Chapter 1

Introduction

The Large Hadron Collider (LHC) is a two-ring-superconducting-hadron accelerator and collider installed in the existing 26.7 km tunnel that was constructed between 1984 and 1989 for the CERN LEP machine. The LEP tunnel has eight straight sections and eight arcs and lies between 45 m and 170 m below the surface on a plane inclined at 1.4% sloping towards the *Léman* lake. Approximately 90% of its length is in molasse rock, which has excellent characteristics for this application, and 10% is in limestone under the Jura mountain. There are two transfer tunnels, each approximately 2.5 km in length, linking the LHC to the CERN accelerator complex that acts as injector. Full use has been made of the existing civil engineering structures, but modifications and additions were also needed. Broadly speaking, the underground and surface structures at Points 1 and 5 for ATLAS and CMS, respectively, are new, while those for ALICE and LHCb, at Points 2 and 8, respectively, were originally built for LEP.

The approval of the LHC project was given by the CERN Council in December 1994. At that time, the plan was to build a machine in two stages starting with a centre-of-mass energy of 10 TeV, to be upgraded later to 14 TeV. However, during 19956, intense negotiations secured substantial contributions to the project from non-member states, and in December 1996 the CERN Council approved construction of the 14 TeV machine in a single stage. The non-member state agreements ranged from financial donations, through inkind contributions entirely funded by the contributor, to in-kind-contributions that were jointly funded by CERN and the contributor. Confidence for this move was based on the experience gained in earlier years from the international collaborations that often formed around physics experiments. Overall, non-member state involvement has proven to be highly successful.

The decision to build LHC at CERN was strongly influenced by the cost saving to be made by re-using the LEP tunnel and its injection chain. The original LEP machine was only made possible by something that was once referred to by N. Cabbibo, INFN, Italy, as the exo-geographic transition. Although at its founding, CERN was endowed with a generous site in the Swiss countryside, with an adjacent site for expansion into the even emptier French countryside, the need for space outstripped that available when the super-proton synchrotron, or SPS, was proposed. In this instance, the problem was solved by extensive land purchases, but the next machine, LEP, with its 27 km ring, made this solution impractical. In France, the ownership of land includes the underground volume extending to the centre of the earth, but, in the public interest, the Government can buy the rights to the underground part for a purely nominal fee. In Switzerland, a real estate owner only owns the land down to a “reasonable” depth. Accordingly, the host states re-acted quickly and gave CERN the right to bore tunnels under the two countries, effectively opening a quasiinfinite site that only needed a few “islands” of land ownership for shafts. In 1989, CERN started LEP, the world’s highest energy electron-positron collider. In 2000, LEP was closed to liberate the tunnel for the LHC.

The LHC design depends on some basic principles linked with the latest technology. Being a particle-particle collider, there are two rings with counter-rotating beams, unlike particle-antiparticle colliders that can have both beams sharing the same phase space in a single ring. The tunnel geometry was originally designed for the electron-positron machine LEP, and there were eight crossing points flanked by long straight sections for RF cavities that compensated the high synchrotron radiation losses. A proton machine such as LHC does not have the same synchrotron radiation problem and would, ideally, have longer arcs and shorter straight sections for the same circumference, but accepting the tunnel “as built” was the cost-effective solution. However, it was decided to equip only four of the possible eight interaction regions and to suppress beam crossings in the other four to prevent unnecessary disruption of the beams. Of the four chosen interaction points, two were equipped with new underground caverns.

The tunnel in the arcs has a finished internal diameter of 3.7 m, which makes it extremely difficult to install two completely separate proton rings. This hard limit on space led to the adoption of the twin-bore magnet design that was proposed by John Blewett at the Brookhaven laboratory in 1971. At that time, it was known as the “two-in-one” super-conducting magnet design [1] and was put forward as a cost saving measure [2, 3], but in the case of the LHC the overriding reason for adopting this solution is the lack of space in the tunnel. The disadvantage of the twin bore design is that the rings are magnetically coupled, which adversely affects flexibility. This is why the Superconducting Super Collider (SSC) was designed with separate rings [4].

In the second half of the twentieth century, it became clear that higher energies could only be reached through better technologies, principally through superconductivity. The first use of superconducting magnets in an operational collider was in the ISR, but always at 4 K to 4.5 K [5]. However, research was moving towards operation at 2 K and lower, to take advantage of the increased temperature margins and the enhanced heat transfer at the solid-liquid interface and in the bulk liquid [6]. The French Tokamak Tore II Supra demonstrated this new technology [7, 8], which was then proposed for the LHC [9] and brought from the preliminary study to the final concept design and validation in six years [10].

The different systems in the LHC will be reviewed in more details in the following chapters. The principal references used for the technical design are the early design studies [11, 12] and the LHC Design Report [13], which is in three volumes.

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