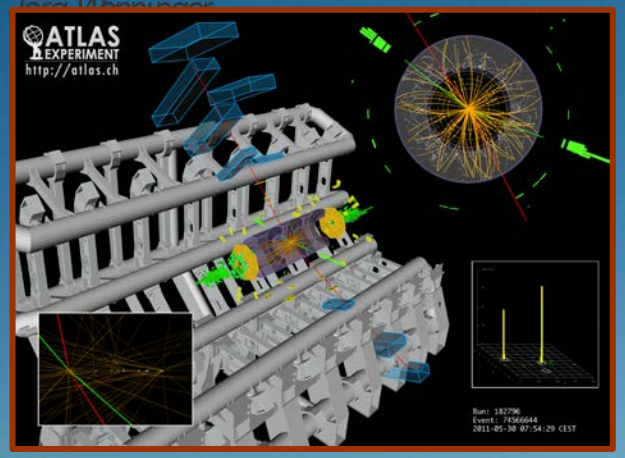
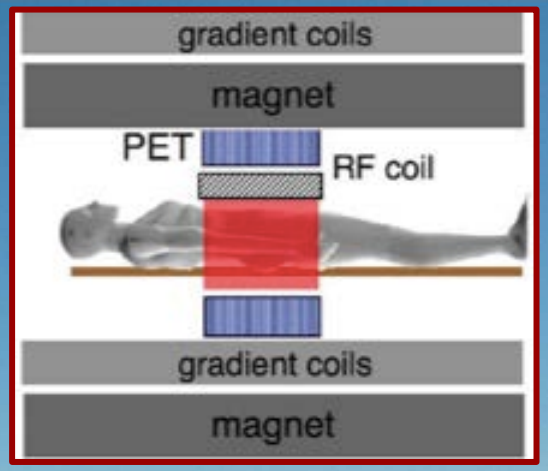




The Higgs boson and our life

Fabiola Gianotti (CERN, Physics Department)

We Are ~ Here →

LHC

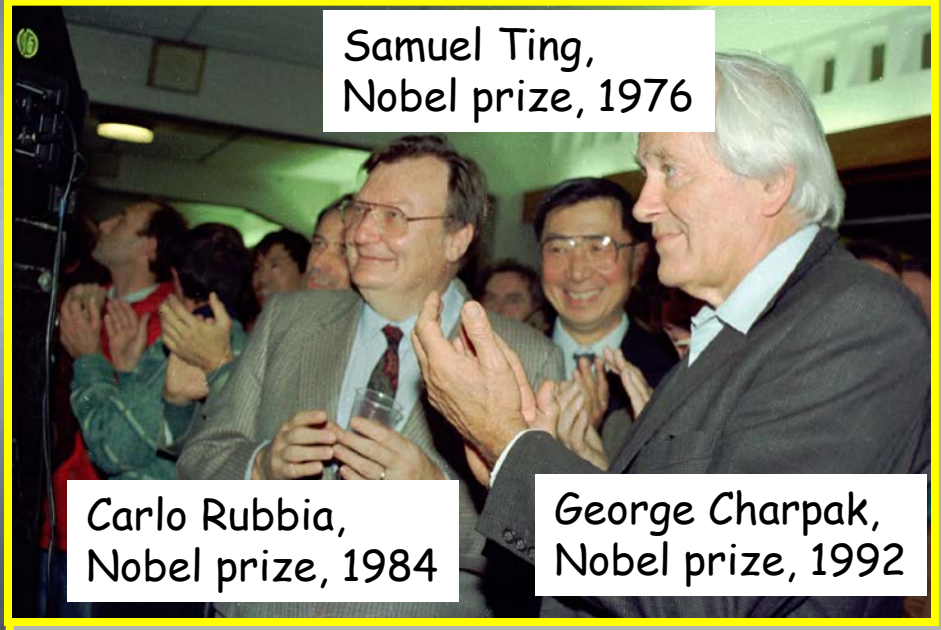
2013 Physics Nobel Prize

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

Almost 60 years of:

- fundamental research and discoveries (and Nobel prizes ...)
- technological innovation and technology transfer to society
  (e.g. the World Wide Web)
- training and education (young scientists, school students and teachers)
- bringing the world together (11000 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 ("Science for peace")
Today: 21 Member States

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

Candidate for Accession: Romania

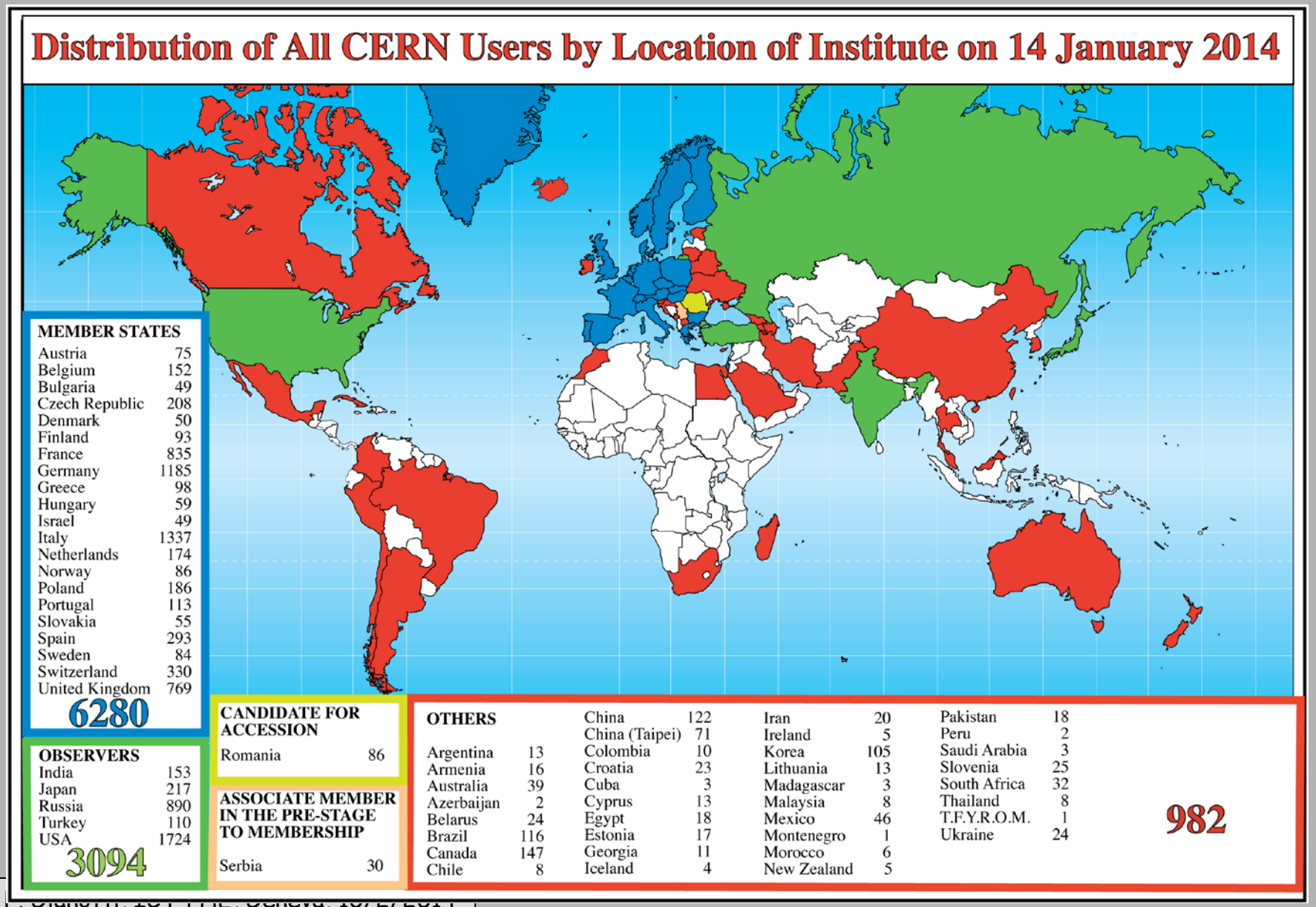
Associate Members in Pre-Stage to Membership: Serbia

Applicant States for Membership or Associate Membership: Brazil, Cyprus, Pakistan, Russia, Slovenia, Turkey, Ukraine

Observers to Council: India, Japan, Russia, Turkey, United States of America; European Commission and UNESCO

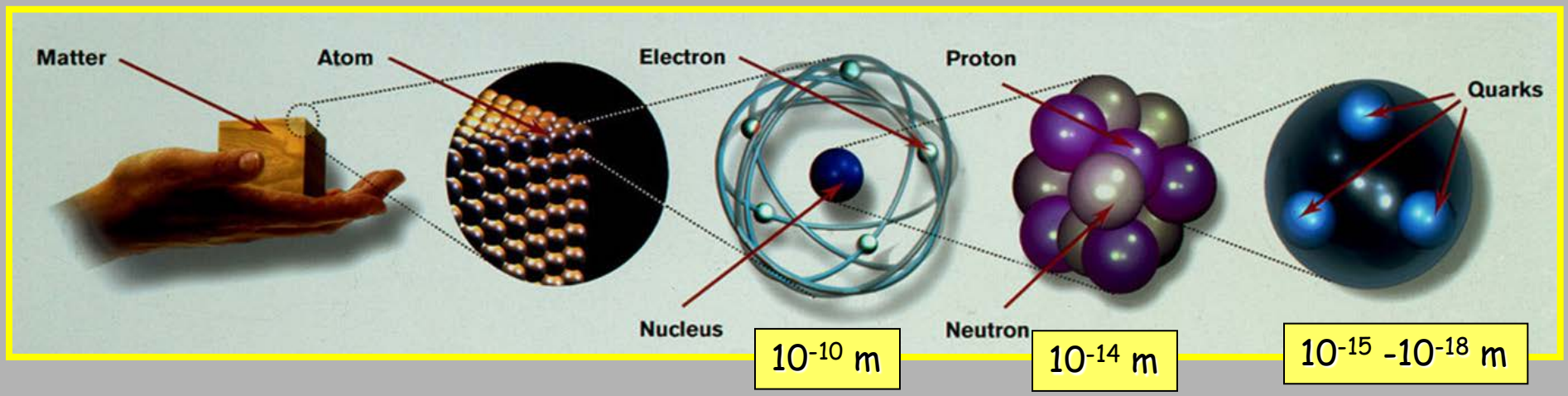
~ 2300 staff
~ 11000 users
Budget (2013) ~1000 MCHF (on average: 1 cappuccino/European citizen): each Member State contributes in proportion to its income

About 11000 users from > 60 countries



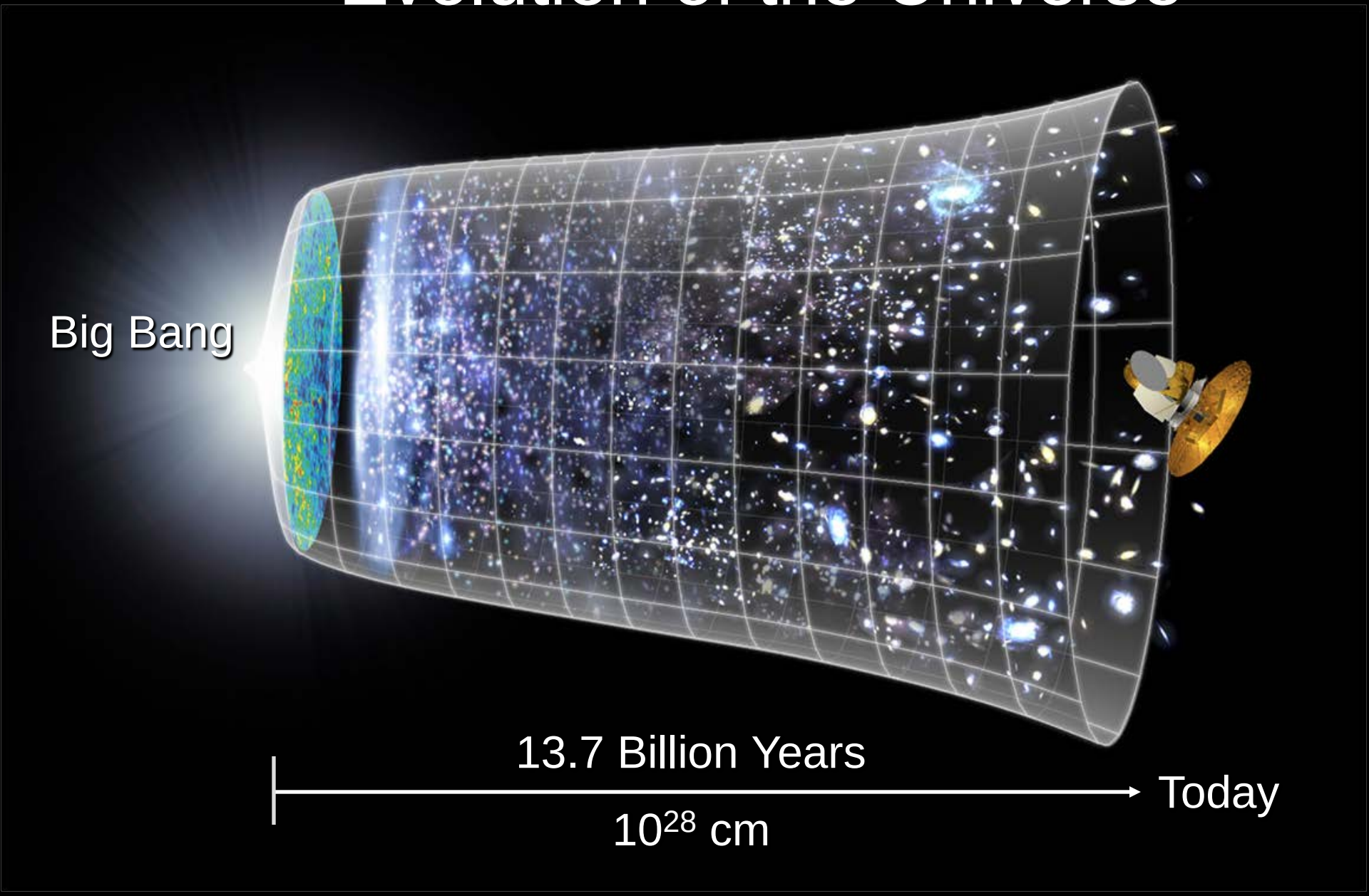
CERN's primary mission is SCIENCE

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



To study the elementary particles and their interactions:

prot
bear

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

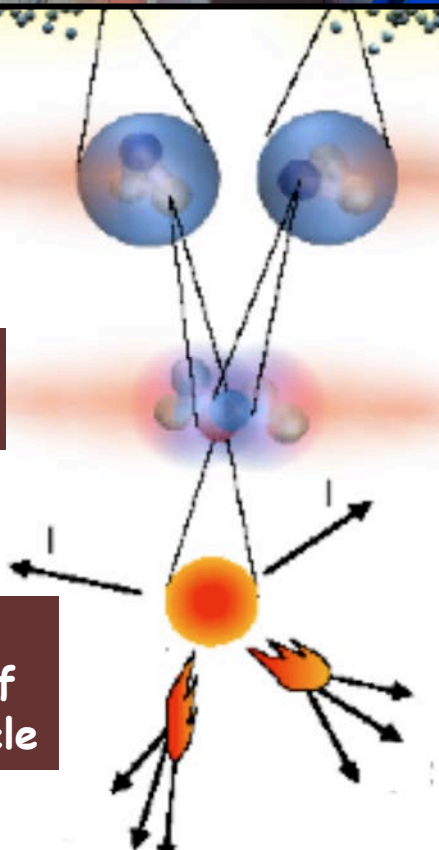
→ (new) heavy particles can be produced in the collision ($E=mc^2$). The higher the accelerator energy, the heavier the produced particles can be. These particles then decay into lighter (known) particles: electrons, photons, etc

→ reproduce the temperature (~10^{16} K) of the Universe a few instants (10^{-11} s) after the Big Bang

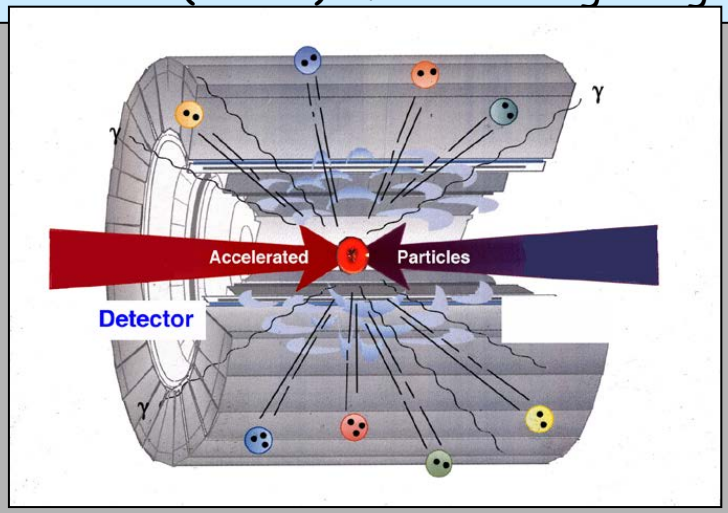
colliding protons

interacting quarks

production and decay of a new particle



Collision products detected by high-tech powerful detectors surrounding the collision point



The Large Hadron Collider (LHC) at CERN

the most powerful accelerator

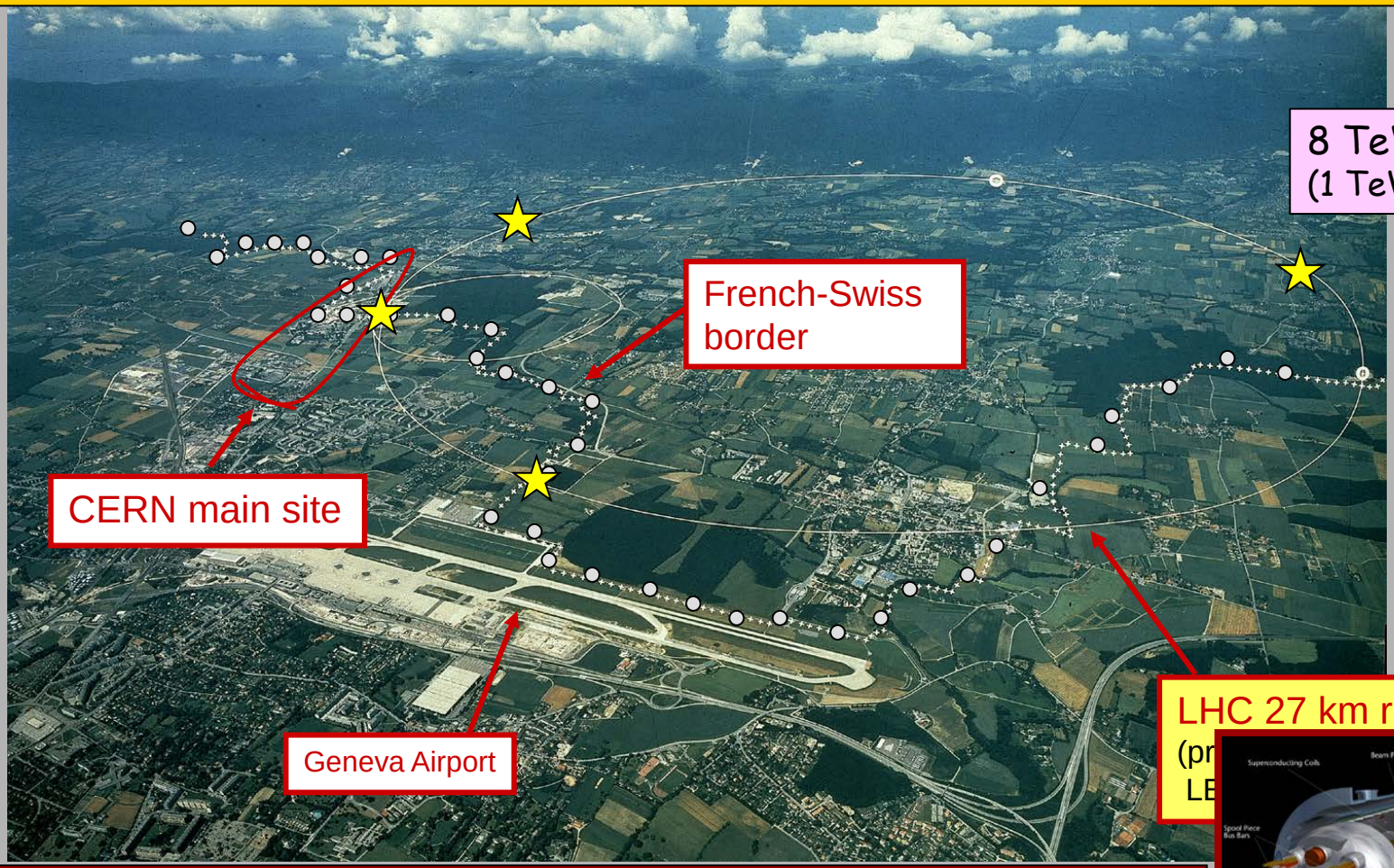
…. and also ….

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

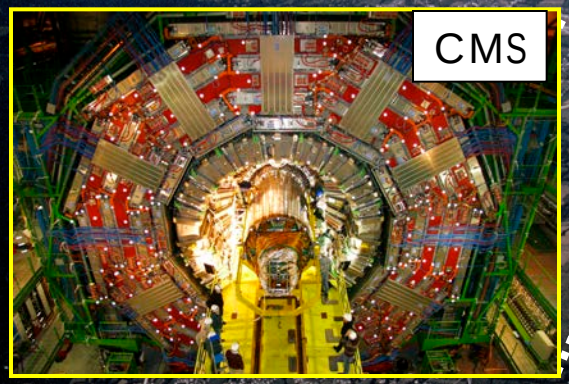
ever achieved in accelerator particle physics.
One of the most ambitious projects in science in general.

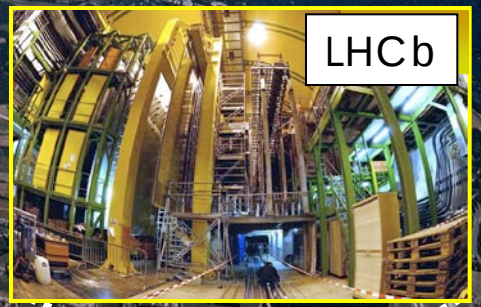
- > 20 years from concept to start of operation
- Operation started 20 November 2009
- First data-taking period: April 2010-February 2013
  → a new era in fundamental science with the exploration of a new energy frontier

The LHC is a 27 km ring, 100 m below ground, across France/Switzerland
2010-2013: two high-energy proton beams have been circulating in opposite directions, colliding at 4 points, where 4 big experiments had been installed.
Unprecedented collision energy: 4 times larger than the previous collider (Tevatron/Fermilab)
Starting in 2015: reach design collision energy of ~14 TeV

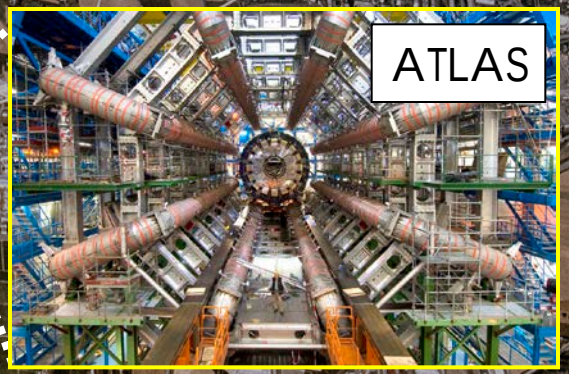


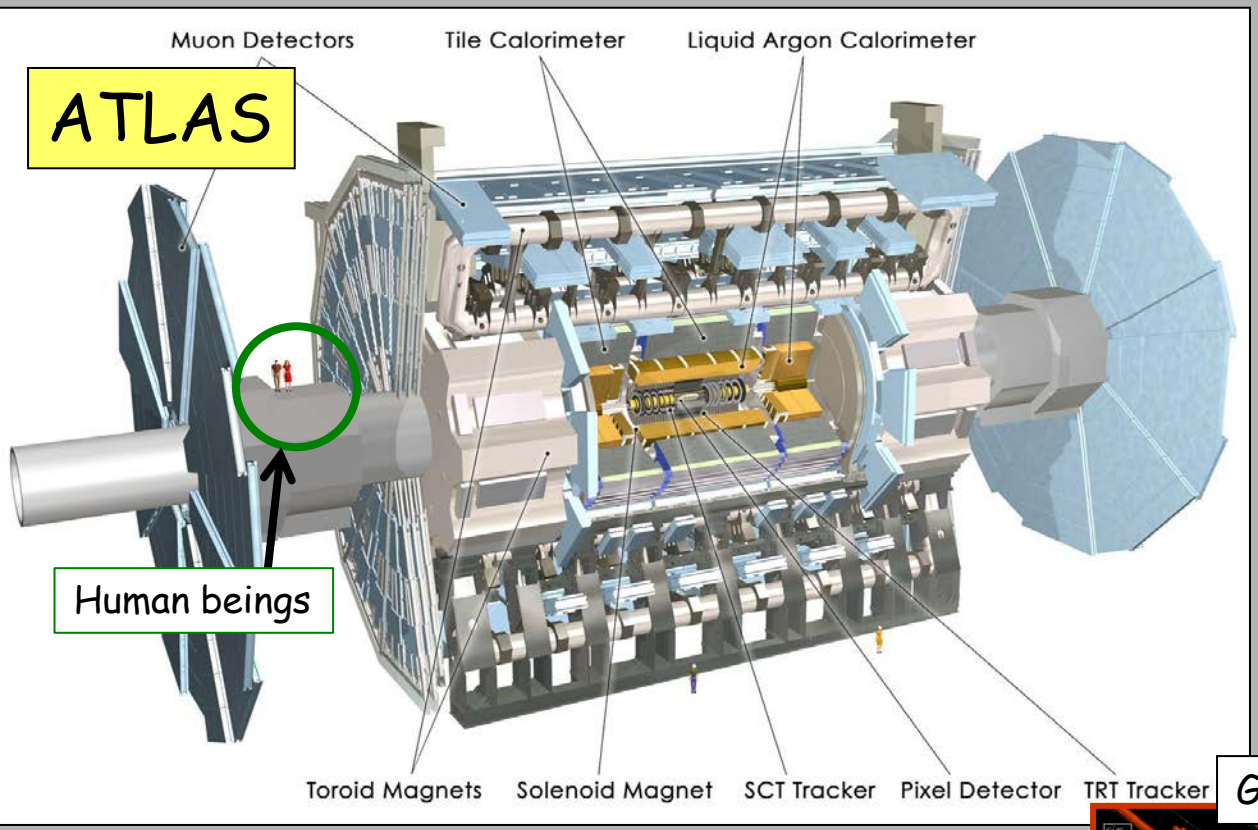
Most challenging component: 1232 high-tech superconducting magnets, providing 8.3 T field (to bend 7 TeV beams inside a 27 km ring).
Made of 7600 km of NbTi superconducting cable





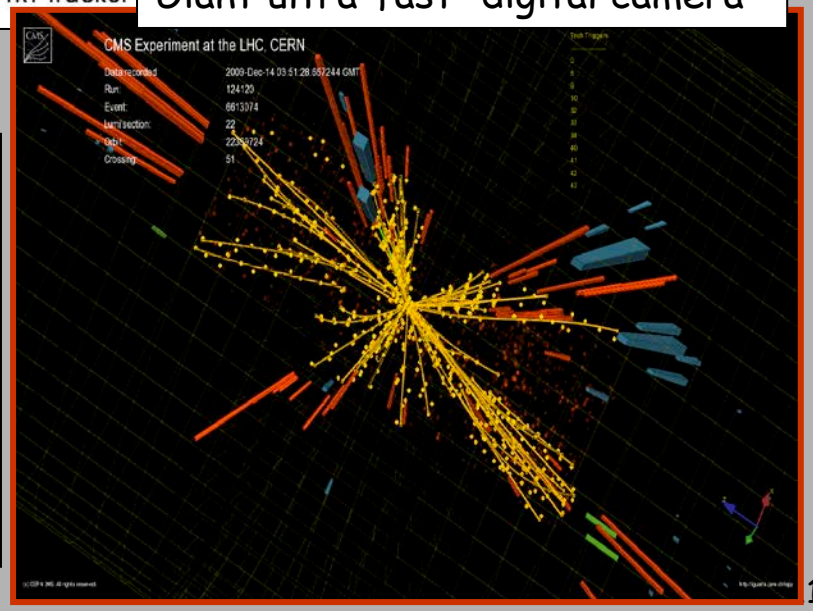
On 4th July 2012, ATLAS and CMS announced the discovery of a new particle (Higgs boson)





LHC detectors: a big jump in concepts and technologies

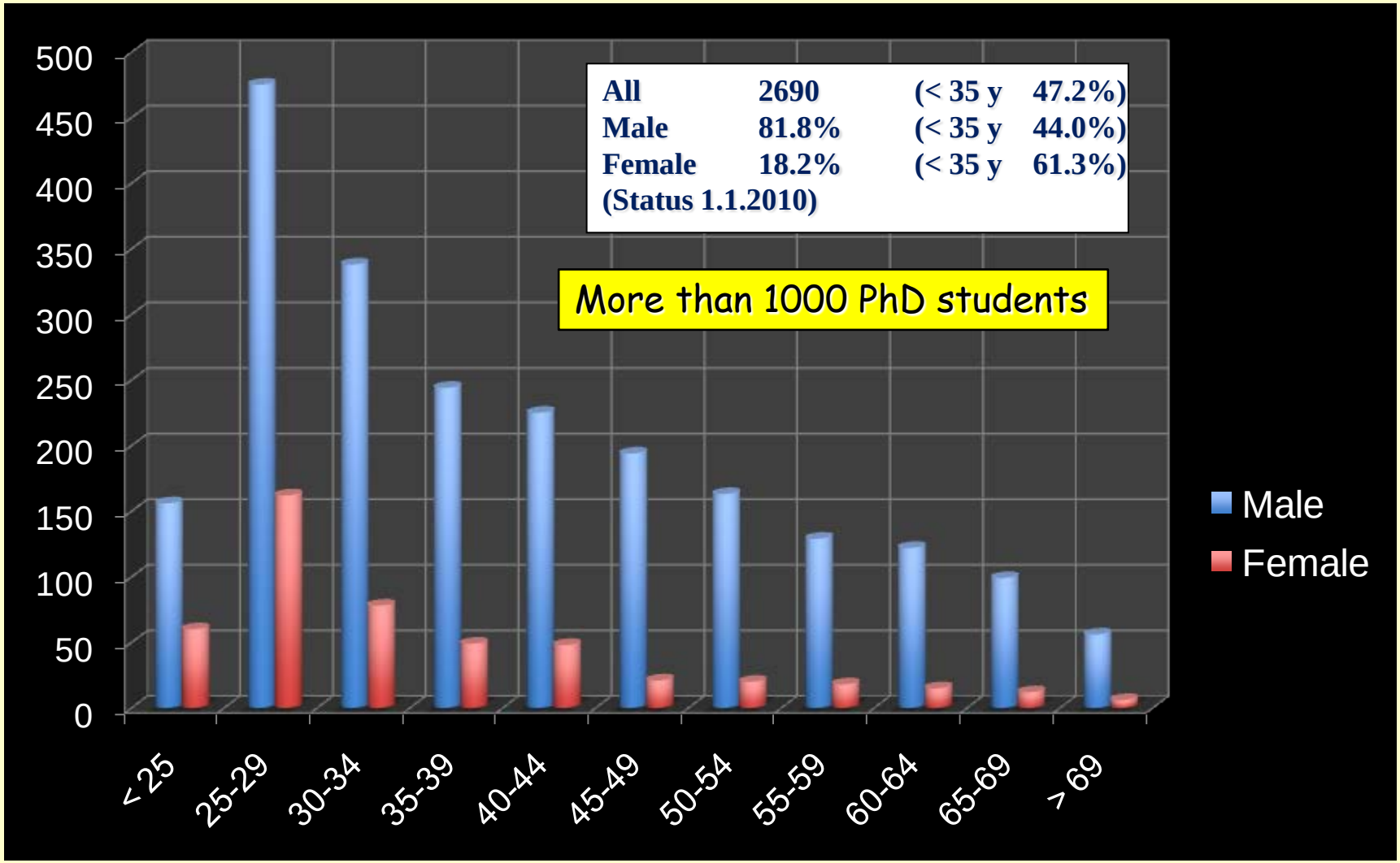
Giant ultra-fast "digital camera"



- 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)
- Fast response (~50 ns, 1 ns = 10^{-9} s): 40 million beam-beam collisions per second

~ 3000 scientists from 177 Institutions from 38 Countries

Age distribution of the ATLAS population



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 ... er space

Energy st ... 12 knots

The CMS exp ... on than the Tour Eiffel

WHY ???

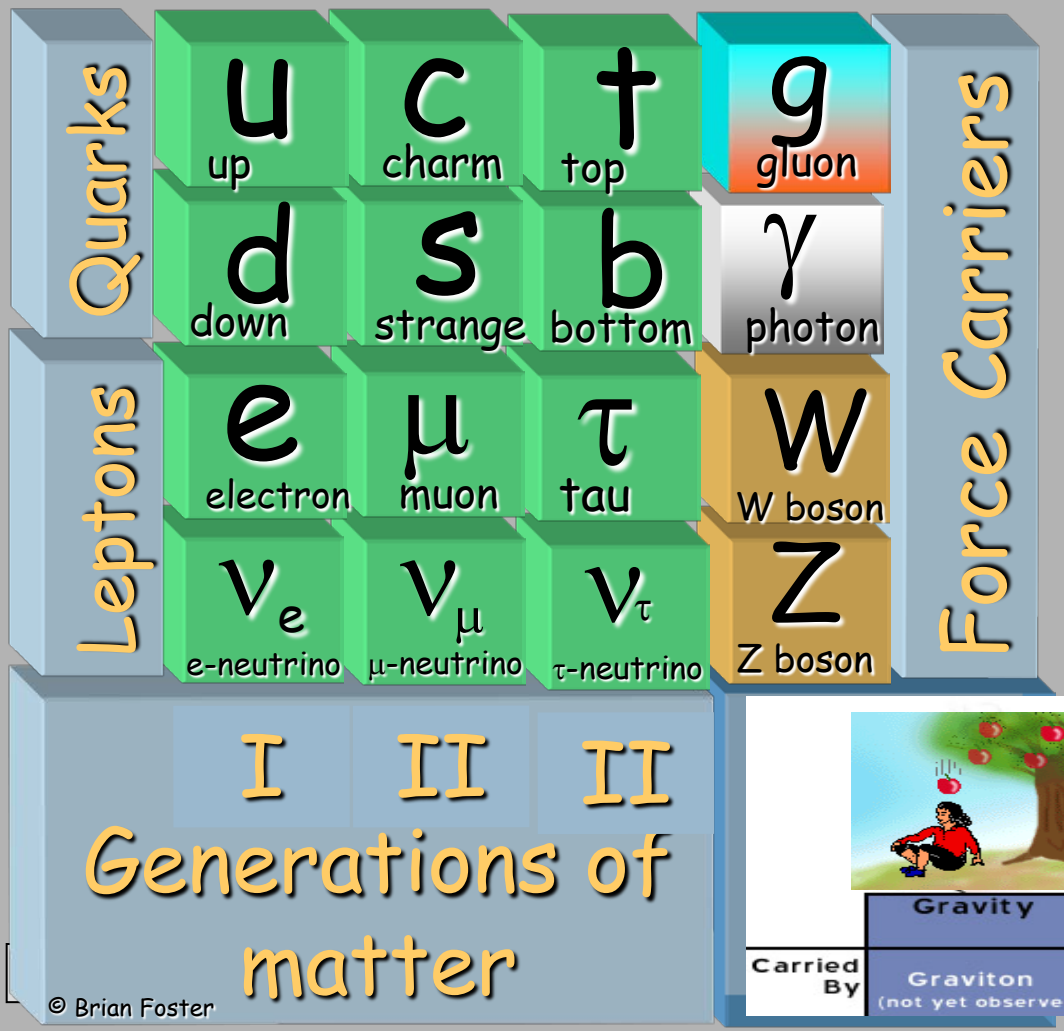
3000 km of cables used to transfer the signals from the ATLAS detector to the control rooms

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 ...)

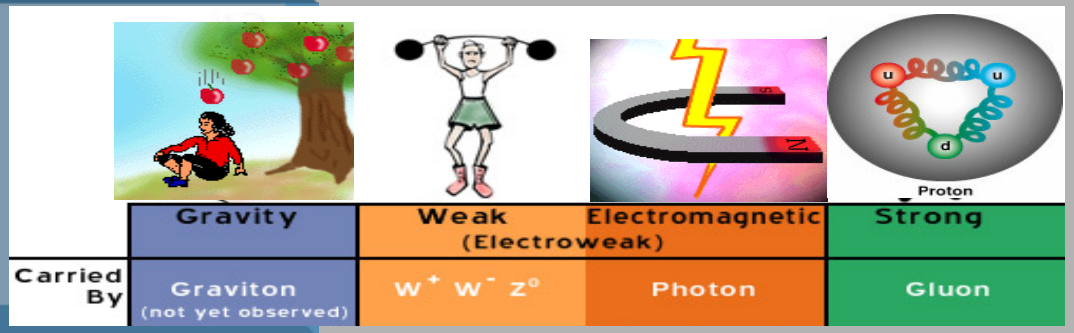
Cost: ~ 8000 MCHF

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 other labs all over the world



Particles and forces



Several outstanding questions in fundamental physics ….

What is the origin of the elementary particle masses ?
Related to the Higgs boson ✔ — 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

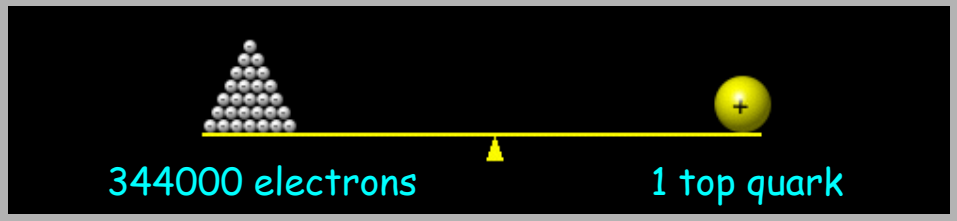
What happened in the first moments of the Universe life (10^{-11} s after the Big Bang) ? — ATLAS, CMS

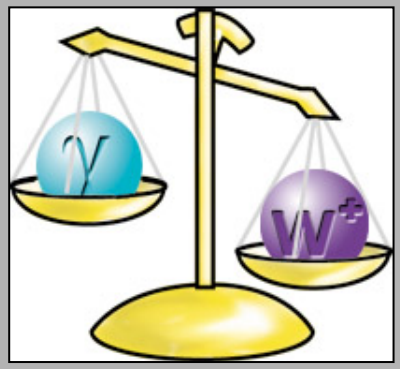
Are there other forces in addition to the known four ?
Are there additional (microscopic) space dimensions ? — ATLAS, CMS

Etc. etc.

LHC built to address these and other fundamental questions

What is the origin of the particle masses ?



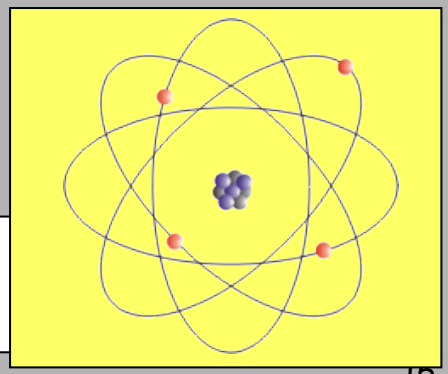


Photon is massless (pure energy), W and Z bosons have x 100 proton mass
Mass of top quark (heaviest elementary particle observed) ≈ mass of Gold atom
Electron mass is ~350000 times smaller
WHY ???

Proposed explanation (Brout, Englert, Higgs et al., 1964),
"Brout-Englert-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
→ find

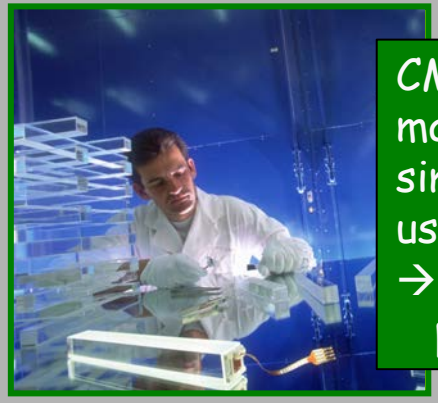
The 1st link with our life



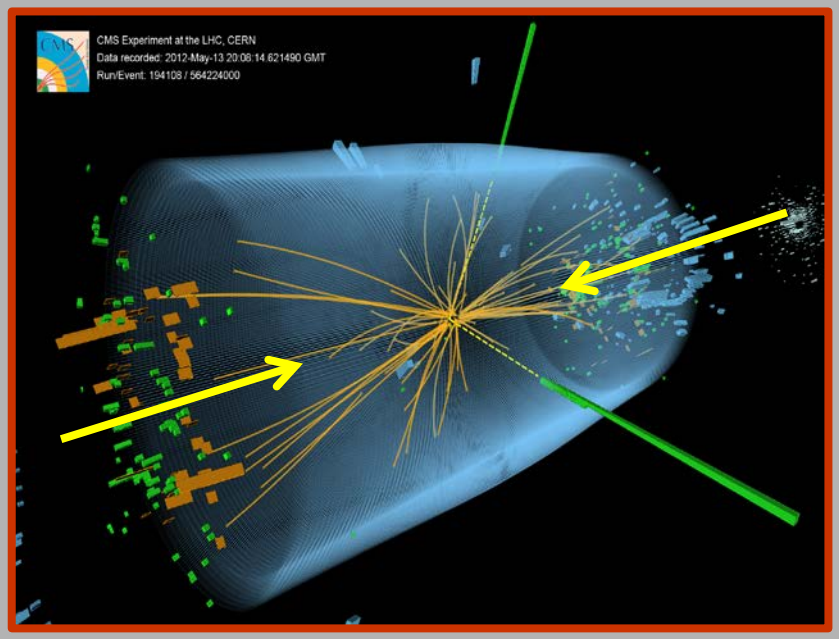
Note: world without the BEH mechanism would be very strange
Atoms may not exist, and the Universe would be very different

What did we observe ?

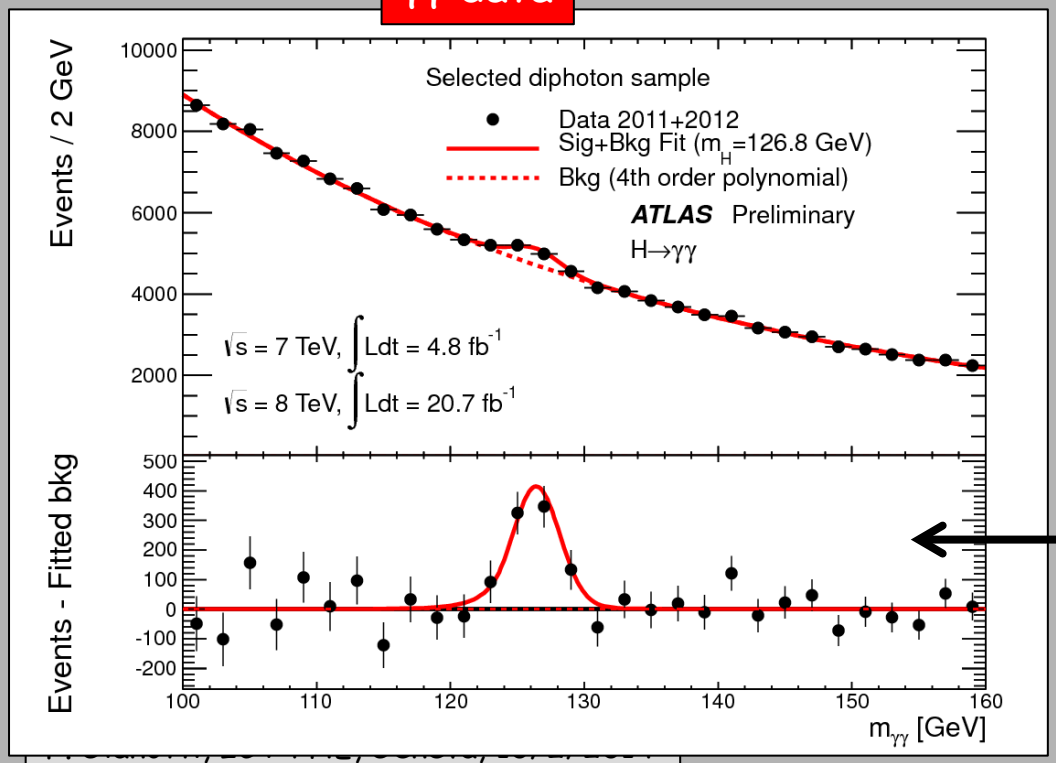
Once produced the Higgs boson is expected to decay into known particles, for instance into two photons → looked at the γγ spectrum in our data



CMS calorimeter made of crystals similar to those used in modern PET → spin-off of particle physics



γγ data



Peak ("resonance") at $m_{\gamma\gamma}$ around 125 GeV (~130 x proton mass) indicates the production of a (new) heavy particle

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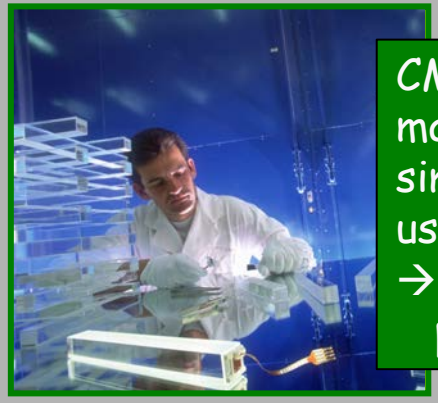

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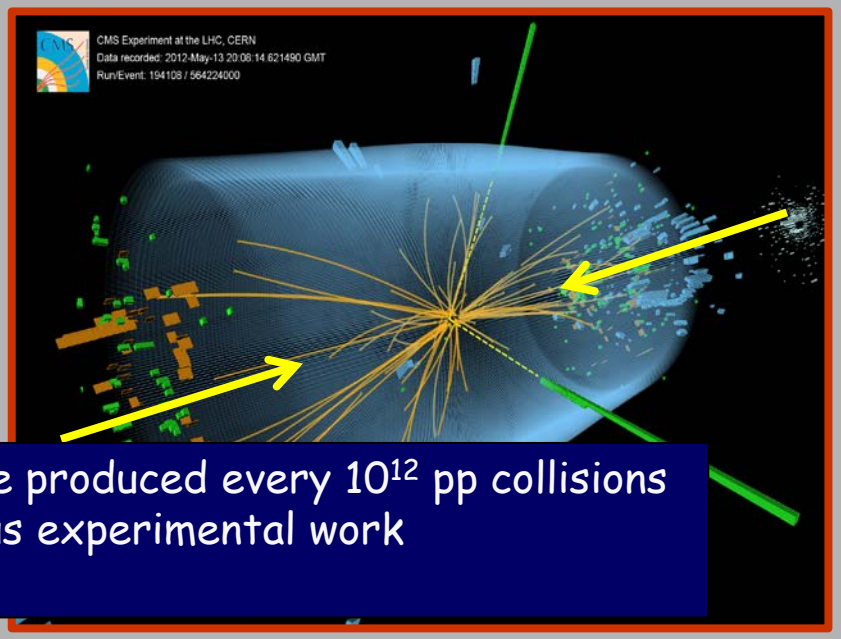
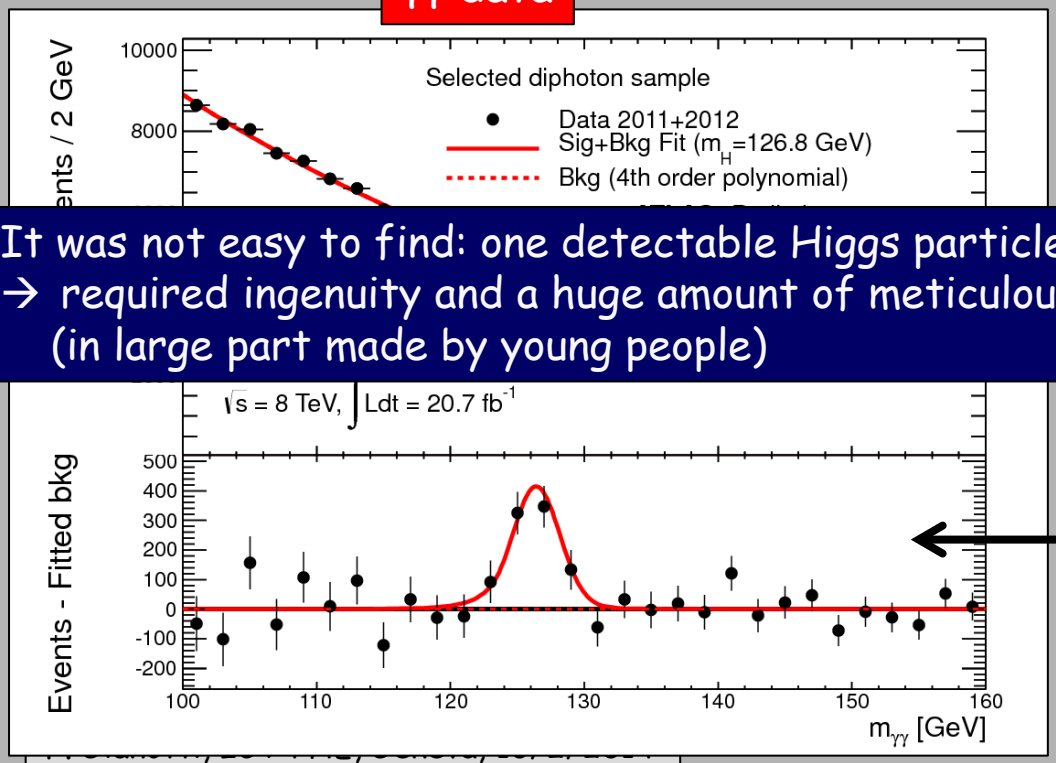


γγ data



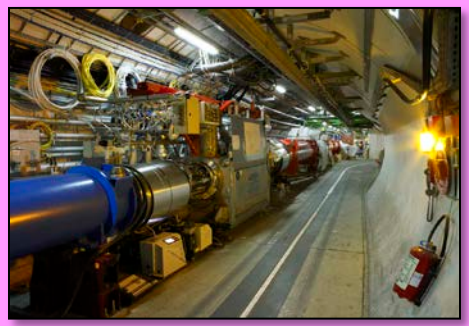
It was not easy to find: one detectable Higgs particle produced every 10^{12} pp collisions → required ingenuity and a huge amount of meticulous experimental work (in large part made by young people)

Peak ("resonance") at $m_{\gamma\gamma}$ around 125 GeV (~130 x proton mass) indicates the production of a (new) heavy particle

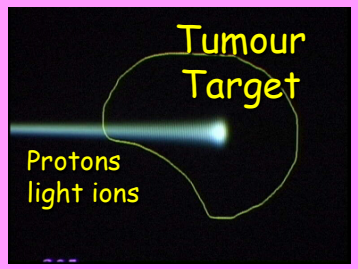
Will the Higgs boson change our life ? It did already !

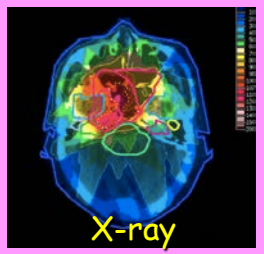
Extreme performance required in particle and nuclear physics → cutting-edge technologies developed at CERN and collaborating Institutes, and then transferred to society.

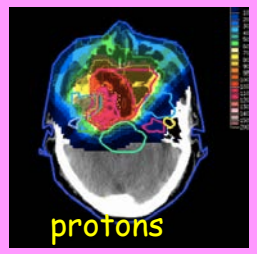
Applications: medical imaging (e.g. PET), cancer therapy, materials science, airport scanners, cargo screening, food sterilization, nuclear waste transmutation, analysis of historical relics, etc. …not to mention the GRID-based computing and the WEB ..



Hadron Therapy



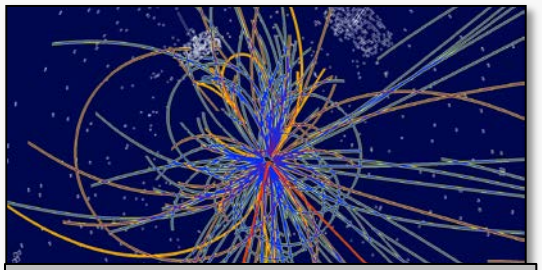




Accelerating particle beams
~30'000 accelerators worldwide
~17'000 used for me

→ 100000 patients treated worldwide (45 facilities)
14 facilities)

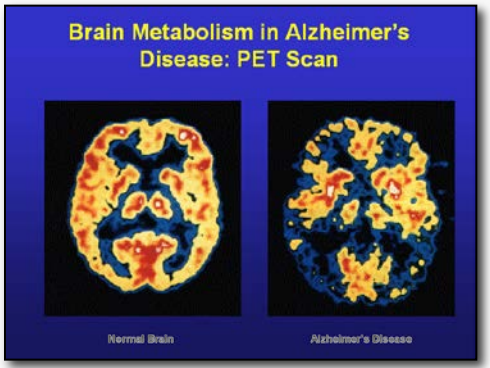
The 2nd link with our life



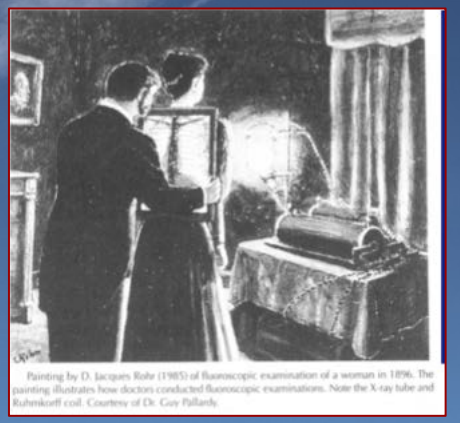
Detecting particles

Imaging

e.g. PET scanner



CERN and the LHC



- Seeking answers to fundamental questions about elementary particles and the Universe → a new era has started with the exploration of an unprecedented energy scale at the LHC and the dicovery of a Higgs boson: a big step forward in fundamental science
- Training: students, high-school teachers, young scientists
- Promoting diversity (gender, age, ethnicity, …) as a strength and asset for a richer and more stimulating environment, better science and peace
- Advancing the frontiers of technology, also to the benefit of other fields and society

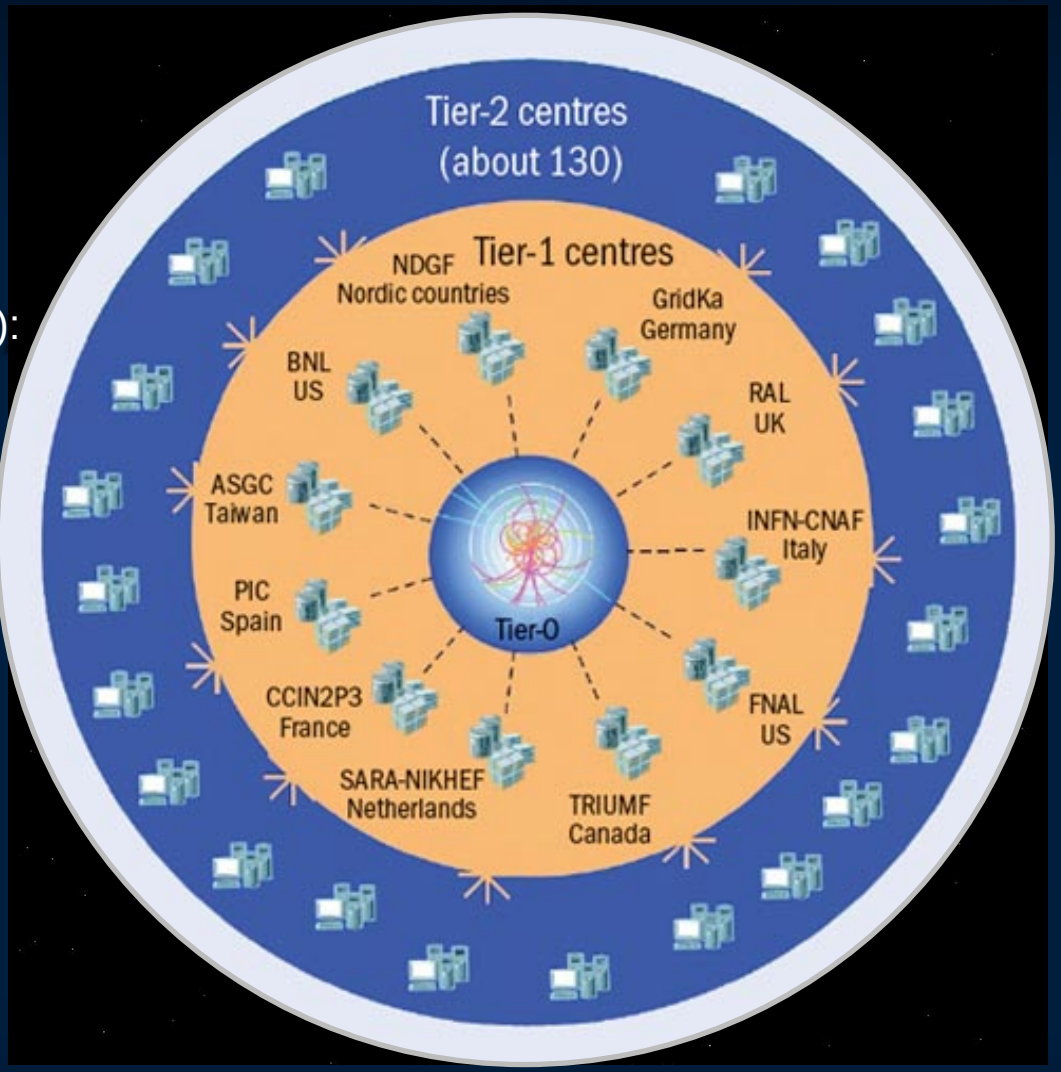
SPARES

The Worldwide LHC Computing Grid

Tier-0
(CERN and Hungary):
data recording,
reconstruction and
distribution

Tier-1: permanent
storage, re-
processing,
analysis

Tier-2: Simulation,
end-user analysis



nearly 160 sites,
35 countries

~250'000 cores

173 PB of storage

> 2 million jobs/day

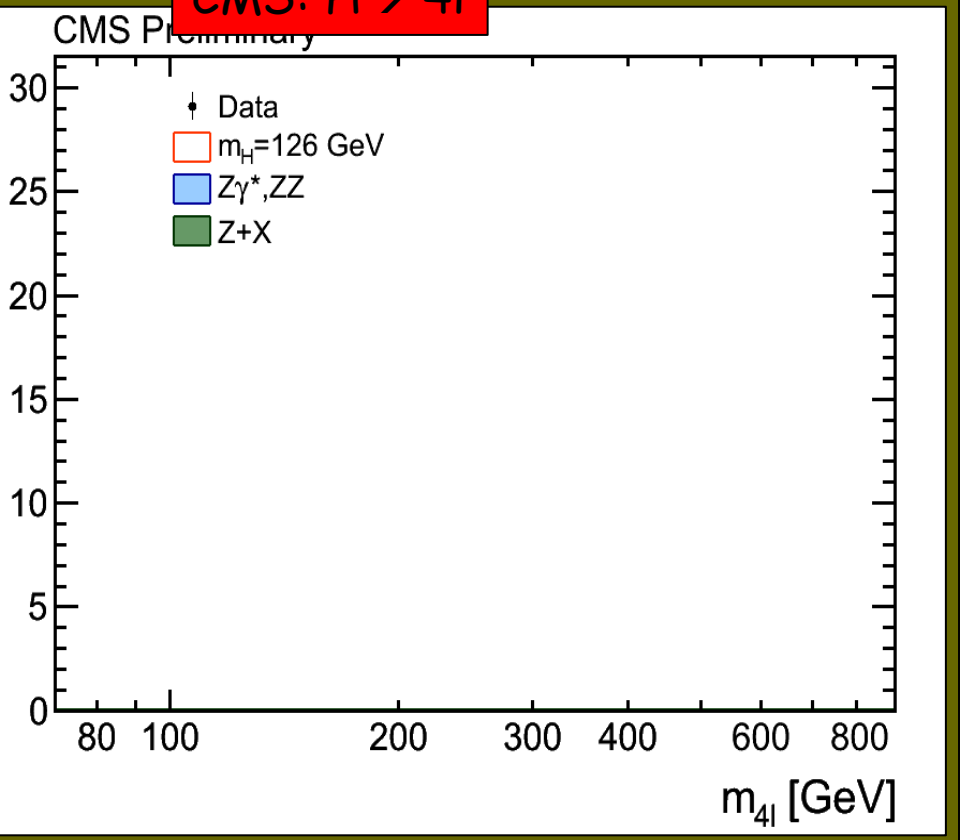
10 Gb links

WLCG:
An International collaboration to distribute and analyse LHC data

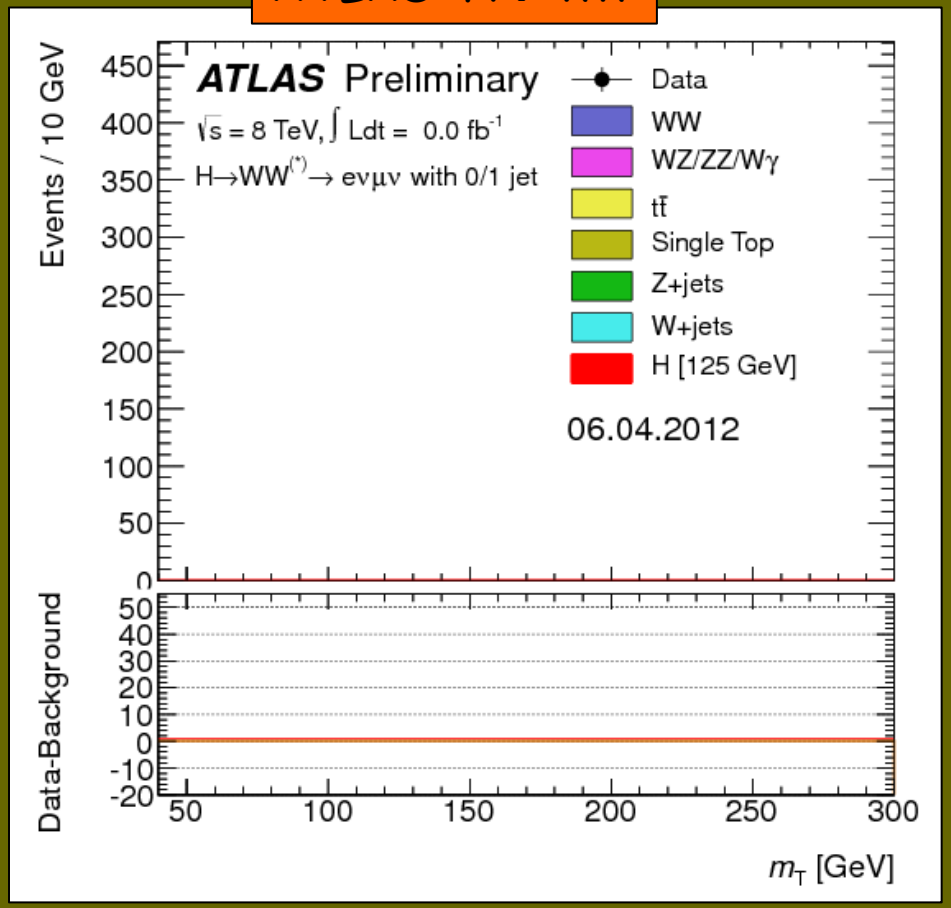
Integrates computer centres worldwide that provide computing and storage resource into a single infrastructure accessible by all LHC physicists

Birth and evolution of a signal

CMS: H→ 4l

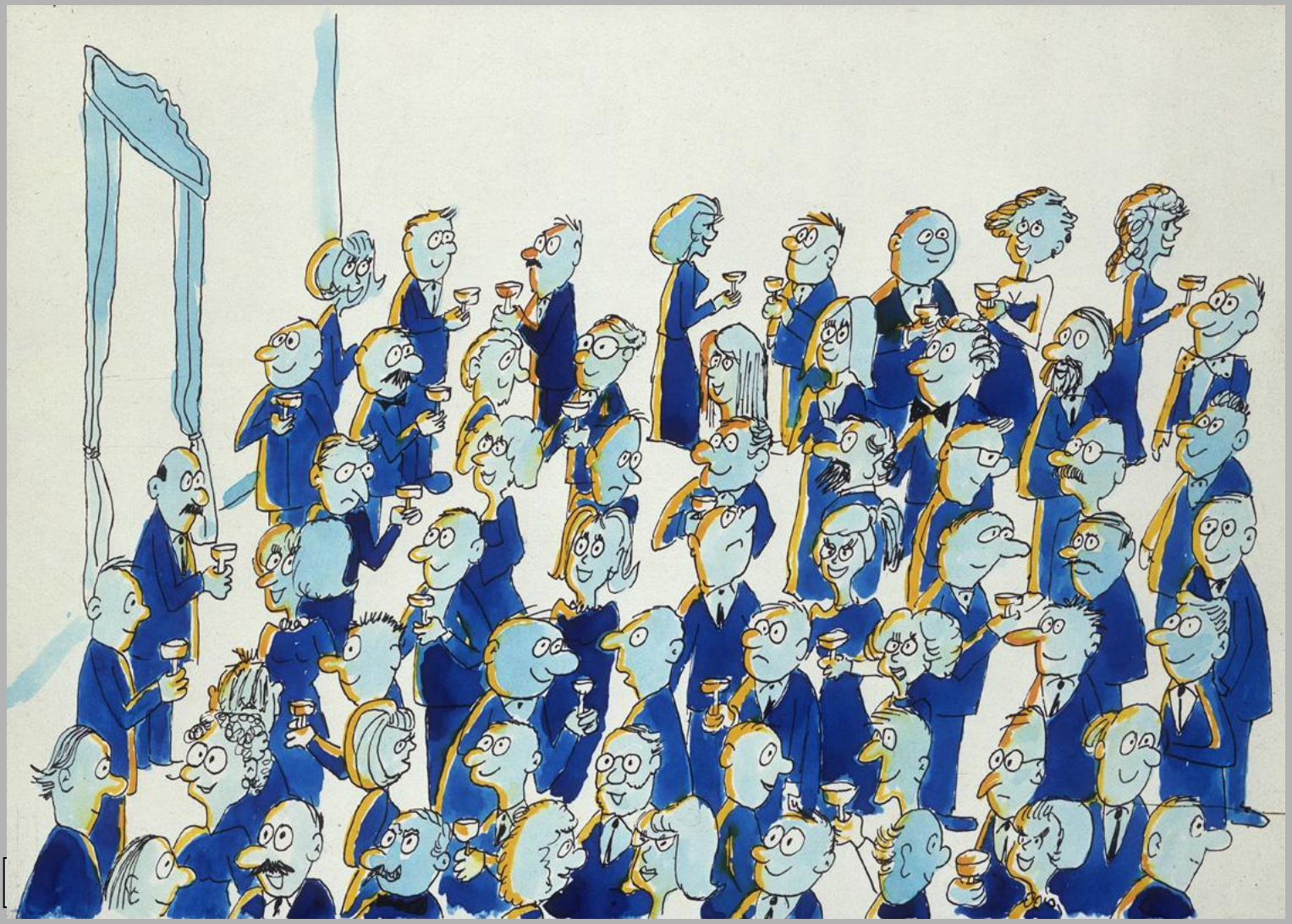


ATLAS: H→ lνlν

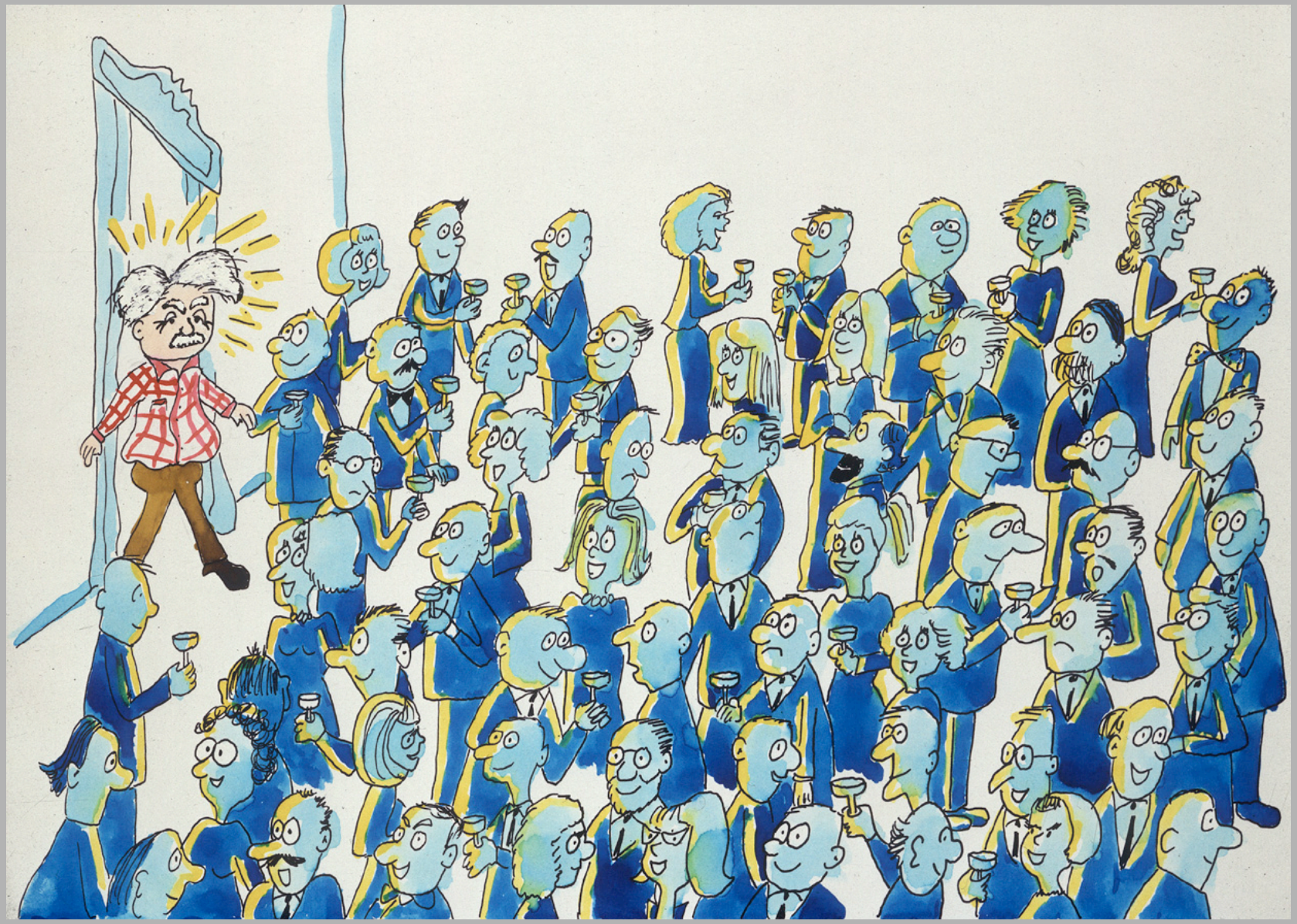


The Higgs mechanism … as exemplified by Prof. David Miller

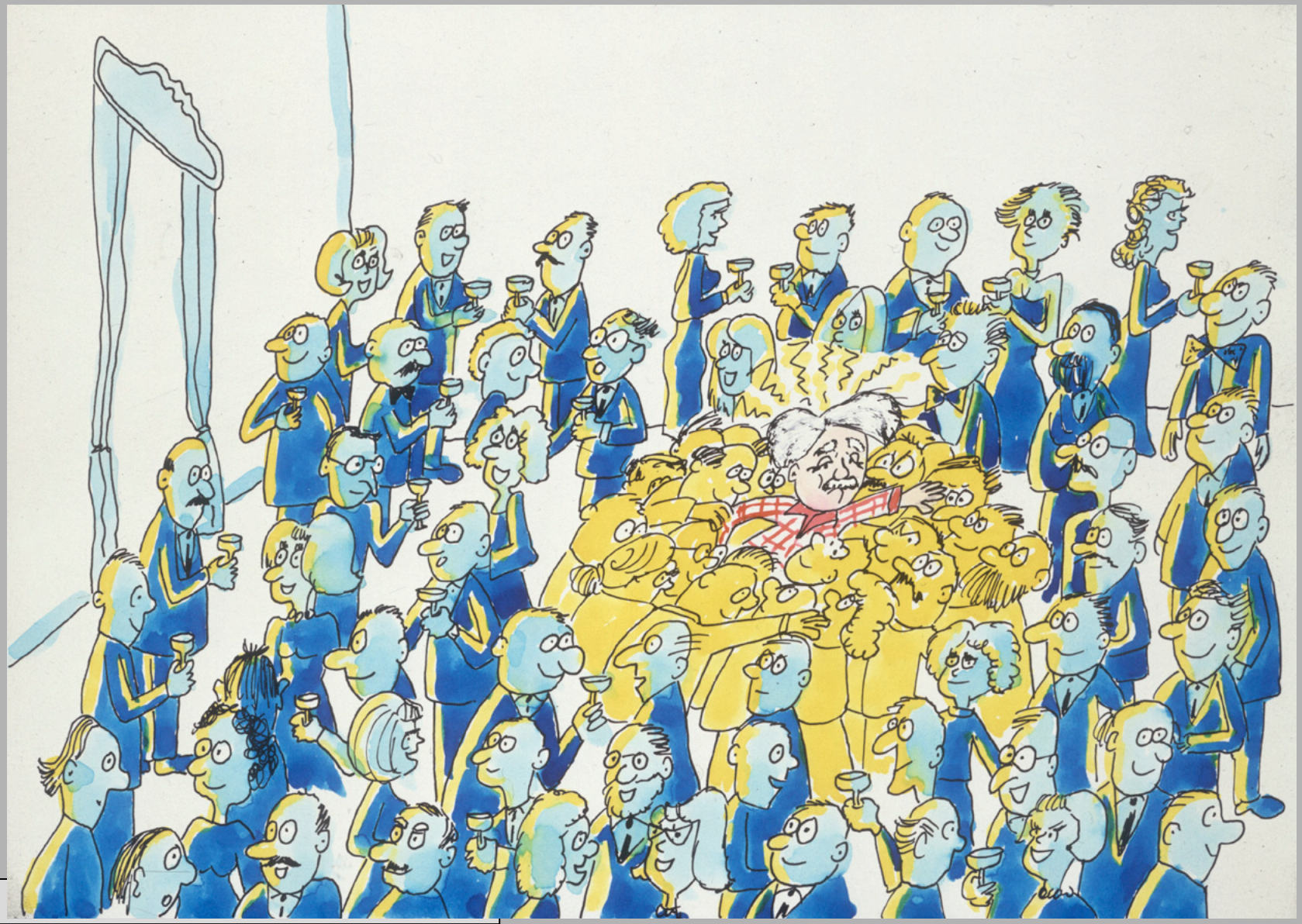
Imagine a room full of people quietly chattering … this is like space filled only with the Higgs field …



a well known actor walks in, creating a disturbance as he moves across the room, and attracting a cluster of admirers with each step ... the actor is like a particle traversing the Higgs field



this increase his resistance to movement, in other words, he acquires mass, just like a particle moving through the Higgs field ...



... Imagine now that a rumour crosses the room ...

it creates the same kind of clustering, but this time among the people in the room. In this analogy, these clusters are the Higgs particle.