CERN Existing and Future Tunnels

26 January 2024

John Osborne
Site and Civil Engineering Department
Future Studies Section
(SCE – SAM – FS)

CERN, European Centre for Nuclear Research

My Background : John Osborne

john.andrew.osborne@cern.ch

- Graduated from Liverpool University 1988 with Civil Engineering Degree
- Worked for 10 years for UK Contractor, Carillion (formally Tarmac) on :
  - Conwy tunnel : Tarmac/Costain JV
  - 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. Swiss country Rep for ICE.
- Now working on CERN's Future Accelerator Projects

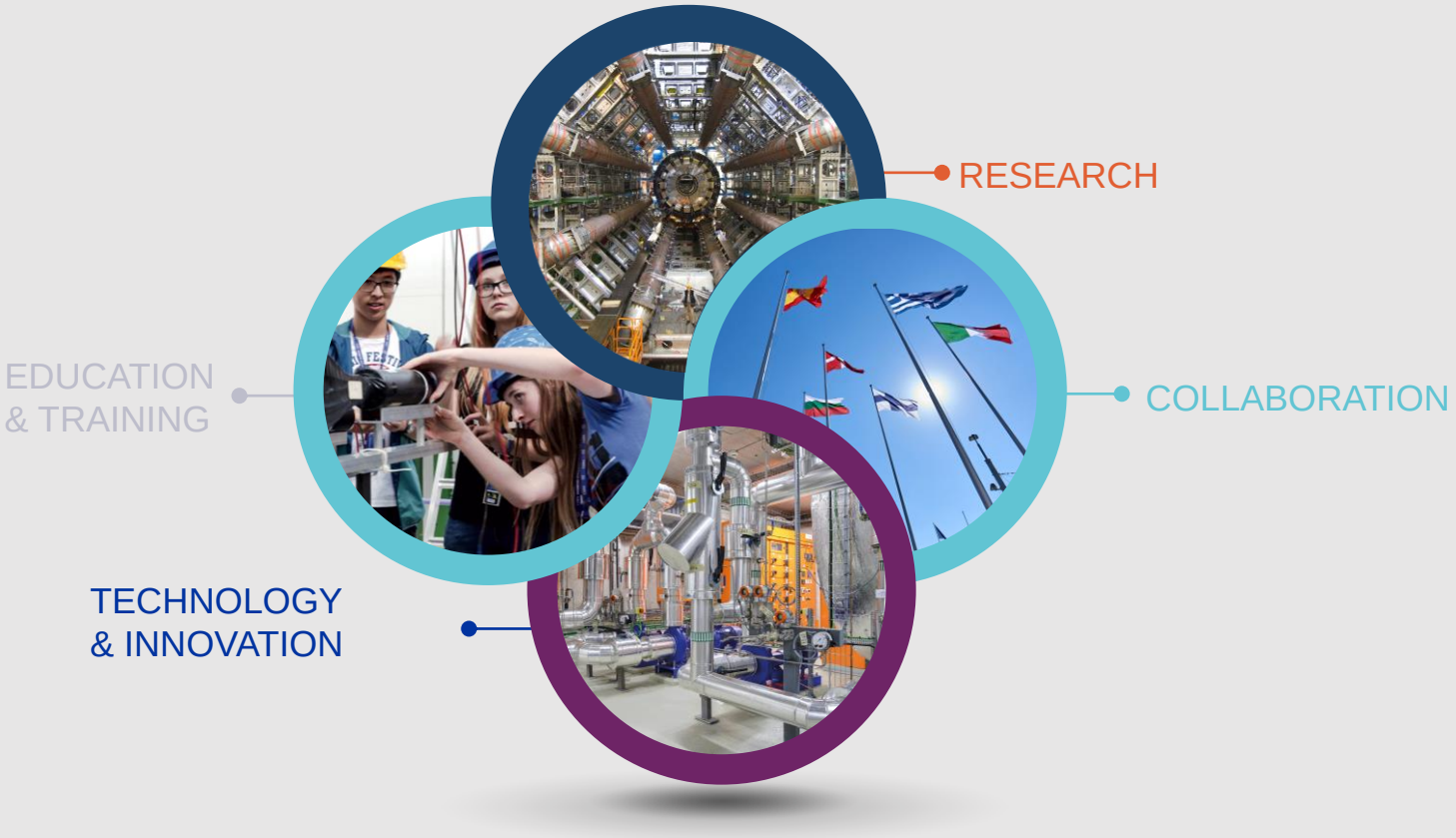
Contents

- Introduction
- CERN Existing Tunnels
- Tunnel Asset Management of CERN Tunnels
- CERN Future Projects

CERN – European Centre for Nuclear Research

- CERN is the world’s biggest laboratory for particle physics
- Our goal is to understand the most fundamental particles and laws of the universe.

Four pillars underpin CERN’s mission



Science for peace

CERN was founded in 1954 with 12 European Member States

23 Member States
Austria – Belgium – Bulgaria – Czech Republic
Denmark – Finland – France – Germany – Greece
Hungary – Israel – Italy – Netherlands – Norway
Poland – Portugal – Romania – Serbia – Slovakia
Spain – Sweden – Switzerland – United Kingdom

3 Associate Member States
in the pre-stage to membership
Cyprus – Estonia – Slovenia

7 Associate Member States
Croatia – India – Latvia – Lithuania – Pakistan
Türkiye – Ukraine

6 Observers
Japan – Russia (suspended) – USA
European Union – JINR (suspended) – UNESCO

Geographical & cultural diversity
110 nationalities,
from **77** countries

~ **2676** Staff members
~ **2000** contractors' employees
~ **13000** physicists /users

Around 50 Cooperation Agreements
with non-Member States and Territories
Albania – Algeria – Argentina – Armenia – Australia – Azerbaijan – Bangladesh – Belarus – Bolivia
Bosnia and Herzegovina – Brazil – Canada – Chile – Colombia – Costa Rica – Ecuador – Egypt – Georgia – Honduras
Iceland – Iran – Jordan – Kazakhstan – Lebanon – Malta – Mexico – Mongolia – Montenegro – Morocco – Nepal
New Zealand – North Macedonia – Palestine – Paraguay – People's Republic of China – Peru – Philippines – Qatar
Republic of Korea – Saudi Arabia – Sri Lanka – South Africa – Thailand – Tunisia – United Arab Emirates – Vietnam

Yearly budget ~ 1347 MCHF

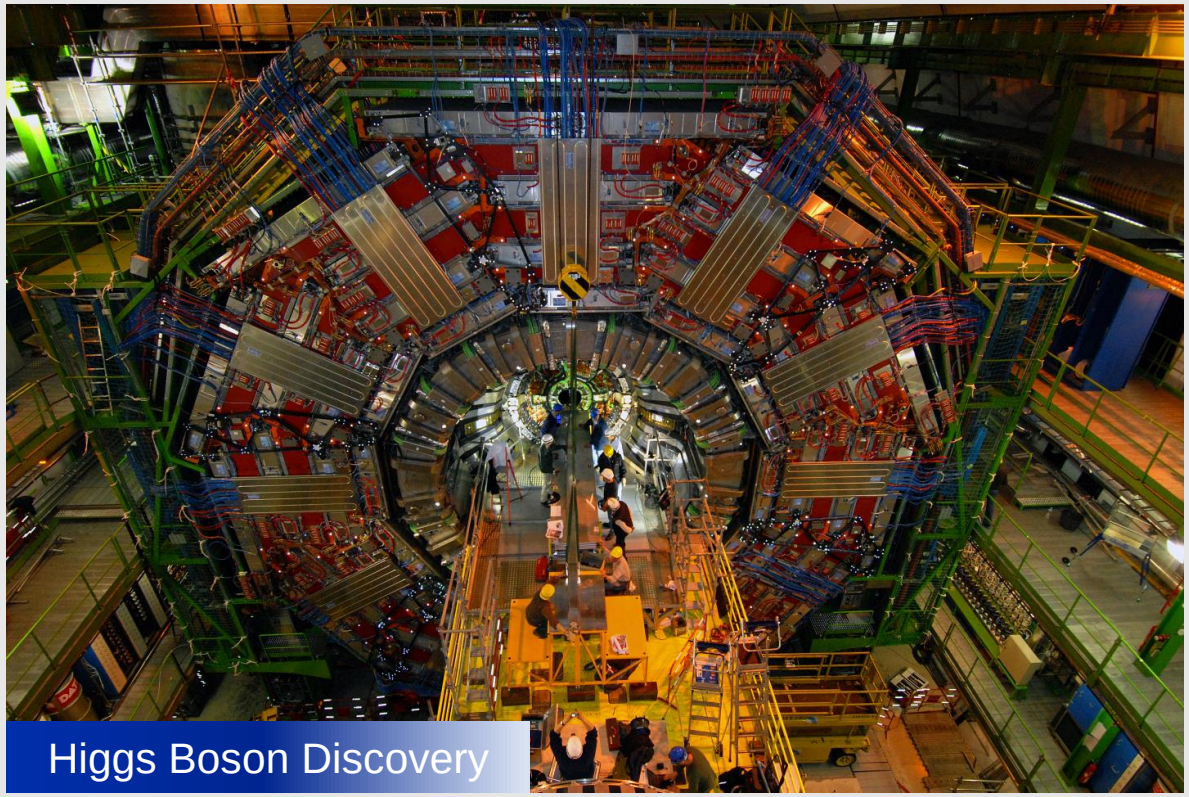
Large Hadron Collider (LHC)

Large Hadron Collider (LHC)

- 27 km in circumference
- About 100 m underground
- Superconducting magnets steer the particles around the ring
- Particles are accelerated to close to the speed of light

CERN Experiments

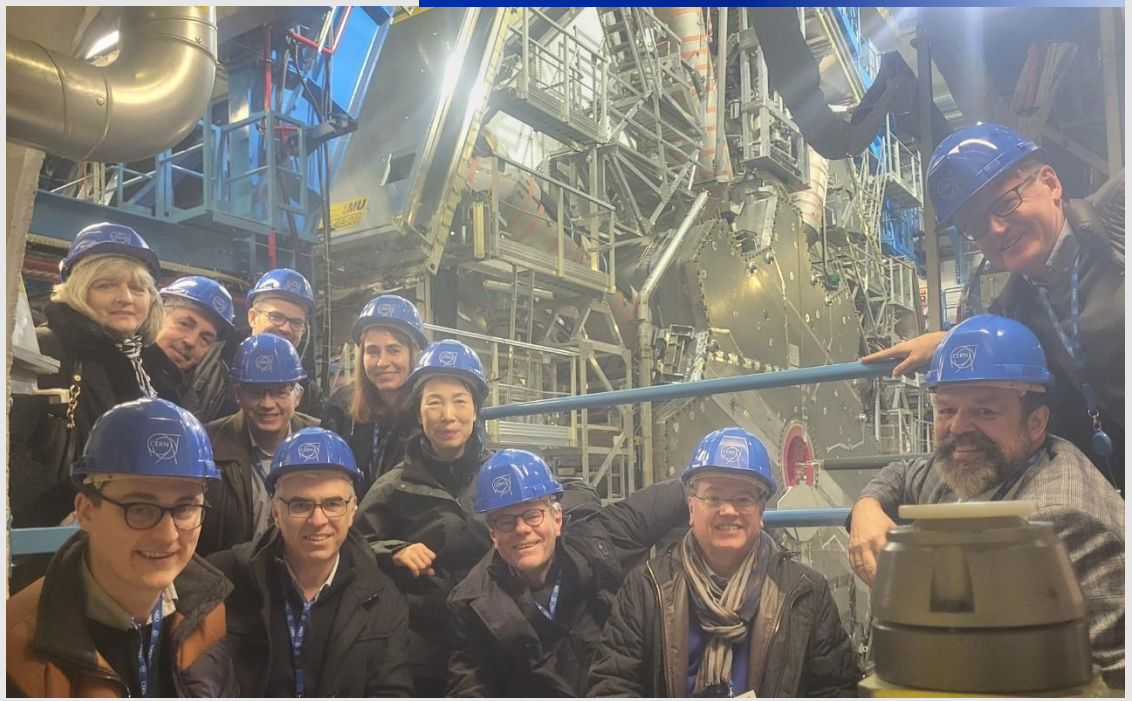
CERN Detectors



Higgs Boson Discovery

CMS Detector in France

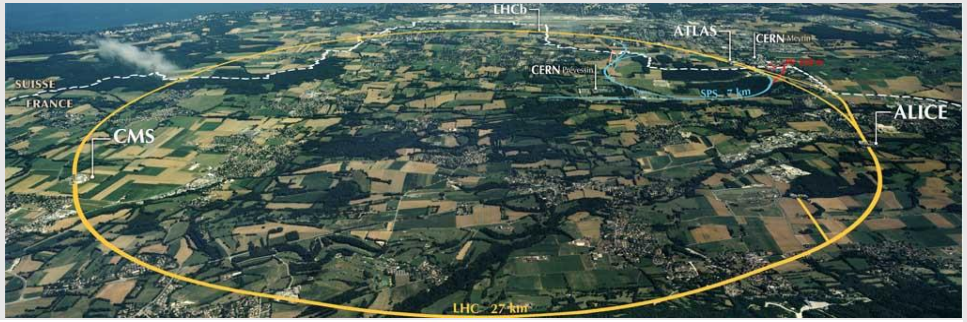
ATLAS Detector
(ITA Executive Council Visit
December 2022)

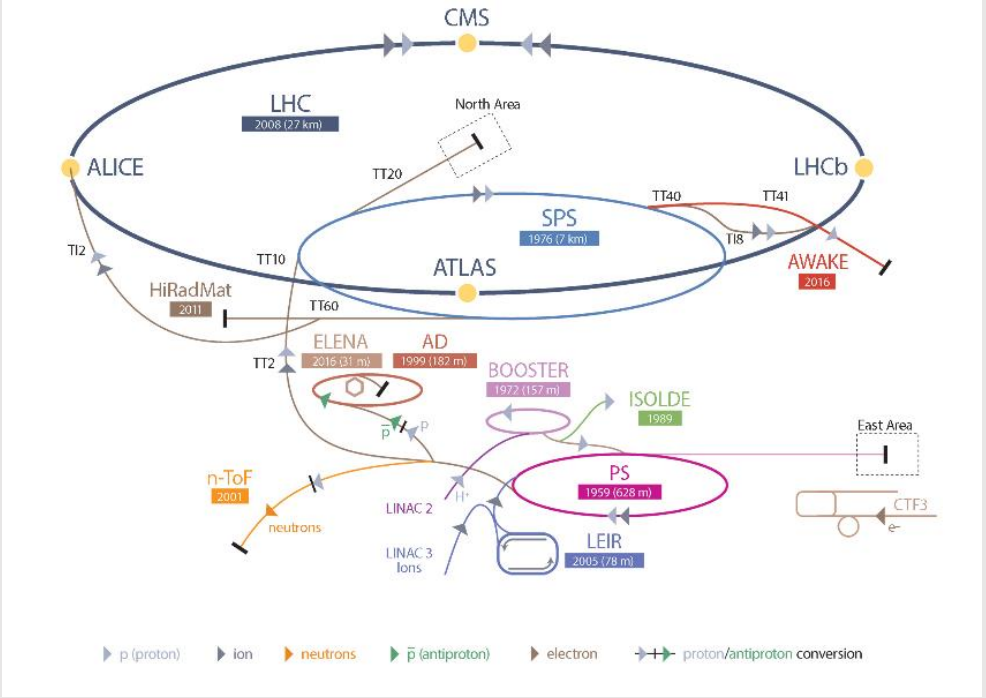


CERN Tunnels and Geology

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

Total underground tunnels >70km
More than 80 Caverns



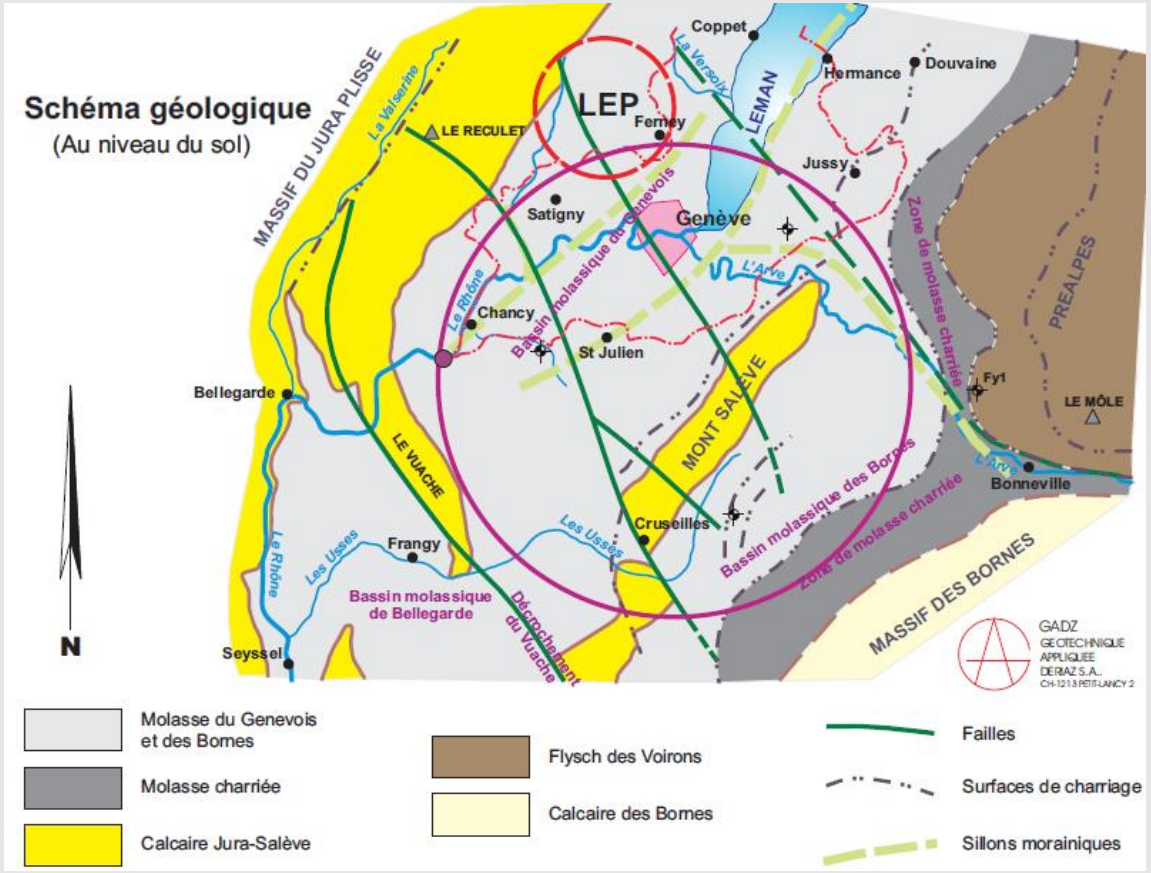


Geology

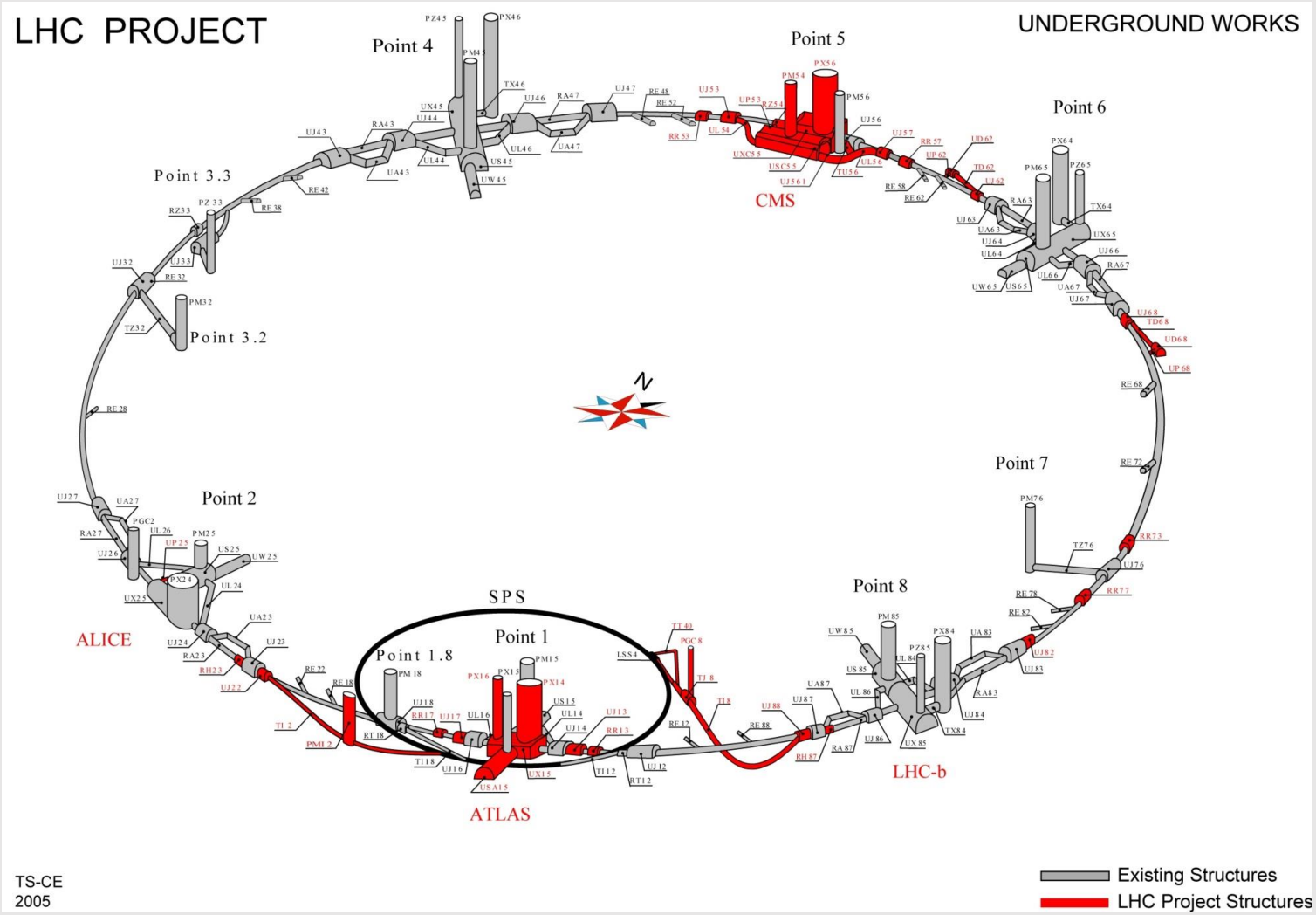
Molasse
- Mixture of sandstones, marls and formations of intermediate composition
- Relatively weak rock (Avg. 5.5 - 48 Mpa)
- Good excavation rock
- Relatively dry and stable
- Faulting due to the redistribution of ground stresses
- Structural instability (swelling, creep, squeezing)

Moraines (Quaternary Deposits)
- Glacial deposits comprising gravel, sands silt and clay
- Water bearing unit
- Unfavourable tunneling

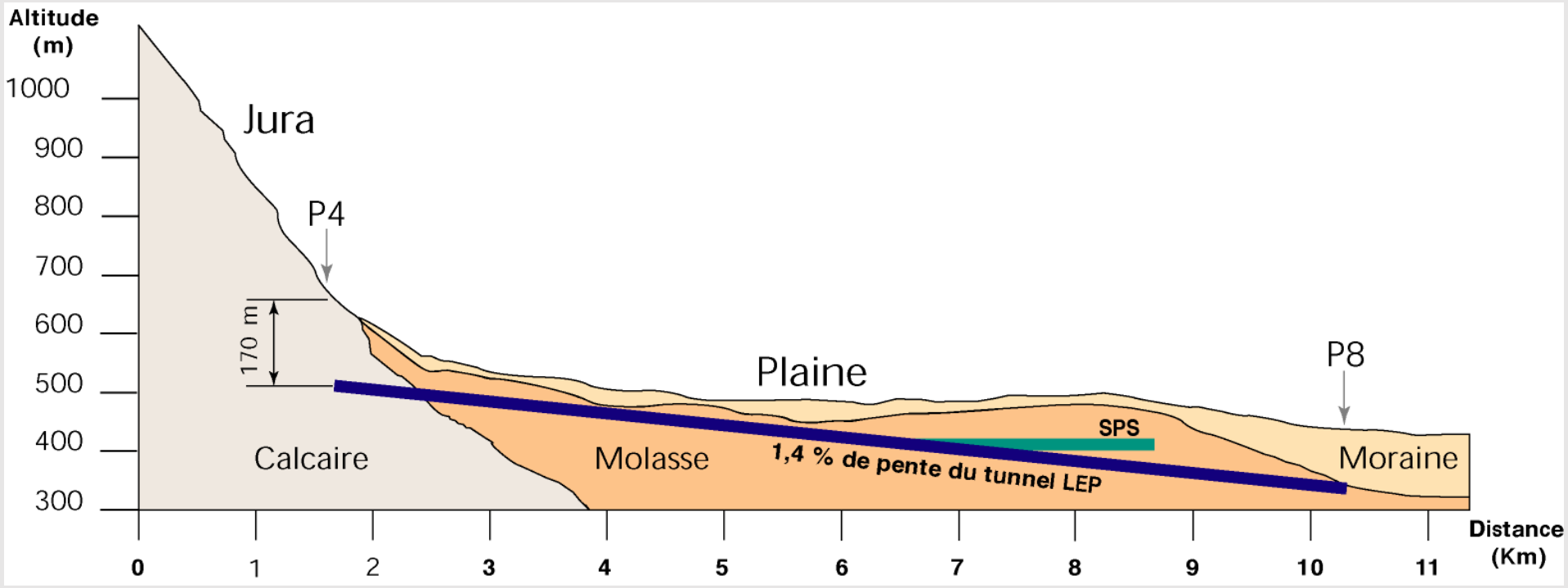
Limestone
- Hard rock
- Good tunneling rock
- Fractures and karsts likely present
- High inflow rates during LEP construction (600L/sec)
- Rock mass instabilities



LHC Civil Engineering 1998-2005

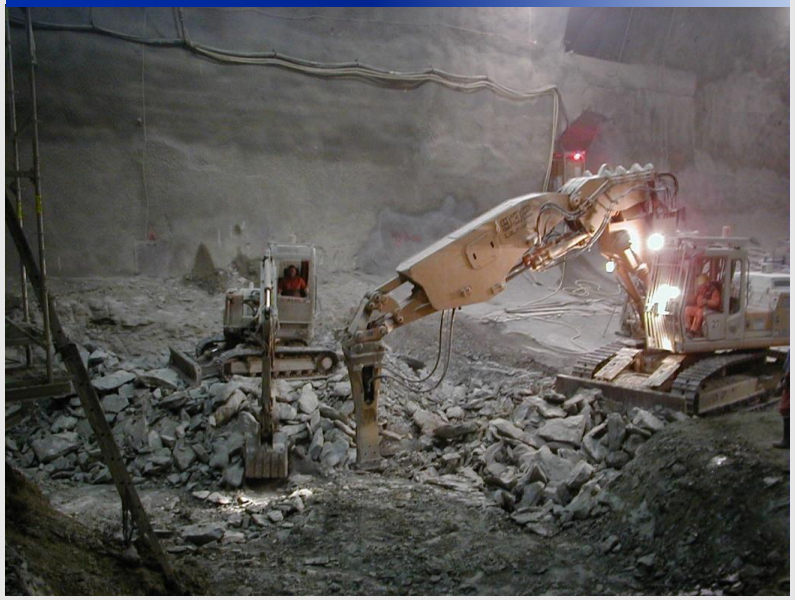


LHC Tunnel Alignment



Tunnel excavation options

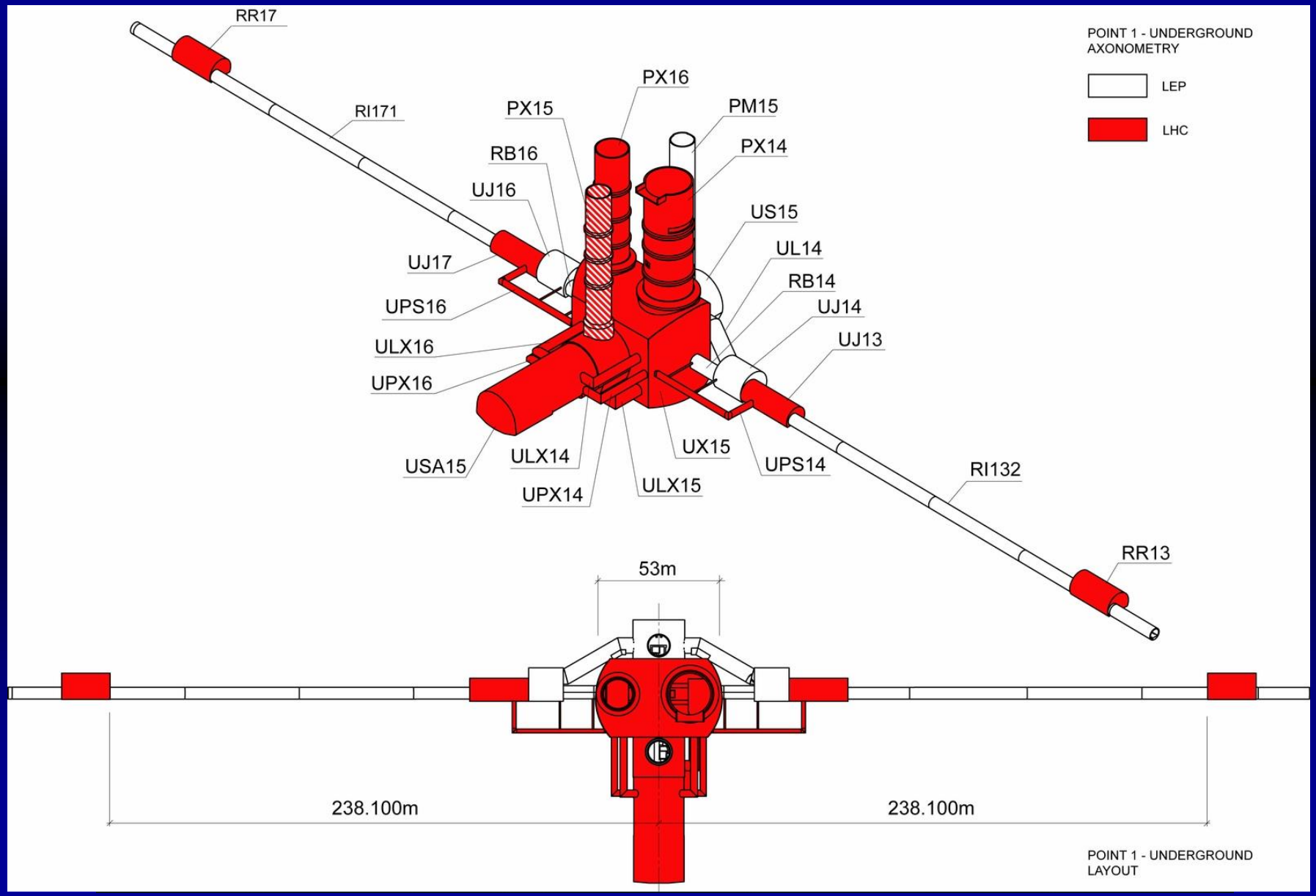
Rock Breakers



TBM

Roadheader

No explosives were used for LHC excavation


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

LHC Civil Engineering ATLAS

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LHC Civil Engineering ATLAS

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LHC Civil Engineering -CMS

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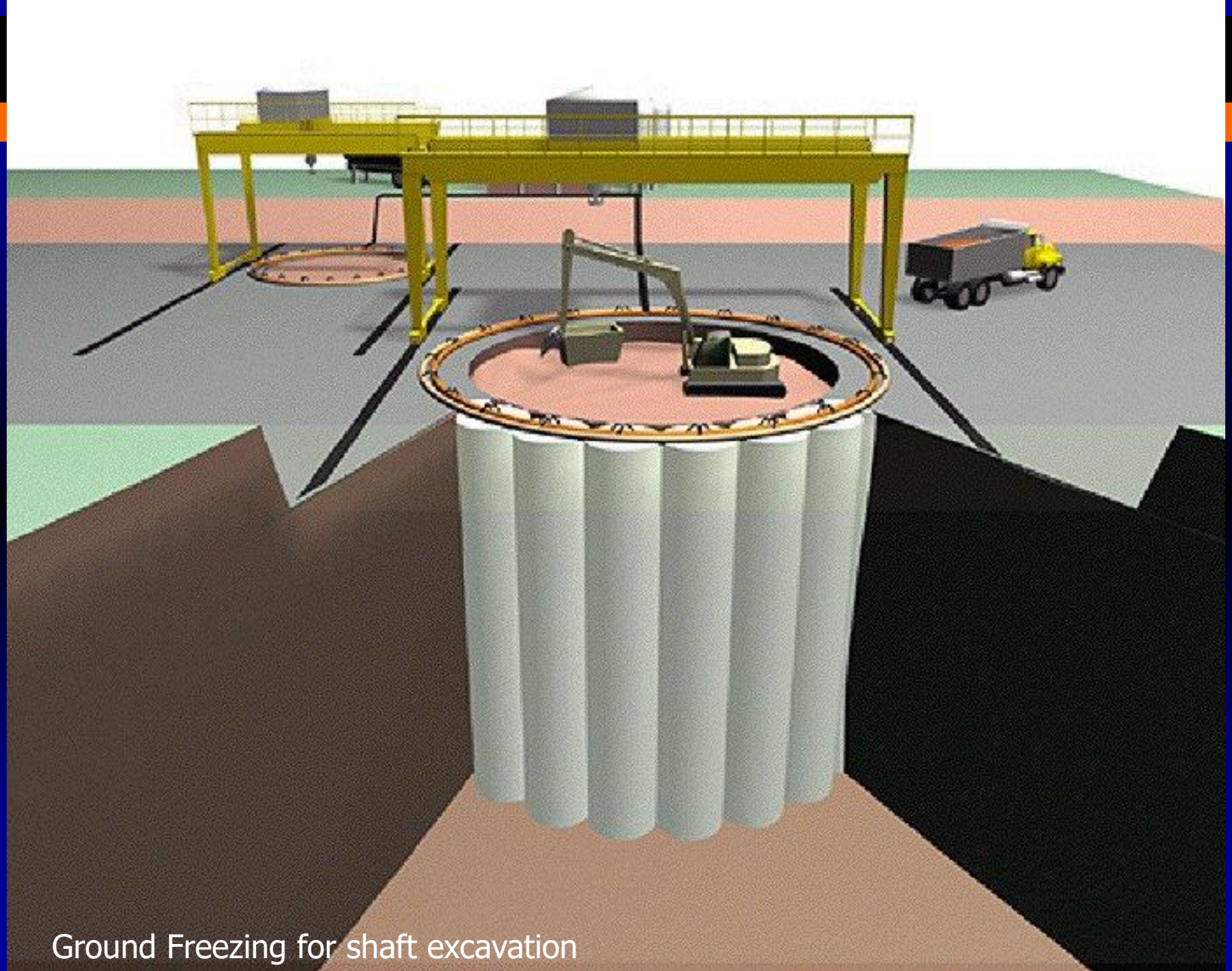

Ground Freezing for shaft excavation

LHC Civil Engineering CMS ground freezing

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LHC Civil Engineering CMS ground freezing

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

ERING

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Draçados

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

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2000

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

2000

LHC Civil Engineering CMS shaft

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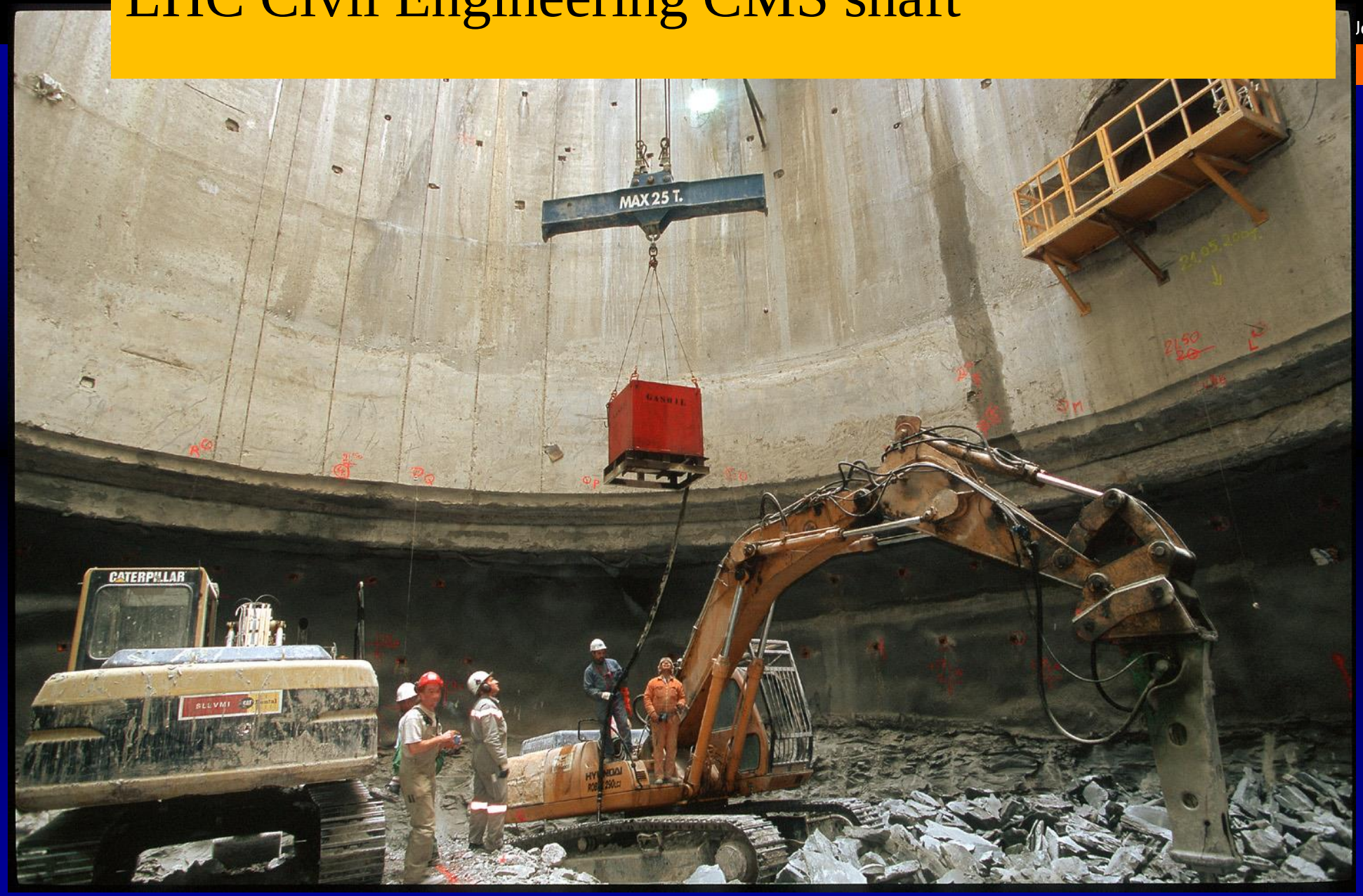
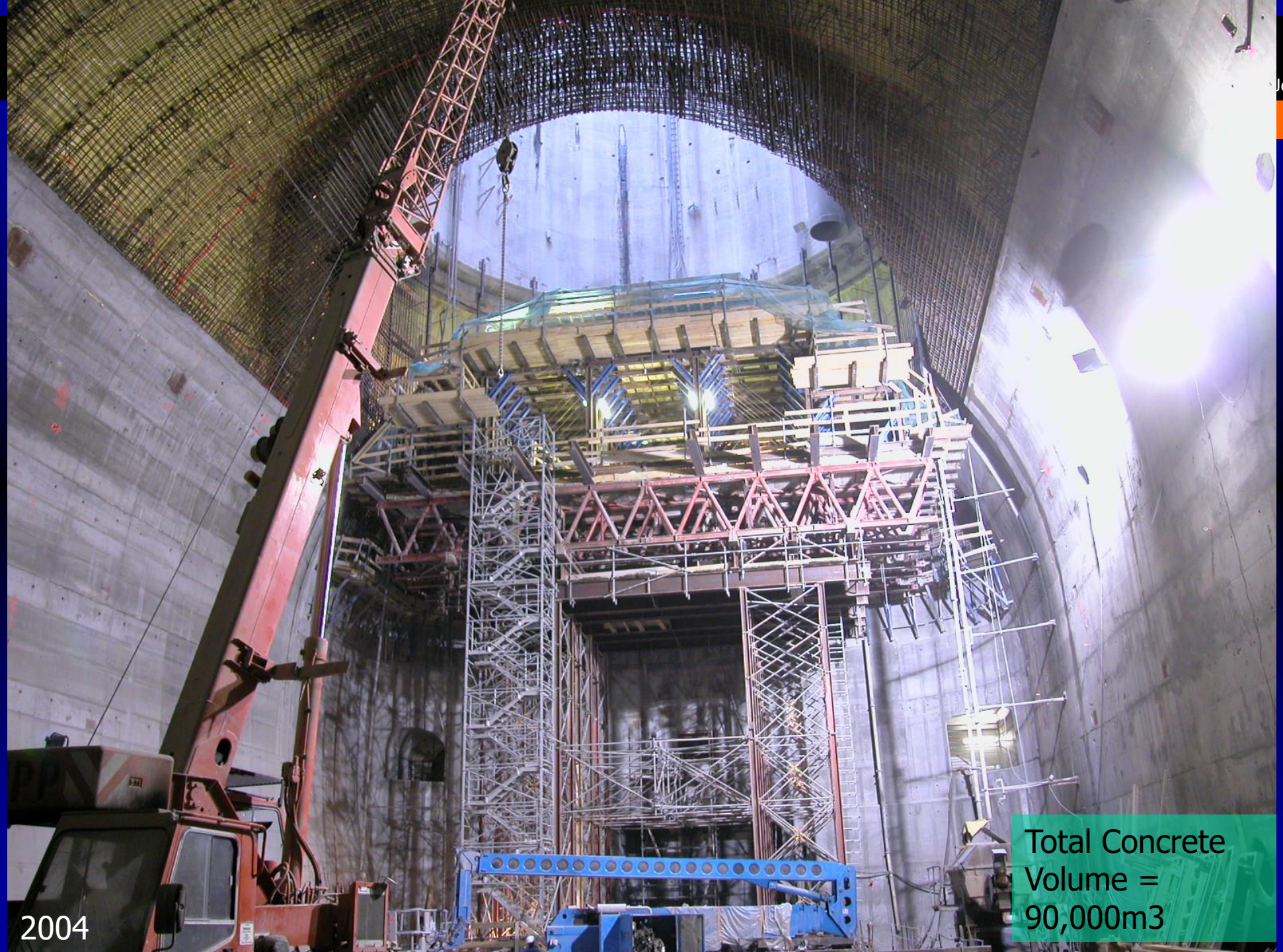


2000

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

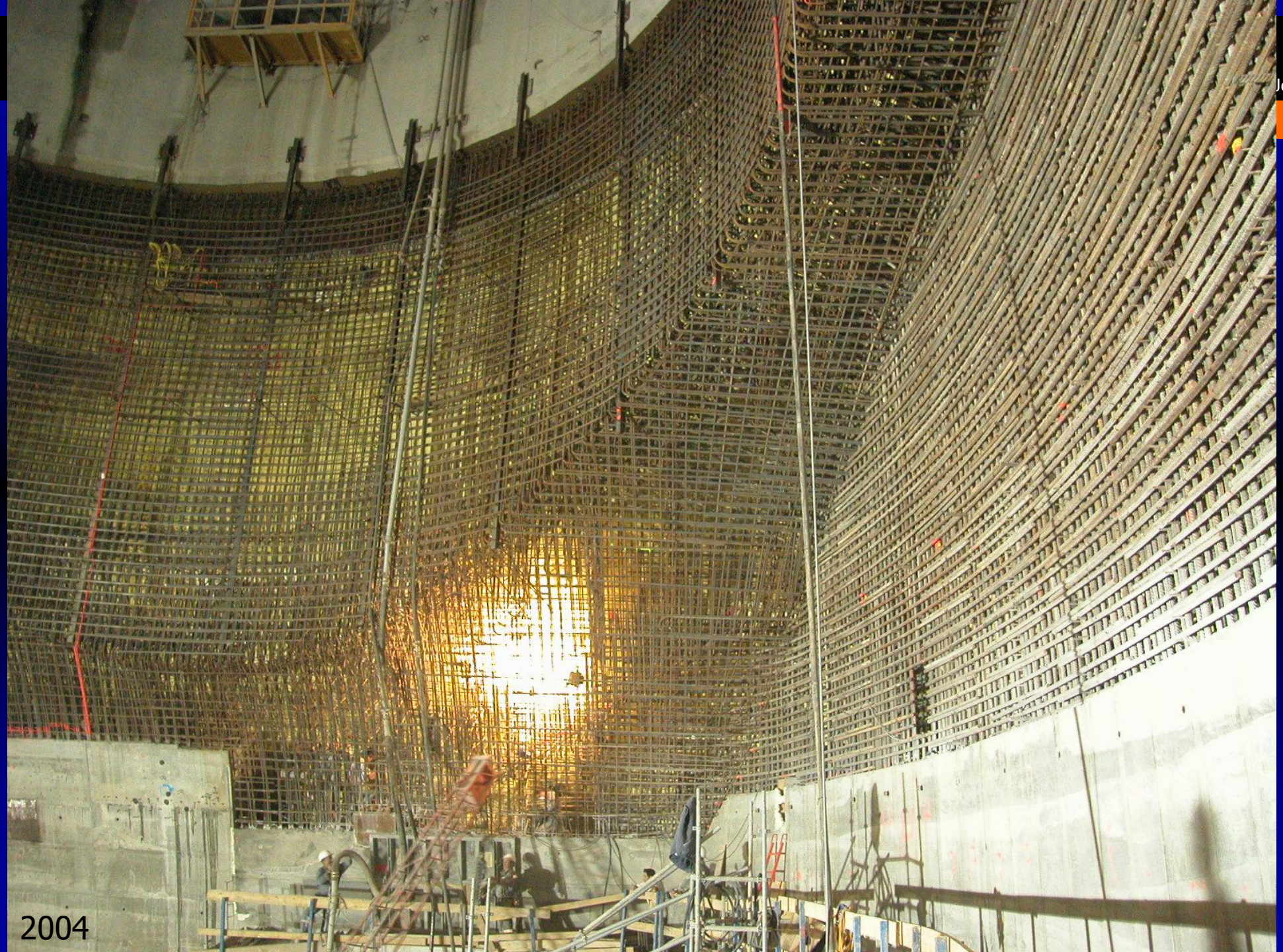
Total Volume excavated = 216,000m3

2003



2004

Total Concrete Volume = 90,000m3



2004

2005

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

LHC Civil Engineering simplified schedule

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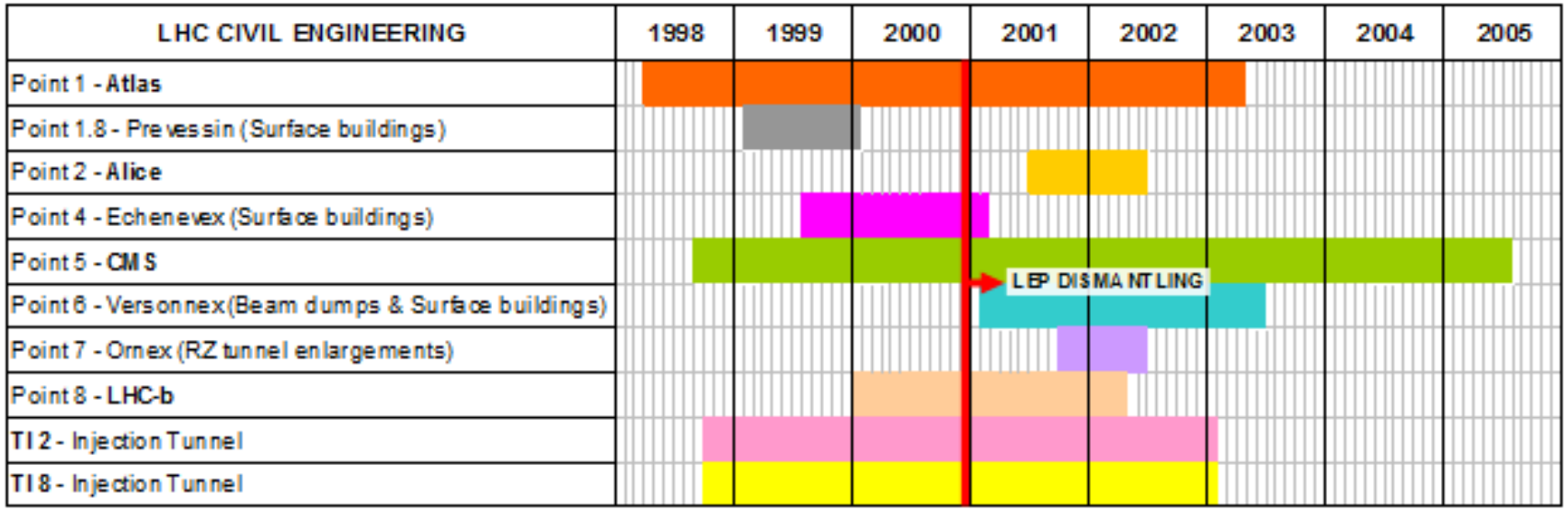
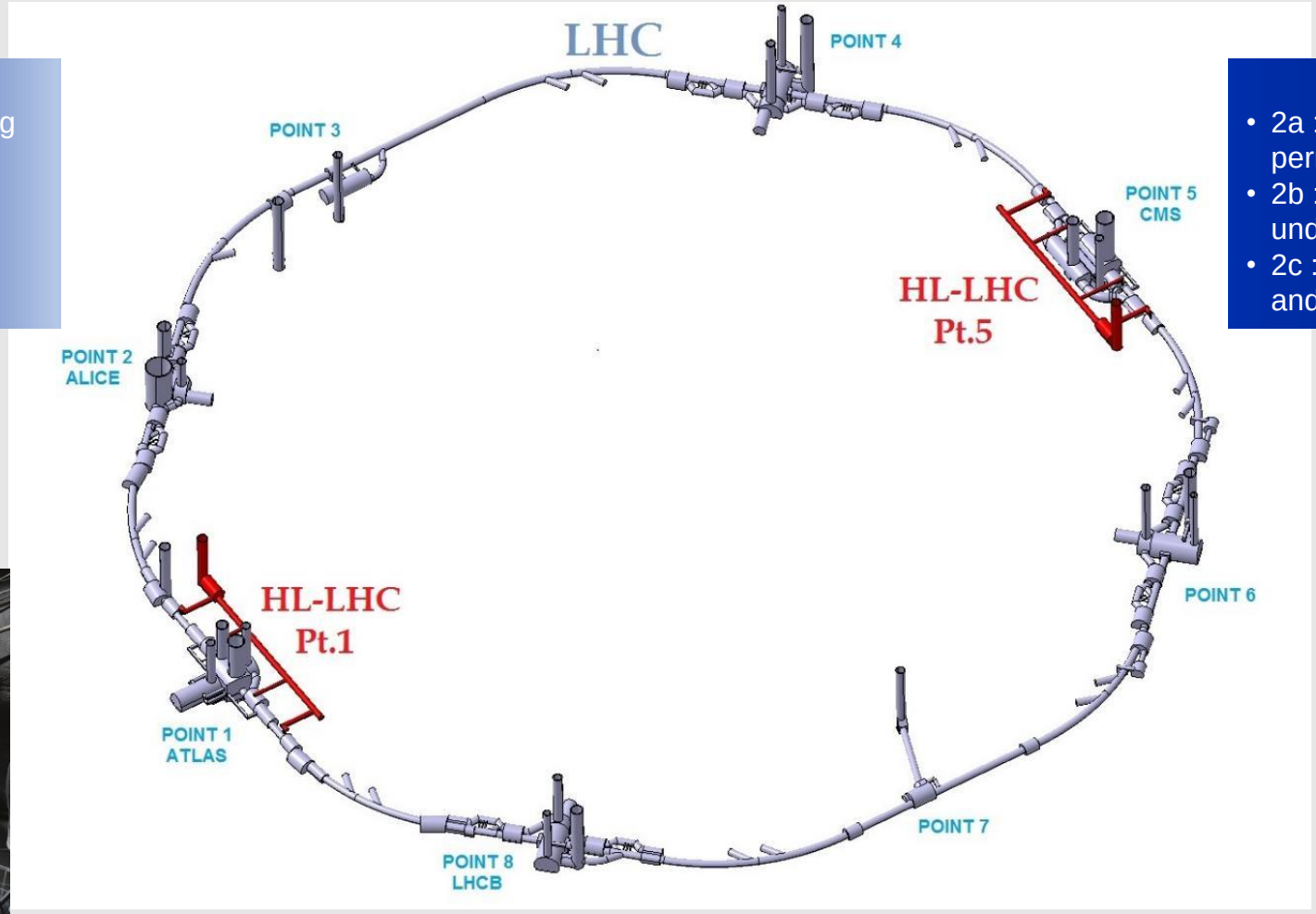


Civil Engineering as-built schedule

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

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

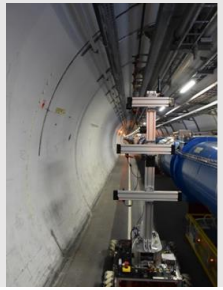


Packages 2:
- 2a : Architect contract for building permit submission (F)
- 2b : Consultants for design of underground and surface
- 2c : Contractor for underground and surface works

Tunnel Asset Management

Automated Image data acquisition

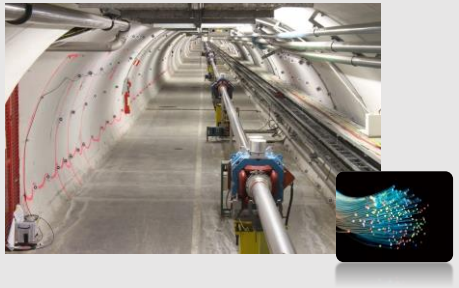
- Robotics solutions (**CERNbot & TIM**) for remote monitoring of CERN underground
- R&D for photogrammetry for crack detection and quantification (machine learning and structure from motion)

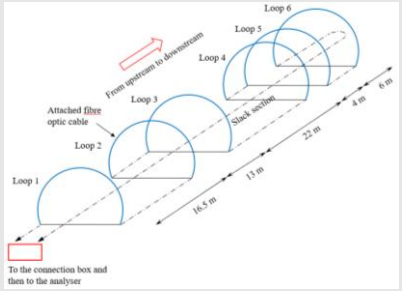


CERNbot

CERN Tunnel Inspection Monorail (TIM)

- R&D for Distributed Fibre Optic Sensors (**DFOS**) monitoring





Tunnel Inspections

- LHC, PS, SPS, Transfer Tunnels Inspections during YETS
- Collaboration with BE-GM Survey team to measure beam movement & floor movement

Other Monitoring technologies

- Drone ie. Flyability Elios 3
- Laser scanning (Point Cloud system)

Tunnel Asset Management Workshop at CERN

- TAM Innovation Workshop on the 26-27th October 2023

CERN
TAM Innovation Workshop
Tunnel Asset Management
2023

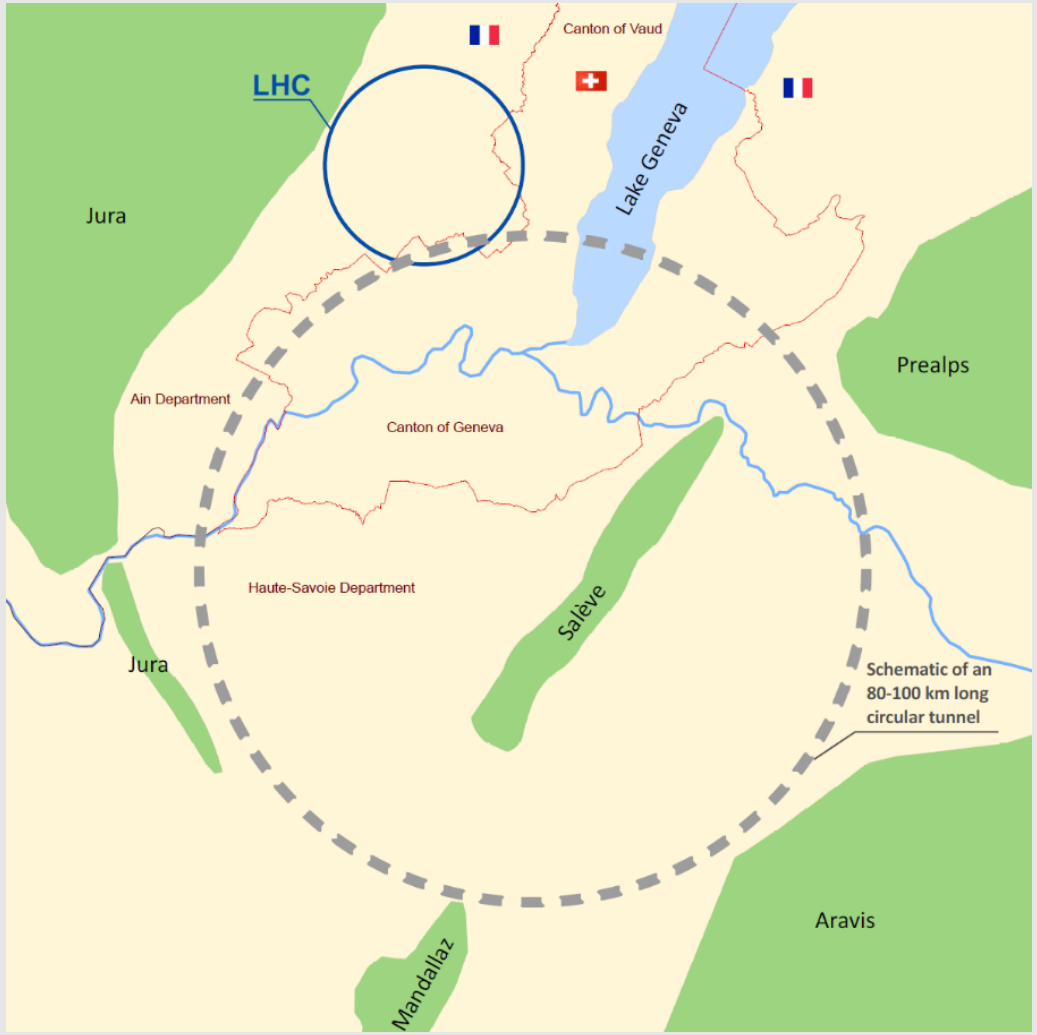
Collaboration with University College Cork (UCC)

UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

- 4th International Symposium of Machine learning and Big Data in Geoscience ISMLG2023
  29th August - 1st September 2023

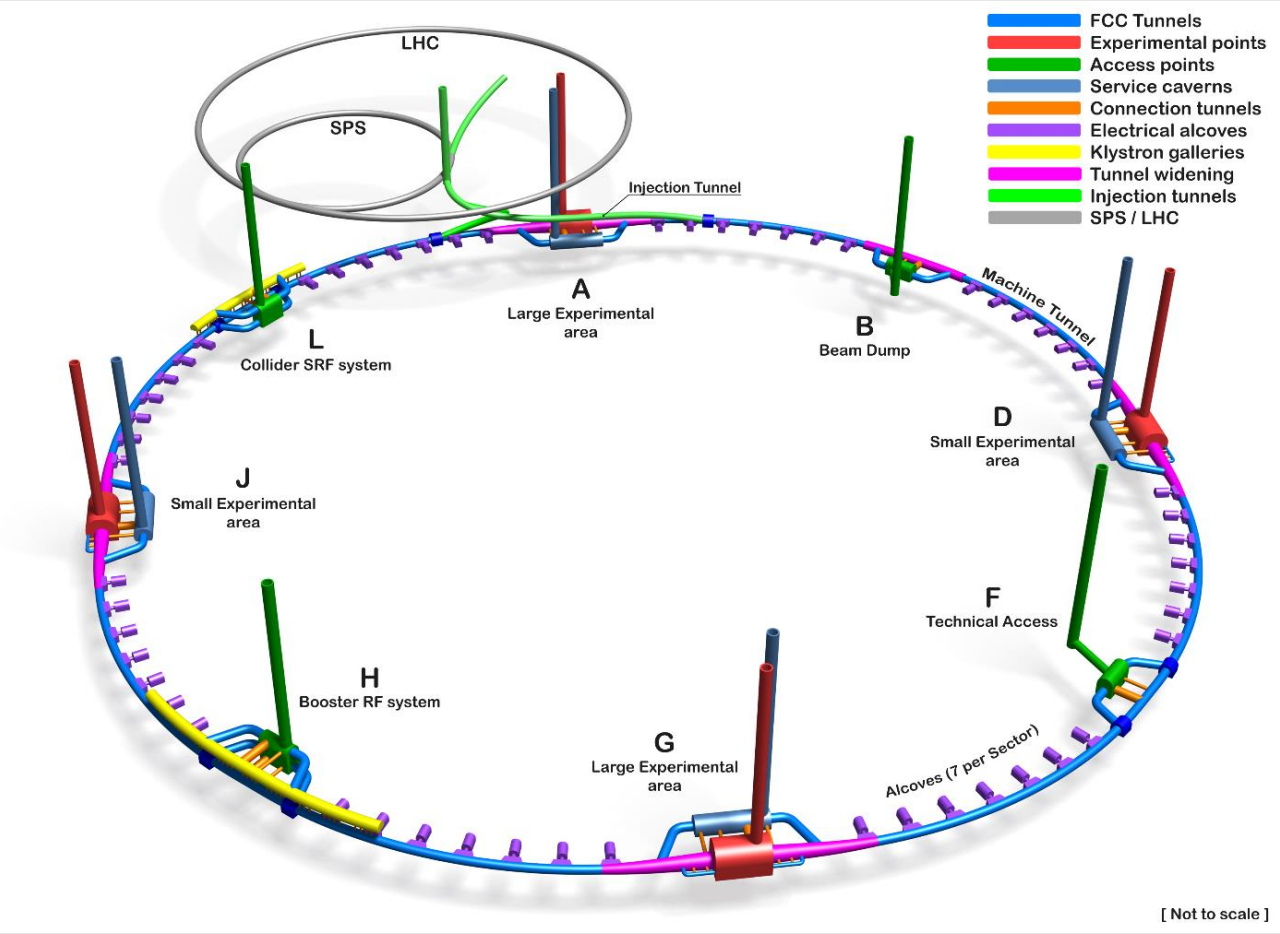
The Future Circular Collider Study (FCC)

- **Collision energy:**
  100TeV
- **Circumference:**
  91km
- **Physics considerations:**
  Enable connection to the LHC (or SPS)
- **Construction:**
  c.2033-2043
- **Aims of the civil engineering feasibility study:**
  What is the cost ?
  What is the optimal position?
  Site Investigations to confirm assumptions.

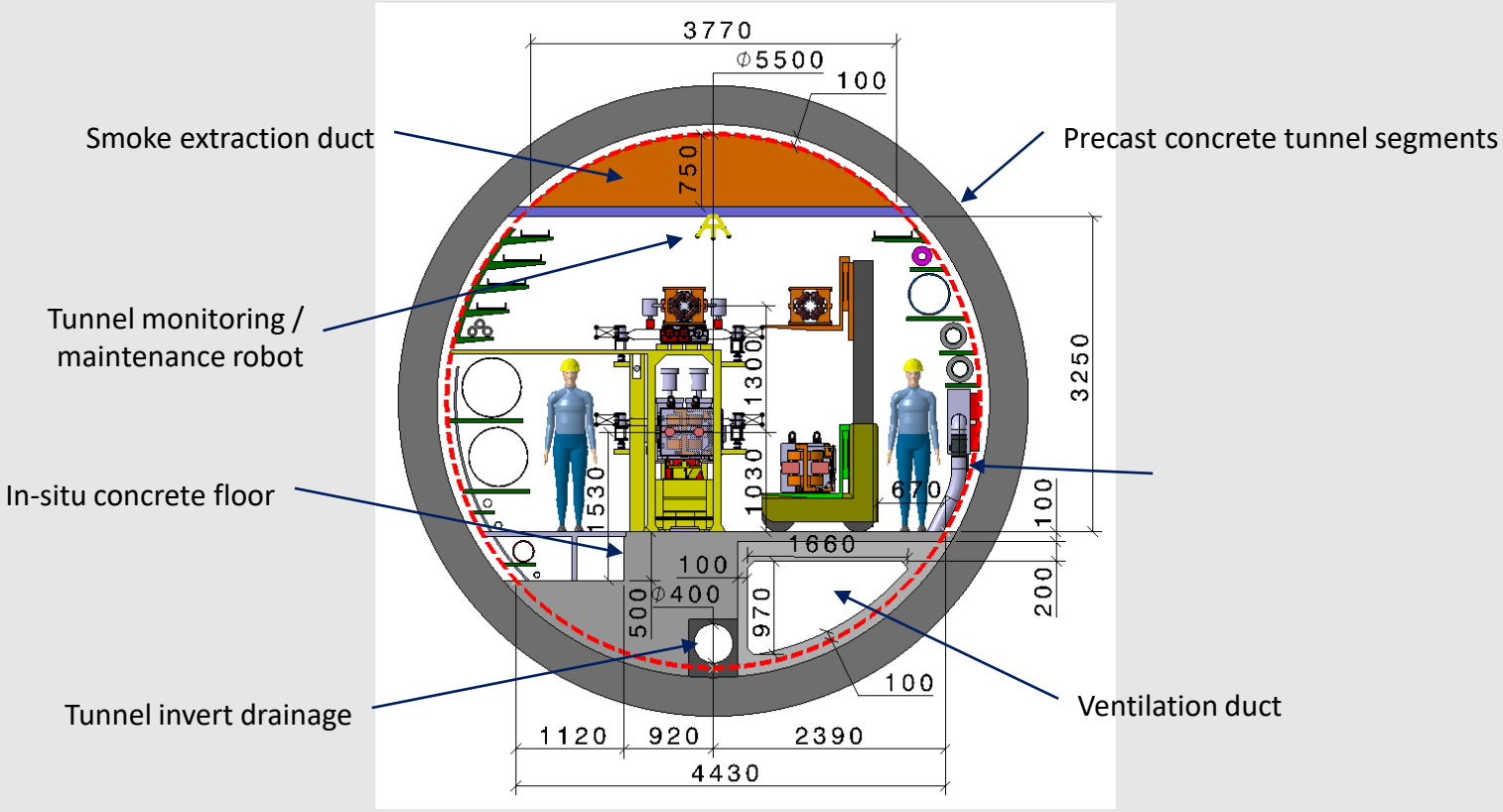


Civil Engineering Sub Surface

- 8 surface sites
- 13 shafts
- 4 experiment caverns
- 8 service caverns
- Beam dump
- RF klystron galleries
- SPS injection lines



Main Beam Tunnel



Credit: Fani Valchkova-Georgieva

Areas with the highest geological uncertainty

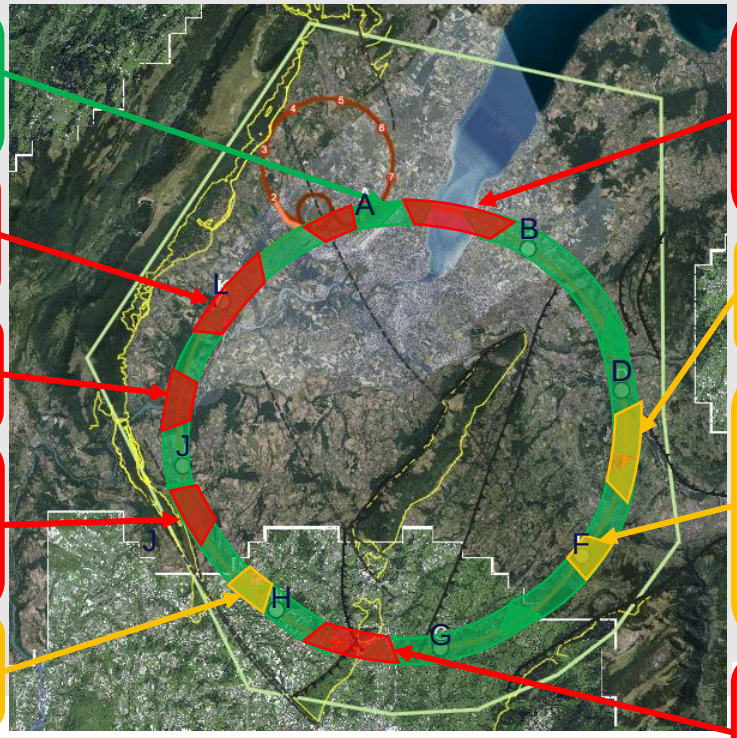
- Good knowledge of the ground (e.g information near to CERN from LEP/LHC projects)
- Good confidence that the tunnel alignment is in molasse

Jura
- Limestone/molasse interface uncertain.
- Risk of karts and high water pressures

Le Rhône
- Moraine/molasse interface not certain.
- Proximity to protected area

Vuache
- Limestone/molasse interface not certain.
- Risk of karts and high water pressures
- Proximity to main active fault

Les Usses
- Moraine/molasse interface not certain.
- Low tunnel rock cover

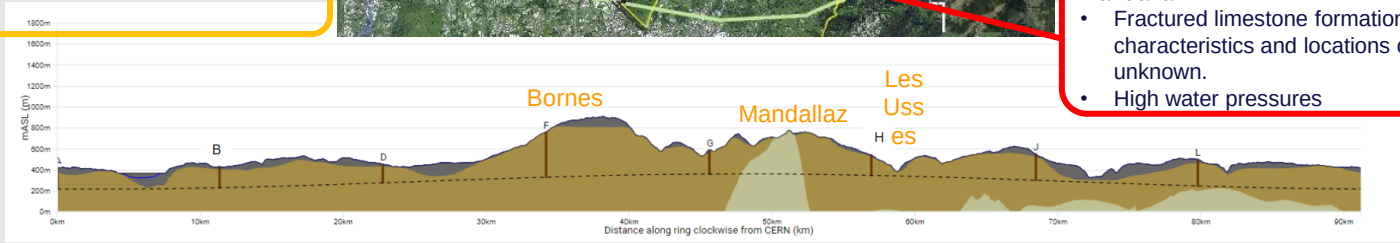


Lac Léman
- Moraine/molasse interface uncertain
- Soils and rock properties uncertain
- High uncertainty in the hydrogeological conditions and water pressure

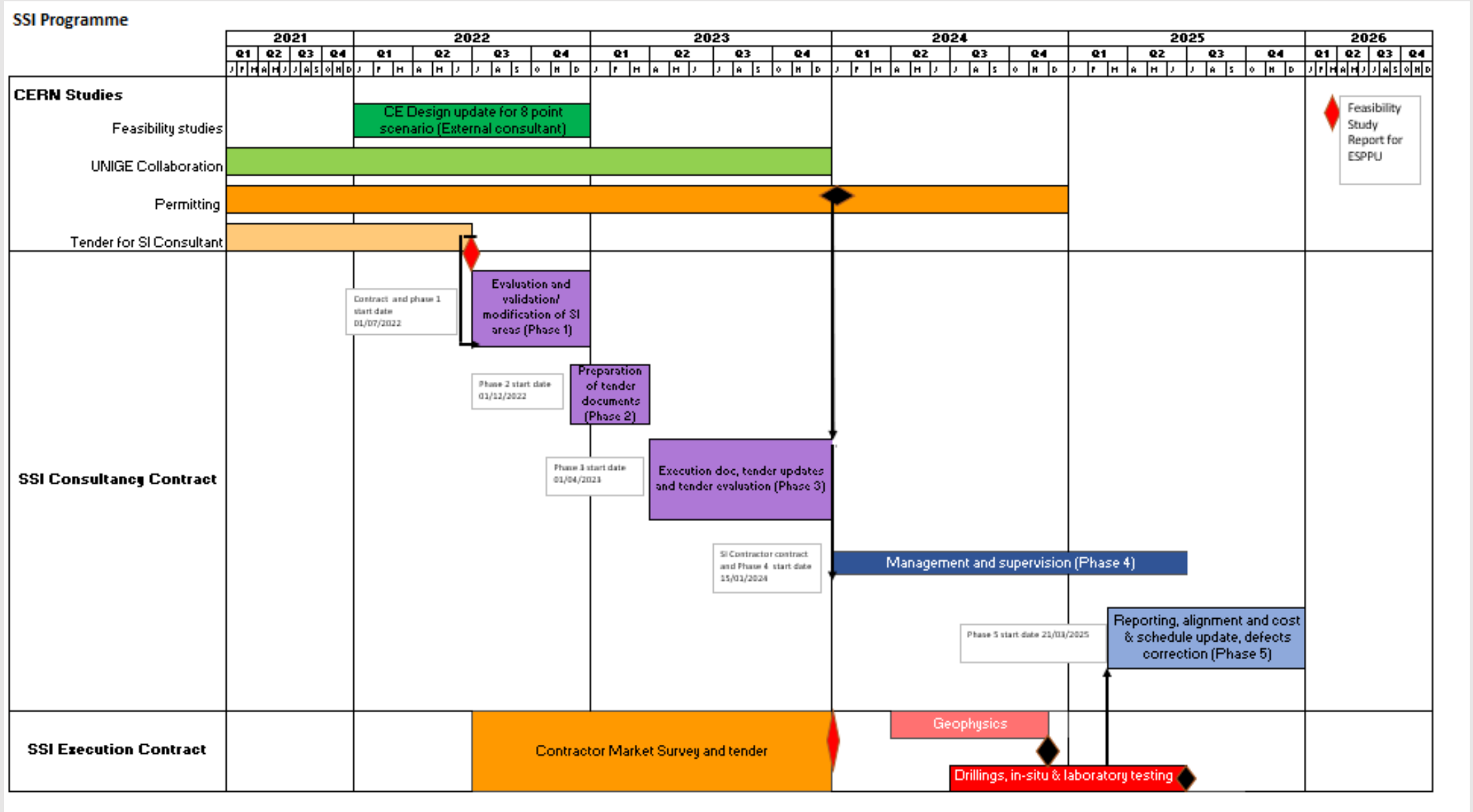
Vallée de l'Arve
- Moraine/molasse interface uncertain.
- Lack of reliable boreholes

Bornes
- Insufficient deep boreholes information
- Complex faulted region, thrust zone.
- Quality of molasse is uncertain. High overburden. Large span experimental caverns should be constructed in good molasse.

Mandallaz
- Fractured limestone formations, characteristics and locations of karsts unknown.
- High water pressures

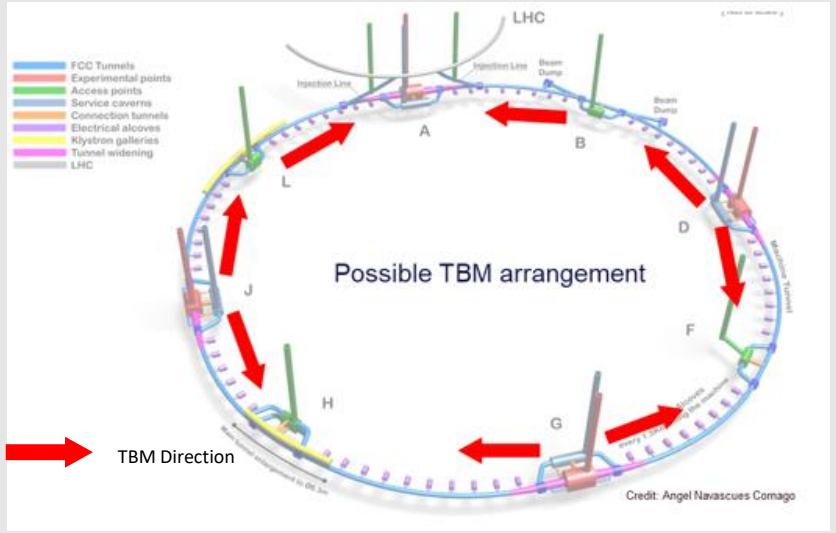


On-site investigation works 2024-25
Planned start of civil works mid 2030's


SSI Programme
2021
2022
2023
2024
2025
2026
Q1 Q2 Q3 Q4
CERN Studies
Feasibility studies
UNIGE Collaboration
Permitting
Tender for SI Consultant
CE Design update for 8 point scenario (External consultant)
Feasibility Study Report for ESPPU
SSI Consultancy Contract
Contract and phase 1 start date 01/07/2022
Evaluation and validation/ modification of SI areas (Phase 1)
Phase 2 start date 01/12/2022
Preparation of tender documents (Phase 2)
Phase 3 start date 01/04/2023
Execution doc, tender updates and tender evaluation (Phase 3)
SI Contractor contract and Phase 4 start date 15/01/2024
Management and supervision (Phase 4)
Phase 5 start date 21/03/2025
Reporting, alignment and cost & schedule update, defects correction (Phase 5)
SSI Execution Contract
Contractor Market Survey and tender
Geophysics
Drillings, in-situ & laboratory testing

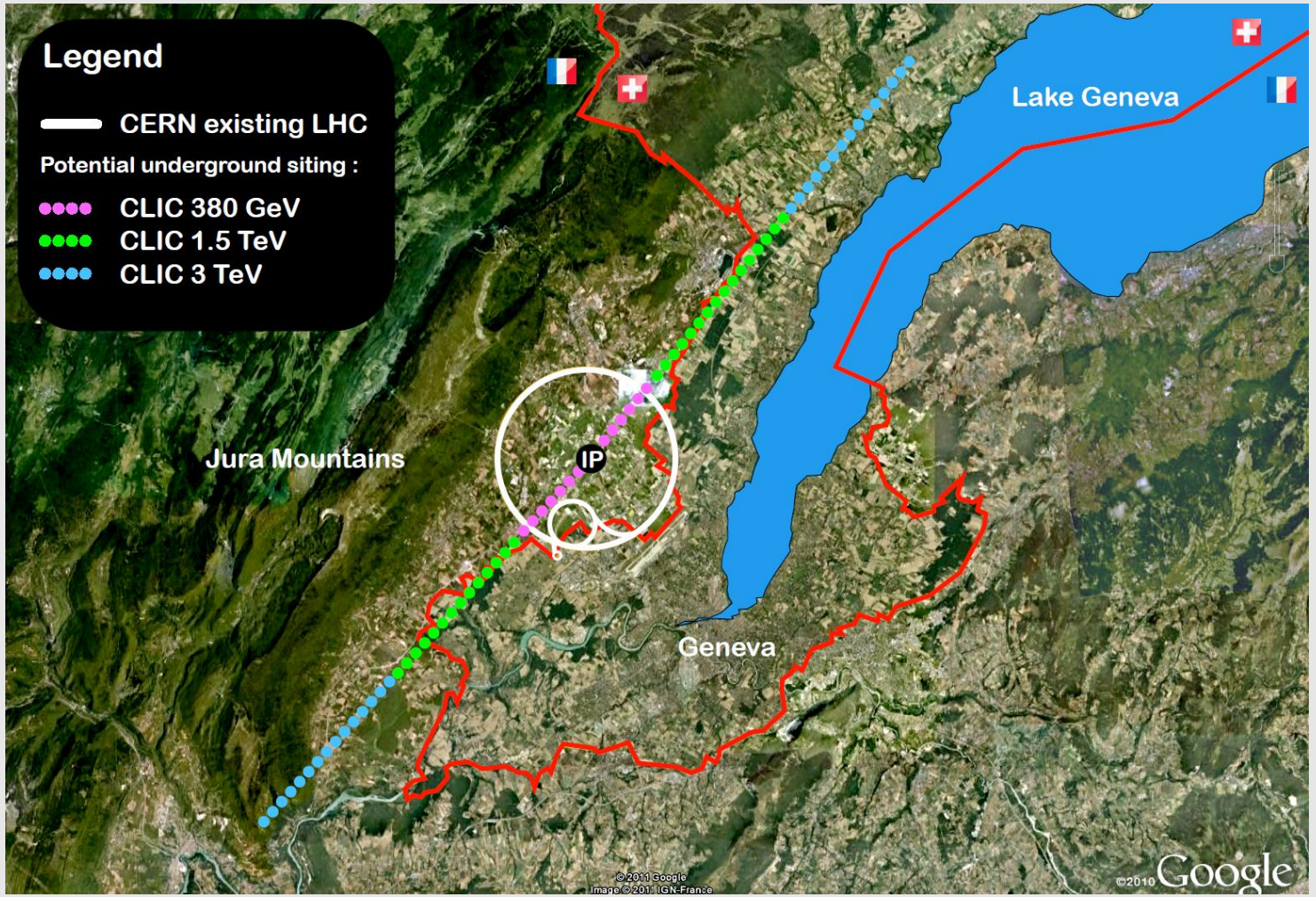
MATEX Study

- Study to estimate quantity and disposal of excavated material
- Baseline TBM layout and direction of drives
- Balance of material between France and Switzerland
- 96% molasse
- 3% limestone
- 1% moraine
- Total, 8,100,000 m^3



Base. TBM	A	B	D	F	G	H	J	L	Inj. Prevessin	Inj. SPS	Total
Vol.	569,119	559,922	1,288,361	153,735	1,378,880	291,486	1,300,330	583,564	28,867	82,197	6,236,461
Bulk Vol.	739,855	727,898	1,674,869	199,856	1,792,544	378,932	1,690,429	758,633	37,527	106,856	8,107,399
% of Total	9%	9%	21%	2%	22%	5%	21%	9%	0%	1%	
Vol. France	534,959	42,143	1,204,564	153,735	1,378,880	291,486	1,300,330	201,784	28,867	39,638	5,176,386
% France	94%	8%	93%	100%	100%	100%	100%	35%	100%	48%	83%
Vol. Suisse	34,160	517,772	83,797	-	-	-	-	381,754	-	42,560	1,060,043
% Suisse	6%	92%	7%	0%	0%	0%	0%	65%	0%	52%	17%

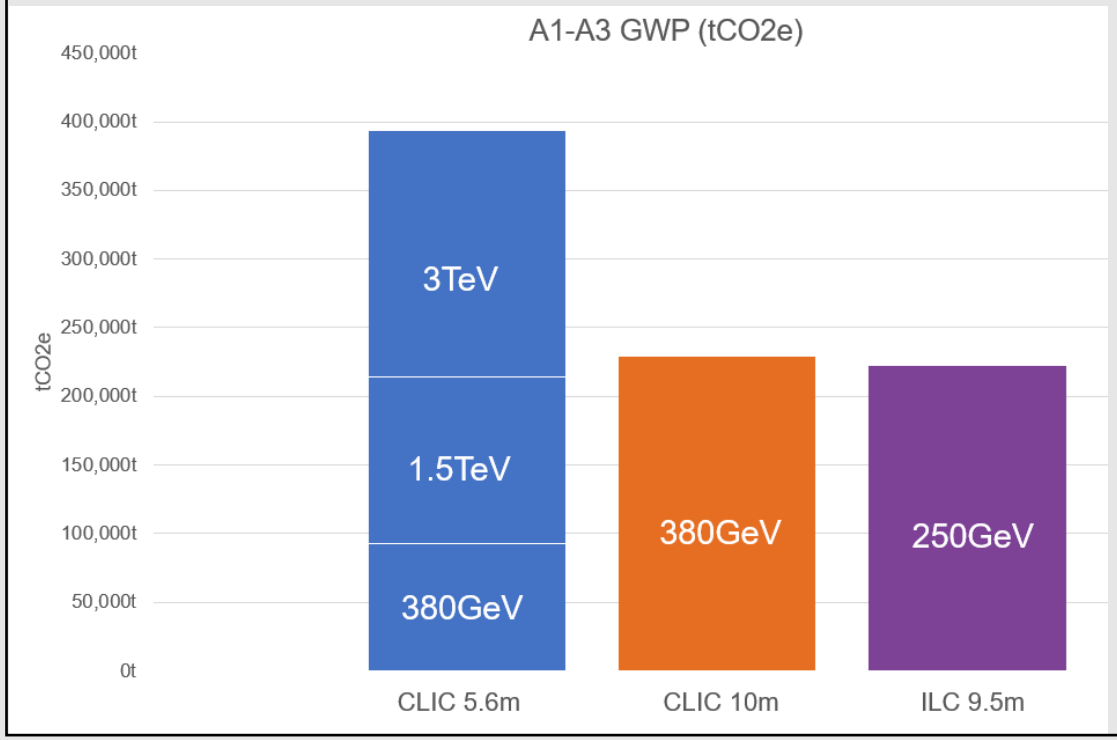
Compact Linear Collider (CLIC)

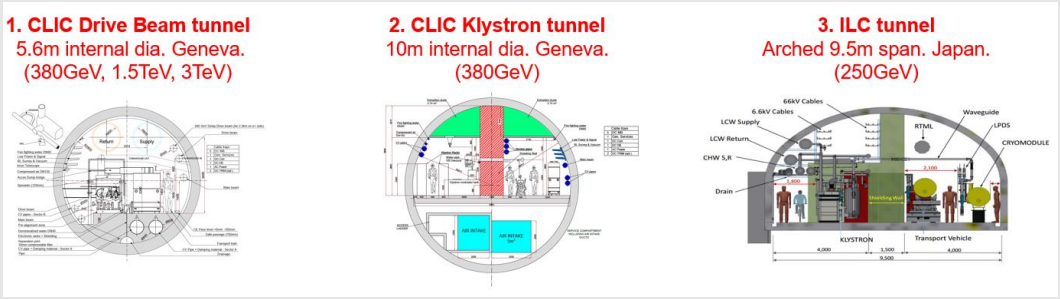


Sustainability of Future Physics Tunnels

ARUP

Study Progress: Preliminary results, April 2023





- Arup undertaking lifecycle assessment (LCA) of future CERN tunnels.
- Study of the total embodied carbon across a project's lifetime
- Project carbon cost is now a major factor in the decision making process.
- Assessment of embodied carbon can identify significant areas to reduce CO2.

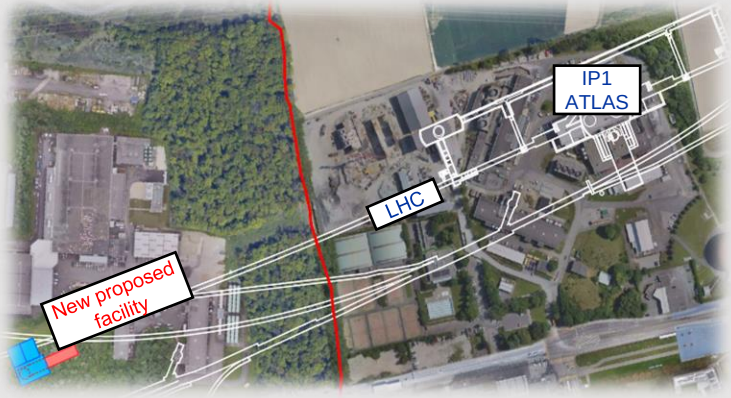
Physics Beyond Colliders (PBC)

PBC is a programme aimed at exploiting the full scientific potential of CERN's accelerator complex and its scientific infrastructure through projects complementary to the LHC, HL-LHC and other possible future colliders.

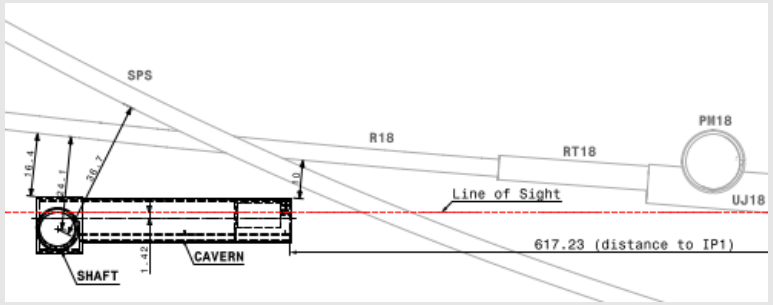
- Main studies:
  - Beam Dump Facility (BDF)
  - Forward Physics Facility (FPF)
  - electrons in the SPS (eSPS)
  - ForwArd Search ExpeRiment (FASER)
  - Neutrinos from STORed Muons (nuSTORM)
  - Plasma Electron Proton/Ion Collider (PEPIC)
  - Advanced Proton driven Plasma Wakefield Experiment (AWAKE)++
  - Electric Dipole Moments (EDM) Storage Ring
  - MAssive Timing Hodoscope for Ultra Stable neutraL pArticles (MATHUSLA)

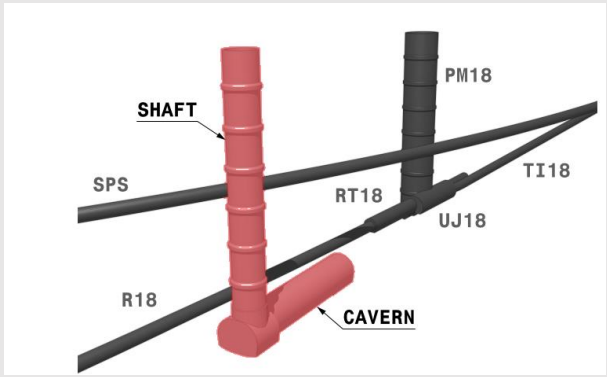
Forward Physics Facility

- Location approx. 617m from IP1 on the French side of CERN land, 10m away from the LHC tunnel
- Design includes:
  - A 65m long experimental cavern, experiments centralised on the line of sight (LoS)
  - An 88m deep access shaft
  - Support buildings and infrastructure



- Site Investigation drilling completes in March 2023





Civil Engineering companies

Large Hadron Collider (LHC)

CE Contracts approx. EUR 600m

Package	Consultants	Contractors
POINT1 ATLAS	▪ EDF (F) ▪ KNIGHT & PIESOLD (GB)	▪ TEERAG-ASDAG (A) ▪ BARESEL (D) ▪ LOCHER (CH)
POINT 5 CMS	Joint Venture: • GIBB (NOW JACOBS) (GB) • GEOCONSULT (AT) • SGI (CHH)	▪ DRAGADOS (E) ▪ SELI (I)
Other points	▪ BROWN & ROOT (GB) ▪ INTECSA (E) ▪ HYDROTECHNICA (P)	▪ TAYLOR-WOODROW (GB) ▪ AMEC (GB) ▪ SPIE-BATIGNOLLES (F)
TI 8	▪ DITO	▪ LOSINGER (CH)

Civil Engineering companies

High Luminosity LHC Project (HL-LHC)

CE Contracts approx. EUR 200m

Package	Consultants	Contractors
POINT1	Consortium ORIGIN: ▪ SETEC (F) ▪ CSD ENGINEERS (CH) ▪ ROCKSOIL (I)	Joint Venture Marti Meyrin: ▪ MARTI TUNNELBAU (CH) ▪ MARTI DEUTSCHLAND (DE) ▪ MARTI ÖSTRERREICH (A)
POINT 5	Consortium LAP ▪ LOMBARDI (CH) ▪ ARTELIA (F) ▪ PINI SWISS ENGINEERS (CH)	Consortium CIB: ▪ IMPLENIA (CH/ F) ▪ BARESEL (DE)
Building Permit	▪ DELTA ARCHITECTS ▪ ASS ARCHITECTS	

Civil Engineering companies

Future Circular Collider (FCC)		
Package	**Consultants**	**Contractors**
PRE-DESIGN	▪ ILF (A) GADZ (CH) ▪ ARUP (UK) ▪ AMBERG (CH)	
Permitting GiS suppport	▪ SETEC (FR) ▪ SETEC (FR) & ARUP (UK)	
PRELIM SITE INVESTIGATION	▪ EGIS (F) BG (CH)	Tender out now!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THANK YOU
FOR YOUR ATTENTION