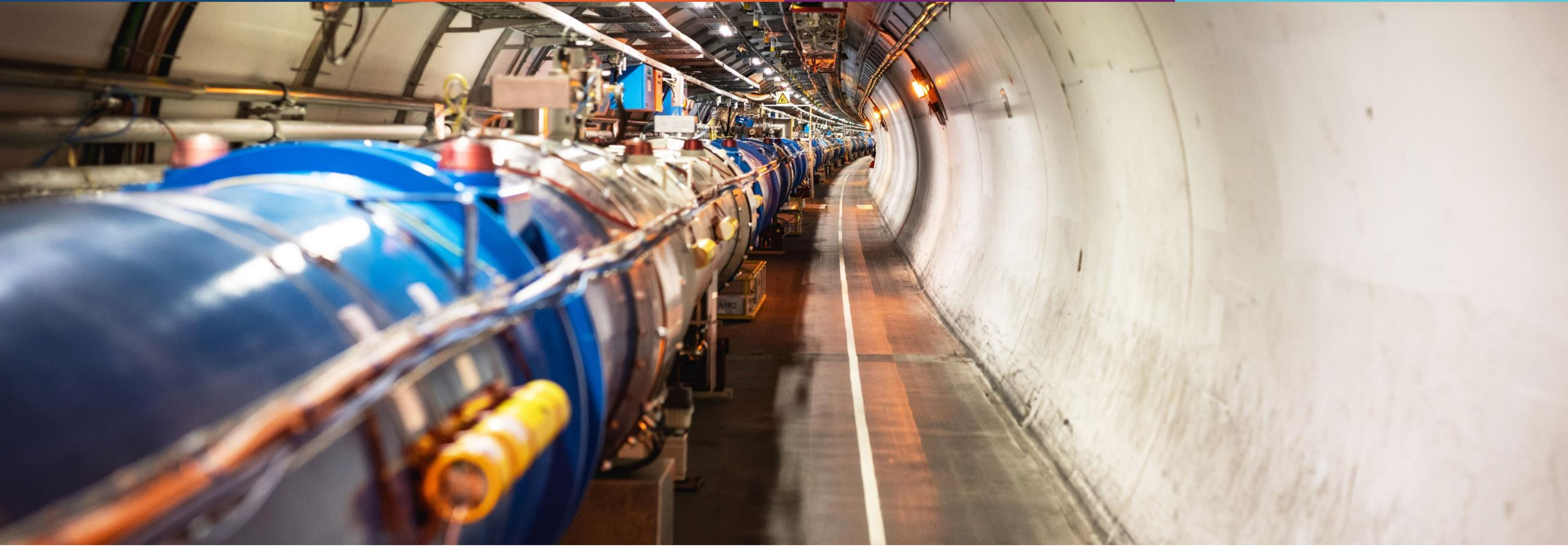
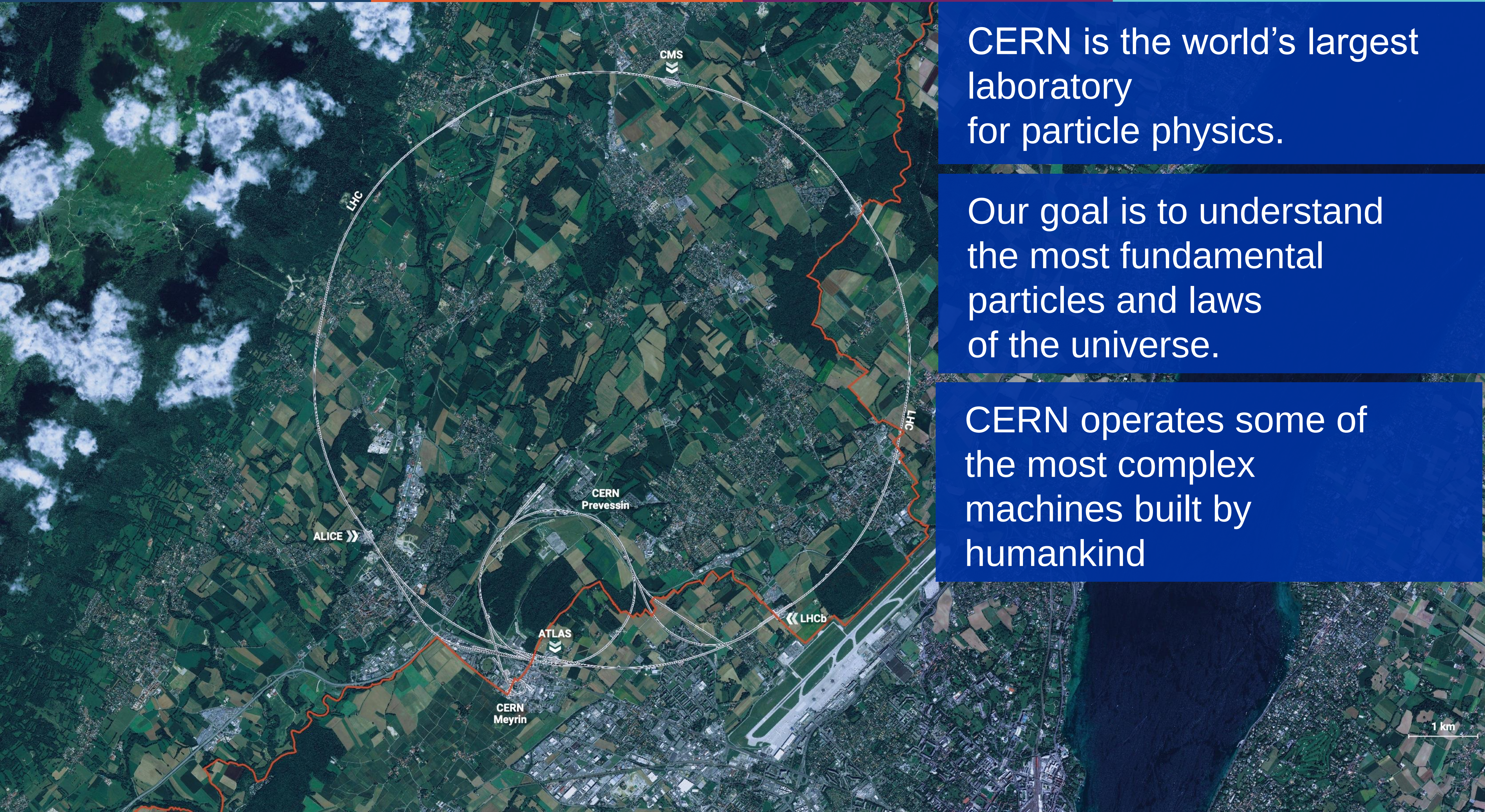


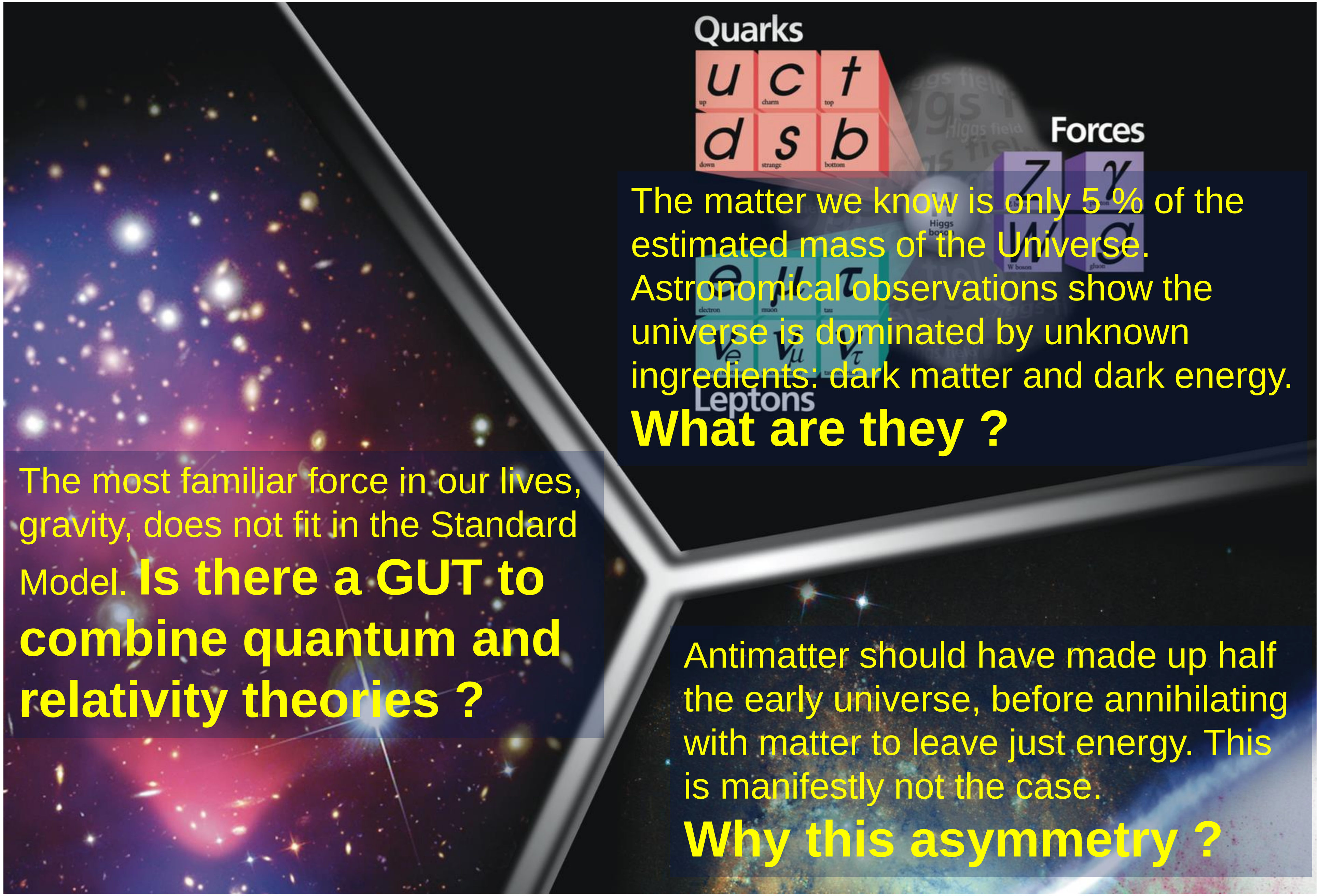
WELCOME TO CERN



CERN is the world's largest laboratory
for particle physics.

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

CERN operates some of the most complex machines built by humankind



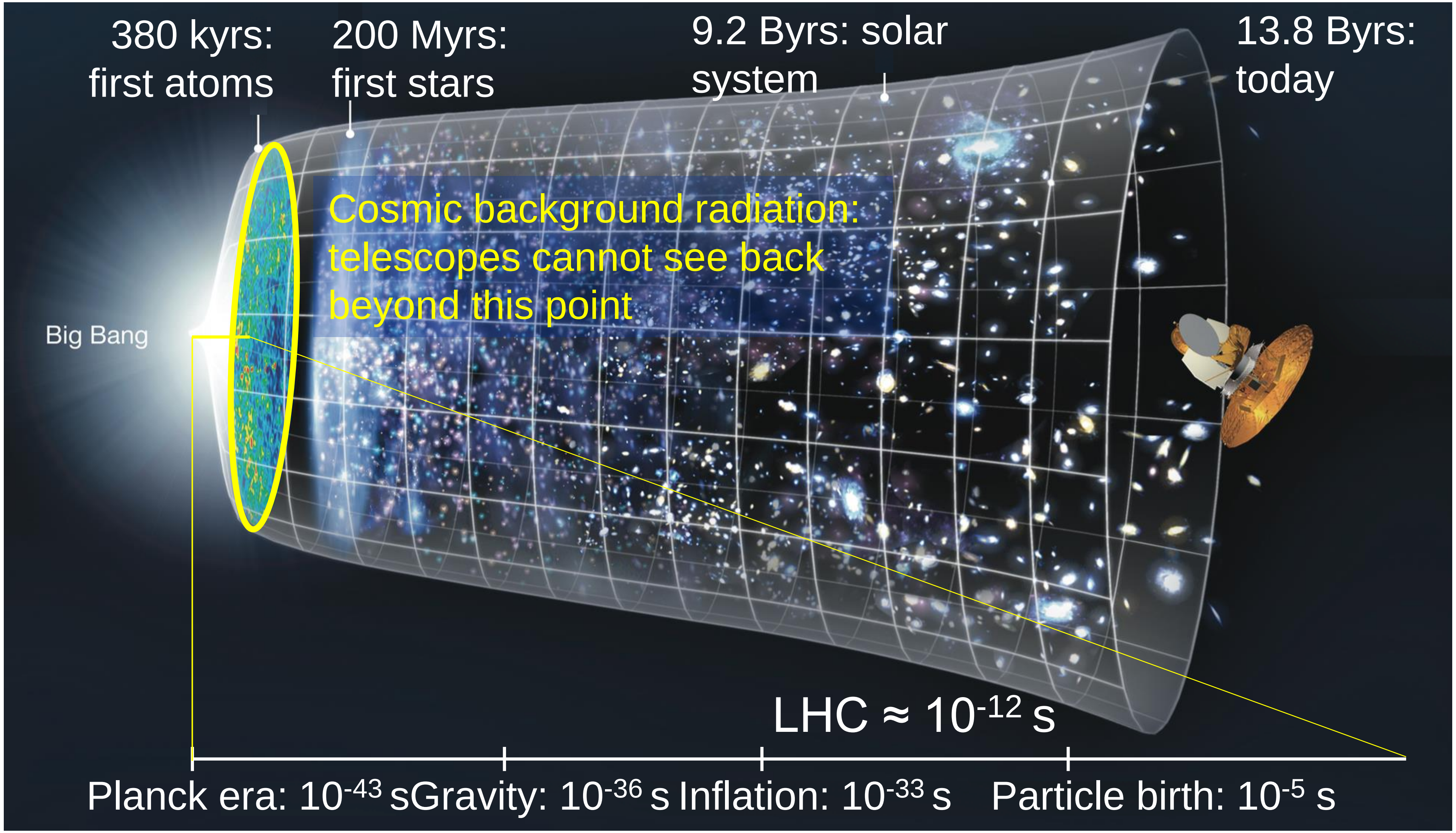
The matter we know is only 5 % of the estimated mass of the Universe. Astronomical observations show the universe is dominated by unknown ingredients: dark matter and dark energy.

What are they ?

The most familiar force in our lives, gravity, does not fit in the Standard Model. **Is there a GUT to combine quantum and relativity theories ?**

Antimatter should have made up half the early universe, before annihilating with matter to leave just energy. This is manifestly not the case.

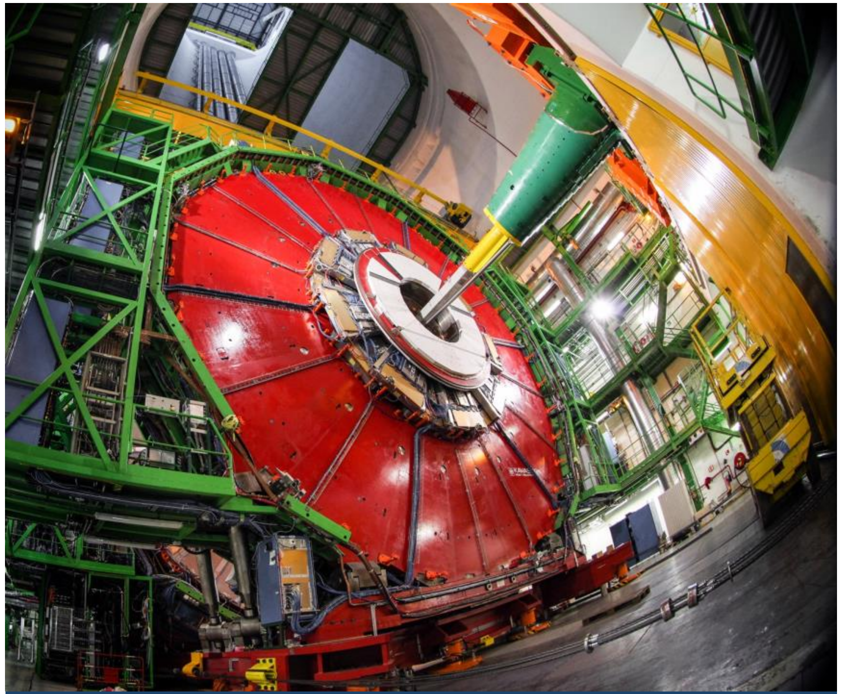
Why this asymmetry ?


380 kyrs:
first atoms
200 Myrs:
first stars
9.2 Byrs: solar
system
13.8 Byrs:
today
Cosmic background radiation:
telescopes cannot see back
beyond this point
Big Bang
LHC ≈ 10^{-12} s
Planck era: 10^{-43} s
Gravity: 10^{-36} s
Inflation: 10^{-33} s
Particle birth: 10^{-5} s

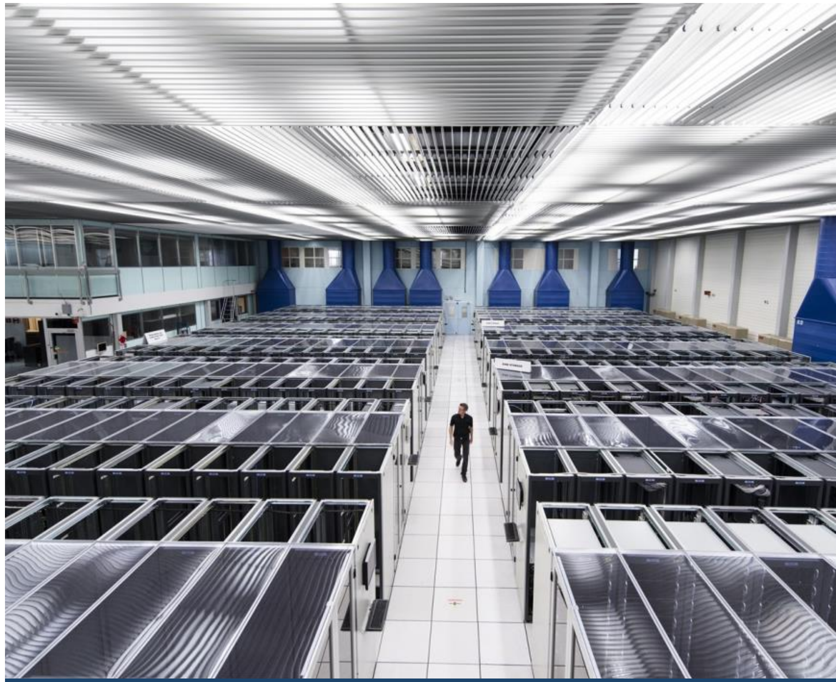
How do we do it?

- We build the largest machines to study the smallest particles in the universe
- We develop technology to advance the limits of what is possible
- We perform world-class research in theoretical and experimental particle physics

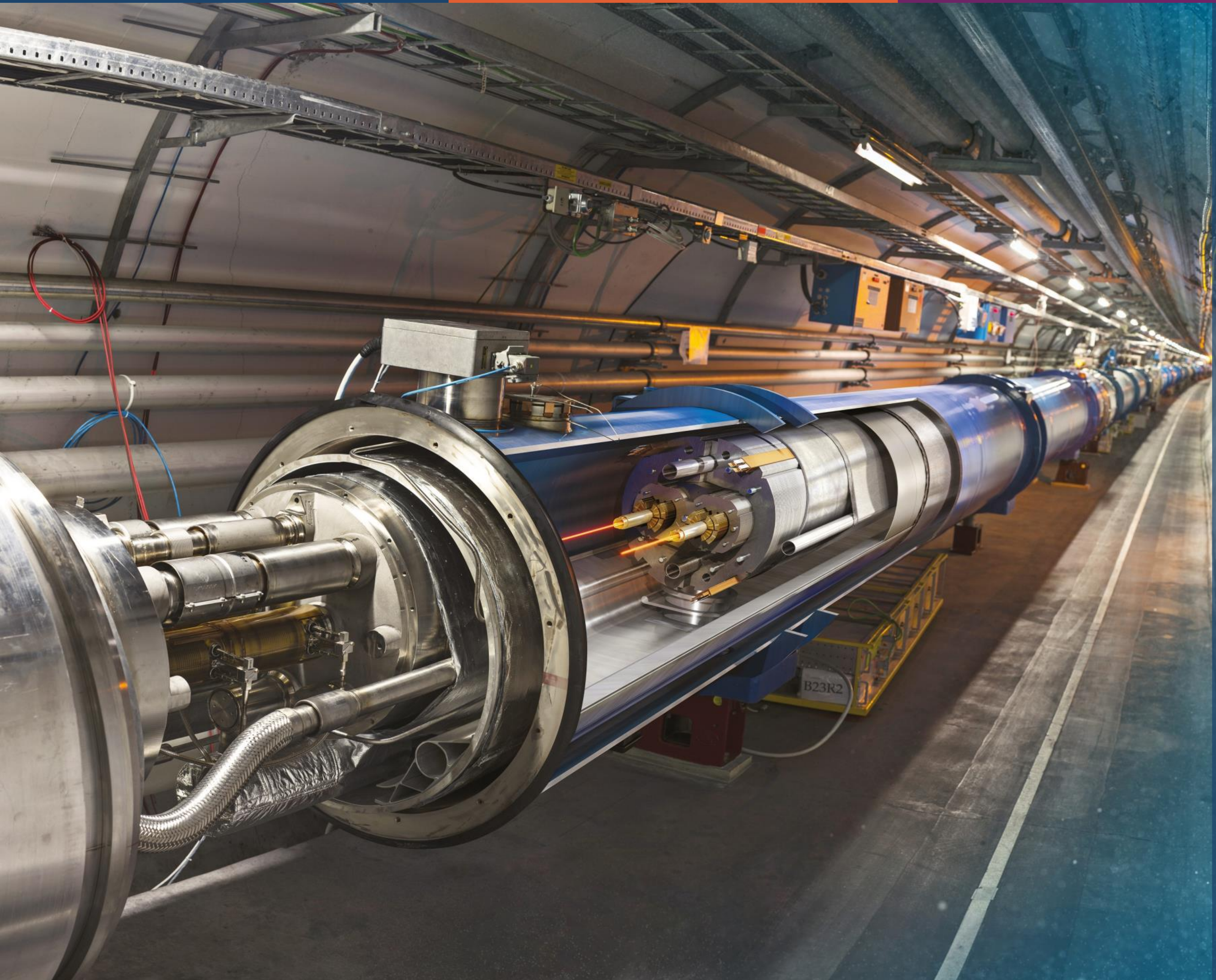
ACCELERATORS



DETECTORS



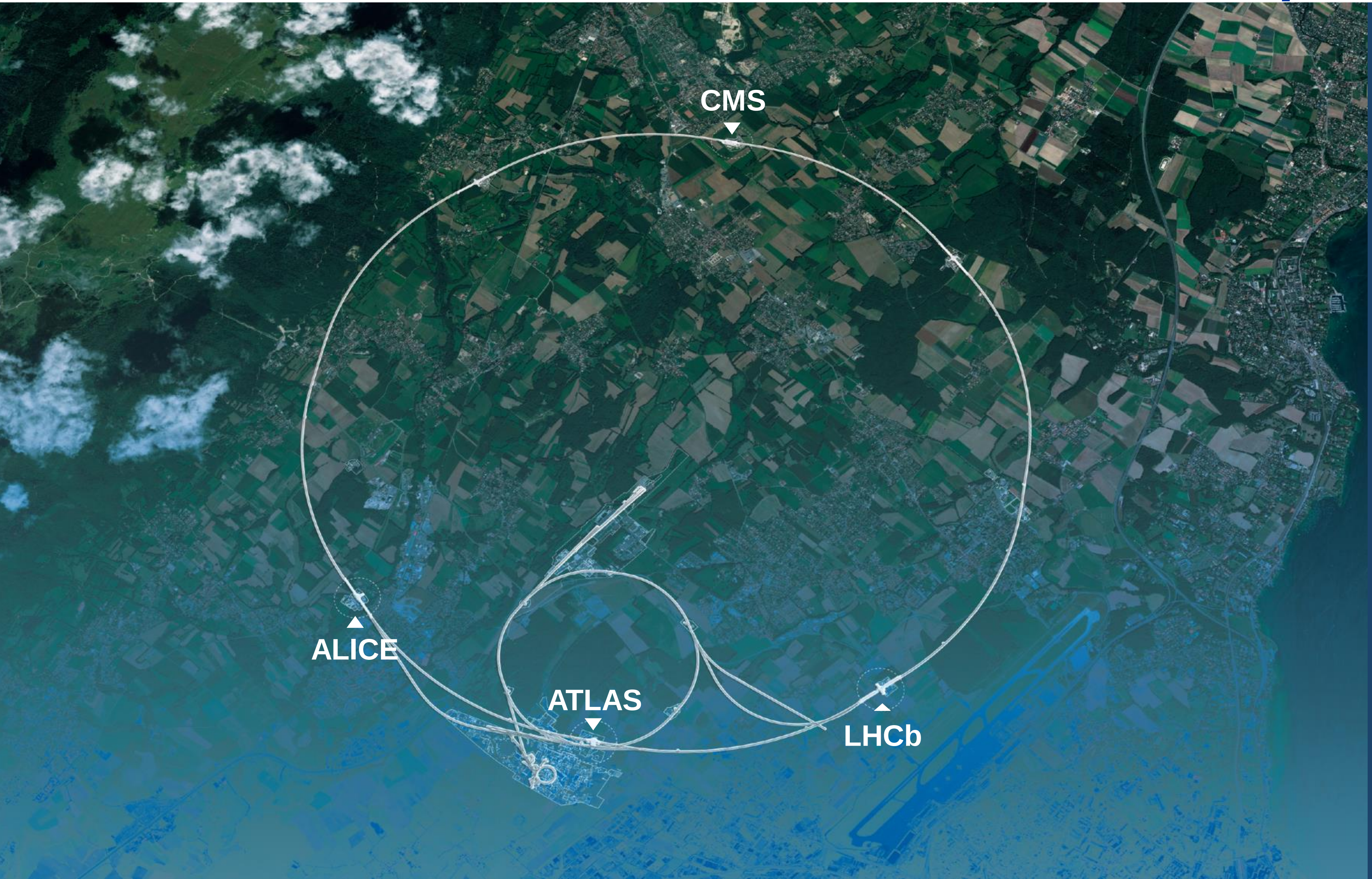
COMPUTING

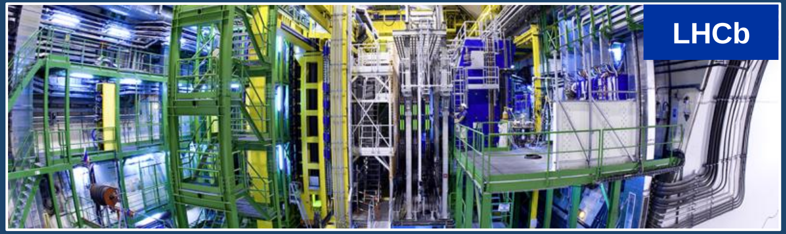


Large Hadron Collider (LHC)

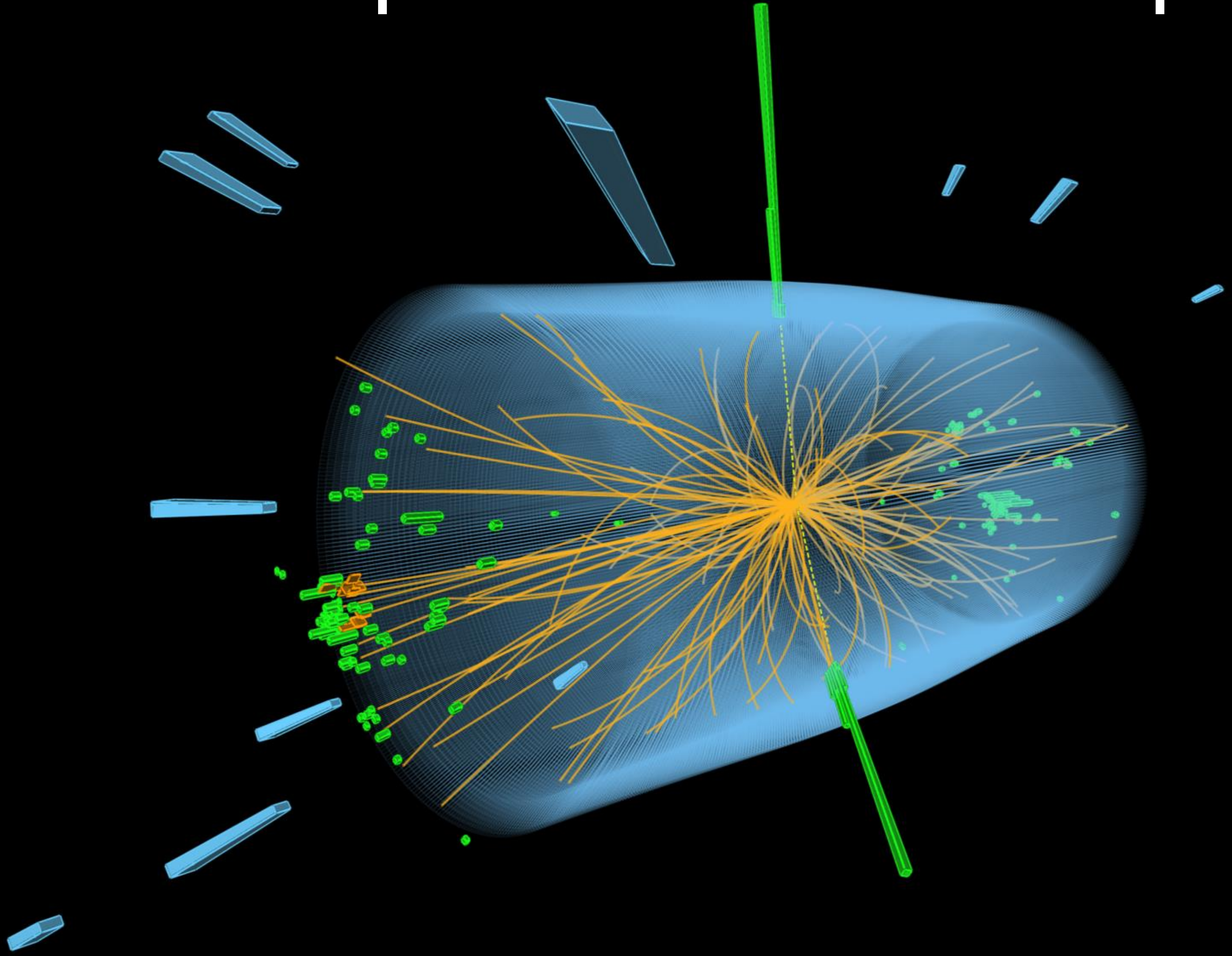
- 27 km in circumference
- About 100 m underground
- Superconducting magnets steer the particles around the ring
- Particles are accelerated to close to the speed of light

Giant detectors record the particles formed at the four collision points



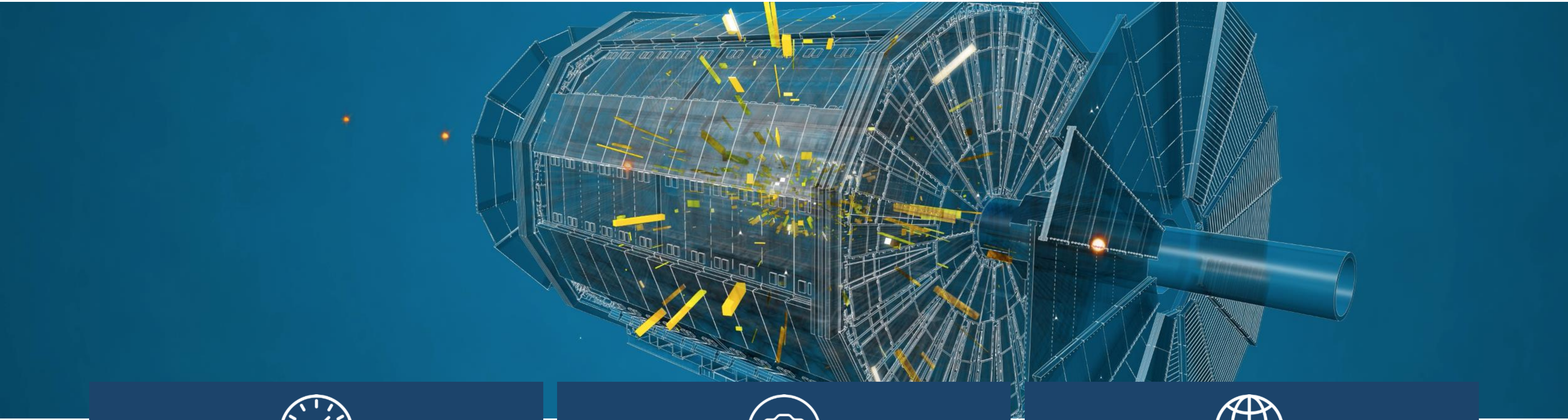


The LHC produces more than 1 billion particle collisions per second



The energy of the particles in collision is converted into new particles.

The LHC detectors are analogous to 3D cameras



The detectors measure the energy, direction and charge of new particles formed.

They take 40 million pictures a second. Only 1000 are recorded and stored.

The LHC detectors have been built by international collaborations covering all regions of the Globe.

The Worldwide LHC Computing Grid (WLCG)

Used to store, distribute, process and analyse data.

1 million processing cores in about 170 data centres and 42 countries.

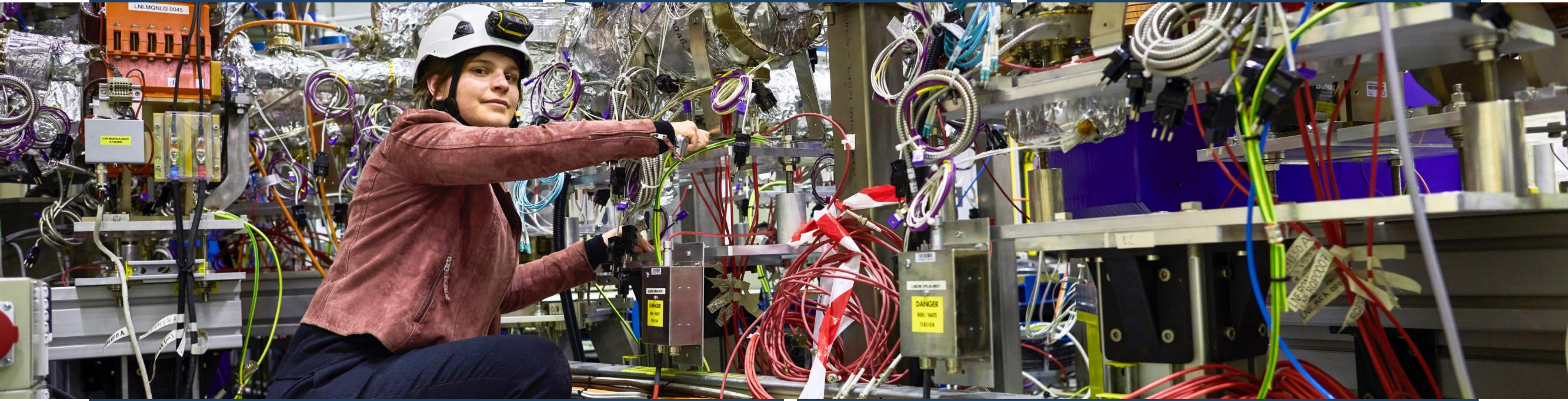
More than 1000 Petabytes of CERN data stored world-wide.

CERN has a diverse scientific programme

Nuclear Physics
(ISOLDE)

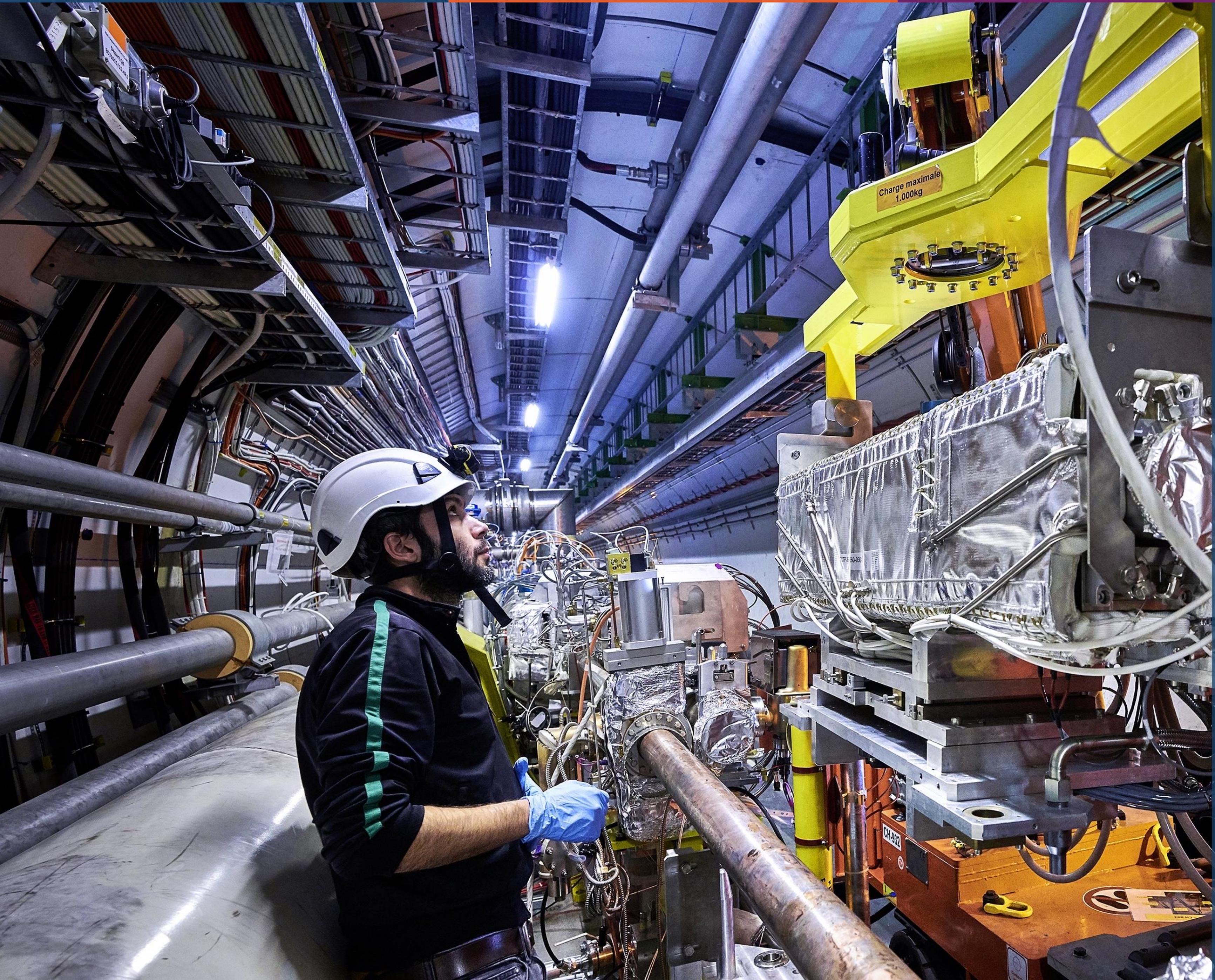
Antimatter Research
(Antiproton Decelerator)

Cosmic rays and cloud formation
(CLOUD)



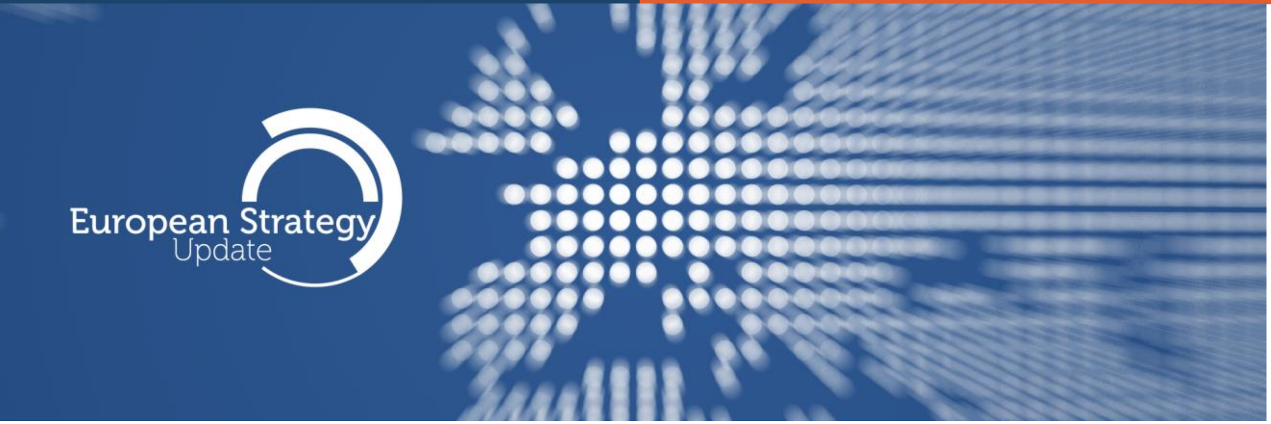
Fixed-target experiments,
which include searches for rare phenomena

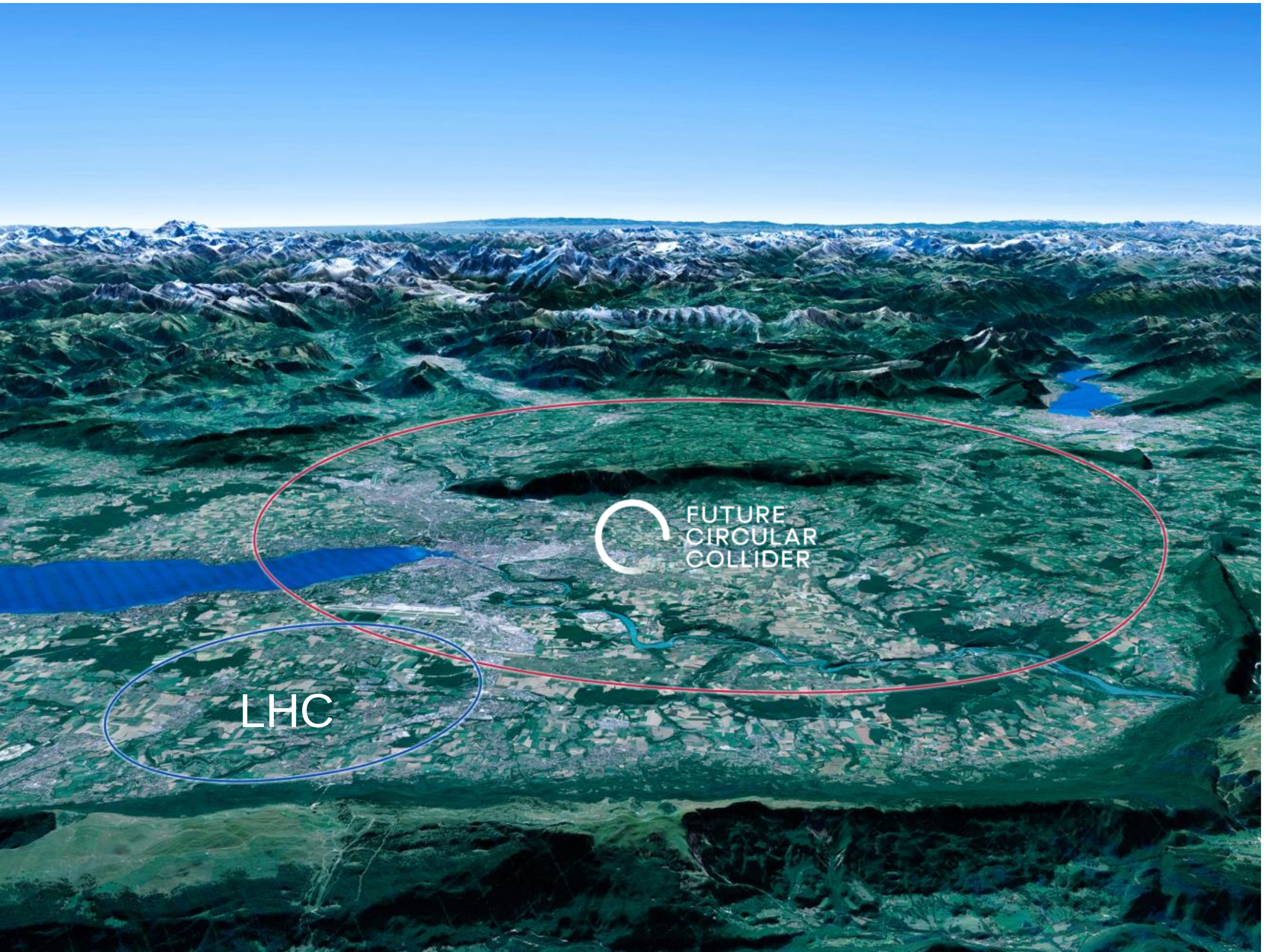
Contribution to the Long Baseline
Neutrino Facility in the USA (LBNF)



Upgrade to the High-Luminosity LHC is under way

- The HL-LHC will use new technologies to provide 10 times more collisions than the LHC.
- It will give access to rare phenomena, greater precision and discovery potential.
- It will start operating in 2027, and run until 2040.





Scientific priorities for the future

Implementation of the recommendations of the **2020 Update of the European Strategy for Particle Physics**:

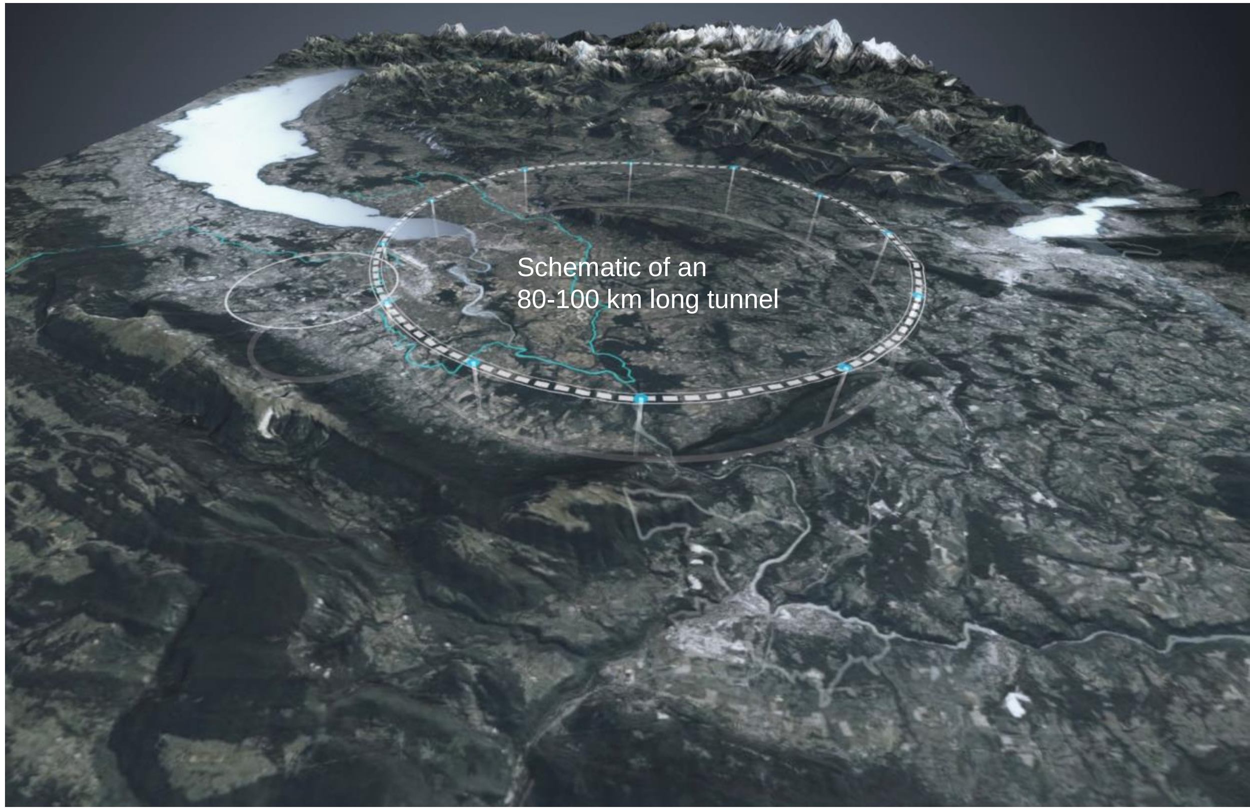
- Fully exploit the HL-LHC
- Build a Higgs factory to further understand this unique particle
- Investigate the technical and financial feasibility of a future energy-frontier 100 km collider at CERN
- Ramp up relevant R&D
- Continue supporting other projects around the world

Which collider after the LHC ?

For the longer-term : the European particle physics community has recommended to assess the technical and financial feasibility of the FCC (Future Circular Collider)

FCC: Future Circular Collider: 100 km ring

- Technologically very ambitious → will push innovation
- Cost: ~ 10 BCHF for first stage
  (LHC: ~ 5 BCHF as tunnel pre-existed)
- Tentative timescale: project approval **~ 2028**,
  construction start **~ 2030**,
  first-stage operation **2045-2060**,
  second-stage operation **2070-2090++**
- Strong support from the US (strong, historical partnership of reciprocal contributions)
- Competition with China, which wants to realise the same project



FCC Feasibility Study

FCC Feasibility Study (FS) will address a recommendation of the 2020 update of the European Strategy for Particle Physics (ESPP):

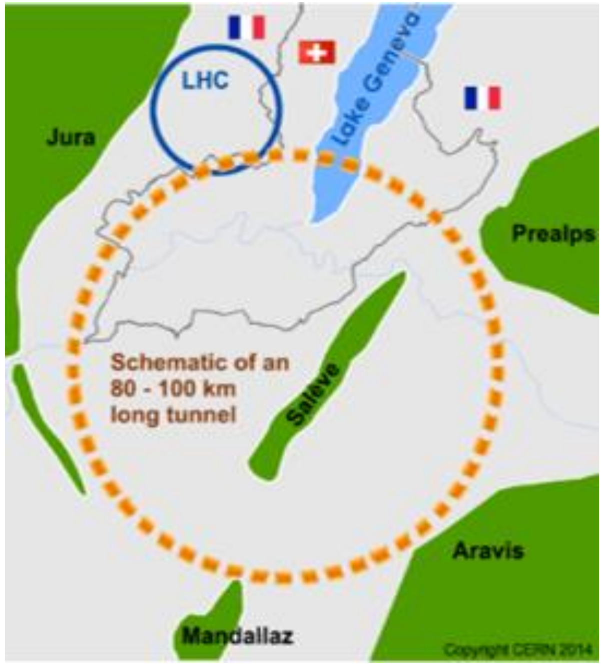
- "Europe, together with its international partners, **should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage.**
- Such a feasibility study of the colliders and related infrastructure should be established as a global endeavour and be completed on the timescale of the next Strategy update."

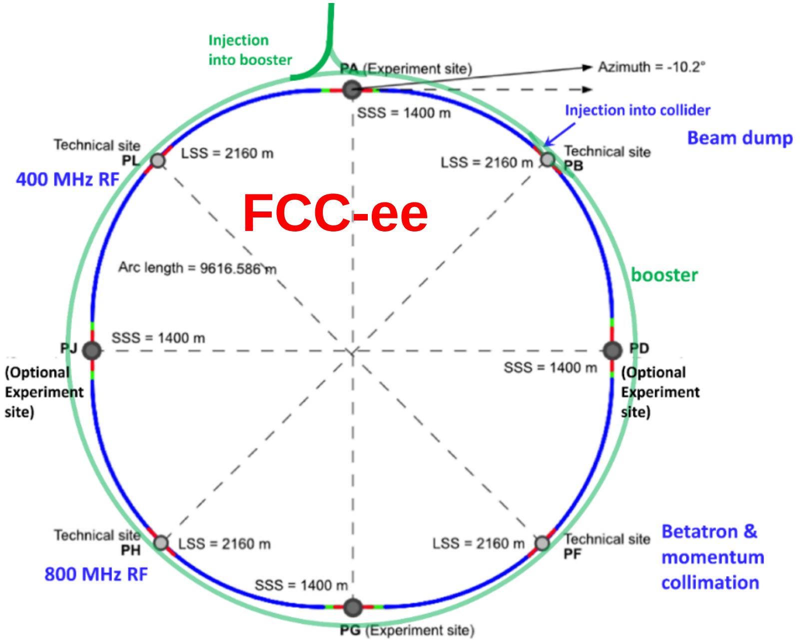
FUTURE CIRCULAR COLLIDER

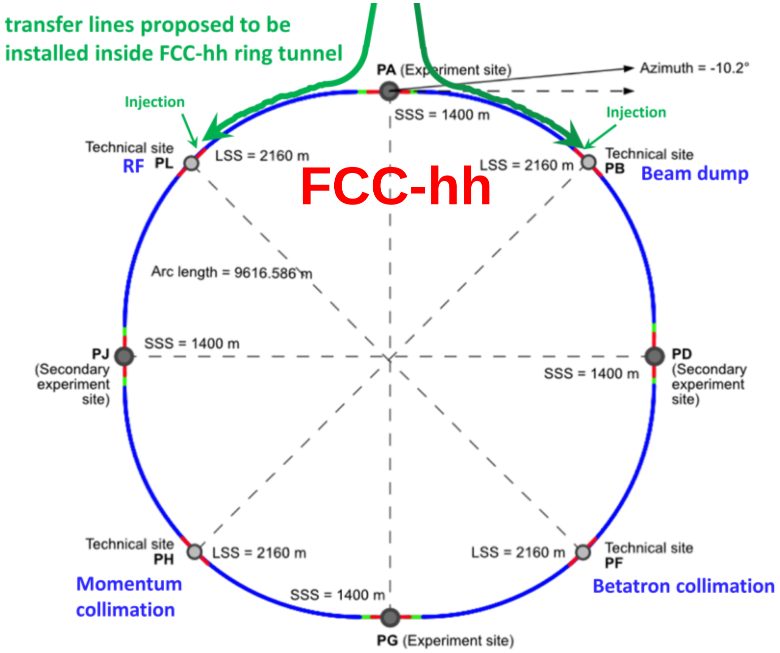
The FCC integrated program
inspired by successful LEP – LHC programs at CERN

comprehensive long-term program maximizing physics opportunities

- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, with ion and eh options**
- complementary physics
- common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure
- FCC integrated project allows seamless continuation of HEP after completion of the HL-LHC program







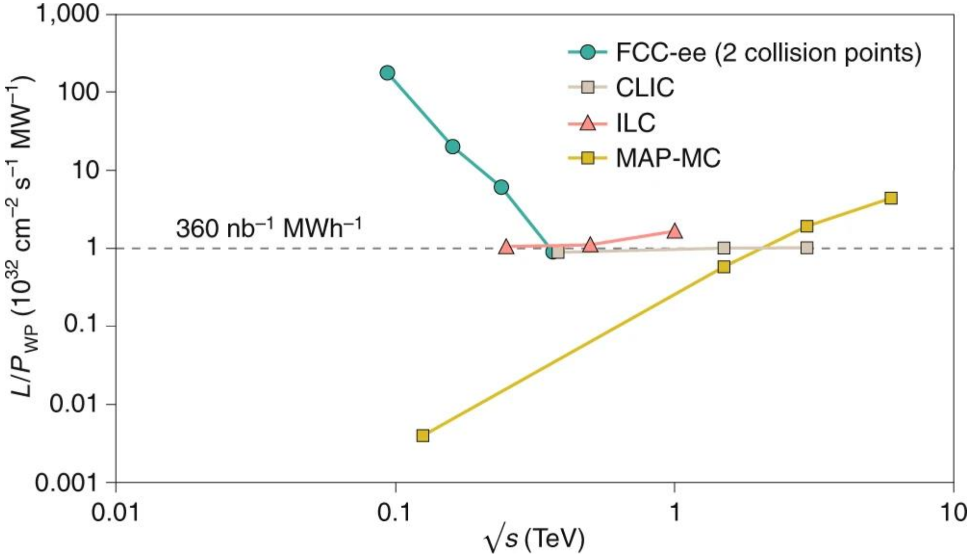
2020 - 2040 | 2045 - 2060 | 2065 - 2090

a similar two-stage project CEPC/SPPC is under study in China

FUTURE CIRCULAR COLLIDER — Sustainability aspects and studies

highly sustainable Higgs factory

luminosity vs. electricity consumption



Thanks to twin-aperture magnets, thin-film SRF, efficient RF power sources, top-up injection

optimum usage of excavation material

int'l competition "mining the future®"

https://indico.cern.ch/event/1001465/

FCC-ee annual energy consumption ~ LHC/HL-LHC

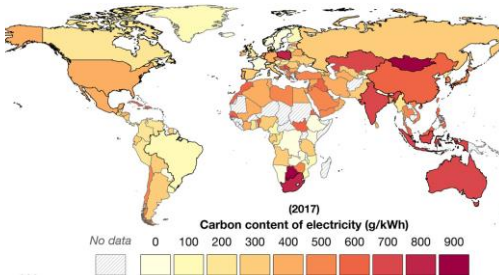
120 GeV	Days	Hours	Power OP	Power Com	Power MD	Power TS	Power Shutdown		
Beam operation	143	3432	293					1005644	MWh
Downtime operation	42	1008	109					110266	MWh
Hardware, Beam commissioning	30	720		139				100079	MWh
MD	20	480			177			85196	MWh
technical stop	10	240				87		20985	MWh
Shutdown	120	2880					69	199872	MWh
Energy consumption / year	365	8760						1.52	TWh
Average power								174	MW

J.-P. Burnet, FCC Week 2022

incl. CERN site & SPS

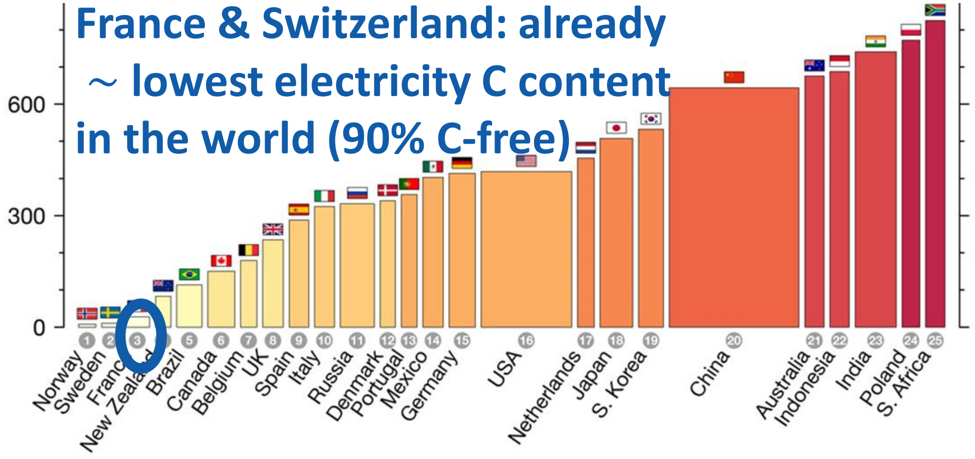
CERN Meyrin, SPS, FCC	Z	W	H	TT
Beam energy (GeV)	45.6	80	120	182.5
Energy consumption (TWh/y)	1.82	1.92	2.09	2.54

powered by mix of renewable & other C-free sources



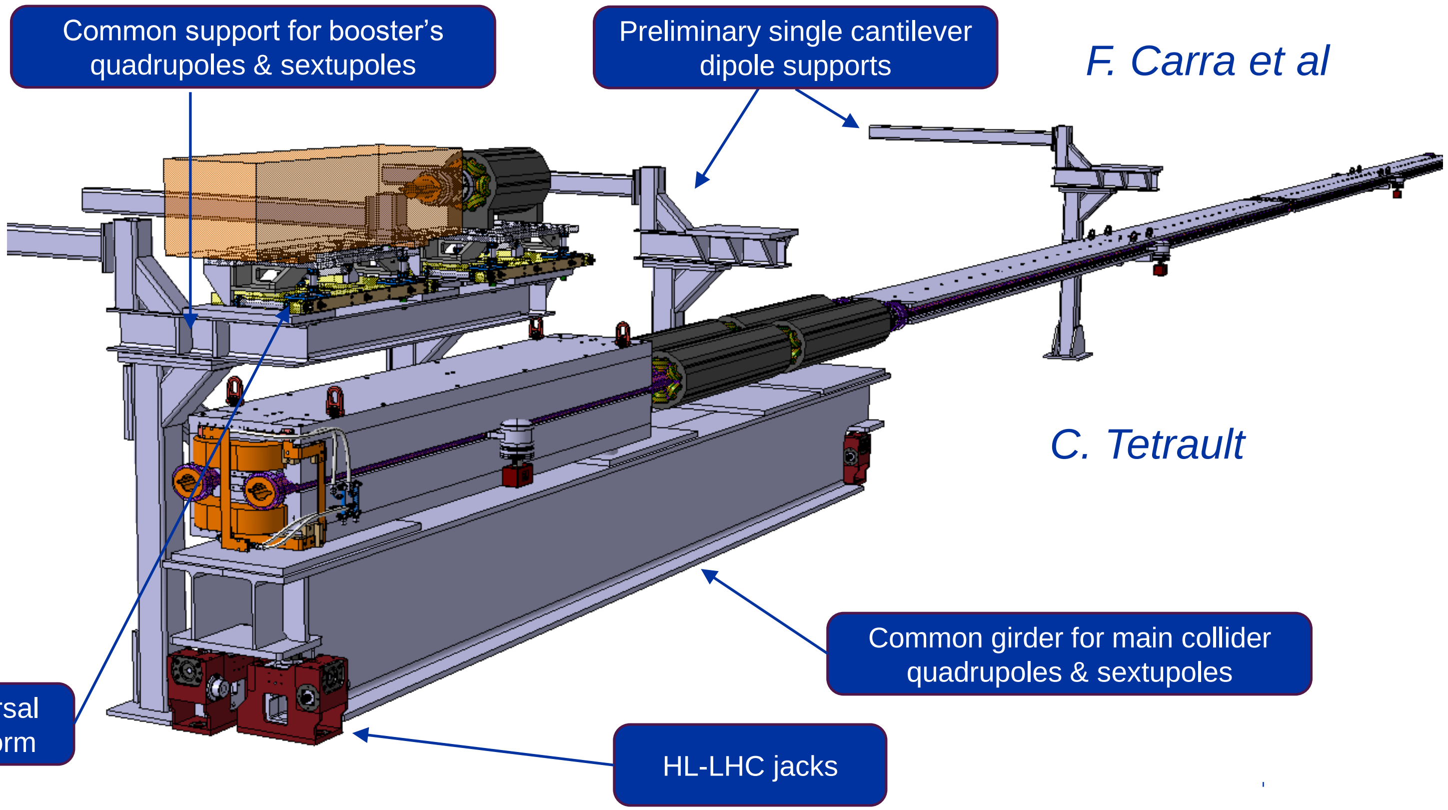
https://www.carbonbrief.org/

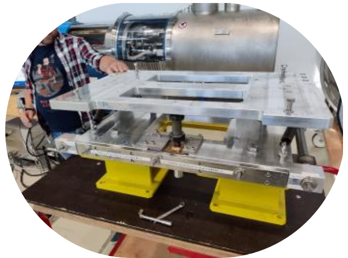
France & Switzerland: already ~ lowest electricity C content in the world (90% C-free)



FCC-ee Accelerator Layout

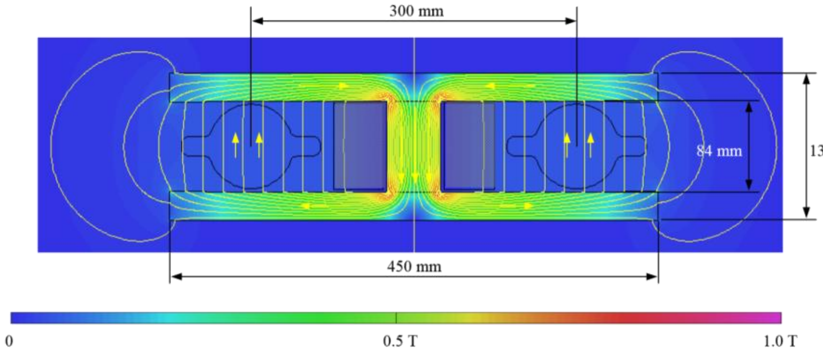
- **The arc cells are repeated 2000 times around the ring**
  - Critical to understand and optimize the layout for cost, installation, alignment, operation, and maintenance
  - Includes placement of the main rings and the Booster
- **The RF regions are also tightly constrained**
  - Optimize cryomodule lengths and waveguides

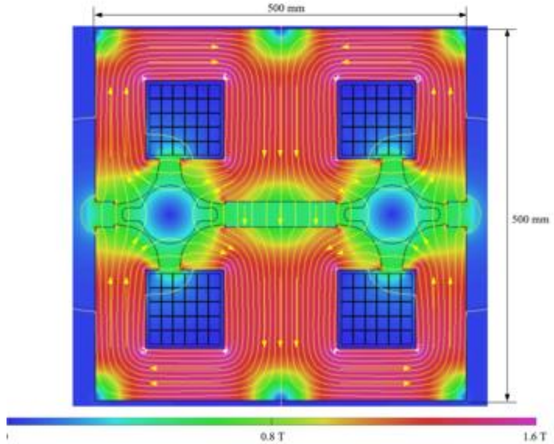




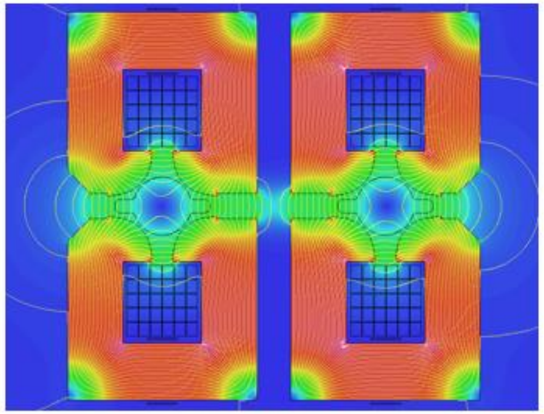
FCC-ee Power Consumption

- **Roughly 300 MW operating at Higgs**
  - Complete power accounting
- **High efficiency RF sources (150 MW) 80 → 90%**
- **High Q RF Cavities (20 MW)**
- **Magnet systems (40 MW)**
  - Dipole quite efficient
  - Quadrupole and sextupole magnets simplified and power reduced with smaller bore or HTS
  - Cable losses may be reduced with in-tunnel PS
- **Efficient cooling and ventilation (40 MW)**





CDR cross-section



Modified cross-section

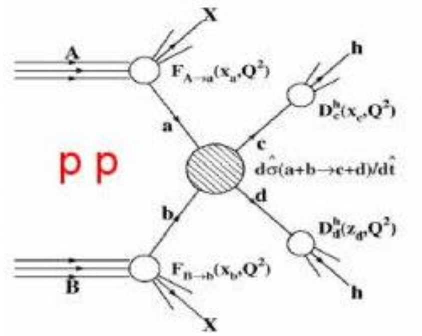
Collider Choices

Hadron collisions: compound particles

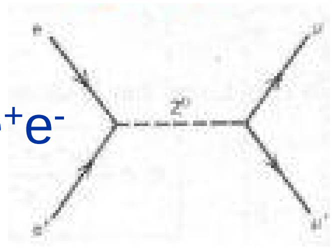
- LHC collides 13.6 TeV protons
- Protons are mix of quarks, anti-quarks and gluons
- **Very complex to extract physics**
- **But can reach high energies**

Lepton collisions: elementary particles

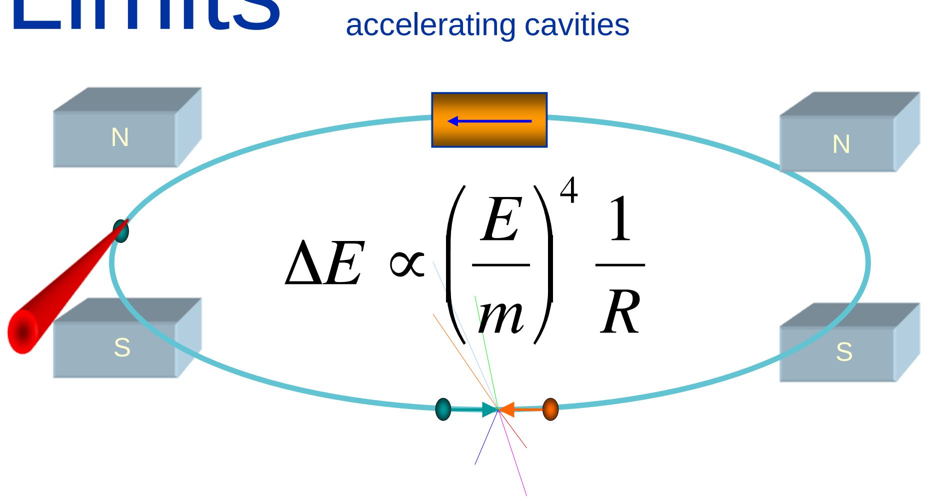
- LEP reached 0.205 TeV with electron-positron collisions
- Clean events, easy to extract physics
- **Lepton collisions $\Rightarrow$ precision measurements**
- **Hard to reach high energies**



e^+e^-



Energy Limits

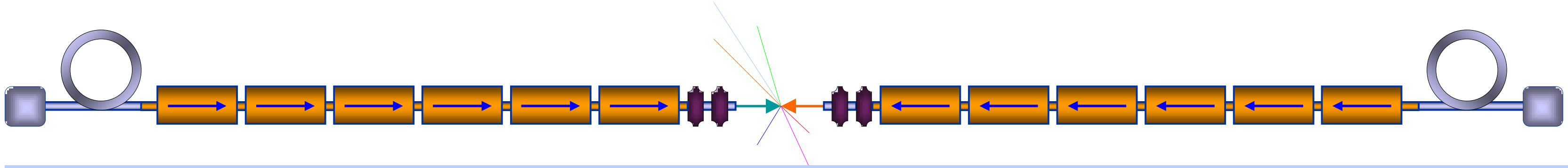


$$\Delta E \propto \left(\frac{E}{m}\right)^4 \frac{1}{R}$$

Electron-positron rings are **multi-pass** colliders limited by synchrotron radiation

Hence **proton rings** are energy frontier

Electron-positron linear colliders avoid synchrotron radiation, but are **single pass**
Typically cost proportional to energy and power proportional to luminosity,



Novel approach: **muon collider**
Large mass suppresses synchrotron radiation => **multi-pass**
Fundamental particle requires less energy than protons
But lifetime at rest only 2.2 μs (increases with energy)

Therefore part of European Accelerator R&D Roadmap

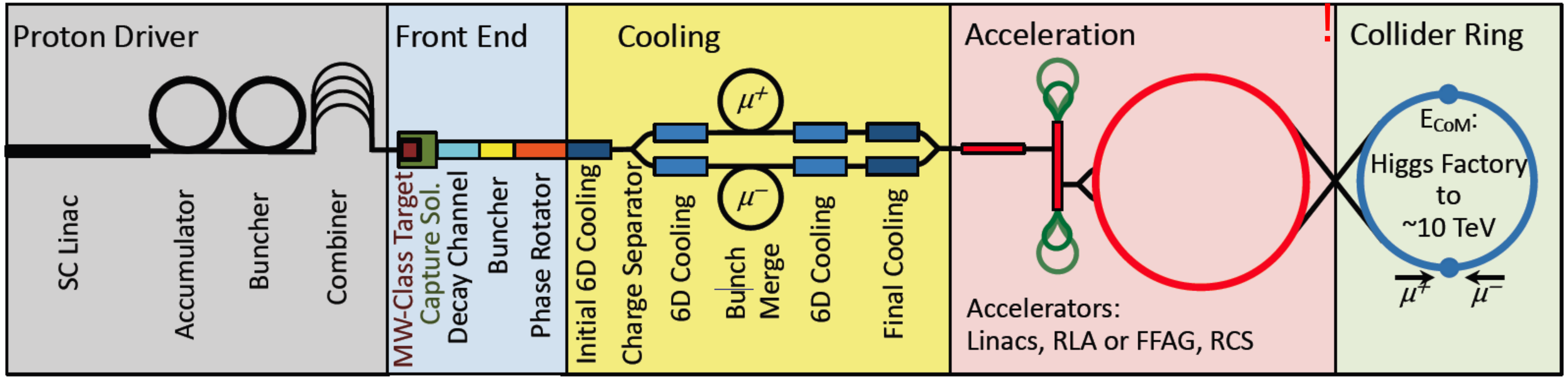
Proton-driven Muon Collider Concept

Produce a low emittance muon beam…

Produce a short, intense proton bunch…

… muons are cooled by ionisation cooling in matter…

… collide !



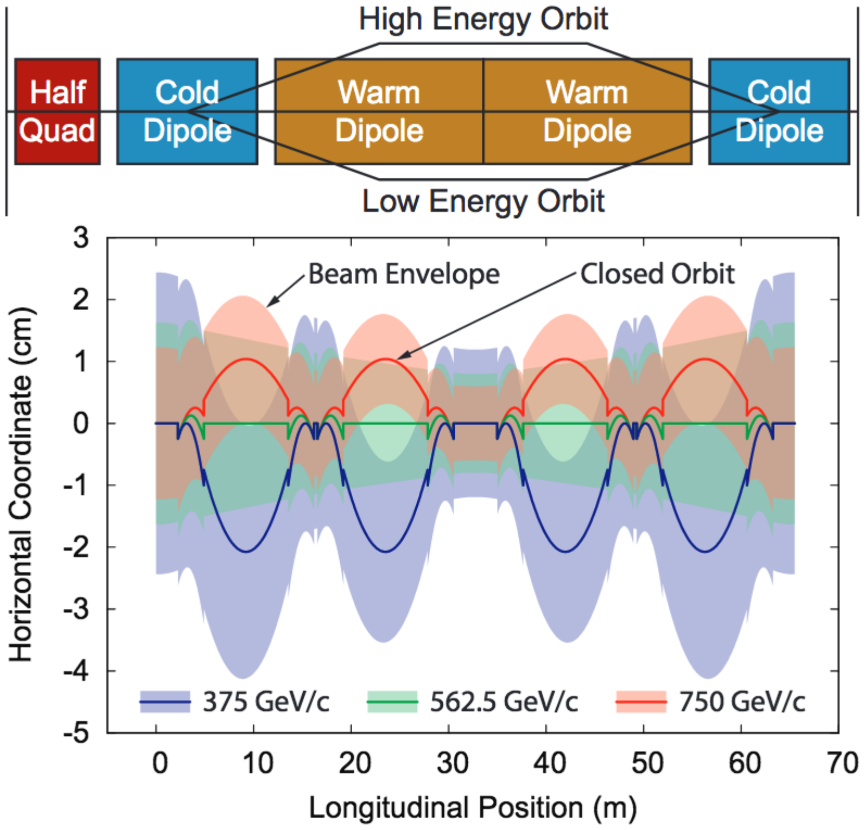
… protons hit a target and produce pions which decay into muons - muons are captured…

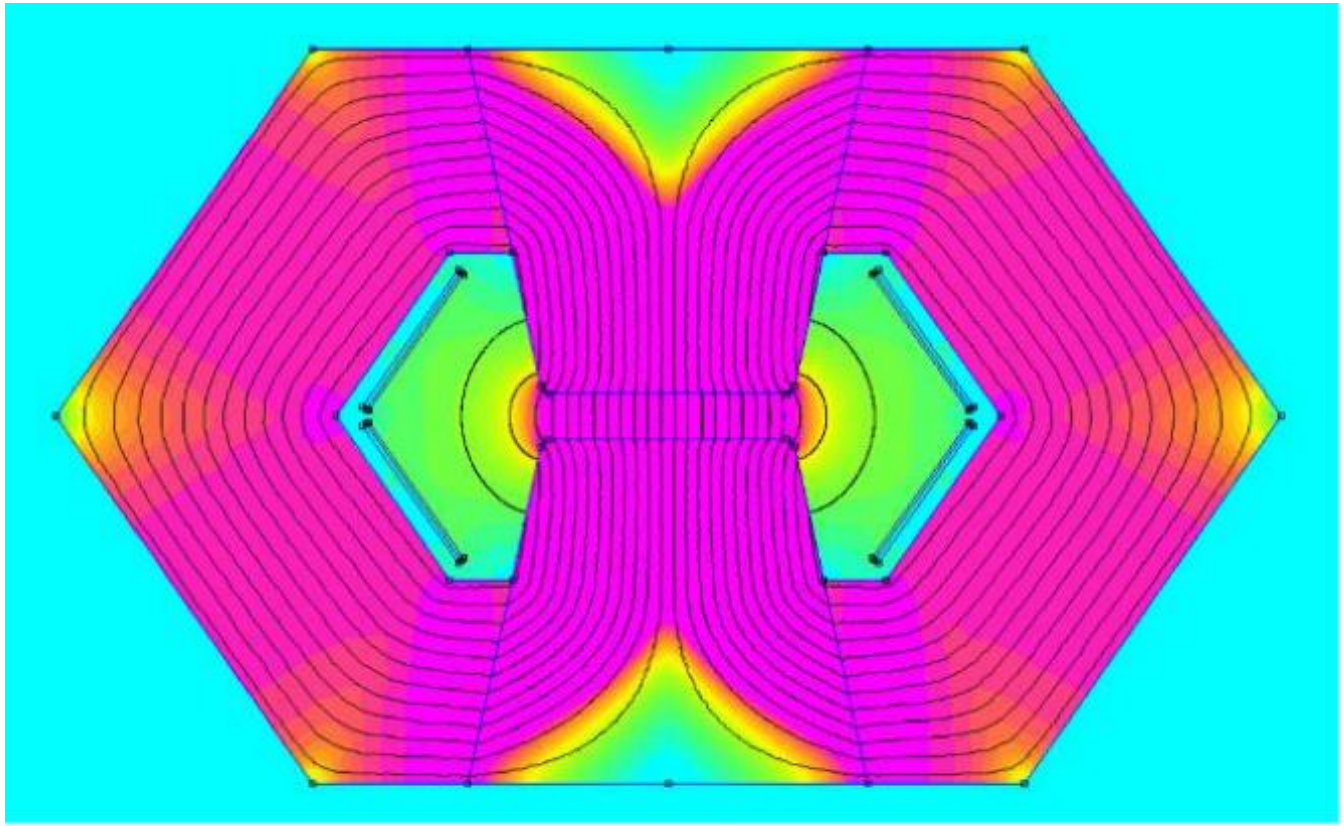
… accelerate muons to collision energy …

Credits to US-DOE MAP

Courtesy of D. Schulte

Accelerator magnets





Combination of DC SC (up to 10 T) and AC resistive (1.8 T) magnets. The resistive magnets are ramped in times as short as 0.4 ms (400 Hz)

Stored energy: o(50 MJ)

Pulsed power: o(50 GW)

Science for peace

CERN was founded in 1954 with 12 European Member States

CERN's annual budget is 1200 MCHF (equivalent to a medium-sized European university)

As of 31 December 2021
Employees:
2676 staff, **783** fellows

Associates:
11 175 users, **1556** others

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
Turkey – Ukraine

6 Observers

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

More than 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

A laboratory for people around the world

Distribution of all CERN Users by the country of their home institutes as of 31 December 2021

Geographical & cultural diversity
Users of **110 nationalities**
19.4% women

Member States 6642

Austria 74 – **Belgium** 122 – **Bulgaria** 39 – **Czech Republic** 227
Denmark 42 – **Finland** 71 – **France** 811 – **Germany** 1129
Greece 133 – **Hungary** 69 – **Israel** 67 – **Italy** 1423
Netherlands 157 – **Norway** 69 – **Poland** 278 – **Portugal** 89
Romania 105 – **Serbia** 36 – **Slovakia** 66 – **Spain** 328
Sweden 88 – **Switzerland** 372 – **United Kingdom** 847

Associate Member States **55**
in the pre-stage to membership

Cyprus 10 – **Estonia** 24 – **Slovenia** 21

Associate Member States **367**

Croatia 36 – **India** 130 – **Latvia** 11 – **Lithuania** 12 – **Pakistan** 30
Turkey 122 – **Ukraine** 26

Observers **2918**

Japan 189 – **Russia** (suspended) 971 – **United States of America** 1758

Non-Member States and Territories **1193**

Algeria 3 – **Argentina** 16 – **Armenia** 10 – **Australia** 20 – **Azerbaijan** 3 – **Bahrain** 2 – **Belarus** 24 – **Brazil** 106
Canada 189 – **Chile** 23 – **Colombia** 18 – **Cuba** 3 – **Ecuador** 6 – **Egypt** 16 – **Georgia** 36 – **Hong Kong** 17
Iceland 3 – **Indonesia** 6 – **Iran** 11 – **Ireland** 6 – **Jordan** 5 – **Kuwait** 5 – **Lebanon** 15 – **Madagascar** 1
Malaysia 4 – **Malta** 2 – **Mexico** 48 – **Montenegro** 5 – **Morocco** 18 – **New Zealand** 8 – **Oman** 1
People's Republic of China 314 – **Peru** 2 – **Philippines** 1 – **Republic of Korea** 113 – **Singapore** 3
South Africa 52 – **Sri Lanka** 10 – **Taiwan** 45 – **Thailand** 18 – **United Arab Emirates** 6

CERN is a model for open and inclusive collaboration

The LHC experiments are models of consensus building, competition and cooperation.

SESAME, a synchrotron light source in Jordan, is modelled on CERN's governance structure.

CERN provides the IT infrastructure for the satellite-analysis technology used for emergency response.

CERN's technological innovations have applications in many fields

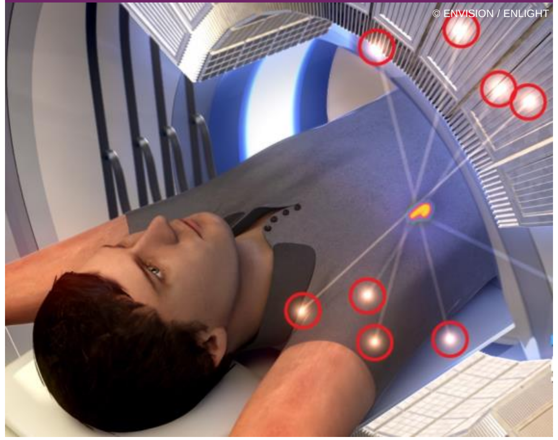
CERN is the birthplace of the World Wide Web

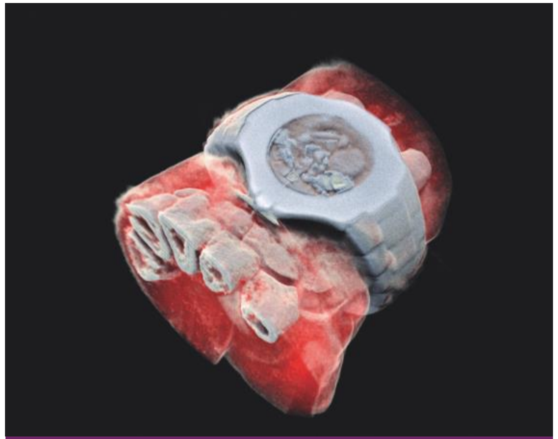
And there are many more examples
Medical imaging, cancer therapy, material science, cultural heritage, aerospace, automotive, environment, health & safety, industrial processes.

CERN's technological innovations have important applications in medicine and healthcare

Accelerator technologies are applied in cancer radiotherapy with protons, ions and electrons.

Technologies applied at CERN are also used in PET, for medical imaging and diagnostics.





Pixel detector technologies are used for high resolution 3D colour X-ray imaging.

CERN produces innovative radioisotopes for nuclear medicine research.

CERN trains the next generation of physicists, engineers and technicians

>3000 PhD students are registered at CERN.

600 PhD theses are completed each year.

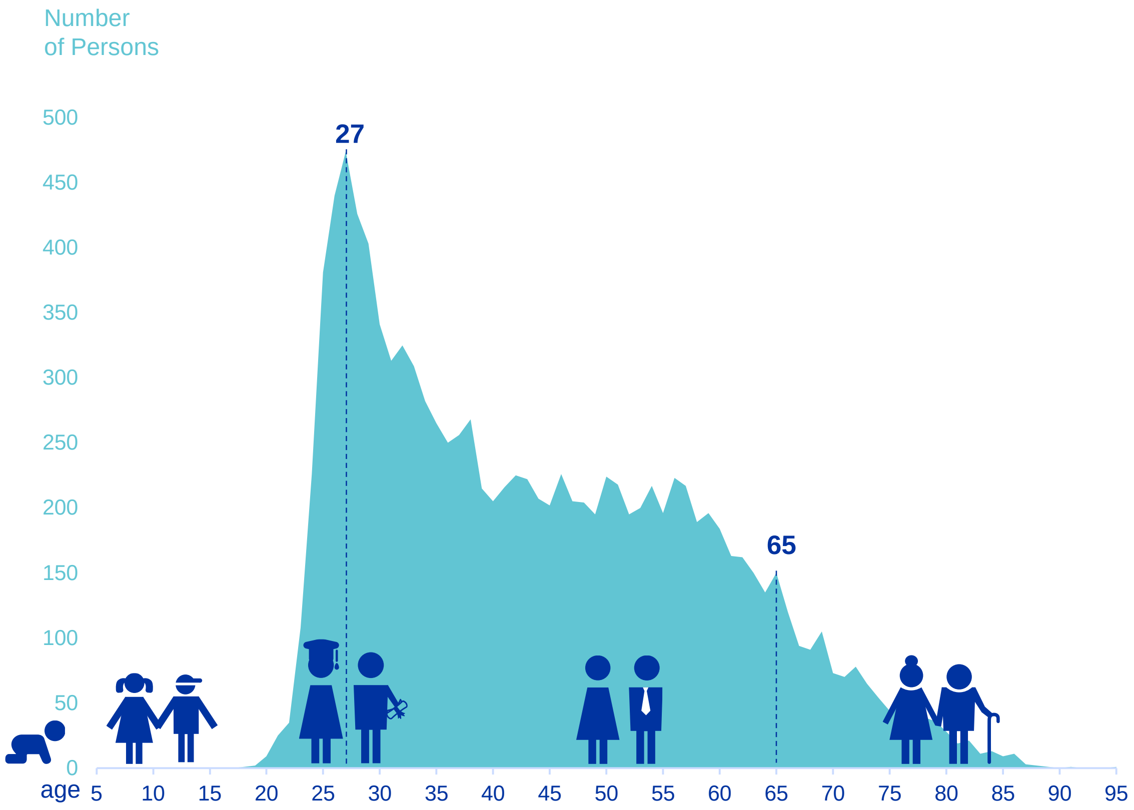
300 undergraduate students in Summer programmes.

~800 fellows in research and applied physics, engineering and computing.

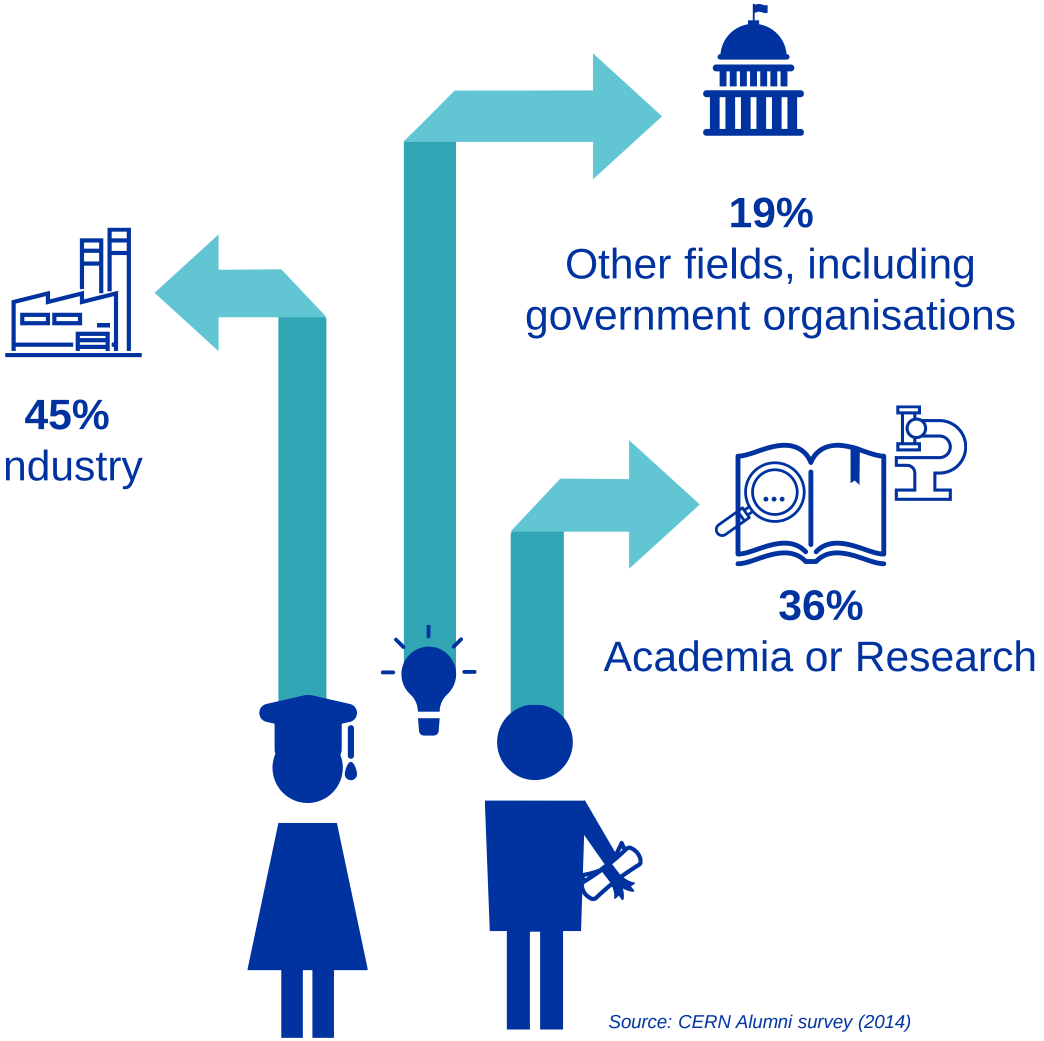
~200 Technical and Doctoral Students in applied physics, engineering and computing.

CERN organises schools for undergraduates and postgraduates, in all regions.

CERN opens a world of career opportunities



Age Distribution of Scientists working at CERN



Source: CERN Alumni survey (2014)

PhD and Technical students leaving CERN

Our education programmes reach thousands of teachers and students from around the world each year

Numbers for Italy

14 summer students during 2019
1066 teachers in Teacher Programmes since 1998
146 teams in BL4S competition since 2014
1765 students participating in S’Cool LAB since 2015

Teachers from > 40 countries participate in National and International Teacher Programmes

> 6000 students use S’Cool Lab, for hands-on physics experiments

> 1000 students propose an experiment to carry out at CERN in the Beamline4Schools competition

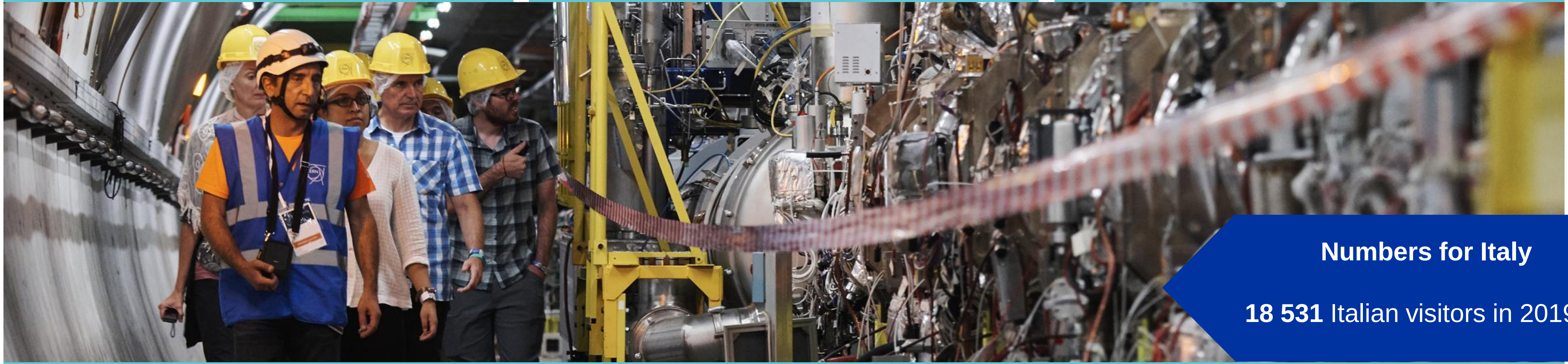
22 students from each Member State shadow researchers in the High-School Student Internship Programme

CERN engages with citizens across the globe

151 000 visitors on guided tours of CERN in 2019, from 95 countries
(> 60% come from more than 600 km away).

On-site and travelling exhibitions in 15 countries, with >1 million visitors.

Open Days during Long Shutdowns: two days in 2019, 75 000 visitors, 2800 volunteers.



Numbers for Italy

18 531 Italian visitors in 2019

During the COVID-19 pandemic, several outreach and education activities moved online:
virtual talks by CERN guides for schools and general public; educational resources;
social media “lives” from LHC experiments and other facilities.

CERN Science Gateway

CERN's new education and outreach centre for all publics aged 5-plus.

Opening beginning of 2023.

Immersive exhibitions, education labs, events and shows.

Four pillars underpin CERN’s mission