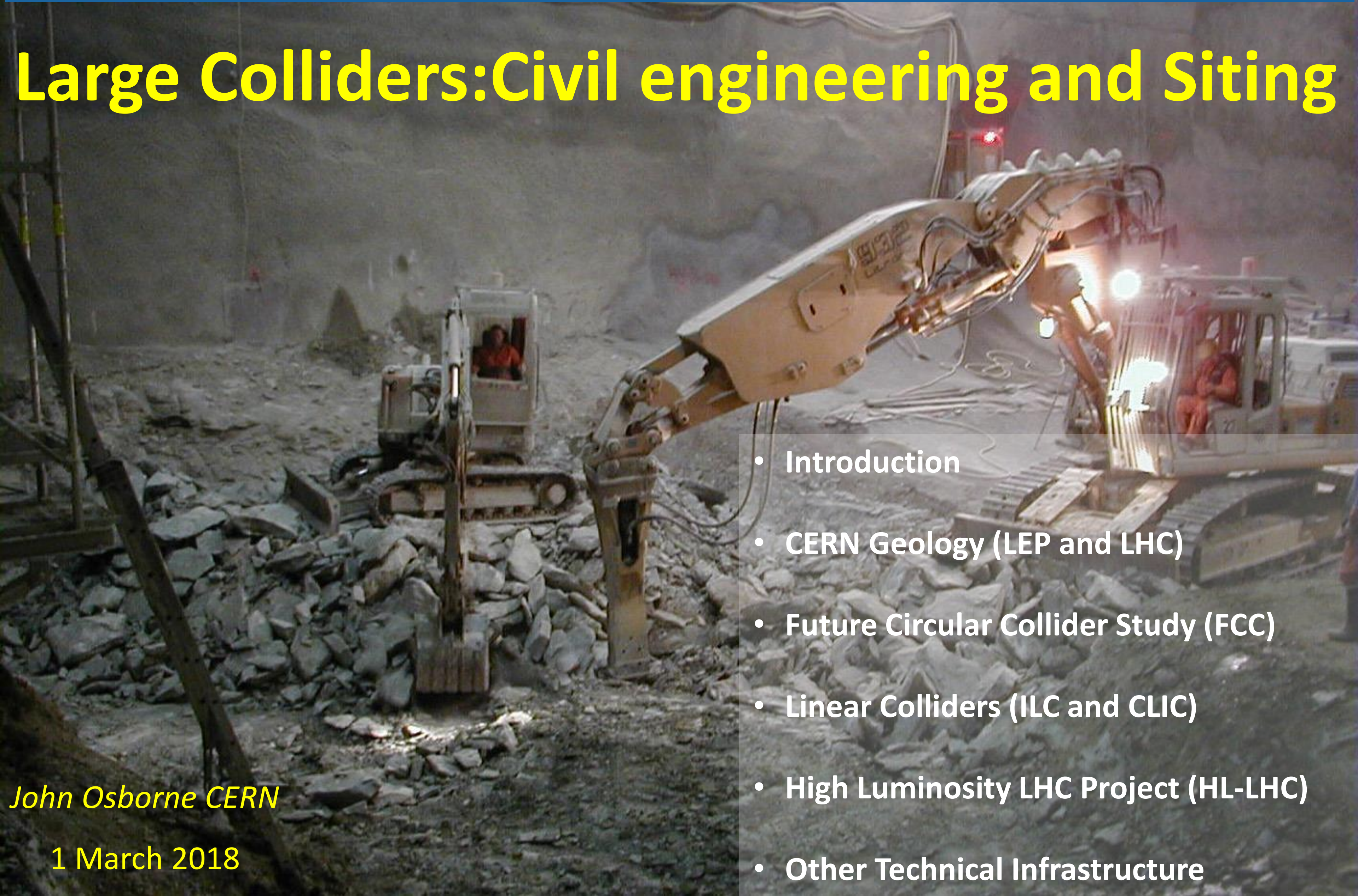
https://edms.cern.ch/document/1908998/1

Beam Dynamics and Technologies for Future Colliders

The CERN Accelerator School

Large Colliders:Civil engineering and Siting



- **Introduction**
- **CERN Geology (LEP and LHC)**
- **Future Circular Collider Study (FCC)**
- **Linear Colliders (ILC and CLIC)**
- **High Luminosity LHC Project (HL-LHC)**
- **Other Technical Infrastructure**

John Osborne CERN

1 March 2018

My Background

- Graduated from Liverpool University 1988 with Civil Engineering Degree

- Worked for 10 years for UK Contractor, Carillion (formally Tarmac) on :

  - Conwy tunnel
  - Design Secondment in Glasgow with Sir Alexander Gibb & Partners (now Jacobs)
  - Medway tunnel
  - Jubilee Line Extension, Canary Wharf Station
  - A13 extension, Dagenham, Precast Segmental Bridge over Ford's factory

- Joined CERN in 1998 for Large Hadron Collider Works (CMS)

- Fellow of Institution of Civil Engineers (UK) in 2017

- Now working on CERN's Future Accelerator Projects

Introduction

- Why should civil and infrastructure costs be considered at such an early stage :
  - Approximately 30-40% of budget for large scale physics projects
  - Infrastructure works can make or break projects

- What are the key challenges ?
  - 90% of Infrastructure costs are for Civil Engineering, HVAC and Electricity
  - Safety, Environmental….

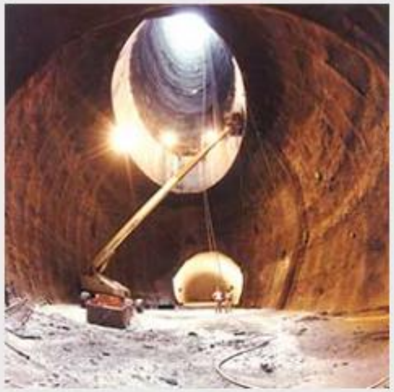
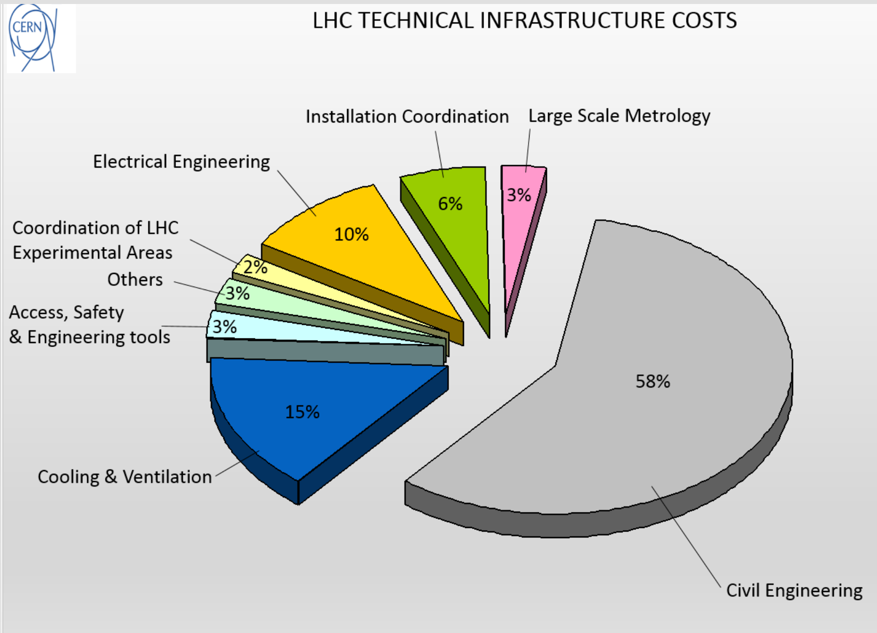
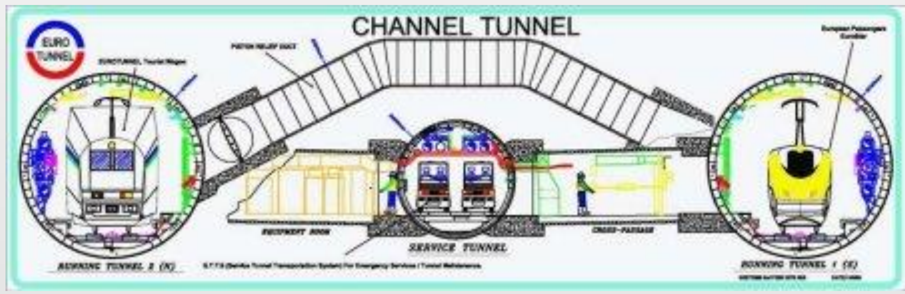


Photo: Fermilab Archives

View along the SSC's main ring tunnel, as seen while under construction in early 1993.

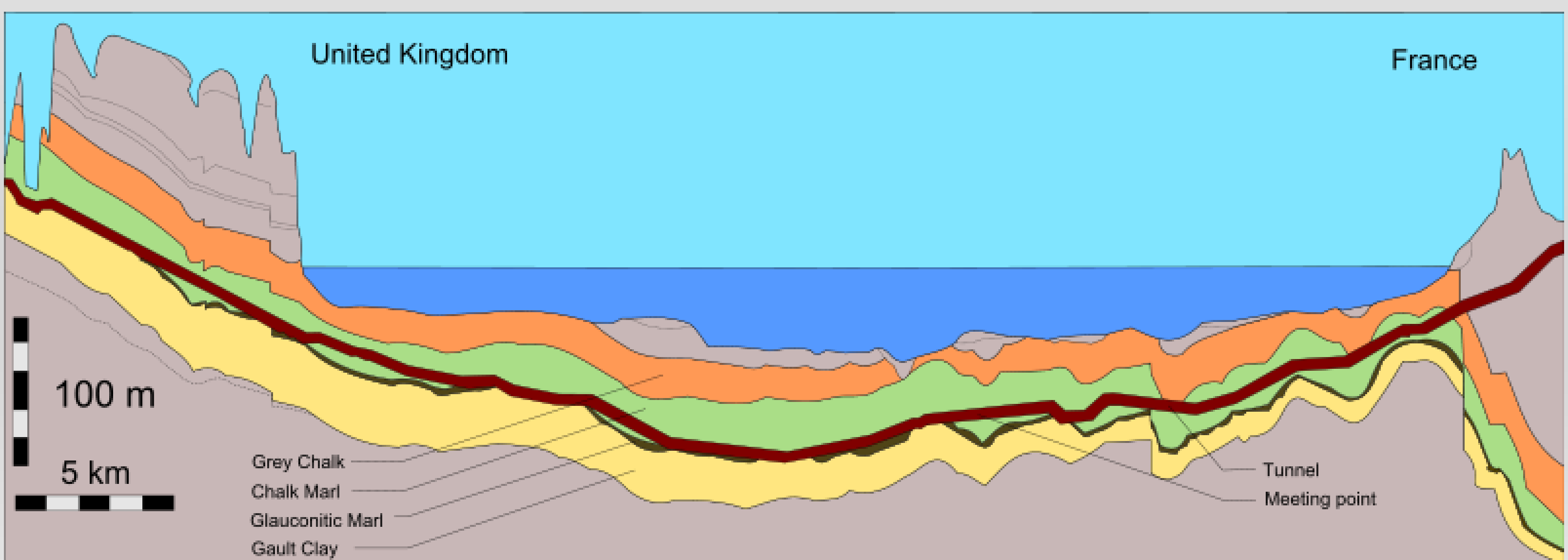


For FCC, CLIC & ILC, similar World Projects: eg Channel Tunnel



7.6mØ 4.8m Ø 7.6mØ

50Km



Channel Tunnel Construction (2)

1987 - 15th December
Boring of the service tunnel starts on the UK side.

1988 - 28th February
Start of service tunnel boring on the French side.

1990 - 1st December
British and French teams achieved the first historic breakthrough under the Channel, in the service tunnel, 22.3 km from the UK and 15.6 km from France.

1991 - 22nd May
Breakthrough in the North rail tunnel.

1991 - 28th June
Breakthrough in the South rail tunnel.

1993 - 10th December
Handover from TML to Eurotunnel.

1993 - 1994
Equipment installation and testing.

- 7 years from first excavation to operation
- At peak 15,000 workers
- 6 TBM's used for tunnelling
- Very approximate cost = $9.1billion (1985 prices)
- Difficulties :
  - Financing
  - Political
  - Water ingress
  - Safety (10 workers died), fire..
  - Cost overruns….

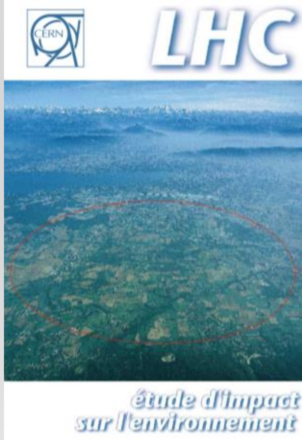
Feasibility studies started 200years ago with in **Napoleonic** times !!!

Main civil engineering risks (1)

*A full risk assessment must be carried out for both the **pre-construction phase and execution phase** of the works.*

*The **Pre-construction phase** must assess risks such as :*

- Delay during the planning permission approval process
- Objections raised from the public on environmental grounds
- Problems with the project management team
- Project financing uncertainties
- Tenders submissions not reaching minimum bidding standards
- Non appropriate sharing of risk in tender documents



Main civil engineering risks **(2)**

The execution phase of the works must assess risks such as :

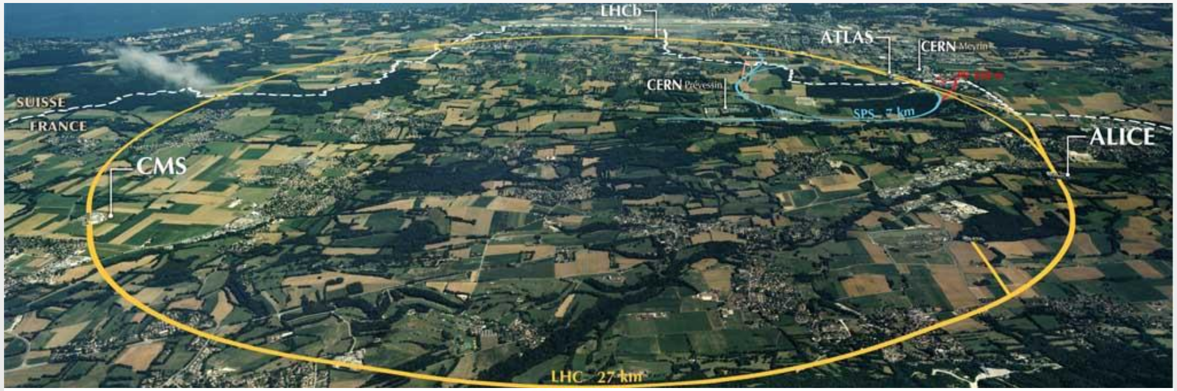
- Uncertainties with geological, hydrological and climate conditions, including:
  - Unstable tunnel excavation face
  - Fault zones
  - Large amounts of water inflow
  - Unexpected ground movements (especially in large caverns)

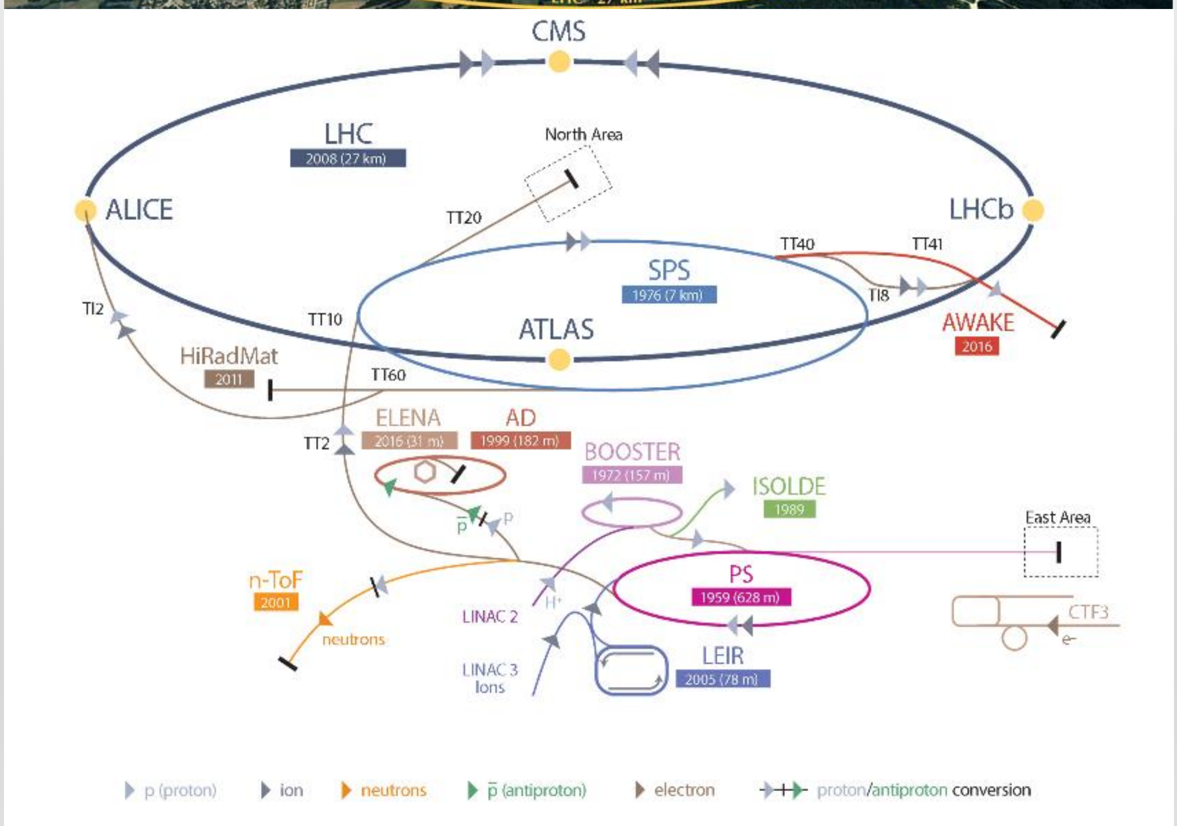
- Anomalies in contract documents (e.g. large quantity inaccuracies)
- Interference from outside sources
- Delayed submission of approved execution drawings
- Design changes from the consultants and/or owner
- Lack of thorough safety and/or environmental control
- Changes in legislation
- Labour relations
- etc

Civil Engineering : Geology & Site Investigation

- Thorough site investigation is essential in order to avoid surprises during tendering/construction
- For LHC studies, all LEP geotechnical investigative reports were collated and new specific borings executed 3-4 years before the start of the worksite.
- As an example, for the CMS worksite, 11 new boreholes were drilled and tested. Information collated included :
  - Detailed cross sections of ground geology
  - Any known faults in the underlying rock identified
  - Ground permeability
  - Existence of underground water tables
  - Rock strengths etc etc
- Separate contracts were awarded for these site investigations prior to Tender design studies starting.
- Even with all this very detailed knowledge of the local geology some unforeseen ground conditions were encountered during the works

CERN tunnels and geology





- Large Hadron Collider :
  - 27km long
  - 50-175m depth
  - 4.5m ø TBM tunnels
  - Molasse and limestone

Total underground tunnels >70km
More than 80 Caverns

‘CERN’ Geology

Rock properties

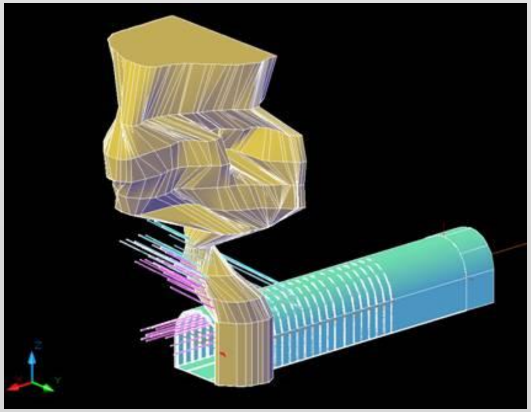
Moraines
- Glacial deposits comprising gravel, sands silt and clay
- Water bearing unit
- Low strength

Molasse
- Mixture of sandstones, marls 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 due to the redistribution of ground stresses
- Structural instability (swelling, creep, squeezing)

Limestone
- 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

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

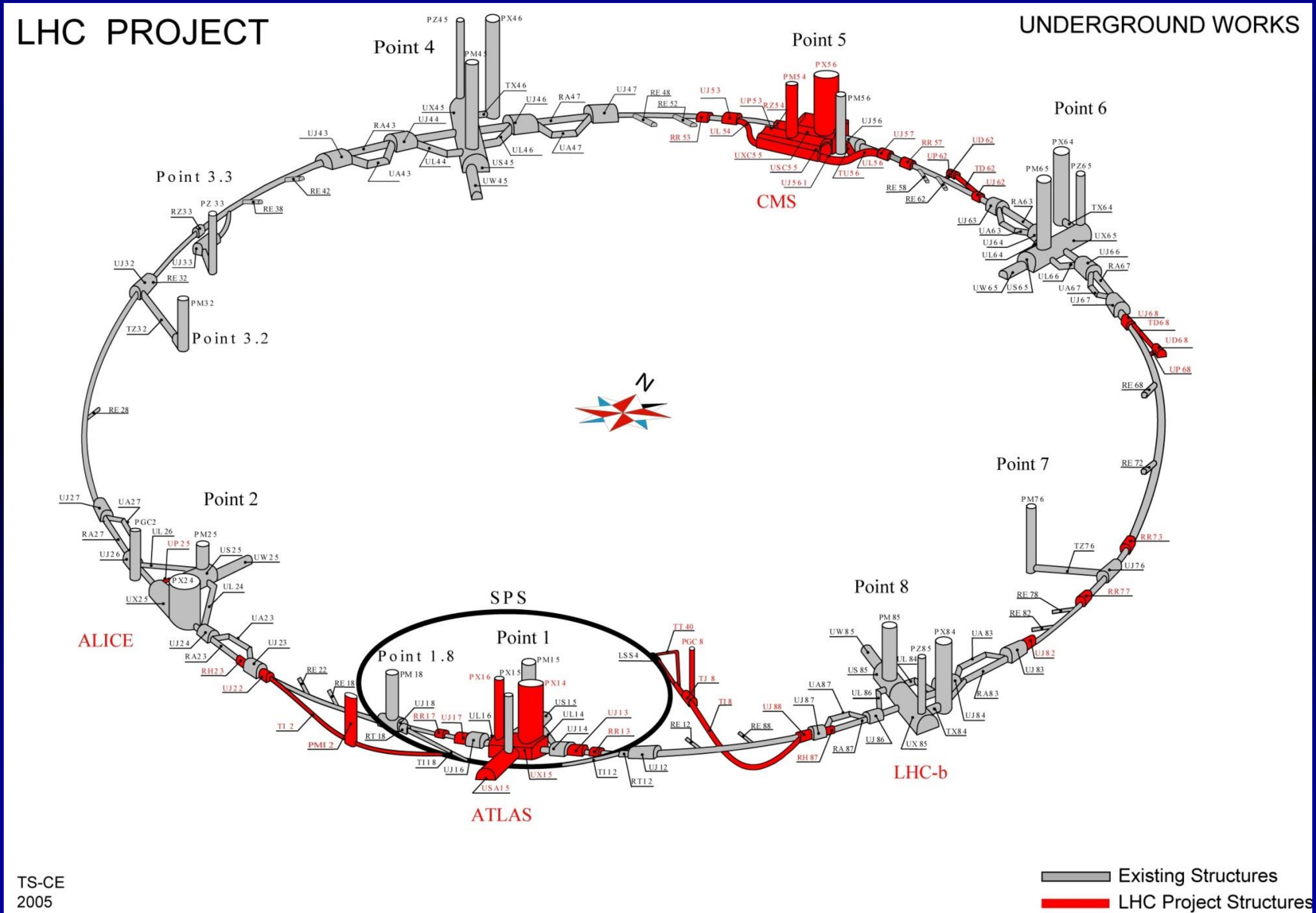
Molasse Compression strengths



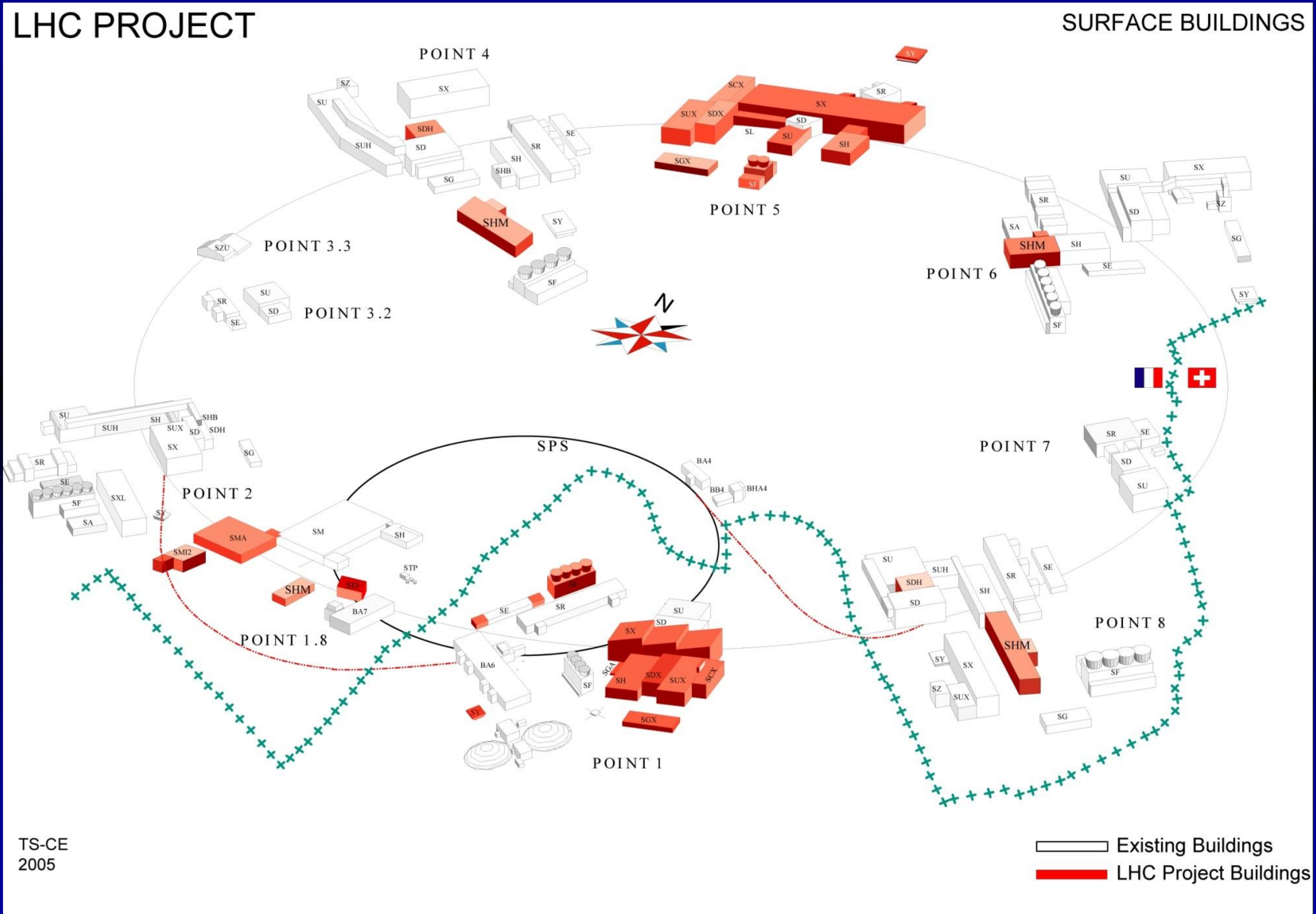
Model of tunnel collapse caused by Karsts


ALICE
ATLAS
CMS
LHCb

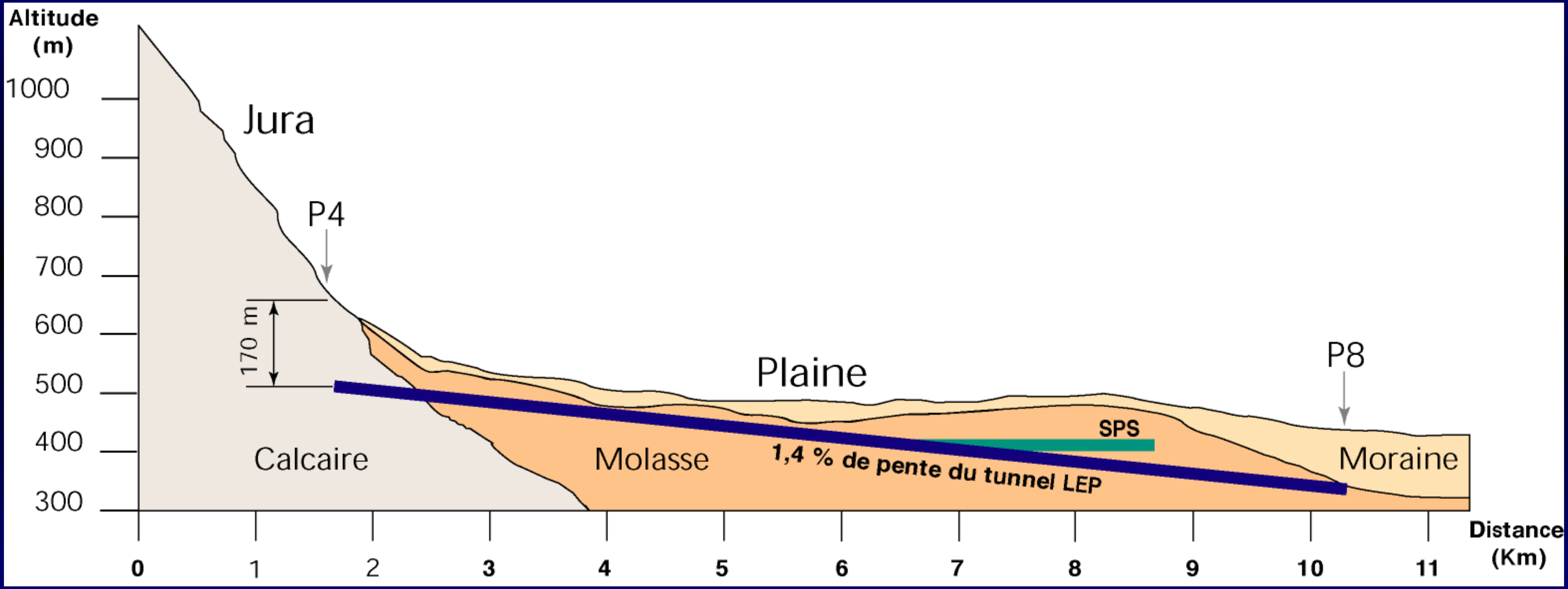
LHC Civil Engineering 1998-2005



LHC Civil Engineering 1998-2005



LHC tunnel aligment



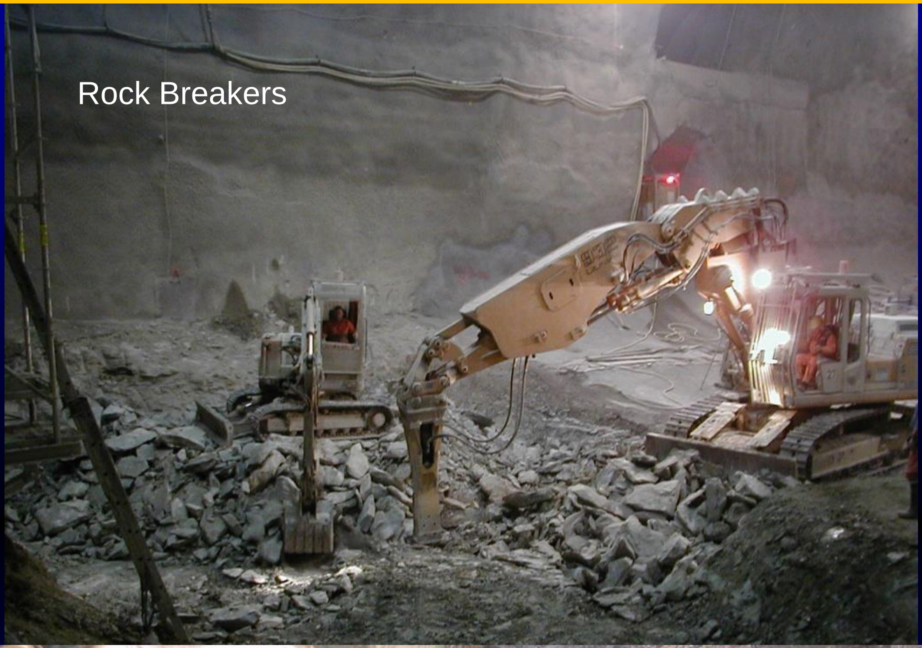
LHC Civil Engineering 1998-2005

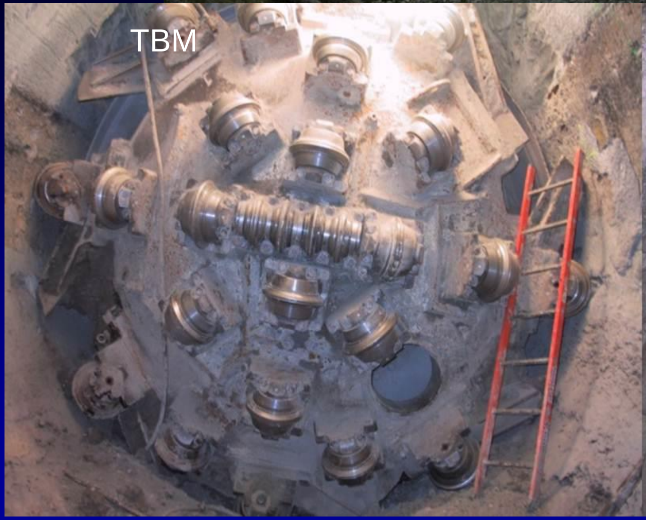
	LEP	LHC
Number of Shafts	19	6
Number of underground caverns	37	32
Tunnel lengths (all diameters)	32’600m	6’500m
Number of buildings	70	30
Surface Area of buildings	59’000m2	28’000m2
Excavated Volumes	1’100’000m3	420’000m3
Volume of Concrete underground	230’000m3	125’000m3
Volume of Concrete on Surface	85’000m3	42’000m3

LHC Civil Engineering companies

Package	Place		Consultants	Contractors
1	POINT 1	ATLAS	- EDF (F) - KNIGHT & PIESOLD (GB)	- TEERAG-ASDAG (A) - BARESEL (D) - LOCHER (CH)
2	POINT 5	CMS	- GIBB (GB) - GEOCONSULT (A) - SGI (CH)	- DRAGADOS (E) - SELI (I)
3A	Other Points	All other points except TI8 (including ALICE and LHC-b)	- BROWN & ROOT (GB) - INTECSA (E) - HYDROTECHNICA (P)	- TAYLOR-WOODROW (GB) - AMEC (GB) - SPIE-BATIGNOLLES (F)
3B	TI 8	TI 8 tunnel	DITO	- LOSINGER (CH)

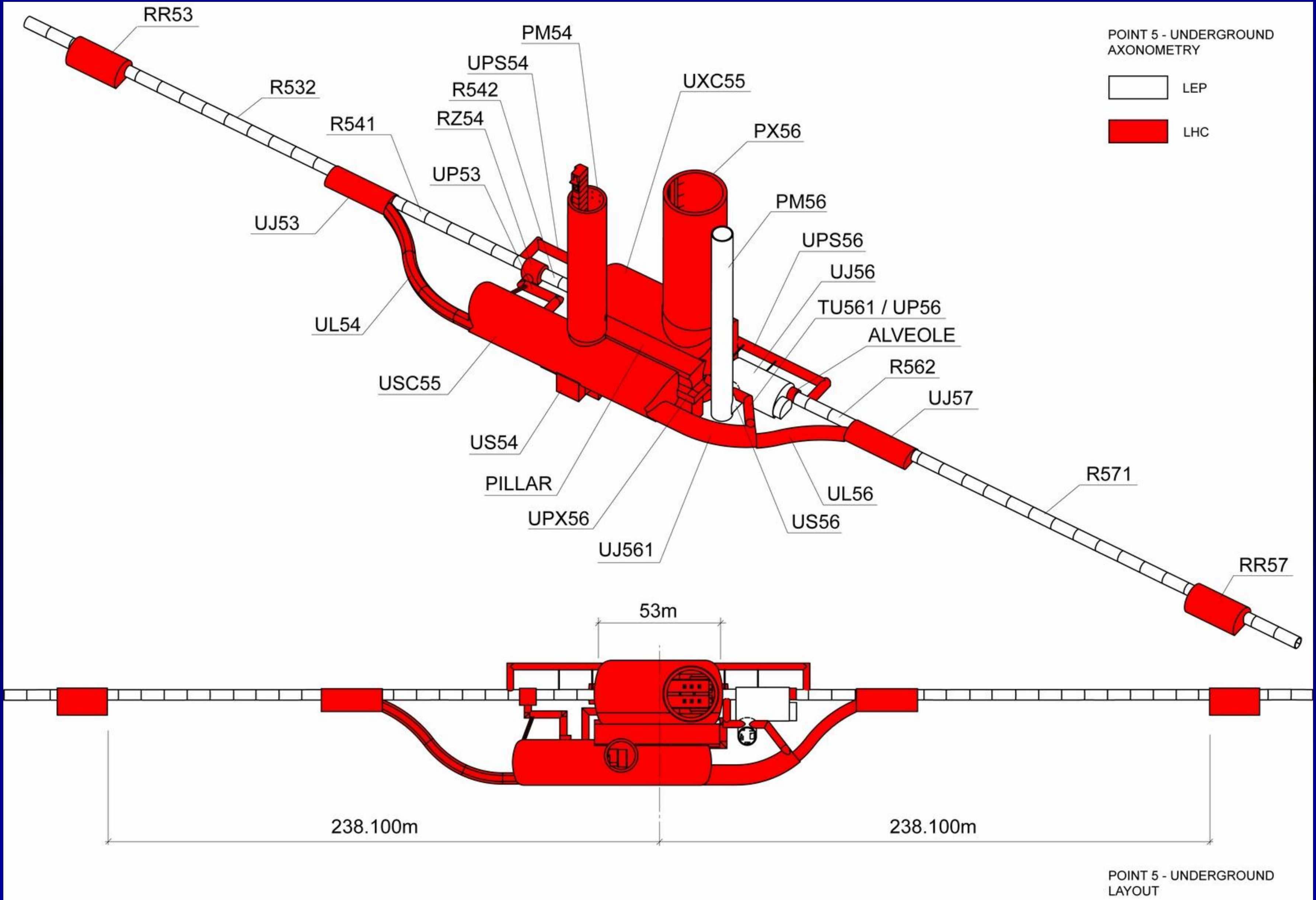
Tunnel excavation options





No explosives were used for LHC excavation

LHC Civil Engineering - CMS



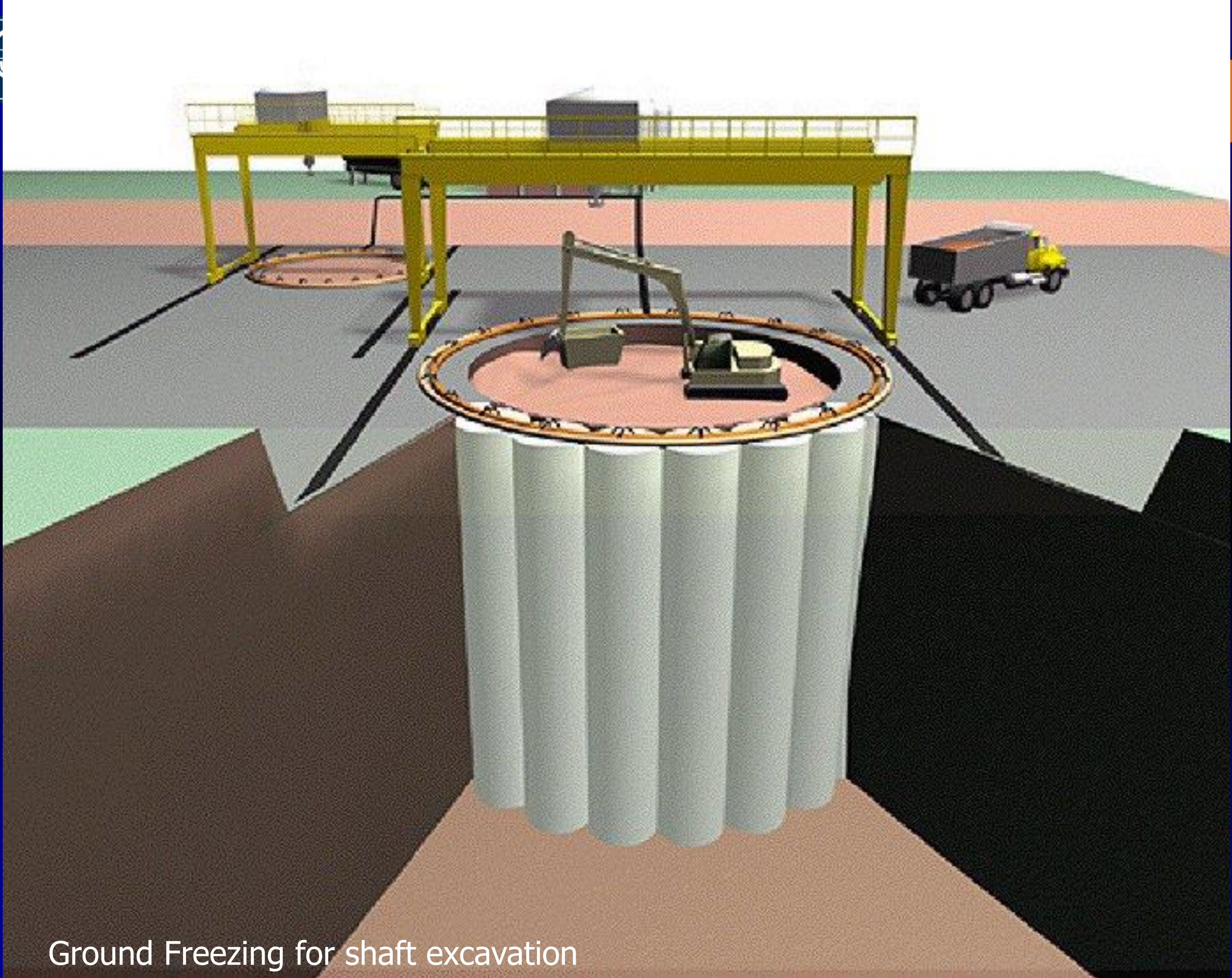
LHC Civil Engineering -CMS

LHC Civil Engineering - CMS

Roman Villa

LHC Civil Engineering - CMS

2001



Ground Freezing for shaft excavation

LHC Civil Engineering CMS ground freezing

1999

LHC Civil Engineering CMS ground freezing

Point 5 -Excavation commencement of PM54 shaft - July 09, 1999 - CERN ST-CE

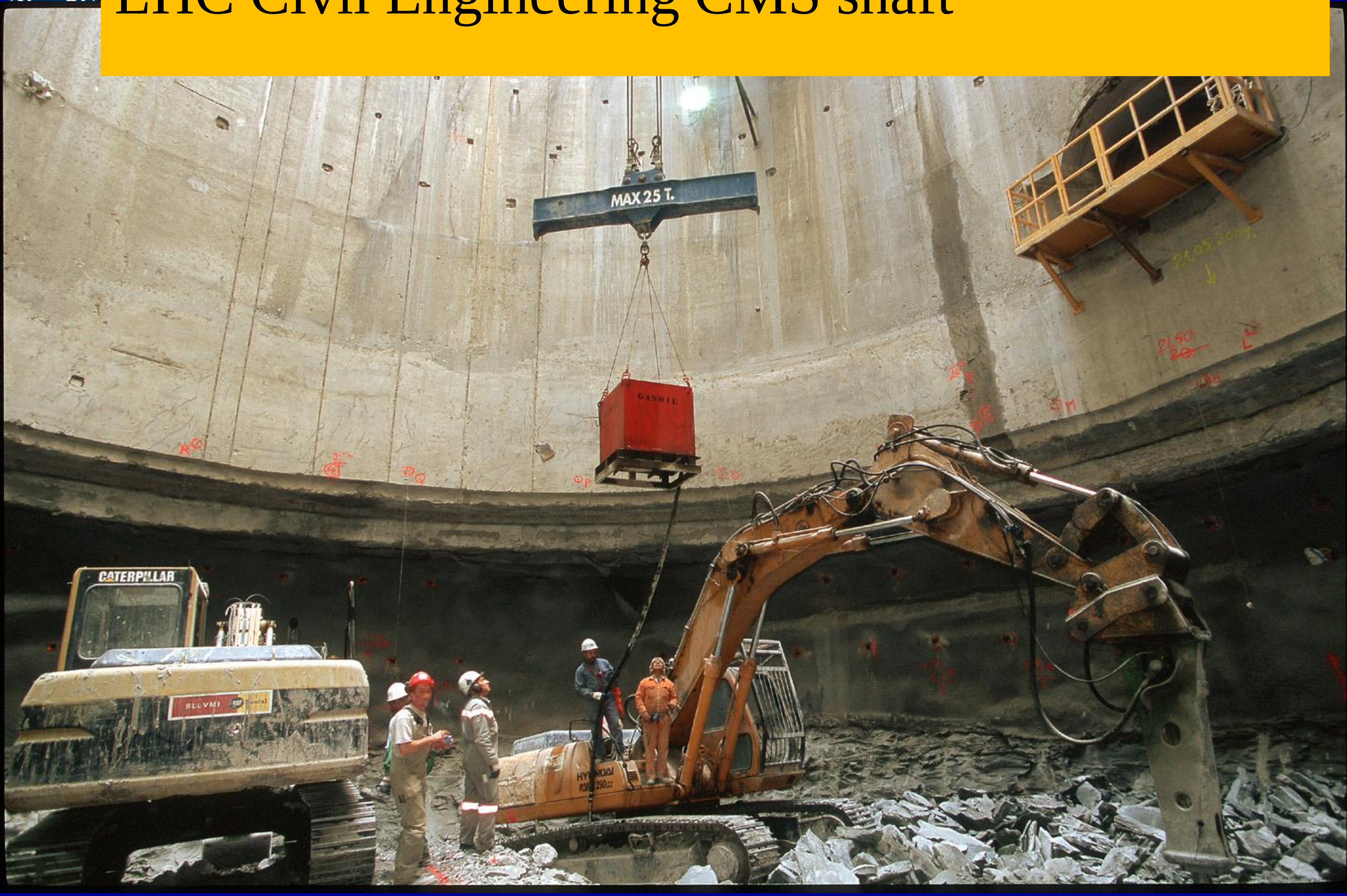

Dragados

Point 5 - PM54 additional drilling for grouting - October 01, 1999 - CERN ST-CE

2000

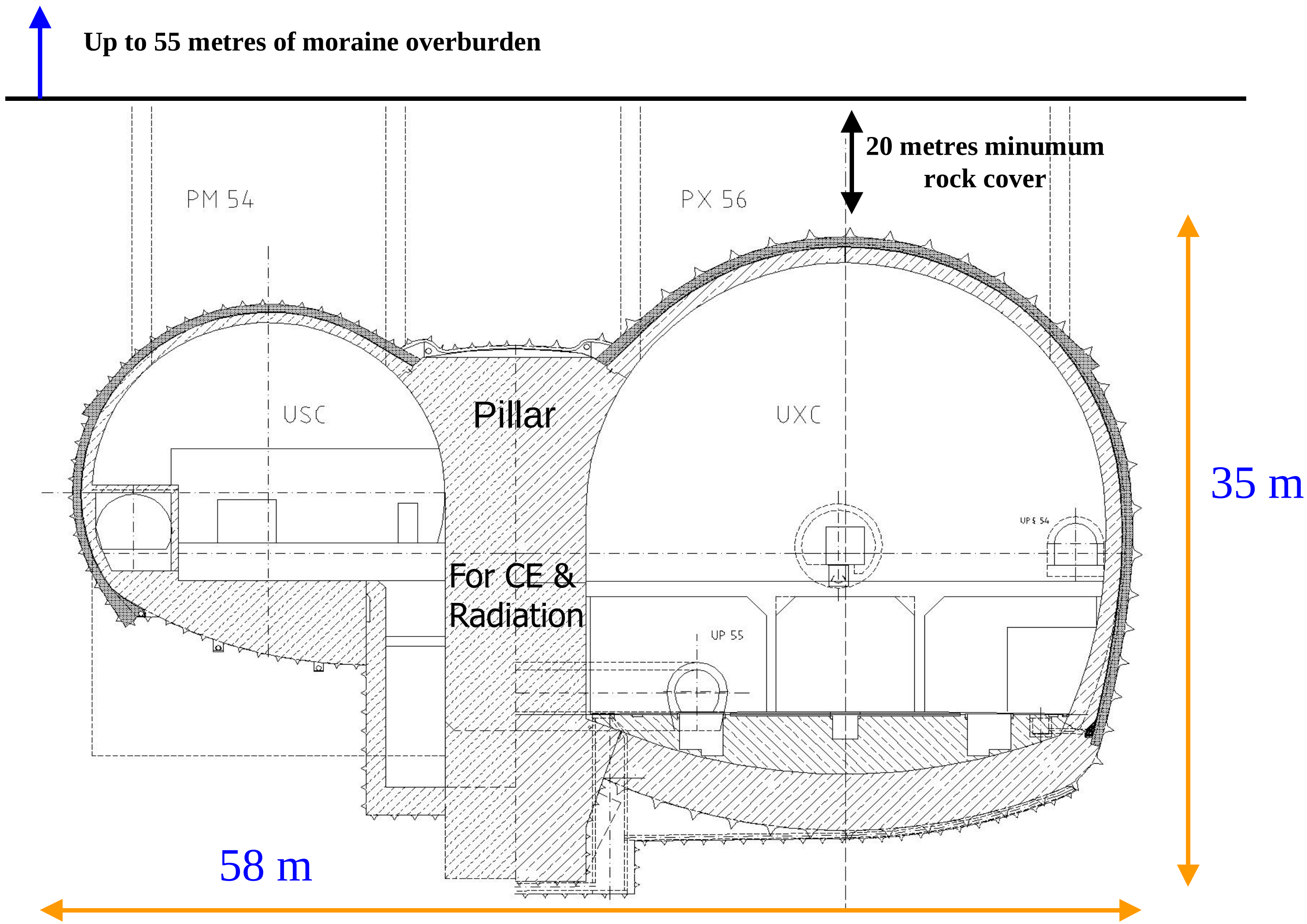
Shafts 12.1m and 20.5m diameters, both approx. 100m deep

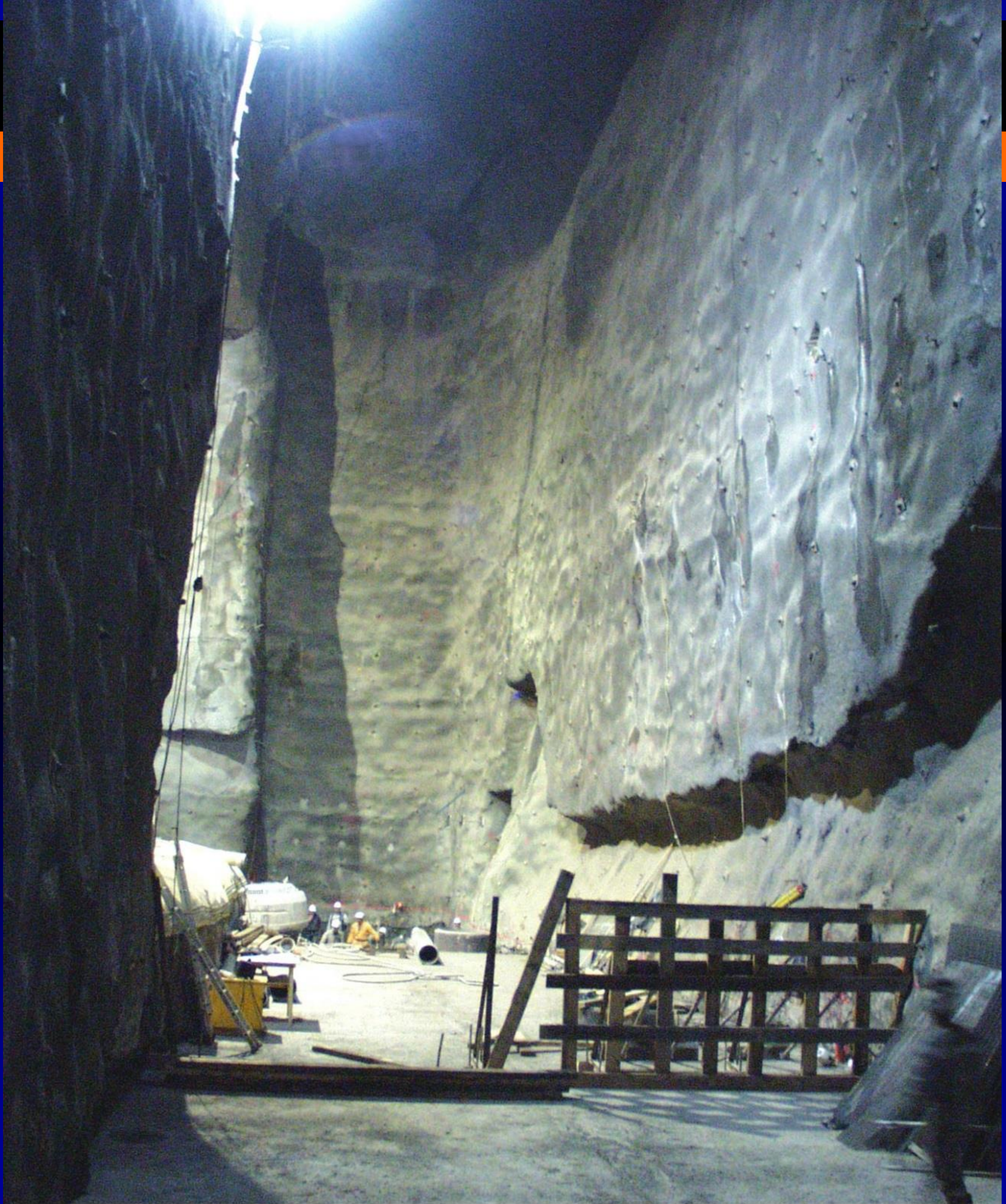
LHC Civil Engineering CMS shaft



2000

Section through cavern complex at point 5

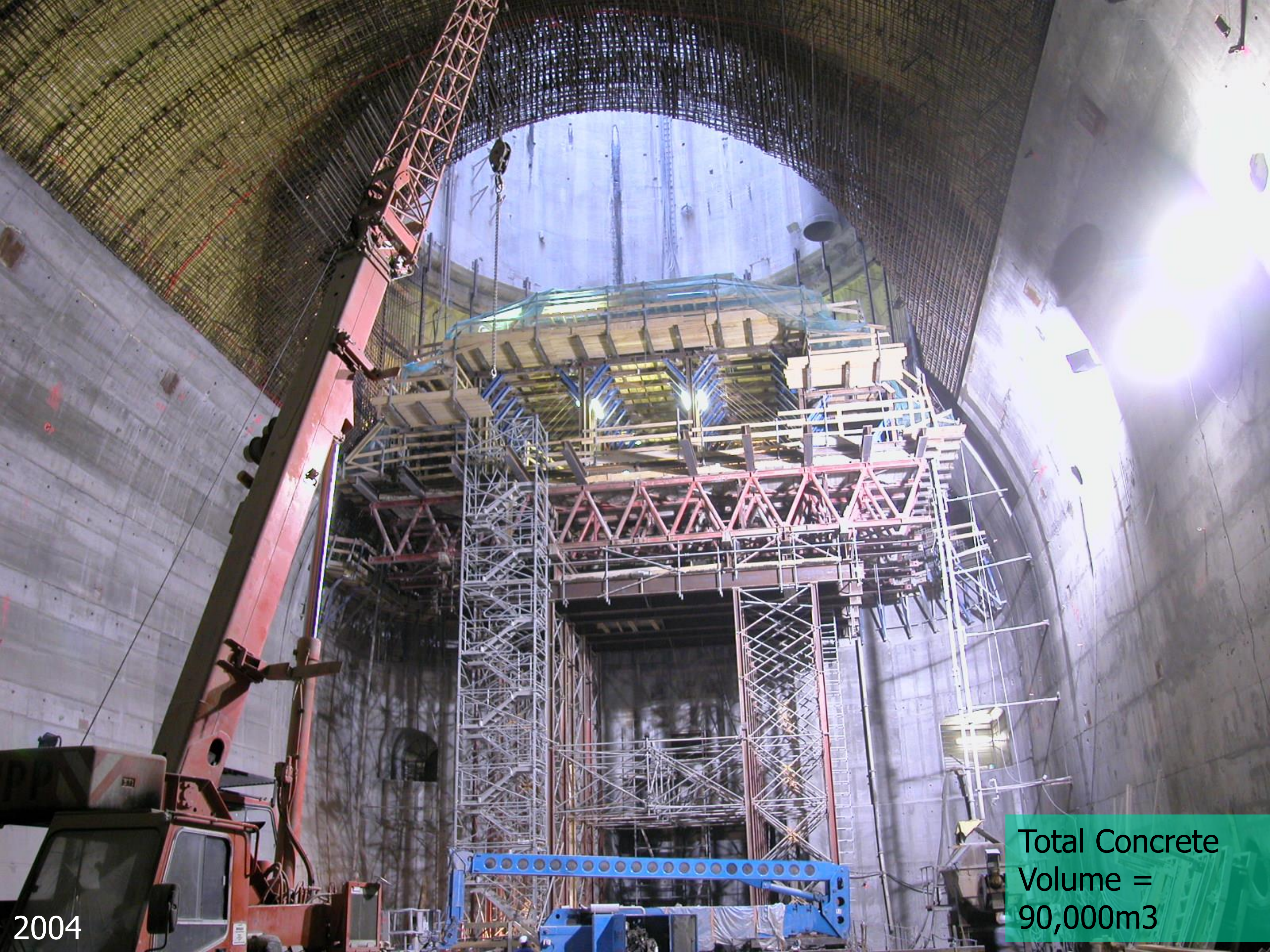


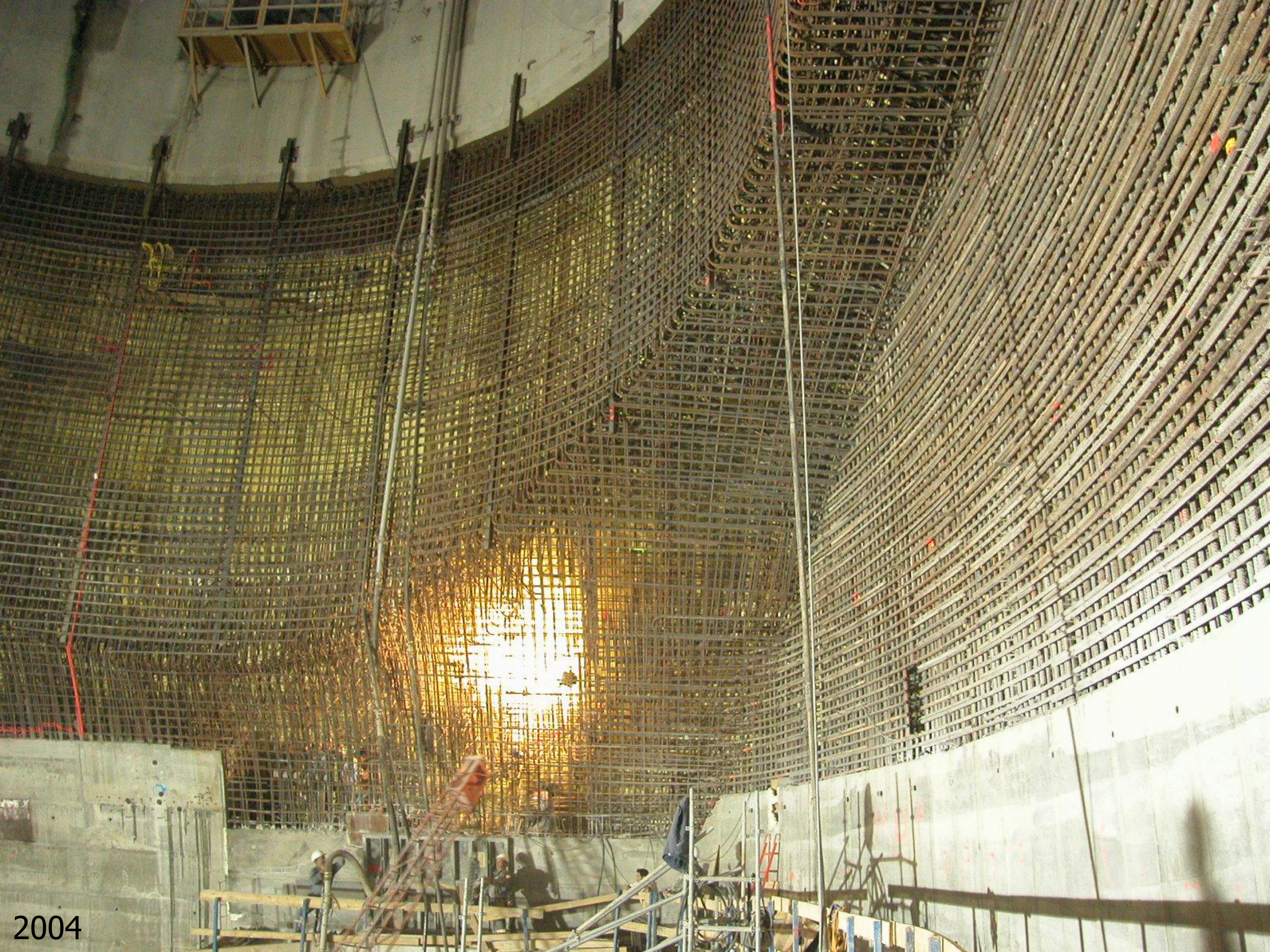


Point 5 - Shuttering for the first layer of pillar concrete - April 20, 2001 - CERN ST-CE

Point 5 - UXC55 cavern excavation - LEP demolition - January 23, 2002 - CERN ST-CE


Total Volume excavated = 216,000m3
2003

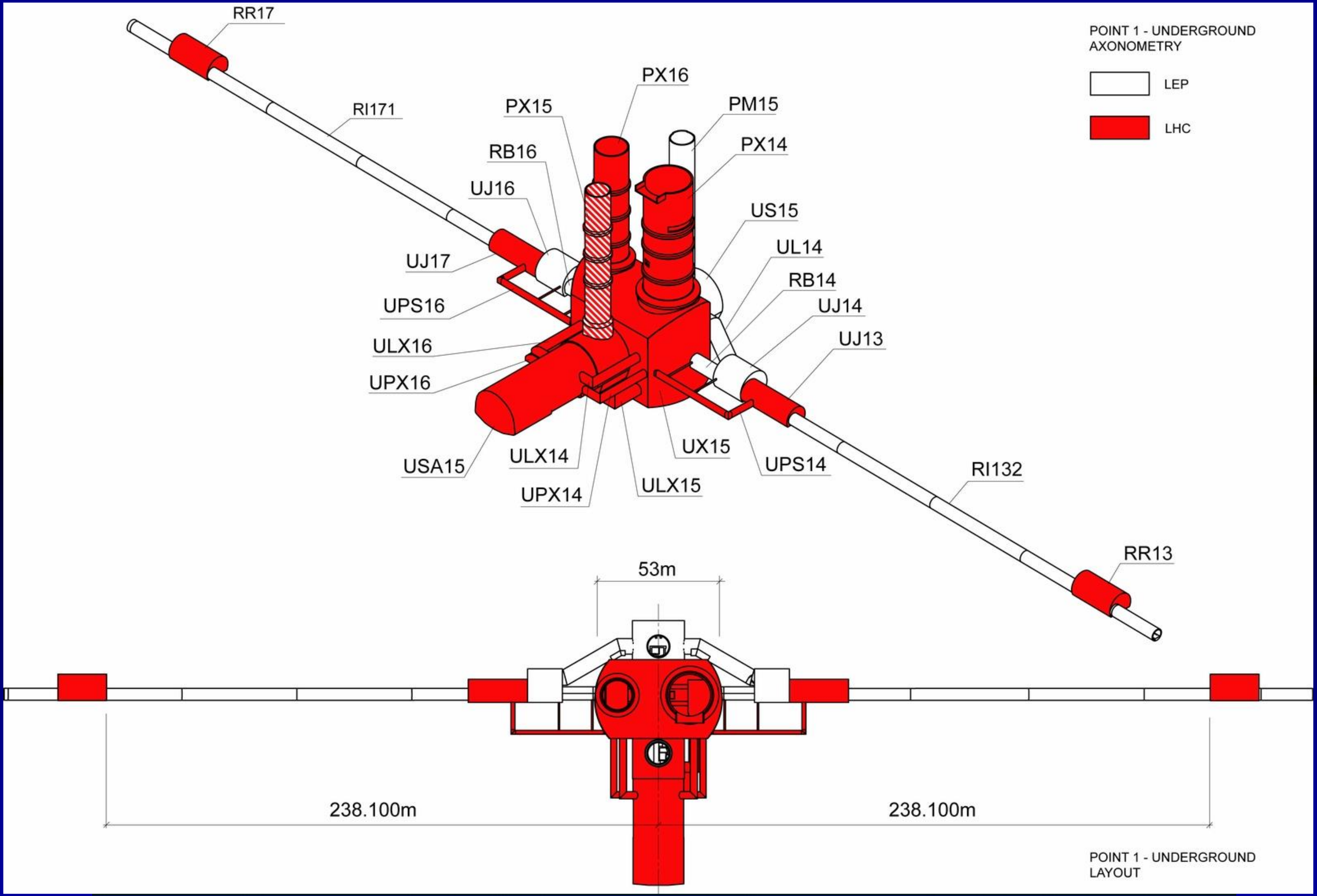

2004
Total Concrete
Volume =
90,000m3



2004


2005
CMS cavern 53m long, 27m wide by 25m high

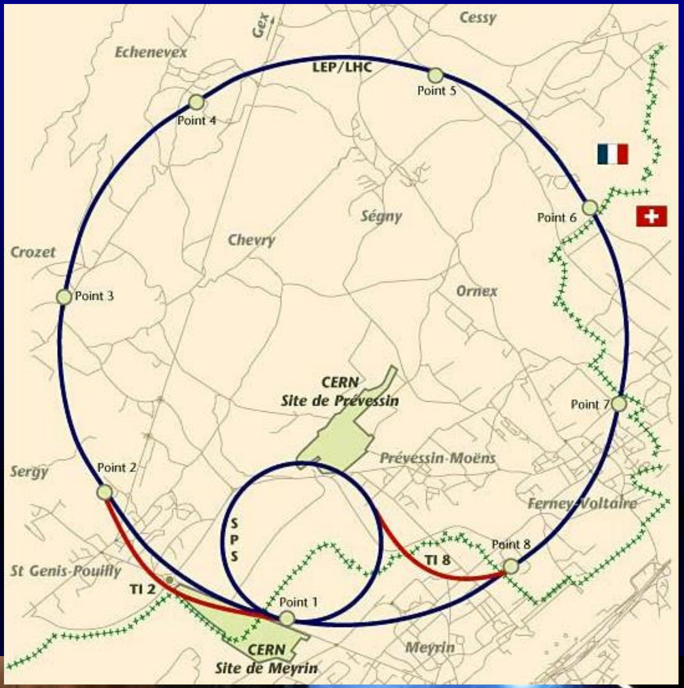
ATLAS

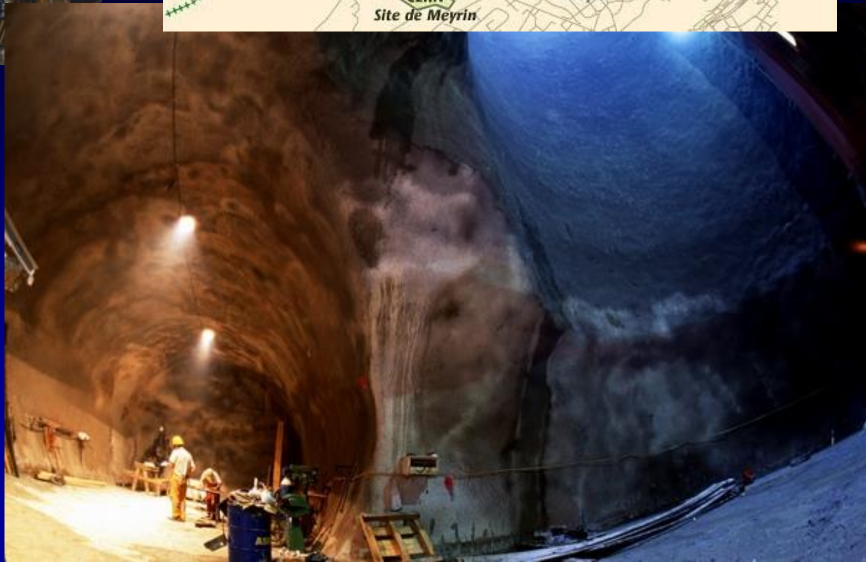

POINT 1 - UNDERGROUND AXONOMETRY
LEP
LHC
RR17
RI171
PX16
PX15
PM15
RB16
PX14
UJ16
US15
UL14
UJ17
RB14
UPS16
UJ14
ULX16
UJ13
UPX16
UX15
USA15
ULX14
UPS14
RI132
UPX14
ULX15
RR13
53m
238.100m
238.100m
POINT 1 - UNDERGROUND LAYOUT

LHC Civil Engineering ATLAS

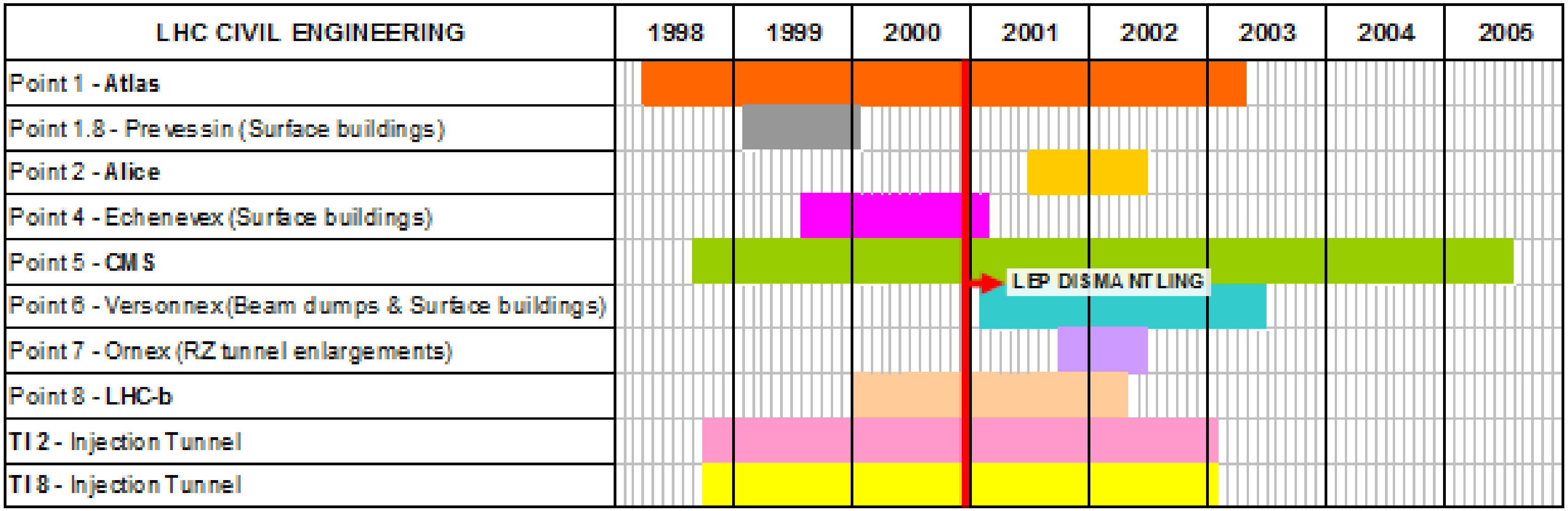
LHC Civil Engineering ATLAS

LHC Civil Engineering injection tunnels





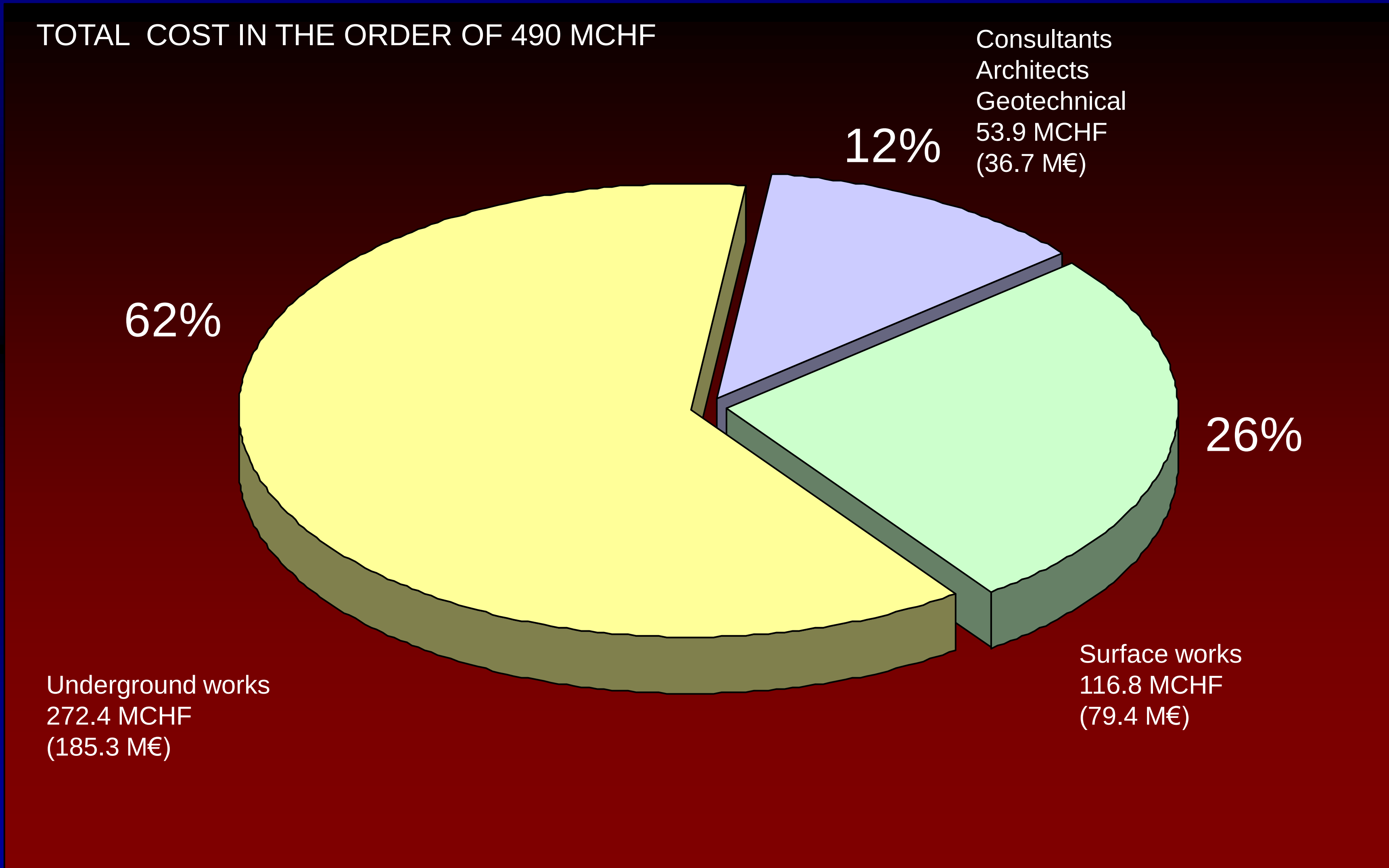
LHC Civil Engineering simplified schedule



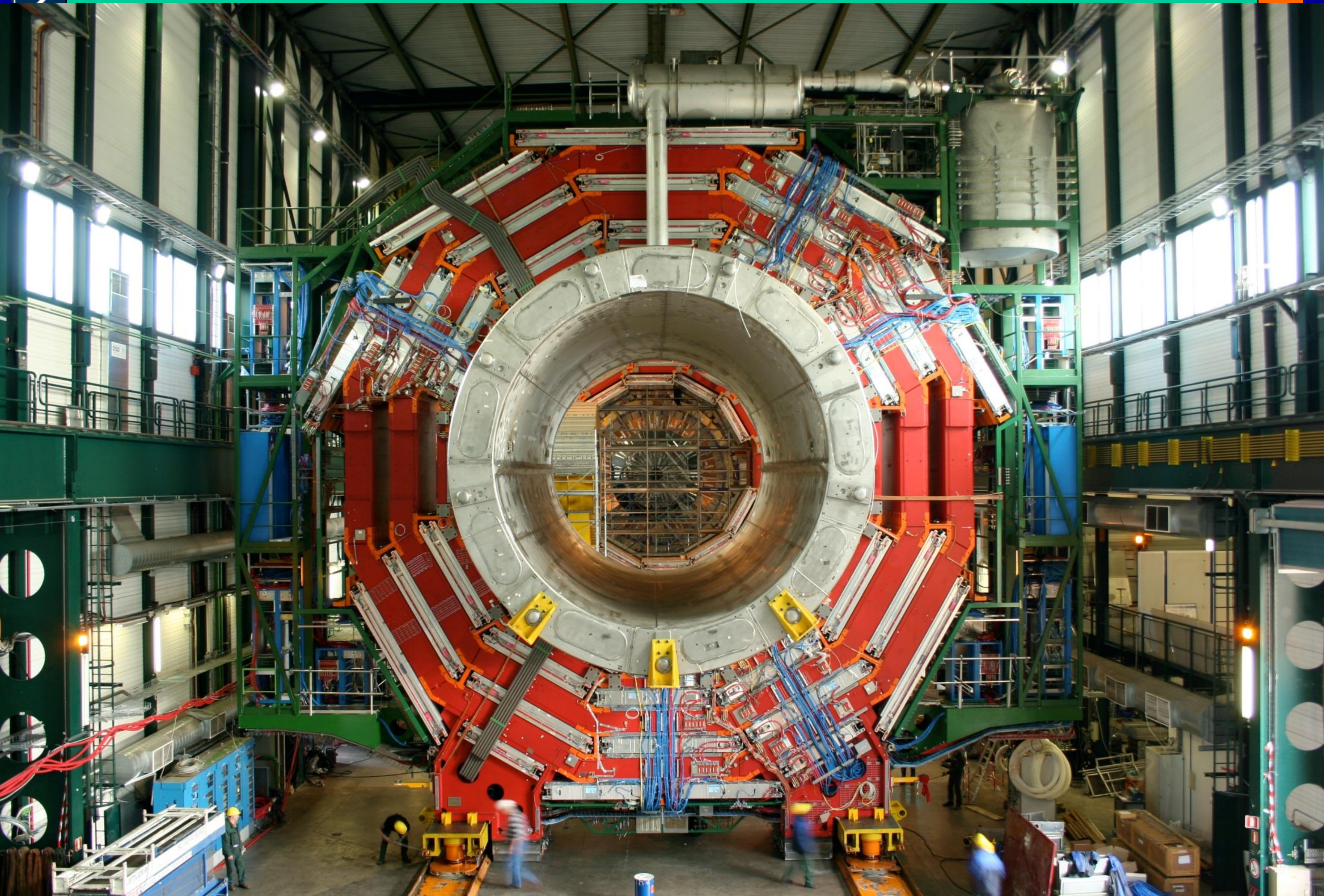
Civil Engineering as-built schedule

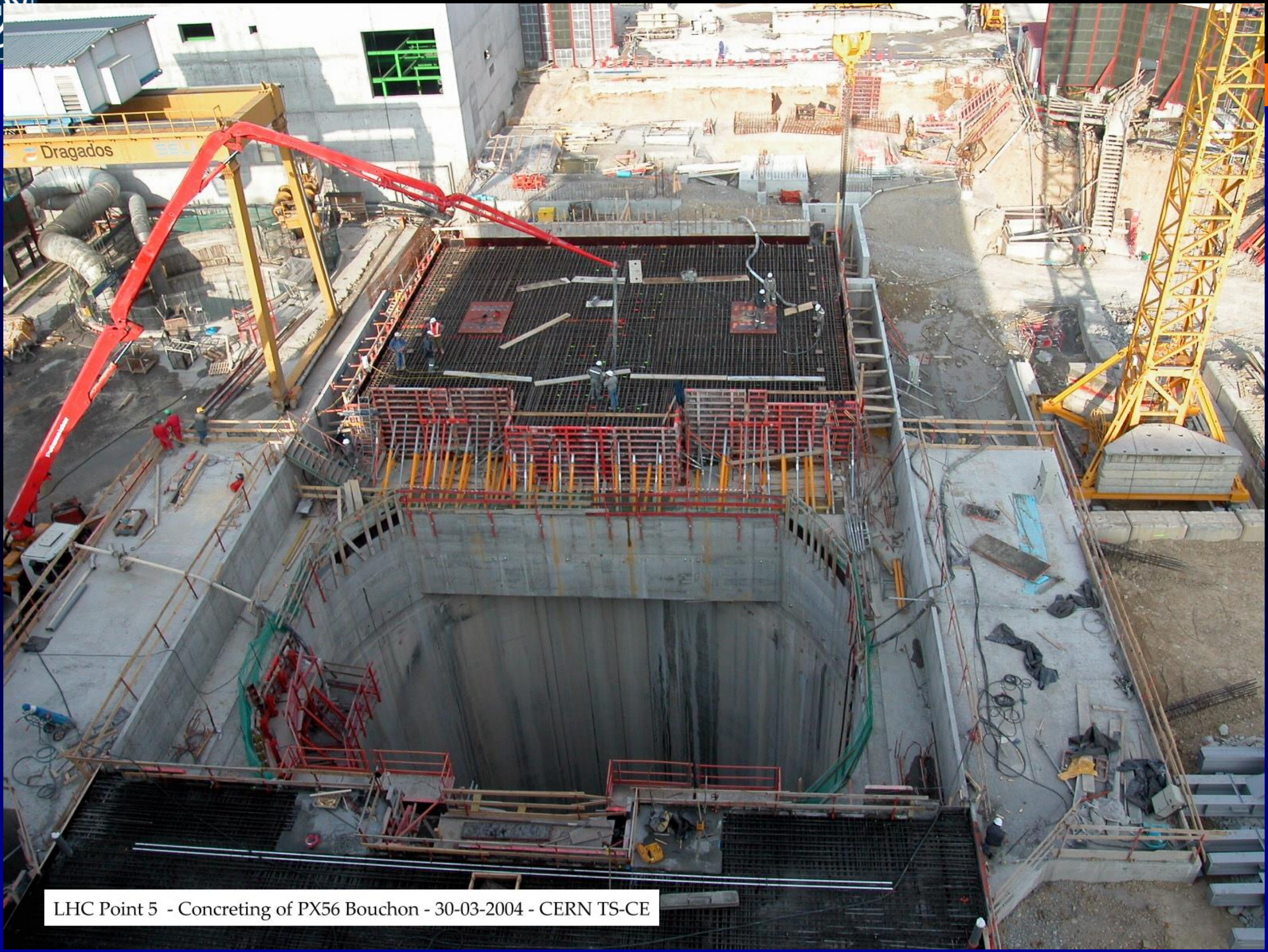
- LHC : 3 years pre-construction preparation (Site investigation, Environmental Impact Study, Tendering etc.)
- LEP civil engineering approximately 6 years (27km tunnels)

LHC Civil Engineering costs



CMS Detector Assembly and Lowering



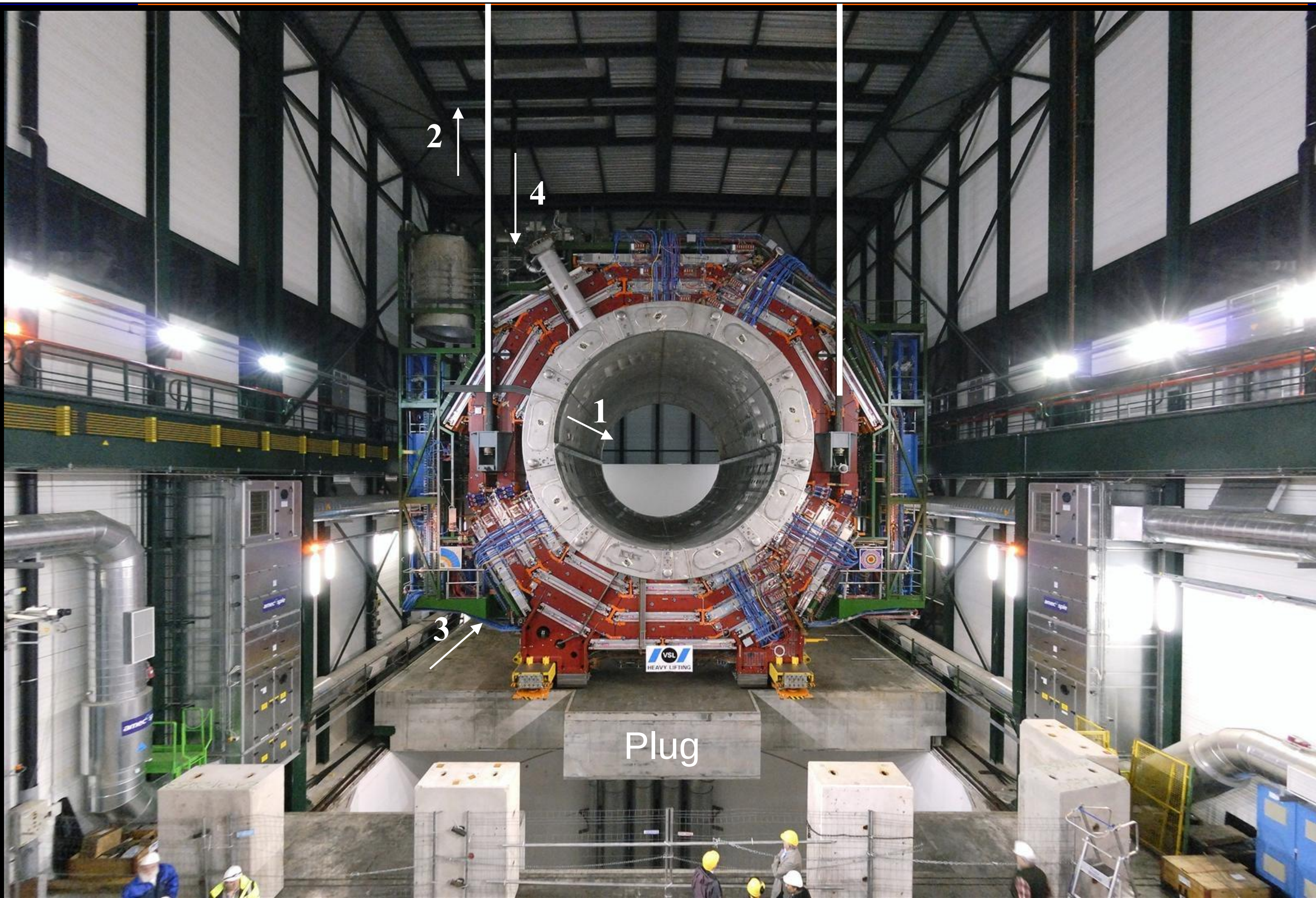


LHC Point 5 - Concreting of PX56 Bouchon - 30-03-2004 - CERN TS-CE

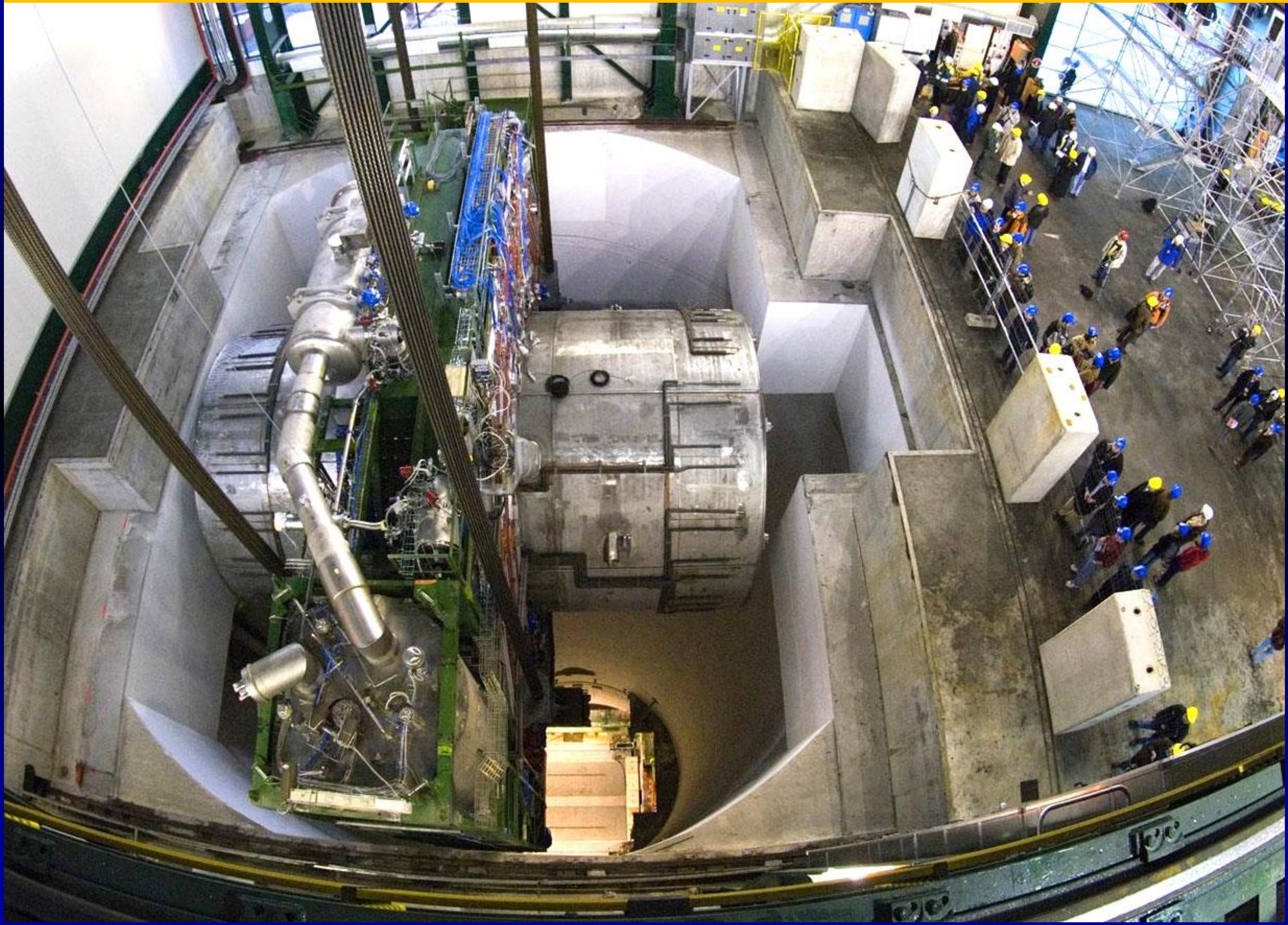

Dragados
LHC Point 5 - SX5 Extension - Bouchon Complete - 20 April 2004 - CERN TS-CE

Gantry Installation

Opening the plug under the 2000-ton load

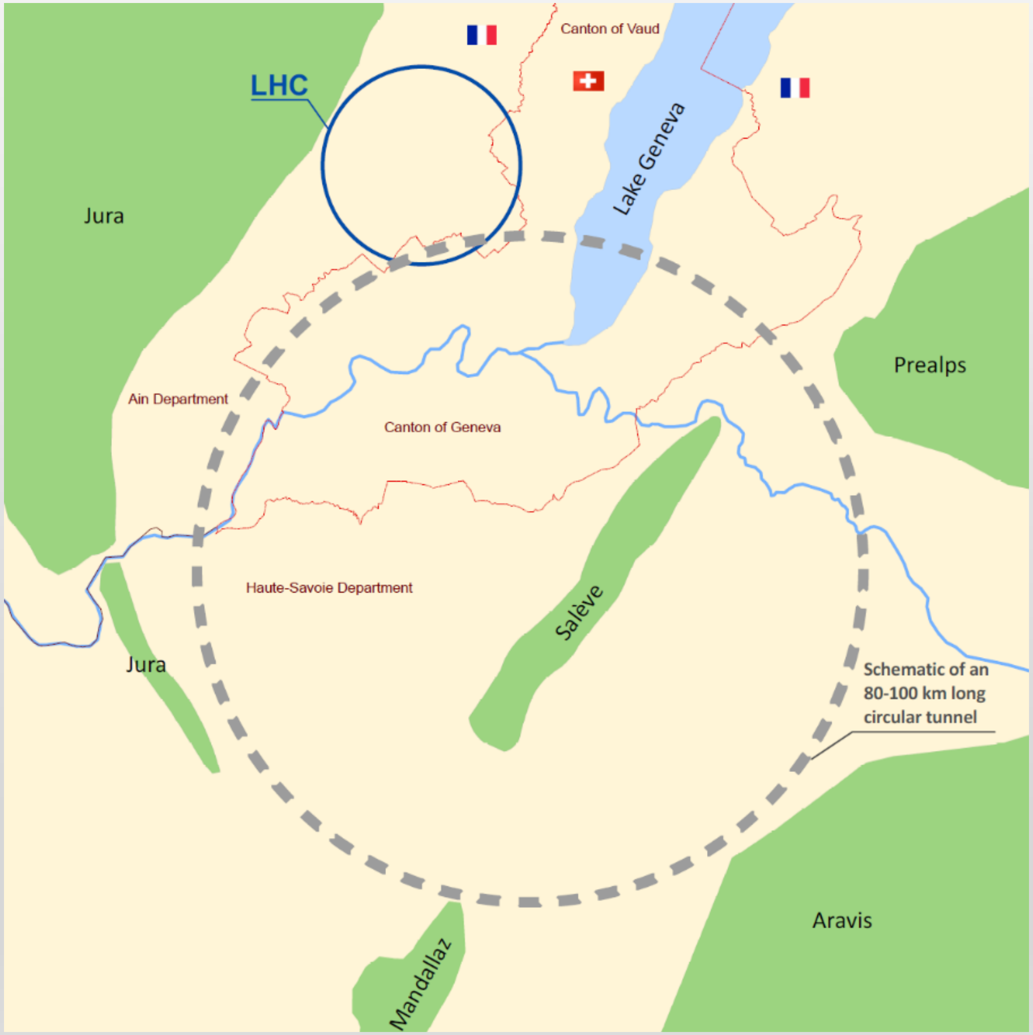


LHC Civil Engineering CMS lowering



The Future Circular Collider Study (FCC)

Collision energy:
100TeV
Circumference:
80km-100km
Physics considerations:
Enable connection to the LHC (or SPS)
Construction:
c.2025-35
Cost:
TBC
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?



Potential locations : European Strategy : Krakow 2012

Pre-feasibility study focused on:

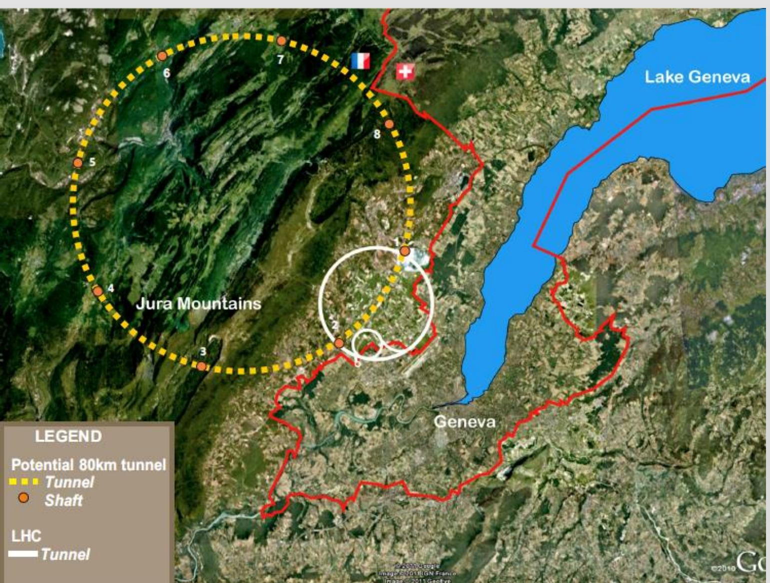
- geology & hydrogeology,
- tunneling & construction,
- environmental impacts

Result: for the 80km long tunnel location 2 '80km Lakeside' is most feasible.

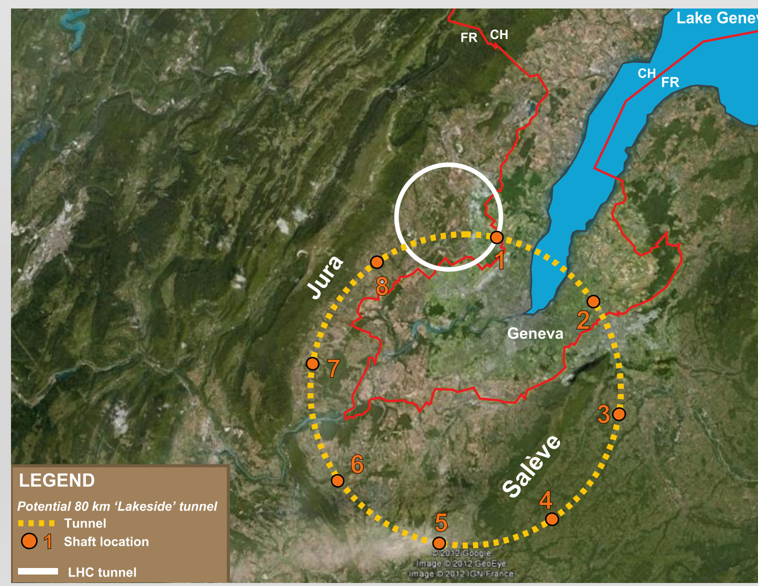
Risk

	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**

Feasibility
Low
High



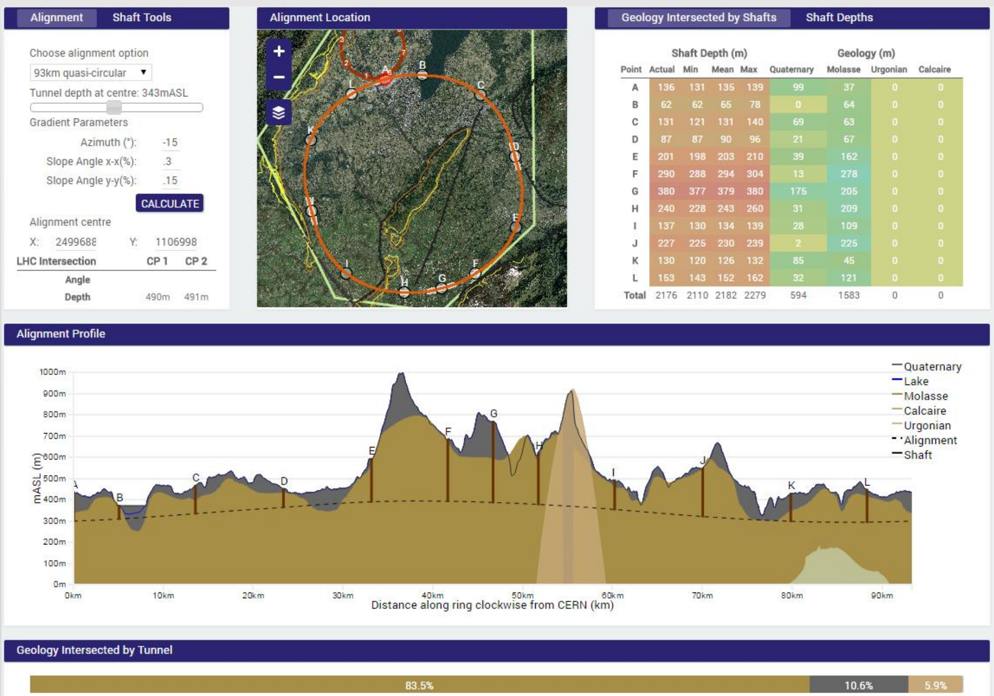
Option 1: 80km Jura



Option 2: 80km Lakeside

The Digital Approach – ARUP & the Tunnel Optimisation Tool (TOT)

- Optimisation studies for the project configuration have been the focus of work since the Kick-Off meeting
- ARUP(UK) mandated to produce a 3D geological model to allow various layouts for the machines to be analysed. This model will allow different tunnel shapes, circumferences, inclinations etc. to be entered into the model and determine the rock types housing the machine



	Shaft Depth (m)				Geology (m)			
Point	Actual	Min	Mean	Max	Quaternary	Molasse	Urgonian	Calcaire
A	136	131	135	139	99	37	0	0
B	62	62	65	78	0	64	0	0
C	131	121	131	140	69	63	0	0
D	87	87	90	96	21	67	0	0
E	201	198	203	210	39	162	0	0
F	290	288	294	304	13	278	0	0
G	380	377	379	380	175	205	0	0
H	240	228	243	260	31	209	0	0
I	137	130	134	139	28	109	0	0
J	227	225	230	239	2	225	0	0
K	130	120	126	132	85	45	0	0
L	153	143	152	162	32	121	0	0
Total	2176	2110	2182	2279	594	1583	0	0

User Inputs

- Initially 6 Alignments Options
- Interactive alignment location on map
- Alter Shaft locations - slidebar
- Select Tunnel Depth - slidebar
- Select Tunnel Gradient - slidebar

Outputs

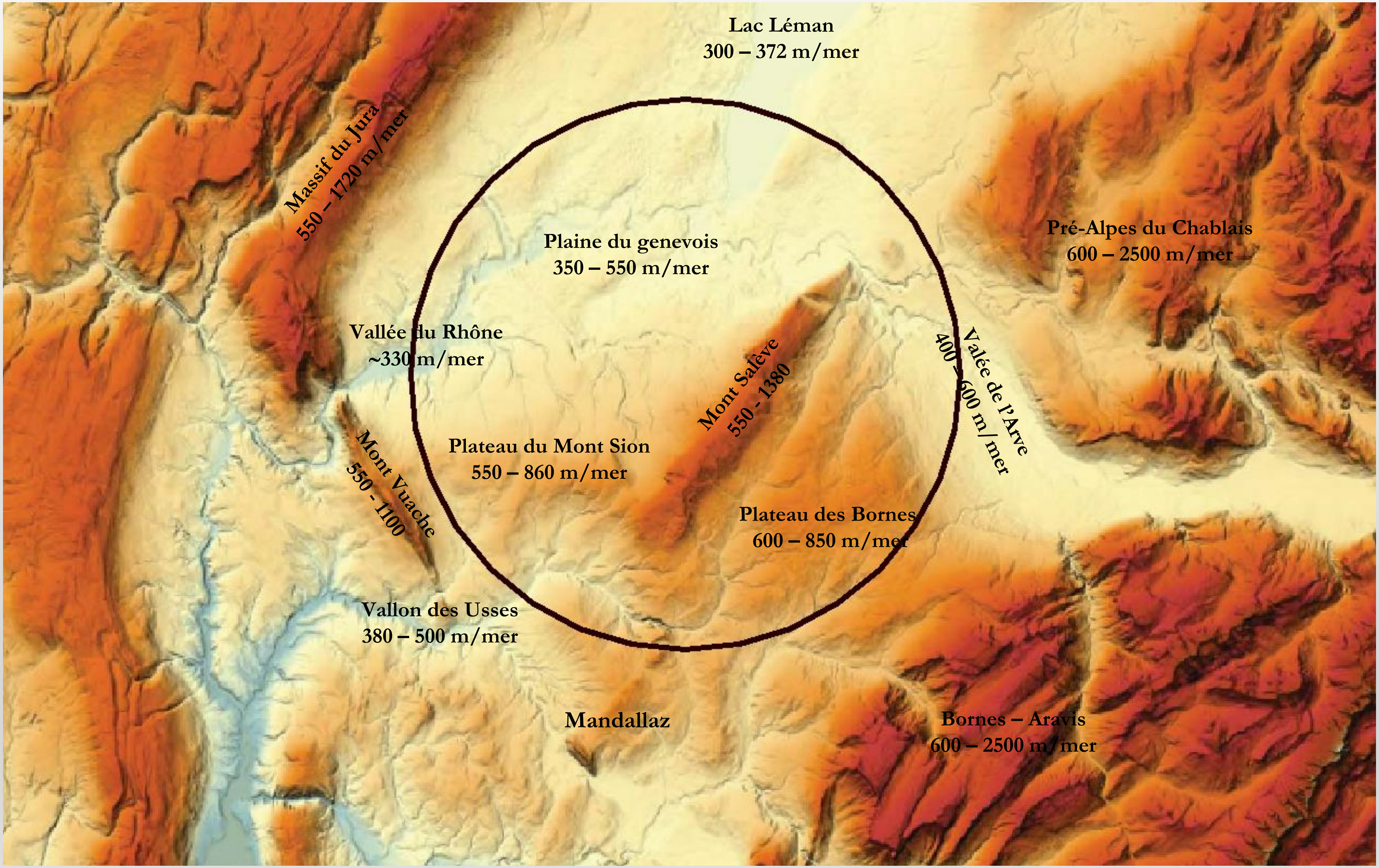
Dynamic Chart:

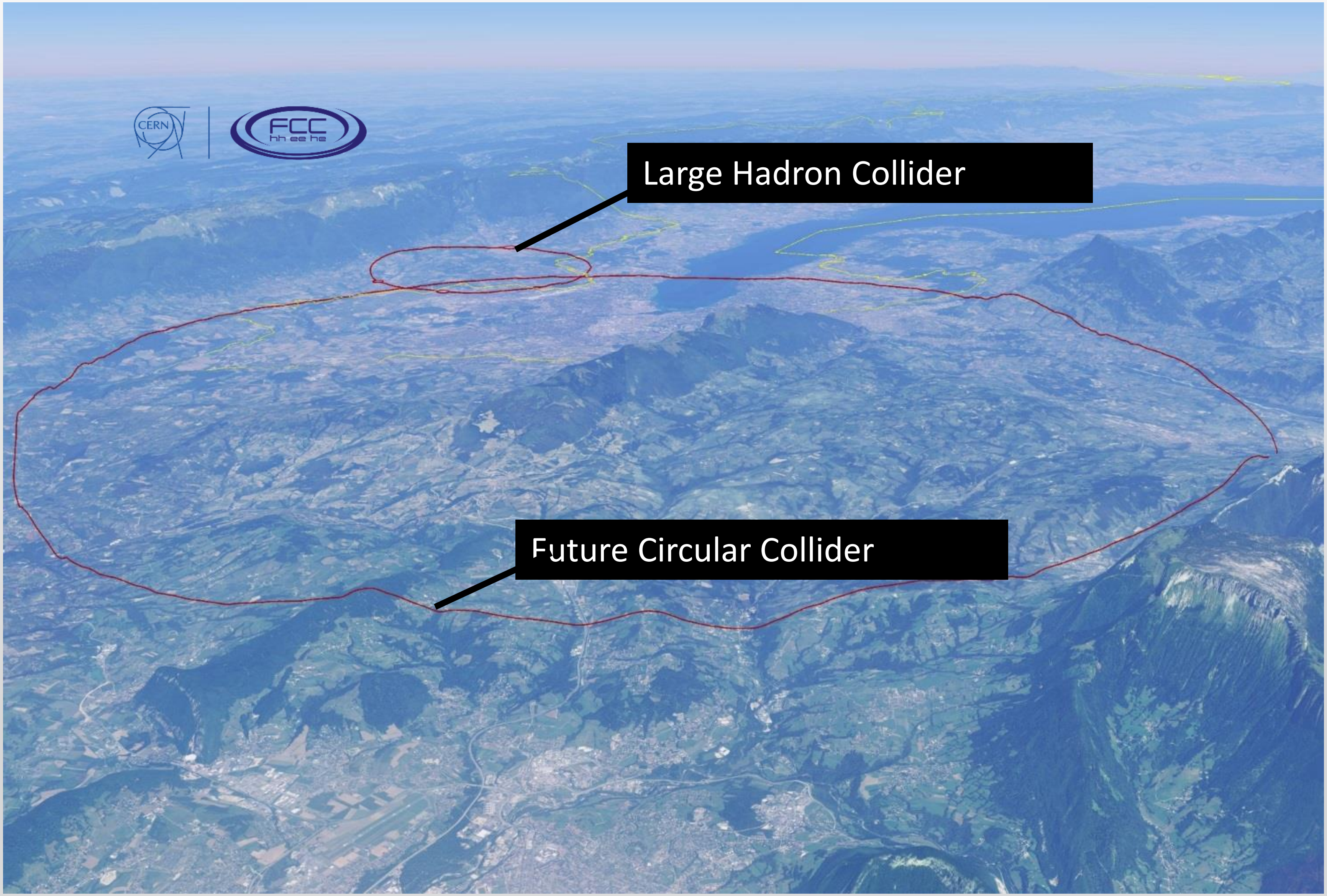
- Profile surface elevation and geology
- Profile of tunnel
- Shaft Locations
- Warnings when tunnel above ground level

Dynamic Tables:

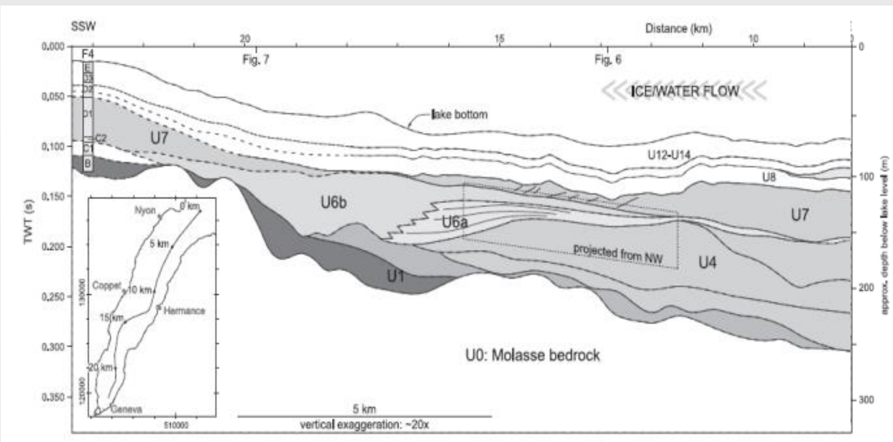
- Depth to tunnel (mASL)
- Shaft Length intersecting geology layer
- % age of tunnel intersecting geology

CE considerations for input into the tool : *topography*




Large Hadron Collider
Future Circular Collider

CE considerations for input into the tool : *some critical areas*



Depth under lake Geneva
(in molasse or moraines)

Rhone leaving the Geneva Basin

Avoid Vuache faulting

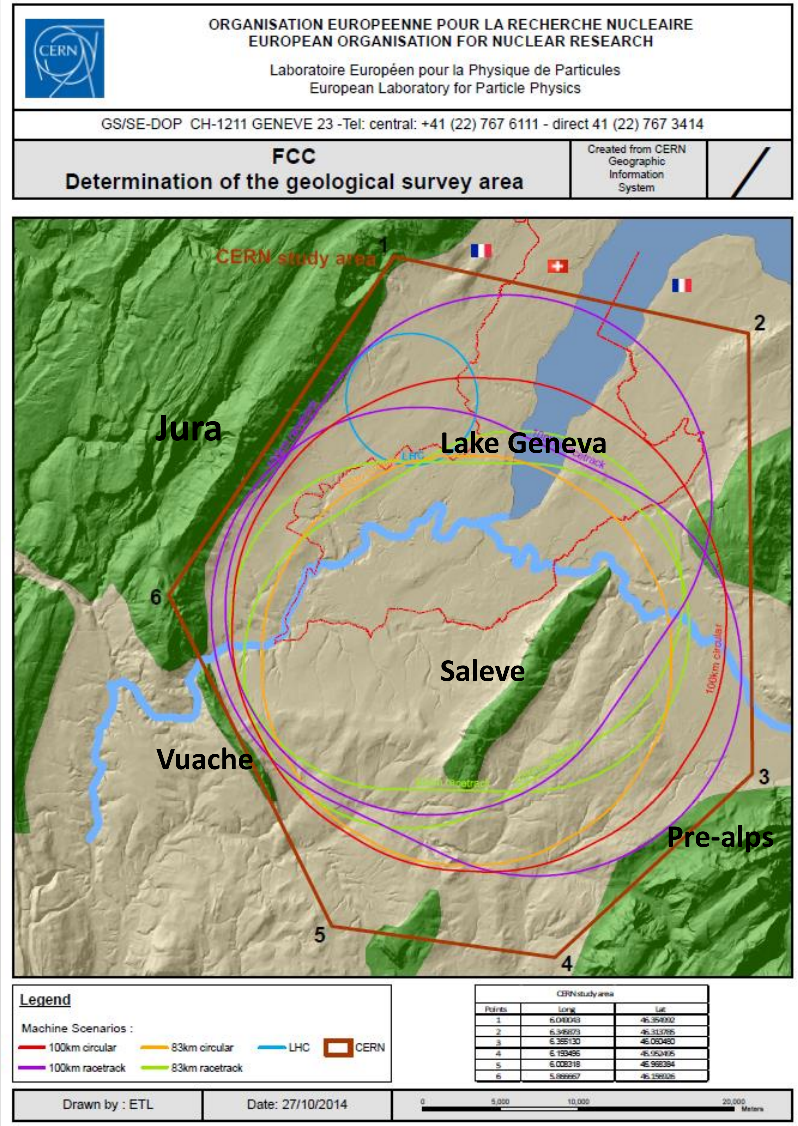
Feasibility Study – Study Boundaries

Jura
High overburden
Karstic limestone

Vuache
Highly fractured limestone with karst

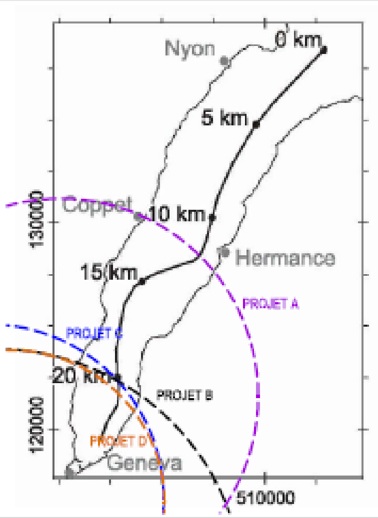
Pre-alps
Rapidly increasing tunnel depth
Less well-known limestone

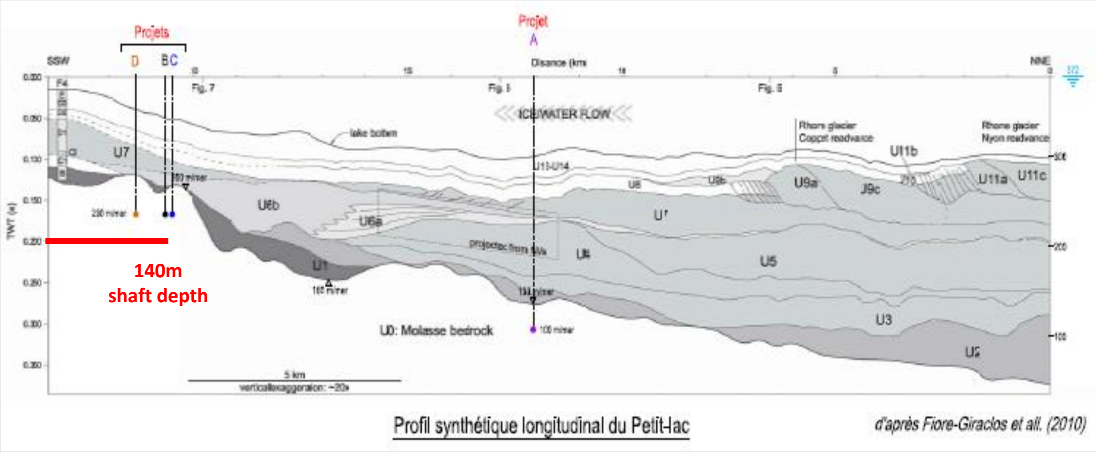
Lake Geneva
Lake depth increases quickly in NE direction



Feasibility study – Lake Geneva

- Geology is not yet well understood
- Some seismic soundings performed for the possible construction of a road tunnel
- Molasse bedrock covered by a deep layer of moraines



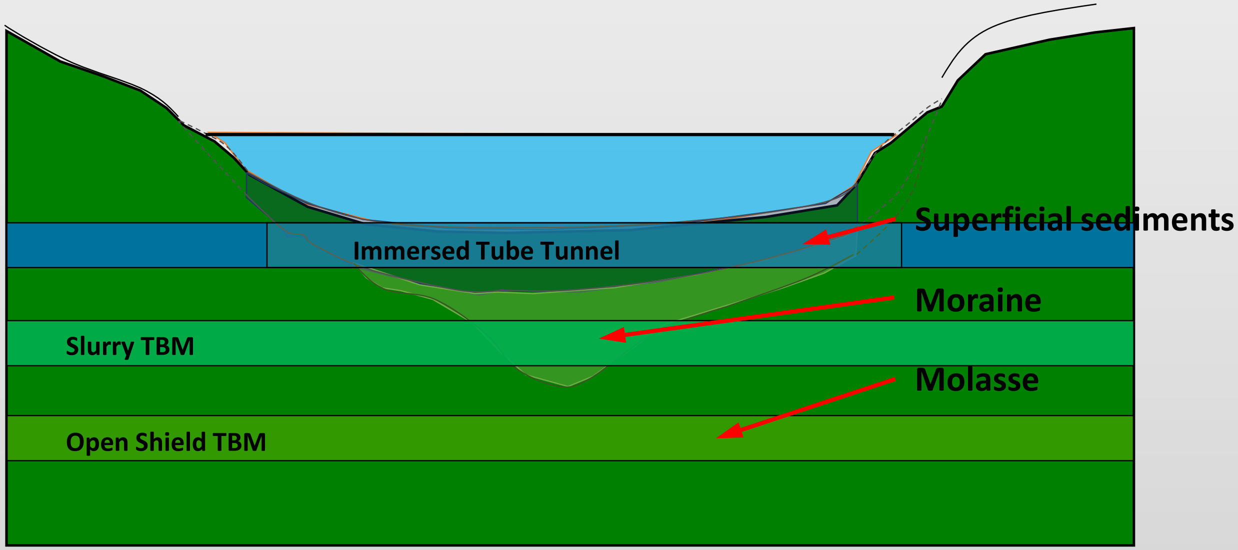


Profil synthétique longitudinal du Petit-lac

d'après Fiore-Giraclos et al. (2010)

Feasibility Study – Geology

Lake Crossing: Tunnelling Considerations

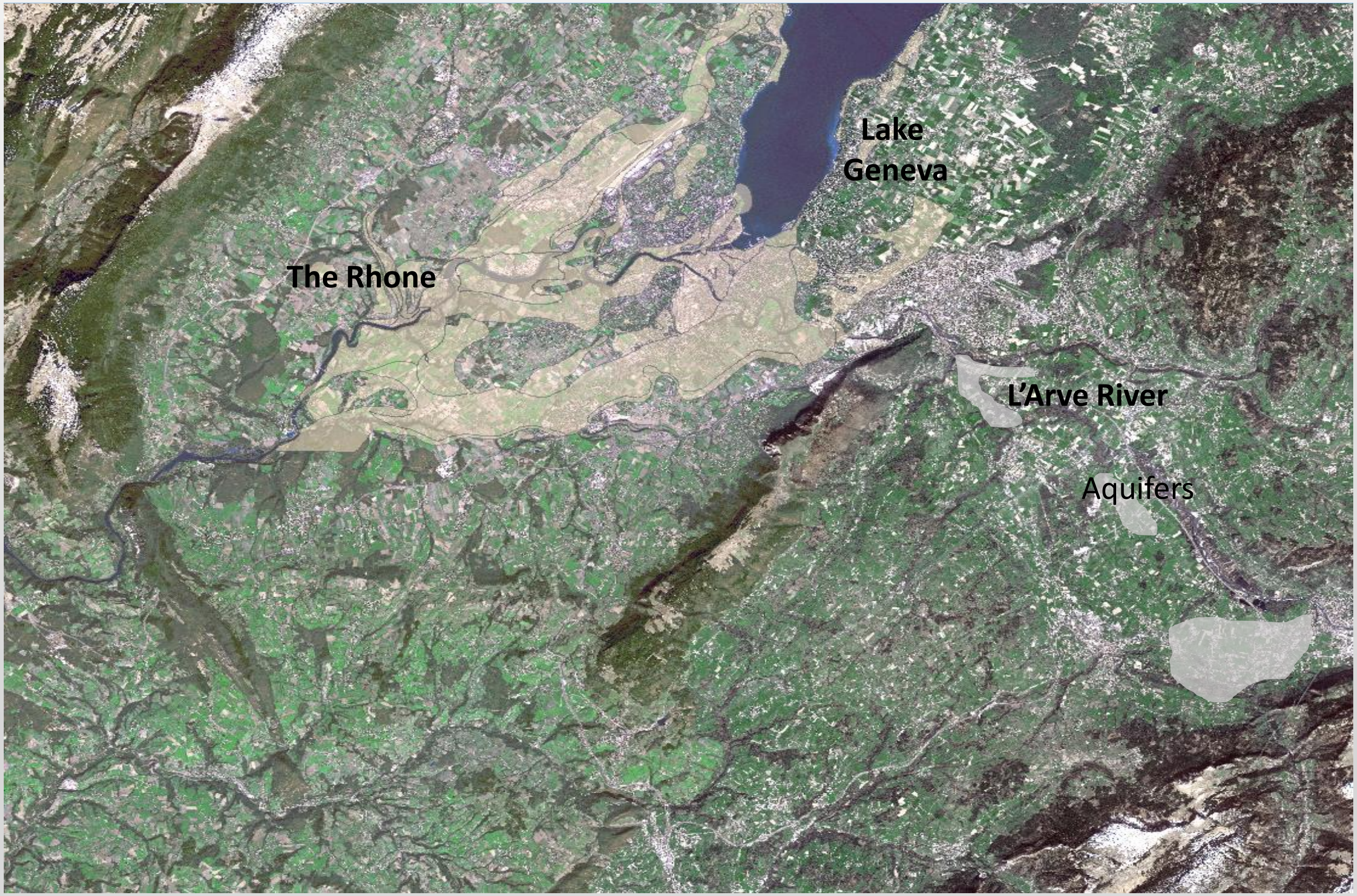


Medway Tunnel Immersed Tube Tunnel

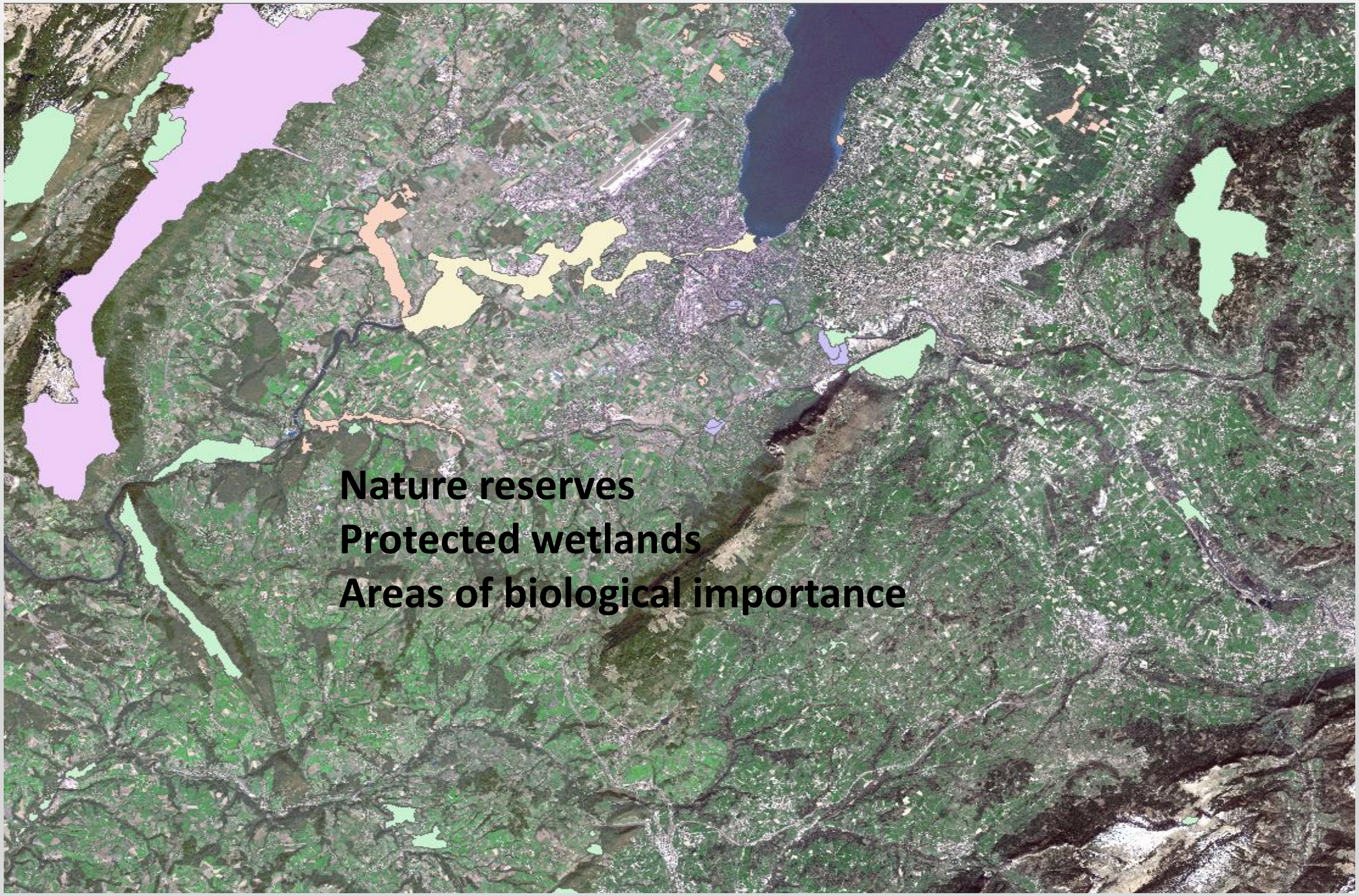
BIM – Tunnel Optimisation Tool

- Streamlines the conventional approach which is broadly linear and manual
- Max value extracted from early project data
- Single Source of Data
- Visual decision aid
- Clash detection – Regional Scale
- Iterative process and comparison of options

Feasibility Study – Hydrology

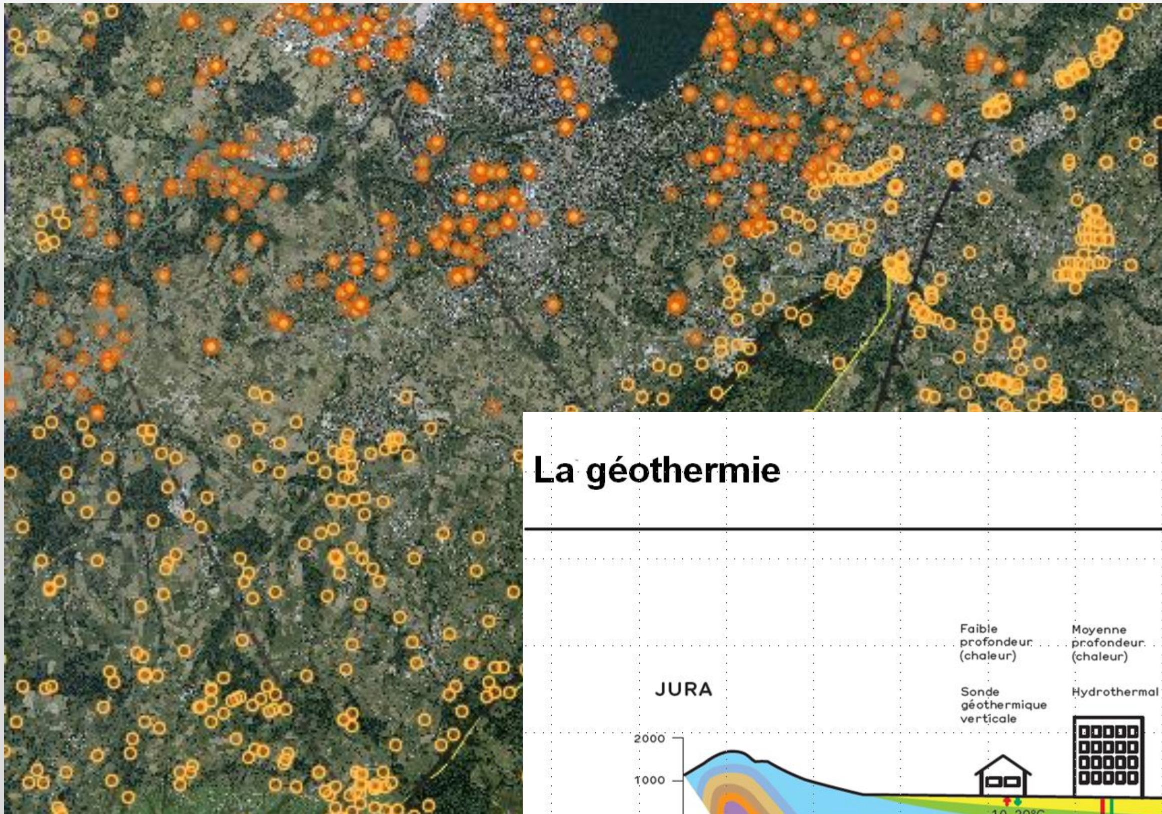


Feasibility Study – Environmental Considerations

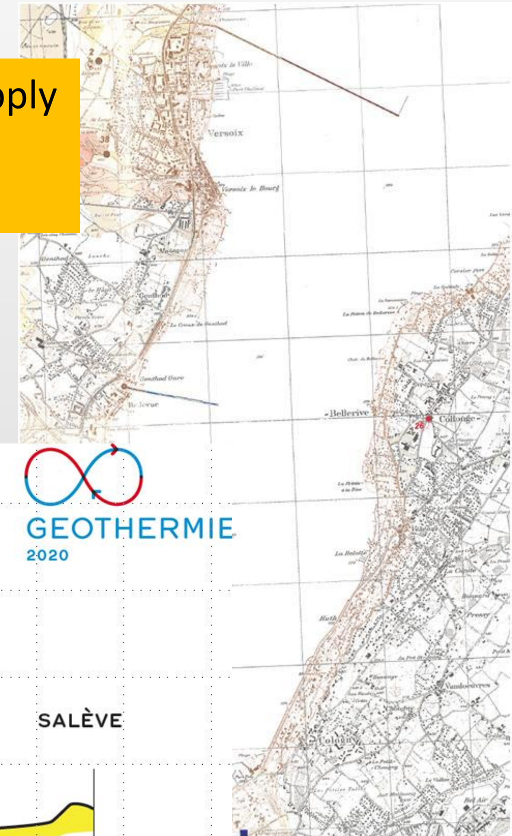


Feasibility Study – Buildings

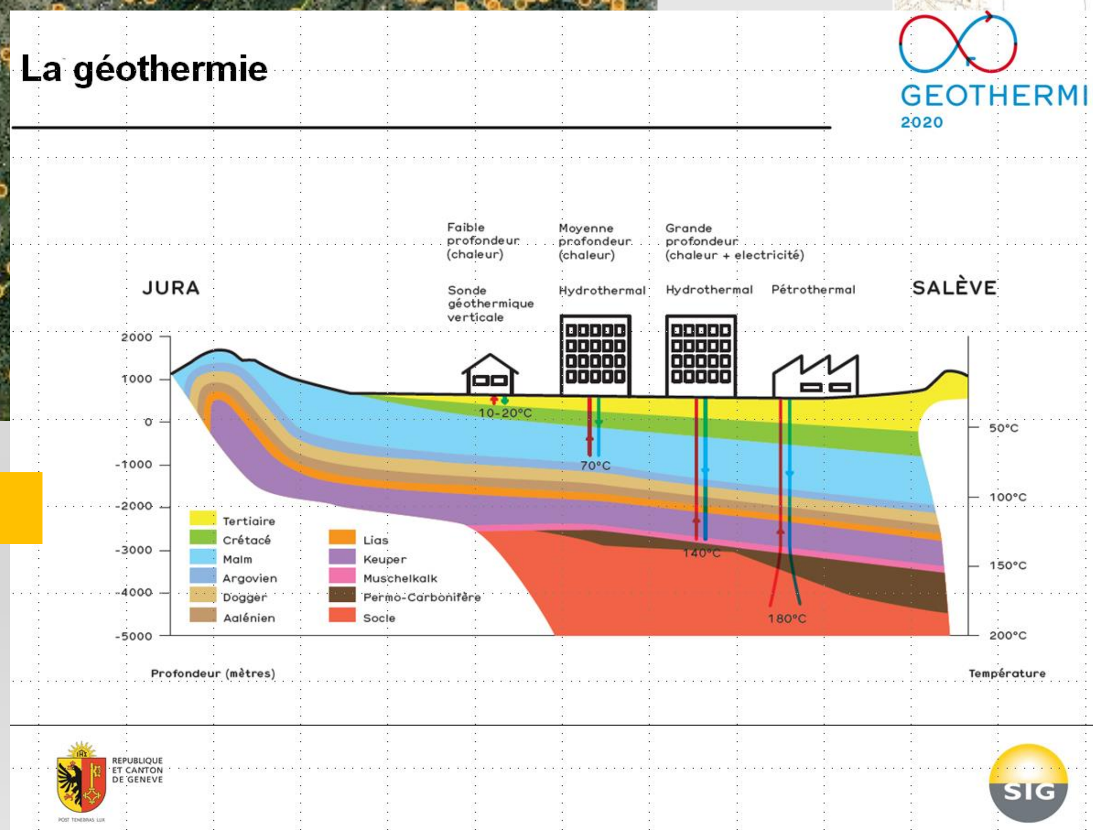
Feasibility Study – Geothermal Boreholes



Geothermal drillings

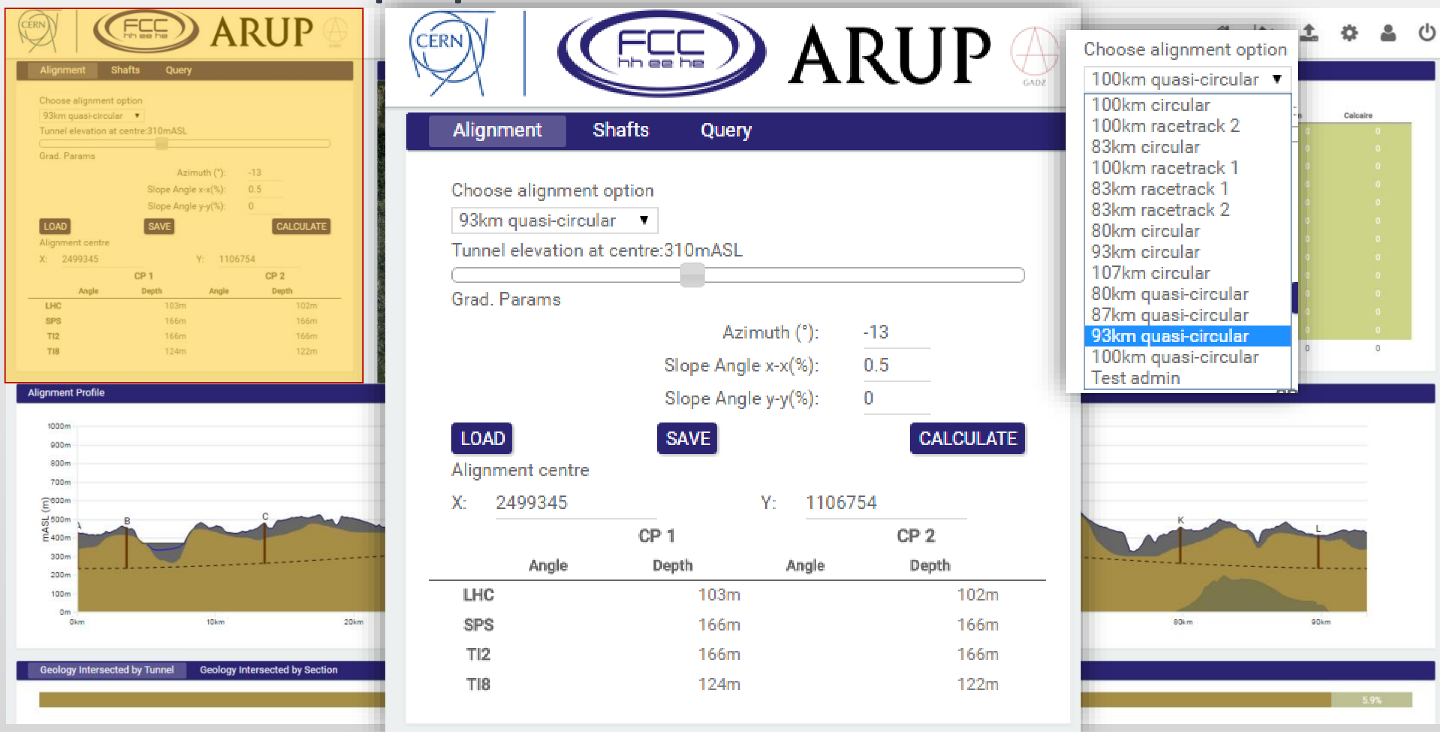


Water supply pipelines



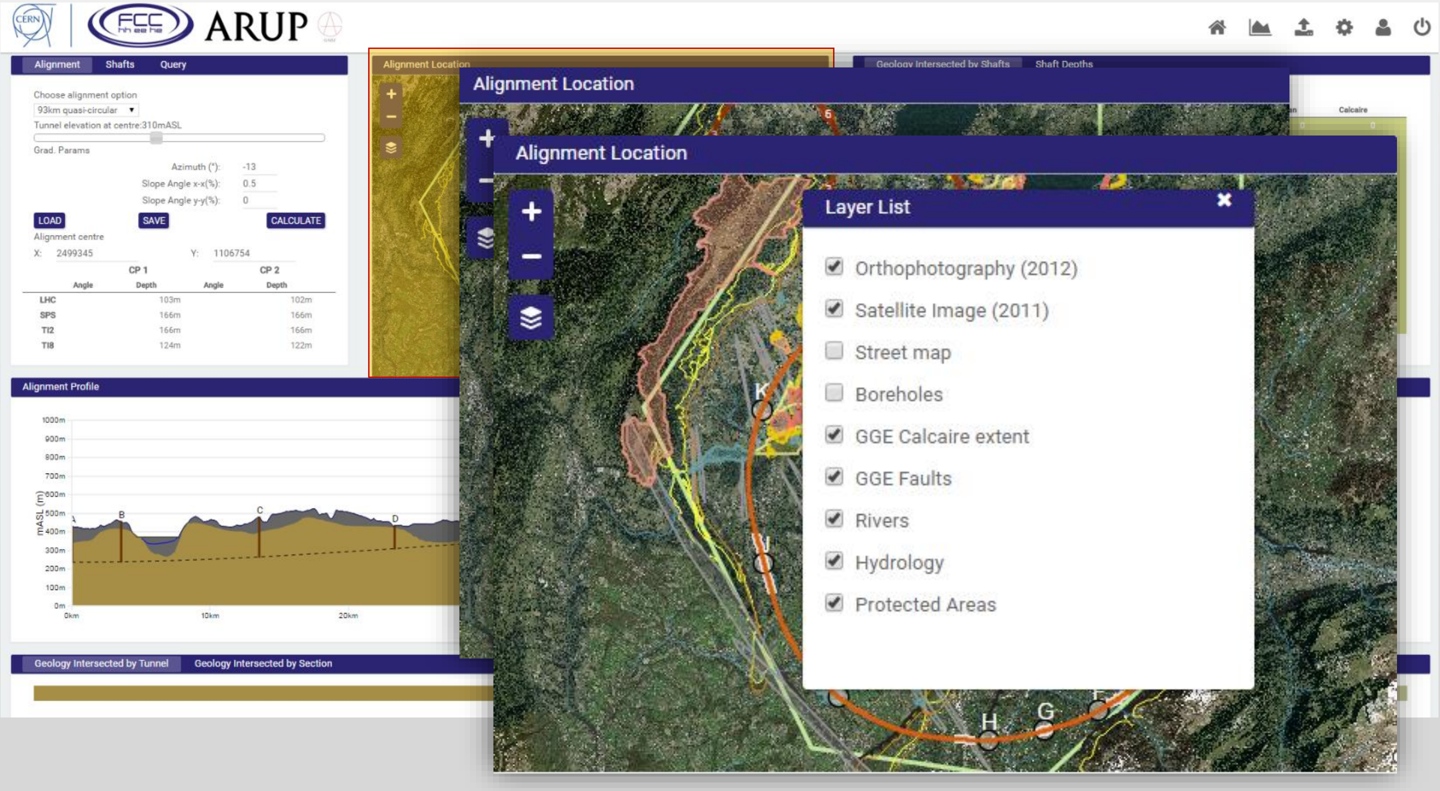
BIM – Tunnel Optimisation Tool

User interface - Input parameters



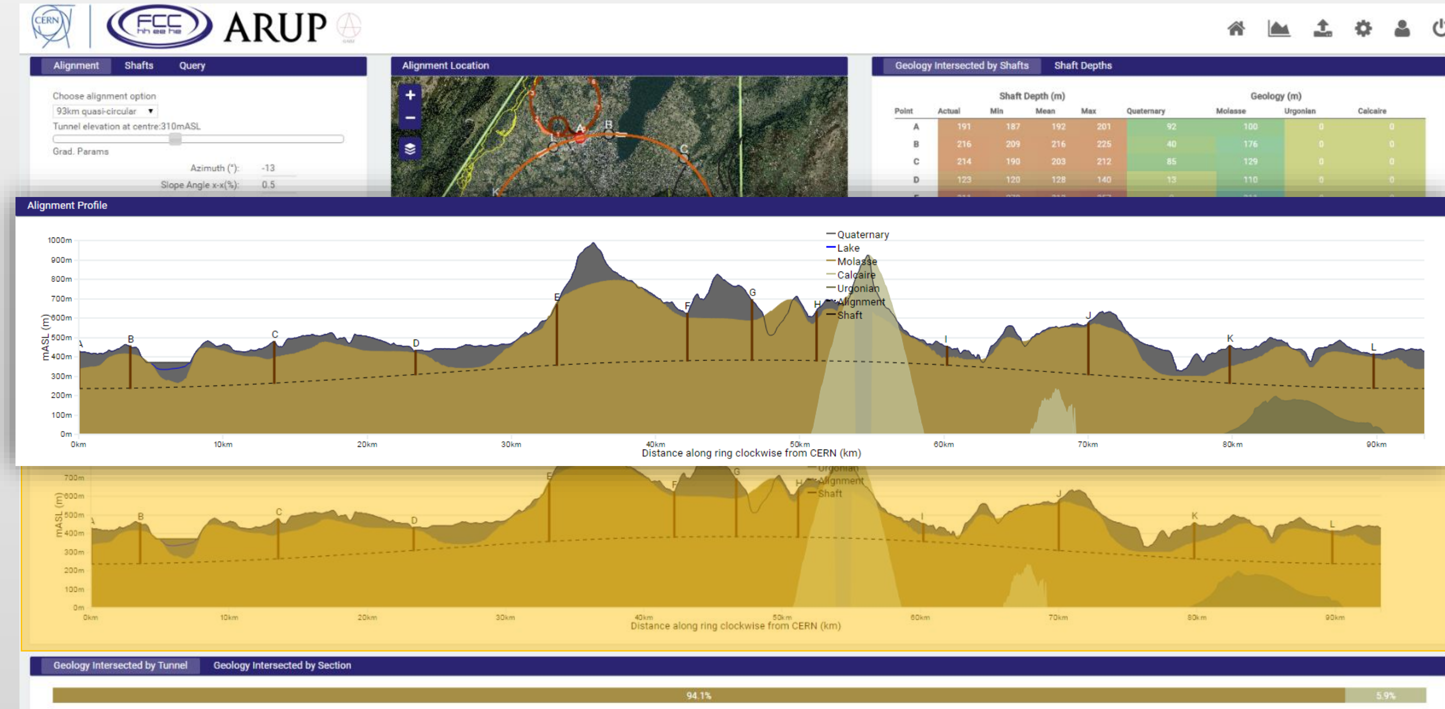
BIM – Tunnel Optimisation Tool

User interface - Input parameters



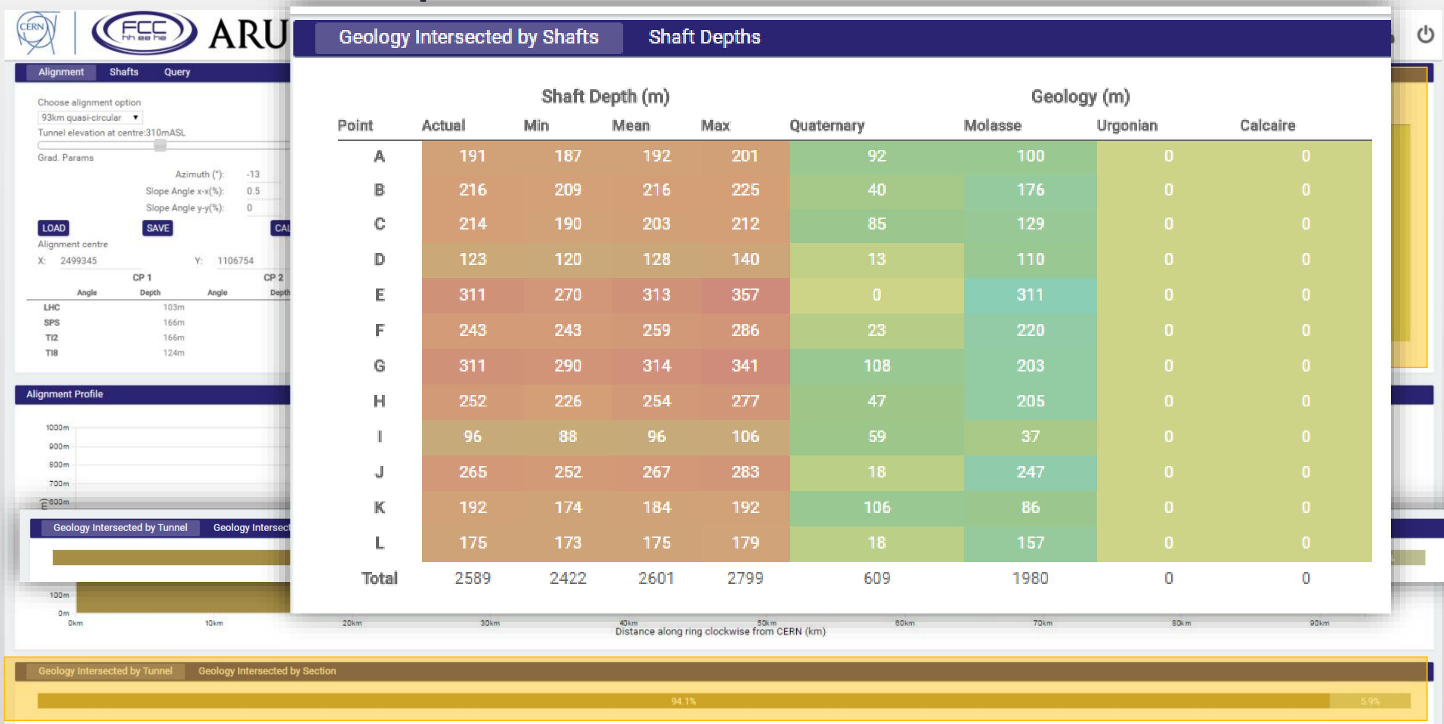
BIM – Tunnel Optimisation Tool

User interface – Alignment profile



BIM – Tunnel Optimisation Tool

User interface – Outputs



Geology Intersected by Shafts | Shaft Depths

Point	Shaft Depth (m) Actual	Min	Mean	Max	Geology (m) Quaternary	Molasse	Urgonian	Calcaire
A	191	187	192	201	92	100	0	0
B	216	209	216	225	40	176	0	0
C	214	190	203	212	85	129	0	0
D	123	120	128	140	13	110	0	0
E	311	270	313	357	0	311	0	0
F	243	243	259	286	23	220	0	0
G	311	290	314	341	108	203	0	0
H	252	226	254	277	47	205	0	0
I	96	88	96	106	59	37	0	0
J	265	252	267	283	18	247	0	0
K	192	174	184	192	106	86	0	0
L	175	173	175	179	18	157	0	0
Total	2589	2422	2601	2799	609	1980	0	0

Feasibility Study – Early results
93km circumference in Molasse under Lake Geneva

Alignment | **Shaft Tools**

Choose alignment option: 93km quasi-circular

Tunnel depth at centre: 299mASL

Gradient Parameters

Azimuth (°): -15

Slope Angle x-x(%): .5

Slope Angle y-y(%): 0

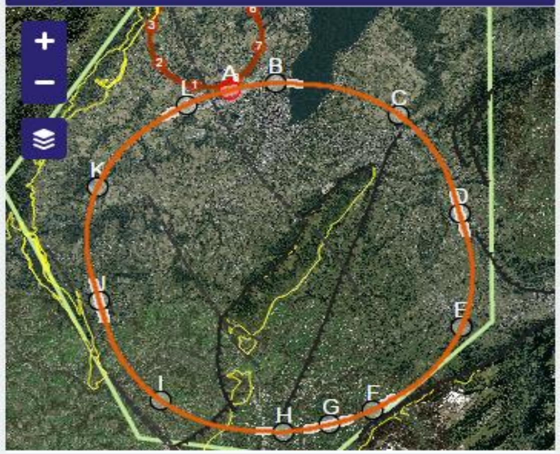
CALCULATE

Alignment centre

X: 2499812 Y: 1106889

LHC Intersection	CP 1	CP 2
Angle		
Depth	586m	587m

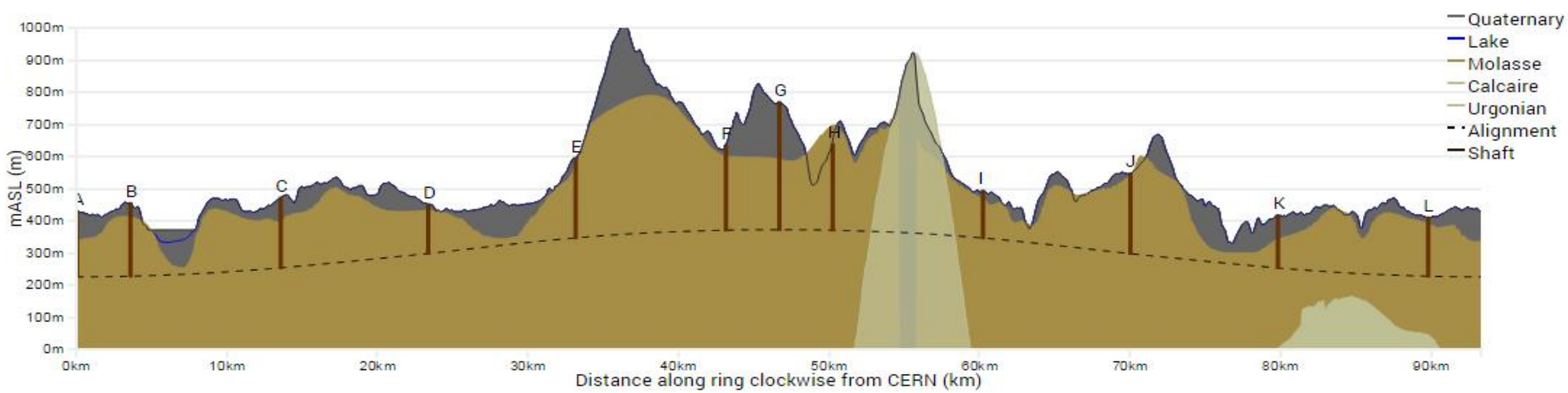
Alignment Location



Geology Intersected by Shafts | **Shaft Depths**

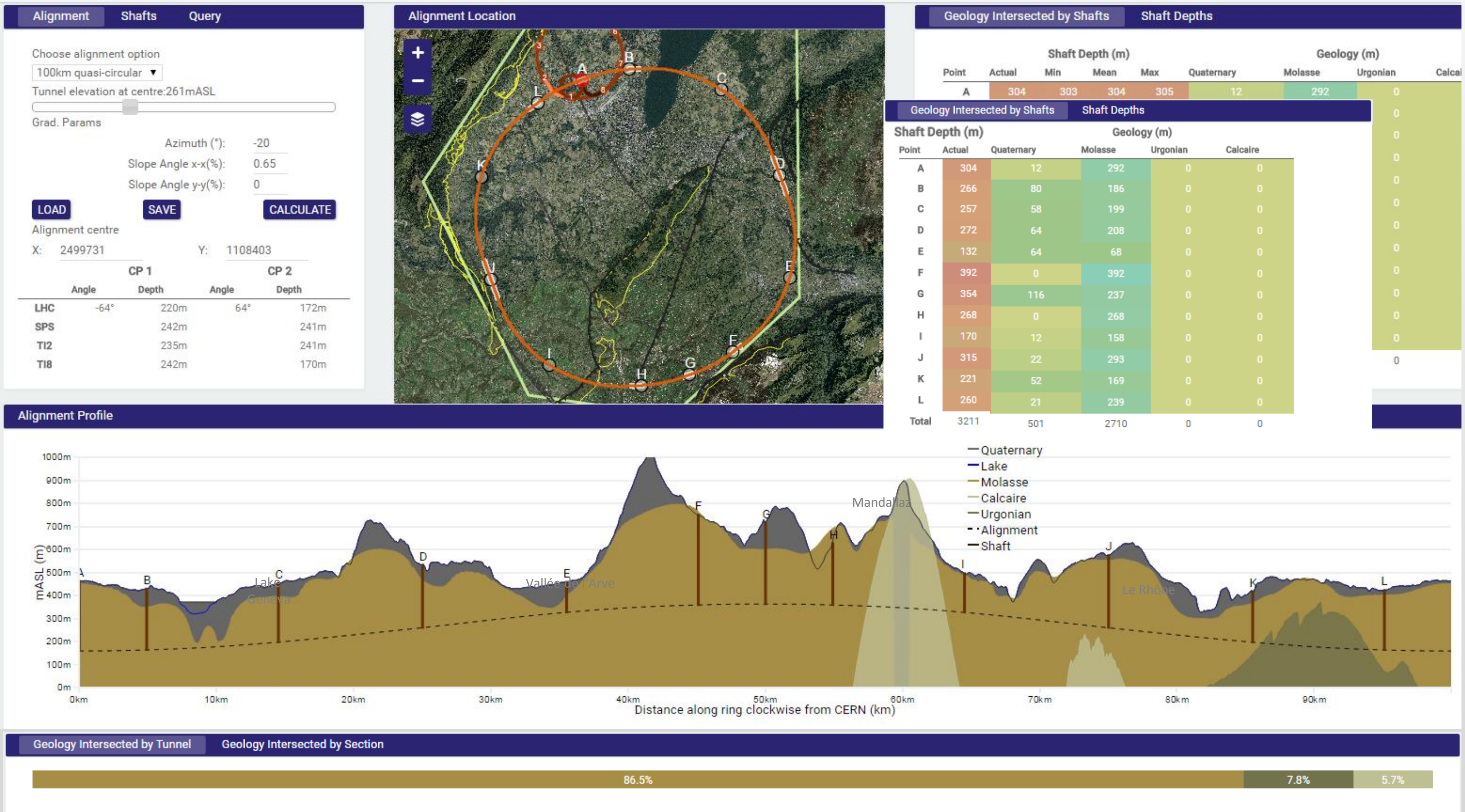
	Shaft Depth (m)				Geology (m)			
Point	Actual	Min	Mean	Max	Quaternary	Molasse	Urgonian	Calcaire
A	203	200	204	212	93	111	0	0
B	226	213	224	231	42	185	0	0
C	218	208	217	225	75	143	0	0
D	153	150	154	158	19	134	0	0
E	247	233	249	261	24	223	0	0
F	262	251	269	304	32	230	0	0
G	396	392	393	396	177	220	0	0
H	266	231	274	322	0	325	0	0
I	146	141	144	149	26	120	0	0
J	248	247	251	258	6	242	0	0
K	163	153	159	164	76	87	0	0
L	182	182	184	187	17	165	0	0
Total	2711	2601	2722	2867	586	2184	0	0

Alignment Profile



Geology Intersected by Tunnel

Feasibility Study – Early results
100km circumference : “LHC Intersecting option”



Point	Shaft Depth (m) Actual	Geology (m) Quaternary	Molasse	Urgonian	Calcaire
A	304	12	292	0	0
B	266	80	186	0	0
C	257	58	199	0	0
D	272	64	208	0	0
E	132	64	68	0	0
F	392	0	392	0	0
G	354	116	237	0	0
H	268	0	268	0	0
I	170	12	158	0	0
J	315	22	293	0	0
K	221	52	169	0	0
L	260	21	239	0	0
Total	3211	501	2710	0	0

- Avoids Jura limestone: **No**
- Max overburden: **650m**
- Deepest shaft: **392m**
- % of tunnel in limestone: **13.5%**
- Total shaft depths: 3211m

Point A Campus: Prevessin (large potential area)

Challenges:
- 7.8km tunnelling through Jura limestone
- 300m-400m deep shafts and caverns in molasse

Feasibility Study – Early results
100km circumference : “Non-intersecting option”

Alignment | Shafts | Query

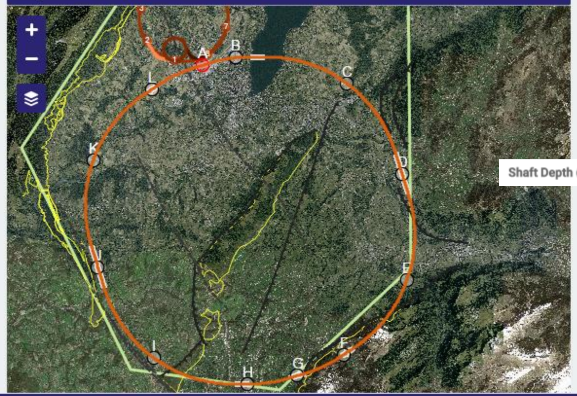
Choose alignment option
100km quasi-circular
Tunnel elevation at centre:291mASL
Grad. Params
Azimuth (°): -17
Slope Angle x-x(%): 0.48
Slope Angle y-y(%): 0

LOAD | SAVE | CALCULATE

Alignment centre
X: 2500583 Y: 1105970

	CP 1 Angle	CP 1 Depth	CP 2 Angle	CP 2 Depth
LHC		122m		122m
SPS		187m		187m
TI2		187m		187m
TI8		139m		137m

Alignment Location

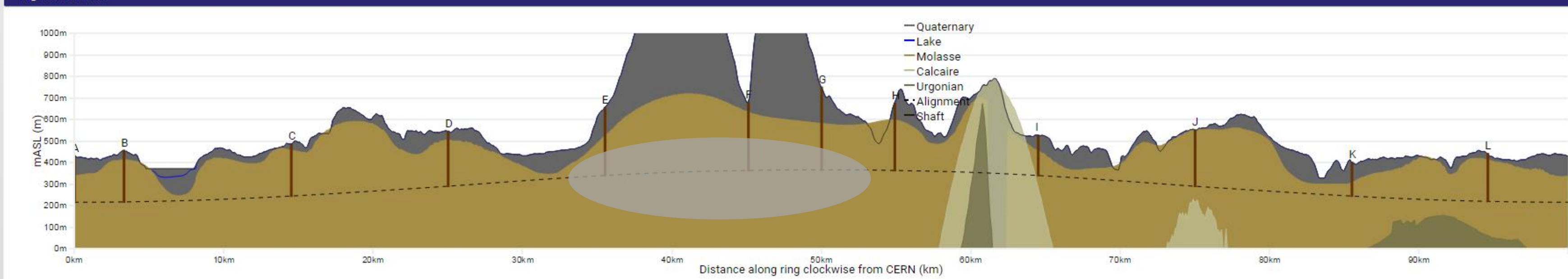


Geology Intersected by Shafts | Shaft Depths

Shaft Depth (m)

Point	Actual	Geology (m) Quaternary	Molasse	Urgonian	Calcaire
A	214	93	122	0	0
B	238	42	196	0	0
C	241	26	215	0	0
D	254	42	212	0	0
E	315	131	184	0	0
F	316	44	273	0	0
G	383	166	216	0	0
H	311	77	235	0	0
I	186	70	116	0	0
J	260	0	260	0	0
K	156	93	63	0	0
L	221	28	193	0	0
Total	3095	812	2282	0	0

Alignment Profile



Geology Intersected by Tunnel | Geology Intersected by Section

94.6% | 1.0 | 4.4%

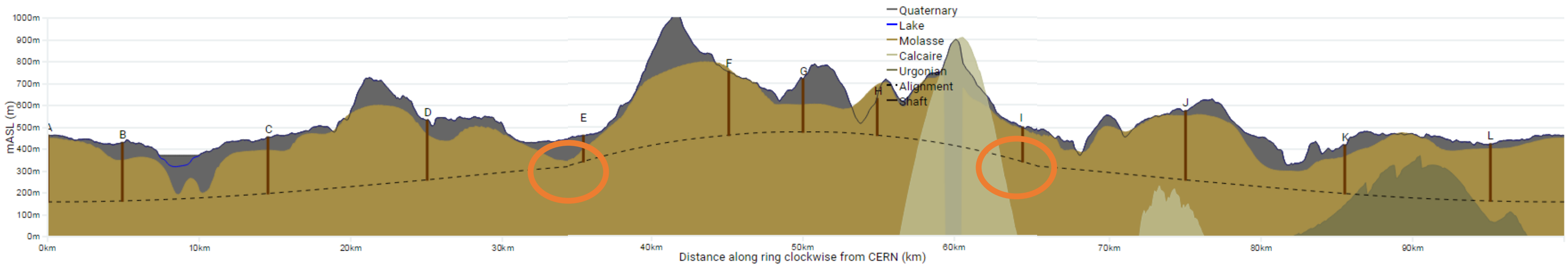
- Avoids Jura limestone: **Yes**
- Max overburden: **1350m**
- Deepest shaft: **383m**
- % of tunnel in limestone: **4.4%**
- Total shaft depths: **3095m**

Point A Campus: Meyrin (small potential area, next to airport)

Challenges:
- 1.35km tunnel overburden
- 300m-400m deep shafts and caverns in molasse

Non Planar Options – Introducing 'Kinks'

100km Single Kink Example



100km Example

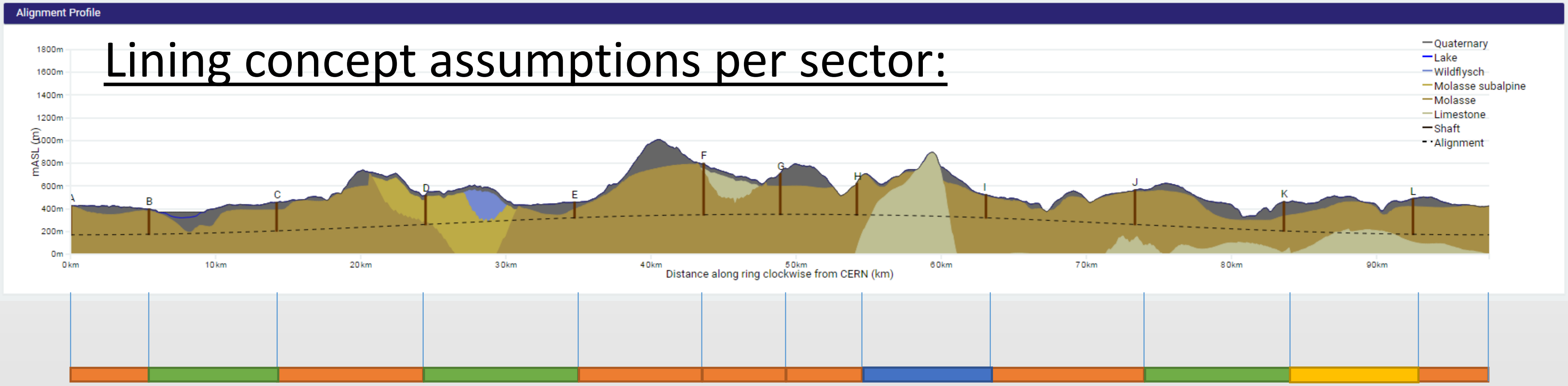
Slope after kink [%]	Change in slope [%]	Shaft Depths E	F	G	H	I	Total depth (of all 12 shafts)	Shaft depths % Reduction
0.5	**0.0**	132	392	354	268	170	3211	0%
0.9	**0.25**	131	378	339	254	169	3166	1%
1.4	**0.75**	128	350	307	226	166	3072	4%
2.4	**1.75**	110	290	241	166	157	2859	11%

Benefits to CE:

- 50m-100m reduction in depth of the deepest shafts is possible
- Overall shaft construction reduced by 140m – 352m (equivalent to removing 1 shaft)

FCC Tunnel Lining Concepts

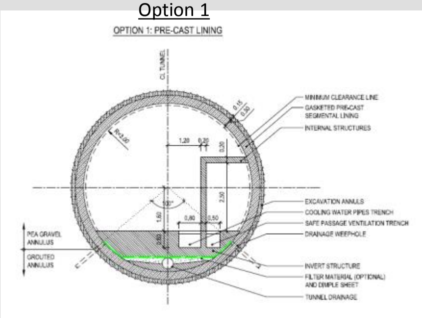
Lining concept assumptions per sector:



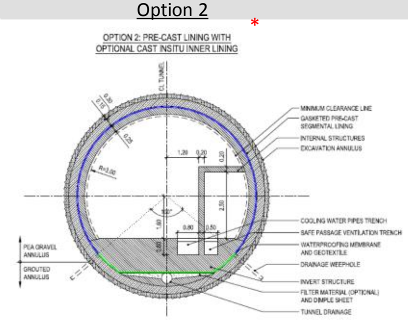
Lining option:	1	2	1	2	1	1	1	3	1	2	4	1

TBM Tunnel options

Option 1



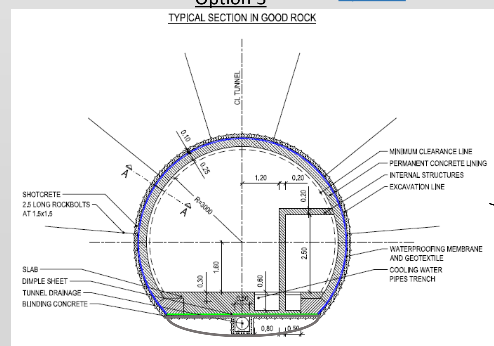
Option 2 *



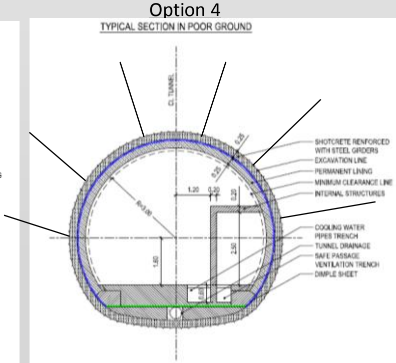
*It is assumed 50% will have optional inner lining

Mined Tunnel options

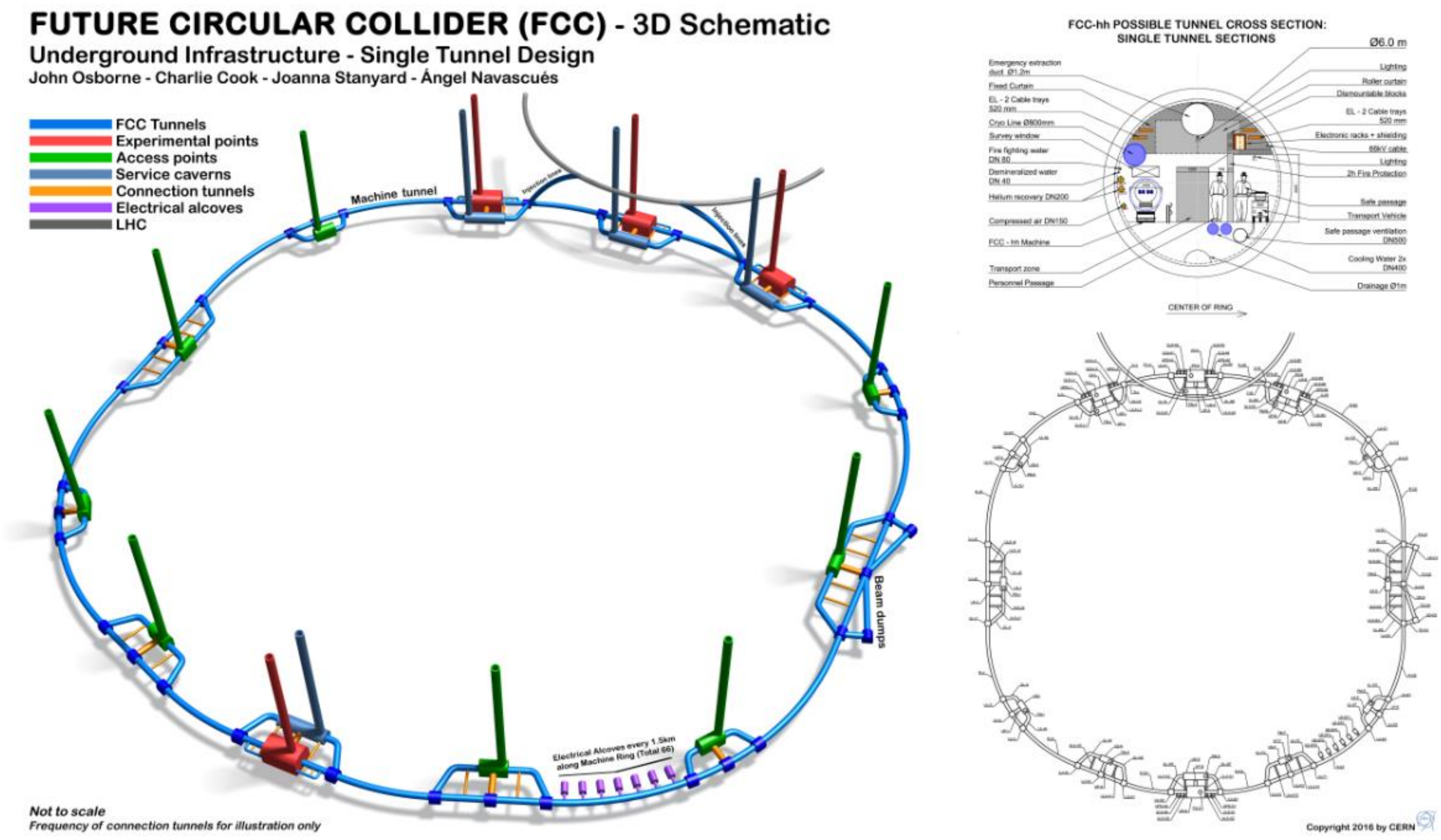
Option 3



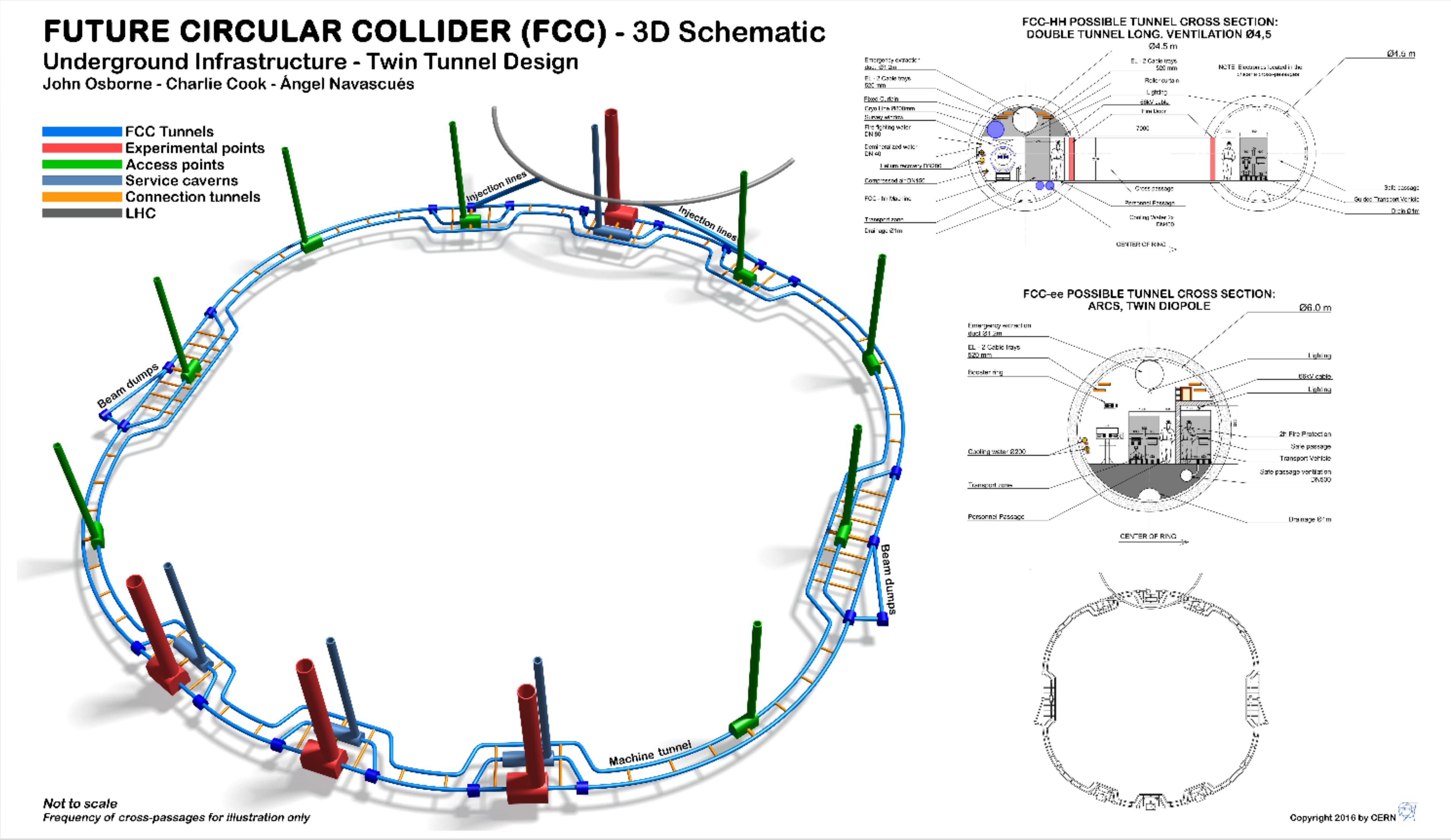
Option 4



FCC Baseline Schematic : Single Tunnel

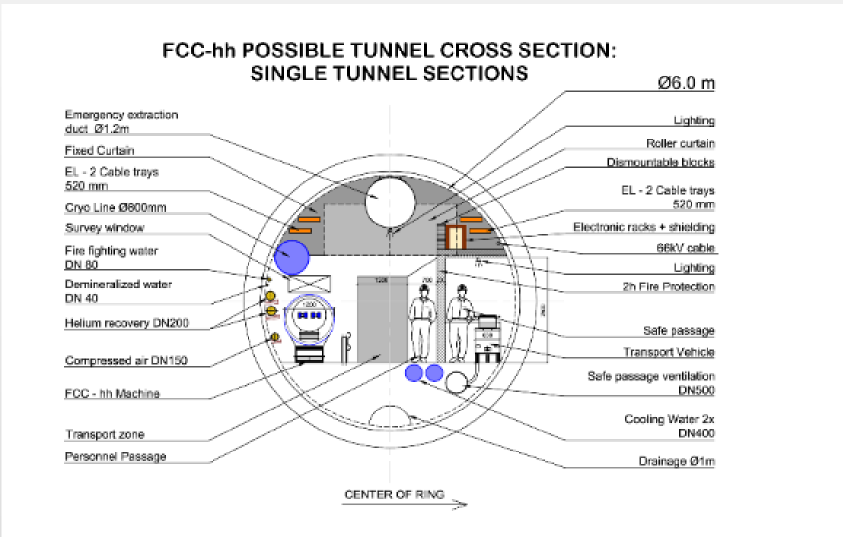


FCC Baseline Schematic : Double Tunnel

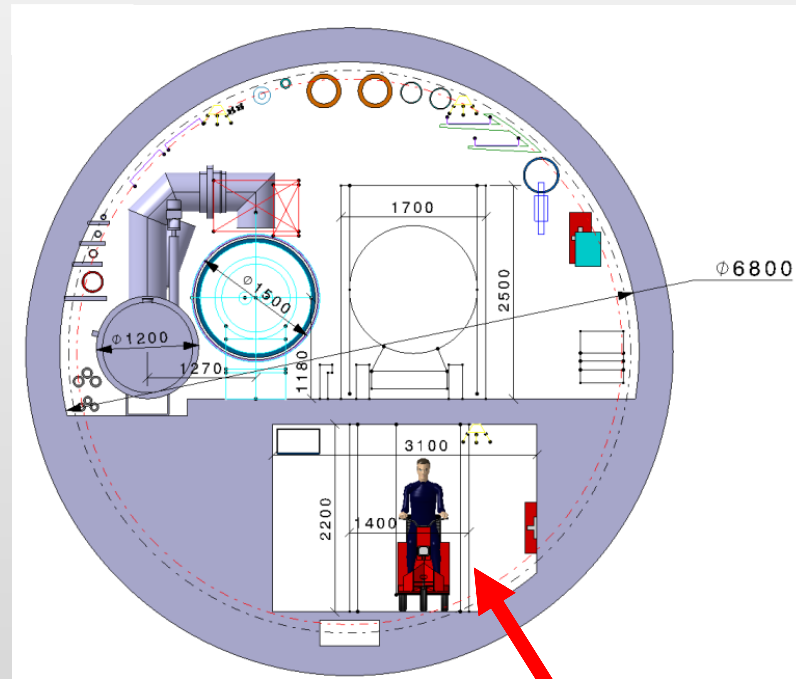


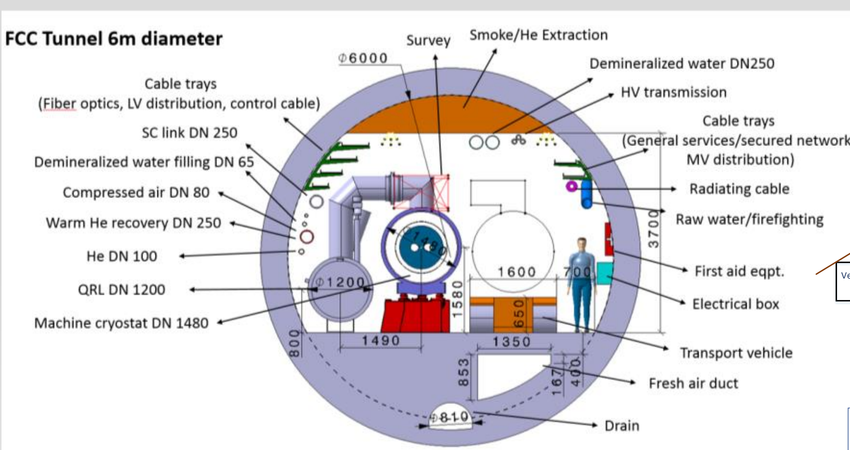
FCC Single tunnel – possible cross-sections

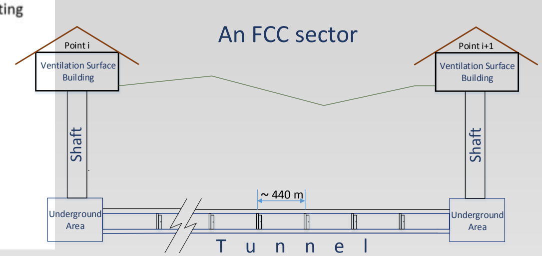
6.0m tunnel



6.8m tunnel





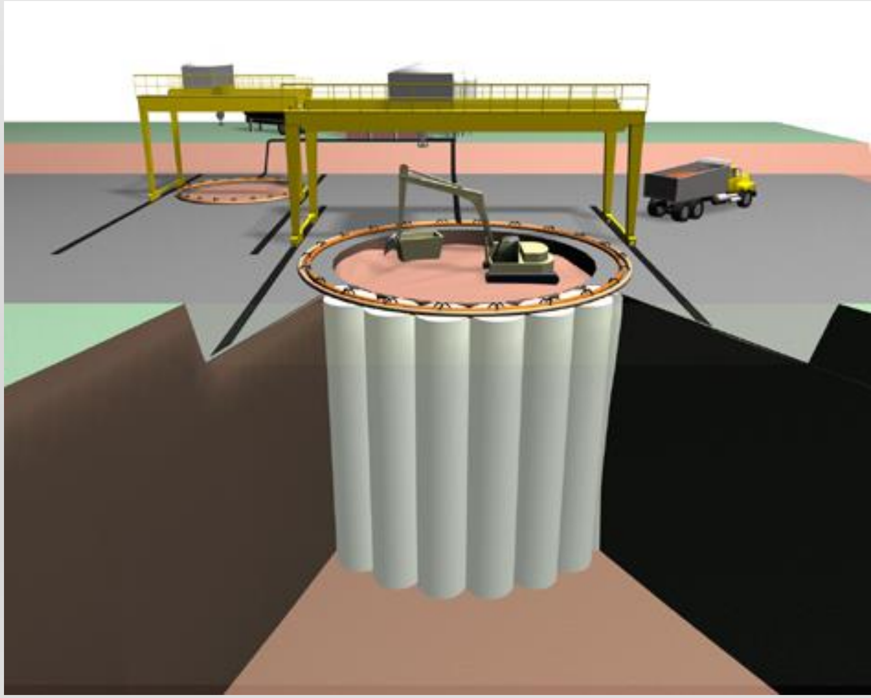


Emergency escape under floor ?

FCC Shafts

- Several possible shaft excavation methods :

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

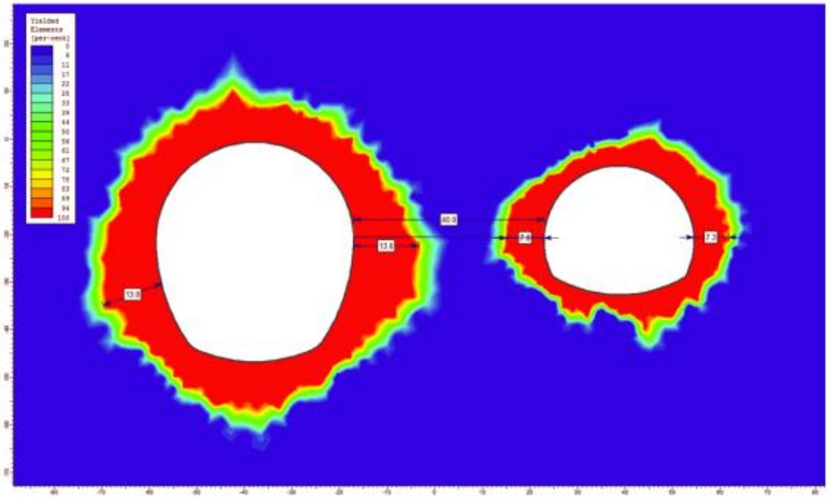


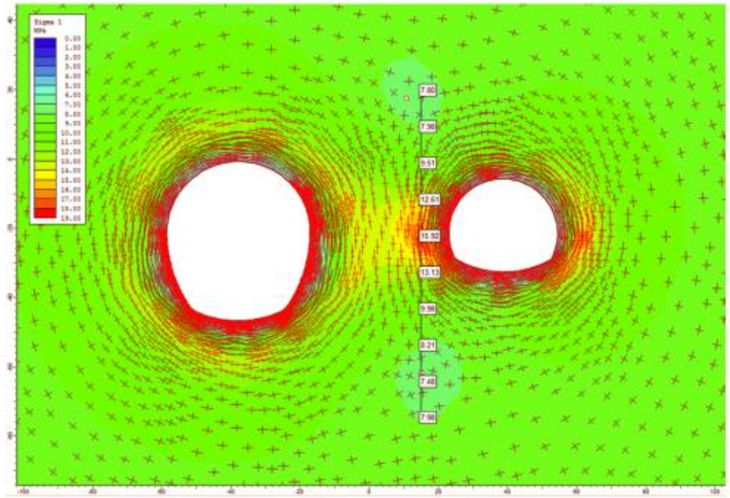
Ground freezing technique used at P5

FCC Experimental/Service Cavern spacing

Basic Stress Analysis

Cavern situated in Good Molasse, Spacing 40m





- Depth of failure zone = 13 m
- Remaining pillar width = 20 m

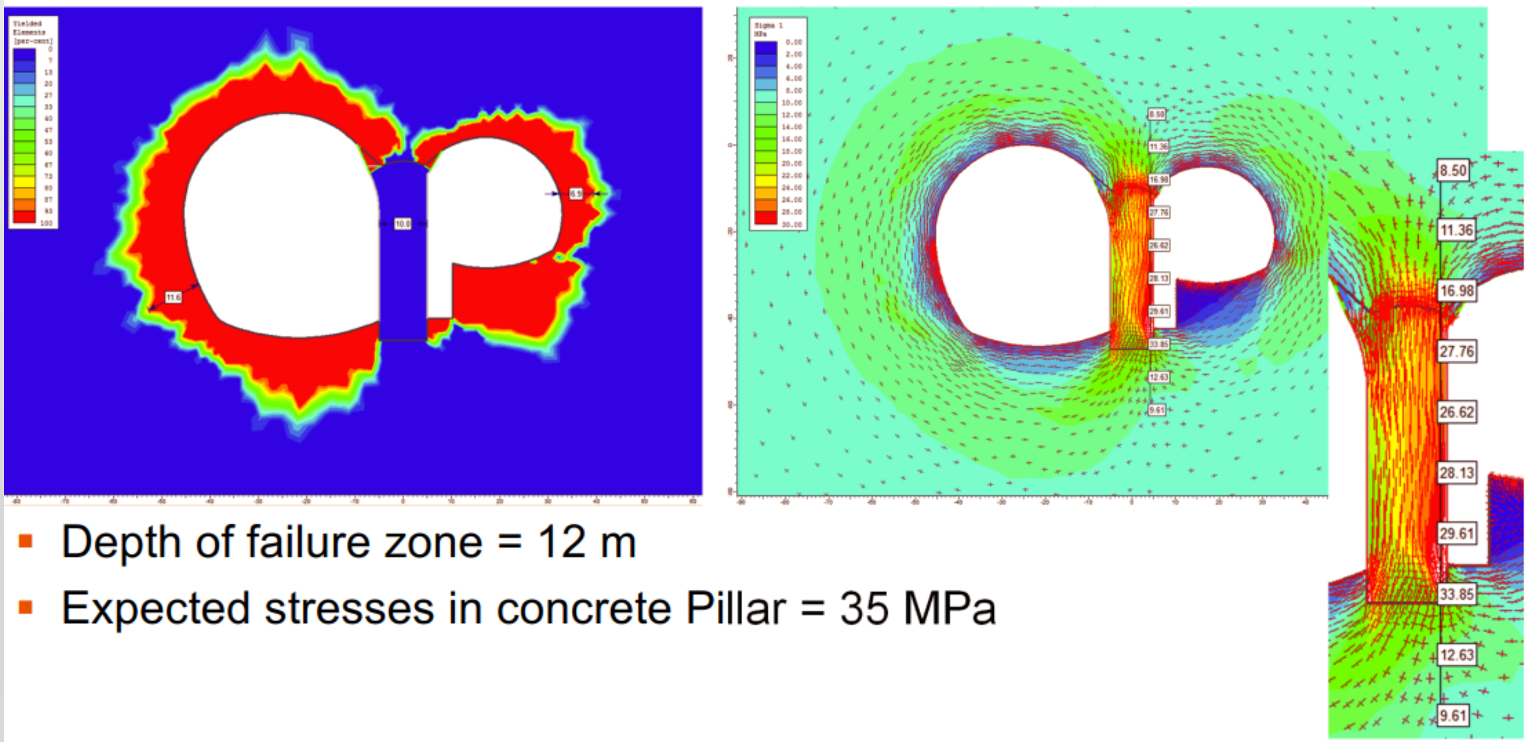
AMBERG ENGINEERING

FCC Cavern spacing : Concrete Pillar required

FCC Cavern Study - CERN

Basic Stress Analysis

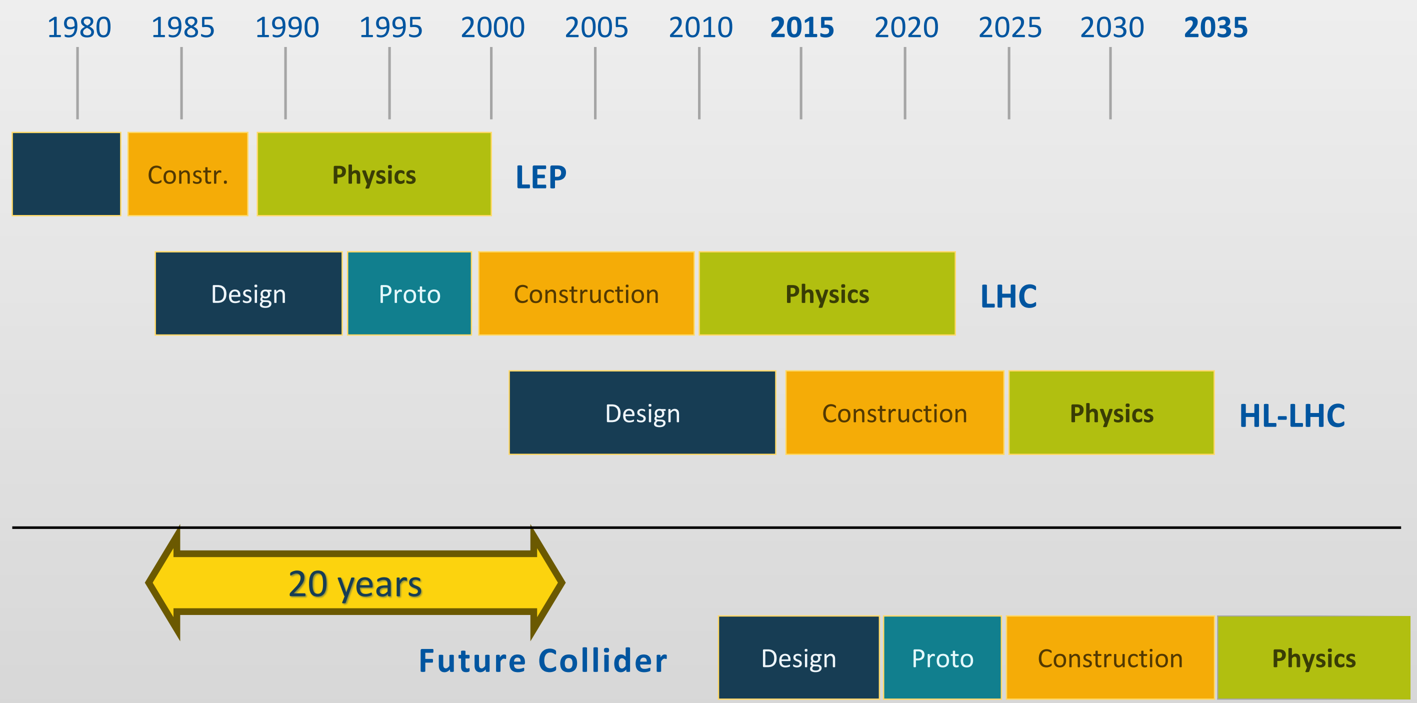
Cavern situated in Good Molasse, Spacing 10m



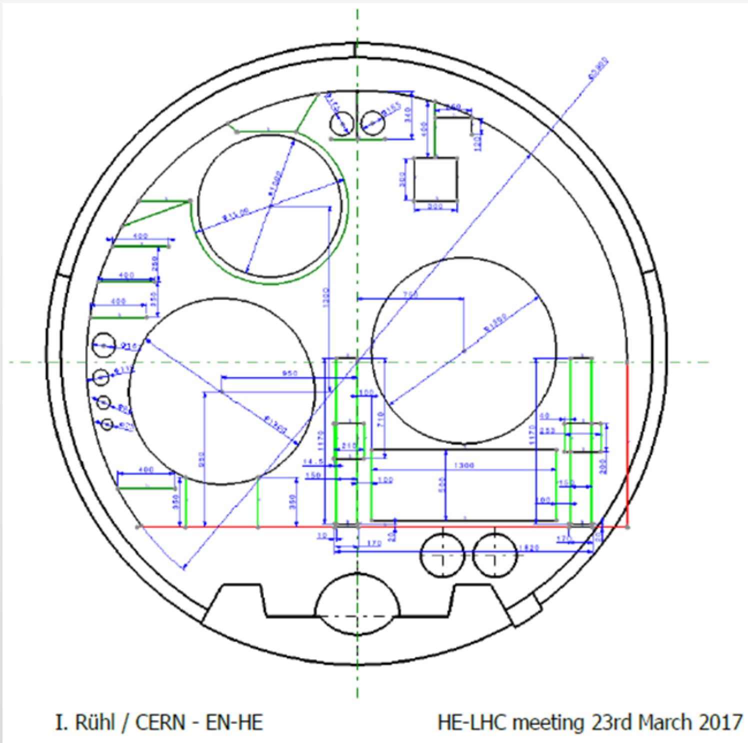
- Depth of failure zone = 12 m
- Expected stresses in concrete Pillar = 35 MPa

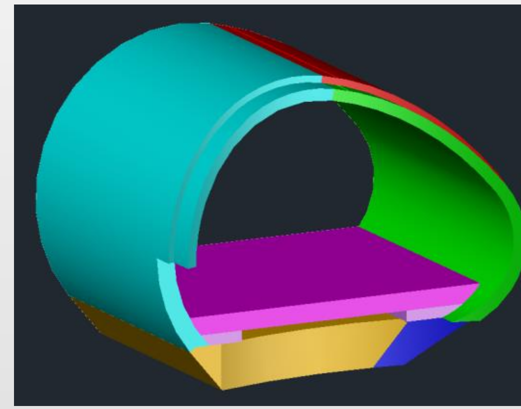
AMBERG ENGINEERING

CERN Circular Colliders + FCC



High Energy LHC Civil Engineering



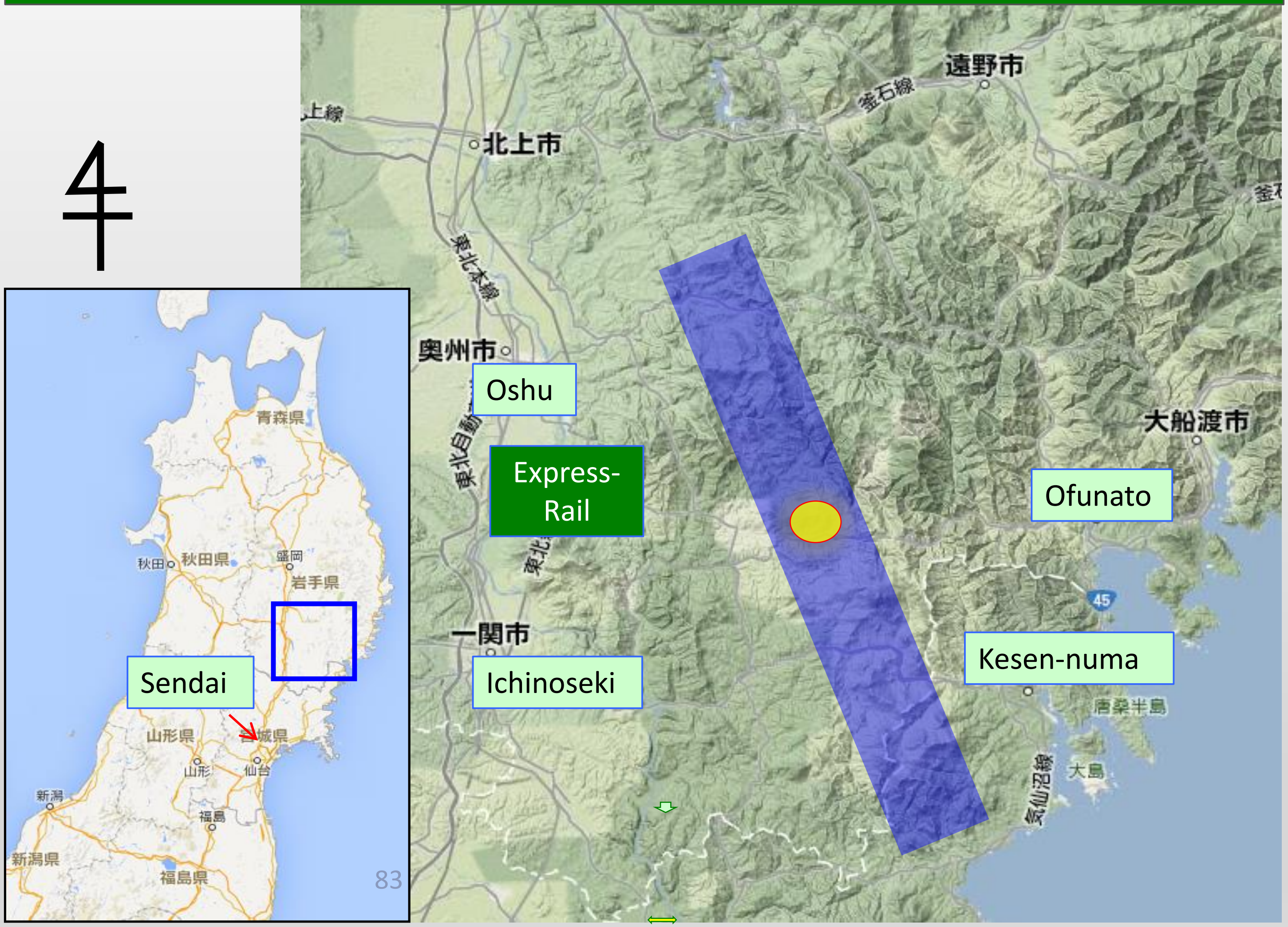


SPS beam dump tunnel enlargement

Crossrail – Cross Passage Temporary Frames

- If it is concluded High Energy LHC cannot fit into the current LHC envelope, a technical and cost and study will be launched to evaluate an option to enlarge the cross-section of the existing tunnel.

ILC Site Candidate Location in Japan: Kitakami



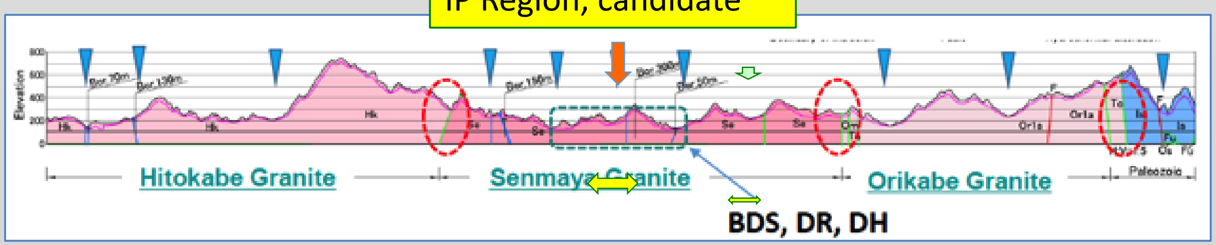
A. Yamamoto,
15/11/02

A New Borehole at a Candidate Interaction Point

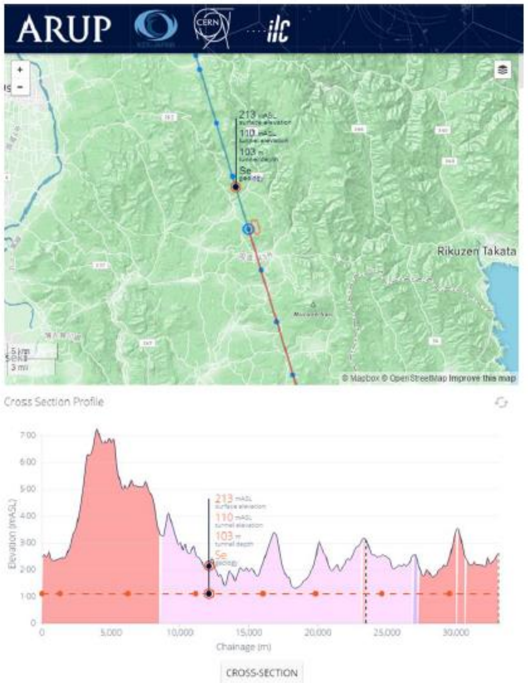
Courtesy: T. Sanuki

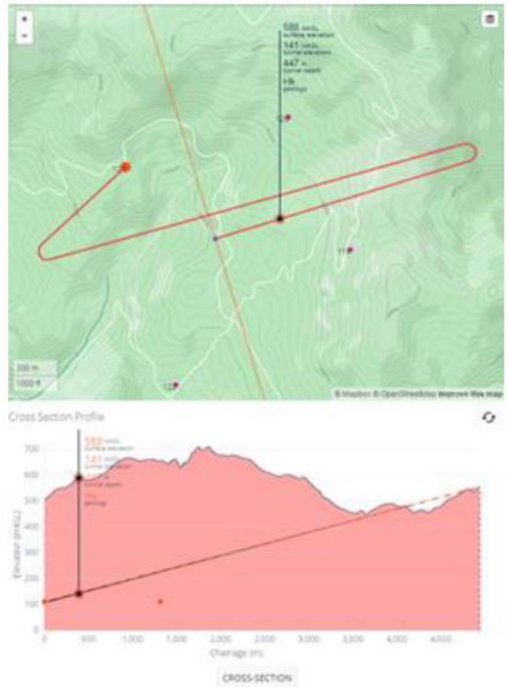
A new boring test progressed to demonstrate the "vertical access feasibility" for detector hall at IP

IP Region, candidate



CERN/KEK Collaboration to develop TOT for ILC Optimisation





- Surface elevation: 305mASL
- Tunnel elevation: 110mASL
- Tunnel depth: 195mASL
- Geology: Se

- Surface elevation: 588mASL
- Tunnel elevation: 141mASL
- Tunnel depth: 430mASL
- Geology: Hk

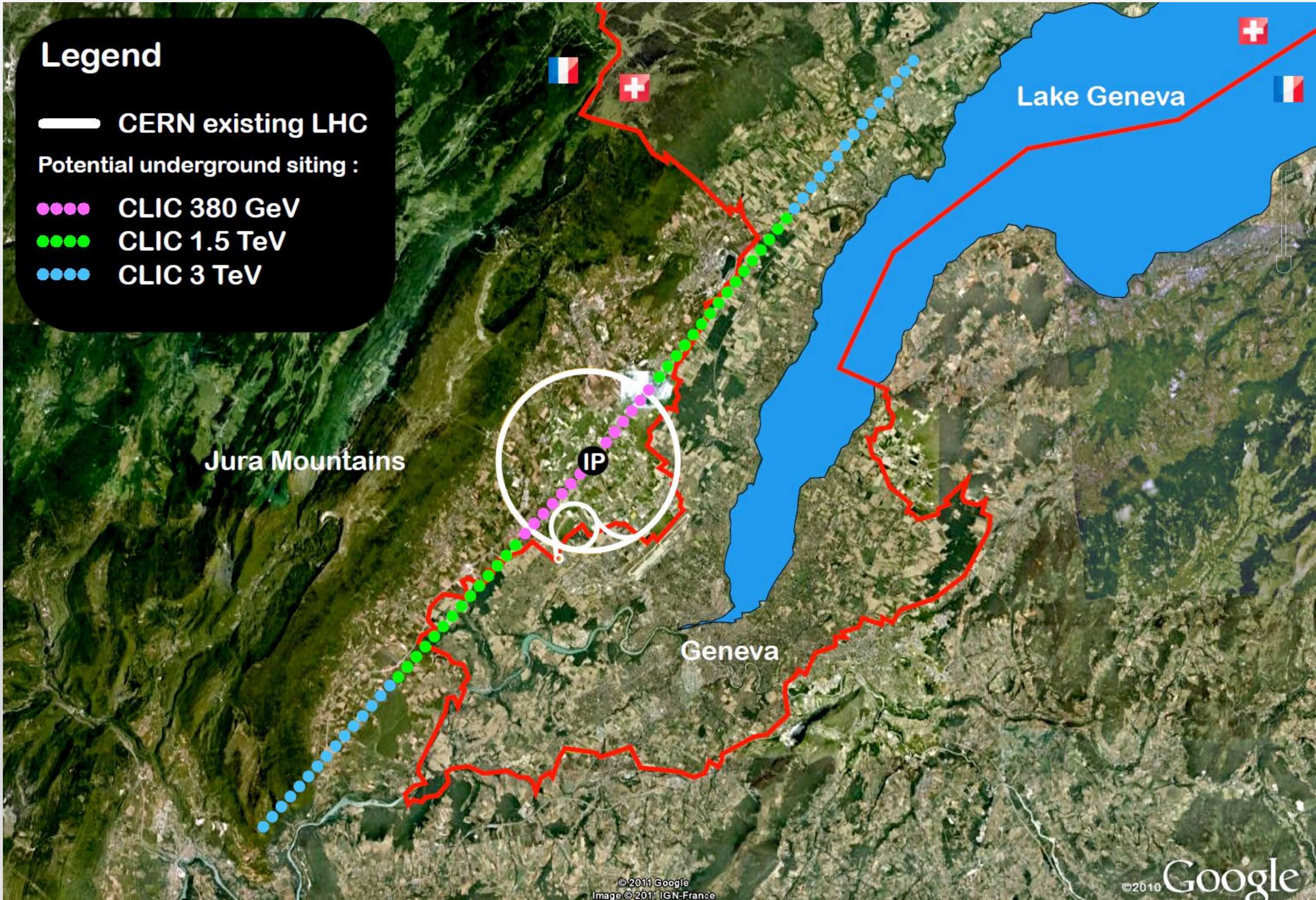
Many new features added to the tool, such as :

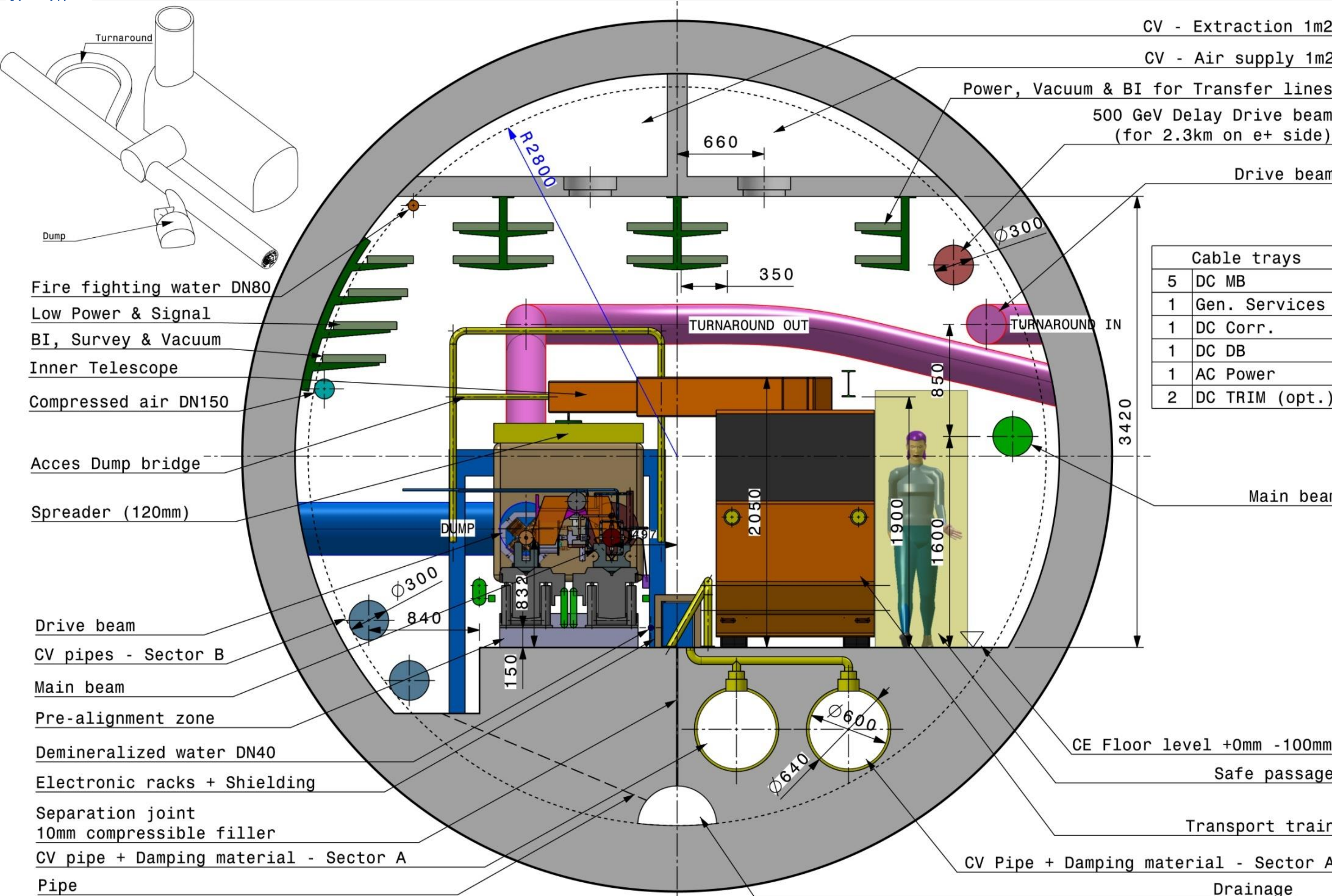
- IP position can be changed
- LINAC Rotation/Flip
- Access tunnels

New 250GeV Layouts/costing in 2017

TOT now being developed for ILC Japan Site and road tunnel under Stonehenge

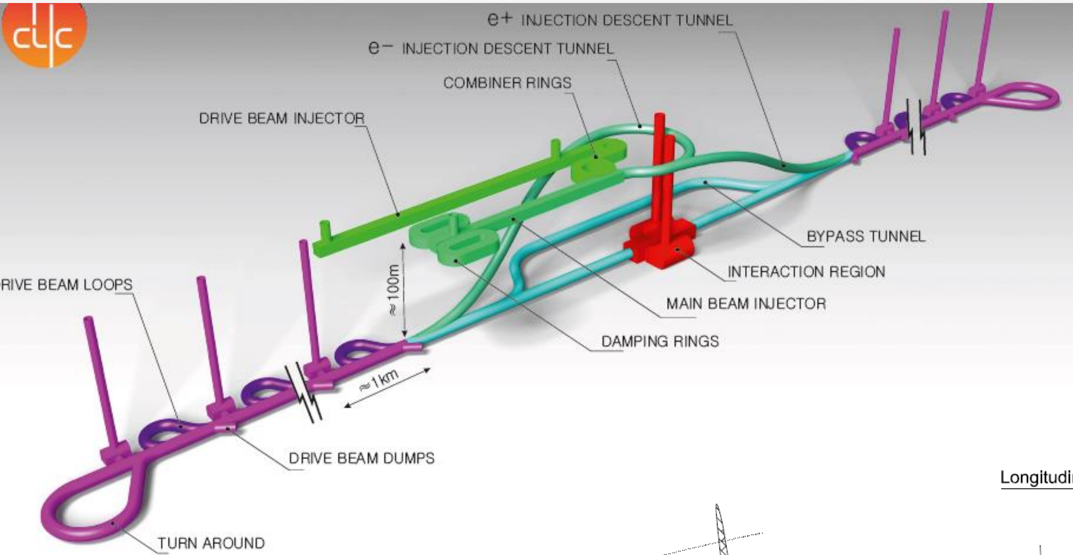
Compact Linear Collider (CLIC) Studies at CERN





CLIC - Typical Cross Section - Diameter 5600mm - Junction with Turnaround - 1:25
Draft - J.Osborne / A.Kosmicki - August 9th 2010

CLIC Studies at CERN



CLIC SCHEMATIC
(not to scale)

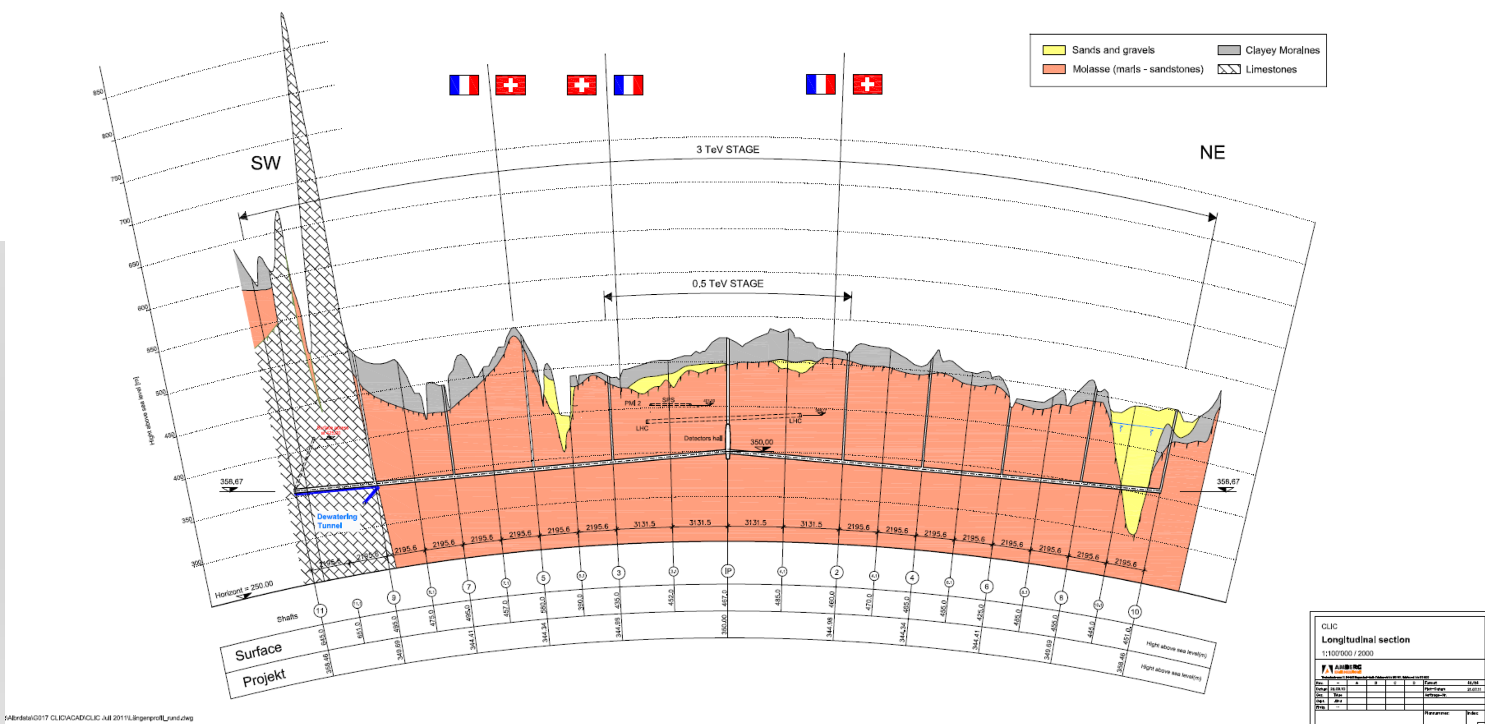
New 380GeV, 1.5TeV and 3.0TeV accelerator layouts to be developed in 2017 ready for next European Strategy update.

Klystron option also being studied.

CLIC TOT ?

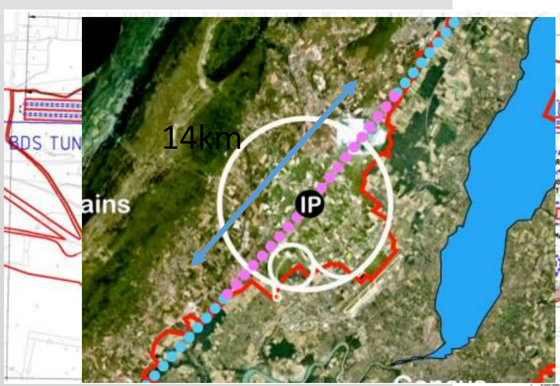
New Infrastructure WG being set-up (CE, EL, CV etc).

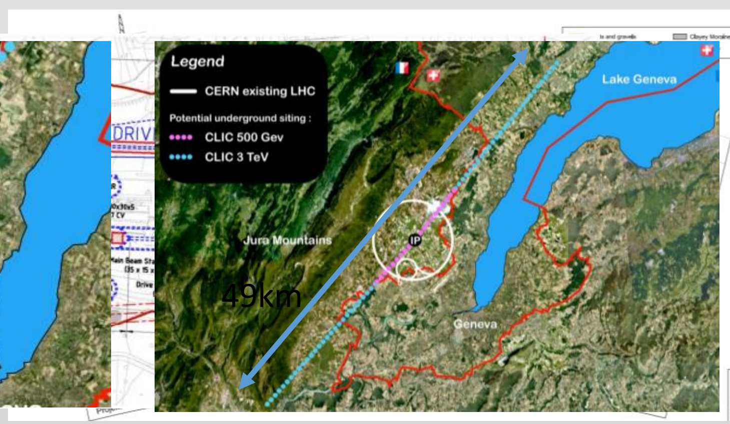
Longitudinal section 1:100'000 / 2000

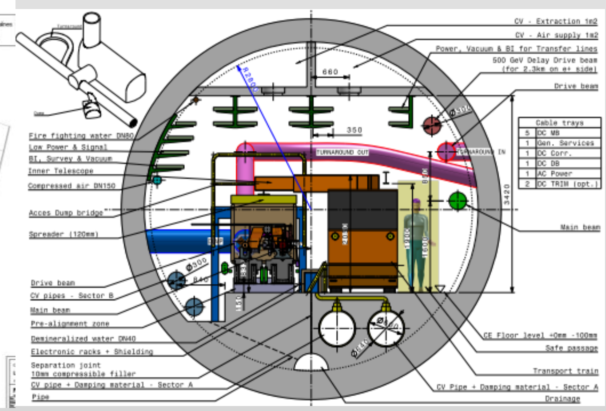


Brief History – CLIC CDR Design

- **Conceptual Design Report: Published in 2012.**
  - 5.6m diameter 2 stage linear collider, an initial 500 GeV with the possibility to upgrade to 3 TeV.
  - 500 GeV energy stage consisted of a site length of 14km
  - 3 TeV energy stage consisted of a site length of 49km
  - 2 Independent Detector assembly halls.
  - Central injection complex located on CERN land.
  - 30m wide and 2.5km Long drive beam building.
  - Depth ranging from approximately 100 – 150m below the surface along the majority of the tunnel length.

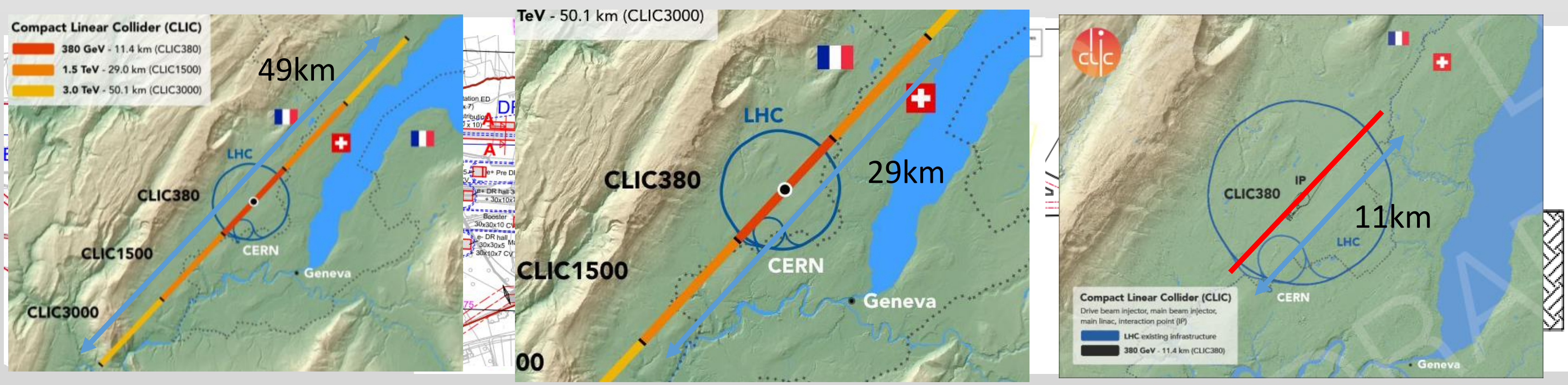






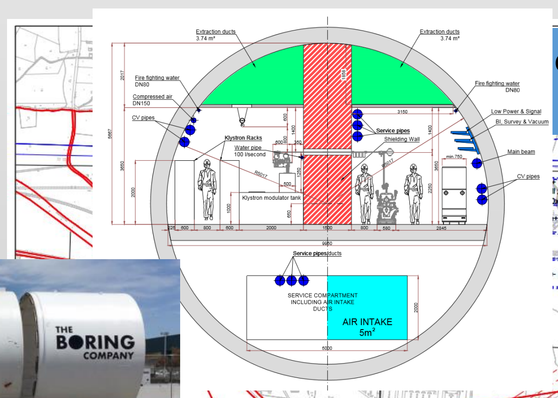
Civil Engineering Changes Since the CDR

- **Civil Engineering, Infrastructure and Siting Working Group (CEIS): Kick off meeting March 2017**
  - 3 stage linear collider, an initial 380 GeV with the possibility to upgrade to 1.5 TeV and 3 TeV.
  - 380 GeV energy stage consists of a site length of 11km
  - 1.5 TeV energy stage consists of a site length of 29km
  - 3 TeV energy stage consisted of a site length of 49km
  - Only one detector assembly hall and a service cavern introduced.
  - 30m wide and 2.5km Long drive beam building with the possibility to reduce the size for lower energy stages.
  - Depth and position of the machine to be optimised using CLIC Tunnel Optimisation Tool.

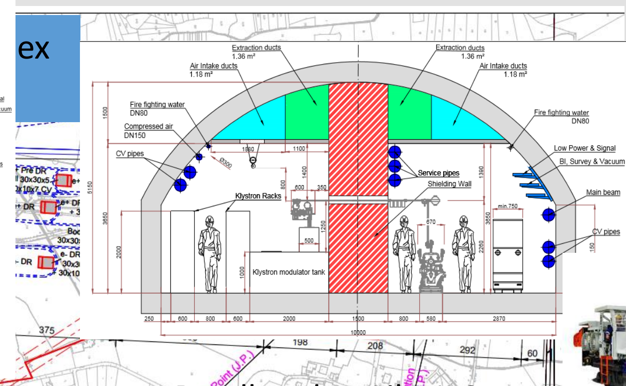


Civil Engineering Changes Since the CDR – NEW Klystron Design

- **Civil Engineering, Infrastructure and Siting Working Group (CEIS): Kick off meeting March 2017**
  - ➢ New Klystron Design introduced for the 380 GeV energy stage
  - ➢ No longer requires the Drive Beam complex.
  - ➢ Larger tunnel to house the Klystron modules and the beam modules – 1.5m shielding based on ILC (currently under study). Roadheader and Tunnel Boring Machine (TBM) tunnelling method considered.



TBM

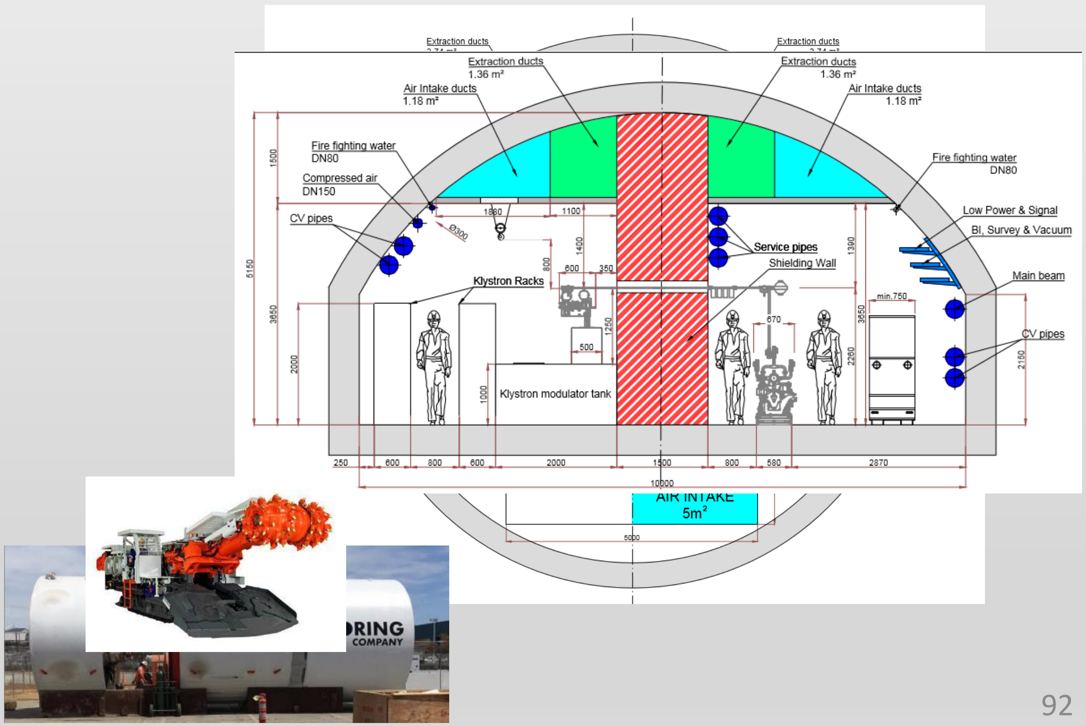


Roadheader- Like ILC

Klystron Design– Civil Engineering

Two options for the Klystron Tunnel have been looked at:

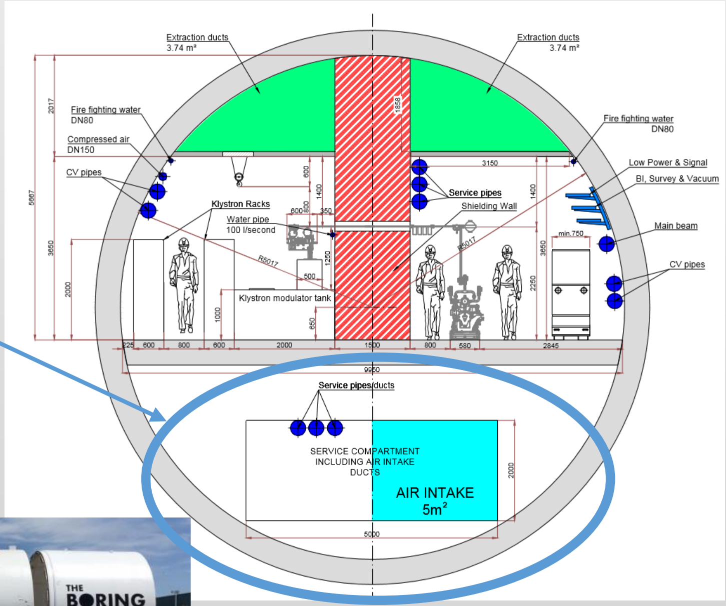
1. <u>10m wide Roadheader mined tunnel – Like ILC.</u>
   - Shape can be determined by tunnel requirements.
   - No wasted space below the tunnel floor.
   - Can mine through varying rock types using one machine.
2. <u>10m internal Diameter TBM Bored tunnel.</u>
   - Considerably quicker rate of excavation through “good rock”.
   - Cheaper per m of tunnel construction for this length of tunnel.
   - Under floor space can be utilised for services to avoid wasted space.



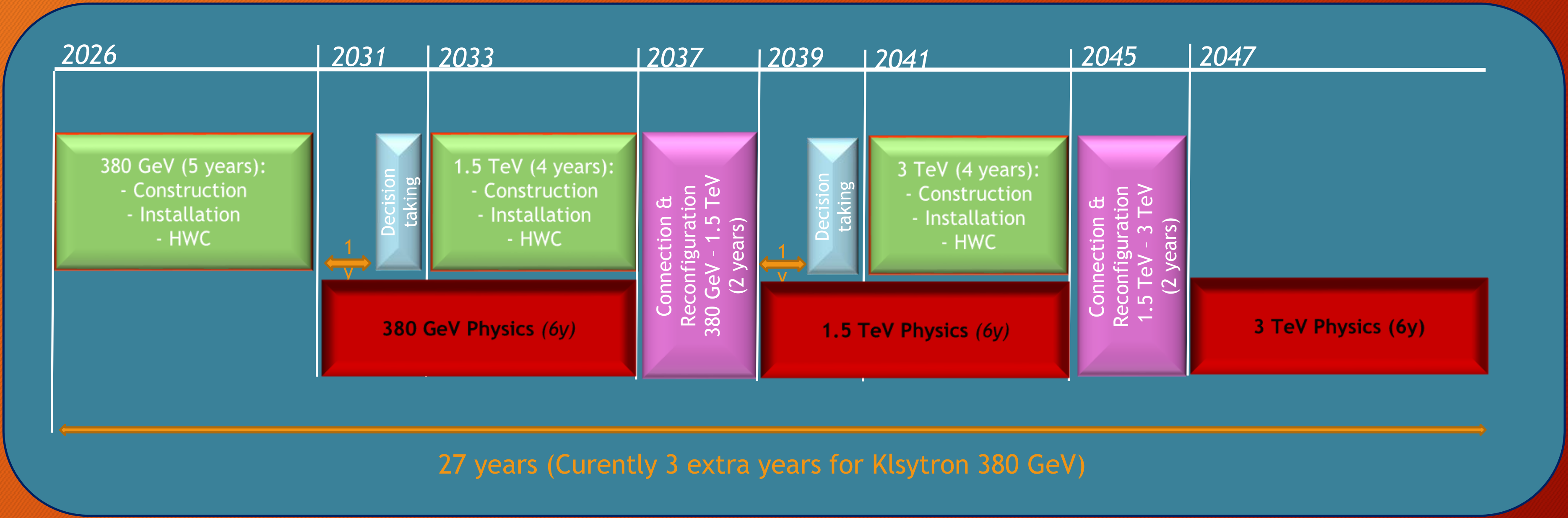
What has been done – Civil Engineering

<u>10m Internal Diameter TBM tunnelling method is proposed for the Klystron 380 GeV design:</u>

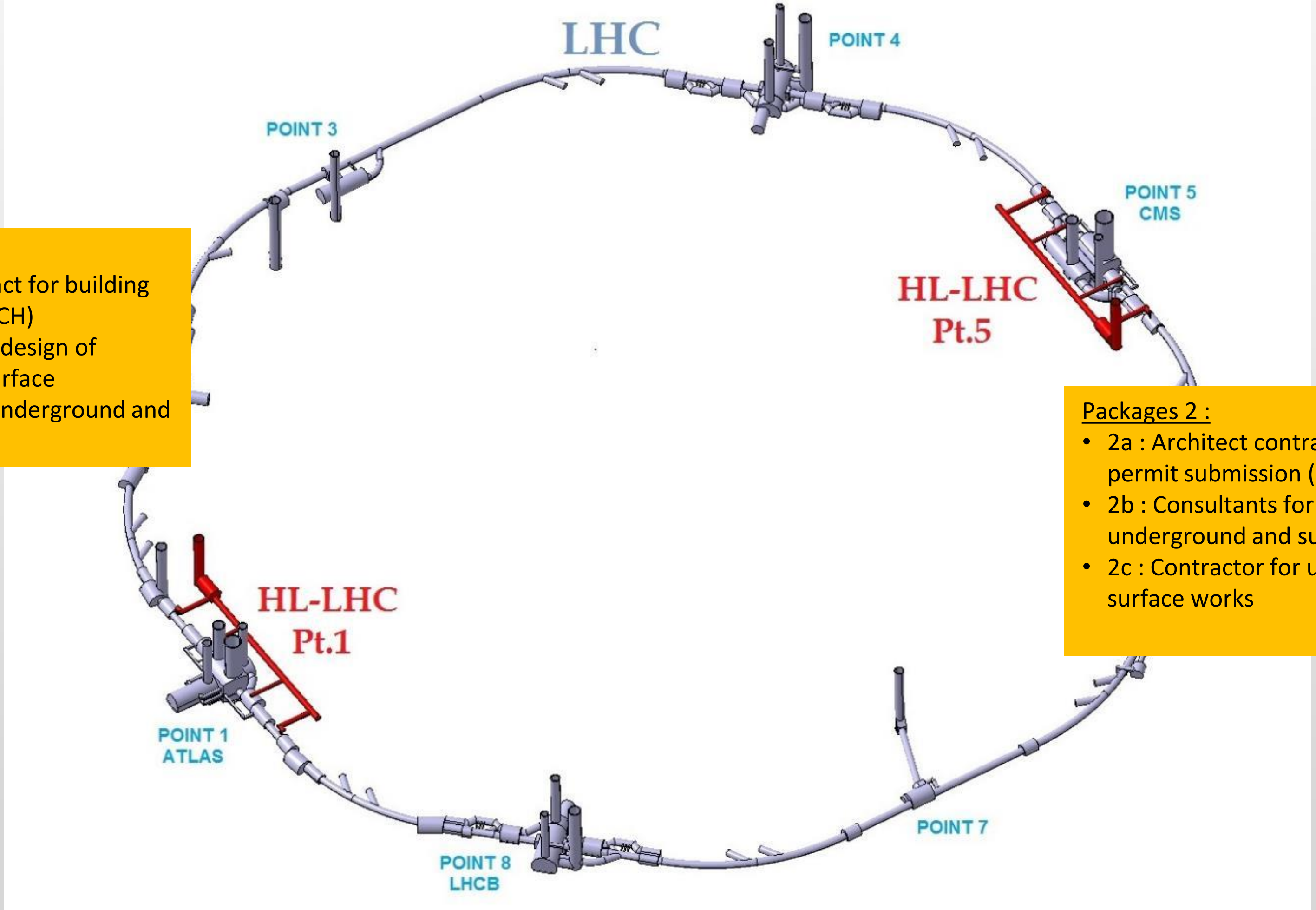
- The cost for an 11km tunnel for the TBM is an estimated 10% cheaper than a mined tunnel.
- The underfloor space can be utilised and therefore reduce the amount of wasted space – <u>to be moved under the Klystron side of the tunnel.</u>
- The excavation rate per m of tunnel is considerably quicker for a TBM and therefore construction time is reduced.
- The geology for the 380 GeV is expected to be entirely molasse and suited for a TBM.



CLIC planning up to 3TeV



• High Luminosity LHC Project (HL-LHC)



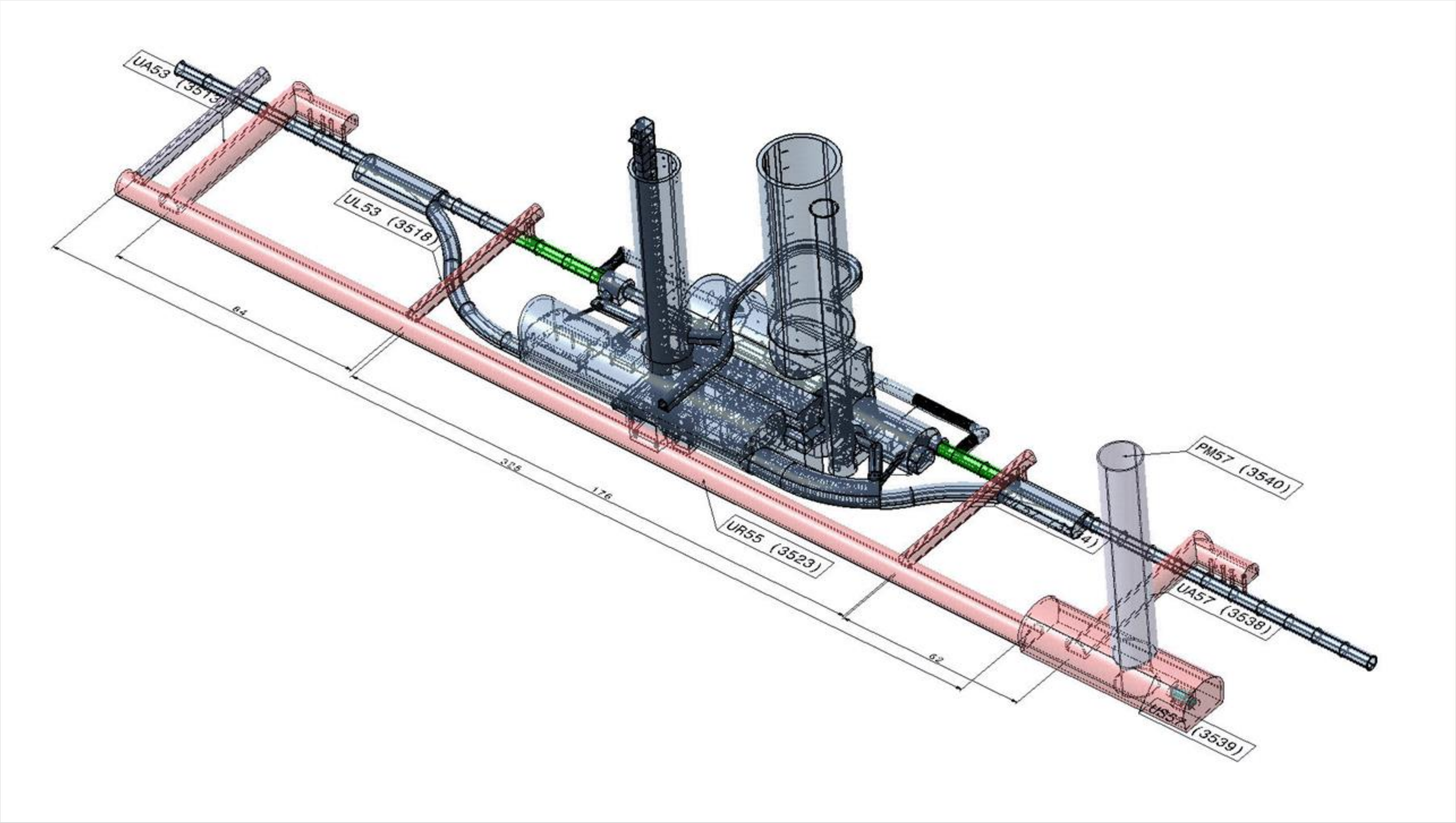
Packages 1 :

- 1a : Architect contract for building permit submission (CH)
- 1b : Consultants for design of underground and surface
- 1c : Contractor for underground and surface works

Packages 2 :

- 2a : Architect contract for building permit submission (F)
- 2b : Consultants for design of underground and surface
- 2c : Contractor for underground and surface works

HL Underground Civil Works at LHC Point 5 (CMS)



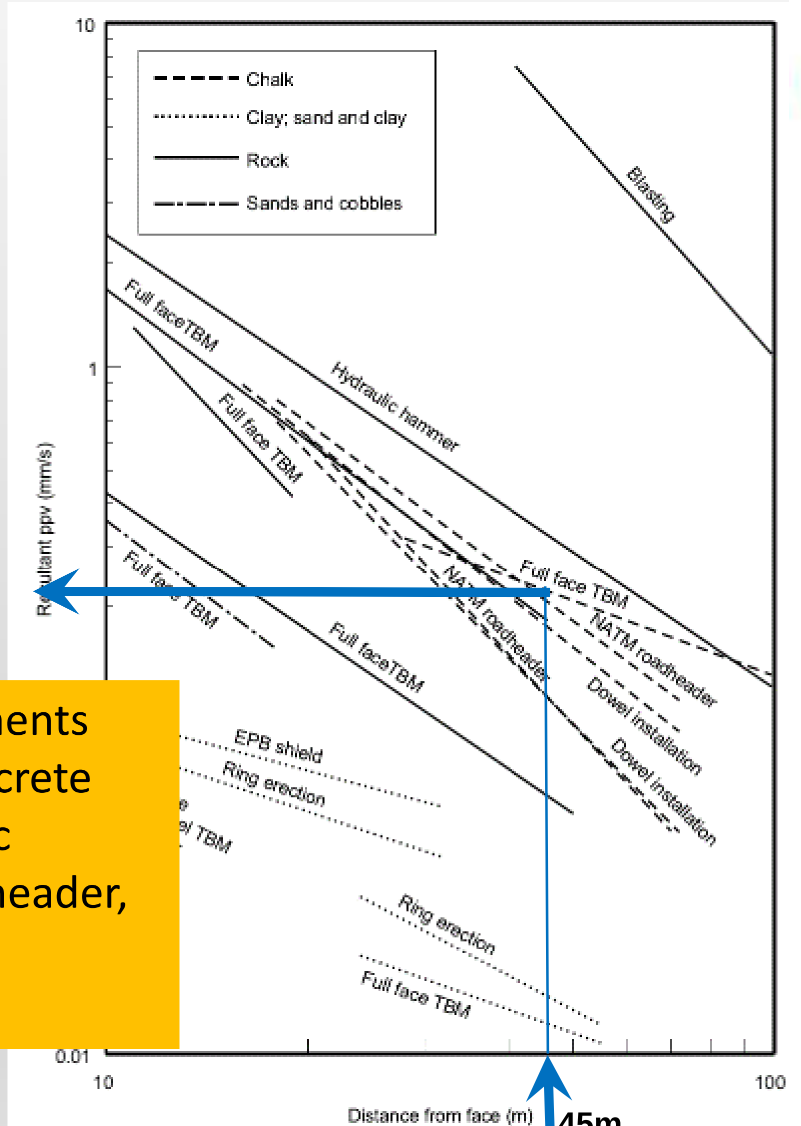
Site boundary enlargement for HL civil works : Point 5 CMS

Surface Works at Point 5 CMS

The main ‘vibration’ activities are driving the civil engineering planning

Results from Dr Hiller’s (Arup) studies - Vibration from tunnelling

0.2 mm/s
$2x10^{-4}$ m/s
200µm/s



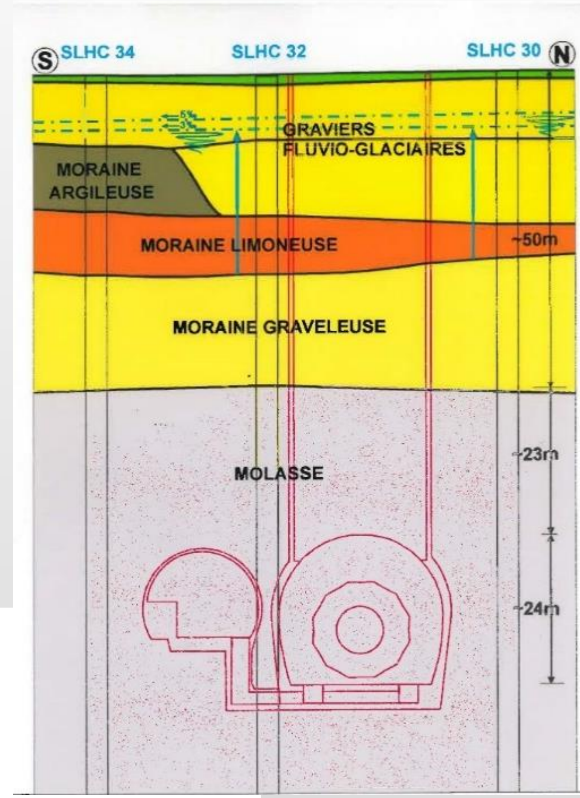
New measurements needed for concrete pump, hydraulic hammer, roadheader, Jumbo

Roadheaders will be used for excavation

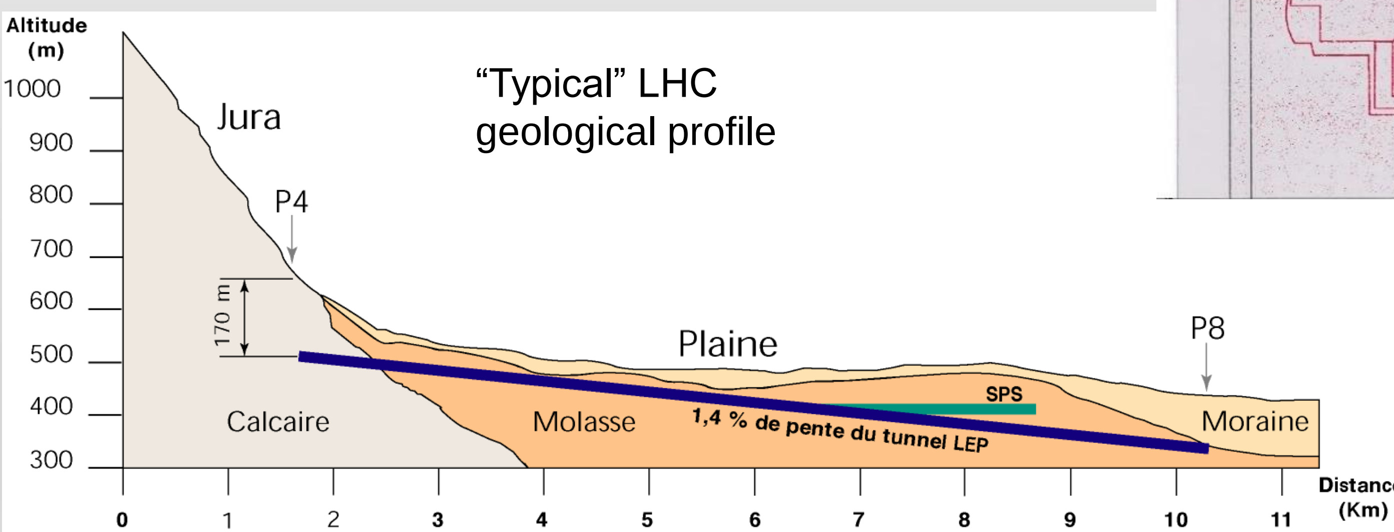
At 45m, tunnelling vibration would give ~200µm/s peak

Technical Challenges : Unexpected ground conditions

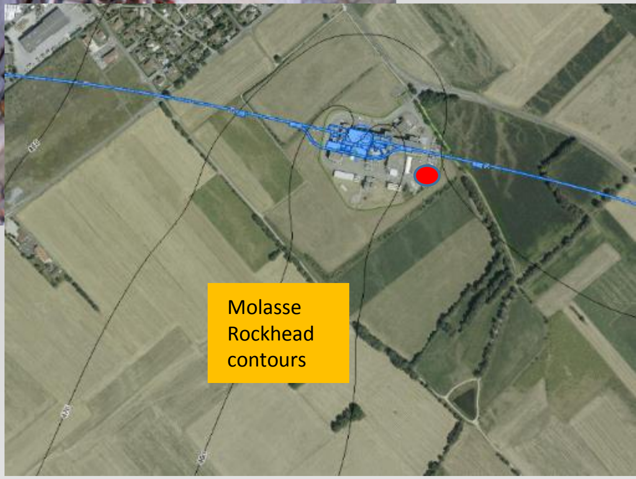
Point 5 CMS geological profile is fairly complex



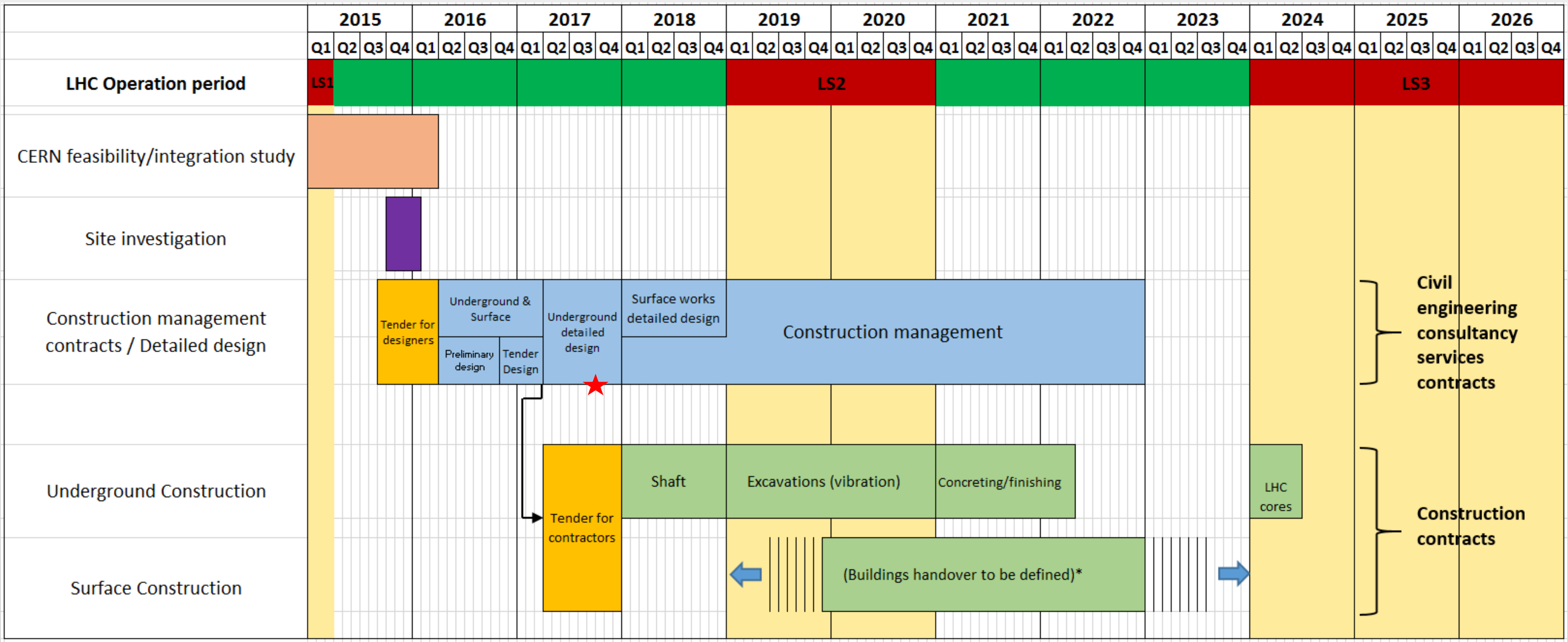
"Typical" LHC geological profile



Technical Challenges : Unexpected ground conditions



Civil Engineering HL-LHC Simplified Schedule



Gathering Infrastructure Requirements
For example for CLIC : Civil Engineering, Infrastructure & Siting (CEIS) Working Group Disciplines:

Discipline	Representative
Chair & Civil Engineering	J.Osborne & **Matthew Stuart**
CLIC Link Persons	S.Stapnes/D.Schulte/C.Rossi/R.Corsini/W.Wuensch/A.Latina/D.Aguglia
Cooling and Ventilation (CV)	M.Nonis/P.Cabral
Electricity (EL)	**Davide Bozzini**
Survey (SU)	H.Mainaud Durand
Transport & Handling (HE)	I.Ruehl/**Michal Czech**
Interaction Region	K.Elsener
Logistics/Lab readiness	M.Tiirakari
CE Layouts & Cross-sections	SMB/CE Design Office
Health Safety & Environment (HSE)	S.Baird/S.Marsh
Schedule	K.Foraz/**Marzia Bernardini**
ILC Link Persons	J.Osborne/A.Yamamoto

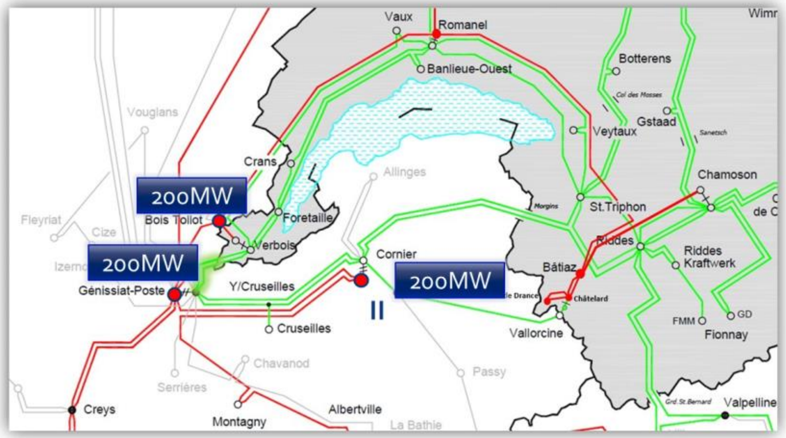
General Objective: *Develop the existing layouts for the project from a civil engineering and technical infrastructure point of view, and work with the various actors towards a realistic design and project planning as needed for the 'CLIC Implementation Plan', due late 2018.*

Meetings for the CEIS Working Group are taking place every 5 weeks to ensure full integration of the work done by each discipline.

Full Activity tracker updated at each meeting outlining the tasks for each discipline.

Other Infrastructure : FCC Supply and distribution of electrical energy

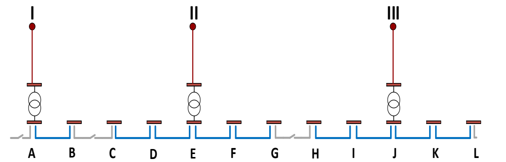
Power available at grid level at horizon 2030



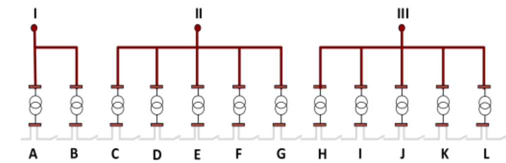
---- 400 *Réseau autour du Lac Léman, base case 2022* ---- 230

- Power estimates are being updated and appear not to exceed the available power.
- „FCC service level“ to be defined (full availability, degraded modes, redundancy).
- Local energy buffers could cover short (100 ms) network interruptions and increase availability.

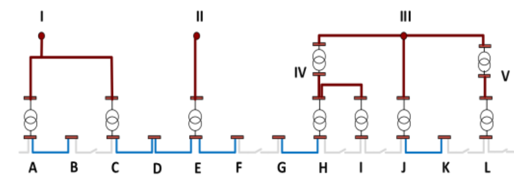
Transmission alternatives



400 kV to nearest FCC point and underground transmission ring

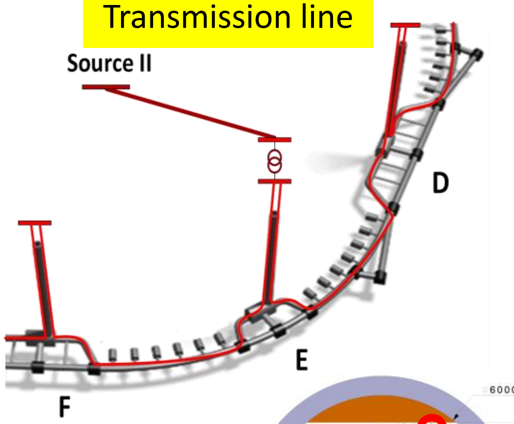


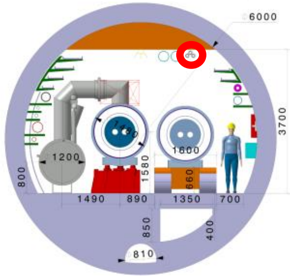
Radial feeding from existing sources



Powering by zones

Transmission line

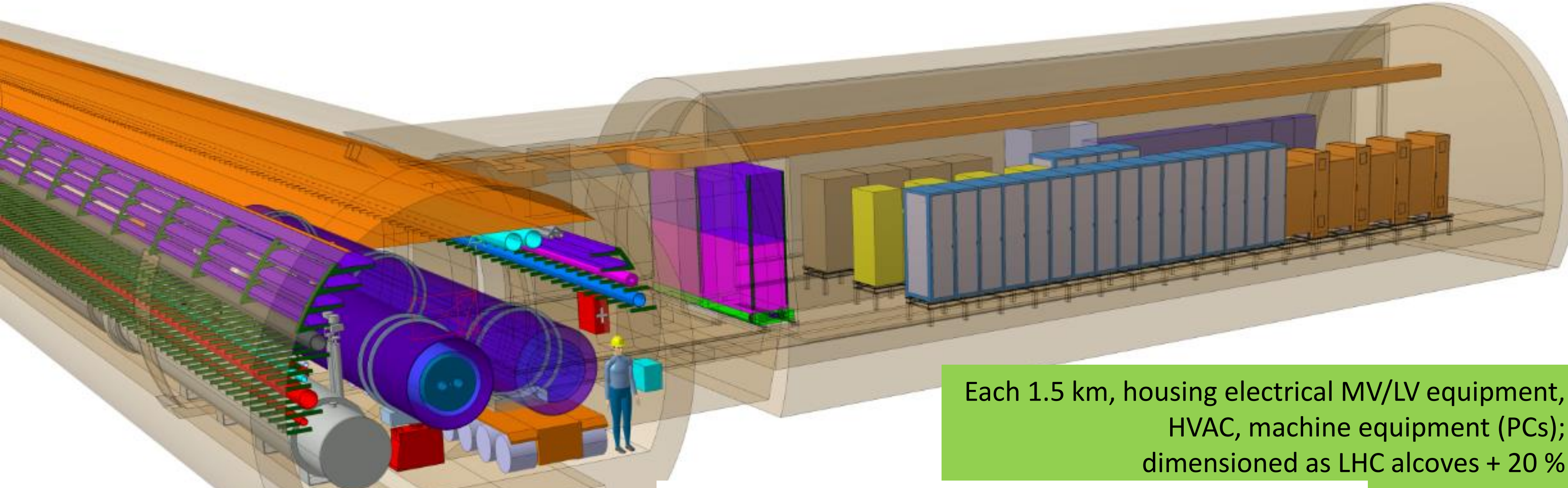




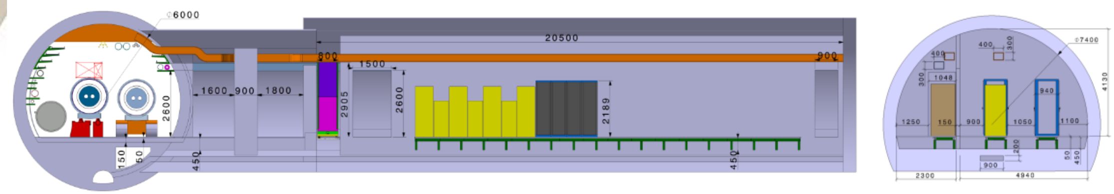
Study ongoing with cable company
Comparative study NC/SC foreseen.

D. Bozzini EN-EL

FCC Alcoves



Each 1.5 km, housing electrical MV/LV equipment, HVAC, machine equipment (PCs); dimensioned as LHC alcoves + 20 %



F. Valchkova-Georgieva

Logistics and transport

FCC collaboration with Fraunhofer Institute for material flow and logistics (FIML, Dortmund)

on several work packages:

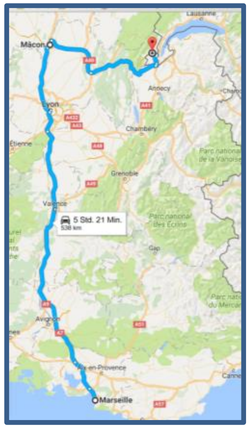
1) Design and evaluation of global supply chains for large and heavy components.
2) Logistics concept for storage, assembly, testing and handling of cryomagnets.
3) Vehicle concept for underground transportation and handling of cryomagnets.

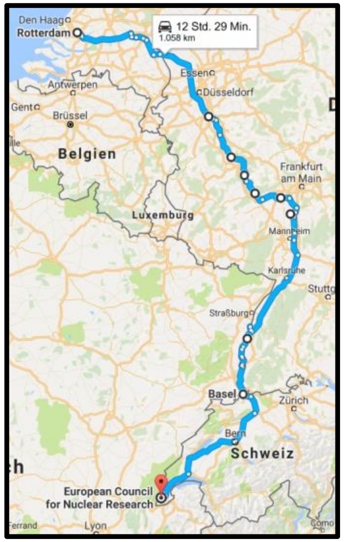
1) Supply chain – investigating and assessing ...

- Transport options (seaship, barge/truck, ...)
- Constraints (road size, maximum weight, road blockage)
- Transport enclosures (non-standard containers, special handling equipment)
- Maximum tolerable g-forces during transport and loading, maximum tilt angles

3) Vehicle

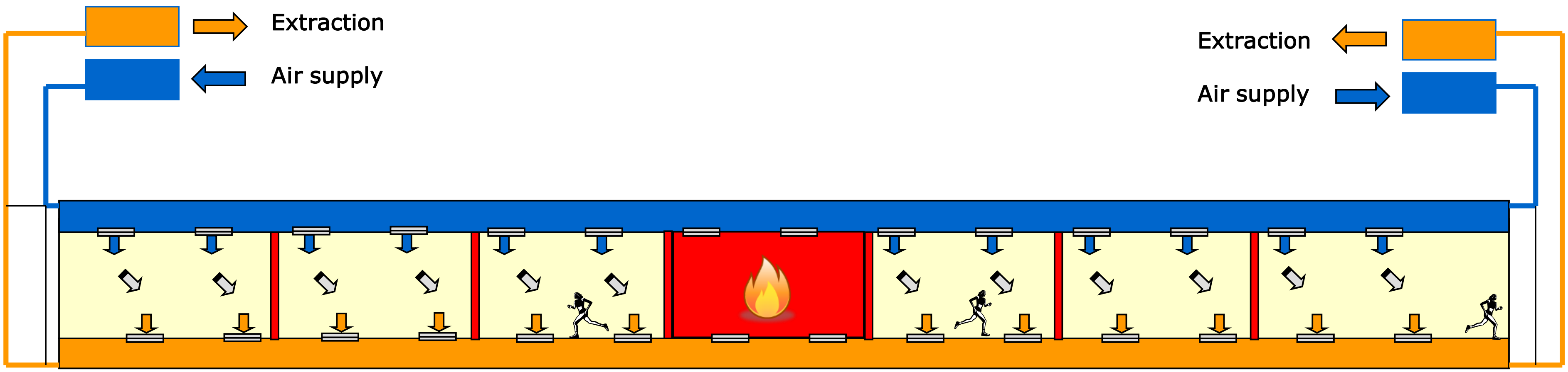
- Rail vs wheel-based
- Track guidance (optical/wire/marker) vs sensor based free navigation
- Ideally covering/compatible with other transport needs
  (other equipment, personnel, remote reconnaissance/interventions)





FIML, M. Tiirakari, I. Rühl

Safety considerations



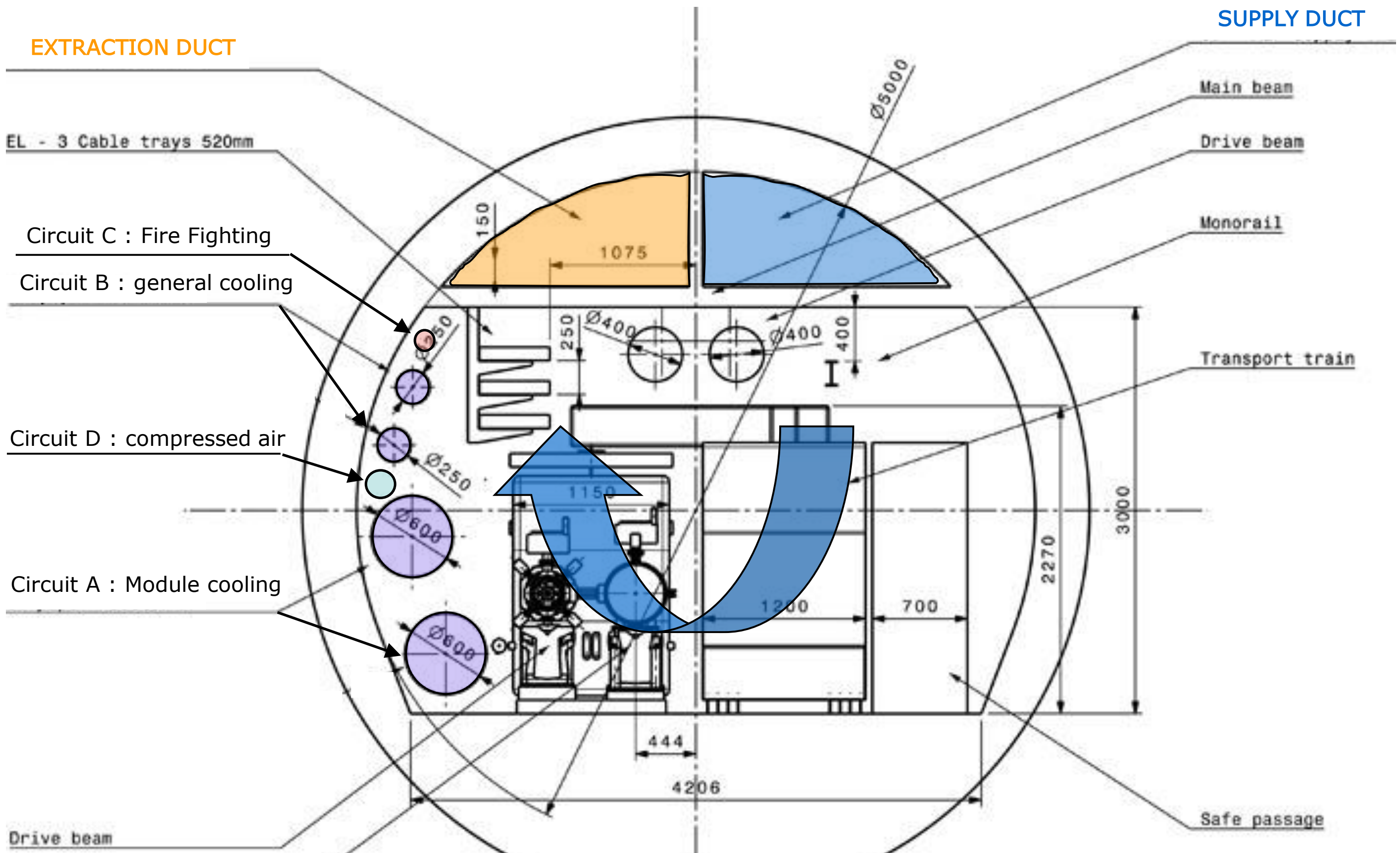
SHAFT POINT

- Control of the pressure from both ends of a sector.
- Control of the pressure (overpressure or underpressure in each area).
- Fire detection per sector compatible to fire fighting via water mist.

Ventilation

Tunnel section

- J. Inigo-Golfin - C. Martel
- CERN TS/CV
- CLIC Workshop 15th October 2008



This cross section is for study purposes only

Approved CLIC tunnel Diameter is currently 4.5m

CLIC - Typical Cross Section - Diameter 5000mm
Draft - J.Osborne / A.Kosmicki - October 14th 2008

Summary

- Civil engineering and Infrastructure requirements should be considered from very early stages of feasibility studies
- Design of machines/detectors should be adapted to suit local geology/environment
- CE and Infrastructure Costs/Schedule critical part of projects
- All the mentioned infrastructure studies will be reported at the next European Strategy meeting 2019/2020.

THANK YOU FOR YOUR ATTENTION

And Questions

John Osborne (CERN SMB Department)