FCC WEEK
Civil engineering status and plans

30.06.2021

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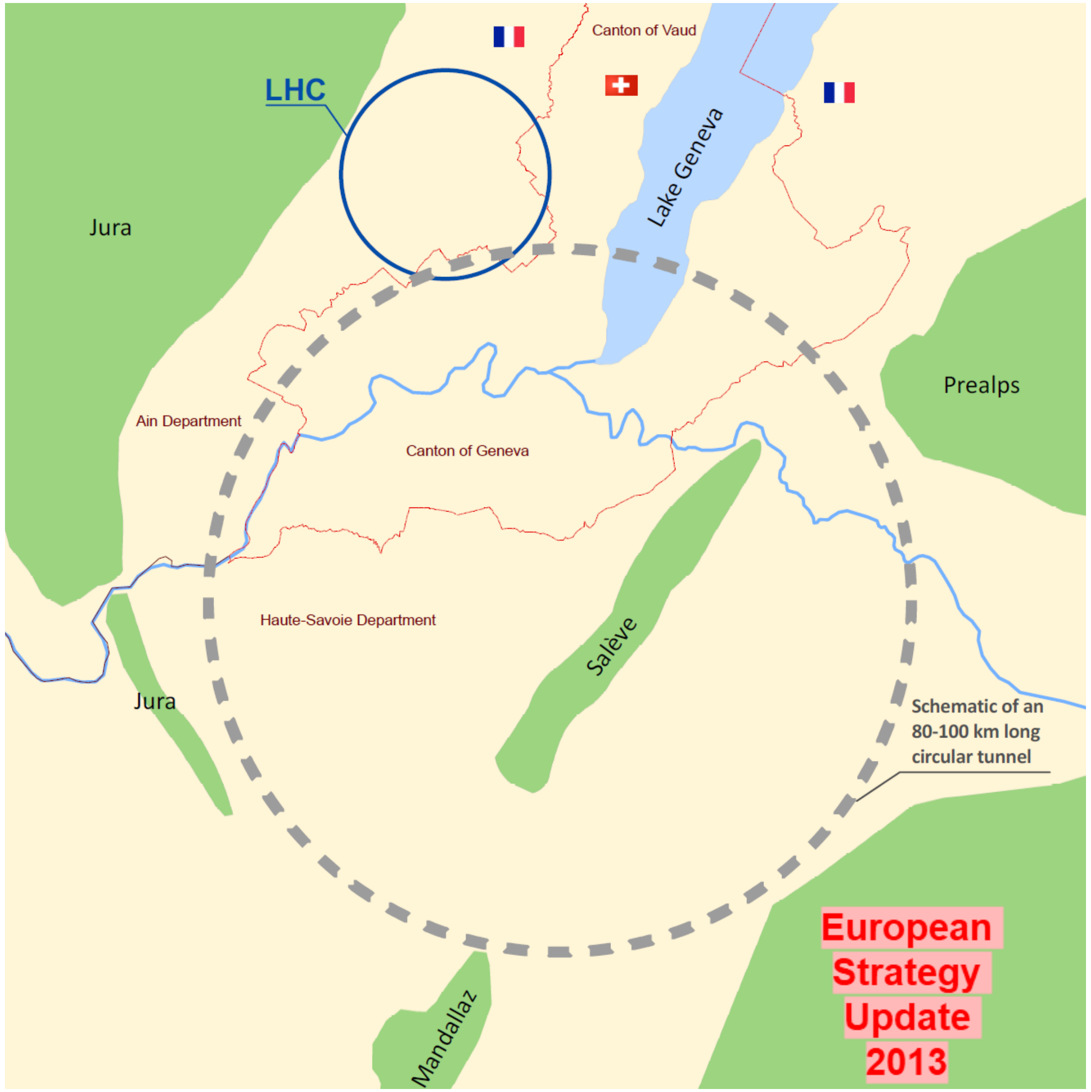
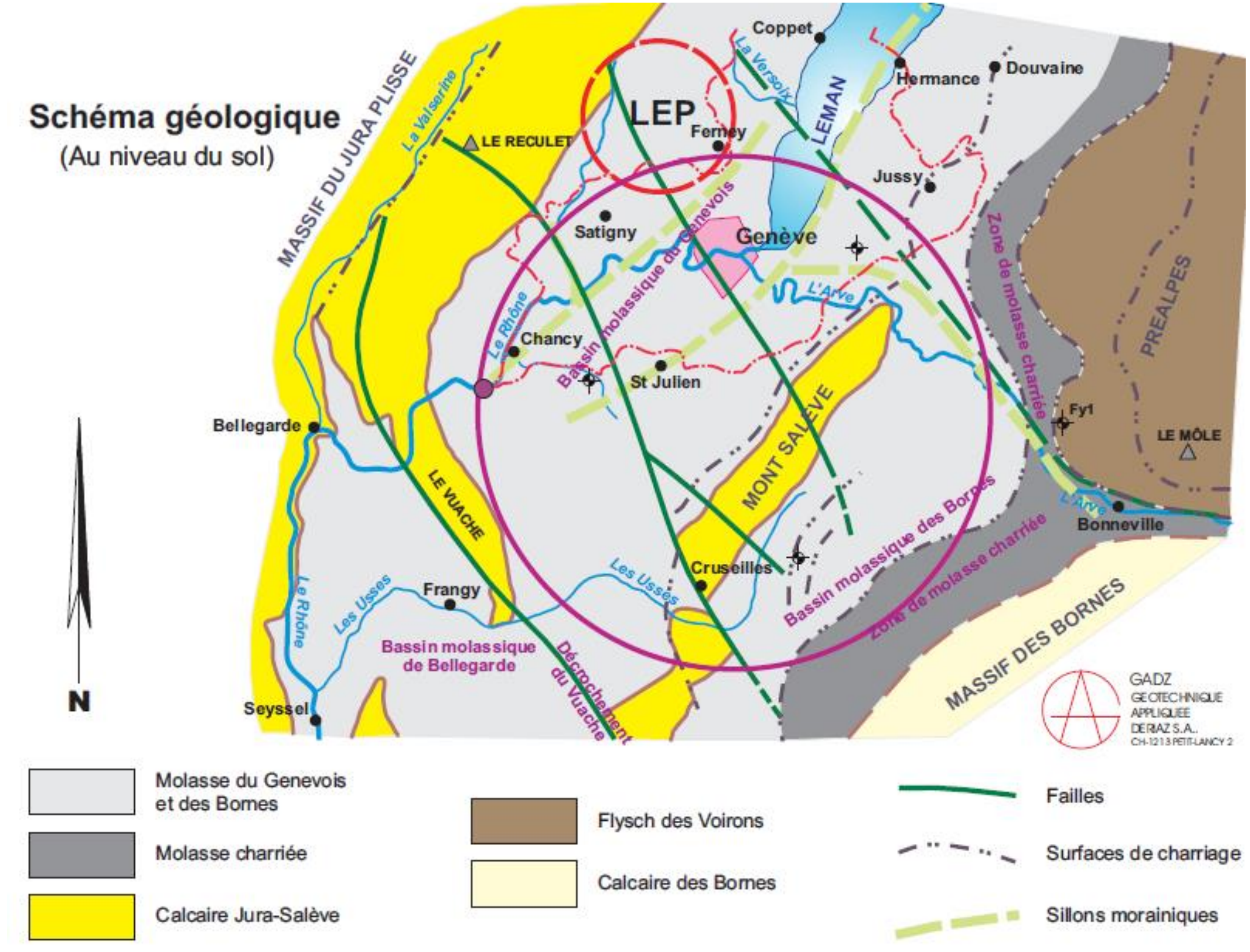
Collaborators To FCC study

The Future Circular Collider
Civil Engineering (CE) constraints

Collision energy:
 100TeV
Circumference:
 80km-100km
Physics considerations:
 Enable connection to the LHC (or SPS)
Construction:
 c.2030-2037
Aims of the civil engineering feasibility study:
 Is 80km-100km feasible in the Geneva basin?
 Can we go bigger?
 What is the 'optimal' size?
 What is the optimal position?



Geology in the FCC region



Main geological units:

Molasse

- Mixture of sandstones, marls and formations of intermediate composition
- Relatively weak rock (Average compressive strength: 5.5-48 Mpa)
- Considered good excavation rock
- Relatively dry and stable
- Faulting due to the redistribution of ground stresses
- Structural instability (swelling, creep, squeezing)

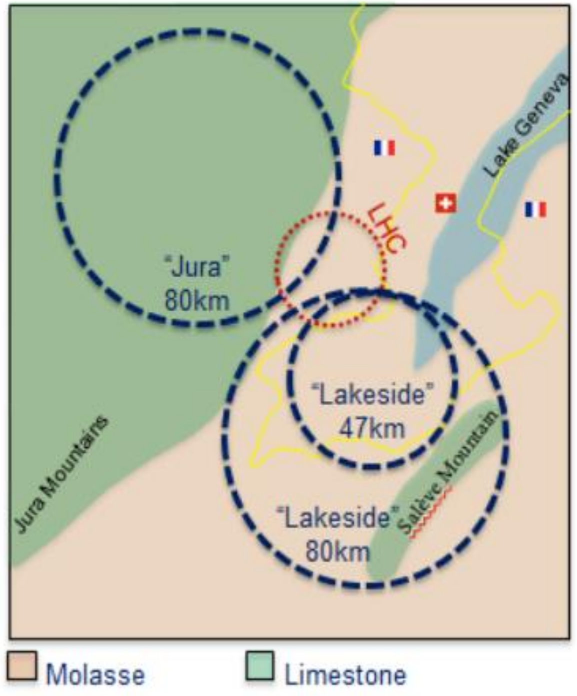
Moraines (Quaternary Deposits)

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

Limestone

- Hard rock
- Normally considered as sound tunneling rock
- In this region fractures and karsts likely present
- High inflow rates measured during LEP construction (600L/sec)
- Clay-silt sediments in water
- Rockmass instabilities

"Lakeside" vs "Jura" options in pre-feasibility stage



Tunnelling in limestone – one of the main civil engineering constraints!

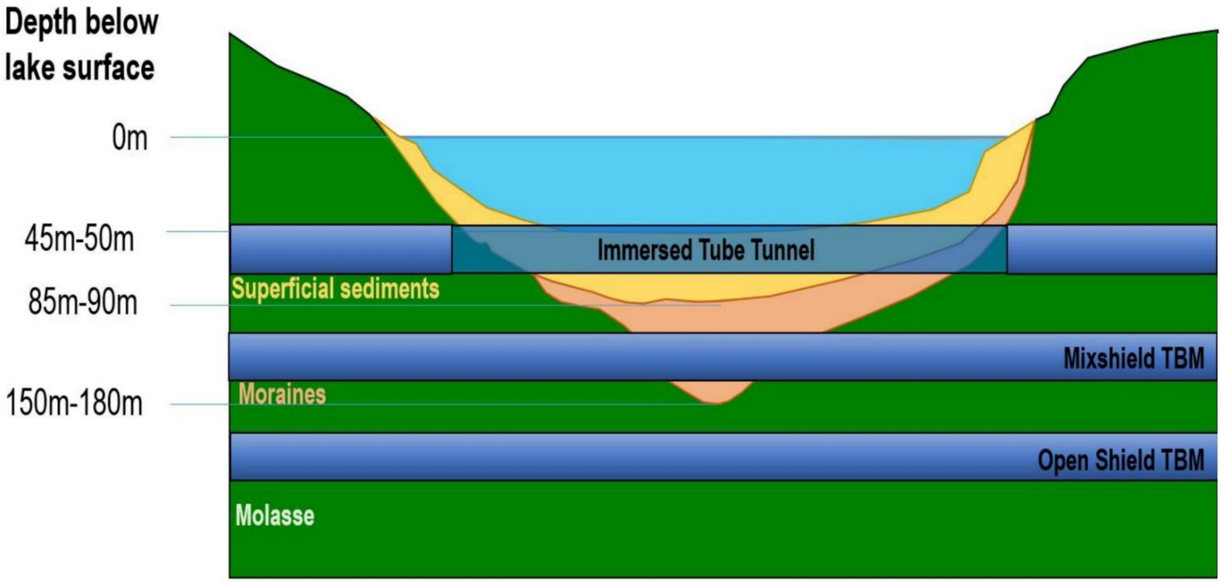
	Risk										
	water ingress	heaving ground	weak marls	hydro carbons	support & lining	ground response & convergence	hydrostatic pressure & drainage	Pollution of aquifers	effect of shafts on nature	effects of shafts on urban areas	**Total**
Jura 80	5	3	0	0	5	4	5	5	4	2	**33**
Lake 80	2	0	3	3	3	3	2	2	3	2	**23**
Lake 47	1	0	2	2	2	2	1	1	2	5	**18**

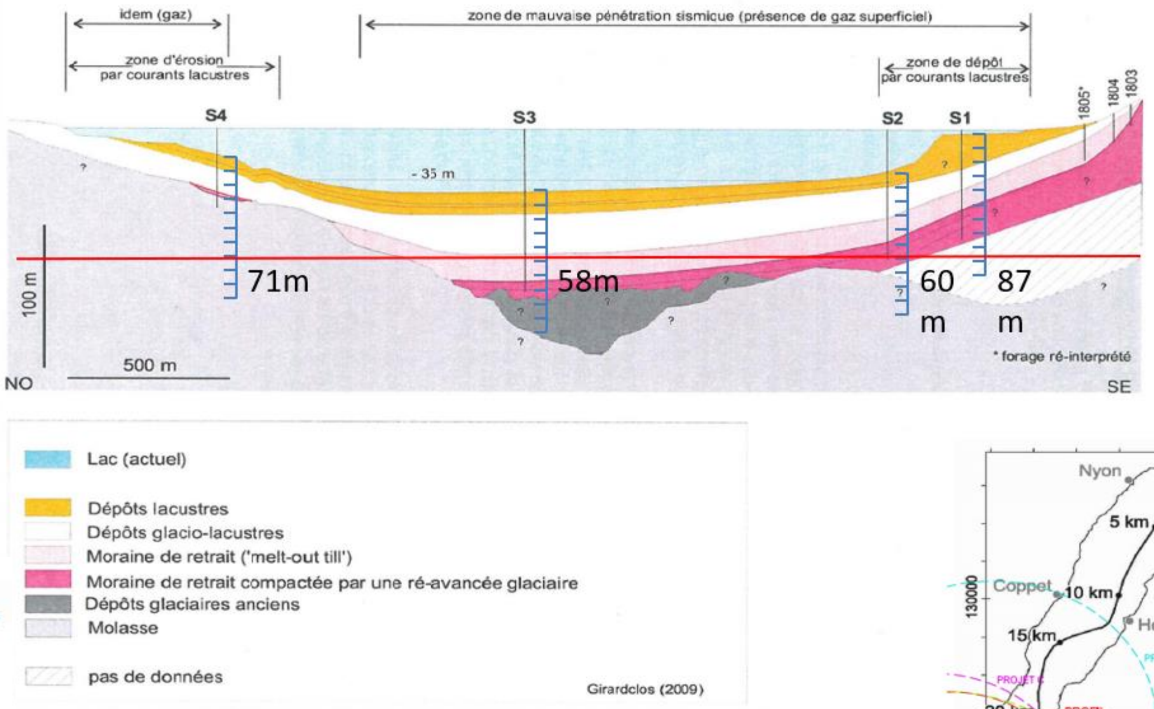
- Lakeside option selected to avoid Jura limestone due to previous issues experienced during LEP construction of sector 3-4
- Molasse considered as a good rock for tunneling.
- Good knowledge and experience from LEP construction in molasse.
- Spoil re-use was not the primary goal in the CE pre-feasibility studies

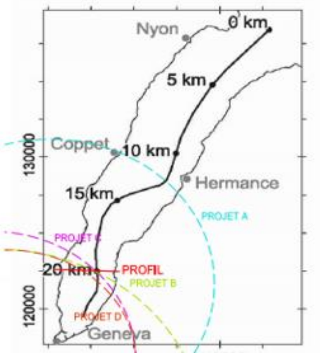
Water inflows during LEP construction

Civil engineering constraints

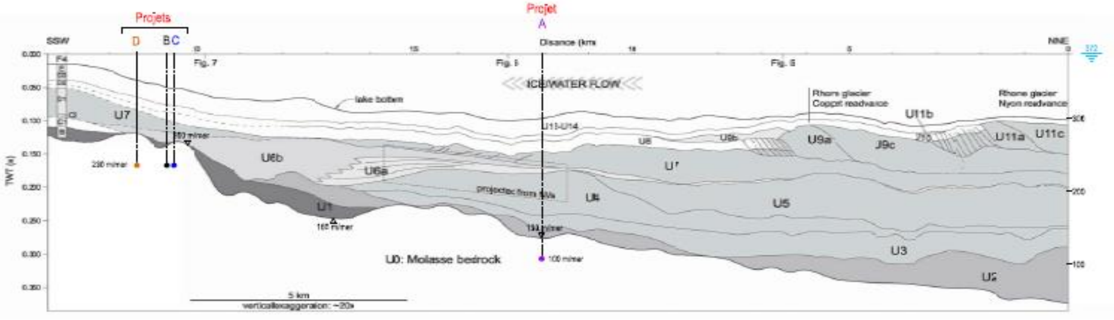
Tunnelling under Lac Léman







Profil géologique Lac Léman (Vengeron-Belotte)

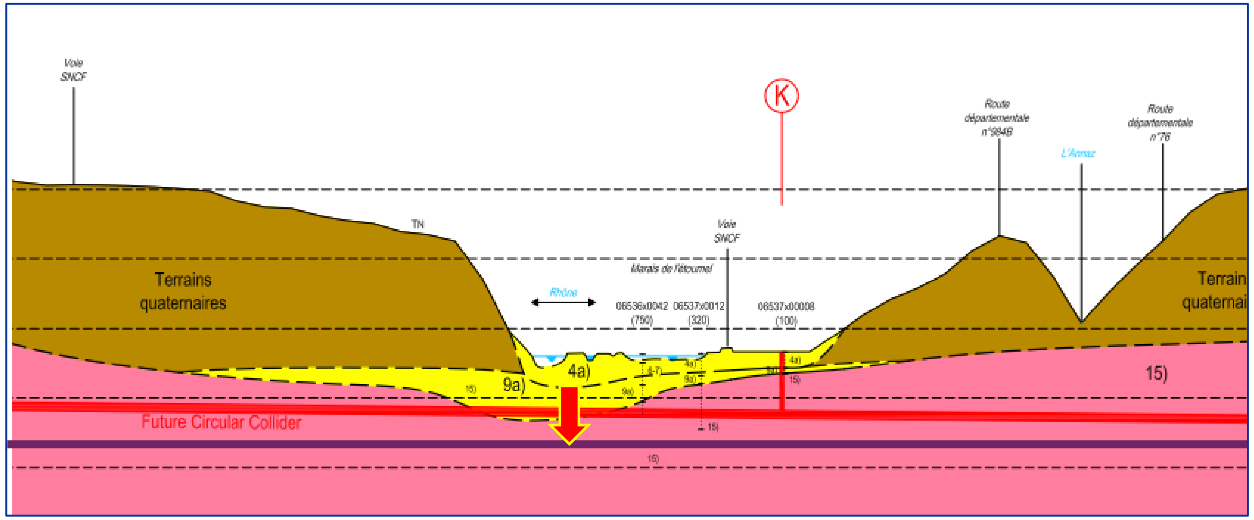


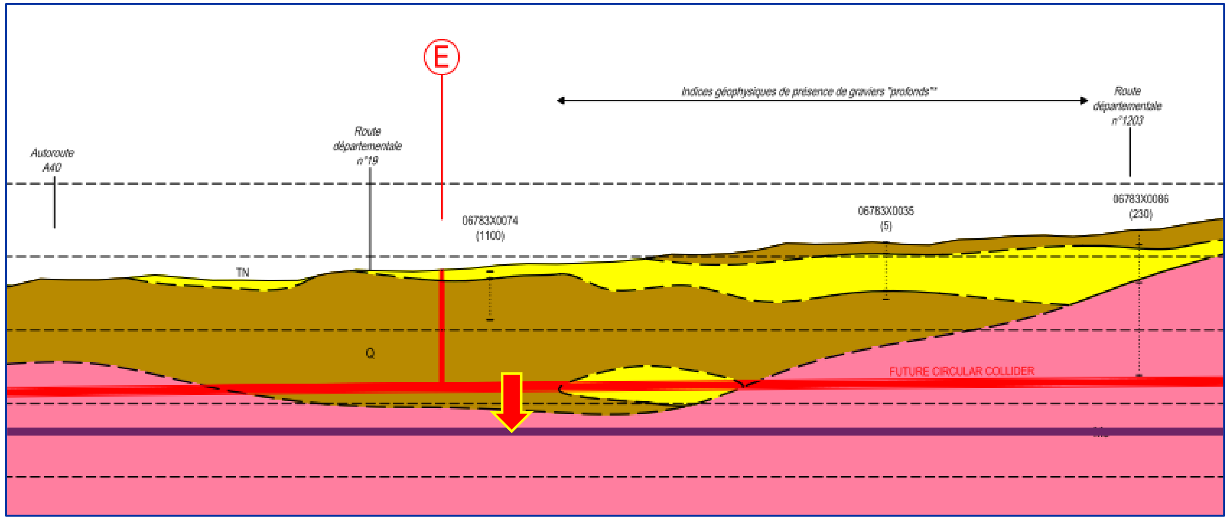
Profil synthétique longitudinal du Petit-lac

d'après Fiore-Giraclos et all. (2010)

Civil engineering constraints

Tunnelling under Arve Valley and Rhone Valley





- Data available from deep destructive drillings for water research in the vicinity of the crossing.
- Aquifers nearby Rhone valley

- Data available from oil surveys, destructive drillings and geological maps.

The alignment was lowered deep enough for the tunnel to sit in the molasse to avoid changing TBM mode for a relatively short distance, avoid placing large span caverns in saturated moraines and minimise the environmental risks.

FCC Study Boundary

The Study Boundary was defined by:
Jura
High overburden
Karstic limestone

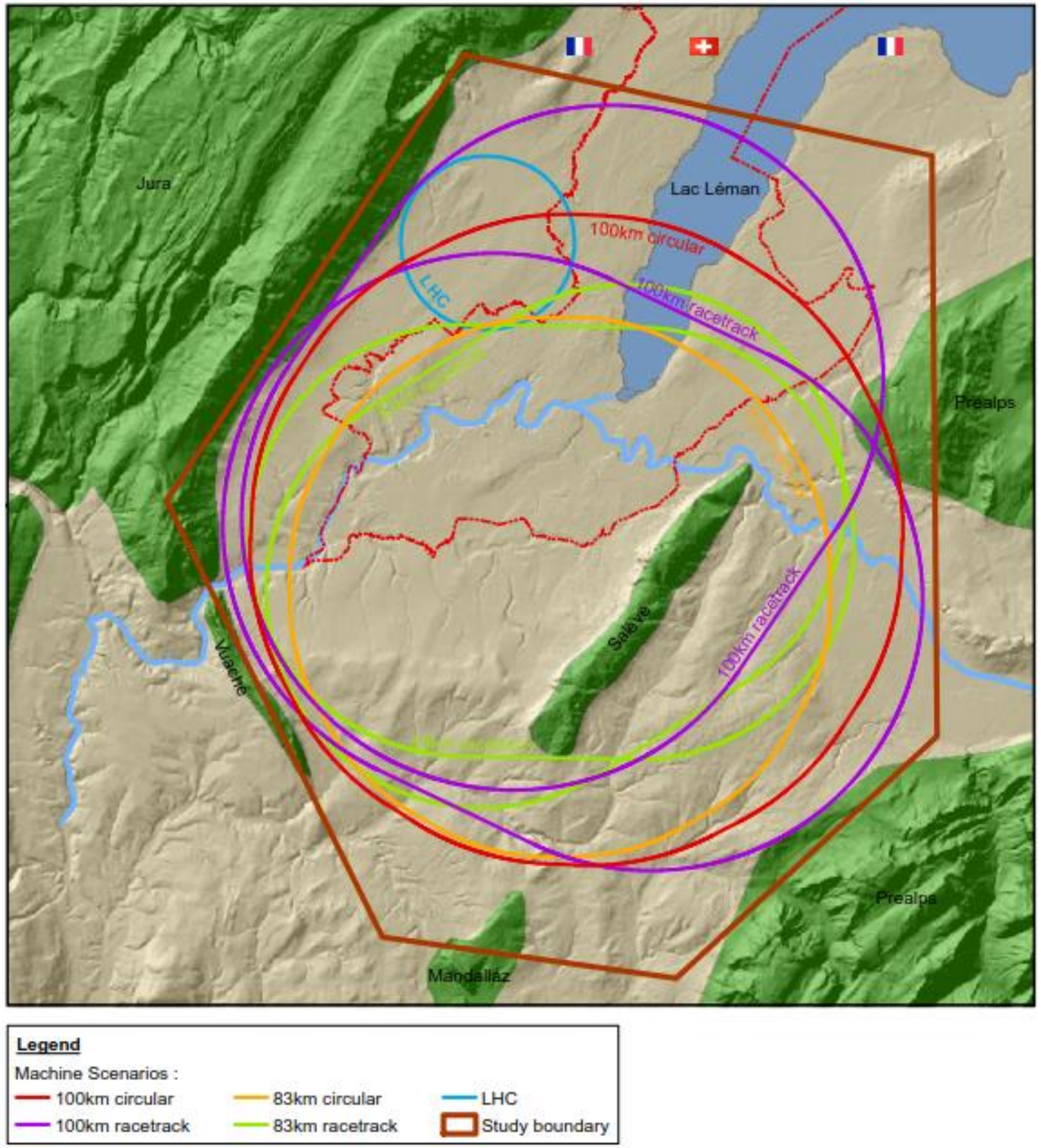
Vuache
Highly fractured limestone with karsts

Pre-alps
High overburden

Lac Léman
Lake depth increases quickly in NE direction

Connections to LHC

Multiple tunnel shapes and sizes studied within the boundary.



ARUP

Tunnel Optimisation Tool

(1) The location (x,y), depth (z), rotation (^{0}) and slope (%) can be changed for any of the stored tunnel shapes and circumferences

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

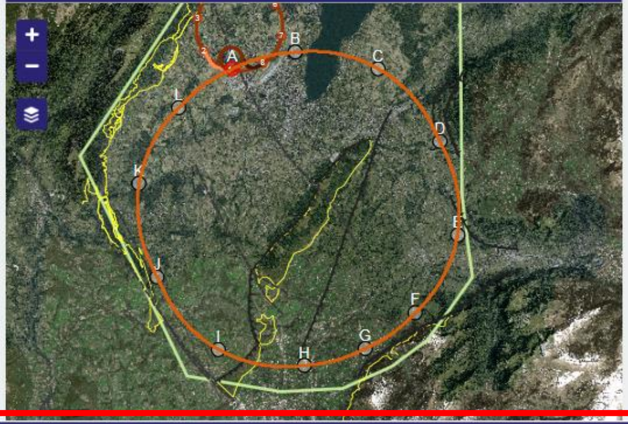
LOAD | CREATE | UPDATE | CALCULATE

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



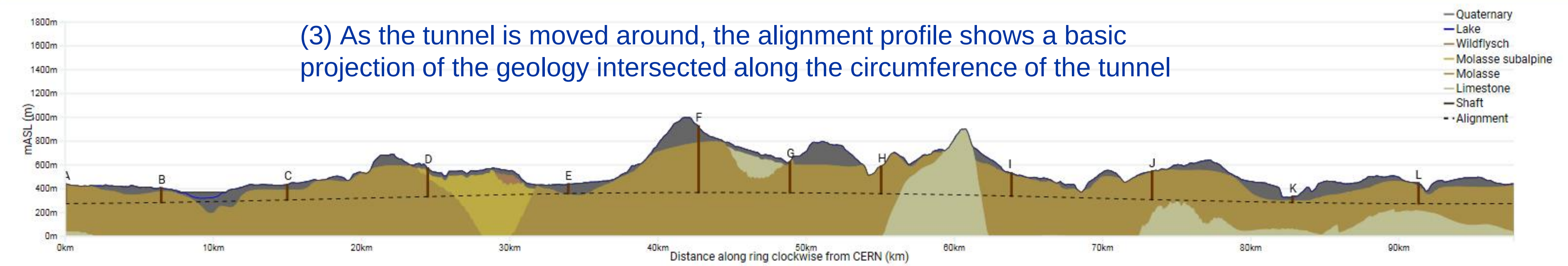
(2) Information about the shafts is given including their depth, the geology intersected by each shaft and the total shaft depth for each tunnel alignment

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

(3) As the tunnel is moved around, the alignment profile shows a basic projection of the geology intersected along the circumference of the tunnel

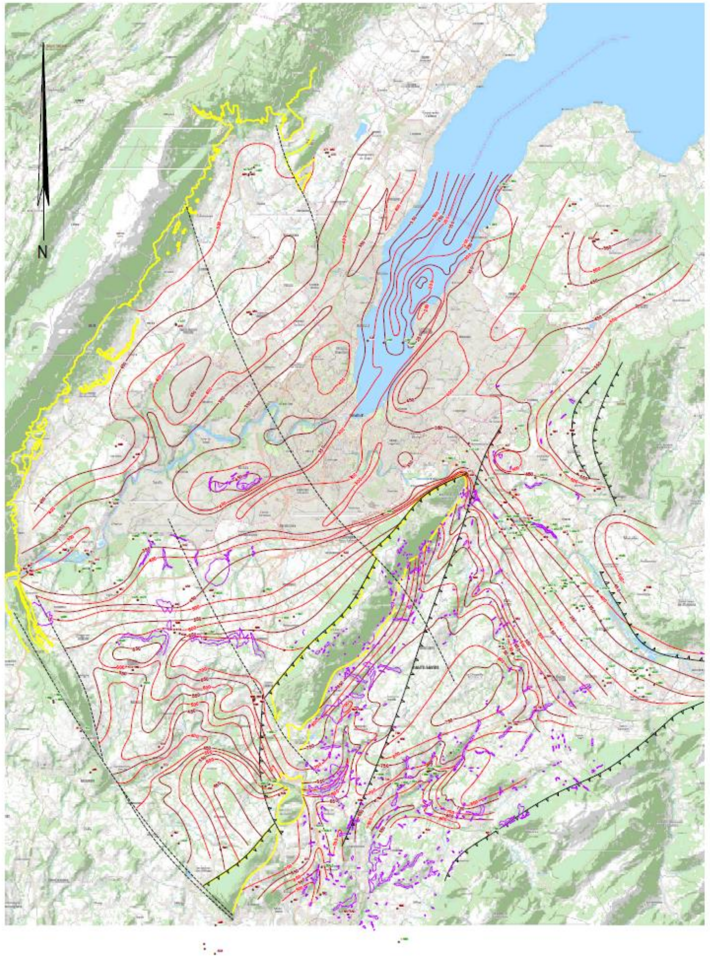


Geology Intersected by Tunnel | Geology Intersected by Section

(4) The percentage of each rock type intersected by the tunnel is given

Data interpretation and input into TOT

Molasse rockhead contours



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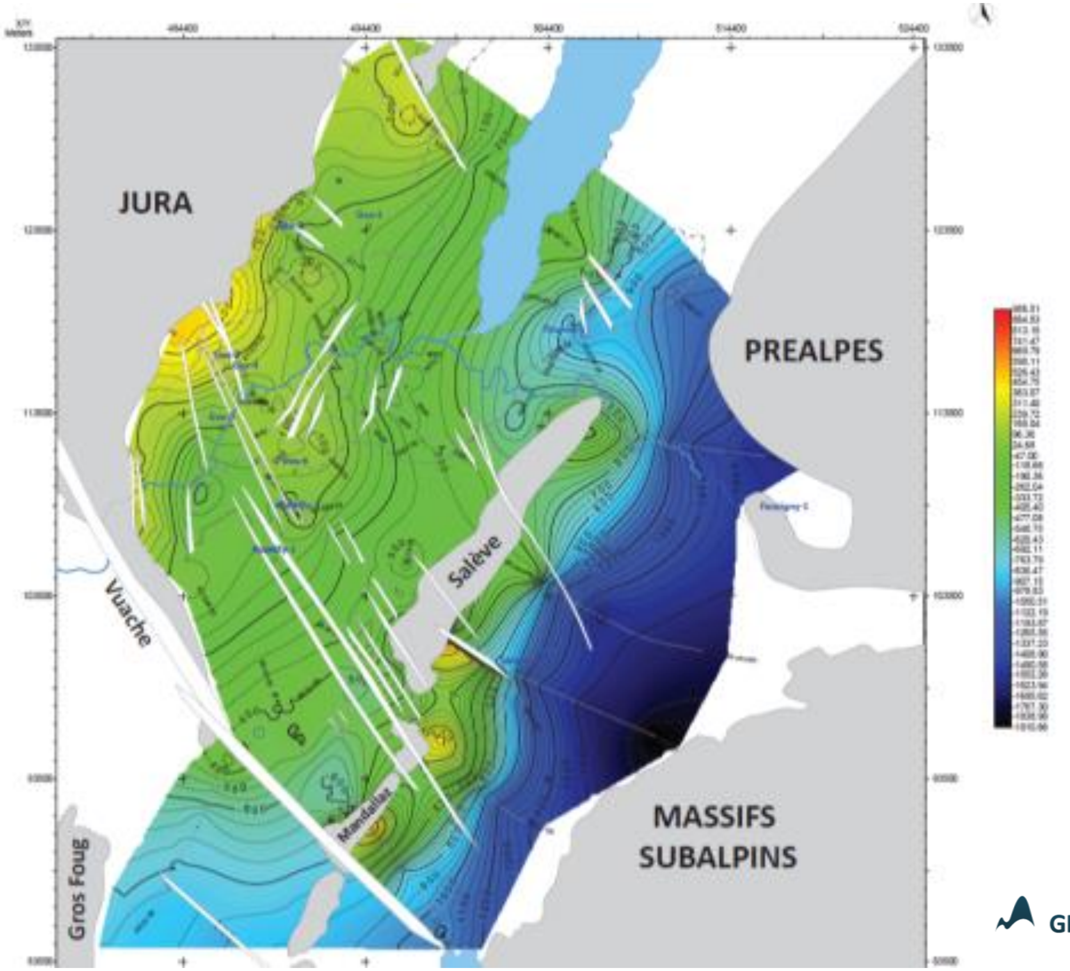
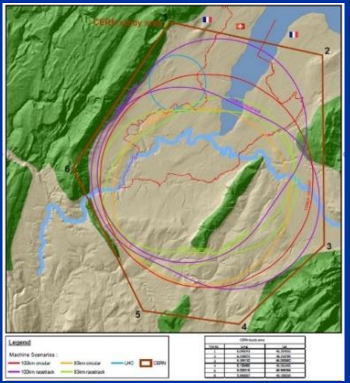
Limestone rockhead contours

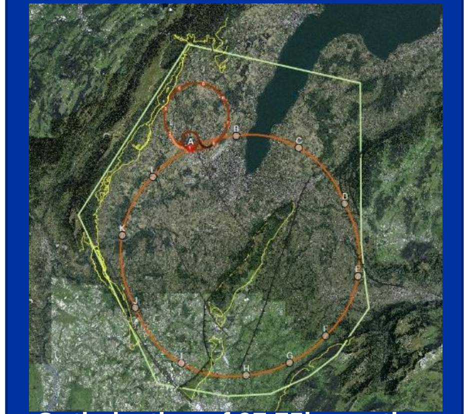


Overview of tunnel alignment development

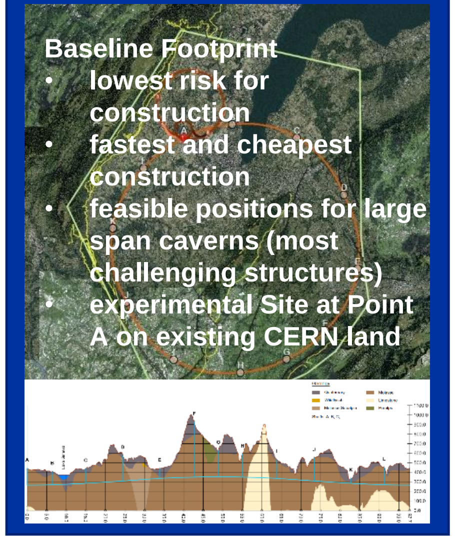
Kick-off meeting, Geneva 2014



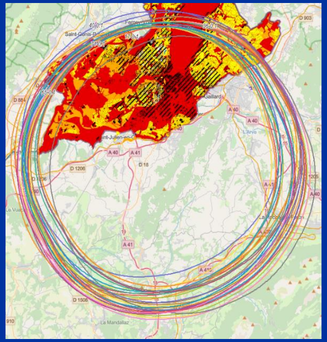
Multiples shapes (racetracks and quasi-circulars) and sizes considered within the study boundary
80km, 87km, 93km, 100km



Optimisation of 97.75km option, intersecting the LHC in plan view and fitting within geological constraints

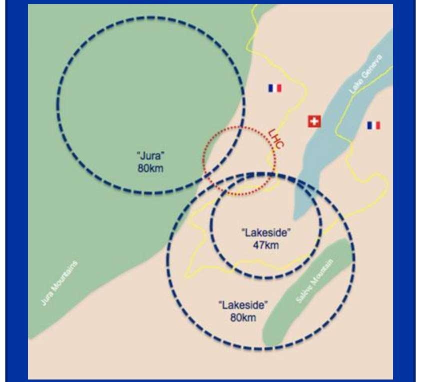


Baseline Footprint
- lowest risk for construction
- fastest and cheapest construction
- feasible positions for large span caverns (most challenging structures)
- experimental Site at Point A on existing CERN land

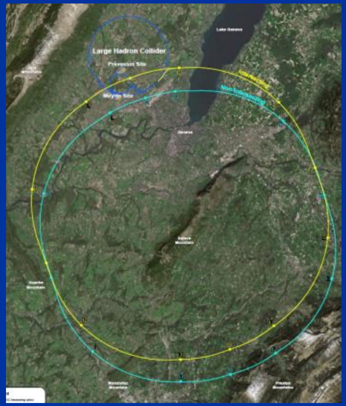


- Surface sites placement optimization;
- Civil Engineering review in TOT of various scenarios varying between 91 – 100 km circumference;
- Development of a GIS database for FCC

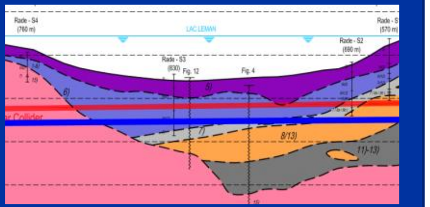
European Strategy Update 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | European Strategy Update 2020 | 2020



80km ''Jura''
80km ''Lakeside''
47km ''Lakeside''



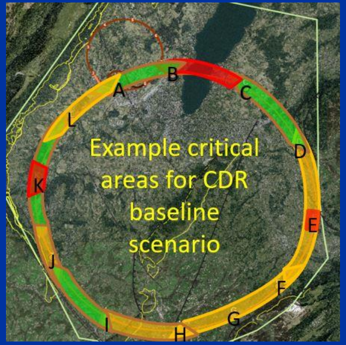
Decision to focus on 100km options
Intersecting vs non-intersecting



Alignment update following geological review of key areas such as lake crossing

CDR volumes submitted to European Strategy update for Particle Physics

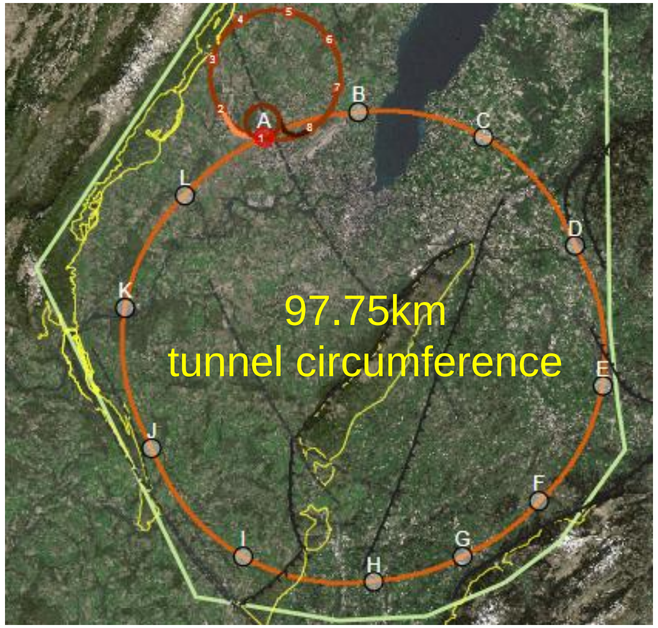
- ILF/GADZ study Kick-off for definition of High-Risk Areas;
- Collaboration with UNIGE to develop a 3D subsurface model

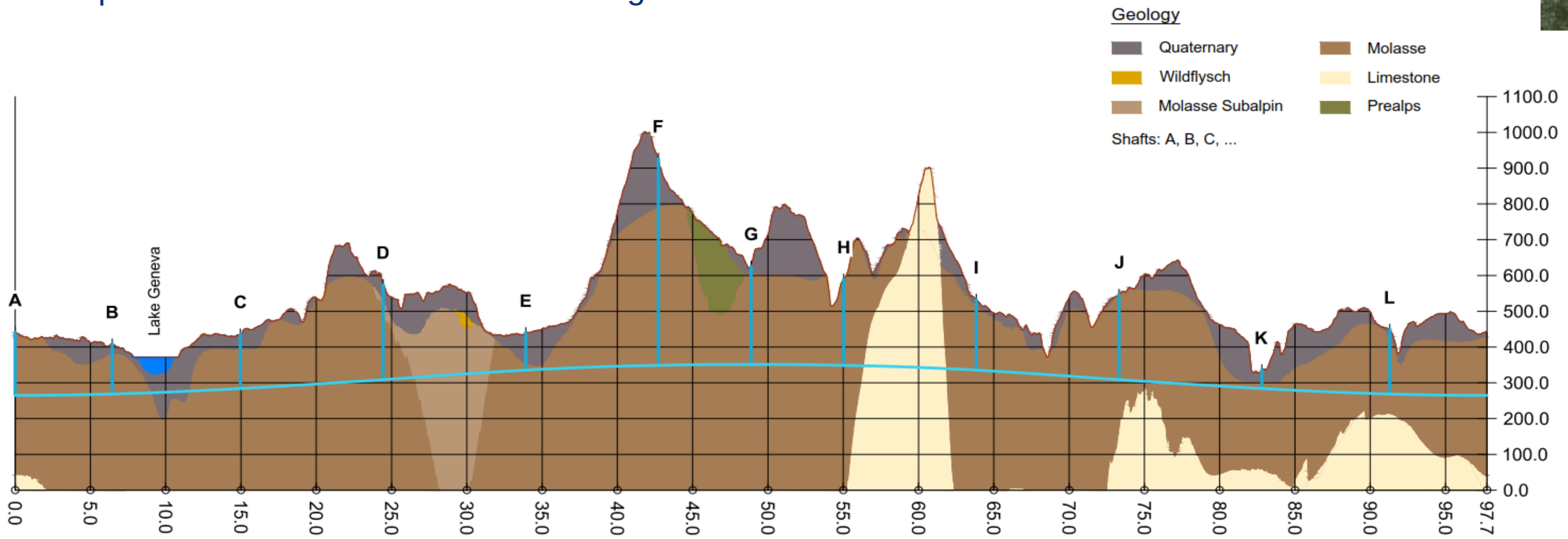


Conceptual design footprint

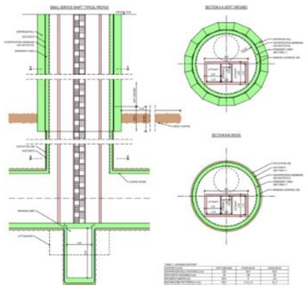
Present baseline position was established considering:

- lowest risk for construction
  - ✓ Avoid Jura limestone and the Pre-Alps
  - ✓ Only one sector containing limestone. ~90 % molasse – suitable ground for tunneling
  - ✓ Significantly reduced total shaft length. Deepest shaft at PF proposed to be replaced with an inclined tunnel
  - ✓ Avoids extremely large overburden.
  - ✓ 0.3% slope
- feasible positions for large span caverns (most challenging structures)
- experimental Site at Point A on existing CERN land.



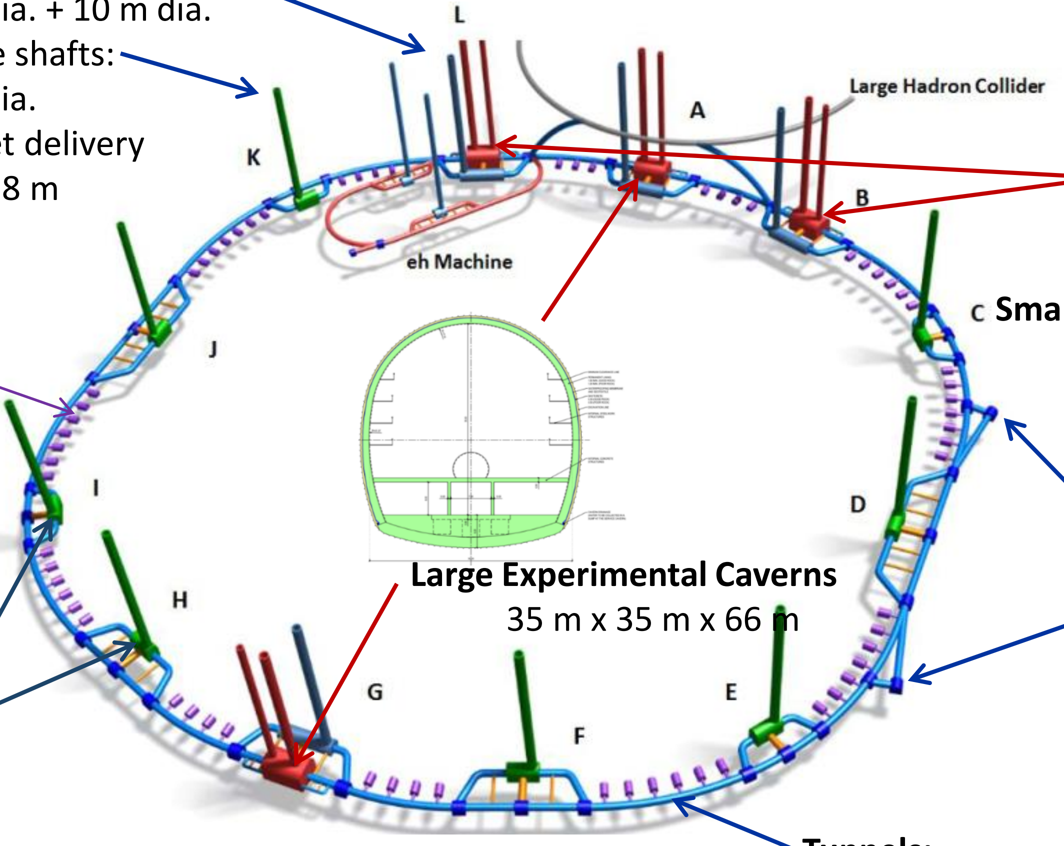


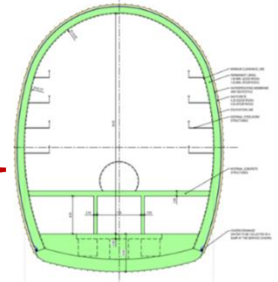
FCC Overview of Underground Structures Conceptual design



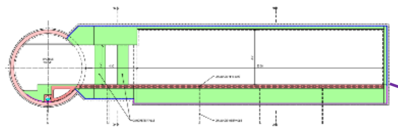
Shafts:
Experimental Shafts:
15 m dia. + 10 m dia.
Service shafts:
12 m dia.
Magnet delivery
shaft:18 m

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



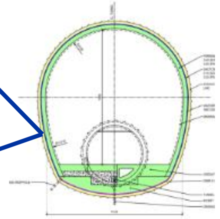


Small Experimental Caverns
30 m x 35 m x 66m

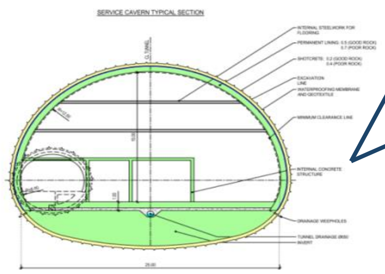


Alcoves
- 25 m x 6 m x 6 m
- Located at 1.5km spacing

Large Experimental Caverns
35 m x 35 m x 66 m



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

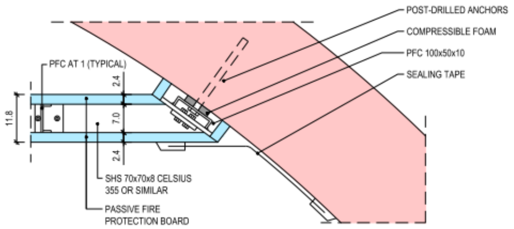


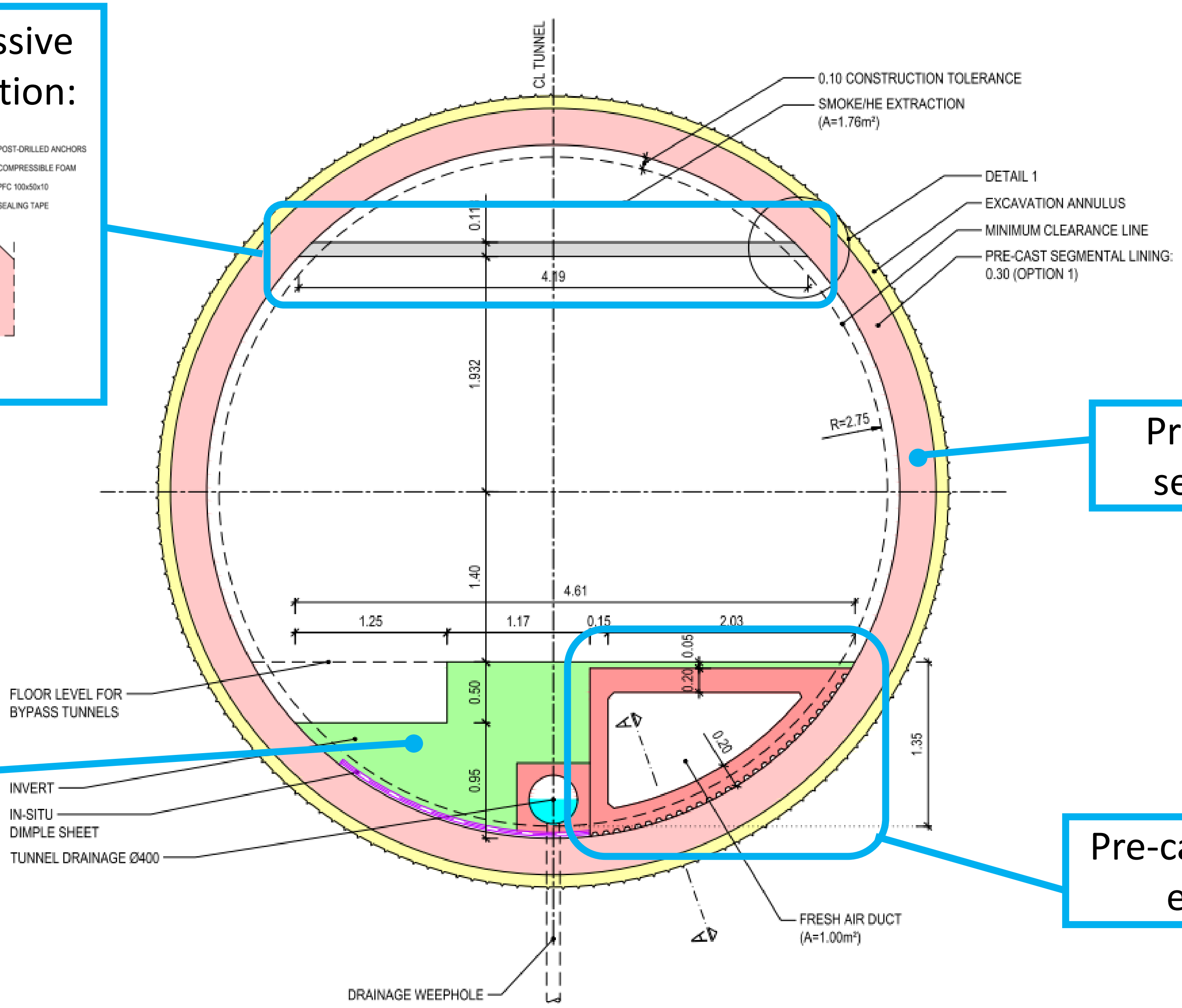
Service Caverns
- 25 m x 15 m x 100 m

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

Typical tunnel cross-section

Steel structure with passive fire protection. Connection:



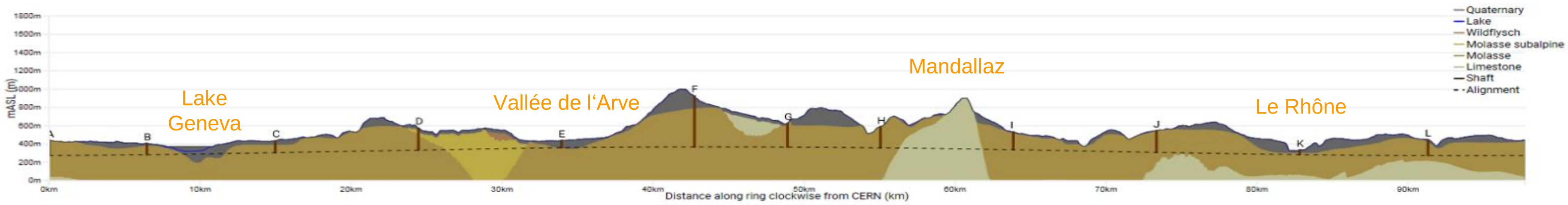


Pre-cast concrete segmental lining

Cast-in-situ concrete invert

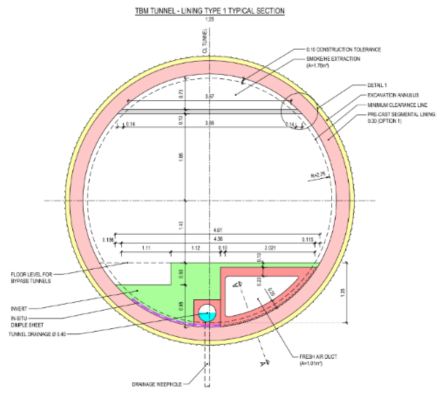
Pre-cast concrete element

Tunnel lining conceptual design



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

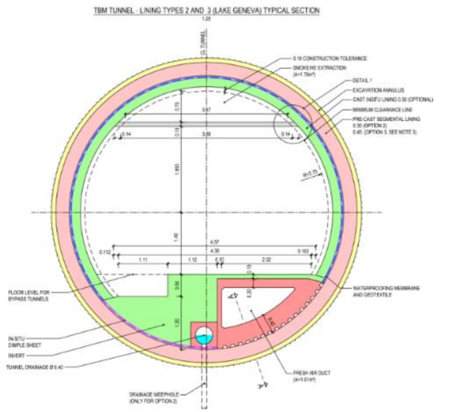
Lining Type 1



TBM tunnel in 'good' molasse

30cm thick pre-cast segmental lining

Lining Type 2 & 3



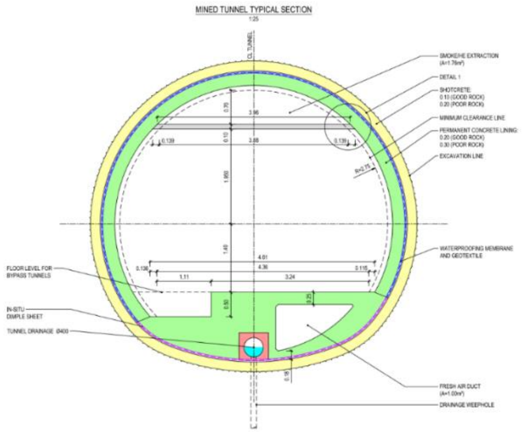
Lining types 2

- TBM tunnel in jointed molasse with high risk of groundwater infiltration
- Precast concrete thickness: 30cm

Lining type 3 (under Geneva Lake)

- Precast concrete thickness: 45cm
- Segments with higher steel bar density

Lining type 4



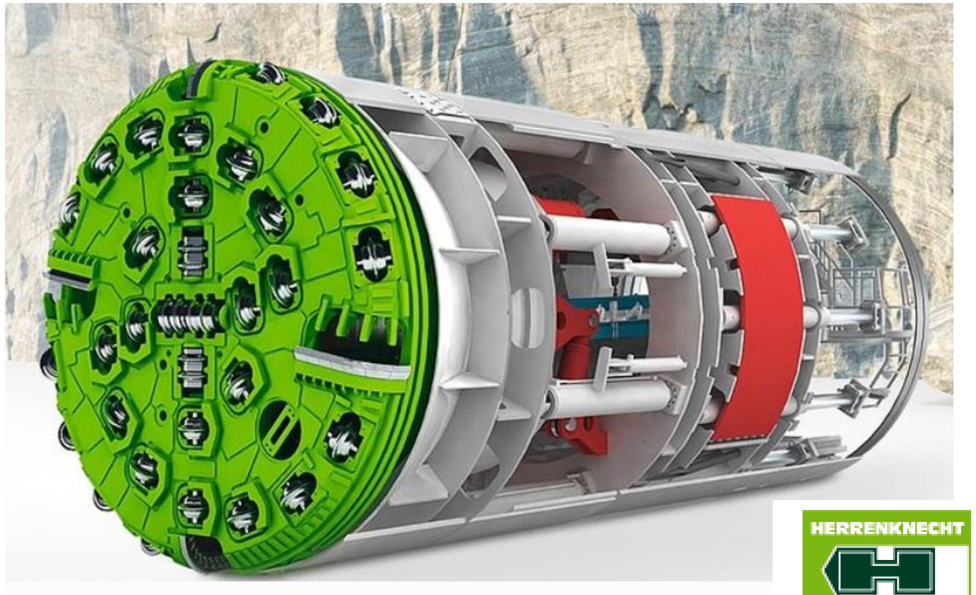
Mined tunnels in limestone

- 10cm shortcrete + 20cm thick cast-in-situ lining in poor rock
- 20cm shortcrete + 30cm thick cast-in-situ lining in good rock

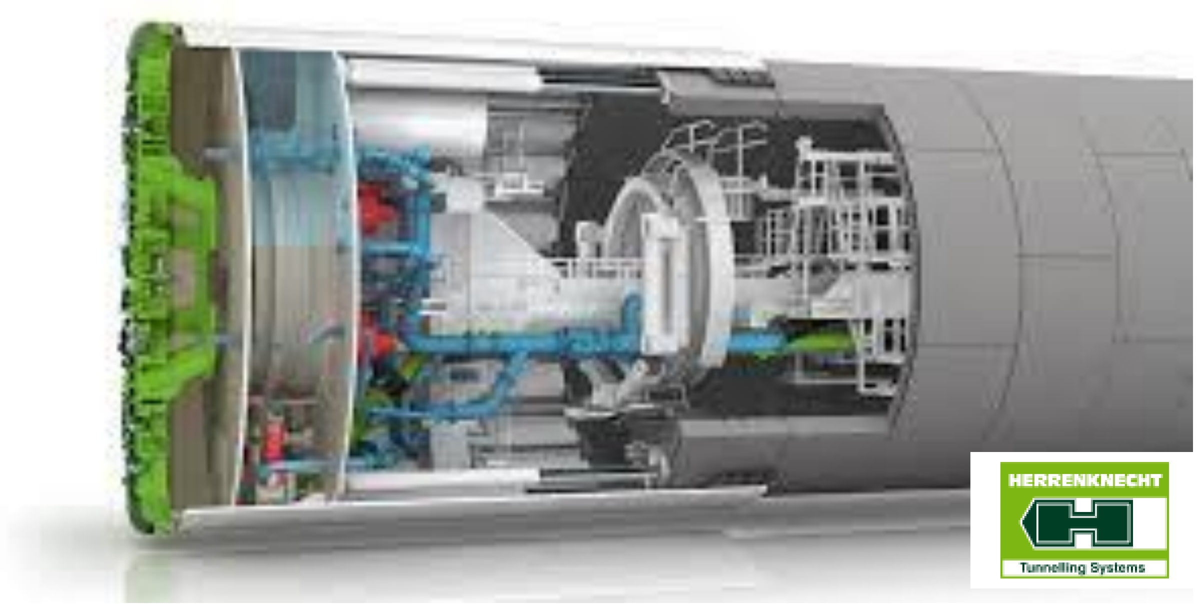
LEGEND:

- 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)

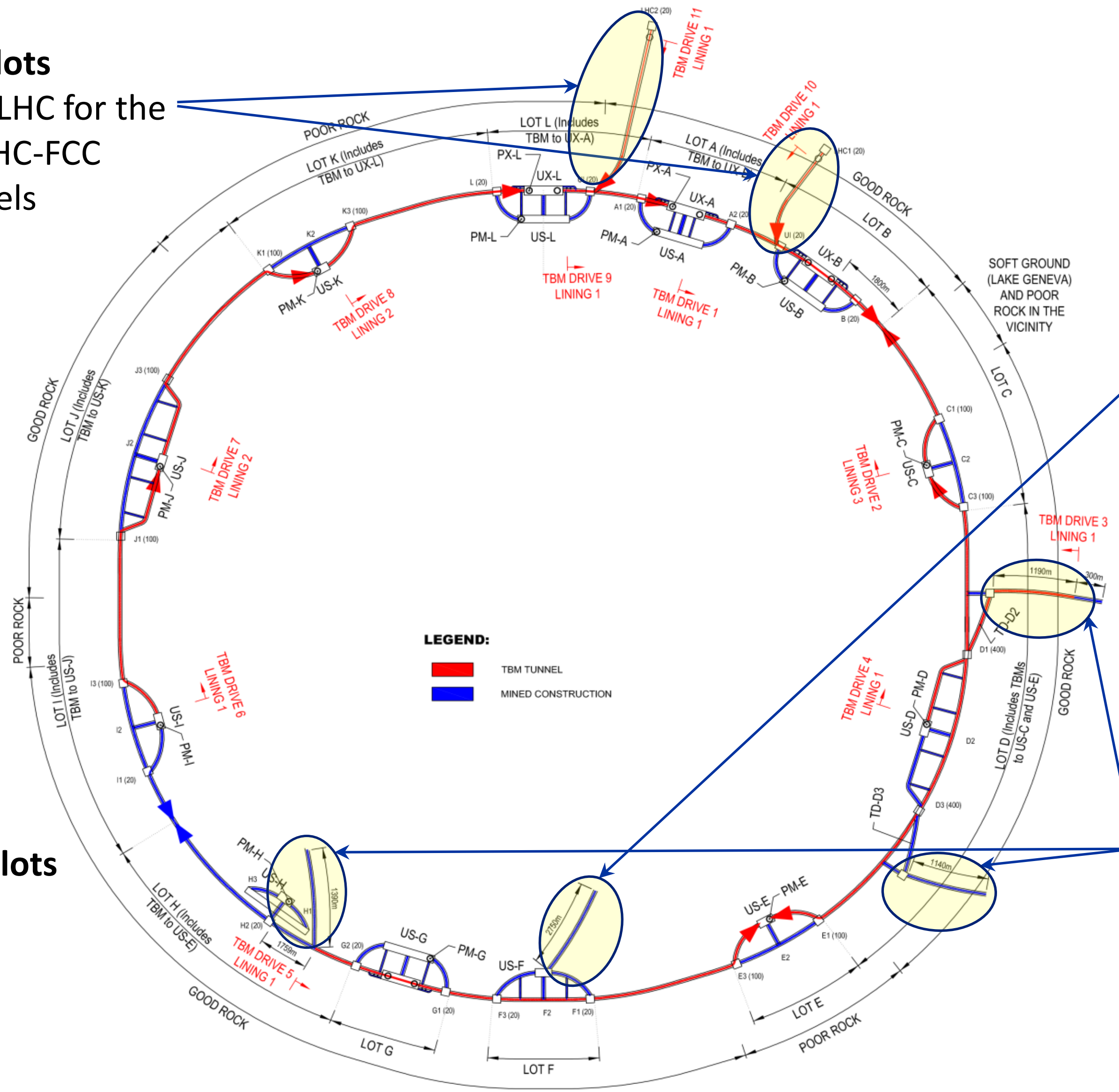
(For LEP and LHC works 'Gripper' and 'Double shield' TBM's were deployed)

Construction Strategy

CONSULTING ENGINEERS

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

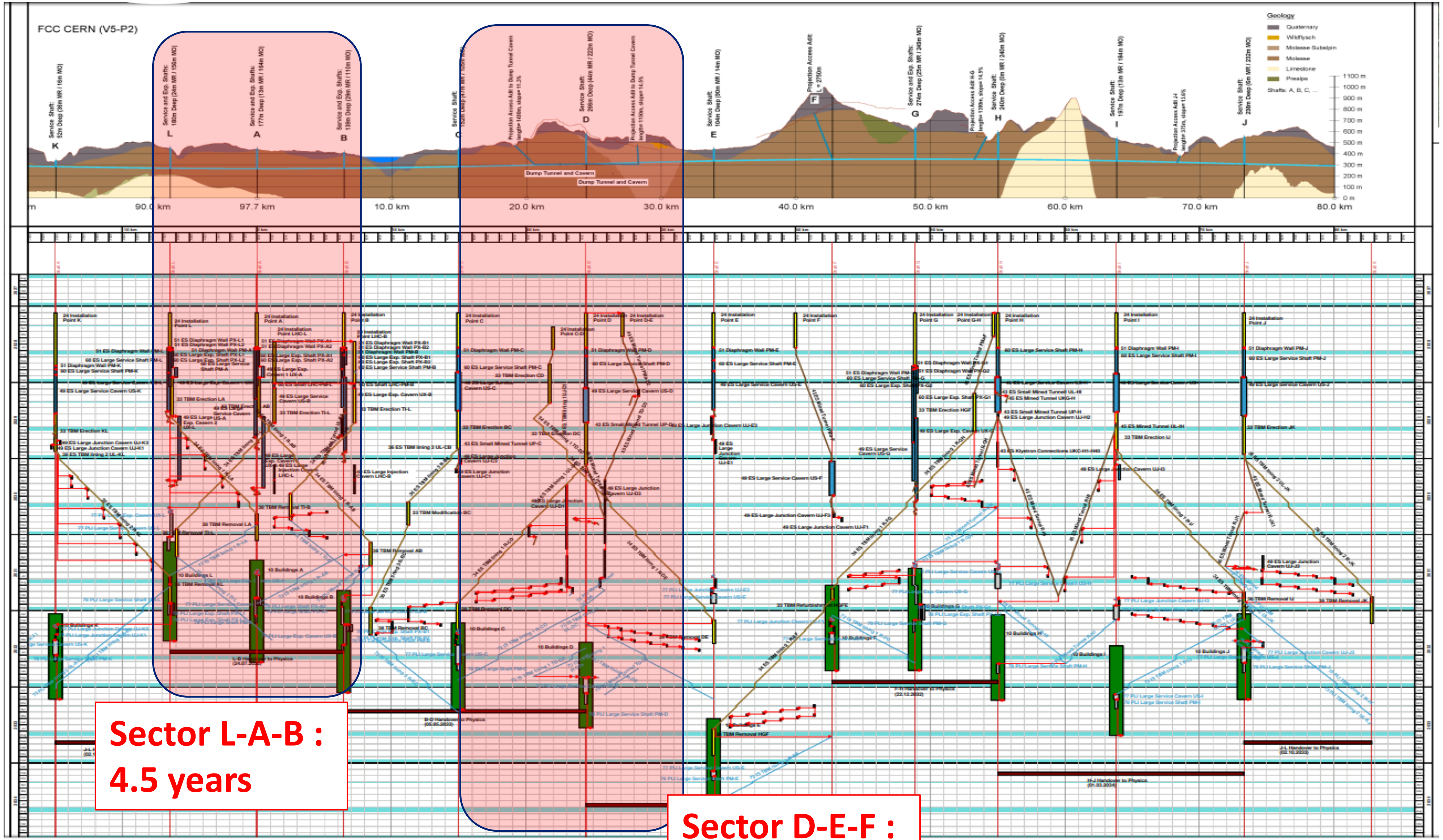
- necessary to cope with overall time schedule to meet deadlines for machine installation

Project divided in 12 construction lots

Construction techniques:

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

Construction Schedule (CDR)



Sector L-A-B :
4.5 years

Sector D-E-F :
6.5 years

ILF CONSULTING ENGINEERS

Civil engineering objectives for the Next European Strategy

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 -* ***10-15 MCHF budget***
- ***Feasibility Study Report*** *including design and cost and schedule updates*

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*

The Civil Engineering team is looking only at the underground constraints and not surface sites!

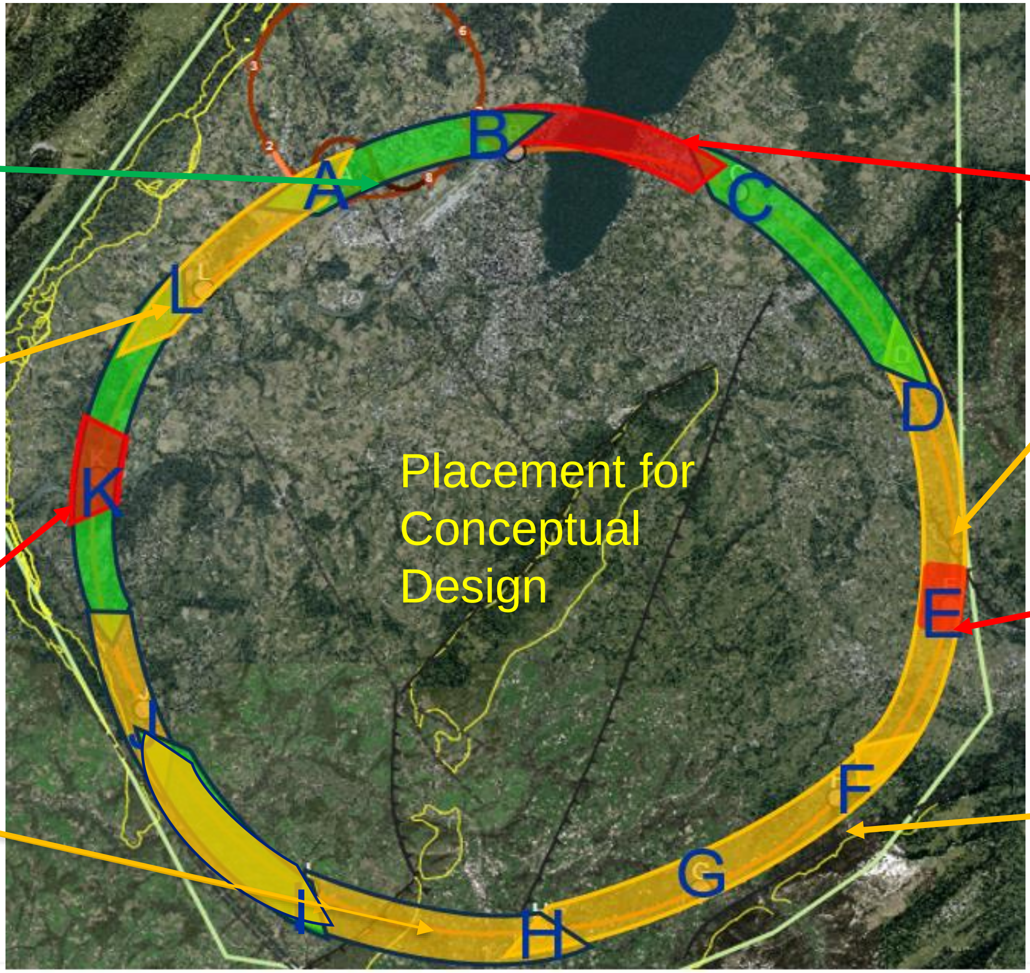
Geological uncertainty and high-risk areas

- Reliable information near to CERN from previous experience on LEP/LHC.
- Multiple deep boreholes in the area.

- Alignment close to limestone rockhead
- Limestone/molasse interface undefined.

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

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

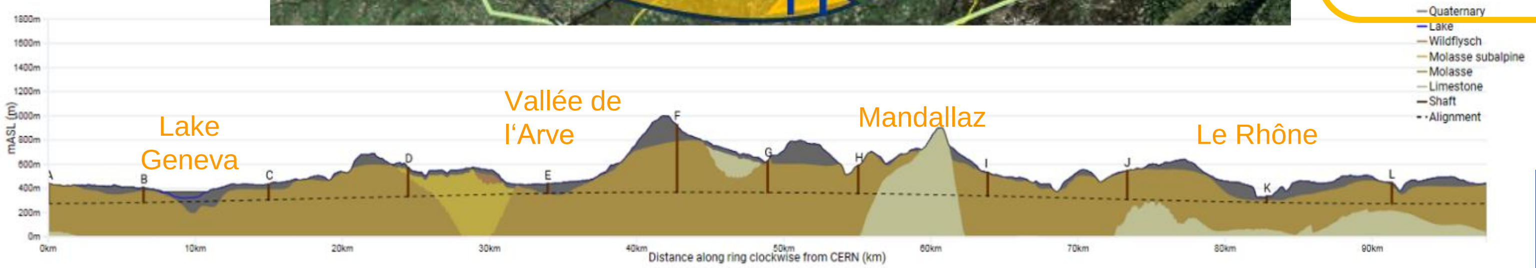


Lake Geneva
- Very few seismic and borehole information for lake crossing from proposed road tunnel, but layered nature of lake bed leads to uncertainty.
- Reliable borehole data missing.

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

Arve Valley
- Moraine/molasse interface not certain, cavern close to interface.

- No deep borehole information available in the area.
- Complex faulted region.
- Geotechnical parameters for molasse need to be confirmed for large span caverns.



ILF/GADZ study of High-Risk Areas

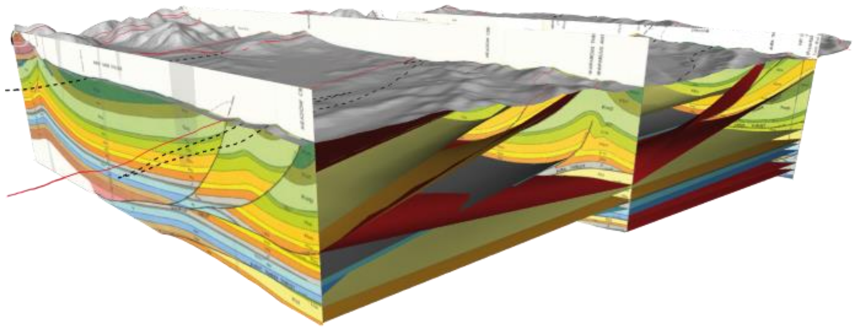
ILF/GADZ High Risk Areas SI preliminary study (November 2020 – August 2021)

- **Definition of 'high risk areas'** for the preferred scenario(s)
- **Input into footprint exploration** –Comparison of scenarios and Geological Risks Assessment
- 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
- **Input into the Technical Specifications to define the Scope of Services for the SI Consultants** and cost estimate and schedule of the deliverables of SI Consultants
- Expert advice from GADZ – local geological expert with previous experience at CERN, LEP and LHC

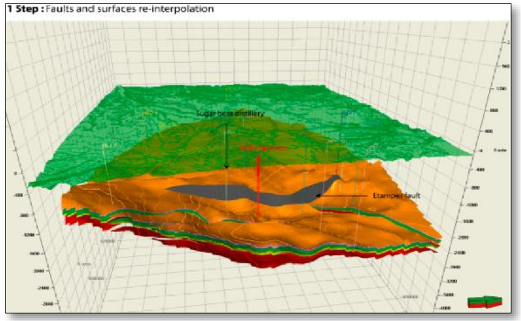
- ILF/GADZ study is focused on the construction risks for underground works and not the impact on machine operations or the environmental impact

UNIGE geological model

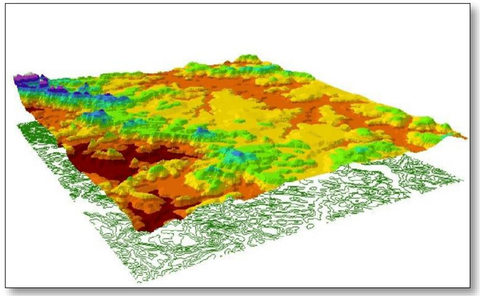
Collaboration with University of Geneva to develop a 3D geological model (October 2020 – August 2022)



Petrel

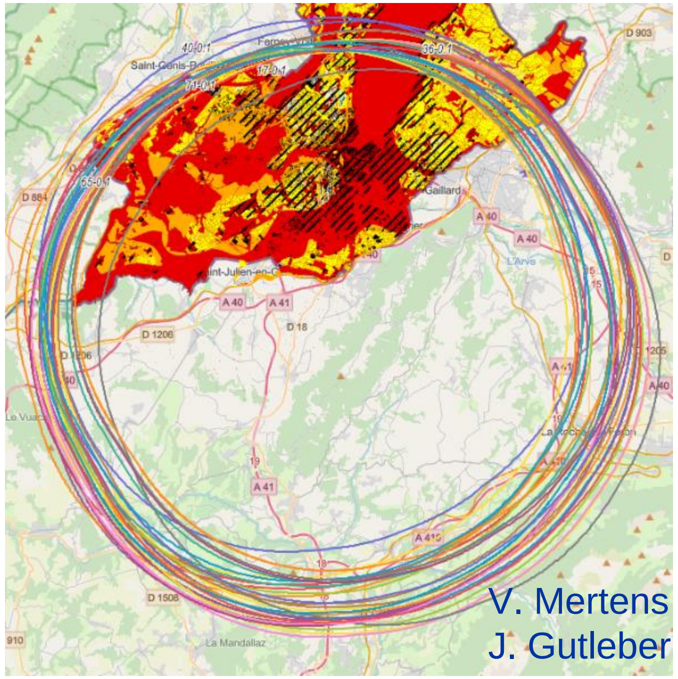


ArcgisPro



- Received an updated molasse and limestone rockhead maps
- Updated fault lines layers
- Ongoing analysis of new boreholes and data integration in the model
- New acquisition of BRGM seismic lines and re-processing

Footprint Exploration



V. Mertens
J. Gutleber

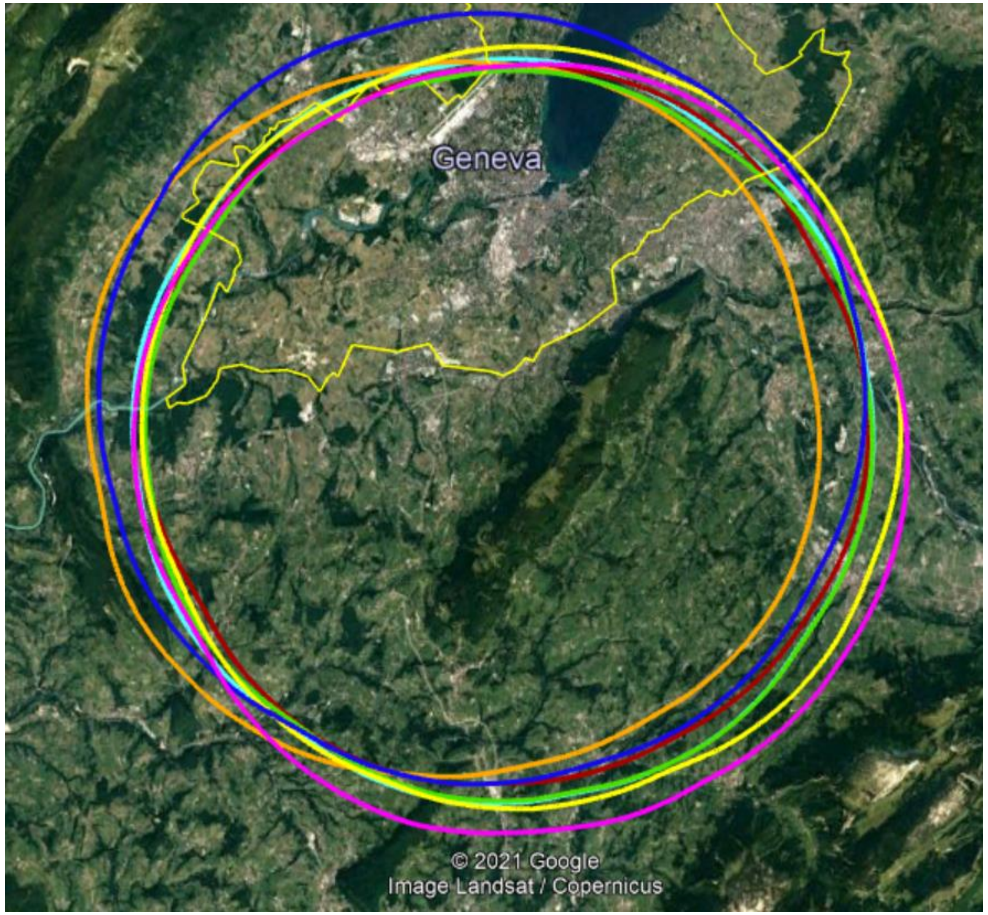
- Surface sites placement optimization – environmental, administrative and legal requirements from the host states.
- **Input from civil engineering is essential to evaluate the feasibility of tunnel alignments and caverns and shaft locations**
- Currently still using **TOT (Tunnel Optimisation Tool)** to provide initial feedback on the suitability of the tunnel placement for each scenario**, elevation,** tilt, shafts depth, information for transfer lines design.
- TOT limitations: geological data uncertainties, difficult to make updates and maintain libraries, accuracy of geodetic survey conversions between TOT and other GIS tools, different reference coordinate systems need to be taken into account.
- The longitudinal profiles are then developed by ILF/GADZ using updated geological data provided by UNIGE (to be presented later by ILF/GADZ)

Scenarios reviewed at Placement studies workshop

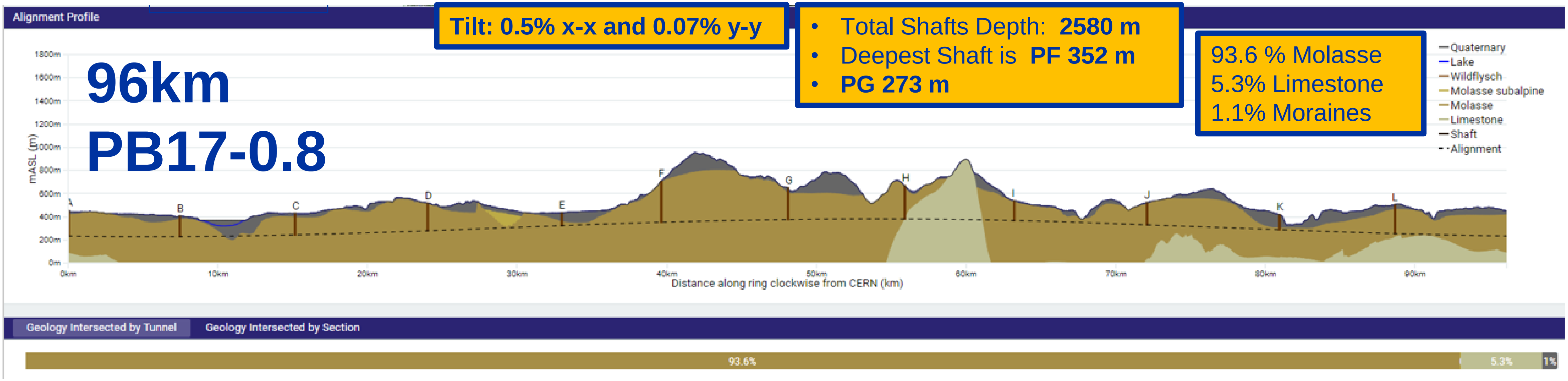
5 MAIN scenarios
Two scenarios with 12 points:
Three scenarios with 8 points:

Additional 2 scenarios evaluated by ILF/GADZ and recommended to avoid because they intersect the Vuache and Jura limestone.

The aim is to identify one feasible scenario before starting tendering for SI.



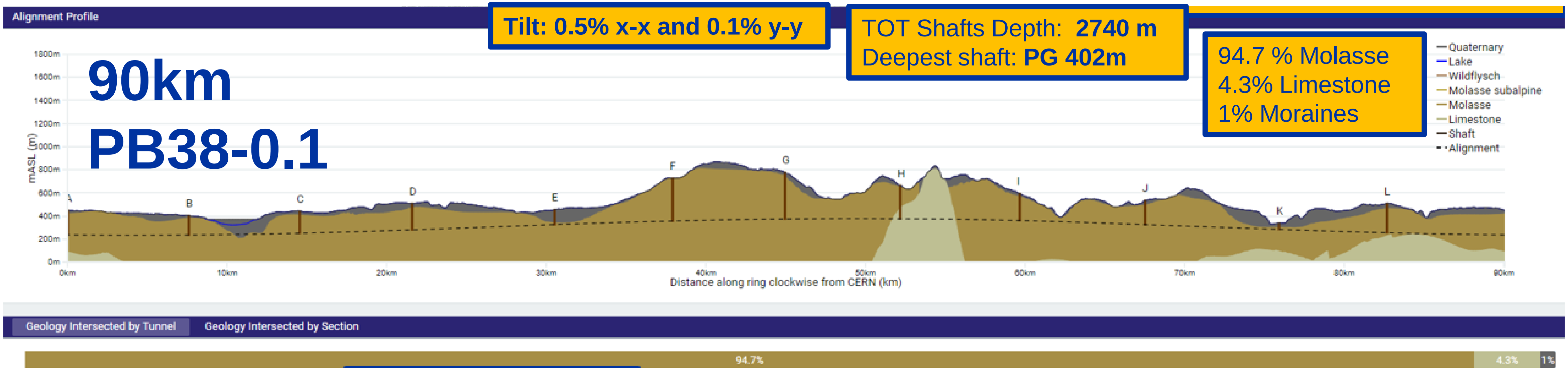
Two scenarios with 12 points



Tilt: 0.5% x-x and 0.07% y-y

- Total Shafts Depth: **2580 m**
- Deepest Shaft is **PF 352 m**
- **PG 273 m**

93.6 % Molasse
5.3% Limestone
1.1% Moraines

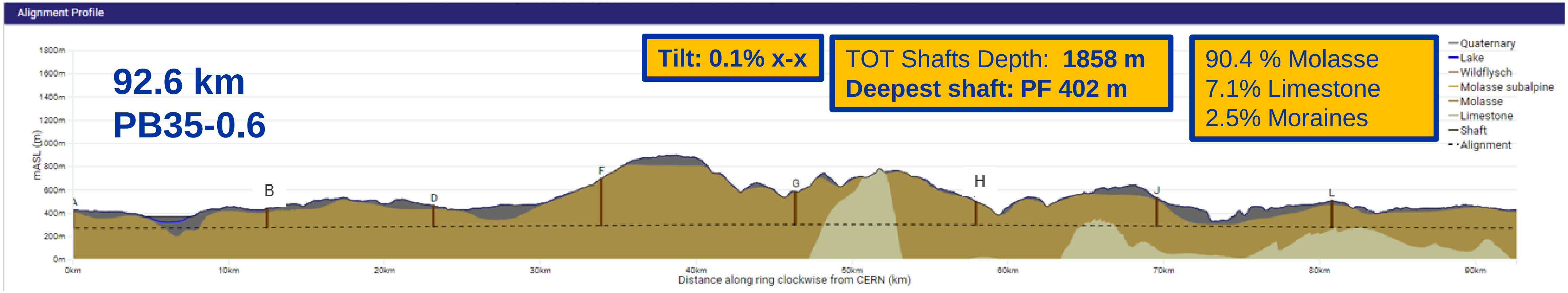


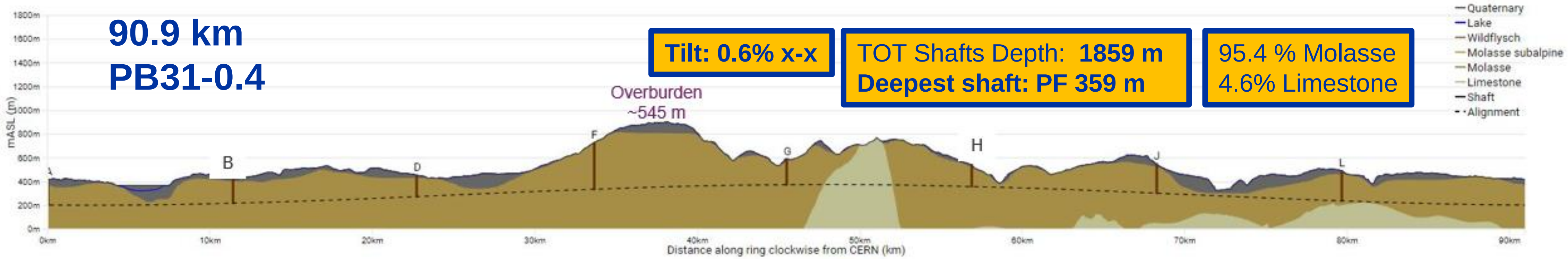
Tilt: 0.5% x-x and 0.1% y-y

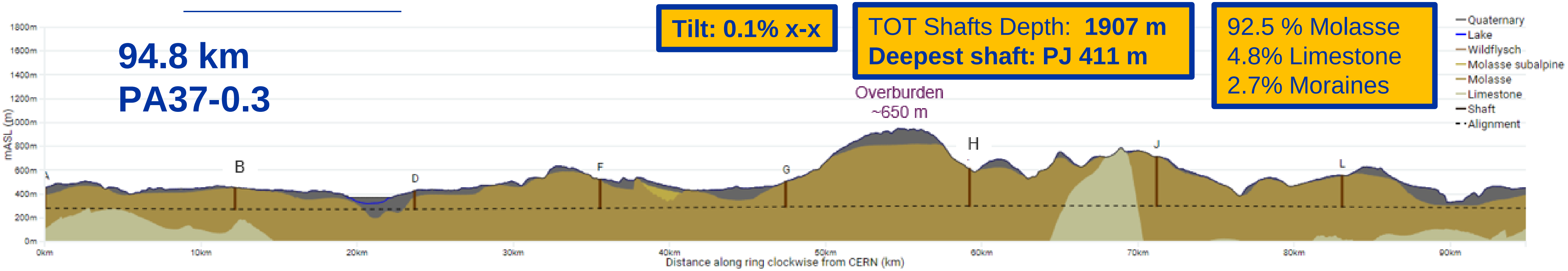
TOT Shafts Depth: **2740 m**
Deepest shaft: **PG 402m**

94.7 % Molasse
4.3% Limestone
1% Moraines

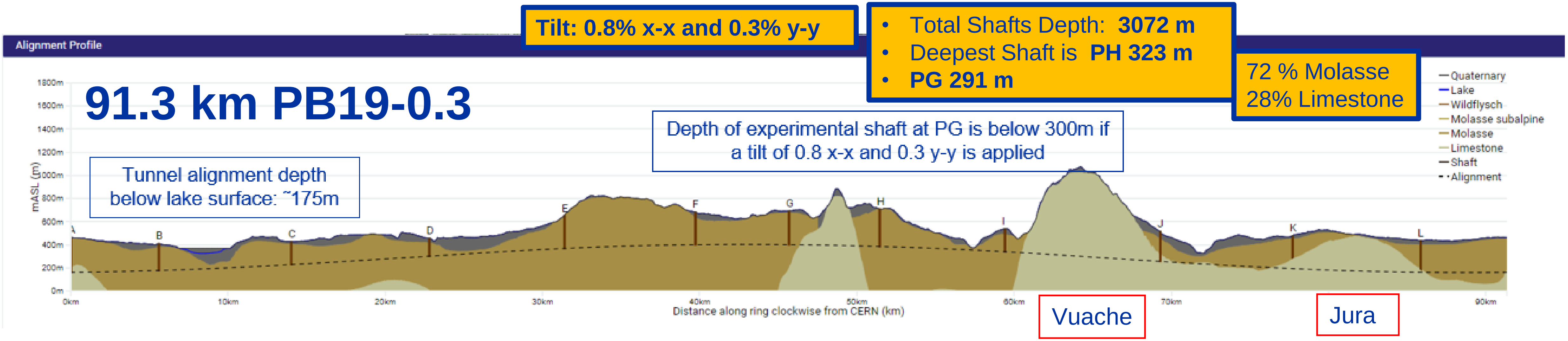
Three scenarios with 8 points

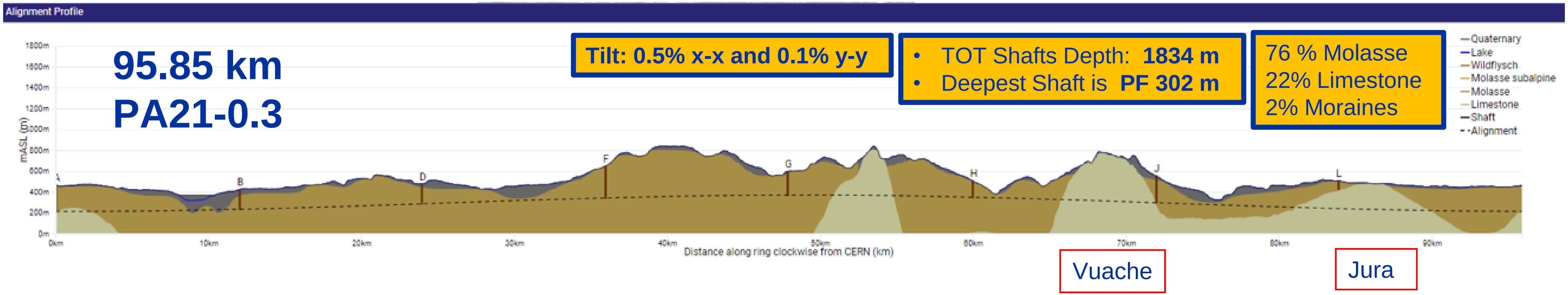






Two scenarios rejected





FCC current tools and software

Surface point exploration

Footprint Explorer Web App

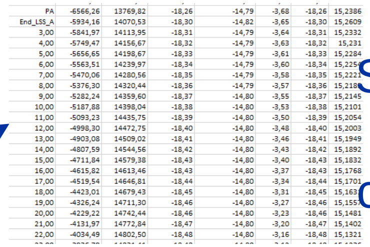
J. Gutleber, V. Mertens

Developing a Central data repository

ArcGIS

Y. Robert

Survey high precision calculations



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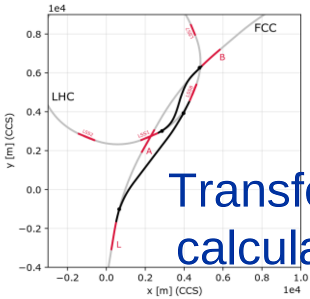
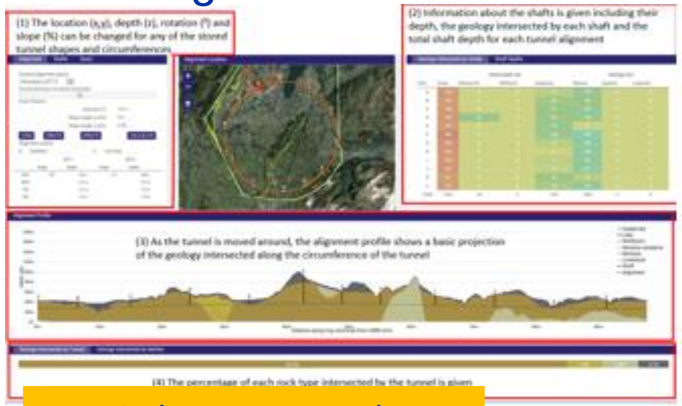
End_LSS_A	-5934,16	14070,53	-18,30	-14,82	-3,65	-18,30	15,2609
3,00	-5841,97	14113,95	-18,31	-14,79	-3,64	-18,31	15,2332
4,00	-5749,47	14156,67	-18,32	-14,79	-3,63	-18,32	15,231
5,00	-5656,65	14198,67	-18,33	-14,79	-3,61	-18,33	15,2284
6,00	-5563,51	14239,97	-18,34	-14,79	-3,60	-18,34	15,2254
7,00	-5470,06	14280,56	-18,35	-14,79	-3,58	-18,35	15,2221
8,00	-5376,30	14320,44	-18,36	-14,79	-3,57	-18,36	15,2185
9,00	-5282,24	14359,60	-18,37	-14,80	-3,55	-18,37	15,2145
10,00	-5187,88	14398,04	-18,38	-14,80	-3,53	-18,38	15,2101
11,00	-5093,23	14435,75	-18,39	-14,80	-3,50	-18,39	15,2054
12,00	-4998,30	14472,75	-18,40	-14,80	-3,48	-18,40	15,2003
13,00	-4903,08	14509,02	-18,41	-14,80	-3,46	-18,41	15,1949
14,00	-4807,59	14544,56	-18,42	-14,80	-3,43	-18,42	15,1892
15,00	-4711,84	14579,38	-18,43	-14,80	-3,40	-18,43	15,1832
16,00	-4615,82	14613,46	-18,43	-14,80	-3,37	-18,43	15,1768
17,00	-4519,54	14646,81	-18,44	-14,80	-3,34	-18,44	15,1701
18,00	-4423,01	14679,43	-18,45	-14,80	-3,31	-18,45	15,163
19,00	-4326,24	14711,30	-18,46	-14,80	-3,27	-18,46	15,1557
20,00	-4229,22	14742,44	-18,46	-14,80	-3,23	-18,46	15,1481
21,00	-4131,97	14772,84	-18,47	-14,80	-3,20	-18,47	15,1402
22,00	-4034,49	14802,50	-18,48	-14,80	-3,16	-18,48	15,1321



Transfer line calculations

Tunnel Optimisation Tool

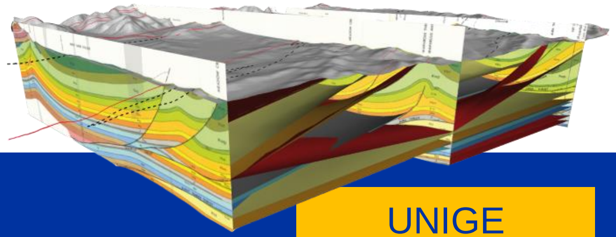
Underground assessment



J. Osborne, A. Tudora

Petrel

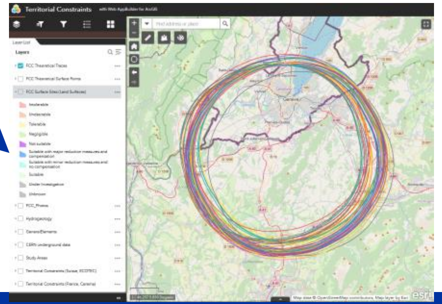
3D geological modelling



UNIGE

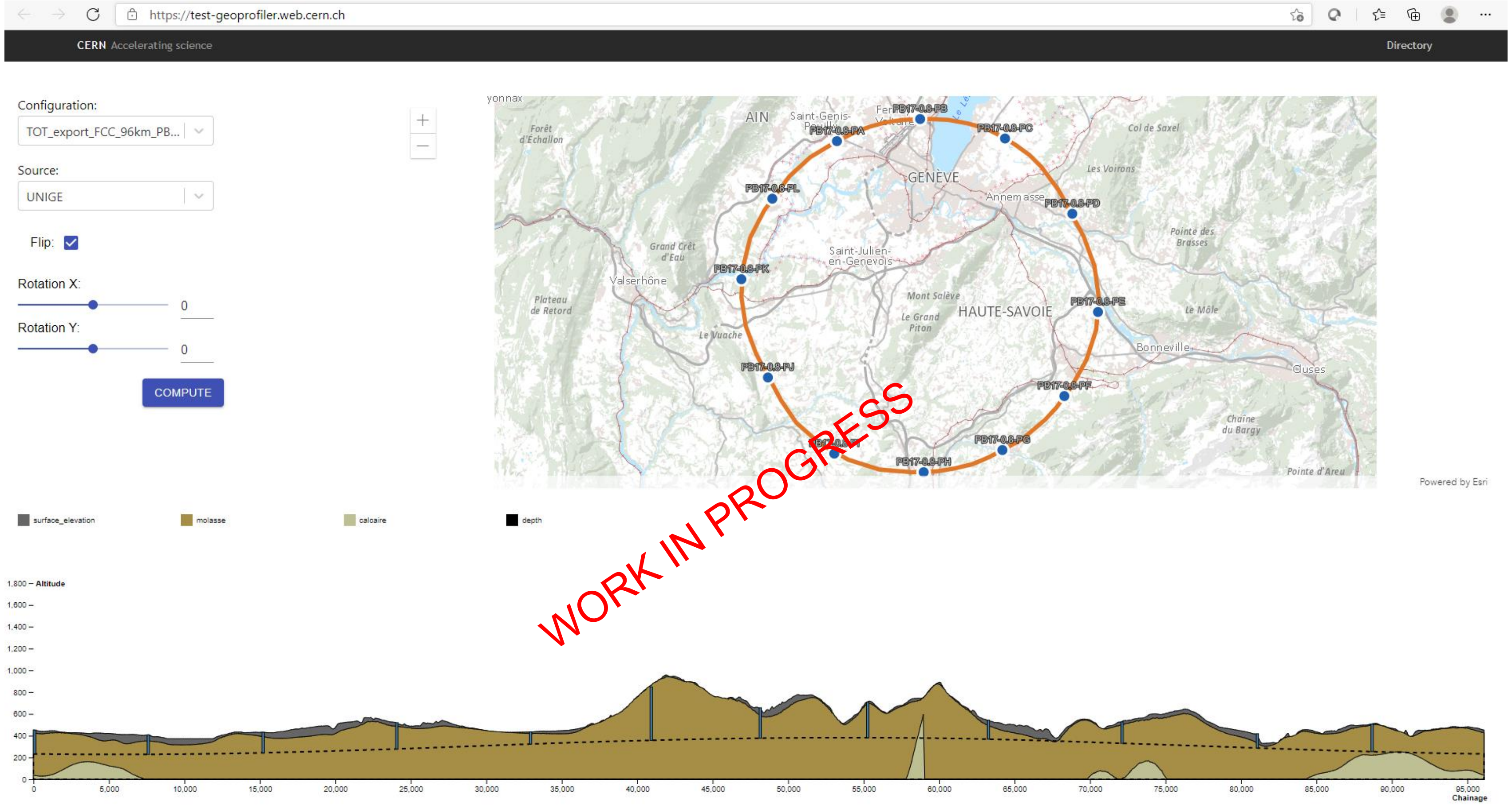
Future External Consultants Software

FCC-GIS Web App

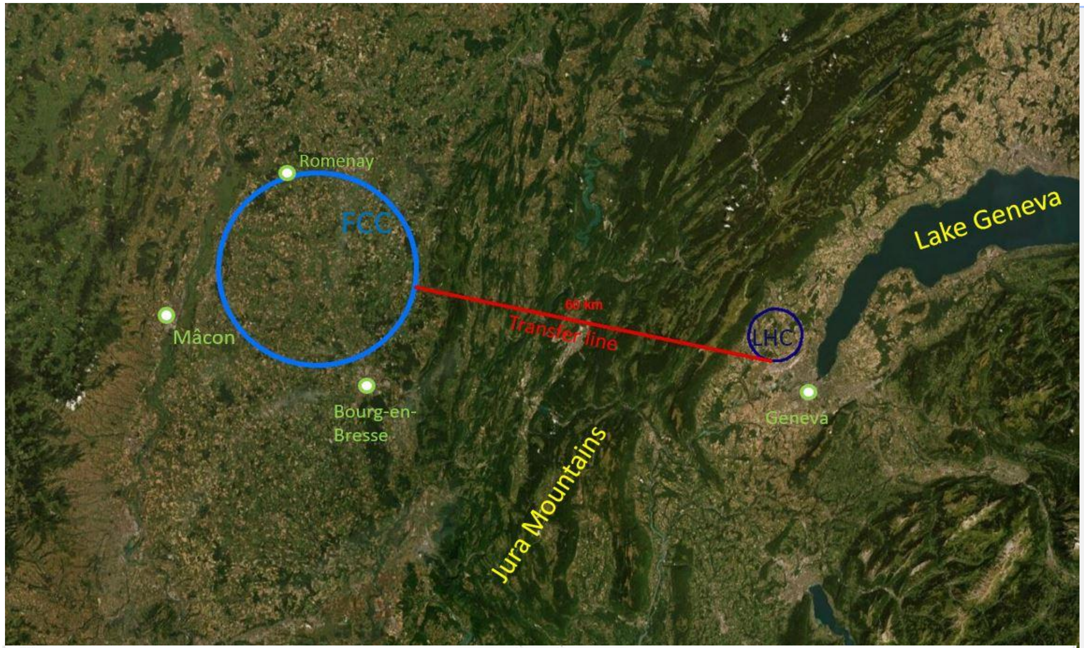


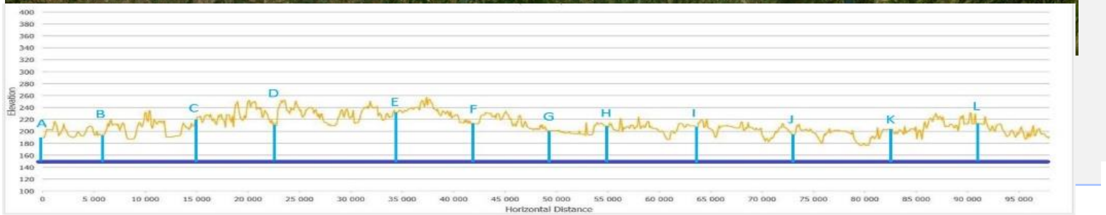
Moving from TOT to ArcGIS

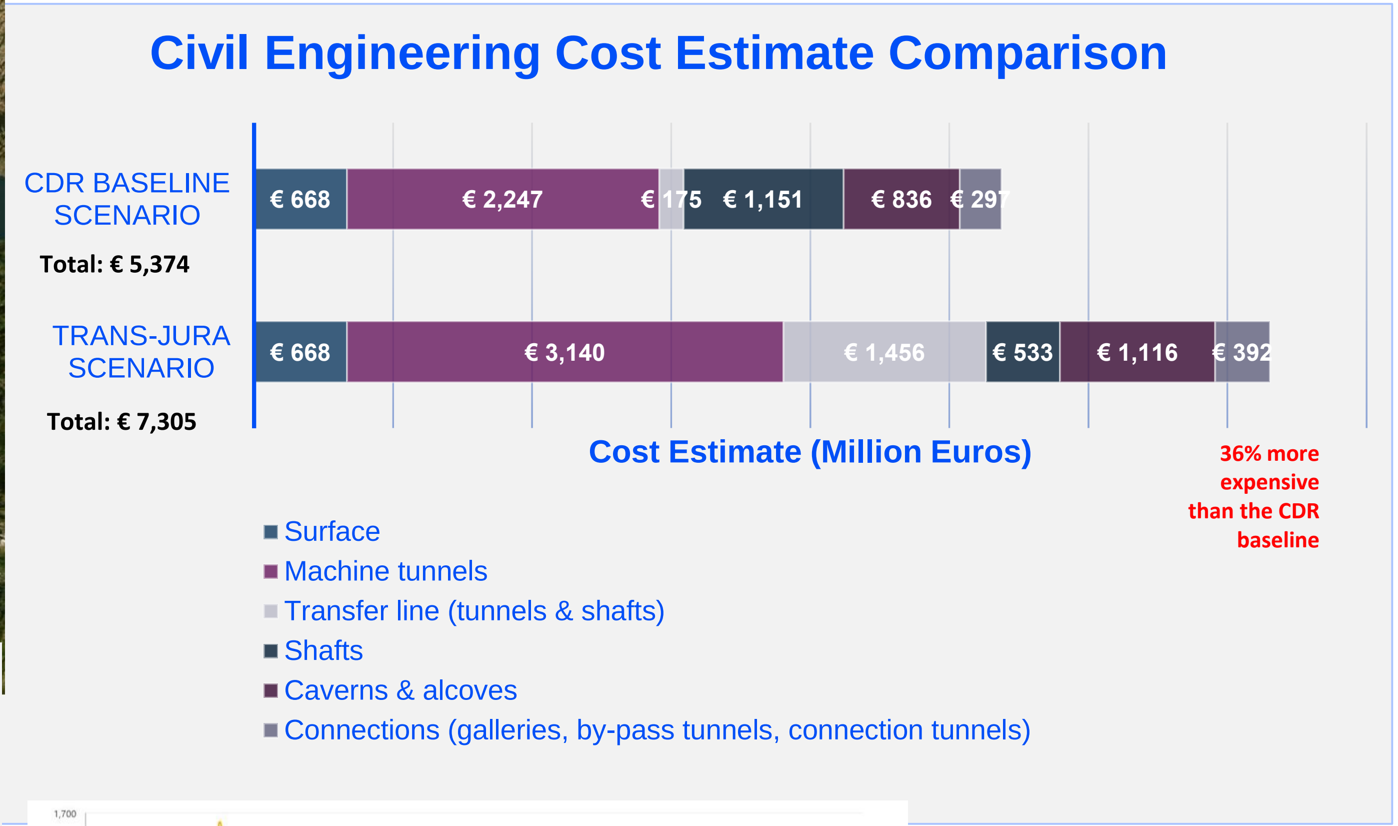
- ArcGIS database and development of geoprofiler web application (under development).
- The web app will include similar functionalities as TOT (and some additional features), and updated geological model based on UNIGE data



FCC Trans-Jura scenario

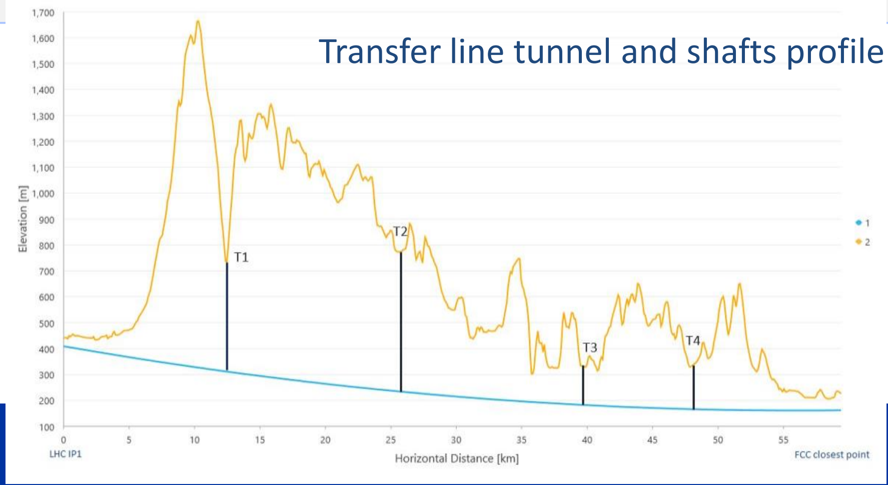






CE cost increase mainly due to

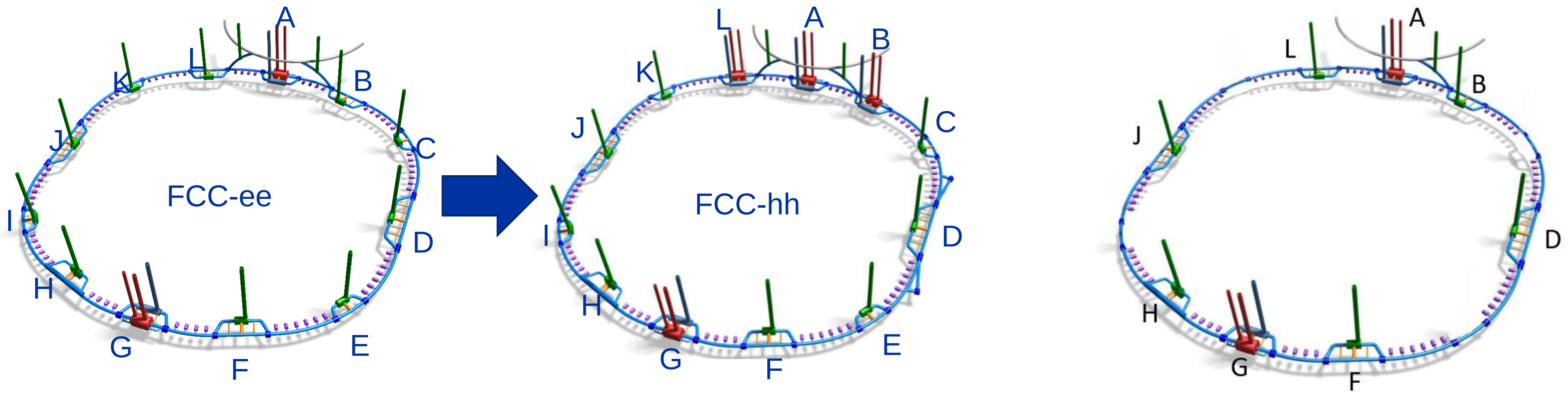
- additional ~50 km of tunnel through the Jura limestone for the beam transfer line connection to the LHC.
- Main tunnel, caverns and shaft excavated in the soft ground of the Bresse formation



Ongoing machine design 12 points vs 8 points

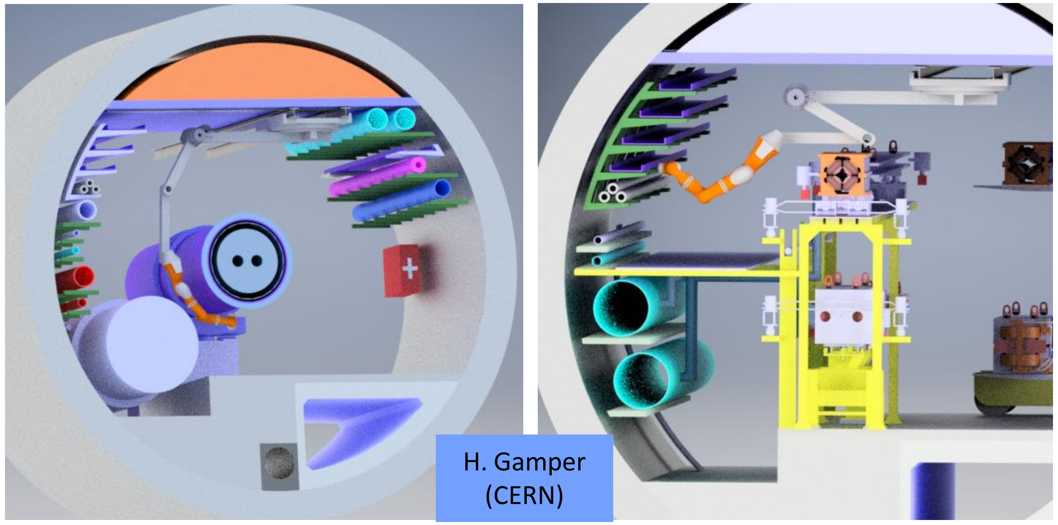
Machine parameters presented at CDR: 12 points (2 experimental points for FCC-ee. 2 additional experiments added later for FCC-hh

New scenarios being explored: 8 points with two experiments



- The tunnel diameter would increase to fulfill the requirements from ventilation, cryogenics, transport, electricity, survey, safety and other services which have not been taken into account at this stage.
- The construction strategy has not been updated for the proposed scenarios assuming 8 access points instead of 12 foreseen in the CDR. The increased distance between points will have an impact on construction schedule, both on the construction of the machine tunnel and caverns as well as the spoil removal schedule. Additional access tunnels could be added to have independent excavation points and to and allow distribution of excavation spoil.

FCC Rail mounted robot – deformation and stress analysis of the tunnel ceiling/ ventilation duct

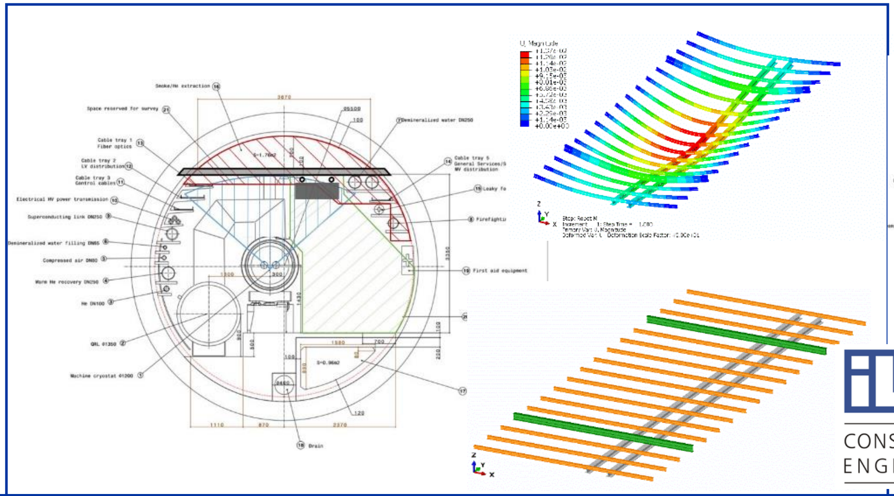


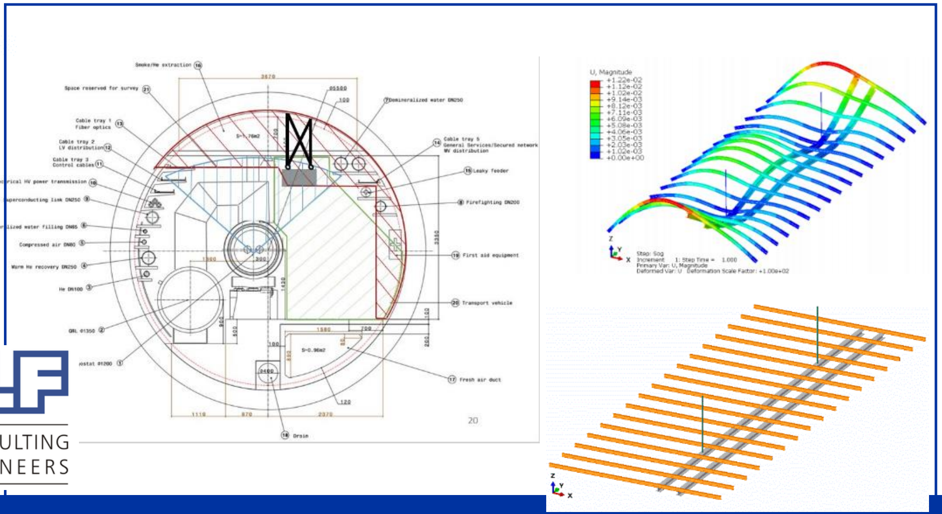
H. Gamper (CERN)

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.





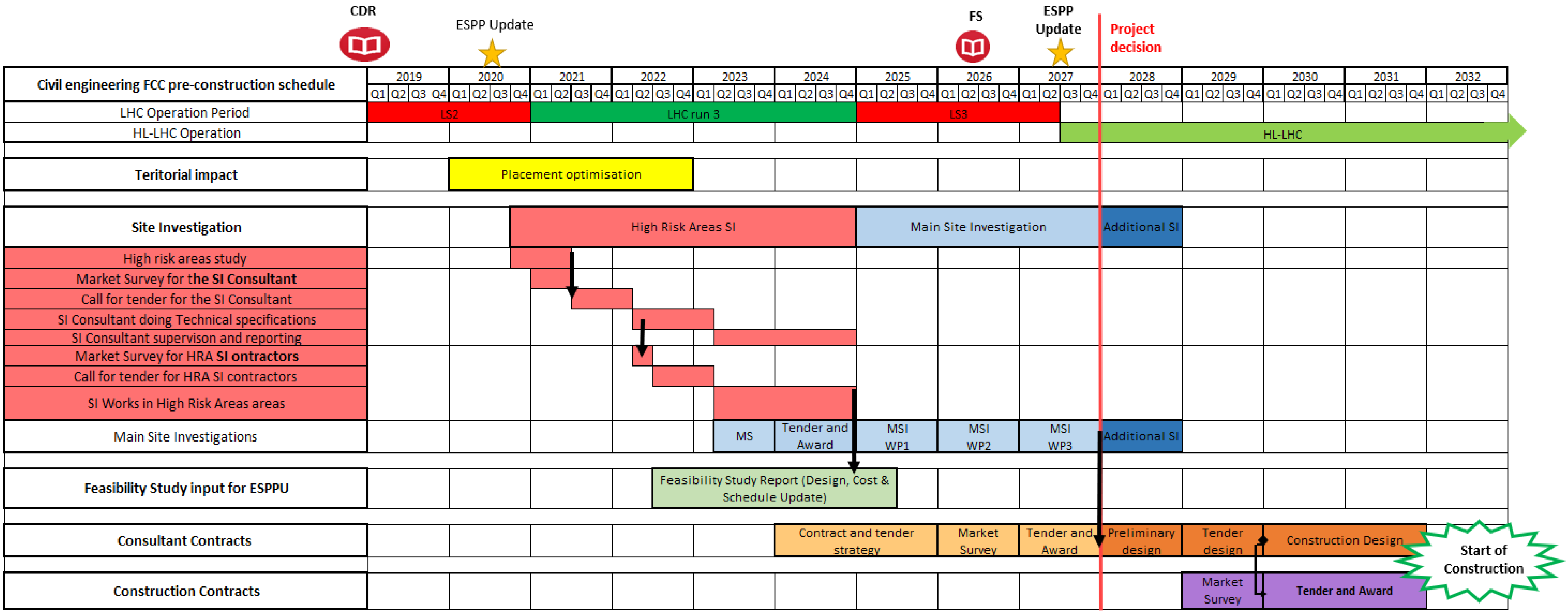
ILF CONSULTING ENGINEERS

Foreseen Features TIM

- Locate and inspect the seat of the fire
- Deploy smoke curtain
- Deploy Extinguish media
- Search for human life
- Project indication on the wall/ground to indicate the escape way using a laser projection system
- Follow and “drone” accessing firefighting team

For more details follow the presentation from H. Gamper on Thursday 1 July at 16.40

FCC Pre-construction schedule and SI planning

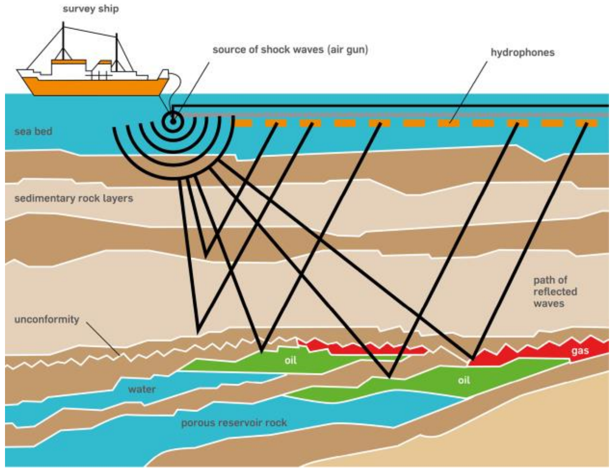


In addition, launching the permitting approval process and environmental impact studies.

Site Investigations

Type of site investigations foreseen in the HRA would include walkover surveys at shaft locations, geophysical investigations, exploration drillings and laboratory testing to not only determine the geotechnical properties of the ground but also to include a chemical analysis for pollution testing and investigating the spoil re-use.

Exploration Drilling, CERN 2020

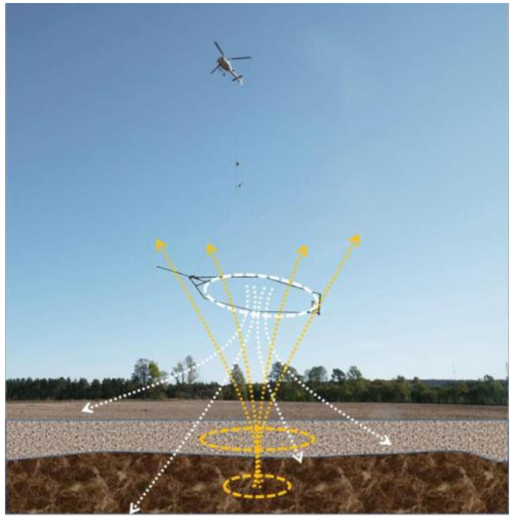


Lake Geneva Geophysical Surveys

Lake Geneva Drillings

Credit: www.swissdrilling.ch

Helicopter Geo-scanning (potential)



Credit: Emerald Geomodelling

Summary

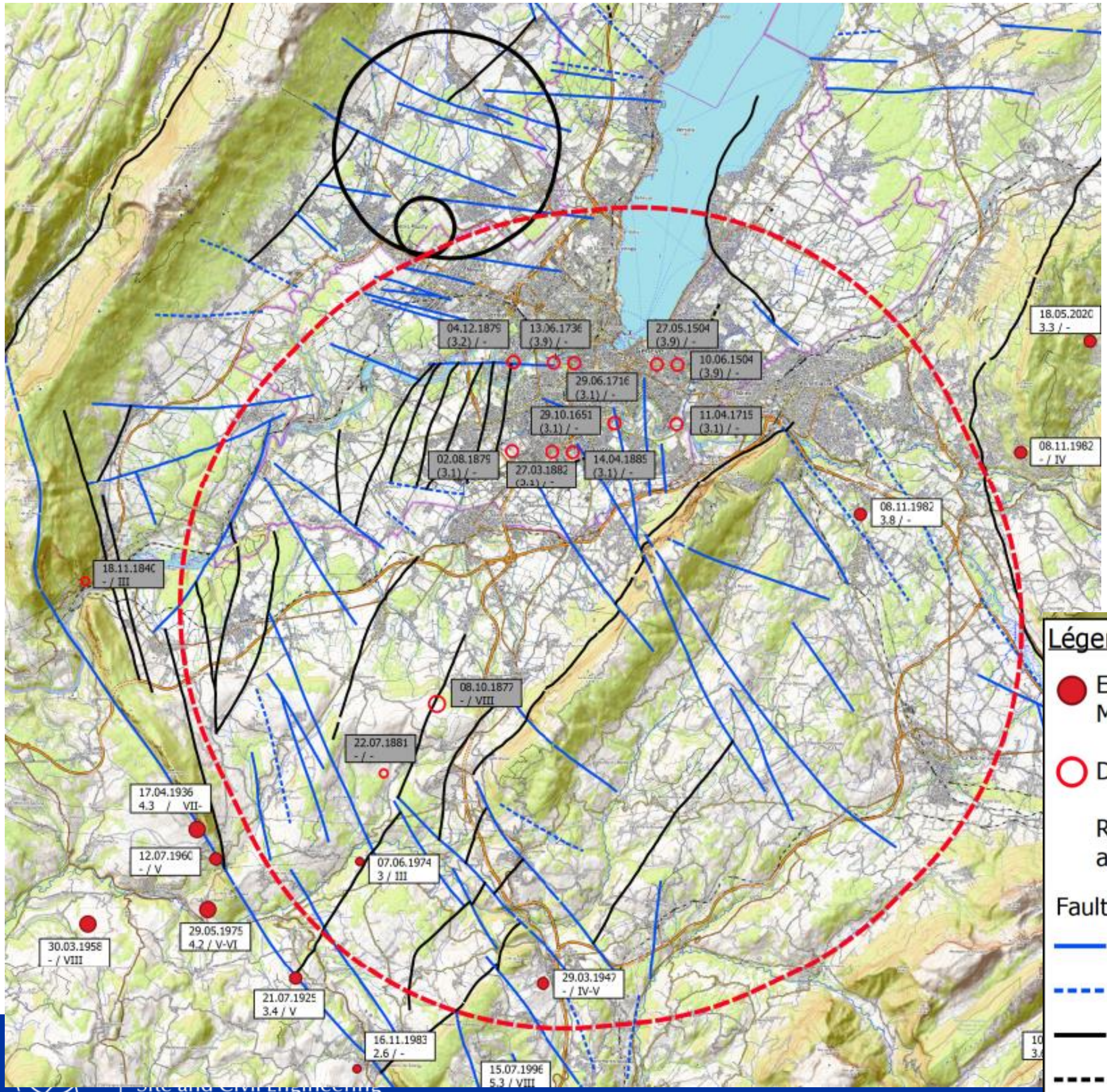
- Since the kick-off of the study, the civil engineering team have focused on finding the optimal placement and layout for the FCC tunnel, the conceptual design and a detailed cost and schedule estimates.
- FCC feasibility studies are ongoing and will deliver an input to the next ESPPU in 2026-2027;
- To confirm the principle feasibility of the 100 km tunnel, CERN is launching a site investigation campaign starting in the High-Risk areas; **Site Investigation contracts will soon be awarded for 100km Future Circular Collider.**
- The design of the underground structures, cost and schedule will be updated based on the outcome of the HRASI, footprint optimization process (including surface sites), machines design and compatibility between FCC-ee and FCC-hh.

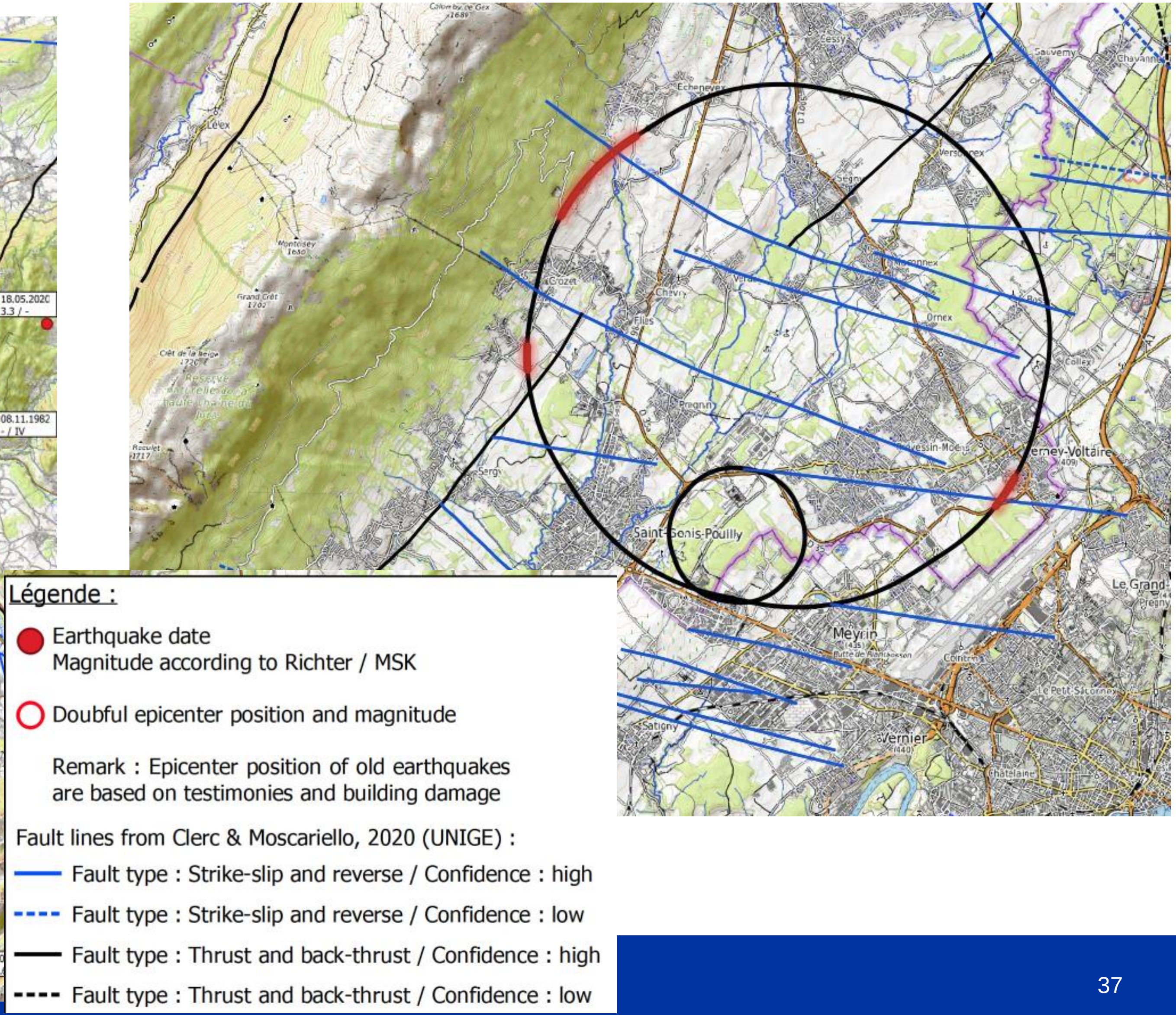
CERN

Back-up

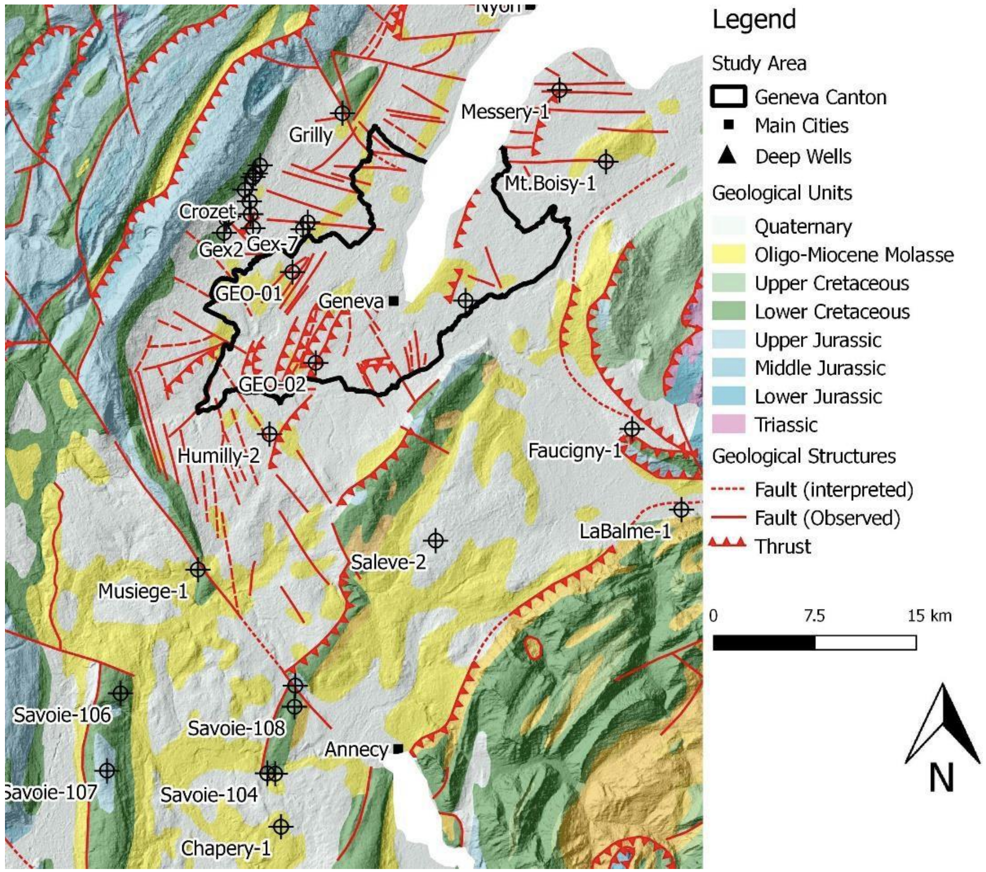
Main civil engineering constraints

Faults

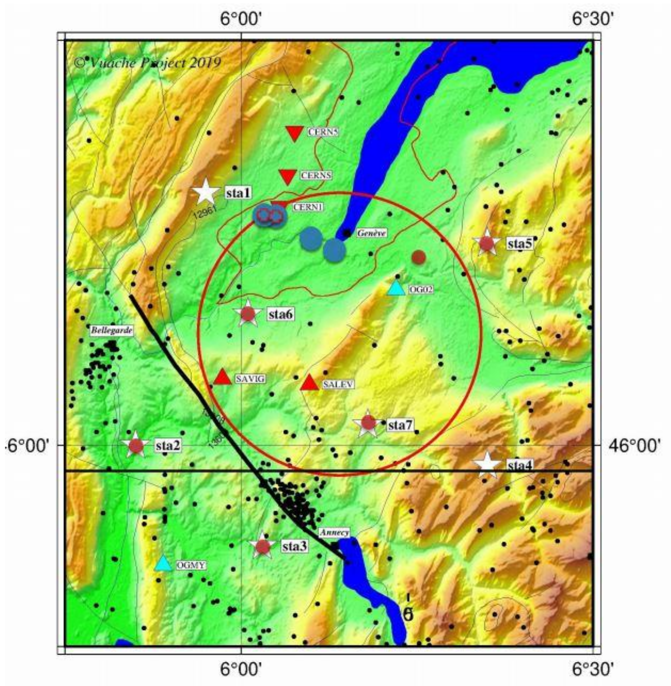




Potential future campaign for seismic activity measurement



TECTONIC MAP OF FGB (Moscariello, 2019)



Understand the local impact of the regional tectonic activity

proposed the monitoring of the Vuache fault which is the best candidate for the generation of seismic and aseismic activity in the area

Following advancements of tunnel works

GPS network installation could be coordinated with FCC activities for the future geodetic network