

# CHALLENGES AND SOLUTIONS IN THE INTEGRATION STUDIES OF THE FUTURE CIRCULAR COLLIDER

F. Valchokova-Georgieva, Foselev Suisse SA, 1214 Vernier, Switzerland  
J.-P. Corso, K. Hanke, CERN, 1211 Meyrin, Switzerland

## Abstract

The Future Circular Collider (FCC) study is developing designs for a new research infrastructure to host the next generation of higher performance particle colliders to extend the research currently being conducted at the Large Hadron Collider (LHC) once the High-Luminosity phase (HL-LHC) reaches its conclusion around 2040. CERN's Integration Office aims to fulfil the requirements of different stakeholders, which includes reviewing alignment defining tunnel cross sections and supporting underground civil engineering designs. After investigating different scenarios, a first layout of an FCC machine tunnel with an inner diameter of 5.5m was defined. This paper describes the integration process for future projects i.e., decisions made and challenges that had to be overcome along the integration studies, from typical cross-sectional dimensioning to 3D machine design.

## INTRODUCTION

In 1989, CERN's Large Electron-Positron (LEP) started operating, being the largest particle accelerator in the world at that time. [1]. The LEP was built in a 27-kilometre tunnel of 3.8m internal diameter (see Fig. 1). The tunnel housed the beam line machine, general services (i.e. electrical, cooling and ventilation equipment) and transport systems.

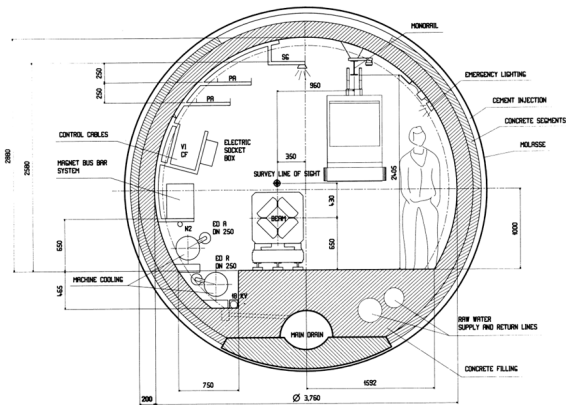


Figure 1: Normal cross-section of the LEP main tunnel

The LEP was decommissioned in 2000 to make way for the construction of the Large Hadron Collider (LHC) in the same tunnel, where the largest and most powerful accelerator operates since 2008. [2]. The LHC is made of super conducting magnets supplied by a 27 km cryogenic distribution line (see Fig. 2).

The LHC is presently being upgraded to the High-Luminosity LHC (HL-LHC) [3] which would become the injector for the Future Circular Collider (FCC) [4]. The FCC

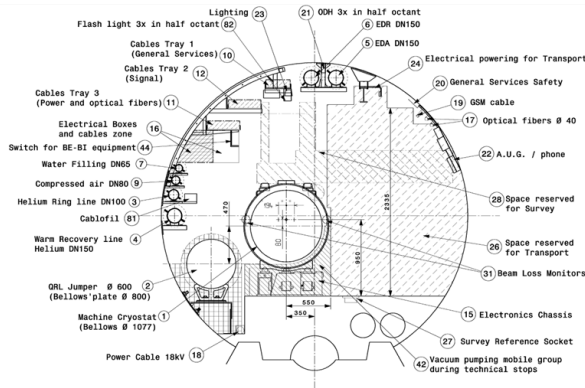


Figure 2: LHC normal cross-section

studies are considering two types of accelerator to be built in a same civil engineering construction with a new tunnel of 80-100 km long; a lepton collider (FCC-ee) spanning the energy from 80 to 400 GeV [5] and a hadron collider (FCC-hh) with a center-of-mass energy in the order of 100 TeV [6].

## INTEGRATION STUDIES

### FCC Study Phase I - Conceptual Design

The spatial integration studies ensure that the layout and configuration of the FCC-ee and FCC-hh machines remain compatible with the FCC tunnel environment. During Phase I of the FCC study, the 3D integration studies were done with approximate volumes to define the possible configuration scenarios with respect to the civil engineering sizing studies.

**Civil Engineering Configuration** In 2018, the FCC was conceived within a 97.75 km quasi-circular tunnel with 5.5 m inner diameter. This tunnel was composed of (see Fig. 3):

- 20 vertical shafts with 12 m and 18 m in diameter,
- 12 service caverns,
- 2 experiment caverns,
- 2 beam transfer tunnels connected with the LHC,
- 2 beam dumps,
- bypass tunnels,
- 2 RF points with klystron galleries,
- 68 electrical alcoves.

**Machine Layout and Configuration** The retained solution in the conceptual design report stage was an horizontal configuration of the FCC-ee. The standard cross section of the FCC-ee in a regular arc of the tunnel represents the e+/e-ring, the booster ring, the associated general services (e.g. cooling, cable trays, etc.) and sufficient space for transport

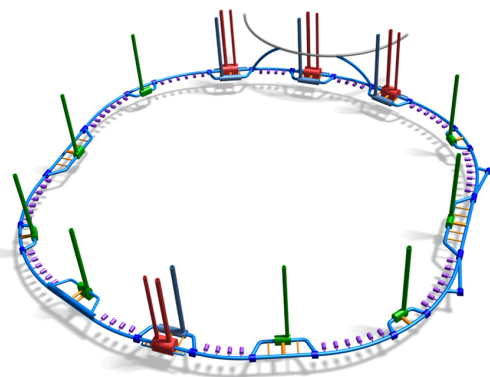


Figure 3: FCC schematic layout - 2018

and handling. The air supply and smoke extraction ducts are integrated into civil engineering infrastructure (Fig. 4).

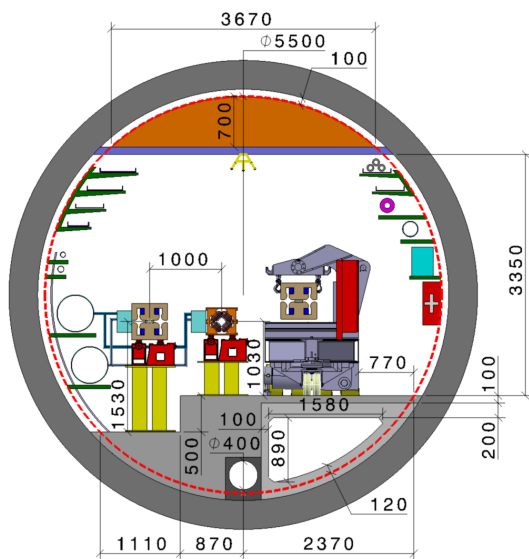


Figure 4: FCC-ee Machine tunnel cross section in a regular arc with machine elements, services and transport equipment

The retained solution for the configuration of the superconducting accelerator FCC-hh is similar to the existing LHC configuration with additional space to allow for personnel passage (see Fig. 5). The cross section shows the position of the magnet cryostat having an overall diameter of 1.2 m (including reinforcement rings, flanges, bellows, etc.) and the cryogenic distribution line with an outer diameter of 1.35 m. Service elements comprise a line for helium, a superconducting link for magnet power, and raw and demineralized water, a leaky feeder radio system cable and cable trays for the power and control cables. The air supply and smoke, and helium extraction ducts remain compatible for the FCC-hh configuration.

The cross section integration has been optimized as much as reasonably acceptable to optimize the overall volume of the tunnel and keeping contingency for additional machine equipment, cable trays and cooling services.

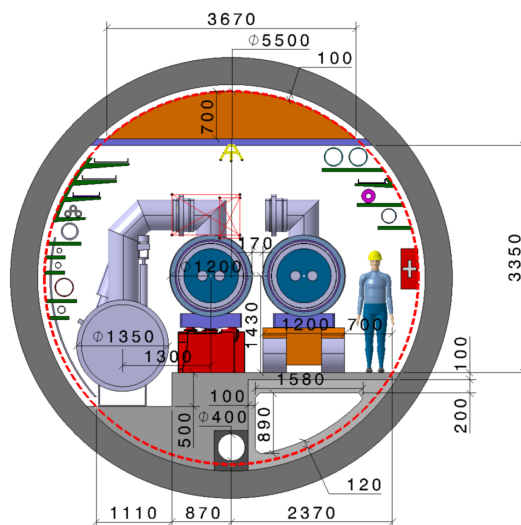


Figure 5: FCC-hh Machine tunnel cross section in a regular arc with machine elements, services and transport equipment

### FCC Study Phase II - Feasibility Design

**Civil Engineering Configuration** During Phase II, the civil engineering configuration was substituted by a 90 km quasi-circular tunnel with 5.5 m internal diameter [6]. It is composed of (see Fig. 6):

- 14 vertical shafts with 12 m and 18 m in diameter,
- 8 service caverns,
- 4 experiment caverns,
- 2 beam transfer tunnels connected to the LHC,
- 2 beam dumps,
- bypass tunnels,
- 2 RF points with klystron galleries,
- 66 electrical alcoves.

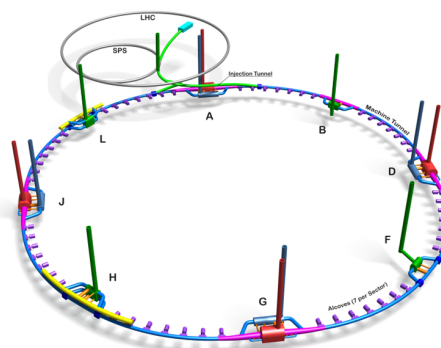


Figure 6: FCC schematic layout - 2023

**Machine Layout and Configuration** The integration team refined the FCC configurations by collecting the updated needs and requirements specifications from all the stakeholders; civil engineering (e.g. buildings, caverns, ma-

chine tunnels, etc.), infrastructure (e.g. metallic framework, lifts, etc.), general services (cooling, HVAC, electrical supply, cable trays, etc.), transport and handling (e.g. crane, transport volume, etc), safety systems (e.g. fire detection, alarms, etc), machine systems (e.g. cryogenics, power converters, radio-frequency, etc.)

At this stage of the FCC study, the space requirement was reviewed by all stakeholders to meet their needs regarding the design concept evolution, and the installation and maintenance accessibility. The integration studies play a crucial role as a central actor in the spatial management of the FCC layout and configuration.

As an example, Figure 7 shows the required volumes for the alignment systems in the FCC-ee with the following requirements:

- Wire Positioning Systems (WPS) (light green),
- WPS replacement System (purple),
- Hydrostatic Levelling System (HLS) (yellow),
- HLS refill system and sensors (blue),
- Girder element (orange),
- Survey Equipment Support (dark orange).

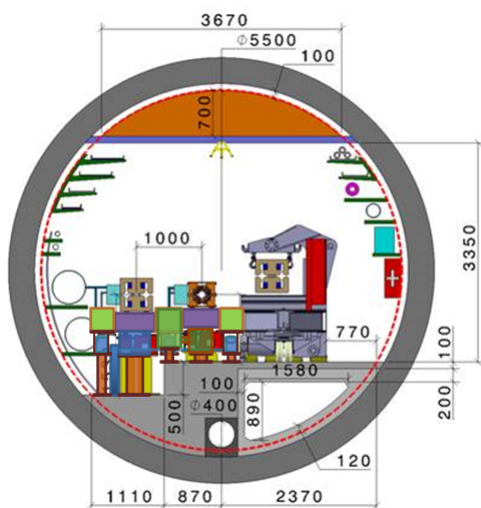


Figure 7: FCC-ee Machine tunnel cross section in a regular arc with machine elements, services, transport equipment and space occupation for alignment systems

The revision of all systems requirements increased the required volume in the tunnel for many of them. As major examples:

- Demineralized water circuits increased by a factor 2,
- Additional chilled water circuits,
- Larger fire-fighting/raw water pipes,
- Larger smoke and Helium extraction and fresh air ducts,
- Addition of fresh air diffuser and fan coil,
- Additional helium pipes.

To keep the 5.5 internal diameter of tunnel, the integration team proposed a new configuration of the FCC-ee by changing the layout to a vertical configuration (see Fig. 8). In this configuration, the booster ring is 1.03 m above the collider ring. This new configuration improves the access

to both sides of the machine, making it simpler for general services (i.e. cooling, electrical and cryogenic equipment) on the outer side. In parallel, the transport team proposed a new type of vehicle which gave the possibility for faster and easier transportation and installation of the magnets.

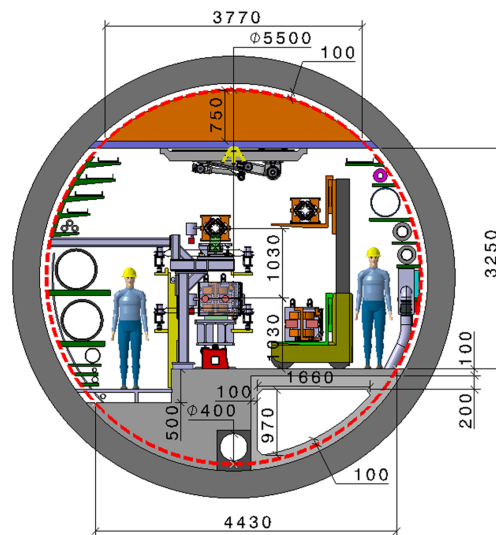


Figure 8: FCC-ee Machine tunnel cross section in a regular arc with machine with up-to-date elements, services, transport equipment and space occupation for alignment systems

For better installation control and maintenance of both the magnets and the support services, a robot was added on the ceiling of the tunnel. This robot would have several functions, such as supporting installations of the magnets, tracking possible incidents on the installed systems, or monitoring and helping the evacuation of people in case of accident in the tunnel.

## CONCLUSION

The layouts for the machine proposed by the integration team are the baselines for FCC-ee and FCC-hh for the mid-term review of the FCC study Phase II. The integration studies on Experimental caverns and technical/service areas (RF klystrons, injection/extraction, dump, etc.) are still progressing. The objective of integration studies in the Feasibility phase is to provide realistic 3D models for the overall FCC, including underground facilities for the detectors, services, accelerators, transfer lines, and access by 2025.

## ACKNOWLEDGEMENTS

The authors would like to acknowledge the FCC Technical Infrastructure Coordination for their inputs and supports in the integration studies.

The integration work was partly funded by the European Union's Horizon 2020 research and innovation program under grant agreement No 951754 (FCCIS).

## REFERENCES

May 2020

- [1] "LEP design report v.2 : The LEP main ring", CERN, Geneva, Switzerland, 1984
- [2] "LHC design report v.2 : the LHC Infrastructure and General Services", CERN, Geneva, Switzerland, 2004
- [3] I. Bejar Alonso, L. Rossi *et al.*, "HiLumi LHC Technical Design Report : Deliverable: D1.10", CERN, Geneva, Switzerland, 2015
- [4] F. Zimmermann, M. Benedikt, A.-S. Müller, "The Future Circular Collider Study", in *IPAC 2020*, Caen, France, 10 - 15
- [5] M. Benedikt *et al.*, "FCC-ee: The Lepton Collider : Future Circular Collider Conceptual Design Report Volume 2", CERN-ACC-2018-0057, 2018
- [6] L. Bromiley and J.A. Osborne, "FCC-ee Civil Engineering and Infrastructure Studies", in *Proc. 65th ICFA Adv. Beam Dyn. Workshop High Luminosity Circular e+e- Colliders (eeFACT'22)*, Frascati, Italy, Sep. 2022, pp. 178–182. doi: 10.18429/JACoW-eeFACT2022-WEZAS0105