FCC-eh Civil Engineering Developments

FCC week 2018 Amsterdam

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Agenda

- Civil Engineering study progress since Berlin 2017
- Update on the principal structures
- Tunnel cross-section and Junction cavern layout options
- Alignment and Geology
- Interaction region design
- Construction cost and schedule
- Ground Investigation Planning and Future Steps

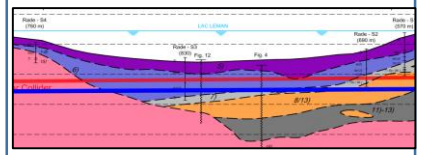
Study progress 2017/18

August 2017

Alignment update following geological review of key areas:

- Lake crossing
- Arve and Rhone Valleys

Led to the lowering of the alignment by 30 m. Including the FCC-eh Machine



September 2017

Phase 3 of cost and schedule study launched.

- Produce a cost and schedule estimate that is compatible with the CDR baseline.

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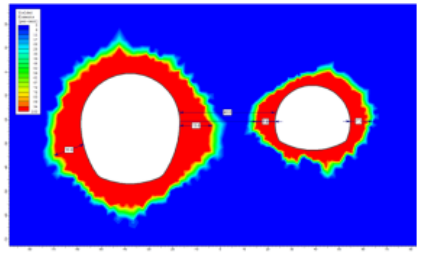
February 2018

Design development with integration, including study to investigate feasibility of connections to FCC.



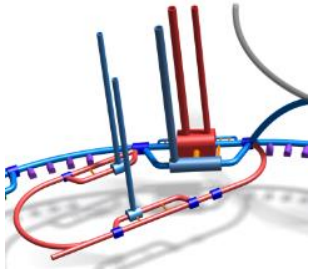
AMBERG ENGINEERING

March 2018

- Cost and schedule round up for all 3 machines:

FCC-hh, FCC-ee and **FCC-eh**

- CDR writing

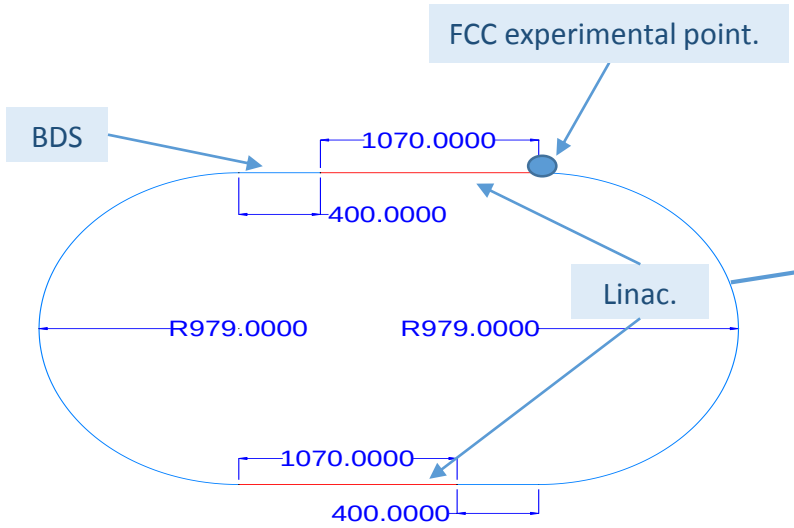


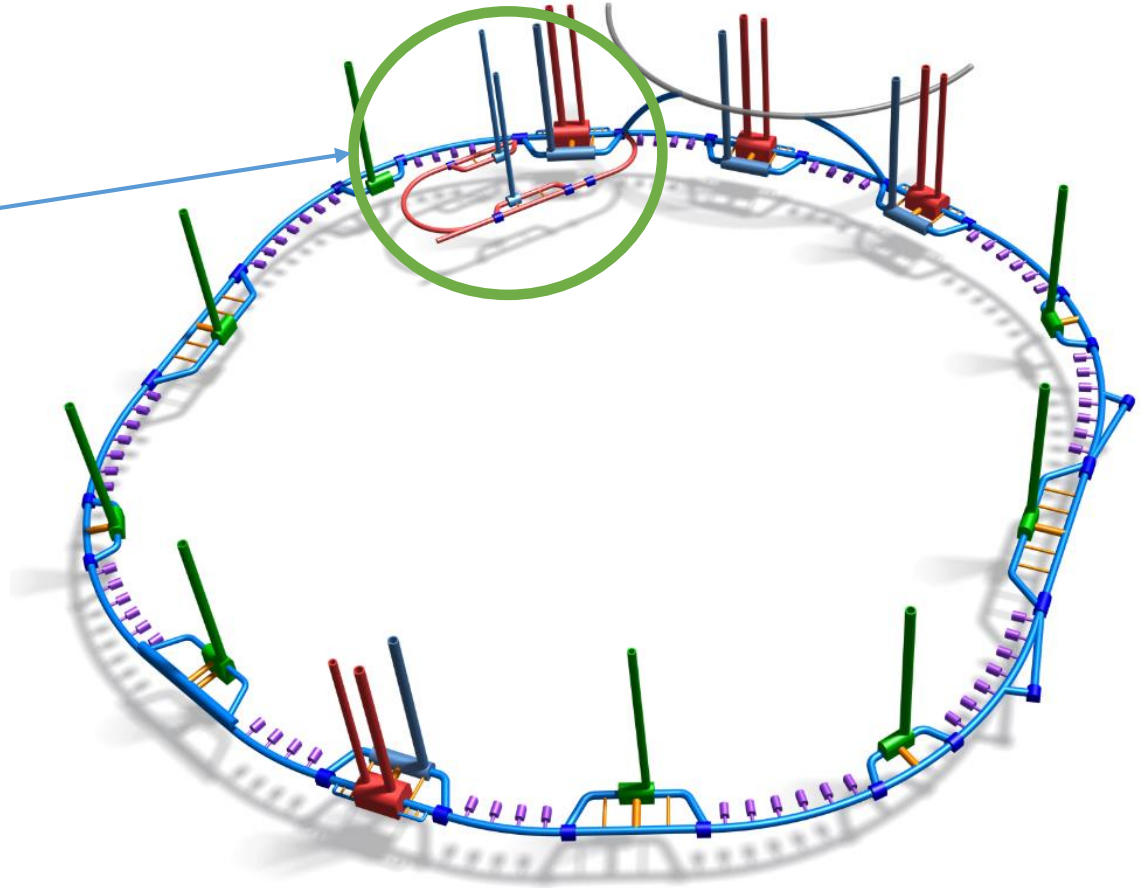
Ongoing

Ongoing work:

- Surface site investigation
- Spoil management study
- Site investigation planning
- Cost and schedule updates

Schematic Layout of FCC-eh





Tunnel Dimensions:

- 400m Beam Delivery System (BDS)
- 1070m Linac
- 979m radius arcs (x2)
- 400m drift section.
- **Total Length of main tunnel = 9091m.**
- **Total Length of RF Tunnel = 2140m**

Structure schedule for FCC-eh

TABLE 12-1: EH MACHINE SCHEDULE OF STRUCTURES

Structure	Quantities	Description	Applicable Section from the Baseline Design
Machine Tunnels	9,091m	5.5mID tunnel	Machine Tunnels
Service Shafts	2No	9mID shaft	9m shaft with same support of the 10mD Experiment Shafts
Service Caverns	2No	25m span, 50m long cavern	Service Cavern
Injection Cavern	1No	25m span, 50m long cavern	Service Cavern
Dump Cavern	1No	16.8m span, 90m long cavern	Junction Cavern
Junction Cavern with the FCC before Point L	1No	25m span, 50m long cavern	Service Cavern
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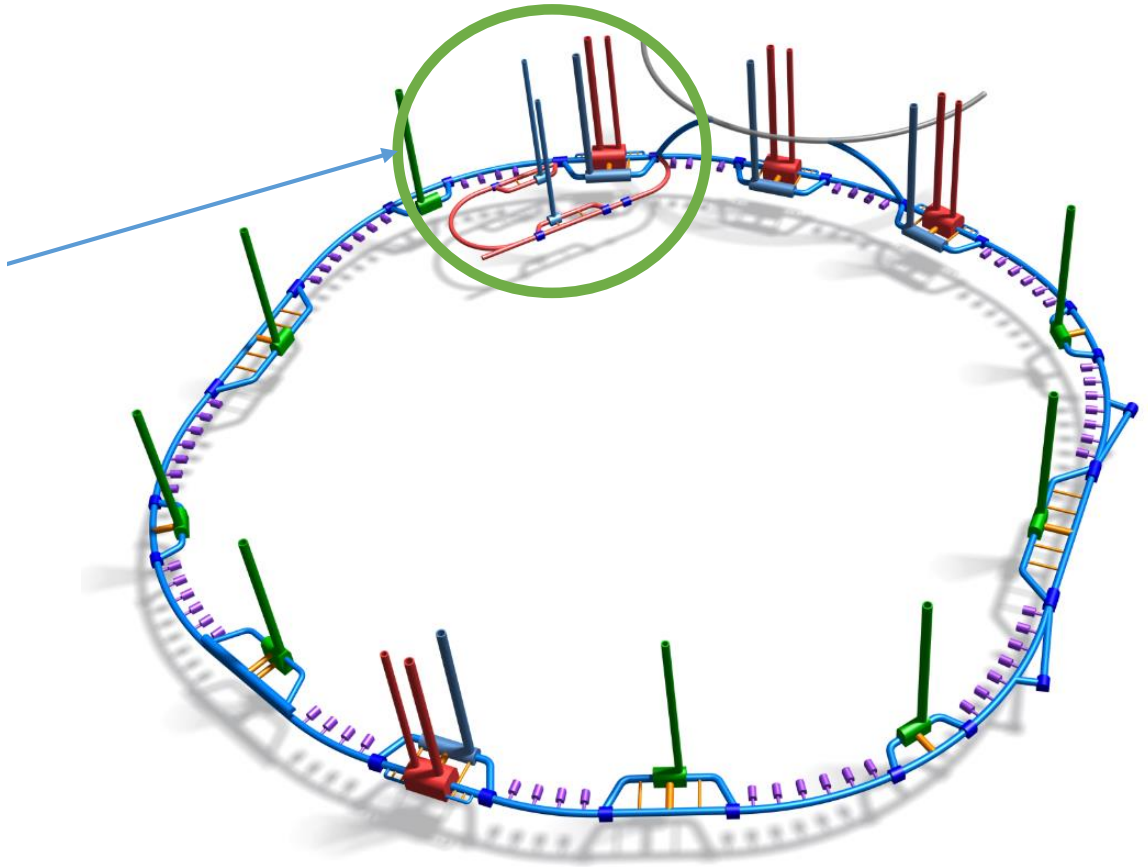
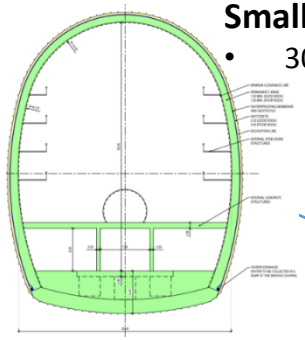
Junction Caverns between Machine Tunnels and FR Galleries	3No	16.8m span, 20m long (x2), 100m long (x1) caverns	Junction Cavern
RF Galleries	2No	5.5m span, 1070m long tunnel	Bypass Tunnel
Waveguide Connections	50No	1mD, 10m long	Klystron Connections
Connection Tunnel	4No	3m span	Connection Tunnels

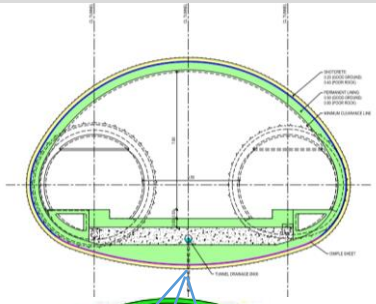


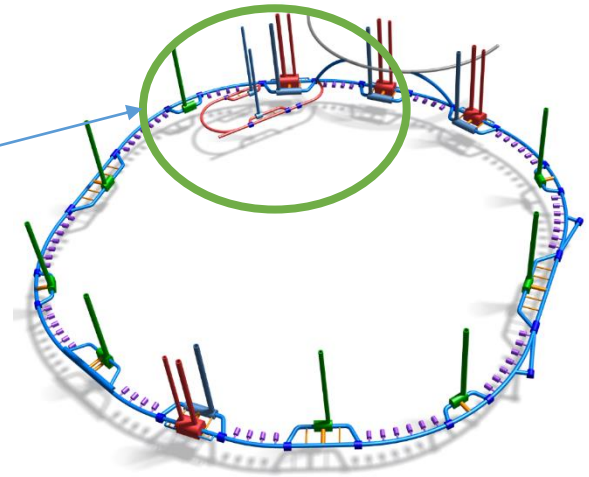
Scope of FCC-eh Structures

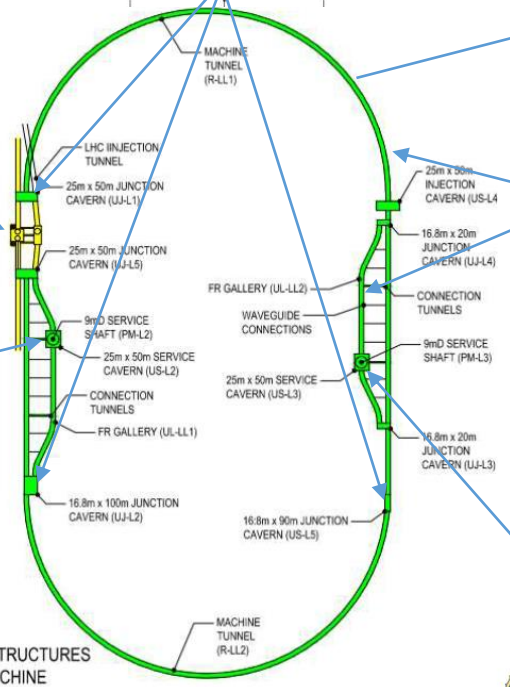
Small Experimental Caverns
- 30 m x 35 m x 66m

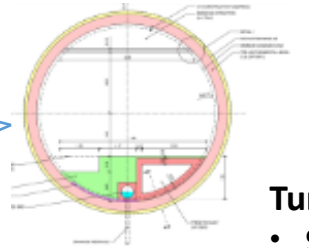


Junction Caverns
- 16.8 m x 15 m x 100 m
- 25 m x 15 m x 50 m
- 16.8 m x 15 m x 90 m



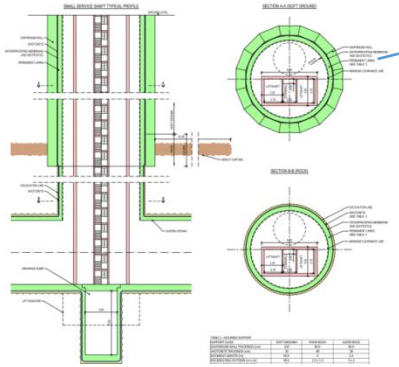


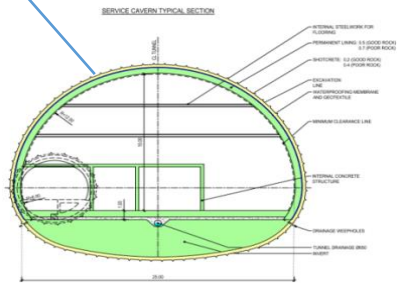




Tunnels:
- 9.091 km of 5.5m dia. machine tunnel.
- 2 x 1.04 km of 5.5m dia RF tunnel.

Shafts:
2 x Service shafts: 9 m dia. x 175 m depth

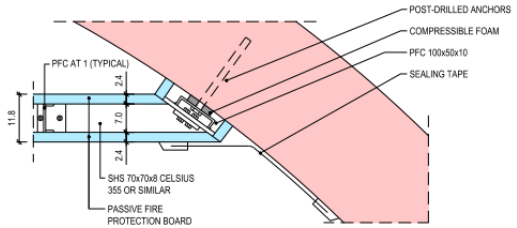


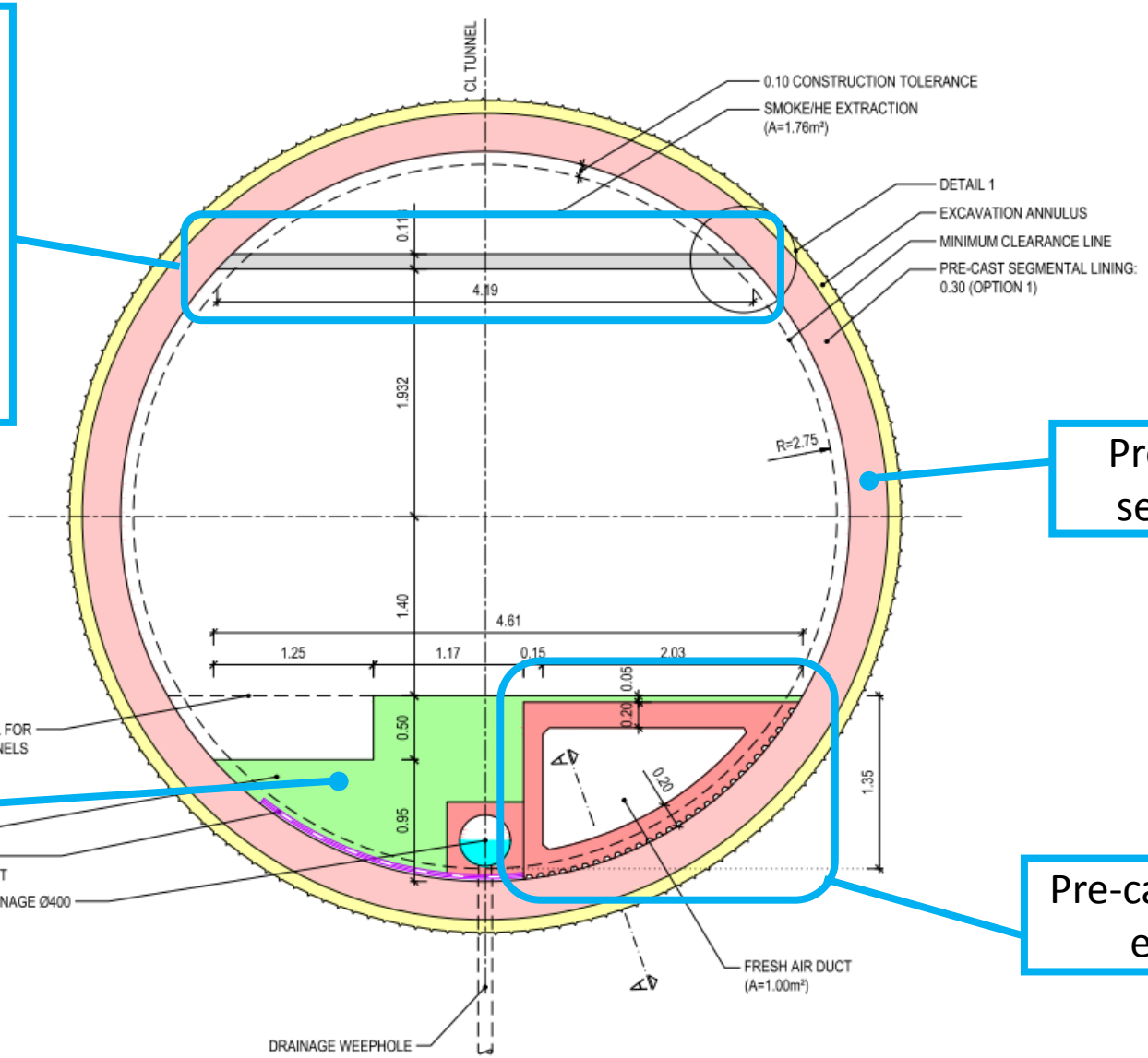


Service Caverns
- 25 m x 15 m x 50 m

Typical tunnel cross-section

Steel structure with passive fire protection. Connection:





Pre-cast concrete segmental lining

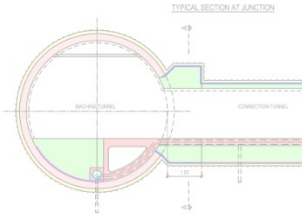
Cast-in-situ concrete invert

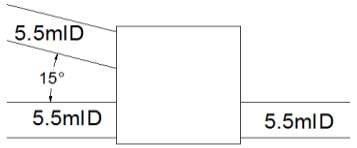
Pre-cast concrete element

Junction cavern refinement

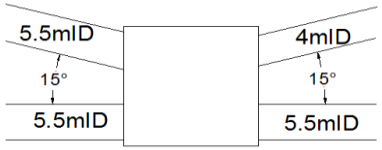
- Junction caverns are required for structural stability when tunnels of similar size connect.
- By evaluating each case individually, it was possible to omit some junction caverns
- The remaining caverns have been grouped into 3 types. (Type 1 below indicates no cavern is needed)
- Types 2, 3 and 4 are utilised for the FCC-eh machine.

TUNNEL TO TUNNEL CONNECTION (NO CAVERN NEEDED)

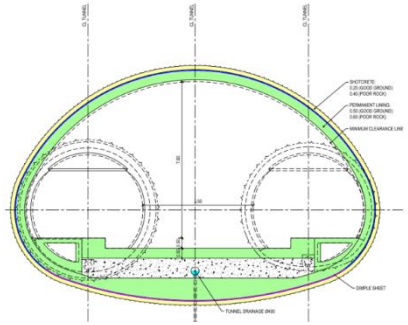


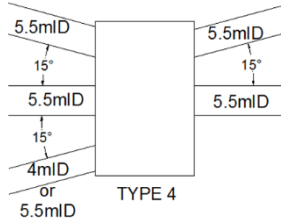


TYPE 2

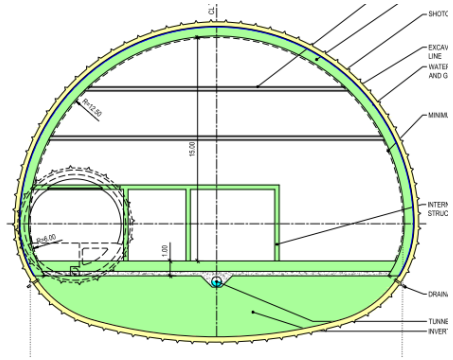


TYPE 3





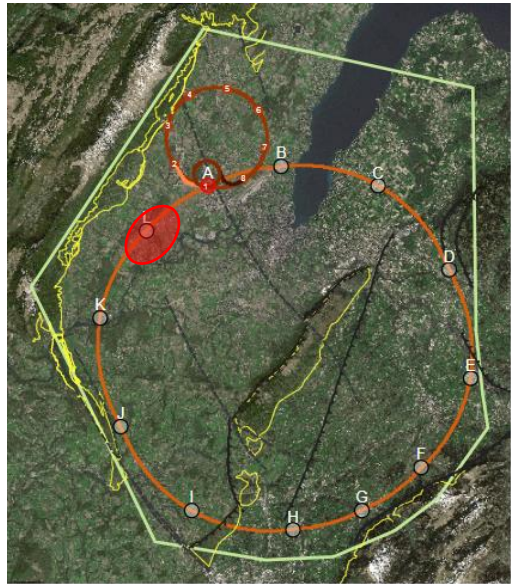
TYPE 4

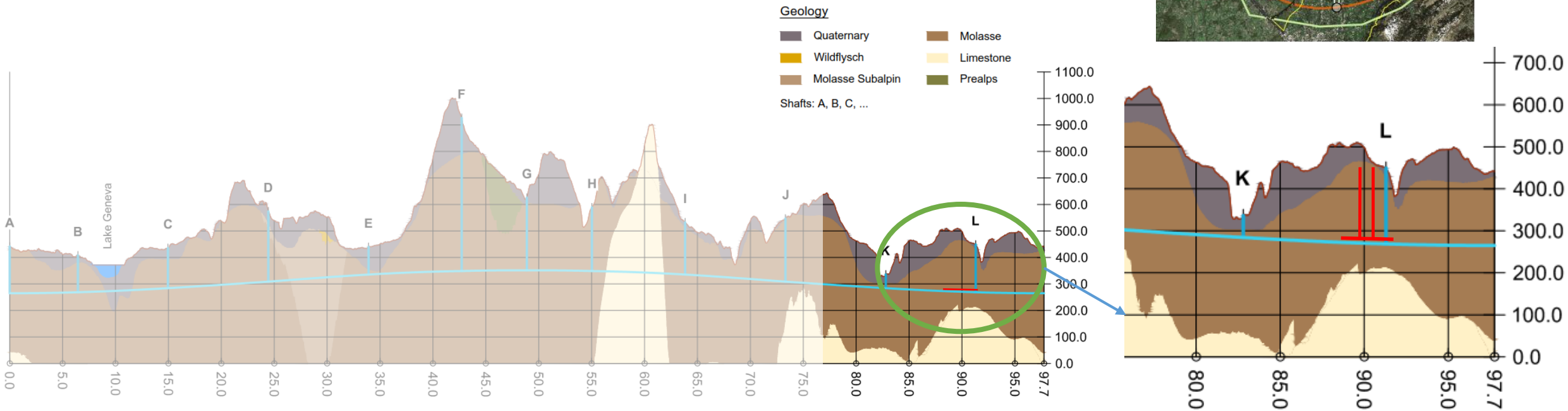


Alignment and Geology

After another round of alignment and geological optimisation the FCC-eh machine remains at FCC experimental point L provides the following benefits:

- Lowest risk for construction, lowest geological risk.
- Fastest and cheapest construction
- Close to existing CERN land.



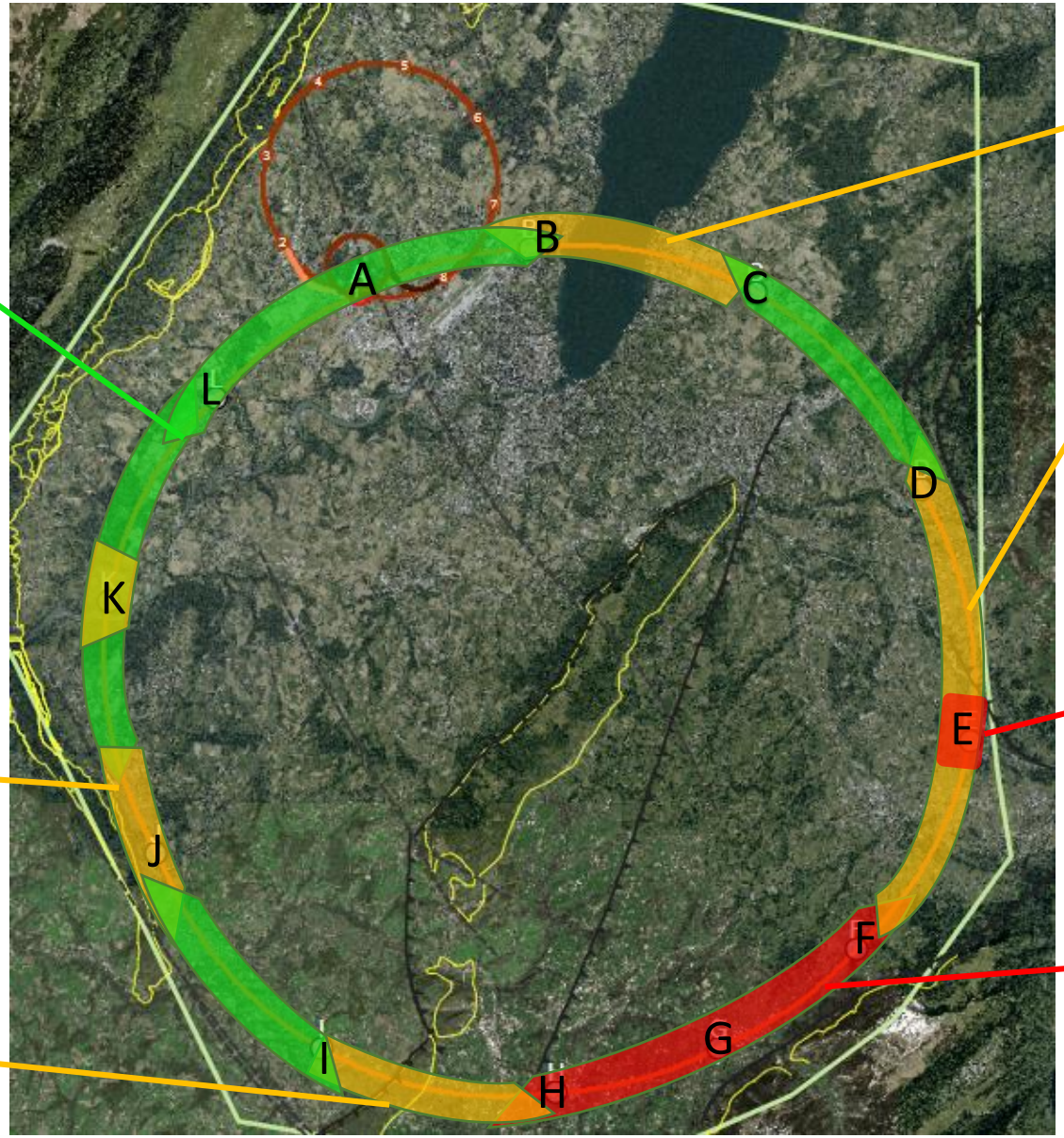


Geological Uncertainty along Alignment

- **FCC-eh Located at Point L**
- Information near to CERN is strong due to previous experience on LEP/LHC.
- Multiple deep boreholes in the area.

- Alignment close to limestone rockhead

- Limestone formation known, but characteristics and locations of karsts unknown.



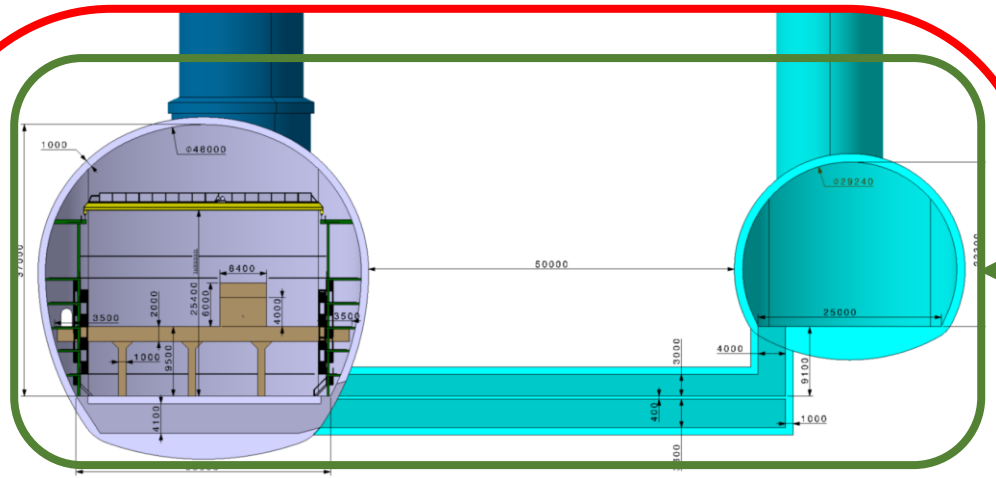
- Seismic and borehole information for lake crossing from proposed road tunnel, but layered nature of lake bed leads to uncertainty.

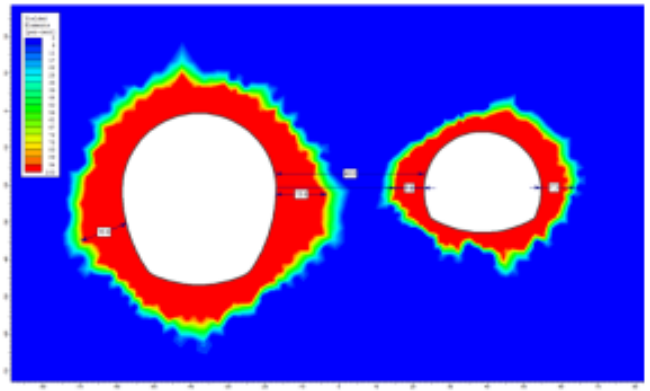
- Location of the interface between molasse and molasse subalpine not certain, tunnel alignment in proximity.

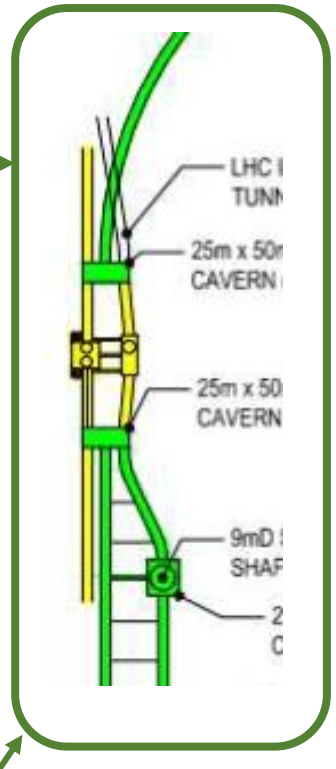
- Moraine/molasse interface not certain, cavern close to interface.
- Lack of deep boreholes in area.

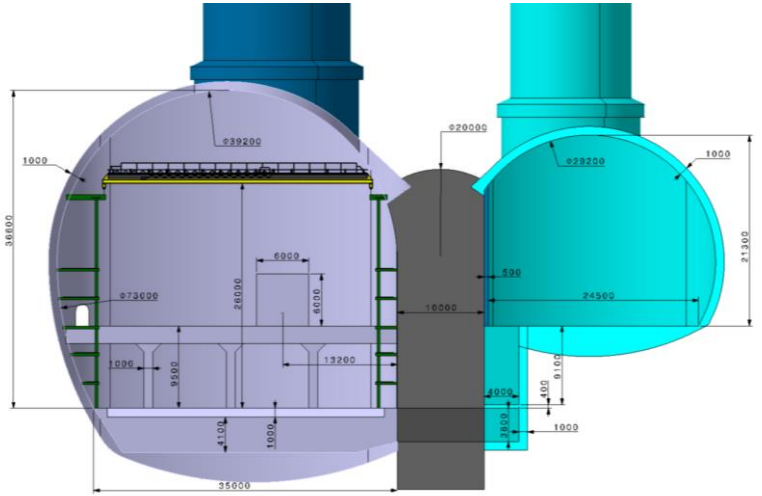
- No deep borehole information available in the area.
- Complex faulted region.
- Molasse/limestone interface not certain.

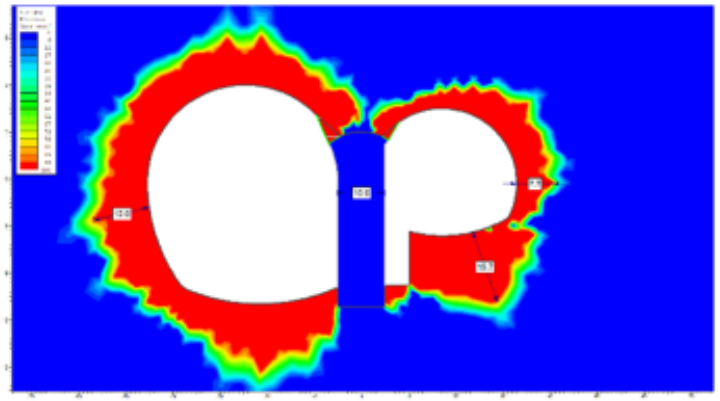
Experimental point layout options











- With 45 m spacing in good molasse, the rock pillar alone is sufficient.
- Cheapest and lowest risk option for CE
- Separation to be maintained for the FCC & FCC-eh tunnels and caverns where possible.

- With a 10 m spacing it is feasible but a high strength concrete pillar is required.

Cost and schedule study progress

Phase 1

Cost & Schedule estimate for “baseline” single tunnel design.

Phase 2

Cost & Schedule implications of variations considered:

- Double tunnel design
- Shallow option
- Alternative tunnel diameters
- Alternative shaft diameters
- Alternative cavern dimensions
- ee machine requirements
- Alternative schedule + Inclined access tunnels

Phase 3

Refinement of results from Phases 1 and 2:

- Review to include updates made to baselined design.
- Incorporate desirable variations from Phase 2.
- **Incorporate FCC-eh Design**

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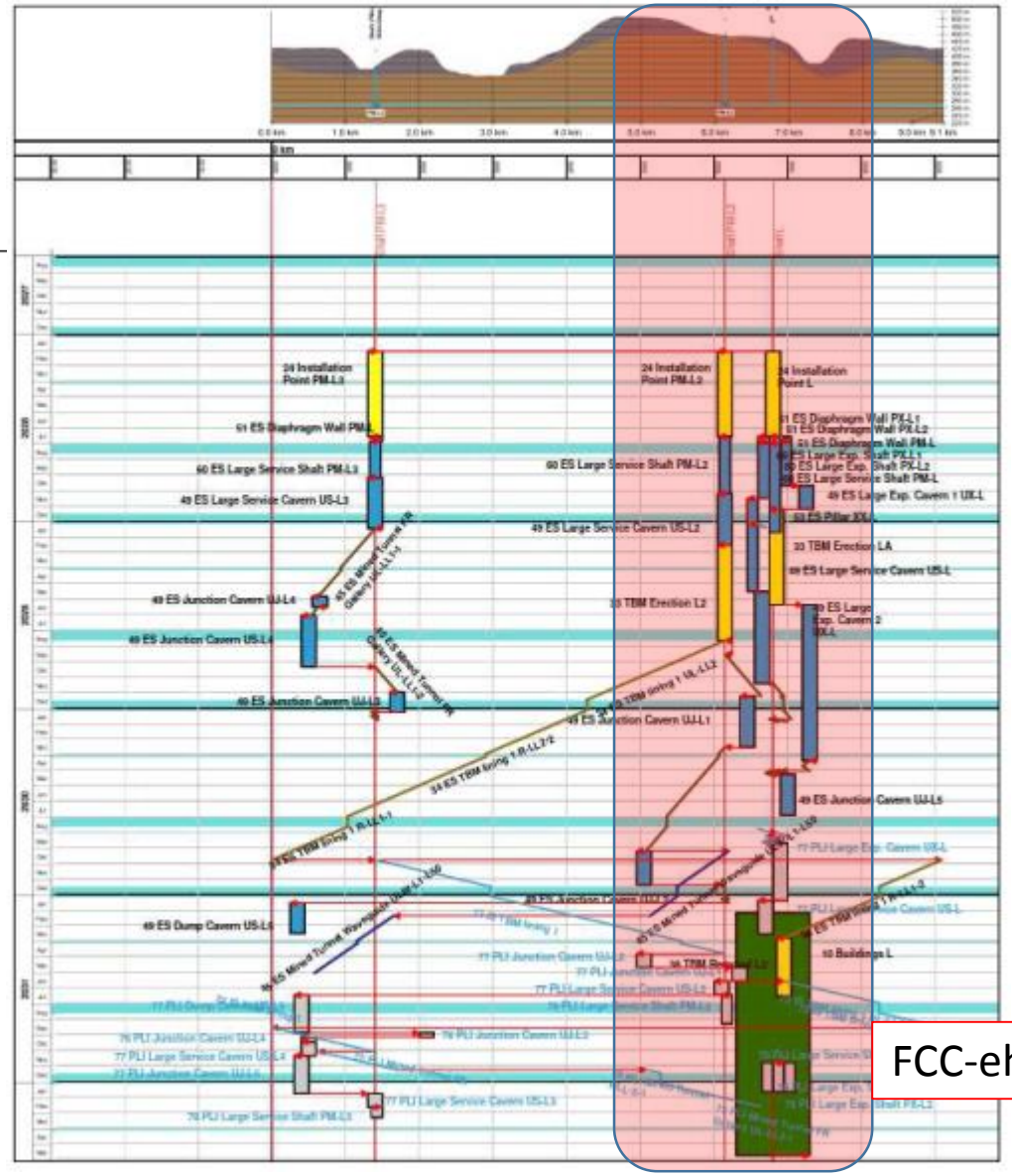
Construction Schedule



FCC-eh Schedule Considerations:

- The eh Civil Engineering work is expected to be undertaken as part of the FCC construction
- This schedule is therefore based on the schedule produced for the FCC main tunnel.
- FCC overall CE schedule 6.5 years

FCC-eh: 4.5 years

Cost Update

TABLE 12-1: EH MACHINE SCHEDULE OF STRUCTURES

Structure	Quantities	Description	Applicable Section from the Baseline Design
Machine Tunnels	9,091m	5.5mID tunnel	Machine Tunnels
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Waveguide Connections	50No	1mD, 10m long	Klystron Connections
Connection Tunnel	4No	3m span	Connection Tunnels

	2011 Dimensions	
	Total length (m)	Diameter/width (m)
Tunnel	7201	5
Total Shaft	160	8
RF Gallery	2842	6
Shaft Caverns	60	20
Dump Tunnel	180	5
Dump Caverns	40	12
Junction Tunnel	7	6
Waveguide Boreholes	500	1
Junction Caverns 1	55	20
Junction Caverns 2	80	12

Contributors to cost changes

- Tunnel Length for FCC is 9091m
- Ventilation ducts and fire compartments Included
- Connection Tunnels between RF Gallery and Main Tunnel.
- Increased Shaft depth to a total of 350m
- Consultancy and contractors profit % increase
- Injection Cavern added to structures schedule
- Price escalation

Spoil Management

Extraction Site	Volume (m^3)			
	Soft Ground	Limestone	Molasses	Total
Construction Shaft at LHC1	11,031	0	133,735	144,765
Construction Shaft at LHC2	0	0	202,589	202,589
Shafts at Point A	26,469	0	791,948	818,417
Shafts at Point B	35,161	0	326,482	361,643
Shaft at Point C	181,807	0	385,920	567,727
First Construction Tunnel at Point D	0	0	709,452	709,452
Shaft at Point D	15,992	8,806	668,961	693,760
Second Construction Tunnel at Point D	0	0	235,355	235,355
Shaft at Point E	6,528	0	174,792	181,320
Tunnel at Point F	0	1,206	375,414	376,621
Shaft at Point G	33,086		471,215	504,301
Construction Tunnel at Point H	0	244,081	750,620	994,701
Shaft at Point H	0	7,329	421,401	428,730
Shaft at Point I	6,528	0	796,634	803,161
Shaft at Point J	6,528	0	805,629	812,157
Shaft at Point K	13,381	0	610,972	624,353
Shafts at Point L	29,990	0	671,700	701,690
Total Spoil Volume	**366,500**	**261,422**	**8,532,821**	**9,160,743**

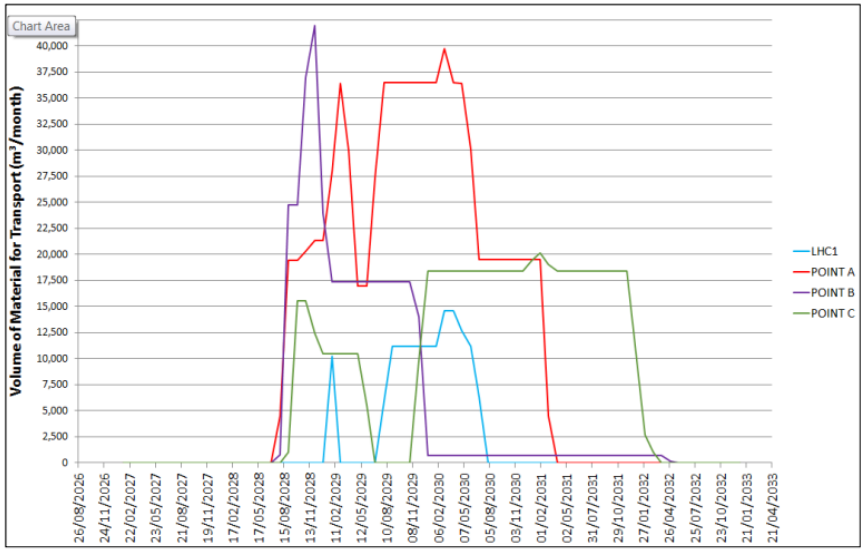


FIGURE 14-1: SPOIL SCHEDULE FOR LHC, A, B AND LHC1

Assumed bulking factor of 1.3

Total Spoil volume of FCC-eh = 598,140m^3

Production of up to 42,000m^3 per month
9million cubic meters to dispose
Can the molasse be re-used?

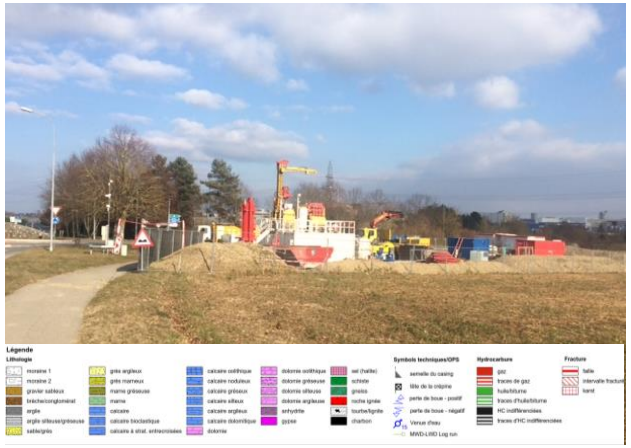
Ground Investigation Planning

	2019				2020				2021				2022				2023				2024				2025				2026				2027				2028			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
CERN feasibility	CERN conceptual design																																							
Site Investigation									Feasibility SI								Principal SI								Additional SI as necessary															
Consultant Contracts					Contract and tender strategy								Market Survey				Tender and Award				Preliminary design				Tender design								Construction Design							
Construction Contracts																													Market Survey				Tender and Award							
EIA and permitting documents	EI and permitting documentation																																							

Start of Construction

Types of site investigation:

- *Collection of existing information*
- Walkover survey
- Geophysical investigation
- Boreholes
- Site testing (eg Insitu stress test, point load testing, SPT)
- Rock laboratory testing.



Geothermal site investigation in Satigny 2017/2018 (500m deep)

Other Future Steps

- A further round of alignment optimisation for FCC following input from surface site investigations and potentially ground investigations.
  - This will require an optimisation of the FCC-eh machine when/if the alignment is optimised.

- Continuing to work with integration to refine designs for all structures and integrate the eh machine with the FCC machine.

- Spoil disposal planning for FCC-eh as part of the overall spoil disposal plan.

- A further cost update to be undertaken to refine the FCC-eh Costs.