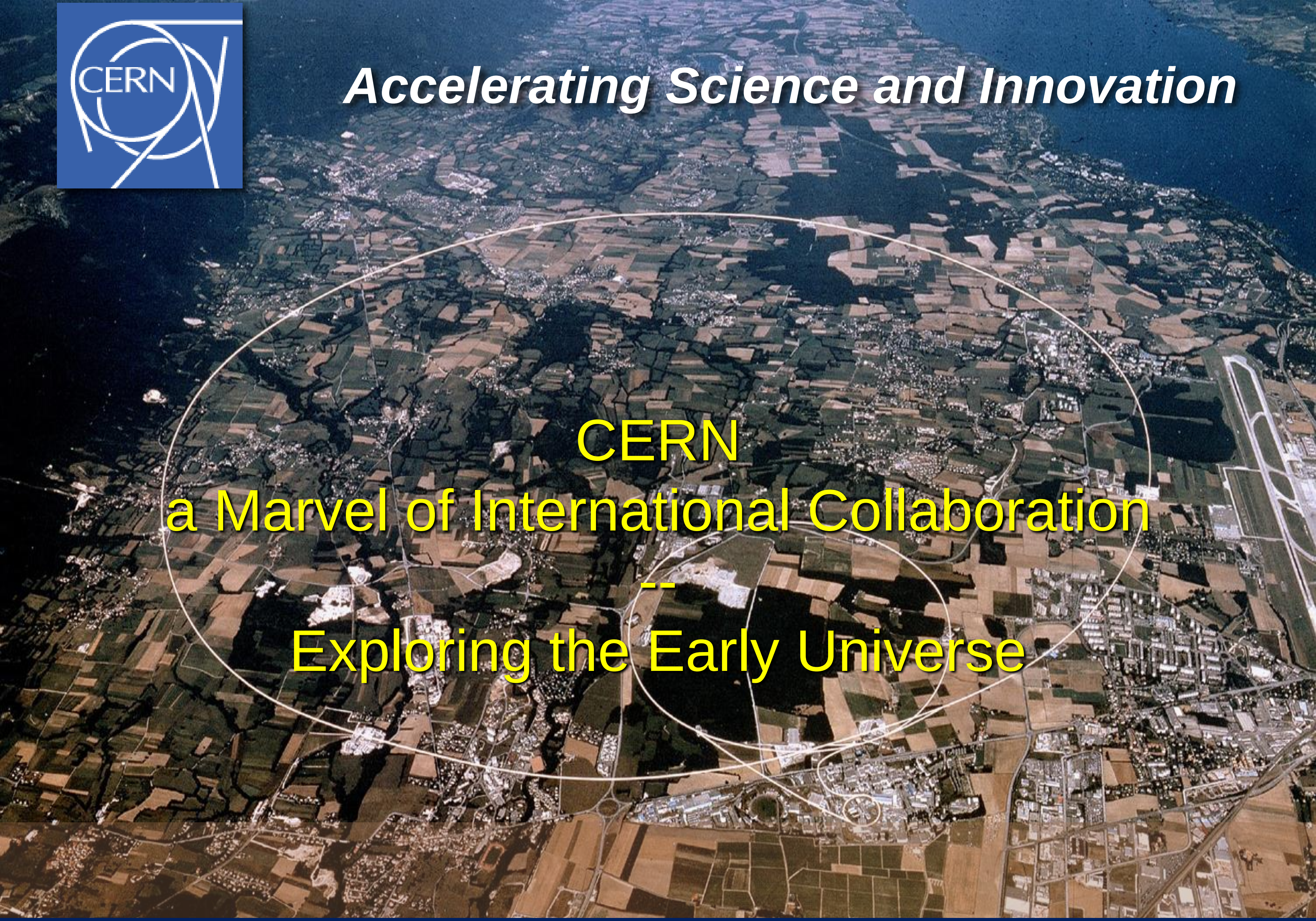


Accelerating Science and Innovation

CERN
a Marvel of International Collaboration
--
Exploring the Early Universe

Science for peace

CERN was founded in 1954 with 12 European Member States

Today

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

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

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

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 in the pre-stage to membership **55**

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

Associate Member States **367**

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

Observers **2917**

Japan 189 – **Russia** (suspended) 971 – **United States of America** 1757

Non-Member States and Territories **1194**

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

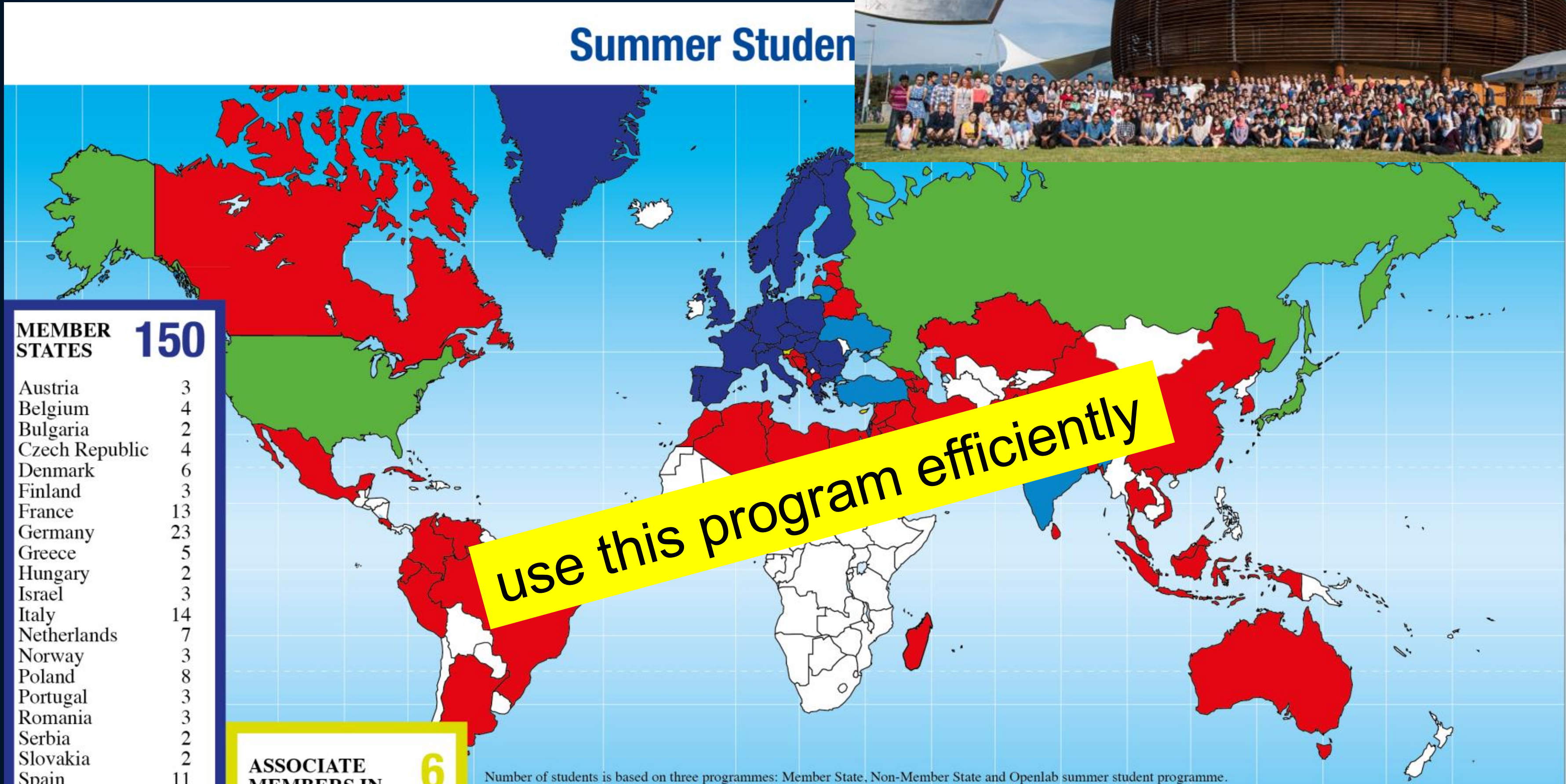
founded 1954, going beyond national borders

since 2010, going beyond regional borders

today scientist from all over the world are coming to CERN

CERN is attractive as you can judge from the students….

Summer Students 2019



Number of students is based on three programmes: Member State, Non-Member State and Openlab summer student programme.

MEMBER STATES 150

Austria	3
Belgium	4
Bulgaria	2
Czech Republic	4
Denmark	6
Finland	3
France	13
Germany	23
Greece	5
Hungary	2
Israel	3
Italy	14
Netherlands	7
Norway	3
Poland	8
Portugal	3
Romania	3
Serbia	2
Slovakia	2
Spain	11
Sweden	7
Switzerland	5
United Kingdom	17

ASSOCIATE MEMBERS 24

India	13
Lithuania	2
Pakistan	4
Turkey	3
Ukraine	2

ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP 6

Cyprus	4
Slovenia	2

OBSERVERS 34

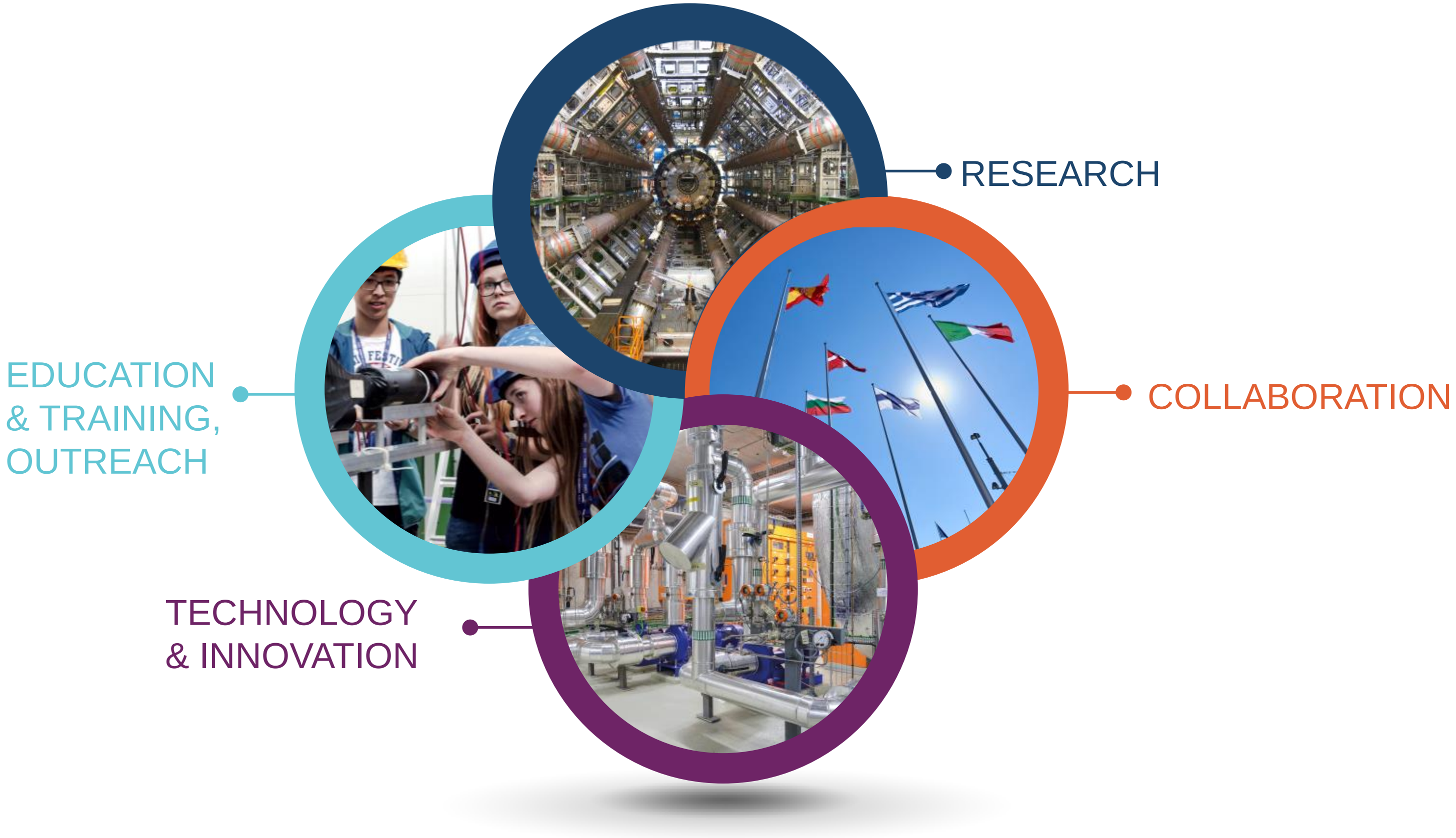
Japan	4
Russia	10
USA	20

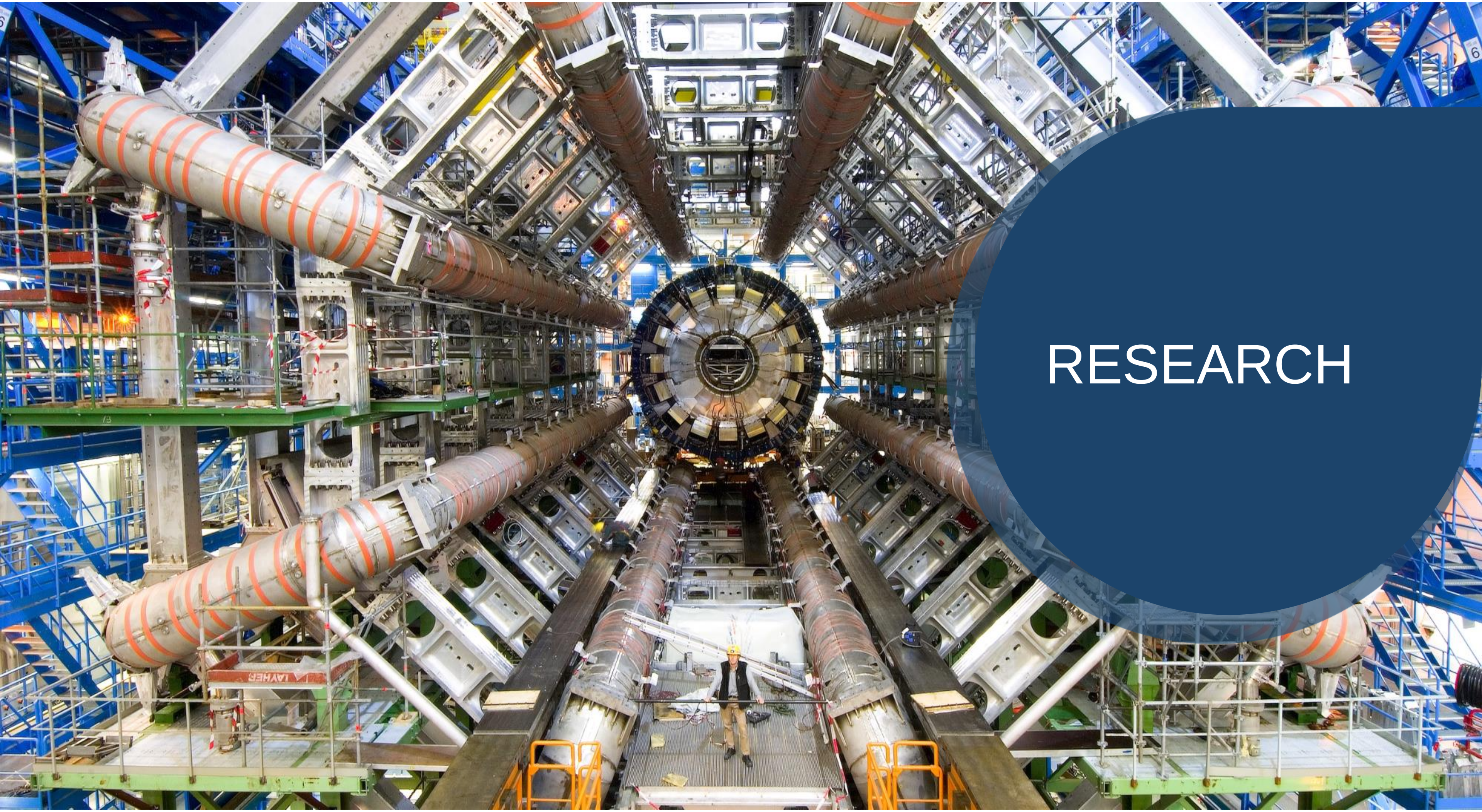
OTHERS 122

Afghanistan	1
Albania	1
Algeria	4
Argentina	1
Armenia	1
Australia	1
Azerbaijan	2
Bahrain	2
Bangladesh	2
Belarus	1
Bolivia	1
Bosnia & Herzegovina	1
Brazil	4
Canada	6
Chile	1
China	10
Colombia	1
Costa Rica	4
Croatia	4
Cuba	2
Ecuador	3
Egypt	4
Estonia	2
Georgia	1
Ghana	1
Hong Kong	2
Indonesia	1
Iran	2
Iraq	1
Jordan	1
Kazakhstan	3
Korea	2
Kosovo	1
Kuwait	1
Latvia	1
Lebanon	3
Libya	1
Madagascar	1
Malaysia	3
Malta	3
Mauritius	1
Mexico	1
Moldova	1
Montenegro	4
Morocco	1
Nepal	1
North Macedonia	1
Oman	1
Palestine	2
Peru	1
Saudi Arabia	1
Singapore	2
Sri Lanka	4
Sudan	1
Syrian Arab Republic	1
Taiwan	1
Tajikistan	1
Thailand	4
Tunisia	2
U.A.E.	1
Venezuela	1
Viet Nam	1
Yemen	1

CERN

Four pillars underpin CERN’s mission

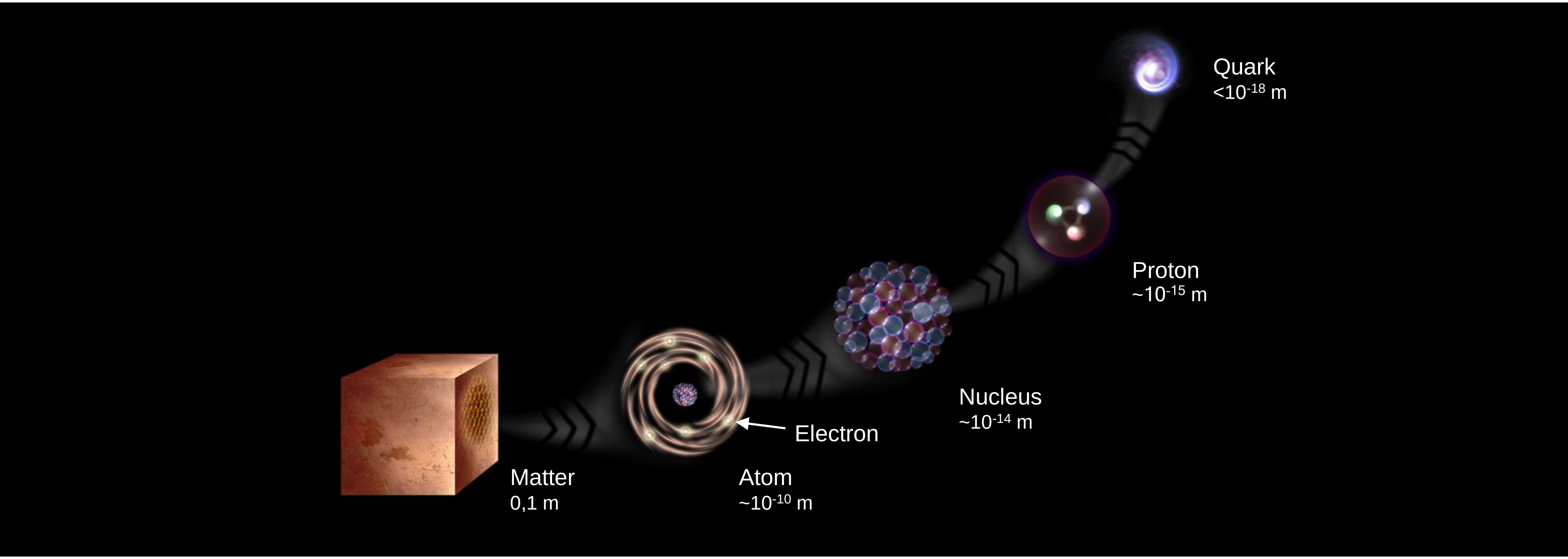




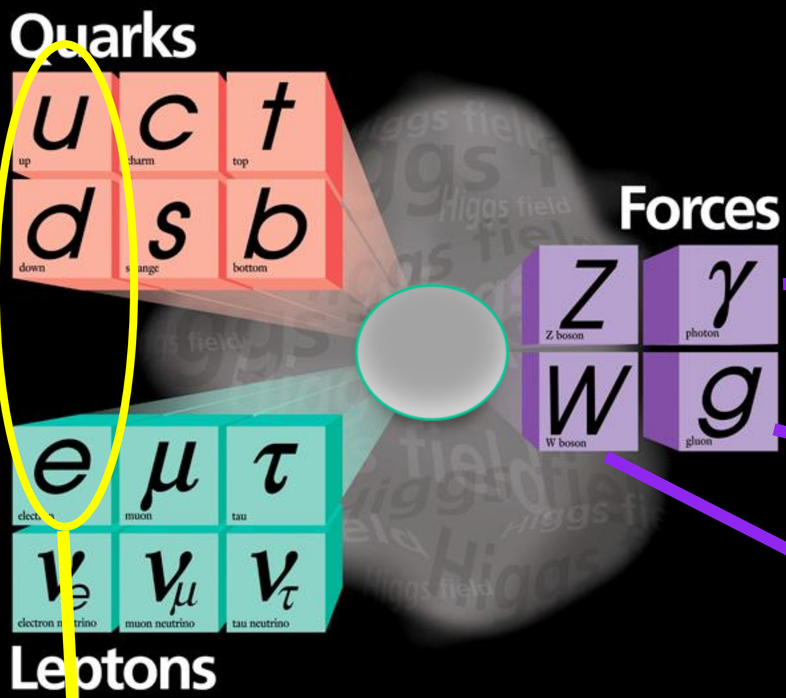
RESEARCH

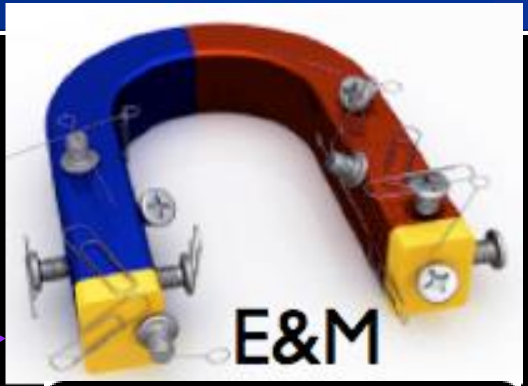
What is the universe made of?

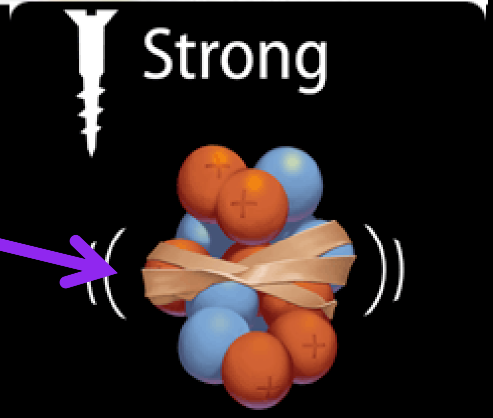
At CERN we study the elementary building blocks of matter and the forces that control their behaviour

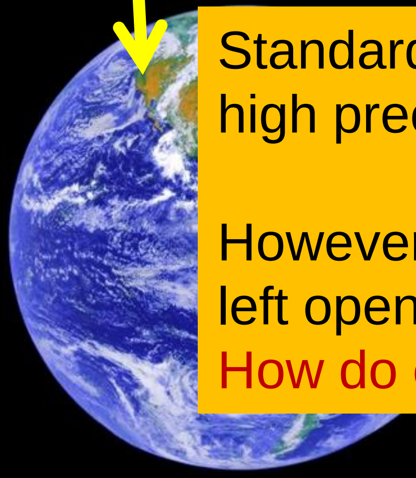


The Standard Model



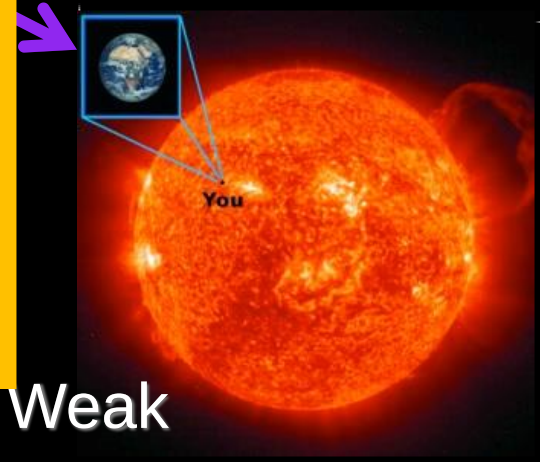




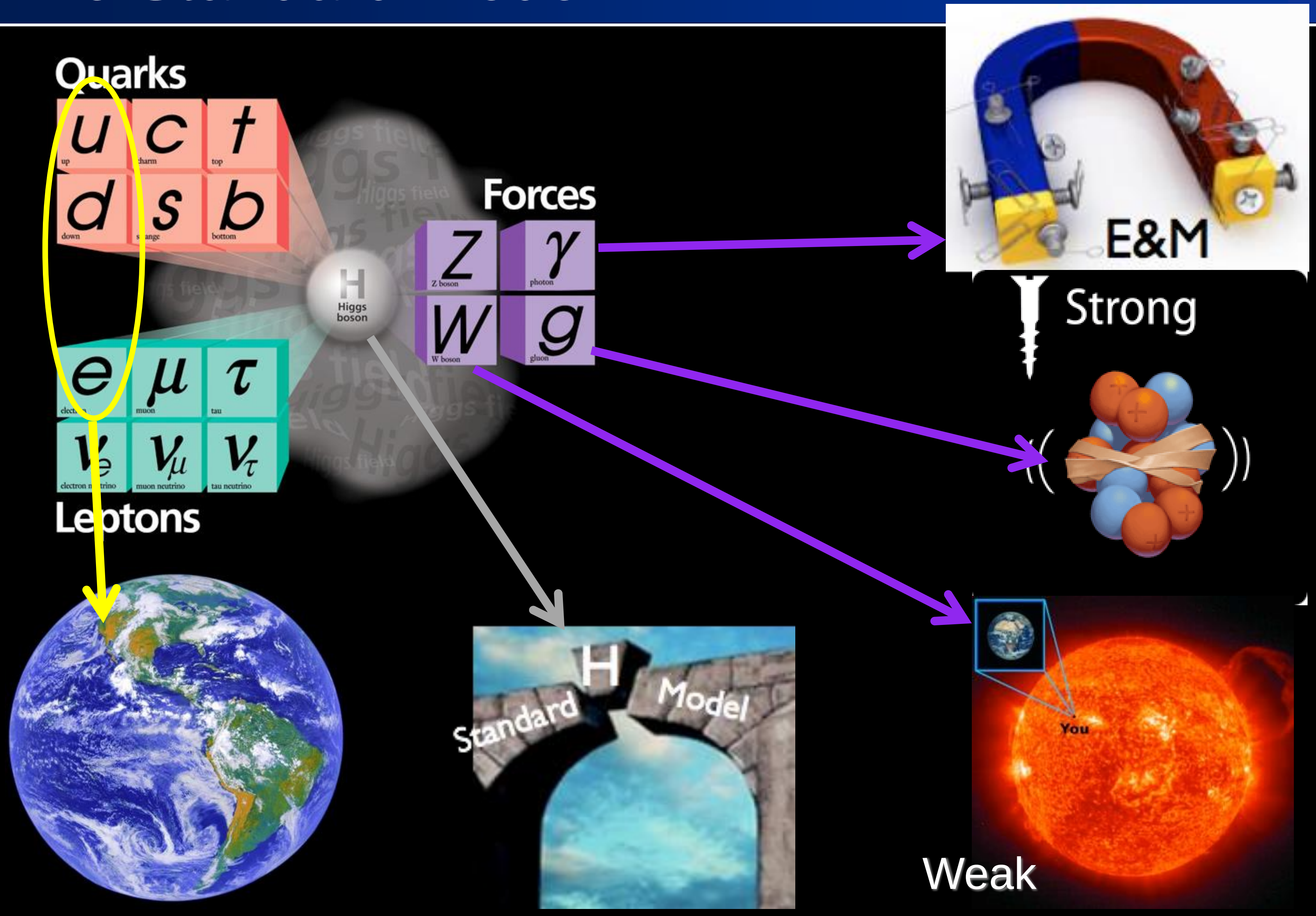


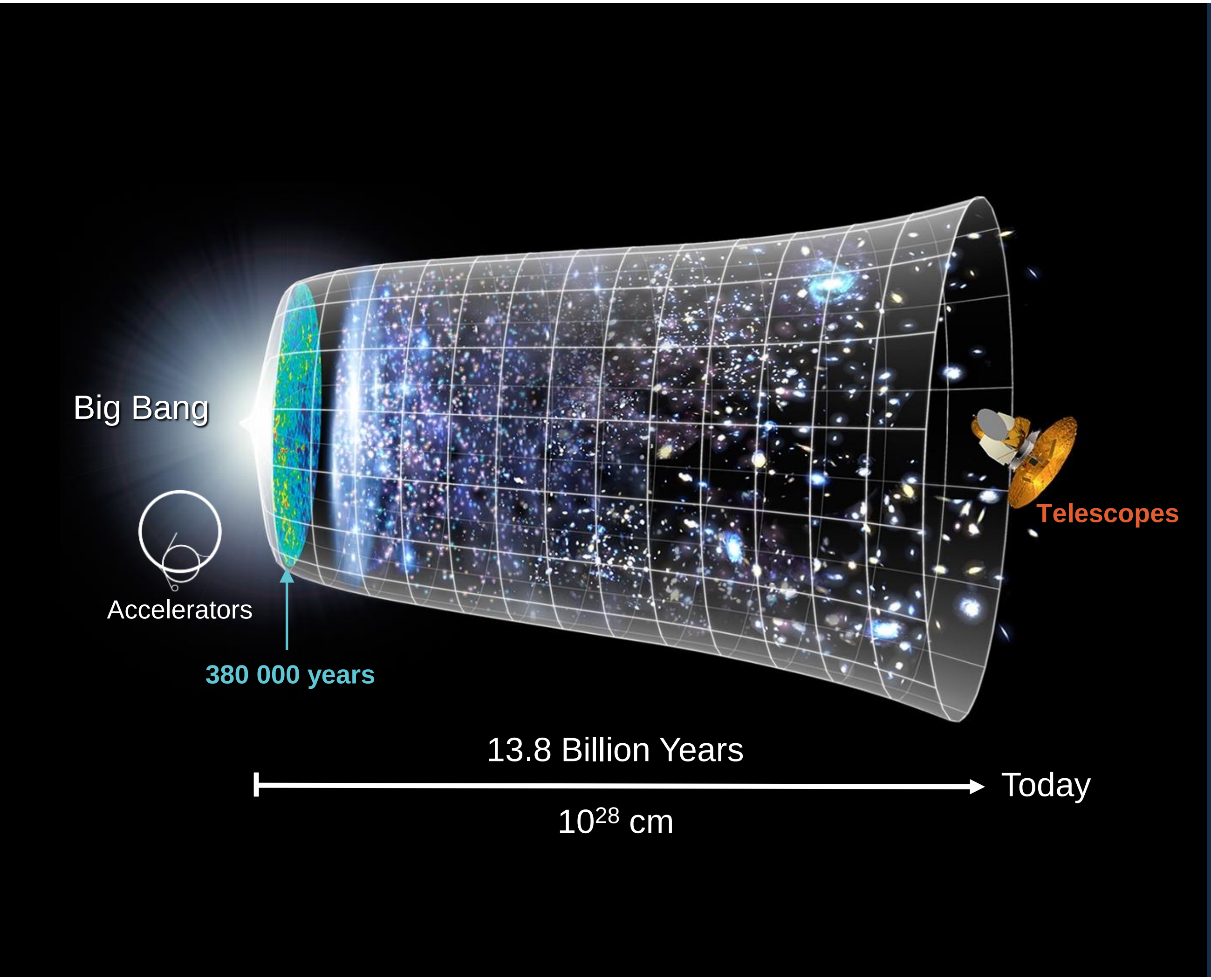
Standard Model tested over decades with high precision.

However before LHC many crucial questions left open, in particular:
How do elementary particles acquire mass?



The Standard Model



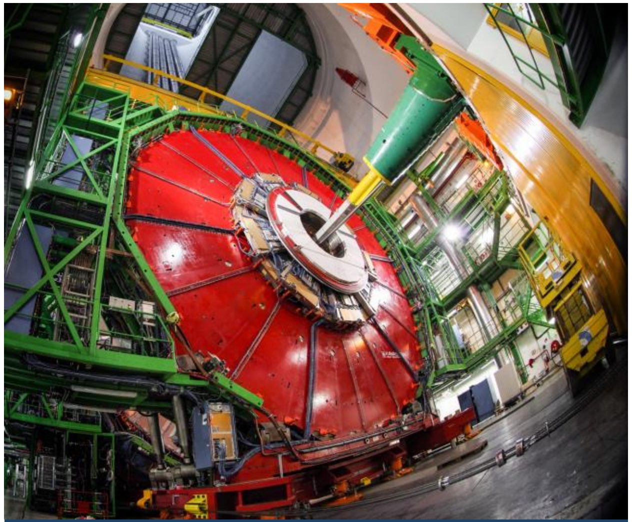


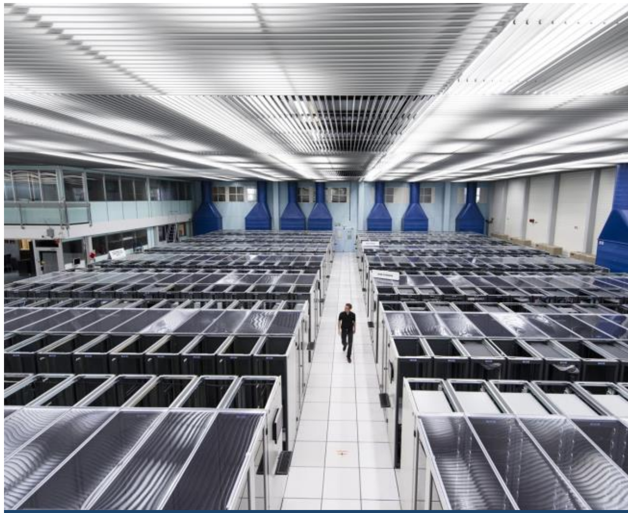
How did the universe begin?

We reproduce the conditions a fraction of a second after the Big Bang, to gain insight into the structure and evolution of the universe.

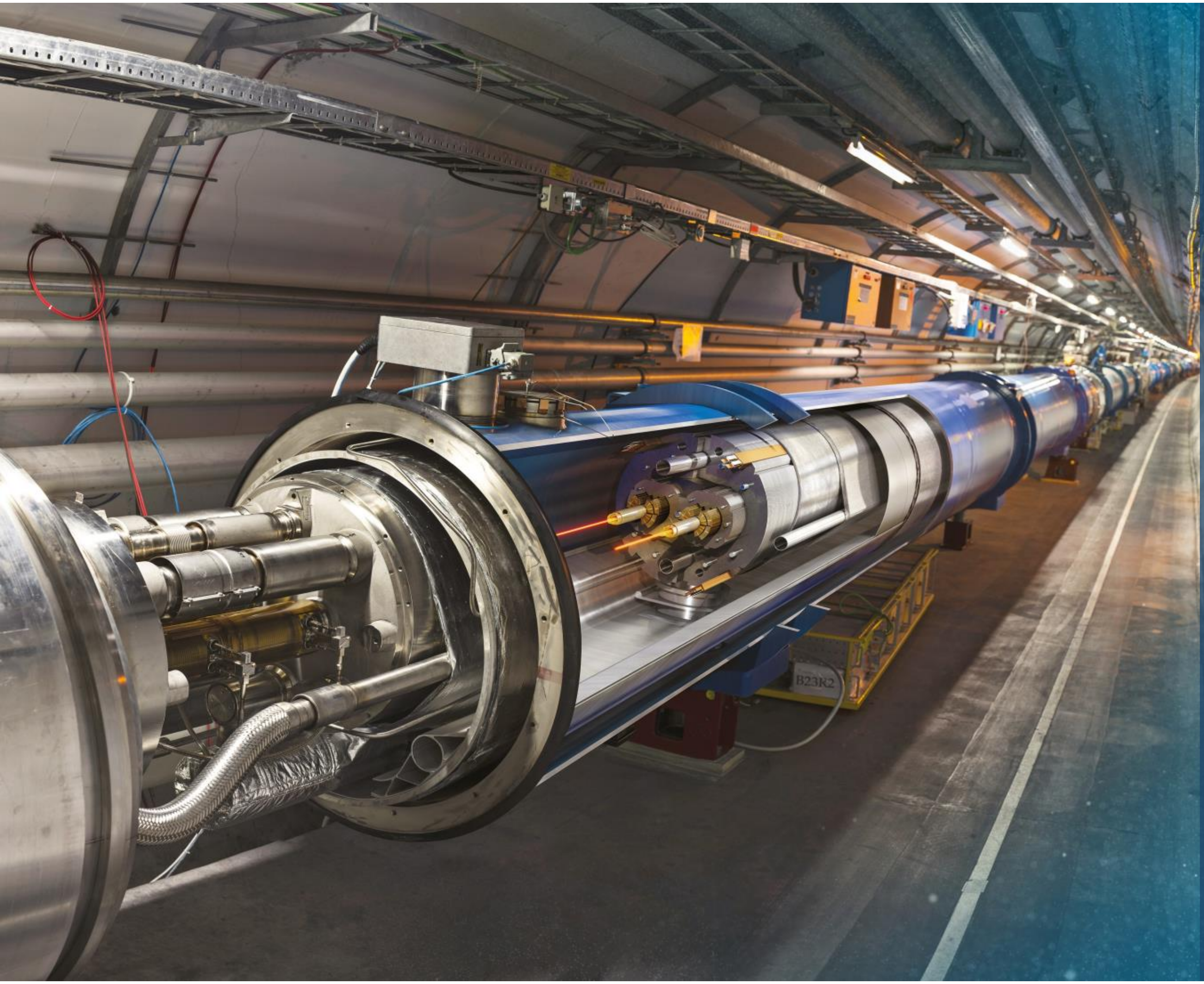
In order to do this
CERN together with his partners develops technologies in three key areas


ACCELERATORS


DETECTORS


COMPUTING

Excellent example: 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

Large Hadron Collider (LHC) Project

To design and construct such a project
many thousands of technicians, engineers and physicists
from **all over the world**,
from **many different disciplines**,

had to **develop new technologies**,
develop new engineering concepts,

had to **work together over decades**

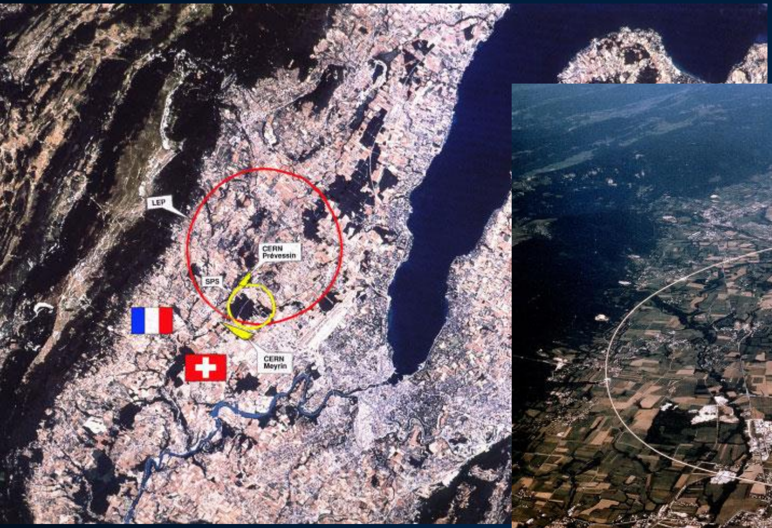
can that work?

LHC 27 km

at ***Accelerating Science and Innovation***

We need:

The **fastest** racetrack on the planet…



Trillions of protons bunched in up to 2808 packets race around the 27km ring in opposite directions over 11,000 times a second, travelling at 99.9999991 per cent the speed of light.

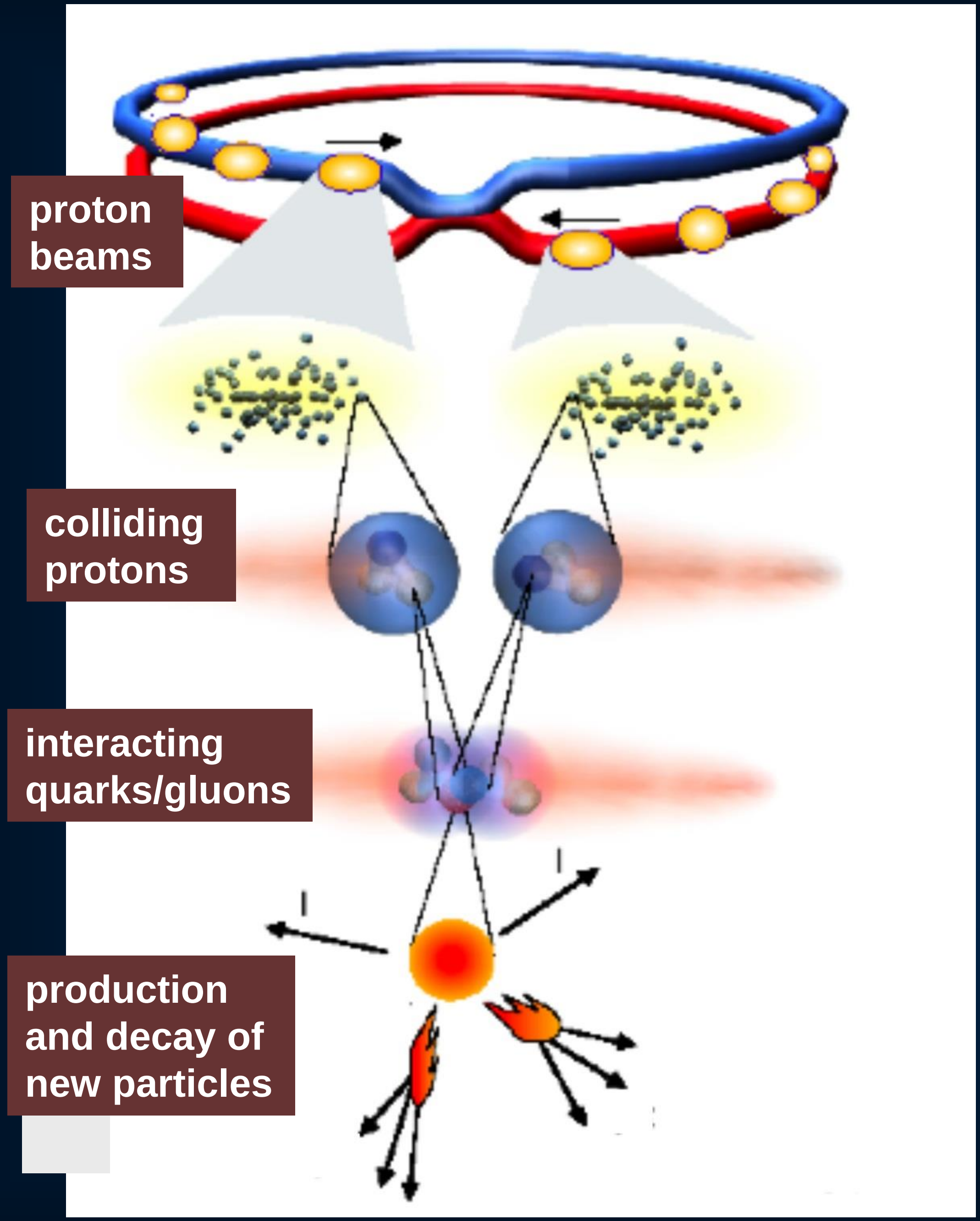
They are kept on track by 1232 superconducting dipole magnets, 15m long, 8.3 Tesla magnetic field

We need to create

One of the **coldest** places in the universe…

With an operating temperature of about -271 degrees Celsius, just 1.9 degrees above absolute zero, the LHC is colder than outer space.

It uses **superfluid** Helium to cool the magnets down to that temperature.



accelerator

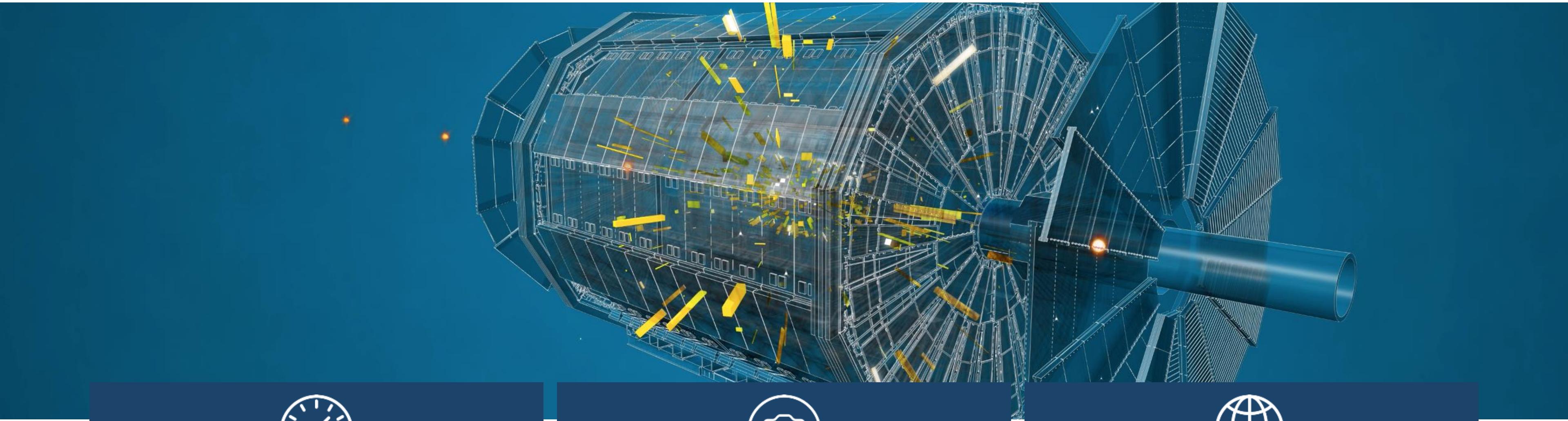
proton collisions

detecting what happened in the collisions

LHC : a New Era in Fundamental Science

Four huge detectors register what happens in these collisions

The LHC detectors are analogous to 3D cameras

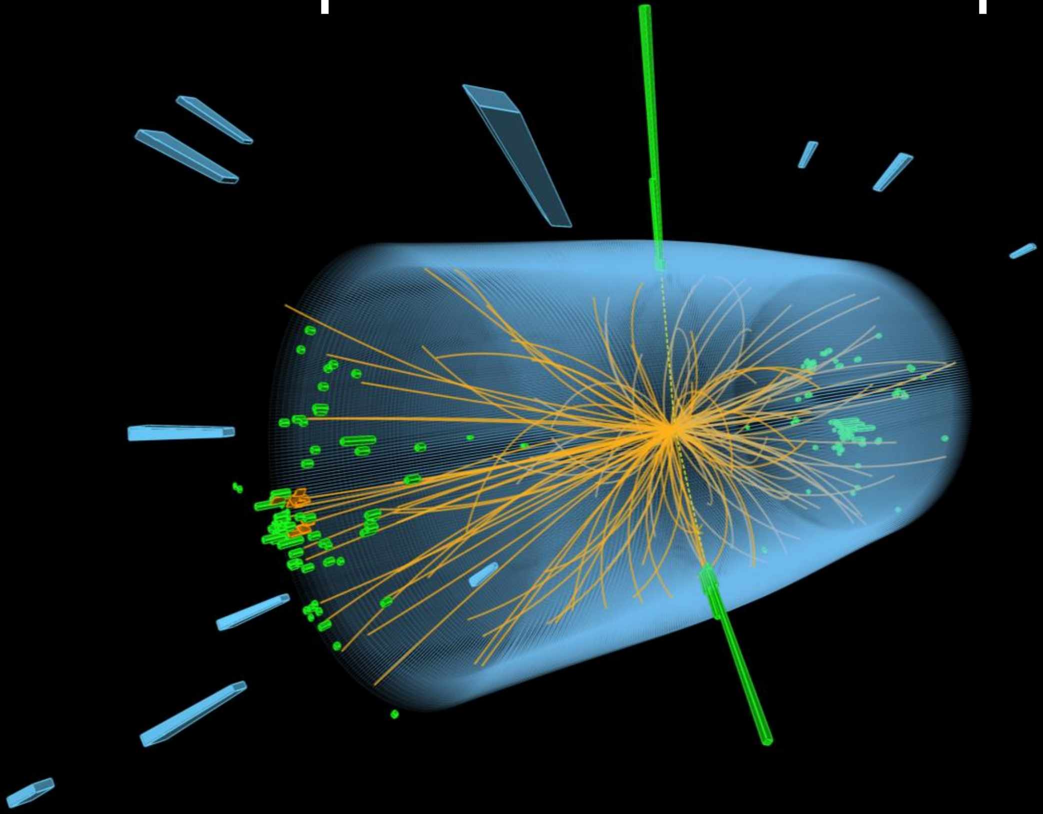


The detectors measure the energy, direction and charge of new particles formed.

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

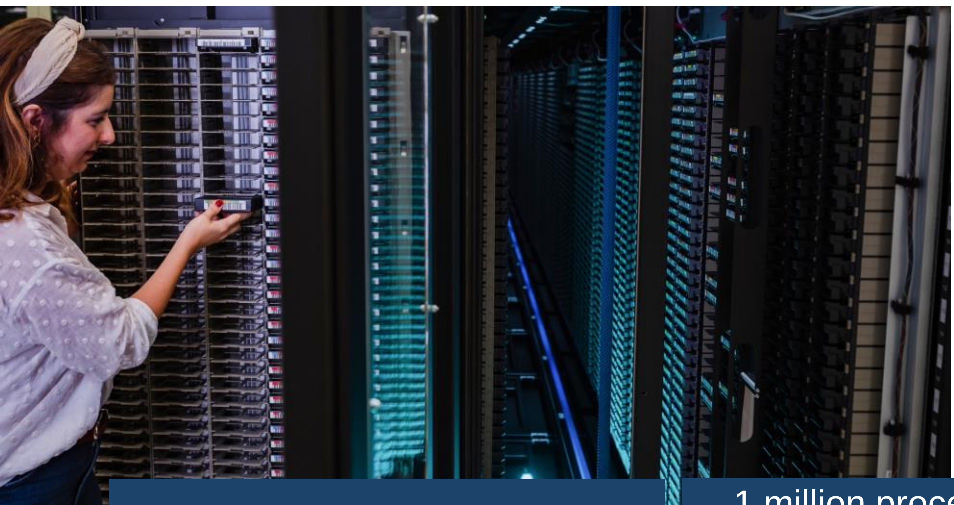
The LHC detectors have been built by international collaborations covering all regions of the Globe.

The LHC produces more than 1 billion particle collisions per second



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

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.

→The first highlight result 2012…….

Discovery 2012, Nobel Prize in Physics 2013

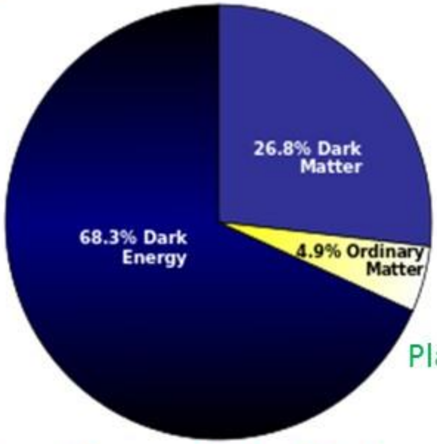
Discovery 48 years after prediction, only possible through global effort at a unique large scale facility after development of new technologies

The Nob... ...nglert and Pete... ...echanism that *contributes... ...of mass of subatomic particles, a... ...med through the discovery of the predicted fu... ..., by the ATLAS and CMS experiments at CERN's Larg... ...Collider".*

The Higgs boson discovery is only the beginning!
What's next?

- Is it ***the*** Higgs boson…or one of many?
- Measure with precision the properties of the discovered Higgs boson
  - …its properties could give information on Dark Matter
  - …its properties could give first indications on Dark Energy

Research programme at the LHC for the next ~20 years



Planck Space Observatory, ESA (2013)

Our understanding of the Universe is changing!

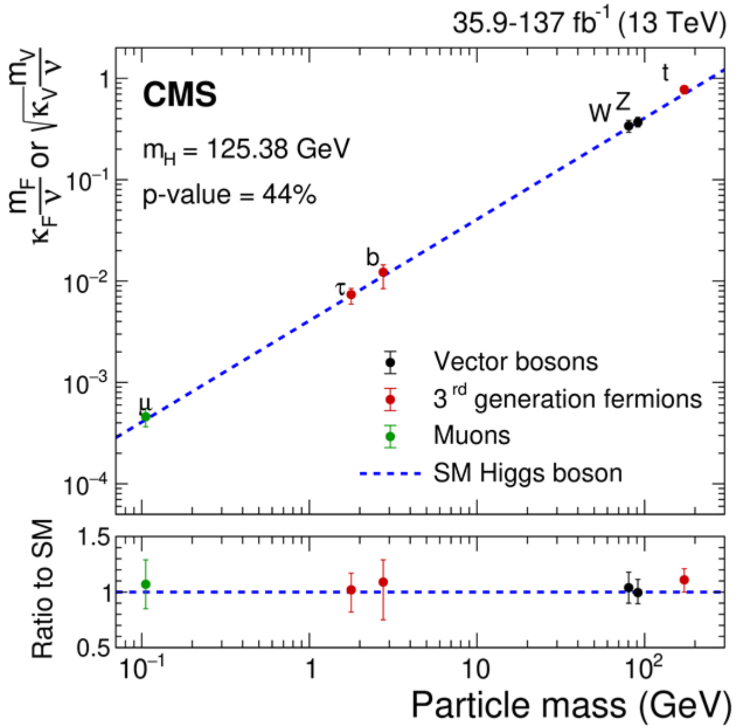
Achievements since the Higgs Boson Discovery

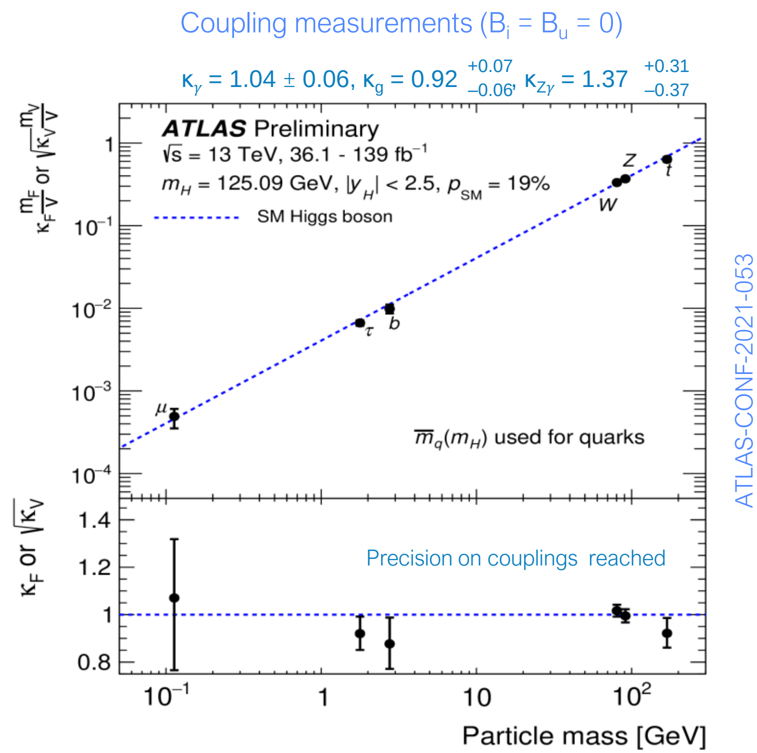
Example: measurement of the Higgs couplings to fundamental particles

ATLAS result based on the full data set (Run 2)

Key prediction of the Standard Model:

Higgs coupling to particles is proportional to their mass





Impressive verification with an accuracy often better than 10%

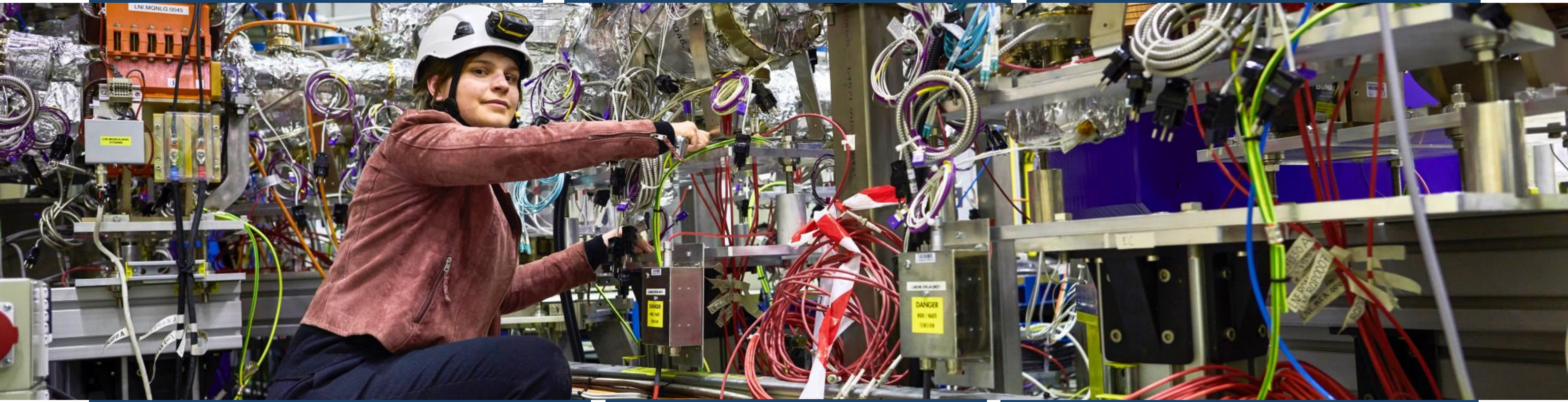
CERN is much more

CERN has a diverse scientific programme

Nuclear Physics (ISOLDE, n_TOF)

Antimatter Research (Antiproton Decelerator)

Cosmic rays and cloud formation (CLOUD)

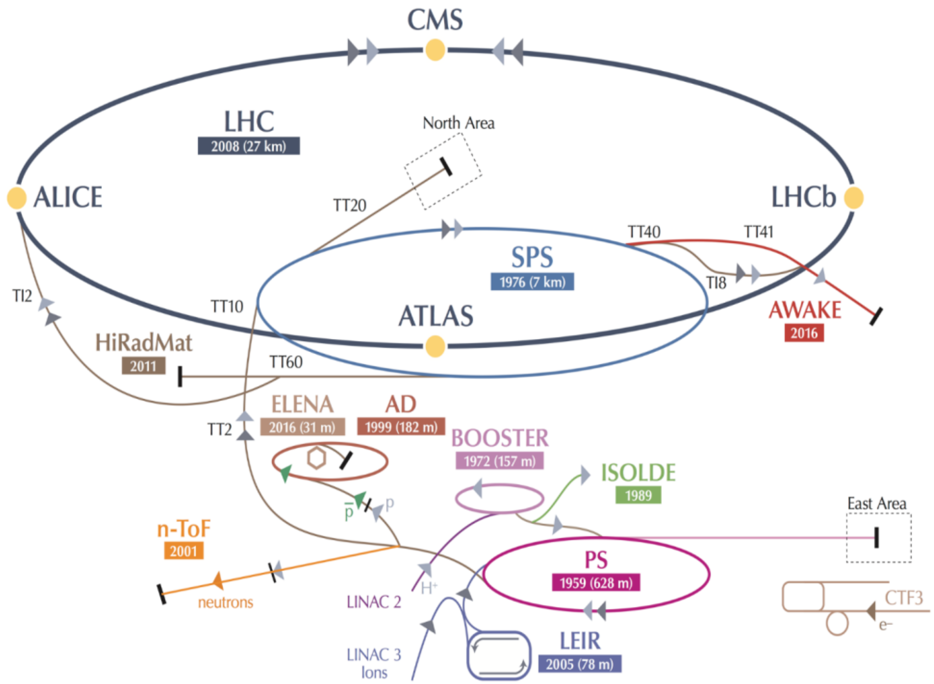


Fixed-target experiments, which include searches for rare phenomena

Theory

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

CERN's Diverse Programme



~20 projects other than LHC with > 1200 physicists

- AD: Antiproton Decelerator for antimatter studies
- AWAKE: proton-induced plasma wakefield acceleration
- CAST, OSQAR: axions
- CLOUD: impact of cosmic rays on aeorosols and clouds → implications on climate
- COMPASS: hadron structure and spectroscopy
- ISOLDE: radioactive nuclei facility
- LHC
- NA61/Shine: ions and neutrino targets
- NA62: rare kaon decays
- NA63: radiation processes in strong EM fields
- NA64: search for dark photons
- Neutrino Platform: ν detector R&D for experiments in US, Ja
- n-TOF ... ections
- ... ystal collimation

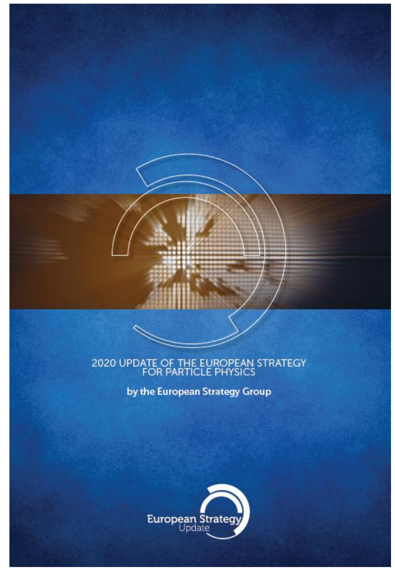
many opportunities for diverse research interests

The path forward:

Update European Strategy for Particle Physics

CERN Council updated the European Strategy for Particle Physics in June 2020

Scientific recommendations
- Full exploitation of the LHC and HL-LHC
- Highest-priority next collider: e+e- Higgs factory
- Increased R&D on accelerator technologies
- Investigation of the technical and financial feasibility of a future ≥ 100 TeV hadron collider
- Long-baseline neutrino projects in US and Japan
- High-impact scientific diversity programme complementary to high-energy colliders
- R&D on detector and computing
- Theory

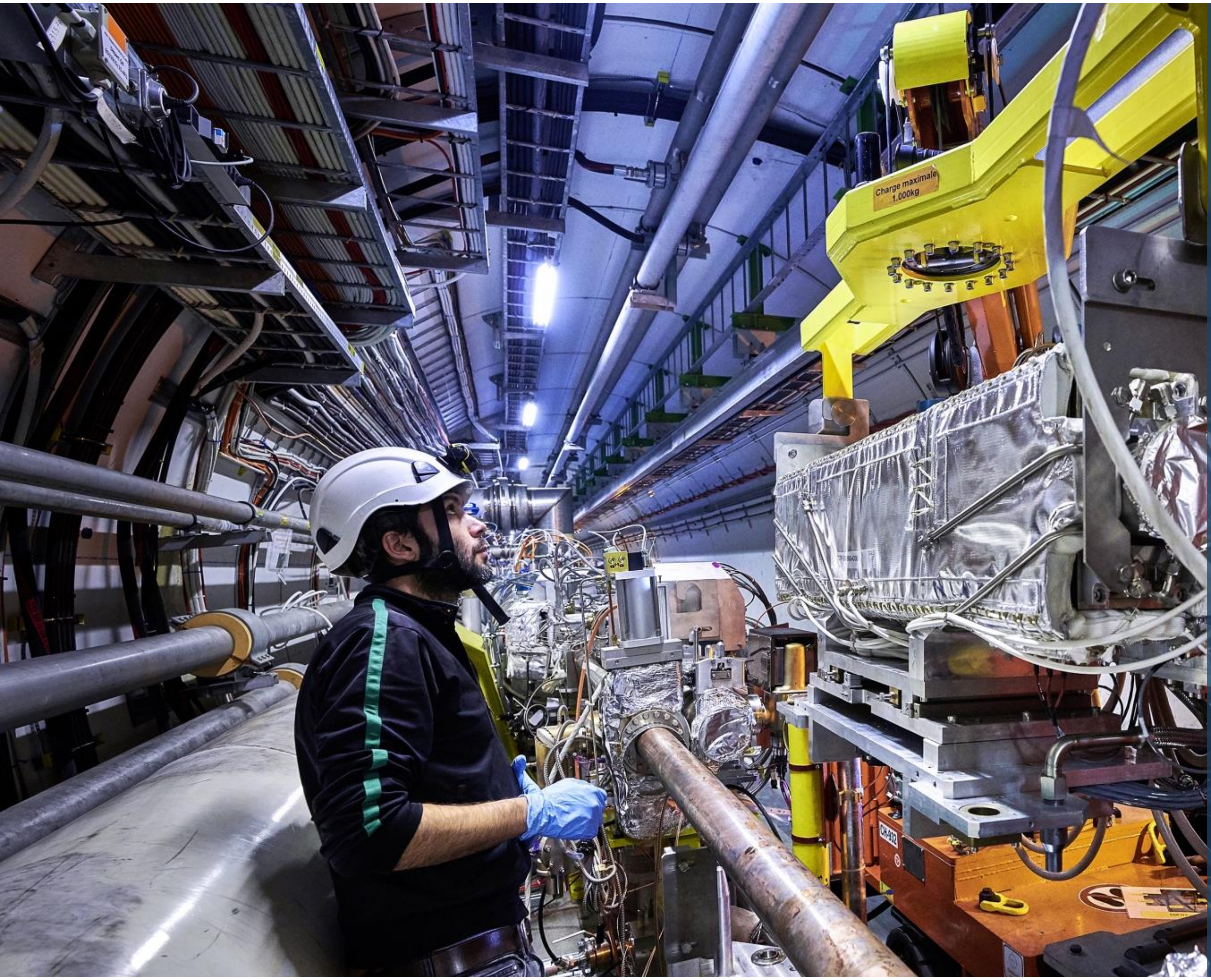


Other high priority items:
- Exploit synergies with neighboring field, in particular nuclear and astroparticle physics
- Mitigate environmental impact of particle physics
- Invest in next generation of researchers
- Support knowledge and technology transfer
- Public engagement, education and communication

Importance of collaboration between CERN and national labs hi...

ESPPU provid... CERN for the coming years

many opportunities for research, for engineering, for IT



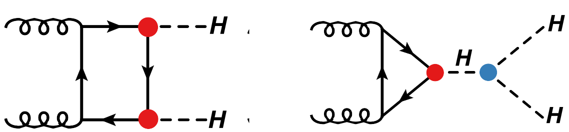
Upgrade to the High-Luminosity LHC is under way

- 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 2029, and run until approx. 2040.

Future of Higgs Physics at the LHC

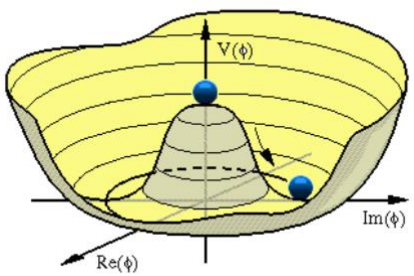
One of the key questions is the self coupling of the Higgs Boson

Search for di-Higgs boson production to experimentally constrain Higgs self-coupling and thus Higgs potential



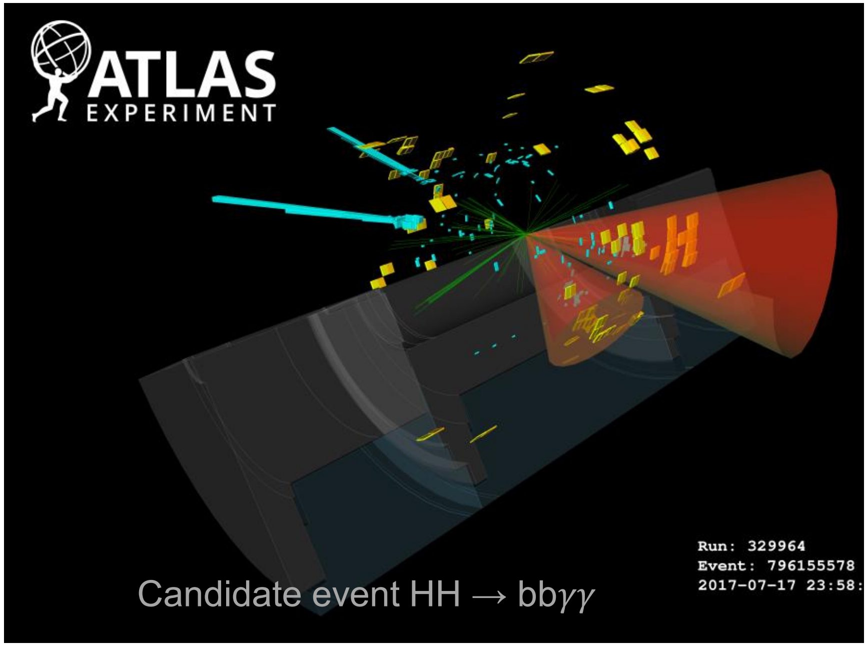
$$\lambda_{HHH} = \frac{m_H^2}{2v^2} \sim 0.13$$

$$\mathcal{L} \supset \frac{1}{2} m_h^2 h^2 + \frac{m_h^2}{2v} h^3 + \frac{m_h^2}{2v^2} h^4$$



$$-1.5 < \frac{\lambda_{HHH}(\mathrm{obs})}{\lambda_{HHH}(\mathrm{SM})} < 6.7$$

Higgs boson pair production will be a primary physics goals for the HL-LHC



Physics Beyond Collider Study

PBC is an exploratory study launched in 2016 aimed at exploiting the full scientific potential of CERN's accelerator complex and its scientific infrastructure

http://pbc.web.cern.ch/

- complementary to LHC and other high-energy colliders
- target fundamental physics questions that are similar in spirit to those addressed by high-energy colliders

Provided input to the ESPP

- PBC Summary Report: arXiv:1902.00260

Study will continue

- Workshops ongoing
- https://indico.cern.ch/event/1002356/

Topics include:

- ❑ LHC injectors:
- ❑ Low energy facilities
- ❑ High energy fixed target
- ❑ Other opportunities gamma-factory
- ❑ nuSTORM @CERN
- ❑ Precision measurement and rare decays
- ❑ High energy beam dumps
- ❑ Low energy hidden sector (axions, EDM)
- ❑ QCD and HI

COLLABORATION

Experiments: Large International Collaborations

- A place where people learn to work together.
- Collaboration and competition.
- Diversity: good opportunity to recognize differences, accept them and learn to use them.
- Influence the way of thinking & planning.
- Information sharing: role of computing in internationalization and communication.
- Experience can be used by individuals and in other fields.

→ management through ‘common goals’

→ management by ‘convincing partners’

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.

Excellent training ground for Academia and private sector

Key Message

International collaboration is mandatory in many areas today, not only in science

- It needs trust between partners
- It needs commitment, and sustainability from all partners

Science shows: It is possible

CERN as an Example

CERN is an example of a unique international institute, a global research infrastructure, vital for large scale projects,

which in turn allow to support the sustainable development of science and technology necessary for the upturn and growth of everybody's economy

But CERN is only strong through its close collaboration with national institutes

TECHNOLOGY & INNOVATION

CERN’s technological innovations have applications in many fields

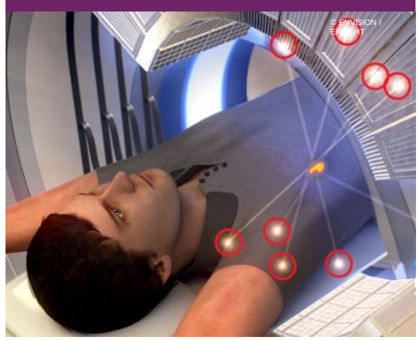
CERN is the birthplace of the World Wide Web

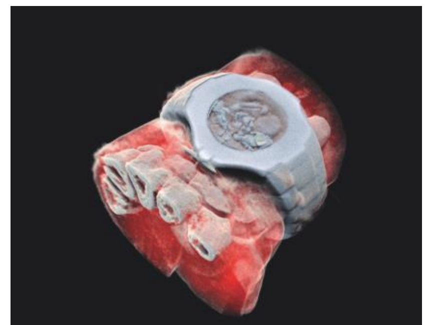
And there are many more examples
Medical imaging, cancer therapy, material science, cultural heritage, aerospace, automotive, environment, health & safety, industrial processes.

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.

The Virtuous Circle

basic research ↔ innovation ↔ applied research

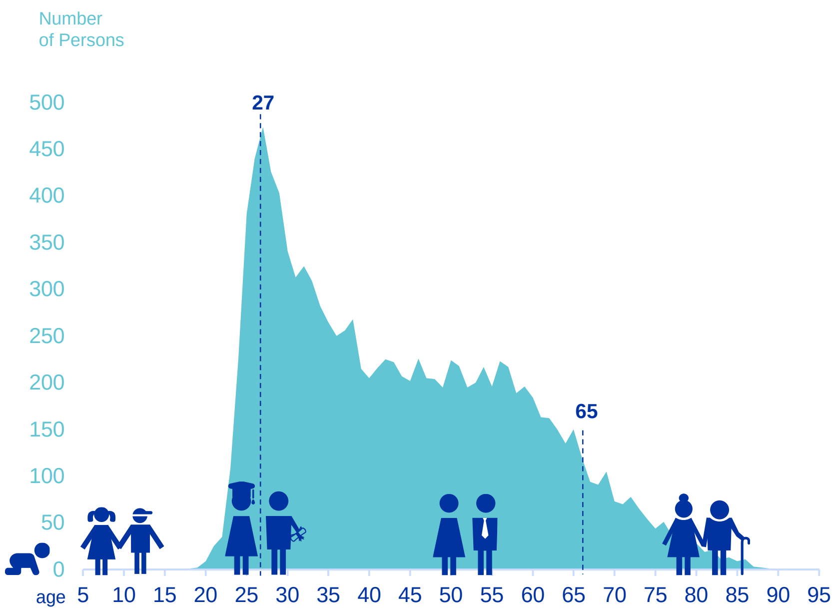
- Synergy between research and innovation results not only in societal and economic impact but also, and very importantly, in the creation of enhanced opportunities for further developments.

- This circle needs to remain strong, to be unbroken and to be supported over long term.

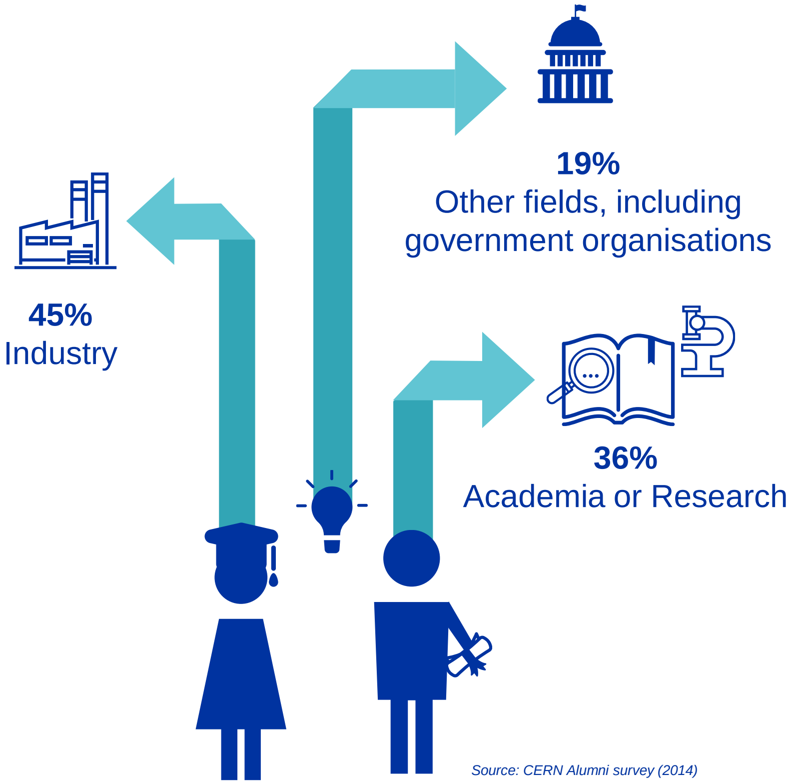
CERN

EDUCATION & TRAINING OUTREACH

CERN opens a world of career opportunities



Age Distribution of Scientists working at CERN



PhD and Technical students leaving CERN

CERN’s training, education and outreach programmes

Beamline for Schools

300 Undergraduate students in Summer programmes
>3000 registered PhD students.

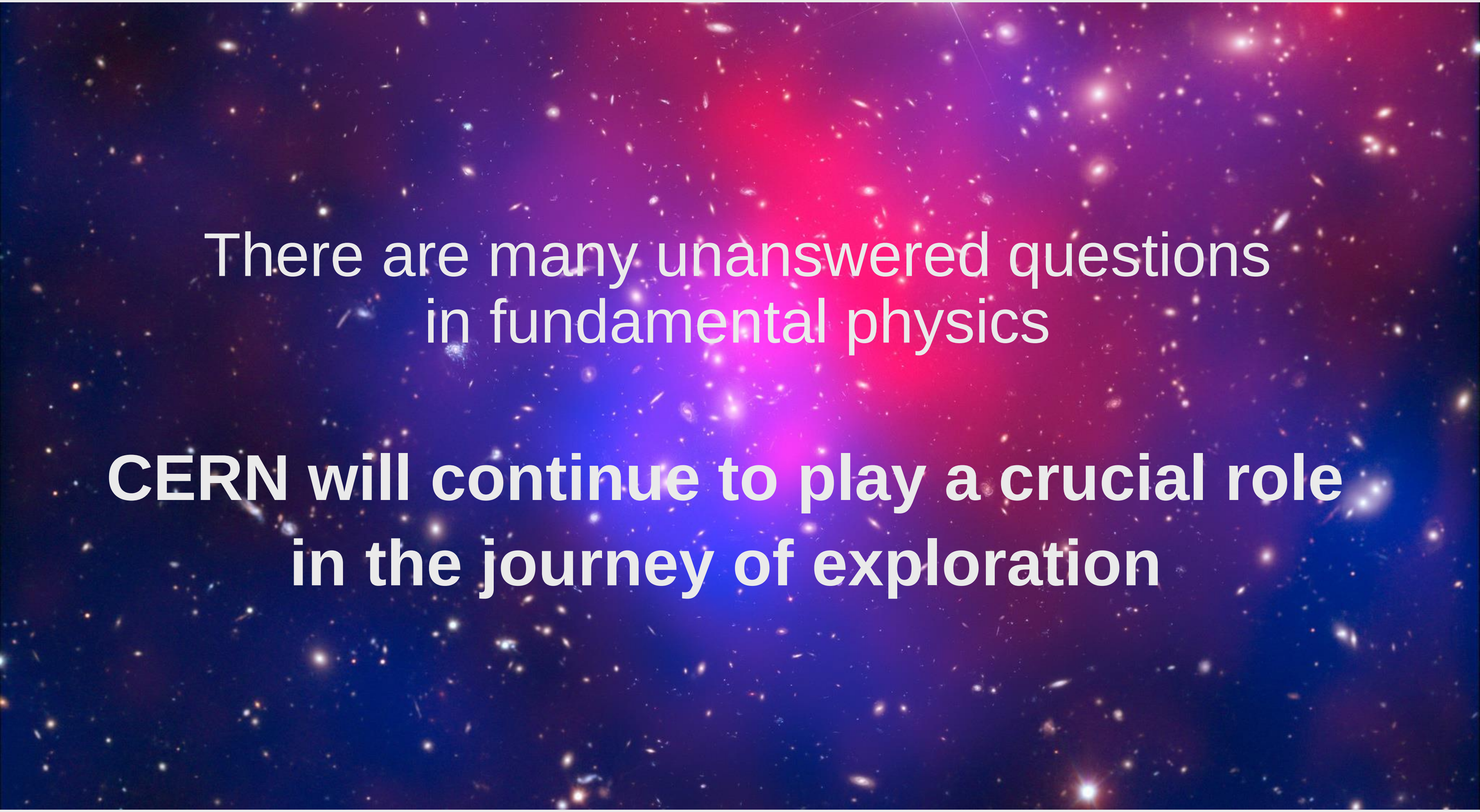
>1000 Fellows, Technical and Doctoral Students in research and applied physics, engineering and computing.

13 304 teachers since 1998 and 2000 participants in the webinar since 2020.

151 000 visitors on guided tours of CERN in 2019, from 95 countries.

CERN engages with citizens across the globe:
on-site and travelling exhibitions in 15 countries, > 1 million visitors

Science Gateway will open in 2023, expanding CERN’s outreach reach and impact, locally and globally.


There are many unanswered questions in fundamental physics
CERN will continue to play a crucial role in the journey of exploration

Concluding Remarks

Science and Technology in the Next Decades

with strong sustained support for research,

with trust developed and kept between all partners,

with international collaboration,

with scientists as ambassadors for peaceful cooperation

will pave the way towards
a sustainable future