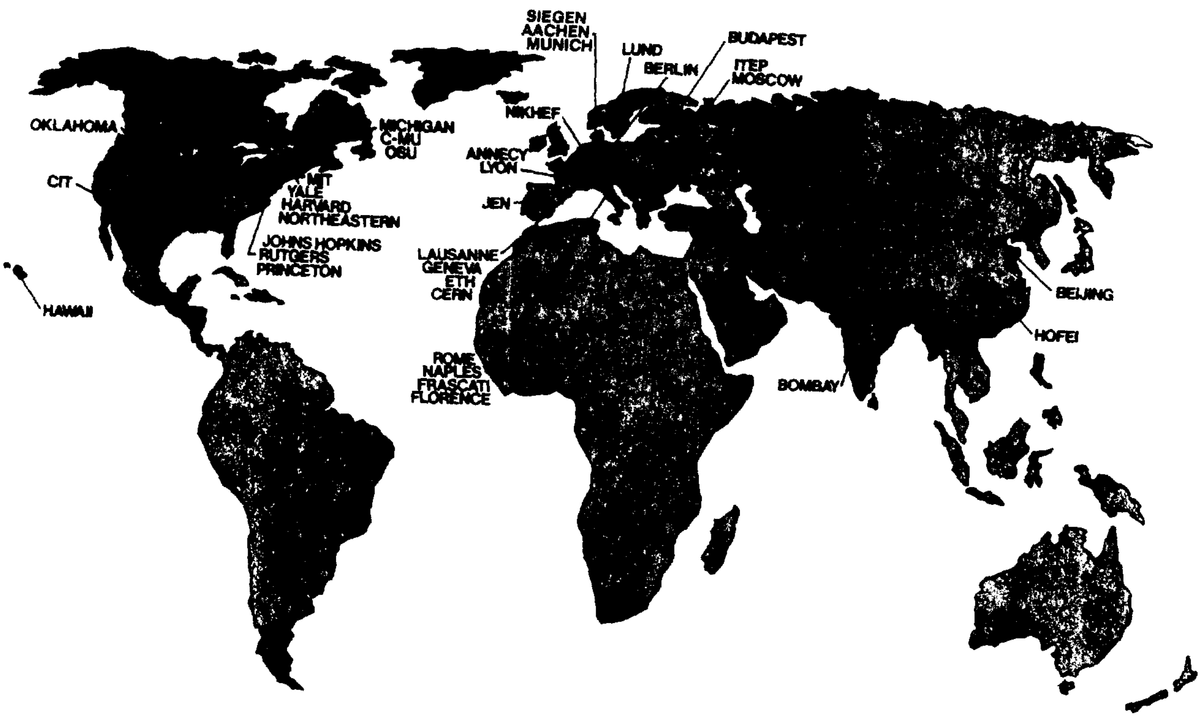
# TECHNICAL PROPOSAL




# L3

# MAY 1983

**CHAPTER 1**

## PARTICIPATING INSTITUTIONS AND CONTACT PERSONS

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# CHAPTER 2

## PHYSICS

Since the submission of our Letter of Intent much has been learned from the brilliant work at the $p\bar{p}$ collider at CERN. The results of the $p\bar{p}$ collider experiments confirm the general features of our current understanding of electroweak interactions. Much time will have elapsed before the coming of LEP and undoubtedly many more new results will have emerged from $p\bar{p}$ collider at CERN and perhaps from colliders elsewhere. Therefore, this is the time to review and to re-examine the purpose of the L3 experiment.

There are four unique features of this experiment:

1) Measurement of photons, electrons and muons with a resolution of $\frac{\Delta p}{p} \simeq 1\%$.

2) Measurement of hadron jet energies with a good resolution together with leptons.

3) Precision measurement of vertices.

4) The large magnetic hall with a $BL^2 = 160$ kG-m$^2$ and the fact that the central part of the detector can be easily modified or removed, making this experiment readily adaptable for future phases of LEP.

These four features are unique and our detector is optimized for the following:

1. To perform precise measurement in the framework of the Standard Model and to search for scalar particles, such as Higgs, by performing missing mass measurements of the type $e^+e^- \to \ell\ell + x$.

2. To explore new phenomena (not predicted by theory) by precise measurements of e, $\mu$, $\gamma$ and hadron jets.

To achieve these objectives, in the technical design of this experiment every effort has been made to ensure that the resolution of detecting photons, leptons and hadron jets is optimized. We will be able to use this detector to explore new phenomena in unknown regions extending beyond the first phase of LEP.

CHAPTER 3

# DESCRIPTION OF THE DETECTOR

The detector housed in a large volume solenoid magnet will be situated in an experimental hall approximately 50 m below the surface at interaction point 2 of the LEP machine (Fig. 1).

Charged particles from the interaction region (r = 0) are tracked in a Time Expansion Chamber (TEC) up to r = 50 cm with high spatial and double track resolution. Electrons and photons will deposit their energy in cylindrical array of Bismuth Germanate Oxide (BGO) shower counters of 22 $X_o$. Hadron showers will continue developing into the hadron calorimeter extending to r = 213 cm (Fig. 2). Only muons will penetrate into the muon spectrometer which analyzes their momenta in a ~ 0.5 T field with three chamber layers, extending to r = 568 cm (Fig. 3).

Figs. 4 and 5 show the magnet iron return yoke, poles (in the form of split doors) and coil, having a total weight of 7000 t, resting in a concrete cradle.

All detector parts are supported by an adjustable tube (170 t), concentric with the beam-line, extending almost the length of the hall. The detector central portion is located inside the octagonal section of the tube and consists of a 400 t hadron calorimeter sectioned to allow access to the electromagnetic calorimeter (BGO) and vertex chamber inside (Fig. 2). The BGO (12 t) is suspended from the hadron calorimeter, while the vertex chamber (0.3 t), which may be integrated with the vacuum pipe, is also held by the same detector. The muon chambers are arranged in half-length octant modules and supported from the exterior surface of the tube. The muon chamber array is completed by a set of three vertically split chambers in the forward direction and supported on rails suspended from the upper walls of the tube. Also in this region are located the integrated 2-photon and luminosity detectors fixed to the machine quadrupole magnet and the hadron calorimeter endcaps.

## I. DIMENSIONAL PARAMETERS

The mutually agreed-upon radial and longitudinal dimensions of each of the detector components described are summarized in Fig. 6. Also the clearances are indicated which include manufacturing tolerances, alignment motions, and deflections due to load. The arrows indicate boundaries each design must not exceed in order to ensure safe mechanical assembly. Details of the beam pipe have yet to be defined.

## II. ASSEMBLY

The assembly of all detector components depends on the installation of the magnet and the support tube in the experimental hall.

The possible sequence is as follows:

1. 2 x 32 t cranes and lights
2. Magnet tooling and jacks
3. Magnet yoke base (3/8)
4. Upper ventilation and perhaps auxiliary lifting gear
5. No. 1 tube support structure
6. Magnet coil jigs
7. Magnet coil
8. Magnet coil primary connection
9. Coil connectors continued
10. Magnet pole No. 1, far end, and rails
11. Magnet pole No. 2 and rails
12. Remainder of magnet yoke (5/8)
13. No. 2 tube support structure
14. False floor and rails for tube
15. Thermal shield
16. Octagonal tube plus end support
17. Cylindrical tube plus end support

Once the support tube is installed, detector components will be transported into the experimental hall.

The overall layout (Fig. 7) shows that the detector assembly areas can be split into 2 major zones. Most of the central detector components are installed, after passing over the magnet, through the octagonal entrance of the tube by the use of simple roller and rail systems.

The shaft, surface building and crane can be seen in Fig. 8. During or after the magnet installation this shaft will be partially occupied by 6 stories of counting house, computer, and service rooms.

Each muon module is brought from the surface to the loading zone under the shaft. With the magnet doors open, the module is placed in the upper section of a Ferris wheel structure (which is outside the magnet) and then rotated around the cylindrical part of the tube (see Fig. 9). The completed and tested assembly is moved into the magnet with the help of air cushions.

## III. SCHEDULE

The planned detector installation procedure will consist of two parallel operations: the central portion will be inserted during the assembly of the radial muon chambers. The work inside the tube is assumed as a series operation where the installation times estimated for the hadron calorimeter, electromagnetic calorimeter and vertex chamber are four and a half months, five weeks and four weeks respectively. The planning is based on a free access to the cranes and shaft during this period, as outlined in the following.

a. Calorimeter Schedule

Following installation of support tube:

- Assembly of the eight octants of segment three in final position at the walls of the calorimeter tube (duration one month)
- Assembly of 16 octants of the inner segments (two and three) outside the support tube (two months)
- Move above assembly to final position
- Cabling and installation of gas supply (one month)
- Barrel part of hadron calorimeter operational
- Endcap installation including cabling and gas-supply (one month), according to the BGO and vertex chamber schedule

b. BGO Schedule

- Installing two elements is a one-week-long task.
- A continuous installation is not mandatory.
- The following sequence could be envisaged:
  (1) Putting the two half end-caps at the far end of the detector in withdrawn position: 1 week

(2) Putting two half-barrels of the same side in final position: 1 week

(3) Idem on the other side (thus completing the barrel): 1 week

(4) Putting the two half end-caps at the near end of the detector in withdrawn position: 1 week

(5) Closing the detector by putting the end-caps in final position, plus final alignment: 1 week

c. Muon Chamber Schedule

In parallel with the installation of the inner part of the detector the assembly of the radial muon chambers proceeds. A period of six months of installation in the hall seems necessary and will occupy a large part of the hall's surface for this operation, as shown in Table 1.

A summary of general detector assembly following the magnet and support tube installation is shown in Fig. 10. This schedule does not list the forward detectors, which will be gradually implemented. Other installations may influence the continuity as for example the equipping of the hall, the beam-line and the fitting of the control rooms.

Fig. 11 a,b summarizes the time schedules, the places of assembly[1], and the institutes carrying it out.

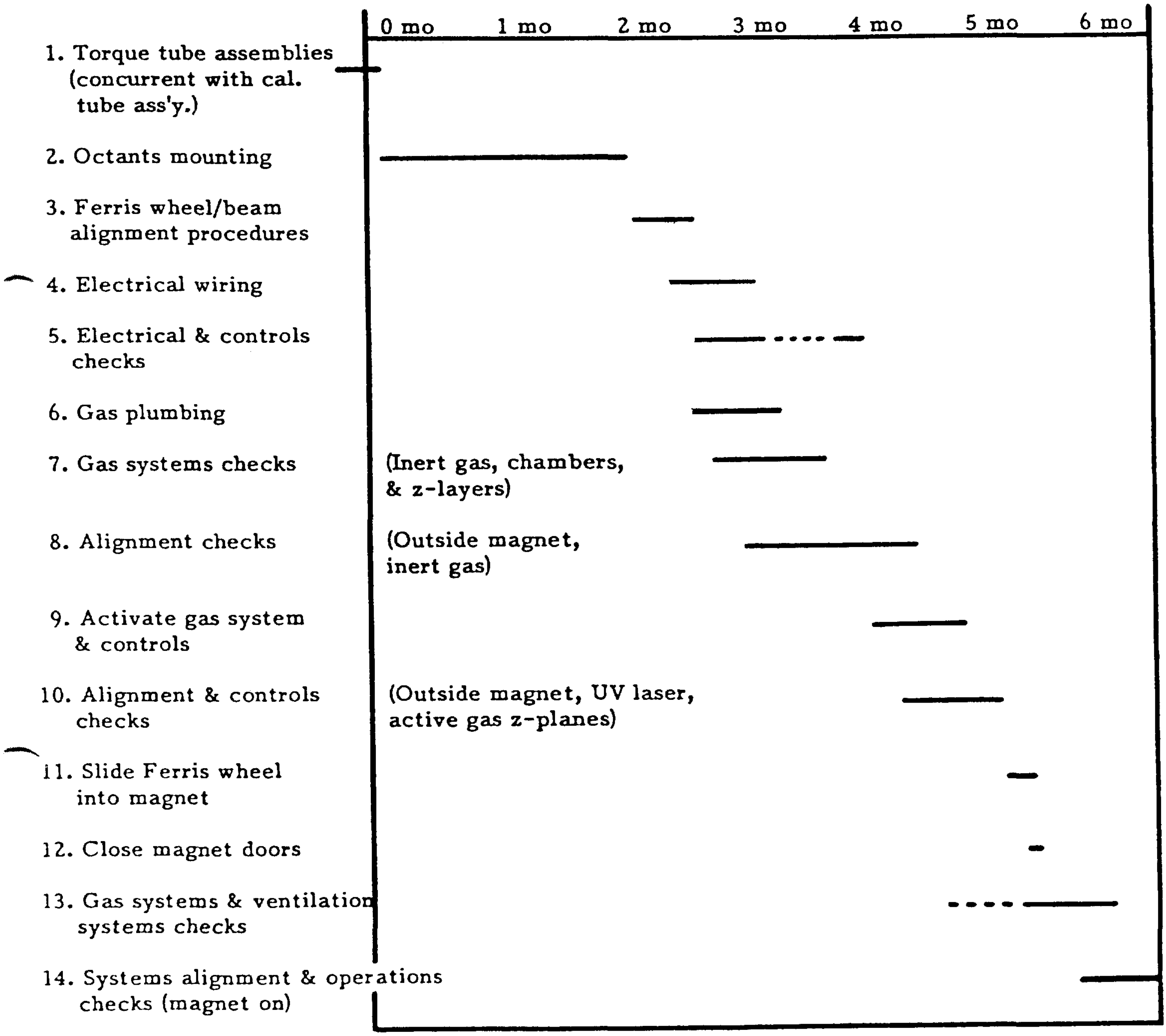
**REFERENCE**

(1) Memorandum to the CERN Space Committee (December 1982)

**FIGURE CAPTIONS**

# TABLE 1

DOWN-HOLE INSTALLATION - MUON CHAMBER ARRAY



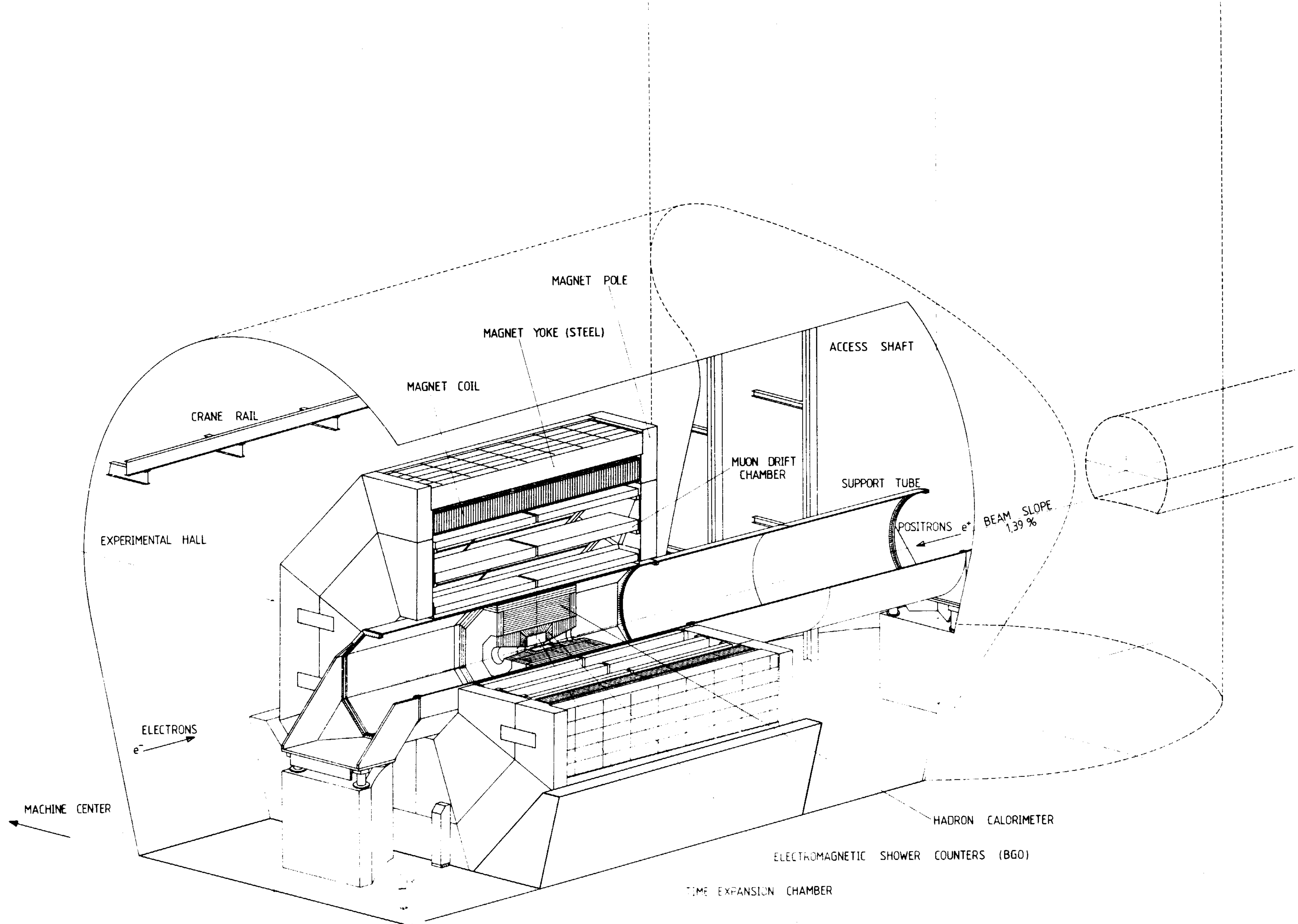

MAGNET POLE
MAGNET YOKE (STEEL)
ACCESS SHAFT
MAGNET COIL
CRANE RAIL
MUON DRIFT CHAMBER
SUPPORT TUBE
POSITRONS e+
BEAM SLOPE 1,39 %
EXPERIMENTAL HALL
ELECTRONS e−
MACHINE CENTER
HADRON CALORIMETER
ELECTROMAGNETIC SHOWER COUNTERS (BGO)
TIME EXPANSION CHAMBER

FIG.1

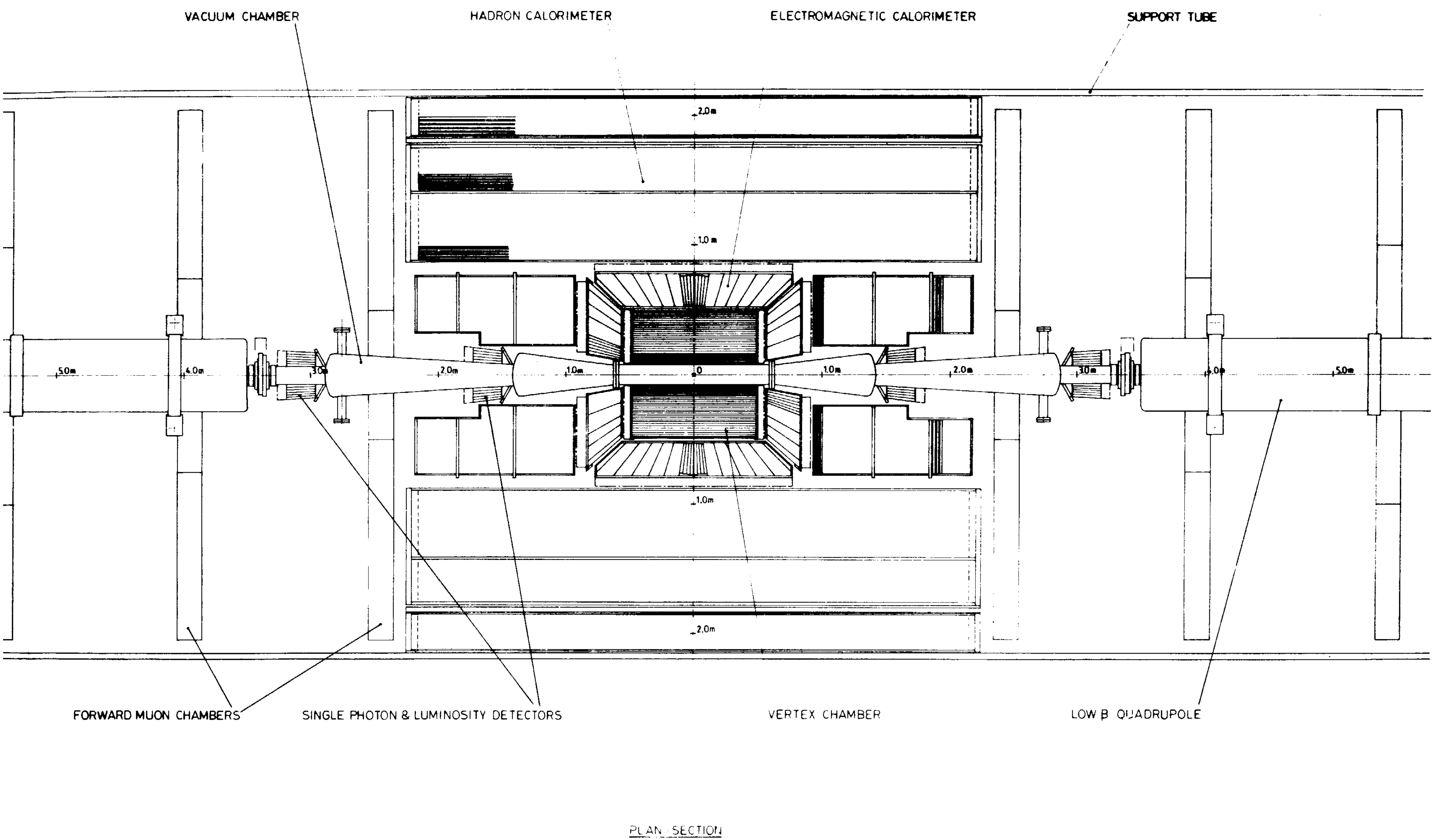

VACUUM CHAMBER
HADRON CALORIMETER
ELECTROMAGNETIC CALORIMETER
SUPPORT TUBE
FORWARD MUON CHAMBERS
SINGLE PHOTON & LUMINOSITY DETECTORS
VERTEX CHAMBER
LOW β QUADRUPOLE
PLAN SECTION

FIG. 2

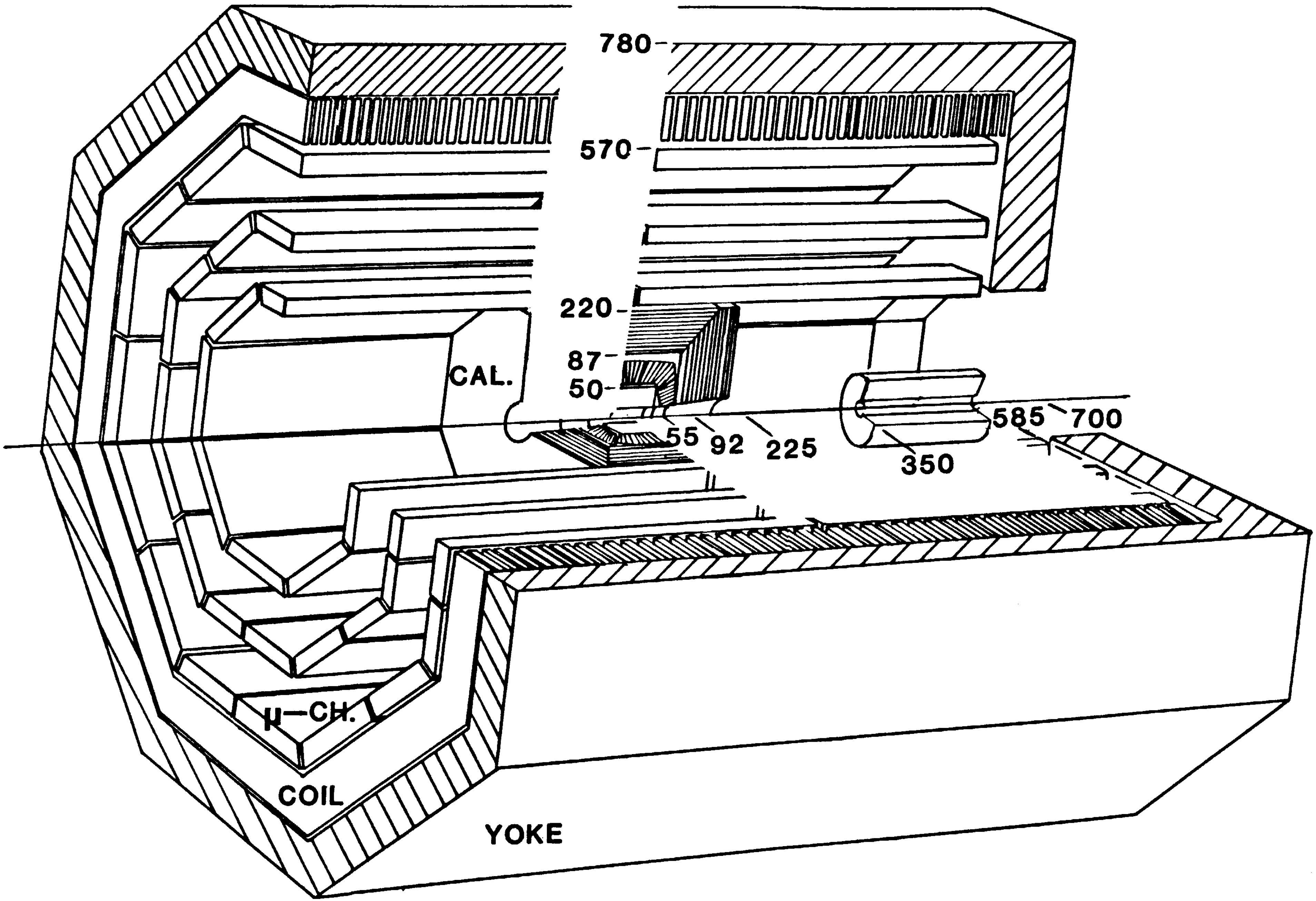
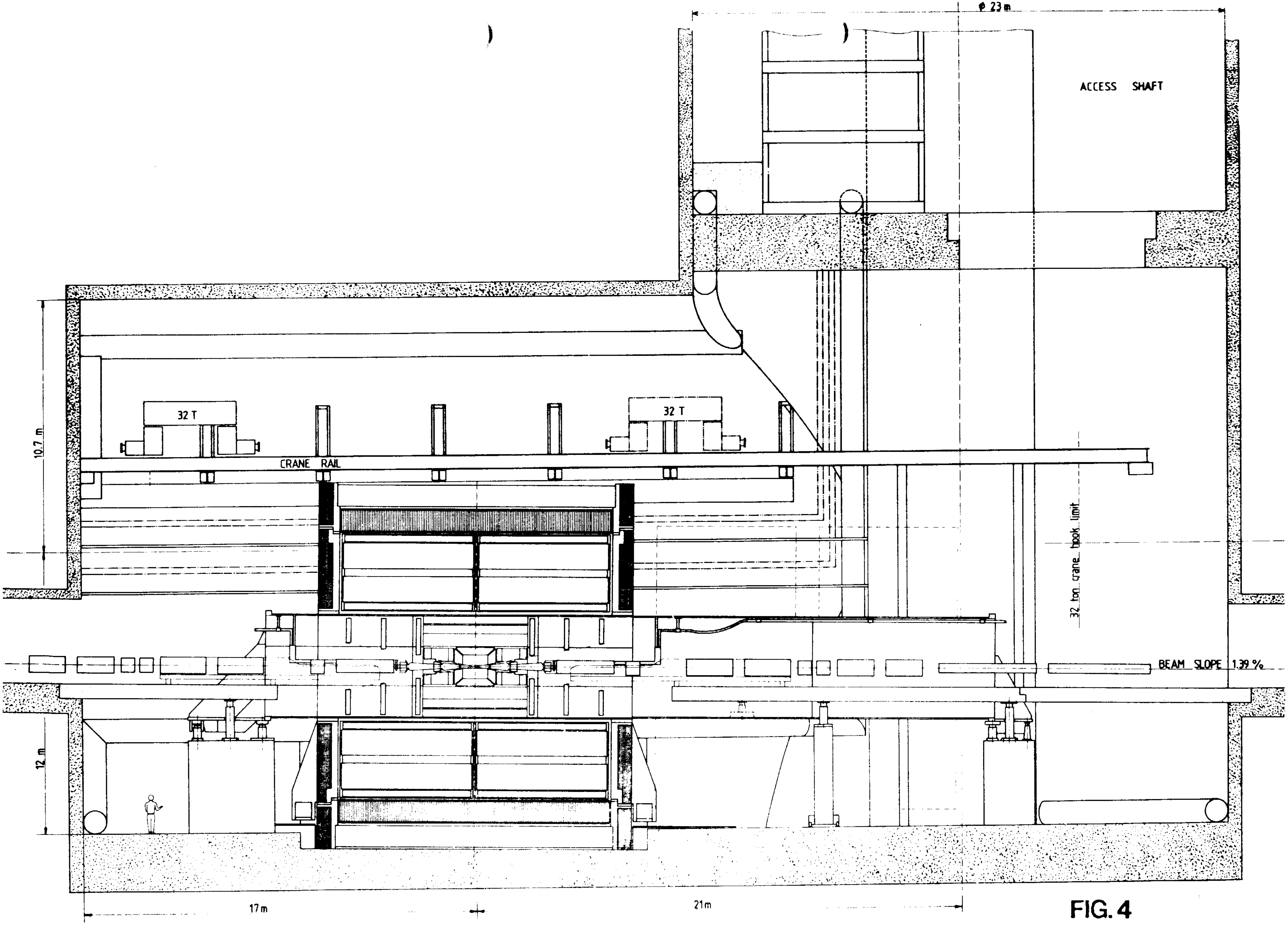



FIG. 3



ø 23 m
ACCESS SHAFT
32 T
32 T
CRANE RAIL
10.7 m
32 ton crane hook limit
BEAM SLOPE 1.39 %
12 m
17 m
21 m


FIG. 4

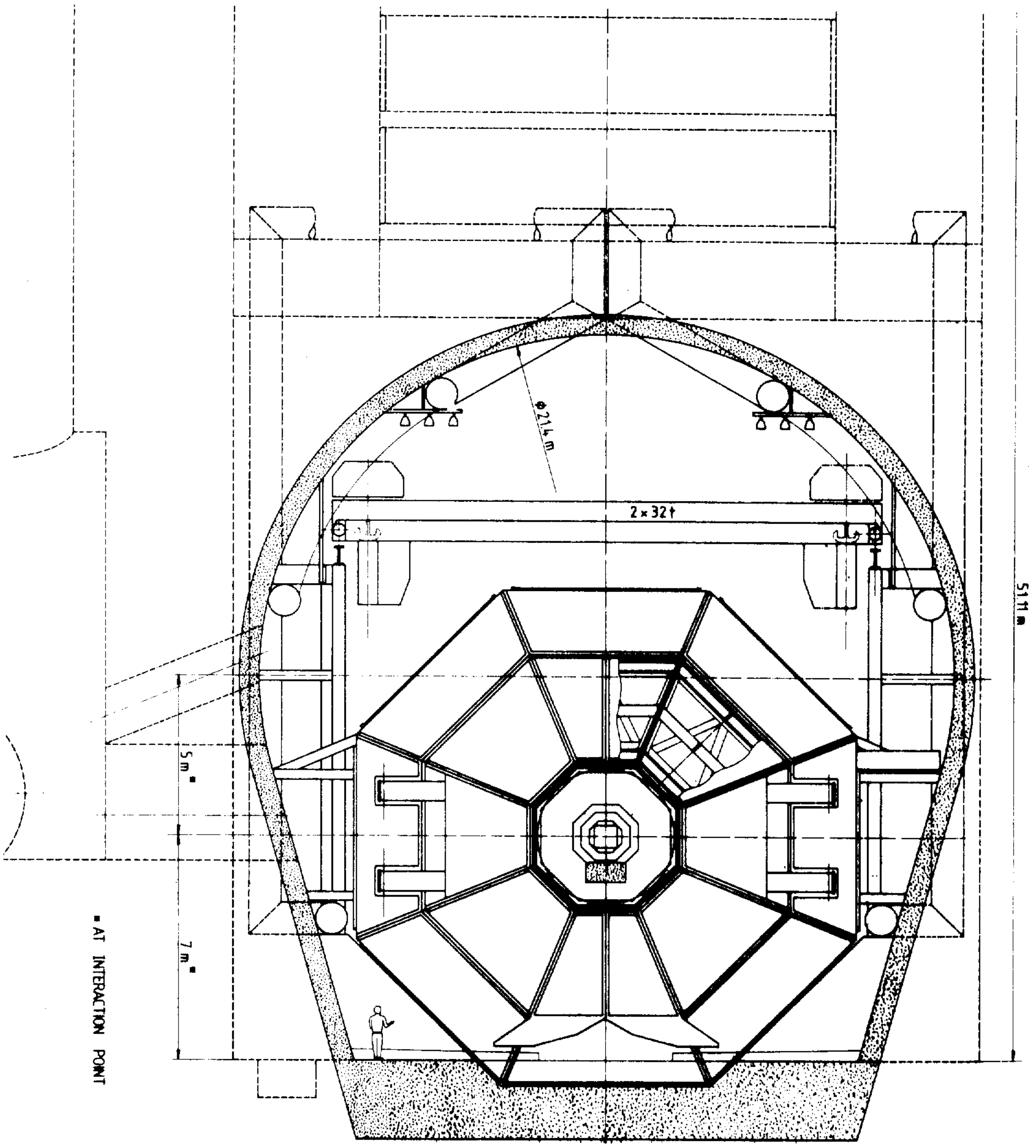
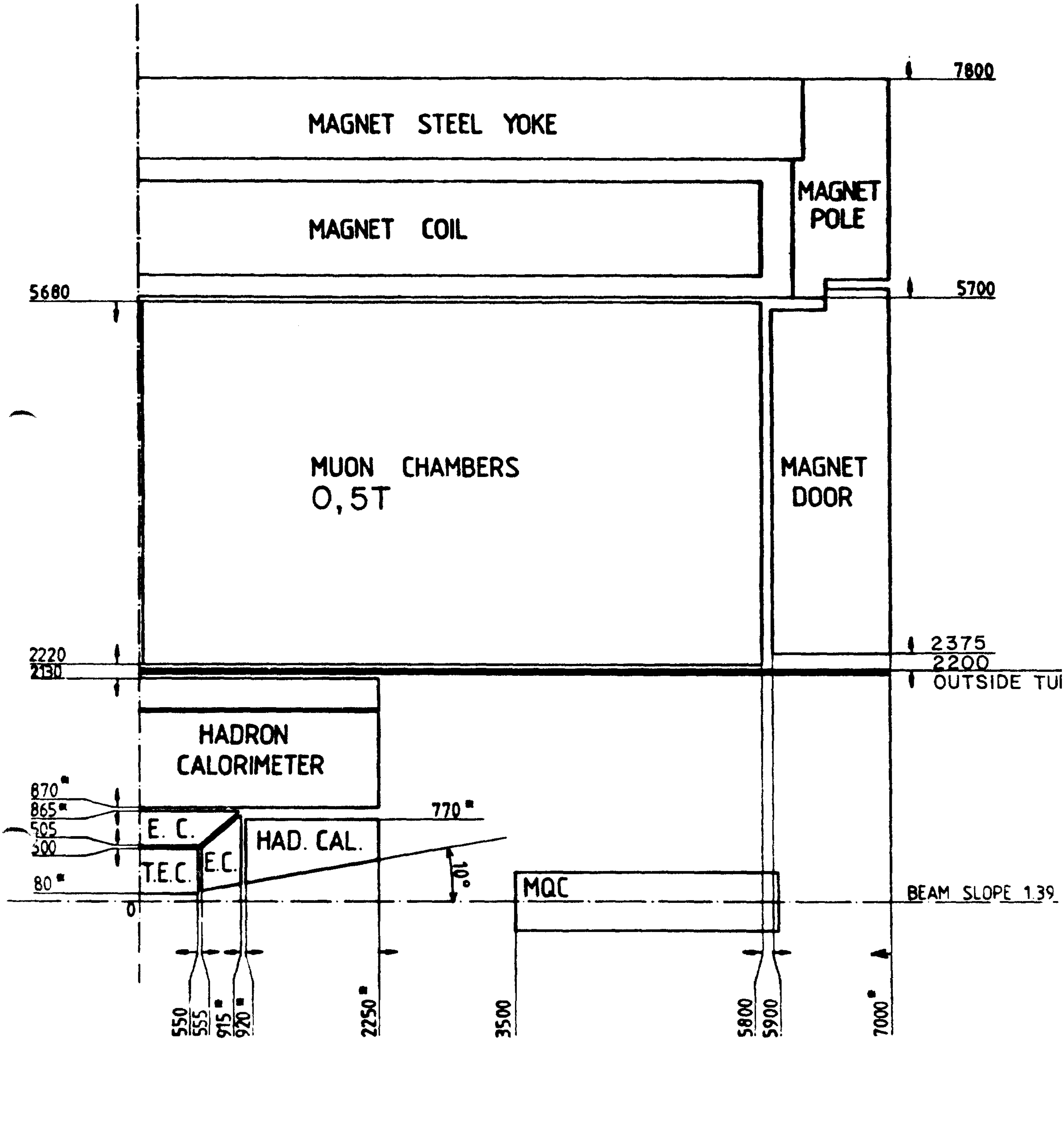



FIG. 5




* DIMENSIONS TO BE CONFIRMED

DIMENSIONS IN mm.

FIG. 6 EXPERIMENTAL PARAMETERS

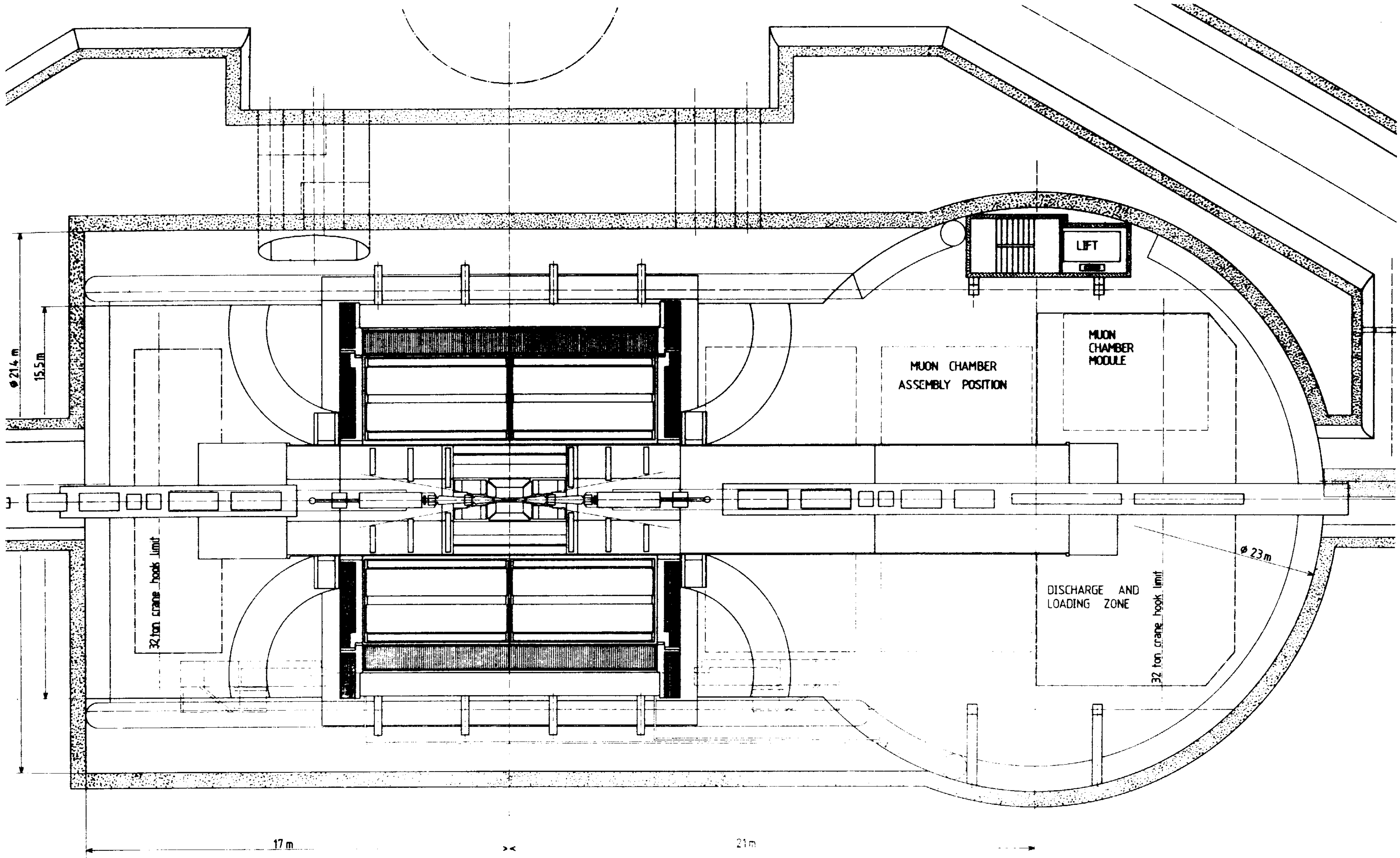
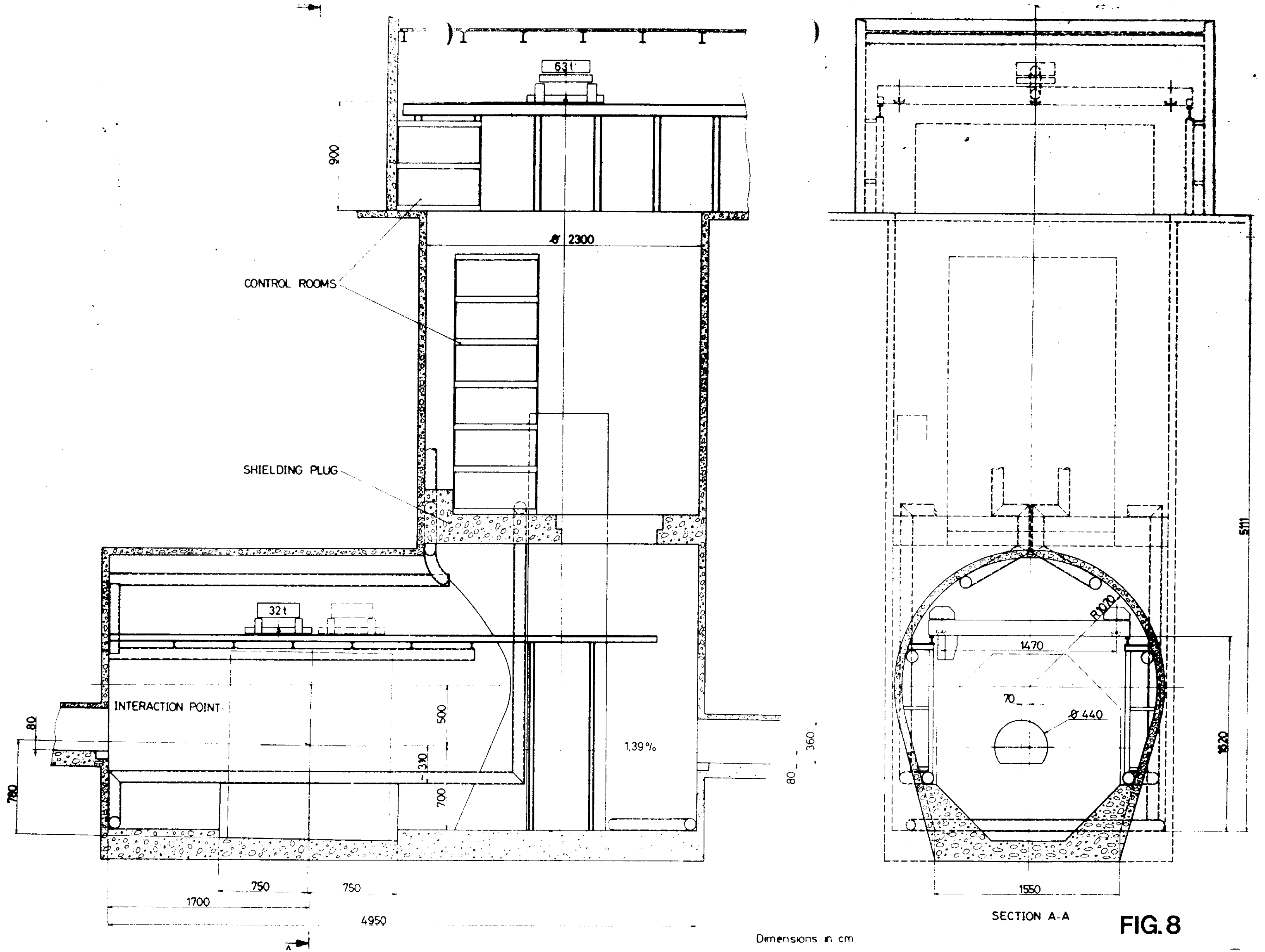

LIFT
MUON CHAMBER MODULE
MUON CHAMBER ASSEMBLY POSITION
DISCHARGE AND LOADING ZONE
32 ton crane hook limit
32 ton crane hook limit
ø 23 m
ø 21.4 m
15.5 m
17 m
21 m

FIG. 7




Dimensions in cm

FIG. 8

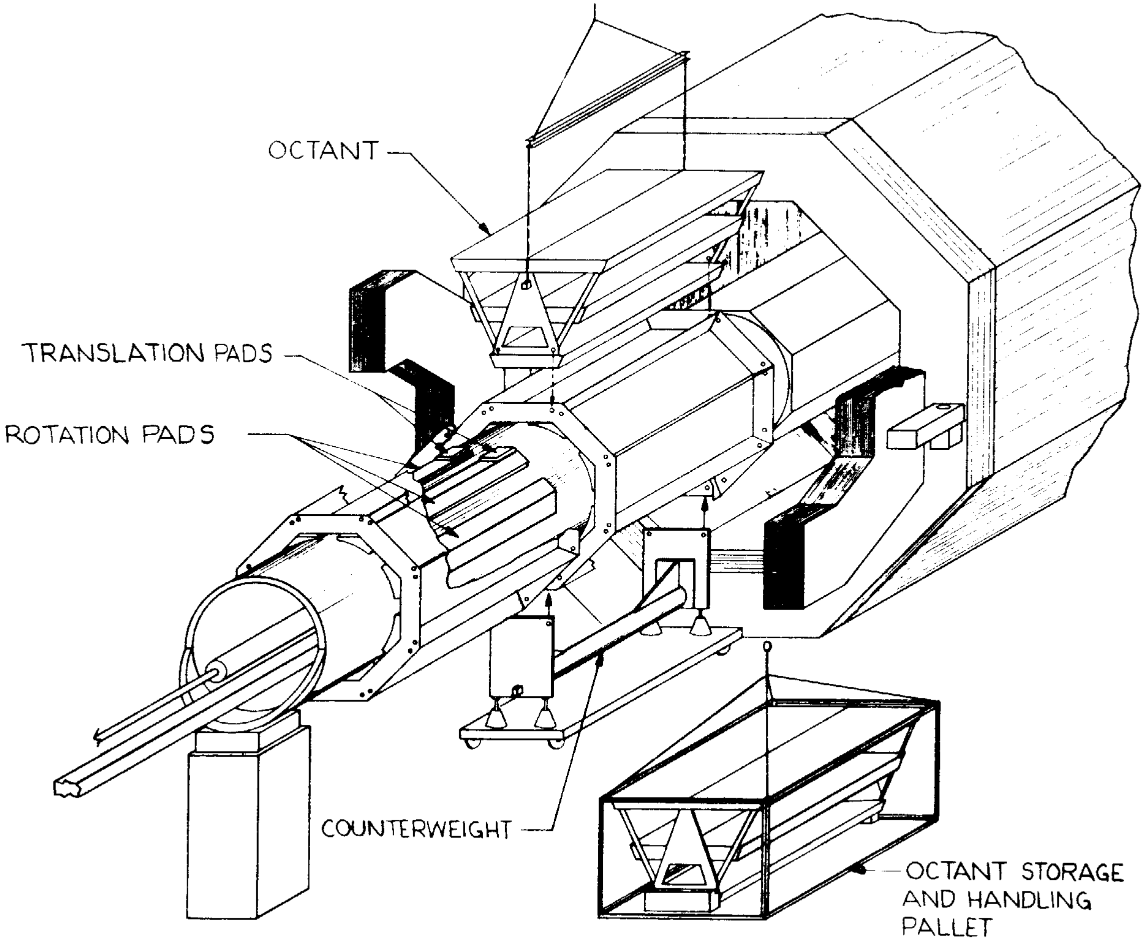



**FIG. 9** MUON DETECTOR MECHANICAL DESIGN

# General Detector Assembly Schedule

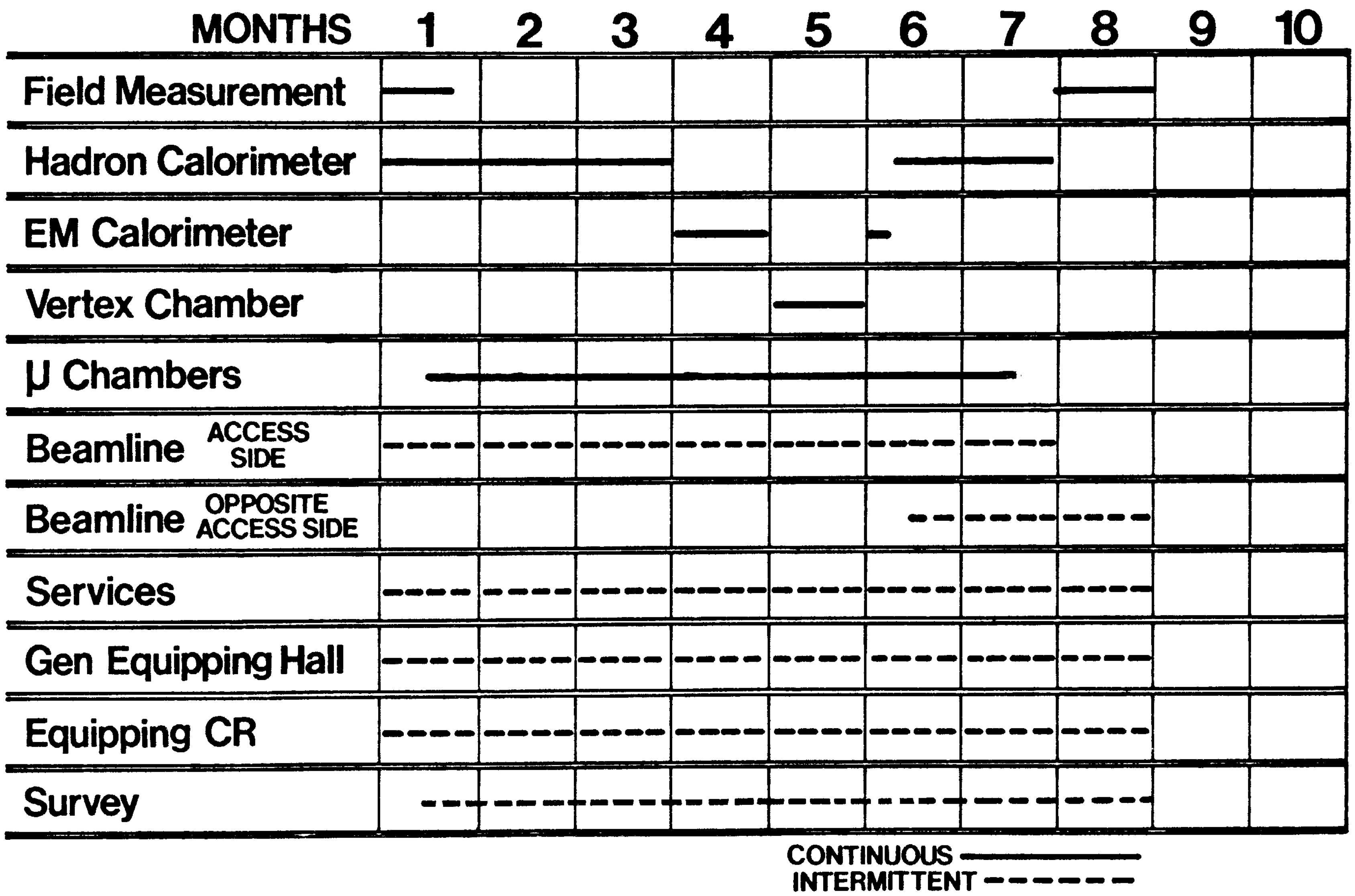



FIG. 10

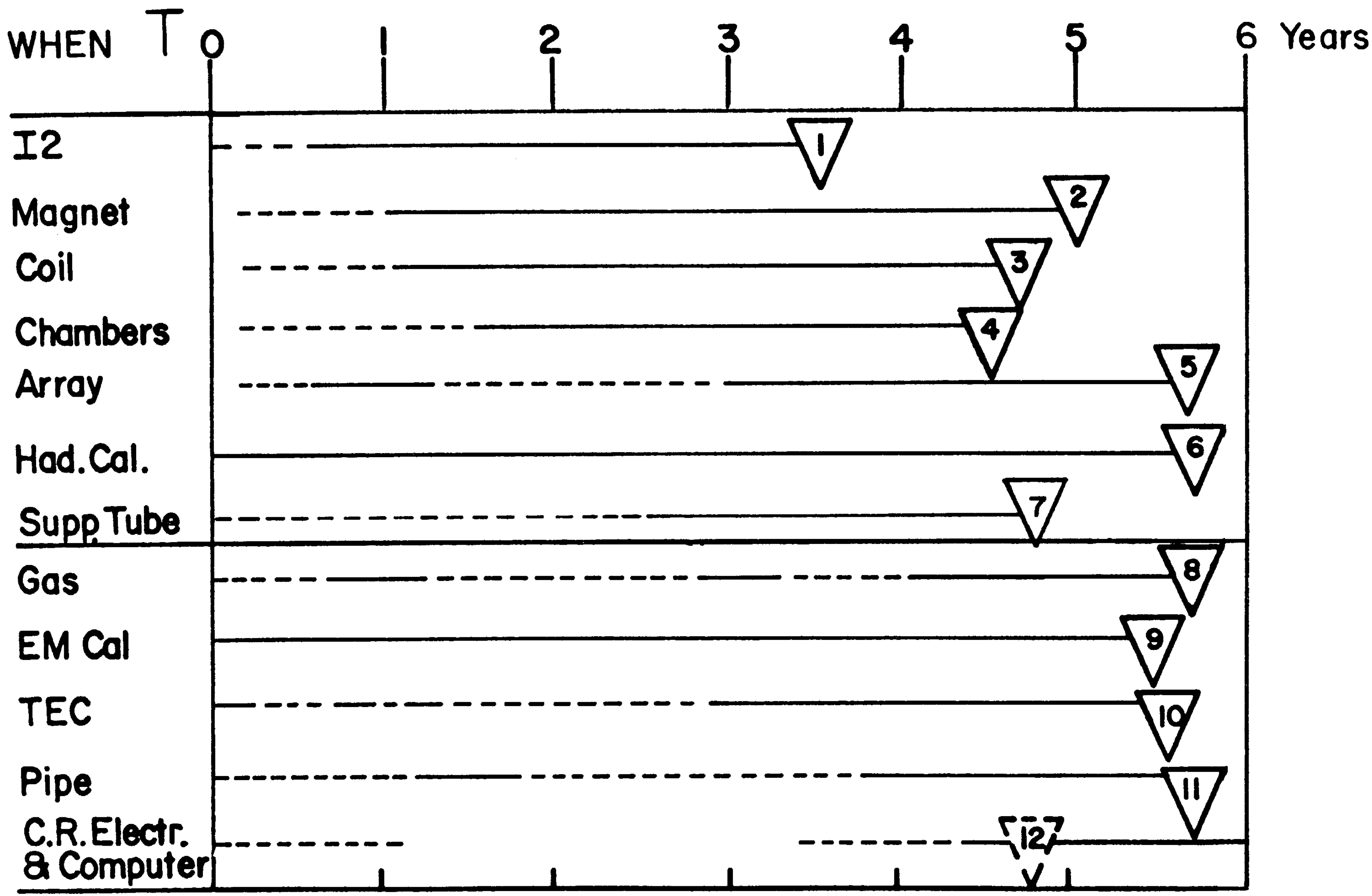

WHEN
T
0
1
2
3
4
5
6
Years
I2
Magnet
Coil
Chambers
Array
Had. Cal.
Supp Tube
Gas
EM Cal
TEC
Pipe
C.R. Electr.
& Computer
1
2
3
4
5
6
7
8
9
10
11
12

FIG.11 a

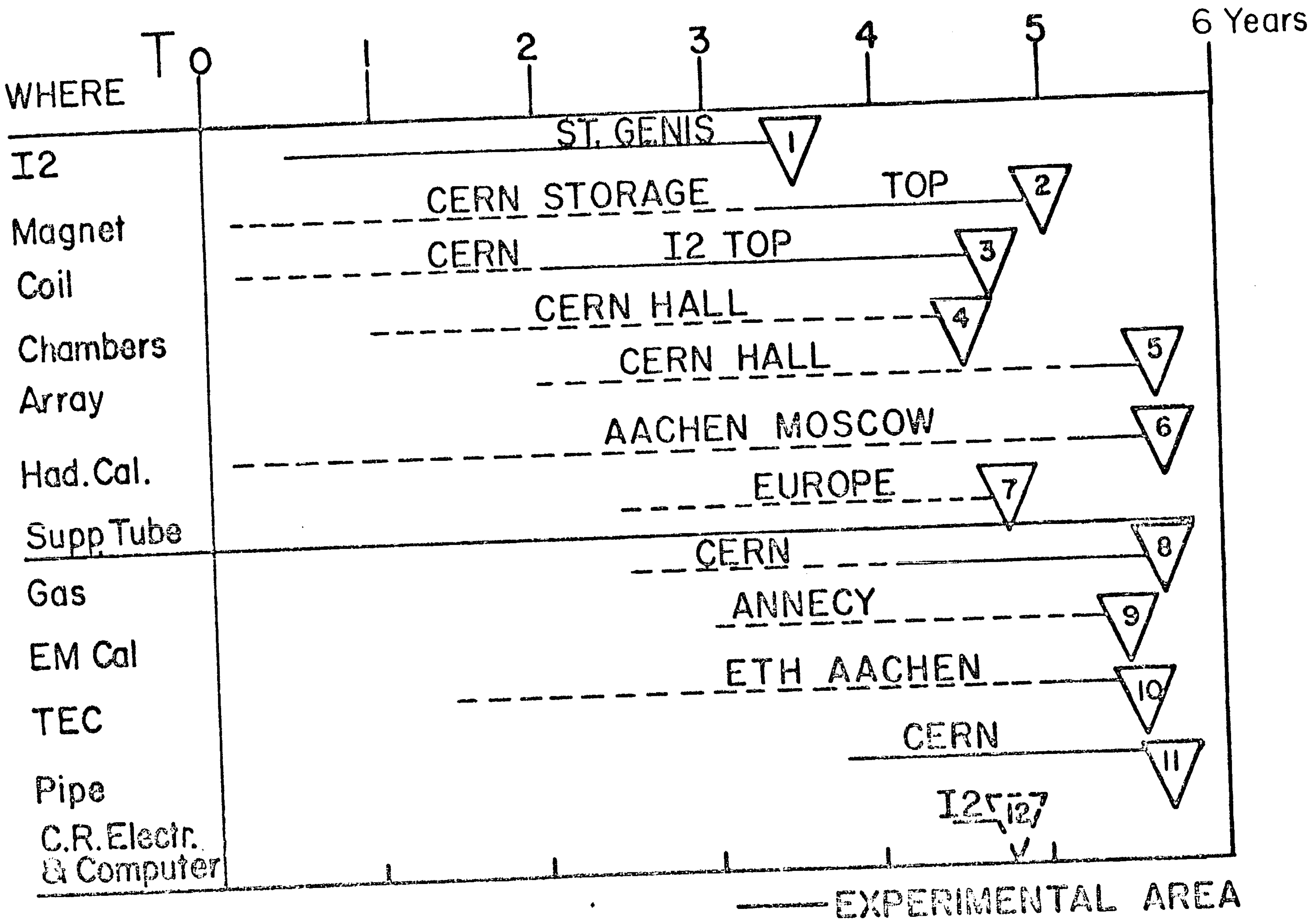

WHERE
T0
1
2
3
4
5
6 Years
I2
Magnet
Coil
Chambers
Array
Had.Cal.
Supp.Tube
Gas
EM Cal
TEC
Pipe
C.R.Electr. & Computer
ST.GENIS
CERN STORAGE
TOP
CERN
I2 TOP
CERN HALL
CERN HALL
AACHEN MOSCOW
EUROPE
CERN
ANNECY
ETH AACHEN
CERN
I2
EXPERIMENTAL AREA

FIG.11 b

CHAPTER 4

# MAGNET AND EXPERIMENTAL AREA

## A. INTRODUCTION

The design of the experimental hall has been adapted to the particular need of L3 equipment. The major difficulty has been to create an experimental area that would introduce a minimum of limitations in the detector design without violating basic civil engineering requirements. The basic concept of the L3-magnet has had a decisive influence on the hall design, i.e., a "magnetic cave" supported by the hall foundation giving the largest possible magnetic volume. Finally, the considerable weight of the magnet and the relatively short installation period made it necessary to find a convenient and direct access to the experimental area.

The magnet's present design has been adapted to the request of the collaboration and CERN, taking into account the dimensions imposed by the civil engineering. The maximum DC power authorized for the magnet has been spread over the maximum free volume for the coil. Finally, standard industrial capabilities have been considered for the basic design.

The support tube, as its name indicates, supports all the detectors inside the magnet. It provides for the complete experiment to be fully independent of the magnet structure. Not only must the tube act as a support for the detectors in their working positions (Fig. 1), but it must also provide a guiding structure for the mounting and dismounting of the various detectors, mainly for the hadron calorimeter and the muon chamber assembly. During the radial muon chamber installation, the LEP beam-line must also be supported by the tube.

The following institutions are contributing to the group activities: CERN, ETH Zurich, ITEP Moscow and MIT Cambridge.

The major engineering contribution is given by the CERN group: EHS-L3 support. This group, which is led by D. Guesewell, has been built up by the CERN EF Division. The divisional activities of EF devoted to the LEP experiments are coordinated by F. Bonaudi. Additional support to this group is given by: D. Luckey, M.I.T., J. Tarrh, M.I.T., G. Chanel and M. Feldmann from CERN.

The responsibilities have been distributed as follows :

| | |
|---|---|
| Experimental area: | O. Leistam |
| Magnet: | F. Wittgenstein |
| Detector support tube: | A. Hervé |
| General engineering support: | M. Harris |
| Survey linkman: E. Menant | |

O. Leistam is the linkman to the LEP machine group.

Meetings are organized weekly at CERN (Friday, 2 p.m., Building 892). The minutes are issued by O. Leistam.

## B. EXPERIMENTAL AREA

### I. LONGITUDINAL HALL

The standard hall design (see drawing LEP-ESI-2000-103) was designed for the roll in - roll out concept and is, therefore, clearly unsuitable for the fixed design of the L3-magnet. Instead, a longitudinal hall, having the same volume and cross-section as the standard hall, becomes a more realistic alternative. It furthermore facilitates the axial installation of detectors into the magnetic volume. In the standard hall design, this would not be possible without providing large side alcoves.

The size of the largest pieces for the magnet determines the size of the access to the hall. As described later, the longest iron piece is 12.3 m and the complete coil has a diameter of 14 m. It is also accepted that the installation of the magnet is irreversible and the maximum-access cross-section, after the completed installation of the magnet, is limited to 8 m x 5 m. This opens the possibility to use part of the access shaft for other purposes.

Fig. 2 shows the proposed hall design for the L3 experiment. A 23 m diameter and 52 m deep access shaft is joined to a 21.4 m diameter, 26.5 m long hall. The foundation of the hall has been adapted to the size of the magnet so as to allow the overhead cranes to span the entire width of the magnet. The vertical access shaft has the combined function of access for personnel and hall services (lifts, staircases, water pipes, gas pipes, cables, air cond. ducts), to provide space for a multistories counting room (see B.III) and to serve as access for the experimental equipment.

The safety aspects in the design of the experimental area are described in chapter on Safety.

## II. CRANES

All parts of the L3 experiment have been adapted to a maximum weight of 60 tons. A single 63-ton crane placed on the surface is therefore required to serve the access shaft and overlap with two 32-ton cranes in the experimental hall.

## III. COUNTING ROOM

The various activities in a counting room have different requirements concerning air conditioning, noise level and distance from detectors (cable lengths). In L3, the counting room has therefore been divided into three different parts following these different requirements.

a. Equipment Control Room:

Six floors, each 100 $m^2$, of equipment control room are installed in the 23 m diameter access shaft. Two floors are reserved for air-conditioning and experimental area services. The minimum cable length to the bottom floor is about 50 m.

b. Offices and Computer Room:

Space for offices and computers, of approximately 300 $m^2$ should be placed on the ground surface in close vicinity to the access shaft.

c. Rack Space Near the Detectors:

In order to avoid reamplification of the signals from the detectors and to provide short cable and gas tube runs, it is necessary to arrange 60 $m^2$ of rack space within 25 m distance from the interaction point. This is possible by providing space in the bypass (US 25) cavern. Access should be possible, even during LEP operation, via the machine access shaft (PM 25).

## IV. SURFACE BUILDINGS AND ASSEMBLY HALLS

The need for surface buildings and assembly halls, in close vicinity to the access shaft of the experimental area is determined by the detailed design and assembly procedure of each detector system. The assembly and fabrication of the magnet must be performed in situ, since even short transport on normal roads is practically excluded. Most detector systems must undergo final tests and survey immediately before installation. These operations can only be performed in a surface hall situated on top of the access shaft.

Our needs correspond to:

- 1000$m^2$ coil assembly hall, equipped with 63-ton crane capacity and having direct access to experimental access shaft.
- 1000$m^2$ coil storage space in immediate connection to above hall.
- 1000$m^2$ permanent hall (SX) for final detector assembly, equipped with a 63-ton crane and having direct access to experimental access shaft.
- Gas storage and mixing hall (SG), with 70$m^2$ for mixing and monitoring equipment.
- Space for 4 MW power supply very close to access shaft.
- Space for low-beta compressor units (according to LEP Note 357).

It is important that the implantation of the two halls is such that they have an independent access to the experimental access shaft.

## V. INSTALLATION PROGRAM

The installation program for the L3 experiment is dominated by the installation of the magnet. The foundation of the magnet, or 3/8 of the iron barrel structure, is embedded into the concrete floor of the experimental hall. This operation should therefore be interleaved with the civil engineering work in the hall and it will be necessary to use the temporary worksite crane to lower the magnet foundation into the experimental hall. In addition, the cranes in the experimental hall (2 x 32 tons) must be installed immediately after termination of the civil engineering work. The remaining part of the magnet assembly will continue after the completion of the surface hall.

The general installation program can be divided in the following blocks:

Months after official start $T_o$

```
                           To    +42   45    48    51    54    57    60    63    66
                                  *     *     *     *     *     *     *     *     *
1. Termination of
   civil eng. work for            1
   hall and access          xxxxxxx   2
2. Inst. of 2x32T cranes         xxxx   3
3. 3/8 of iron                       xxxx
4. Surface building +
   infrastructure of                4
   access shaft                  xxxxxxxxxxxxxxxxxxx    5
5. Counting room                                  6      xxxxxxxxxxxxxxxxxxx
6. Magnet assembly                                xxxxxxxxxxxxxxxxxxx    7
7. Detector inst.                                                  xxxxxxxxxxxxxxx
```

## VI. BEAM LINE LAYOUT

The layout of the beam line will necessarily become a compromise between the needs for assembly and maintenance of the central detectors and the technical and physical limitations set by the low-beta quadrupoles and by the vacuum chamber.

The present design of the LEP machine (LEP 12) is still evolving and changes in the design of the low-beta quadrupoles are not excluded.(1) The free space between the last quadrupoles has, however, been fixed to 7.0 m by LEPC (LEPC 7/82-7, 18.11.82).

The L3 beam line layout, shown in Fig. 3, is based on the most likely low-beta design and adapted to the basic requirements of the forward detector system.
The vacuum chamber consists of a central part in Be followed by a double cone arrangement. This allows the forward detector to cover the angles between 25-120 mrad with a minimum of obstructing material.

It should be stressed that Fig. 2 represents a conceptual design and will most certainly evolve with the design of the central detectors and the engineering study of the low-beta magnets.

## VII. BACKGROUND AND COLLIMATORS

The various sources of particle background that can be expected at LEP will have the following origins:

off-momentum electrons
synchrotron radiation from bending magnets
synchrotron radiation from quadrupole magnets
beam losses
beam-beam induced radiation
indirect "skyshine" from LEP tunnel.

The degree and kind of background which can be tolerated differs significantly among the different detectors and a separate evaluation of the background must be made for each detector system.

In the following, some general statements will be made about the character of each of the various types of background.
It should be stressed that background calculations are heavily dependent on the beam parameters and the design of the low-beta quadrupoles. Changes to the beam emittance for instance could greatly affect the calculations, e.g., doubling the emittance increases the incident photon flux by two orders of magnitude.

### a. Off-Momentum Electrons

The backgrounds from off-momentum particles to be expected with LEP at 51.5 GeV have been calculated using the program Decay-Turtle.(2) These backgrounds depend of course of the vacuum quality achieved in the machine, and estimates have been obtained of the expected residual pressures and gas compositions in the regions of interest.

Following the earlier work reported in LEP notes 164 and 186 in which the region upstream of the weak bend was found to be the major source of these backgrounds, the LEP vacuum group responded by adding increased pumping capacity in the last full bending magnet and in the weak bend. This should reduce the residual pressure and hence the background from that region by a factor of six.

As LEP 12's magnetic structure, particularly that in the straight section, is currently undergoing major revision, the backgrounds have been calculated using the more reliable LEP 11 structure, but with the latest values for the low beta magnets. A moveable collimator will be necessary in the region of Q6, about 120 m from the interaction region. This collimator will effectively eliminate all particles of energy greater than 40 GeV produced upstream of the weak bend.

The presence of collimators between the low-beta quads, QS2 and QS1, is already foreseen to provide shielding from synchrotron radiation. These shields will also reduce the off-momentum particle background within 3.5 m of interaction region by a factor of 2. The resulting rate of off-momentum particle in this region is calculated to be $1.6 \times 10^{-3}$ particles per bunch for each beam, which gives a total integrated rate from both beams of 140 particles/sec.

b. Synchrotron Radiation from Bending Magnets

This background results from bending of beam particles in the magnetic field in the last dipole magnets before the straight section. A LEP dipole generates large numbers of low energy photons: $5 \cdot 10^{16}$ $\gamma$'s/mA/beam with a critical energy of 98 KeV and a lower energy cut-off at 10 KeV.

Photons with energies above the absorption cut-off value for a given beam pipe material (about 20 KeV for aluminium, and about 5 KeV for beryllium) will penetrate through the pipe and deposit energy in sensitive elements of the detector by photoelectric absorption and Compton scattering. Since very large numbers of photons are involved, the pulse-to-pulse variation of energy deposit is small; this would result in a relatively sharp turn-on/turn-off level for a detector with a fixed threshold, such as a scintillation counter or a rather constant amplitude analog signal such as current in a proportional counter. This is to be contrasted with beam-gas events (off momentum electrons) which occur with "poor statistics" and are characterized by large fluctuations in energy deposit.

The synchrotron radiation is emitted strongly forward along a line tangent to the electron trajectory and inside a cone having a very small opening angle. Most of this background strikes the walls of the vacuum pipe in the straight section or is stopped by a collimator situated at 100 m from the intersection point. It has been estimated (LEP note 413) that less than $10^4$ $\gamma$'s/mA/beam will escape the collimator and strike the wall of the vacuum chamber in the vicinity of the interaction point.

c. Synchrotron Radiation from Quadrupoles

The other source of synchrotron radiation is the intersection quadrupoles. Since these magnets are situated relatively close to the detectors, shielding is a much more difficult problem. In fact, this is the **major** source of potential synchrotron radiation to the experiment, with nearly $10^{16}$ $\gamma$'s/mA/beam being radiated towards the detectors.

A study (LEP note 439) of the background to be expected from quadrupole synchrotron radiation has been made using the LEP 12 parameters. The flux, average energy, and direction of the radiation generated clearly depends on the LEP configuration (e.g. beam size, quadrupole strengths and positions, etc.) and beam energy, while the amount of synchrotron radiation detected depends on the local geometry (collimators, beam pipe, detector locations) and the properties of the materials (reflectivity, transmittance for photons).

The study uses a computer simulation of the generation of synchrotron radiation in the two intersection quadrupoles, given the strengths of these elements and the intersection beam parameters. The initial beam of photons is made to scatter against the actual geometry of the vacuum chamber and aperture obstructions. The reflected and re-radiated photon flux is tracked towards in a 4 meter section of the central vacuum chamber.

With a 160 mm central vacuum chamber and a collimator placed at distance of 8-9 m from the intersection point, the resulting photon flux is $10^4$ $\gamma$'s/mA/beam. Using the LEP 12 luminosities, this could give a total number of photons/bunch of less than 10.

The result of the above calculations must be considered as optimistic and only valid for a "perfect machine". Any change in the beam phase space or even slight off-centering of the beam relative to the magnetic axis or a non-gaussian population of beam particles could change the background by several orders of magnitude.

d. Beam Losses

Beam losses occur during injection or as spontaneous loss of a large number of beam particles, presumably due to some beam instability or power transient. These events should occur relatively rarely and therefore they do not present a serious background problem. However, the dose deposited by such a beam loss could be considerable and limit the lifetime of dose-sensitive detectors.

It is therefore important that the aperture in the intersection region is large enough to guarantee minimum losses during injection.

e. Beam-Beam Induced Radiation

The synchrotron radiation emitted by one beam does traverse the intersection point and encounters the electrons in the other beam. The luminosity for this process has been calculated and reported in the first LEP design study (CERN/ISR-LEP/78-17).

There is another source of synchrotron radiation which contributes to similar photon-electron interactions: the electromagnetic field created by one beam in the interaction point acts on the opposite beam and generates bremsstrahlung radiation.

Most of this beam-beam radiation will be emitted at very small angles and therefore will add to the general flux of backscattered radiation.

f. Indirect "Skyshine" from LEP-Tunnel

The large amount of radiation generated by the bending magnets and electron radiation from the RF cavities will give rise to a low energy "skyshine" channeled, by the LEP tunnel, towards the intersection.

In order to prevent this radiation from entering the experimental hall, thick (20-30 $X_o$) shielding walls should be placed in the LEP tunnel as close as possible to the experimental hall.

VIII. SERVICES REQUESTED FROM CERN/LEP IN THE EXPERIMENTAL AREA

The L3 collaboration expects CERN to provide the experimental hall and surface buildings with the necessary services (cranes, power, water, air-conditioning, etc.) according to what has been outlined above.

CERN should furthermore provide the basic elements of the beam line; the low-beta quadrupoles, a vacuum chamber, collimators or radiation masks.

Due to the very high accuracy requirements of several of the L3 detectors, it will be necessary to have a dedicated and substantial assistance from the LEP survey group throughout the assembly and installation period. The initial (and very important) alignment of the magnet will also require the help of the LEP survey group.

Special transport to CERN, transports within CERN, and the operation of cranes will require the assistance from the CERN transport group.

It is understood that an infrastructure budget is available within the EF Division to cover the cost for "individual" experimental services, such as:

radiation shielding
counting room structure
electrical distributions
refrigeration units and distribution
ventilation systems
gas detectors
gas storage
alarm systems
interlocks
communications systems (audiovisual)
special vacuum chambers

Since the whole experimental installation must be terminated before LEP starts, it is of great importance that the CERN services and the LEP construction program be integrated with the installation program of the L3 experiment.

## C. MAGNET CONCEPTUAL DESIGN AND OVERALL DIMENSIONS

### I. ENGINEERS GROUP

The last description of this magnet is given in a report of 1982 presented by the Francis Bitter National Magnet Laboratory.[3] After the acceptance of the project by the council of CERN, the responsibility of the magnet has been transferred to CERN.

An "AD HOC" engineers' group has been built up to design manufacture and implant this magnet under the responsibility of F. Wittgenstein.

The coil design, the manufacturing process, the transportation, and its implantation shall be executed under the responsibility of M. Feldmann.

The magnetic frame design, its manufacturing and assembly, the implantation in the experimental area shall be carried out by A. Herve. The tests, measurements, data acquisition operations, and the definition of the electrical power supply shall be performed by F. Wittgenstein.

## II. DESIGN

The goals of the previous report(3) remain valid, as described in the next sections of this chapter. The details of the manufacturing concept have been worked out.

## III. COIL

The joints of the 8 sectors building a turn are welded using the electron beam welding technics. The advantages of this electron beam system are due to the high power density of the electron beam, the purity of the atmosphere in which the weld takes place, the stiffness of the electron beam, which allows welding in all positions and the production of narrow, deep-penetrating welds of high joint efficiency, and last but not least, a reduction of the manpower costs due to the high speed of welding and to the excellent reproducibility of the results.

The selected material--Anticorodal 041 with heat treatment 71--has about 6% less conductivity than pure aluminium (electrolytic aluminium 99.5%e) but at least a 3 times better mechanical strength and better welding capabilities.

The rated current has been kept to a level of 30 kA as a consequence of a compromise between the production capabilities of aluminium suppliers, the number of turns (manufacturing costs), and the troubles inherent in the transport of high currents.

The cooling shall be provided by two independent water circuits consisting of aluminium tubes (Extrudal 050) welded by the MIG process on the edges of the aluminium sectors; each circuit is dimensioned to evacuate the full power of the magnet.

The assembly process in the pit should be reduced to a minimum. Therefore the assembly of the turns being carried out in the direct vicinity of the pit, the pre-assembly, should be started as soon as possible on the present CERN site. It is foreseen to supply the first working station with sectors ready for welding and already equipped with welded cooling tubes prepared by the industry. All other operations shall be carried out by CERN.

### IV. IRON FRAME

The main contributions of the steel frame are to increase the quality of the field homogeneity and to increase the field by 30%. The restrictions concerning the maximum outside dimensions and the detector requirements for the inner free bore of the magnet increase the previous induction in the pole and in the return path.

Inexpensive long bars assembled in bundles can be used for the barrel. However, the pole pieces subjected to difficult mechanical conditions (moveable doors to allow access to the internal detectors), important stresses given by the magnetic field and need to secure the mechanical rigidity of the whole setting up request the use of 1/3 in weight of more expensive cast elements.

### V. INTERNAL COOLING SHIELD

To avoid large temperature gradients in the magnet free bore, the internal diameter of the magnet coil will be covered with a cooled skirt. An intermediate insulation should restrict the installed cooling power (water) to 5% of magnet power.

### VI. OVERALL DIMENSIONS AND DATA

Figs. 4, 5, 6 and 7 give the L3 magnet parameters, magnet dimensions stacking, magnet geometry and magnet flux lines.

## D. MAGNET COIL FABRICATION

### I. INTRODUCTION

The L3 magnet coil will be constructed from 1/8th sections of a single turn. These sections will be supplied by industry after completion of machining and fixing of the cooling circuit tubes.

At CERN, the assembly of 336 half-turns by electron beam welding four 1/8th sections together and manual TIG welding of the cooling circuit connections will be performed at the first work site (Hall 1). (Fig. 8) The half-turns will then be transfered by a special trailer to a second work site (Hall 2) close to the access shaft P2 for the experimental area.

On this second site, the electron beam welding of half-turns to form 28 packages of 6 full turns, fitting of the insulation, manual TIG welding of cooling circuit connections, and fitting of the mechanical blocking clamps, will be performed (Fig. 9).

By means of an overhead crane the packages will be lowered to the experimental area where two other overhead cranes linked together will be used to move the packages into their final position; there the electrical connection between packages will be performed by manual MIG welding and cooling circuit connections will be made by manual TIG welding.

A schematic representation of the construction procedure for the coil is shown in the attached figure. (Fig. 10)

## II. WELDING PROCESSES

For the coil construction, three welding processes are required, namely:

Manual MIG welding for the electrical connection between packages.

Manual TIG welding for the cooling circuit connections.

Electron-beam welding for assembly of the 1/8th coil sections.

The first two processes are conventional welding technologies and require no technical development. For assembly of the 1/8th sections, the L3 collaboration has ordered through CERN an electron beam gun whose main characteristics are: Power of 45 kW and high voltage of 60 kV, resulting in a beam current of 750 mA.

Control of the welding parameters during the weld cycle will be performed by a numerical computer control system. The auxiliary equipment for the electron beam welding gun is being studied by the CERN SB Central Workshop design office, and involves essentially the upper local vacuum chamber with X and Y movements for the gun, the lower local vacuum chamber with support plate for the molten weld pool, the turntable to support the 1/8th coil sections, and the vacuum system (Fig. 11).

## III. WORK PROGRESS

A series of electron beam welding tests on 60 mm thick Antico 041 is underway in the SB Central Workshops. These tests should allow determination or control of the feasibility of the process, of the inherent defects of the process and of the Anticorodal 041, of the temperature profile as a function of distance from the weld, and of the welding parameters.

The results of these first tests are encouraging.

A contract has been passed with a specialized Institute to study the conditions for the electron beam welding. The first conclusions from this study confirm the results of the CERN tests, and we are now considering the possibility of obtaining a metallurgical analysis of the welds through a university. A first short finite element analysis of the stress and temperature distribution in the coil has been performed at CERN. It has shown that this problem is not critical. A model is being used at CERN to examine the current distribution in the inter-package connections.

## E. IRON FRAME

## I. INTRODUCTION

The present design (Fig.12) is based on a magnet of octagonal shape with swinging doors at both ends. The external dimensions of the structure are 13.6 m in length and 15.6 m in height. The thickness of the poles is 0.9 m and the thickness of the return yoke is 0.765 m. The total weight of the iron frame is around 6000 tons.

We have tried to minimize the cost of the structure by using as far as possible unsophisticated techniques, bearing in mind that the amount of work to be done in the underground area must be kept to a minimum and that the crane usage must also be minimized, and thus the various pieces must be designed at the maximum crane capacity. Even in these conditions the assembly of the magnet in the experimental hall is clearly on the critical path.

## II. DESCRIPTION OF THE STRUCTURE

The basic structure (Fig. 13) is a self-supporting skeleton made up of 1000 tons of cast pieces giving the structural rigidity and being used as a support and as a reference frame for the mounting of the filling material. The pole structure (both crowns and doors) is made up of cast open frames (Fig. 14). The filling material (5000 tons in total) is there to provide the mass needed for the magnetic flux return both in the poles and the barrel. The filling will be made up of 50 mm thick iron plates cut to the desired shapes. Fig. 15 shows how the various types of plates could be arranged in individual masses of 50 tons for the barrel and 25 tons for the poles.

To replace the cast pieces, a construction using welded plates is also under consideration.

## III. STRUCTURAL INTEGRITY

Even if the field strength is relatively low, causing a magnetic equivalent pressure of only one bar on the poles, the enormous surface on which these forces act creates stresses in the poles which must be carefully studied.

Theoretical analysis by strength-of-material techniques indicates that the most delicate parts are the door elements. These doors could be described as a semi-circular pierced flat ring (Fig. 16a) submitted to a uniform load over the entire surface, supported on its outer edge, the inner edge being free. Consequently, this plate deflects. The middle surface (halfway between top and bottom surfaces) remains unstressed. The maximum stress occurs at the surface of the plate. At the nominal field (0.5 T) the maximum deflection of the inner corner of the door is 27 mm and the maximum applied stress is 7.3 daN/mm$^2$. Although this stress level is acceptable for the bending stress of the massive pieces, it does create problems at the boundary between two adjacent elements. The bending moment can only be transmitted if the two pieces are welded together on their inner oundaries. This weld will be done in the underground area before loading the filling material.

The external part of the poles (or crown) could be described as a circular pierced flat ring (Fig. 16b). This ring is submitted to the axial load of the door on its inner edge, a variable load on its surface due to the magnetic field and is supported on its outer edge. To take into account the fact that the crown is supported on the full return yoke width, the following model has been used:

The crown is supported on its outer rim, but another support is provided at the inner edge of the return yoke, and the reaction at this diameter is chosen such that there is no deflection between those two diameters. In these conditions the deflections and the stresses induced in the crown are small. However, this favourable stable situation can be achieved only if the magnetic pressure between pole and return yoke is sufficient. To prevent any problem of stability, prestressed cables will be strung on the outside diameter between the two poles to produce a total force of around 1000 tons.

### IV. ASSEMBLY PROCEDURE

Although final details have yet to be worked out, the scenario for the assembly of the complete magnet could be summarized as follows:

Assemble 3/8 of the return yoke, align it with respect to the beam, and pour concrete to get a stable reference structure (Fig. 17).
Mount the coil on this structure (Fig. 18).
Mount both poles (crowns and doors) with empty open frames; check operation of doors (Fig. 19).
Assemble the rest of the return yoke.
Load the filling material in the pole structure (Fig.12).

## F. MAGNET TESTS, MONITORING, DATA ACQUISITION, AND POWER SUPPLY

### I. TESTS

a. Welding.

As already reported in section D.III., tests are performed at CERN and in outside laboratories. Analysis methods should be developed to check easily the quality of joints.

b. Manufacturing Al Sectors.

An order for the delivery of 4 Al sectors completely equipped with cooling tubes shall be placed very soon. These prototypes will go through the industrial process foreseen for the production of the whole lot.

c. Electrical Tests.

A test power supply 40kA/7.5V has been ordered and when installed will allow to check joint quality and connection design.

d. Thermal Tests.

Can be run soon, together with the electrical tests.

e. Magnetic Tests.

A measurement station has been equipped to measure the magnetic parameters of long iron bars.

## II. MONITORING AND DATA ACQUISITION.

For the measurement of the high current, a NMR system is envisaged. Water flow, pressure, temperature distribution and stresses will be monitored using standard analog devices. Digital transmission will secure a good signal quality.
Because of the lack of time, a full field mapping cannot be envisaged before starting the assembly of the detectors.

It is foreseen to equip the supports of the muon-chambers with a large amount of cheap Hall plates to be calibrated individually. Computer programs should be developed to clarify the field distribution as soon as the iron frame will be better defined in quality and geometry.

## III. POWER SUPPLY.

Discussions with the industry have shown that the manufacturing of this device presents no special problems. However, because of the noise level, only diodes should be used in the DC circuit. Thyristors should be avoided but eventually tolerated in the AC circuit if no other regulation system can be envisaged with the given time constant.

## G. MAGNET TIME SCHEDULE, COST ESTIMATE, AND MANPOWER

### I. TIME SCHEDULE.

The main milestones of the proposed time schedule are summarized in Fig. 20. Under the assumption that the minimum requested staff will be operatively engaged as foreseen and that the working area could be prepared in due time, following periods could be envisaged:

a. Preparation (from now to mid-1984)
Designing - ordering tools - assembly of the first working area - testing models -testing welding process - ordering Aluminium and Steel.

b. Welding Half-Turns (until beginning 1986)
Welding - designing tools for the second working area - ordering tools - designing piping - receiving steel for basement - moving to the second working place.

c. Welding Full-Turns (until mid-1987)
Welding - packing - receiving the steel - designing busbars - ordering electrical power supply - assembling base of the steel frame.

d. Assembly (until mid-1988)
Assembling coils and auxiliaries - assembling the complete steel structure.

e. Magnetic Measurements and First Detectors Assembly (until end 1988)
Finishing magnet assembly - power tests - first field mapping-detectors.

### II. COST ESTIMATE.

Figs. 21, 22 and 23a, b give a project description report, a columnar job report and a job description. (In these figures costs are expressed in US dollars). As of April 1983 orders have been placed for a total of about 800 kSfr, especially concerning the electron beam welding gun N01 and some auxiliaries and the electrical test power supply and auxiliaries for the test station. First discussions with aluminum, iron, and insulation suppliers allow us to estimate properly the major investments of the project. These items represent about 2/3 of the total estimated cost.

The job has been subdivided into about 50 tasks and the analysis is made on a quarterly basis (3 months).

A rough distribution of the monetary cost needed in addition to the USSR steel and auxiliaries is shown below:

| | kSfr | kSfr |
|---|---|---|
| Coil (including cooling circuits): | 12800 | |
| Tools for coil, working area: | 1900 | |
| Iron frame: | 7075 | |
| Tools for iron frame: | 520 | |
| Test + measurements: | 755 | |
| General expenditures: | 1050 | |
| TOTAL: | 24100 | |
| Expressed in another way | | |
| Direct cost: | | 19825 |
| Manpower cost: | | 3225 |
| General expenditures: | | 1050 |
| TOTAL: | | 24100 |

Cost Distribution Matrix

| Year | USA | ETHZ | Others | Sum |
|---|---|---|---|---|
| 1983 | 1.0 | | 0.3 | 1.3 |
| 1984 | 2.1 | 5.0 | 1.2 | 8.3 |
| 1985 | 2.3 | 1.6 | 1.6 | 5.5 |
| 1986 | 2.3 | 1.4 | 1.5 | 5.2 |
| 1987 | 2.3 | — | 1.5 | 3.8 |
| | 10.0 | 8.0 | 6.1 | 24.1 |

## III. MANPOWER

Because of the shortage of manpower at CERN, the "AD HOC" task force engaged in this project should be supplemented by outside manpower. The actual figure concerning this item is evaluated to about 600 man-months.

## H. MAGNETIC FIELD HOMOGENEITY

It is essential to have as homogeneous a field as possible so that corrections to the trajectories of high energy muons are minimized, and more importantly, that the corrections due to different Lorentz angles in the drift chamber are known and do not limit the required accuracy.

Fig. 24 shows the effects of not knowing the drift angle in the worst case.

Suppose that a particle goes very near the cathode and one measures the drift time t. Then assuming a drift velocity v and Lorentz angle in the magnetic field one can calculate the x-coordinate. The relative error in x is equal to the error relative to the axial magnetic field times the sine squared of the Lorentz angle.

For a drift of 50 mm and an angle of $20^{\circ}$, an error of 1% in B results in a error of 50 microns. Large magnets have been measured and fitted with 20-30 gauss RMS errors (axial components) so that with a sufficiently elaborate map one can correct for the drift angle to satisfactory accuracy.

The important place to know these fields is at the drift chambers, and it is planned that their outer surfaces can be used to move measuring probes. The field between the two surfaces can then be found using the method of H. Wind.[4]

Since we are only interested in the component parallel to the wires of the drift chamber, we may need to measure only one component.[5] The high precision is needed only for the drift angle correction in the angular range of approximately $45^{\circ}$ to $135^{\circ}$ so that precise maps are not needed over all the surfaces. Inhomogeneity is expected near the poles, and one will have to map more points there.

Our magnet differs from the ideal in the following ways:

There are large holes in the pole pieces where there is no iron.

The coil does not occupy all the space between the poles, and the unoccupied space varies in azimuth because the coil is a helix.

The high flux density introduces local field distortion.

There are mechanical tolerances due to the use of standard industrial material and to the use of flame cutting rather than major machining.

There are asymmetries in current flow because the coil cannot be constructed in one single piece and joints must be on the outside.

We discuss below each one of these items:

The large hole in the pole does not influence the muon chamber region very much. It will result in maximum variation of the field in the TEC chamber of .24% and could influence the magnetic operating point of the second quadrupole of the machine.

The coil not completely occupying the space between the pole causes inhomogeneities near the end of the outer muon chamber. A series of calculations using a doughnut-shaped slot in which the coil begins has been started. Additional current in the turn nearest the pole lessens the problem as seen in Figs. 25 and 26. Additional calculations will be made to minimize this inhomogeneity.

The rippling of the field due to the present packing factor of the coil does not cause any difficulties in the outer drift chamber.

To estimate the effects of finite permeability on field uniformity, a completely enclosed iron cylinder of uniform permeability was studied. The coil extended from pole to pole. Fig. 27 shows the locations where a percentage deviation from the central field is plotted. In this geometry the zero deviation intersects the outer chamber about half the distance to the pole, and hence the percentage deviation is a good measure of the variation along the chamber. Fig. 28a, b shows in percentages the deviation of the field from the central field as a function of the permeability. From the figure it can be seen that 1% deviations at point a require a permeability greater than 110 and at point d require a permeability greater than 170 or, expressed another way, if the flux density is 1.9 T then the permeability is about 100 and the accuracy about 1.5%.

For economy it is planned to build the magnet out of commonly produced steels. In this section, we describe the effects of various impurities on magnetic performance near saturation. All the impurities reduce the B field in the steel that can be attained with a given H. The effect of a one per cent contamination by various elements[(6)] is:

| Element | Change in B (Tesla) |
|---|---|
| Carbon | 0.30 |
| Silicon | 0.032 |
| Manganese | 0.075 |
| Chromium | 0.033 |
| Copper | 0.016 |
| Aluminum | 0.068 |

For the proposed USSR steel we expect a magnetic behavior equivalent to that of the British reference En2.[(7)] Fig. 29 shows a BH curve for this steel as well as a BH curve for steel castings.[(8)]

The actual B H curves for the materials we can obtain will need to be measured and put into the field program to get a final idea about what field homogeneity problems we will actually face. Mechanical tolerances can result in inhomogeneities of the same order of magnitude as the impurities.

Asymmetry in current flow due to the presence of a joint every six turns has been studied using the model shown in Fig. 30. At the distance of the outer drift chamber wall, the amplitude of field variation is less than 20 gauss, so this is not a problem.

The magnetic field can be measured using the conventional methods of Hall probes and nuclear magnetic resonance. There are other possibilities using magneto-optical effects which can be used and which we briefly describe.

Use of the Faraday effect, the rotation of the plane of polarization of a light beam moving in the direction of a magnetic field, is attractive because only a passive optical element needs to be moved around the magnetic field. The magnitude of the Faraday effect is such that a piece of lead glass 5 cm thick would rotate the plane of polarization by about $40^{o}$ in the field of 5 kG. Accuracy in rotations of $.005^{o}$ are reported in the literature[9] so that the field can be measured better than 1 part in $10^{3}$. A homogeneous optical element is needed because mechanical stress results in birefringence. The literature deals with the elimination of such effects. Fig. 31 shows a possible setup.

Fig. 32 shows another optical method in which only a lamp needs to be moved on the drift chamber surface; the frequency of the Zeeman effect then measures the field. Accuracy of better than 1 part per 1000 should be easy to achieve.[10]

Much preparation must go into the plans for a magnetic field map because there will be little time to do the actual mapping. The optical methods could be used in place after the experiment is assembled, and possibly while taking data.

At the given 4 MW dissipated in the coil, the central field is 0.5 Tesla.

## I. SUPPORT TUBE

### I. DESCRIPTION

The present design (Fig.1) could be described as a 50 mm thick composite tube (15.7 m octagonal part and 15 m cylindrical part) with one support at each end to transmit the load to the ground.

The outside diameter of the cylindrical part is 4.35 m and the octagonal part is 4.4 m outside flat to flat. The octagonal portion of the tube which is inside the magnet has to be amagnetic so as not to disturb the field map and the best choice seems to be 304 Stainless-Steel. All the rest, including the two supports, could be in common construction carbon steel.

The main load to be supported is the hadron calorimeter, which could weigh up to 500 tons (Fig. 33). It is clear that such a load can be supported by the tube if and only if the load is reasonably well distributed in length and along the circumference; otherwise punching effects will be present. To do that, we will provide a double-walled structure in the central section of the tube (Fig.34 ). This allows modules of 37 tons to be individually loaded in each cavity. This double-walled section will also reduce the section's deformation due to the shearing load.

Each support rests on two 500-ton hydraulic jacks equipped with oil cushions. This will allow movement of the center of the central section back to the interaction point and also will permit alignment of the local axis of the tube with the beam around the interaction point.

The total weight of the tube is around 240 tons (including supports) and it is clear that the tube has to be mounted in sections down in the experimental hall. The first design[11] was based on an assembly using re-entrant flanges and prestressed bolts. Stress analysis has shown that those flanges were difficult to design in the allowable space, and anyway they were very expensive to weld and machine. The present design (Fig. 35) is based on an all-welded assembly. Sections will be prepared near the maximum crane capacity. The sections will be arranged such that all welds between stainless-steel and carbon steel will be done at the contractor shops in order that only stainless-steel to stainless-steel or steel to steel welds will have to be done in the underground area. These welds will be part of the main contract.

## III. STRUCTURAL INTEGRITY

Although this tube is designed for minimum strain and deformation the stresses are not negligible, especially if the stress flux has to go through a bolted flange. Fig. 36 shows the analysis of the tube as a loaded beam. This analysis is certainly correct, except for the deformation of the section due to the shearing load, which is best looked at using finite element programs. This first analysis shows that the sagging will be less than 20 mm and that it will be easy, using the hydraulic jacks, to get the tube axis near the interaction point aligned with the beam. The maximum stress due to the bending moment in the lower and upper walls is around 6 daN/mm$^2$.

A first look at the structure using finite element programs[12] has shown that the section deformation in the central region will not exceed 20 mm.

A complete study, taking into account the double-walled central section and the two supports, is now in progress[13] using sophisticated finite element programs. Fig. 37 shows a view of the deformed tube (the deformations are magnified by a factor of 100).

## IV. COST ESTIMATE

In addition to the USSR stainless steel, the following cost estimate has been done using available industrial information:

| | |
|---|---|
| - Contract for independent check of structure | 65 kSfr |
| - Stainless steel part: 100 tons at 18.2 Sfr/kg | 1820 |
| - Carbon steel part: 70 tons at 6 Sfr/kg | 420 |
| - Two supports: 60 tons at 6 Sfr/kg | 360 |
| - Four 500-ton hydraulic jacks and adjustments | 135 |
| - Tooling for installation inside magnet | 150 |
| | 2950 kSFr |

The staging of expenses could be the following:

| | | |
|---|---|---|
| 30 kSfr | on | 1/6/83 |
| 40 | on | 1/1/84 |
| 750 | on | 1/1/86 |
| 750 | on | 1/1/87 |
| 670 | on | 1/1/88 |
| 260 | on | 1/1/89 |

## V. PLANNING

The tube must be mounted after the completion of the magnet. This allows enough time before ordering to adapt the support tube to the evolving design of the various detectors. However, if we foresee a delivery time of two years, the order should be placed around January 1986 for a delivery around January 1988.

The assembly time is estimated at 3 months and in the present magnet planning this assembly will take place between April and July 1988 (assuming that the civil engineering starts in July 1983).

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