LHC STATUS AND PLANS

L.R. Evans, CERN, CH - 1211 Geneva 23, Switzerland

Abstract

The Lagre Hadron Collider project (LHC) was approved by the CERN Council in December 1994 as a two-stage project, the first stage at two thirds of the final centre-of-mass energy of 14 TeV to become operational in 2004 and the final stage to be completed in 2008. The CERN management was also requested to solicit contributions to the machine construction from Non-member States involved in the experimental programme in order to allow construction of the machine in a single stage. Taking into consideration the strong support for the project from a number of countries outside the Member States, the CERN Council decided in December 1996 that the machine should be constructed in a single stage with first physics in 2005. Although global participation in detector construction has been well established for many years, this is the first large CERN project in which Non-member States have been involved in the construc-tion of a machine. A brief status report is given and future plans are discussed.

1 INTRODUCTION

The Large Hadron Collider, originally approved for construction as a two-stage machine in December 1994, has now been fully approved for construction in a single stage to be completed with a first physics run in 2005. The project has moved from a conceptual to an implementation phase with many large contracts in preparation, to be let by the end of 1997.

The basic parameters have not changed since the last report to this conference [1] and are reproduced for convenience in Table 1. The machine will provide proton-proton collisions with a centre-of-mass energy of 14 TeV and a nominal luminosity of 10^{34} cm^{-2} s^{-1} and heavy (Pb) ion collisions with a nominal luminosity of 10^{27} cm^{-2} s^{-1}.

The only parameters modified in Table 1, compared to the previous table, are the separation between the beams which has been increased from 180 to 194 mm and a slight decrease in field due to better optimisation of the interconnects.

Three experiments are now approved, the two high luminosity detectors ATLAS and CMS at intersection Points 1 and 5 respectively (Fig. 1), and the heavy ion experiment ALICE to be installed in the existing cavern at Point 2. A fourth detector optimised for B-physics (LHCB) is at the stage of preparation of a technical proposal.

The allocation of the eight straight sections for experiments and machine utilities remains unchanged with one major exception. The RF system has been moved from Point 8, where it was common for the two beams and cohabited with the LHCB detector and the counter-clockwise injection system, to Point 4. In addition, the common RF system has been replaced by separate systems for the two beams, which presents numerous advantages. However, in order to fit in the cavities, the beam separation has to be increased from its value of 194 mm in the arcs to 420 mm through the straight section at Point 4.

Table 1: *Machine parameters*

Energy	(TeV)	7.0
Dipole field	(T)	8.3
Coil aperture	(mm)	56
Distance between apertures	(mm)	194
Luminosity	(cm^{-2} s^{-1})	10^{34}
Beam-beam parameter		0.0032
Injection energy	(GeV)	450
Circulating current/beam	(A)	0.530
Bunch spacing	(ns)	25
Particles per bunch		1×10^{11}
Stored beam energy	(MJ)	332
Normalized transverse emittance	(μm)	3.75
R.m.s. bunch length	(m)	0.075
Beta values at I.P.	(m)	0.5
Full crossing angle	(μrad)	200
Beam lifetime	(h)	22
Luminosity lifetime	(h)	10
Energy loss per turn	(keV)	6.9
Critical photon energy	(eV)	45.6
Total radiated power per beam	(kW)	3.7

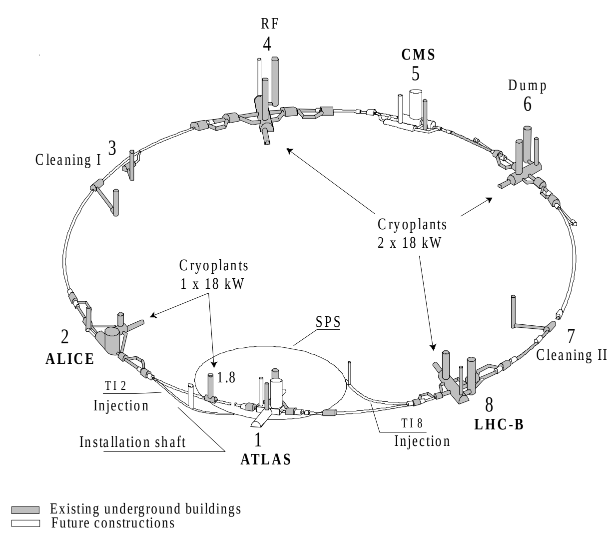

Figure 1: Overall layout

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2 OPTICS

A detailed status report on the optics is given elsewhere in these Proceedings [2]. The most visible change compared to previous versions is the addition of a fourth quadrupole in the outer triplet of the insertions in order to improve the flexibility of the machine and to reduce the maximum value of the beta function in the detuned low-beta insertions. However, many other improvements have been made at the level of the dispersion suppressors and at the beginning of the regular arcs in order to increase the tuning range of the machine .

3 INJECTOR CHAIN

In order to provide the beams with the required 25 ns bunch spacing and phase space density (10^{11} particles per bunch, <4 µm.rad, < 1 eV.s.), a considerable amount of work on the injector chain is required [3].The PS Booster and transfer lines are being upgraded from 1 to 1.4 GeV in order to alleviate space charge problems in the PS. The Booster also requires new h=1, 7 kV cavities. In the PS, a combination of 40 and 80 MHz cavities are needed in order to provide the required bunch spacing and bunch length.

In the SPS, considerable progress has been made in identifying the dominant impedances responsible for provoking the microwave instability and consequently diluting the longitudinal phase space density. A programme of work has started to shield the offending elements, mainly vacuum ports and septa. Among the other modifications in the SPS are a major upgrade of the 200 MHz accelerating system and the installation of a new extraction system in order to supply the counter-clockwise rotating beam to the LHC. Beams with nominal LHC parameters will be available in 1999.

4 MAGNETS

4.1 Dipoles and arc quadrupoles

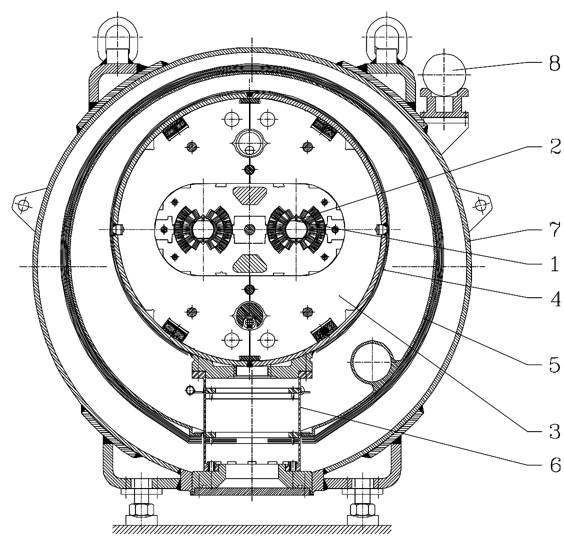
More than 8000 superconducting magnets are required, including 1232 two-in-one dipoles. Each dipole contains small sextupole and decapole correctors integrated into the space at the ends of the magnet in order to correct for persistent current multipoles at the injection field of 0.53 T. In order to achieve the high field (8.3 T) for 7 TeV operation, the magnets must operate in superfluid helium at 1.9 K.

A considerable amount of development work has already been done. More than a dozen short models have been constructed and tested. All of these models have exceeded 9 T with the best reaching 10.5 T. Seven 10 meter long first generation (50 mm aperture) industrially made prototypes have been tested. All have exceeded 9 T with some training. Since then, it has been decided to increase the coil inner diameter from 50 to 56 mm in order to improve the dynamic aperture at injection.

The new dipole design (Figs. 2 and 3) is identical to that presented in the last PAC except that the space between beam channels has been increased from 180 to 194 mm. This was done in order to reduce the prestress required during the collaring operation and to alleviate the design of the quadrupole. In addition, the cryogenic simplification (see below) has allowed much of the ancilliary piping to be removed from the magnet cryostat

Details of the dipole design and performance are given elsewhere in these Proceedings [4].

The arc quadrupoles are separately powered from the dipoles. Their design, undertaken by CEA/Saclay in collaboration with CERN, is based on the outer dipole cable The operational gradient is 223 T/m for 3.1 m length. Two first-generation prototypes have been built and tested successfully at their design gradient. Construction of final prototypes is now under way at Saclay.



1. Beam screen, 2. Cold bore, 3. Cold mass at 1.9 K,
4. Radiative insulation, 5. Thermal shield (55 to 75 K),
6. Support post, 7. Vacuum vessel, 8. Alignment target

Figure 2: Cross section of the dipole magnet and cryostat

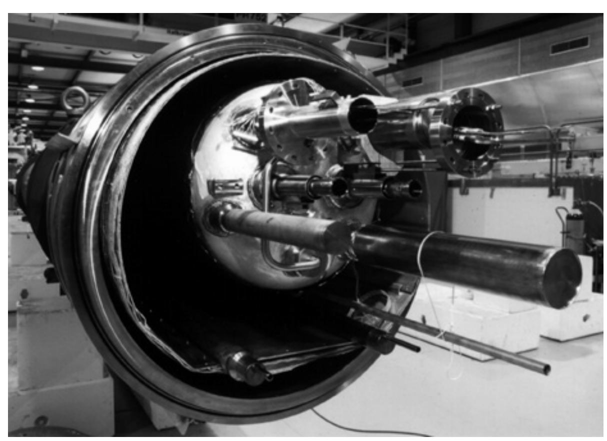


Figure 3: Prototype dipole

4.2 Cable

A lot of effort has gone into cable development. For the first generation of dipoles, more than 14 tons of 17 mm wide cable has been produced. For the final design, the cable width has been reduced to 15.1 mm in order to decrease cost and facilitate winding. Measurements of minimum quench energy, made in collaboration with BNL and LBL, have shown the importance of the degree of compaction of the strands in the cable, a lower compaction allowing more helium penetration and cooling of the strands. This has lead to a small change in cable dimensions and keystone angle. The main cable parameters are given in Table 2.

Table 2: *Dipole strand and cable characteristics*

	Inner layer	*Outer layer*
Strand:		
Diameter (mm)	1.065	0.825
Cu/Sc ratio	1.6	1.9
Filament size (μm)	7	6
Twist pitch (mm)	15	18
Critical current (A)		
at 10 T, 1.9 K	≥ 515	
at 9 T, 1.9 K		≥ 380
Cable:		
Number of strands	28	36
Cable dimensions		
width (mm)	15.1	15.1
keystone angle	1.25°	0.9°
mid thickness (mm)	1.9	1.48
Transposition pitch (mm)	115	105
Critical current (A)		
at 10 T, 1.9 K	≥ 13750	
at 9 T, 1.9 K		≥ 12960

The cable insulation has received a great deal of attention. In superfluid helium, it is particularly important that the helium penetrates the insulation in order to provide additional enthalpy and to profit from its very high thermal conductivity. Various insulation methods have been investigated in collaboration with CEA/Saclay. The classical b-stage epoxy has been abandoned in favour of an all polyimide insulation consisting of a 50 μm thick half-overlapping polyimide tape and a second wrap of adhesive coated tape wound with 3 mm spacing between turns, leaving open channels for helium penetration.

Another very important aspect of the cable development has been the search for a process that guarantees a consistent inter-strand resistance of between 10 and 30 μΩ in order to avoid current sharing between strands during ramping. Best results have been achieved with SnAg (“Stabrite”) coated cables.

4.3 Insertion and corrector magnets

Recently a short model of a large aperture (70 mm) insertion quadrupole has been successfully tested in industry. More details are given in these Proceedings [5]. CERN is collaborating with FNAL and KEK to finalise the design of these magnets with a view to fabricating the full series. The RF insertion layout is based on RHIC coils and is being designed in collabo-ration with BNL.

Many prototype corrector and auxiliary magnets have been tested, including a combined dipole and sextupole for orbit and chromaticity correction, an octupole and the small sextupole and decapole correctors to be incorporated into the ends of the main dipoles.

5 CRYOGENICS

The design of the cryogenics system has undergone a number of detailed changes, although the basic design principles remain the same.

The four LEP cryoplants will be upgraded from 12 to 18 kW and supplemented by four new plants each of 18 kW capacity. These new plants will not be of the LEP type with split upper and lower cold boxes but will have a single cold box on the surface. The original layout grouped the plants in pairs at the four even points of the machine. This symmetry has now been broken by locating the new plant originally foreseen for Point 2 at point 1.8, where the large shaft that was used for the installation of LEP can be re-used to accommodate much of the cryogenic infrastructure feeding the octant from Point 1 to Point 2 (Fig. 1). This is also in close proximity to the hall used for magnetic measurements. A large cryoplant at this location is of considerable interest for component testing, particularly the cold compressor boxes. It also avoids major civil engineering at Point 2, where the surface and underground structures are quite different from the other three even points, and allows more efficient cooling at the 1.9 K level, since the tunnel slopes downwards between Points 2 and 1, facilitating the operation of the cold compressors located at Point 1.8.

Other substantial modifications made since last reported at this conference include the move of much of the cryogenic pipe work into a separate line and the extension of the cell cooling loop to a full period of 107 m (Fig. 4). Static superfluid helium pressurised at 1 bar permeating the magnet laminations is cooled by heat exchange with saturated superfluid helium flowing through a tube running over the whole length of a cell. The superfluid is produced by expanding sub-cooled helium to saturation through a Joule-Thomson valve (TCV1). Before expansion, helium at 4.3 K is pre-cooled in a small heat exchanger (HX), using the cold helium vapour at 1.8K, pumped to saturation pressure (15 mbar) through the line B. This allows one line carrying sub-cooled helium at 2.2 K line A in the previous design) to be suppressed. The connection between the cryogenic line and the magnet cell is made by a jumper at the level of the short straight section. A major consequence of the move to a separate cryoline with connection to the magnet chain only once per period is that the quench discharge can be made only at each end of the cell through quench valves SRV and not at each individual magnet as originally foreseen. Tests on the string have shown that this can be tolerated.

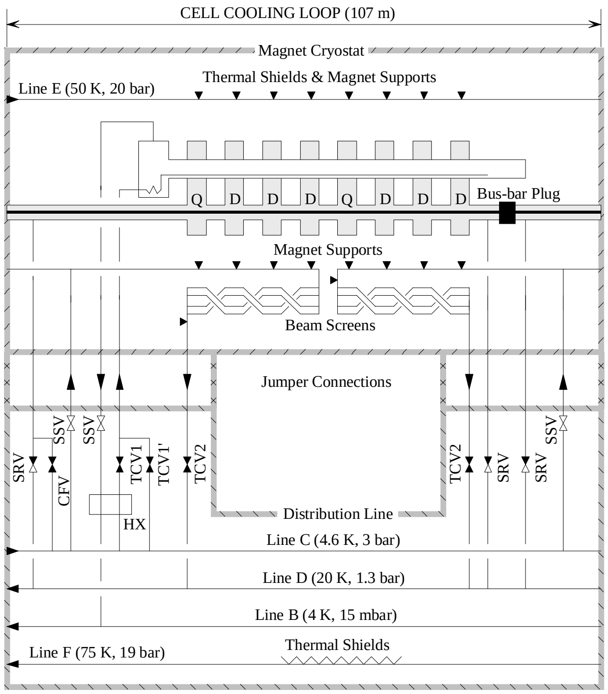


Figure 4: Cell cooling loop

6 THE STRING TEST FACILITY

The string test facility [6] consists of a simulation half-cell of the machine, containing a short straight section and three dipoles. The short straight section contains a prototype three meter long quadrupole and the cryogenic service module needed for cooling the string to 1.9 K. The dipoles are all “first-generation“ prototypes, 10 meters in length with an internal coil diameter of 50 mm.

Since its commissioning in December 1994, the string has totalled more than 1500 hours of operation below 1.9 K and has undergone more than 30 forced quenches from its nominal current or above. It has validated the cooling scheme design and has given a great deal of valuable information which has been used to refine and optimise the machine design. For example, data on quench behaviour with all quench relief valves closed except the one at the end of the string has been invaluable in the decision to implement the separate cryogenic line with jumper connections separated by a full cell length.

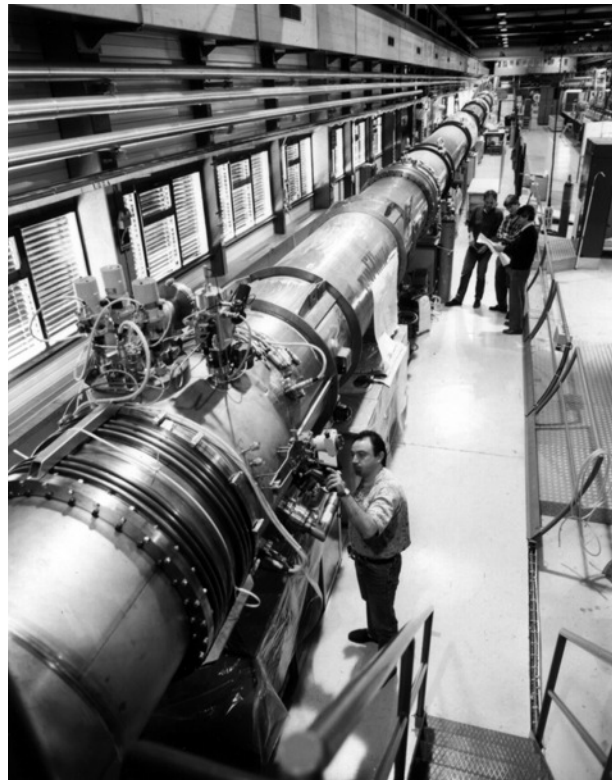


Figure 5: String test facility

Recently, the string has undergone a forced lifetime test, where it has been repetitively cycled more than 2100 times up to its nominal current of 12.5 kA at the nominal LHC ramp rate of 10 A/s, simulating more than 10 years of LHC operation. The current is kept stable for 150 s then ramped down to its nominal injection level of 800 A. This cycle is repeated 24 hours per day. The string dipoles have now been equipped with a prototype beam screen and additional instrumentation for detailed studies of quench propagation.

7 VACUUM

The LHC beam vacuum [7] poses particular problems. Due to the synchrotron radiation emitted by the protons (about 4 kW per ring at 7 TeV) and the heating due to image currents in the wall of the vacuum chamber, the magnet cold bore at 1.9 K must be shielded from the beam, otherwise the required cryogenic power would become excessive. An inner liner cooled to around 20 K through tubes carrying high pressure gas will therefore be installed in the cold bore. Synchrotron radiation impinging on this liner will cause gas to be desorbed from the bulk material which will in turn be cryopumped onto the surface of the liner. Once a substantial fraction of the surface is covered with gas molecules, particularly hydrogen, a catastrophic pressure rise would build up unless remedial action is taken. Slots, filling about 2% of the surface, are therefore cut in the liner so that hydrogen can be cryopumped by the much colder surface of the magnet cold bore. The inner surface must be of high conductivity material but the liner must also be sufficiently strong to withstand the forces induced by eddy currents in case of magnet quench. It is therefore constructed from steel with a very low permeability (high-manganese) with a thin strip of copper on its inner surface. Tests have shown that co-lamination of copper and steel sheets at high pressure give much better results than electroplating. Once the composite strips are formed they are shaped into two half-shells and laser-welded along their edges. Great care is taken in order to adjust the weld parameters to avoid the formation of ferrite in the weld seams.

8 CIVIL CONSTRUCTION

The LHC makes use of the existing infrastructure of LEP, including the four existing experimental halls to house experimental detectors or machine utilities. Nevertheless, a considerable amount of extra investment in civil construction, amounting to about half of that already invested in LEP, is needed to house the two large detectors, for the long transfer tunnels between the SPS and the LHC, and for the surface infrastructure for assembly halls and cryogenic equipment.

At Point 1, the ATLAS detector requires an underground cavern of more than 50000 m^3 and an associated service cavern of nearly 20000 m^3 together with considerable surface hall space.

At Point 5, the CMS detector requires an experimental cavern of about 30000 m^3 and a service cavern of 17000 m^3 as well as considerable surface infrastructure for assembly and testing of the 14000 ton solenoid. The sinking of the shafts at Point 5 poses a particular challenge since they have to pass through water-bearing moraine.

At Points 2 and 8, ALICE and LHCB will use existing experimental halls with very little modification.

Two transfer tunnels, each more than 2.5 km in length, are needed to transport the beams from the SPS. The clockwise injection tunnel, TI2, will also be used for machine installation through a shaft located on the CERN site, needed for the excavation of the tunnel. Finally, two beam dump tunnels, each of some 700 m in length will house the transfer lines to the beam abort caverns. It is foreseen that all civil construction contracts will be let in November 1997, allowing site preparation to start at the beginning of 1998.

9 PLANNING

As mentioned in the introduction, the LHC project has now been approved for construction in a single stage with the first physics run in the second half of 2005. It is planned to run LEP until the end of 1999, although the LHC planning has been adapted in order to allow a further year of LEP running if the physics case justifies it and if appropriate funding can be found. The following major milestones can be identified:

– Start civil engineering	January 1998
– Dismount LEP	October 2000
– Deliver Point 1(ATLAS)	July 2002
– Deliver Point 5 (CMS)	July 2003
– Sector test	October 2003
– Circulating beams	July 2005

A sector test is foreseen in 2003. A beam will be injected in the counter-clockwise direction at Point 8 and transported through one octant to Point 7. It can be observed that the experimental area for CMS is available one year later than for ATLAS. This is due to the fact that geological conditions at Point 5 are less favourable than at Point 1 and is acceptable due to the fact that a complete assembly and test of the CMS magnet will be made on the surface before installation, whereas the ATLAS detector must be completely assembled under-ground.

10 CONCLUSIONS

The Large Hadron Collider project has now moved from a conceptual to an implementation phase, with machine construction to be completed in a single stage with a first physics run in 2005.

The main technical choices are now frozen and much effort is being devoted to the detailed technical specification of major hardware systems. By the end of the year, it is expected that several large contracts will be placed, including those for civil engineering.

The LHC is the first large CERN project in which there is a participaton of external institutes in the machine design and construction.

ACKNOWLEDGEMENTS

On behalf of the CERN LHC team, I would like to acknowledge the enthusiastic collaboration of colleagues from laboratories in Canada, India, Japan, Russia and the USA, as well as from a number of institutes in the CERN Member States, in the realisation of this project.

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