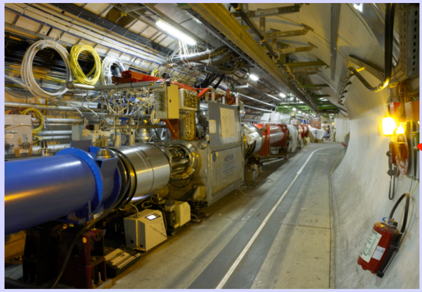
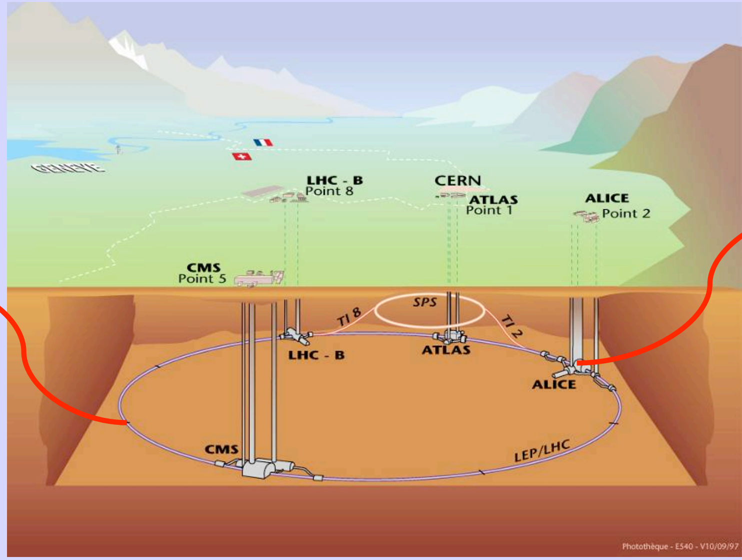
CERN
from particle physics to healthcare

Manjit Dosanjh
Advisor for Life Sciences

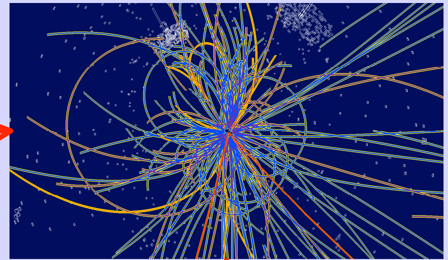
Three key technology areas at CERN:

Accelerating particle beams

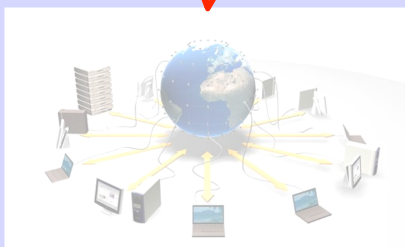




Detecting particles



Large-scale computing (Grid)

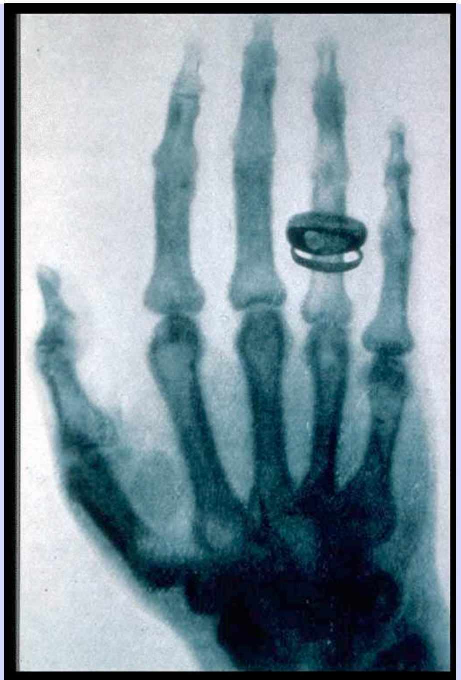


X-Rays, the fastest technology transfer example

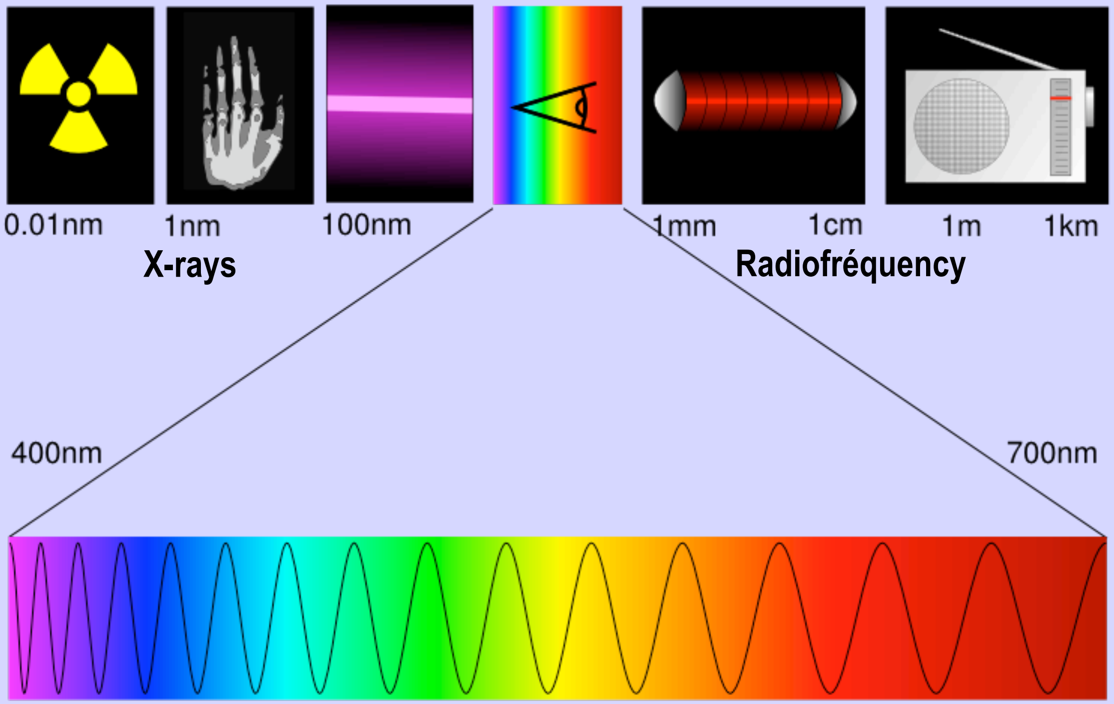
- **On November 8, 1895 Röntgen discovered X-Rays**
- **On November 22, 1895 he takes the first image of his wife's hand**

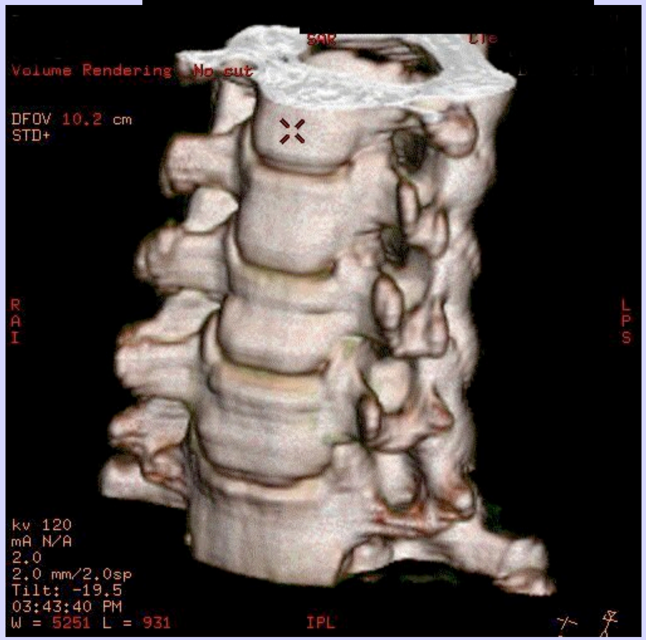
Röntgen received the first Nobel prize in physics in 1901

History: Discovery of X-rays



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





The beginnings of modern medical physics

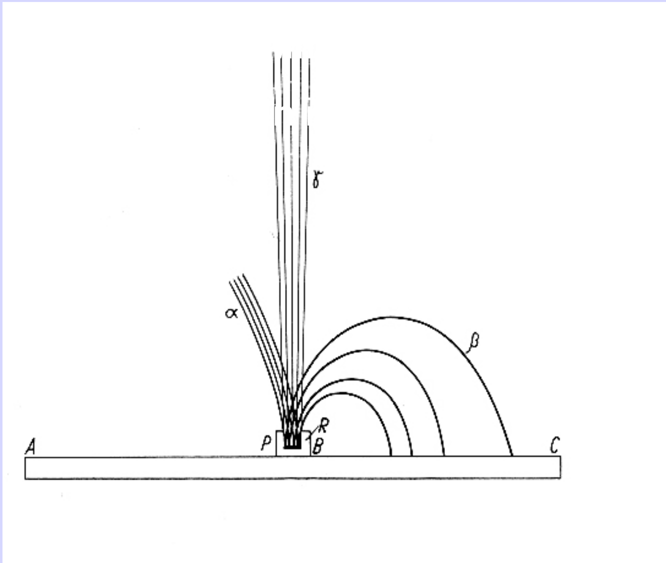
Marie Curie **Pierre Curie**
(1867 – 1934) **(1859 – 1906)**

1898

Discovery of radium

used

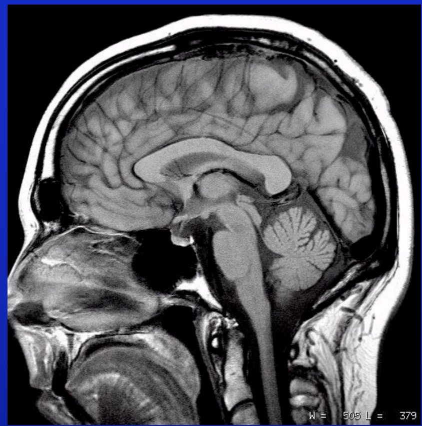
immediately for "Brachytherapy"



MRI, Magnetic Resonance Imaging

The Nobel Prize in Physics 1952

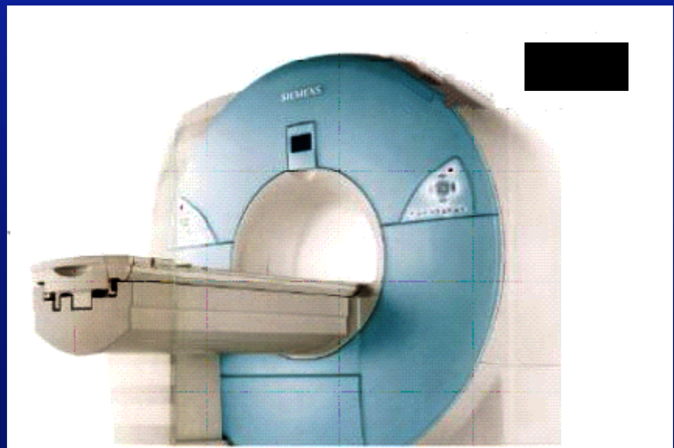
Felix Bloch
Physicist Stanford



Edward M. Purcell
Physicist Harvard

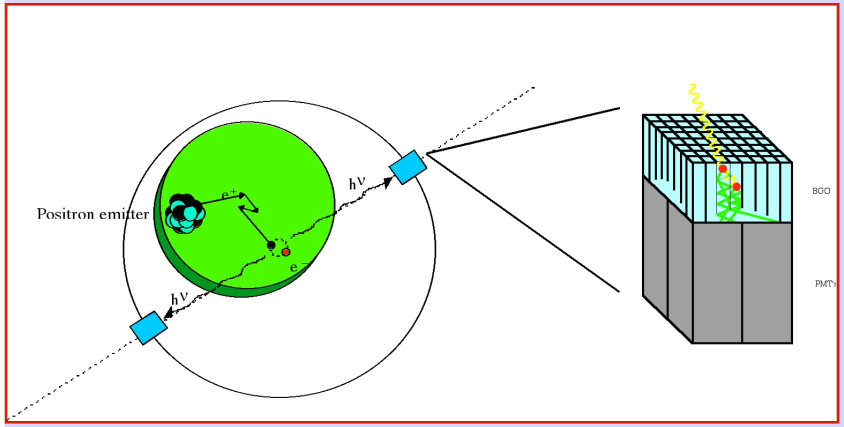
The Nobel Prize in Physiology or Medicine 2003

Sir Peter **Mansfield**
Physicist Nottingham

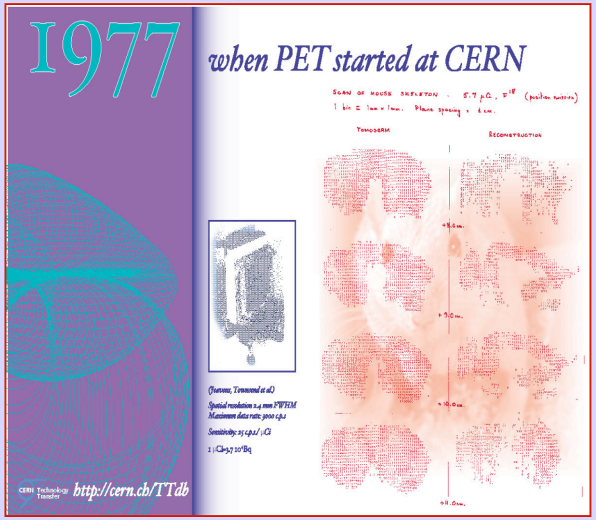


Paul C. **Lauterbur**
Chemist Uni. Illinois

Physics to medicine

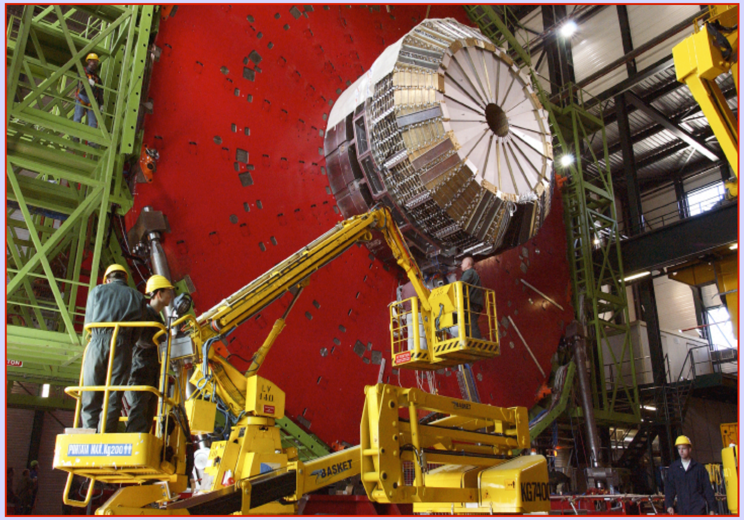


Idea of PET

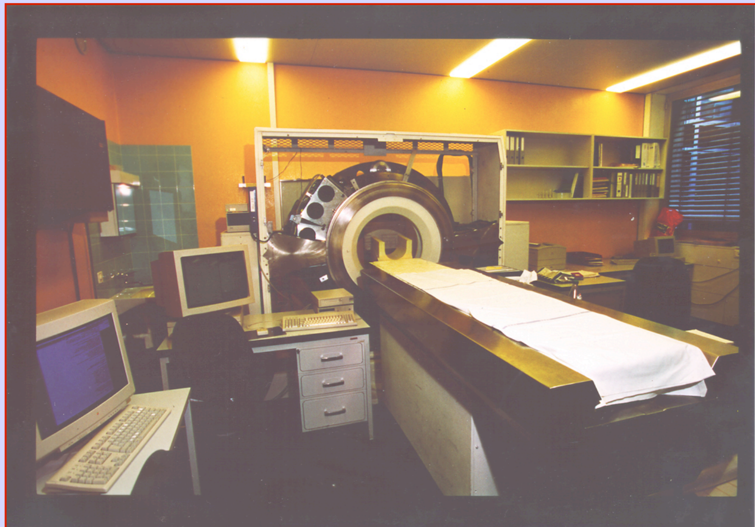


PET today

Photon detection used for calorimetry



CMS calorimeter



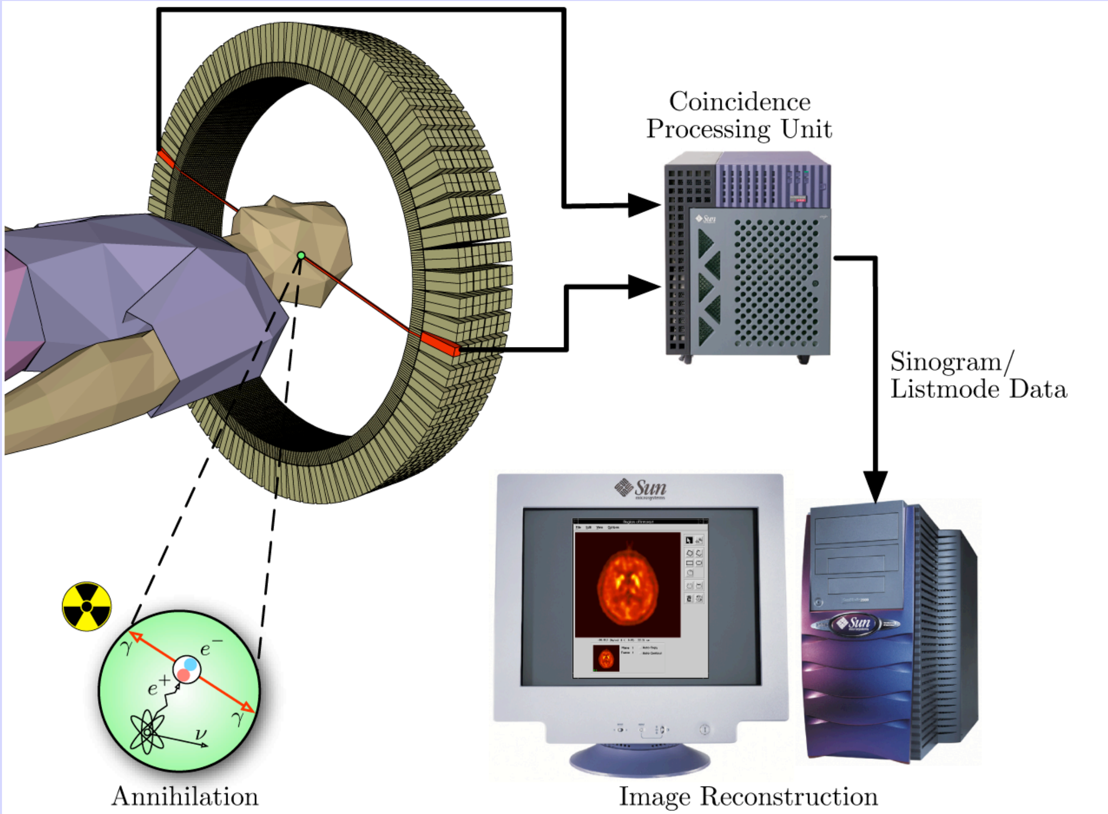
Medical Imaging - PET (Positron Emission Tomography)

Functional Analysis

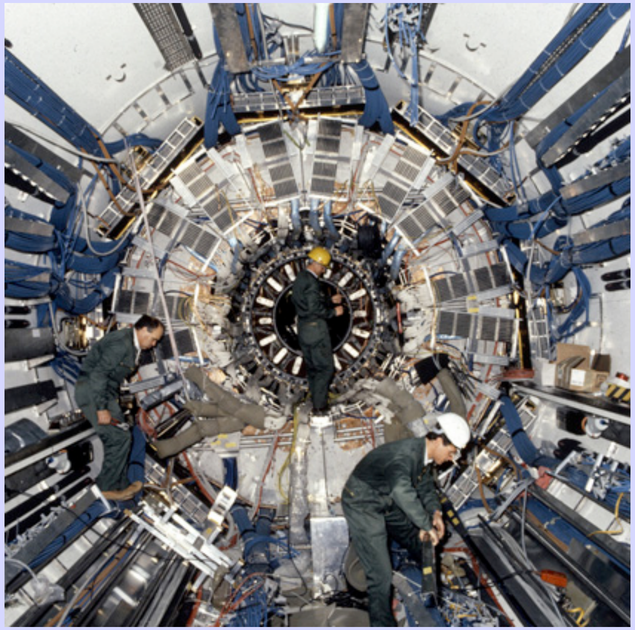
The system detects pairs of gamma rays emitted indirectly by a positron-emitting radionuclide (tracer), which is introduced into the body on a biologically active molecule.

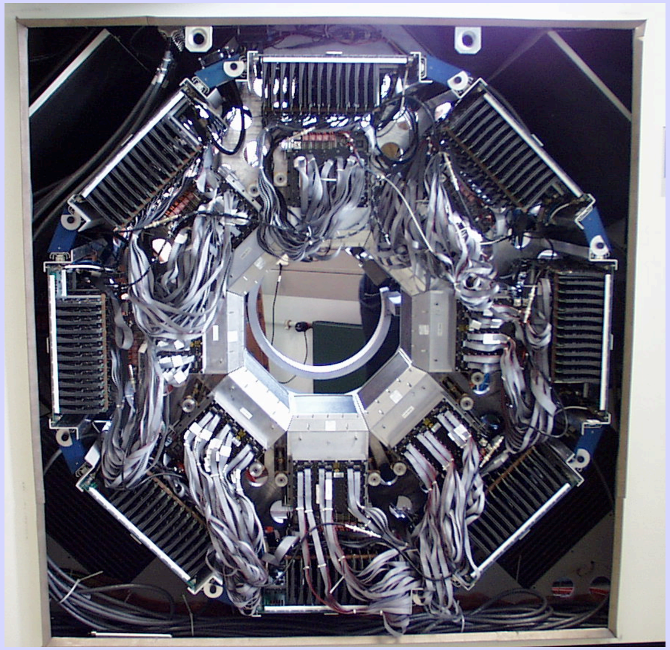
Images of tracer concentration in 3-dimensional space within the body are then reconstructed by computer analysis.

Crystals developed for LHC detectors are used in PET Scanners.



Similar challenges detectors

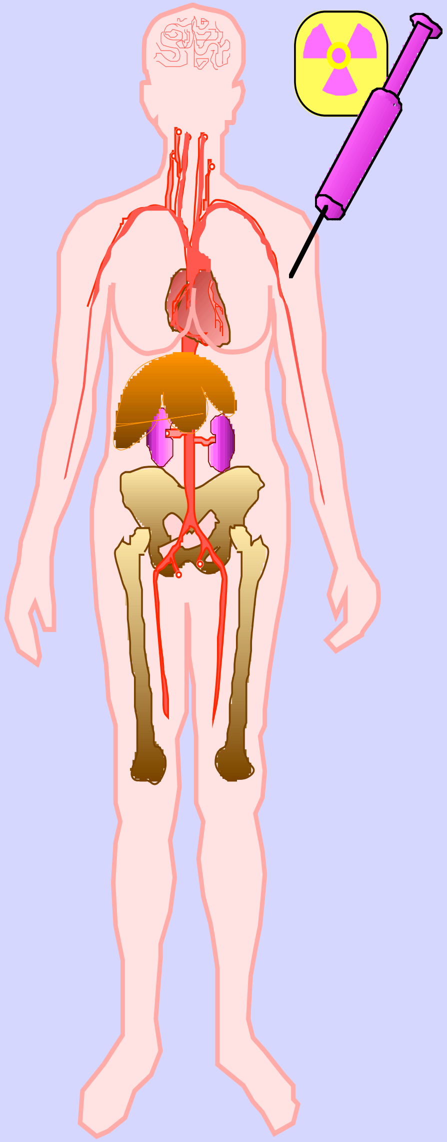




Similar challenges for PET and HEP detectors

- 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)

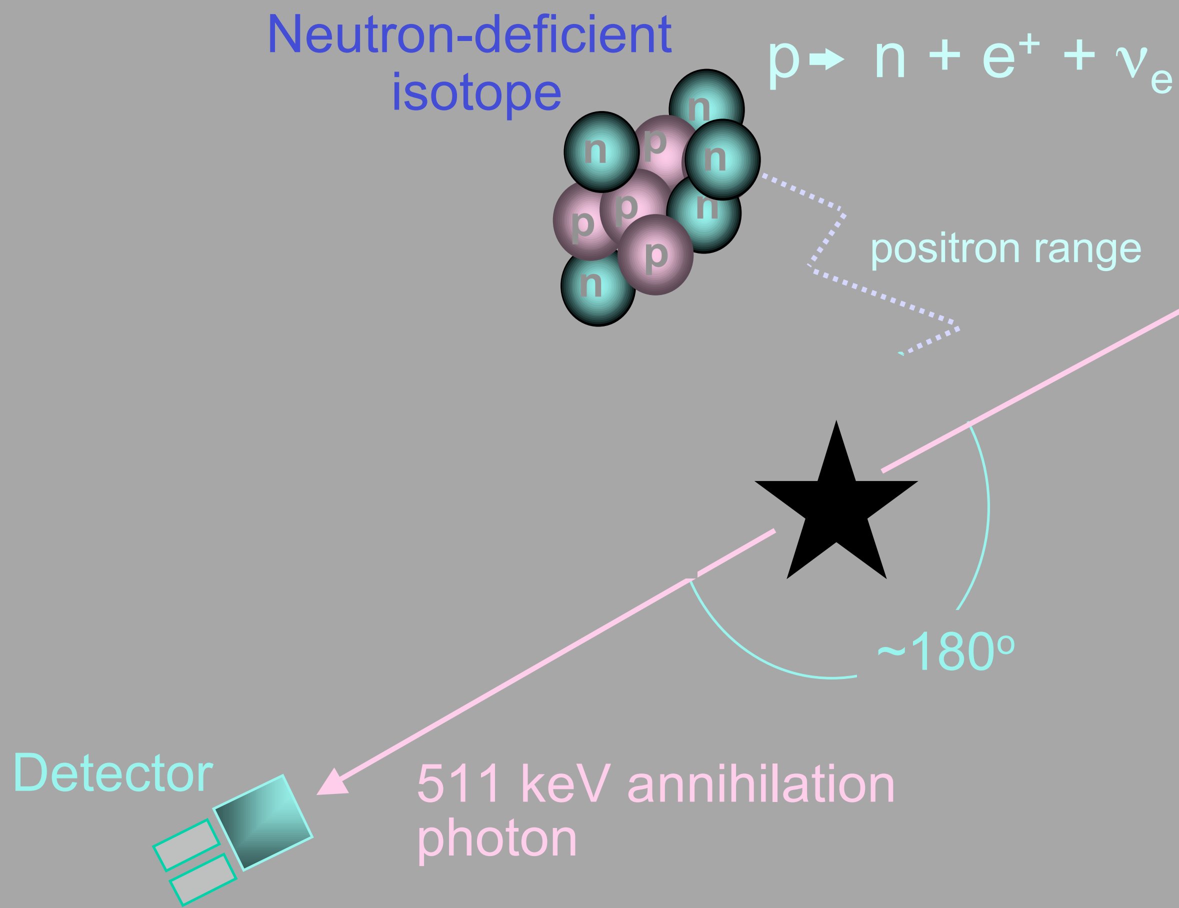
Inject Patient with Radioactive Drug



- 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)

Crystal Clear Collaboration

-New scintillators :

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

- new photodetectors (Avalanche PhotoDiodes)

-new low noise front end electronics

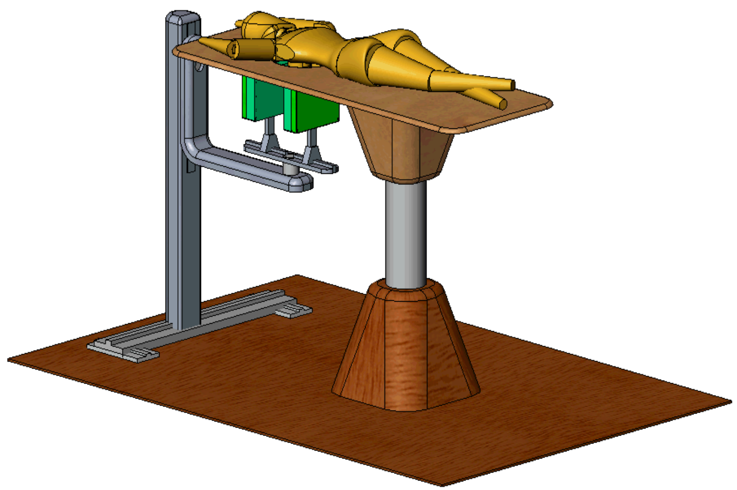
-new intelligent DAQ systems with pipeline and parallelized architecture

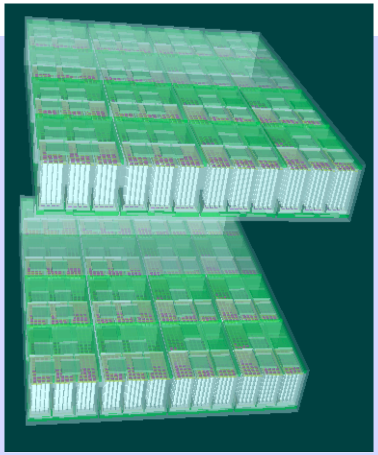
-better simulation GEANT 4

-- better reconstruction algorithms

Positron Emission Mammography
CRYSTAL CLEAR Collaboration

Model of the PEM detector





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

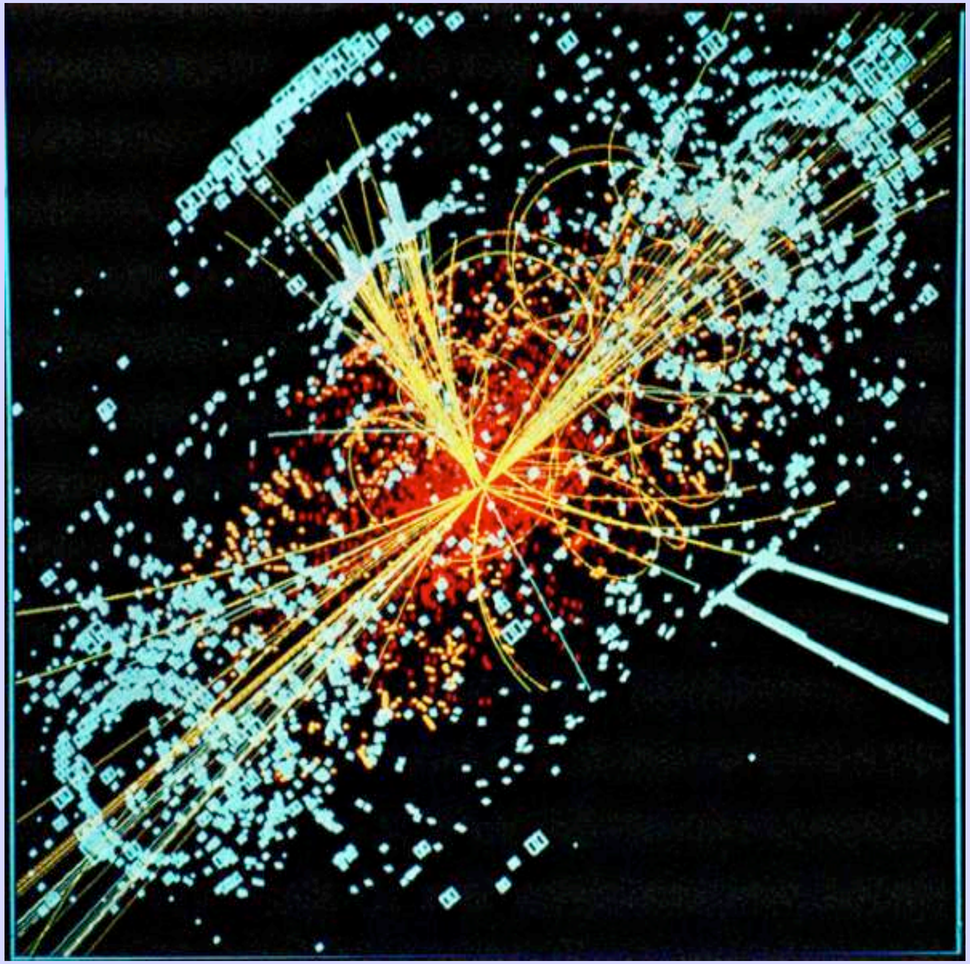
- **Spatial resolution 1-2 mm**
- **High counting sensitivity**
- **Short PET exams**
- **Compatible X-Ray mammography**
- **Compatible stereotactic biopsy**

Technical characteristics:

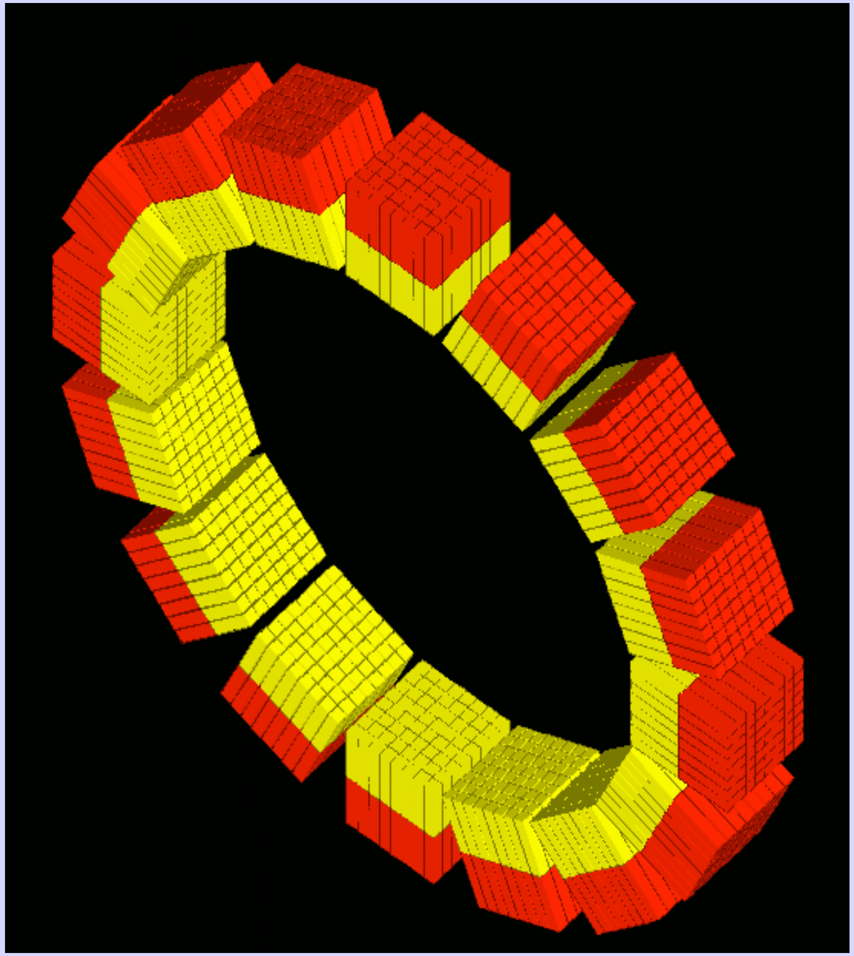
- 6000 crystals 2x2x20 mm
- Avalanche Photodiodes (APD)
- Low noise electronics
- High rate data acquisition
- Spatial resolution 1-2 mm
- Breast and axila region

Simulation

Higgs event at LHC (CMS) with Geant4

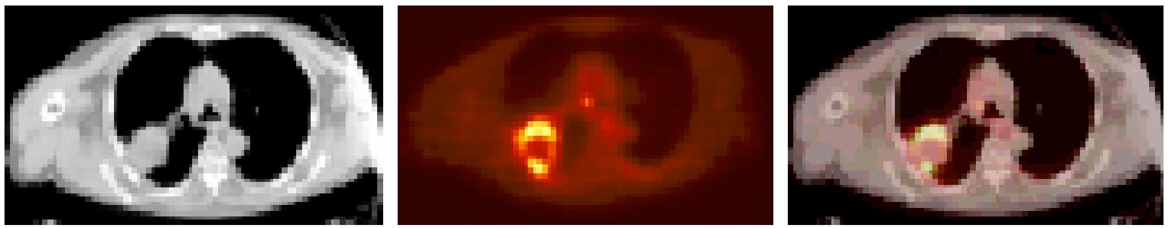


ClearPET with GATE: Geant4 Application for Tomographic Emission

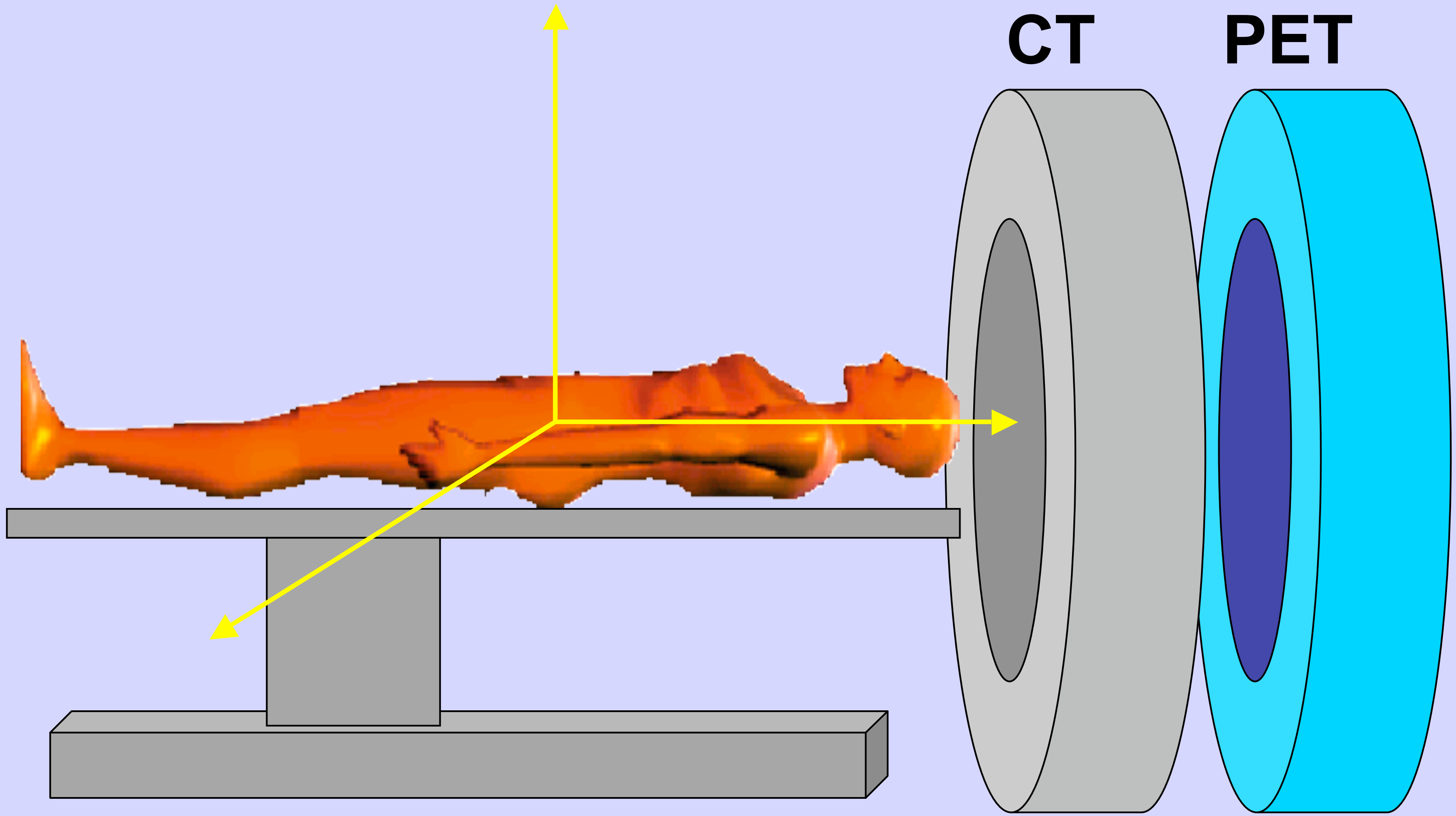


Multi-modality imaging

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

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

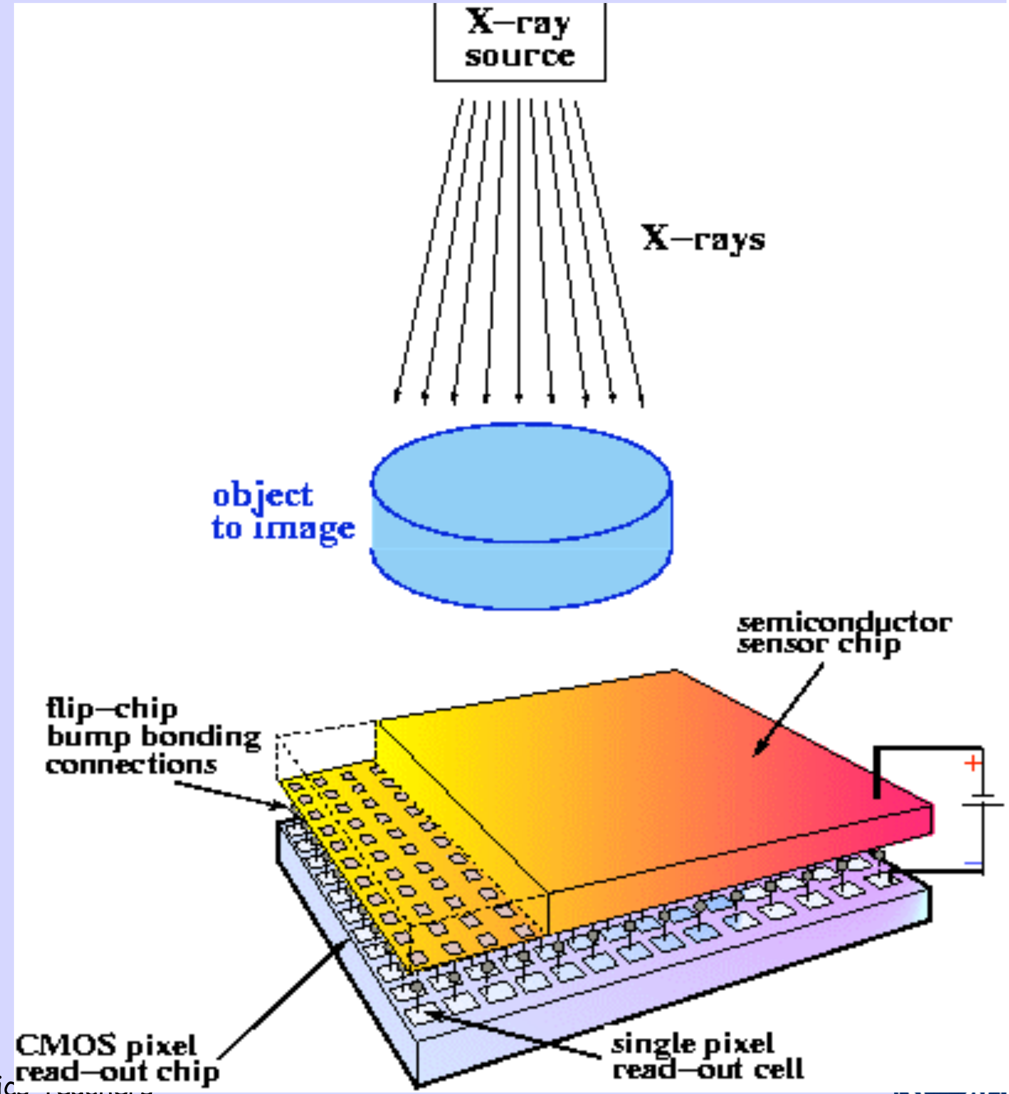
- **Main properties:**

Fully digital device

Very high space resolution

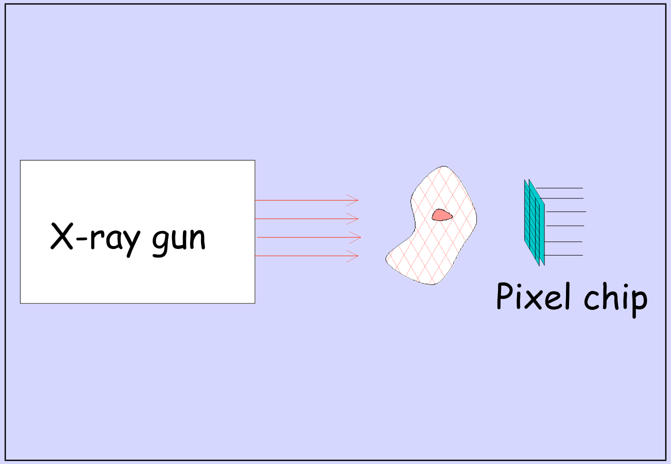
Very fast photon counting

Good conversion efficiency of low energy X-rays



MEDIPIX2

Ga-As array detector bump bonded on a digital Silicon counter especially developed for X-rays Radiography



High Energy Physics original development:
Particle track detectors

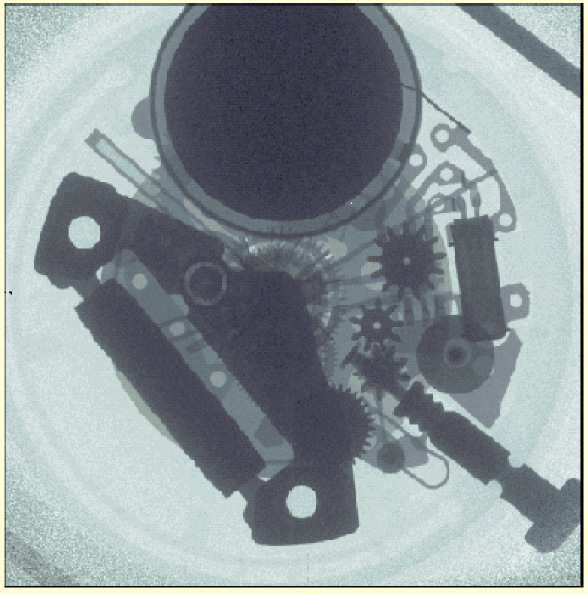
Main technologies involved:
Micro-electronics 0.25 mm C-MOS technology
Flip chip technology
Smart electronics

Main properties:
Fully digital device
Very high space resolution over small areas
Very fast photon counting
Good conversion efficiency of low energy X-rays

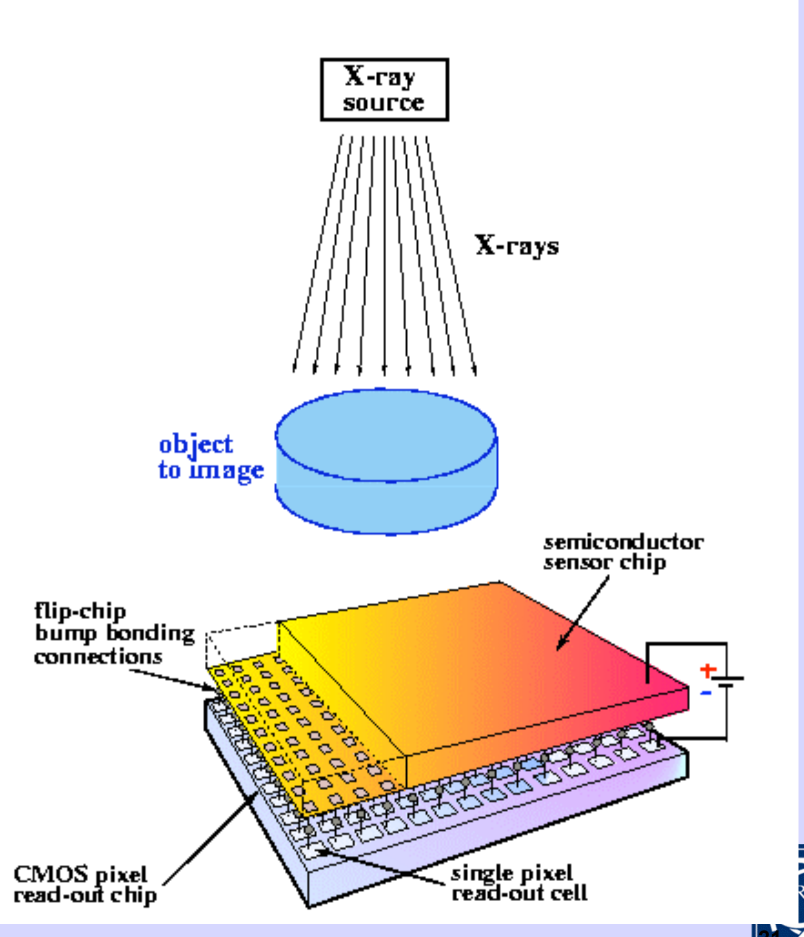
Status of the project:
Design of MEDIPIX2 based on successful MEDIPIX chip in progress

Semiconductor detectors - Medipix

- High contrast, high spatial resolution single photon counting(256x256 pixels)
- Suitable for direct X-ray conversion in various semiconductor X-ray converters connected through bump bonding
- 55x55 um cell size with individually adjustable discriminator threshold
- Access to spectrometric information



5 frame/sec. Limited by DAQ software

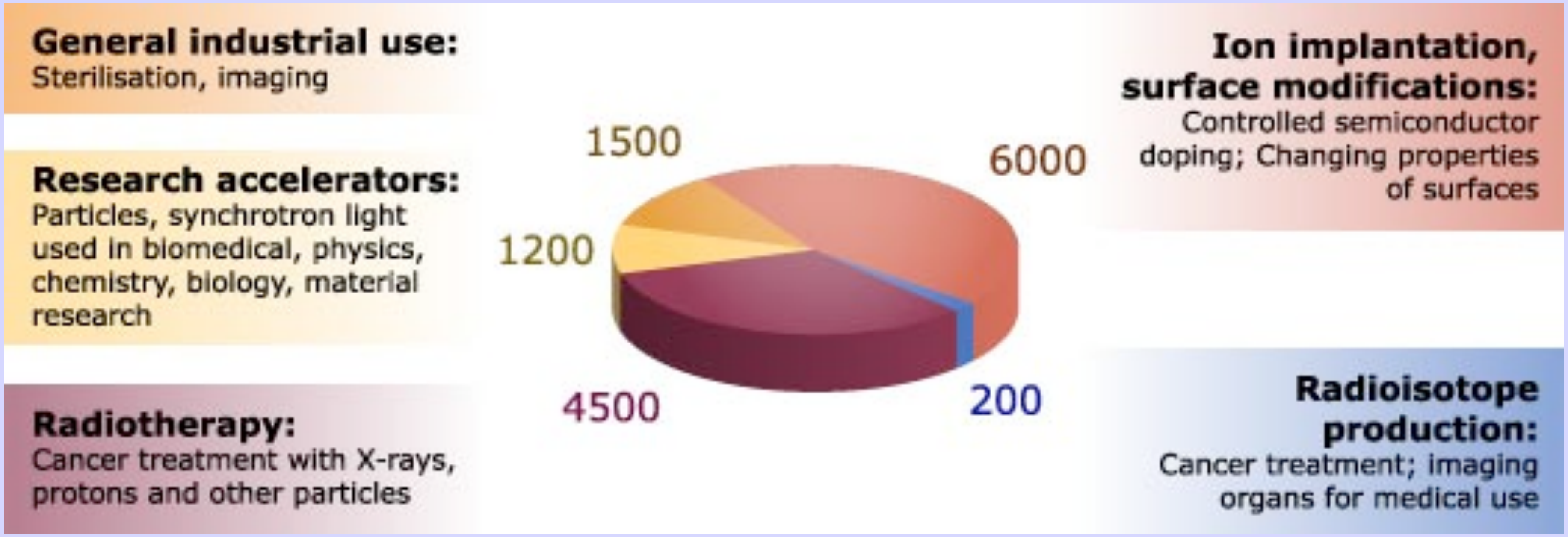


Use of Accelerators for cancer treatment

Acceleratorss: 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

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

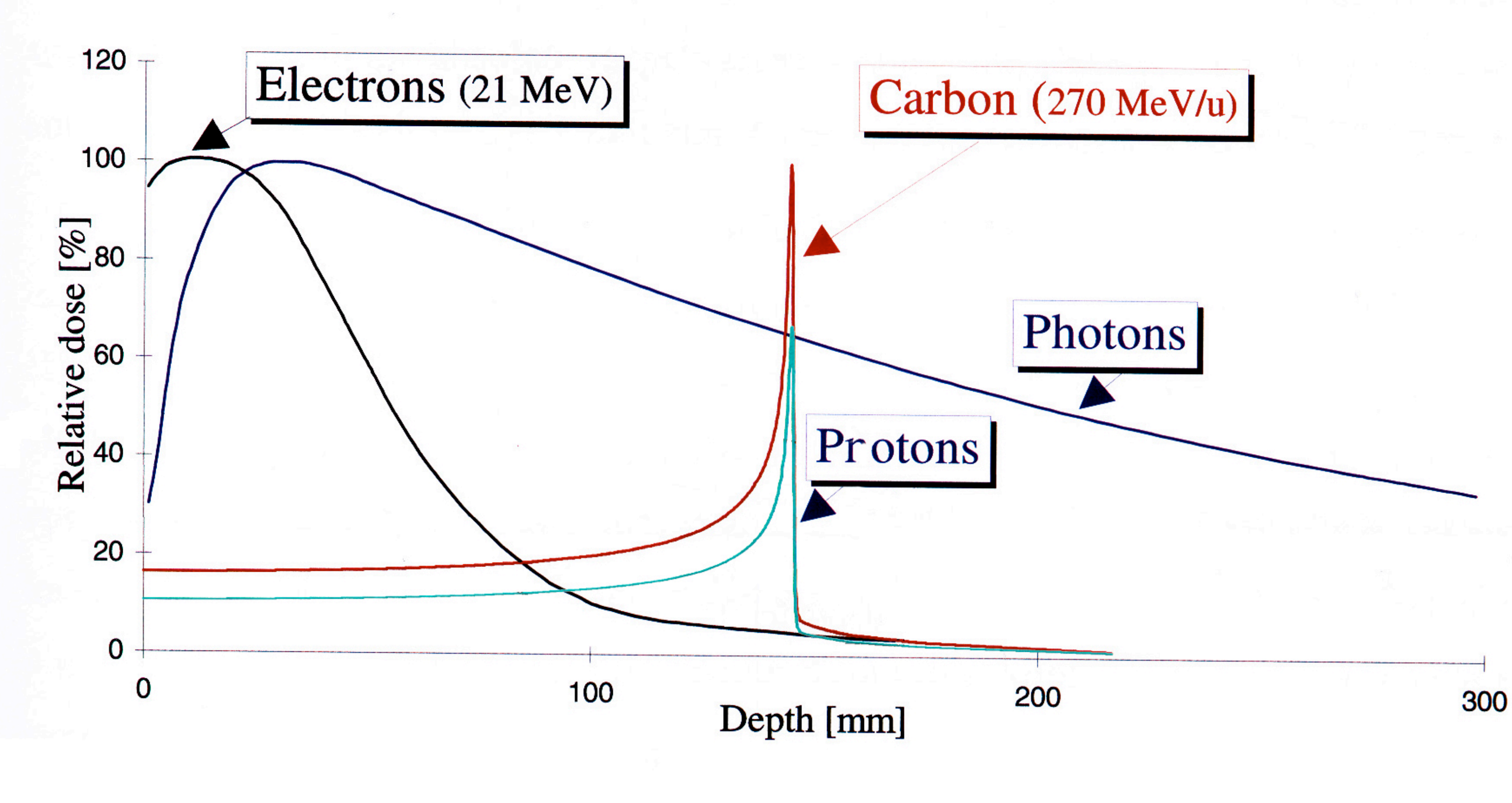
Present Limitation of RT: 30% of patients still fail locally after RT

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

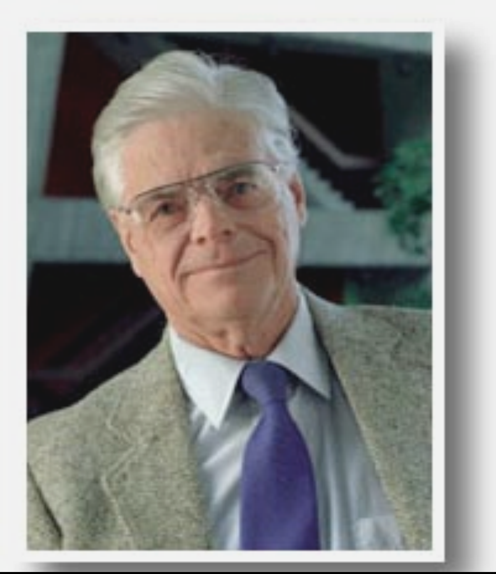
How to overcome failures?

- 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 [%]
Depth [mm]
0
20
40
60
80
100
120
0
100
200
300

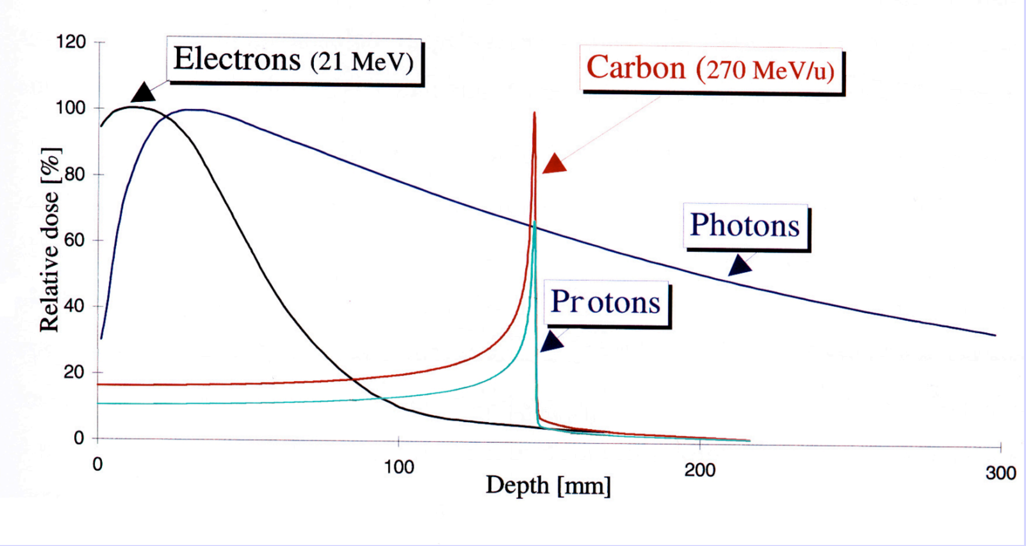
Hadrontherapy: all started in 1946



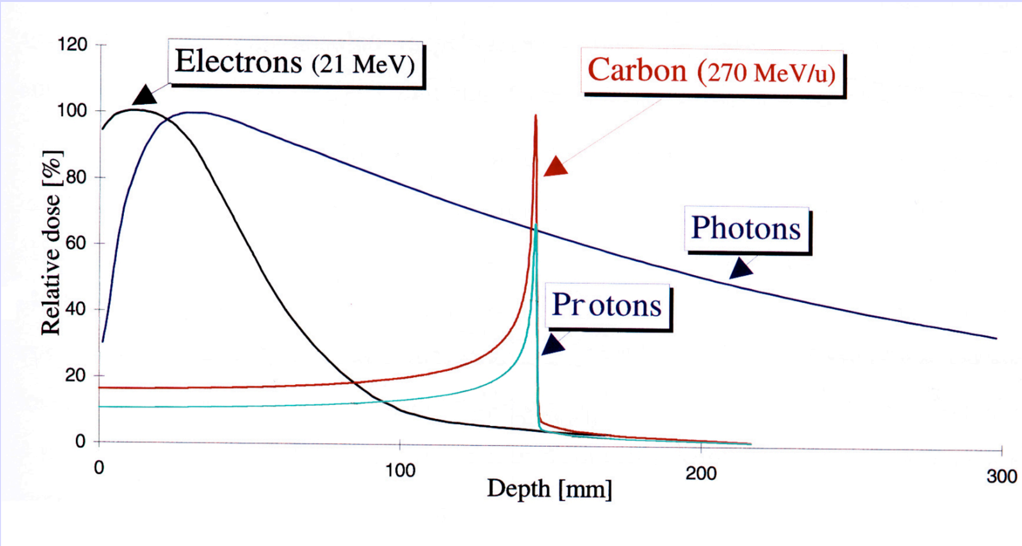
Founder and first director of Fermilab

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

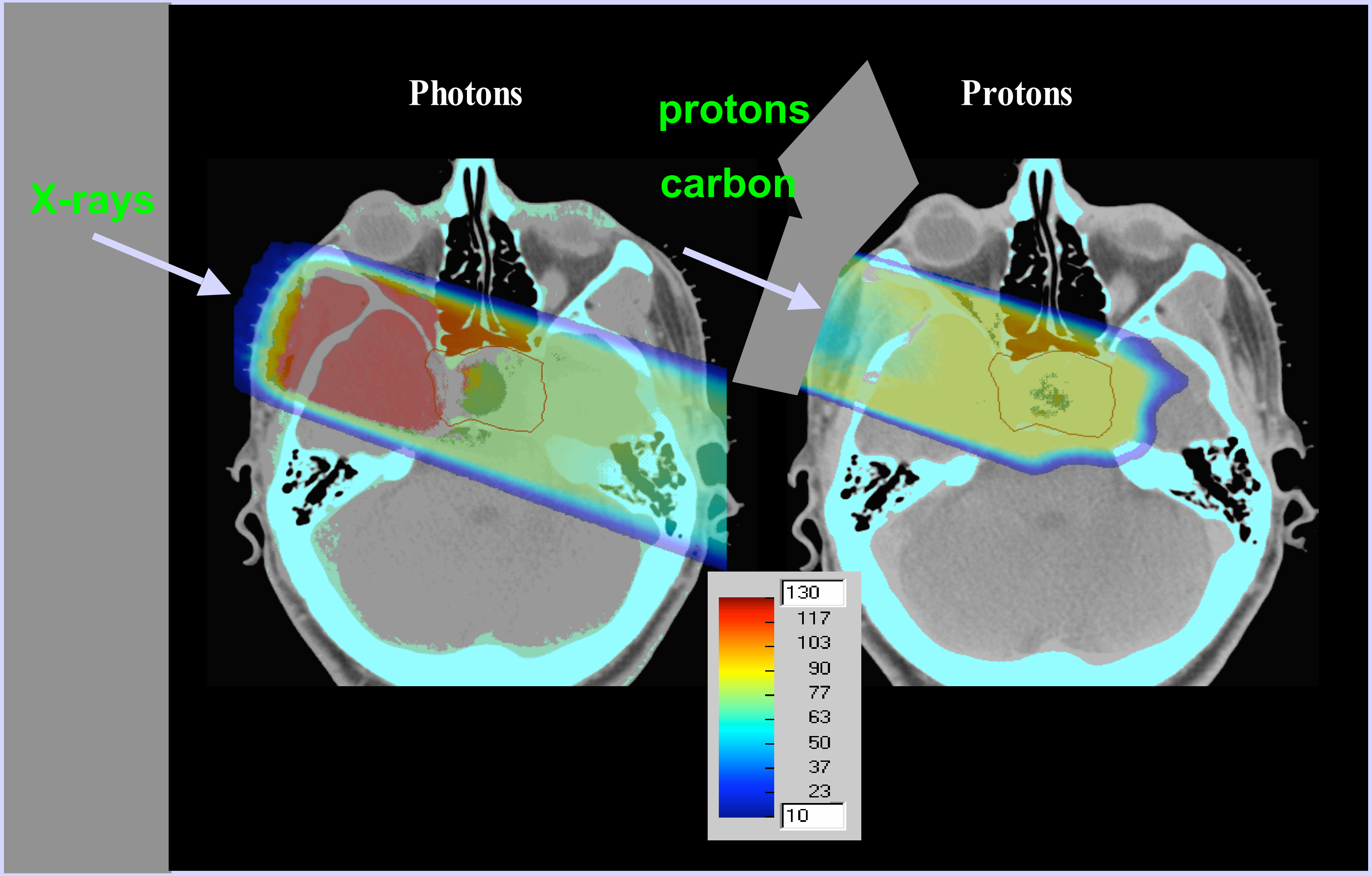
Photons and Electrons

- Physical dose high near surface
- DNA damage easily repaired
- Biological effect lower
- Need presence of oxygen
- Effect not localised

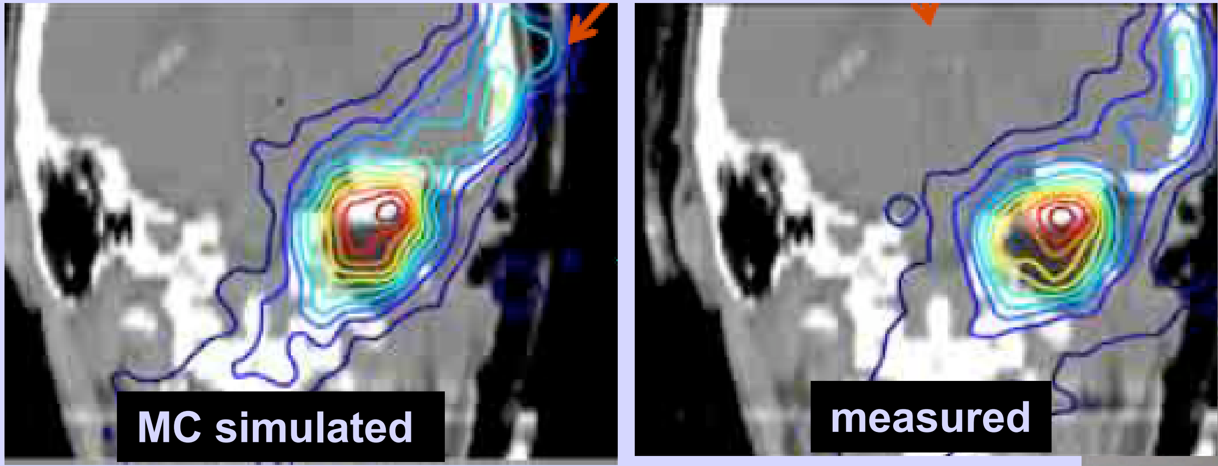
Hadrons

- Dose highest at Bragg Peak
- DNA damage not repaired
- Biological effect high
- Do not need oxygen
- 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