Fundamental research (and much more ...) at CERN
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
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:** each Member State contributes in proportion to its income
Distribution of All CERN Users by Nationality on 10 April 2019

**Associate Members in the Pre-Stage to Membership**
- Cyprus: 26
- Slovenia: 33

**Associate Members**
- India: 387
- Lithuania: 39
- Pakistan: 71
- Turkey: 165
- Ukraine: 116

**Observers**
- Japan: 272
- Russia: 1205
- USA: 1211

**Member States**
- 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

**Others**
- Albania: 4
- Algeria: 14
- Armenia: 22
- Australia: 36
- Azerbaijan: 10
- Bahrain: 1
- Bangladesh: 8
- Belarus: 45
- Benin: 1
- Bolivia: 3
- Bosnia & Herzegovina: 3
- Brazil: 127
- 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
- Israel: 2
- Jordan: 2
- Kazakhstan: 10
- Kenya: 1
- Korea: 183
- 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
- Oman: 3
- Palestine: 7
- Paraguay: 1
- Peru: 6
- Philippines: 3
- Saint Kitts and Nevis: 1
- Senegal: 9
- Singapore: 5
- South Africa: 56
- Sri Lanka: 10
- Sudan: 1
- Syria: 1
- Taiwan: 56
- Thailand: 26
- Tunisia: 4
- Turkey: 1
- Ukraine: 3
- Uzbekistan: 9
- Venezuela: 4
- Viet Nam: 11
- Zambia: 1

**Russian Federation**
- 1205

**Associate Members in the Pre-Stage to Membership**
- Cyprus: 26
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Age distribution of scientists working at CERN

Female scientists: ~ 20% today
< 8% in 1995

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

> 3000 PhD students

What type of organisation do you work in?
- Industry: 45%
- University: 15%
- Research Institute: 7%
- Govt./International Org.: 29%
- Other: 4%

Which domain do you work in?
- Computing: 35%
- Consulting: 2%
- Physics: 4%
- Engineering: 20%
- Finance: 19%
- Communications: 5%
- Others: 5%
CERN education activities

Europe/Russia School
Teacher Programme 1998-2018:
total 12320 participants (Russia: 408)
For young researchers
For physics/engineering students
For high school students
For school teachers

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

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

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

Europe/Russia School
- Teacher Programme 1998-2018: total 12320 participants (Russia: 408)
- For young researchers
- For physics/engineering students
- And ~130000 visitors every year (300000 requests)
- > 60% are high-school students; ~ 80% come from > 700 km away

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

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

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

380,000 years

13.7 Billion Years

10^{28} cm

Today

Accelerators

Telescopes

Hubble

ALMA

VLT

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

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

- 27 km ring, 100 m underground
- operation started in 2010 → exploration of new energy frontier
Accelerator:
- 1232 NbTi high-tech superconducting magnets (built by Alstom, Ansaldo and Babcock Noell)
- Magnet operation temperature: 1.9 K (-271 °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; 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 μs after the Big Bang ?

Are there other forces in addition to the known four ?

Etc. etc.
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.
Next step: the high-luminosity upgrade of the LHC (HL-LHC)

Current LHC ends in 2023 → then upgrade to run with more intense proton beams → HL-LHC will operate from 2027 to 2037, providing 10 times more data than LHC → Increased sensitivities to new physics (dark matter, etc.)

HL-LHC will be the most powerful collider in the world

Major upgrades also for the experiments and computing

1.2 km of accelerator will be upgraded with new technology. → ongoing discussions on possible high-tech contributions by Russian Federation and JINR/Dubna
Various options for future, more powerful colliders being studied and the needed, advanced technologies being developed

**CLIC**: $e^+e^-$ linear collider 11 km $\rightarrow$ 50 km tunnel

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

Japan is also considering a linear collider: ILC

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 $\rightarrow$ cutting-edge technologies developed at CERN and collaborating Institutes $\rightarrow$ 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
Russia and CERN

- Russia has Observer Status in the CERN Council with special rights to attend restricted sessions
- Scientific contacts since the early 1960s
- First International Co-operation Agreement signed in 1967
- Strong involvement in experimental programme at CERN
- Today one of the largest CERN user communities

- Important contributions to the LHC accelerator complex and experiments
- In total ~ 40 industrial plants were involved in the production of the equipment for the LHC project

The ALICE PHOS photon spectrometer which contains 3584 lead tungstate crystals.
Russia and CERN

Strong involvement in the LHC experimental programme
ATLAS, CMS, LHCb and ALICE

ALICE: 10 Institutes
ATLAS: 10 Institutes
LHCb: 6 Institutes
CMS: 6 Institutes

+ non-LHC: COMPASS, DIRAC, AD-6, NA-61, NA-62 UA9

Innovative technologies developed

GRID Tier-1 centre at Kurchatov Institute and Dubna,
accelerator projects (LINAC4) and R&D (RD-50, RD-51, CLIC/CTF3)
Russian Institutes and CERN

Institutes having a long standing collaboration with CERN:

- National Research Centre “Kurchatov Institute” (4 Institutes)
- Russian Academy of Science (4 Institutes)
- Moscow State University
- Moscow Engineering and Physics Institute (MEPhI)
- St. Petersburg State University

Recently more and more universities are joining, including:

- National University of Science and Technology (MISIS), Moscow
- Novosibirsk State University (NSU)
- St. Petersburg Polytechnic University
- Tomsk Polytechnic University (TPU)
- Tomsk State University (TSU)

And our international sister organisation:

- Joint Institute for Nuclear Research (JINR), Dubna
Thank You!

Accelerating Science and Innovation