Future CERN accelerator programme and its technological challenges

Mike Lamont
2024 CERN openlab Technical Workshop
26 March 24

Our goal is to understand the most fundamental particles and laws of the universe.


WE FOUND A NEW PARTICLE

Who is Higgs?

Why did he freeze in the Universe?

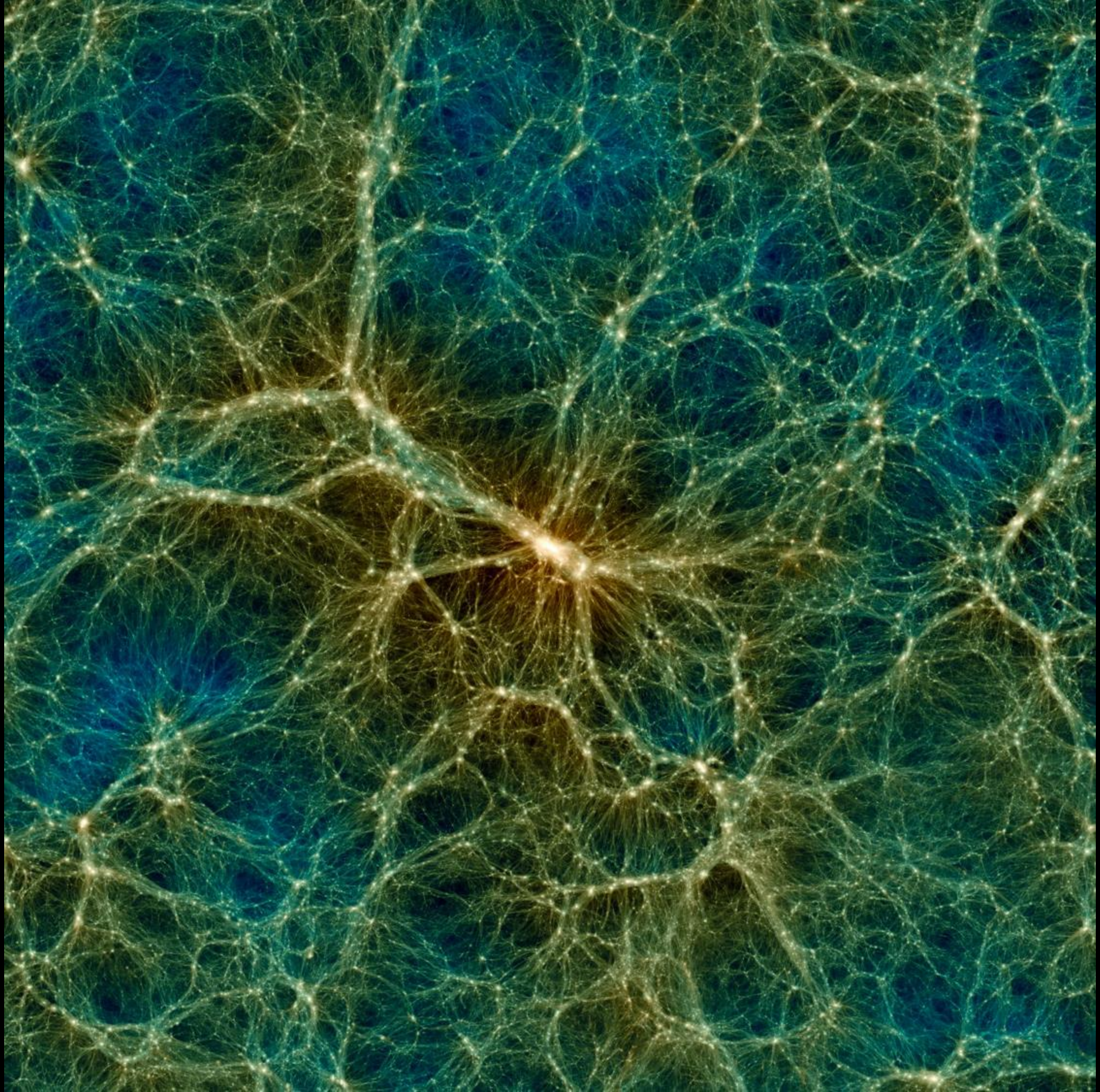
Why do we exist?

Who is dark matter?

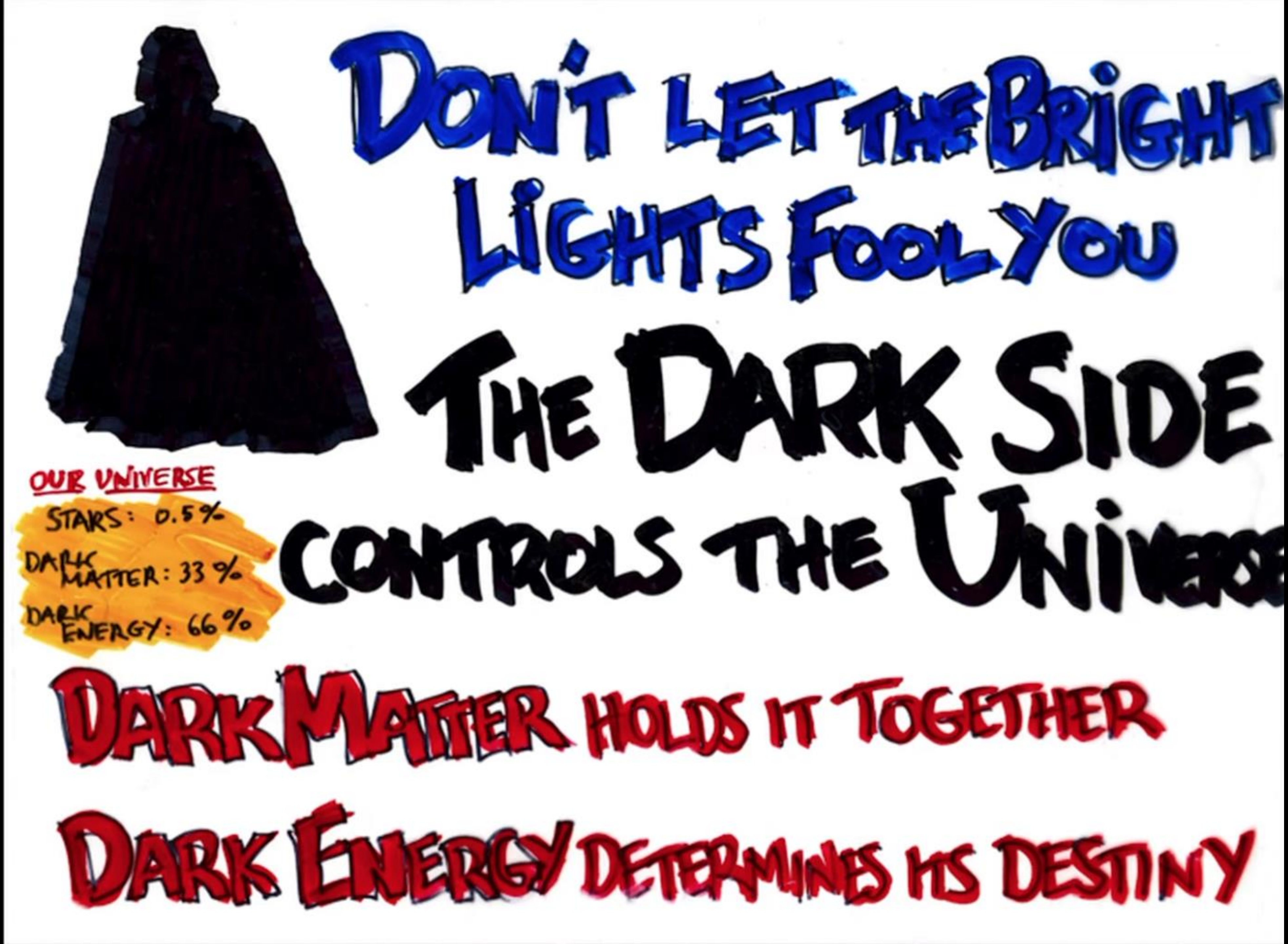
Who saved us from a complete annihilation?

Hitoshi Murayama

Cosmic web of Dark Matter Decorated by Stars



Simulation of the large-scale structure of the universe, showing dense clusters of galaxies, filaments, galactic walls and voids.
Credit: Uchuu project.



Michael Turner

the Higgs discovery does not close the book, it opens a whole new chapter of exploration, based on precise measurements of its properties, which can only rely on a future generation of colliders

Collier options – (some of) the tools of the trade

Circular e+e- Colliders

- Clean collisions – good for precision
- Multi-pass – high luminosity
- Energy eventually limited by synchrotron radiation
- Multiple Interaction Points

Reuse tunnel

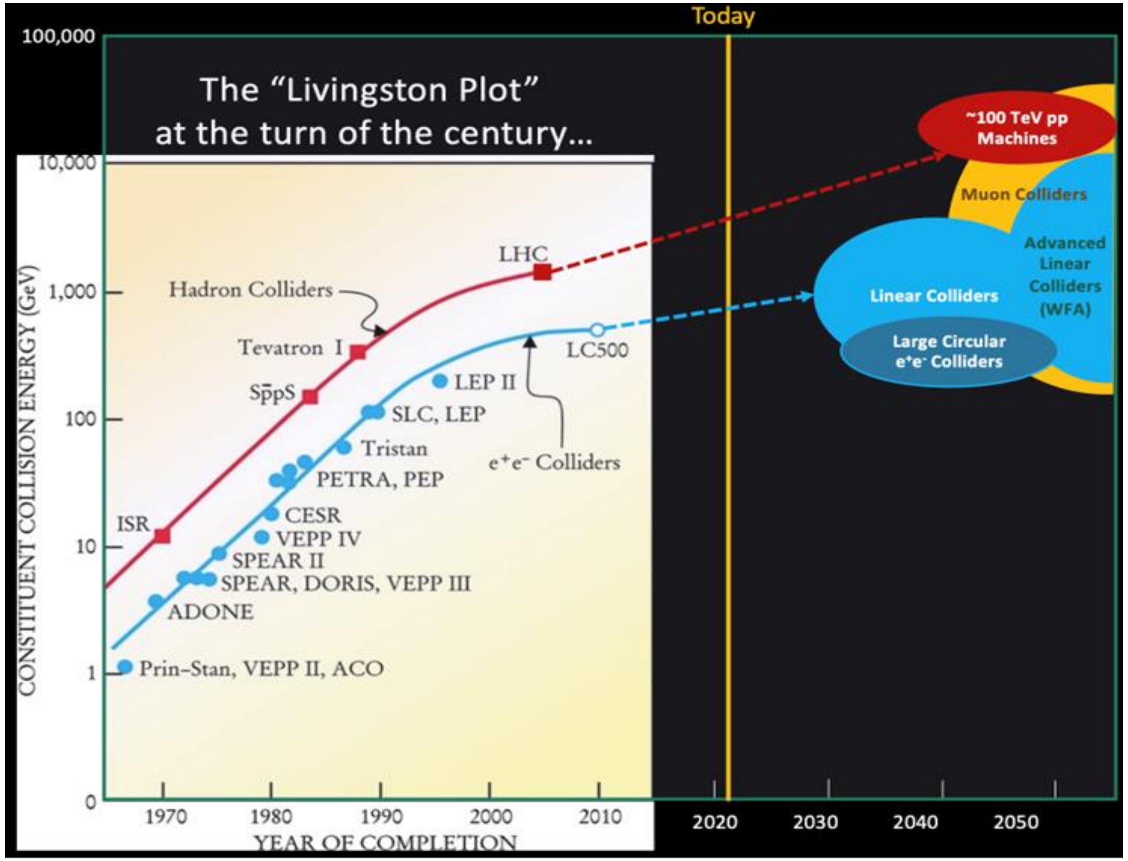
Hadron (protons, ions) colliders

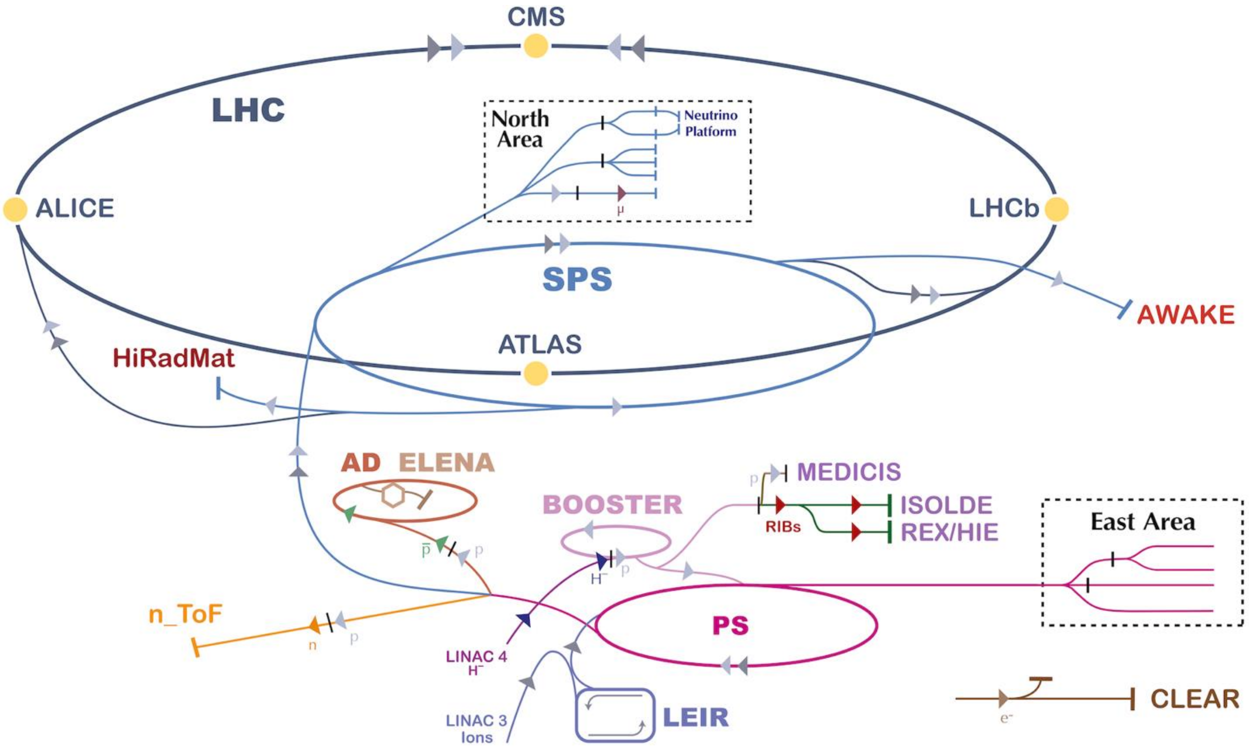
- Messy collisions
- High luminosity
- High energy – good for discovery

Linear e+e- Colliders

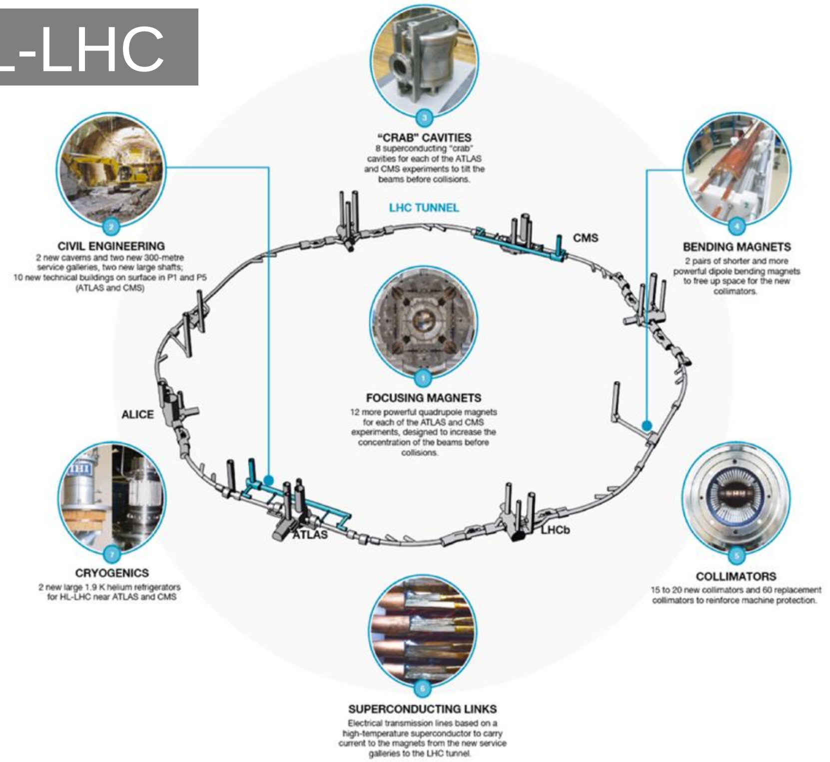
Extend

- Insignificant synchrotron radiation
- 1 Interaction Point, 1 or 2 experiments
- Single pass, nanometre beam sizes at IP

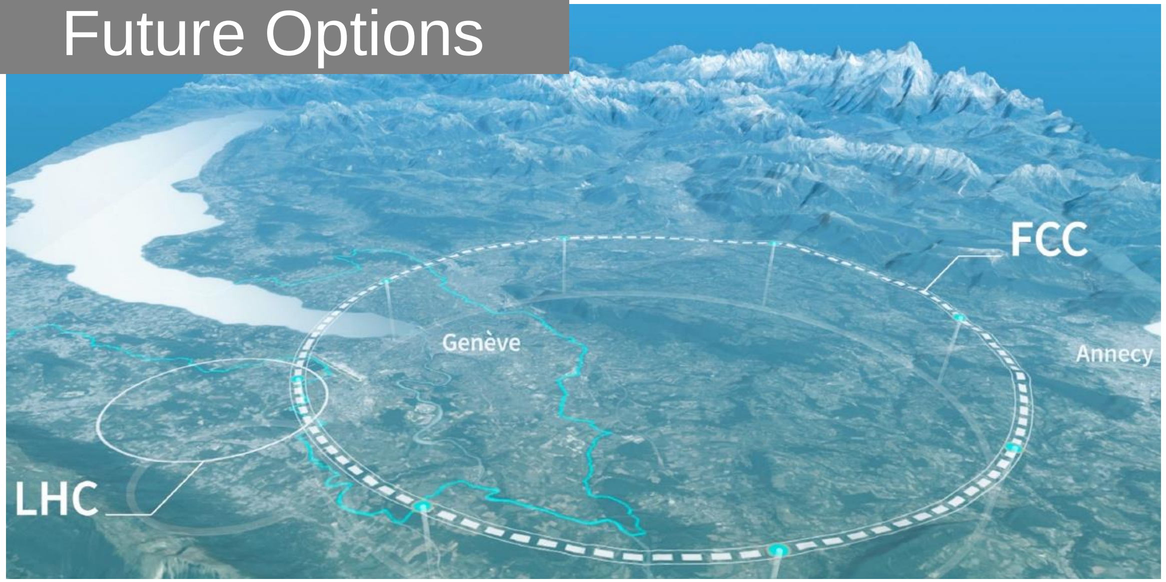




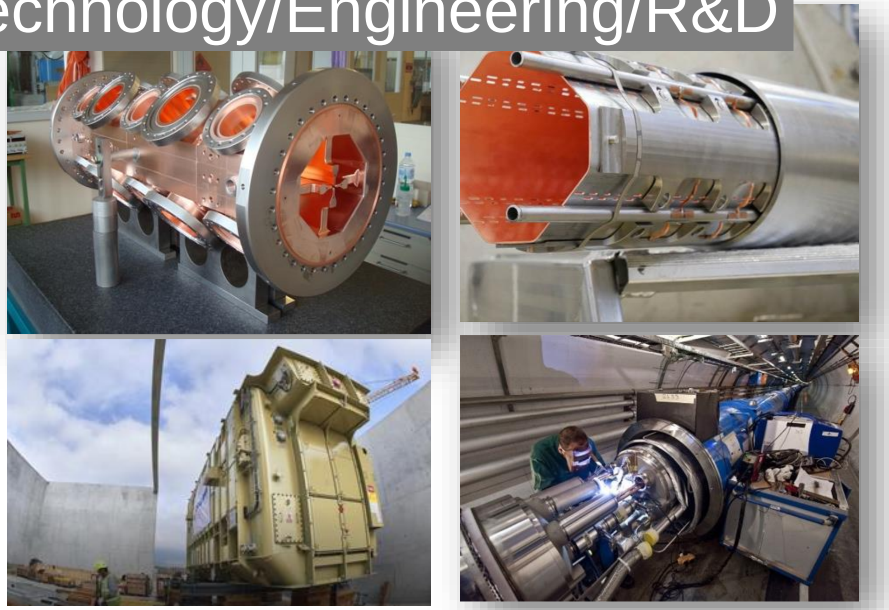
HL-LHC

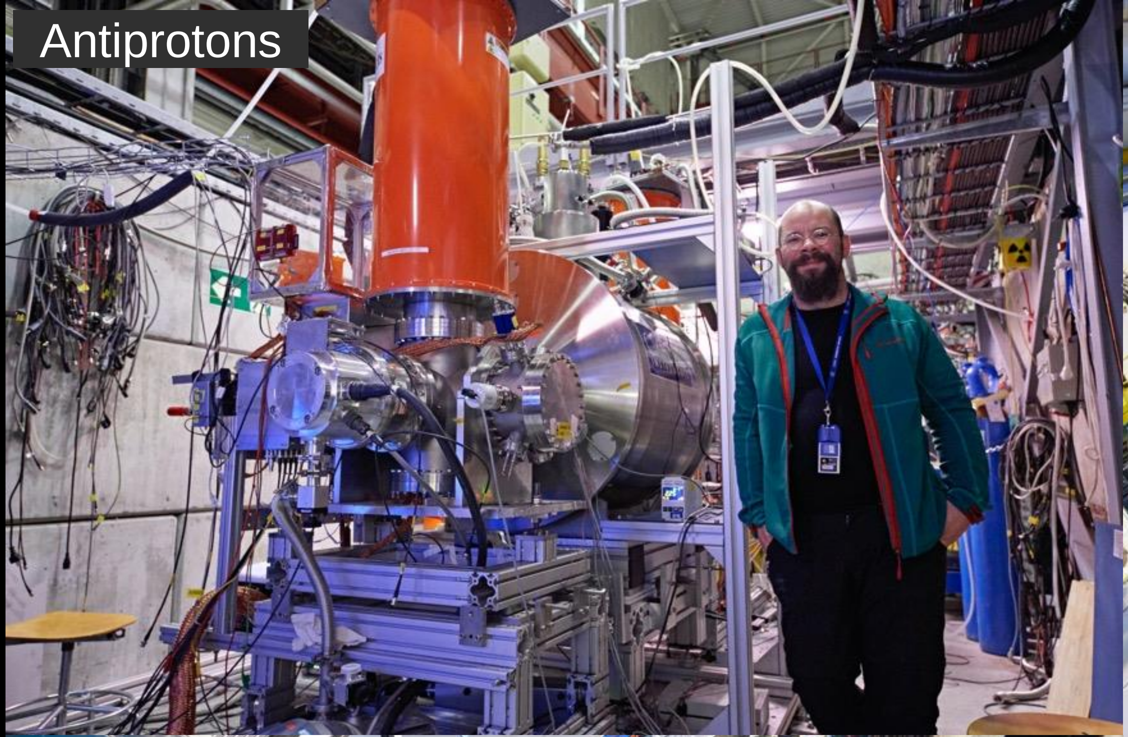


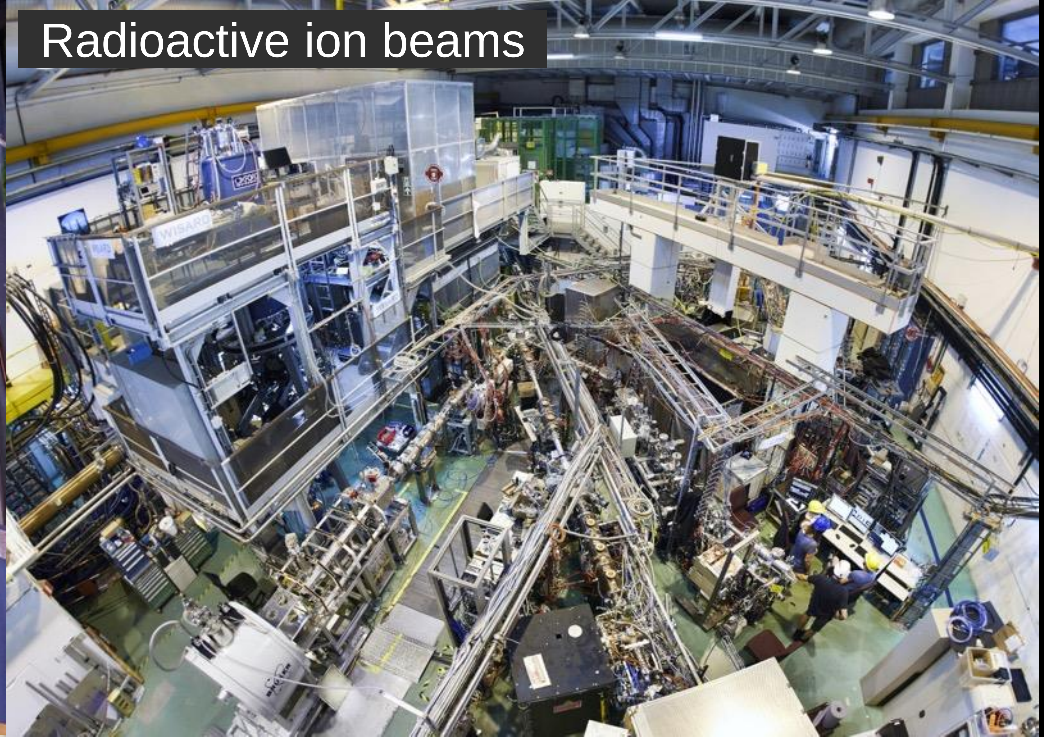
Future Options



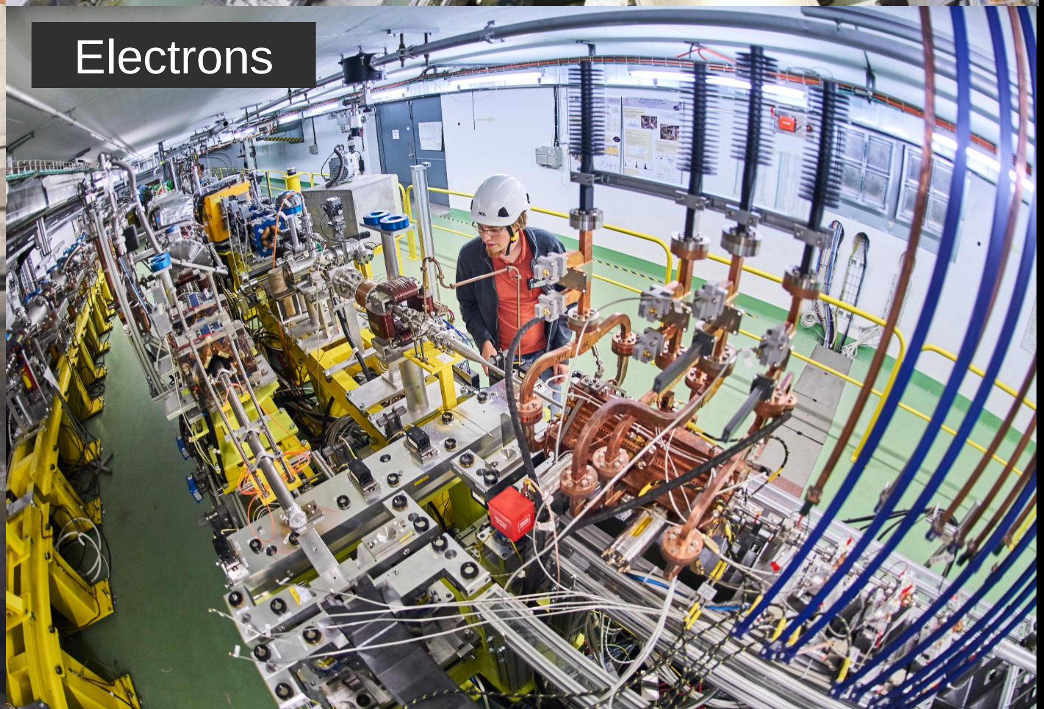
Technology/Engineering/R&D

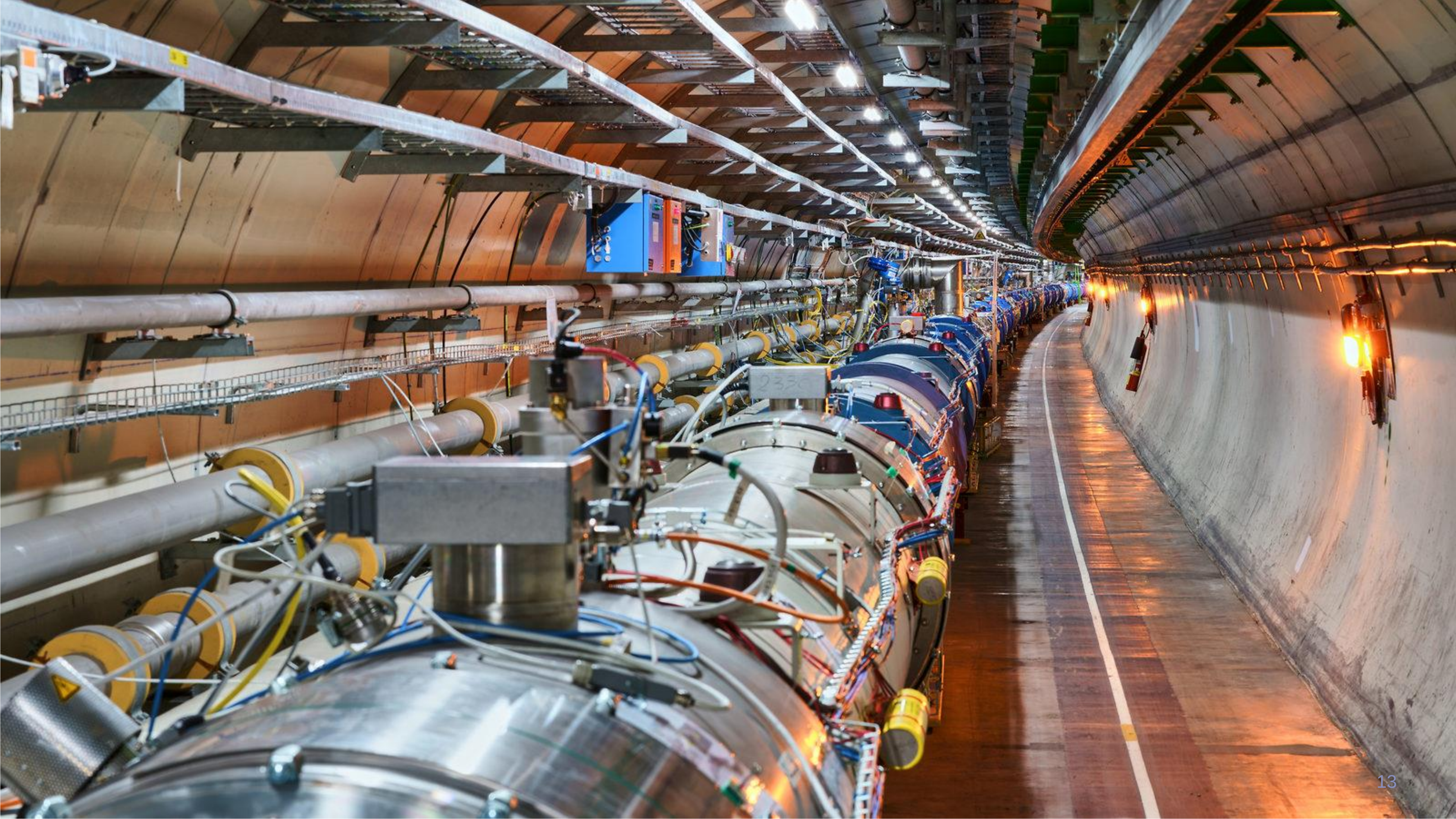



Antiprotons


Radioactive ion beams

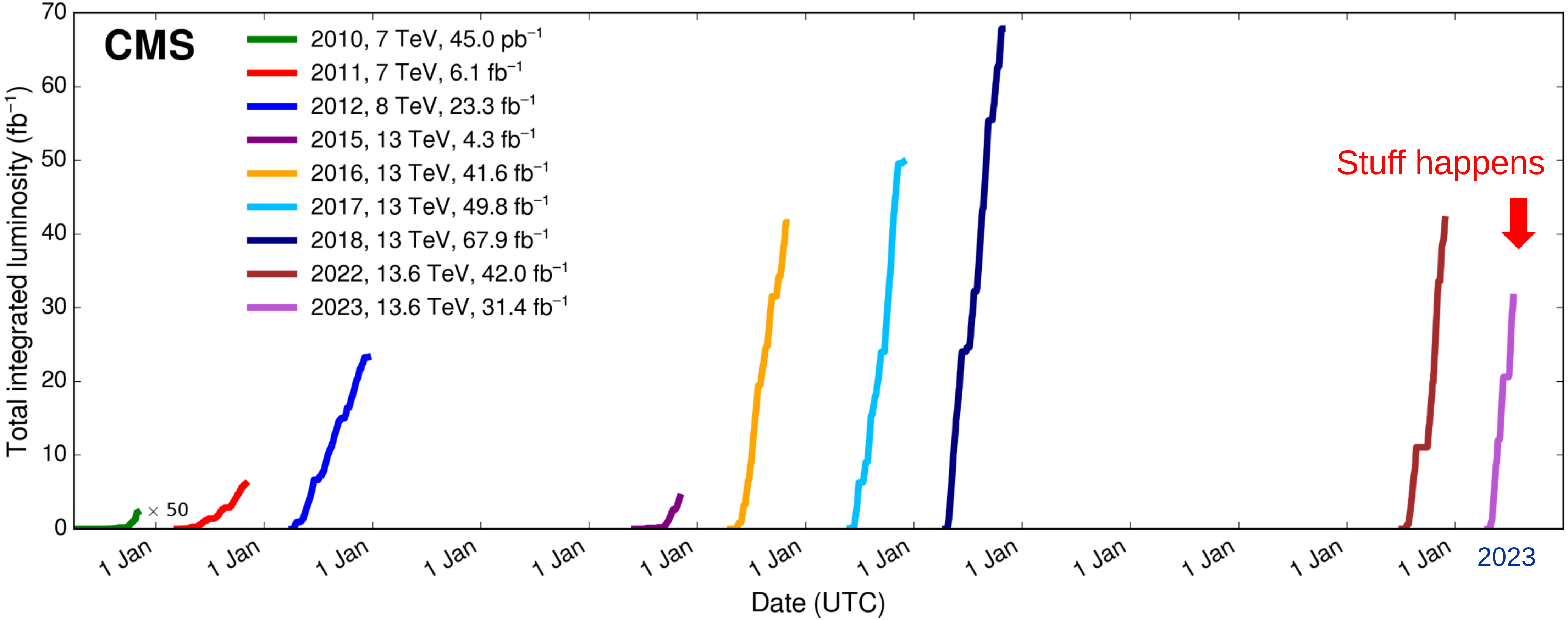

Protons


Electrons



LHC - not bad, some issues…

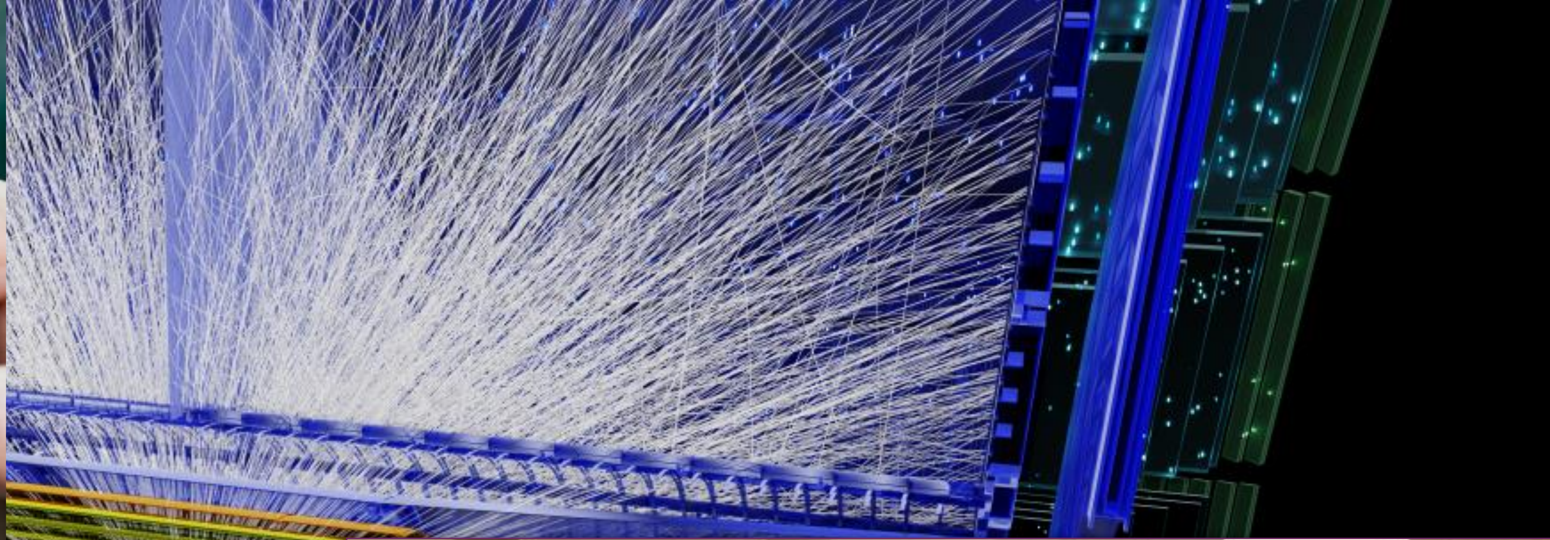
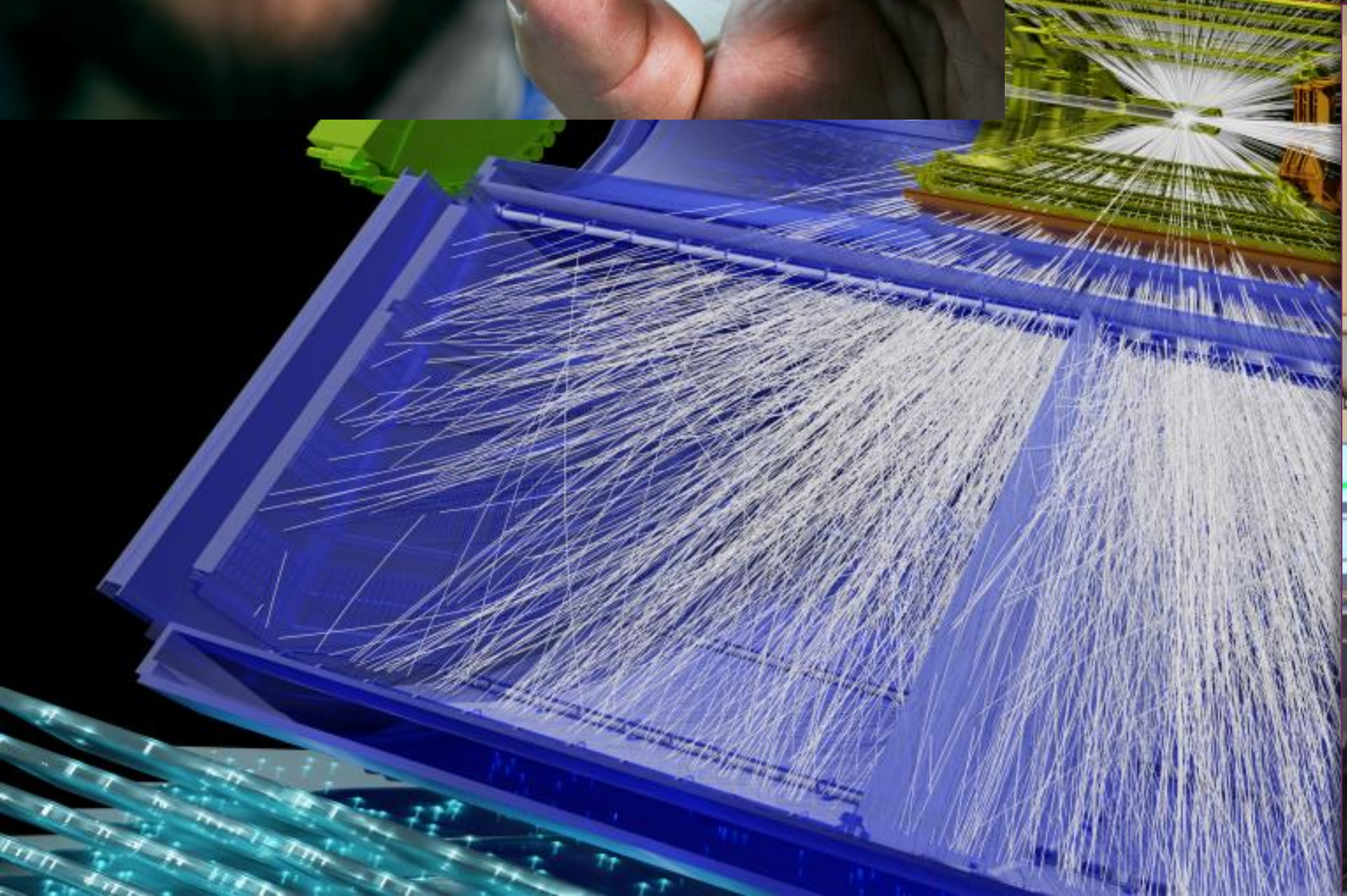
Integrated Luminosity



2010-2012
Run 1: 29 fb^{-1}

2015-2018
Run 2: 164 fb^{-1}

2022-2025
Run 3: 73 fb^{-1}

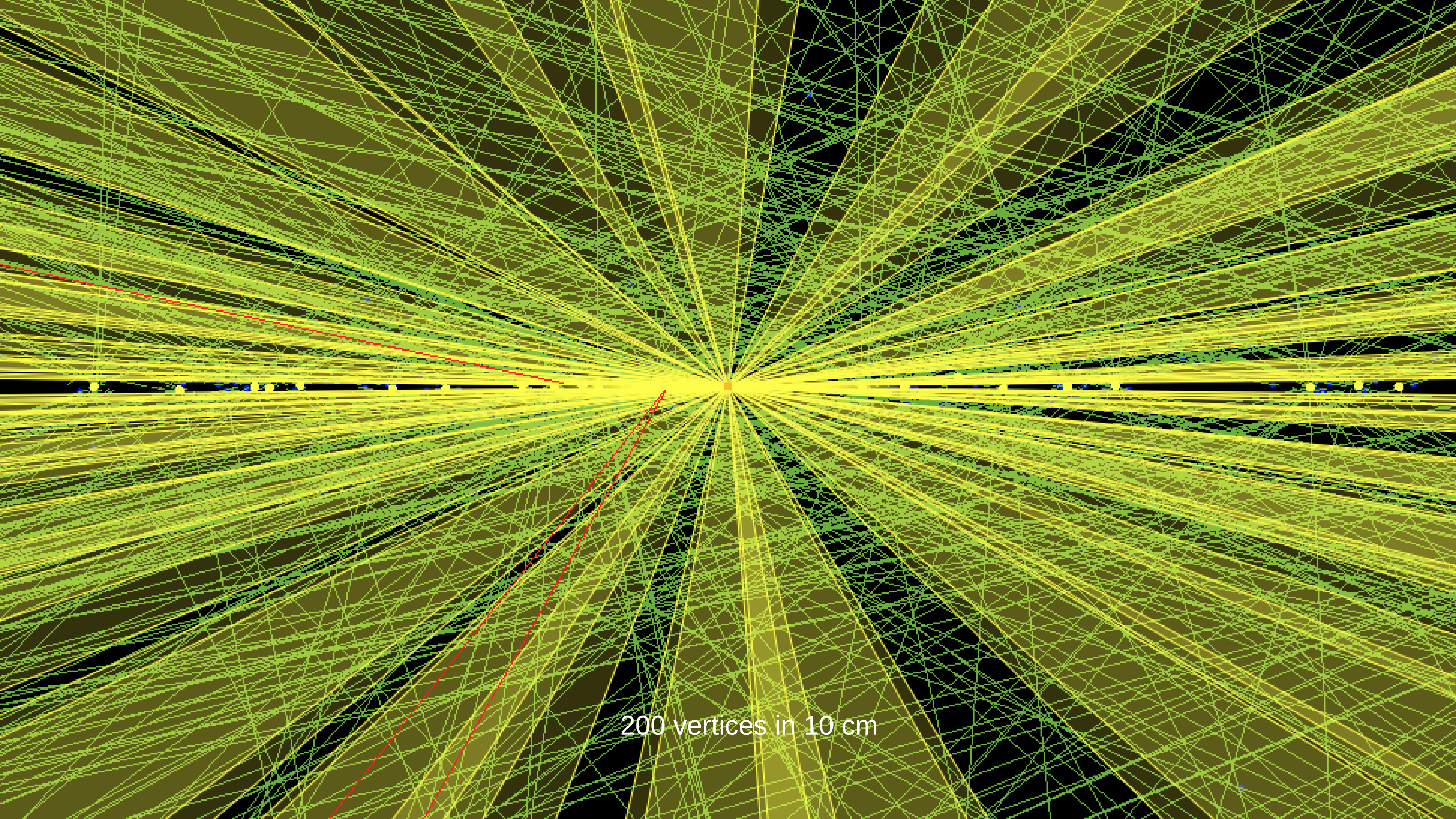
CERN

HL-LHC - goals

Prepare machine for operation beyond 2025 and up to ~2041

Operation scenarios for:

- Total integrated luminosity of **3000 fb^{-1}** in around 10-12 years
- An integrated luminosity of **~250 fb^{-1} per year**
- **Nominal:** levelled luminosity of $5 \times 10^{34}\ cm^{-2}s^{-1}$ (events/crossing ~130)
- **Ultimate:** levelled luminosity of $7.5 \times 10^{34}\ cm^{-2}s^{-1}$ (events/crossing ~200)


200 vertices in 10 cm

HL-LHC technology landmarks

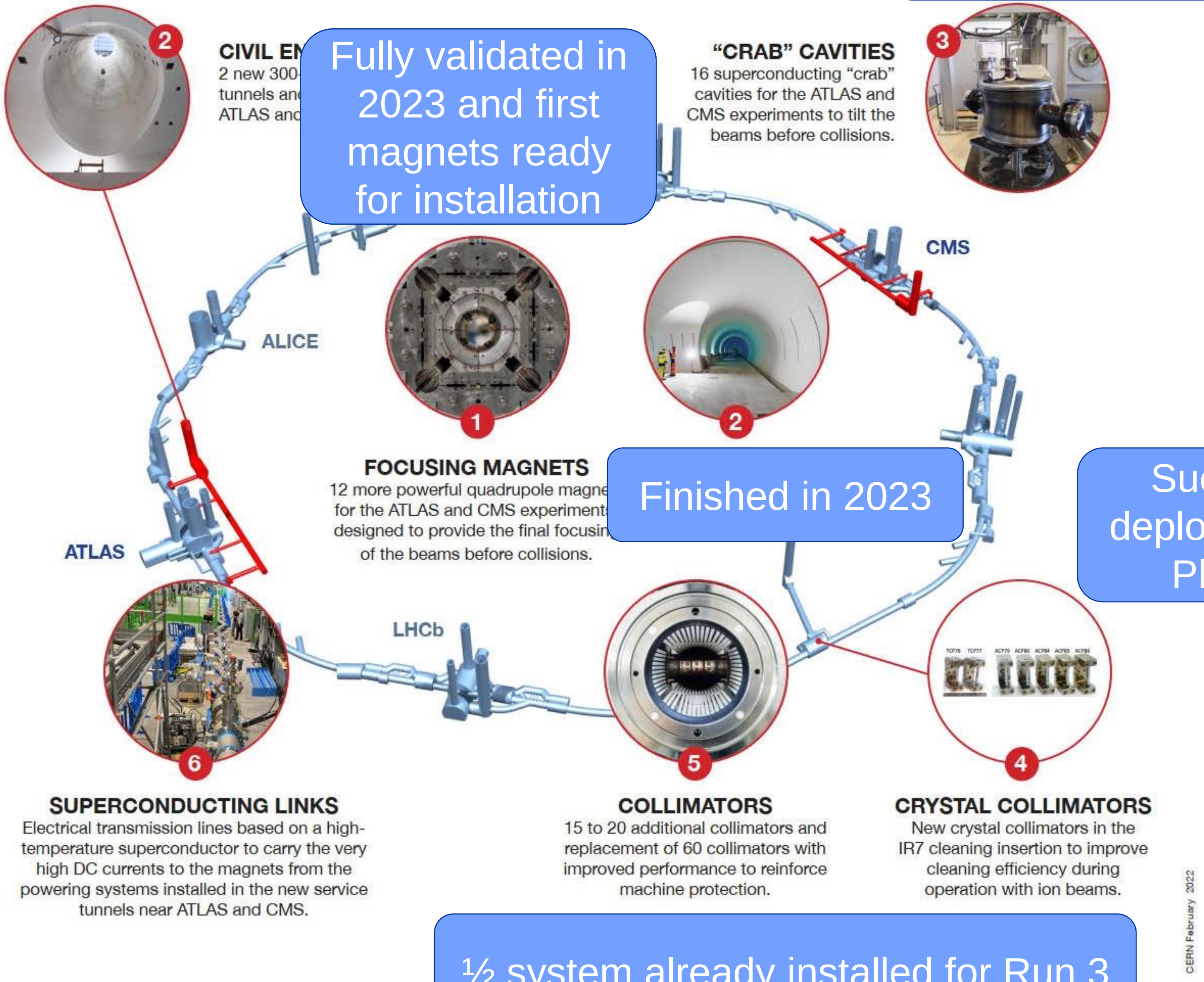
Series production in Industry well underway

Finished in 2023

Fully validated in 2023 and first magnets ready for installation

HL-LHC has many challenging novelties covering a broad technology spectrum

Technology intensive project!



Finished in 2023

Successfully deployed in 2023 Pb-Pb run

Complete Prototype System installed in SM18 and under test

½ system already installed for Run 3

HL-LHC 2023 HIGHLIGHTS

HL-LHC 2023 HIGHLIGHTS
HL-LHC 2023 HIGHLIGHTS

Future Options at CERN

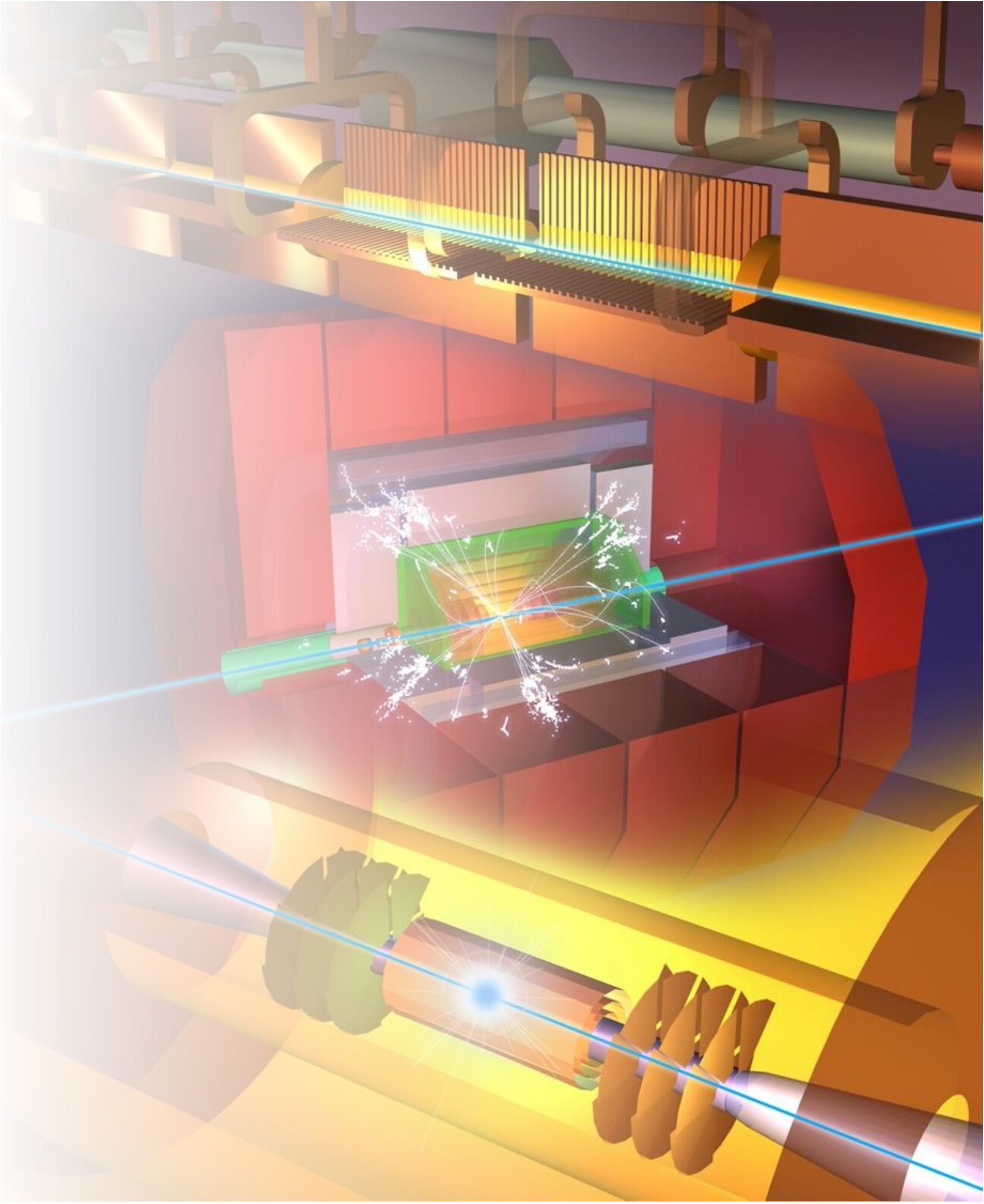
Within specified timeframe (start ops. ~2045)

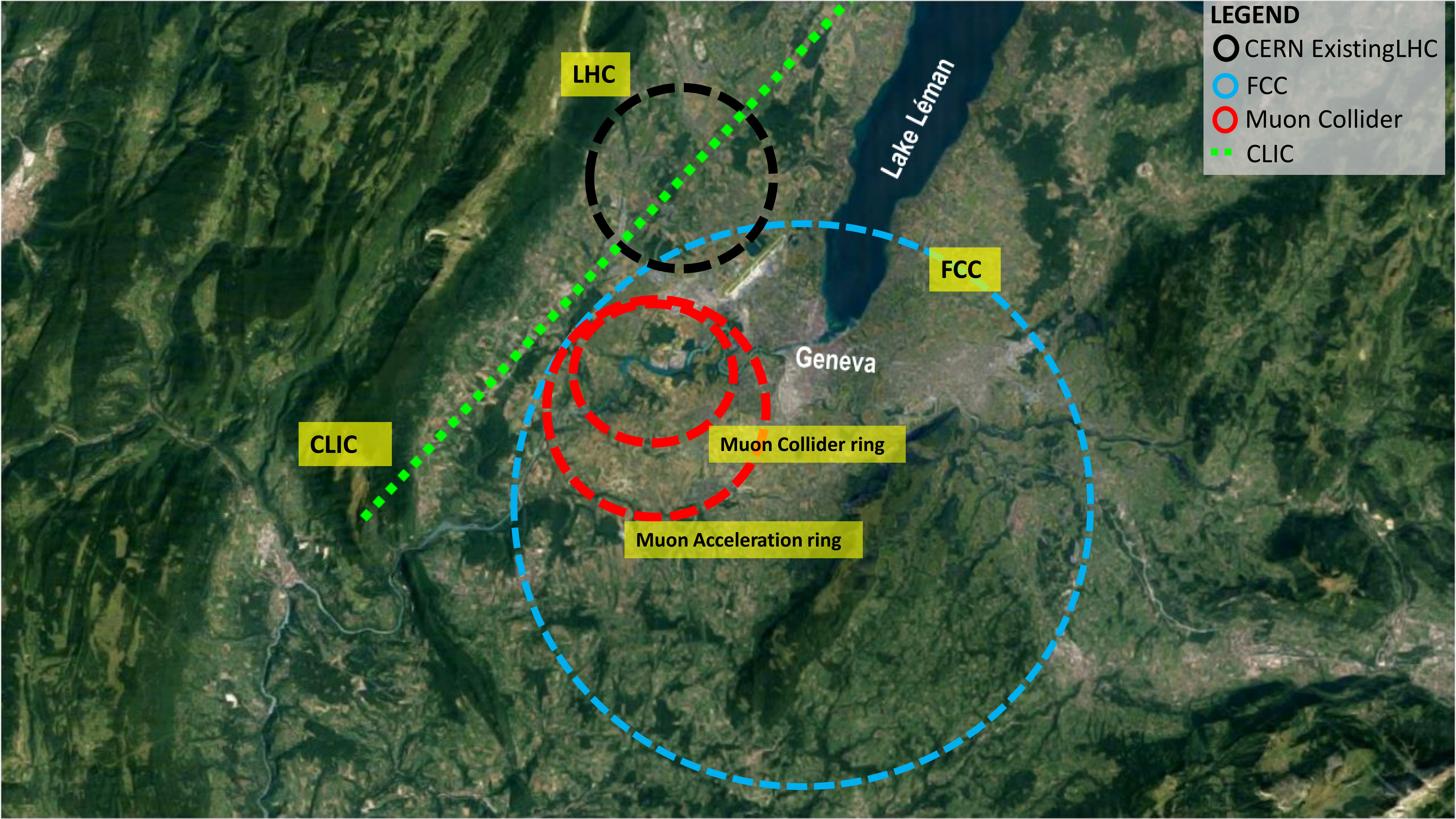
- FCC-ee (electron-positron)
- CLIC (electron-positron)

Outside specified timeframe

- FCC-hh (protons) - in FCC-ee tunnel
- Muon Collider (muons!)

Options possibly in timeframe not at CERN: ILC, CEPC, C^3



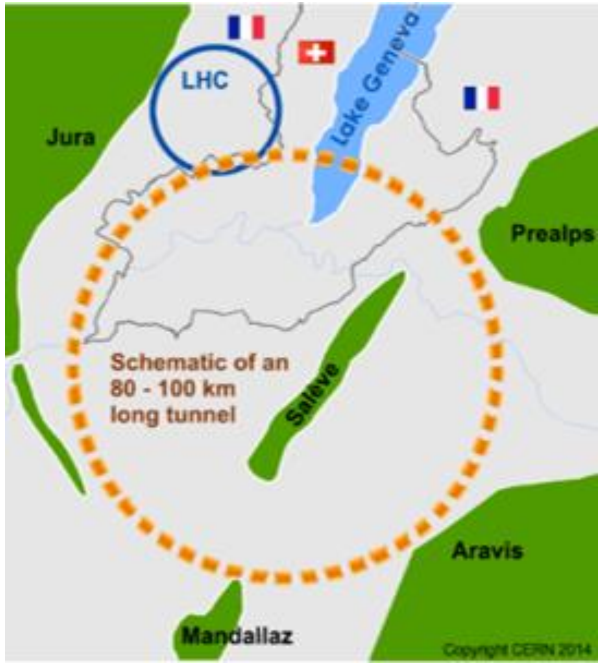

LEGEND
CERN ExistingLHC
FCC
Muon Collider
CLIC
LHC
Lake Léman
FCC
Geneva
CLIC
Muon Collider ring
Muon Acceleration ring

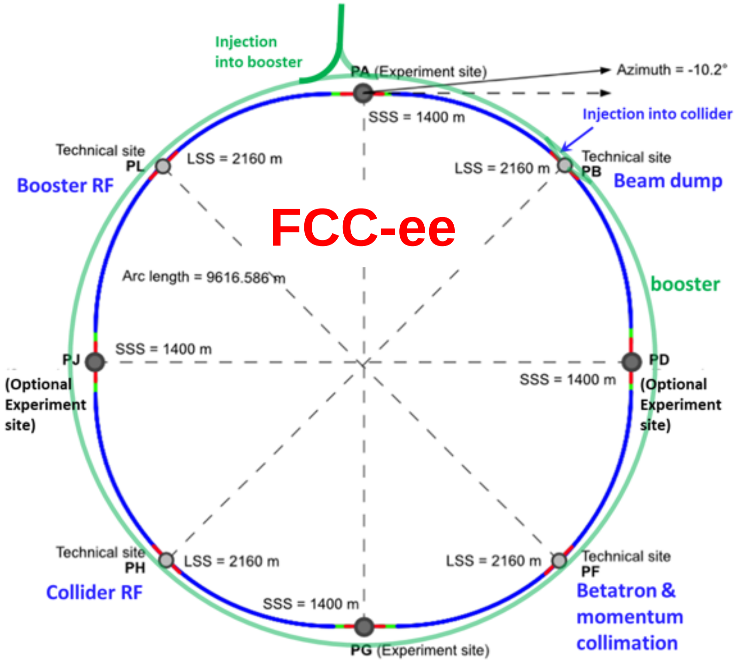

Switzerland
LHC
France
FCC
91 km circumference
LHC
PS
SPS
FCC

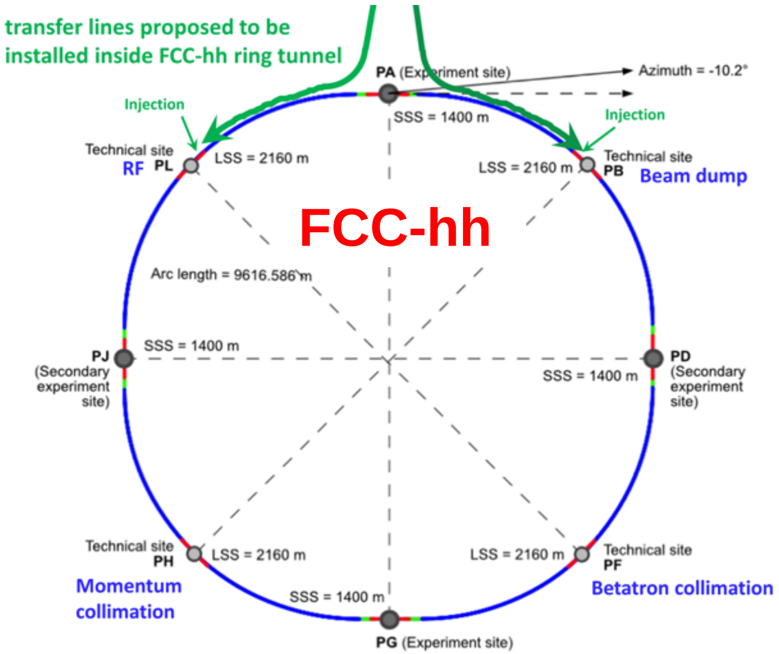
FCC Integrated Programme

Comprehensive long-term programme maximizing physics opportunities:

- Stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as a Higgs factory, electroweak & top factory at highest luminosities
- Stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, proton-proton with options







2020 - 2046 | 2048 - 2063 | 2074 +

Underground Civil Engineering Schematic

Tunnel Circumference: 90.7 km

Excavated vol: 6.2 Mm^3 (in the ground)

Access shafts: 12

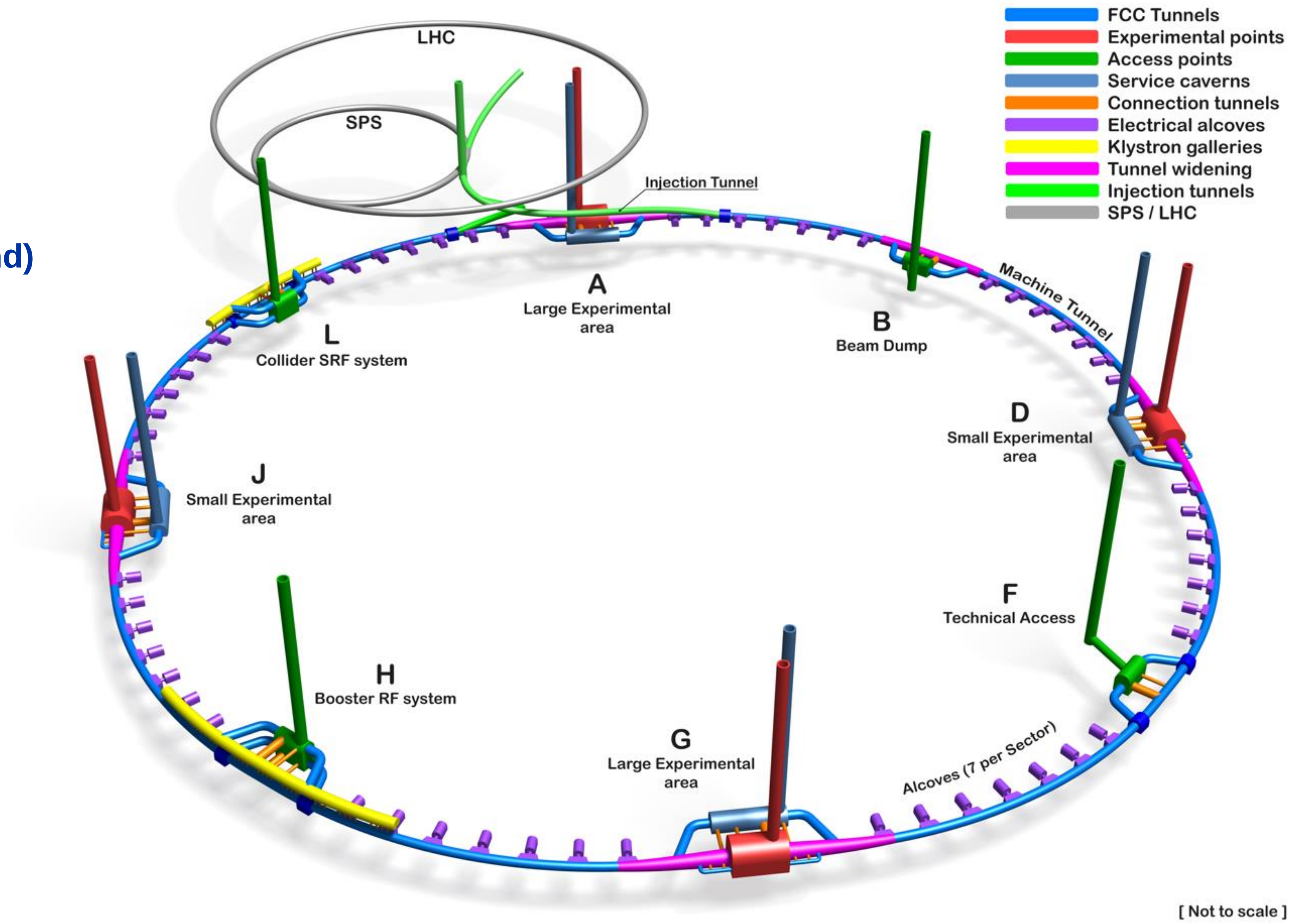
Large experiment areas: 2

Small experiment areas: 2

Technical points: 4

Deepest shaft: 400 m

Average shaft depth: 243 m



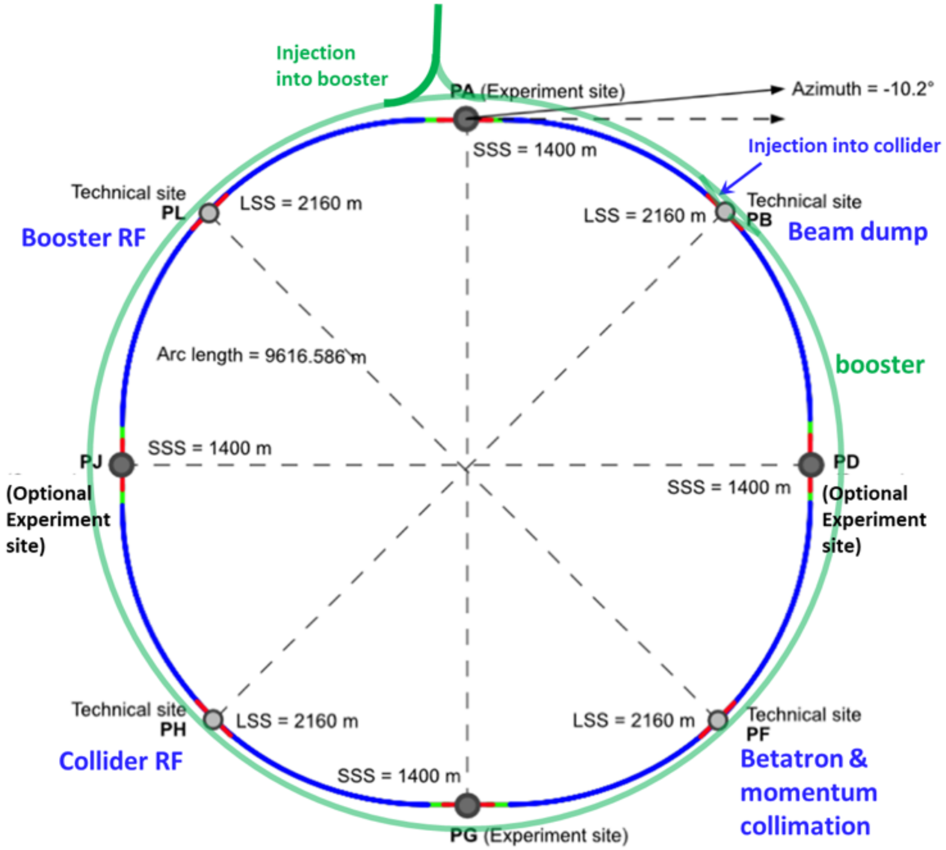
FUTURE CIRCULAR COLLIDER

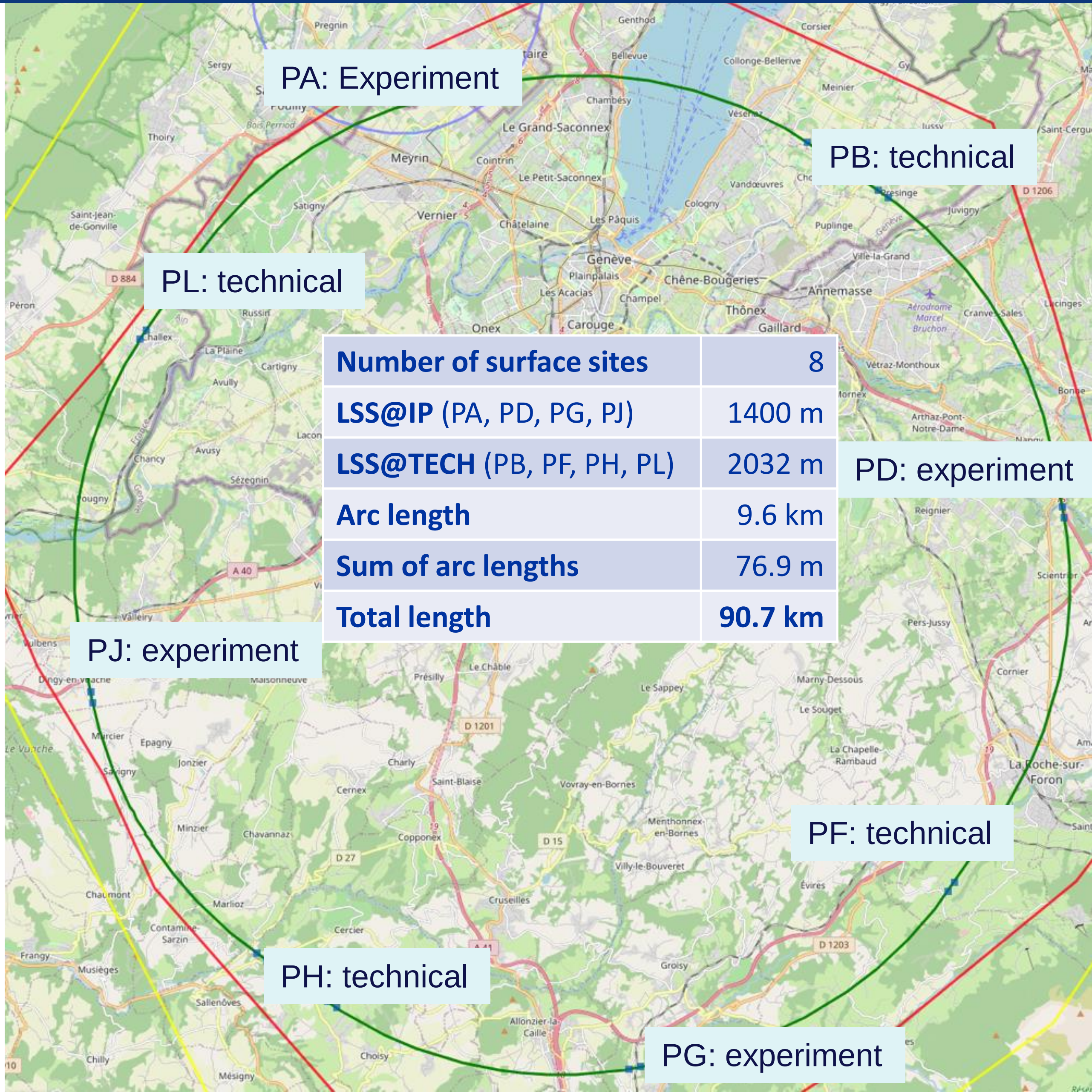
Feasibility study (2021 – 2025) ongoing

Major achievement: optimization of the ring placement
Layout chosen out of ~100 initial variants, based on geological, urban, environmental & infrastructure constraints.

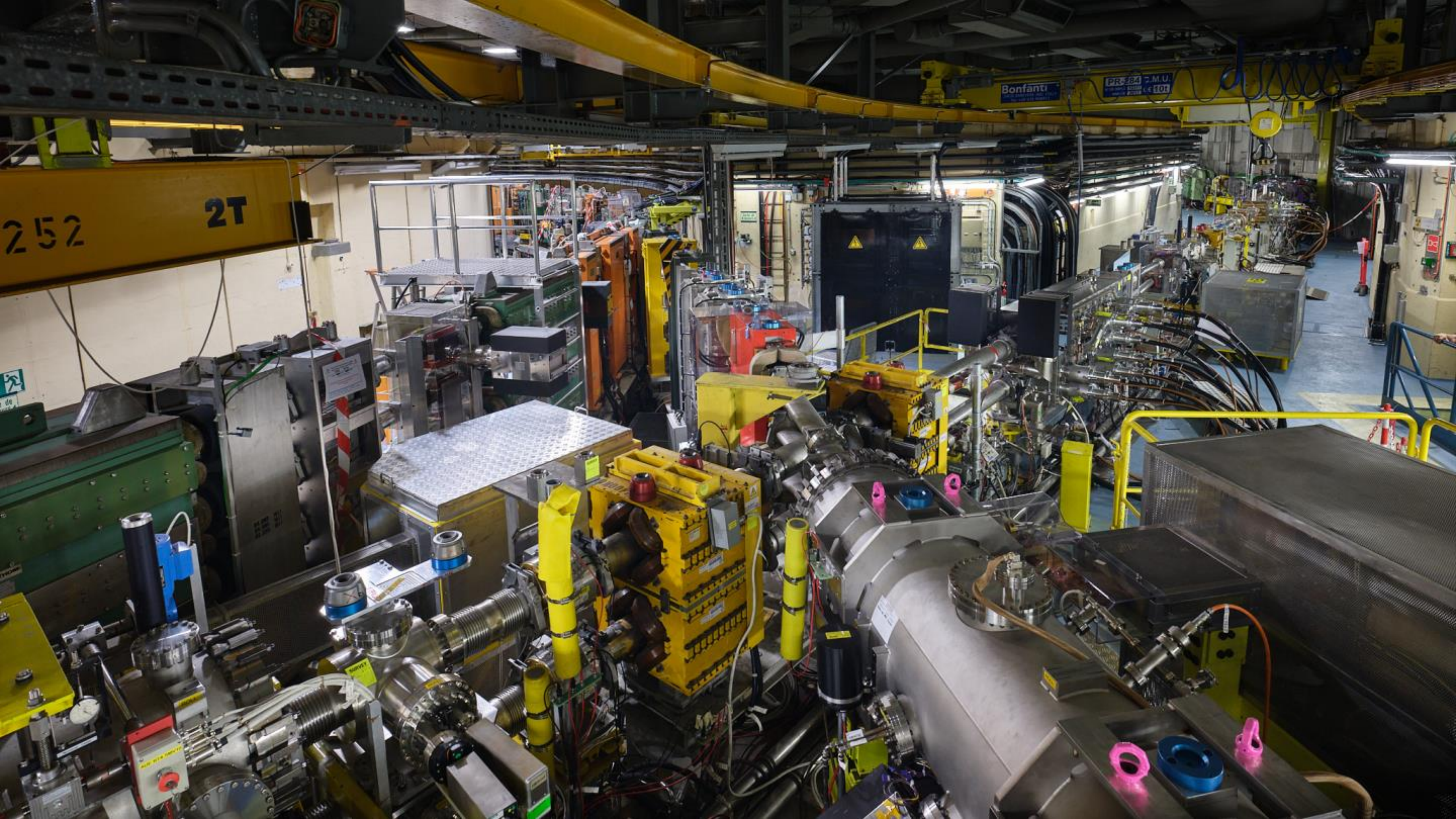
Baseline: 90.7 km ring, 8 surface points

Whole study now adapted to this placement





Number of surface sites	8
LSS@IP (PA, PD, PG, PJ)	1400 m
LSS@TECH (PB, PF, PH, PL)	2032 m
Arc length	9.6 km
Sum of arc lengths	76.9 m
Total length	**90.7 km**


252
2T
Bonfanti

Technology (briefly!)

Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders. It is also a powerful driver for many accelerator-based fields of science and industry.

The technologies under consideration include high-field magnets, high-temperature superconductors, high-gradient accelerating structures etc. etc.

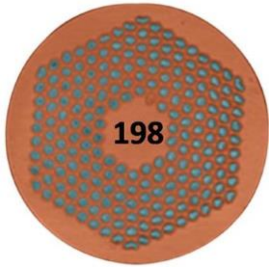
Challenging, highly technical domain

- Large scale, mass production to one off
- High performance – precision engineering
- Harsh environment - robustness and availability
- Affordability
- Sustainability
- Engage industry whenever possible

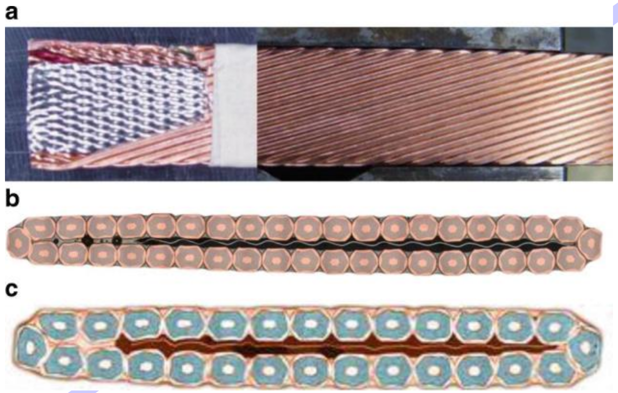
Targets
Beam Incepting Devices
Beam dumps
Collimators
Beam instrumentation
Radiofrequency
Low temperature superconductors
High temperature superconductors
Cryostats
Superconducting magnets
Resistive magnets
Vacuum
Coatings
Cryogenics
Power converters
Rad-hard electronics
Precison timing
Robotics
Pulsed Power Engineering
Kickers
Septa
Fast electronics
Controls

HL-LHC Nb_3Sn magnets

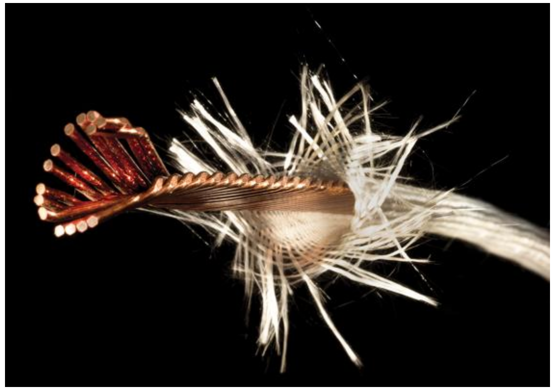
Wire reception tests



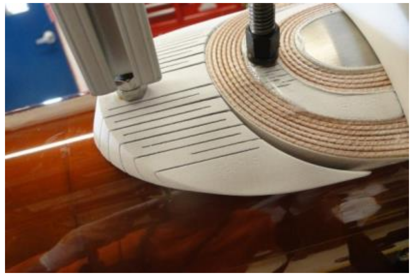
Cable manufacturing and reception tests



Cable insulation

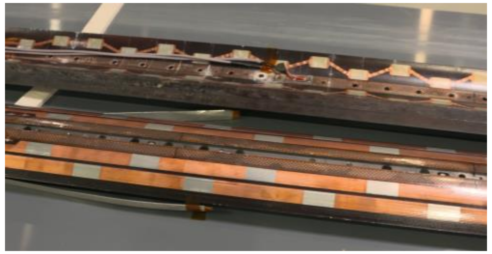


Coil winding



Coil reaction

Impregnation

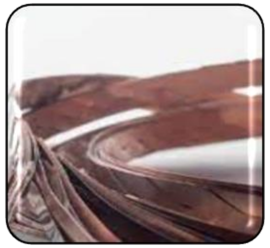


Collaring

Cold mass assembly

High Temperature Superconductors (HTS)

Energy Efficient Cryogenics

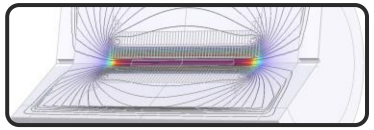


HTS Cables and Conductors

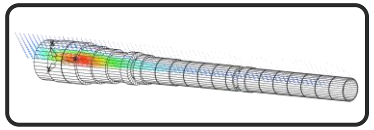
HTS Winding

Diagnostics and Controls

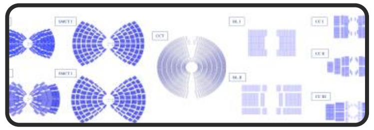
Radiation Hardness



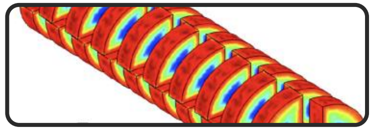
Ultra-High Field Solenoids



Large Bore High Field Solenoids



Accelerator Magnets

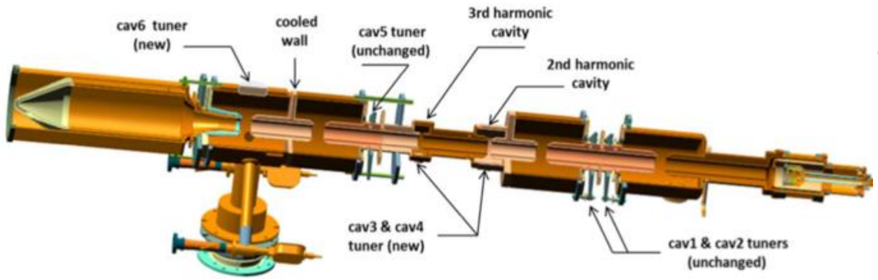


Undulators, Wigglers, Superbends

FCC-ee R&D examples

Efficient RF power sources

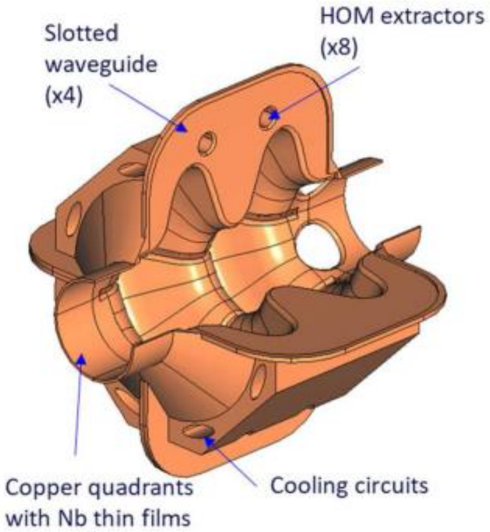
(400 & 800 MHz)



High efficiency klystrons & scalable solid-state amplifiers, FPC & HOM couplers, cryomodule, thin-film coatings

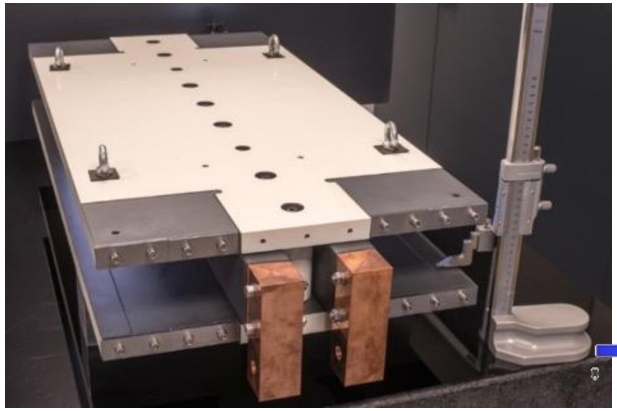
Efficient high-Q SC cavities

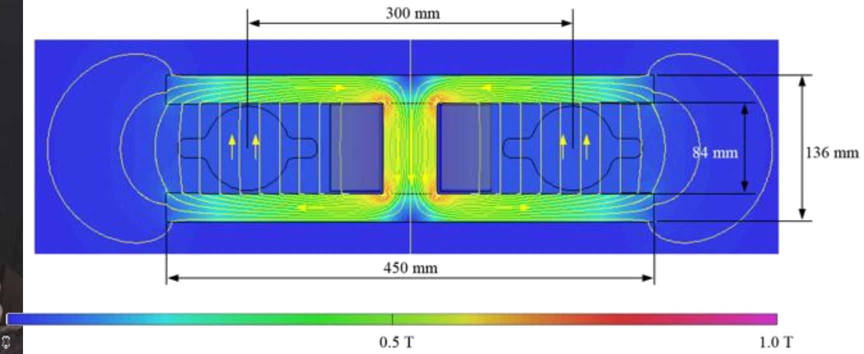
400 MHz 1 & 2 cell Nb/Cu, 4.5 K



Slotted Waveguide Elliptical cavity (SWELL) for high beam current & for high gradient

Energy **efficient** twin aperture **arc dipoles**



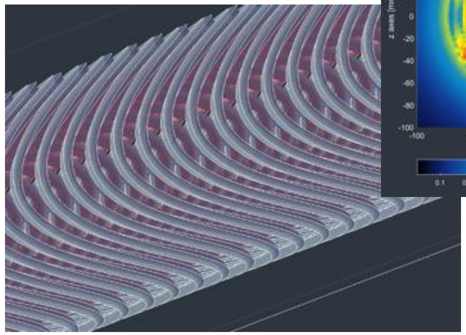


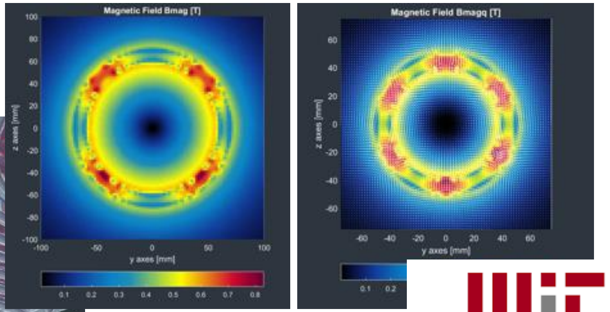
2840 x ~21 m -> 60 km

Under study: **HTS quads & sexts for arcs**

- **reduce energy consumption** by O(50 MW)

PAUL SCHERRER INSTITUT PSI

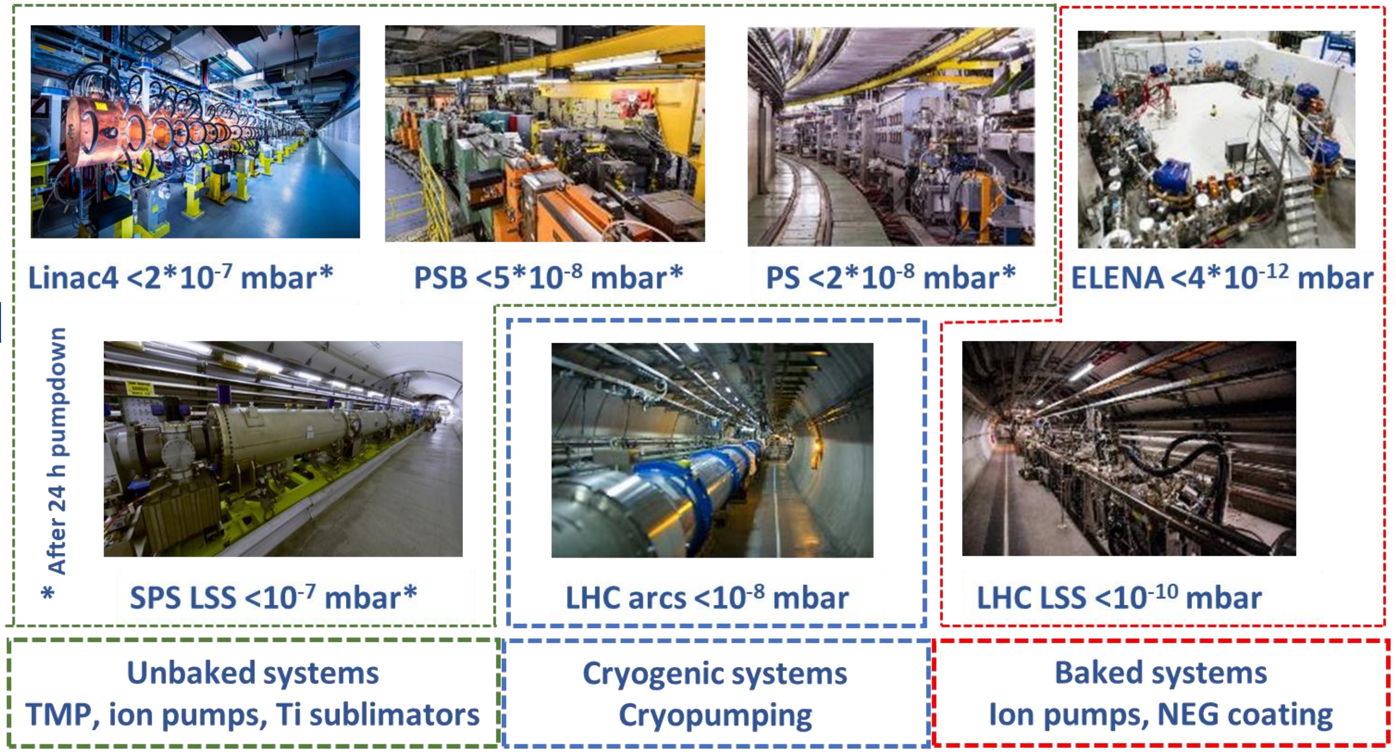


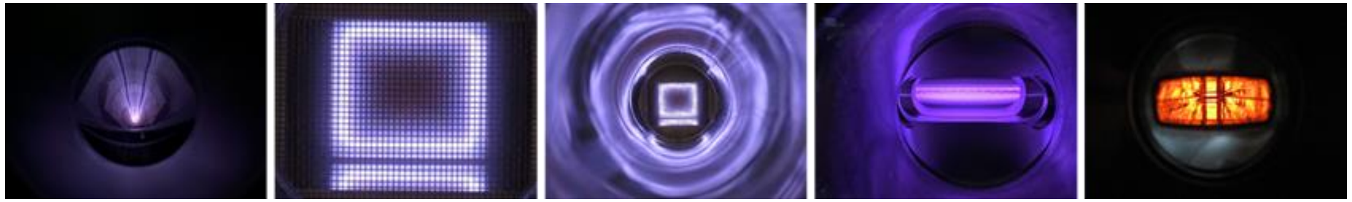


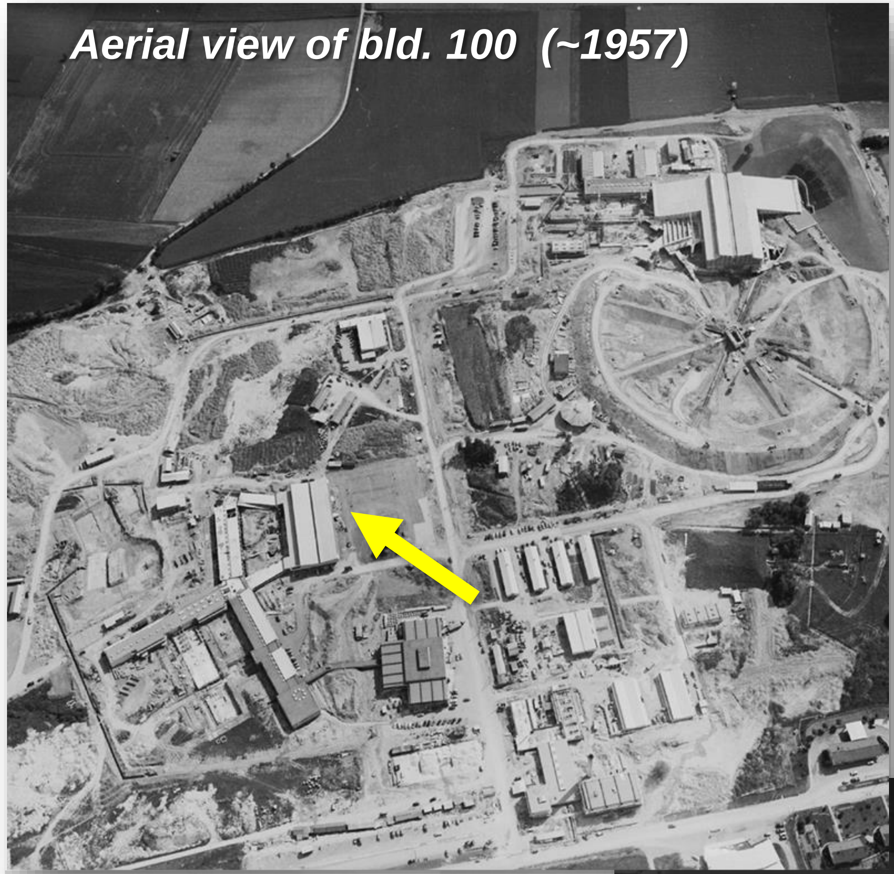
Massachusetts Institute of Technology

Largest Beam Vacuum System Worldwide

- **65 km UHV/XHV lines**
  - Multiple technologies used
- **Coatings and Plasma Processing an integral technology to obtain required vacuum with high intensity particle beams**
  - Thin film coating: evaporation, diode and magnetron sputtering
  - All types of materials including Nb, A15, amorphous-Carbon and Non-Evaporable Getter (NEG) coatings
  - Plasma and laser processing of surfaces
  - Removal of hydrocarbon contamination
  - Numerical simulations







Aerial view of bld. 100 (~1957)

MME Mechanical Workshop

A real **heritage of CERN** (1957-2022)
Guaranteeing 70 years know-how in **fabrication of mechanical components for accelerator and experiments**

Its core mission is to provide service to the Organization for:

- **Urgent needs** (repairing, tunnel interventions, urgent fabrication…)
- **Prototypes / proof of principle**
- **Multi-technology fabrication projects**

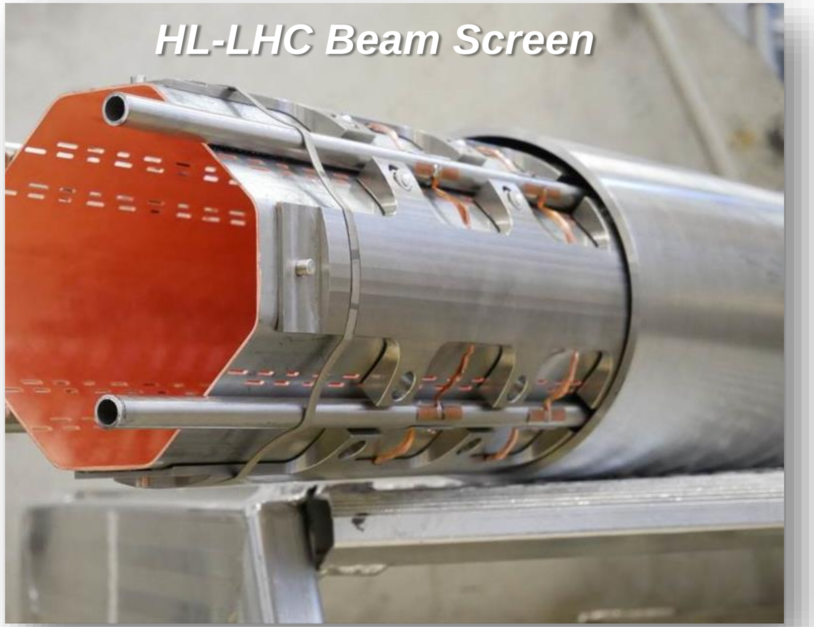
Knowledge Transfer to external collaborations and suppliers

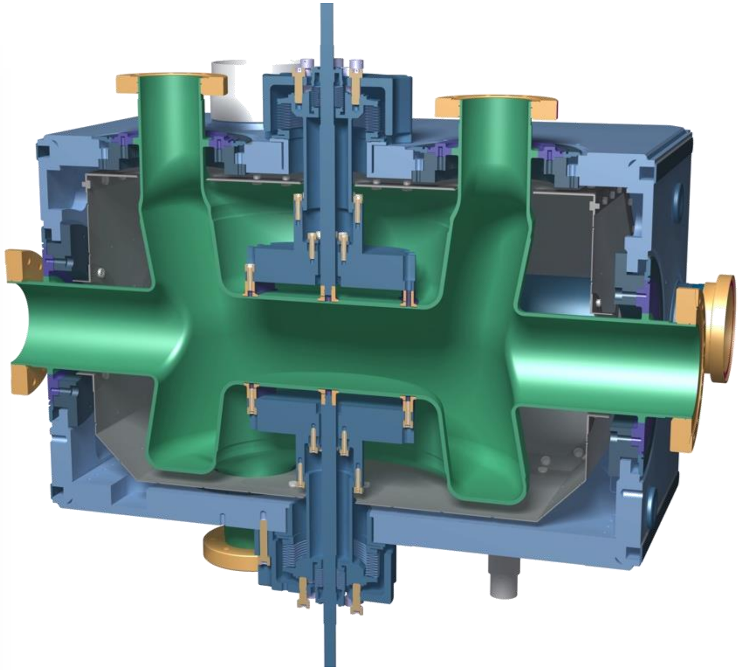
Some numbers…

- Total workshop surface of ~**4000** m2
- Featuring **40**+ conventional and unconventional machines
- ~**90** highly-skilled technical personnel
- Yearly turnover ~**2500** fabrication ‘’jobs”

Multi-technology Components

Most of the equipment produced calls for (simple to) **complex interlacing** of different fabrication **technologies**





Jacketed DQW CRAB Cavity

Behind these pics….

- **800+ fabrication steps**
- **20+ technologies involved**

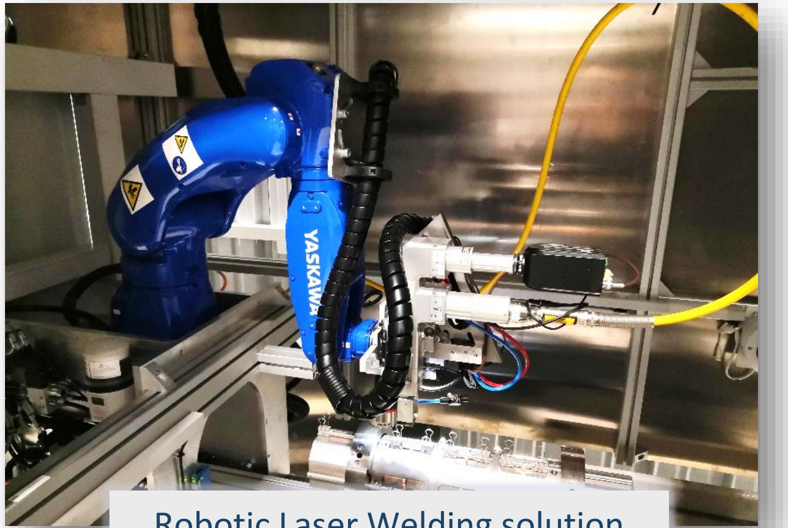
Sheet Metal Forming & Joining Tech.

Wide **variety of technologies & equipment**:

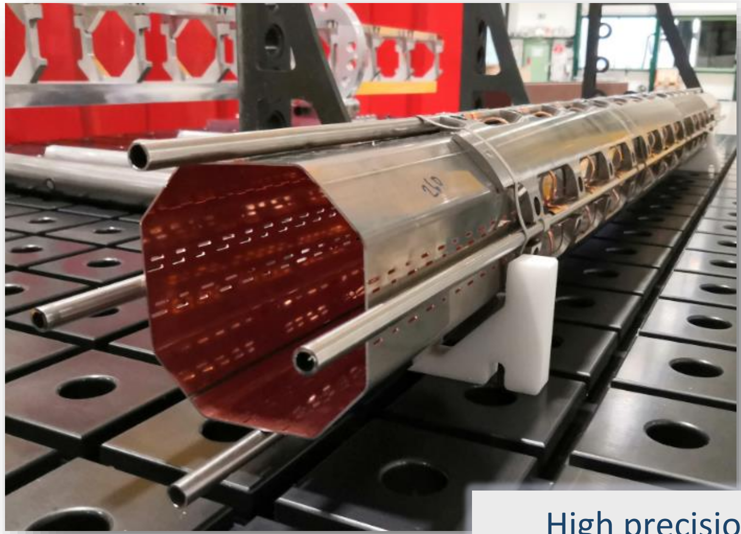
- Rolling, Bending, Deep Drawing, Spinning
- Arc welding (TIG, MIG, Plasma), Beam welding (Electron Beam & Laser Beam)
- Vacuum Brazing & Thermal treatments

Strong emphasis on welding/brazing quality (ISO 3834 approach)

Specific know-how for on-site interventions in accelerator complex and Experiments

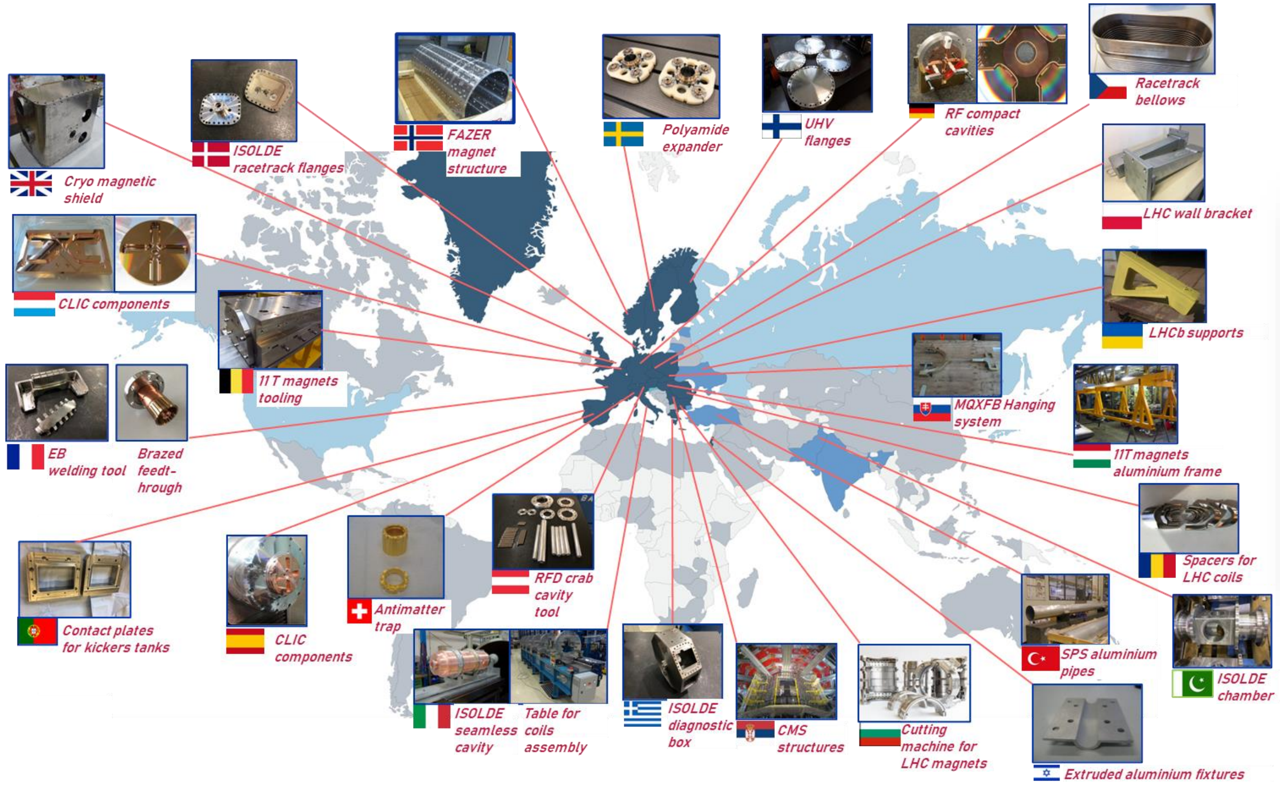


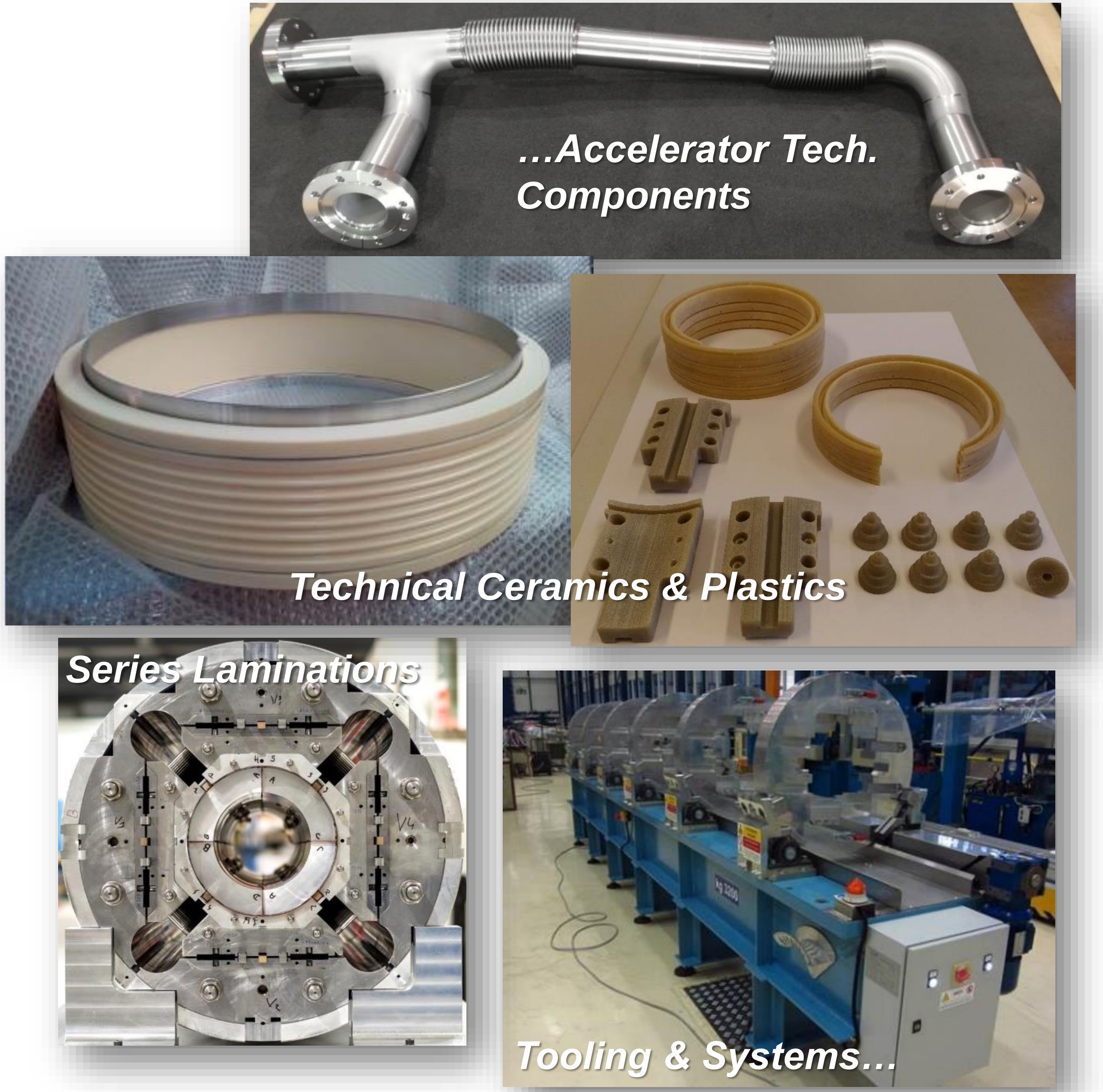
Robotic Laser Welding solution



High precision forming & welding

Technical Subcontracting





~40% semi-finished parts
~60% finished parts / turnkey products
900+ suppliers in all Member States

Full Complementarity with in-house portfolio…
…series… additional technologies

CERN as a Research Infrastructure

CERN evolved before the RI concept

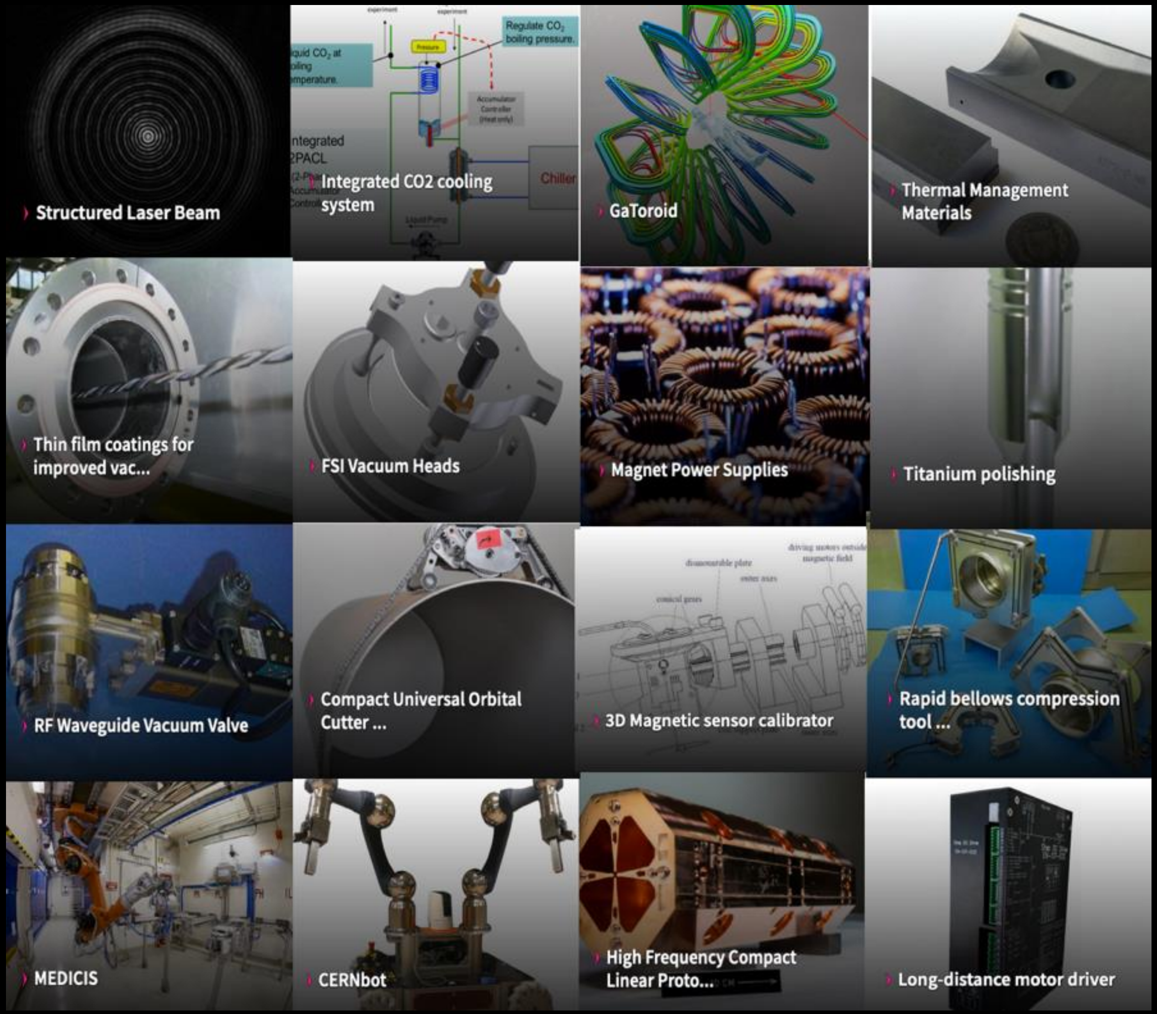
But nonetheless, thanks to its governance and funding model, many of the ingredients are there

Fortunate to enjoy a clear mission, budgetary autonomy, managerial discretion, transparency and openness

The RI paradigm is important and it is how we are viewed by, say, the European Commission

CERN is adapting to make its role as a RI more explicit

- Drive discovery and creation of knowledge
- Driver of innovation
- Integration of research communities
- Strong links to industry
- Collaborative ecosystem
- Societal impact
- Outreach and education



"Places like CERN contribute to the kind of knowledge that not only enriches humanity, but also provides the wellspring of ideas that become the technologies of the future"

Fabiola Gianotti

KT - examples

RENEWABLE AND LOW-CARBON ENERGY

Agreement with **GTT** to support the design of large cryostats for the maritime transportation of liquid hydrogen

GTT
Technology for a Sustainable World

CLEAN TRANSPORTATION AND FUTURE MOBILITY

Partnership with **Airbus** to assess HTS power distribution options for future electric/hybrid airplanes using liquid hydrogen

AIRBUS

CLIMATE CHANGE AND POLLUTION CONTROL

Collaboration with **ESA** Phi-lab to develop AI algorithms to analyse Earth Observation space images for climate monitoring

esa

SUSTAINABILITY AND GREEN SCIENCE

Project with **ABB** to improve energy efficiency of CERN cooling and ventilation with smart sensors and digital twins

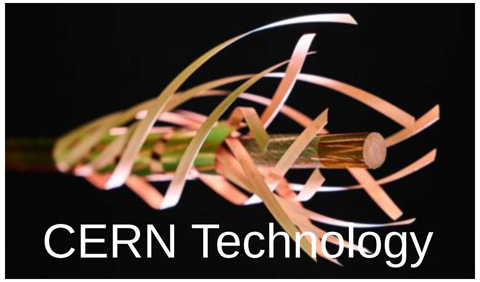
ABB

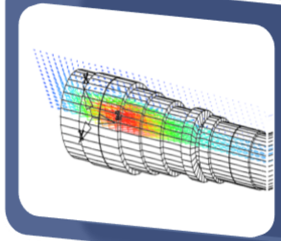
Fusion Technology Coordination Unit

KT initiatives

Public sector:
- ITER
- EUROFusion
- F4E
- UKAEA
- …

Private sector:
- Gauss Fusion
- Tokamak Energy
- Rolf Kind
- …

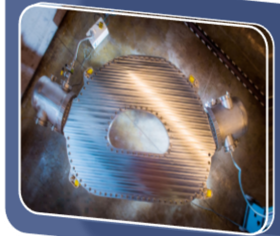




4 agreements signed

Gauss Fusion, Rolf Kind, Tokamak Energy, EUROFusion

2 agreements in negotiation



Contacts with 7 Parties who demonstrated interest

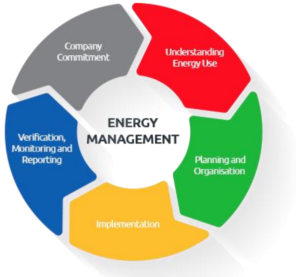
Sustainability - energy

LOW-CARBON ELECTRICITY

Pulling from French grid – low carbon (nuclear & renewables)

ISO 50001 CERTIFICATION

Energy Management - Improvement goals, continuous monitoring – EM plan & panels



POWER PURCHASE AGREEMENTS

Two photovoltaic PPA agreements being pursued for ~135 GWh/year ~10% of our supply

RESOURCE MANAGEMENT

PPAs (Nuclear, PV, aggregation) EU market reform, new contracts, water, gas, helium…

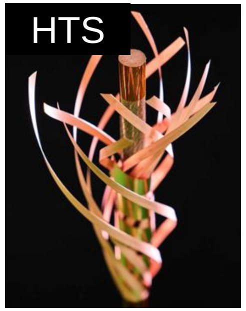
Sustainability - future

SUSTAINABLE DEVELOPMENT GOALS

Continue mapping on to Health, Education, Gender, Clean Energy, Innovation…

TECHNOLOGY

Compact, energy efficient…
Less, Better, Recover

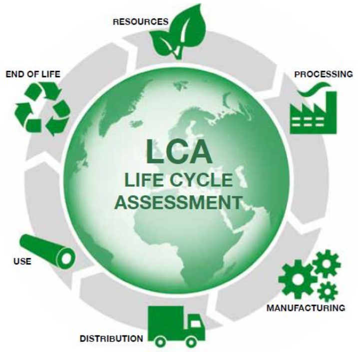


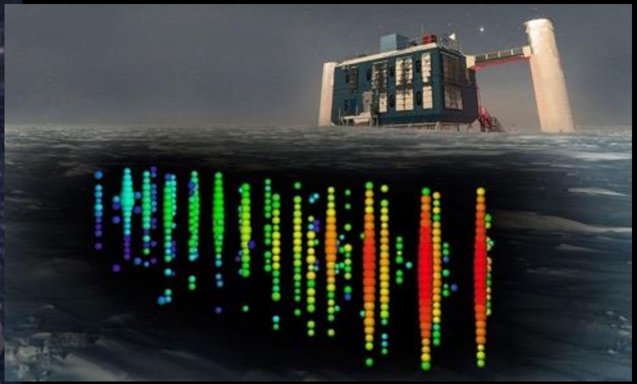
CONCRETE

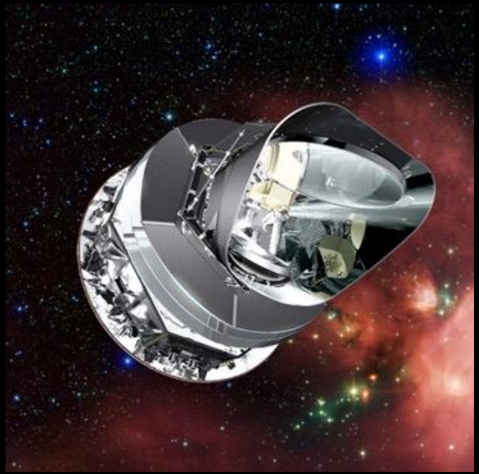
A big one for a project like the FCC: CE optimization, progress in industry…

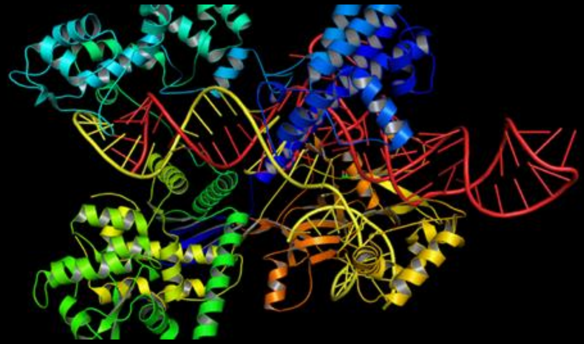
LIFE CYCLE ASSESSMENT

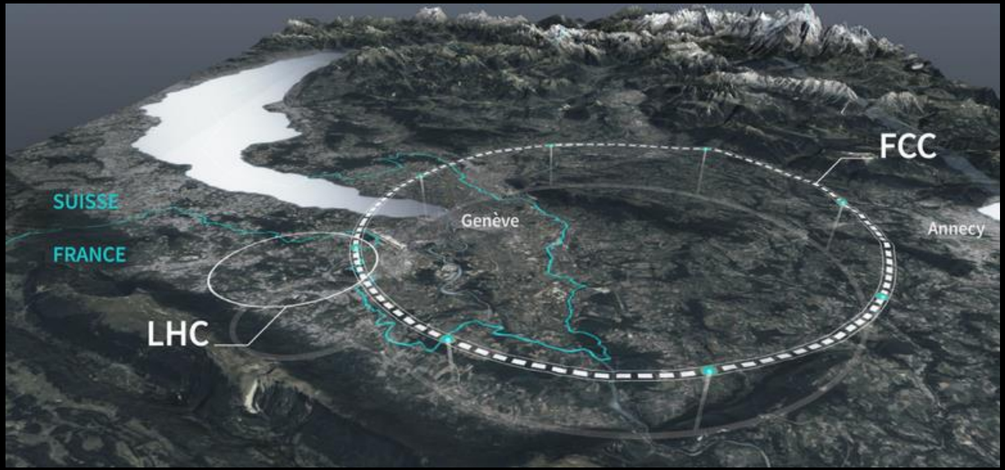
To be become part of our DNA











Interesting times!