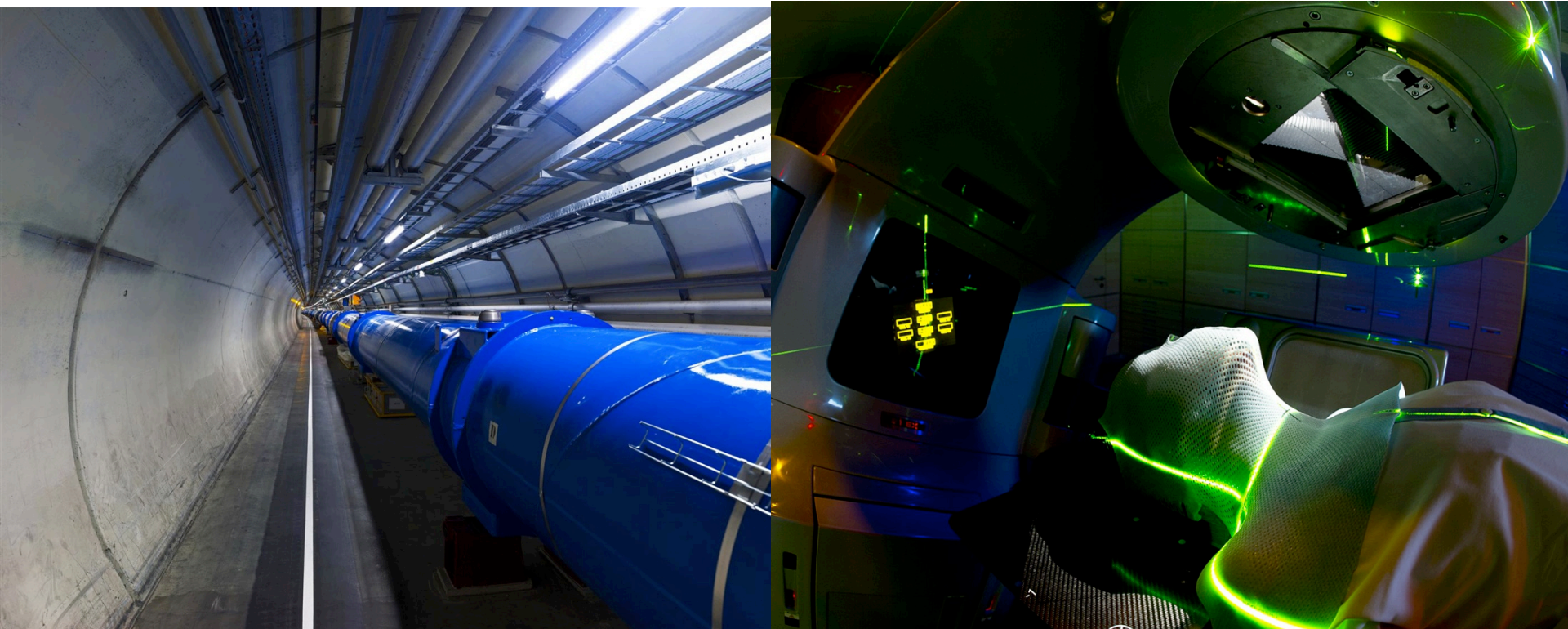
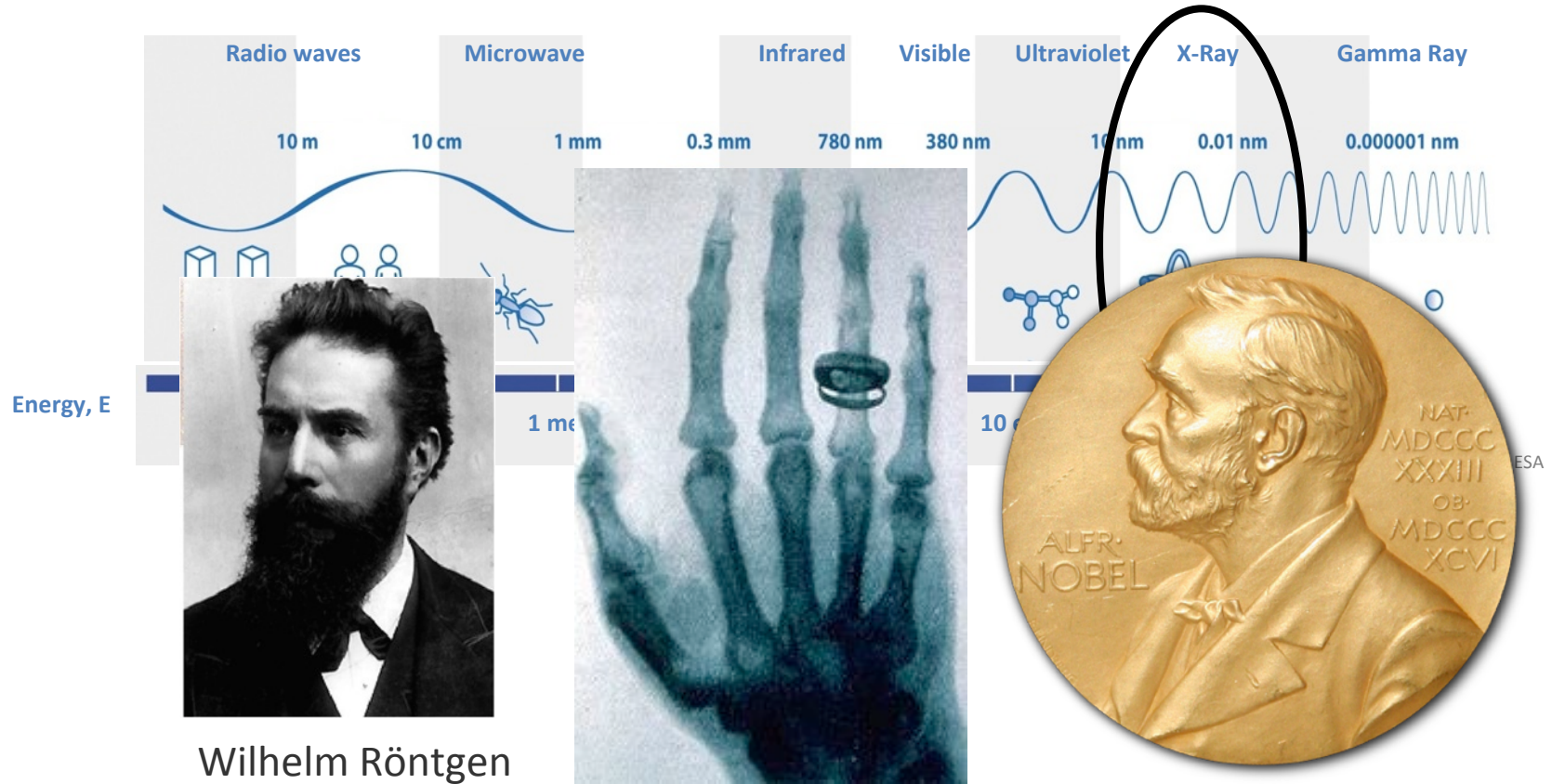


# From Physics to Medical Applications

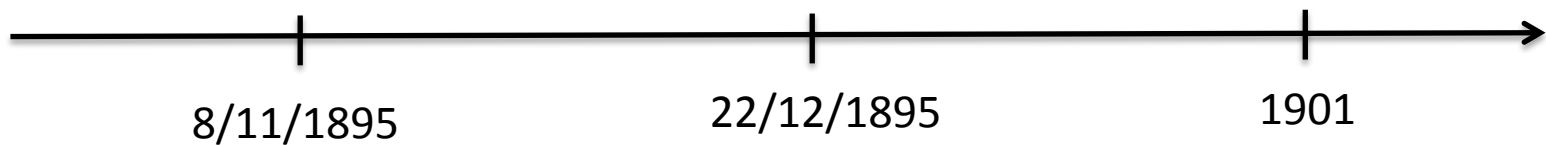


Manjit Dosanjh, CERN  
[manjit.dosanjh@cern.ch](mailto:manjit.dosanjh@cern.ch)

# Modern medical physics– X-rays



Wilhelm Röntgen

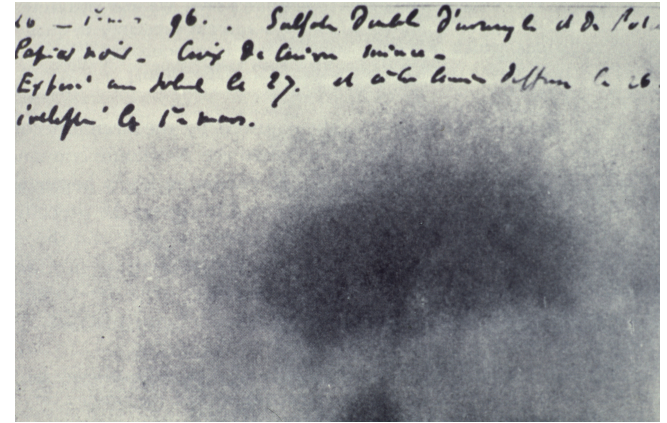


.....beginning of medical physics

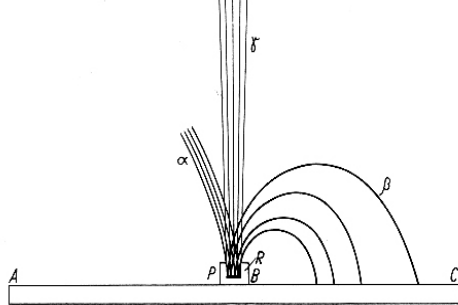


Henri Becquerel

**1896:**  
**Discovery of natural radioactivity**

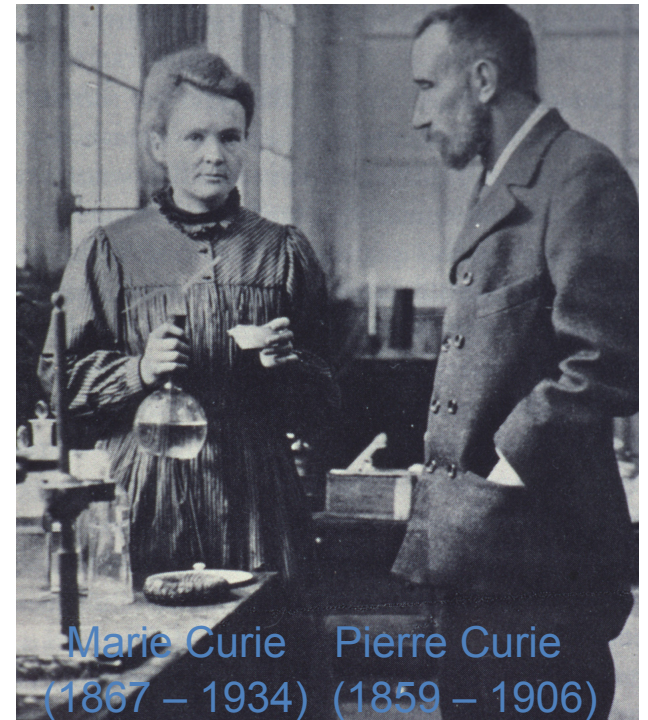


Thesis of Mme. Curie – 1904  
 $\alpha$ ,  $\beta$ ,  $\gamma$  in magnetic field



**1898: Discovery of radium**

**used immediately for “Brachytherapy”**



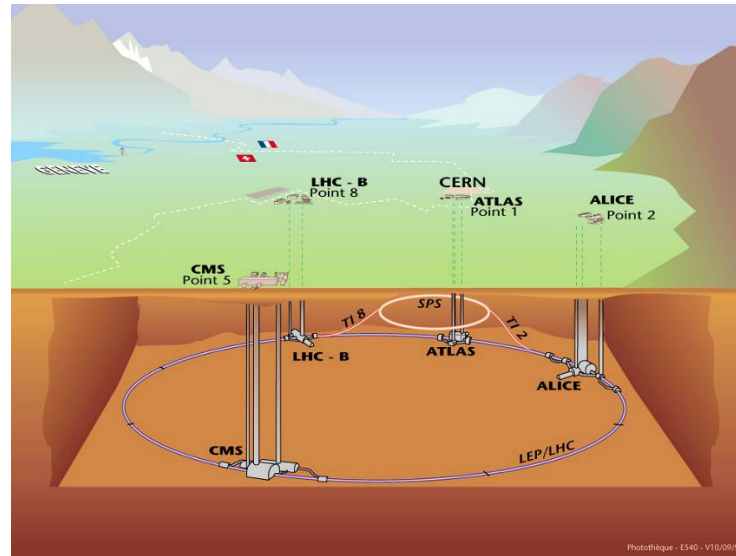
Marie Curie (1867 – 1934) Pierre Curie (1859 – 1906)

# First radiobiology experiment

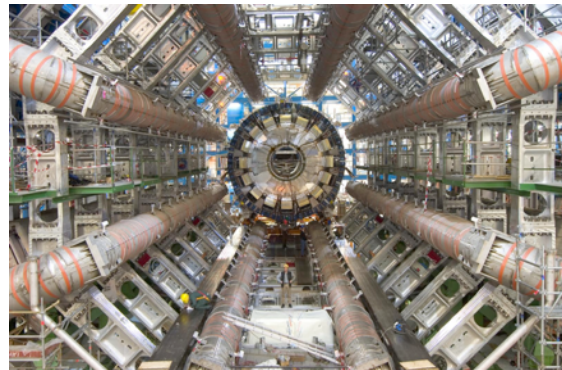


Pierre Curie and Henri Becquerel

# Tools of the trade



Accelerators



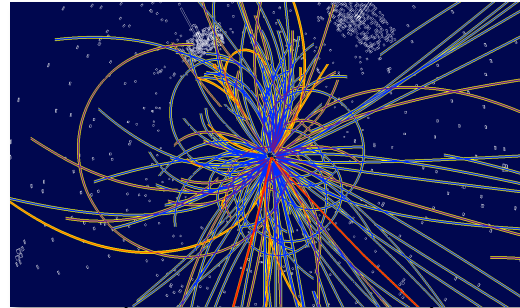
Detectors



Computing

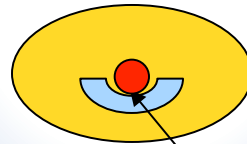
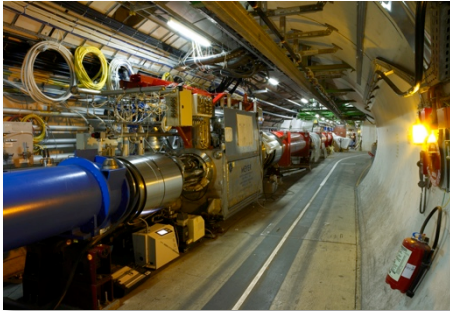
# CERN Technologies and innovation

## For health



Detecting particles

Accelerating particle beams



**CANCER**

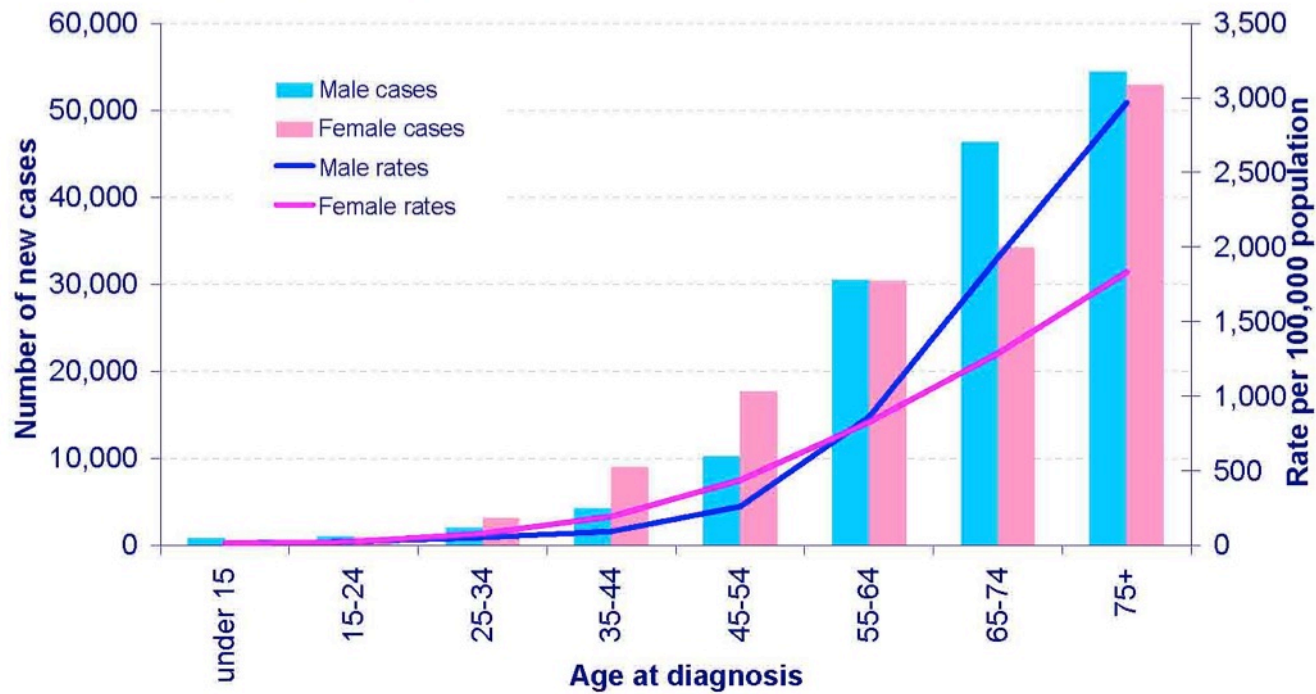
Large-scale computing (Grid)



# Cancer – a growing challenge

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

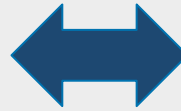


# 4<sup>th</sup> Pillar Catalysing & facilitating collaboration

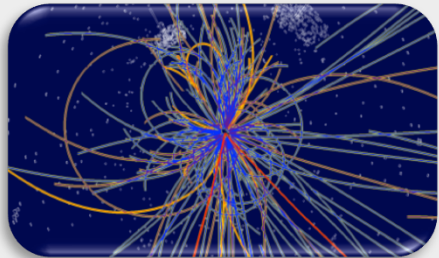
**Accelerating** particle beams



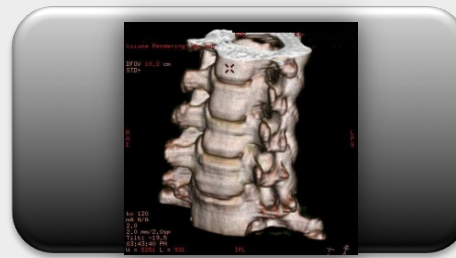
**Particle Therapy**



**Detecting** particles



**Medical imaging**



**Large scale computing (Grid)**



**Grid computing for medical data management and analysis**



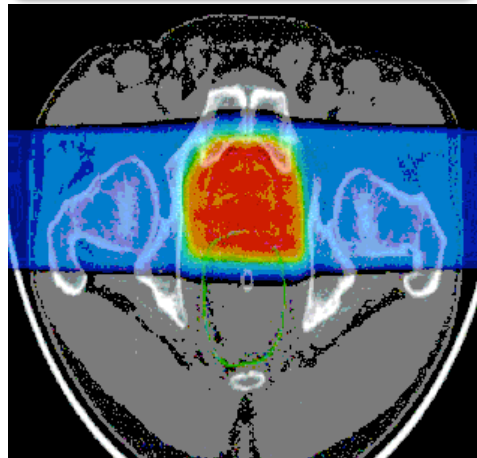


# Treatment options

Surgery



Radiotherapy

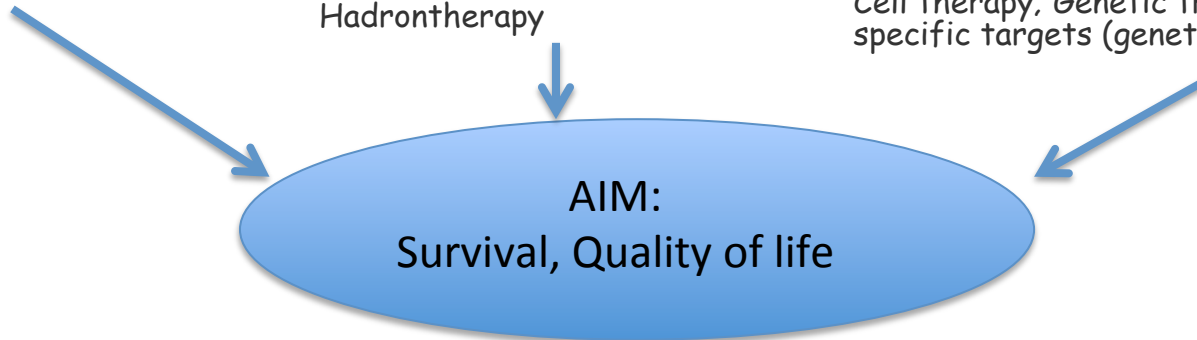


X-ray, IMRT, Brachytherapy,  
Hadrontherapy

Chemotherapy (+ others)

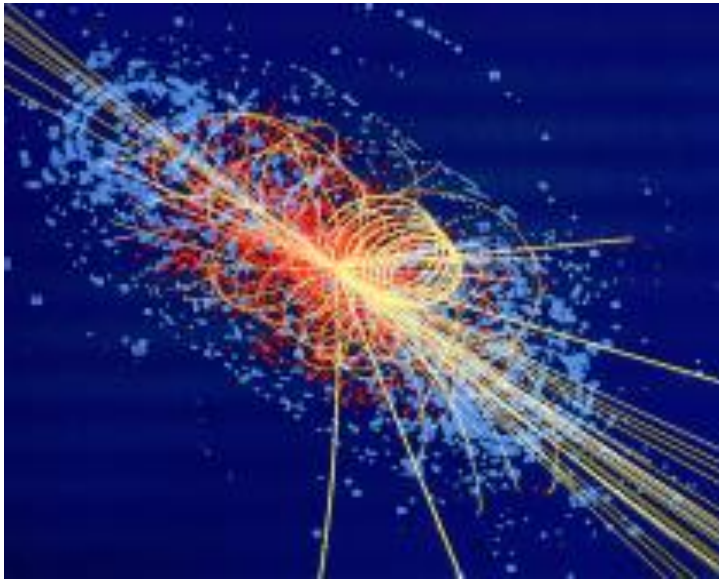


Hormones; Immunotherapy;  
Cell therapy; Genetic treatments; Novel  
specific targets (genetics..)

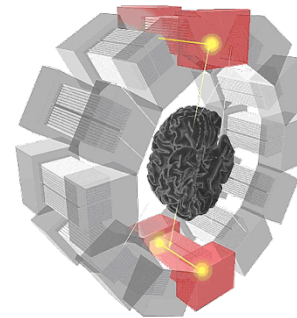


# No treatment without detection!

## Particle Detection

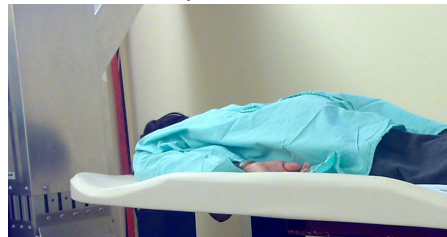


## Imaging

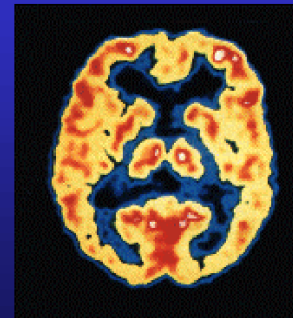


PET Scanner

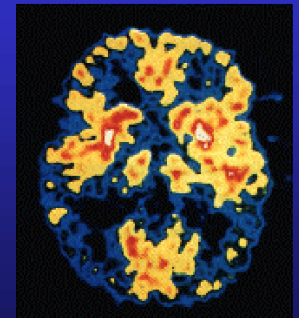
Breast imaging  
(ClearPEM)



Brain Metabolism in Alzheimer's  
Disease: PET Scan

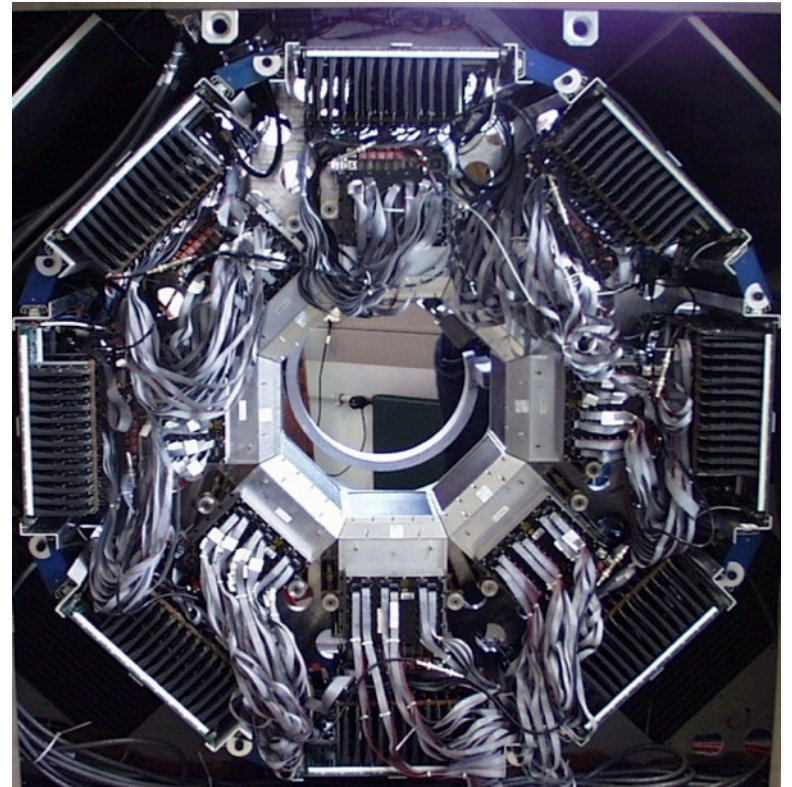


Normal Brain



Alzheimer's Disease

# The detector challenge



# CERN's role in detection and imaging

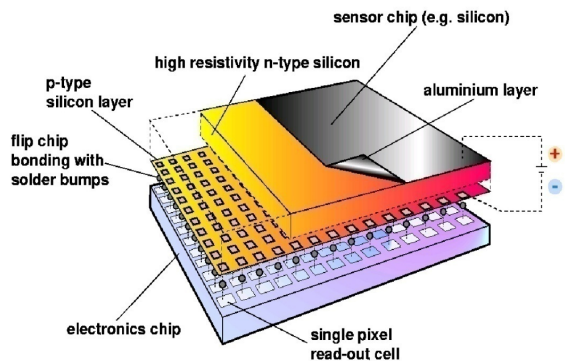
...

## Continuous development in particle physics:

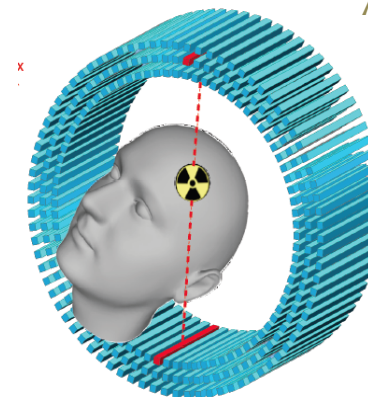
- Scintillating crystals (David Townsend .....
- Pixel detectors (Medipix collaboration)
- Diamond detectors
- Multi-wire proportional chambers/ GEMS (Charpak...)
- Resistive Plate Chambers for imaging

# CERN is contributing to accurate detection

## MEDIPIX

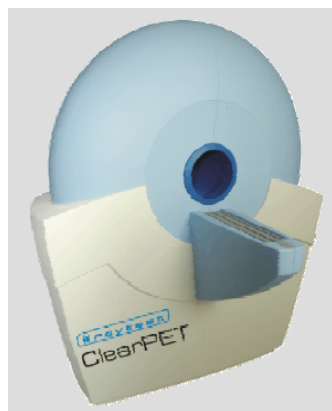


## AXPET

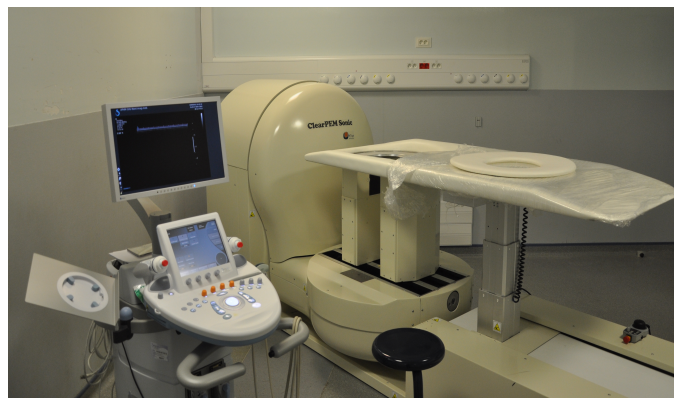


## Crystal Clear projects

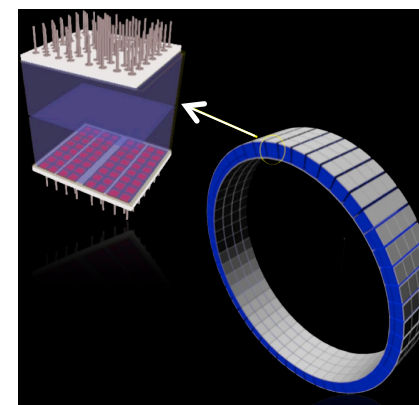
Courtesy of Paul Lecoq



ClearPET



ClearPEM & ClearPEM-Sonic



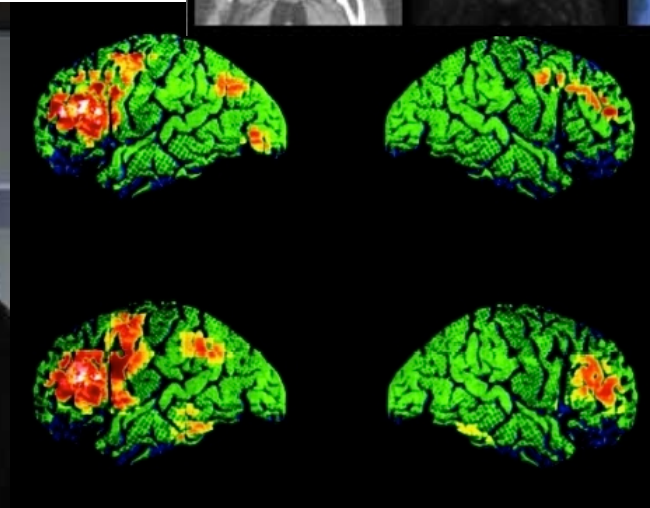
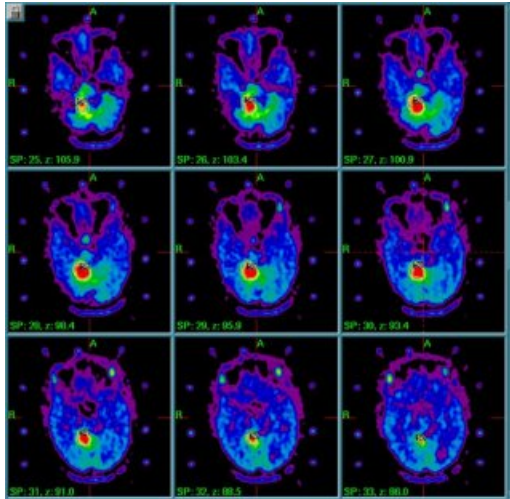
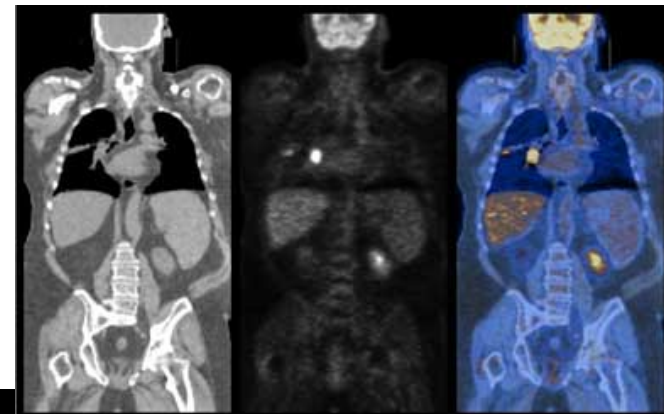
BrainPET

# PET: antimatter for clinical use

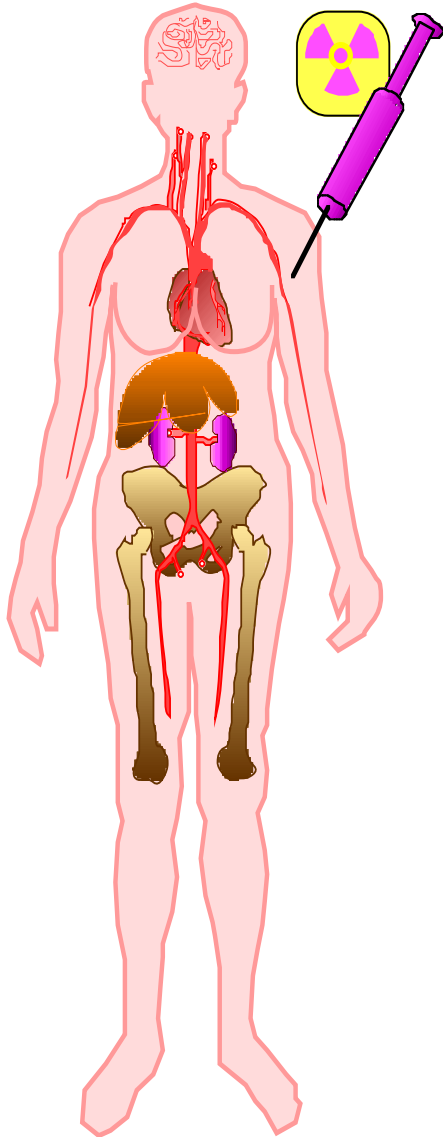


- Not only science-fiction

- ✦ Positrons are used in PET:
- ✦ PET = Positron Emission Tomography



# PET: how it works



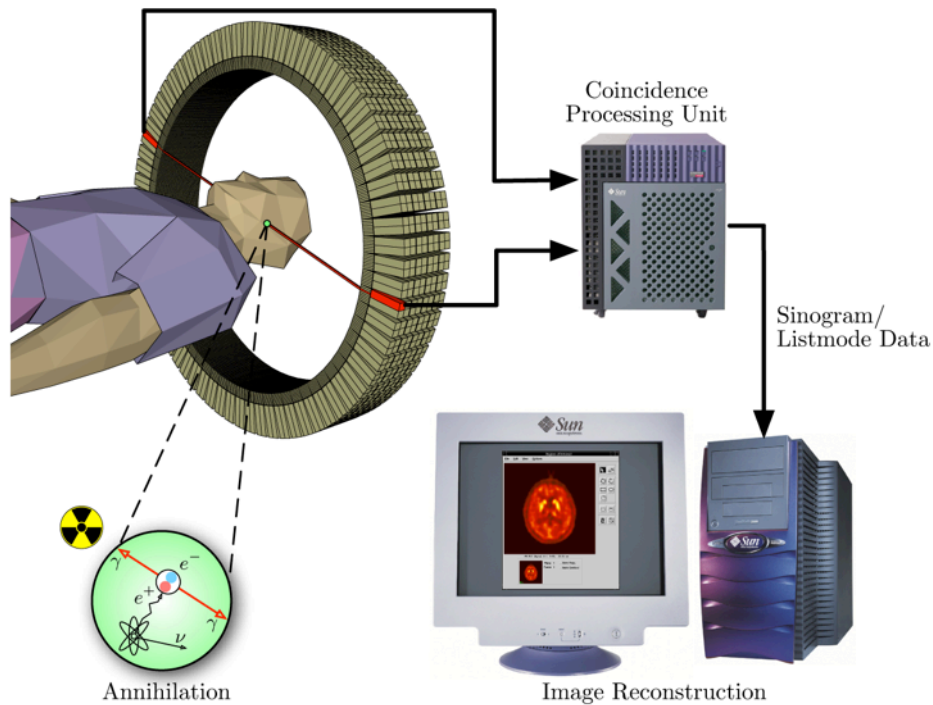
- Drug is labeled with positron ( $\beta^+$ ) emitting radionuclide.
- Drug localizes in patient according to metabolic properties of that drug.
- Trace (pico-molar) quantities of drug are sufficient.
- Radiation dose fairly small (<1 rem = 0.01 Sv).

# PET – How it works

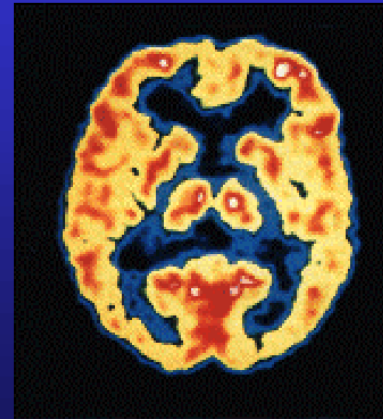
<http://www.nymus3d.nl/portfolio/animation/55>



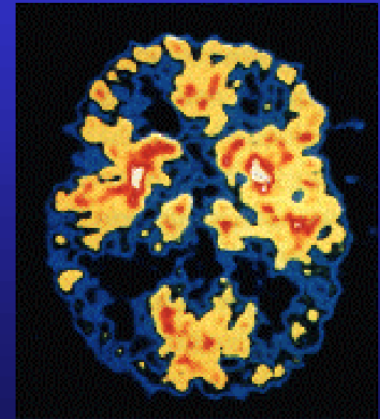
# PET Scan



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



Normal Brain



Alzheimer's Disease



# Crystal Clear Collaboration



Photos: Crystal Clear Collaboration

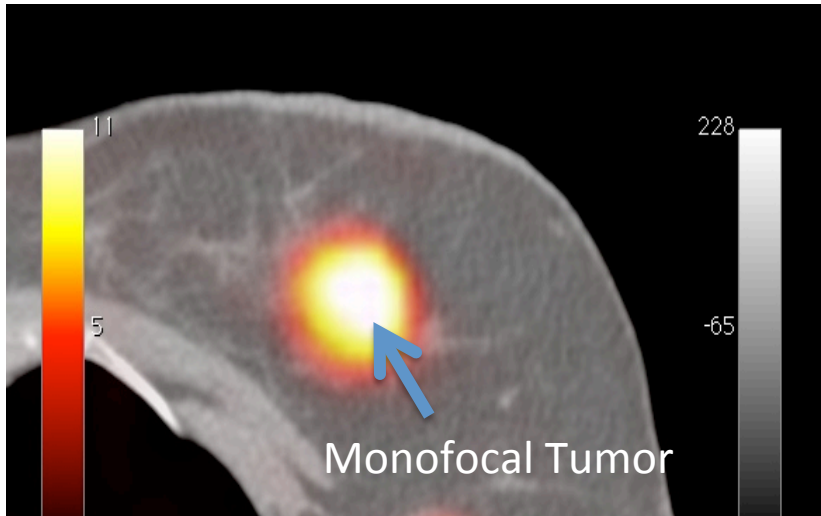
# ClearPEM



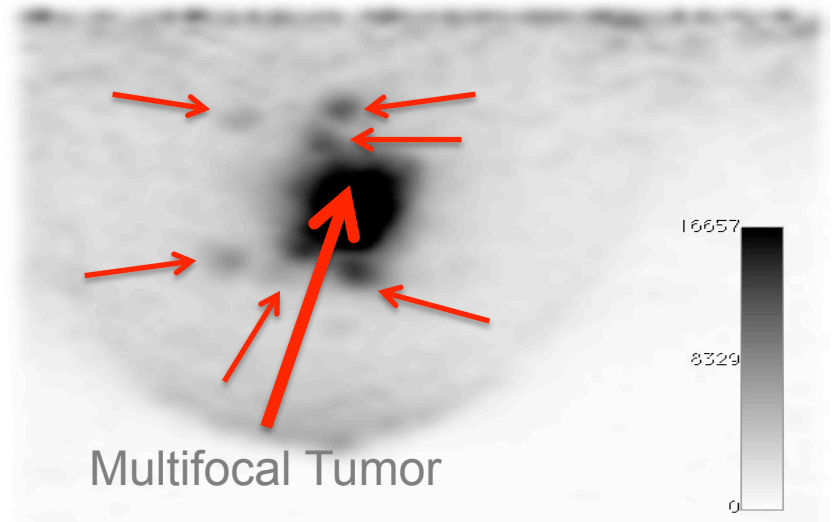
Photos: Crystal Clear Collaboration

PET for mammography: Crystal Clear Collaboration

# Breast Cancer Detection



**PET Wholebody**



**ClearPEM dedicated Breast imaging**

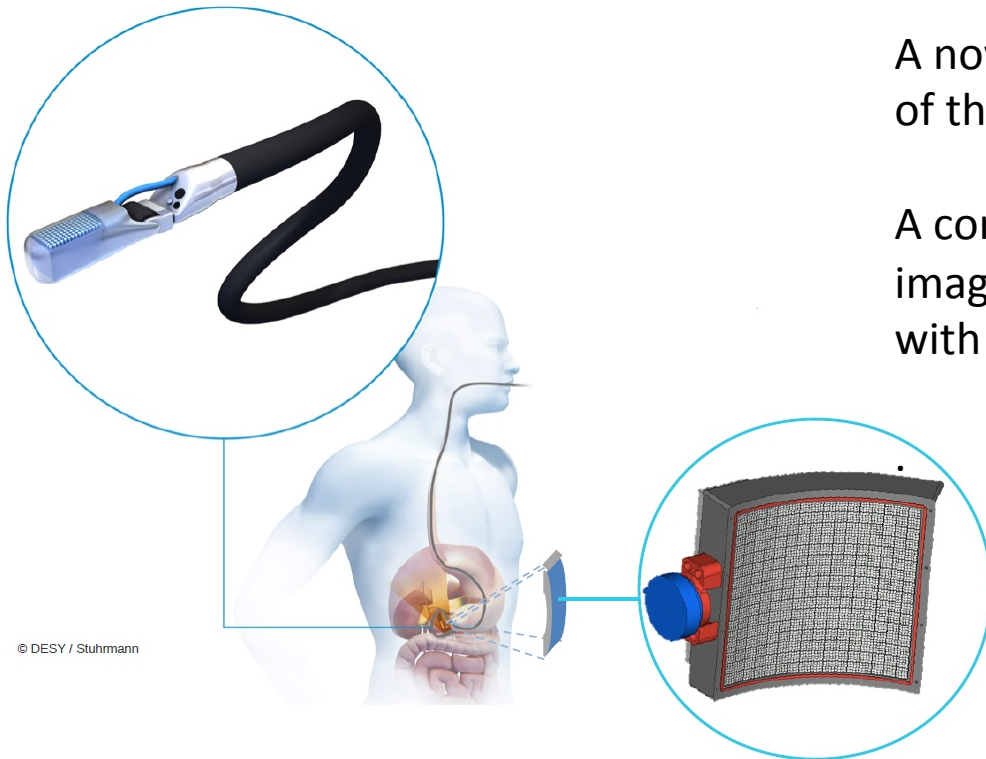
# Endo TOFPET-US

a novel multimodal tool for endoscopy and positron emission tomography

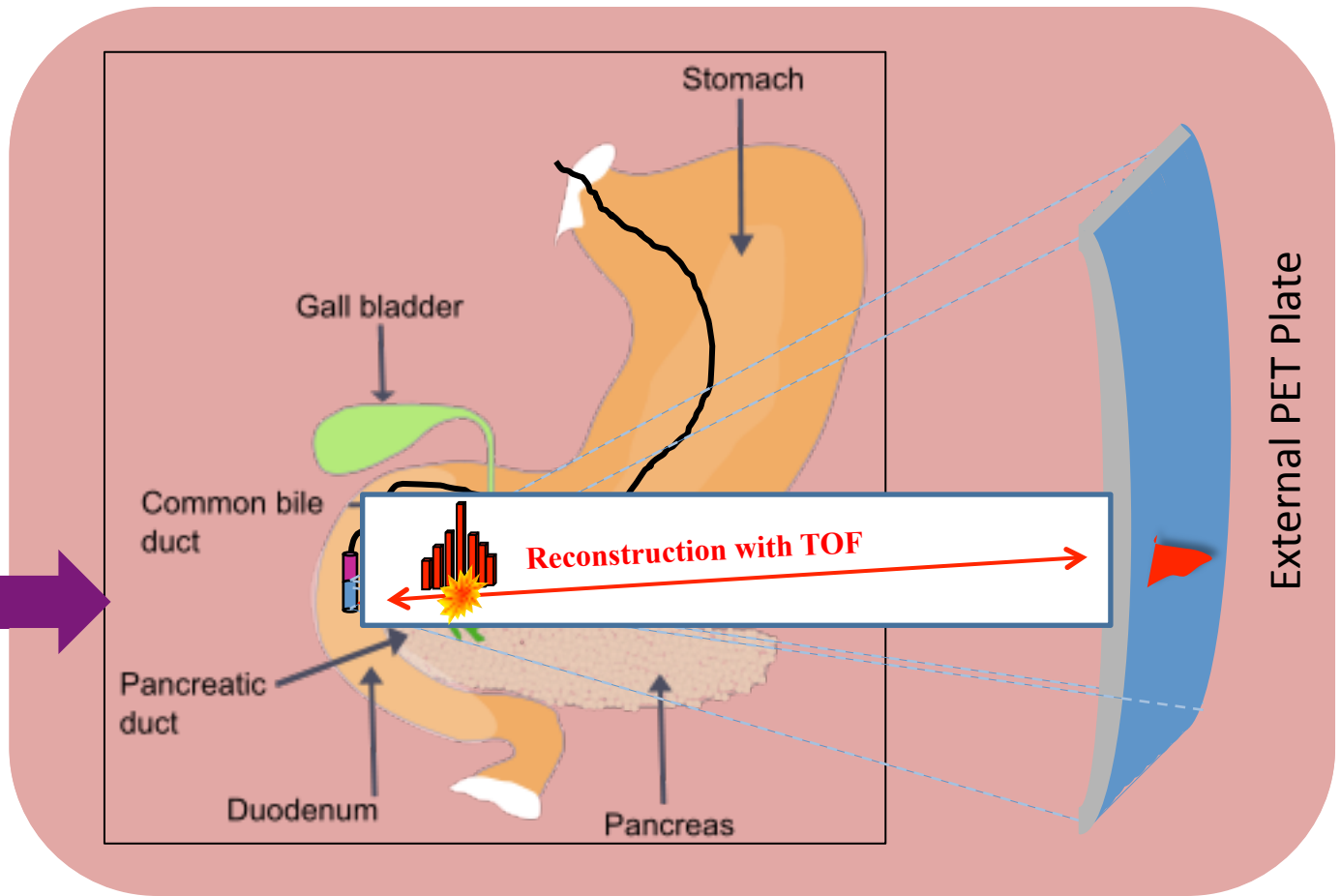
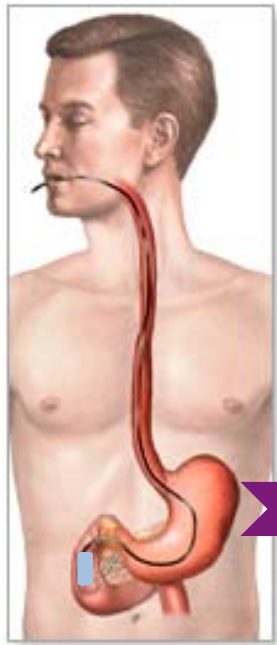
A novel imaging system for endoscopic exams of the pancreas or the prostate.

A combination of high resolution metabolic imaging with TOFPET and anatomical imaging with ultrasound.

Endo = Endoscopic  
TOF = Time of Flight PET  
US = Ultrasound

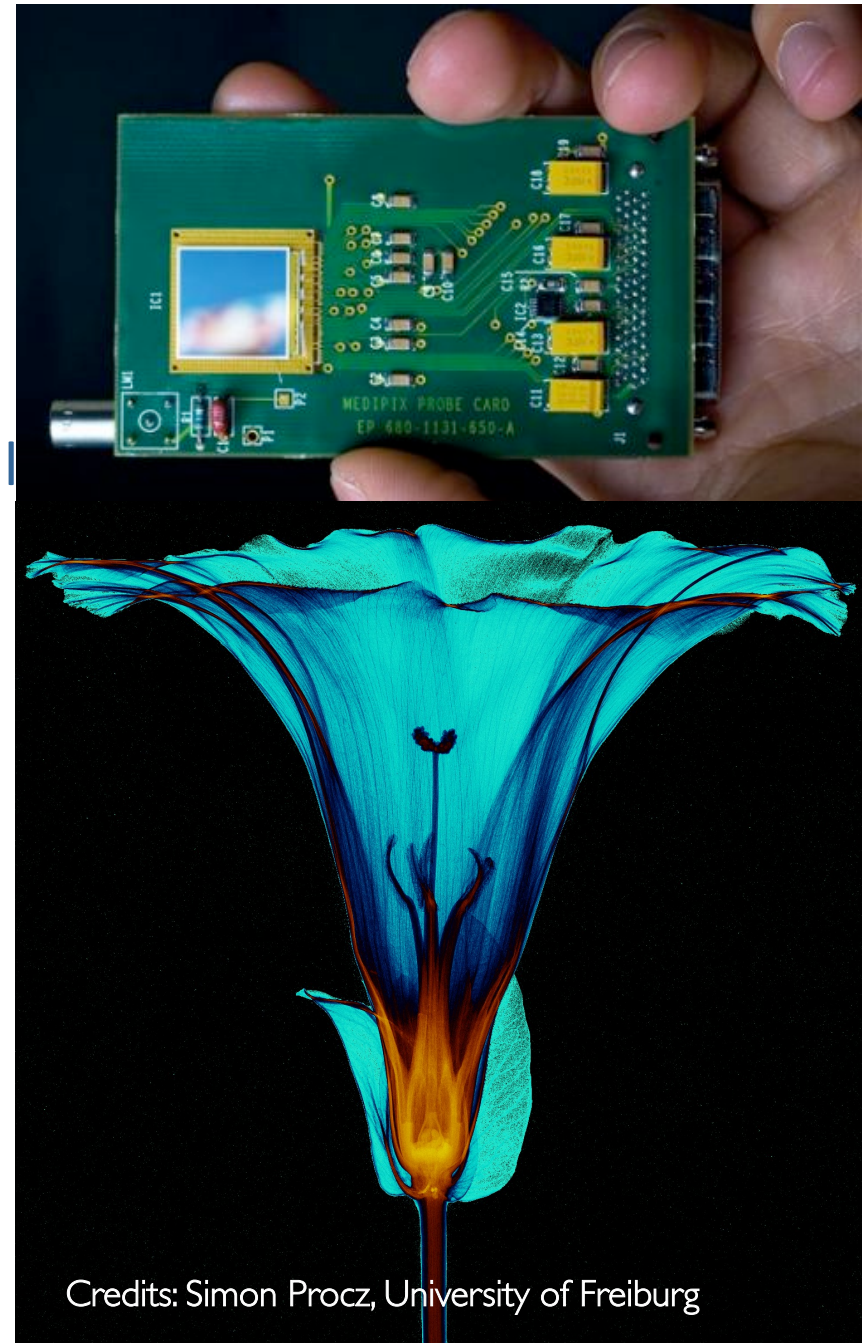


# The Principle



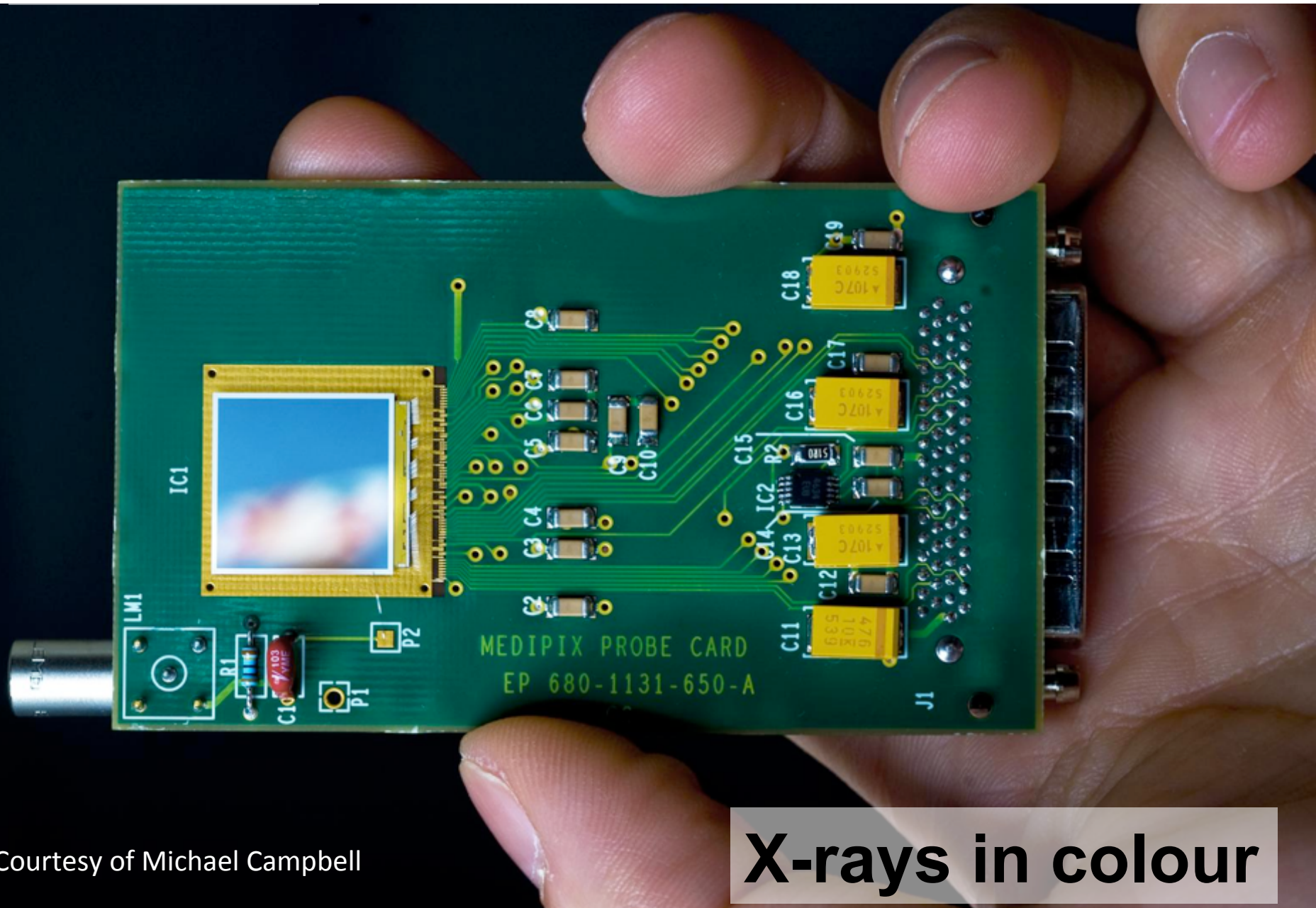
# Medipix

- 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



Credits: Simon Procz, University of Freiburg

# MEDIPIX

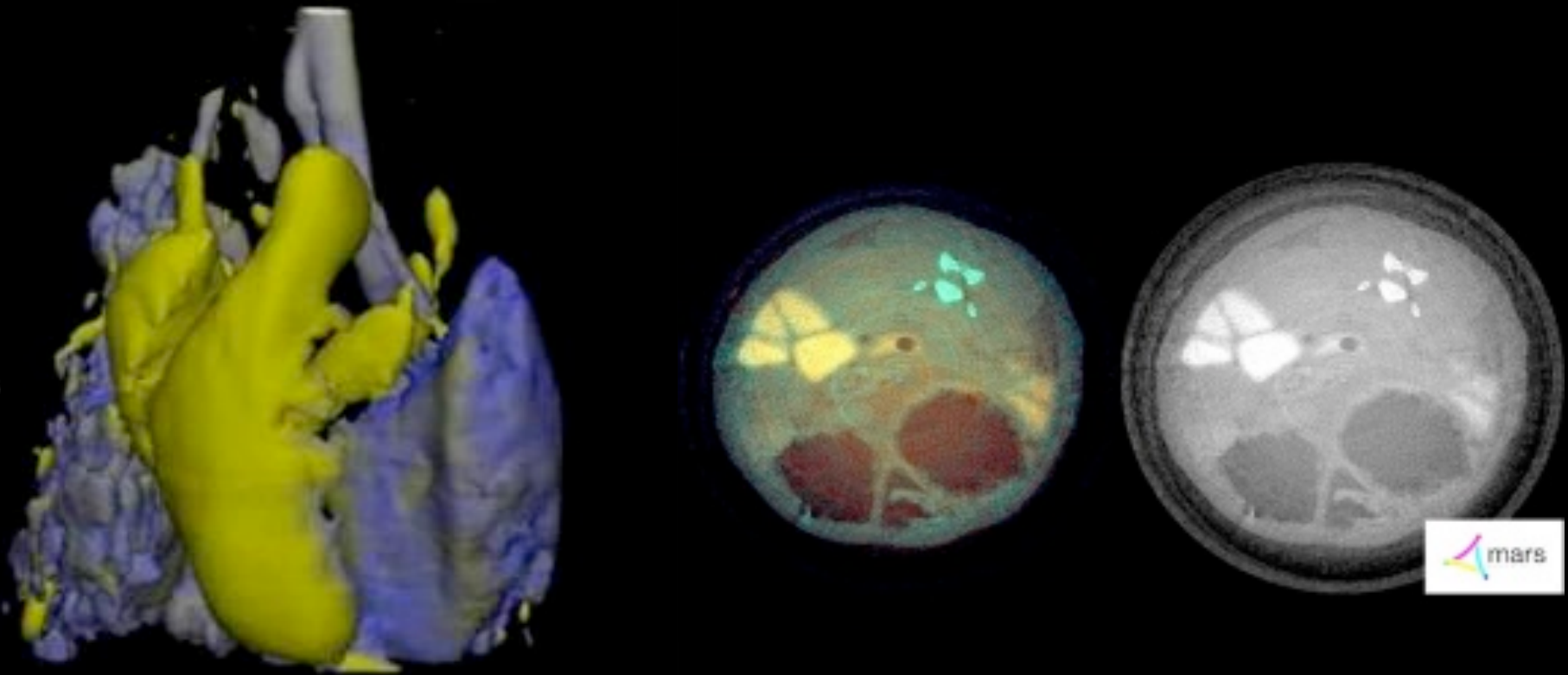


Courtesy of Michael Campbell

**X-rays in colour**



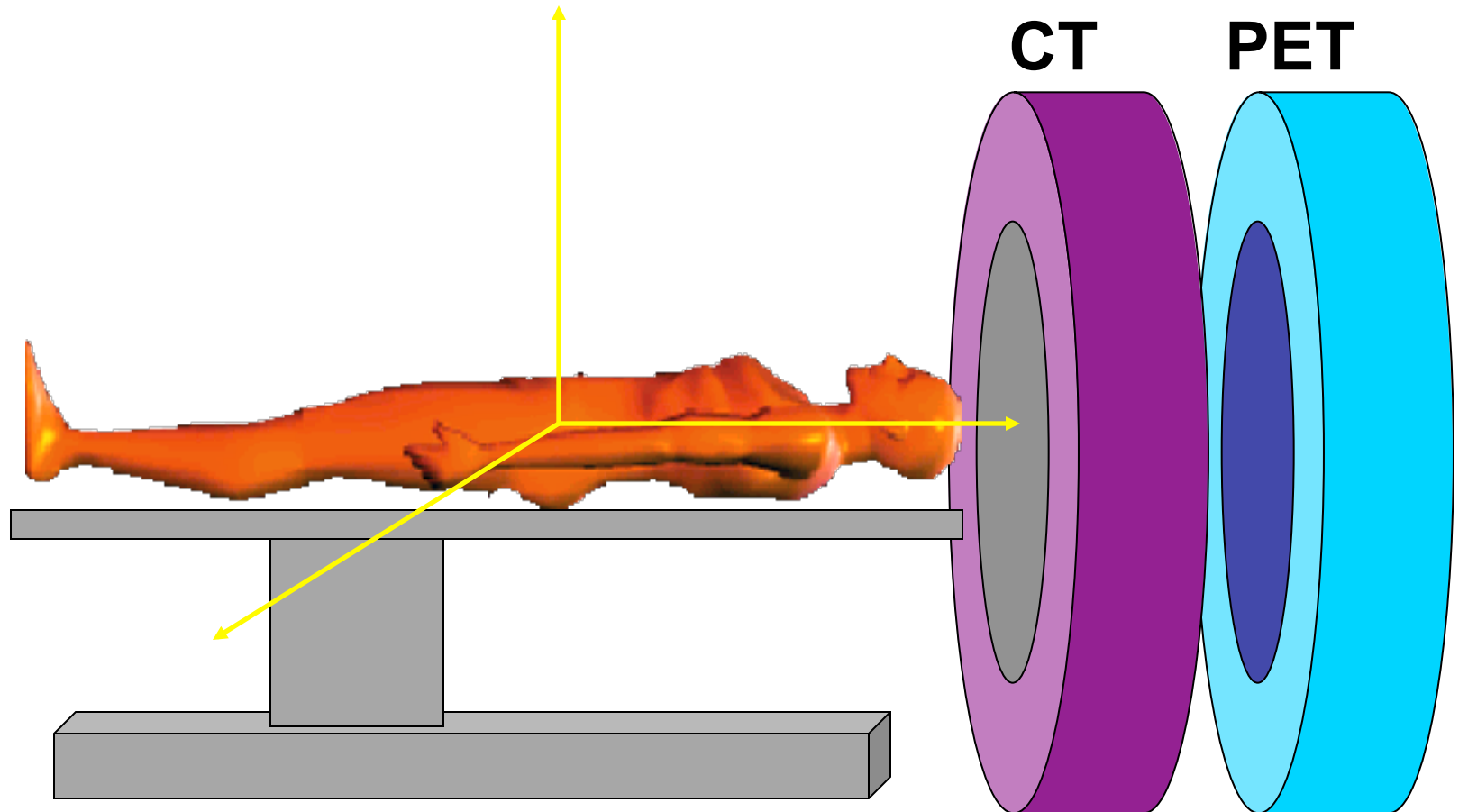
# MARS – MEDIPIX ALL RESOLUTION SYSTEM



(courtesy of MARS Bioimaging Ltd)

# Multi-modality imaging: PET-CT

*David Townsend*

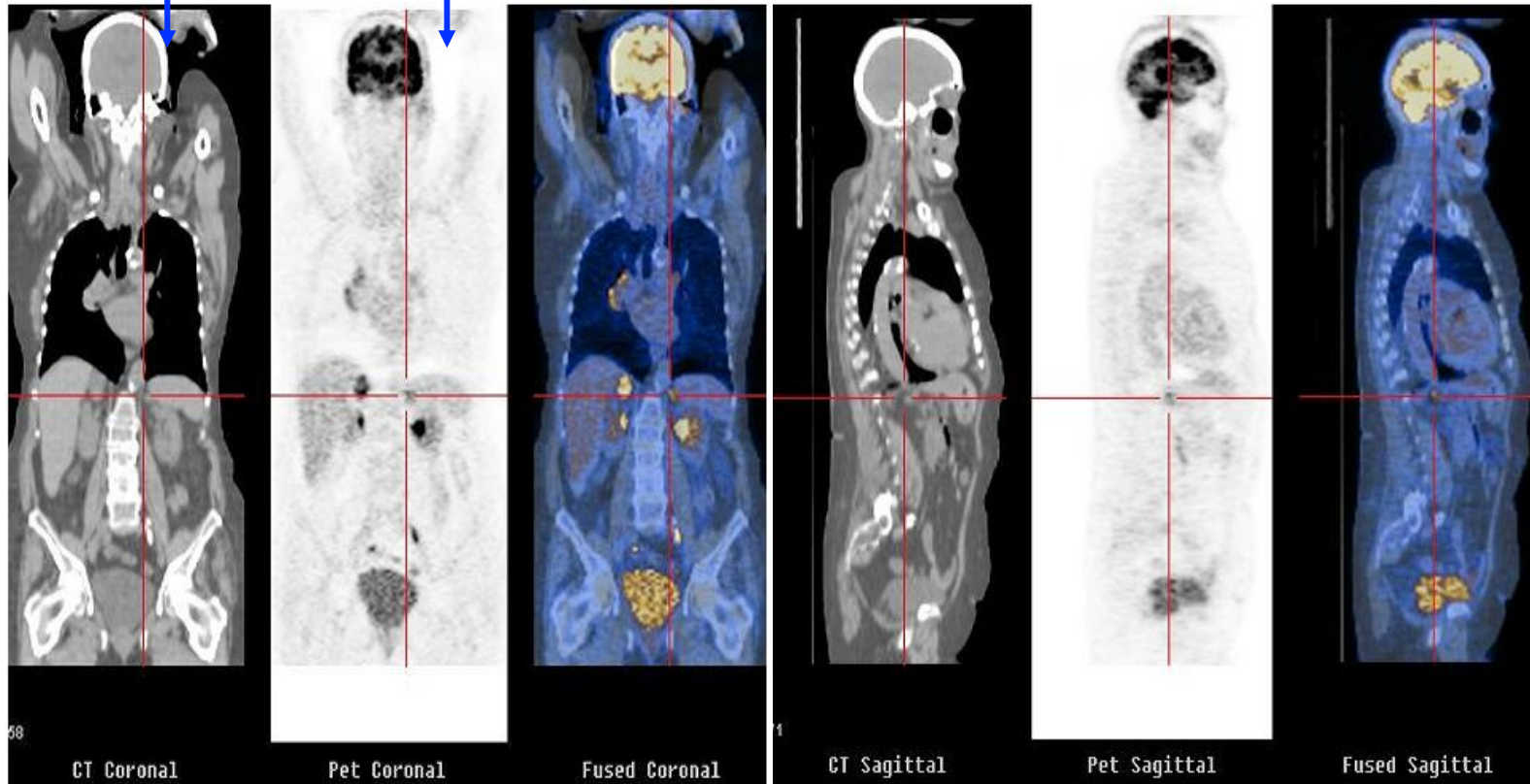


# Multimodality imaging: CT with PET

Combining anatomic and functional imaging

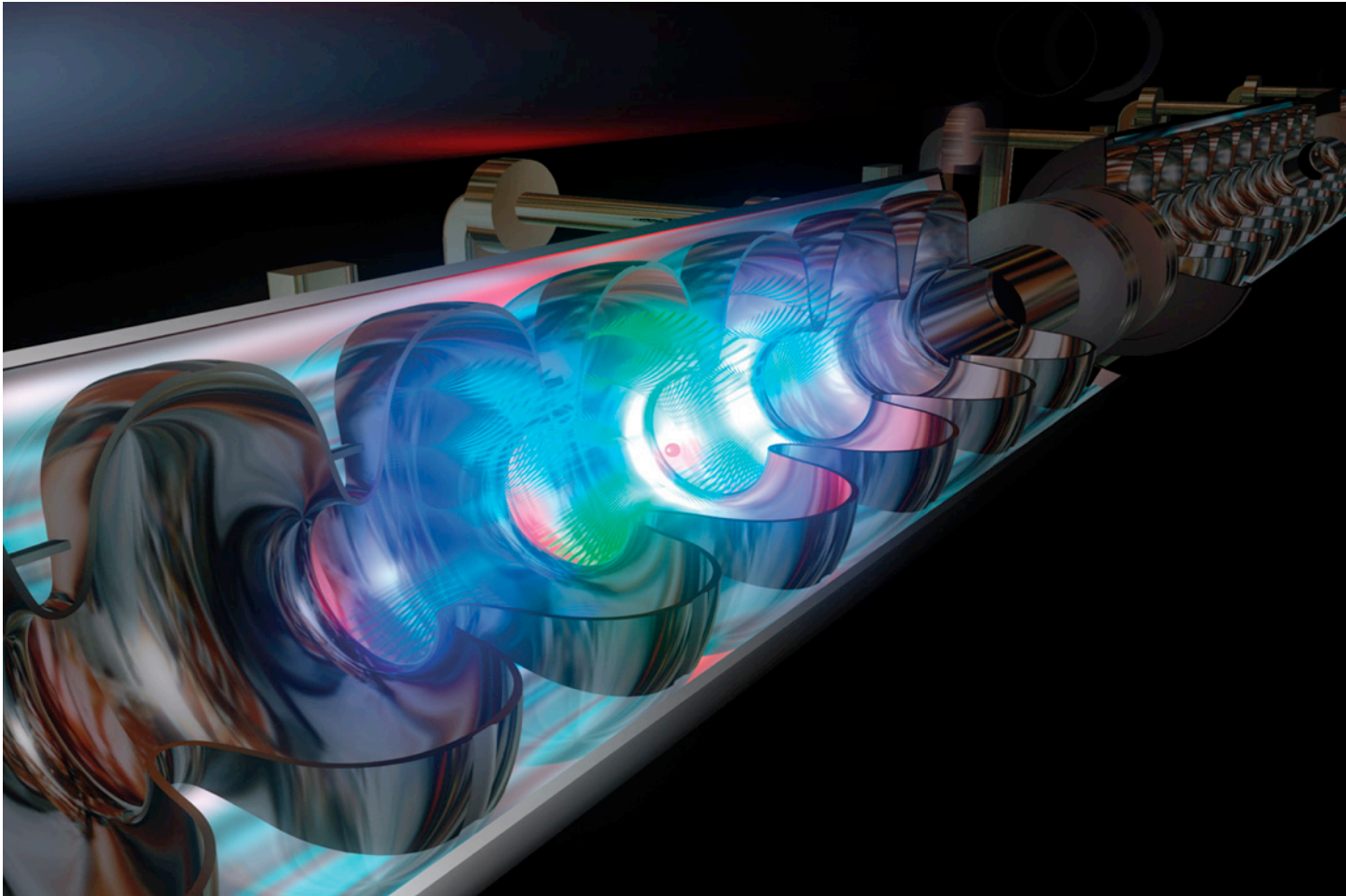
morphology

metabolism



David Townsend, CERN Physicist

# Accelerators for cancer treatment



# Use of Accelerators Today

## General industrial use:

Sterilisation, imaging

## Research Accelerators:

Particles, synchrotron light used in biomedical, physics, chemistry, biology, medical research.

## Radiotherapy:

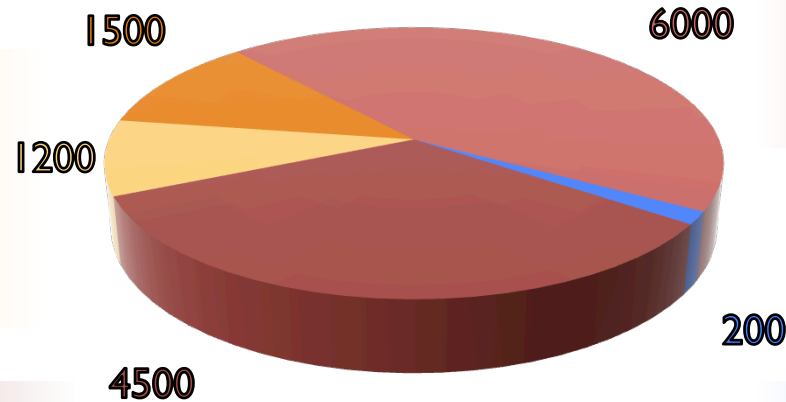
Cancer treatment with X-rays, protons and other particles.

## Ion implantation, surface modifications:

Controlled semiconductor doping; Changing properties of surfaces

## Radioisotope production:

Cancer treatment; imaging organs for medical use.



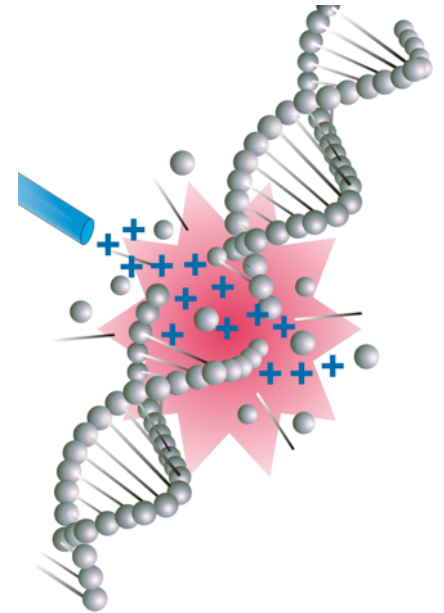
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~ 9000 of the 17000 accelerators operating in the World today are used for medicine.

# Conventional radiotherapy

- least expensive cancer treatment method
- most effective
- no substitute for RT in the near future
- rate of patients treated with RT is increasing

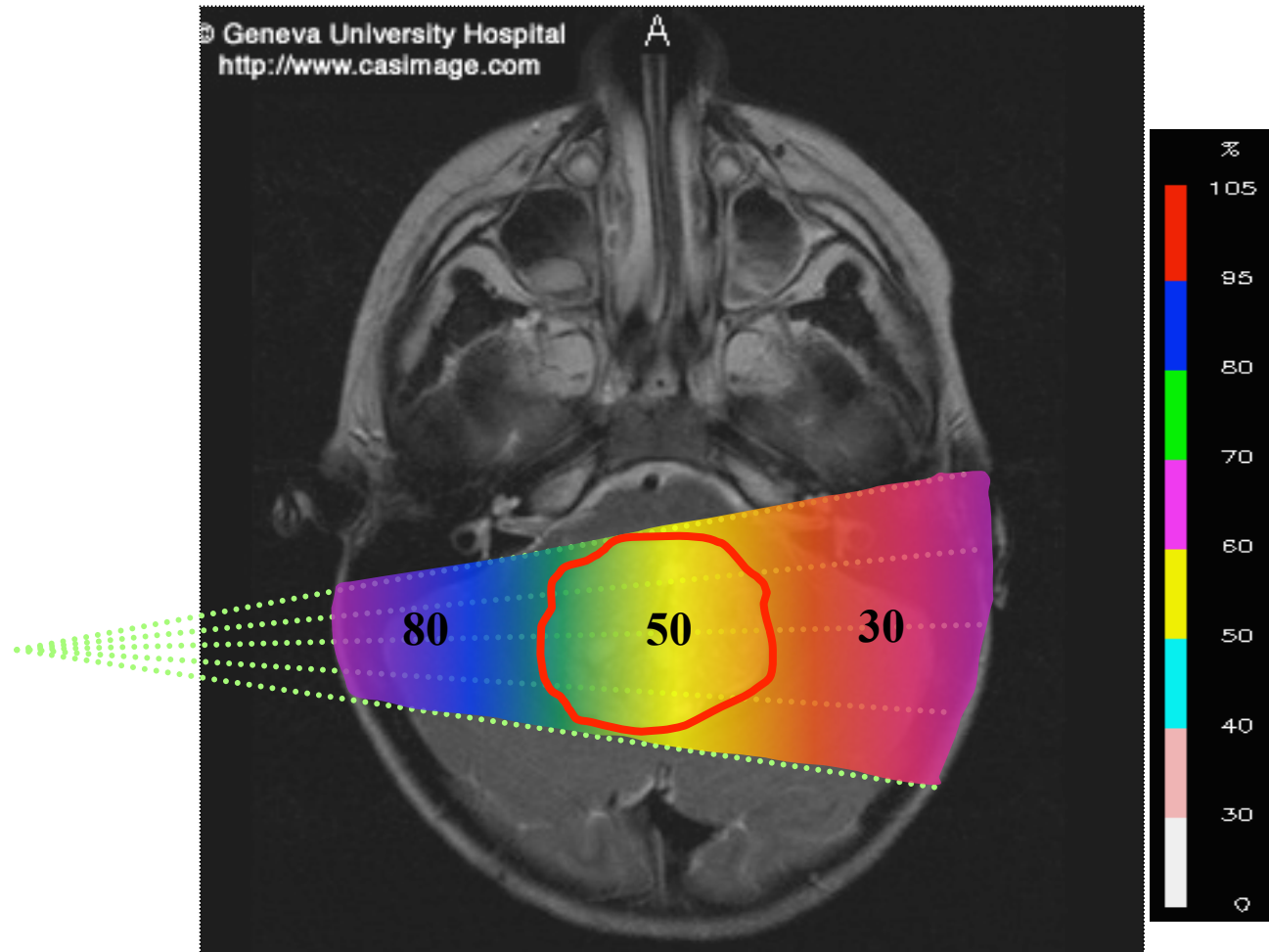
**30% of patients cancer comes back in the same location after RT**



# How to improve outcome?

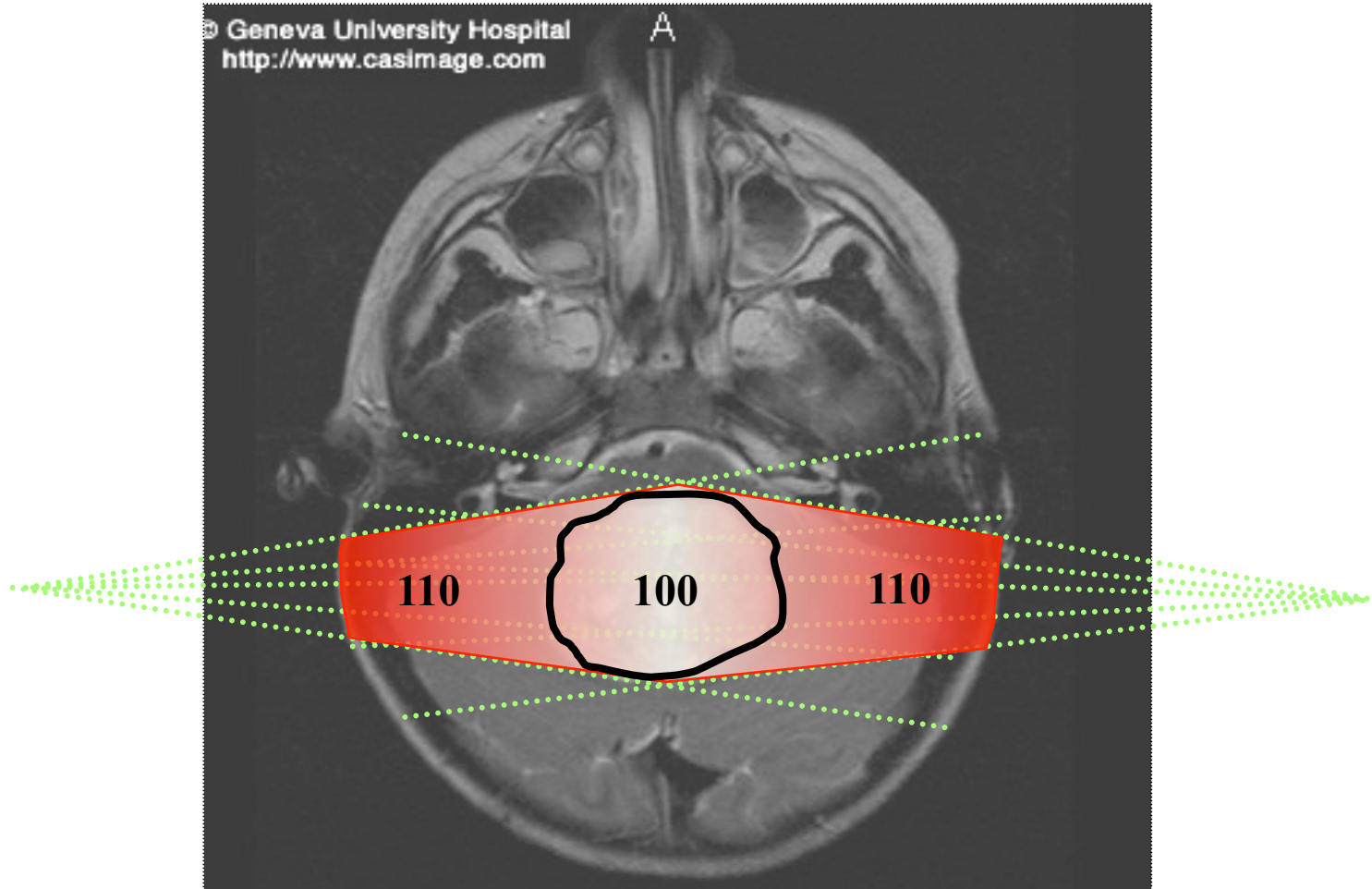
- Physics technologies: higher dose, more localised
- Imaging: accuracy, multimodality, real-time, organ motion
- Data: storage, analysis, sharing, patient referral, second opinion
- Biology: fractionation, radio-resistance, radio-sensitization
- Collaboration: cancer is a multidisciplinary field

# Single beam of photons

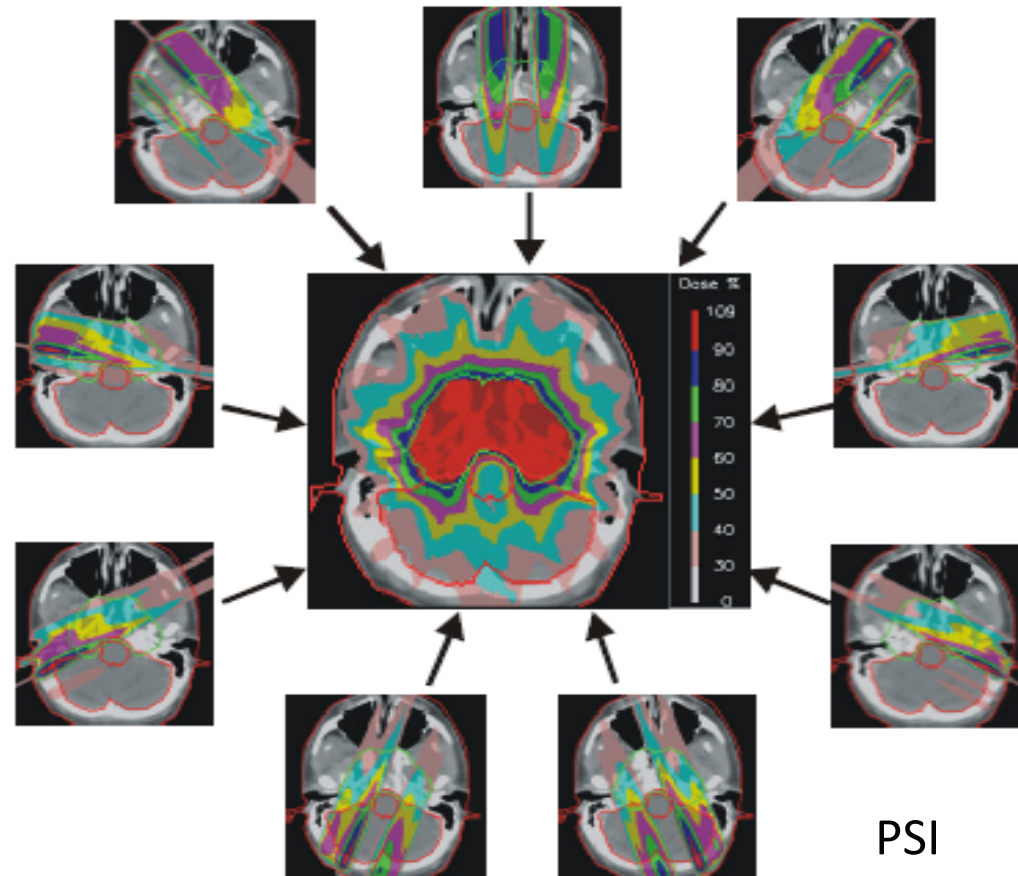




# 2 opposite photon beams

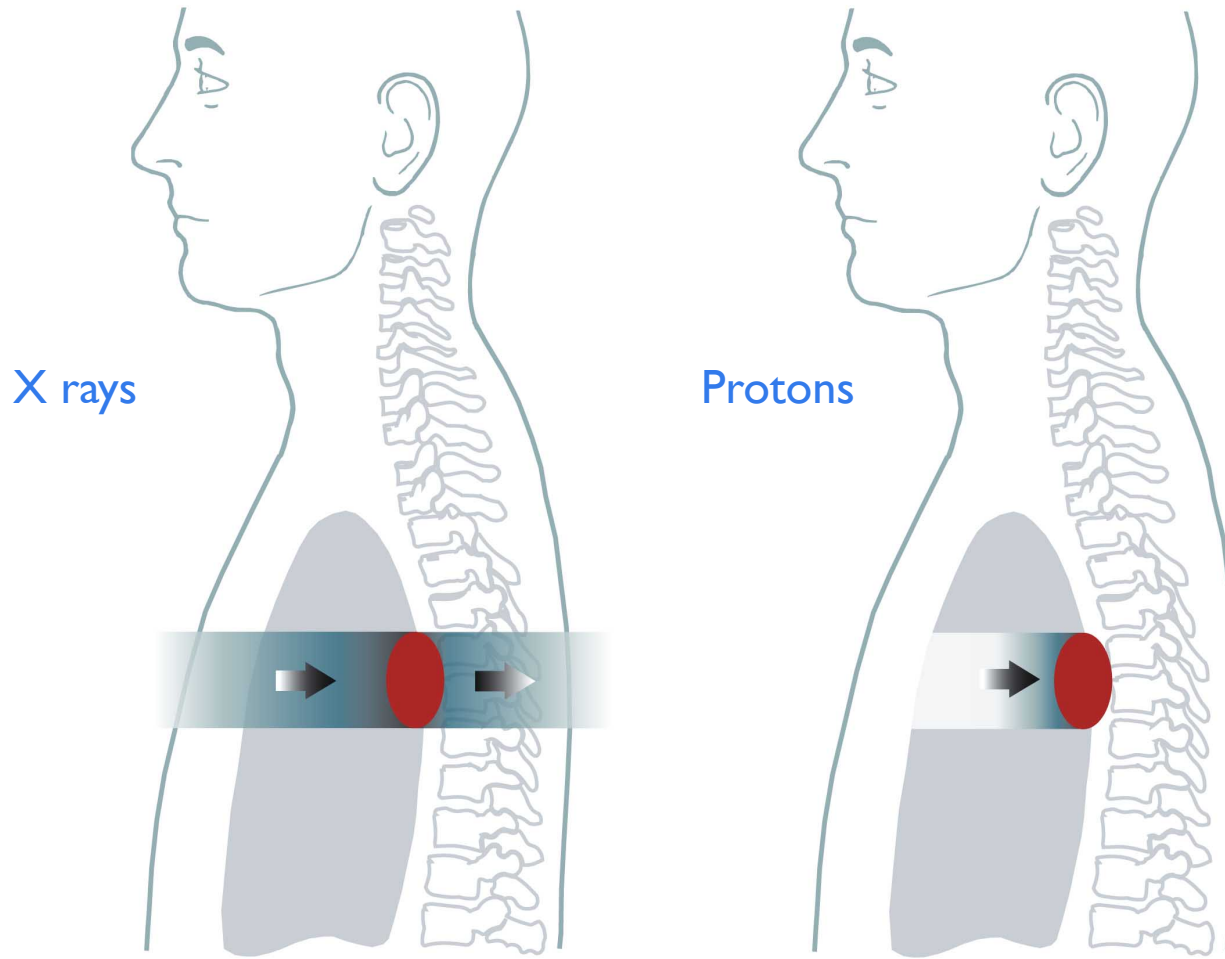


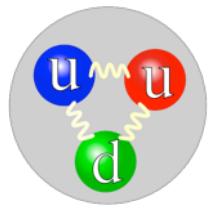
# Intensity Modulated Radiation Therapy



9 NON-UNIFORM FIELDS

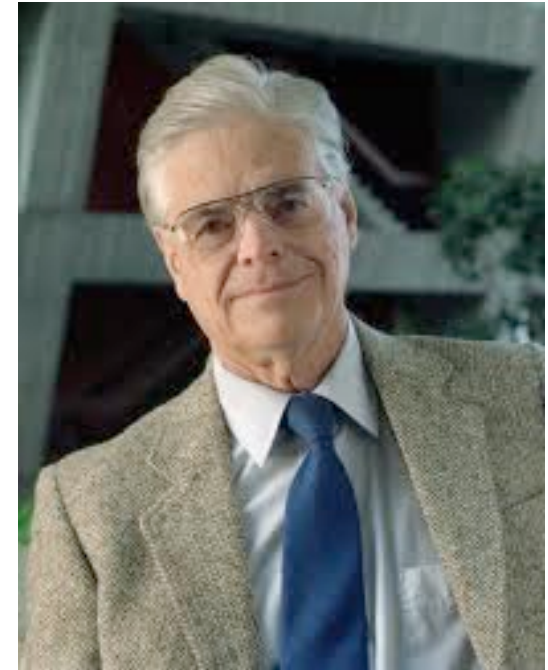
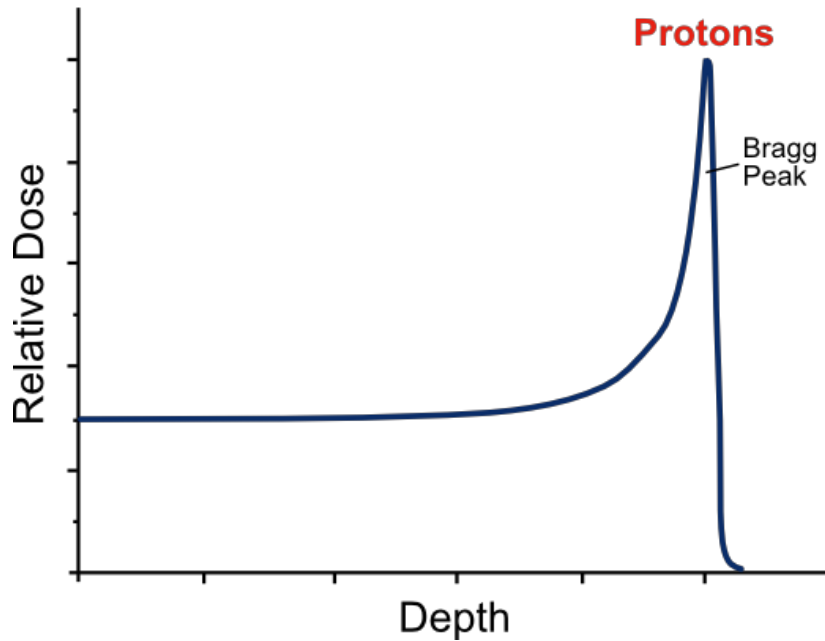
# HADRON THERAPY





# Alternative – Hadron Therapy

- 1946: Robert Wilson  
Protons can be used clinically



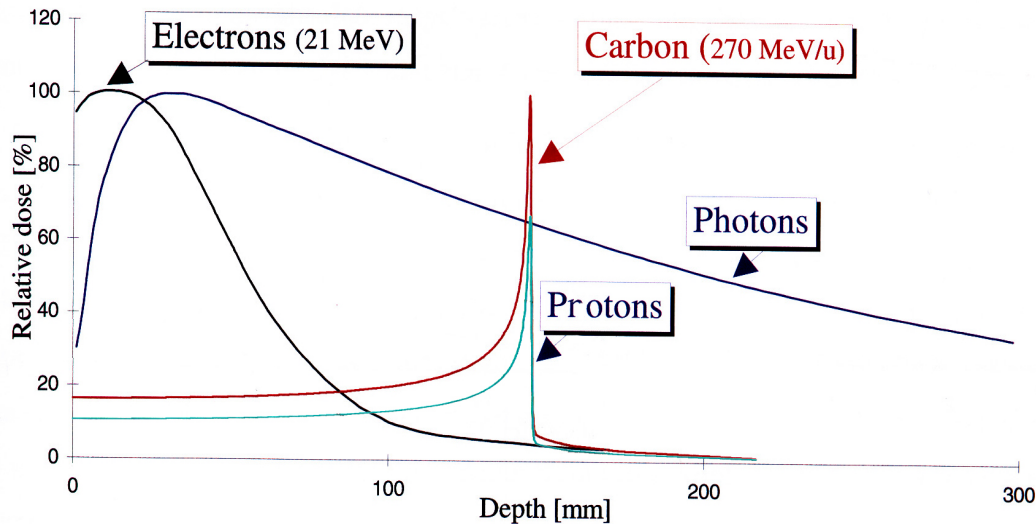
Robert Wilson

# Hadrontherapy

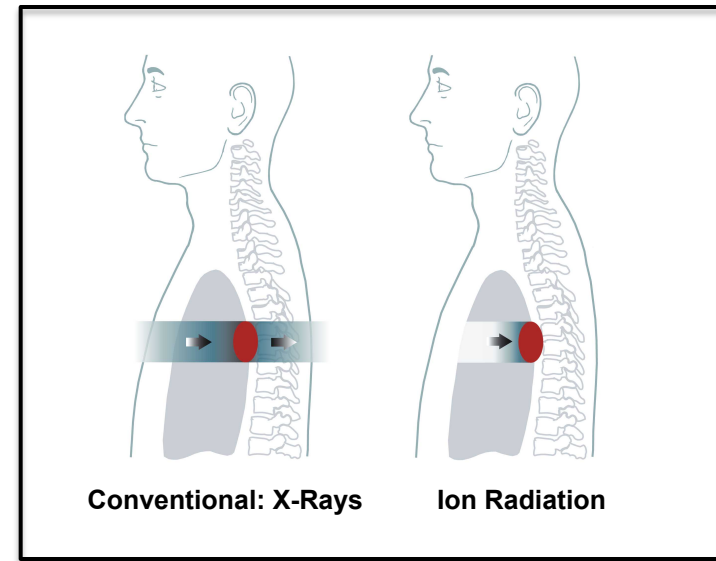
In 1946 Robert Wilson:

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

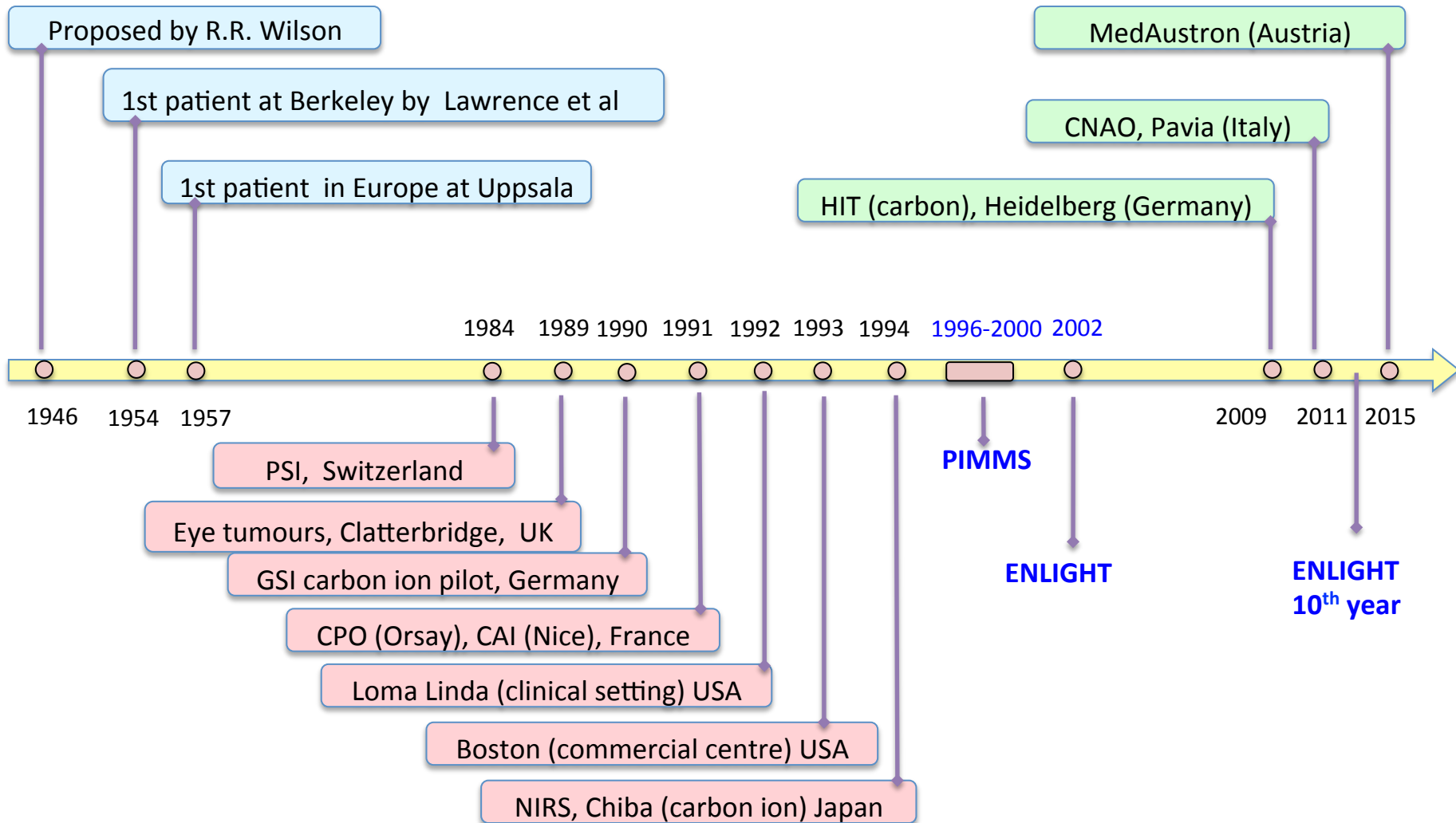
- Tumours near critical organs
- Tumours in children
- Radio-resistant tumours



Depth in the body (mm)



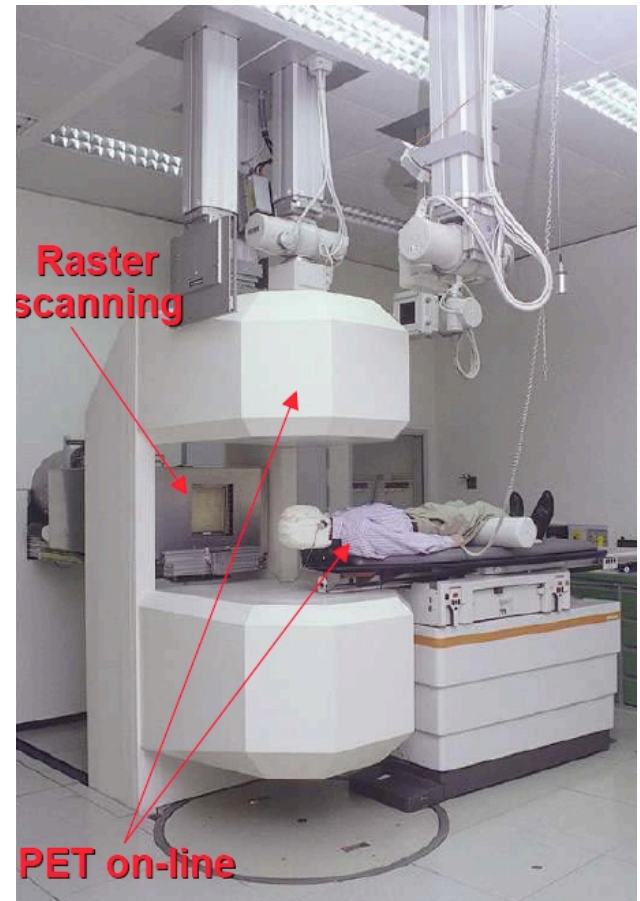
# Particle therapy: a short history



# Carbon ions: pilot project in Europe

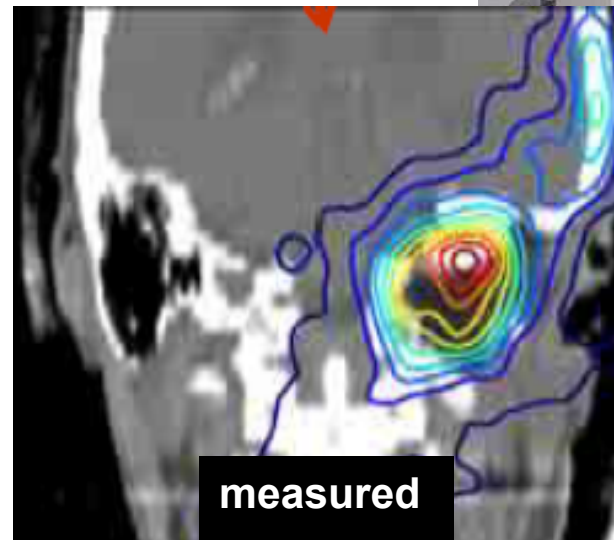
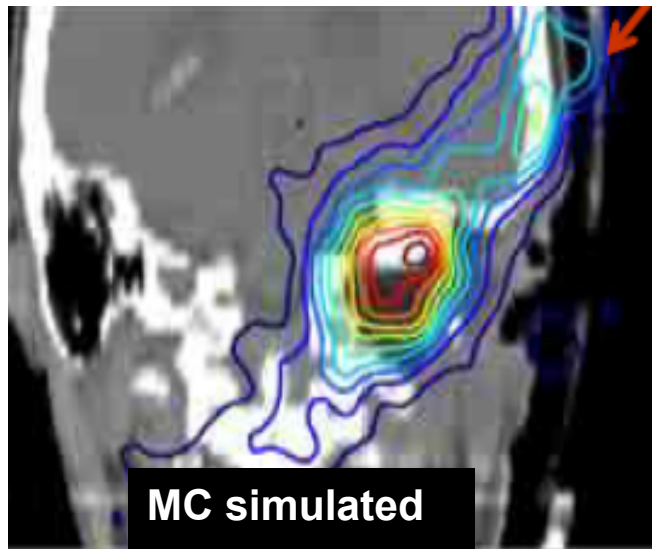
GSI & Heidelberg

– 450 patients treated



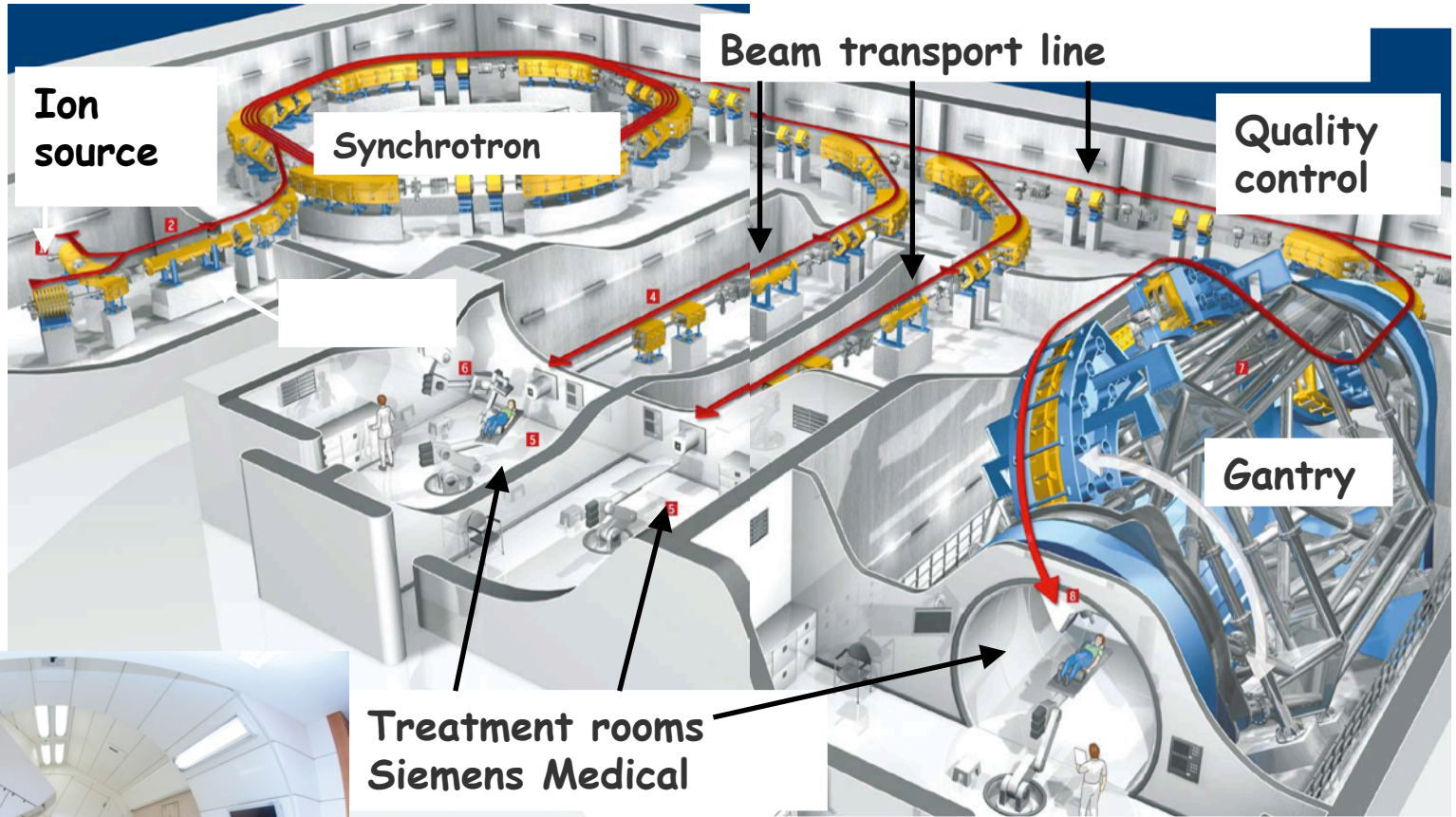
# Real-time monitoring

- In-beam PET @ GSI (Germany)
- MonteCarlo simulations
- Organ motion

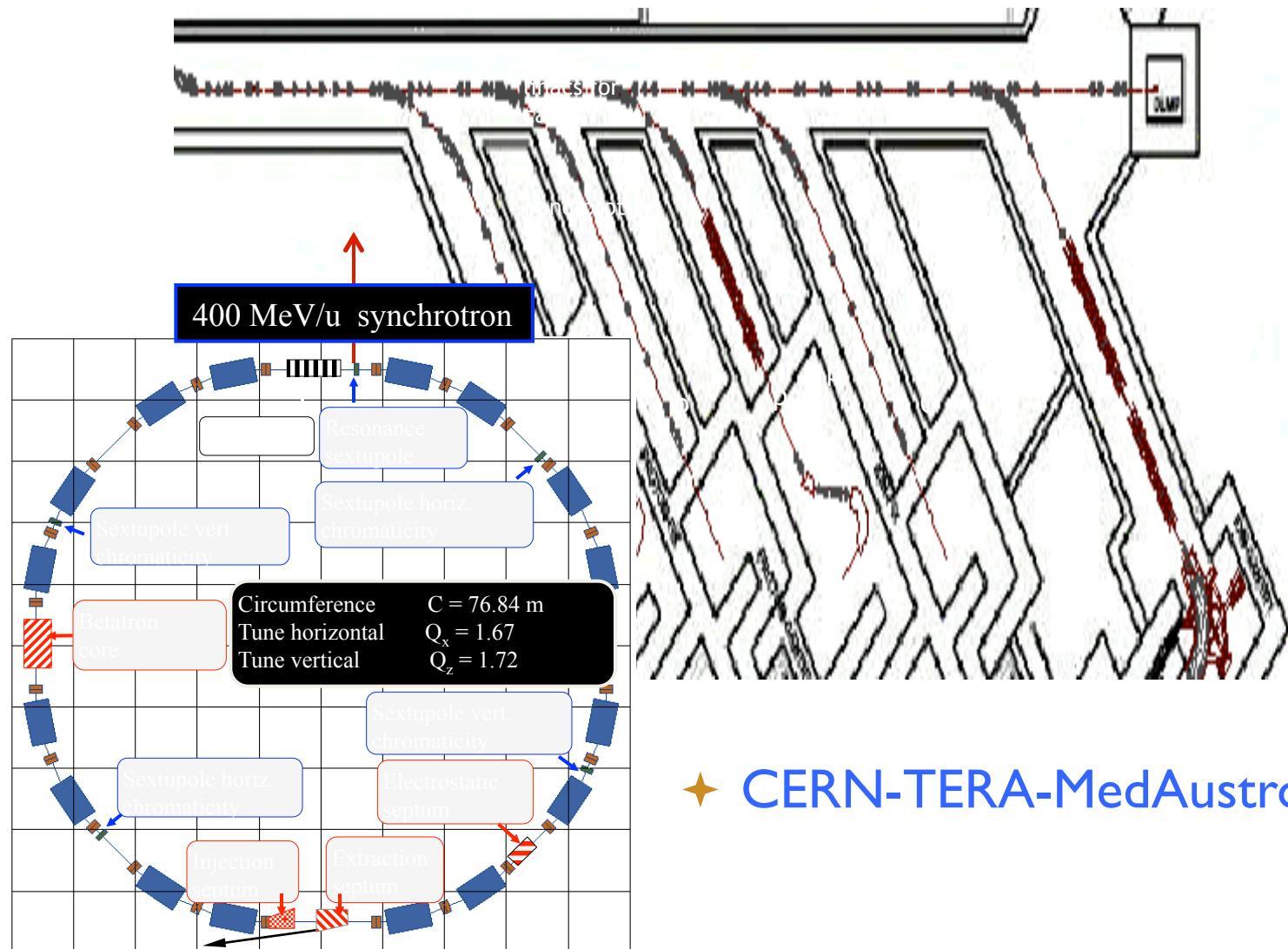




# HIT - Heidelberg



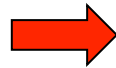
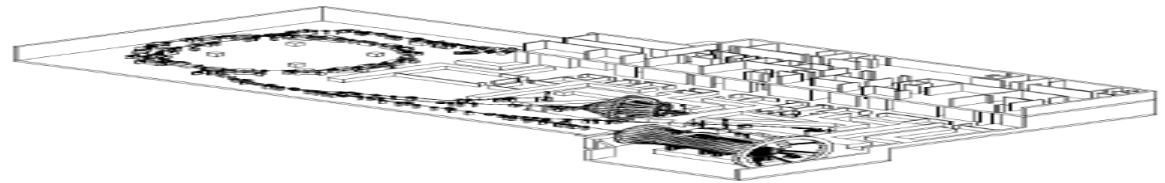
# PIMMS at CERN (1996-2000)



✦ CERN-TERA-MedAustron

# Accelerator Technologies

PIMMS 2000  
(coordinated by CERN)  
has led to:



fondazione **CNAO**

Treatment centre in Pavia, Italy.

**First patient treated with in 2011**

ebg *MedAustron*

Treatment centre in Wiener Neustadt, Austria,  
foundation stone in 2011, installation moved to  
MedAustron at beginning of 2012, first patient in 2015

# From PIMMS study coordinated by CERN



First patient with carbon ions Nov 2012



Will start treatments in 2016

# MedAustron – Wiener Neustadt



Starts treatment in 2016

# Use of Accelerators Today

## General industrial use:

Sterilisation, imaging

## Research Accelerators:

Particles, synchrotron light used in biomedical, physics, chemistry, biology, medical research.

## Radiotherapy:

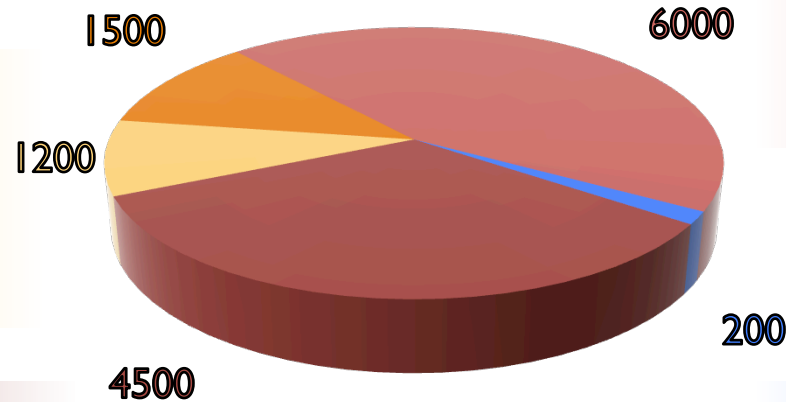
Cancer treatment with X-rays, protons and other particles.

## Ion implantation, surface modifications:

Controlled semiconductor doping; Changing properties of surfaces

## Radioisotope production:

Cancer treatment; imaging organs for medical use.



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



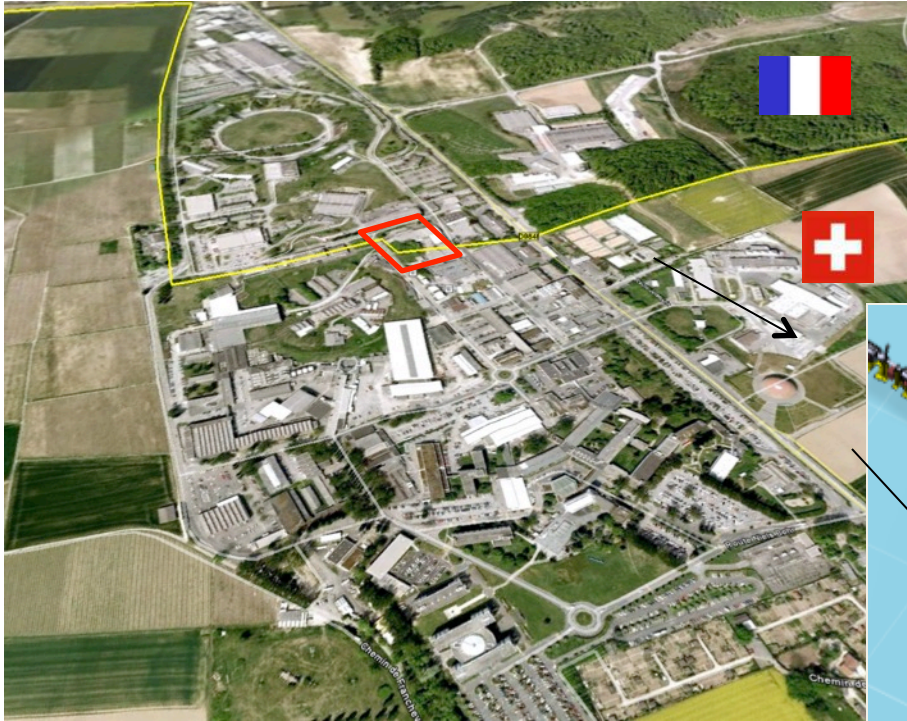
[cern.ch/virtual-hadron-therapy-centre](https://cern.ch/virtual-hadron-therapy-centre)

[http://virtual-hadron-therapy-centre.web.cern.ch/virtual-hadron-therapy-centre/  
cern.ch/virtual-hadron-therapy-centre](http://virtual-hadron-therapy-centre.web.cern.ch/virtual-hadron-therapy-centre/cern.ch/virtual-hadron-therapy-centre)

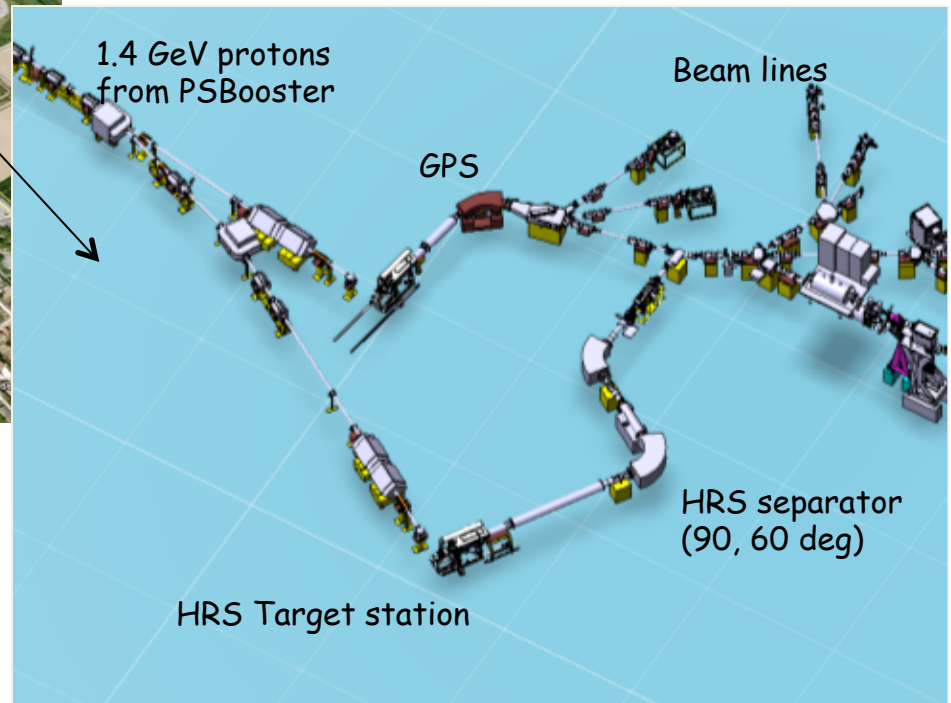


# ISOLDE

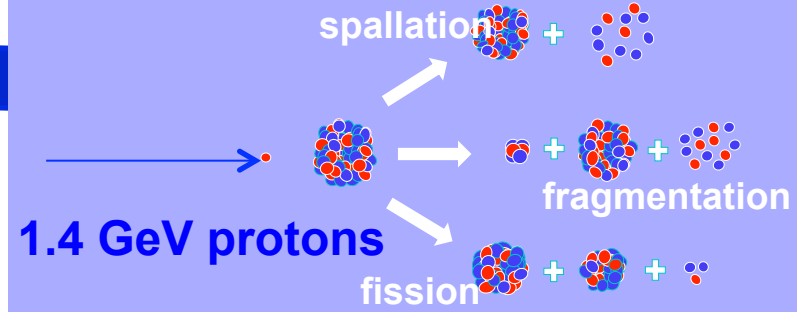
isotopes for detection & treatment



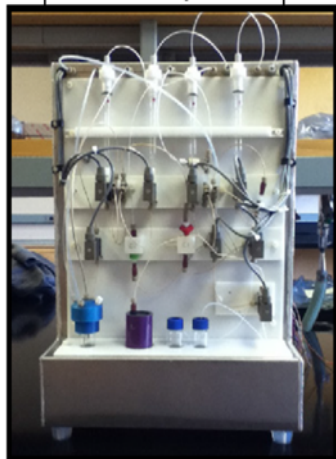
In collaboration with  
University Hospital Geneva



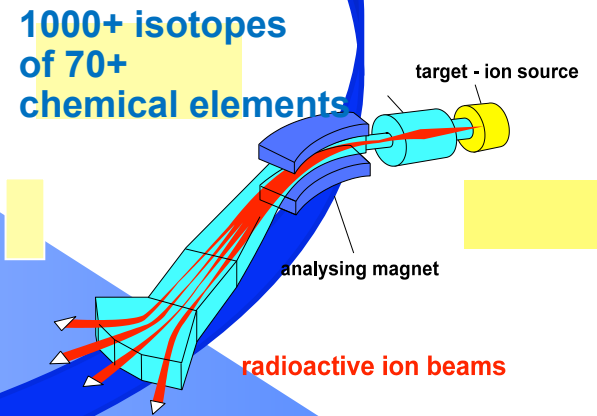
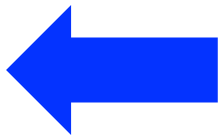
# MEDICIS



## Chemical separation



H

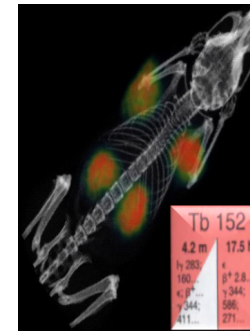


# Terbium: Swiss Army Knife of Nuclear Medicine

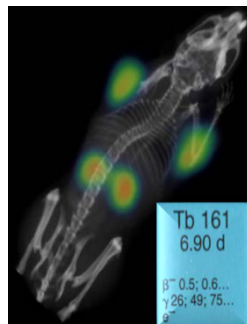
**$^{149}\text{Tb}$ -therapy**



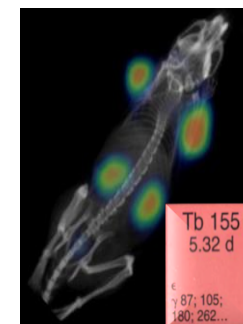
**$^{152}\text{Tb}$ -PET**



**$^{161}\text{Tb}$ -therapy  
& SPECT**



**$^{155}\text{Tb}$ -SPECT**



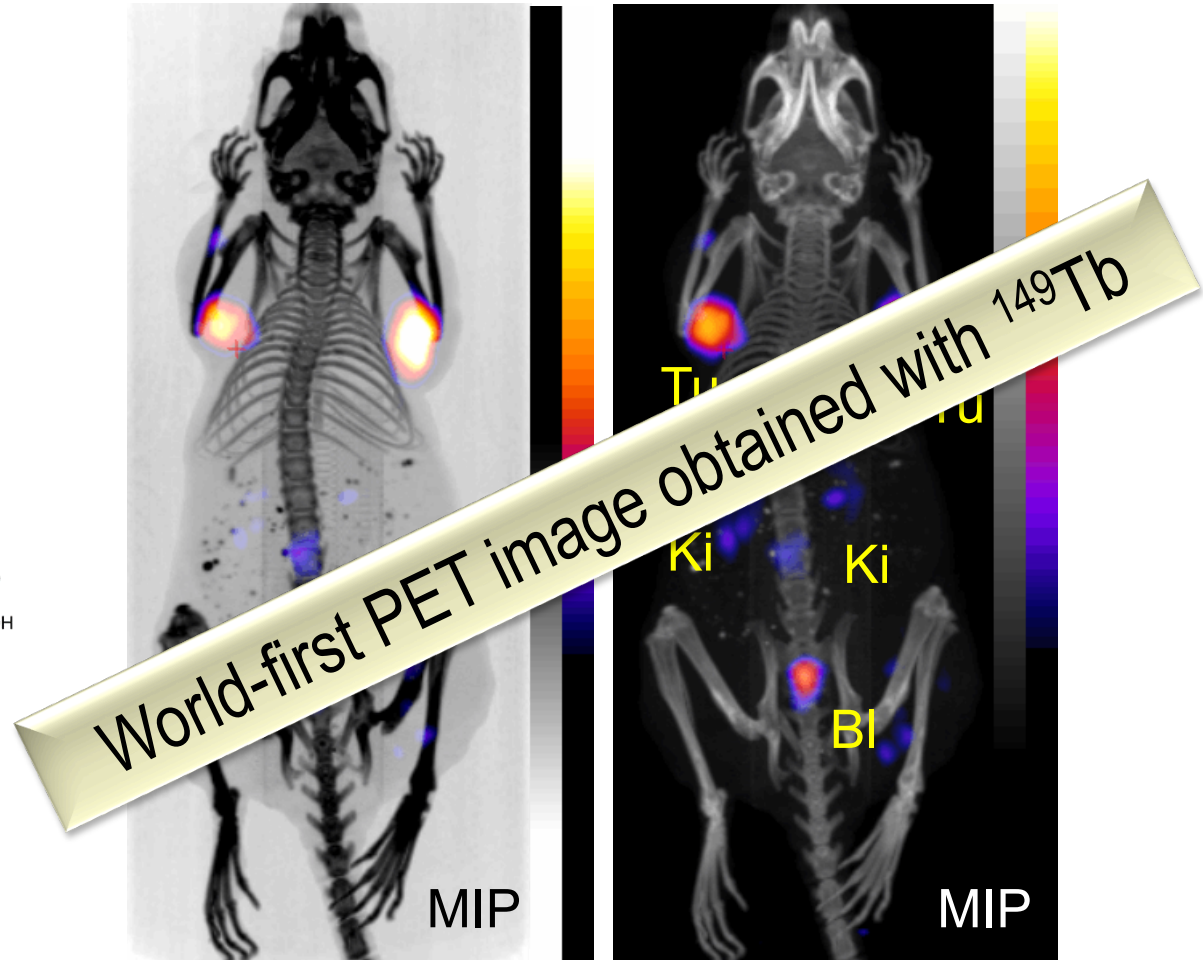
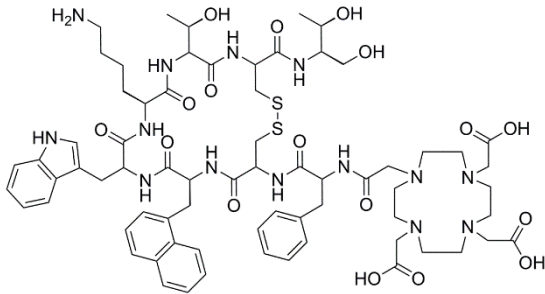
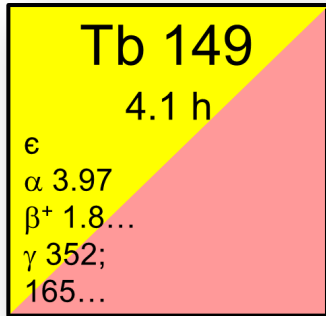
ISOLDE



NEUTRONS FOR SCIENCE

Müller et al., JNM 2012

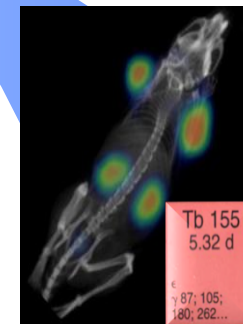
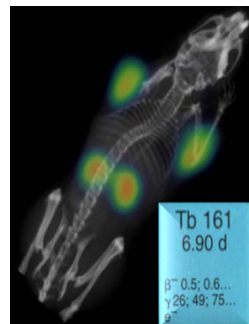
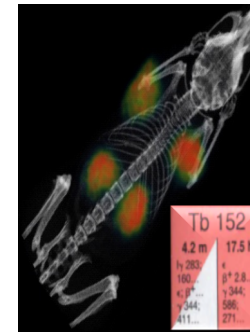
# $^{149}\text{Tb}$ : Useful for $\alpha$ -Therapy and PET Imaging



PET/CT scan of a AR42J tumor-bearing mouse performed 2 h after injection of  $^{149}\text{Tb}$ -DOTANOC

N. van der Meulen et al., PSI, ICTR-PHE2016.

# Terbium: Swiss Army Knife of Nuclear Medicine

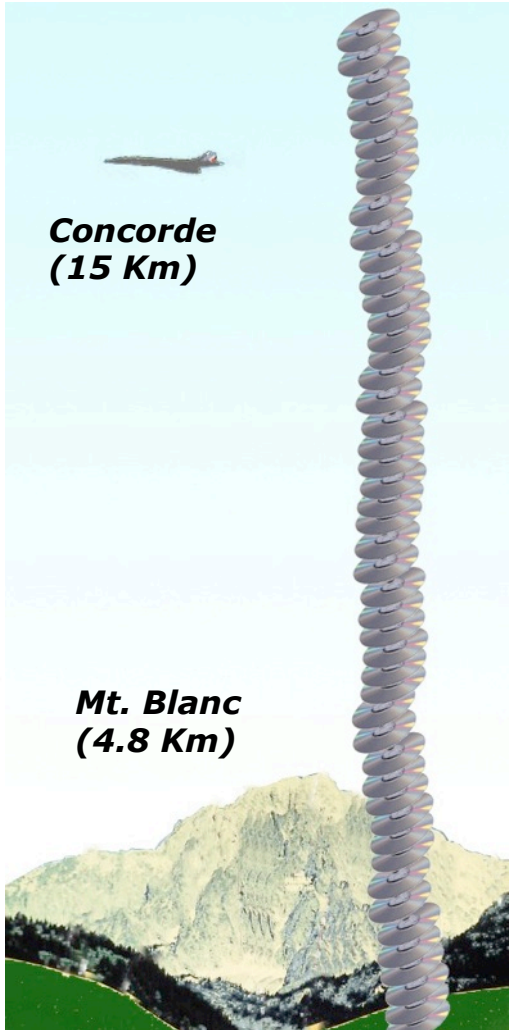


ISOLDE

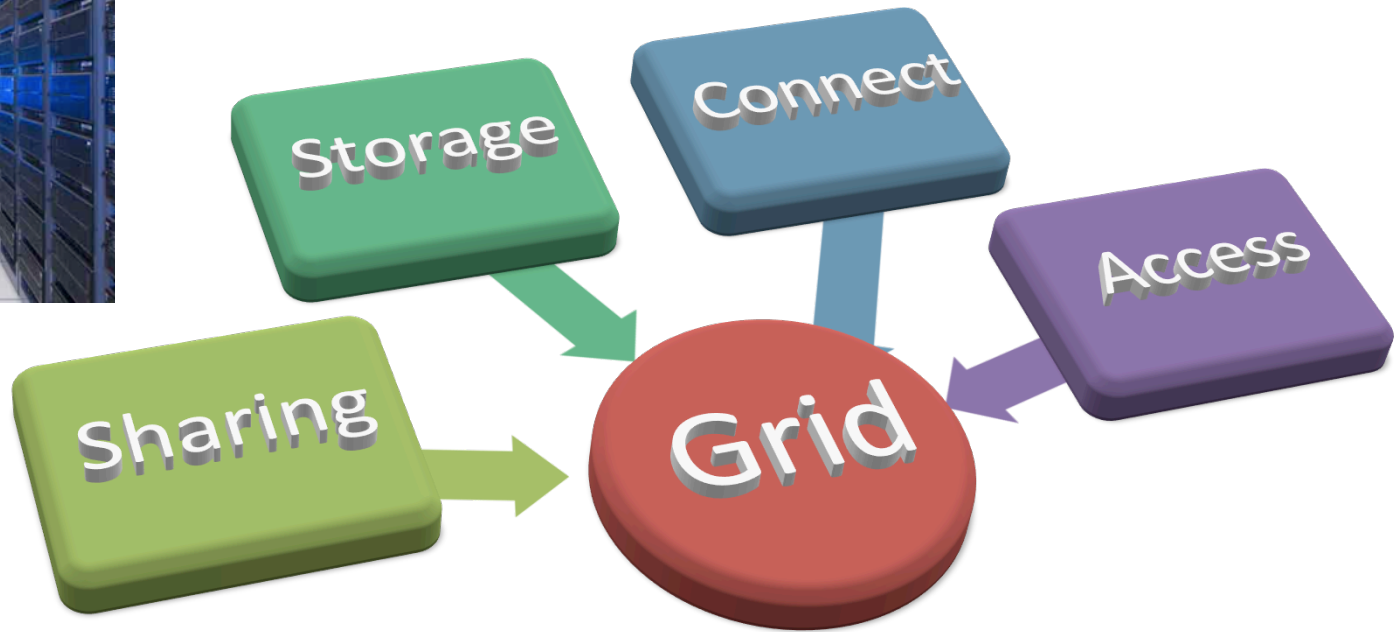


Müller et al., JNM 2012

# Computing for medical applications



# The Grid

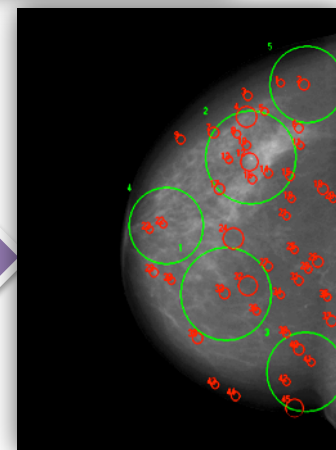
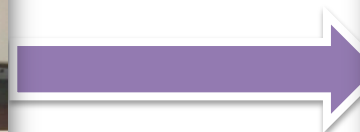
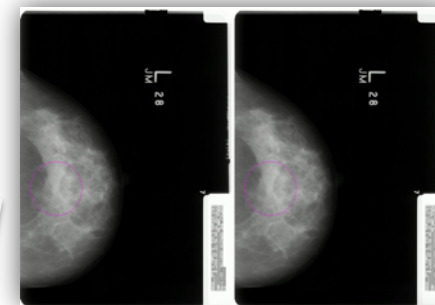
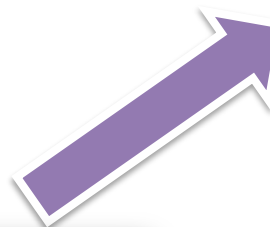


Data and Resources



# Mammogrid - a grid mammography database

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



From: David MANSET, CEO MAAT France, [www.maat-g.com](http://www.maat-g.com)





## **Imaging Animation for ENVISION**

*<http://cds.cern.ch/record/1611721>*

## Many thanks to:

- U. Amaldi, CERN & TERA
- E. Blakely, LBNL, USA
- M Durante, GSI, Germany
- HIT, CNAO, MedAustro, PSI and ENLIGHT colleagues
- Life Sciences Team

## Useful links

- *cern.ch/crystalclear*
- *cern.ch/enlight*
- *cern.ch/virtual-hadron-therapy-centre*
- *http://cds.cern.ch/record/1611721*
- *cern.ch/knowledgetransfer*
- *cern.ch/medipix*
- *cern.ch/twiki/bin/view/AXIALPET*
- *cern.ch/medastron*
- *cern.ch/fluka/heart/rh.html*
- *www.fluka.org/fluka.php*
- *cern.ch/wwwasd/geant*
- *cern.ch/wwwasd/geant/tutorial/tutstart.html*
- [www-pub.iaea.org/MTCD/Publications/PDF/TCS-42\\_web.pdf](http://www-pub.iaea.org/MTCD/Publications/PDF/TCS-42_web.pdf)