Medical Applications from Particle Physics

Teachers Programme

Tbilisi, October 2011

CERN was founded 1954: 12 European States

"Science for Peace"

Today: 20 Member States

20 Member States: Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom

1 Candidate for Accession: Romania

5 Applicant States: Cyprus, Israel, Serbia, Slovenia, Turkey

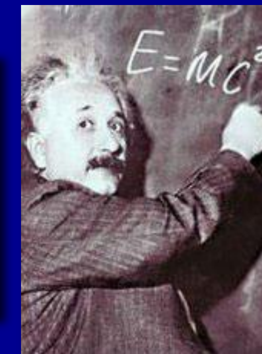
8 Observers to Council: India, Israel, Japan, the Russian Federation, the United States of America, Turkey, the European Commission and UNESCO

Innovation
Education
CERN
uniting people
Research

The Mission of CERN

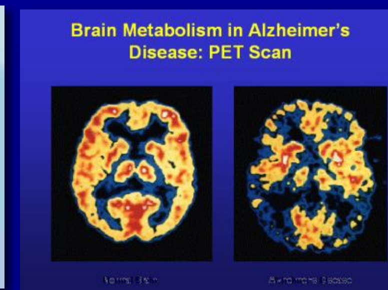
- Push forward the frontiers of knowledge

  E.g. the secrets of the Big Bang … the matter like within the first moments of th… existence?



Innovation
Education
CERN
uniting people
Research

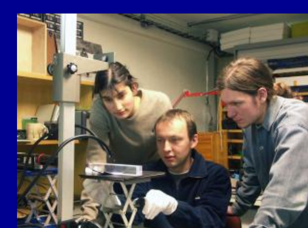
- Develop new tech… accelerators an…



  Information technology - the Web and the GRID

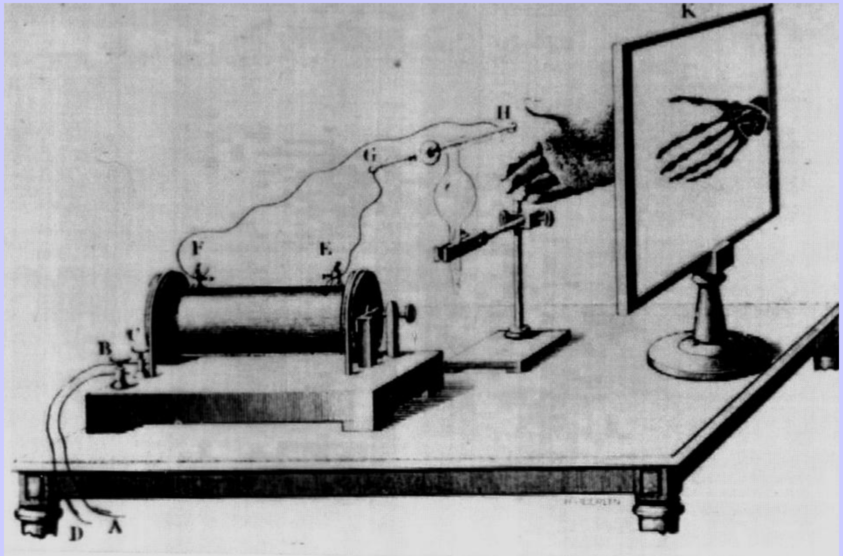
  Medicine - diagnosis and therapy

- Train scientists and engineers of tomorrow



- Unite people from different countries and cultures

The beginnings…………….....



1895
discovery of X rays

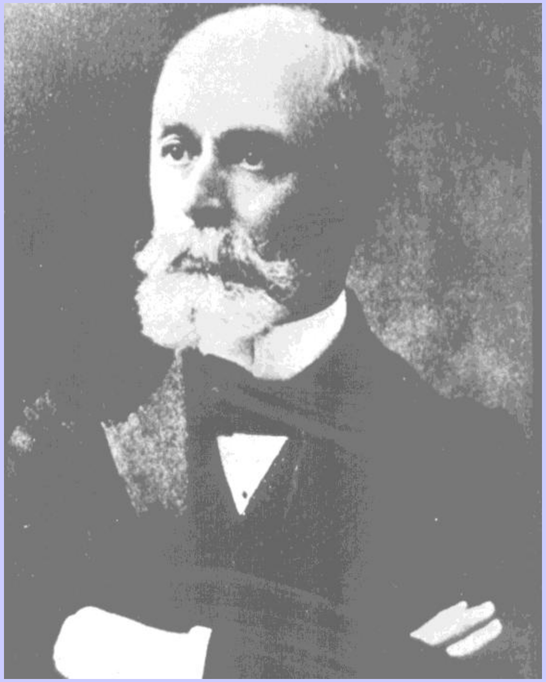
Wilhelm Conrad Röntgen

X-Rays, the fastest technology transfer example

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

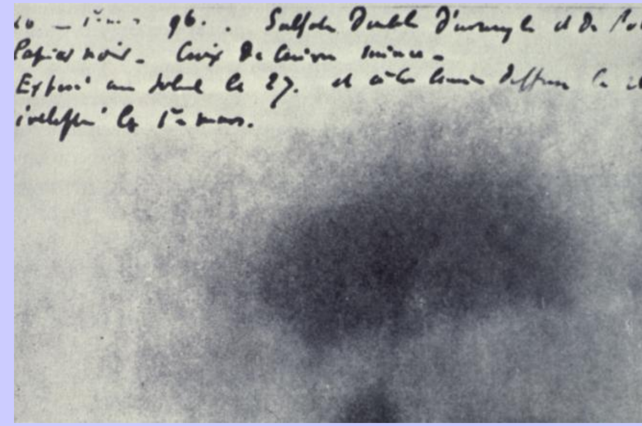
Röntgen received the first Nobel prize in physics in 1901

……….beginning of medical physics

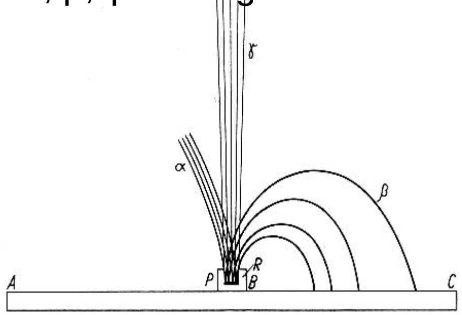


Henri Becquerel

1896:
Discovery of natural radioactivity

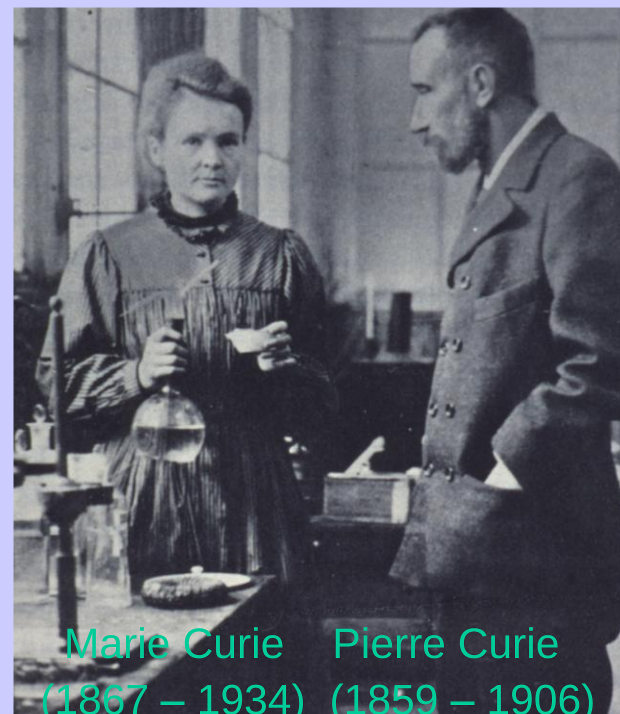


Thesis of Mme. Curie – 1904
α, β, γ in magnetic field



1898: Discovery of radium

used immediately for "Brachytherapy"

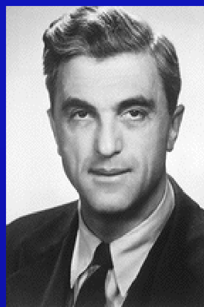


Marie Curie (1867 – 1934) Pierre Curie (1859 – 1906)

First Radiobiological Experiment

The first radiobiology experiment.
Pierre Curie using a radium tube to
produce radiation ulcer on his arm.
Hall fig. 1-2

MRI, Magnetic Resonance Imaging



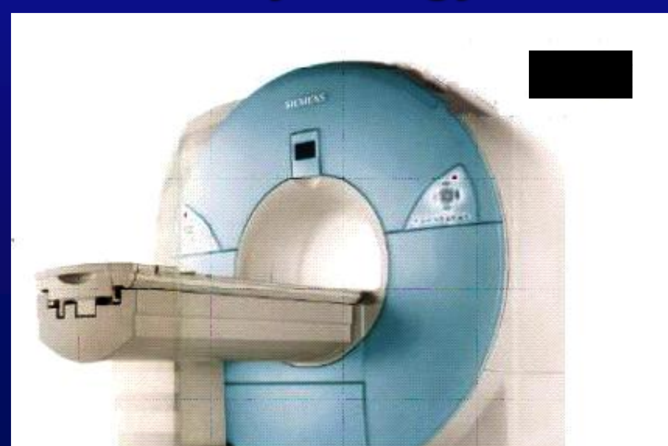
The Nobel Prize in Physics 1952

Felix Bloch
Physicist Stanford

Edward M. Purcell
Physicist Harvard

The Nobel Prize in Physiology or Medicine 2003

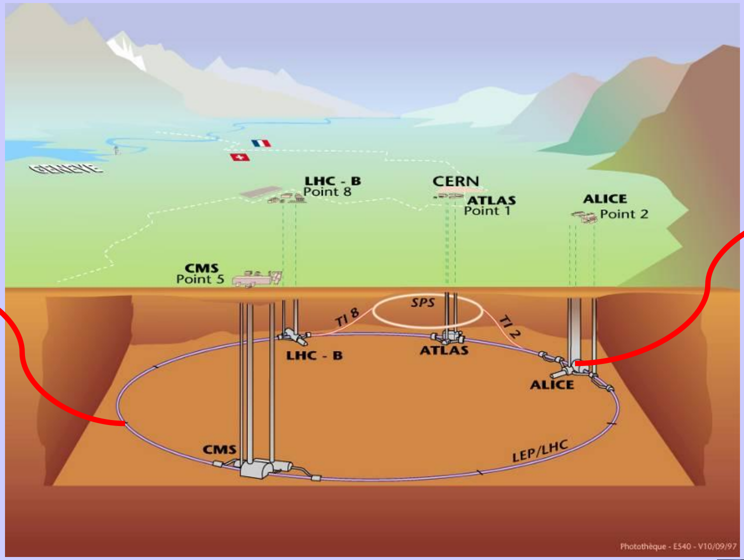
Sir Peter **Mansfield**
Physicist Nottingham



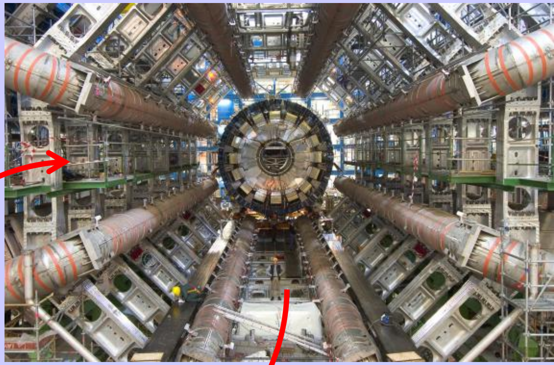
Paul C. **Lauterbur**
Chemist Uni. Illinois

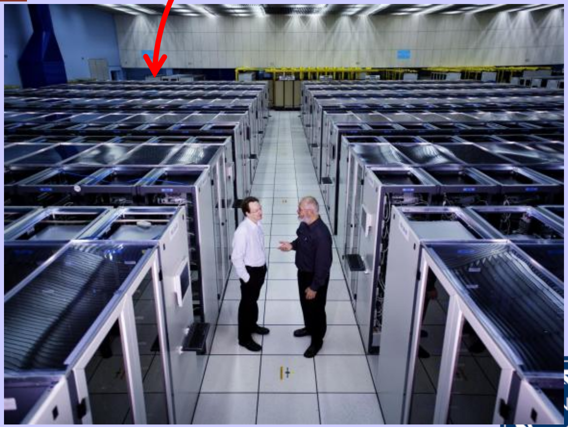
The tools of the trade ………

Accelerators



Detectors



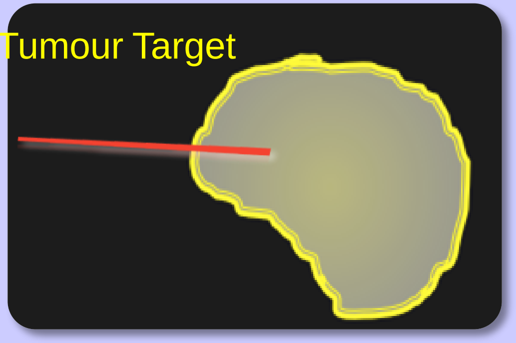


Computers

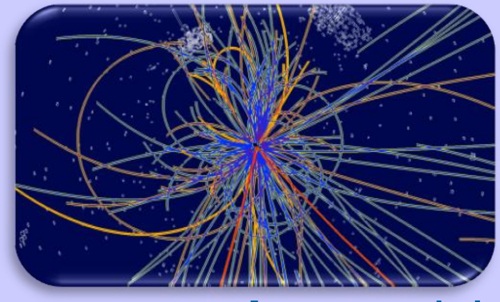
Brain behind the web

CERN technologies

Accelerating particle beams



Particle Therapy



Detecting particles

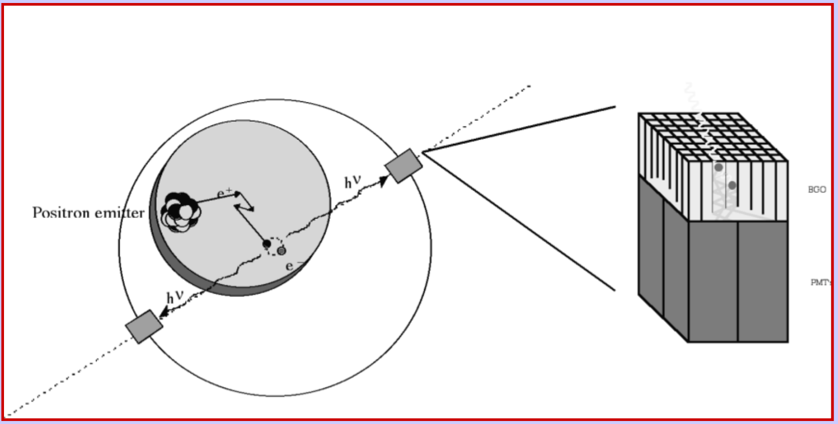
Medical imaging

Large scale **computing** (Grid)

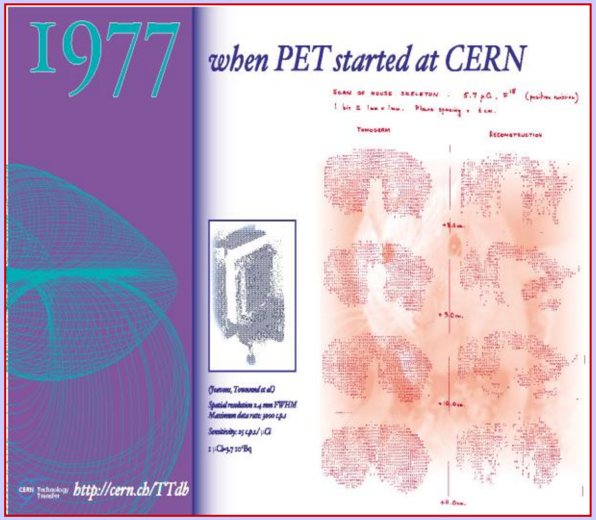
Grid computing for medical data management and analysis

Life.Sciences@cern.ch

Physics to medicine

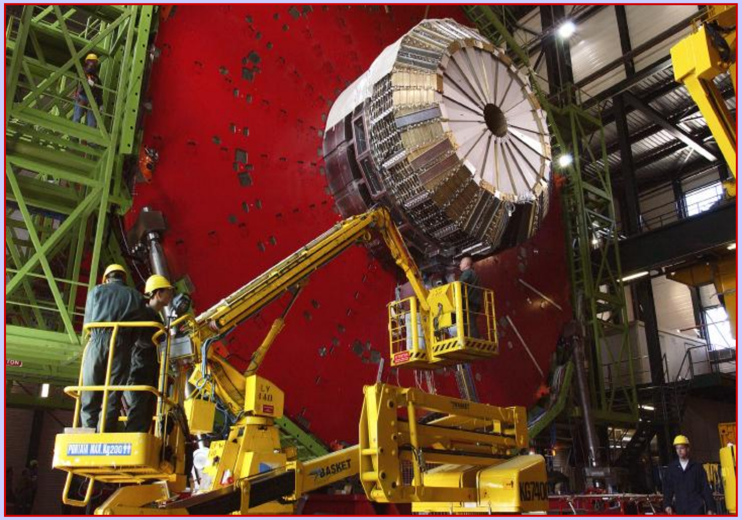


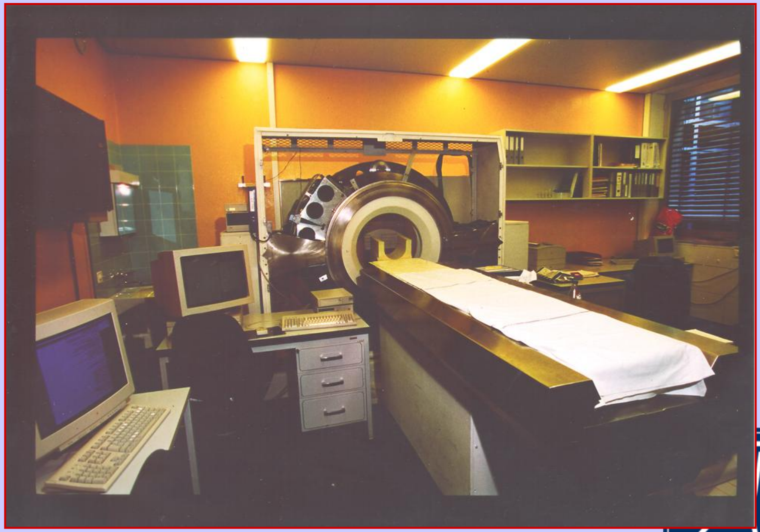
Idea of PET



Photon detection used for calorimetry

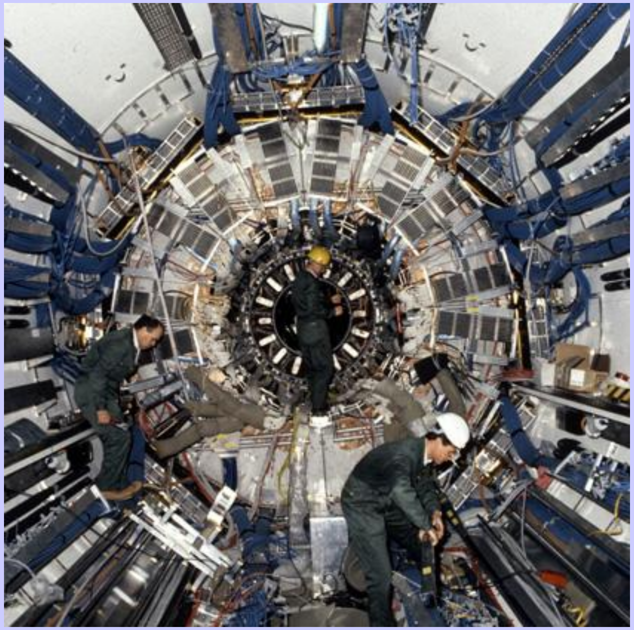
PET today

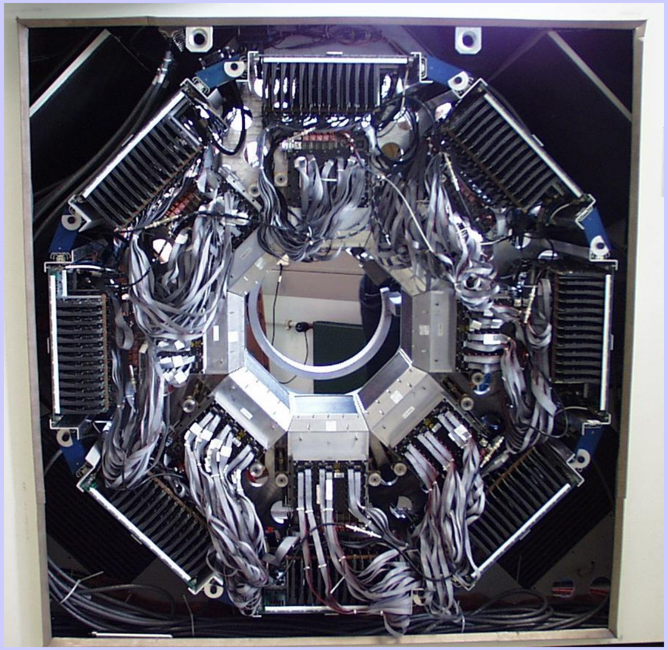




CMS calorimeter

Similar challenges detectors

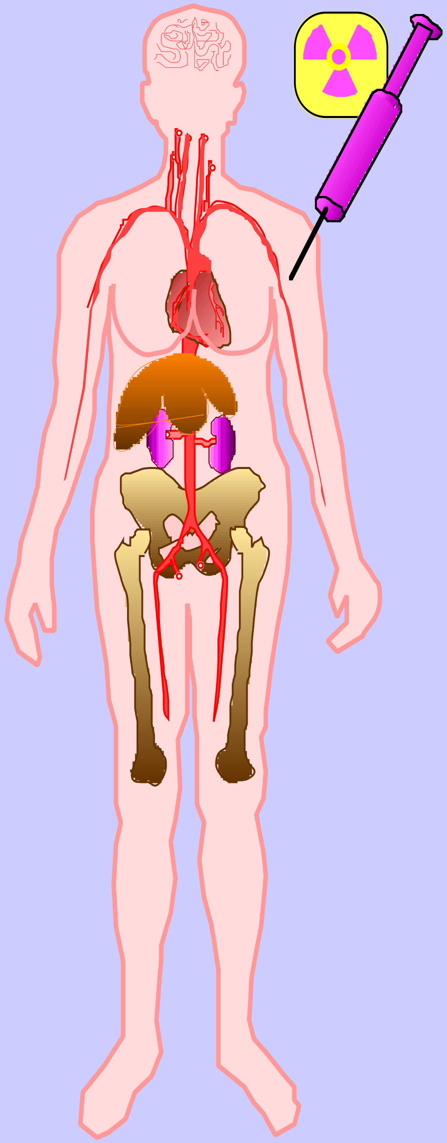




Similar challenges for PET and HEP detectors

- New scintillating crystals and detection materials
- Compact photo-detectors
- Highly integrated and low noise electronics
- High level of parallelism and event filtering algorithms in DAQ
- Modern and modular simulation software using worldwide recognized standards (GATE)

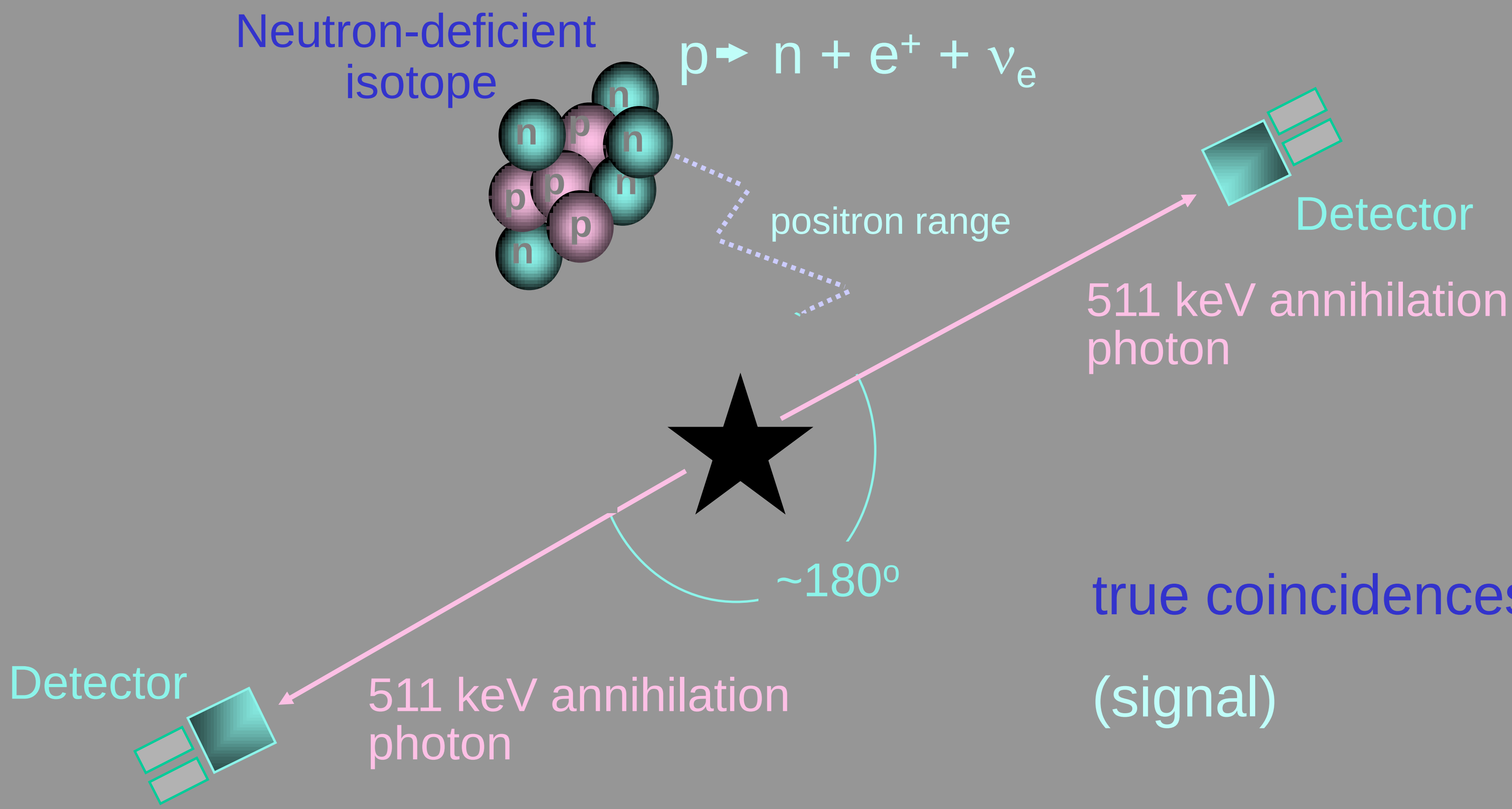
Inject Patient with Radioactive Drug



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

Drug Distributes in Body

PET: true events



true coincidences (T)

(signal)

Crystal Clear Collaboration

-New scintillators :

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

- new photodetectors (Avalanche PhotoDiodes)

-new low noise front end electronics

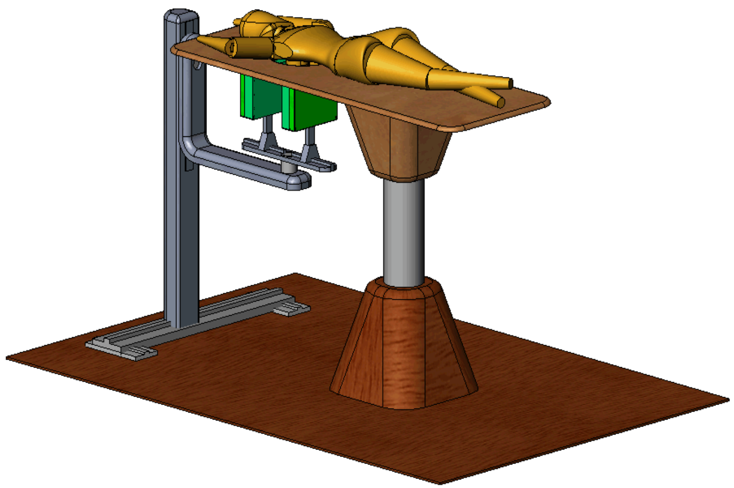
-new intelligent DAQ systems with pipeline and parallelized architecture

-better simulation GEANT 4

-- better reconstruction algorithms

Positron Emission Mammography
CRYSTAL CLEAR Collaboration

Model of the PEM detector



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

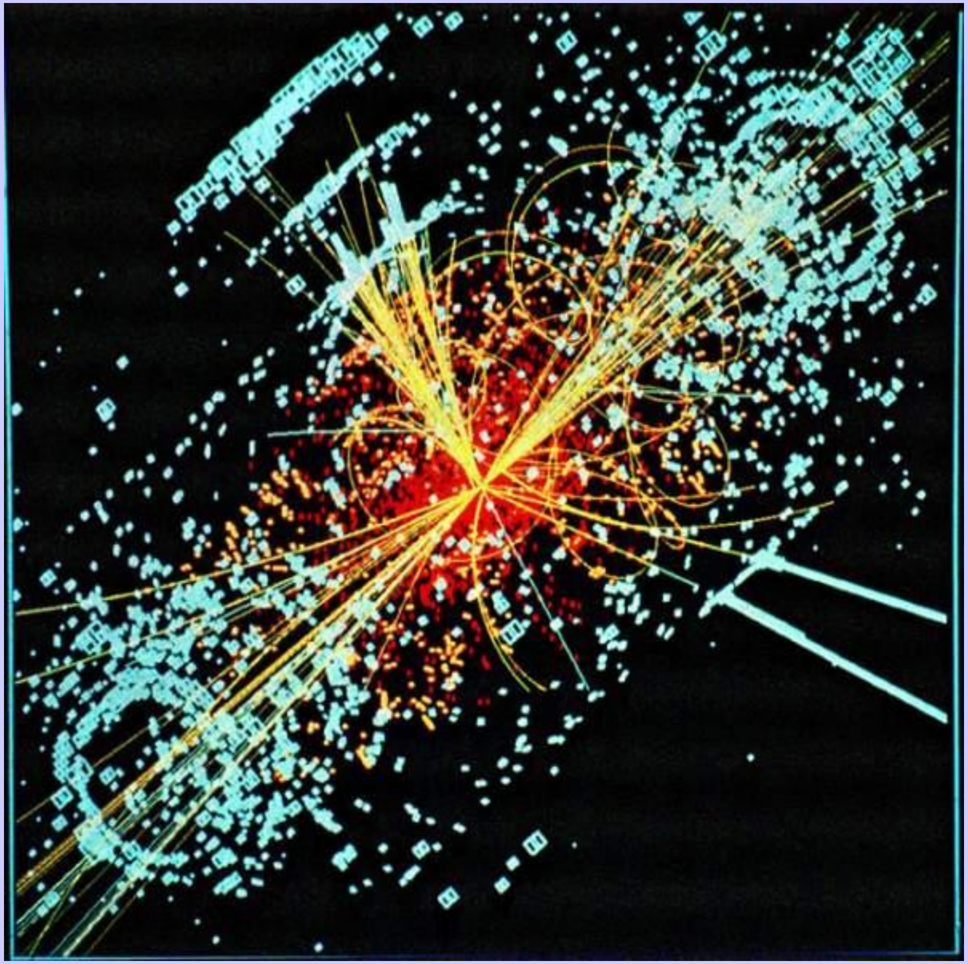
- **Spatial resolution 1-2 mm**
- **High counting sensitivity**
- **Short PET exams**
- **Compatible X-Ray mammography**
- **Compatible stereotactic biopsy**

Technical characteristics:

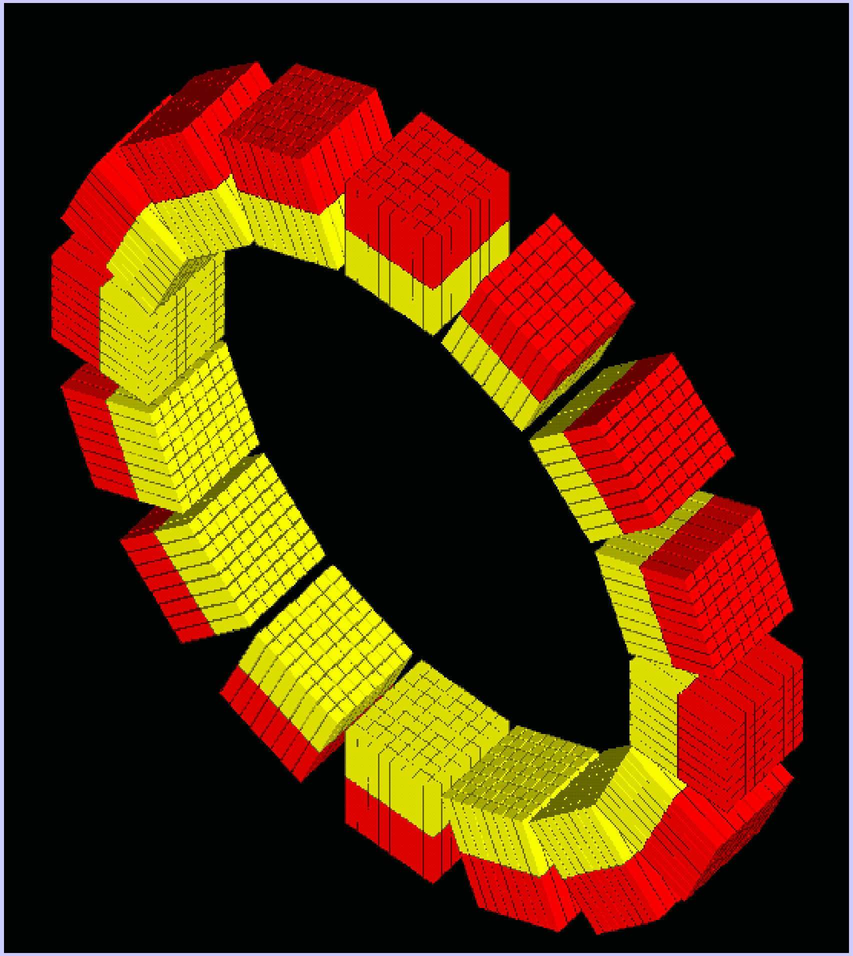
- 6000 crystals 2x2x20 mm
- Avalanche Photodiodes (APD)
- Low noise electronics
- High rate data acquisition
- Spatial resolution 1-2 mm
- Breast and axila region

Simulation

Higgs event at LHC (CMS) with Geant4



ClearPET with GATE: Geant4 Application for Tomographic Emission



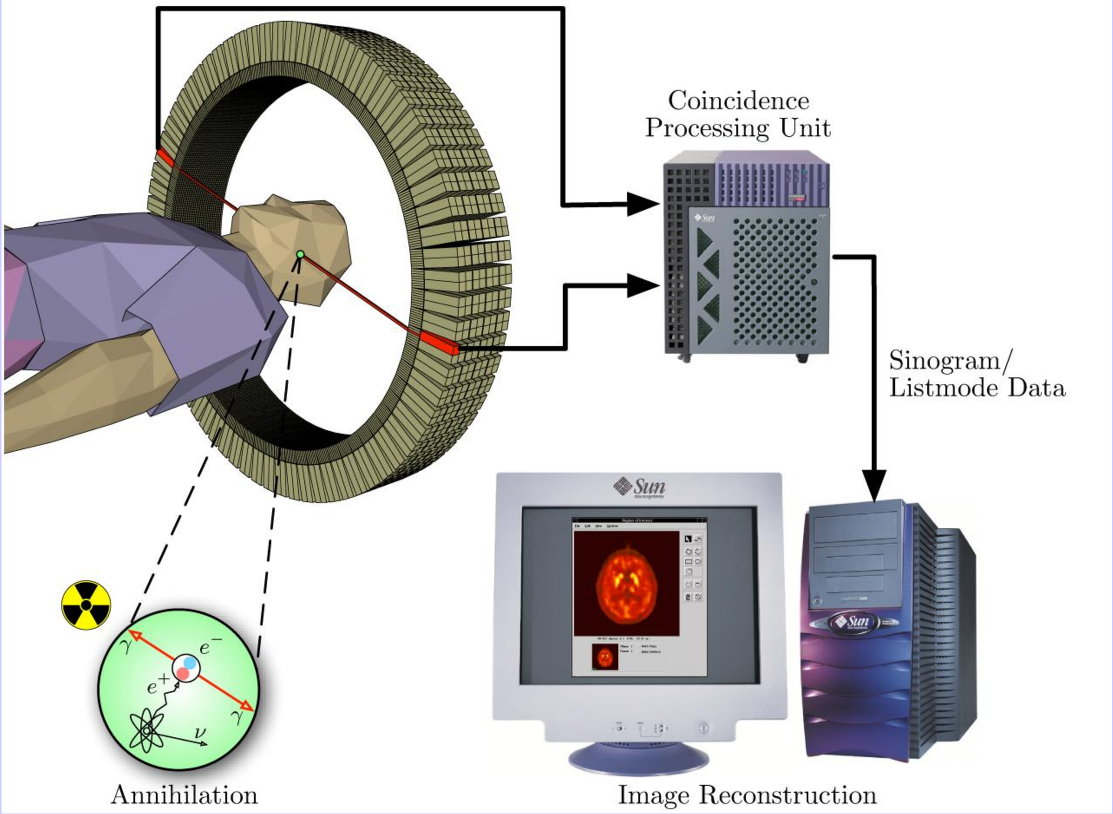
Medical Imaging – PET (Positron Emission Tomography)

Functional Analysis

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

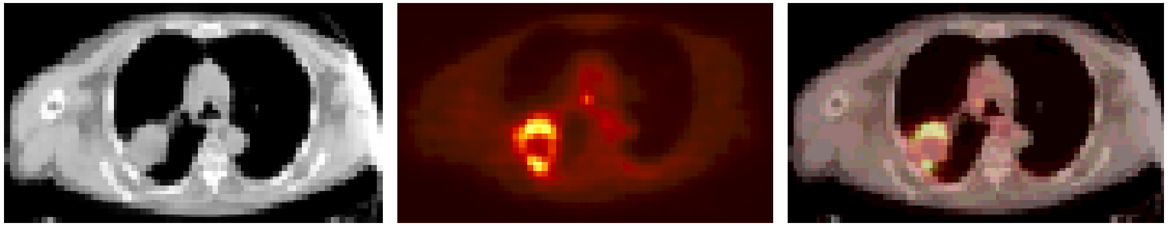
Images of tracer concentration in 3-dimensional space within the body are then reconstructed by computer analysis.

Crystals developed for LHC detectors are used in PET Scanners.

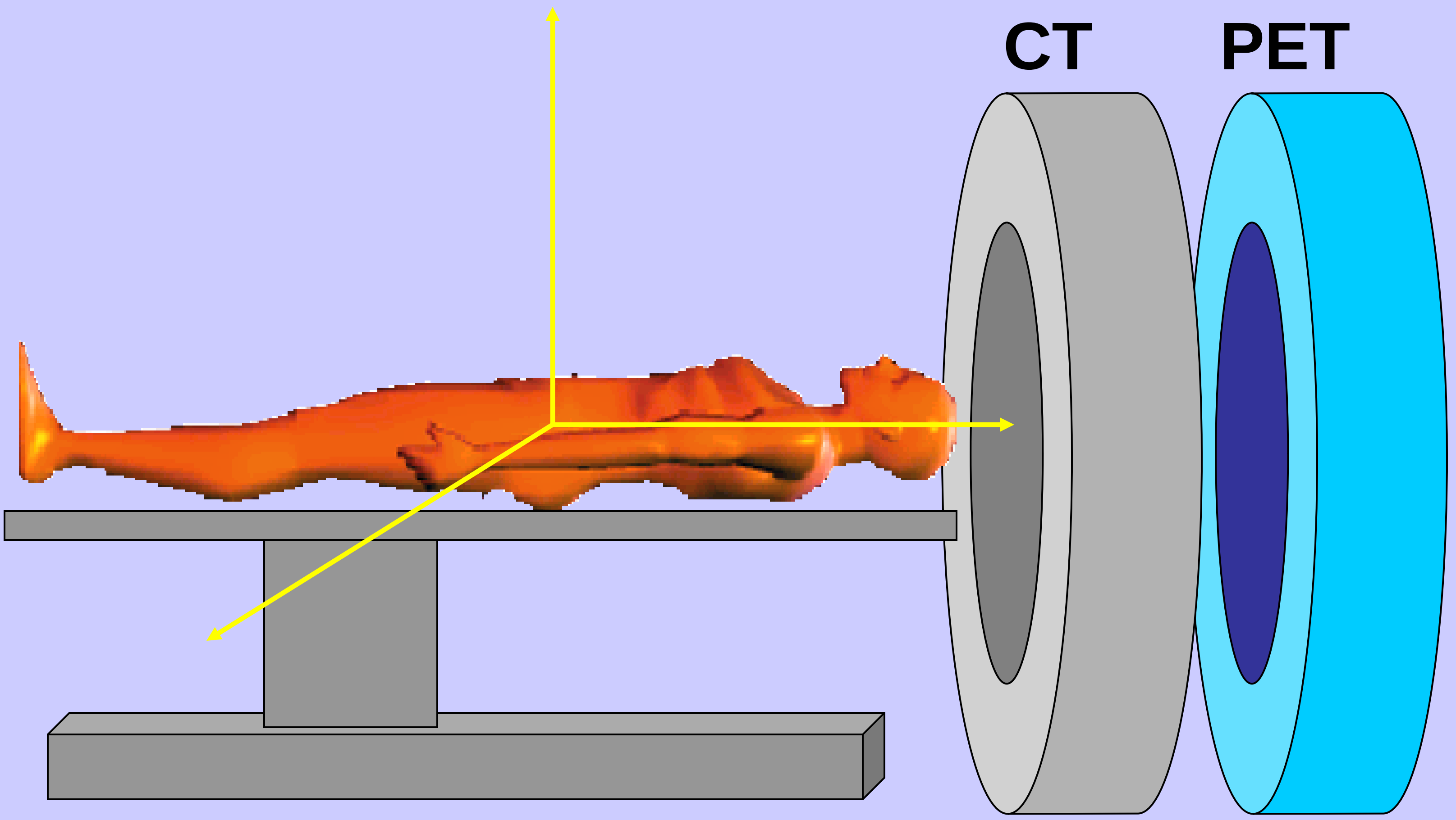


Multi-modality imaging

Primary lung cancer imaged with the Dual/Commercial scanner. A large lung tumor, which appears on CT as a uniformly attenuating hypodense mass, has a rim of FDG activity and a necrotic center revealed by PET.



PET/CT



A changing tide: digital imaging

Current
- Limited contrast
- High dose
  - Restricted screening
  - Limited access to preventive health care

Digital
- High contrast
- Lower dose
  - Opportunity for screening
  - Access to preventive health care

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

- **High Energy Physics original development:**

Particle track detectors

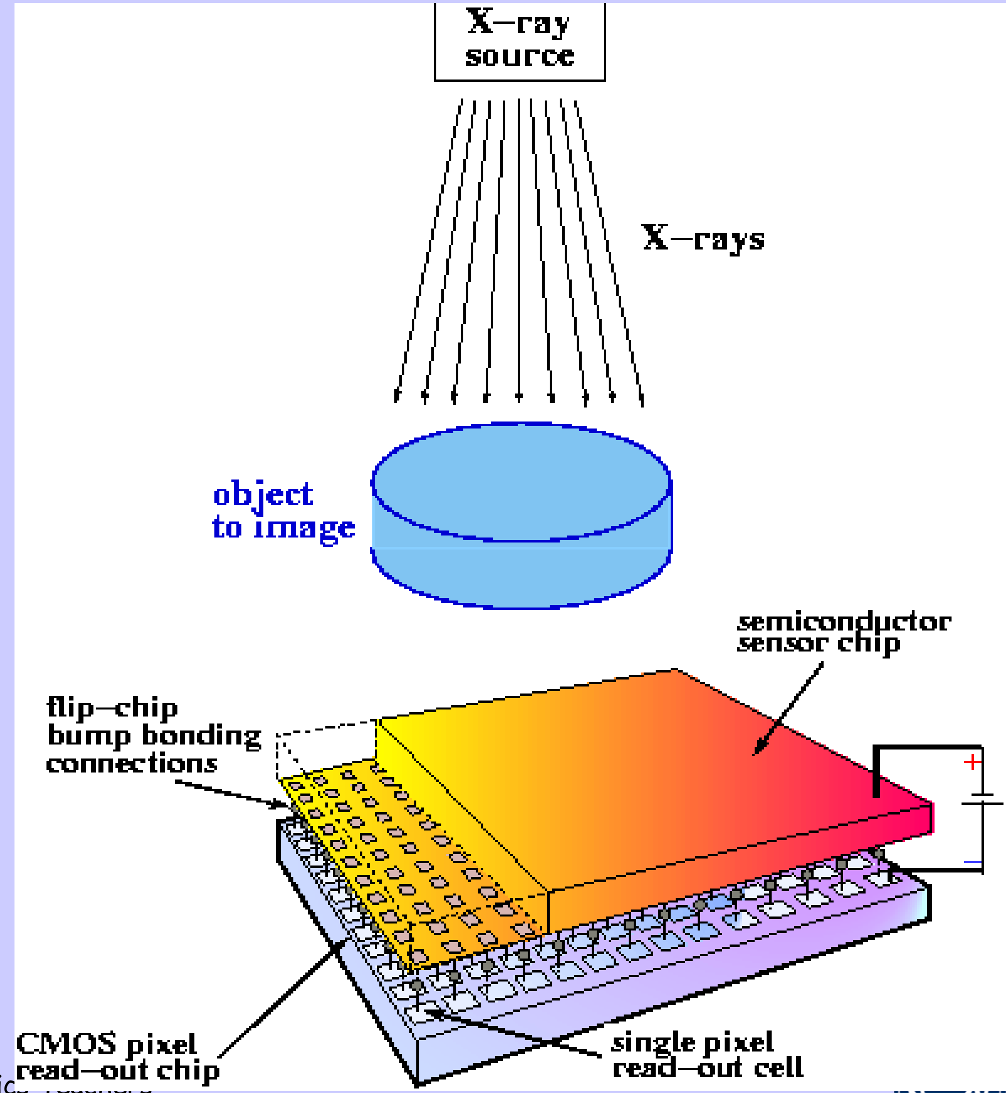
- **Main properties:**

Fully digital device

Very high space resolution

Very fast photon counting

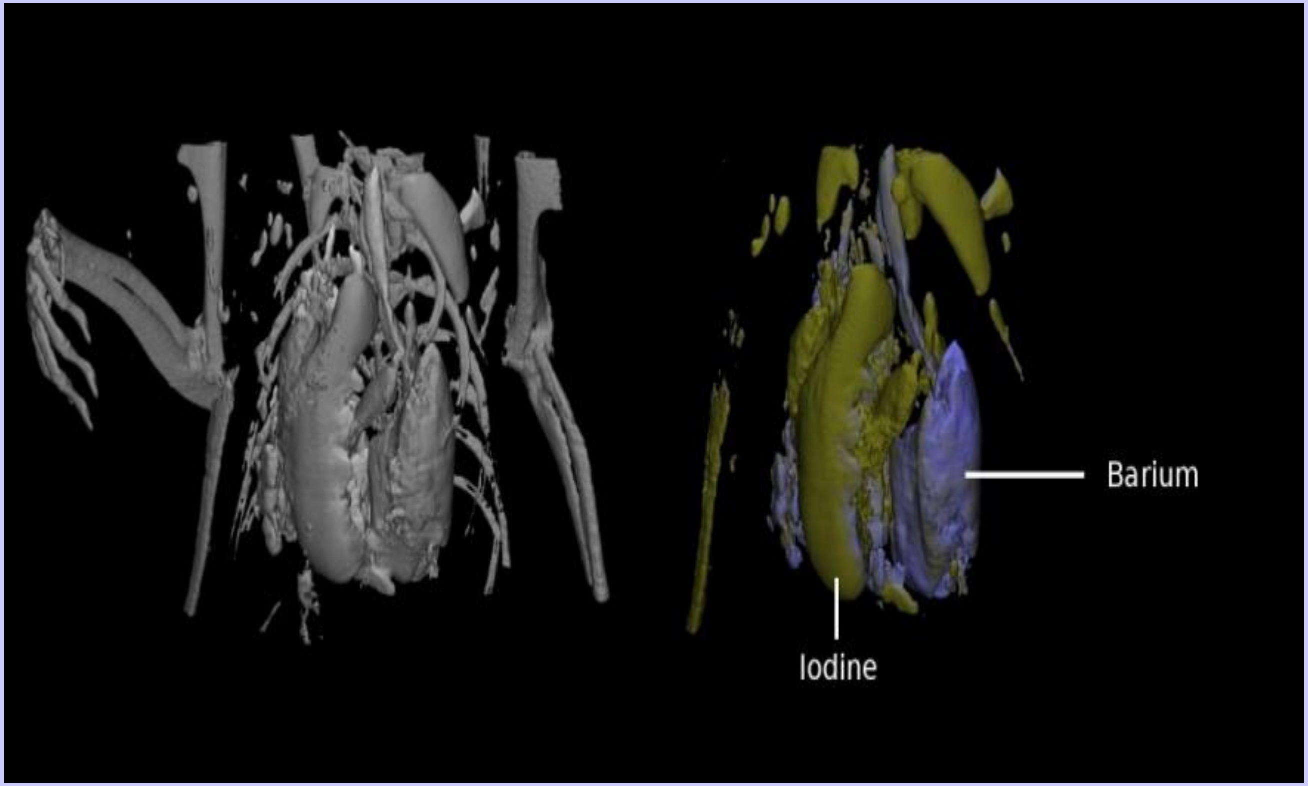
Good conversion efficiency of low energy X-rays



Medical imaging

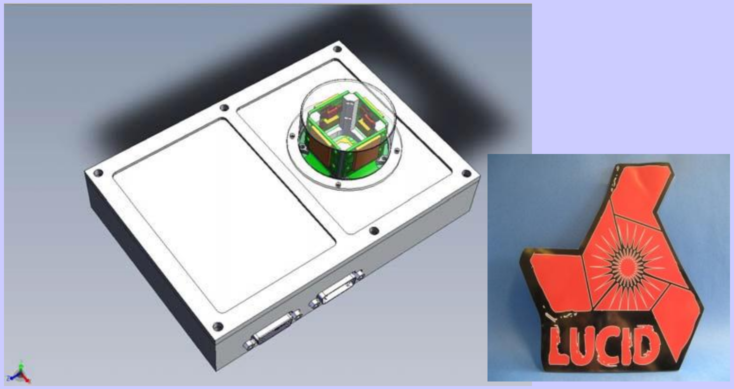
- MARS project

  Colour CT X-ray scanner based on the Medipix technology

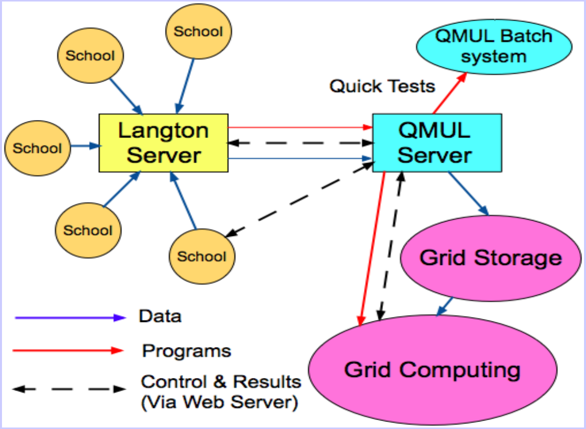


(courtesy of MARS Bioimaging Ltd)

CERN@school allows students to use a Timepix chip in the lab to visualise radiation



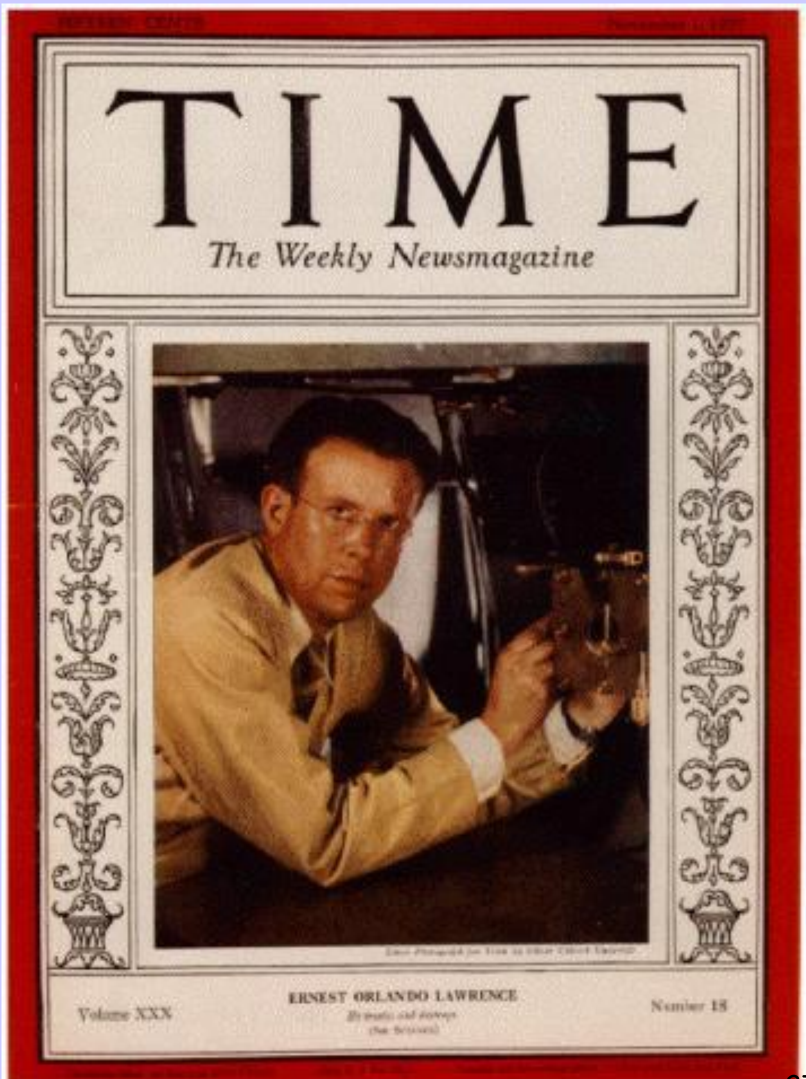
Langton Ultimate Cosmic ray Intensity Detector uses 5 Timepix chips to monitor the radiation environment in Space

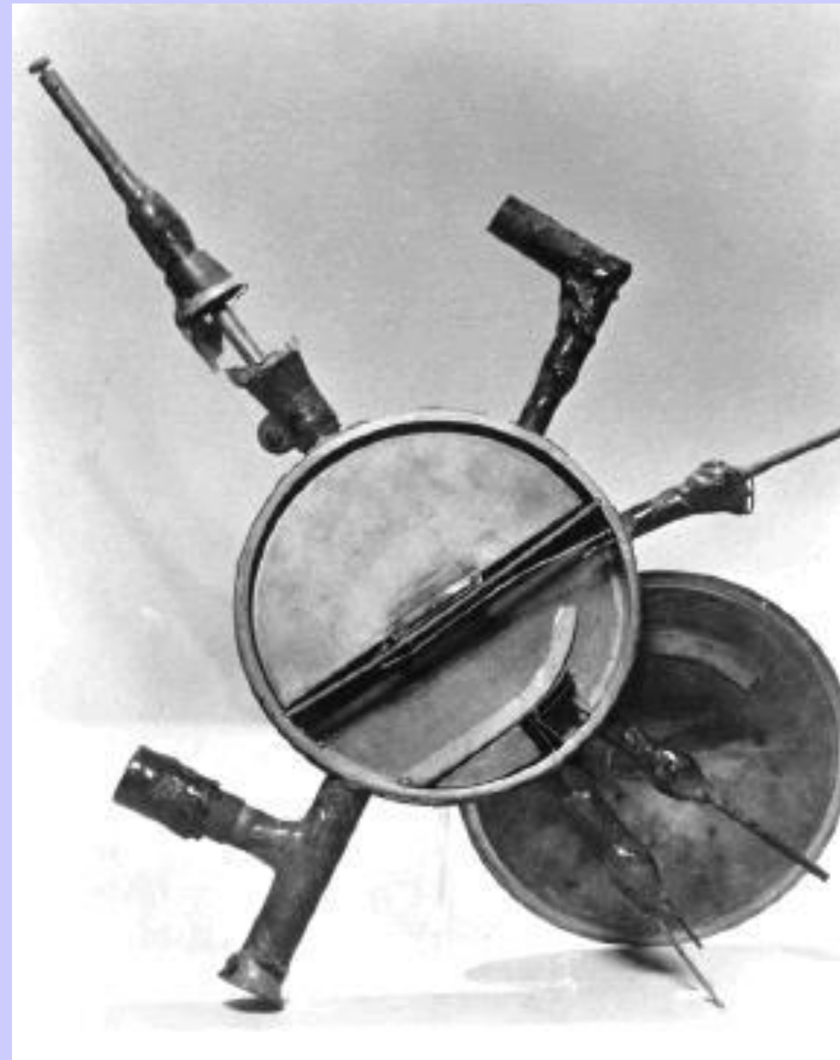


Data from LUCID and CERN@school detectors will be uploaded to the Grid and made available for students to analyse

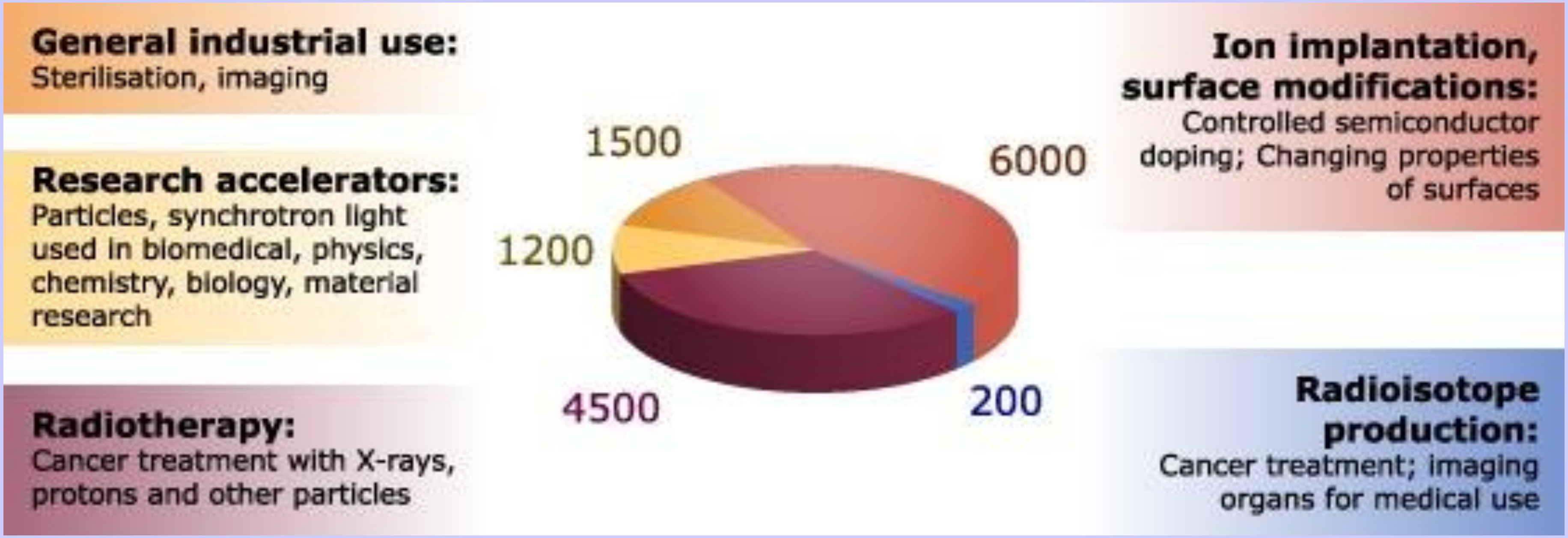
Use of Accelerators for cancer treatment

E. O. Lawrence is awarded Nobel Prize in 1939 for inventing the cyclotron

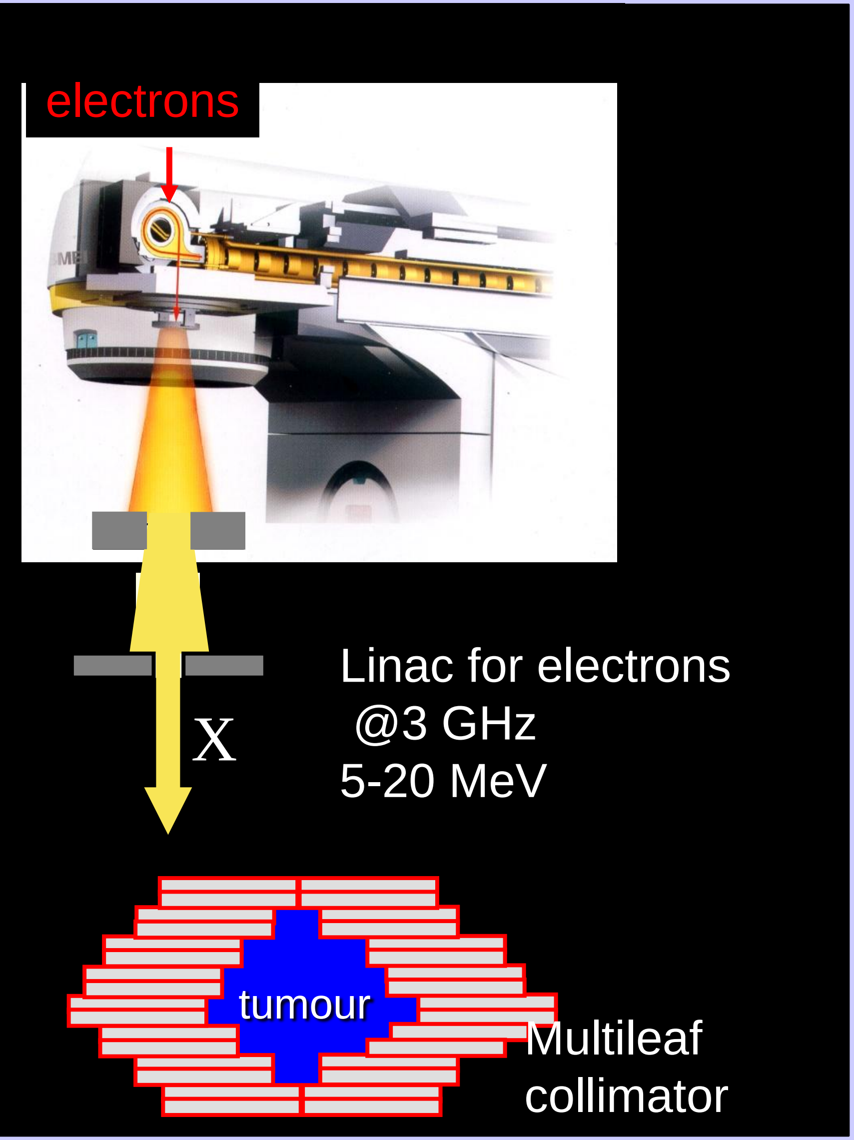




Use of Accelerators Today



'Conventional' radiotherapy: linear accelerators dominate



Courtesy of Elekta

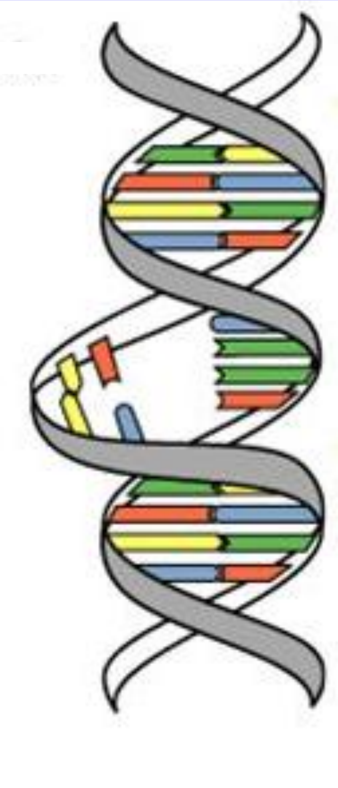
20 000 patients per year every
10 million inhabitants

1 linac every <250,000 inhabitants

Cancer Incidence

- Every year about 2 million new cases in Europe
- The rate of patients treated with RT will likely increase in the years to come
- The main cause of death between the ages of 45 and 65. Second most common cause of death

Radiotherapy in the 21st Century



- 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

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

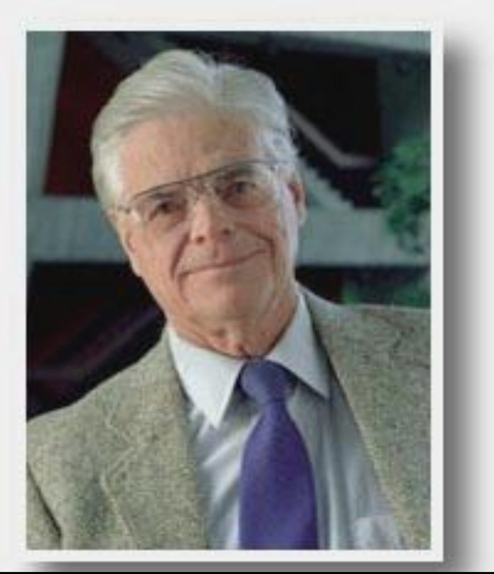
(Acta Oncol, Suppl:6-7, 1996)

How to overcome failures ?

- Physics & treatment technology: dose escalation
- Imaging: MRI, PET, image registration
- Biology: altered fractionation, radiosensitization

Raymond Miralbell, HUG

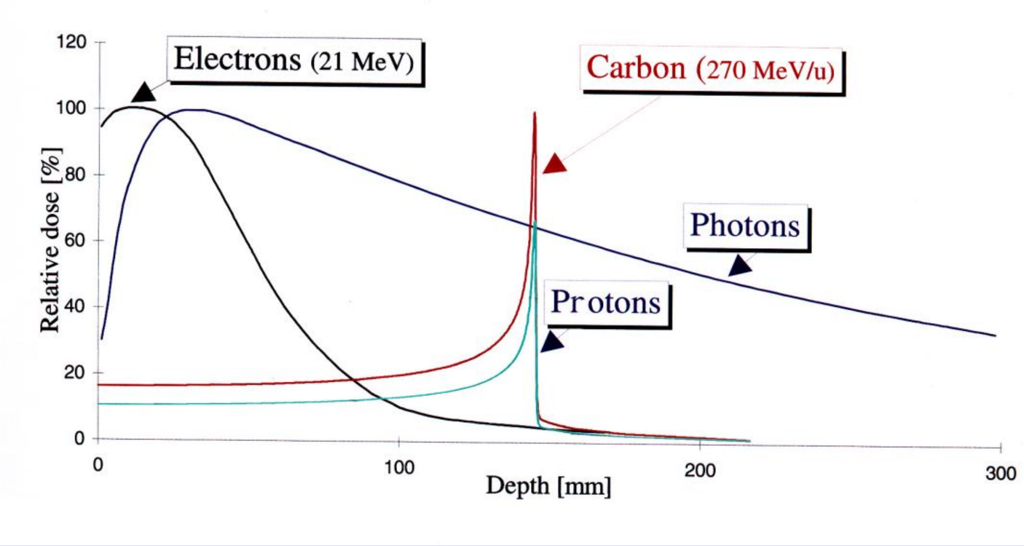
Hadrontherapy: all started in 1946



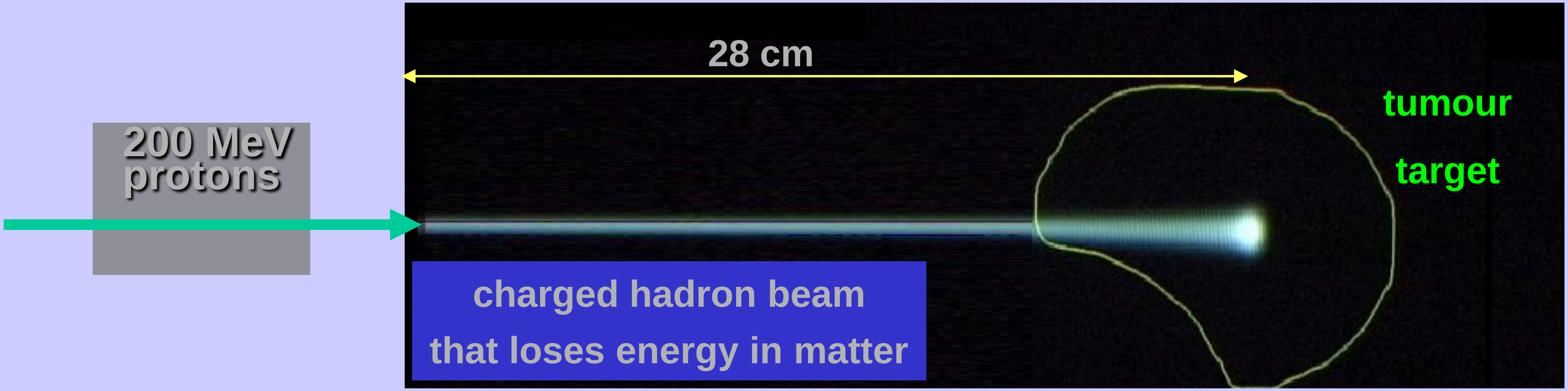
Founder and first director of Fermilab

In 1946 Robert Wilson:

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

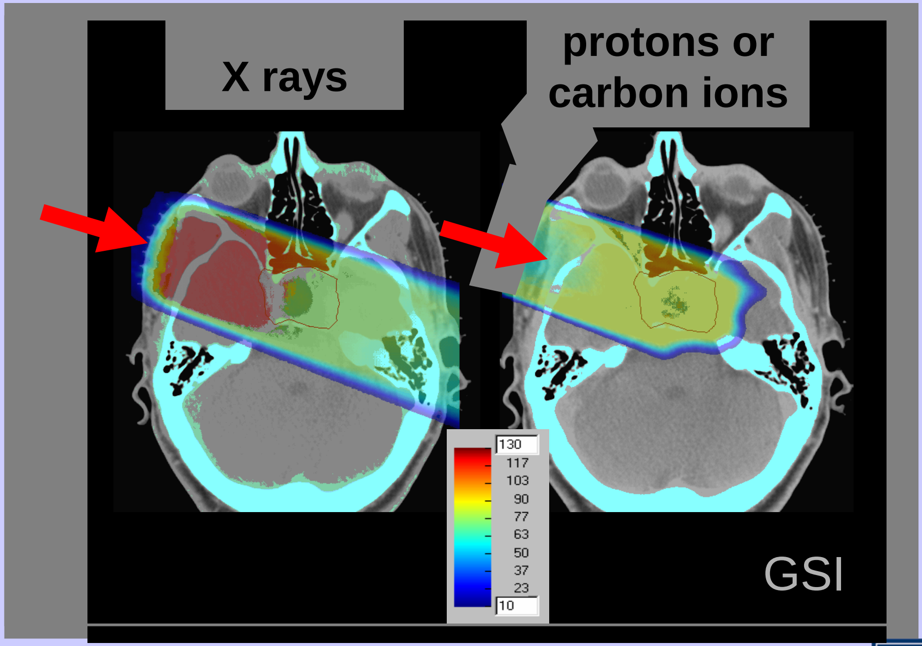


Hadron Therapy – The Principle

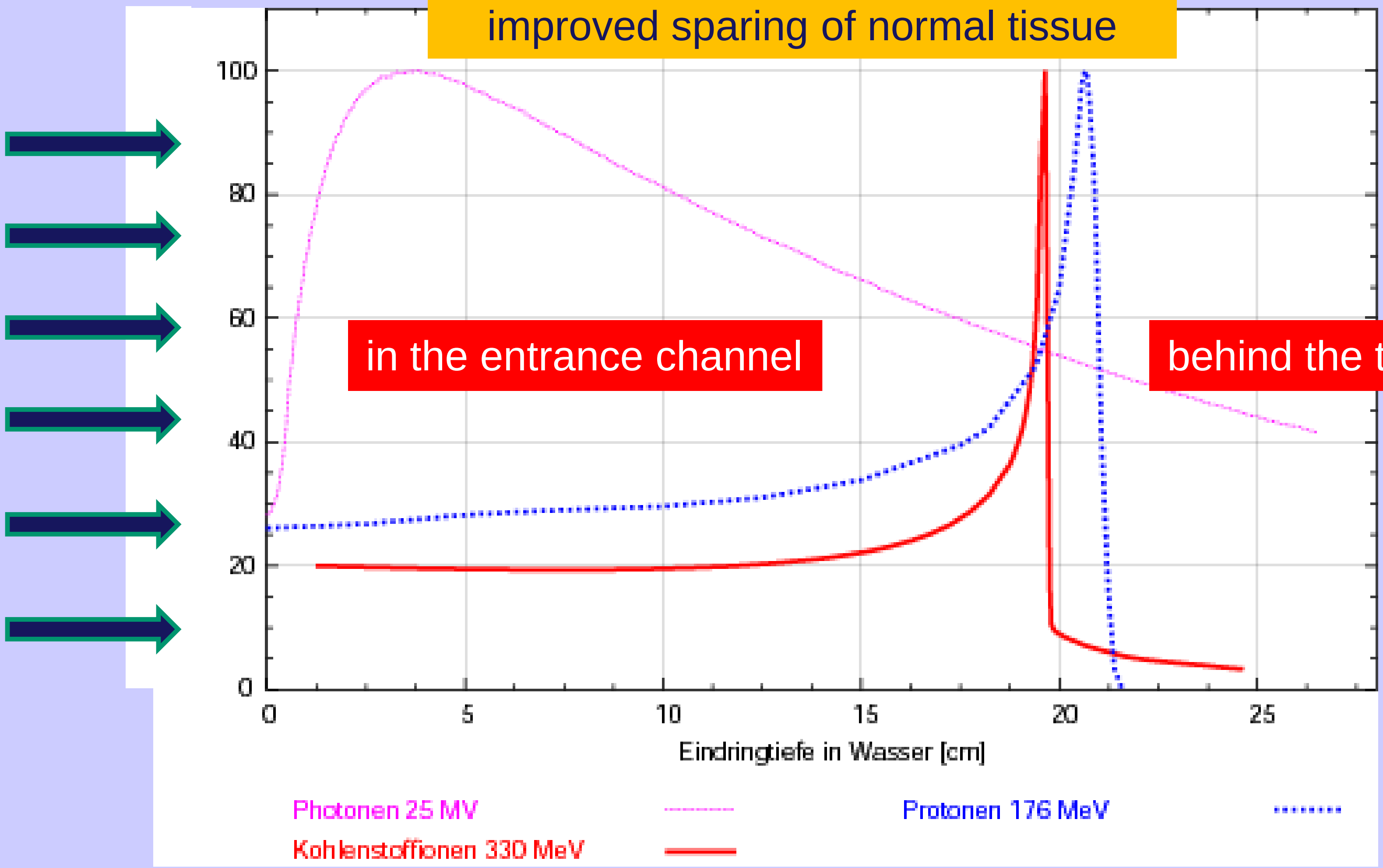


Hadron beams provide treatment for tumours that cannot be easily treated by X-rays

Hadron beams are more effective than X-rays in destroying tumours while sparing healthy tissues nearby.



Due to the physical selectivity improved sparing of normal tissue

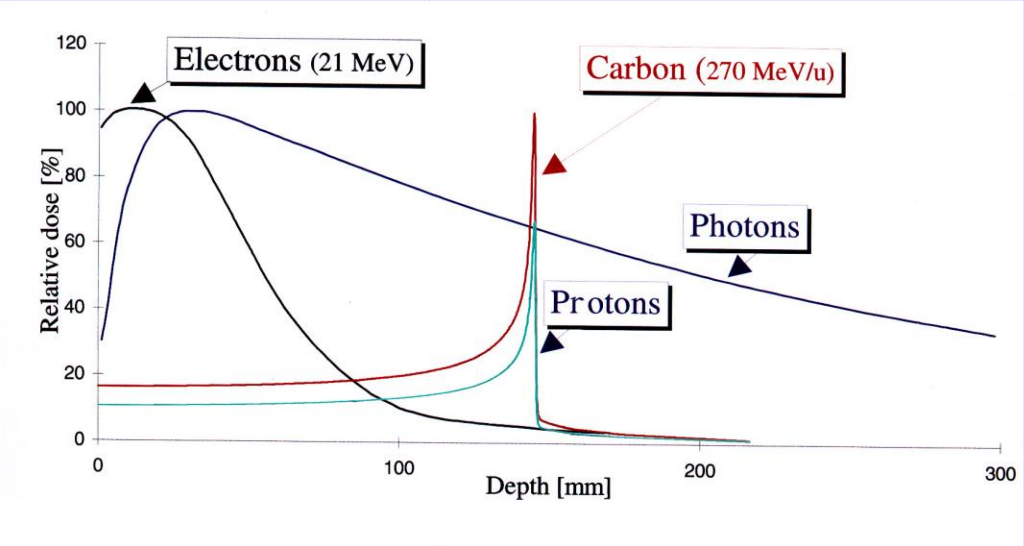


in the entrance channel

behind the tumor

Manjit Dosanjh

Hadrontherapy vs. radiotherapy



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

Photons and Electrons vs. Hadrons

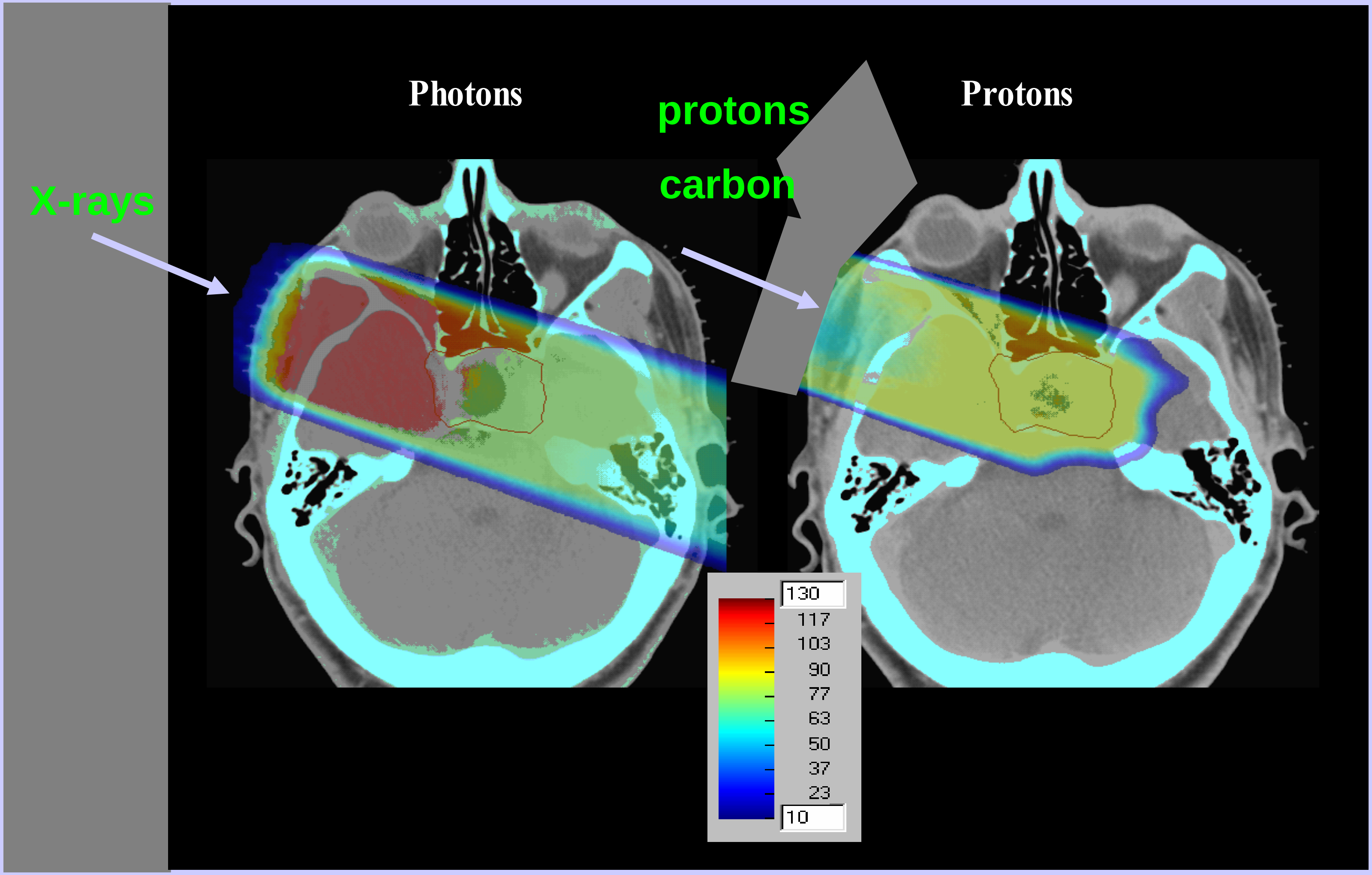
Photons and Electrons

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

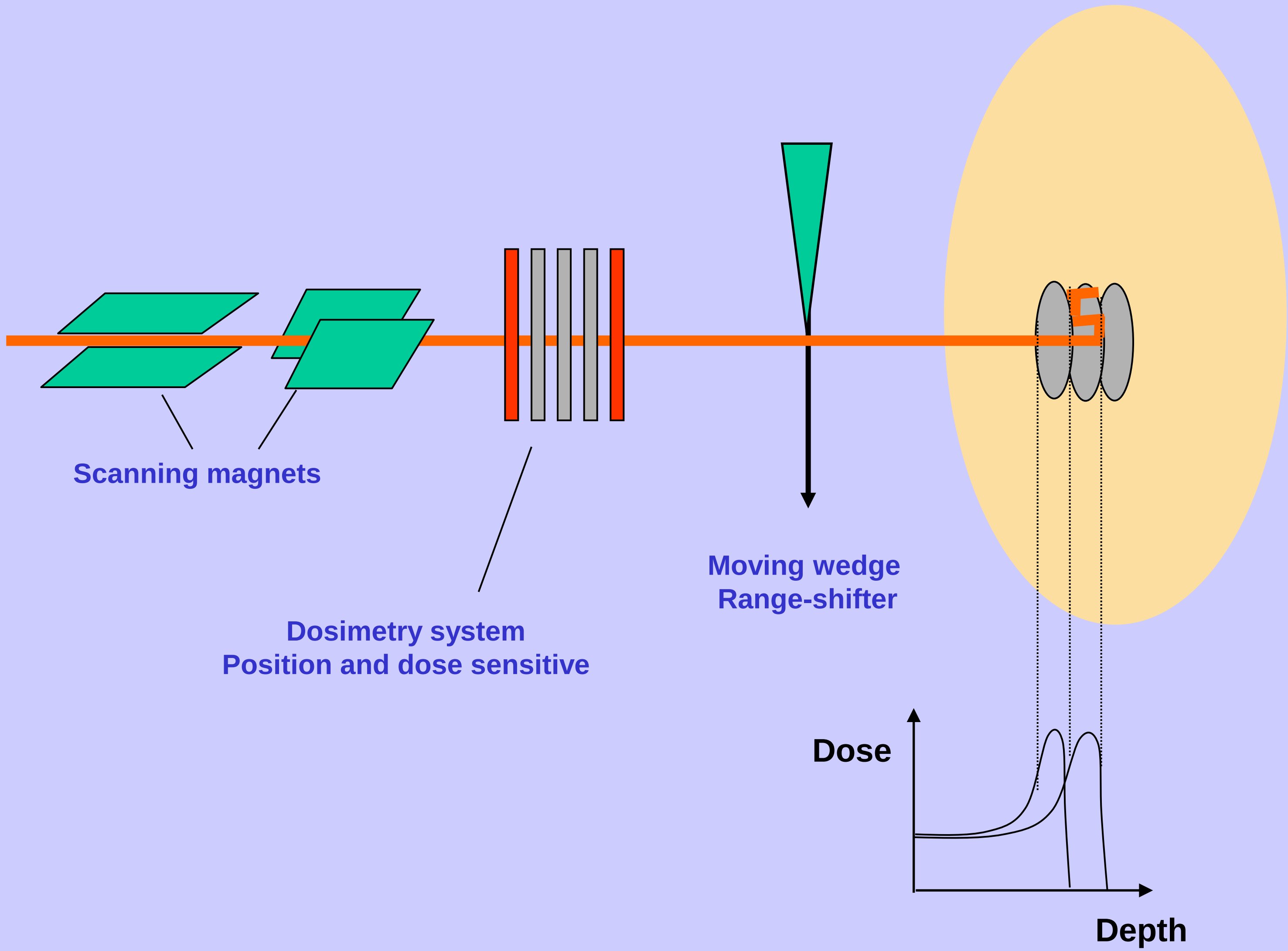
Hadrons

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

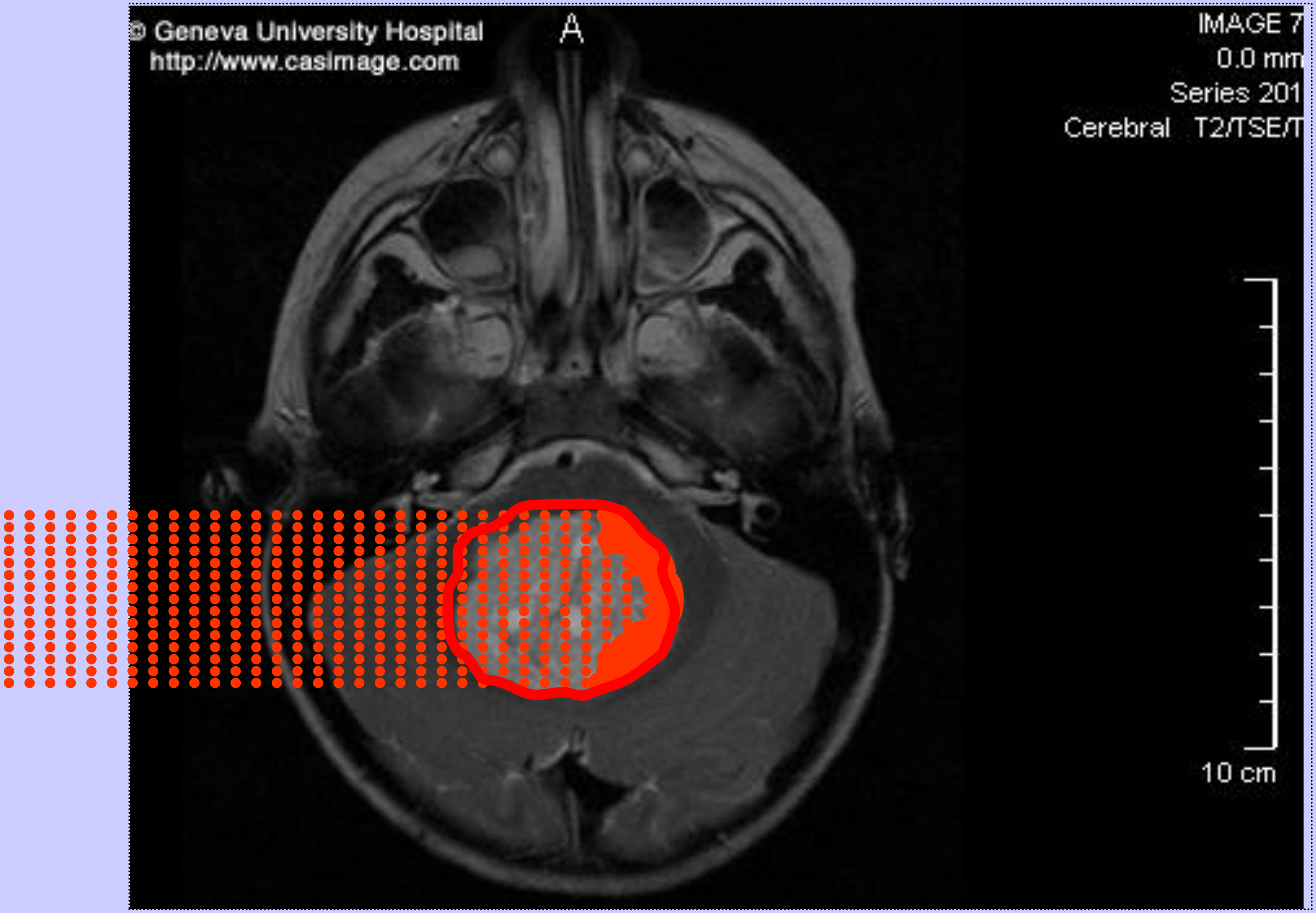
Advantage of hadrontherapy



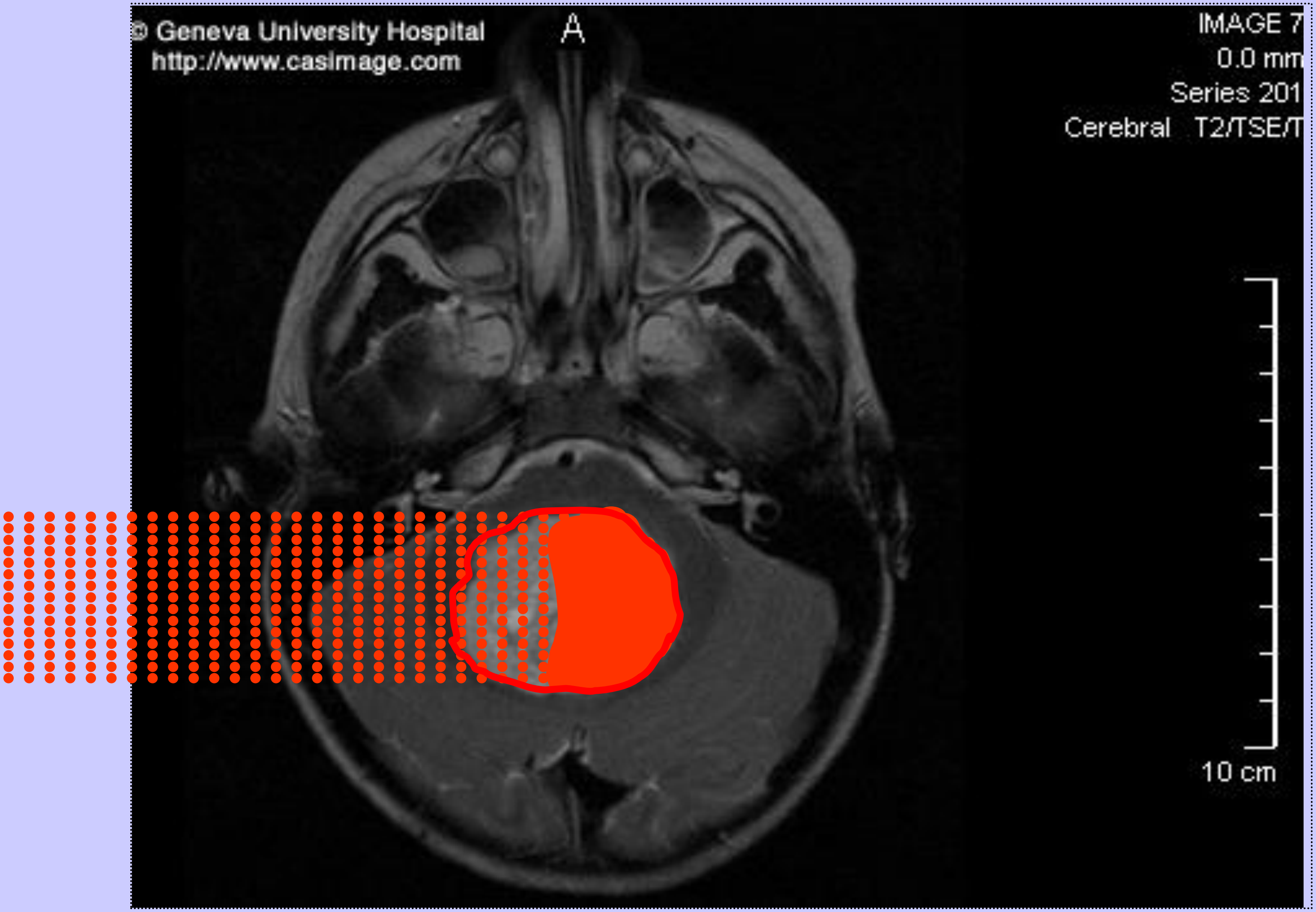
Spot-scanning beam-line schematic



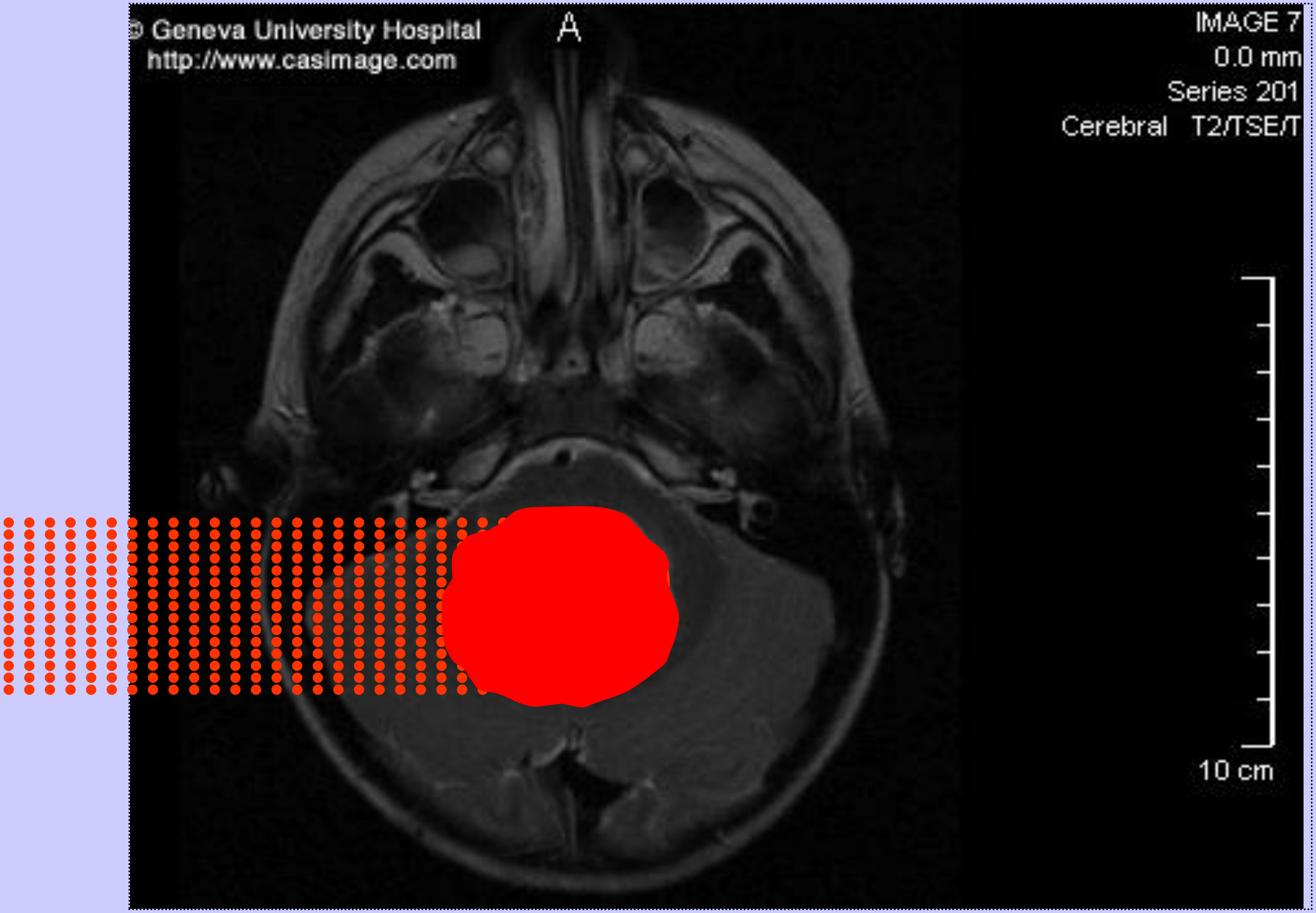
Spot scanning with a proton beam



Spot scanning with a proton beam

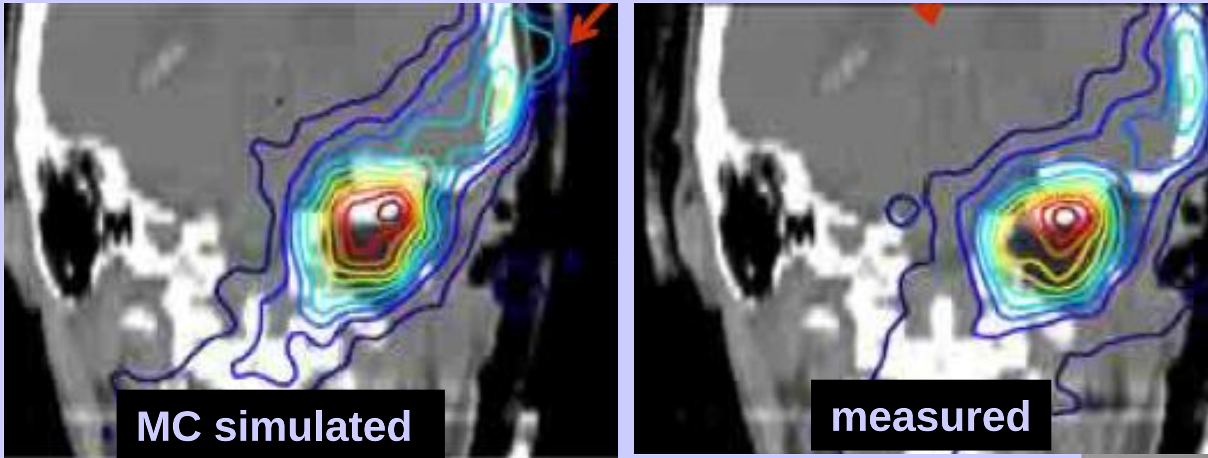


Spot scanning with a proton beam



Manjit Dosanjh

In-beam-PET for Quality Assurance of treatments



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

Modelling of beta^{+} emitters:

- Cross section
- Fragmentation cross section
- Prompt photon imaging
- Advance Monte Carlo codes

The Darmstadt GSI ‘pilot project’ (1997-2008)

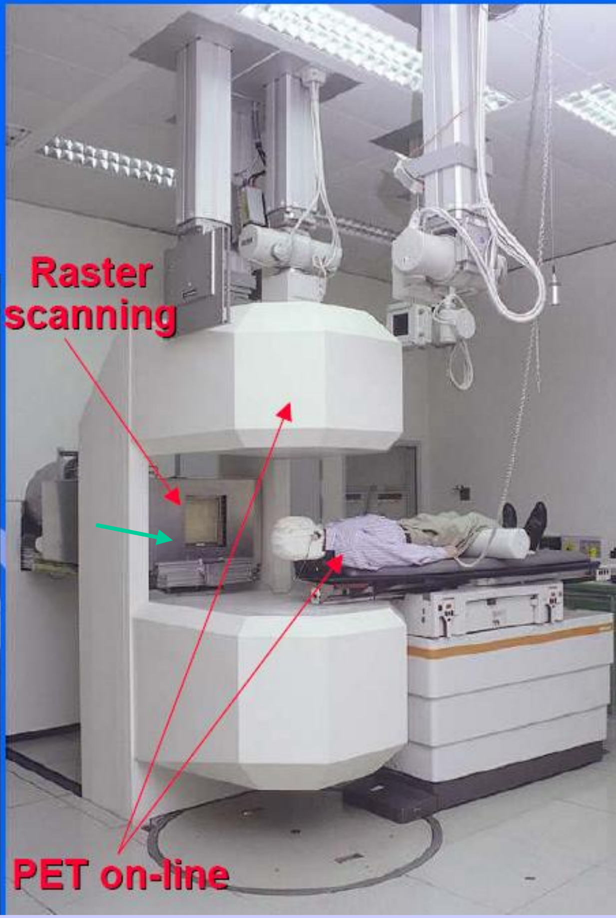
G. Kraft

J. Debus

G. Kraft

450 patients treated with carbon ions

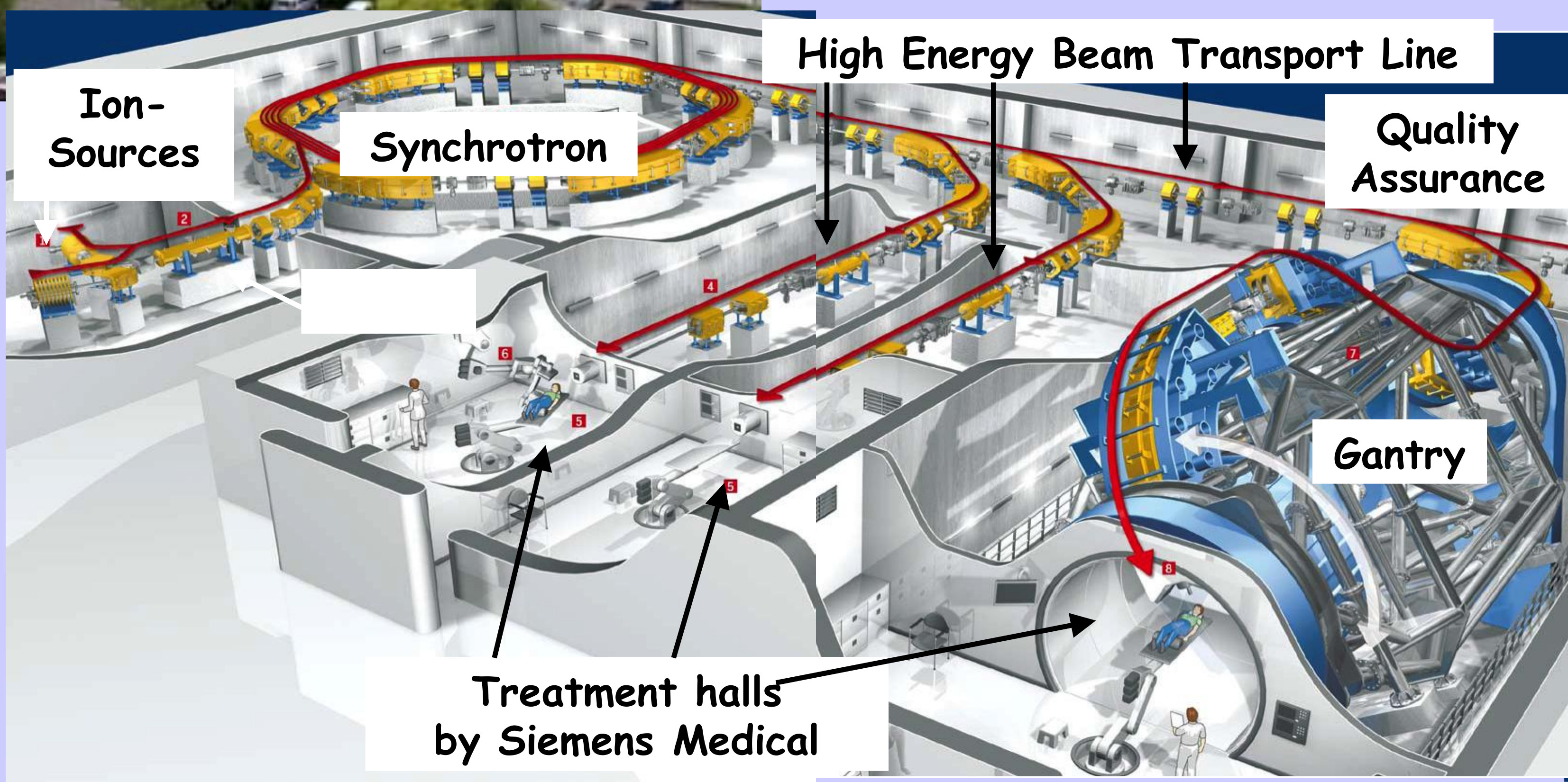
J. Debus (Heidelberg Univ.)



HIT- HEIDELBERG

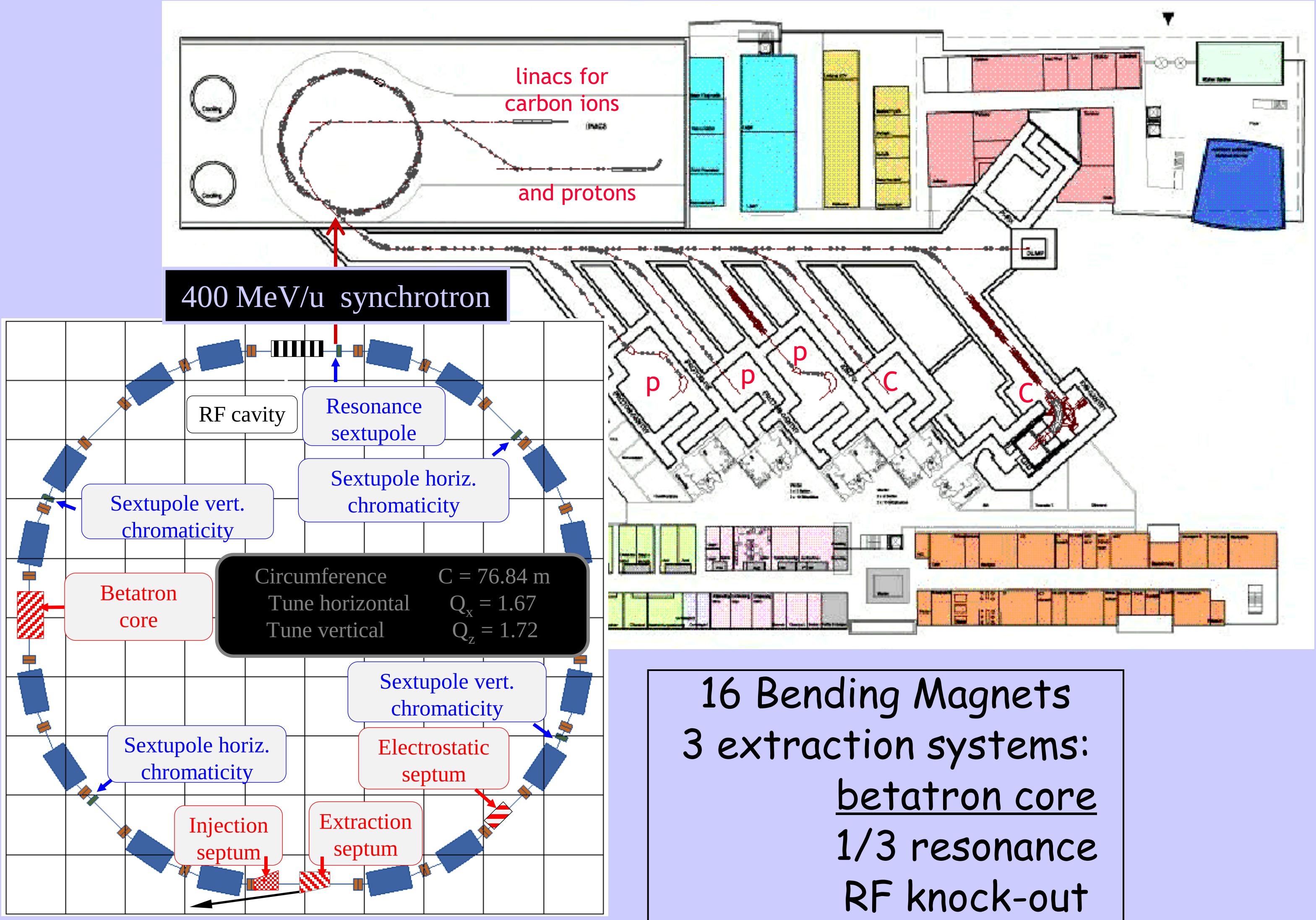
First beam extracted in 2007

First patient: Nov 2009



PIMMS at CERN in 1996 - 2000

CERN –TERA – MedAustron Collaboration for optimized medical synchrotron



16 Bending Magnets

3 extraction systems:

- betatron core
- 1/3 resonance
- RF knock-out

Grids and e-health

The Web

- Was a response to the needs of a distributed collaborating community
- And saved time and effort in fetching information from other places
- It made sharing information so much easier

- Transparent access to information
- Independent of and removing barriers of space and time

The GRID

The Aim of the GRID is to give access,

again easily and transparently,

Not only to simple information,

But also to all of the computing resources and storage distributed around the world

LHC data challenge

- 40 million collisions per second
- After filtering, 100 collisions of interest per second
- 10^{10} collisions recorded each year

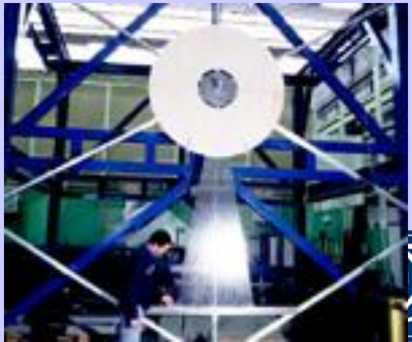
~10 Petabytes/year of data
~10 000 times the world annual book production,
~20km CD stack

CMS

LHCb

ATLAS

ALICE

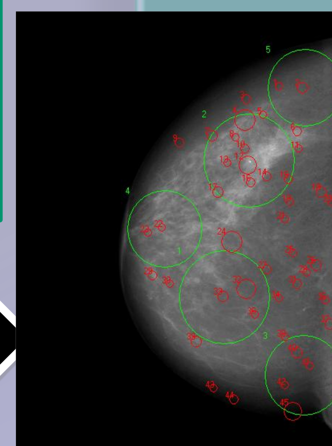


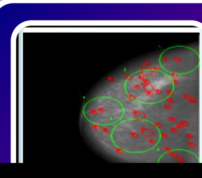
Early example of health application on the grid

Mammogrid

A Grid-powered Mammography Database

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



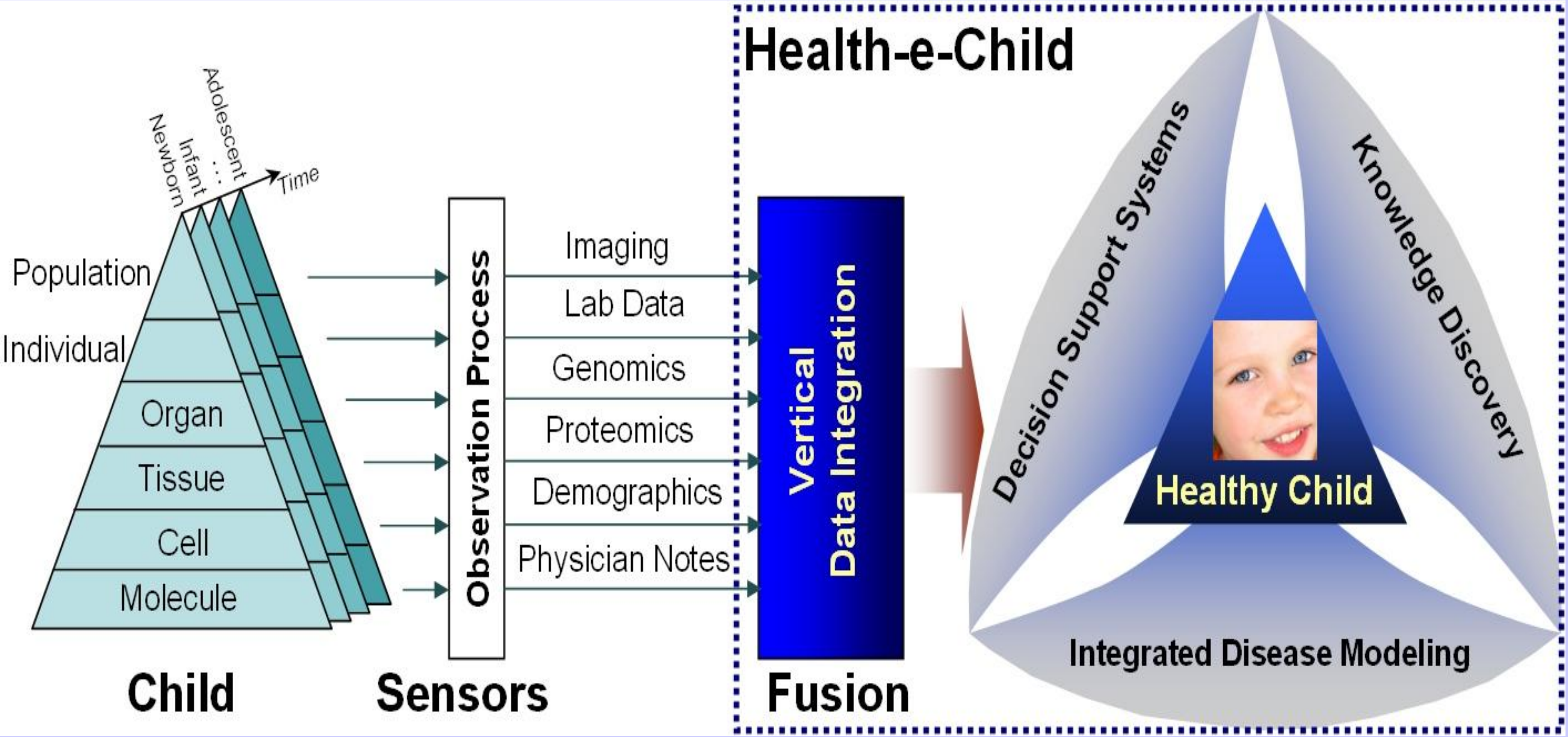


Oncology

- Breast Cancer (micro-calcifications ...s)

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

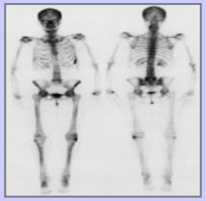
Health-e-Child on a slide



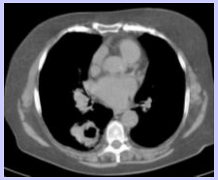
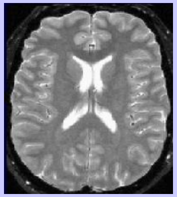
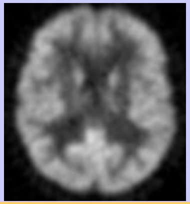
References

- **cern.ch/crystalclear**
- **cern.ch/enlight**
- **cern.ch/medipix**
- **cern.ch/twiki/bin/view/AXIALPET**
- cern.ch/medaustron
- cern.ch/fluka/heart/rh.html
- www.fluka.org/fluka.php
- cern.ch/wwwasd/geant
- cern.ch/wwwasd/geant/tutorial/tutstart.html

MEDICAL IMAGING

TECHNIQUE		YEAR	ENERGY	PHYSICAL PROPERTY	IMAGING
RADIOLOGY	X RAYS IMAGING	**1895**	X RAYS	ABSORPTION	
ECHOGRAPHY	ULTRASOUND IMAGING	1950	US	REFLECTION TRANSMISSION	
NUCLEAR MEDICINE	RADIOISOTOPE IMAGING	1950	γ RAYS	RADIATION EMISSION	

COMPUTERIZED TOMOGRAPHY

TECHNIQUE		YEAR	ENERGY	PHYSICAL PROPERTY	IMAGING	
X RAYS COMPUTERIZED TOMOGRAPHY	**CT**	**1971**	X RAYS	ABSORPTION		MORPHOLOGY
MAGNETIC RESONANCE IMAGING	MRI	1980	RADIO WAVES	MAGNETIC RESONANCE		MORPHOLOGY /FUNCTION
POSITRON EMISSION TOMOGRAPHY	PET	1973	γ RAYS	RADIATION EMISSION		FUNCTION