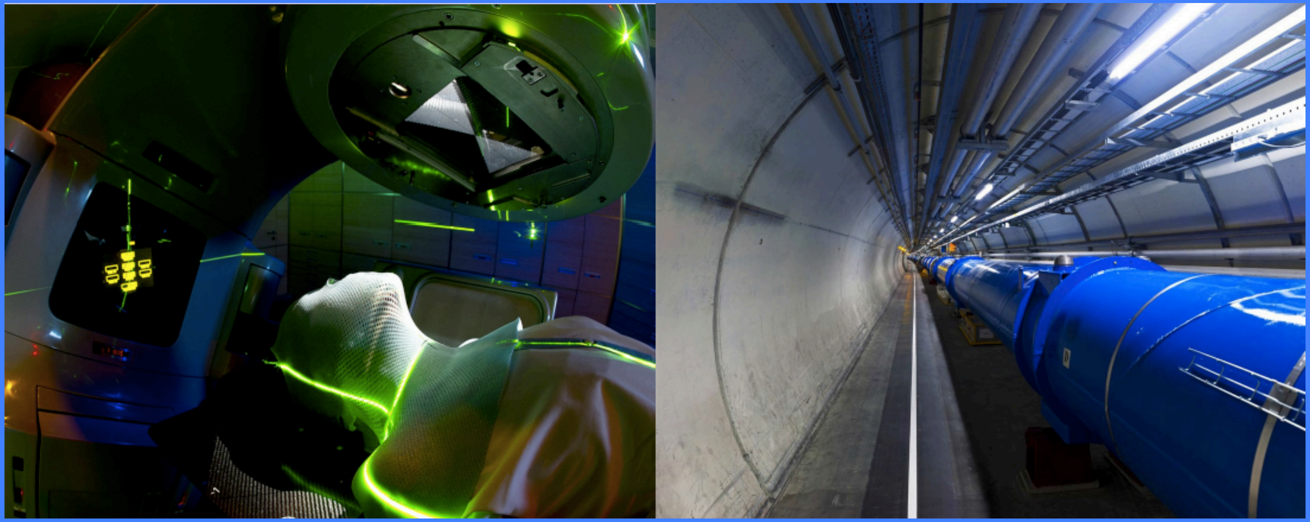
CERN: From Particle Physics to Medical Applications



Evangelos N. Gazis

Professor of Particle Physics

National Technical University of Athens

CERN High School Teachers, 28-31 Aug 2019

Outline

- Medical Applications
- From X-rays to Medical Physics
- Natural Radioactivity
- Synergy of sciences
- CERN Collaboration for the deceases
- Cancer: Diagnosis – Treatment
- Medical Imaging
- PET Imaging
- Medical Imaging Collaborations: Crystal Clear & Medipix
- Digital Imaging
- Multimodality Imaging CT – PET
- MRI
- Accelerators for cancer : diagnosis - treatment
- Hadron Therapy - Timeline
- Carbon Ions – HIT
- PIMMS – CNAO
- ISOLDE – Isotopes Production

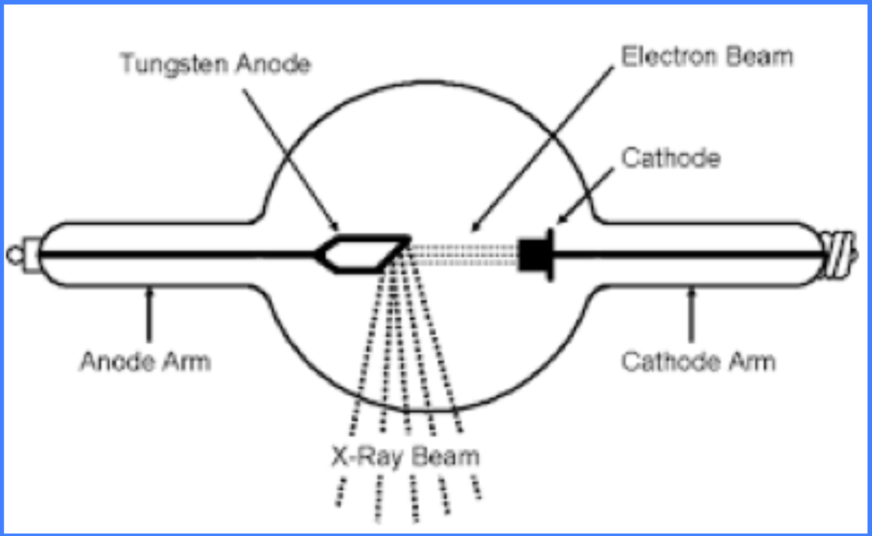
Medical Applications

- **Fundamentals of Radiation Physics**
- **Medical Diagnostic Techniques**
- **Imaging technics (basic)**
- **Radiation Therapy**

Not covered in this talk:

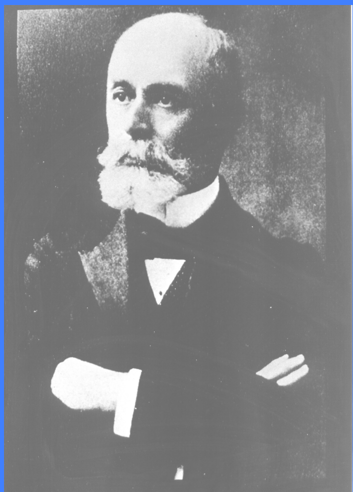
- **Advanced Imaging**
- **Radiation Protection and Dosimetry**
- **Radiobiology**
- **Anatomy and Physiology**
- **Molecular and cellular oncology**

X-rays
Beginning of Modern Medical Physics



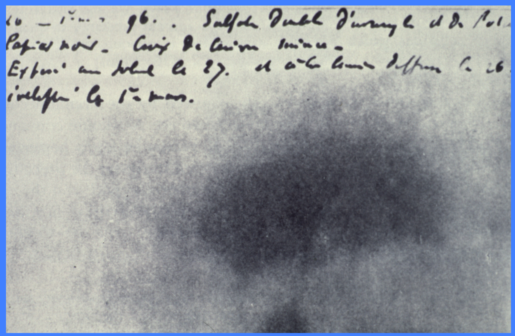
- November 8, 1895 **Wilhelm Röntgen** discovered X-Rays
- December 22, 1895 he takes the first image of his wife's hand
- Röntgen received the first Nobel prize in physics in 1901

Natural Radioactivity
Beginning of Modern Medical Physics

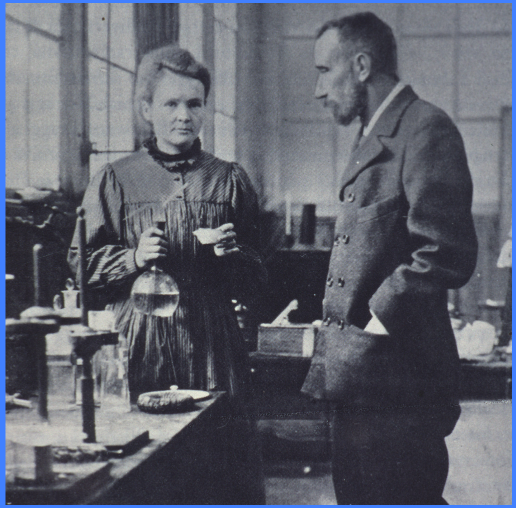


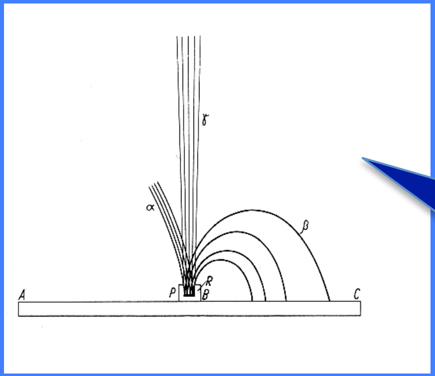
Henri Becquerel

1896: Discovery of natural radioactivity



1898: Discovery of radium used immediately for "Brachytherapy"





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

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

What is the added value of the Physics of Medicine?

….or why should YOU study medical physics?

…or why should senior physicists care about medical research?

…and why care medical researchers/industry about physics???

1st Answer: Synergy

Accelerator physics

X-.-ray source physics

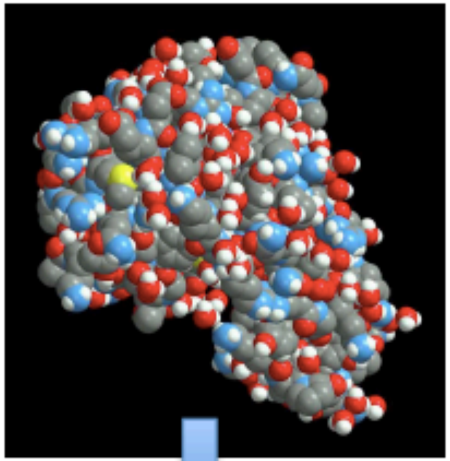
detector physics

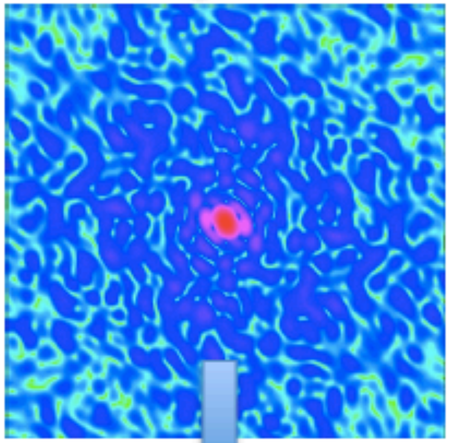
image reconstruction

medical doctors

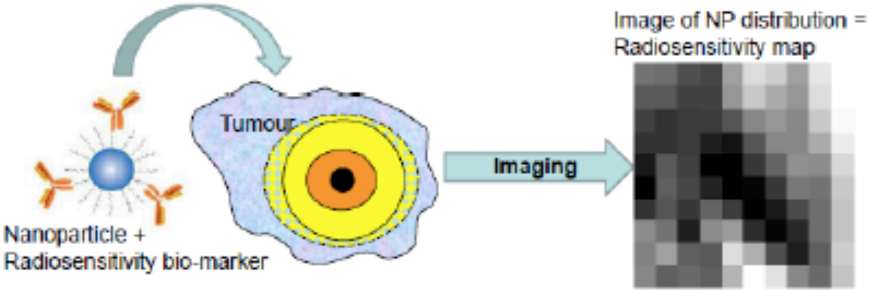
2nd Answer: Overcoming Limits!

single molecule imaging

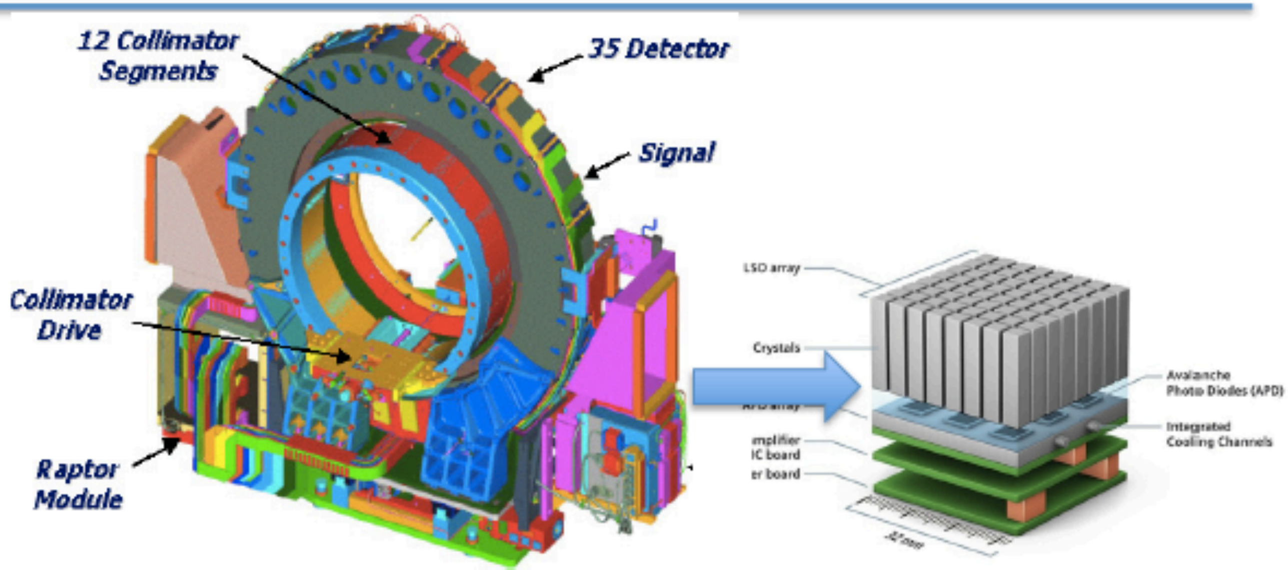




3D protein structure

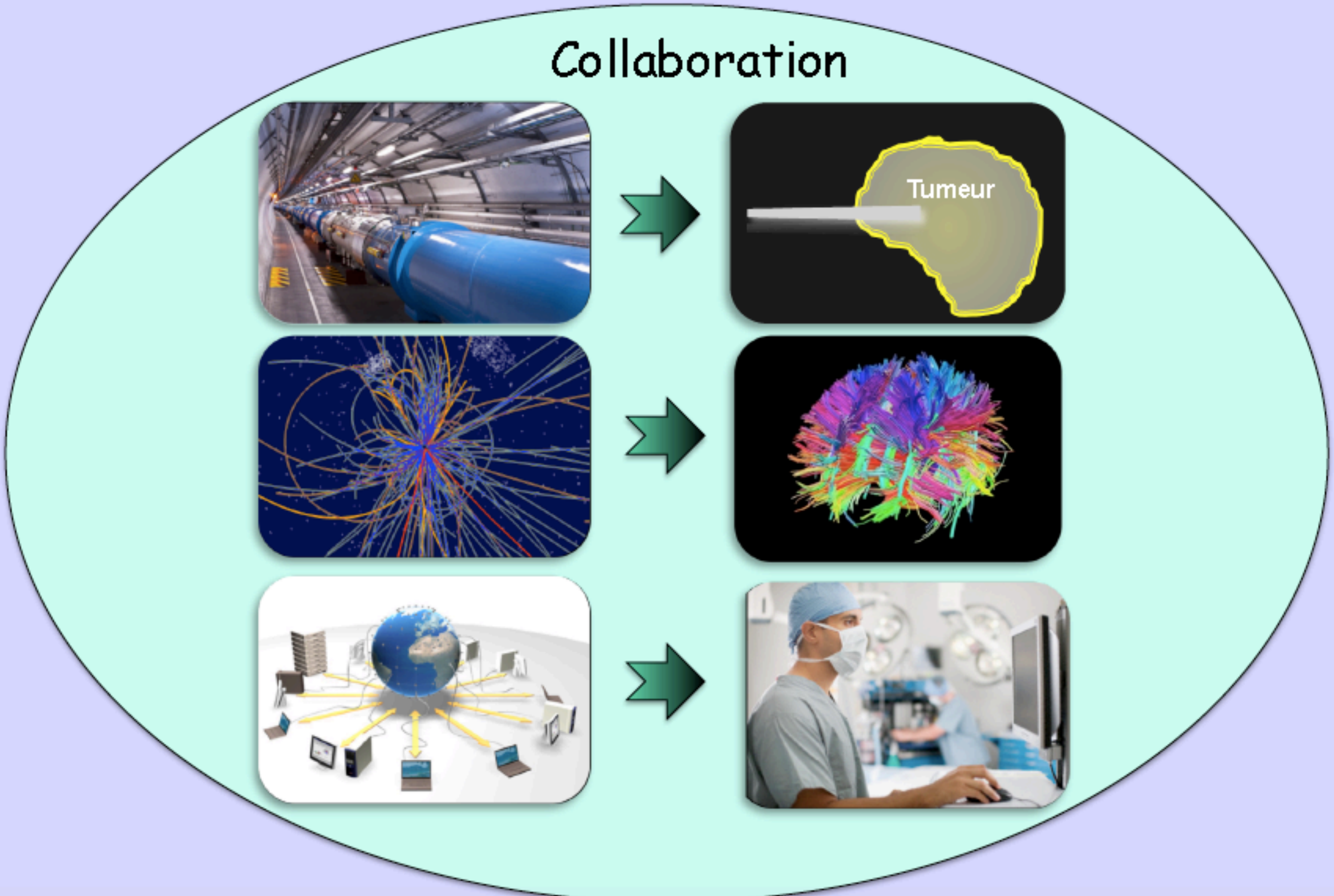


imaging of diagnostic agents not possible in-vivo



CERN-sized detector reduced to patient-size

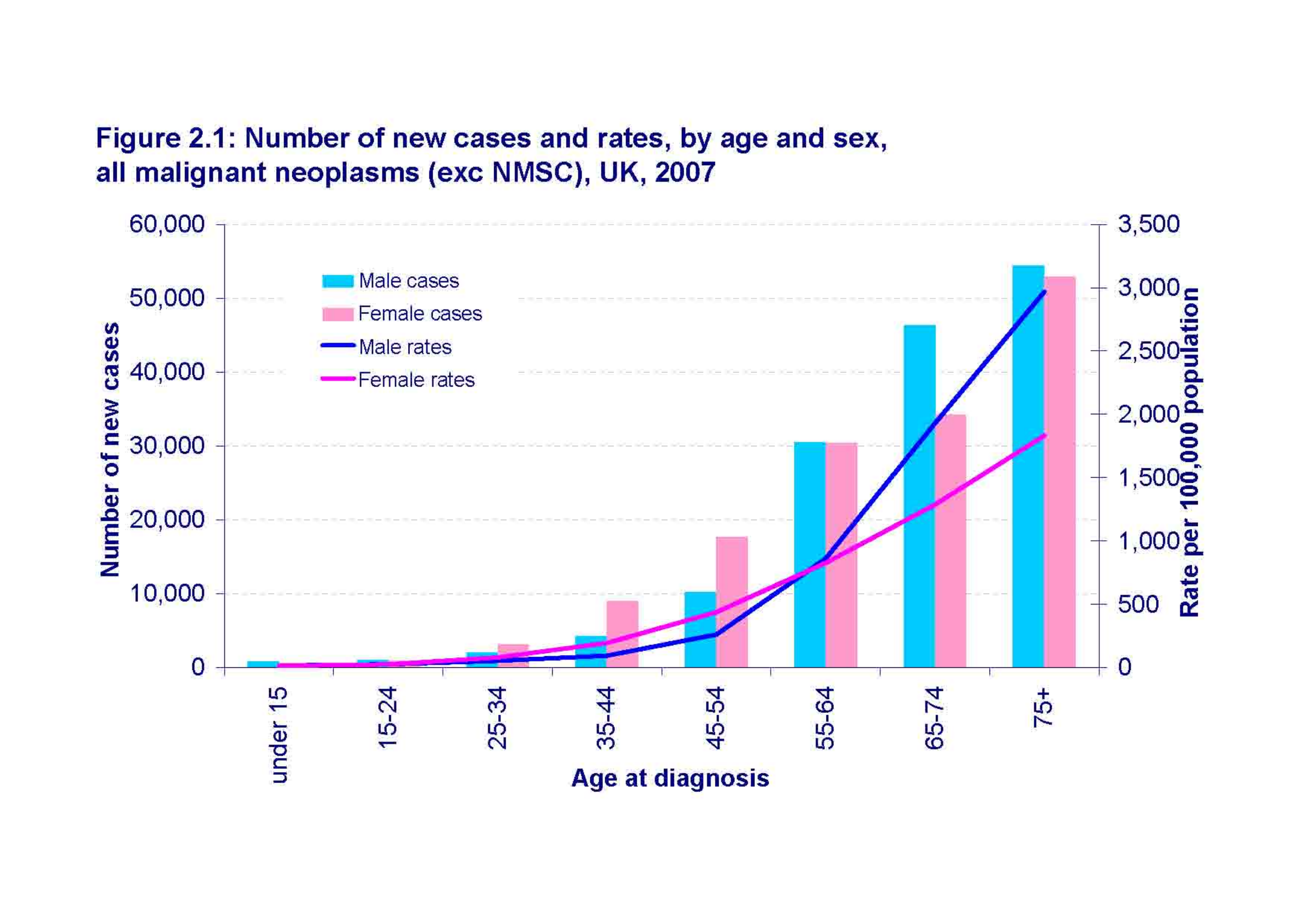
The 4th Pilar of Technology



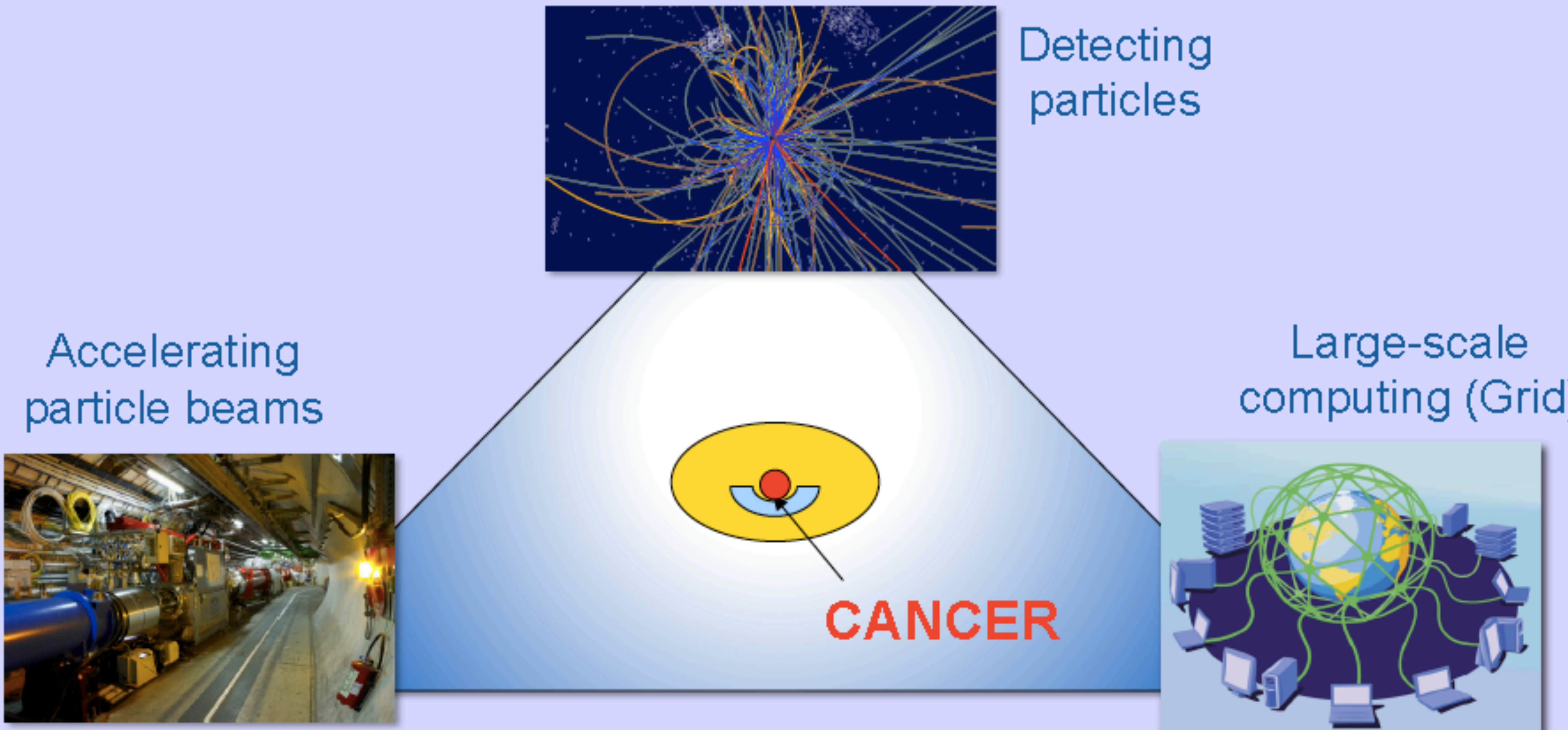
CANCER a growing challence

More than 3 million new cancer cases in Europe each year and 1.75 million associated deaths

Increase by 2030: 75% in developed countries and 90% in developing countries



CERN Technologies & Innovation

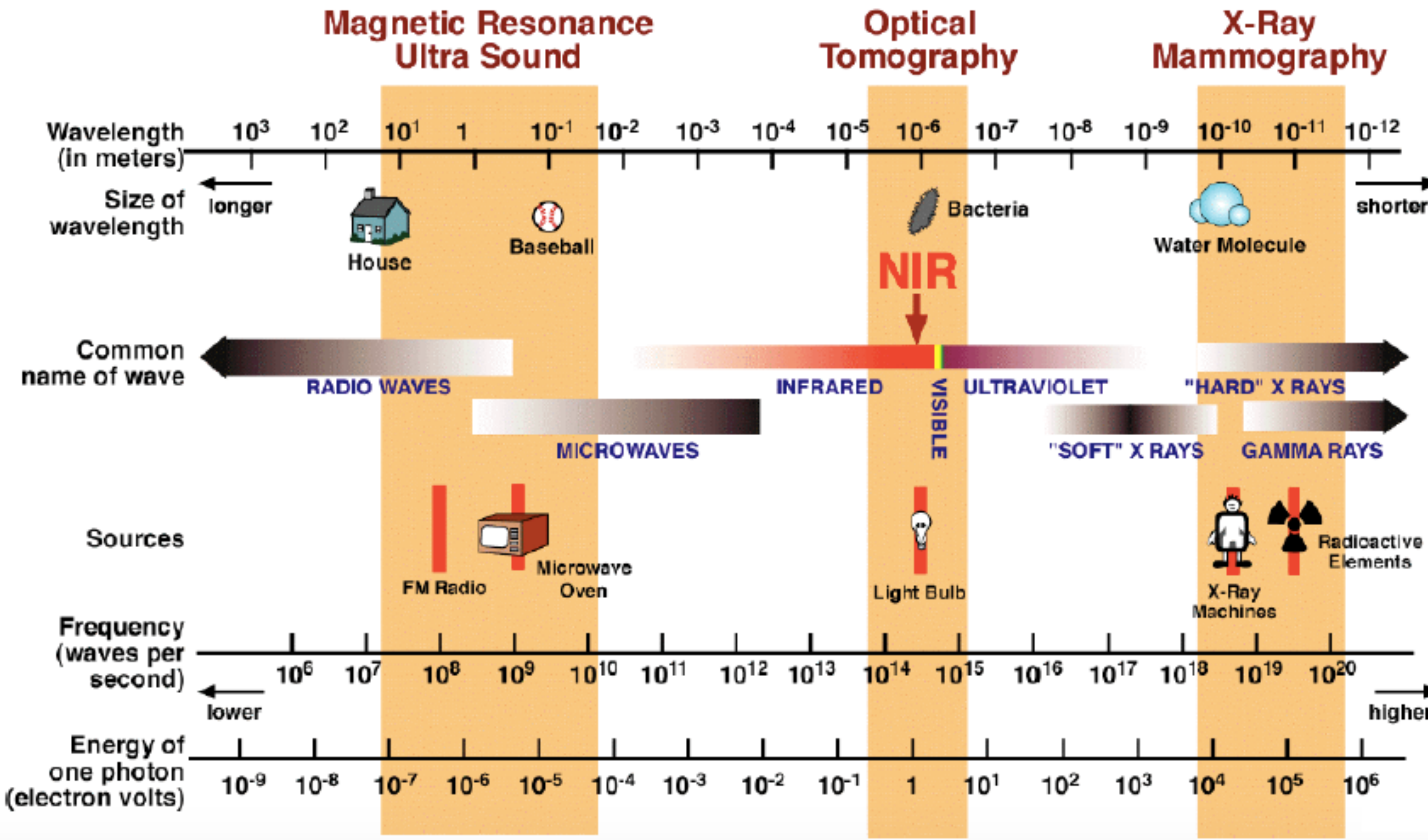


Medical Imaging

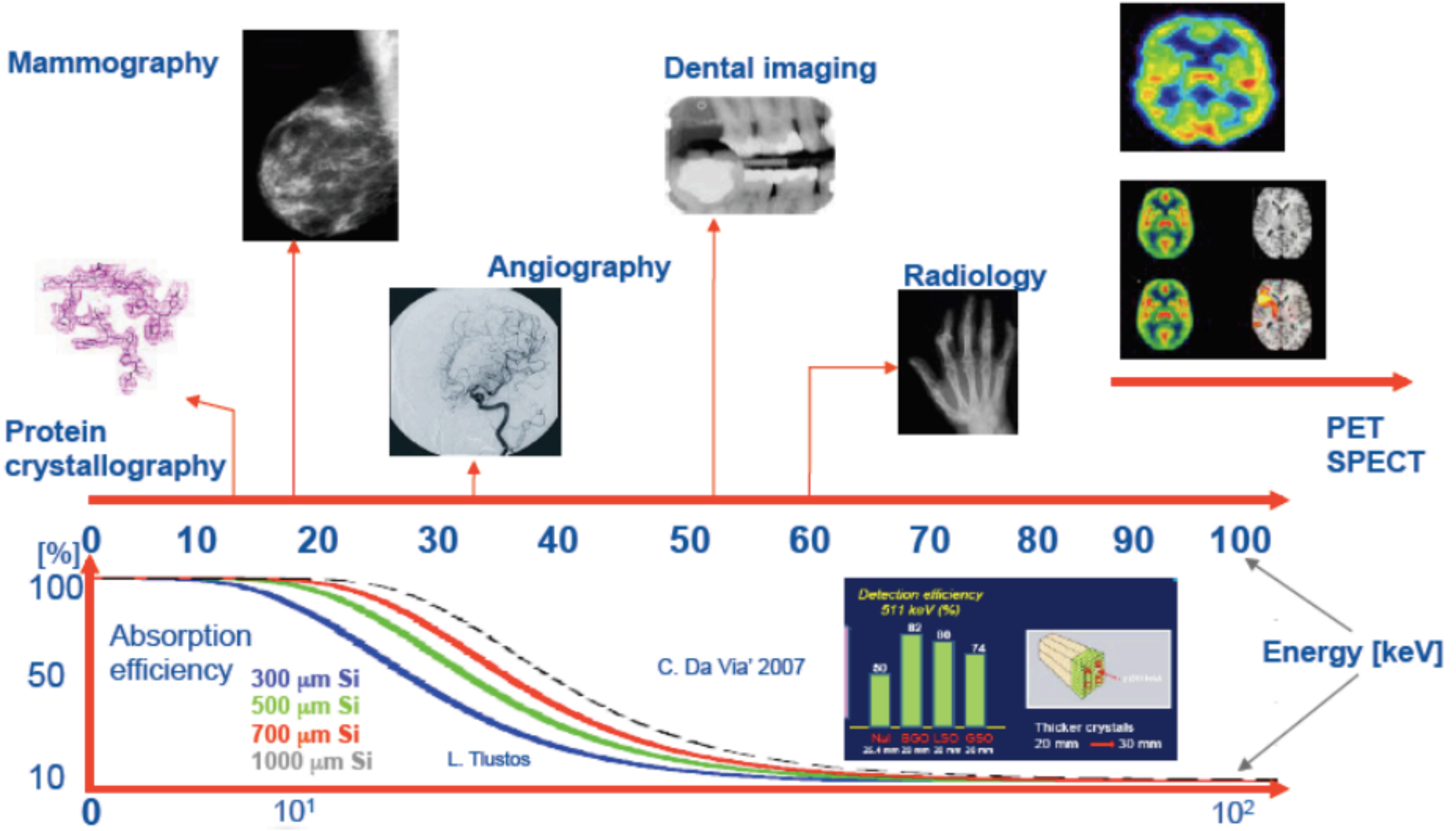
Electromagnetic Waves Used in Medical imaging

larger than 1 Å high attenuation from the body,

shorter than 10^{-2} Å = too high energy (>1MeV) for direct detection



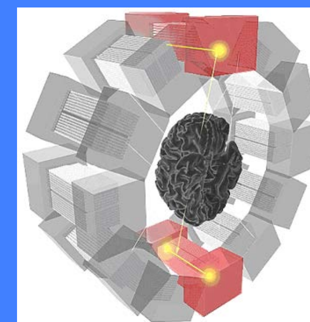
Medical Imaging



Medical Imaging then Treatment

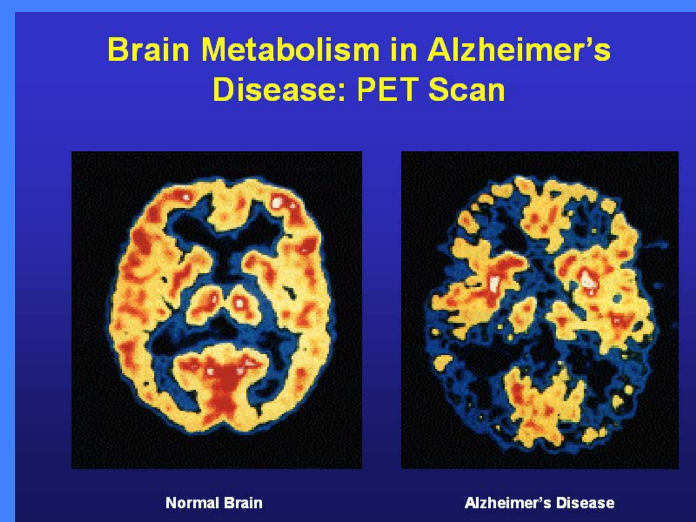
Particle Detection

Imaging

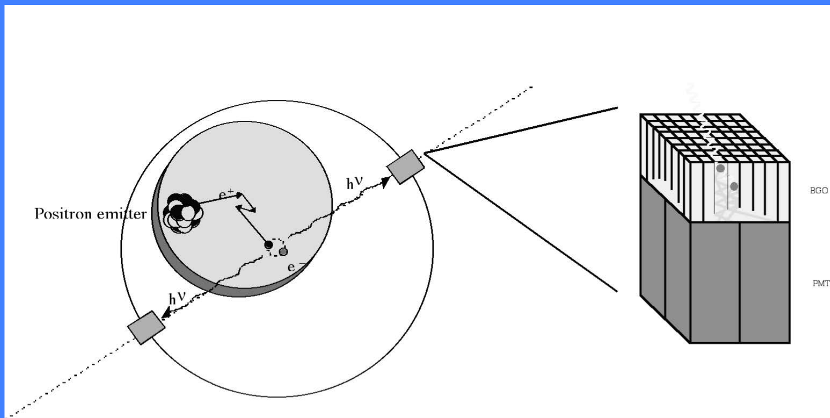


PET Scanner

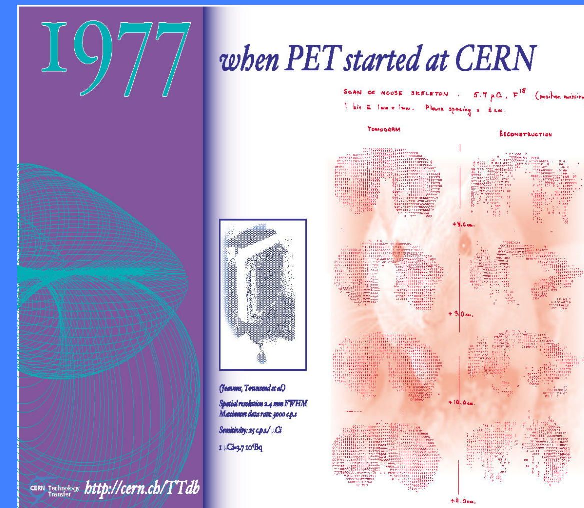
Breast imaging (Clear PEM)

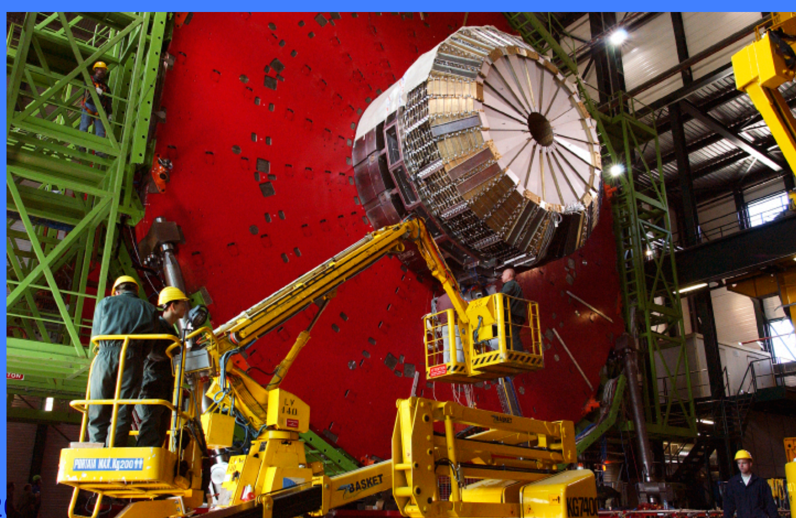


PET Imaging

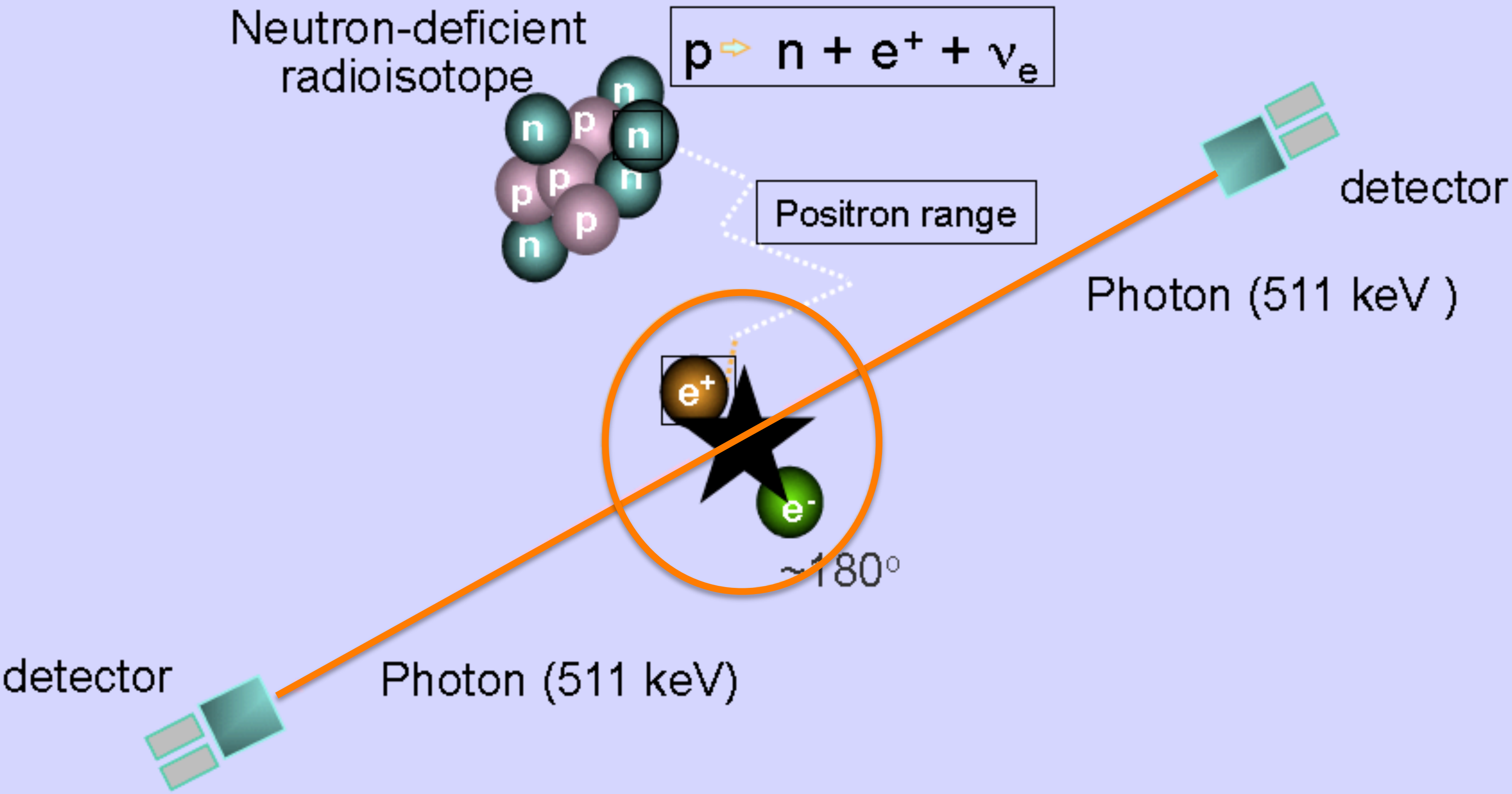


Idea of PET

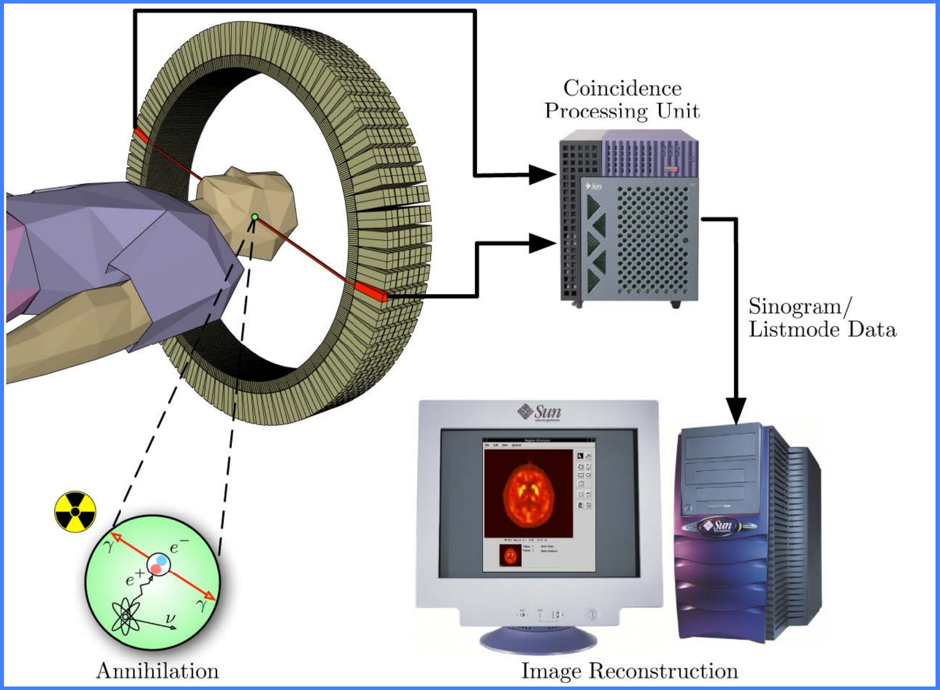


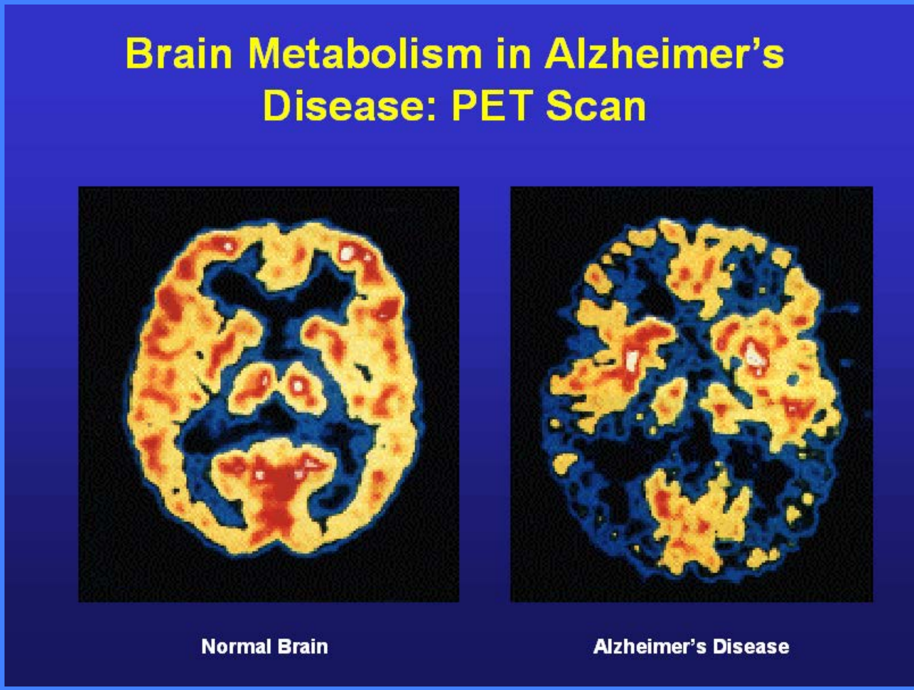


PET : Operation



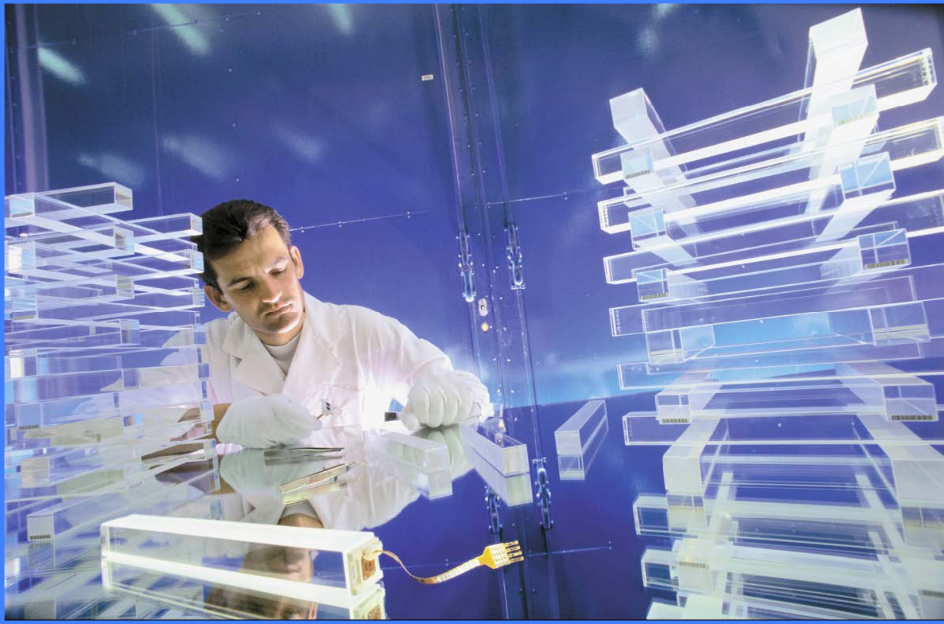
PET : Scan


Coincidence
Processing Unit
Sinogram/
Listmode Data
Annihilation
Image Reconstruction


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

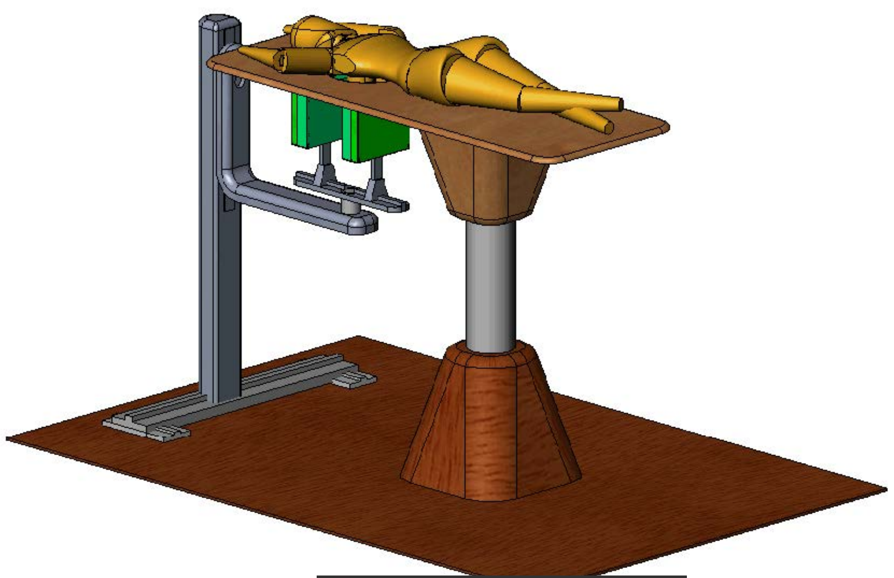
Crystal Clear Collaboration

- New scintillating materials
  - LuAP, phoswich LuAP-LSO (CERN patent)
  - Other crystals
- New photodetectors (Avalanche Photo-Diodes)
- New low noise electronics



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

Crystal Clear Collaboration (PEM)



- PET dedicated to breast cancer screening
  - Extremely sensitive to small tumor masses
- Spatial resolution (1-2mm)
- High counting sensitivity
- Short PET exam
- Coupled to ultrasound

MEDIPIX

- High Energy Physics original development:

– Particle track detectors

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

- Main properties:

– Fully digital device

– Very high space resolution

– Very fast photon counting

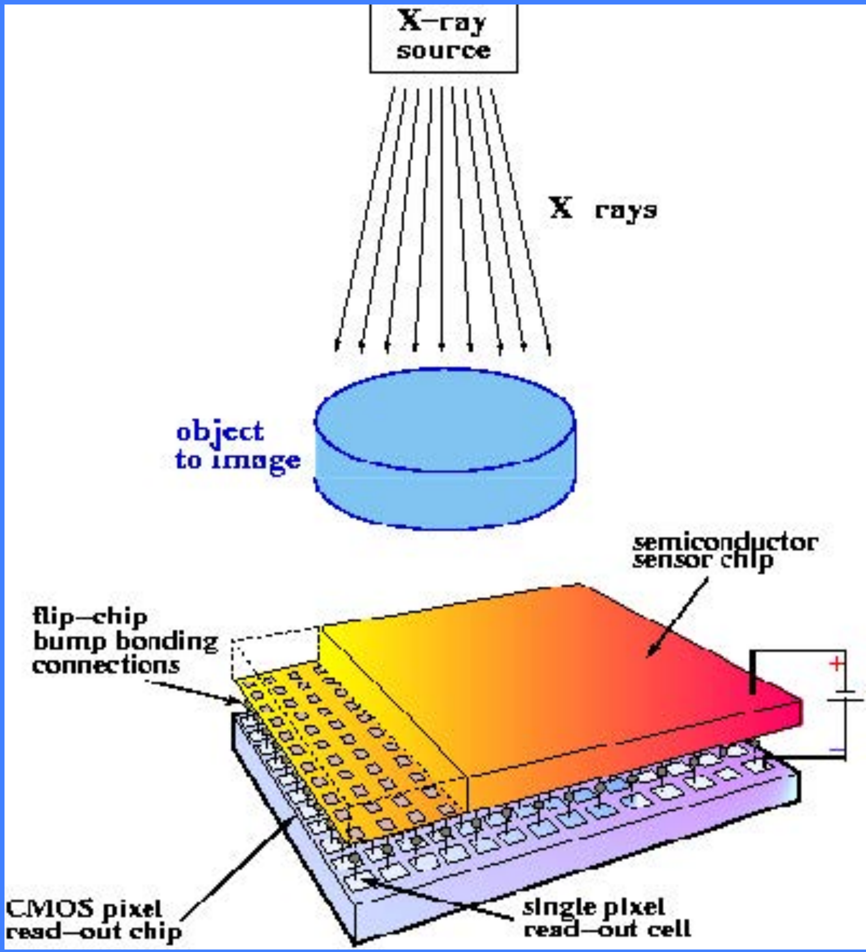
– Good conversion efficiency of low energy X-rays

WHAT IS MEDIPIX ?

- an electronic chip similar to the electronic imaging chip in a digital camera
  - – sensitive to x-rays instead of visible light

- it can create the first true color images with x-rays.
  - – it permits us to move from black and white x-ray images to full color x-ray images

- can be read out very rapidly.
  - – allows the use of the chip for color x-ray digital movies or for fast color x-ray CT scans



Digital Imaging

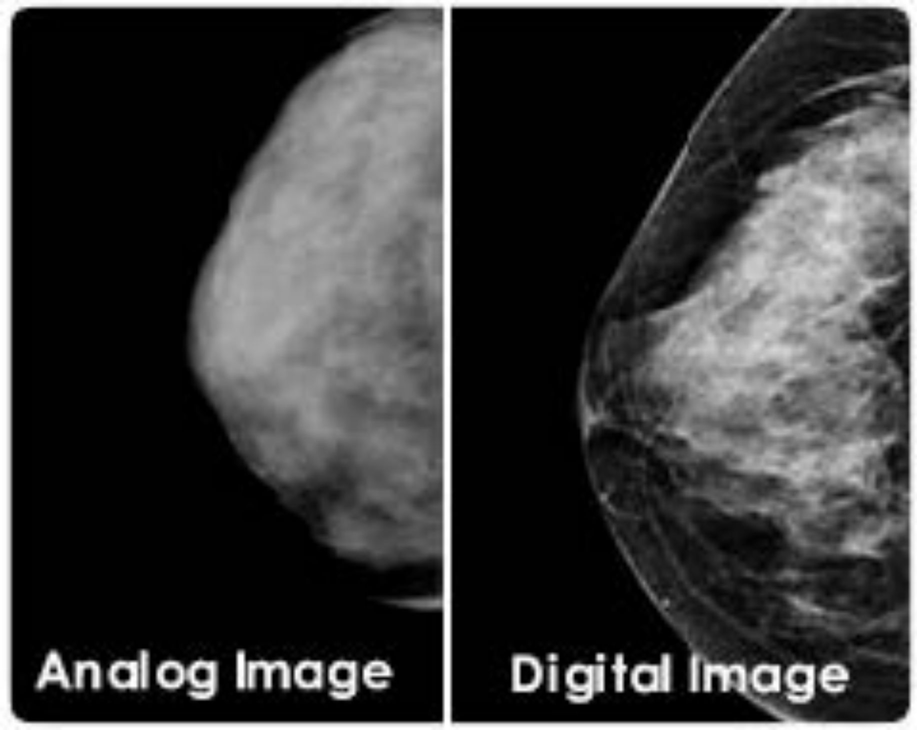
Current

– Limited contrast

– High dose

• Restricted screening

• Limited access to preventive health care



Digital

– High contrast

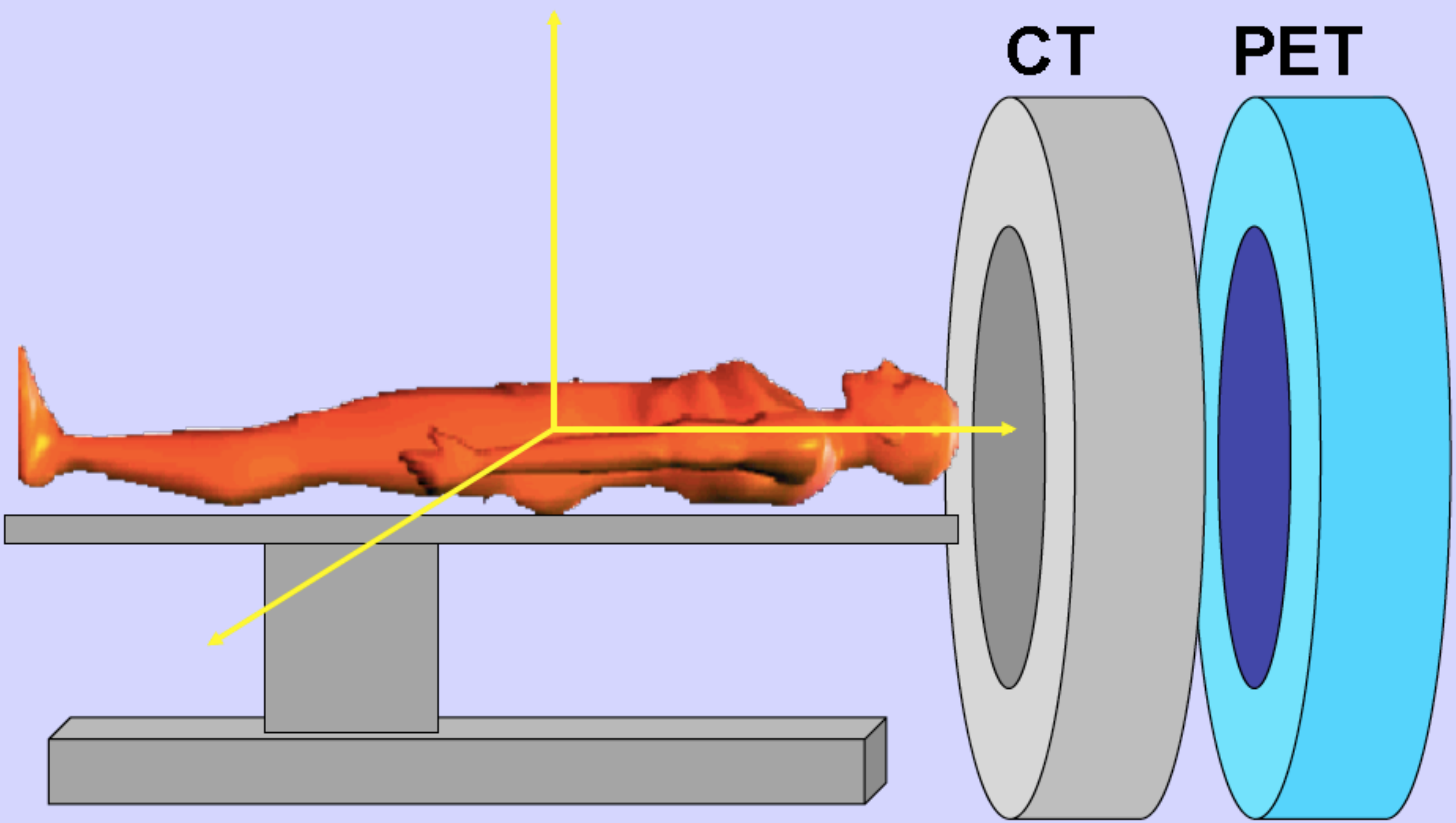
– Lower dose

• Opportunity for screening

• Access to preventive health care

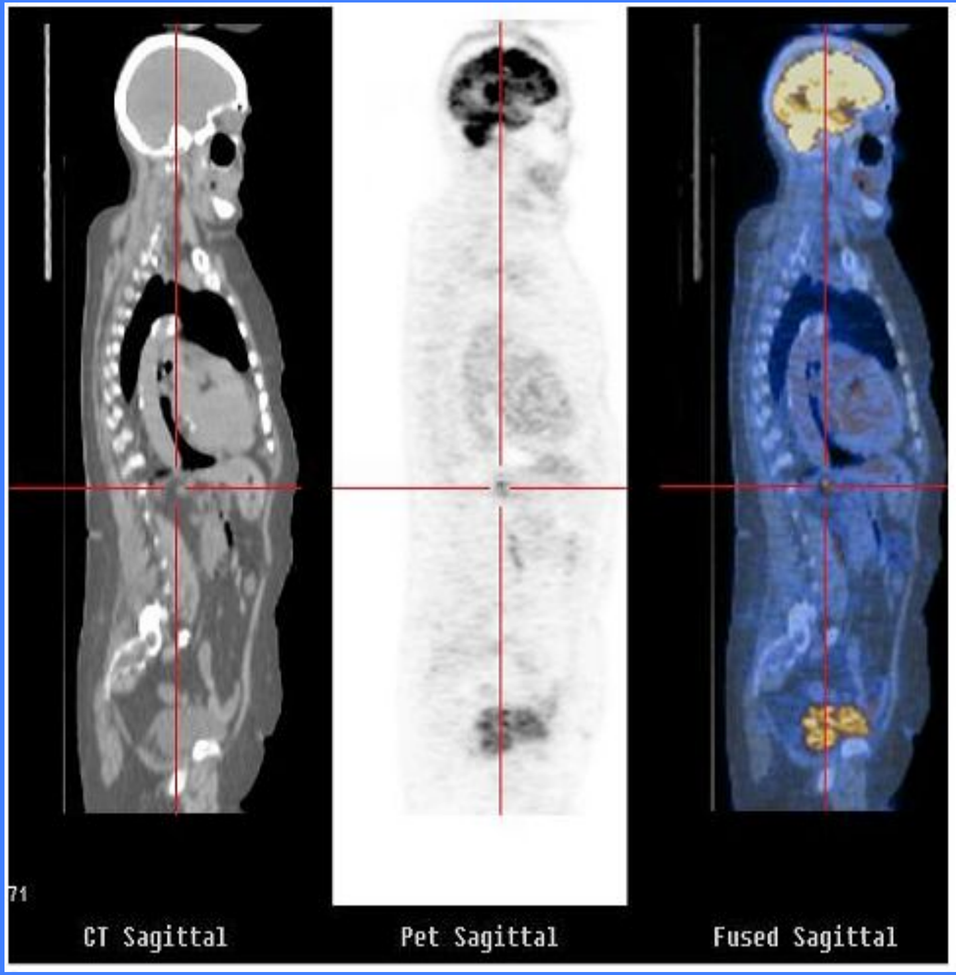
Multimodality Imaging

PET – CT David Townsend

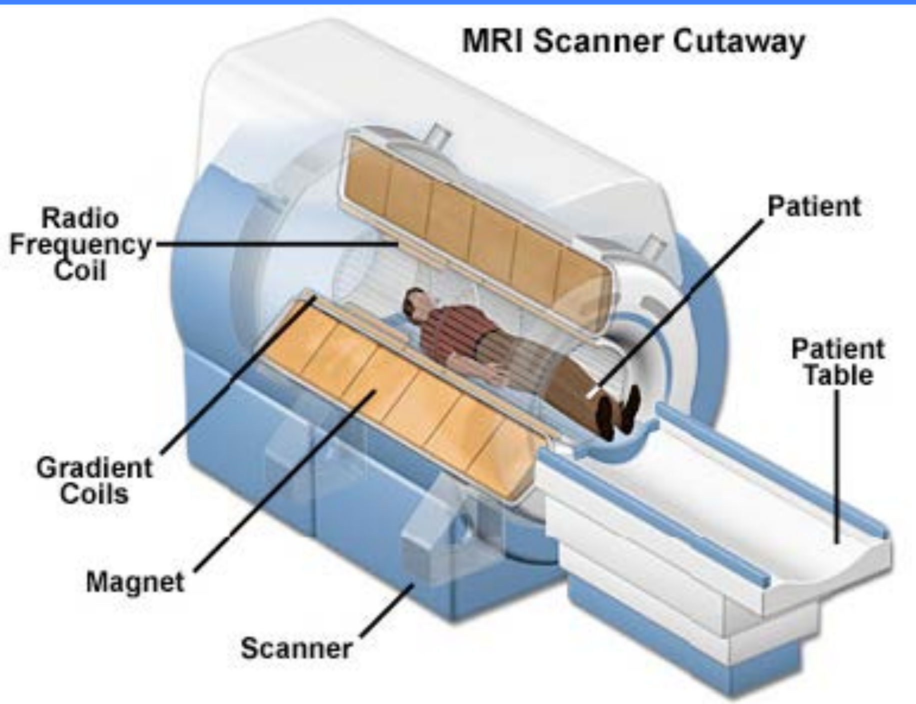


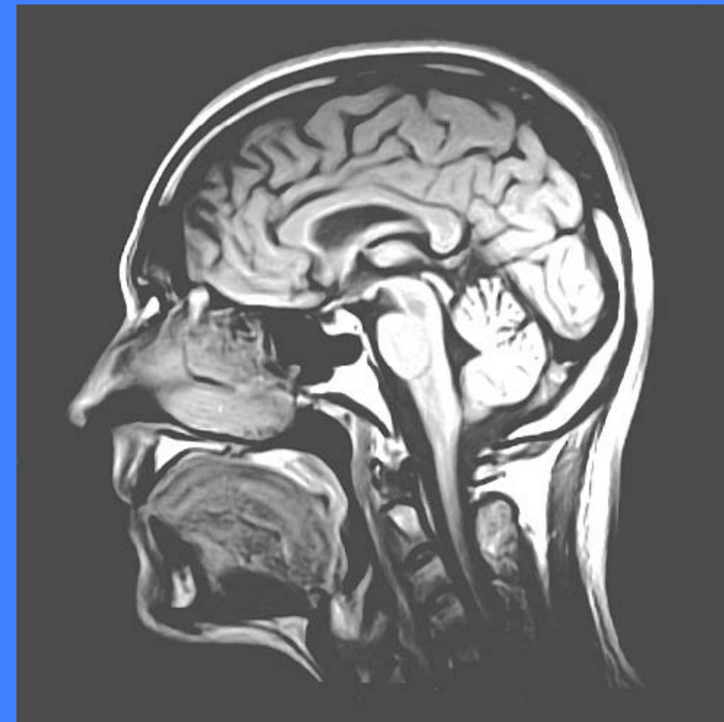
Multimodality Imaging : PET - CT

Morphology Metabolism

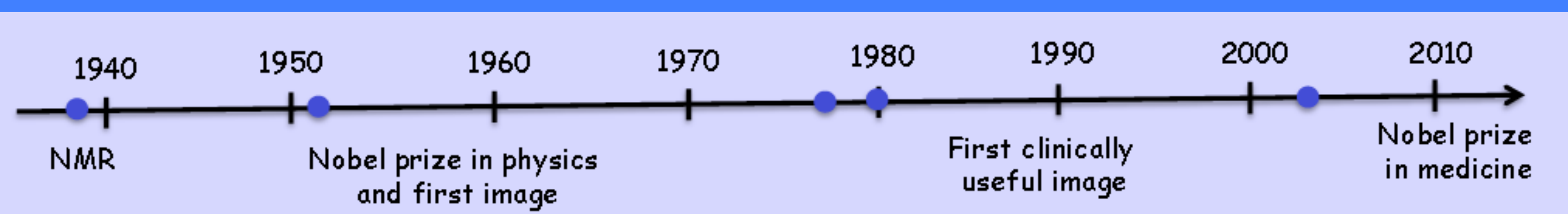


Magnetic Resonance Imaging - MRI

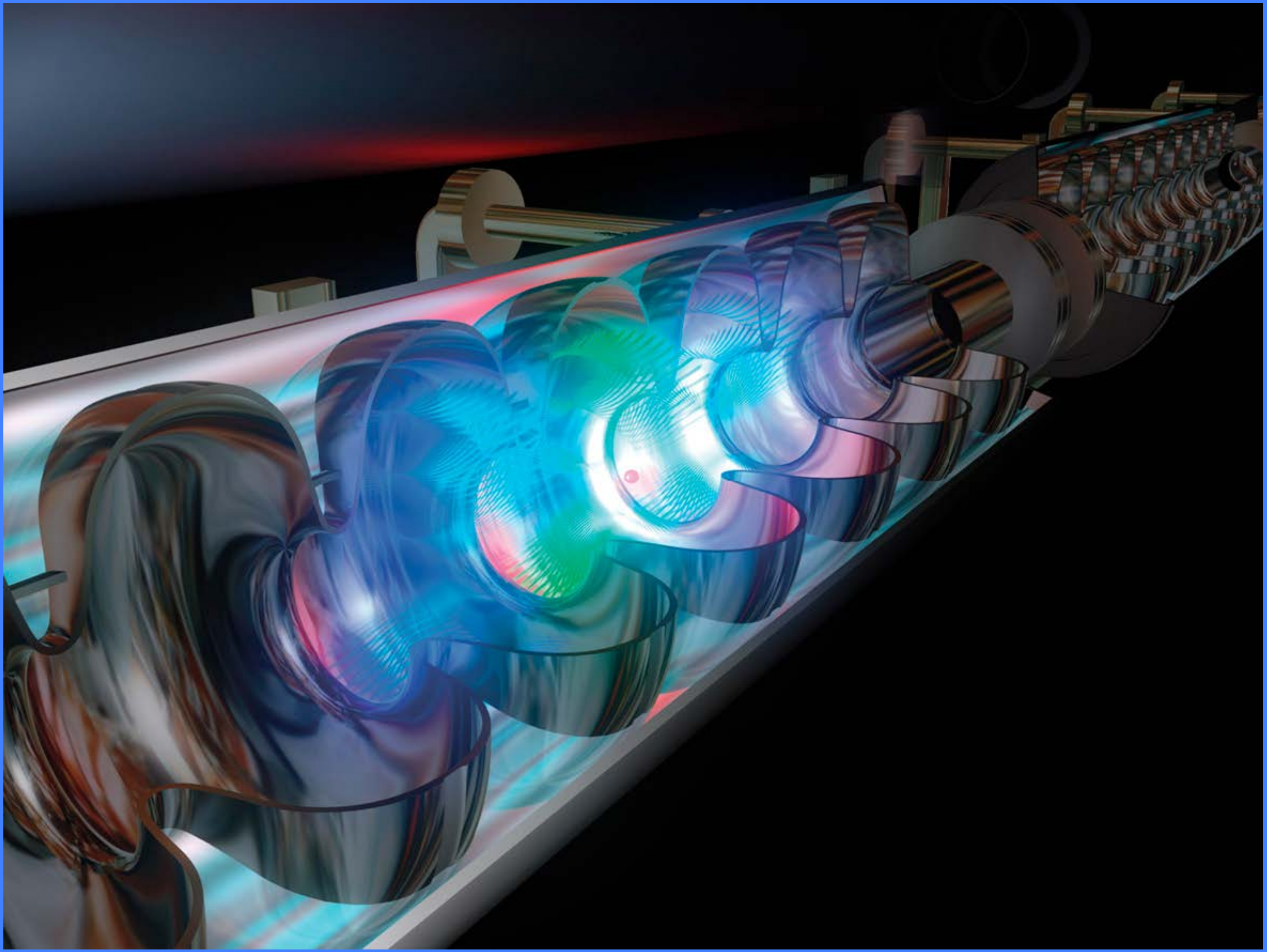




First human body scan



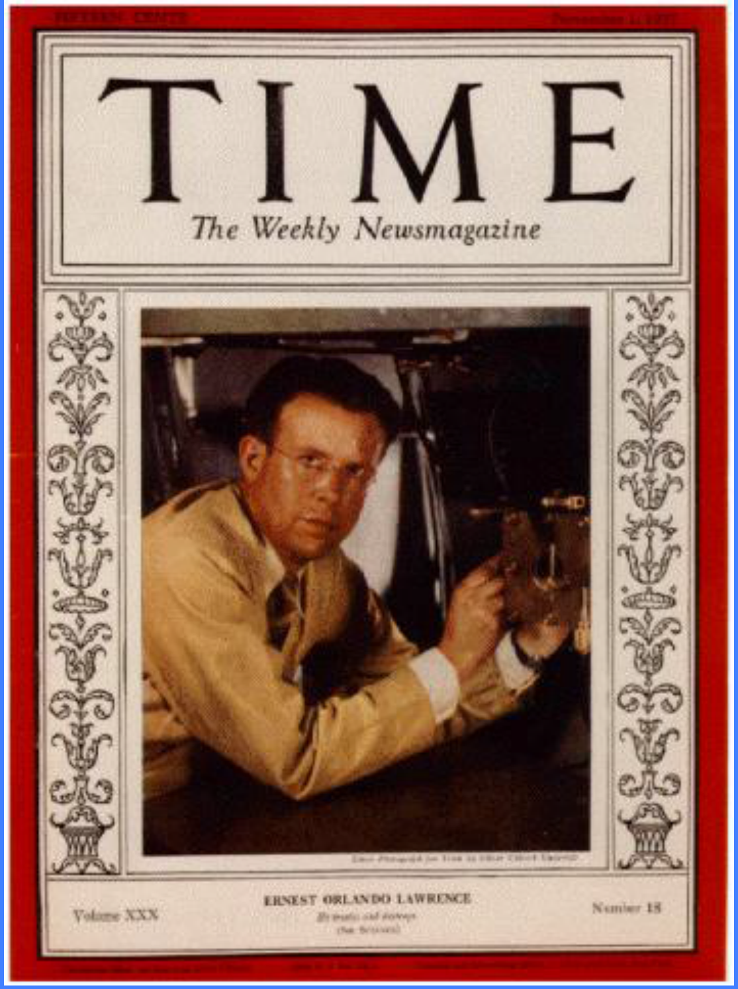
Accelerators for Cancer Treatment

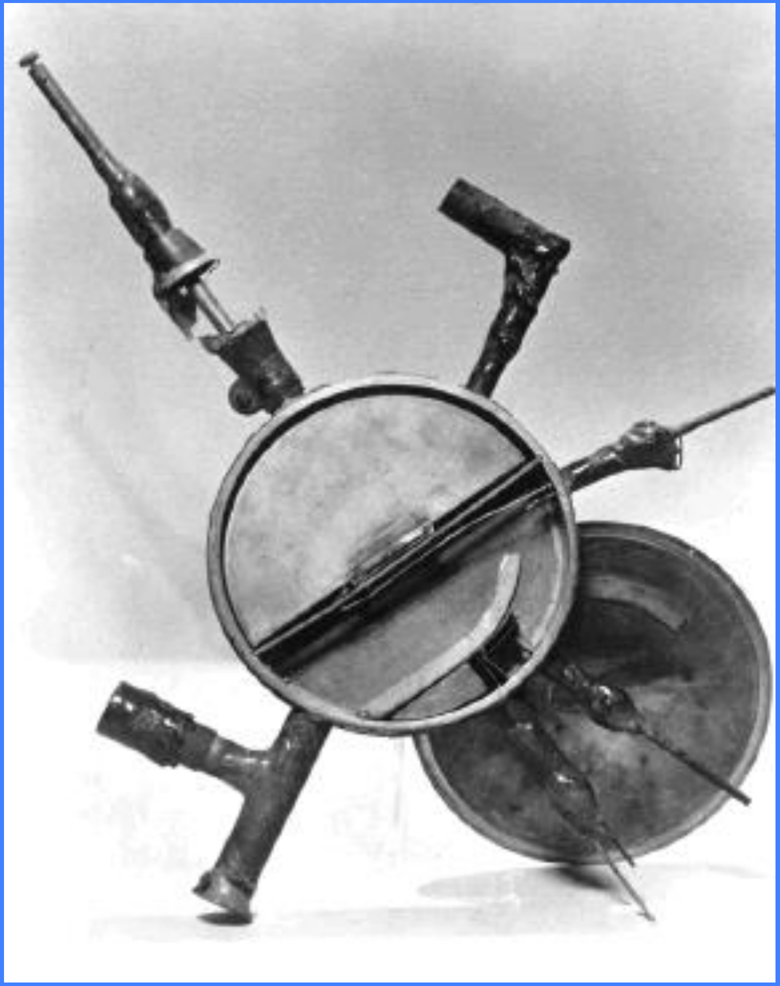


The 1st Cyslotron

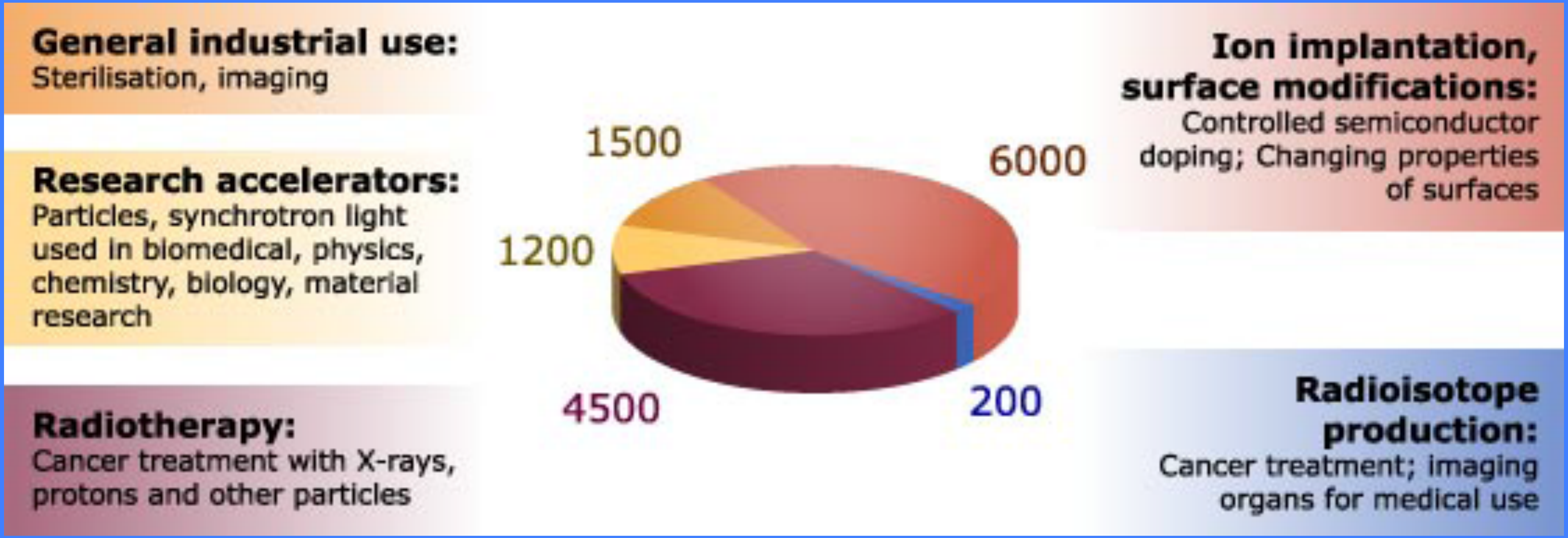
E. O. Lawrence is awarded Nobel Prize in 1939

Ffor inventing the cyclotron 1937





Use of Accelerators Today

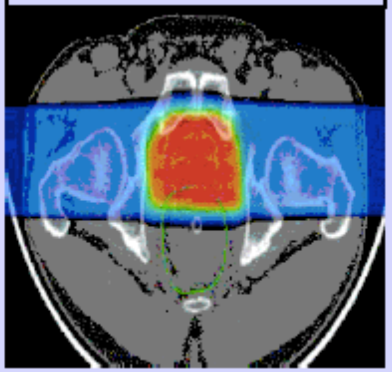


Cancer a growing societal challenge !

Over 3 million cancer cases in Europe each year

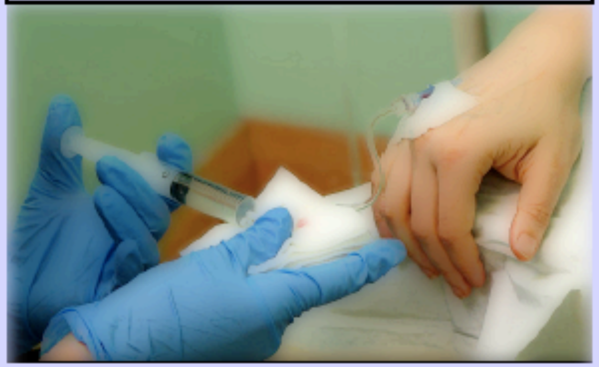
Surgery

Radiotherapy



X-ray, IMRT, Brachytherapy, Hadrontherapy

Chemotherapy & others



Hormones; Immunotherapy; Cell therapy; Genetic treatments; Novel specific targets (genetics..)

Local control

Local control

Limited Local control

Survival
Quality of life

Radiotherapy

After diagnosis some diseases like hyperthyroidism, cancer, blood disorders, etc… can be treated using radiotherapy

Three main methods:

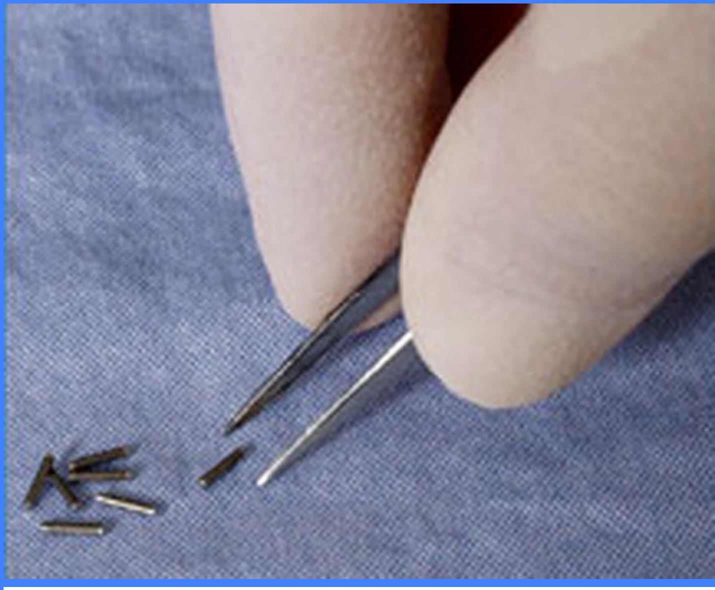
- Unsealed source radiotherapy
- Brachytherapy (sealed source therapy)
- External beam: x--rays, electrons, p, n, heavy ions

Stages in the radiotherapy process:

QA, Imaging, Planning, Simulation,

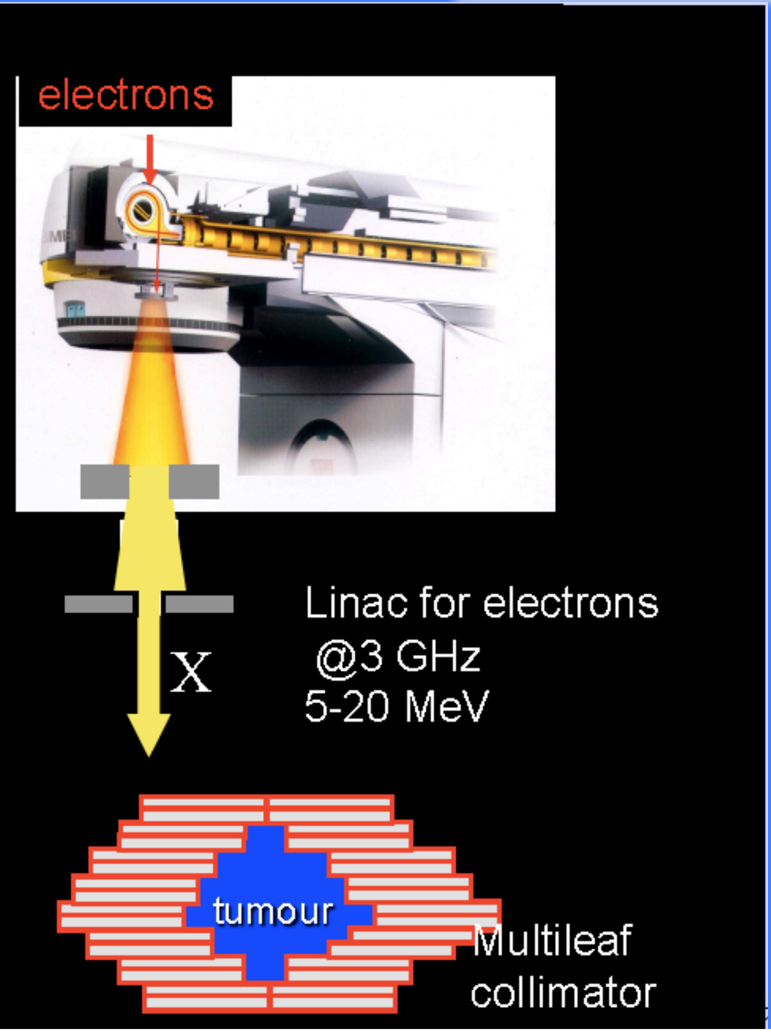
Treatment, Verifikation, Modelling Outcome

Physics, engineering, imaging, technology based



"seeds"- small radioactive rods implanted directly into the tumor

Conventional Radiotherapy



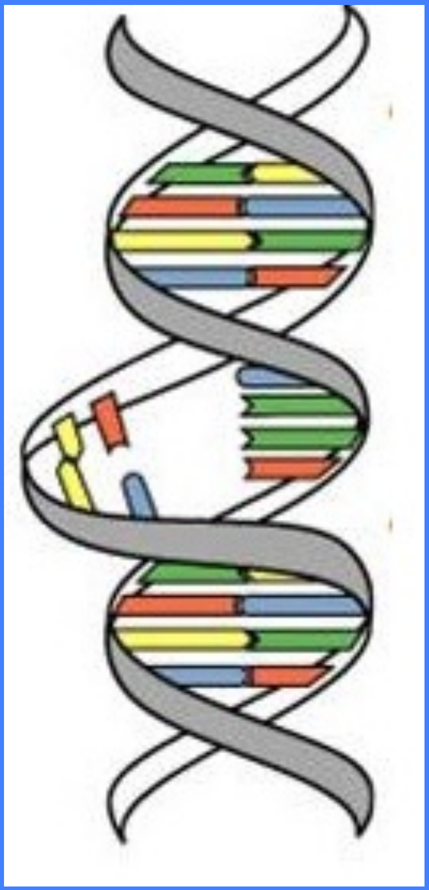
More than 7000 linacs in the world for radiotherapy

20 000 patients per year every

10 tumor million inhabitants

1 linac every <250,000 inhabitants

Radiotherapy in the 21st Century



3 "Cs" of Radiation

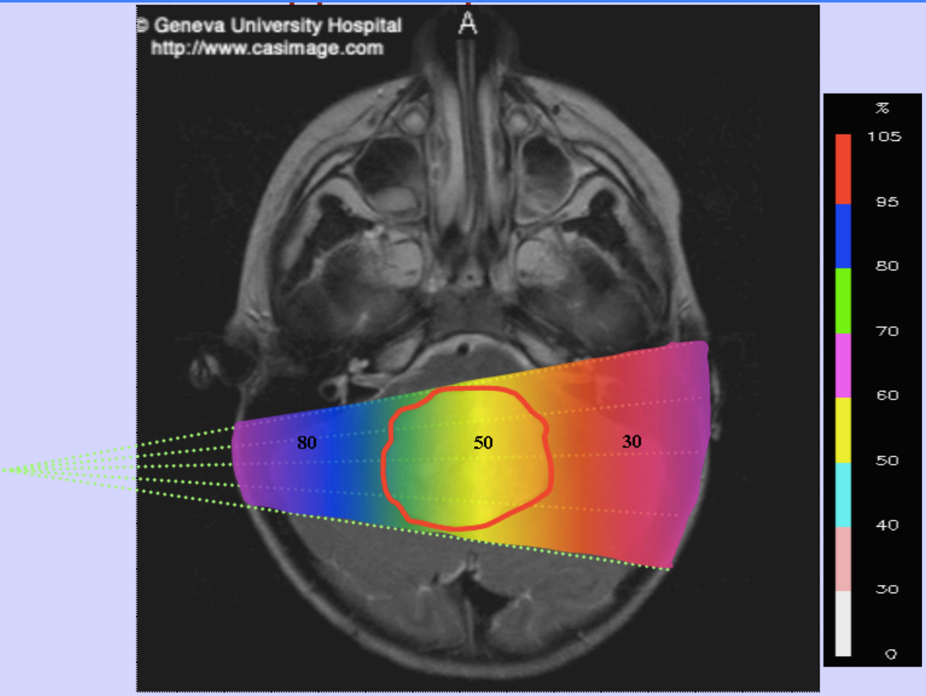
- Cure (~ 45% cancer cases are cured)
- Conservative (non-invasive, few side effects)
- Cheap (~ 5% of total cost of cancer on radiation)

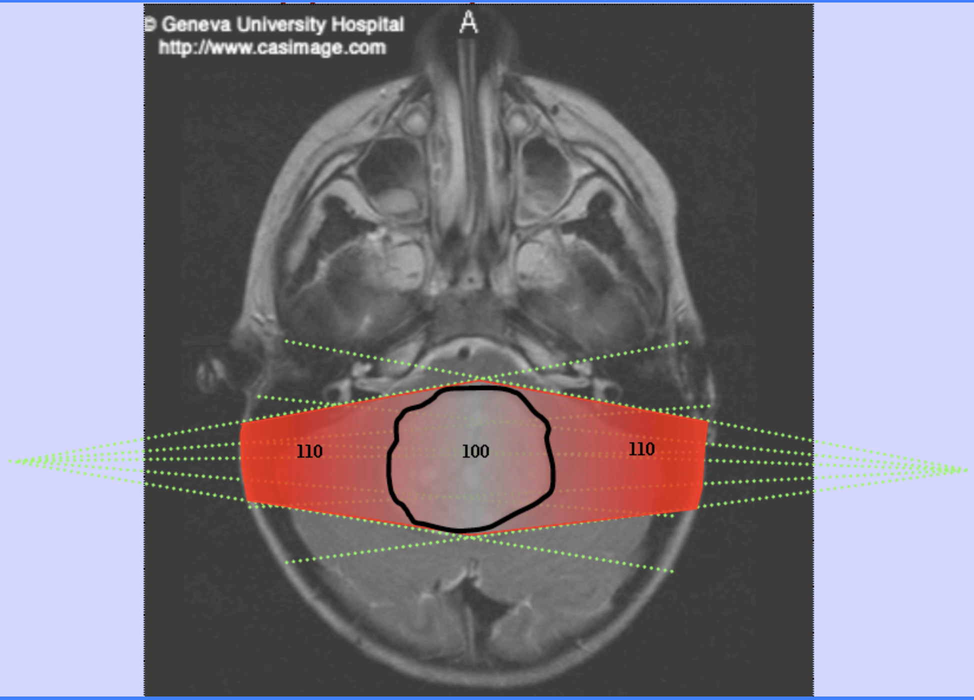
- ➢ There is no substitute for RT in the near future
- ➢ The rate of patients treated with RT is increasing

Present Limitation of RT:

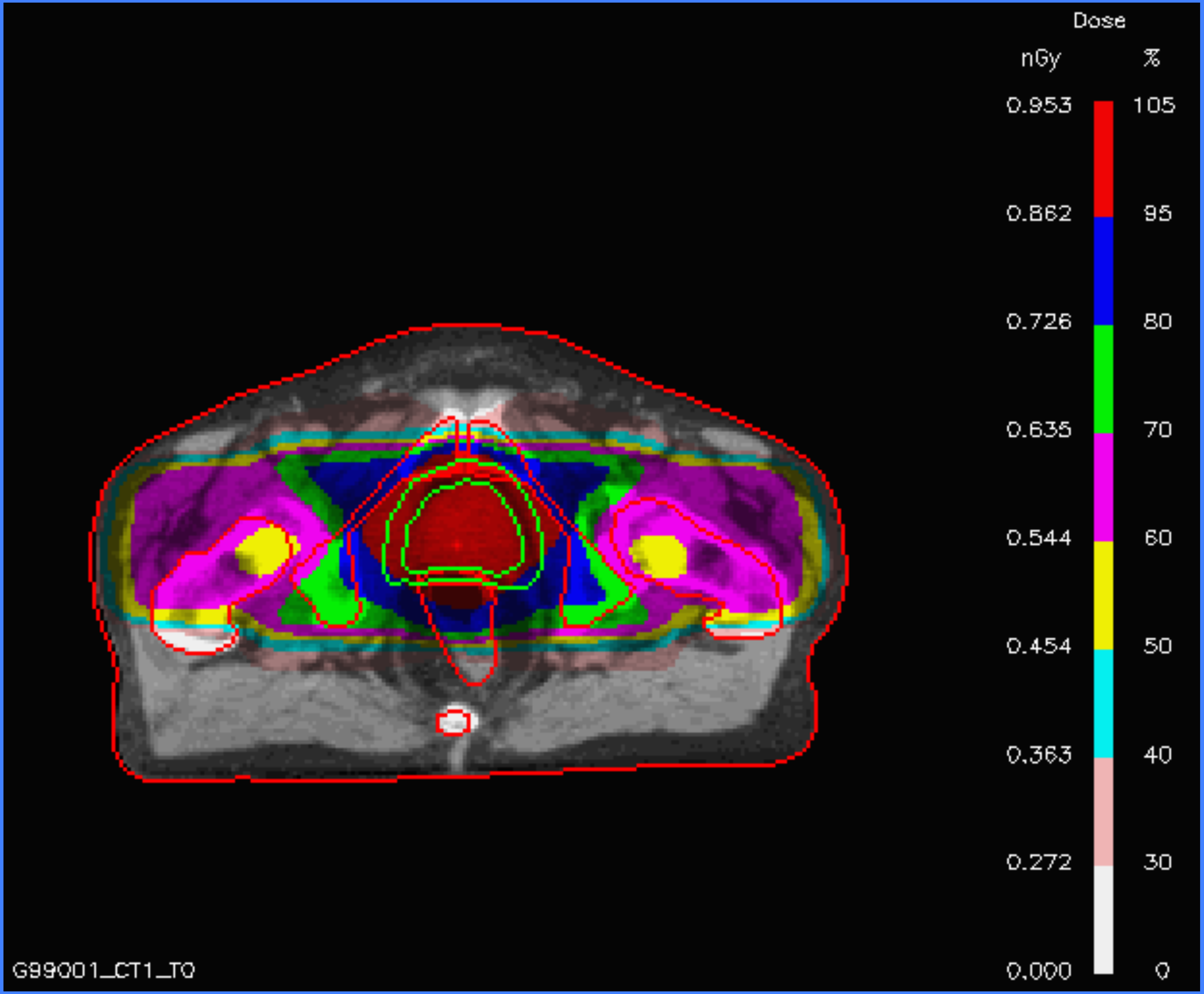
~30% of patients treatment fails locally

Two Opposite Photon Beams





Two Opposite Photon Beams



How to decrease the failure rate?

- Accelerator technologies to improve treatment : higher dose
- Detectors/imaging: accuracy, multimodality, real-time, organ motion
- Biology: fractionation, radio-resistance, radio-sensitization
- Data: storage, analysis and sharing
- Collaboration in this multidisciplinary field is key

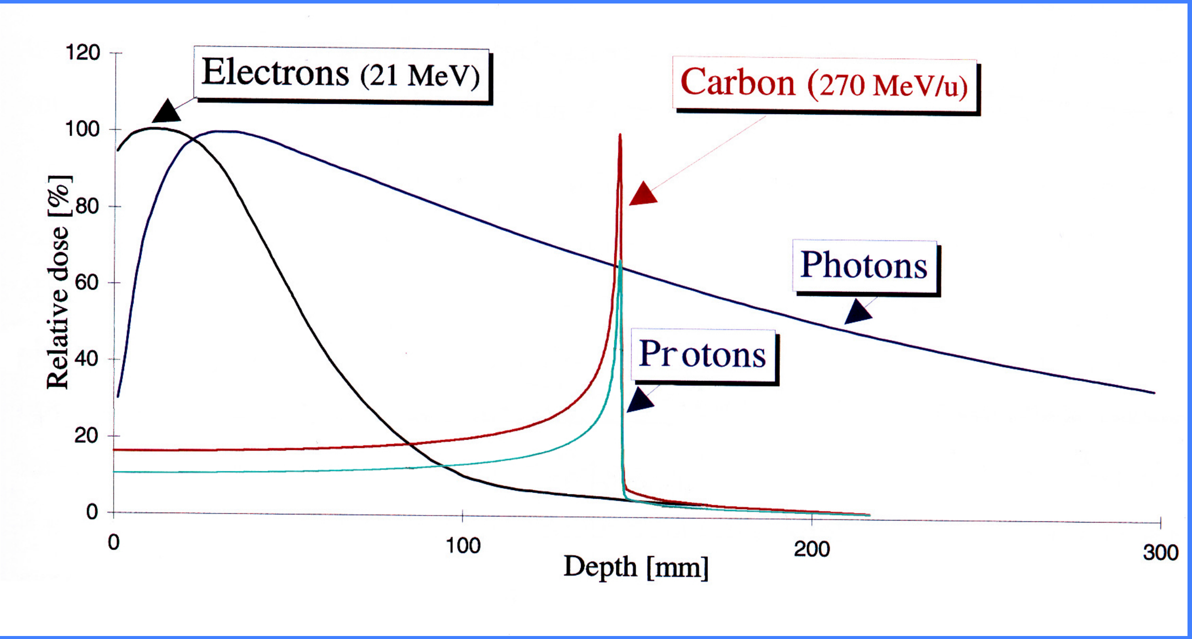
Raymond Miralbell, HUG

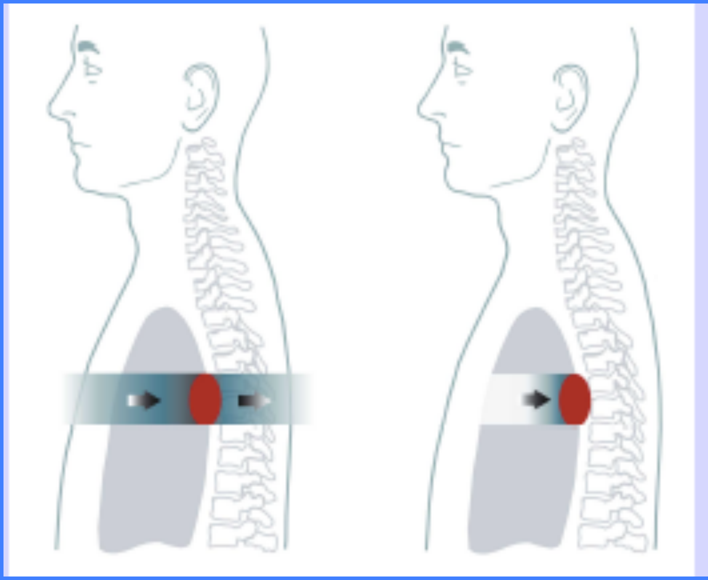
Hadron Therapy : All started in 1946

In 1946 Robert Wilson:

– Protons can be used clinically
– Accelerators are available
– Maximum radiation dose can be placed into the tumor
– Particle therapy provides sparing of normal tissues

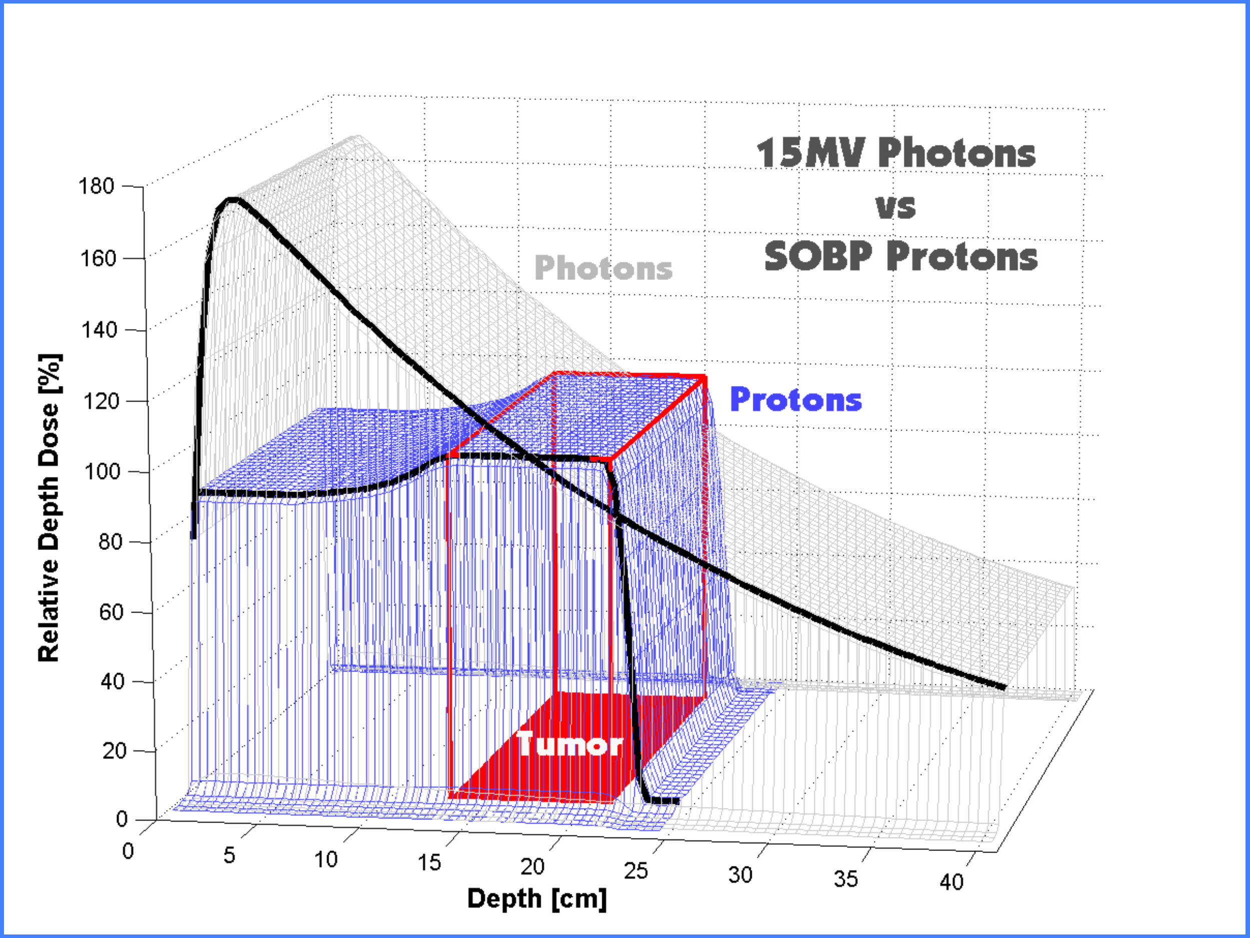
- Tumors near critical organs
- Tumor in children
- Radio-resistant tumors

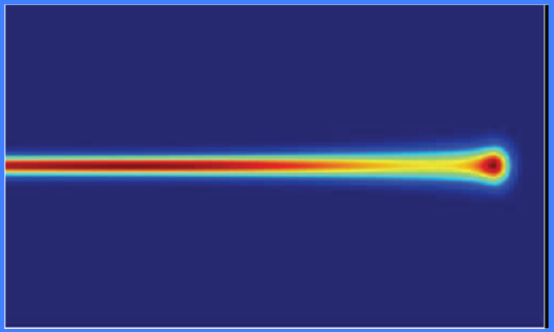




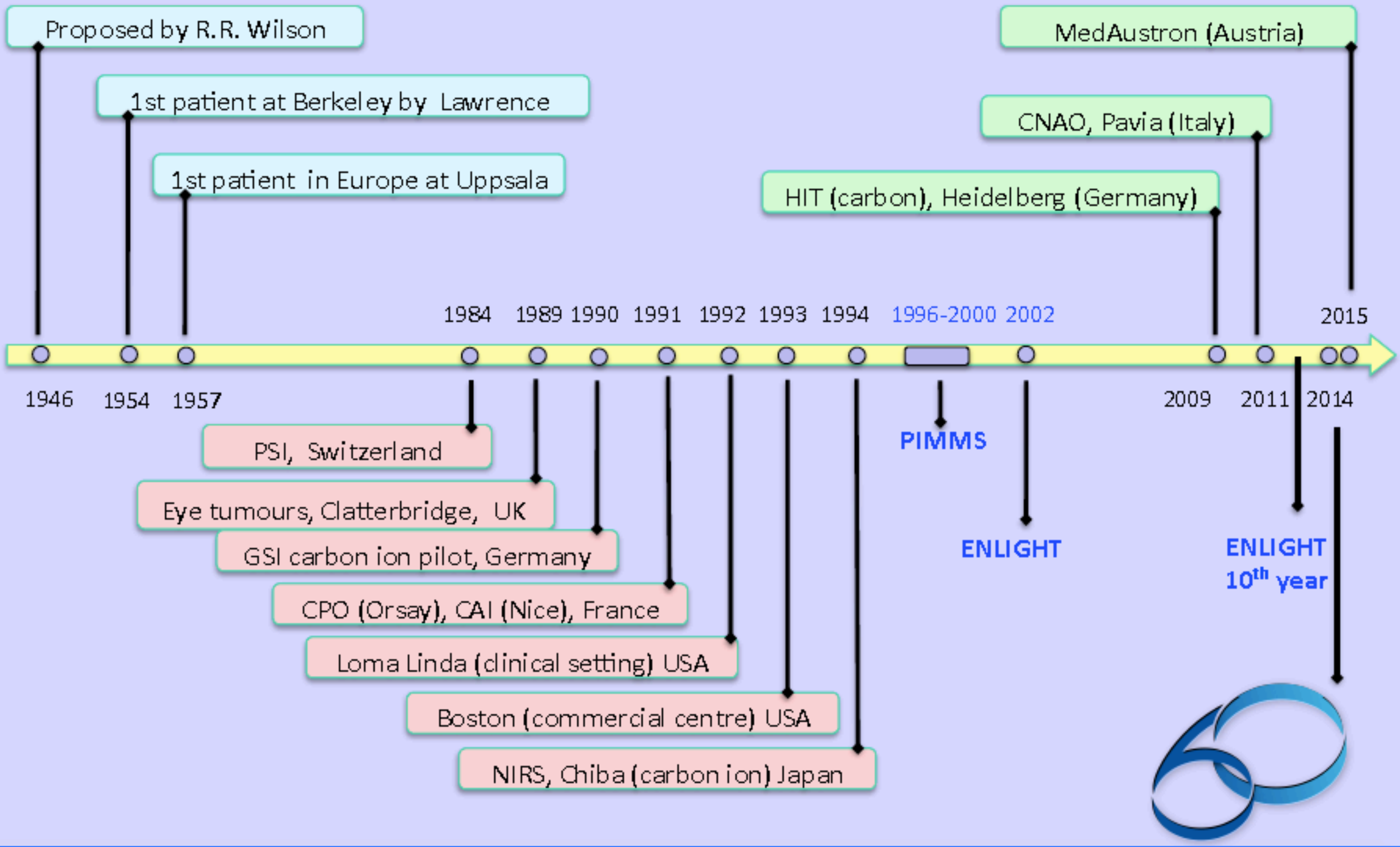
Conventional: X-Rays   Ion Radiation

Optimization of the natural distribution of dose

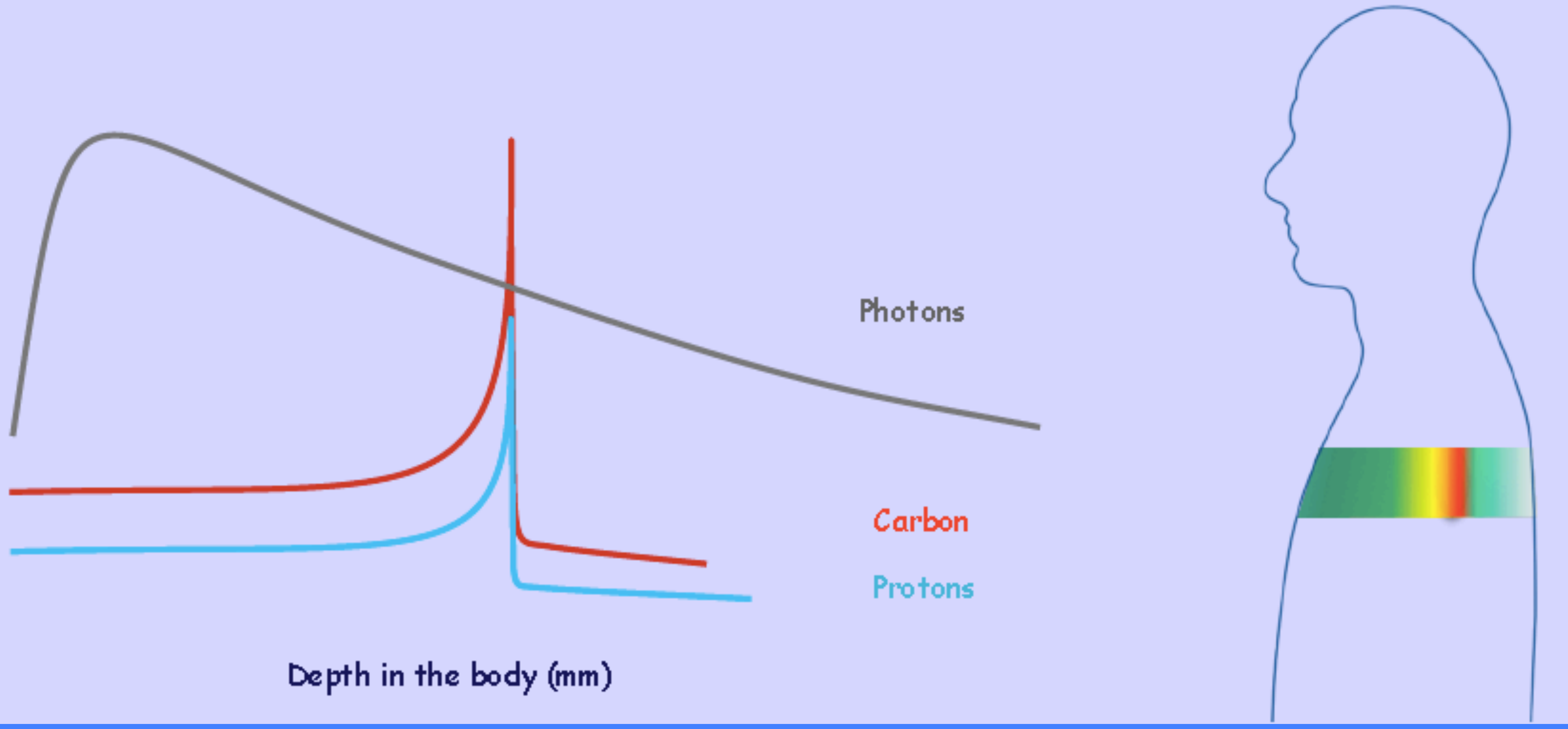




Hadron Therapy Timeline



Why Hadron Therapy

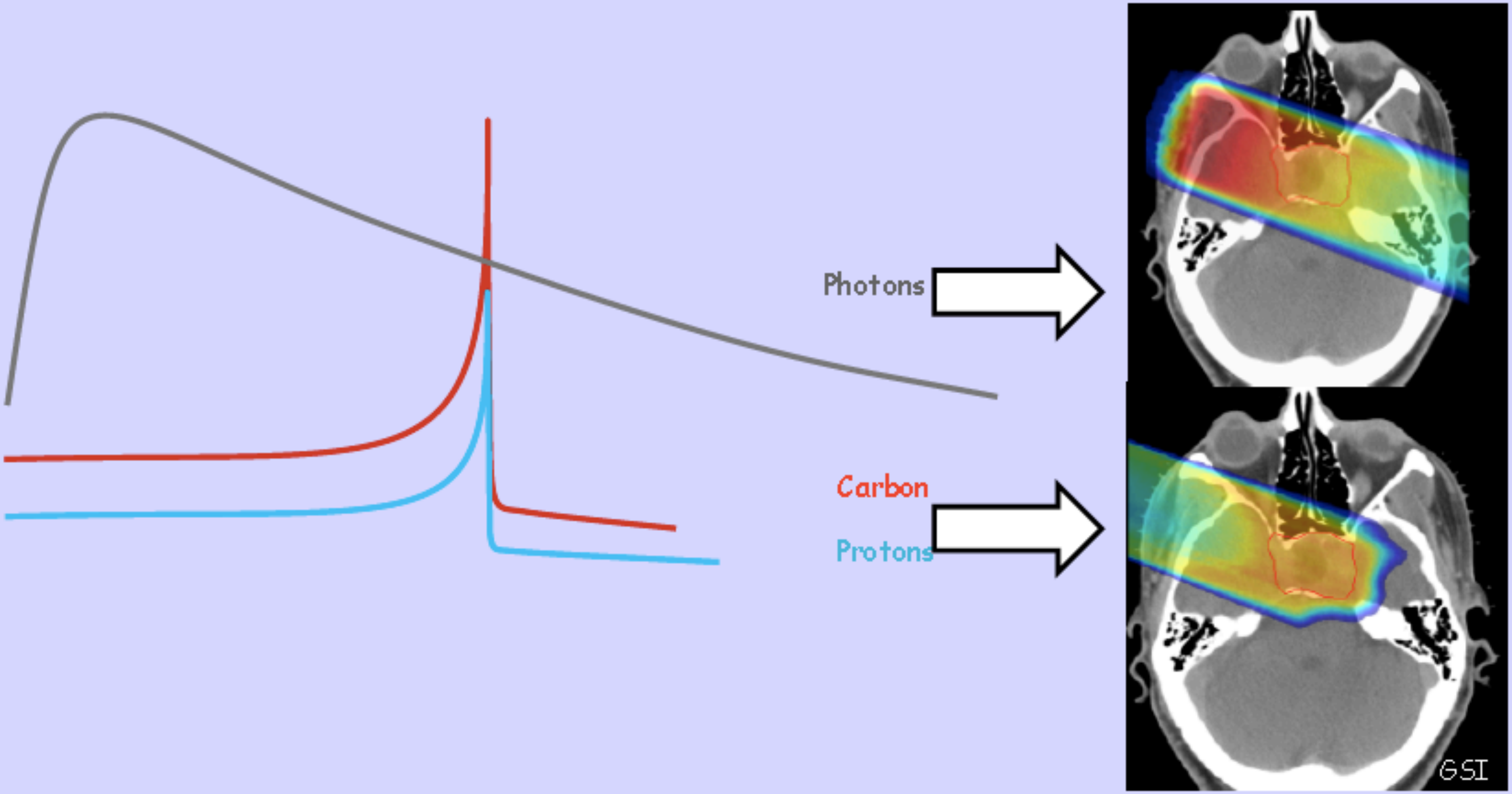


Tumors near critical organs

Tumors in children

Radio-resistant tumors

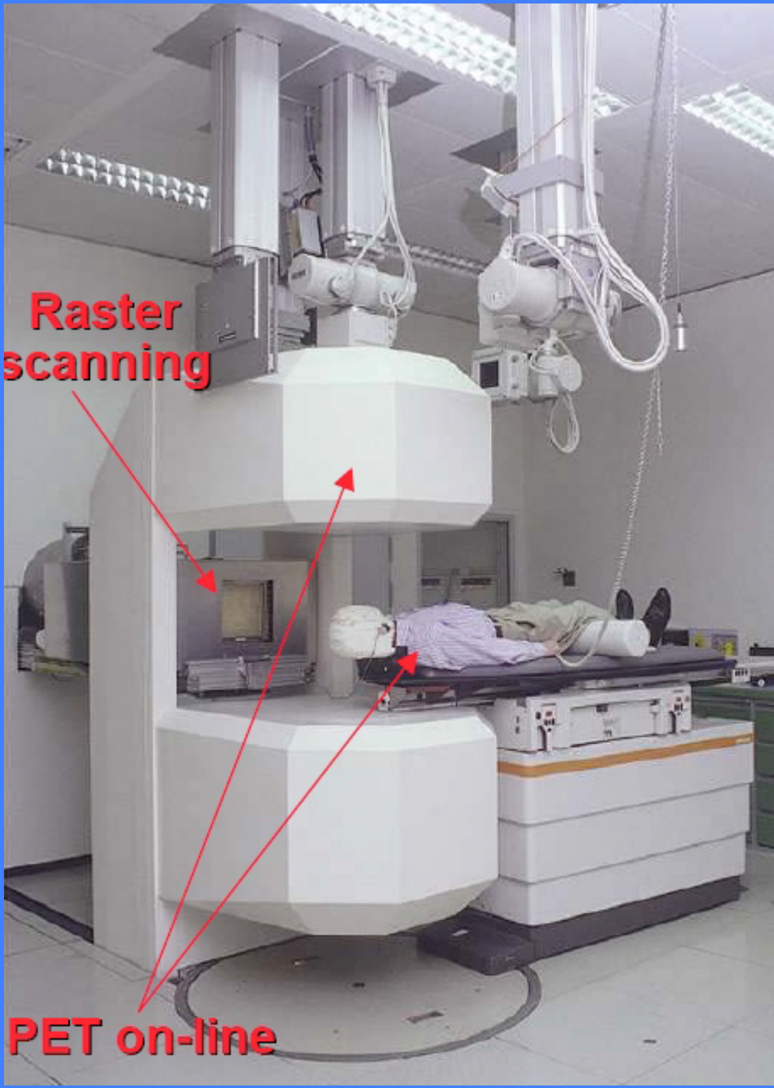
Photons vs Protons



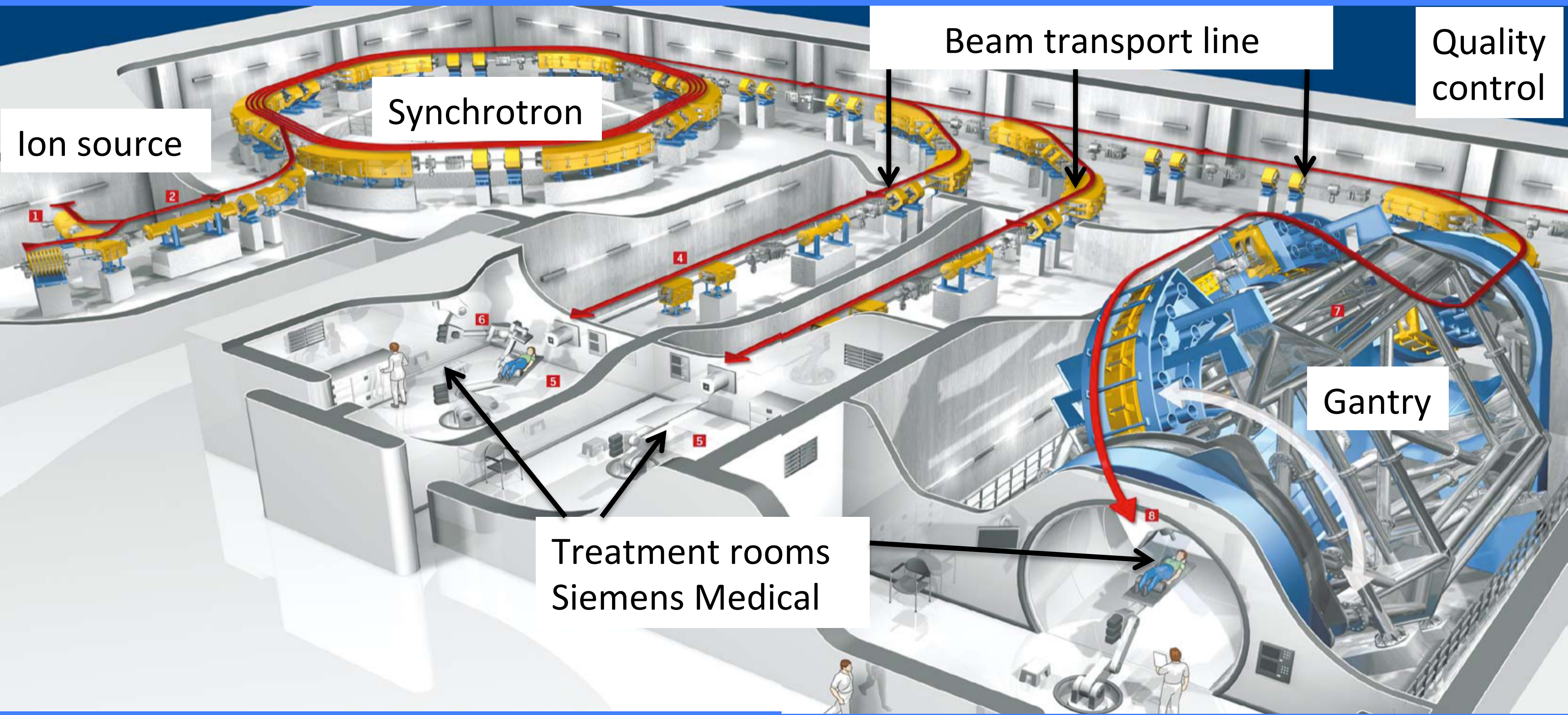
Carbon Ions Project : pilot project in Europe

- GSI – Darmstadt (1997 – 2008)
- G. Kraft (GSI) & J. Debus (Heidelberg)

– 450 patients treated with carbon ions

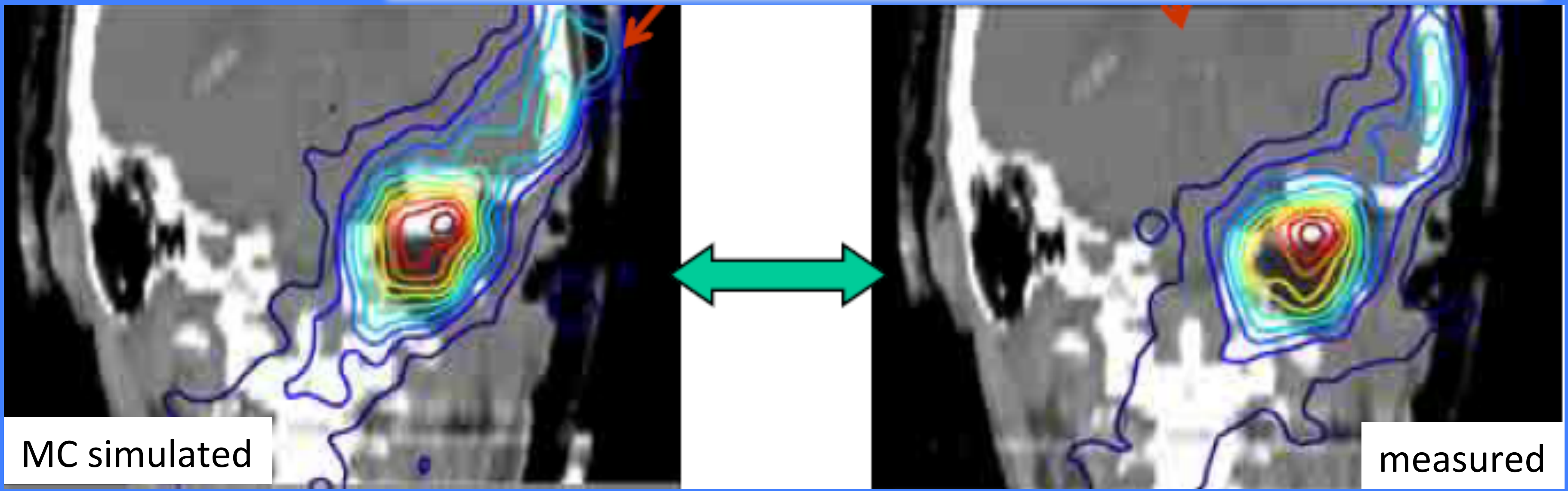


HIT - Heidelberg



HIT - Heidelberg

Real time Monitoring



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

Modeling of beta+ emitters:

Cross section

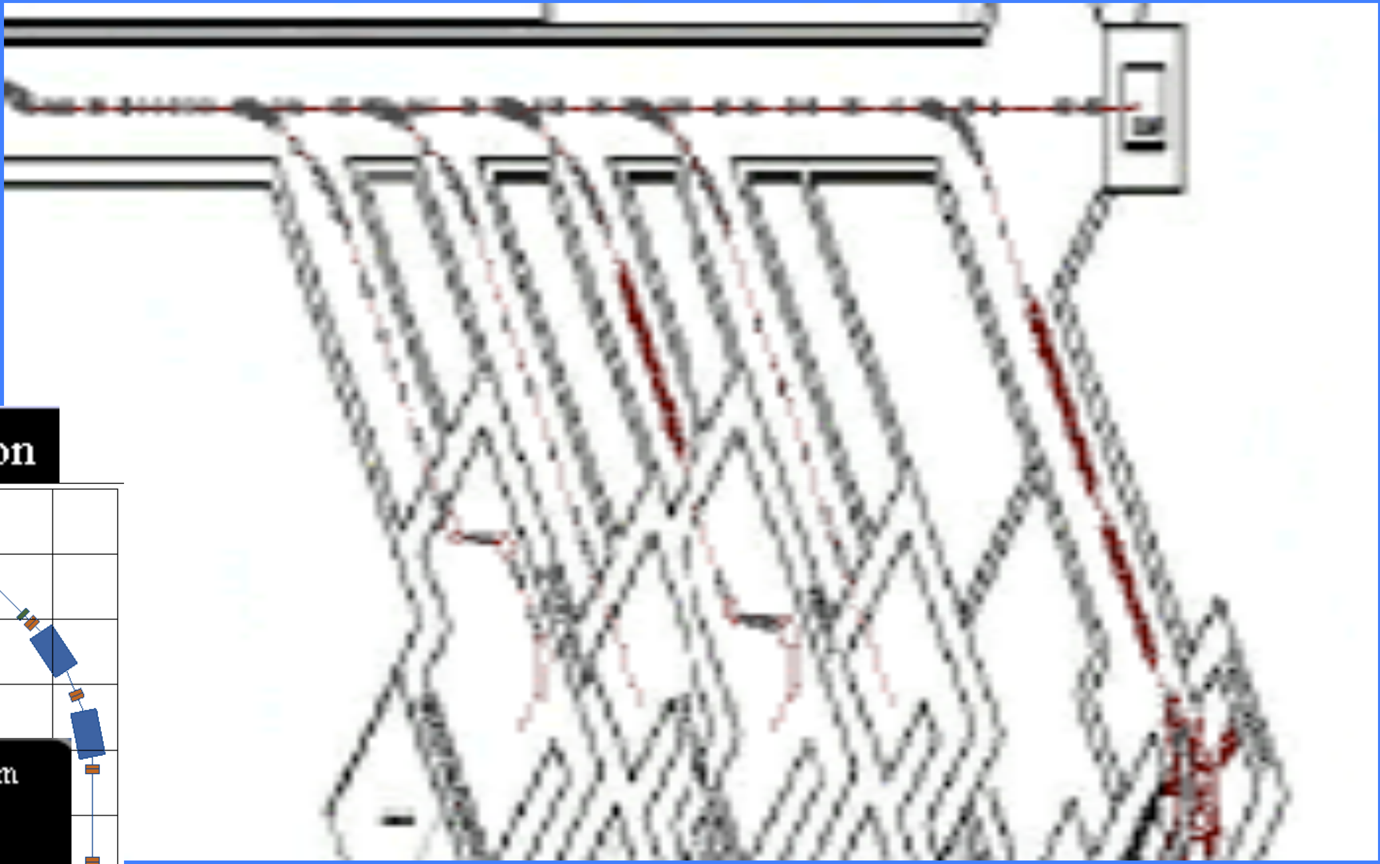
Fragmentation cross section

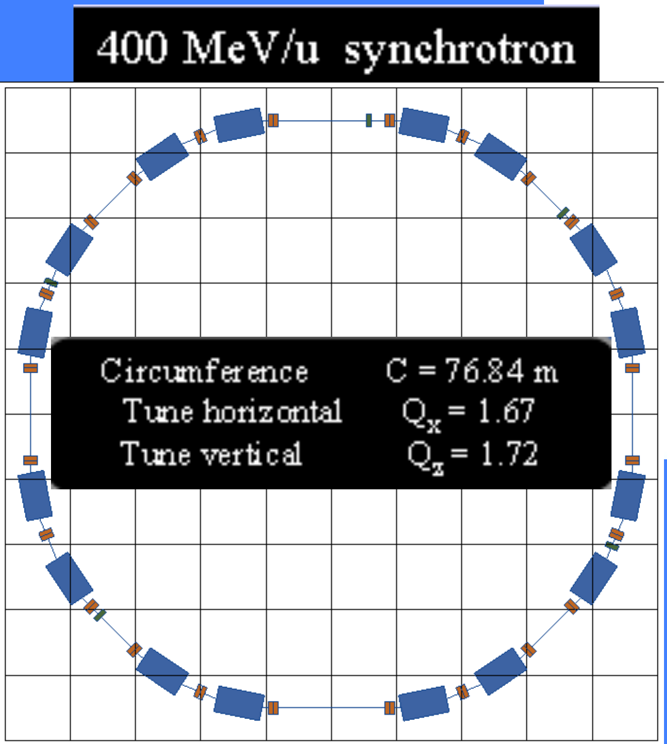
Prompt photon imaging

Advance Monte Carlo codes

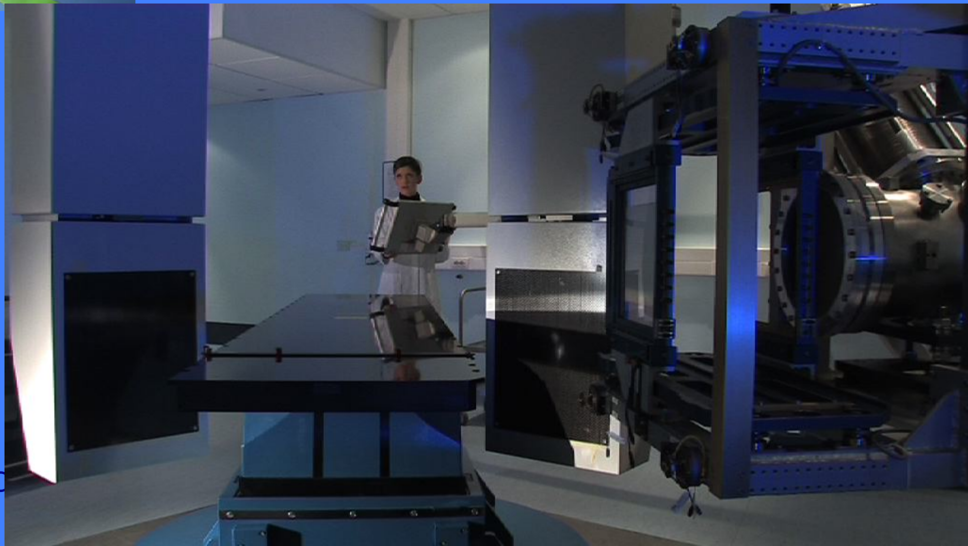
PIMMS project at CERN (1996-2000)

- **P**roton **I**on **M**edical **M**achine **S**tudy

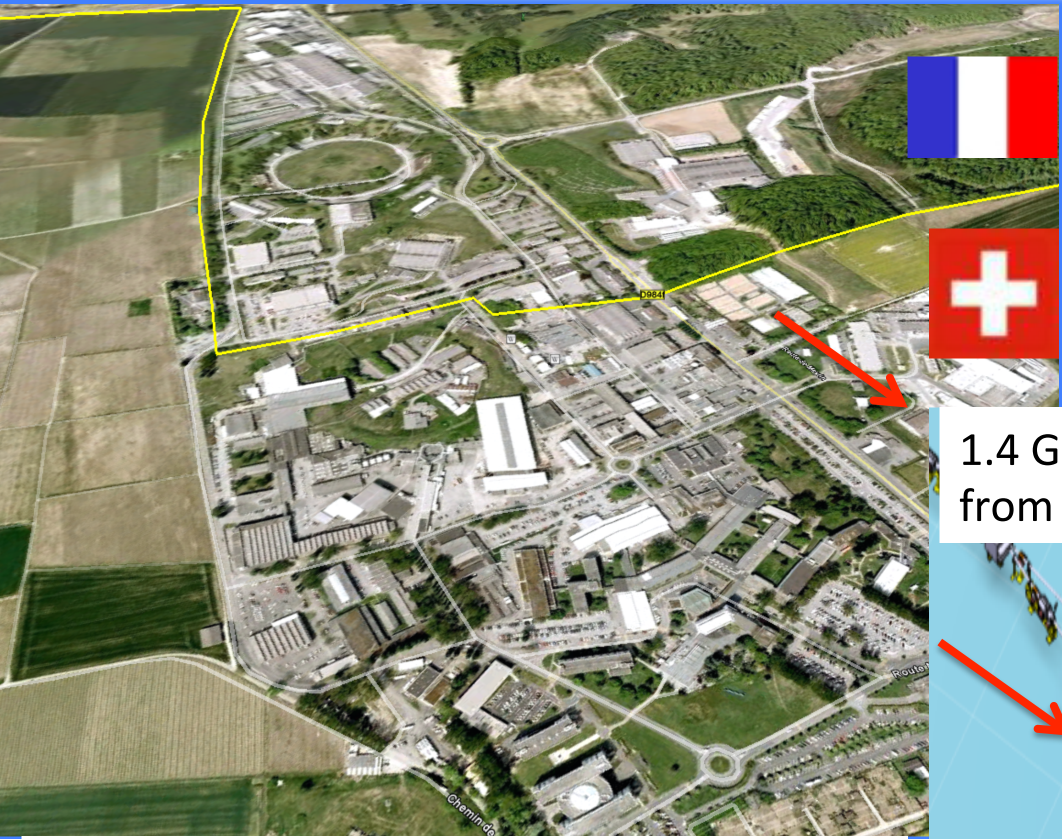




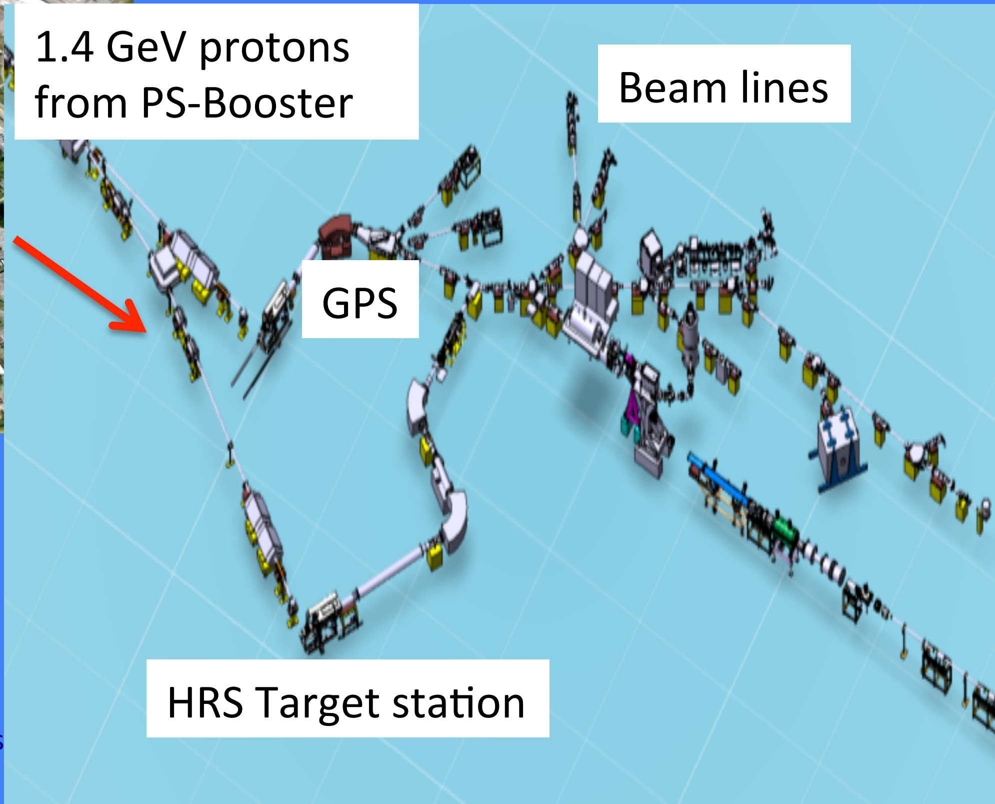
CNAO – Pavia Italy



ISOLDE
Isotopes for detection and treatment



In collaboration with University Hospital Geneva



Radio-Isotopes production

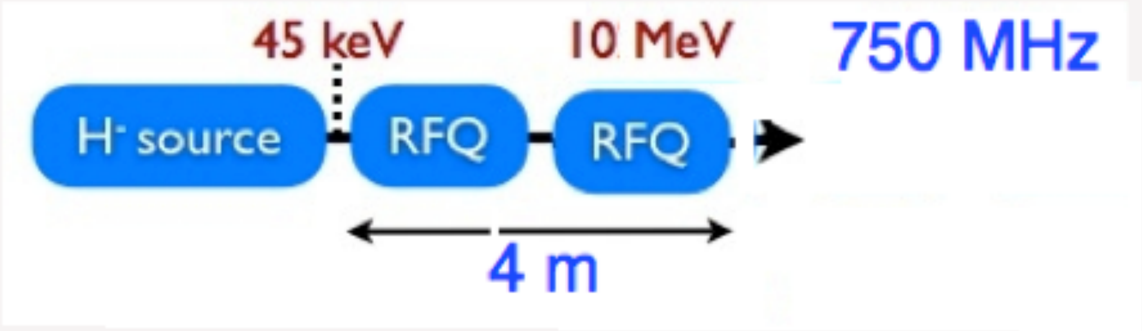
- Nuclear Reactions

- Accelerators
  - Circular

  - Linacs

LINAC for Radio-Isotopes production

The Linac basic architecture is shown here:



RFQ:
CERN BE-ABP-HSL

The first linac designed in USA with energy 7 MeV

Medical isotopes

11C, 15O, 18F, 111In, 123I

LINAC for Radio-Isotopes production

Compact Linear Accelerator for Radio-Isotope production in Hospitals

Advantages vs Cyclotrons:

- NO beam loss,
- NO radiation, min. shileding
- Minimum maintenance
- Light weight, Power (25 kW @ 1.5% duty)

A

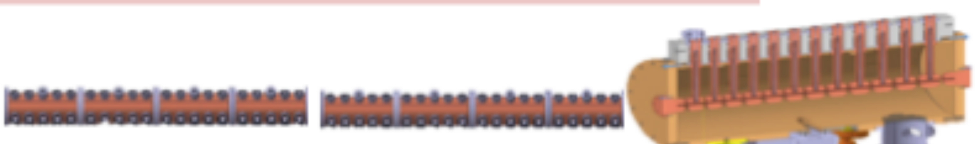
2 RFQs
Source W = 40 KeV
L = 3.2 m
Output W = 8 MeV
Freq. = 750
Aver. current = 50 mA
Duty cycle = 5 %
Peak current = 1 mA

B

2 RFQs
Source W > 70 keV
L = 5 m
Output W = 8 MeV
Freq. = 750
Aver. current = 150 mA
Duty cycle = 1.5 %
Peak current = 10 mA

Being designed

^{99m}TC for BRACHYTHERAPY



- 1 Klystron as RF power source
- Minimum maintenance, low loss
- Low cost (3 MCHF?)

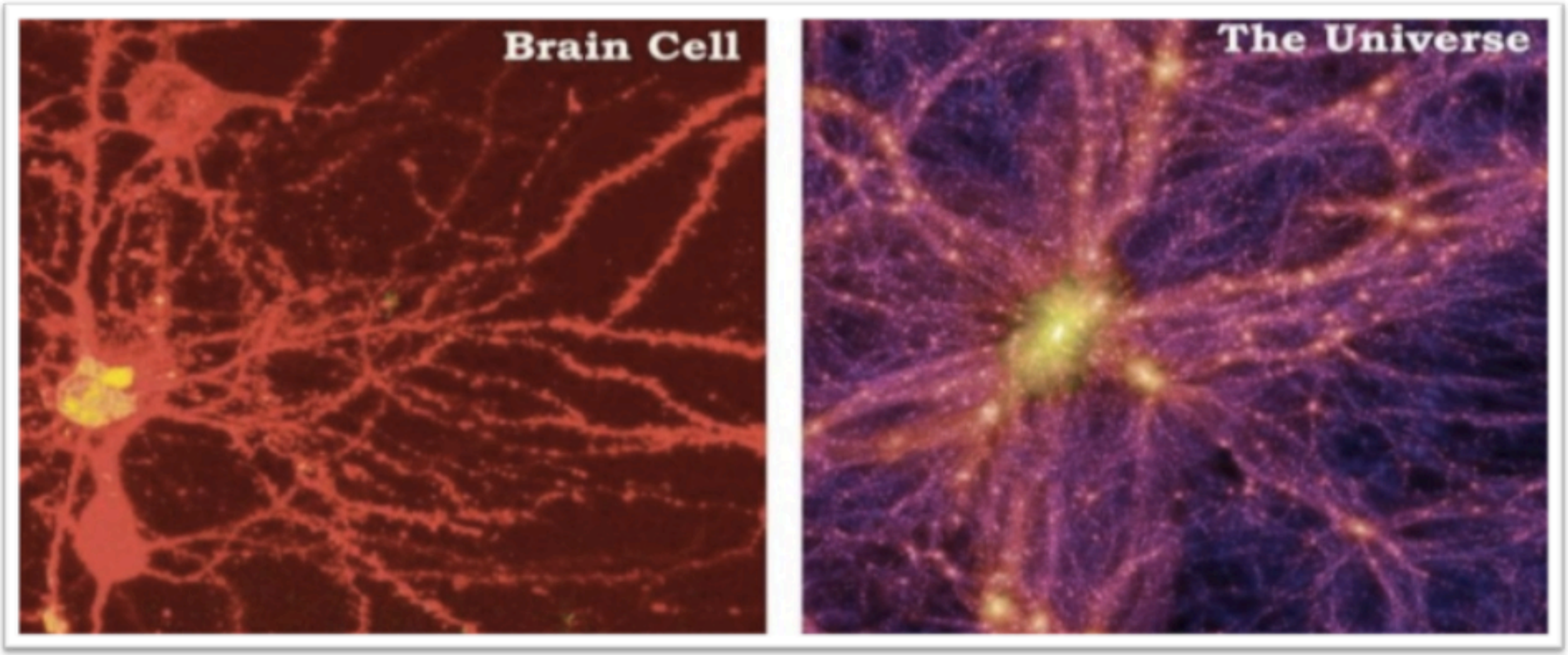
Option:
d^+, 18 MeV, 15 m
For ^{177}Lu production

2 RFQs + 1 DTL
Source W = 90 KeV
L = 10 m
Output W = 18 MeV
Freq. = 704 MHz
Average current = 2 mA
Peak current = 20 mA
Duty cycle = 10 %

Radio-Isotopes for PET

Isotope	Half -time	Maximum Energy (MeV)	Range in H_2O (mm)
F-18	109.7min	0.635	2.39
C-11	20.4min	0.96	4.11
N-13	9.96min	1.19	5.39
O-15	2.07min	1.72	8.2
Rb-82	1,27min	3,150	15,50

Thank you for your attention



Mark Miller

Virgo Consortium