

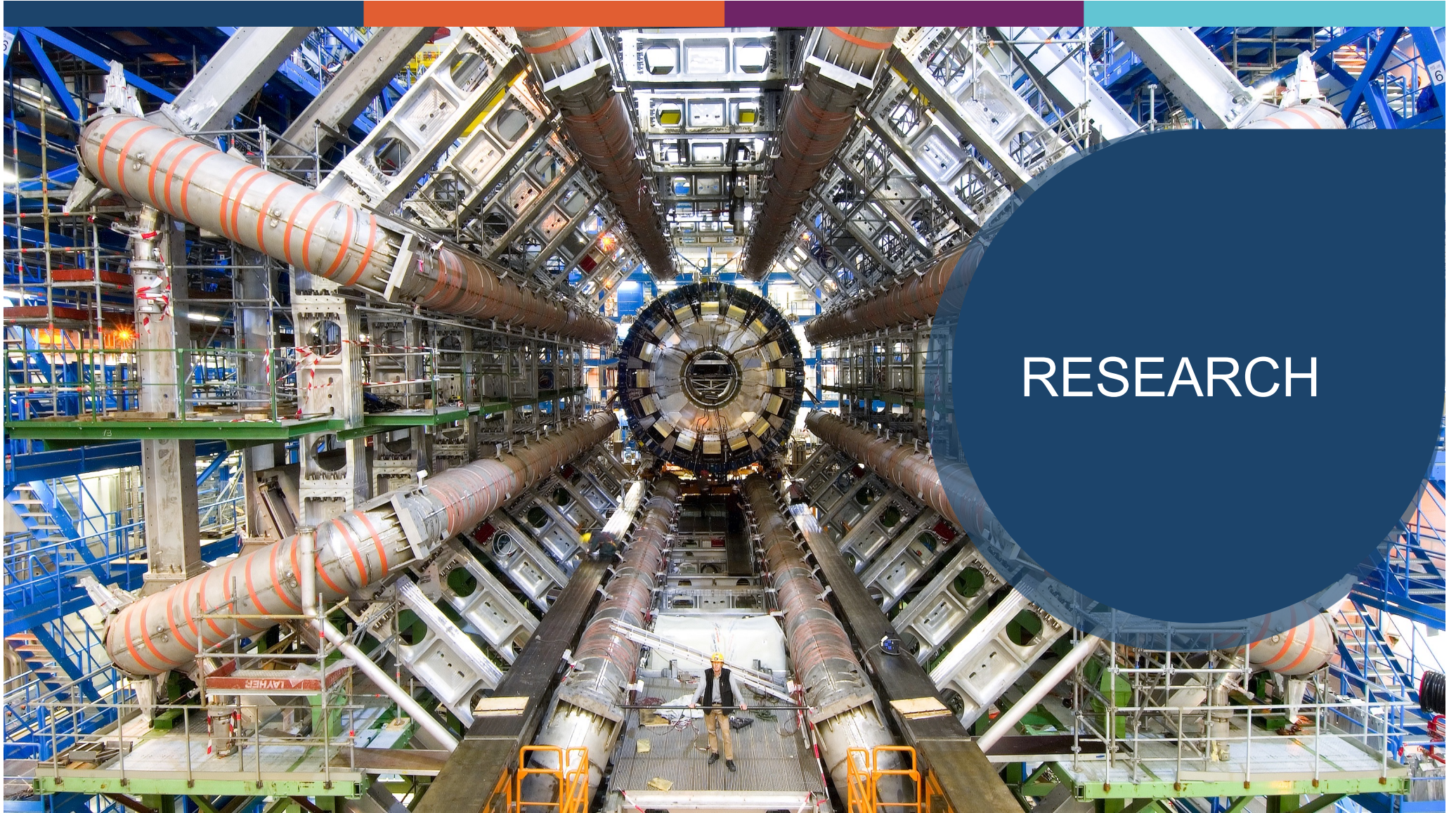
Research (and much more ...) at CERN

Fabiola Gianotti (CERN), 7 July 2025

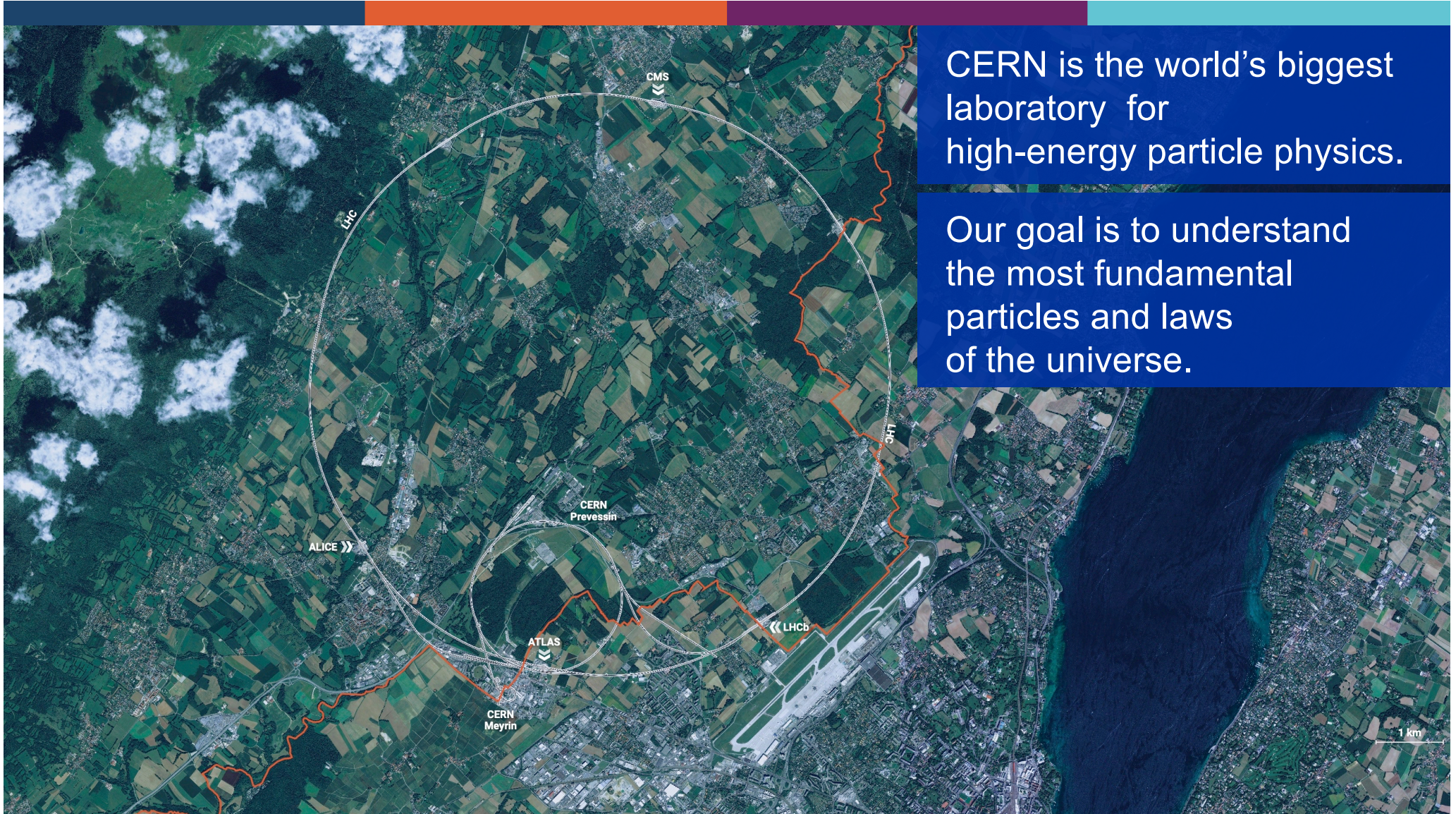


Four pillars underpin CERN's mission





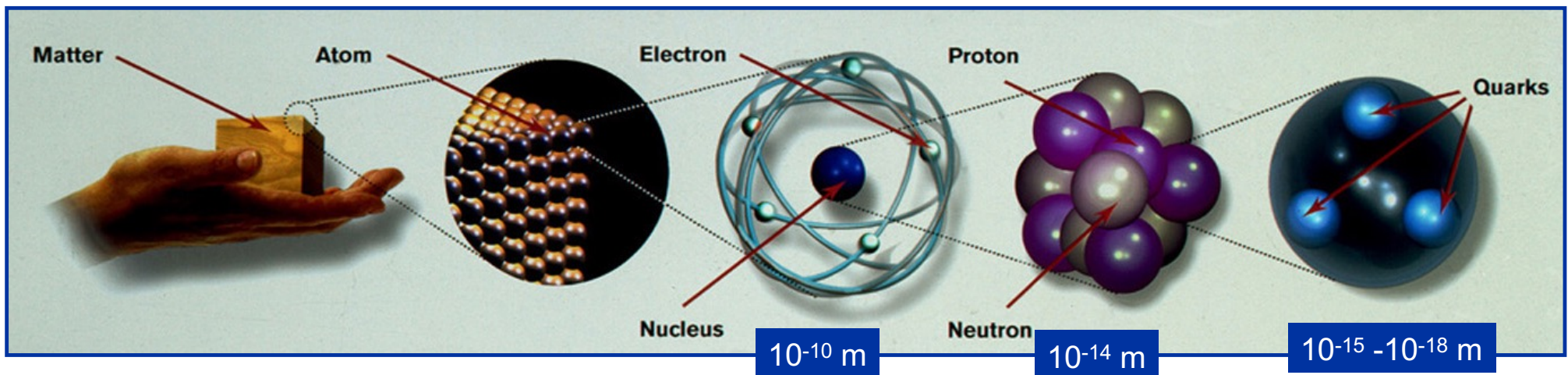
RESEARCH



CERN is the world's biggest laboratory for high-energy particle physics.

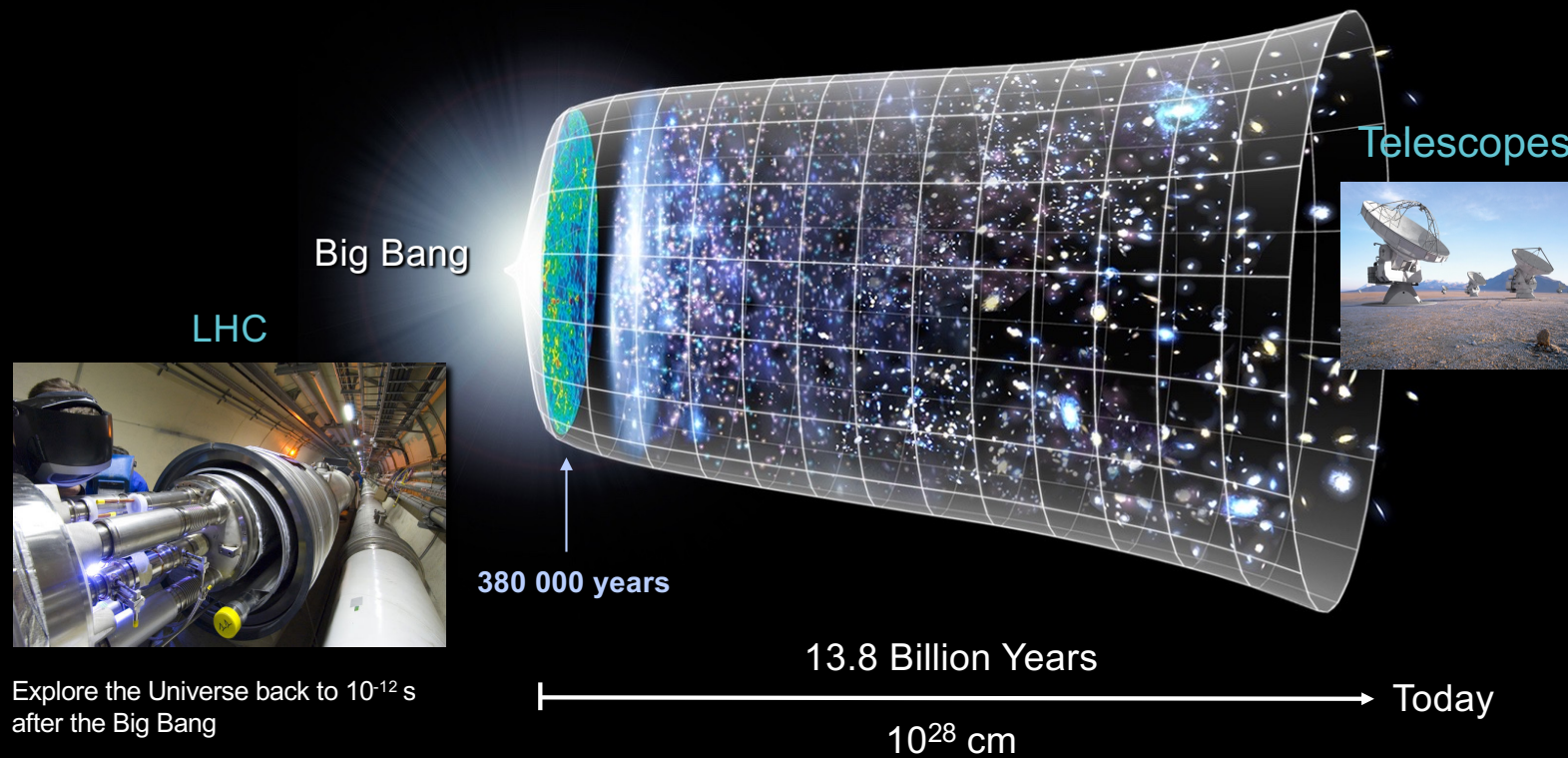
Our goal is to understand the most fundamental particles and laws of the universe.

At CERN we study the elementary particles, i.e., the smallest constituents of matter and the universe, and the laws of physics at the most fundamental level



The Large Hadron Collider (LHC) at CERN allows us to scrutinize matter down to scales of smaller than 10^{-18} m
→ provides insight also into the structure and evolution of the Universe
→ the very small to understand the very big ...

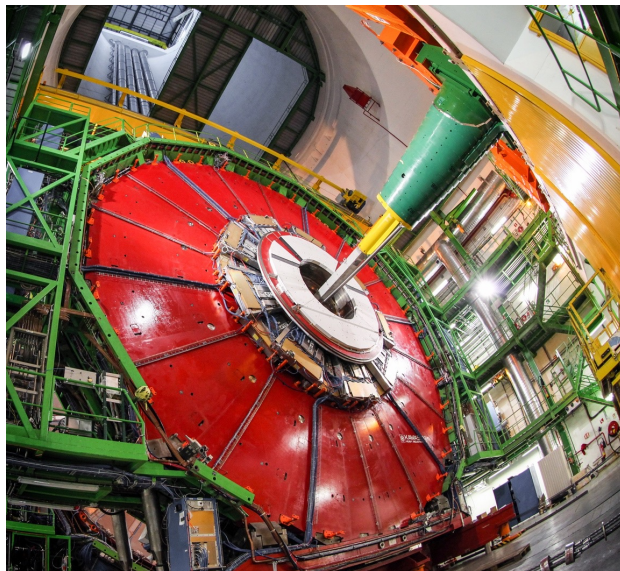
Evolution of the Universe



3 main instruments and a broad spectrum of advanced technologies are needed for our exploration



ACCELERATORS

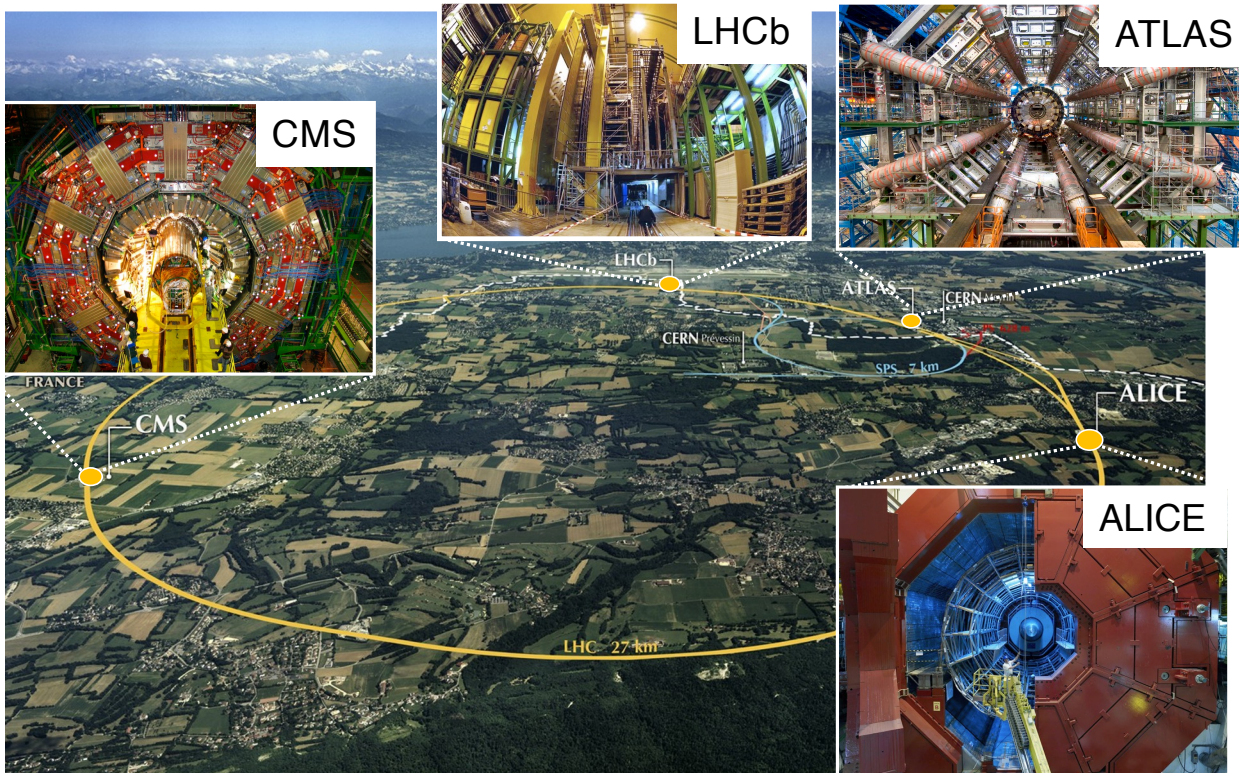


DETECTORS



COMPUTING

Large Hadron Collider - LHC: the most powerful accelerator ever



27 km ring, 100 m underground
Operation started in 2010 →
exploration of a new energy frontier

July **2012**, ATLAS and CMS announced
the discovery of a new (very special!)
particle: the **Higgs boson**.



Francois Englert and Peter Higgs Physics Nobel prize 2013



Collider's backbone: 1232 high-tech superconducting magnets
(built by Alstom-France, **Ansaldo-Italy** and Babcock-Noell-Germany)
→ a brilliant example of partnership between CERN and European industry

Key figures illustrating the technological challenges

1.9 K (-271° C)

The operating temperature of the LHC magnets (colder than outer space)

200 000 billion

The number of protons per beam

11 000

The number of revolutions of the 27 km ring made every second by the protons

40 million

The number of beam-beam collisions in the detectors per second

10^{16} K

(~ 100,000 billion times room temperature): the collision energy in the LHC, corresponding to the temperature of the Universe 10^{-12} seconds after the Big Bang

400 MJ

The energy stored in each of the LHC beams (equivalent to an Airbus 320 at 110 km/h)

3000 km

The length of cable needed to transmit signals from the LHC detectors to the control room

1500 million GB

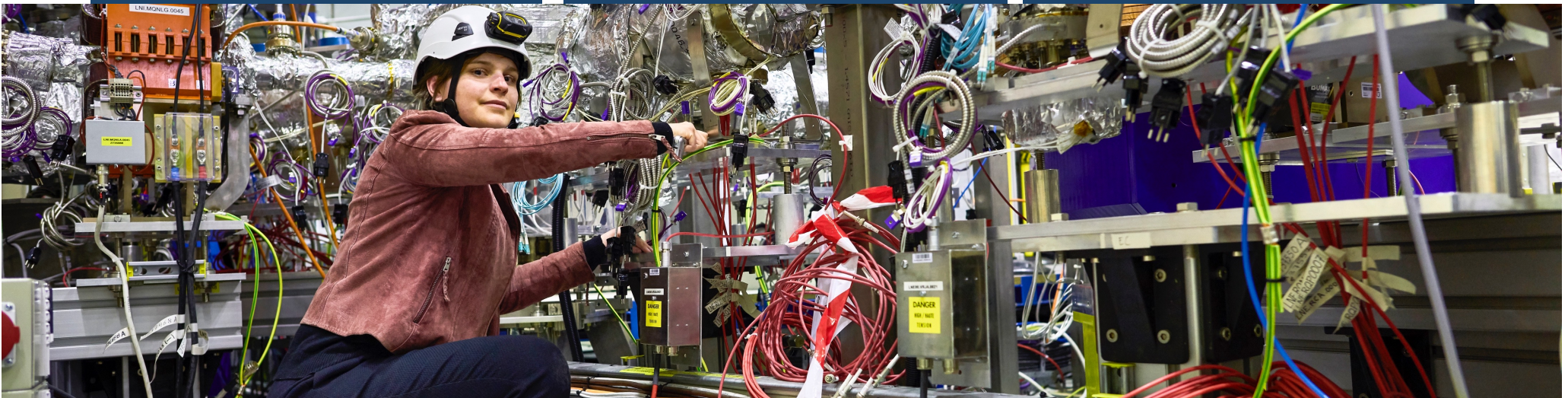
The data from the LHC experiments stored around the world

CERN has a diverse scientific programme

Nuclear Physics
(ISOLDE, n_TOF)

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)

Main outstanding questions in particle physics

Why is the Higgs boson so light?

What is the origin of the matter-antimatter asymmetry in the Universe?

Why 3 families of particles with different masses and behaviours?

What is the origin of neutrino masses and oscillations?

What is the composition of dark matter (~25% of the Universe)?

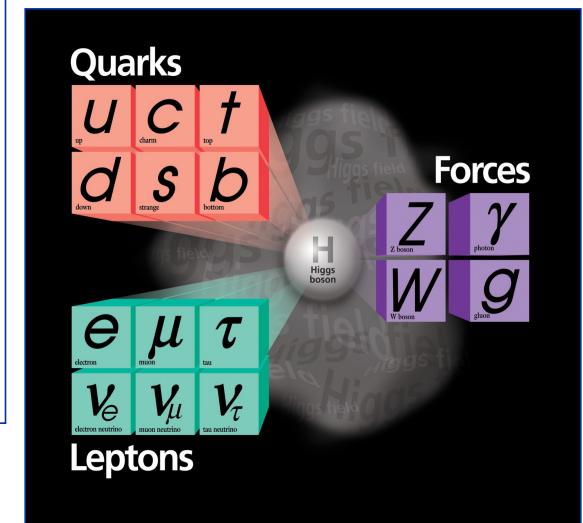
What is the cause of the Universe's accelerated expansion?

Why is Gravity so weak?

These questions require NEW PHYSICS

Dark blue: questions directly accessible to a future collider, in particular using the Higgs boson as a discovery tool

Elementary particles in the Standard Model. All observed experimentally



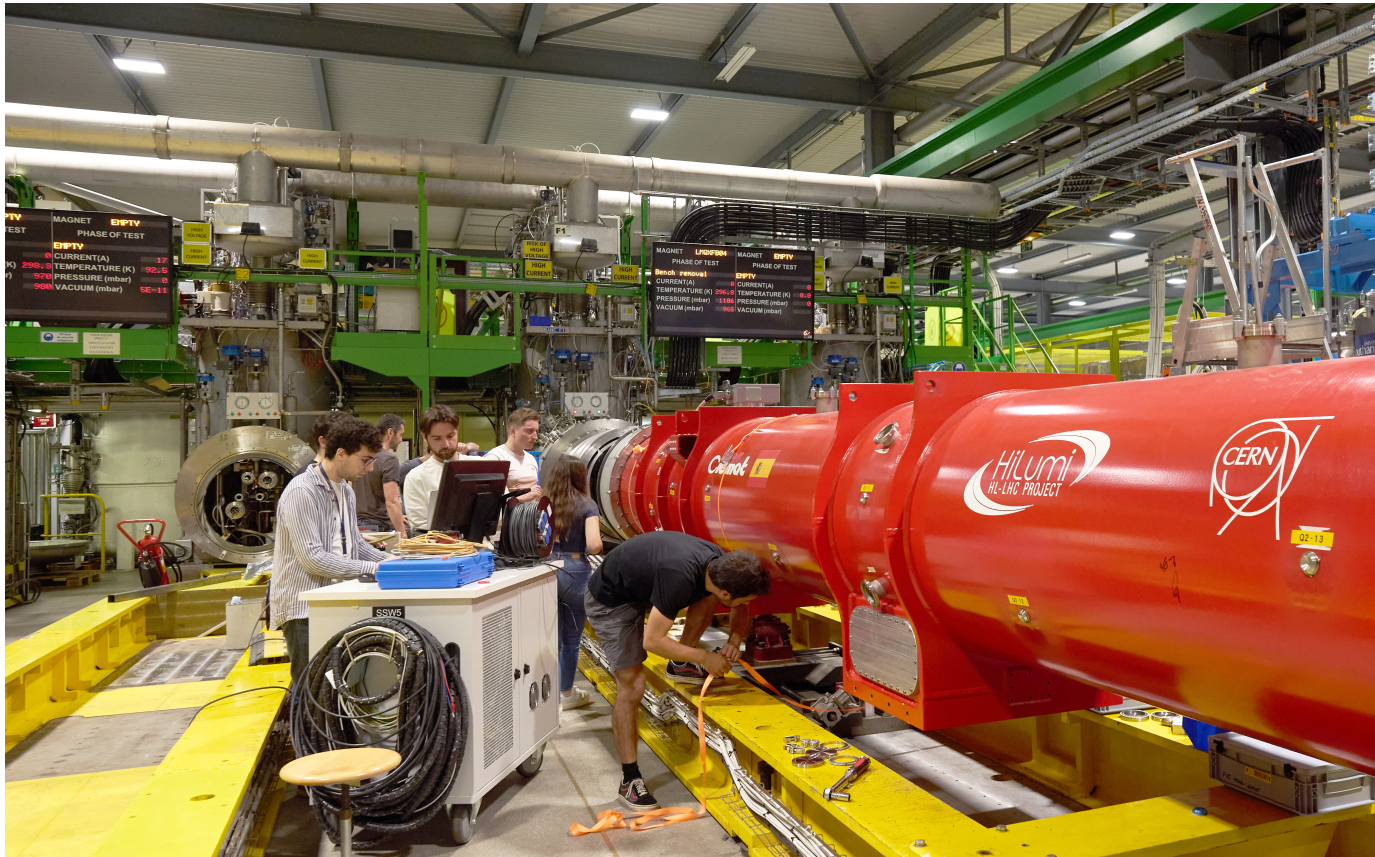
Every problem of the SM originates from Higgs interactions

$$\mathcal{L} = \lambda H \psi \bar{\psi} + \mu^2 |H|^2 - \lambda |H|^4 - V_0$$

↑ ↑ ↑ ↑
flavour naturalness stability C.C.

JWST

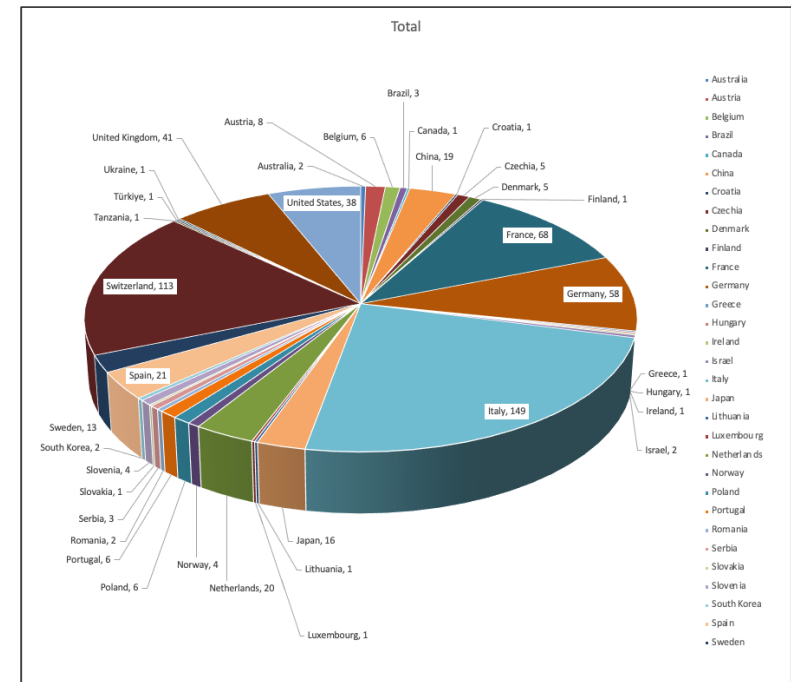
WHAT'S NEXT?



High-Luminosity LHC upgrade

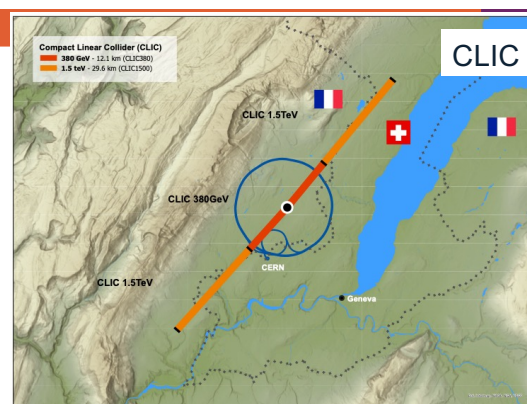
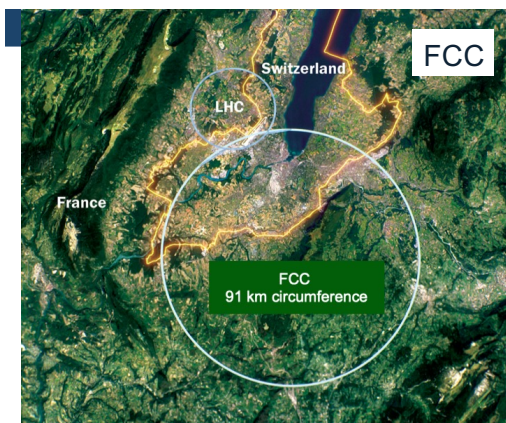
- The HL-LHC will use new technologies to provide 10 times more collisions than the LHC.
- It will give access to rare phenomena, greater precision and discovery potential.

It will start operating in 2030, and run until 2041.

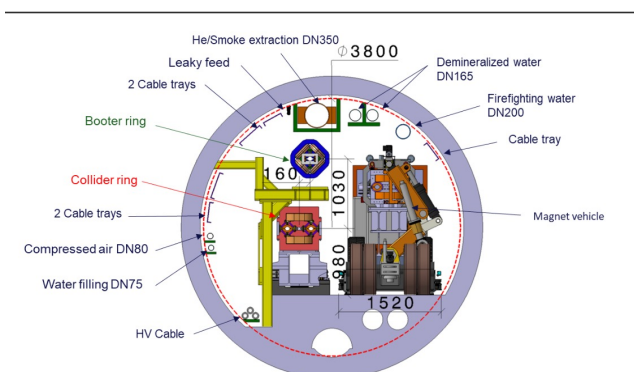
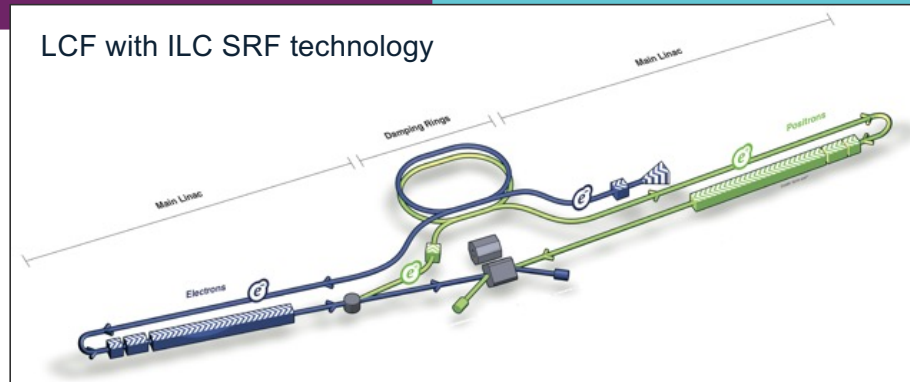


~ 630 in-person participants and ~ 720 remote participants per day

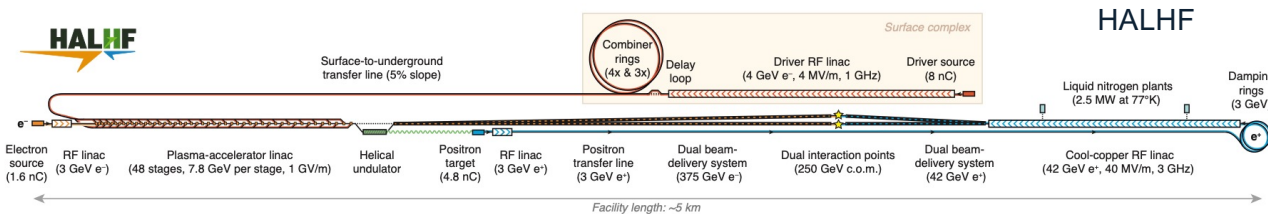
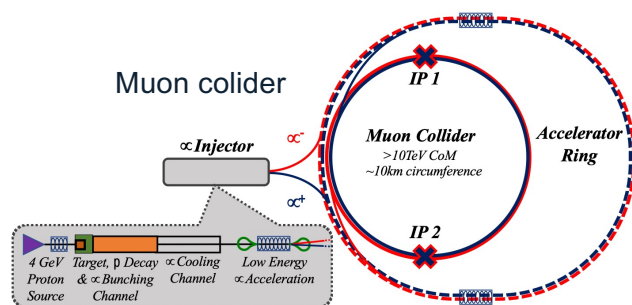
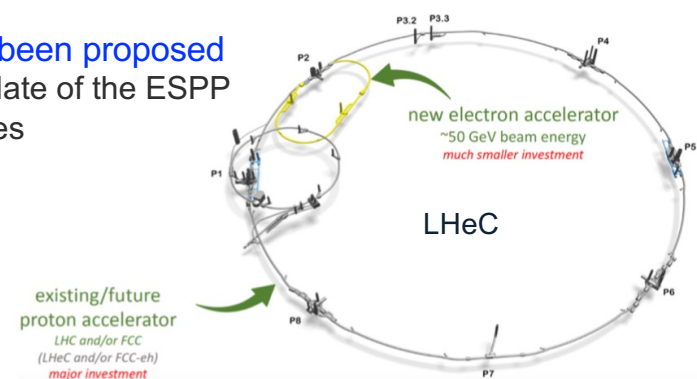
Many thanks to INFN and the Local Organizing Committee chaired by Sandra Malvezzi



LCF with ILC SRF technology

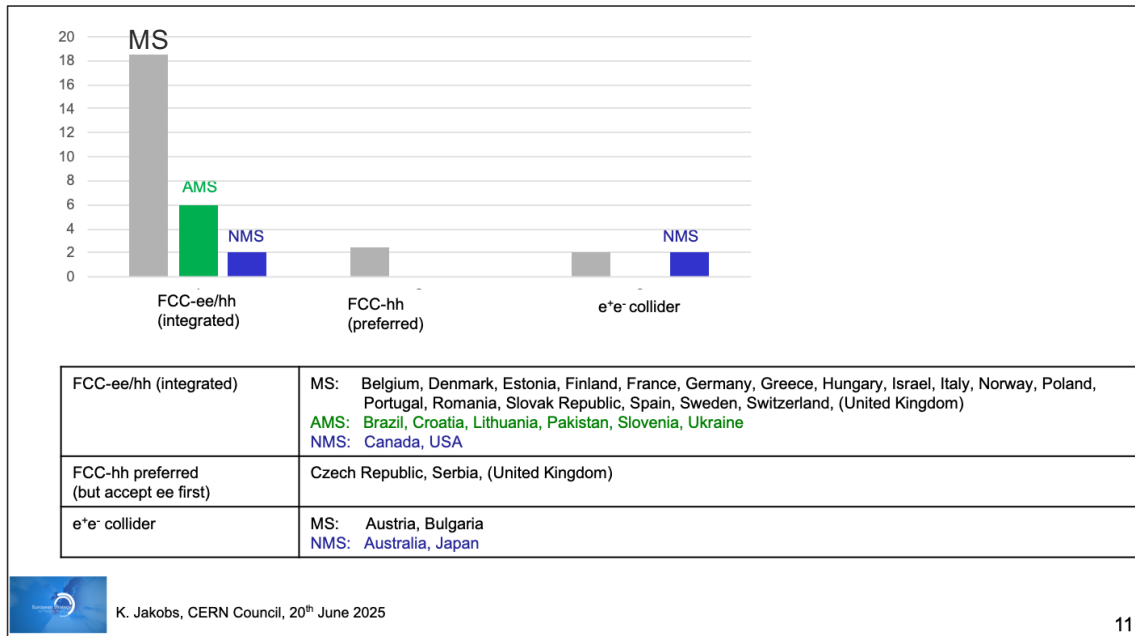


A variety of post-LHC future colliders have been proposed
One of the main objectives of the ongoing update of the ESPP is to select the preferred option and alternatives

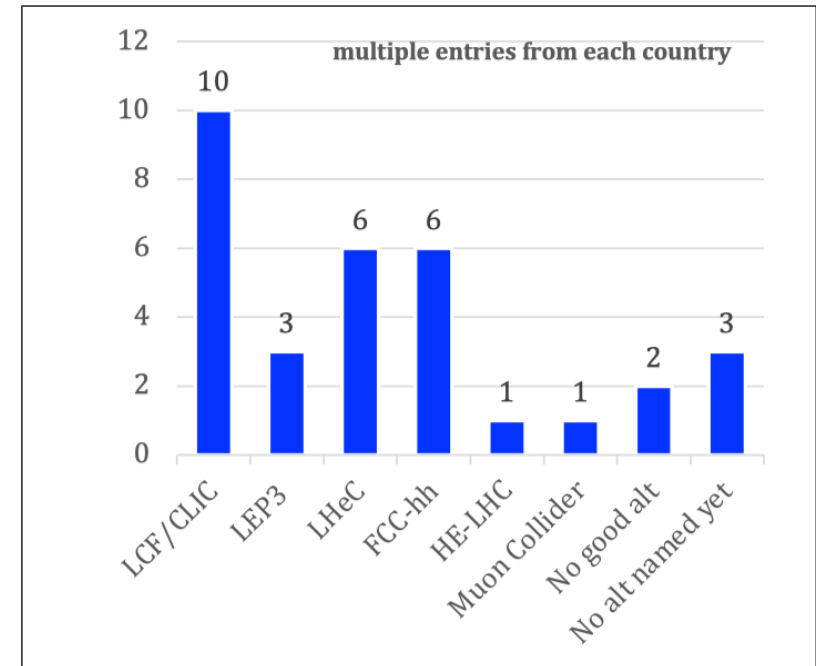


National input to the ESPP

Preferred option



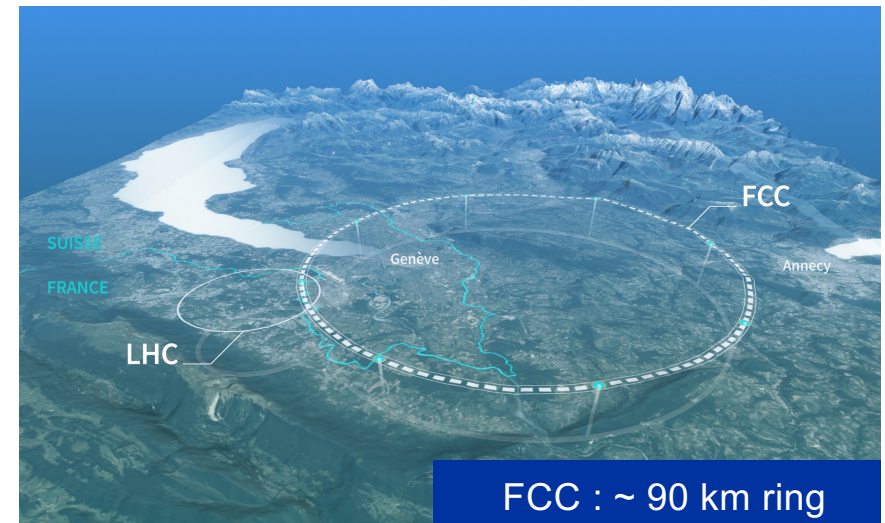
Alternative if preferred option not feasible



Publicly available at: <https://indico.cern.ch/event/1439855/contributions/>
Summary compiled by European Strategy Group

CERN has recently completed the feasibility study of the Future Circular Collider (FCC)

- Potentially the **most extraordinary instrument** ever built to study the laws of nature at the most fundamental level and address many of the outstanding questions about the Universe
- Technologically very ambitious → will push innovation in many domains with applications for medicine, environment, nuclear energy, digital, material science, etc.
- Tentative timescale:
project approval ~ **2028**
construction start ~ **2033**
first-stage operation (e⁺e⁻ Higgs factory) **2048-2063**
- Competition with China, which is considering the same project → risk to lose CERN/Europe leadership in high-energy physics and related technologies



- Cost of tunnel plus first stage machine:
~ **15 BCHF over 12 years**
 - large part covered by CERN's annual budget
 - contributions expected from non-Member States
 - discussing a possible contribution from the European Commission
 - contributions from private donors also being explored

“The future of European competitiveness”

Mario Draghi’s report relased on 9 September 2024



From Box 2 “The CERN success story”

“One of CERN’s most promising current projects, with significant scientific potential, is the construction of the Future Circular Collider (FCC) Chinese authorities are also considering constructing a similar accelerator in China, recognising its scientific potential and its role in advancing cutting-edge technologies. If China were to win this race and its circular collider were to start working before CERN’s, Europe would risk losing its leadership in particle physics, potentially jeopardising CERN’s future.”

“Refinancing CERN and ensuring its continued global leadership in frontier research should be regarded as a top EU priority, given the objective of maintaining European prominence in this critical area of fundamental research, which is expected to generate significant business spillovers in the coming years.”

The background of the slide is a photograph of a server room. On the left, there are large, tangled coils of white network cables. On the right, a single white network cable with an RJ45 connector is shown in sharp focus, extending from the right edge towards the center. The rest of the background is dark and out of focus, showing more server racks and cables.

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 frontier technologies and their impact on society: examples

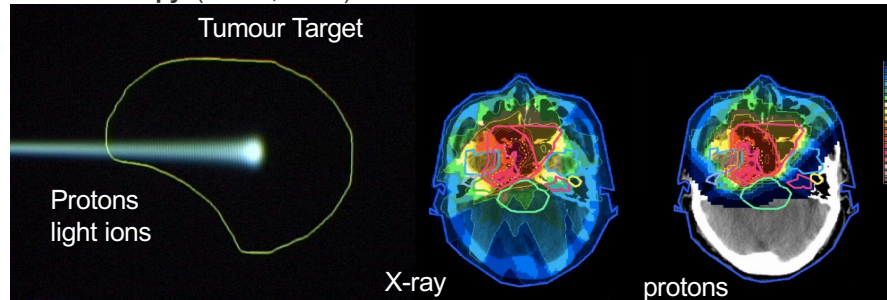
Large variety of cutting-edge, multi-disciplinary technologies developed at CERN: superconducting magnets and materials, electronics, vacuum, cryogenics, robotics, instrumentation, big data, quantum computing and sensors, AI, etc.

Transferred to society at no cost (open science is enshrined in CERN's founding convention).

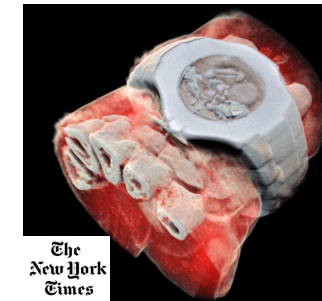
CERN is the birthplace of the World Wide Web



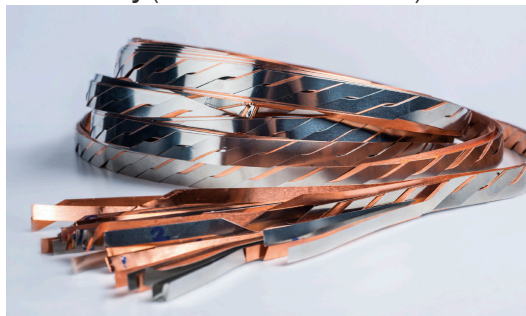
Hadron therapy (CNAO, Pavia)



**Medical imaging:
colour X-ray scanner
using CERN electronics**



**Superconducting cables for loss-free transport
of electricity (collaboration with Airbus)**



CERN | *Fabiola Gianotti – CERN*

Radiation dosimetry for space missions



Machine learning for self-driving cars (collaboration with Volvo)



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CERN and industry: what we buy and develop together

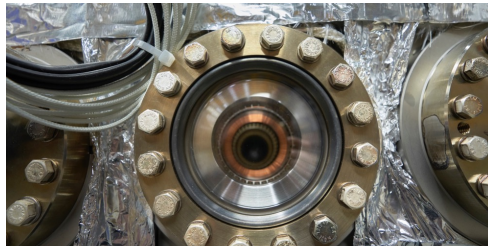
Civil engineering

- Construction
- Renovation of buildings
- Metallic structures
- Earthworks
- Roads



Electrical engineering and magnets

- Transformers
- Switchboards and switchgear
- Cables
- Automation
- Power supplies
- Magnets



Information Technology

- Computing systems
- Servers
- Software
- Network equipment
- Personal computer equipment



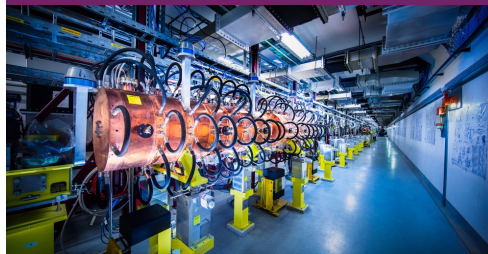
Mechanical engineering and raw materials

- Machining
- Sheet metal work and arc welding
- Special fabrication techniques
- Raw materials, finished and semi-finished products (plates, pipes, etc.)
- Offsite engineering and testing



Electronics and radiofrequency

- Electronic components
- PCBs and assembled boards
- LV and HV power supplies
- Radiofrequency plants
- Amplifiers



> 500 MCHF from CERN budget spent annually to purchase supplies and services from high-tech industry in Member States



As well as

- Cryogenic and vacuum equipment
- Optics and photonics
- Particle and photon detectors
- Health and safety equipment,
- Transport and handling equipment
- Office supply, furniture
- Industrial services on the CERN site

CERN and industry

Not just a client-supplier relationships but a real **partnership** where “non-standard products” (e.g. LHC superconducting magnets) developed together through joint R&D and prototyping

Supplier survey (669 suppliers in 33 countries, 2017) on benefits they got from CERN contracts:

- 48% improved products and services
- 42% developed new products
- 55% improved technical knowledge in their field
- 18% found or opened a new market to address
- 62% used CERN as a marketing reference to boost reputation



Working with CERN is not just about contract value; it's also a driver of excellence, reputation and growth

A low-angle photograph of several flagpoles against a clear blue sky. The flagpoles are dark and extend from the bottom towards the top of the frame. Various national flags are flying from the poles, including the Spanish flag, the Greek flag, the Italian flag, the German flag, the Polish flag, and the Danish flag. A large, semi-transparent orange circle is positioned on the left side of the image, partially overlapping the flagpoles. The word "COLLABORATION" is written in white, uppercase letters across the center of this circle. At the top of the image, there is a horizontal bar with a grey section on the left and a purple section on the right.

COLLABORATION

Science for peace

CERN was founded in 1954 with 12 European Member States



Edoardo Amaldi: one of CERN's founders

25 Member States

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

9 Associate Member States

Brazil – Croatia – Cyprus – India – Latvia – Lithuania
Pakistan – Türkiye – Ukraine

4 Observers

Japan – USA – European Union – UNESCO

Data as of 31 December 2024



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

Employees:
2704 staff,
1181 graduates and fellows
Associates:
12 406 users, **1401** others

~ 50 Cooperation Agreements

Albania – Algeria – Argentina – Armenia – Australia – Azerbaijan – Bahrain – Bangladesh – Bolivia – Bosnia and Herzegovina
Canada – Chile – Colombia – Costa Rica – Ecuador – Egypt – Georgia – Honduras – Iceland – Iran – JINR – 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 – South Africa – Sri Lanka – Thailand – Tunisia – United Arab Emirates – Uruguay – Vietnam

A global laboratory: more than 17 000 people of 110 nationalities work at CERN from more than 600 universities/institutions

Distribution of all CERN users by the country of their home institutes as of 31 December 2024
(distributions below do not include CERN employees)

Geographical & cultural diversity
Users of **110 nationalities**
24 % women

Member States (7704)

Austria 88 – Belgium 142 – Bulgaria 49 – Czech Republic 250
Denmark 50 – Estonia 27 – Finland 88 – France 856 – Germany 1260
Greece 101 – Hungary 84 – Israel 75 – Italy 1657 – Netherlands 174
Norway 88 – Poland 363 – Portugal 110 – Romania 110 – Serbia 42
Slovakia 72 – Slovenia 29 – Spain 448 – Sweden 103 – Switzerland 409
United Kingdom 1029

Associate Member States (602)

Brazil 141 – Croatia 35 – Cyprus 12 – India 158 – Latvia 22
Lithuania 21 – Pakistan 35 – Türkiye 151 – Ukraine 27

Observers (2330)

Japan 229 – United States of America 2101

Cooperation Agreements (1770)

Albania 7 – Algeria 1 – Argentina 17 – Armenia 28 – Australia 31 – Azerbaijan 2 – Bahrain 10 – Canada 203
Chile 58 – Colombia 25 – Costa Rica 8 – Cuba 3 – Ecuador 4 – Egypt 22 – Georgia 36 – Hong Kong 17 – Iceland 3
Indonesia 8 – Iran 18 – Ireland 11 – JINR 305 – Jordan 2 – Kazakhstan 8 – Kuwait 2 – Lebanon 12 – Madagascar 1
Malaysia 1 – Malta 3 – Mexico 66 – Montenegro 4 – Morocco 22 – New Zealand 1 – Nigeria 1 – Oman 1 – Palestine 1
People's Republic of China 472 – Peru 3 – Philippines 1 – Republic of Korea 184 – Saudi Arabia 4 – South Africa 73
Sri Lanka 7 – Taiwan 49 – Thailand 17 – Tunisia 3 – United Arab Emirates 14 – Vietnam 1

Numbers for Italy

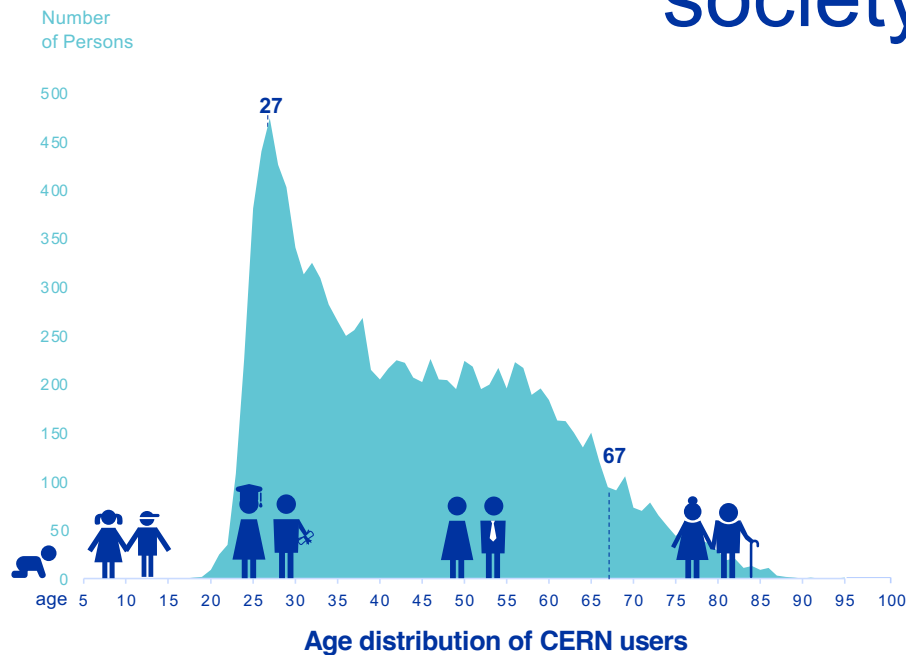


- Personnel by nationality as of 31 December 2024
 - User: **2010**
 - Staff: **329**
 - Graduates and fellows: **176**
 - Doctoral: **42**

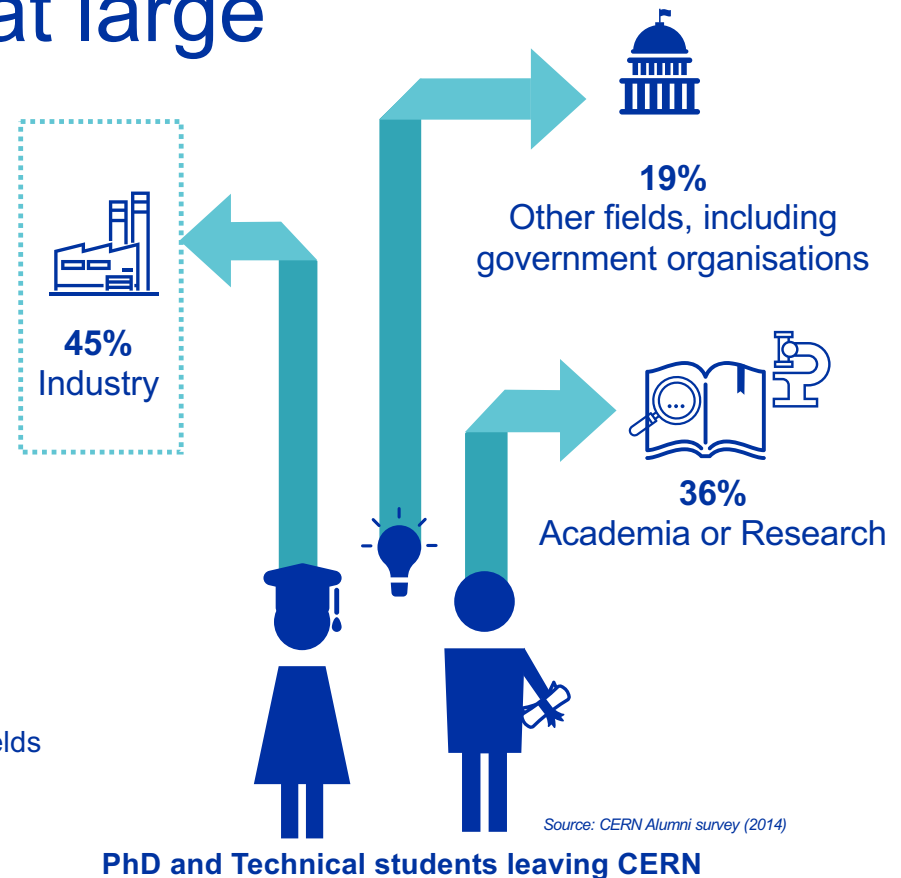


EDUCATION & TRAINING

CERN trains people for career opportunities in society at large

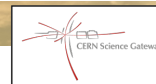


At any given time CERN is training ~ 5500 young people: physicists, as well as engineers and technicians in a larger number of fields (mechanics, robotics, cryogenics, vacuum, electronics, superconducting materials, quantum/AI, civil engineering, etc.)
Only ~ 30% of them remain in particle physics.



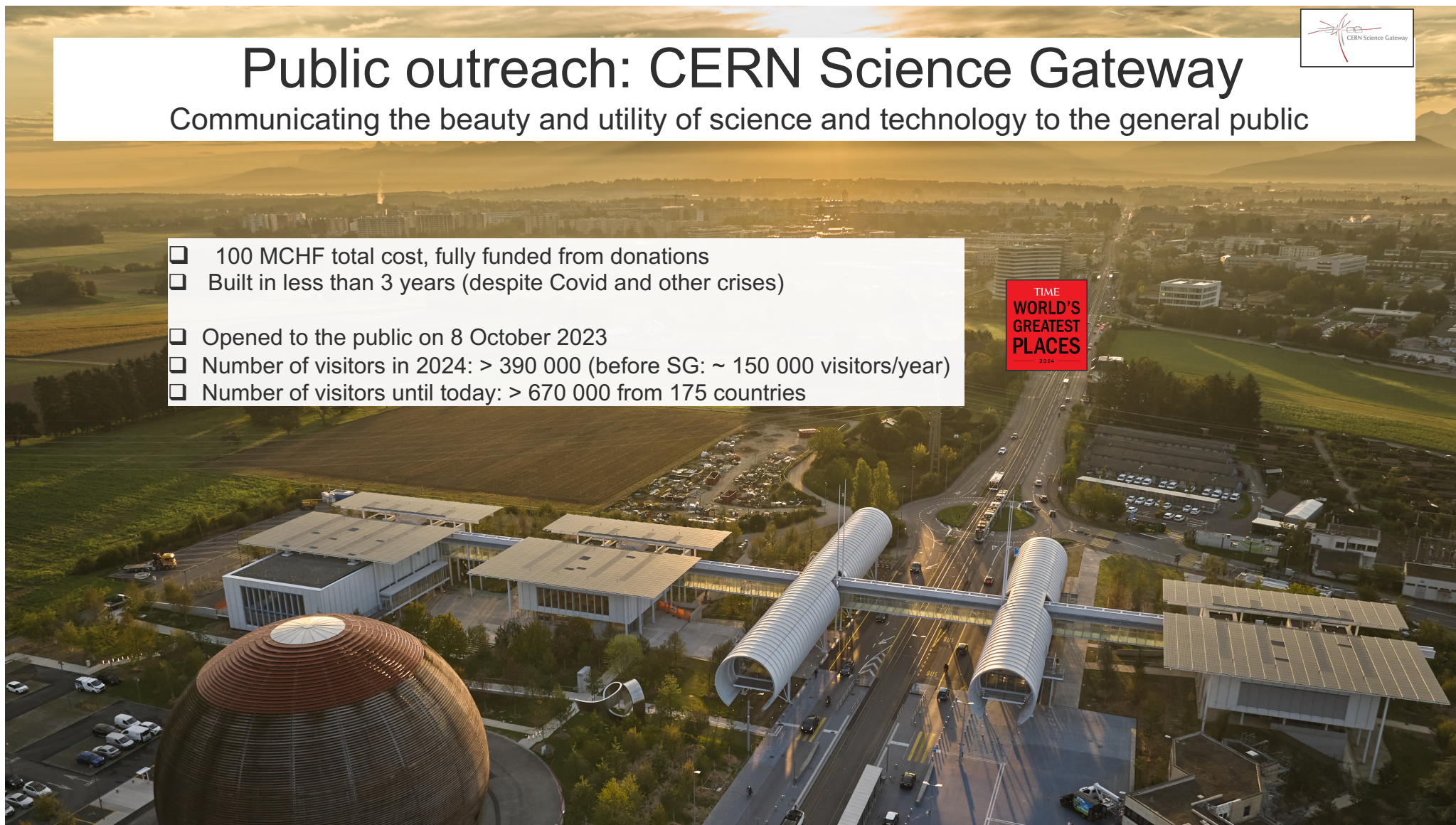
Public outreach: CERN Science Gateway

Communicating the beauty and utility of science and technology to the general public



- ☐ 100 MCHF total cost, fully funded from donations
- ☐ Built in less than 3 years (despite Covid and other crises)
- ☐ Opened to the public on 8 October 2023
- ☐ Number of visitors in 2024: > 390 000 (before SG: ~ 150 000 visitors/year)
- ☐ Number of visitors until today: > 670 000 from 175 countries

TIME
WORLD'S
GREATEST
PLACES
2024



Not only visits ...

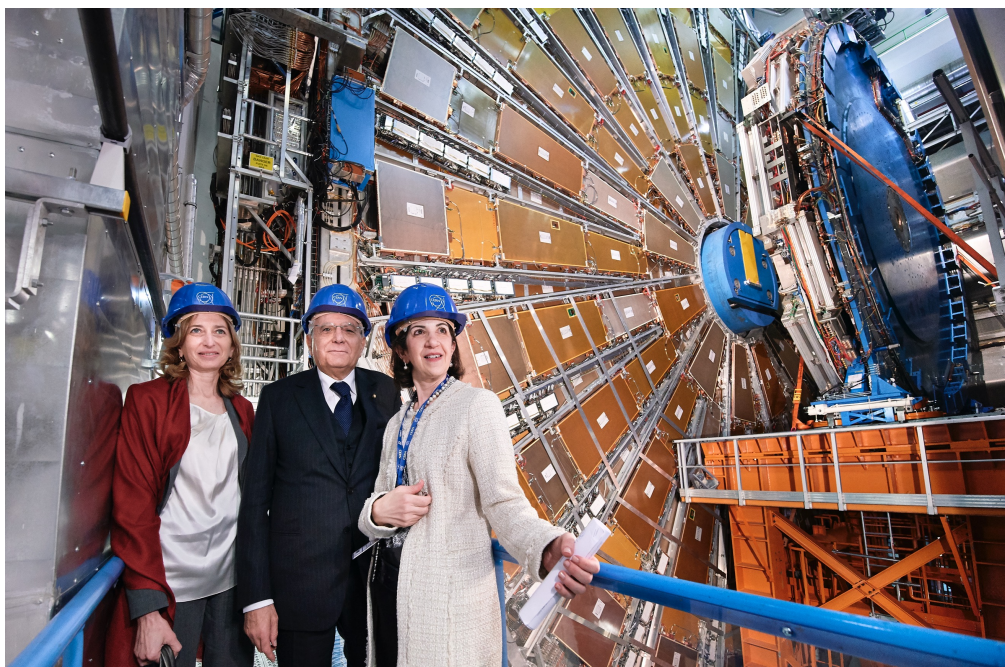


CERN PUBLIC EVENTS — SEASON 24 CERN's 70 th Anniversary	CERN SCIENCE GATEWAY AUDITORIUM SERGIO MARCHIONNE 8 NOVEMBER 2024 7:30 p.m.
Global challenges and the role of science An evening with Al Gore With the participation of: Fabiola Gianotti, CERN Director-General Benoît Delille, CERN Head of Health & Safety and Environmental Protection Unit Rebecca Grynszpan, Secretary General of UN Trade and Development (UNCTAD) Joeri Rogelj, Professor of Climate & Science Policy, Imperial College London Panel discussions moderated by Olivier Desloubert	  
	 CERN & Society Foundation  70 YEARS 1954-2024  CERN & Society Foundation





Contributions of Italy to, and benefits from, CERN's great success



Visit by His Excellency Mr Sergio Mattarella President Italian Republic, 10 June 2019

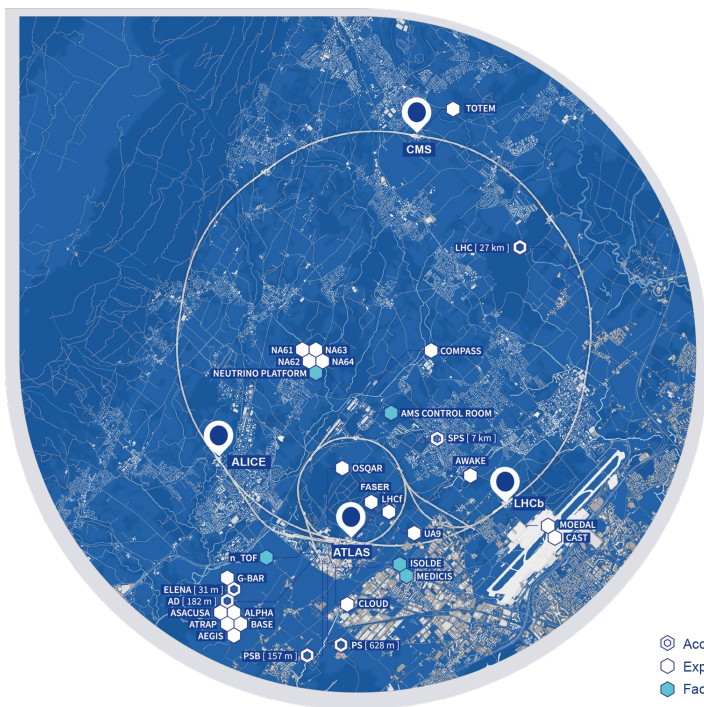
- Italy is one of the 12 founding Member States
- Edoardo Amaldi (Secretary-General 1952-1954)
- 3 Directors-General out of 16:
Carlo Rubbia, Luciano Maiani, Fabiola Gianotti
- INFN is one of strongest partners of CERN
- More than 2600 Italian scientists involved today in projects at CERN (out of ~17000)
- 865 Italian firms in CERN's supplier database
- 1.5 BCHF of (mostly high-tech) contracts adjudicated by CERN to Italian industry over the years.



Strong contributions to accelerator technologies, e.g. superconducting magnets



Italy has a strong involvement across the CERN experimental programme



LHC EXPERIMENTS

ALICE 27 institutes, 281 Participants

ATLAS 18 institutes, 409 Participants

CMS 17 institutes, 614 Participants

LHCb 14 institutes, 227 Participants

OTHER LHC EXPERIMENTS

LHCf 2 institutes, 19 Participants

SND 4 institutes, 71 Participants

TOTEM 3 institutes, 18 Participants

FIXED TARGET EXPERIMENTS

- **COMPASS**,
 - **nToF**,
 - **NA62**
 - **NA64**,
 - **Neutrino Platform**
- in total 57 institutes,
397 Participants

AD EXPERIMENTS

- **AEGIS**,
 - **ASACUSA**
- 12 institutes,
42 Participants

ISOLDE

7 institutes, 45 participants

WLCG Tier-1: INFN-CNAF Bologna



CERN today

Scientific excellence in fundamental research → **world leader** in high-energy particle physics

Driver of innovation → development of advanced, multi-disciplinary technologies in partnership with national labs, universities and industry in Europe and beyond → impact on society: health, environment, nuclear energy, security, digital/computing, etc.

Training of young generations → provides a highly-qualified STEM workforce to society

Collaboration across borders → "CERN model" for cooperation and governance exported to other scientific organisations and considered as template for AI, health, climate change, etc.

Ursula von der Leyen, AI summit, Paris, 10 Feb 2025:

"We want to replicate the success story of the CERN laboratory in Geneva. CERN hosts the largest particle accelerator in the world and allows the best and brightest minds from around the world to work together. We want the same to happen in our gigafactories for artificial intelligence."

Open science → sharing knowledge, technology and education as a means of boosting science, spreading its benefits and reducing inequities across the world.

CERN is a value system and a precious asset of humanity (**thanks in particular to great contributions from Italy**)

We are currently working to ensure a brilliant future for this unique institution

(European in character and global in its activities)

serving knowledge and society.