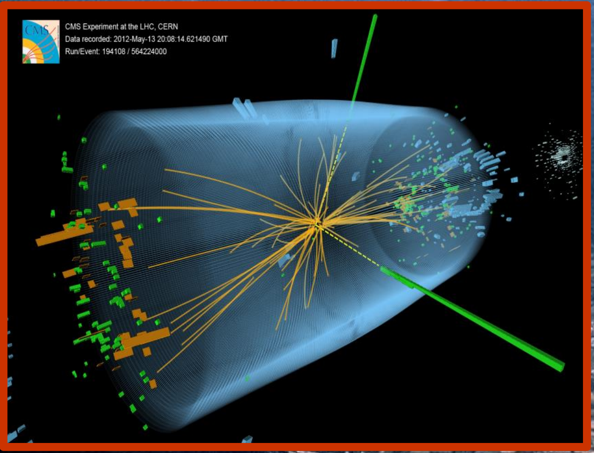
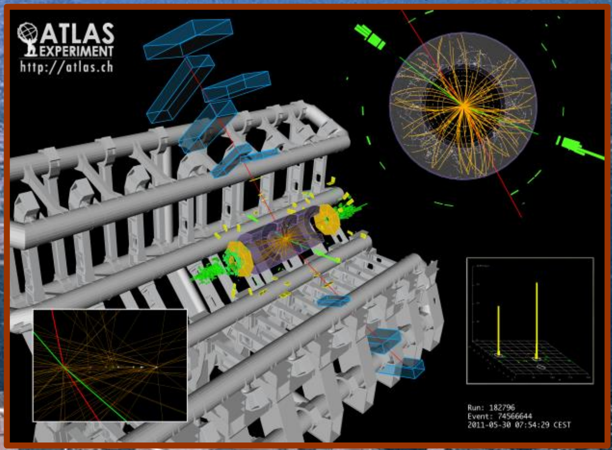




The LHC, the Higgs boson and our life

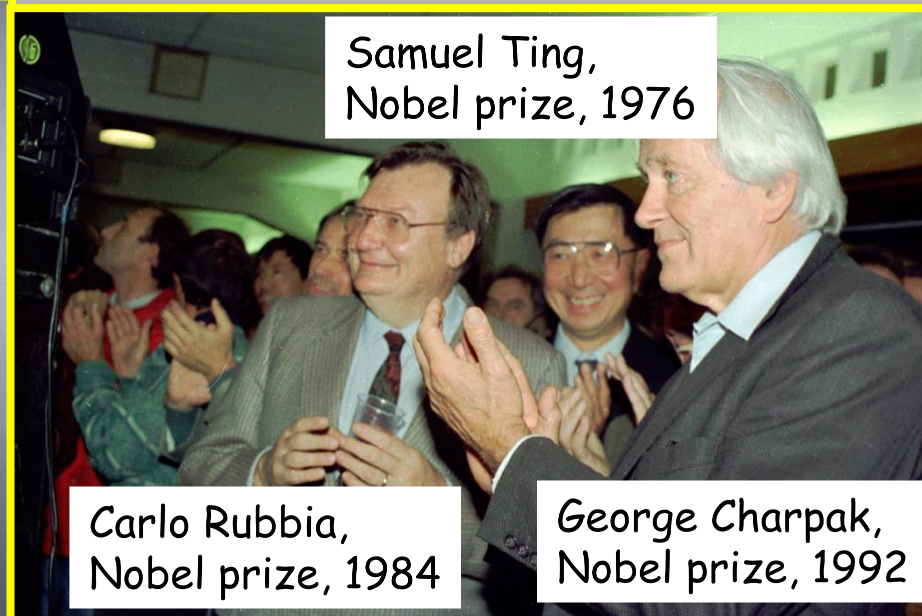
Fabiola Gianotti (CERN, Physics Department)

CERN : European Organization for Nuclear Research
The world's largest particle physics laboratory

More than 50 years of:

- fundamental research and discoveries (and Nobel prizes ...)
- technological innovation and technology transfer to society
  (e.g. the World Wide Web: 20th anniversary on 30 April)
- training and education (young scientists, school students and teachers)
- bringing the world together (10000 scientists from > 60 countries)

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 1954: 12 European States
Today: 20 Member States

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

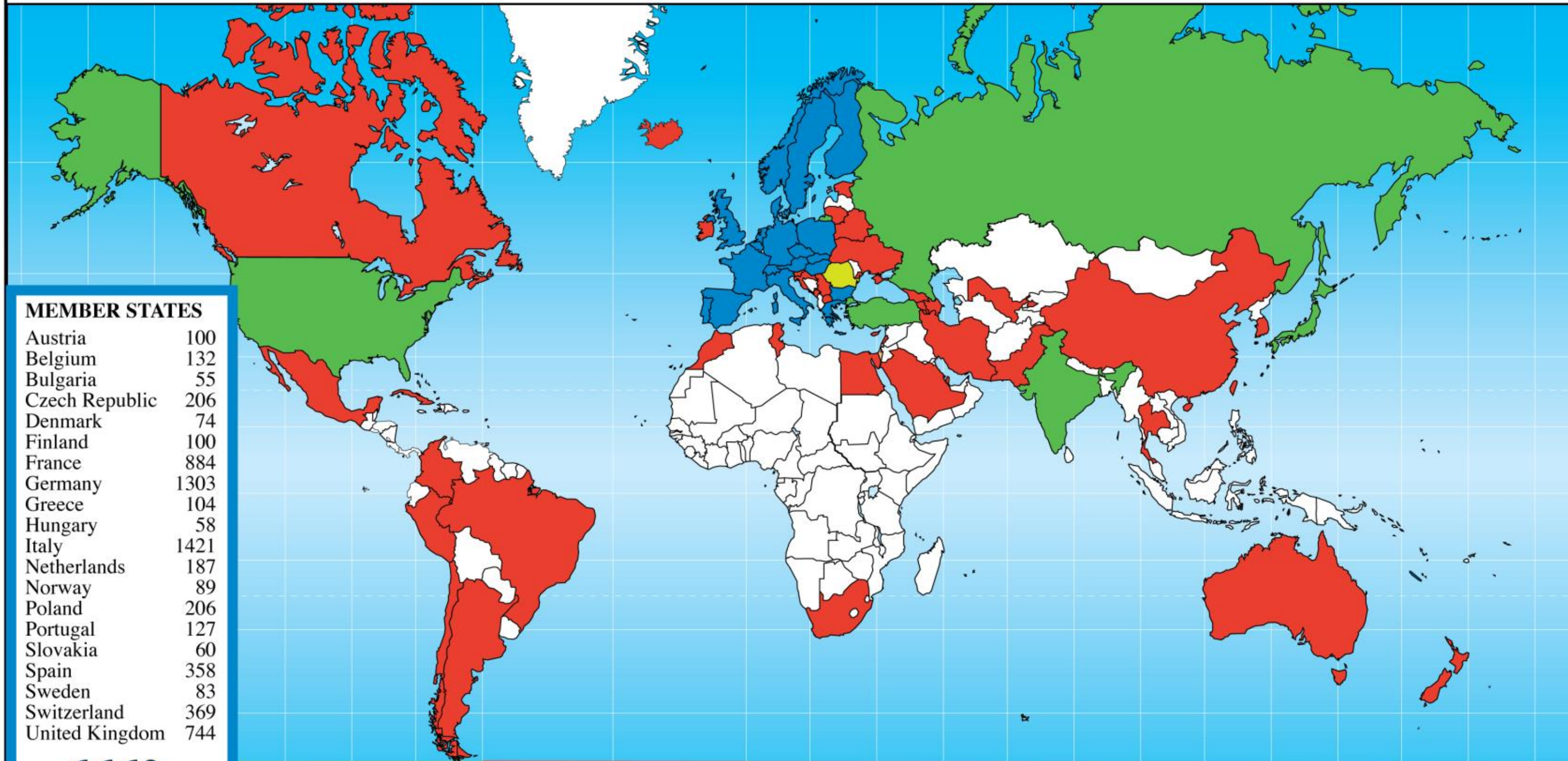
Observers: India, Japan, the Russian Federation, the United States of America, Turkey, the European Commission and UNESCO

Associate, in the pre-stage to membership: Israel

~ 2300 staff
> 10000 users
Budget (2012) ~1000 MCHF (→ ~ 1 cappuccino/citizen) : each Member State contributes in proportion to its income

More than 10000 users from > 60 countries

Distribution of All CERN Users by Nation of Institute on 9 January 2012



MEMBER STATES

Austria	100
Belgium	132
Bulgaria	55
Czech Republic	206
Denmark	74
Finland	100
France	884
Germany	1303
Greece	104
Hungary	58
Italy	1421
Netherlands	187
Norway	89
Poland	206
Portugal	127
Slovakia	60
Spain	358
Sweden	83
Switzerland	369
United Kingdom	744

6660

OBSERVERS

India	115
Japan	225
Russia	856
Turkey	77
USA	1708

2981

CANDIDATE FOR ACCESSION

Romania	75

ASSOCIATE MEMBER IN THE PRE-STAGE TO MEMBERSHIP

Israel	62

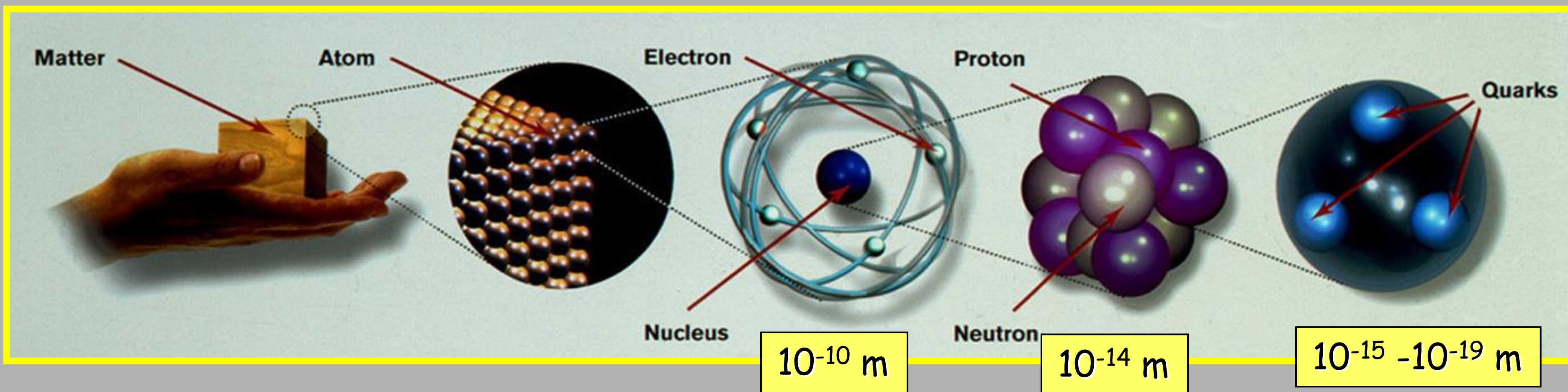
OTHERS

Argentina	18
Armenia	12
Australia	24
Azerbaijan	1
Belarus	22
Brazil	93
Canada	167
Chile	4
China	95
China (Taipei)	67
Colombia	10
Croatia	17
Cuba	4
Cyprus	9
Egypt	7
Estonia	18
Georgia	10
Iceland	3
Iran	14
Ireland	10
Korea	89
Lebanon	1
Lithuania	12
Malta	1
Mexico	43
Montenegro	1
Morocco	5
New Zealand	11
Pakistan	19
Peru	2
Qatar	1
Saudi Arabia	3
Serbia	26
Slovenia	37
South Africa	21
Thailand	5
T.F.Y.R.O.M.	2
Tunisia	1
Ukraine	21
Uzbekistan	1

907

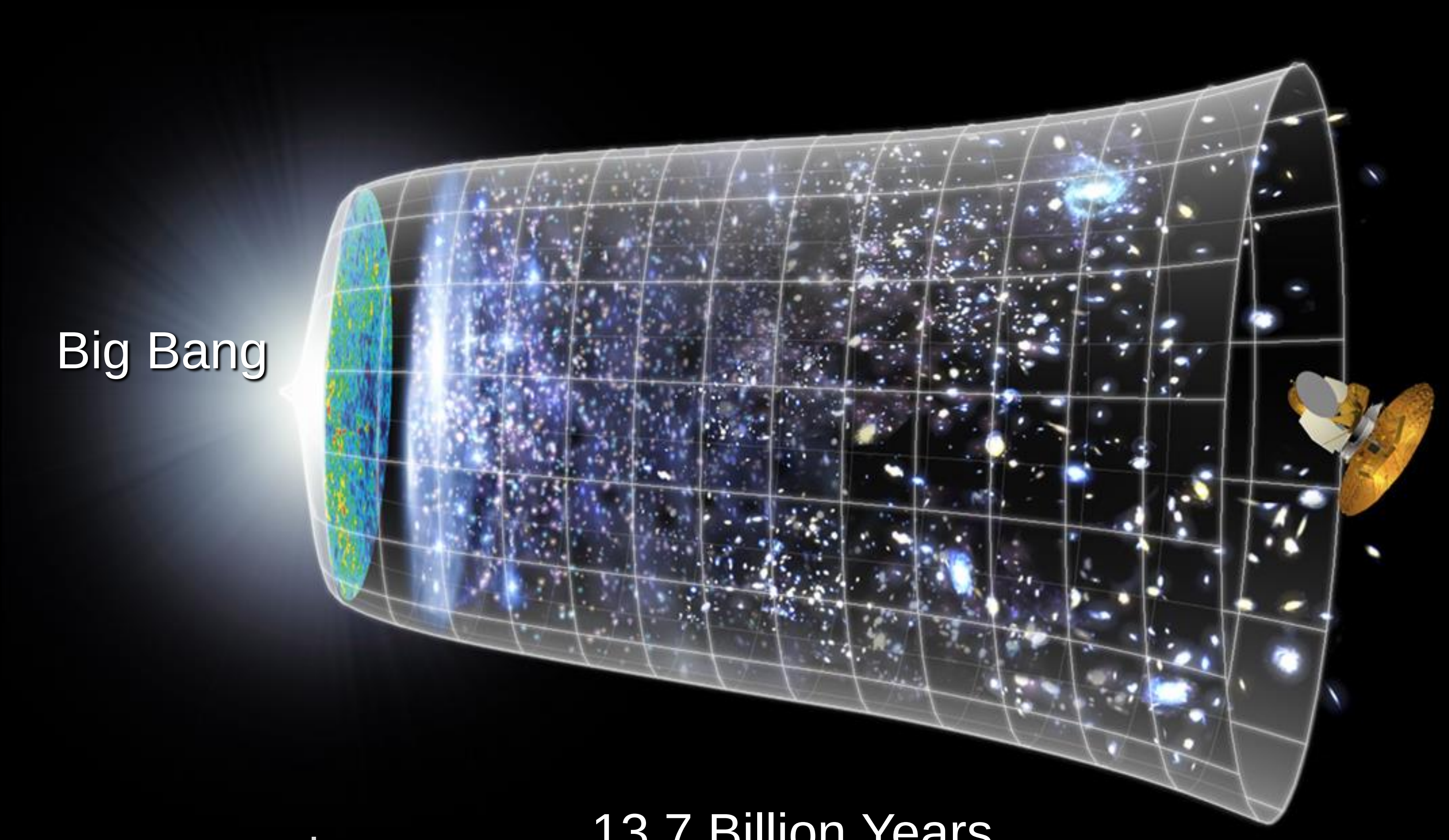
CERN's primary mission is SCIENCE

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



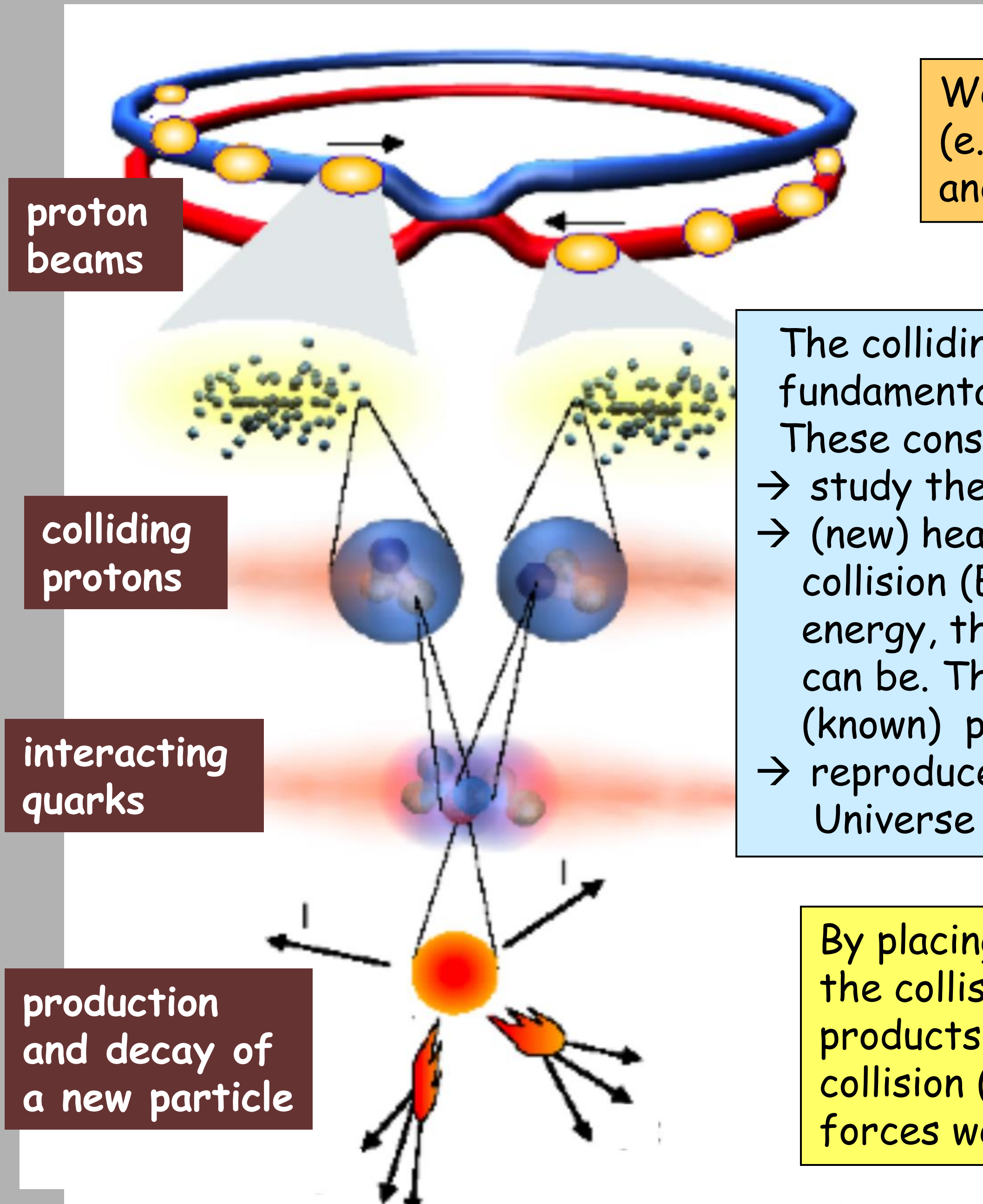
Particle physics at modern accelerators allows us to study the fundamental laws of nature on scales down to 10^{-19} m
→ insight also into the structure and evolution of the Universe
→ from the very small to the very big …

Evolution of the Universe



To study the elementary particles and their interactions:

We accelerate two beams of particles (e.g. protons) close to the speed of light and make them collide



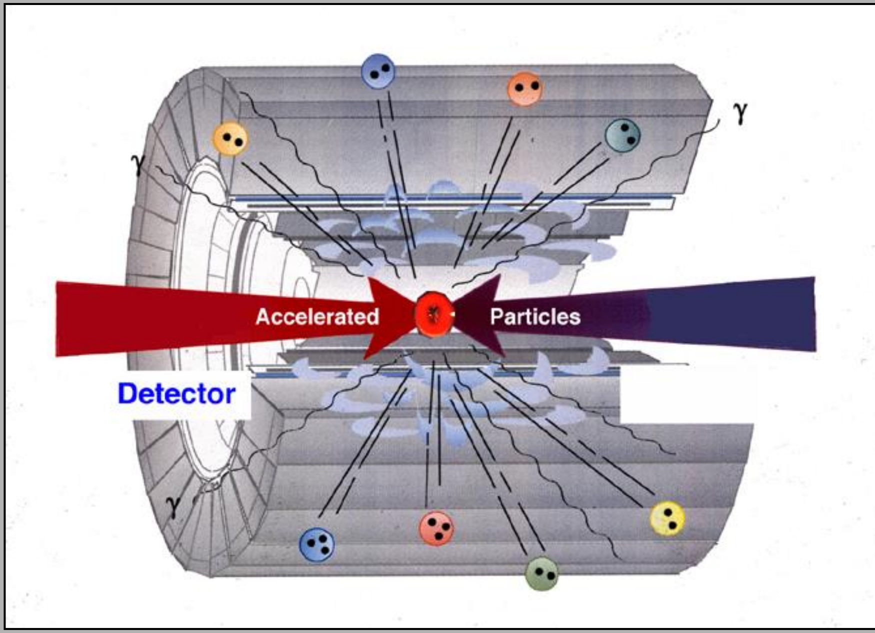
The colliding protons break into their fundamental constituents (e.g. quarks)
These constituents interact at high energy:

→ study the way fundamental matter behave
→ (new) heavy particles can be produced in the collision ($E=mc^2$). The higher the accelerator energy, the heavier the produced particles can be. These particles then decay into lighter (known) particles: electrons, photons, etc
→ reproduce the temperature (~10^{16} K) of the Universe a few instants (10^{-11} s) after the Big Bang

By placing high-tech powerful detectors around the collision point we can detect the collision products and reconstruct what happened in the collision (which phenomena, which particles and forces were involved, etc.)

Therefore, we need three things:

Accelerators: underground tunnels (usually rings) containing electric fields to accelerate particles to very high energy (incrementally at each turn), and magnets to bend the beams inside the ring and bring them into collision
Powerful giant microscopes to explore the smallest constituents of matter !!



Detectors: massive instruments which register the collision products and allow to identify the produced particles and measure their energy and trajectory.

Computing: to store, distribute and analyse the vast amount of data produced by the detectors and thus reconstruct the "event" occurred in the collision.

The Large Hadron Collider (LHC) at CERN

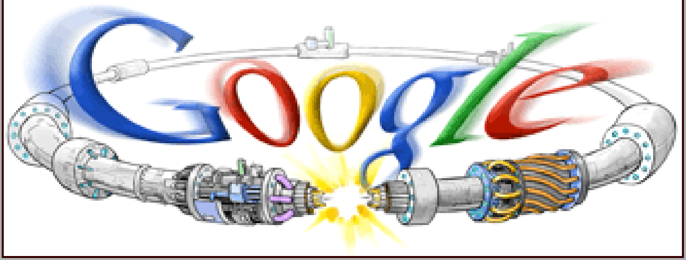
the most powerful accelerator

.... and also ....

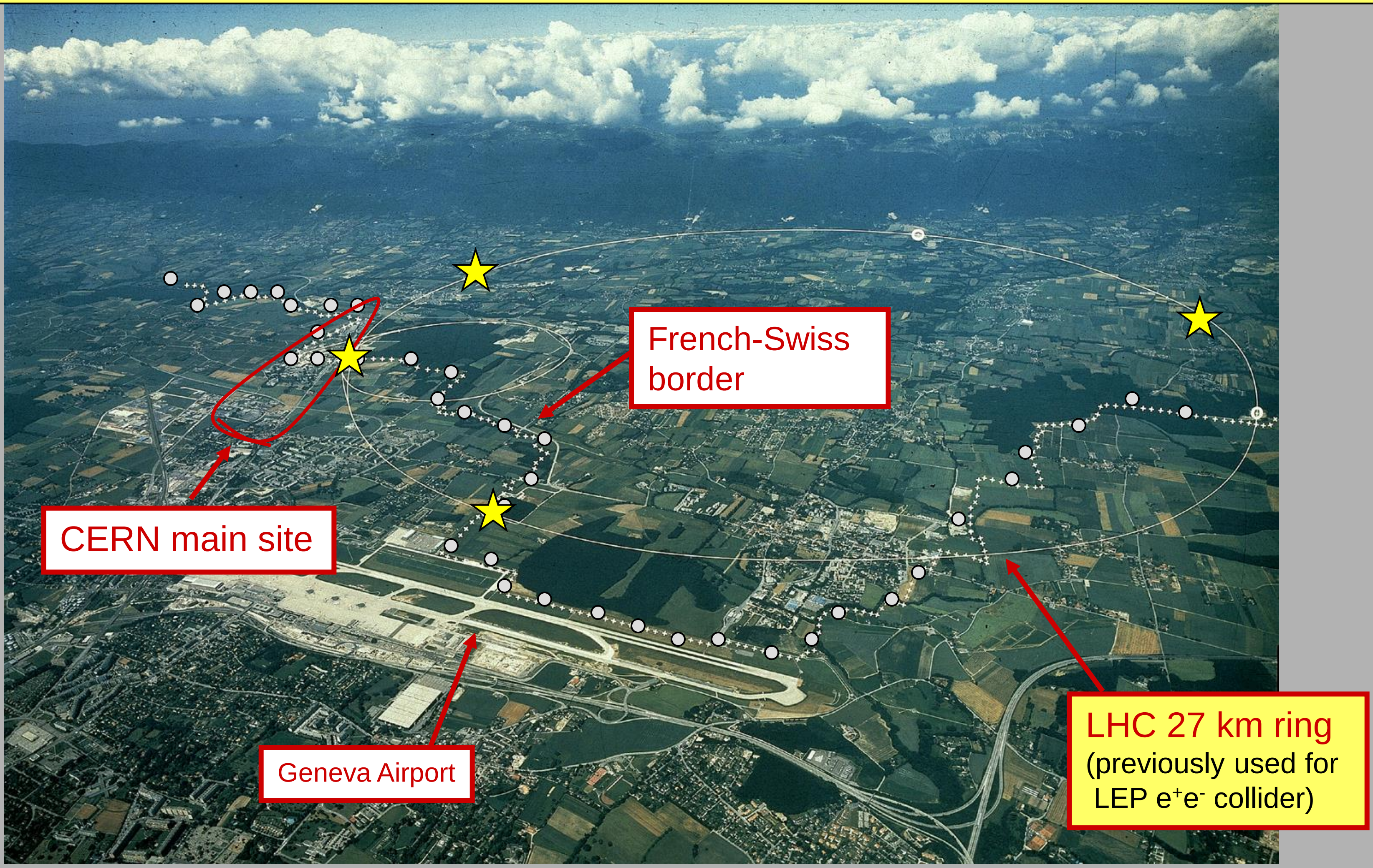
the most high-tech and complex detectors
the most advanced computing infrastructure
the most innovative concepts and technologies
(cryogenics, new materials, electronics, data transfer and storage, etc. etc…)
the widest international collaborations

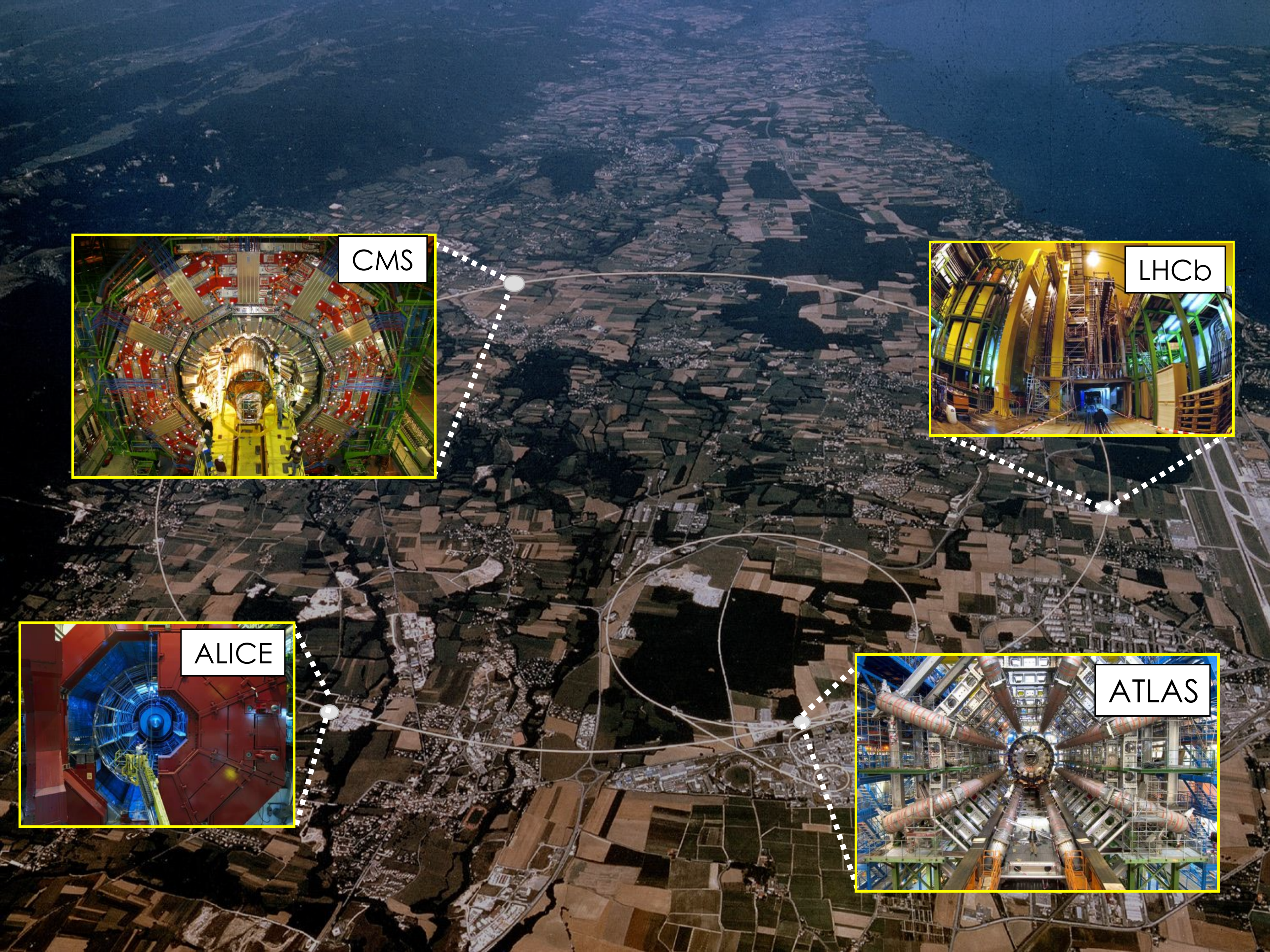
ever achieved in accelerator particle physics.
One of the most ambitious projects in science in general.

Operation started 20 November 2009
(> 20 years from concept to start of operation)
→ End of first data-taking period: February 2013



The LHC is a 27 km ring, 100 m below ground, across France/CH
Over the last three years, two high-energy proton beams have been circulating in opposite directions and colliding at 4 points, where 4 big experiments had been installed.
<u>Unprecedented collision energy</u>: 8 TeV (4 times larger than the Tevatron collider/Fermilab)

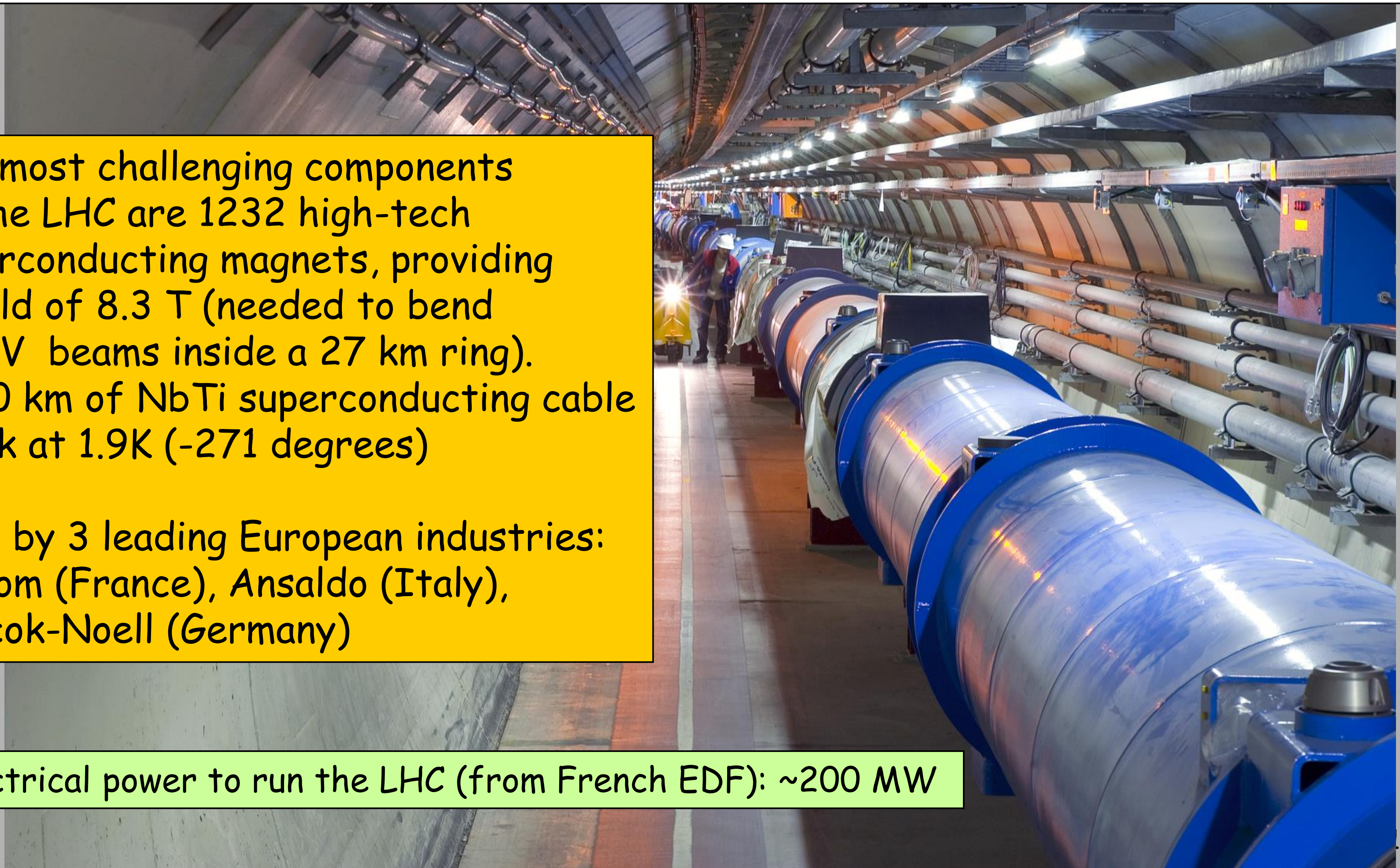



CMS
LHCb
ALICE
ATLAS

Unprecedented energy: 4 TeV per beam particle → collision energy = 8 TeV
(1 TeV= 10^{-7} Joule)

2015 → collision energy to ~ 14 TeV

Note: huge amount of energy concentrated in the collision point
(14 TeV corresponds to 10^{14} times the temperature in this room)
However: small energy on macroscopic scale (1 μJoule is just enough to swat a mosquito)



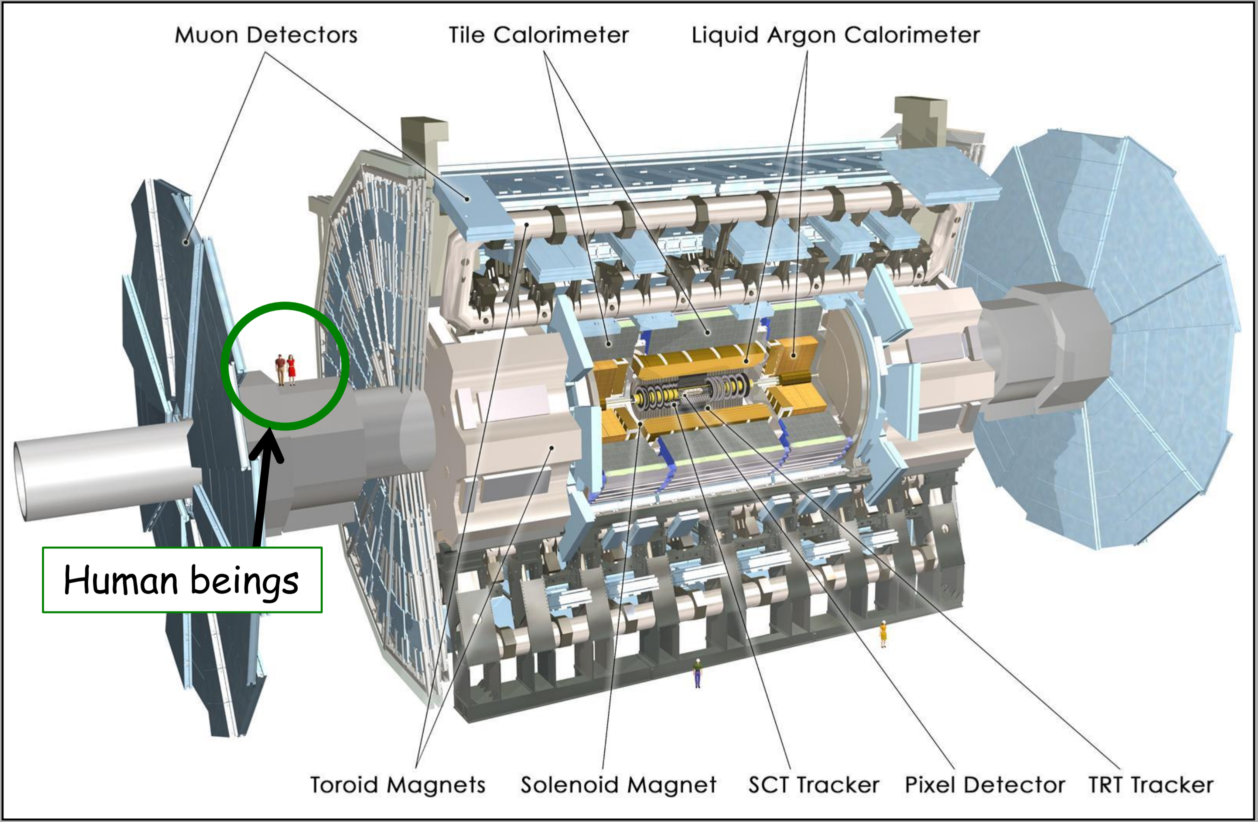
The most challenging components of the LHC are 1232 high-tech superconducting magnets, providing a field of 8.3 T (needed to bend 7 TeV beams inside a 27 km ring).
7600 km of NbTi superconducting cable
Work at 1.9K (-271 degrees)

Built by 3 leading European industries:
Alstom (France), Ansaldo (Italy), Babcok-Noell (Germany)

Electrical power to run the LHC (from French EDF): ~200 MW

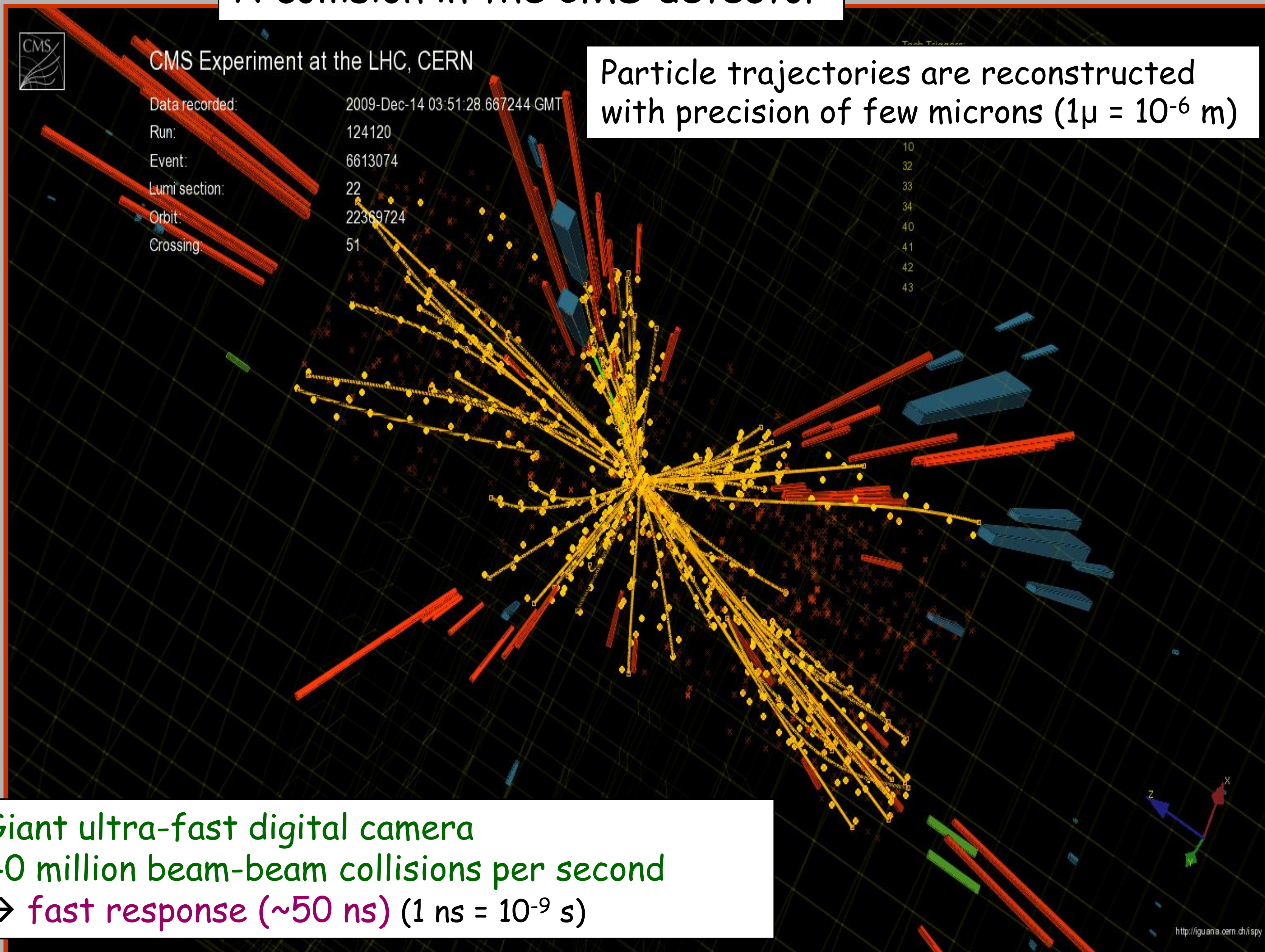
ATLAS

LHC detectors are much more complex, performing and challenging than those at previous/present accelerators
→ a big jump in concepts and technologies



- Size (length 45m, diameter 25m): to measure and absorb high-energy particles
- 10^8 sensors (providing "individual signals"): to track ~1000 particles per event and reconstruct their trajectories with ~10 μm precision (1 μm=10^{-6} m)

A collision in the CMS detector



Particle trajectories are reconstructed with precision of few microns ($1\mu = 10^{-6}$ m)

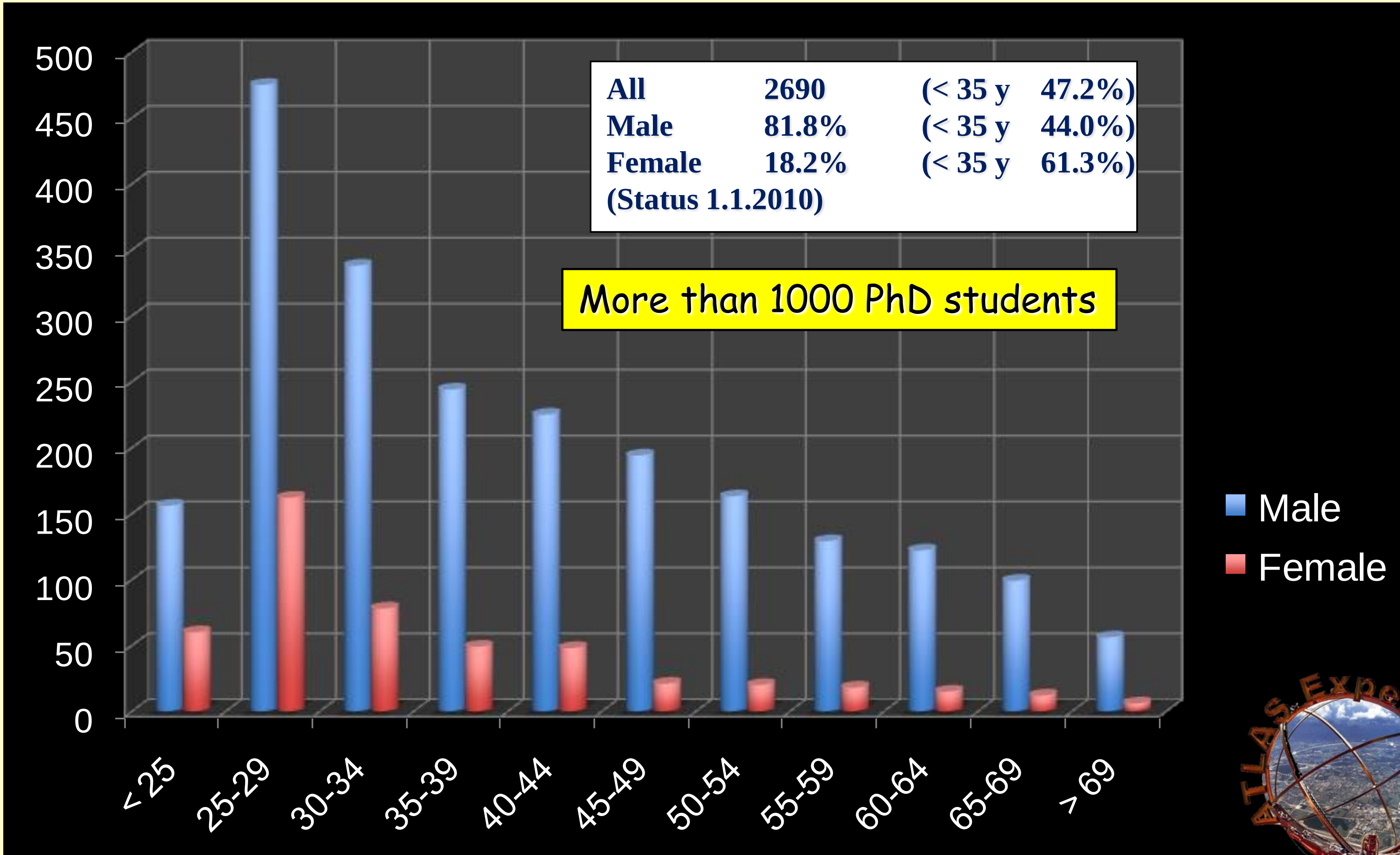
Giant ultra-fast digital camera
40 million beam-beam collisions per second
→ fast response (~50 ns) (1 ns = 10^{-9} s)

~ 3000 scientists from 177 Institutions from 38 Countries

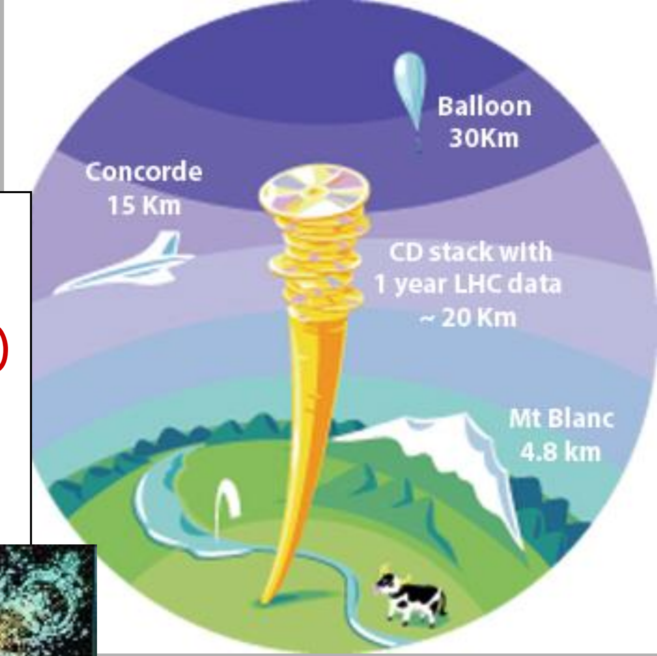
Argentina
Armenia
Australia
Austria
Azerbaijan
Belarus
Brazil
Canada
Chile
China
Colombia
Czech Republic
Denmark
France
Georgia
Germany
Greece
Israel
Italy
Japan
Morocco
Netherlands
Norway
Poland
Portugal
Romania
Russia
Serbia
Slovakia
Slovenia
South Africa
Spain
Sweden
Switzerland
Taiwan
Turkey
UK
USA
CERN
JINR

ATLAS Collaboration

Age distribution of the ATLAS population



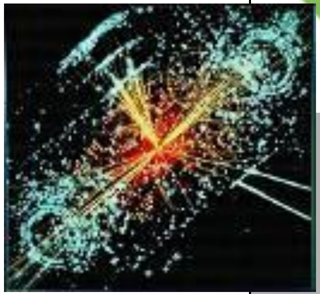
Computing



Each LHC experiment produces ~ 10 PB of data per year   1 PB=10^6 GB

This corresponds to ~ 20 million DVD (a 20 km stack …)

Data analysis requires computing power equivalent to ~100 000 today's fastest PC processors.



The experiment international Collaborations are spread all over the world → computing resources must be distributed.

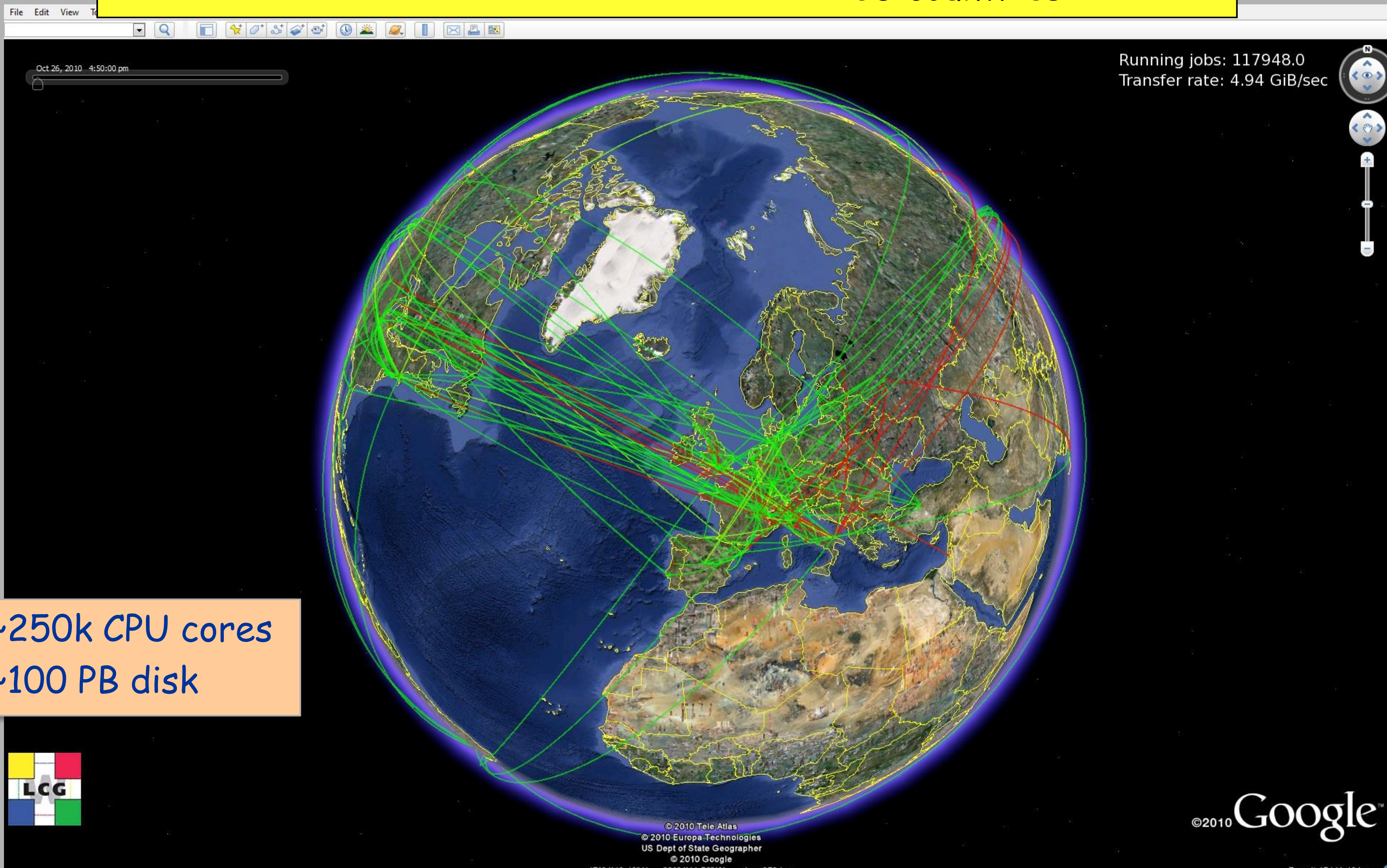
↓

Cooperation of many computer centres all over the world is needed →

Grid

The Grid provides seamless access to computing power and data storage capacity distributed over the globe

Worldwide LHC Computing Grid (WLCG): ~ 150 computing centres
~ 35 countries



~250k CPU cores
~100 PB disk

A few additional numbers .....

Number of turns of the LHC ring made by protons in one second: ~ 11000

Number of beam-beam collisions per second at design operation: 40 million
Beam cross section at the collision point: 16 μm (~ 4 times smaller than that of a typical a human hair)

Magnets work at 1.9K ... than outer space

Energy ... at 12 knots

The CM... on than the Tour Ei...

WHY ???

3000 km of cables used to transfer the signals from the ATLAS detector to the control rooms

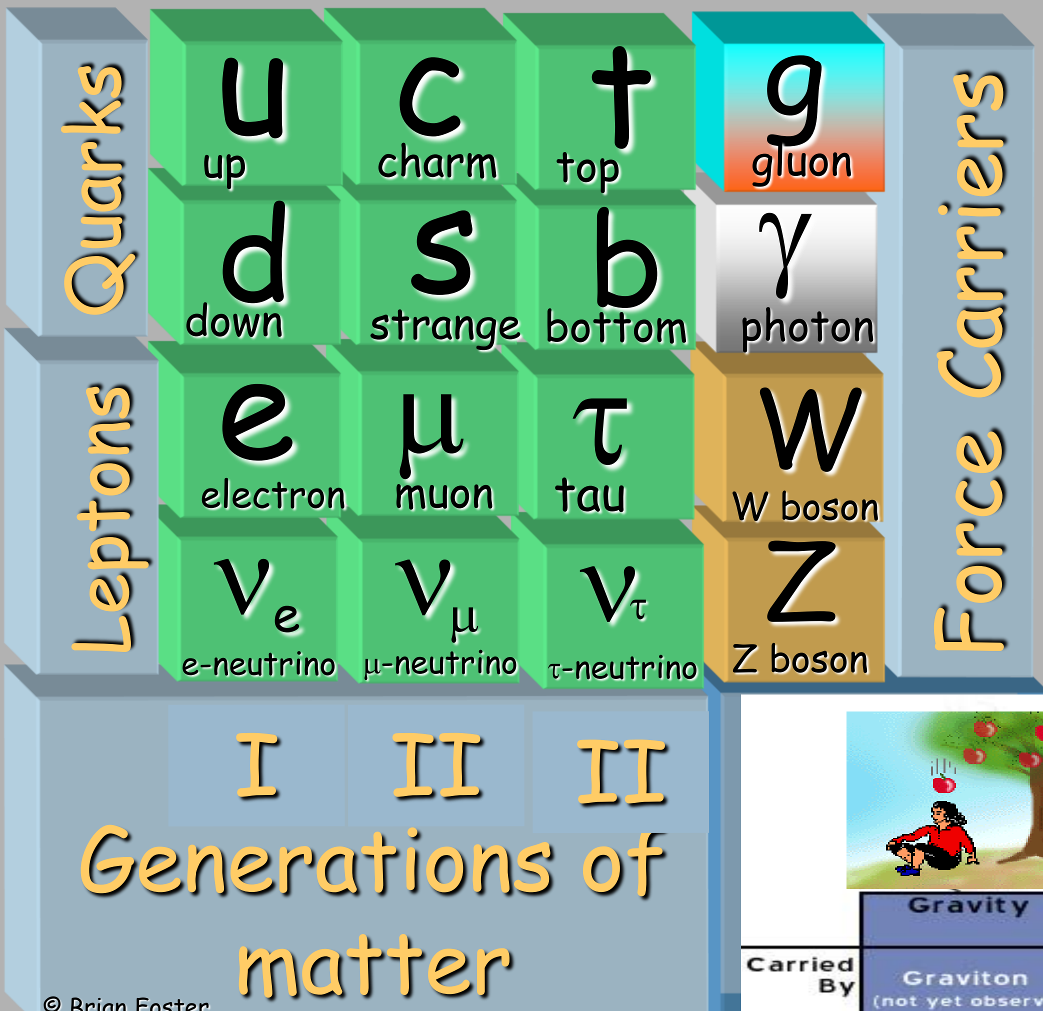
Each LHC experiment produces ~ 10 PB of data per year (1 PB=10^6 GB)
This corresponds to ~ 20 million DVD (a 20 km stack ...)

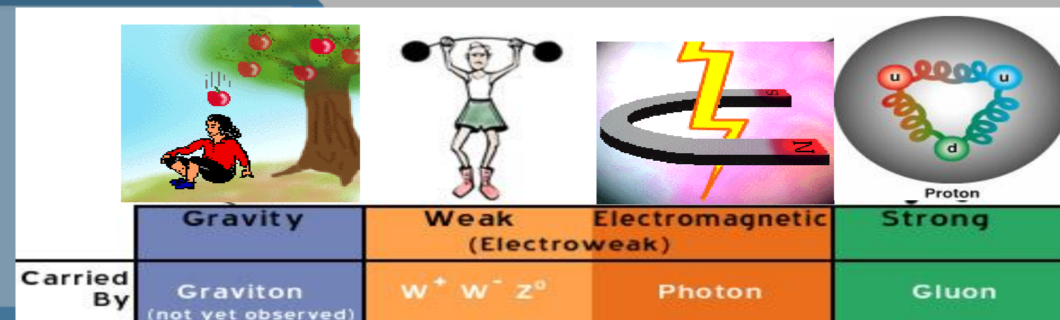
Cost: 6000 MCHF

Etc. etc.

The elementary particles and their interactions are described by a very successful theory: the Standard Model. All particles foreseen by the SM have been observed, and the SM predictions have been verified with extremely high precision over the last 35 years by experiments at CERN and at other labs all over the world

Particles and forces





On the other hand, several outstanding questions remain ….

What is the origin of the particle masses ? ✔	ATLAS, CMS
What is the nature of the Universe dark matter ?	ATLAS, CMS
Why is there so little antimatter in the Universe ? (Nature's favouritism allowed us to exist …)	LHCb
What are the features of the primordial plasma permeating the Universe ~10 μs after the Big Bang ?	ALICE
What happened in the first moments of the Universe life (10^{-11} s after the Big Bang) ?	ATLAS, CMS
Are there other forces in addition to the known four ? Are there additional (microscopic) space dimensions ?	ATLAS, CMS
Etc. etc.	

LHC built to address these and other fundamental questions

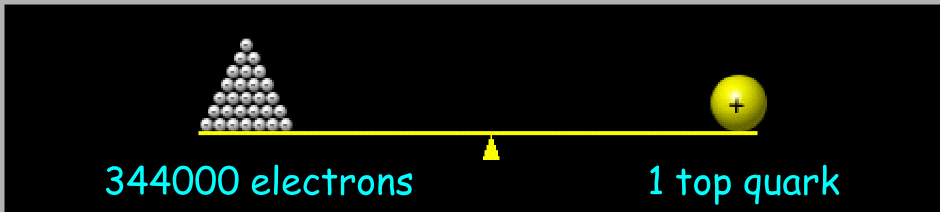
30 March 2010: first proton-proton collisions at an unprecedented energy → exploration of a new energy frontier starts

Since then:

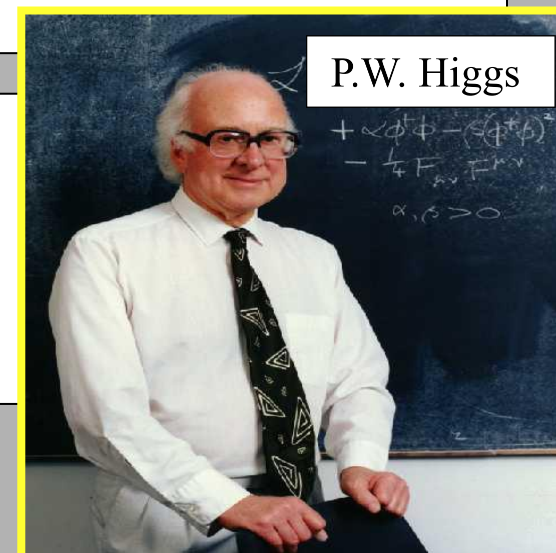
- The accelerator, detectors and computing performed beyond expectations
- Huge amount of data recorded and analyzed (ATLAS and CMS: ~5 billion each)
- The Standard Model and the known particles have been "rediscovered" and measured in the new energy regime
- Many physics scenarios beyond the Standard Model have been investigated and ruled out

July 2012: discovery by ATLAS and CMS of a new Higgs-~~like~~ particle with mass ~ 125 GeV (~ 130 proton masses)

What is the origin of the particle masses ?



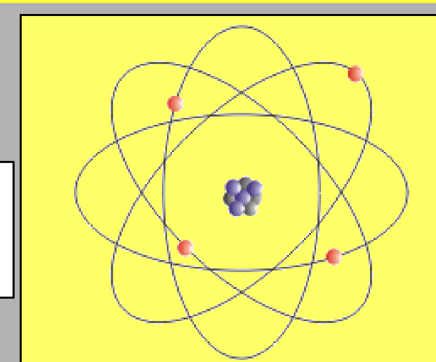
Mass of top quark (heaviest elementary particle observed) ≈ mass of Gold atom
Electron mass is ~350000 times smaller: why ???



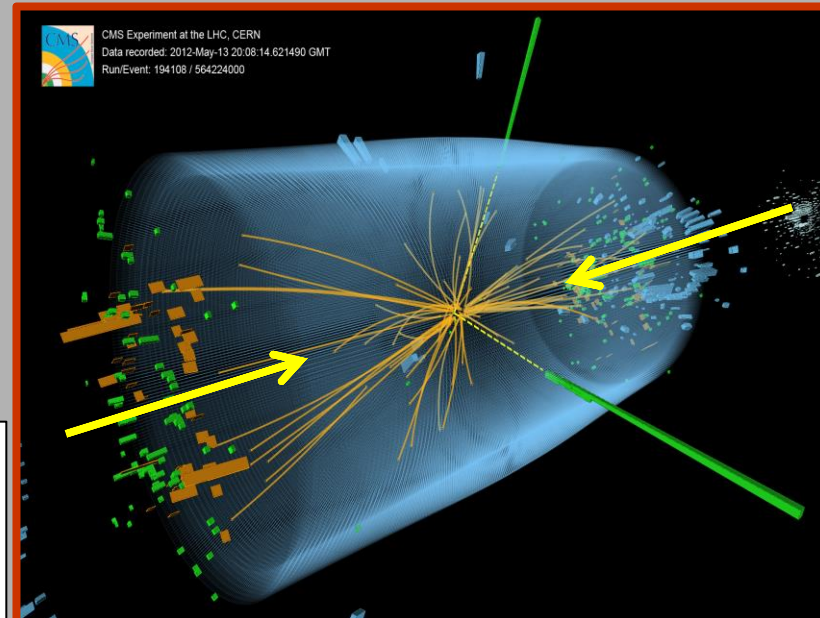
Proposed solution (Brout, Englert, Guralnik, Hagen, Higgs, Kibble):
"Higgs mechanism": origin of masses ~ 10^{-11} s after the Big Bang, when "Higgs field" became active → particles acquired masses proportional to the strength of their interactions with the Higgs field

Consequences: existence of a **Higgs boson**
This particle has been searched for > 30 years at accelerators all over the world
→ finally found at the LHC !

Note: a world without "Higgs" would be a very strange one !
Atoms may not exist, and the Universe would be very different

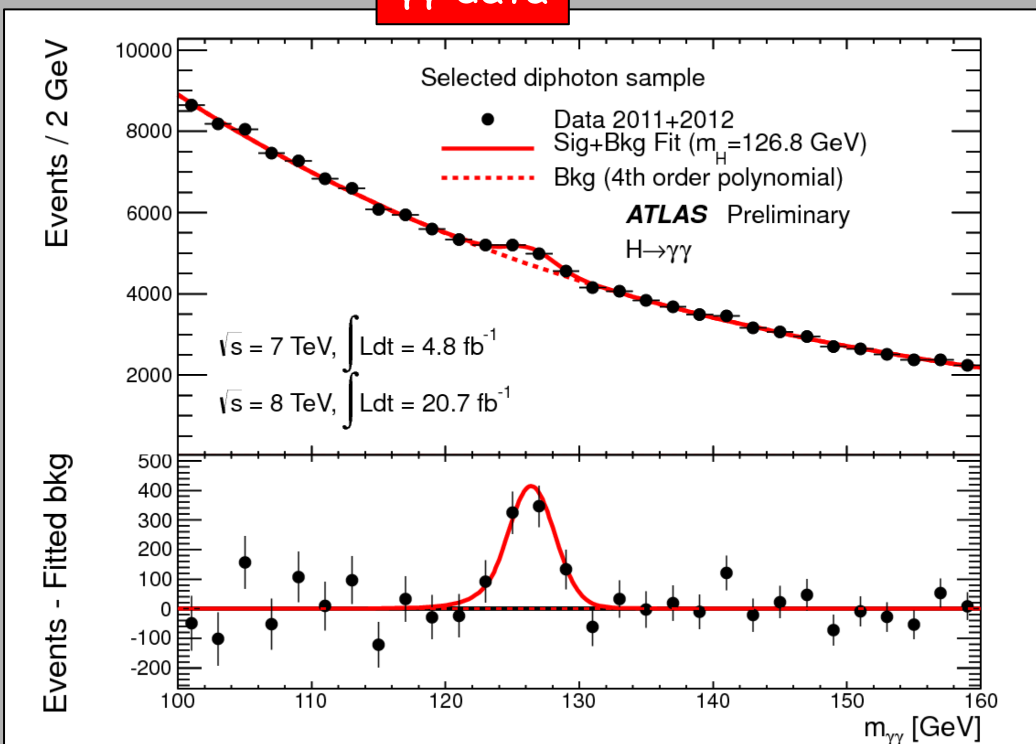


What did we observe ?



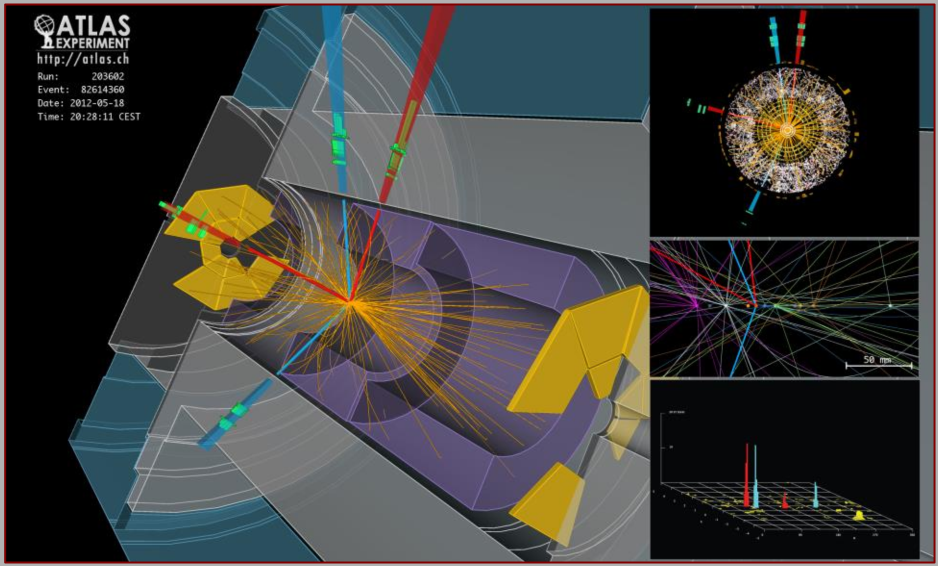
Once produced the Higgs boson is expected to disintegrate ("decay") into known particles, for instance into two photons → looked at the γγ spectrum in our data

γγ data

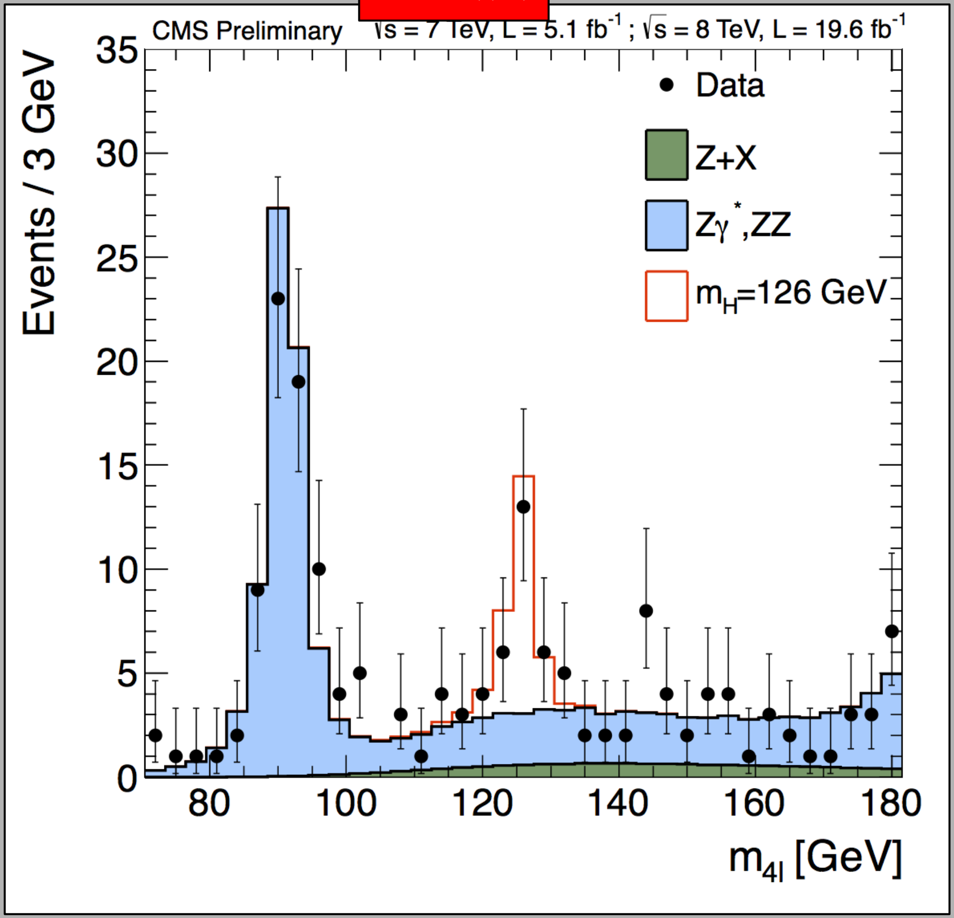


Peak ("resonance") at $m_{\gamma\gamma}$ around 125 GeV indicates the production of a (new) heavy particle

Higgs boson can also decay into 4 leptons (electrons, muons) :
→ looked at 4e, 4μ, 2e2μ spectrum in our data



4l data



A peak is observed also in this case at m_{4l} around 125 GeV

Higgs boson can also decay into 4 leptons (electrons, muons) :
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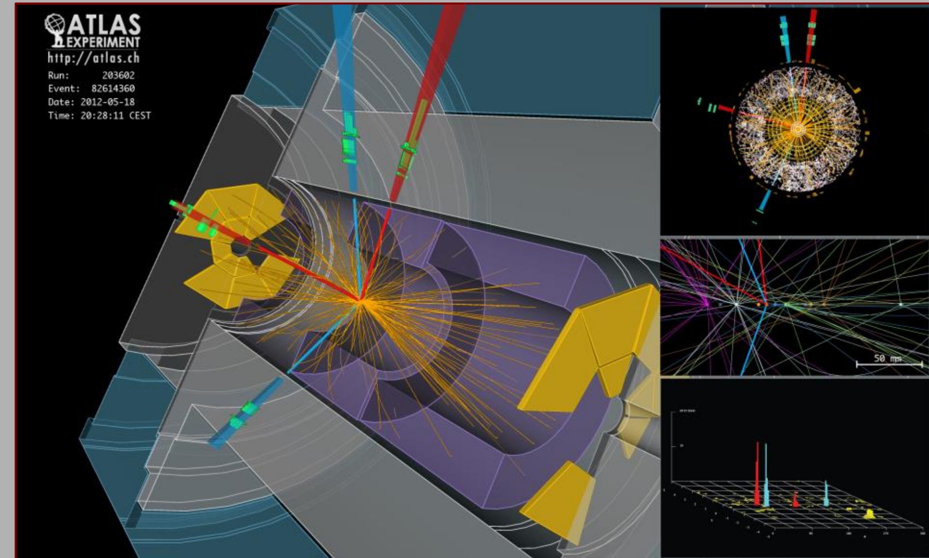
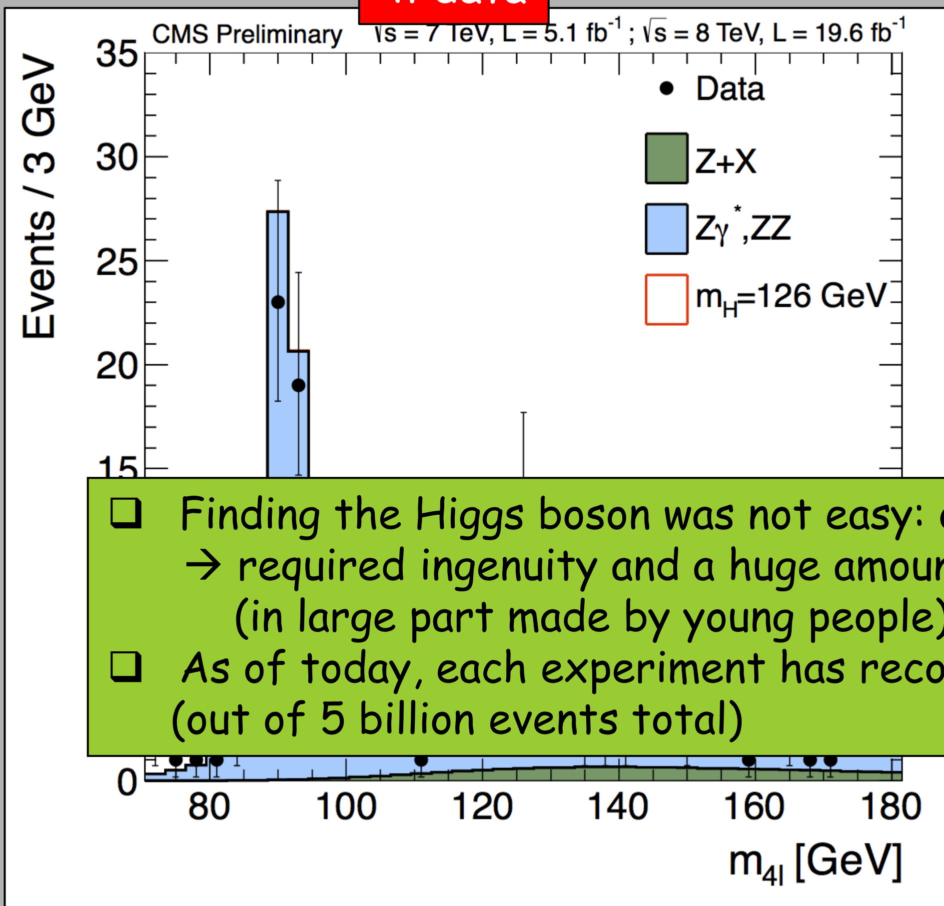


4l data



A peak is observed also in this case at m_{4l} around 125 GeV

- ❑ Finding the Higgs boson was not easy: one H→ 4e produced every 10^{13} pp collisions
  → required ingenuity and a huge amount of meticulous experimental work
  (in large part made by young people)
- ❑ As of today, each experiment has recorded about 700 Higgs events
  (out of 5 billion events total)

Three Frequently-Asked-Questions

1) Is this new particle the Standard Model Higgs boson ?

Present LHC measurements say it's A Higgs boson
However, too early to draw definite conclusions → we will need to measure its properties in detail in the months/years to come with present/future data to understand e.g. if it is THE SM Higgs boson or a more exotic object of a more general theory.

2) Is the task of the LHC over ?

No, this is just the beginning of the LHC exploration phase:

- the new particle needs more measurements and raises several questions (e.g. why is it so light ?)
- the LHC was built to address many more questions (dark matter, etc.), not only to find the Higgs

3) Will the Higgs boson change our day-by-day life ?

It did already !

From fundamental science to everyone's life

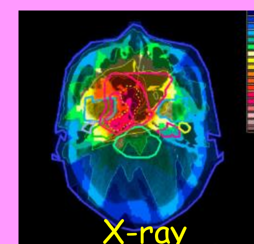
Extreme performance required in particle and nuclear physics → cutting-edge technologies developed at CERN and collaborating Institutes, and then transferred to society.

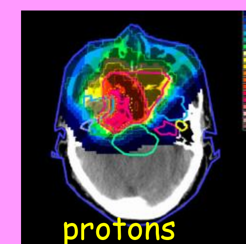
Applications: medical imaging (e.g. PET), cancer therapy, materials science, airport scanners, cargo screening, food sterilization, nuclear waste transmutation, analysis of historical relics, etc. …not to mention the WEB ..

Accelerating particle beams
~30'000 accelerators worldwide
~17'000 used for medicine

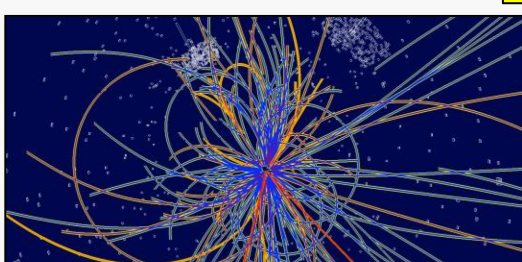
See talk by E. Garutti

Hadron Therapy





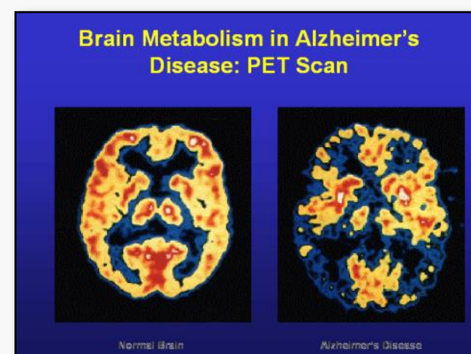
> 90000 patients treated worldwide (~40 facilities)



Detecting particles

Imaging

e.g. PET scanner



CERN and the LHC

- Seeking answers to fundamental questions about elementary particles and the Universe.
- Advancing the frontiers of technology (also to the benefit of society)
- Training (students, high-school teachers, young scientists)
- Bringing nations together through science
- A new era of discoveries has started with the exploration of an unprecedented energy scale at the LHC and the observation of a Higgs boson: a big step forward in fundamental science

Two final remarks:

- Fundamental knowledge is the fuel of progress
- Knowledge, as art, is among the highest expressions of human beings as clever beings

"Fatti non foste a viver come bruti ma per seguir virtute et conoscenza", Dante Alighieri (1265-1321), Divina Commedia, Inferno, Canto XXVI