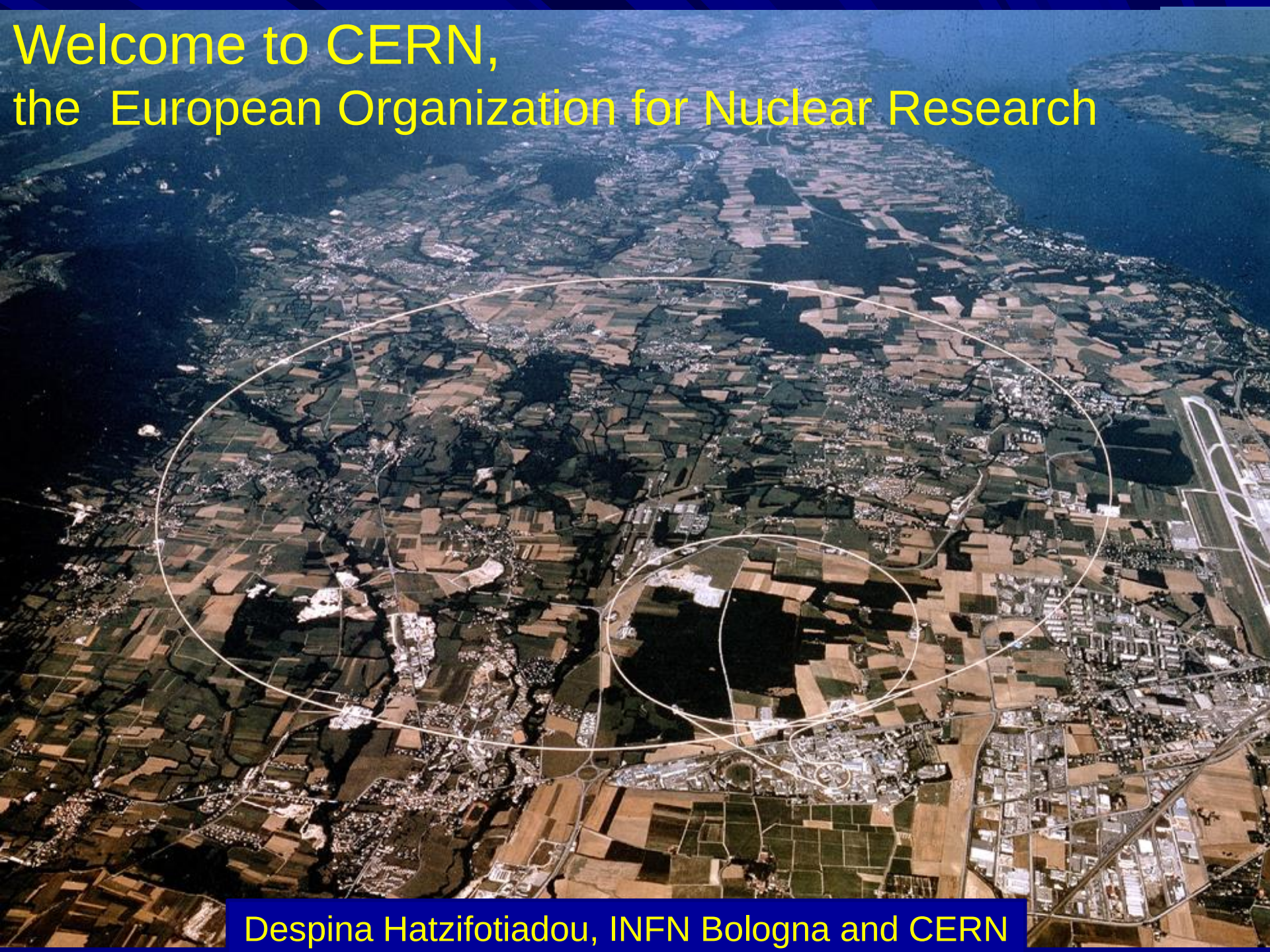
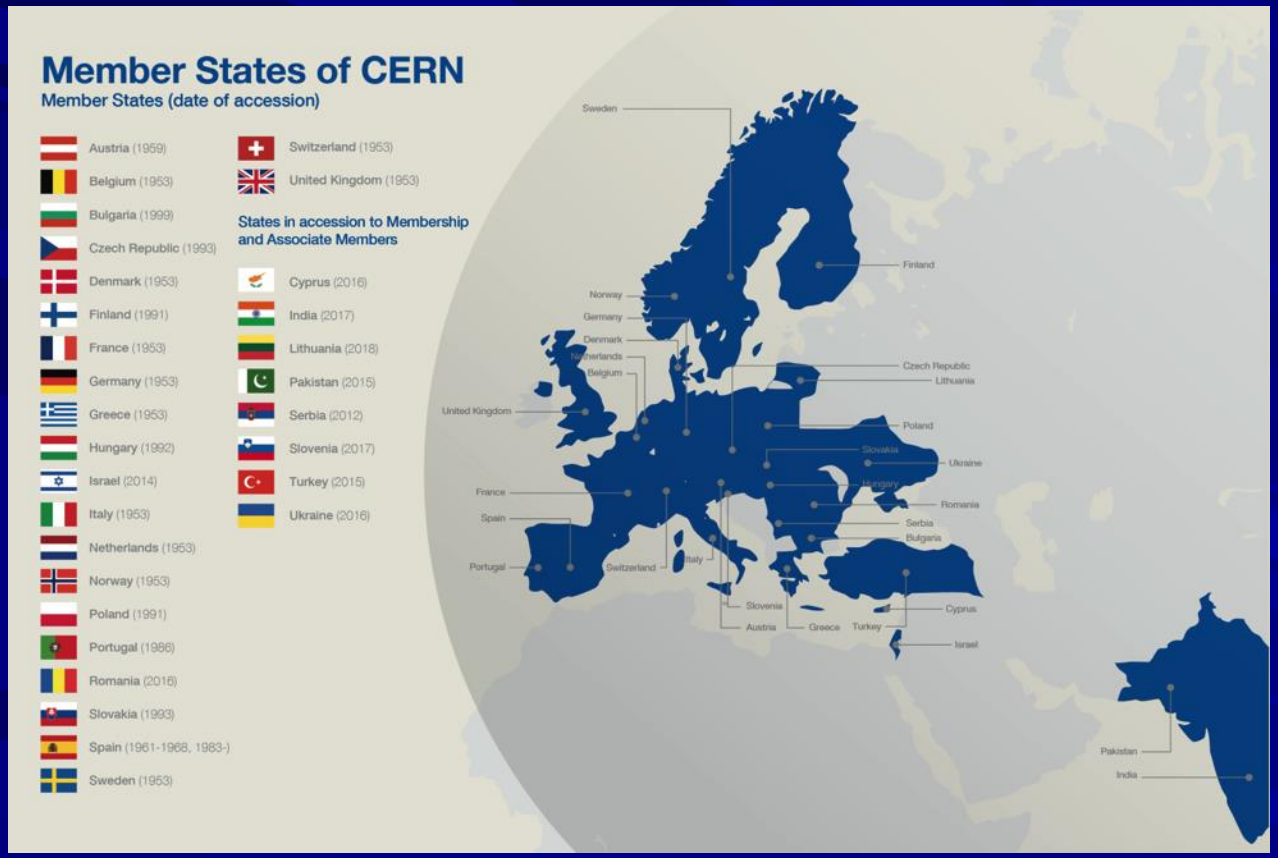
# Welcome to CERN,
# the European Organization for Nuclear Research



Despina Hatzifotiadou, INFN Bologna and CERN

# The world's largest laboratory for particle physics

CERN was founded in 1954 by 12 European states
Today : 23 member states

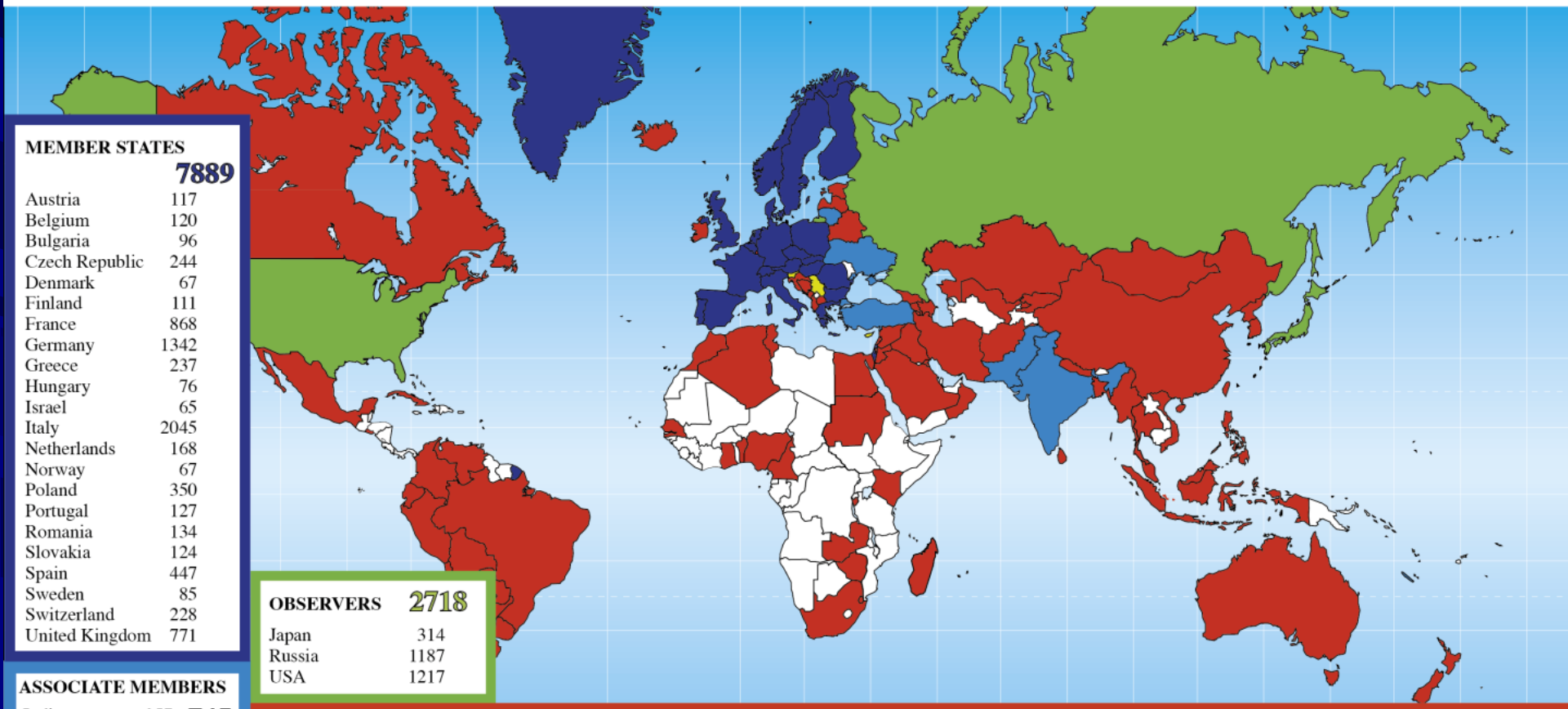



Yearly budget:
~ 1000 MCHF (920M€)

Personnel:
~2660 Staff members
~840 Fellows
~350 Students
~14000 Users

Observers:
EU, USA,Japan, UNESCO

# Distribution of All CERN Users by Nationality on 24 January 2018



**MEMBER STATES** **7889**

| | |
|---|---|
| Austria | 117 |
| Belgium | 120 |
| Bulgaria | 96 |
| Czech Republic | 244 |
| Denmark | 67 |
| Finland | 111 |
| France | 868 |
| Germany | 1342 |
| Greece | 237 |
| Hungary | 76 |
| Israel | 65 |
| Italy | 2045 |
| Netherlands | 168 |
| Norway | 67 |
| Poland | 350 |
| Portugal | 127 |
| Romania | 134 |
| Slovakia | 124 |
| Spain | 447 |
| Sweden | 85 |
| Switzerland | 228 |
| United Kingdom | 771 |

**OBSERVERS** **2718**

| | |
|---|---|
| Japan | 314 |
| Russia | 1187 |
| USA | 1217 |

**ASSOCIATE MEMBERS** **745**

| | |
|---|---|
| India | 357 |
| Lithuania | 35 |
| Pakistan | 65 |
| Turkey | 173 |
| Ukraine | 115 |

**ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP** **118**

| | |
|---|---|
| Cyprus | 26 |
| Serbia | 57 |
| Slovenia | 35 |

**OTHERS** **1872**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Afghanistan | 1 | Bolivia | 4 | Egypt | 31 | Kazakhstan | 5 | Mongolia | 2 | Philippines | 3 | Thailand | 22 |
| Albania | 3 | Bosnia & Herzegovina | 2 | El Salvador | 1 | Kenya | 3 | Montenegro | 11 | Saint Kitts and Nevis | 1 | T.F.Y.R.O.M. | 2 |
| Algeria | 14 | Brazil | 135 | Estonia | 15 | Korea Rep. | 185 | Morocco | 20 | Saudi Arabia | 2 | Tunisia | 5 |
| Argentina | 27 | Burundi | 1 | Georgia | 46 | Kyrgyzstan | 1 | Myanmar | 1 | Senegal | 1 | Uruguay | 1 |
| Armenia | 19 | Cameroon | 1 | Ghana | 1 | Latvia | 2 | Nepal | 10 | Singapore | 4 | Uzbekistan | 4 |
| Australia | 31 | Canada | 161 | Hong Kong | 1 | Lebanon | 23 | New Zealand | 5 | South Africa | 56 | Venezuela | 10 |
| Azerbaijan | 10 | Chile | 20 | Iceland | 3 | Luxembourg | 2 | Nigeria | 3 | Sri Lanka | 6 | Viet Nam | 13 |
| Bangladesh | 11 | China | 510 | Indonesia | 11 | Madagascar | 4 | North Korea | 1 | Sudan | 1 | Zambia | 1 |
| Belarus | 48 | Colombia | 45 | Iran | 51 | Malaysia | 15 | Oman | 3 | Swaziland | 1 | Zimbabwe | 2 |
| Benin | 1 | Croatia | 41 | Iraq | 1 | Malta | 9 | Palestine (O.T.). | 7 | Syria | 1 | | |
| | | Cuba | 12 | Ireland | 16 | Mauritius | 1 | Paraguay | 2 | Taiwan | 51 | | |
| | | Ecuador | 6 | Jordan | 1 | Mexico | 82 | Peru | 7 | | | | |

# What is CERN

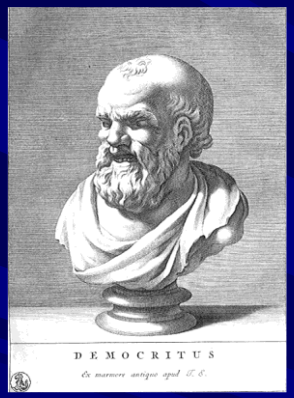
- CERN is the world's largest particle physics laboratory

- Particle physics is about:
  - elementary particles which all matter in the Universe is made of
  - fundamental forces which hold matter together

- Particle physics requires:
  - special tools to create and study new particles

- The special tools for particle physics are:
  - ACCELERATORS and DETECTORS

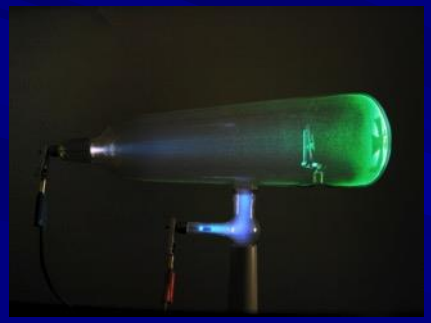
Democritus believed that all matter is made of indivisible elements, the atoms



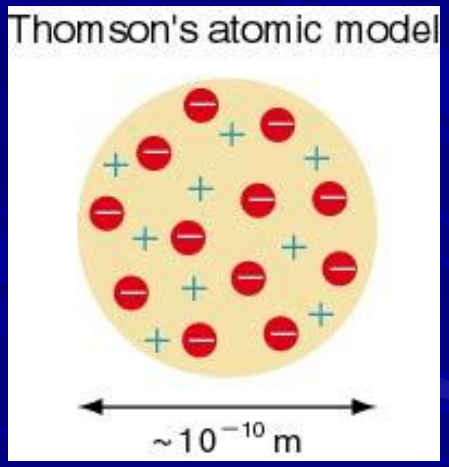

Mendeleev's periodic table of elements (1869) – 80 different indivisible atoms

| I | II | III | IV | V | VI | VII | VIII |
|---|---|---|---|---|---|---|---|
| H 1.01 | | | | | | | |
| Li 6.94 | Be 9.01 | B 10.8 | C 12.0 | N 14.0 | O 16.0 | F 19.0 | |
| Na 23.0 | Mg 24.3 | Al 27.0 | Si 28.1 | P 31.0 | S 32.1 | Cl 35.5 | |
| K 39.1 | Ca 40.1 | | Ti 47.9 | V 50.9 | Cr 52.0 | Mn 54.9 | Fe 55.9 Co 58.9 Ni 58.7 |
| Cu 63.5 | Zn 65.4 | | | As 74.9 | Se 79.0 | Br 79.9 | |
| Rb 85.5 | Sr 87.6 | Y 88.9 | Zr 91.2 | Nb 92.9 | Mo 95.9 | | Ru 101 Rh 103 Pd 106 |
| Ag 108 | Cd 112 | In 115 | Sn 119 | Sb 122 | Te 128 | I 127 | |
| Ce 133 | Ba 137 | La 139 | | Ta 181 | W 184 | | Os 194 Ir 192 Pt 195 |
| Au 197 | Hg 201 | Ti 204 | Pb 207 | Bi 209 | | | |
| | | | Th 232 | | U 238 | | |

JJ Thomson

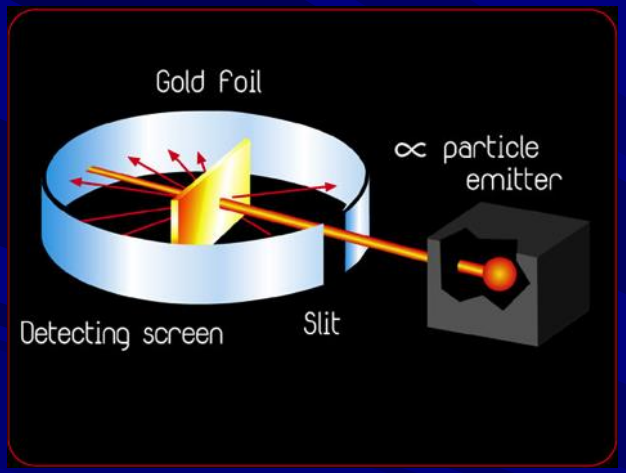


Discovery of the electron with cathode ray tube
first elementary particle
1896

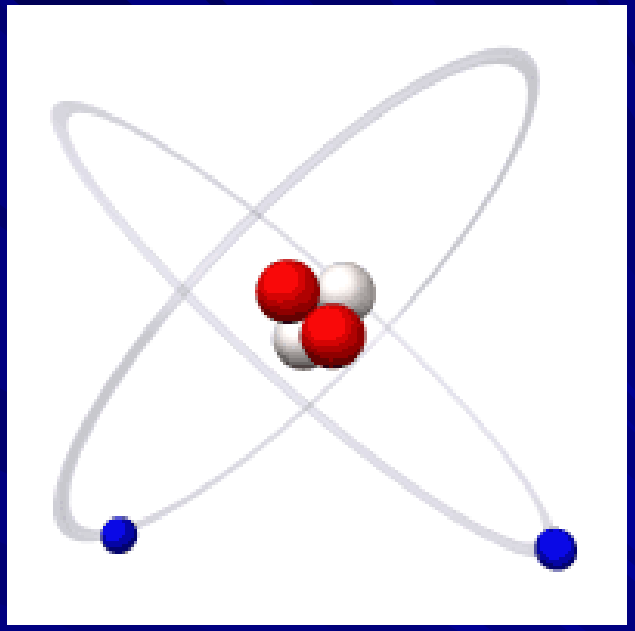



Thomson's plum pudding model (1904)

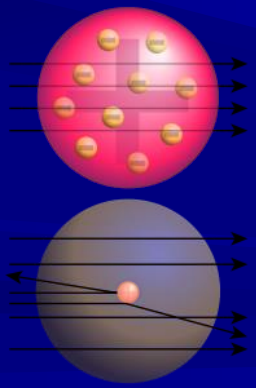
2011 : 100-year anniversary from the introduction of Rutherford's atomic model




alpha scattering experiment
Geiger – Marsden

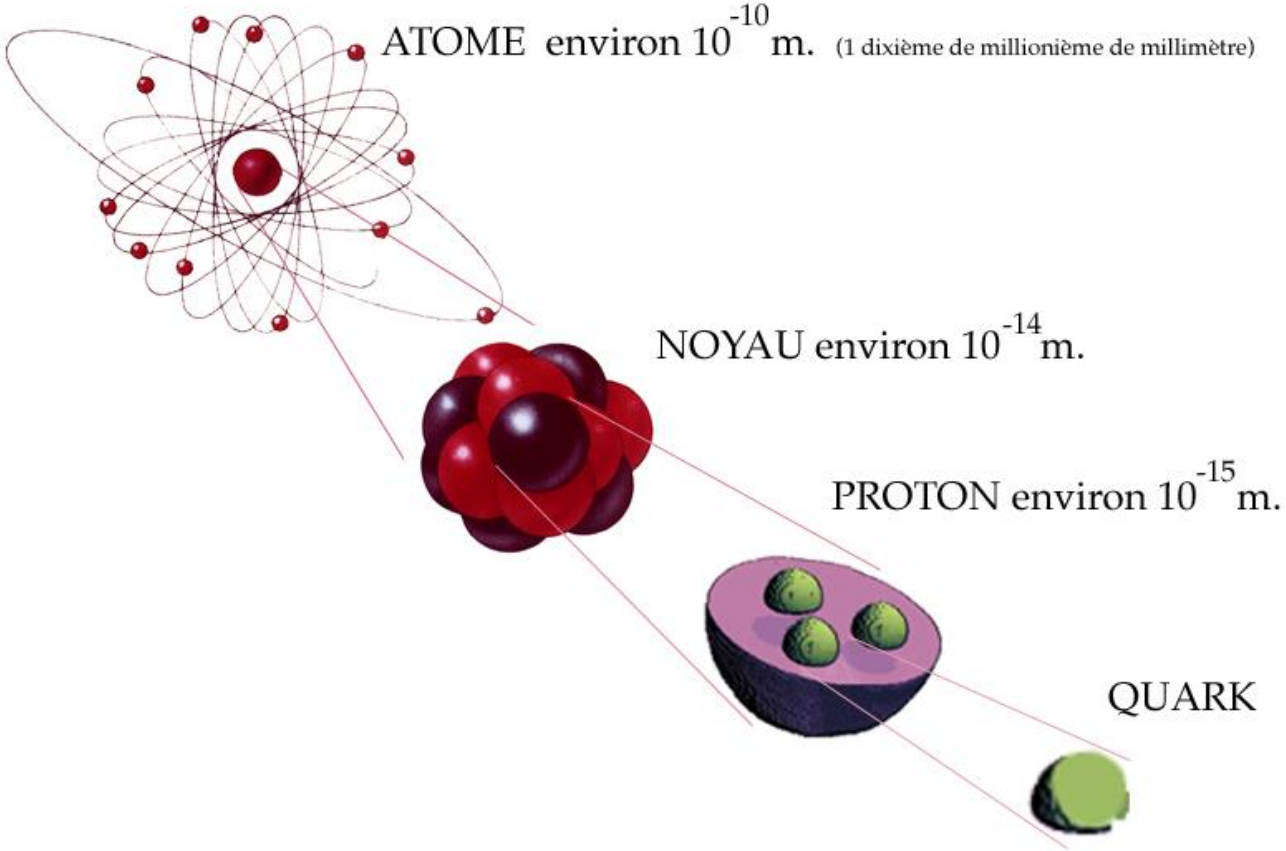


Ernest Rutherford



Nucleus: most of the mass, positive charge; atom is mainly empty
Later on found that the nucleus consists of protons and neutrons

# The constituents of matter

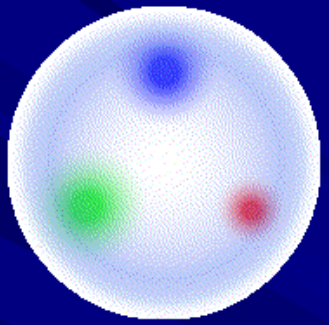



Il y a environ onze milliards de milliards d'atomes de fer dans un milligramme de fer !

D.Bertola/CERN

# The constituents of matter

Quarks (Gell-Mann) 1964



Today's periodic system of the fundamental building blocks

| | Quarks | | Leptons | |
|---|---|---|---|---|
| Generation 3 | t Top | b Bottom | τ Tau | $\nu_\tau$ Tau-neutrino |
| Generation 2 | c Charm | s Strange | μ Muon | $\nu_\mu$ Muon-neutrino |
| Generation 1 | u Up | d Down | e Electron | $\nu_e$ Electron-neutrino |

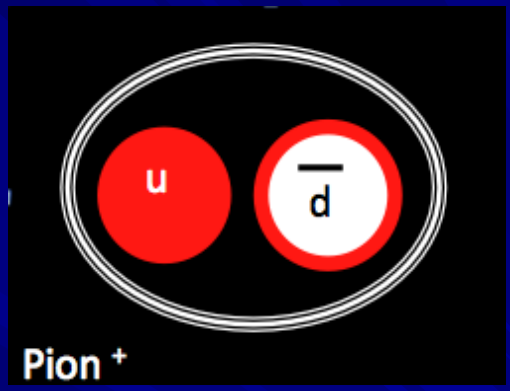
# Quark Confinement

Quarks can not exist free in nature

They can only exist bound inside hadrons


baryons consisting of 3 quarks

mesons consisting of a quark and an anti-quark




**Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$**

Baryons are fermionic hadrons.

These are a few of the many types of baryons.

| Symbol | Name | Quark content | Electric charge | Mass GeV/$c^2$ | Spin |
|---|---|---|---|---|---|
| **p** | proton | **uud** | 1 | 0.938 | 1/2 |
| $\bar{\mathbf{p}}$ | antiproton | $\bar{\mathbf{u}}\bar{\mathbf{u}}\bar{\mathbf{d}}$ | –1 | 0.938 | 1/2 |
| **n** | neutron | **udd** | 0 | 0.940 | 1/2 |
| $\Lambda$ | lambda | **uds** | 0 | 1.116 | 1/2 |
| $\Omega^-$ | omega | **sss** | –1 | 1.672 | 3/2 |

**Mesons $q\bar{q}$**

Mesons are bosonic hadrons

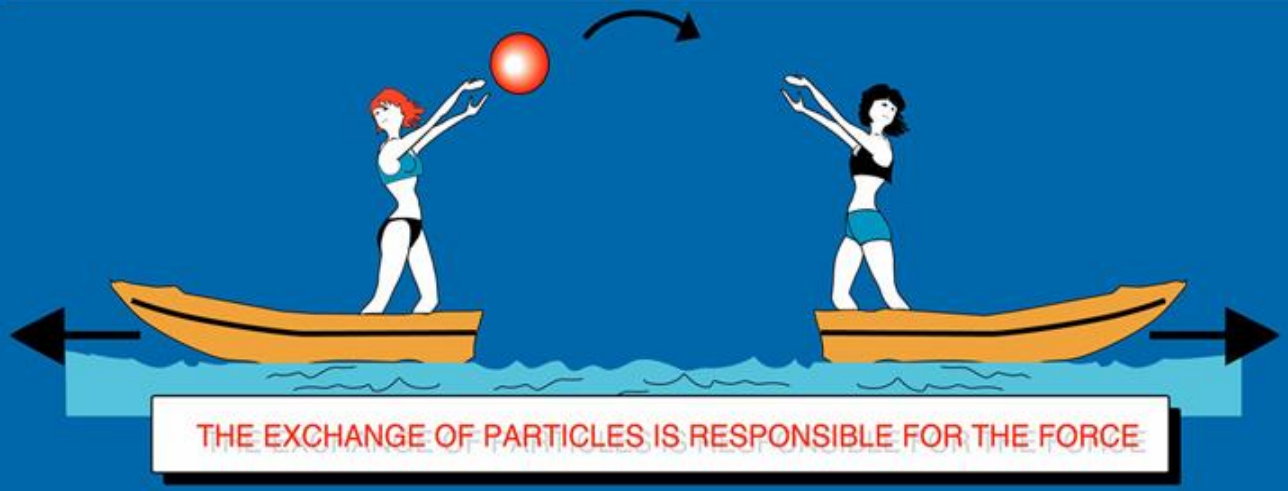
These are a few of the many types of mesons.

| Symbol | Name | Quark content | Electric charge | Mass GeV/$c^2$ | Spin |
|---|---|---|---|---|---|
| $\pi^+$ | pion | $\mathbf{u\bar{d}}$ | +1 | 0.140 | 0 |
| $\mathbf{K^-}$ | kaon | $\mathbf{s\bar{u}}$ | –1 | 0.494 | 0 |
| $\rho^+$ | rho | $\mathbf{u\bar{d}}$ | +1 | 0.776 | 1 |
| $B^0$ | B-zero | $\mathbf{d\bar{b}}$ | 0 | 5.279 | 0 |
| $\eta_c$ | eta-c | $\mathbf{c\bar{c}}$ | 0 | 2.980 | 0 |

# The forces in Nature

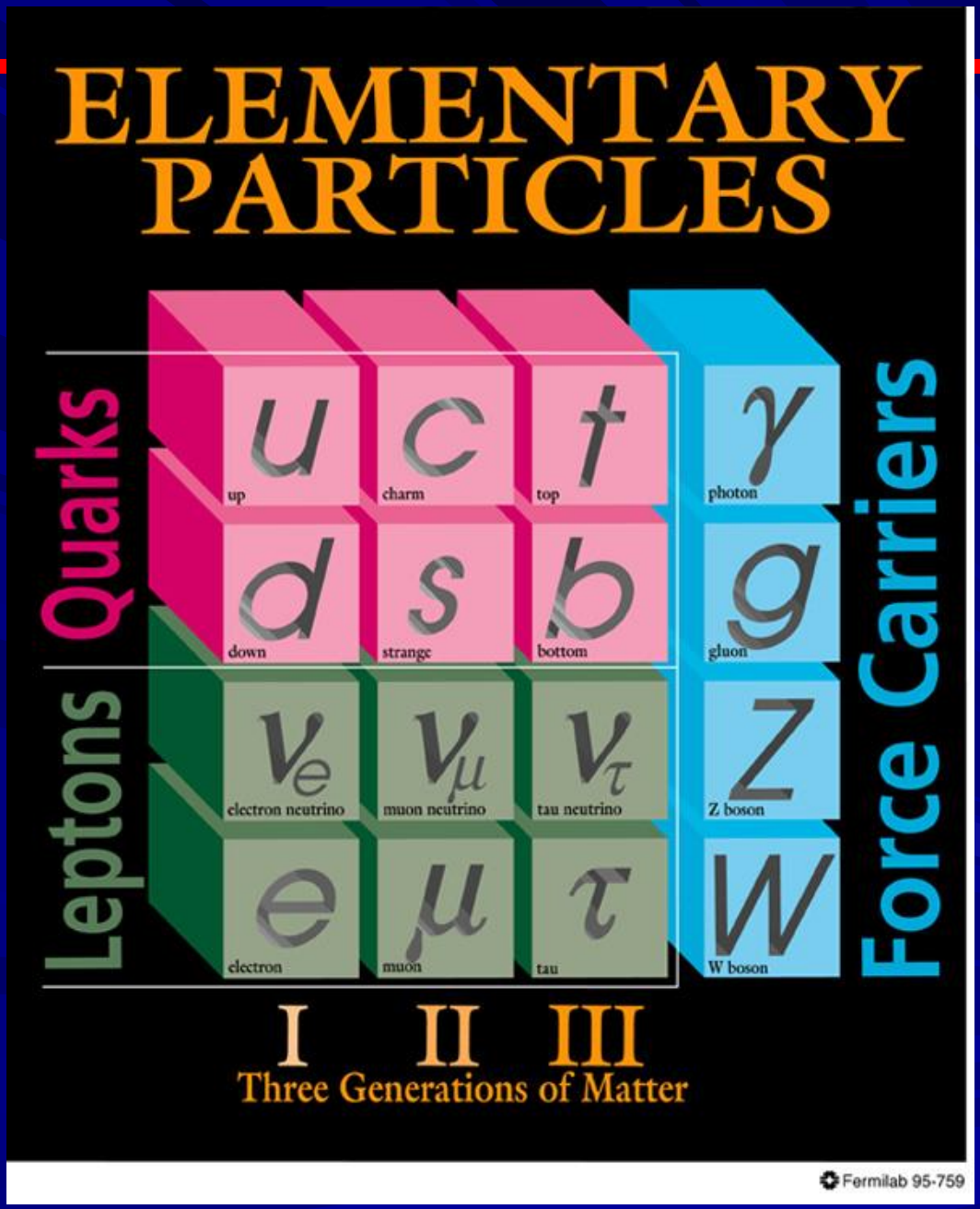
## The forces in Nature

| TYPE | INTENSITY OF FORCES ( DECREASING ORDER ) | BINDING PARTICLE ( FIELD QUANTUM ) | OCCURS IN : |
|---|---|---|---|
| STRONG NUCLEAR FORCE | ~ 1 | GLUONS ( NO MASS ) | ATOMIC NUCLEUS |
| ELECTRO -MAGNETIC FORCE | ~ $10^{-3}$ | PHOTONS ( NO MASS ) | ATOMIC SHELL ELECTROTECHNIQUE |
| WEAK NUCLEAR FORCE | ~ $10^{-5}$ | BOSONS $Z^{o}$ , W+ , W- ( HEAVY ) | RADIOACTIVE BETA DESINTEGRATION |
| GRAVITATION | ~ $10^{-38}$ | GRAVITONS ( ? ) | HEAVENLY BODIES |



# The Standard Model

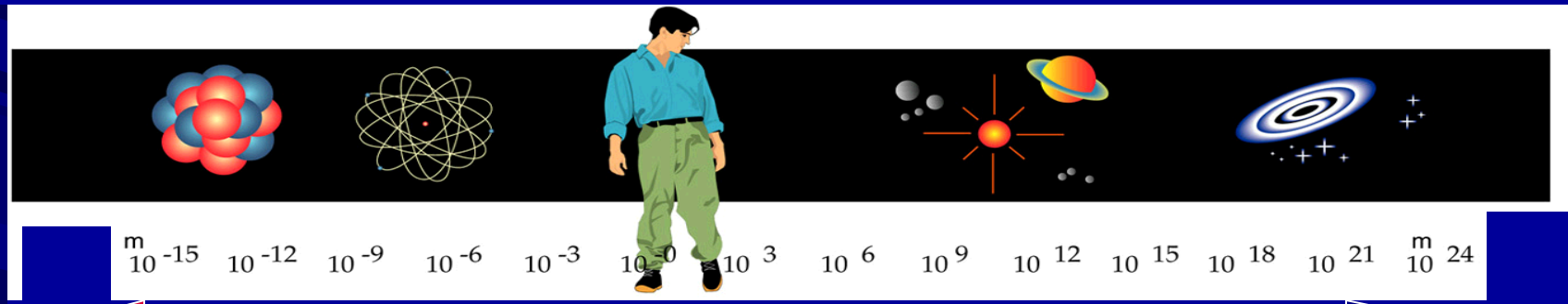
fermions
Fermi-Dirac
statistics
Spin half-integer
(1/2, 3/2,...)




bosons
Bose-Einstein
statistics
Spin integer
(0, 1, 2,..)

# CERN's mission : to build particle accelerators

## Why accelerators? To investigate Particle Physics




Accelerators

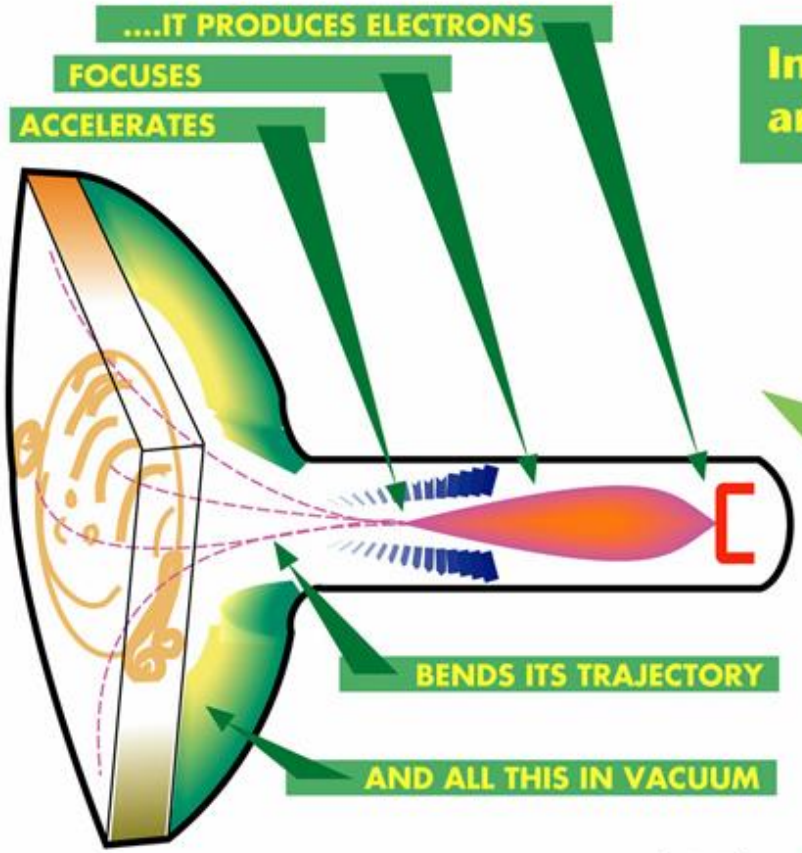
Microscopes

Binoculars

Optical and radio telescopes

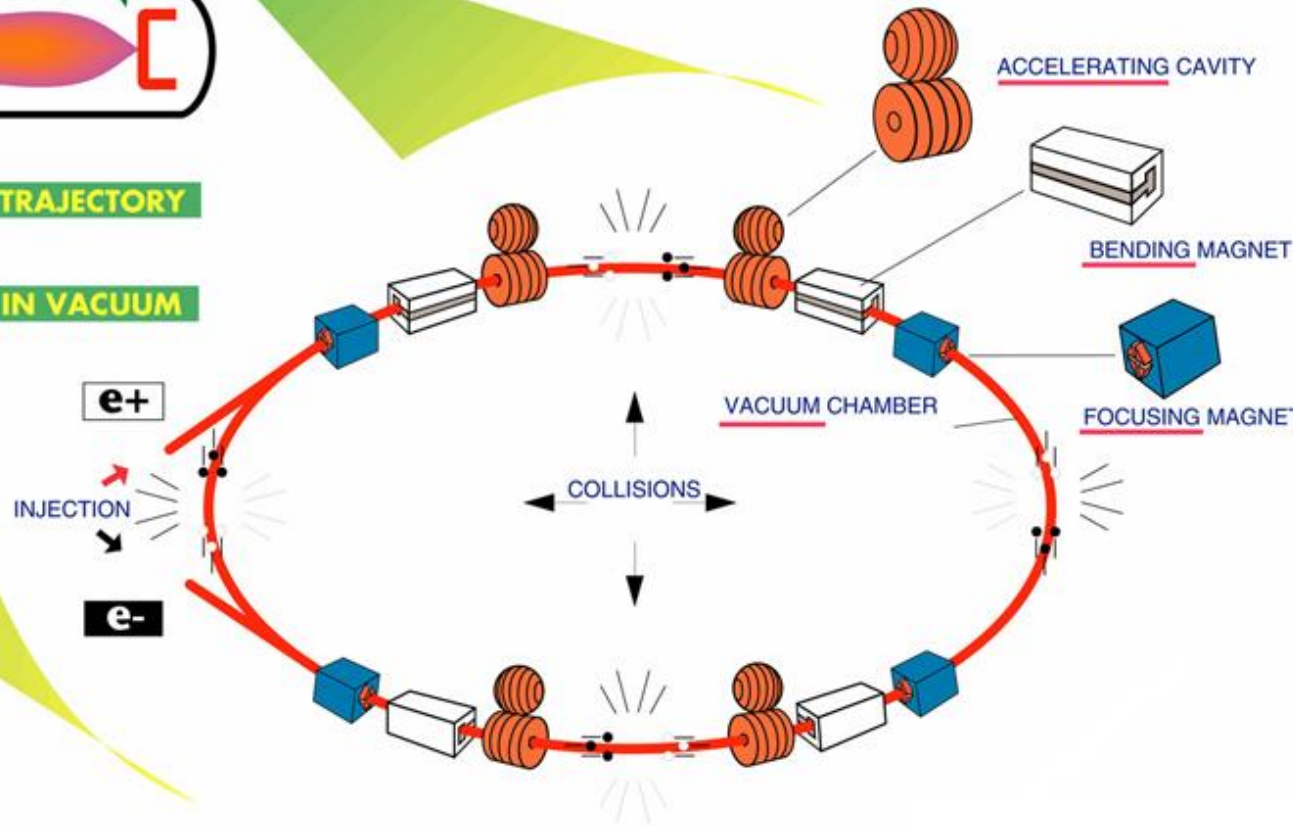
Particle physics looks at matter in its smallest dimensions

# DID YOU KNOW YOUR TELEVISION SET IS AN ACCELERATOR ?



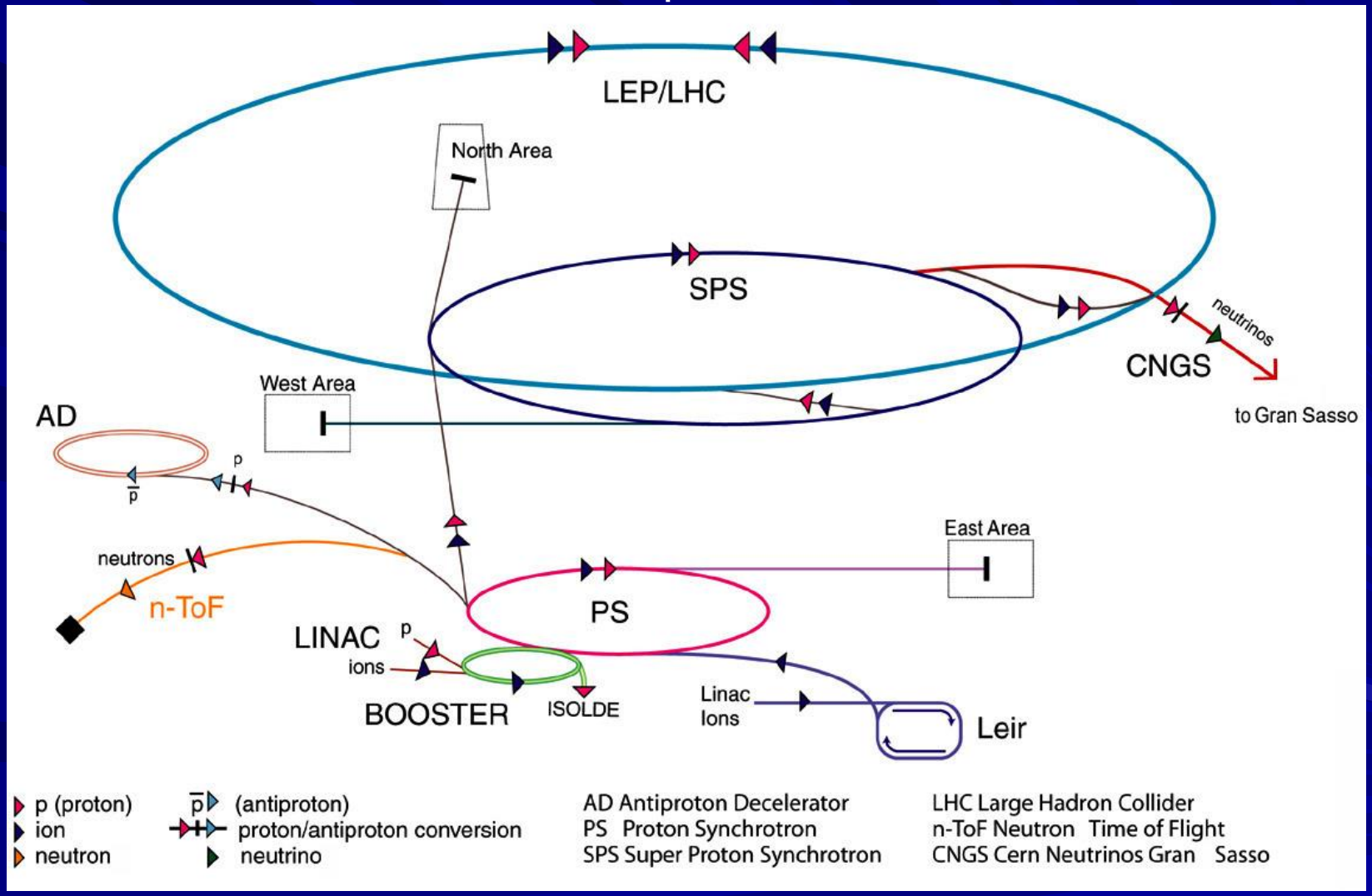

**In your TV set, the electrons are accelerated to 20000 volts.**

**In LEP, they are accelerated to 100 000 000 000 volts.**

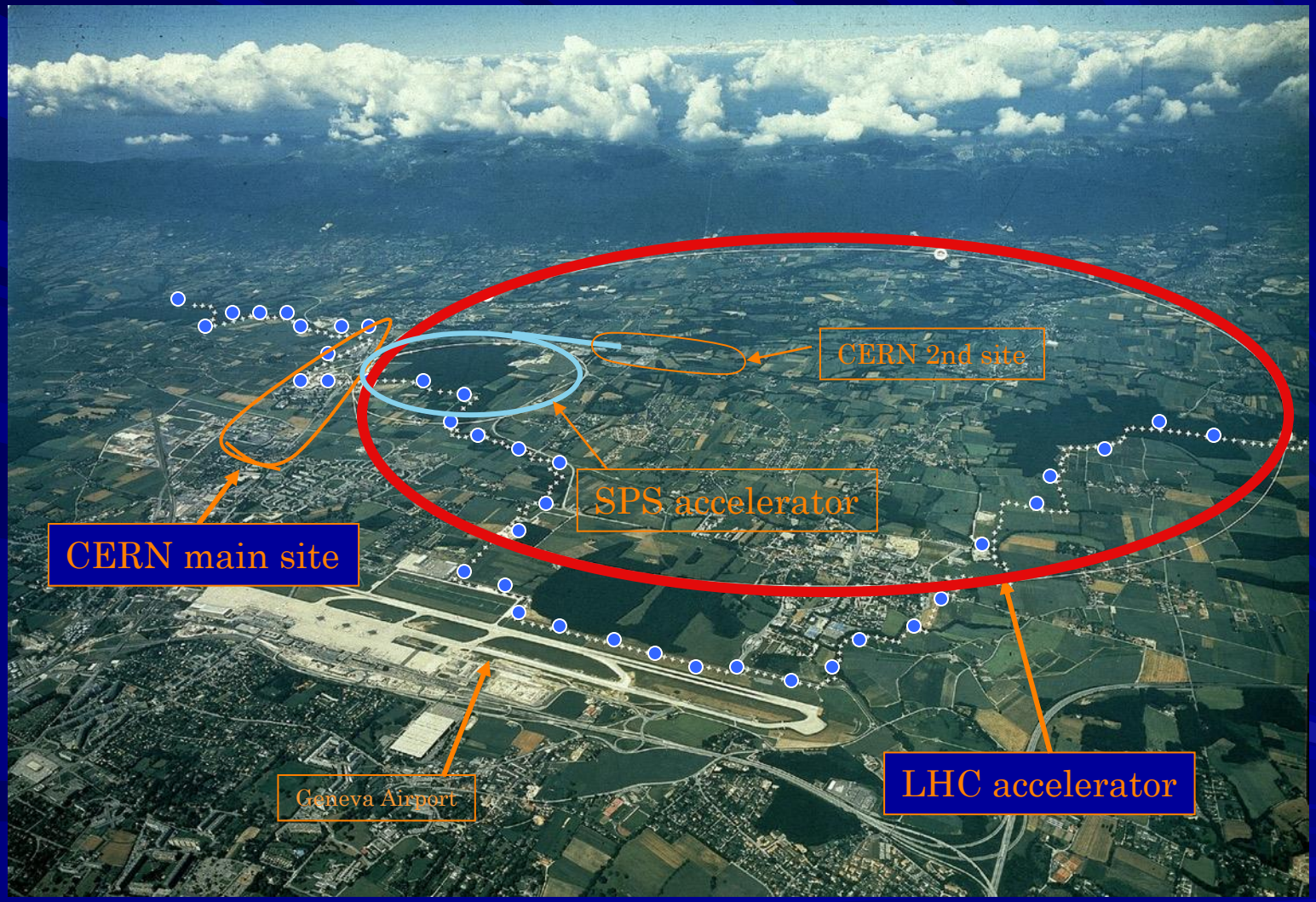


# CERN's mission: to build particle accelerators

## Accelerator chain at CERN, a complex business

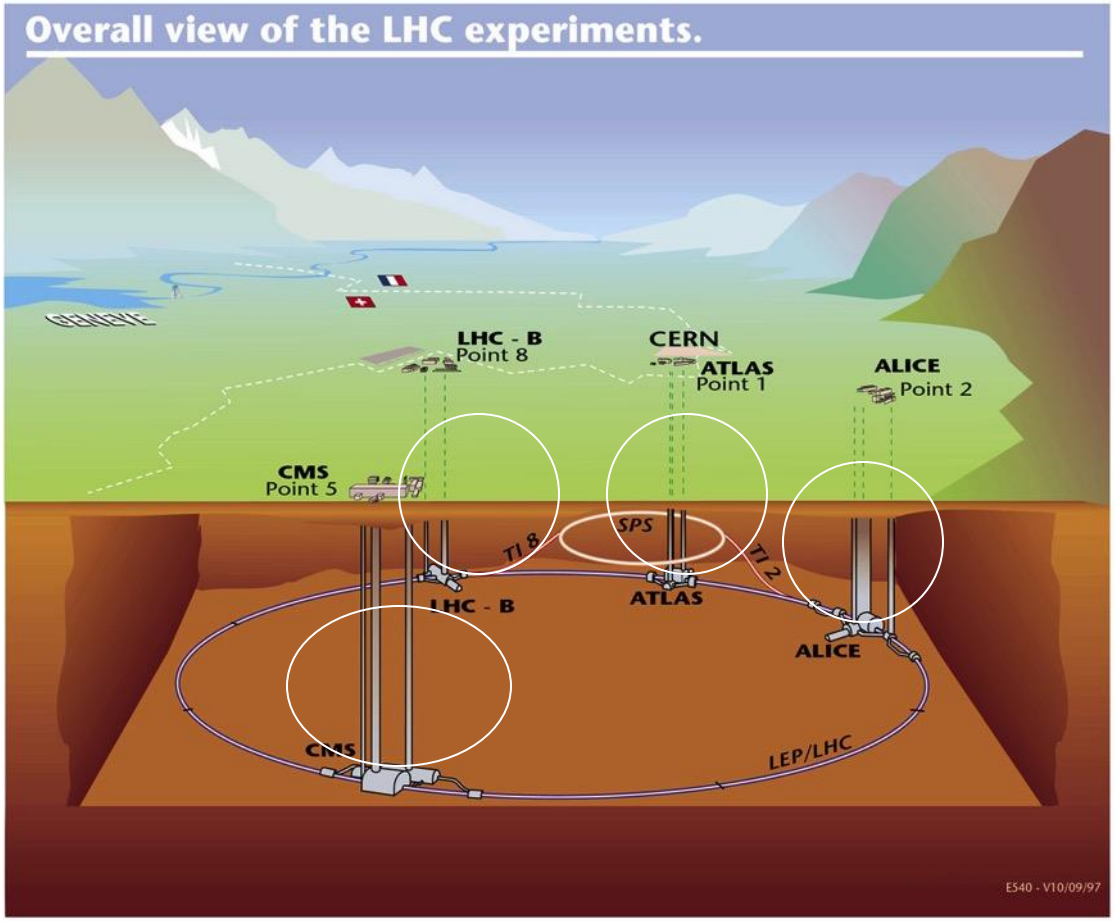


# CERN site


CERN 2nd site
SPS accelerator
CERN main site
Geneva Airport
LHC accelerator

# LHC : The Large Hadron Collider

Installed 100 m below ground, in the tunnel built for LEP

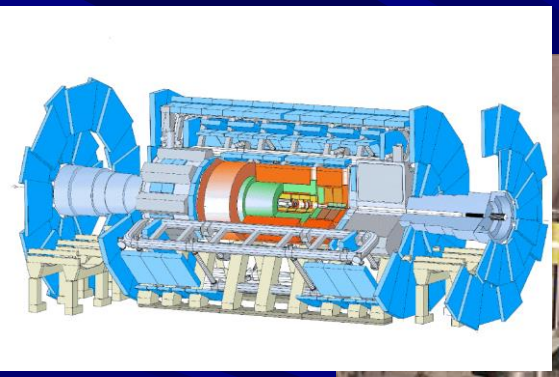


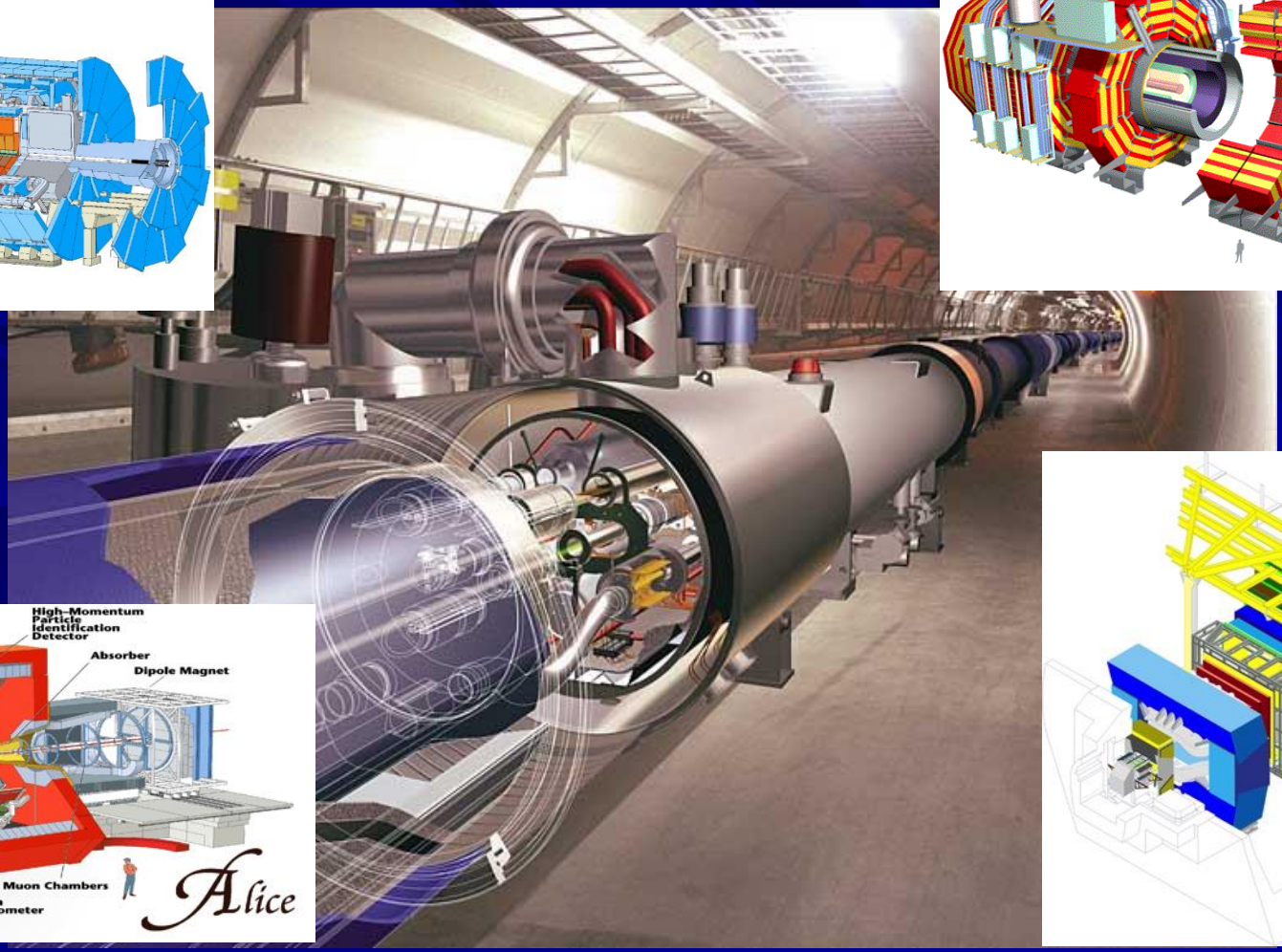

- LHC collides beams of protons at an energy of 13 TeV (the highest energy of any accelerator in the world)

- Using the latest superconducting technologies, it operates at - 271$^0$C ( just above absolute zero, colder than outer space)

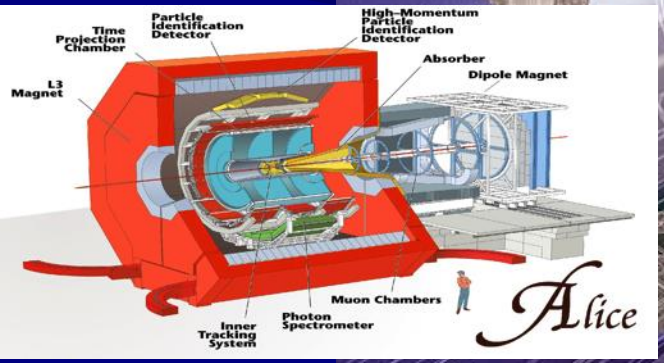
- With its 27 km circumference, the LHC is the largest superconducting installation in the world.

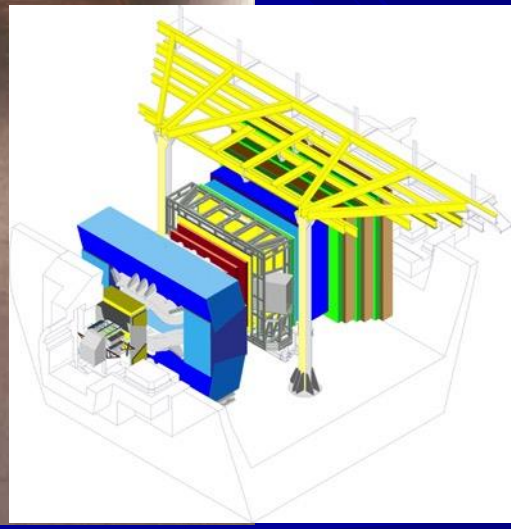
# 4 big experiments have been installed at LHC





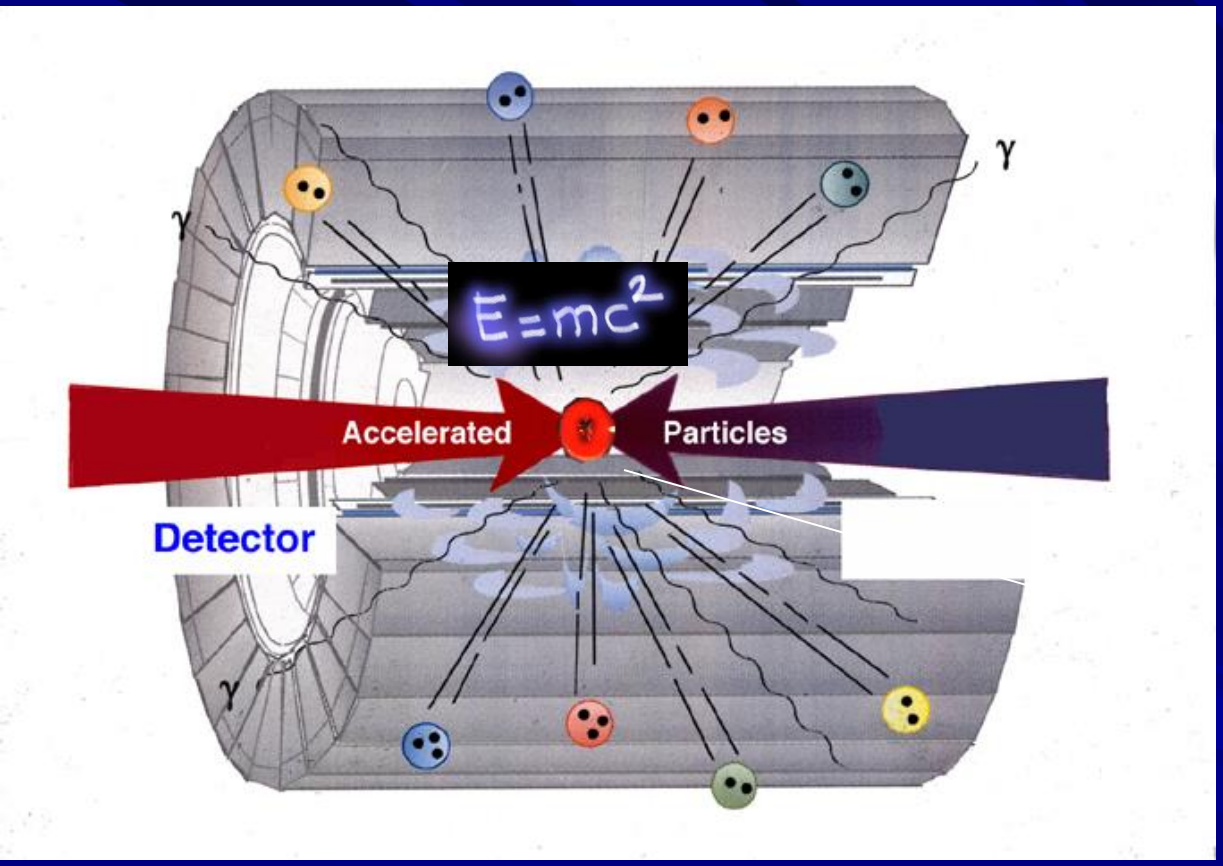




First data taking in November 2009 (900 GeV pp collisions)
First data taking at higher energy in March 2010 (7 TeV pp collisions)

# Methods of Particle Physics




1) Concentrate energy on particles (**accelerator**)

2) **Collide** particles (recreate conditions after Big Bang)

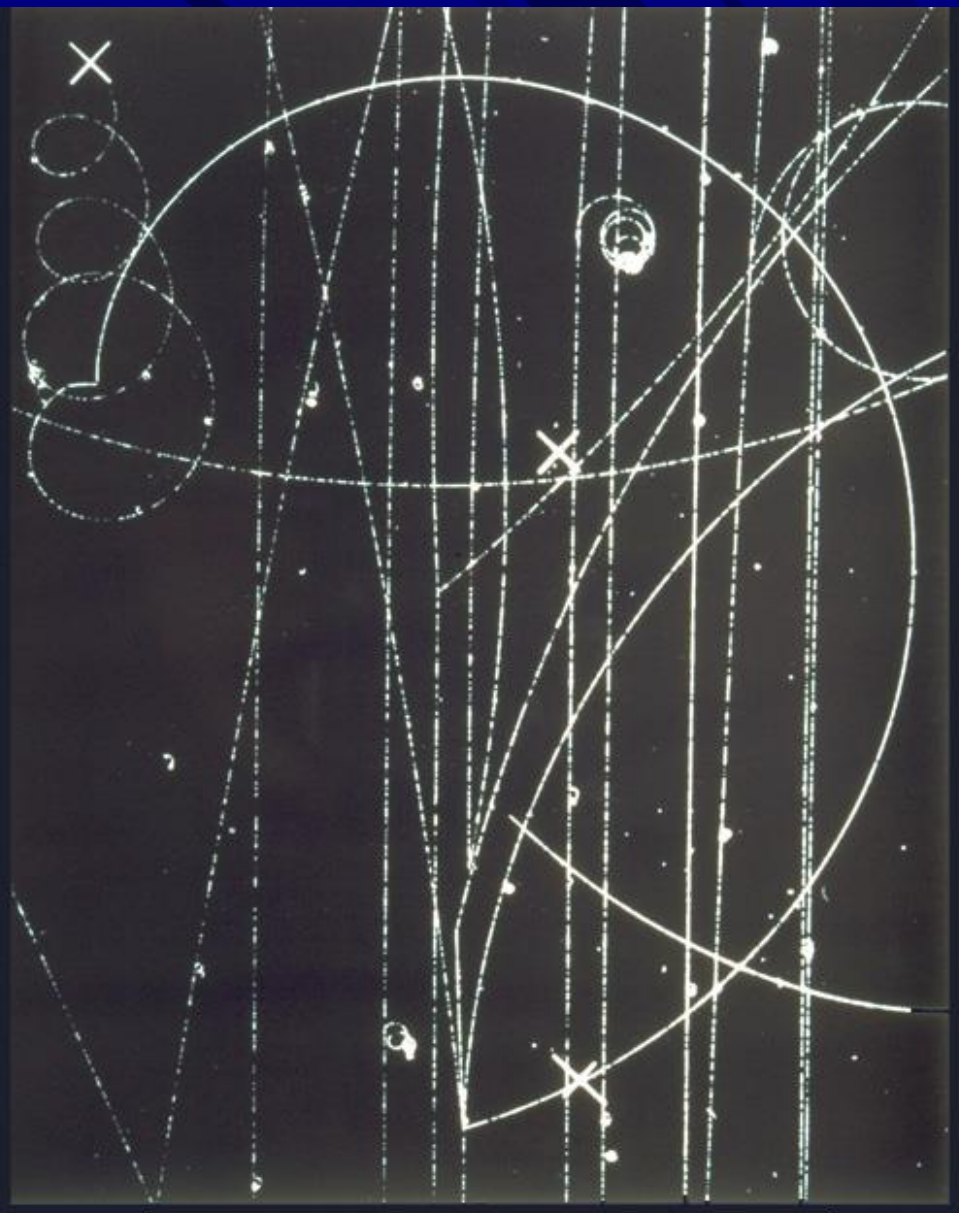
3) Identify created particles in **Detector** (search for new clues)

# Particle Detectors

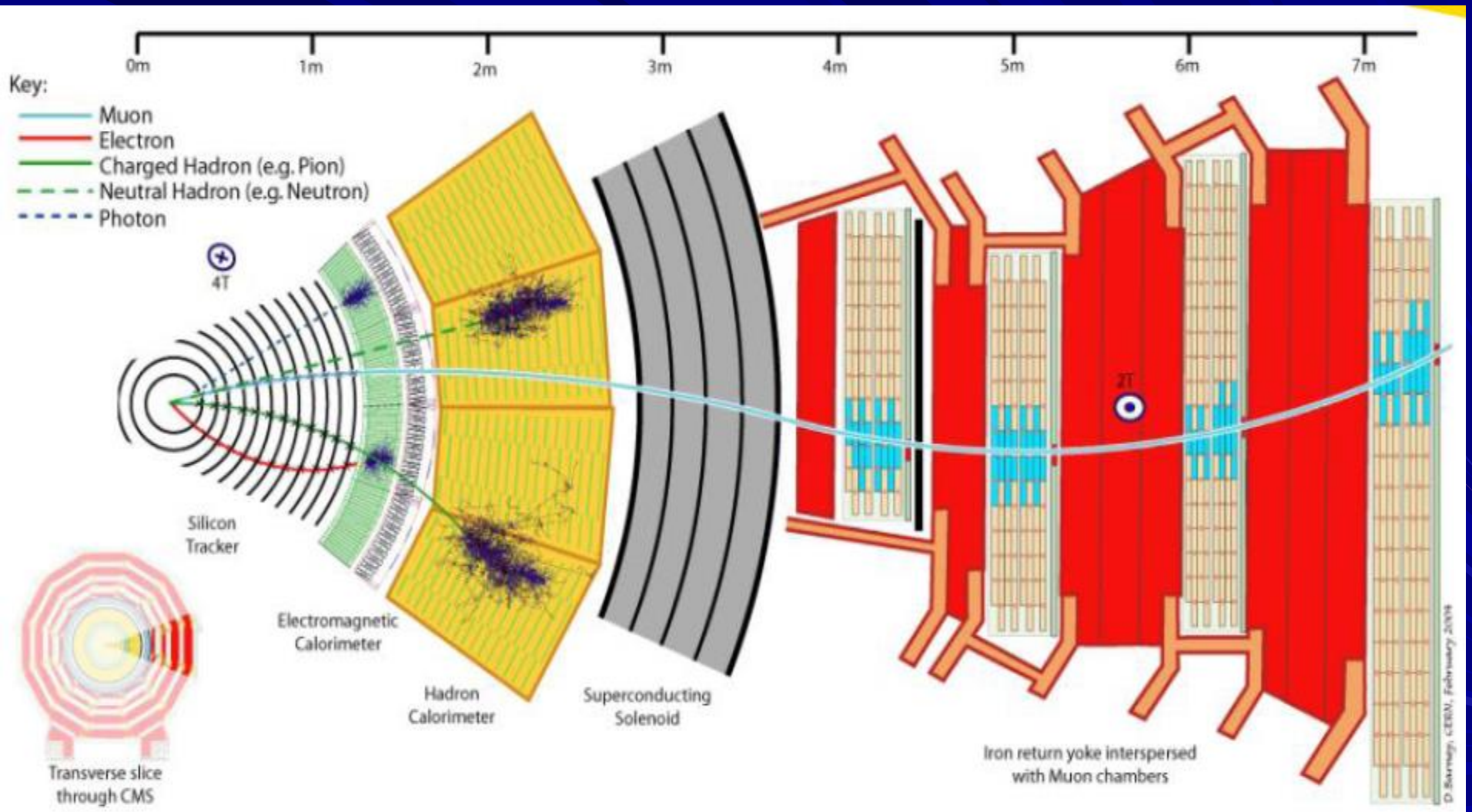
- They “see” the particles produced from beam-beam or beam-target collisions
- The detection is based on interaction of the particles with matter and eventually production of an electrical signal
- Various types of detectors :
  - Solid state detectors (semiconductors),
  - Gaseous detectors,
  - Scintillators …

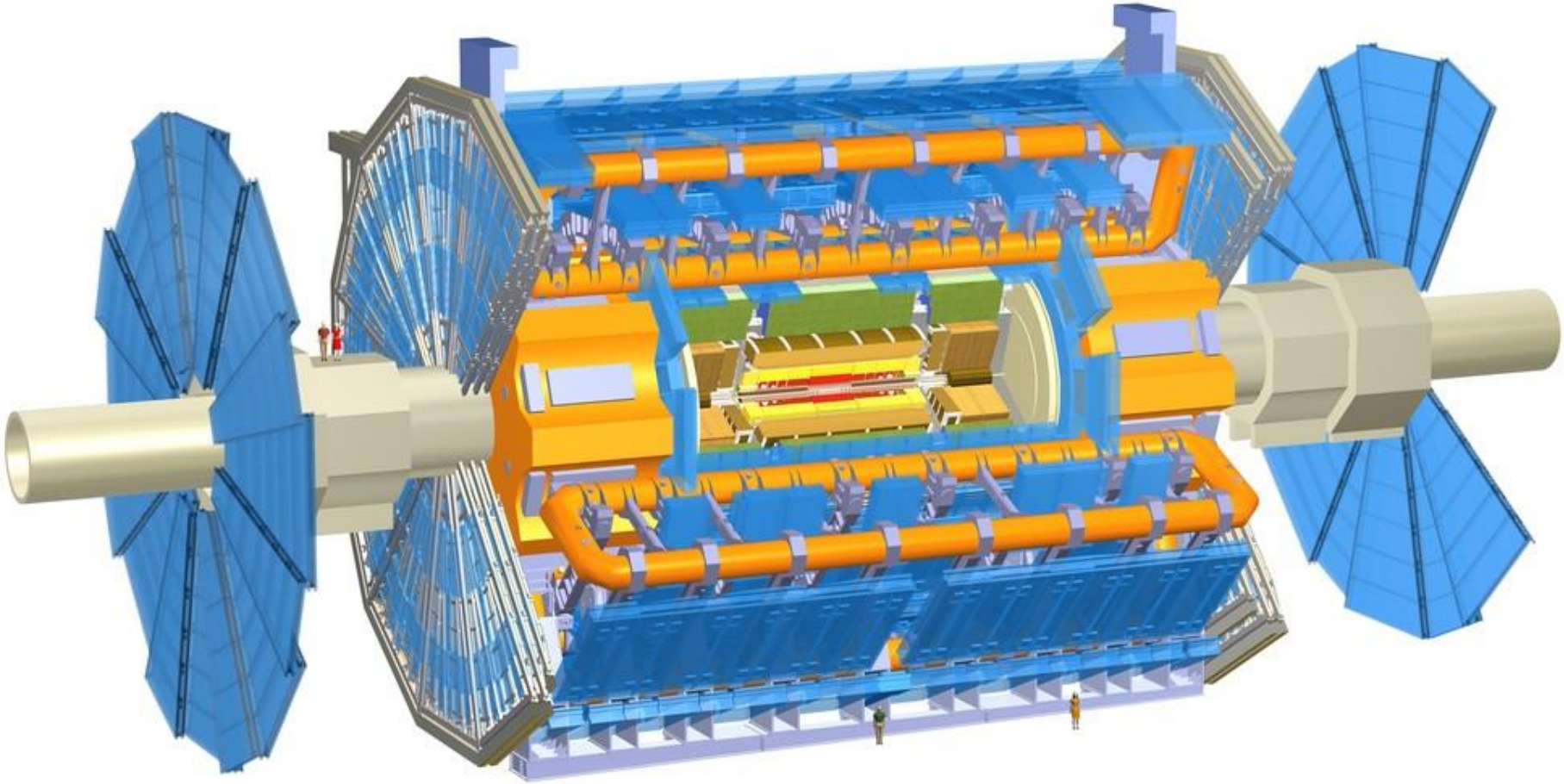
- They convey information about :
  - The particle energy (calorimeteres)
  - The particle type (particle identification)
  - Particle trajectory (tracking devices)

# Bubble chamber photograph



A 8 GeV/c $K^-p$ picture taken in the CERN 2m chamber


0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS



25 m x 25 m x 46 m  7000 tons

# In brief, what happens when the experiments are running

- A particle collision = an event

- $E = mc^2$ multitude of new particles produced

- Particles interact inside the detectors and produce electrical signals which are digitized and recorded by computers

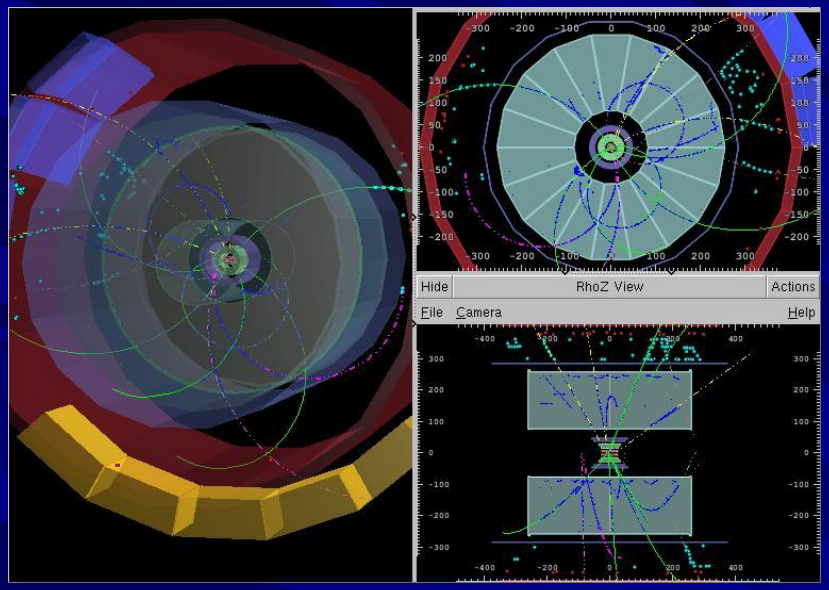
- By analysing this information - translating raw numbers to quantities like energy, position etc, the physicists characterize all the particles produced and fully reconstruct the process.

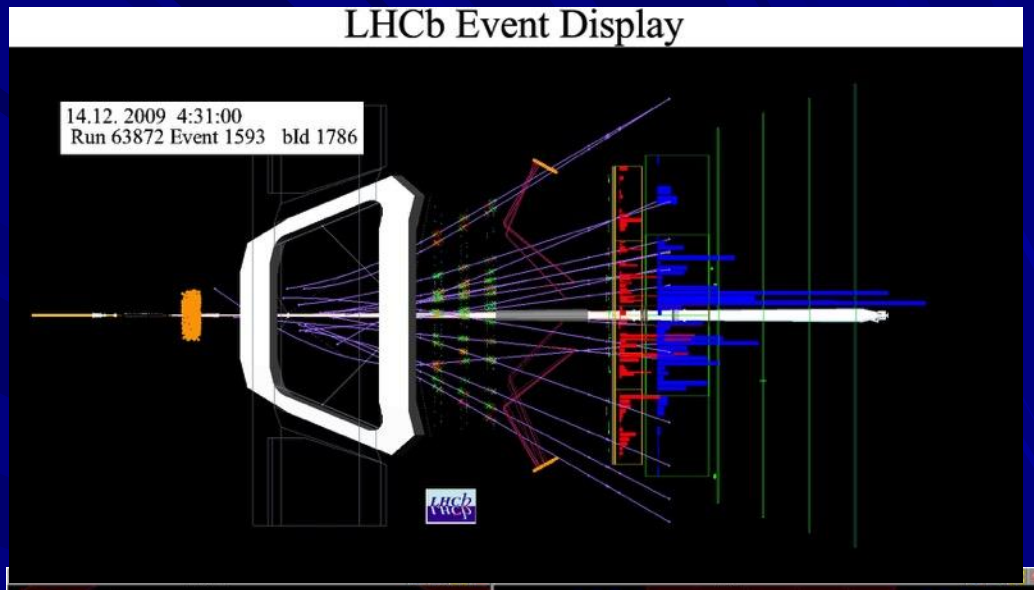
- Among all tracks, the presence of “special shapes” is the sign for the occurrence of interesting interactions.

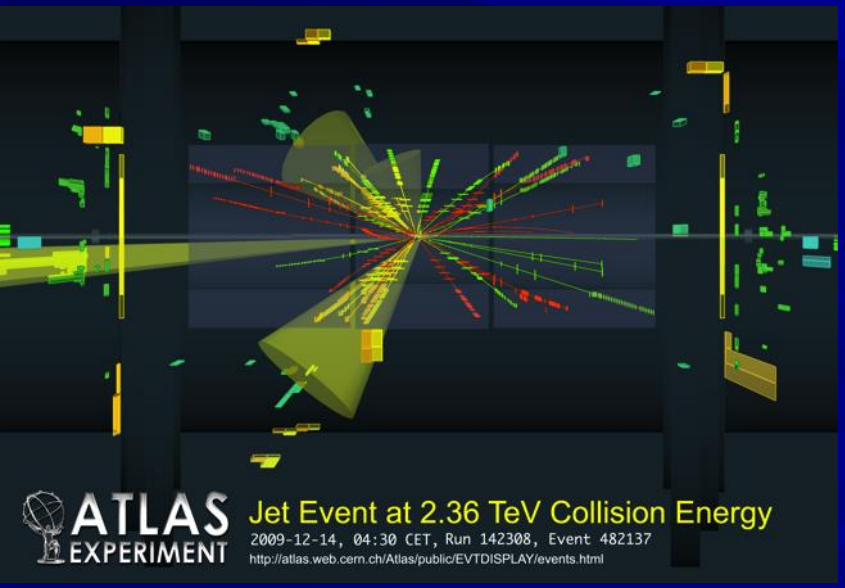
- Since the phenomena we are studying are characterized by a “probability”

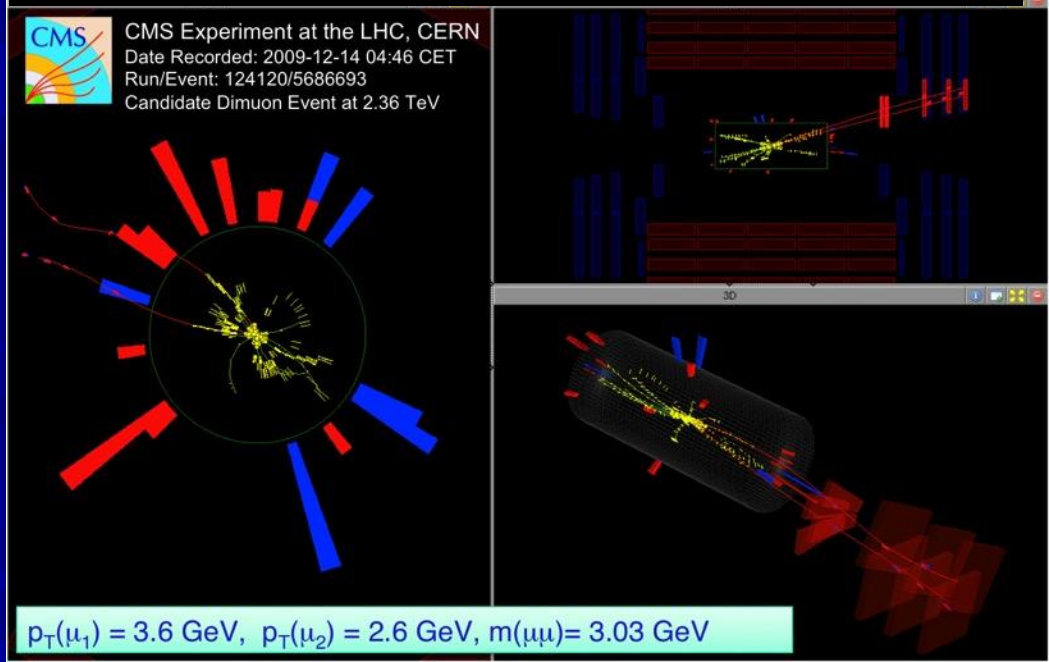
We need to collect a lot of statistics…

Experiments “run” (=collect data) during many years


Hide
RhoZ View
Actions
File
Camera
Help


LHCb Event Display
14.12. 2009 4:31:00
Run 63872 Event 1593 bId 1786


ATLAS
EXPERIMENT
Jet Event at 2.36 TeV Collision Energy
2009-12-14, 04:30 CET, Run 142308, Event 482137
http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html


CMS
CMS Experiment at the LHC, CERN
Date Recorded: 2009-12-14 04:46 CET
Run/Event: 124120/5686693
Candidate Dimuon Event at 2.36 TeV
3D
$p_T(\mu_1)$ = 3.6 GeV, $p_T(\mu_2)$ = 2.6 GeV, m($\mu\mu$)= 3.03 GeV

# LHC data

- protons in bunches (of 100 billion p) every 25 ns;
- 40 million times/s bunches pass each collision point
- 31.2 MHz crossing rate
- 20 collisions expected from (100 on 100 billion p)
- 600 million particle collisions per second

- After filtering, 100 collisions of interest per second

- A Megabyte of data digitised for each collision = recording rate of 0.1 Gigabytes/sec

- $10^{10}$ collisions recorded each year

= 10 Petabytes/year of data

**1 Megabyte (1MB)**
**A digital photo**

**1 Gigabyte (1GB) = 1000MB**
**A DVD movie**

**1 Terabyte (1TB) = 1000GB**
**World annual book production**

**1 Petabyte (1PB) = 1000TB**
**Annual production of one LHC experiment**

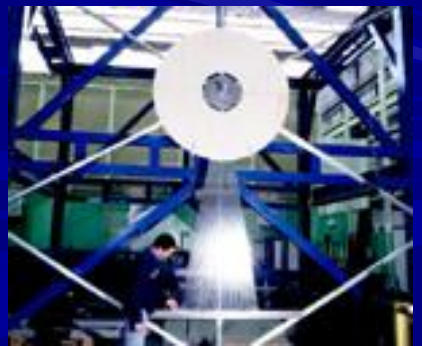
**1 Exabyte (1EB) = 1000 PB**
**World annual information production**

**CMS**

**LHCb**

**ATLAS**

**ALICE**



# LHC data

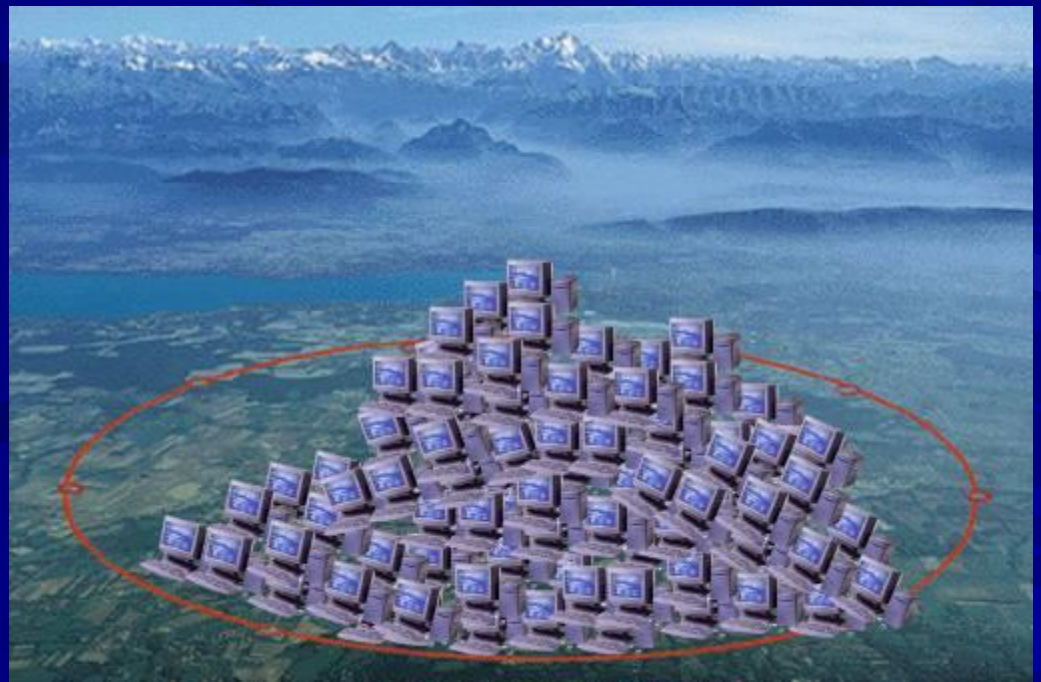
**LHC data correspond to about 20 million CDs each year!**

**Where will the experiments store all of these data?**

# LHC processing

**LHC data analysis requires a computing power equivalent to ~ 100,000 of today's fastest PC processors!**

**Where will the experiments find such a computing power?**

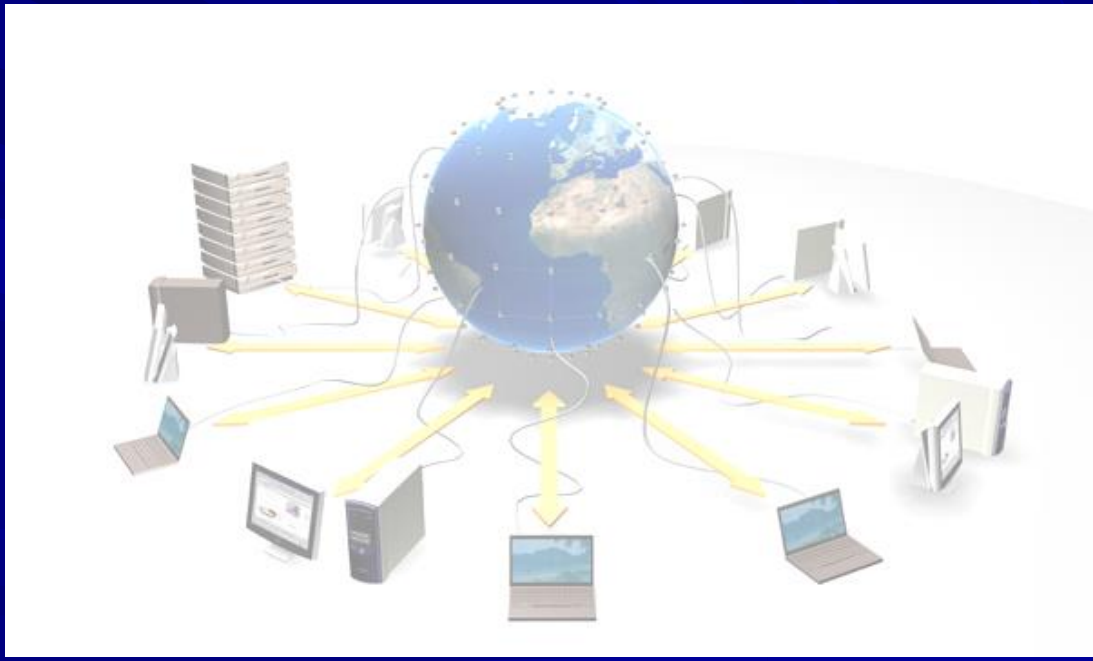


# The GRID

The GRID is:

- A service built on top of the Internet, like the web
- But the GRID goes one step further..
- Computers and instruments connected to the GRID share not only information…
- but also..
- Computing power
- Resources
- Disk storage
- Databases
- Software applications

…



# The LHC will help solving the unsolved mysteries


Why three generations?


The mystery of mass and the Higgs boson

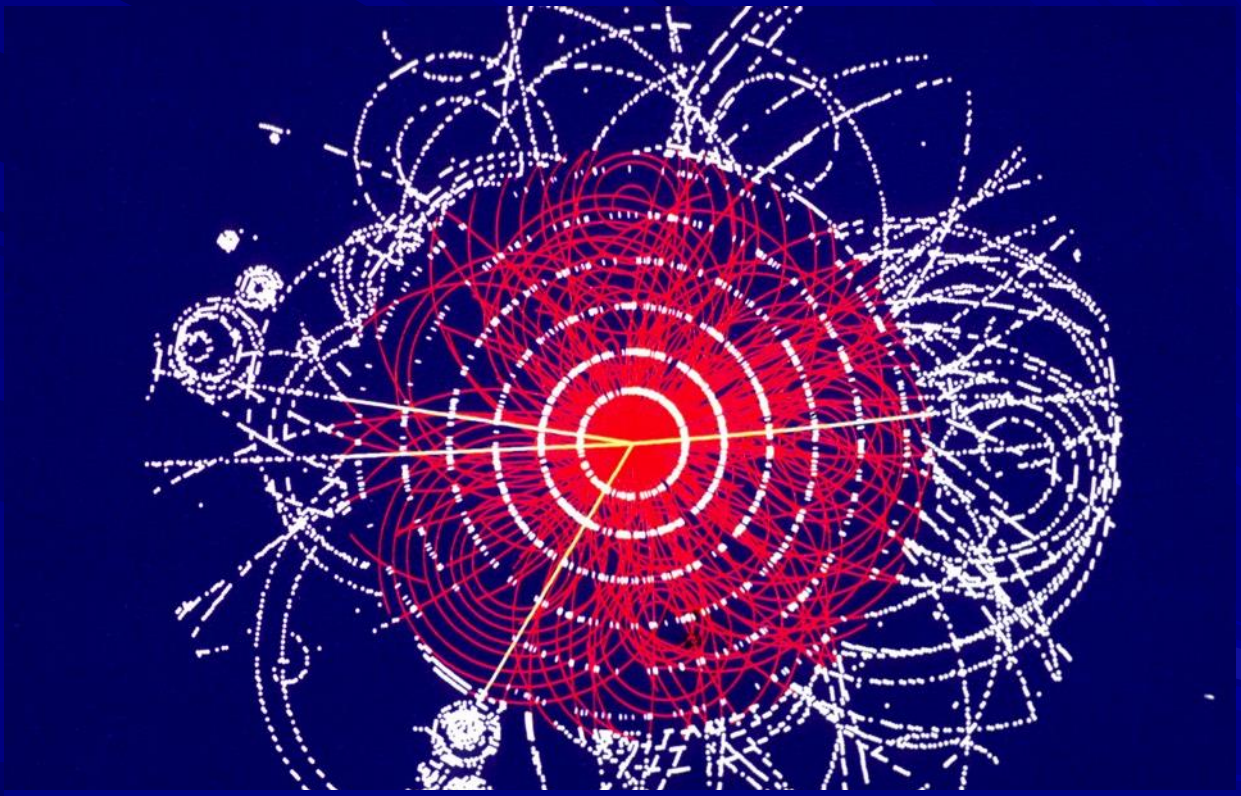

Beyond the standard model - supersymmetry


Dark matter


The difference between matter and antimatter

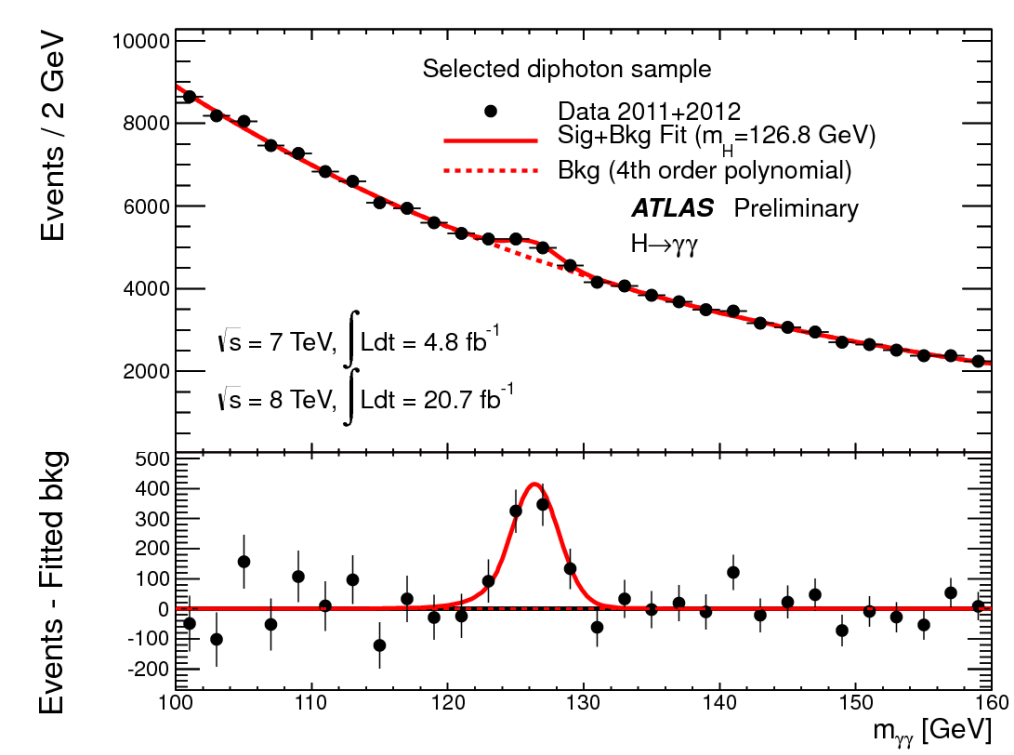
# Higgs signature at the LHC

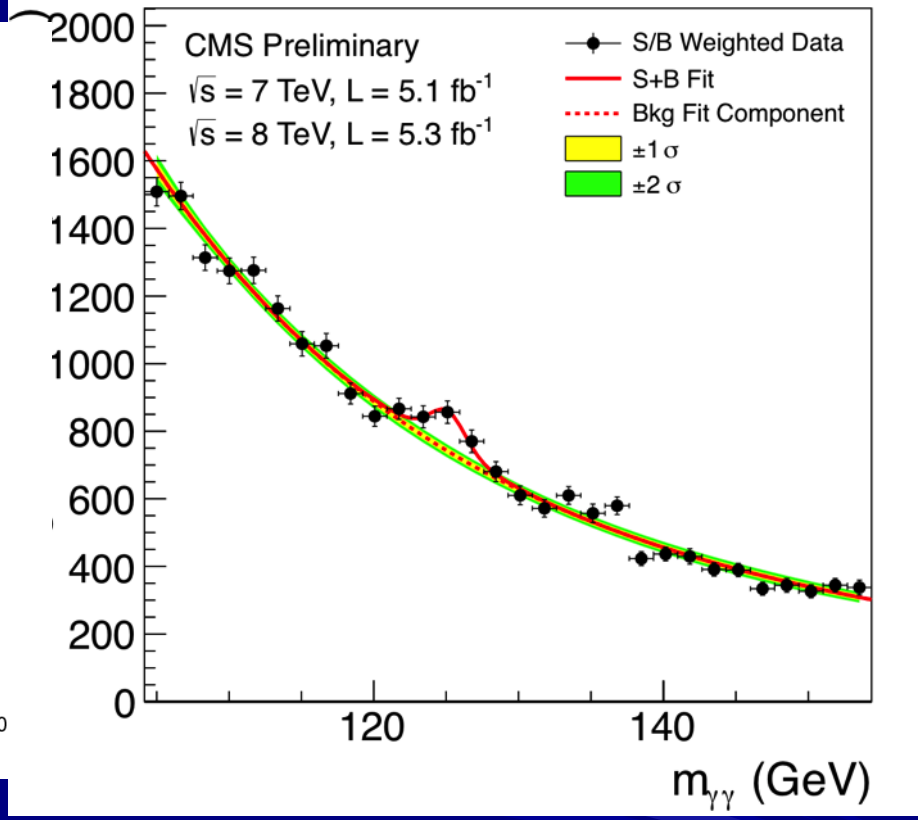
If the Higgs decays : H -> ZZ -> μμμμ



We expect only 1 Higgs in 1,000,000,000,000 events

# Search for Higgs -> γγ, invariant mass distribution for two-photon candidates



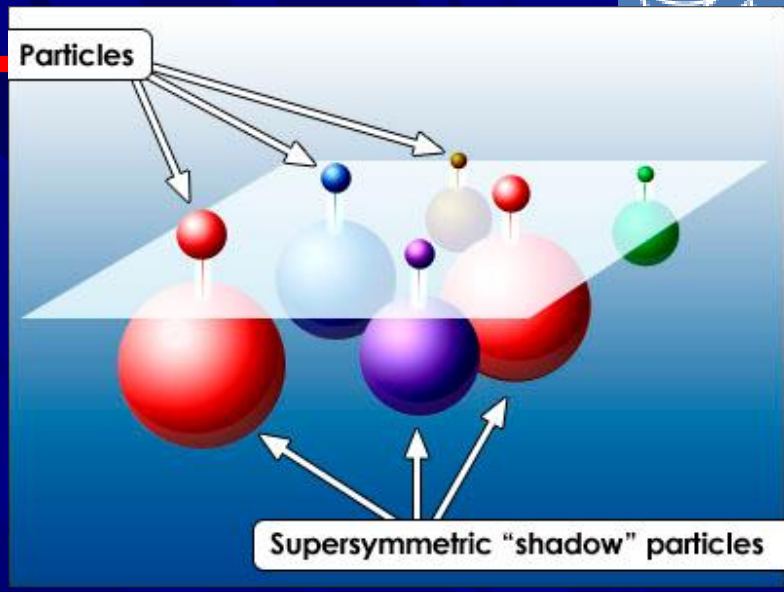



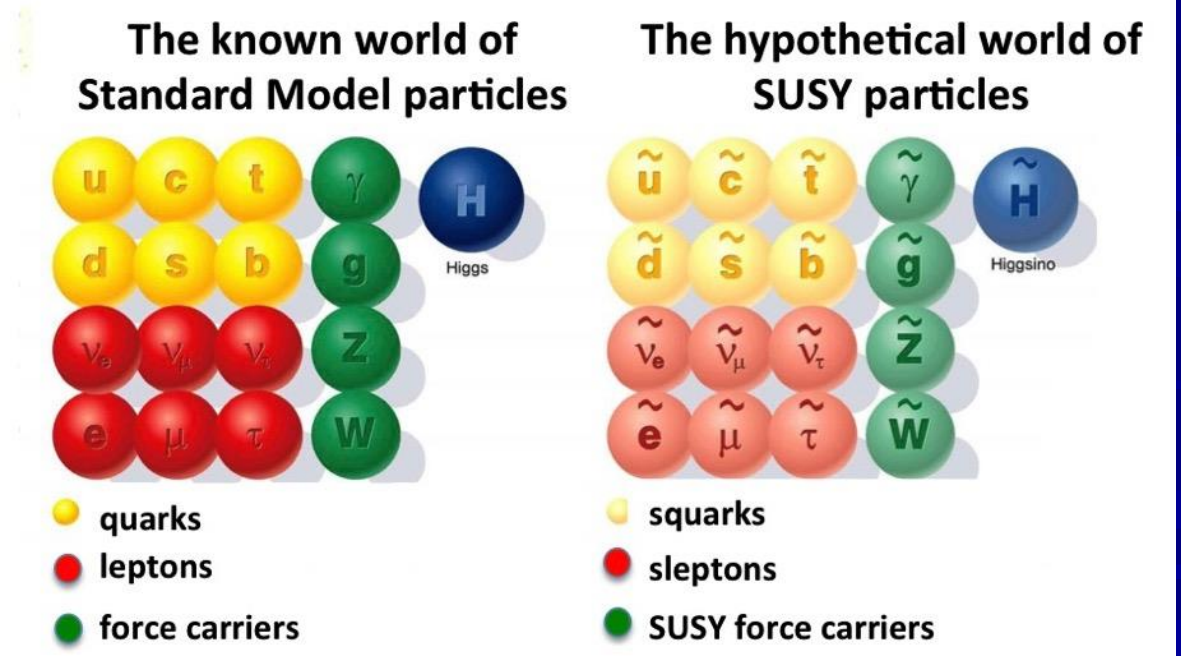

We have to separate the Higgs from the background (continuous line) : random pairs of photons, mainly from $\pi^0$ and $\eta$ decays

# SUperSYmmetry (SUSY)

Symmetry between matter (elementary particles -> fermions) and forces (force carriers -> bosons)

To unify the forces
To solve problems in the Standard Model (deviations in the Higgs mass)



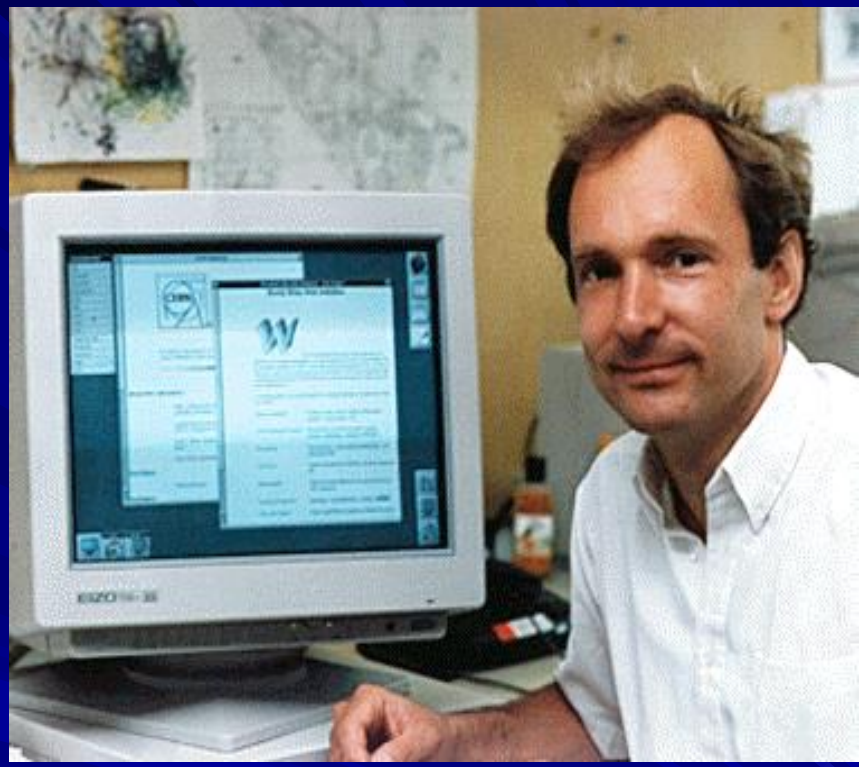




Every particle with spin s has its supersymmetric partner with spin s-1/2

Quark (s=1/2) -> squark (s=0)
Gluon (s=1) -> gluino (s=1/2)

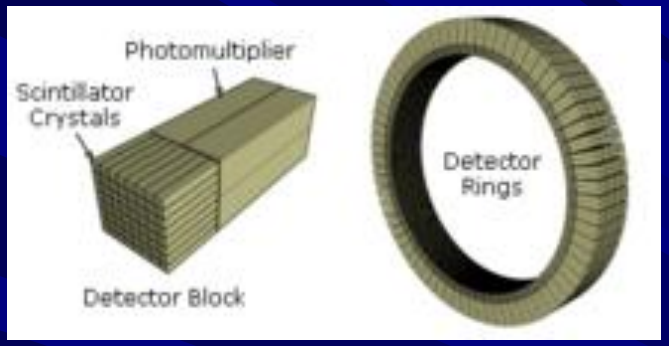
# The World Wide Web

Invented by Tim Berners-Lee,
a CERN physicist, in 1989,
to meet the need of physicists in
Institutes all over the world for
Automatic information sharing

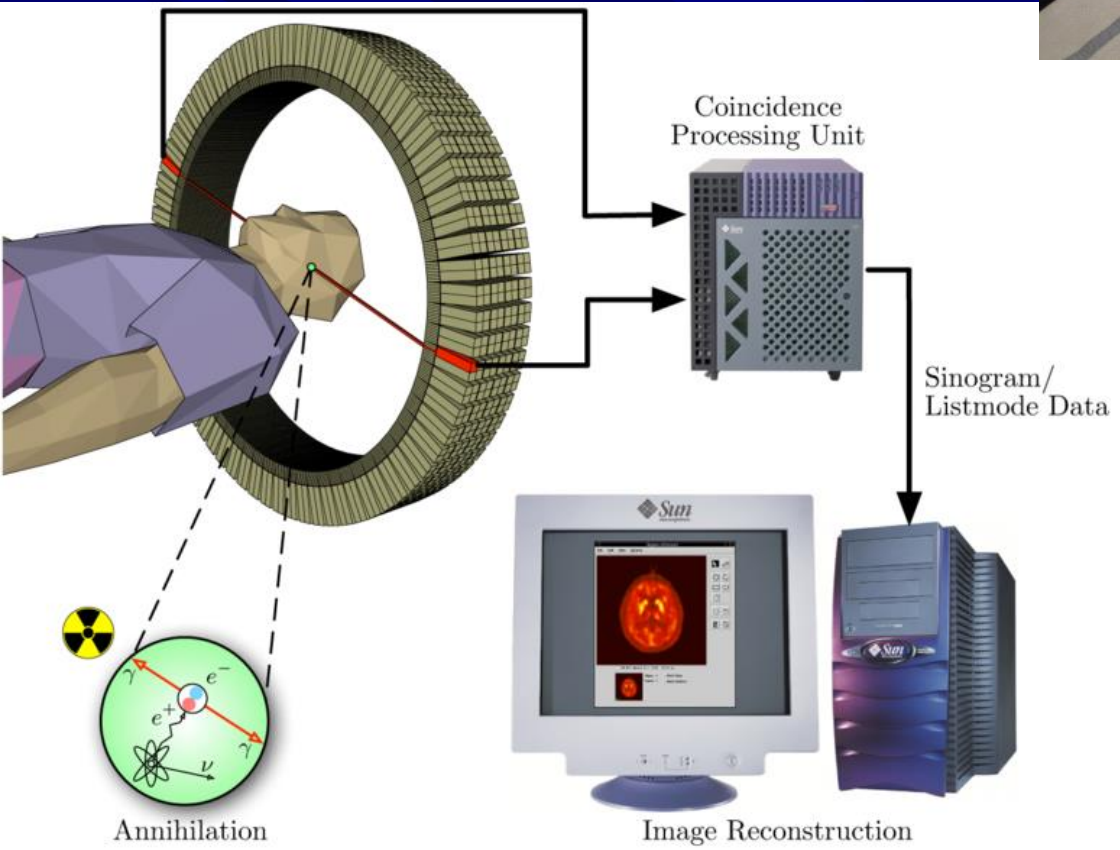



Nowadays, the WWW has
expanded and has
**millions** of academic and
commercial **users**

# Positron Emission Tomography (PET)



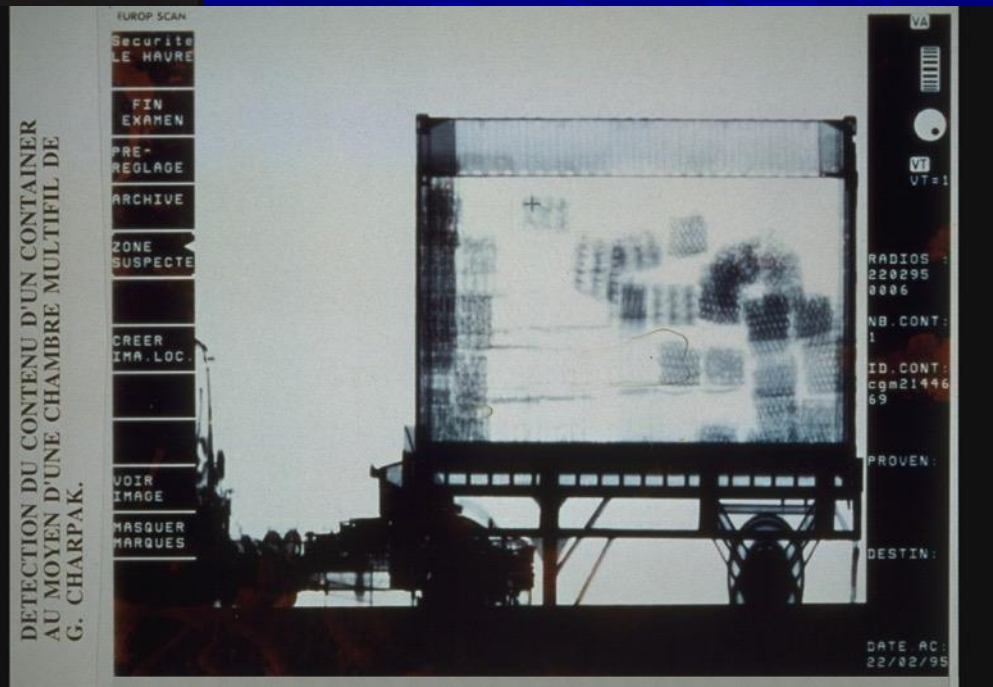





And many more spin-offs

- Accelerators for medicine
  radio-isotope production
  patient irradiation
- High vacuum technology
- Superconducting magnets
  cryogenics
- Fast electronics
- Fast computers


Spin-offs (applications) from developments done at CERN for pure research

# Summary

- CERN, the European Laboratory for Particle Physics Research, provides the accelerators - the tools for creating high energy beams of charged particles

- Detectors are used to identify and measure various properties of the particles produced by beam collisions

-Particle physics studies the constituents of matter in its smallest dimension and deepens the human understanding of the laws of nature

-The technological developments needed to meet the requirements of this research produce applications - spin offs.

- In addition CERN acts as a training centre for young scientists