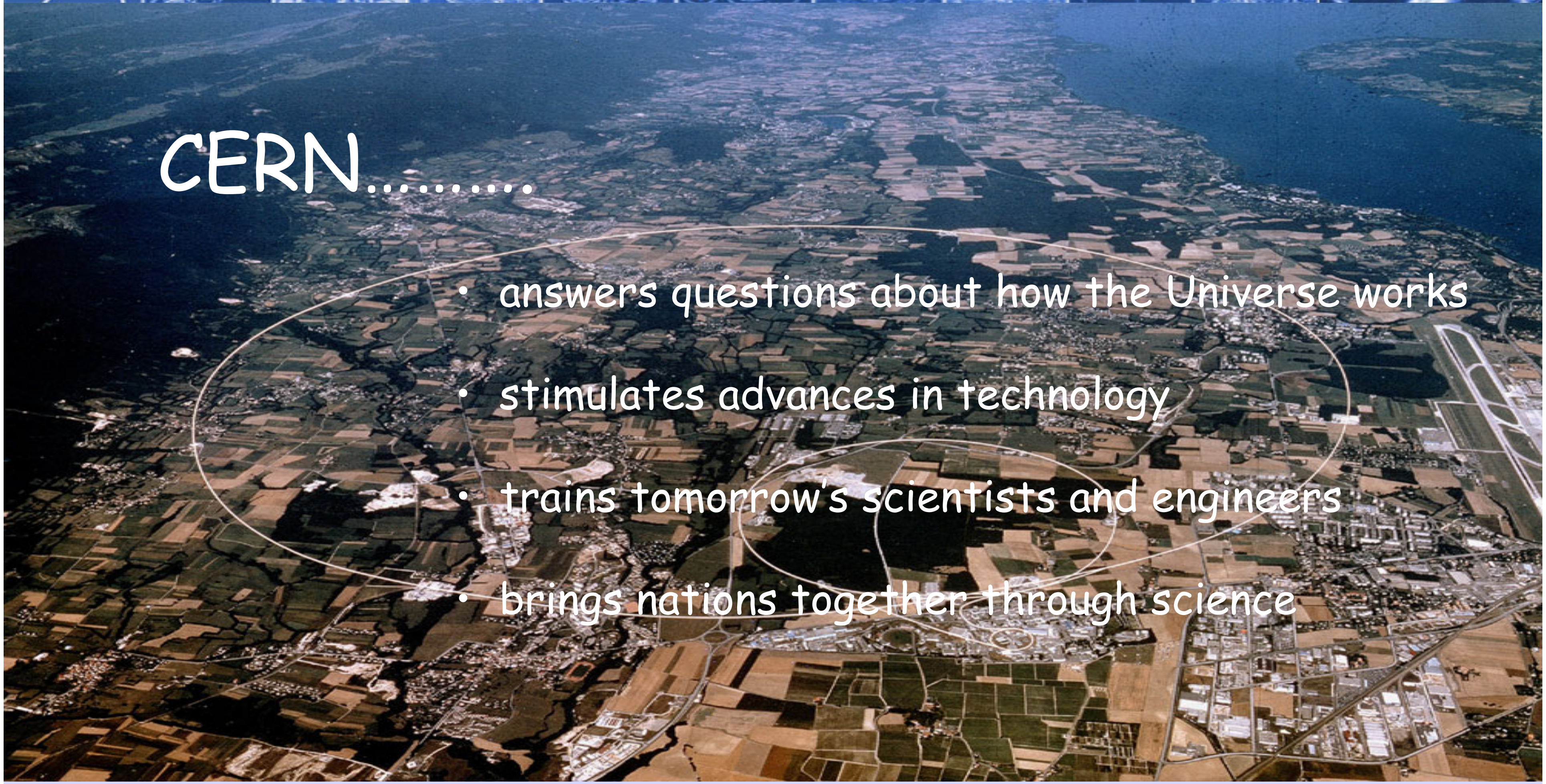
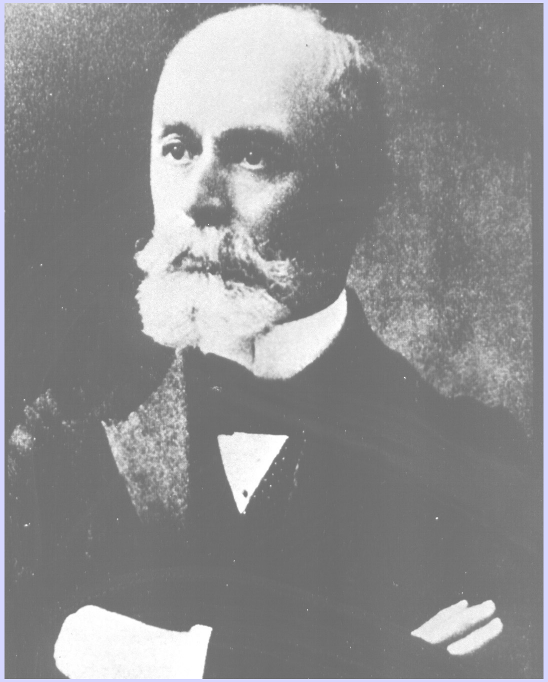
CERN
from particle physics to healthcare

Manjit Dosanjh
Advisor for Life Sciences



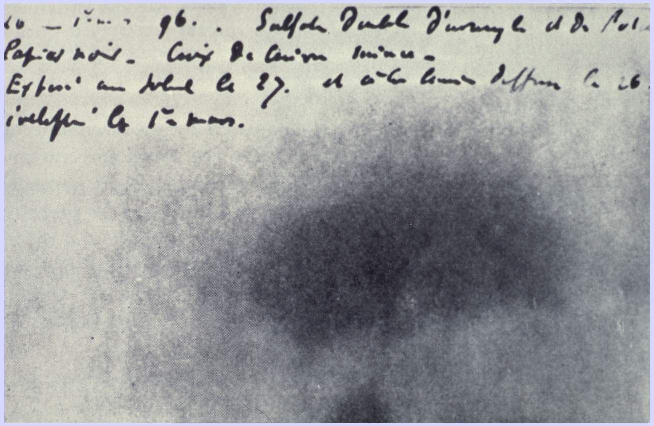
Manjit Dosanjh, CERN

..........beginning of medical physics

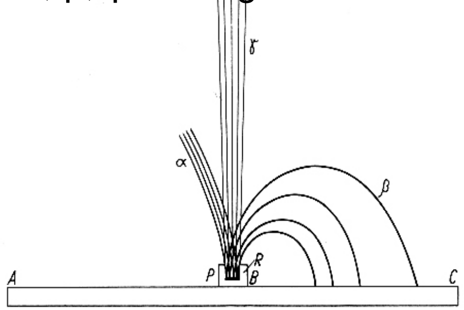


Henri Becquerel

1896:
Discovery of natural radioactivity



Thesis of Mme. Curie – 1904
α, β, γ in magnetic field



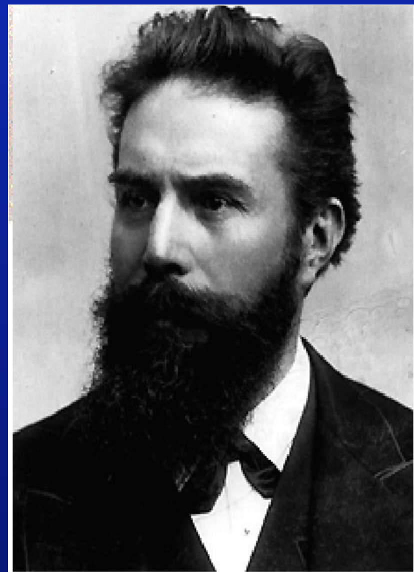
1898: Discovery of radium

used immediately for "Brachytherapy"

Marie Curie (1867 – 1934)   Pierre Curie (1859 – 1906)

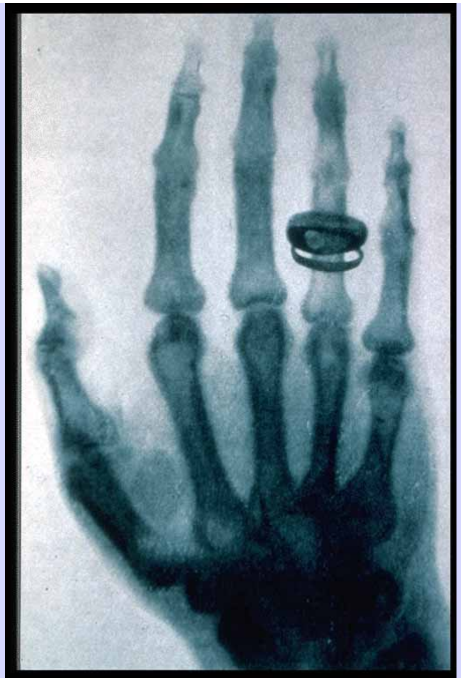
X-Rays, the fastest technology transfer example

- **On November 8, 1895 Röntgen discovered X-Rays**
- **On November 22, 1895 he takes the first image of his wife's hand**

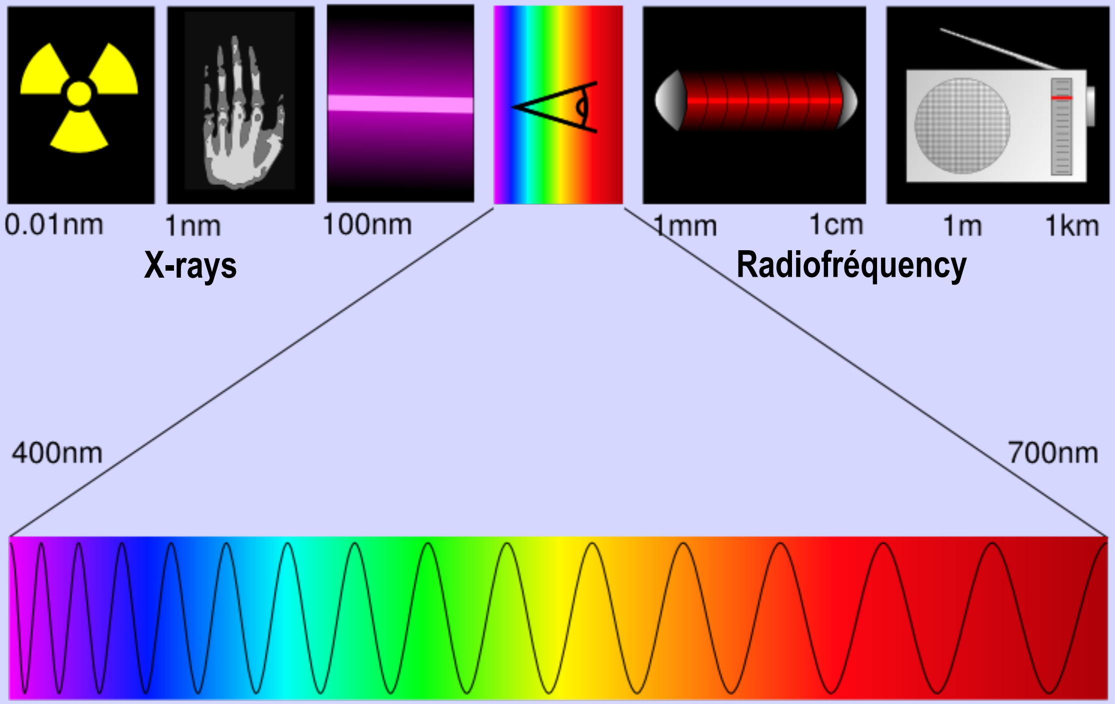


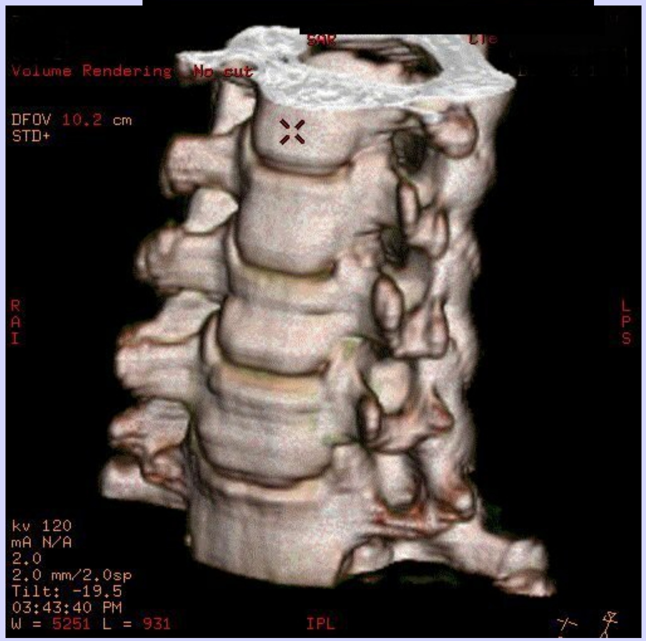
Röntgen received the first Nobel prize in physics in 1901

History: Discovery of X-rays



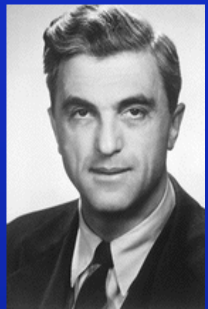
- Since 1895, inventor Wilhelm Rötgen
- EM wave, with energy range: 30 -100 keV
- From film to digital devices



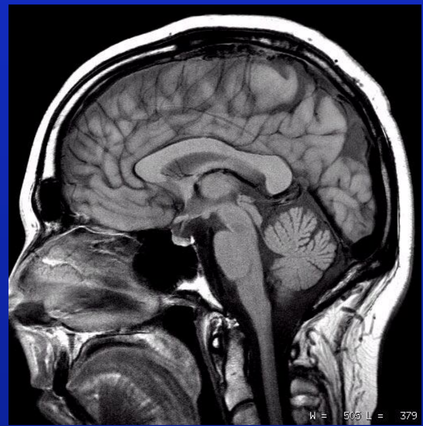


MRI, Magnetic Resonance Imaging

The Nobel Prize in Physics 1952



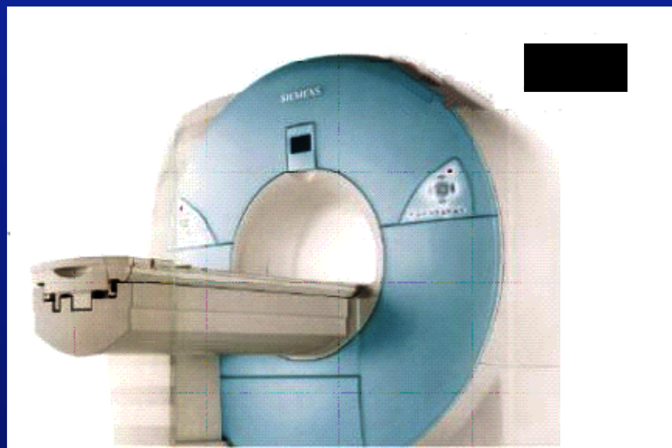
Felix Bloch
Physicist Stanford



Edward M. Purcell
Physicist Harvard

The Nobel Prize in Physiology or Medicine 2003

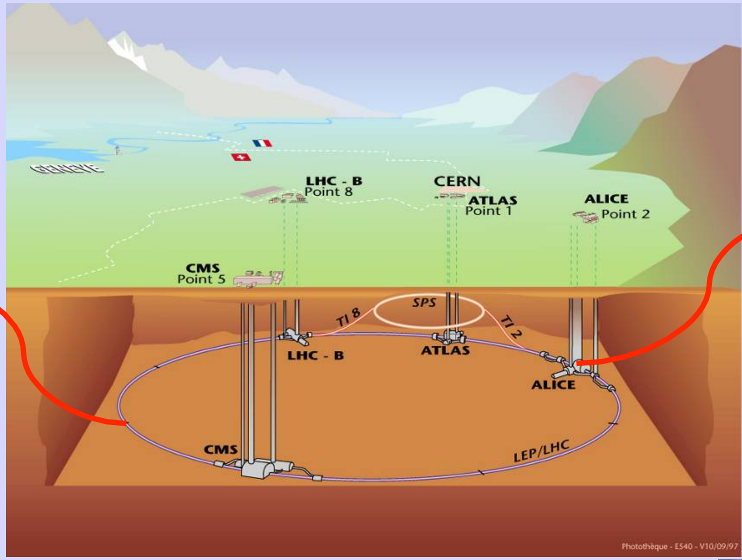
Sir Peter **Mansfield**
Physicist Nottingham



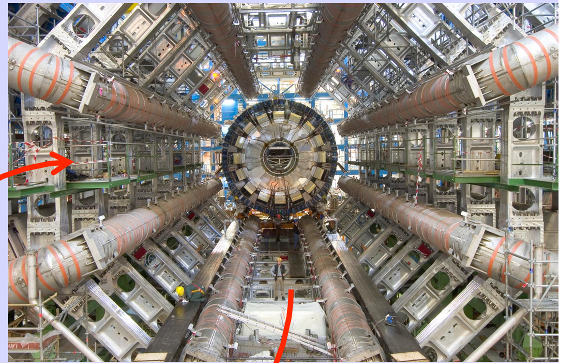
Paul C.
Lauterbur
Chemist Uni.
Illinois

The tools of the trade ………

Accelerators



Detectors

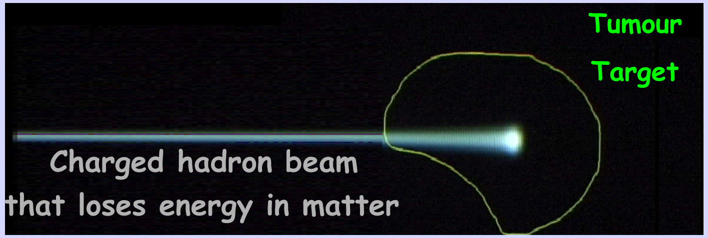


Computers

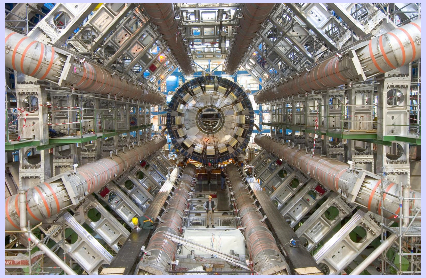
Brain behind the web

Medical Applications

Particle beams for cancer treatment

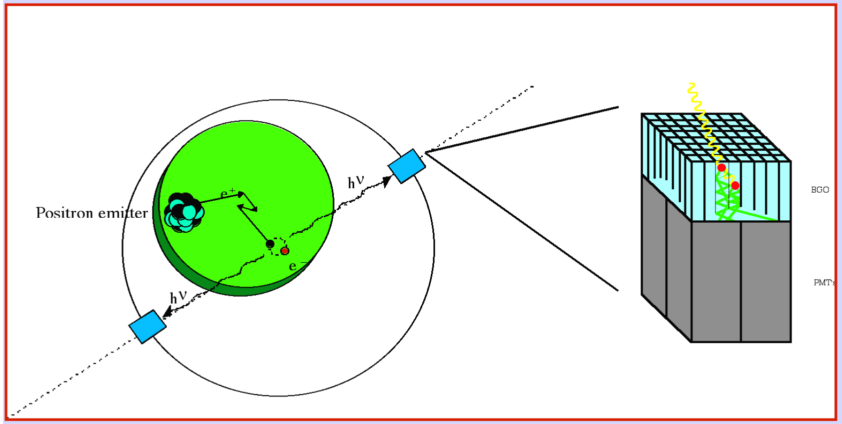


Particle detector technologies for medical imaging

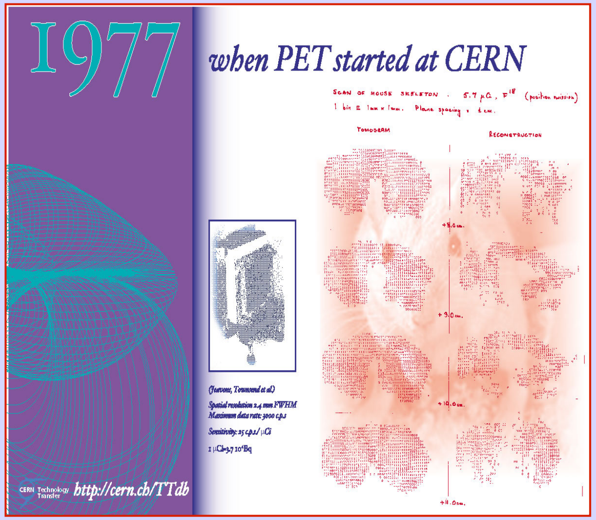


Grid computing for medical data management and analysis

Physics to medicine

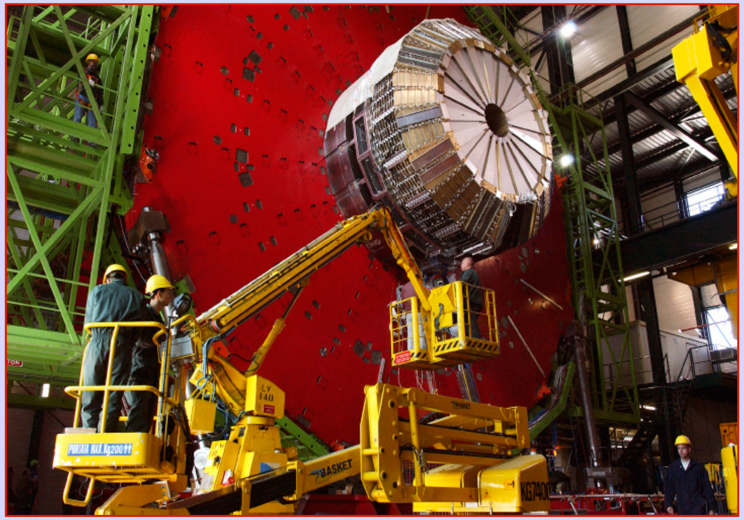


Idea of PET



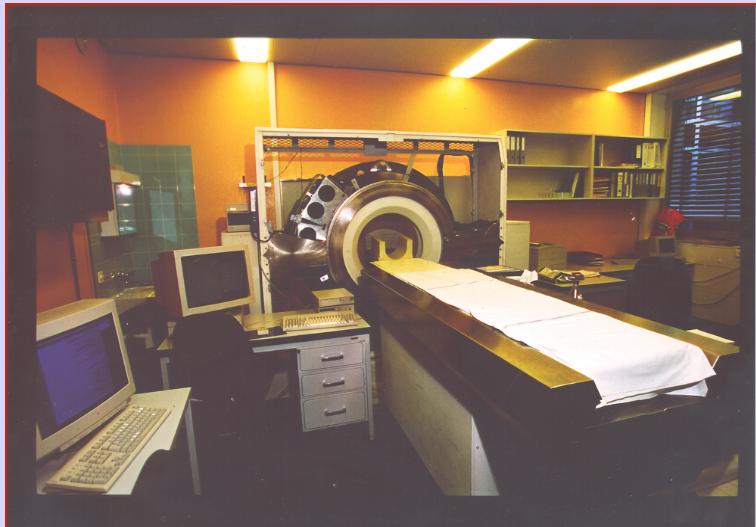
PET today

Photon detection used for calorimetry

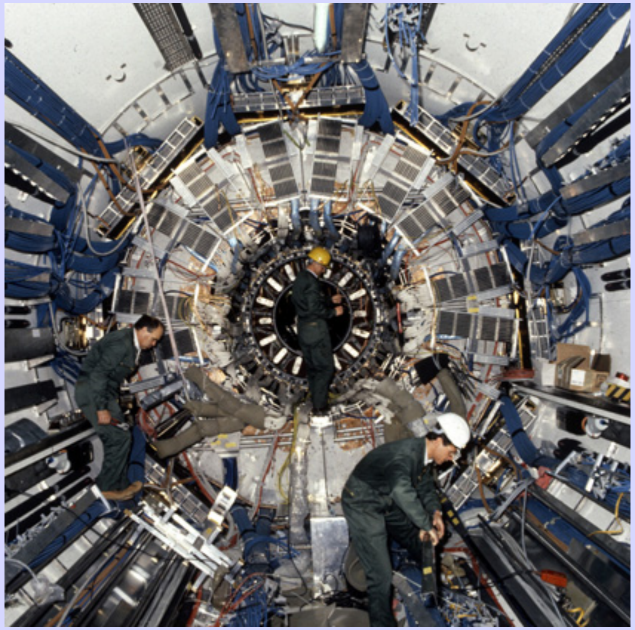


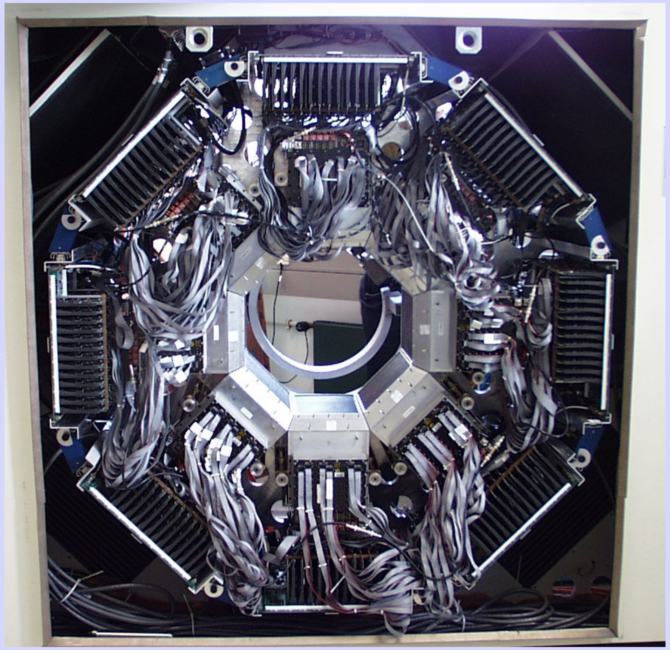
CMS calorimeter

Physics Teachers



Similar challenges detectors

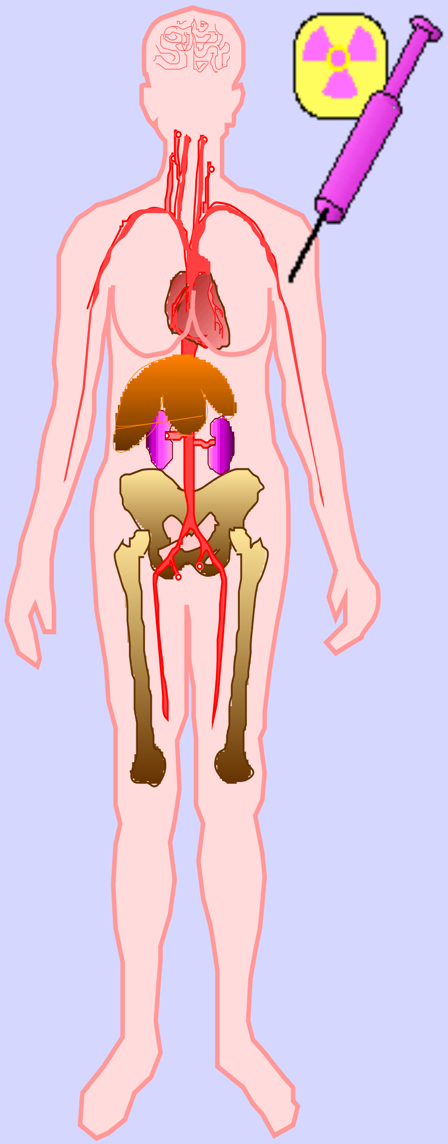




Similar challenges for PET and HEP detectors

- New scintillating crystals and detection materials
- Compact photo-detectors
- Highly integrated and low noise electronics
- High level of parallelism and event filtering algorithms in DAQ
- Modern and modular simulation software using worldwide recognized standards (GATE)

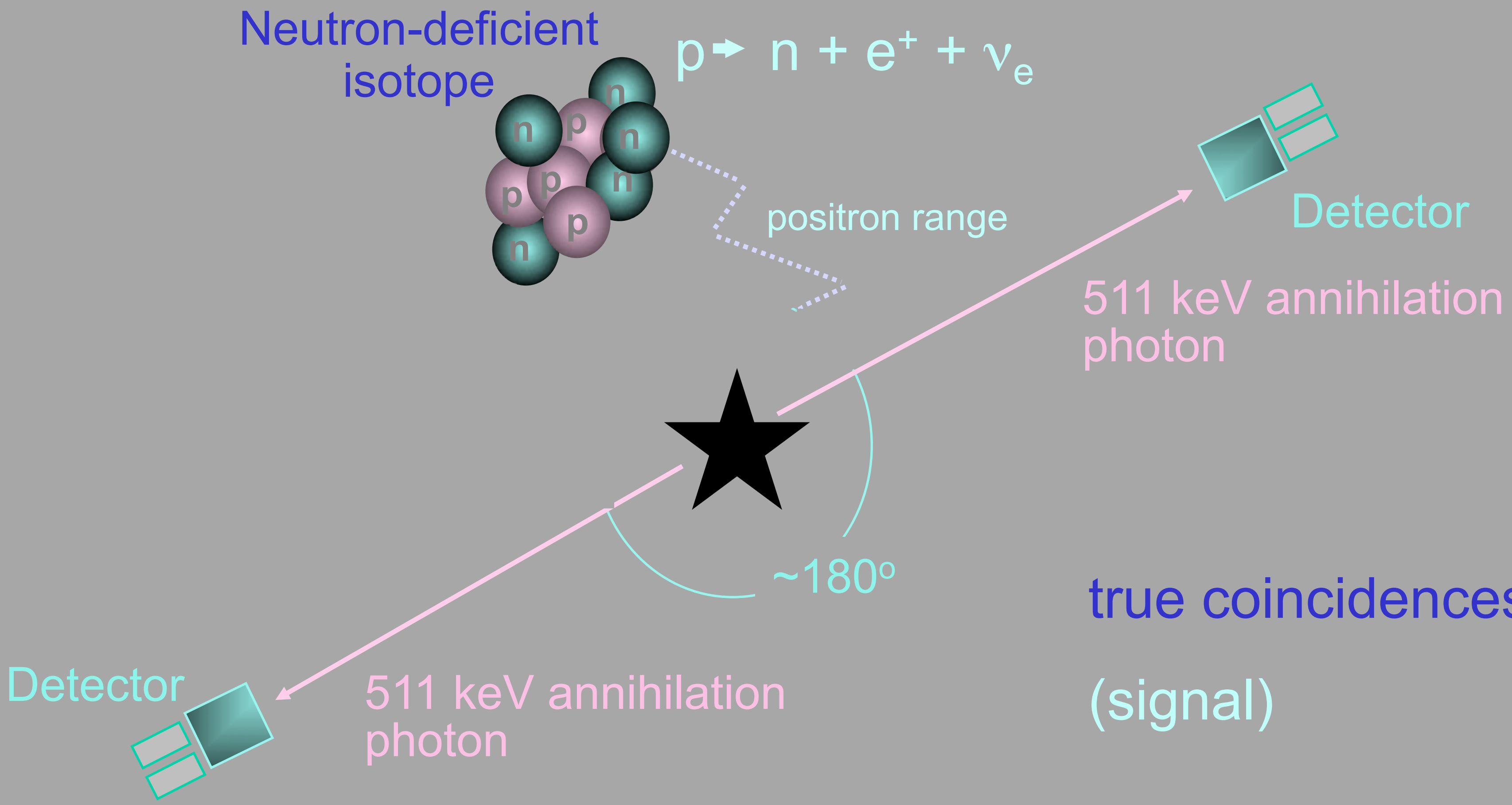
Inject Patient with Radioactive Drug



- Drug is labeled with positron (β^+) emitting radionuclide.
- Drug localizes in patient according to metabolic properties of that drug.
- Trace (pico-molar) quantities of drug are sufficient.
- Radiation dose fairly small (<1 rem).

Drug Distributes in Body

PET: true events



true coincidences (T)

(signal)

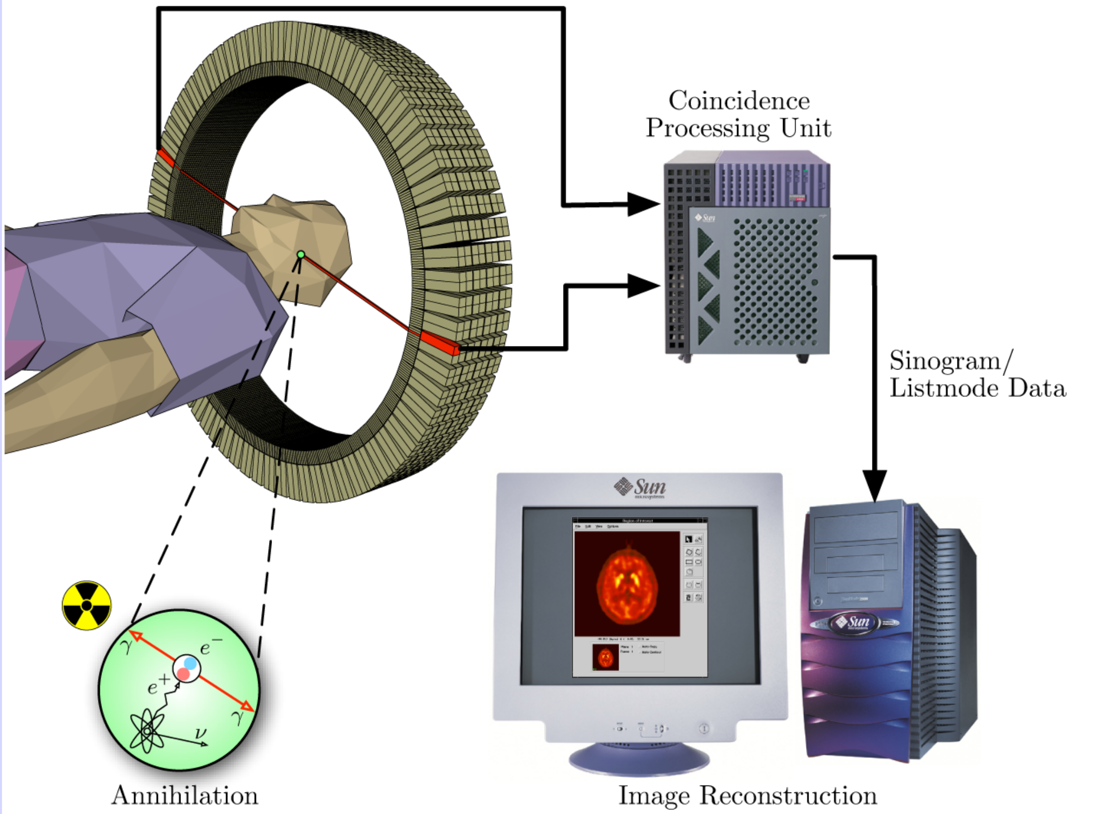
Medical Imaging – PET (Positron Emission Tomography)

Functional Analysis

The system detects pairs of gamma rays emitted indirectly by a positron-emitting radionuclide (tracer), which is introduced into the body on a biologically active molecule.

Images of tracer concentration in 3-dimensional space within the body are then reconstructed by computer analysis.

Crystals developed for LHC detectors are used in PET Scanners.



Crystal Clear Collaboration

-New scintillators :

- LuAP, phoswich LuAP-LSO (CERN patent)
- other crystals

- new photodetectors (Avalanche PhotoDiodes)

-new low noise front end electronics

-new intelligent DAQ systems with pipeline and parallelized architecture

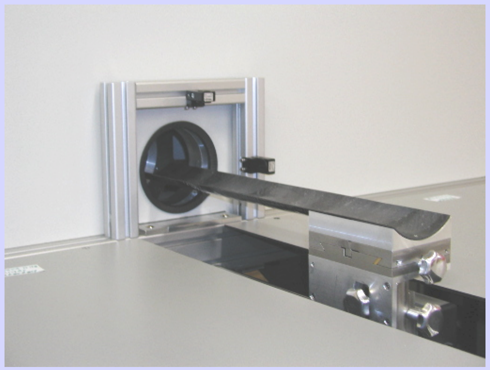
-better simulation GEANT 4

-- better reconstruction algorithms

The ClearPET™ LYSO/LuYAP Phoswich Scanner

A high Performance Small Animal PET System

Higher ef … er spatial resolution



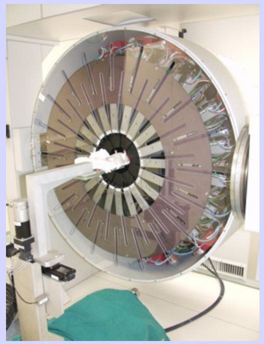
The Design

- 20 detector cassettes on the ring
- each cassette has 4 PM in line
- each PM has 64 photocathodes
- each photocathode reads 1 phoswich
- each phoswich has 2 crystals LYSO and LuYAP
- each crystal is 2 x 2 x 10mm³
- open gantry diameter adjustable 120 - 240mm
- rotation 360 degree

T_{cosine} resolution 2 ns FWHN

Spatial resolution 1.5 mm at centre

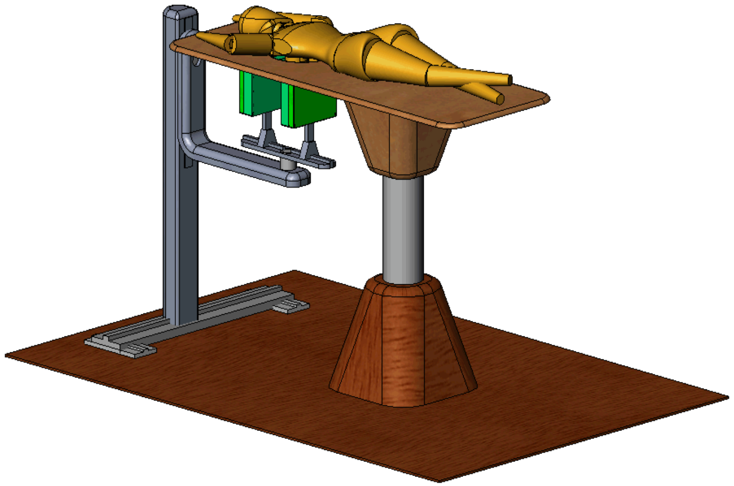
Peak sensitivity >4%

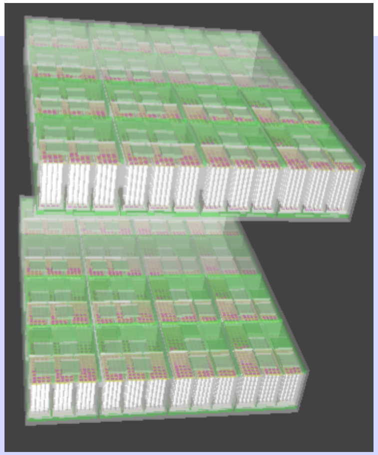


 By Courtesy of Raytest, Germany

Positron Emission Mammography CRYSTAL CLEAR Collaboration

Model of the PEM detector





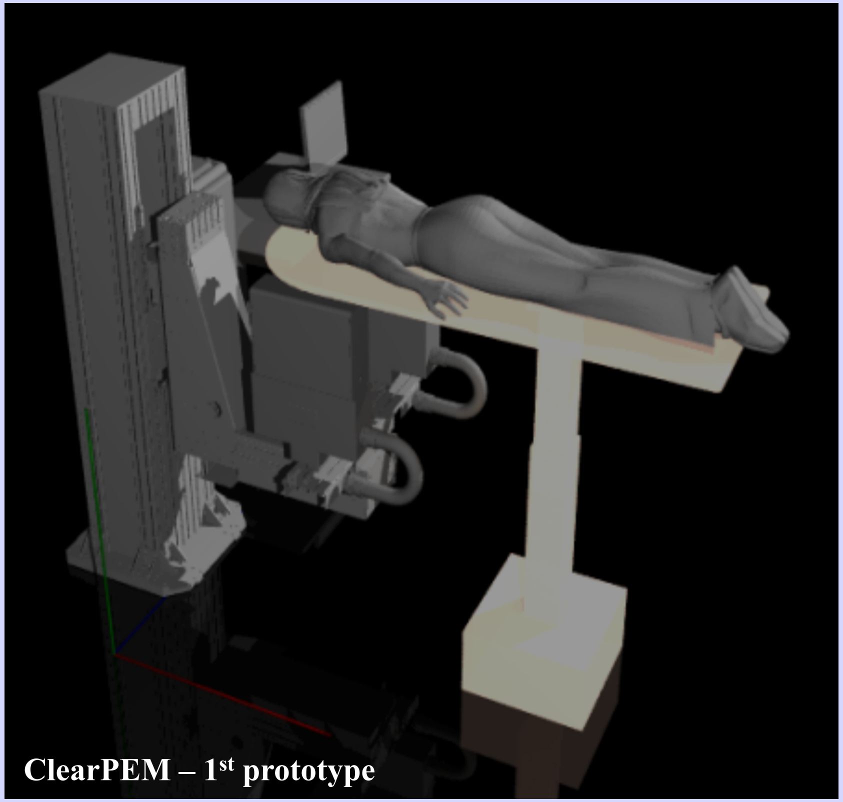
Dedicated breast PET detector allowing high sensitivity to the small tumor detection

- **Spatial resolution 1-2 mm**
- **High counting sensitivity**
- **Short PET exams**
- **Compatible X-Ray mammography**
- **Compatible stereotactic biopsy**

Technical characteristics:

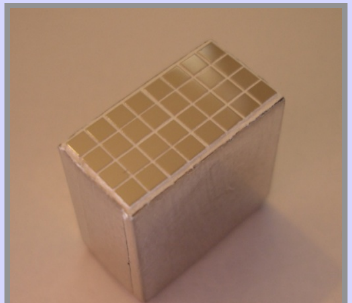
- 6000 crystals 2x2x20 mm
- Avalanche Photodiodes (APD)
- Low noise electronics
- High rate data acquisition
- Spatial resolution 1-2 mm
- Breast and axila region

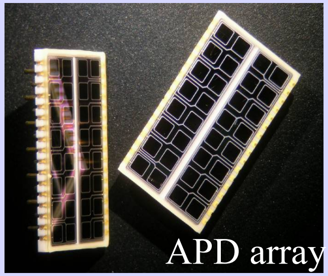
ClearPEM: The Project



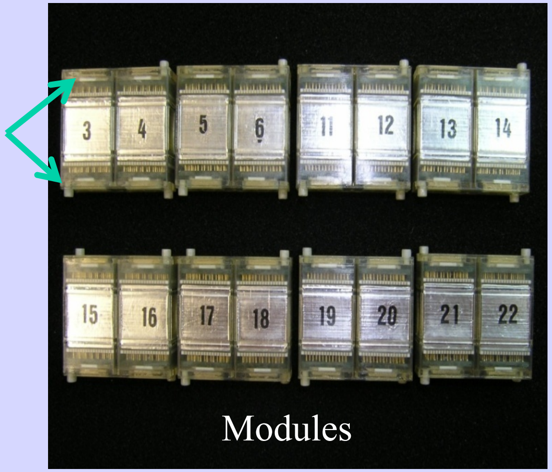
- **A dedicated mammography PET (Positron Emission Tomograph):**
  - Breast exams with the patient in prone position
  - The plates rotate around the breast
  - PEM plates can be rotated for axillary exams
- **Good spatial resolution : 1.4mm (FWHM)**
  - Fine crystal segmentation (2x2 mm)
  - Reduced parallax effect by optimised depth of interaction resolution: 2 mm
- **High Sensitivity:**
  - Solid angle coverage as large as possible
  - High photon interaction probability (20 mm long crystals)
  - High efficiency due to good energy resolution at 511 keV: 15.9%
- **Excellent Time Resolution:**
  - Single photon time resolution 1.5 ns (RMS)
  - Coincidence window: 5.2 ns

ClearPEM: The Machine


LYSO/BaSO4 Matrix


APD array

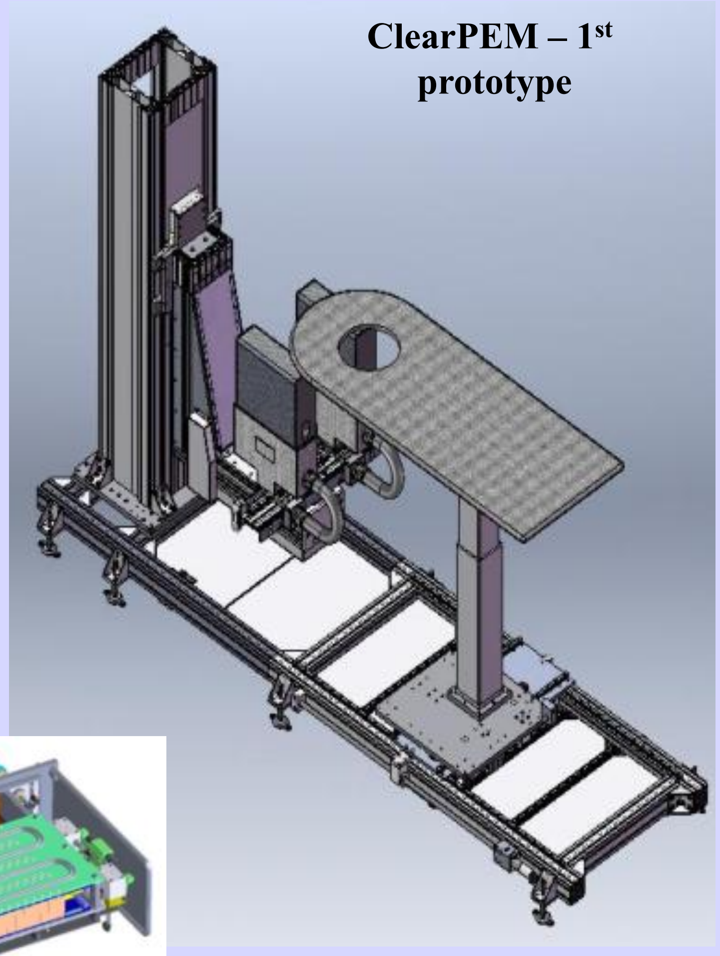
Front-back readout



Modules

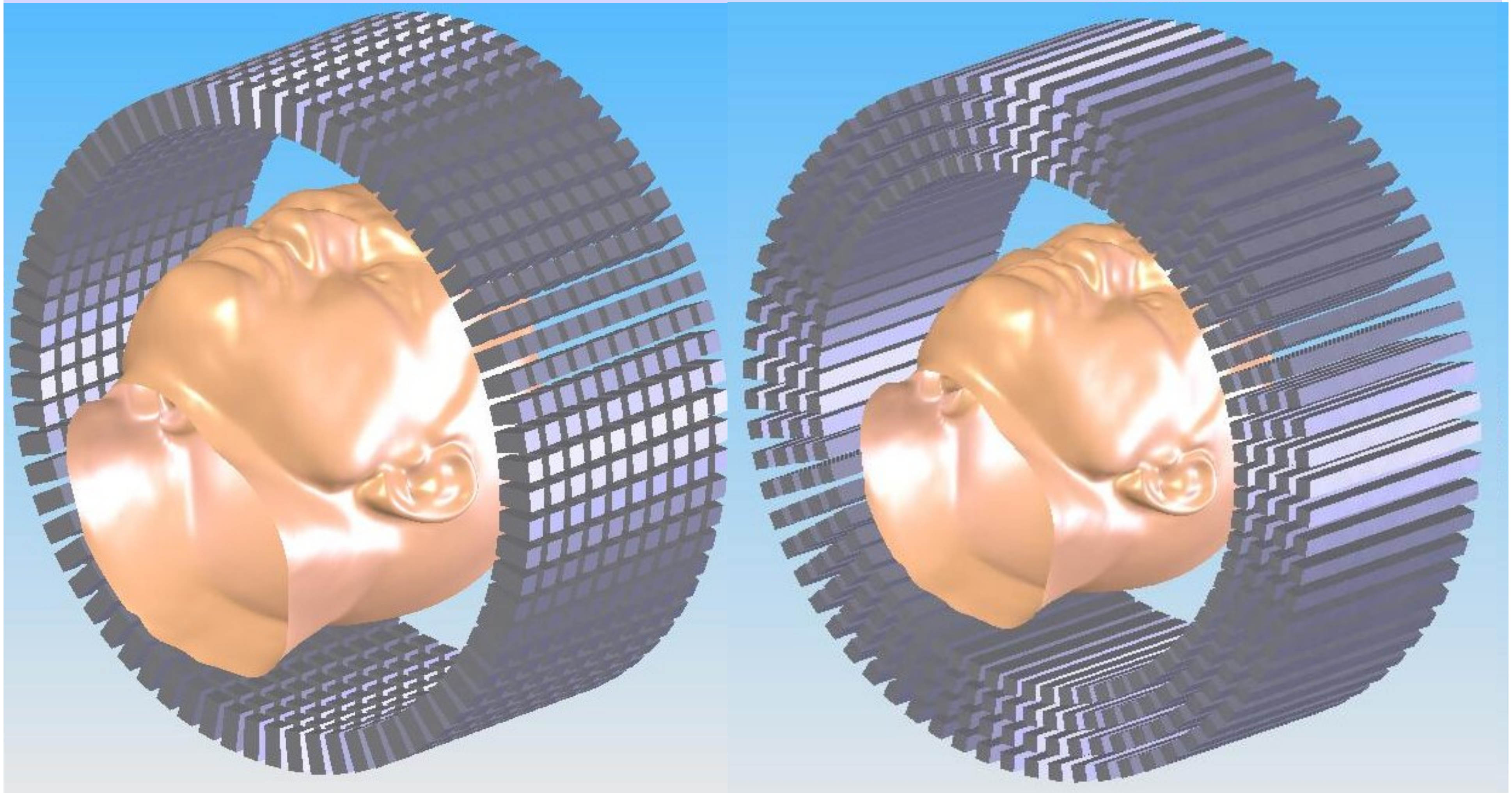
- 6144 LYSO:Ce crystals in 192 matrices
- APD readout on both sides of the crystal
- Fast Front-End readout with dedicated ASICs
- Two detector plates

→ 0.8MHz acquistion rate


ClearPEM – 1st prototype


Detector Plate

The AX-PET (axial brain PET) concept



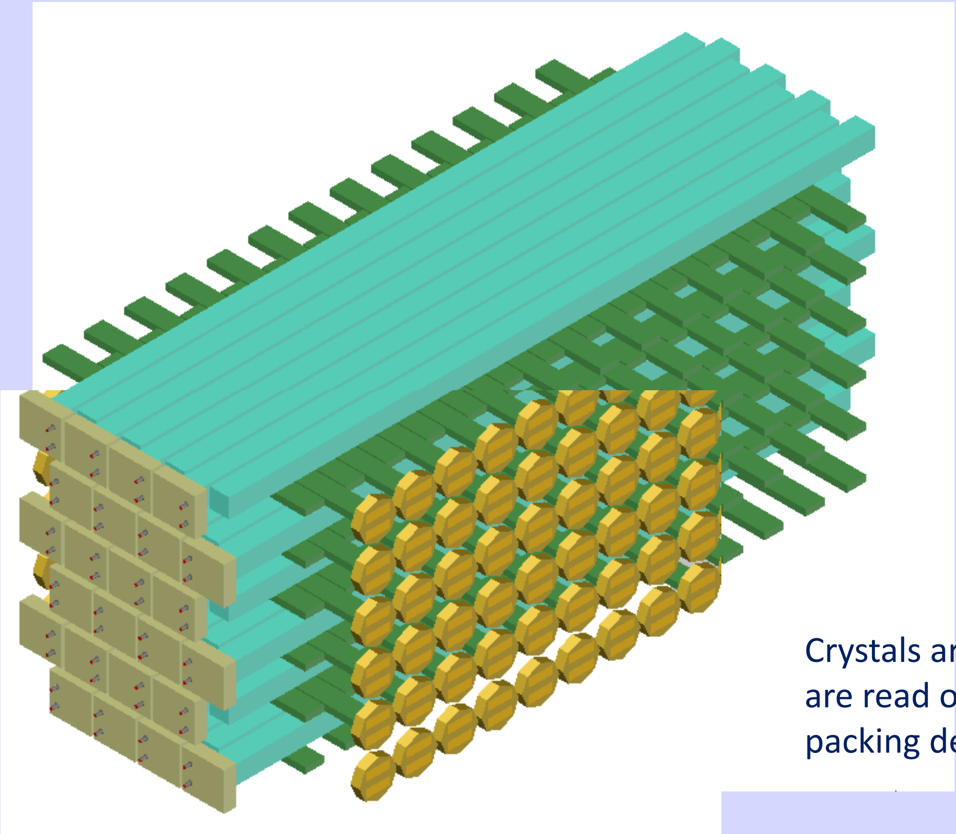
From short radially oriented,
block readout crystals …

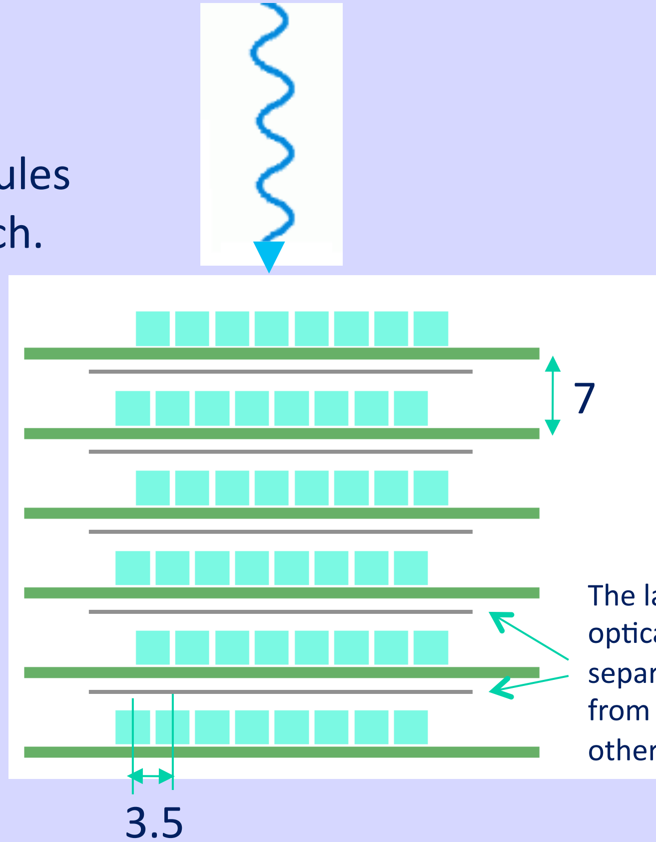
… to long, axially oriented,
individually readout crystals

AX-PET module geometry

- 48 crystals (6 layers x 8 crystals)
- 156 WLS strips (6 layers x 26 strips)

} 2 modules → 408 ch.





The layers are optically separated from each other.

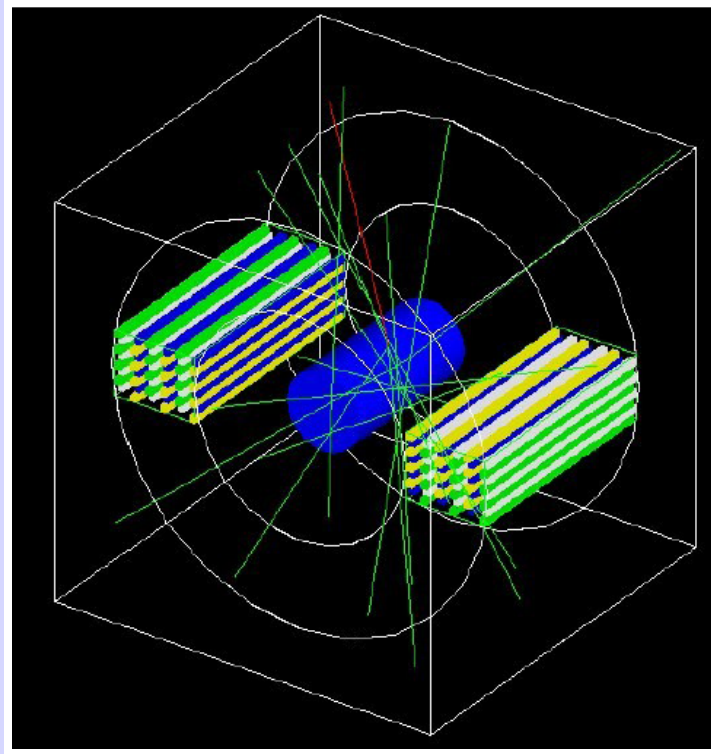
Crystals are staggered by 2 mm. Crystals and WLS strips are read out on alternate sides to allow maximum packing density.

AX-PET main features

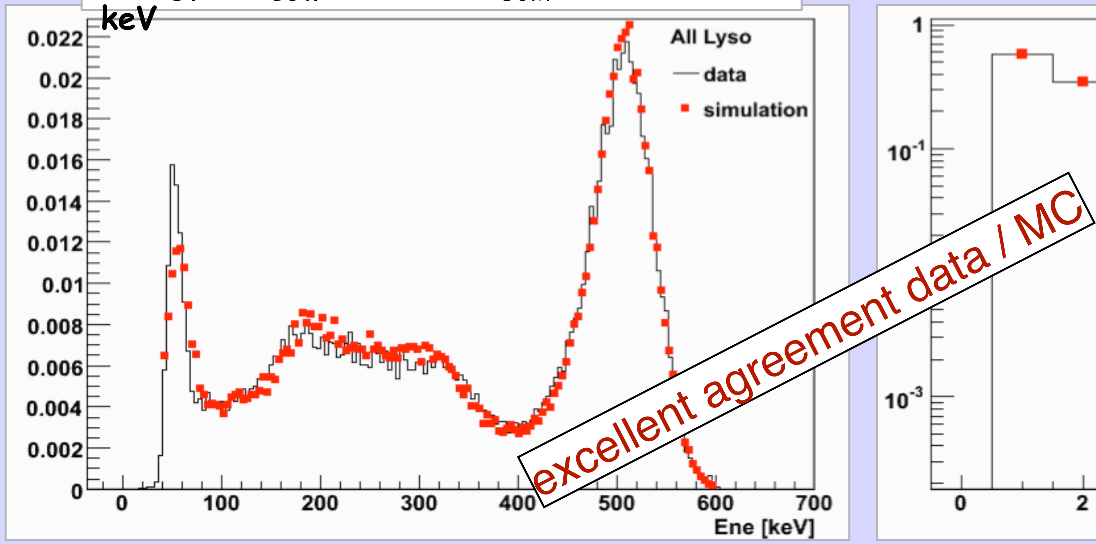
- parallax-free 3D localization of photons.
- Spatial resolution (crystal and WLS strip dimensions) and sensitivity (additional layers) can be optimized independently. Physical limits in reach.
- The 3D capability should allow to identify a significant fraction of Compton interactions (Inter Crystal Scatter).
  ICS events can either be discarded (resolution fully maintained) or reconstructed (increased sensitivity).
- AX-PET concept can be scaled in size and number of layers to match specific needs.
  → small animal PET
  → brain PET
  → full body PET
  → PEM (mammography)
- Concept and components are in principle MRI compatible and TOF extendable.

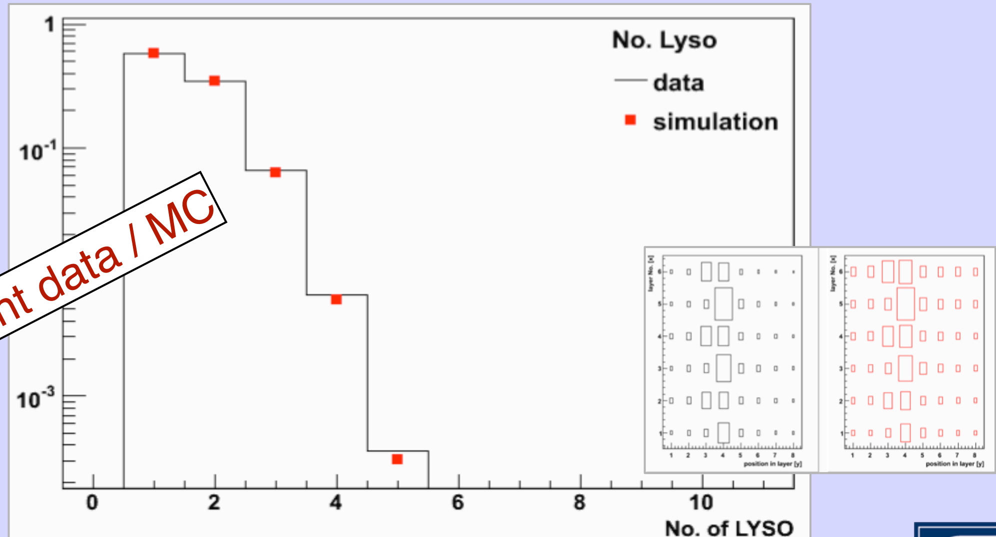
AX-PET simulation

- **Geant4** (multi-purpose Monte Carlo tool, optical transport, dedicated geometry)
- **GATE** (PET dedicated MC, including time dependent phenomena, scanner rotation, source/phantoms…)



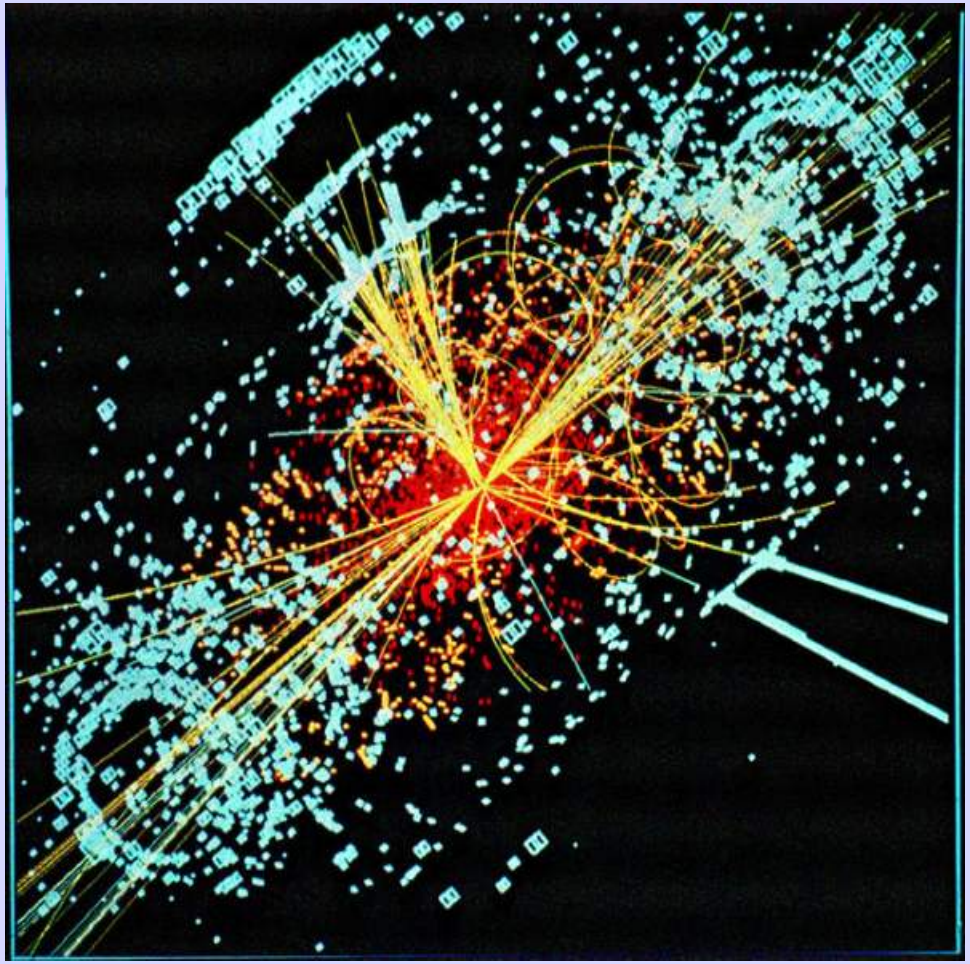
Energy - E_{LOW}=40 keV, E_{SUM}=[400,600] keV



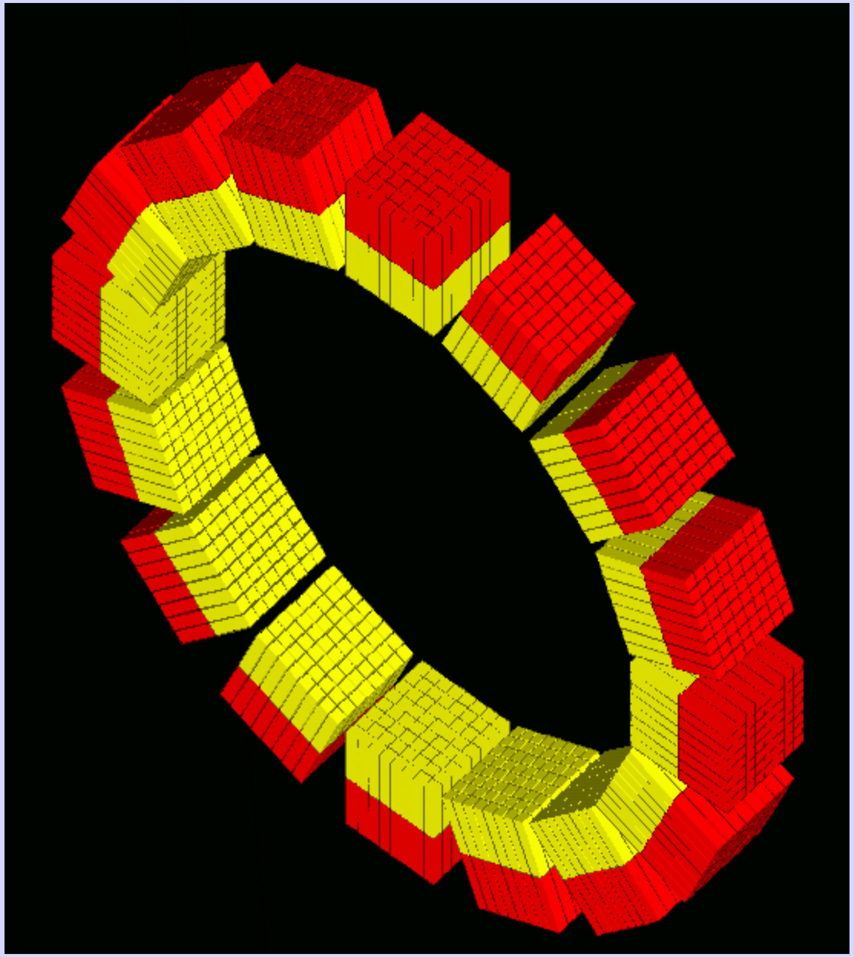


Simulation

Higgs event at LHC (CMS) with Geant4

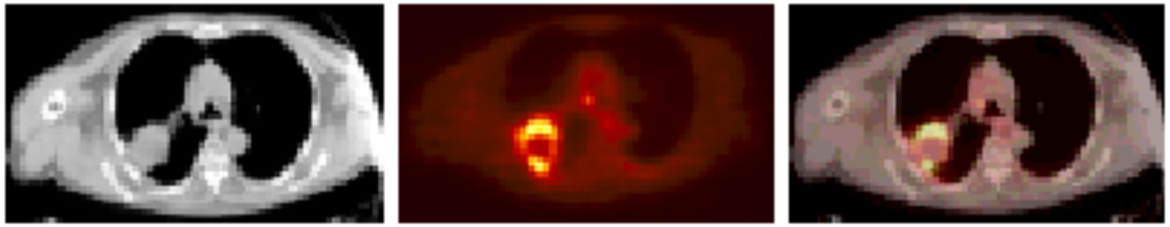


ClearPET with GATE: Geant4 Application for Tomographic Emission

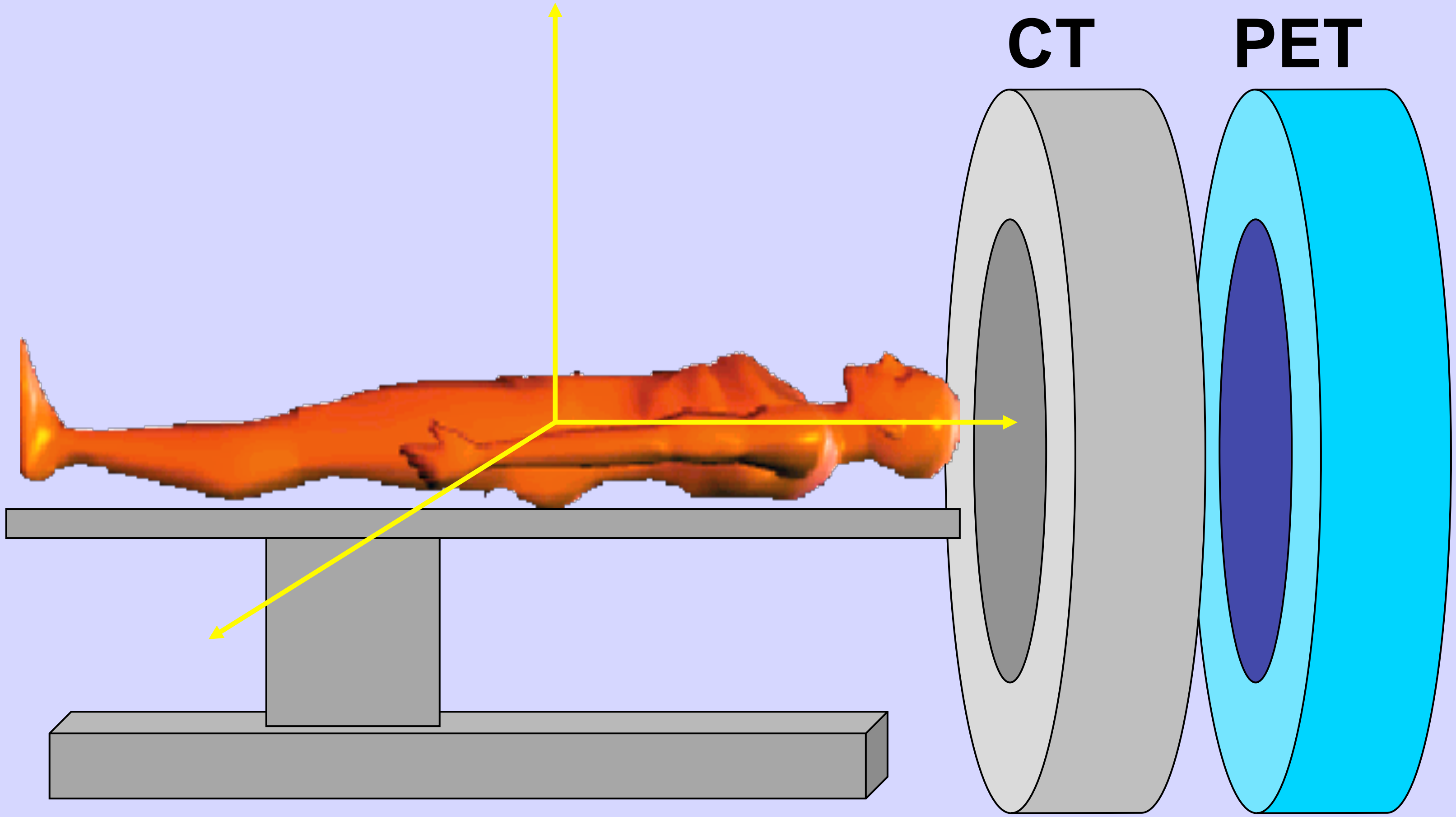


Multi-modality imaging

Primary lung cancer imaged with the Dual/Commercial scanner. A large lung tumor, which appears on CT as a uniformly attenuating hypodense mass, has a rim of FDG activity and a necrotic center revealed by PET.



PET/CT



A changing tide: digital imaging

Current

- Limited contrast
- High dose
  - Restricted screening
  - Limited access to preventive health care

Digital

- High contrast
- Lower dose
  - Opportunity for screening
  - Access to preventive health care

What is Medipix?

The Medipix is an electronic chip similar to the electronic imaging chip in a digital camera. One difference is that the Medipix chip is sensitive to xrays instead of visible light. What is unique about the Medipix chip is that it can create the first true colour images with x-rays. Thus, it permits us to move from black and white x-ray images to full colour x-ray images. The chip also can be read out very rapidly. This allows the use the chip for colour x-ray digital movies or for fast colour x-ray CT scans

MEDIPIX: Allows counting of single photons in contrast to traditional charge integrating devices like film or CCD

- **High Energy Physics original development:**

Particle track detectors

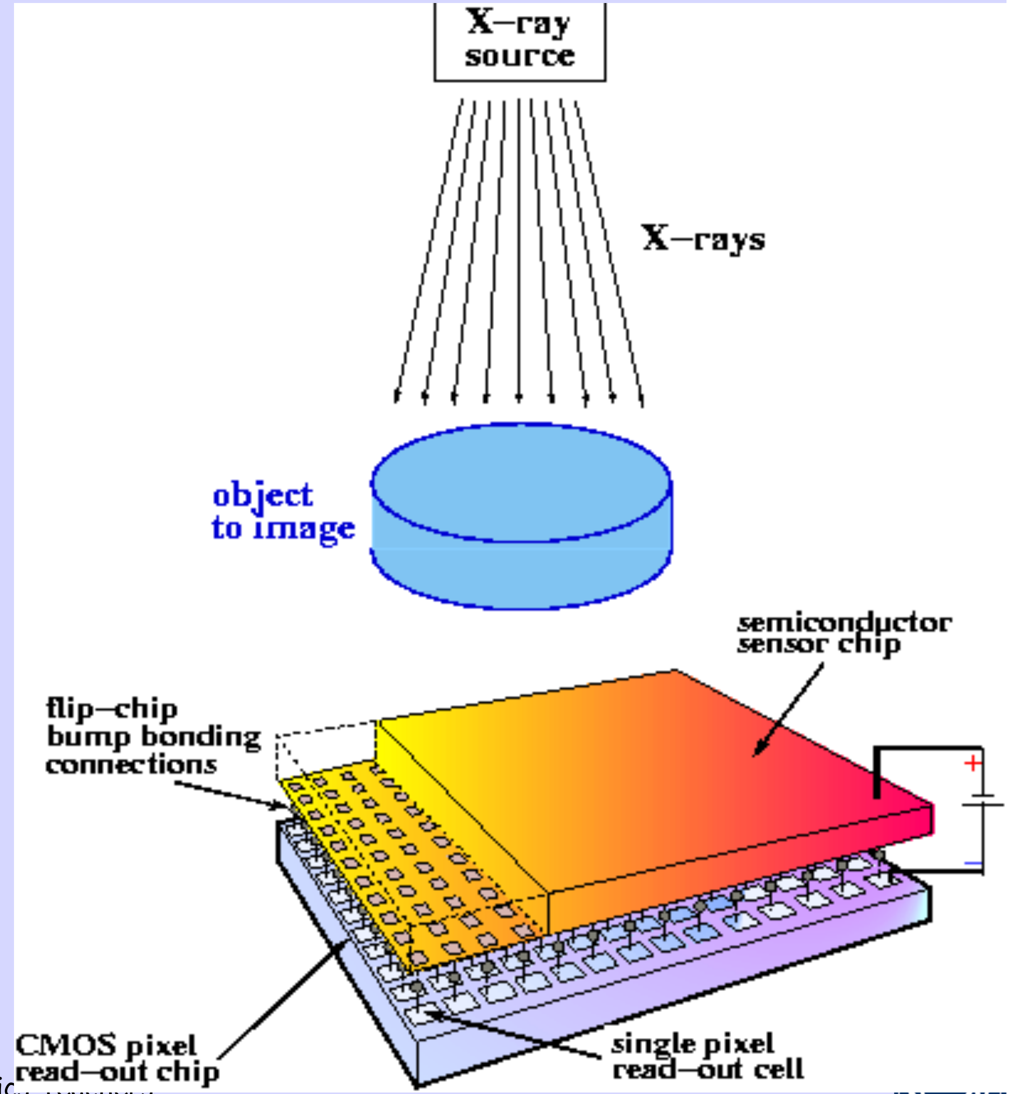
- **Main properties:**

Fully digital device

Very high space resolution

Very fast photon counting

Good conversion efficiency of low energy X-rays

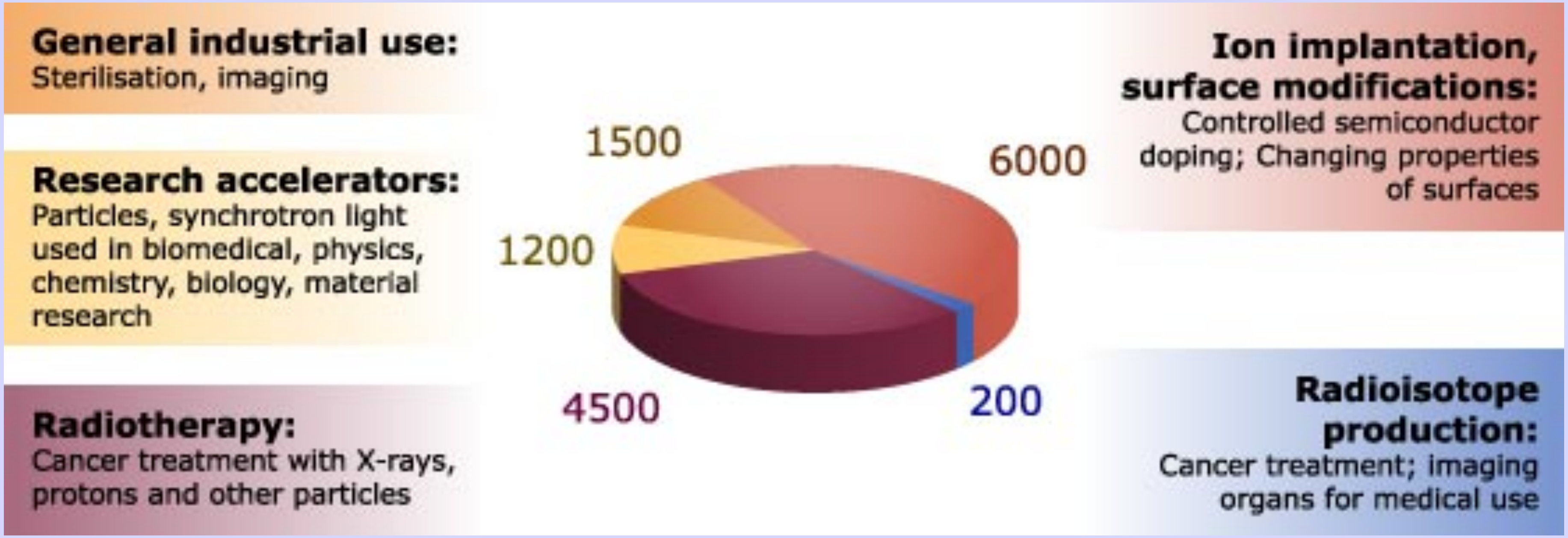


Use of Accelerators for cancer treatment

Acceleraters: developed in physics labs are used in hospitals

Around 9000 of the 17000 accelerators operating in the World today are used for medicine.

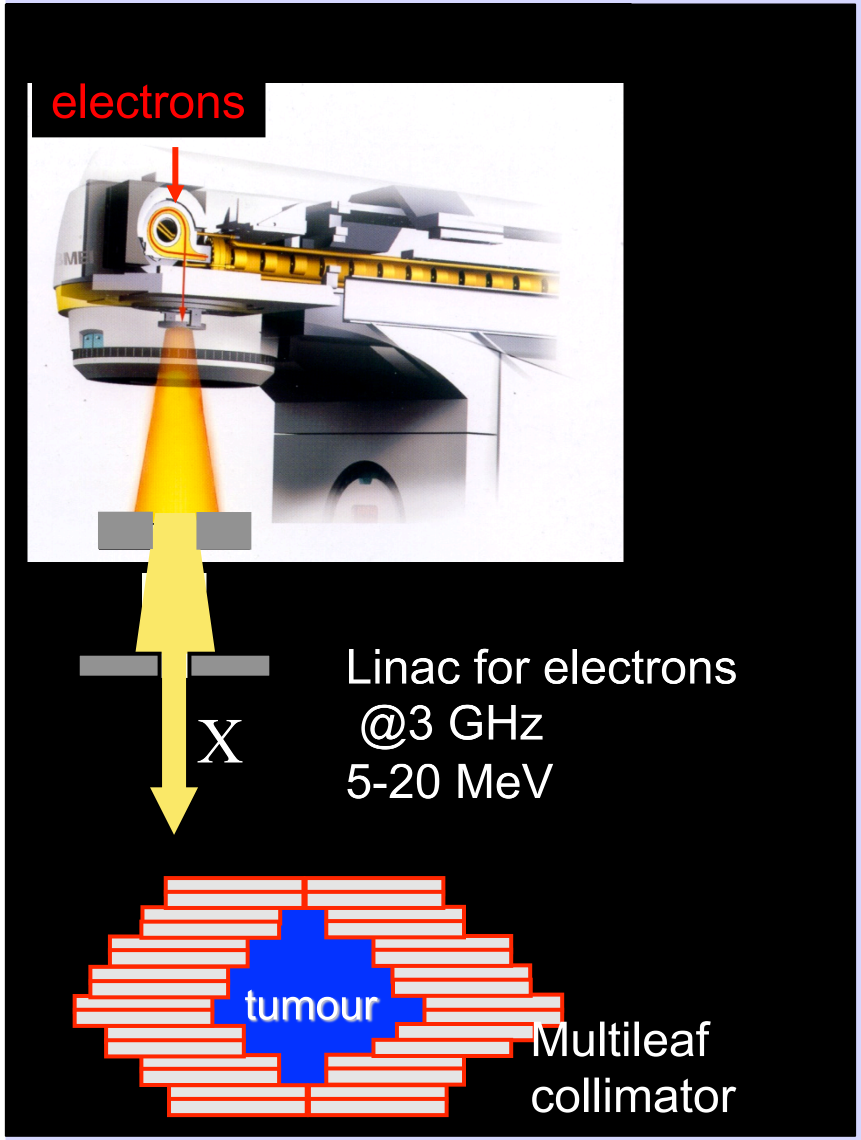
Use of Accelerators Today



Cancer Incidence

- Every year about 2 million new cases in Europe
- The rate of patients treated with RT will likely increase in the years to come
- The main cause of death between the ages of 45 and 65. Second most common cause of death

'Conventional' radiotherapy: linear accelerators dominate



Courtesy of Elekta

20 000 patients per year every
10 million inhabitants

1 linac every <250,000 inhabitants

Cancer and Radiotherapy in 21st Century

- RT is, nowadays, the least expensive cancer treatment method (around 5% of cost)
- Good cure rate (30-40%)
- Conservative (non-invasive, fewer side effects)
- There is no substitute for RT in the near future

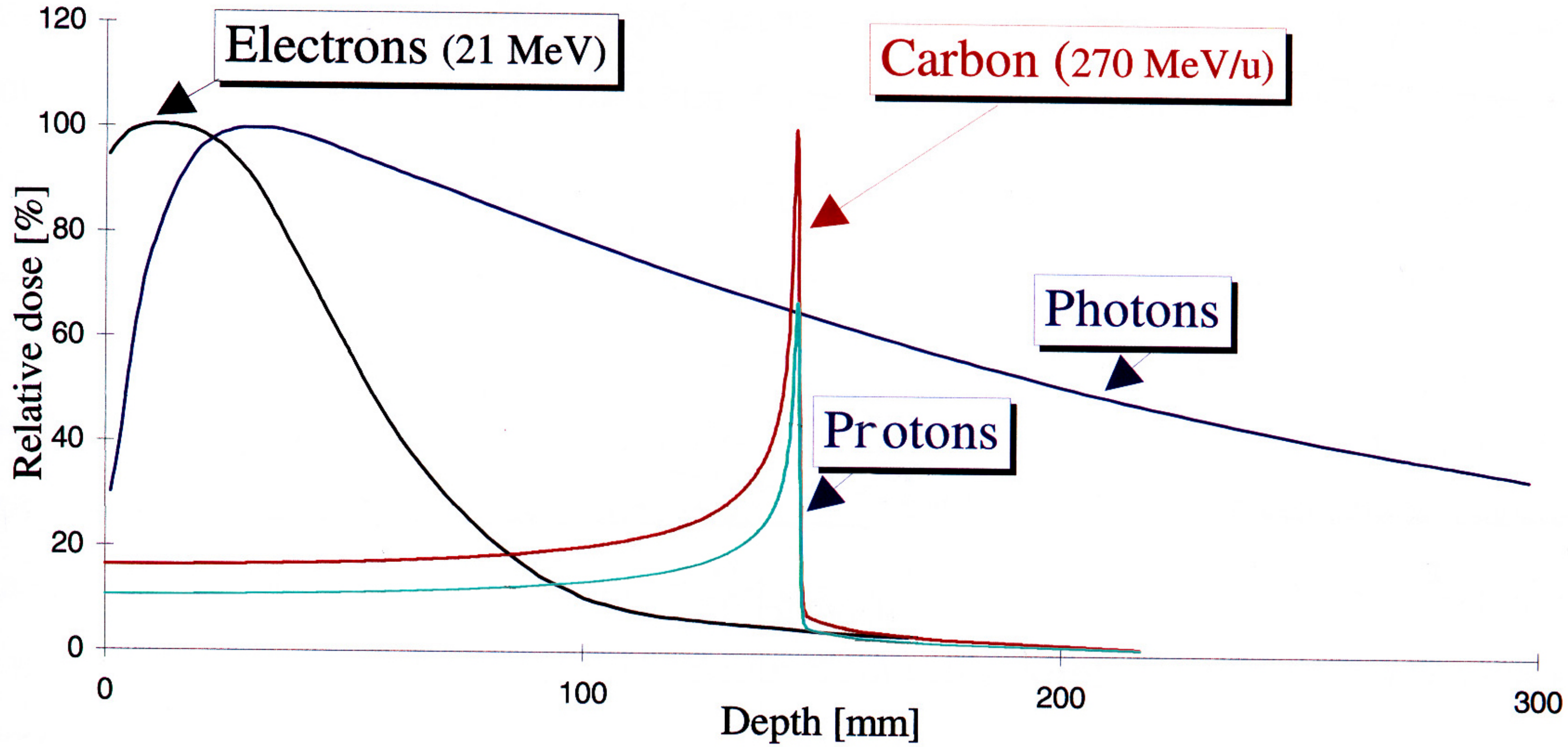
Present Limitation of RT: 30% of patients still fail locally after RT

(Acta Oncol, Suppl:6-7, 1996)

How to overcome failures?

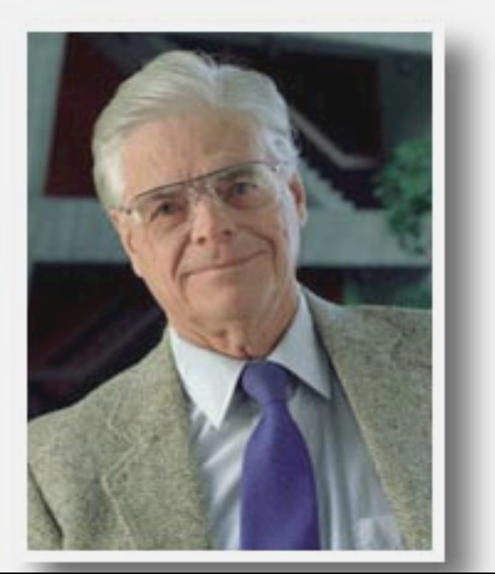
- Physics & treatment technology: dose escalation
- Imaging: MRI, PET, image registration
- Biology: altered fractionation, radiosensitization

Raymond Miralbell, HUG



Electrons (21 MeV)
Carbon (270 MeV/u)
Photons
Protons
Relative dose [%]
120
100
80
60
40
20
0
0
100
200
300
Depth [mm]

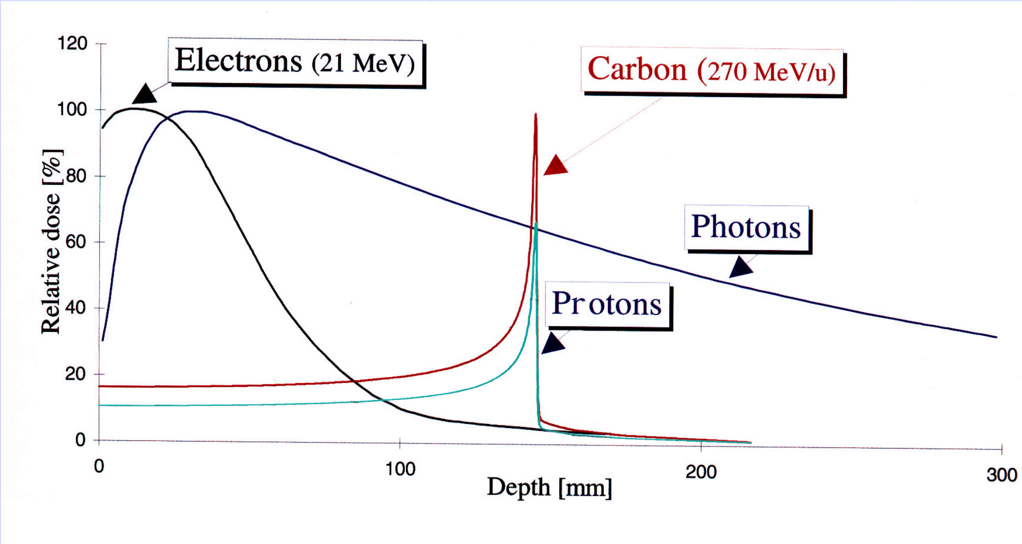
Hadrontherapy: all started in 1946



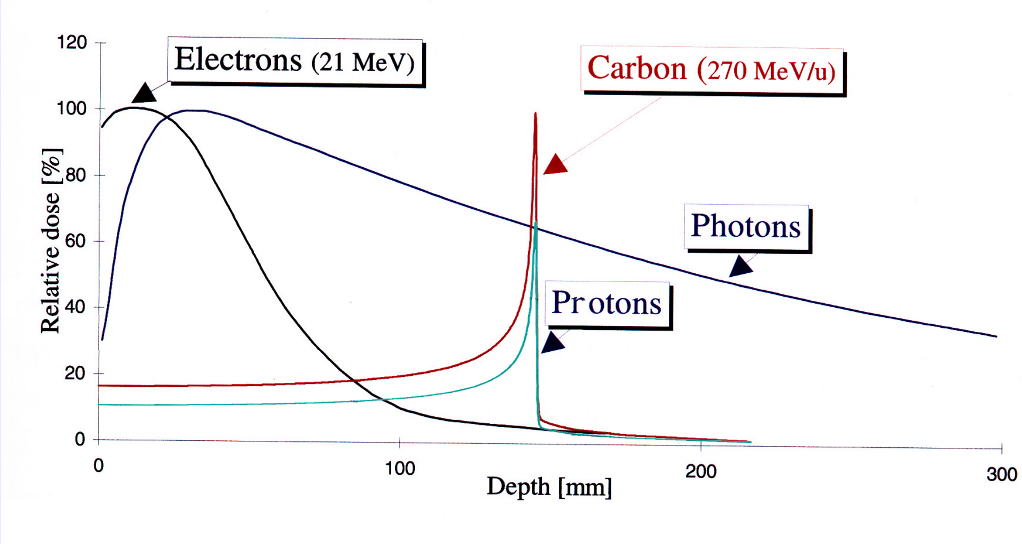
Founder and first director of Fermilab

In 1946 Robert Wilson:

- Protons can be used clinically
- Accelerators are available
- Maximum radiation dose can be placed into the tumour
- Proton therapy provides sparing of normal tissues



Hadrontherapy vs. radiotherapy

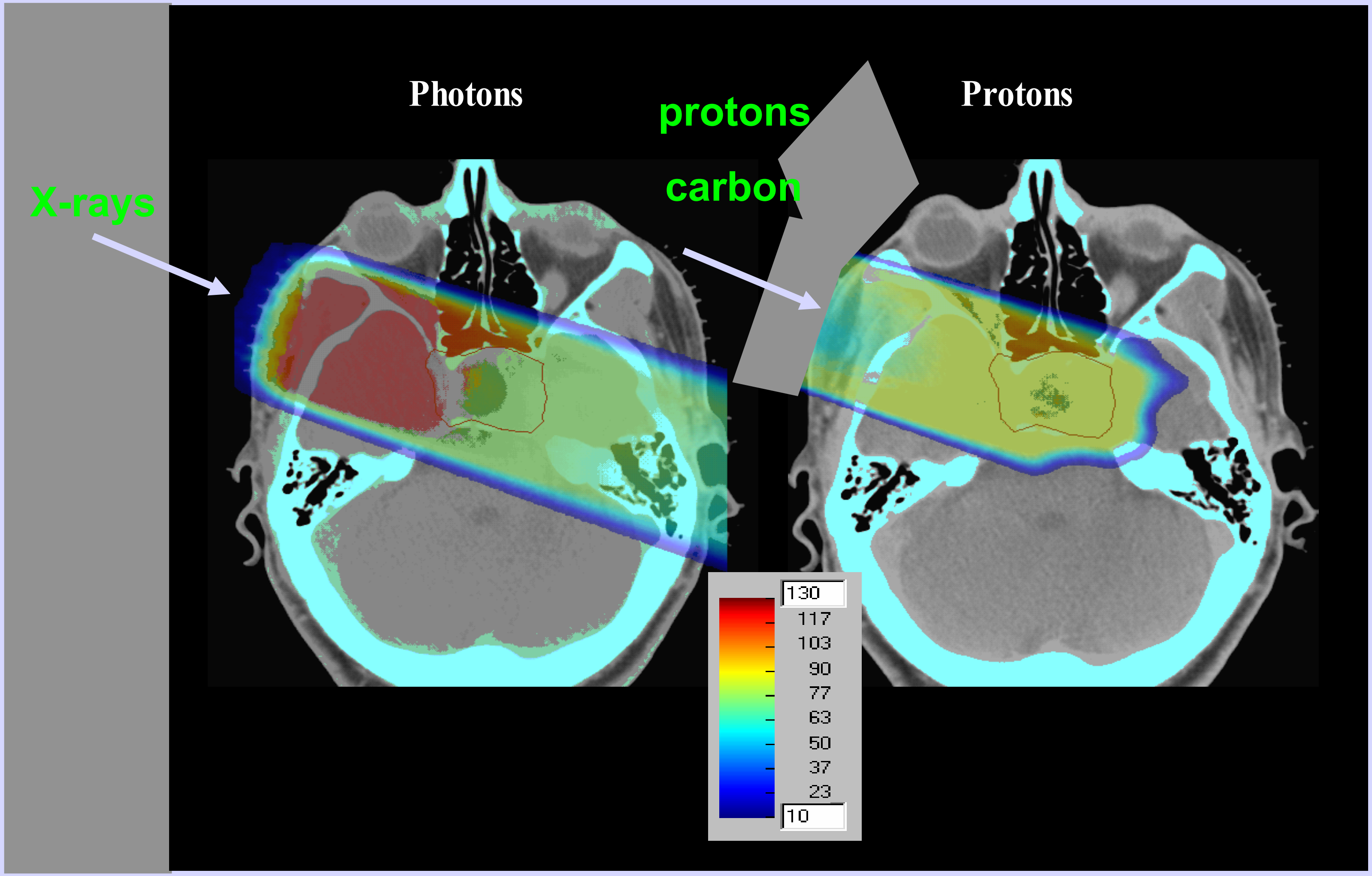


- Tumours close to critical organs
- Tumours in children
- Radio-resistant tumours

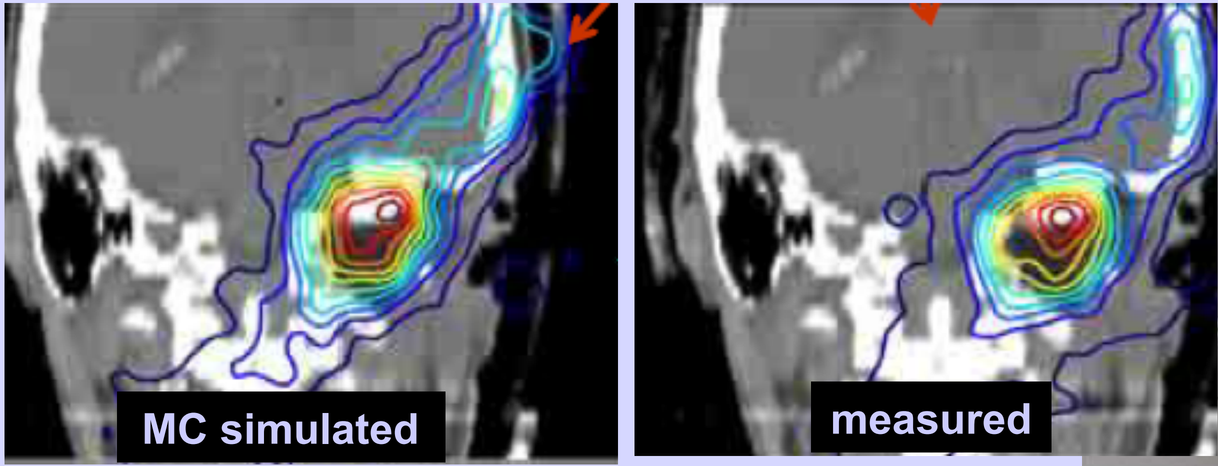
Photons and Electrons vs. Hadrons

Photons and Electrons	Hadrons
Physical dose high near surface	Dose highest at Bragg Peak
DNA damage easily repaired	DNA damage not repaired
Biological effect lower	Biological effect high
Need presence of oxygen	Do not need oxygen
Effect not localised	Effect is localised

Advantage of hadrontherapy



In-beam-PET for Quality Assurance of treatments

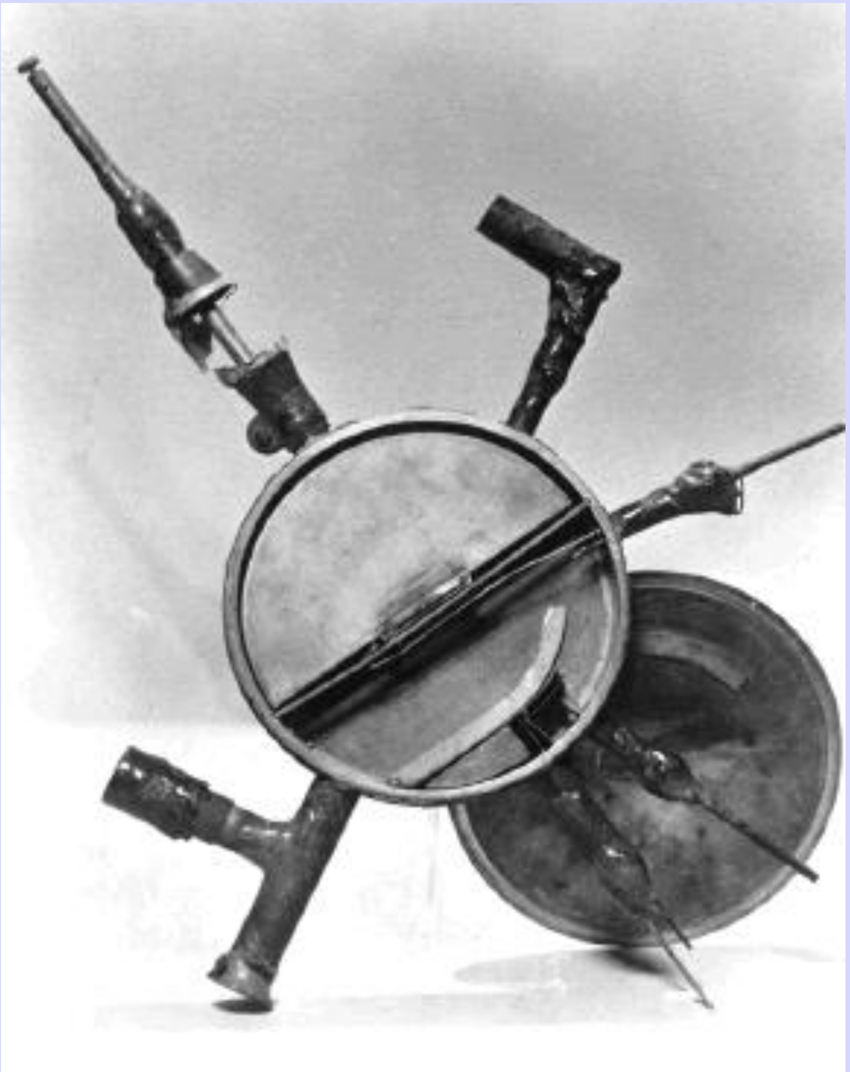


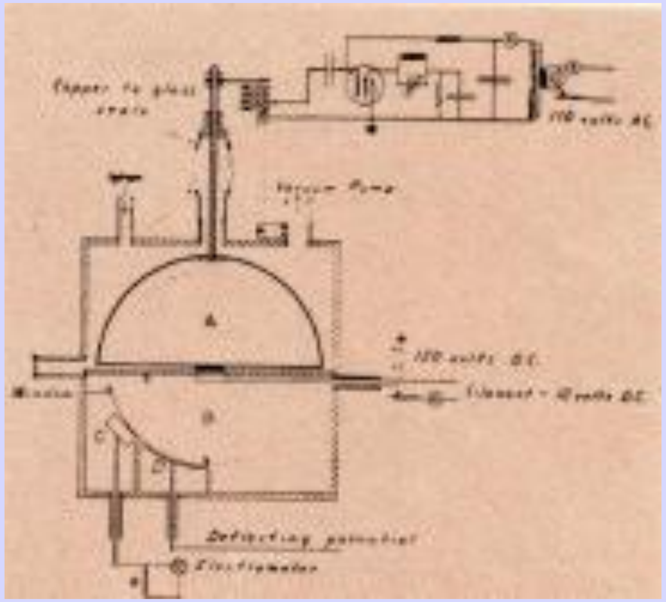
On-line determination of the dose delivered
First time in 110 years!

Modelling of beta⁺ emitters:

- Cross section
- Fragmentation cross section
- Prompt photon imaging
- Advance Monte Carlo codes

The First Successful Cyclotron……………..





The first successful cyclotron constructed by Lawrence and M. S. Livingston (1930).

12 cm in diameter.

184-Inch Cyclotron

1945

The first beam, November 1, 1947.

Grids and e-health

The GRID

The Aim of the GRID is to give access,

again easily and transparently,

Not only to simple information,

But also to all of the computing resources and storage distributed around the world

LHC data challenge

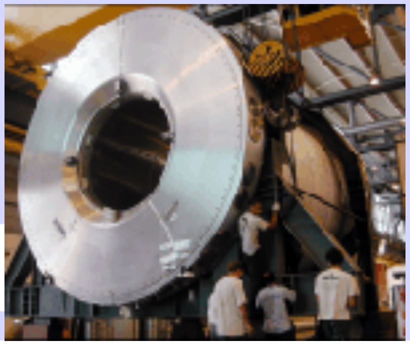
- 40 million collisions per second
- After filtering, 100 collisions of interest per second
- 10^{10} collisions recorded each year

~10 Petabytes/year of data
~10 000 times the world annual book production,
~20km CD stack

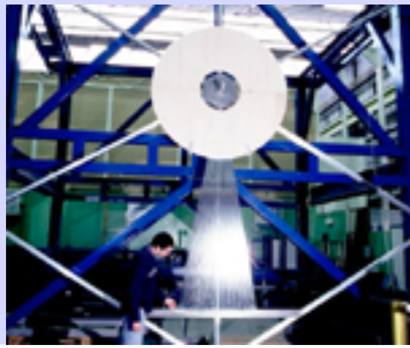
CMS

LHCb

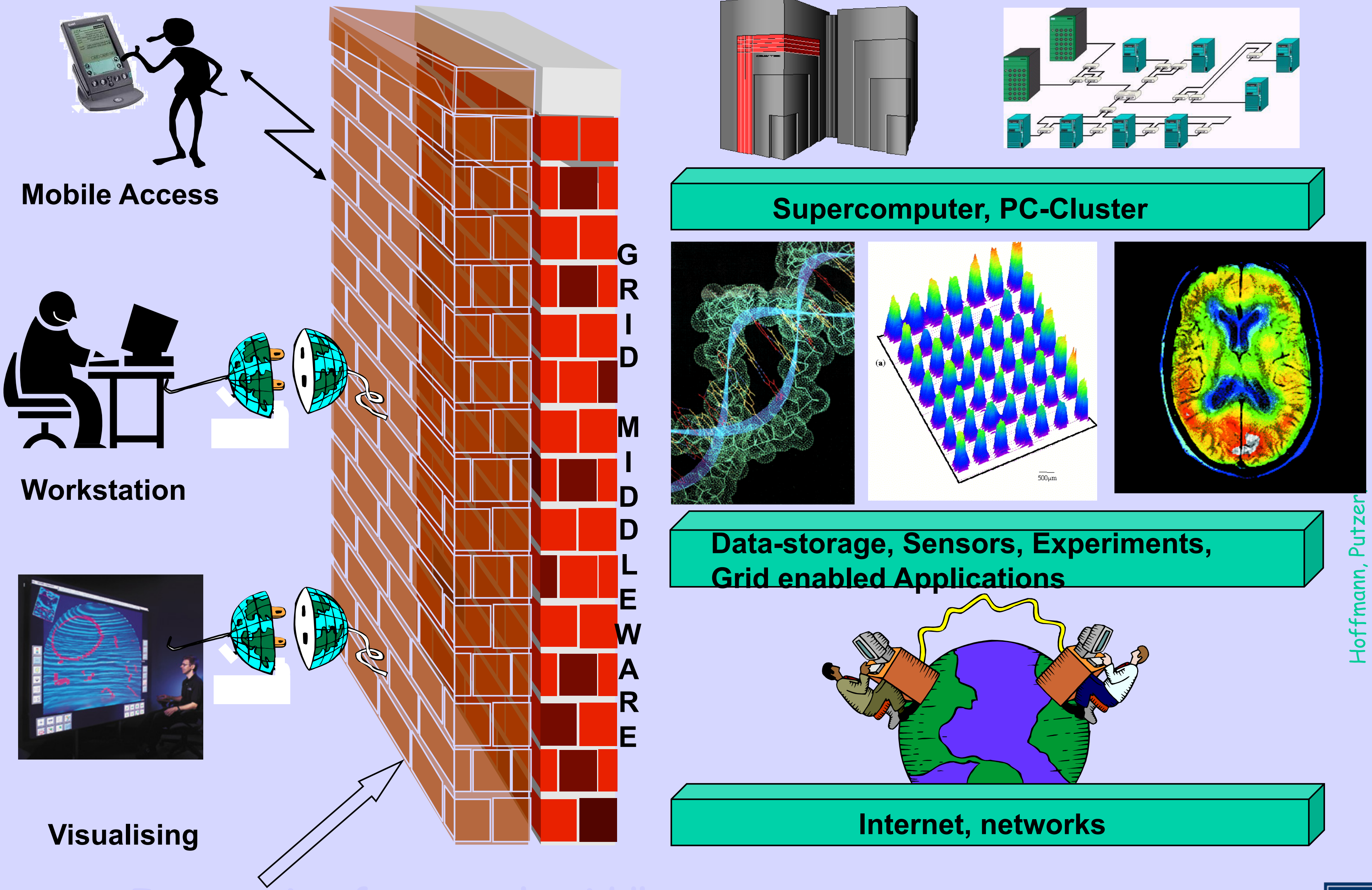
ATLAS



ALICE



The User connects to his "Virtual Laboratory" or "Workbench Environment"



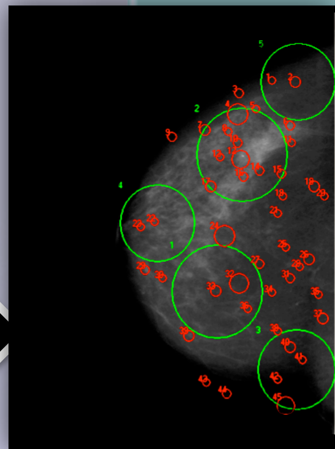
Integrating framework middleware

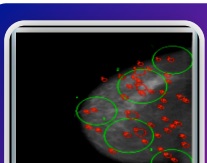
Early example of health application on the grid

Mammogrid

A Grid-powered Mammography Database

- Second Opinion
- Cancer Screening
- Education and Training
- Reference Database / Repository





Oncology

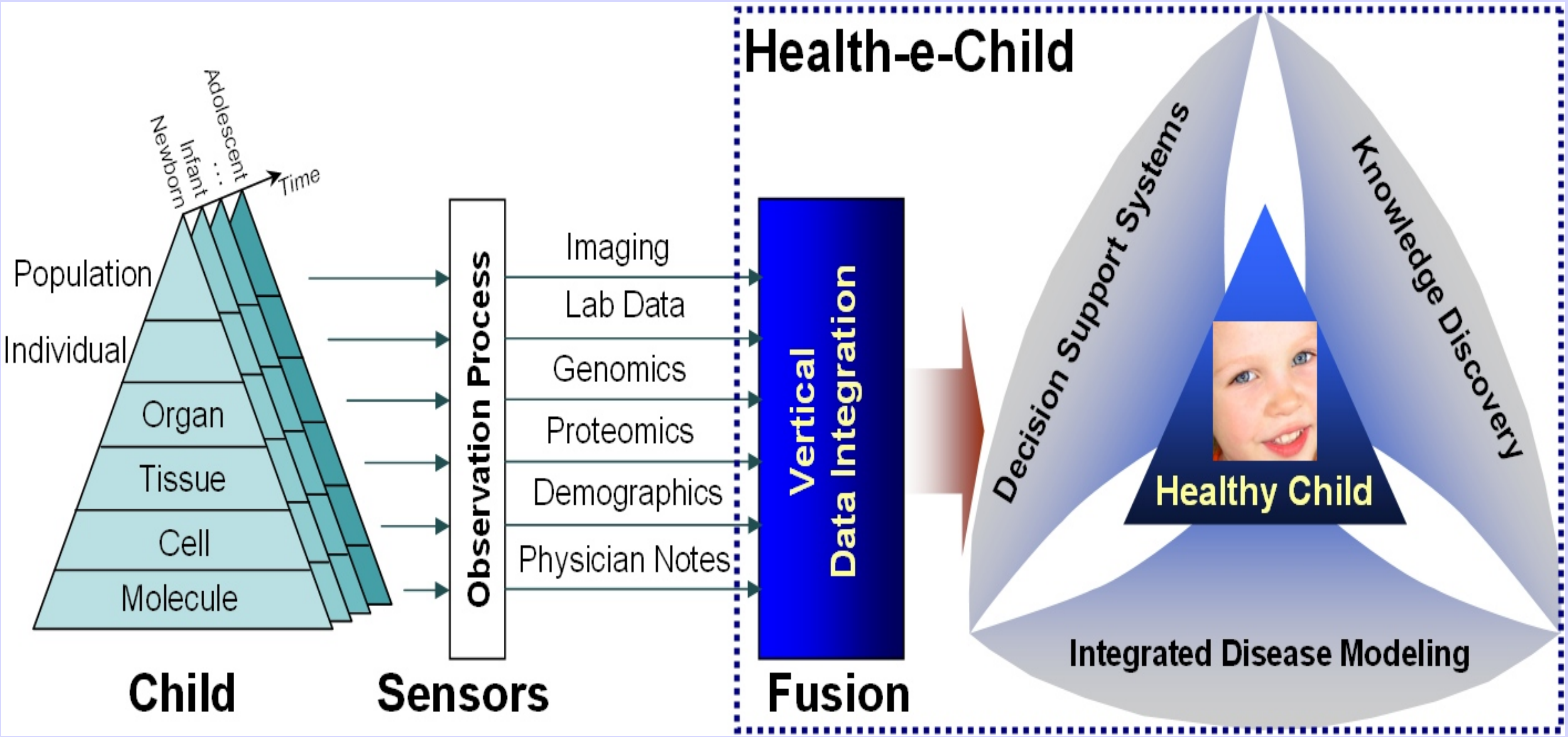
- Breast Cancer (micro-
…tions and masses)

From: **David MANSET**, CEO MAAT France, www.maat-g.com

MammoGrid Project

- To manage health care information for screening
- Acquisition of large sample of mammograms
- Standardization of mammograms
- Distributed data management system, cross-institute, cross-country queries
- Sharing of computing resources for the purpose of optimizing data storage and execution of computing-intensive algorithms\
- To assist health operators in their work environment and exchange data and practices

Health-e-Child on a slide



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