CERN: from fundamental research to medical applications

C. Aller .

ATLA







Fabiola Gianotti, CNAO, 24 November 2021

CERN the largest particle physics laboratory in the world



Intergovernmental organisation based in Geneva

Mission:

- science: fundamental research in particle physics \rightarrow discoveries (e.g. Higgs boson in 2012), Nobel prizes
- technology and innovation → transferred to society (e.g. the World Wide Web, medical applications, etc.)
- training and education
- bringing the world together: ~ 17000 scientists, > 110 nationalities



CERN was founded in 1954, in the aftermath of World War II (i.e. after a crisis), with two goals:
 □ rebuild scientific research in Europe (→ awareness that economic recovery depends also on scientific excellence)
 □ foster peaceful collaboration among European countries (→ awareness that science can break walls)

Main ingredients of CERN's founding Convention:

scientific research of fundamental character with no military purpose

 \Box results and information should be disseminated and made available to everybody (\rightarrow open science!)

- \Box promote international cooperation (\rightarrow science for peace!)
- □ training and education

organisation européenne pour la recherche nucléaire CERN european organization for nuclear research

CONVENTION

FOR THE ESTABLISHMENT OF A EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PARIS, Ist JULY, 1953

As amended

CONVENTION

POUR L'ÉTABLISSEMENT D'UNE ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE

PARIS, 10 147 JUILLET 1953

Telle qu'elle a été modifiée

ÜBEREINKOMMEN

ZUR ERRICHTUNG EINER EUROPÄISCHEN ORGANISATION FÜR KERNFORSCHUNG

PARIS, I. JULI 195

Revidierte Fassung

One of the founding fathers: Edoardo Amaldi

Signed by 12 Member States in Paris on 1st July 1953



CERN today



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

10 Associate Member States: Croatia, Cyprus, Estonia, India, Latvia, Lithuania, Pakistan, Slovenia, Turkey, Ukraine

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

~ 50 International Cooperation Agreements: more and more developing countries (recent examples: Paraguay, Sri Lanka, Nepal) sign cooperation agreements with CERN and other research organisations
 → engaging internationally on fundamental research is part of their efforts towards development, building knowledge-based economies and strengthening relations with other countries

Annual budget (2020) ~1200 MCHF (<u>on average</u>: ~ 1 cappuccino/year per European citizen): Member States contribute in proportion to their income (NNI): <u>Italy</u>: ~ 10.5%, ~ 122 MCHF Budget stability over decades and international cooperation have allowed accomplishment of extremely ambitious and complex projects that no single country could afford alone.

Distribution of All CERN Users by Nationality on 9 December 2019





Age distribution of scientists working at CERN



< 50% of the young people stay in particle physics: where do the others go?



CERN prepares them for variety of jobs also outside particle physics



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

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



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



27 km ring, 100 m underground. Operation started in 2010 \rightarrow exploration of new energy frontier



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

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

Accelerator:

1232 high-tech superconducting magnets (built by Alstom, Ansaldo and Babcok-Noell)

 \rightarrow a great example of research-industry partnership

- □ magnet operation temperature: 1.9 K (-271 °C)
- $\rightarrow\,$ LHC is one of coldest places in the universe
- number of protons per beam: 200000 billions
- I number of turns of the 27 km ring per second: 11000
- number of beam-beam collisions per second: 40 millions
- └ collision "temperature": 10¹⁶ 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
- □ recorded data in 1 year/experiment: ~10 PB

Discovery in 2012 \rightarrow Nobel Prize in Physics in 2013







Note: a world without the Higgs boson would be very strange. Atoms would not exist \rightarrow 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".



Cultural heritage



Colour X-ray imaging with CERN's electronics



Applications to society: examples

Hadron therapy (e.g. CNAO, Pavia)







Medical imaging (PET)

Brain Metabolism in Alzheimer's Disease: PET Scan





2C

Normal Brain

Alkindimans Bisassa

Radiation dosimetry for space missions



Machine learning and FPGA for car automation



Medical applications: the particle physics toolbox





Medical applications: the particle physics toolbox





CERN now working on R&D for critical accelerator technologies for innovative ion therapy (NIMMS, Next Ion Medical Machine Study), comprising magnet technologies, ion linacs, improved synchrotron designs and superconducting gantries

Accelerators







First 3D colour X-ray of a human using the Medipix3 technology developed at CERN. Pixel-sensor chips developed for the LHC detector readout \rightarrow led to high-definition images of the density and composition of human tissues

CERN-MEDICIS

20/ Vent'anni di Cnao.

Accelerator-driven production of non-conventional radioisotopes for medical applications Building on 50+ years of expertise in producing isotopes with the ISOLDE facility



On behalf of CERN: happy anniversary CNAO!







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, Fabiola Gianotti
- Many Italian scientists in other important leading roles
- Nobel prize: Carlo Rubbia
- ~ 2400 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



~ 400 Italian firms in the CERN supplier database
 Returns (industrial purchases): up to 110% of contribution in LHC construction period; today 25-40%

Particle accelerators and detectors





colliding protons

interacting quarks and gluons

production and decay of a new particle



- \rightarrow study fundamental constituents of matter
- → produce (new) heavy particles

 \rightarrow collision energy = temperature of universe 10⁻¹² s after Big Bang





Some of the outstanding questions in fundamental physics

What is the origin of the masses of the elementary particles (quarks, electrons, ...)? \rightarrow related to the Higgs boson

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

Why is there so little antimatter in the universe ?

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

Are there other forces in addition to the known four ?

Etc. etc.