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Future Circular Colliders Study
Kickoff Meeting

12-15 February 2014
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# Civil Engineering and Geology for an ≈ 80-100km Tunnel near CERN

John Osborne (CERN GS-SE) 14 February 2014

AMBERG ENGINEERING

ARUP

GADZ
GÉOTECHNIQUE APPLIQUÉE
DERIAZ S.A.

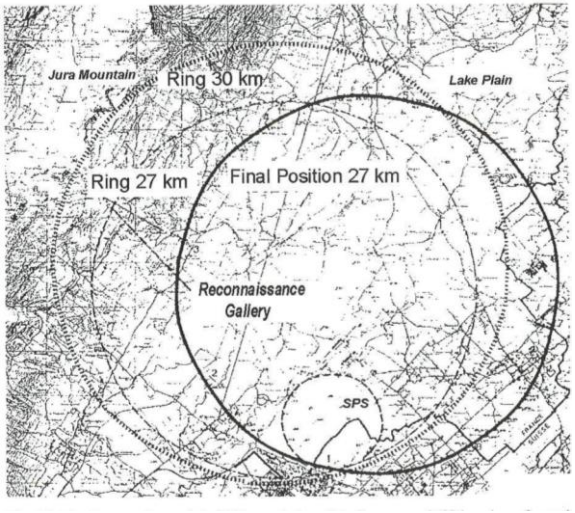
# Outline

- Potential locations
- CE considerations
  - Geotechnical
  - Tunneling
  - Environmental
  - Optimization
- Cost estimate method
- Feasibility / Risk issues
- Next steps

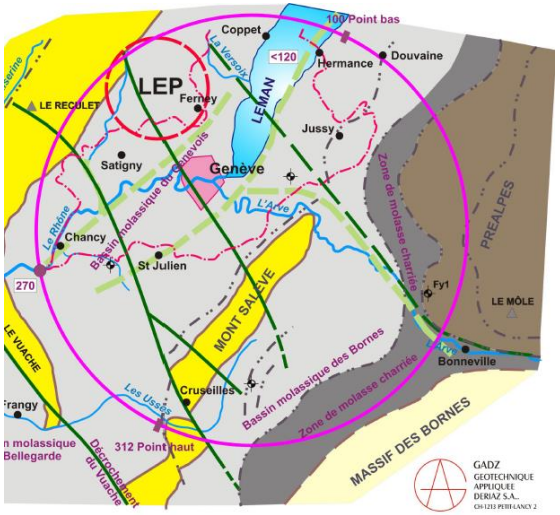
# Potential locations

- Options for a ring tunnel have been proposed in the past :

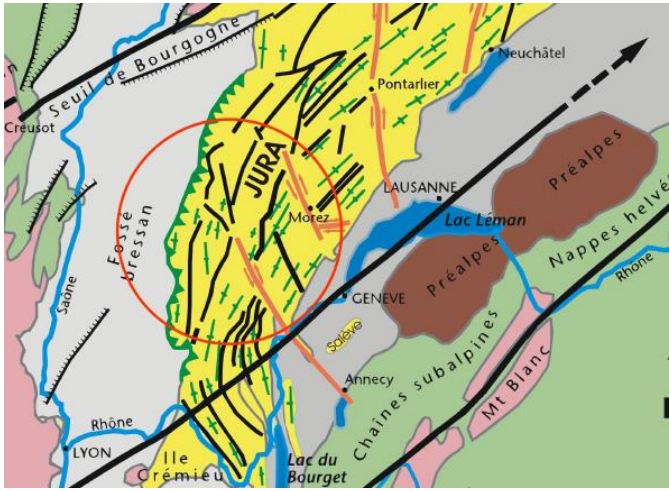
*1980's :LEP 30km and 27km tunnel locations*




*1997 : VLHC 113km tunnel location*




*2001 : VLHC 240km tunnel location*



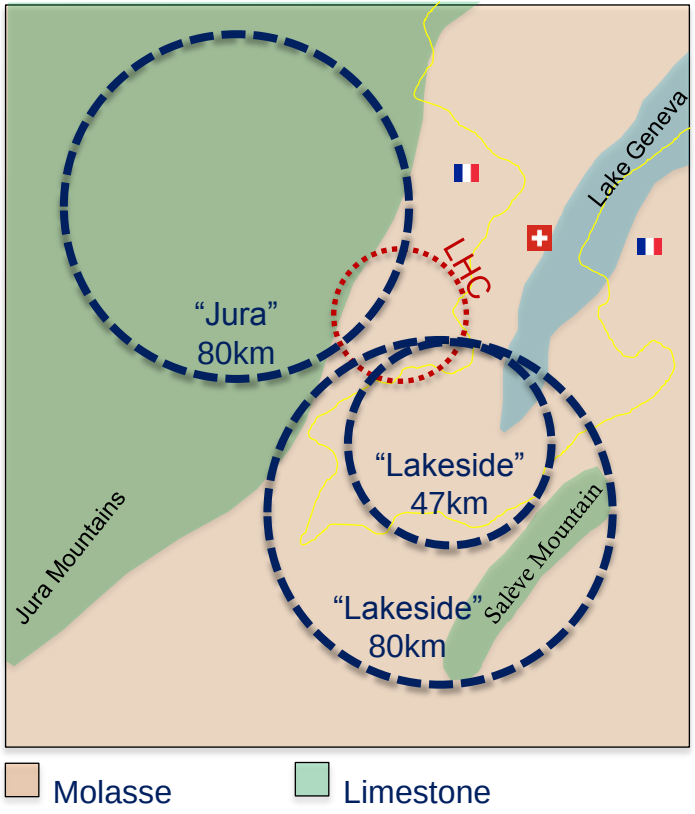

- Summer 2012 CERN GS-SE group studied the pre-feasibility of an 80km ring tunnel in the CERN area.

- Pre-feasibility study of an 80km tunnel project at CERN prepare for the European Strategy for Particle Physics 2012 : http:/ / indico.cern.ch/ event/ 175067/ call-for-abstracts/ 165/ file/ 1.pdf

# Potential locations : European Strategy for Particle Physics

- Several locations have been studied for the possibility to construct an 80km ring tunnel in the CERN area.
  - Location constraints
    - CERN area
    - Connected to LHC/ SPS at one point
    - Depth (access shafts)

| | Circumference | Average Depth | Max Depth below surface |
|---|---|---|---|
| LEP/LHC | 27 km | 100 m | 170m |
| Jura | 80 km | 590 m | 1270 m |
| Lakeside | 80 km | 280 m | 690 m |
| Lakeside | 47 km | 220 m | 320 m |

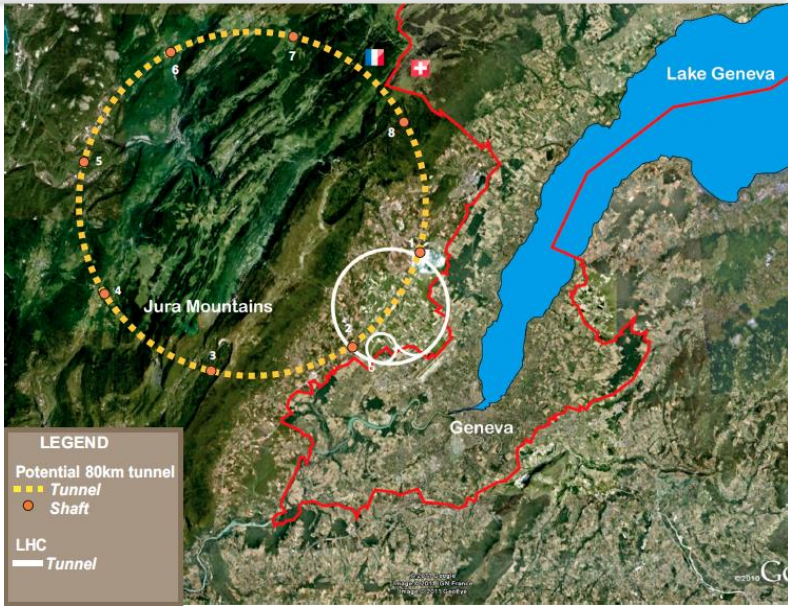


# Potential locations

- Location 1:

  **80km Jura** option

  - Fully housed in France
  - 90% in Jura Limestones
  - 10% in Molasse
  - Connected to LHC
  - Shafts every 10km

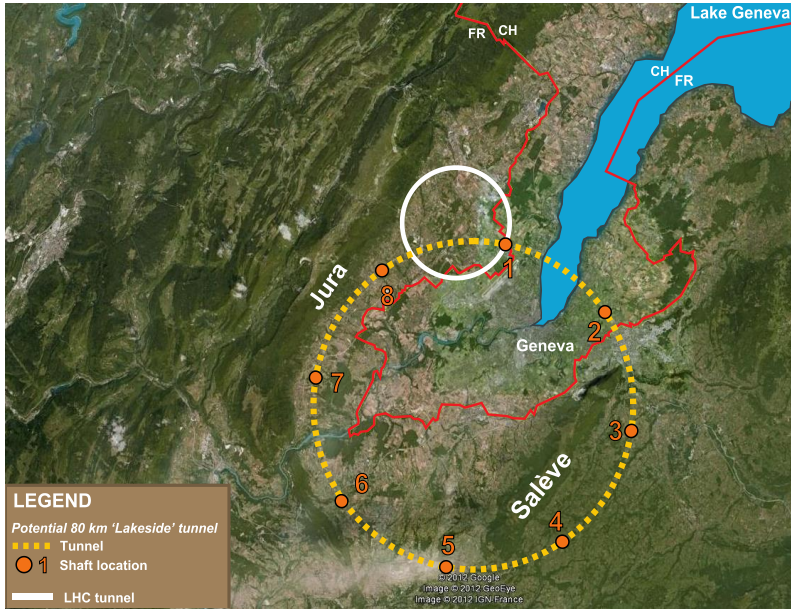



*Option 1: 80km Jura*

- Location 2:

  **80km Lakeside** option

  - Housed in France and Switzerland
  - 10% in Limestones (Jura, Salève)
  - 90% in Molasse
  - Passes under Lake Geneva
  - Around the back of the Salève
  - Connected to LHC
  - Shafts every 10km




*Option 2: 80km Lakeside*

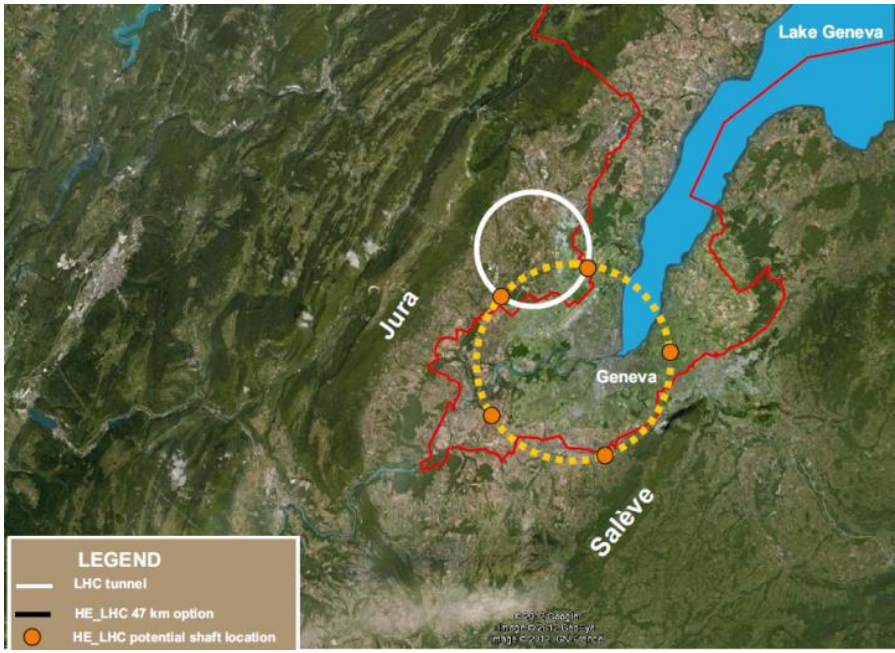
# Potential locations

- Location 3:

  **47km Lakeside** option

  *Studied from geotechnical viewpoint*

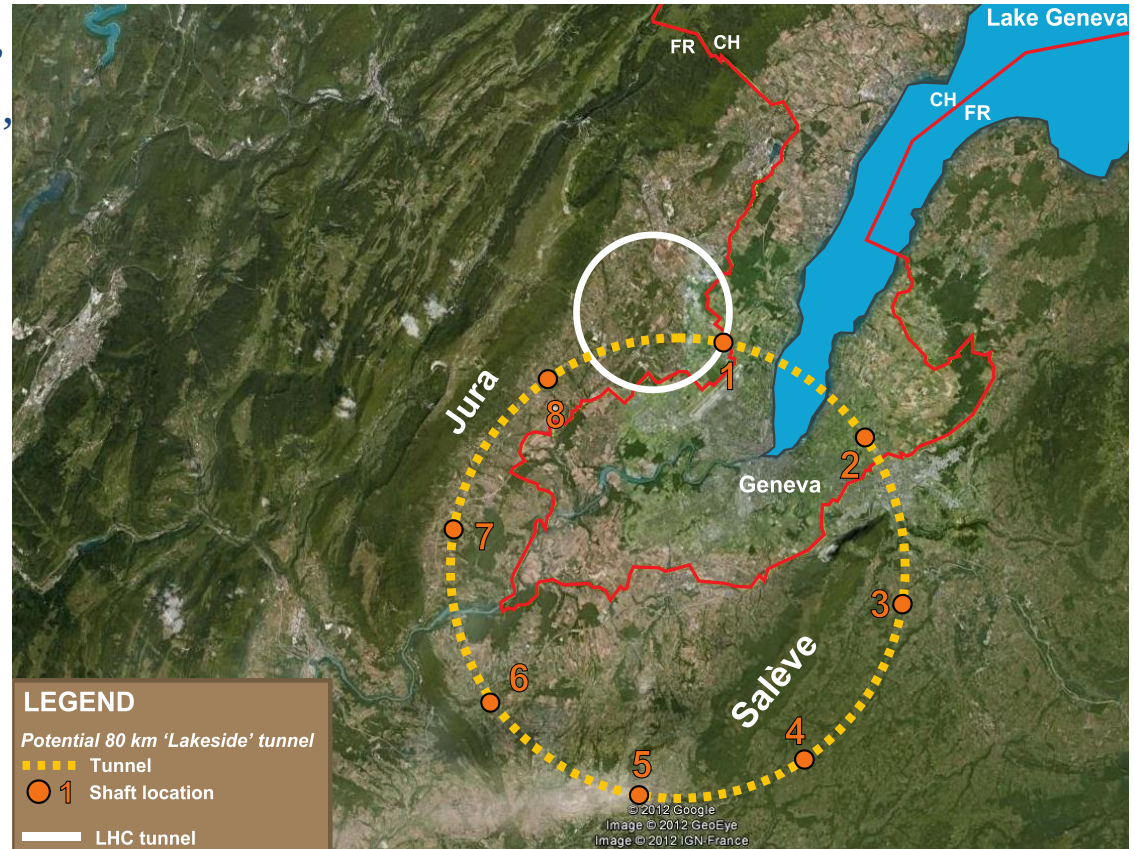
  – Fully housed in the Molasse rock (preferred excavation rock in the Geneva area)
  – Under Lake Geneva
  – In front of Salève and Jura
  – Housed in France and Switzerland
  – Connected to LHC
  – Shafts every 10km
    - Too short for physics goal?




*Option 3: 47km Lakeside*

# Potential locations

- Pre-feasibility study performed by CERN and the specialized firms ARUP and GADZ.
  - Focused on
    - 80km 'Lakeside' Option
    - geology & hydrogeology,
    - tunneling & construction,
    - environmental impacts



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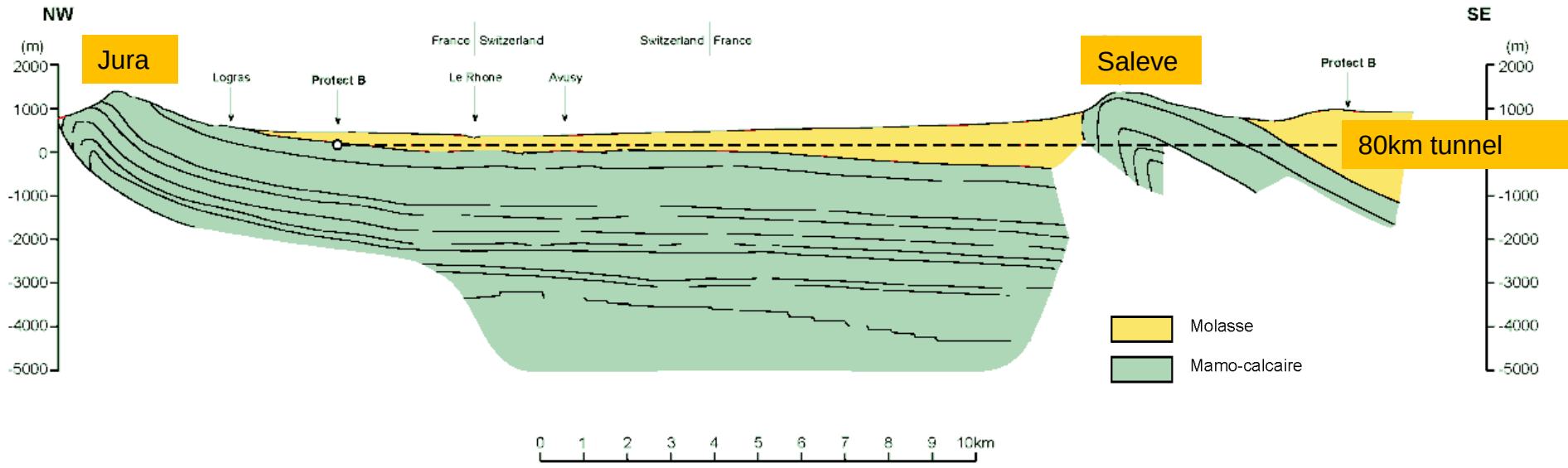
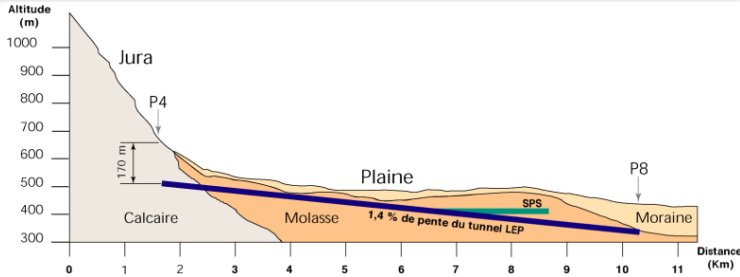
Tunnel passes through

- Moraines
- Molasse
- Limestones




*Simplified geological profile*

## Rock properties

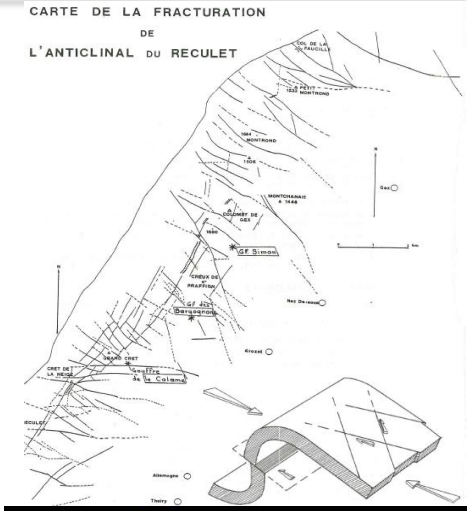


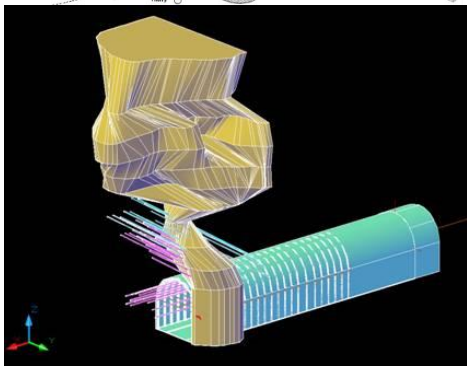

- Moraines
  - Glacial deposits comprising gravel, sands silt and clay
  - Water bearing units
- Molasse
  - Mixture of marls, sandstones and formations of intermediate composition
  - Considered good excavation rock:
    - » Relatively dry and stable
    - » Relatively soft rock
  - However, some risk involved
    - » Weak marl horizons between stronger layers are zones of weakness
    - » Faulting and fissures due to the redistribution of ground stresses
    - » Structural instability

*Compression strengths*

| **Rock type** | | **Average σc (Mpa)** |
|---|---|---|
| **Sandstone** | *weak* | 10.6 |
| | *strong* | 22.8 |
| | *Very strong* | 48.4 |
| **Sandy marl** | | 13.4 |
| **Marl** | | 5.7 |

Above: fractures in Jura
Below: model of tunnel collapse due to karst



## Rock properties

- Limestones
  - Hard rock
  - Normally considered as sound tunneling rock
  - In this region fractures and karsts encountered
    - » Risk of tunnel collapse
    - » High inflow rates measured during LEP construction (600L/ sec)
    - » Clay-silt sediments in water
    - » Rockmass instabilities
- Evaporates could be encountered
  - Known to exist in the 'deeper' parts of the Jura mountain
  - Unknown if these formations also exist at the foot of the Jura and Salève
  - Contain the mineral anhydrite, which reacts to water and pressure changes -> bad rock for tunneling
    - » Major structural instabilities

Geneva plain
Underneath Lake Geneva
Through Jura and Salève Mountains

- **80km ring passes located :**
  - Geneva plain
  - Underneath Lake Geneva
  - Through Jura and Salève Mountains (~ 10%)

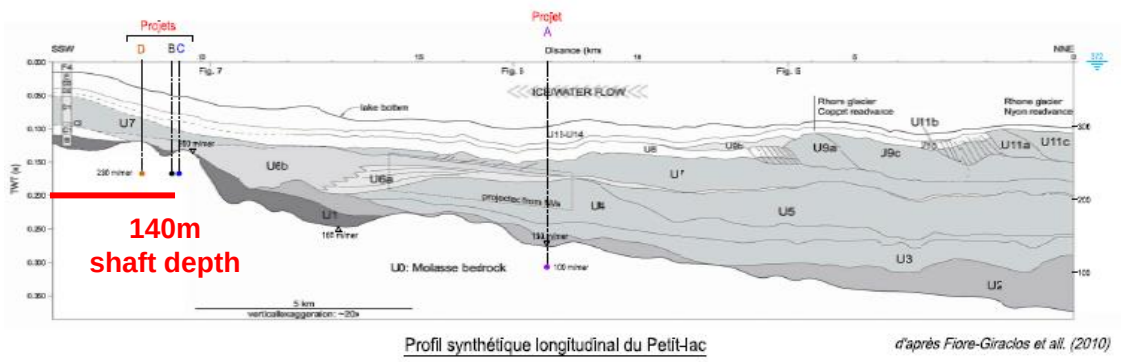
- **Geneva plain area**
  - Consists of Moraines and Molasses
    - Tunnel, tunnel enlargements and caverns located in Molasse
    - Shafts located in Moraines and Molasse
  - Near CERN the ground conditions are relatively well understood
  - More information and studies needed for the south and east areas (below Rhone River and east of Geneva)
  - During tunneling hydrocarbons could be encountered -> environmental issues and possible delays

# CE considerations

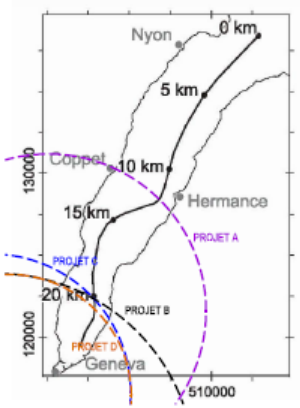
*Tunneling*

Geneva plain
Underneath Lake Geneva
Through Jura and Salève Mountains

- **Lake area** consists of Moraines and Molasse
  - Geology is not yet well understood
  - Depth Moraine-Molasse interface needs to be determined
  - Some seismic soundings performed for the possible construction of a road tunnel
    - Problems due to gas trapped in sediments -> more studies needed
  - We know that the depth of the Molasse increases rapidly towards NE
  - To ensure the positioning of the tunnel in the Molasse a minimal depth of ~ 140m is probably required



Profil synthétique longitudinal du Petit-Lac d'après Fiore-Giraclos et all. (2010)



# CE considerations

*Tunneling*

Geneva plain
Underneath Lake Geneva
Through Jura and Salève Mountains

- **Mountain area** consists of Limestones and evaporates
  - For 10% of tunnel
  - Difficult tunneling conditions
    - Local and unpredictable karst features
      - » Water conduits
      - » High flow rates (600L/ sec)
    - Water transports silt-clay sediments
      - » Difficult to drawing off water through pressure relief holes
      - » Increase of water inflow over time
      - » Difficulties in removal of the water
      - » Risk of aquifer pollution & depletion
    - Anhydrites -> 'badrock' causes swelling
      - » Heaving of the tunnel invert
      - » Structural instabilities
      - » Probably low risk for 80km Lakeside option but high risk for 80km Jura option

*LEP tunnel collapse*

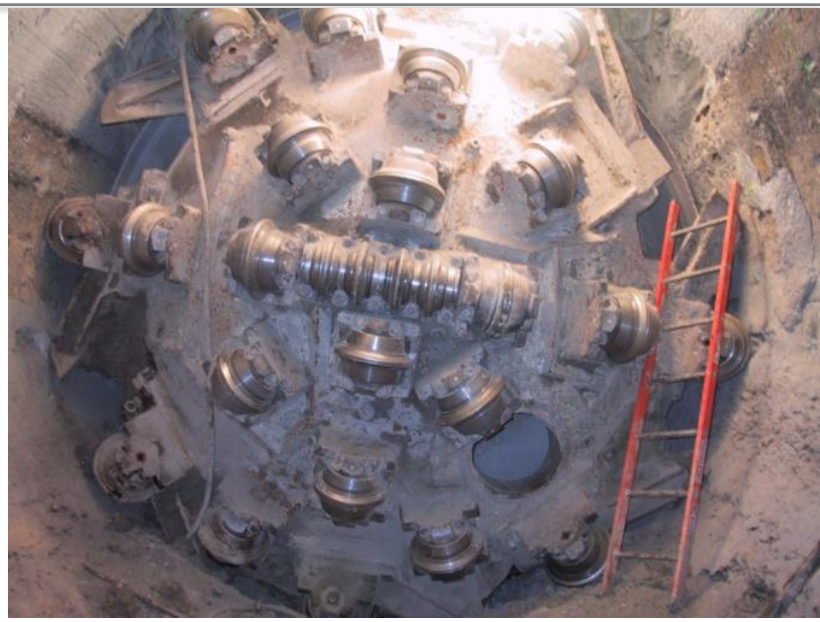
*Example of tunnel invert heave Chienberg tunnel, Switzerland*

# CE considerations

*Tunneling*

- Excavation methods
  - Tunnel in Molasse
    - TBM for main tunnel
      - Tunnel advancement rate 150m/ week
    - Rockbreakers and roadheader for tunnel enlargements
      - Tunnel advancement rate 30m/ week
  - Caverns in Molasse
    - Rockbreakers and roadheader
  - Explosives trials carried out for CMS cavern proved inefficient

*TBM*



*Roadheader*

- Excavation methods
  - Tunnel in Limestone
    - Choice between TBM and Drill & Blast (D&B)
      - » Amount of tunneling through limestones is relatively short; D&B preferred
      - » In areas with karstic features D&B allows free access to the face for grouting/ dewatering ahead of the face
      - » Tunnel advancement rate 20m/ week

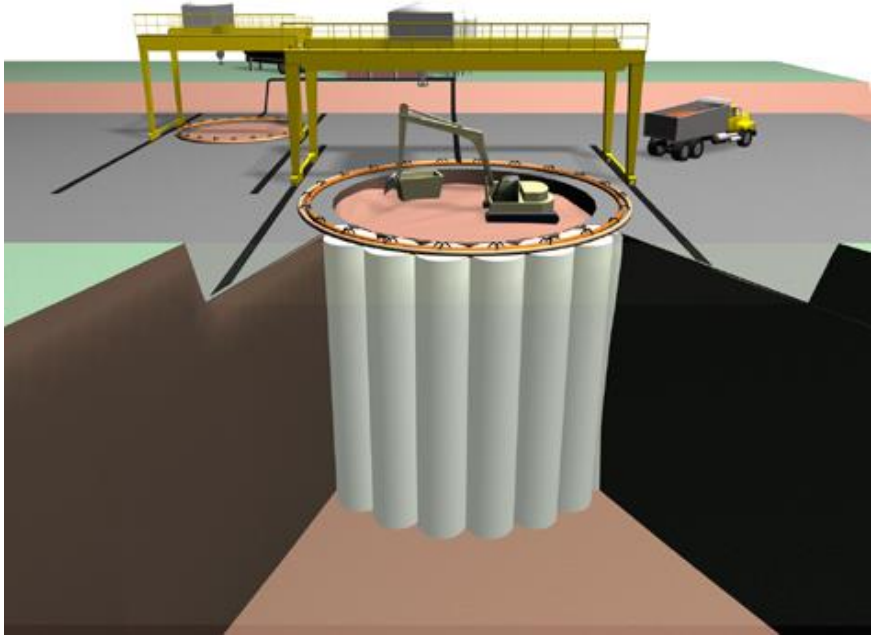
*Drill & Blast*

| | **TBM** | **Drill & Blast** |
|---|---|---|
| Ground Type | Molasse | Jura Limestone |
| Water Pressures | up to 10bar | up to 30bar ? |
| Lining Options | • One pass undrained lining down to 100m<br>• Two pass drained lining below 100m | Two pass drained lining |

# CE considerations Shafts

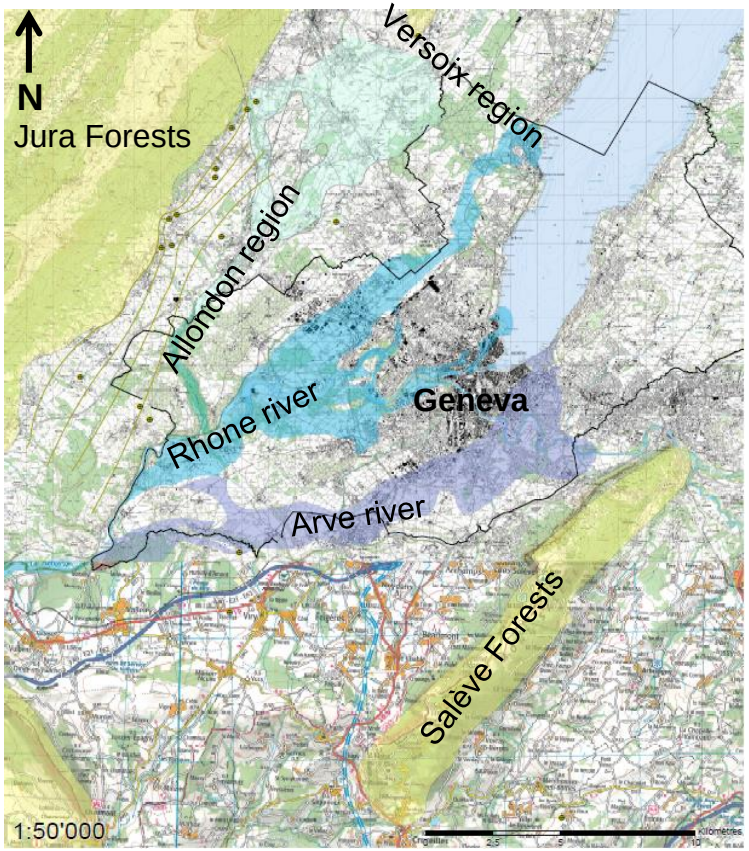
- Several possible shaft excavation methods :

  - Traditional in-situ lining during excavation
  - Diaphragm walling or ground freezing
  - Slipform technique for lining shaft



*Ground freezing technique used at P5*

- For the 80km tunneling project, the environmental impacts should not be underestimated
  - project crosses many sensitive areas:
    - urban, agriculture, natural parks, protected groundwater areas etc.
  - Some main impacts issues to consider
    - Civil Engineering
    - Social acceptance
    - Landscape
    - Water protection
    - Natural areas
    - Radiation
    - Waste
    - Traffic



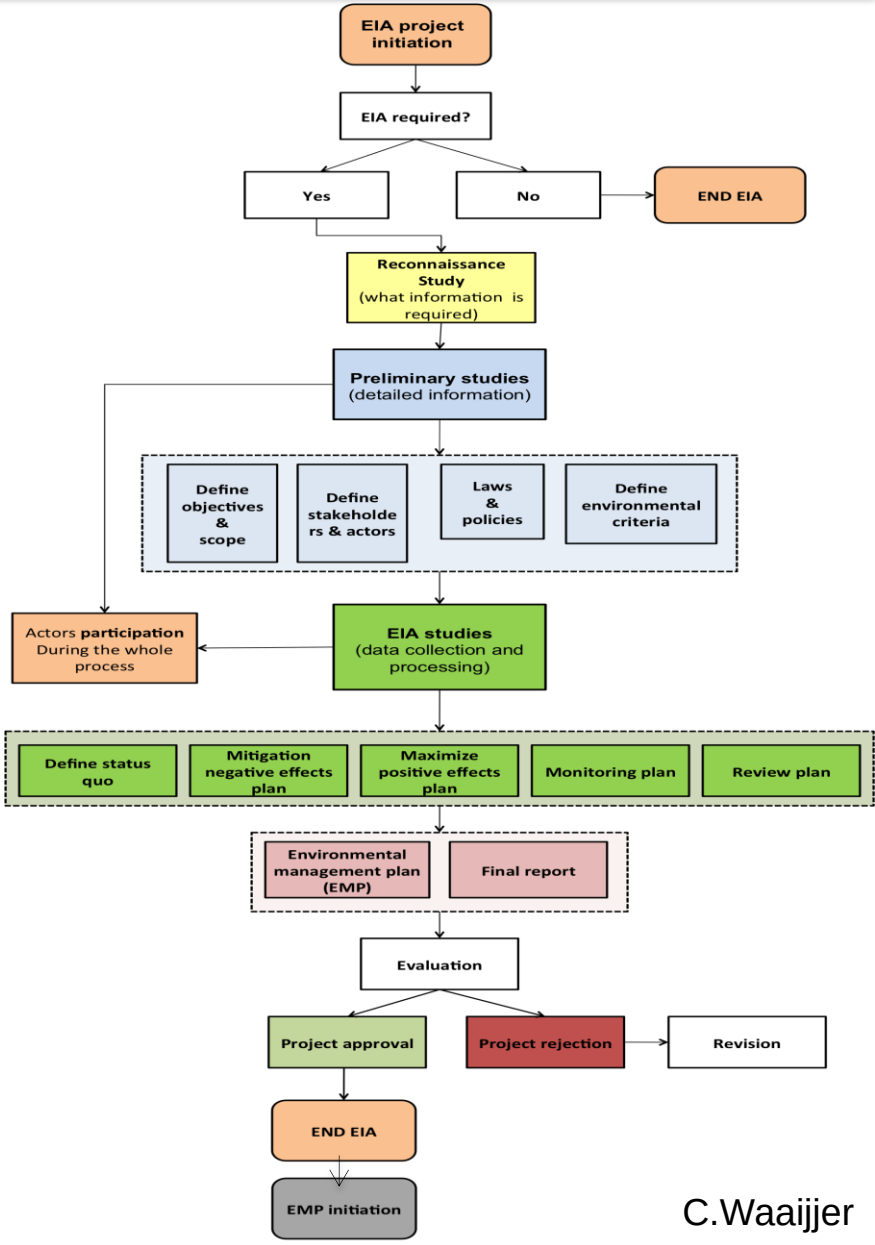
# CE considerations *Environmental*

- Some examples of issues to consider
  - Civil Engineering
    - Spoil deposit (≈ 10mill m3 (1.4mill m3 from LEP was mostly landfilled))
    - Risk of encountering hydrocarbons in the Geneva plain
    - Risk of polluting aquifers due to Civil Engineering works
    - Risk of depleting aquifers due to pumping water related to water inflow in the tunnel (karst related)
  - Social acceptance & landscape
    - Location of shafts in urban and natural areas
    - Electricity cables, roads etc
    - Radiation effects

*CERN LHC CMS 200km3 permanently stockpiled on-site*

# CE considerations *Environmental*

- Environmental Impact Assessment (EIA)
  - Long process, several stages, start early
  - Will have to be approved by <u>both</u> FR and CH
    - Approval difficulties may be encountered as with the "Annemasse Railway CEVA", and the Geneva bypass tunnel "La traversee de la rade"

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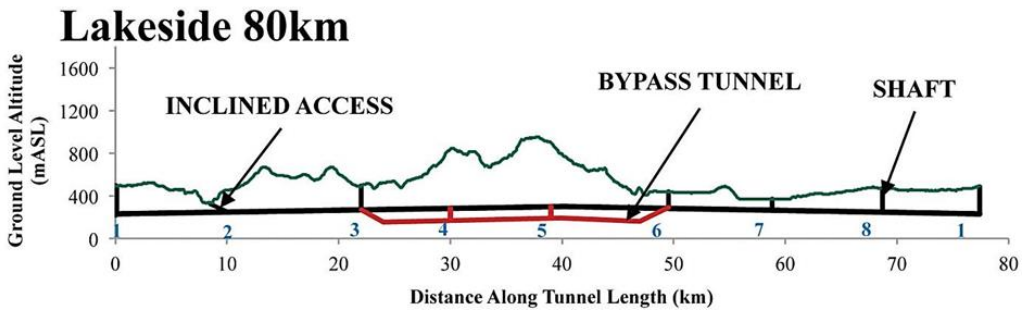
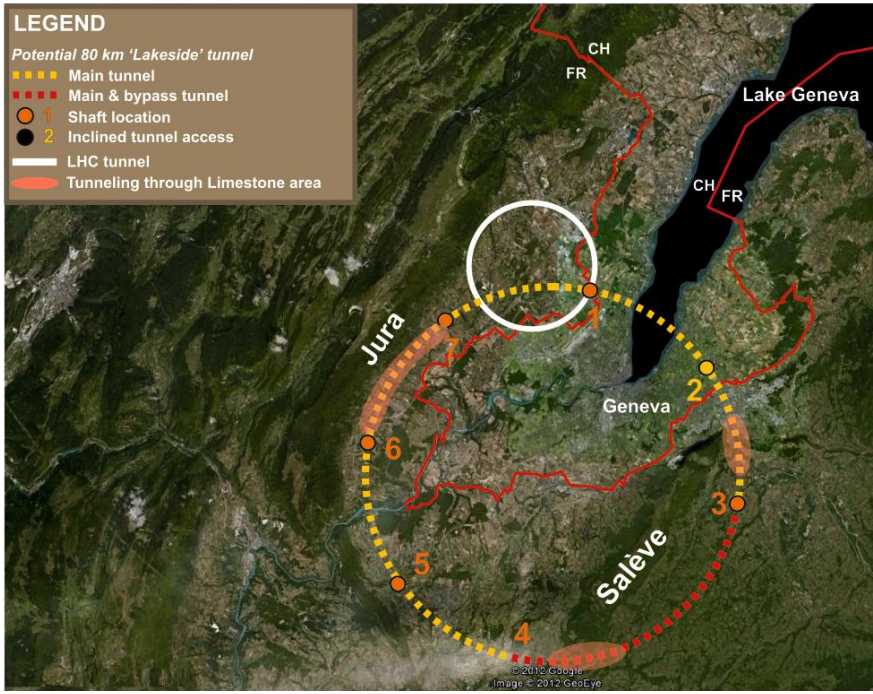
- Optimization studies for the project configuration have been started
  - Bypass tunnel in geological and environmental sensitive area
  - Inclined access tunnel in urban area

- More optimization studies needed
  - Incline tunnel?
  - More bypass tunnels?



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# Cost Estimate

- Costing performed by the CERN GS-SE group
- Based on
  - Historical data (LEP, LHC, CLIC, ILC)
  - 2012 'project unit' costs from similar projects and contractors
  - Swiss standard catalogue used for cost breakdown structure
    - NO technical drawings available -> costing based on assumptions for project configuration
  - No optimization studies for the tunnel configuration have been performed yet.

# Cost Estimate

- Assumptions
  - Tunnel
    - Internal diameter 5.6m
      - same as CLIC, standard size for European subway tunnels
    - 80km for machine tunnel
    - No tunnel enlargements
    - Bypass tunnels and inclined access tunnel
  - Caverns
    - Two detector caverns
    - Six medium sized caverns at access points
  - Shafts
    - Two 18m internal diameter shafts connecting detector caverns with the surface
    - 9m internal diameter access shafts connecting the main tunnel with the surface

# Cost Estimate

- Costs
  - Only the minimum civil requirements (tunnel, shafts and caverns) are included
  - 5.5% for external expert assistance (underground works only)
- Excluded from costing
  - Other services like cooling/ ventilation/ electricity etc
  - service caverns
  - beam dumps
  - radiological protection
  - Surface structures
  - Access roads
  - In-house engineering etc etc
- Cost uncertainty = 50%
- Next stage should include costing based on technical drawings

| CE works | Costs [pu] |
|---|---|
| Underground | |
| Main tunnel (5.6m) | |
| Bypass tunnel & inclined tunnel access | |
| Dewatering tunnel | |
| Small caverns | |
| 2 Detector caverns | |
| Shafts (9m) | |
| Shafts (18m) | |
| Consultancy (5.5%) | |
| **TOTAL** | |

AMBERG ENGINEERING

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# Feasibility / Risk Issues

*Some examples of issues (that need further studies)*

- Geotechnical
  - Unknown geology in lake area
  - Local ground stresses unknown
  - Alpine thrust
  - Risk of water ingress in limestone areas & moraines
  - Some site investigation may be required

- Tunneling
  - Risks related to karstic features and weak zones in Jura (eg Vuache Fault)
  - Degree of tunneling support
  - Heave of tunnel invert

# Feasibility / Risk Issues

*Some examples of issues (needs to be studied in more detail)*

- Environment
  - Risk of environmental impacts such as civil engineering, social acceptance, pollution of aquifers etc
  - Risk of encountering hydrocarbons
  - Risk of EIA rejection
- Costs
  - Risk of cost increase due to all issues mentioned

| | 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 | Feasibility |
| **Jura 80** | 5 | 3 | 0 | 0 | 5 | 4 | 5 | 5 | 4 | 2 | 33 | Low |
| **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 | High |

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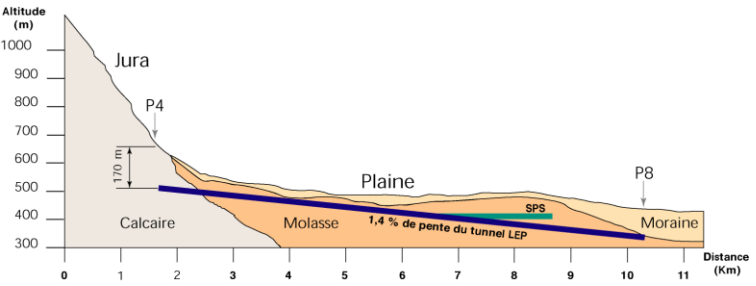
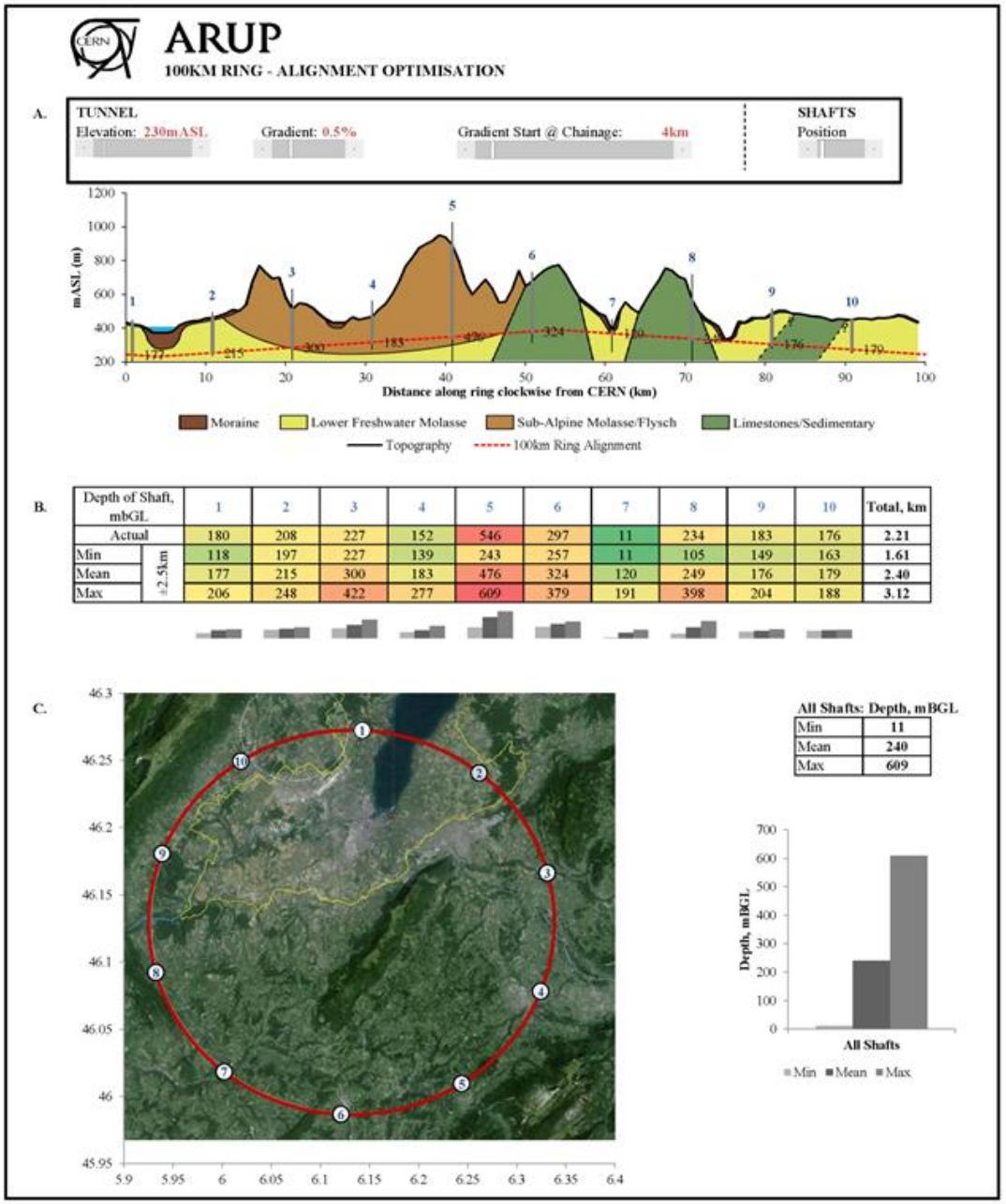
# Next Steps

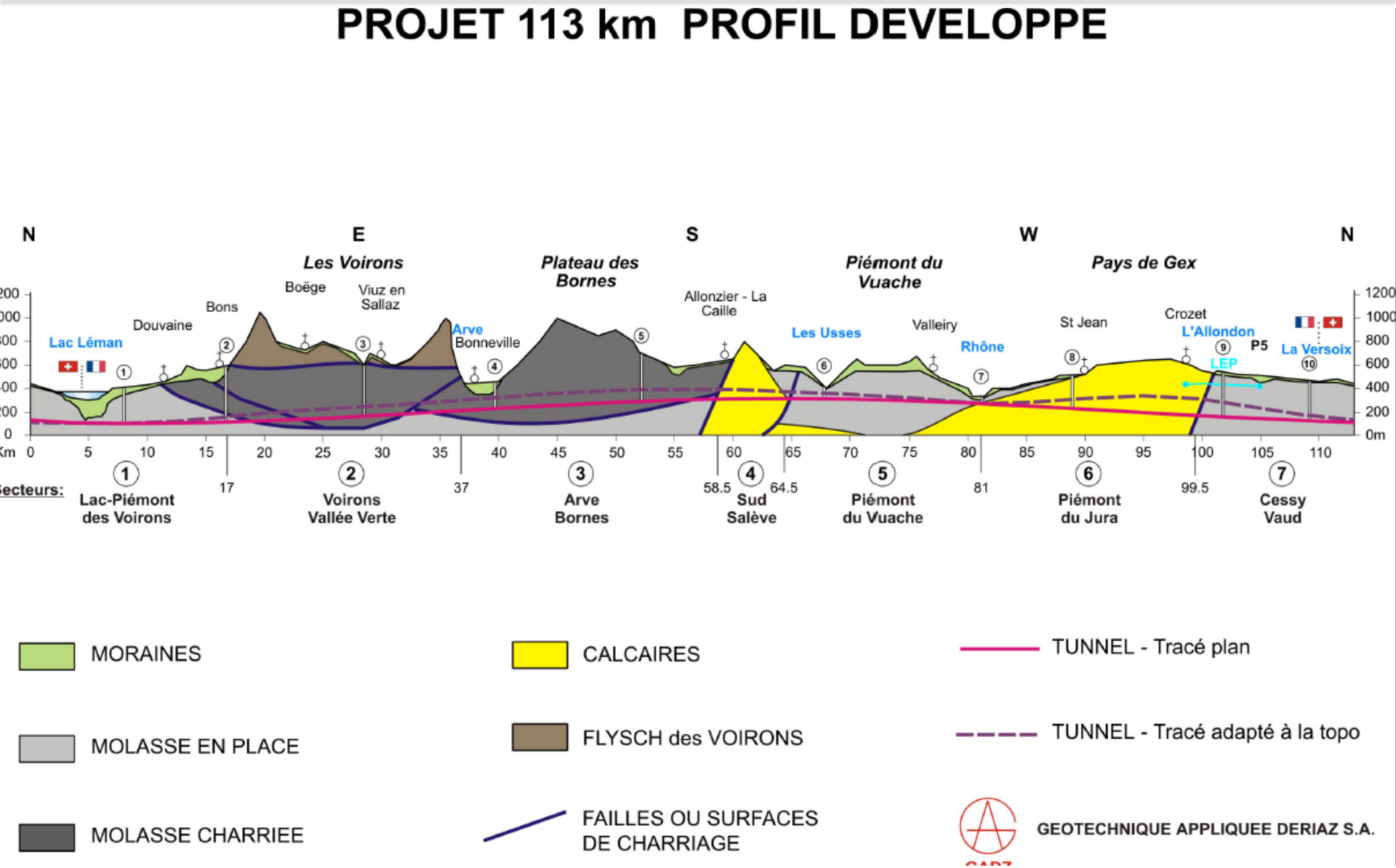
- Develop a geological tool to allow comparison of the various tunnel options linked to our GIS system.
- Circumferences, shapes, inclination (max 2%, out of plane ?) etc. to be easily compared
- Optimise shaft positions to minimise depth (+/ - 2km ?)




| Depth of Shaft, mbGL | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total, km |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Actual | | 180 | 208 | 227 | 152 | 546 | 297 | 11 | 234 | 183 | 176 | 2.21 |
| Min | ±2.5km | 118 | 197 | 227 | 139 | 243 | 257 | 11 | 105 | 149 | 163 | 1.61 |
| Mean | ±2.5km | 177 | 215 | 300 | 183 | 476 | 324 | 120 | 249 | 176 | 179 | 2.40 |
| Max | ±2.5km | 206 | 248 | 422 | 277 | 609 | 379 | 191 | 398 | 204 | 188 | 3.12 |

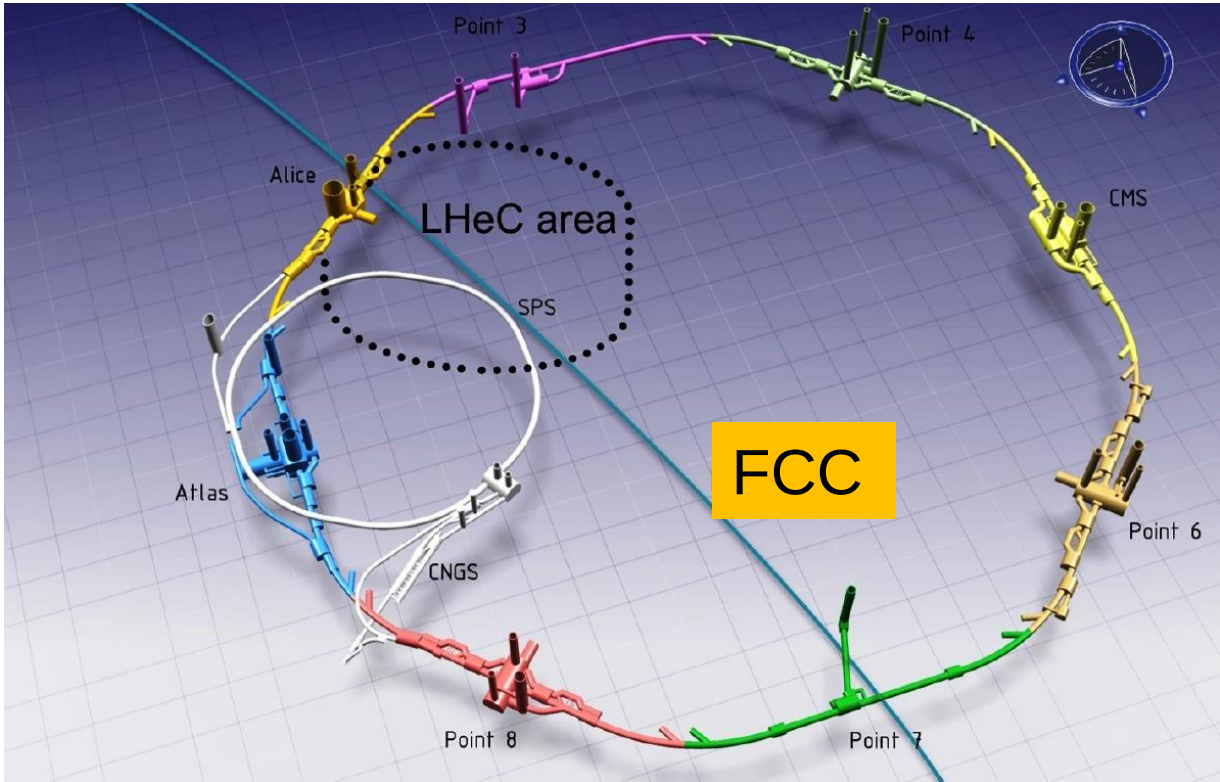
# Next Steps : Optimisation



# Next Steps

- To continue further the following steps are required
  - Define project requirements
    - Detector cavern requirements, dump caverns, shielding requirements, other services defined, synergy with LHeC etc.etc.
  - Optimization studies for the tunnel configuration
    - E.g. shaft locations, inclined access tunnels (like ILC in Japan) or vertical shafts etc
  - Continue environmental impact studies

- ***Civil Engineering plays a key role in helping define a feasible location / length of tunnel / project parameters***



# THANK YOU FOR YOUR ATTENTION

**John Osborne (CERN GS Department)**

# BACK UP

# Gothard v FCC

**Comparison of Gotthard Base Tunnel (GBT) with Future Circular Collider (FCC) CERN**
**(c = comparable, nc = not comparable)**

| | item | GBT | FCC | c | nc |
|---|---|---|---|---|---|
| purpose | use in operation | single track high speed train tunnel | experimental structure | | x |
| geographical and geological conditions | rock conditions | pre alpine and alpine rock formations heavily tectonically deformed with great fault zones (expl. Piora) | mostly flat layers of bedrock few disturbed in contact zones with pre alpine rock and limestone of Jura formations | | x |
| | overburden | up to 2000 m middle hard to hard rock often tectonically deformed metamorphic rock | up to 600 m soft to middle hard rock mostly undisturbed bedrock | | x |
| | core drilling (geol. prospection) | in the high mountains often impossible to find access or place to drill systematically every some 100 m | in FCC area every point of the future construction can be easily reached with a core drill | | x |
| Tunnel climate (temperature and air) | tunnel temperature | rock temperature span lies between some minus degrees (winter time) up to over 40 degrees | more or less constant rock temperature, variations of temperature might influence experiments | | x |
| | air movements | high speed trains are pushing the air through the tunnel when passing | no air movements except turbulences in areas where a machine is producing a lot of heat | | x |
| | fresh air | during operation air has to be changed continuously also to avoid upcoming mist which affects train drivers sight | during maintenance FCC to be ventilated according to number of staff and machines in tunnel, for operation specifications are to be fixed | | x |
| safety | fire-life-safety-system | persons in trains are not trained to behave during any hazard or how to extinguish a fire | staff of CERN will be trained and well instructed about where to go or handle any hazard | | x |
| | evacuation | Up to 1000 persons in one train have to be brought as fast as possible to a save well illuminated and ventilated protected room or trough an escape tunnel to the surface | staff in sectors which can be evacuated can use this way, all others can be brought to safety chambers (also used during construction and accelerator installation) to wait there for being rescued | | x |
| Realization of FCC | owners organisation (planning/ realization/ starting operation) | complex project with different stages (planning construction, rail engineering and safety/ tendering and realization civil construction / tendering and realization rail engineering / tendering and realization safety / hand over from construction to rail engineering and safety installations, starting operation) | complex project with different stages (planning construction, accelerator and safety / tendering and realization civil construction / tendering and realization accelerator / tendering and realization safety / hand over from construction to accelerator and safety installations, starting operation) | x | |
| | site logistic | 5 big building sites were necessary to realize the whole project, sites also used for rail engineering and safety purposes | 4 – 5 big building sites and 4 to 5 middle sized building sites will be necessary to realize the whole project, sites also used for accelerator installation and safety purposes | x | |
| | aggregate processing of muck and/or disposal | all building sites were equipped with aggregate processing plants to prepare aggregates for the concrete, muck was disposed in landfills and lake Lucerne | Encountered rock is mostly not suited for aggregate processing, muck could be used for landscaping around surface buildings of shaft accesses, rest to be deposed in landfills and/or lakes | x | (x) |