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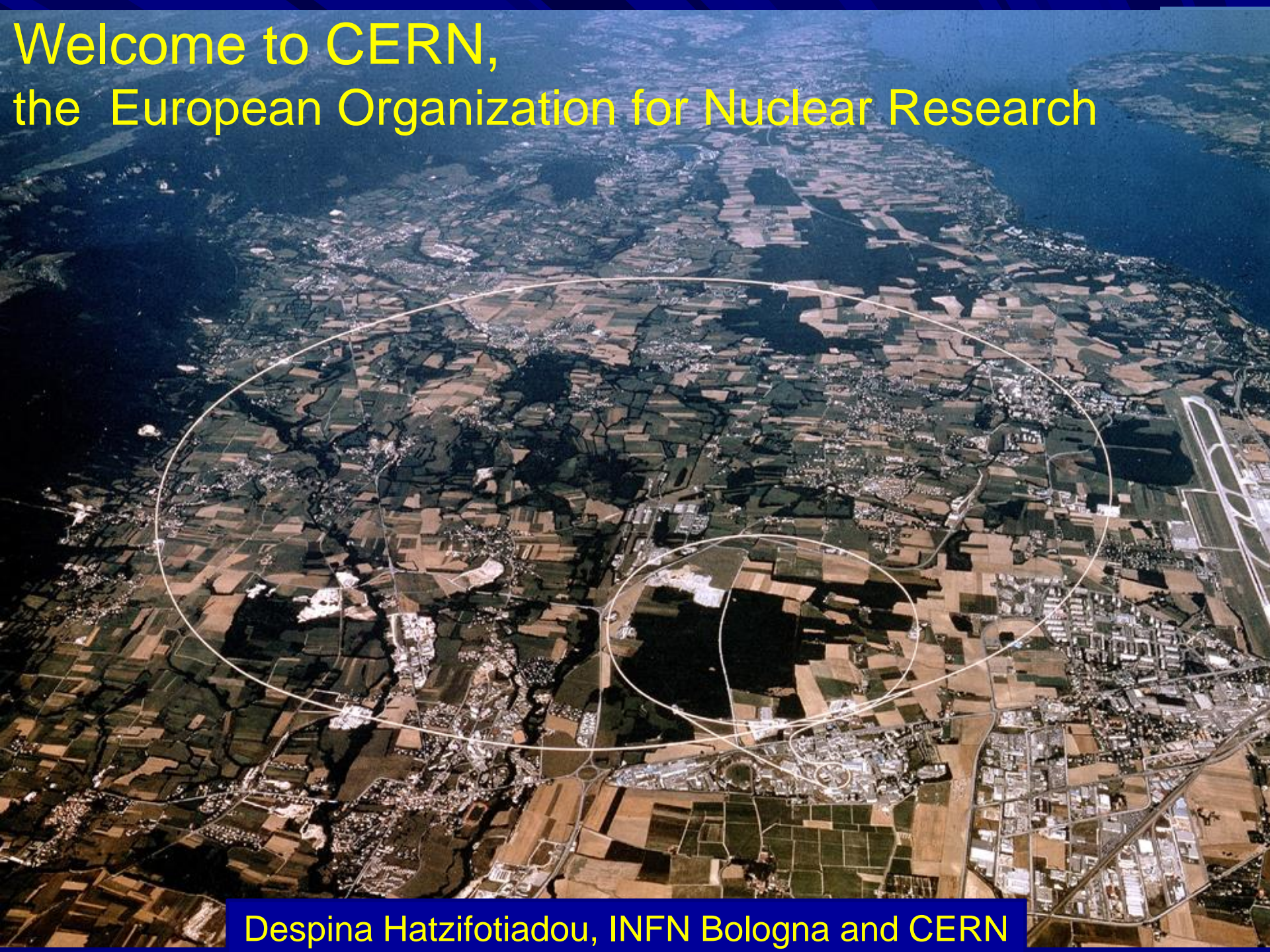## the European Organization for Nuclear Research

Despina Hatzifotiadou, INFN Bologna and 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
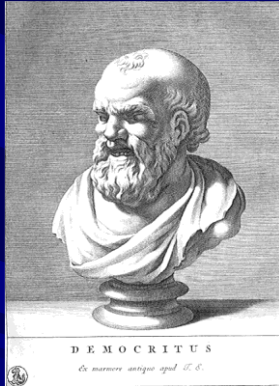
Mendeleev's periodic table of elements (1869) – 80 different indivisible atoms

DEMOCRITUS

| I							
H 1.01	**II**	**III**	**IV**	**V**	**VI**	**VII**	
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	**VIII**
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		
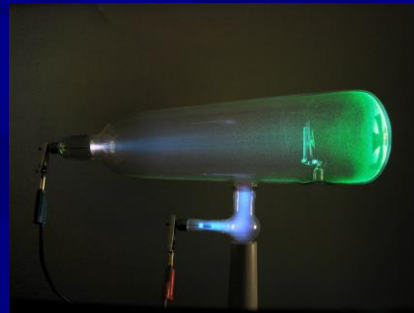
Discovery of the electron with cathode ray tube **first elementary particle** 1896
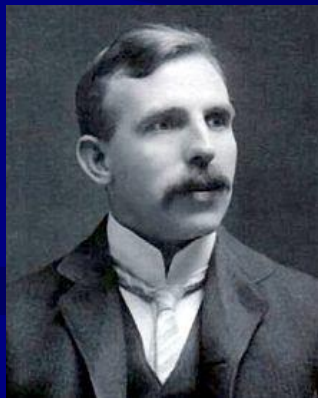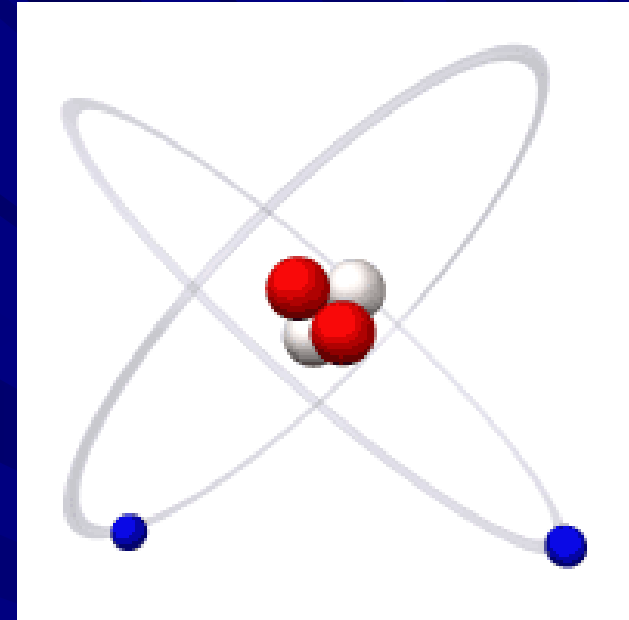

Thomson's atomic model

$\sim 10^{-10}$ m
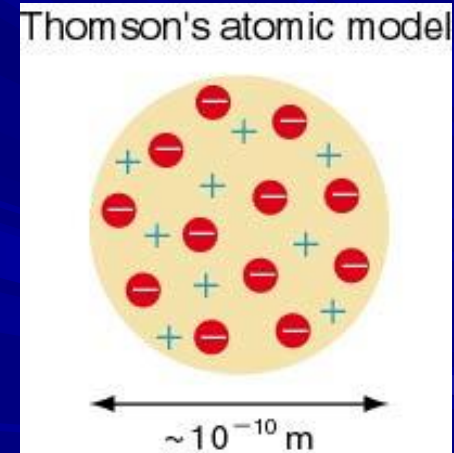
JJ Thomson

Thomson's plum pudding model (1904)

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

Gold foil
∝ particle emitter
Detecting screen
Slit
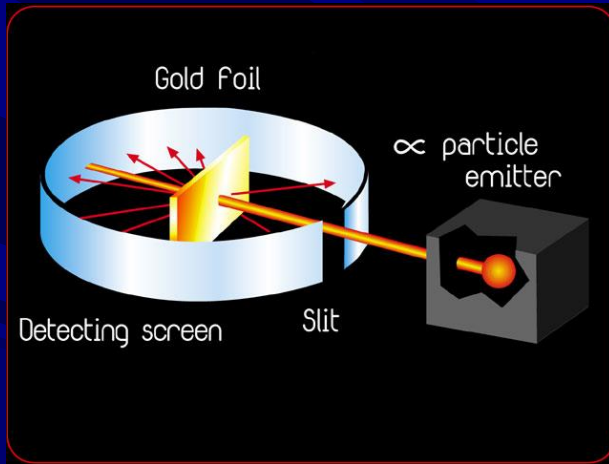
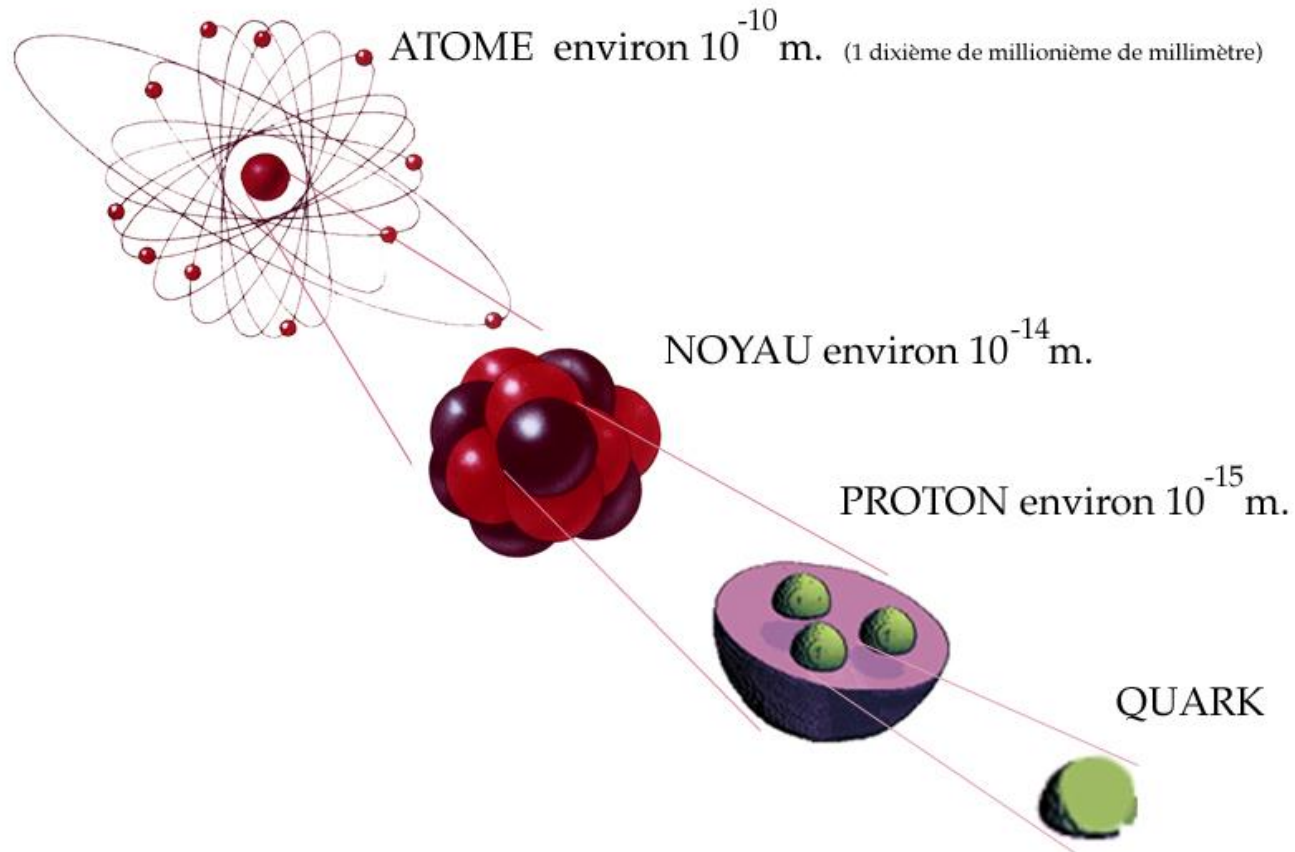alpha scattering experiment
Geiger – Marsden

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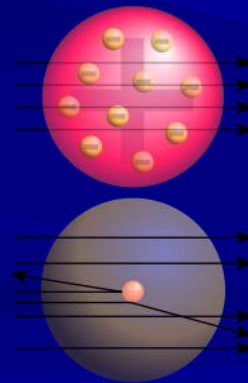
Nucleus: most of the mass, positive charge; atom is mainly empty
Later on found that the nucleus consists of protons and neutrons

ATOME environ 10^{-10} m. (1 dixième de millionième de millimètre)

NOYAU environ 10^{-14} m.

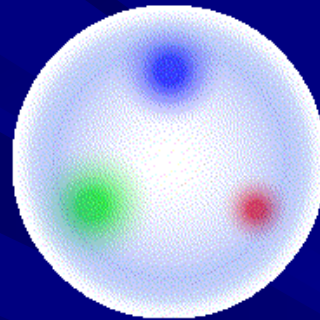PROTON environ 10^{-15} m.

QUARK

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

D.Bertola / CERN

Quarks (Gell-Mann) 1964

Today's periodic system of the fundamental building blocks

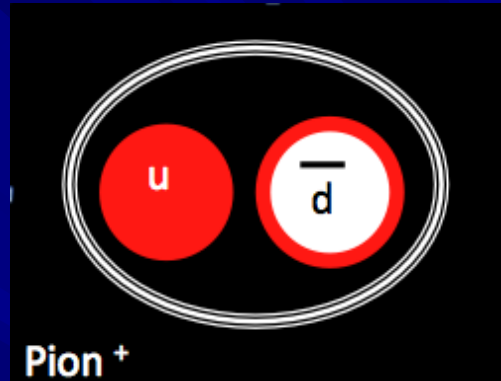|	Quarks		Leptons	
Generation 3	t — Top	b — Bottom	τ — Tau	ν_τ — Tau-neutrino
Generation 2	c — Charm	s — Strange	μ — Muon	ν_μ — Muon-neutrino
Generation 1	u — Up	d — Down	e — Electron	ν_e — Electron-neutrino

Quark Confinement
Quarks can not exist free in nature
They can only exist bound inside hadrons
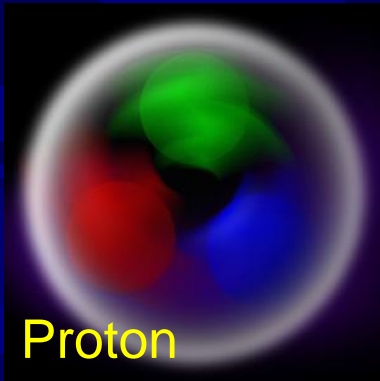
Proton

baryons
consisting of
3 quarks

mesons
consisting of
a quark and
an anti-quark

Pion +

	Baryons qqq and Antibaryons q̄q̄q̄				
	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
p̄	antiproton	ūūd̄	−1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω$^-$	omega	sss	−1	1.672	3/2

	Mesons qq̄				
	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
π$^+$	pion	ud̄	+1	0.140	0
K$^-$	kaon	sū	−1	0.494	0
ρ$^+$	rho	ud̄	+1	0.776	1
B^0	B-zero	db̄	0	5.279	0
η$_c$	eta-c	cc̄	0	2.980	0

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	$\sim 10^{-3}$	PHOTONS (NO MASS)	ATOMIC SHELL ELECTROTECHNIQUE
WEAK NUCLEAR FORCE	$\sim 10^{-5}$	BOSONS Z^o, W+, W- (HEAVY)	RADIOACTIVE BETA DESINTEGRATION
GRAVITATION	$\sim 10^{-38}$	GRAVITONS (?)	HEAVENLY BODIES

THE EXCHANGE OF PARTICLES IS RESPONSIBLE FOR THE FORCE
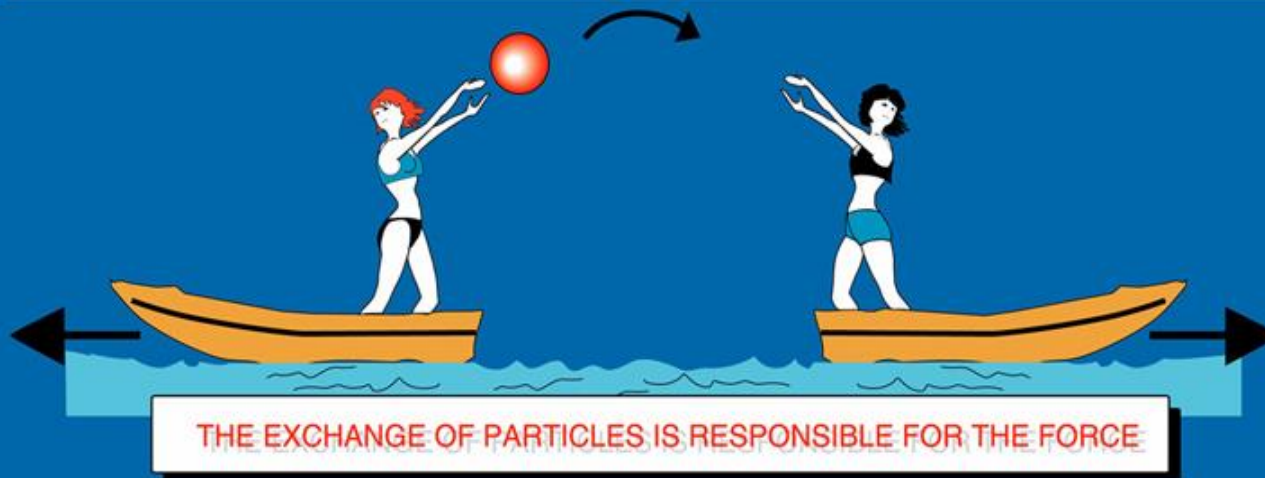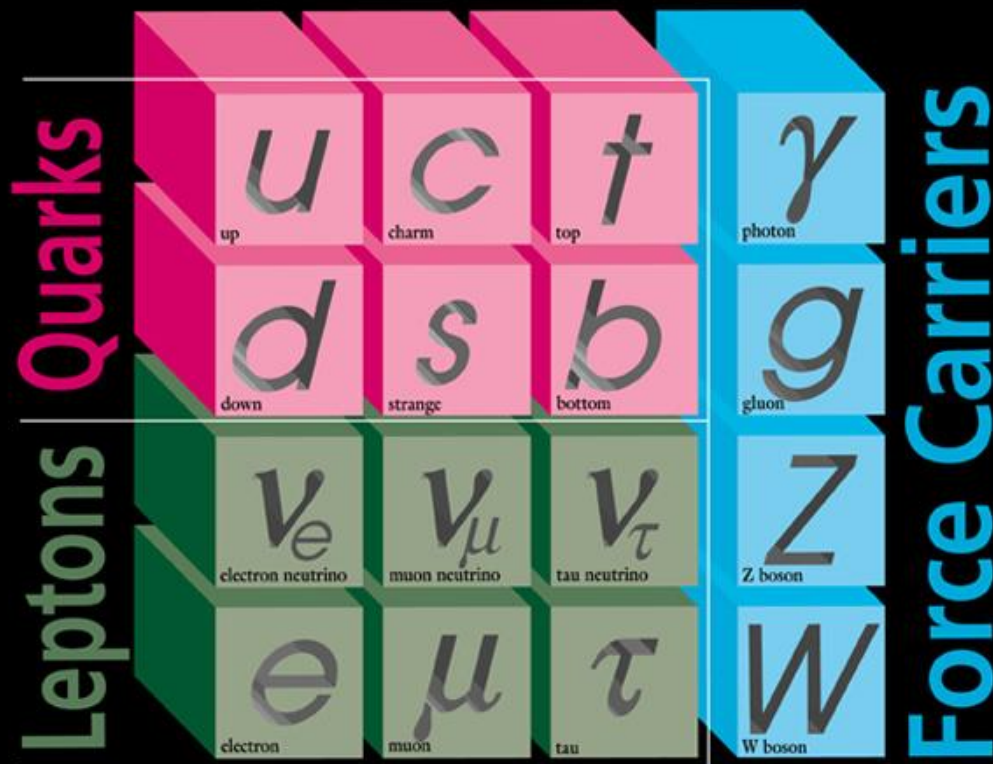
fermions
Fermi-Dirac
statistics
Spin half-integer
(1/2, 3/2,...)

ELEMENTARY PARTICLES

Three Generations of Matter

Fermilab 95-759

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

Why accelerators? To investigate Particle Physics

| Accelerators | Microscopes | Binoculars | Optical and radio telescopes |
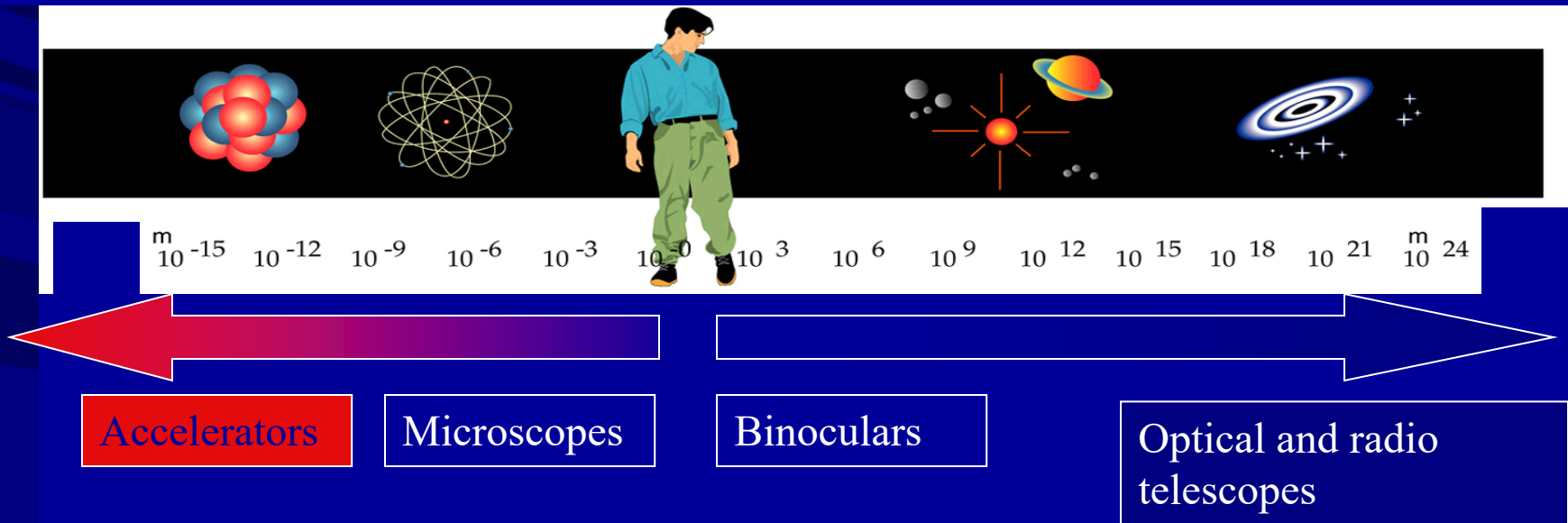
Particle physics looks at matter in its smallest dimensions

Accelerator chain at CERN, a complex business

CERN site

CERN 2nd site
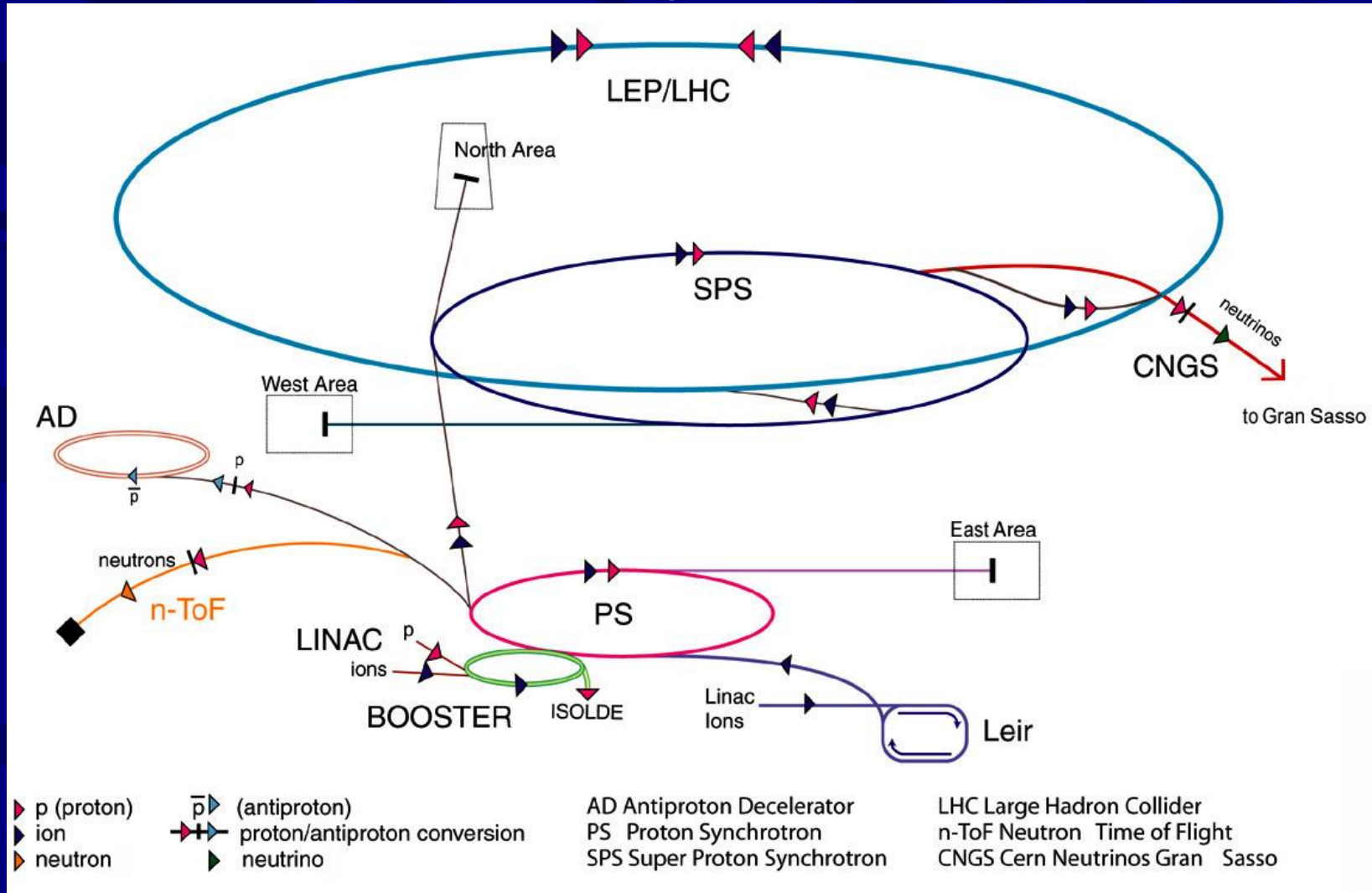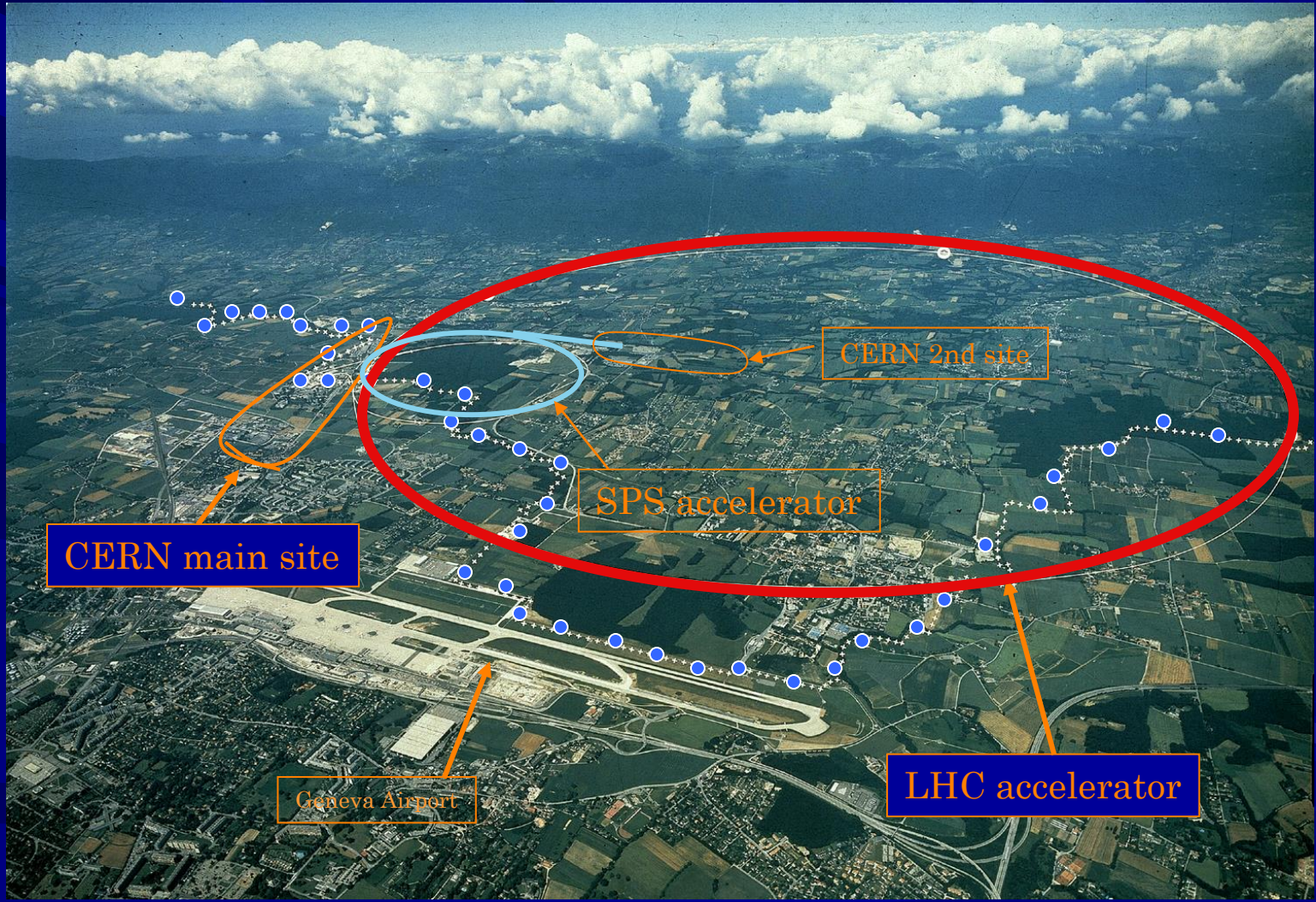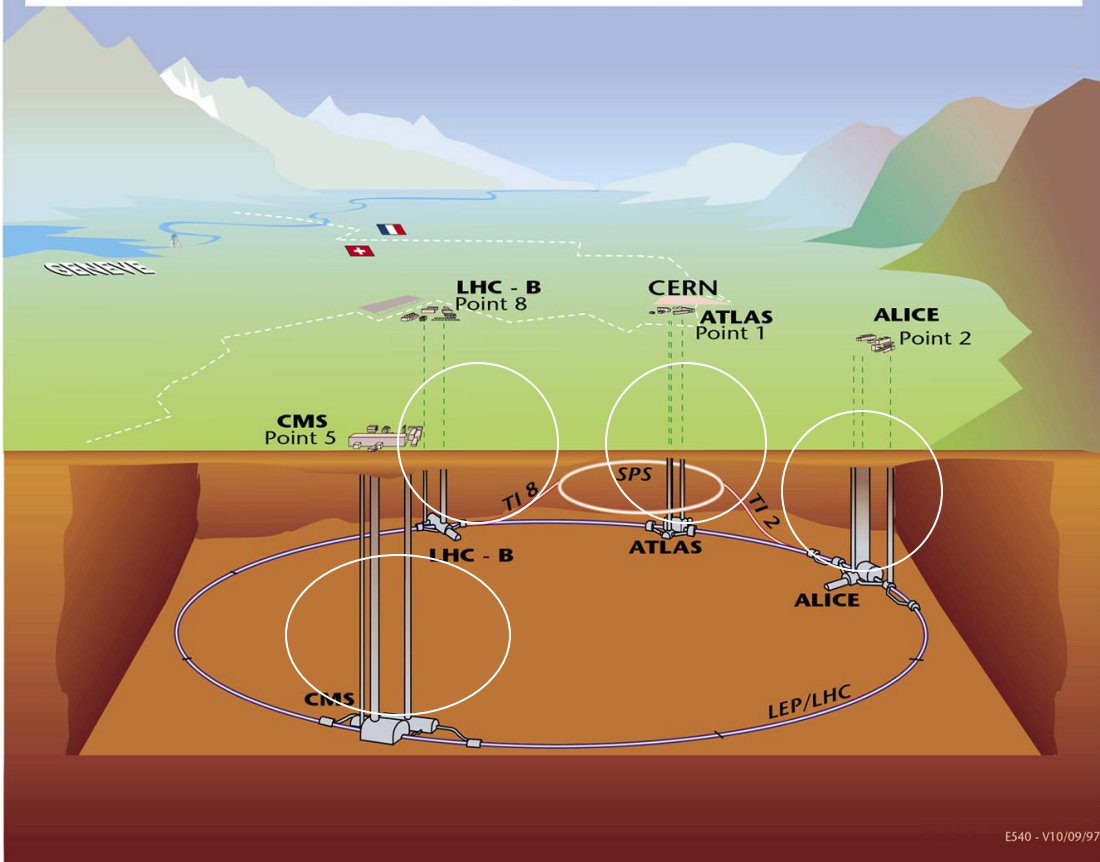
SPS accelerator

CERN main site

Geneva Airport

LHC accelerator

LHC : The Large Hadron Collider

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


Overall view of the LHC experiments.

• LHC collides beams of protons at an energy of 13.6 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
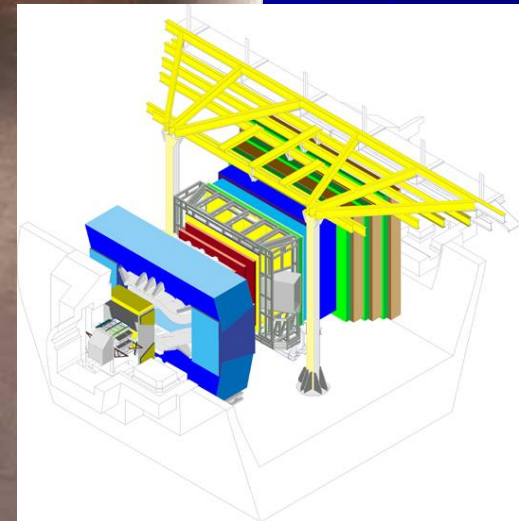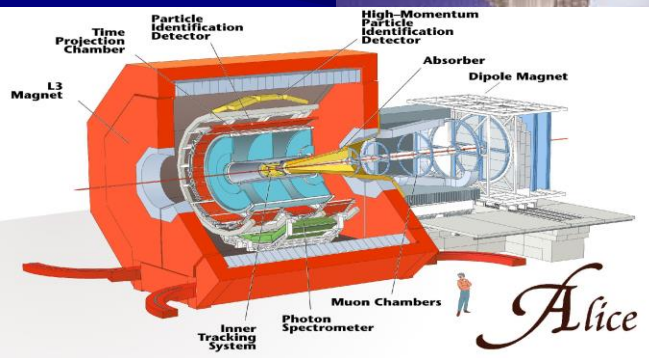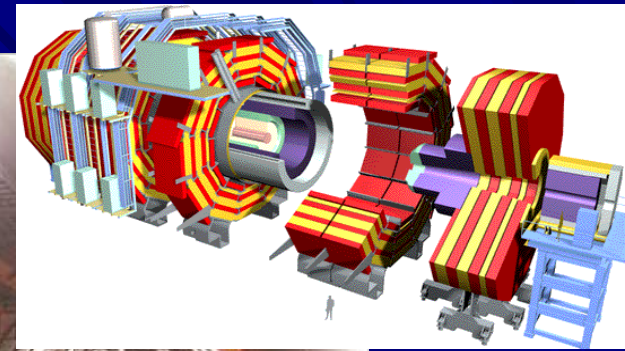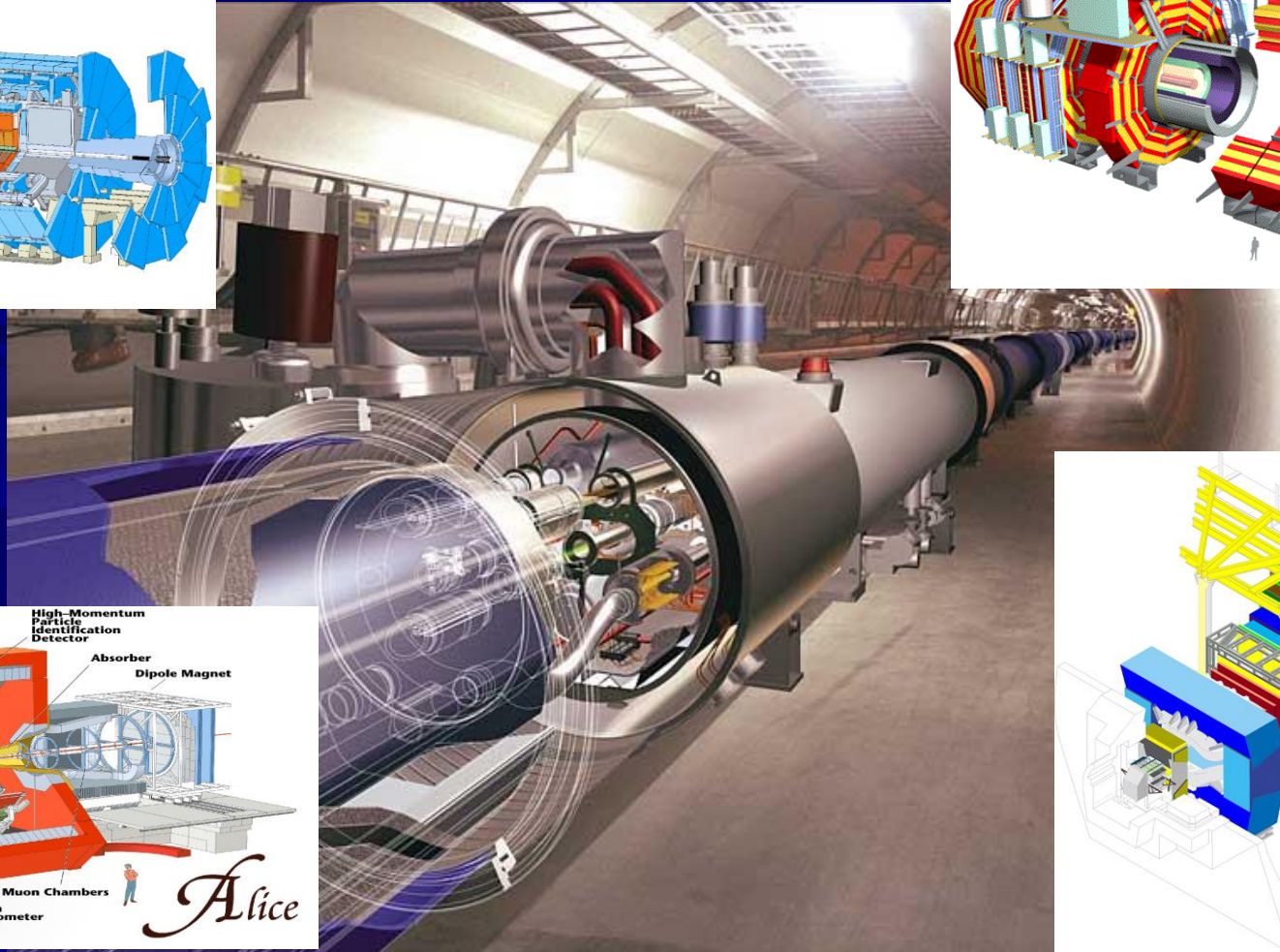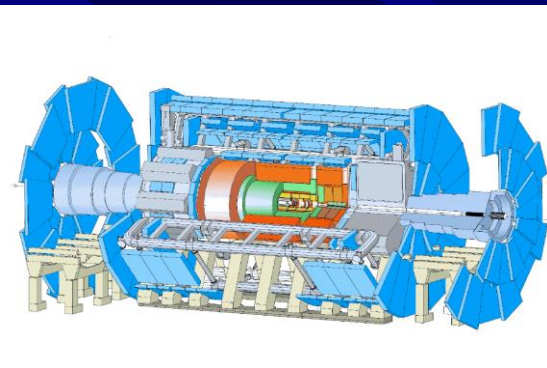
First data taking in November 2009 (900 GeV pp collisions)
First data taking at higher energy in March 2010 (7 TeV pp collisions)

$E = mc^2$

Accelerated · Particles
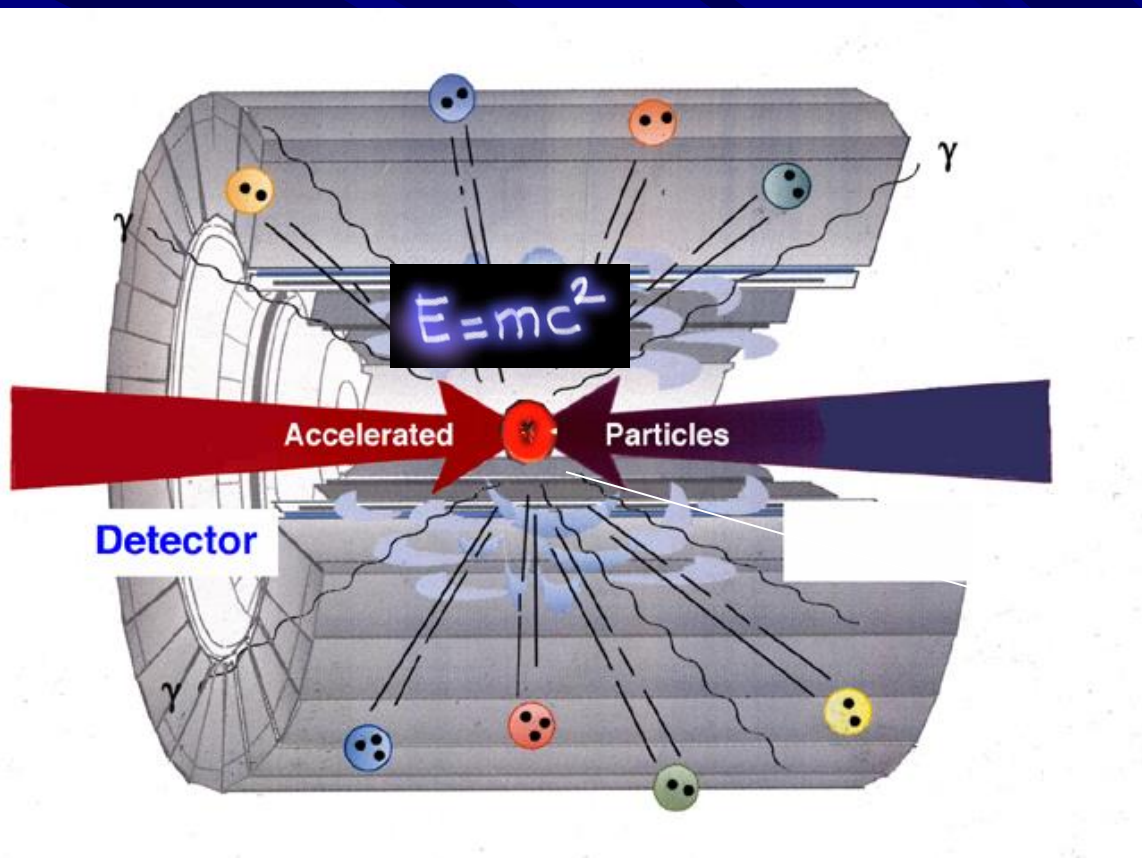
Detector

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

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

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

• 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
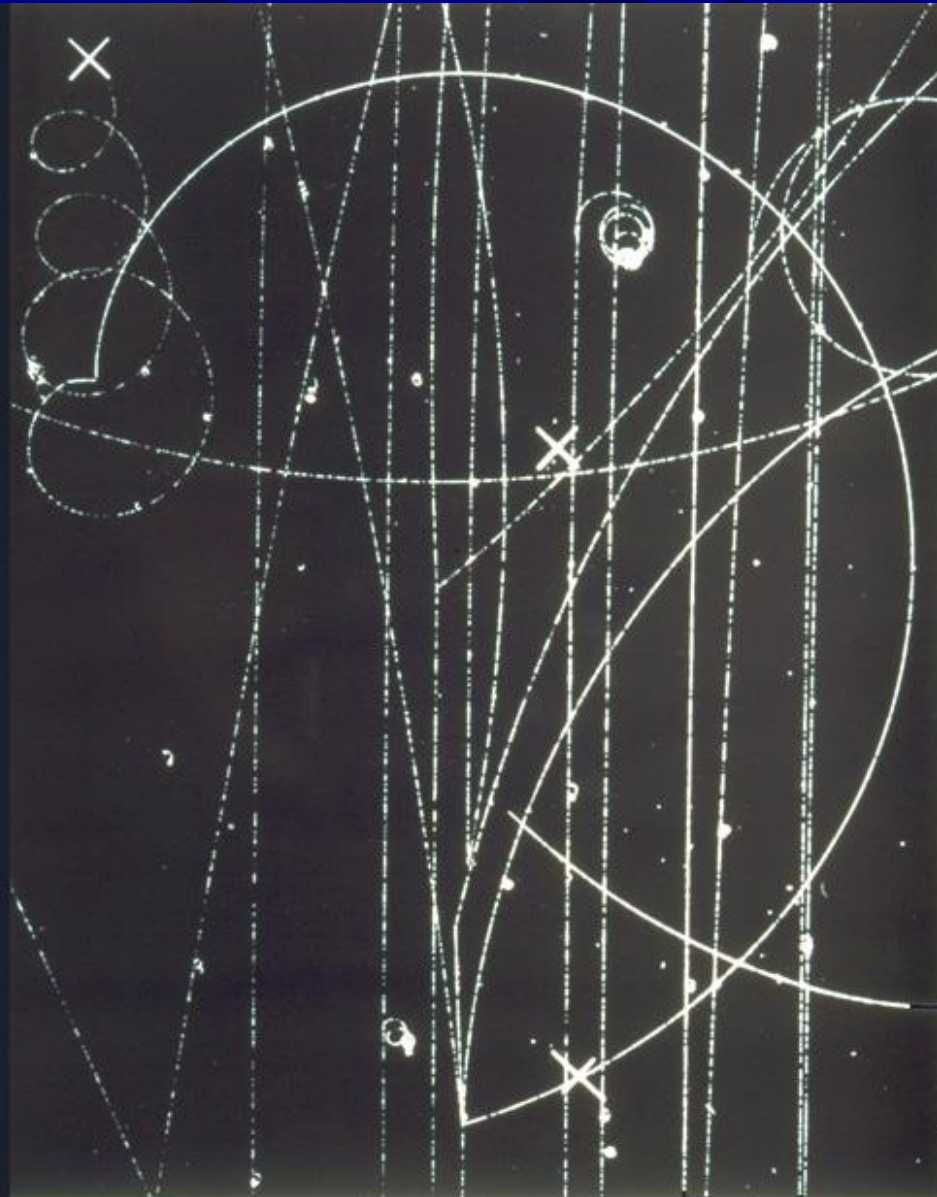• Various types of detectors :

      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

Key:
— Muon
— Electron
— Charged Hadron (e.g. Pion)
--- Neutral Hadron (e.g. Neutron)
----- Photon

Silicon Tracker

Electromagnetic Calorimeter

Hadron Calorimeter

Superconducting Solenoid

Iron return yoke interspersed with Muon chambers

Transverse slice through CMS

D. Barney, CERN, February 2004
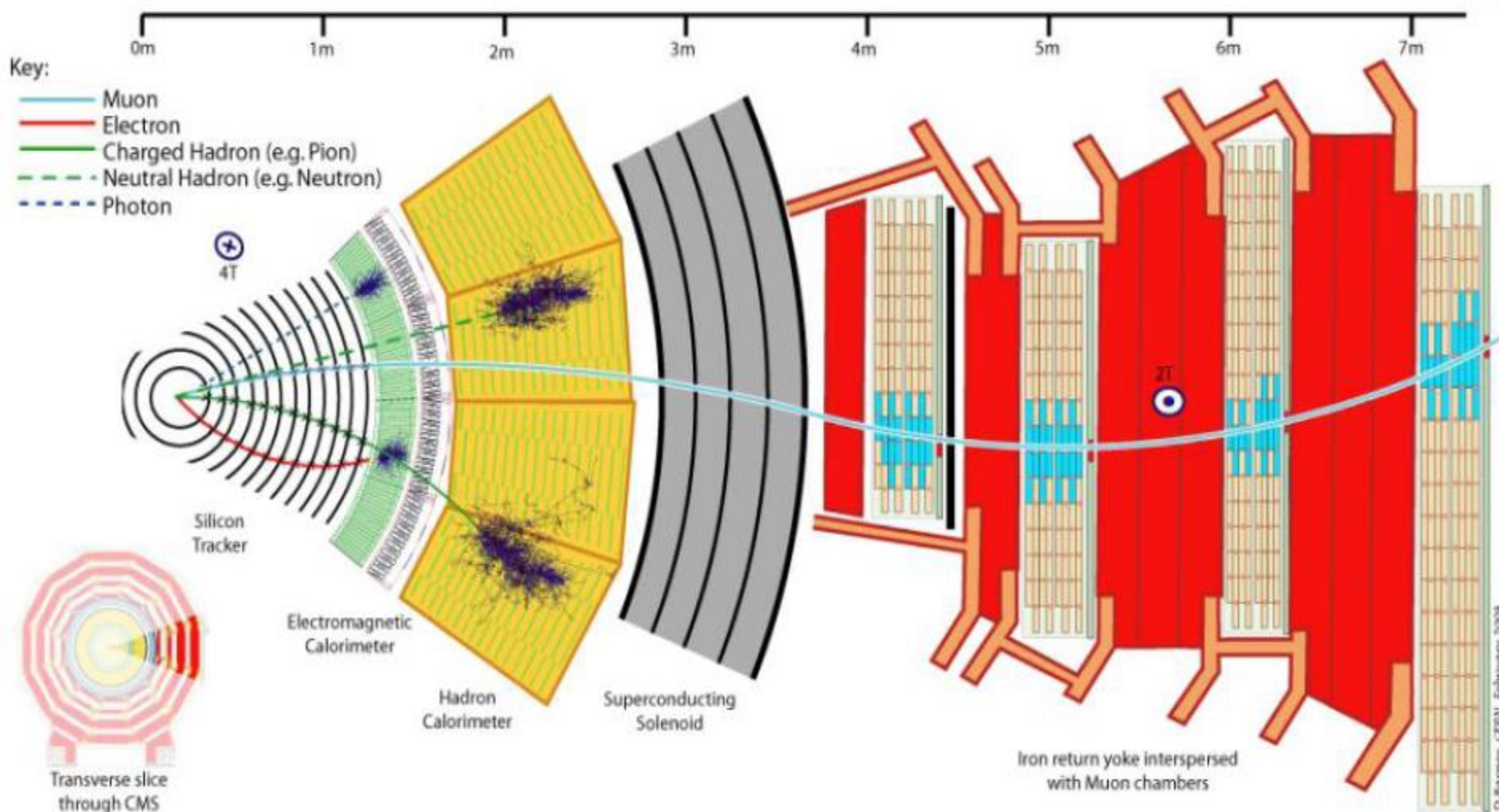
• A particle collision = an event

• $E = mc^2$ 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

Why three generations?

The mystery of mass and the Higgs boson

Beyond the standard model - supersymmetry

Dark matter

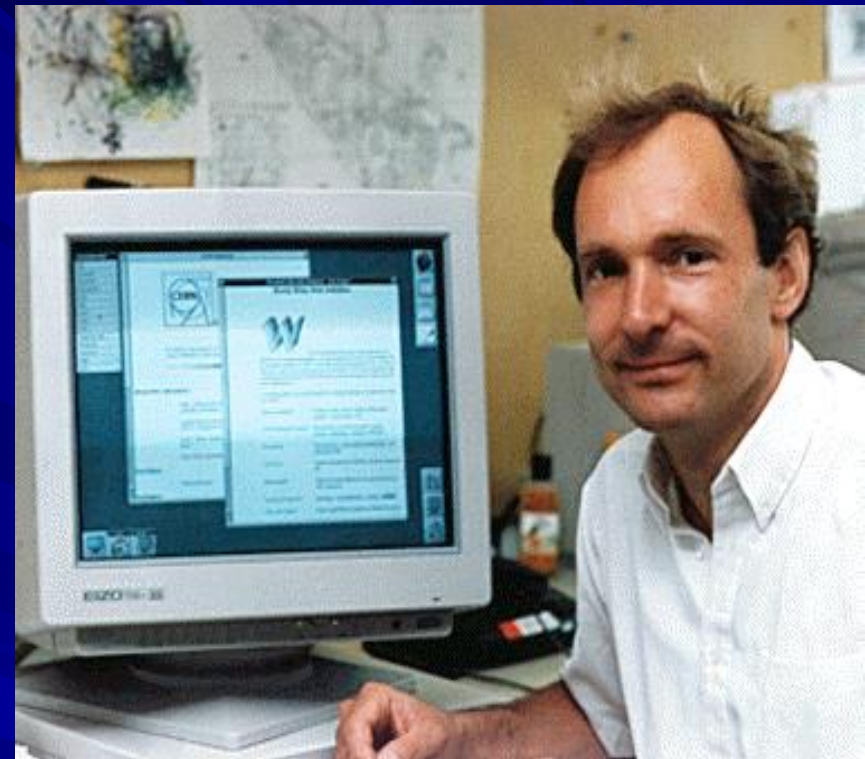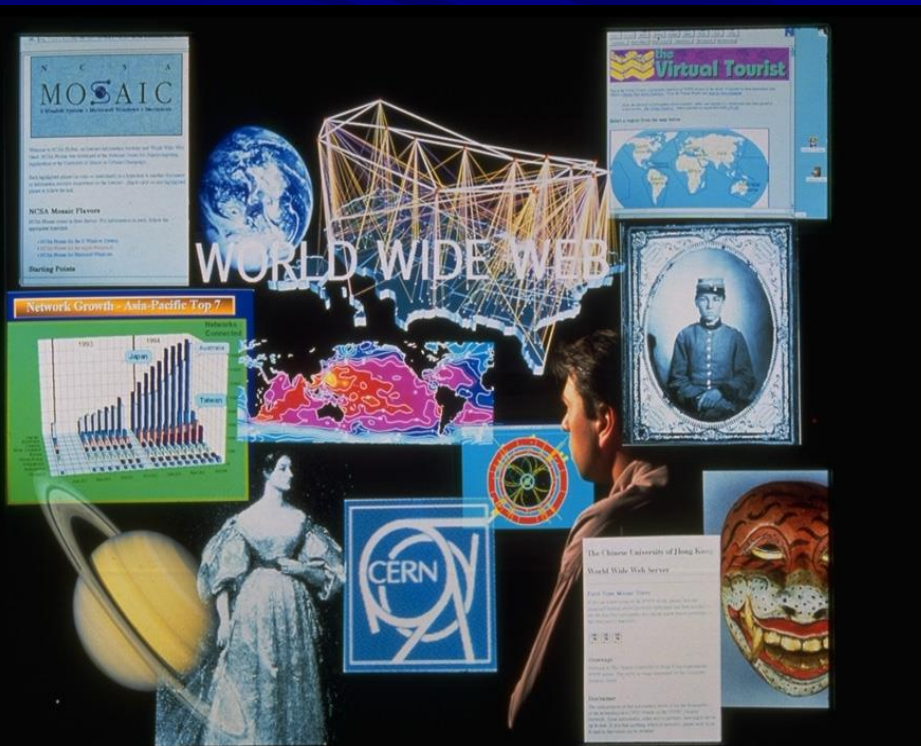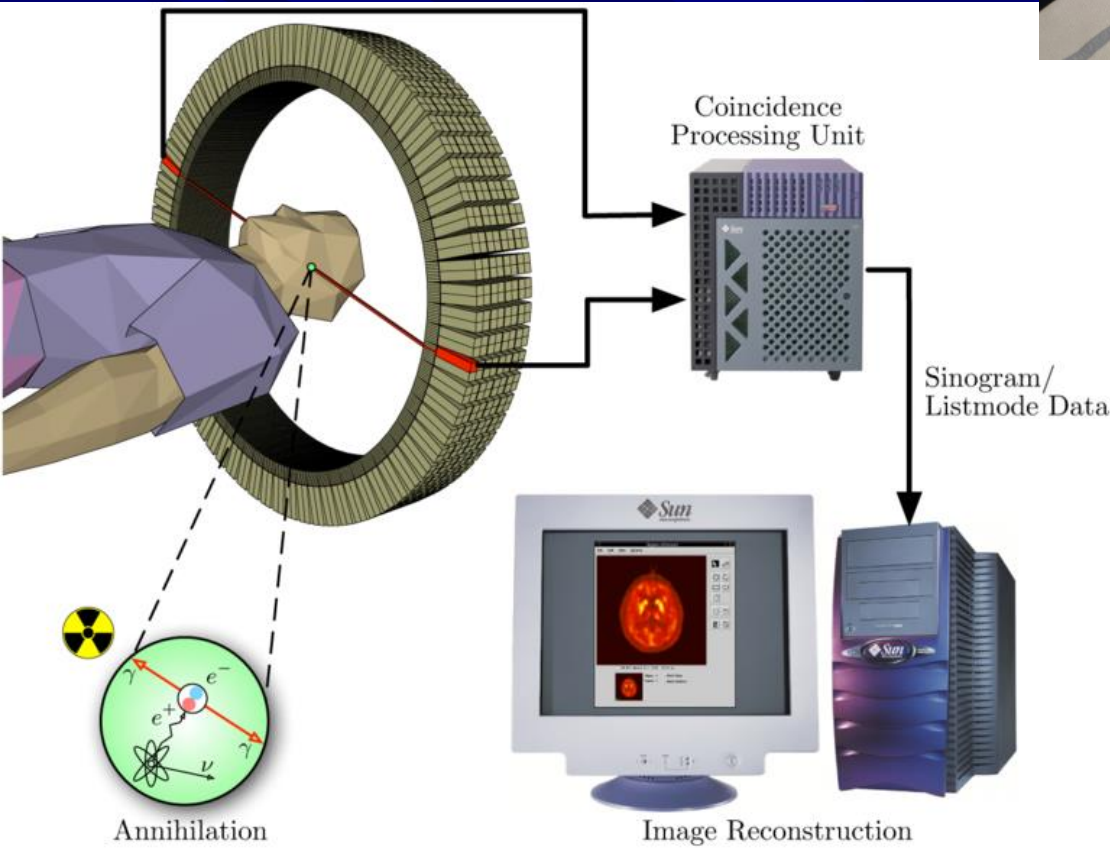The difference between matter and antimatter
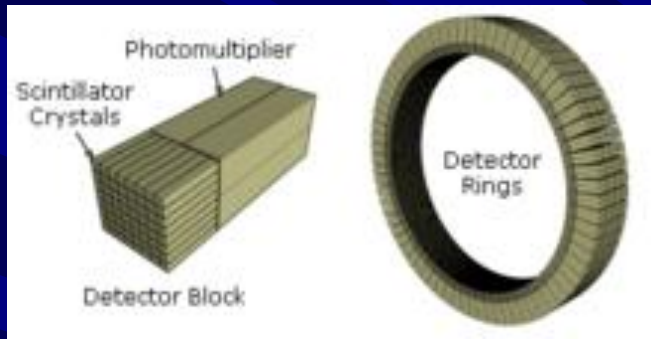
Invented by Tim Berners-Lee,
a CERN physicist, in 1989,
to meet the need of physicists in
Institutes all over the world for
Automatic information sharing

Nowadays, the WWW has expanded and has **millions** of academic and commercial **users**
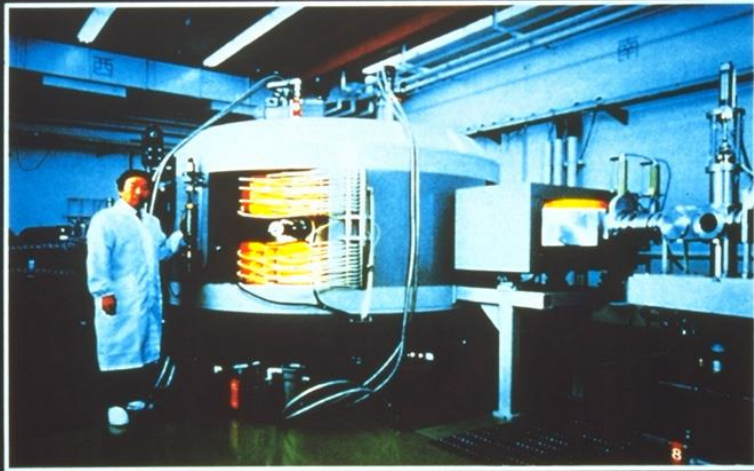
Positron Emission Tomography (PET)

Photomultiplier
Scintillator Crystals
Detector Rings
Detector Block

Coincidence Processing Unit

Sinogram/ Listmode Data

Annihilation

Image Reconstruction
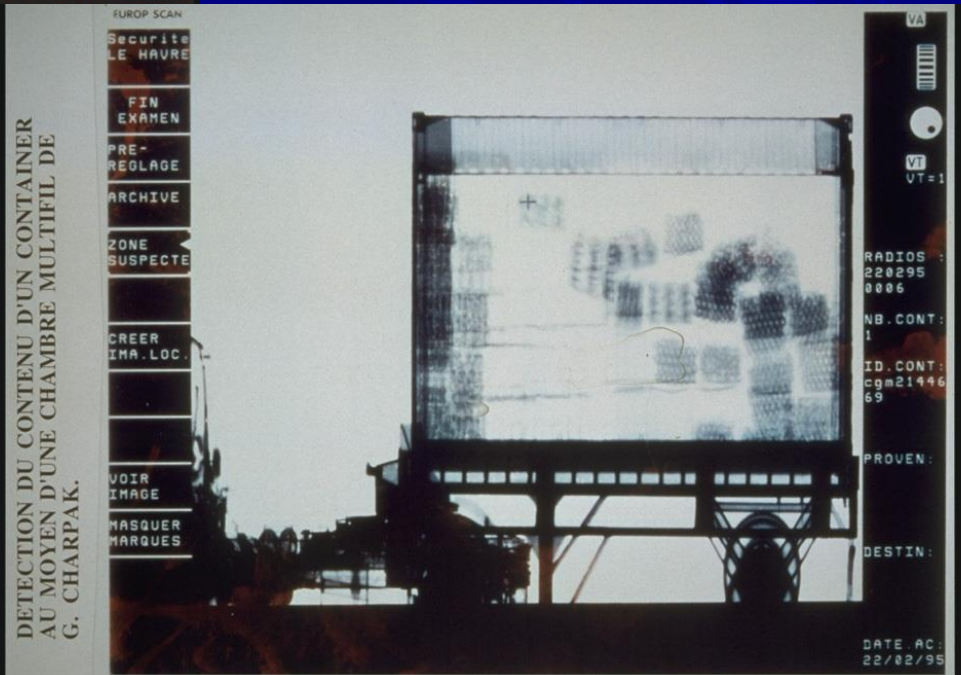
And many more spin-offs

- 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