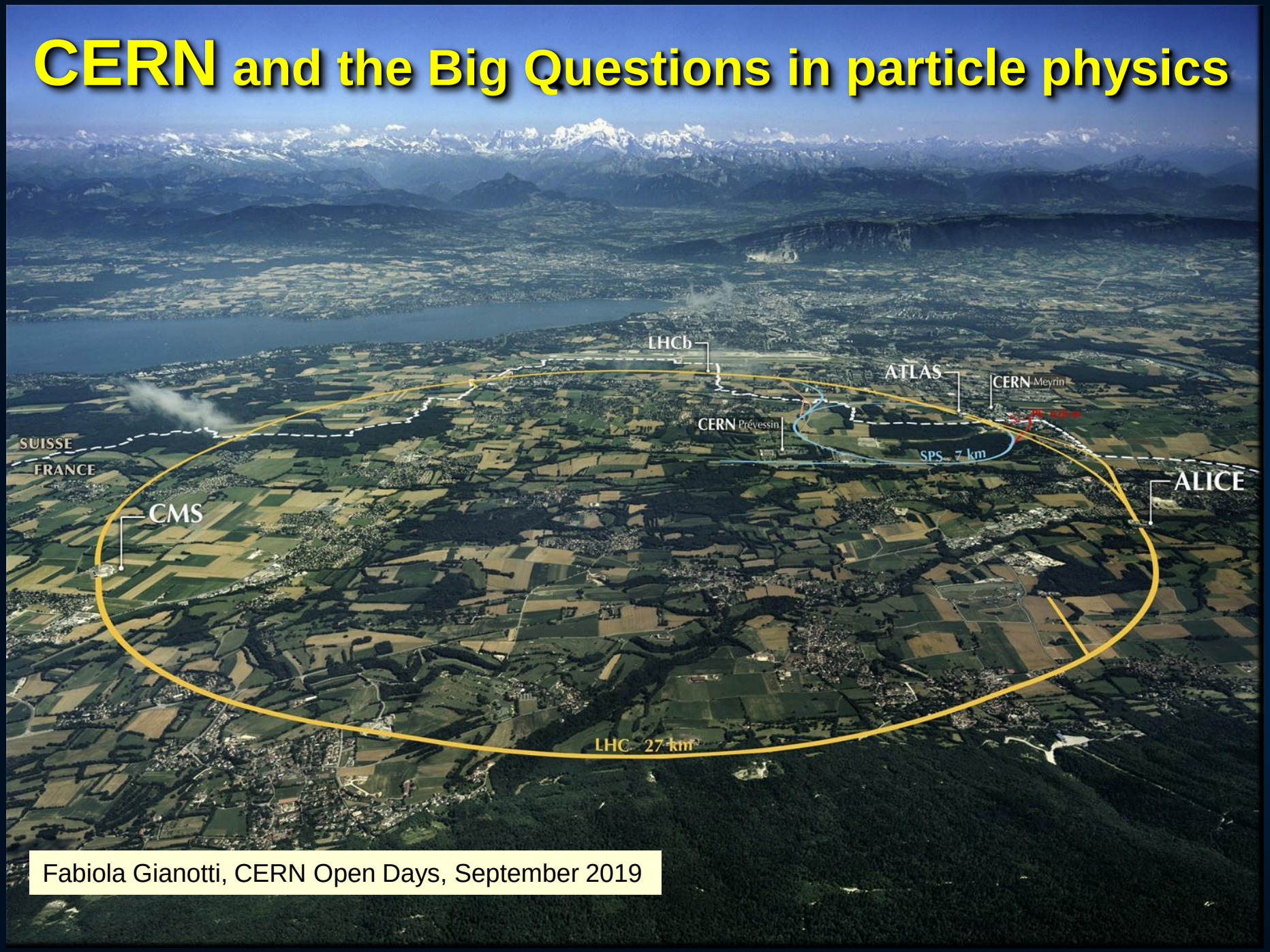
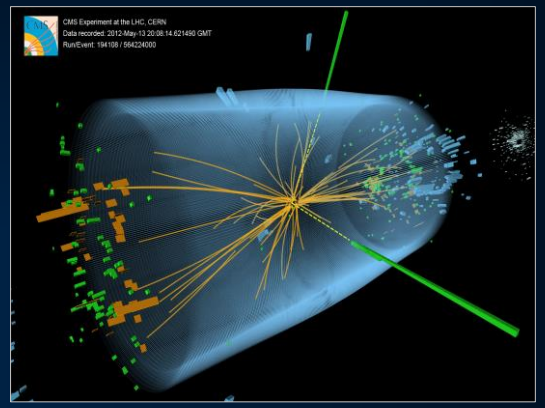
# CERN and the Big Questions in particle physics



Fabiola Gianotti, CERN Open Days, September 2019

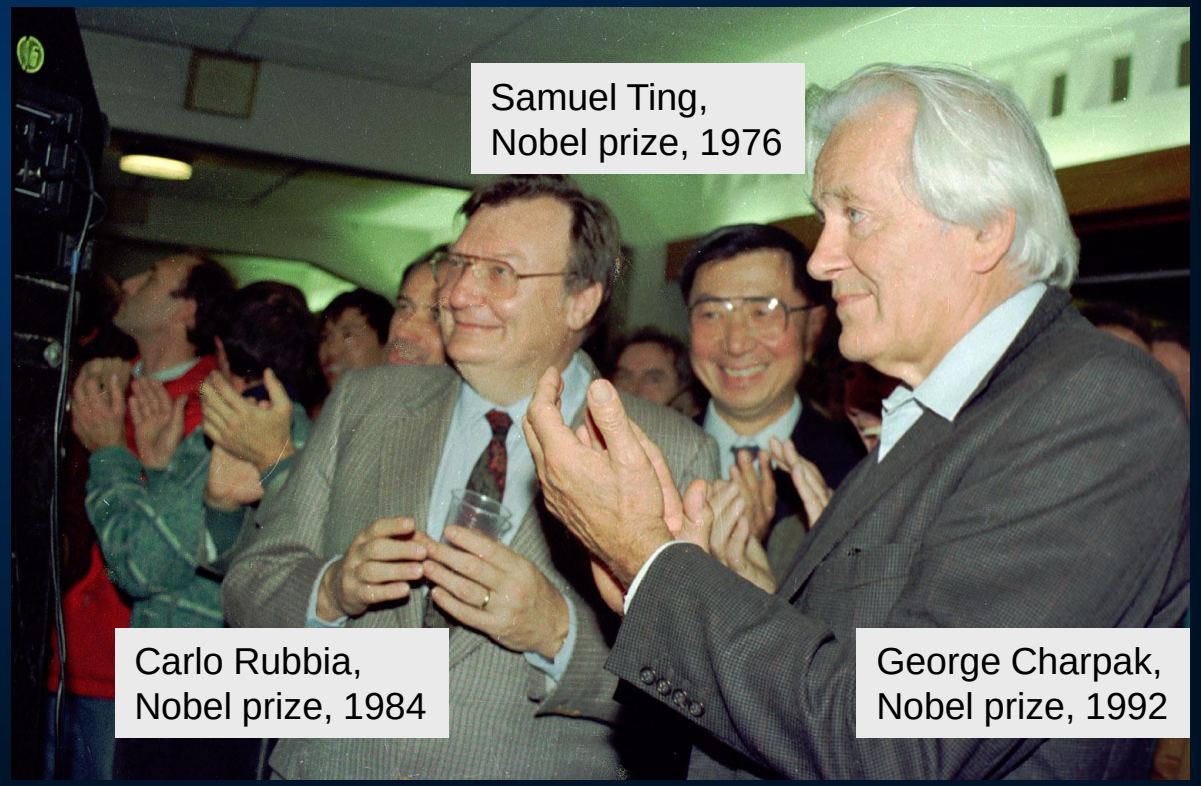
# CERN : the largest particle physics laboratory in the world

Intergovernmental organisation based in Geneva, Switzerland

Mission:

- science: fundamental research in particle physics → discoveries (e.g. Higgs boson in 2012), Nobel prizes
- technology and innovation → transferred to society (e.g. the World Wide Web, medical applications)
- training and education
- bringing the world together: ~ 18000 scientists, > 110 nationalities


WEB@30 celebration, 12 March 2019 at CERN,
with T. Berners-Lee, former CERN staff member



# CERN was founded in 1954: 12 European States

23 Member States: Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, the Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Spain, Sweden, Switzerland and the United Kingdom

7 Associate Member States: Cyprus, India, Lithuania, Pakistan, Slovenia, Turkey, Ukraine

6 Observers to Council: Japan, Russian Federation, USA, EU, JINR/Dubna, UNESCO

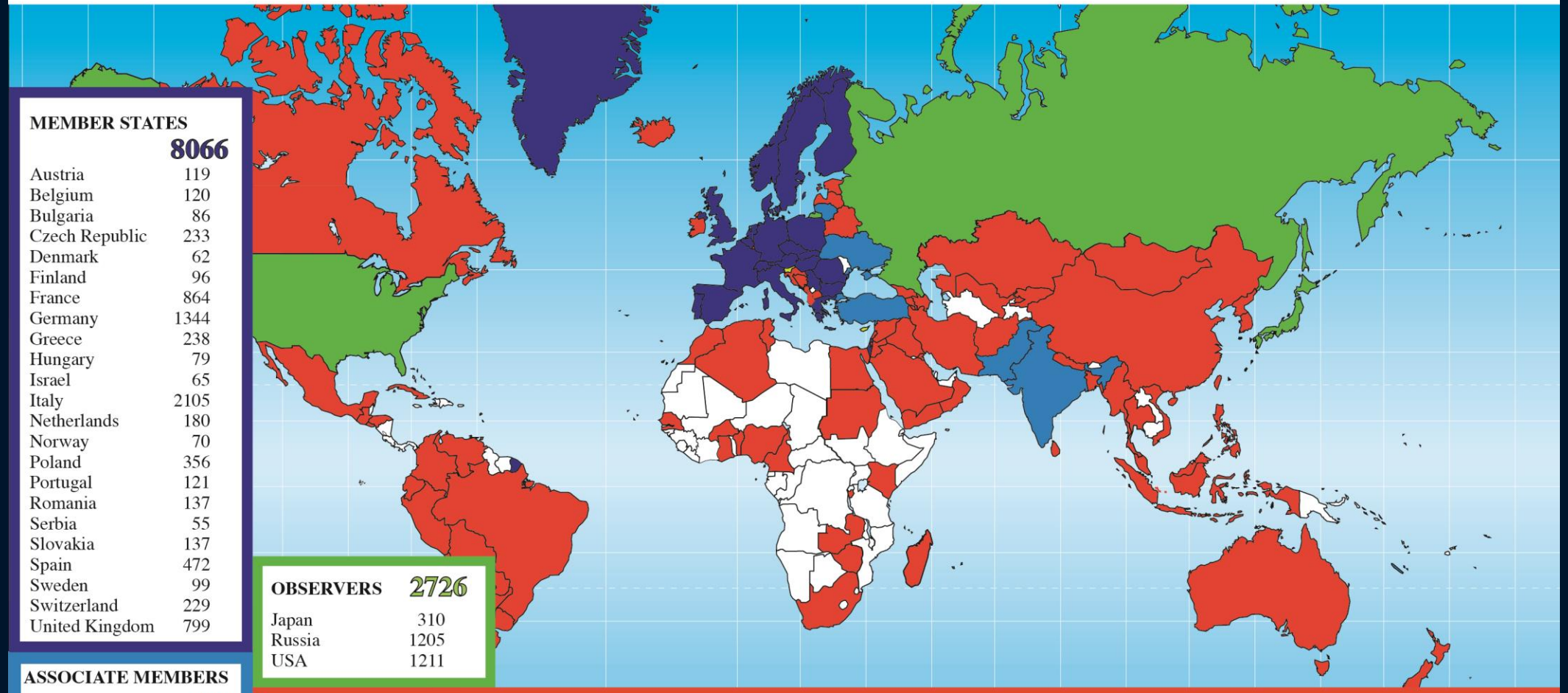
~ 2600 staff, 4400 in total on payroll

~ 13600 users from all over the world

Annual budget (2018) ~1200 MCHF (on average ~1 cappuccino/European citizen per year):

each Member State contributes in proportion to its income

# Distribution of All CERN Users by Nationality as of mid-April 2019



**MEMBER STATES** **8066**

| | |
|---|---|
| Austria | 119 |
| Belgium | 120 |
| Bulgaria | 86 |
| Czech Republic | 233 |
| Denmark | 62 |
| Finland | 96 |
| France | 864 |
| Germany | 1344 |
| Greece | 238 |
| Hungary | 79 |
| Israel | 65 |
| Italy | 2105 |
| Netherlands | 180 |
| Norway | 70 |
| Poland | 356 |
| Portugal | 121 |
| Romania | 137 |
| Serbia | 55 |
| Slovakia | 137 |
| Spain | 472 |
| Sweden | 99 |
| Switzerland | 229 |
| United Kingdom | 799 |

**OBSERVERS** **2726**

| | |
|---|---|
| Japan | 310 |
| Russia | 1205 |
| USA | 1211 |

**ASSOCIATE MEMBERS** **778**

| | |
|---|---|
| India | 387 |
| Lithuania | 39 |
| Pakistan | 71 |
| Turkey | 165 |
| Ukraine | 116 |

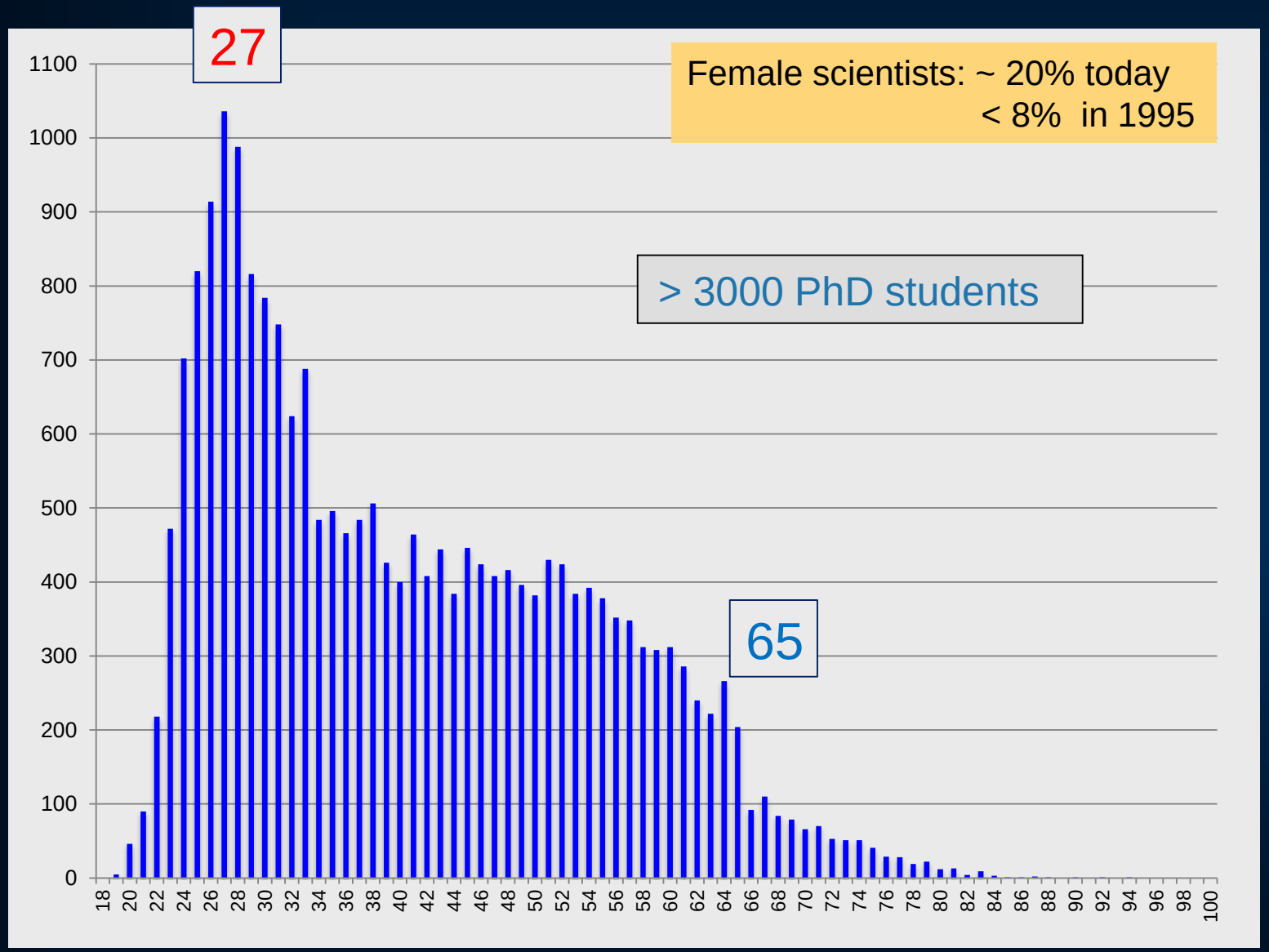
**ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP** **59**

| | |
|---|---|
| Cyprus | 26 |
| Slovenia | 33 |

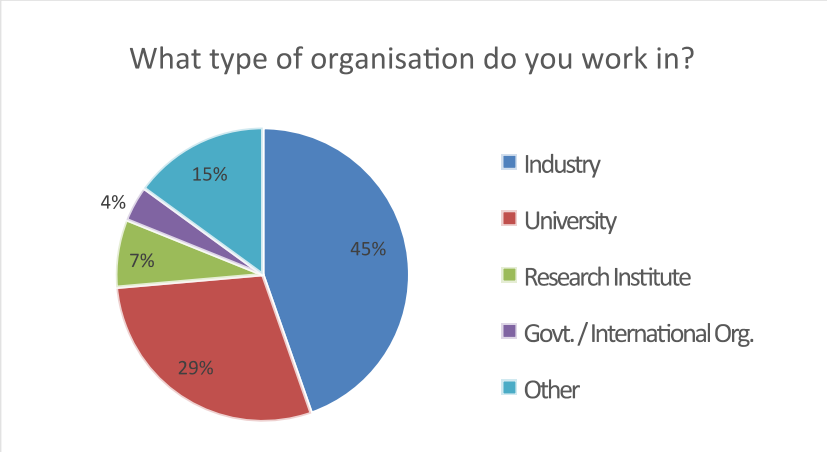
**OTHERS** **1999**

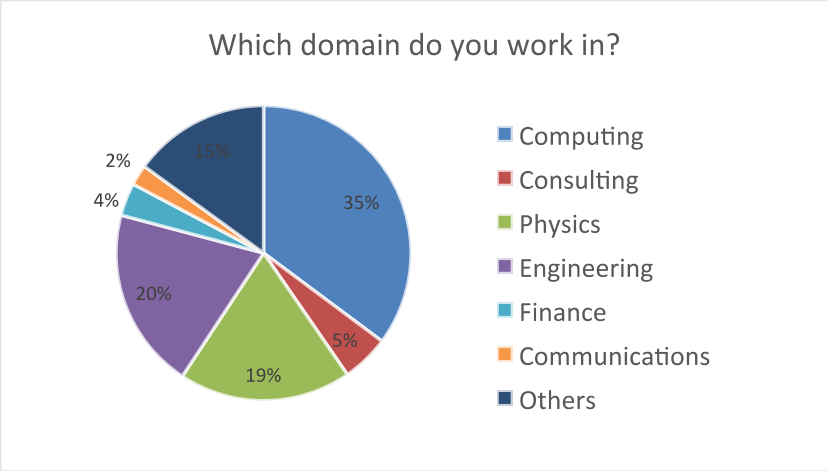
| | |
|---|---|
| Albania | 4 |
| Algeria | 14 |
| Argentina | 26 |
| Armenia | 22 |
| Australia | 36 |
| Azerbaijan | 10 |
| Bahrain | 1 |
| Bangladesh | 8 |
| Belarus | 45 |
| Benin | 1 |
| Bolivia | 3 |
| Bosnia & Herzegovina | 3 |
| Brazil | 127 |
| Burkina Faso | 1 |
| Burundi | 1 |
| Cameroon | 1 |
| Canada | 170 |
| Chile | 21 |
| China | 576 |
| Colombia | 44 |
| Croatia | 50 |
| Cuba | 16 |
| Ecuador | 10 |
| Egypt | 27 |
| El Salvador | 1 |
| Estonia | 15 |
| Georgia | 51 |
| Ghana | 1 |
| Guatemala | 1 |
| Hong Kong | 1 |
| Honduras | 1 |
| Iceland | 4 |
| Indonesia | 11 |
| Iran | 58 |
| Iraq | 1 |
| Ireland | 13 |
| Jordan | 2 |
| Kazakhstan | 10 |
| Kenya | 1 |
| Korea | 183 |
| Kyrgyzstan | 1 |
| Latvia | 4 |
| Lebanon | 27 |
| Luxembourg | 4 |
| Madagascar | 1 |
| Malaysia | 22 |
| Malta | 9 |
| Mexico | 85 |
| Mongolia | 2 |
| Montenegro | 11 |
| Morocco | 24 |
| Myanmar | 2 |
| Nepal | 7 |
| New Zealand | 5 |
| Nigeria | 4 |
| North Korea | 4 |
| North Macedonia | 3 |
| Oman | 3 |
| Palestine | 7 |
| Paraguay | 1 |
| Peru | 6 |
| Philippines | 3 |
| Saint Kitts and Nevis | 1 |
| San Marino | 1 |
| Saudi Arabia | 4 |
| Senegal | 1 |
| Singapore | 5 |
| South Africa | 56 |
| Sri Lanka | 10 |
| Sudan | 1 |
| Syria | 1 |
| Taiwan | 56 |
| Thailand | 26 |
| Tunisia | 4 |
| Uruguay | 1 |
| Uzbekistan | 3 |
| Venezuela | 9 |
| Viet Nam | 11 |
| Zambia | 1 |
| Zimbabwe | 2 |

# Age distribution of scientists working at CERN



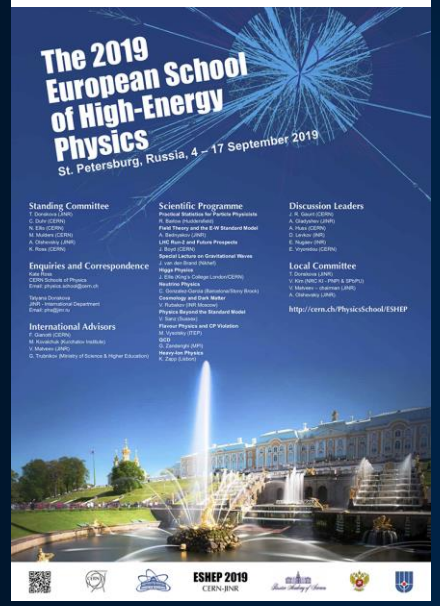

~ 10% of the young people stay in particle physics: where do the others go?



# CERN education activities

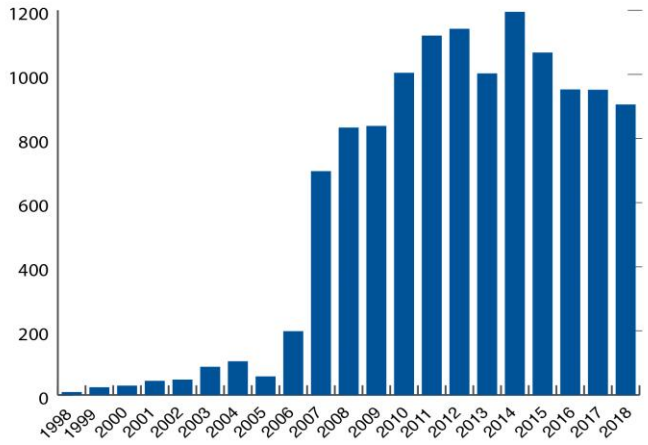
Europe/Russia School



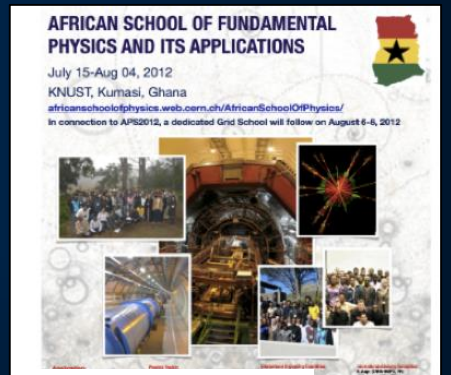

For young researchers
For physics/engineering students
For high school students
For school teachers

Asia-Europe-Pacific School:
India 2014,
China 2016,
Vietnam 2018

Teacher Programme 1998-2018:
total 12320 participants




Latin American School:
Ecuador 2015,
Mexico 2017,
Argentina 2019




African School:
Ghana 2012,
Senegal 2014,
Rwanda 2016,
Namibia 2018

# CERN education activities

Europe/Russia School

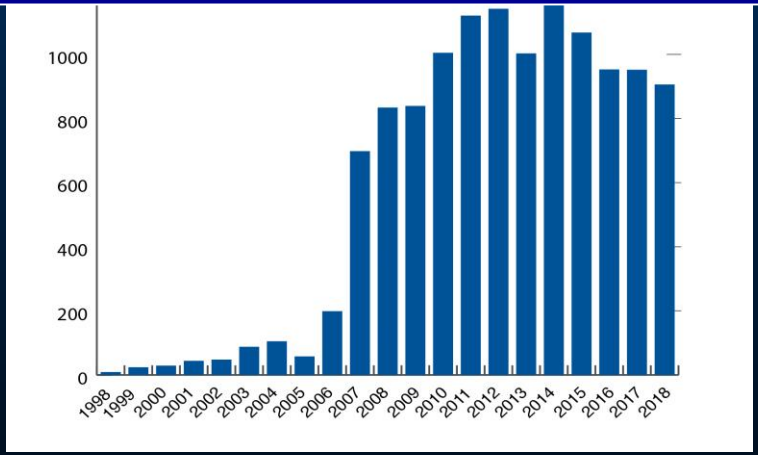

For young researchers
For physics/engineering students
For high school students

Asia-Europe-Pacific School:
India 2014,
China 2016,
Vietnam 2018

And ~130000 visitors every year (300000 requests)

> 60% are high-school students; ~ 80% come from > 700 km away

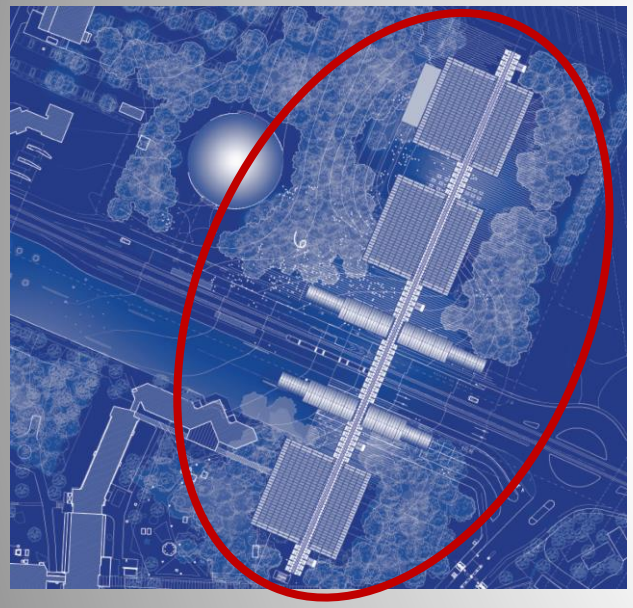
Ecuador 2015,
Mexico 2017,
Argentina 2019




African School:
Ghana 2012,
Senegal 2014,
Rwanda 2016,
Namibia 2018

# CERN's Science Gateway – Portail de la science

A new facility for scientific education and outreach targeting the general public of all ages, with the goal in particular of stimulating vocations for careers in STEM (Science, Technology, Engineering, Mathematics). It will include exhibitions, hands-on experiments for children and school students (from 5 years up), immersive tours, etc. Aim at more than 300 000 visitors/year.

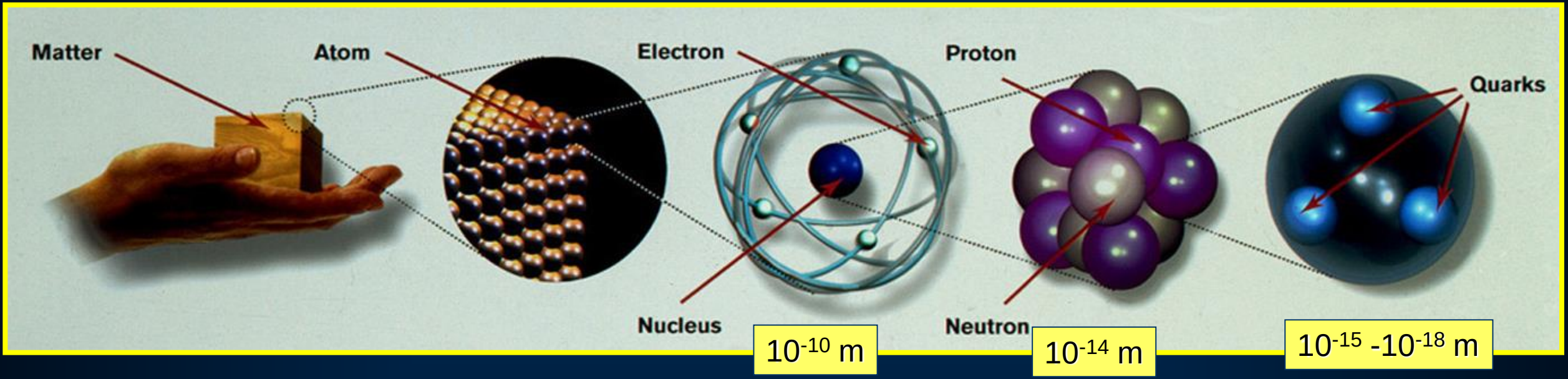


- It will be housed in an iconic building complex designed by architect Renzo Piano
- Construction will start in 2020 and will be completed in 2022
- Total cost: 79 MCHF to be fully covered by donations (~ 65 MCHF secured so far)

It will increase opportunities of collaboration with similar initiatives in CERN's Member States and other scientific research organisations in Europe and beyond

# CERN's primary mission is SCIENCE

Study the elementary particles (e.g. the building blocks of matter: electrons and quarks) and the forces that control their behaviour at the most fundamental level

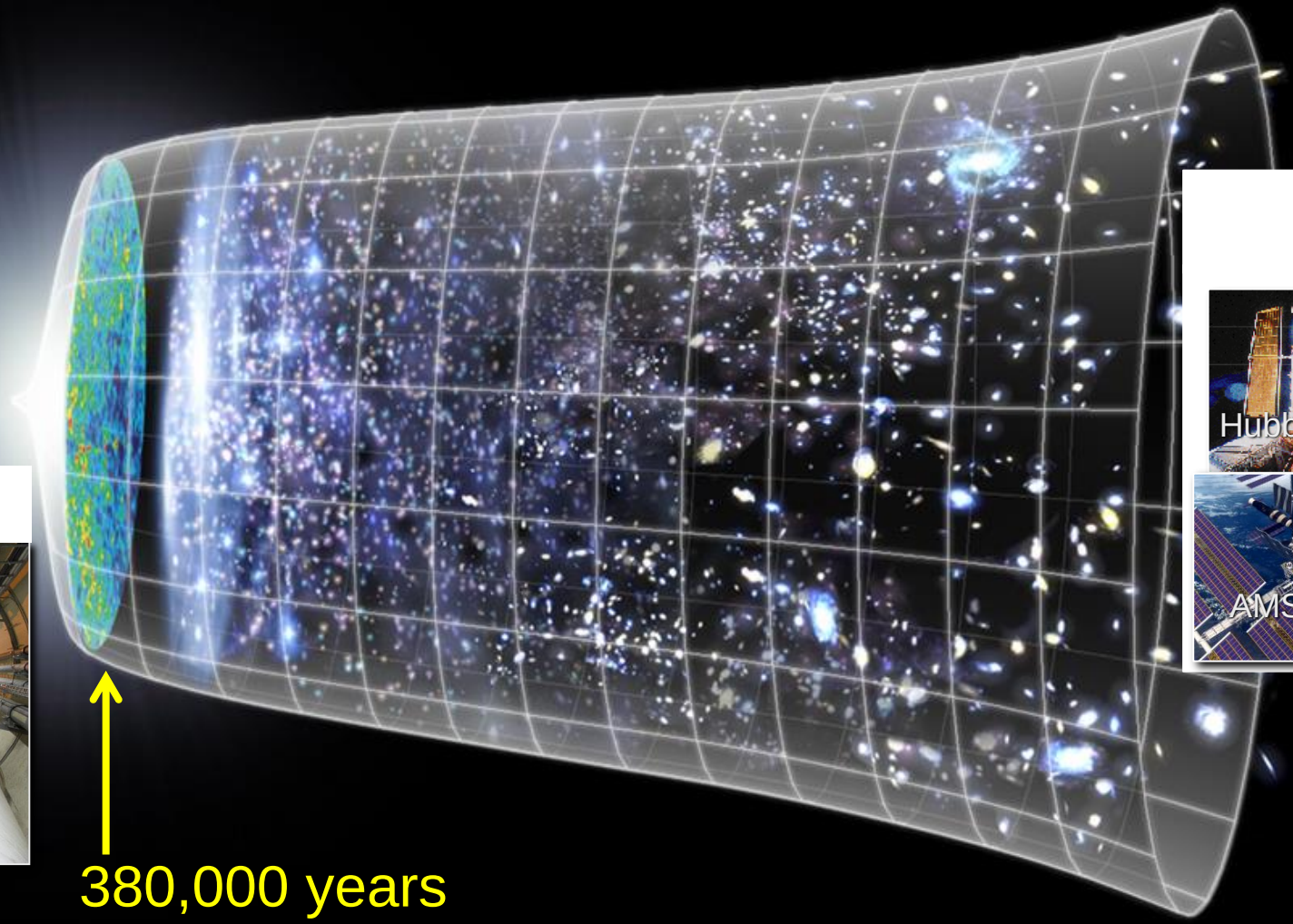



Particle physics at modern accelerators allows us to study the fundamental laws of nature on scales down to smaller than $10^{-18}$ m

→ insight also into the structure and evolution of the Universe

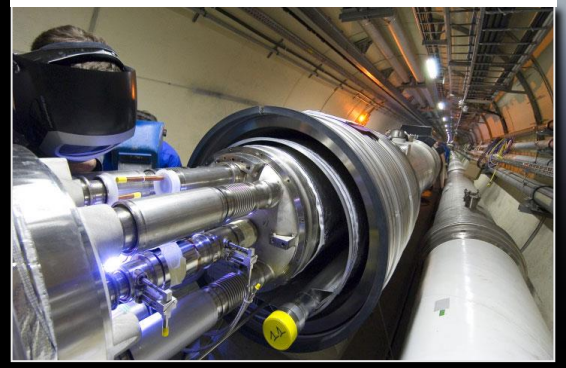
→ from the very small to the very big …

# Evolution of the Universe



Big Bang

Accelerators



380,000 years

13.7 Billion Years

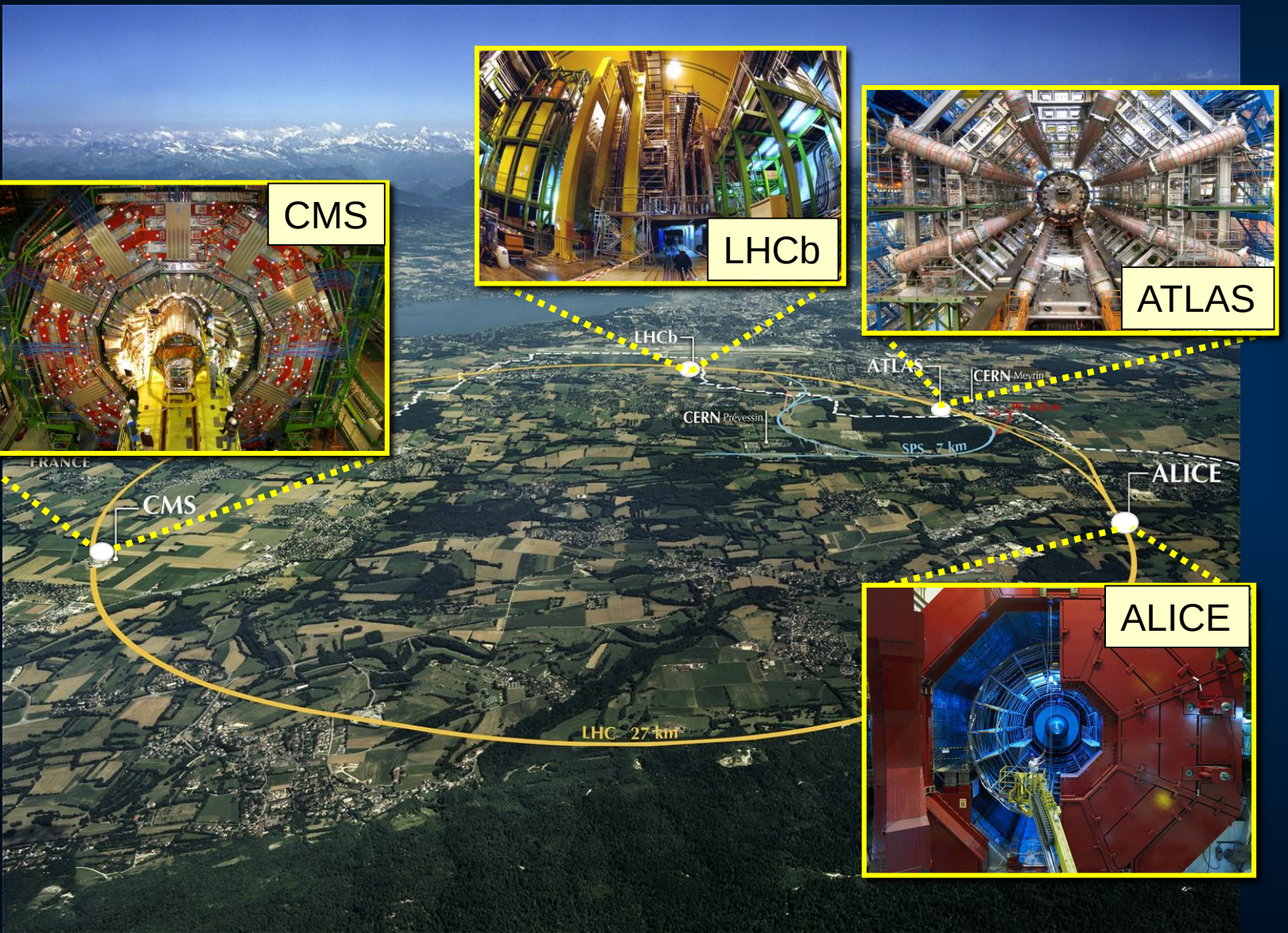
Today

$10^{28}$ cm

Telescopes

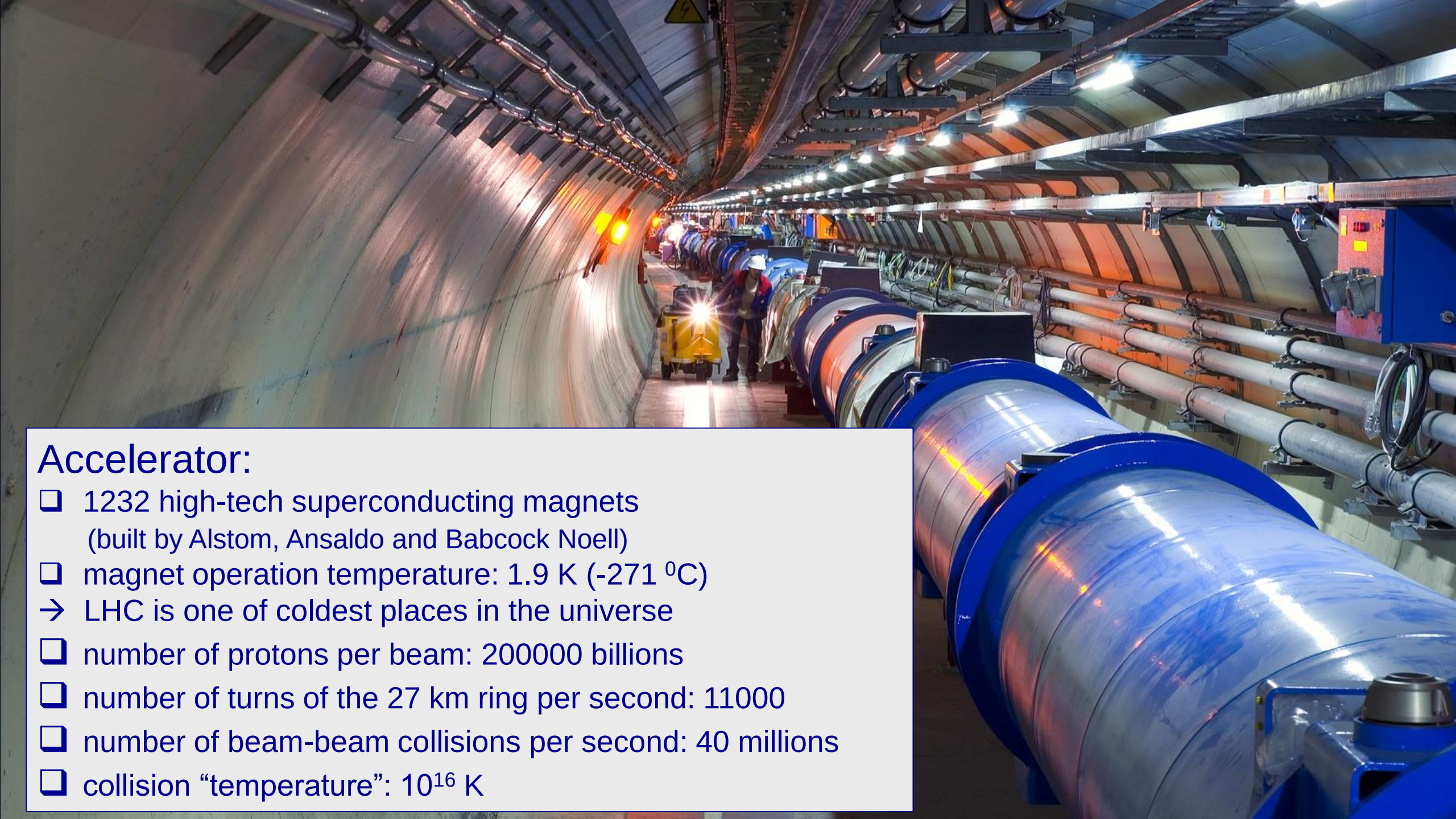



# The Large Hadron Collider (LHC): the most powerful accelerator ever




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

On 4th July 2012, ATLAS and CMS announced the discovery of a new (very special!) particle:
the Higgs boson

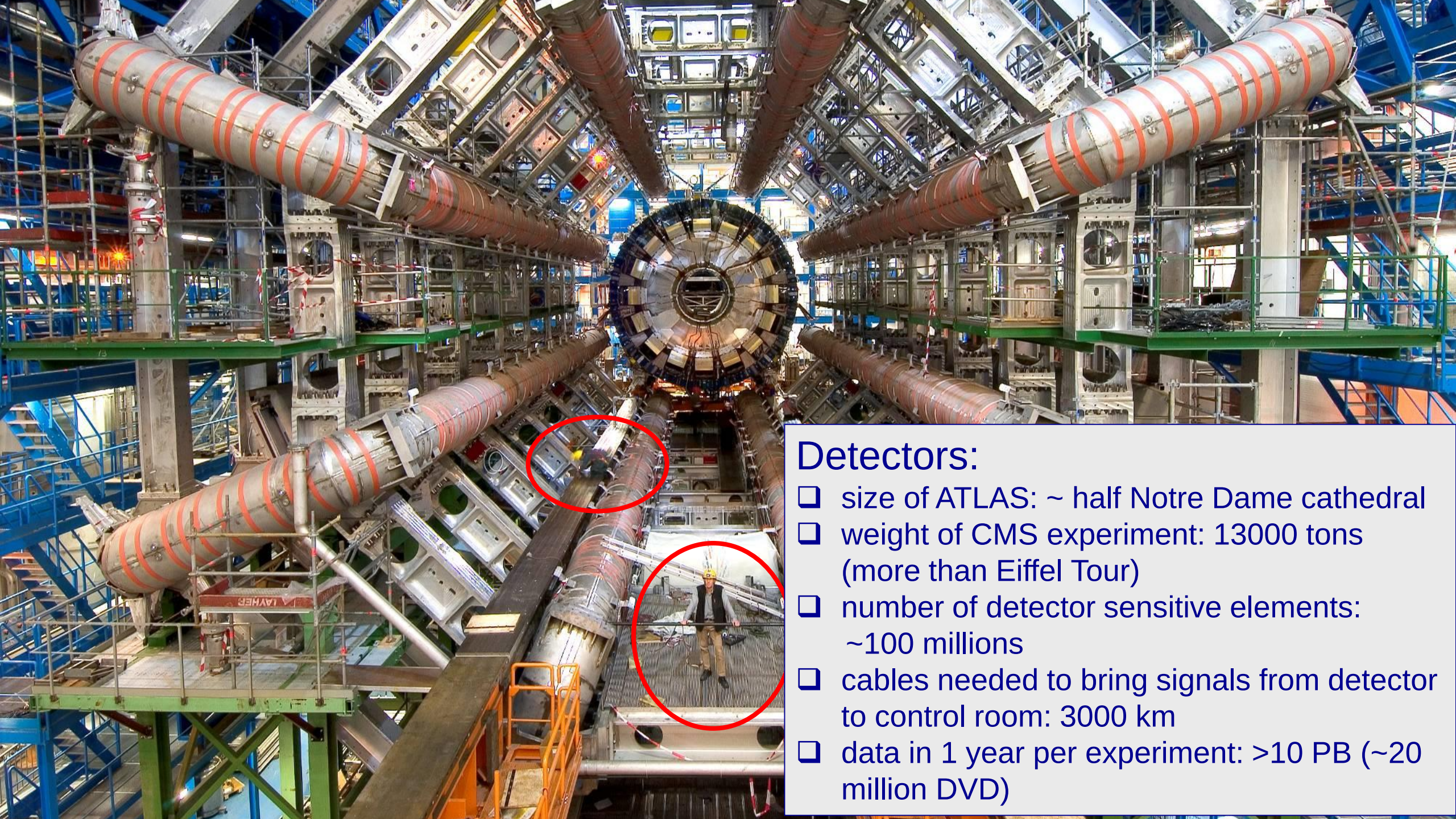


# Accelerator:

- 1232 high-tech superconducting magnets
  (built by Alstom, Ansaldo and Babcock Noell)
- magnet operation temperature: 1.9 K (-271 $^{0}$C)

→ LHC is one of coldest places in the universe

- number of protons per beam: 200000 billions
- number of turns of the 27 km ring per second: 11000
- number of beam-beam collisions per second: 40 millions
- collision “temperature”: $10^{16}$ K



# Detectors:

- size of ATLAS: ~ half Notre Dame cathedral
- weight of CMS experiment: 13000 tons (more than Eiffel Tour)
- number of detector sensitive elements: ~100 millions
- cables needed to bring signals from detector to control room: 3000 km
- data in 1 year per experiment: >10 PB (~20 million DVD)

# WHY ???

# LHC built to address outstanding questions in fundamental physics

What is the origin of the masses of the elementary particles (quarks, electrons, … ) ? → related to the Higgs boson ✓

95% of the universe is unknown (dark): e.g. 25% of dark matter

Why is there so little antimatter in the universe ?

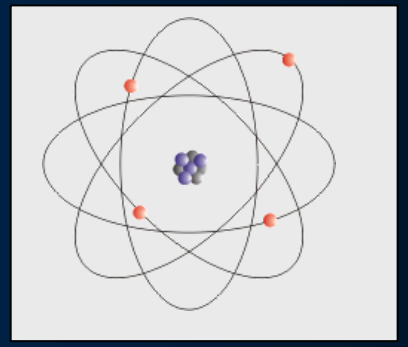
What are the features of the primordial plasma permeating the universe ~10 μs after the Big Bang ?

Are there other forces in addition to the known four ?

Etc. etc.

# Discovery in 2012 → Nobel Prize in Physics in 2013

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider".*



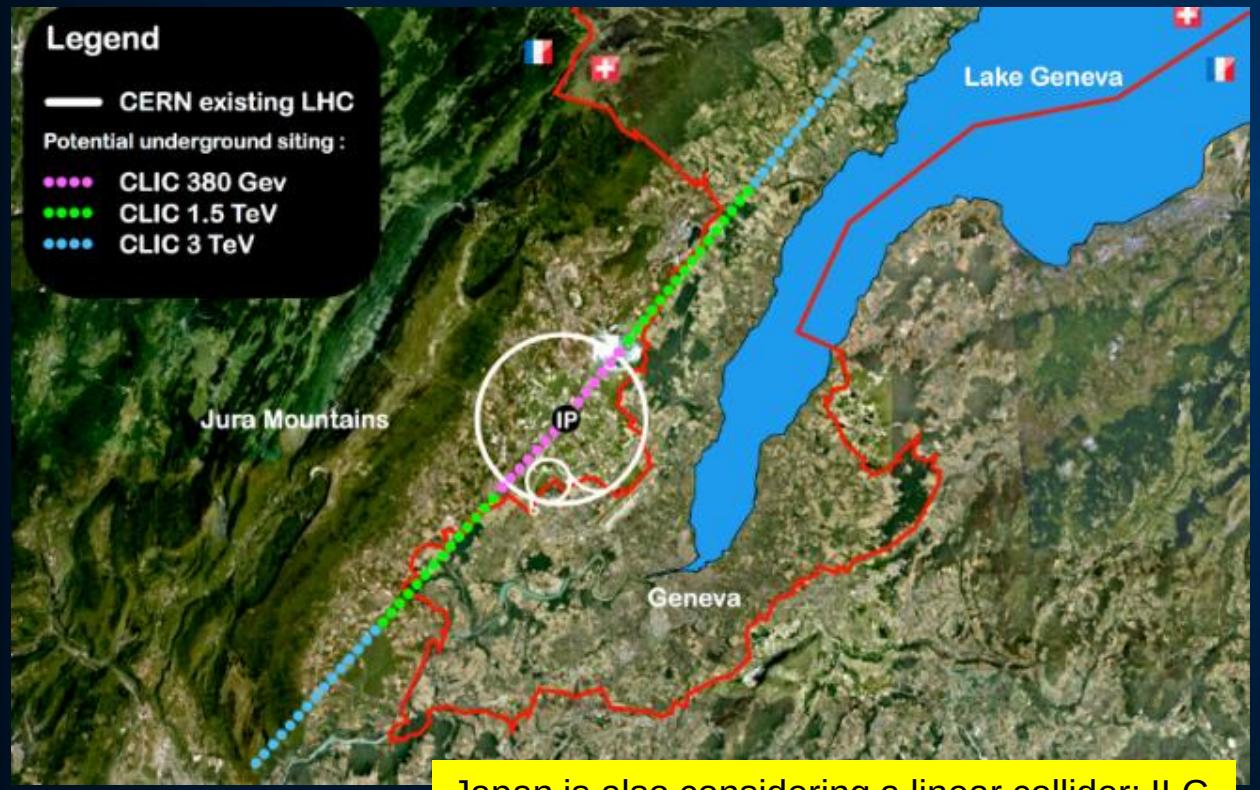
Note: a world without the Higgs boson would be very strange. Atoms would not exist → universe would be very different

# Which accelerator after the LHC ?

LHC being upgraded to run with more intense proton beams → High-Luminosity LHC will operate from 2027 to 2037, providing 10 times more data than LHC and increased sensitivity to new physics.

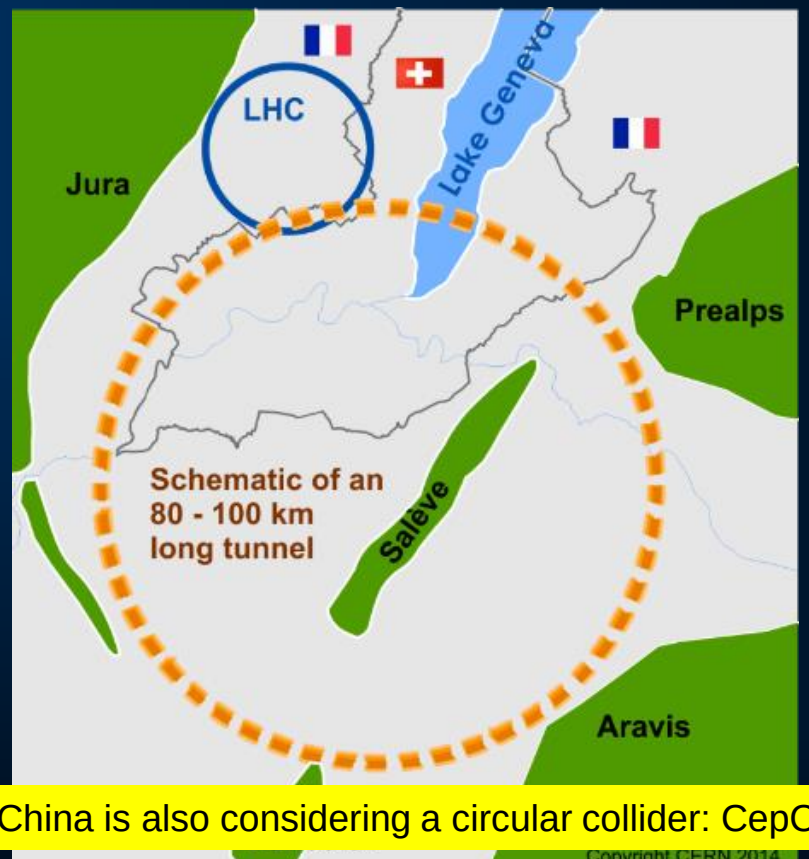
In parallel, various options for future, more powerful colliders being studied and the needed, advanced technologies being developed

CLIC: $e^+e^-$ linear collider 11 km → 50 km tunnel




Japan is also considering a linear collider: ILC

FCC: Future Circular Collider: 100 km ring for $e^+e^-$ and proton-proton collisions



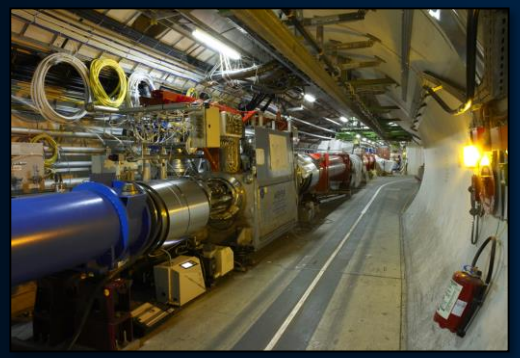

China is also considering a circular collider: CepC

Will the Higgs boson change our life ?

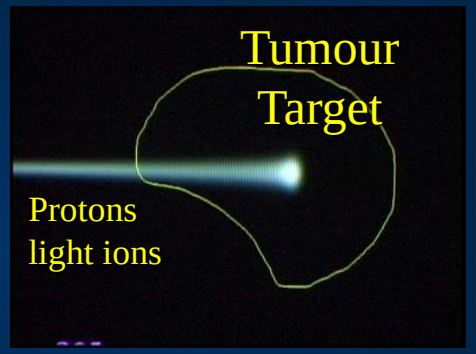
It already has !

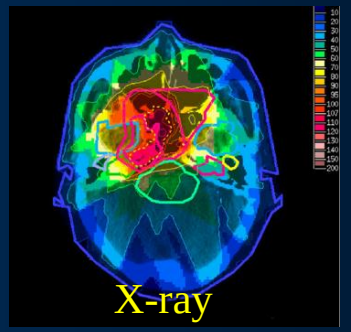
# Complex, high-tech instruments needed in particle physics → cutting-edge technologies developed at CERN and collaborating Institutes → transferred to society

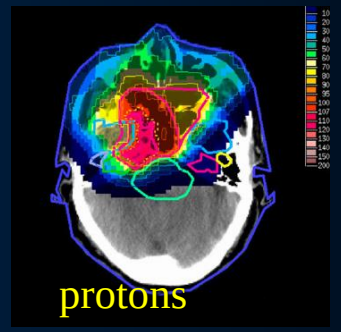
Examples of applications: medical imaging, cancer therapy, solar panels, material science, airport scanners, cargo screening, food sterilization, nuclear waste transmutation, analysis of historical relics, etc. etc. … not to mention the WEB …



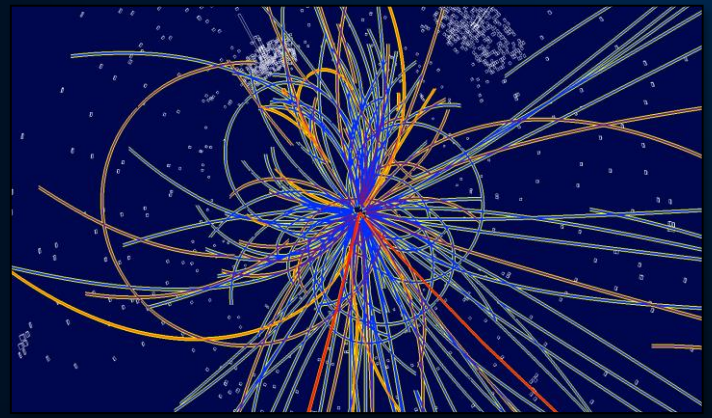
Hadron Therapy



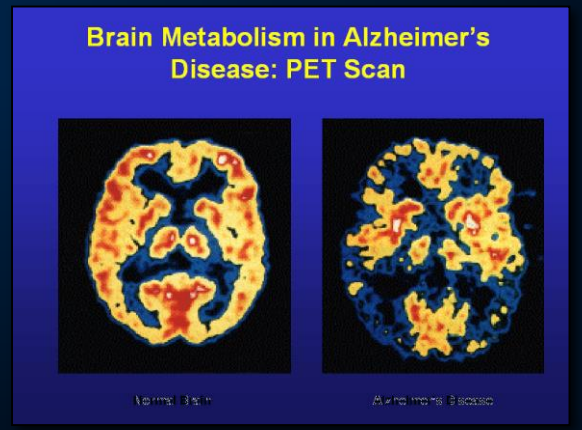




Particle accelerators: ~30’000 worldwide, of which ~17’000 used for medical applications
E.g. Hadron Therapy: > 50000 patients treated in Europe (14 facilities for protons, two for Carbon ions)



Imaging

e.g. PET scanner (based on CERN technology) is main cancer diagnostic technique since 2000




# Thank you!

*Accelerating Science and Innovation*

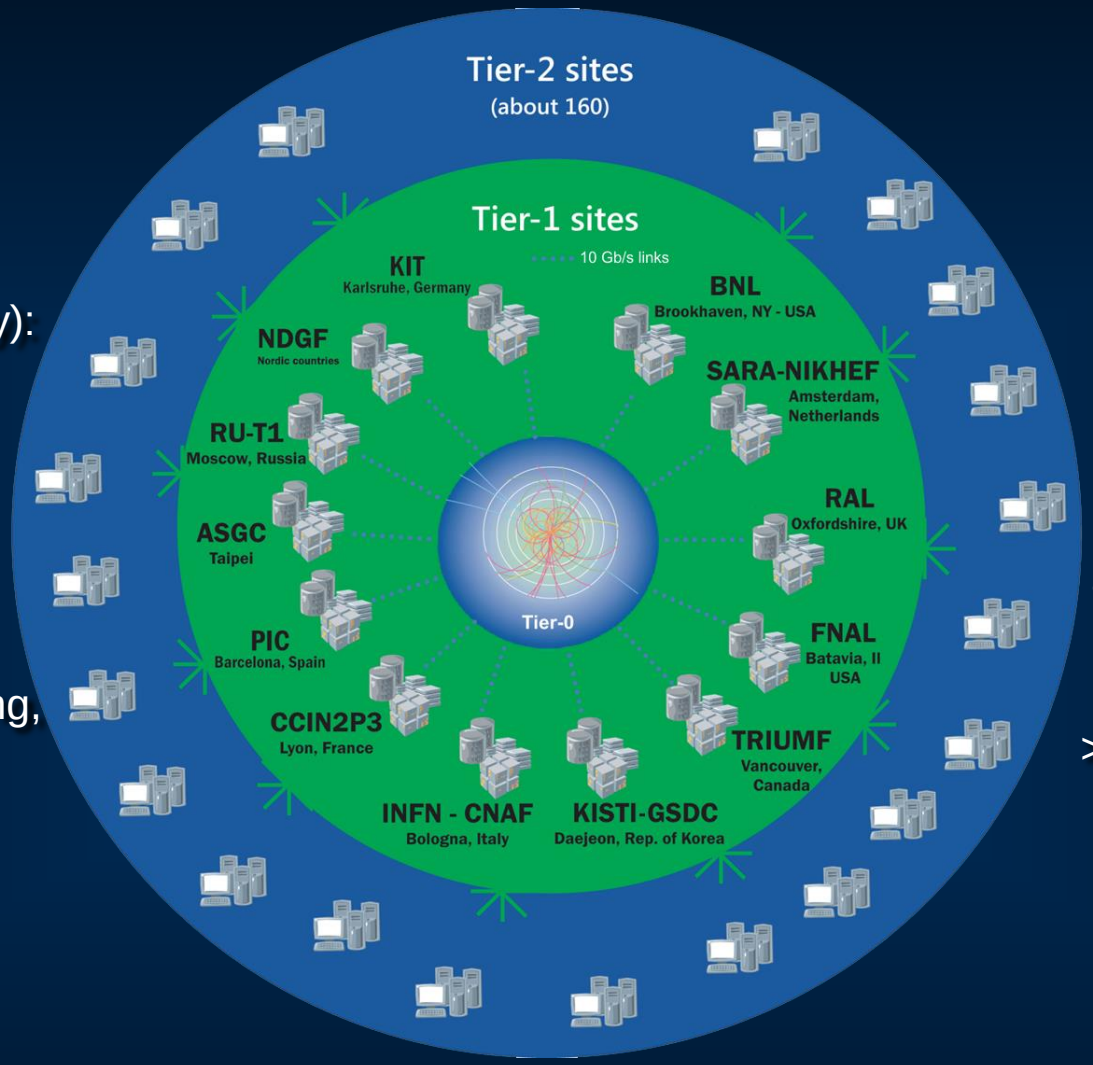
# The Worldwide LHC Computing Grid

Also used by other disciplines

Tier-0 (CERN and Hungary): data recording, reconstruction and distribution

Tier-1: permanent storage, reprocessing, analysis

Tier-2: simulation, end-user analysis




>170 sites in, 42 countries

750k CPU cores

800 PB of storage

> 2 million jobs/day

35 GB/s global transfers

WLCG:
An International collaboration to distribute and analyse LHC data

Integrates computer centres worldwide that provide computing and storage resource into a single infrastructure accessible by all LHC physicists