latter are the need to minimize the external diameter of the vacuum envelope (which determines the bore diameter of the FODO quadrupole) and yet be able to tolerate a high outgassing from copper (2×10^{-10} Torr $\ell s^{-1} cm^{-2}$) as bake out of the structure is not possible for mechanical reasons.

Instrumentation

The two linacs need several types of beam measuring devices in order to ensure, especially in the case of positrons, minimum losses and correct matching between production and beam output. Four main types of monitor are :

- Beam intensity and charge monitor of the "wall current type" which is the only type on LIL capable of analyzing the 12 ns pulse shape.

- Beam position monitor of a magnetic type, which gives the position of the centre of the beam in both planes for each linac pulse. This monitor also allows the measurement of the total beam charge.

- Profile monitor named "wire scanner" which measures the secondary electron from a berylium wire as it crosses the beam path. It is used just before the converter to monitor the beam profile, and just after the matching doublet to determine the emittance of the positron beam.

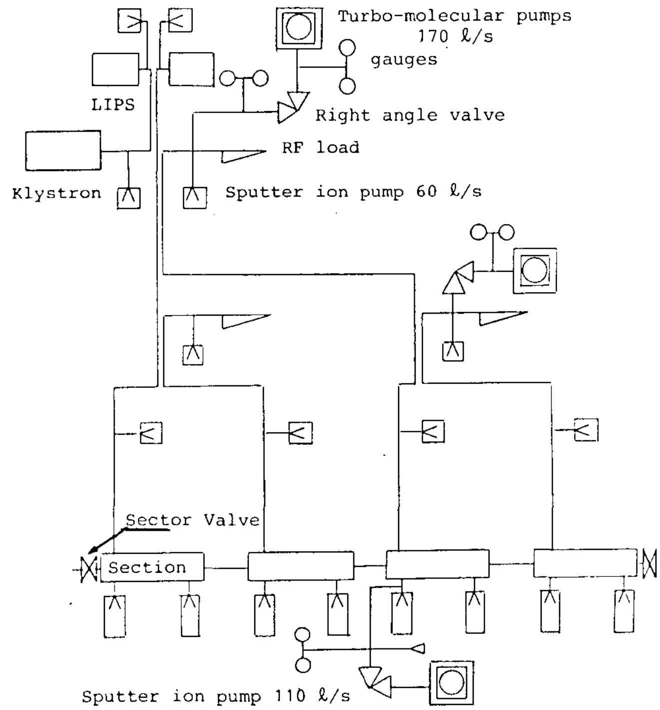

Fig. 6 : Part of the vacuum system of LIL

- Beam energy monitors at the output of both linacs (V and W) consist of a bending magnet followed by a secondary electron monitor with a titanium grid (SEMGRID) which measures the beam profile. A special magnet is required at linac V output but the normal bending magnet in the e^+ and e^- beam transport to EPA can be used for linac W with the SEMGRID output signal used to adjust the beam energy via the phase of the last two accelerating sections (see above "RF Distribution").

Controls

Four aspects of the control schema have been considered in detail :

- The timing sequence necessary to have proper triggering between parts of the linacs and between linacs and EPA.

- The "operation scenario" of the linacs describing the various types of operation needed e.g. commissioning, routine operation and preventive maintenance.

- The local grouping of CAMAC modules into meaningful sub-assemblies with respect to the operating scenarios can be broadly classified as "systems oriented" or "function oriented". Thus for LIL the groupings are: modulators ; klystrons ; electron guns V and W ; focussing and steering ; RF distribution and phasing vacuum ; beam instrumentation ; timing. The interfacing of the most important system oriented grouping, the modulator-klystron ensemble, has been studied in detail to provide a pattern for other groupings.

- The global control system of LIL combines the above aspects using CAMAC interfacing and standard PS software structure, so that, for overall operation, it forms an extension to the PS control system network. and will eventually be operated from the main PS control room.

Building

To satisfy the floor stability requirements for the linac (e.g. 1 mm over 30 m), the building is supported on piles anchored in the molasse and the lateral shielding blocks are on separate foundations. Even with the minimum practicable linac length, the restricted site requires the linac to cross EPA and inject from the inside of EPA racetrack. As both linac tunnel and the modulator/klystron gallery above it, have been designed to match the requirements closely (Fig. 7), the equipment handling and installation require careful preparation.

Status and Schedule

All major contracts have been placed. The civil engineering was completed on schedule and the cooling water, main electrical cabling and other utilities are now being installed. The cells for the first accelerating sections have been machined and a complete section will be available in October 1984. The first modulators will be installed before the end of 1984. Since the prototype klystron tests were successful, series fabrication of the klystrons can start within the next months and a set of six klystrons should be available by spring 1985. Gun and buncher V have been tested at LAL and installation at CERN is foreseen at the beginning of 1985. Gun and buncher W also become available at the same time. The first electron beam in linac W is scheduled for fall 1985, linac V will be commissioned some six months later. The first positron beam is planned for the middle of 1986.

References

1. R. BELBEOCH et al. "Rapport d'Etudes sur le Projet des linacs injecteur de LEP (LIL)", LAL-PI 82-01/T (1982)
2. The LEP Injector Study Group "The LEP Injector Chain", CERN/PS/DL/83-31 and LAL/RT/83-09 (June 1983) Ch. 3.
3. LEP Injector Study Group "The Chain of LEP Injectors" IEEE Trans. Nucl. Sci. NS-30, (1983), 2022.
4. G. BIENVENU, J.C. BOURDON, P. BRUNET and J. RODIER, These Proceedings.
5. P. BRUNET and R. CHAPUT, These Proceedings
6. G. STANGE, IEEE Trans. Nucl. Sci. NS-26, (1975) 4146.
7. Z.D. FARKAS et al., IEEE Trans. Nucl. Sci. NS-22, (1975) 1299.
8. A. FIEBIG and R. HOHBACH, IEEE Trans. Nucl. Sci. NS-30, (1983), 3563.
9. E. PLOUVIEZ, These Proceedings.

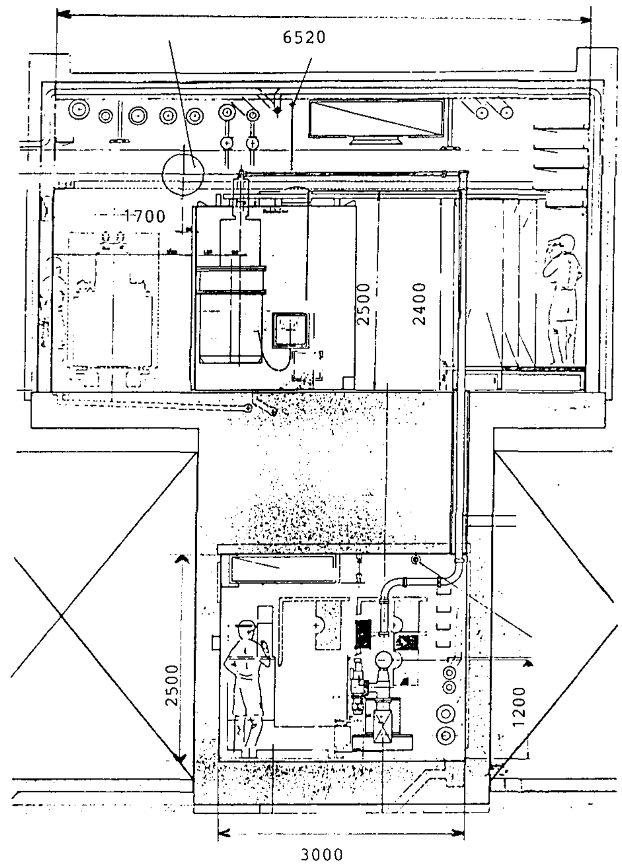

Fig. 7 : Cross section of the LIL building

Table III

NOMINAL LINAC PARAMETERS

Accelerating Sections

Frequency (30° under vacuum)	2998.55 MHz
Type	TW, quasi-constant gradient
Mode	$2\pi/3$
Length incl. coupling cavities	4.505 m
Filling Time	1.22 μs
Normal accelerating rate	13 $MeV.m^{-1}$

Klystrons

Power	35 MW
Pulse length (-3 dB)	4.5 μs

	Linac V		Linac W	
Number of sections (with LIPS	4		8	
(without LIPS)	–		4	
Number of klystrons	1 (a) + 1		4	
Pulse repetition rate		100 Hz		
Beam pulse length (FWHH)		12 ns		
Energy	200 MeV		600 MeV	
Particles	e^-		e^+	e^-
Peak current	2.5 A		12 mA	60 mA
Emittance/π (mm.mrad) (b)	<1.3		4	<< 1
Relative energy spread (%)	<10		2	< 1

(a) powers both bunchers

(b) containing > 80% of resolved output current