CHAPTER 9

INTEGRATION AND OVERALL MACHINE EQUIPMENT LAYOUT

9.1 INTRODUCTION

Integrating the large and complex LHC machine into the existing LEP tunnel is a major challenge. Space was less of a problem when integrating LEP into its tunnel. However, the LHC cryostats are much larger than the LEP quadrupoles and the external cryogenic line fills even more of the tunnel. Space problems here lead to small clearances. Conflicts, at least the most penalising ones, must be solved beforehand in order to avoid unacceptable delays and extra costs during the installation. These conflicts can arise between the different equipment elements to be installed or with space required for transport.

This chapter presents the study work done to prepare for a smooth installation including the related data management and the tools provided to the teams procuring and operating the equipment.

9.2 INTEGRATION STUDIES

The difficulties to integrate the LHC machine into the existing tunnel are due to dimensional problems of two types. Firstly the machine is very long and the precise longitudinal positioning of the numerous elements is essential. Secondly, the transverse dimensions of the machine and its services must fit into the tunnel.

It was already a challenge to integrate the LEP machine in the tunnel, the quadrupoles were the widest elements, having a transverse section of about 0.7 m^2, but the LHC cryostats and the cryogenics line occupy four times more transverse space.

When space inside the tunnel is a problem clearances become a major concern, especially since the tunnel dimensions do not have the same precision as the mechanical parts of the accelerator. The tunnel is itself a very large piece of civil engineering with offsets of centimetres or even decimetres with respect to its theoretical position and dimensions.

Given these space constraints, an in depth study had to be carried-out to ensure that all the equipment would fit in the available space and that no interference between components would be encountered not only during installation but also during handling and transport. After a feasibility study, the overall integration work started in mid 2001[1]. Three working groups were created and each was given the task of studying a particular part of the collider: the underground service areas, the tunnel and the shafts. At the beginning of 2003, the integration work was entrusted to the Installation Coordination group (TS-IC) together with the LHC Reference Database [2][3] and the configuration management.

9.2.1 Methodology

Experience with LEP showed the advantages that computer-aided engineering (CAE) software could provide for integration. Because LHC integration is much more complex, the use of CAE software is essential. Specific tools, based on the CAE software, have been developed in the two dimensional domain for the longitudinal positioning of elements and in the three-dimensional domain for the complete digital mock-up (DMU) of the LHC.

The integration study required the creation of 3-D computer models of all the major components (cold and warm magnets, electrical feedboxes, dump resistors, racks, electronics crates, transformers, etc.), the services (cable trays, cables, pipes, metallic structures, etc.) as well as the civil engineering works (as-built models).

Each group was asked to provide the 3-D models of the equipment they designed and the installation they were procuring. These were introduced in a library of “standard” models which were made available to all those involved in integration studies. Since the studies strongly rely on the quality of the models, a lot of effort was put in maintaining the coherence of the models whilst the design and integration studies progressed, often in parallel.

The integration process relies on the DMU and the LHC reference database to position the models in the tunnel or the service areas. Two specific parts of the underground areas are treated by the DMU: the periodic part consisting of the "standard" tunnel sections and the repetitive cells of the machine and are automatically generated and the non-periodic part, typically underground service areas. The shafts have been integrated manually.

As a result of this effort, 3-D representations of any part of LHC can be produced. Priority has been given to the most crowded areas and major difficulties were encountered in some specific zones where civil engineering modifications were deemed necessary. However, in most of these cases, a thorough integration study confirmed that civil engineering could be avoided, albeit at the expense of a very dense and complex installation.

The 3-D views produced through DMU are very thorough representations, but sometimes difficult to use by non-specialists. In order to satisfy the requirements from users groups, two types of coherent and consistent documents have been prepared on the basis of the 3-D views: standard tunnel cross-sections and 2-D dimensioned drawings. The 2-D dimensional drawings are produced with each layout version but the latest changes are available on-line and equipment layouts can be produced on-the-fly for installation [4].

9.2.2 Quality Assurance

The integration studies are only useful if they are reliable, meaning that quality control is essential. The first step is the quality of the “standard” models under the responsibility of the groups. The second step is the quality of the integration itself which is the responsibility of the integration team: no model must be forgotten and all elements must be at their correct position. Finally, the third step is the quality of the installation itself.

The standard models should correspond to the equipment installed and only the relevant groups have a thorough knowledge of this.

The quality of the integration is enforced by meetings with the parties preparing equipment for installation (on a weekly basis). When the studies converge, i.e. when it is shown that the equipment can be installed without interfering with other installations or the tunnel boundaries, a folder containing 3-D drawings, plans and other documents is submitted for approval to all parties involved.

The underground installation of equipment has started. After each installation phase, measurements are taken to verify that the equipment was installed as planned by the integration studies. The survey is done either visually or, when needed, with sophisticated techniques such as laser scanning. Any anomaly is checked against the next layer of equipment. This quality assurance procedure ensures the feasibility of the installation of the next phase. In conjunction with this, non-conformity reports are issued and followed-up until all are either resolved or accepted as-is with technically bearable consequences.

9.2.3 Documentation

The integration working groups have created a web site [5] where all the relevant information can be viewed. The documentation includes about 3500 standard models, the status of the studies, approval folders, about 110 3-D integration models and a large series of pictures of the underground areas.

A total of 70 standard tunnel cross-sections and 514, 2-D installation drawings are accessible in the CERN Drawing Directory [6]. Equipment layouts can also be produced on the fly for each system or any combination of systems.

Some examples of documentation taken from these two repositories is shown in Sec. 9.4.

9.3 NAMING OF UNDERGROUND STRUCTURES

To localise equipment or a place is quite often a burden in such a large site as the LHC. In order to speak the same simple language, an abbreviation system [3] has been put in place. In fact, the abbreviation system used for the LEP underground works has been kept for LHC. New works are identified according to this system, while existing installations kept their LEP name, even if their usage for LHC is different.

9.3.1 Definition of Abbreviations

Each name is made of up to six alphanumeric characters, split in two groups of three. The first group is alphabetic and defines the works type and the second the works number. This convention totally conforms to the Naming conventions for LEP buildings and Civil Engineering [7].

9.3.2 WORKS TYPE

First Character

The first character of the works type determines the kind of Civil Engineering works, according to the following list:

- P = Pit (Shaft)
- R = Ring underground works on the beam path
- S = Surface buildings
- T = Tunnels and underground galleries
- U = Tunnel enlargements, experimental caverns, other underground works which are not directly on the beam path.

Second Character

This indicates the main usage of the building and underground work, with the following list:

- A = Acceleration and Radio-frequency equipment
- B = Equipment for Low Beta section
- C = Controls and Communications
- D = Material unloading
- E = Electricity
- F = Fluids
- G = Gas for detectors
- H = Cryogenics
- I = Injection
- J = Junction caverns
- L = Liaison galleries
- M = Magnets and other machine equipment
- P = Personnel Protection and Fire Brigade
- R = Power Converters
- S = Services
- T = Beam transfer
- U = Ventilation
- W = Water
- X = Experiments
- Y = Access control
- Z = Access

Third Character

This character is optional and is used either to be more precise about the usage of the works concerned or to distinguish between different specific parts of that works or to distinguish two works having a similar usage.

A web page [8] gives the list of civil engineering works abbreviations actually in use.

9.3.3 WORKS NUMBERING

Up to three digits follow the works type and are used to localise the works concerned. The first numeric character is the octant number defined as the LEP access point. The digit 0 is used to designate the whole LHC site, while 9 is used for zones outside the CERN domain. The second digit allows more precise localisation with respect to the middle of the octant: this point (the former LEP collision point) is given the number 5 and the octant is split in equal parts, numbered from 1 to 9 clockwise. The last and optional digit can be used for specifying the floor number of a building or for distinguishing between two neighbouring works.

9.4 TYPICAL DOCUMENTATION

9.4.1 Tunnel Cross-Sections

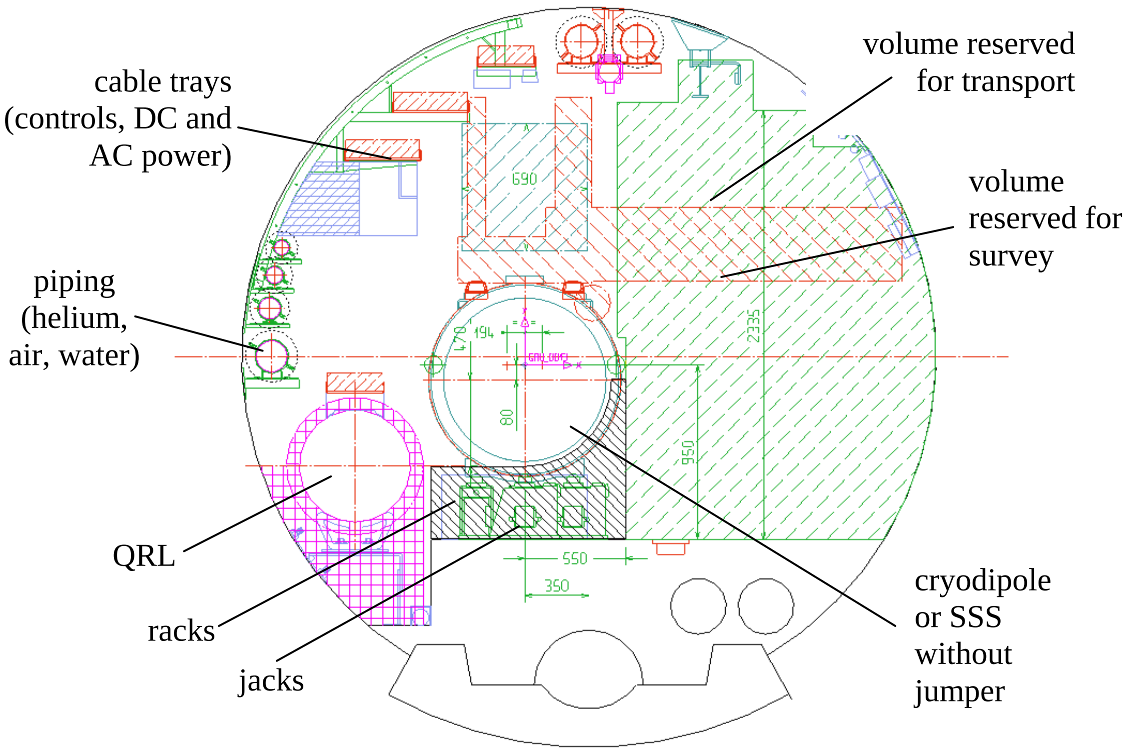

Figure 9.1: Standard Tunnel Cross section

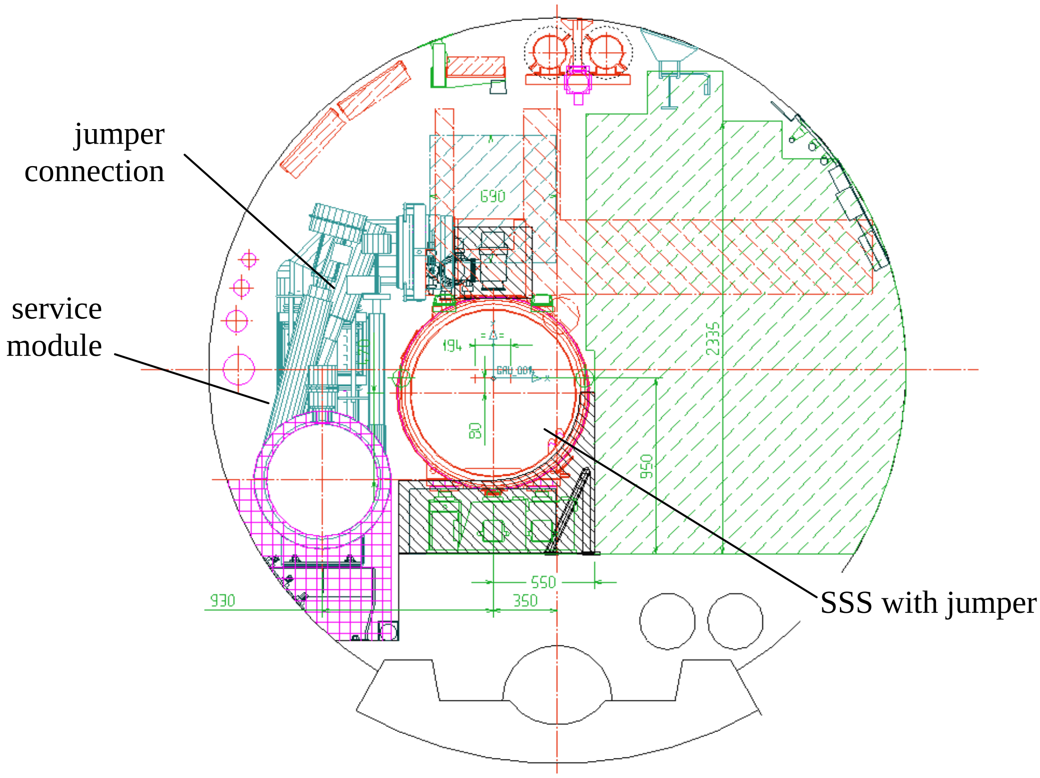

Figure 9.2: Standard tunnel cross section with jumper connection to the QRL

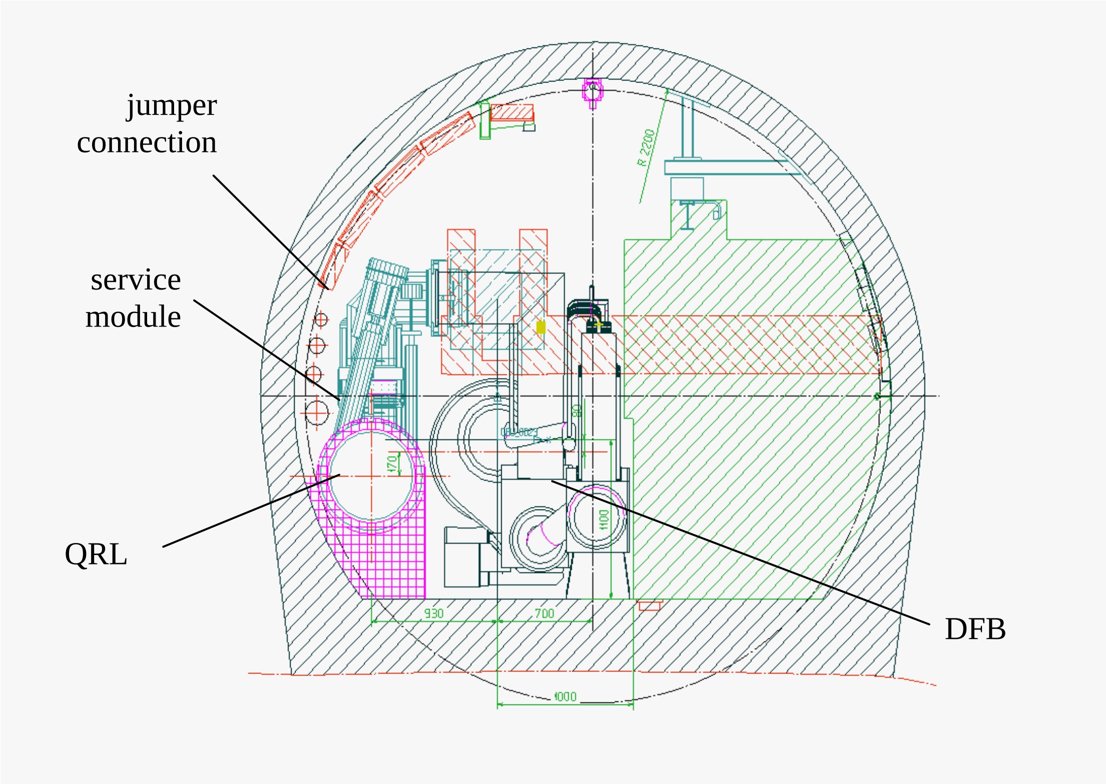

Figure 9.3: Enlarged tunnel cross section (RA) with DFBA

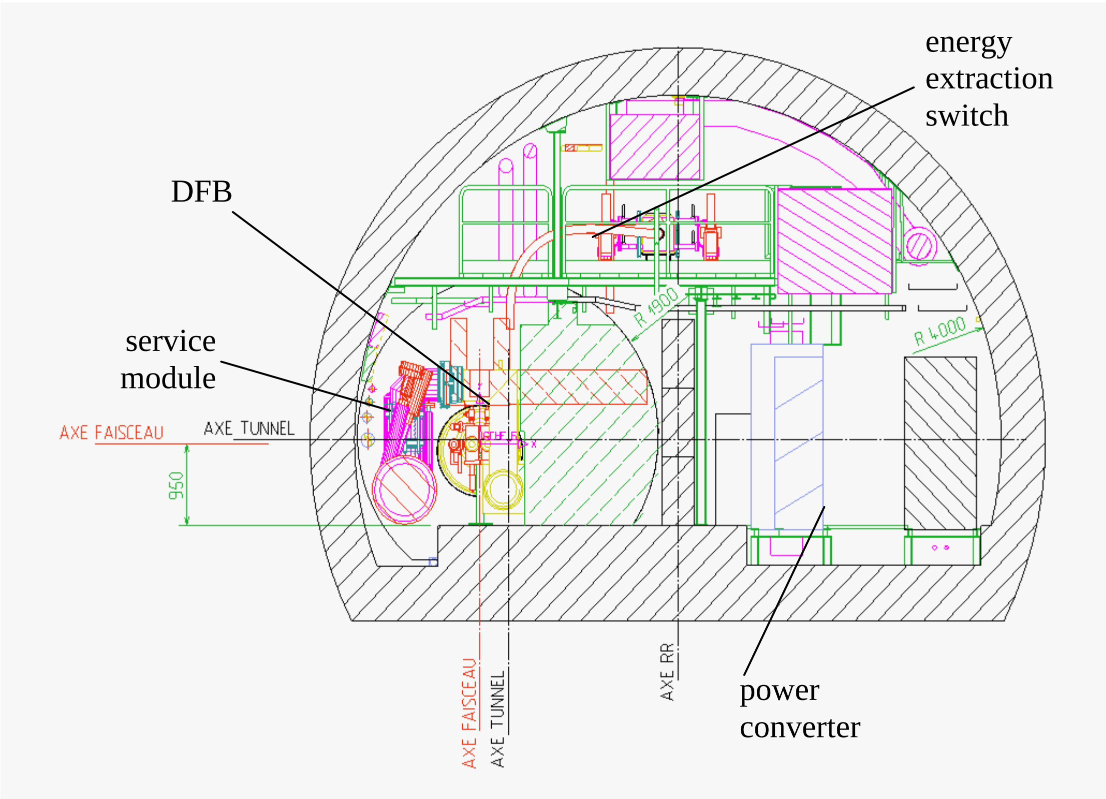

Figure 9.4: Service Area RR77 cross section

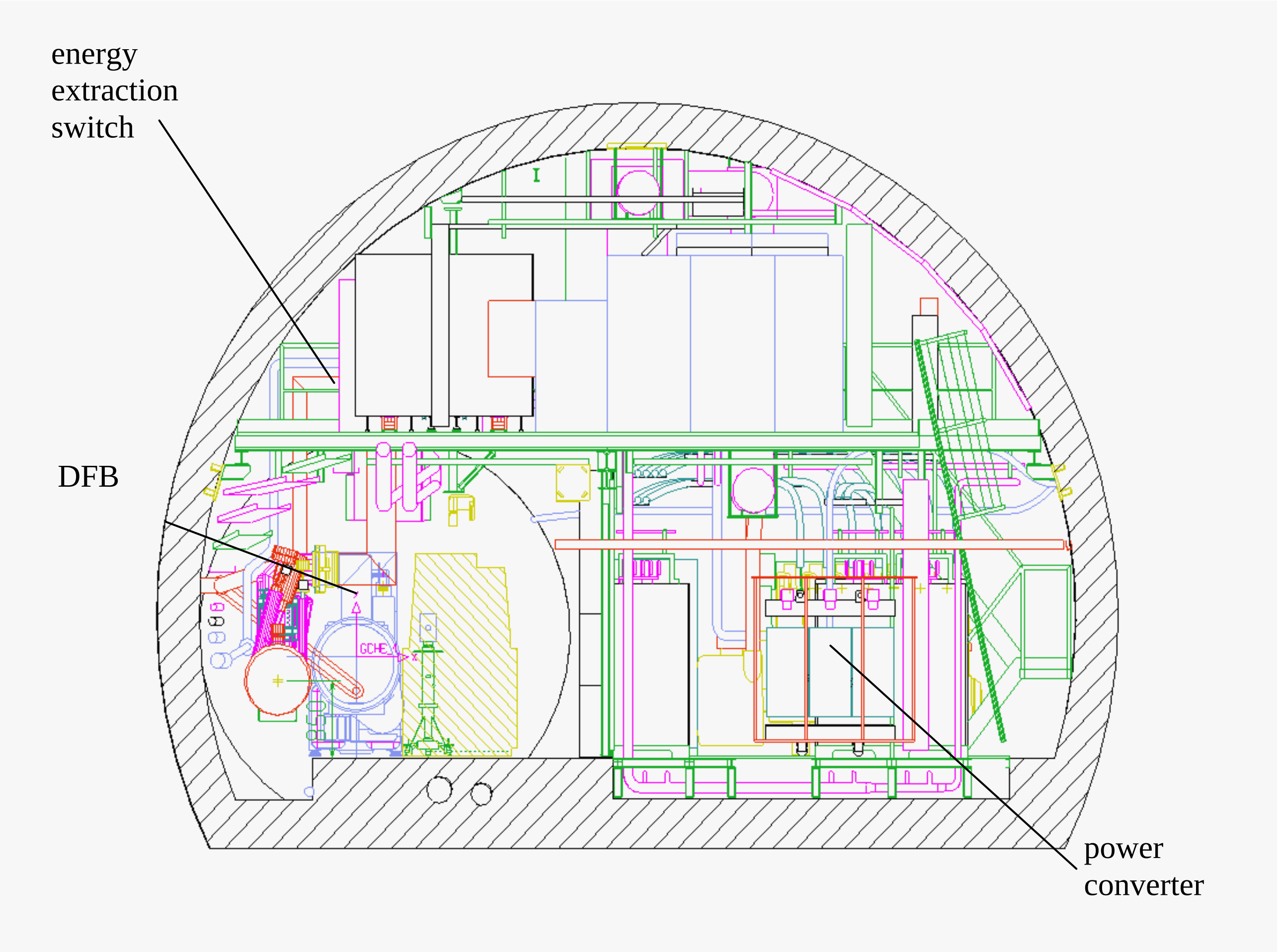

Figure 9.5: Service Area RR13 cross section

9.4.2 3-D Views

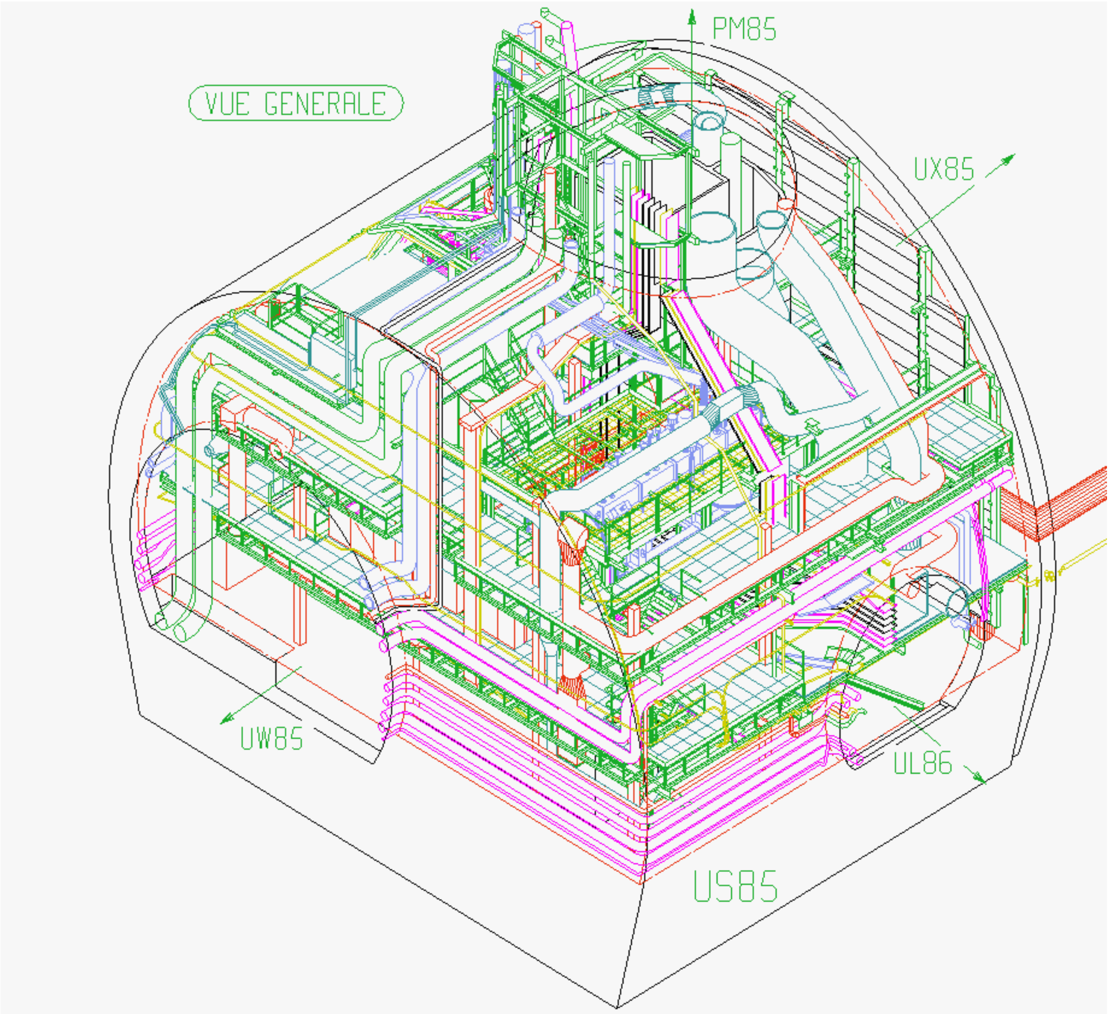

Figure 9.6: Service Areas – US85

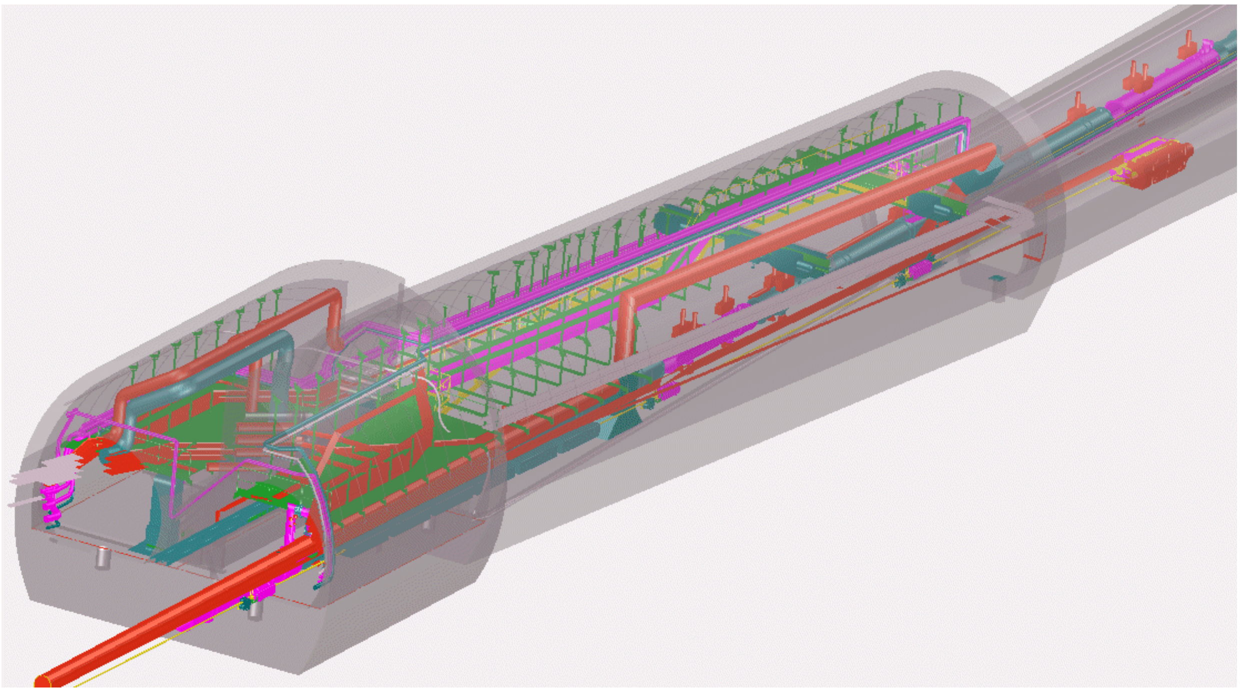

Figure 9.7: Junction with the TI2 Injection Tunnel – UJ22

9.4.3 2-D Installation Drawings

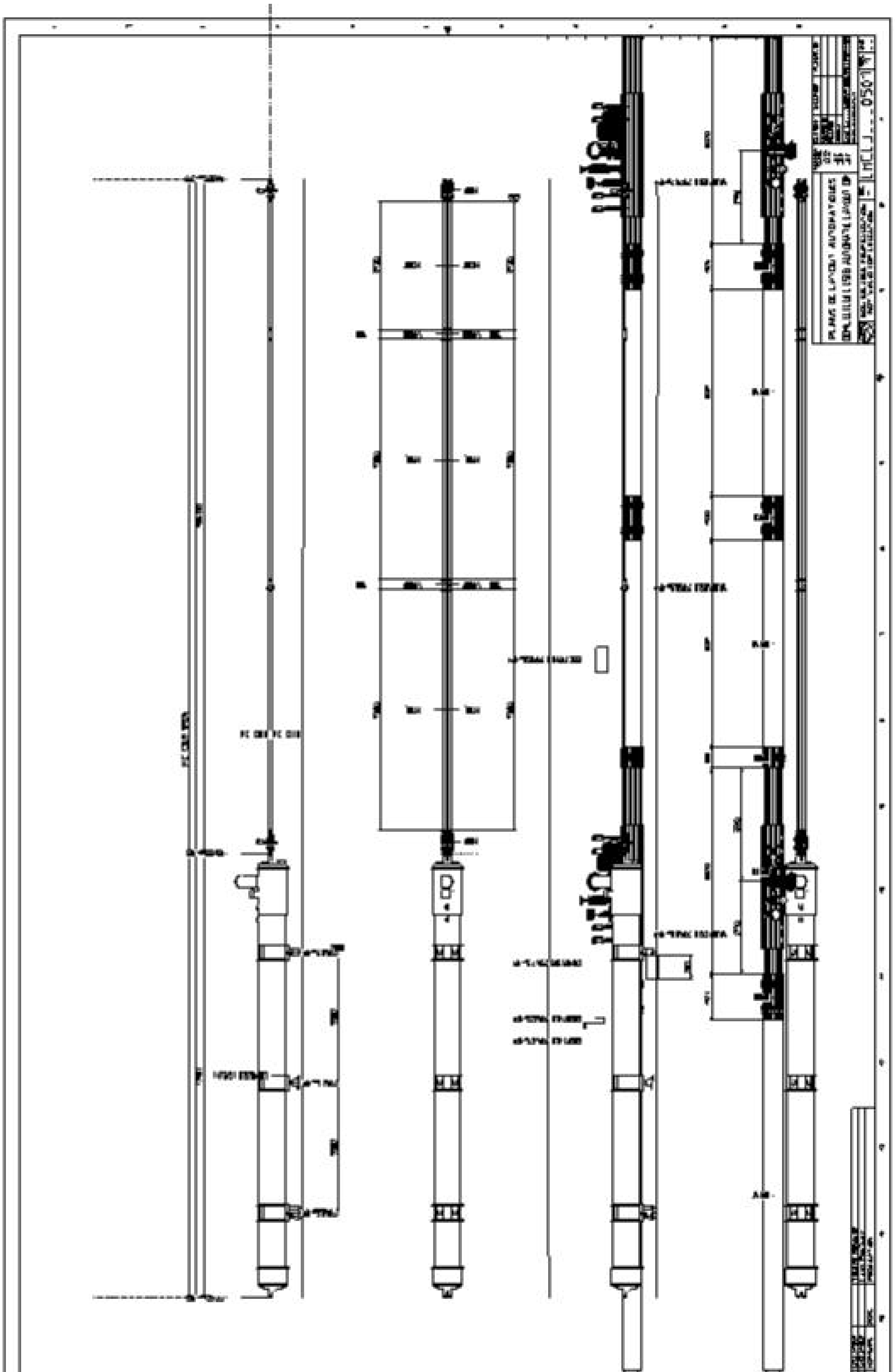

Figure 9.8: Example of an automatically generated 2-D drawing of a half-cell

REFERENCES

[1] Chemli S. et al., *'A Virtual CAD Model of the LHC'*, EPAC 2000, Vienna, Austria, June 2000.

[2] Section 14.6, LHC Design Report Vol. I: The LHC Main Ring, CERN-2004-003, June 2004.

[3] Le Roux P. et al., *'LHC Reference Database; Towards a Mechanical, Optical and Electronic Layout Database'*, EPAC 2004, Lucerne, Switzerland, July 2004.

[4] Chemli S. et al.,*'Layout Drawings of the LHC Collider'*, EPAC 2004, Lucerne, Switzerland, July 2004.

[5] http://cern.ch/ts-dep-ic/IN/index.html

[6] https://edms.cern.ch/cdd/plsql/c4w.get_in

[7] *'Naming Conventions for Buildings and Civil Engineering Works'*, LHC-PM-QA-207, EDMS: 107398.

[8] http://cern.ch/st-div/Groups/ce/lhc/ListeStruc.htm