LHC PROGRESS AND STATUS

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Abstract

The LHC is a superconducting collider to be installed in the LEP tunnel for high energy pp, Pb ions and ep collisions. An overall machine optimization, including a new lattice arrangement and an increased dipole aperture (56 mm), will be presented. The increased energy to field ratio is (0.81 TeV/T). Recent results from a magnet model with industrially produced coils assembled at CERN reached 10 T with a limited training and ultimately attained 10.5 T. demonstrating that operational fields in excess of 9 T can be obtained.

Results from previous models and a 10 m-long prototype will be given. In total seven of these prototypes are being constructed by industry. In December 1991, the CERN Council unanimously adopted a resolution stating that the LHC is the right machine for the future of CERN and requesting a final proposal in 1993, which is being actively prepared and is sumarized in this report.

1. INTRODUCTION

The general design of the collider, which essentially consists of a ring of high-field superconducting magnets to be installed above LEP in the 27 km tunnel, was described in the last International Conference in Hamburg[1]. A Design Study [2] was published in May, 1991.

The magnets are of the so-called 'two-in-one' structure, namely incorporating two beam channels in the same mechanical structure and cryostat (Fig. 1).

Such a magnetic structure added to LEP can provide three types of collisions, namely proton-proton, heavy ions (Pb-Pb) and electron-proton by colliding the LEP electron beam with one of the proton beams.

The most important parameters of these collisions are given in Table 1.

Emphasis is put on luminosity since the point-like nature of quark-quark interactions implies that the cross sections decrease as the collision energy E increases. To maintain equally effective physics programmes, the luminosity should increase as E^2, and thus, to explore rare processes such as Higgs $\rightarrow$ 2Z $\rightarrow$ 4 μ, the LHC is designed to provide luminosities in excess of $10^{34}cm^{-2}s^{-1}$.

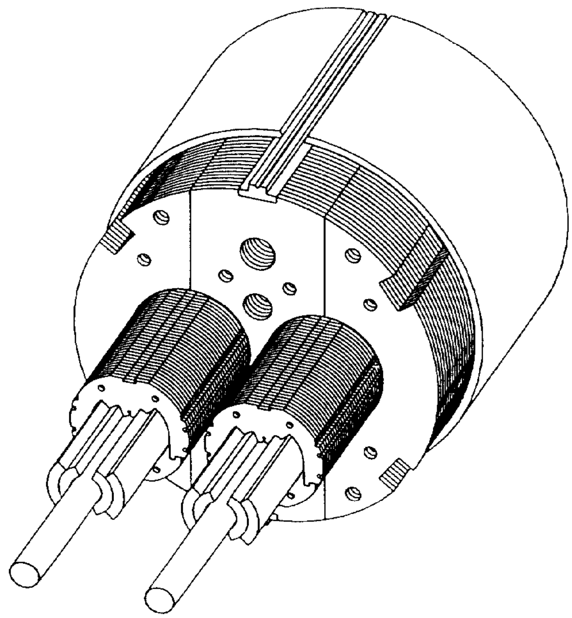

Fig. 1 Perspective view of a 'two-in-one' dipole

Table 1 : LHC Main Parameters

		pp	e-p	Pb-ions
C.m.energy for B=8.7 T	[TeV]	14.0	1.3	1150
Luminosity	[cm^{-2} s^{-1}]	10^{34}	2.5 10^{32}	1.8 10^{27}
Number of bunches		2835	508	560
Bunch spacing	[ns]	25	164.7	135
Particle/bunch	(p)	10^{11}	3.0 10^{11}	9.4$10^7$
" "	(e)		9.2 10^{10}	
Particles/beam	(p)	4.7 10^{14}	1.5 10^{14}	5.2 10^{10}
" "	(e)		4.7 10^{13}	
Number of experiments		2		1
β at intersect. point ($\beta_x\beta_y$)	[m]	0.5	0.85, 0.26 32.7, 3.05	0.5
r.m.s. radius at intersection point (x,y)	[µm]	15	120 / 37	15.9
r.m.s. collision length	[cm]	5.3	3.8	5.3
Crossing angle	[µrad]	200	0	200

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2. INJECTORS

The basic injection scheme is unchanged (Fig. 2) and makes use of all existing accelerators, namely Linac, Booster, 26 GeV PS and 450 GeV SPS for pp operation with only relatively minor modifications and additions.

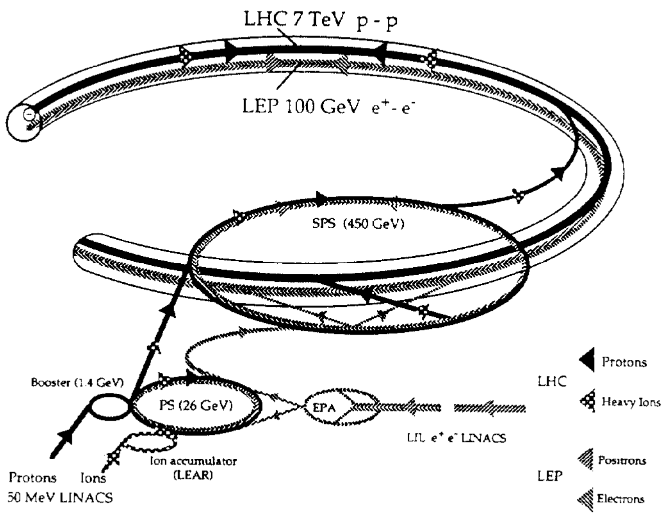

Fig. 2. The LHC injection complex

The nominal high luminosity operation requires two Booster cycles to fill the PS circumference, with the injected beam first accelerated by the existing RF system on h = 8, debunched and recaptured by a new 40 MHz RF system, to form a bunch train with 25 ns bunch spacing. The bunches are then compressed using an 80 MHz system and transferred to the SPS. Three such bunch trains are captured in the SPS and compressed to fit into the standard 200 MHz buckets by a new 80 MHz system, accelerated to 450 GeV and finally transferred into the LHC, via two new transfer lines. The whole operation is repeated 12 times to fill the entire LHC circumference.

The New developments are

In the Linac/Booster complex beams within 10% of the nominal parameters have been obtained after the installation of the new RFQ in front of the linac. A test of the LHC pre-injector, up to PS extraction energy, using prototypes in a configuration close to the final version, is scheduled for the end of the year 1993. In the SPS, a prototype of the 400 MHz LHC superconducting cavities will also be installed this year in order to test the bunch compression technique which will be required before transfer of the proton bunches into LHC.

3. GENERAL LAYOUT

The two interlaced LHC rings are placed 1.21 m above the LEP ring. The LHC lattice must follow very closely the LEP geometry, in particular the two machines must have the same revolution time in order to allow a later conversion of LHC and LEP into an e-p collider. The constraints on the compatibility of the two machines has been reduced with the decision that LEP will be stopped as an e^+e^- collider before LHC is installed; the e-p collisions will anyway require a rearrangement of both LHC and LEP insertions.

The LHC lattice is, like LEP, made of 16 half-octants (about 1.7 km long) in which one finds successively the 24 regular half-cells of the arc, the 4 pseudo-half cells of the dispersion suppressors and the long straight section. Each octant has been separately equipped with its own cryogenic plant, its own power converter set, etc. so that it can be independently installed, tested and maintained.

Two of the eight long straight sections have been reserved for the machine: SS5 for beam dumping and SS3 for beam cleaning. Four straight sections will be equipped with low-beta insertions: SS1 and SS2 reserved for large LHC experiments, the injection of the clockwise circulating beam is in SS1; SS4 (or 6) for ions collisions and SS8 where the injection of the anti-clockwise circulating beam will be made in a detuned low-beta. The two remaining straight sections, SS6 and SS7, are kept in reserve as possible alternatives or for not yet specified applications (B-physics or gas-jet experiments). This layout is detailed in Fig. 3.

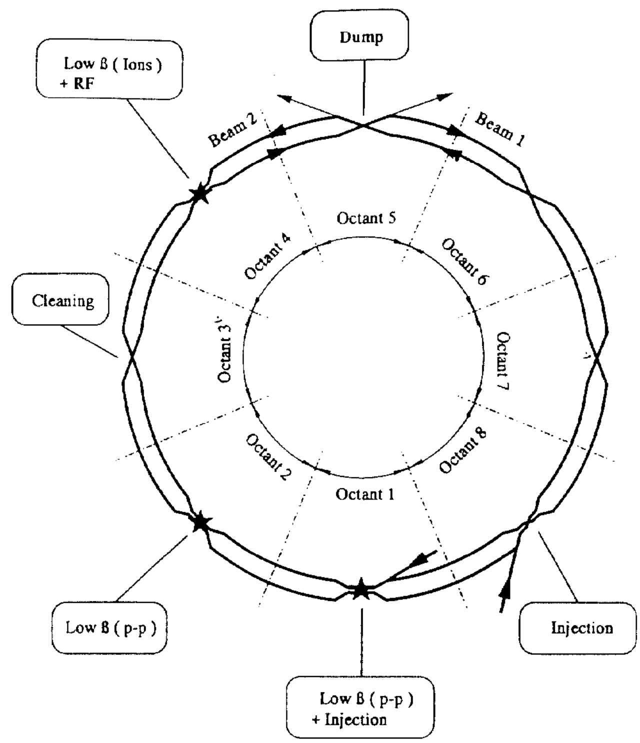

Fig. 3 LHC schematic layout

3.1. The arc half-cell

As indicated in Fig. 4 the 51 m long arc half-cell contains three 13,15 m long bending magnets and a 6.5 m long short straight section. In the straight section are installed: the 3.05 m main quad., a beam position monitor and two corrector magnets, one with a combined dipole sextupole corrector and the other one with a tuning quadrupole and an octupole corrector. A set of sextupole and decapole correctors are attached to each main dipole to compensate the field errors introduced by these superconducting magnets. The effect of these field errors on the dynamic aperture has been reduced by enlarging the dipole aperture from the previous 50 mm to 56 mm (inner coil diameter).

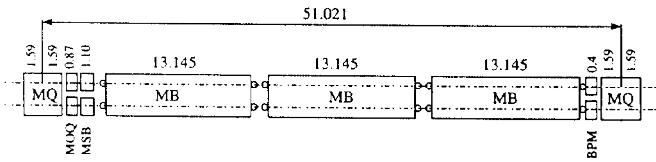

Fig. 4 The LHC half-cell
(new layout with three long dipoles)

The main magnets (dipole and quadrupole) of both rings are powered in series, one supply per half-octant, while the tuning quadrupoles allow an independent control of the tune of each ring over two integers in both planes.

A beam screen placed as shown on Fig. 5, inside the vacuum chamber allows the evacuation of synchrotron radiation power at about 10^{o}K rather than at the 1.9^{o}K of the superconducting magnet and vacuum chamber. The cryopumping is still ensured by the 1.9^{o}K vacuum chamber through holes in the beam screen. The design of this screen has raised a number of interesting problems detailed in a companion paper [3].

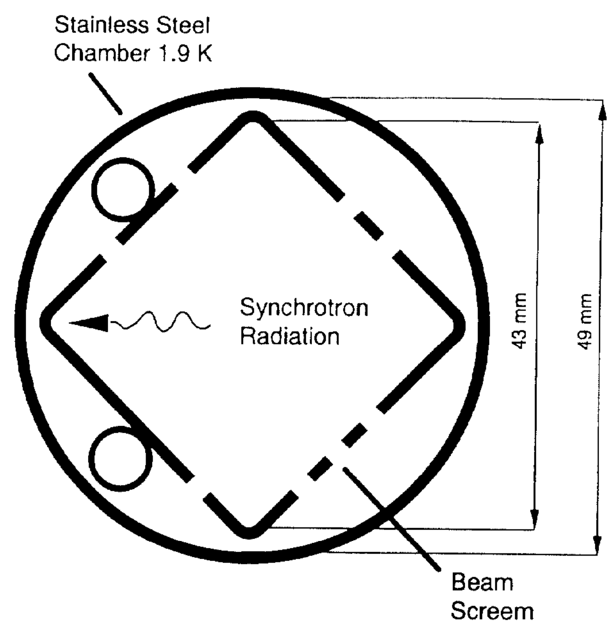

Fig. 5 Vacuum chamber cross-section

3.2. Dispersion suppressors

The dispersion suppressors are made of 4 pseudo half-cells. One half-cell contains a shortened magnet in order to match the LEP tunnel curvature. The matching to the long straight section induces larger beta values which have imposed an enlargement of a number of quadrupoles. For the same reason the quadrupoles are not equipped with beam screen.

3.3. Low-beta insertions

The low beta insertions in SS1, 2, 4 and 8 use two triplets. The outer triplet made of two-in-one quadrupoles matches the dispersion suppressor to the inner triplet. In between those triplets a set of two separator magnets is used to install the two beams in the same vacuum chamber, so that the inner triplet uses single bore quadrupoles. These low beta superconducting quadrupoles are enlarged to 70 mm (inner coil diameter). In SS1 and 2, a collimator is placed between the interaction point and the quadrupoles of the inner triplet in order to protect them against the secondaries coming from the high luminosity interactions. In spite of this protection the heat deposition in these quadrupoles is about 30 to 40 W per quadrupole at luminosities of 10^{34} cm^{-2} s^{-1}.

During injection and acceleration the low beta's are detuned to values of $\beta*$ of 15 m. In pp mode the low beta's are squeezed in straight sections 1 and 2 down to 0.5 m. In ion collisions mode only SS4 is squeezed to the same value of $\beta*$.

3.4. Cleaning insertions

The superconducting magnets working at 1.9^{o}K cannot stand the flux of about 10^{9} protons per second which, at maximum luminosity, diffuses toward the vacuum chamber due to the scattering in the collisions and the combined effect of non-linearities and power converter ripple. A study of the heat deposition process due to these losses indicates that the localized losses must be limited to a few 10^{6} protons per second at high energy, while about 30 times more are acceptable at injection. The diffusion of particles must be stopped before it reaches the superconducting elements; this is achieved in a dedicated insertion placed in straight section 3 and called the cleaning insertion.

In this crossing point, the lattice is arranged so that the beta values (and therefore the phase advance) are the same in both planes. For each beam. a set of four collimators, one primary and three secondaries are installed between the two separator magnets with the aim of trapping the large amplitude particles and absorbing them and their secondaries. The very high capture efficiency requested is achieved by installing the collimators very precisely around the beam at amplitudes not larger than about 6 σ of the transverse distribution. The inefficiency results from small beam impact parameters, alignment and mechanical errors. The computer programs to simulate the cleaning process, including errors, are being prepared. The proper operation of the cleaning system will be part of the learning process during the build up of luminosity after running in.

3.5. Beam dump

In various operation conditions it will be necessary to dump the beams under clean conditions so that the superconducting elements are not deteriorated. Also, a number of calorimeters placed on the magnet coils or beam loss detectors will request an emergency dumping of the beams in case losses in the ring exceed acceptable values.

The beam dump section mainly consists of powerful kickers capable of deflecting the beams into separate channels leading to dedicated absorber blocks. The two circulating beams are foreseen to have a 'hole' in the bunch train in which the beam dump kickers will be fired.

The beam dump must be able to absorb the 550 MJ of each beam. A central core of graphite surrounded by aluminium and shielded by massive iron blocks is proposed.

4. MAGNETS

The detailed results of the R&D programme obtained so far are summarized here for completeness.

- A 10 m-long twin dipole, in which two sets of HERA coils are incorporated into an LHC two-aperture structure, was tested at CEA-Saclay both at 4.5 K and at 1.9 K.
  At 4.5 K it behaved exactly as good HERA single magnets, while at 1.9 K it reached the short sample field of 8.3 T in five quenches.
- A few 1 m-long models of full cross-section reached their short-sample field of ~ 8 T in two to three quenches at 4.2 K; they also reached the short-sample field of 9.8 to 10 T but after a long training above 9 T. The great majority of the quenches are located in the ends. In particular only three quenches occur in the central part before the short sample field is reached. A single aperture magnet built by KEK - Japan, with different cables, collars and steel structure on the basis of their own design, gave very similar results [4].
- In all magnets there is no sign of any negative influence of the 'two-in-one' structure.

These results give confidence that final magnets operating satisfactorily close to the maximum field of 9.5 T could be built.

Recently, a new model with the same industrially made coils, but separate stainless steel collars, was assembled at CERN and gave excellent results. At 4.3 K it reached the short-sample field of 8.1 T at the second quench and at 1.8 K ultimately reached 10.5 T (Fig. 6). Fields in excess of 10 T are readily obtained in current operation. It incorporates excellent 17 mm-wide cables with 5 μm filaments. It is believed that the improved behaviour with respect to the previous models is due to the higher compression on the coil obtained by design and actually achieved at mounting.

Seven 10 m-long prototypes [5], all with the same set of coils but with three different mechanical structures are being built in industry. They will start to be delivered to CERN in the second half of 1993.

After an individual test, four of them will be mounted, together with a lattice quadrupole, to form a half-cell for extensive cryogenic tests.

The final dipoles will have an inner coil diameter of 56 mm and a magnetic length of 13.15 m. Maintaining the same short-sample field of 10 T would imply a somewhat larger cold mass and intra-beam distance and hence an increased cost. Therefore, as an alternative, we are considering to use narrower cables (~ 13 mm) made of strands very similar to those used for the SSC. In such a case, the cold mass and intra-beam distance remain the same as for the 50 mm aperture, the superconductor volume decreases considerably and the field is reduced by ~ 5%.

At CERN new models are being built to optimize the coil design (especially ends) and mechanical structure.

The lattice quadrupole has been designed by CEA-Saclay and two full-scale units are being built. The first one is being tested at cryogenic temperature.

Prototypes of various correctors have also been built and some of them satisfactorily passed first tests.

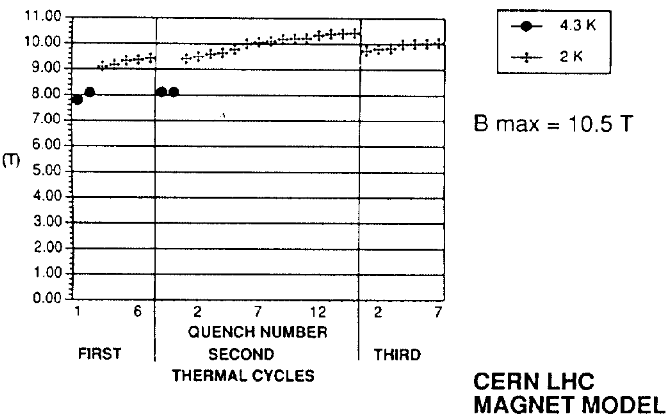

Fig. 6 Training curve of magnet model

5. CRYOGENICS

The block diagram of the cryogenic refrigeration system which corresponds to a half-cell (~ 51 m) is shown in Fig. 7.

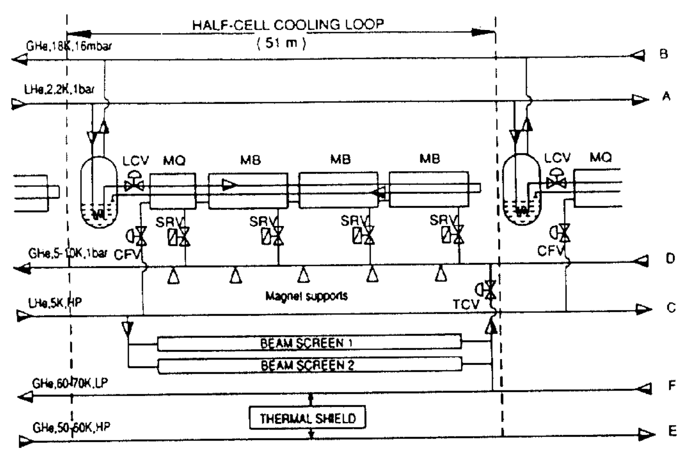

Fig. 7 Block diagram of cryogenic refrigeration

The magnets are immersed in static pressurized superfluid He at 1.9 K and cooled by heat exchange with saturated superfluid He flowing in a tube passing through the magnets and running all along the length of the half-cell. In this way the heat transfer path is streamlined from the magnet windings to the linear cold source constituted by the heat exchanger tube. Moreover, the magnet baths are hydraulically decoupled from each other, as well as from the cooling circuit.

An important advantage of this system is that the working temperature of each magnet is little dependent on its location in the machine, with respect to the octant cryoplant.

To test this scheme in realistic conditions, a cryoloop model was built [5] in which the magnets are replaced by 10 m-long cryostat modules with an almost full scale heat exchanger tube. The actual magnet heat loads are provided by electrical heaters.

The experimental results have demonstrated correct operation of this cooling scheme, with excellent heat transfer capability, extracting the nominal heat load of 0.3 W/m across a temperature difference of a few mK between static baths and the flowing helium.

Each octant of the LHC will be cooled by its own refrigerator, with an installed capacity of :

- 1.8 kW isothermal refrigeration at 1.8 K,
- 8.5 kW non-isothermal refrigeration at 4.5-10 K
- 30 g/s liquefaction at 4.5 K
- 30 kW non-isothermal refrigeration at 50-75 K.

The four 12 kW cryoplants at 4.5 K already acquired for LEP 200 and installed at the even points, suitably boosted to 18 kW by additional compressors, will be used for LHC.

Four additional plants for the odd points and suitable cold boxes for lowering the temperature from 4.5 K to ~ 1.8 K will have to be installed in order to complete the refrigeration system.

6. EXPERIMENTAL AREAS

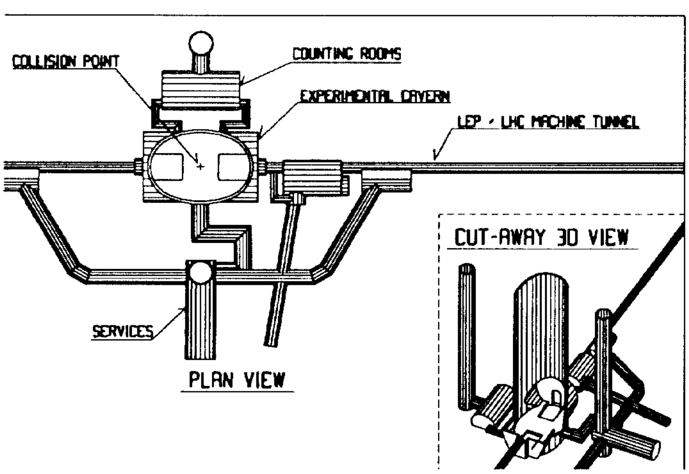

Fig. 8 Example of LHC underground experimental area

The design of the new LHC areas is actively pursued in close collaboration with proponents of experiments.

LHC experiments will be about twice the size of the LEP detectors and weigh between 10,000 and 30,000 tons. A design study for a suitable underground cavern, with a 40 m × 28 m elliptical section access shaft directly over the collision point is shown in Fig. 8. Relatively modest alcoves are added along the beam-line to allow the forward detectors to slide along the beam pipe and give access to the central region for repair and maintenance. In this way the underground handling of heavy components will be minimised. The counting room for the experiment and machine services are housed in separate caverns.

7. TIME TABLE AND CONCLUSION

The basic design of all machine components and the layout of equipment in the LEP tunnel are completed. They will form the basis of the final project proposal which is being prepared.

The construction schedule is based on the completion of the installation by the year 2000. It is therefore envisaged to complete the experimental programme with the LEP collider before the commissioning of the LHC, thus offering the opportunity of using very rationally the considerable infrastructure which exists in and around the LEP tunnel. Of course, the LEP machine itself will be fully preserved in view of a future ep operation.

The experimentation with both pp and ion collisions could start in the year 2001.

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