LCWS2021

INTERNATIONAL WORKSHOP ON FUTURE LINEAR COLLIDERS

International Workshop on Future Linear Colliders, LCWS2021

Civil Engineering Status and Plans for CERN's Future Circular Collider (FCC)

John Osborne CERN

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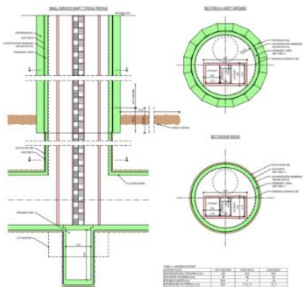
CERN

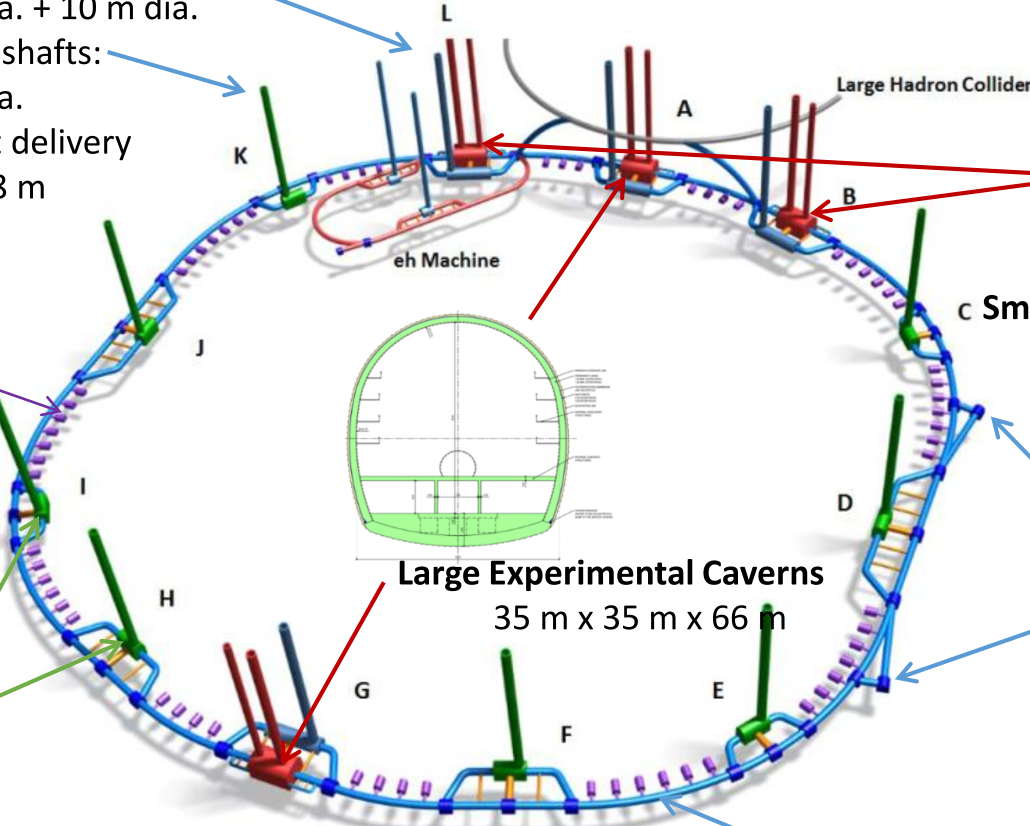
Acknowledgement of SCE CE team and Infrastructure WG members, in particular, Alexandre Tudora and Volker Mertens

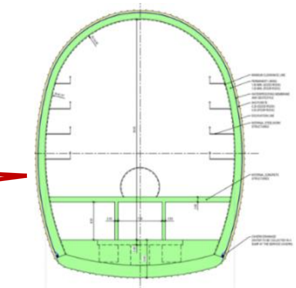
FCC civil engineering overview

Underground civil infrastructure for FCC - 3D schematic (not to scale)

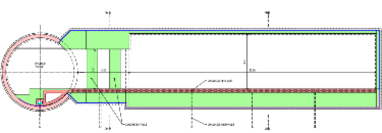


Shafts:
Experimental Shafts:
15 m dia. + 10 m dia.
Service shafts:
12 m dia.
Magnet delivery shaft:18 m



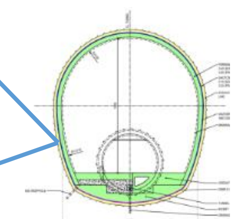


Small Experimental Caverns
30 m x 35 m x 66m

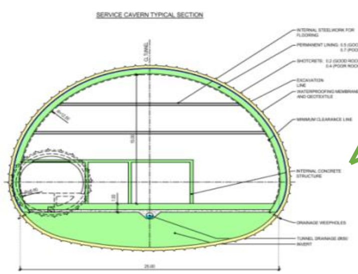


Alcoves
- 25 m x 6 m x 6 m
- Located at 1.5km spacing

Large Experimental Caverns
35 m x 35 m x 66 m



Beam Dump Caverns
- 10 m x 10 m x 50 m

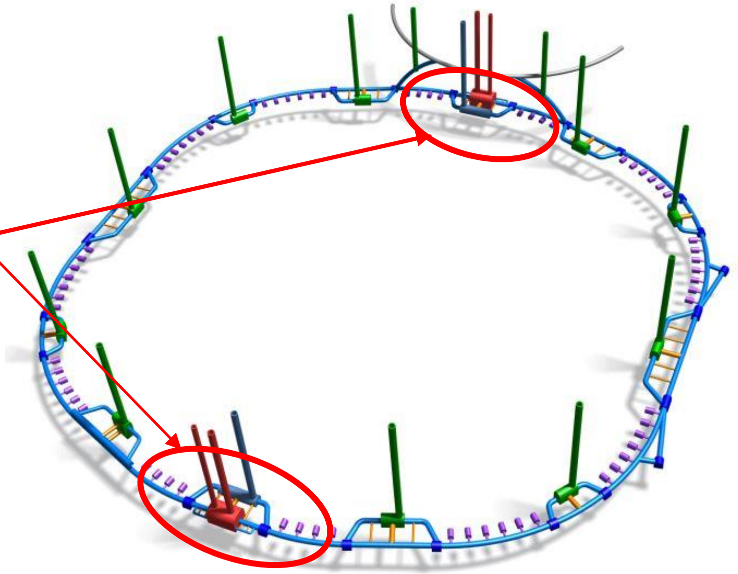


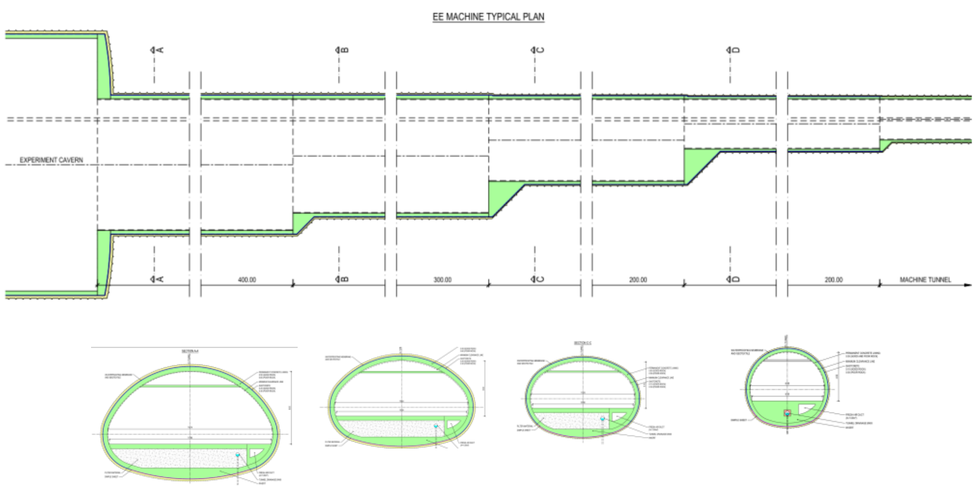
Service Caverns
- 25 m x 15 m x 100 m

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

FCC-ee

- 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 CDR baseline footprint

Alignment | Shafts | Query

Choose alignment option

V4variation_2017-5

Tunnel elevation at centre:322mASL

Grad. Params

Azimuth (°): -25.5

Slope Angle x-x(%): 0.3

Slope Angle y-y(%): 0.08

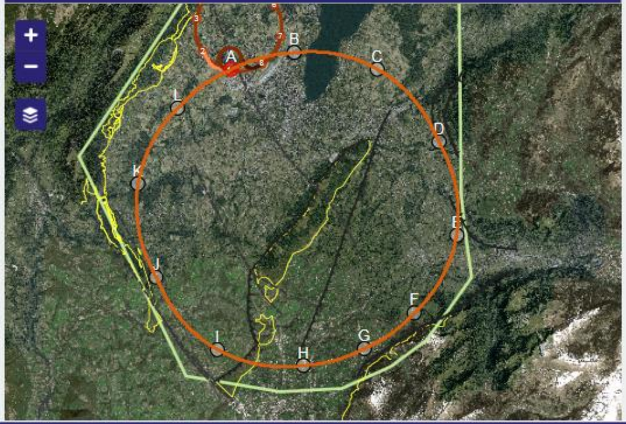
LOAD | CREATE | UPDATE | CALCULATE

Alignment centre

X: 2499941   Y: 1107760

	CP 1		CP 2	
	Angle	Depth	Angle	Depth
LHC	38°	48m	-41°	88m
SPS		121m		127m
TI2		121m		127m
TI8		51m		119m

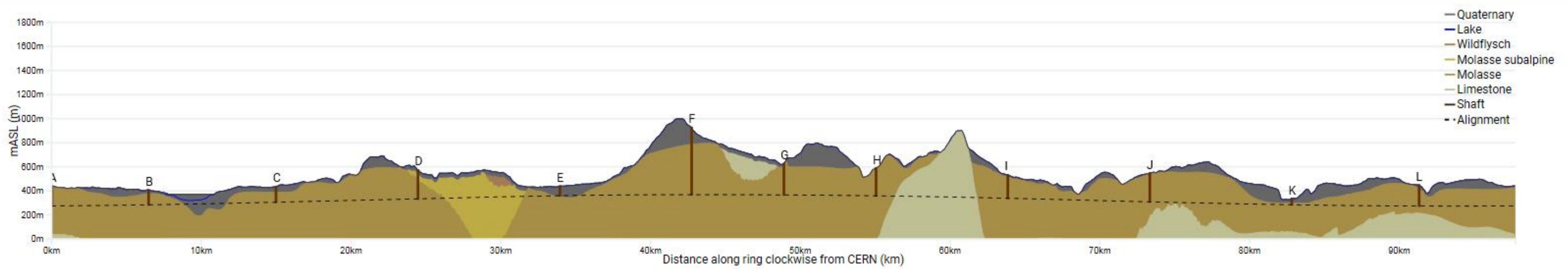
Alignment Location



Geology Intersected by Shafts | Shaft Depths

	Shaft Depth (m)			Geology (m)			
Point	Actual	Molasse SA	Wildflysch	Quaternary	Molasse	Urgonian	Limestone
A	166	0	0	13	153	0	0
B	123	0	0	29	94	0	0
C	130	0	0	47	83	0	0
D	240	45	0	40	155	0	0
E	79	0	0	79	0	0	0
F	558	0	0	139	419	0	0
G	259	0	0	13	246	0	0
H	230	0	0	0	230	0	0
I	193	0	0	13	181	0	0
J	237	0	0	6	231	0	0
K	51	0	0	36	15	0	0
L	175	0	0	24	151	0	0
Total	2442	45	0	439	1958	0	0

Alignment Profile



Geology Intersected by Tunnel | Geology Intersected by Section

97.75km tunnel circumference

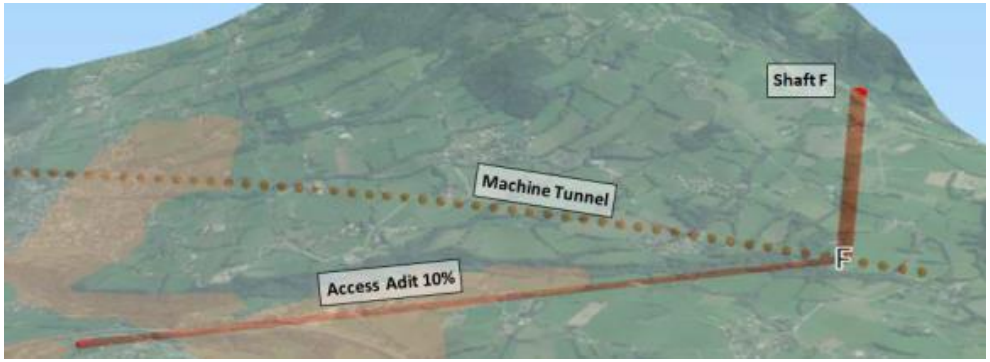
~90 % molasse – suitable ground for tunneling. Only one sector in limestone.

3720 m sum of shaft depths

558 m deepest shaft (F): proposed to be replaced with an inclined tunnel

Inclined access tunnel at point F

Option	558 m Shaft	10% inclined access	15% inclined access
Excavation length	558 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

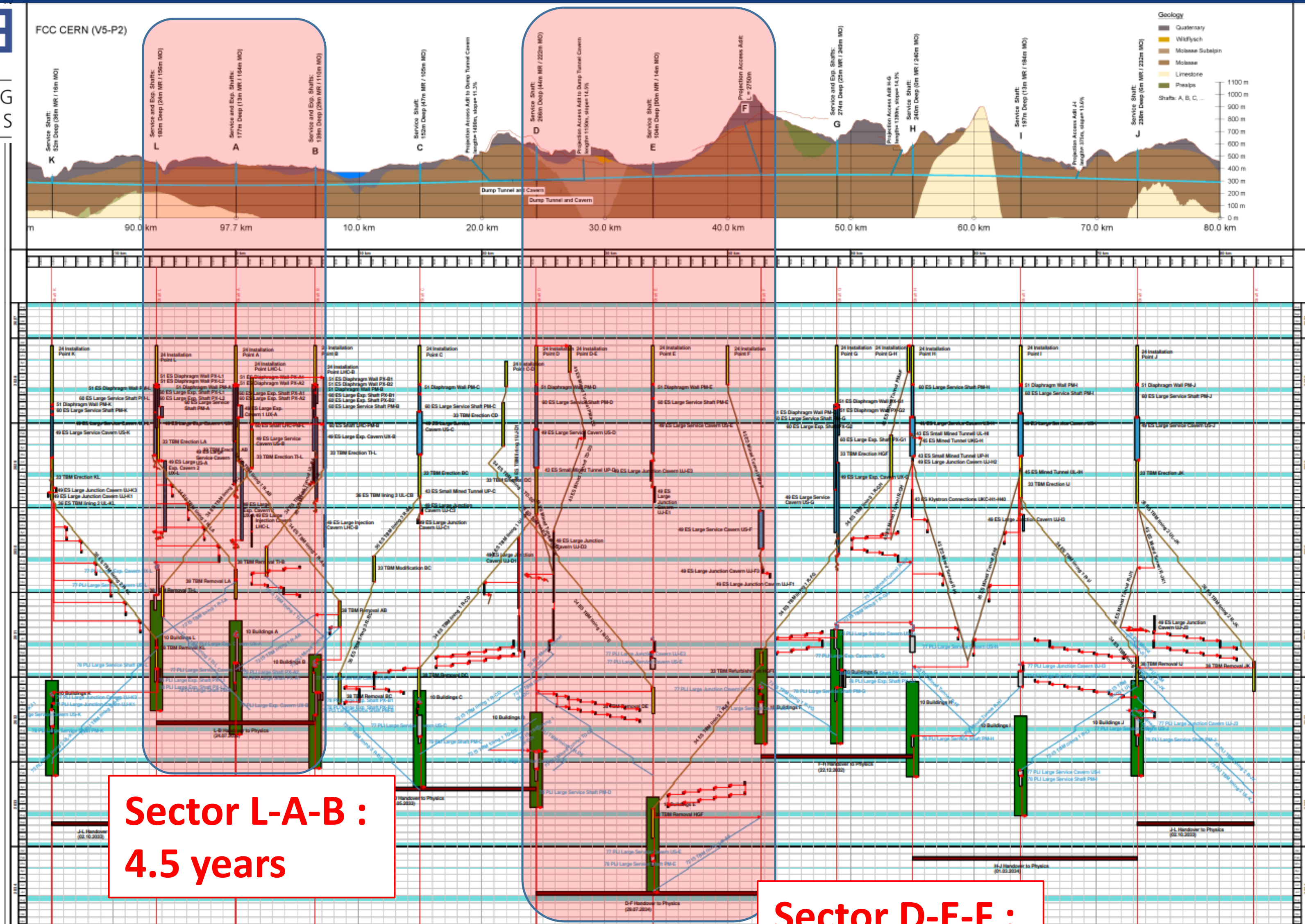


Existing LEP transfer tunnel TI18 15% from SPS to LHC

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

Construction Schedule

CONSULTING ENGINEERS

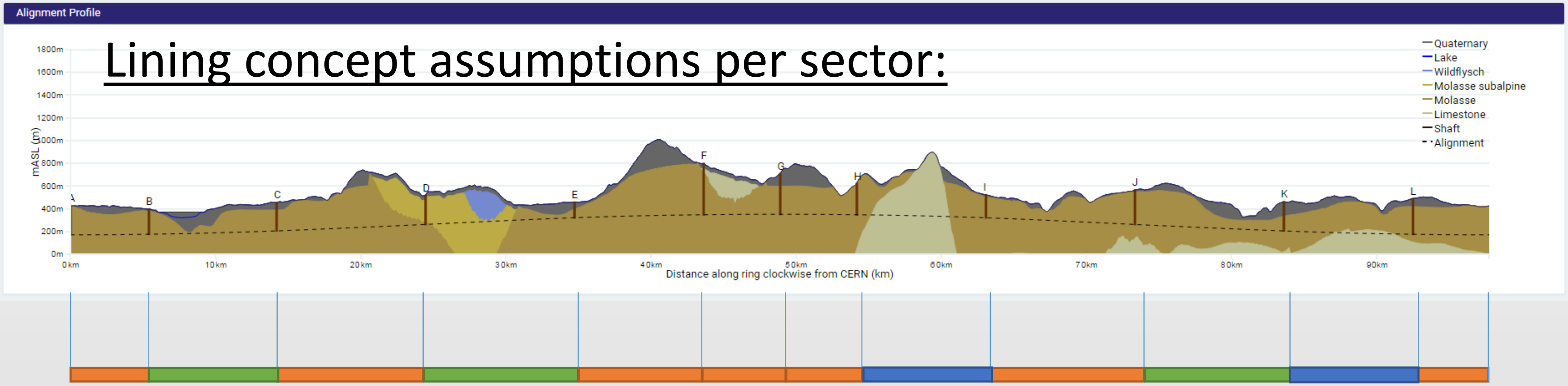


Sector L-A-B : 4.5 years

Sector D-E-F : 6.5 years

FCC Machine Tunnel – Lining concept

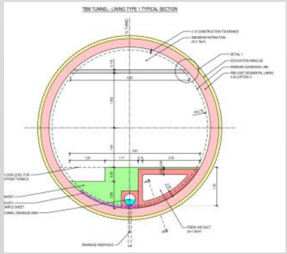
Lining concept assumptions per sector:



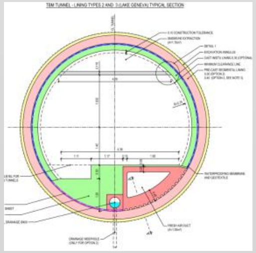
Lining Type	1	2/3	1	2	1	1	1	4	1	2	4	1

TBM Tunnel Types

Type 1

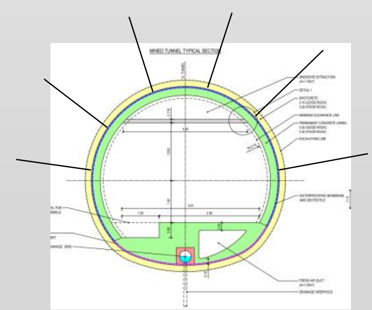


Type 2 / 3 *



Mined Tunnel Type

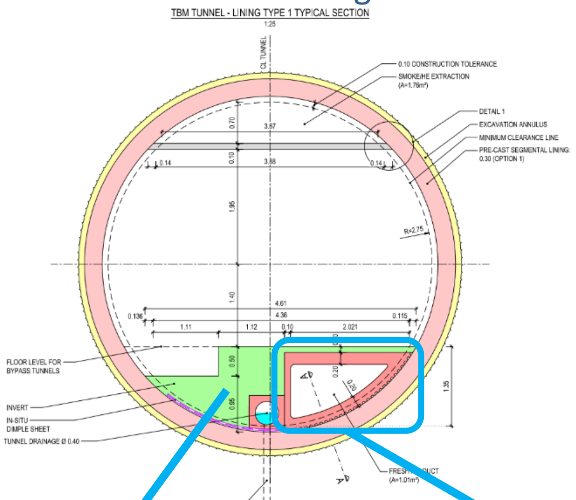
Type 4



*It is assumed 50% will have optional inner lining

Machine tunnel cross sections and lining concepts

Lining Type 1
- TBM tunnel in 'good' molasses

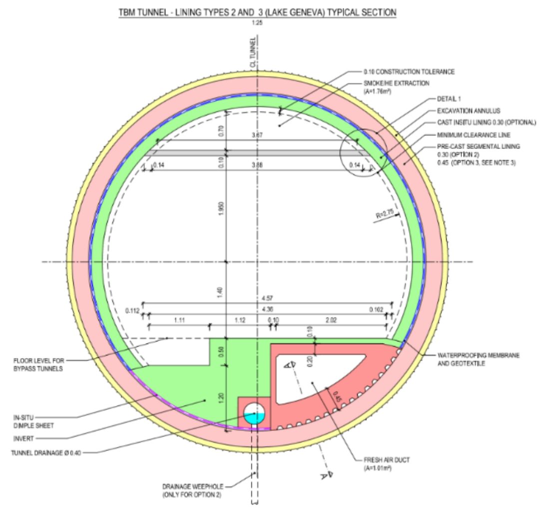


Cast-in-situ concrete invert

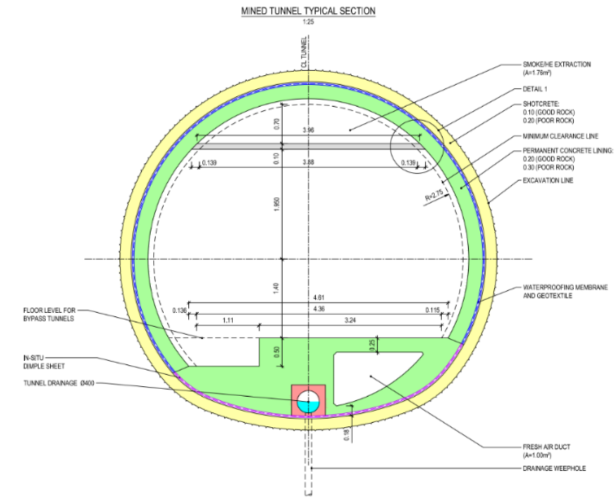
Pre-cast concrete element

Pre-cast concrete invert (HL-LHC)

Lining Type 2 & 3



Lining type 4
- Mined tunnels in limestone

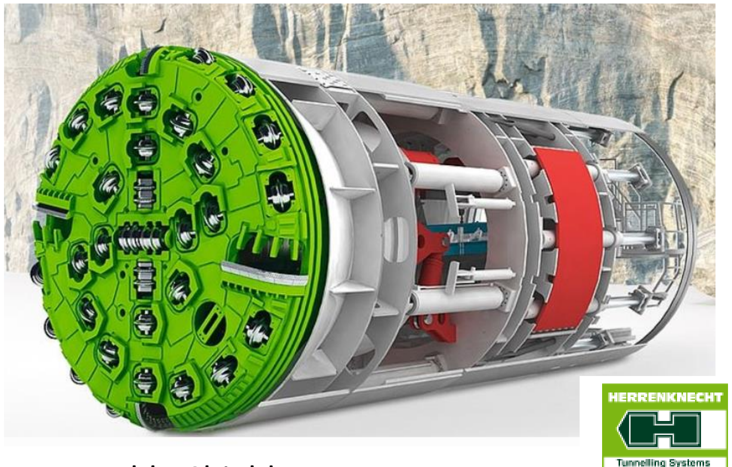


Lining types 2
- TBM tunnel in jointed molasse with high risk of groundwater infiltration
- In sectors where there is relatively low rock cover to the water bearing moraine deposits
- Precast concrete thickness: 30cm

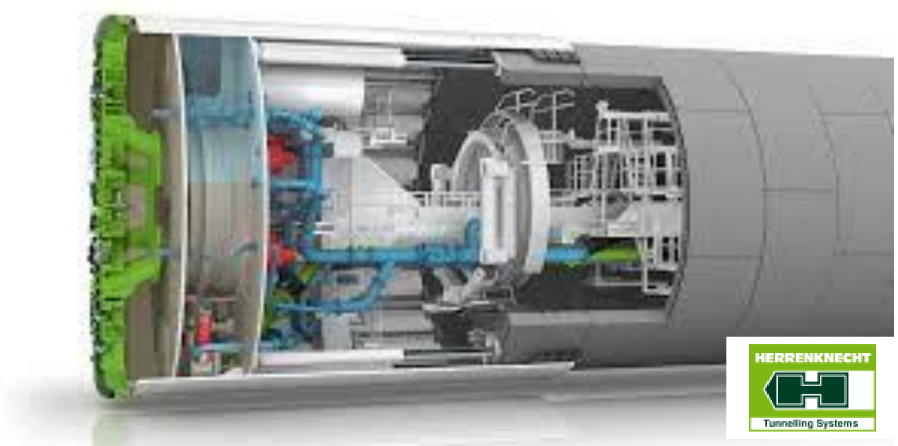
Lining type 3 (under Geneva Lake)
- Precast concrete thickness: 45cm
- Segments with higher steel bar density

LEGEND:
- CAST INSITU CONCRETE
- GROUT
- PRE-CAST CONCRETE
- STEELWORK
- PASSIVE FIRE PROTECTION

Tunnel Boring Machines



Double-Shield TBM

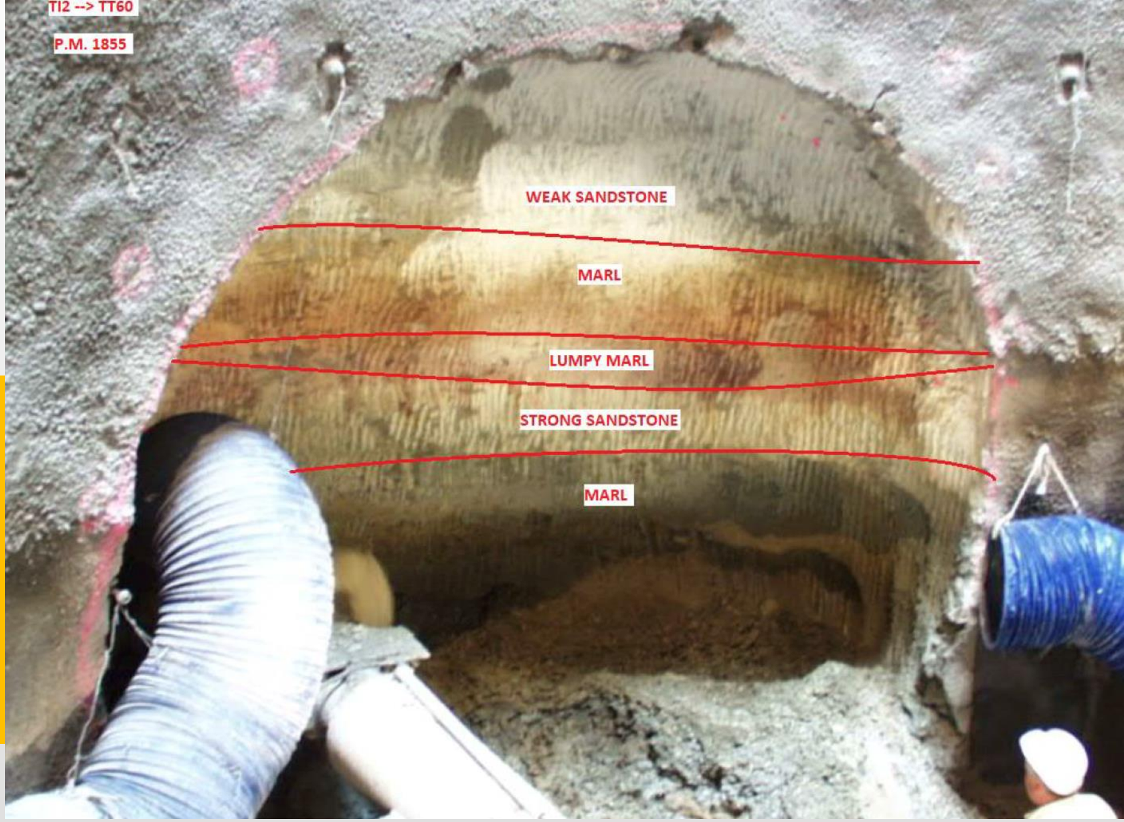


Mixshield TBM

CERN CNGS tunnel : Gripper machine in Molasse

In the conceptual design, ‘double shield’ TBM’s have been proposed for FCC, except for in Moraines under the lake (Slurry/Mixshield TBM) (For LEP and LHC works ‘Gripper’ and ‘Double shield’ TBM’s were deployed)

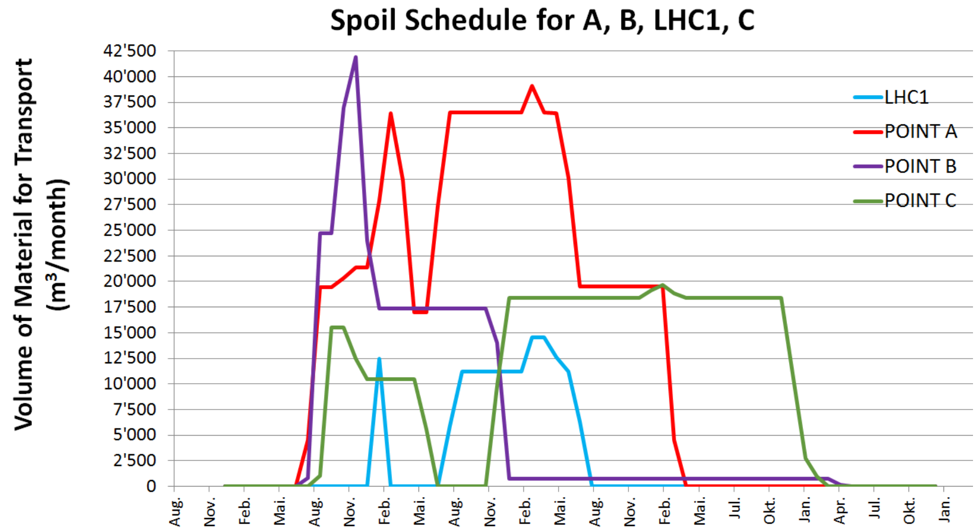
Typical 'Molasse' tunnel/cavern cross section from LHC construction. Individual units typically vary in thickness between approximately 0.1m and 3.0m.



Spoil from TBM's will be a mixture of Marls, Sandstones etc. which makes 'filtering' for re-use challenging

Planning – Spoil Disposal

Extraction Site	Volume (m³)			
	Soft Ground	Limestone	Molasse	Total
Shaft at LHC1	11,031	0	133,735	144,765
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
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**

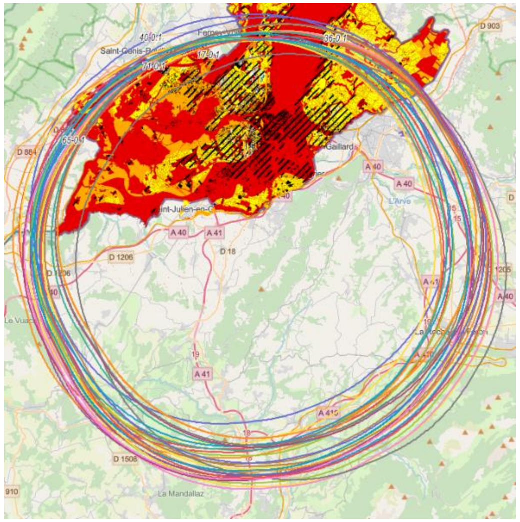


Production of up to 42,000m³ per month
9million cubic meters to dispose

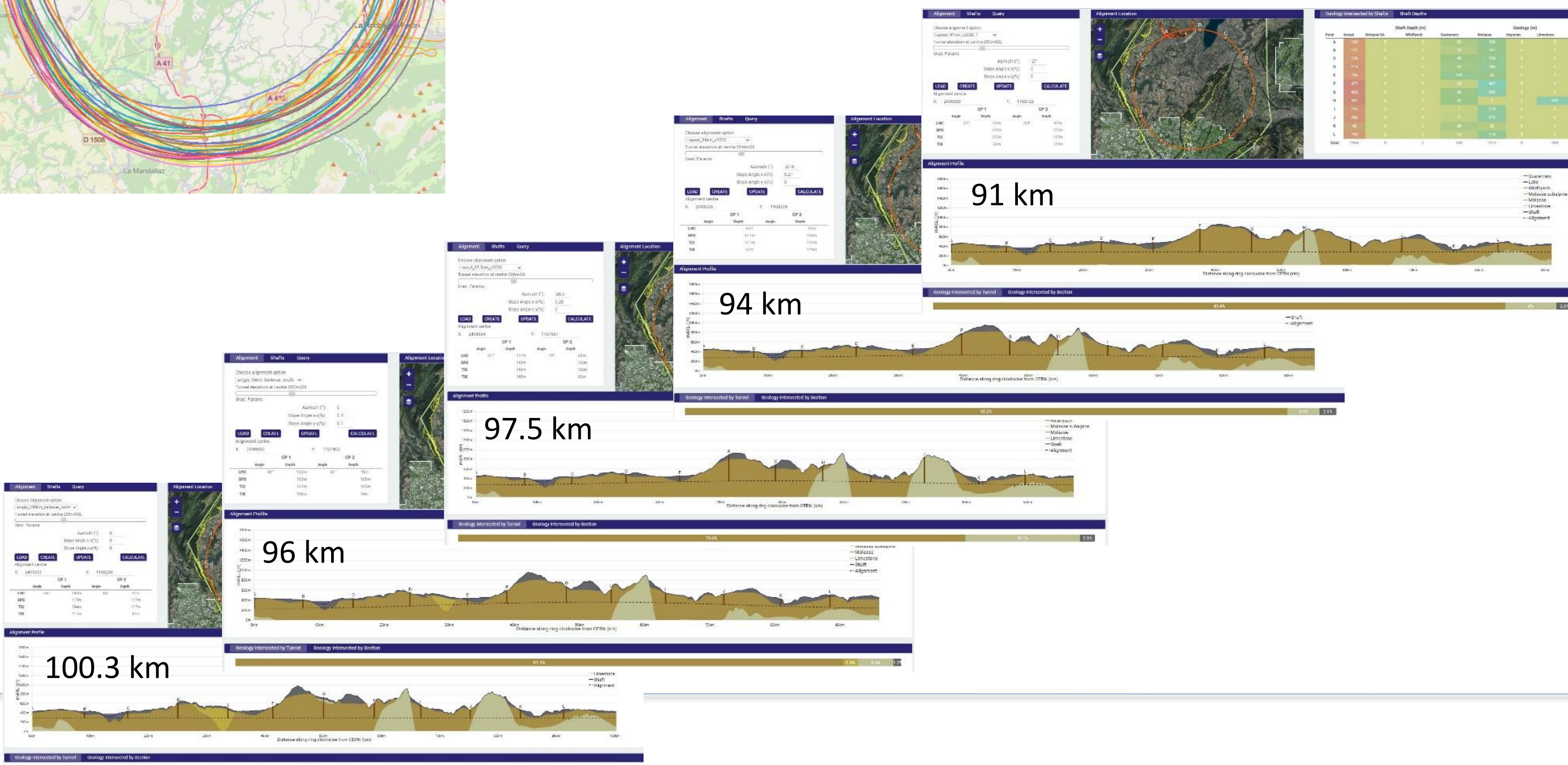
A competition "mining the future" will soon be published (15th April).

FCC CE study progress

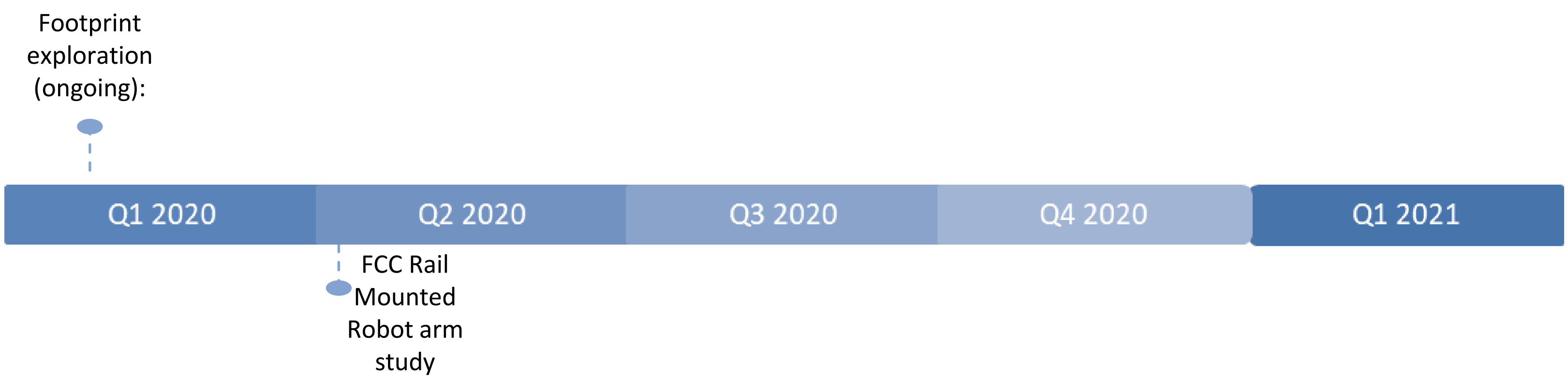
FCC Footprint Exploration



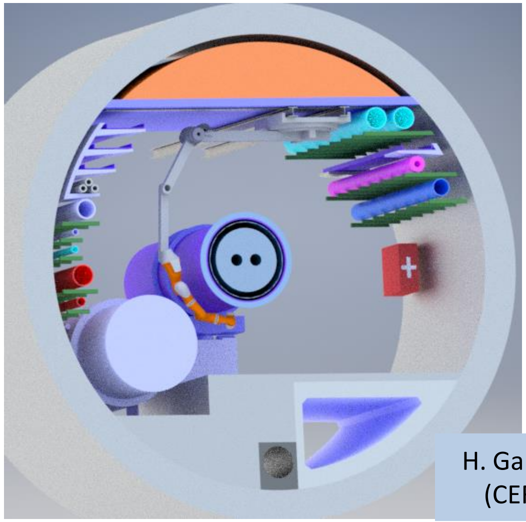
- Surface sites placement optimization – administrative and legal requirements from the host states
- **Input from civil engineering is essential to evaluate the feasibility of tunnel alignments and caverns and shaft locations**
- Currently still using TOT, though exploring additional software options
- The main focus is to identify max. 3 **preferred scenarios** by the end of Q1 2021 and one feasible scenario before starting tendering for SI

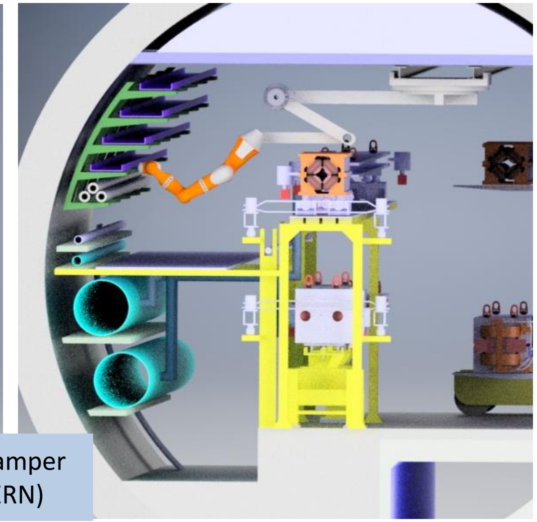


FCC CE study progress



FCC Rail mounted robot
Deformation and Stress analysis



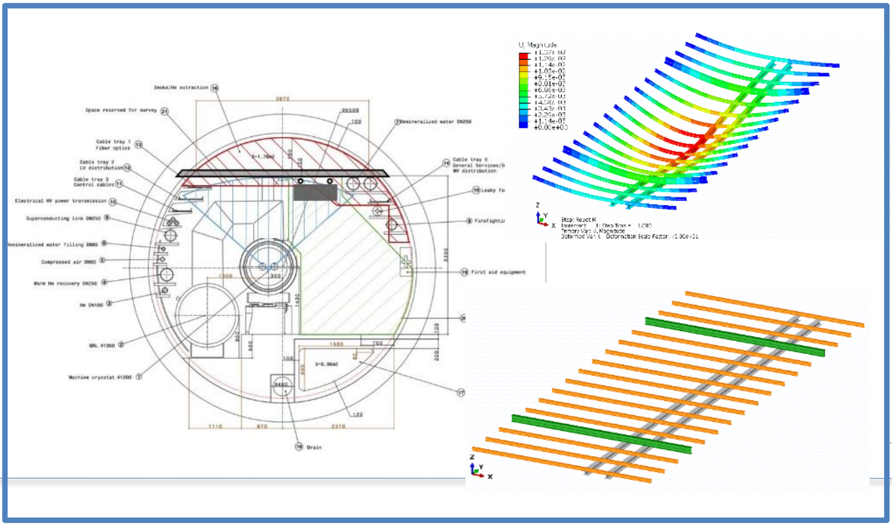


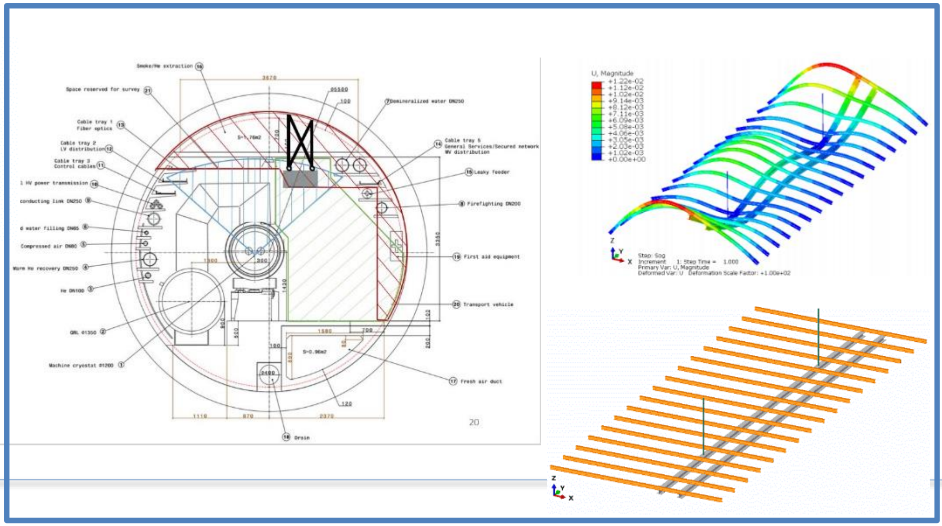
H. Gamper (CERN)

Proposed tasks for the robot:

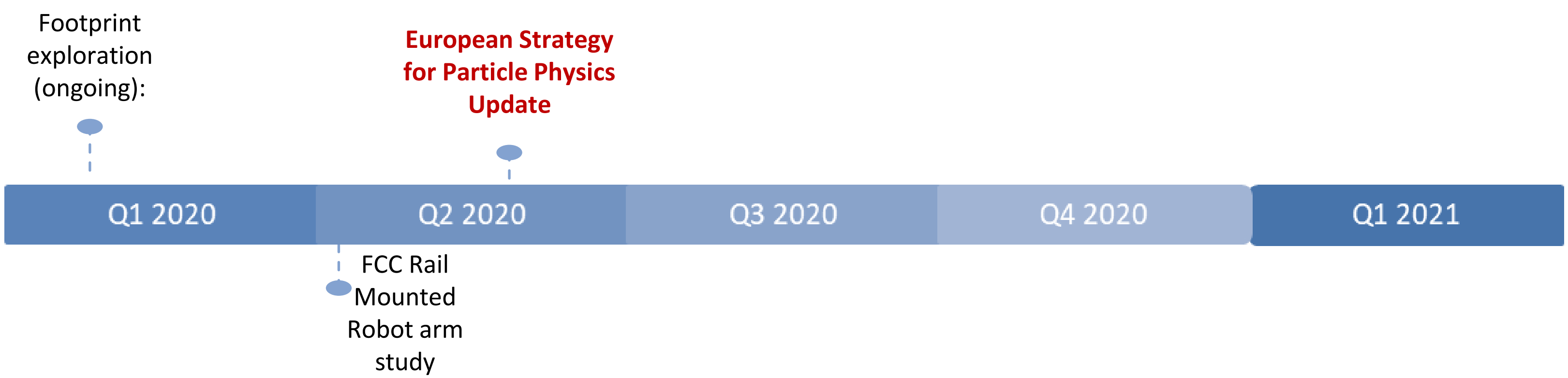
- Tunnel inspections
- Carrying tools/materials
- Preventive maintenance
- Performs repair work and reach areas which are difficult to be accessed by people
- Hazard detection (e.g. Measure radiation, oxygen levels, smoke, Helium leaks)
- Fire-fighting intervention
- Tests Sensors
- Alignment measurements
- Disconnects broken devices of the collimator

- Different layout options for the robot have been studied taking into account the allowable space and load increase.
- Civil engineering ILF study: Deformation and stress analysis of the tunnel ceiling / ventilation duct.





FCC CE study progress



European Strategy objectives for civil engineering

ESPPU 2020

More comprehensive feasibility study to be delivered end 2025 as **input for ESPP Update expected for 2026/2027**:

- ***Feasibility study of the 100 km tunnel***
- ***High-risk areas site investigations****, to confirm principle feasibility -* ***10-15MCHF approved***

Additionally, a CDR+ will be prepared as an input into the next ESPPU.

To achieve these objectives, the CERN civil engineering team are launching a site investigation campaign for High-Risk Areas for FCC.

High Risk Areas include:

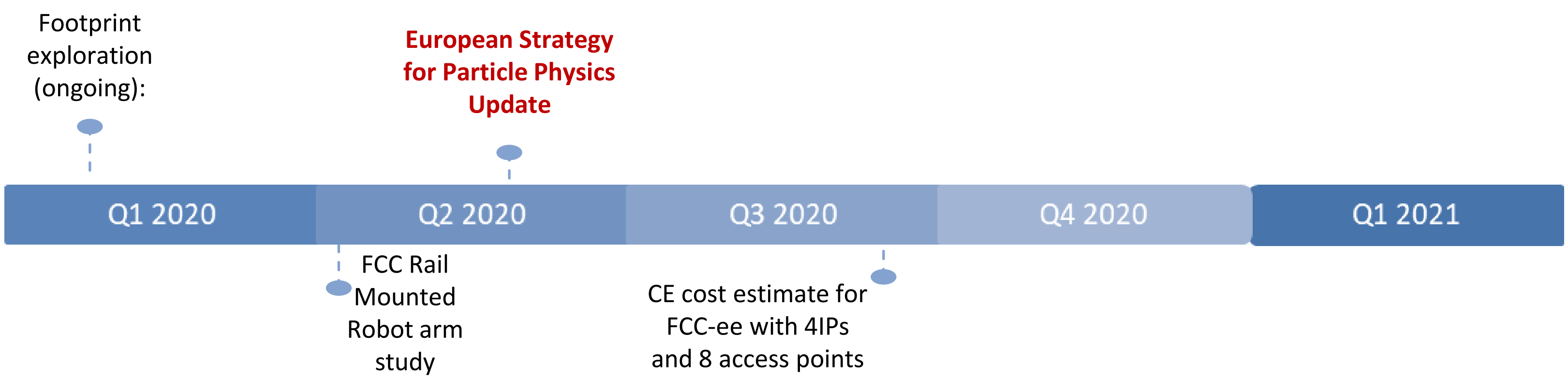
- *Areas along the FCC tunnel alignment where there is high uncertainty in the geological boundary layers and ground conditions, critical to determine the vertical and the horizontal alignment of the FCC tunnel.*
- *Areas to avoid where the complexity of the ground and hydrogeological conditions would dramatically increase the costs/risks during construction works and/or maintenance*
- *Shafts locations situated in the vicinity of aquifers and where construction works could impact the environmentally sensitive areas*

ILF/GADZ will deliver a preliminary study to identify these High-Risk Areas, propose necessary SI as well as providing a cost and schedule for the SI works.

Additionally, ILF/GADZ will provide input into the technical specifications to define the scope of services for "the JV" (CE experts, geotechnical engineers, geologists) for the HRASI.

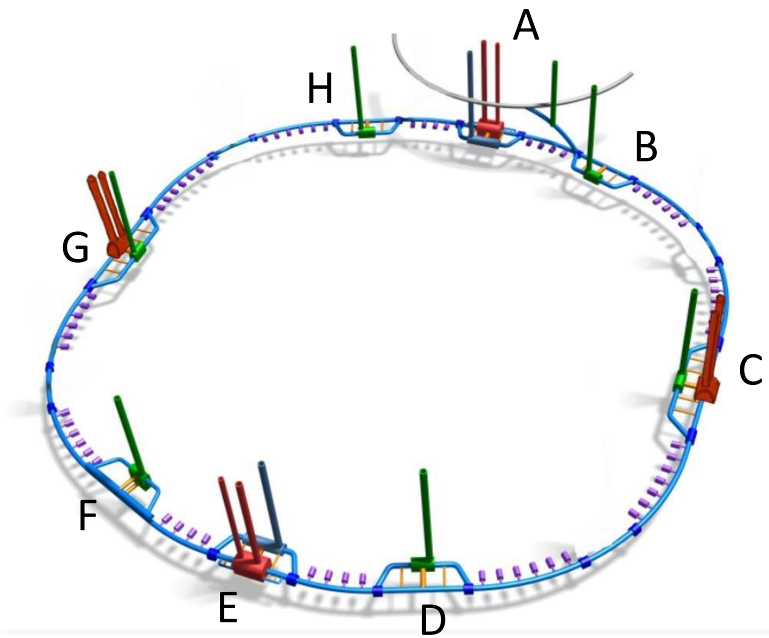
University of Geneva to develop a 3D subsurface model and a GIS database for FCC studies.

FCC CE study progress



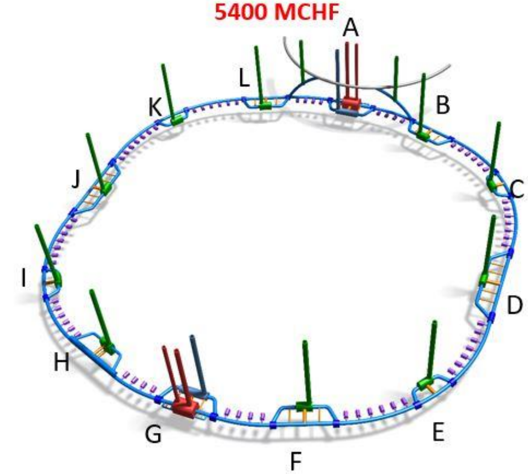
CE Cost estimate for FCC-ee with 8 access points and 4 IPs

5800 MCHF

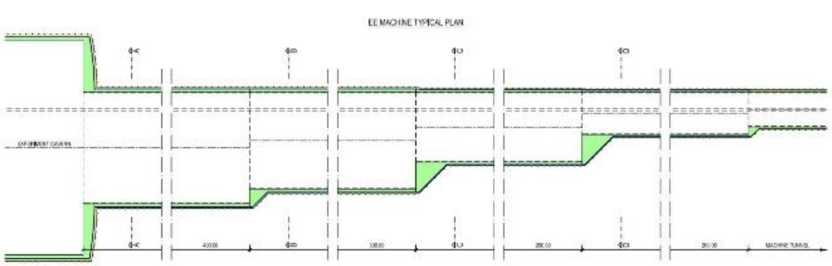


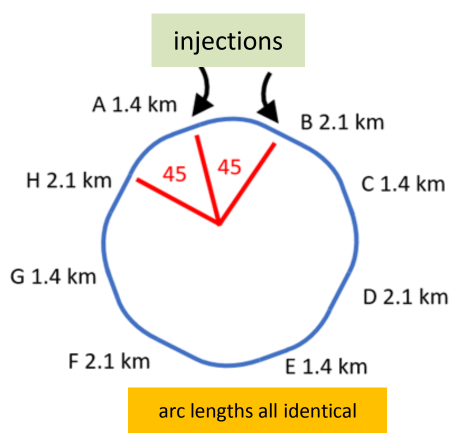
Higher cost for CE than the FCC-ee CDR baseline due to the tunnel enlargements at each experimental point and additional shafts and caverns for the experiments.

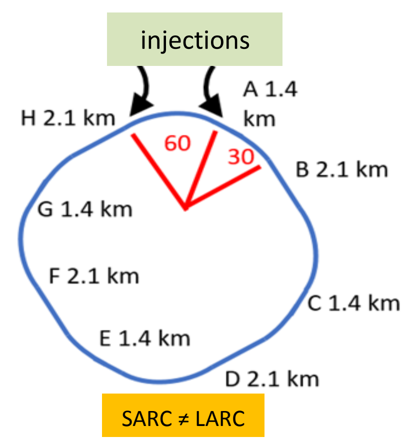
CDR baseline FCC-ee
5400 MCHF



FCC-ee 6m ID (8 points, 4IPs (PA+PE, PC+PG), with tunnel enlargements)



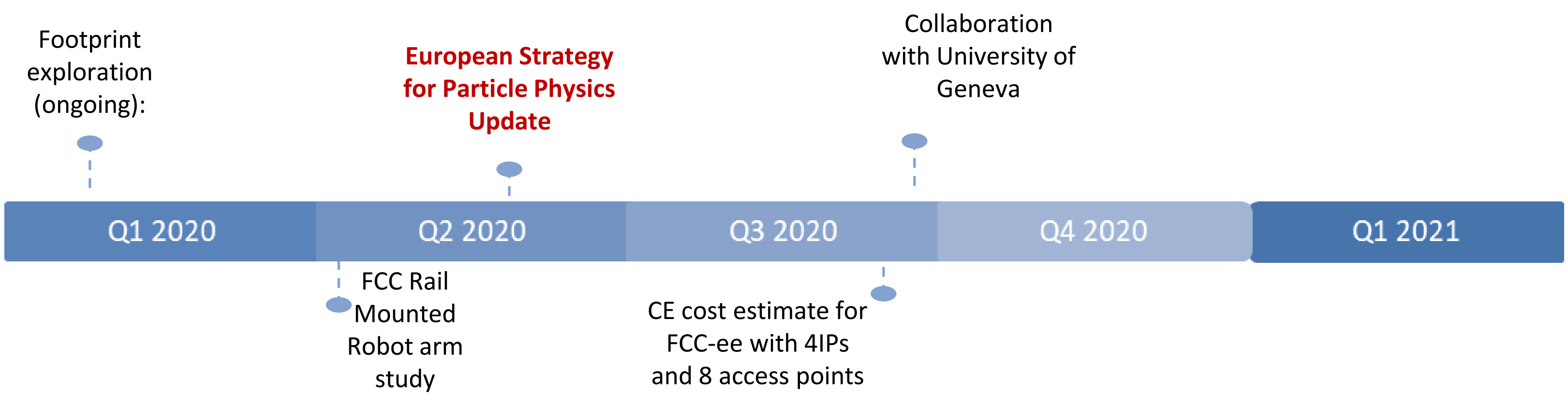




V. Mertens (CERN)

Largest distance between two points: approx. **12km** for 45˚-45˚ option and approx. **16km** for 30˚-60˚ option

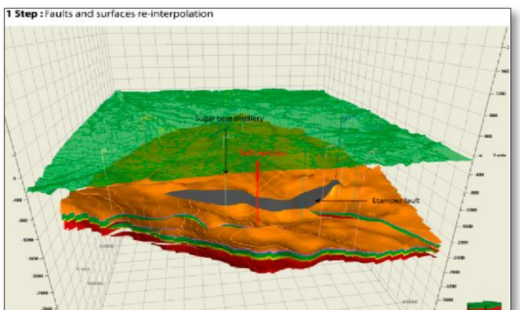
FCC CE study progress



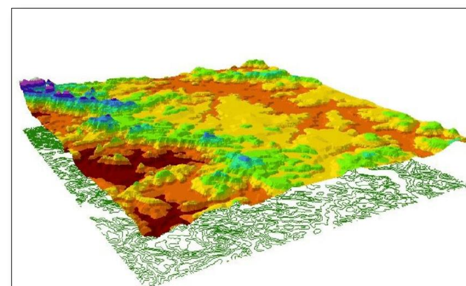
University of Geneva Collaboration (UNIGE)

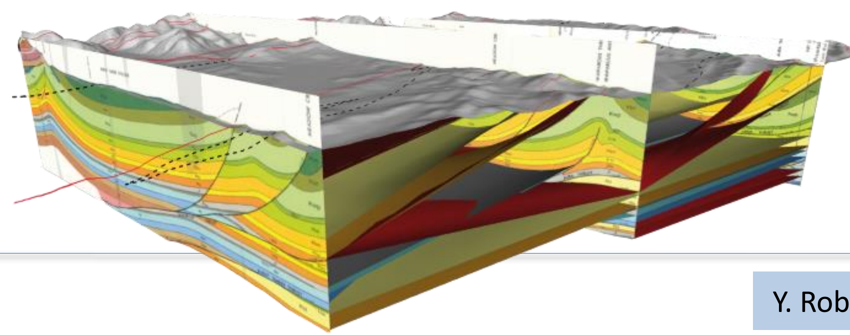
- UNIGE and CERN to act as research/scientific partners, whereby UNIGE's expertise and knowledge will be used to assist CERN on FCC technical matters w.r.t. geology and hydrogeology
- Establish a database (ArcGIS) in support of the feasibility and execution of FCC CE works (geological data from France and Switzerland, faults, hydrogeology etc)
- Develop a consistent 3D geological model which will be continuously updated with new emerging data

Petrel



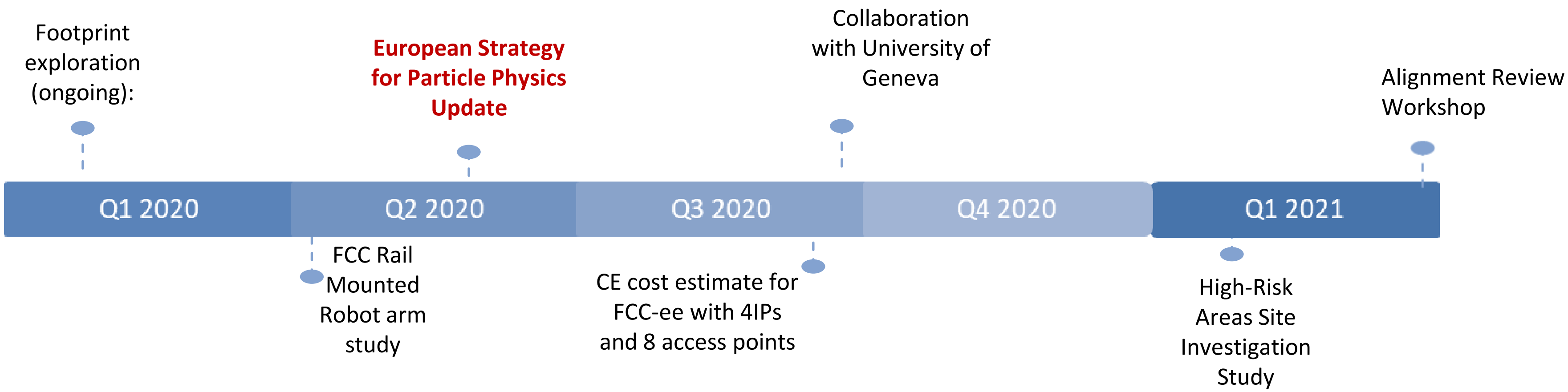
ArcgisPro





Y. Robert (CERN)

FCC CE study progress



High-Risk Areas Site Investigations

ILF/GADZ High Risk Areas SI preliminary study (November 2020 – June 2021)

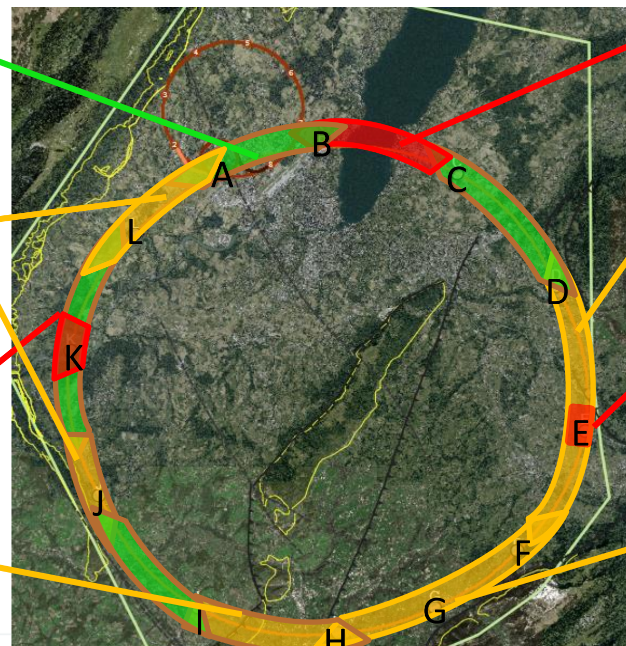
- Input into footprint exploration – Civil Engineering Risks Assessment of the preferred scenarios
- Definition of 'high risk areas' for the preferred scenario(s)
- Propose site investigations in the HRA to reduce the uncertainty of the geological condition
- Cost estimates and schedule of the SI in the HRA
- Procurement strategy for HRA SI and Main SI
- Technical Specifications for the JV and cost estimate and schedule of the JV deliverables

- Information near to CERN is strong due to previous experience on LEP/LHC.
- Multiple deep boreholes in the area.

- Alignment close to limestone rockhead
- The exact location and angle of the limestone/molasse interface undefined.

- Moraine/molasse interface not certain, cavern close to interface.
- Proximity to protected area

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

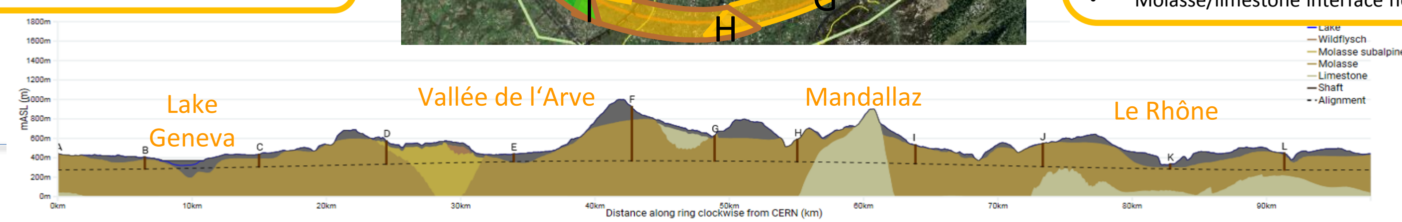


- Some seismic and borehole information for lake crossing from proposed road tunnel, but layered nature of lake bed leads to uncertainty.
- Reliable borehole data missing.

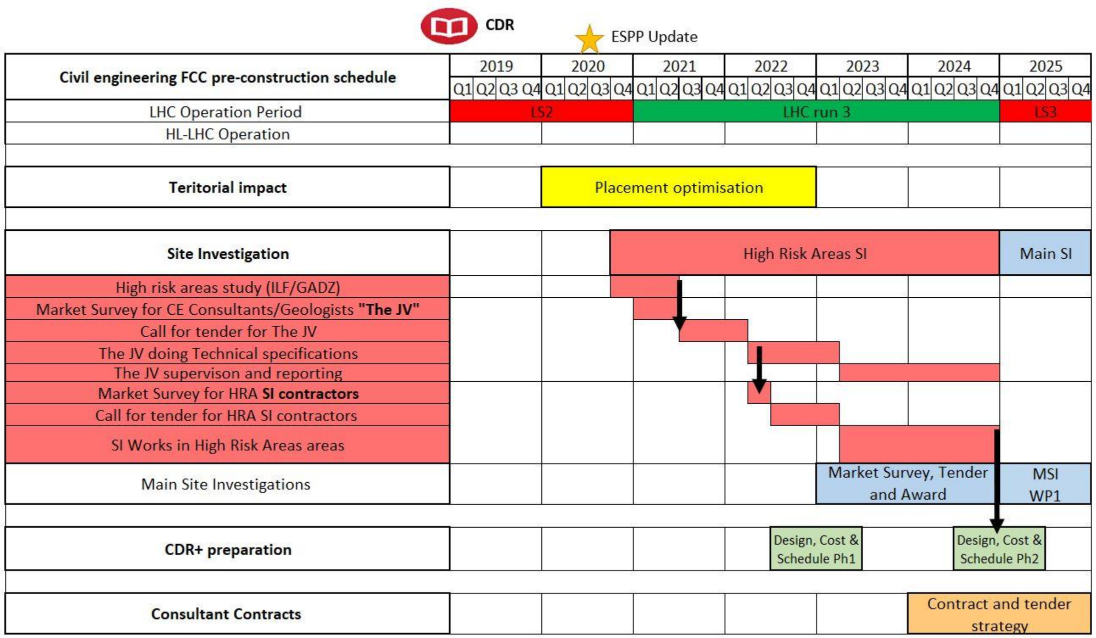
- Location of the interface between molasse and molasse subalpine not certain, tunnel alignment in proximity.

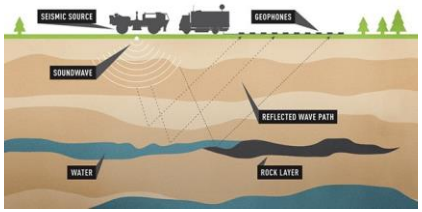
- Moraine/molasse interface not certain, cavern close to interface.
- Lack of deep boreholes in area.

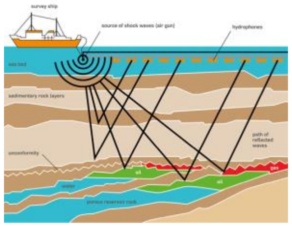
- No deep borehole information available in the area.
- Complex faulted region.
- Quality of molasse is uncertain. Large span experimental caverns should be constructed in good molasse.
- Molasse/limestone interface not certain.



CE Pre-construction schedule







Geophysical Survey

Exploration Drillings

Market Survey/Tender for a joint venture consortium ("The JV") between a general consultant/ geotechnical/ geologist experts will have a mandate to :

- prepare the very detailed technical specifications and tender documents to procure contractors to do all site investigations
- Supervise the works on site
- produce factual and interpretive reports further to the testing
- given the results of the site investigations, provide reports on the suitability of the geology for the siting of the machine/caverns and plan the main site investigations

Next steps for FCC civil engineering

- Site Investigation in ‘High Risk Areas’
- Market Survey for SI consultants will be issued in April 2021.
- On-site investigation works in 2023/24
- At the same time tunnel alignment optimisation is on-going looking both at situation on surface and underground
- Construction strategy/methods will be adapted to take account of any alignment changes and any new geological data