



# What is CERN doing under Switzerland?

**A brief journey to the frontiers of physics and technology**

Andreas Hoecker (CERN)

*European Congress of Radiology (ECR) 2026, Vienna, 6 March 2026*



*Hand mit Ringen*



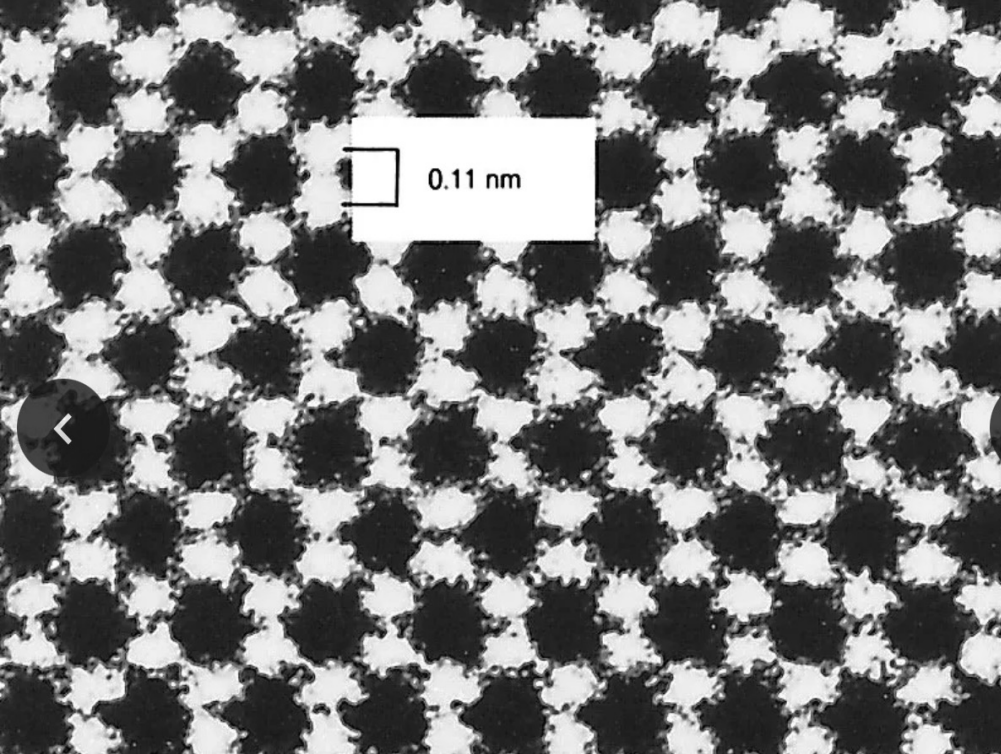
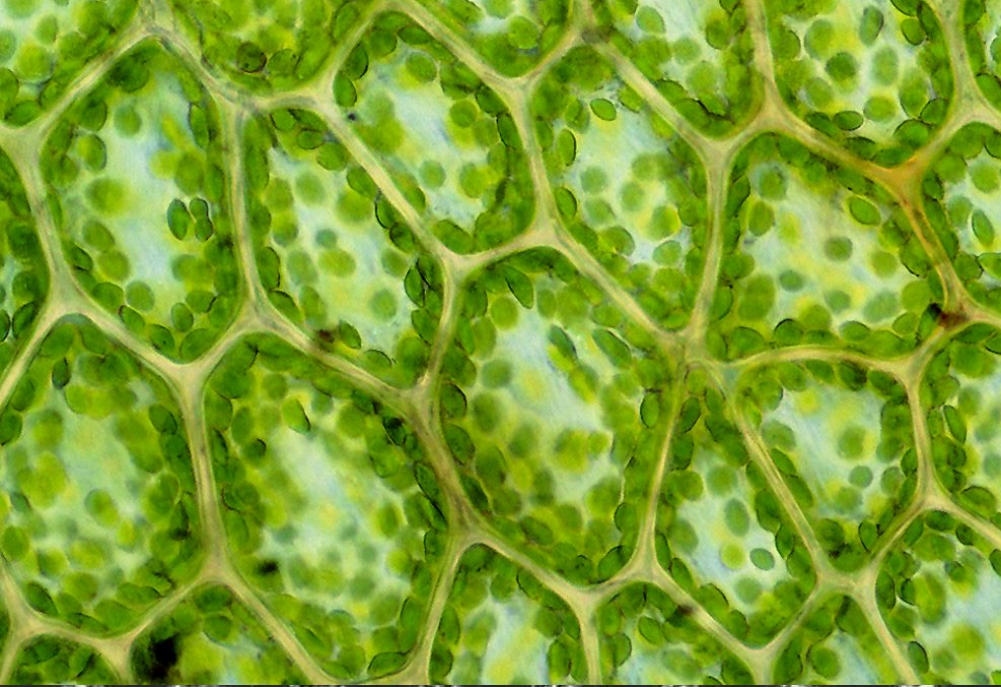
**Physicists have long sought to uncover the structure of matter and make the invisible visible**

Energetic (= short wavelength) light allows us to visualise hidden structures

Hand mit Ringen (Hand with Rings): print of Wilhelm Röntgen's first "medical" X-ray, of his wife's hand, taken on 22 December 1895.

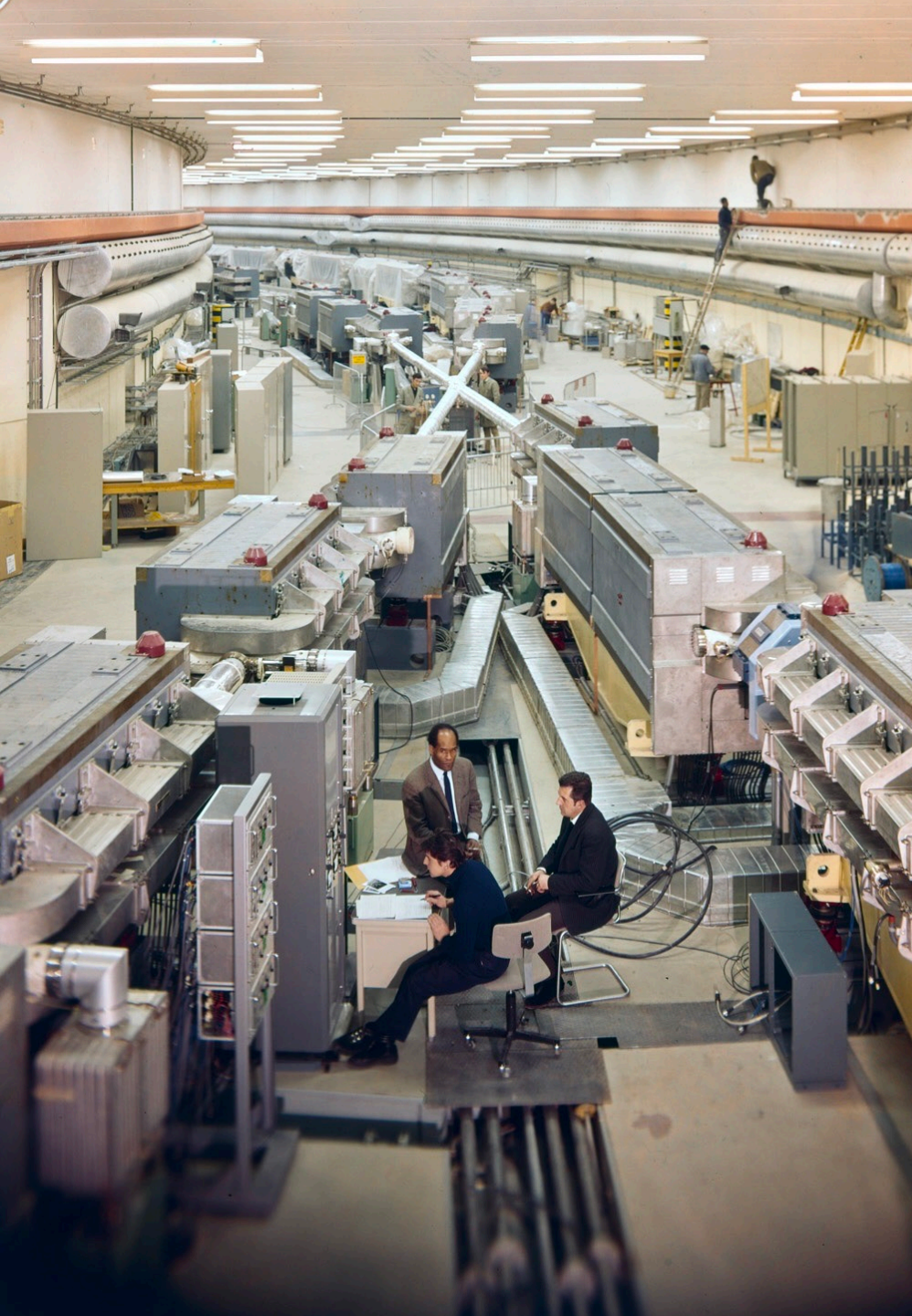
Source: Wikipedia





Light microscopes enabled the discovery of cells, while more energetic (shorter-wavelength) electron microscopes can resolve far smaller structures, such as viruses, and even reveal details at the atomic scale





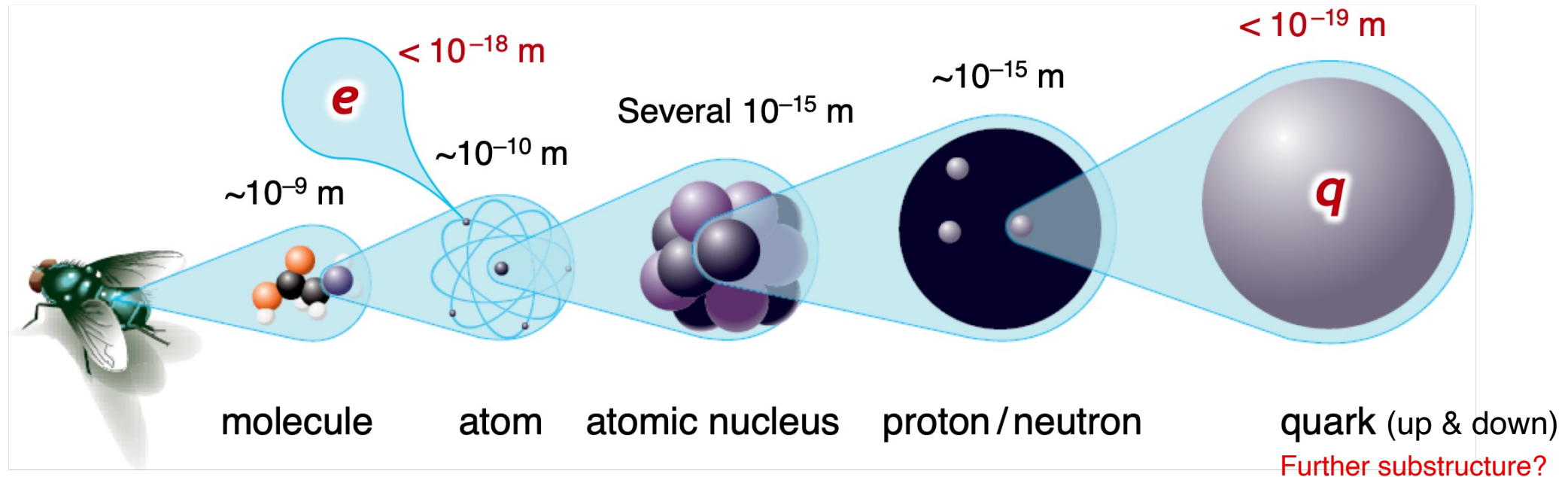
The energies generated in modern particle accelerators and colliders allow to resolve space almost a billion times smaller than today's best electron microscopes ...

... and to produce heavy particles through  $E = mc^2$  that governed the early history of the universe



# And we are seeing a strange universe, indeed

The sub-atomic structure of matter and its interactions is elegantly simple (a very simplified picture)



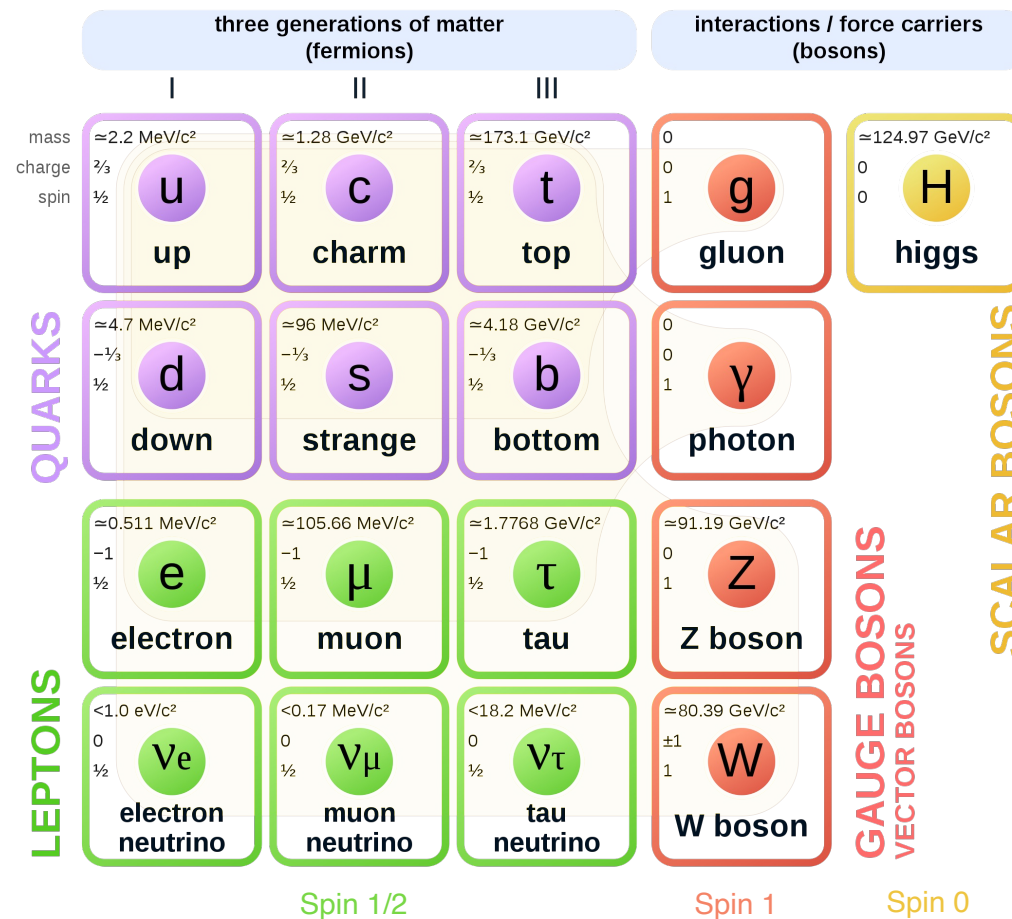
- Elementary particles appear point-like, with no spatial extent at all (this is likely not true)
- Without some remarkable mechanism at play (Higgs mechanism, 1964), elementary particles would have no mass (simply assigning them their measured masses leads to deep problems in the equation of physics)



# And we are seeing a strange universe, indeed

But significantly more complex than seemingly necessary — this is today's **Standard Model**

## Standard Model of Elementary Particles



Completely new type of force, nothing to do with known forces

The Higgs boson is the manifestation of a background vacuum field that gives elementary particles mass according to how strongly they couple to it

Higgs Mechanism



**But significantly more complex than seemingly necessary — this is today's [Standard Model](#)**

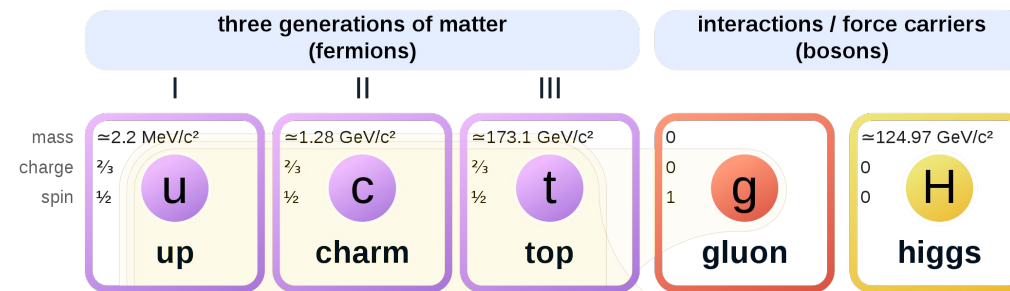
☀️ Particles discovered through decades of **international, high-technology accelerator-based** research



# And we are seeing a strange universe, indeed

But significantly more complex than seemingly necessary — this is today's **Standard Model**

## Standard Model of Elementary Particles

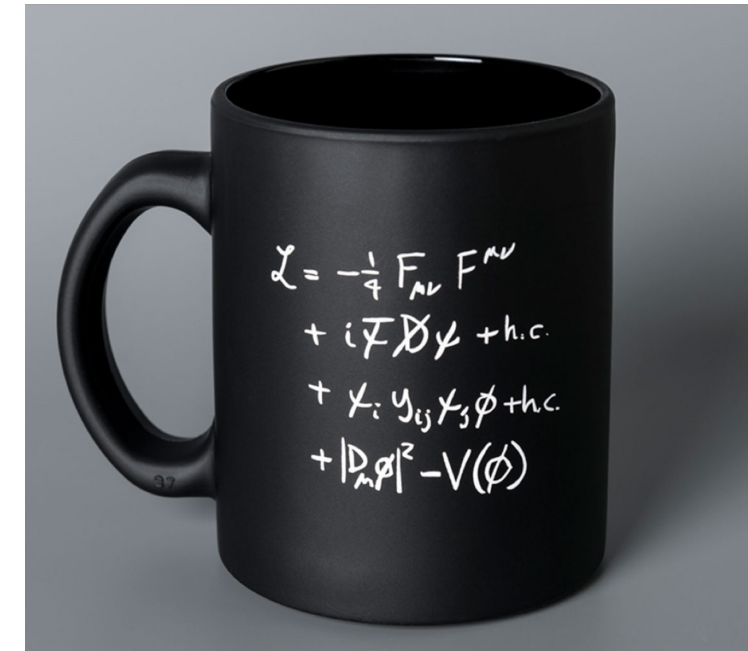
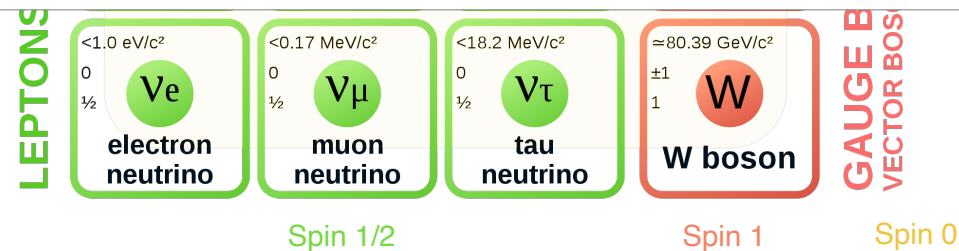


### The Standard Model is a highly predictive theory

For example, the g-factor characterising the magnetic moment of the electron is predicted as:

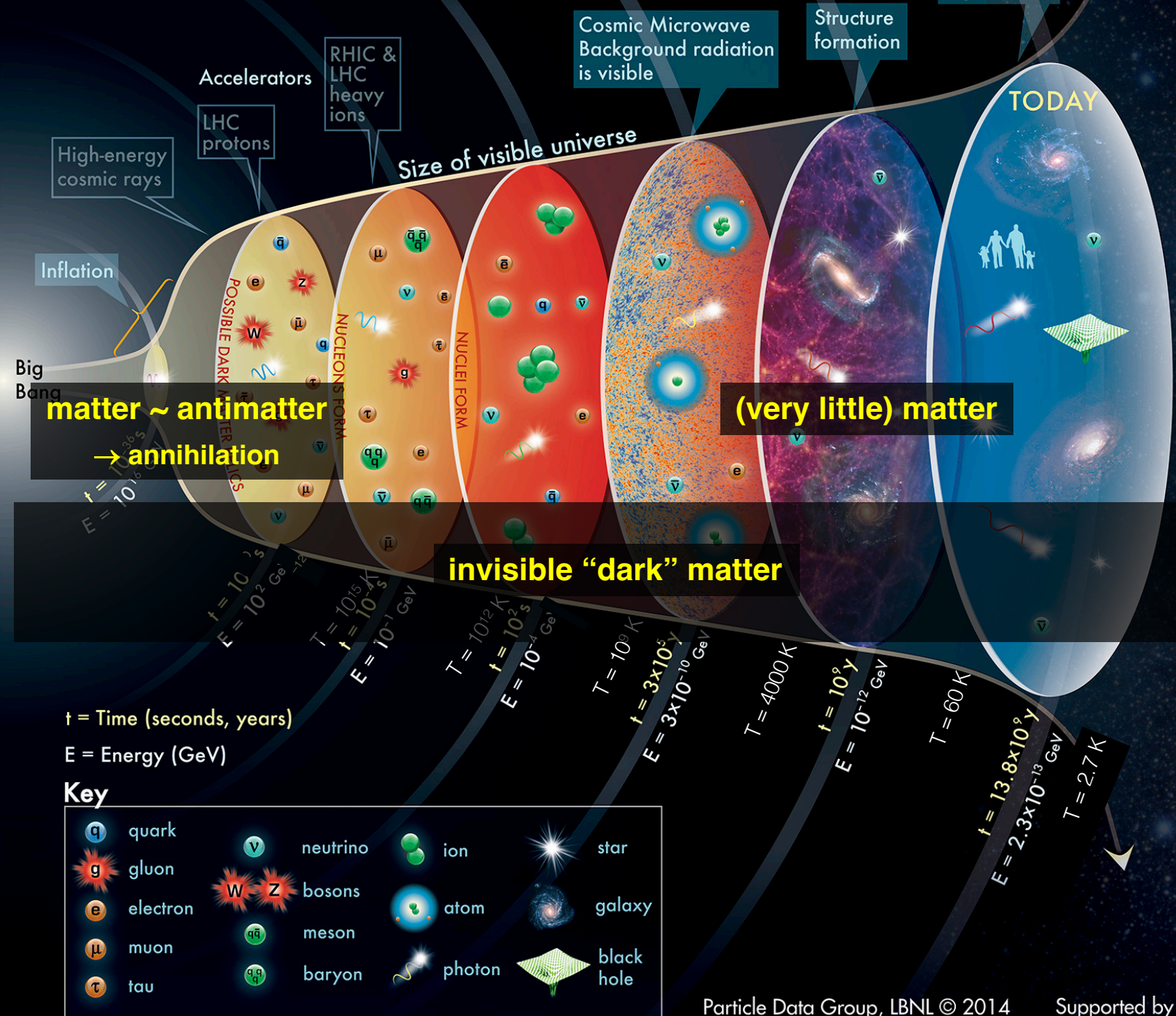
$$g_e = 2.002\,319\,304\,361\,18 \pm 0.000\,000\,000\,000\,26$$

in agreement with experiment within a precision of  $10^{-10}$  !



Mathematical structure of the Standard Model





# The Standard Model

... should not only work today, but also describe the history of the universe since the Big Bang 13.8 billion years ago

But why is there matter left in the universe?

And what is the origin of the huge quantity of *dark matter* (5 times more than visible matter)?

How do elementary particles obtain mass? Is it through the Higgs mechanism?

We do not know why the laws and parameters of physics are set in a way to enable complex chemistry and life



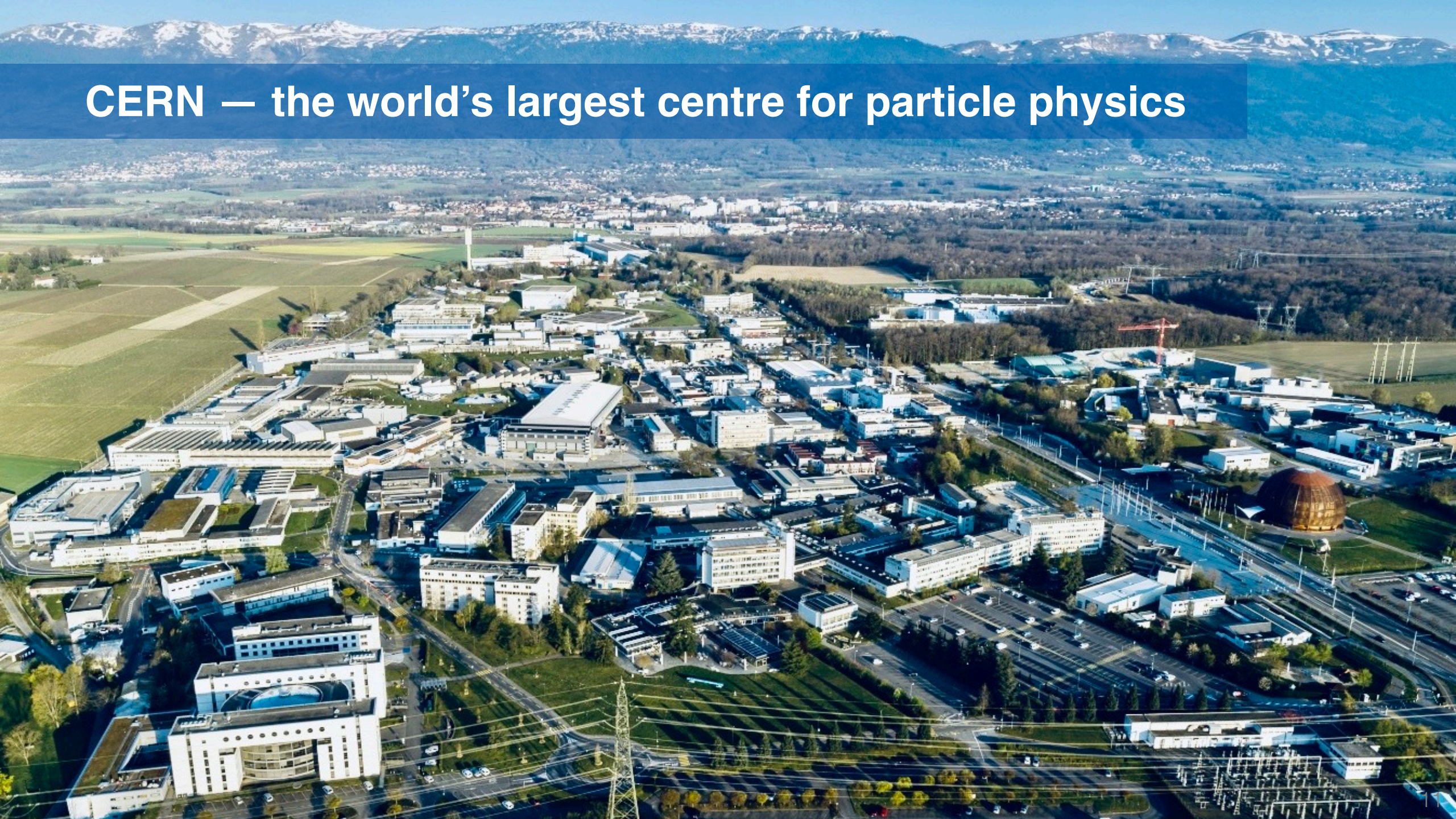
Addressing these questions and pushing the boundaries of our knowledge requires a huge accelerator

This accelerator has been built at CERN





# CERN — the world's largest centre for particle physics





Science for peace

**CERN was founded in 1954 by 12 European Member States. Today: 25**



A laboratory for people around the world

### 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

### 10 Associate Member States

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

### 4 Observers

Japan – USA – European Union – UNESCO

Data as of 31 December 2024

### ~ 50 Cooperation Agreements

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

CERN members:

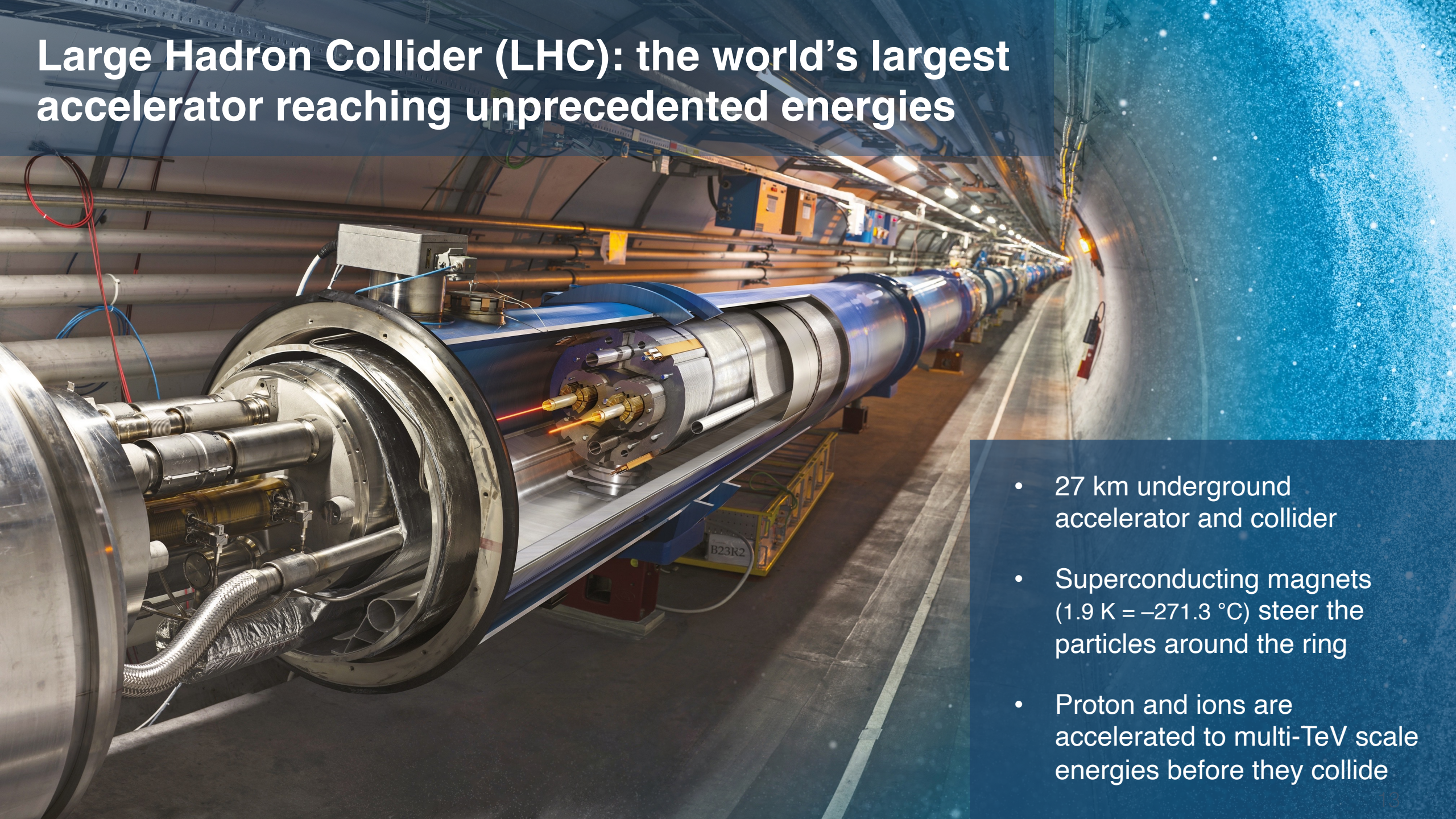
- 2700 staff
- 1200 graduates and fellows
- 14000 users (3000 Ph.D. students)



Education & training is one  
of CERN's core mission



# Large Hadron Collider (LHC): the world's largest accelerator reaching unprecedented energies



- 27 km underground accelerator and collider
- Superconducting magnets ( $1.9\text{ K} = -271.3\text{ }^{\circ}\text{C}$ ) steer the particles around the ring
- Proton and ions are accelerated to multi-TeV scale energies before they collide



LHC



CMS

LHC

LHC

CERN  
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ALICE >>

ATLAS

CERN  
Meyrin

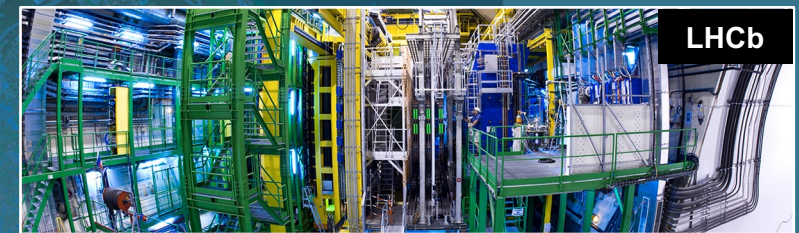
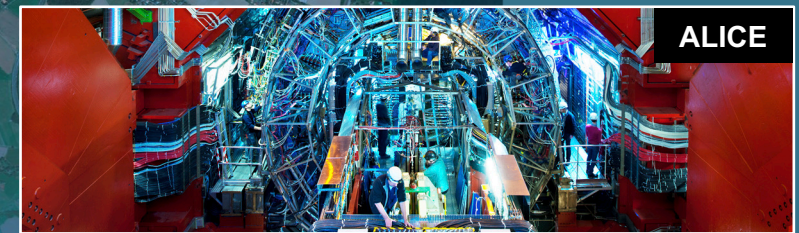
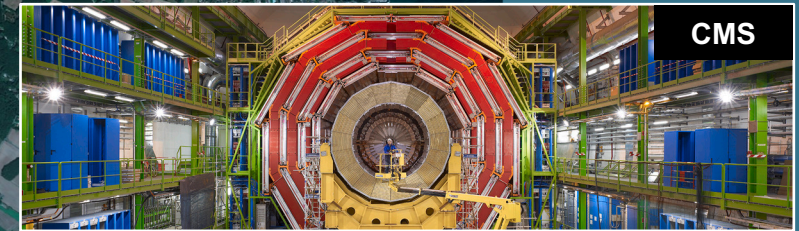
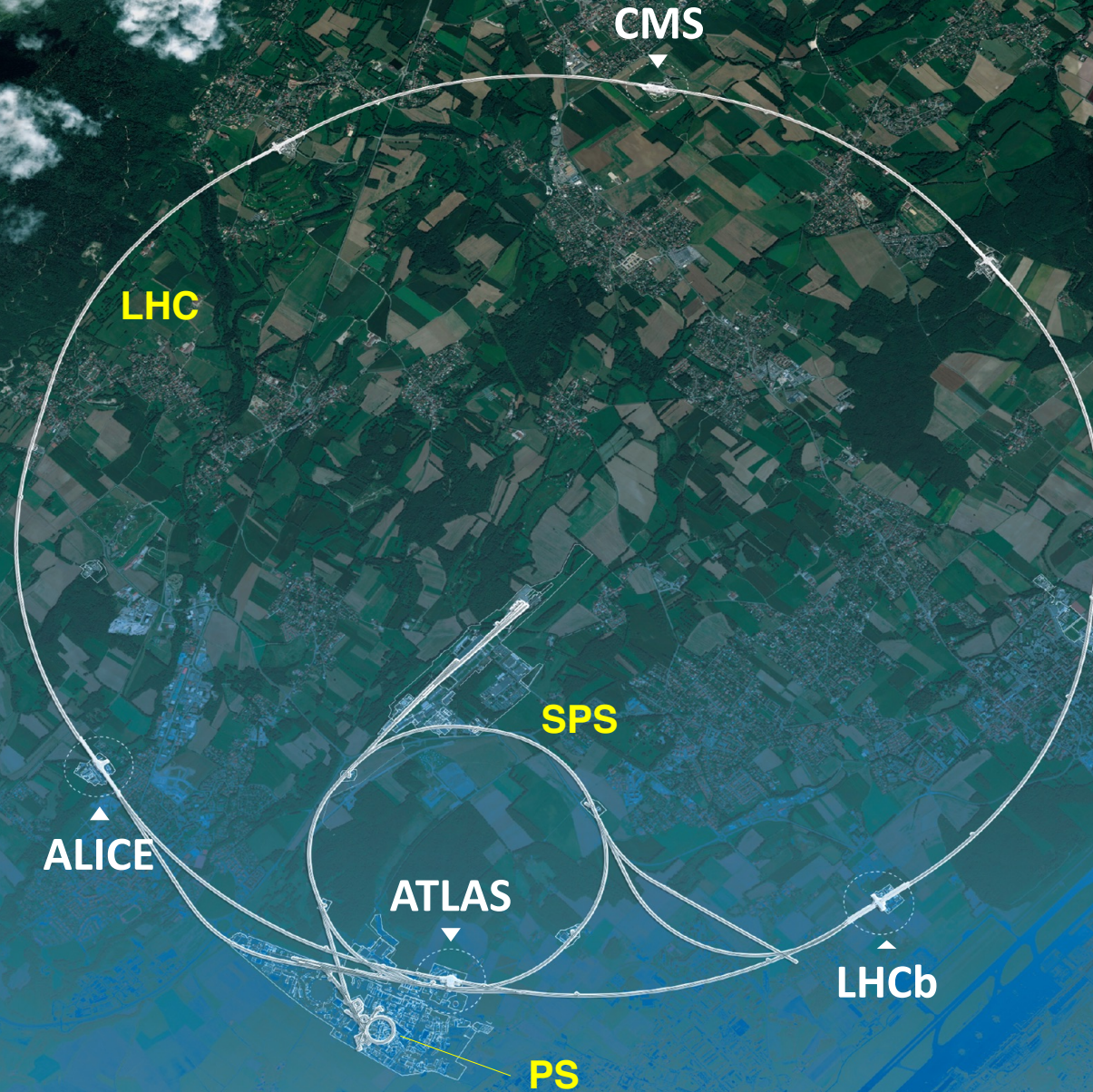
<< LHCb

Aerial view

1 km



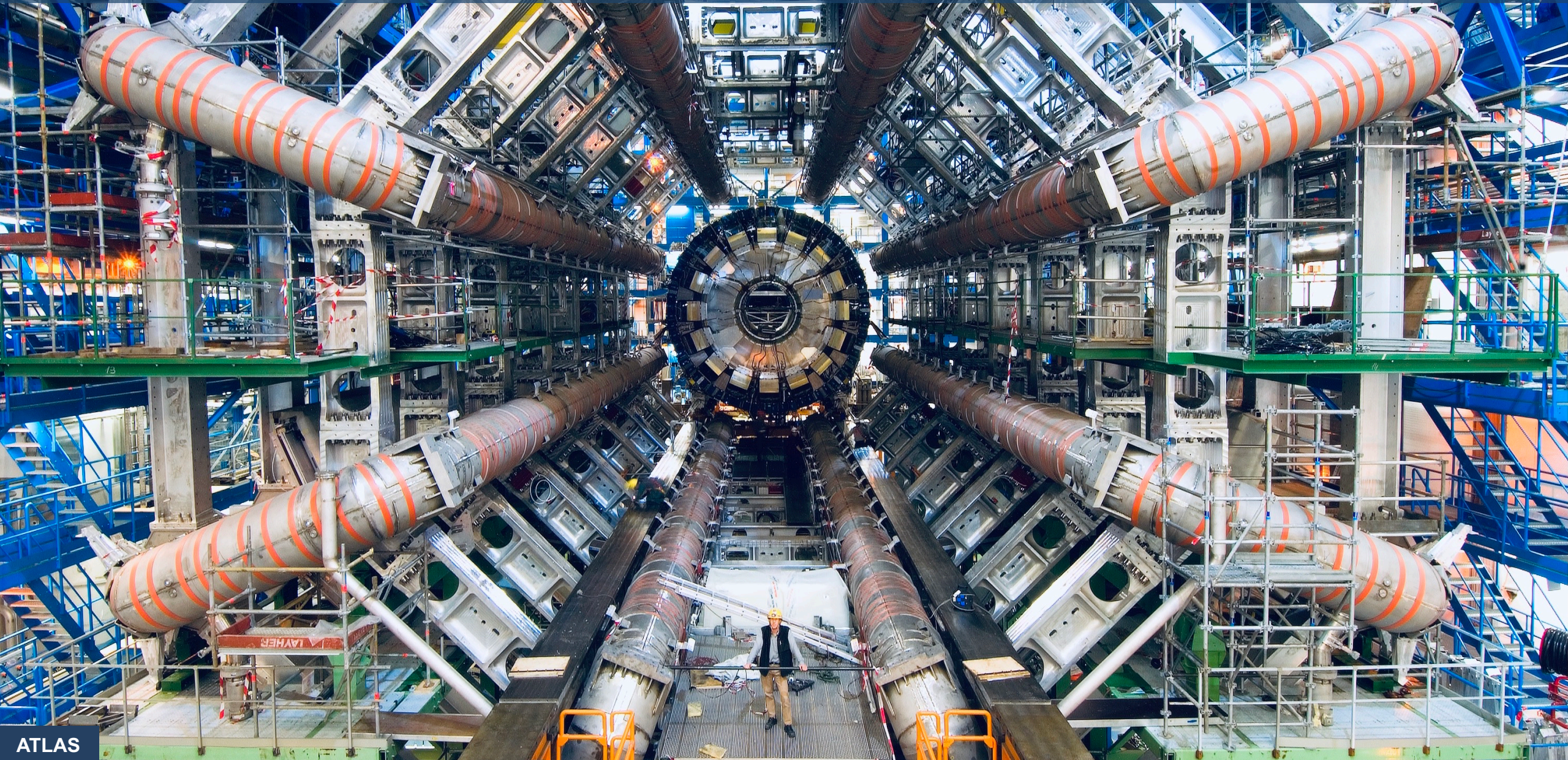
# LHC and Experiments



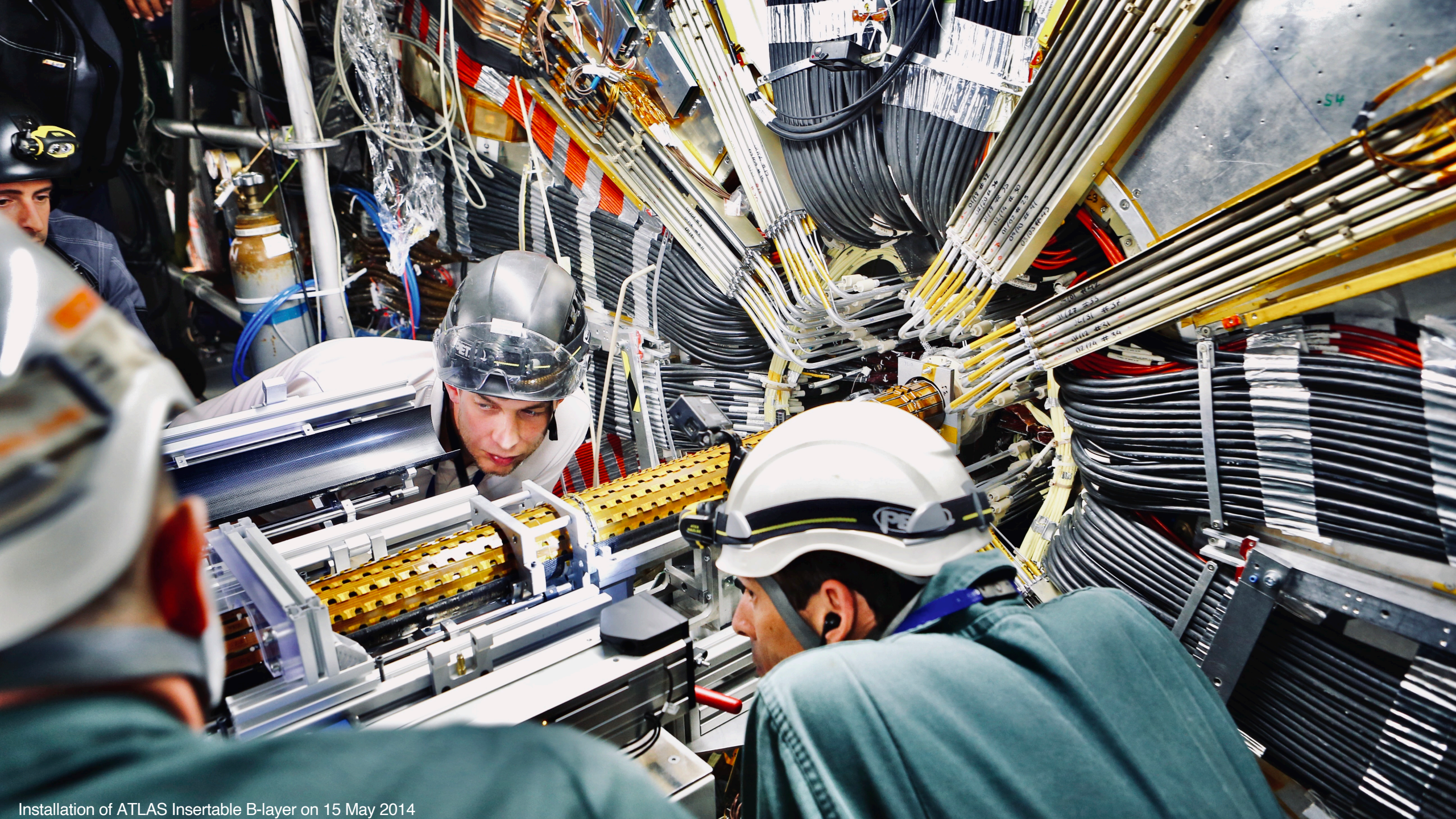
Aerial view



Giant detectors record the particles formed at the collision points

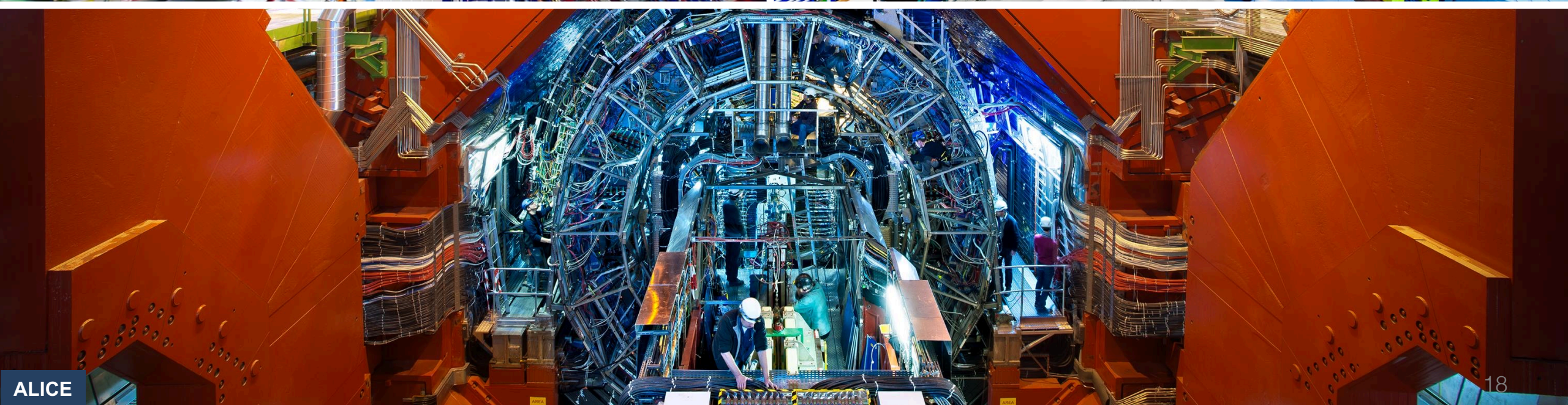






Installation of ATLAS Insertable B-layer on 15 May 2014







# CERN is the birthplace of the World Wide Web and the Worldwide LHC Computing Grid (WLCG)



WLCG stores, distributes,  
processes and analyses  
LHC experiments' data

1.4 million processing cores  
in 170 data centres and  
more than 40 countries

> 2000 Petabytes (2 Exabytes)  
of LHC data stored worldwide

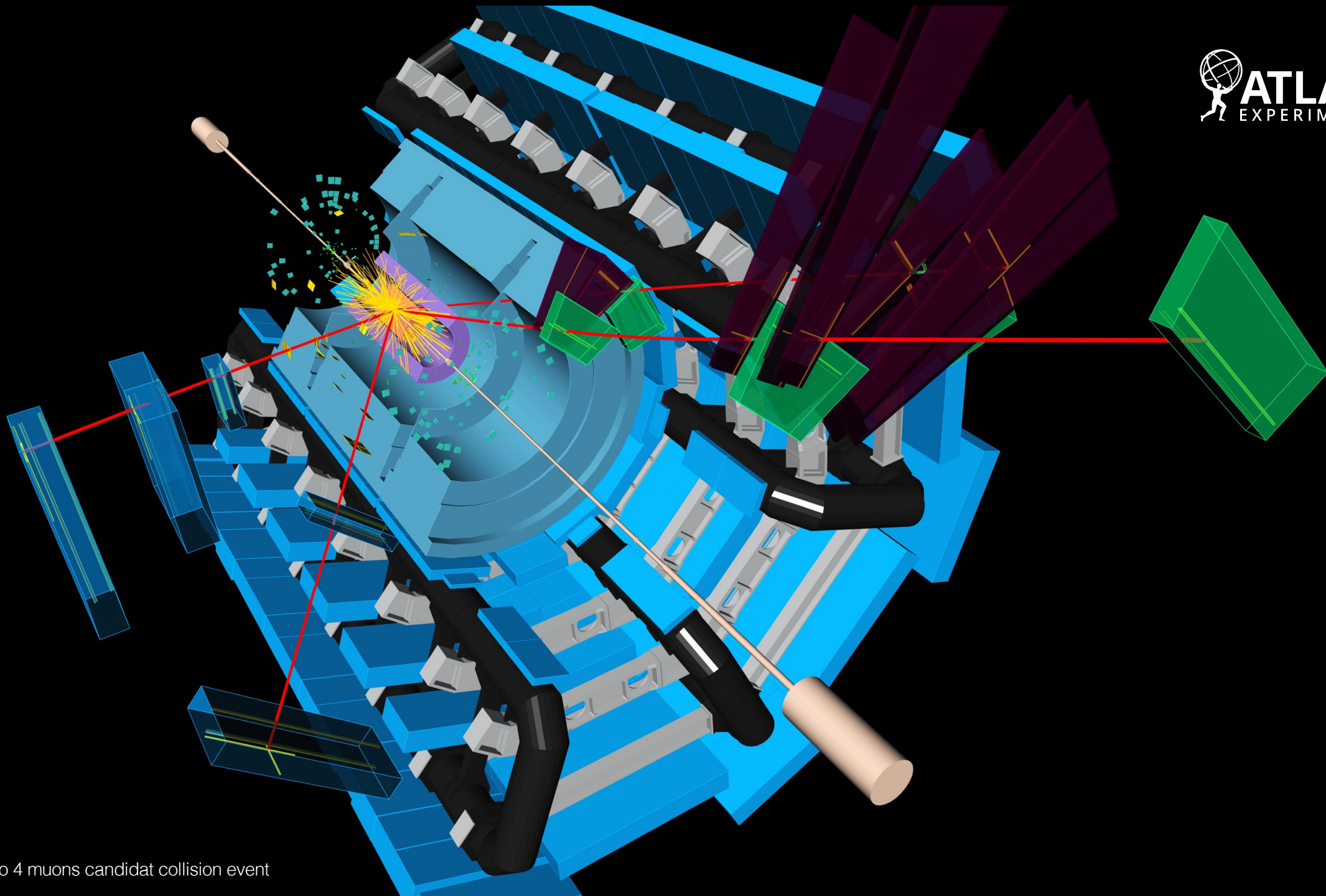


The detectors are sophisticated cameras operating at 40 million frames per second



**ATLAS**  
EXPERIMENT





A Higgs boson to 4 muons candidat collision event



# The Higgs boson is special

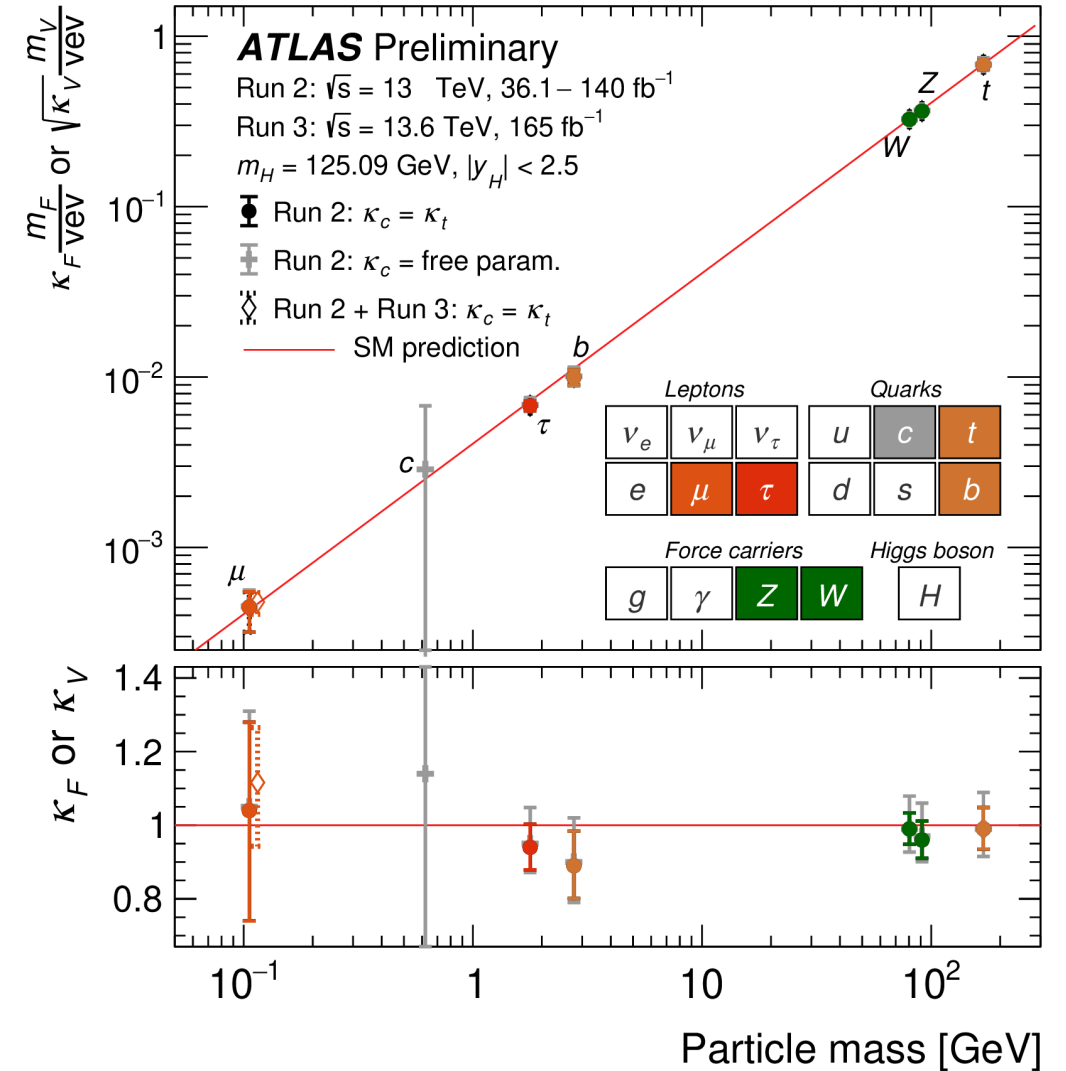




# The Higgs boson is special

Measurements at the LHC have confirmed the mass-dependent coupling strengths of the Higgs boson to elementary particles

The Higgs mechanism is related to very deep and important questions. Its discovery enables an ambitious research programme to address them

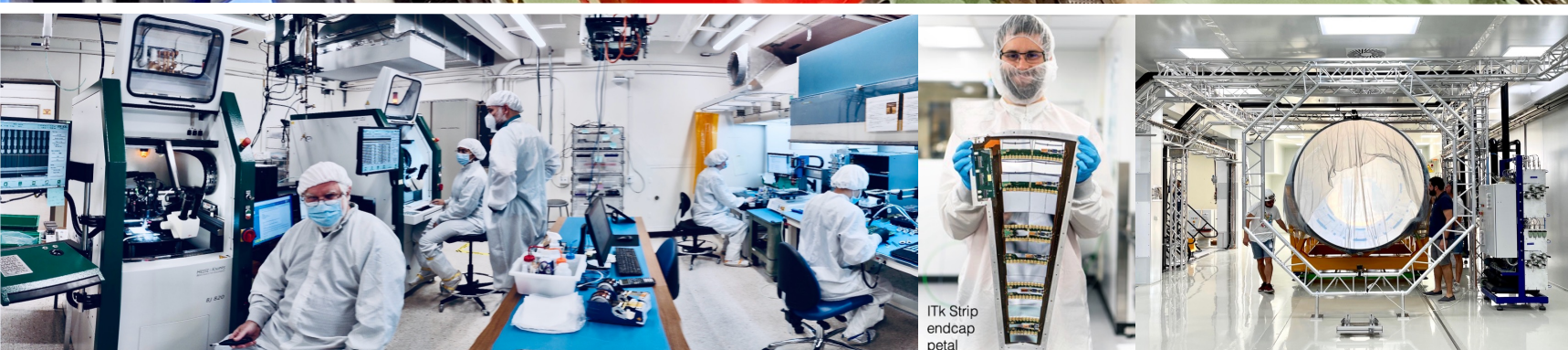






# Upgrade to the High-Luminosity LHC is under way

- The HL-LHC will use new technologies to provide 10 times more collisions than the LHC
- We are also upgrading the detectors
- It will give access to rare phenomena, greater precision and discovery potential
- It will start operating in 2030 and run until 2041
- **Largest project at CERN for almost 20 years**







# CERN's technological innovations have an important impact on society



Accelerator technologies for cancer radiotherapy with protons, ions and electrons

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



© MARS Bioimaging



Developing and testing superconducting power distribution for low-emission aviation

Time synchronization hardware and software used in financial services for accurate time stamping

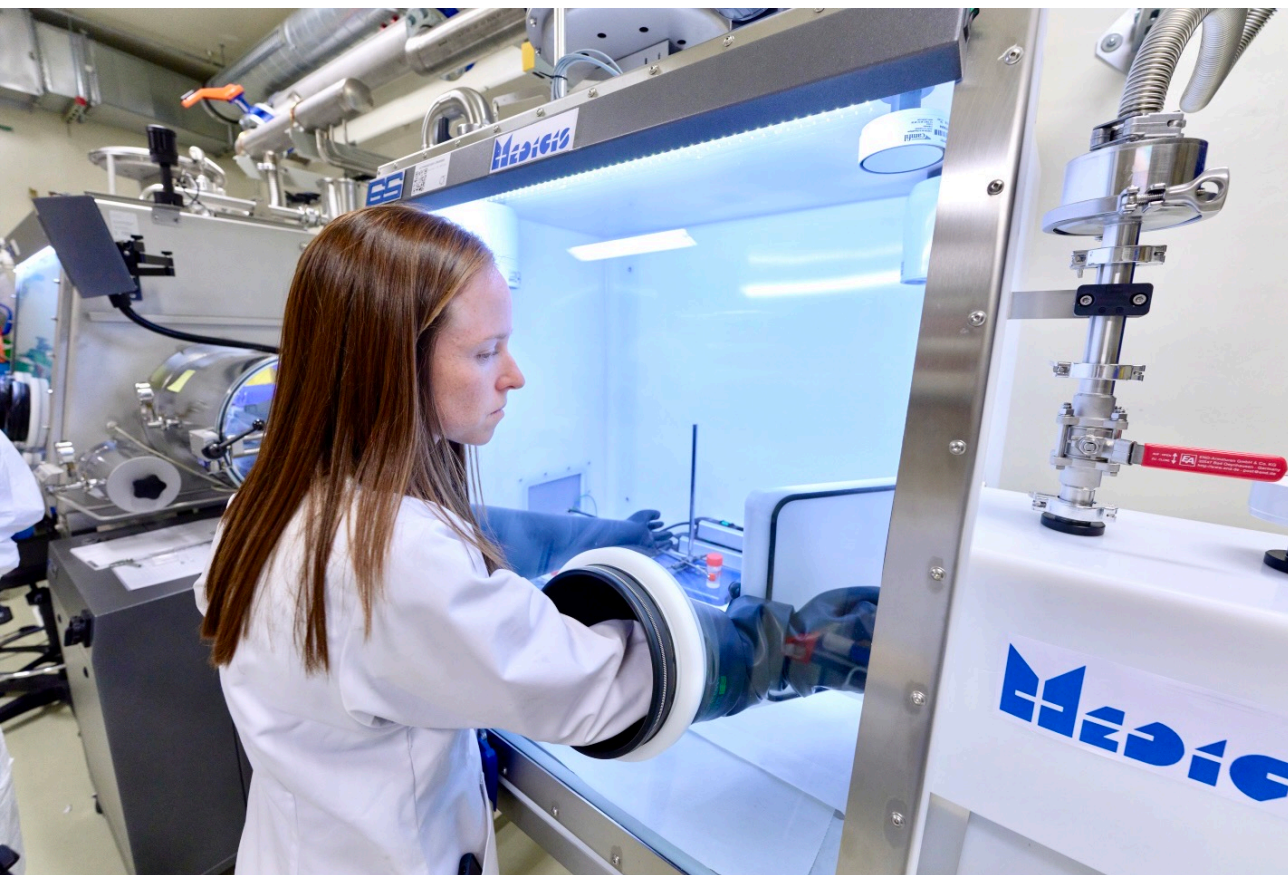




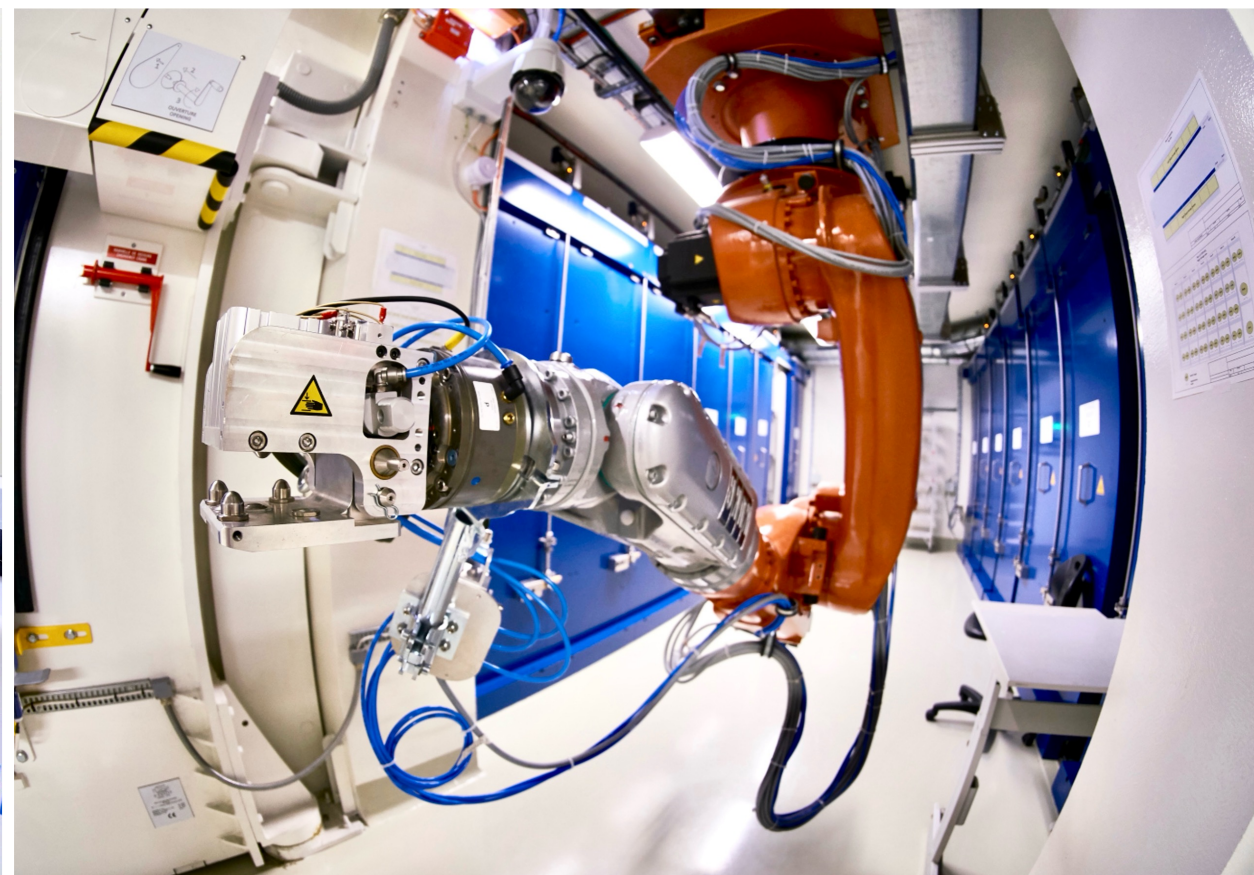


# CERN's MEDICIS facility

Production of novel radioactive isotopes for diagnostics and therapeutics



Preparation of radionuclides at CERN-MEDICIS, one of the eight production facilities involved in the European project PRISMAP. Over the past five years, the PRISMAP network has provided access to novel radionuclides, contributing to research on cancer imaging and treatment



CERN-MEDICIS robot to collect, process, and package radioactive isotopes



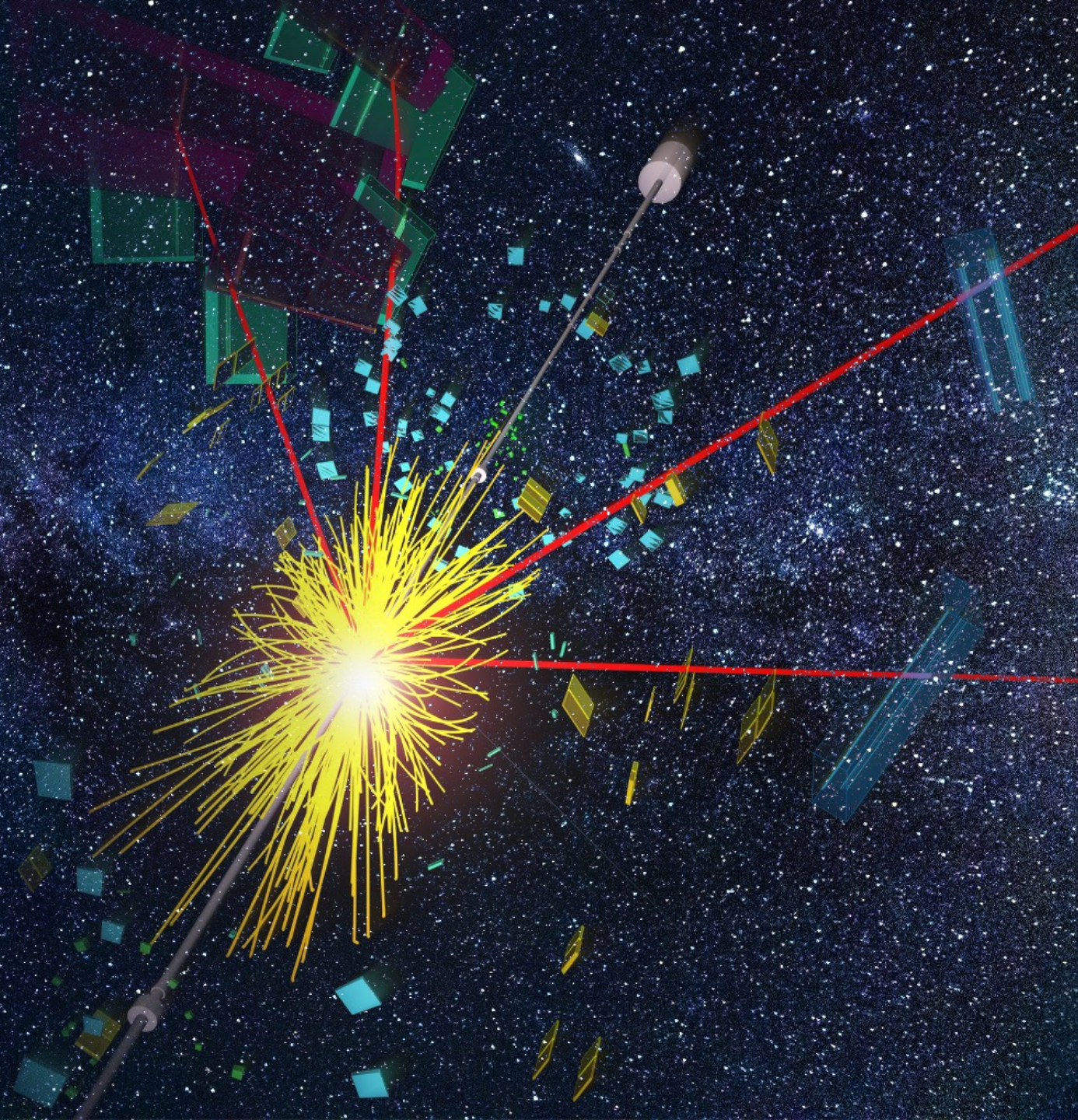


# What is CERN doing under Switzerland?

**We address the most fundamental questions about the structure of matter, its interactions, and the origin of the universe, through large-scale, high-technology research, and global collaboration**



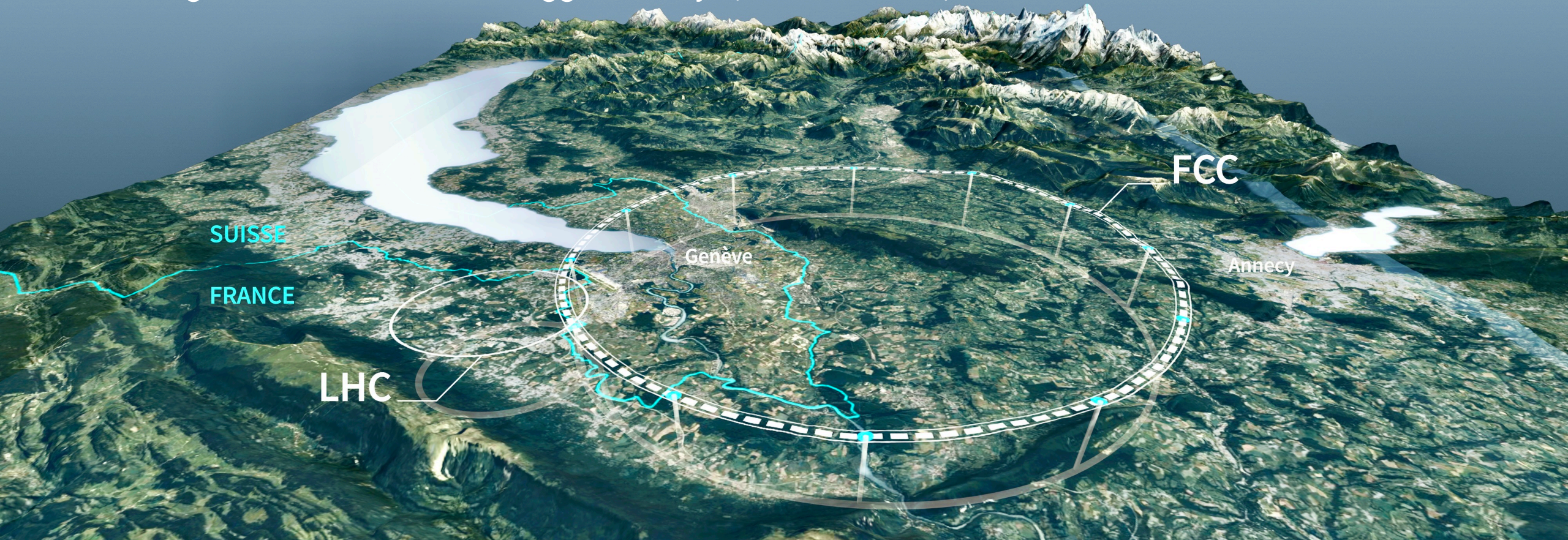
Extra slides





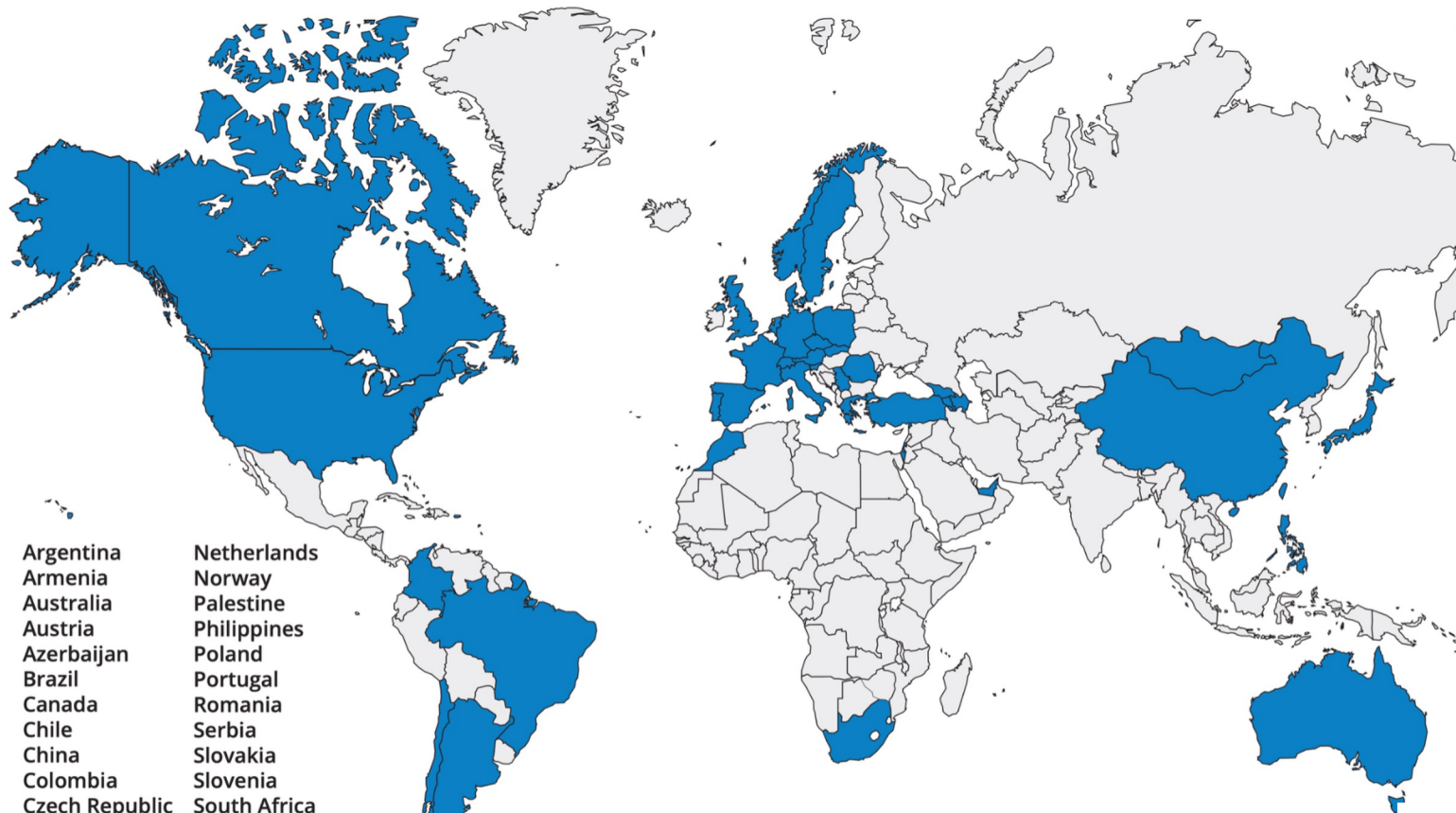
# CERN's long-term vision: Future Circular Collider (FCC)

The Higgs boson is a genuinely new and unique type of particle, and a window to discovery — strong scientific case for a “Higgs Factory” (and much more)



FCC: a new 91 km ring colliding electrons & positrons with a very broad (beyond Higgs) and ambitious scientific precision and discovery programme. Top priority from the recent European Strategy process. Targeting start of operations in 2045~2048. Not yet approved, but we are hoping for a positive decision in 2028~2029.





|                |              |
|----------------|--------------|
| Argentina      | Netherlands  |
| Armenia        | Norway       |
| Australia      | Palestine    |
| Austria        | Philippines  |
| Azerbaijan     | Poland       |
| Brazil         | Portugal     |
| Canada         | Romania      |
| Chile          | Serbia       |
| China          | Slovakia     |
| Colombia       | Slovenia     |
| Czech Republic | South Africa |
| Denmark        | Spain        |
| France         | Sweden       |
| Georgia        | Switzerland  |
| Germany        | Taiwan       |
| Greece         | Türkiye      |
| Israel         | UAE          |
| Italy          | UK           |
| Japan          | USA          |
| Mongolia       | CERN         |
| Morocco        | JINR         |

## ATLAS Collaboration

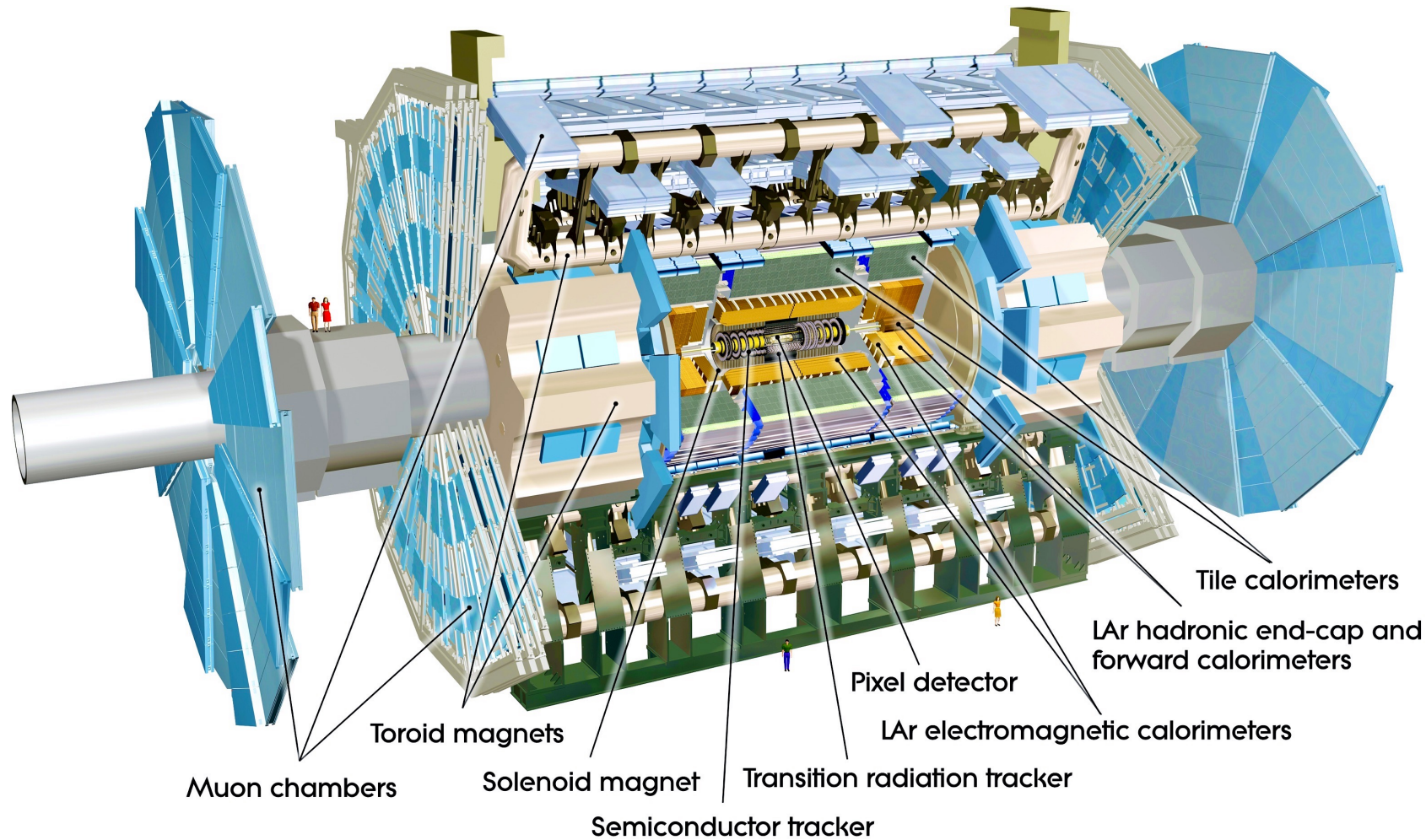


248 Institutes from 41 countries (>100 nationalities)

- 2900 scientific authors
- **1200 physics PhD students**
- **1300 engineers and technicians**
- 6000 members



# The ATLAS Detector



Axial field provided by **solenoid** (2 T) in central region (momentum measurement)

High resolution silicon **detectors**:

- 100 Mio. channels ( $50\ \mu\text{m} \times 250\ \mu\text{m}$ )
- 6 Mio. channels ( $80\ \mu\text{m} \times 12\ \text{cm}$ )

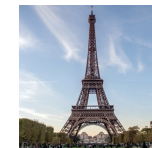
spatial resolution  $\sim 15\ \mu\text{m}$  (in azimuthal direction)

Energy measurement down to  $1^\circ$  to the beam line with a **calorimeter system**

Independent **muon spectrometer** (superconducting toroidal magnet system)

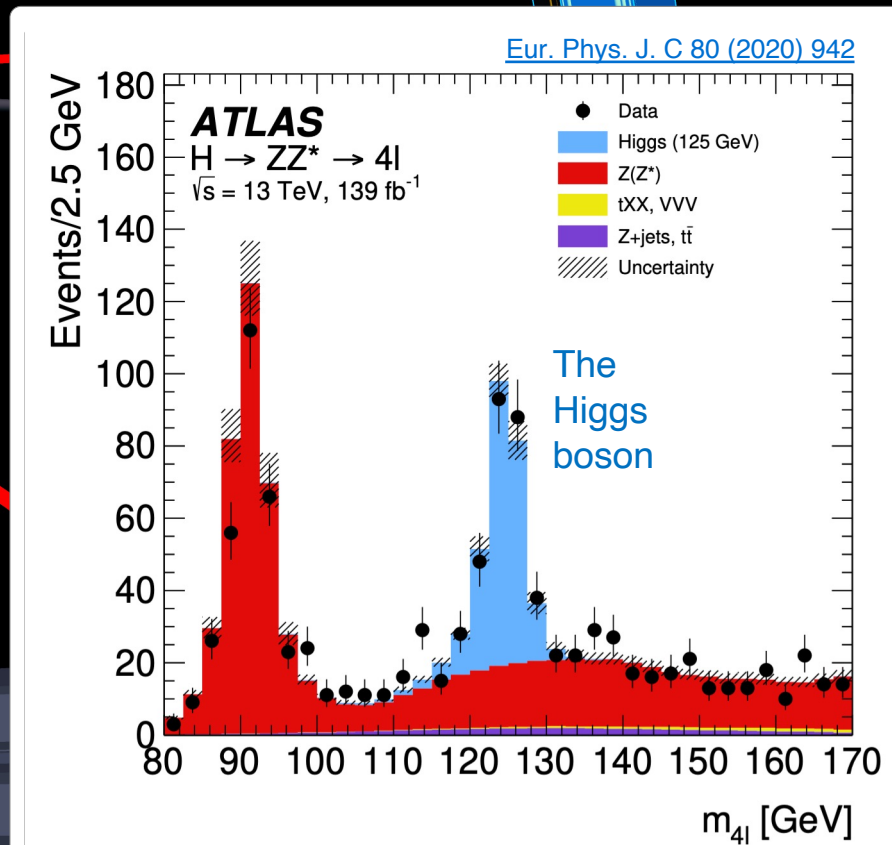
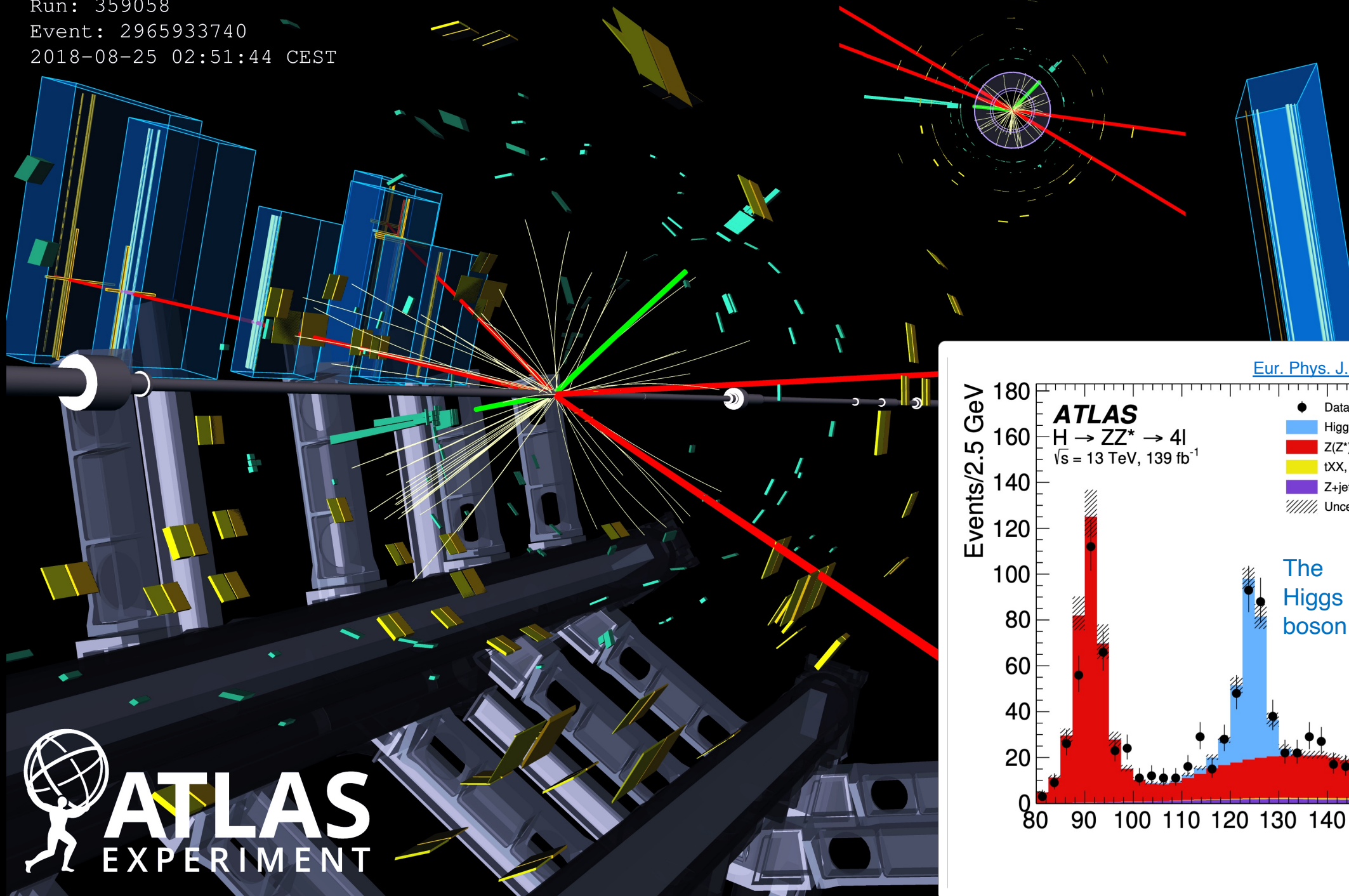
**Ultra-fast custom electronics and high-performance computers filter** the collisions: only 1 out of 20,000 collisions is kept

25 m diameter, 44 m long, 7000 tons weight ~





Run: 359058  
Event: 2965933740  
2018-08-25 02:51:44 CEST

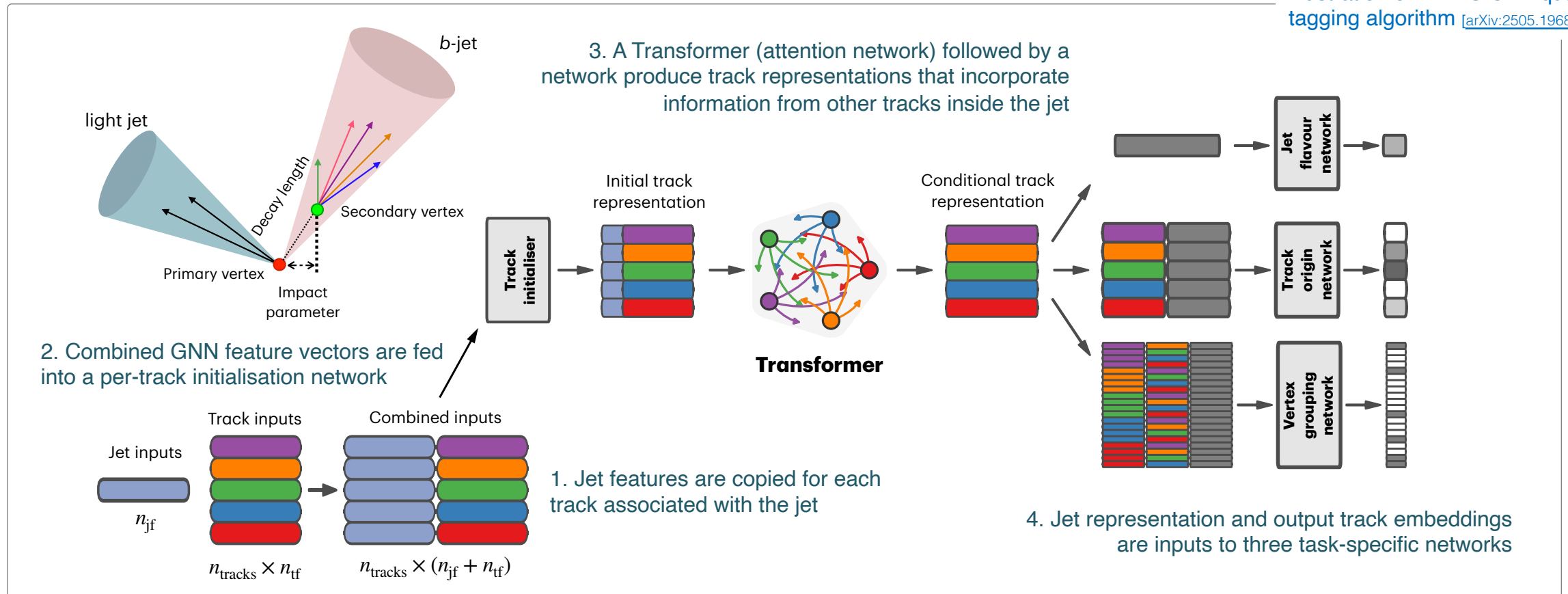




# Particle reconstruction — eldorado for modern ML

Neural networks have been used in particle physics since the 1990s; boosted decision trees since the 2000s  
GNNs with Transformers are currently among the most performing ML algorithms (but much smaller than LLMs)

Illustration of ALTAS GN2 quark tagging algorithm [\[arXiv:2505.19689\]](https://arxiv.org/abs/2505.19689)



Jet/track features → Per-track embeddings → Transformer builds context across tracks → 3 heads deliver (i) jet flavour, (ii) track origins, and (iii) explicit displaced-vertex structure