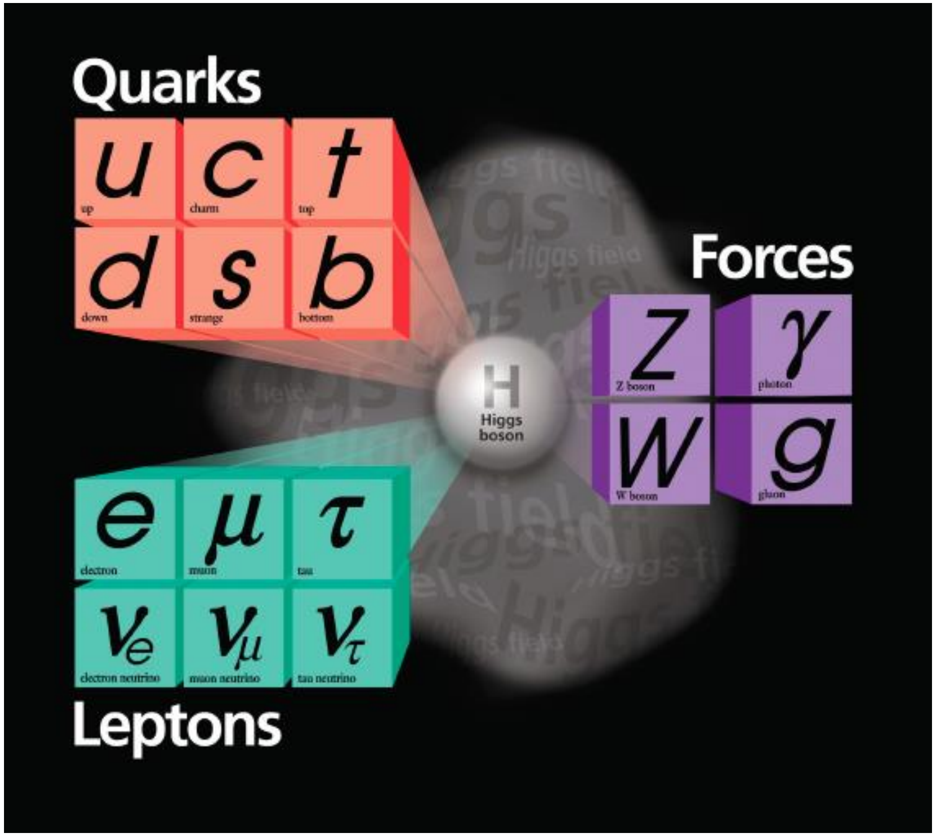
Technologies for HEP and life applications

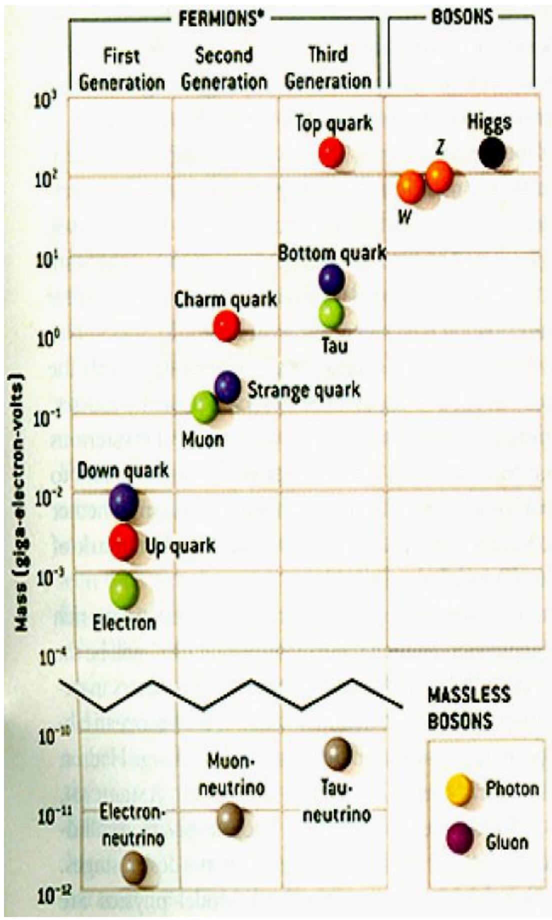
The Standard Model of Particle Physics
3 Quark families, 3 Lepton Families, 4 Forces



- *Matter*
  - is made out of fermions
- *Forces*
  - are mediated by bosons
- *Higgs boson*
  - breaks the electroweak symmetry and gives mass to fermions and weak gauge bosons

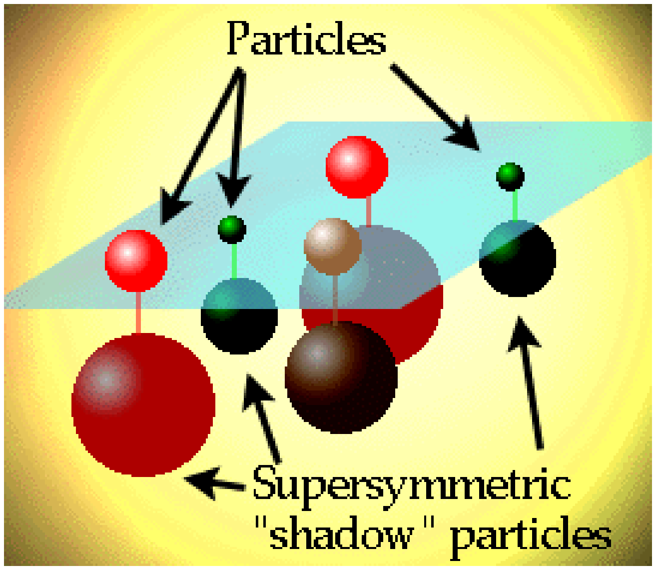
The theory describes the known forces and particles, with the exception of *Gravity*

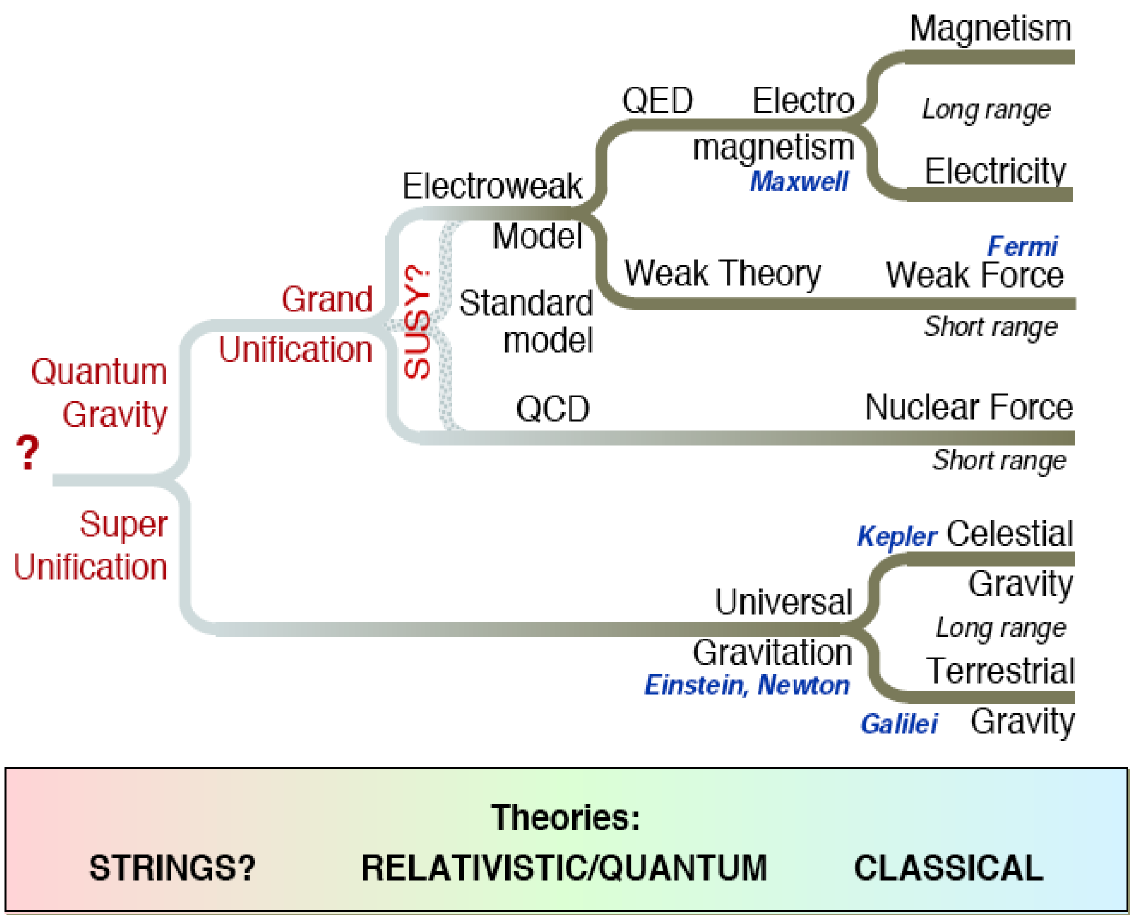
Have we done it?



1. *Is Nature Unified ? Is there Supersymmetry ?*
2. *What is the nature of dark matter ?*
3. *Why is gravity so weak; are there extra space-time dimensions?*
4. *Why is any matter left in the universe?*
5. *Why do neutrino and quark flavors oscillate ?*
6. *What is the dark energy ?*

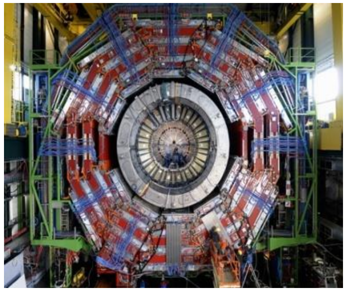
Path to Unification





What we need

Accelerators: powerful machines to accelerate particles to extremely high energies and bring them into collision with other particles

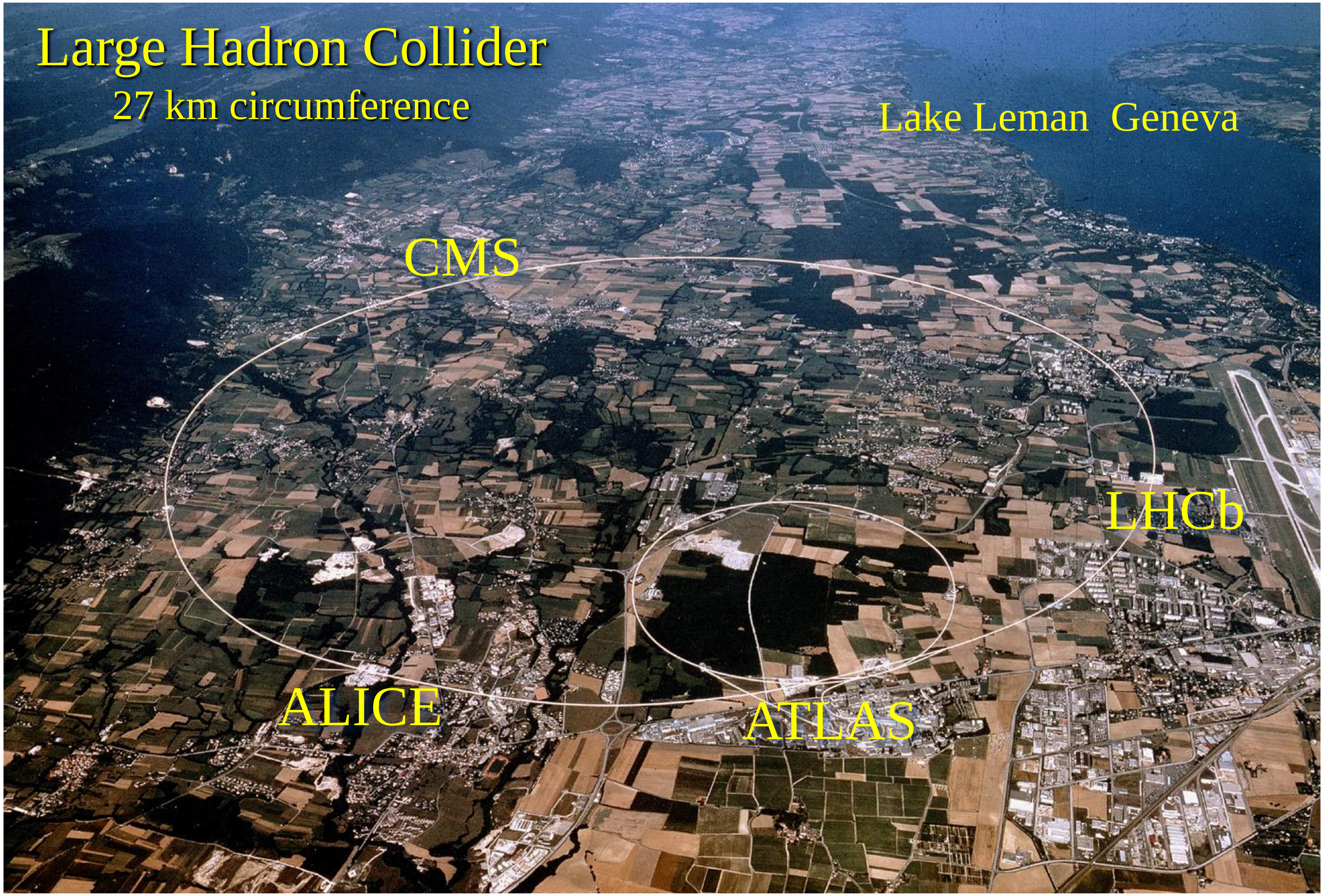


Detectors: gigantic instruments that record the particles as they “stream” out from the point of collision

Computing & software: to collect, store, distribute and analyse the vast amount of data

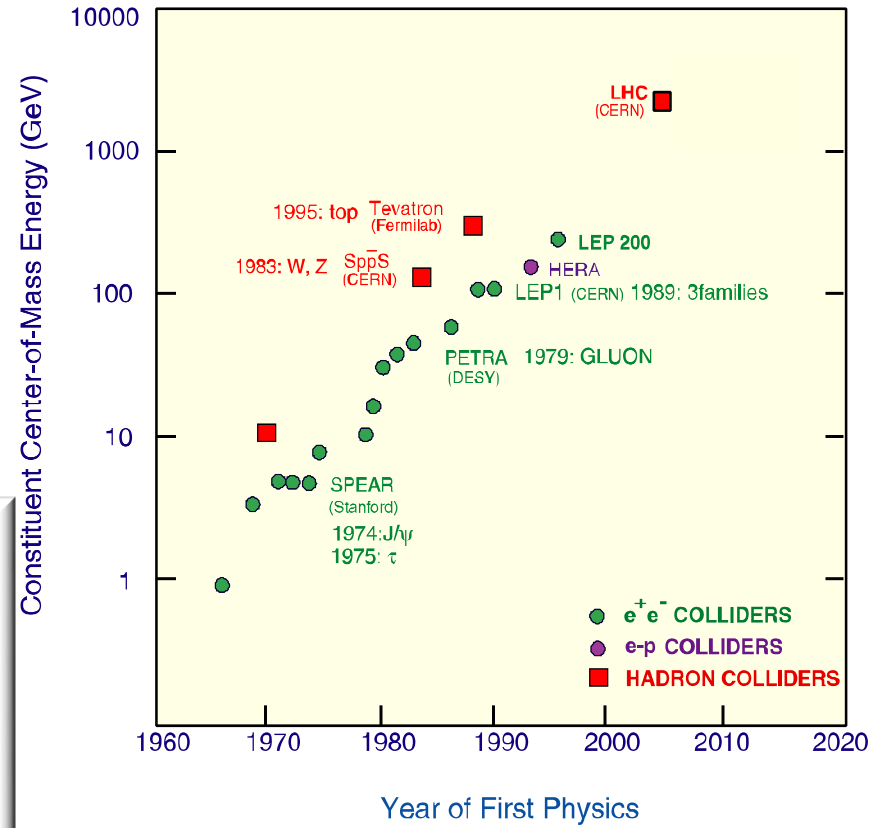
People: worldwide collaboration of scientists, engineers, technicians to design, build and operate a complex instruments

The LHC project



The Large Hadron Collider

Cover domain ~ 1 TeV
Largest possible primary energy
Largest possible luminosity

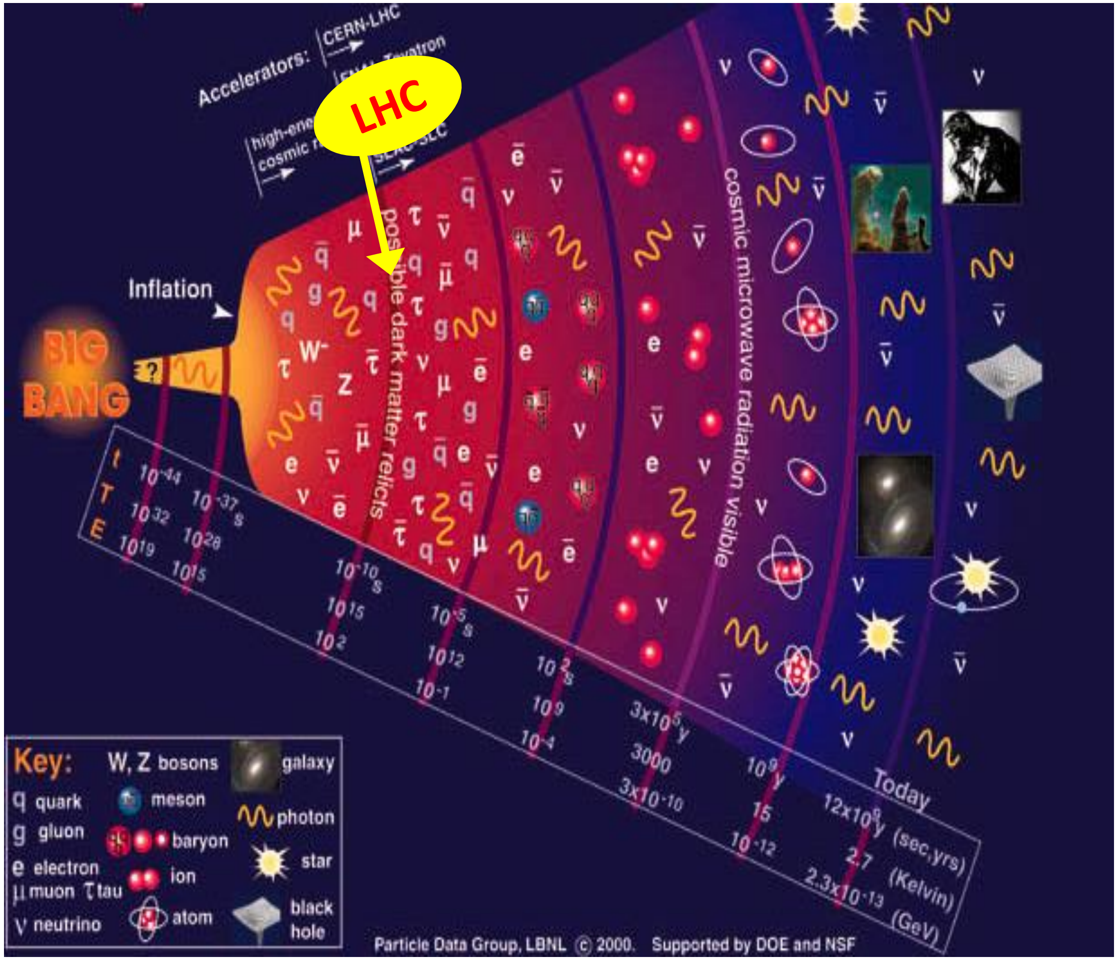


1982 : First studies for the LHC project
1983 : Z0/W discovered
1989 : Start of LEP operation
1994 : Approval of the LHC by the CERN Council
1996 : Final decision to start the LHC construction
2000 : Last year of LEP operation above 100 GeV
2002 : LEP equipment removed
2003 : Start of the LHC installation
2005 : Start of LHC hardware commissioning
2008 : First LHC beams

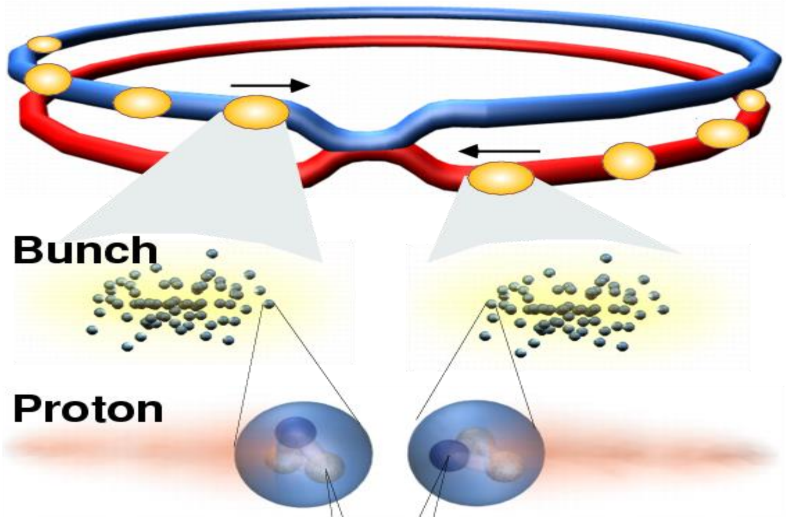
The LHC allow us to recreate particles *rarely* seen in nature since 10^{-12} seconds after the Big Bang

<u>*A Brief History of Time*</u>

10^{-43} s	*Quantum gravity era*
10^{-35} s	*Grand unification era*
10^{-10} s	*Electro-weak era*
10^{-4} s	*Protons and neutrons*
100 s	*Nuclei*
0.3 Myr	*Atoms formed*
1 Gyr	*Galaxy*



Proton – Proton	2808 x 2808 Bunches
Protons/Bunch	$1.1 \cdot 10^{11}$
Beam Energy	7 TeV (7×10^{12} eV)
Luminosity	10^{34} cm^{-2} sec^{-1}
Crossing Rate	40 MHz
Collisions	~10^9 Hz



The LHC surpasses existing accelerators/colliders in 2 aspects :

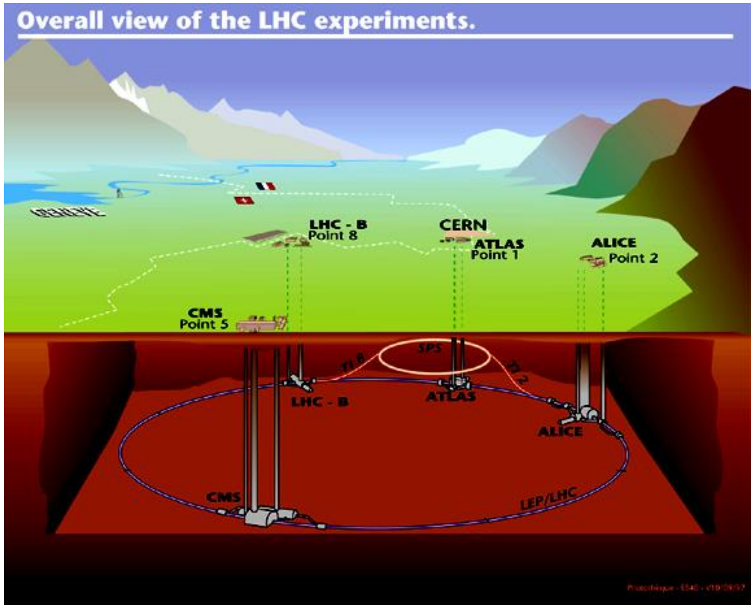
- The energy of the beam of 7 TeV that is achieved within the size constraints of the existing 26.7 km LEP tunnel.

LHC dipole field	8.3 T
HERA/Tevatron	~ 4 T

- The luminosity of the collider that will reach unprecedented values for a hadron machine:

LHC	pp	~ 10^{34} cm^{-2} s^{-1}
Tevatron	pp	2×10^{32} cm^{-2} s^{-1}

The LHC project



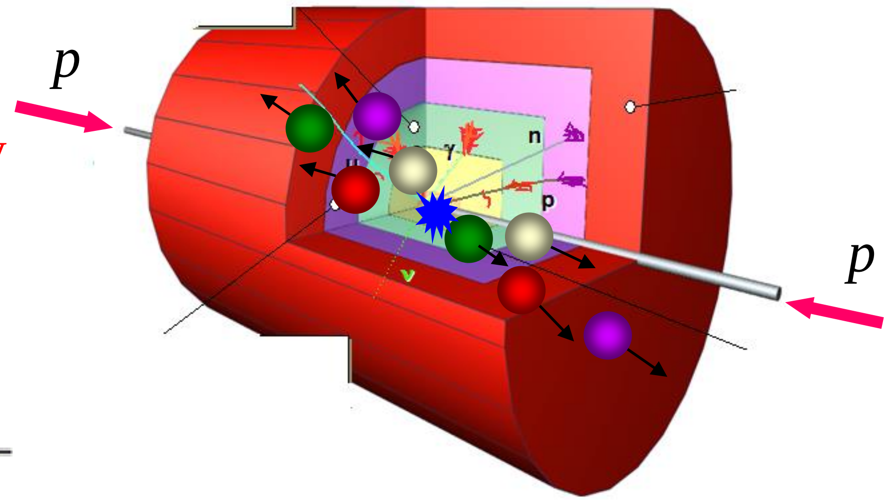
To reach the required energy in the existing 27 km tunnel, the super conducting magnets operate at **83 Kilogauss** (200.000 x Earth’s field) in super fluid helium.

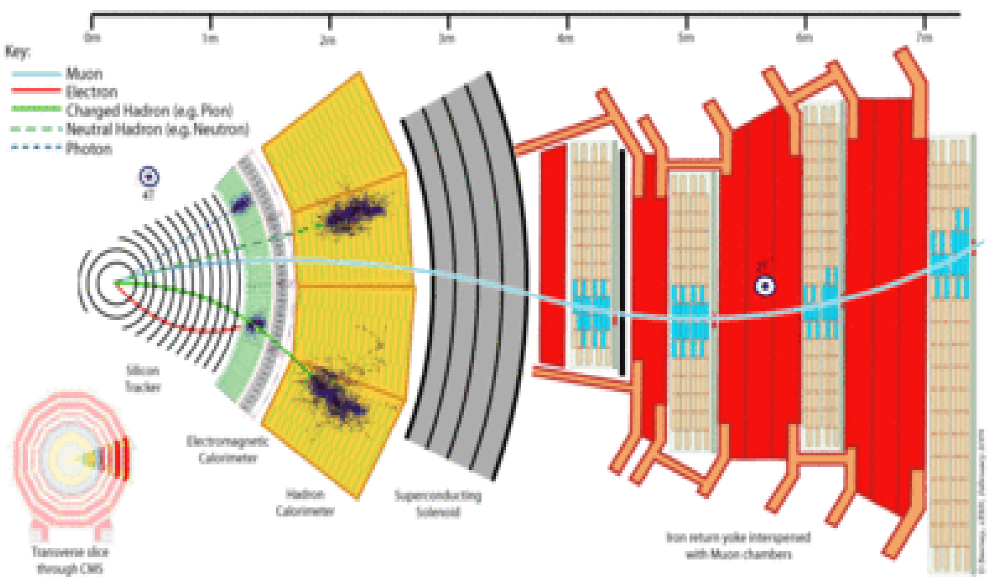
Protons travel in a tube with **better vacuum & colder than interplanetary space at T = 4-20 ^{o} K**

Coverage of full solid angle

Measurement of momentum and/or energy

Detect, track and identify all particles (mass, charge)

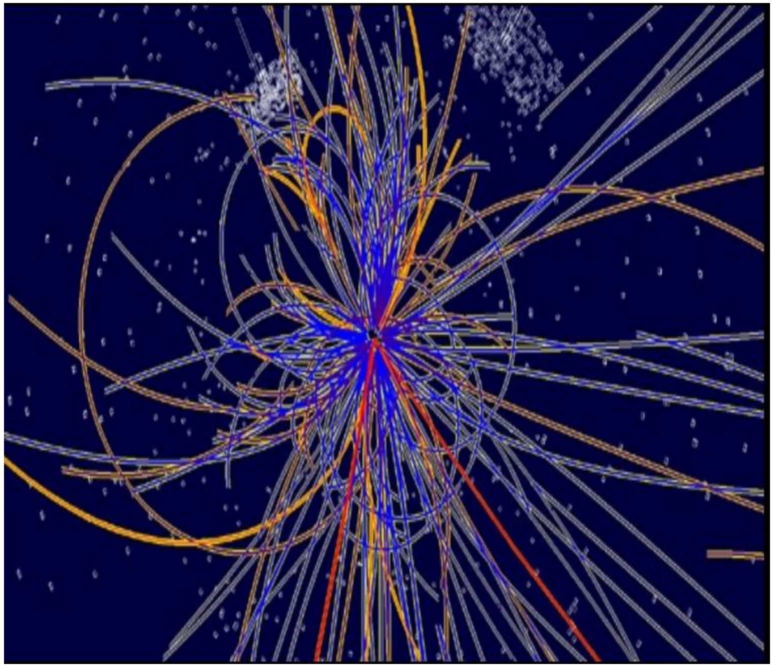




Relevant scale is the nuclear interaction length λ_L (for Fe 16.8 cm).

$\lambda_L \approx 10\ X_0$, so hadronic showers are longer than EM

Experimental Challenge



High Interaction Rate

- *1 billion interactions/s*
- *Data can be recorded for only ~100 out of the 40 million crossings/sec*
- *Level-1 trigger decision will take ~2-3 ms*

Large Particle Multiplicity

- *~ <20> superposed events in each crossing*
- *~ 1000 tracks stream into the detector every 25 ns need highly granular detectors with*

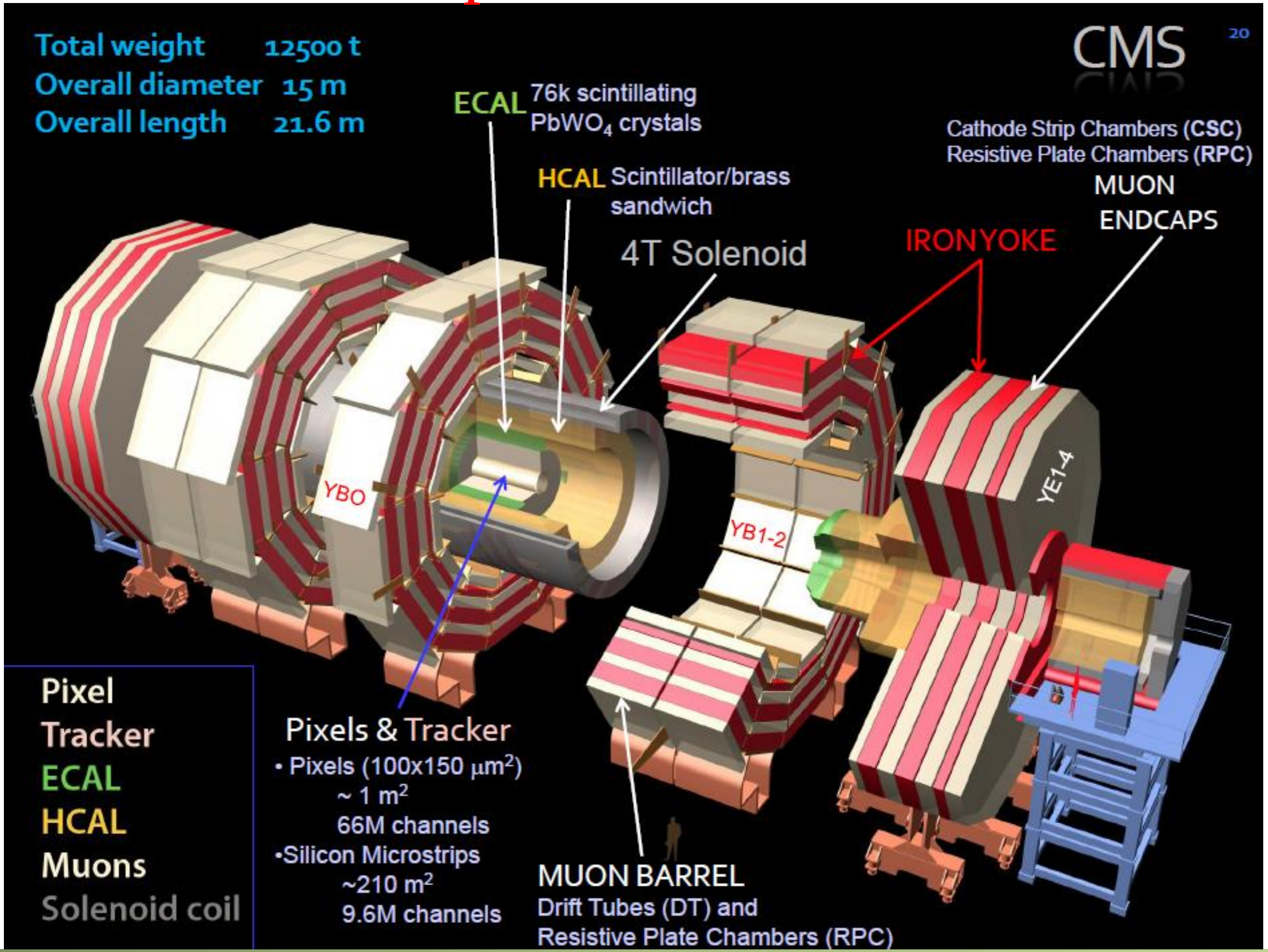
High Radiation Levels

- *radiation hard (tolerant) detectors and electronics*

We need

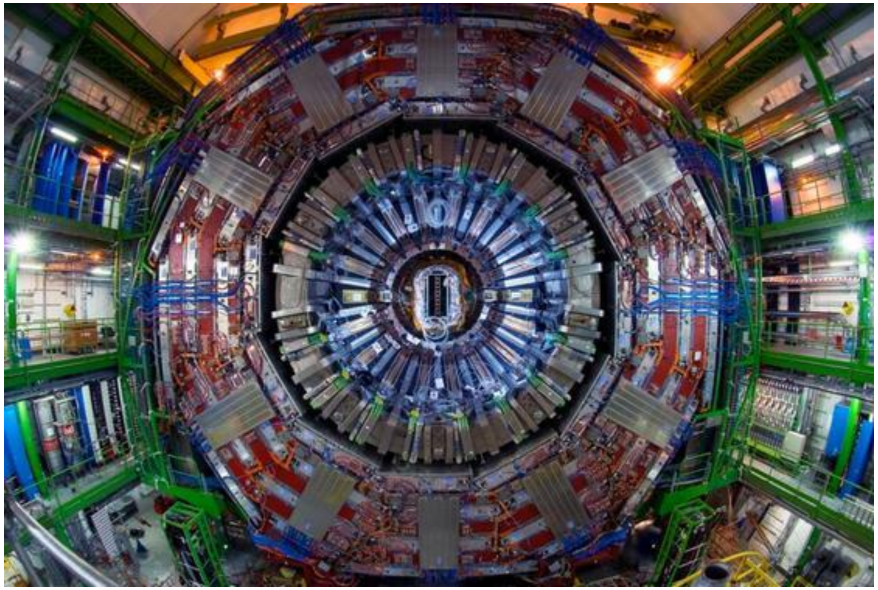
- High frequency of sampling (40 MHz)
- High resolution in space and time (100 μm and few ns)
- No dead time
- High data storage capability (TB)

The Compact Muon Solenoid



Gigantic, but "compact"

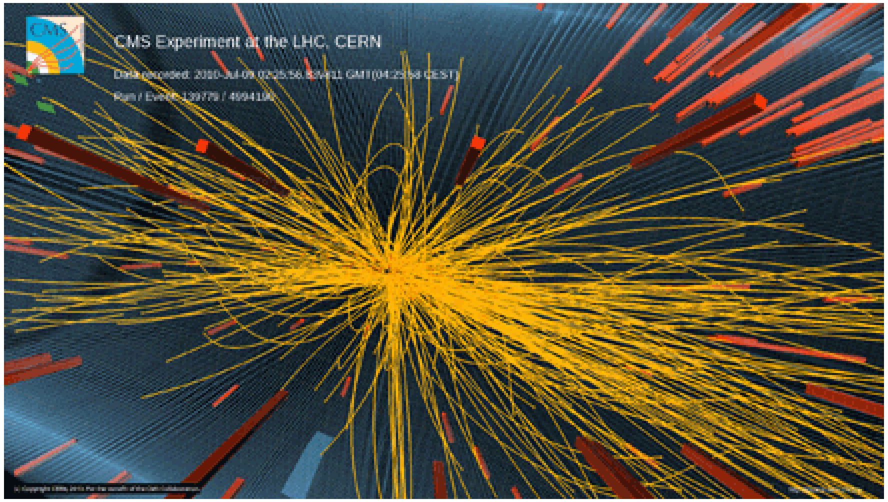
The detectors



Detect 600 million proton-proton collisions per second

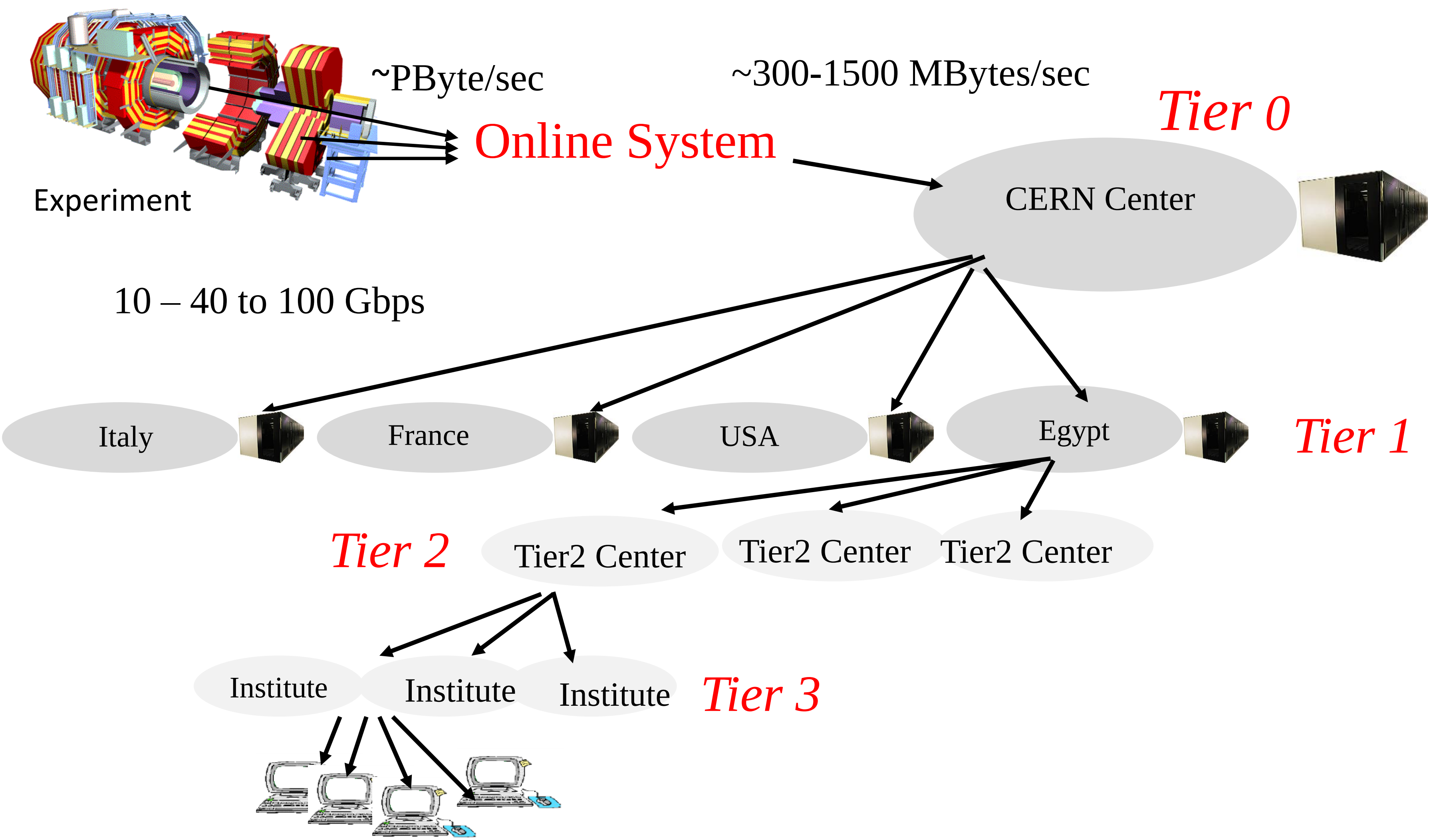
Sophisticated detectors to precisely measure the passage of a particle with time accuracies of 10^{-9} second and space accuracy of 10^{-5} meter.

- Crystal
- Gaseous detectors
- Silicon detectors

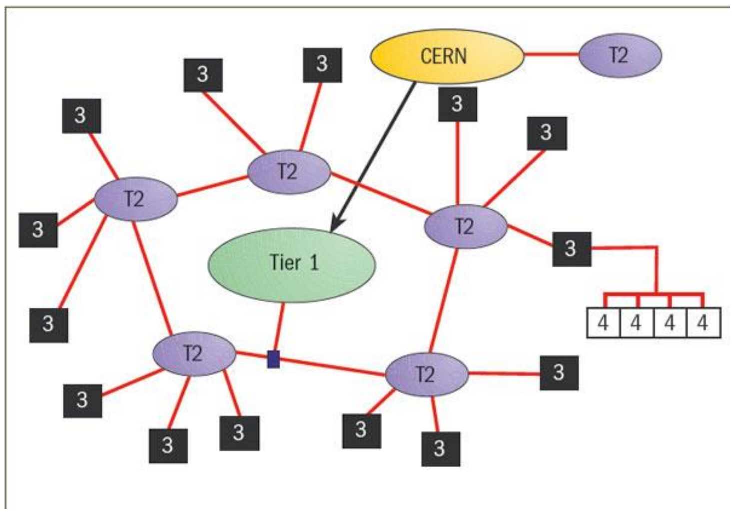


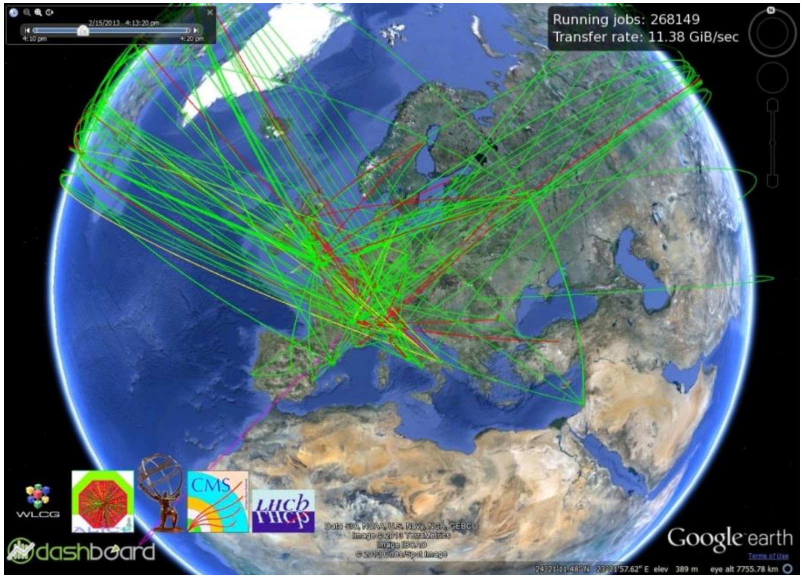
Data analysis

The CMS Data Grid Hierarchy



Worldwide LHC Computing Grid (WLCG)





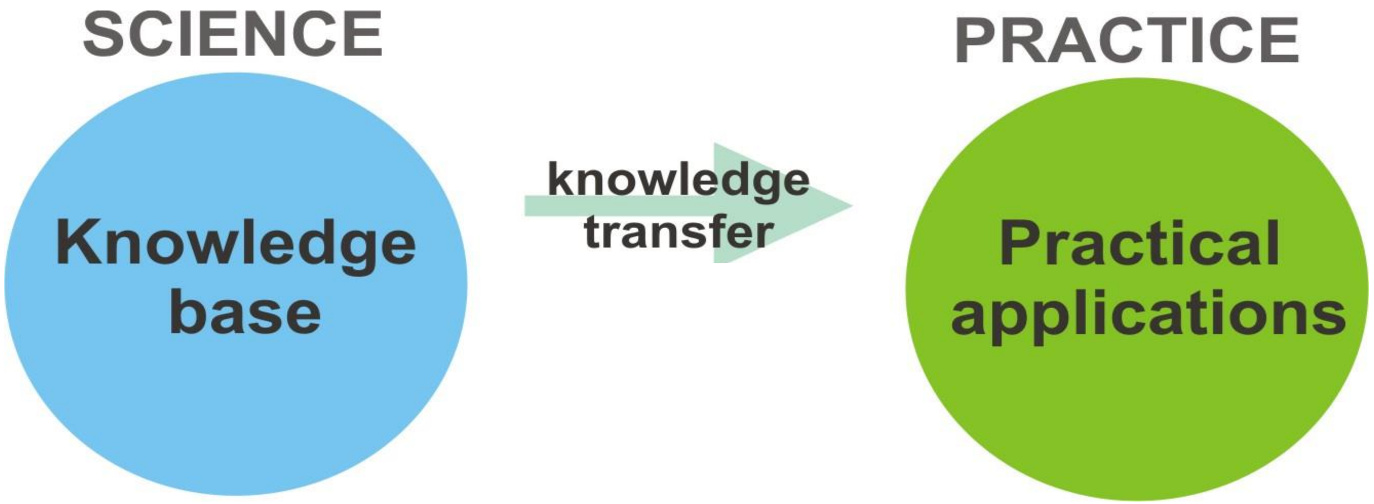
370 Sites

40,000 computers

Tens of Thousands of GRID jobs running concurrently

The mission of the WLCG project is to provide global computing resources to store, distribute and analyse the ~30 Petabytes (30 million Gigabytes) of data annually generated by the Large Hadron Collider.

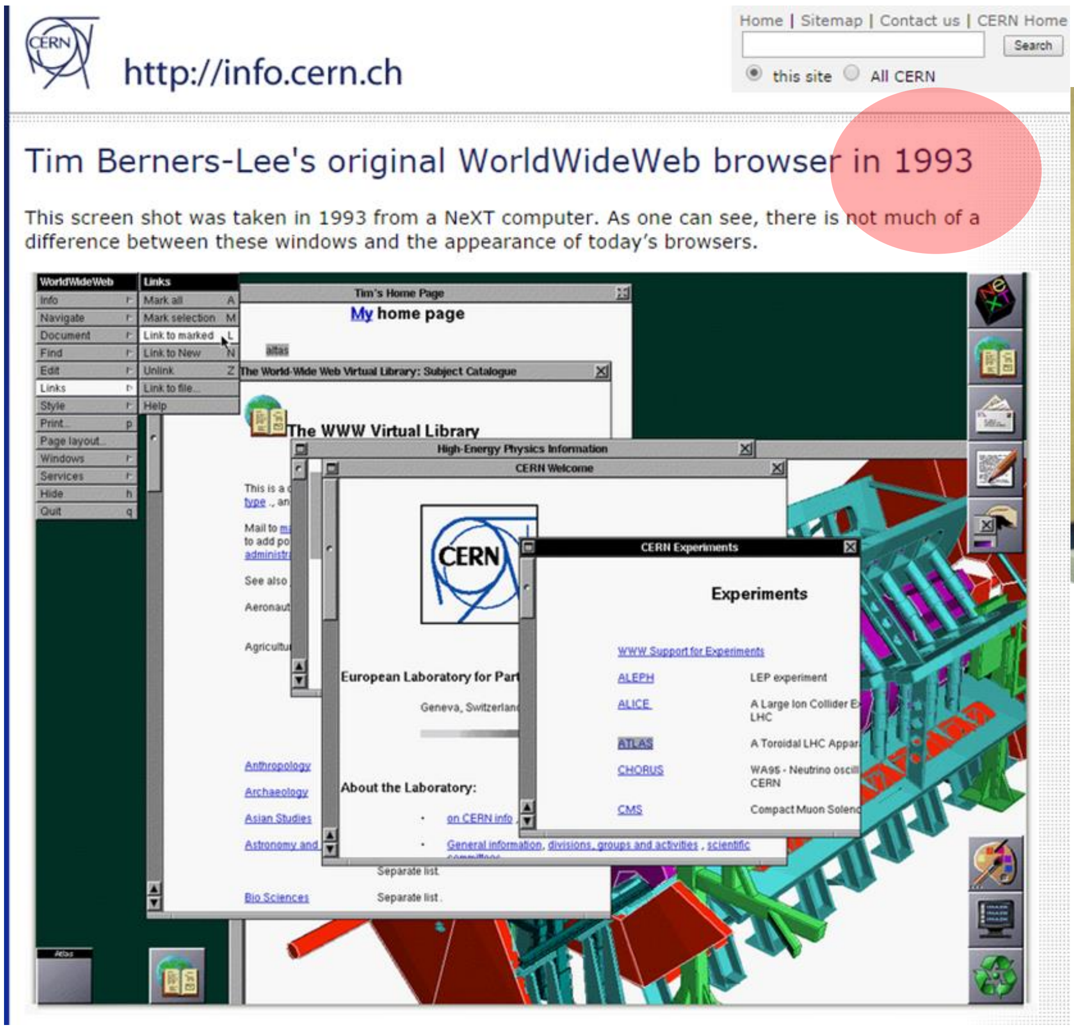
HEP technologies transfer to everyday life

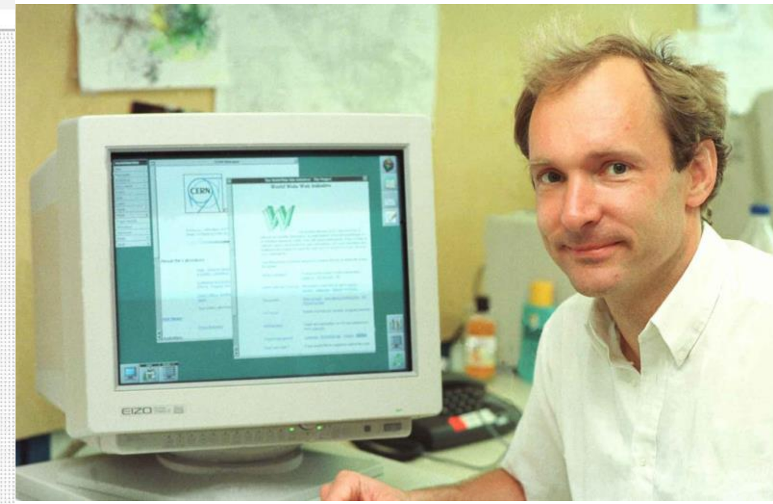


Physics underpins so much of modern life

The global positioning systems (GPS) that are used to achieve pinpoint position accuracy in today's most modern vehicles depend on general relativity, Einstein's theory of gravity.

A milestone case: WWW

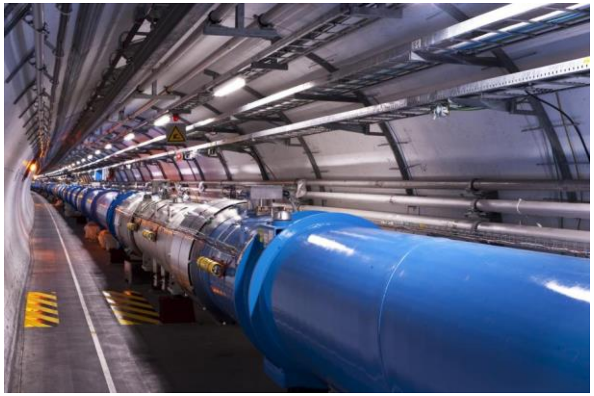




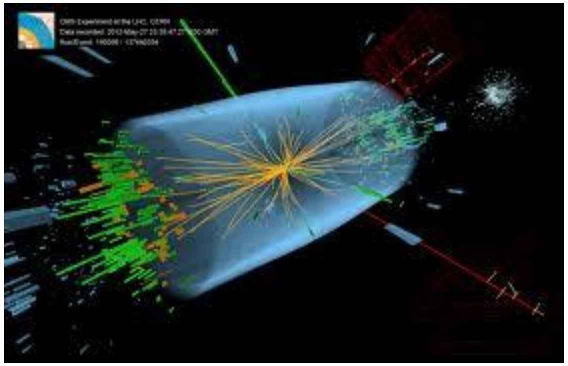
Tim Berners Lee with his NeXT computer that he used to invent the World Wide Web

HEP technologies

Accelerating particle beams

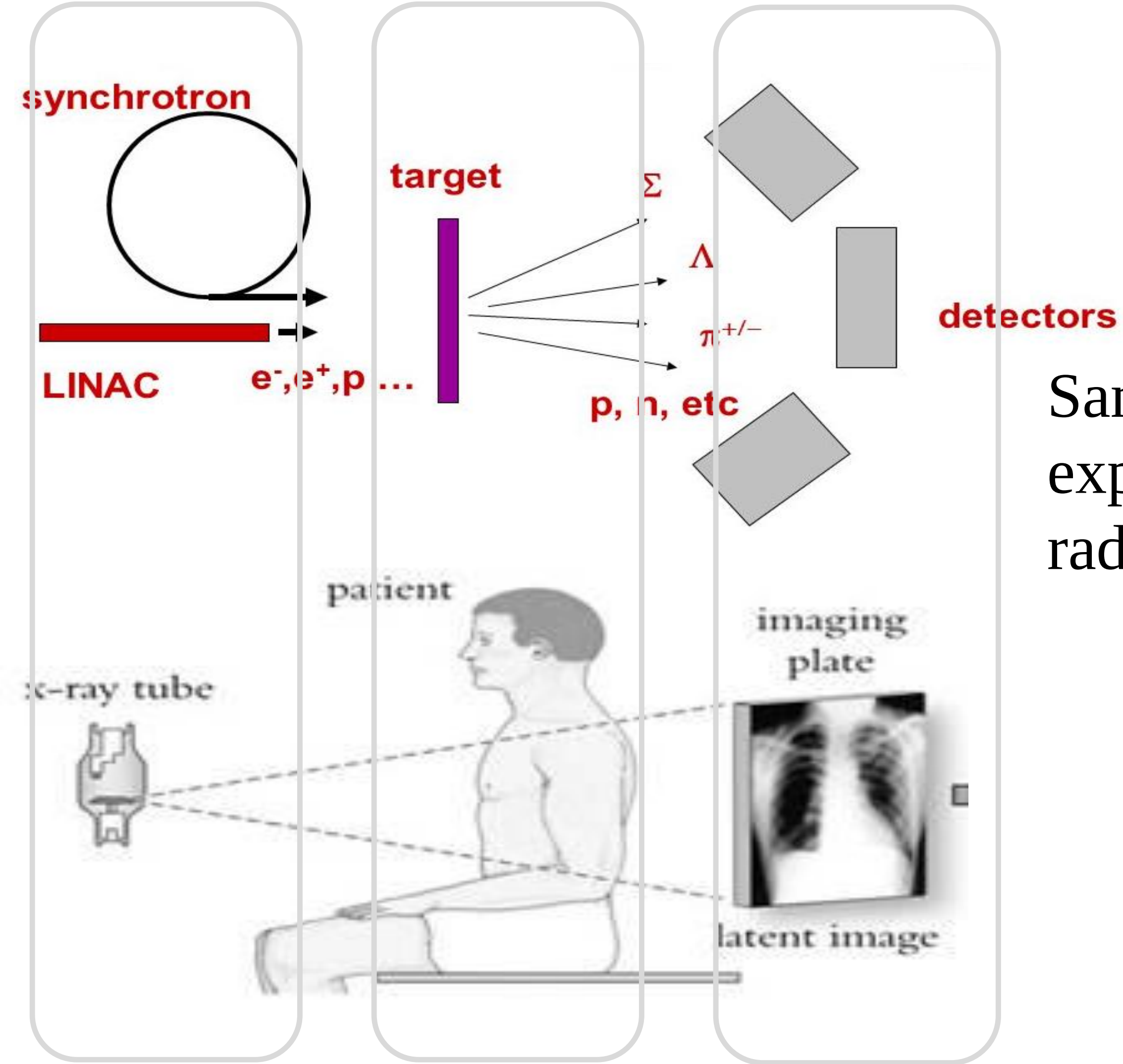


Detecting particles



Large scale computing & software

HEP technologies for medicine

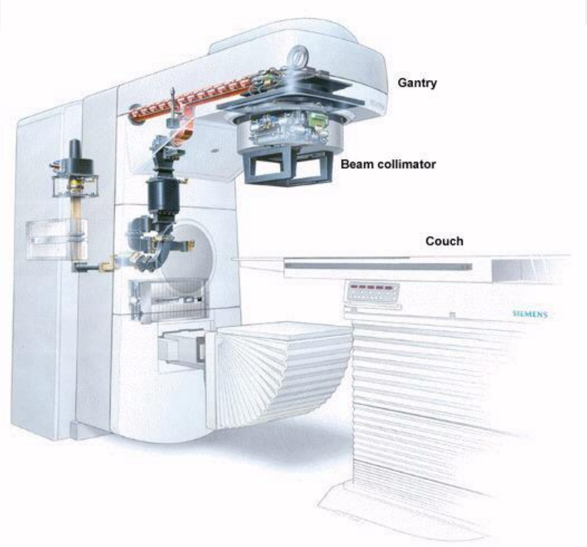


Same concept for an HEP experiment and a radiological investigation

There are many medical application of accelerators

Basic type of accelerators

-Linear
-Cyclotron
-Betatron
-Synchrotron



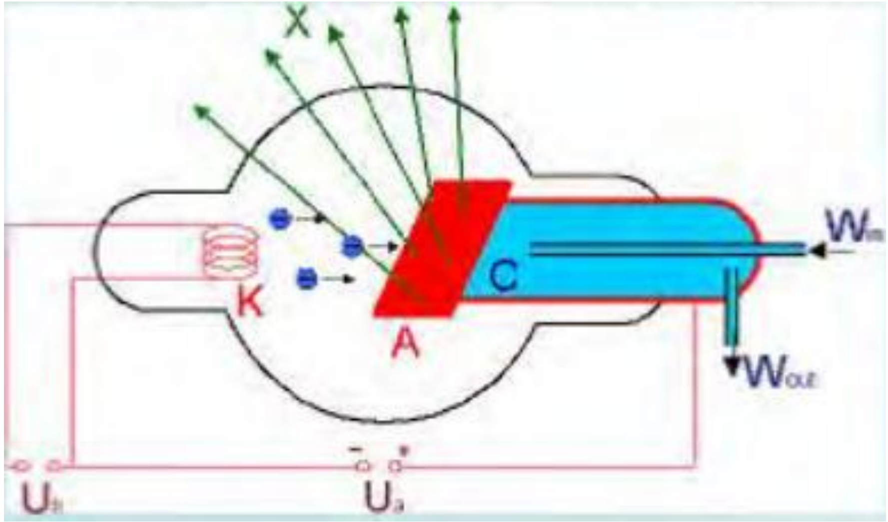
Common medical application

-Radiation therapy (photon/electron)
-Isotope production (Cyclotron)
-Equipment sterilization
-Hadron therapy

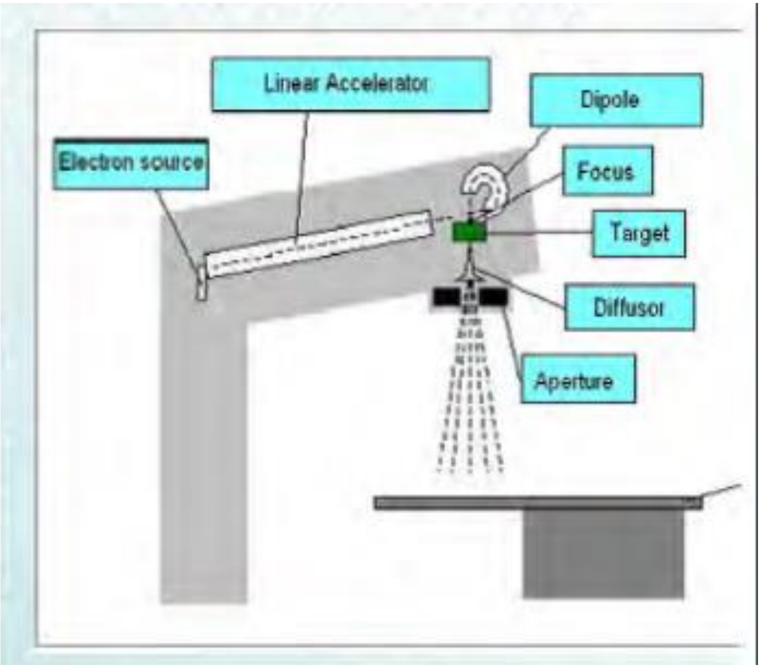
Future Application
-Angiography
-Boron neutron Capture Therapy

Linear accelerators (LINAC) for radiotherapy

Schematics of an X ray tube for an electrostatic accelerator



Modern LINAC concept

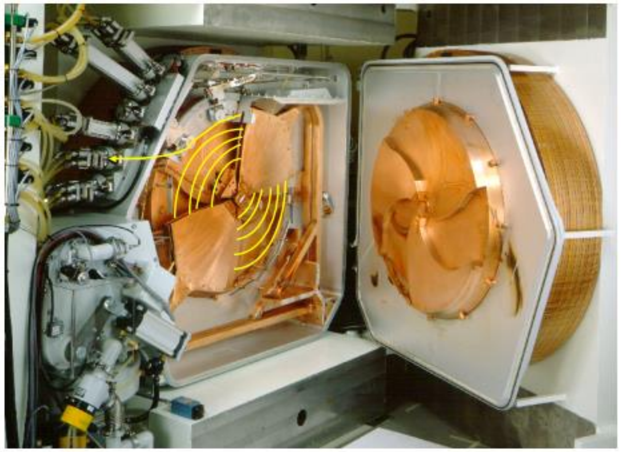


LINAC

LINAC uses microwave technology to accelerate electrons in a part of the LINAC called waveguide, then allows these electrons to collide with a heavy metal target. As a result of these collisions, high energy X-Rays (Photons) are produced from the target.

Accelerating particles for medical treatments

The synchrotron at CNAO for hadron therapy accelerates protons up to 250 MeV and carbon ions up to 4800 MeV

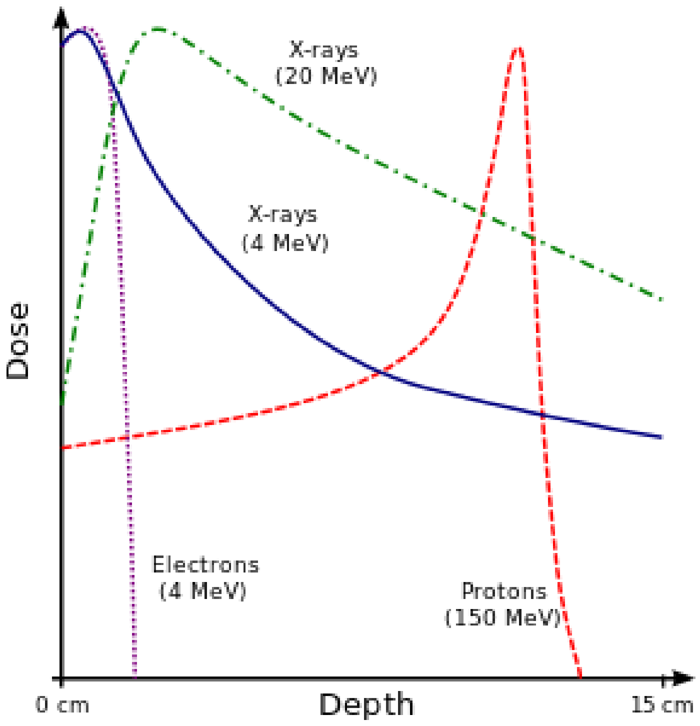


Cyclotrons for production of radio pharmaceutics substances are now quite common

es. $^{14}N + p \rightarrow {}^{11}C + \alpha + Q\ (MeV)$

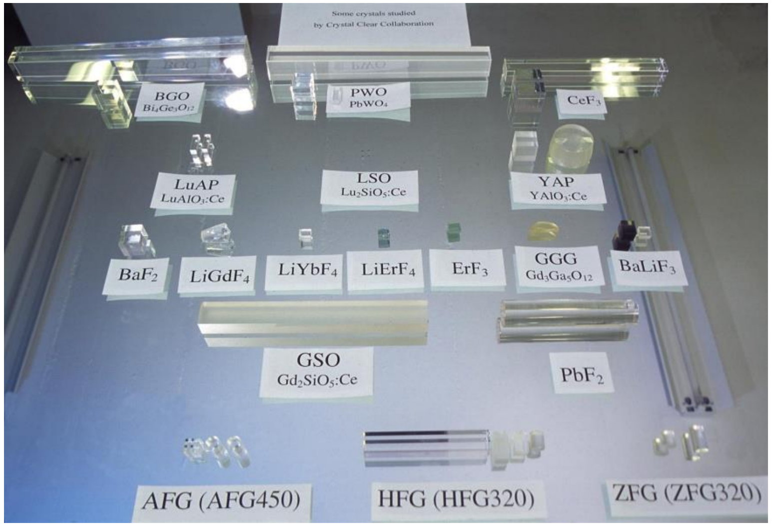
Hadron therapy

For protons and heavier ions the dose increases while the particle penetrates the tissue and loses energy continuously. Hence the dose increases with increasing thickness up to the Bragg peak that occurs near the end of the particle's range. Beyond the Bragg peak, the dose drops to zero (for protons) or almost zero (for heavier ions).



Scintillators detectors

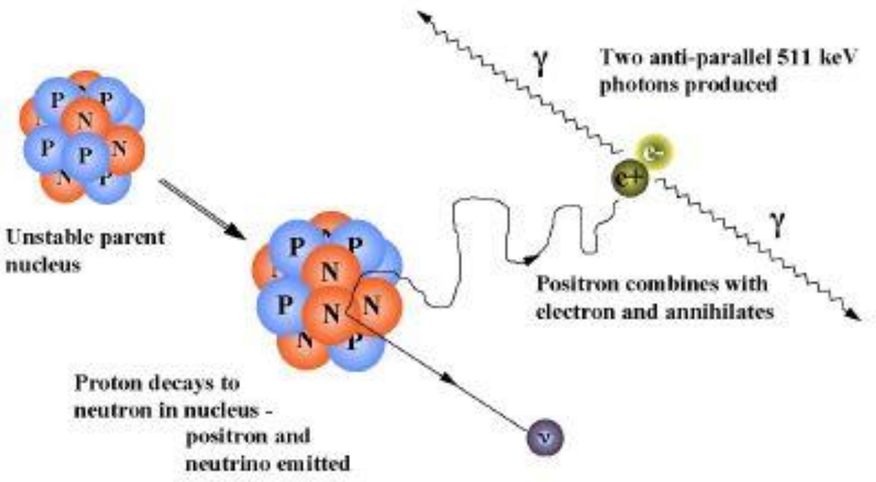
Scintillators are applied in high-energy physics to measure the energy of particles that are produced in particle physics experiments. Their use is motivated by the very good detection efficiency of these materials for hard radiation

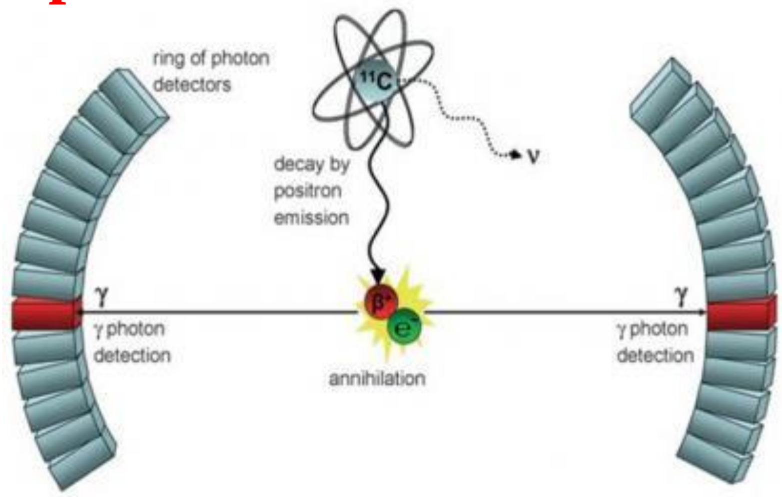


A wide range of applications

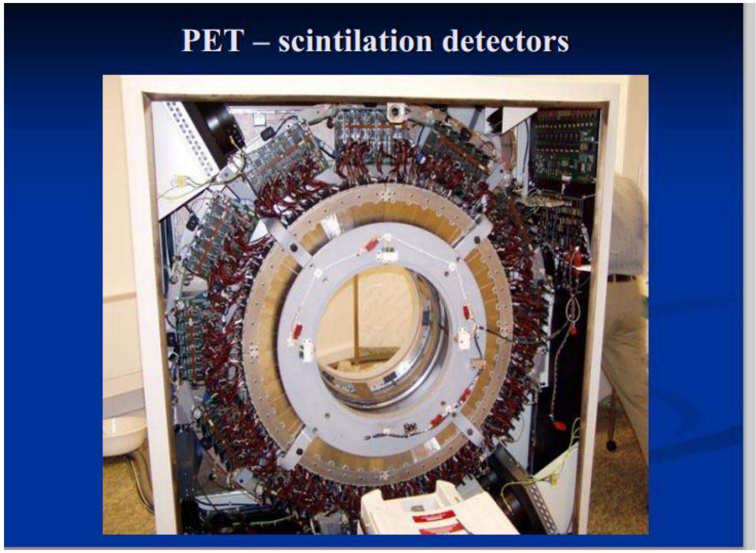
- Dosimetry: radiation therapy, equipment calibration, active exposure monitoring
- Nuclear applications: homeland security, nuclear reactors and fusion experiments
- Synchrotrons: white beam monitoring
- UV detectors: photolithography, flame detection and solar physics
- Alpha/Beta: air-Flow and survey meters, waste incineration

The PET concept





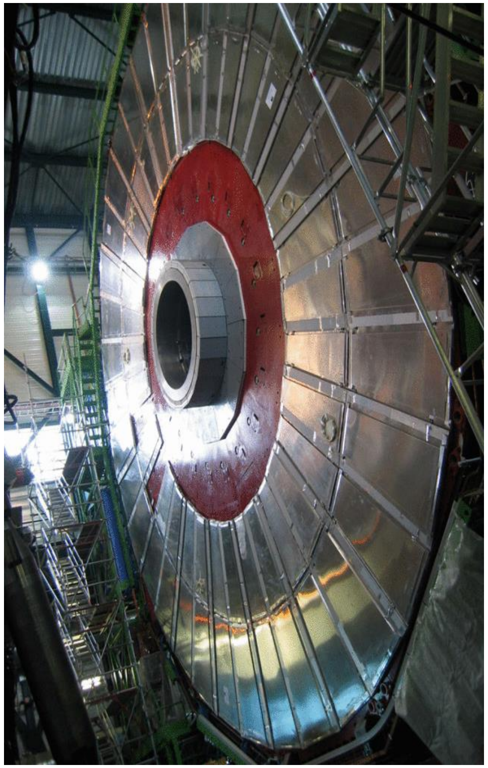
A PET detector is as complex as an HEP detector



Inorganic scintillators are widely used in PET imaging and medical imaging in general.

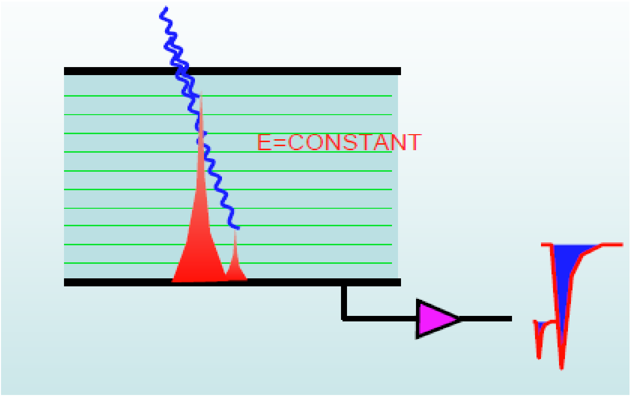
Gaseous detectors

Various type of detectors, GEMs, RPCs, MRPCs, MICROMEGA, traditional WIRE CHAMBERS and DRIFT TUBES



Large areas, extreme time resolution, extreme spatial resolutions, high rate capability

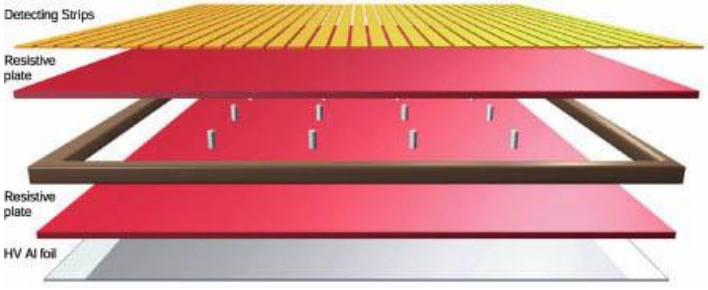
Gaseous detectors



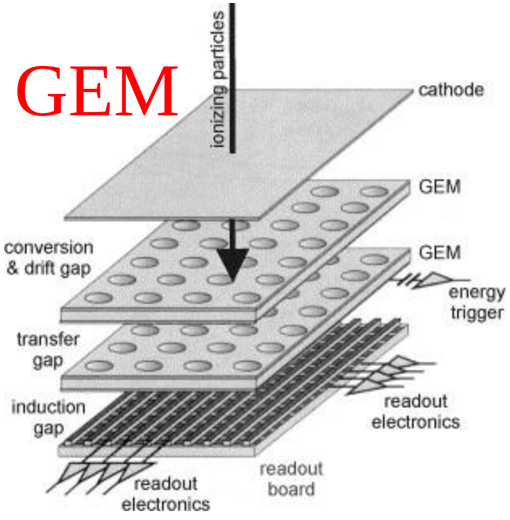
Use ionization in gas. Then collect the electrons on an appropriate electrode produces our signal. To drive the electrons towards the electrode, an electric field is needed

Mostly used as muon detectors

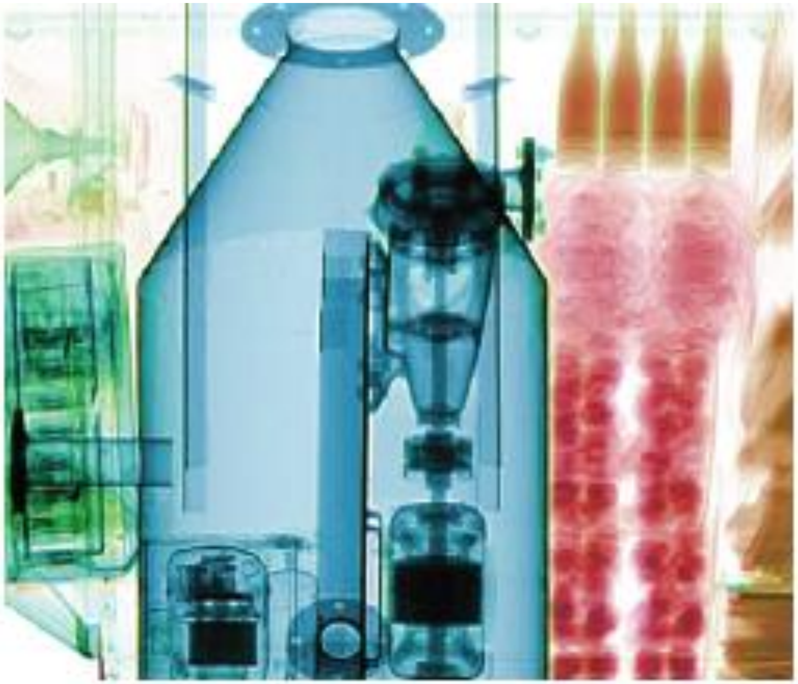
RPC



GEM



x rays screening with GEM



Large-area micro-pattern gaseous detectors with fast electronics can offer a unique opportunity for rapid air cargo scanning at affordable costs. Joint ventures with academia, industry and funding bodies to develop are in progress

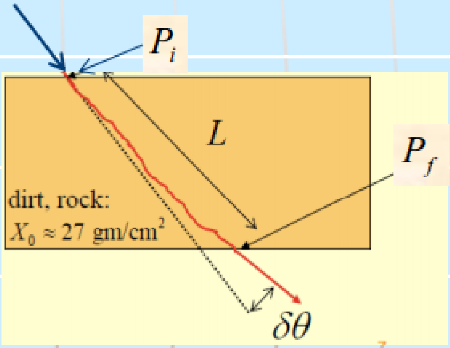
Muon Scattering

"Multiple Coulomb Scattering"

High energy muons undergo minimal scattering – travel in ~straight lines

$$\delta\theta \sim \frac{13.6MeV}{\sqrt{P_i P_f}}\sqrt{\frac{L}{X_0}}$$

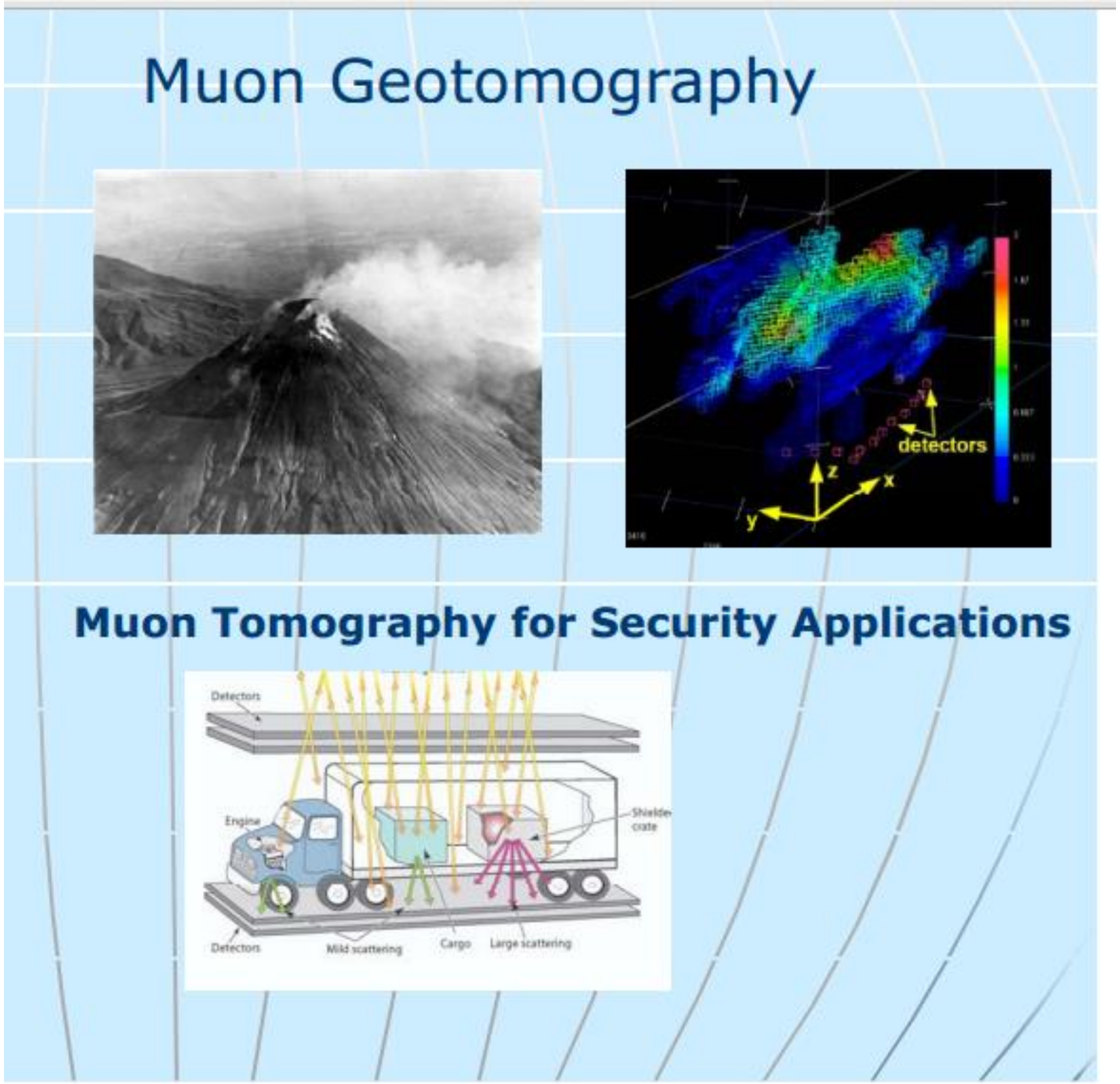
$$P_i - P_f = L\frac{dE}{dx}$$



Angular deviation for P> 300 GeV: δθ≤10 mrad;

10 mrad: **1 m at 100 m.**

Detecting particles



Large scale gaseous detector with high spatial resolution are needed

Image reconstruction can spot material of different density

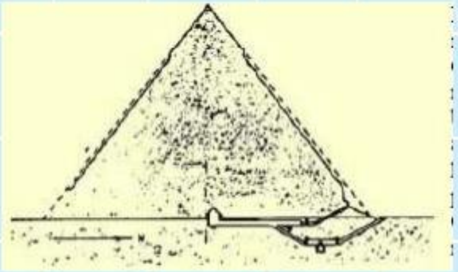
Reconstruction software is crucial

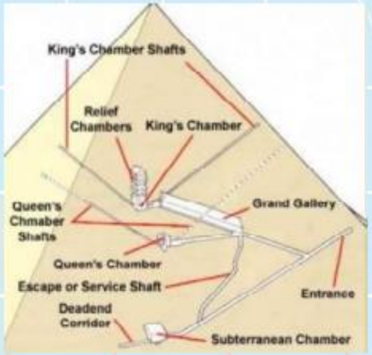
The concept is not new, but now we can profit of advanced instruments

Luis Alvarez
1965

Cosmic ray muons used to search for chambers at Giza.

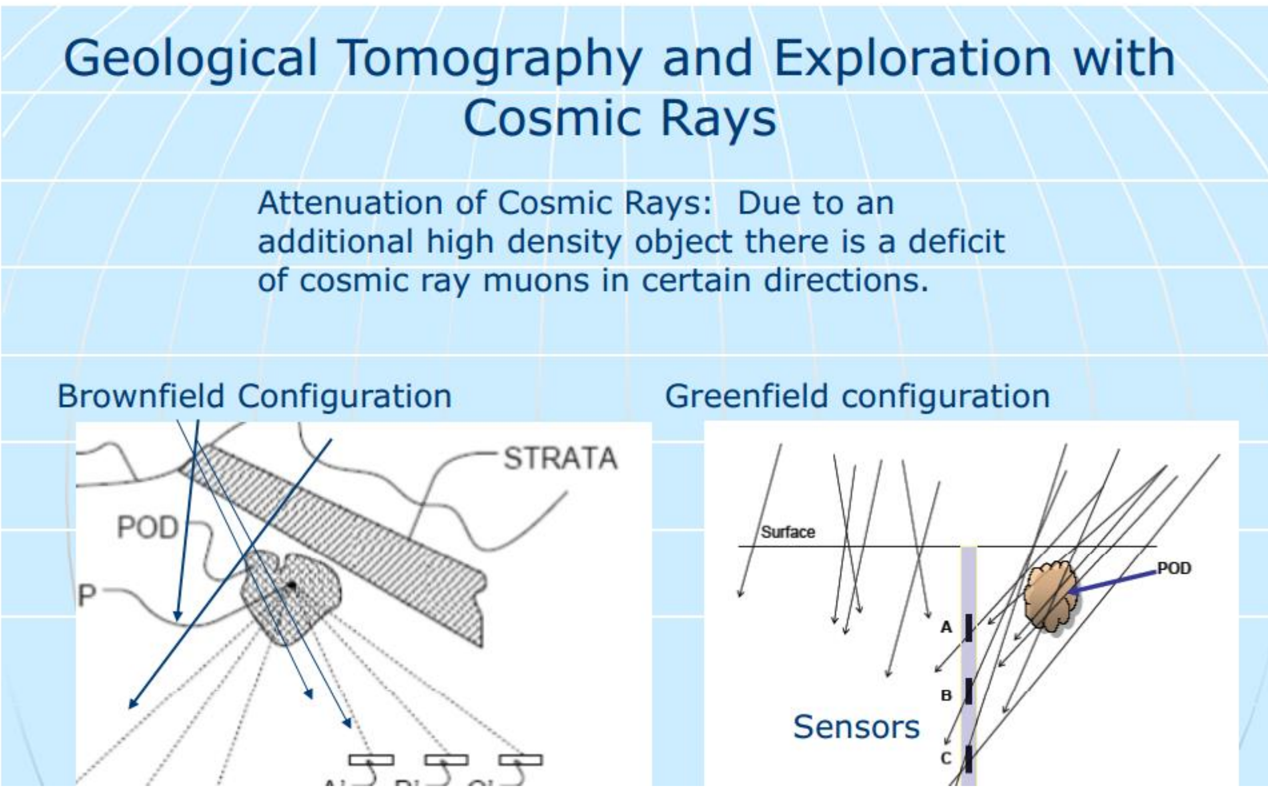
Khufu's Great Pyramid





L.W. Alvarez et al., Science 167 (1970) 832. Photo Source: www.touregypt.net/featurestories/secretchambers1.htm by Alan Winston

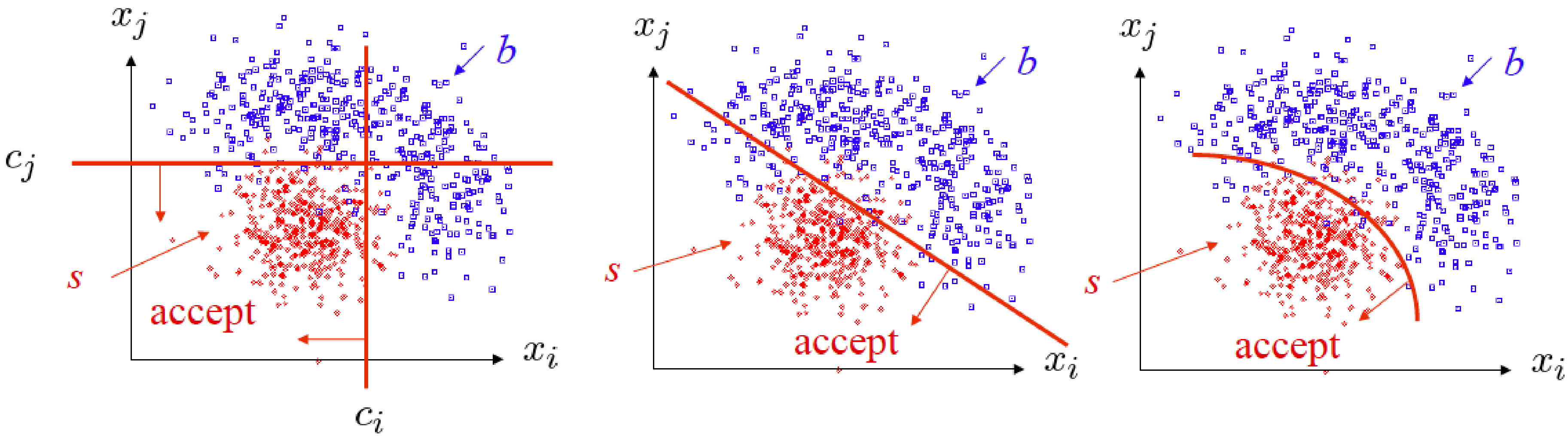
An interesting application is the determination of high density object in mines



Machine Learning in Particle Physics

In HEP experiments each event yields a collection of numbers $\vec{x} = (x_1, \ldots, x_n)$

which depends on the type of event produced, i.e., signal or background.



What kind of decision boundary best separates the two classes?

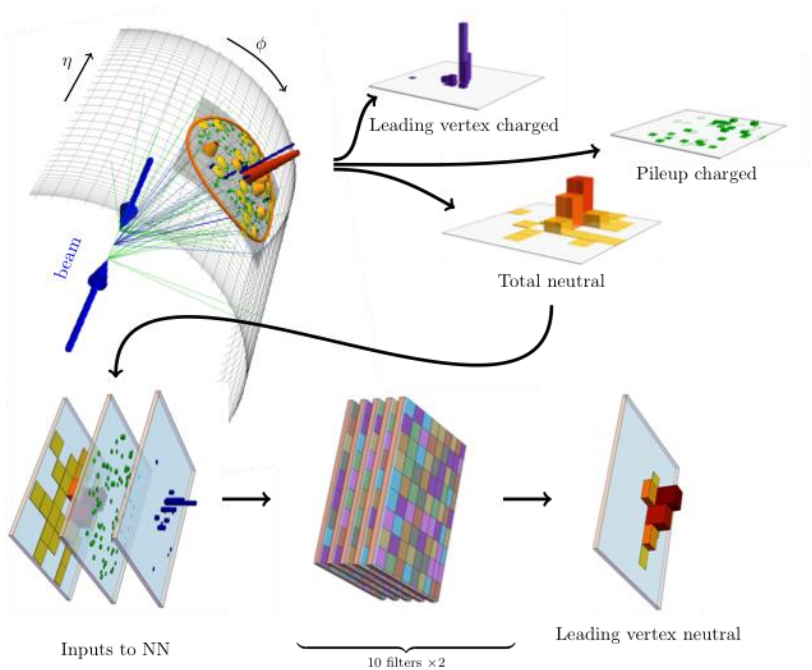
What is optimal test of hypothesis that event sample contain sonly background?

Machine Learning in Particle Physics

Machine learning has been used in particle physics for 30 years, mostly neural networks (NN) and more recently boosted decision trees (BDT). These methods were crucial for the following recent discoveries:

1. 2009 Discovery of single top quark production (D0, CDF)
2. 2012 Discovery of the Higgs boson (ATLAS, CMS)

The focus today is using lower-level data (calorimeter hits, tracks, etc.) to build more powerful classifiers. A recent example (Pileup Mitigation with Machine Learning, Metodiev, Komiske, Nachman, Schwarz, JHEP 12 (2017) 051) applies image classification to remove from jets the contribution of neutral particles that come from vertices other than the leading one, *i.e.*, to remove pileup.

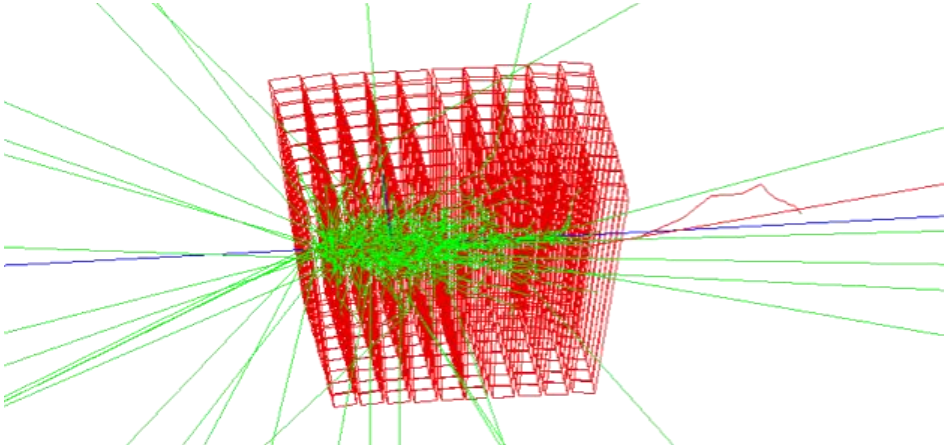


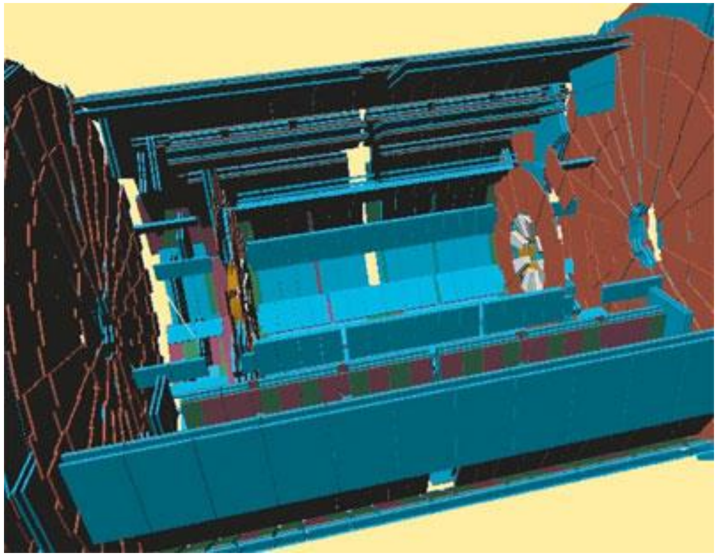
Machine Learning fields other then HEP

- Machine learning is preferred approach to
  - Speech recognition, Natural language processing
  - Computer vision
  - Medical outcomes analysis
  - Robot control
  - Computational biology
- This trend is accelerating
  - Improved machine learning algorithms
  - Improved data capture, networking, faster computers
  - Software too complex to write by hand
  - New sensors / IO devices

GEANT 4: The physics simulation toolkit

Geant4 is a toolkit developed at CERN for the simulation of the passage of particles through matter. The simulation reproduces in detail the detector geometry, the generation of events at the interaction point, the propagation of the resulting particles through the detector and the response of the detector to these particles. Detector response quantities are then used to construct candidate events which may analyzed as if they were real data.





GEANT 4: applications

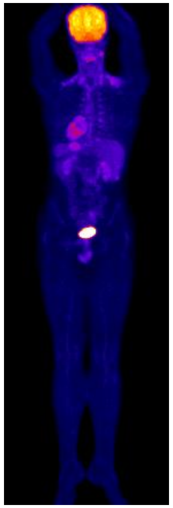
Because of its general purpose nature, Geant4 is well suited for development of computational tools for analyzing interactions of particle with matter in many areas:

Space applications where it is used to study interactions between the natural space radiation environment and space hardware or astronauts;

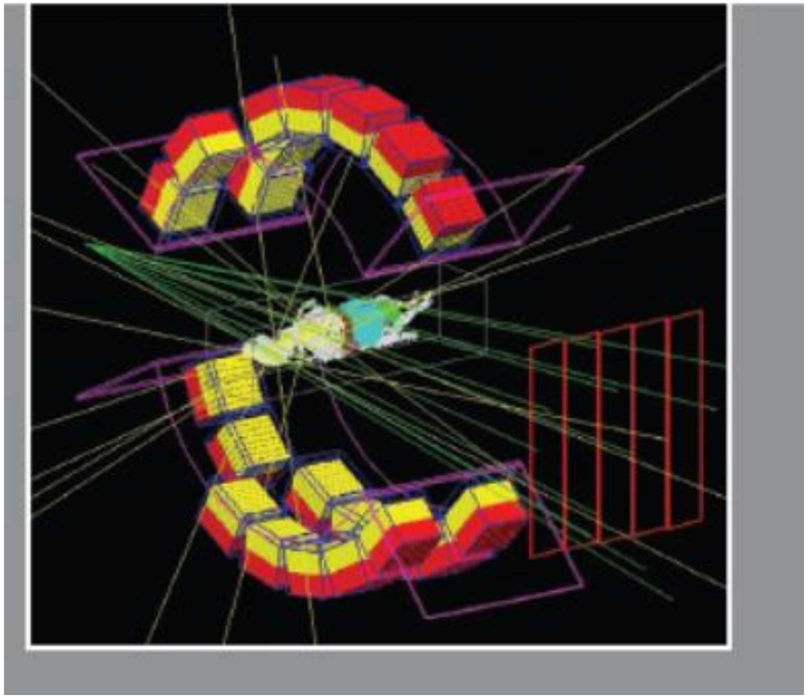
Medical applications where interactions of radiations used for treatment are simulated.

Nuclear physics where radiation effects in microelectronics semiconductor devices are modeled.

Simulations of Emission Tomography (Positron Emission Tomography – PET)



OpenGATE

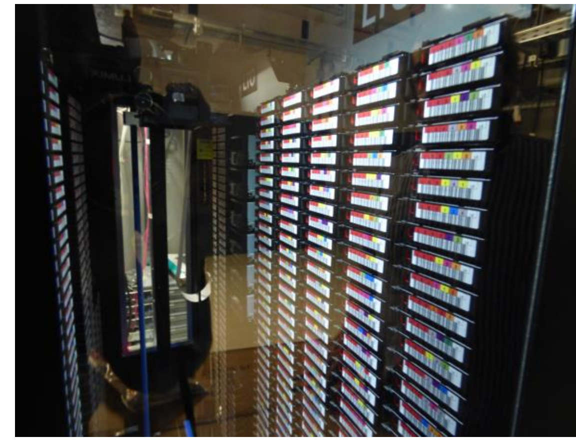


OpenGATE is an extension of GEANT4, and provides a complete environment for simulating the behaviour of the next generation of nuclear medicine scanners, which may be used in clinics or for the development of drugs.

The simulation platform incorporates the basis of nuclear physics, the electronic response of the scanners, and various image reconstruction algorithms.

ReCaS BARI

The Bari ReCaS DataCenter originally was set up in 2009 to support scientific computing needs of the ALICE and CMS experiments running at the Large Hadron Collider (LHC) at CERN in Geneva.



Some of non HEP projects

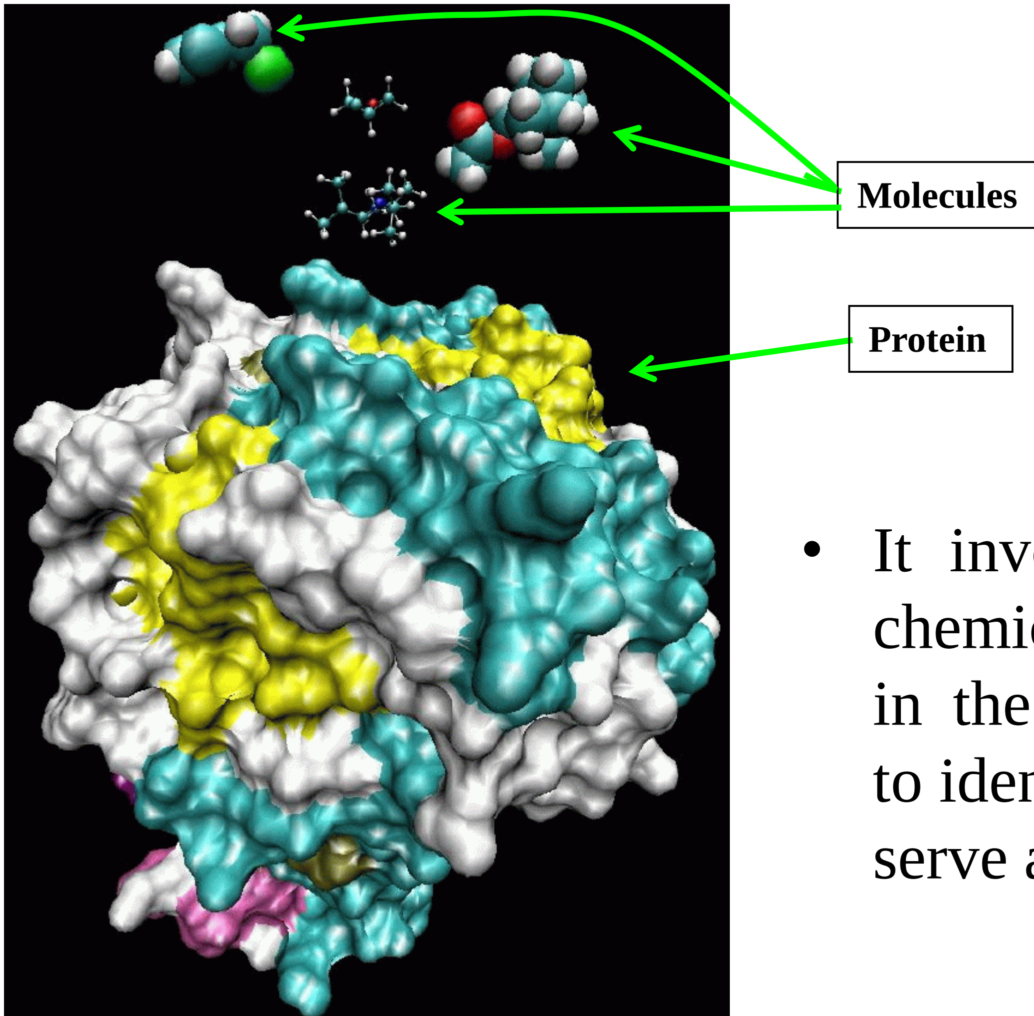
PERSON
PERvasive game for perSOnalized treatment of cognitive and functional deficits associated with chronic and Neurodegenerative diseases

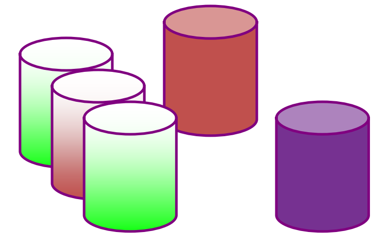
ENPADASI
European Nutritional Phenotype Assessment and Data Sharing Initiative

OCP
OPEN CITY PLATFORM

PRISMA
PIATTAFORME CLOUD INTEROPERABILI PER SMART-GOVERNMENT

Drug Design: Data Intensive Computing on Grid





Chemical Databases
(legacy, in .MOL2 format)

- It involves screening millions of chemical compounds (molecules) in the Chemical DataBase (CDB) to identify those having potential to serve as drug candidates.

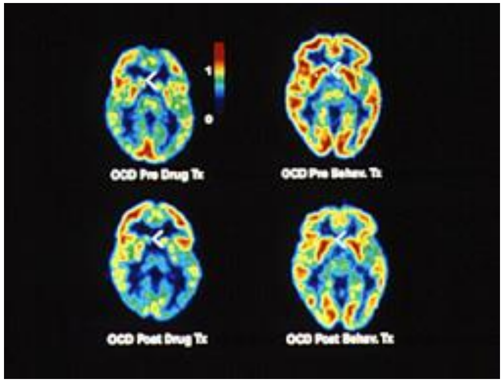
Computing

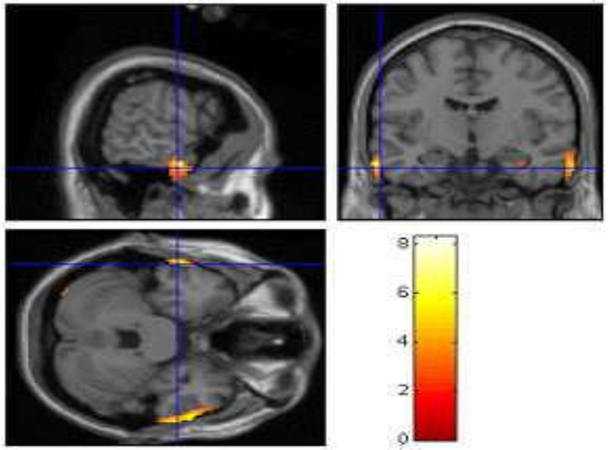
Distributed Data (Image) Analysis

- Patient history (query to the MetaData Catalogue)
- Exam Comparison (download the previous exam(s))
- Comparison with reference data base

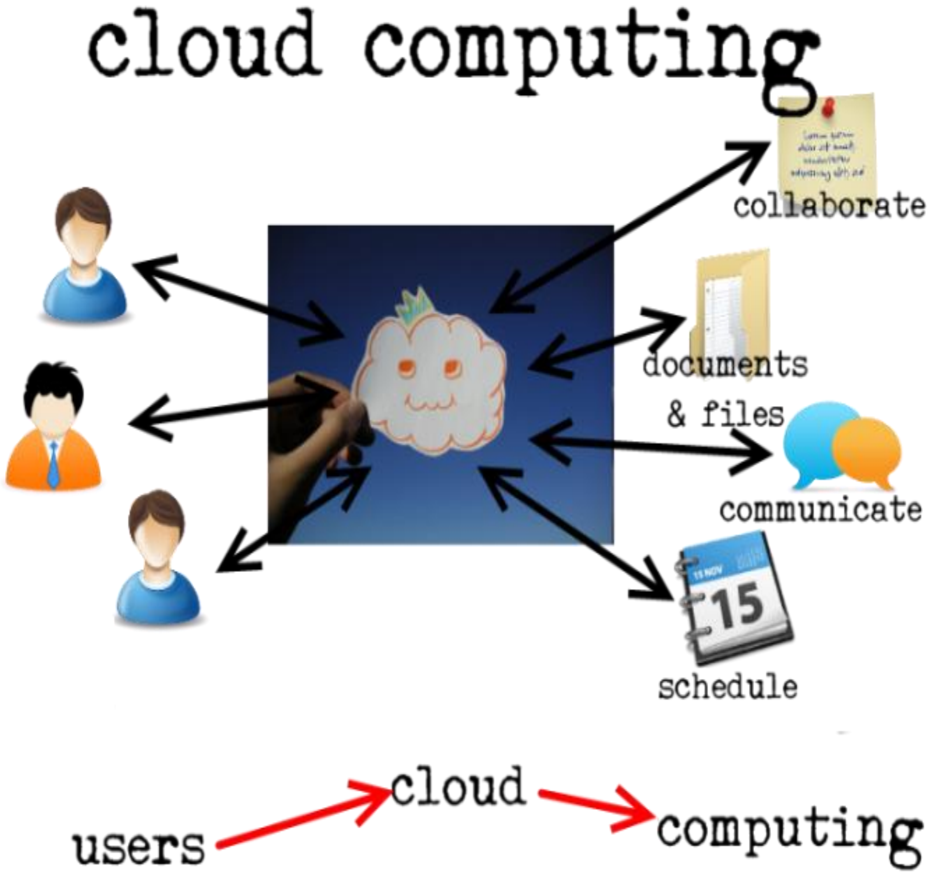
Analysis Station

Statistical analysis data base





Computing



Cloud computing is now developing fast in every day life: your smartphone, notebook and tablet are interconnected and exchange information through a database server

Conclusion

Large impact of HEP projects on technologies development

Pushing industrial capabilities and developing new production protocols

Important impact for everyday life (medical diagnostic, sustainable energy, parallel computing)

Role of CERN (and other funding agency) is crucial