Investing in Big Science

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Perspectives on Big Science and the Question of Justice
22 April 2021

CERN

Accelerating Science and Innovation

Investing in Science and Technology

Which type of research to support?

Basic – Applied ?

Small scale – Large scale ?

Individual – International ?

Investing in Science and Technology

Which type of research to support?

Basic – Applied ?

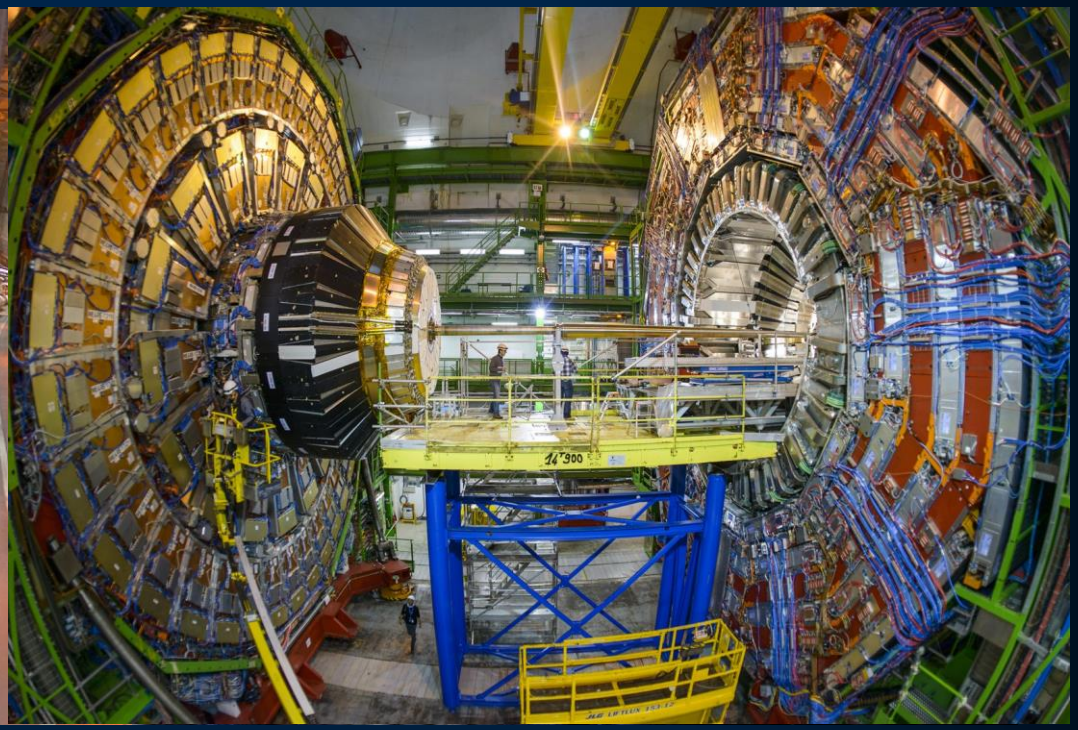
Small scale – Large scale ?

the scale appropriate for the research to be carried out

Individual – International ?

The role of Big Science:

– innovate, discover, publish, share



…what is its role for Society ?

Big Science

generates Knowledge

thereby creating educated minds

generates Innovation

thereby changing society

can generate Disruptive Innovation

thereby transforming society

Four Pillars Underpin Big Science

CERN & Large-scale Science Projects

- Address
  - Fundamental science questions at the forefront of research and technology.
- Require
  - Large and sustained infrastructures.
  - Global collaboration on long time scales.
- Provide
  - Unique equipment.
  - Challenging requests for high technology & innovation.
  - Stimulating ideas which in turn attract good people.
  - Occasion to bring people together via collaboration.

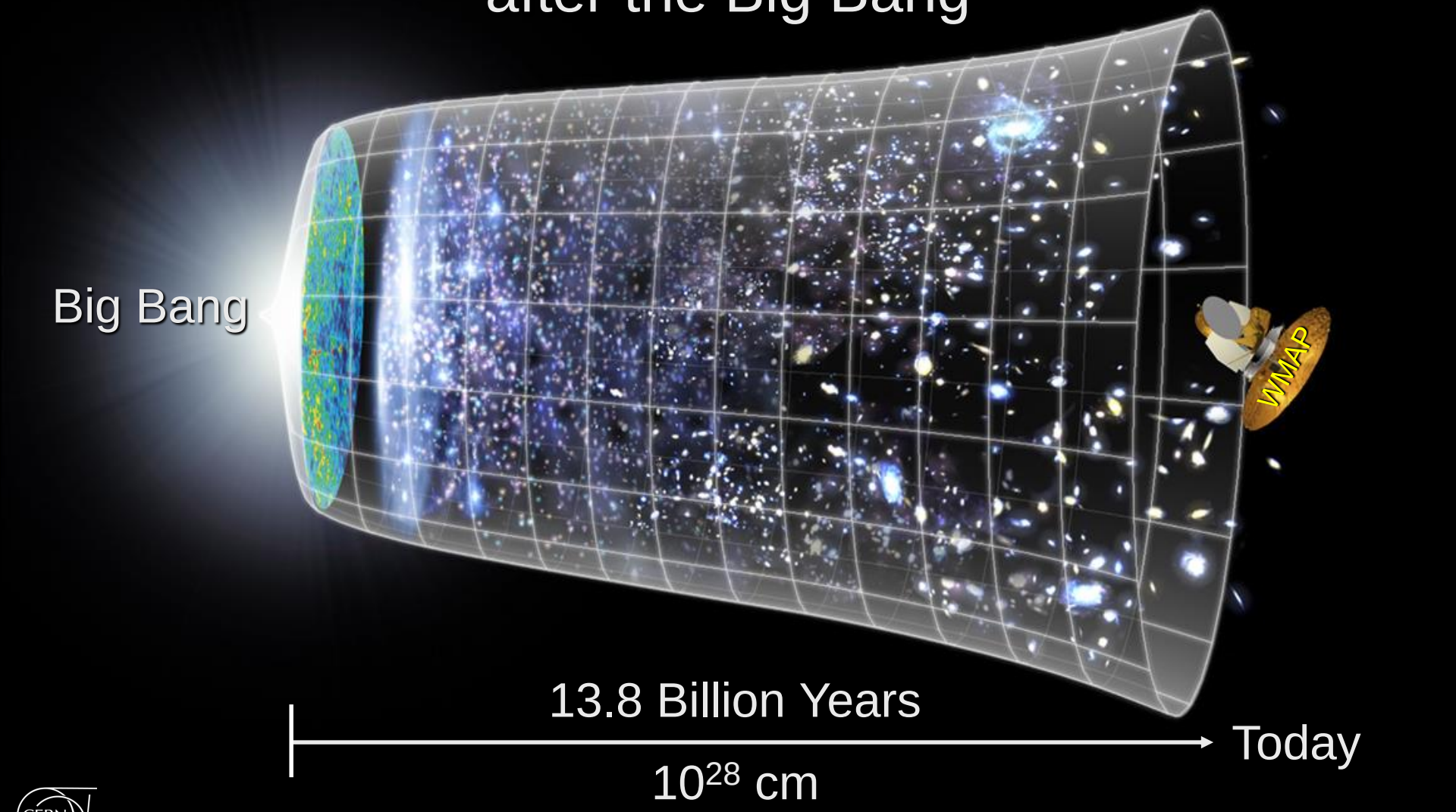
I. Research

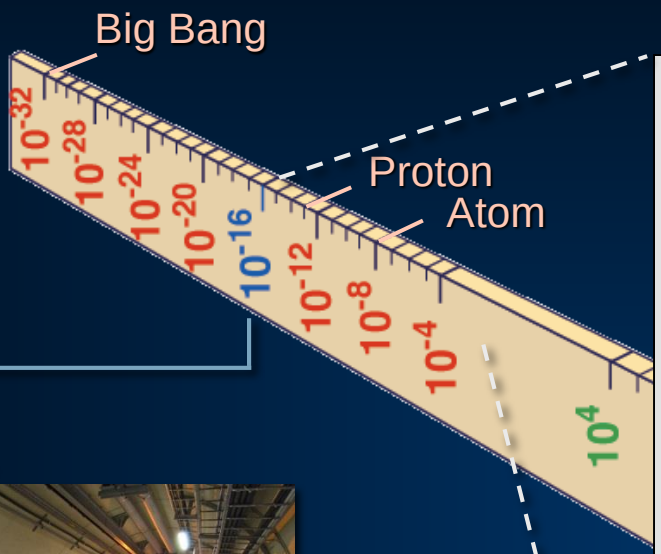
CERN is the world's biggest laboratory for particle physics.

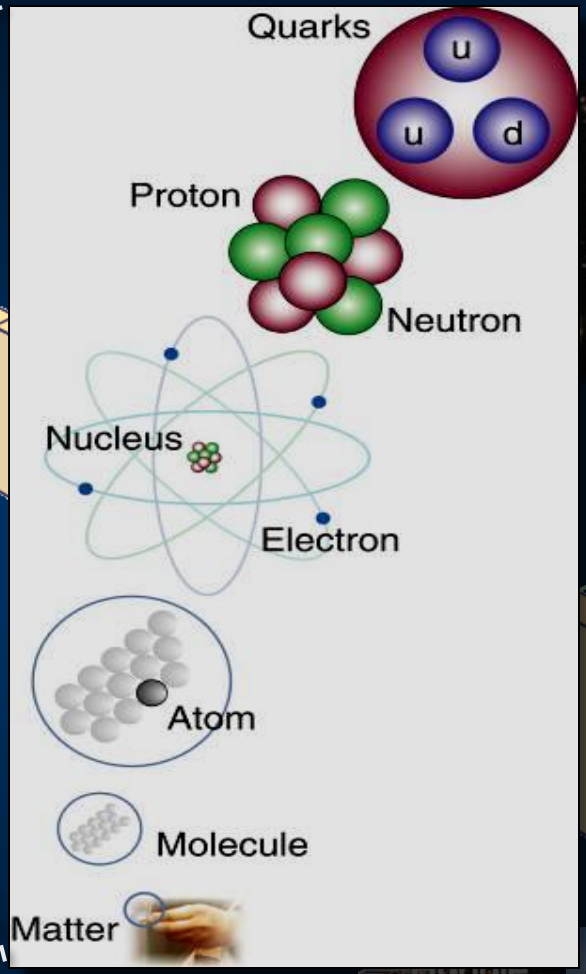
Its goal is to understand the most fundamental particles and laws of the universe.

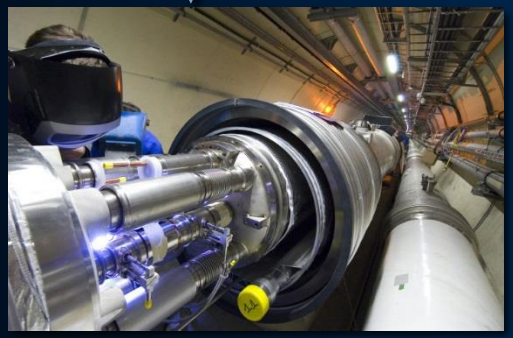
Scientific Challenge

to understand the very first moments of our Universe after the Big Bang



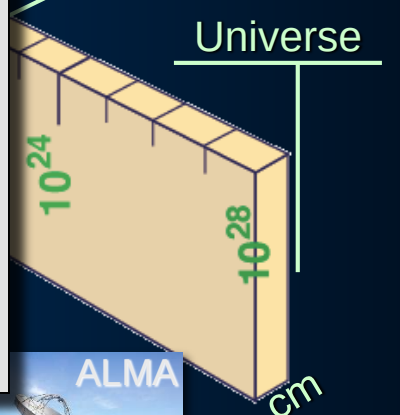






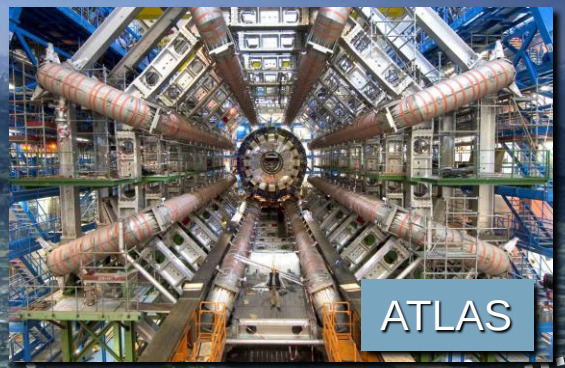
LHC

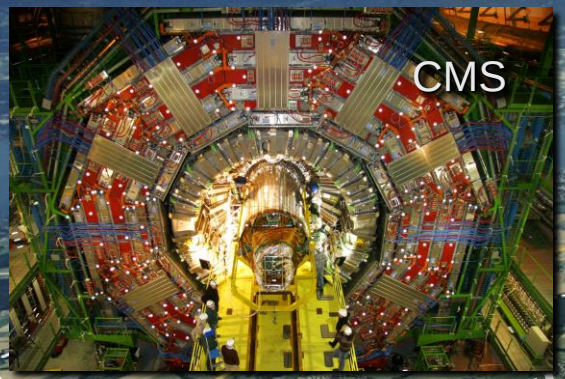
Super-Microscope



Study physics laws of first moments after Big Bang
Increasing Symbiosis between Particle Physics, Astrophysics and Cosmology

2010: a New Era in Fundamental Science





Exploration of a new energy frontier
in p-p and Pb-Pb collisions

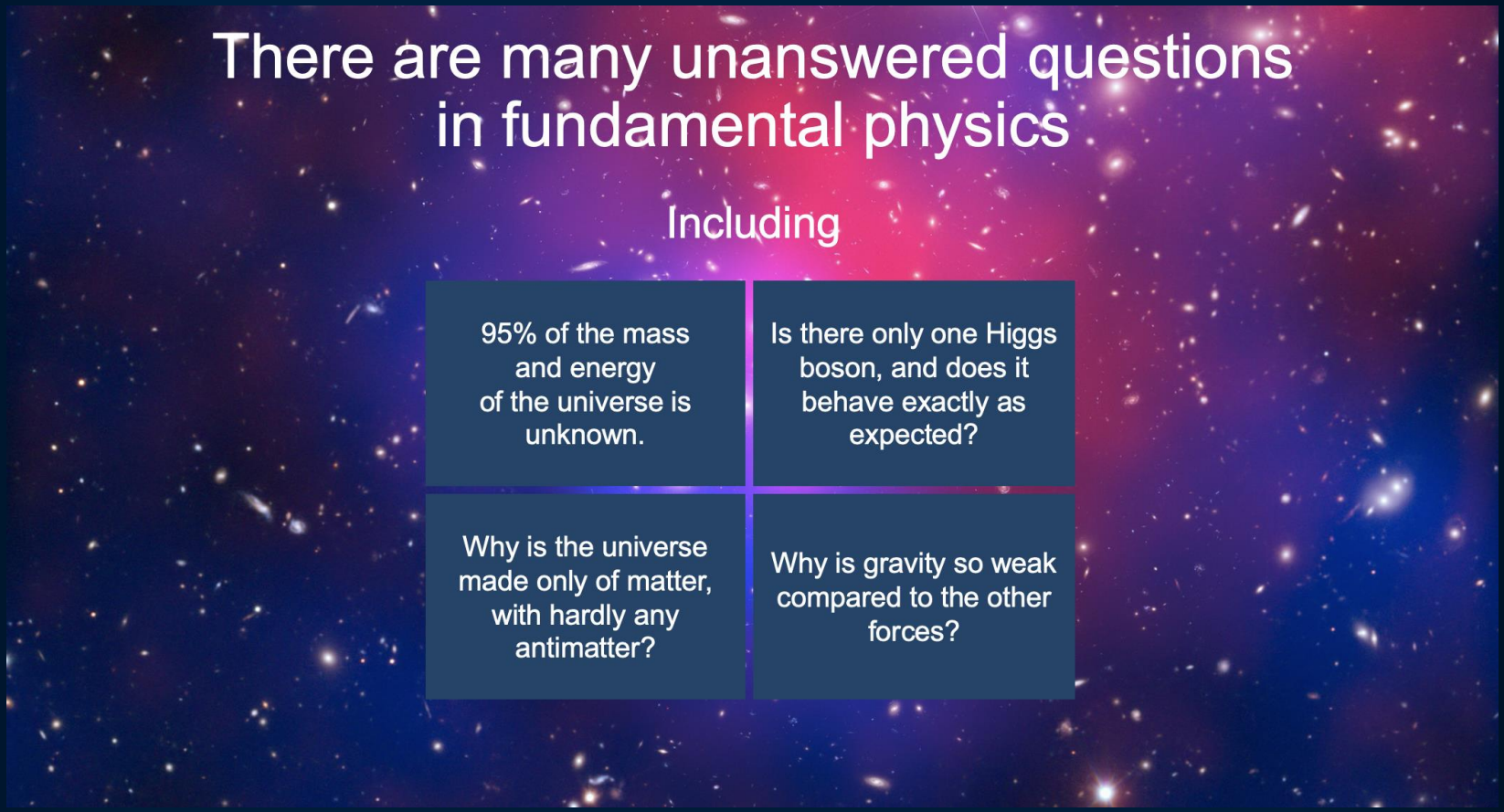
CERN

Discovery 2012, Nobel Prize in Physics 2013

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".*

CERN

Unanswered Questions in Physics

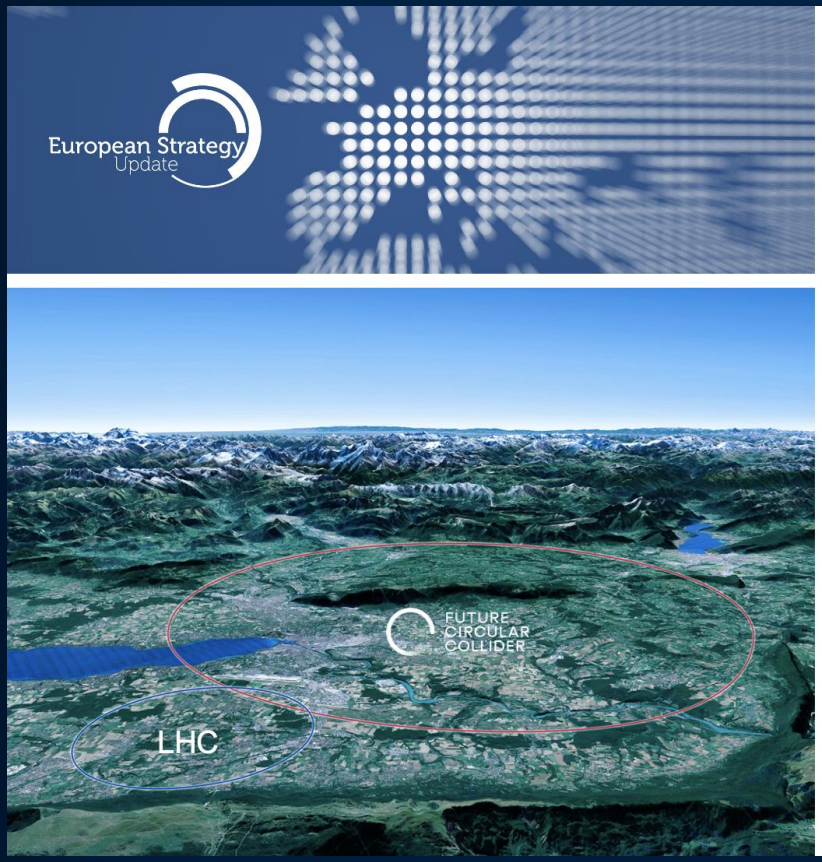


The High-Luminosity LHC (HL-LHC)

Upgrade to the High-Luminosity LHC is under way

- The HL-LHC will use new technologies to provide 10 times more collisions than the LHC.
- It will provide greater precision and discovery potential.
- It will start operating in 2027, and run until 2040.

Scientific Priorities for the Future



Scientific priorities for the future

Implementation of the recommendations of the **2020 Update of the European Strategy for Particle Physics**:

- Fully exploit the HL-LHC
- Build a Higgs factory to further understand this unique particle
- Investigate the technical and financial feasibility of a future energy-frontier 100 km collider at CERN
- Ramp up relevant R&D
- Continue supporting other projects around the world

Key issue: Scientific Instrumentation

- Cutting-edge science relies on cutting-edge instrumentation

- need to develop new technologies and techniques
- significant market for high-tech industry
- high initial costs and long time scales

→ **strengthen the relations between RIs and industry in the field of scientific instrumentation**

→ **promote knowledge and technology transfer**

Investing in Science and Technology

Which type of research to support?

Basic – Applied ?

Small scale – Large scale ?

Individual – International ?

II. Technology and Innovation

Science and Technology

Investments in Science and Technology in the past have laid the basis for our society today, for our well-being today.

Investments in Science and Technology today will lay the basis for our society tomorrow, for our well-being tomorrow.

Primary Motivation for Research: *CURIOSITY*

- Results of Research:
  - Fundamental research → Applied research
  - Knowledge/Know-how → Application / Use
  - Culture → Technology

- Primary aim of fundamental research – KNOWLEDGE/KNOW-HOW
- Primary aim of applied research – APPLICATION/USE

- Fundamental & applied research are inseparably connected.

An Example…

Where do detailed studies on a candle lead to…?

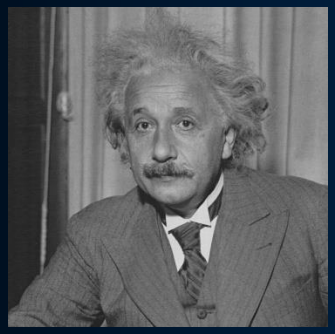
…certainly not to light bulb.

Need fundamental research to discover electricity

Fundamental Research

- Fundamental research results in gain of knowledge/know-how.
- But also results in applications
  - Time frame and areas of application are not predictable.
- Fundamental research
  - Is innovation.
  - Needs innovation.
  - Drives innovation.

Fundamental research has always been a driver for Innovation

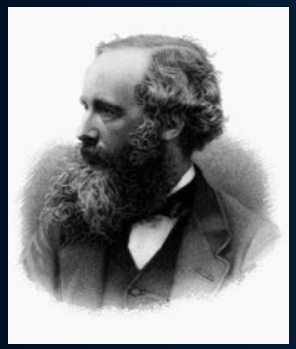


A. Einstein

Relativity

100% SCIENCE

GPS



J.C. Maxwell

Electromagnetism

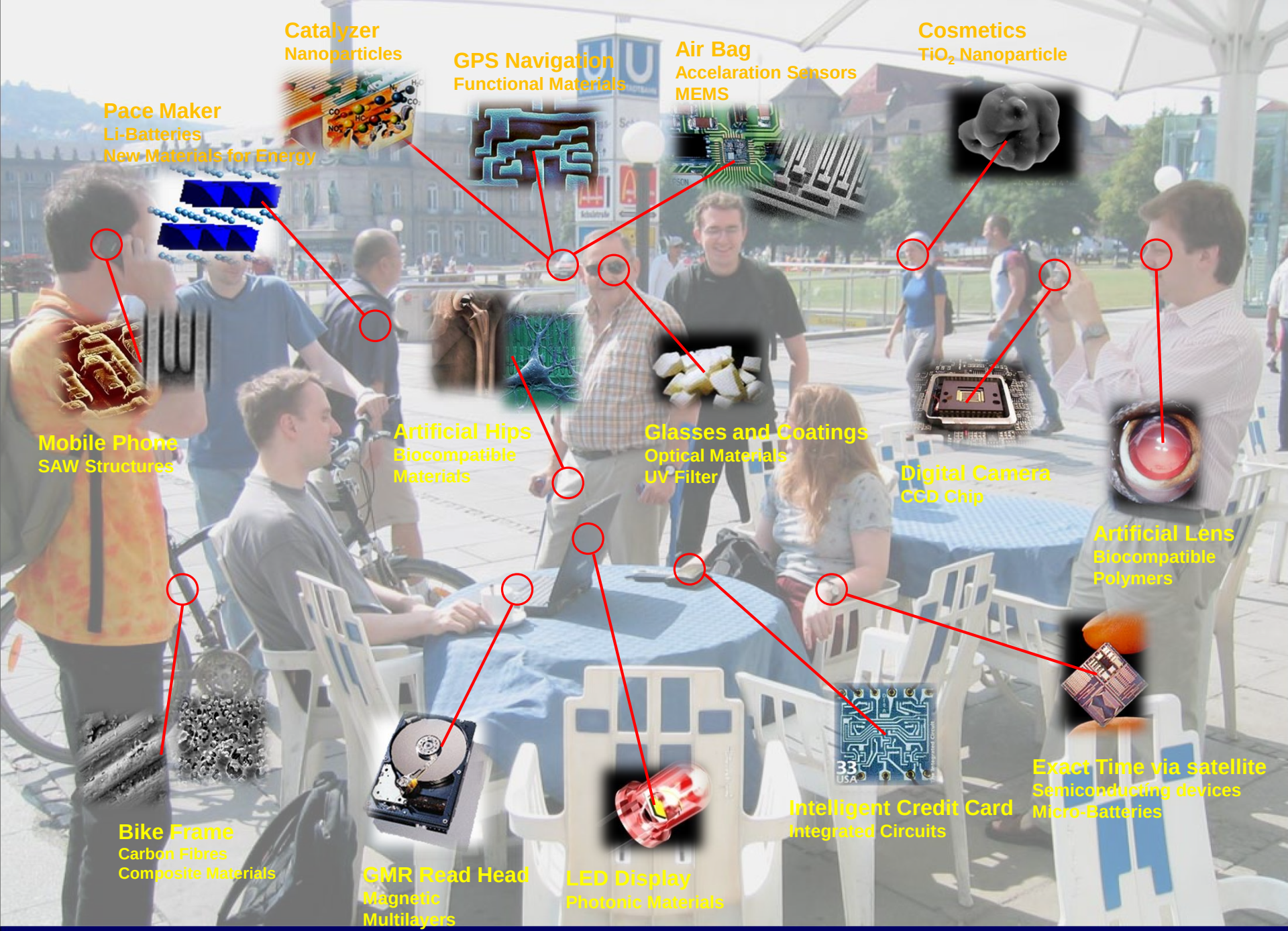
100% SCIENCE

GSM

Investing in Science and Technology

Example of innovation through the interplay between (basic and applied) science and technological developments:

On a typical day somewhere in the world…


Catalyzer
Nanoparticles
GPS Navigation
Functional Materials
Air Bag
Accelaration Sensors
MEMS
Cosmetics
TiO_2 Nanoparticle
Pace Maker
Li-Batteries
New Materials for Energy
Mobile Phone
SAW Structures
Artificial Hips
Biocompatible
Materials
Glasses and Coatings
Optical Materials
UV Filter
Digital Camera
CCD Chip
Artificial Lens
Biocompatible
Polymers
Bike Frame
Carbon Fibres
Composite Materials
GMR Read Head
Magnetic
Multilayers
LED Display
Photonic Materials
Intelligent Credit Card
Integrated Circuits
Exact Time via satellite
Semiconducting devices
Micro-Batteries

Large-scale Science Projects

- Address
  - fundamental science questions
    at the forefront of research and technology
- Provide
  - unique equipment
  - stimulating ideas which in turn attract good people
  - occasion to bring people together
  - challenging requests for high technology and innovation

Innovation in Fundamental Research

Large scientific projects stimulate innovation

- Space : Apollo missions, Space Station,
  Pioneer/Voyager Missions
- Particle Physics : accelerators in general
  - at CERN : LEP, LHC

Pushing the frontiers of technology. CERN examples:

- Superconductivity, magnets, cryogenics, vacuum, survey/metrology.
- Transport and installation of heavy equipment.
- Solid-state detectors resistant to high-intensity radiation.
- Large-scale industrial control systems.
- Electronic and information systems.
- Project management and co-ordination.

Investing in Science and Technology

All science must be supported, don't distinguish between basic and applied research, it's

science, it is **research**

Criteria: Excellence

Investing in Science and Technology

Example of innovation through the interplay between (basic and applied) science and technological developments:

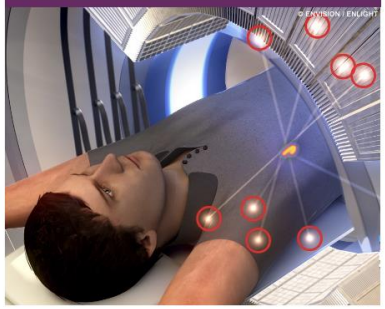
Medical Applications

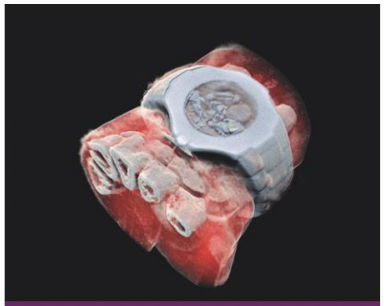
Applications in Medicine & Healthcare

CERN's technological innovations have important applications in medicine and healthcare

Accelerator technologies are applied in cancer radiotherapy with protons, ions and electrons.

Technologies applied at CERN are also used in PET, for medical imaging and diagnostics.





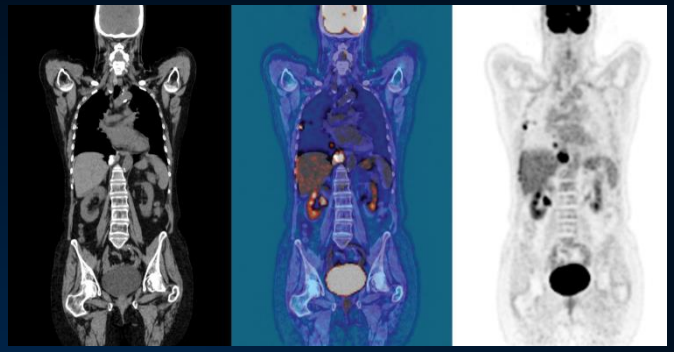
Pixel detector technologies are used for high resolution 3D colour X-ray imaging.

CERN produces innovative radioisotopes for nuclear medicine research.

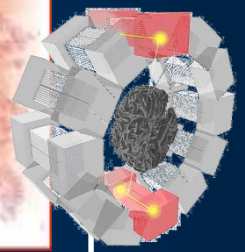
Medical diagnosis using Antimatter

"See more and better" with less radiation dose

Positron- **E**mission-**T**omography



CT CT+PET PET



prediction and discovery of Antimatter

new PET Generation (cristals from LHC detectors)

1900 1925 1950 1975 2000

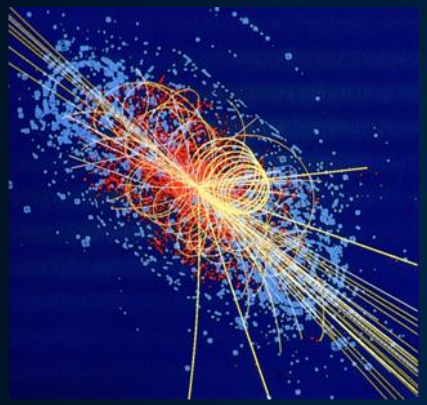
45 years

Basic Research

Technology

Medical Application as an Example of Particle Physics Spin-off

Combining Physics, ICT, Biology and Medicine to fight cancer

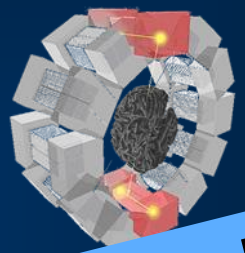


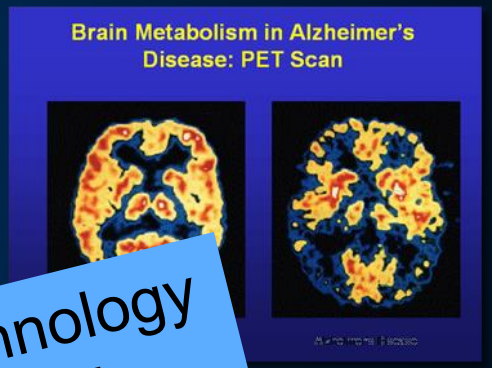
Detecting particles

⟺ Imaging

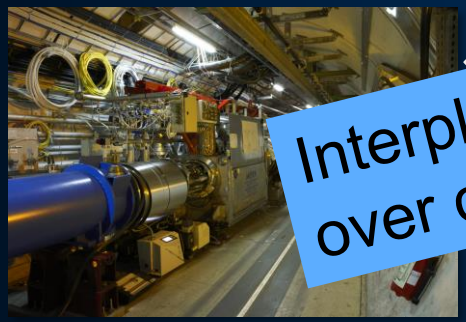
Clinical trial in Portugal, France and Italy for new breast imaging system (ClearPEM)

PET Scanner





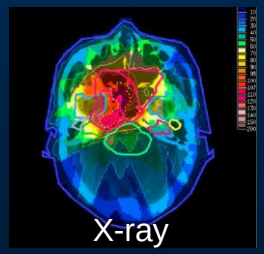
Interplay between science and technology over decades to improve human health

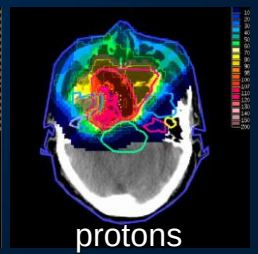


Accelerating particle beams

~30'000 accelerators worldwide

~17'000 used for medicine





Leadership in Ion Beam Therapy now in Europe and Japan

>100'000 patients treated worldwide (>45 facilities)

>50'000 patients treated in Europe (>14 facilities)

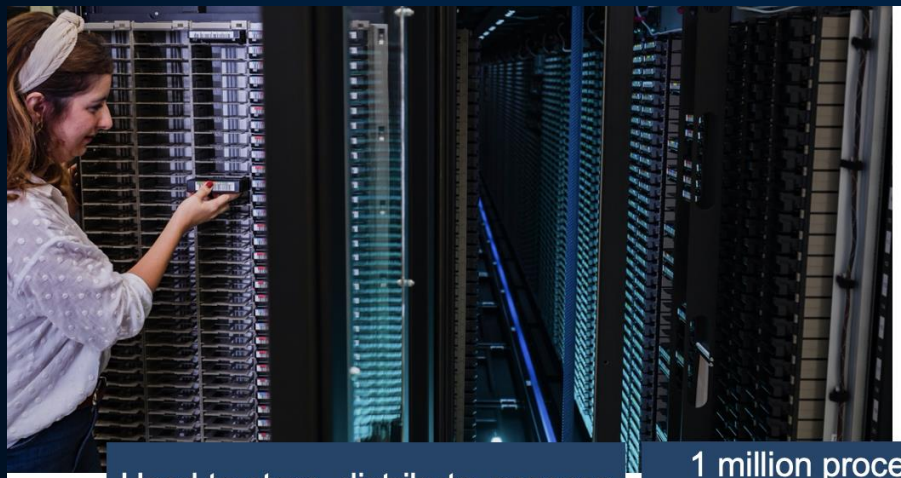
CERN

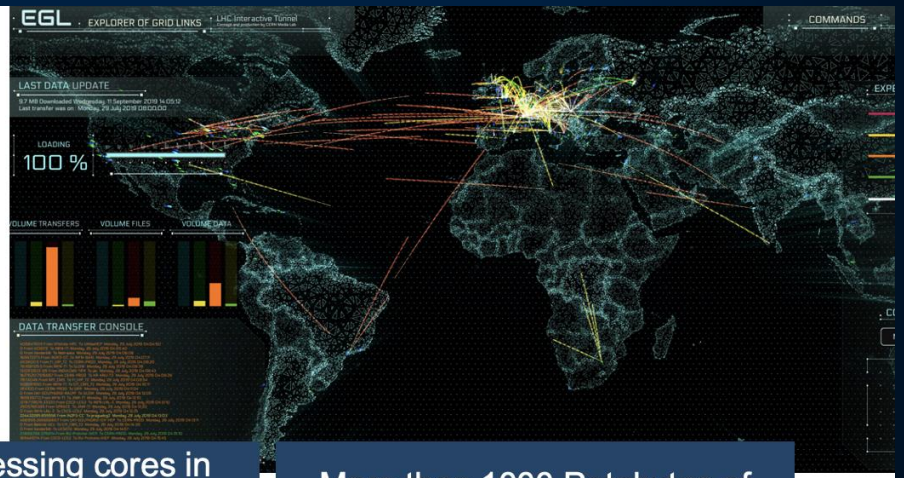
Example of Disruptive Innovation

Large scale international research at CERN required a paradigm shift in communication between researchers:

In 1989 the World Wide Web was born at CERN and a few years later given to society, transforming our daily life.

The Worldwide LHC Computing Grid (WLCG)





Used to store, distribute, process and analyse data.

1 million processing cores in about 160 data centres and 42 countries.

More than 1000 Petabytes of CERN data stored world-wide.

The Virtuous Circle
Basic research ↔ Innovation ↔ Applied research

- Synergy between research and innovation results not only in societal and economic impact but also, and very importantly, in the creation of enhanced opportunities for further developments.

Key Message (I)

- This circle needs to remain strong, to be unbroken and to be supported over long term.

Key Message (II)

In today's challenging period, all regions need to step up support for research and innovation in order to ensure, in a global competitive environment, the sustainable development of science and technology necessary for the upturn and growth of everybody's economy.

Big Science

is vital for our society

Investing in Science and Technology

Which type of research to support?

Basic – Applied ?

Small scale – Large scale ?

the scale appropriate for the research to be carried out

Individual – International ?

cooperation and competition are both vital for research

Essential Ingredients to Drive Innovation

- A concrete project with ambitious goals and deadline.
- Highly competent and motivated teams in all domains and at all levels.
- Investment in training and education.
- Open collaboration with competent partners
  - Prestigious universities and research institutes.
  - Industrial partners for key technologies.
  - Learning from others, sharing the results freely.

III. Collaboration

CERN as an Example

CERN is an example of a unique international institute, a global research infrastructure, vital for large scale projects,

which in turn allow to support the sustainable development of science and technology necessary for the upturn and growth of everybody's economy

But CERN is only strong through its close collaboration with national institutes

Large International Collaborations

- A place where people learn to work together.
- Collaboration and competition.
- Diversity: good opportunity to recognize differences, accept them and learn to use them.
- Influence the way of thinking & planning.
- Information sharing: role of computing in internationalization and communication.
- Experience can be used by individuals and in other fields.

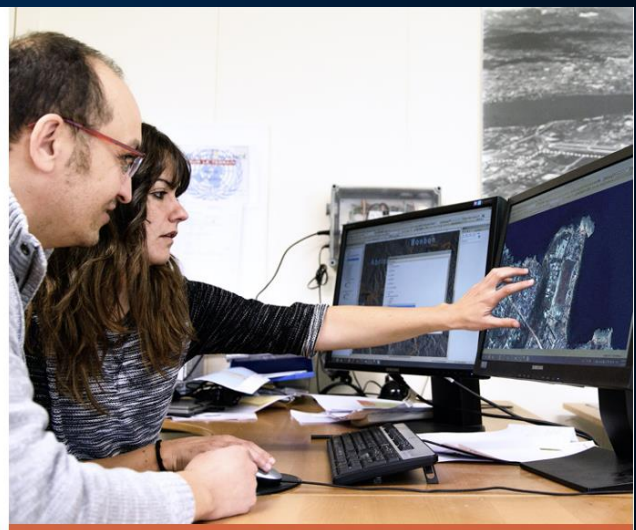
→ management through ‘common goals’

→ management by ‘convincing partners’

CERN is a model for open and inclusive collaboration

The LHC experiments are models of consensus building, competition and cooperation.

SESAME, a synchrotron light source in Jordan, is modelled on CERN's governance structure.



CERN provides the IT infrastructure for the satellite-analysis technology used for emergency response.

CERN: founded in 1954: 12 European States
"Science for Peace"
Today: 23 Member States

Employees: ~2 635 staff, 756 fellows
Associates: ~11 399 users, 1 687 others
Budget (2021) ~ 1 200 MCHF

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

Associate Members in the Pre-Stage to Membership: Cyprus, Estonia, Slovenia

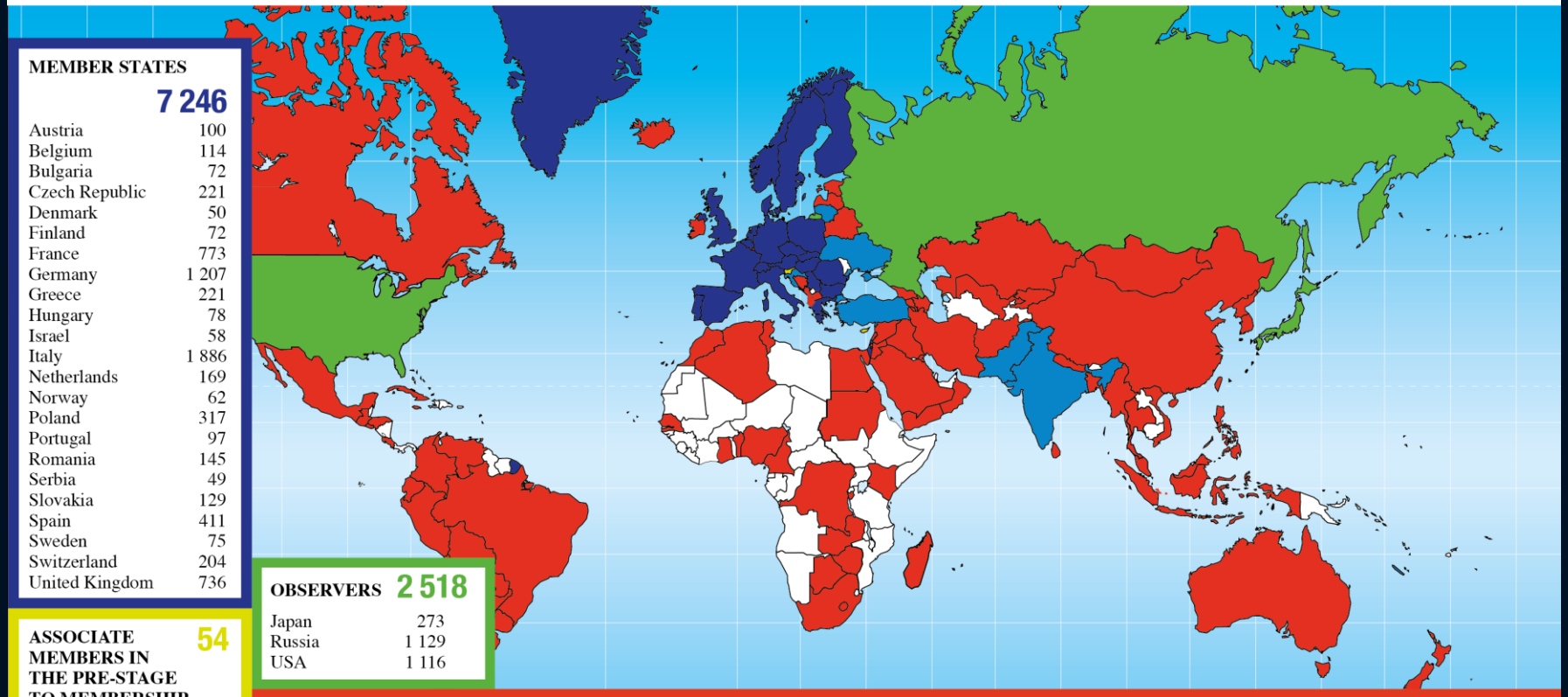
Associate Member States: Croatia, India, Lithuania, Pakistan, Turkey, Ukraine

Applications for Membership or Associate Membership: Brazil, Latvia

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

Science is getting more and more global

Distribution of All CERN Users by Nationality on 31 December 2019



MEMBER STATES **7 246**

Austria	100
Belgium	114
Bulgaria	72
Czech Republic	221
Denmark	50
Finland	72
France	773
Germany	1 207
Greece	221
Hungary	78
Israel	58
Italy	1 886
Netherlands	169
Norway	62
Poland	317
Portugal	97
Romania	145
Serbia	49
Slovakia	129
Spain	411
Sweden	75
Switzerland	204
United Kingdom	736

ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP **54**

Cyprus	21
Slovenia	33

ASSOCIATE MEMBERS **771**

Croatia	46
India	370
Lithuania	31
Pakistan	63
Turkey	164
Ukraine	97

OBSERVERS **2 518**

Japan	273
Russia	1 129
USA	1 116

OTHERS **1 837**

Albania	4	Bolivia	2	Ecuador	10	Iraq	1	Malaysia	19	Palestine	7	Taiwan	47
Algeria	9	Bosnia & Herzegovina	2	Egypt	26	Ireland	14	Malta	5	Paraguay	1	Thailand	23
Argentina	22	Bostwana	1	El Salvador	1	Jamaica	1	Mexico	81	Peru	6	Tunisia	5
Armenia	18	Brazil	121	Estonia	16	Jordan	1	Mongolia	2	Philippines	3	Uruguay	1
Australia	29	Burundi	1	Georgia	53	Kazakhstan	12	Montenegro	8	Saint Kitts and Nevis	1	Uzbekistan	3
Azerbaijan	8	Cameroon	1	Ghana	1	Kenya	1	Morocco	26	Saudi Arabia	3	Venezuela	10
Bahrain	3	Canada	161	Gibraltar	1	Korea	158	Myanmar	1	Senegal	1	Viet Nam	9
Bangladesh	5	Chile	20	Guatemala	1	Kyrgyzstan	1	Nepal	8	Singapore	4	Yemen	1
Belarus	49	China	570	Hong Kong	1	Latvia	4	New Zealand	6	South Africa	58	Zambia	1
Benin	1	Colombia	36	Honduras	1	Lebanon	23	Nigeria	2	Sri Lanka	6	Zimbabwe	2
		Congo	1	Iceland	5	Lesotho	1	North Korea	3	Sudan	2		
		Costa Rica	1	Indonesia	11	Luxembourg	3	North Macedonia	2	Syria	2		
		Cuba	16	Iran	48	Madagascar	1	Oman	1				

But there is more to it…..

Sustainable Development
needs trust,
trust between all people involved

Science for Peace

CERN

Conceived late 1940s – two aims:

- Enable construction of a facility for (then) nuclear and (now) particle physics research beyond the means of individual members
- Foster cooperation between peoples recently in conflict

SESAME

(Synchrotron-light for Experimental Science and Applications in the Middle East)

Conceived late 1990s – two aims:

- Enable construction of a facility for a broad range of scientific research beyond the means of individual members
- Foster cooperation between peoples

SESAME (Synchrotron-light for Experimental Science and Applications in the Middle East)

SESAME is a synchrotron radiation facility in Allan (Jordan)

1) to promote scientific and technical excellence in the Middle East and beyond (and in particular to enable and achieve the return of scientists and engineers from the region)

Synchrotron radiation allows research in many areas, e.g. biology, physics, chemistry, archaeology, medicine, material science, environmental science, arts,…….

→ **Building scientific capacity**

SESAME is a synchrotron radiation facility in Allan (Jordan)

2) to build scientific and cultural bridges between different societies in the Middle East and beyond

International Cooperation as example of peaceful cooperation

Pakistan

Key Message (III)

International collaboration is mandatory in many areas today, not only in science

- It needs trust between partners
- It needs commitment, and sustainability from all partners

Science shows: It is possible

IV. Education, Outreach and Training

Key Issue: Outreach and Education

- All countries need more scientists, engineers, staff, . . .

- targeted outreach activities
- encourage interest in careers in science

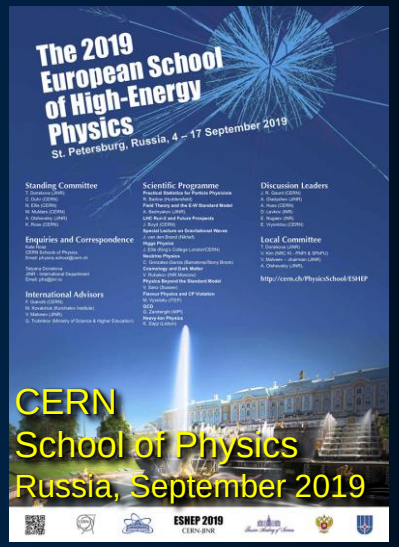
- Society needs to realize and appreciate science

- bring innovative science and exciting results (achieved at Research Infrastructures, Universities, etc), and their application to societal challenges, to the notice of society, and, in particular, to the schools

CERN Education Activities

Scientists at CERN
Academic Training Programme

Young Researchers
CERN School of High Energy Physics
CERN School of Computing
CERN Accelerator School



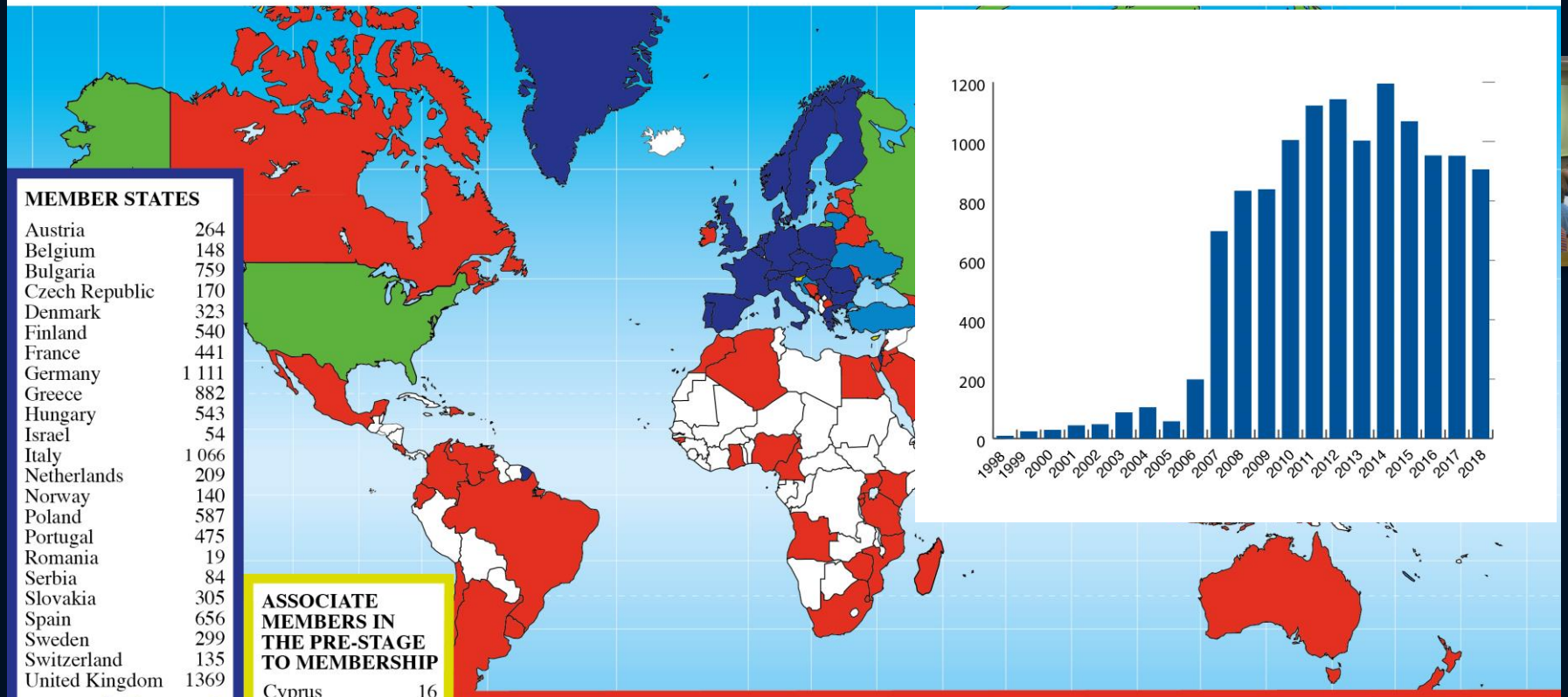
Undergraduates
Summer Students Programme

CERN Teacher Schools
International and National Programmes

Public visitors
150 thousand per year

CERN Teacher Programme

Teacher Programme Participants 1998 - 2019 (Total: 13 224)



MEMBER STATES

Austria	264
Belgium	148
Bulgaria	759
Czech Republic	170
Denmark	323
Finland	540
France	441
Germany	1 111
Greece	882
Hungary	543
Israel	54
Italy	1 066
Netherlands	209
Norway	140
Poland	587
Portugal	475
Romania	19
Serbia	84
Slovakia	305
Spain	656
Sweden	299
Switzerland	135
United Kingdom	1369

10 579

ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP

Cyprus	16
Slovenia	44

60

ASSOCIATE MEMBERS

Croatia	113
India	12
Lithuania	64
Pakistan	9
Turkey	364
Ukraine	206

768

OBSERVERS

Japan	12
Russia	431
USA	126

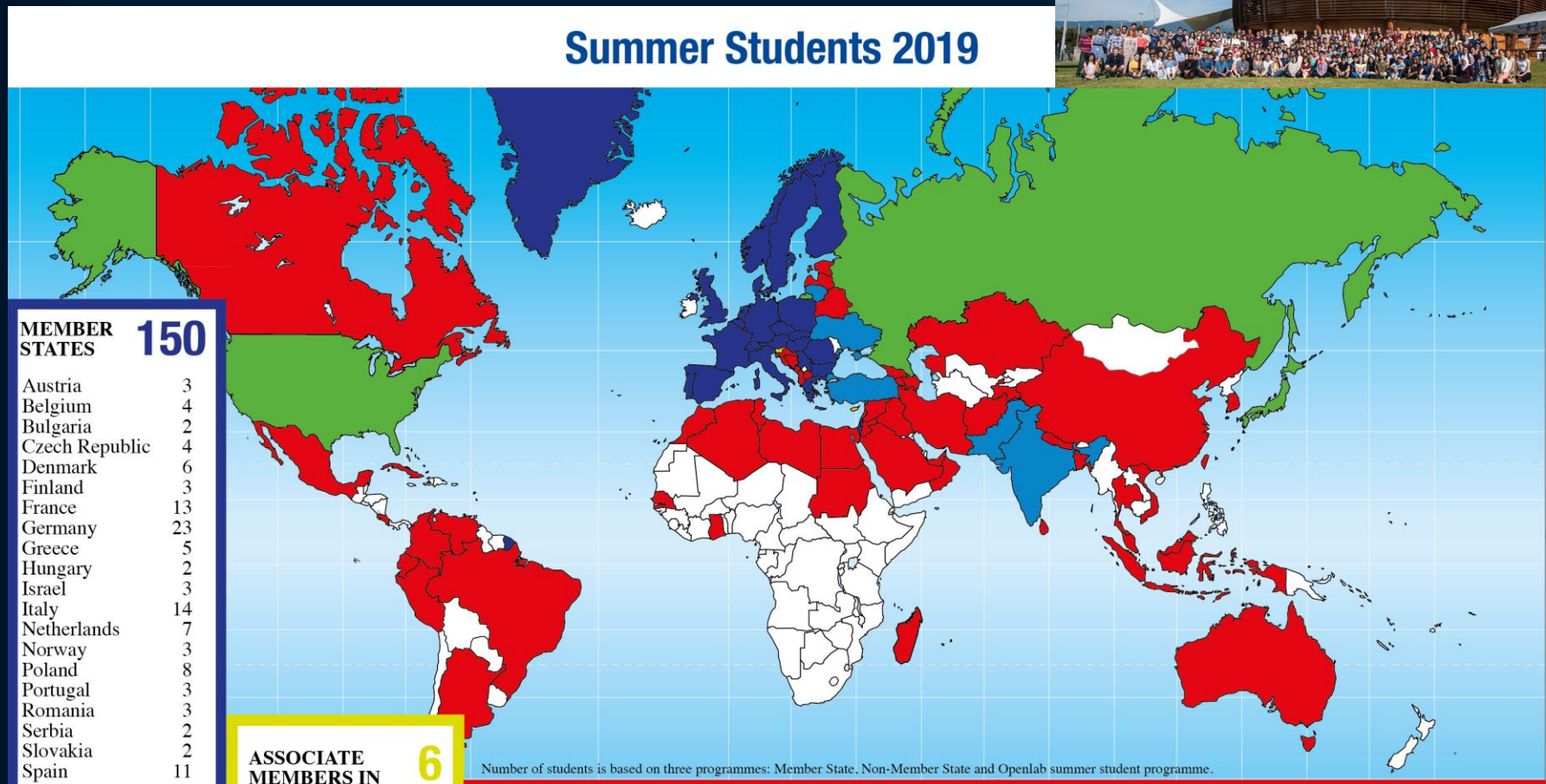
569

OTHERS

Algeria	11	Brazil	252	Estonia	105	Kuwait	1	Nepal	4	Sri Lanka	3
Angola	9	Burundi	2	Eswatini	1	Latvia	76	New Zealand	4	Taiwan	1
Argentina	3	Cameroon	9	Georgia	173	Lebanon	21	Nigeria	2	Tanzania	1
Armenia	3	Canada	17	Ghana	7	Madagascar	2	North Macedonia	13	Thailand	21
Australia	12	Cape Verde	4	Guinea Bissau	1	Malaysia	1	Palestine	5	Timor-Leste	9
Azerbaijan	2	Chile	4	Indonesia	3	Malta	51	Philippines	3	Uganda	3
Bahrain	3	China	3	Iran	13	Mexico	96	Qatar	1	U.A.E.	1
Bangladesh	1	Colombia	7	Ireland	9	Moldova	4	Rwanda	20	Uruguay	3
Belarus	11	Costa Rica	4	Jordan	13	Mongolia	1	Sao Tome	7	Venezuela	1
Bosnia and Herzegovina	11	Dominican Rep.	73	Kazakhstan	14	Montenegro	16	Saudi Arabia	1	Vietnam	2
		Ecuador	2	Kenya	4	Morocco	2	Singapore	2	Zimbabwe	1
		Egypt	3	Korea	49	Mozambique	22	South Africa	9		

1 248

Summer Students 2019



MEMBER STATES 150

Austria	3
Belgium	4
Bulgaria	2
Czech Republic	4
Denmark	6
Finland	3
France	13
Germany	23
Greece	5
Hungary	2
Israel	3
Italy	14
Netherlands	7
Norway	3
Poland	8
Portugal	3
Romania	3
Serbia	2
Slovakia	2
Spain	11
Sweden	7
Switzerland	5
United Kingdom	17

ASSOCIATE MEMBERS 24

India	13
Lithuania	2
Pakistan	4
Turkey	3
Ukraine	2

ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP 6

Cyprus	4
Slovenia	2

OBSERVERS 34

Japan	4
Russia	10
USA	20

OTHERS

Afghanistan	1	Bolivia	1	Egypt	4	Kuwait	1	Nepal	1	Tajikistan	1
Albania	1	Bosnia & Herzegovina	1	Estonia	2	Latvia	1	North Macedonia	1	Thailand	4
Algeria	4	Brazil	4	Georgia	1	Lebanon	3	Oman	1	Tunisia	2
Argentina	1	Canada	6	Ghana	1	Libya	1	Palestine	2	U.A.E.	1
Armenia	1	Chile	1	Hong Kong	2	Madagascar	1	Peru	1	Venezuela	1
Australia	1	China	10	Indonesia	1	Malaysia	3	Saudi Arabia	1	Viet Nam	1
Azerbaijan	2	Colombia	1	Iran	2	Malta	3	Singapore	2	Yemen	1
Bahrain	2	Costa Rica	4	Iraq	1	Mauritius	1	Sri Lanka	4		
Bangladesh	2	Croatia	4	Jordan	1	Mexico	1	Sudan	1		
Belarus	1	Cuba	2	Kazakhstan	3	Moldova	1	Syrian Arab Republic	1		
		Ecuador	3	Korea	2	Montenegro	4				
				Kosovo	1	Morocco	1	Taiwan	1		

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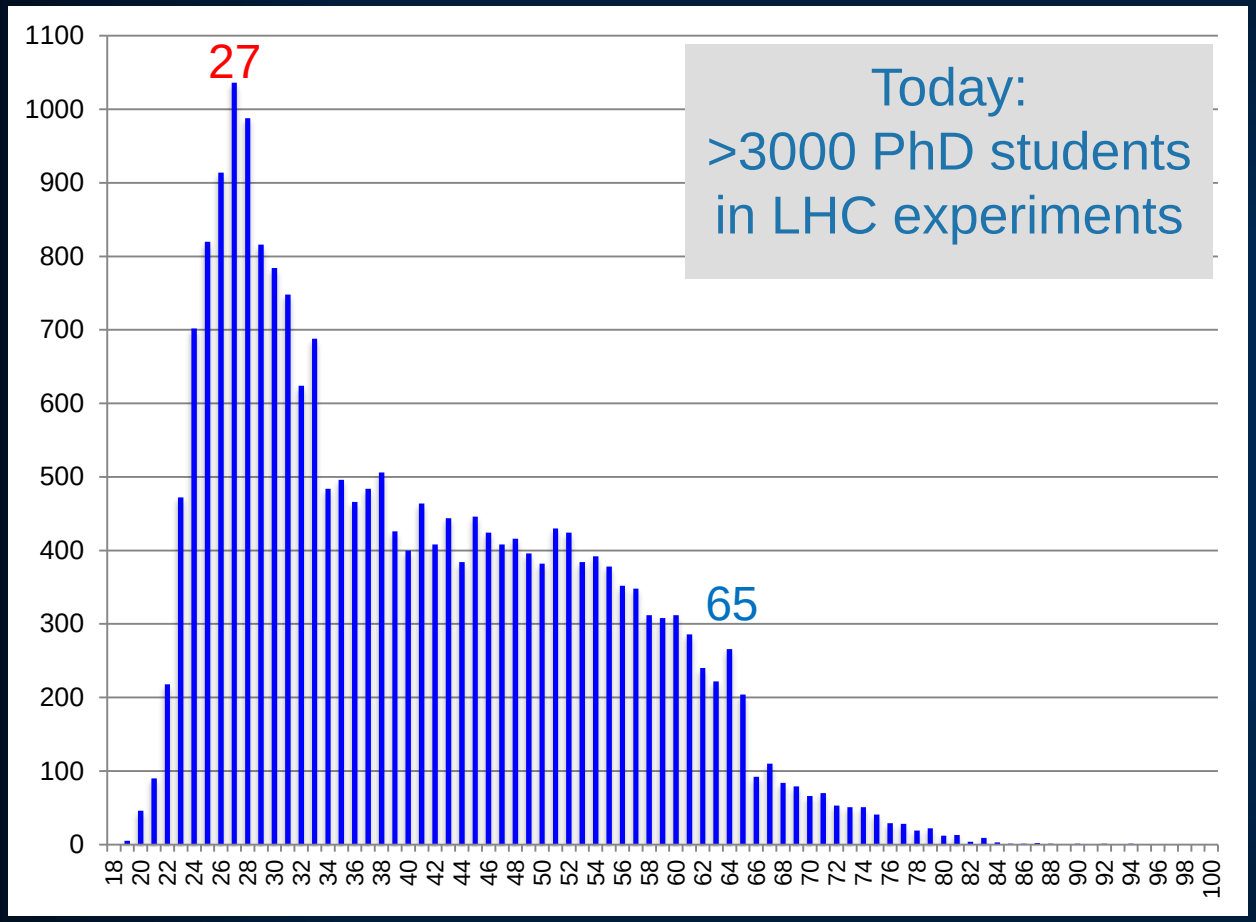
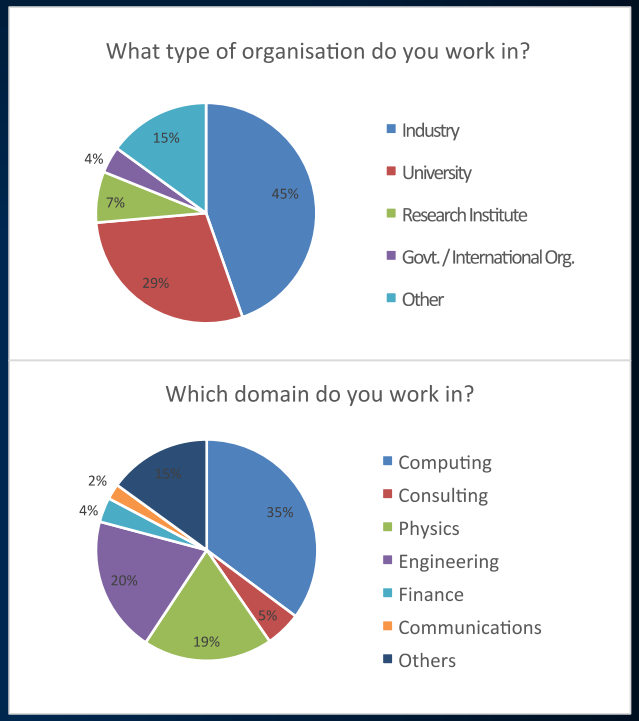
Age Distribution of Scientists
- and where they go afterwards





They do not all stay: where do they go?

Public Acceptance of Science

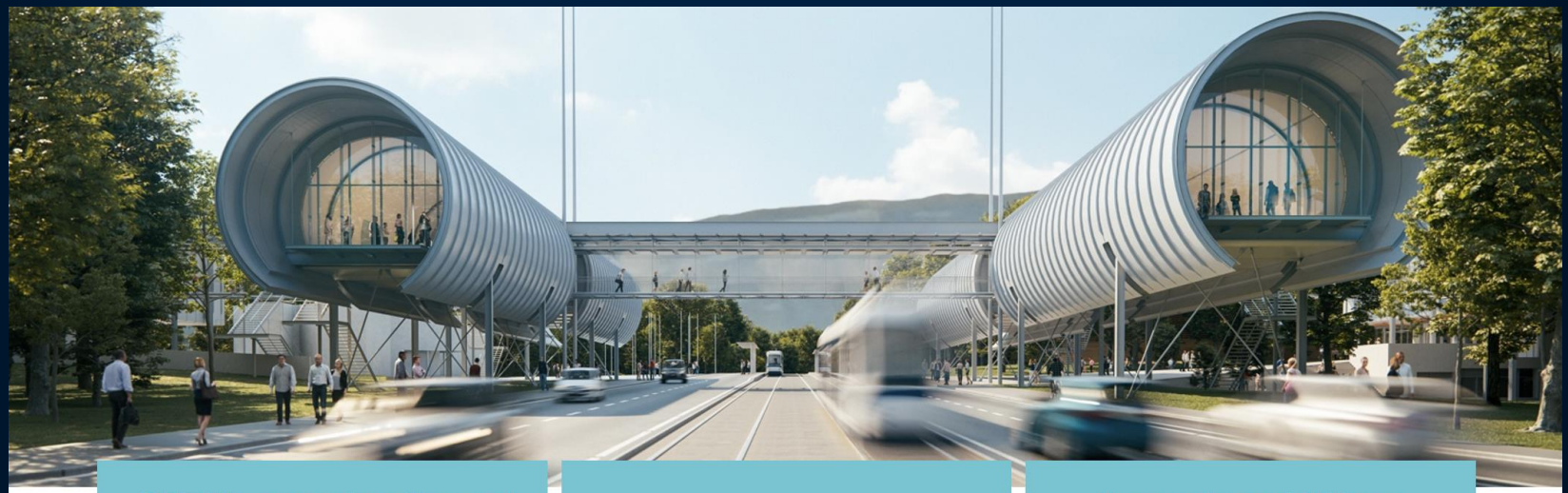
- Society needs to realize and appreciate science

- Bring innovative science and exciting results (achieved at Research Infrastructures, Universities, etc), and their application to societal challenges, to the notice of society, and, in particular, to the schools.

Key Message (IV)

Scientists need to be ambassadors of science

CERN Science Gateway



CERN's new education and outreach centre for all publics aged 5-plus.

Opening beginning of 2023.

Immersive exhibitions, education labs, events and shows.

V. Concluding Remarks

Science and Technology in the Next Decades

with strong sustained support for research,

with trust developed and kept between all partners,

with international collaboration,

with scientists as ambassadors for peaceful cooperation

will pave the way towards
a sustainable future

And finally….

- The relationship between basic research and sustainable progress is fundamental (contrary to common belief, technology does not sustain itself on the long term).
- In a globalized world, **knowledge** is becoming the **most important asset**.
- Developed countries are about to make a major strategic error by underestimating the value of fundamental research (whereas emerging countries are doing the opposite and catching up fast).

Last paragraph of the Editorial in The Guardian, 4 March 2015, on CERN/LHC

The search will invoke mini black holes, antimatter, quark-gluon plasma, and extra dimensions of space. The partnership so far has spun off colossal technological and computing rewards, but that is not the point. The point is that Europe is working together in a thrilling intellectual exploration that can have no conceivable commercial or political payoff but could, in some still intangible way, enlighten all humankind. In these otherwise murderous and mean-spirited times, that is something to salute.

Thank You!

CERN

Accelerating Science and Innovation