Civil Engineering Summary

Cost drivers, Risk factors, Schedule for preparatory phase

FCC Week 2019 Brussels

27 June 2019

J. Osborne, **A. Tudora**

Agenda

- Civil Engineering study progress
- Overview of civil engineering for baseline footprint
- HE-LHC Civil Engineering developments
- Risk factors and cost drivers
- Schedule for preparatory phase
- Ongoing work and future steps

CE study progress

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

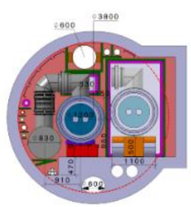
Refinement of results (fire compartments, caverns spacing)

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:

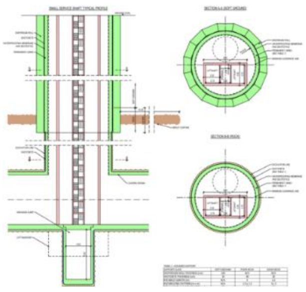
- Surface site investigation
- Site investigation planning
- Spoil management study
- Transfer line design

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

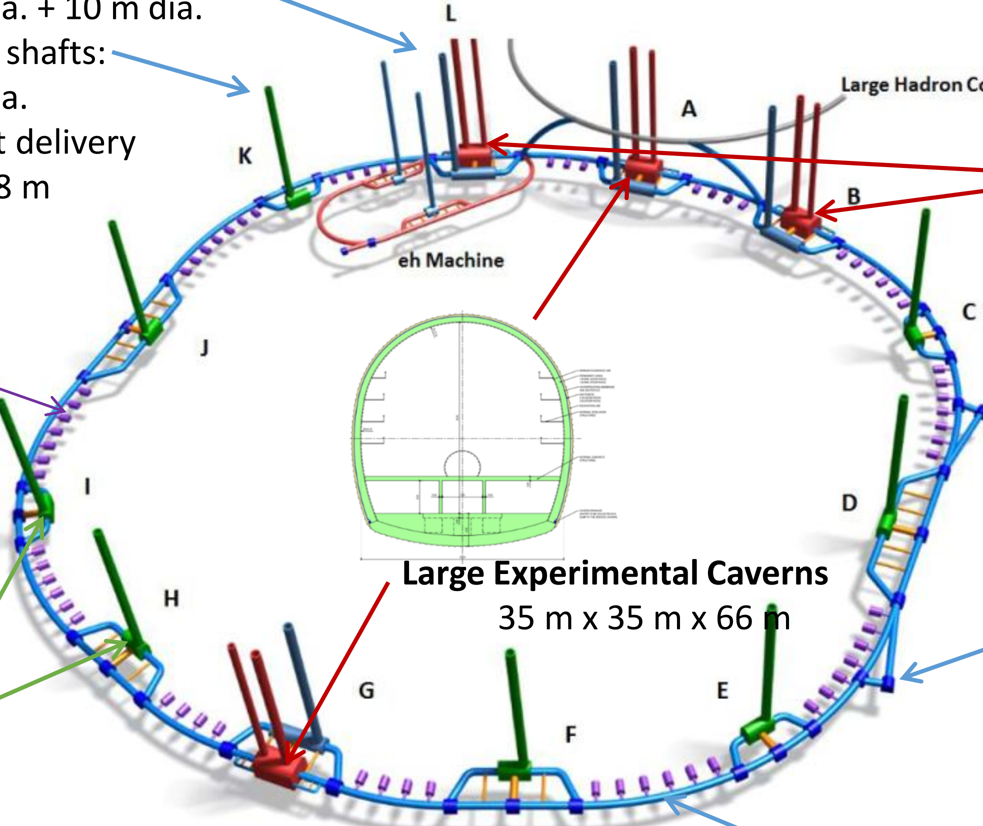
CDR volumes submitted to European Strategy update for Particle Physics

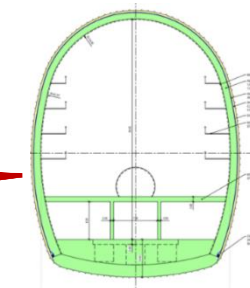
FCC civil engineering overview

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

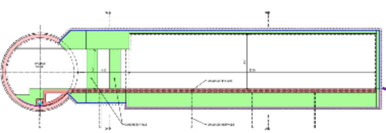


Shafts:
Experimental Shafts:
15 m dia. + 10 m dia.
Service shafts:
12 m dia.
Magnet delivery shaft:18 m



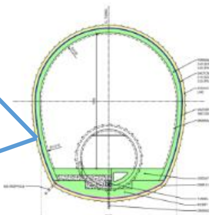


Small Experimental Caverns
30 m x 35 m x 66m

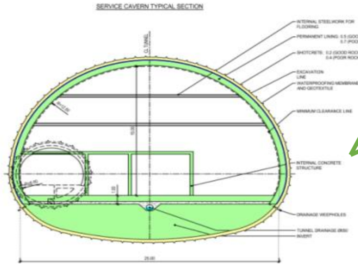


Alcoves
- 25 m x 6 m x 6 m
- Located at 1.5km spacing

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

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

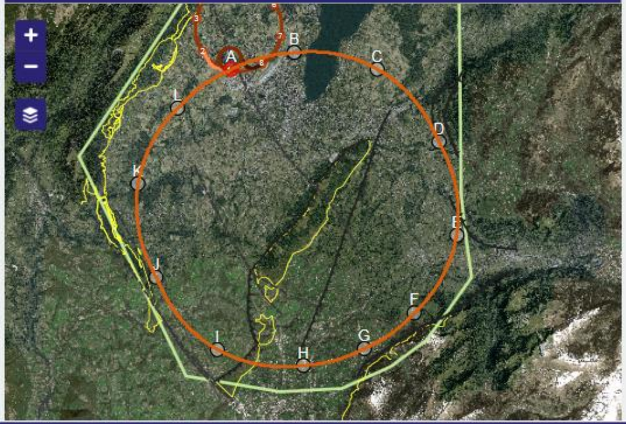
LOAD | CREATE | UPDATE | CALCULATE

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

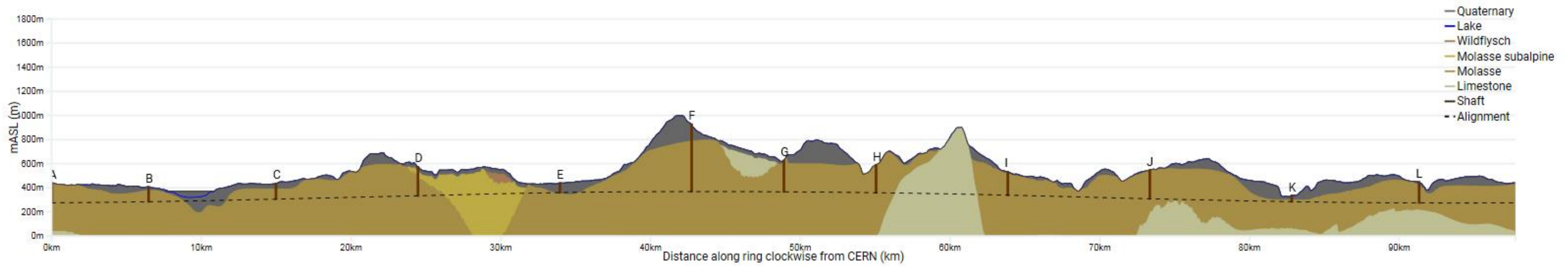
Alignment Location



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.

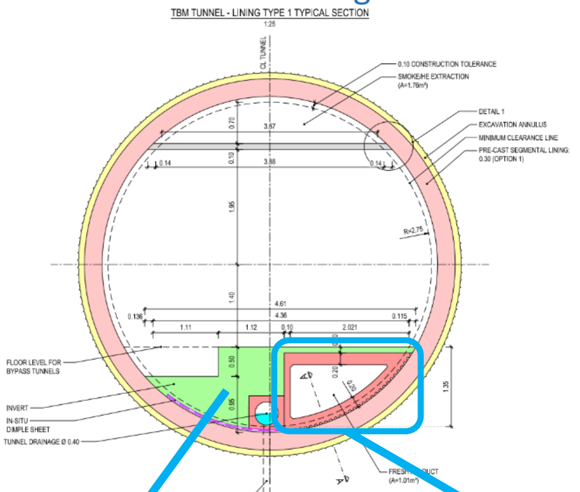
3720 m sum of shaft depths

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

Machine tunnel cross sections and lining concepts

Lining Type 1

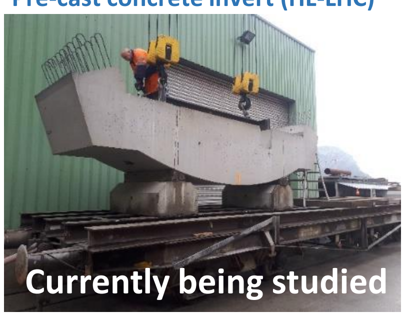
- TBM tunnel in 'good' molasses



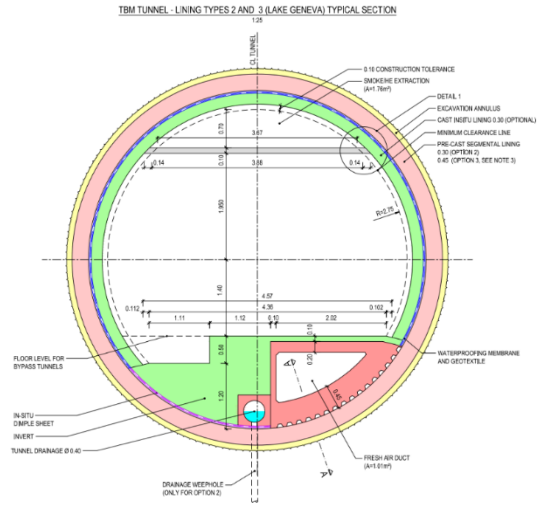
Cast-in-situ concrete invert

Pre-cast concrete element

Pre-cast concrete invert (HL-LHC)

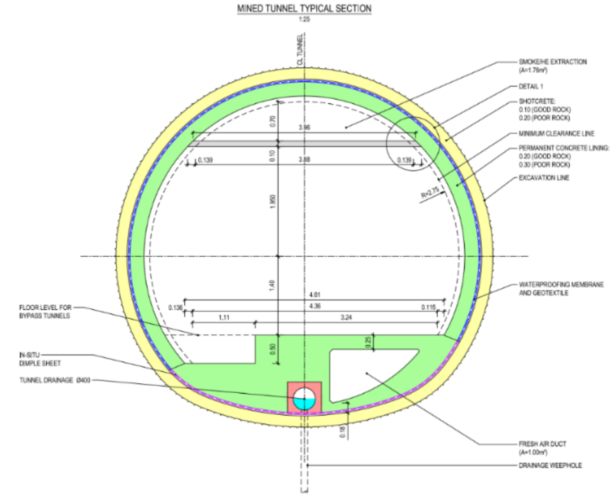


Lining Type 2 & 3



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

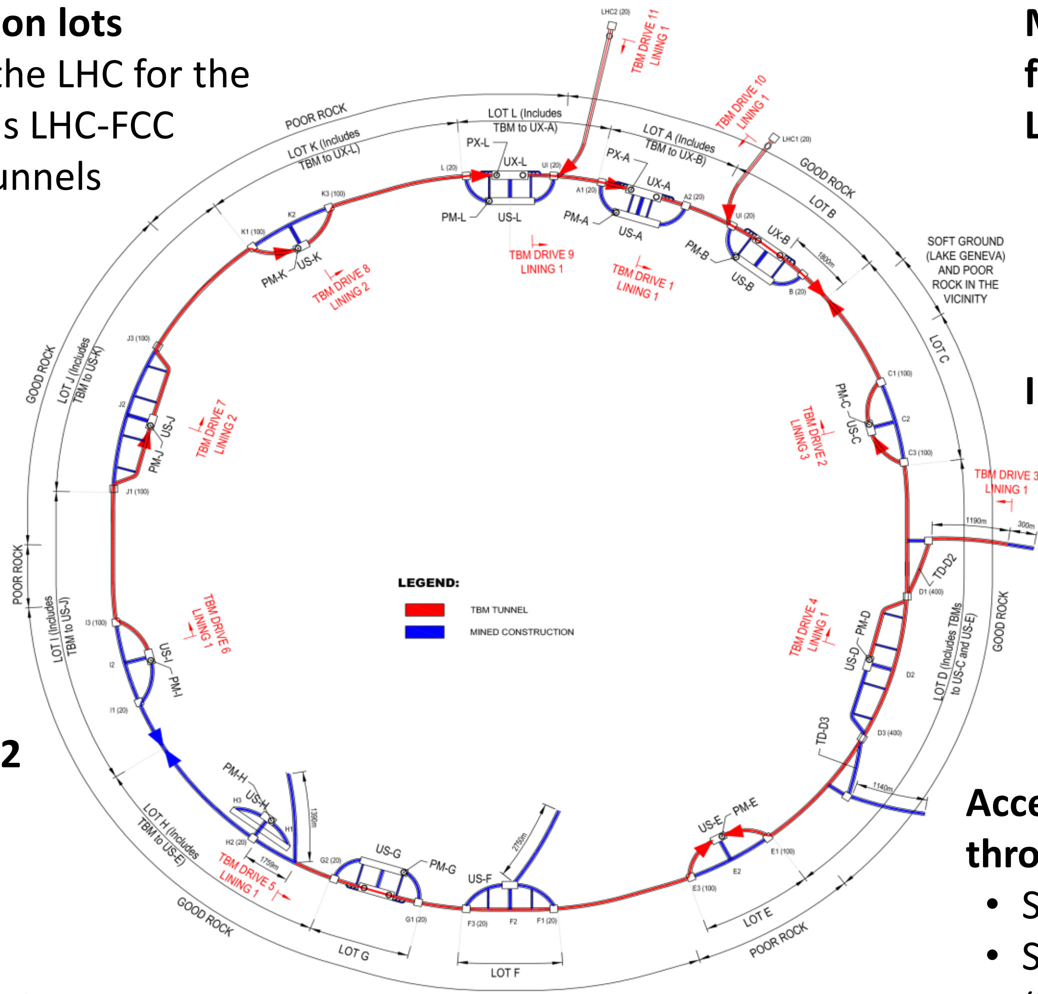
LEGEND:

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

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:

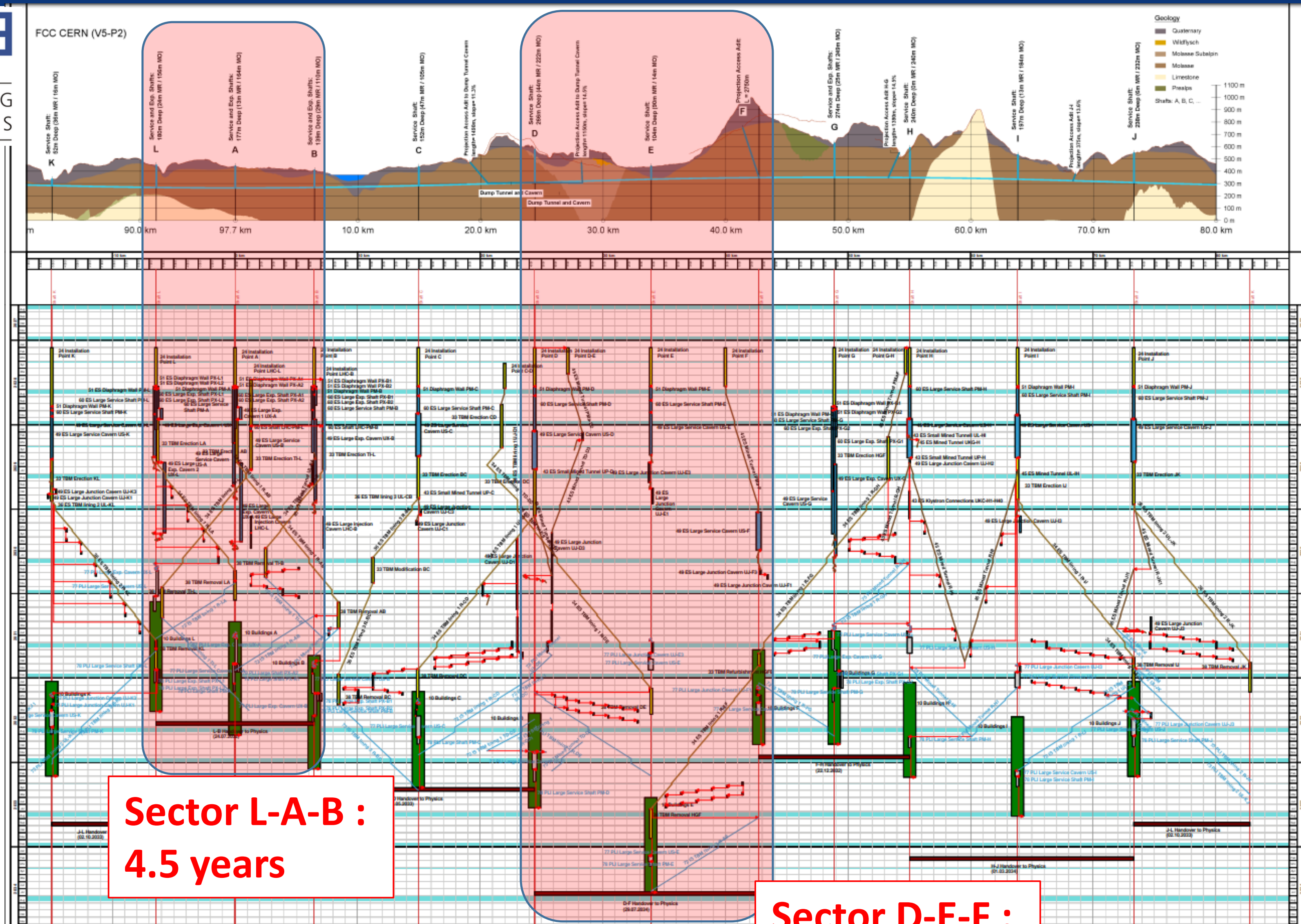
- Shafts at 11 points
- Sloped Access adit at 1 point (instead of 570 m shaft)

Construction techniques:

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

Construction Schedule

ILF CONSULTING ENGINEERS

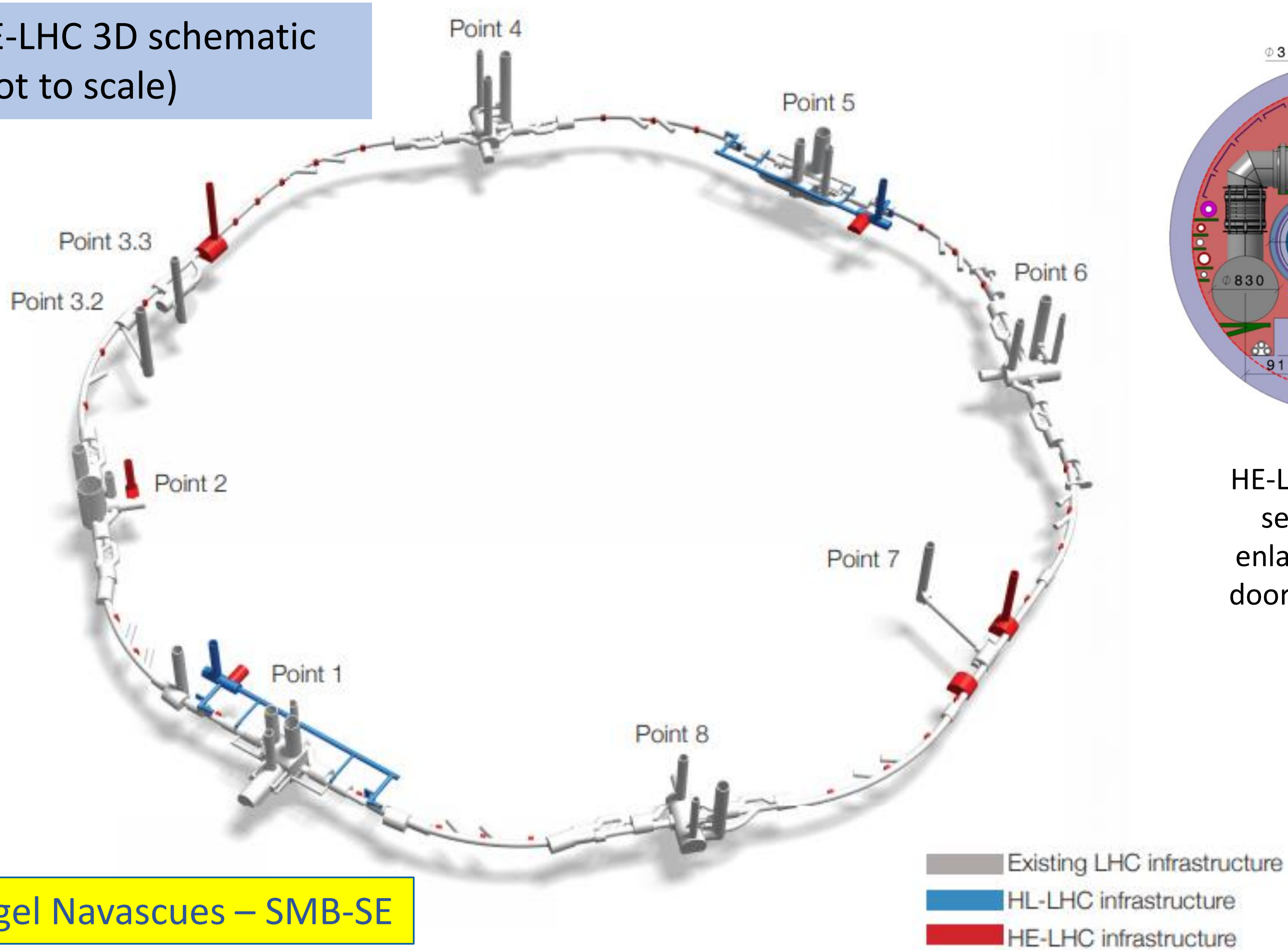


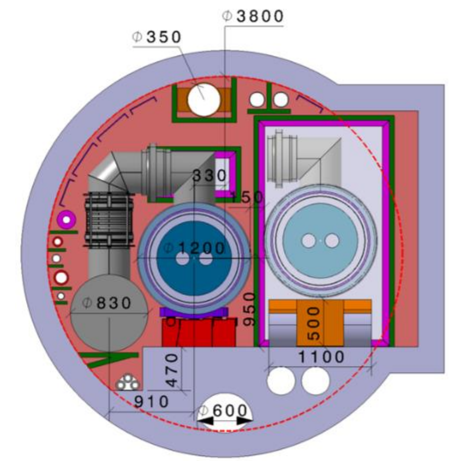
Sector L-A-B : 4.5 years

Sector D-E-F : 6.5 years

HE-LHC civil engineering developments

HE-LHC 3D schematic
(not to scale)





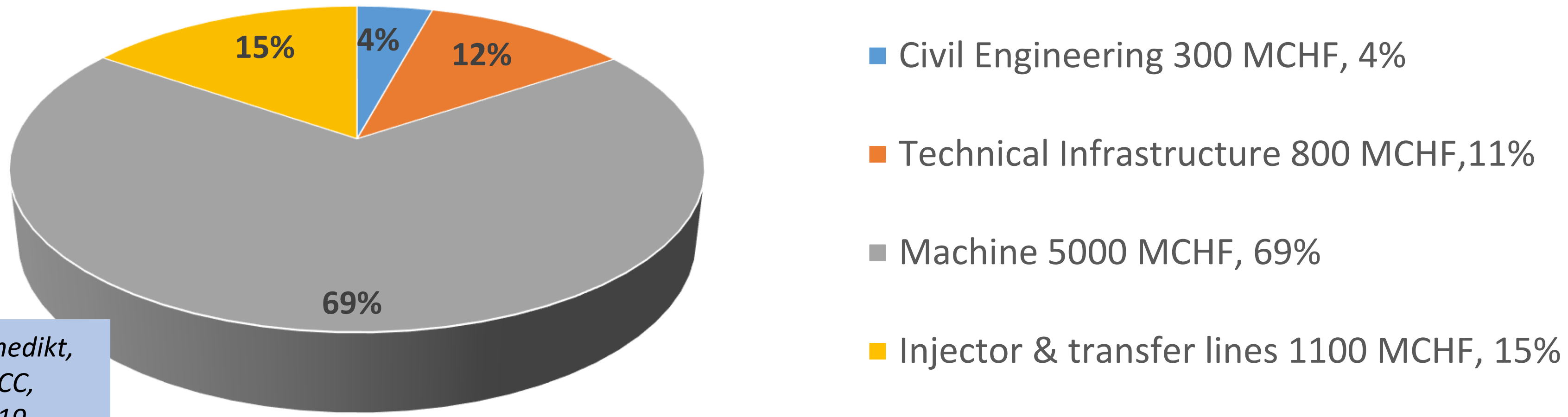
HE-LHC tunnel cross-section showing enlargement for fire door (548 m spacing)

Angel Navascues – SMB-SE

HE-LHC civil engineering developments

Preliminary cost estimate produced for civil engineering: ~300 MCHF

HE-LHC: capital cost per domain



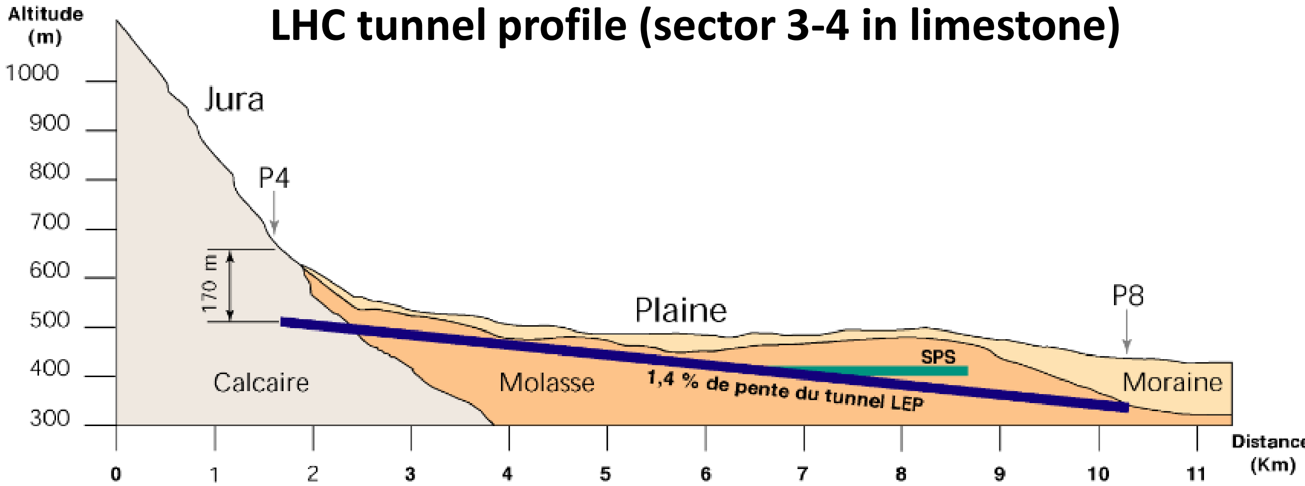
Michael Benedikt, Physics at FCC, 4 March 2019

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

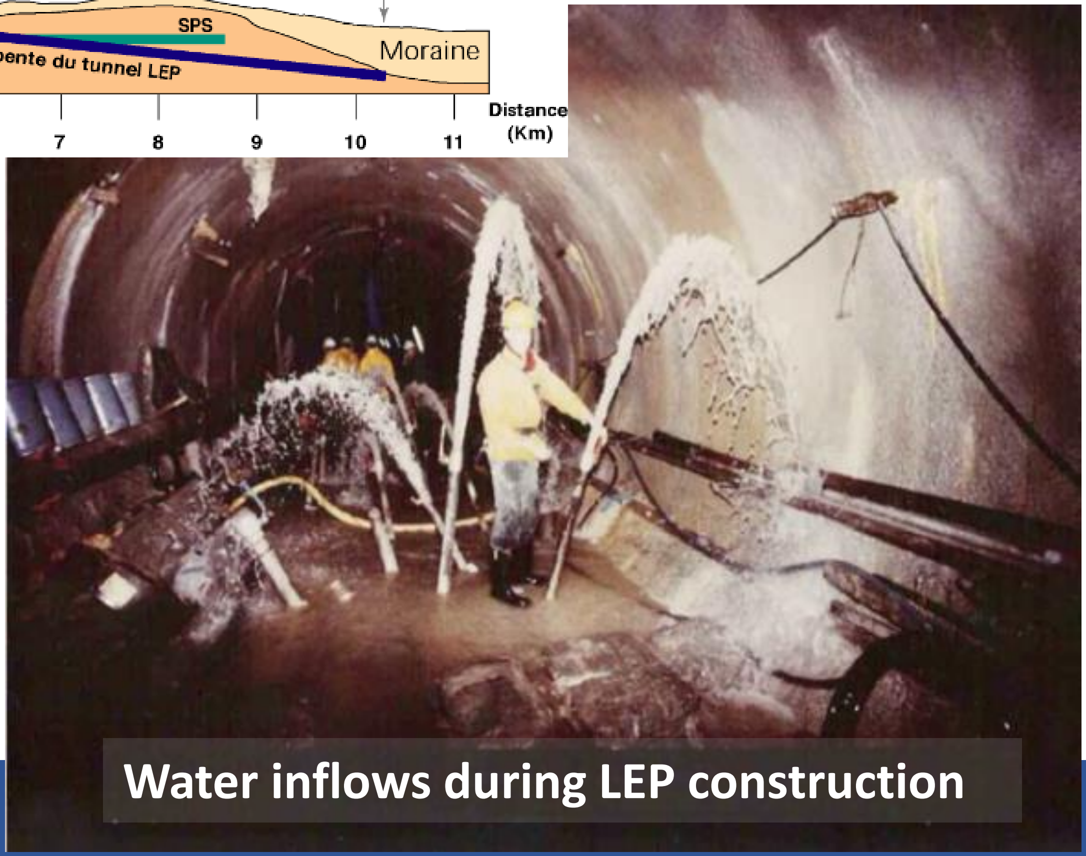
- New cryogenic caverns and electrical alcoves
- New access shafts
- New buildings for cryogenics, electrical and ventilation equipment
- Installation of fire separation walls including extension of the tunnel envelope every 548 m
- Partial refurbishment of LHC Sector 3-4

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

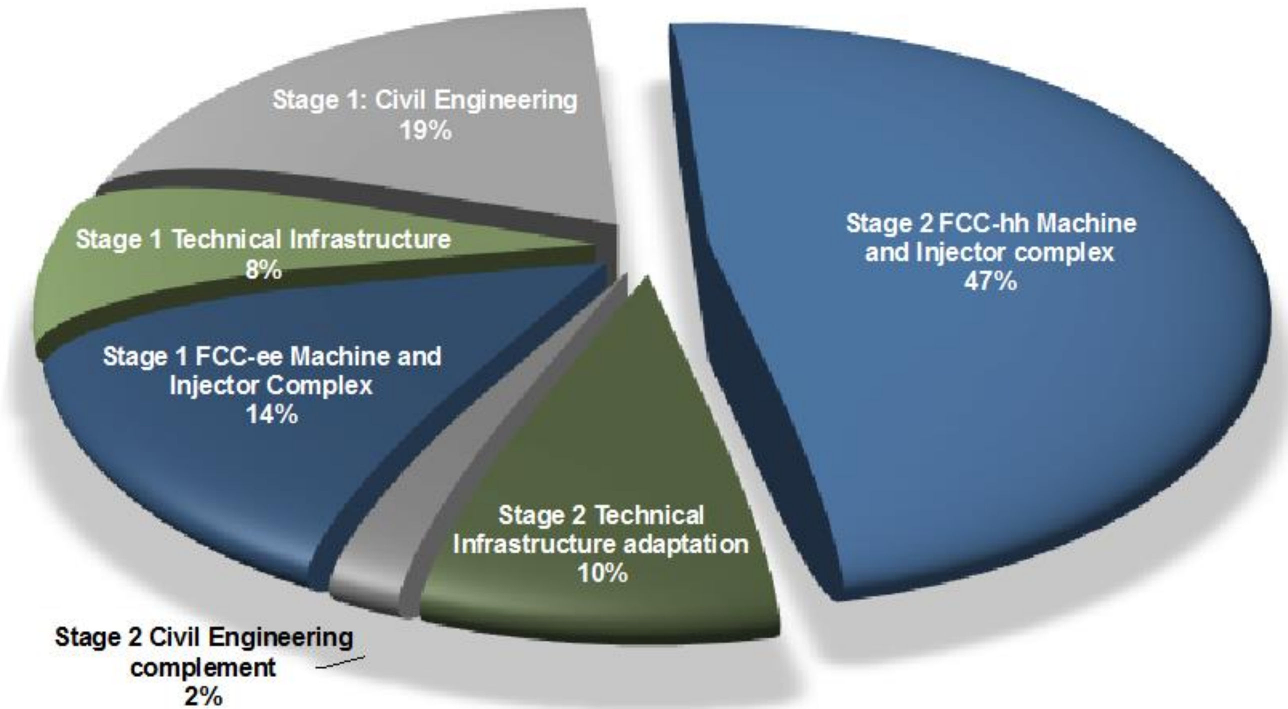
Sector 3-4 refurbishment

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.

Cost estimates for civil engineering

FCC integrated project cost estimate



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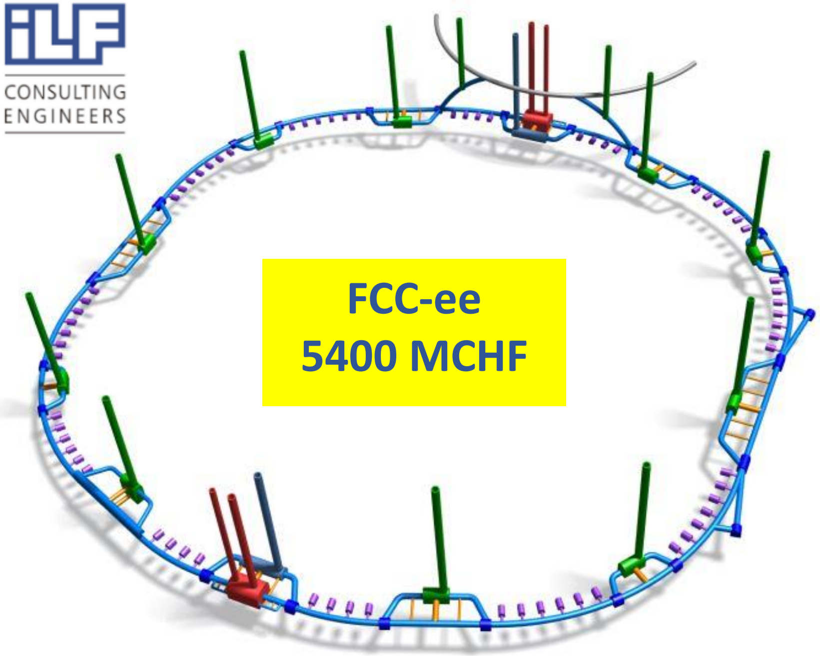
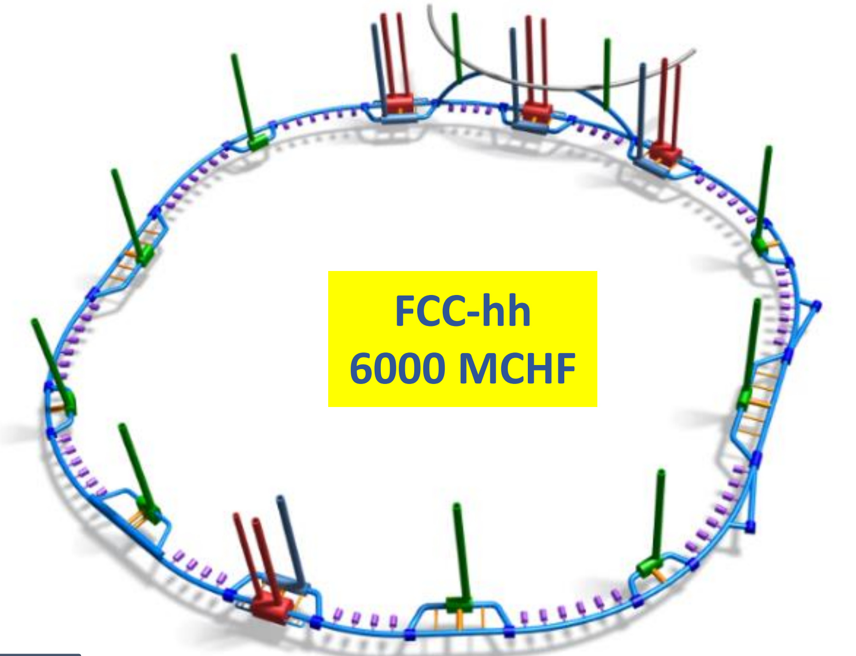
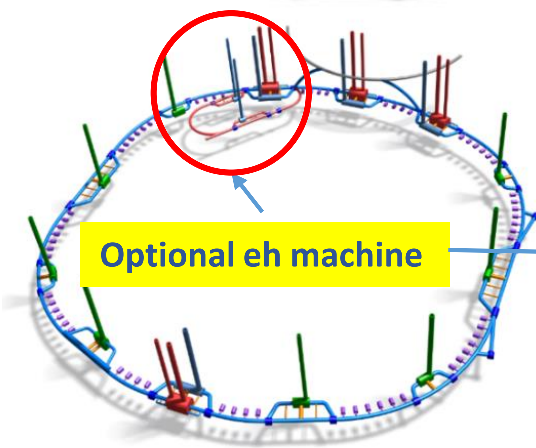
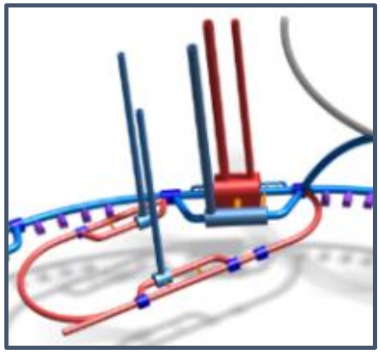
Cost estimates for civil engineering





Two additional experimental points and associated civil infrastructure

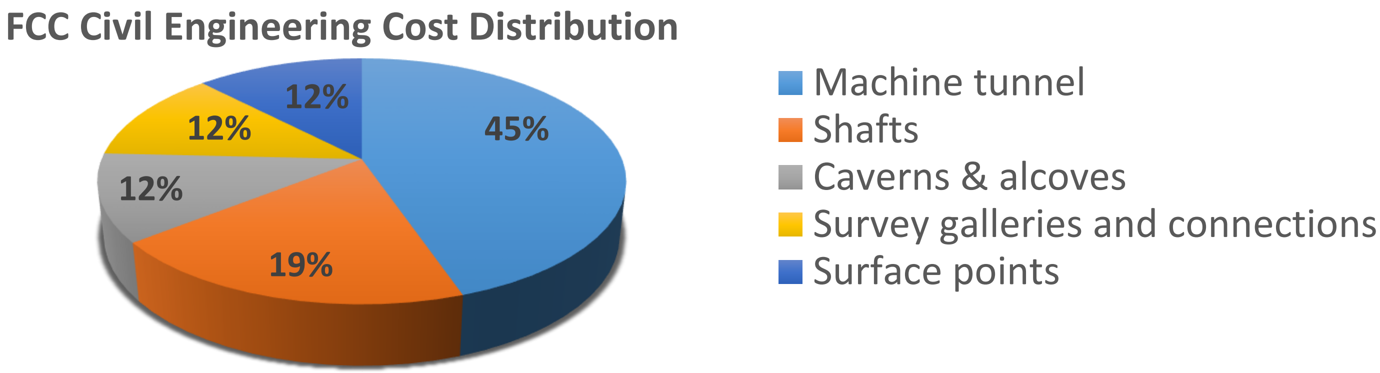




FCC-eh underground: 430MCHF

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

Main risk factors and cost drivers



- **Geology**

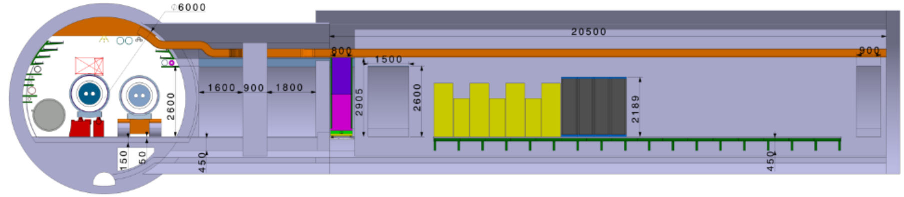
3 ground types have been considered. The cost varies with the support class (eg. cost of tunneling in soft ground is generally higher)

Support class	Ground type	Material quality	Temporary support	Permanent support
Good Rock (75%)	Molasse, flysch and limestone	Fresh and massive rock with none to moderate jointing	Shotcrete and rockbolts	Relatively thin permanent concrete linings lightly reinforced with steel bars, steel fibre or unreinforced
Poor Rock (18%)	Limestone, flysch and molasse	Jointed and fractured rock	Highly reinforced shotcrete and rockbolts	Permanent concrete linings with medium steel bar reinforcement densities
Soft Ground (7%)	Moraines and other quaternary and tertiary soils	Sand to clay with variable geotechnical Condition	Diaphragm walls for shafts and heavily reinforced shotcrete	Permanent concrete linings with high steel bar reinforcement densities

Main risk factors and cost drivers

❑Tunnelling under Geneva Lake

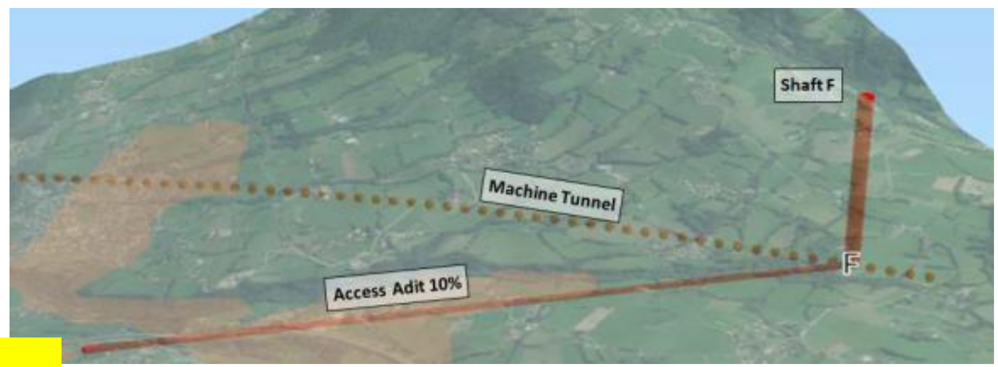
- Mixshield TBM – (higher cost)
- Difficulties of constructing alcoves in soft ground (high water ingress)



Cross-section of machine tunnel and alcove

❑ Deep shafts

- Deepest shaft is 558m (of which 140m in moraines). Depth of the other shafts vary between 51m and 259m.
- The initial excavation for each shaft will be through the moraines.
- Baseline design is based on diaphragm walls. Equipment cost would be different if VSM / SBS machines are used.



Inclined access at point F replacing vertical shaft

Main risk factors and cost drivers

❑ Overburden pressure

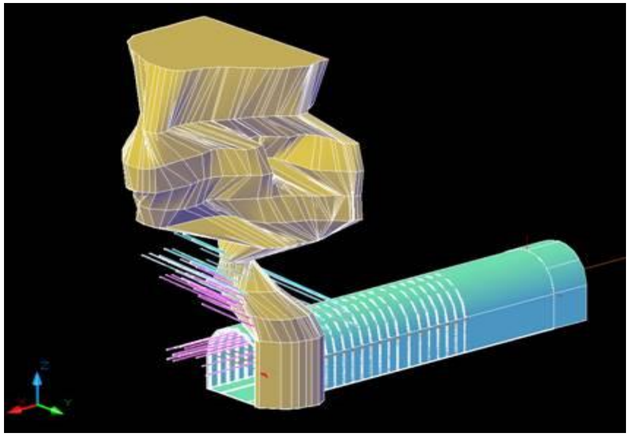
- Tunnelling in weak rock, with high deformability and low strength, combined with high overburden (squeezing rock conditions) increases the risk of TBM immobilization.
- Understanding the geotechnical parameters of the ground is needed to assess the risk of 'squeezing rock', associated with deformations of the tunnel perimeter

❑ Tunneling under Rhone Valley and Arve Valley

- The alignment was lowered by 20m to avoid passing trough Rhone alluviums and the moraines in Arve Valley, hence avoid changing of TBM for a relatively short distance

❑ Excavating in Mandallaz limestone:

- Sector H-I
- Possibility to encounter karstic features
- Water inflow
- Extended support measures have to be considered to stabilize the surrounding rock.

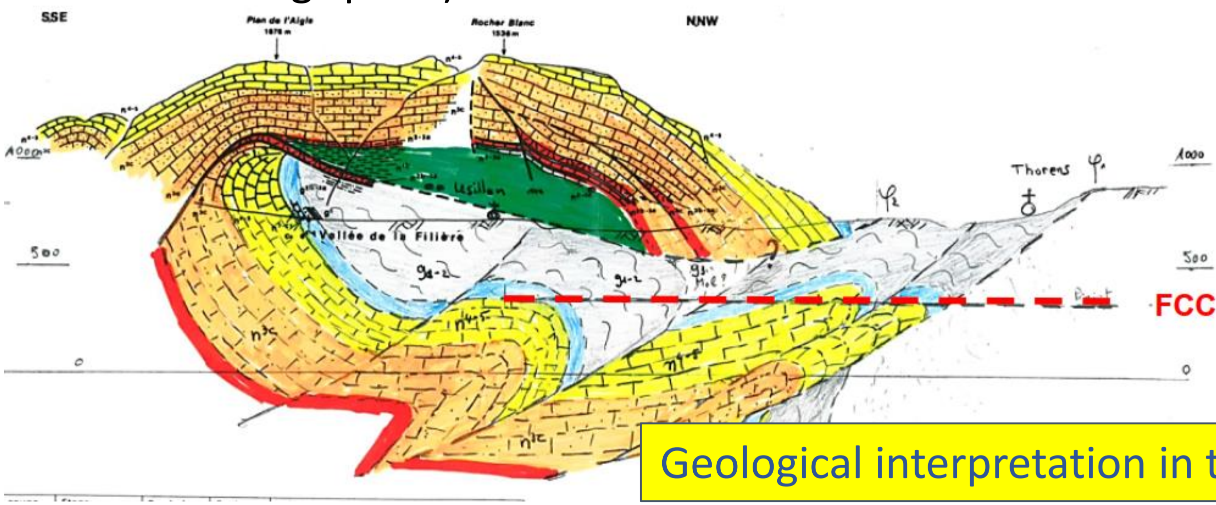


Model of tunnel in karstic formation

Main risk factors and cost drivers

❑ Faults

- Known faults are intersecting the tunnel layout
- Extensive site investigations are necessary previous to driving through fault zones.
- However, no major difficulties were encountered during LEP construction while crossing Allondon fault
- Pre-Alps – complex faulted area, uncertain what layer the tunnel will cross (reduced advancing speed)



tunnel in folded and sheared flysch formation

Geological interpretation in the Pre-Alps area

GADZ

❑ Encountering hydrocarbons

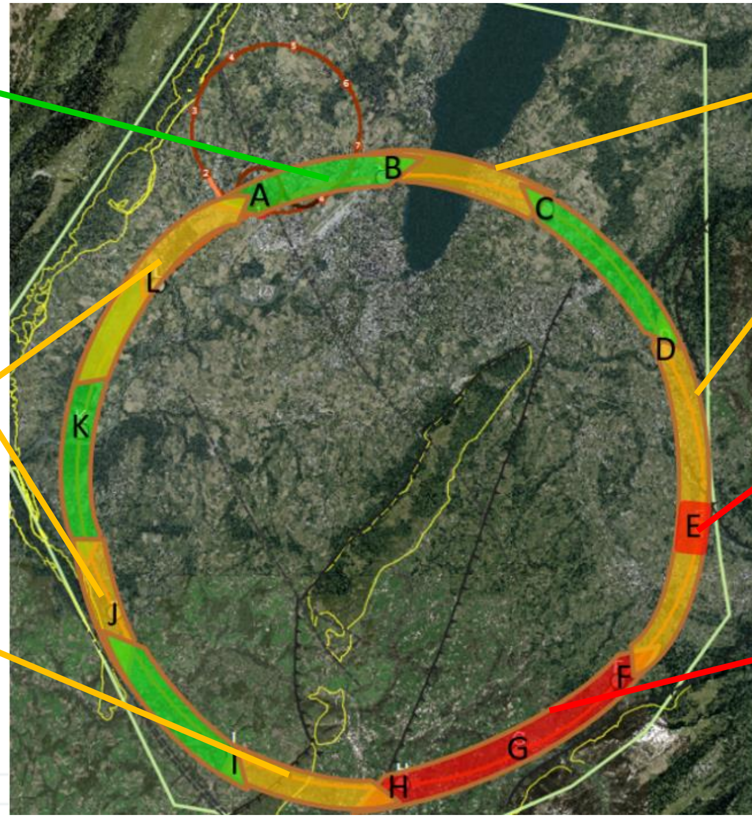
- Potential costs arising from hydrocarbon contamination (not included in the cost estimate)

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.

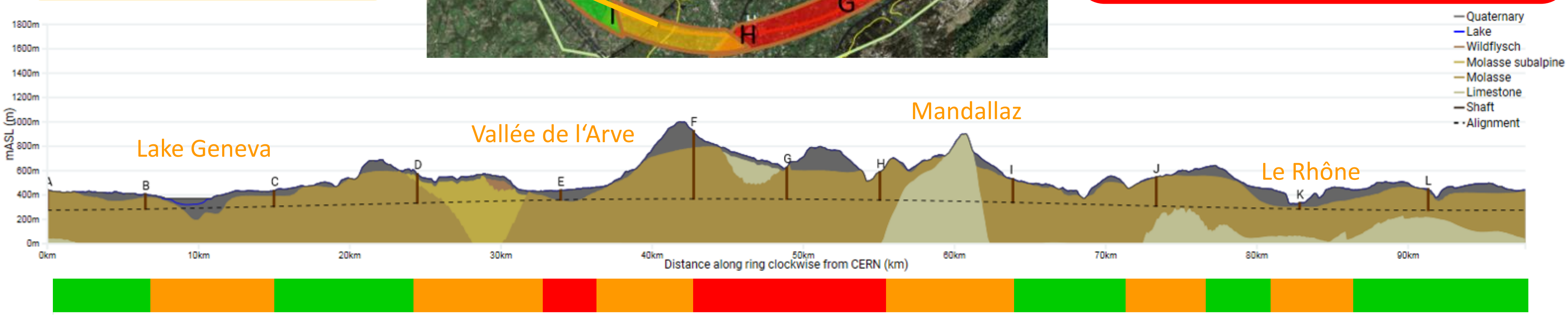


- Location of the interface between molasse and molasse subalpine not certain, tunnel alignment in proximity.

- 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

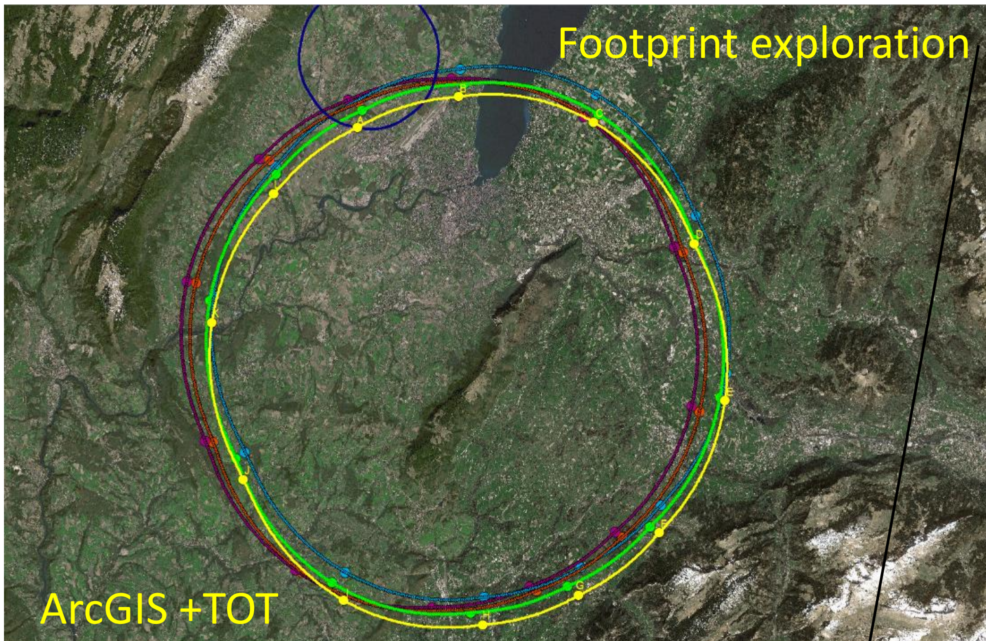
Types of site investigations:
- Boreholes
- Site testing (eg insitu stress test, point load testing, SPT, CPT, permeability tests)
- Rock laboratory testing (eg uniaxial compressive strength, petrographic studies)

Additional SI (2024-2025)

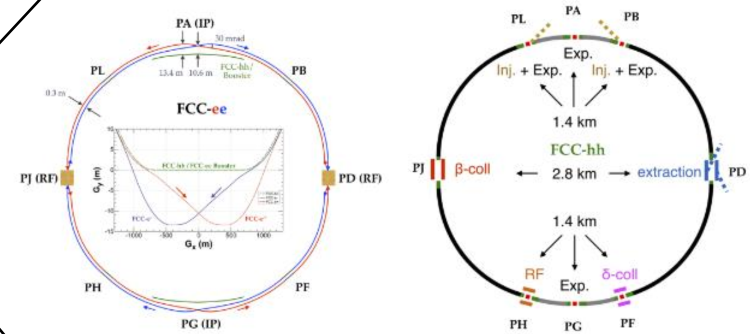
Phase 3 – additional explorations needed in order to obtain a reliable cost estimate

Ongoing work and future steps

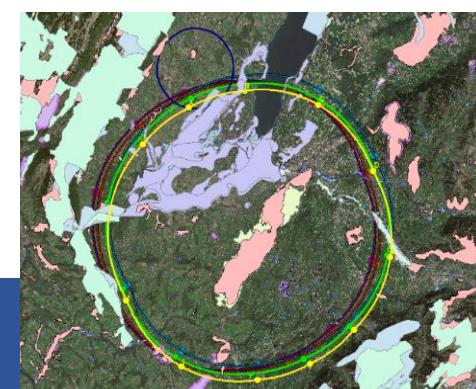
❑A further round of alignment optimisation following input from surface site review



- **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 planned in October 2019
- ❑ Site investigations planning
- ❑ Spoil management study
- ❑ Transfer line design

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hh ee he

Thank you for your attention!