3. THE CMS MAGNET PROJECT

3.1 INTRODUCTION

This chapter gives a general overview of the project and provides familiarity with the current naming of major items and activities, and, for the benefit of those who don't require much technical detail, summarises the following chapters.

The magnet for the CMS detector is the major element of the CMS experiment in terms of size, weight and structural rigidity; for this reason it is used as the principal support structure for all the other detectors.

The magnetic yoke contains the muon chambers while the barrel part of the hadron calorimeter, HB, of the electromagnetic calorimeter EB, and the Tracker are situated inside, and supported from, the inner shell of the vacuum tank, (Chapt. 4).

The infrastructure project of the experimental cavern is largely influenced by the role of the CMS magnet's support structure. By the heading "Magnet Project" we refer to all the activities related to the design, construction and commissioning of the:

- magnet Yoke (Barrel + End Cap) and Vacuum Tank,
- superconducting Coil (cold mass),
- ancillaries (Cryogenics, Power supply, Process control etc.),
- installation of the magnet and definition of the conventional magnet infrastructure.

The Main Parameters of the CMS Magnet which are related to the physics requirement (see Chapt. 2) are the following:

- field: 4 Tesla,
- yoke diameter: 14 m on flats,
- axial yoke length including endcaps: 21.6 m,
- total weight including the coil: approximately 10800 tonnes.

The CMS Magnet Project is a common project of the CMS Collaboration, and as such, is financed by all participating institutes on a prorata basis with respect to their participation in CMS, through ad-hoc procedures, as explained in Chapt. 31.

A CERN based team has been formed, as part of the CMS Collaboration, to organise and co-ordinate all the activities for the Magnet Project. Teams from different institutes are also participating in defining and designing items for the project, as explained in Chapt. 30.

The master planning for the CMS detector and the experimental area construction is largely determined by the activities of the Magnet Project. The magnet will be tested at full current in the surface building SX5, around September 2003, before being lowered into the experimental cavern UXC5. This will enable CMS to be ready for LHC by July 2005, (Chapt. 26 and Fig. 26.17, p. C-67).

An open section of the CMS magnet, with the major project item names is shown in Fig. 3.1.

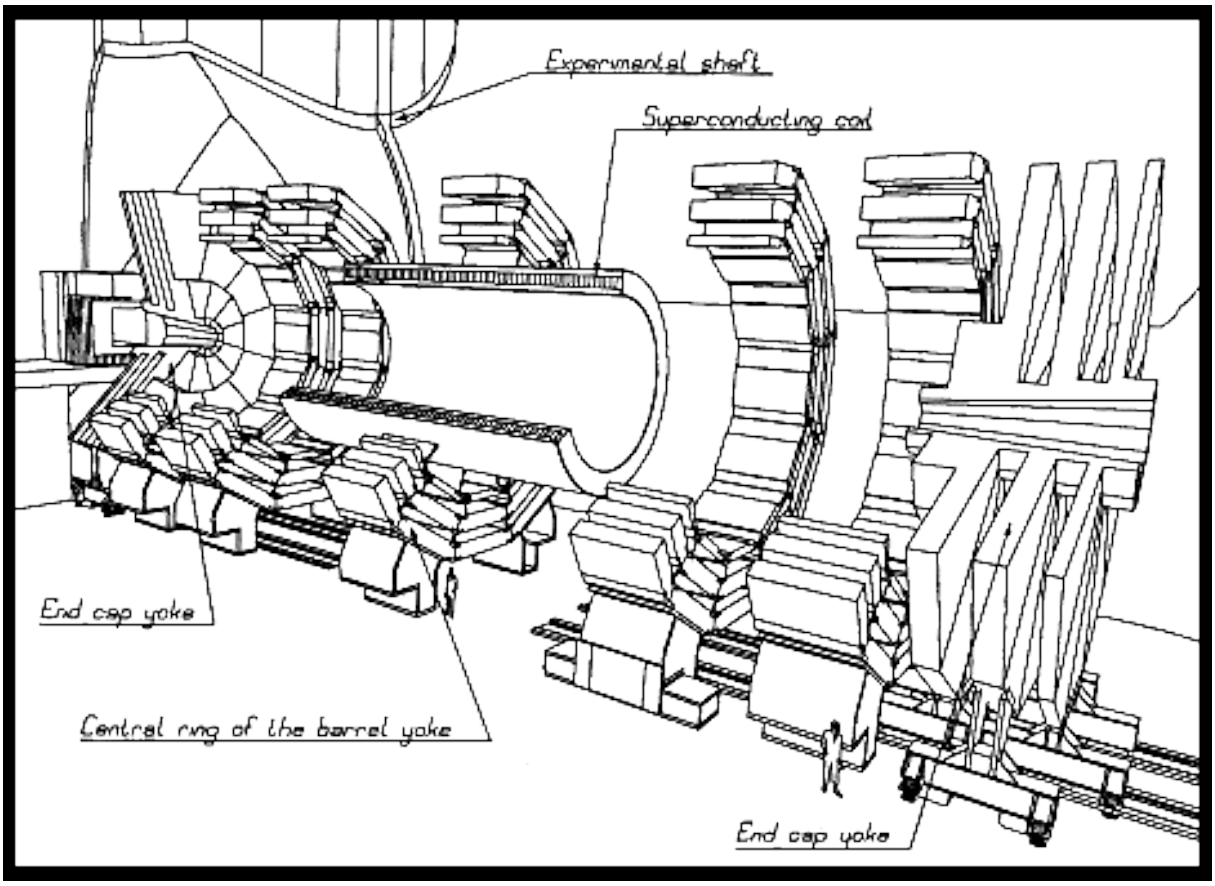

Fig. 3.1: Open view of the CMS Magnet with the major project item names.

3.2 THE MAGNETIC YOKE

The magnetic flux generated by the superconducting coil is returned via a 1.5 m thick saturated iron yoke. This yoke is designed as a 12-sided structure. A balance has been achieved between the outer diameter of the yoke and the size of the muon stations, while trying to maximise the acceptance in azimuth of the interlayer muon chambers that are interleaved between the iron plates of the yoke.

The yoke is divided into two main components:

- the barrel yoke: the cylinder surrounding the superconducting coil,
- the endcap yoke: the disks that magnetically close the barrel yoke.

The magnetic configuration is analysed in Chapt. 6.

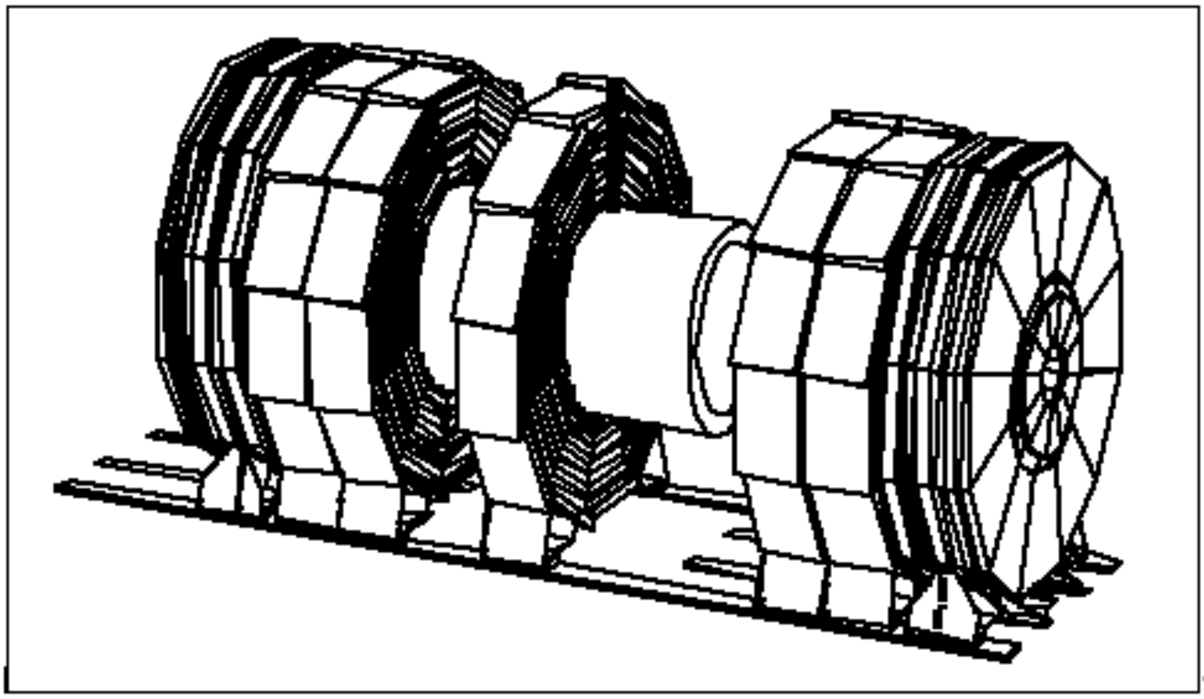

Fig. 3.2 shows an overview of the five Barrel Rings, and the two End Caps.

3.3 THE BARREL YOKE

The barrel yoke is a 12-sided structure designed at CERN. It is 11 m long, giving a total iron weight for the barrel of about 6000 tonnes, (see Chapt. 7).

The barrel yoke is subdivided along the beam axis into five rings approximately 2.5 m long. The central barrel ring, centred on the interaction point, supports the superconducting coil.

Each barrel ring is made up of three iron layers. The thickness of the inner layer is 295 mm, the middle layer and the outer layers are 630 mm. Connecting brackets join together the steel plates forming the three layers and provide the required structural rigidity.

The central barrel ring is the only stationary part around the interaction point and it is used to support the vacuum tank and the superconducting coil. The other four barrel rings and the endcap disks slide on common floor rails, running in the beam direction, to allow insertion and maintenance of the muon stations, Fig. 3.2.

From the beginning strong technical ties have been developed with ITEP/Moscow as potentially interesting manufacturing possibilities do exist in Russia. Nevertheless a world wide tender is in preparation for the procurement and trial assembly of the barrel rings.

3.4 THE END CAP YOKE

The endcap yoke is being designed at the University of Wisconsin at Madison, in connection with PSL. Wisconsin is also in charge of the integration of the forward muon chambers, these forward muon chambers being a US project inside CMS.

Each endcap is built from three independent disks which can be separated to provide access to the forward muon stations, Fig. 3.3.

Due to the axial magnetic field the two inner disks must withstand an attraction force of about 85 MN and resist the large bending moments induced. Therefore these two disks are 600 mm thick whereas the outer disk is only 250 mm thick. Each endcap weighs 2300 tonnes, (see Chapt. 8).

A world wide tender, to be managed by the Wisconsin group, is in preparation for the procurement of the end-cap disks.

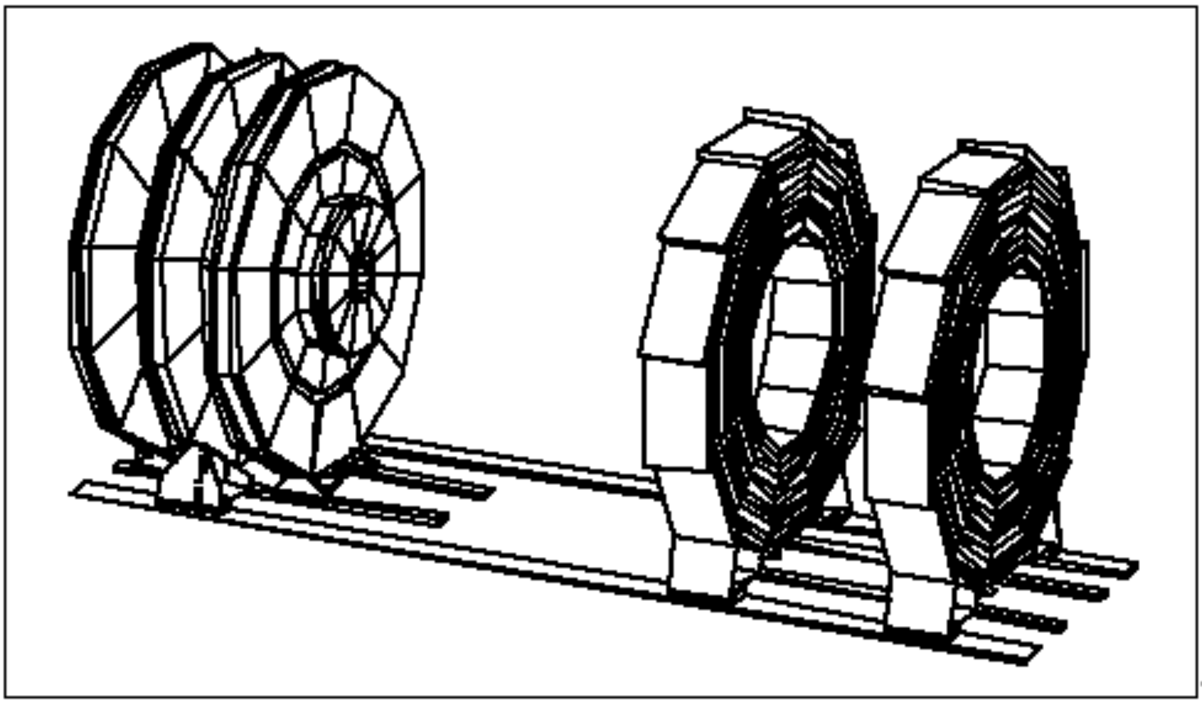

Fig. 3.3 gives a partial view of the open magnet showing three separated End Cap disks and two outer Barrel Yoke Rings.

3.5 VACUUM TANK

The vacuum tank is made of stainless steel and houses the superconducting coil.

The outer shell of the vacuum tank is attached to the inner part of the central barrel ring and the coil is symmetrically supported from it.

All the barrel sub-detectors, HB, EB and Tracker are supported by the inner shell of the vacuum tank via a system of horizontal welded rails, (see Chapt. 9).

3.6 SUPERCONDUCTING COIL SYSTEM

The superconducting coil system is defined as the coil and the ancillary subsystems required for its operation. This is the main subject of Chapt. 11 to 24.

In the following paragraph a short description will be given of the main items of the cold mass and some of the major sub-components.

3.6.1 The superconducting Coil

The conceptual design of the CMS superconducting coil is based on experience gained by CEA/Saclay over the past fifteen years with superconducting magnets for high energy physics, in particular from the ALEPH design. This experience has been incorporated into the design together with several new features, (see Chapt. 11).

The reinforced conductor cable of the 4 layer CMS coil is capable of sustaining by itself all the induced magnetic forces.

A collaboration agreement between CERN and CEA-Saclay for the engineering of the superconducting coil up to the time of the commissioning has been agreed upon.

The engineering of the superconducting coil includes the detailed definition of the internal cryogenics, the protection system and the definition of the technical requirements for the ancillary subsystems.

Figure 3.4 shows an open view of the superconducting coil inside its vacuum tank with some of its sub-systems attached.

These items will be discussed in the following paragraphs; Table 3.1 resumes the most important parameters of the cold mass.

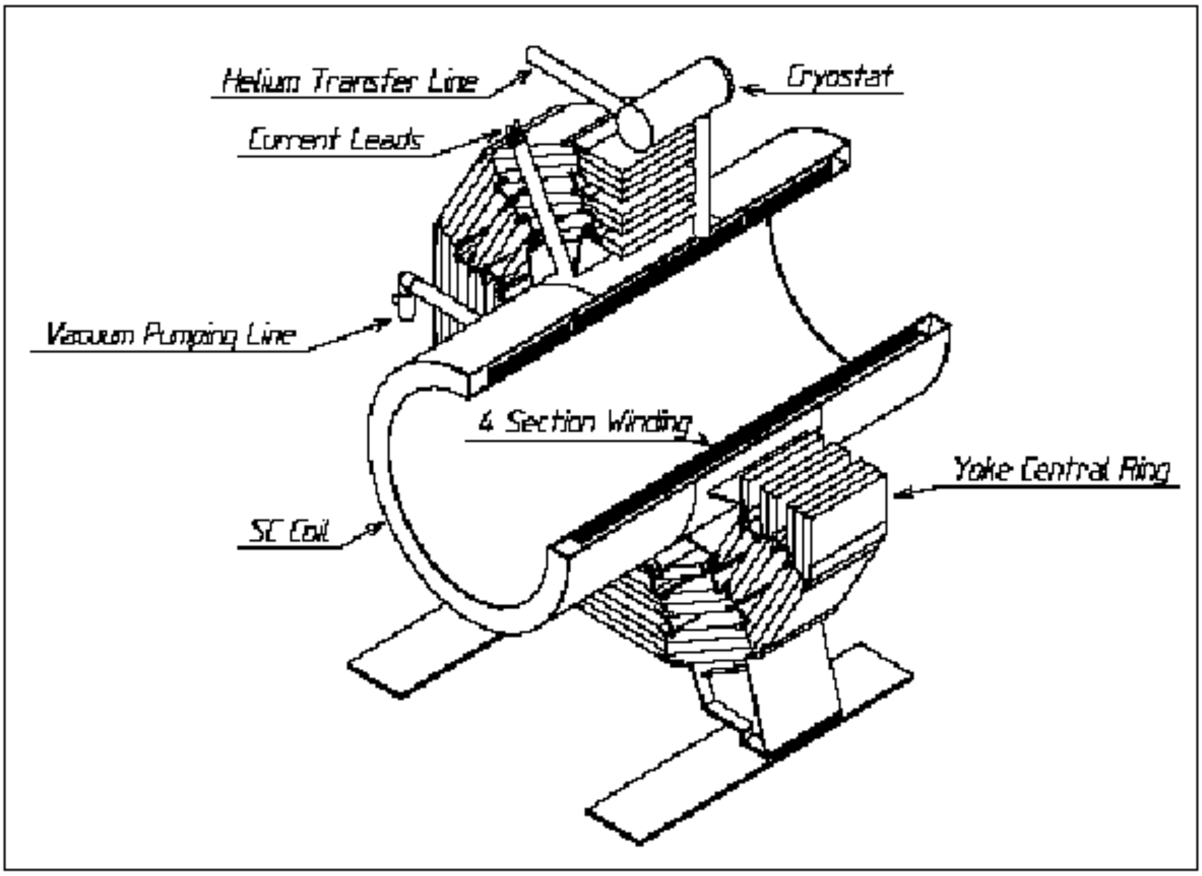

Fig. 3.4: Open view of the cold mass.

Table 3.1
Main parameters of the cold mass.

Magnetic induction at interaction point	T	4.0
Peak magnetic induction on the conductor	T	4.6

Magnetic length	m	12.48
Stored energy	G J	2.52
Magnetomotive force	MAt	42.24
Magnetic radial pressure	MPa	6.47
Axial compressive force at mid plane	MN	122

3.6.2 The Superconducting Conductor

One of the major engineering challenges of the superconducting coil is its self-supporting structure, whereby magnetic forces are resisted where they are produced, rather than transferring them to an external heavy mechanical structure, causing dangerously high shear stresses in the insulation.

As the forces induced in the conductor by the magnetic and thermal loads go beyond the yield stress of the pure aluminium a metallurgically bonded mechanical reinforcement is needed. The best way is to have this reinforcement acting axially and tangentially to the coil, thus minimising the conductor construction and winding operation as shown in Fig. 3, (see Chapt. 12).

3.6.3 Ancillaries for the Superconducting Coil

This heading comprises:

- the external cryogenic system from the flanges of the outer cryostat,
- the power supply from the current breakers,
- the vacuum system from the flange on the pumping line,
- the process control and the interface to the Slow control system of the experiment.

CEA-Saclay will define the characteristics of the ancillary equipment and will write the functional part of the technical specifications.

3.6.4 The external cryogenics

The external cryogenic sub-system consists of the compressors, the cold box, the vessels containing the 200 m^3 of pressurised helium gas, the 5000 l LHe container and the cryogenic lines. The cold box and LHe container will be installed near the magnet whereas the compressors and pressure vessel will be at the surface level. The complete system will be installed temporarily on the surface for refrigerator commissioning and coil tests, (see Chapt. 21).

From a cryogenic point of view, coil operation is continuous, apart from annual shut-down periods for the necessary maintenance of electrical and cryogenic components. A dedicated helium refrigerator has been dimensioned for all the operating phases. A pre-cooler, fed with 500 l/h of liquid nitrogen, provides additional refrigeration power for the cool-down which is expected to last approximately 30 days from room temperature. Re-cooling from the post-fast-discharge temperature of 50 K will last three days.

3.6.5 Power Supply

The power supply is located alongside the refrigerator cold box in the service cavern. It will deliver a coil current of up to 20 kA at a maximum ramping voltage of 16 V. Current ramping time will be five hours, (see Chapt. 20).

There are two modes for slow discharging of the coil current: in normal operation discharge will be performed by the power supply and the energy will be injected back into the mains power network, this will last 18 h. In the case of a fault in the magnet power supply, the current will be dumped into the resistor bank set at its lowest resistance value of 2 mW. This last mode will last three hours.

In case of emergency, a fast discharge in a 50 mW resistor bank can be used. The time constant of the current decay is then 280 s, (see Chapt. 16 and 20).

In case of a mains power failure electrical power could be generated for helium recovery by using some of the stored magnetic energy. A study is under way to see if a DC/AC inverter can be incorporated in the magnet circuit for this purpose.

3.6.6 Process Control

The Magnet Process Control System, which is a part of the CMS Detector Control System (DCS) is capable of working independently and includes four parts, (see Chapt. 22):

- the sensors and actuators,
- the Programmable Logic Controllers including a Test and Development Station,
- the Magnet Safety System which in case of a fault automatically secures the magnet and its auxiliary equipment using hardware protection systems.
- the Magnet Supervisor which provides the user with:
    - supervision and control facilities,
    - operator's assistance and diagnostic facilities.

The process control of the CMS Magnet will be standardised with the process controls of the other LHC experiments including the cryogenics.

3.7 EXPERIMENTAL AREA

The proposal for the construction phase of the CMS experiment has been achieved taking into account the necessity to minimise any interference between the exploitation of LEP and the construction of the CMS subdetectors while at the same time reducing time and costs, (see Chapt. 25).

For these reasons we have adopted the solution of assembling and testing the magnet in the large surface hall before lowering it into the underground experimental cavern.

This solution allows us to start working on the magnet assembly already by the end of 1999 while LEP is still in operation. The choice of using a surface hall rather than the underground area, allows us to construct the magnet and detectors in parallel and not in series as would have been the case if the assembly was done underground. It also reduces to the strict minimum the size of the underground cavern. Fig. 3.5 shows an overview of the CMS experimental area.

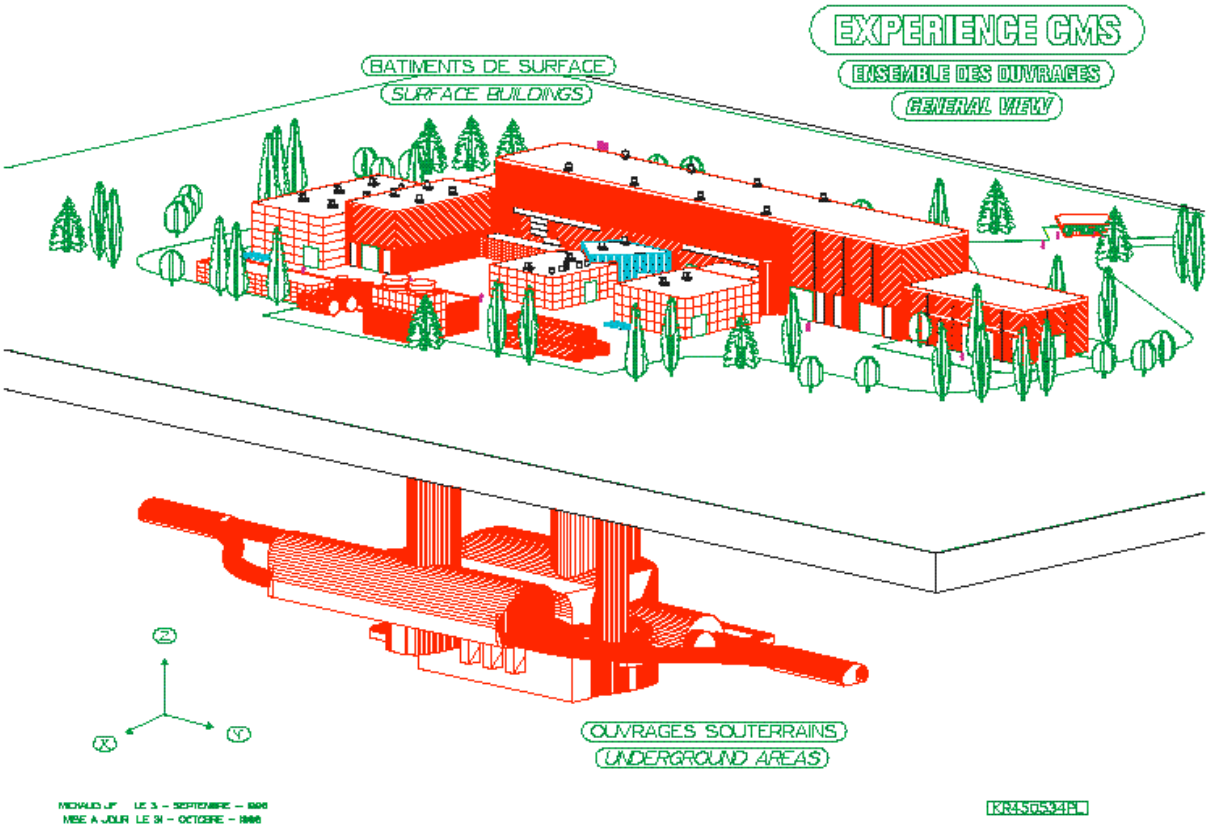

Fig. 3.5: View of the CMS Experimental Area Complex.

3.7.1 Surface buildings

The surface building complex will be located at point 5 of LHC. During the construction phase the main assembly hall will have a length of 140 m, a width and height of 23.5 m. After the magnet has been tested these dimensions will be reduced to a length of about 100 m and a height of 16 m thus having no major impact on the environment, (see Chapt. 25).

The surface assembly hall will also have two temporary alcoves which will be used as garage for the HB when moving large sections of the experiment through the hall. A third alcove will be used for testing the external cryogenics and the power supply before the surface test.

The temporary addition to the assembly hall, SXL5, is built to allow the final on-site reinforcement of the coil superconductor. Other buildings to be used for gas, primary cryogenics, ventilation etc. will be also built on the surface at point 5.

3.7.2 Underground area

The underground areas include the experimental cavern UXC5, the auxiliary cavern USC5, the access pits, PX56 and PM54, and the LHC machine bypass, (see Chapt. 25). The main access shaft PX56 is separated from UXC5 by a smaller removable metallic structure at the level of the experimental cavern ceiling.

The main cavern has a diameter of about 26.5 m and a length of 53 m. These are the minimum dimensions needed to open the CMS magnet and handle the major sub-components.

The auxiliary cavern is separated by a wall 7 m thick, (the radiation shielding requires 3 m) and will lodge the auxiliary services for the detector and the counting room.

The underground areas will be separated from the surface hall by a mobile radiation shielding situated at the top of PX56 which will also be used a support structure for the transfer of the magnet in UXC5 (see Chapt. 29).