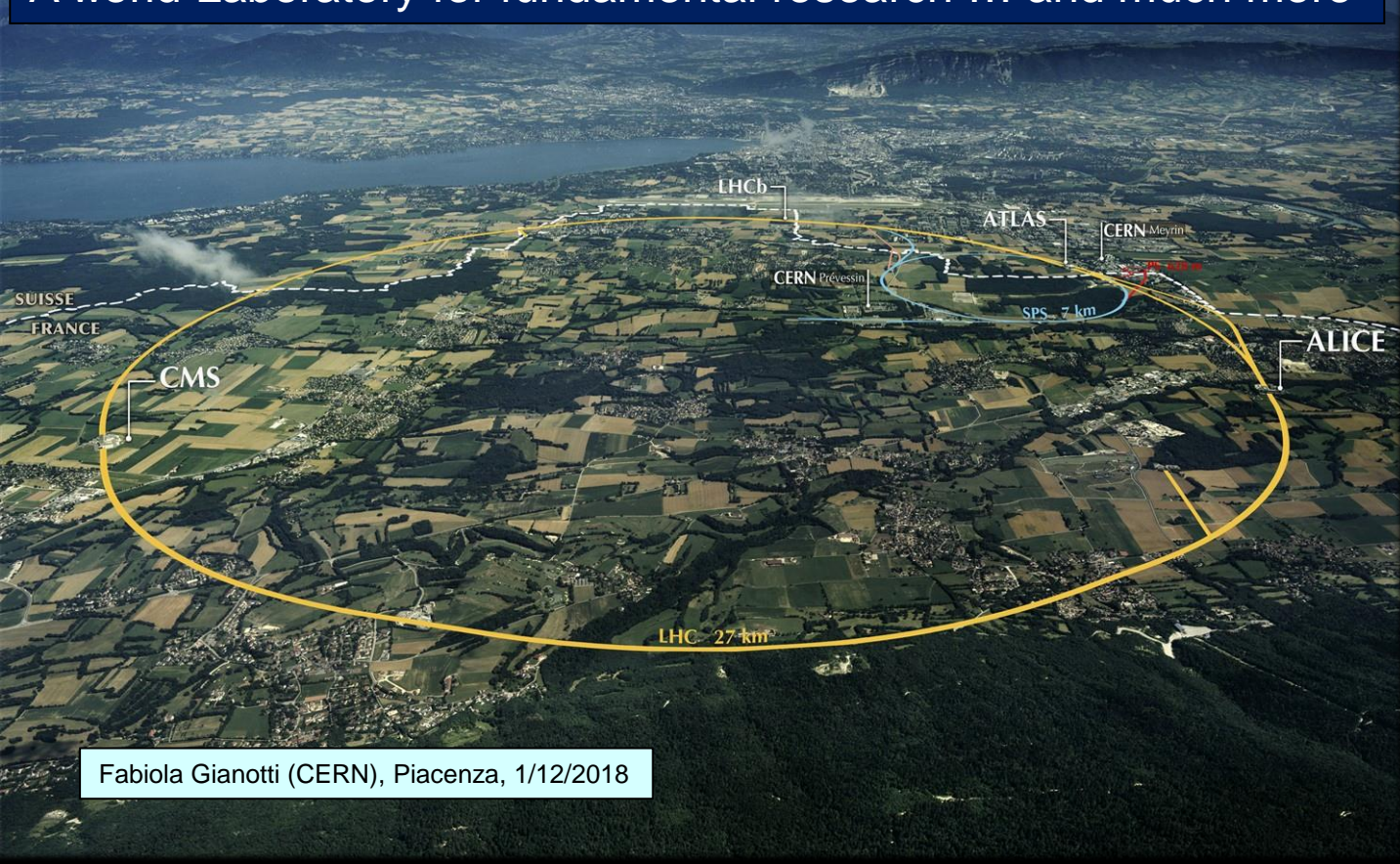
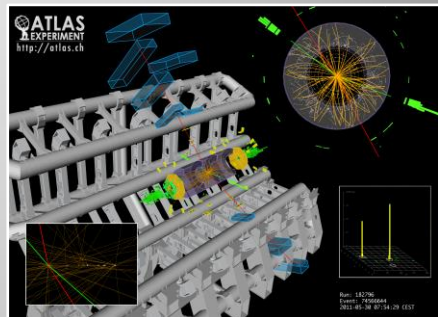


# CERN

A world Laboratory for fundamental research ... and much more



Fabiola Gianotti (CERN), Piacenza, 1/12/2018





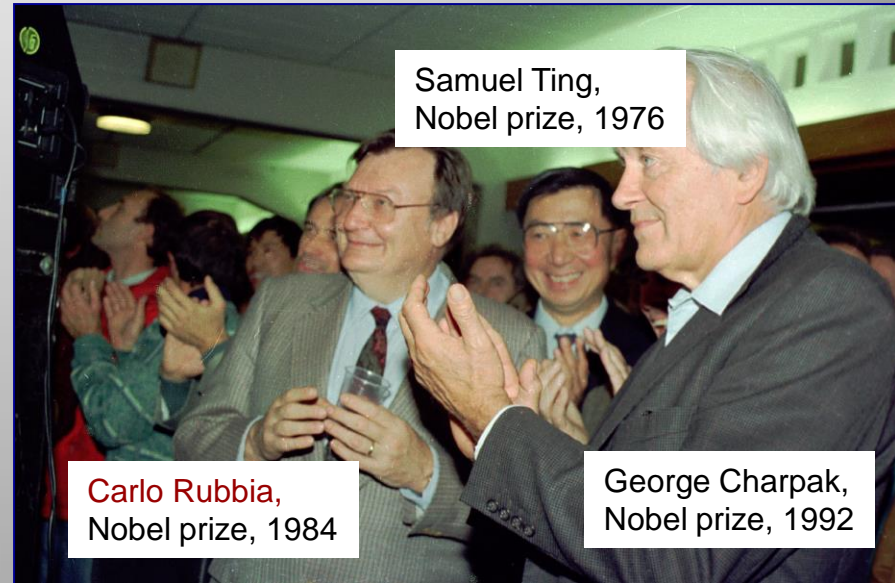
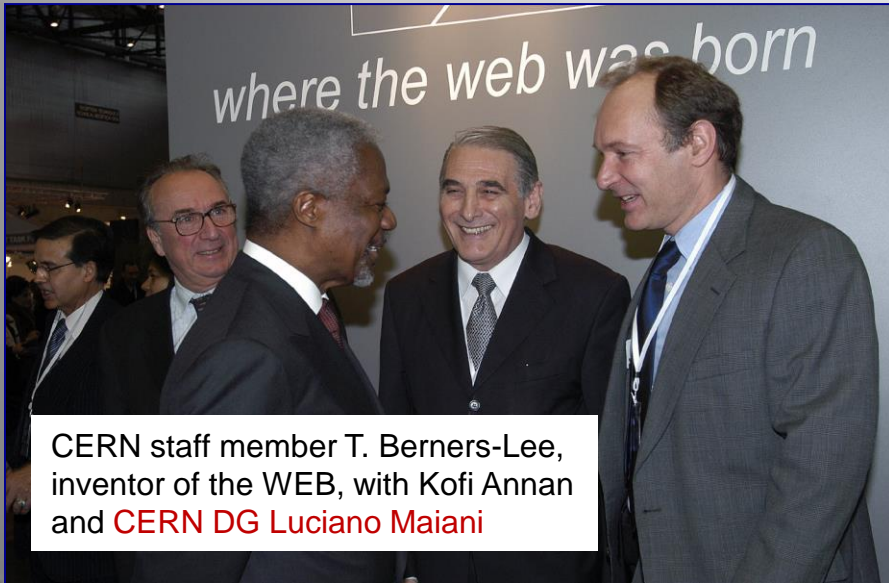
# CERN : the largest particle physics laboratory in the world



International Organization based in Geneva

## Mission:

- ❑ science: fundamental research in particle physics (discoveries, e.g. Higgs boson, Nobel prizes)
- ❑ technology and innovation → transferred to society (e.g. the World Wide Web, medical applications)
- ❑ training and education
- ❑ bringing the world together: ~ 17000 scientists, > 110 nationalities







# CERN was founded in 1954: 12 European States

(One of the founding fathers: Edoardo Amaldi)

Today: 22 Member States

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

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

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

~ 2300 staff, 3700 in total on payroll

~ 13000 users from all over the world

**Budget (2018) ~1100 MCHF** (on average: ~ 1 cappuccino/year per European citizen):

each Member State contributes in proportion to its income.

**Italy: ~ 10.5% (~ 120 MCHF) → return ~ 45 MCHF in industrial supplies and services**



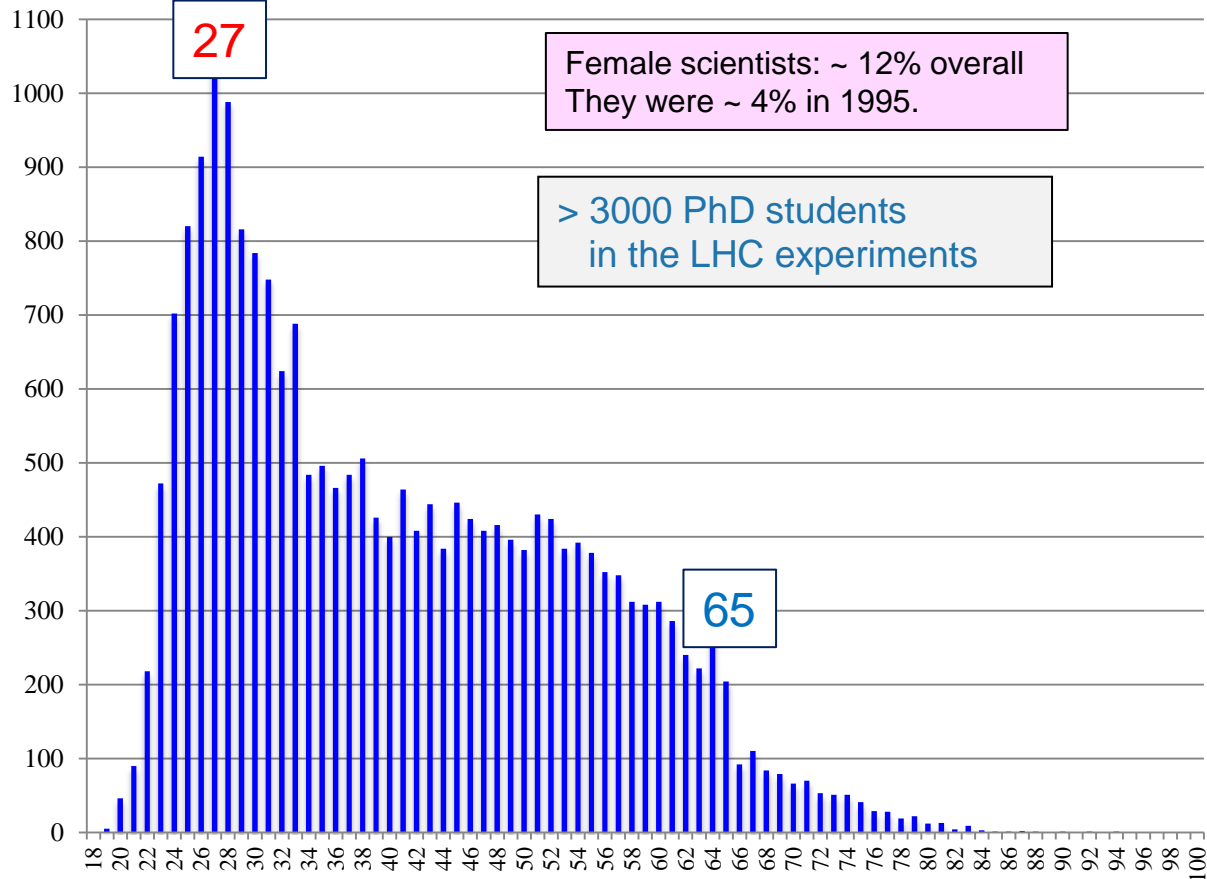
# Distribution of All CERN Users by Nationality on 24 January 2018



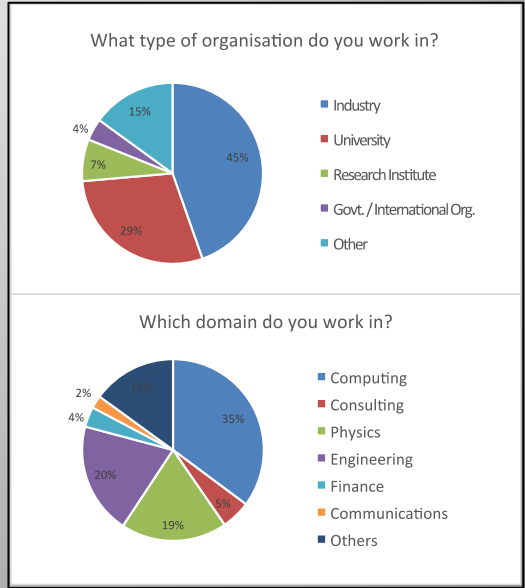
Science is becoming more and more global



# Age distribution of scientists working at CERN



Only ~10% of the students stay in particle physics.  
Where to the others go?



CERN/JINR  
European School  
of HEP  
Maratea 2018

# CERN education activities

Asia-Europe-Pacific school:  
Japan 2012, India 2014,  
China 2016, Vietnam 2018

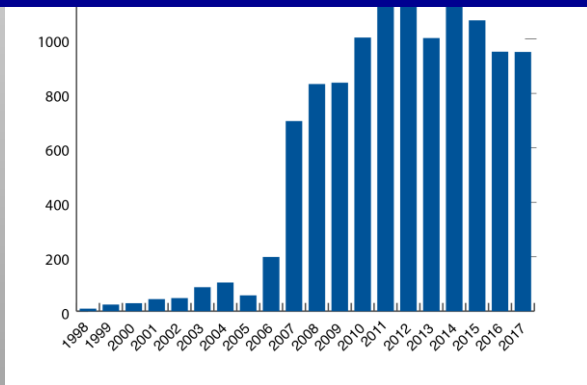
For young researchers, physics/engineering students,  
high school students, school teachers



## And ~130000 visitors every year

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

Brazil 2011, Peru 2013,  
Ecuador 2015, Mexico 2017



**AFRICAN SCHOOL OF FUNDAMENTAL PHYSICS AND ITS APPLICATIONS**  
July 15-Aug 04, 2012  
KNUST, Kumasi, Ghana  
[africanschoolofphysics.web.cern.ch/AfricanSchoolOfPhysics/](http://africanschoolofphysics.web.cern.ch/AfricanSchoolOfPhysics/)  
In connection to APS2012, a dedicated Grid School will follow on August 6-8, 2012



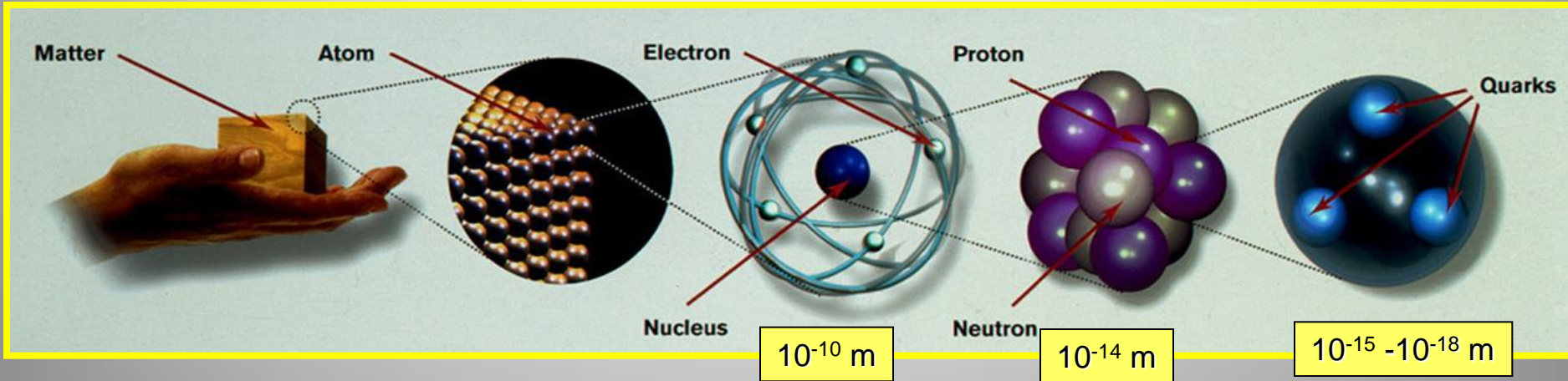




# CERN's primary mission is SCIENCE



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



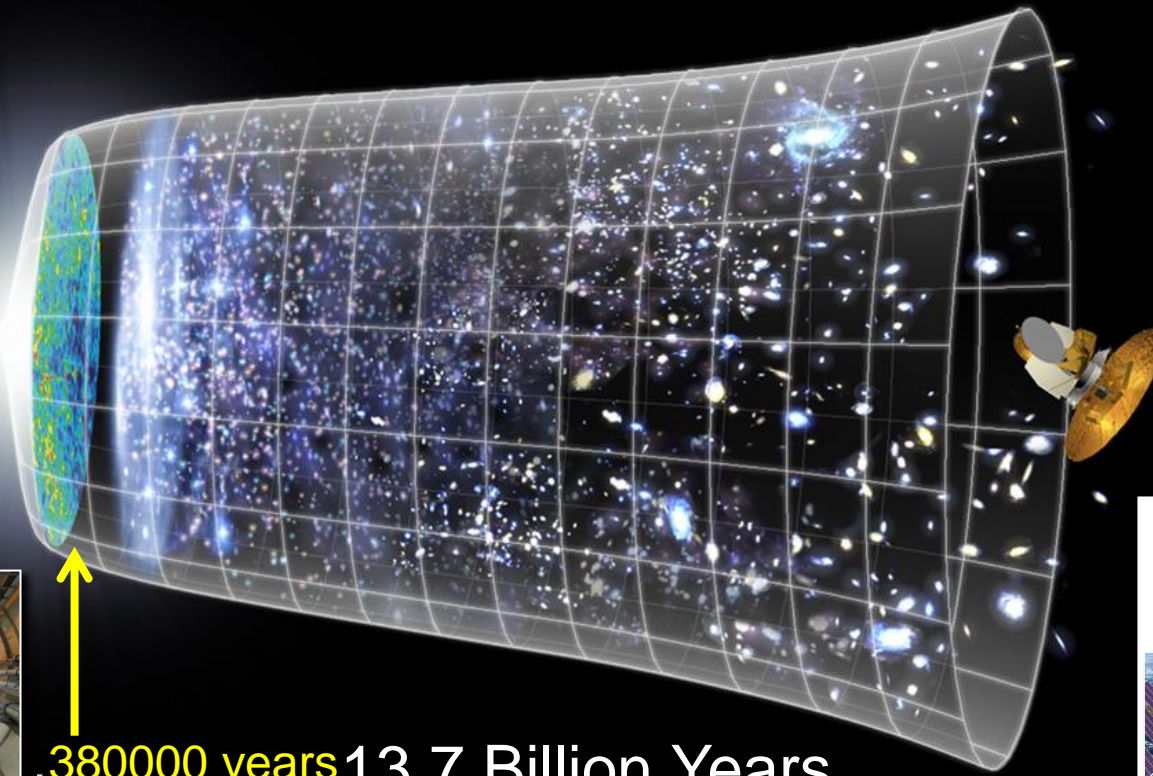
Particle physics at modern accelerators allows us to study the fundamental laws of nature on scales down to smaller than  $10^{-18}$  m

- insight also into the structure and evolution of the Universe
- from the very small to the very big ...

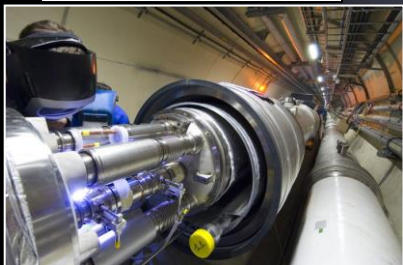


# Evolution of the Universe

Big Bang



Accelerators



380000 years 13.7 Billion Years

$10^{28}$  cm

Telescopes



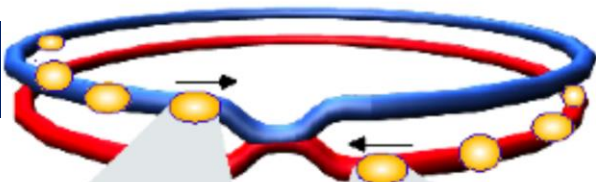
Today



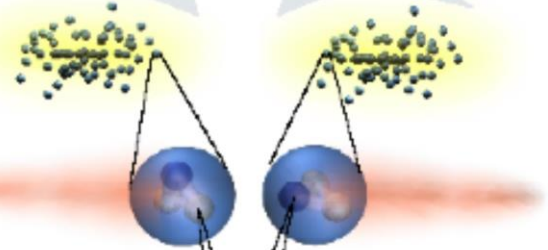
# To study the elementary particles and their interactions



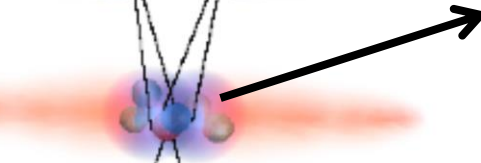
proton beams



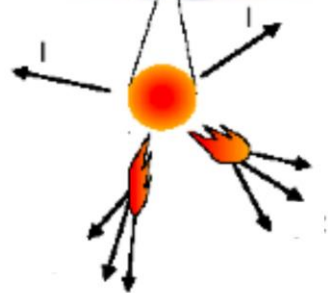
colliding protons



interacting quarks

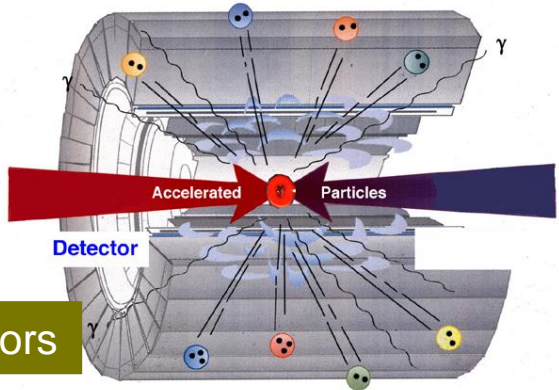


production and decay of a new particle



Accelerators

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

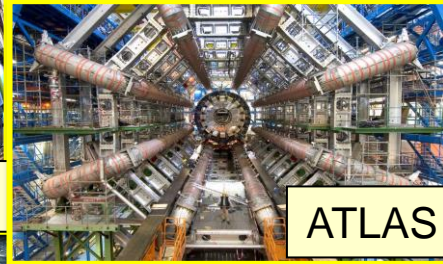
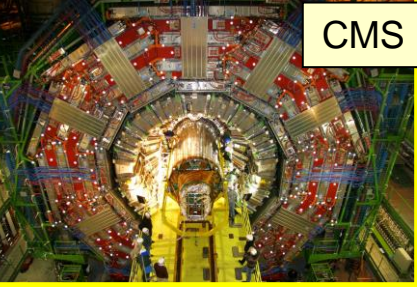


Particle detectors



# 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 4<sup>th</sup> July 2012, ATLAS and CMS announced the discovery of a new particle: the Higgs boson

Italy, through Istituto Nazionale di Fisica Nucleare (INFN), Universities and industry, contributed in a very significant way to the four experiments, the accelerator and the computing infrastructure.

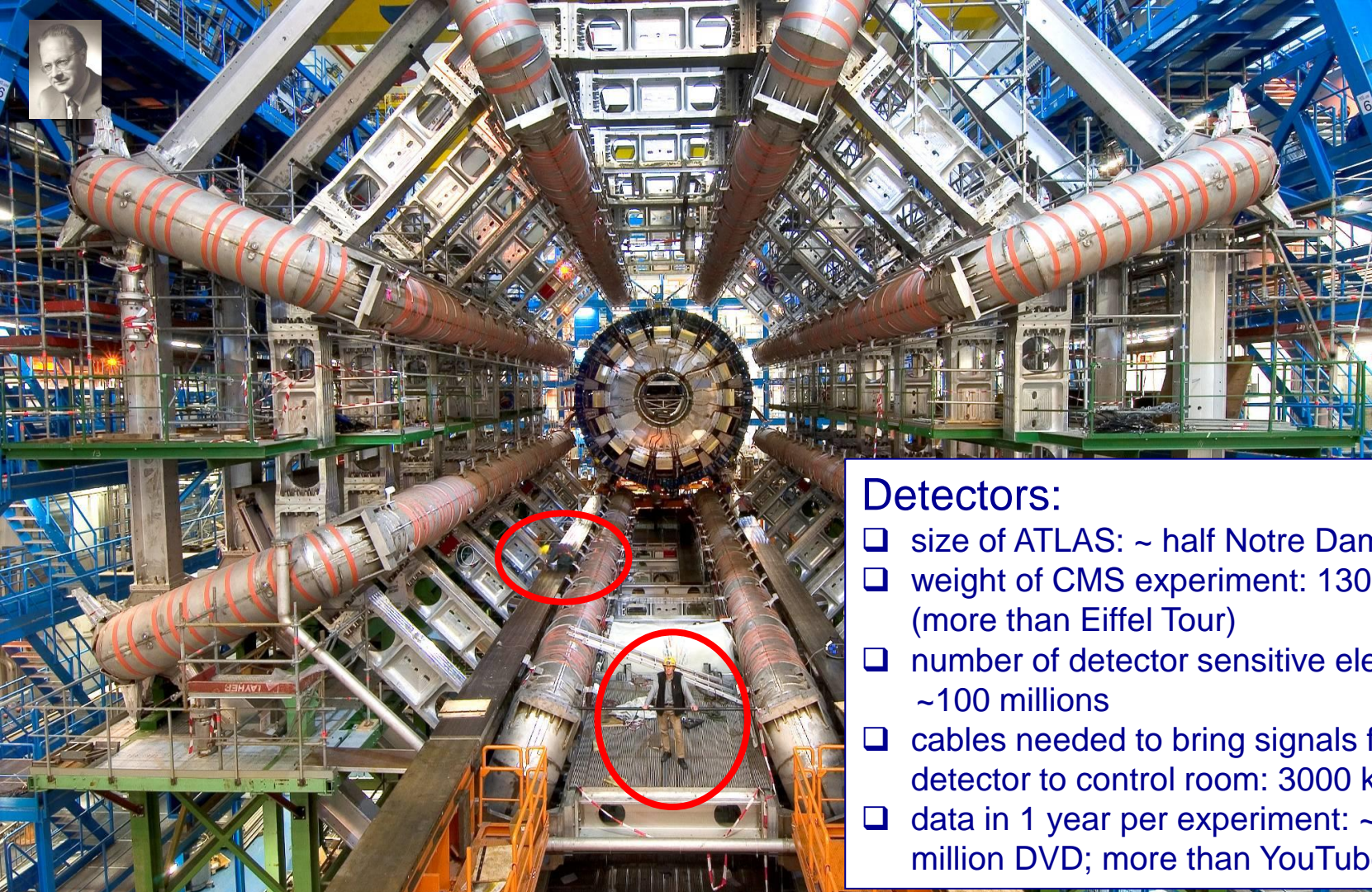




## Accelerator:

- ❑ 1232 high-tech superconducting magnets (built by Alstom, **Ansaldo** and Babcock-Noell)
- ❑ magnet operation temperature: 1.9 K (-271 °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)



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% dark matter

Why is there so little antimatter in the universe ?

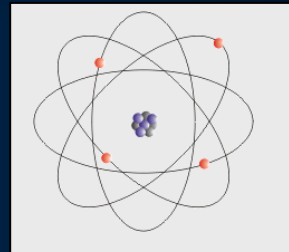
What are the features of the primordial plasma permeating the universe  $\sim 10 \mu\text{s}$  after the Big Bang ?

Are there other forces in addition to the known four ?

Etc. etc.



# Discovery 2012, Nobel Prize in Physics 2013



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

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*".



# Italy and CERN



Italy has a strong tradition in particle physics and is a founding member of CERN

- ❑ Edoardo Amaldi (Secretary General 1952-1954)
- ❑ Directors General: Carlo Rubbia, Luciano Maiani, F. G.
- ❑ Many Italian scientists in other important leading roles
- ❑ Nobel prize: Carlo Rubbia
- ❑ ~ 2600 Italian scientists involved today in projects at CERN (out of ~17000)

INFN (Istituto Nazionale di Fisica Nucleare),  
Universities, and industry: crucial intellectual and  
and technological contributions to the LHC  
E.g. Ansaldo built 1/3 of the high-tech dipole magnets



~ 1100 Italian firms in the CERN supplier database

Returns (industrial purchases): up to 110% of contribution in LHC construction period; today 25-40%



Will the Higgs boson change our life ?

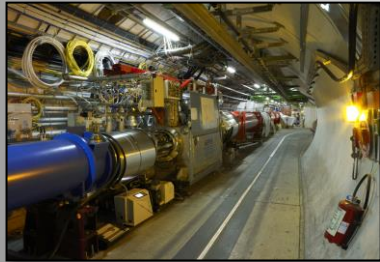
It already has !



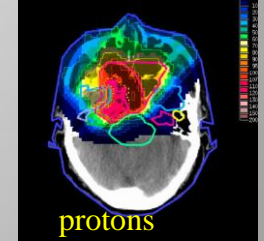
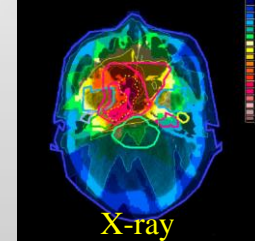
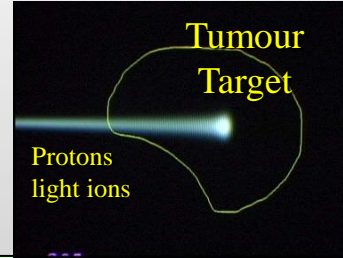


Complex, high-tech instruments needed in particle physics → cutting-edge technologies developed at CERN and collaborating Institutes → transferred to society

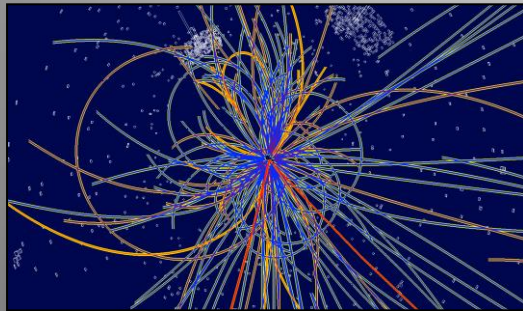
Examples of applications: medical imaging, cancer therapy, solar panels, material science, airport scanners, cargo screening, food sterilization, nuclear waste transmutation, analysis of historical relics, etc. etc. ... not to mention the WEB ...



## Hadron Therapy



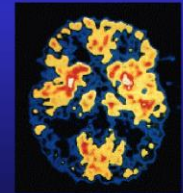
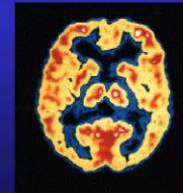
Particle accelerators: ~30'000 worldwide, of which ~17'000 used for medical applications  
E.g. Hadron Therapy: > 50000 patients treated in Europe (14 facilities for protons, only two for Carbon ions)  
CNAO (Centro Nazionale Adroterapia Oncologica), Pavia



## Imaging

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

### Brain Metabolism in Alzheimer's Disease: PET Scan



Normal Brain

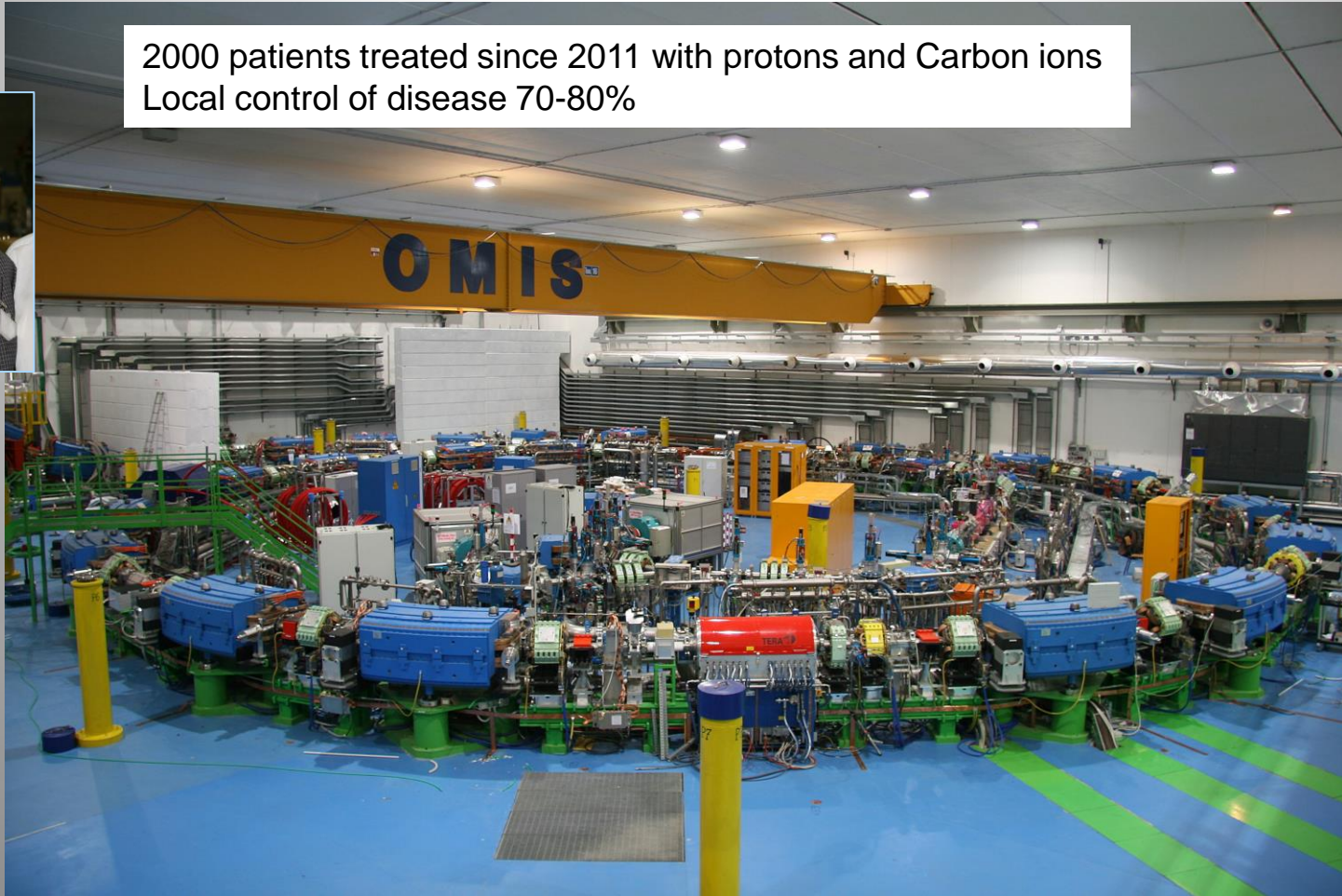
Alzheimer's Disease



# CNAO, Pavia



2000 patients treated since 2011 with protons and Carbon ions  
Local control of disease 70-80%





## The usefulness of “useless” knowledge (Abraham Flexner, US educator, 1939)



Ideas and creativity are the fuel of progress: without new, revolutionary ideas, progress sooner or later stagnates.

Fundamental research is the one that mostly stimulates ideas and creativity, because it is curiosity-driven, with no constraints from profit or delivery of specific products

History shows that often major breakthroughs come from fundamental research, e.g.

- ❑ quantum mechanics → transistors
- ❑ relativity → GPS

Perhaps most importantly, knowledge (as the arts) is among the highest expressions of human beings as clever beings → it is justified by its intrinsic value.

“Nati non foste a viver come bruti, ma per seguir virtute et conoscenza”, D. Alighieri, Inferno, XXVI

In the 1970s, Bob Wilson, founder of Fermi National Accelerator Laboratory, Illinois (the second biggest accelerator laboratory in the world, after CERN), asked by US Congress “What will your lab contribute to the defense of the US?”, replied: “Nothing, but it will make it worth defending”





LHCb

ATLAS

CERN Meyrin

CERN Prévessin

SPS 7 km

SUISSE  
FRANCE

CMS

ALICE

LHC 27 km