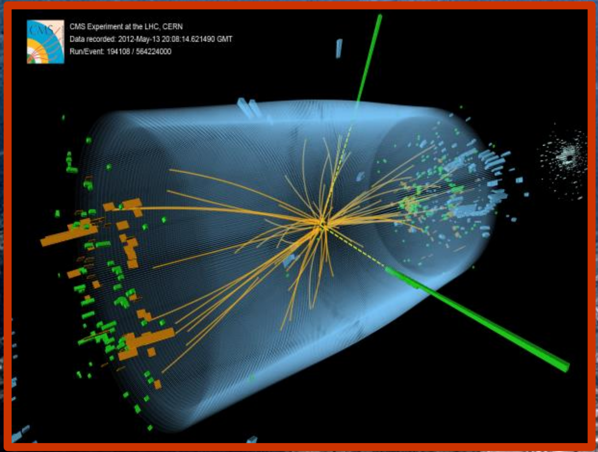
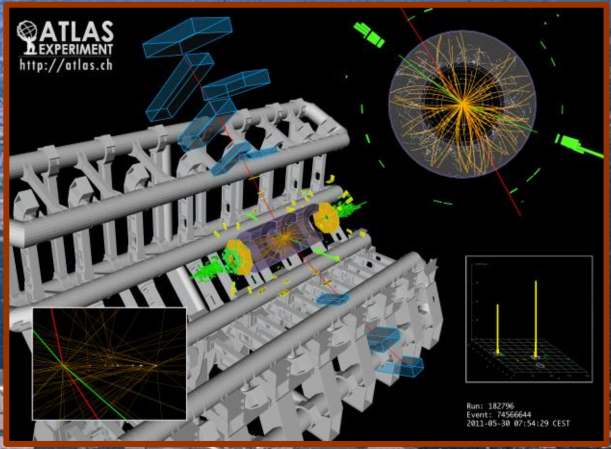
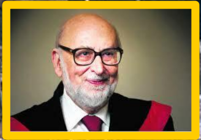




The Higgs boson and our life

Fabiola Gianotti (CERN, Physics Department)

2013 Physics Nobel Prize



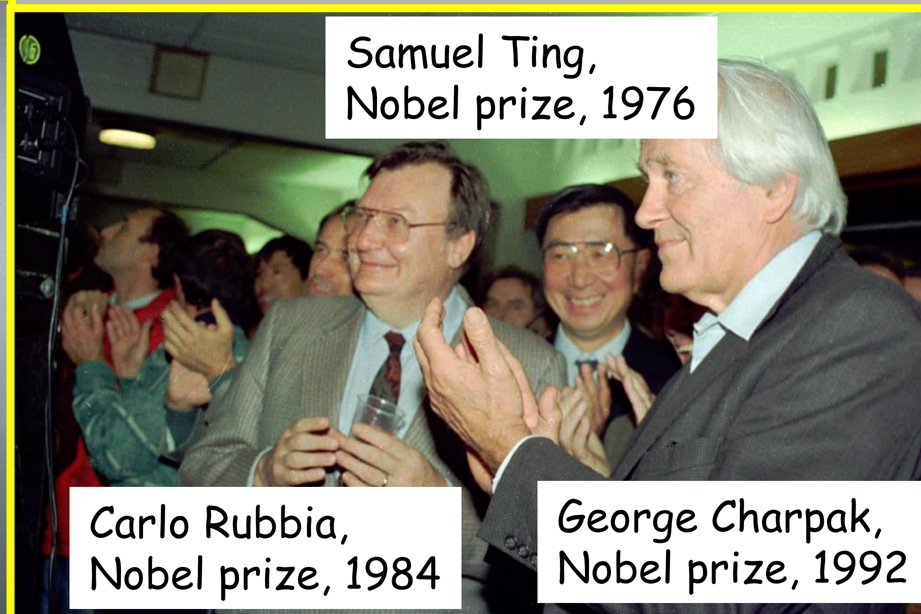
YEARS/ANS CERN

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

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 (1100 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: 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

States in accession to Membership: Romania, Serbia

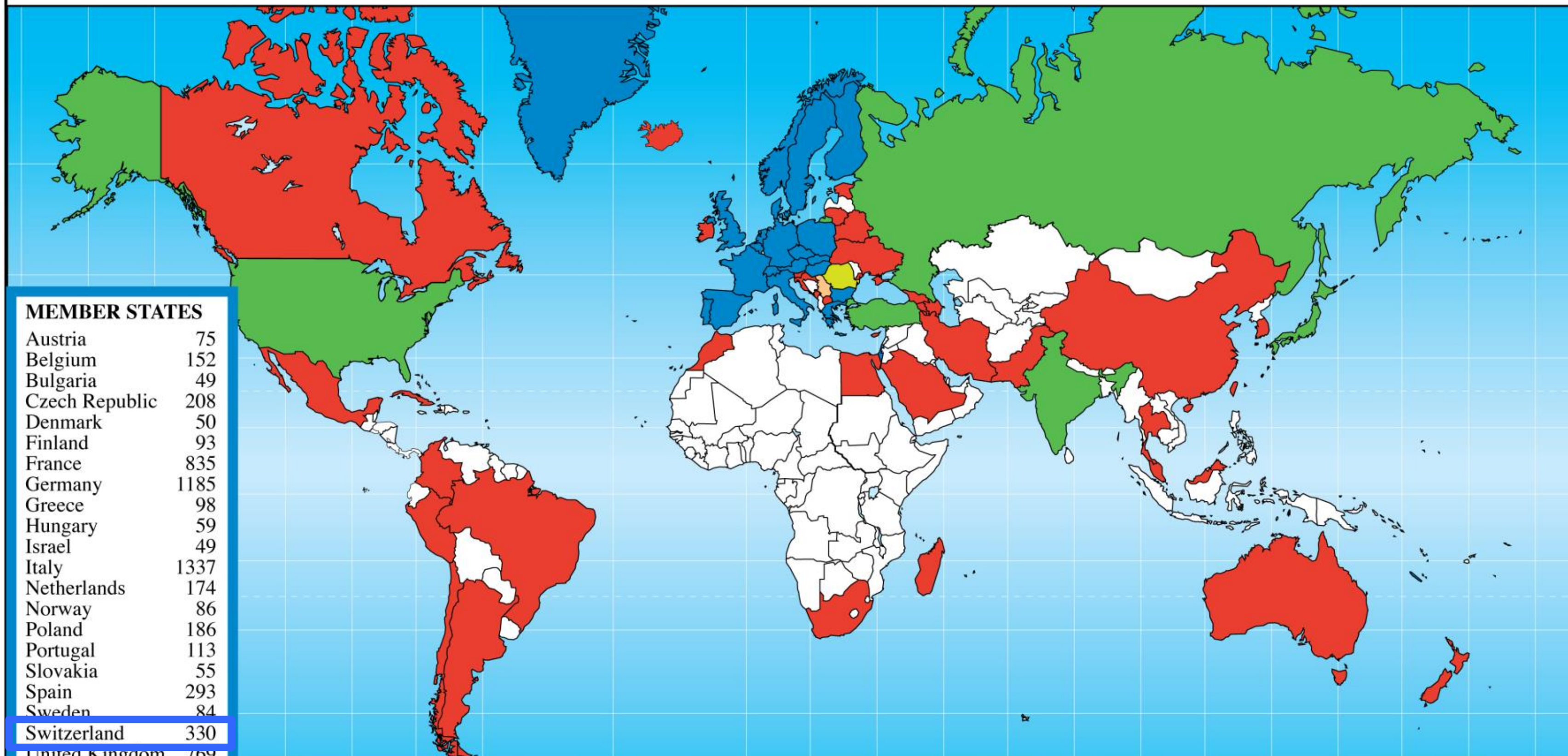
Applicant States for Membership or Associate Membership:
Brazil, Croatia, Cyprus, Pakistan, Russia, Slovenia, Turkey, Ukraine

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

~ 2300 staff, ~ 1600 other paid personnel
~ 11000 users
Budget (2014) ~1000 MCHF (on average: 1 cappuccino/European citizen):
each Member State contributes in proportion to its income
(CH: ~ 2.5%, ~25 MCHF)

About 11000 users from > 60 countries

Distribution of All CERN Users by Location of Institute on 14 January 2014



MEMBER STATES

Austria	75
Belgium	152
Bulgaria	49
Czech Republic	208
Denmark	50
Finland	93
France	835
Germany	1185
Greece	98
Hungary	59
Israel	49
Italy	1337
Netherlands	174
Norway	86
Poland	186
Portugal	113
Slovakia	55
Spain	293
Sweden	84
Switzerland	330
United Kingdom	769

6280

OBSERVERS

India	153
Japan	217
Russia	890
Turkey	110
USA	1724

3094

CANDIDATE FOR ACCESSION

Romania	86

ASSOCIATE MEMBER IN THE PRE-STAGE TO MEMBERSHIP

Serbia	30

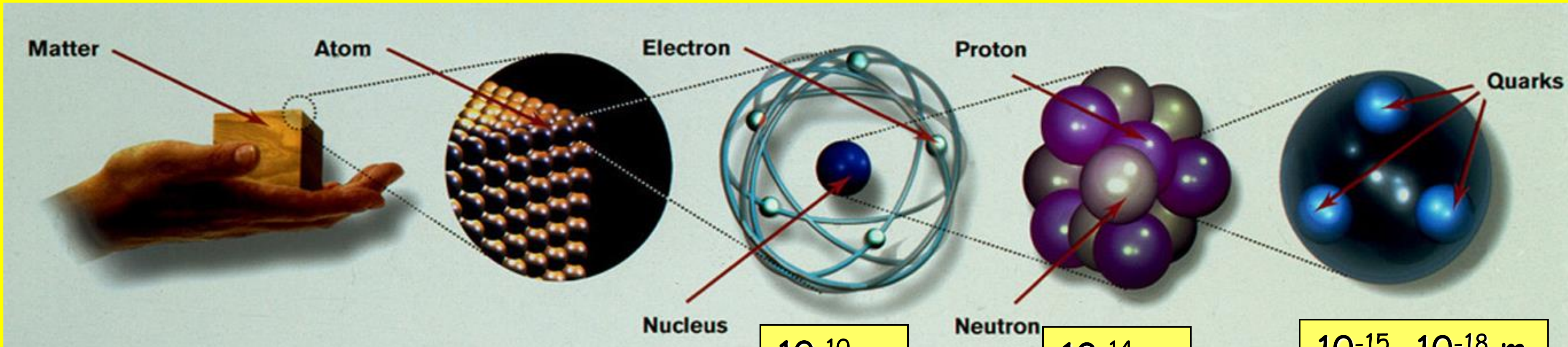
OTHERS

Argentina	13
Armenia	16
Australia	39
Azerbaijan	2
Belarus	24
Brazil	116
Canada	147
Chile	8
China	122
China (Taipei)	71
Colombia	10
Croatia	23
Cuba	3
Cyprus	13
Egypt	18
Estonia	17
Georgia	11
Iceland	4
Iran	20
Ireland	5
Korea	105
Lithuania	13
Madagascar	3
Malaysia	8
Mexico	46
Montenegro	1
Morocco	6
New Zealand	5
Pakistan	18
Peru	2
Saudi Arabia	3
Slovenia	25
South Africa	32
Thailand	8
T.F.Y.R.O.M.	1
Ukraine	24

982

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



10^{-10} m

10^{-14} m

10^{-15} - 10^{-18} m

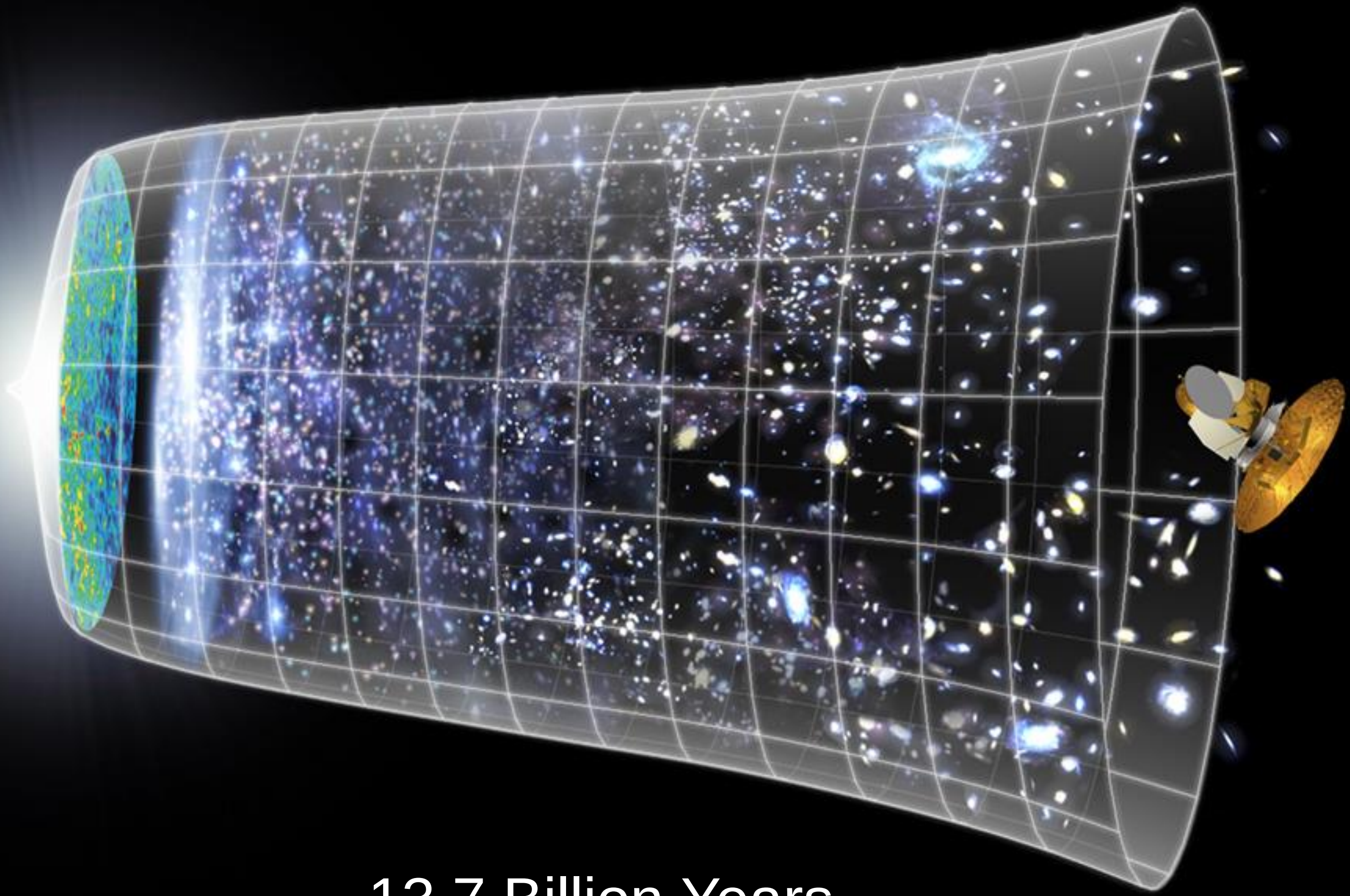
Particle physics at modern accelerators allows us to study the fundamental laws of nature on scales down to smaller than 10^{-18} m

→ insight also into the structure and evolution of the Universe

→ from the very small to the very big …

Evolution of the Universe

Big Bang



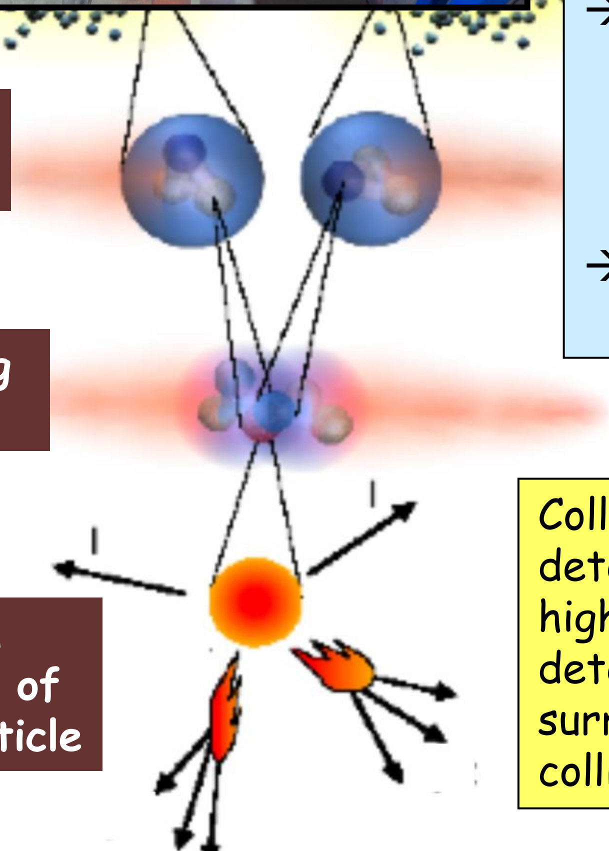
13.7 Billion Years

Today

10^{28} cm

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



prot
bear

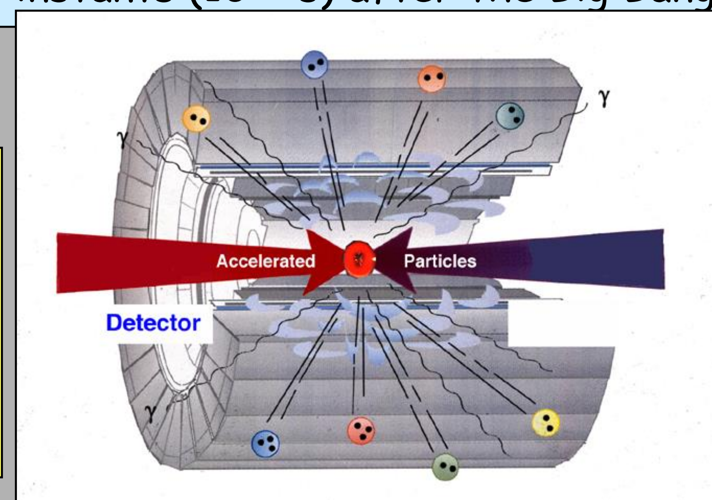
colliding
protons

interacting
quarks

production
and decay of
a new particle

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

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



The Large Hadron Collider (LHC) at CERN

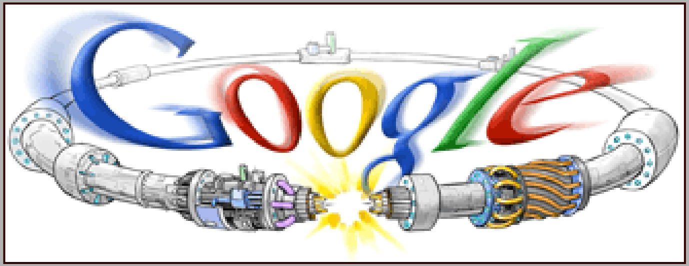
the most powerful accelerator

.... 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

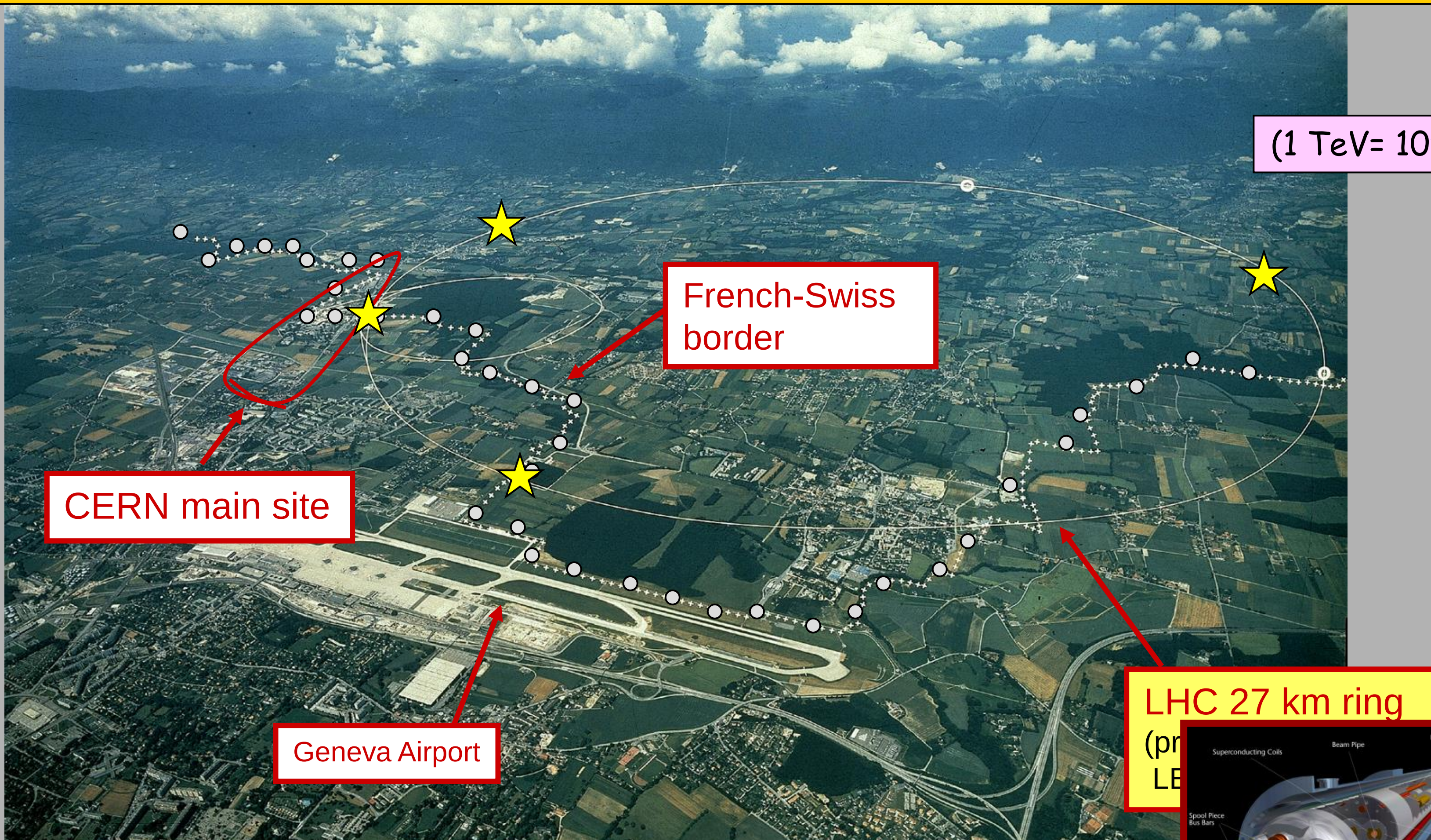
ever achieved in accelerator particle physics.
One of the most ambitious projects in science in general.

- > 25 years from concept to start of operation
- Operation started 20 November 2009
- First data-taking period: April 2010-February 2013

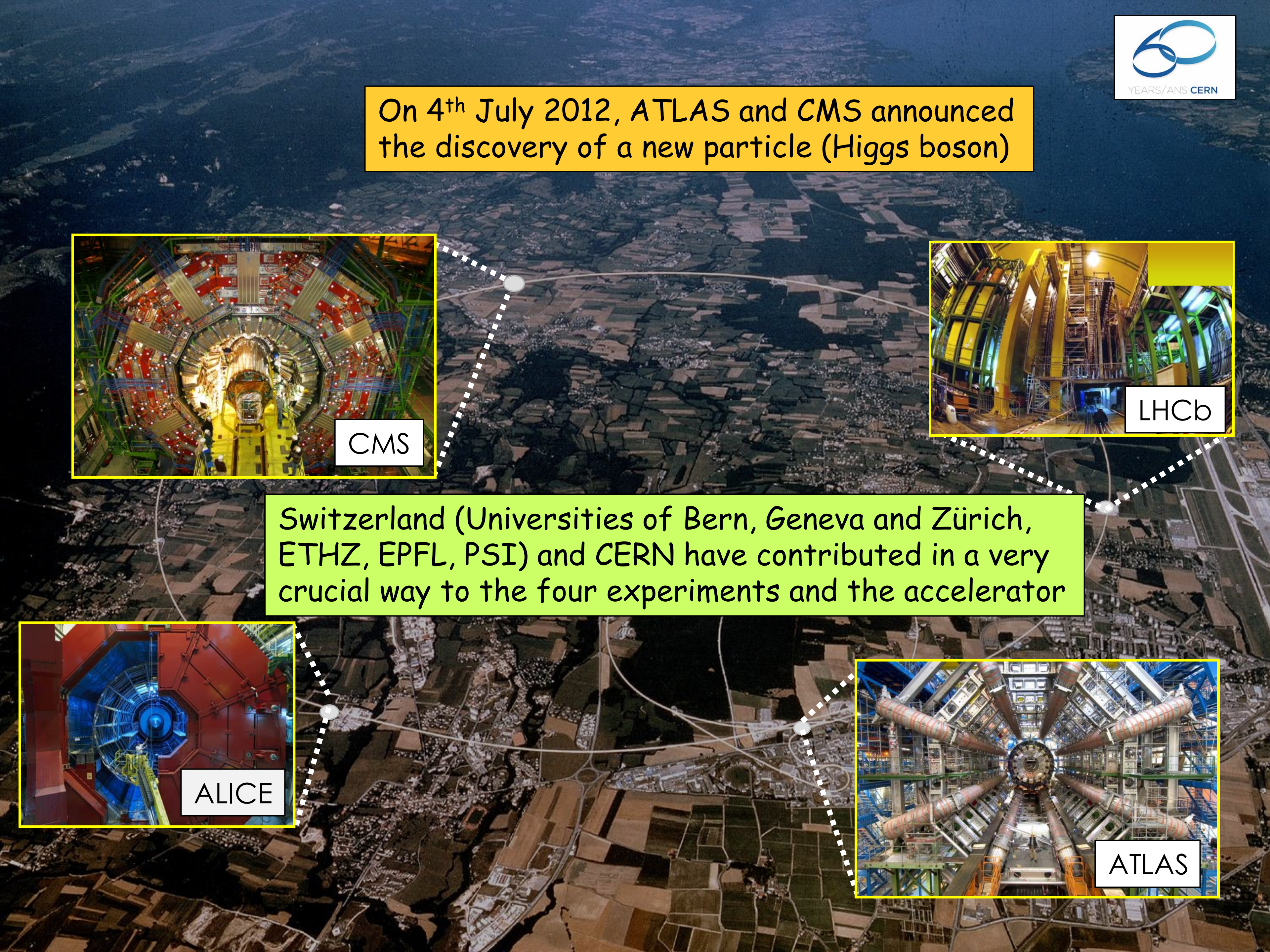


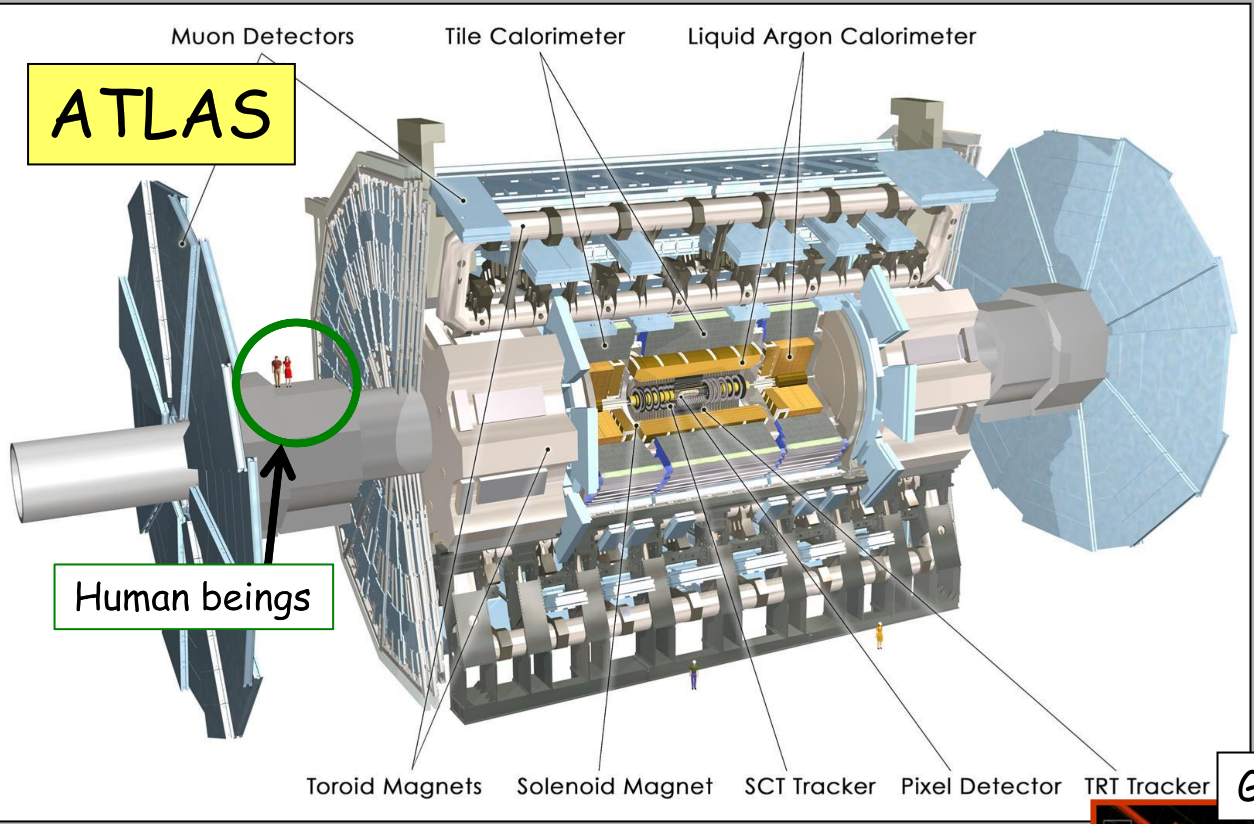
The LHC is a 27 km ring, 100 m below ground, across France/Switzerland
2010-2013: two high-energy proton beams have been circulating in opposite directions, colliding at 4 points, where 4 big experiments had been installed.
Unprecedented collision energy: 8 TeV, 4 times larger than previous collider (Tevatron Fermilab)
Starting in 2015: reach design collision energy of ~14 TeV

(1 TeV= 10^{-7} Joule)



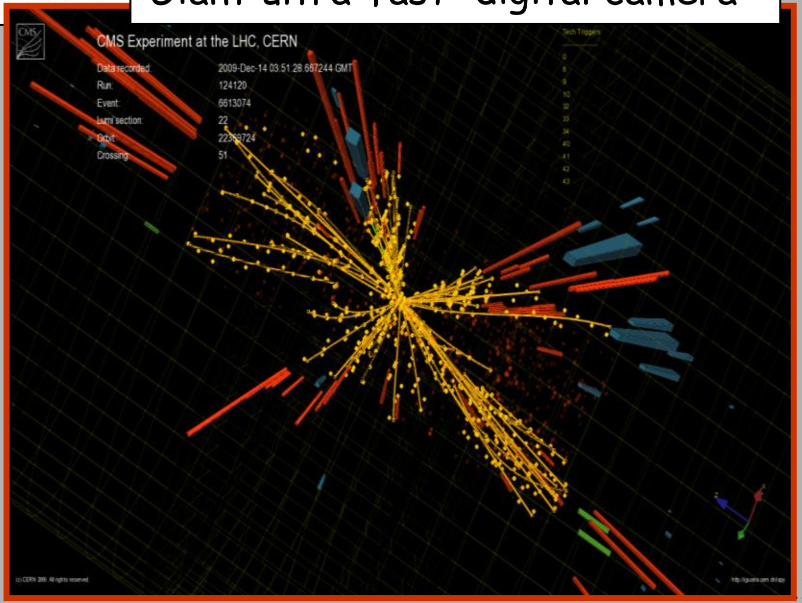
Most challenging component: 1232 high-tech superconducting magnets, providing 8.3 T field (to bend 7 TeV beams inside a 27 km ring).
Made of 7600 km of NbTi superconducting cable


On 4th July 2012, ATLAS and CMS announced the discovery of a new particle (Higgs boson)
CMS
LHCb
Switzerland (Universities of Bern, Geneva and Zürich, ETHZ, EPFL, PSI) and CERN have contributed in a very crucial way to the four experiments and the accelerator
ALICE
ATLAS
YEARS/ANS CERN



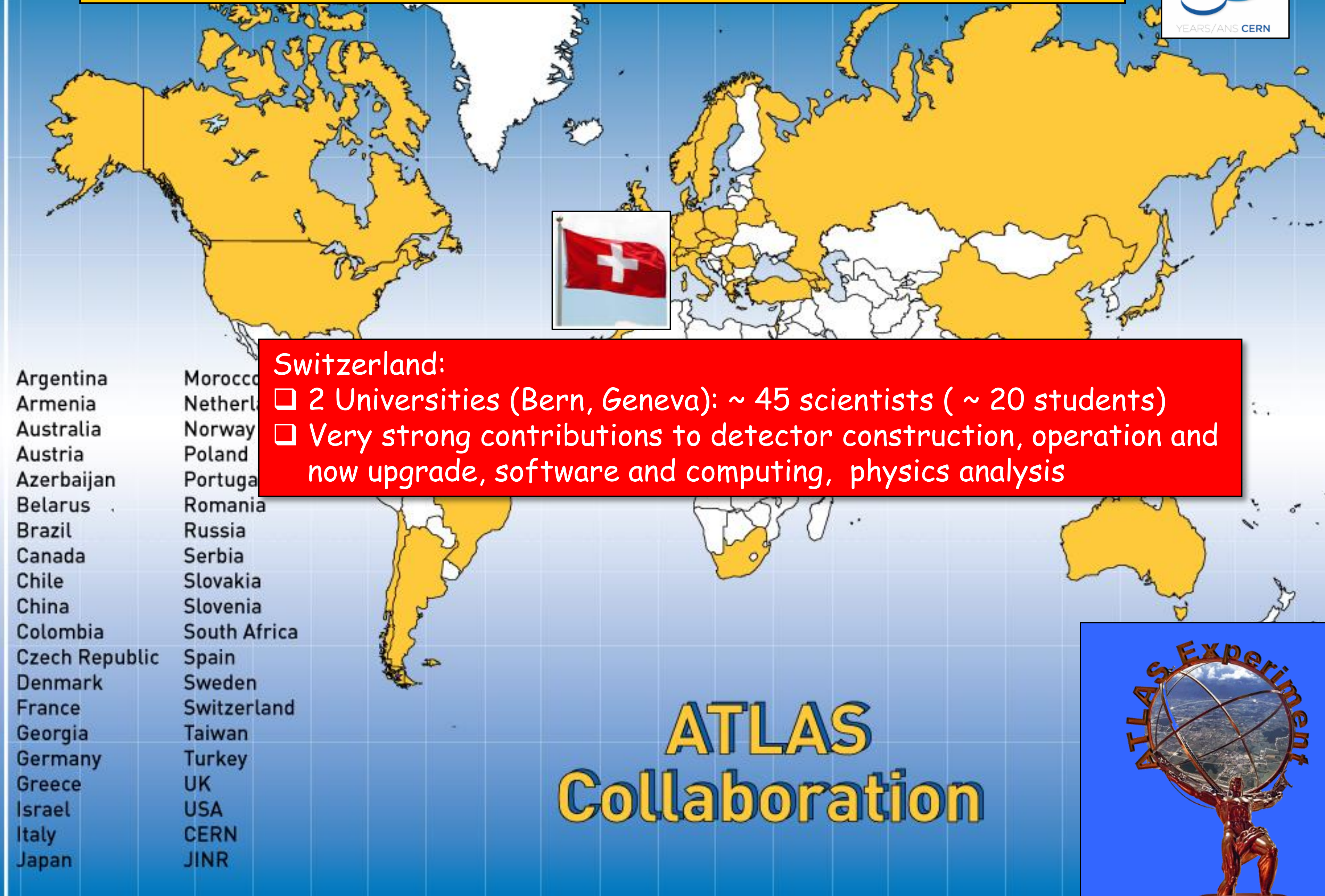
LHC detectors: a big jump in concepts and technologies

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 and 38 Countries



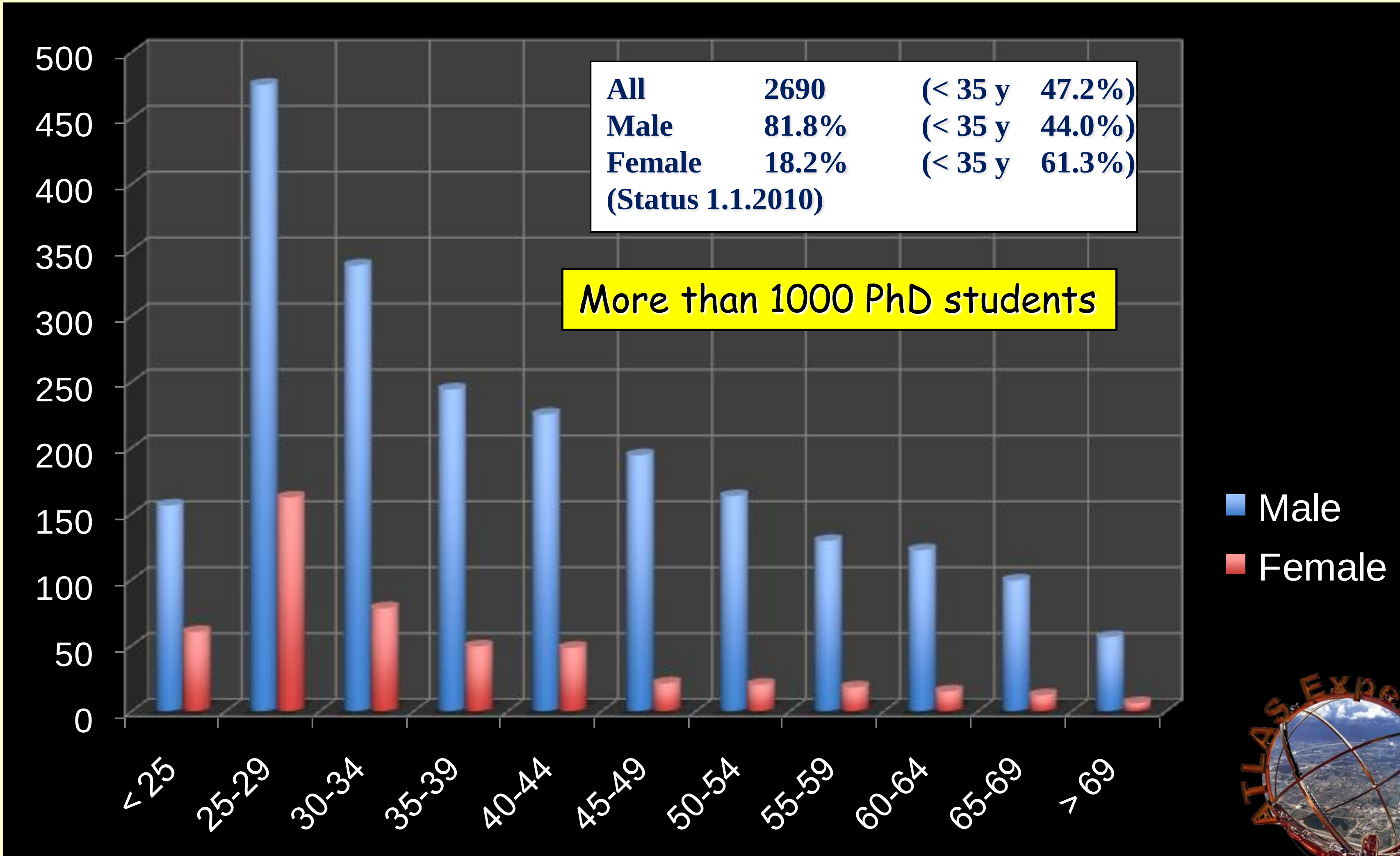
Switzerland:

- 2 Universities (Bern, Geneva): ~ 45 scientists (~ 20 students)
- Very strong contributions to detector construction, operation and now upgrade, software and computing, physics analysis

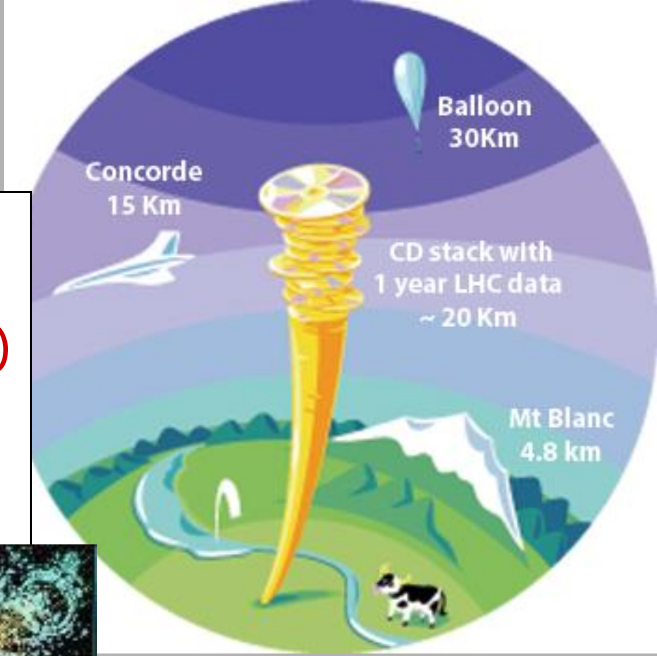
Argentina	Morocc
Armenia	Netherl
Australia	Norway
Austria	Poland
Azerbaijan	Portuga
Belarus	Romania
Brazil	Russia
Canada	Serbia
Chile	Slovakia
China	Slovenia
Colombia	South Africa
Czech Republic	Spain
Denmark	Sweden
France	Switzerland
Georgia	Taiwan
Germany	Turkey
Greece	UK
Israel	USA
Italy	CERN
Japan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

ATLAS Collaboration

Age distribution of the ATLAS population

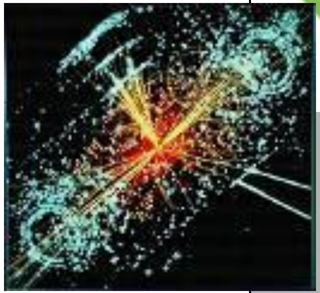


Computing



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.

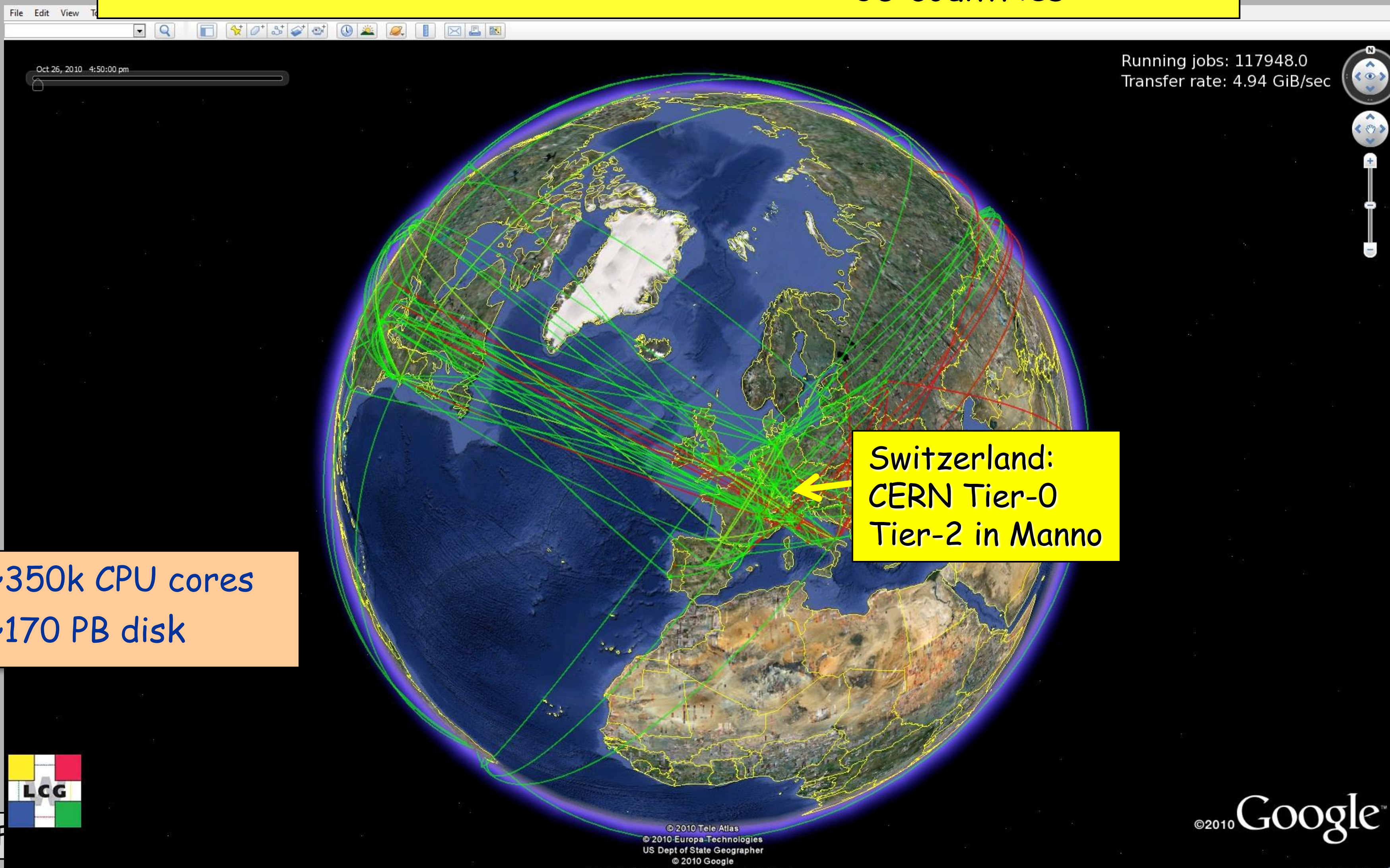
Cooperation of many computer centres all over the world is needed

Grid

F. Gianotti, SPS, Fribourg, 30/6/2014

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

Worldwide LHC Computing Grid (WLCG): ~ 160 computing centres
~ 35 countries



Switzerland:
CERN Tier-0
Tier-2 in Manno

~350k CPU cores
~170 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 ... r space

Energy st ... 12 knots

WHY ???

The CMS exp ... on than the Tour Eiffel

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

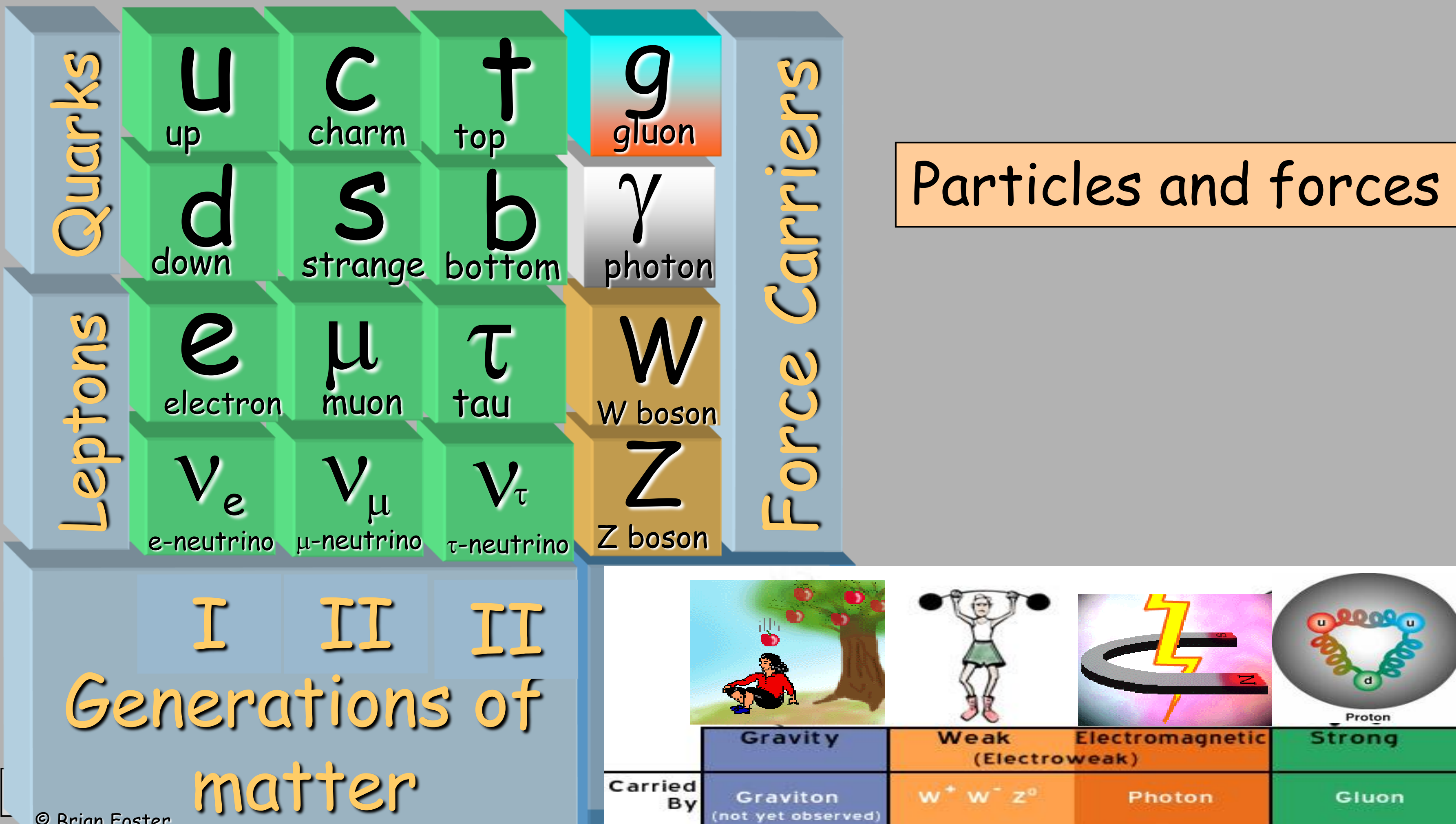
Each LHC experiment produces ~ 10 PB of detector data per year (1 PB=10^6 GB)
This corresponds to ~ 20 million DVD (a 20 km stack ...)

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

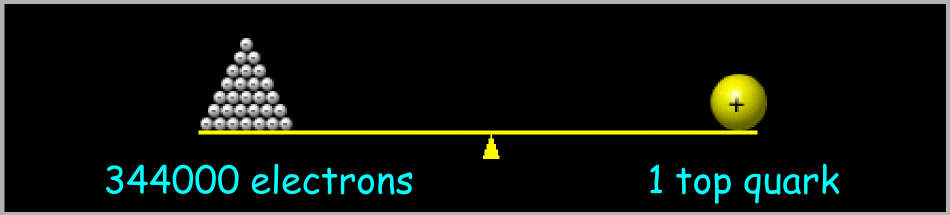
Are there other forces in addition to the known four ?
Are there additional (microscopic) space dimensions ?

ATLAS, CMS

Etc. etc.

LHC built to address these and other fundamental questions

What is the origin of the particle masses ?



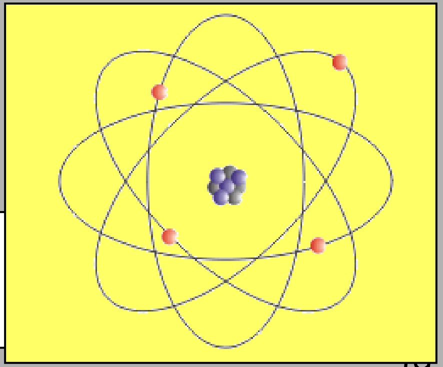
Photon is massless (pure energy), W and Z bosons have x 100 proton mass
Mass of top quark (heaviest elementary particle observed) ≈ mass of Gold atom
Electron mass is ~350000 times smaller
WHY ???

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

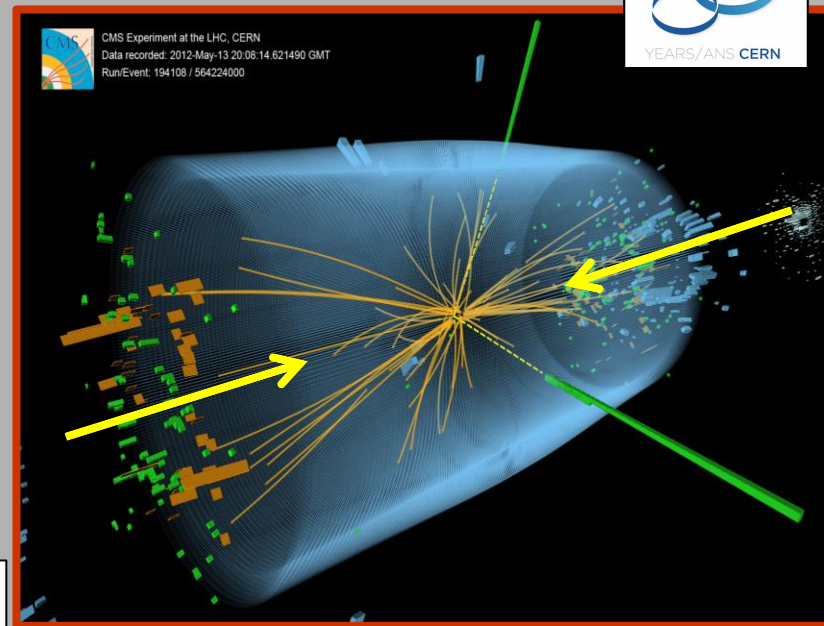
The 1st link to our life

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

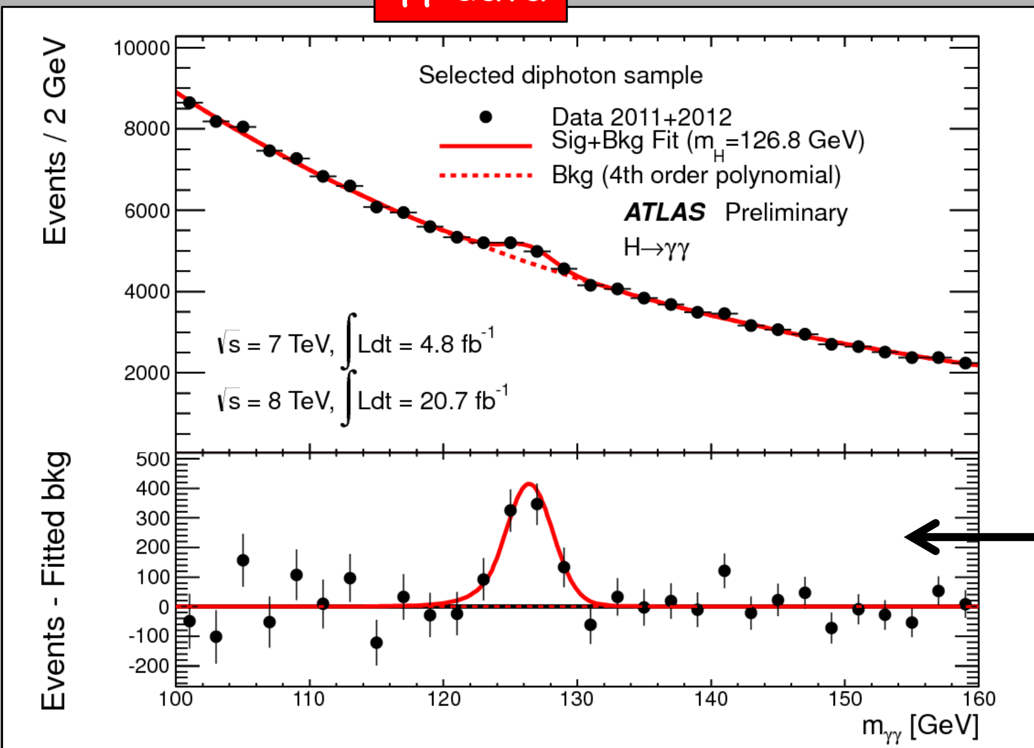


What did we observe ?

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



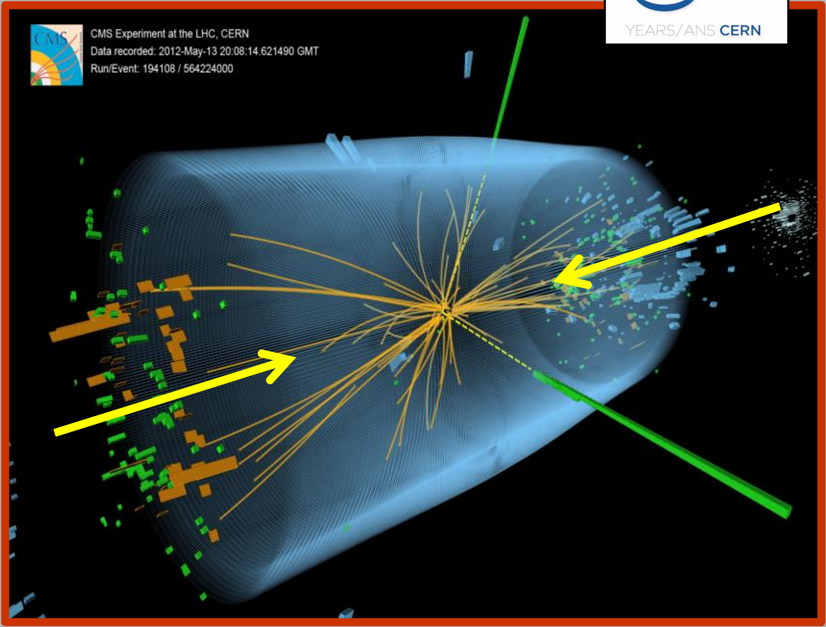
γγ data



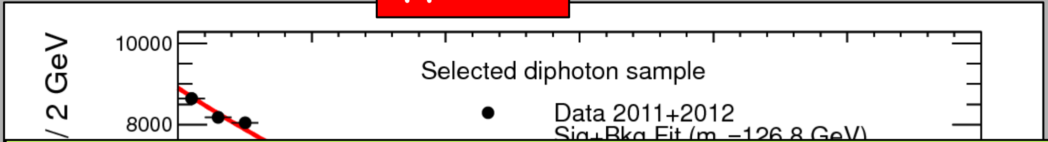
Peak ("resonance") at $m_{\gamma\gamma}$ around 125 GeV (~130 x proton mass) indicates the production of a (new) heavy particle

What did we observe ?

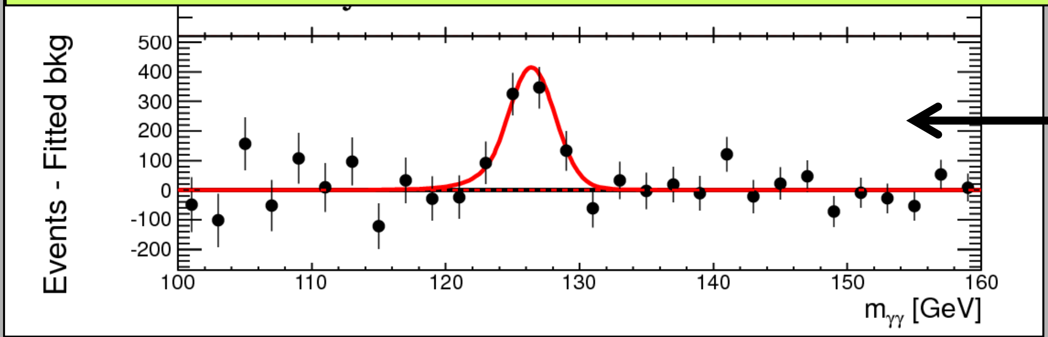
Once produced the Higgs boson is expected to decay into known particles, for instance into two photons → looked at the γγ spectrum in our data



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)
- As of today, each experiment has recorded about 700 Higgs events (out of 5 billion events total)



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

Both experiments have shown since then that the new particle is consistent with a Higgs boson

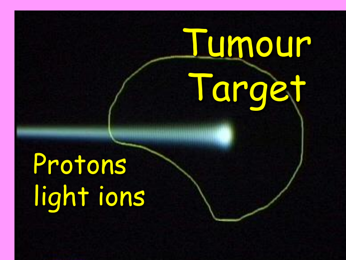
Will the Higgs boson change our life ? It did already !

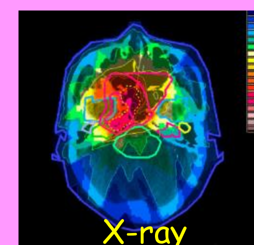
Extreme performance required in particle and nuclear physics → cutting-edge technologies developed at CERN and collaborating Institutes, and then transferred to society.

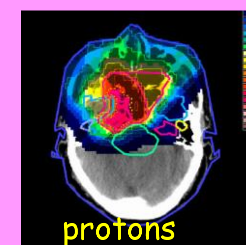
Applications: medical imaging (e.g. PET), cancer therapy, materials science, airport scanners, cargo screening, food sterilization, nuclear waste transmutation, analysis of historical relics, etc. …not to mention the GRID-based computing and the WEB ..

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

↔ **Hadron Therapy**

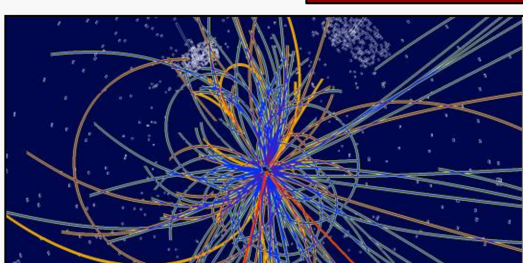






> 100000 patients treated worldwide (45 facilities)
ope (14 facilities)

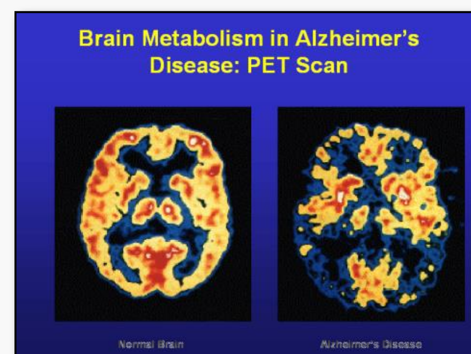
The 2nd link to our life



Detecting particles

↔ **Imaging**

e.g. PET scanner



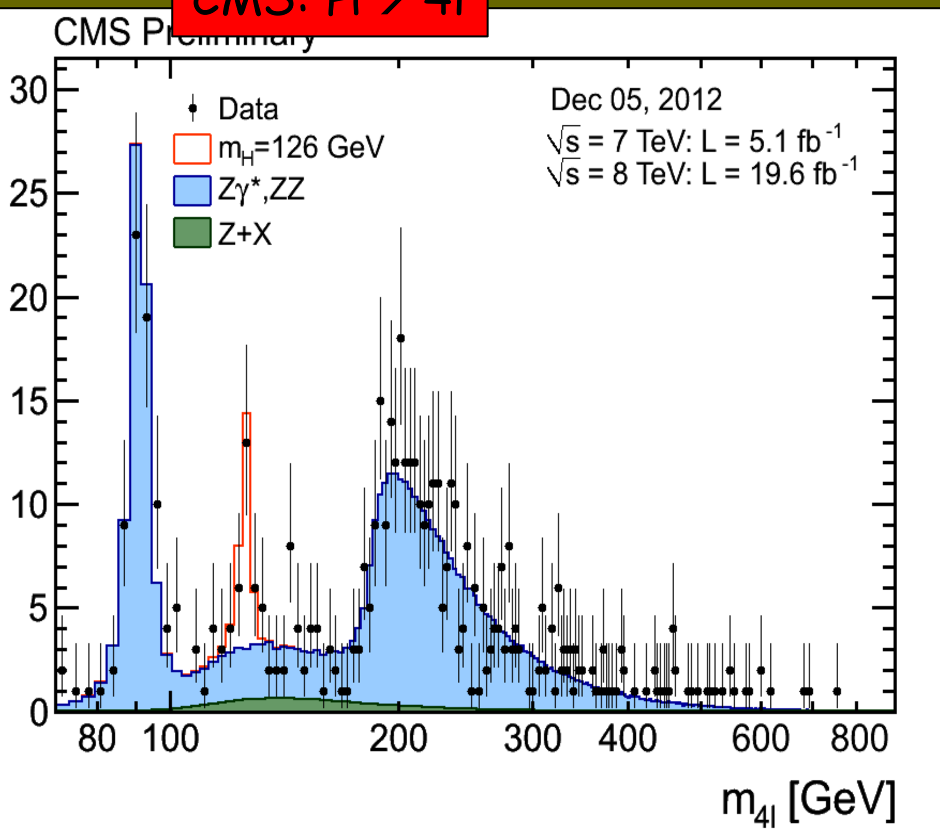
CERN and the LHC

- 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
- Advancing the frontiers of technology, also to the benefit of other fields and society
- Promoting diversity (gender, age, ethnicity, …) as a strength and asset for a richer and more stimulating environment, better science and peace

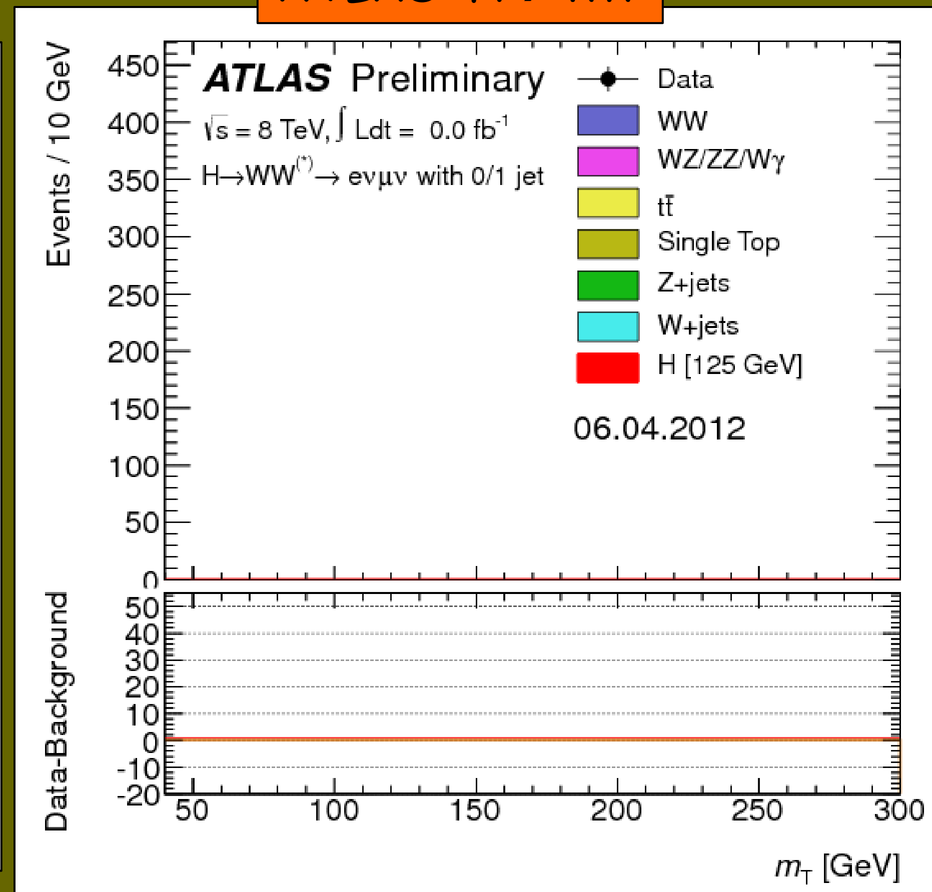
SPARES

Birth and evolution of a signal

CMS: H→ 4l



ATLAS: H→ lvlv



Unprecedented energy: 4 TeV per beam particle → collision energy = 8 TeV

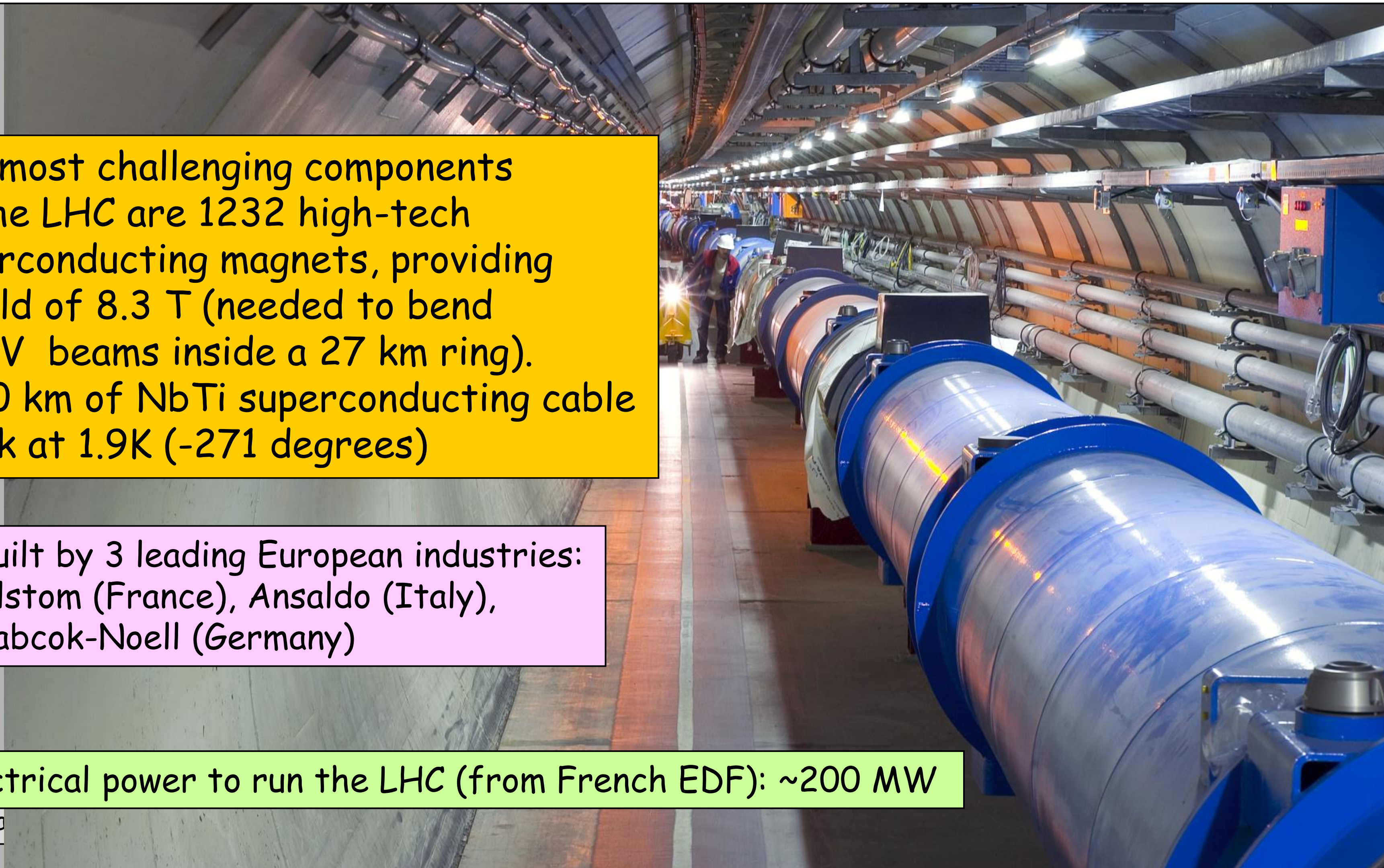
(1 TeV= 10^{-7} Joule)

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).

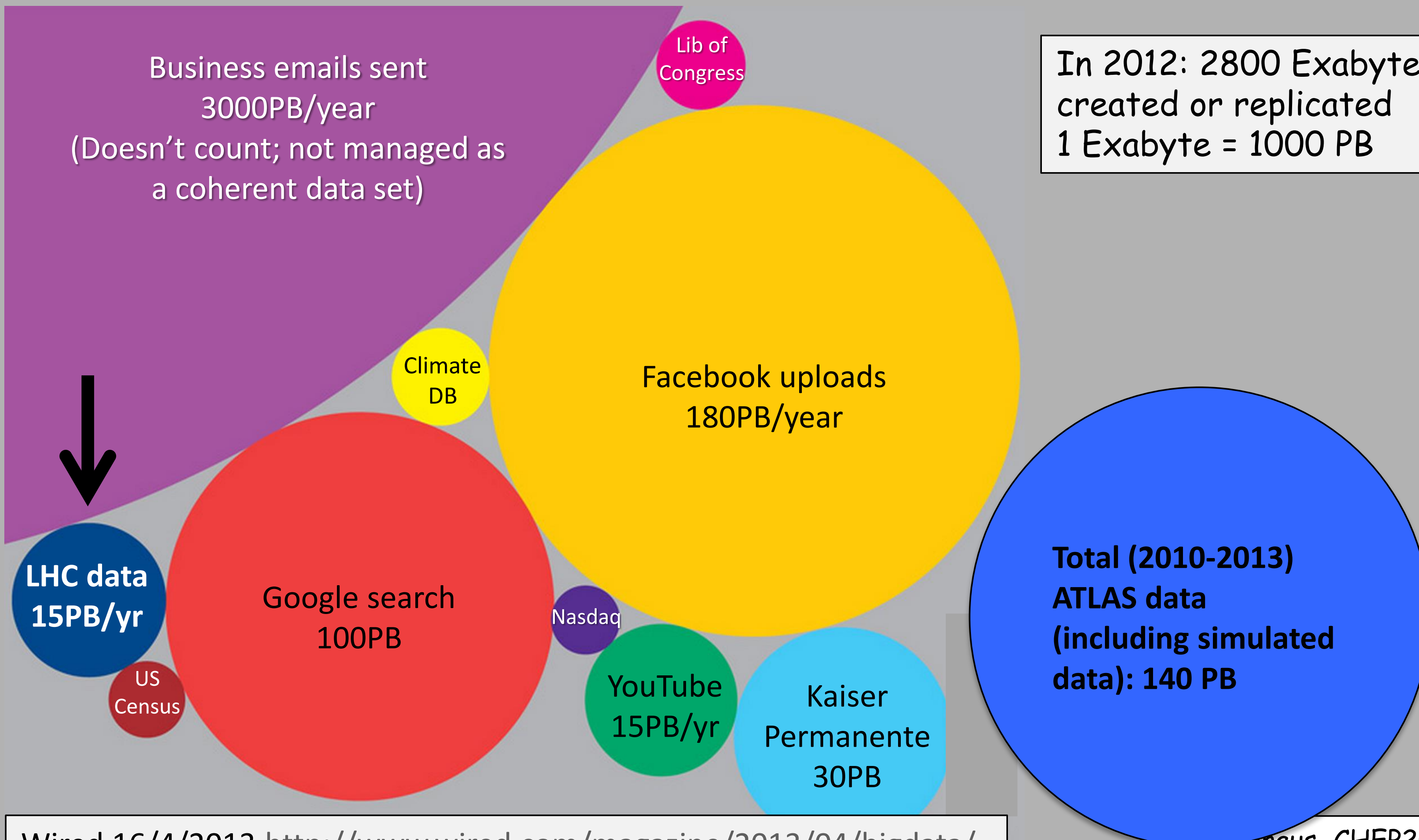
7600 km of NbTi superconducting cable

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

Big Data in 2012



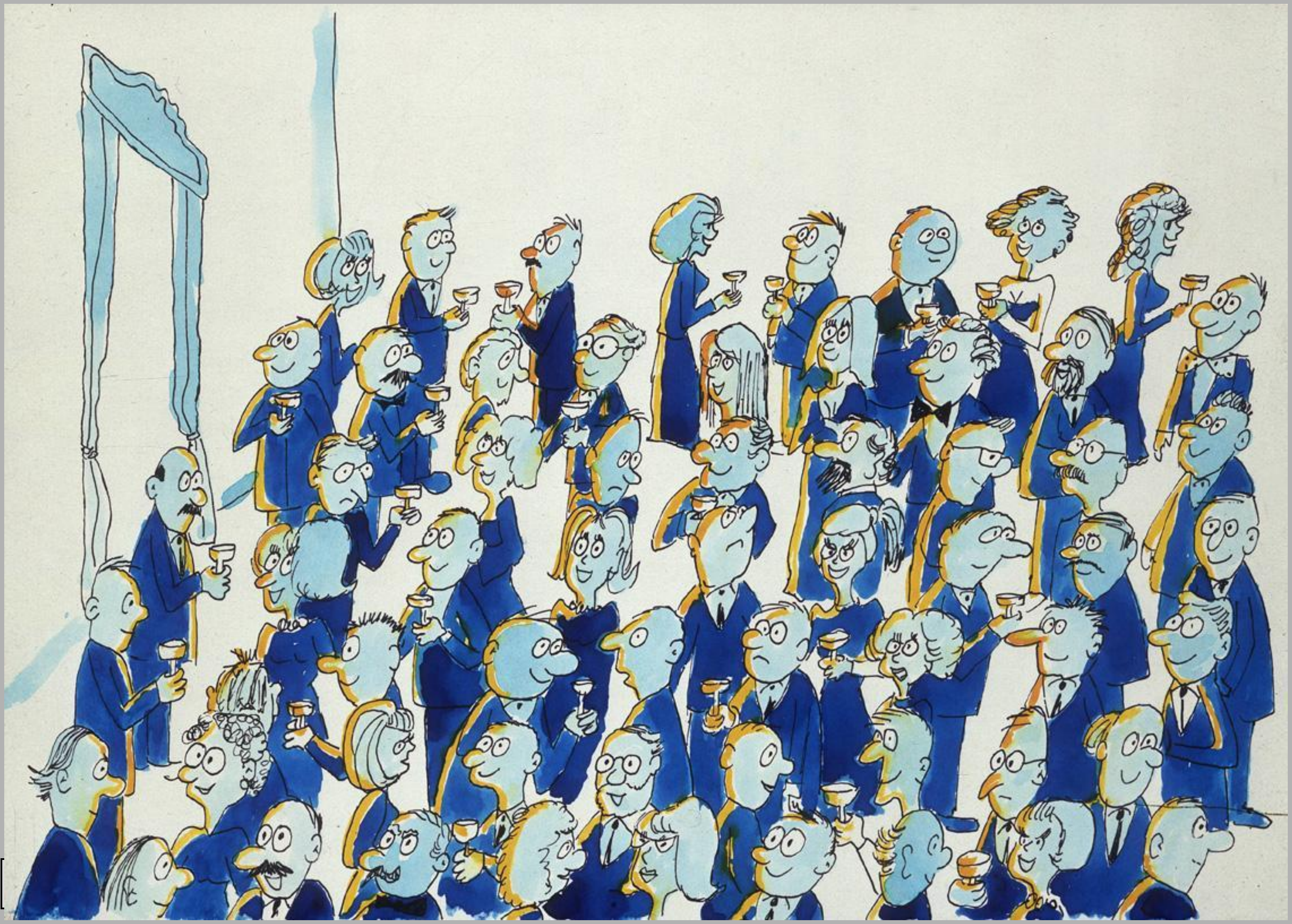
In 2012: 2800 Exabytes created or replicated
1 Exabyte = 1000 PB

Wired 16/4/2013 http://www.wired.com/magazine/2013/04/bigdata/

Wenaus, CHEP2013

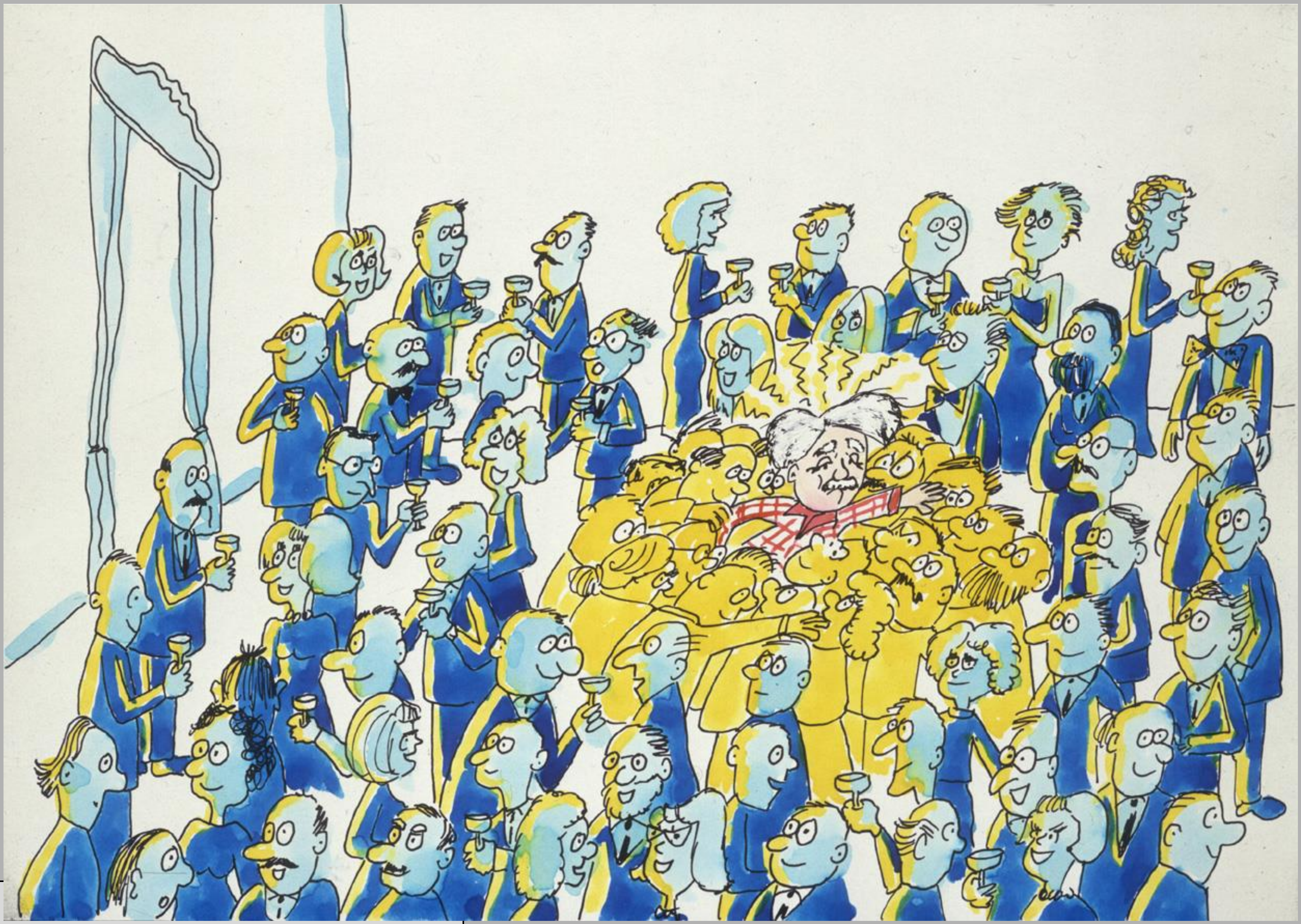
The Higgs mechanism … as exemplified by Prof. David Miller

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.