Civil Engineering Developments

FCC week 2018 Amsterdam

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Agenda

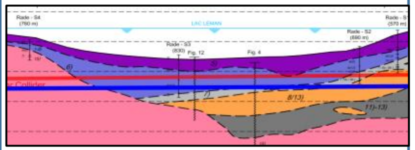
- Civil Engineering study progress since Berlin 2017
- Scope of Civil Engineering for:
  - FCC-hh
  - FCC-ee
  - FCC-eh
  - HE-LHC
- Alignment and Geology Update
- Update on the principal structures and position
- Typical tunnel cross-section
- Experimental cavern layout options
- Cost and Schedule Study
- Spoil Management Study
- 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.



September 2017

Phase 3 of cost and schedule study launched.

- Refinement of results from previous phases
- Produce a cost and schedule estimate that is compatible with the CDR baseline.

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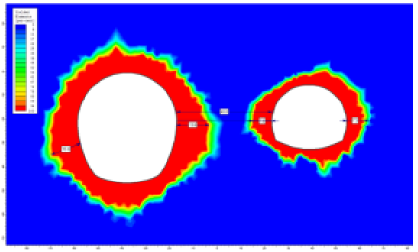
February 2017

Design development with integration, including study to investigate feasibility of interaction region layout.



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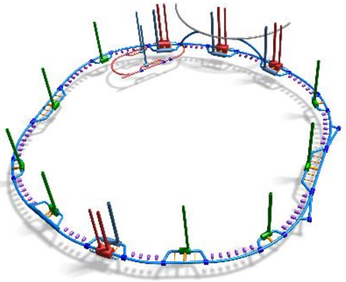
March 2018

- Cost and schedule round up for all 3 machines:

FCC-hh, FCC-ee and FCC-eh

- CDR writing



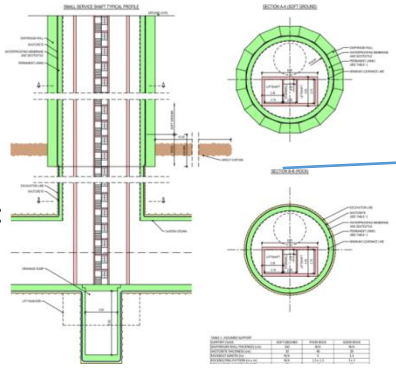
Ongoing

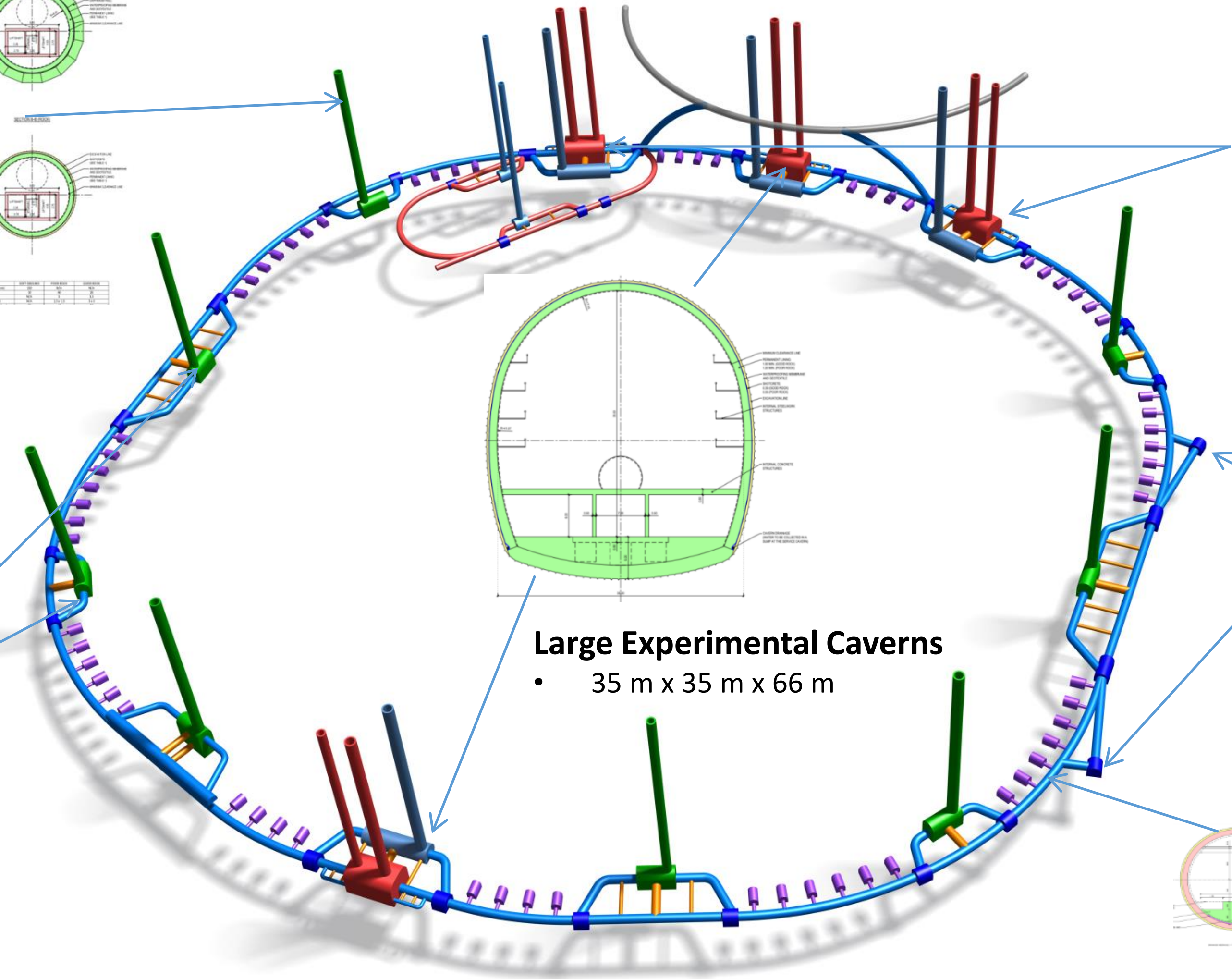
Ongoing work:

- Surface site investigation
- Spoil management study
- Site investigation planning
- HE-LHC feasibility and cost
- Transfer line design

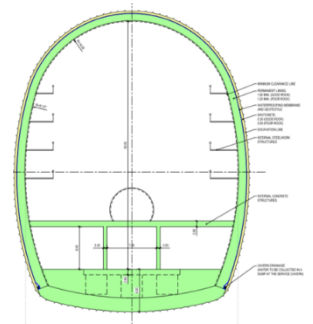
Scope of FCC-hh

Shafts:
Experimental Shafts:
15 m dia. + 10 m dia.
Service shafts:
12 m dia.
Magnet delivery shaft:
18 m

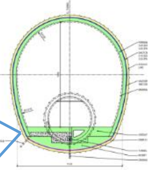




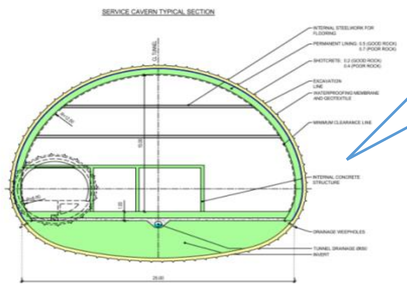
Large Experimental Caverns
- 35 m x 35 m x 66 m



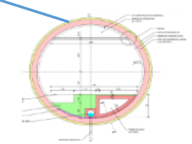
Small Experimental Caverns
- 30 m x 35 m x 66m



Dump Caverns
- 10 m x 10 m x 50 m

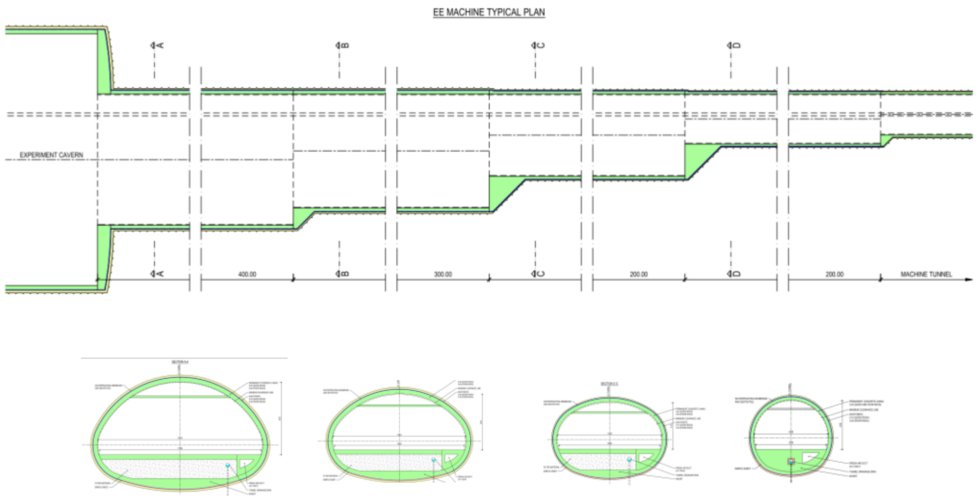


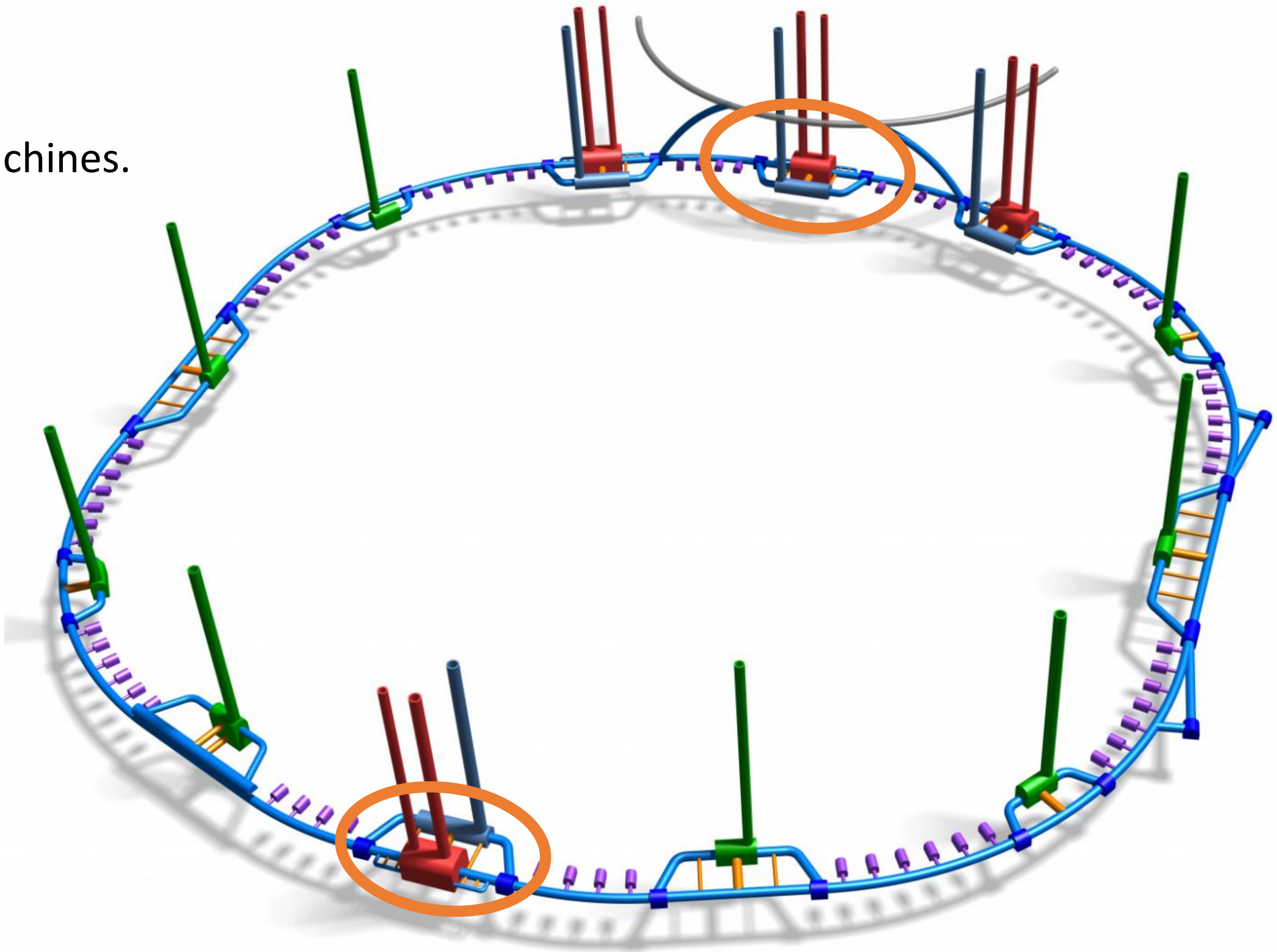
Service Caverns
- 25 m x 15 m x 100 m



Tunnels:
- 97.75 km of 5.5 dia. machine tunnel
- Approx. 8 km 5.5 dia by-pass tunnels

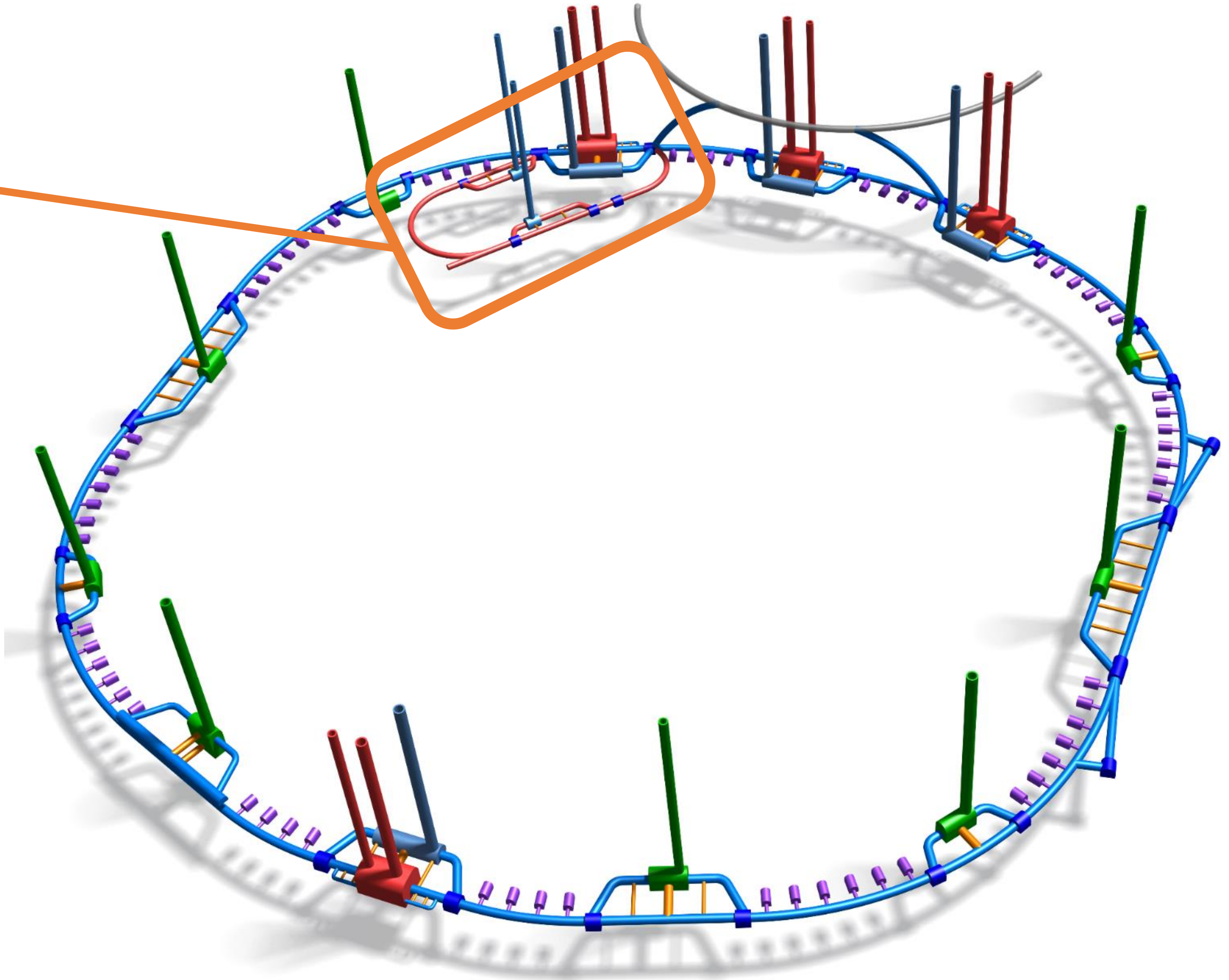
- Would be constructed at the same time as FCC-hh
- Infrastructure must be able to accommodate both machines.
- Enlargements required at experiment points A and G.





FCC-eh

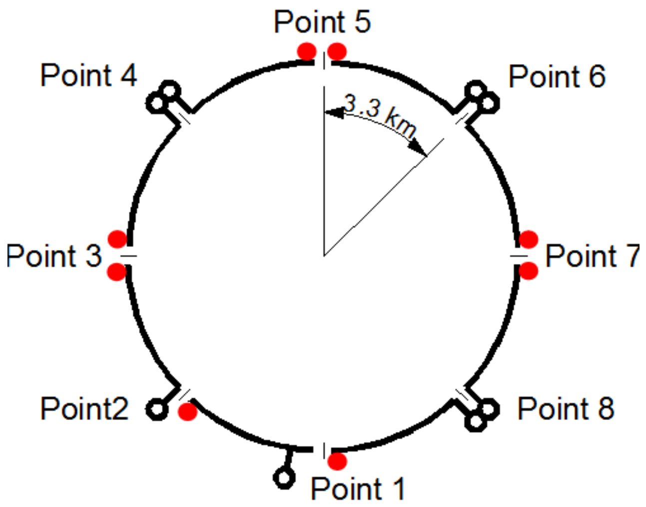
Structure	Quantities	Description	Applicable Section from the Baseline Design
Machine Tunnels	9,091m	5.5mID tunnel	Machine Tunnels
Service Shafts	2No	9mID shaft	9m shaft with same support of the 10mD Experiment Shafts
Service Caverns	2No	25m span, 50m long cavern	Service Cavern
Injection Cavern	1No	25m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

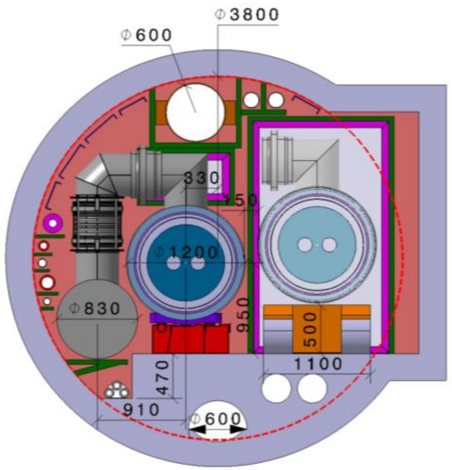


Civil Engineering of FCC-eh – J.Osborne

Thursday 12th April 9:00, Berlage Zaal 1.9

- For HE-LHC modifications are required to house a new accelerator, including:
    - Cryogenic caverns and buildings
    - Installation of fire separation walls including extension of the tunnel envelope each 400 m
    - Maintenance of the existing structure.





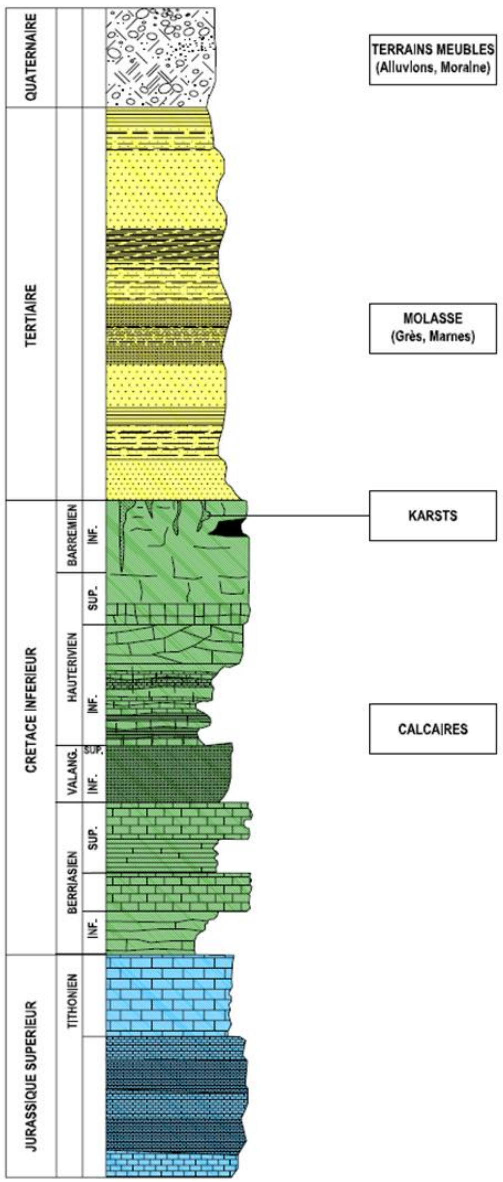
Crossrail – Cross Passage Temporary Frames

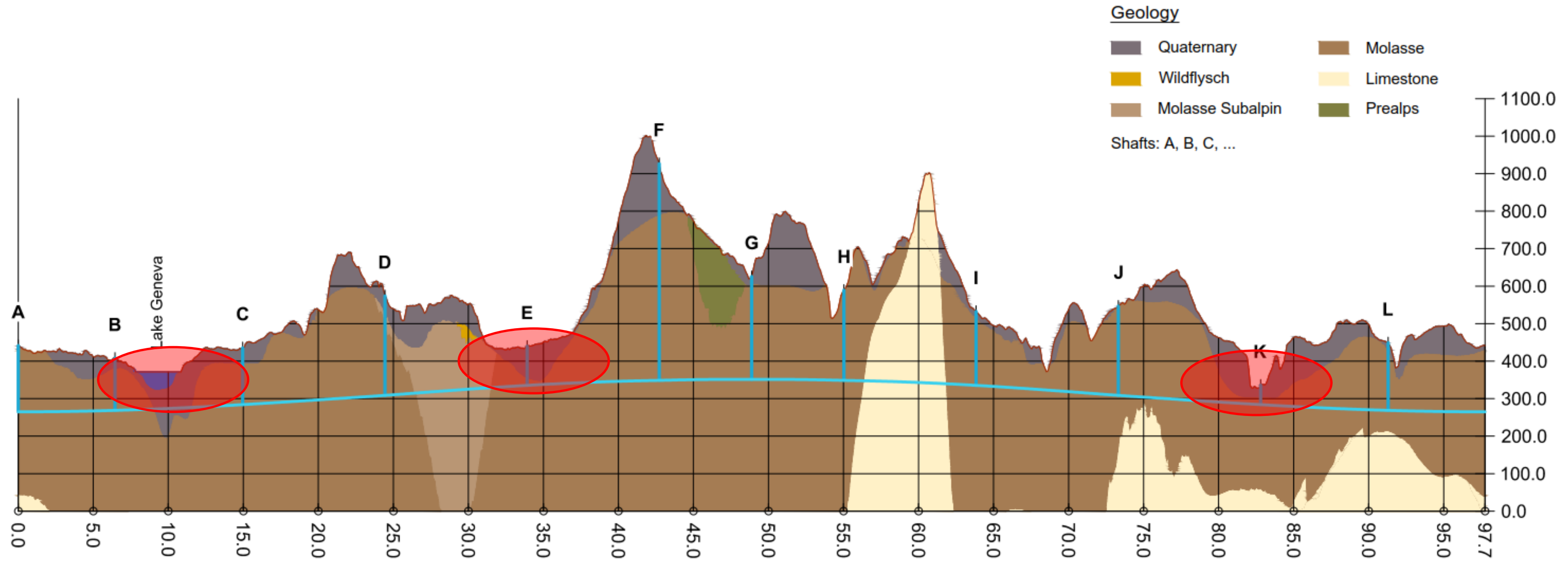
Brisbane – Airport Link
(Similar ground to CERN)

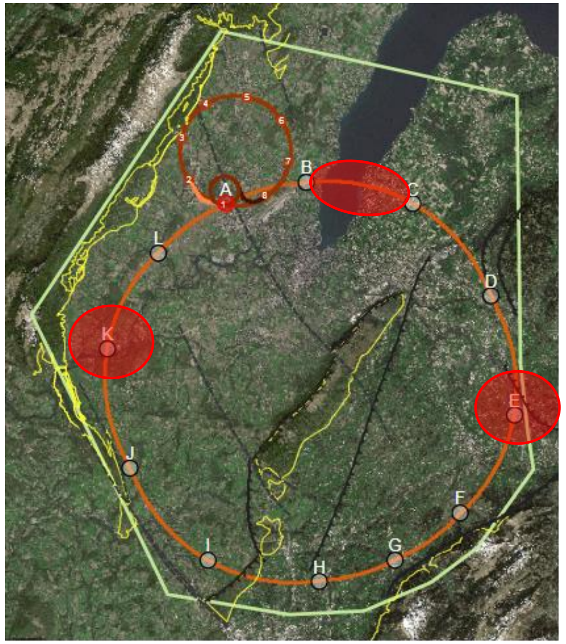
Moraines
- Glacial deposits comprising gravel, sands, silt and clay
- Water bearing unit
- Low strength

Molasse
- Mixture of sandstones, marls and formations of intermediate composition
- Relatively dry and stable
- However, some risk involved: structural instability (swelling, creep, squeezing)

Limestone
- Hard rock
- In this region fractures and karsts encountered
- High inflow rates measured during LEP construction (600L/sec)
- Clay-silt sediments in water filling karsts







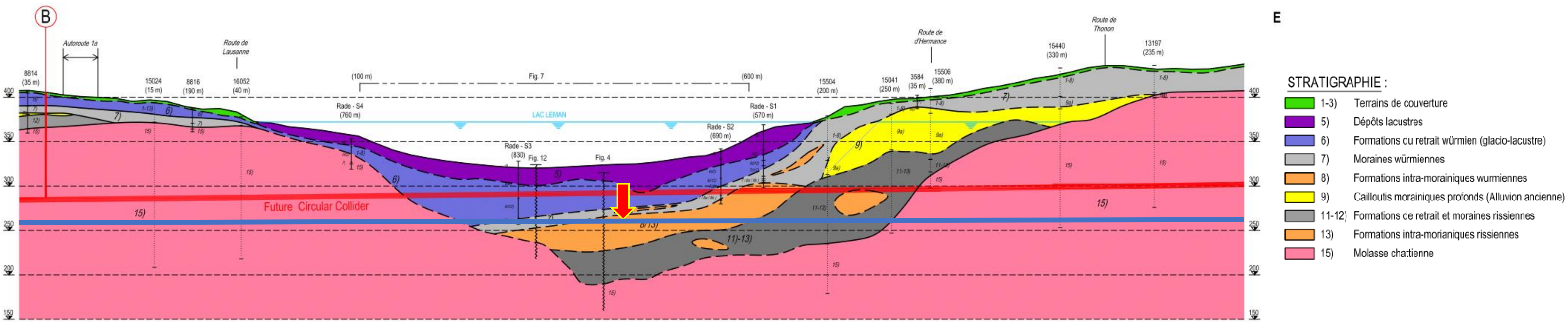
Following another round of geological review of the most challenging areas this is the baseline position considering:

- Lowest risk for construction
- Fastest and cheapest construction
- Feasible positions for large span caverns (the most challenging structures)

Not considering:

- Results from initial feedback on surface site locations

Geology under lake

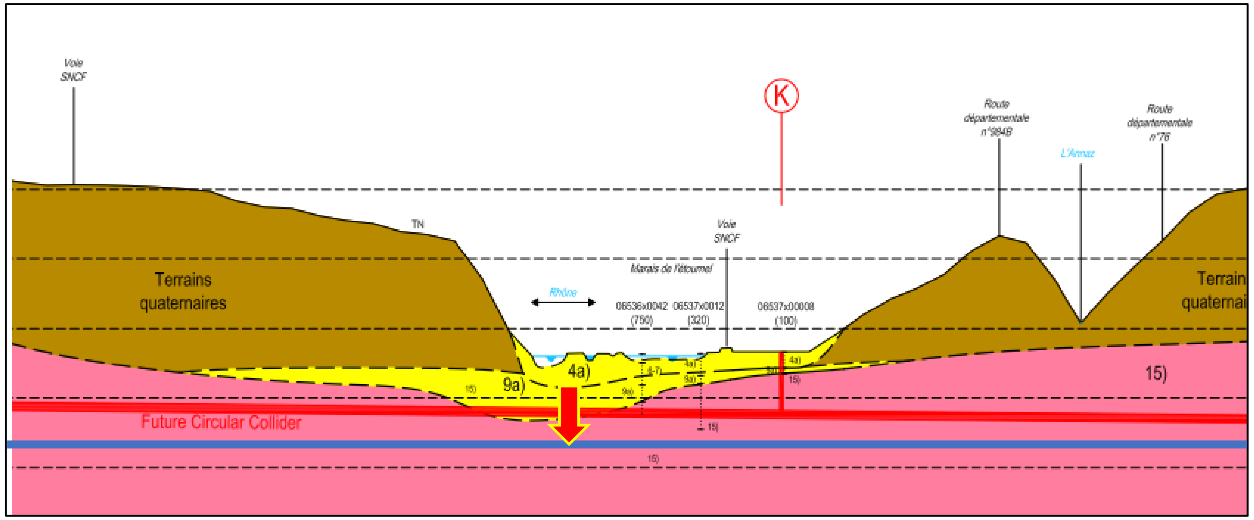


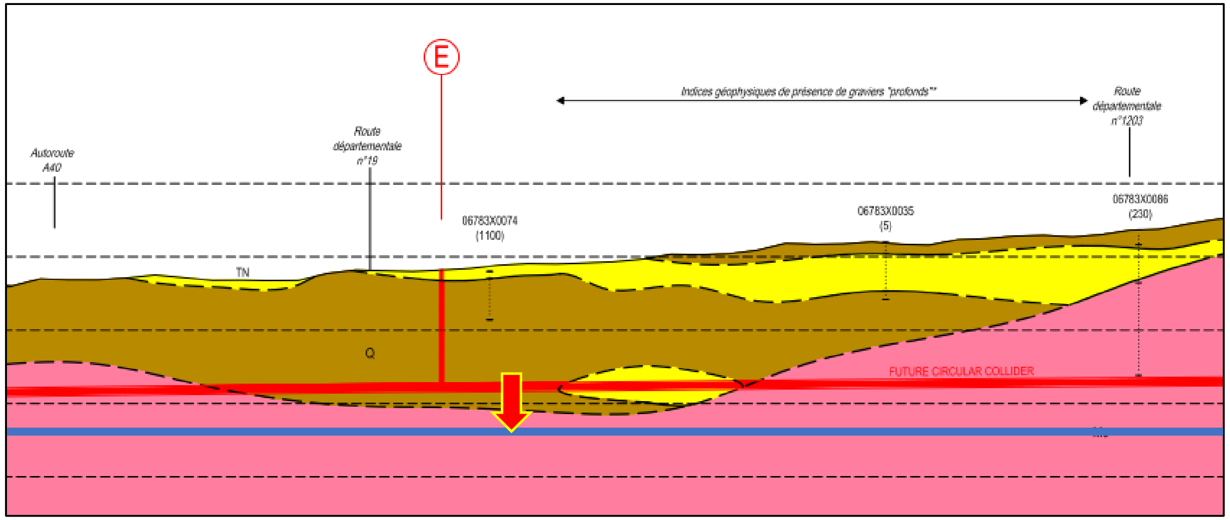
- Data available from boreholes and seismic scans for potential lake road crossing.
- Tunnel to cross moraine layer below lake.
- Layered moraine types, improving in quality with depth. However, the deeper the tunnel in the moraines, the greater the pressure on the tunnel gaskets.

Conclusion: Lower alignment by 30 m in order for the tunnel to be at a depth with a reduced construction risk and that will not be affected by changes in the lake depth during the operation phase.

Construction method: Slurry TBM

Geology of Rhone and Arve valleys





- Data available from deep destructive drillings for water research in the vicinity of the crossing.
- Tunnel previously crossing saturated moraines below Rhone in NATURA 2000 protected area.

- Data available from oil surveys, destructive drillings and geological maps.
- Tunnel previously crossing moraine later, including permeable layers (shown in yellow)

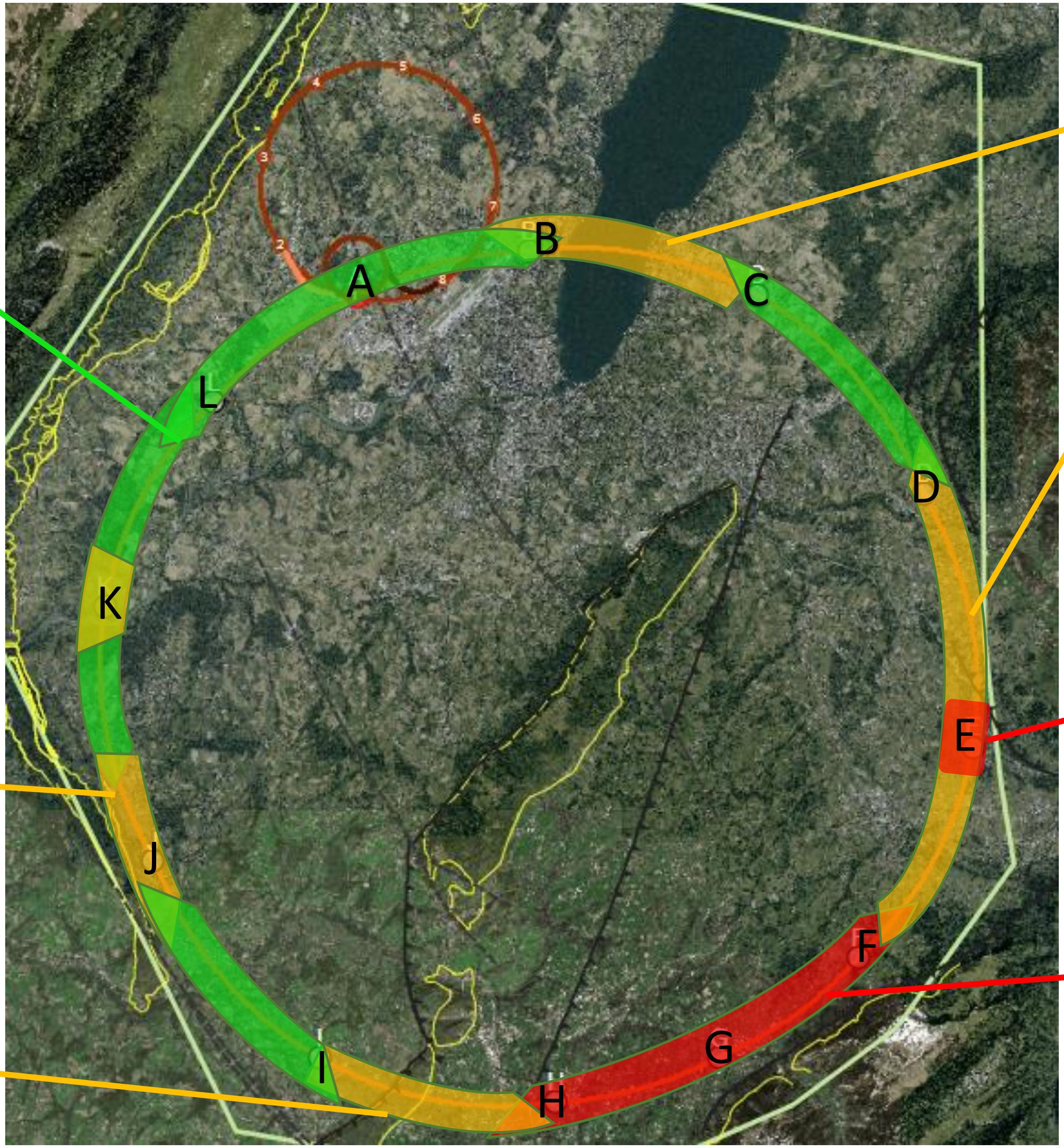
Conclusion: Lower alignment by 20 m so that the TBM mode does not need to be changed and environmental risks are minimised.

Geological Uncertainty along Alignment

- 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.

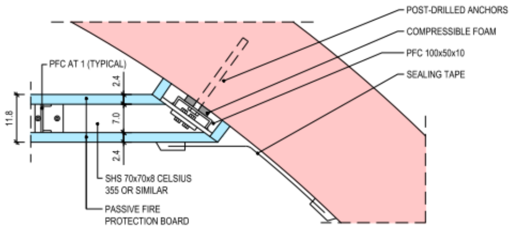
- Location of the interface between molasse and molasse subalpine not certain, tunnel alignment in proximity.

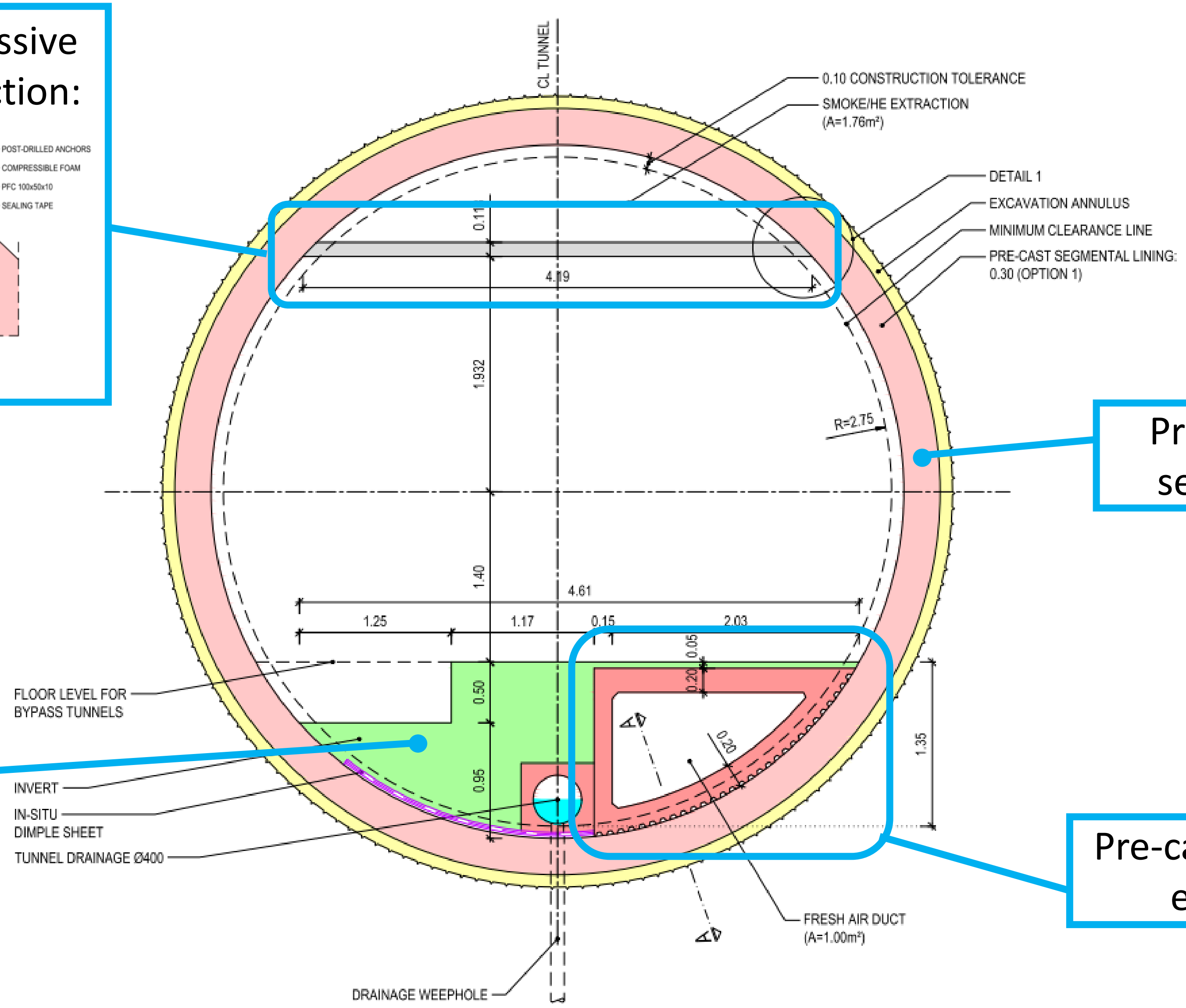
- Moraine/molasse interface not certain, cavern close to interface.
- Lack of deep boreholes in area.

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

Typical tunnel cross-section

Steel structure with passive fire protection. Connection:

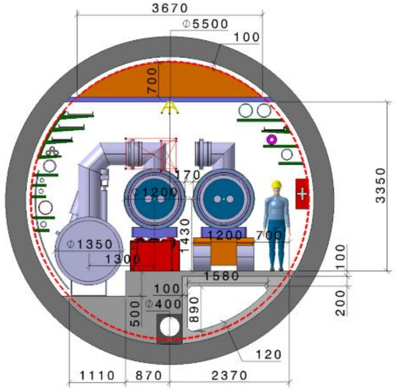




Pre-cast concrete segmental lining

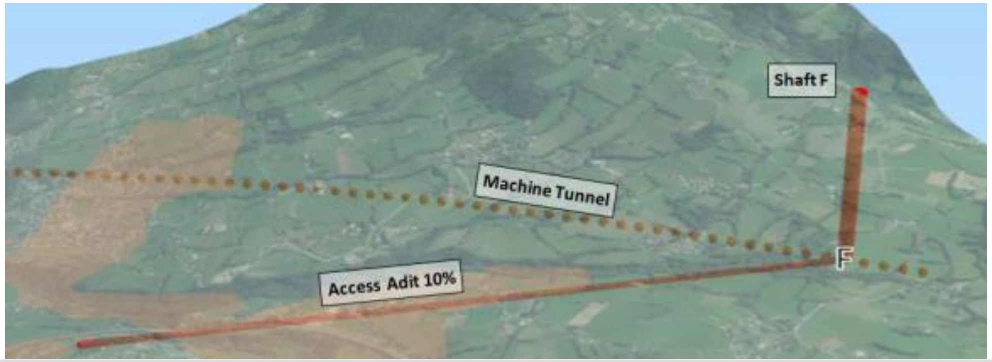
Cast-in-situ concrete invert

Pre-cast concrete element



Point F options

Option	576 m Shaft	10% inclined access	15% inclined access
Excavation length	576 m (12 mID)	3820 m (9.0mID)	2750 m (9.0mID)
Total duration (months)	22.2	25.8	23.2
Relative CE Cost	1	1.08	0.78
Advantages	• Shorted length of services	• Improved surface site location and access • TBM ready in cavern for tunnel excavation	• Improved surface site location and access • TBM ready in cavern for tunnel excavation
Disadvantages	• Baseline lift mechanism not feasible • Surface site has difficult access	• Increased length of services	• Increased length of services • Transport method at 15% to be confirmed

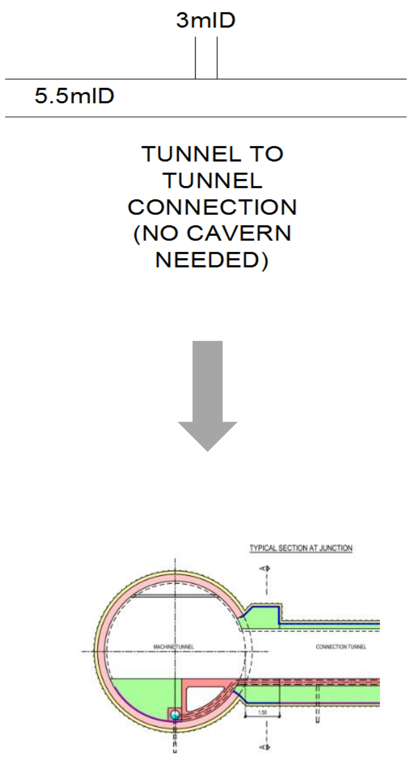


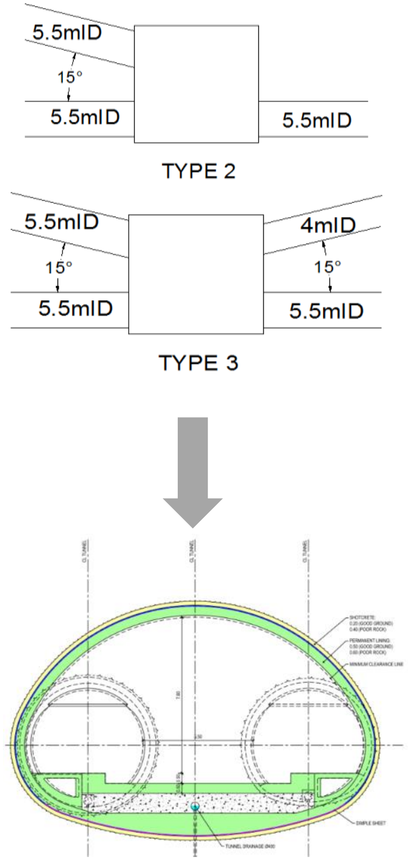
Existing LEP transfer tunnel TI18 15% from SPS to LHC

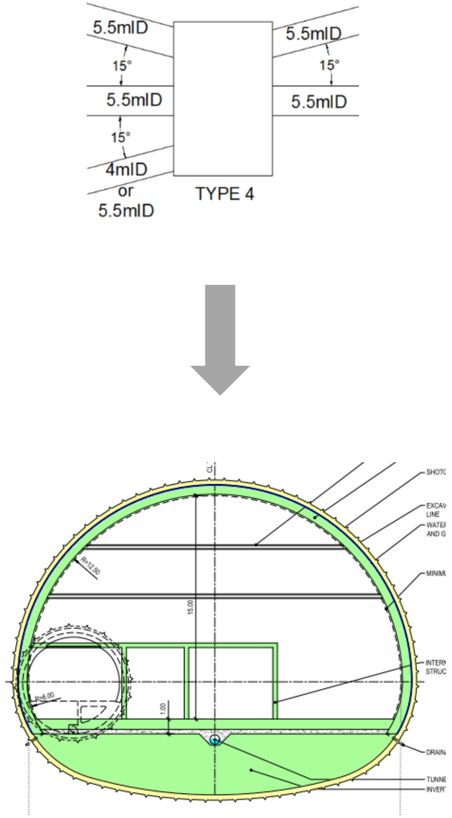
Whole project cost and schedule implications, including transport and services, still to be evaluated.

Junction cavern refinement

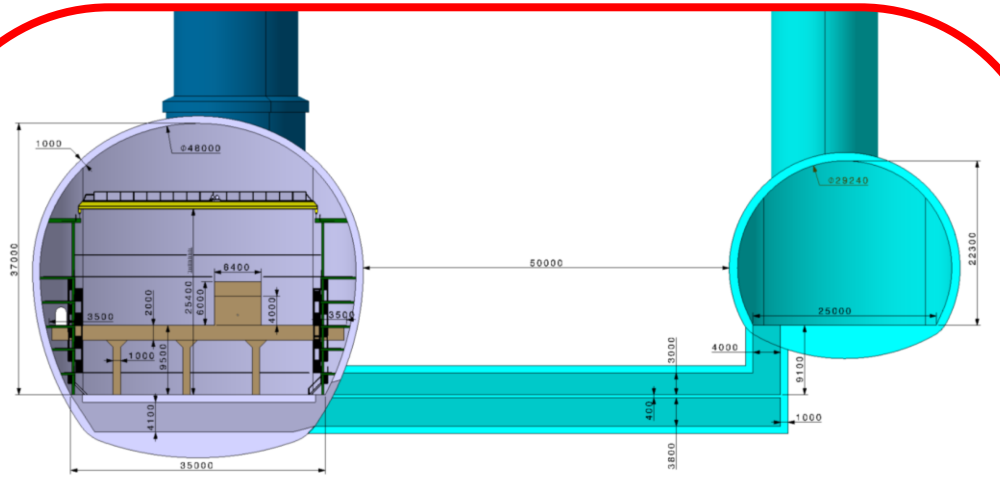
- Junction caverns are required for structural stability when tunnels of similar size connect.
- By evaluating each case individually, it was possible to omit some junction caverns
- The remaining caverns have been grouped into 3 types. (Type 1 below indicates no cavern is needed)

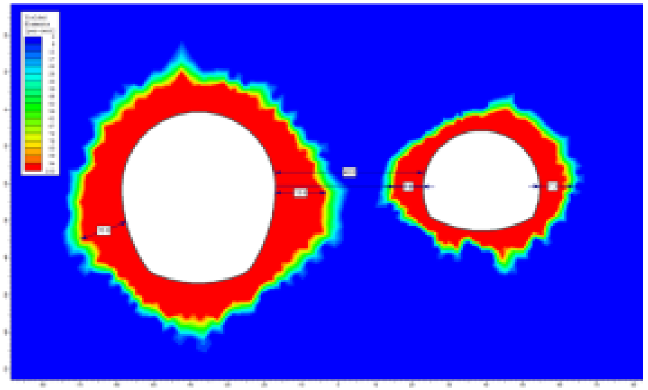




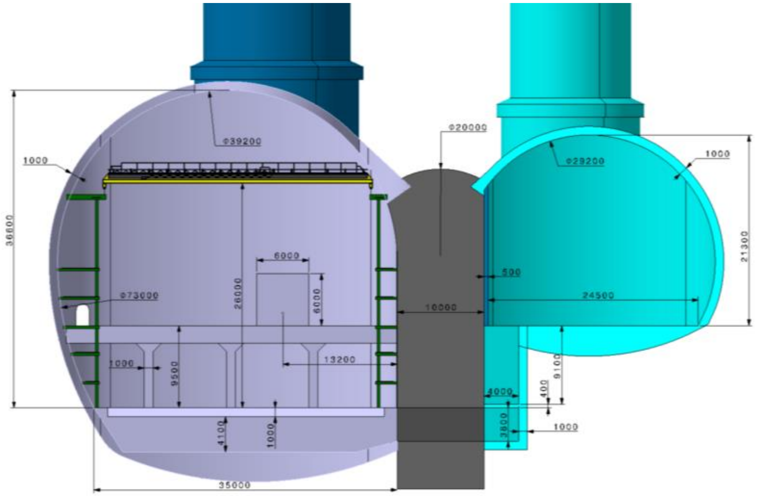


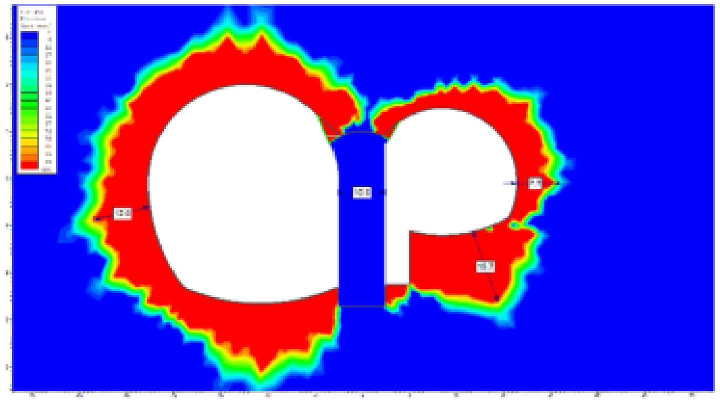
Experimental point layout options





- With 45 m spacing in good molasse, the rock pillar alone is sufficient.
- Cheapest and lowest risk option for CE





- 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

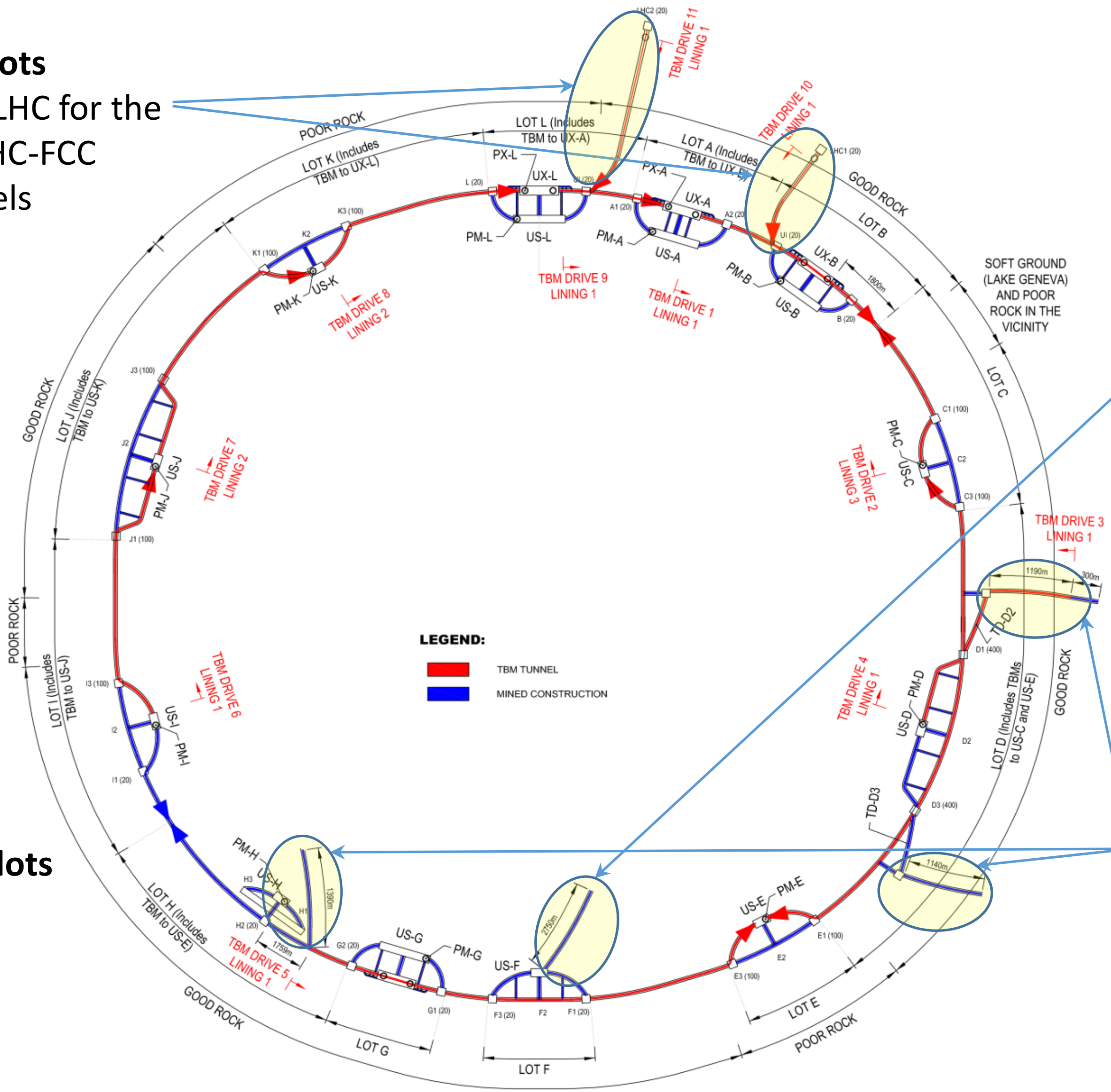
Phase 3

Refinement of results from Phases 1 and 2:

- Review to include updates made to baselined design.
- Incorporate desirable variations from Phase 2.

Construction Strategy

Additional construction lots
- 2 no. Shafts near the LHC for the connection tunnels LHC-FCC
- 2 Beam transfer tunnels



Access to main tunnel works through:
- Shafts at 11 points
- Sloped Access adit at 1 point (instead of 570 m shaft)

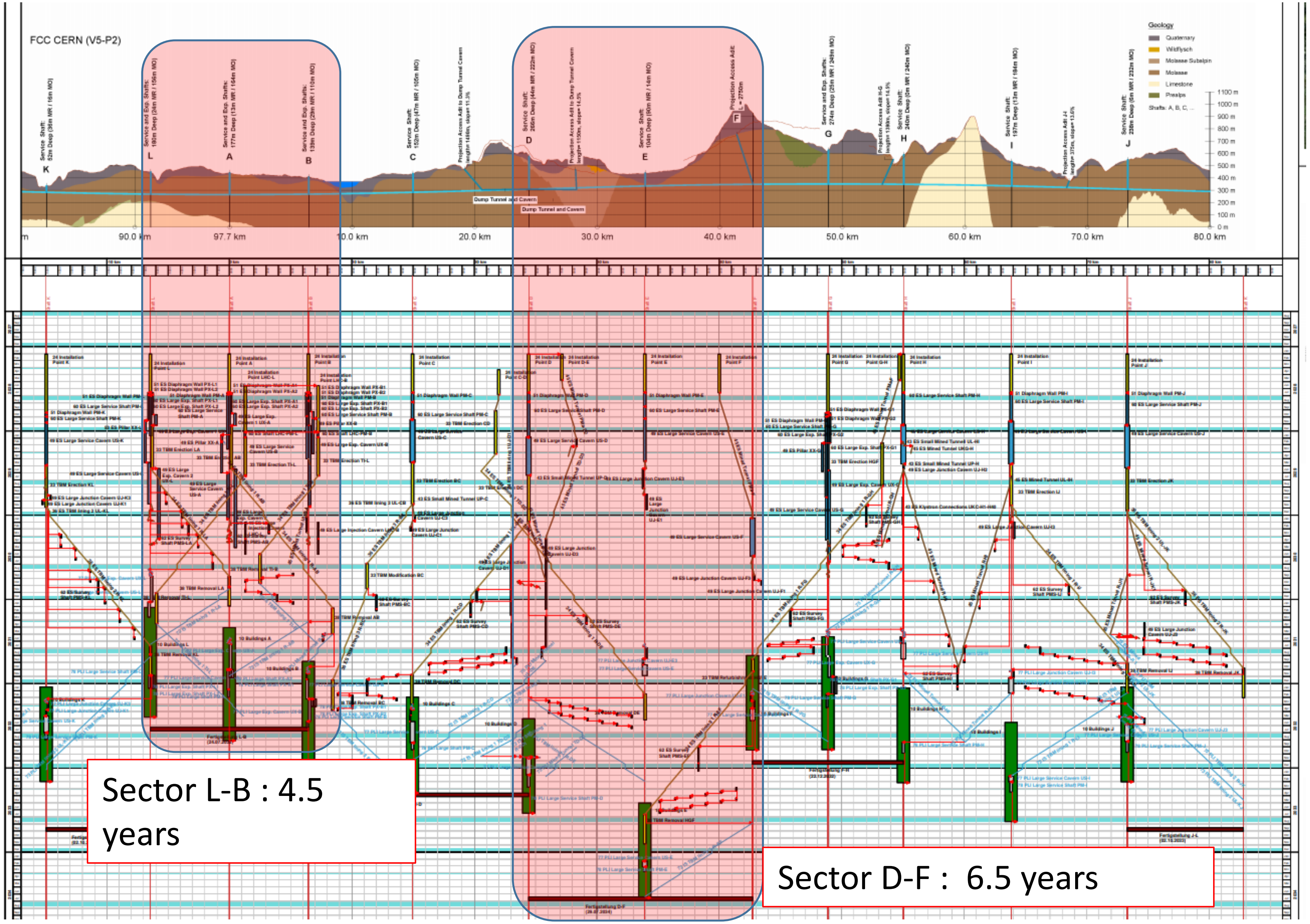
Intermediate Access Adits
- necessary to cope with overall time schedule to meet deadlines for machine installation

Project divided in 12 construction lots

Construction techniques:

1) TBM tunnels (red)
2) Mined tunnels (blue)

Construction Schedule



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**

Assumed bulking factor of 1.3

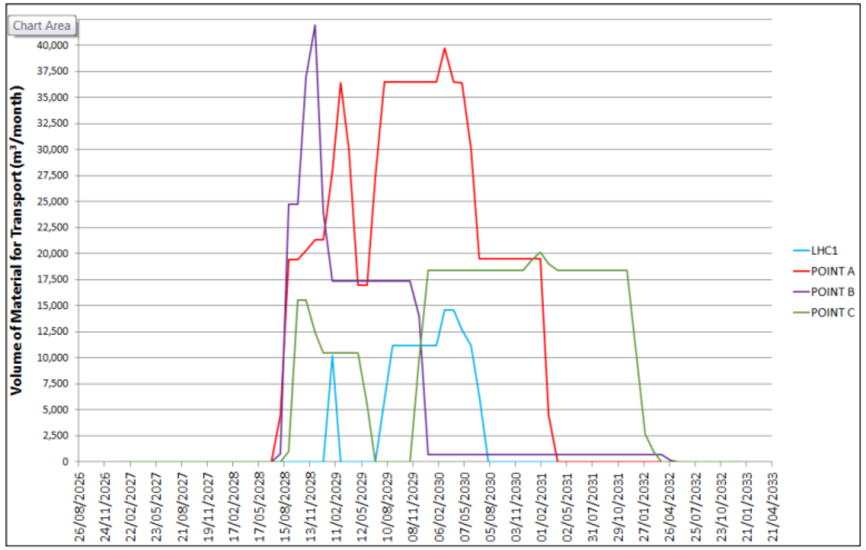
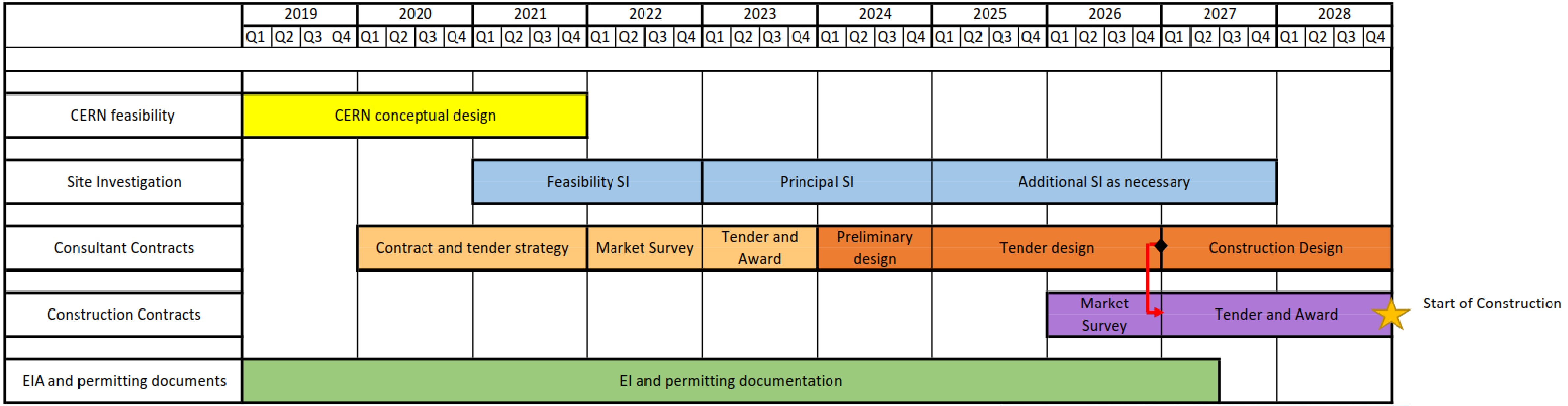


FIGURE 14-1: SPOIL SCHEDULE FOR LHC, A, B AND LHC1

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



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)

- A further round of alignment optimisation following input from surface site investigations and potentially ground investigations
- Continuing to work with integration to refine designs for all structures
- Spoil disposal planning
- Development of HE-LHC requirements
- Maintenance planning for injection chain.

FCC
hh ee he