Infrastructure News for CERN's FCC and CLIC studies

John Osborne CERN

31 October 2019 – Sendai, Japan

CERN

FCC CE study progress

Cost and schedule estimate compatible with the CDR baseline for all 3 machines: FCC-hh, FCC-ee and FCC-eh

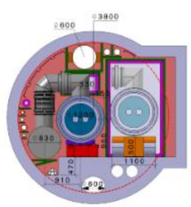
Refinement of results (fire compartments, caverns spacing)

Additional ILF studies (cash flow, spoil volume per site, HL-LHC cost comparison)

HE-LHC

Requirements gathered from cryogenics, electrics and HVAC, which determined the modifications needed for HE-LHC for civil engineering

Cost estimate produced



Spoil Management

Study of the molasses re-use (approx. 9 million cubic meters of spoil)

Samples tested from HL-LHC sites

Optimisation of tunnel alignment

Tunnel layout optimisation based on geology, shafts depth, construction risks and surface sites

Potential surface areas identified following first review with host states

Ongoing work:

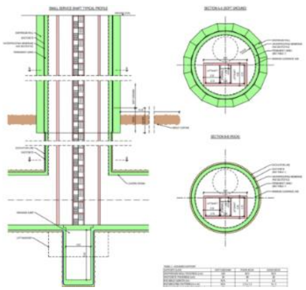
- Surface site investigation
- Site investigation planning
- Spoil management study
- Transfer line design

May 2018 → Aug. 2018 → Sep. 2018 → Dec. 2018 → Jan.- June 2019 → Ongoing

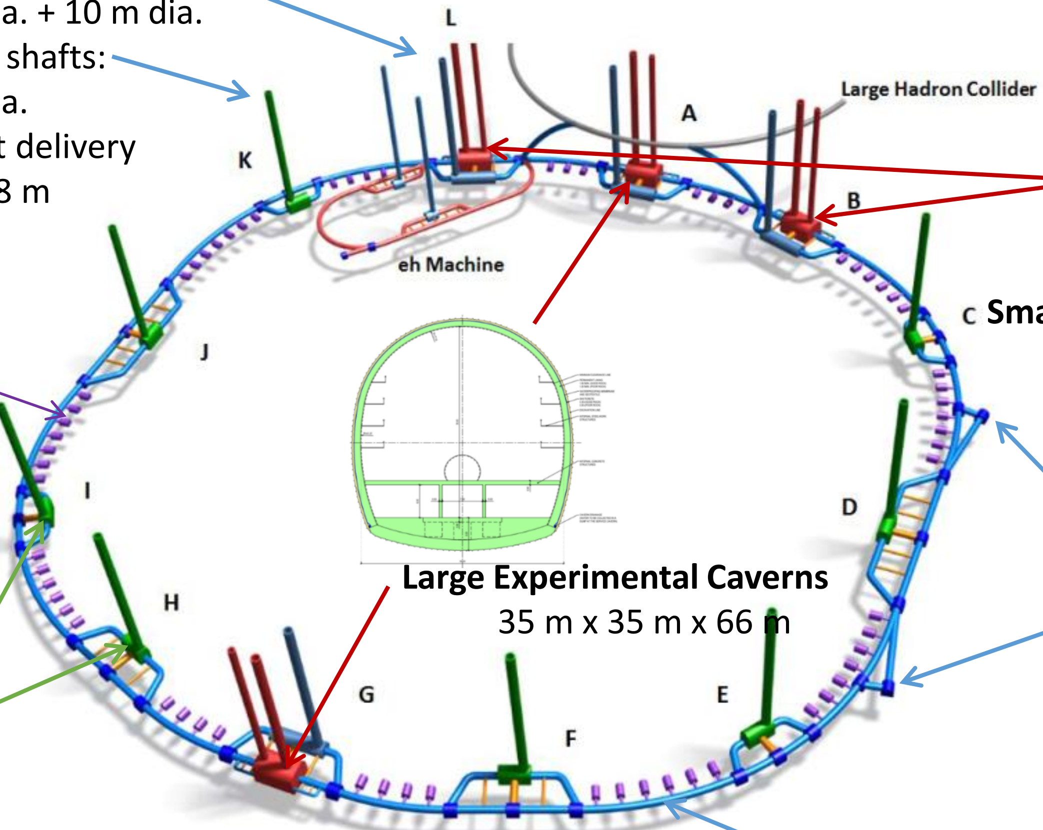
CDR volumes submitted to European Strategy for Particle Physics Update

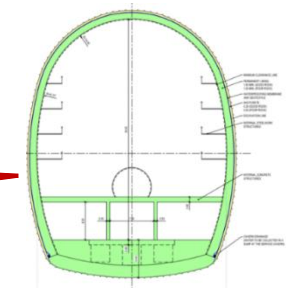
FCC civil engineering overview

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

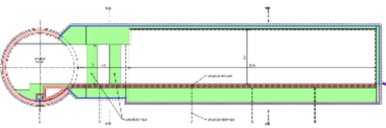


Shafts:
Experimental Shafts:
15 m dia. + 10 m dia.
Service shafts:
12 m dia.
Magnet delivery shaft:18 m



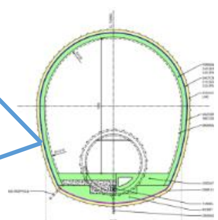


Small Experimental Caverns
30 m x 35 m x 66m

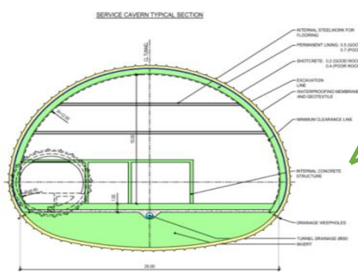


Alcoves
- 25 m x 6 m x 6 m
- Located at 1.5km spacing

Large Experimental Caverns
35 m x 35 m x 66 m



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

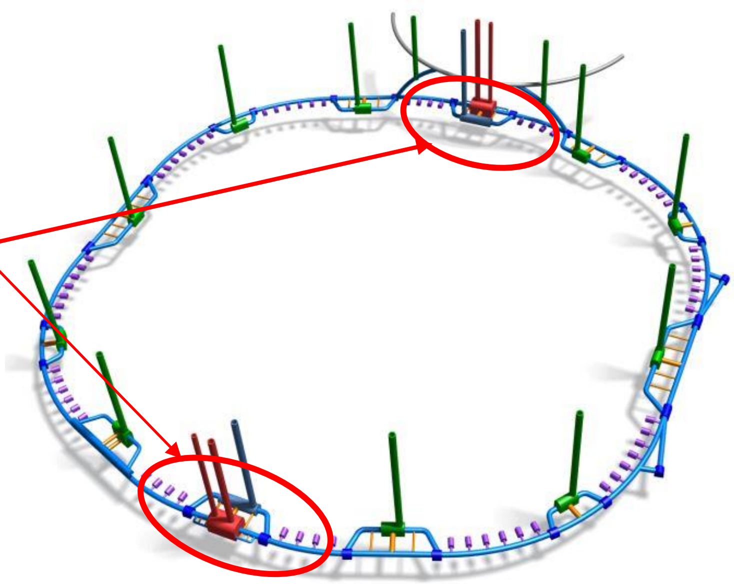


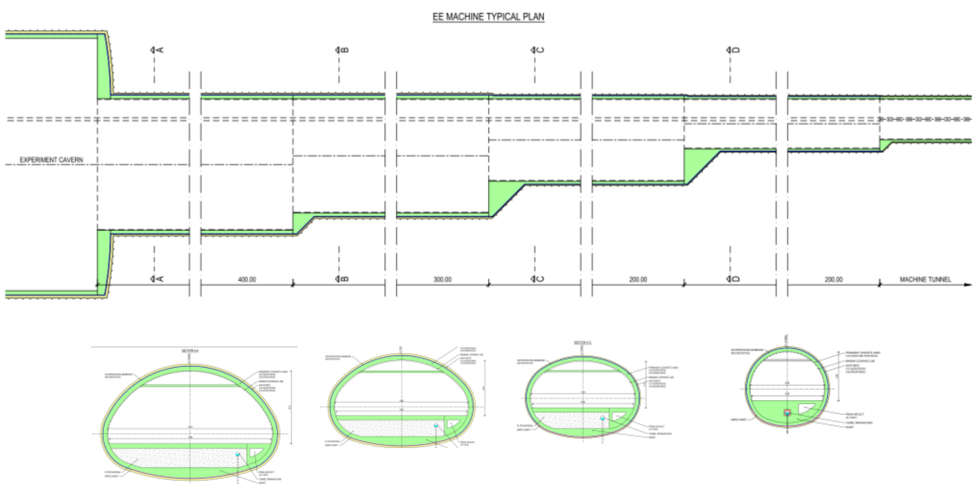
Service Caverns
- 25 m x 15 m x 100 m

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

FCC-ee

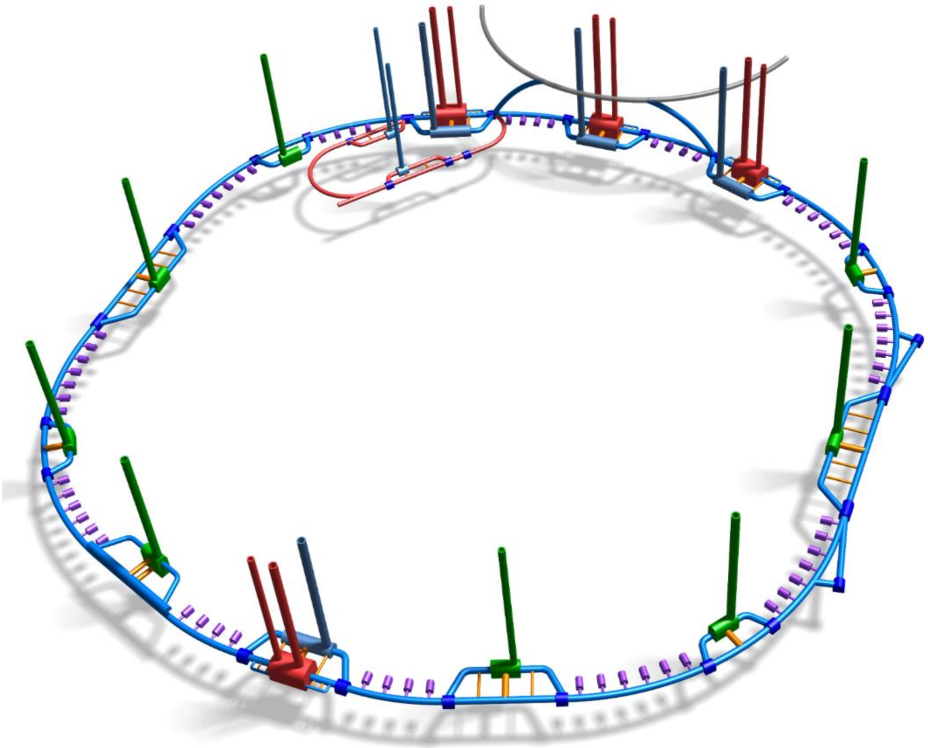
- Would be constructed at the same time as FCC-hh
- Infrastructure must be able to accommodate both machines.
- Enlargements required at experiment points A and G.





FCC-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



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

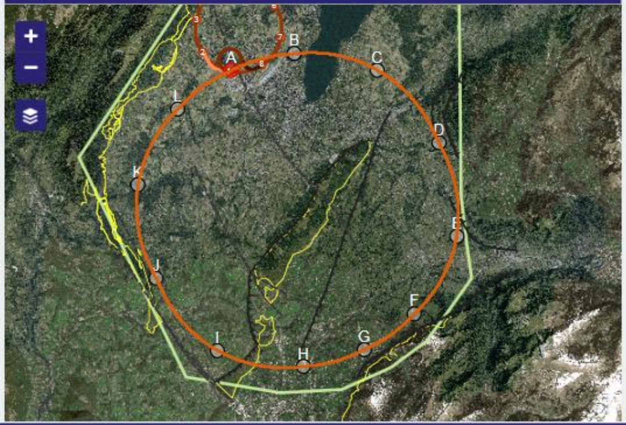
LOAD CREATE UPDATE CALCULATE

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

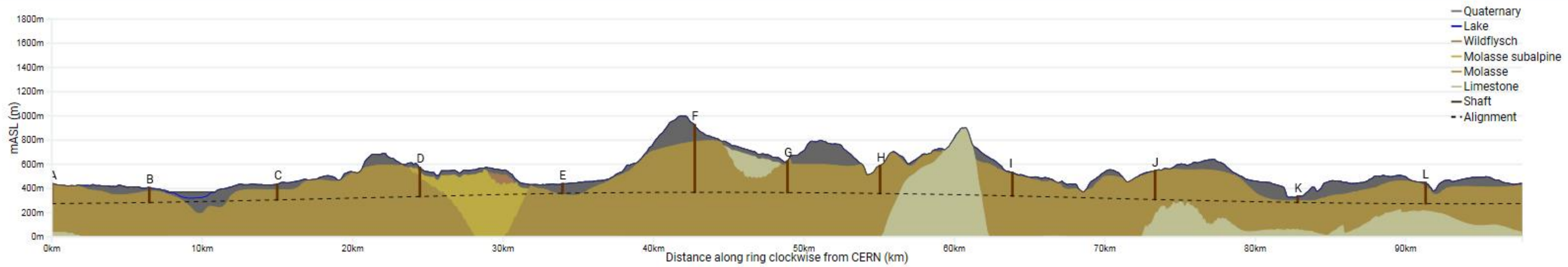
Alignment Location



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

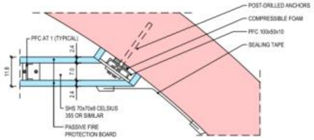
~90 % molasse – suitable ground for tunneling. Only one sector in limestone.

3720 m sum of shaft depths

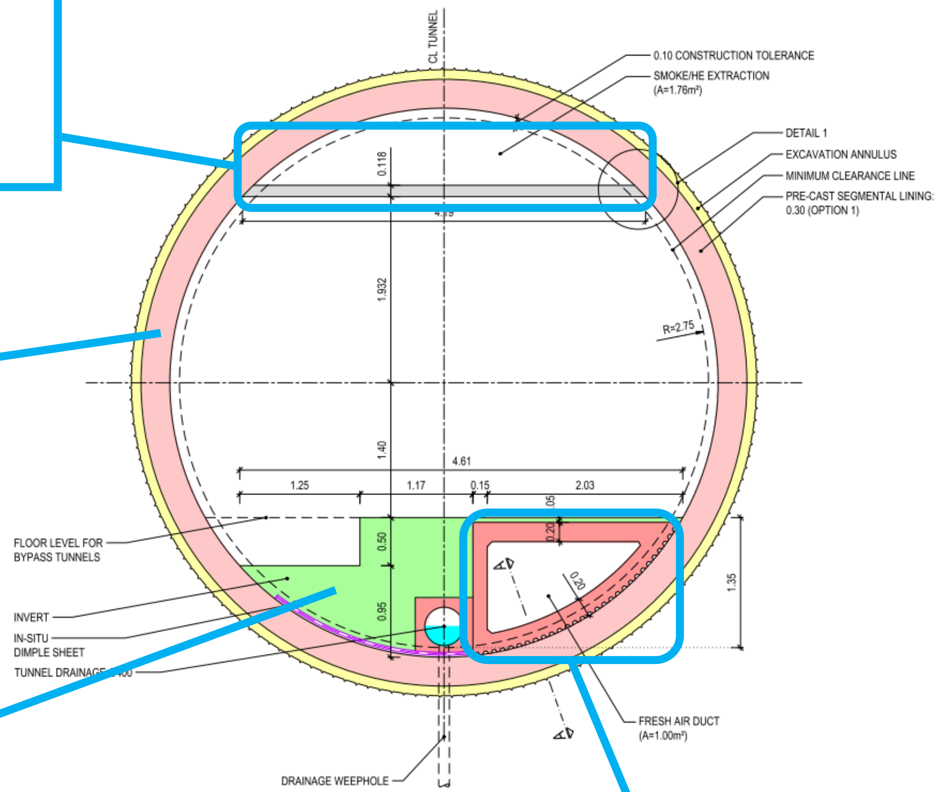
558 m deepest shaft (F): proposed to be replaced with an inclined tunnel

Typical tunnel cross section

Steel structure with passive fire protection. Connection:



5.5m inner diameter

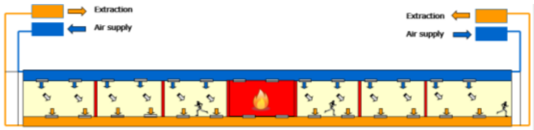


Pre-cast concrete segmental lining

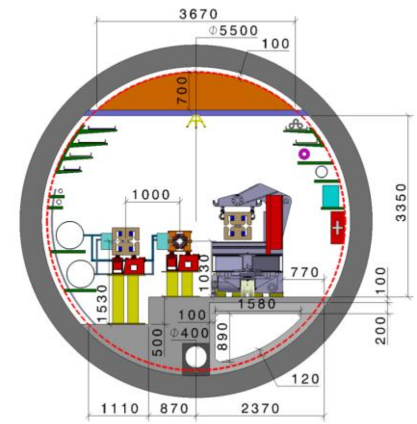
Cast-in-situ concrete invert

Pre-cast concrete element

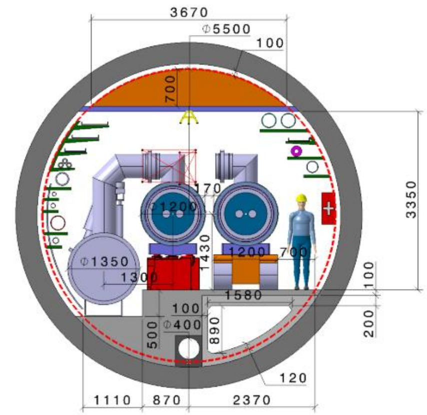
Safety comparments



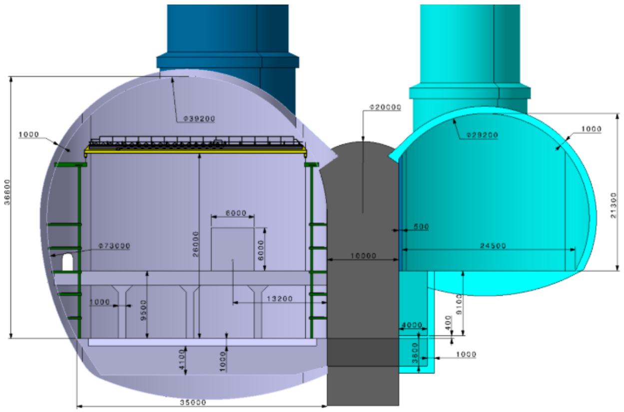
FCC-ee

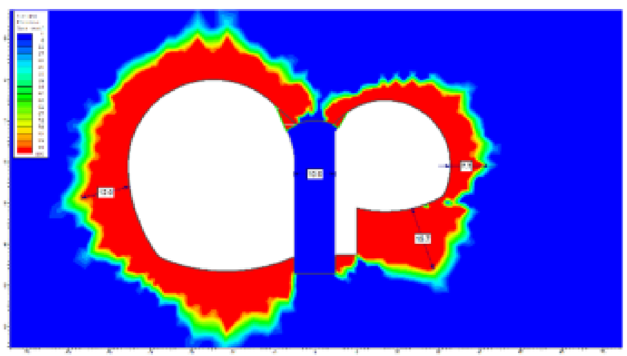


FCC-hh

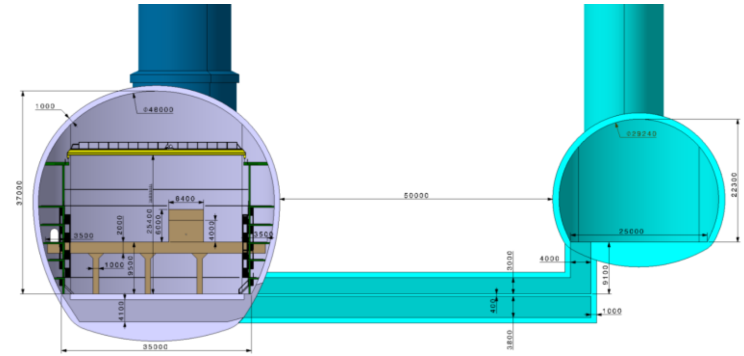


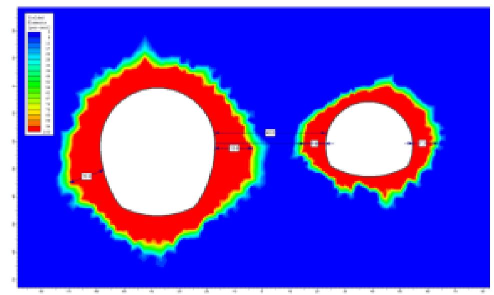
Experimental points cavern layouts





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

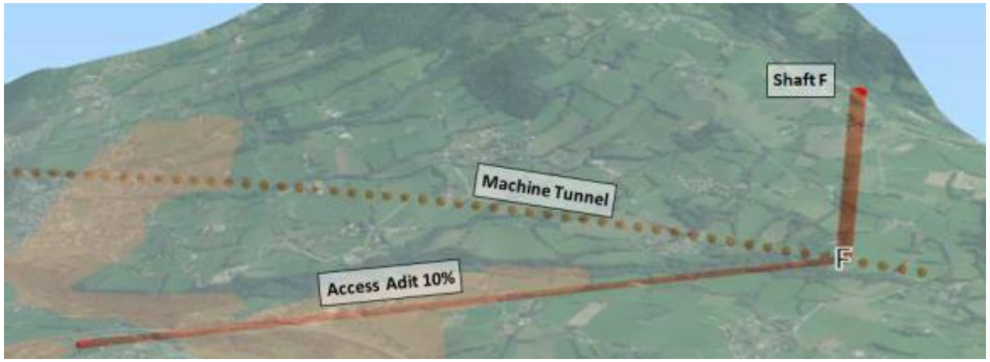




- With 45 m spacing in good molasse, the rock pillar alone is sufficient.
- Cheapest and lowest risk option for CE

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



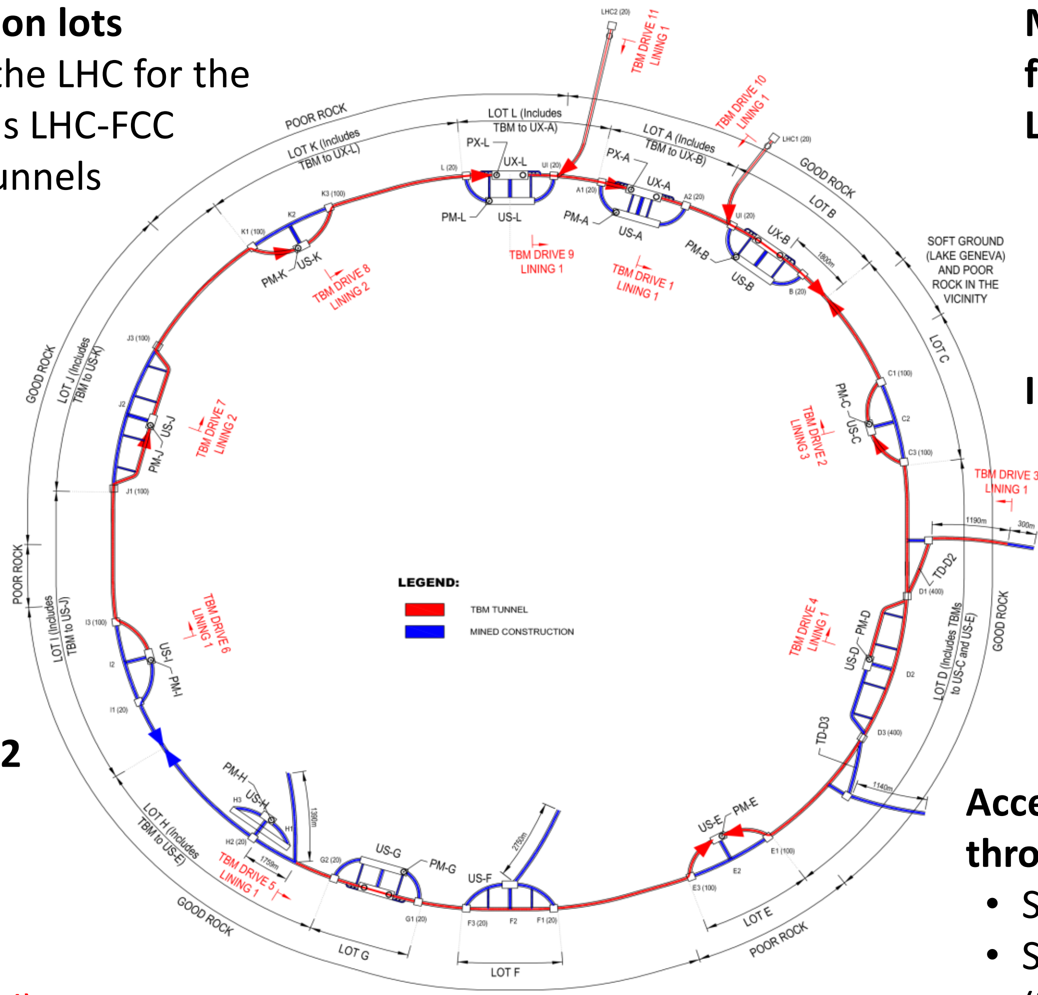
Existing LEP transfer tunnel TI18 15% from SPS to LHC

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

Construction Strategy

Additional construction lots

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



Mixshield TBM used for tunneling under Lake Geneva

Intermediate Access Adits

- Necessary to cope with overall time schedule to meet deadlines for machine installation

Project divided in 12 construction lots

Access to main tunnel works through:

- Shafts at 11 points
- Sloped Access adit at 1 point (instead of 570 m shaft)

Construction techniques:

1) TBM tunnels (red)

2) Mined tunnels (blue)

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

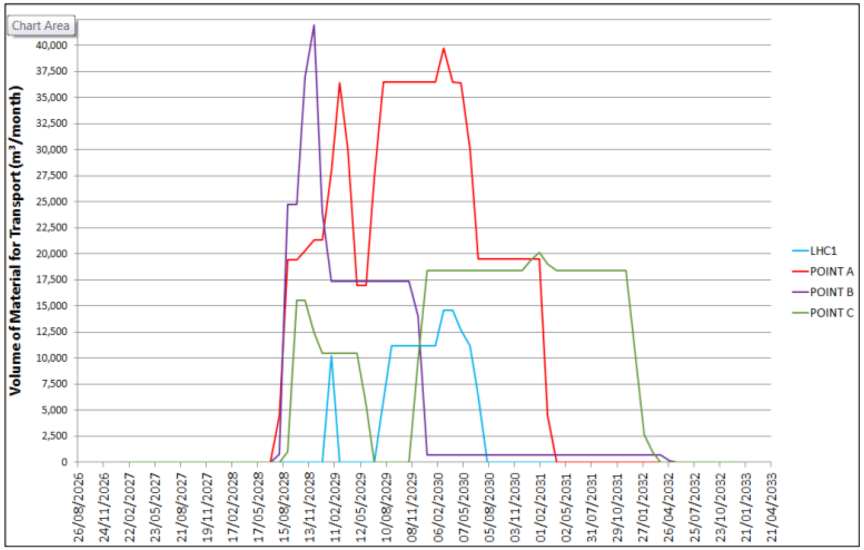
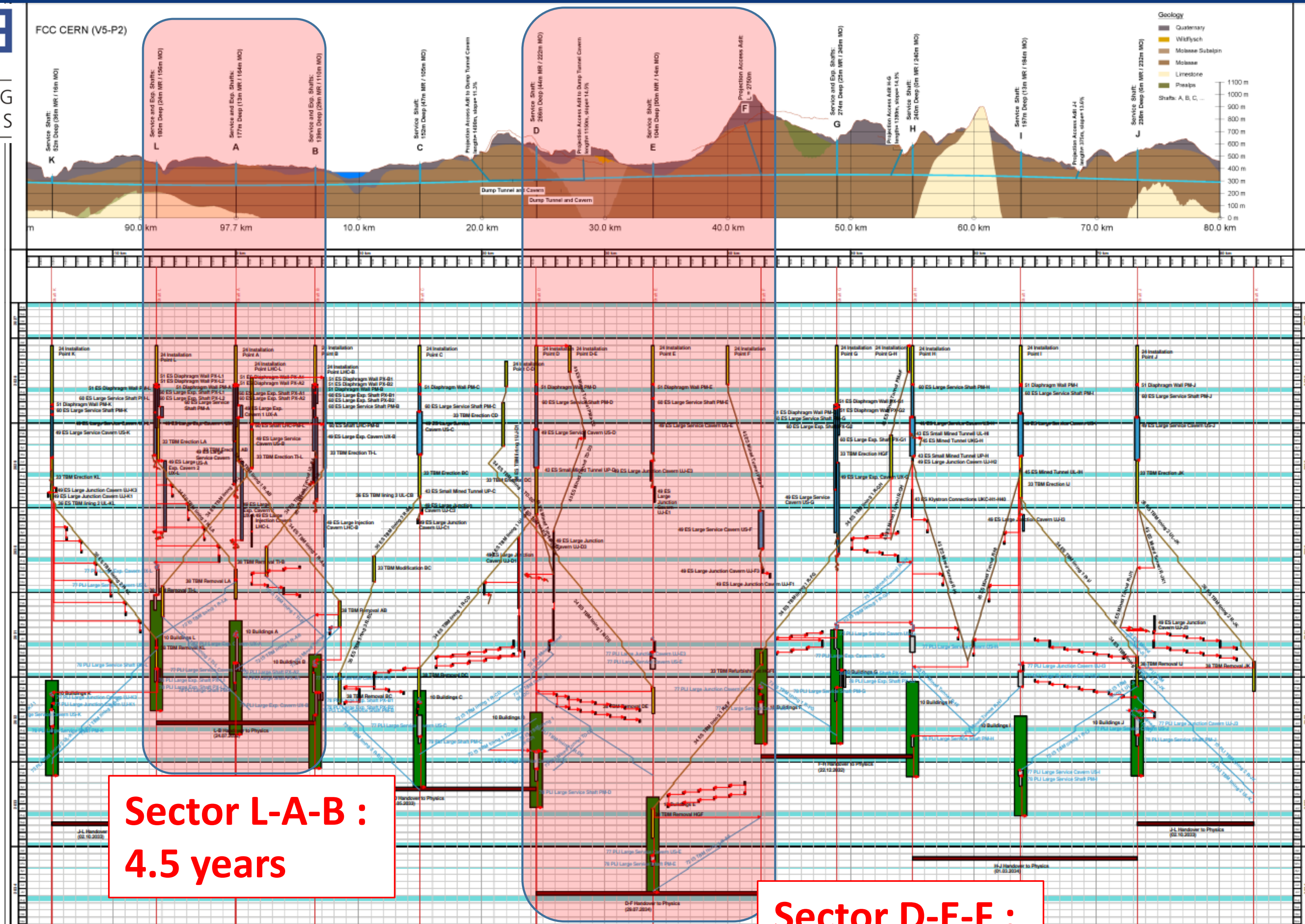


FIGURE 14-1: SPOIL SCHEDULE FOR LHC, A, B AND LHC1

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

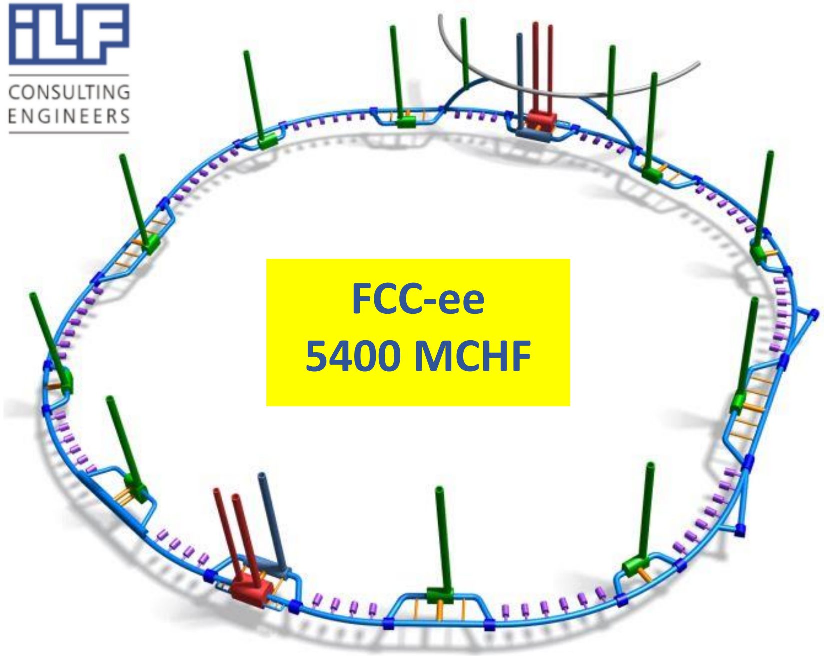
Construction Schedule

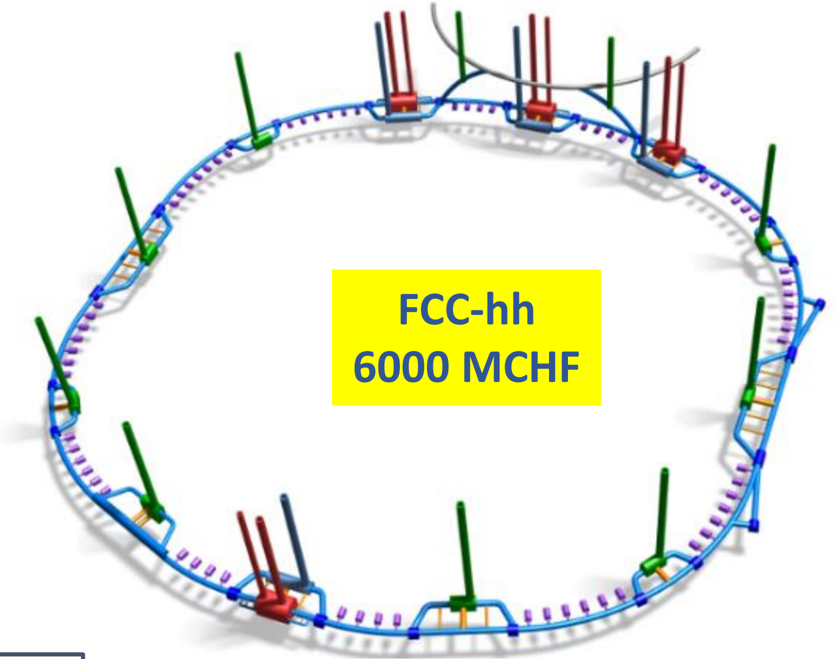


Sector L-A-B : 4.5 years

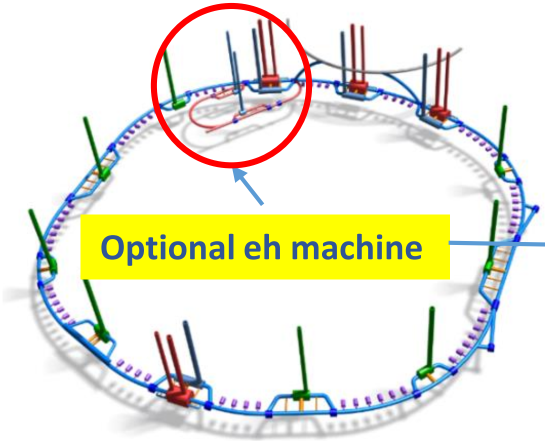
Sector D-E-F : 6.5 years

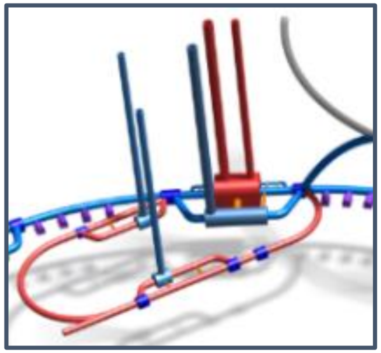
FCC Cost estimates for civil engineering





Two additional experimental points and associated civil infrastructure





FCC-eh underground: 430MCHF

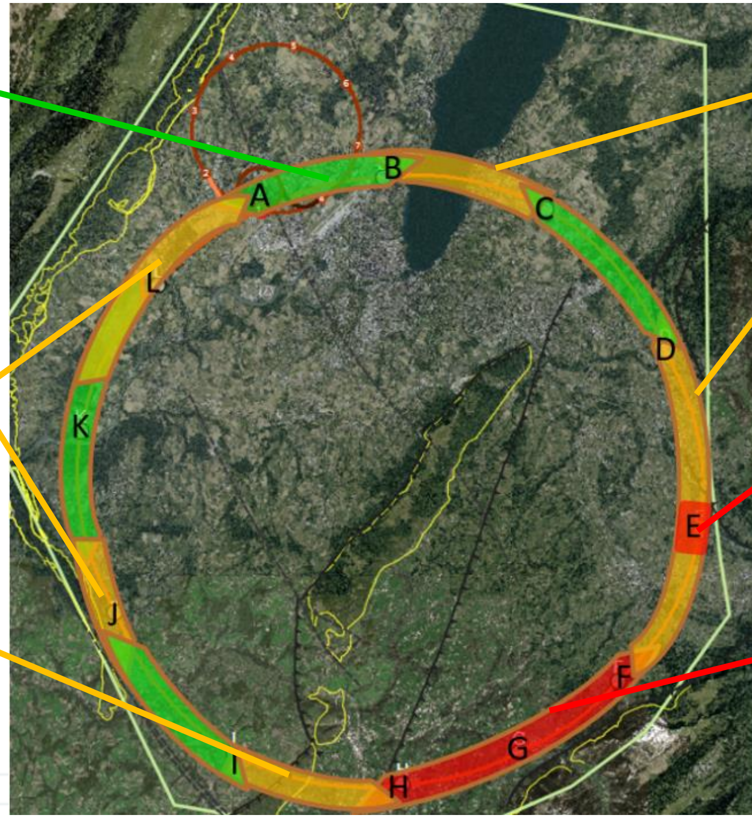
**The expected accuracy range is between -30% and +50% for feasibility stage*

Geological uncertainty

- 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.

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

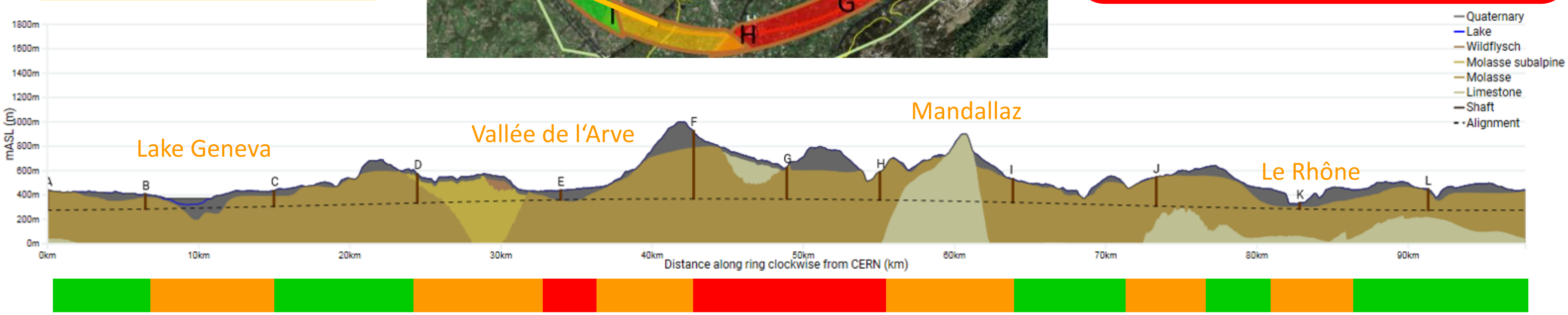


- Location of the interface between molasse and molasse subalpine not certain, tunnel alignment in proximity.

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

- 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 uncertain.



Schedule for preparatory phase

CDR

European Strategy Update 2020

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
LHC operation	LS2		LHC run3			LS3			LHC run4	
CERN feasibility	Alignment optimisation									
Site investigations		Feasibility SI		Phase 1	Phase 2	Phase 3				
Consultant Contracts		Contract and tender strategy		Market Survey	Tender and Award	Preliminary Design	Tender Design		Construction Design	
Construction								Market Survey	Tender and Award	
EIA and permitting documents	EI and permitting documentation									

Start of construction

Site investigations

Feasibility SI (2020-2021)

- Walkover survey
- Geophysical investigation of all the access points, Geneva Lake crossing, Rhone and Arve Valley

Principal SI (2022-2023)

Phase 1 – site investigations required for the development of preliminary design

Phase 2 – confirmation of geological profiles and engineering design parameters

Types of site investigations:

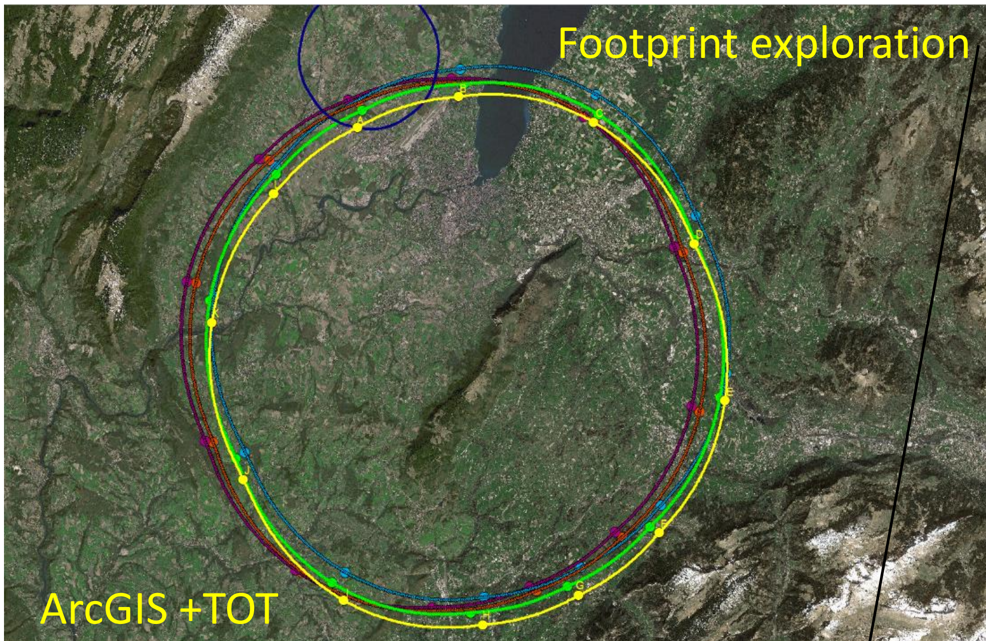
- Boreholes
- Site testing (eg insitu stress test, point load testing, SPT, CPT, permeability tests)
- Rock laboratory testing (eg uniaxial compressive strength, petrographic studies)

Additional SI (2024-2025)

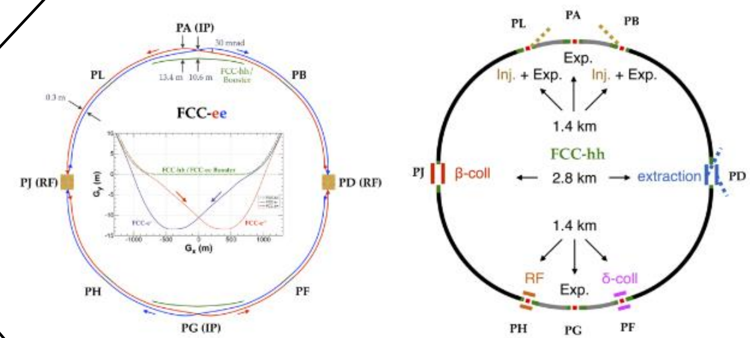
Phase 3 – additional explorations needed in order to obtain a reliable cost estimate

Ongoing work and future steps

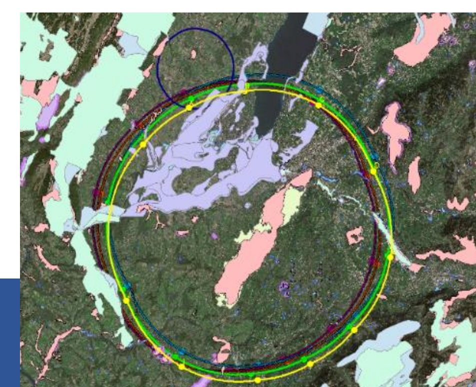
- A further round of alignment optimisation following input from surface site review



- **Machine shape**



- **Access (vertical shafts / inclined tunnels)**
- **Existing infrastructure (eg road networks, buildings) and future developments**
- **Environmental protected areas**



- **Geology and construction risks**

Ongoing work and future steps

- ❑ Continuous desktop study of geology (collaboration with geological survey public institution and engineering consultants)

- ❑ Exploring GIS tools and alignment optimisation software - Workshop with industries at CERN held in October 2019 on tunnel alignment tools and tunnel monitoring :

  https://indico.cern.ch/event/823271/

Long term tunnel monitoring for maintenance should be built into designs for ILC at concept stage

- ❑ Site investigations planning

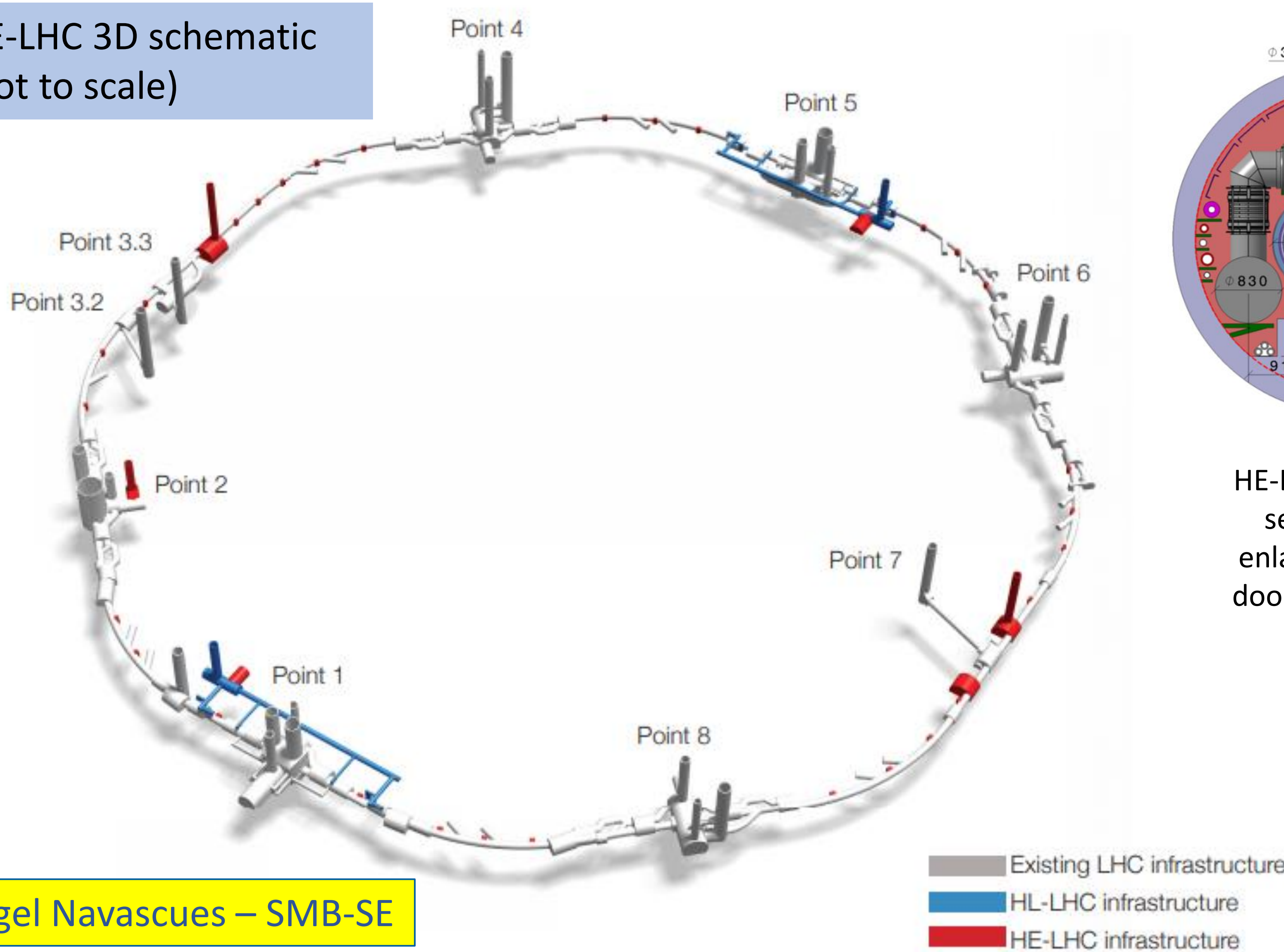
- ❑ Spoil management study

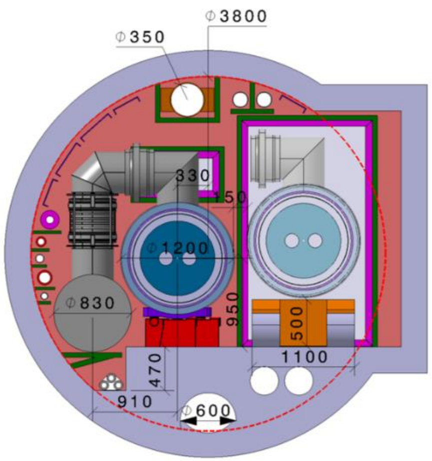
- ❑ Transfer line design

Other Studies

HE-LHC civil engineering developments

HE-LHC 3D schematic (not to scale)





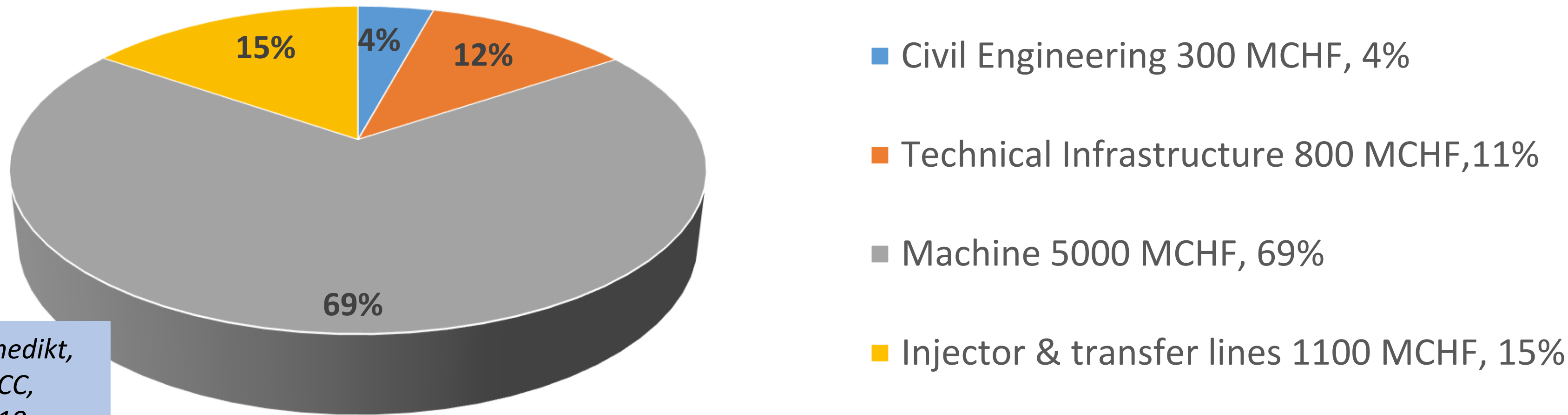
HE-LHC tunnel cross-section showing enlargement for fire door (548 m spacing)

Angel Navascues – SMB-SE

HE-LHC civil engineering developments

Preliminary cost estimate produced for civil engineering: ~300 MCHF

HE-LHC: capital cost per domain



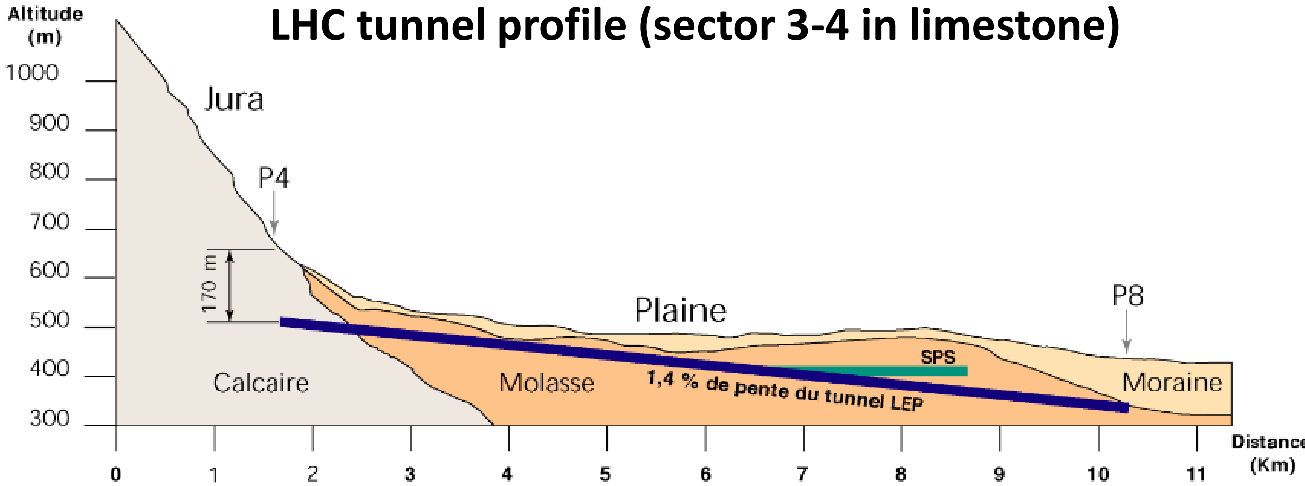
Michael Benedikt,
Physics at FCC,
4 March 2019

For HE-LHC modifications to existing LHC infrastructure are required to house a new accelerator:

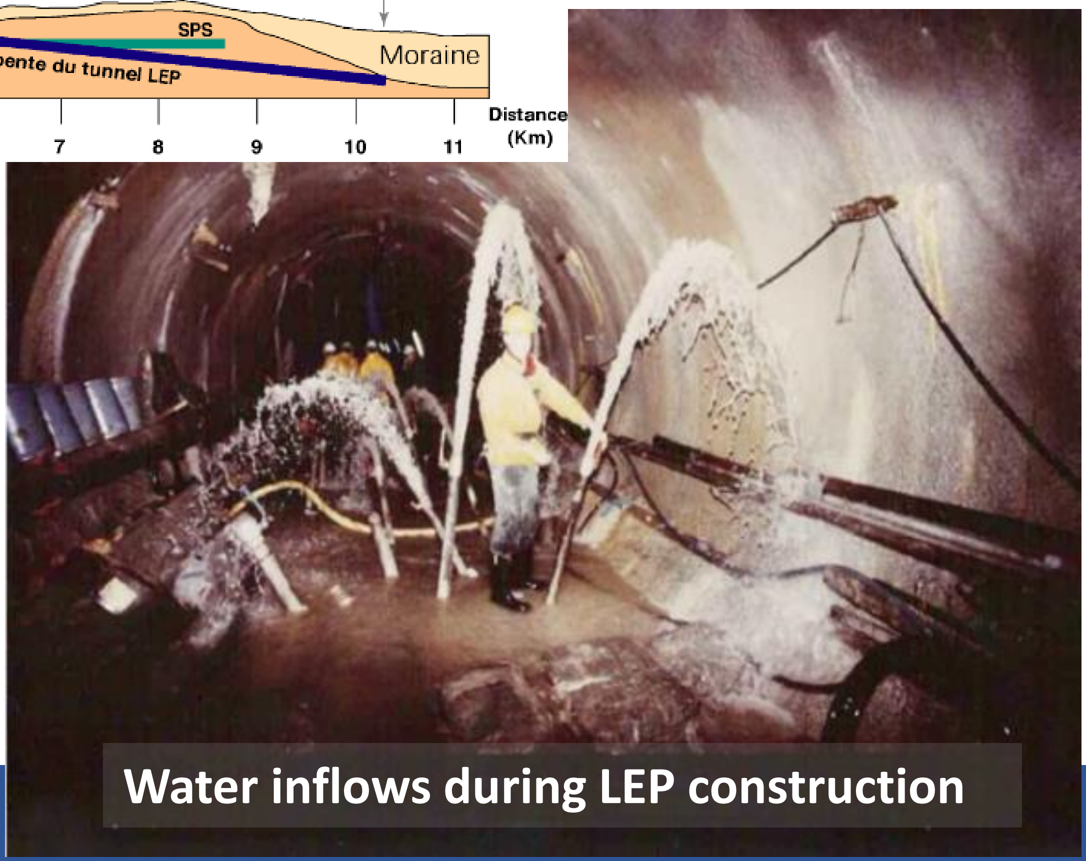
- New cryogenic caverns and electrical alcoves
- New access shafts
- New buildings for cryogenics, electrical and ventilation equipment
- Installation of fire separation walls including extension of the tunnel envelope every 548 m
- Partial refurbishment of LHC Sector 3-4

Sector 3-4 refurbishment

LHC tunnel profile (sector 3-4 in limestone)



1999 'Submarine' proposal – heavy steel lining of 600m section - Rejected because of high costs and reduction of tunnel diameter

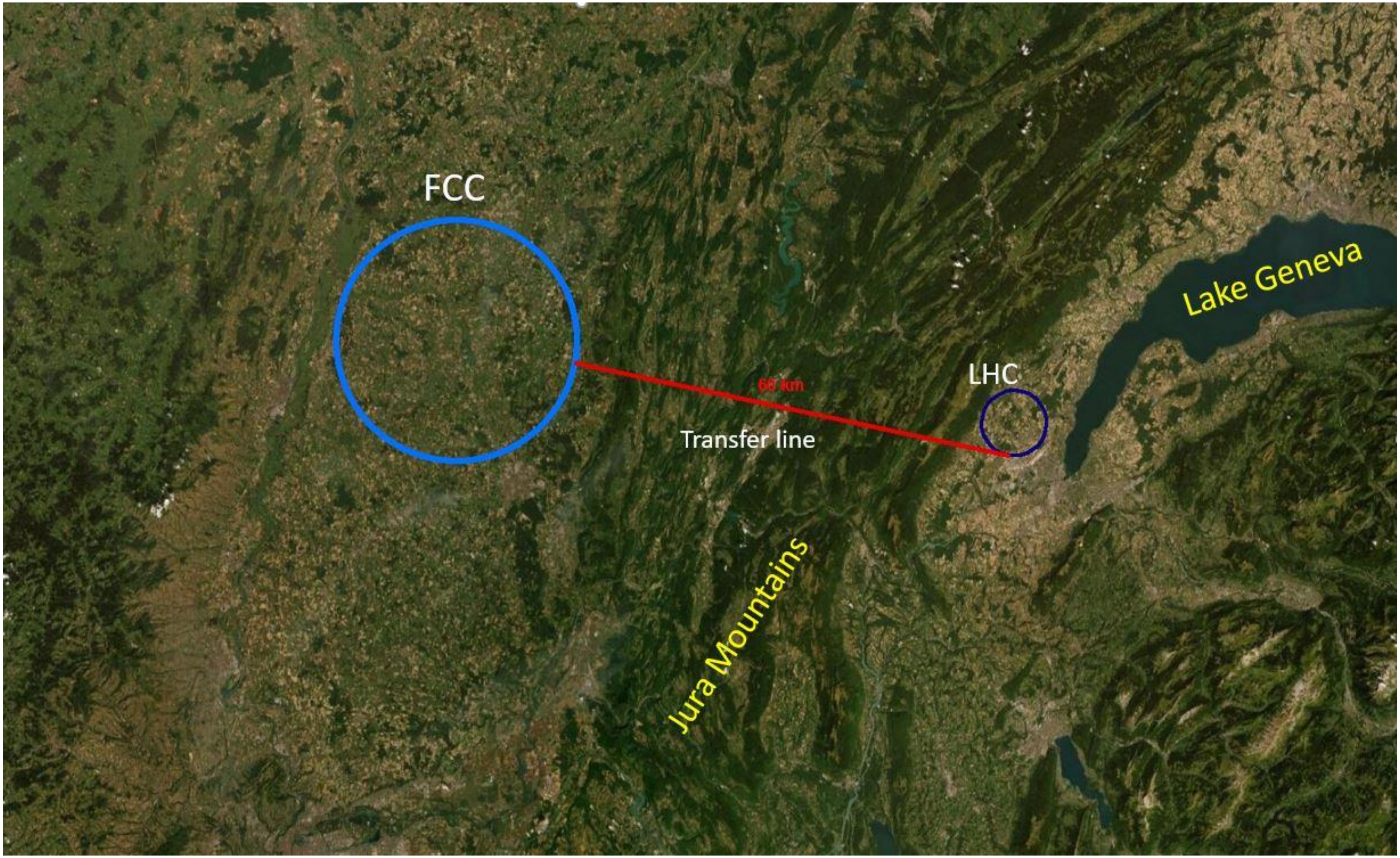

Water inflows during LEP construction

Sector 3-4 refurbishment

Tunnel inspection 2019 (current condition of sector 3-4)

Continuous monitoring, maintenance and refurbishment works are necessary to extend the lifetime of the LHC tunnel for the use of a future particle collider.

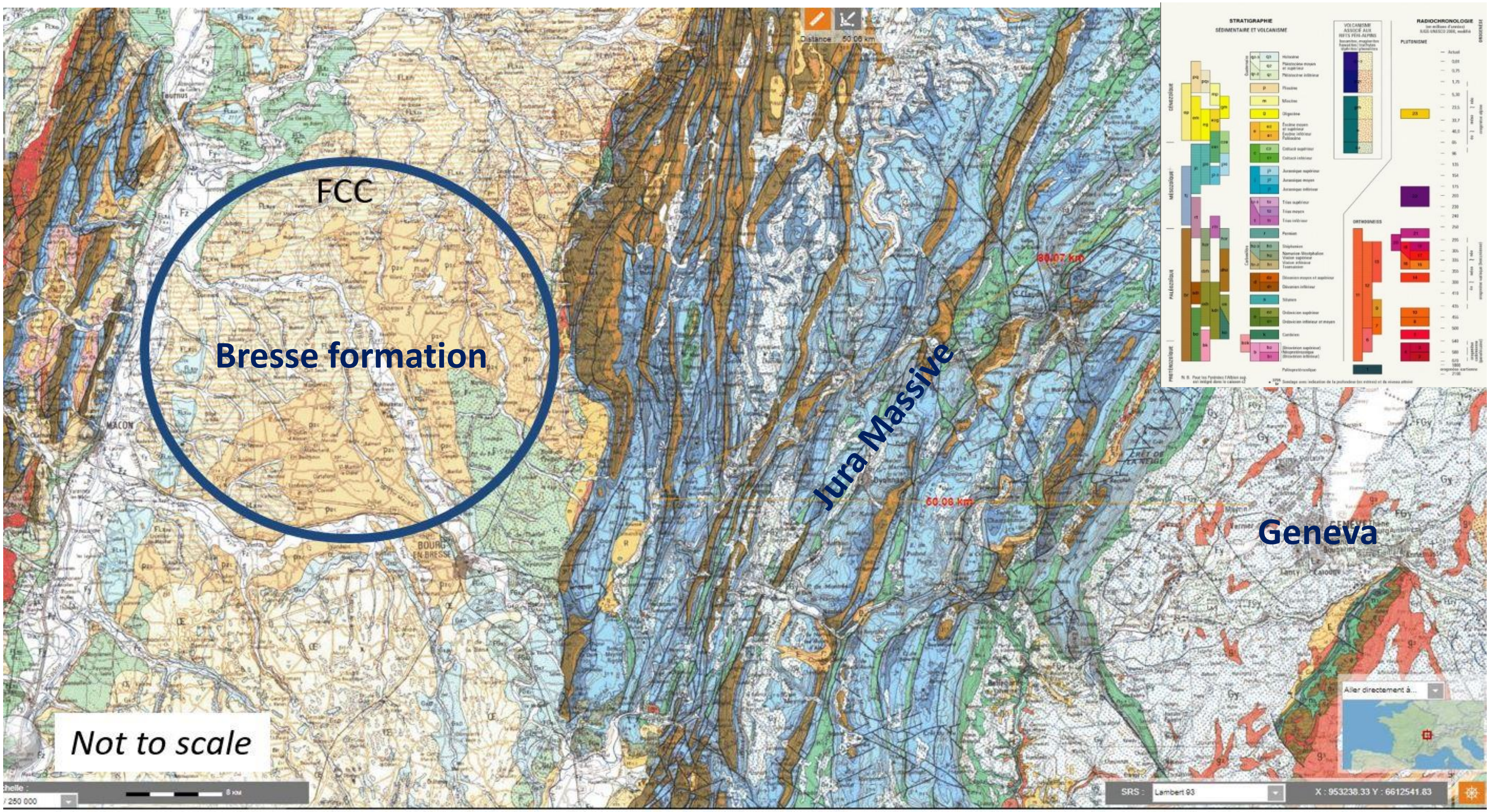
FCC ring situated West of Jura with a single transfer line to LHC



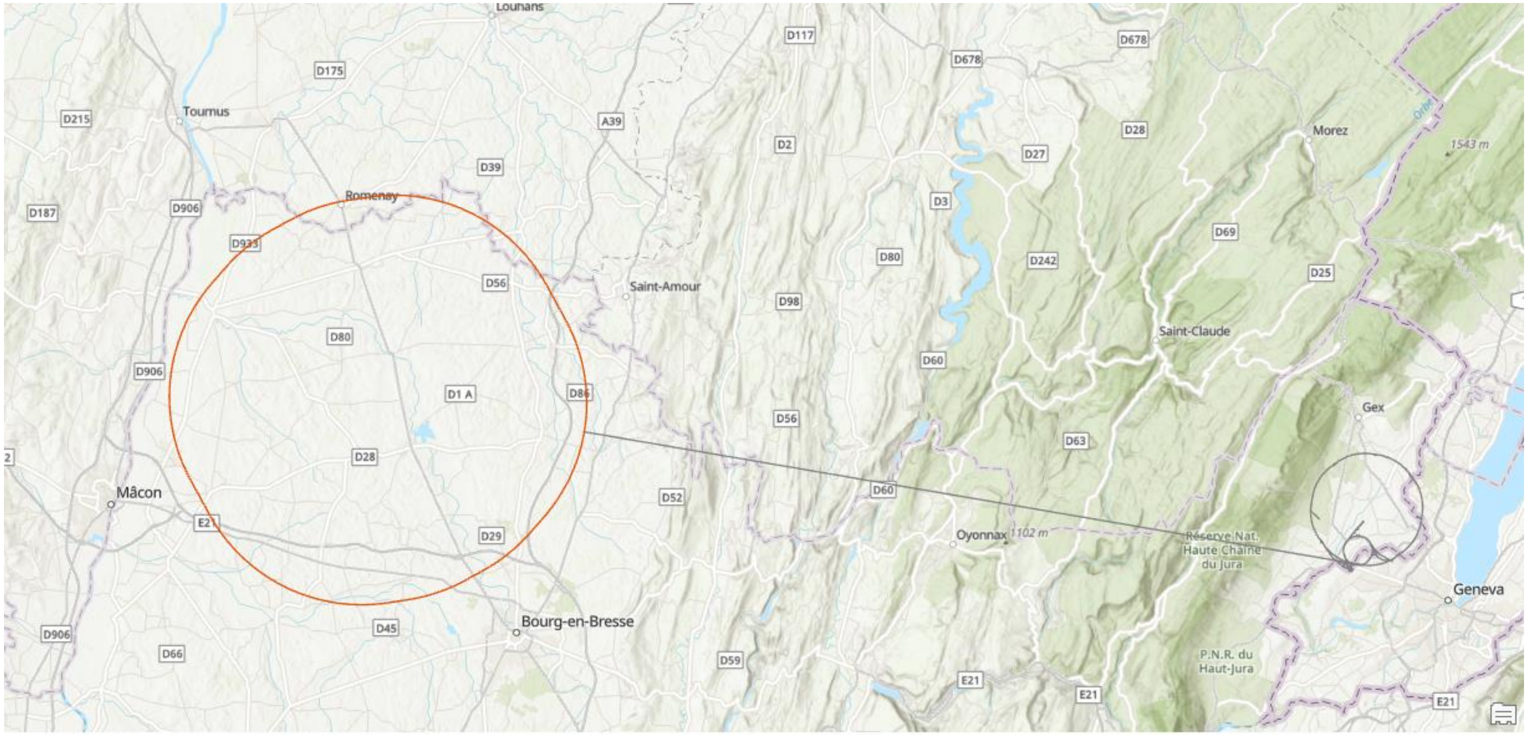
THIS CONCEPT IS NOT PART OF EUROPEAN STRATEGY INPUT !!

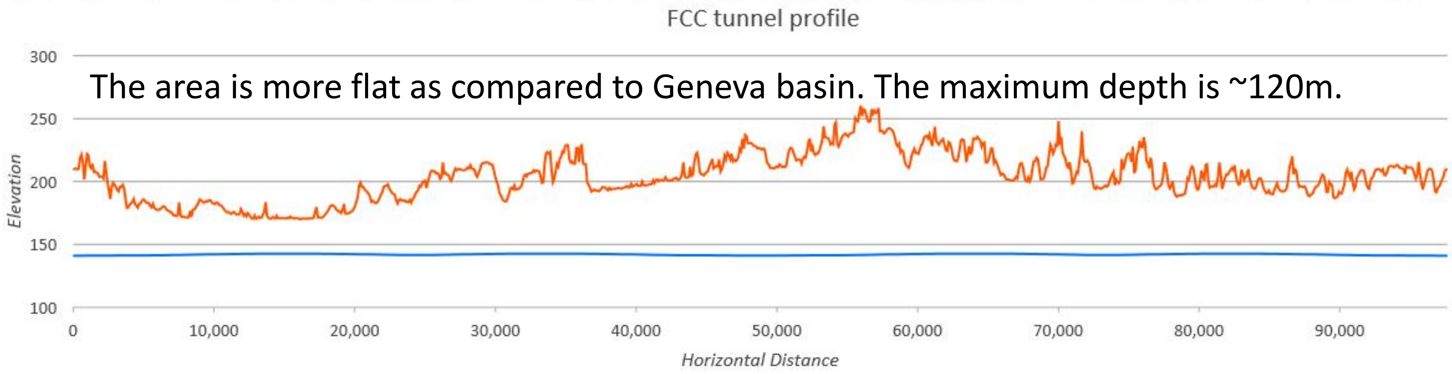
FCC ring situated West of Jura with a single transfer line to LHC

Variable geology – mainly soft ground : Bresse marls and clay. Locally sandstone and limestone.
Some borehole show presence of gypsum.



FCC ring situated West of Jura with a single transfer line to LHC

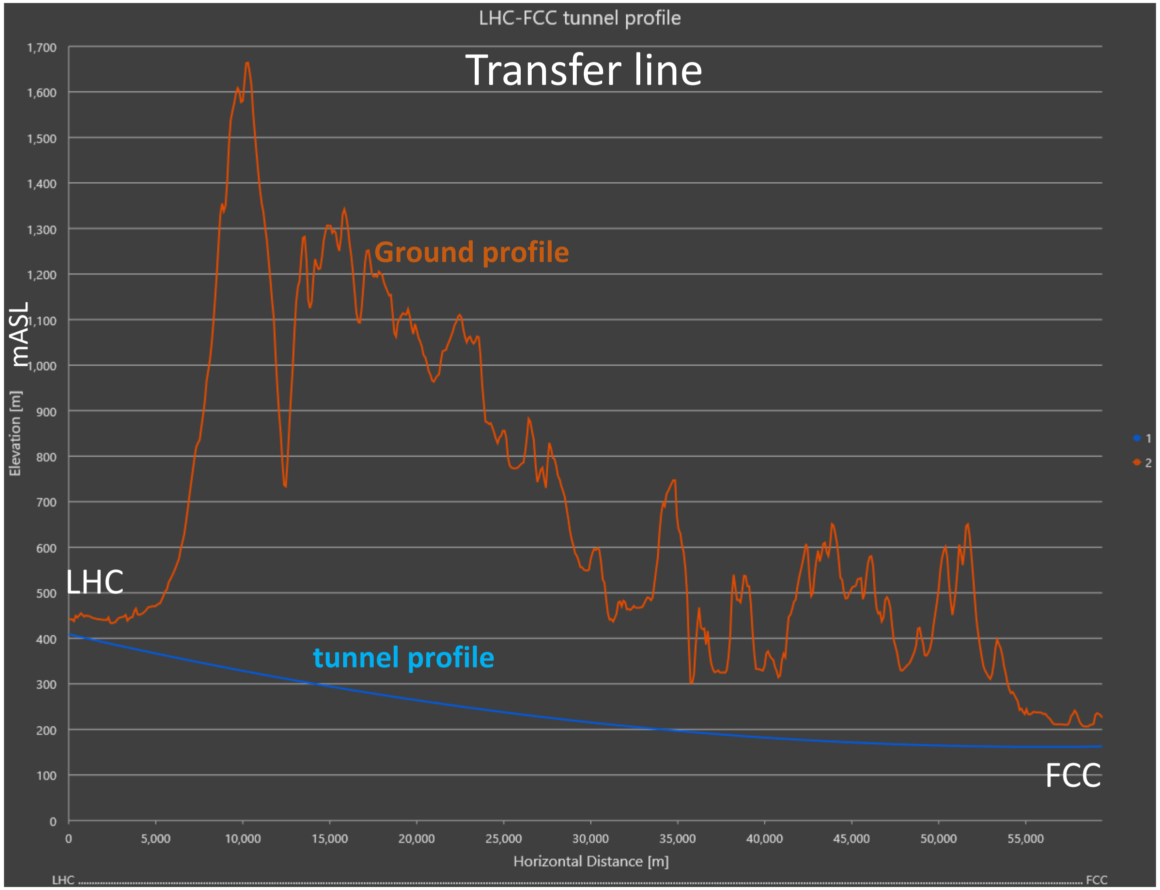




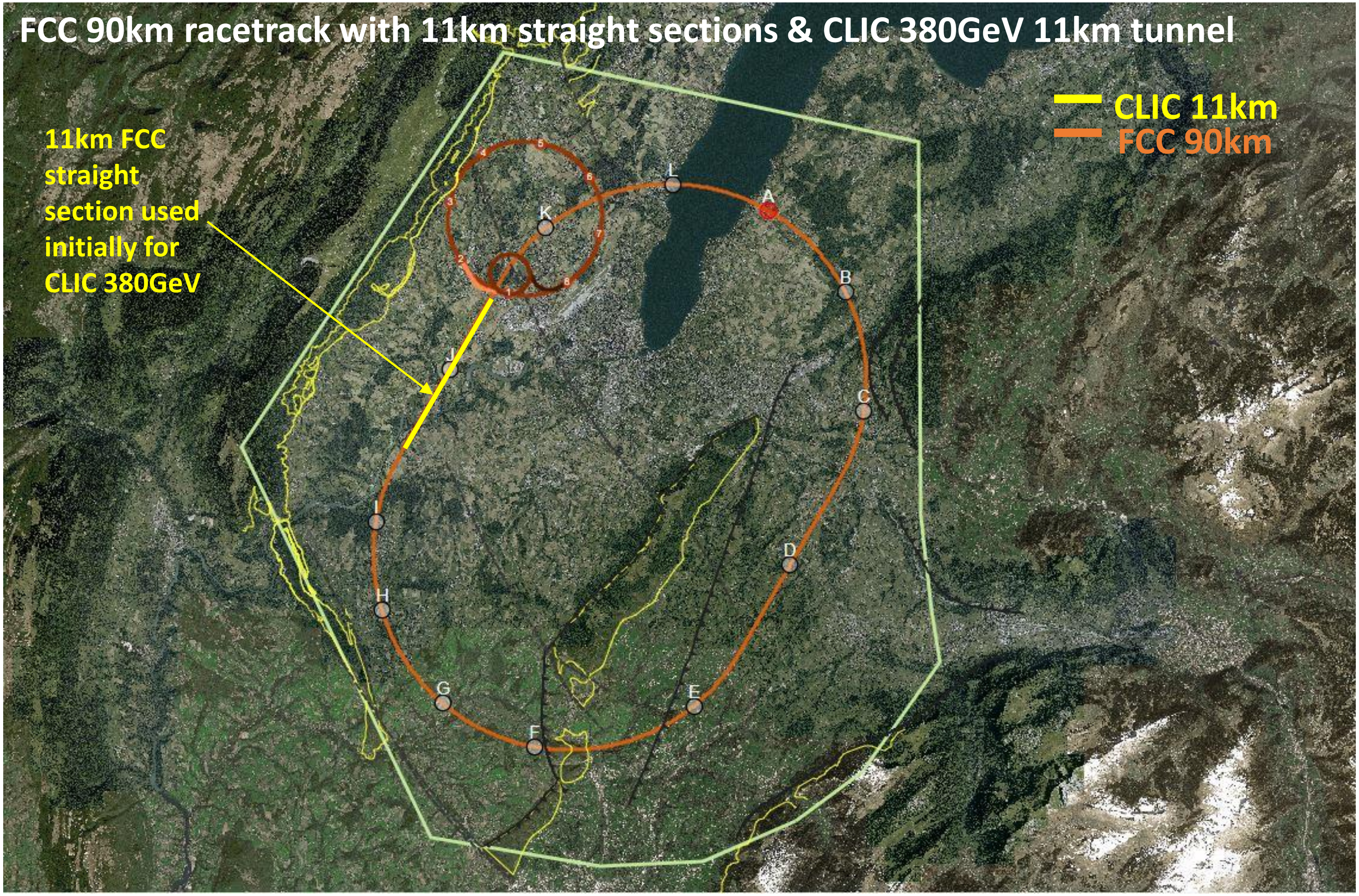
FCC ring situated West of Jura with a single transfer line to LHC

- An transfer line of 60km length connects LHC to FCC crossing through the Jura Mountains. This raises risks associated to tunnelling though limestone such as karstic features, water inflow and instability during excavation.

- High overburden (up to 1300m) and very deep shafts in the Jura.



FCC + CLIC combined alignments



THIS CONCEPT IS NOT PART OF EUROPEAN STRATEGY INPUT !!

FCC + CLIC combined alignments

TOT output for FCC 90km racetrack + 11km CLIC

Alignment | Shafts | Query

Choose alignment option

90km racetrack 11km straight ▾

Tunnel elevation at centre:300mASL

Grad. Params

Azimuth (°): 30

Slope Angle x-x(%): 0.14

Slope Angle y-y(%): 0

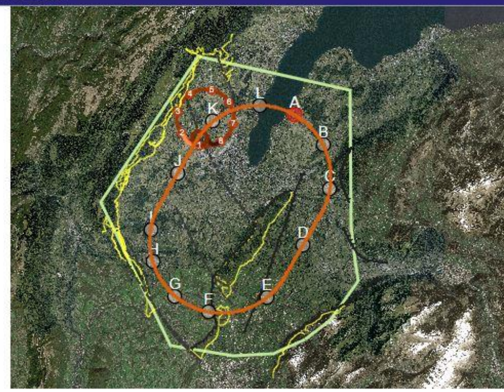
LOAD | CREATE | UPDATE | CALCULATE

Alignment centre

X: 2499424 Y: 1111846

	CP 1		CP 2	
	Angle	Depth	Angle	Depth
LHC	78°	90m	58°	84m
SPS		124m		128m
TI2		134m		128m
TI8		124m		57m

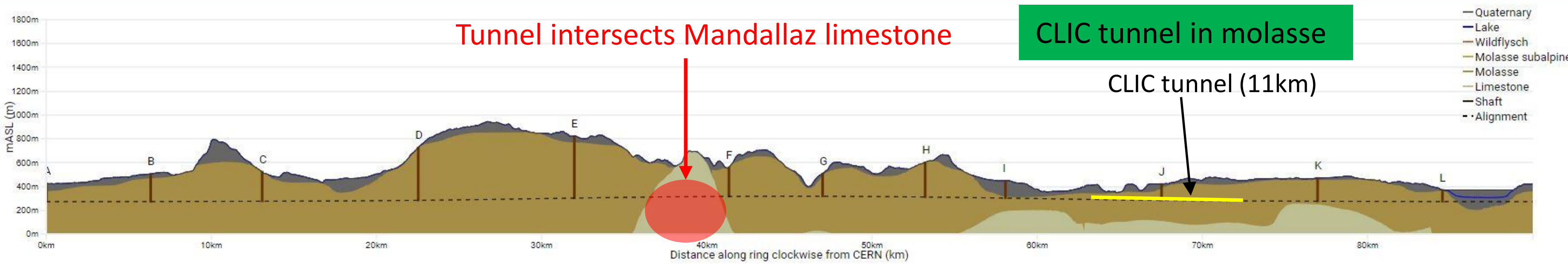
Alignment Location



Geology Intersected by Shafts | Shaft Depths

	Shaft Depth (m)			Geology (m)			
Point	Actual	Molasse SA	Wildflysch	Quaternary	Molasse	Urgonian	Limestone
A	151	0	0	66	84	0	0
B	231	0	0	39	192	0	0
C	248	0	0	0	248	0	0
D	441	0	0	11	430	0	0
E	520	0	0	57	463	0	0
F	242	0	0	0	242	0	0
G	189	0	0	21	168	0	0
H	290	0	0	0	290	0	0
I	146	0	0	135	11	0	0
J	136	0	0	43	94	0	0
K	195	0	0	20	175	0	0
L	98	0	0	10	88	0	0
Total	2886	0	0	402	2484	0	0

Alignment Profile

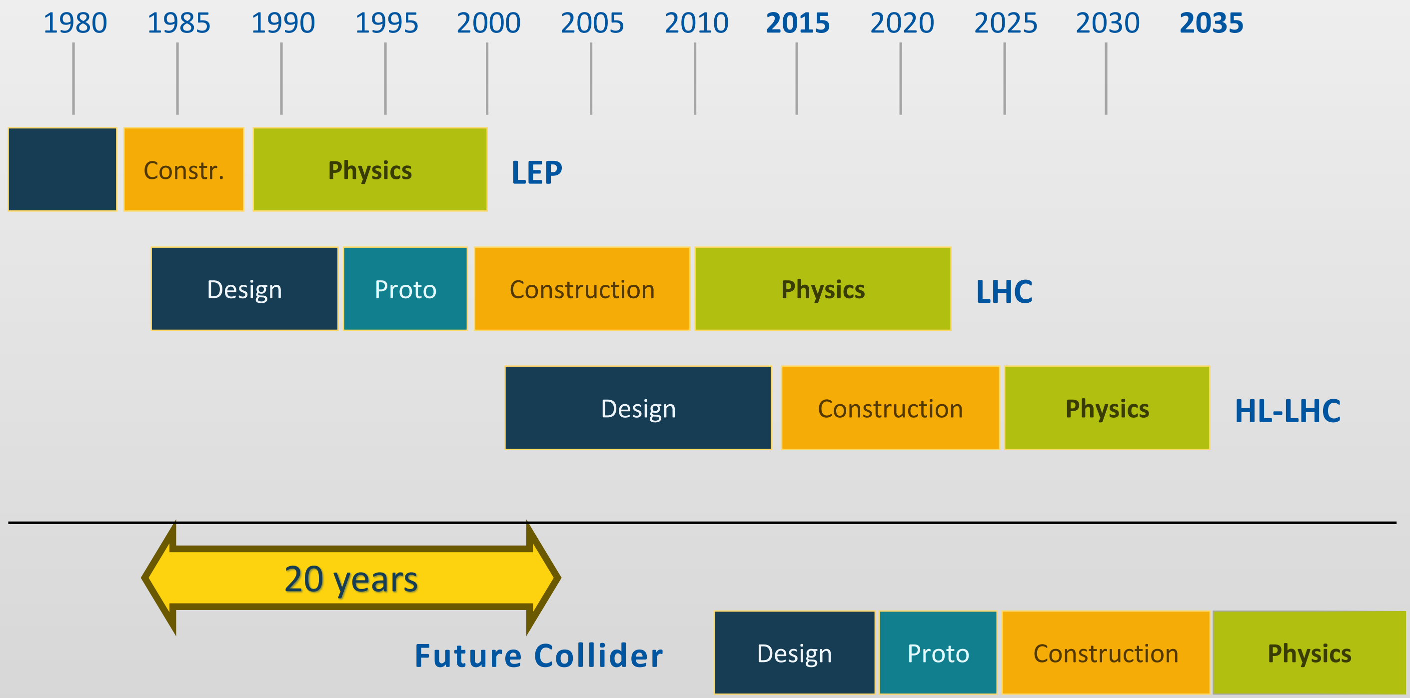


Geology Intersected by Tunnel | Geology Intersected by Section

More layouts combining FCC and CLIC have been studied.

THIS CONCEPT IS NOT PART OF EUROPEAN STRATEGY INPUT !!

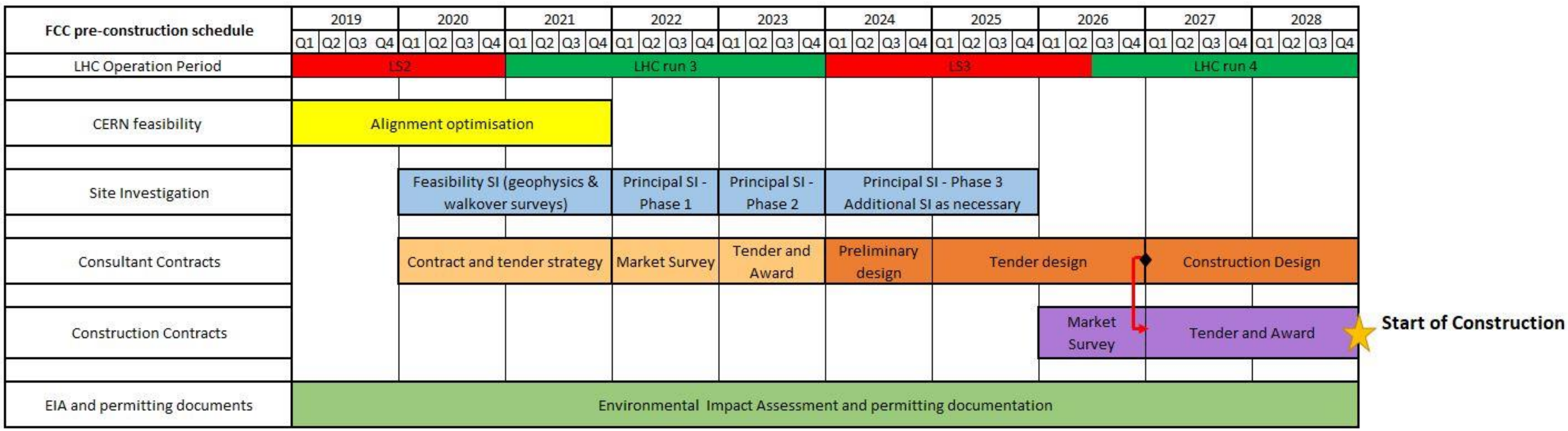
What next for FCC (and/or CLIC ?!) : Long Term LHC Plan



Site investigation planning and pre-construction planning (FCC or CLIC similar)

Conceptual Design Report

European Strategy Update 2020



<u>Types of site investigation:</u>

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

<u>Phases:</u>

<u>Feasibility</u>: Non-intrusive investigations to allow consolidation of alignment. Focus on access points, Lake crossing and the Rhone and Arve crossings.
<u>Principal</u>: Substantial portion of the geotechnical investigations. As a result of this, the alignment might need to be changed.
<u>Additional:</u> Any investigations required for the final design, emphasis on obtaining date required for the contractors.
<u>Administration</u>

Thank you and Questions !

John Osborne