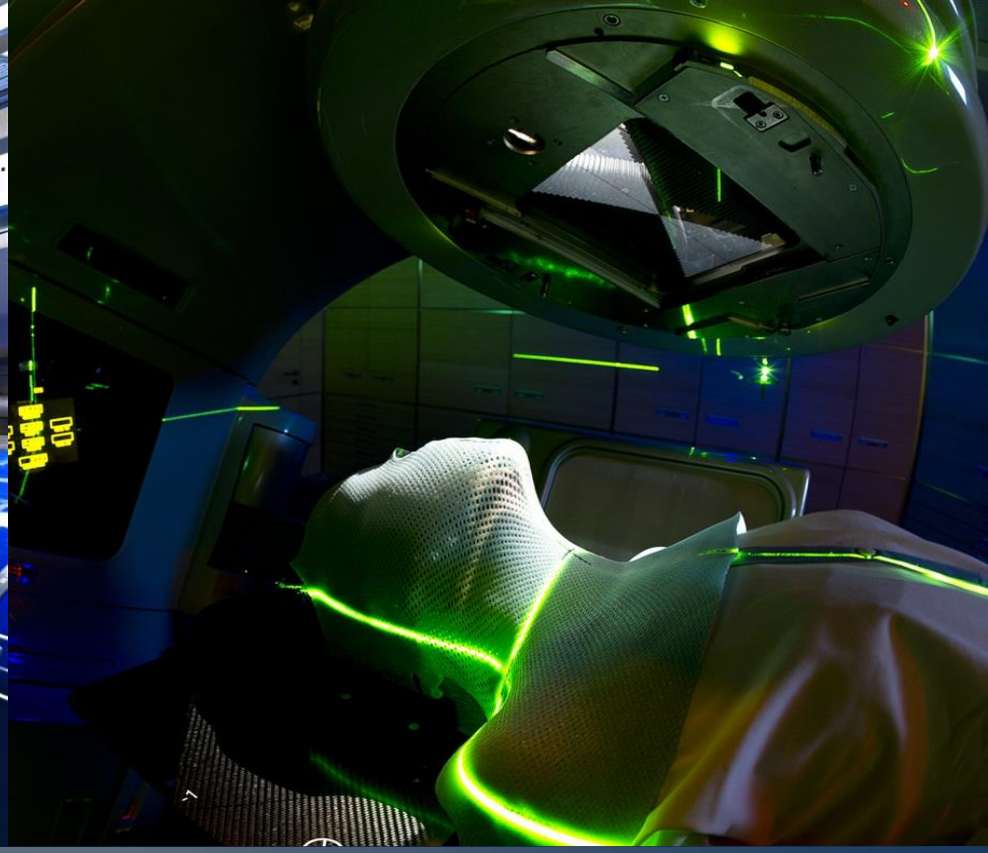


Medical applications of particle physics

Martina Bucciantonio Giovanni Porcellana

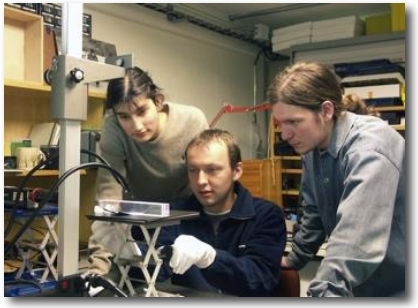
Tera Foundation

Credits: Manuela Cirilli, CERN Knowledge transfer
Life science section

CERN's mission

RESEARCH

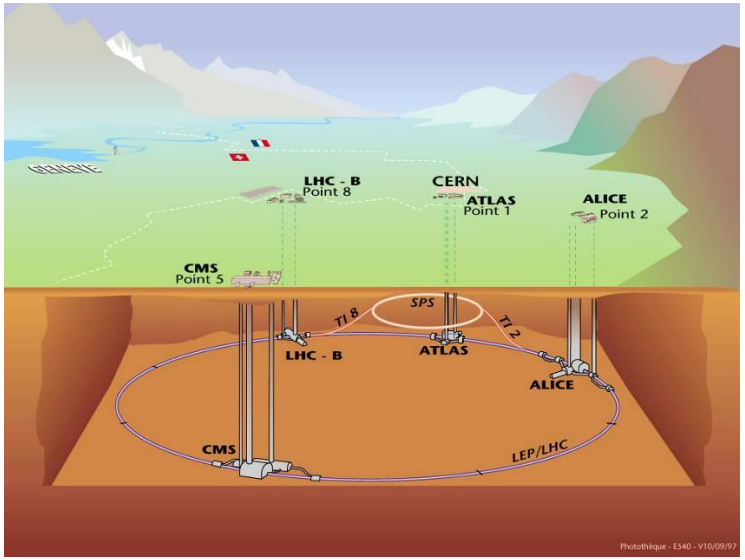
INNOVATION



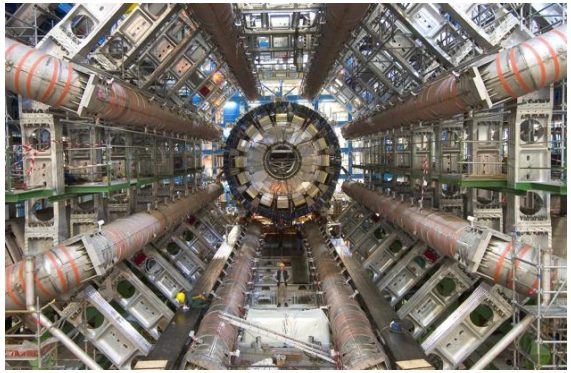
EDUCATION

UNITING PEOPLE

Tools of the trade



Accelerators

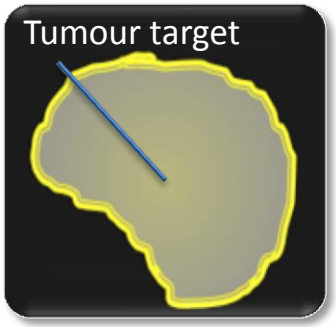


Detectors

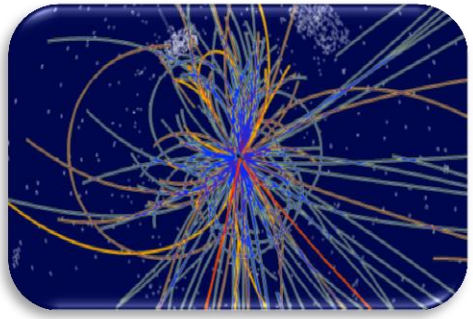
Computing

HEP technologies

Accelerate particle beams



Radiotherapy



Detect particles

Medical imaging

Large scale **Computing** (Grid)

Grid computing for medical data management and analysis

Cancer is a large and growing challenge

Need: Earlier diagnosis, better control, fewer side-effects

- How?
  - New technologies **imaging, dosimetry, accelerator & detector technology**
  - Better understanding – **genetics, radiobiology**…
  - Advanced healthcare **informatics** …

- International **collaboration** if progress is to be maintained

- Although cancer is a common condition, each tumour is individual
  - Personalised approach
  - Large patients data to understand the key drivers of the disease

Medical imaging

X-rays

Wilhelm Röntgen
(1845–1923)

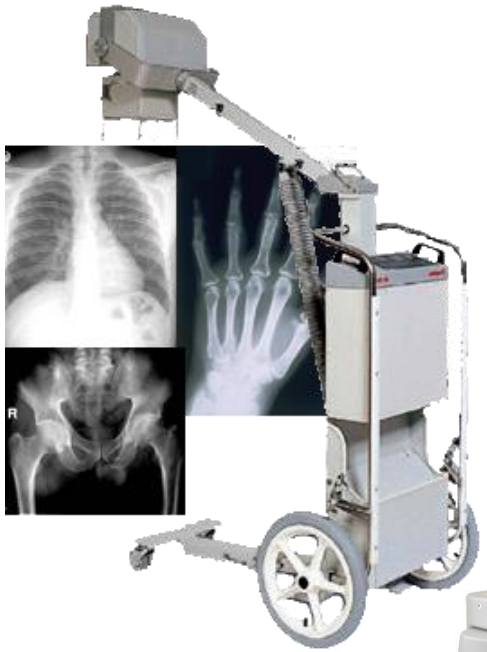
1901: Nobel prize

8 November 1895:
X-rays discovery

22 December 1895:
first radiography

Courtesy of Roentgen museum

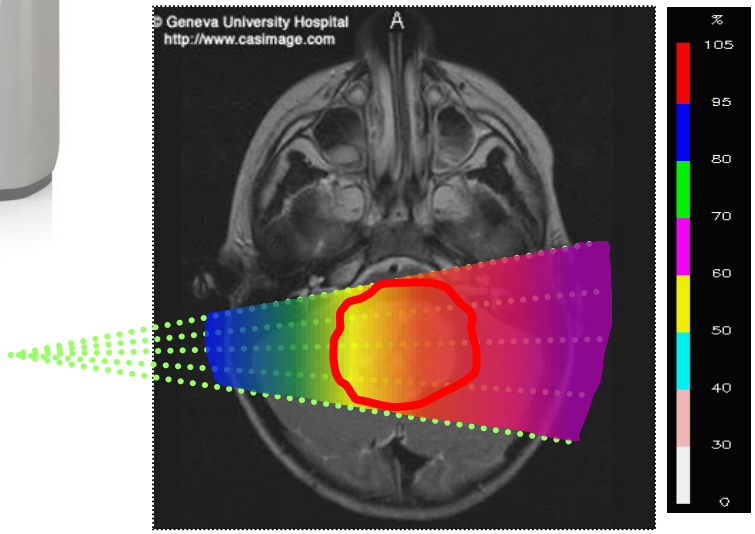
X-rays evolution



Diagnosis

Courtesy of Philips

Cancer treatment



Magnetic resonance Imaging

1924 – Pauli
suggests that nuclear particles may have angular momentum (spin)

1946 – Purcell
shows that matter absorbs energy at a resonant frequency
1946 – Bloch
demonstrates that nuclear precession can be measured in detector coils
1952 – They share Nobel prize in Physics

1972 – Damadian
patents idea for large NMR scanner to detect malignant tissue

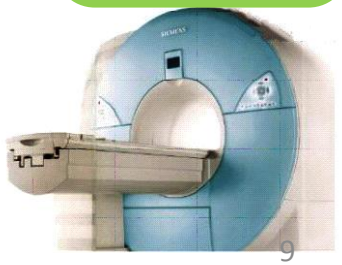
M R I

1920 1930 1940 1950 1960 1970 1980 1990

1937 – Rabi
measures magnetic moment of nucleus. Coins "magnetic resonance" wins Physics Nobel prize

1973 – Mansfield and Lauterbur
independently publish gradient approach to MR
2003 – They share the Nobel prize in Physics

MRI scanners
become clinically prevalent



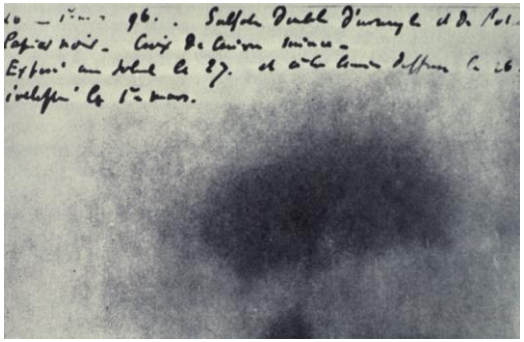
More and more details

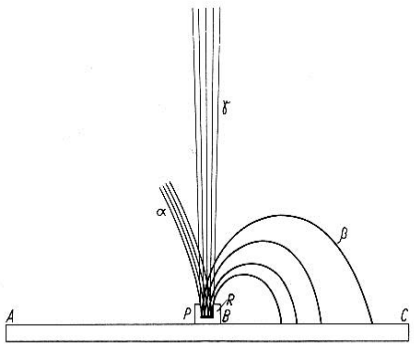
Images courtesy of Dr. F. Fellner

Birth of medical physics

Henri Becquerel

1896 - discovery of natural radioactivity



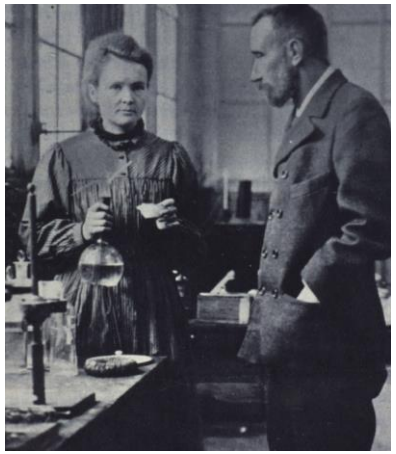


Mme. Curie thesis – 1904
α, β, γ in magnetic field

1898 - discovery of Radium (used for “brachytherapy”)

1903 - Becquerel, Pierre e Marie Curie share the Nobel prize in Physics

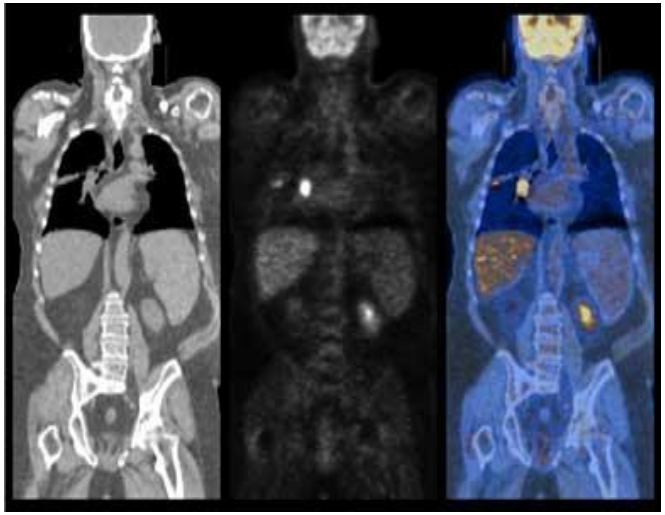
1911 - Marie Curie wins the Nobel prize in Chemistry

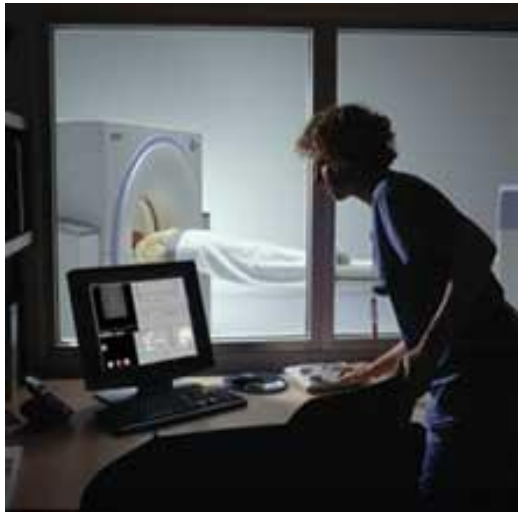


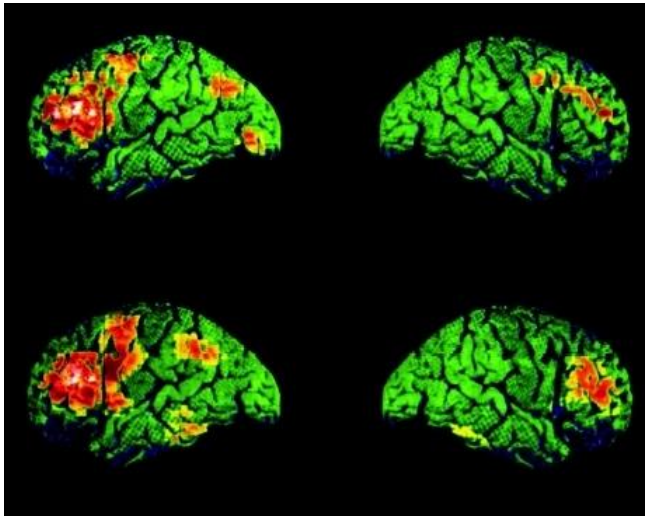
Pierre and Marie Curie

Antimatter – ~~science fiction~~?

Positrons are used daily in oncology

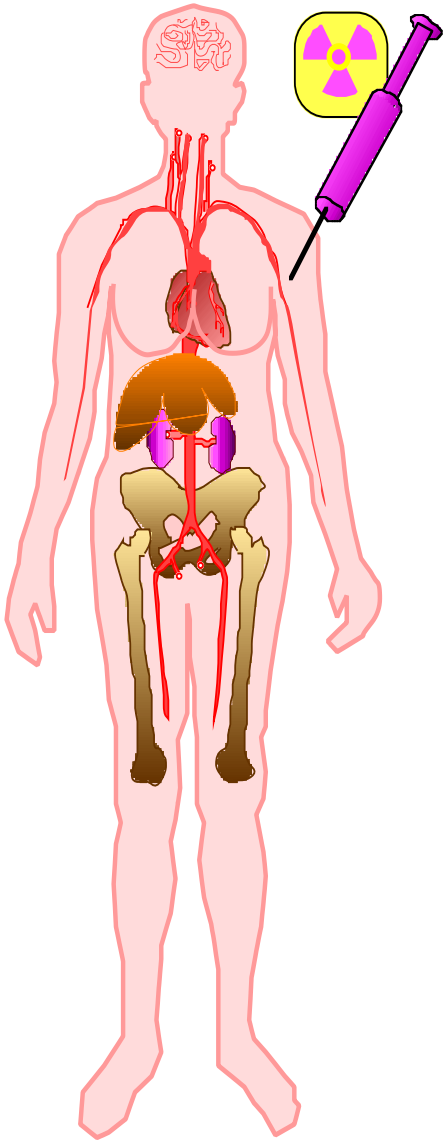






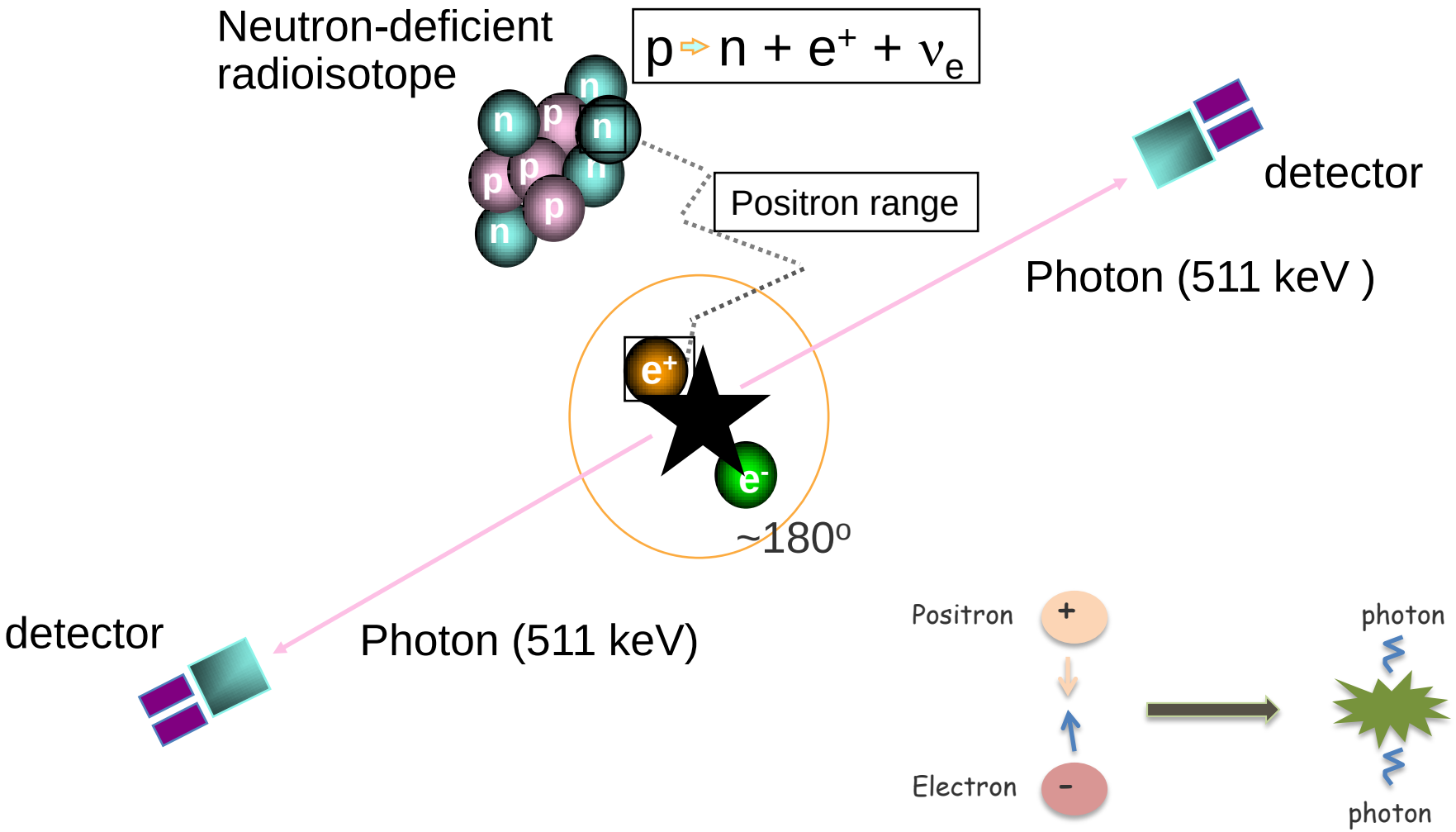
PET = Positron Emission Tomography

PET: How it works

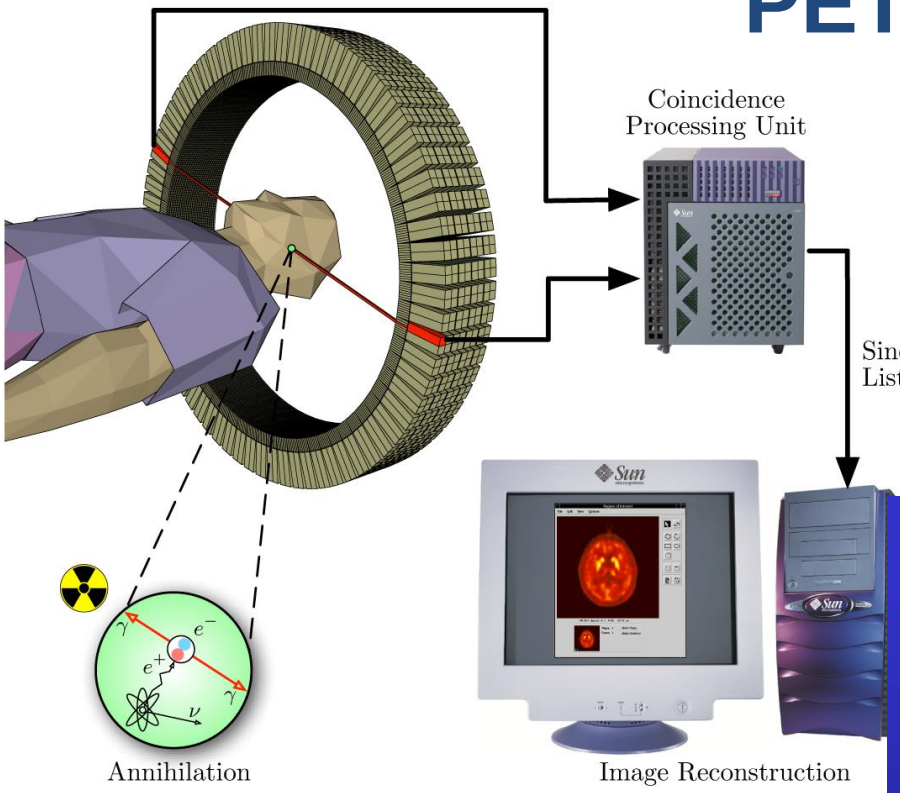


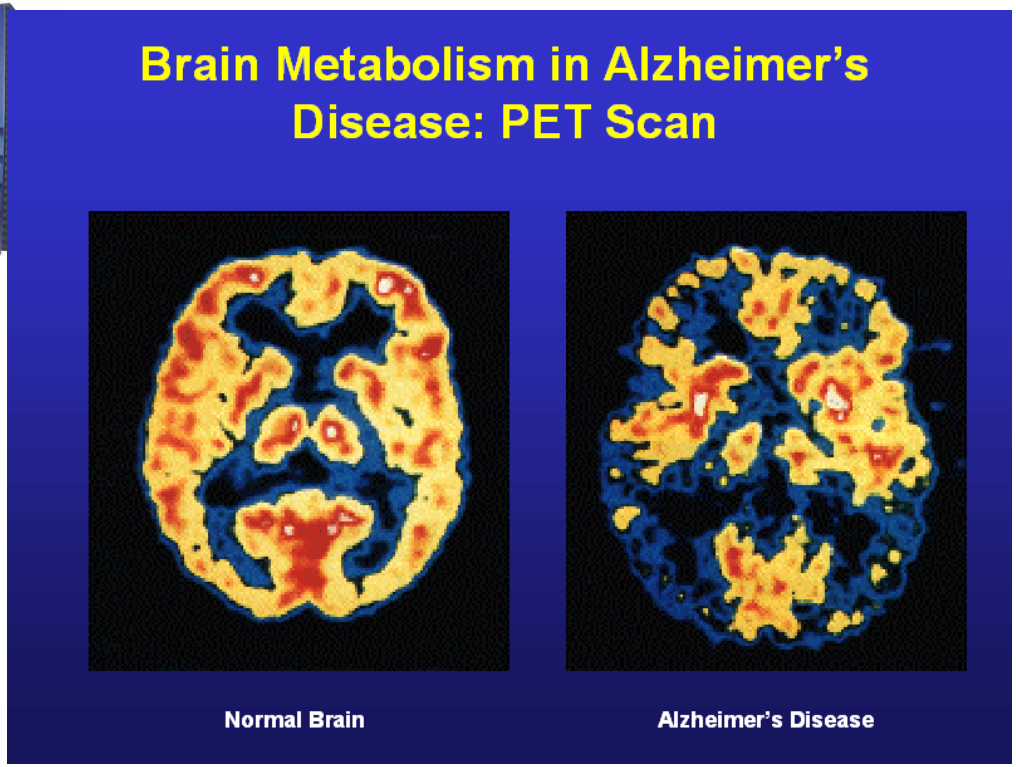
- Drug is labelled with positron (β+) emitting radionuclide
- Drug localizes in patient according to metabolic properties of that drug
- Trace (pico-molar) quantities of drug are sufficient
- Radiation dose fairly small (<1 rem = 0.01 Sv)

PET: Detection



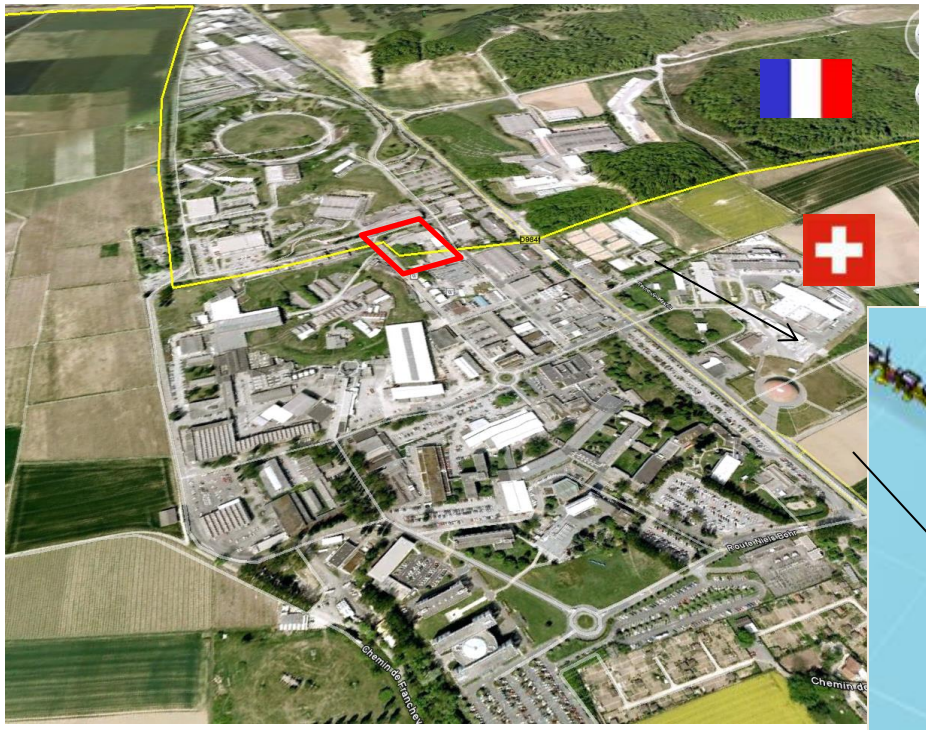
PET scan

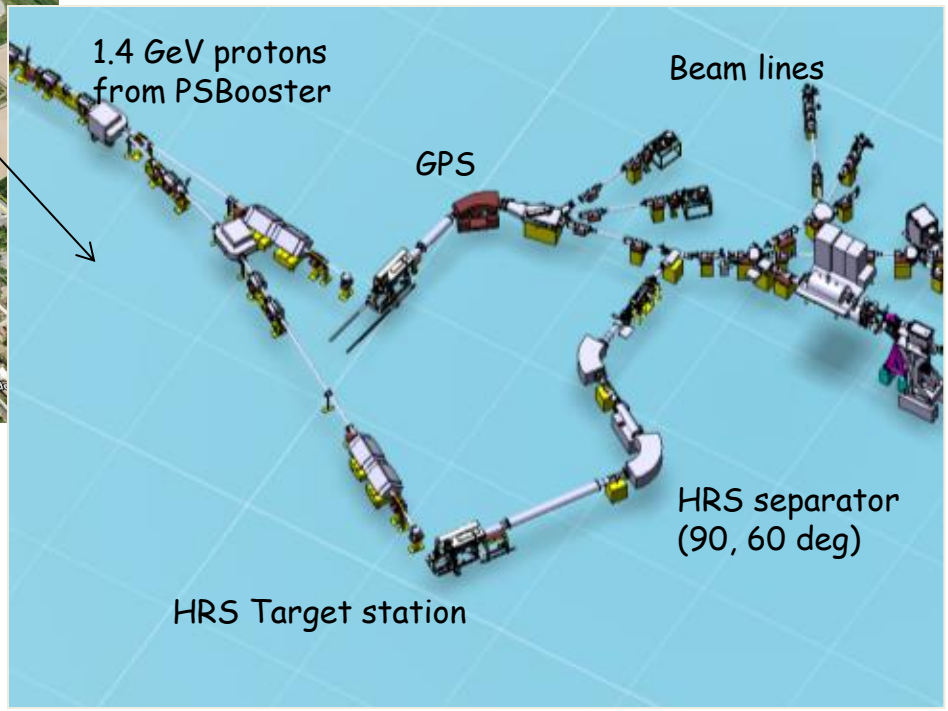

Coincidence
Processing Unit
Sinogram/
Listmode Data
Annihilation
Image Reconstruction


Brain Metabolism in Alzheimer's Disease: PET Scan
Normal Brain
Alzheimer's Disease

ISOLDE

Isotopes for detection & treatment

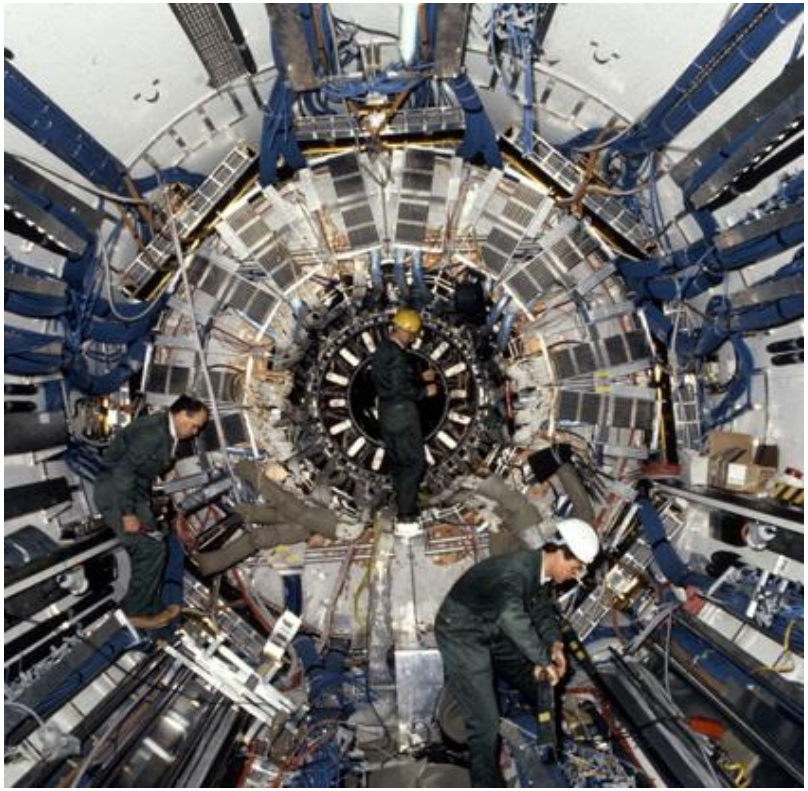


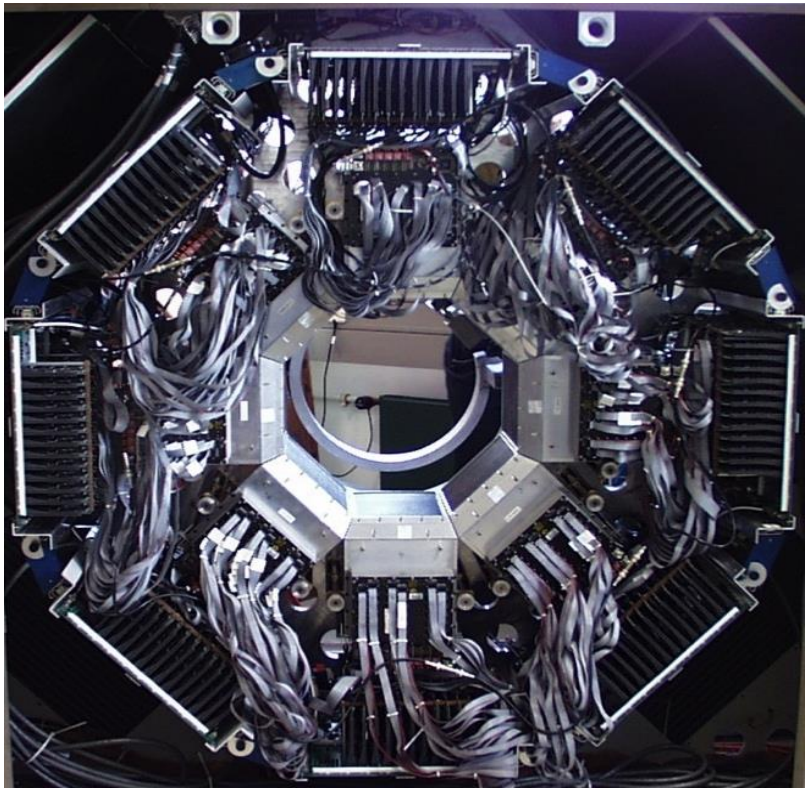


In collaboration with

University Hospital Geneva

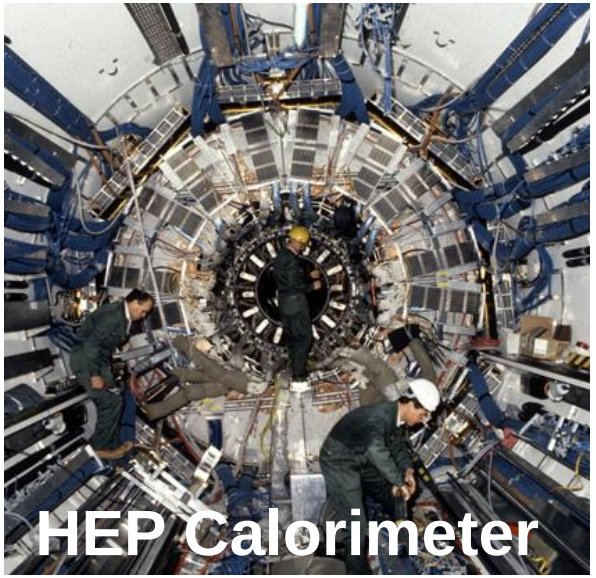
Medical imaging and particle physics: The same challenge?



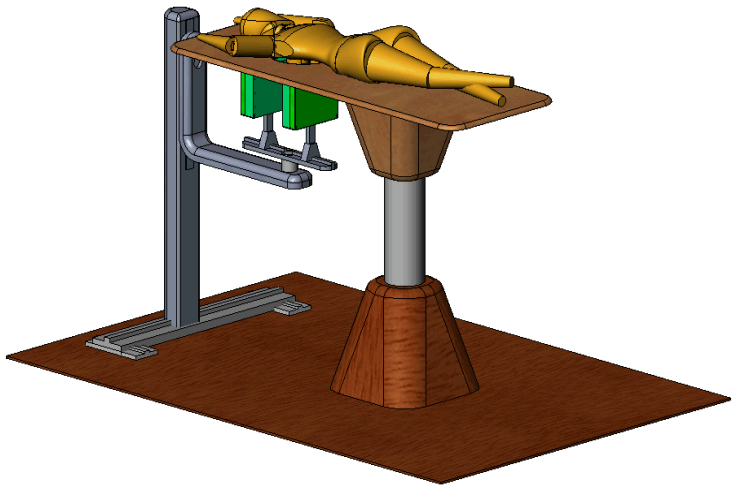


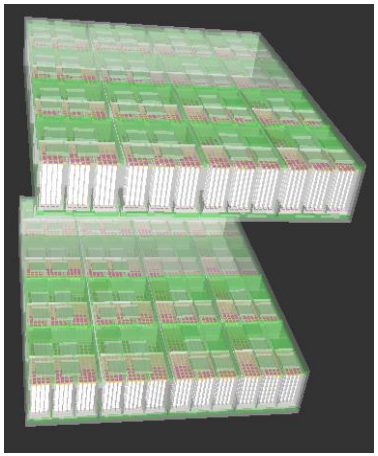
Similar challenges

- 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



Crystal PEM



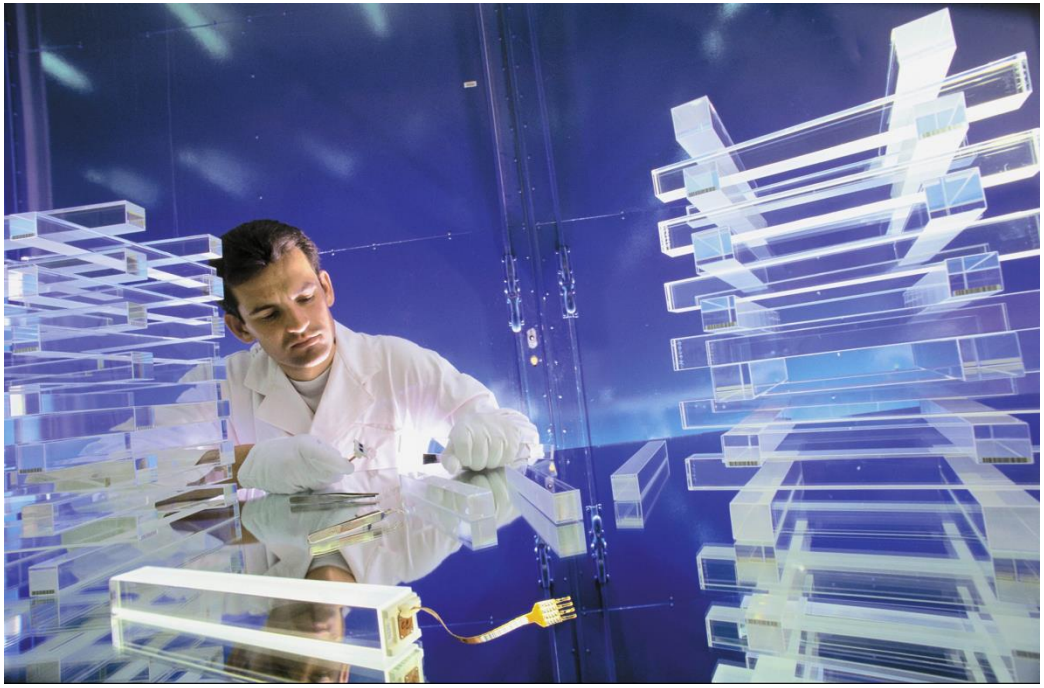


- PET detector dedicated to breast cancer screening
  - extremely sensitive to small tumour masses
- Spatial resolution1-2 mm
- High counting sensitivity
- Short PET exam
- Coupled to ultrasound

Crystal Clear

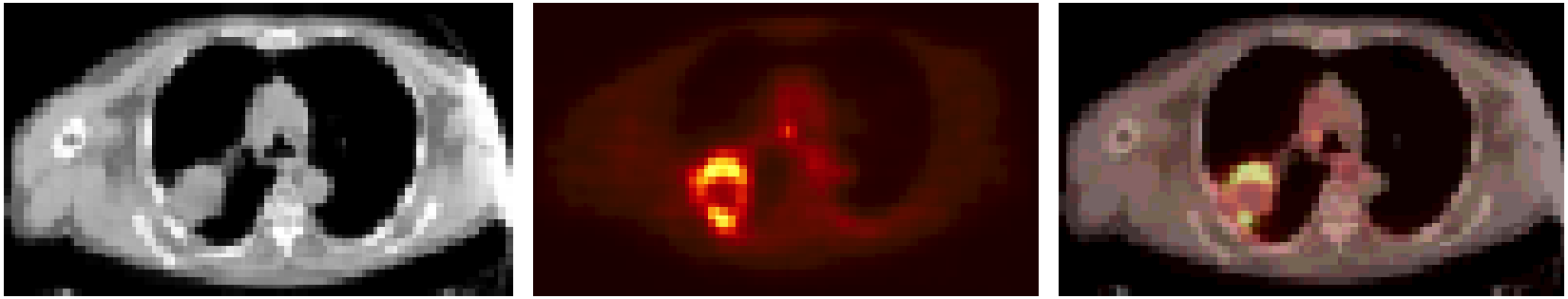
- New scintillating materials
  - LuAP, phoswich LuAP-LSO (CERN patent)
  - other crystals
- New photodetectors (Avalanche PhotoDiodes)
- New low noise electronics

- New intelligent DAQ systems with pipeline and parallel architectures
- Better simulation GEANT 4
- Better reconstruction algorithms

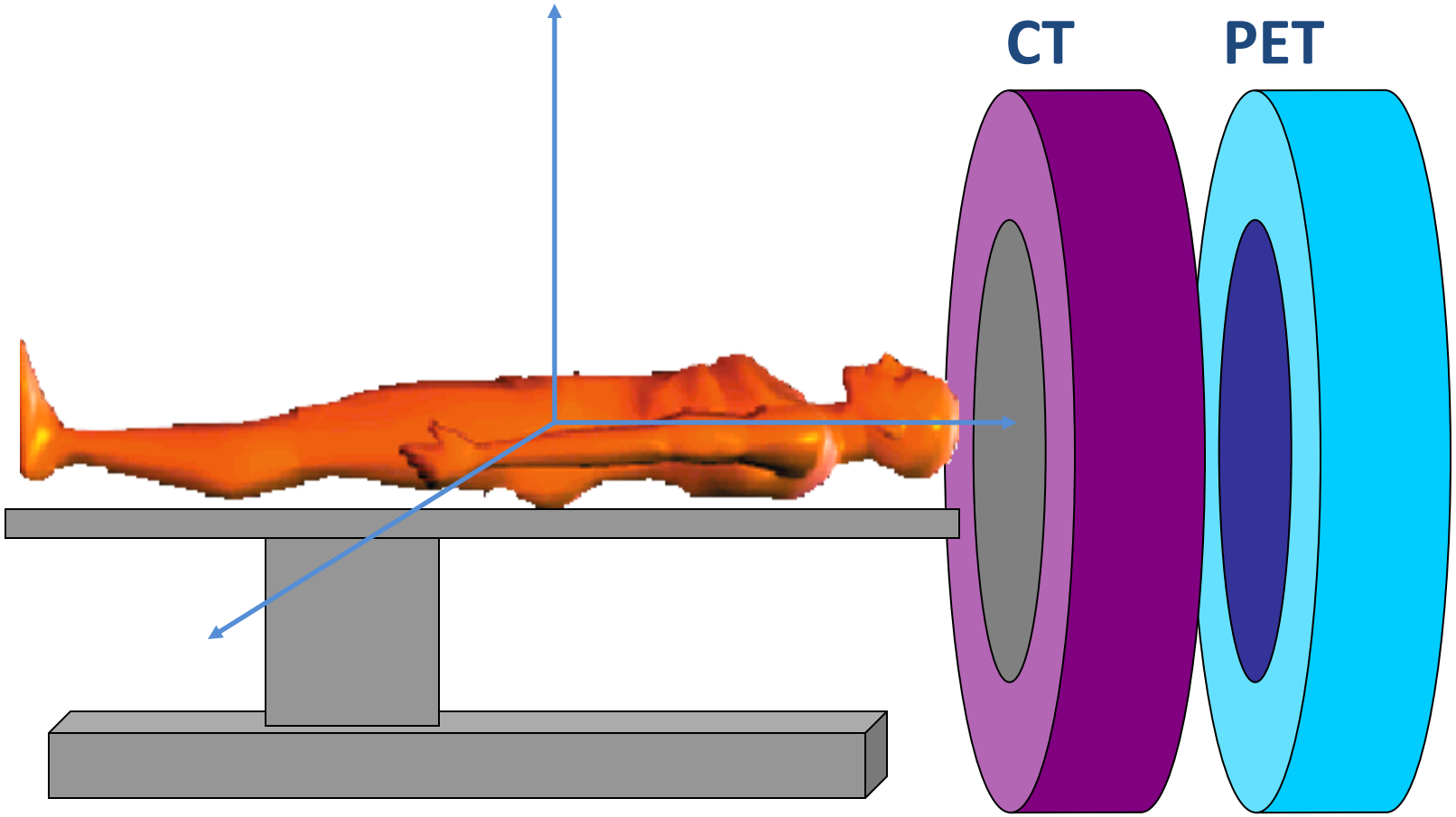


Multimodal imaging

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.

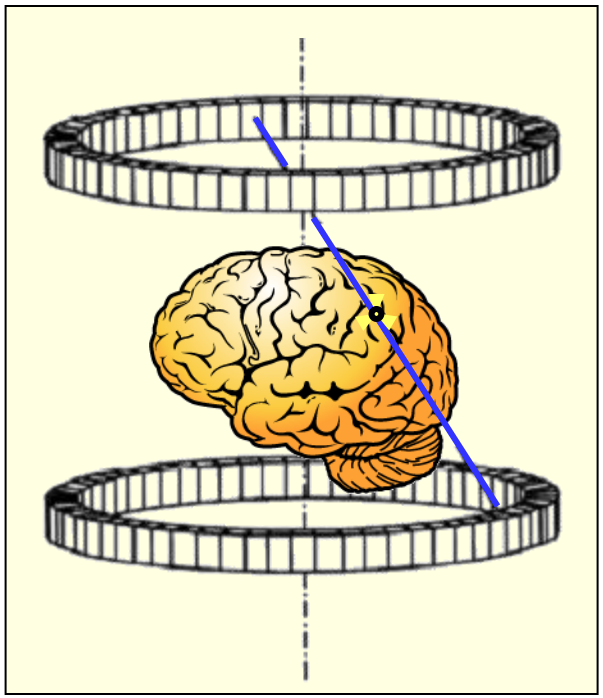


PET/CT



3D Axial PET

Conventional concept



Rings of block detectors

New 3D axial concept

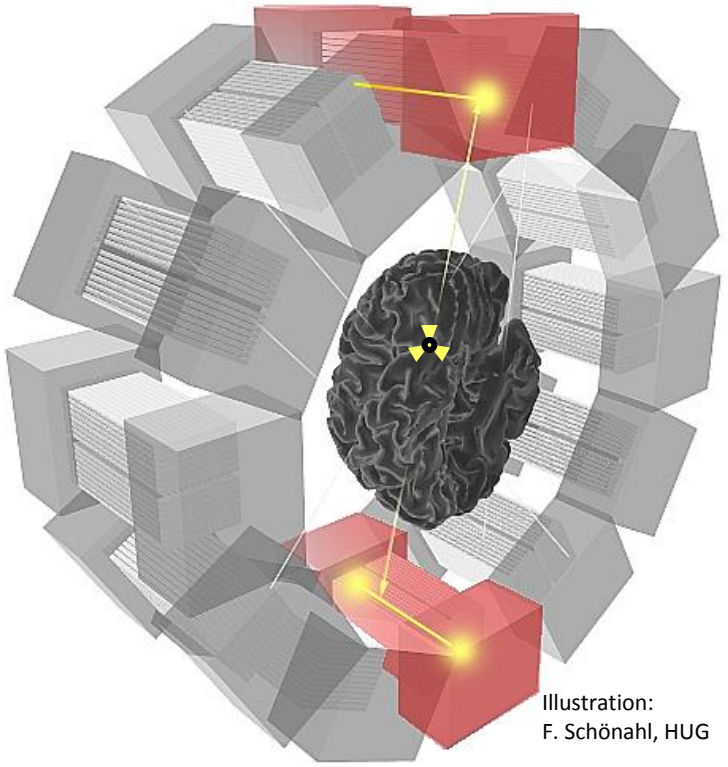
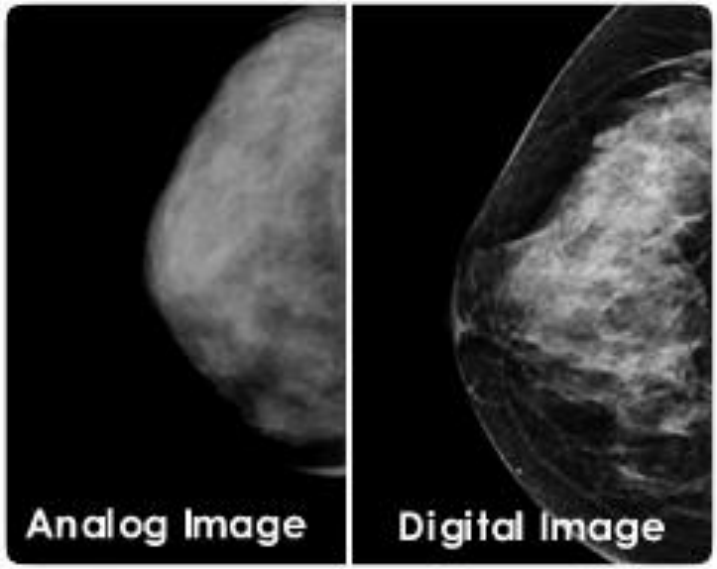


Illustration:
F. Schönahl, HUG

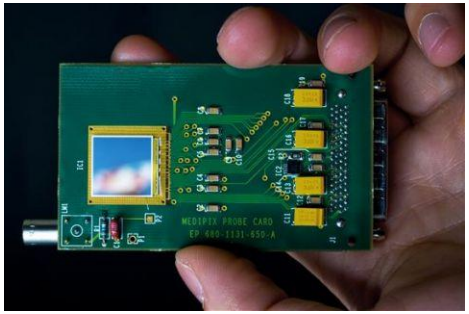
Axial arrangement of camera modules based on matrices of long crystals read out on both sides by HPDs

Towards digital imaging

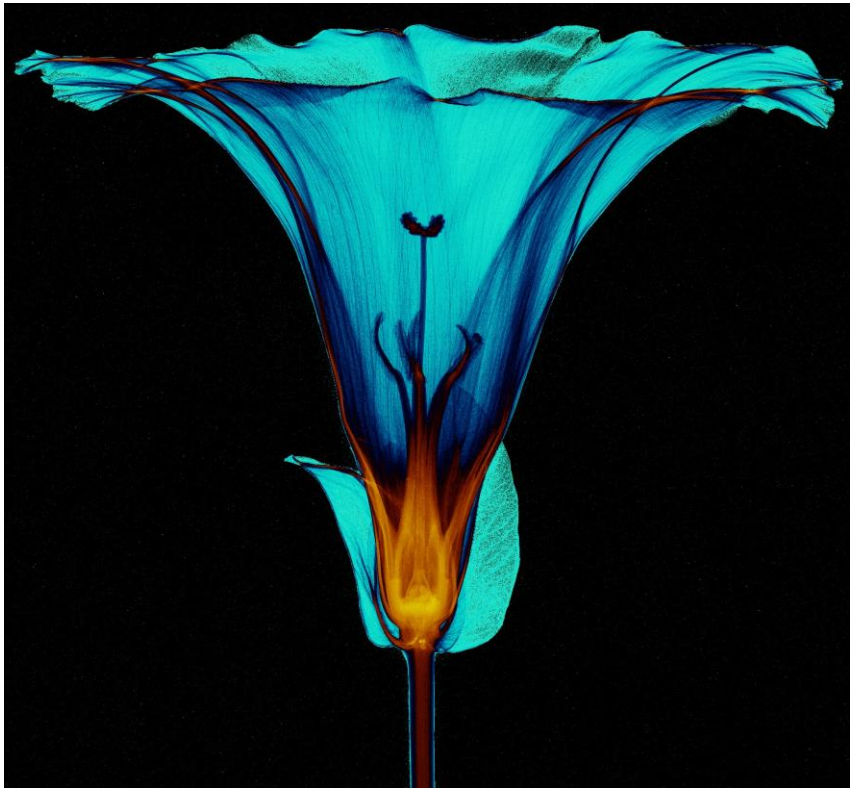
- High contrast => accurate diagnosis
- Low dose
- Screening opportunities
- Access to preventive healthcare
- Storage, easy-access, sharing images



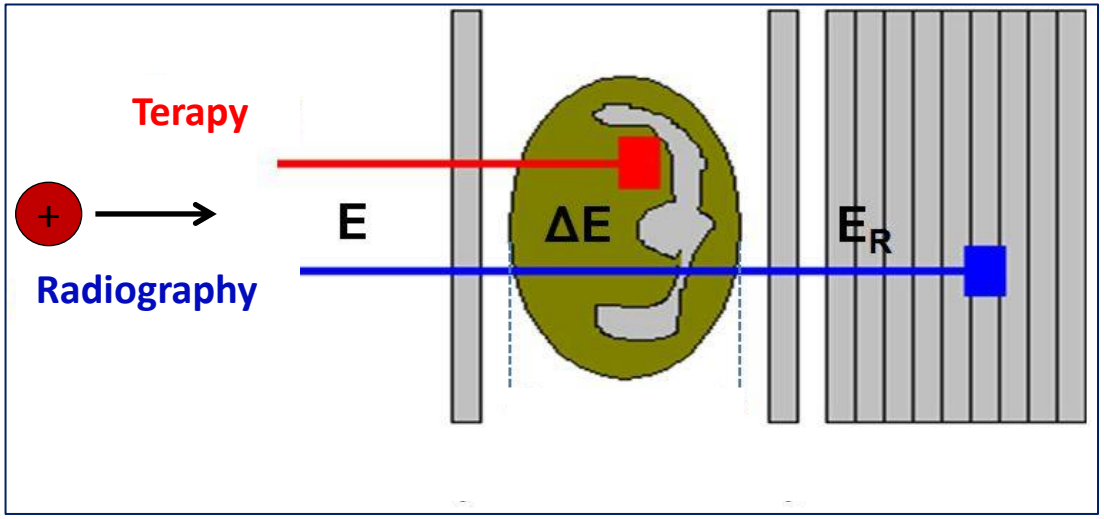
MediPix

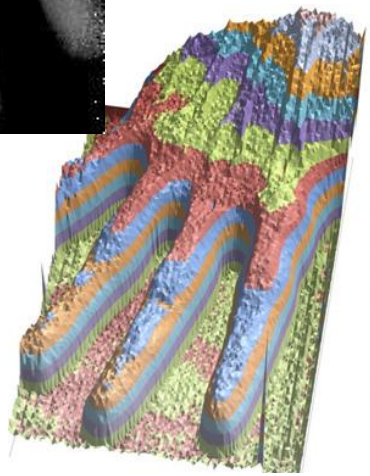


- High Energy Physics original development:
  - particle track detectors
- Main properties:
  - fast fully digital device similar to the electronic chip in a digital camera but sensitive to X-rays instead of visible light
  - good conversion efficiency of low energy X-rays
  - it can create the first true colour images with X-rays



Proton radiography





- Early studies in the 70s

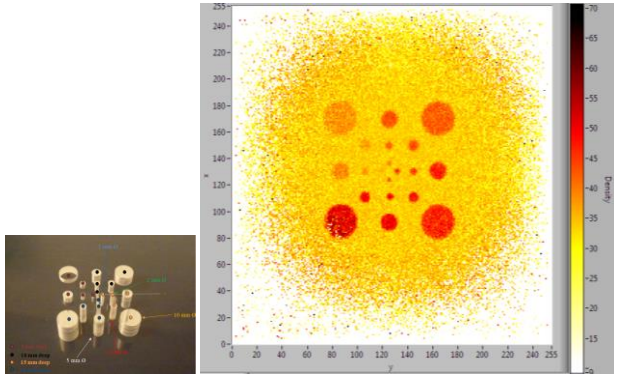
- High-rate medical diagnostics fully digital=> increase in the recording speeds in medical diagnostic tools, leading to faster scanning and lower body doses than X-rays.

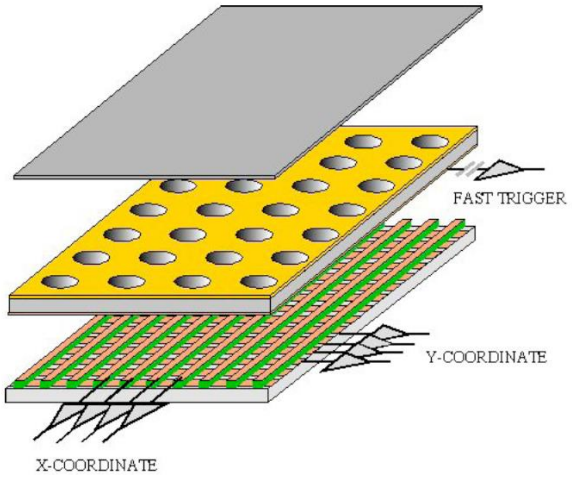
Images courtesy of H. Sadrozinski

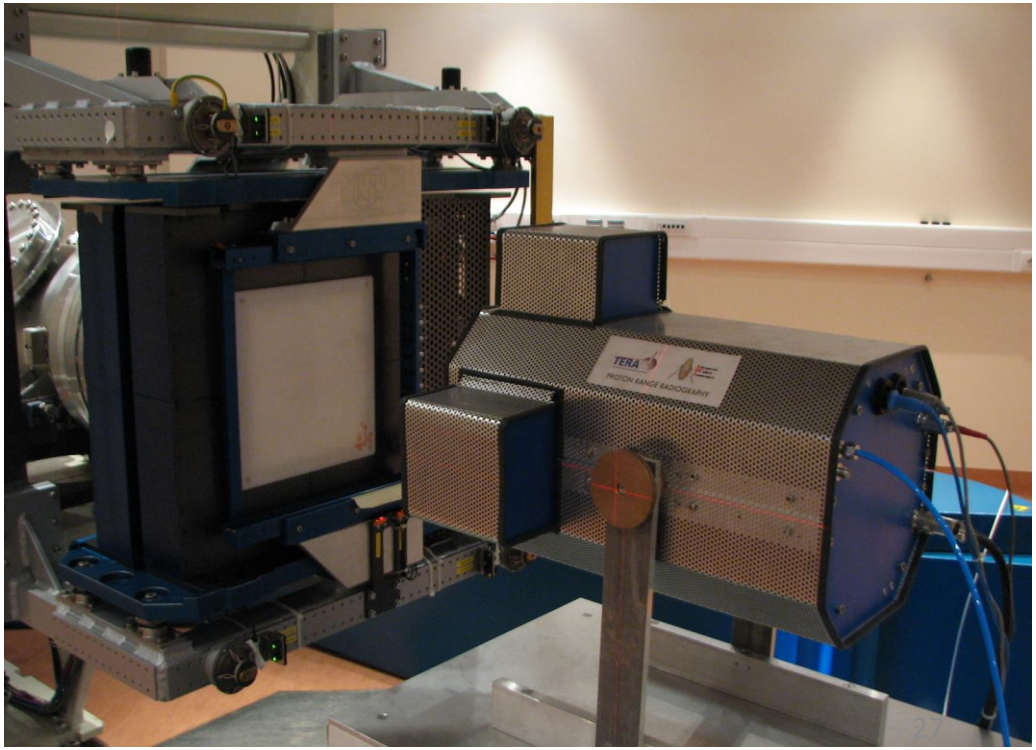
Proton radiography

TERA Foundation

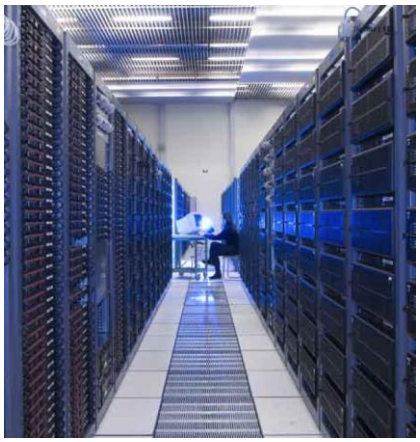
GEM – Gas electron multiplier
1996: Fabio Sauli at CERN
for HEP experiments

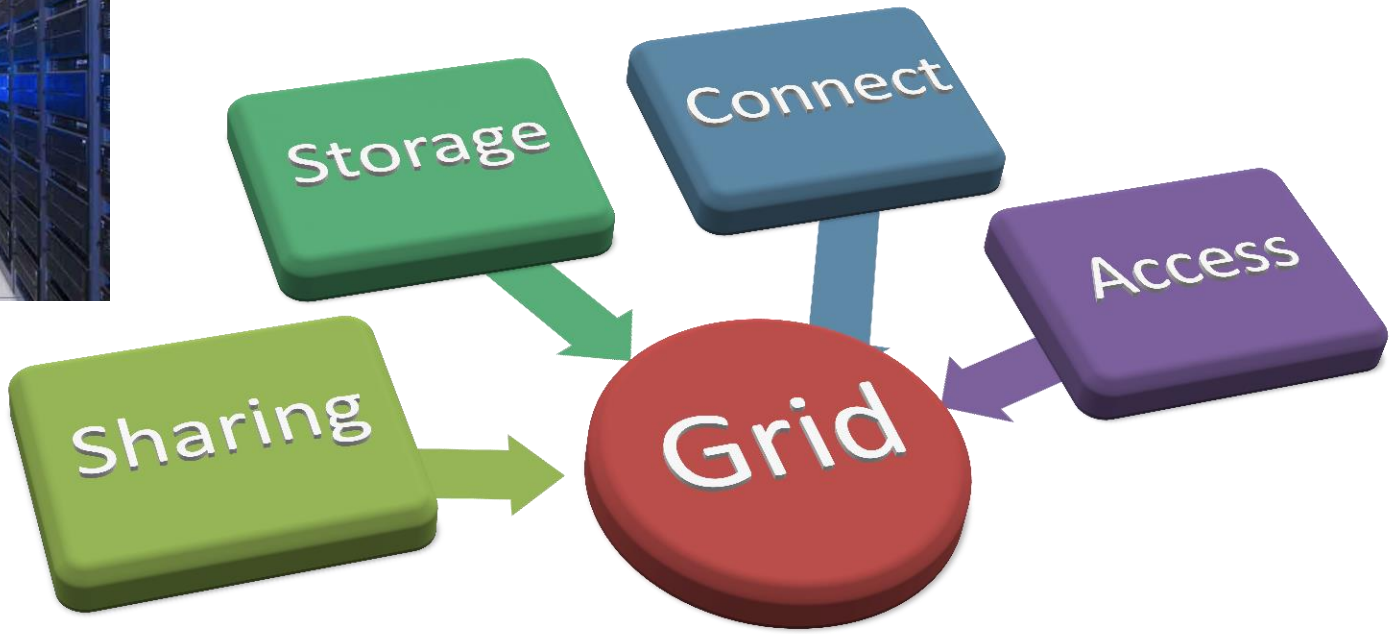


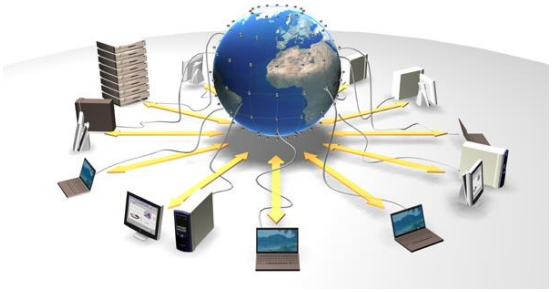




Computing for medical applications





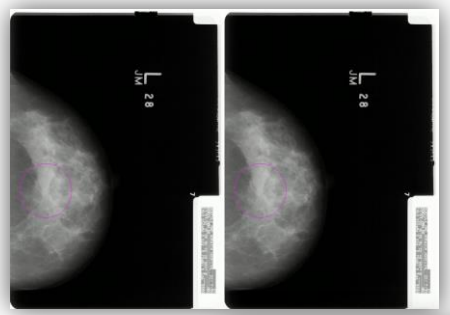


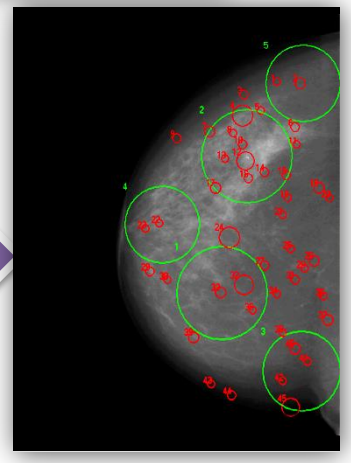
Data and Resources

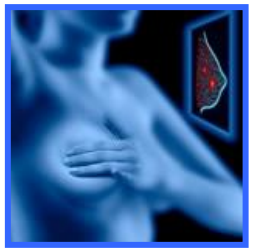
Mammogrid

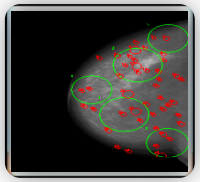
A grid mammography database

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





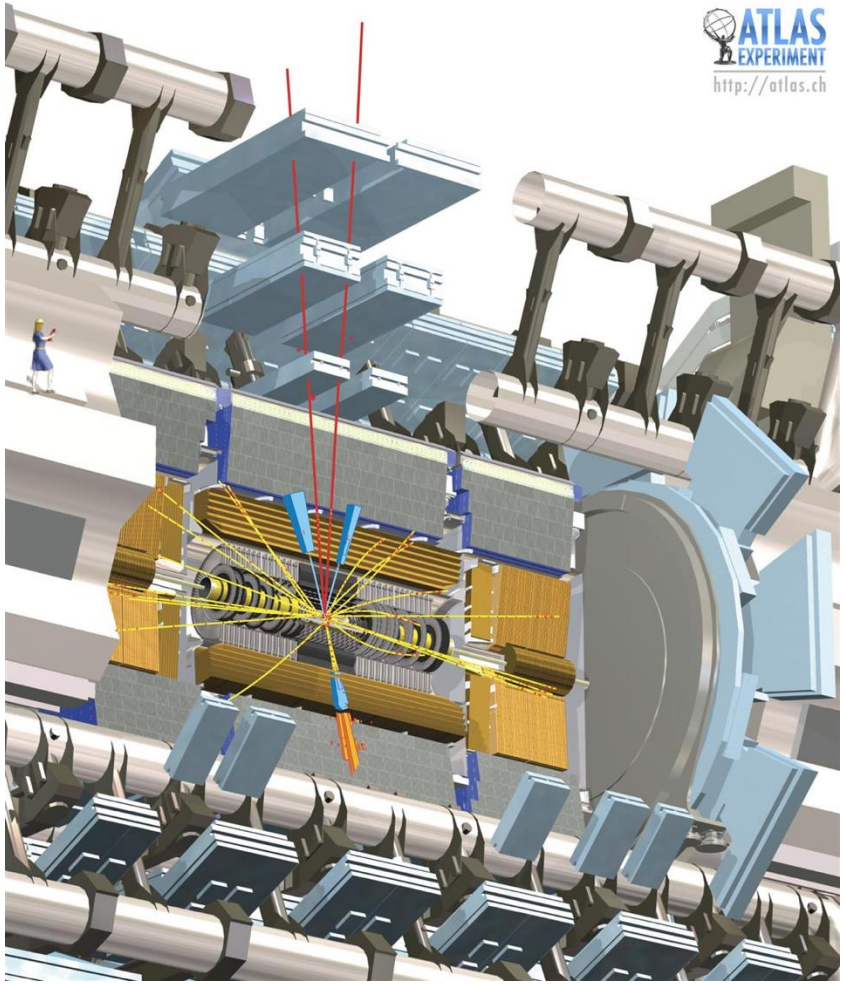


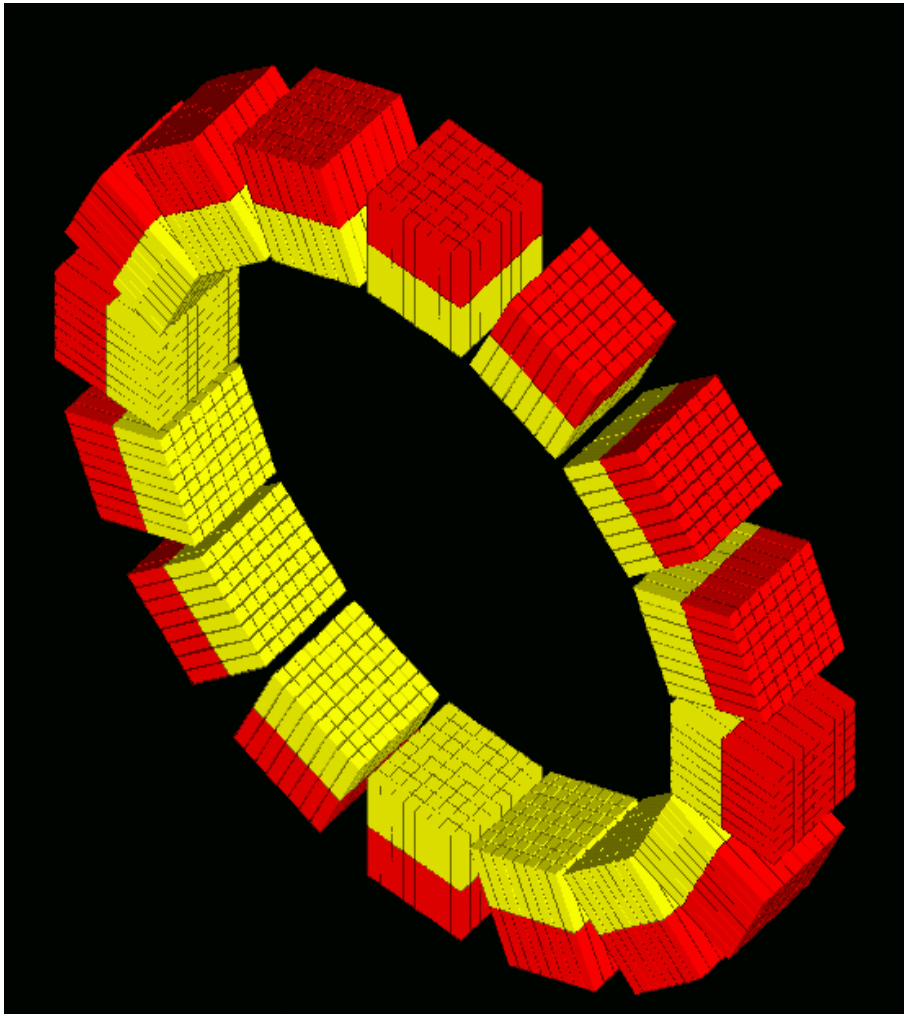


Oncology
- Breast Cancer (micro-calcifications and masses)

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

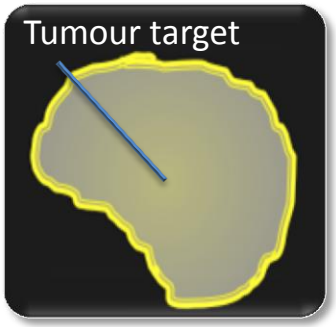
Simulation



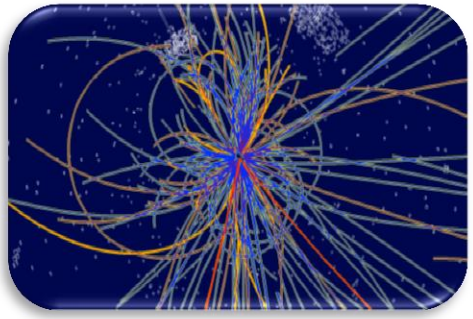


HEP technologies

Accelerate particle beams



Radiotherapy



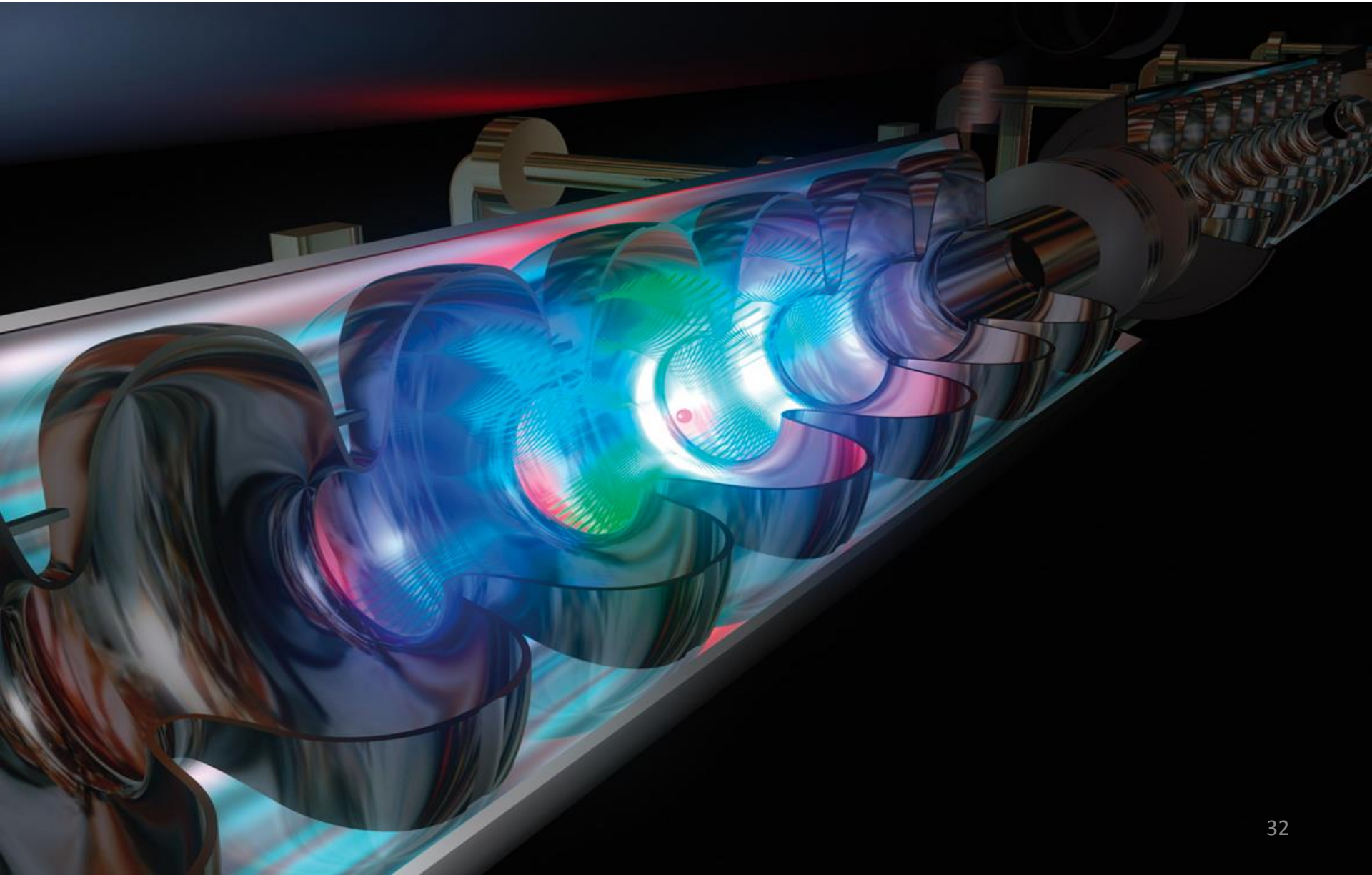
Detect particles

Medical imaging

Large scale **Computing** (Grid)

Grid computing for medical data management and analysis

Accelerators for cancer treatment



Cancer and its treatments

⇒ Every year millions of new cases globally every year

⇒ Second most common cause of death in Europe, Canada, US

Conventional

Surgery

Chemotherapy

Radiotherapy (X, IMRT)

Non Conventional

Immunotherapy

Hyperthermia

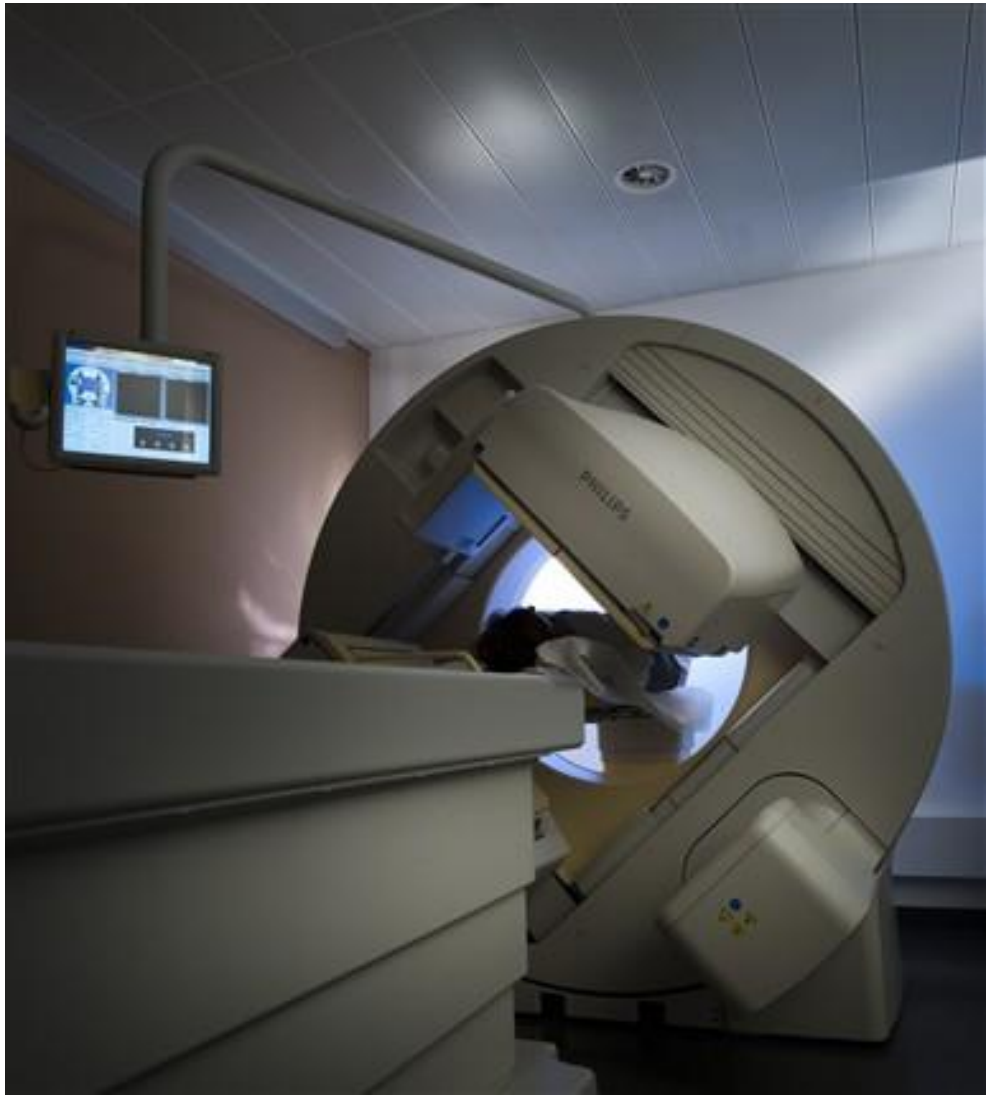
Hadrontherapy …

Local control

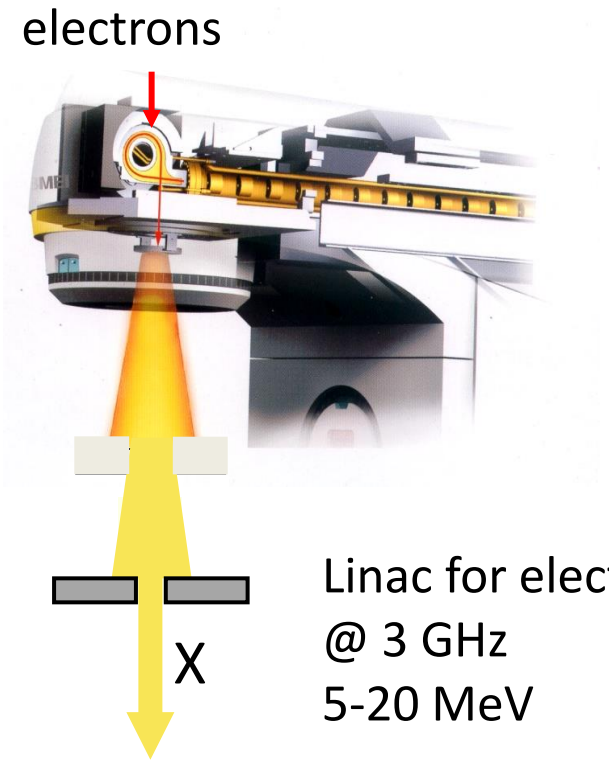
Survival
Quality of life

The 3 Cs of radiotherapy

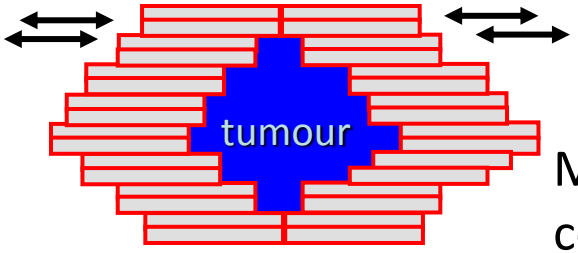
- Cheap:
  - the least expensive cancer treatment method (around 5% of total cost)
- Cure:
  - good cure rate (30-40%)
- Conservative:
  - generally non-invasive, fewer side effects



Conventional radiotherapy dominated by linear accelerators



Linac for electrons
@ 3 GHz
5-20 MeV



Multileaf collimator

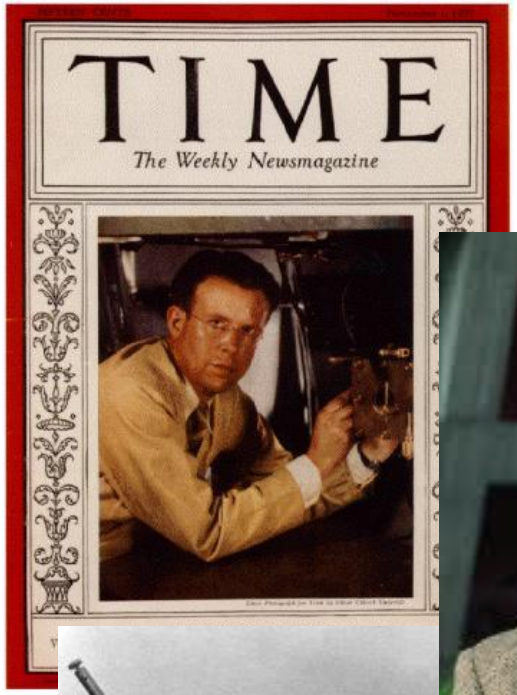
$\Rightarrow$ 20 000 patients per year every 10 million inhabitants

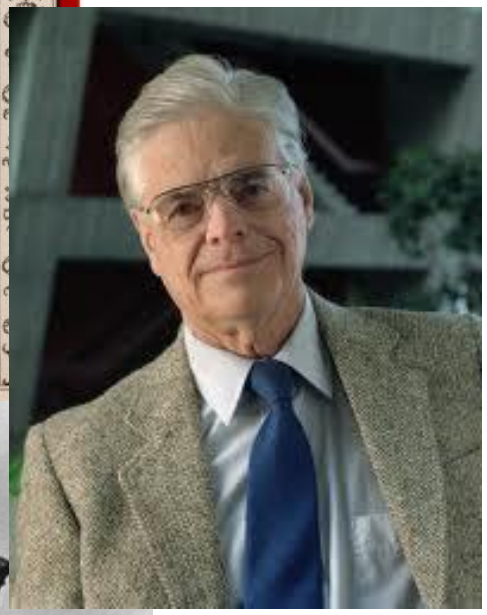
$\Rightarrow$ 1 linac every $<$ 250 000 inhabitants

Alternatives

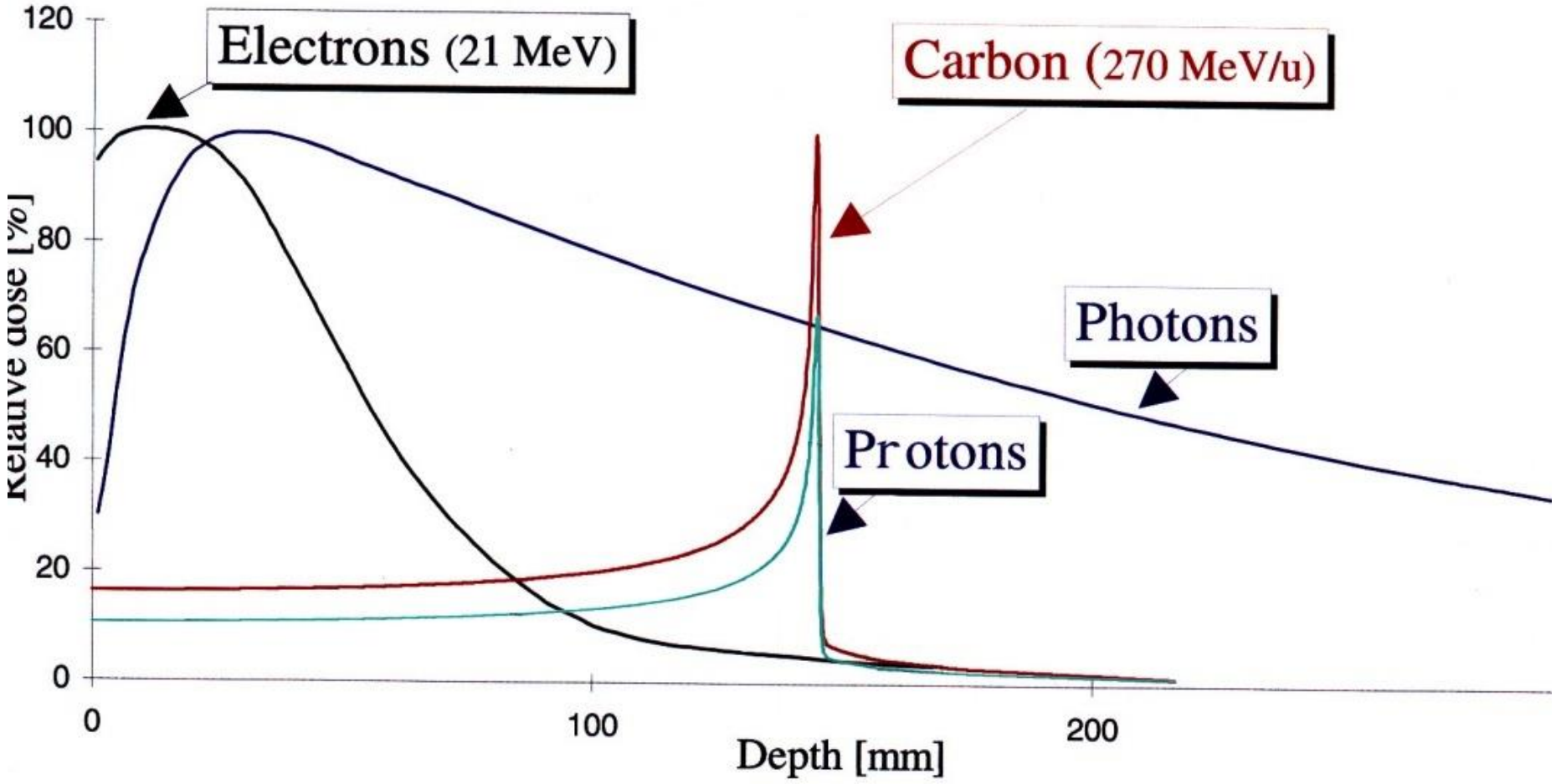
- 1932: Cyclotron by Ernest Lawrence
- 1946: article by Robert Wilson on using protons for therapy

  $\Rightarrow$ Birth of hadrontherapy
- 1954: first patients treated in Berkeley

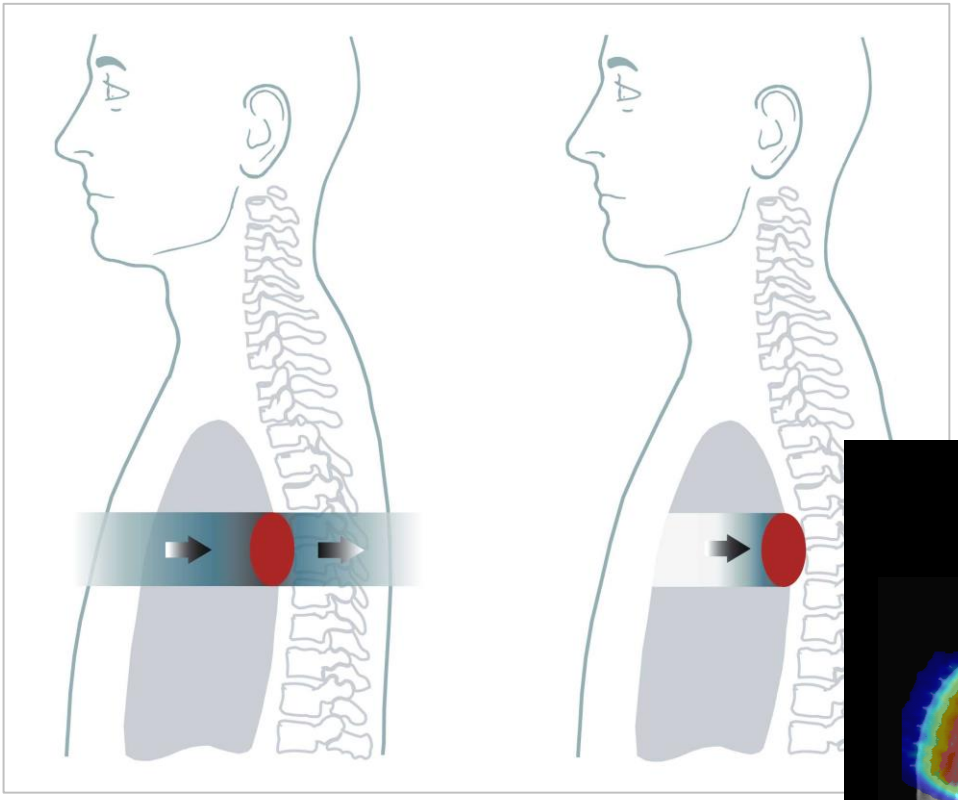




Hadrontherapy

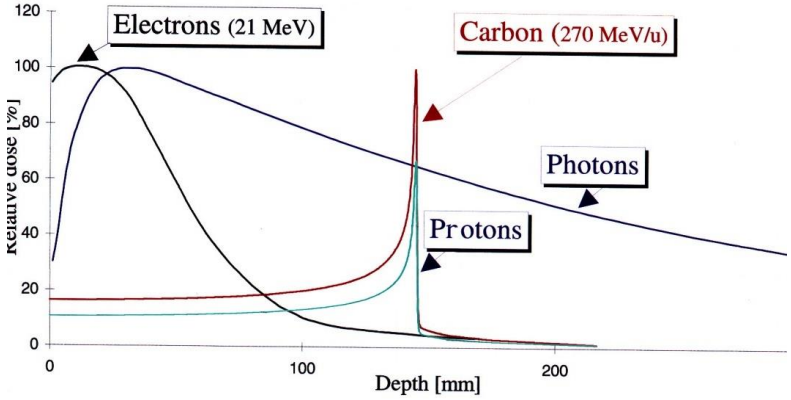


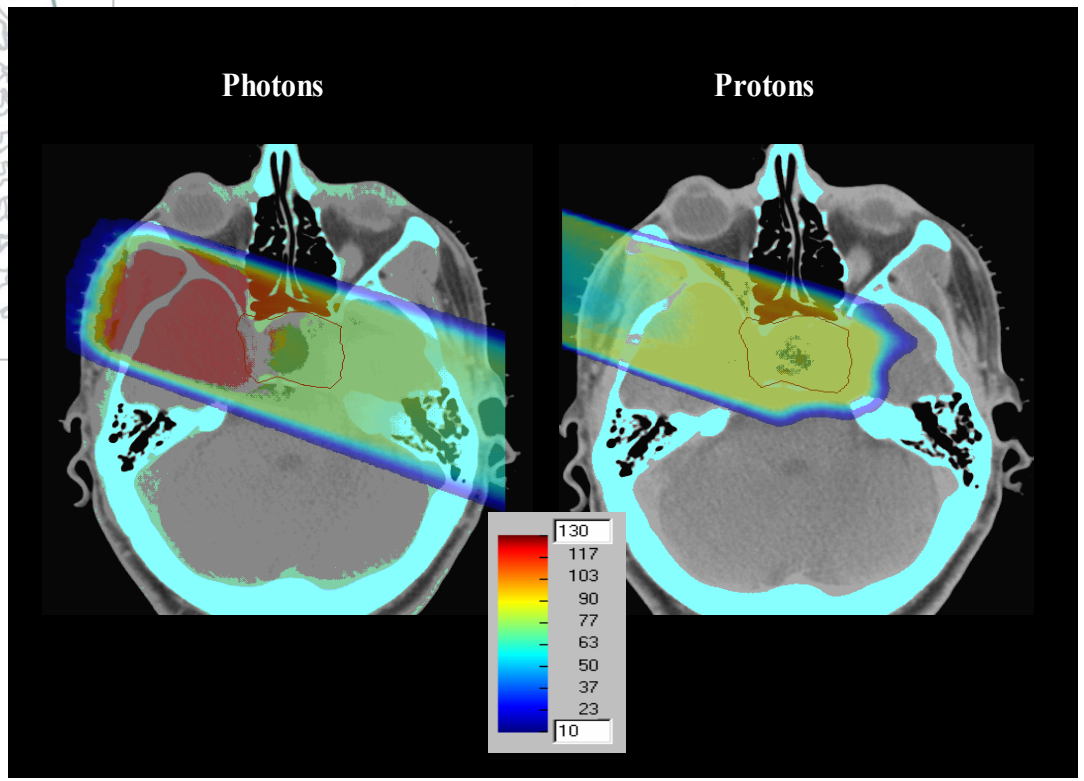
Protons vs X-rays



X-rays

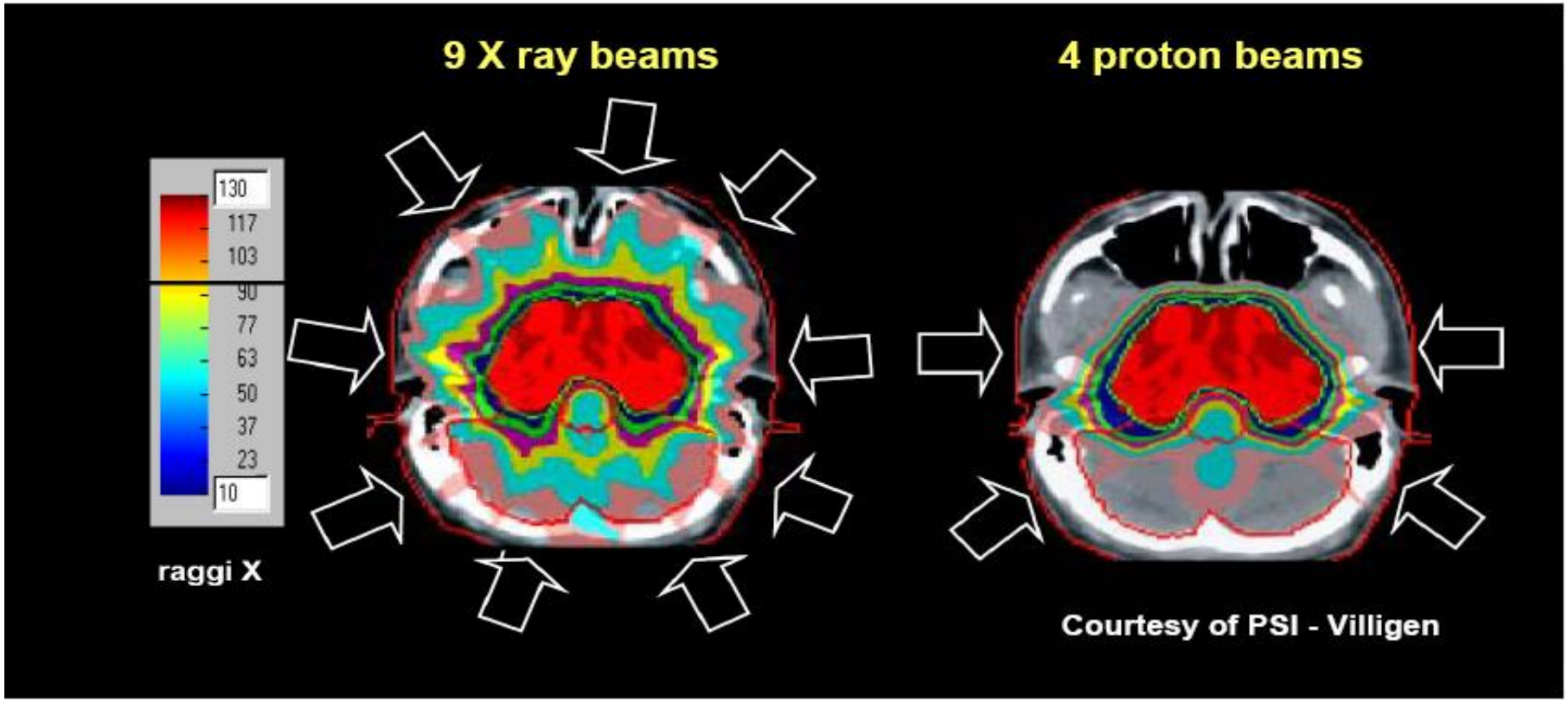
Protons





Courtesy of MedAustron

Protons vs X-rays (2)

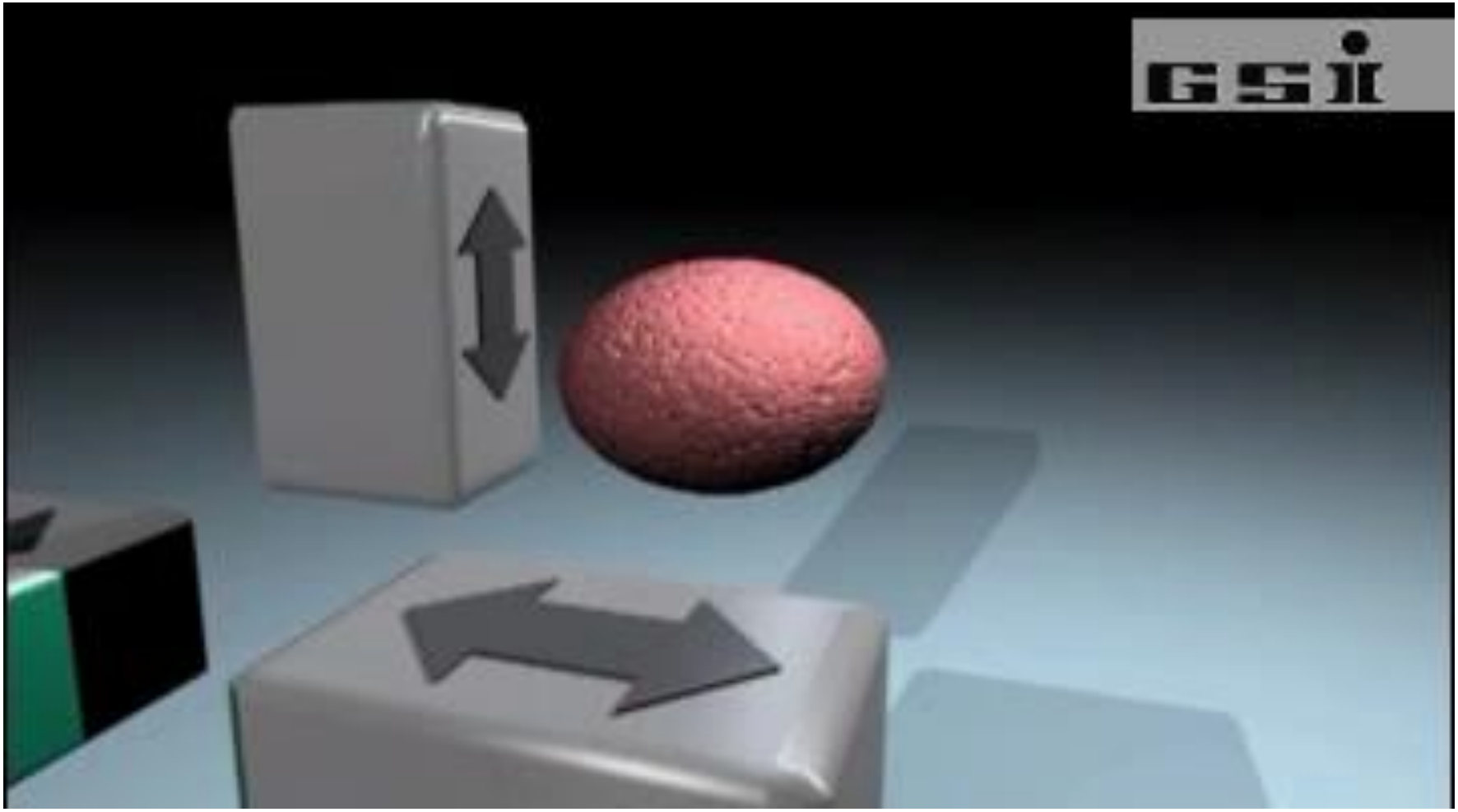


Hadrons:

- ✧ Critical areas
- ✧ Children
- ✧ Radio-resistant tumours (carbon ions)

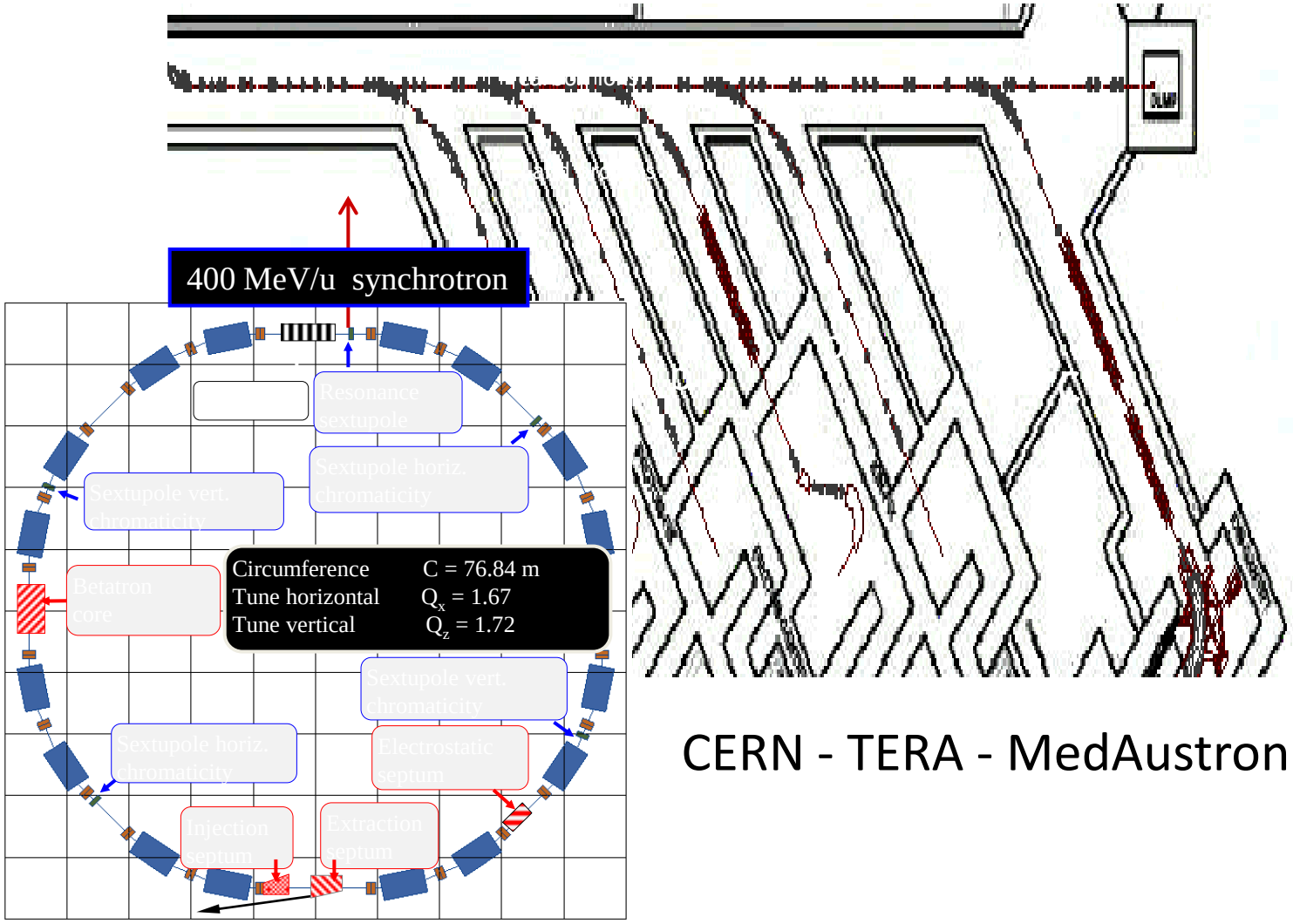
Proton Treatment @ GSI

Raster scanning



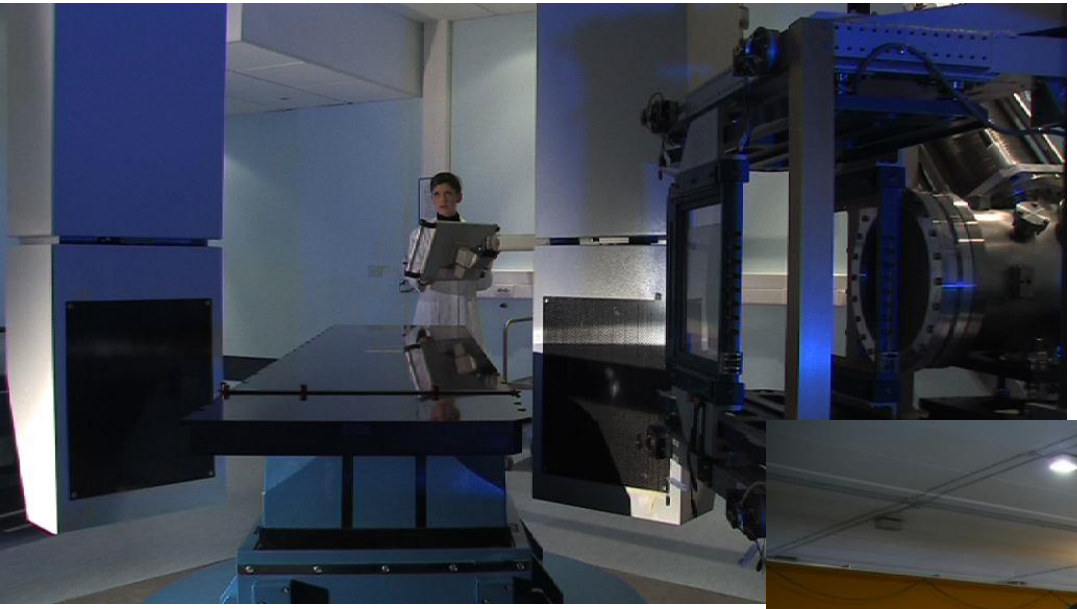
PIMMS at CERN (1996-2000)

- Proton Ion Medical Machine Study



CERN - TERA - MedAustron

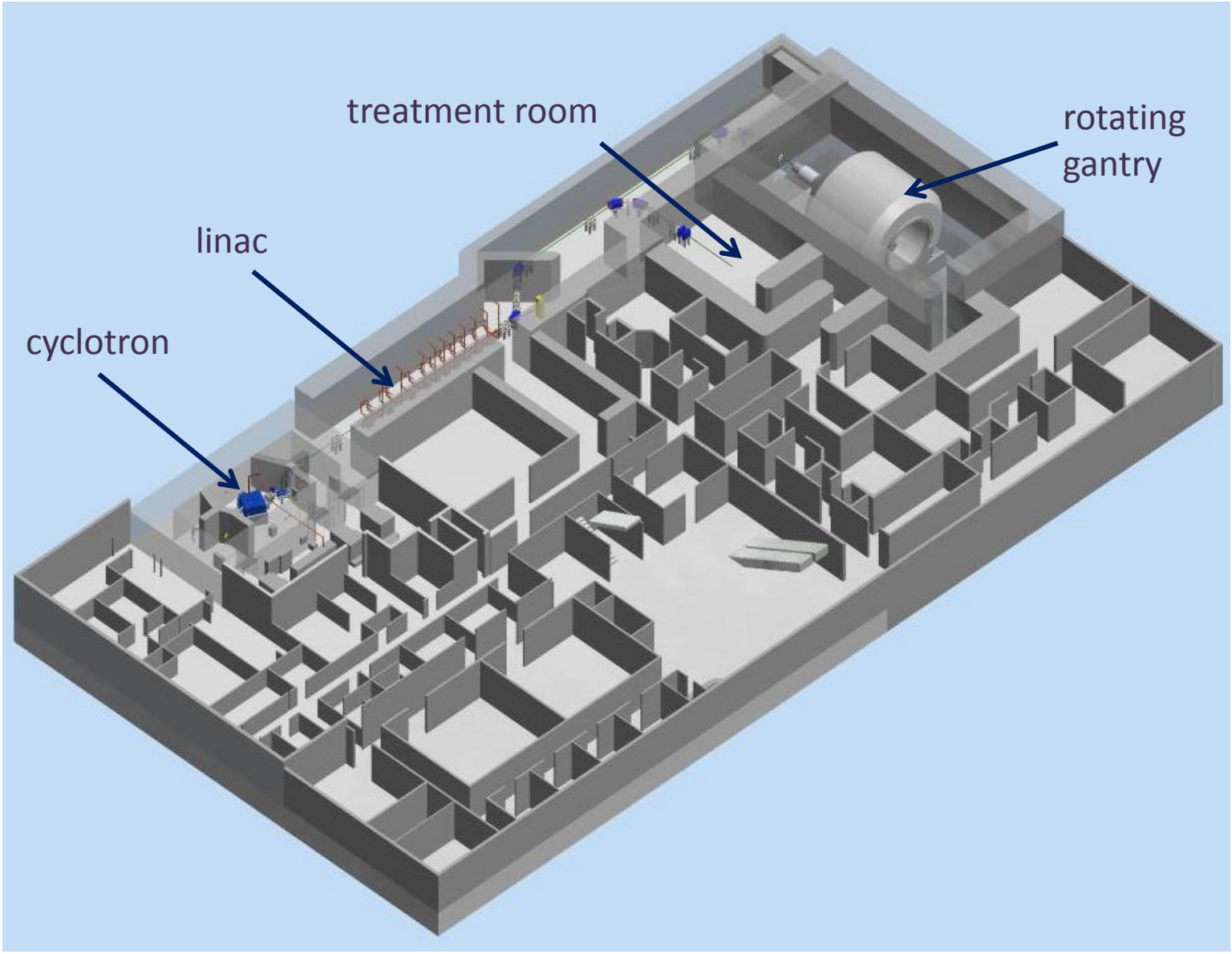
CNAO, Italy (Pavia)



TERA

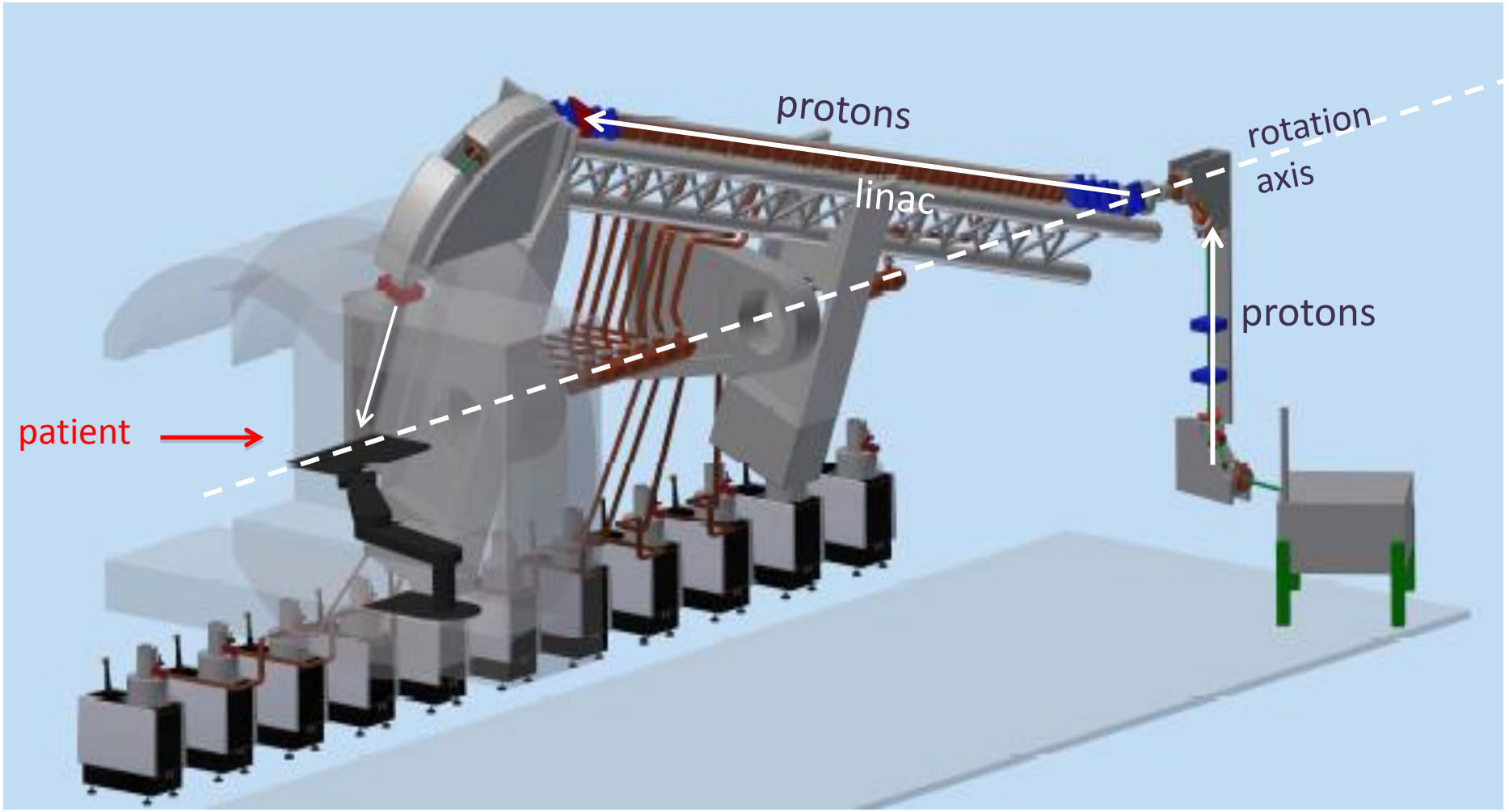
TERA Programmes: PERLA

Protontherapy and **E**xotic **R**adioisotopes from **L**inked **A**ccelerators



TERA Programmes: TULIP

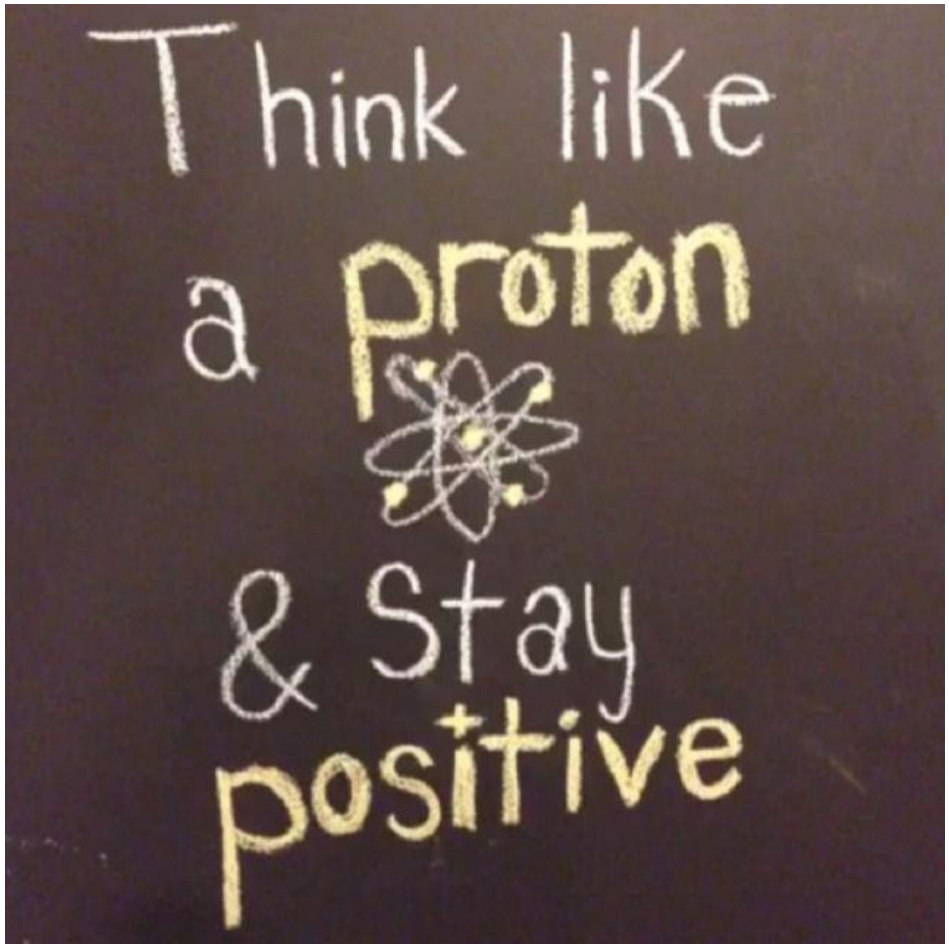
TUrning **LI**nac for **P**rotontherapy



ENVISION

https://cds.cern.ch/record/1611725

The collaborative spirit of particle physics and medical applications



Thanks for your attention!!!