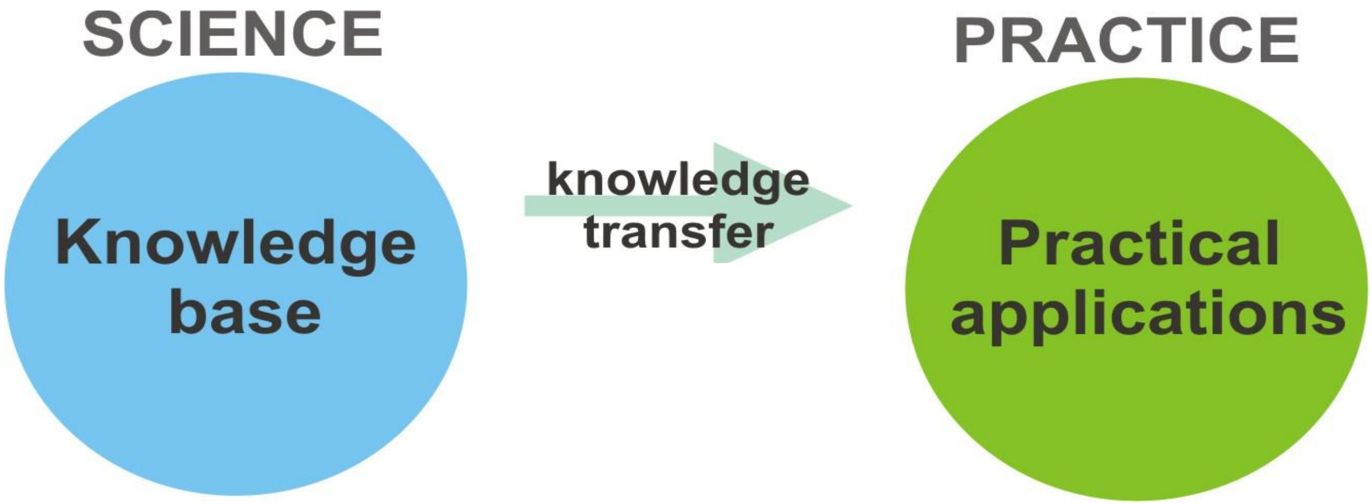
HEP technologies and transfer to industry

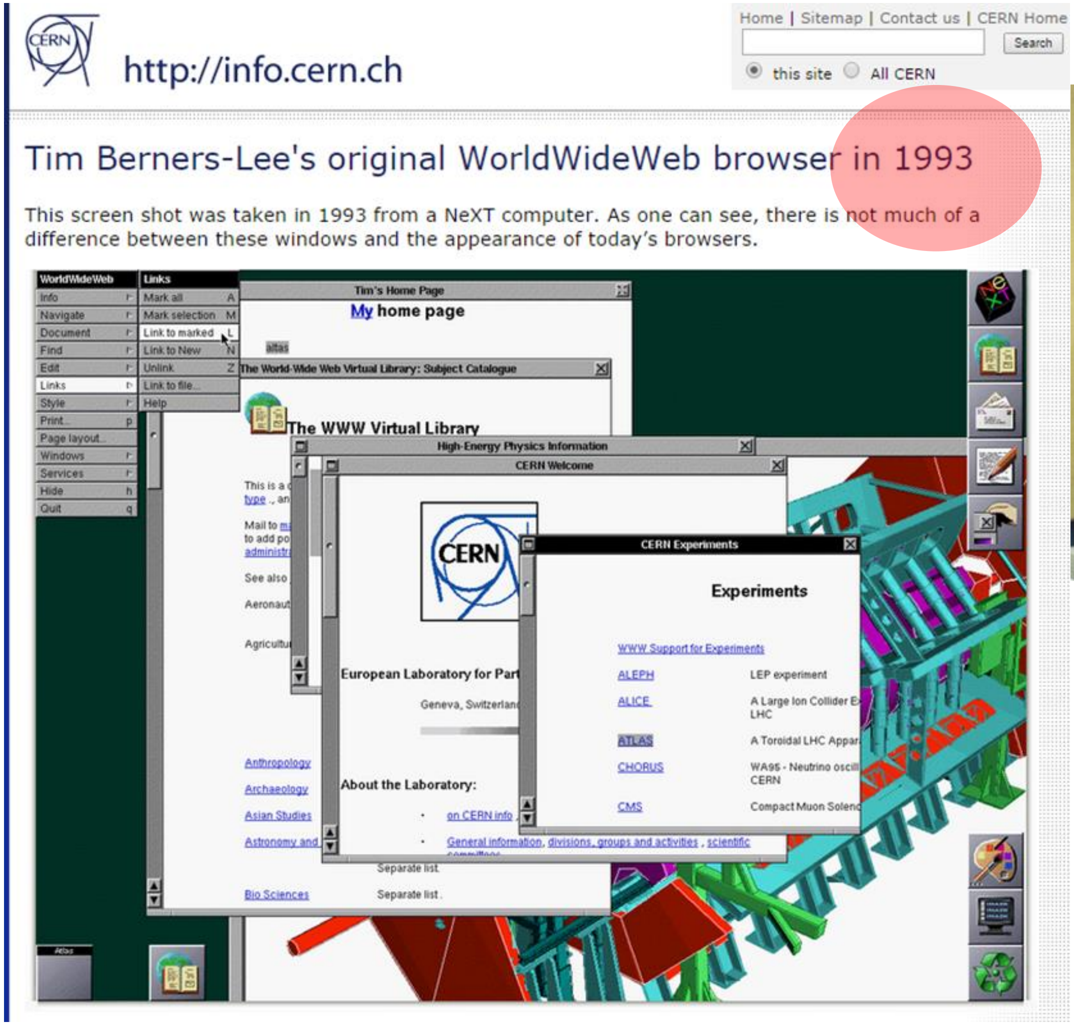


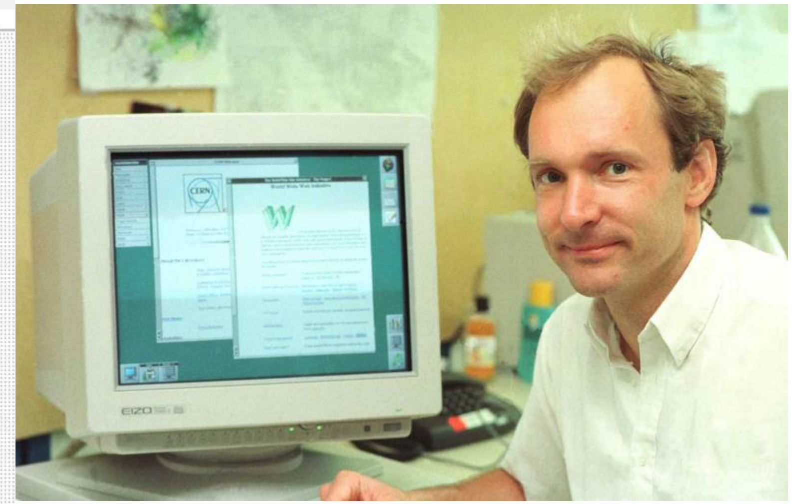
Physics underpins so much of modern life

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

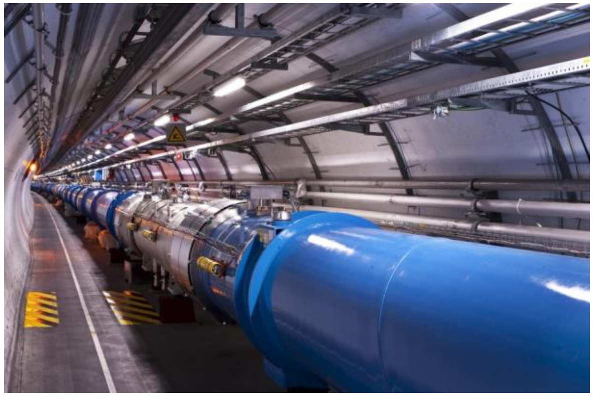




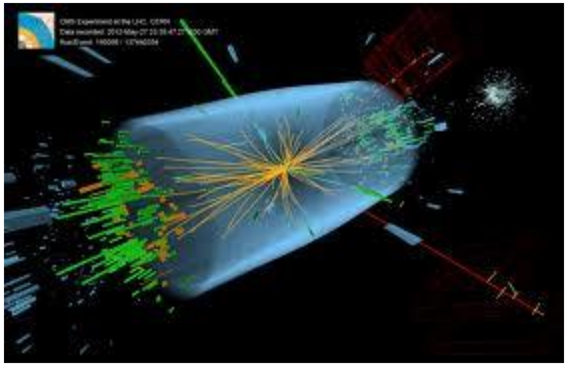
Tim Berners Lee with his NeXT computer that he used to invent the World Wide Web

HEP technologies

Accelerating particle beams



Detecting particles



Large scale computing (Grid)

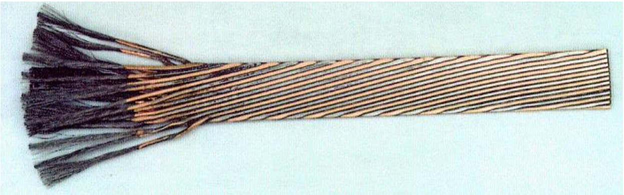
LARGE HADRON COLLIDETR

1232 Main Dipoles + 448 Main Quadrupoles cooled by 120 Tons of Liquid Helium

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**

Super conducting Niobium-Titanium cable.
Typical 2000 A/mm^2 @ 4.2 K @ 6T

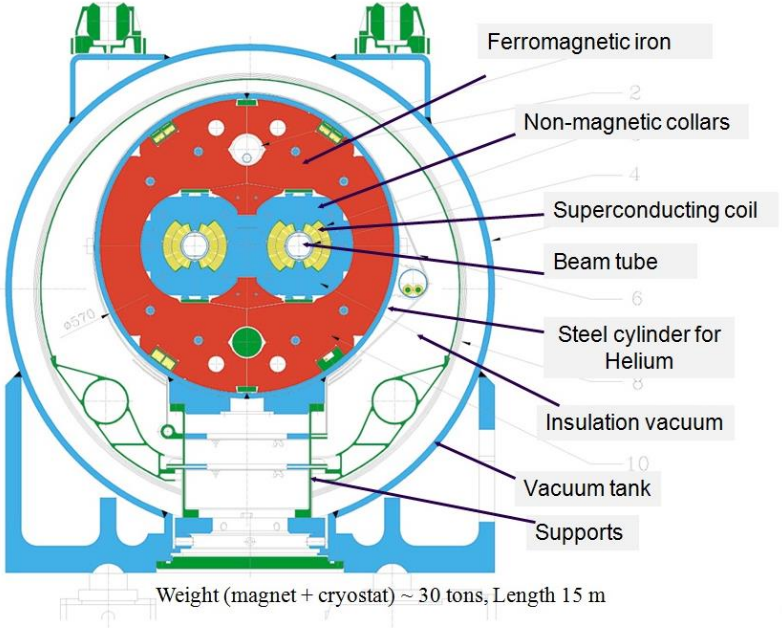


Vacuum
(10^{-13} atm)

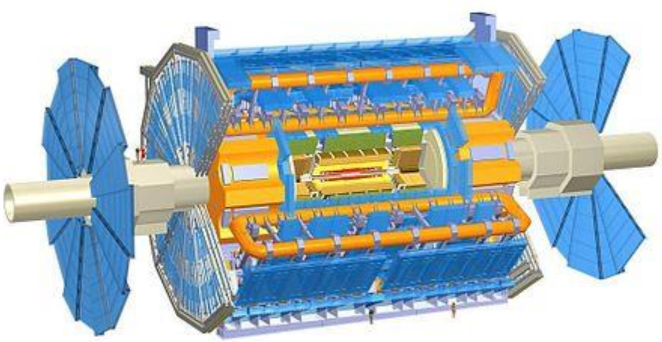
Cryogenics
(1.9 K)

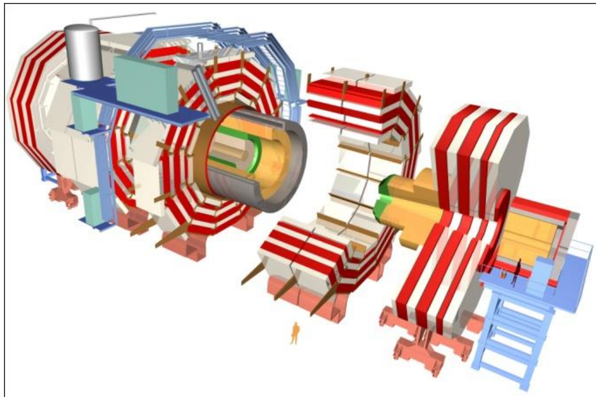
Superconductivity
(12kA)

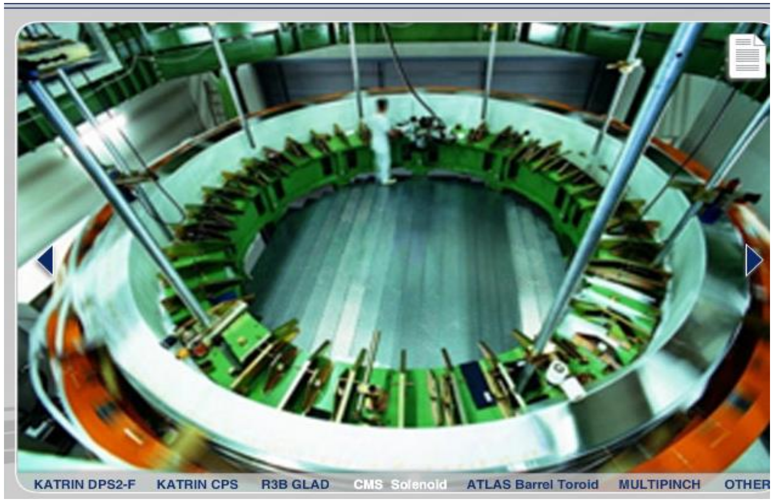
Magnets
(8 T)



The CMS solenoid and the ATLAS toroid have been designed by physicist but the prototyping and the construction was completed at external enterprises





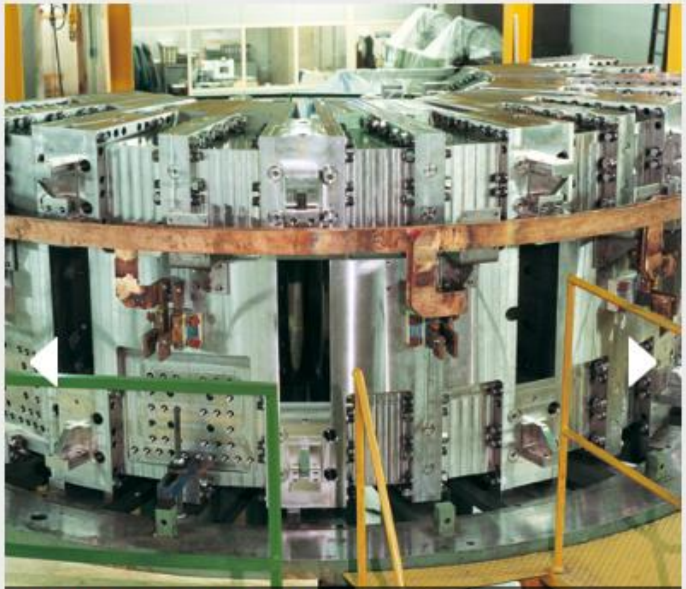


Transfer to industry: ANSALDO

Magnets for nuclear fusion

The production of clean energy through nuclear fusion, which reconciles the energy needs of the modern world while safeguarding the environment, is a challenge that researchers and industries have been striving to meet.

The quality of ASG's nuclear fusion offering is the result of unequalled technical and productive expertise. ASG magnets have been used in all the main fusion experiments undertaken so far in Europe. ASG plays a leading role - as a supplier of magnets - in ITER (Europe) and JT-60SA (Japan), the two principal research projects which aim to study the feasibility of producing clean energy by replicating the process that takes place in the sun and stars.

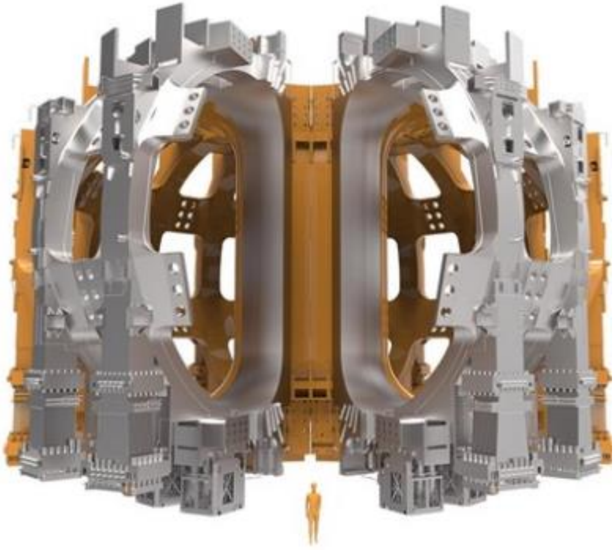


FTU Toroidal coils modules assembly

For nuclear fusion ASG produces:

- superconducting and resistive toroidal coils
- superconducting and resistive poloidal coils
- coils for divertors
- Central SC and resistive solenoid coils
- ELM coils
- Stellarator coils
- Gyrotron system coils.

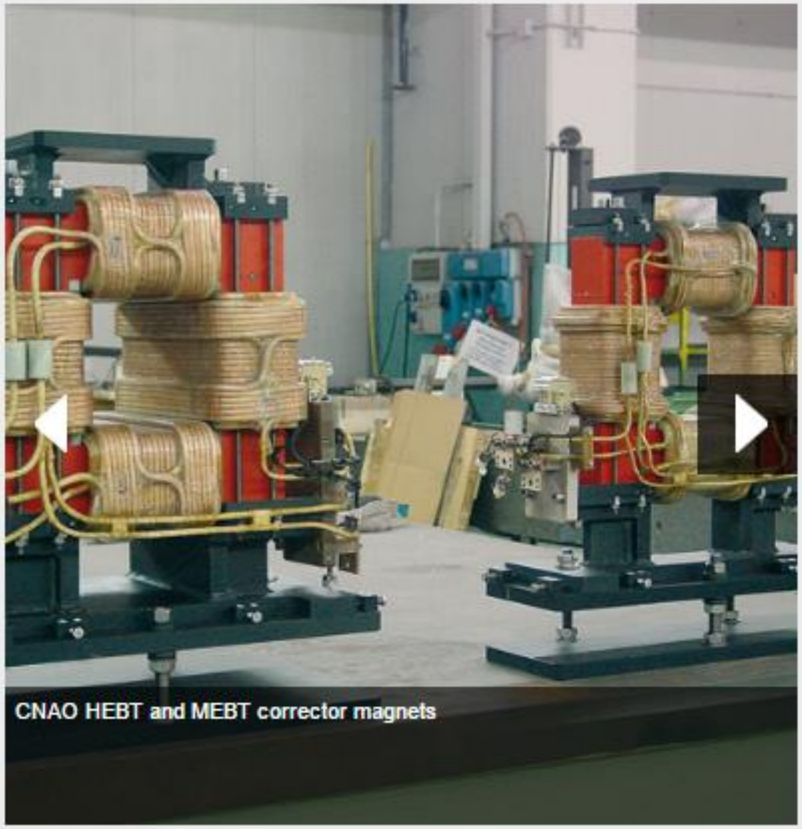
The ITER magnet



Eighteen "D"-shaped toroidal field magnets placed around the vacuum vessel produce a magnetic field whose primary function is to confine the plasma particles. The toroidal field coils are designed to produce a total magnetic energy of 41 gigajoules and a maximum magnetic field of 11.8 tesla. Weighing 310 tonnes each, and measuring 9 x 17 m, they are among the largest components of the ITER machine.

Transfer to industry: ANSALDO

Magnets for medical applications



Superconducting technologies and magnets are increasingly finding application in medical diagnostics and therapies.

Over the past 10 years, ASG has invested and created true innovation through its subsidiaries Columbus Superconductors and Paramed Medical Systems. Columbus produces an innovative superconducting "high temperature" cable using the peculiar characteristics of magnesium diboride (MgB_2), while Paramed operates in the healthcare sector for which it has realized an open, cryogen-free magnetic resonance system that reduces patients' sense of claustrophobia and allows for "load bearing "diagnostic analysis of patients.

Superconducting magnets are also used in hadron therapy and proton therapy for the treatment of numerous types of tumor. ASG supplied its magnets to the synchrotron at Pavia's CNAO as well as to the first of a series of synchro-cyclotron machines for IBA.

Capitalizing on skills and experiences derived from industrial collaborations, ASG is able to design and build the following types of magnets for medical diagnostics:

From high vacuum …

NEG (Non-Evaporable Getter thin film coatings) technology used to create and maintain ultra-high vacuum in the accelerator vacuum chambers.

to solar energy

Using this vacuum technology, CERN has developed an evacuable flat solar panel that collects direct and diffused sunlight at temperatures as high as 350^{o}C, even at latitudes above the 45th parallel.

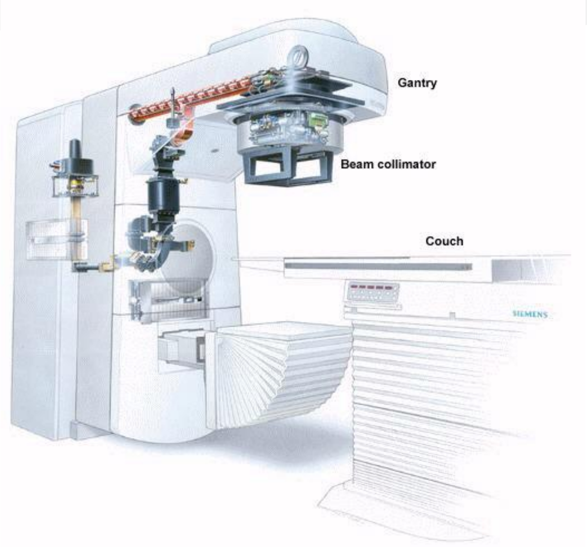
The industrial market for accelerator in 2010

Application	Total systems	Systems sold/year	Sales/year (€ million)	System price (€ million)
Cancer therapy	9,100	500	1,800	2.0 - 5.0
Ion implantation	9,500	500	1,400	1.5 - 2.5
e^- welding & cutting	4,500	100	150	0.5 - 2.5
e^- and X-ray irradiators	2,000	75	130	0.2 - 8.0
Radioisotopes	550	50	70	1.0 - 30
Non-destructive testing	650	100	70	0.3 - 2.0
Ion analysis	200	25	30	0.4 - 1.5
Neutron generators	1,000	50	30	0.1 - 3.0
Total	**27,000**	**1,400**	**3,680**	

There are many medical application of accelerators

Basic type of accelerators

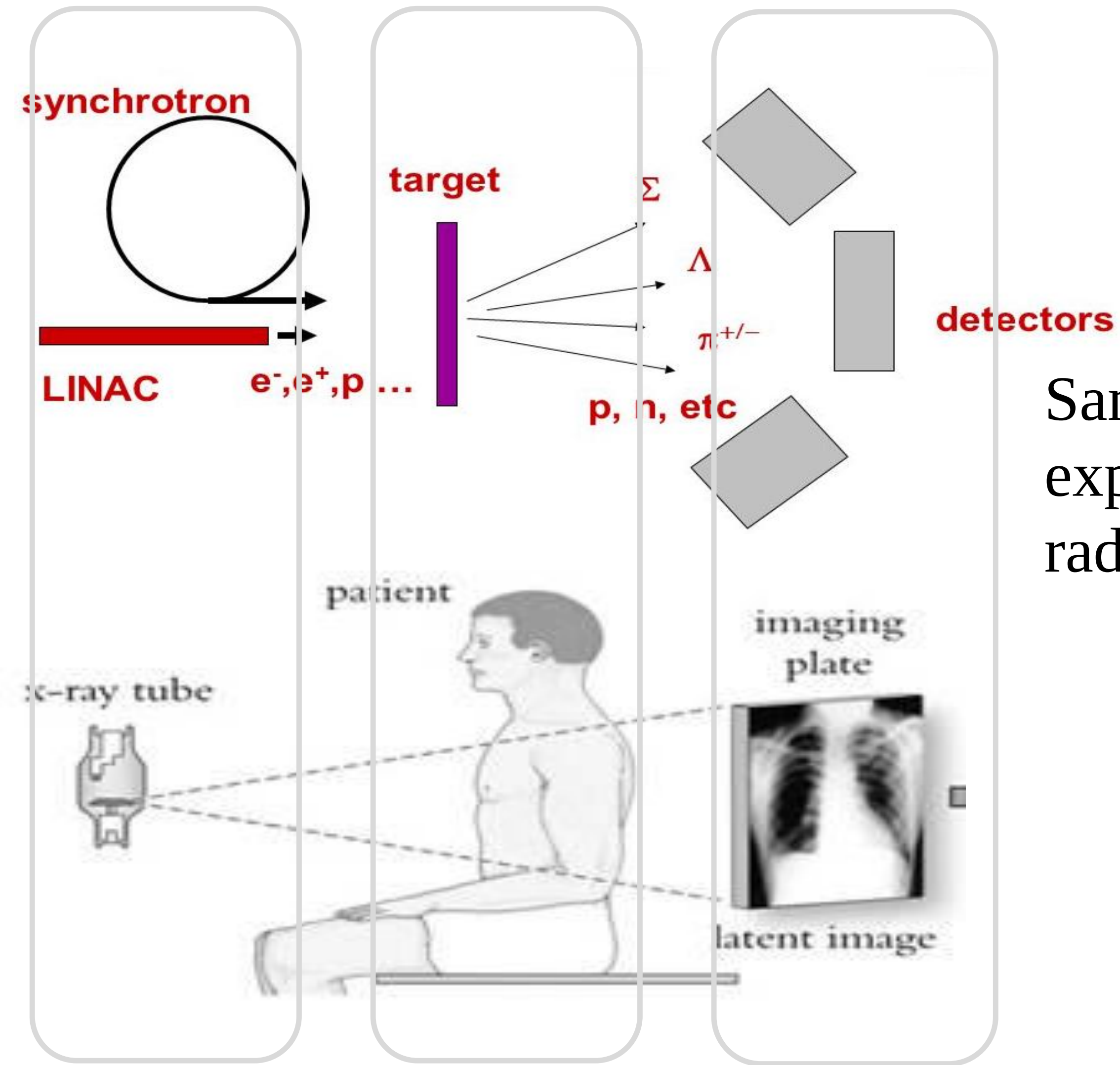
- Linear
- Cyclotron
- Betatron
- Synchrotron



Common medical application

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

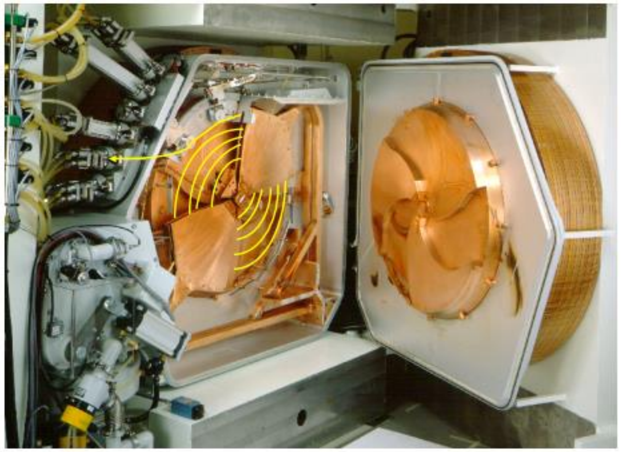
Future Application
- Angiography
- Boron neutron Capture Therapy



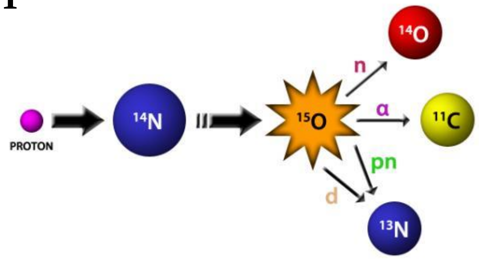
Same concept for an HEP experiment and a radiological investigation

Producing radioisotopes for medical treatments

1. Inserting target in a nuclear reactor - fine for longer-lived isotopes as some time is needed for processing and shipment
2. Using a charged-particle accelerator called a 'cyclotron' - needed locally for short-lived isotopes ($T_{1/2} \sim 1$ to 100 min).

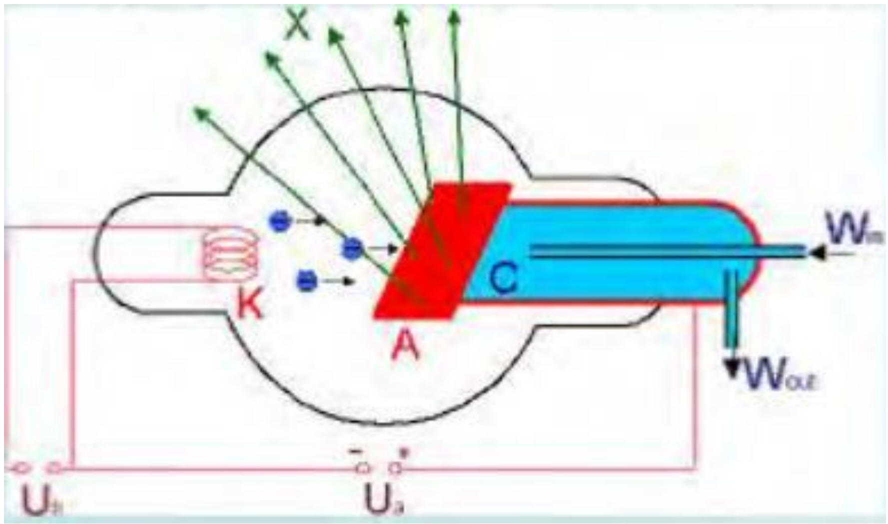


Cyclotrons for production of radio pharmaceutics substances are now quite common

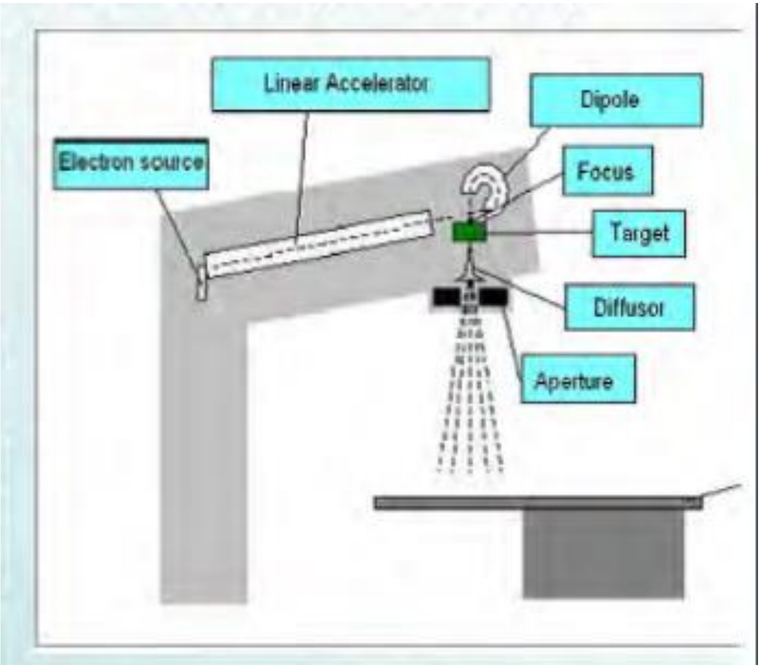


Linear accelerators (LINAC) for radiotherapy

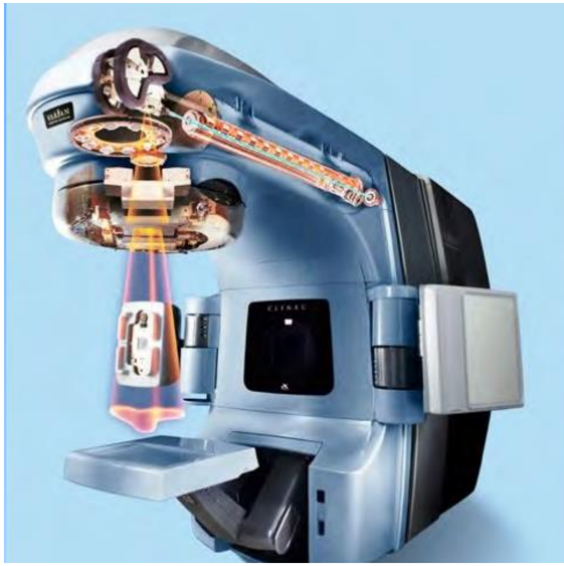
Schematics of an X ray tube for an electrostatic accelerator

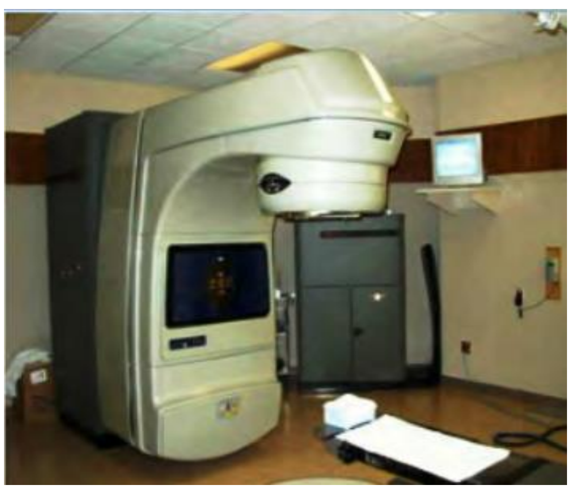


Modern LINAC concept



LINAC

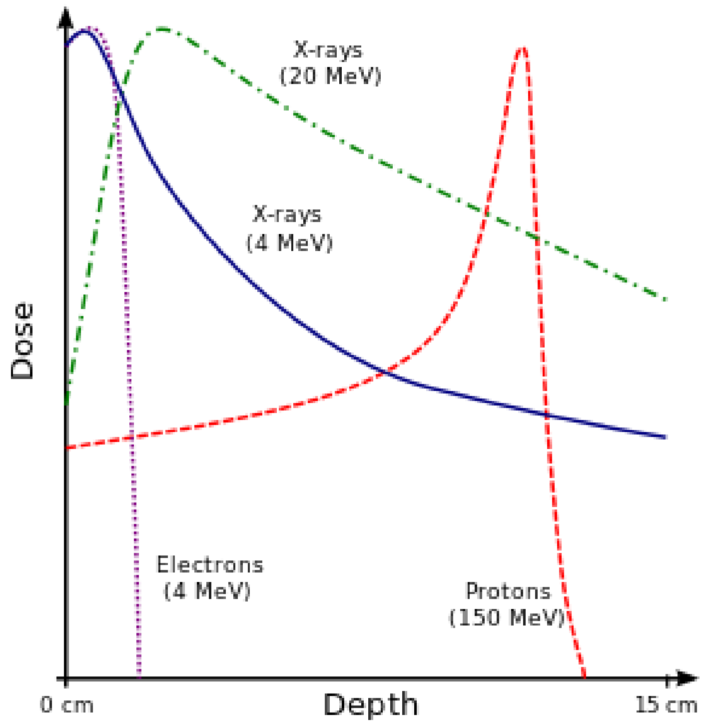




LINAC uses microwave technology to accelerate electrons in a part of the LINAC called waveguide, then allows these electrons to collide with a heavy metal target. As a result of these collisions, high energy X-Rays (Photons) are produced from the target.

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).

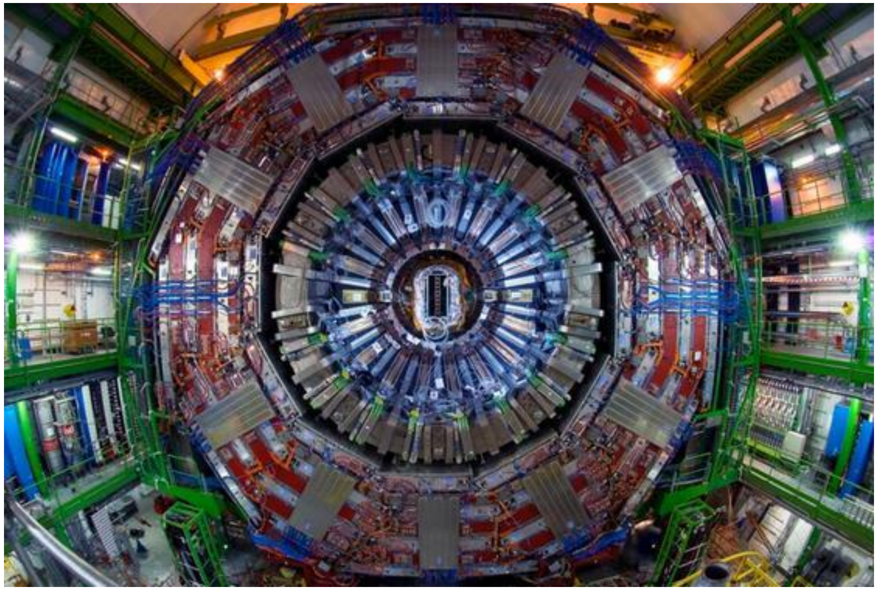


Hadron therapy

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

CERN, GSI (Germany), TERA (Italy), Med-Austron (Austria) and Oncology 2000 (Czech Rep.) all contributed to the conceptual. Five more are under construction in France, Germany, Austria and Sweden.

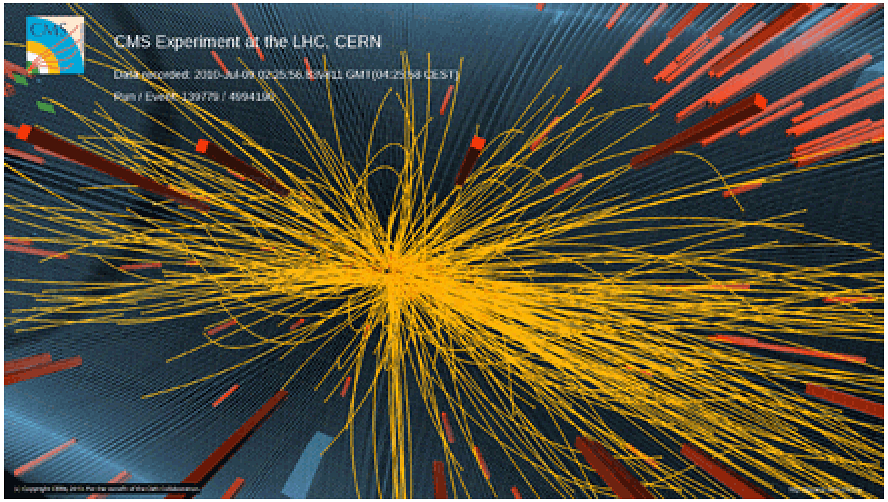
Detector technologies



Detect 600 million proton-proton collisions per second

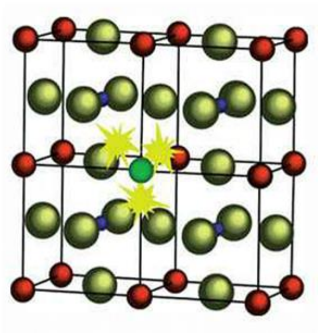
Sophisticated detectors to precisely measure the passage of a particle with time accuracies of 10^{-9} second and space accuracy of 10^{-5} meter.

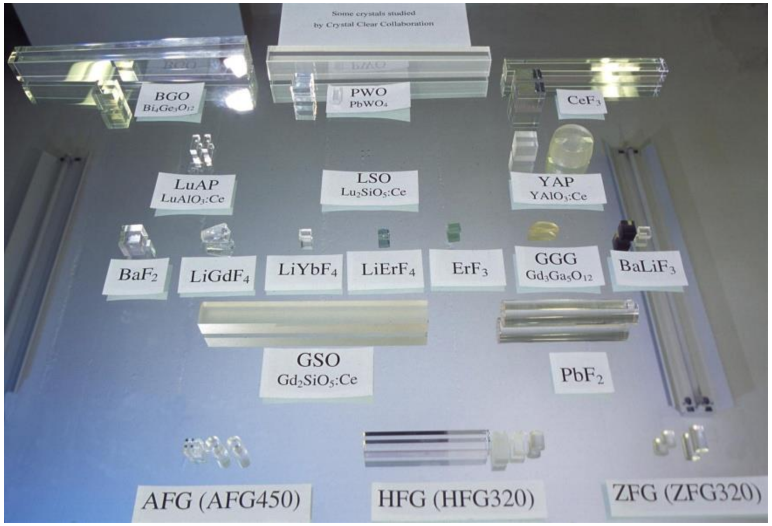
- Crystal
- Gaseous detectors
- Silicon detectors

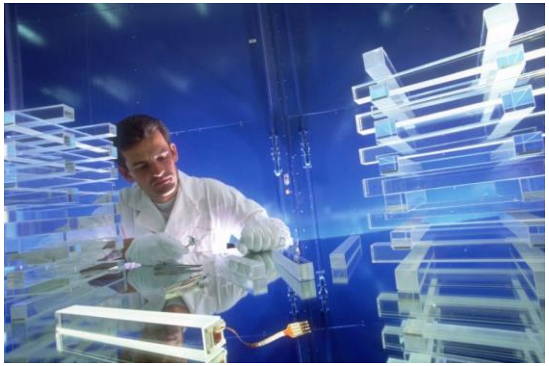


Crystal detectors

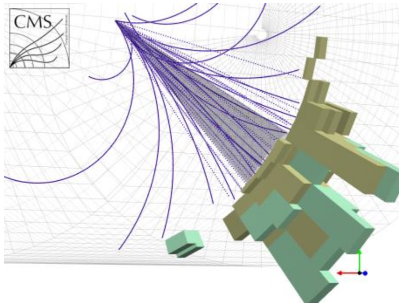
Scintillators are applied in high-energy physics to measure the energy of particles that are produced in particle physics experiments. Their use is motivated by the very good detection efficiency of these materials for hard radiation



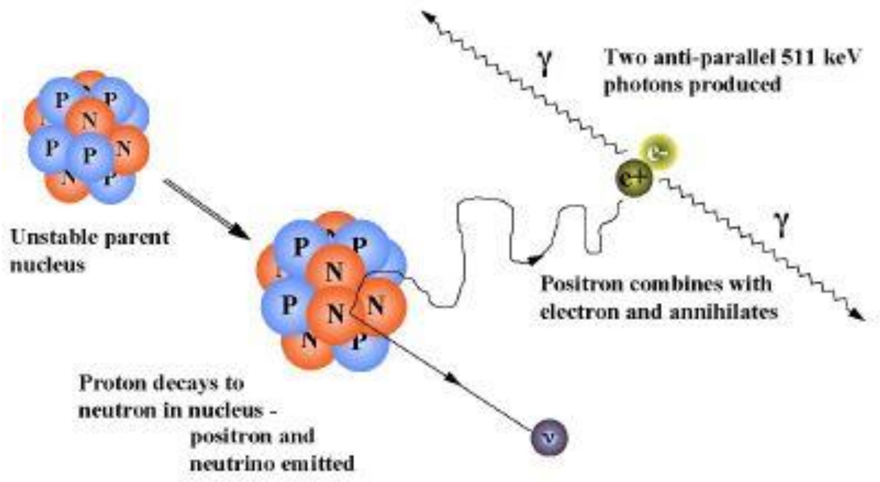


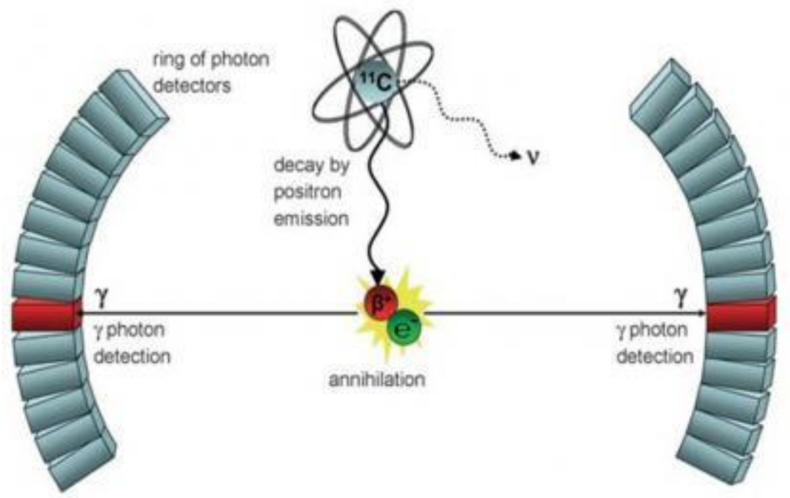


The CMS electromagnetic calorimeter uses lead tungstate (PbWO4) for the almost 80,000 crystals: a material with high density that produces scintillation light in fast, small, well-defined photon showers.



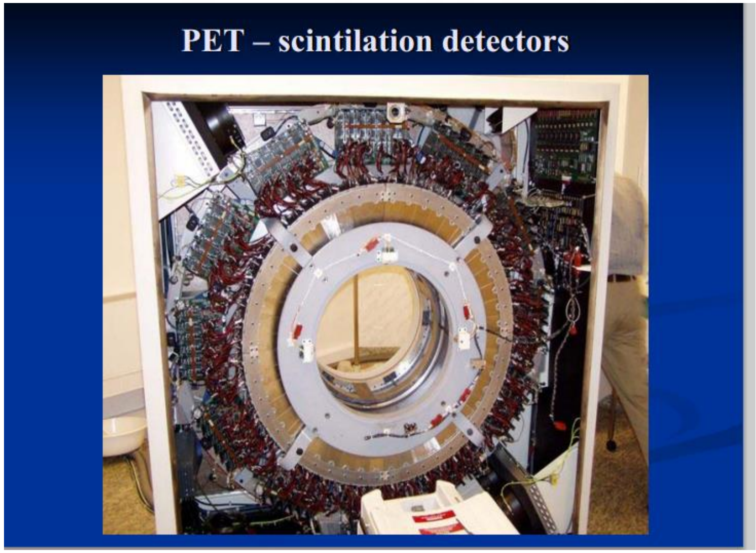
The PET concept





A PET detector is as complex as an HEP detector

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



Polycrystalline Diamond

Developed for Beam Condition Monitoring

Radiation Hardness

High sensitivity

Good spatial and temporal resolution

Low (and stable) noise

Can fabricate robust, compact devices

High temperature operation

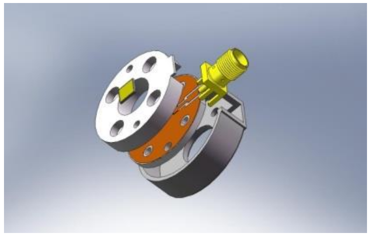
Single particle counting
ATLAS @ CERN

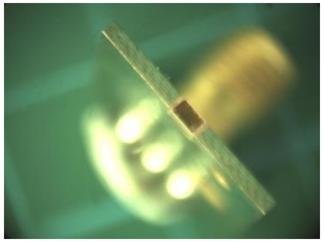
Particle flux measurement
Babar @ Stanford
Belle @ KEK
CDF @ Fermilab

A wide range of detector 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

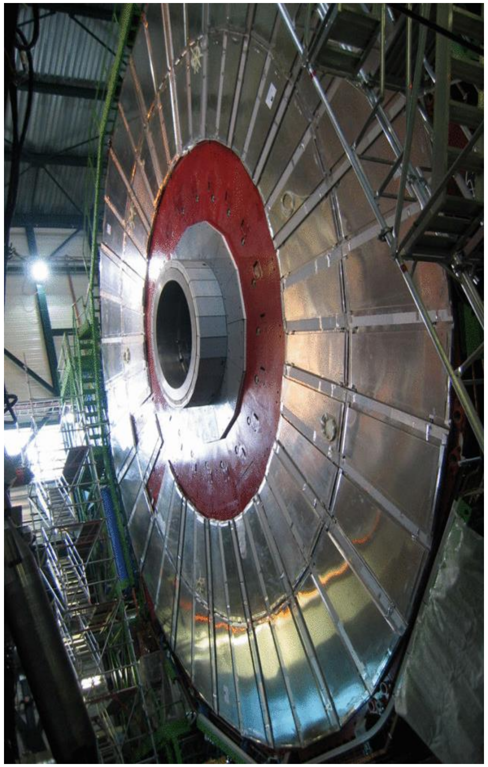
DIAMOND DETECTORS LIMITED





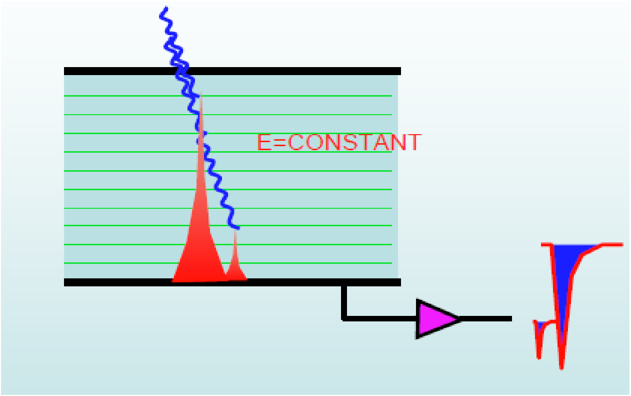
Gaseous detectors

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

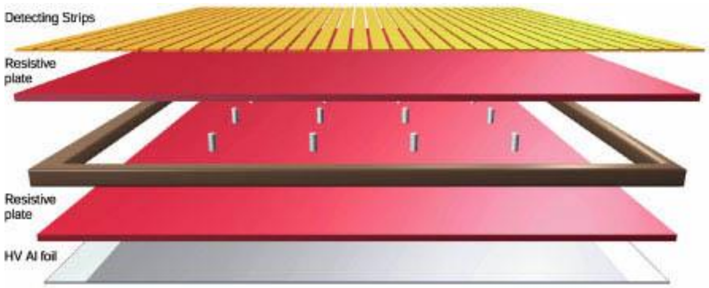
Gaseous detectors



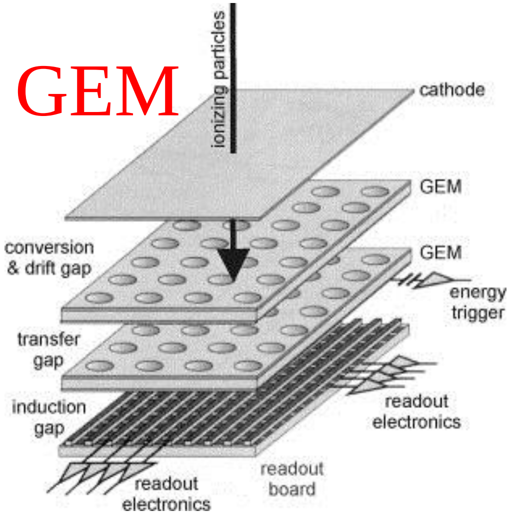
Use ionization in gas. Then collect the electrons on an appropriate electrode and produces a signal. To drive the electrons towards the electrode, an electric field is needed

Mostly used as muon detectors

RPC



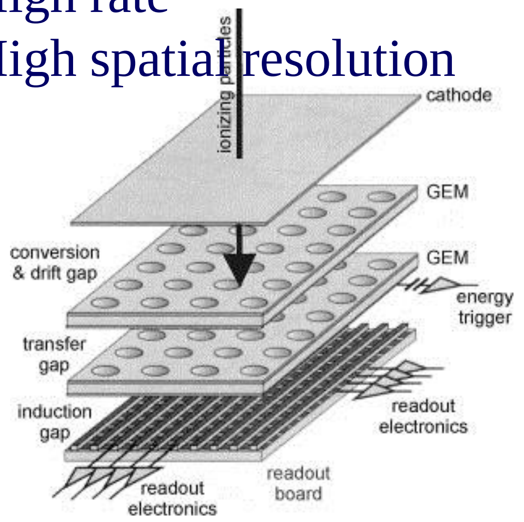
GEM

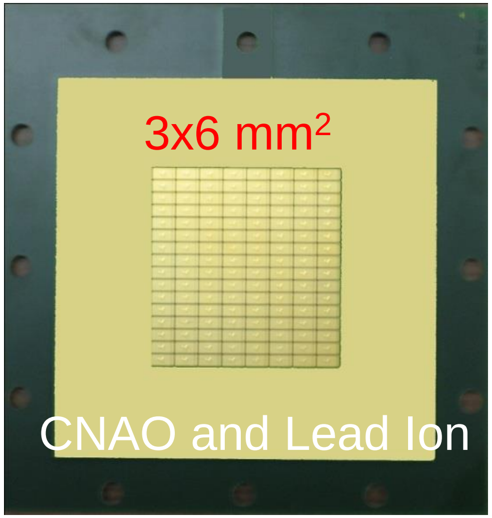


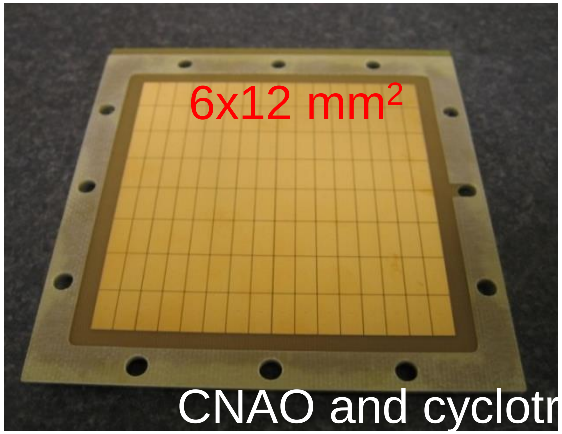
GEM

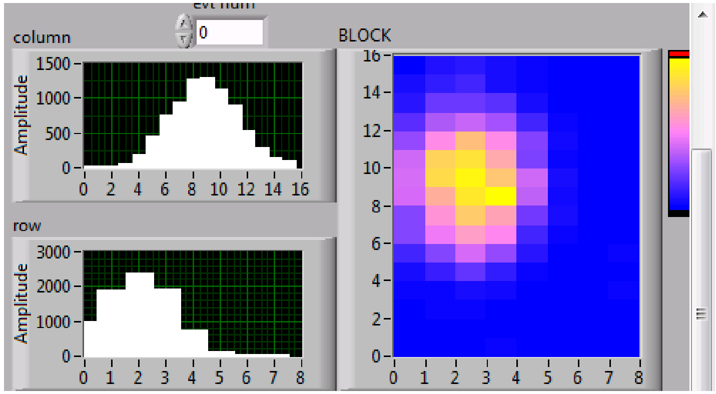
High rate

High spatial resolution





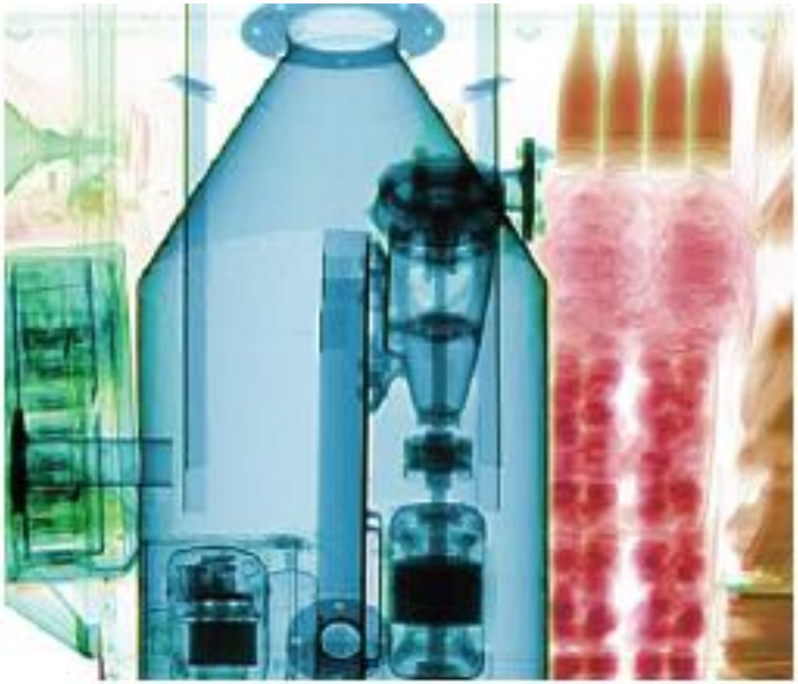




Monitor for a fast neutron beam with energies ranging from a few meV to 800 MeV. Tested at neutron beam of the Vesuvio facility at RAL-ISIS.

Courtesy of F. Murtas, INFN LNF

GEM

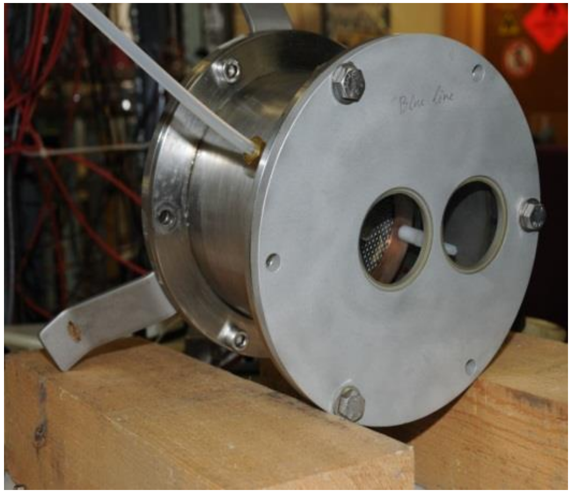


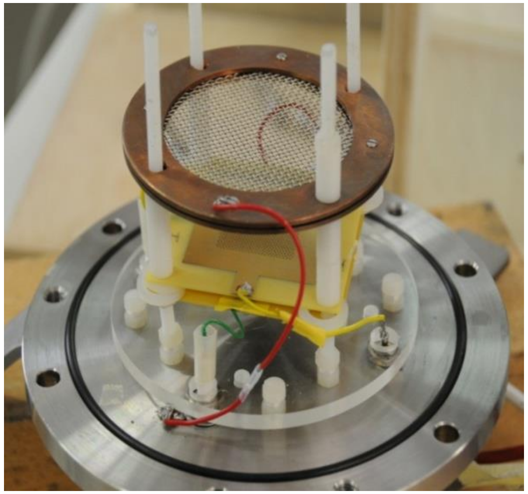
Air cargo screening

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

Smoke detectors (CERN development)

Wire and GEM-based gaseous detectors operate in proportional mode and can detect various flames, including sparks, in direct sunlight conditions. Combined with compact pulse UV sources they can detect simultaneously not only flames, but also smoke and some dangerous gases, for example benzene or toluene vapours. GEM-based detectors supplied with a lens can also provide information on the position of the flame and smoke.





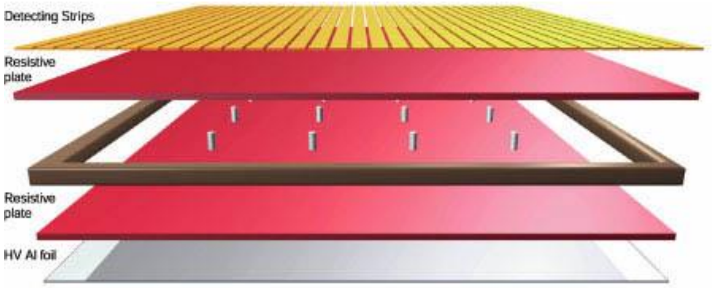
Material analysis (CERN Development)

Partnership and license agreements with a company to build a X-ray diffractometer

X-ray powder diffraction is one of the simplest and most widespread crystallographic techniques
it is possible to evaluate lattice parameters and to estimate internal stress and strain; using the peak shapes, it is possible to examine the sample microstructure.

RPC

High time resolution
High spatial resolution
Large scale



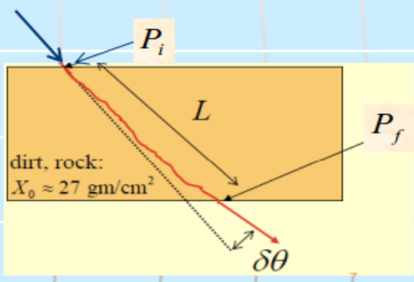
Muon Scattering

"Multiple Coulomb Scattering"

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

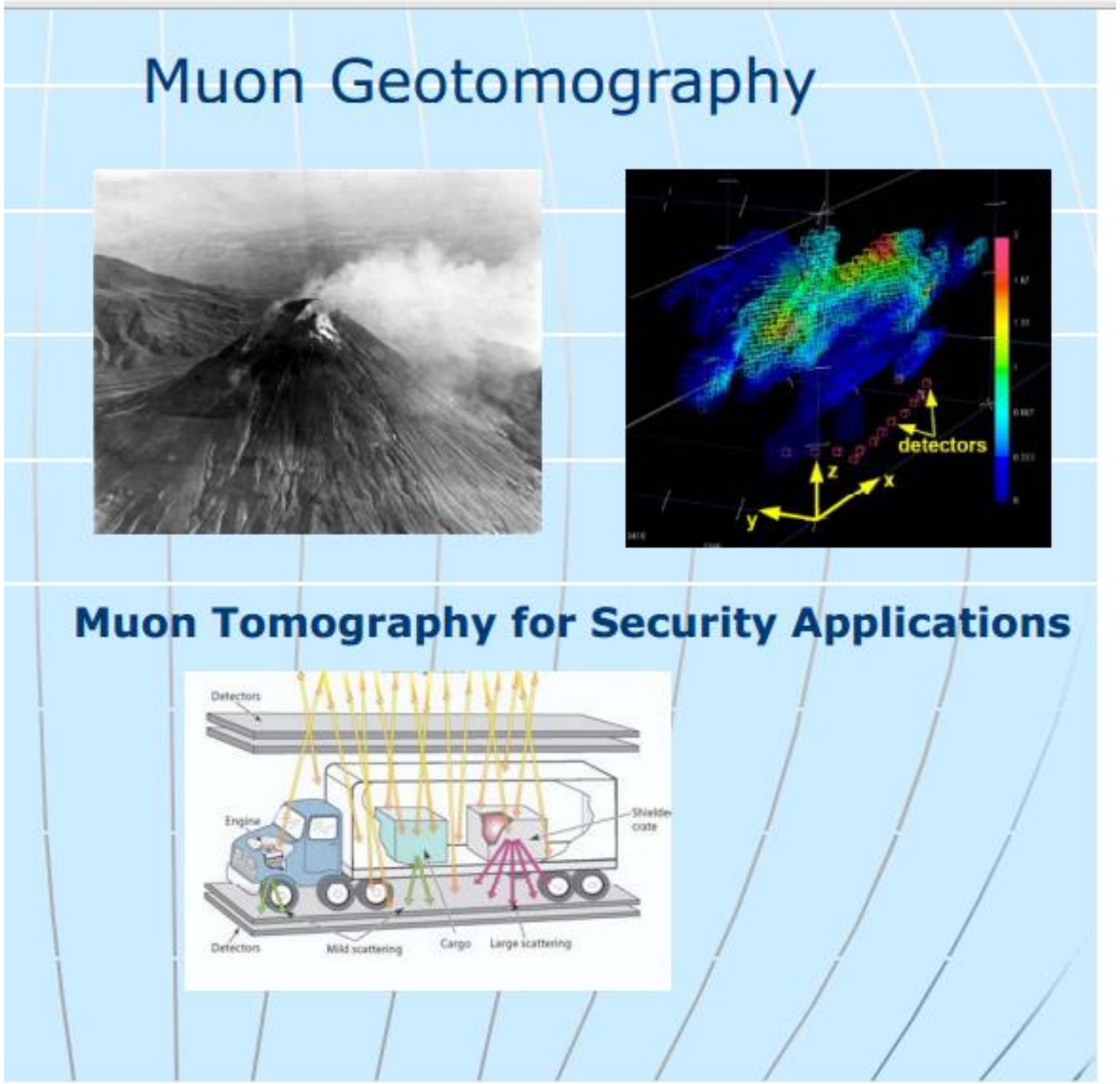
$$\delta\theta \sim \frac{13.6MeV}{\sqrt{P_i P_f}} \sqrt{\frac{L}{X_0}}$$

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



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

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

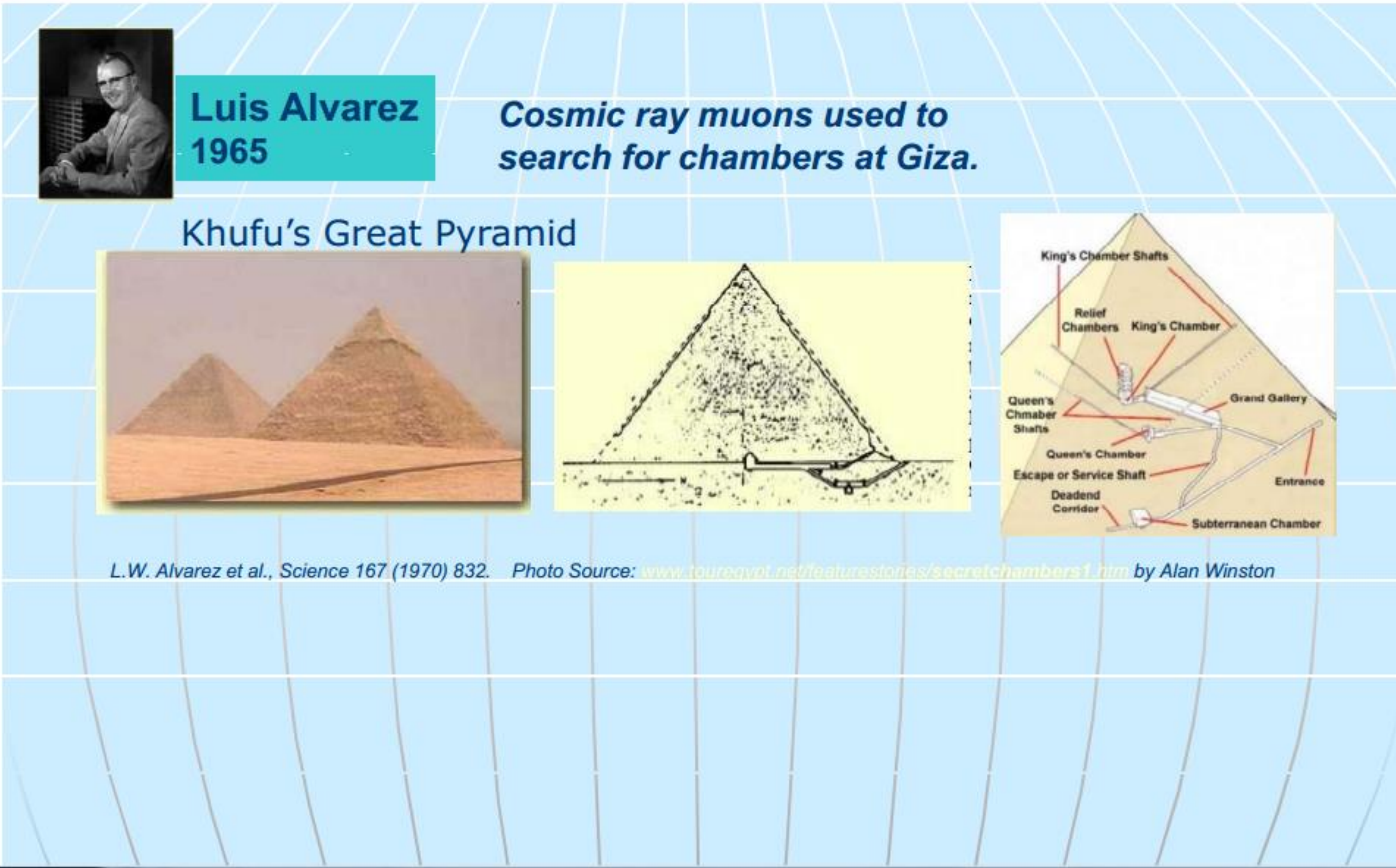


Large scale gaseous detector with high spatial resolution are needed

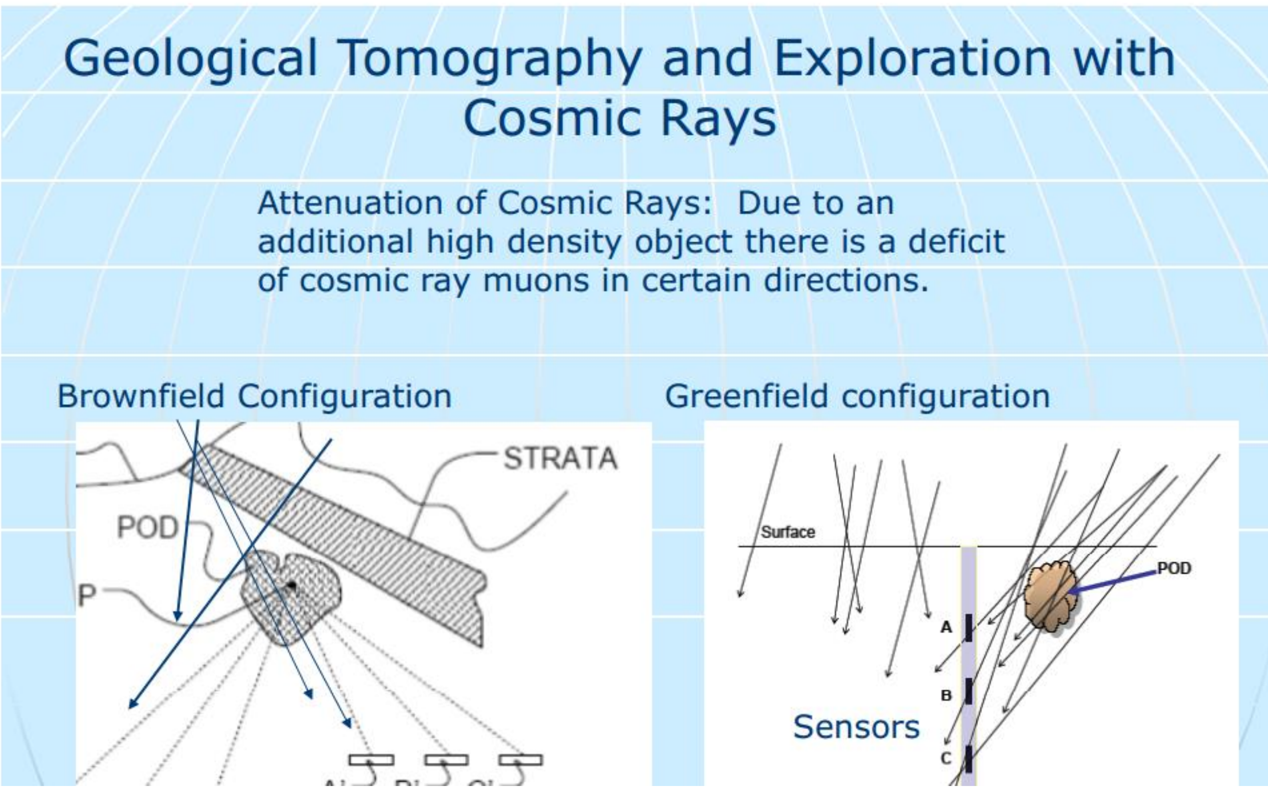
Image reconstruction can spot material of different density

Reconstruction software is crucial

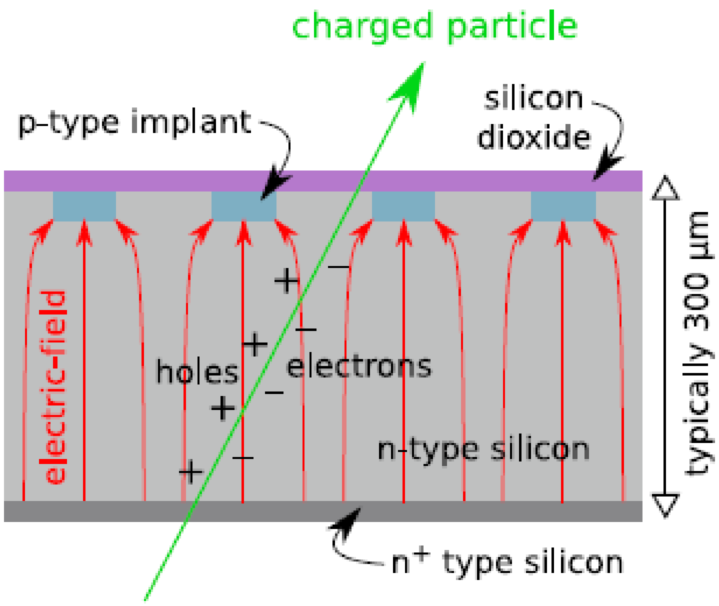
The concept is not new, but now we can profit of advanced instruments



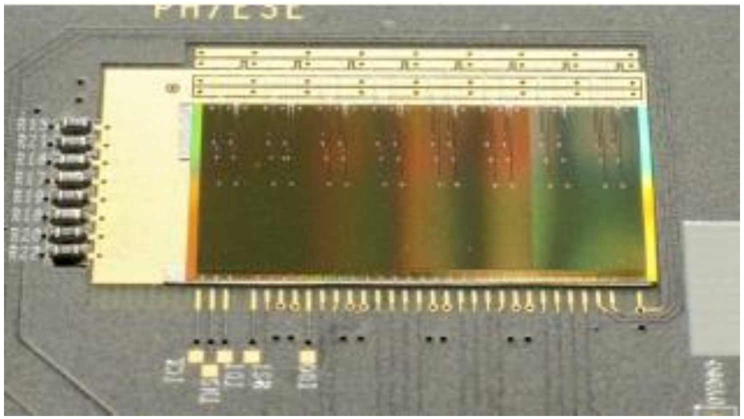
An interesting application is the determination of high density object in mines

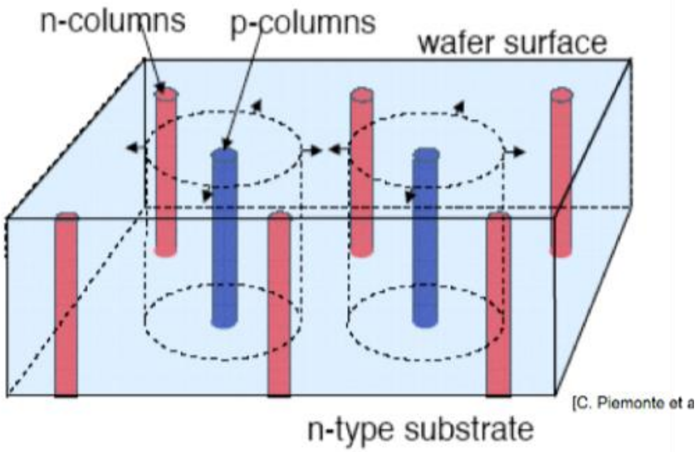


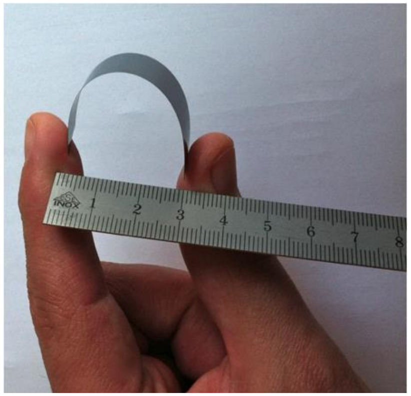
Silicon detectors



Innovative 3D Pixel Sensors







Thinning 8” wafers to 50 µm, wafer post-processing, interconnect techniques, hybrid module assembly and much more are of remarkable interest for industrial and bio-medical application

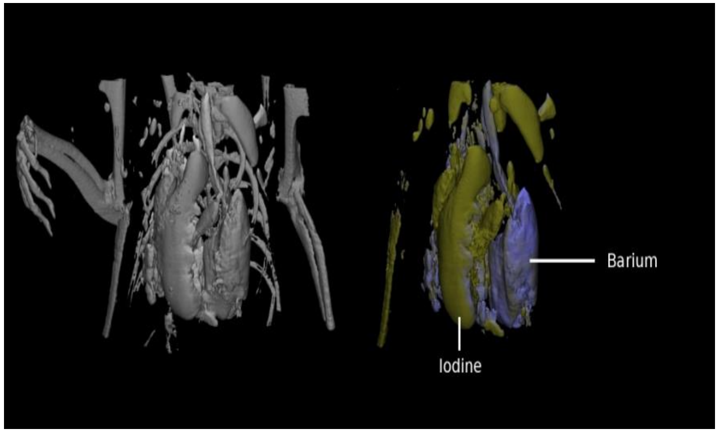
Pushing the industrial infrastructure to the limit of technical capabilities

MEDIPIX

- A family of single photon counting integrated circuits used in Hybrid Silicon Pixel Detectors
- The Medipix collaborations (close to 20 institutes) contributed to the development and dissemination of the technology

MARS project

Colour CT X-ray scanner based on the Medipix technology



(courtesy of MARS Bioimaging Ltd)

Semiconductor application


Automotive Applications


Circuit Protection Applications


Computing & Peripherals Applications


Consumer Applications


Industrial Applications


LED Lighting Applications


Medical Applications


Military & Aerospace Applications


Networking & Telecommunications Applications


Portable & Wireless Applications

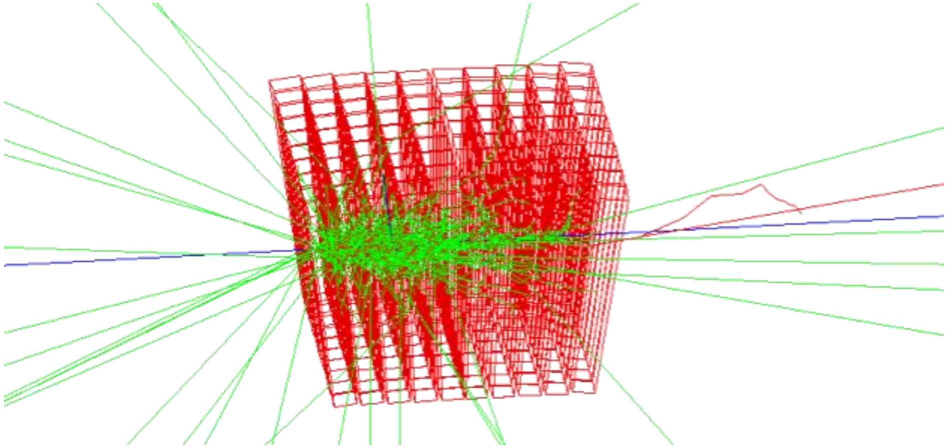

Power Supply Applications

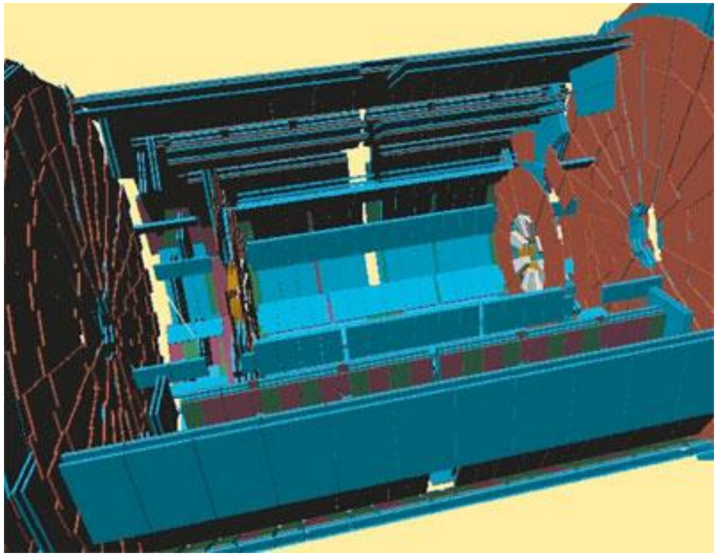

Motor Control Applications

Industry here has certainly overtaken Academy!!!!

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

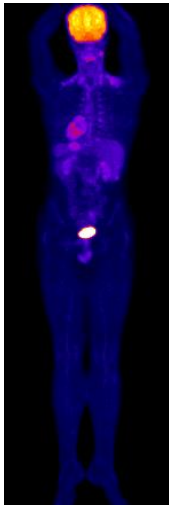
Because of its general purpose nature, Geant4 is well suited for development of computational tools for analysing interactions of particle with matter in many areas:

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

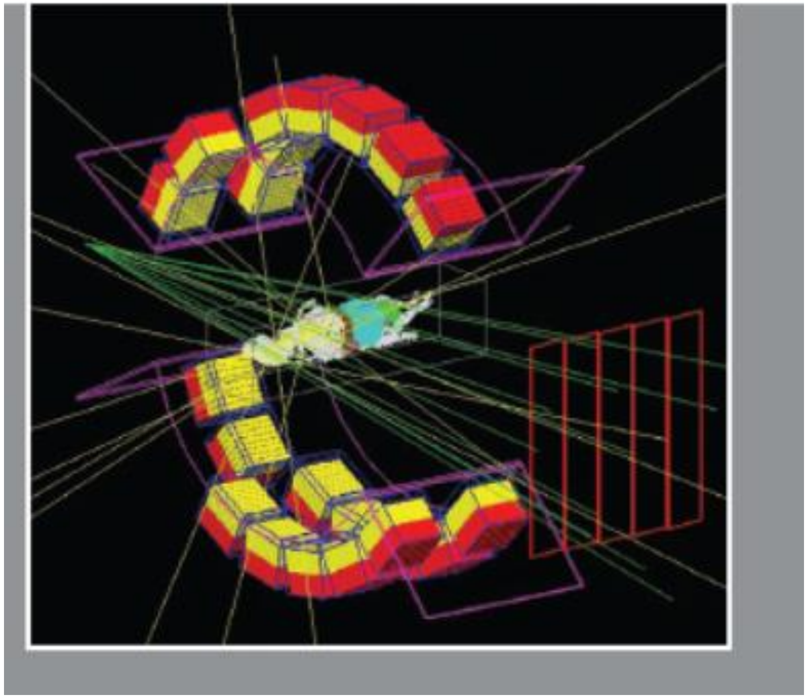
Medical applications where interactions of radiations used for treatment are simulated.

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

Simulations of Emission Tomography (Positron Emission Tomography – PET)



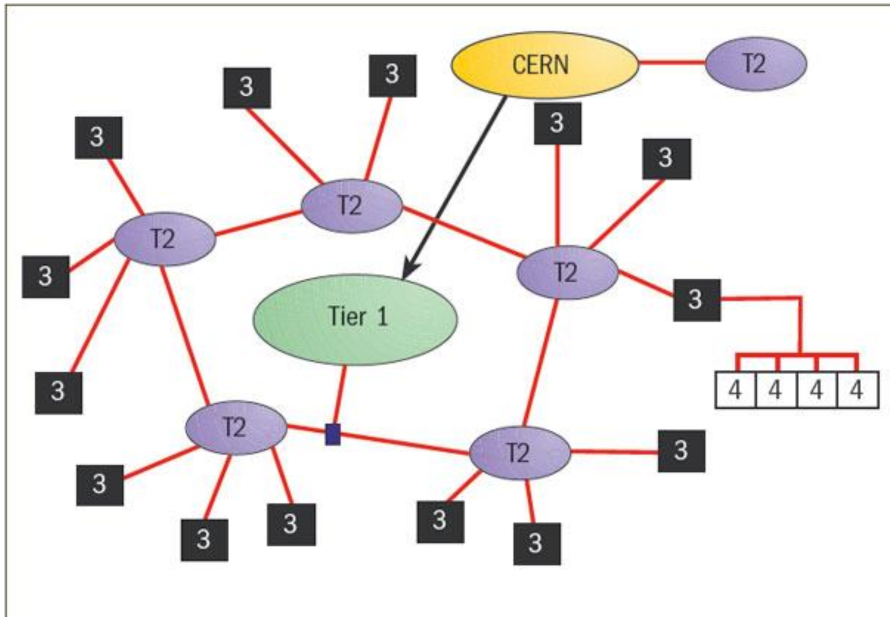
OpenGATE

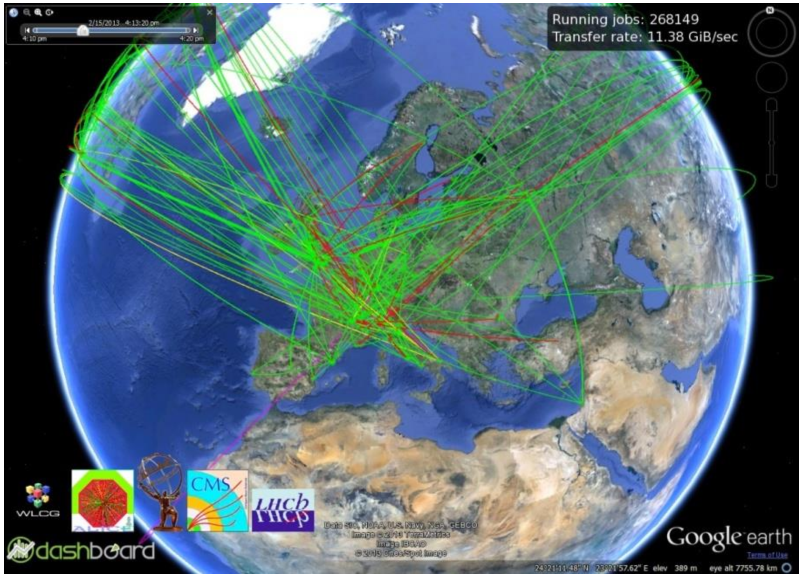


OpenGATE is an extension of GEANT4, and provides a complete environment for simulating the behaviour of the next generation of nuclear medicine scanners, which may be used in clinics or for the development of drugs.

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

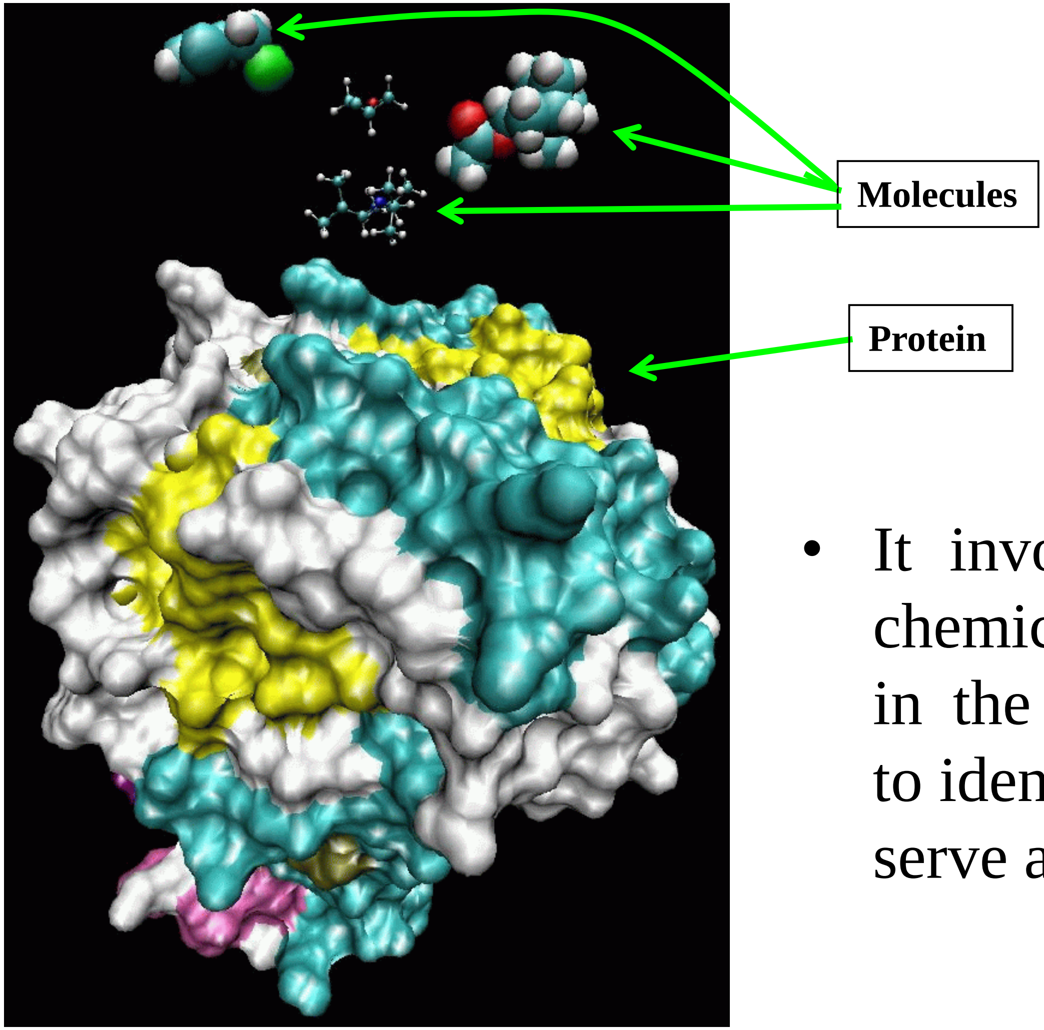
Worldwide LHC Computing Grid (WLCG)

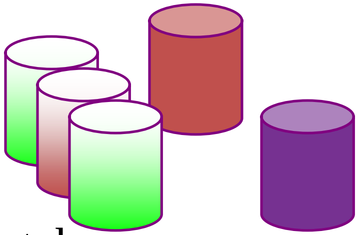




The mission of the WLCG project is to provide global computing resources to store, distribute and analyse the ~30 Petabytes (30 million Gigabytes) of data annually generated by the Large Hadron Collider.

Drug Design: Data Intensive Computing on Grid





Chemical Databases

(legacy, in .MOL2 format)

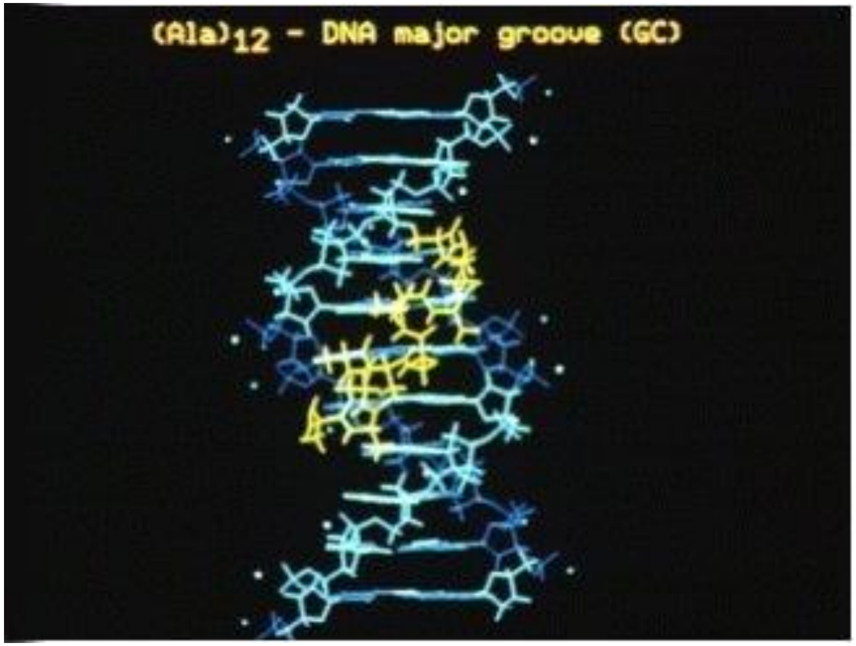
- It involves screening millions of chemical compounds (molecules) in the Chemical DataBase (CDB) to identify those having potential to serve as drug candidates.

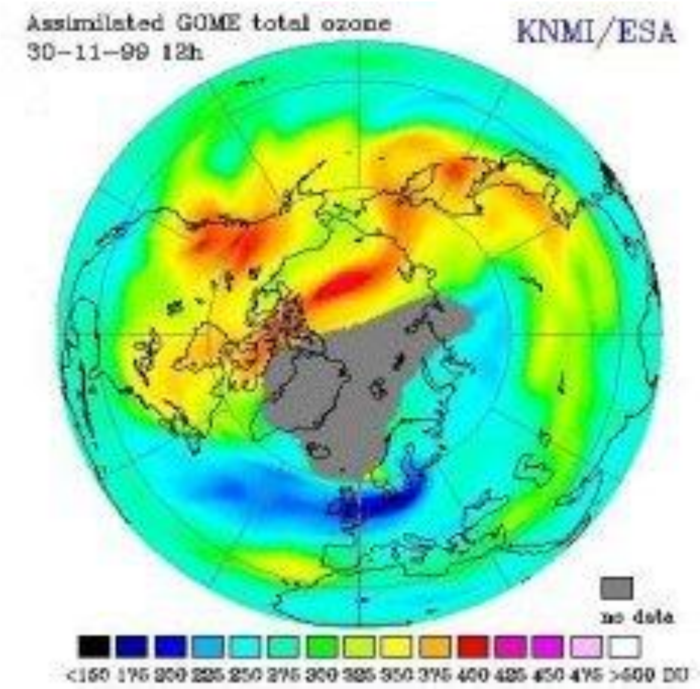
Genome Research

Data mining
Code management
Remote GUI interfaces

Atmospheric Ozone Observation

Large scale data collection



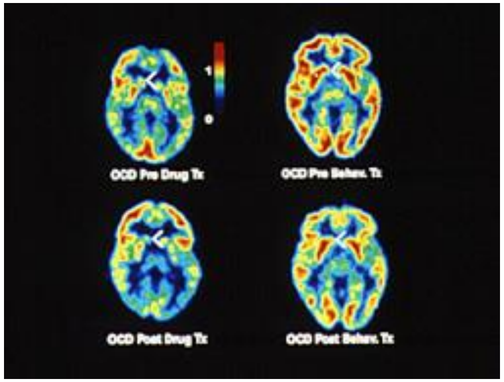


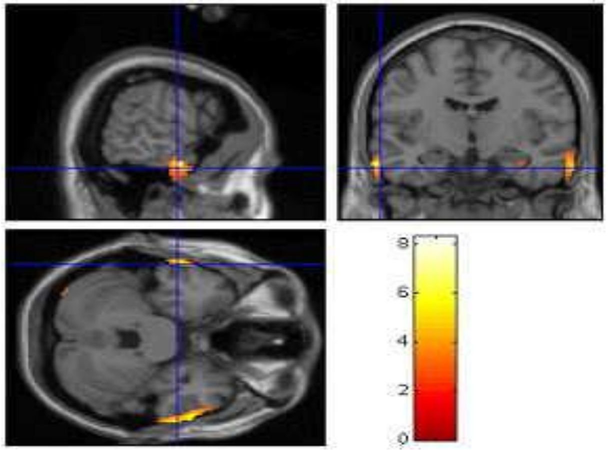
Distributed Data (Image) Analysis

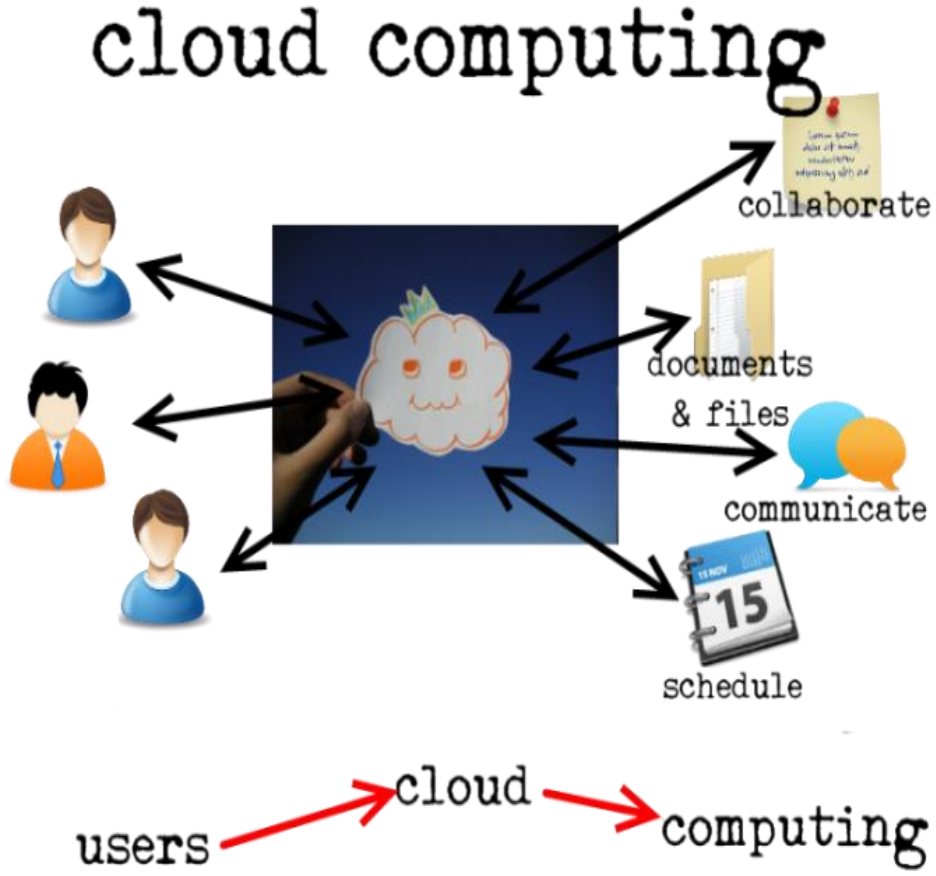
- Patient history (query to the MetaData Catalogue)
- Exam Comparison (download the previous exam(s))
- Comparison with reference data base

Analysis Station

Statistical analysis data base

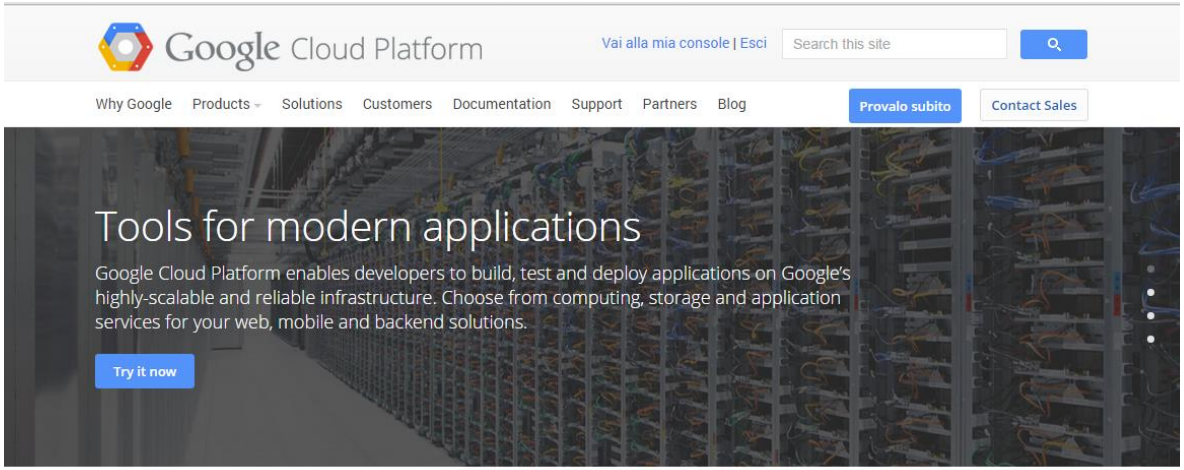




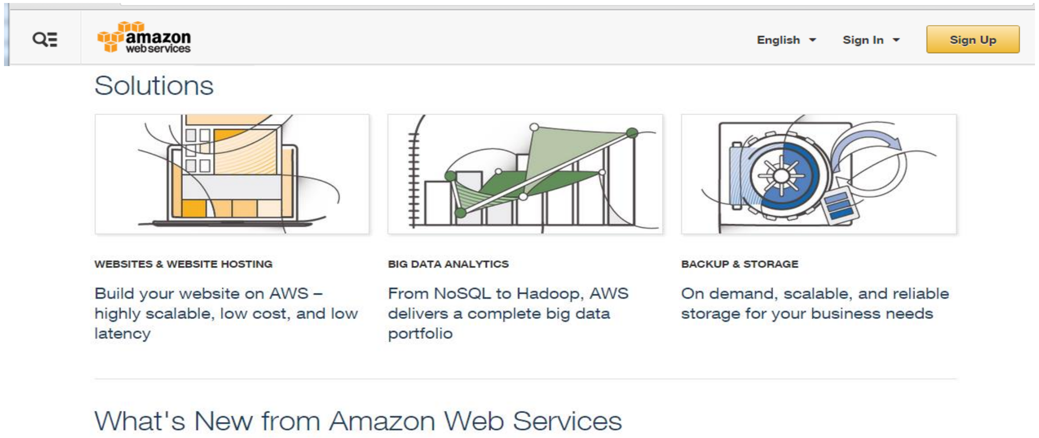


Cloud computing is now developing fast in every day life: your smartphone, notebook and tablet are interconnected and exchange information through a database server

Commercial platforms



Google



Amazon

Networks

The European networks

Forum for European Intergovernmental Research Organizations

EEN, Enterprise Europe Network

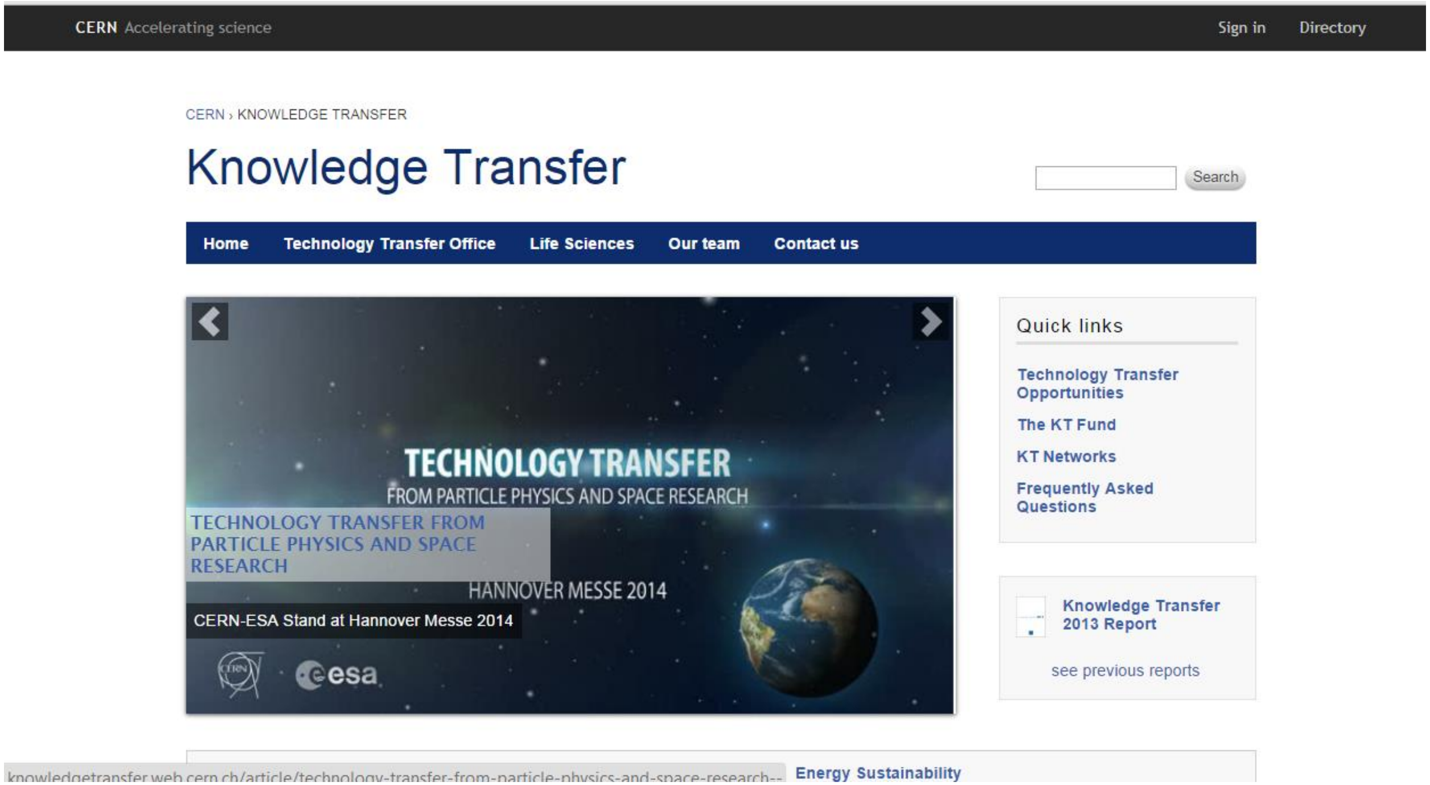
TTN, Technology Transfer Network

TTO Circle - European Technology Transfer Offices Circle

The European Network for LIGht ion Hadron Therapy

CERN Knowledge Transfer (KT) group

Visit the page : http://knowledgetransfer.web.cern.ch/



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