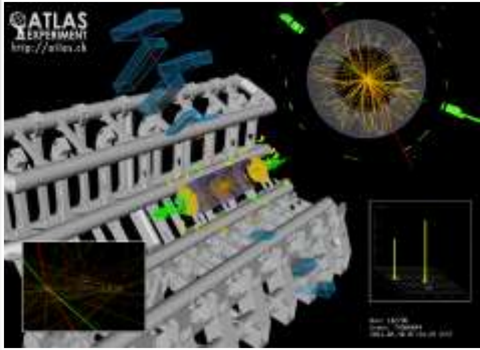
# Fundamental research (and much more) at CERN


Fabiola Gianotti (CERN)




# CERN : the largest particle physics laboratory in the world

International Organization based in Geneva

Mission:

- science: fundamental research in particle physics (many discoveries, e.g. Higgs boson)
- technology and innovation → transferred to society (e.g. the World Wide Web, medical applications)
- training and education → see C. Warakaulle's talk for human resources aspects
- bringing the world together: ~ 13000 scientists,  > 110 nationalities


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

Samuel Ting, Nobel prize, 1976

Carlo Rubbia, Nobel prize, 1984

George Charpak, Nobel prize, 1992

# CERN was founded in 1954: 12 European States
# Today: 22 Member States

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

**Associate Member States:** Cyprus, India, Pakistan, Serbia, Turkey, Ukraine

**Observers to Council:** Japan, **Russia**, USA, EU, JINR, UNESCO

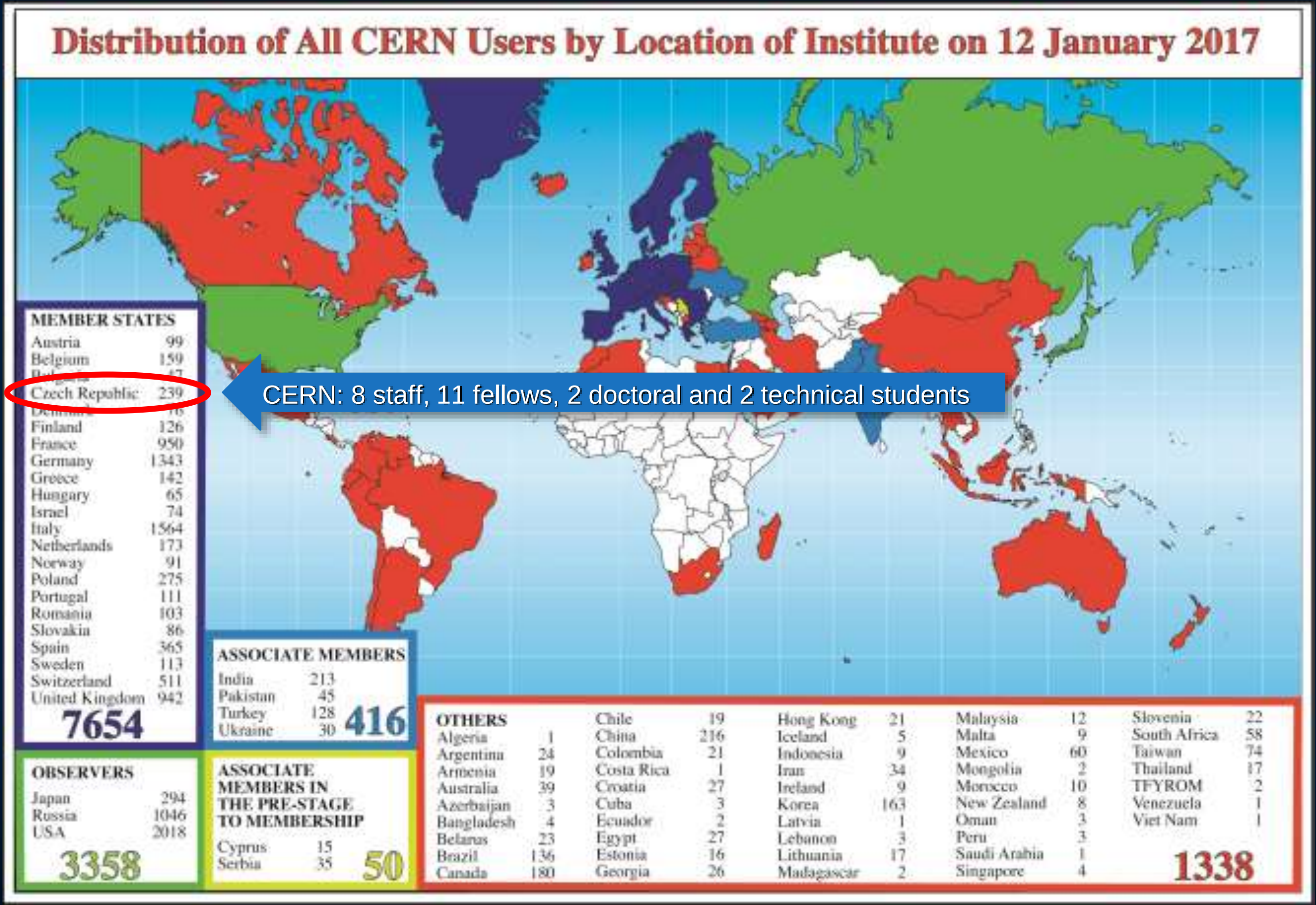
~ 2500 staff, 3700 on payroll

~ 13000 users

Budget (2016) ~1.1 BCHF (~ 1 cappuccino/year per European citizen):

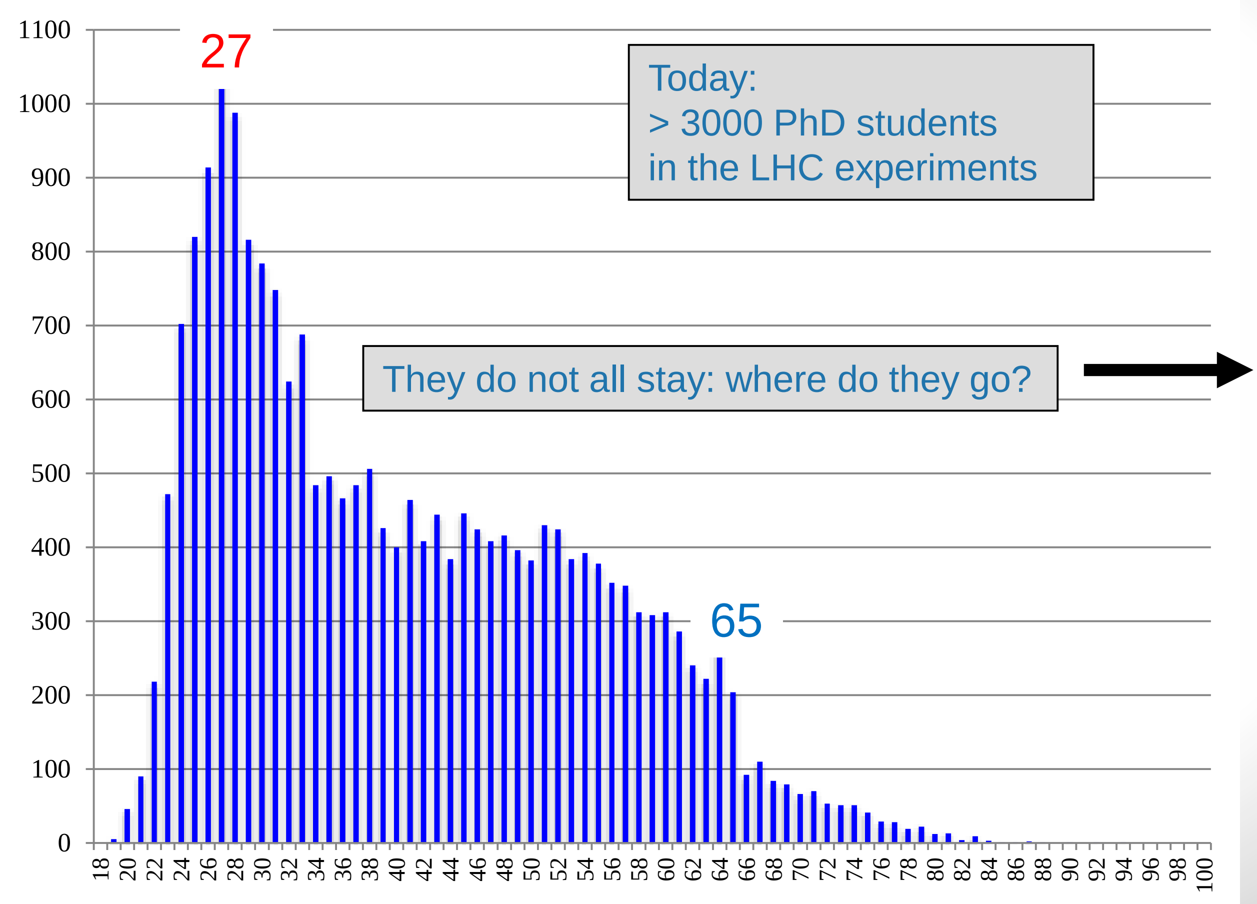
each Member State contributes in proportion to its income **(Czech Republic: ~ 0.9%)**

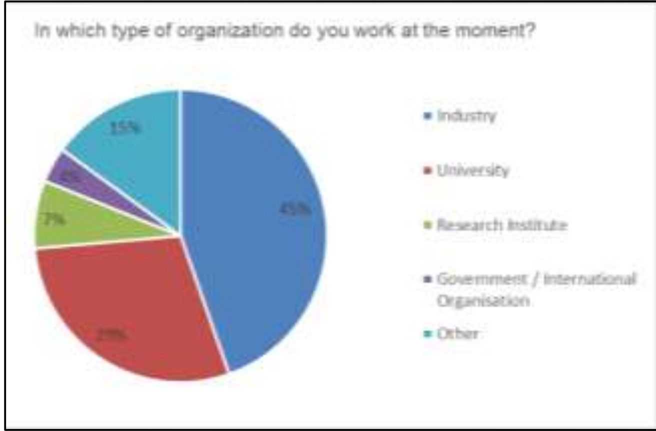
# Science is getting more and more global

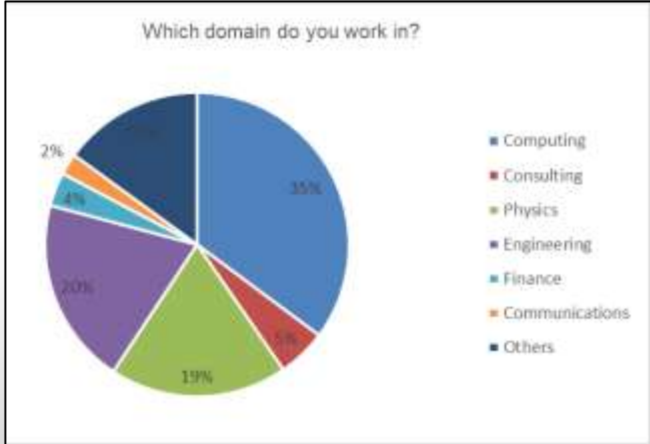


# Age distribution of scientists working at CERN

## - and where they go afterwards -



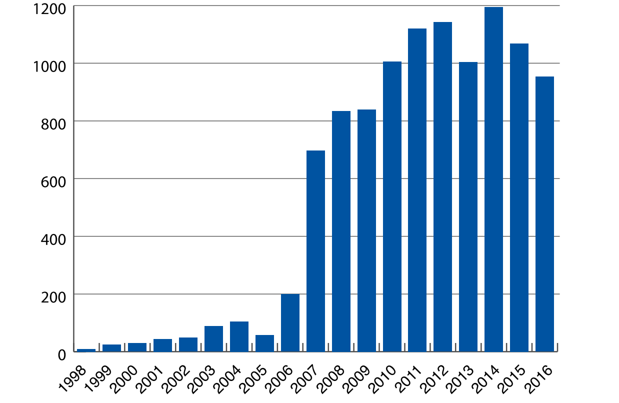
# CERN education activities

Europe/Russia School


Asia-Europe-Pacific School:
Japan 2012, India 2014,
China 2016

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

Teacher programme 1998-2016: total 10462 participants (Czech Republic: 155)




Latin American School:
Brazil 2011, Peru 2013,
Ecuador 2015,
Mexico 2017

African School:
South Africa 2010,
Ghana 2012,
Senegal 2014,
Rwanda 2016

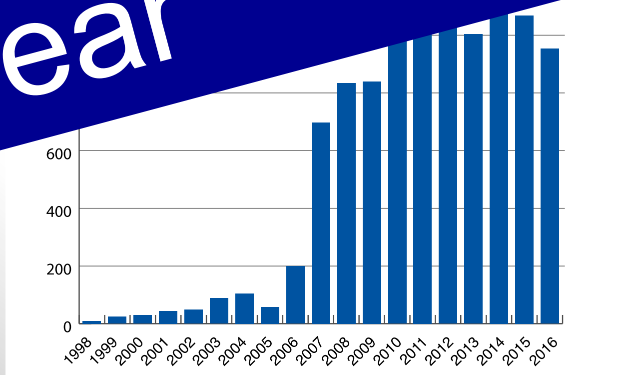
# CERN education activities

Europe/Russia School


Asia-Europe-Pacific School:
Japan 2012, India 2014,
China 2016

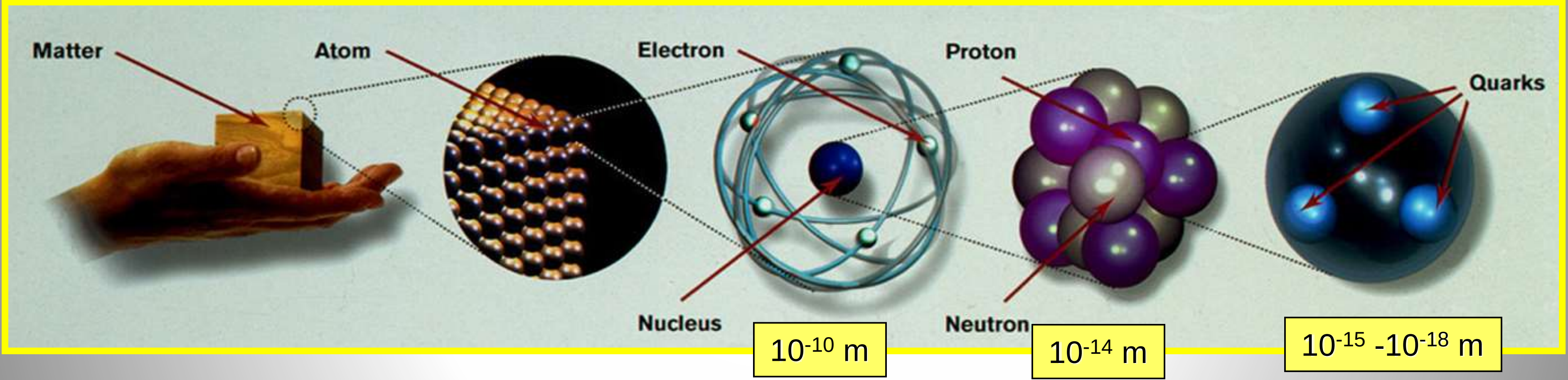
For young researchers
For physics/engi…
For hig…

And ~120'000 visitors every year




# 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



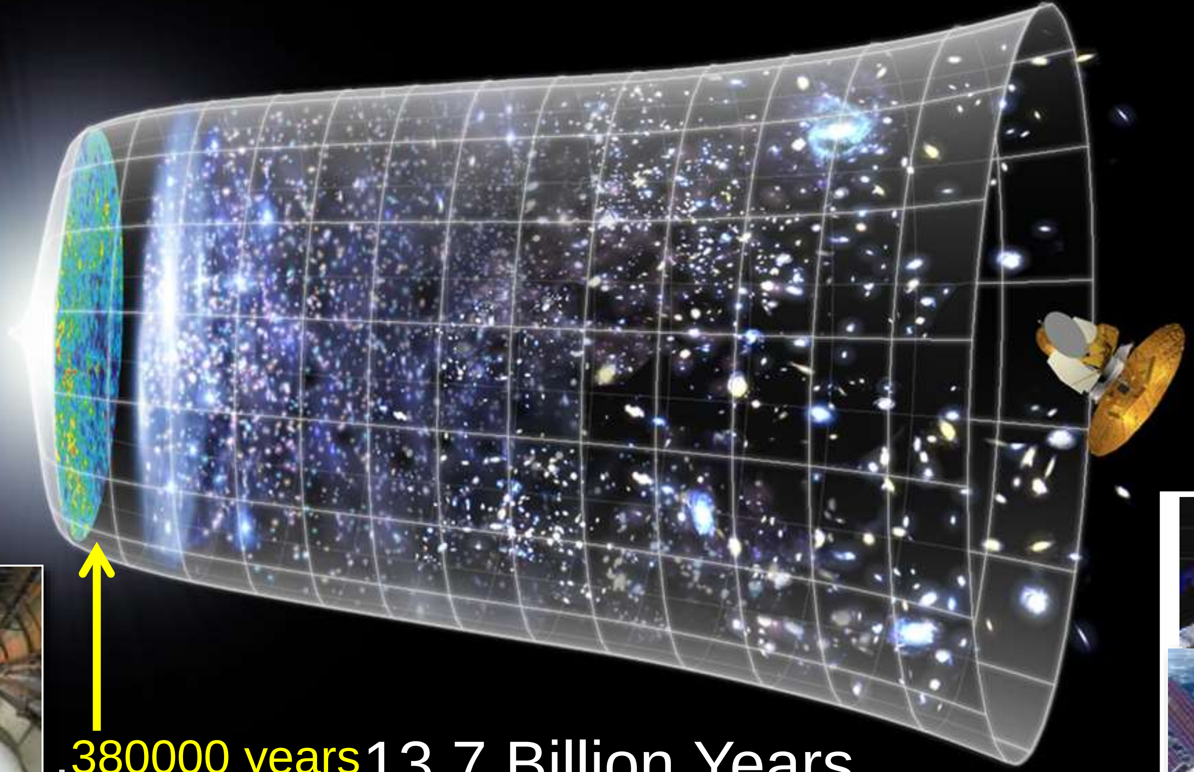

Particle physics at modern accelerators allows us to study the fundamental laws of nature on scales down to smaller than $10^{-18}$ m

→ insight also into the structure and evolution of the Universe

→ from the very small to the very big …

# Evolution of the Universe

Big Bang



380000 years

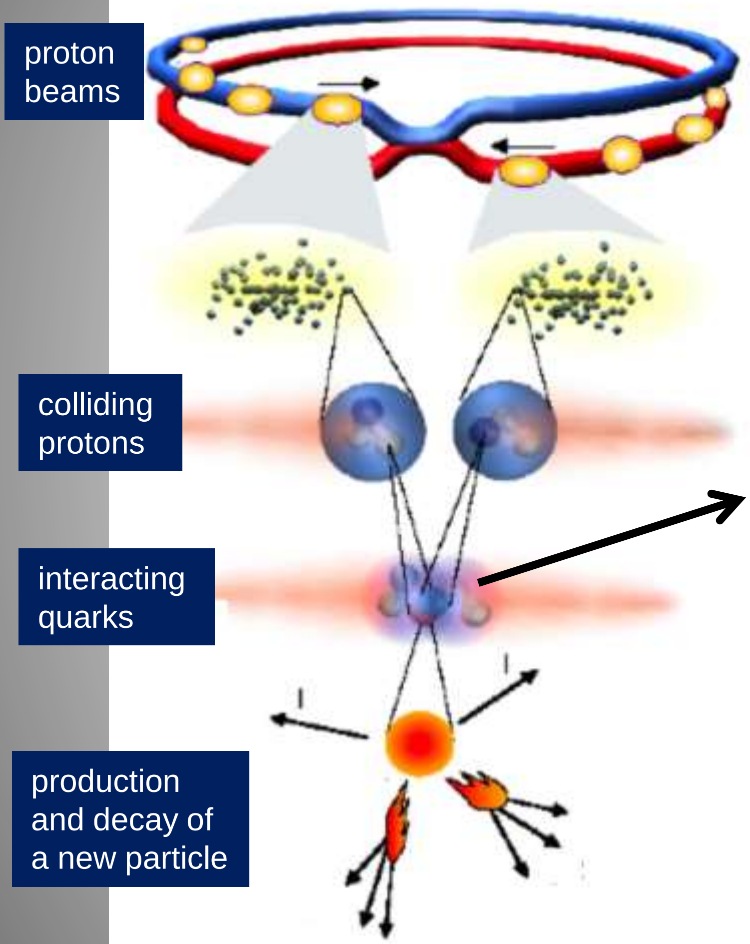
13.7 Billion Years

$10^{28}$ cm

Accelerators

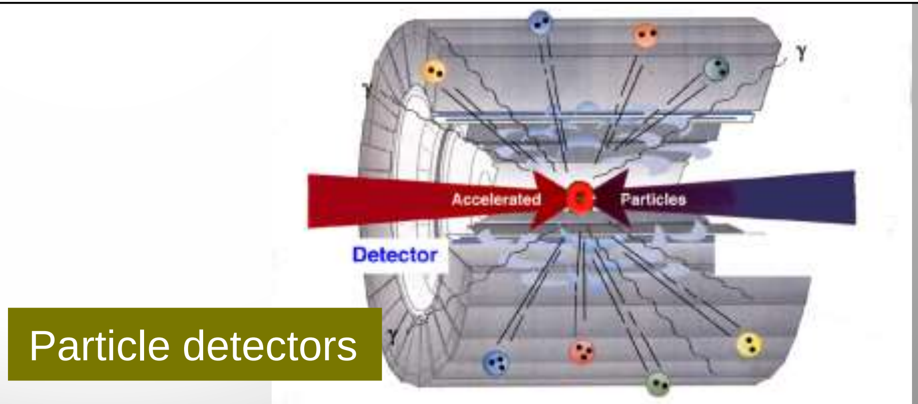
Telescopes

# To study the elementary particles and their interactions



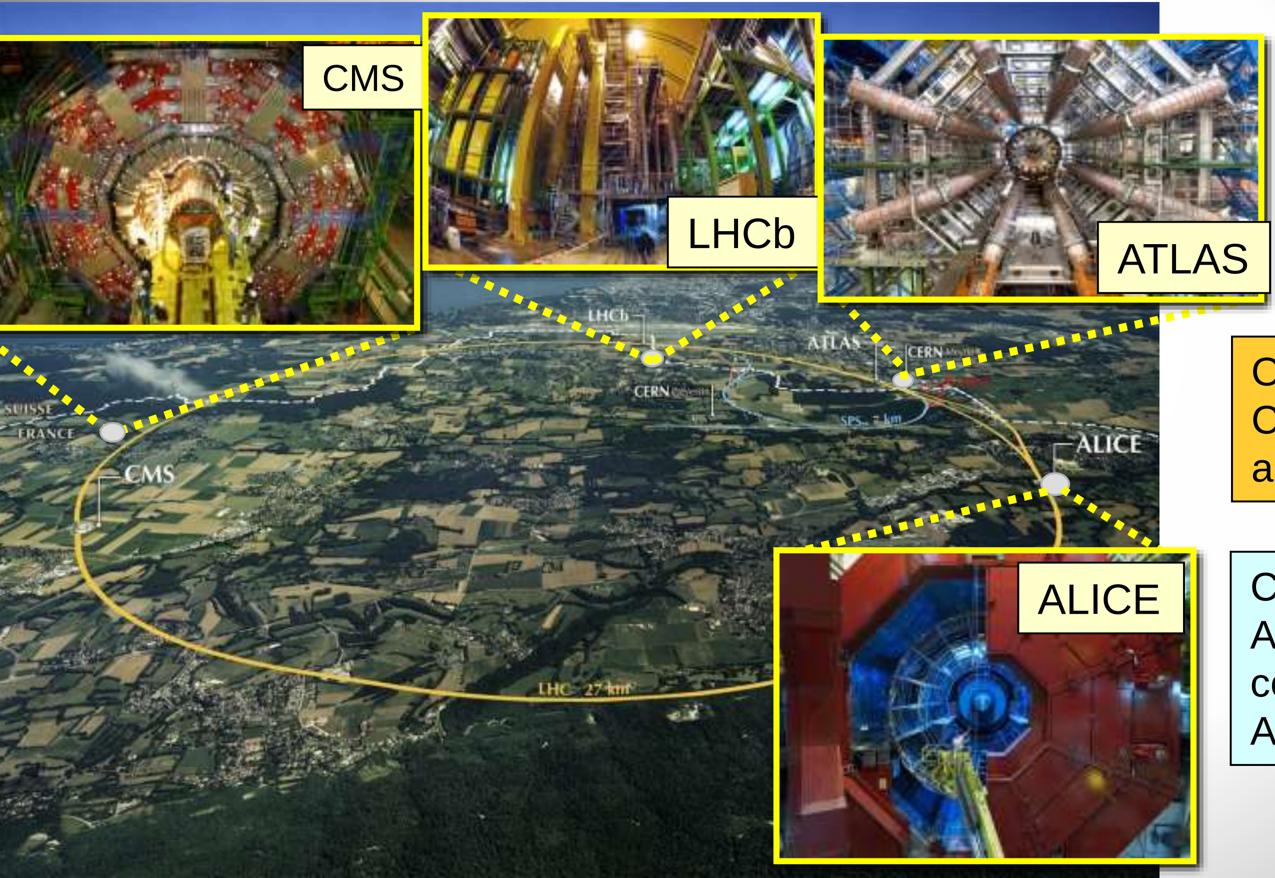


- → study fundamental constituents of matter
- → produce (new) heavy particles
- → collision energy = temperature of universe $10^{-12}$ s after Big Bang



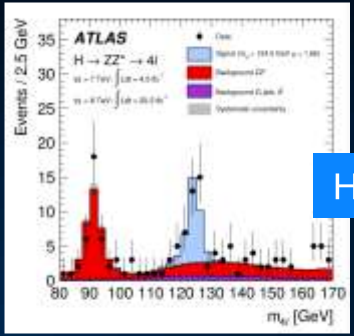
The Large Hadron Collider (LHC): the most powerful accelerator ever

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

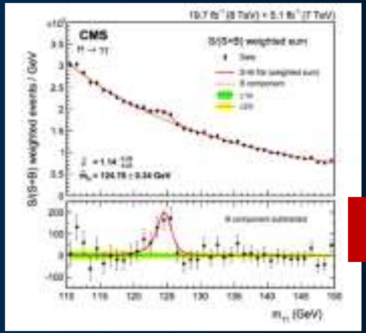



On 4th July 2012, ATLAS and CMS announced the discovery of a new particle: the Higgs boson

Czech Universities and Institutes of Academy of Sciences have contributed in a **crucial way** to ALICE and ATLAS

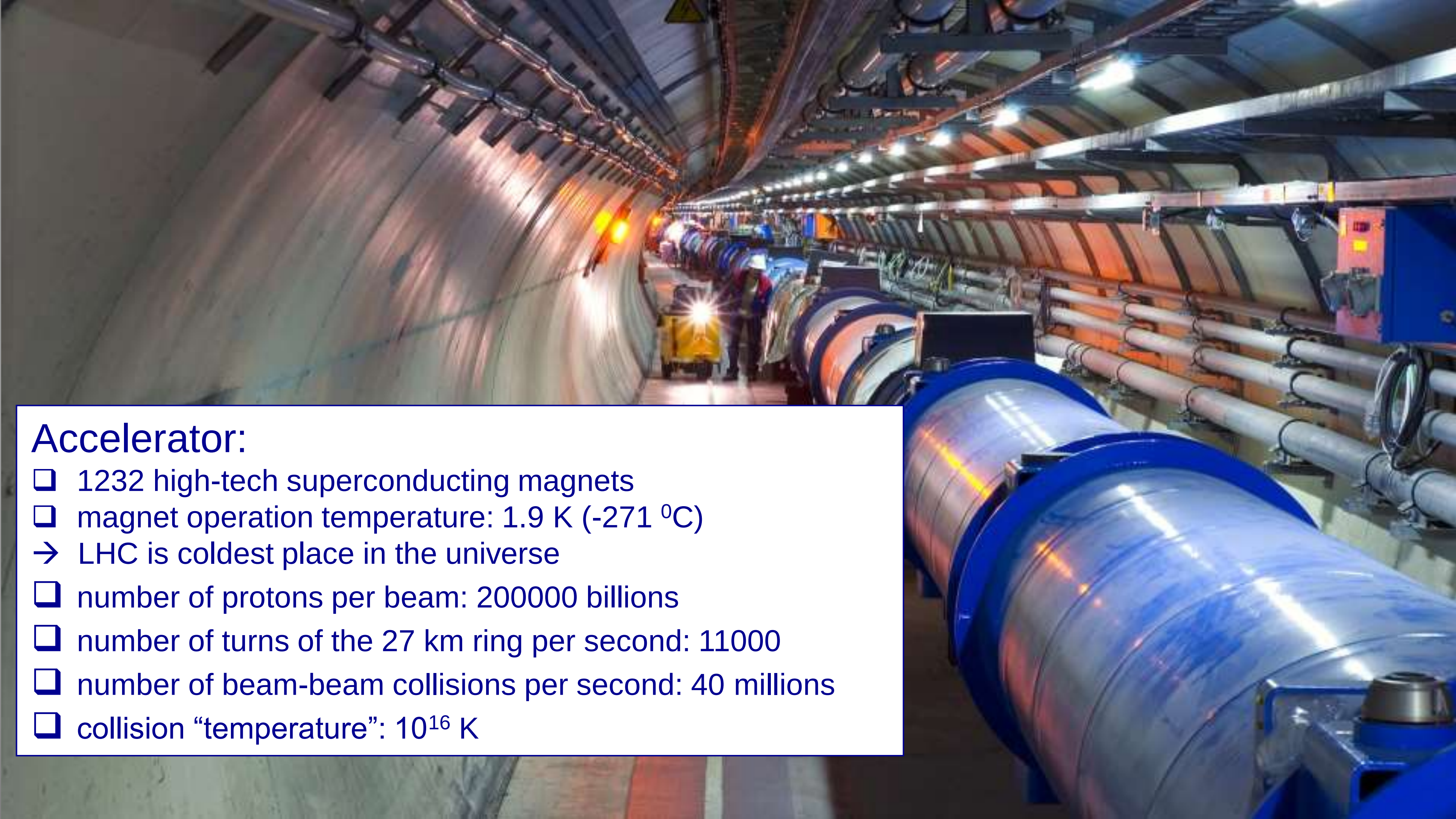



H→ 4l



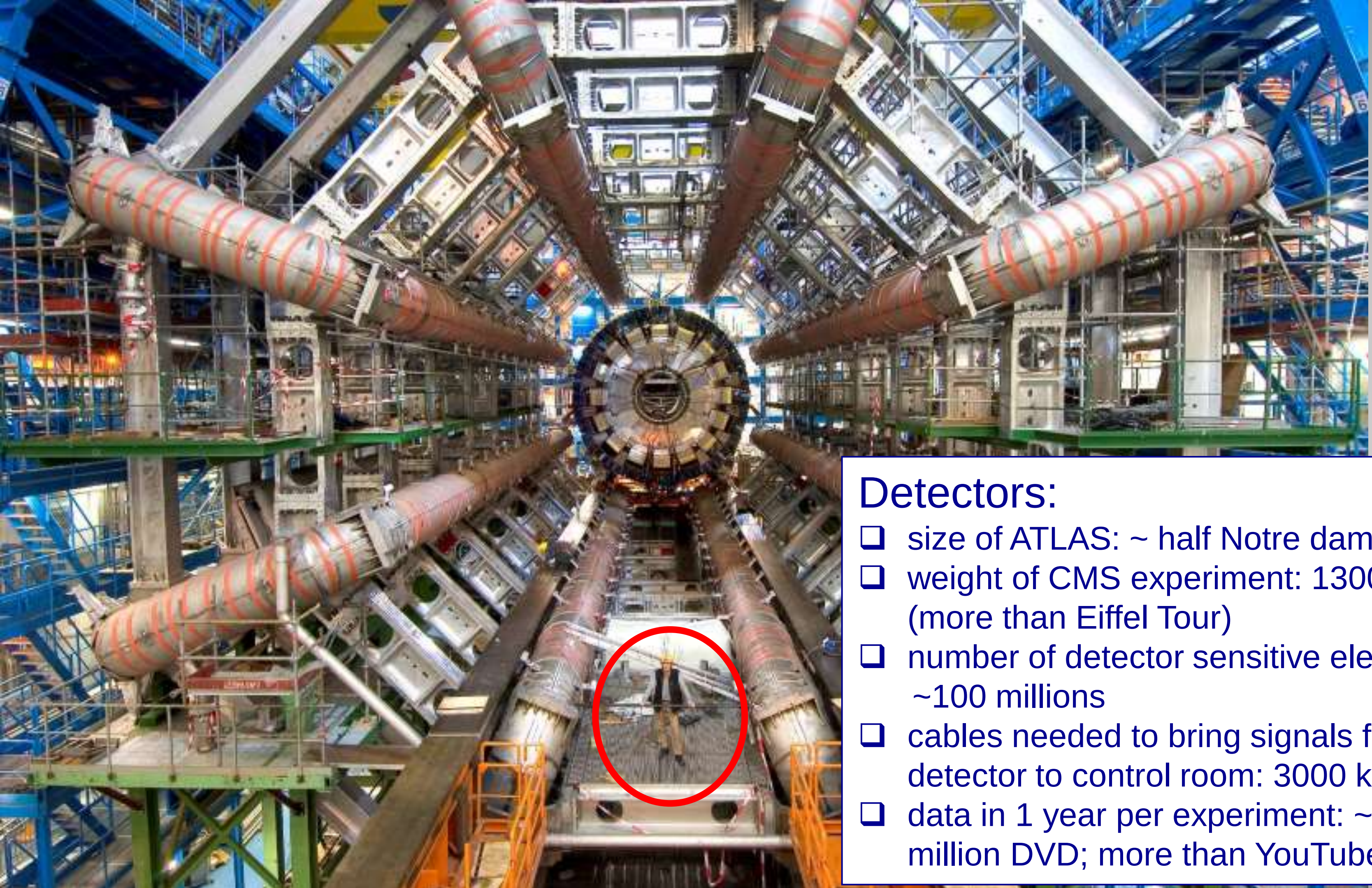

H→ γγ

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".*



# 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
- 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)

# 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 $\mu$s after the Big Bang ?

Are there other forces in addition to the known four ?

Etc. etc.

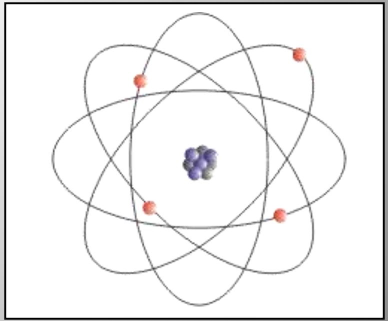
# The fundamental role of the Higgs boson

Before the discovery of the Higgs boson at the LHC in 2012 we didn’t know how the elementary particles get their masses


Proposed mechanism (Brout, Englert, Higgs et al., 1964): origin of masses ~ $10^{-11}$ s after the Big Bang, when the “Higgs field” permeated the universe → particles acquired masses proportional to their interactions with the Higgs field

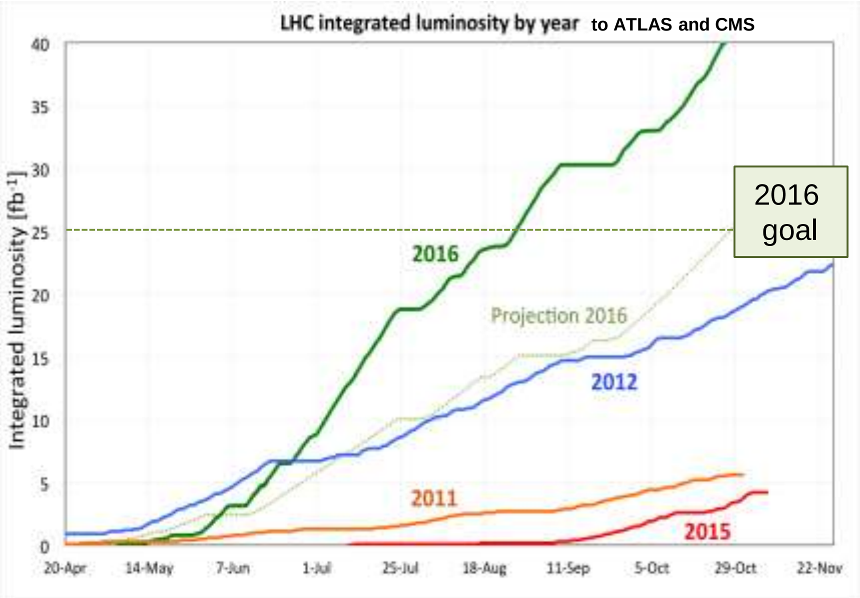
Consequence of the BEH theory: existence of the Higgs boson. This particle has been searched for > 30 years at accelerators all over the world → finally found at the LHC in 2012
→ 2013 Physics Nobel Prize to F. Englert and P. Higgs

Note: a world without Higgs boson would be very strange. If electrons and quarks had no mass, atoms would not exist
→ universe would be very different



# Since then: great progress

- As of 2015, LHC moved from $\sqrt{s}$ = 8 TeV to $\sqrt{s}$ = 13 TeV
- Achieved peak luminosity: ~ 1.5 x $10^{34}$ $cm^{-2}$ $s^{-1}$ (beyond design value)
- Total integrated luminosity to ATLAS and CMS in 2016: ~ 40 $fb^{-1}$




- Physics programme includes precise measurements of the Higgs boson and searches for new physics
- This is only the beginning as LHC will operate until ~ 2035 through several upgrades → projected total integrated luminosity: ~ 3000 $fb^{-1}$

Experiments and computing also running very efficiently → many beautiful physics results produced quickly

# CERN's scientific strategy (based on European Strategy for Particle Physics ): three pillars

Full exploitation of the LHC:

- successful operation of the nominal LHC (Run 2, LS2, Run 3)
- construction and installation of LHC upgrades: LIU (LHC Injectors Upgrade) and HL-LHC

Scientific diversity programme serving a broad community:

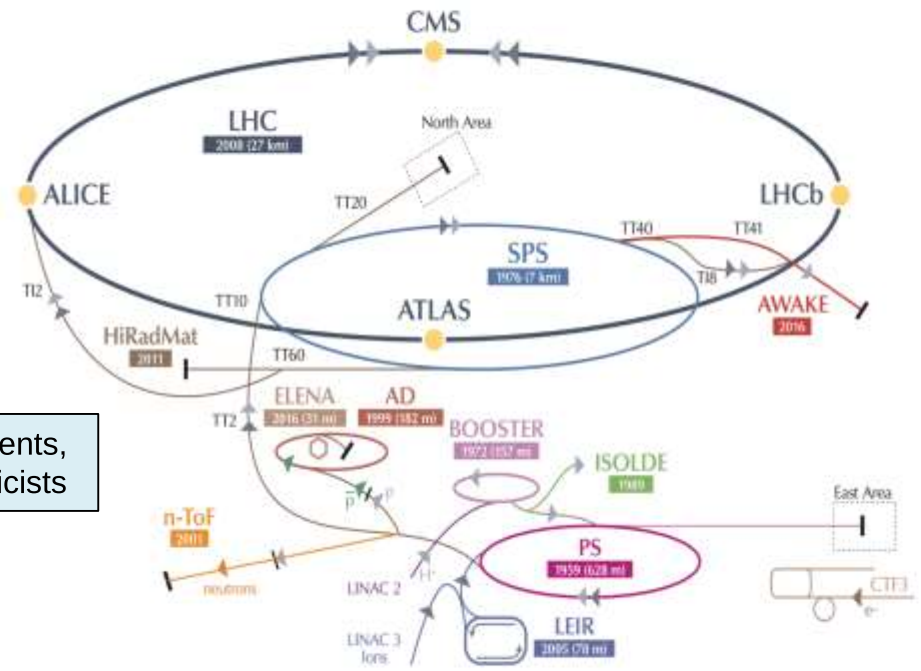
- ongoing experiments and facilities at Booster, PS, SPS and their upgrades (ELENA, HIE-ISOLDE)
- participation in accelerator-based neutrino projects outside Europe (presently mainly LBNF in the US) through CERN Neutrino Platform

Preparation of CERN's future:

- vibrant accelerator R&D programme exploiting CERN's strengths and uniqueness (including superconducting high-field magnets, AWAKE, etc.)
- design studies for future accelerators: CLIC, FCC (includes HE-LHC)
- future opportunities of diversity programme (new): "Physics Beyond Colliders" Study Group

Important milestone: update of the European Strategy for Particle Physics (ESPP): to be completed in May 2020

# CERN's scientific diversity programme




~20 experiments,
> 1200 physicists

Red: projects involving Czech groups

**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

**NA61/Shine**: heavy ions and neutrino targets

**NA62**: rare kaon decays

**NA63**: radiation processes in strong EM fields

**NA64**: search for dark photons

**Neutrino Platform: ν** detectors R&D for experiments in US, Japan

**n-TOF:** n-induced cross-sections

**UA9**: crystal collimation

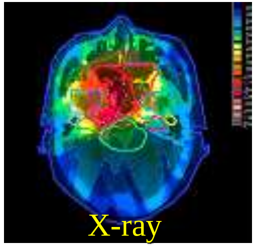
Will the Higgs boson change our life ?

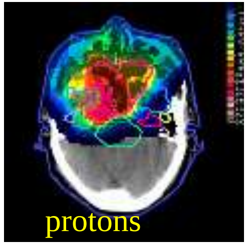
It already has !

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

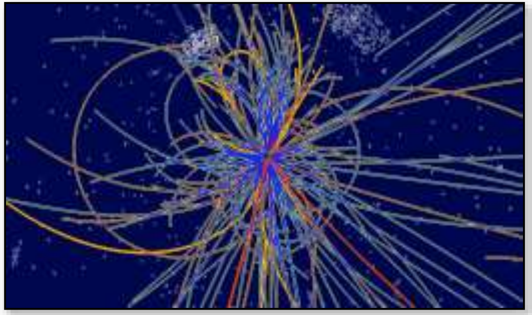
Examples of applications: medical imaging, cancer therapy, solar panels, materials science, airport scanners, cargo screening, food sterilization, nuclear waste transmutation, analysis of historical relics, etc. etc.  … not to mention the WEB …

## Hadron Therapy


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



## Imaging

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

# Czech Republic and CERN

The Czech Republic became CERN Member State in 1992
and in 1993 as an independent State
Today: strong involvement in the LHC experimental programme
ATLAS, ALICE, Totem, Moedal

**ALICE:**
3 Institutes
~ 35 members

**ATLAS:**
4 Institutes
~ 130 members


**Totem** **(next to CMS)**
3 Institutes
~ 12 members

Innovative technologies developed

A high performance Tier-2 centre is operated in Prague
Other experiments: AeGiS, COMPASS, DIRAC,OSQAR, NA62,  nTOF


LHCb
ATLAS
CERN
CERN
SUISSE
FRANCE
SPS 7 km
ALICE
CMS
Thank You!
Děkuji Vám!
LHC 27 km
Accelerating Science and Innovation