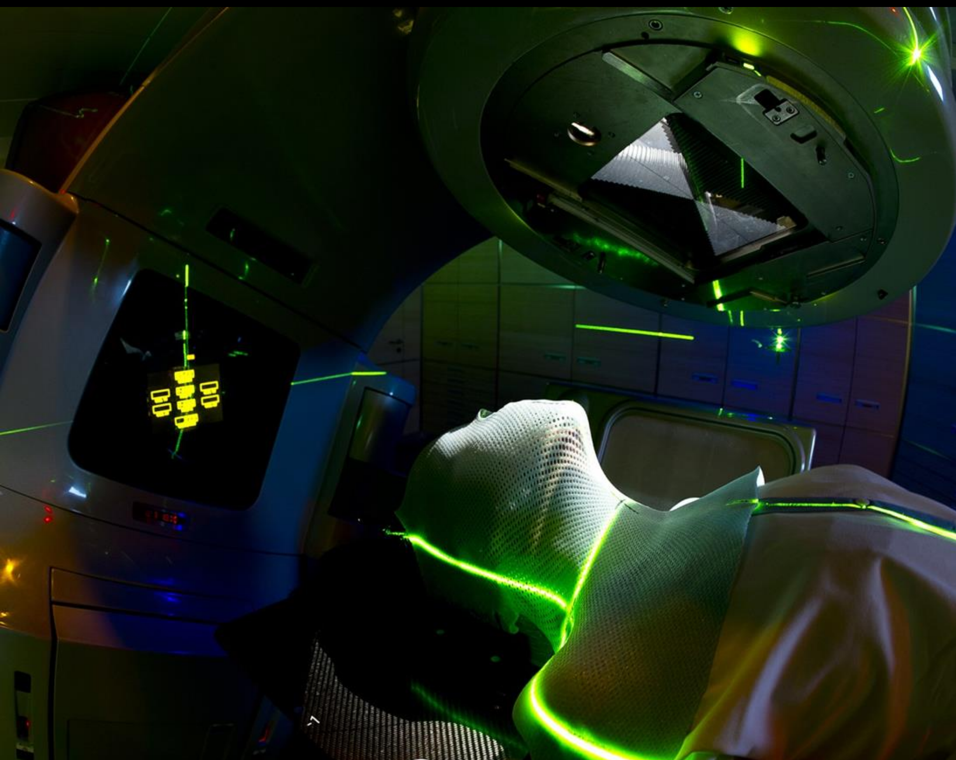
Medical applications at CERN




Alberto Degiovanni
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from a presentation of M. Cirilli / CERN-KT

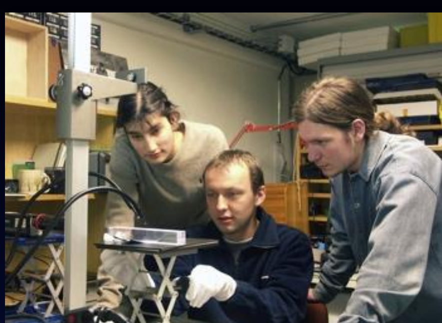
The mission of CERN

✦ Research

Push forward the frontiers of knowledge

✦ Innovation

Develop new technologies for accelerators, detectors, computing



✦ Education

Train the scientists and engineers of tomorrow

✦ Uniting people

From different countries and cultures

Technology transfer

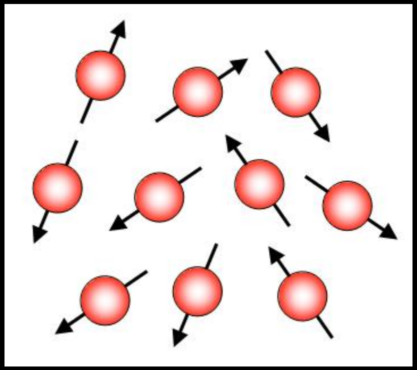
- The case of x-rays
  - 8 November1895: Röntgen discovers x-rays
  - 22 December1895: first radiography of his wife's hand

- Nobel prize in 1901

Magnetic resonance

Nobel prize in Physics, 1952

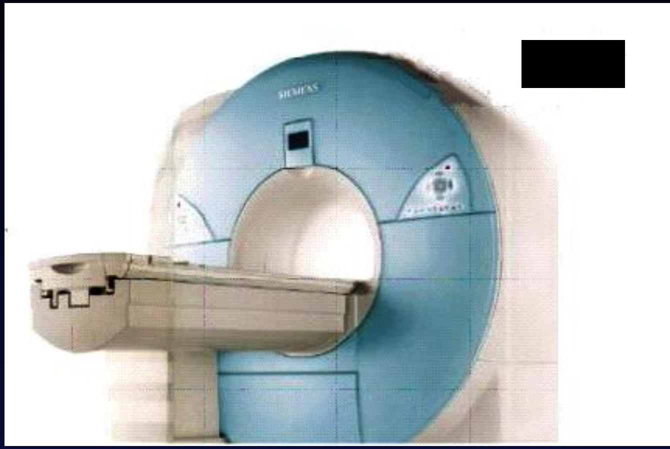
Felix Bloch, physicist



Edward M. Purcell, physicist

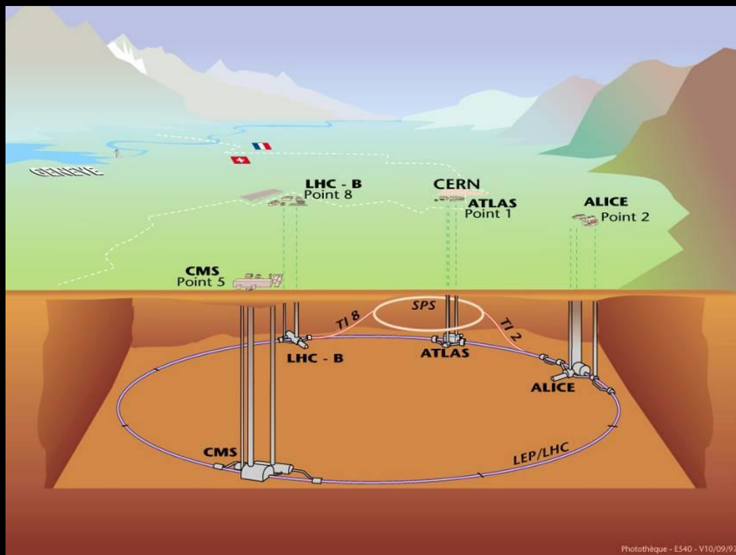
Nobel prize in medicine, 2003

Sir Peter Mansfield, physicist

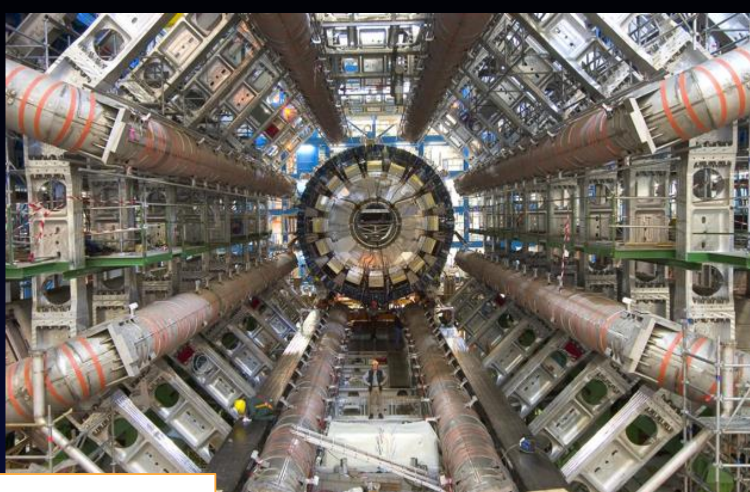


Paul C. Lauterbur, chemist

The tools of the trade



Accelerators

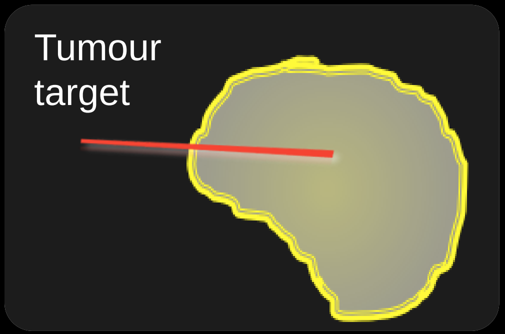


Detectors

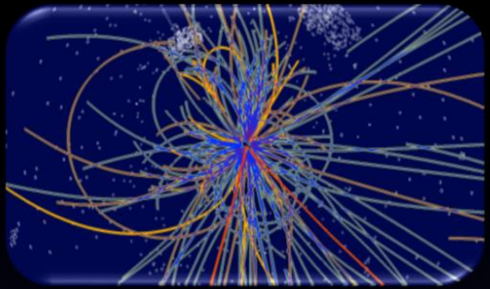
Computing

CERN technologies

Accelerate particle beams



Hadron therapy



Detect particles

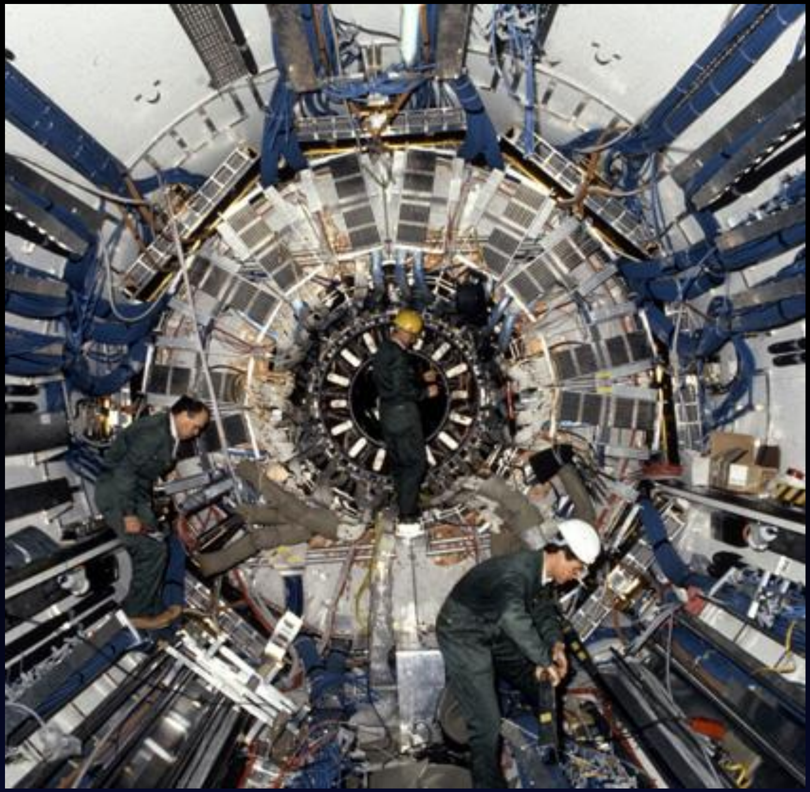
Medical imaging

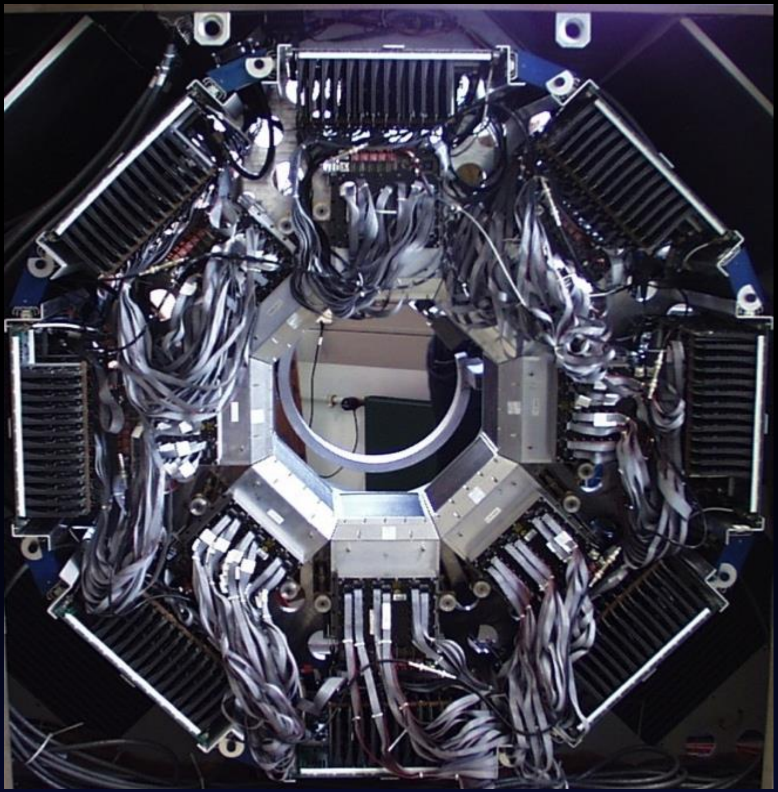
Large scale **Computing** (Grid)

Grid computing for medical data management and analysis

Medical Imaging

Medical imaging and particle physics: the same challenge?



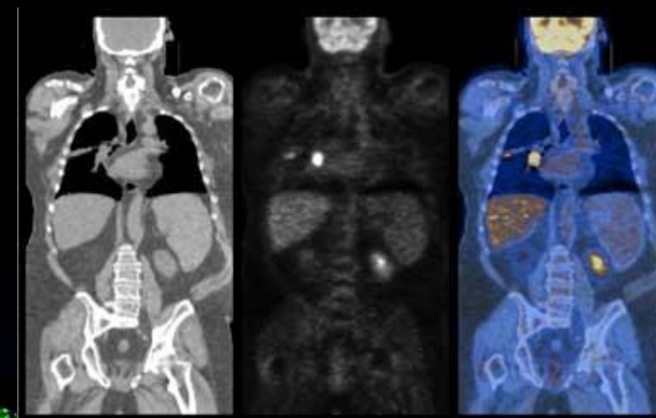


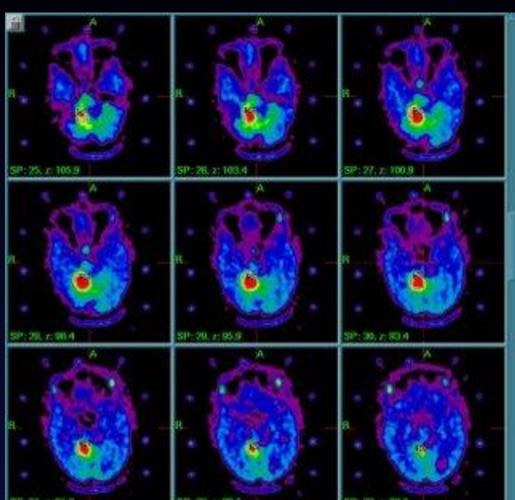
Antimatter

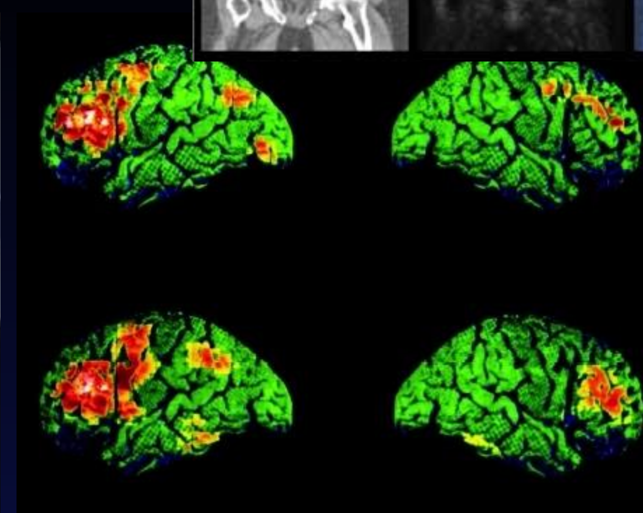
PET: antimatter for clinical use

- Not only science-fiction

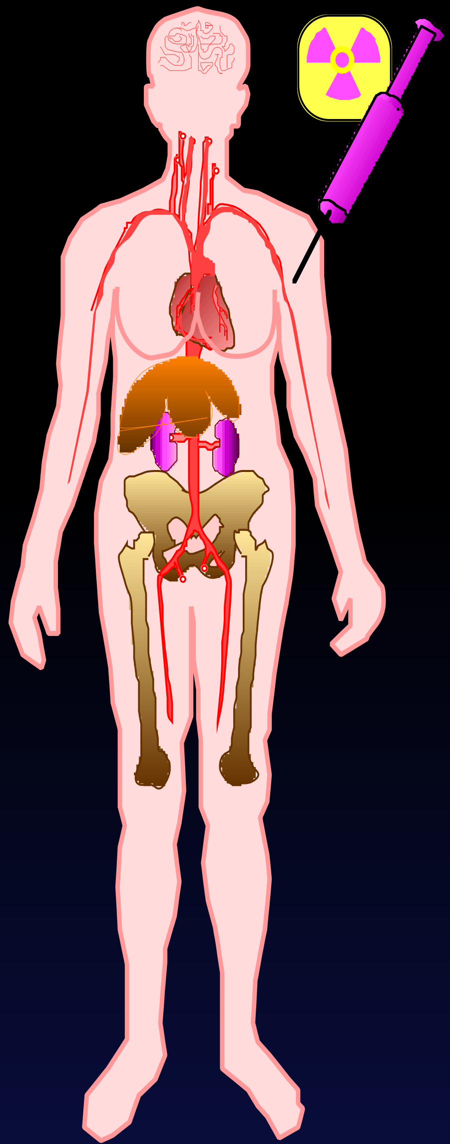
- Positrons are used daily in oncology
- PET = Positron Emission Tomography





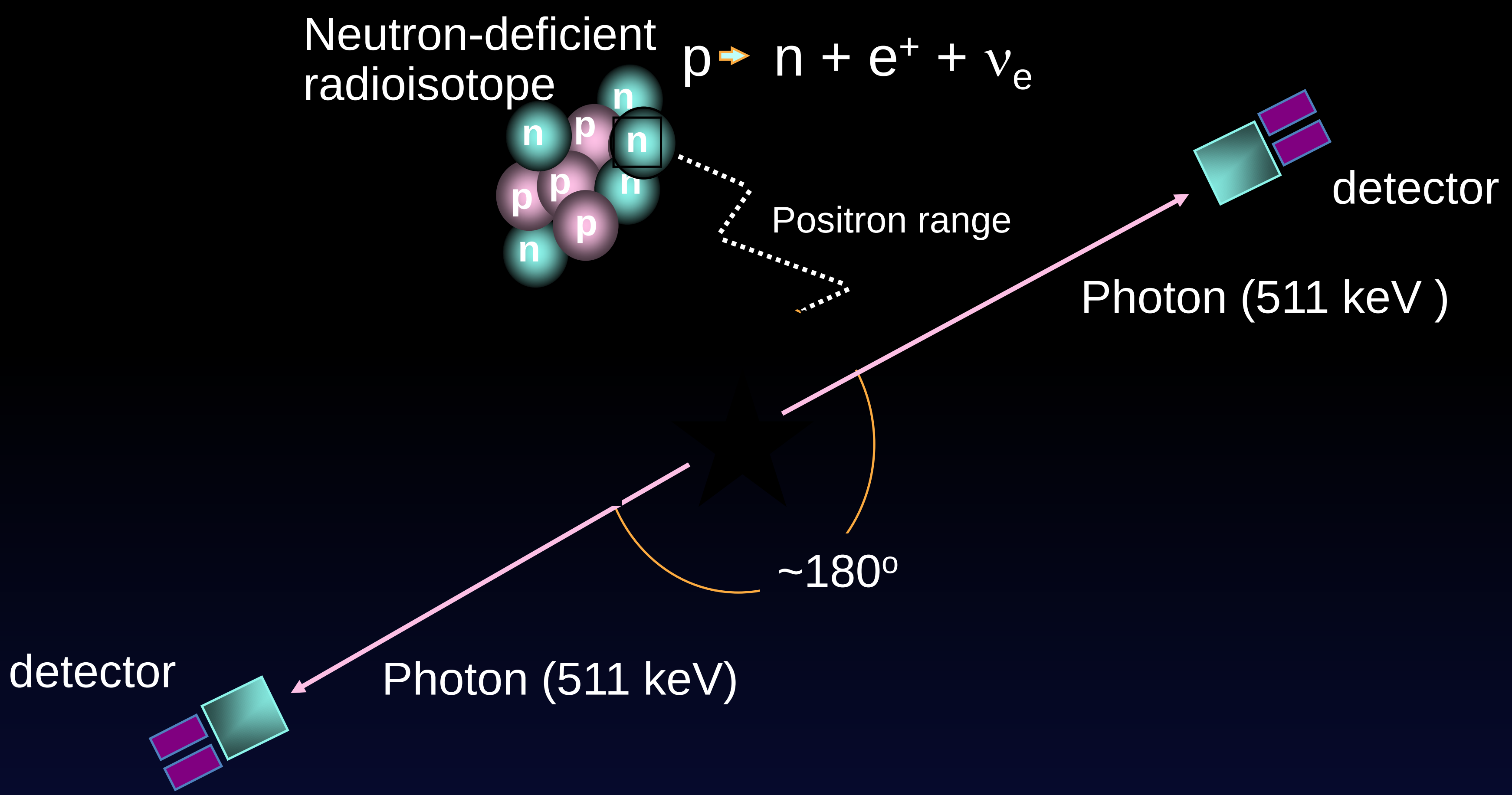


How does it work



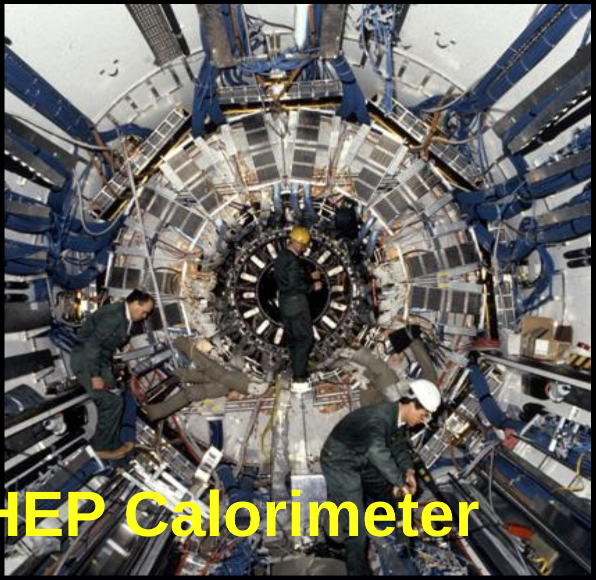
- Drug is labeled with positron (e+) emitting radionuclide.
- Drug localizes in patient according to metabolic properties of that drug.
- Trace (pico-molar) quantities of drug are sufficient.
- Radiation dose fairly small (<1 rem = 0.01 Sv).

PET: detection



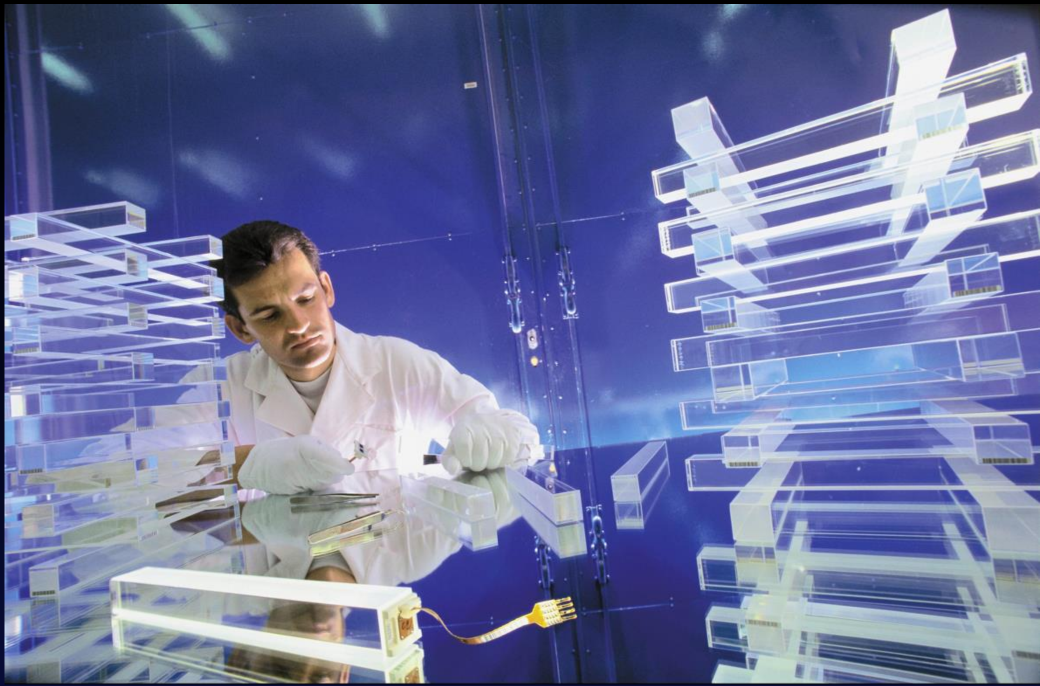
PET vs photon detection in HEP: same challenges

- 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

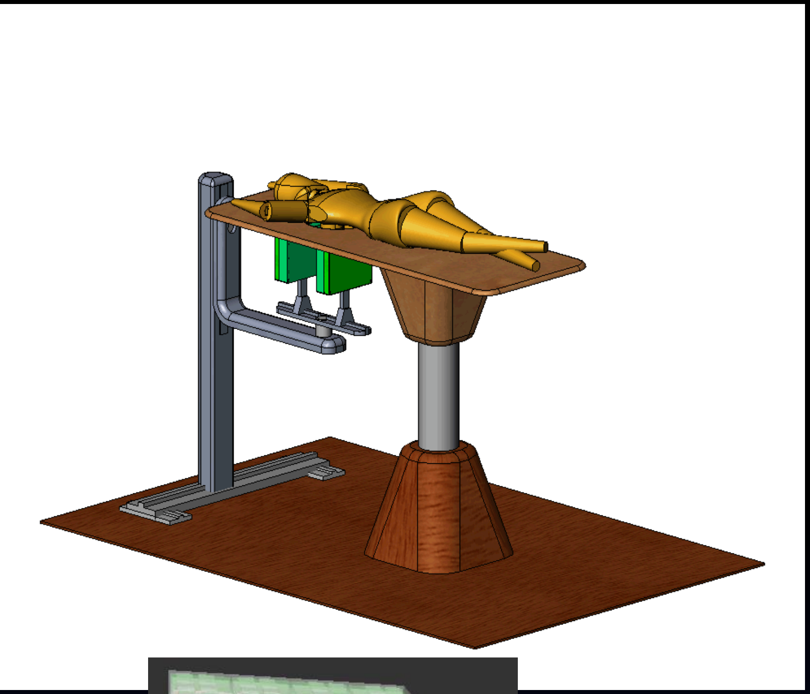


Crystal Clear

- 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



Clear PEM

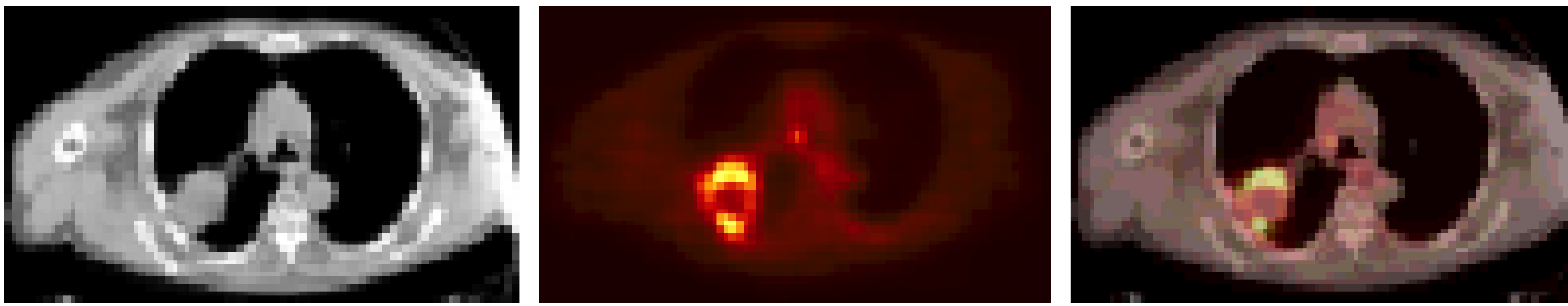


- PET detector dedicated to breast cancer screening
  - Extremely sensitive to small tumour masses
- Spatial resolution1-2 mm
- High counting sensitivity
- Short PET exam
- Coupled to ultrasound

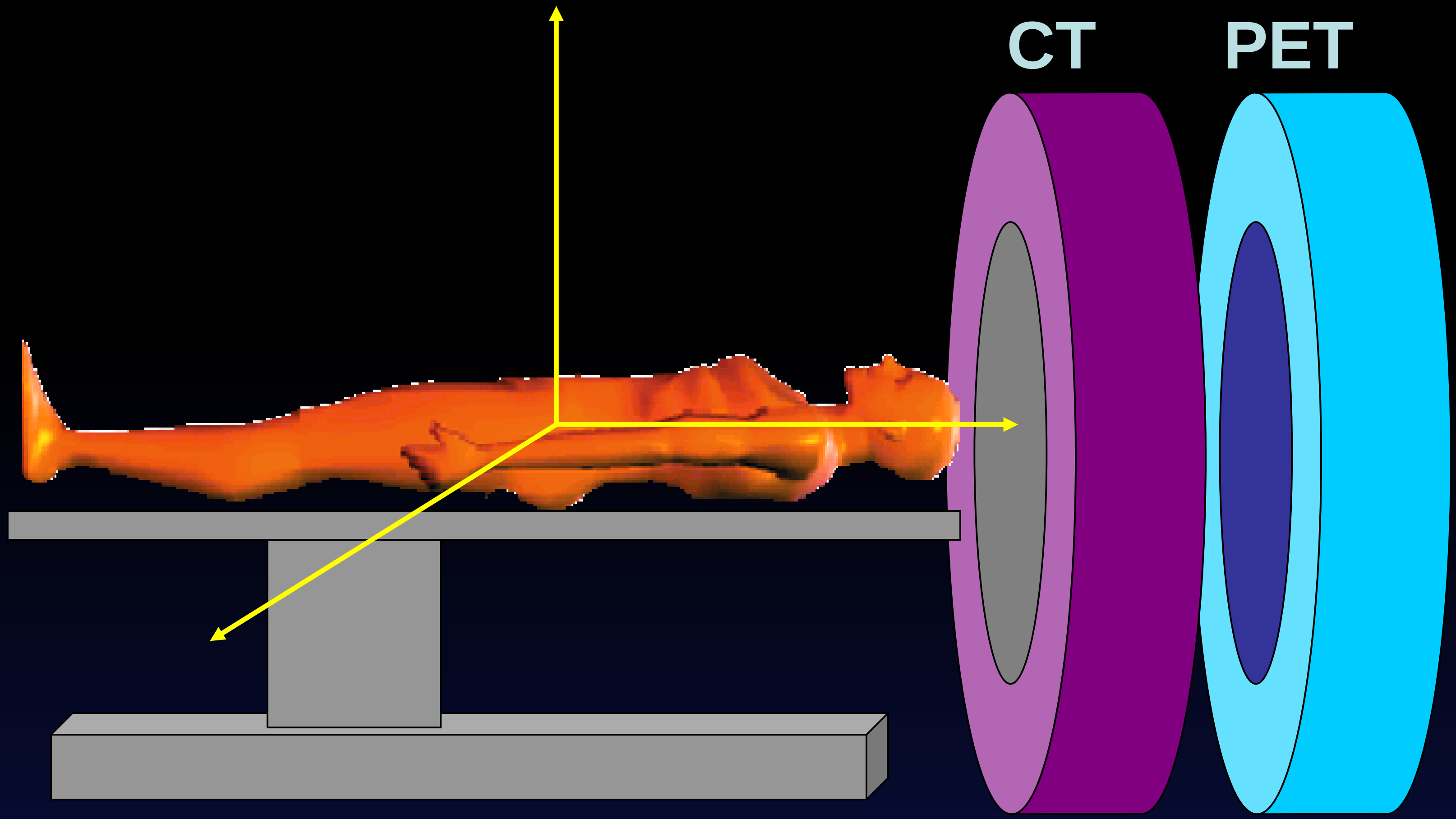
Scanners



Multimodal imaging



PET/CT

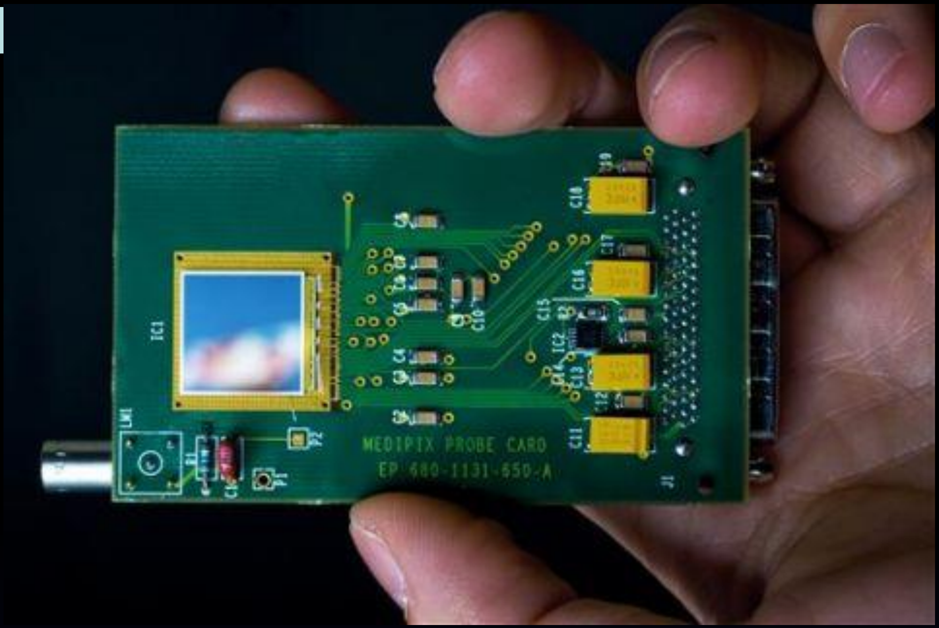


Towards digital imaging

- Today
  - Limited contrast
  - High dose
- Consequences
  - restricted screening
  - limited access to preventive healthcare
- Digital
  - high contrast
  - low dose
- Consequences
  - screening opportunities
  - access to preventive healthcare

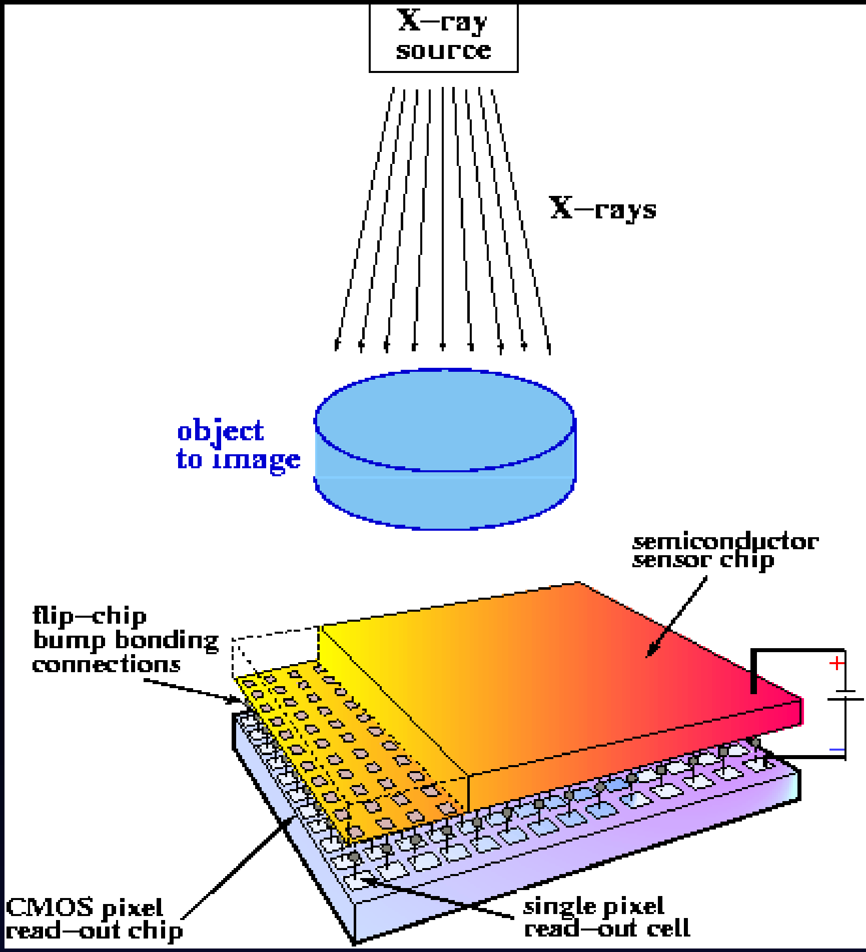
MEDIPIX

- 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

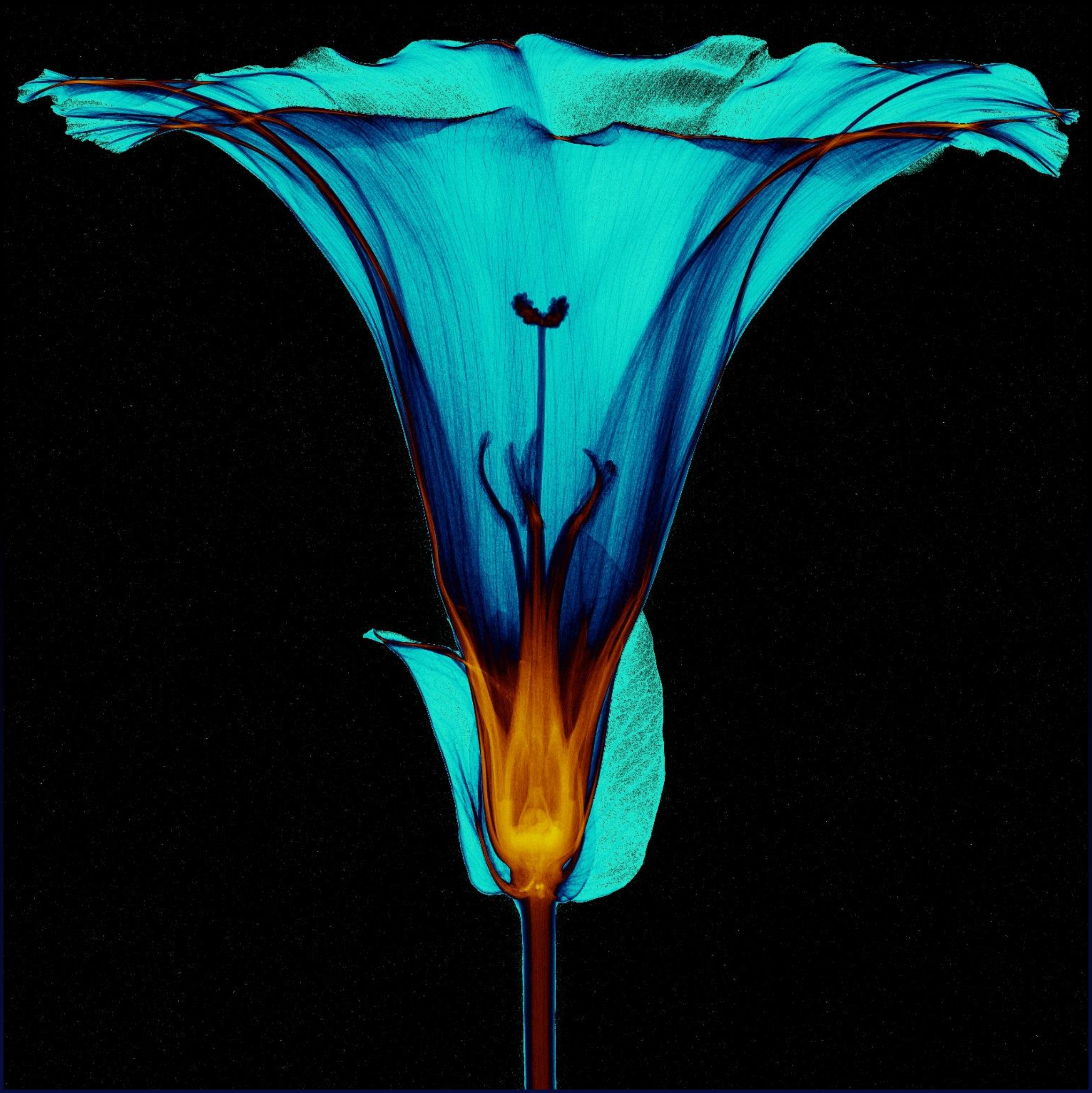


What is Medipix

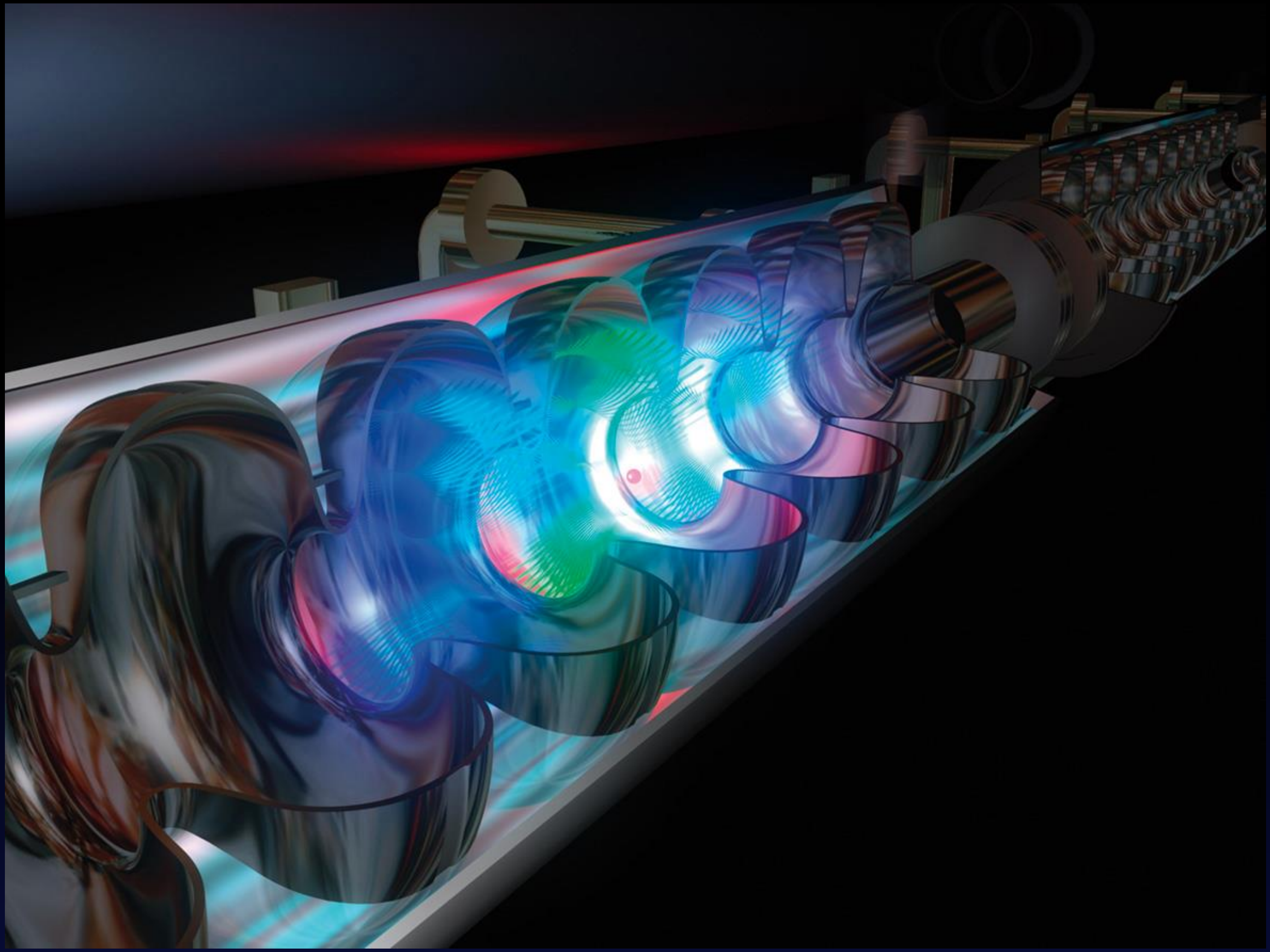
- an electronic chip similar to the electronic imaging chip in a digital camera
  - sensitive to xrays instead of visible light.
- it can create the first true colour images with x-rays.
  - it permits us to move from black and white x-ray images to full colour x-ray images.
- can be read out very rapidly.
  - allows the use of the chip for colour x-ray digital movies or for fast colour x-ray CT scans



Beautiful resolution



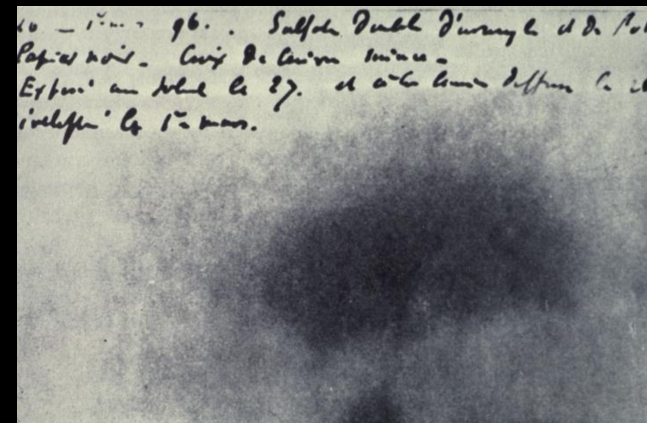
Accelerators for cancer treatment



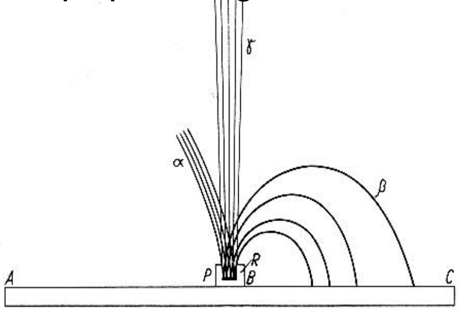
Birth of medical physics

Henri Becquerel

- 1896: discovery of natural radioactivity



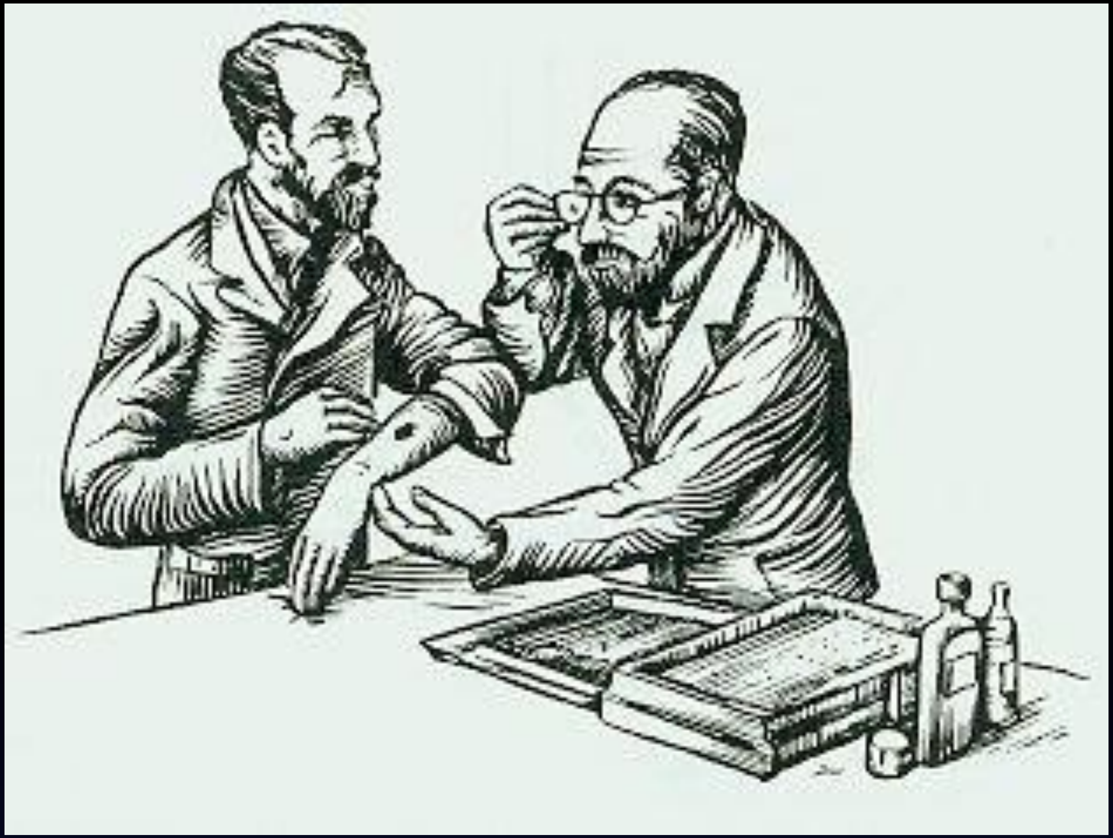
Mme. Curie thesis – 1904
α, β, γ in magnetic field



- 1898: discovery of radium
- Used for “brachitherapy”

Pierre and Marie Curie

Pioneers



- First radiobiology experiment: Pierre Curie

Today: cancer incidence

- Every year millions of new cases globally
- The number of patients needing treatment is increasing in the years to come
- The main cause of death between the ages of 45 and 65 in Europe, Canada and the US
- Second most common cause of death in Europe, Canada, US

Treatment options

Primary tumour

Surgery

Radiotherapy

X-ray, IMRT

Hadron therapy

Metastasis

Other treatments

Hormones; Chemotherapy; Immunotherapy; Cell therapy; Genetic treatments…

Novel specific targets (genetics..)

(?)

Local control

Survival
Quality of life

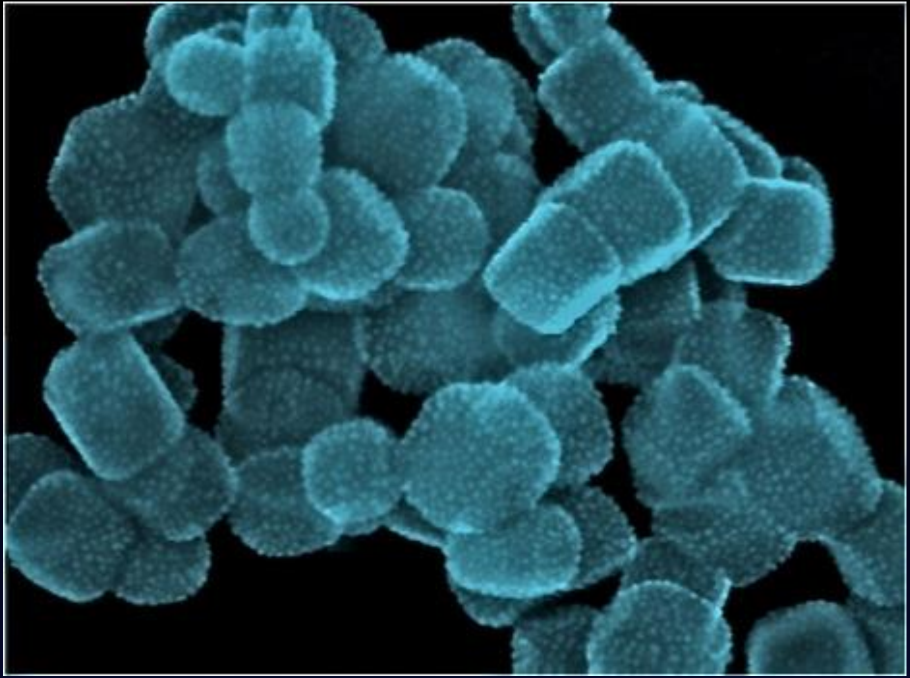
The 3 Cs of radiotherapy

- 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

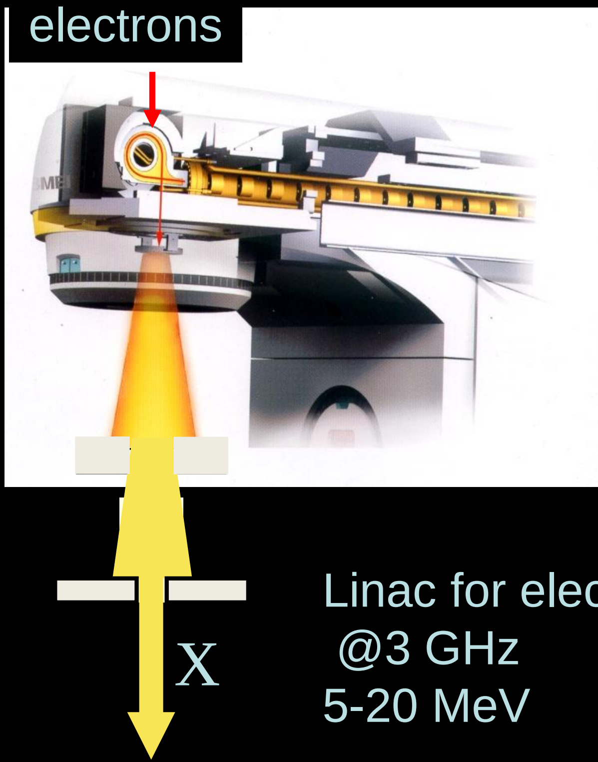
The ideal treatment

eliminate all tumour cells without affecting normal cells

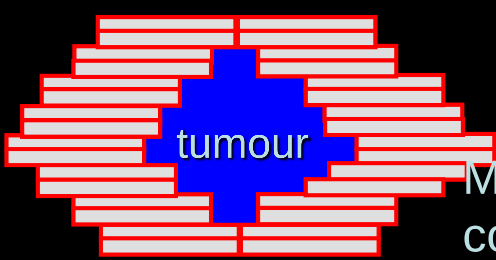
- Physics :
  - 100% of the dose on target
  - 0% of the dose in surrounding healthy tissues or critical organs
- Biology :
  - differential effect
  - kill 100% of cancer cells
  - "protect" normal cells



Conventional radiotherapy: dominated by linear accelerators



Linac for electrons
@3 GHz
5-20 MeV



Multileaf collimator

Courtesy of Elekta

20 000 patients per year every 10 million inhabitants

1 linac every <250,000 inhabitants

Conventional radiotherapy

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

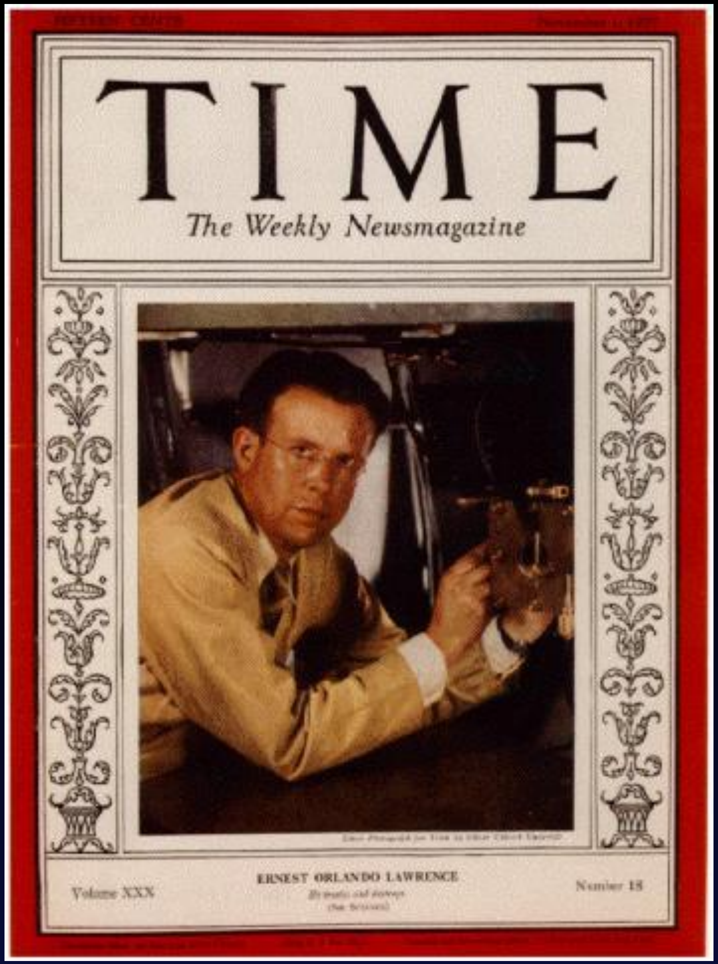
30% of patients still fail locally after RT

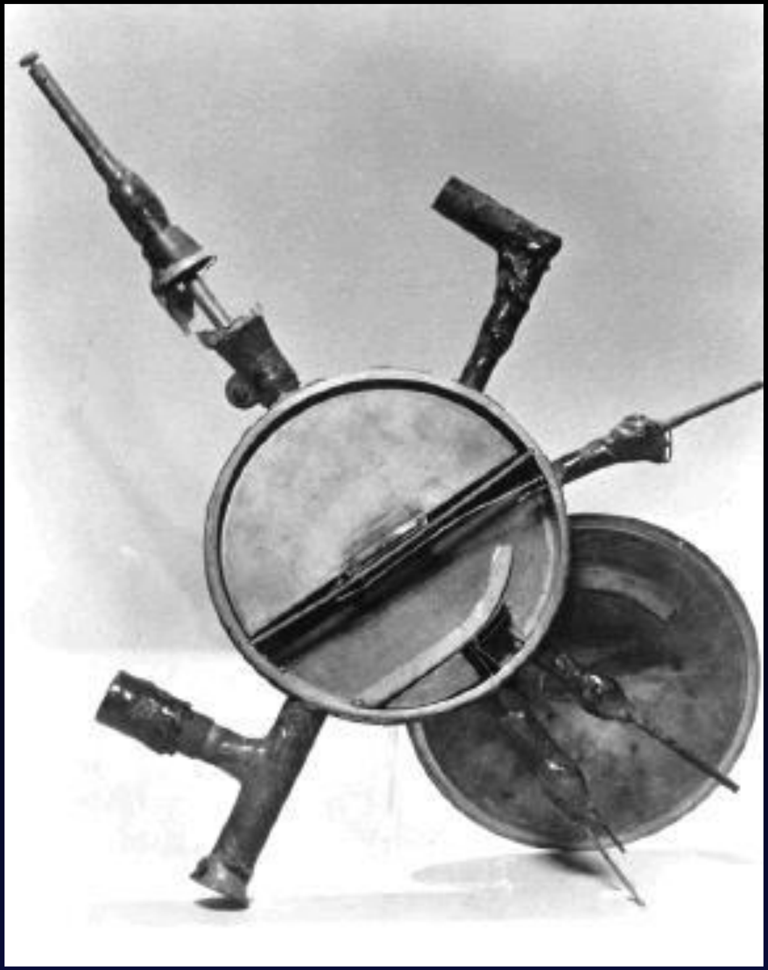
Alternatives

- 1946: article by Robert Wilson
  - Protons can be used clinically
  - Accelerators are available
  - Maximum radiation dose can be deposited into the tumour
  - Healthy tissues are not damaged
- Birth of hadron therapy
- 1954: first patients treated in Berkeley

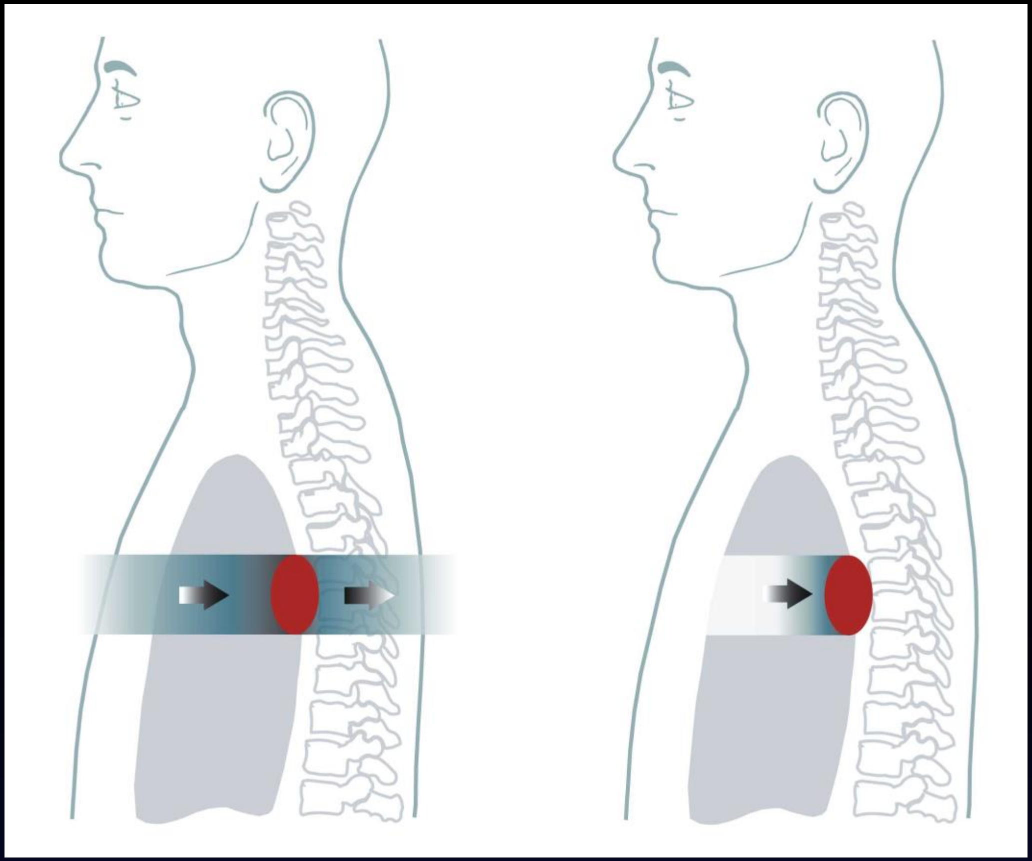
Cyclotron

- E. O. Lawrence, Nobel Prize in 1939





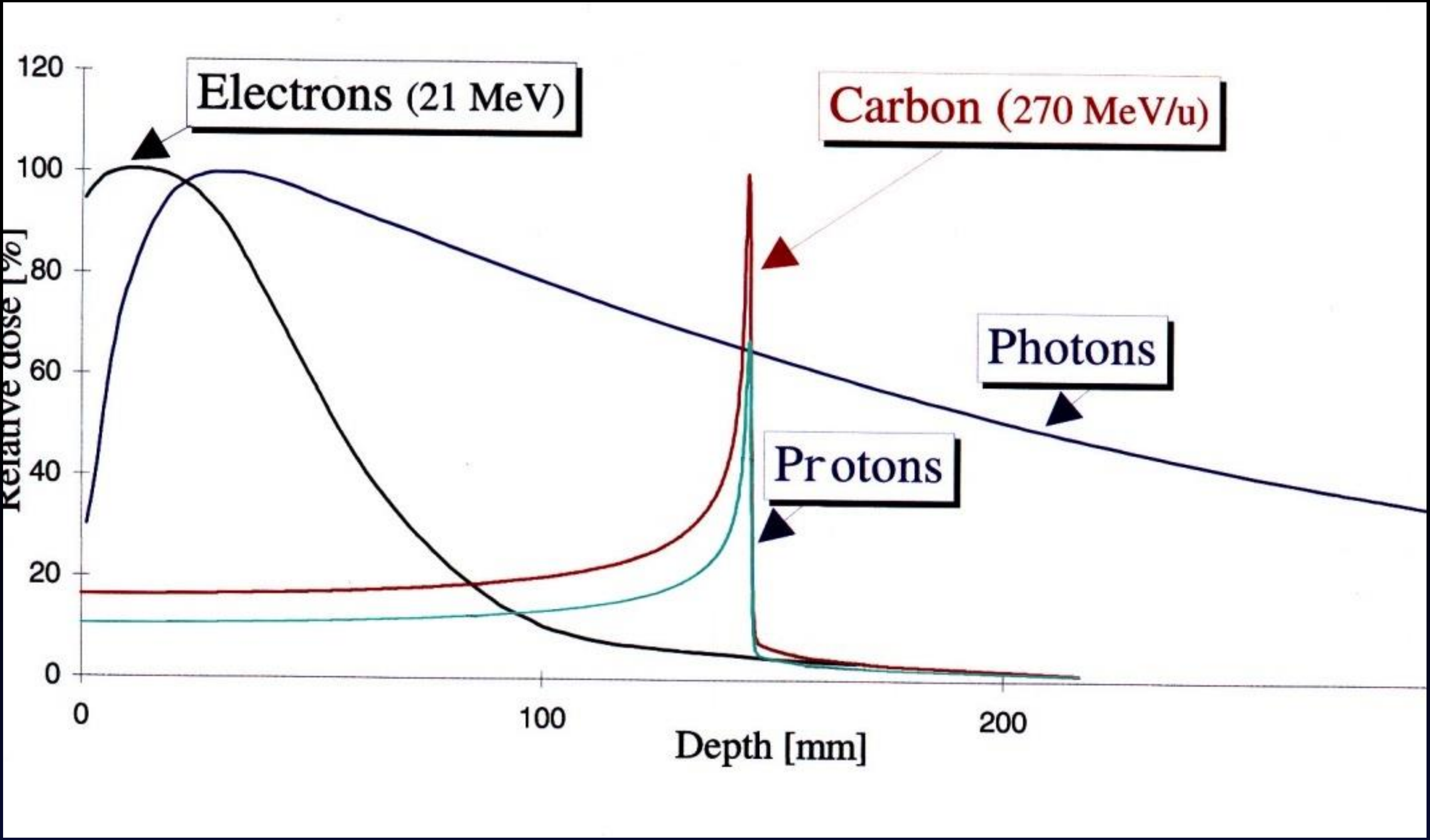
Protons vs X-rays



X rays | Protons

Image courtesy MedAustron

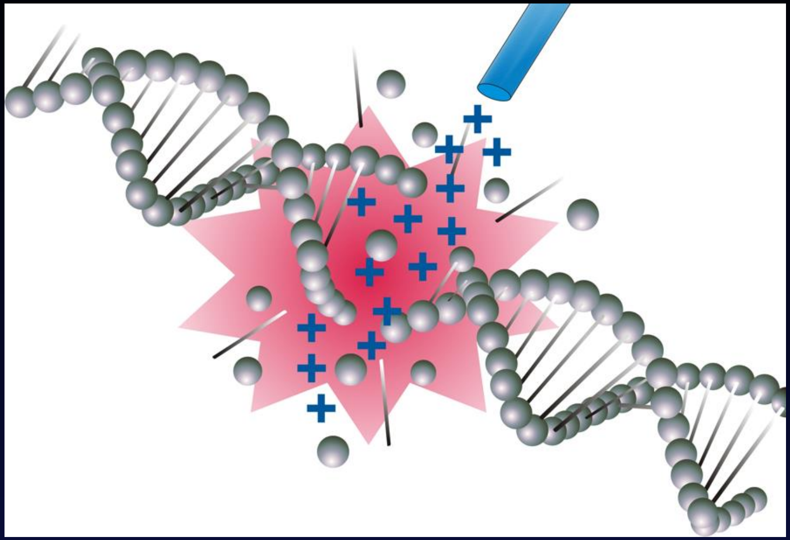
Alternatives: hadron therapy



Hadron therapy vs classical radiotherapy

Photons and electrons

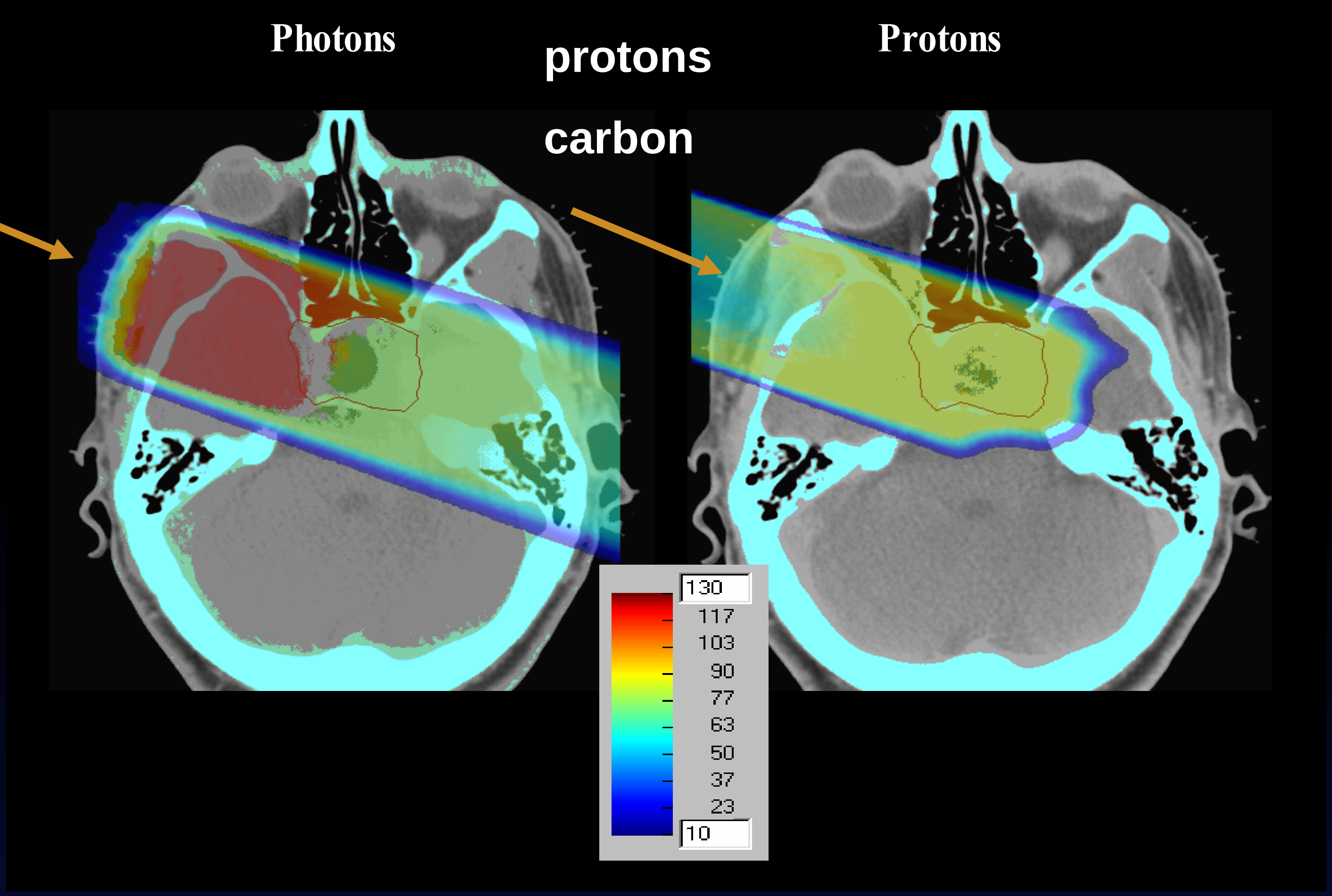
- Physical dose high near surface
- DNA damage easily repaired
- Biological effect lower
- Need presence of oxygen
- Effect not localised



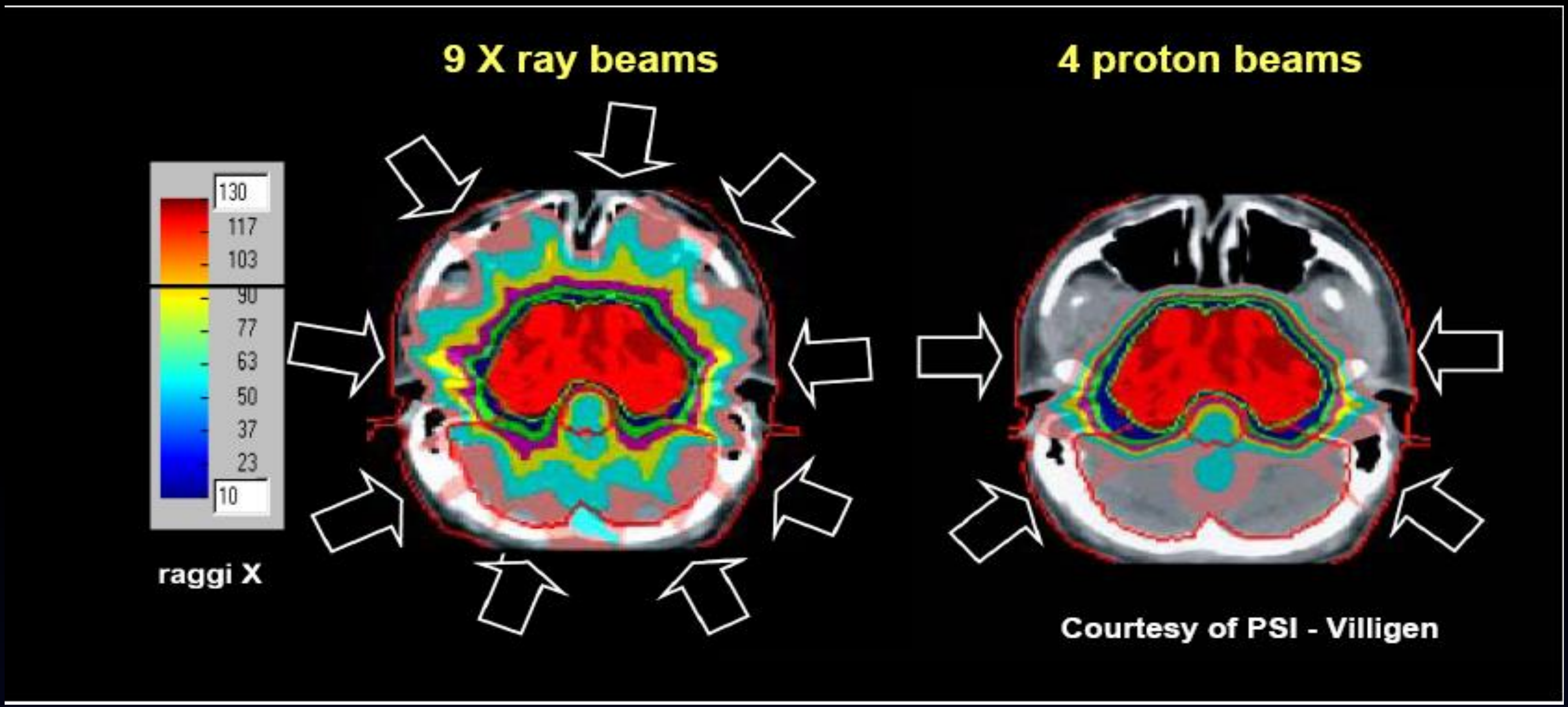
Hadrons

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

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


Photons
protons
carbon
Protons
X-rays
130
117
103
90
77
63
50
37
23
10

Protons are qualitatively different from X-rays

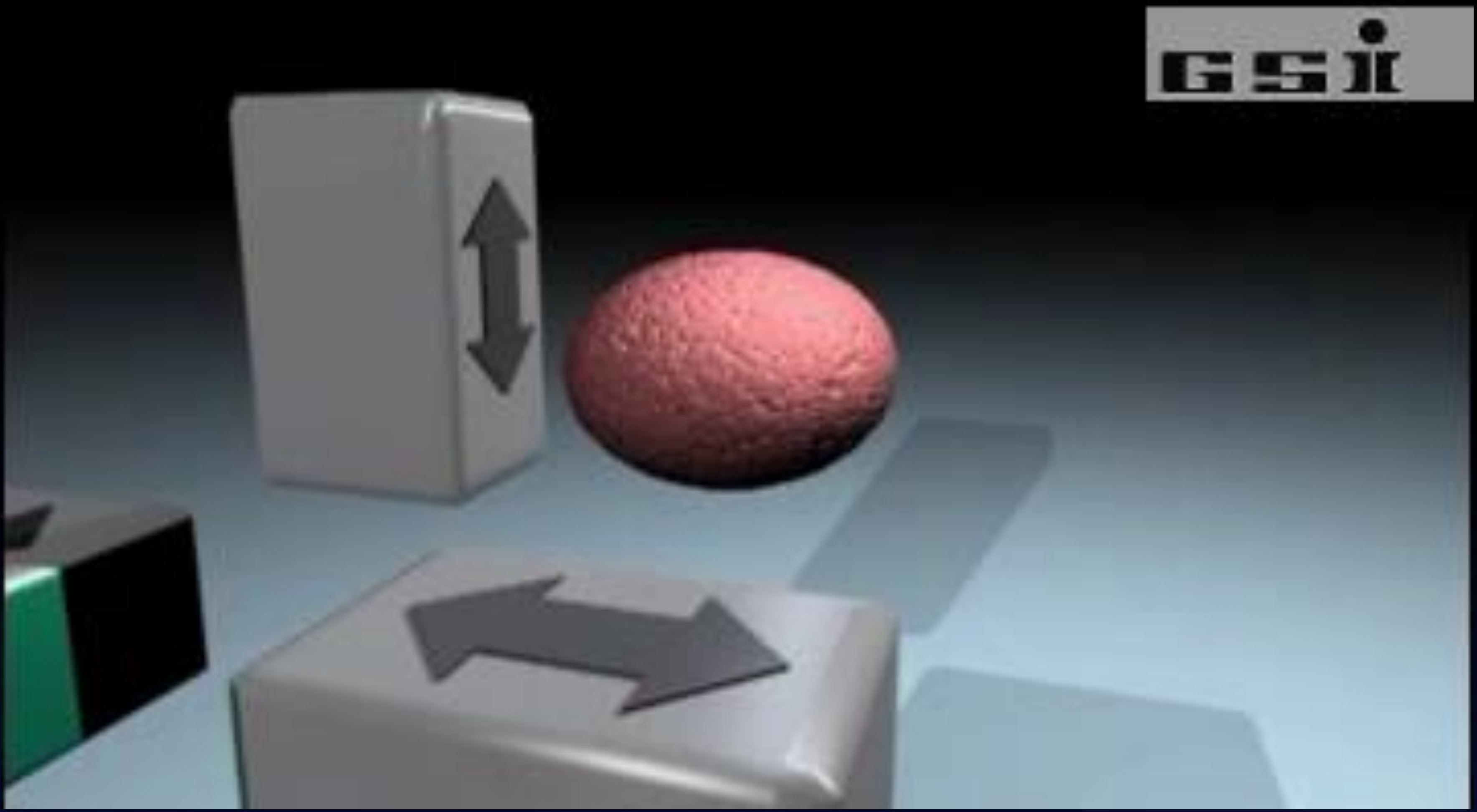


Carbon ions deposit in a cell 20 times more energy than a proton

producing not reparable <u>multiple close-by double strand breaks</u>

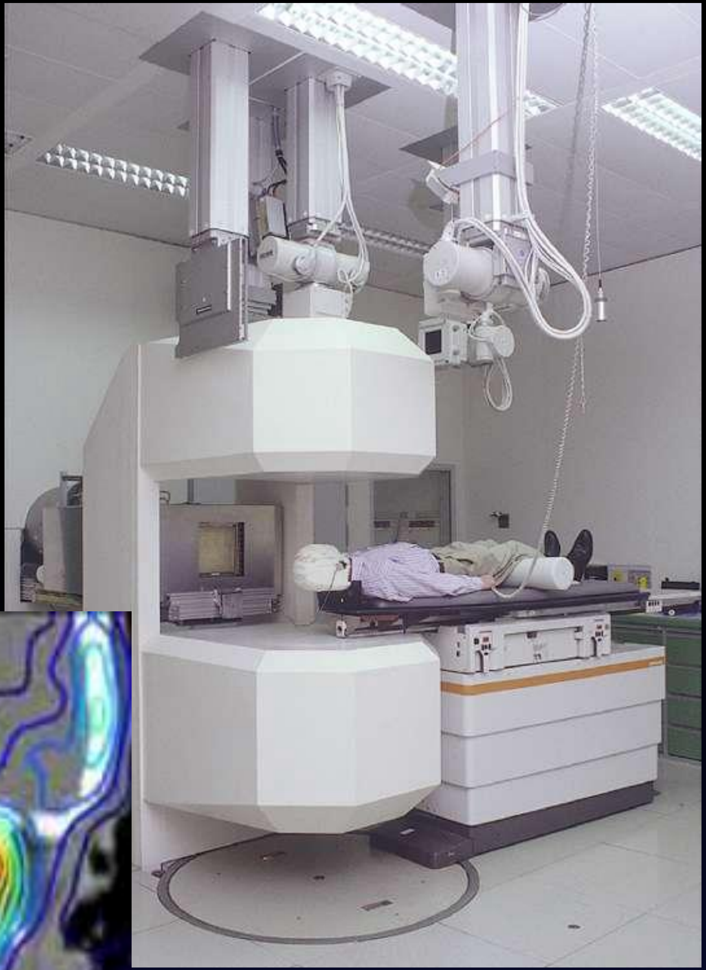
Carbon ions can control radio-resistant tumours

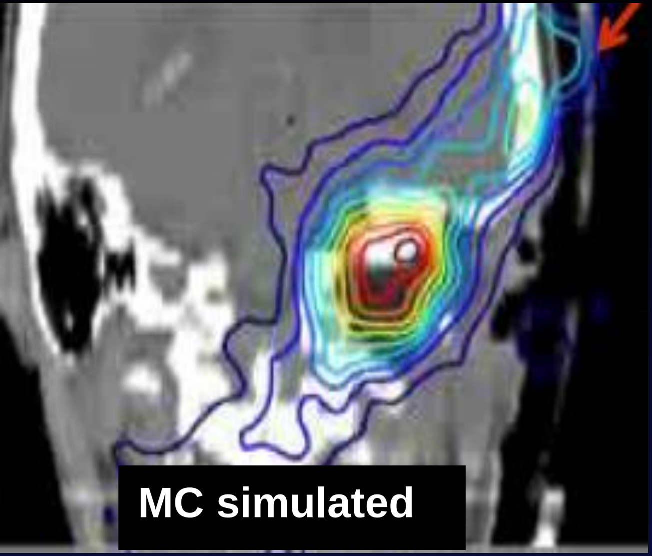
Raster scanning

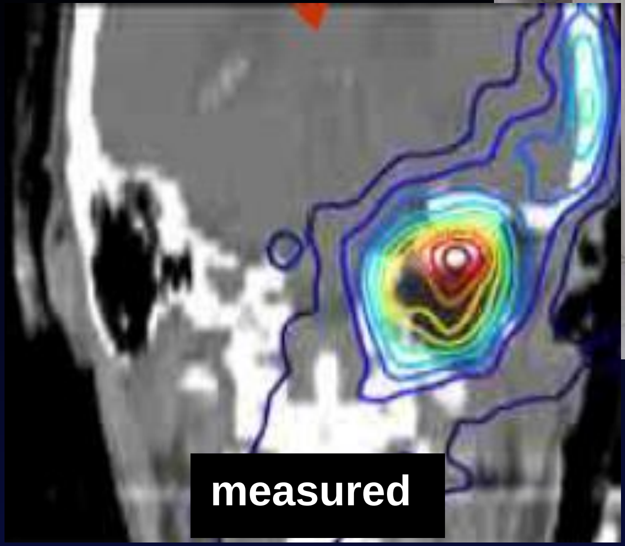


Real-time monitoring

- In-beam PET @ GSI (Germany)
- MonteCarlo simulations
- Prompt photons detection
- Time-of-flight
- Organ motion

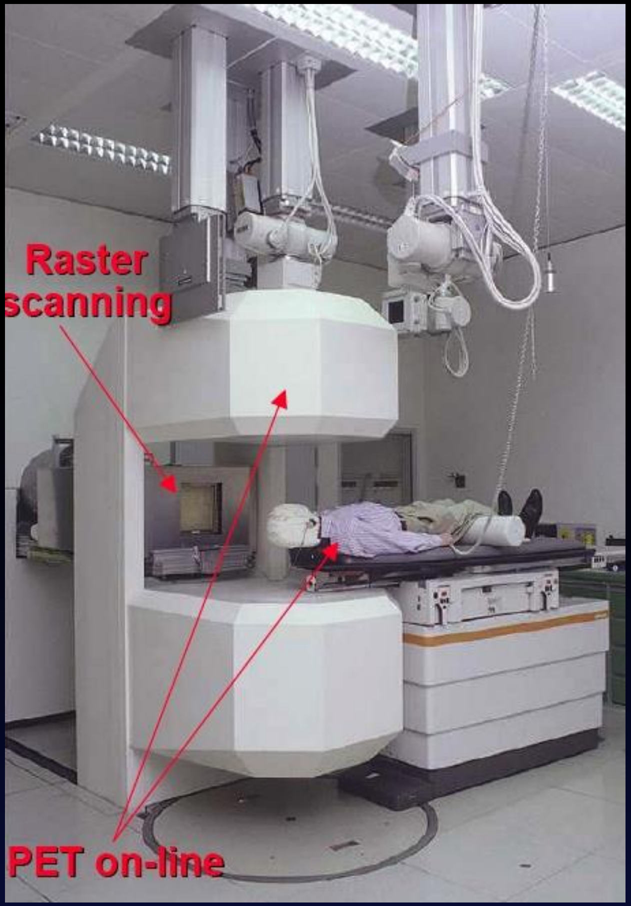




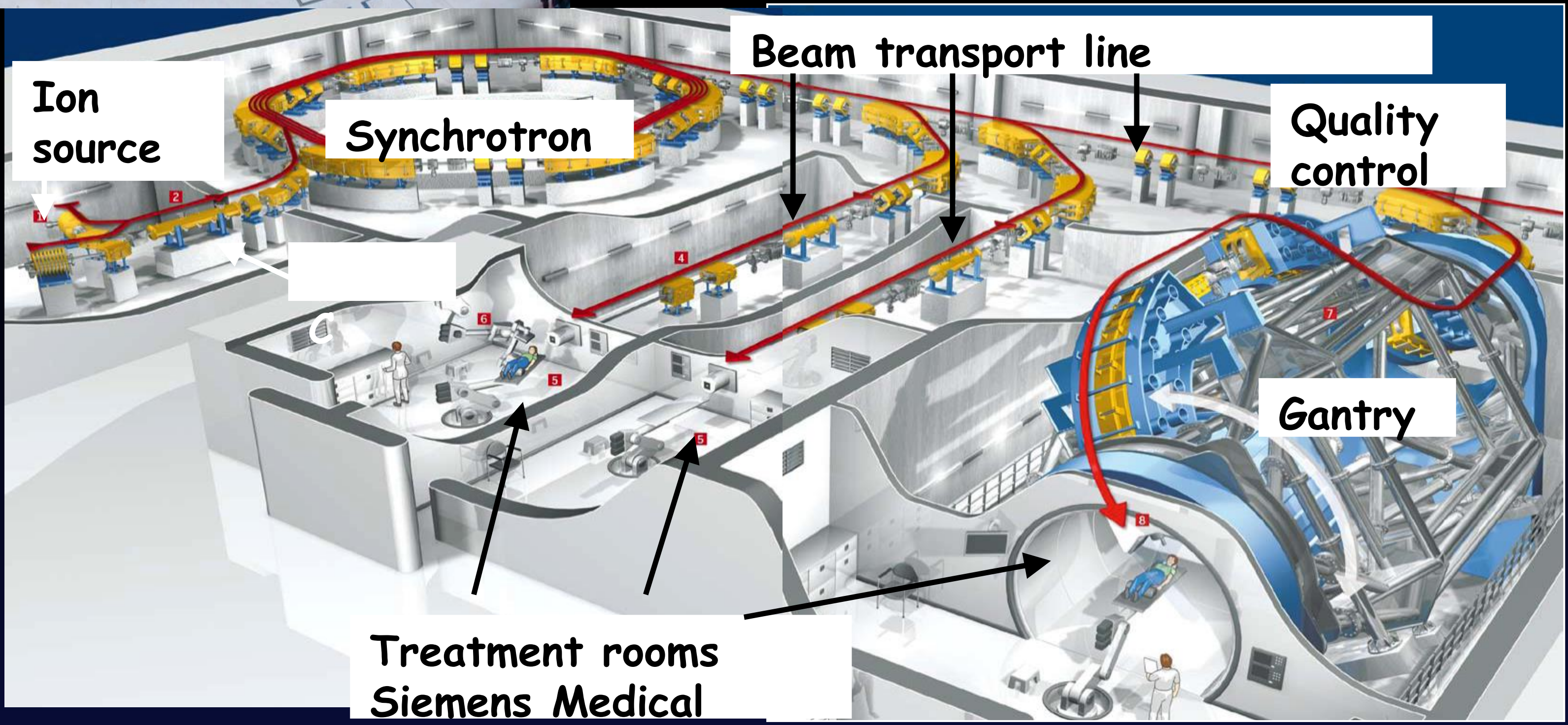


Carbon ions: pilot project in Europe

- GSI – Darmstadt (1997 – 2008)
- G. Kraft (GSI) & J. Debus (Heidelberg)
  - 450 patients treated with carbon ions

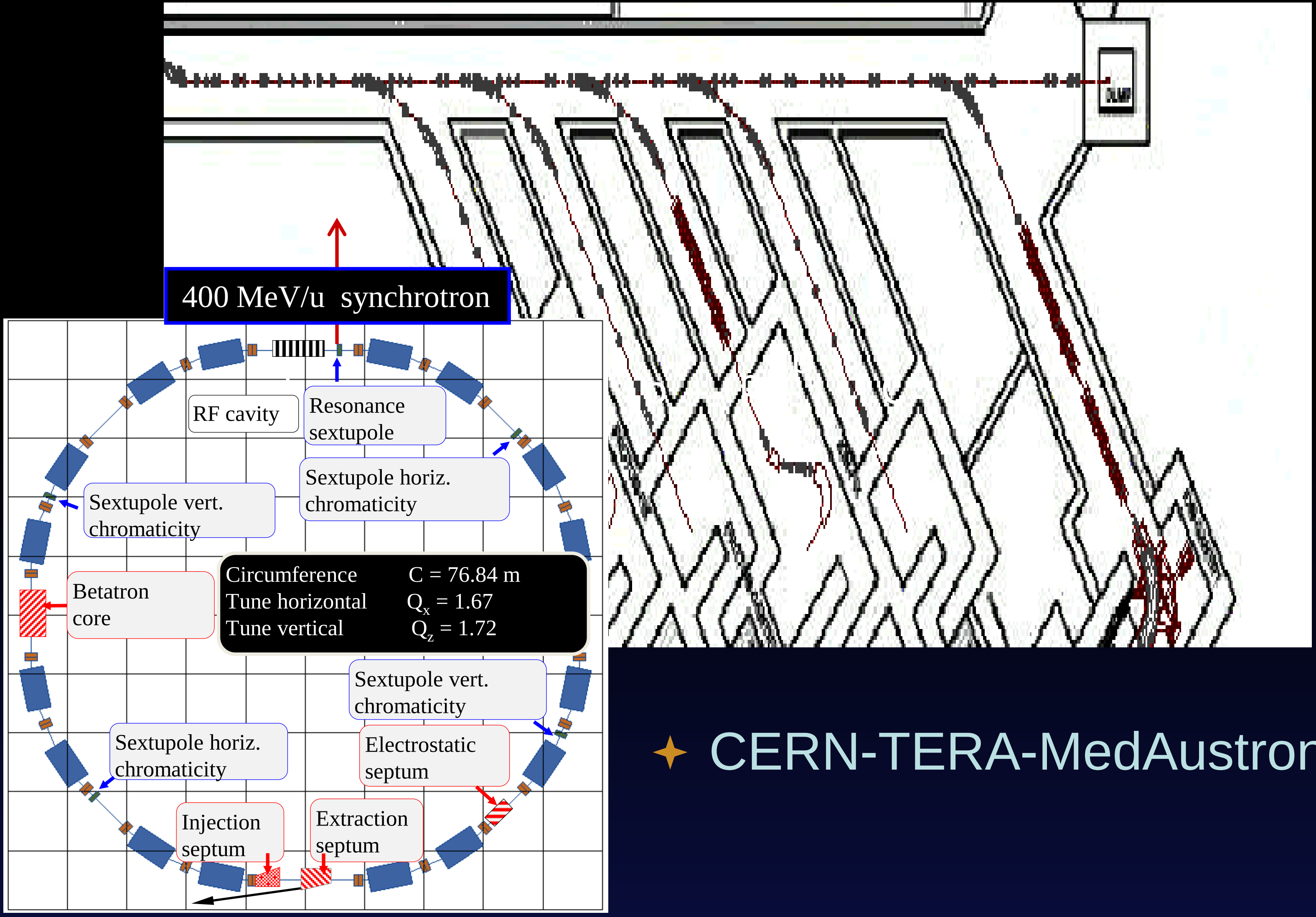


HIT - Heidelberg



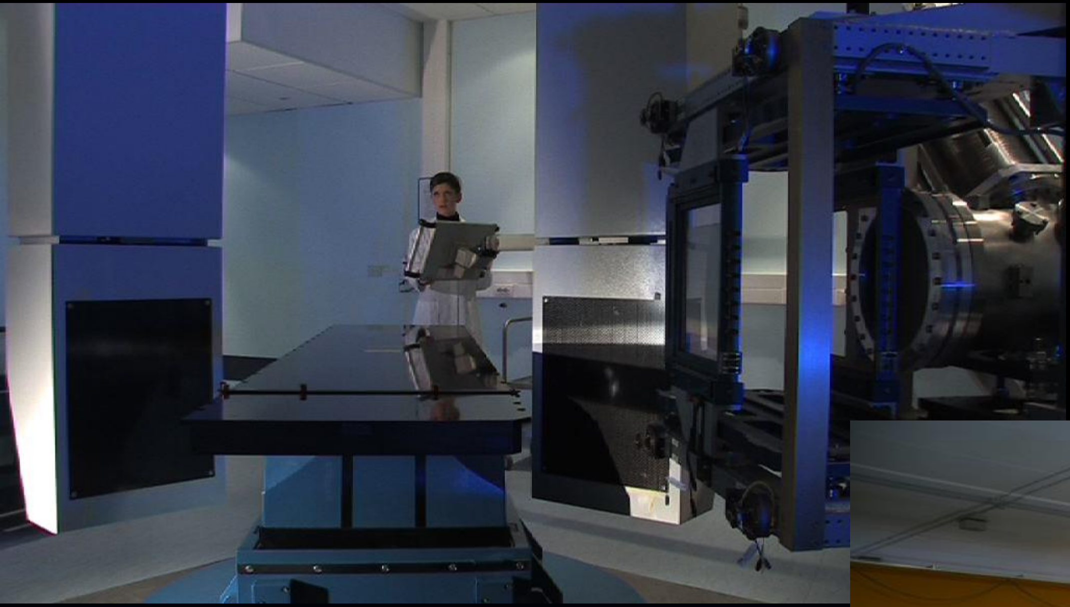
PIMMS at CERN (1996-2000)

- Proton Ion Medical Machine Study



- CERN-TERA-MedAustron

CNAO – Italia (Pavia)



E-health
Computing grids

www and grid

- WWW: sharing information
- GRID: sharing computing power

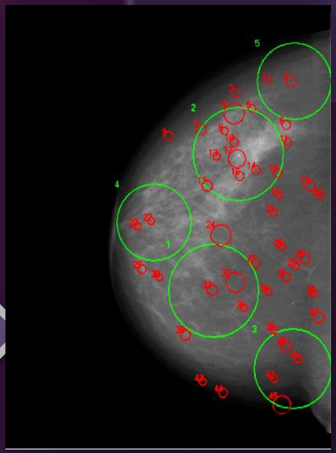
LHC: the data challenge

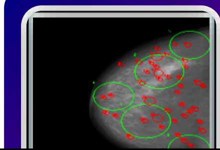
- 40 M collisions per second
- After several selections, we record 100 collisions per second
- 10^{10} collision events per year
- ~10 Petabytes/year of data
- ~10 000 the world books' production
- ~20 Km CD stack!

Mammogrid

A grid mammography database

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



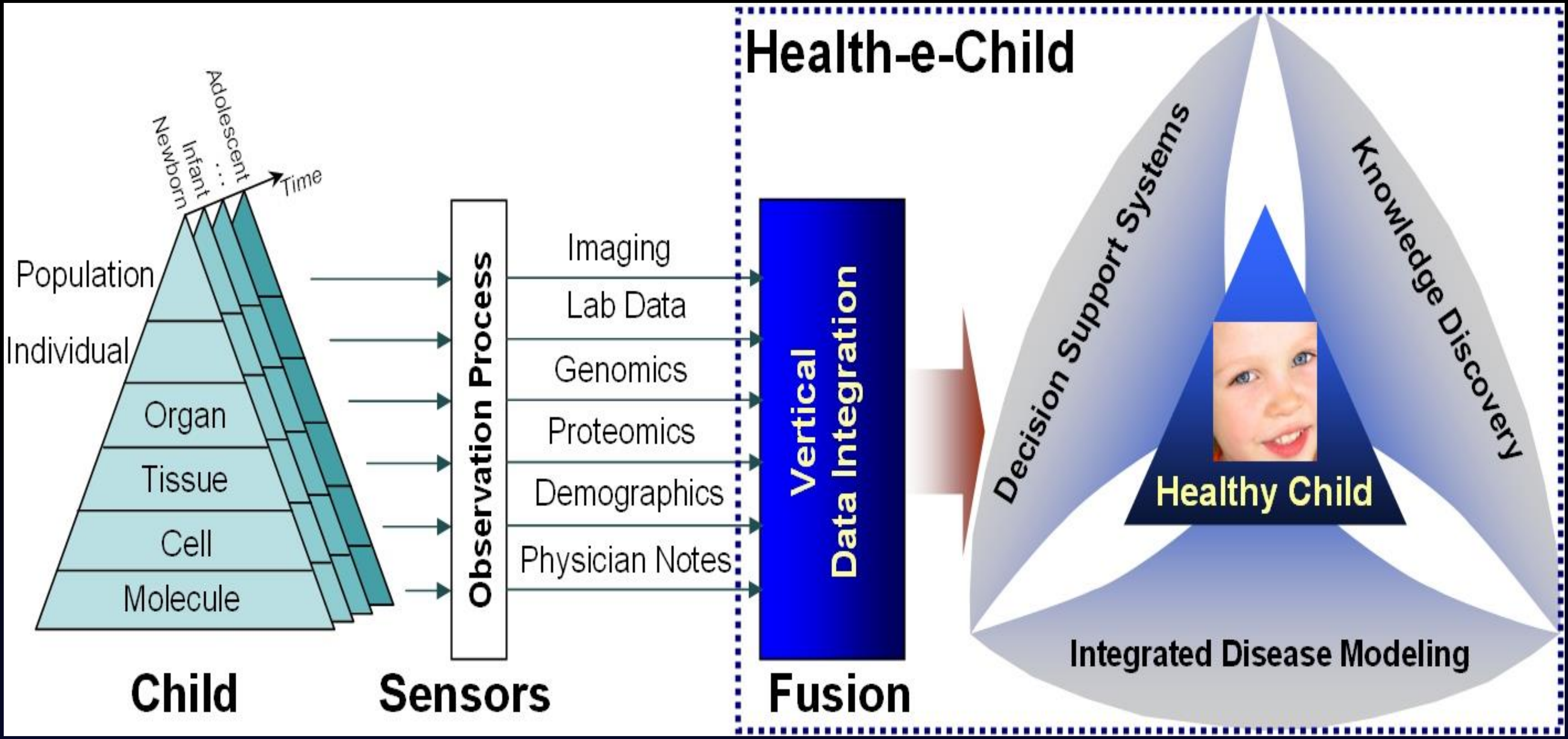


Oncology

- Breast Cancer (micro-calcifications and

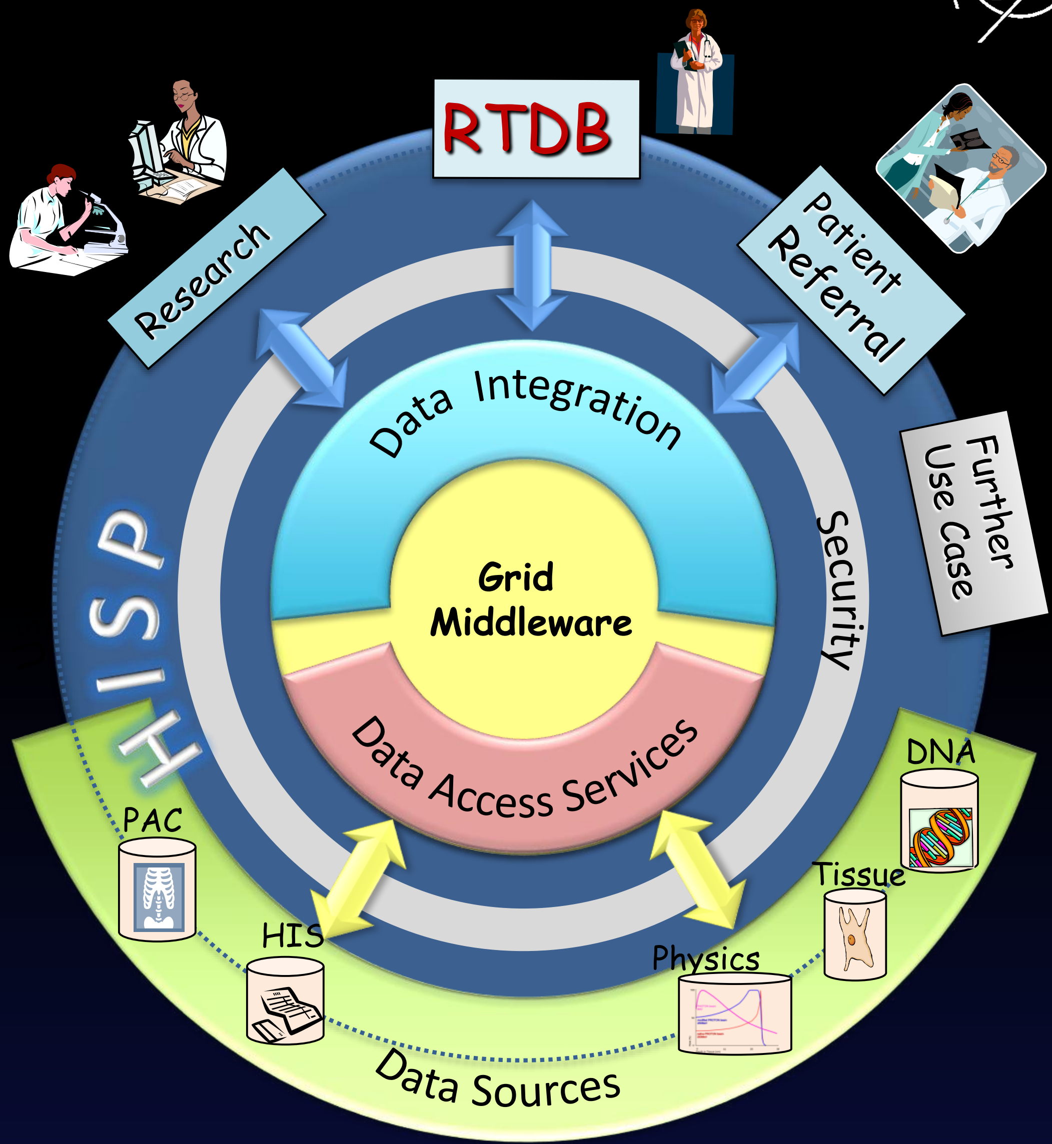
From: **David MANSET,** CEO MAAT France, www.maat-g.com

Health e-child

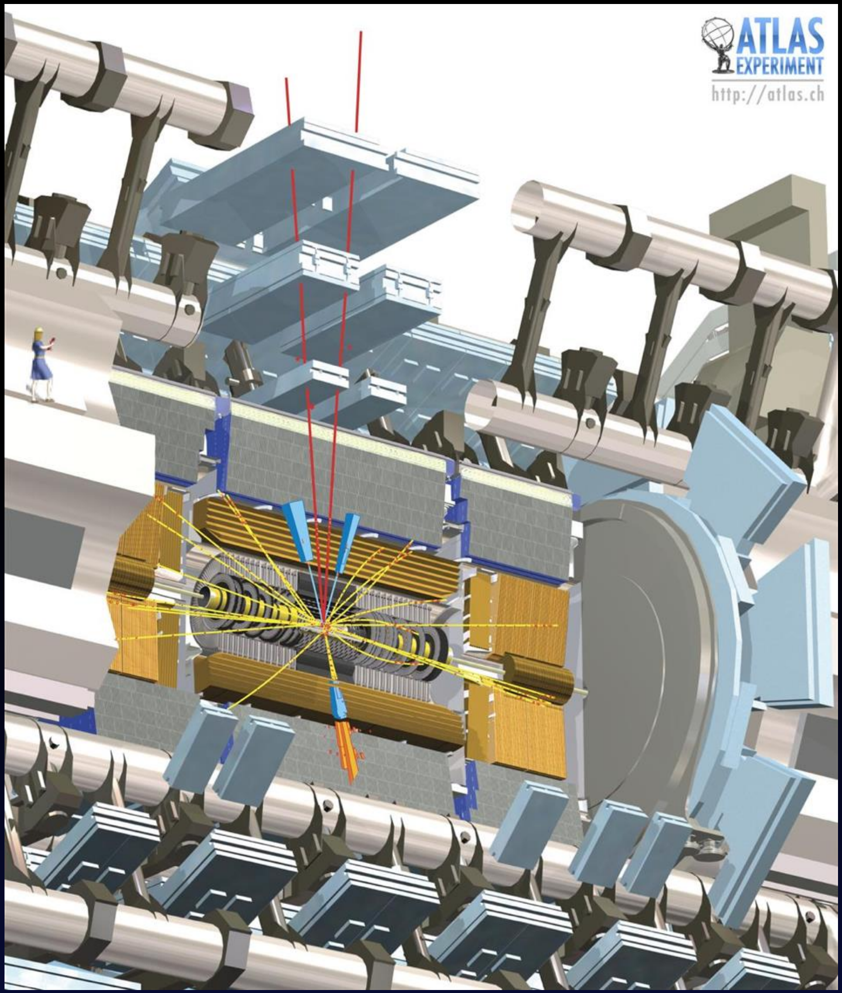


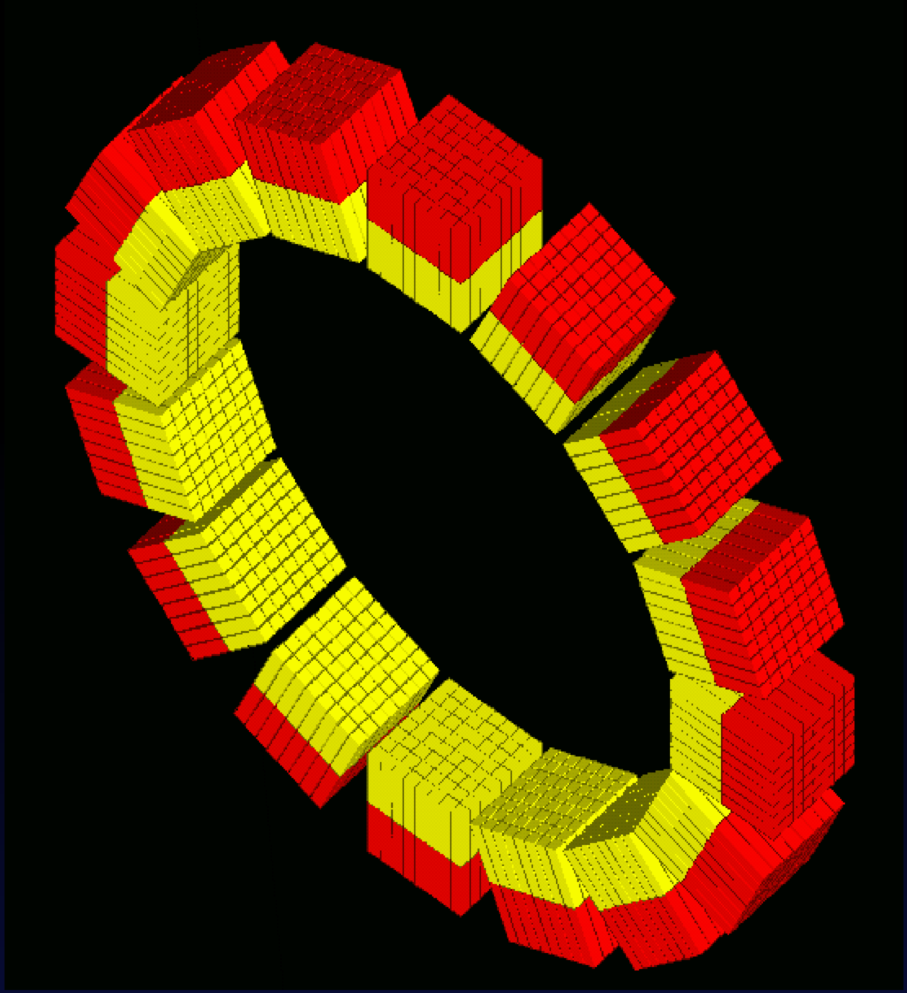
Hadrontherapy Information Sharing Platform (HISP)

- Connect:
  - Users
  - Data sources
- by
  - Grid core
  - Security
  - Integration
  - Portals
  - Interfaces



Simulation



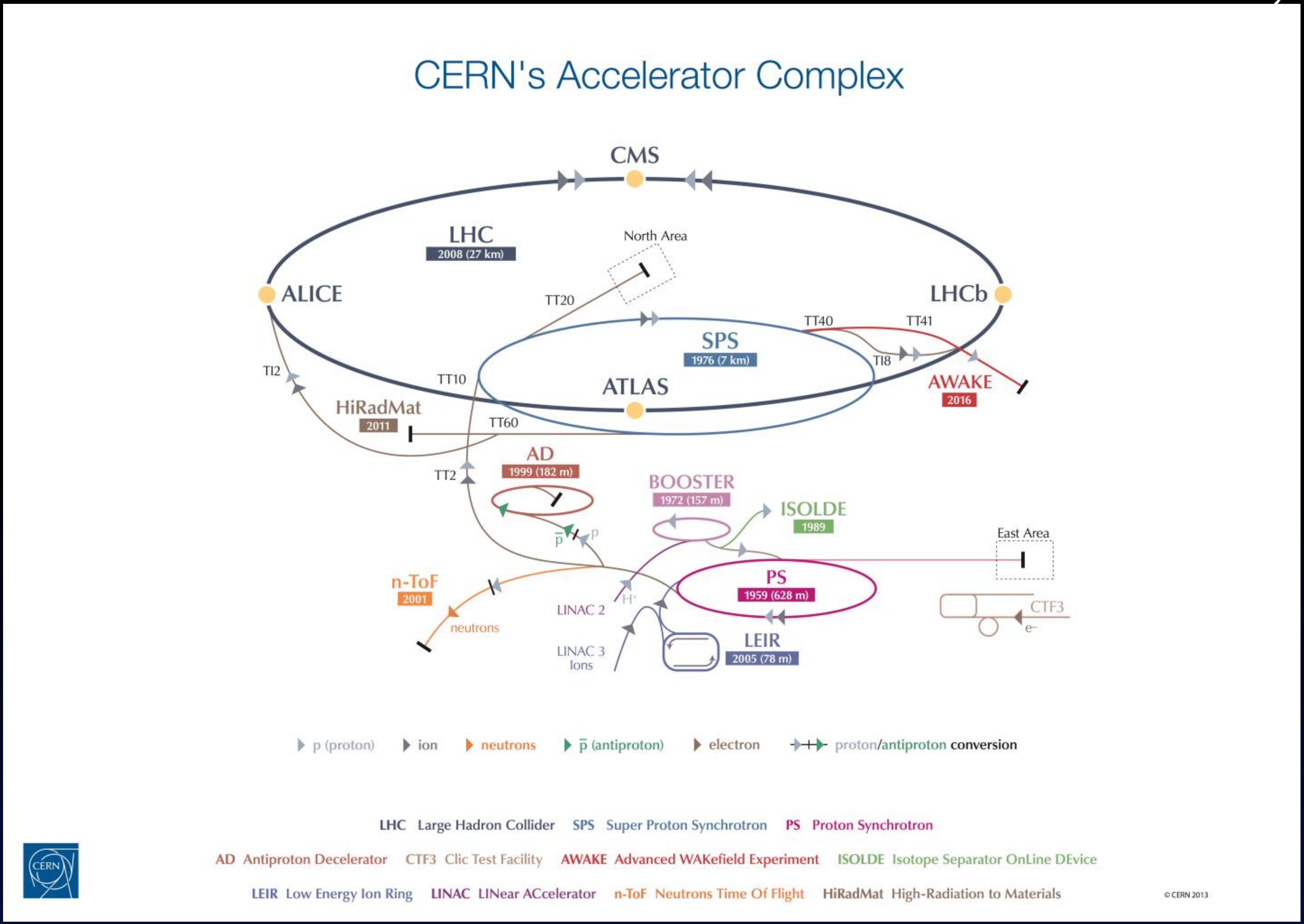


Put everything together

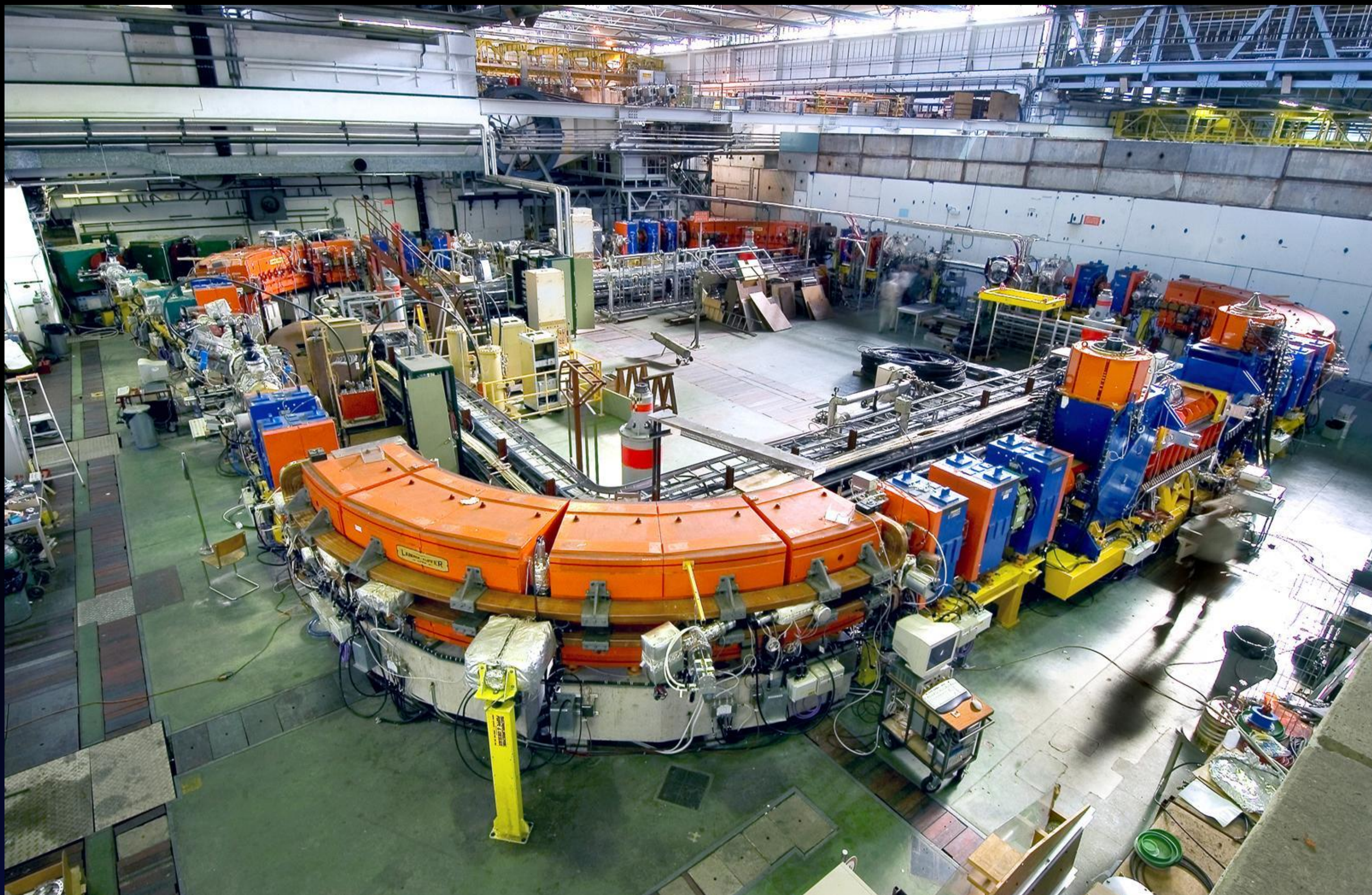
What can CERN do for medical applications

- Provider of Know-how and Technologies
  - Design studies for Hadron Therapy facilities
  - Scintillating crystals for PET scanners
  - Fast detector readout electronics for counting mode CT
  - Grid middleware for Mammogrid, Health-e-Child
- Training centre
  - Coordinator of large multidisciplinary EC-ITN funded programmes, e.g. Particle Training Network for European Radiotherapy (PARTNER), ENTERVISION, EndoTOFPET-US…
- Driving force for collaboration
  - Coordinator of the European Network for Light Ion Hadron Therapy (ENLIGHT) Platform

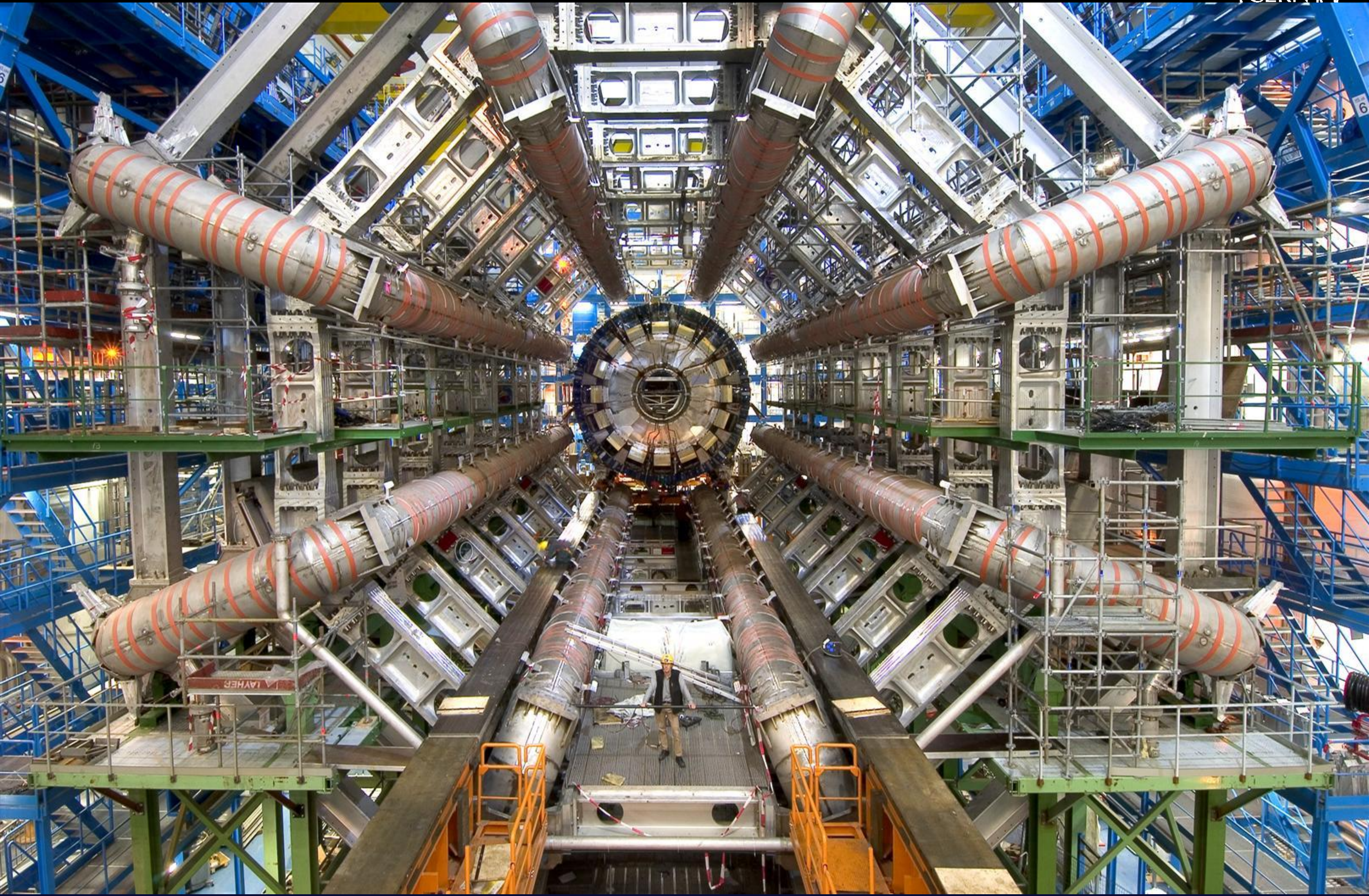
A biomedical facility at CERN



A biomedical facility at CERN



Collisions and collaborations



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- www.fluka.org/fluka.php
- cern.ch/wwwasd/geant
- cern.ch/wwwasd/geant/tutorial/tutstart.html