Future Circular Collider

Study progress and future plans

CERN Tunnelling Workshop

23 October 2019

J. Osborne
A. Tudora

Collaborators
To FCC study

CETU ARUP

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GADZ

AMBERG ENGINEERING

ILF CONSULTING ENGINEERS

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GENEVA GEO ENERGY

Cerema

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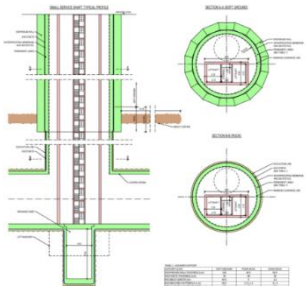
Agenda

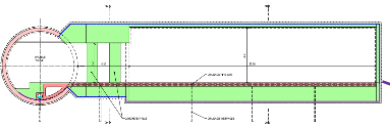
- Overview of civil engineering, schedule and cost estimate
- Alignment Development and Tunnel Optimisation Tool
- Limitations/challenges of TOT and future aspirations
- Conclusions

FCC civil engineering overview

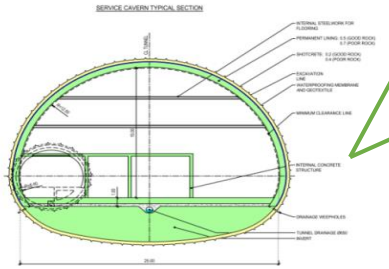
Underground civil infrastructure for FCC - 3D schematic (not to scale)



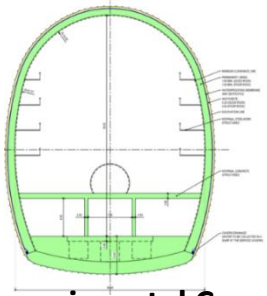
Shafts:
Experimental Shafts:
15 m dia. + 10 m dia.
Service shafts:
12 m dia.
Magnet delivery shaft:18 m



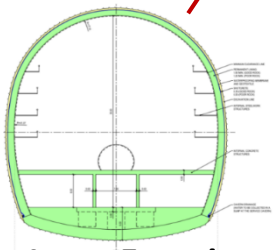
Alcoves
- 25 m x 6 m x 6 m
- Located at 1.5km spacing



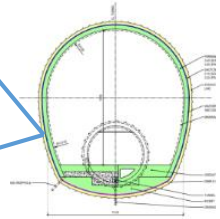
Service Caverns
- 25 m x 15 m x 100 m



Small Experimental Caverns
30 m x 35 m x 66m



Large Experimental Caverns
35 m x 35 m x 66 m

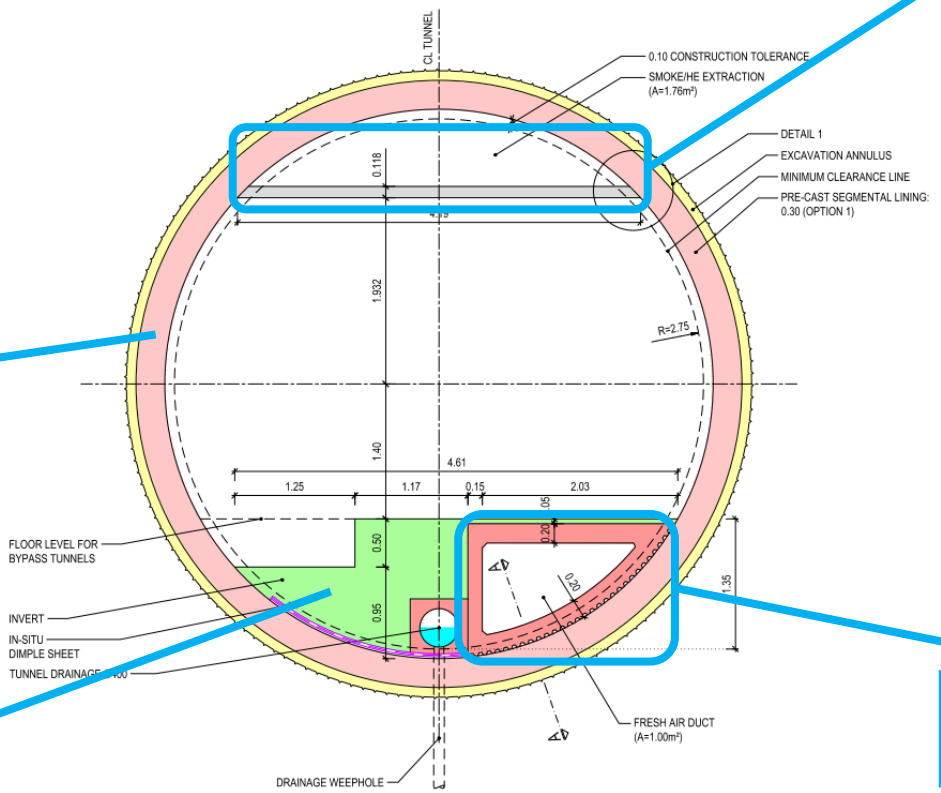


Beam Dump Caverns
- 10 m x 10 m x 50 m

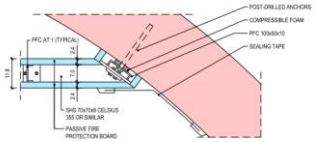
Tunnels:
- 97.75 km of 5.5 dia. machine tunnel
- Approx. 8 km 5.5 dia by-pass tunnels

Typical tunnel cross section

5.5m inner diameter



Steel structure with passive fire protection. Connection:



Pre-cast concrete segmental lining

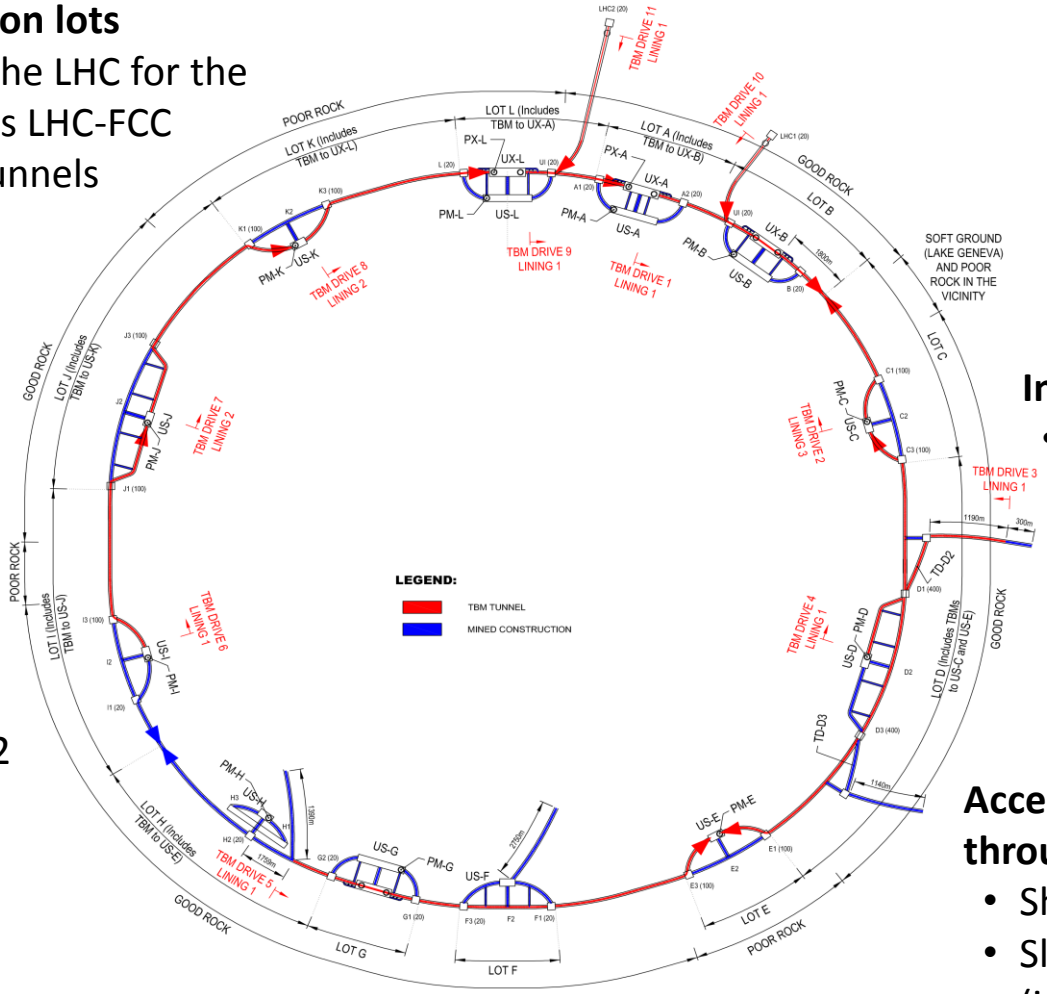
Cast-in-situ concrete invert

Pre-cast concrete element

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

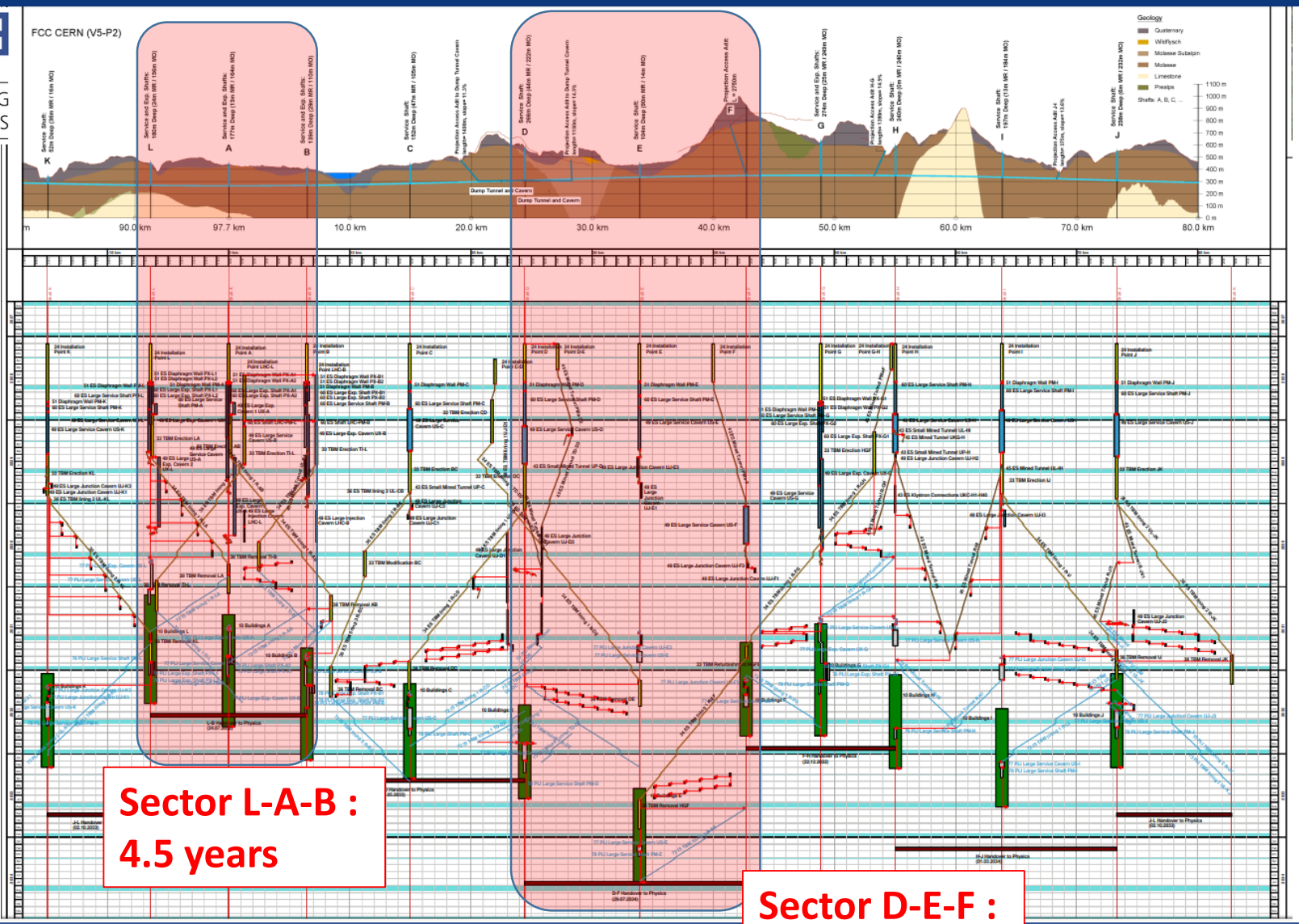
Construction techniques:

1) TBM tunnels
2) Mined tunnels

Access to main tunnel works through:

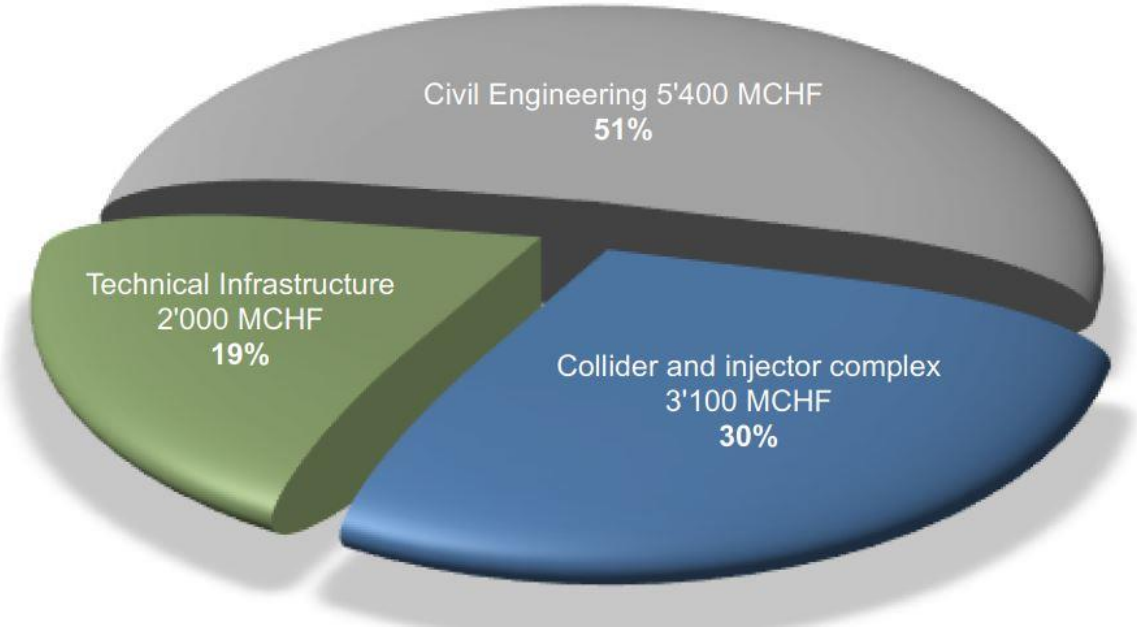
- Shafts at 11 points
- Sloped Access adit at 1 point (instead of 570 m shaft)

Construction Schedule



Cost estimates

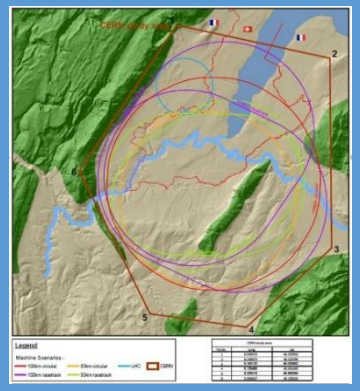
Total cost estimate for civil engineering: **5.4 BCHF**



Total FCC-ee cost estimate : **10.5 BCHF**

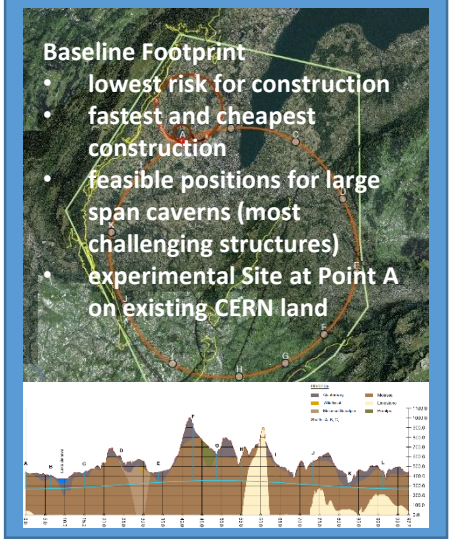
Brief history of alignment development

Kick-off meeting,
Geneva 2014

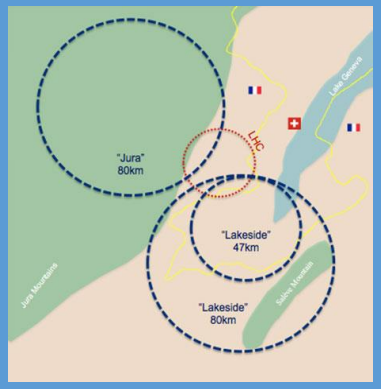


Multiples shapes (racetracks and quasi-circulars) and sizes considered within the study boundary
80km, 87km, 93km, 100km

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

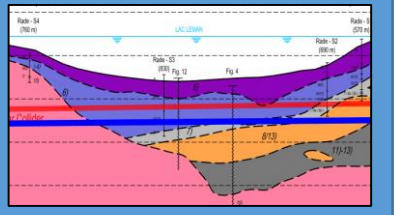


2014 2015 2016 2017 2018 2019



80km "Jura"
80km "Lakeside"
47km "Lakeside"

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



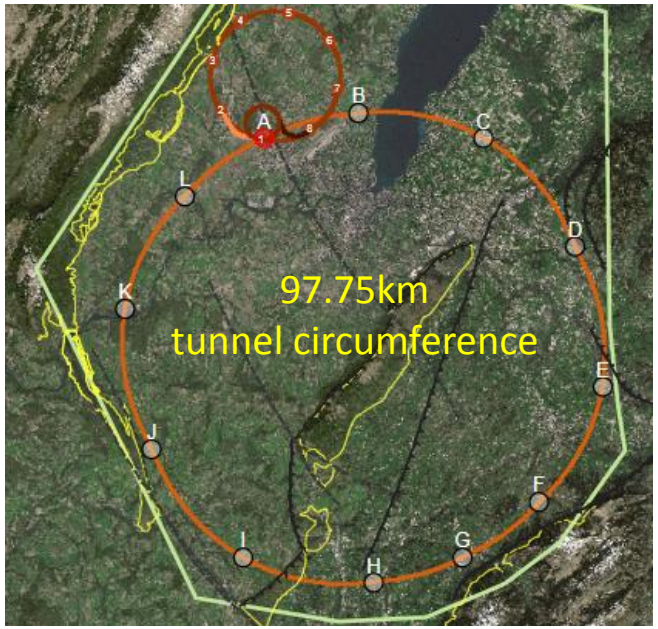
Alignment update following geological review of key areas such as lake crossing

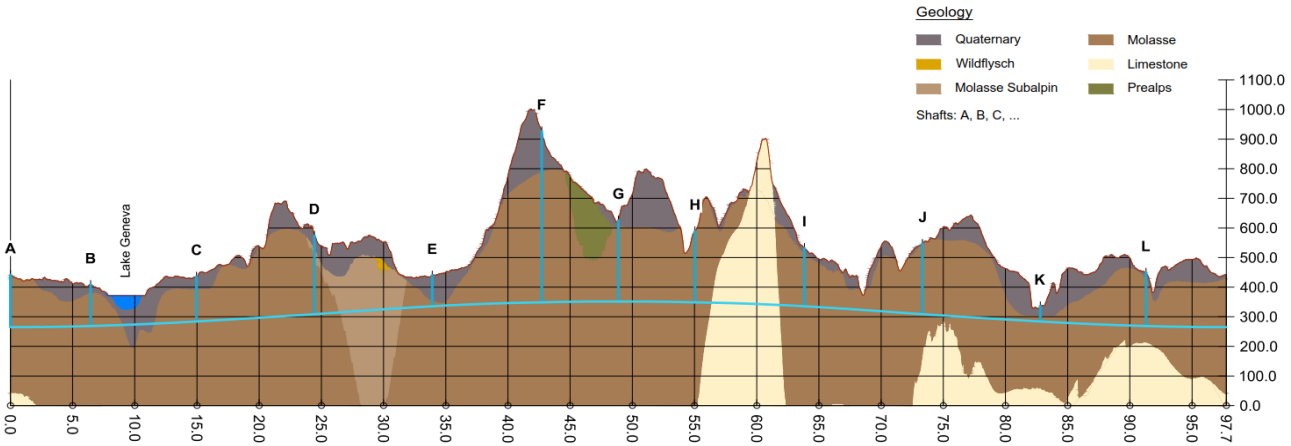
CDR volumes submitted to European Strategy update for Particle Physics

Conceptual baseline footprint

Present baseline position was established considering:

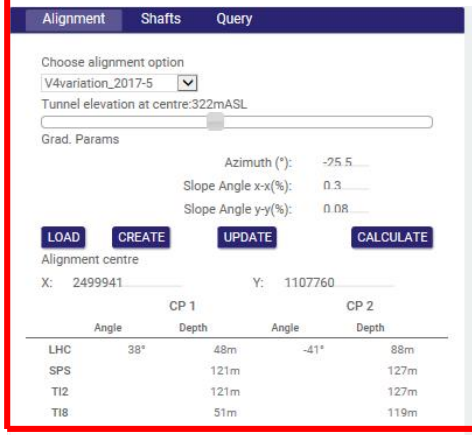
- lowest risk for construction
  - ✓ Avoid Jura limestone and the Pre-Alps
  - ✓ Only one sector containing limestone. ~90 % molasse – suitable ground for tunneling
  - ✓ Significantly reduced total shaft length. Deepest shaft at PF proposed to be replaced with an inclined tunnel
  - ✓ Avoids extremely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

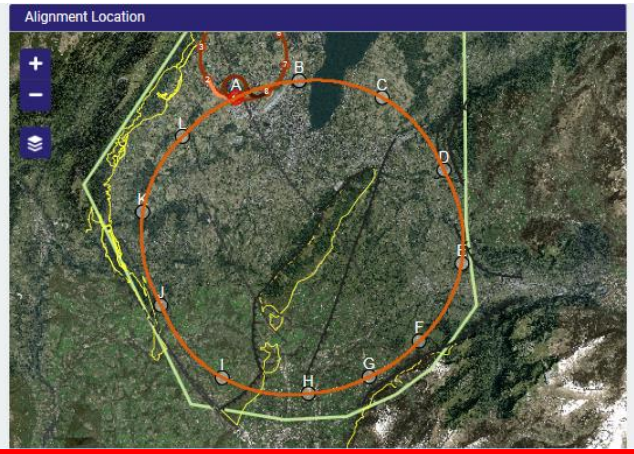




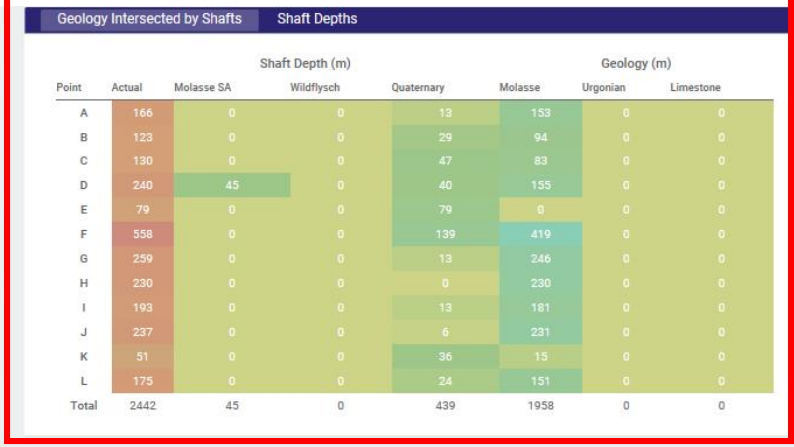
Tunnel Optimisation Tool

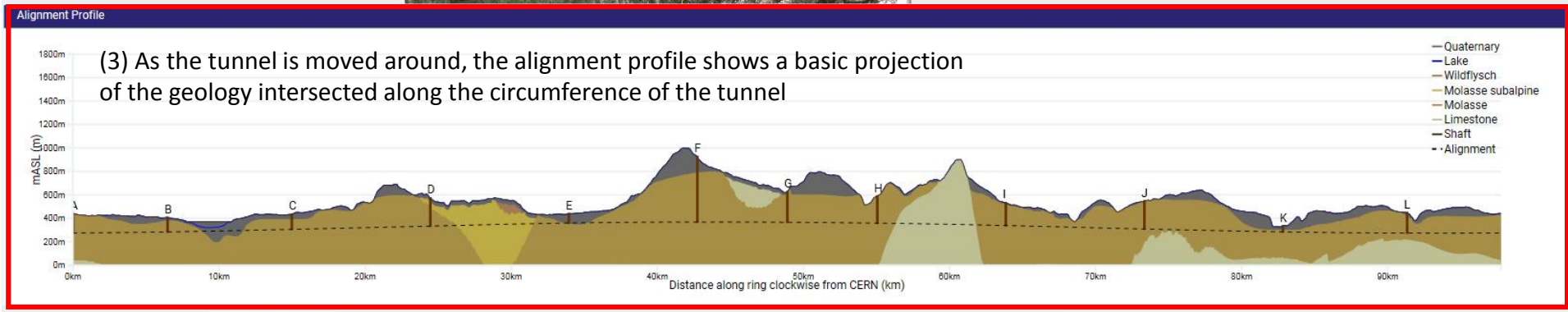
(1) The location (x,y), depth (z), rotation (^{0}) and slope (%) can be changed for any of the stored tunnel shapes and circumferences

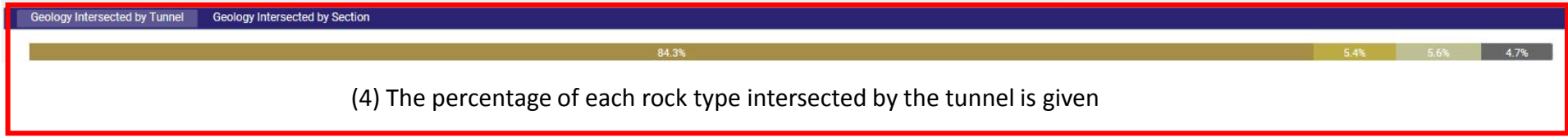




(2) Information about the shafts is given including their depth, the geology intersected by each shaft and the total shaft depth for each tunnel alignment

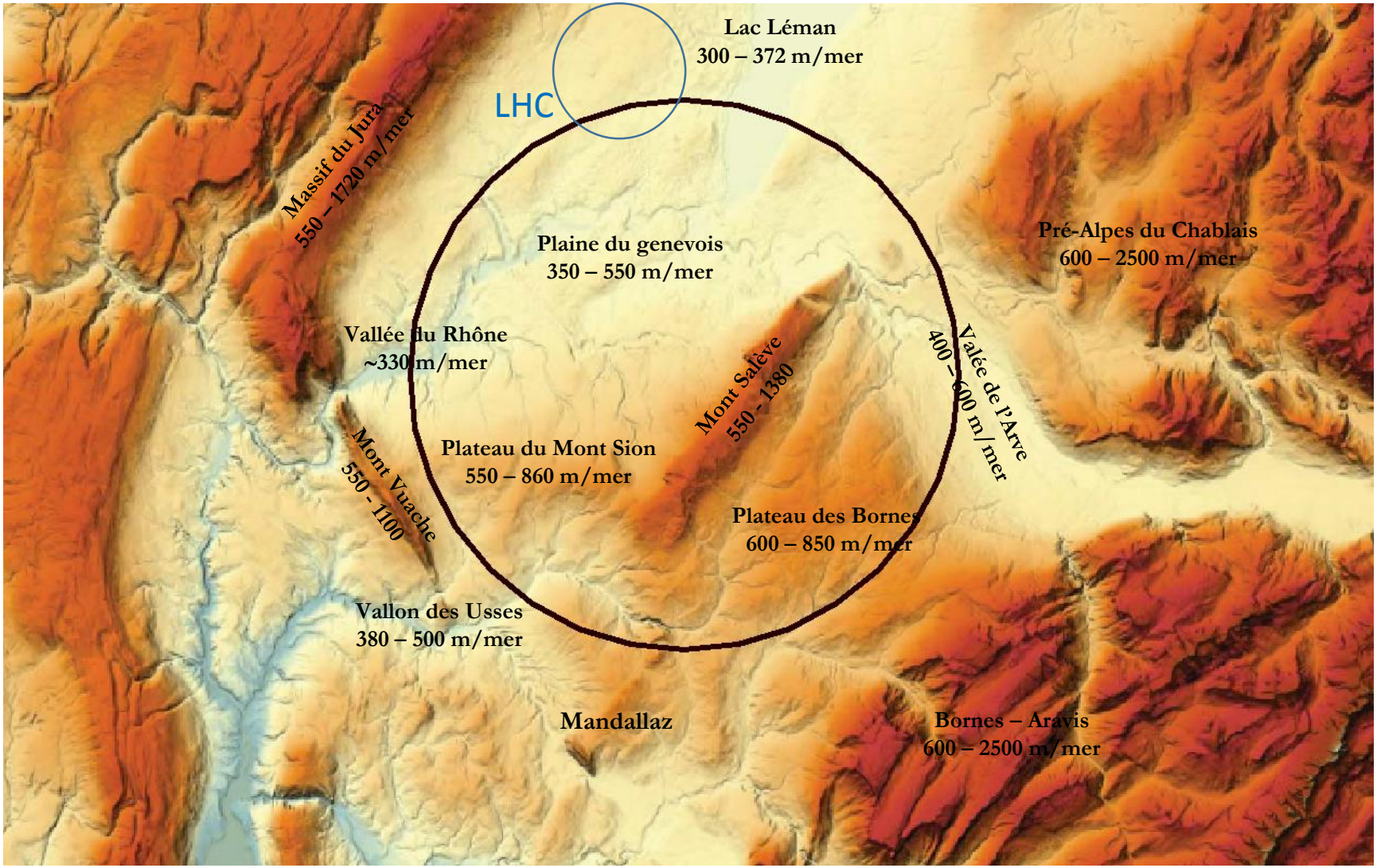






(4) The percentage of each rock type intersected by the tunnel is given

Topography


Lac Léman
300 – 372 m/mer
LHC
Massif du Jura
550 – 1720 m/mer
Plaine du genevois
350 – 550 m/mer
Pré-Alpes du Chablais
600 – 2500 m/mer
Vallée du Rhône
~330 m/mer
Mont Salève
550 - 1380
Valée de l'Arve
400 – 600 m/mer
Mont Vuache
550 - 1100
Plateau du Mont Sion
550 – 860 m/mer
Plateau des Bornes
600 – 850 m/mer
Vallon des Usses
380 – 500 m/mer
Mandallaz
Bornes – Aravis
600 – 2500 m/mer

Geology

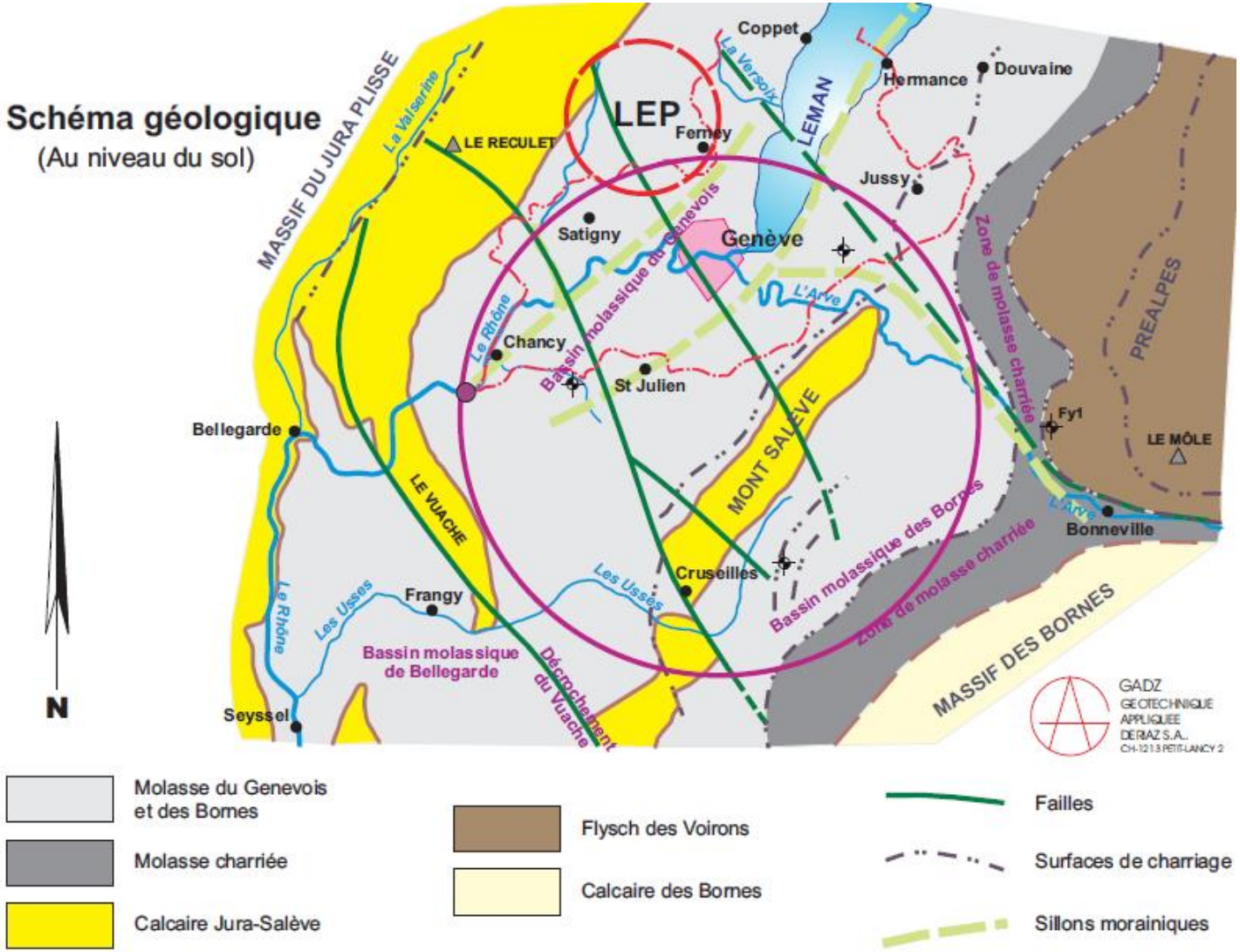
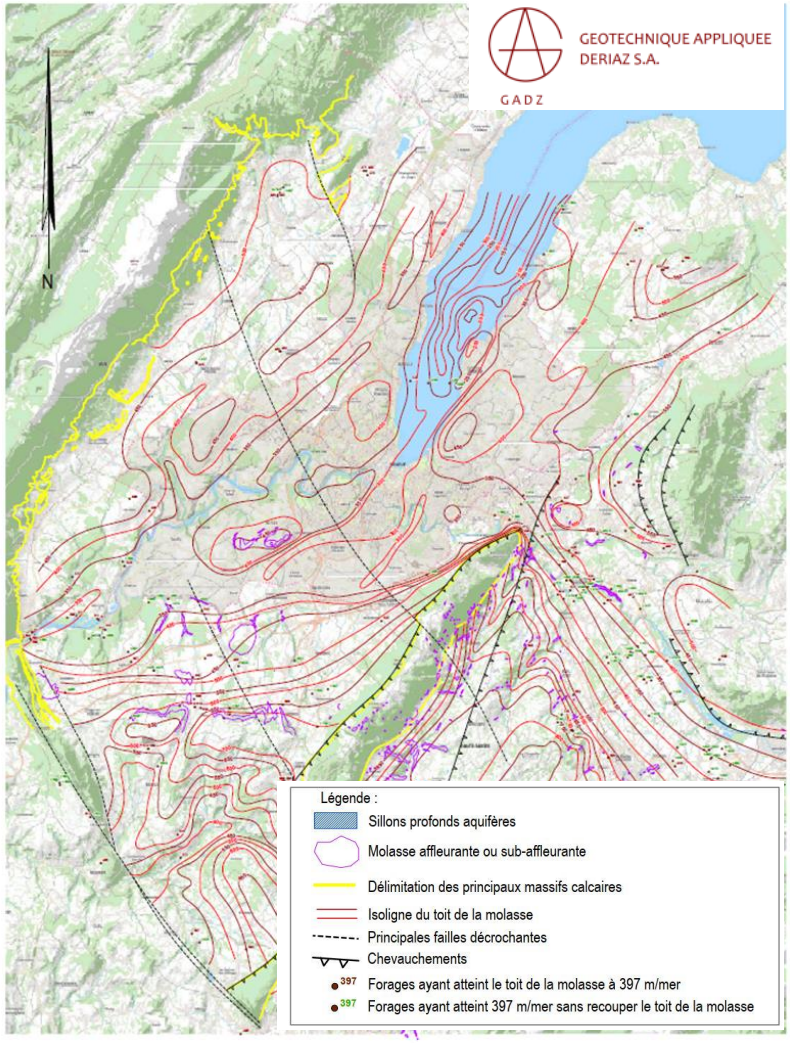


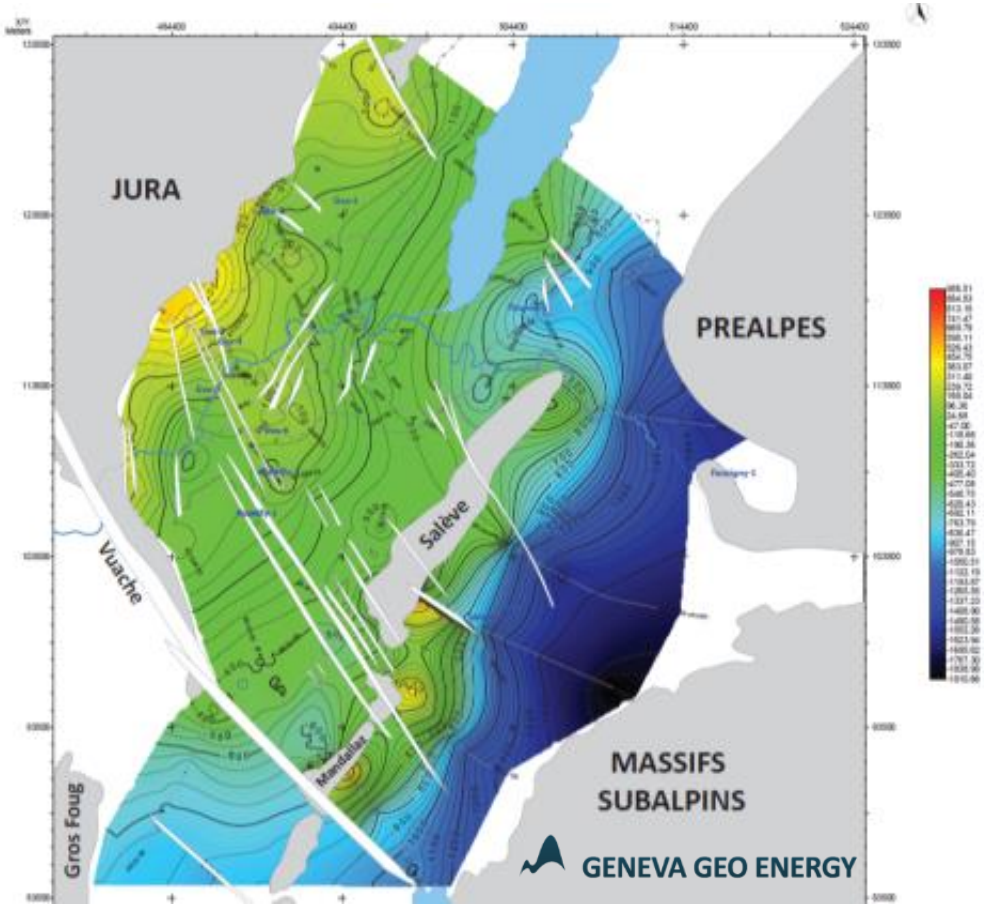
Schéma géologique
(Au niveau du sol)
MASSIF DU JURA PLISSE
La Valserine
LE RECULET
LEP
Ferney
Coppet
La Versoix
LEMAN
Hermance
Douvaine
Jussy
Satigny
Genève
Le Rhône
Bassin molassique du Genevois
L'Arve
Chancy
St Julien
Zone de molasse charriée
PREALPES
Fy1
LE MÔLE
Bellegarde
LE VUACHE
MONT SALÈVE
Bonneville
Cruseilles
Bassin molassique des Bornes
Zone de molasse charriée
Les Usses
Frangy
Le Rhône
Bassin molassique de Bellegarde
Décrochement du Vuache
MASSIF DES BORNES
Seyssel
N
GADZ
GEOTECHNIQUE APPLIQUÉE DERIAZ S.A.
CH-1213 PETIT-LANCY 2
Molasse du Genevois et des Bornes
Molasse charriée
Calcaire Jura-Salève
Flysch des Voirons
Calcaire des Bornes
Failles
Surfaces de charriage
Sillons morainiques

Data collection and processing

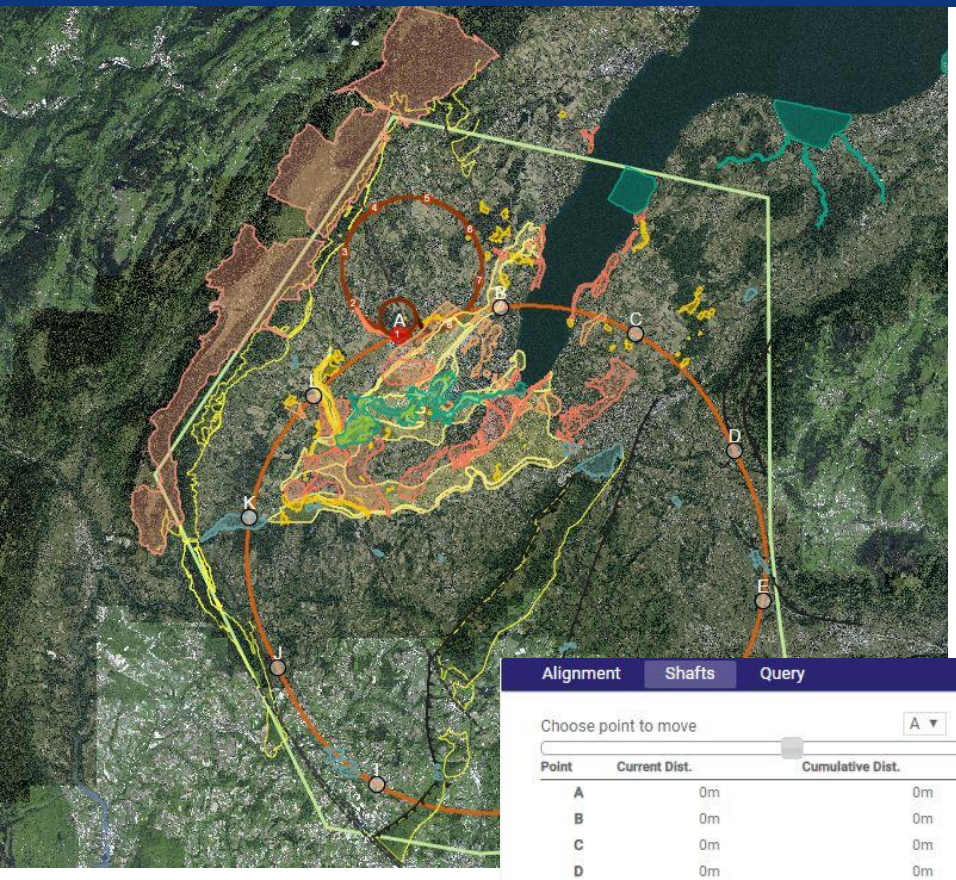
Molasse Rockhead contours



Limestone rockhead



Hydrology, protected areas and existing buildings



Alignment | Shafts | Query

Choose point to move: A

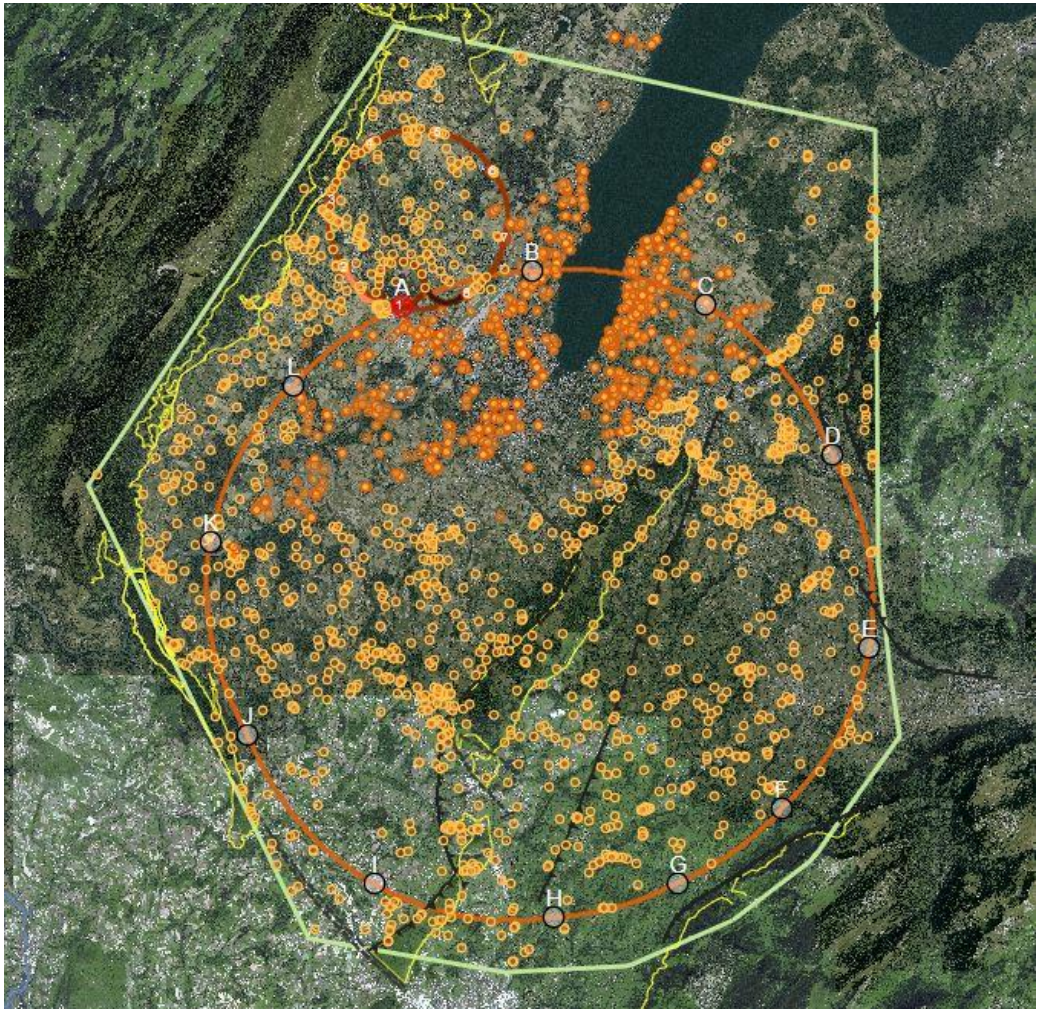
Point	Current Dist.	Cumulative Dist.
A	0m	0m
B	0m	0m
C	0m	0m
D	0m	0m
E	0m	0m
F	0m	0m
G	0m	0m
H	0m	0m
I	0m	0m
J	0m	0m
K	0m	0m
L	0m	0m

Building search dist.(m): 10

SEARCH

Alignment Location

Boreholes

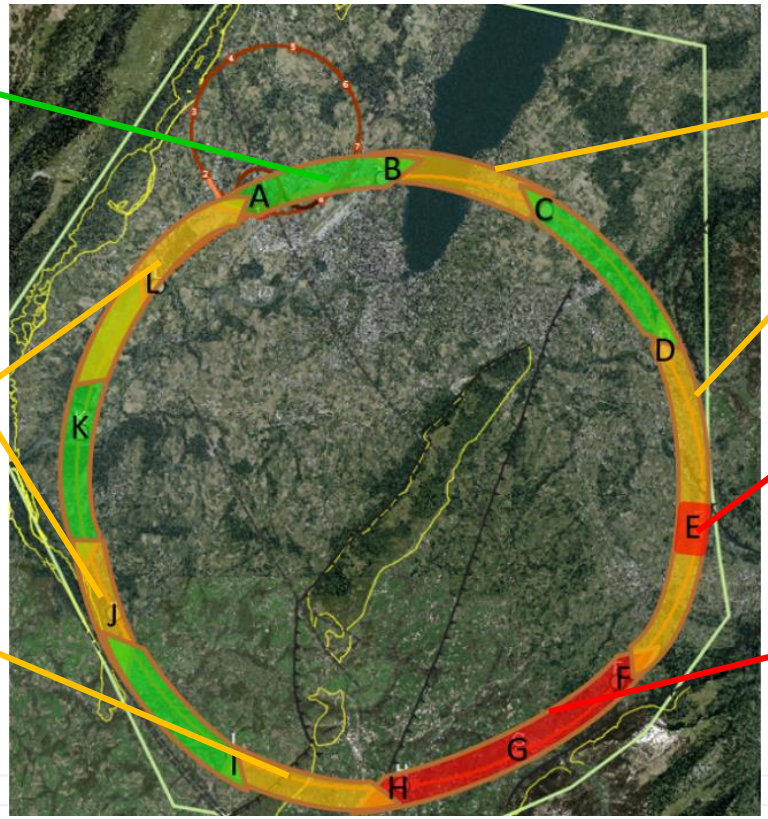


Geological uncertainty

- 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.

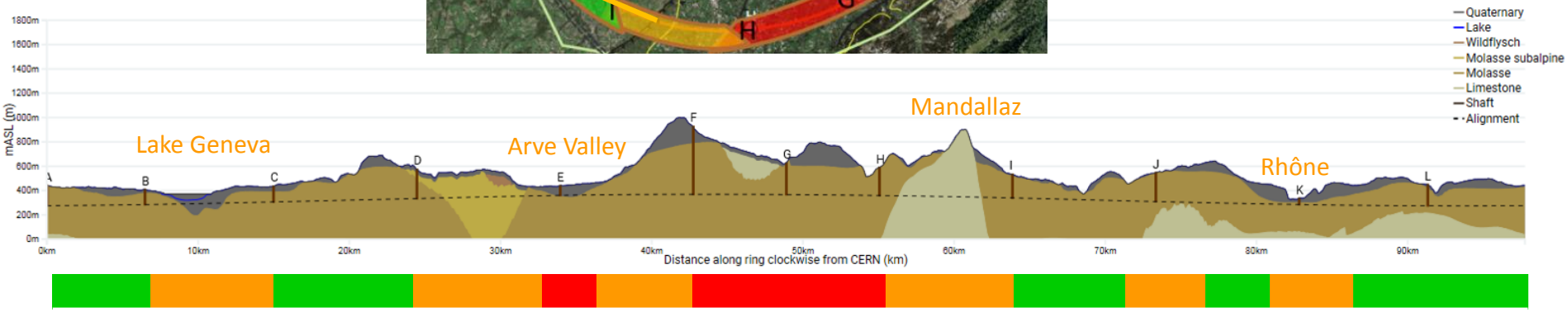


- Seismic and borehole information for lake crossing from proposed road tunnel, but layered nature of lake bed leads to uncertainty.

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

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

- No deep borehole information available in the area.
- Complex faulted region.
- Molasse/limestone interface uncertain.



Ongoing footprint exploration

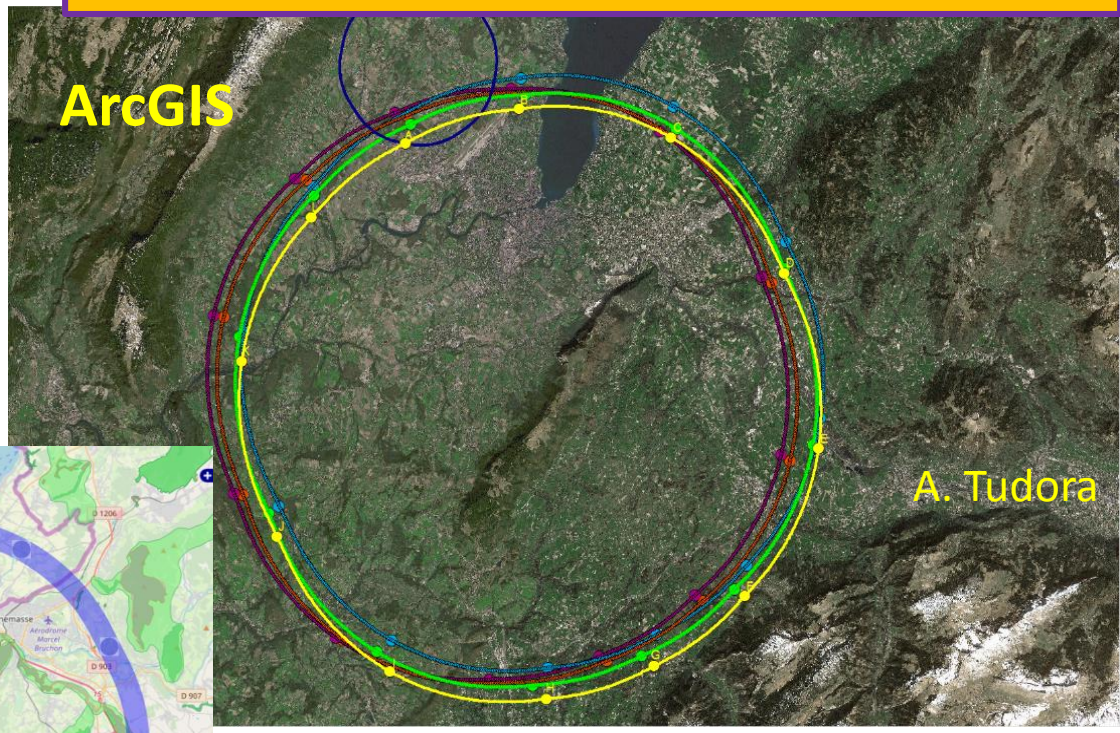
In addition to TOT, other tools/software were used

A further round of alignment optimisation following input from surface sites review

J. Gutleber

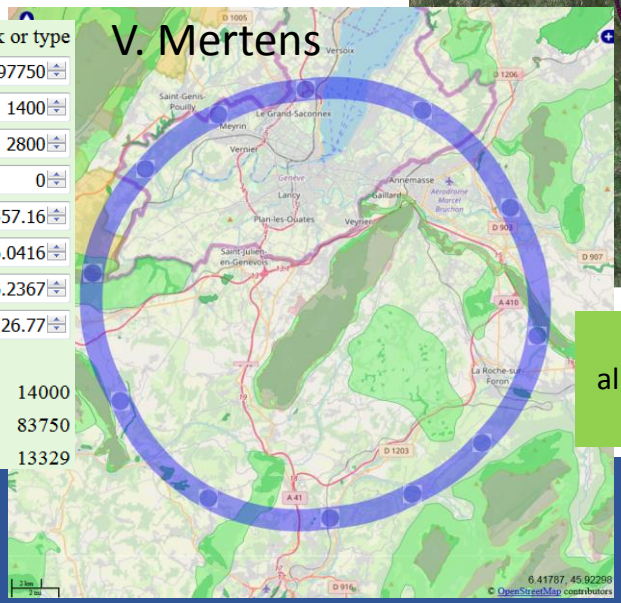
Identification of exclusion areas and recommended alternatives

New layers (eg. Biodiversity, Risks (eg. Flooding, seismic), population density, landscape protection, electrical Network, Transport network etc)



Input parameters:	Click or type
Total length [m]	97750
LSS_A ... length [m]	1400
LSS_D, J length [m]	2800
LSS_C ... length [m]	0
SHORT_ARC length [m]	5557.16
LON_A [x.xx° E]	6.0416
LAT_A [xx.xx° N]	46.2367
Azimuth [xx.x°]	26.77
Resulting parameters:	
Sum LSS lengths [m]	14000
Sum ARC lengths [m]	83750
ARC radius [m]	13329

V. Mertens



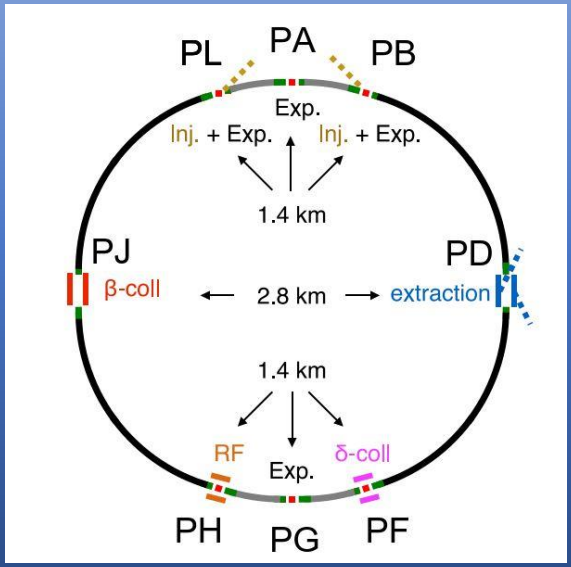
JavaScript front-end based on **OpenStreetMap/OpenLayers** allows rapid first exploration of different access point configurations wrt to constraints from surface features and zones (in 2D).

Key footprint constraints

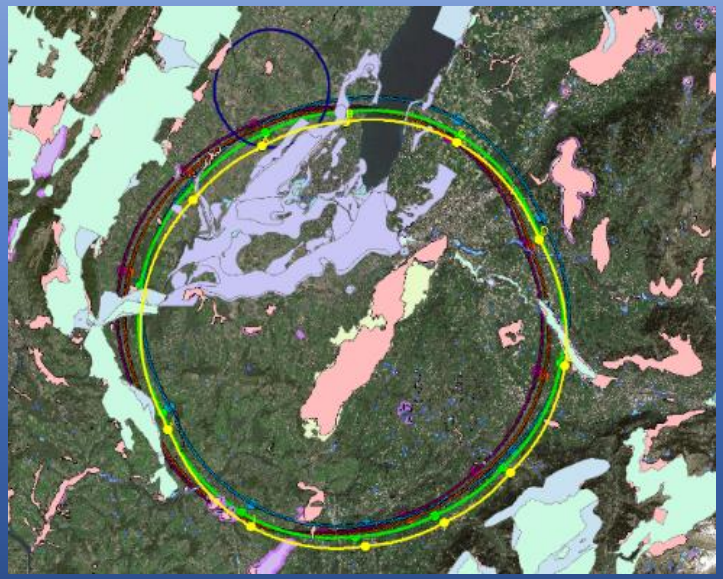
Geology and construction risks

Existing infrastructure (eg road networks, buildings) and future developments

Machine design and performance (circumference, arc length and radius, straight sections lengths, transfer lines)



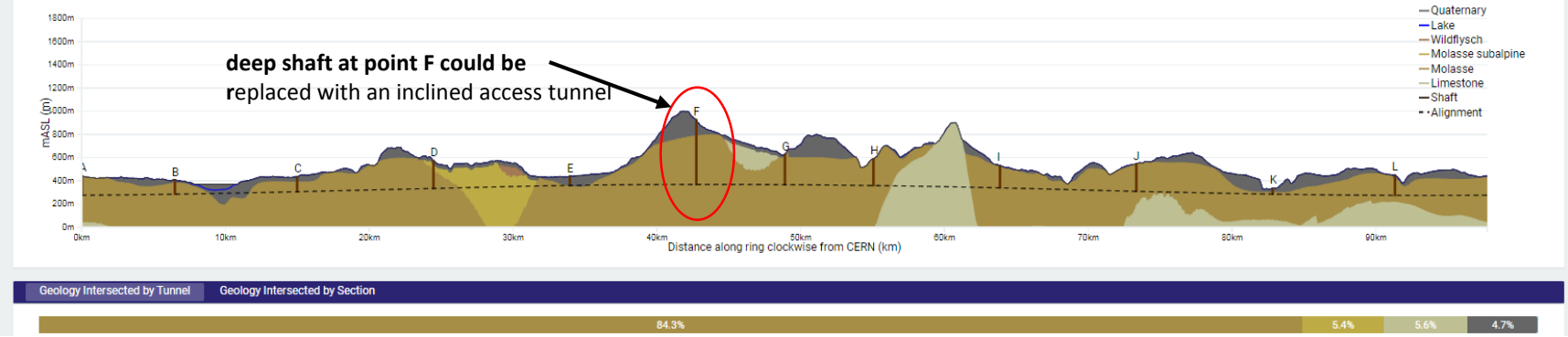
Environmental protected areas

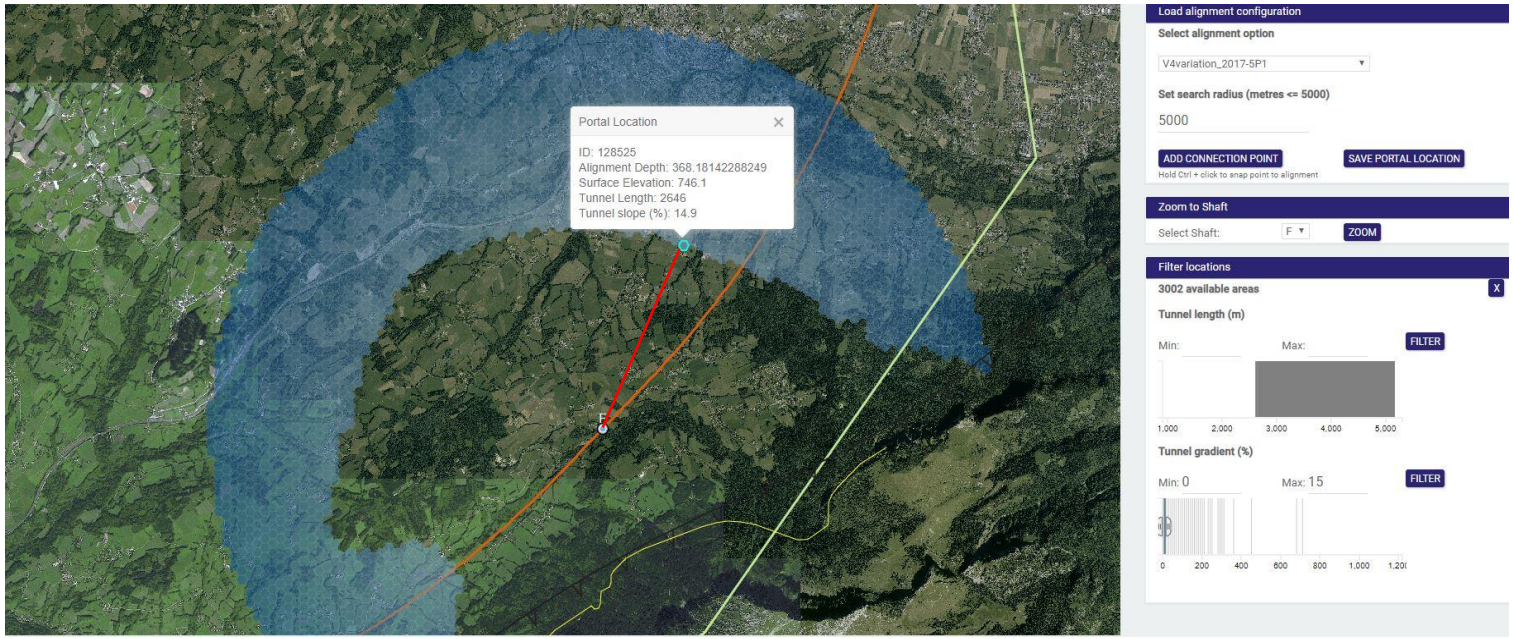


Access (vertical shafts / inclined tunnels) and road access to sites

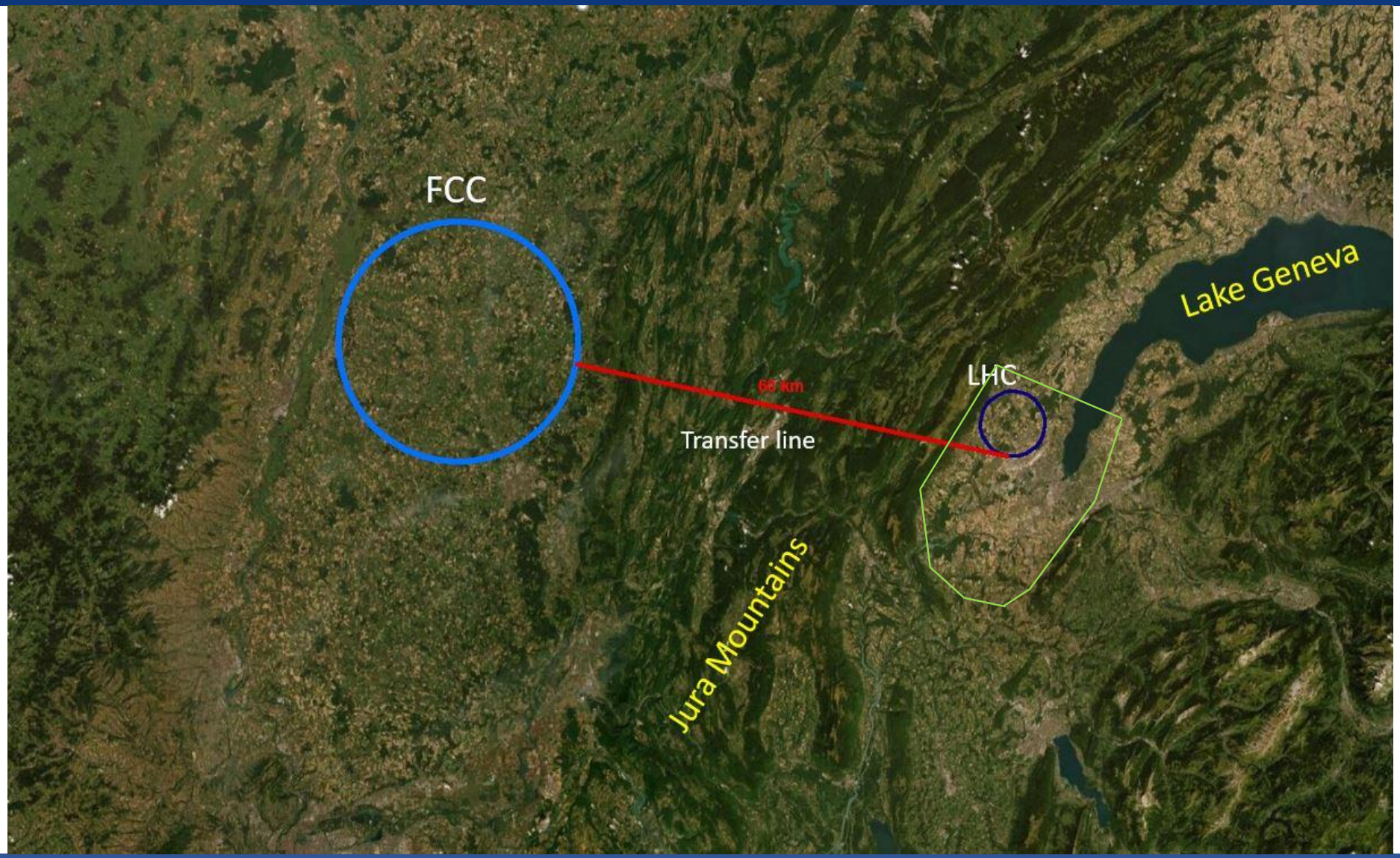
Administrative processes and approvals specific to both Switzerland and France w.r.t surface sites and disposal / re-use of spoil

Inclined tunnel at point F

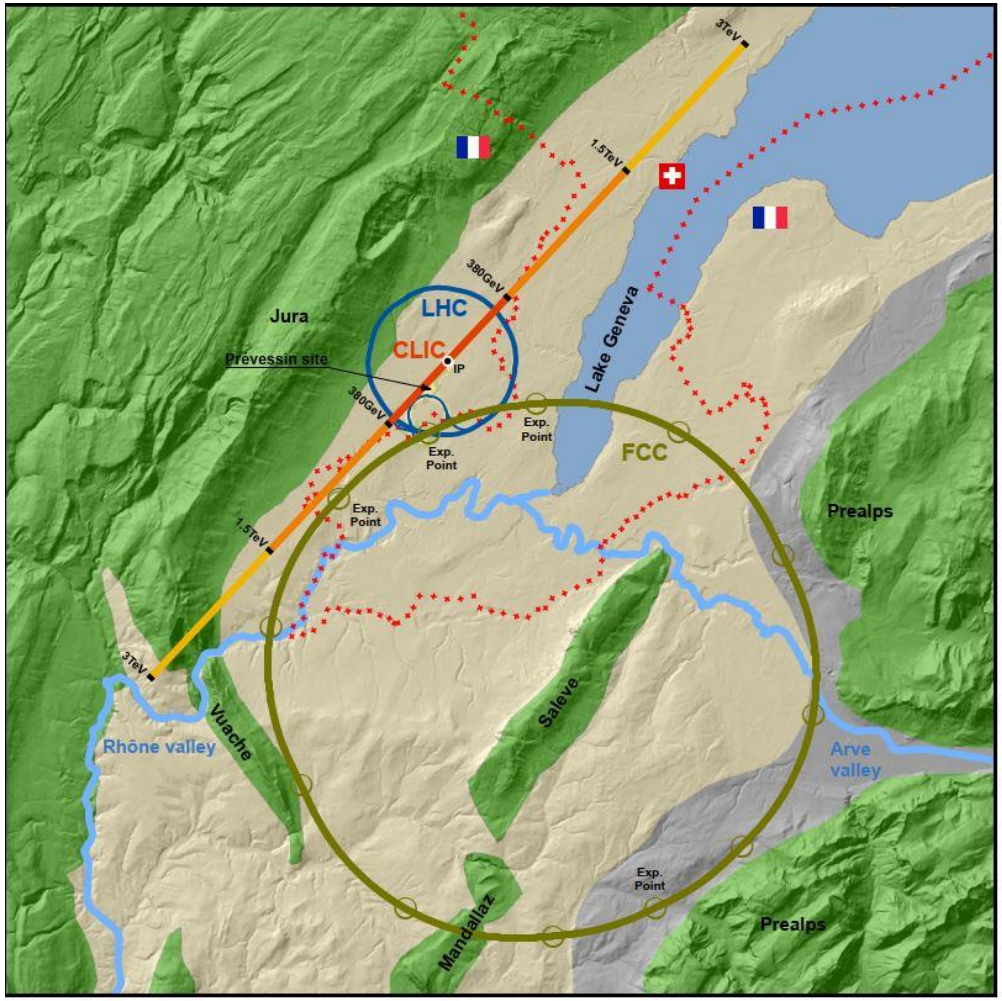




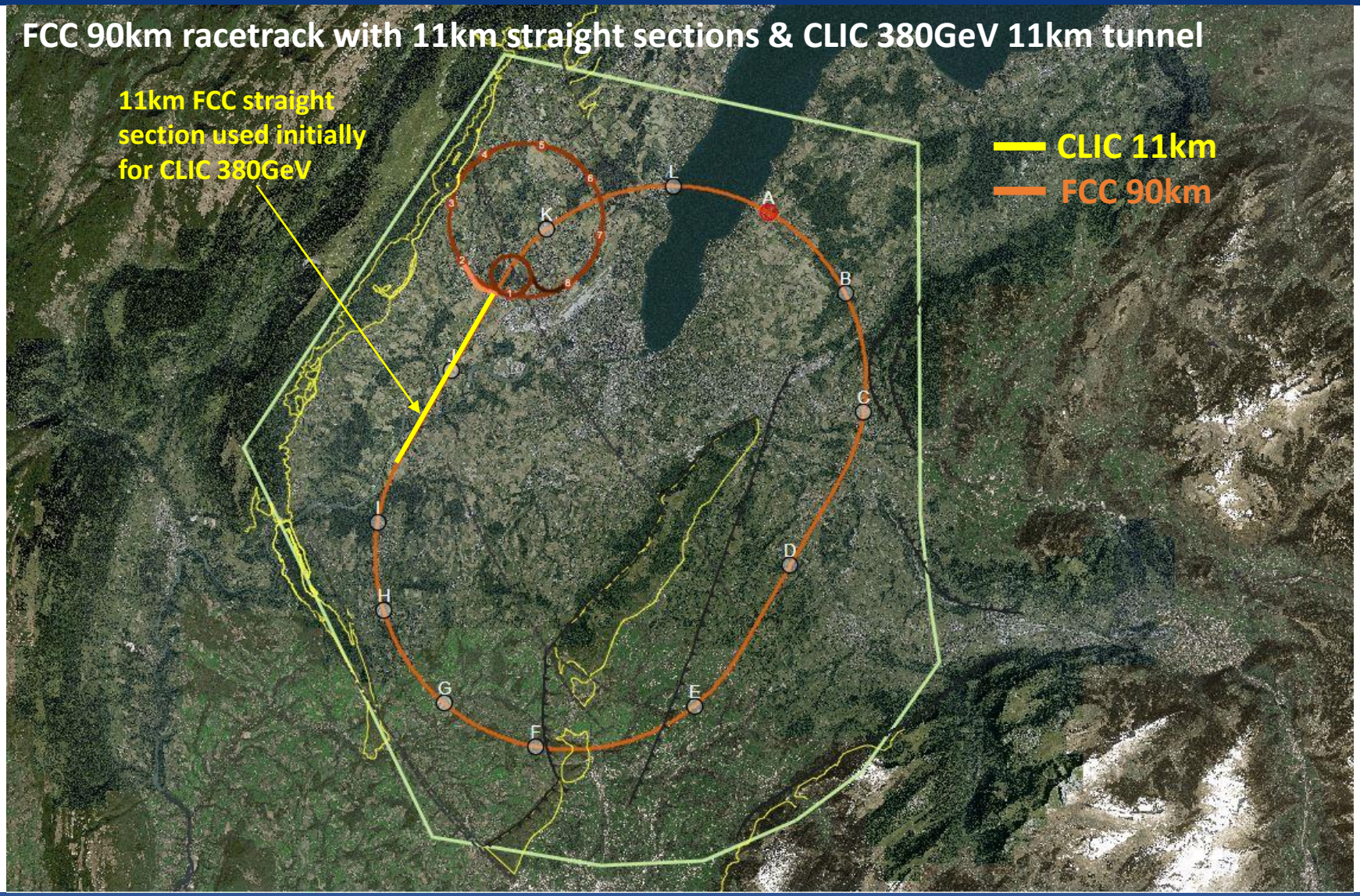
FCC ring situated West of Jura with a single transfer line to LHC



Circular or Linear colliders?



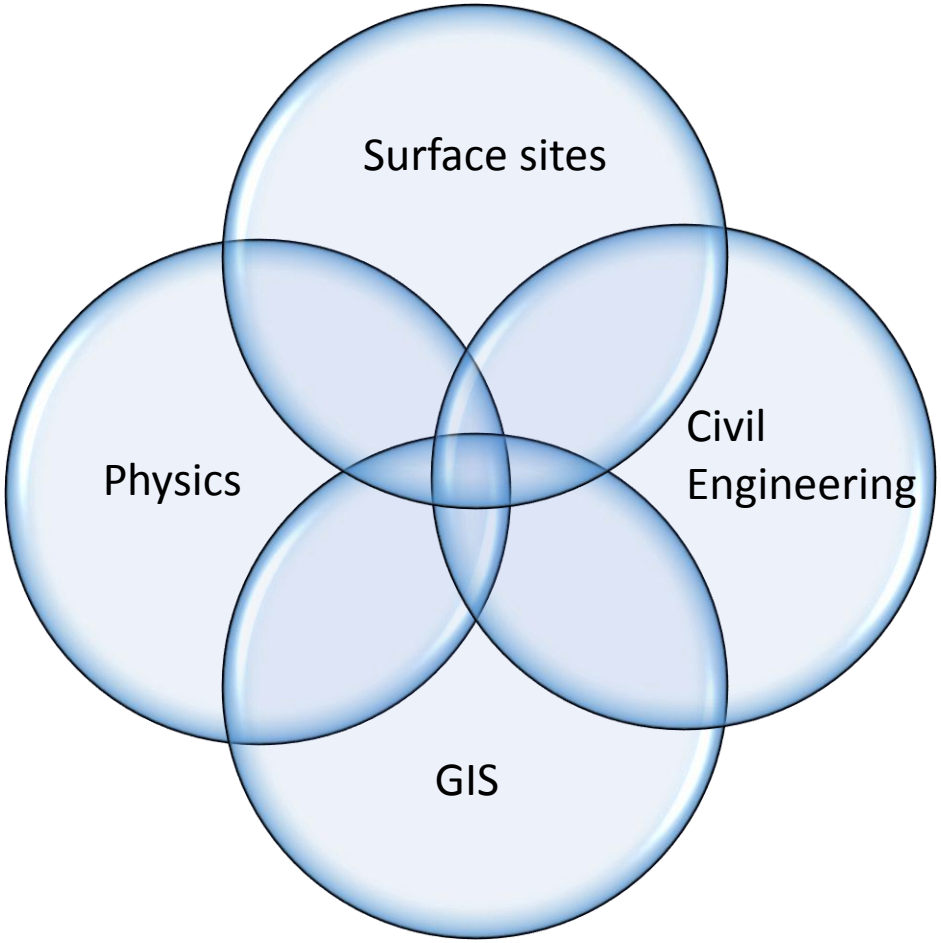
Combined layout for FCC & CLIC



Integrated project data

- New layers/shape files should be easily added/updated within the tool, following feedback from French and Swiss authorities

- Easy adjustment of machine design parameters (straight sections, arc length and radius)
- Possibility to use the tool/software for various alignment configurations (linear and circular colliders)



- Continuous feeding of geological data that will be gathered from site investigations
- Boreholes information
- Show geological profiles for inclined tunnels (and injection tunnels)

- Maintenance of web application/software and libraries
- Compatible GIS geodetic reference systems with CERN GIS systems

Conclusions

- Currently focusing on
  - continuous desktop study of geology
  - planning for preparatory works to start the site investigations campaign
  - optimising the footprint

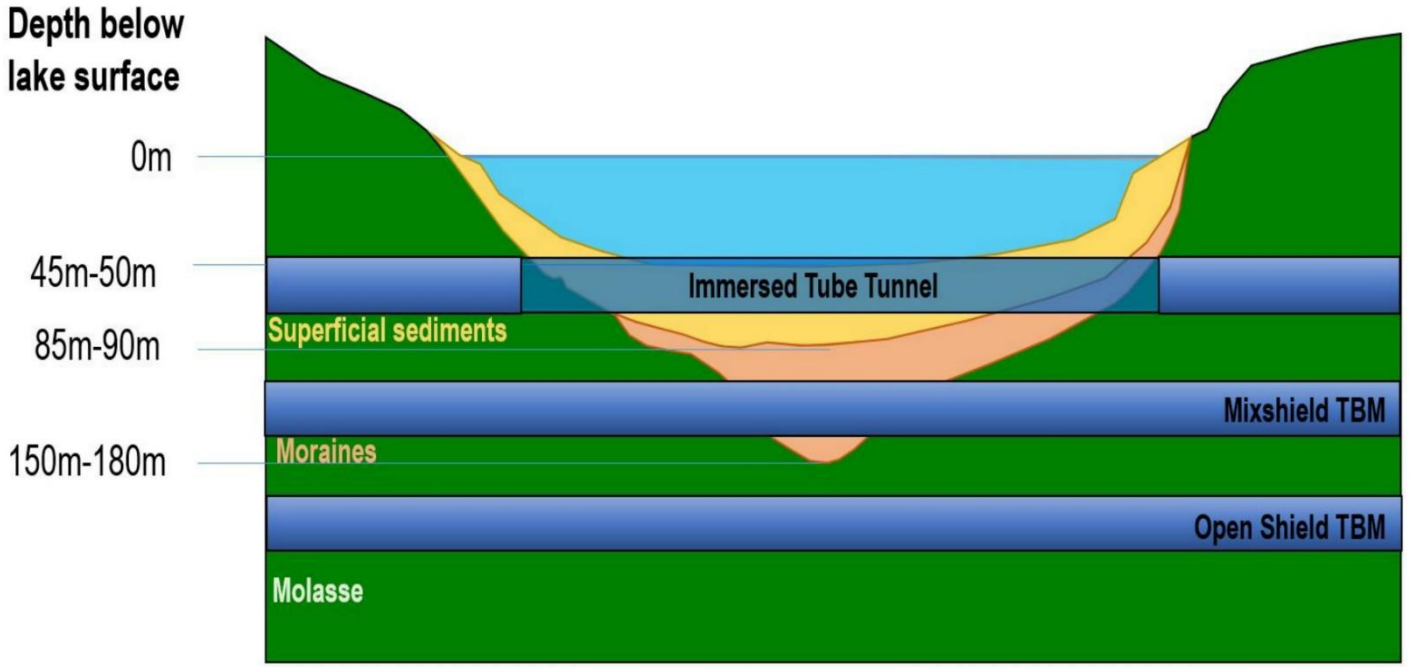
- Exploring GIS tools and alignment optimisation software that could facilitate future colliders studies from feasibility stage throughout detailed design stage up to construction start

OR a Software/programme that could automatically generate the best location and layout for an alignment?

Thank you for your attention!

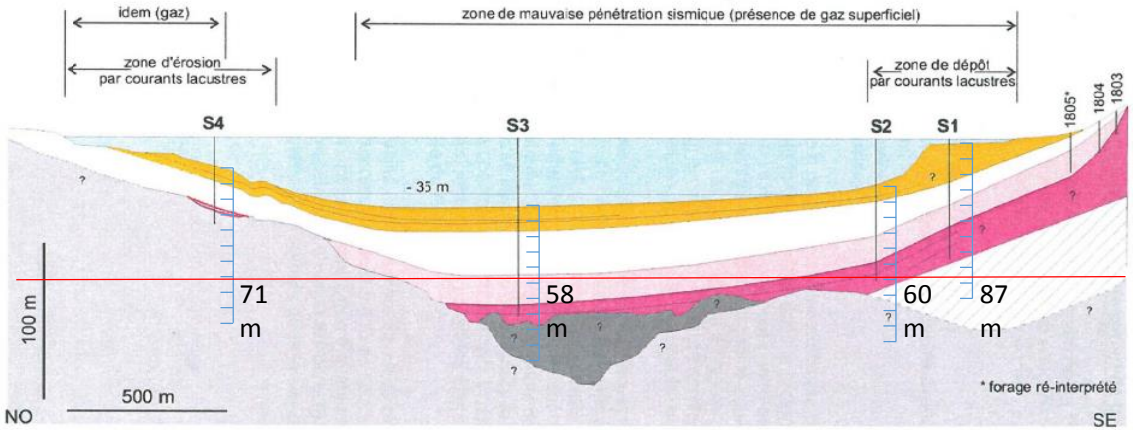
Back up slides

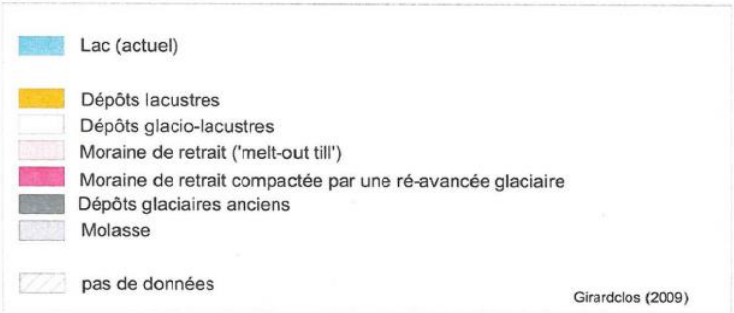
Options for tunneling under the lake



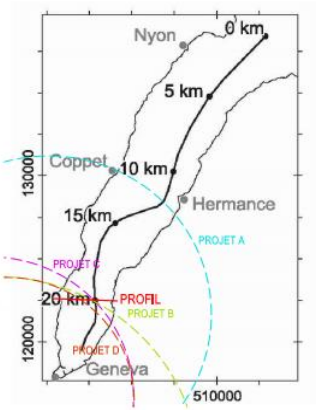
Geneva Lake profiles

- Geology underneath Lake Geneva is not yet well understood.
- Data available from a few boreholes and seismic scans





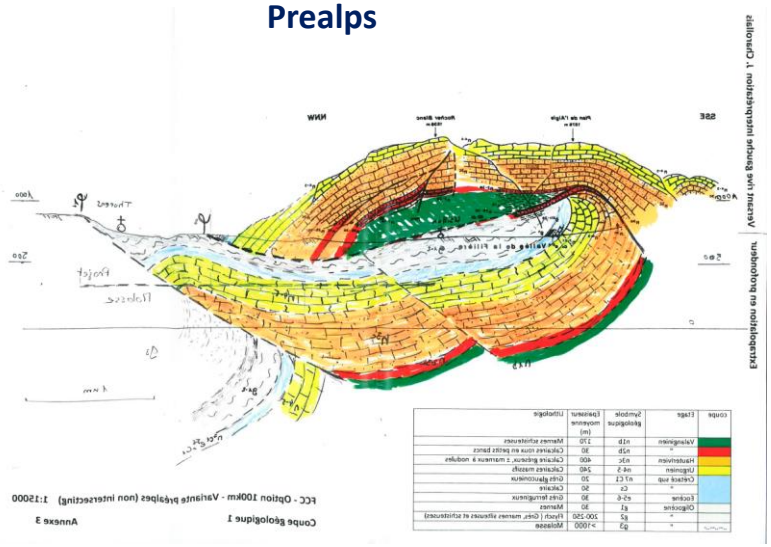
Profil géologique Lac Léman
(Vengeron-Belotte)



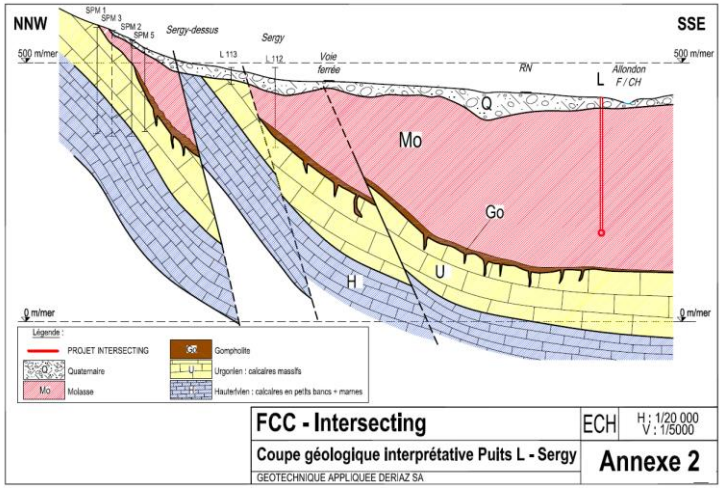
Geological interpretation

Regions with high uncertainty and challenging geology

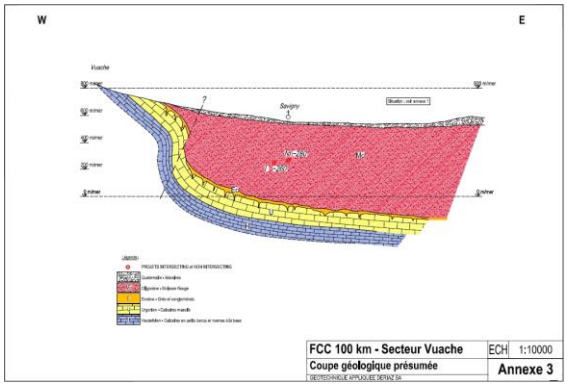
Prealps



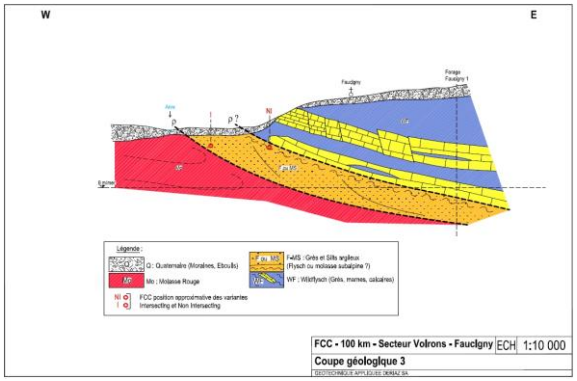
Jura



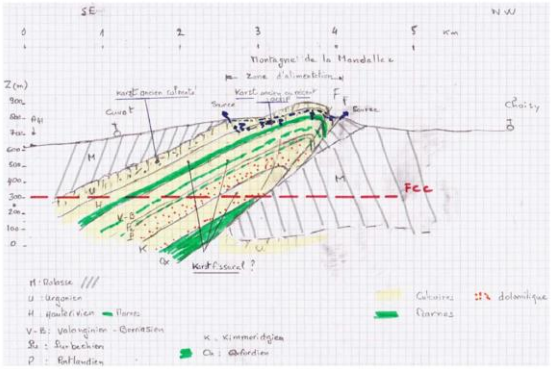
Vuache



Voirons - Faucigny



Mandallaz



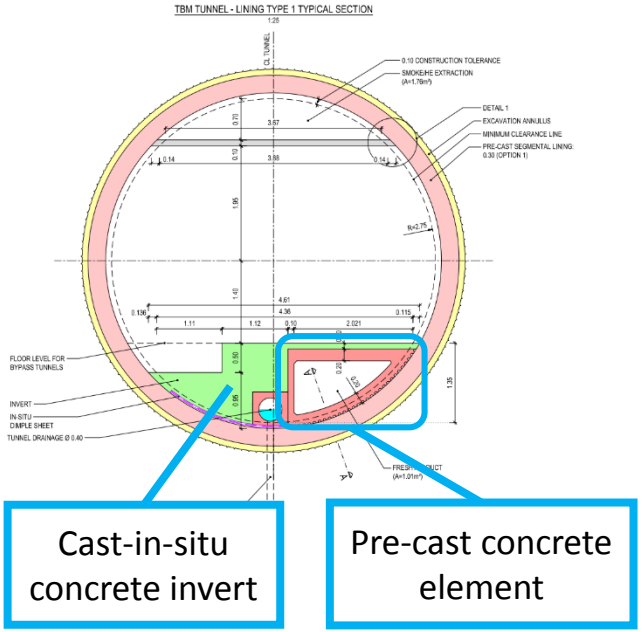
CERN

GEOTECHNIQUE APPLIQUEE DERIAZ S.A.
GADZ

Machine tunnel cross sections and lining concepts

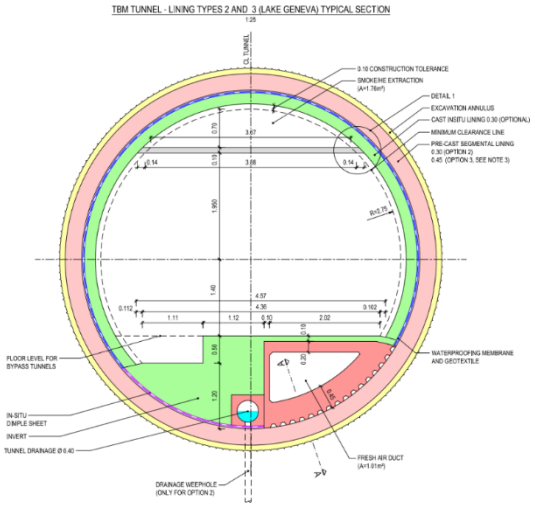
Lining Type 1

- TBM tunnel in ‘good’ rock



‘Good rock’ is defined as fresh and massive rock with none to moderate jointing.

Lining Type 2 & 3



Lining types 2

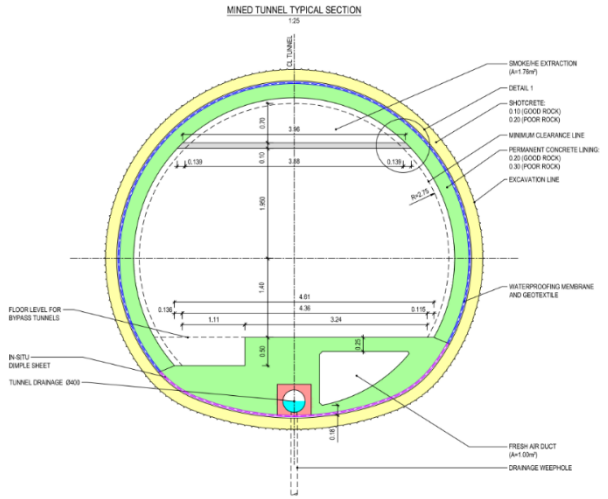
- TBM tunnel in jointed molasse with high risk of groundwater infiltration
- In sectors where there is relatively low rock cover to the water bearing moraine deposits
- Precast concrete thickness: 30cm

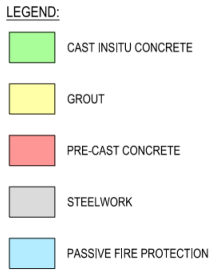
Lining type 3 (under Geneva Lake)

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

Lining type 4

- Mined tunnels in limestone





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

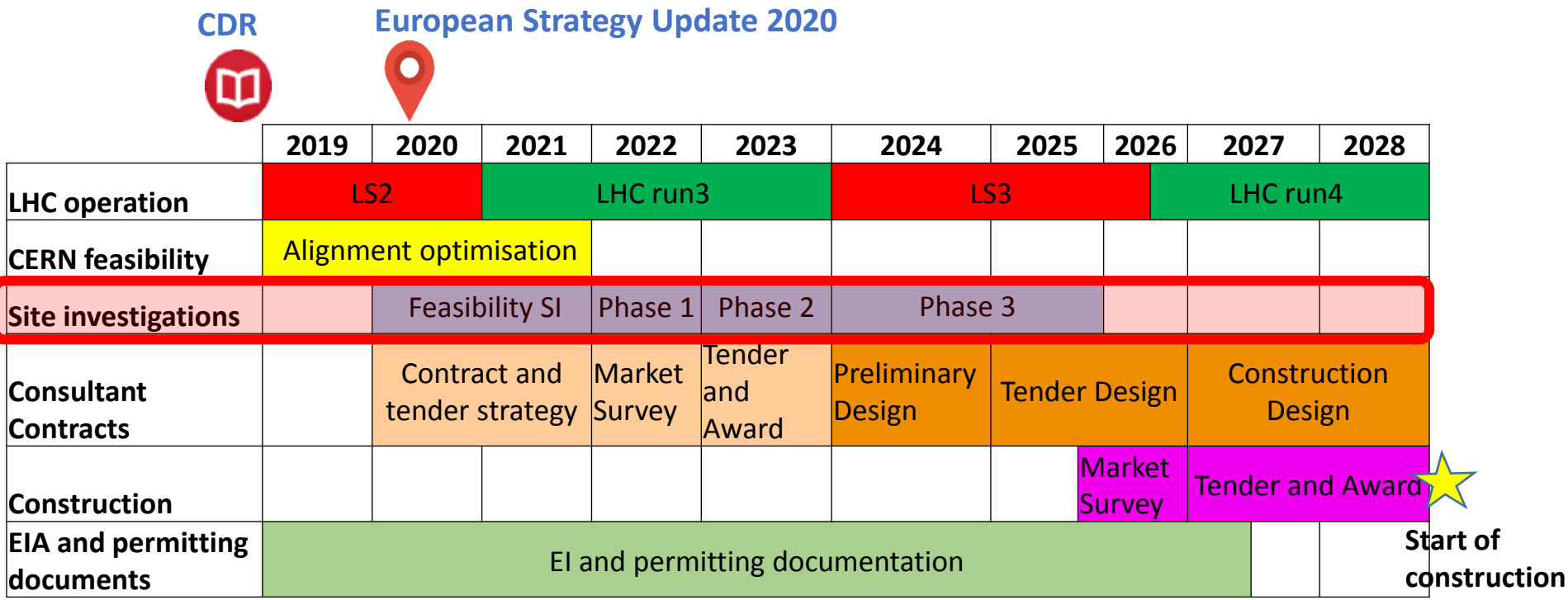
Types of site investigations:

- 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

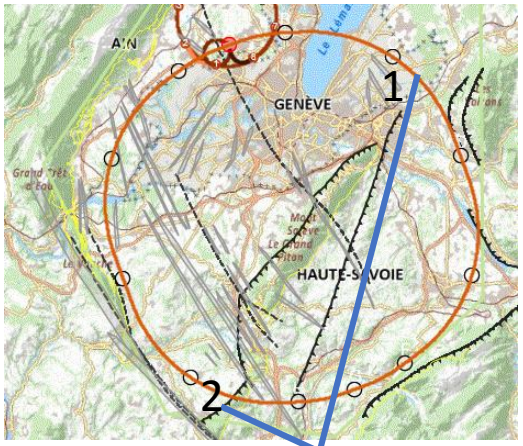
Schedule for preparatory phase



Mapping of fault lines

The available information for fault lines has come from three sources:

- Geological map from GADZ (dotted fault lines in TOT)
- Limestone roof map from GGE (grey fault lines in TOT)
- GeoMol's geological model (fault lines shown in red and purple)

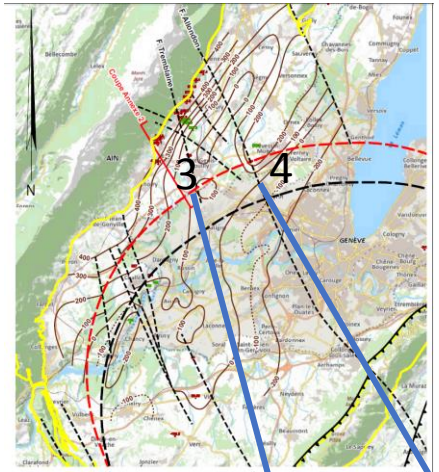


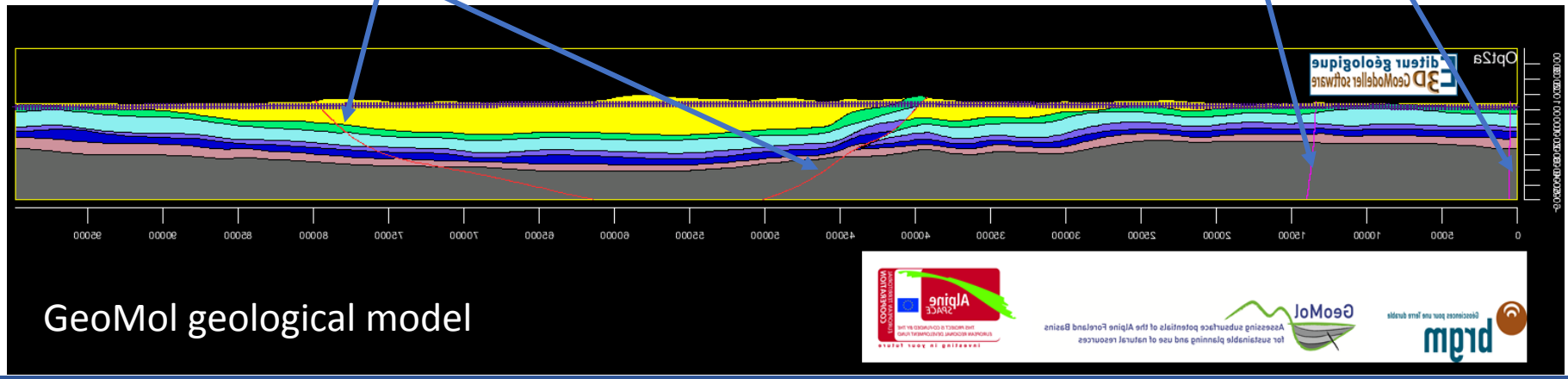
[1] Un-mapped fault? (not shown in TOT)

[2] Fault through Mandallaz

[3] Tremblaine fault

[4] Allondon fault

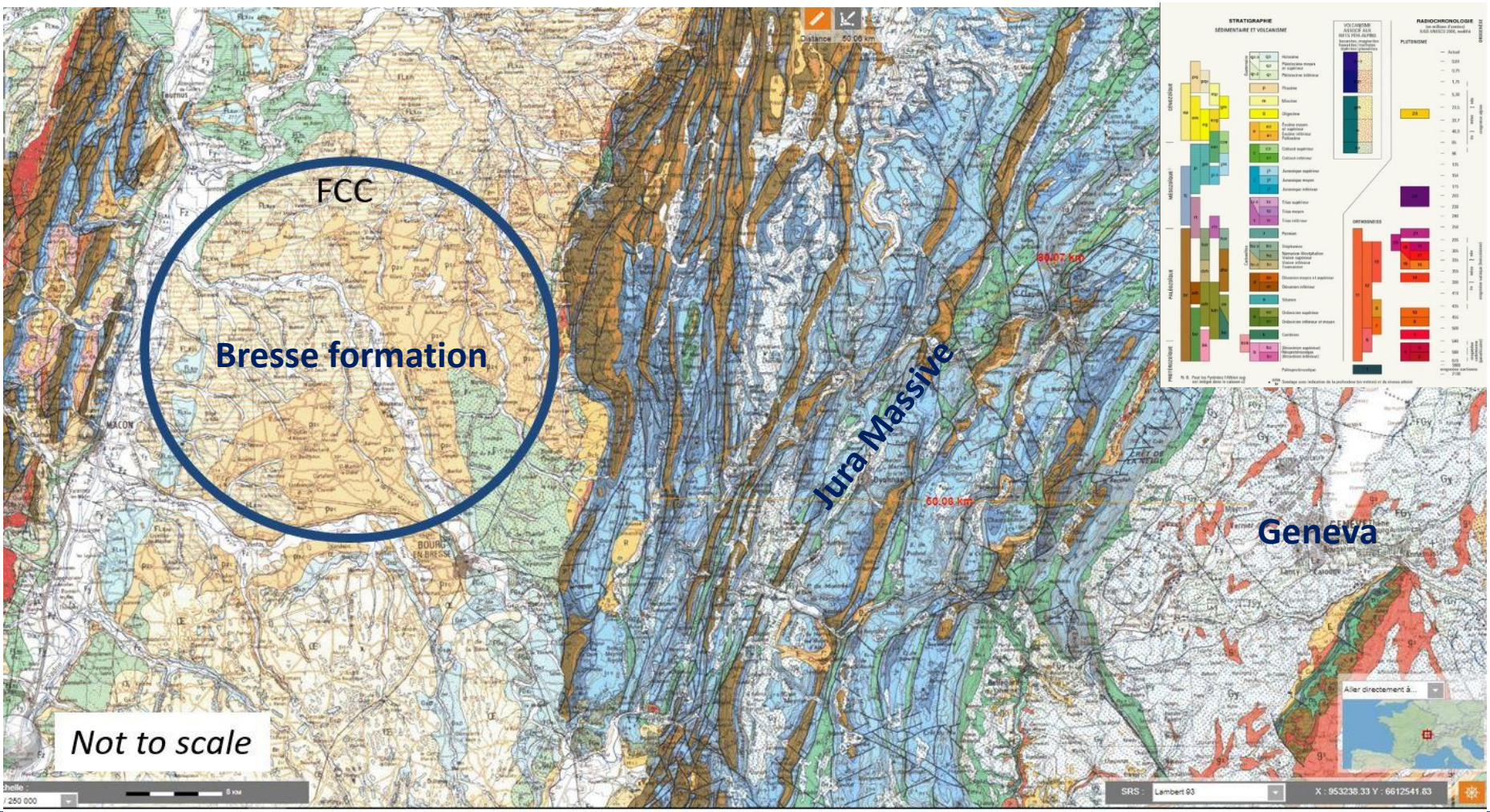




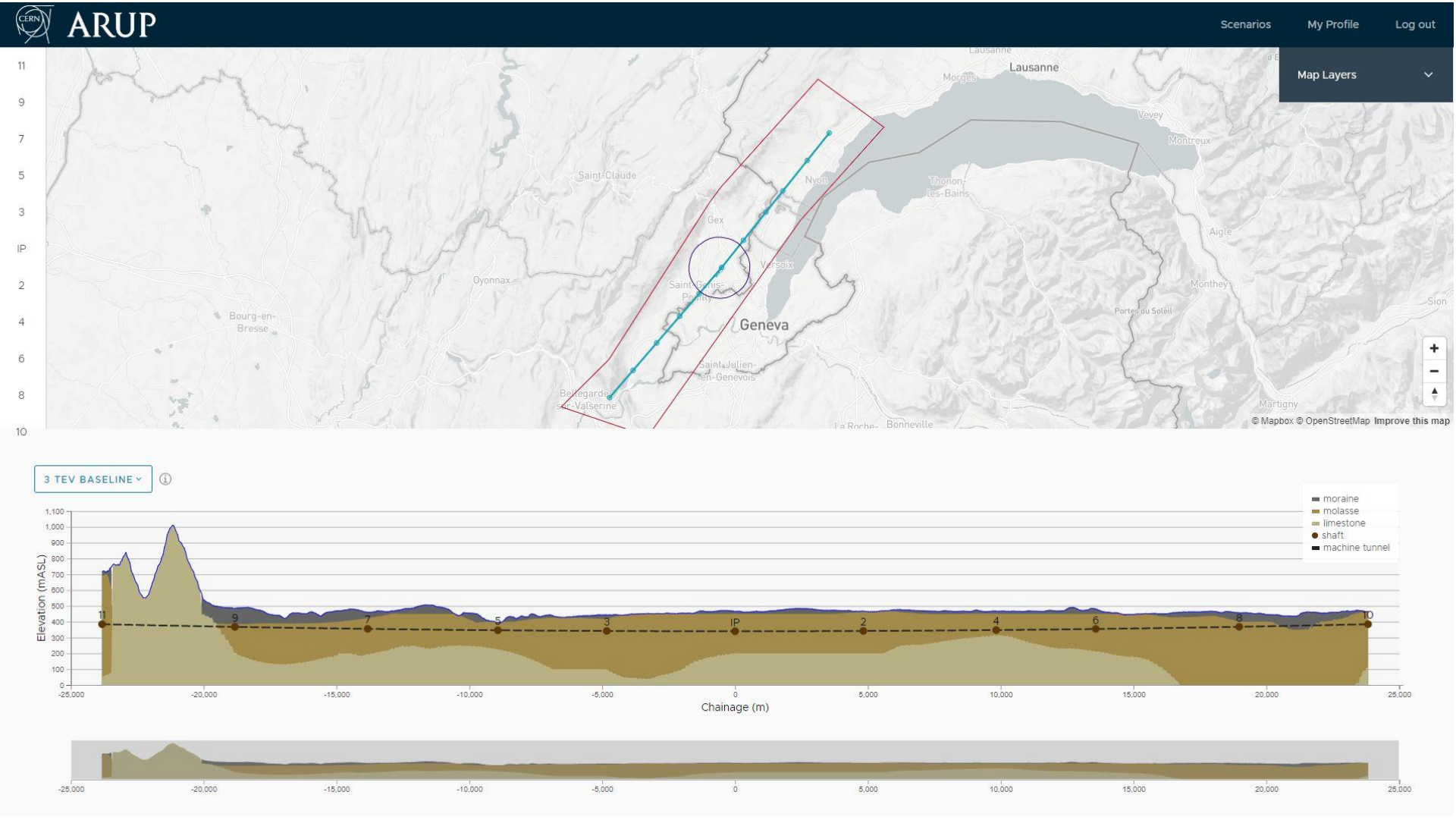
GeoMol geological model

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.



CLIC Tunnel Optimisation Tool



FCC + CLIC combined alignments

FCC 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

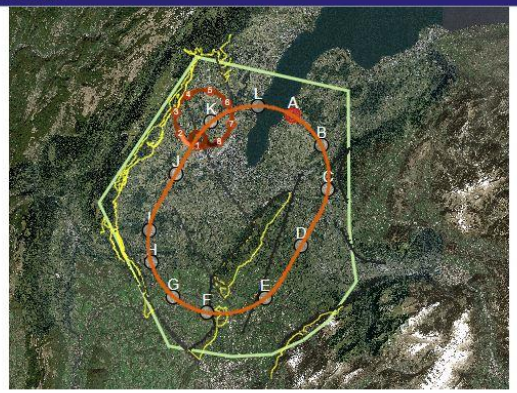
LOAD CREATE UPDATE CALCULATE

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

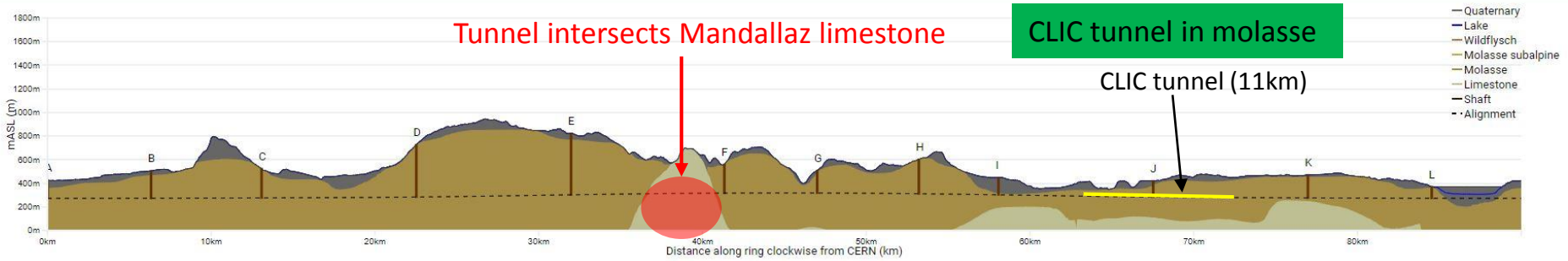
Alignment Location



Geology Intersected by Shafts | Shaft Depths

Point	Actual	Shaft Depth (m) Molasse SA	Wildflysch	Quaternary	Geology (m) 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

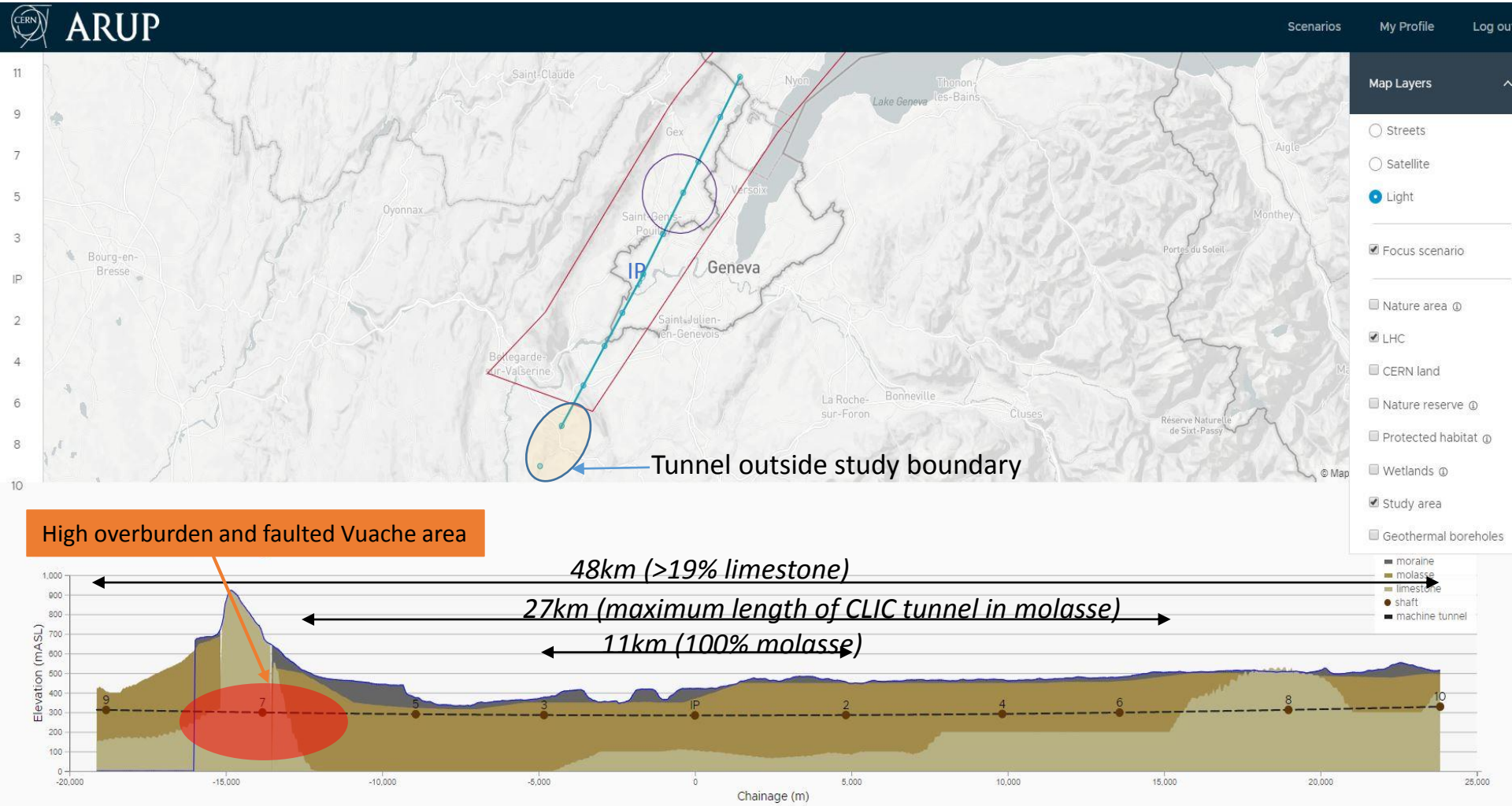


Geology Intersected by Tunnel | Geology Intersected by Section

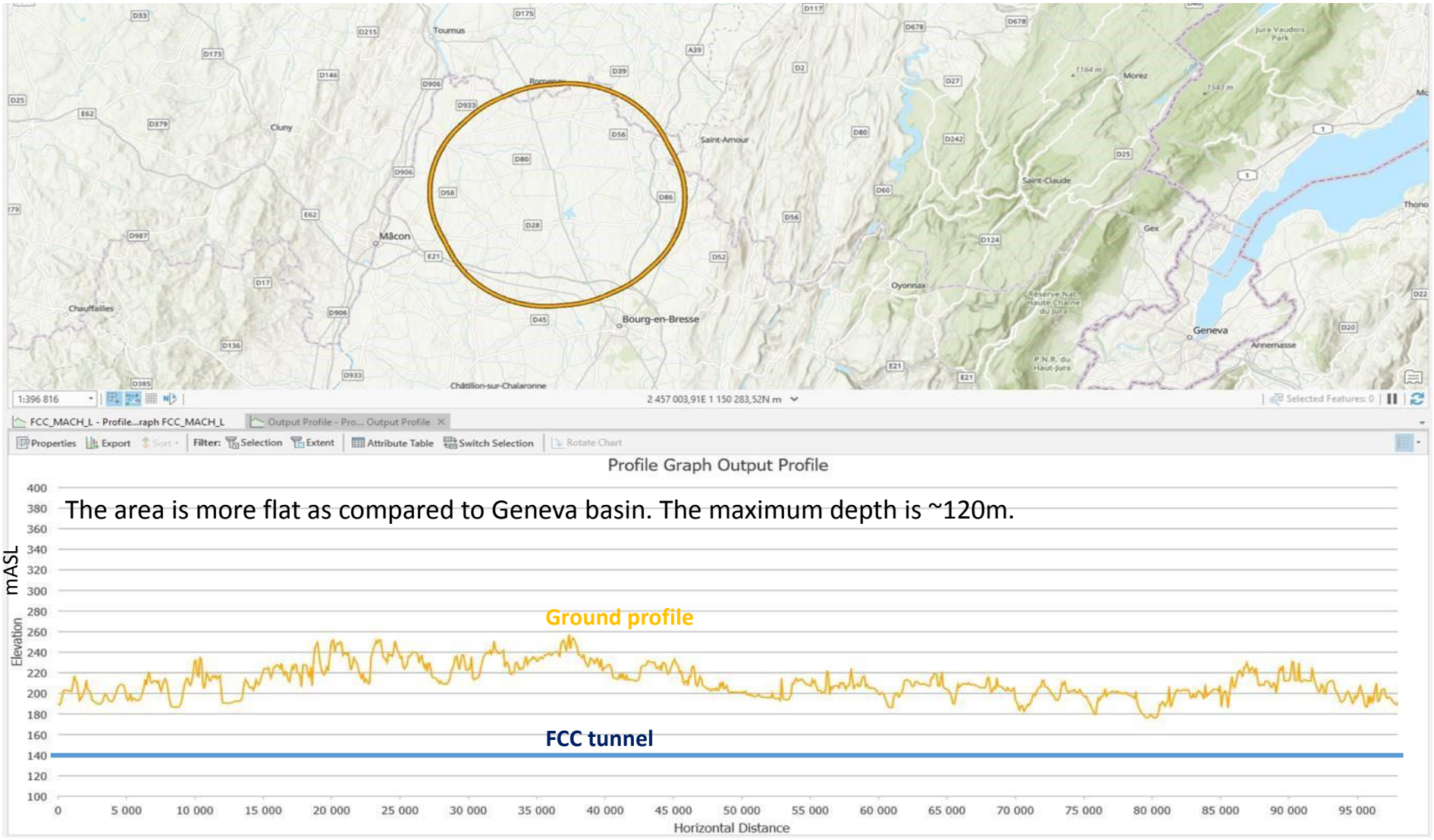
More layouts combining FCC and CLIC have been studied.

FCC & CLIC combined alignments

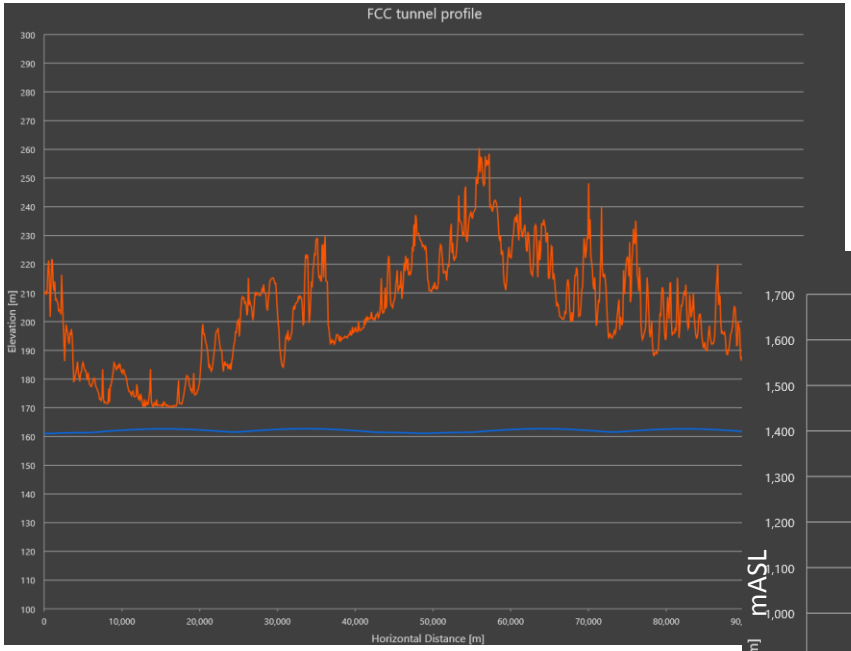
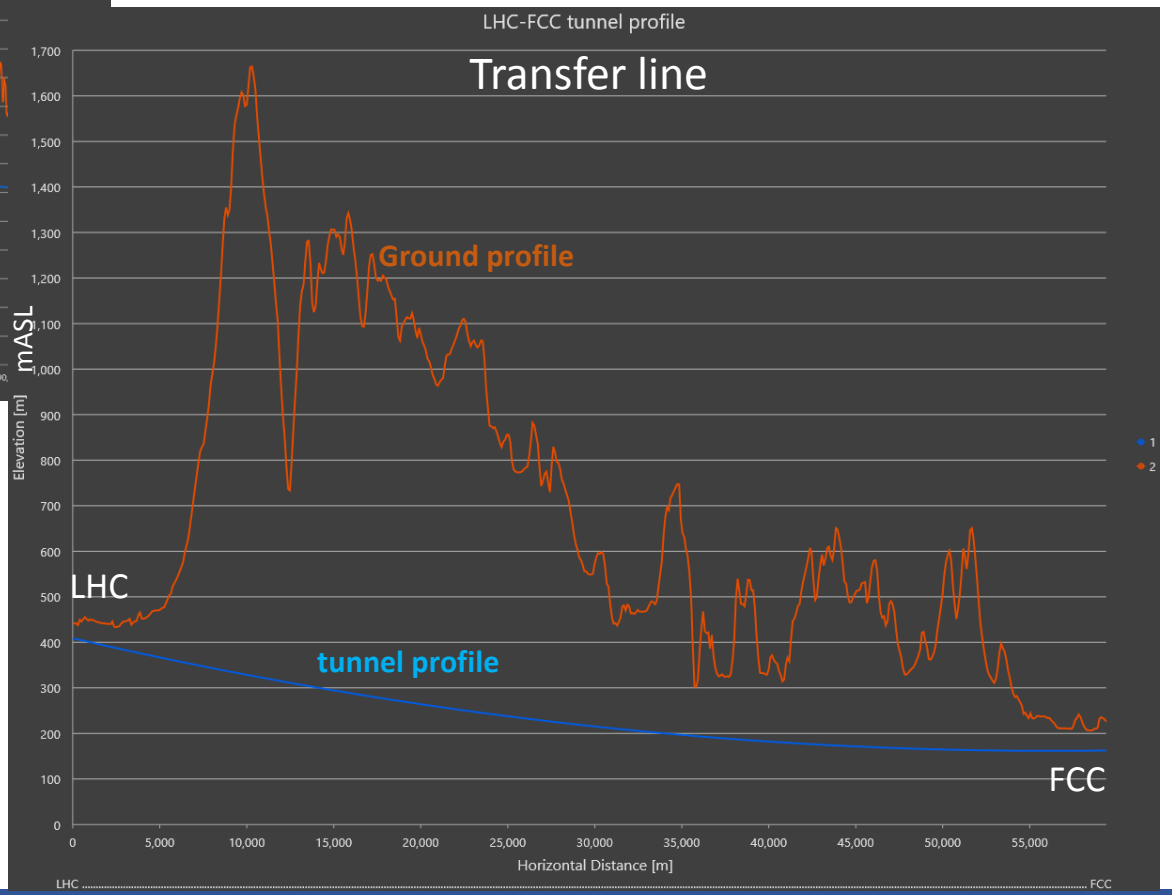
CLIC TOT output for full length CLIC tunnel



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.