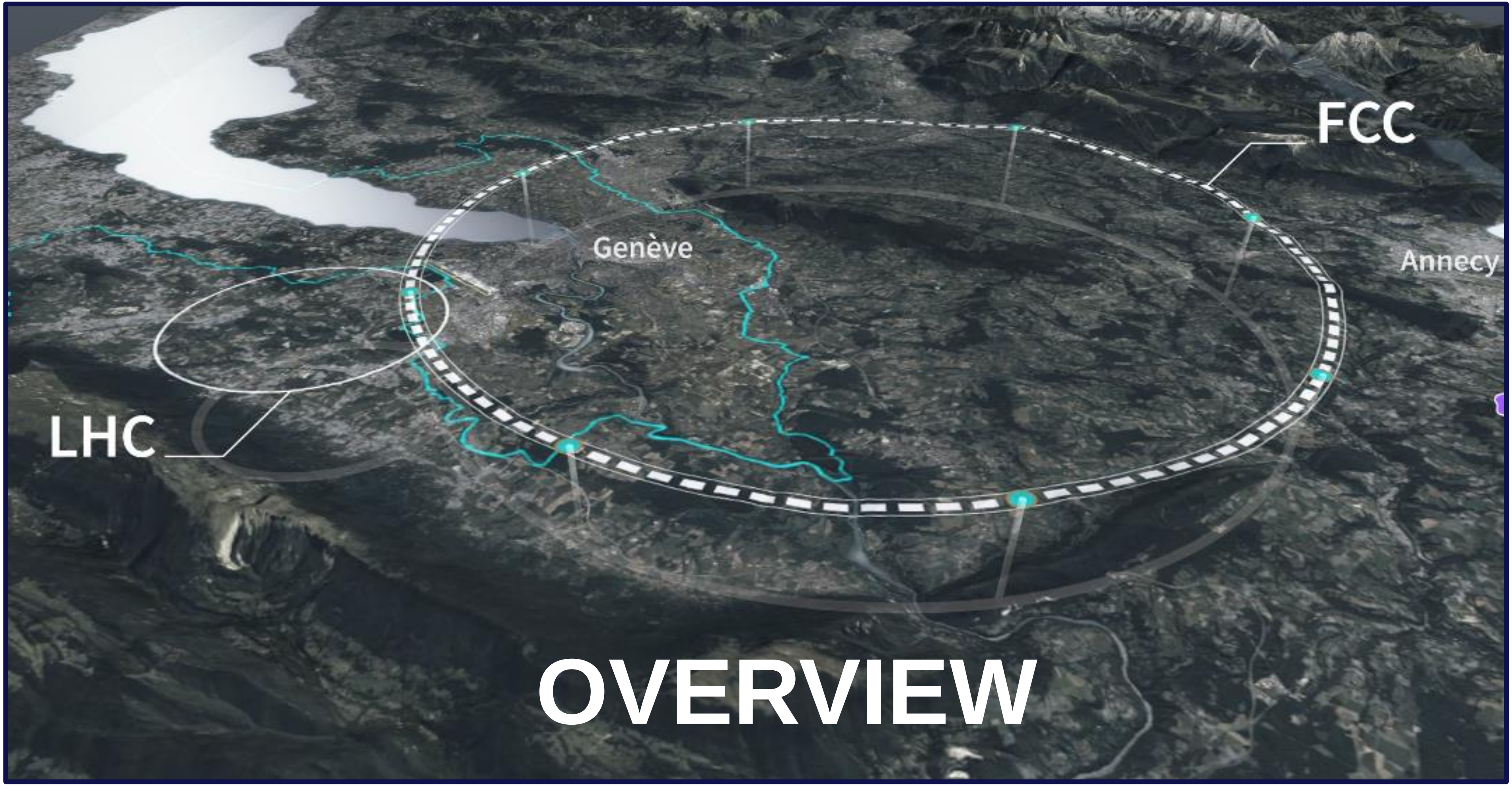
PROGRESS OF CIVIL ENGINEERING STUDIES FOR THE FCC

24 JANUARY 2024

TIM WATSON – WP 5 COORDINATOR

Agenda



OVERVIEW

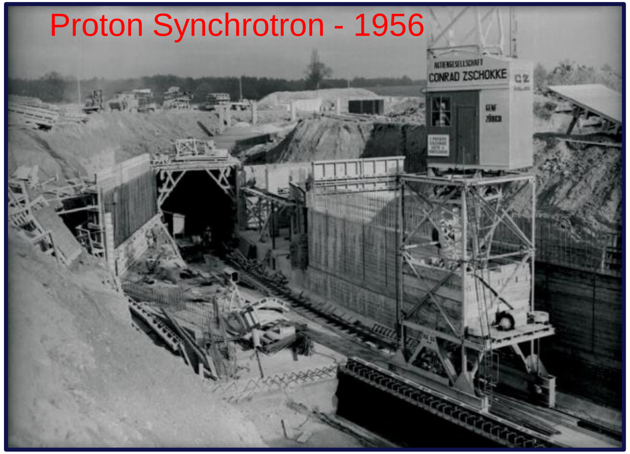
- Civil engineering is not a core activity of CERN. Some may say it is just an expensive nuisance!
- However, the cyclical nature of the construction and operation of CERN's infrastructure and accelerators over the years means that CERN must be prepared to undertake ever more complex and challenging civil engineering as part of the continuous development of the laboratory.
- Today, we are at the beginning of what we hope will be the next intense period of civil engineering activity namely the design and construction of the FCC.
- Although the FCC is currently in "Study" Phase, the long planning and procurement cycles means that for civil engineering at least, work needs to commence soon if we are to achieve the planned (or faster!) commissioning of the FCC ee machine and associated detectors.

Start of Civil Engineering March 1954

Foundation Stone Ceremony June 1955

1957

1961



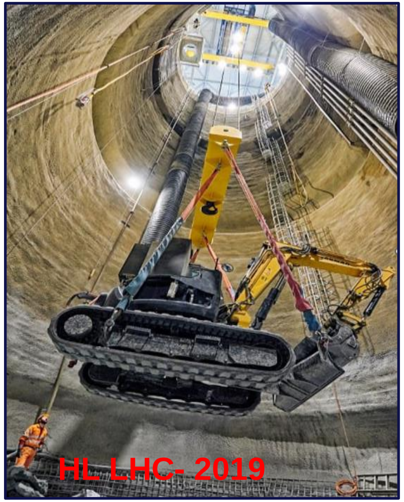
Proton Synchrotron - 1956


ISR – 1967


SPS – 1973


LEP - 1985


LHC – 2002

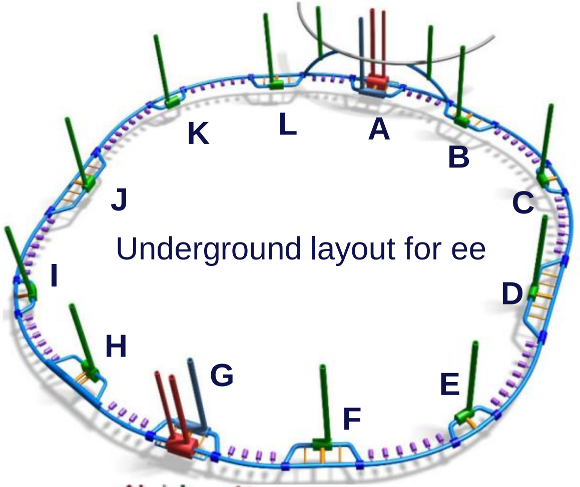

HL LHC- 2019

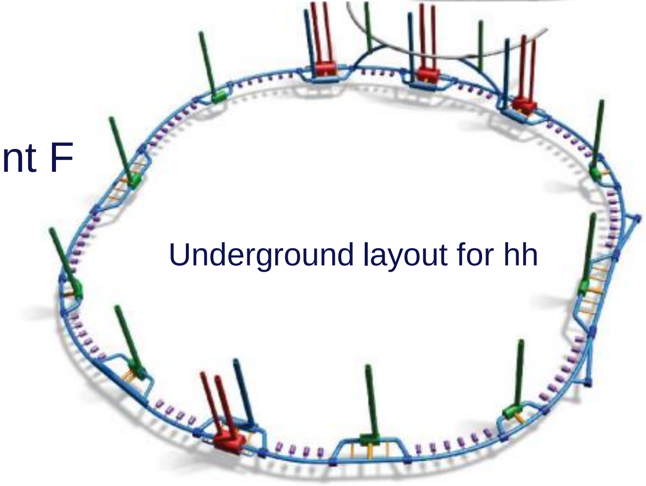
Overview

- The civil engineering group at CERN has been working on the FCC for almost 10 years!
- The work up to 2018 (end of conceptual design phase) focused on technical aspects for a series of options that were being considered by the FCC team for the tunnel location and circumference.
- This early work was carried out by small team consisting of a senior civil engineer (working part time) and a Fellow (full-time) supported by external consultants ILF for the underground design/costing/schedule work.
- The tunnel layout and associated civil engineering structures included in the conceptual design included a 98km long beam tunnel with 12 access points and 4 Interaction Points.
- Little work was done on development of surface buildings at the CDR Phase.

Overview – Concept Designs (2018)

- Twelve access points (A..L)
- Two experimental areas for ee
- Four experimental areas for hh
- Tunnel circumference of 98 km
- 21 access shafts (hh) Including 2 for each experimental cavern
- Beam dump civil engineering (hh only)
- Deepest shaft 274m
- One inclined tunnel to replace 578m deep shaft at Point F
- Alcoves every 1.5 km





Resources for FCC Civil Engineering Feasibility Study

Coordinator
Tim Watson

Sub-Surface Civil Engineering

CERN
John Osborne (PT)
Roddy Cunningham
Liam Bromiley

External Consultants
ILF
Quantum (Egis)
UNIGE

CERN Draftsman
Angel Cornago (PT)

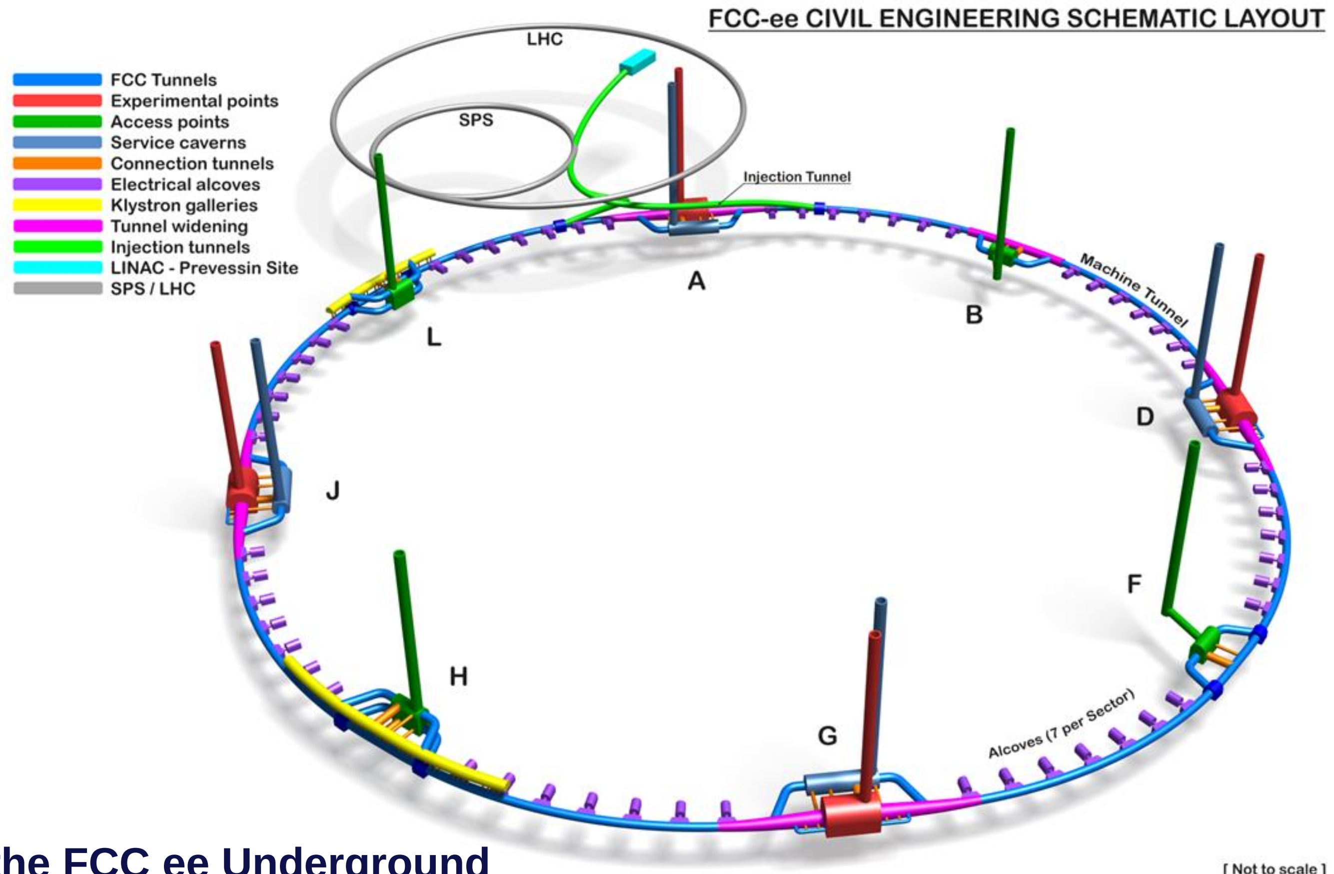
Surface Civil Engineering

CERN
Antoine Mayoux

External Consultants
Fermilab
Ingérop

Underground Works - Main Developments Since CDR

- Rationalization and simplification of the overall layout.
- Better understanding of needs of RF, ee Injection and ee beam dump now incorporated into the civil engineering.
- Maturity of the placement studies has allowed surface constraints to be considered for the layouts of surface and underground civil engineering.
- Circumference of the ring reduced from 97.8 km to 90.6 km
- Number of shafts reduced to 12 (+1).
- Beam Dump for ee integrated into beam tunnel (with widening required)
- Single tunnel for clockwise and anti-clockwise ee injection
- Increase in the civil engineering necessary to house the RF systems
- Development of a staged strategy for some structures
- Inclusion of a new LINAC chain at Prevessin as alternative to using SPS for ee injection

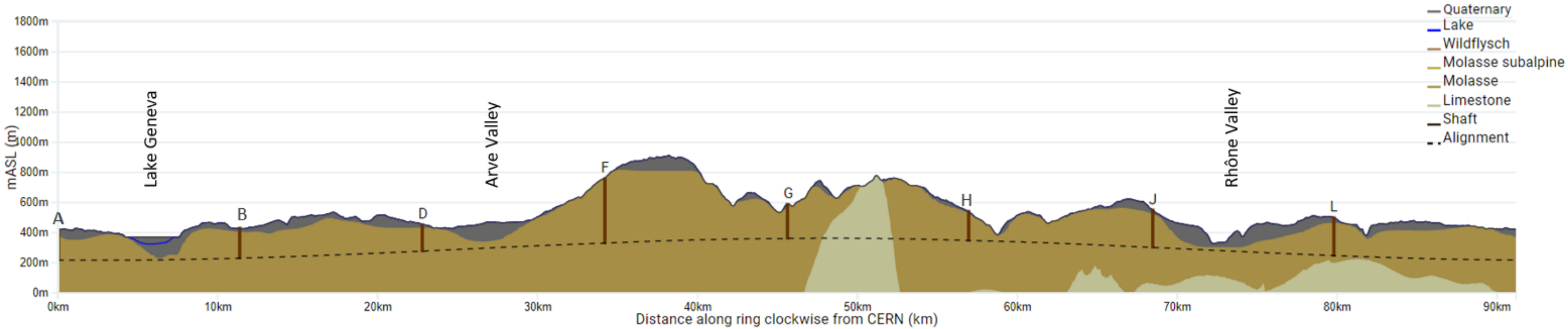


Schematic Layout of the FCC ee Underground Works as Baselined for the Mid-term Review.

Main Beam Tunnel

- To maintain the tunnel within the preferred Molasse rock horizon, the tunnel, is located within an inclined plane with its centre located 300m above sea level.
- This gives a tunnel depth below the surface of between about 50m and 500m
- Since the interfaces between the molasse rock and the underlying limestone and overlying moraine is not precisely known in all areas of the proposed tunnel location, the actual depth and inclination of the tunnel is likely to change once the results from the SI are known.
- The tunnel will need to pass through a limestone outcrop that cannot be avoided. Current expectation is that this limestone can be traversed using tunnel boring machines but that the geological conditions will result in a reduced tunnelling rate of advance.
- The current baseline assumes the tunnel will be constructed using 8 tunnel boring machines with each machine excavating one sector between two access points i.e., a length of about 11km.

Tunnel Long Profile



Shaft depths:

A: 201 m B: 201 m D: 181 m F: 400 m G: 226 m H: 235 m J: 253 m L: 250 m

Main Beam Tunnel

- The tunnel diameter required is determined by the integration team from a consideration of the space requirements needed for the machine, cables, pipes, transport, maintenance etc.
- The tunnel internal diameter is 5.5m which would require an excavated diameter of about 6.5m to allow for the ground support and tolerances.
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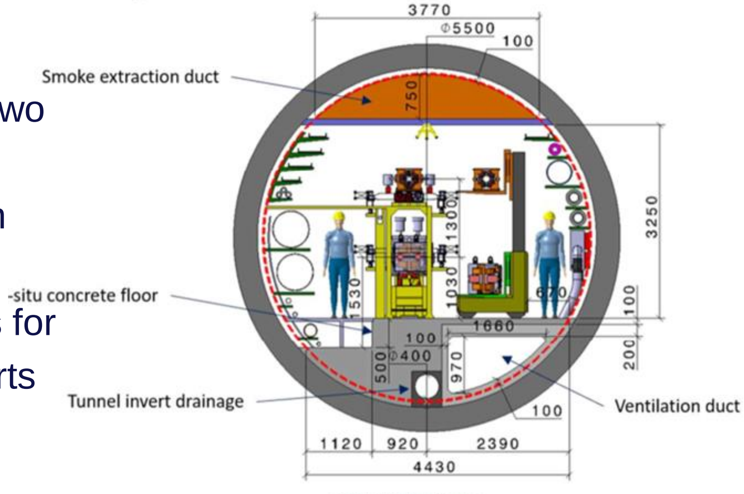
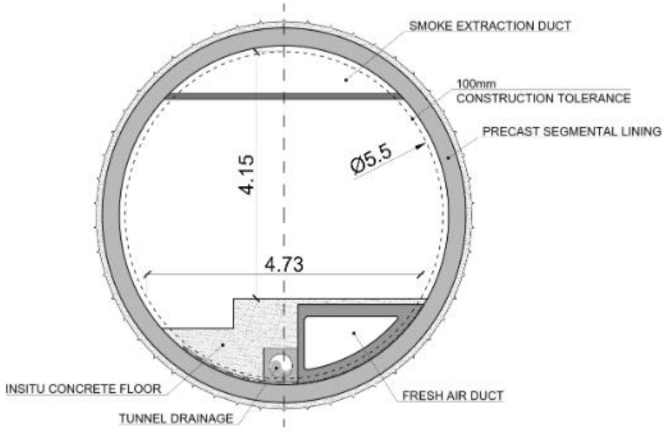
- Current operational requirements call for two air ducts that can be isolated from the main tunnel. The lining will incorporate fixing rails for cable and pipe supports to be installed later.



Credit: Fani Valchkova-Georgieva



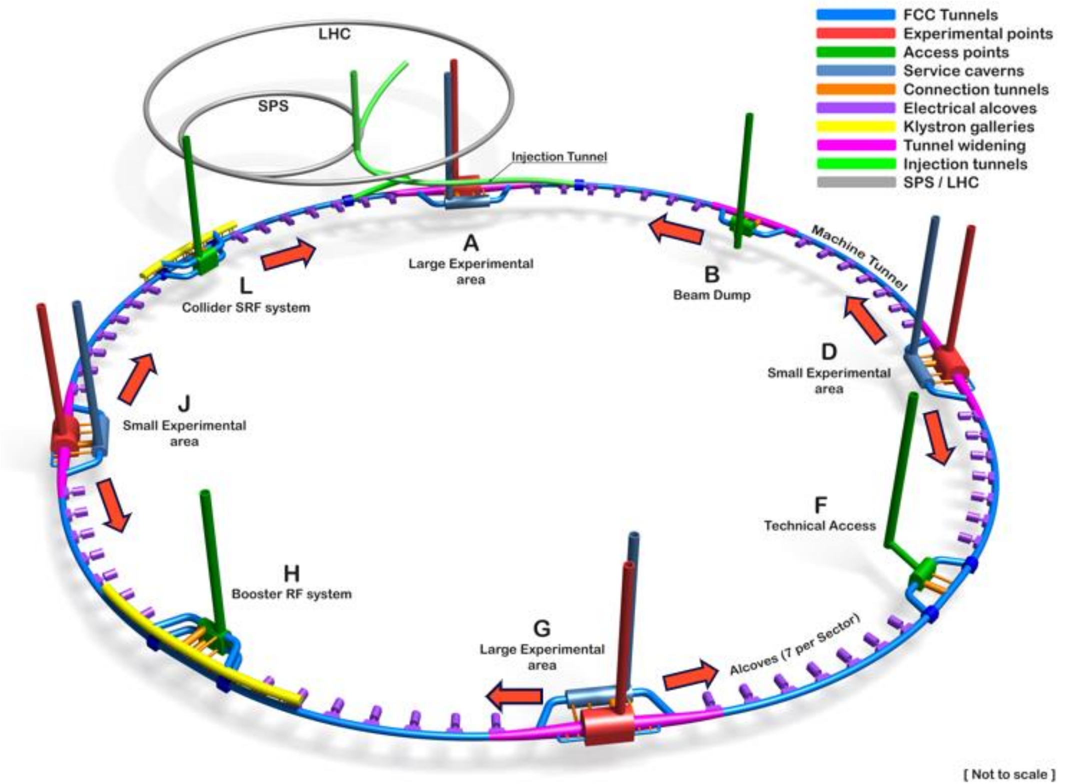
Main Beam Tunnel

- The tunnel will be excavated using a Tunnel Boring Machine (TBM). A shield machine that enables rock cutting and support installation to be carried out either in parallel or sequentially is likely to be used.
- For excavating through the limestone areas, the TBM will need additional features for probing ahead of the TBM and stabilizing the ground in advance of the tunnel face.

Fig. 3 Double shield TBM. Credit: Herrenknecht

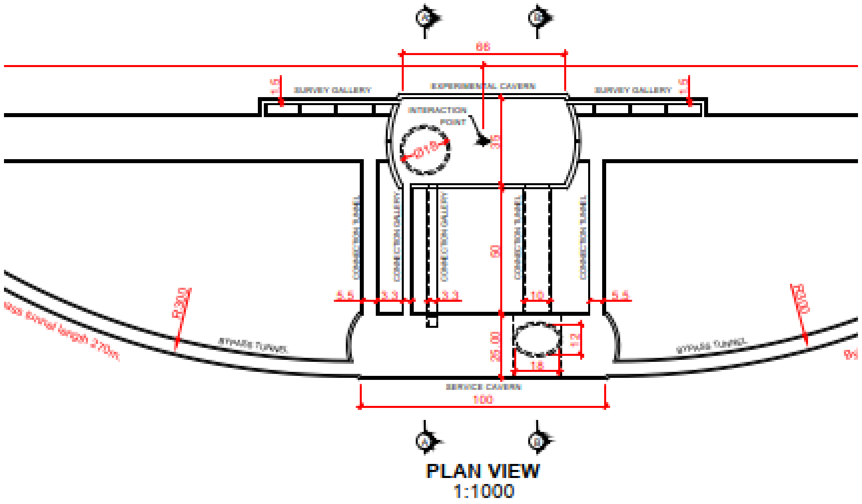
Main Beam Tunnel – Construction Sequence

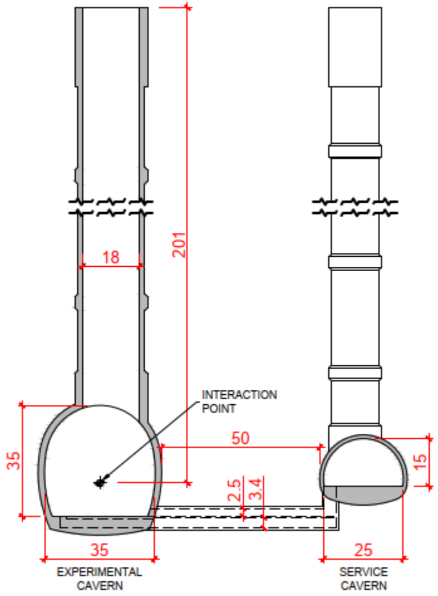
- Tunnel Boring Machines are designed to work almost continuously 24/7 other than periodic maintenance for example to change the cutter tools on the cutting head. However, due to the logistics chain support the TBM the actual utilization rate is never 100%.
- Arate of 18m/day in the Molasse to take account of the larger tunnel diameter and longer drive lengths.
- Each sector will take about 21 months to complete other than sector PG to PH where 27 months will be required.



Shafts

- Shafts are required during the operational phase to access the machine tunnel and the experimental caverns.
- In experiment areas, two shafts are planned, one to access the experiment cavern and the second to access the service cavern and the beam tunnel.





Shafts at Experiment Site

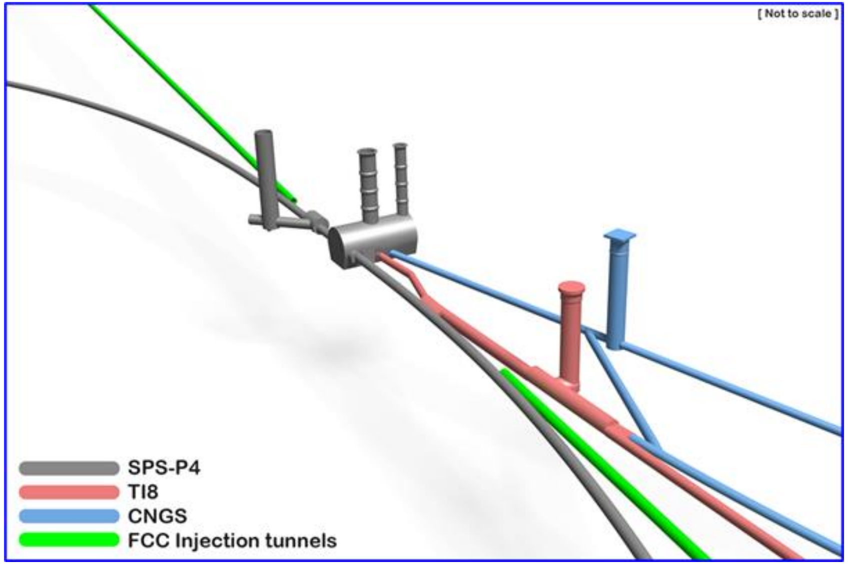
Shafts

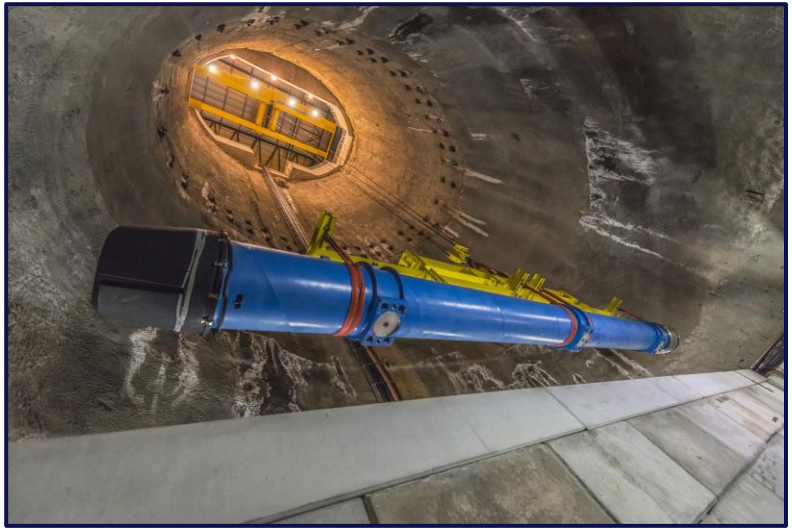
- A total of thirteen shafts will be required for the FCC ee.
- Four shafts connecting each of the experiment caverns (UX) to the surface. These will be of circular cross section and have a diameter of up to 18m.
- Eight shafts will be required to connect the service caverns to the surface. Six of these shafts shall be circular with a diameter of 12 metres and two will have a diameter of 18m to accommodate the lowering of magnets.
- One shaft will be needed for the construction of the transfer line tunnel. This shaft may not be required for the operation of the machine. An existing shaft may be refurbished rather than excavate a new shaft.

PA	PB	PD	PF	PG	PH	PJ	PL	Transfer line
201 m	201m	181 m	400 m	226m	235m	253 m	250m	40m

Shafts

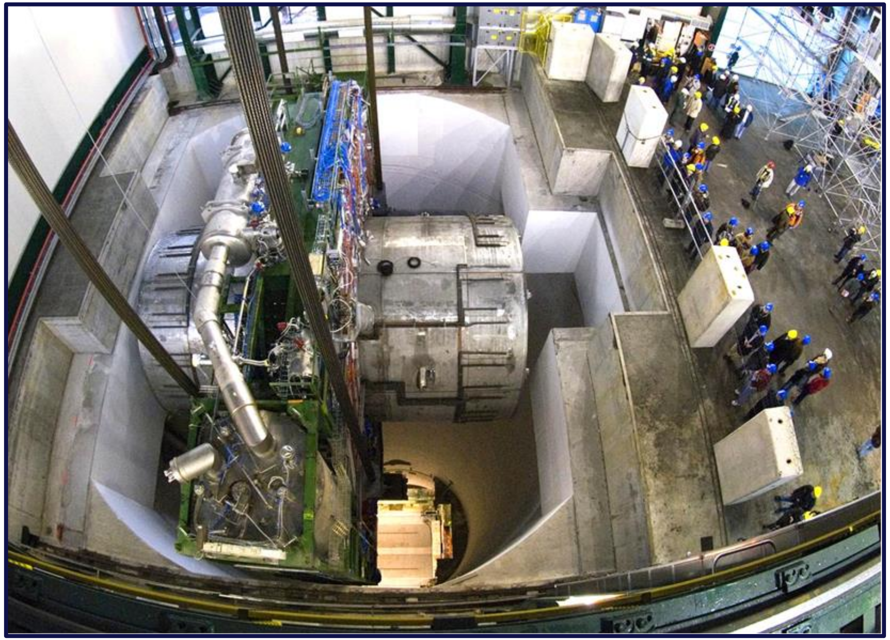
Re-Use of Existing Shafts near SPS Point 4





LHC Elliptical shaft

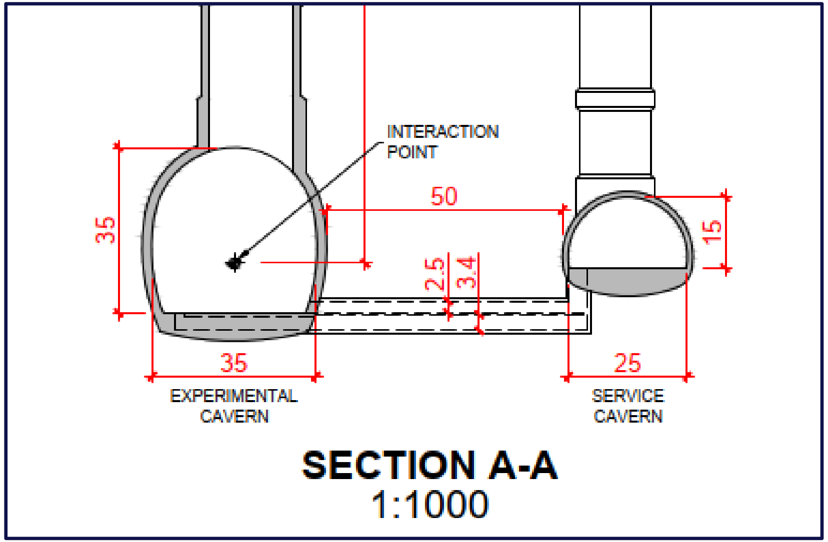
Shafts

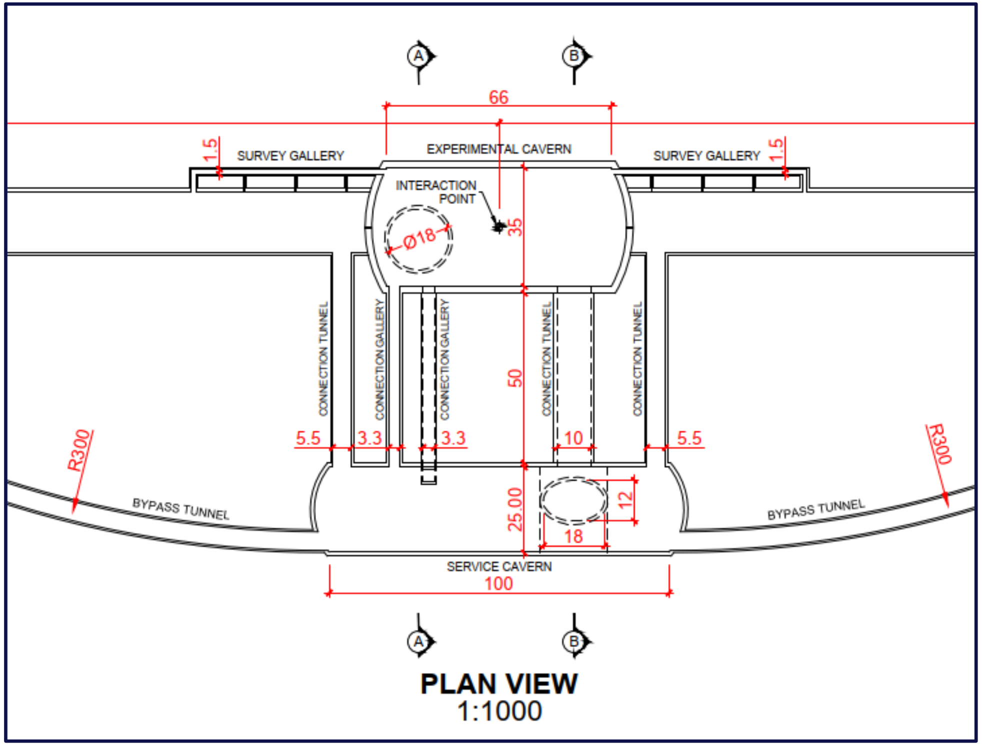


Lowering CMS Detector down 100m deep LHC shaft

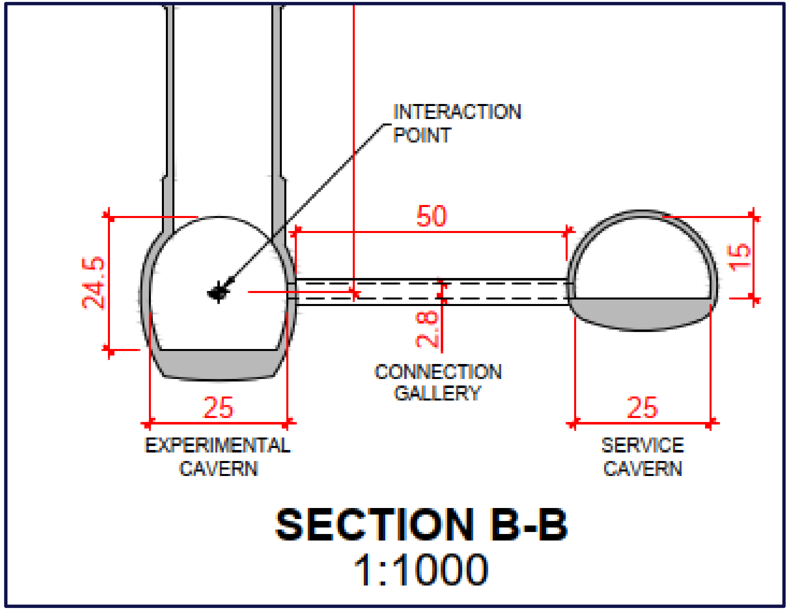
Ground Freezing used on Previous CERN Shafts

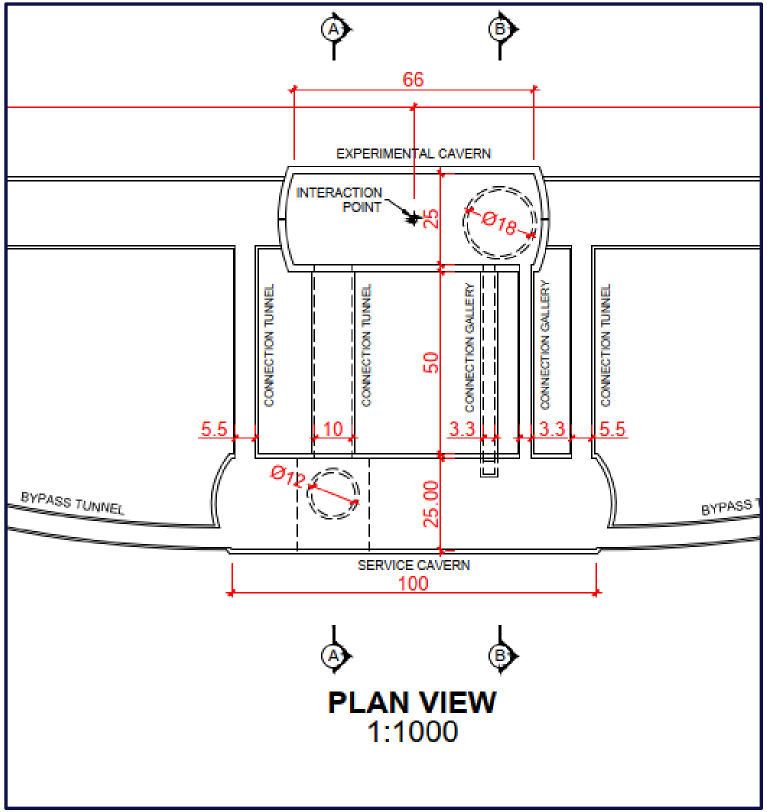
Large Cavern Complex



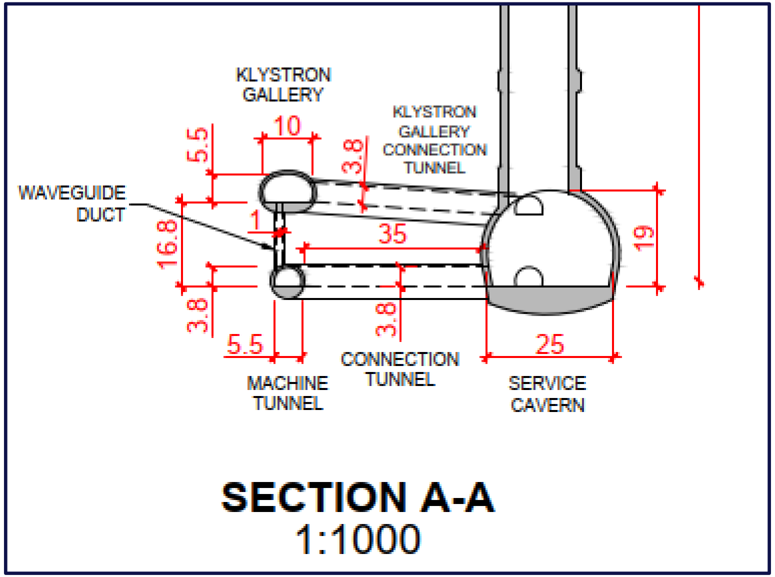


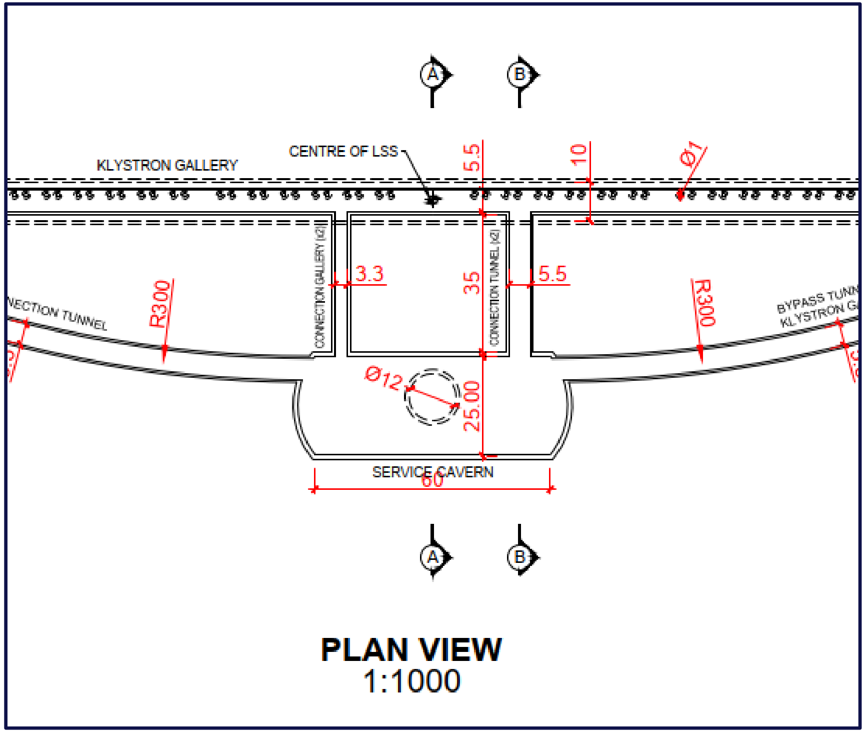
Small Cavern Complex





Technical Cavern (typical)

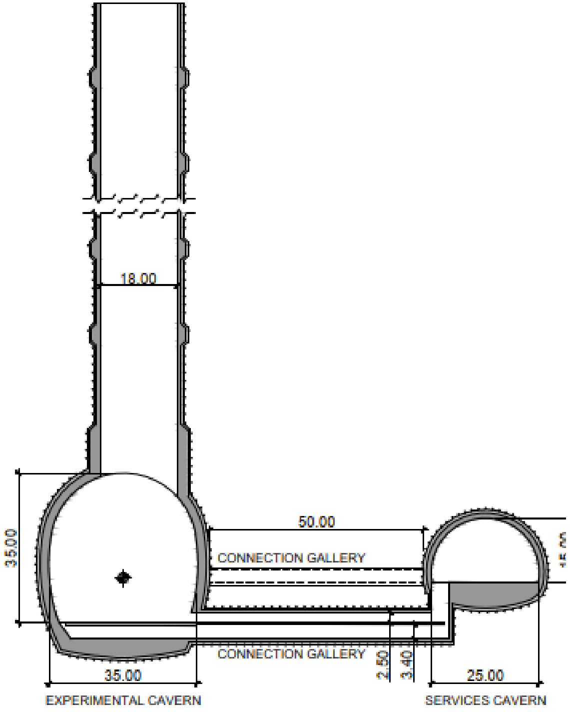




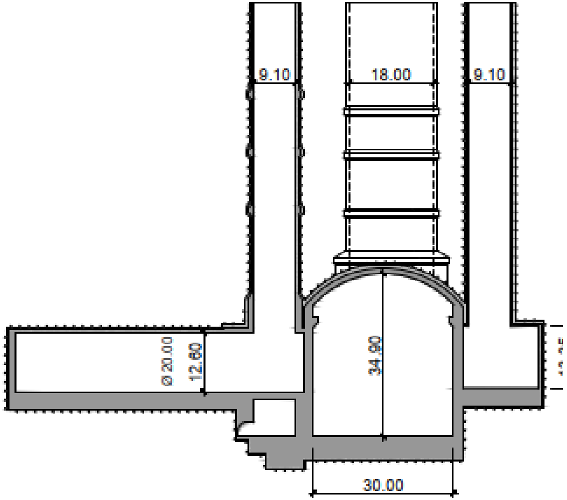
Large Caverns

- The caverns to be constructed are similar in span to the CMS and Atlas caverns constructed for the LHC
- This gives us some confidence that these caverns can be constructed within the molasse rock
- Unlike CMS and ATLAS, there is no specific requirement for the Experimental cavern and service caverns to be very close together and a distance of 50m is currently considered as the optimum spacing between the caverns.
- Although this increases the lengths of the connecting tunnels between the two caverns, it results in less interference in the rock stress distribution around the excavations which should make their design simpler and construction less risk.

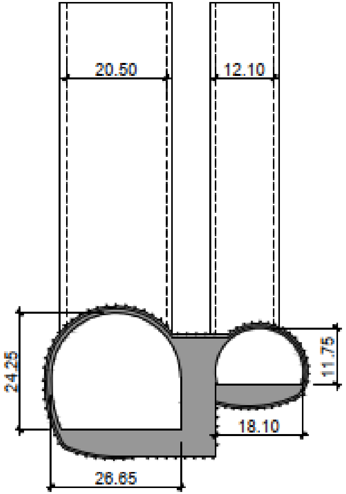
Comparison FCC to ATLAS and CMS Cavern Complexes



FCC

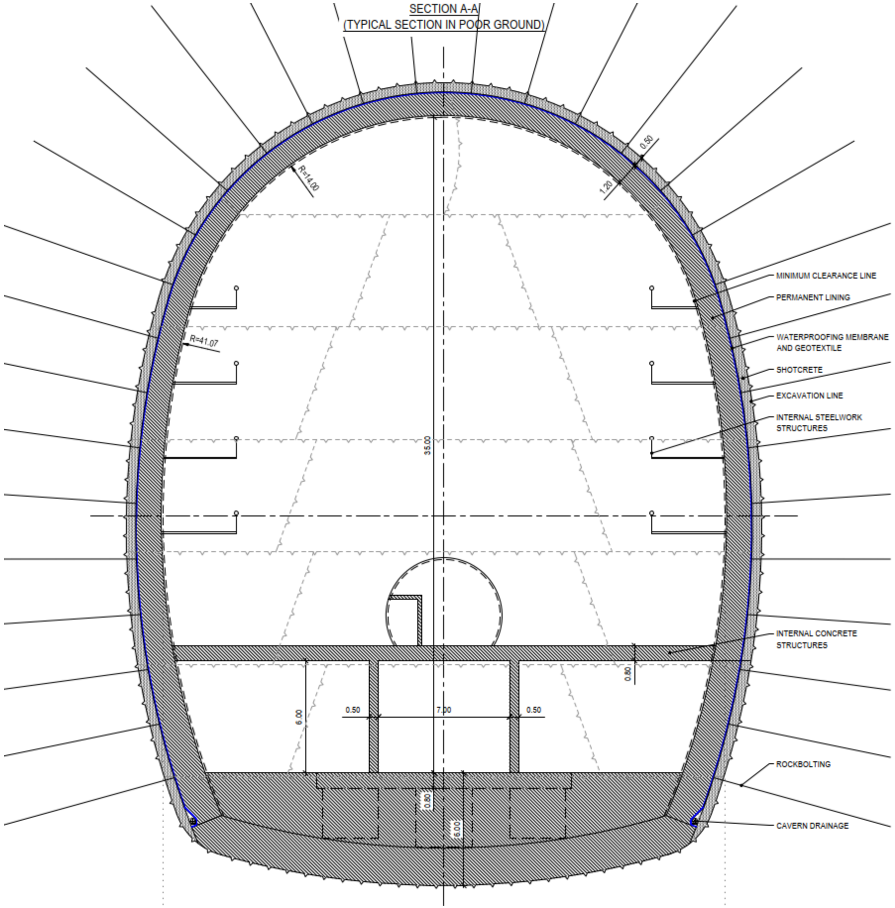


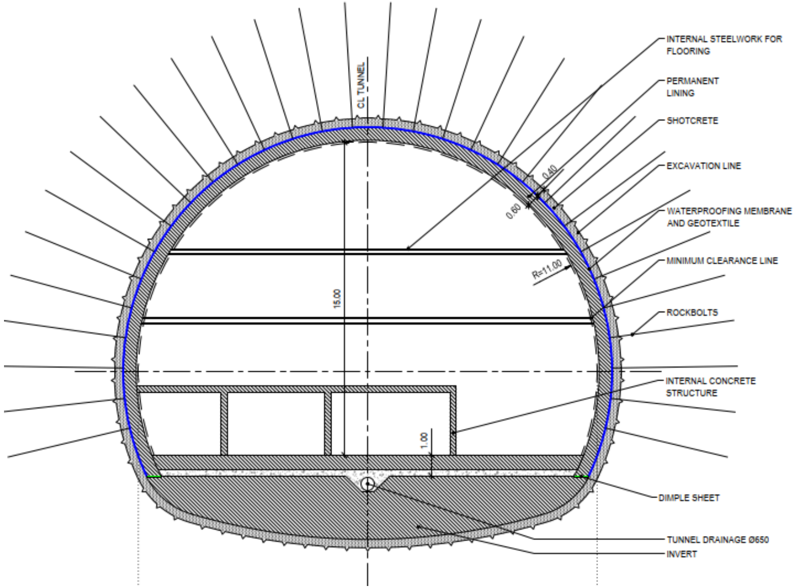
ATLAS

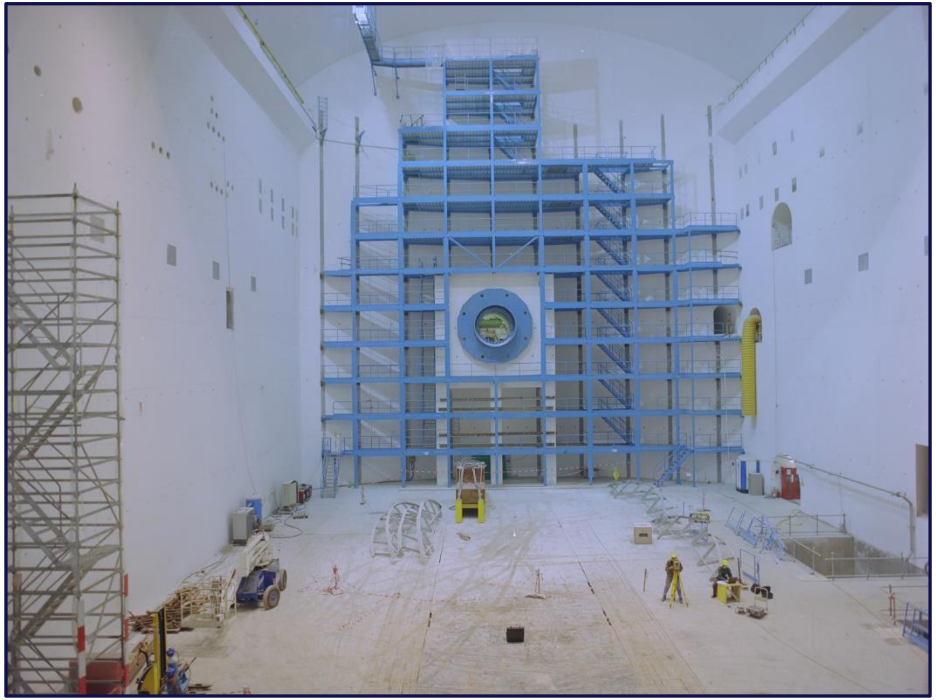


CMS

Typical Designs for Large Caverns





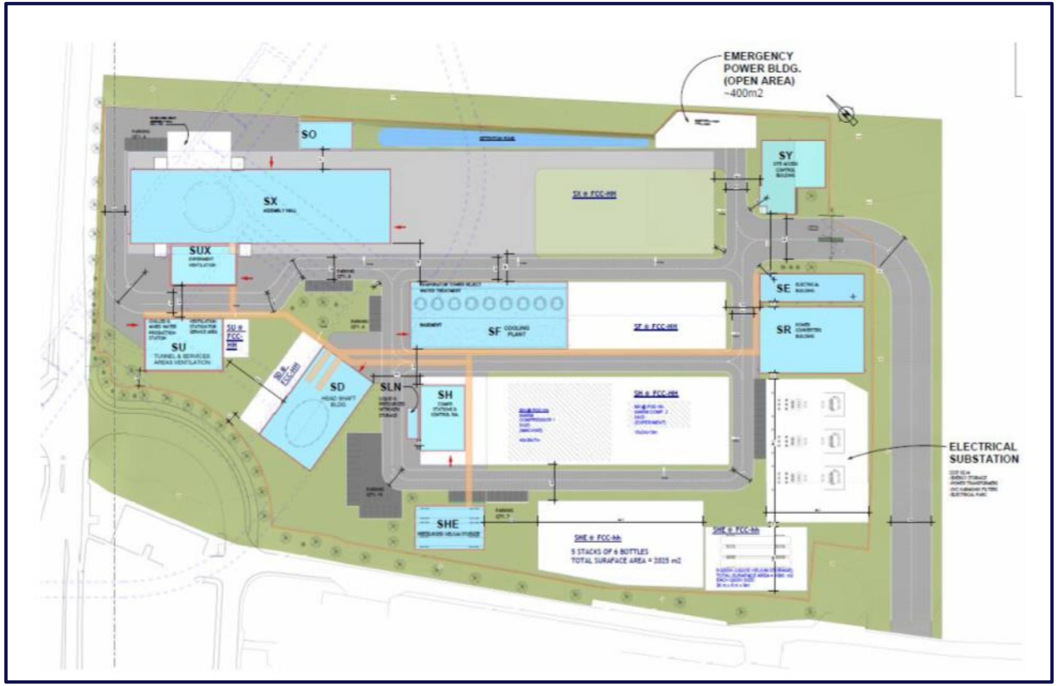


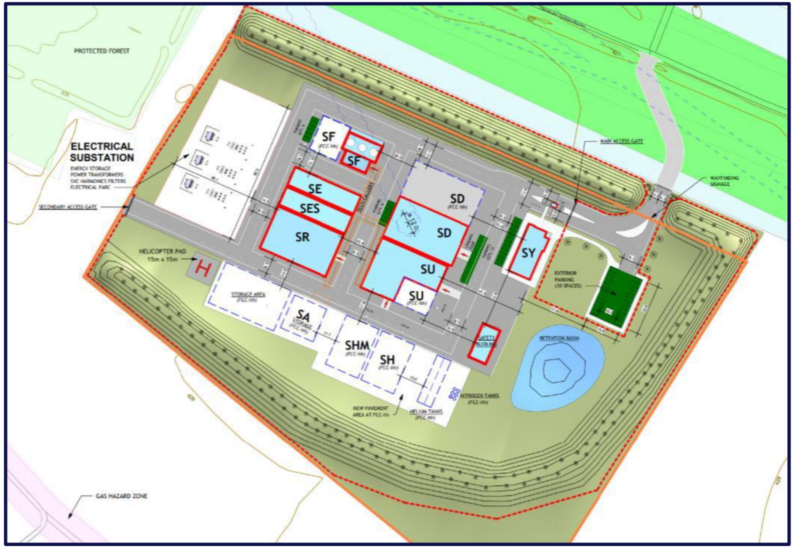
ATLAS Detector Cavern

CMS Detector Cavern

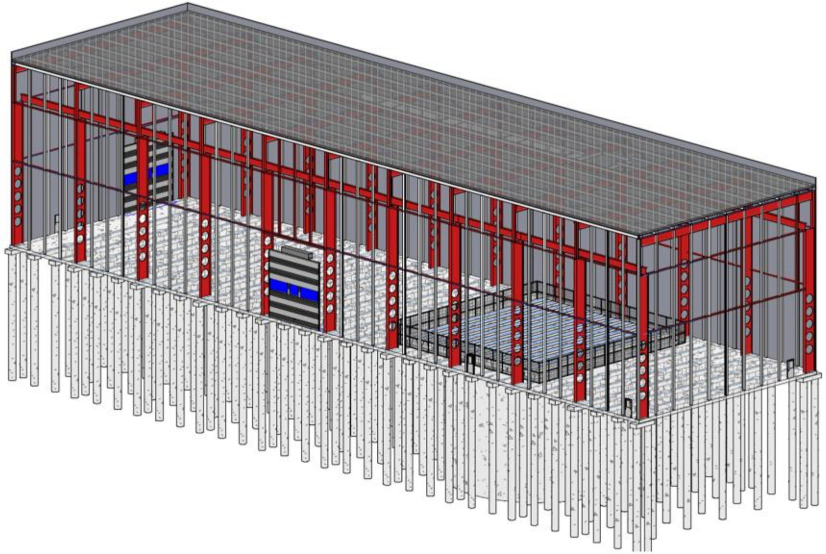
Surface Sites

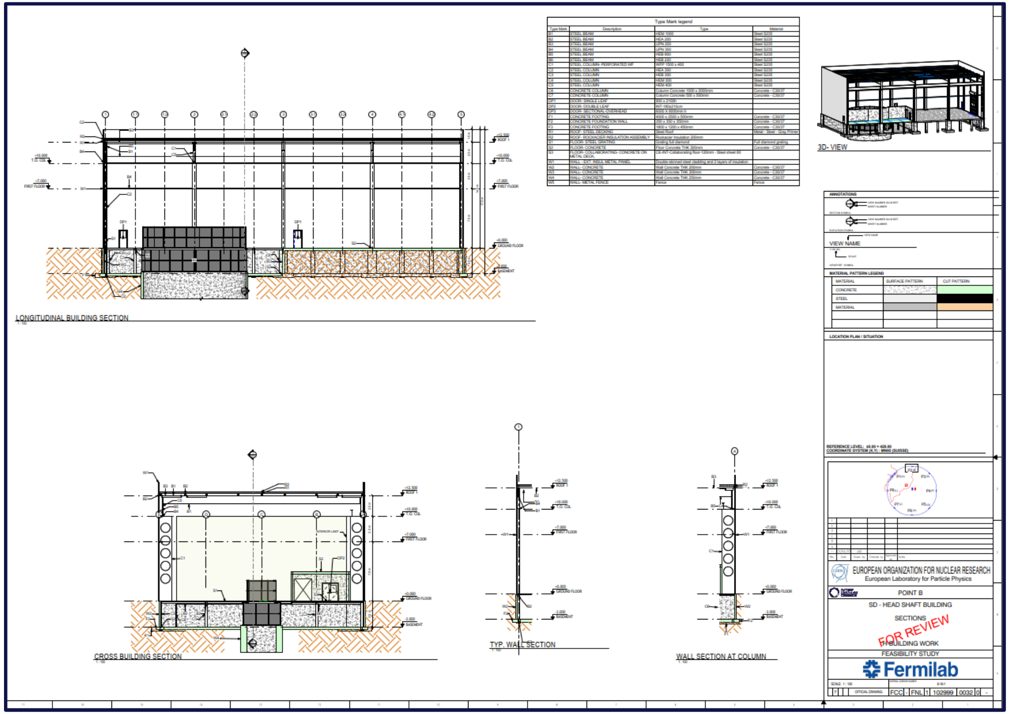
- Preliminary Layouts are under development for the Eight Surface Sites.
- Sites will be developed on the basis of ee and hh needs but the future FCC hh buildings will not be constructed until needed.
- It is currently assumed the FCC ee detector assembly will require a surface hall of about 80 to 100m in length and with a width to accommodate the access shaft to underground.
- For FCC hh initial studies suggest larger surface halls will be required as the detector components will in some cases be too large to transport on public roads. This requires further investigation
- One important constraint is that surface sites must be minimized to reduce the impact on the environment and to fit into the constrained available space.





Fermilab Example Layouts (prepared for MTR costing purposes only)





Examples of Fermilab Building Designs for MTR Costing Purposes only

Preparatory Phase

- Complete the current site investigation campaign and freeze the alignment/location (this is part of the current Feasibility Study that ends December 2025)
- Decide on a procurement model for the civil engineering (how to partition the work)
- Undertake the additional site investigation to obtain necessary data to commence the design
- Procure design consultants for each of the planned construction packages
- Undertake detailed designs suitable for tendering for each package
- Prepare all Tender Packages for construction
- Procure Contractors for each construction package contract
- Sign contracts and commence site preparation works

Site Investigation in areas of Geological Uncertainty

- To ascertain the location of the target rock for the underground structures CERN has commenced a campaign of site investigation.
- An external consultant QUANTUM has been working for about 12 months to define the work that needs to be done.
- A call for tender has been launched for the works themselves which will consist of about 48 boreholes and 80km of seismic lines.
- The intention of this initial campaign is primarily to identify the location of the molasse rock in those areas where there is currently insufficient data/knowledge.
- The Site investigation will commence in Spring 2024 and continue through the first half of 2025.
- If the project is approved, additional site investigation campaigns will be required especially in the location of the experiment caverns.

Areas with highest geological uncertainty

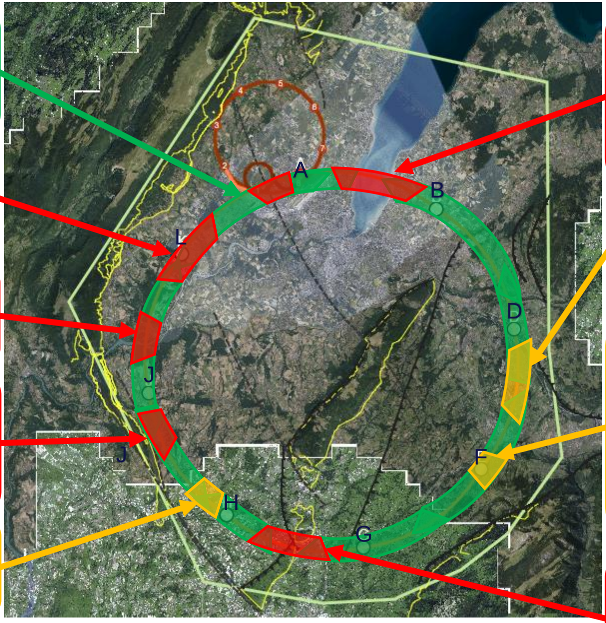
- Good knowledge of the ground (e.g information near to CERN from LEP/LHC projects)
- Good confidence that the tunnel alignment is in molasse

Jura
- Limestone/molasse interface uncertain.
- Risk of karts and high water pressures

Le Rhône
- Moraine/molasse interface not certain.
- Proximity to protected area

Vuache
- Limestone/molasse interface not certain.
- Risk of karts and high water pressures
- Proximity to main active fault

Les Usses
- Moraine/molasse interface not certain.
- Low tunnel rock cover



Lac Léman
- Moraine/molasse interface uncertain
- Soils and rock properties uncertain
- High uncertainty in the hydrogeological conditions and water pressure

Vallée de l'Arve
- Moraine/molasse interface uncertain.
- Lack of reliable boreholes

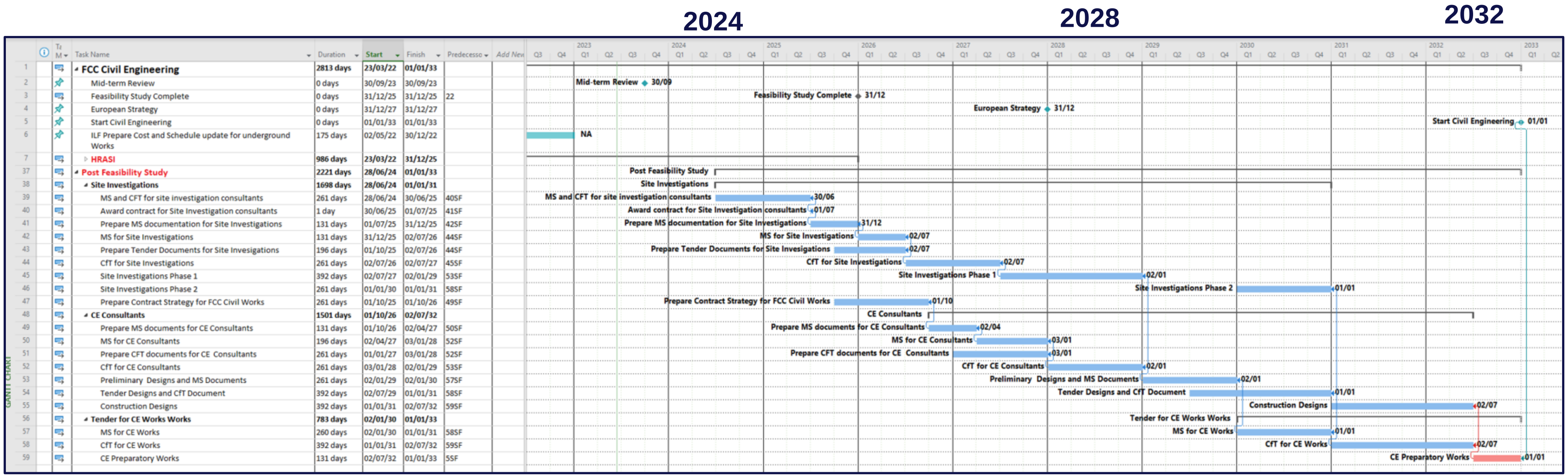
Bornes
- Insufficient deep boreholes information
- Complex faulted region, thrust zone.
- Quality of molasse is uncertain. High overburden. Large span experimental caverns should be constructed in good molasse.

Mandallaz
- Fractured limestone formations, characteristics and locations of karsts unknown.
- High water pressures

On-site investigation works 2024-25

Preparatory Phase

- There is a significant amount of preparatory work to be undertaken after the Feasibility Study if the target date for shaft excavation is to be respected.
- This requires time as well as financial and human resource.
- An initial assessment has been made of the work and resources needed.
- The main critical tasks for civil engineering are shown on the Gantt Chart on the next slide. It is considered to be quite a challenging schedule to arrive at a start of shaft construction by 2033.

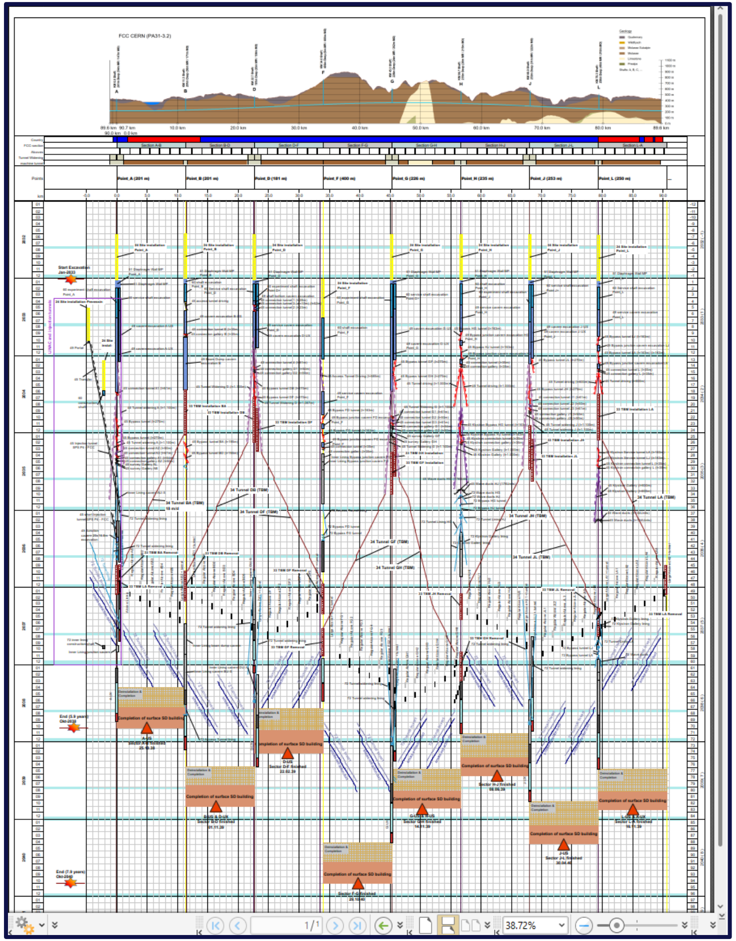


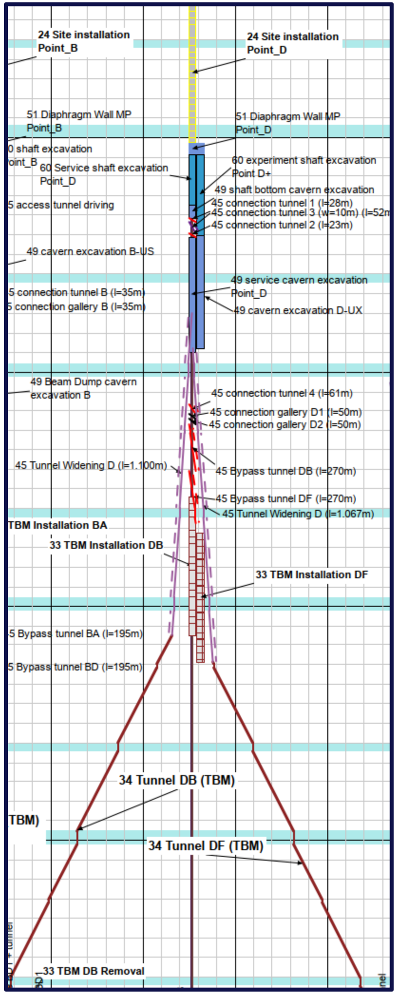
ID	Task Name	Duration	Start	Finish	Predecessors
1	FCC Civil Engineering	2813 days	23/03/22	01/01/33	
2	Mid-term Review	0 days	30/09/23	30/09/23	
3	Feasibility Study Complete	0 days	31/12/25	31/12/25	22
4	European Strategy	0 days	31/12/27	31/12/27	
5	Start Civil Engineering	0 days	01/01/33	01/01/33	
6	ILF Prepare Cost and Schedule update for underground Works	175 days	02/05/22	30/12/22	
7	HRASI	986 days	23/03/22	31/12/25	
37	Post Feasibility Study	2221 days	28/06/24	01/01/33	
38	Site Investigations	1698 days	28/06/24	01/01/31	
39	MS and CFT for site investigation consultants	261 days	28/06/24	30/06/25	40SF
40	Award contract for Site Investigation consultants	1 day	30/06/25	01/07/25	41SF
41	Prepare MS documentation for Site Investigations	131 days	01/07/25	31/12/25	42SF
42	MS for Site Investigations	131 days	31/12/25	02/07/26	44SF
43	Prepare Tender Documents for Site Invesigations	196 days	01/10/25	02/07/26	44SF
44	CfT for Site Investigations	261 days	02/07/26	02/07/27	45SF
45	Site Investigations Phase 1	392 days	02/07/27	02/01/29	53SF
46	Site Investigations Phase 2	261 days	01/01/30	01/01/31	58SF
47	Prepare Contract Strategy for FCC Civil Works	261 days	01/10/25	01/10/26	49SF
48	CE Consultants	1501 days	01/10/26	02/07/32	
49	Prepare MS documents for CE Consultants	131 days	01/10/26	02/04/27	50SF
50	MS for CE Consultants	196 days	02/04/27	03/01/28	52SF
51	Prepare CFT documents for CE Consultants	261 days	01/01/27	03/01/28	52SF
52	CfT for CE Consultants	261 days	03/01/28	02/01/29	53SF
53	Preliminary Designs and MS Documents	261 days	02/01/29	02/01/30	57SF
54	Tender Designs and CfT Document	392 days	02/07/29	01/01/31	58SF
55	Construction Designs	392 days	01/01/31	02/07/32	59SF
56	Tender for CE Works Works	783 days	02/01/30	01/01/33	
57	MS for CE Works	260 days	02/01/30	01/01/31	58SF
58	CfT for CE Works	392 days	01/01/31	02/07/32	59SF
59	CE Preparatory Works	131 days	02/07/32	01/01/33	5SF

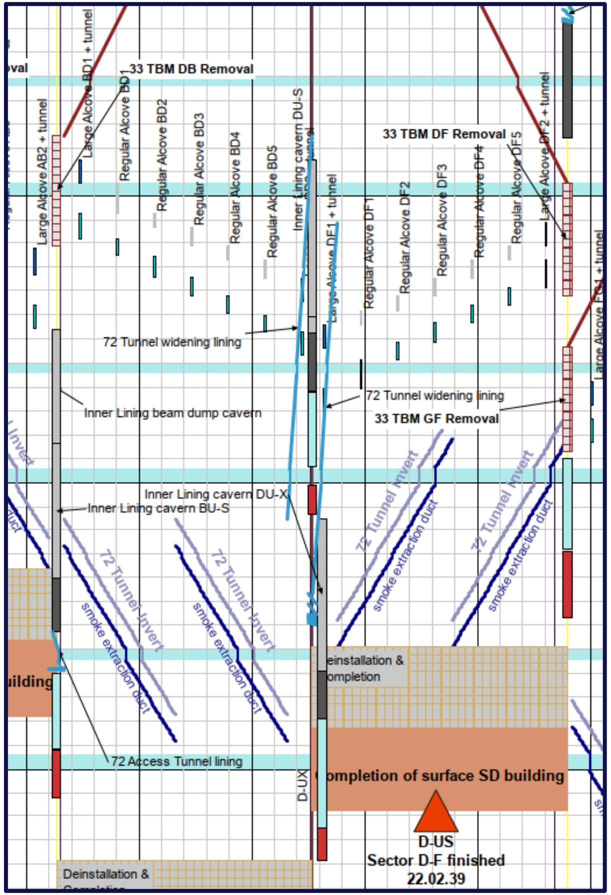
Draft of a Potential Schedule for Civil Engineering Only

Construction Schedule Summary

- Current assumption is to have 9 sites and 9 Contracts (8 FCC surface sites plus the Injection complex/transfer tunnel)
- Six months site preparation prior to starting shaft construction
- A Sector is a section of the main beam tunnel between two access points including at least one access shaft for infrastructure installation
- 5.9 years for underground works for first Sector delivery
- 7.9 years for underground works for last Sector delivery
- Assume most of the surface works will be done in parallel with the underground works
- Completion of each Sector to a level where machine installation could begin would be between 2038 and 2040.







Point D – Example of Linear Schedule

Conclusions

- Significant advances have been made since completion of the Conceptual Design
- Designs have been simplified where possible and two “standard” layouts for experiment areas have been developed.
- Mid-term review was successful and positive feedback and areas for additional work was identified
- Site Investigations should start in Spring 2024 allowing a more robust geological model to be completed by Q3 2025.