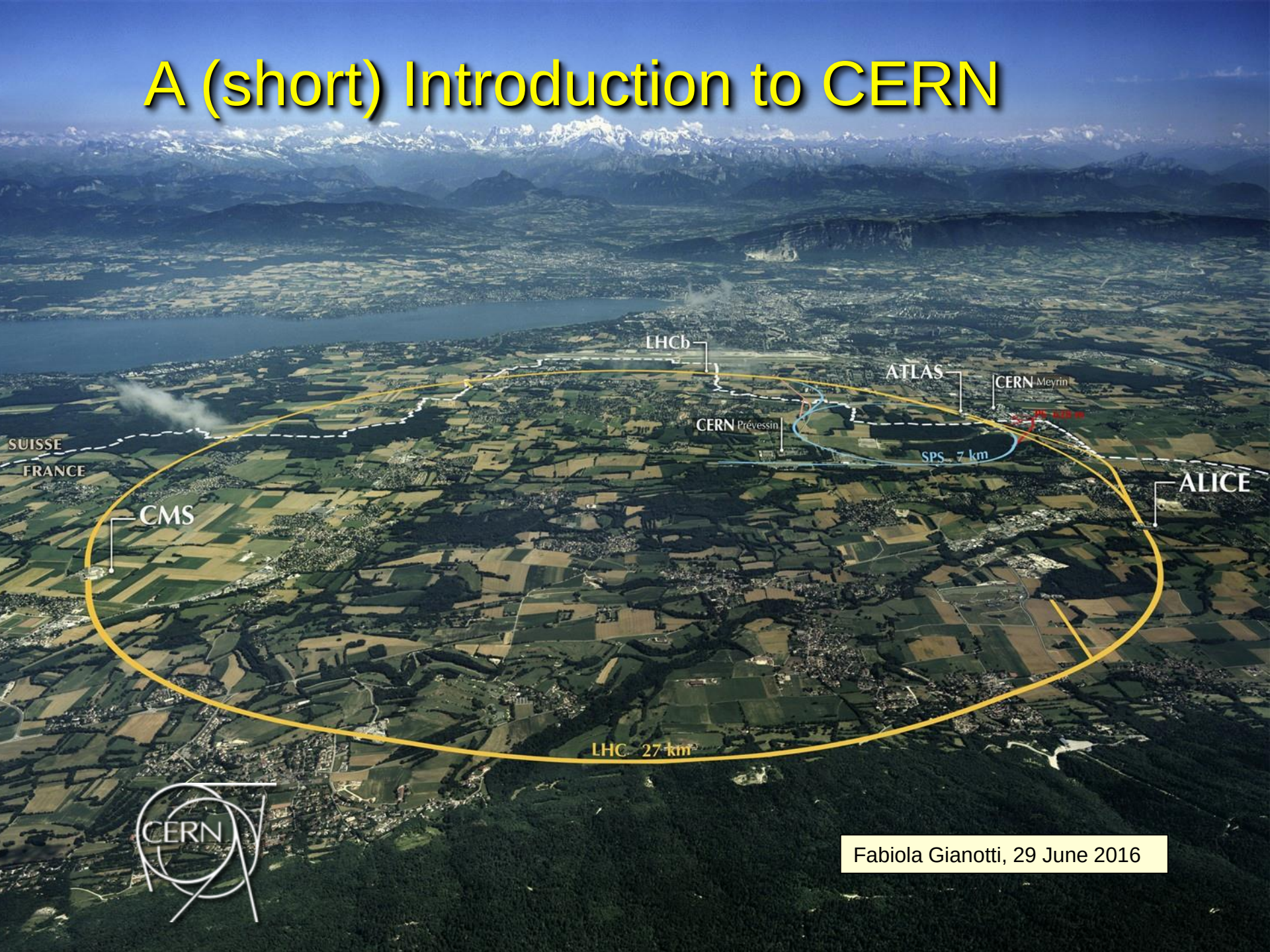
A (short) Introduction to CERN

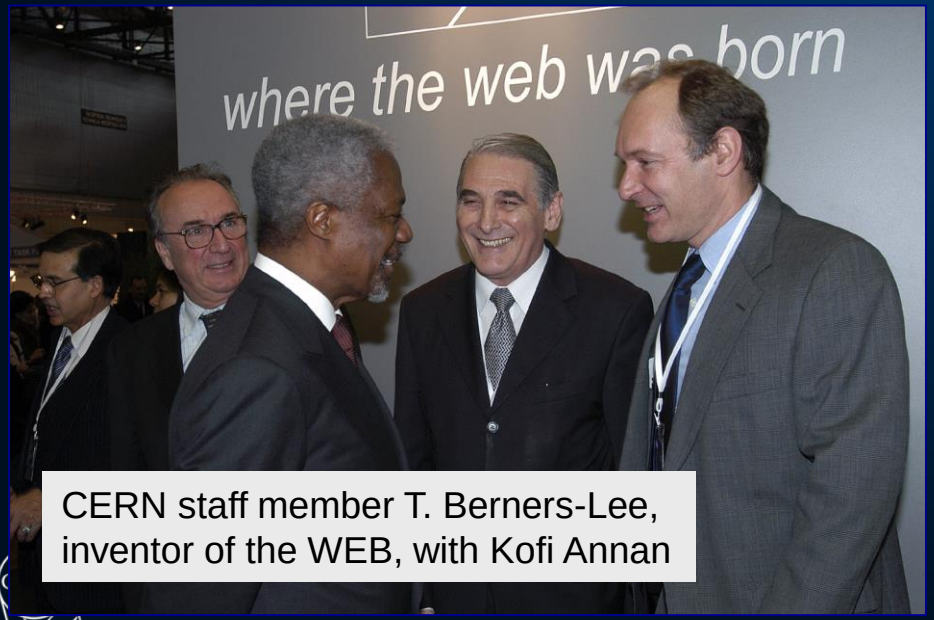


Fabiola Gianotti, 29 June 2016

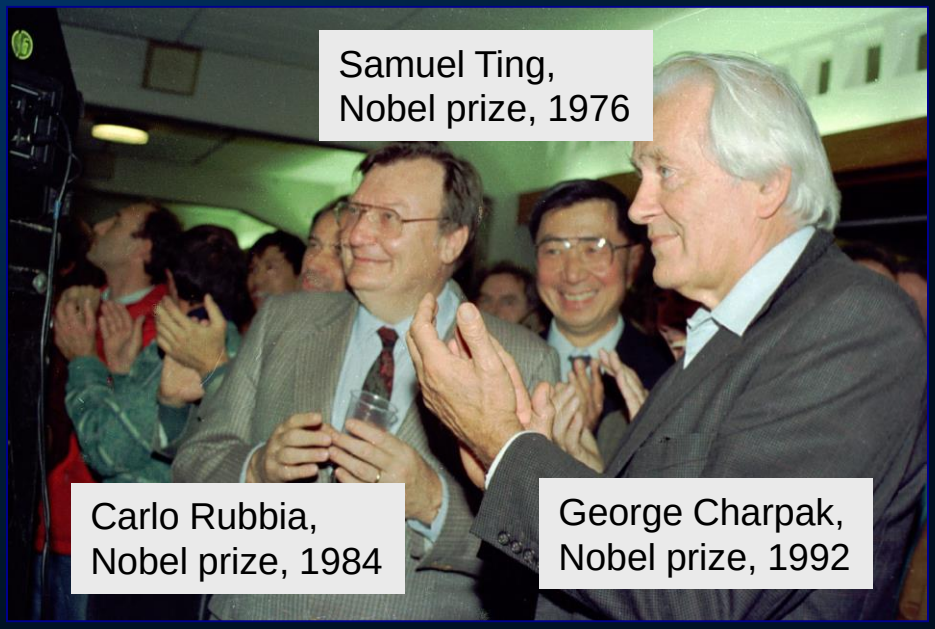
CERN: the largest particle physics laboratory in the world

Mission:

- science: fundamental research in particle physics
- technology and innovation → transferred to society (e.g. the World Wide Web)
- training and education
- bringing the world together: > 12000 scientists, > 110 nationalities



CERN staff member T. Berners-Lee, inventor of the WEB, with Kofi Annan



Samuel Ting, Nobel prize, 1976

Carlo Rubbia, Nobel prize, 1984

George Charpak, Nobel prize, 1992

CERN: founded in 1954: 12 European States
Today: 21 Member States

~ 3700 staff or paid personnel
~ 12300 scientific users

Budget (2016) ~1000 MCHF

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

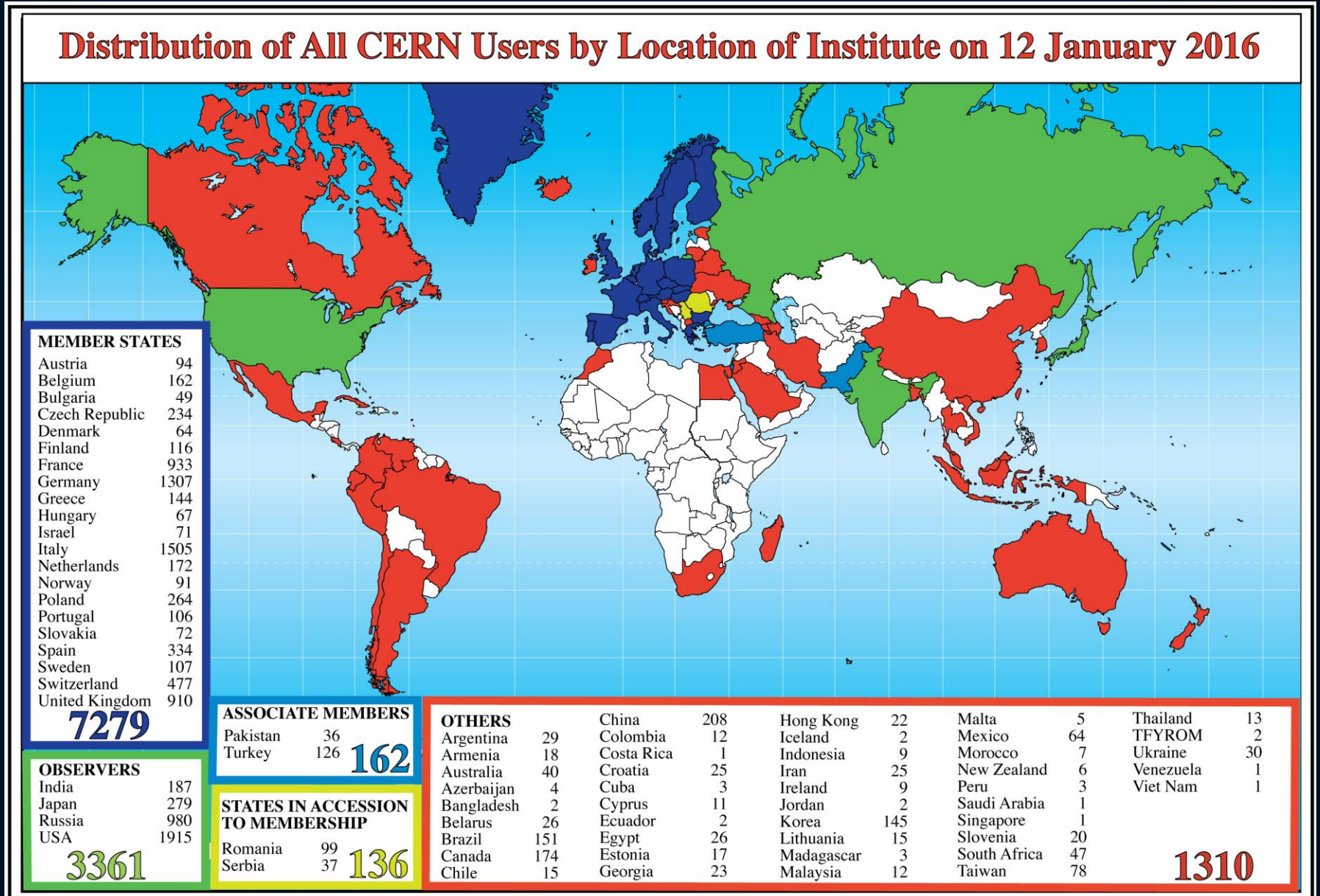
Associate Member States: Pakistan, Turkey

States in accession to Membership: Cyprus, Romania, Serbia

Applications for Membership or Associate Membership: Brazil, Croatia, India, Ireland, Russia, Slovenia, Ukraine

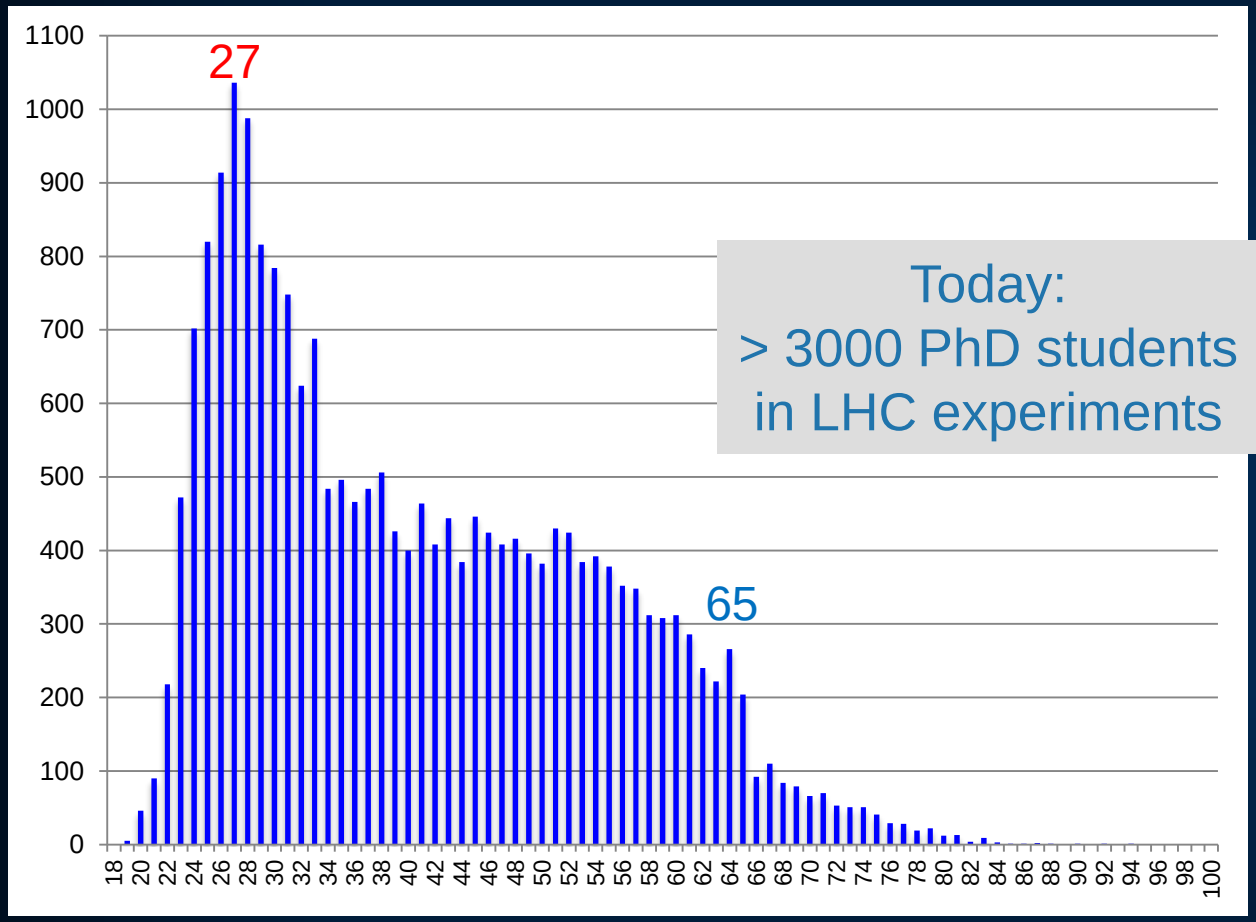
Observers to Council: India, Japan, Russia, United States of America; European Union, JINR and UNESCO

More than 12000 scientists from all over the world

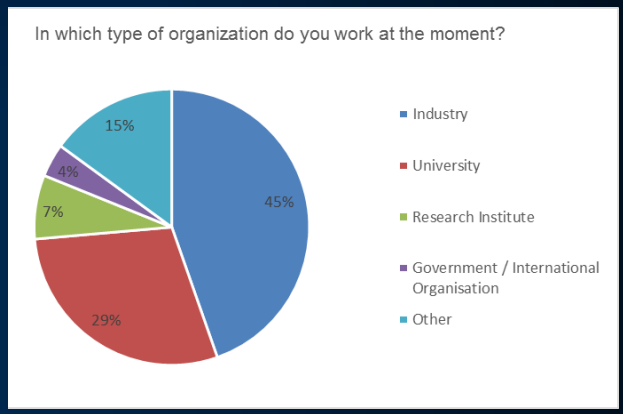


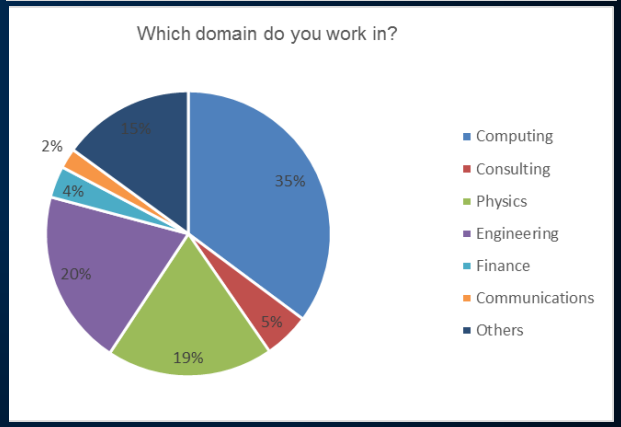
Age Distribution of Scientists

- and where they go afterwards



Today:
> 3000 PhD students
in LHC experiments

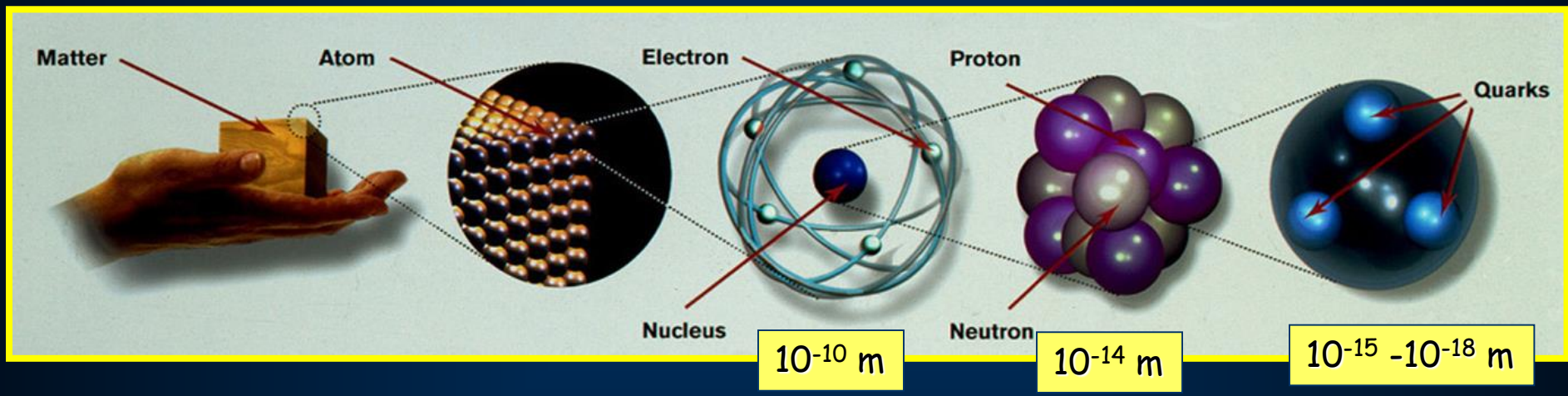




They do not all stay: where do they go?

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

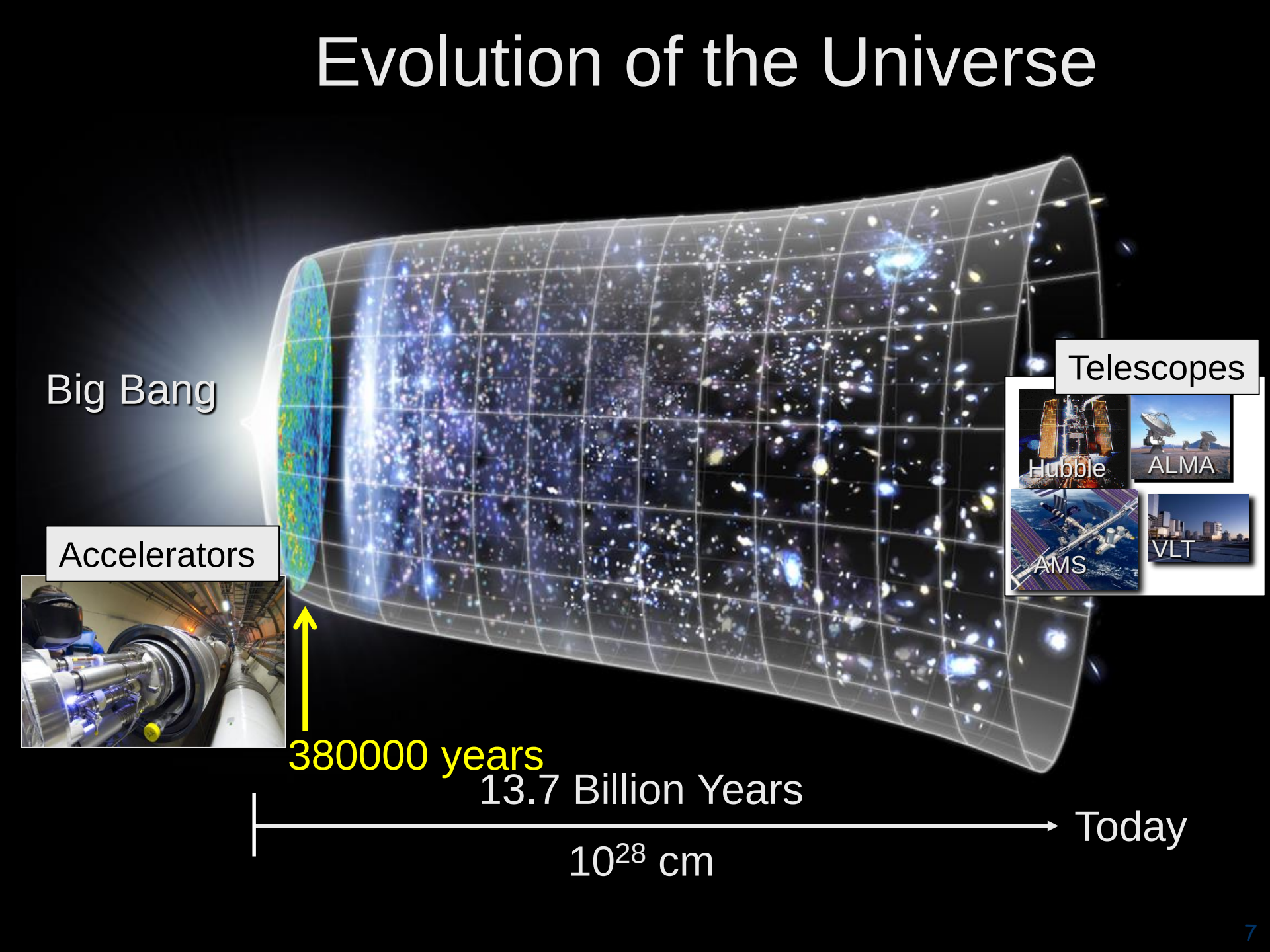


Particle physics at modern accelerators allows us to study the fundamental laws of nature on scales down to smaller than 10^{-18} m

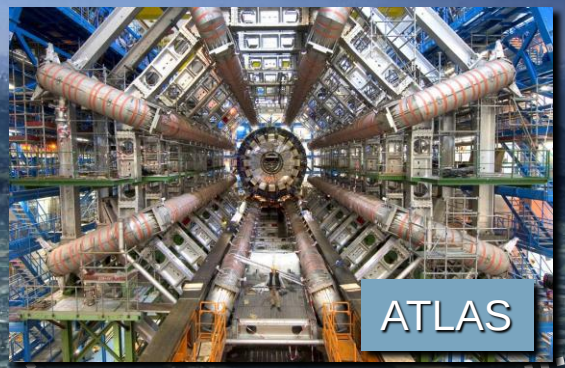
→ insight also into the structure and evolution of the Universe

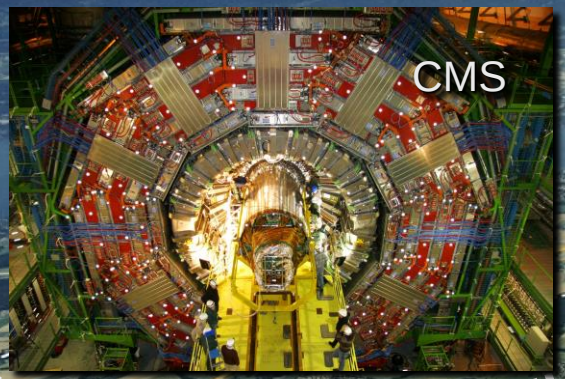
→ from the very small to the very big …

Evolution of the Universe

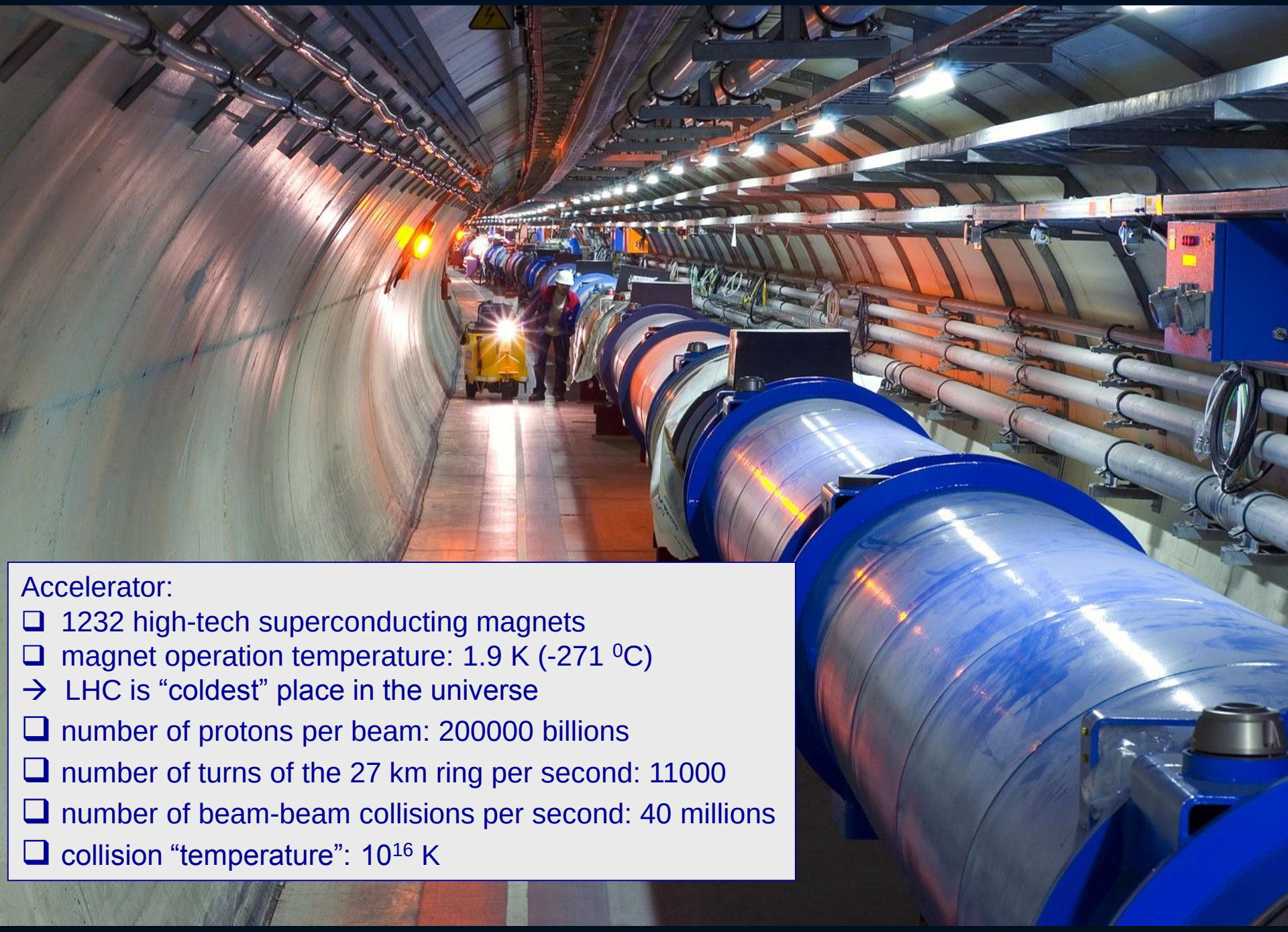


2010: a New Era in Fundamental Science





Exploration of a new energy frontier

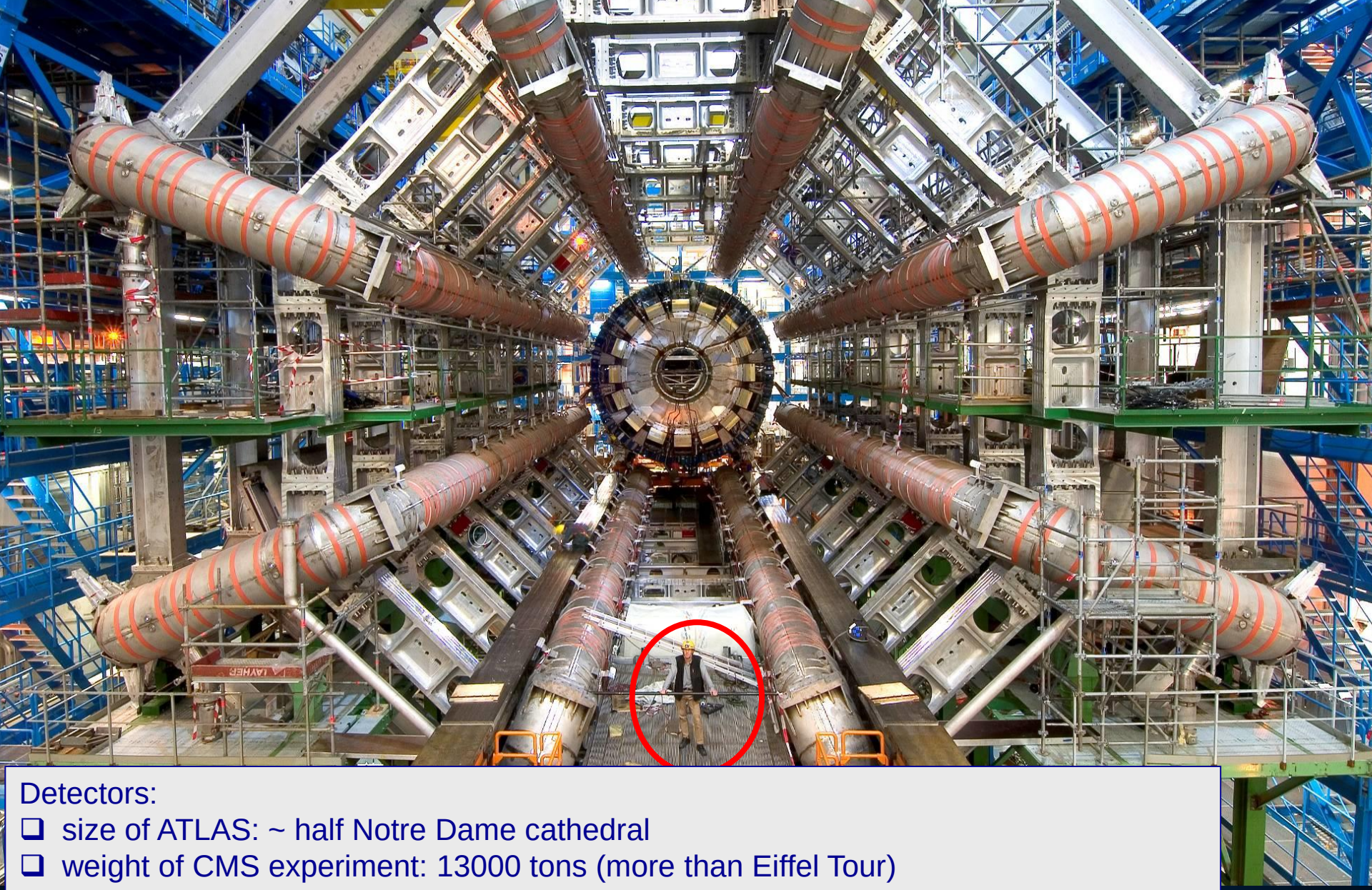


Accelerator:

- ❑ 1232 high-tech superconducting magnets
- ❑ magnet operation temperature: 1.9 K (-271 ^{0}C)

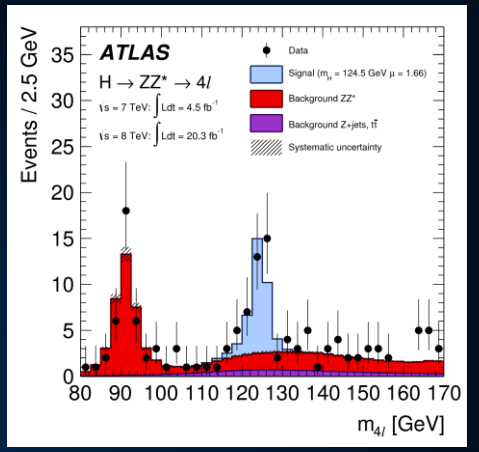
→ LHC is “coldest” place in the universe

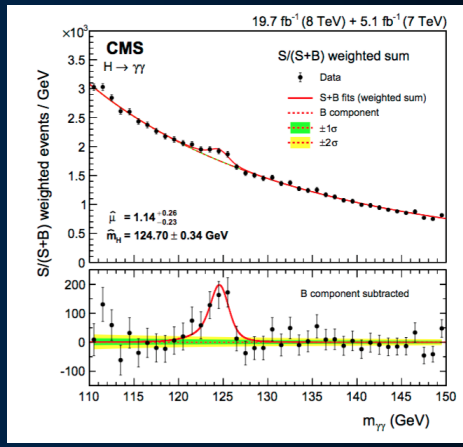
- ❑ number of protons per beam: 200000 billions
- ❑ number of turns of the 27 km ring per second: 11000
- ❑ number of beam-beam collisions per second: 40 millions
- ❑ collision “temperature”: 10^{16} K



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; more than YouTube, Twitter)



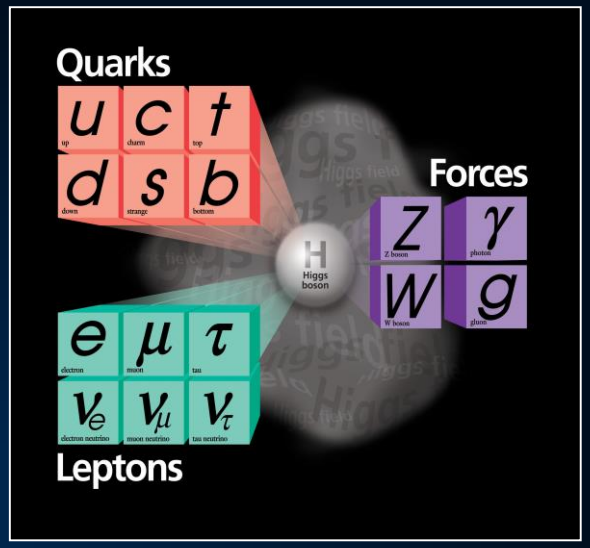


The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental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

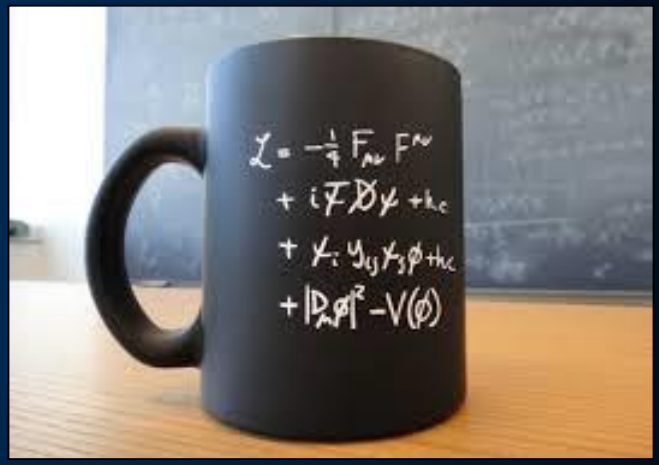
These are very exciting times in particle physics!

With the discovery of the Higgs boson,
we have completed the Standard Model
(> 50 years of theoretical and experimental efforts !)

Note: fermions (c, b, t, τ) discovered at accelerators in the US, bosons (g, W, Z, H) in Europe !



We have tested the Standard Model with very high precision (wealth of measurements since early '60s, in particular at accelerators)
→ it works BEAUTIFULLY (puzzling …)
→ no significant deviations observed (but difficult to accommodate non-zero neutrino masses)



However: the SM is not a complete theory of particle physics, as several outstanding questions remain (raised also by precise experimental observations) that cannot be explained within the SM.

These questions require NEW PHYSICS

Main questions in today's particle physics (a non-exhaustive list ..)

Why is the Higgs boson so light (so-called "naturalness" or "hierarchy" problem) ?

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

Why 3 fermion families ? Why do neutral leptons, charged leptons and quarks behave differently ?

What is the origin of neutrino masses and oscillations ?

What is the composition of dark matter (23% of the Universe) ?

What is the cause of the Universe's accelerated expansion (today: dark energy ? primordial: inflation ?)

Why is Gravity so weak ?

However: there is NO direct evidence for new particles (yet…) from the LHC or other facilities

Where is the NEW PHYSICS ???

i.e. at what E scale(s) will we find the answers to these questions?

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In the next 20 years the LHC (as well as other projects at CERN and elsewhere in the world) will try to address these and other questions

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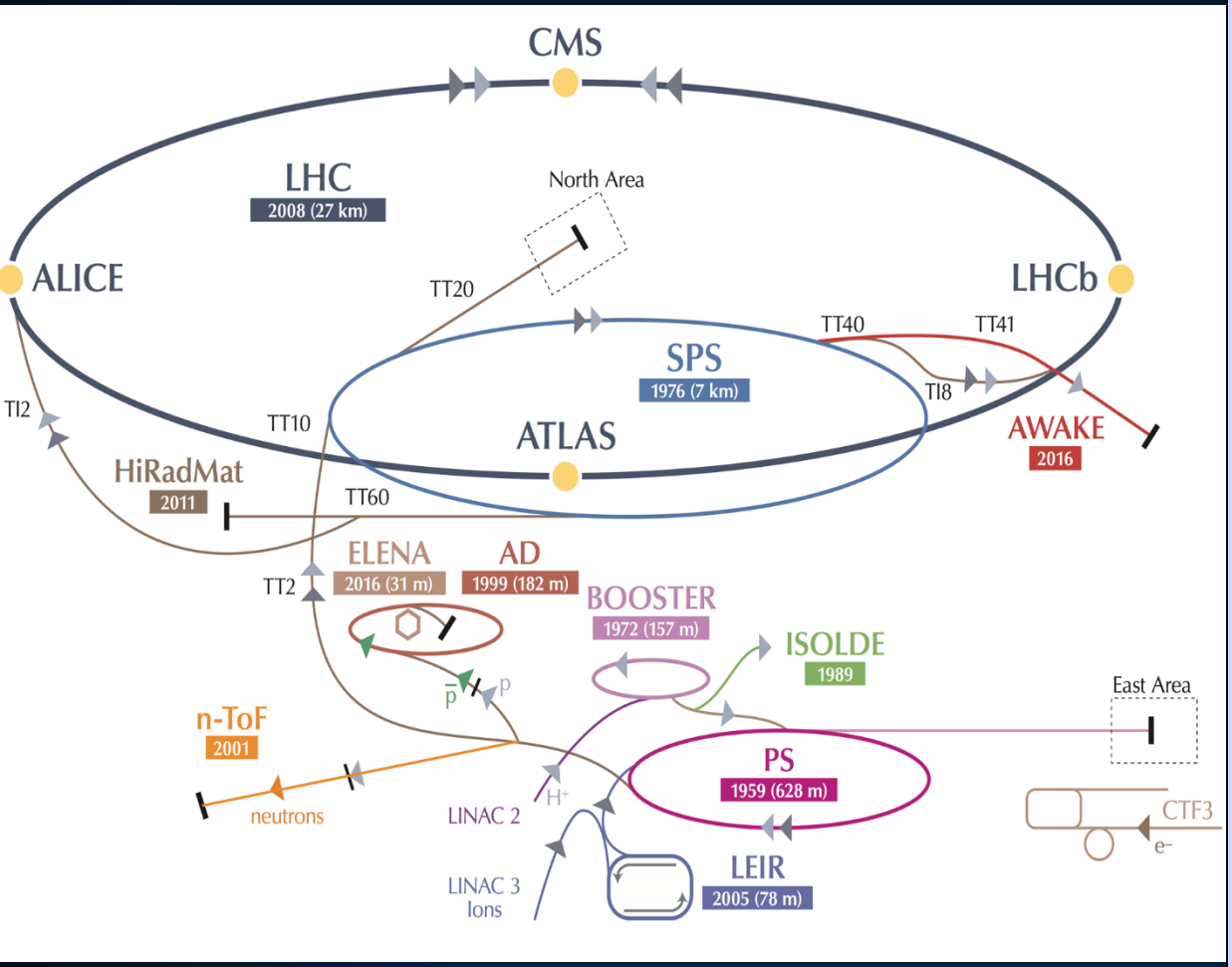
CERN scientific programme



Exploits unique capabilities of CERN's accelerator complex; complementary to other efforts in the world.

~20 projetcs 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

Neutrino Platform: collaborating with experiments in US and Japan

n-TOF: n-induced cross-sections

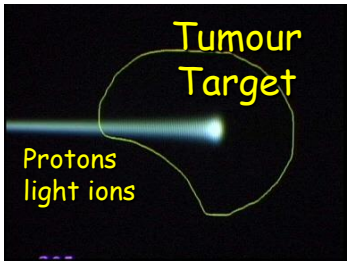
UA9: crystal collimation

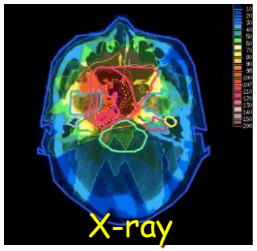
Etc.

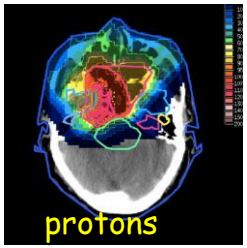
Complex, high-tech instruments needed in particle physics → cutting-edge technologies developed at CERN and collaborating Institutes → transferred to society

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

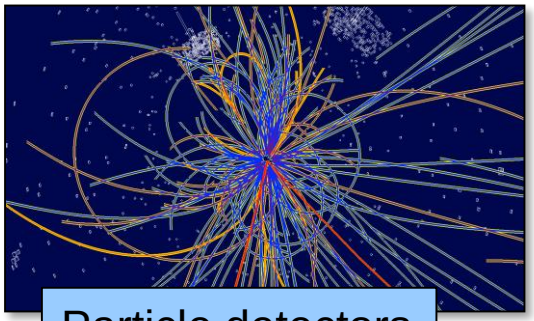
Hadron Therapy







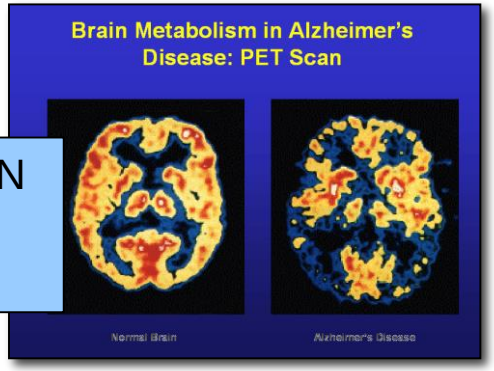
Particle accelerators: ~30'000 worldwide, of which ~17'000 used for medical applications



Particle detectors

Imaging

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



Have a nice stay at CERN!