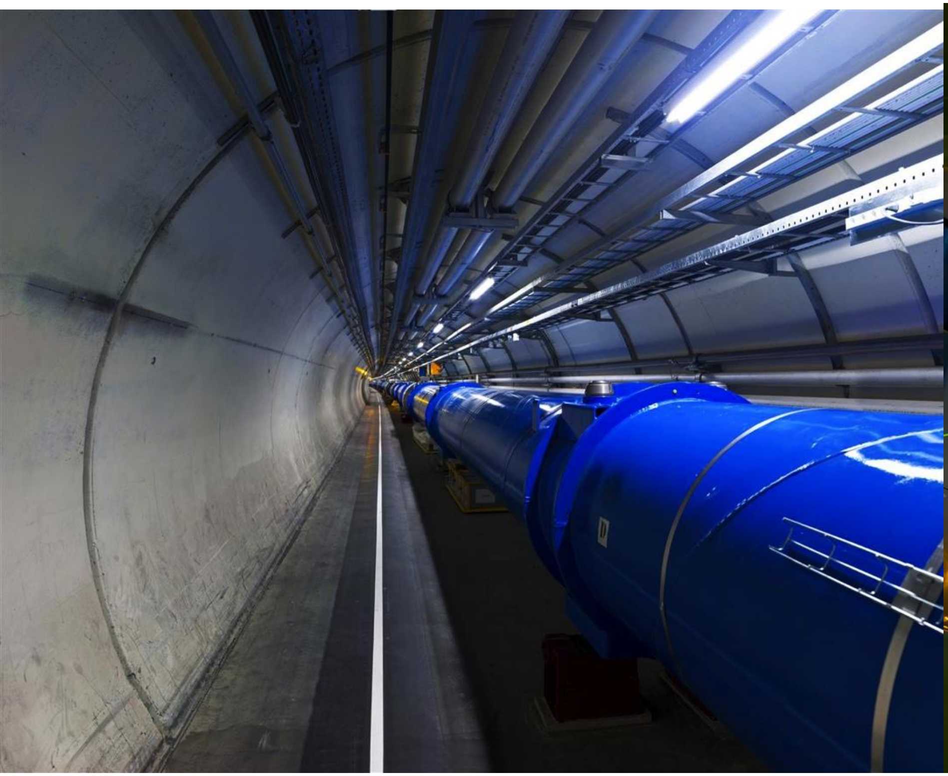
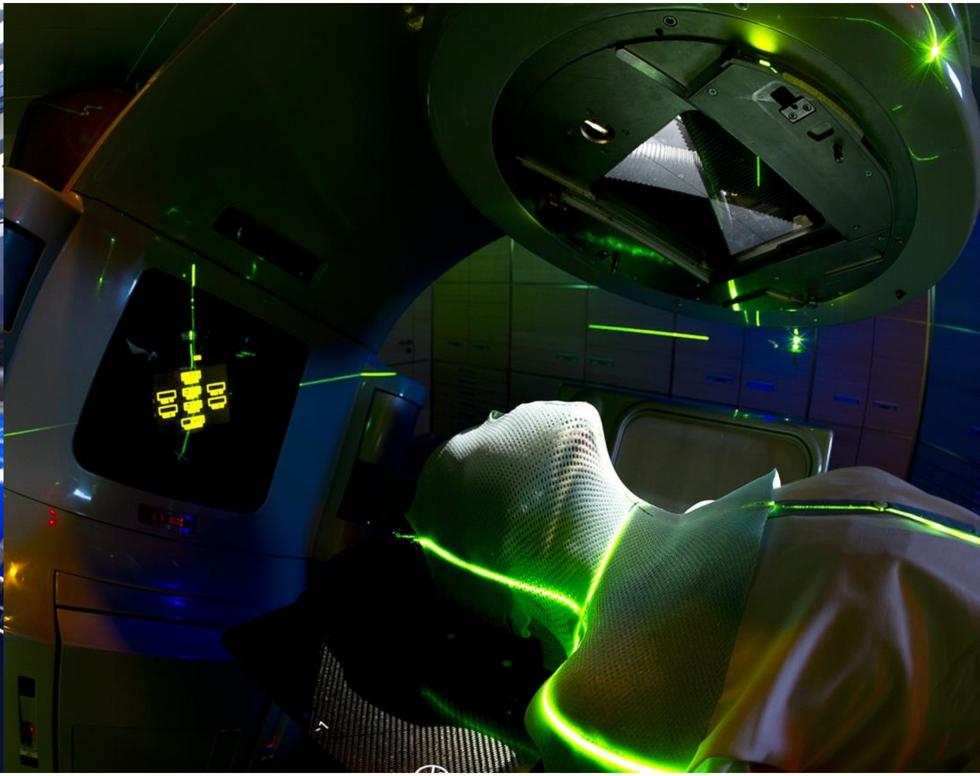
cern.ch/virtual-hadron-therapy-centre

Particle physics to medical applications

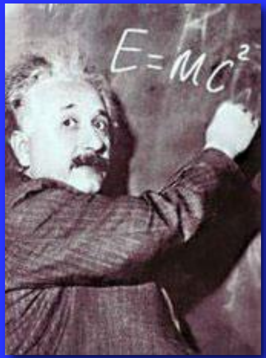
Manjit Dosanjh, CERN

What is CERN?

History of CERN

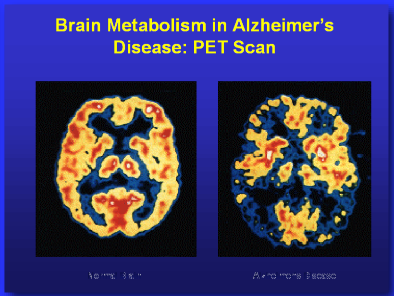

CERN: founded in September 1954: 12 European States
"Science for Peace"
Today: 23 Member States
~ 2500 staff
~ 1800 other paid personnel
~ 13000 scientific users
Member States: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovak Republic, Spain, Sweden, Switzerland and United Kingdom
Associate Members in the Pre-Stage to Membership: Cyprus, Slovenia
Associate Member States: India, Lithuania, Pakistan, Turkey, Ukraine
Applications for Membership or Associate Membership: Brazil, Croatia, Estonia
Observers to Council: Japan, Russia, United States of America;
European Union, JINR and UNESCO

What does CERN do?



- **Push back** the frontiers of knowledge

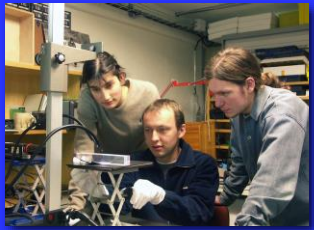
  E.g. what is matter, antimatter, the secrets of the Big Bang …first moments of the Universe's existence?

- **Develop** new technologies for accelerators and detectors

  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 tools used

1. Particle accelerator :

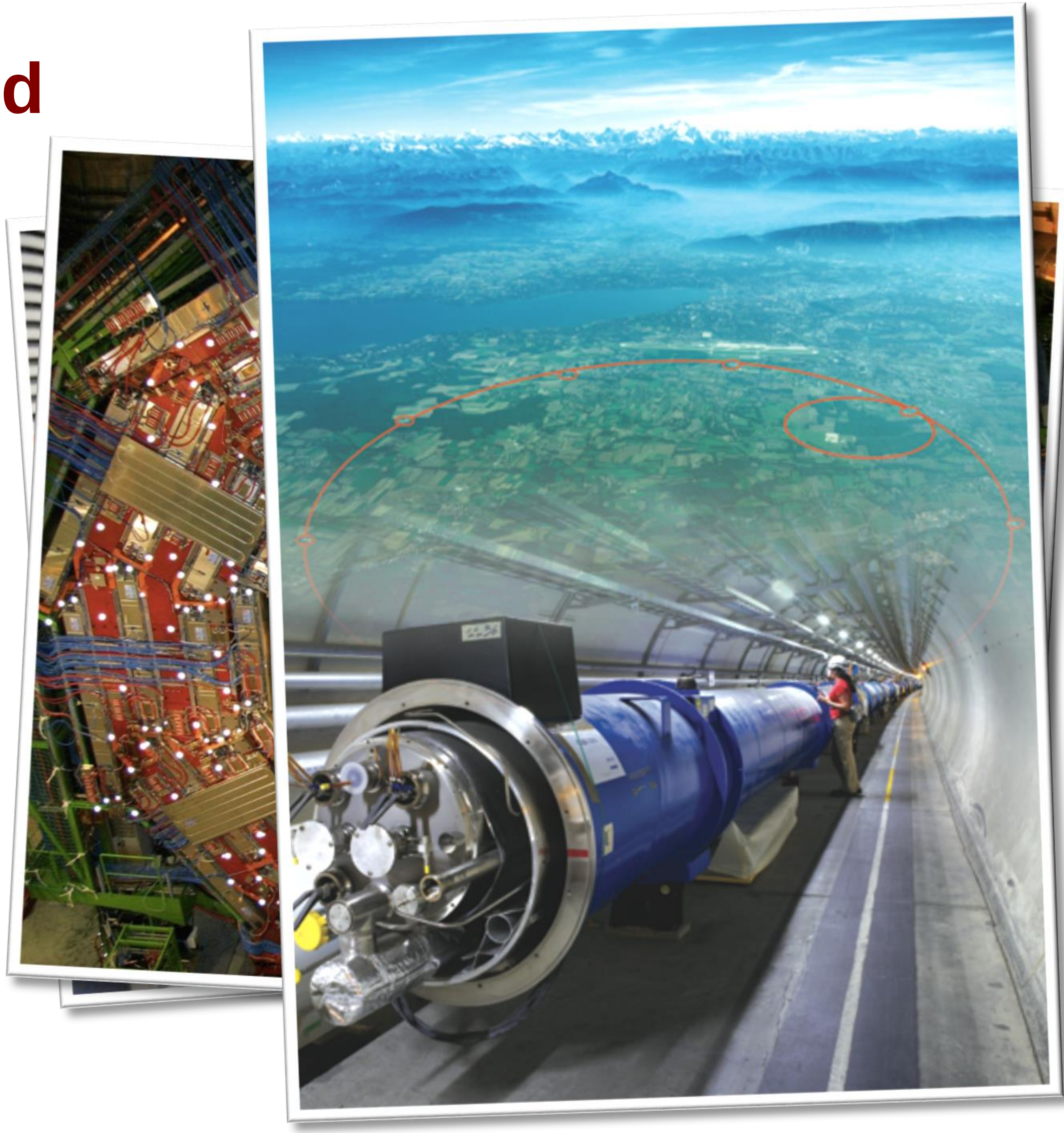
Accelerate particles and make them collide

2. Detectors :

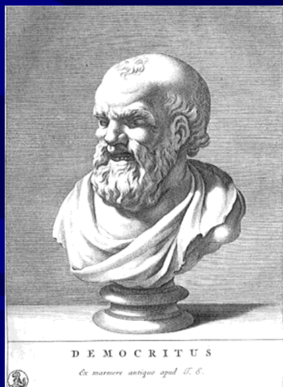
Huge instruments that detect and record the results of the collisions

3. Computers :

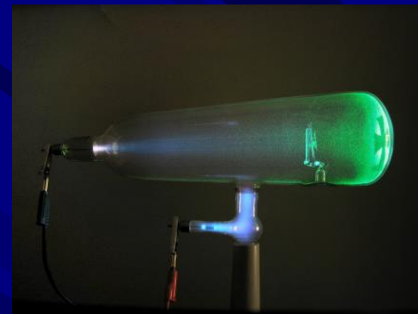
Collect, store, and share the huge quantity of data received from the detectors and analyse.



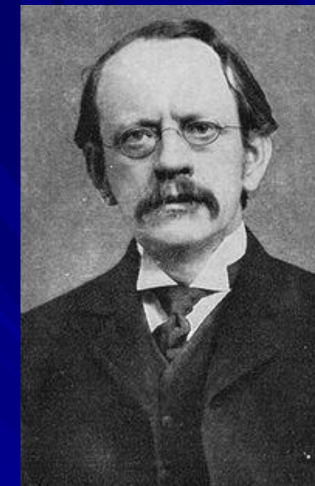
Democritus believed that all matter is made of indivisible elements, the atoms



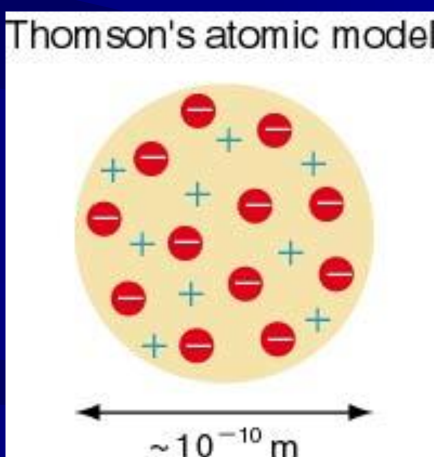
460-370BC



Discovery of the electron with cathode ray tube
first elementary particle
1896



JJ Thomson

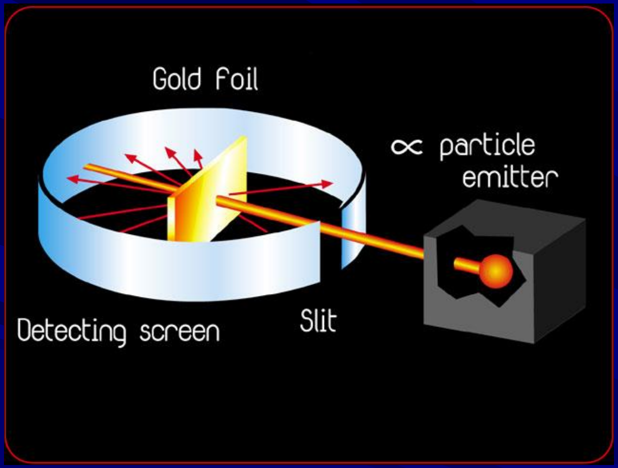


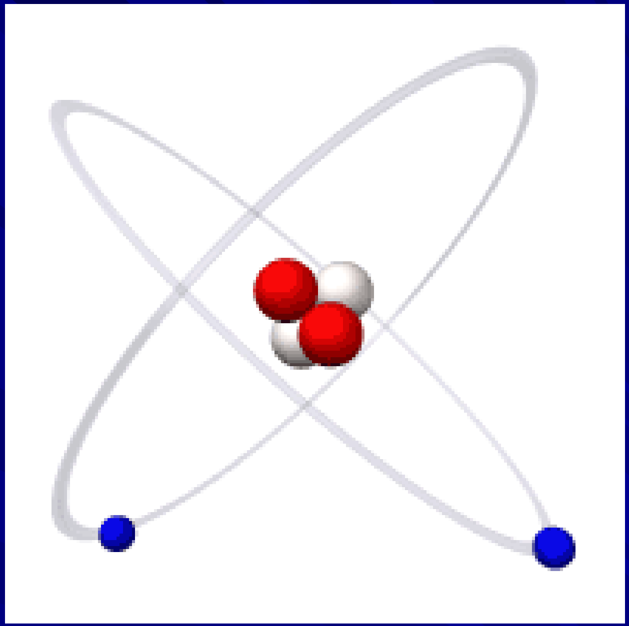
Thomson's plum pudding model (1904)

I	II	III	IV	V	VI	VII	VIII		
H 1.01									
Li 6.94	Be 9.01	B 10.8	C 12.0	N 14.0	O 16.0	F 19.0			
Na 23.0	Mg 24.3	Al 27.0	Si 28.1	P 31.0	S 32.1	Cl 35.5			
K 39.1	Ca 40.1		Ti 47.9	V 50.9	Cr 52.0	Mn 54.9	Fe 55.9	Co 58.9	Ni 58.7
Cu 63.5	Zn 65.4			As 74.9	Se 79.0	Br 79.9			
Rb 85.5	Sr 87.6	Y 88.9	Zr 91.2	Nb 92.9	Mo 95.9		Ru 101	Rh 103	Pd 106
Ag 108	Cd 112	In 115	Sn 119	Sb 122	Te 128	I 127			
Ce 133	Ba 137	La 139		Ta 181	W 184		Os 194	Ir 192	Pt 195
Au 197	Hg 201	Ti 204	Pb 207	Bi 209					
			Th 232		U 238				

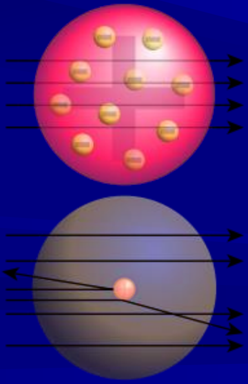
Mendeleev's periodic table of elements (1869) – 80 different indivisible atoms

1911 : introduction of Rutherford’s atomic model

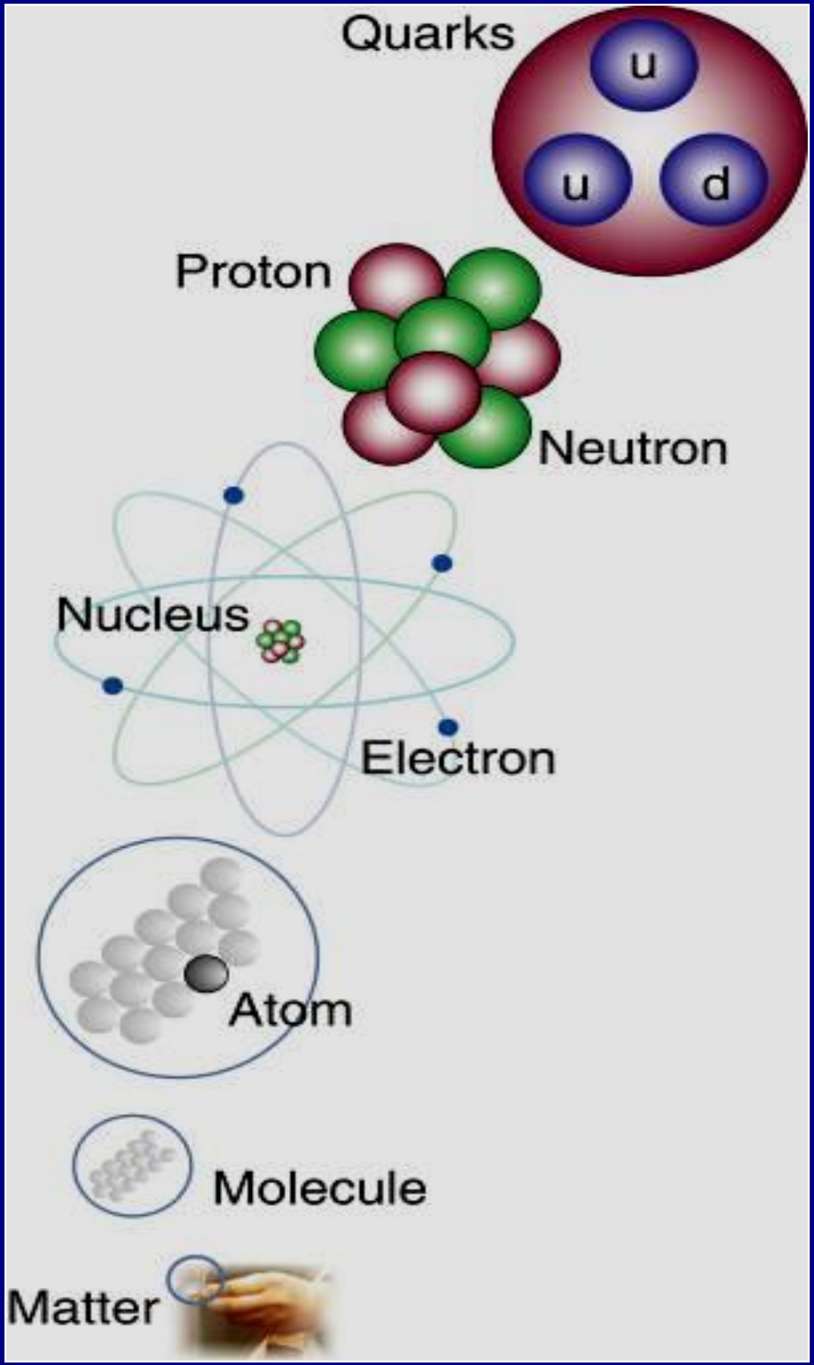


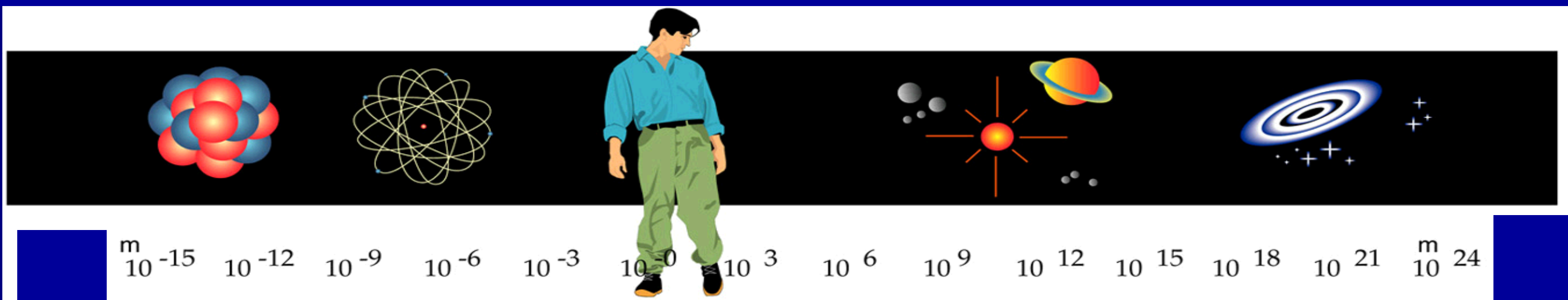


Rutherford



Nucleus: most of the mass, positive charge; atom is mainly empty
Later on found that the nucleus consists of protons and neutrons


Quarks
u
u
d
Proton
Neutron
Nucleus
Electron
Atom
Molecule
Matter



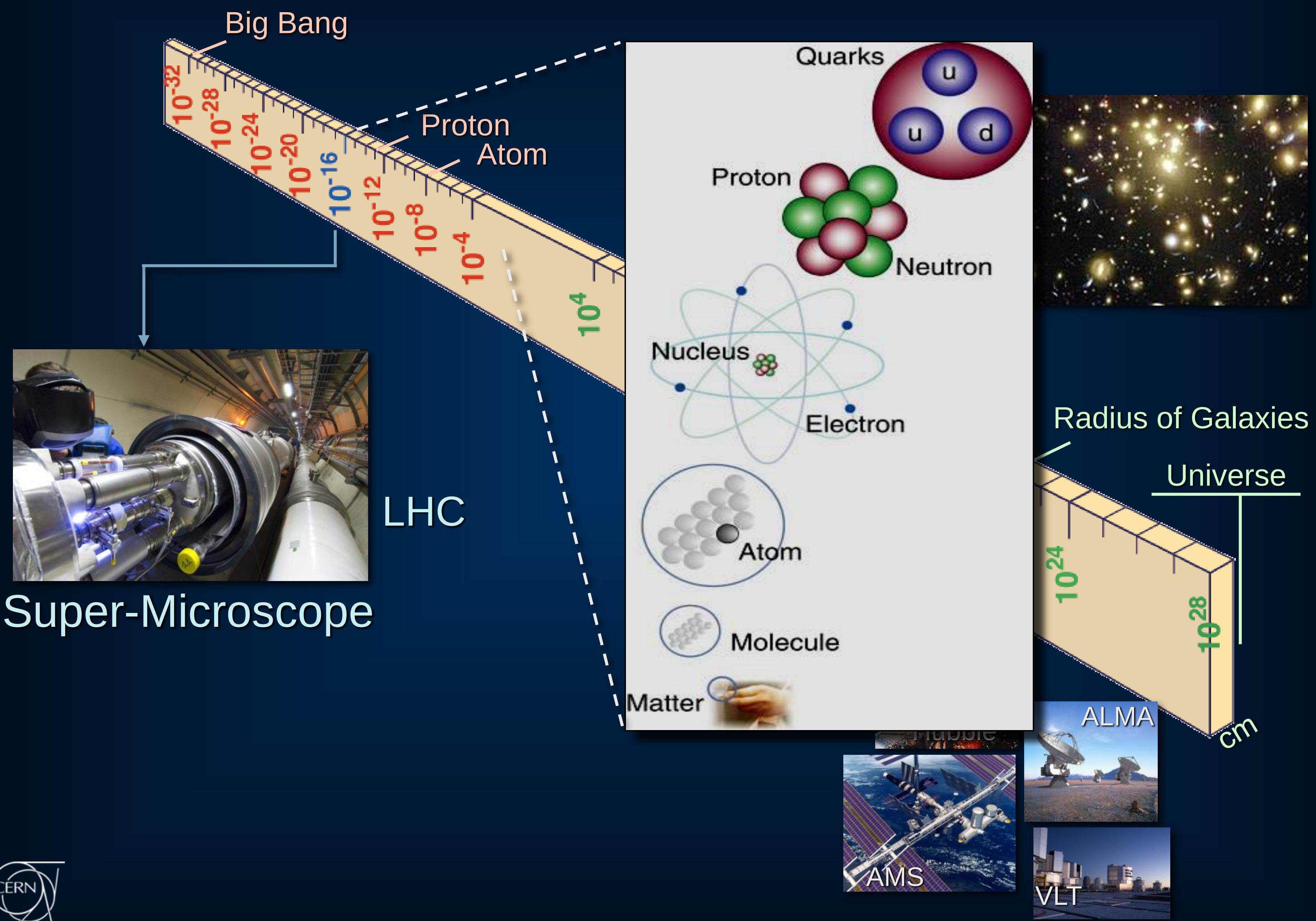
Accelerators

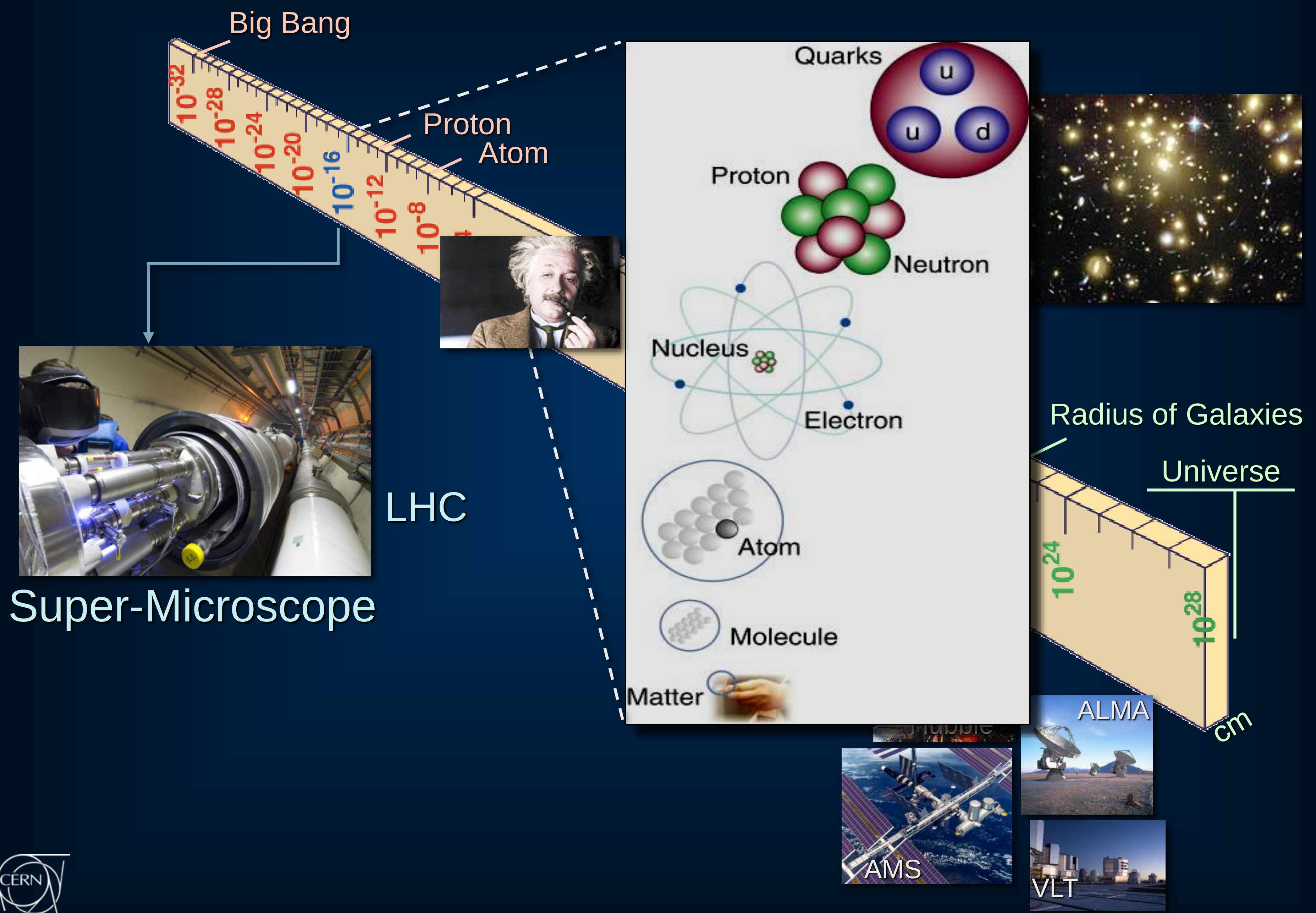
Microscopes

Binoculars

Optical and radio telescopes

Particle physics looks at matter in its smallest dimensions


Big Bang
10^{-32}
10^{-28}
10^{-24}
10^{-20}
10^{-16}
10^{-12}
10^{-8}
10^{-4}
10^{4}
Proton
Atom
Quarks
u
u
d
Proton
Neutron
Nucleus
Electron
Atom
Molecule
Matter
Radius of Galaxies
Universe
10^{24}
10^{28}
cm
ALMA
AMS
VLT
LHC
Super-Microscope


Big Bang
Proton
Atom
10^-32
10^-28
10^-24
10^-20
10^-16
10^-12
10^-8
Quarks
u
u
d
Proton
Neutron
Nucleus
Electron
Atom
Molecule
Matter
Radius of Galaxies
Universe
10^24
10^28
cm
LHC
Super-Microscope
ALMA
AMS
VLT

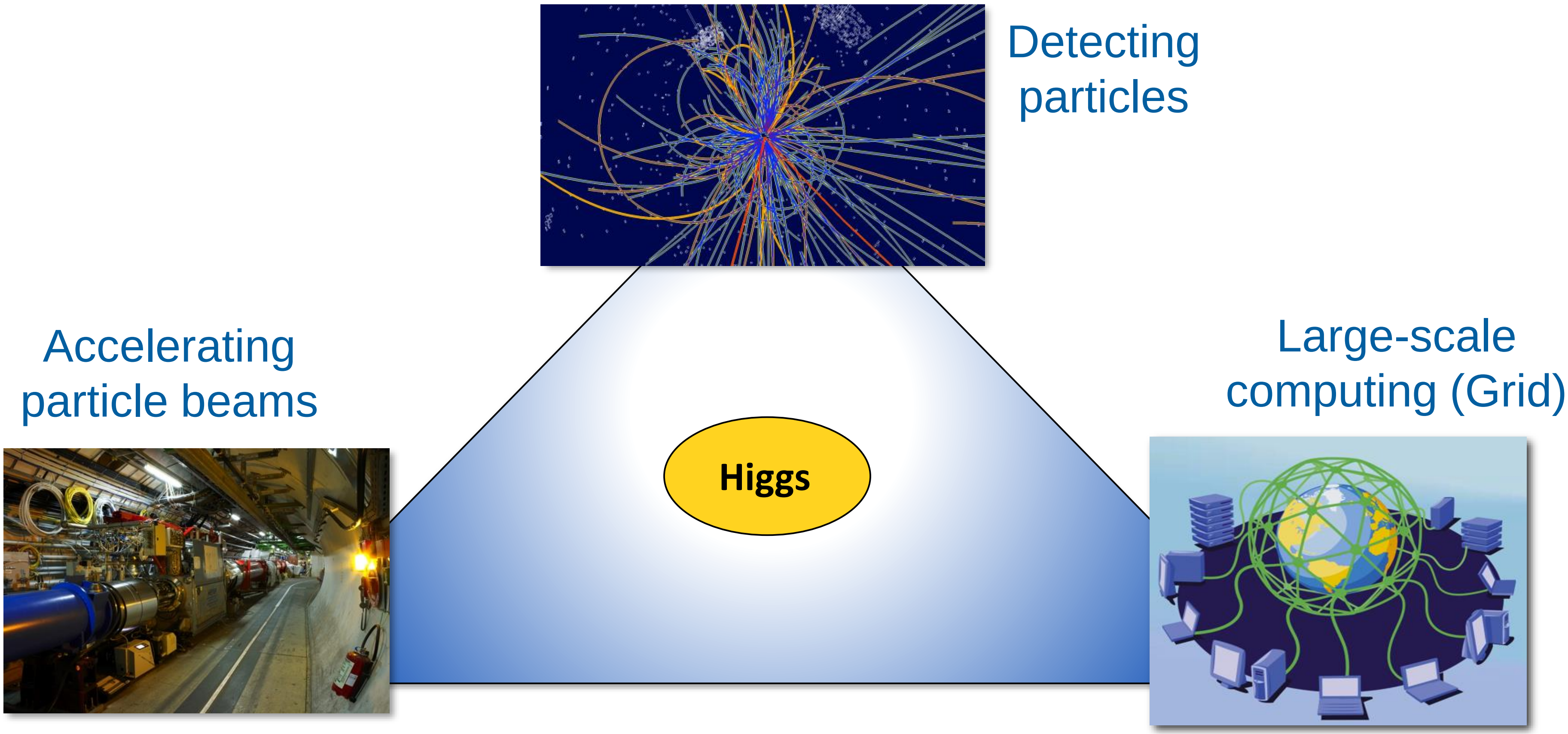
LHC and the 4 big experiments

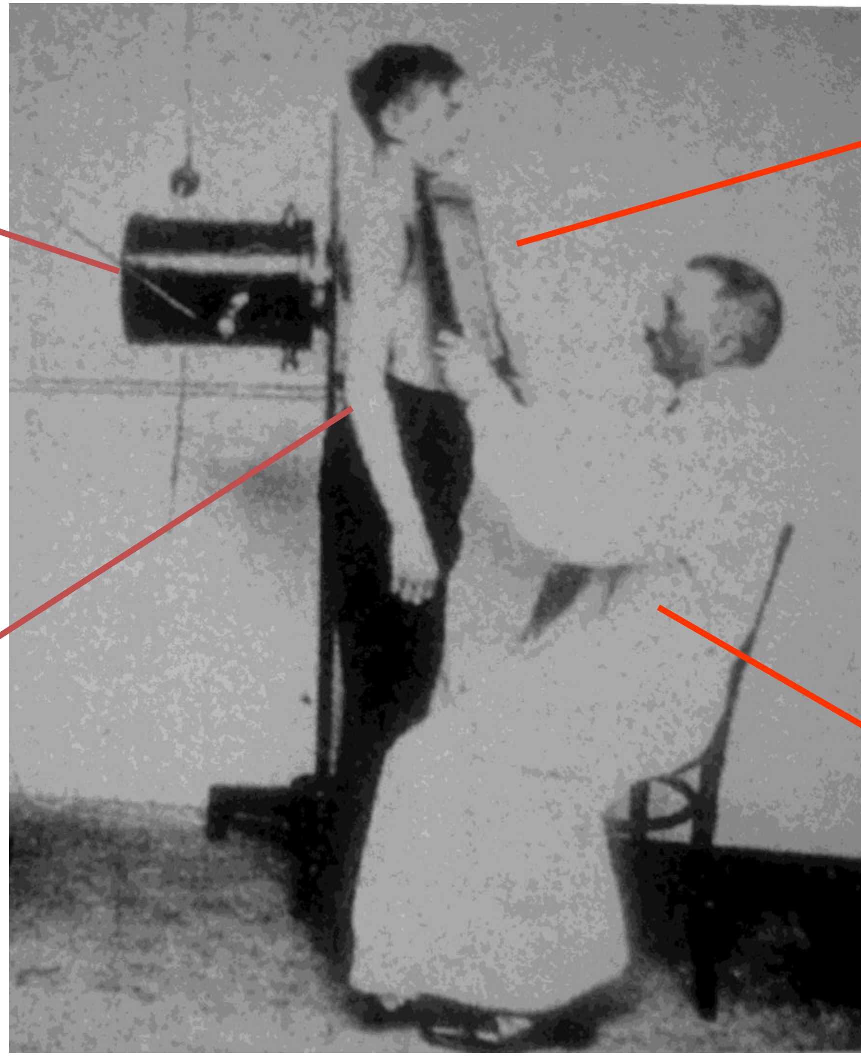
Discovery 2012, Nobel Prize in Physics 2013

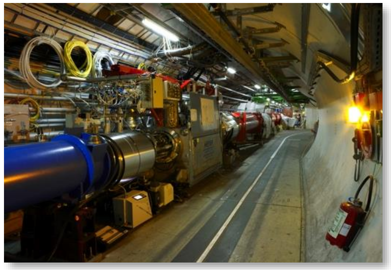
The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments*

Physics and Medical Applications

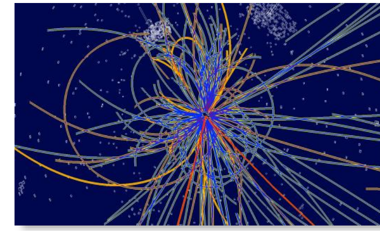
Physics Technologies



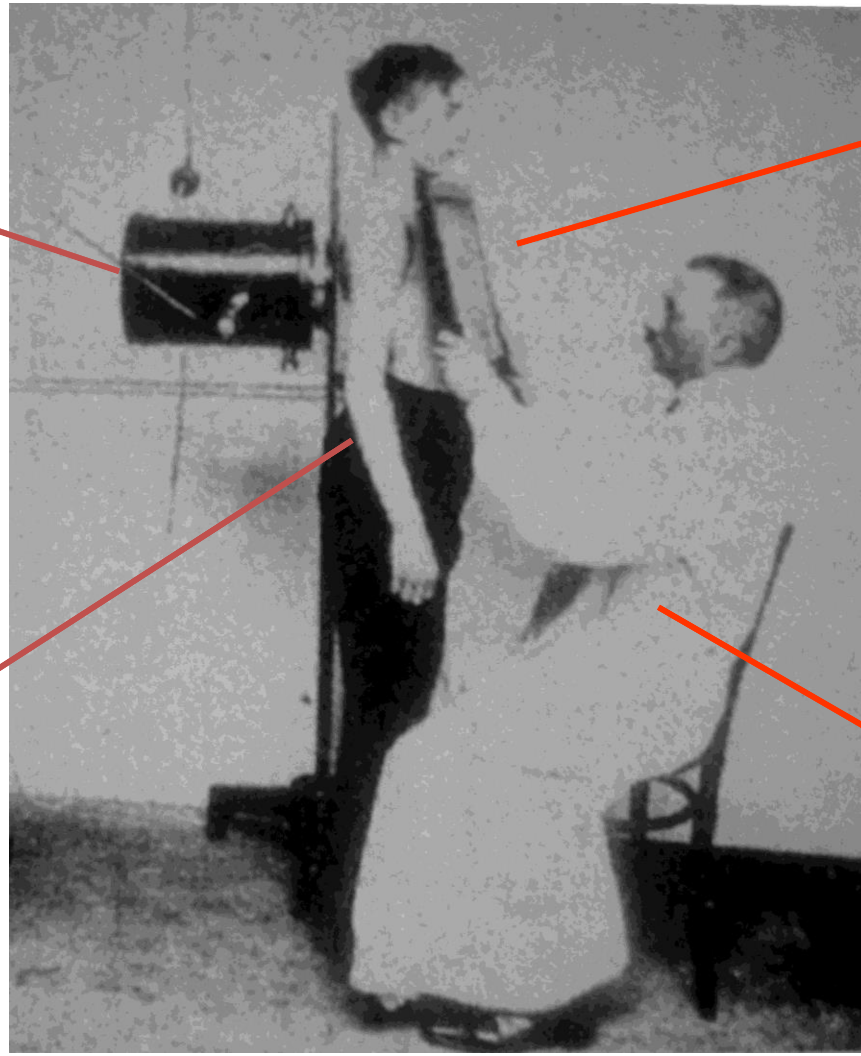

X-ray source
Detector
Object
Pattern Recognition System



X-ray source



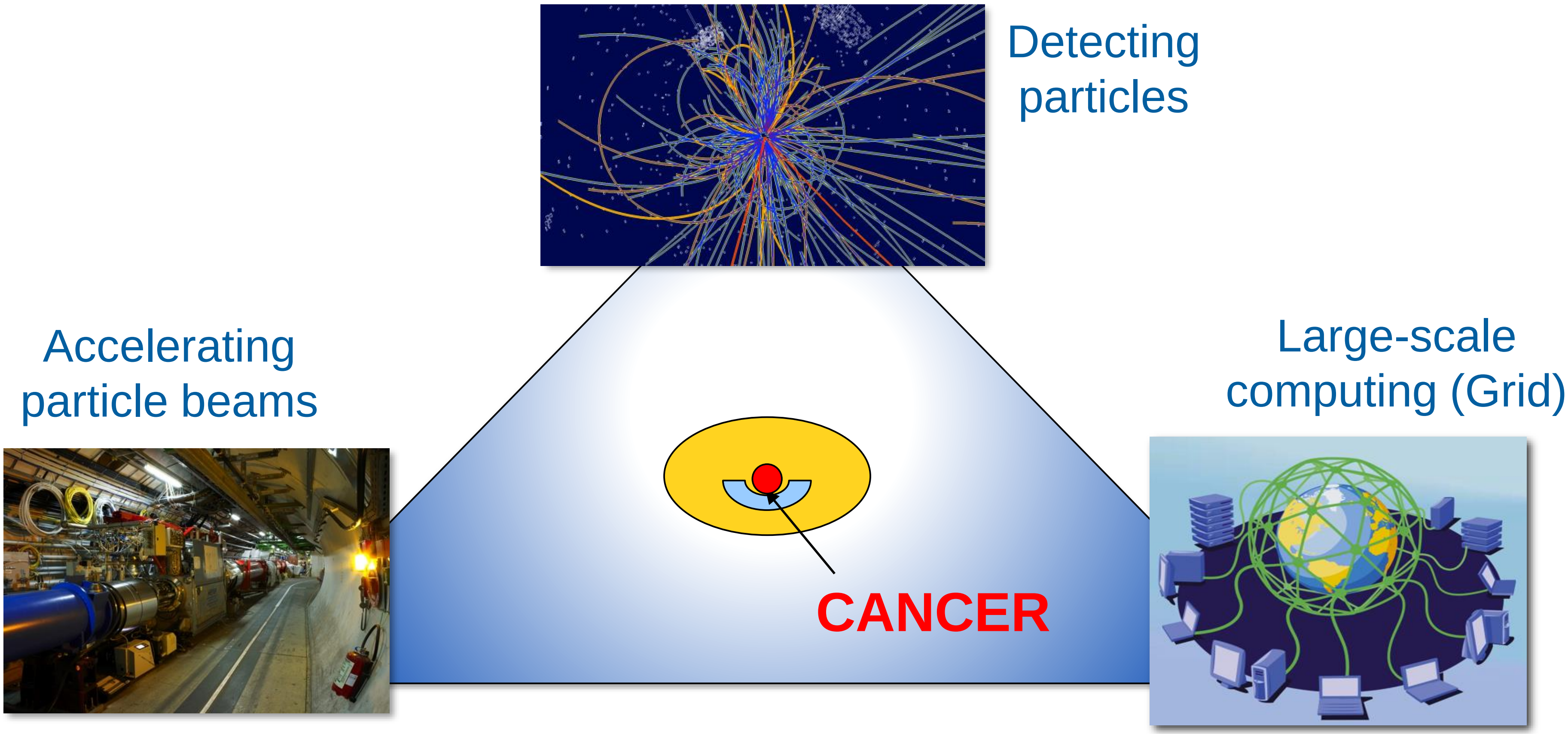
Detector



Object

Pattern Recognition System

Physics Technologies



Why Cancer and Physics Technologies?

It is a large and a growing societal challenge:

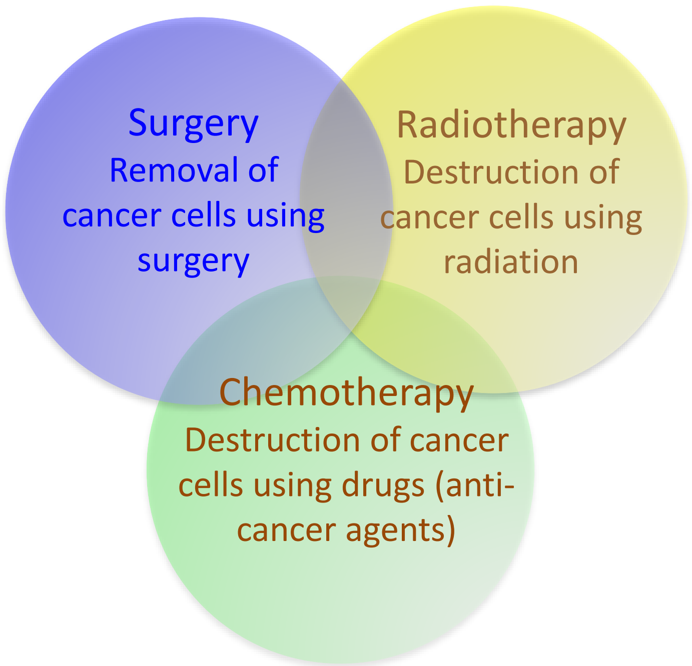
- More than **3 million new cancer cases** in Europe in 2015
- Nearly 15 million **globally** in 2015
- This number will increase to 25 million in **2030**
- Currently around **8 million deaths** per year

How can physics help?

Cancer

Tumour: what is it and why?

- Abnormal growth of cells
- Uncontrolled growth, can spread → cancer



The Challenge of Treatment

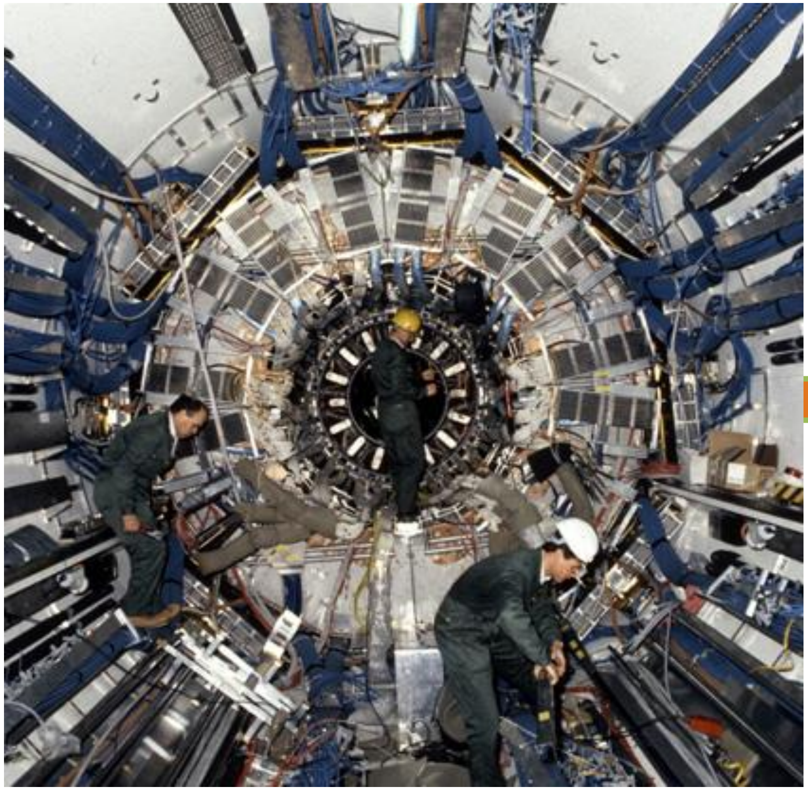
Ideally one needs to treat:

- The tumour
- The whole tumour
- And nothing **BUT** the tumour

Treatment has two important goals to kill the tumour and protect the surrounding normal tissue. Therefore "seeing" in order to know where and precise "delivery" to make sure it goes where it should are key.

Imaging Slides

Art of seeing………

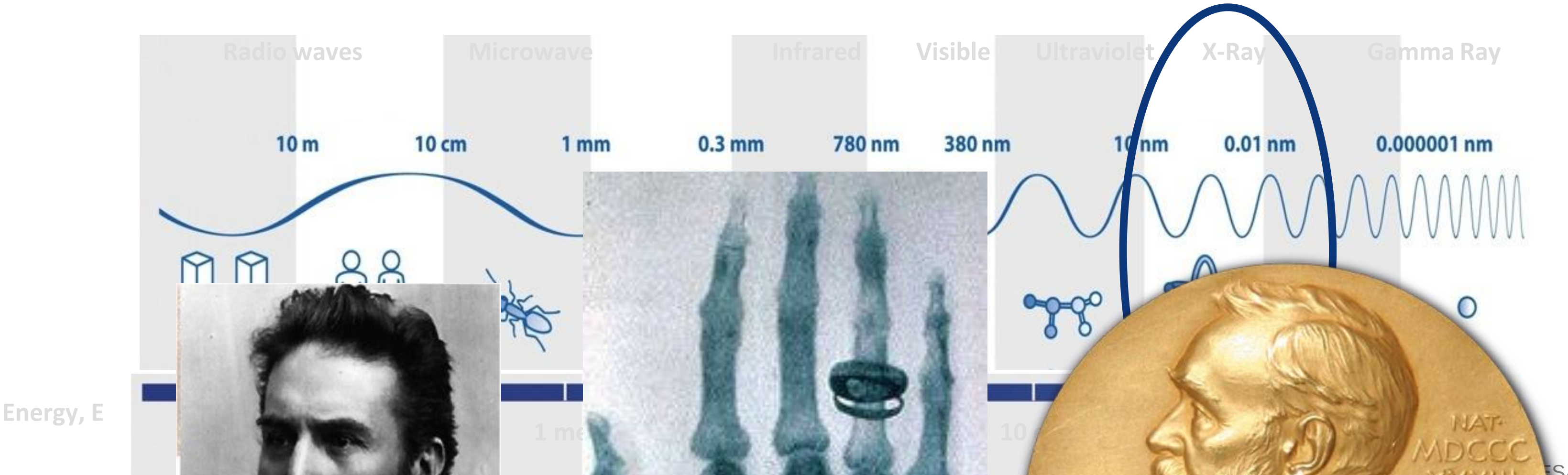


X-ray, CT, PET, MRI

Imaging

Particle Detection

Beginnings of X-ray imaging



Wilhelm Röntgen

8/11/1895

22/12/1895

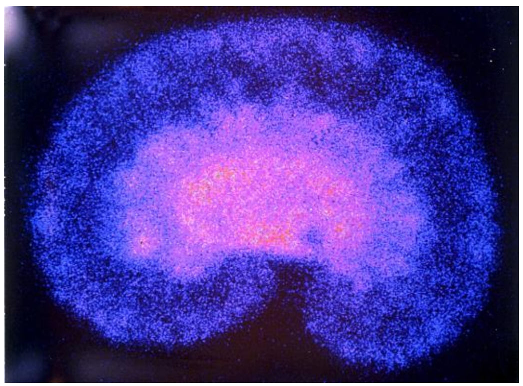
1901

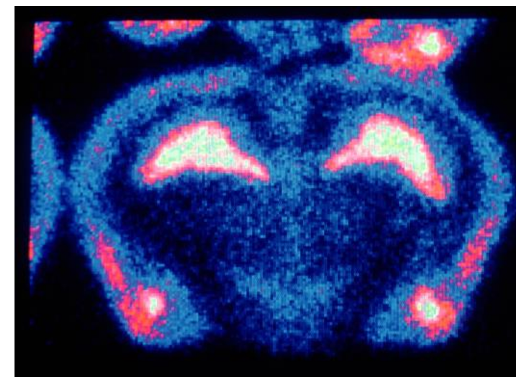
Low dose digital X-Ray Imaging

1968

Physics Nobel Prize 1992

Georges Charpak

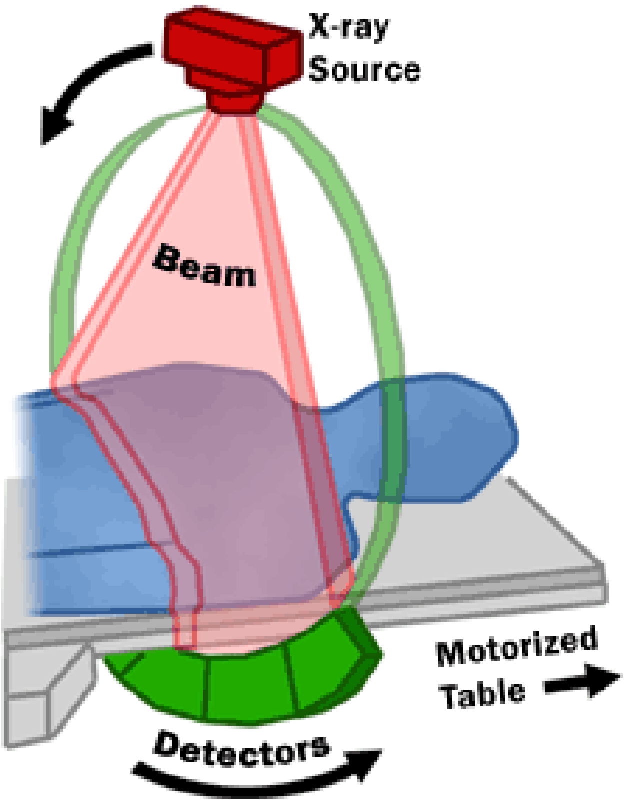




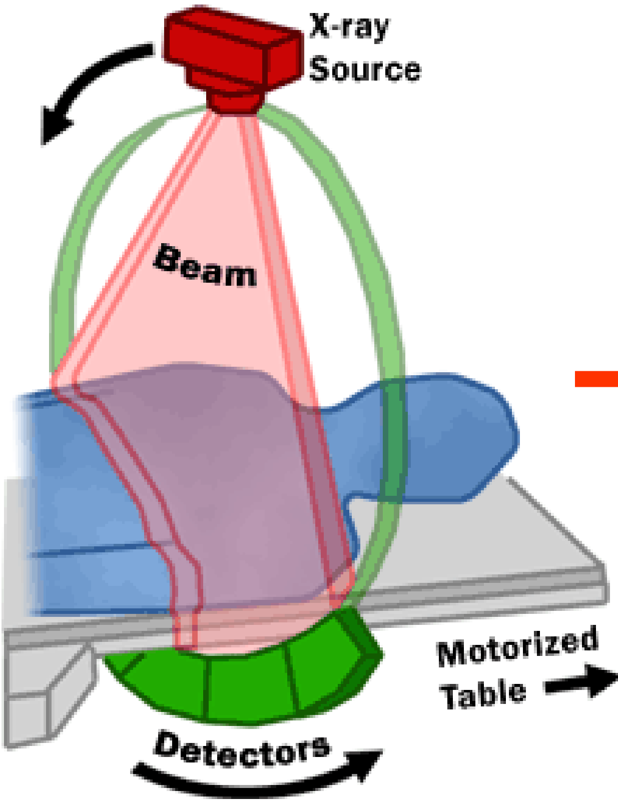
Low dose X-ray image of rat brain and kidney the use of MWPC

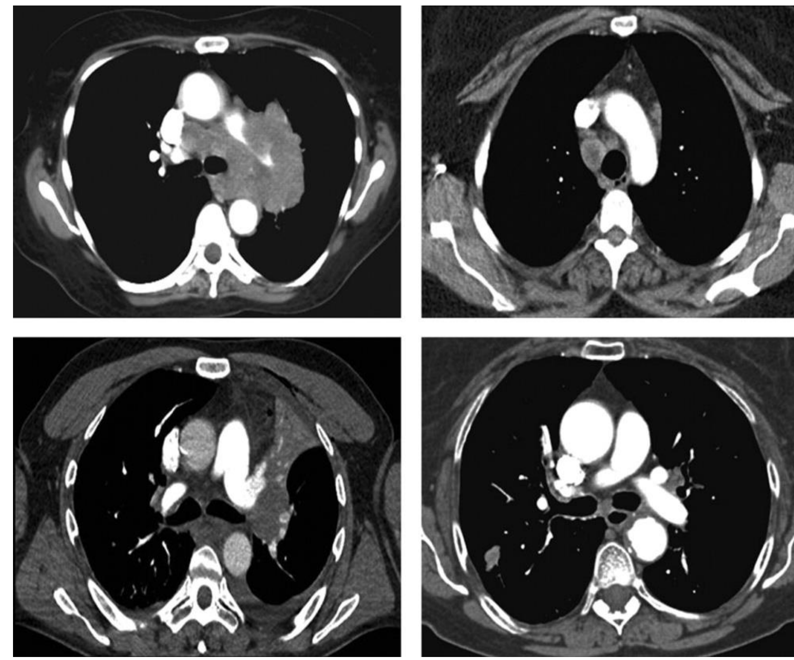
CT – Computed Tomography

"3d X-rays"



CT – Computed Tomography





"3D-imaging"

Real Time Imaging

Revolution in Photography

From black and white photos To Modern High-Tech photography

Revolution in X-ray imaging

simple X-Ray

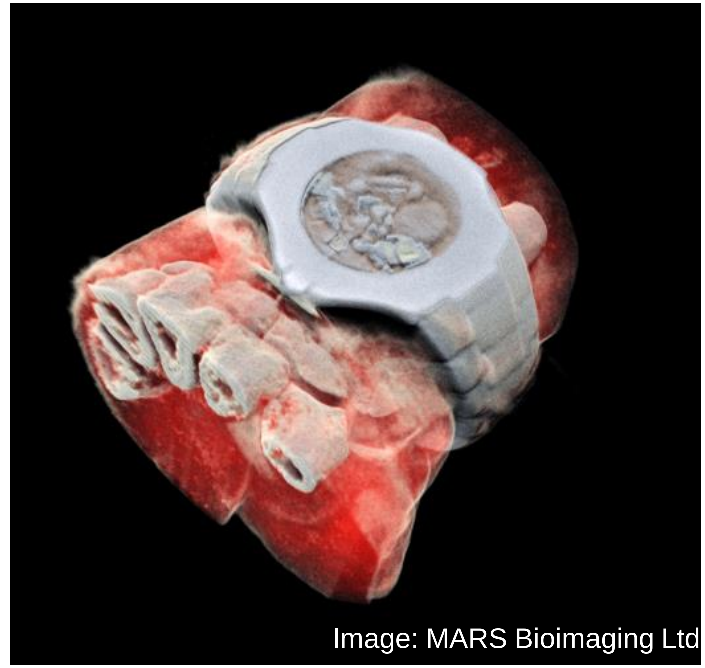
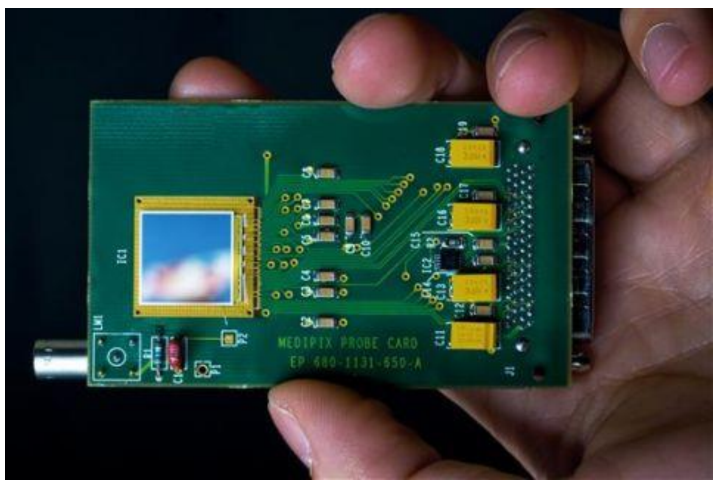


Image: MARS Bioimaging Ltd

3D human colour image



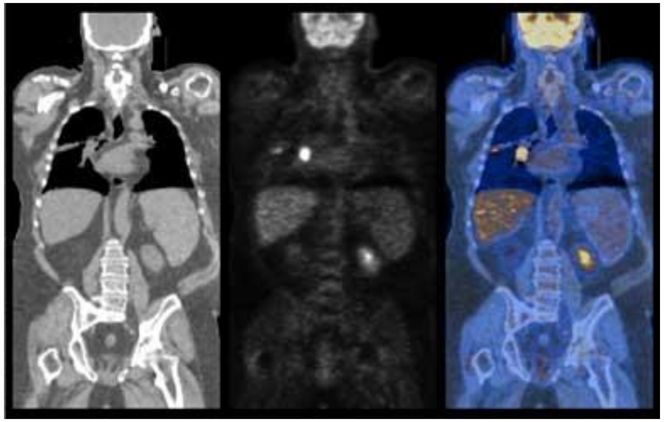
Medipix Chip

medipix collaboration

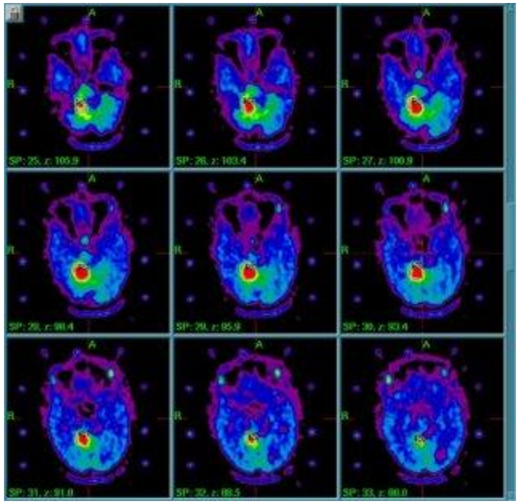
How can you tell that something is wrong inside the body?

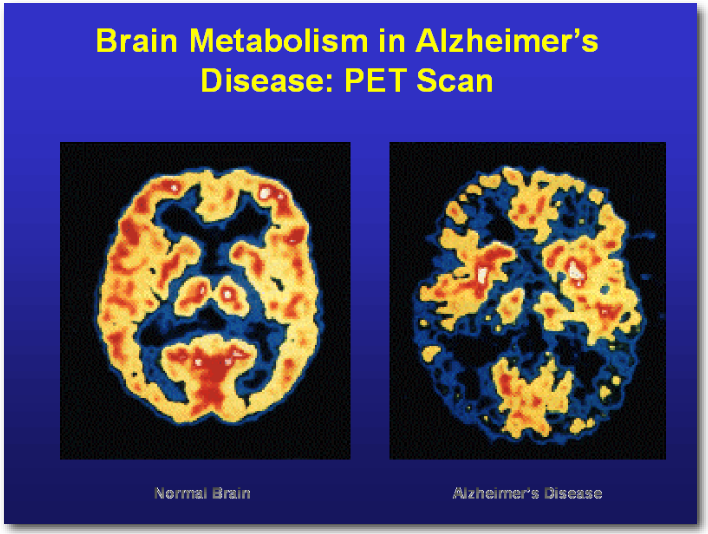
PET: antimatter for clinical use

- Not only science-fiction

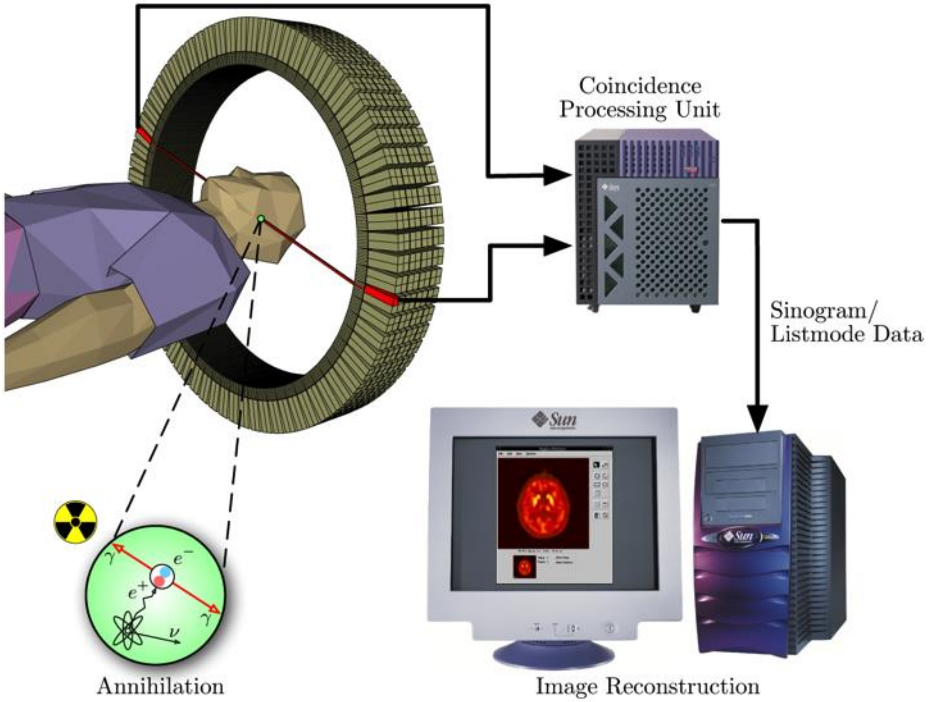


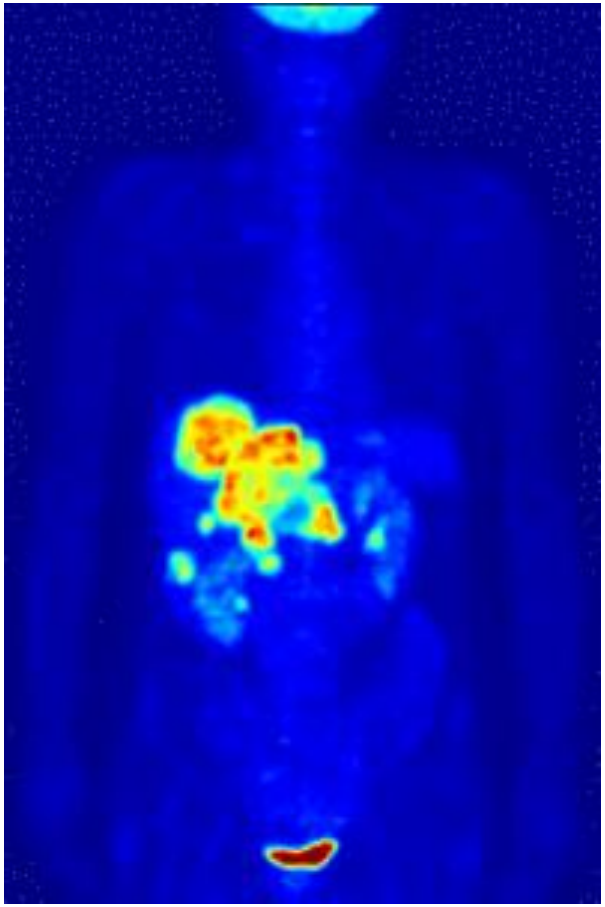
- Positrons are used in PET:
- PET = Positron Emission Tomography





Positron Emission Tomography



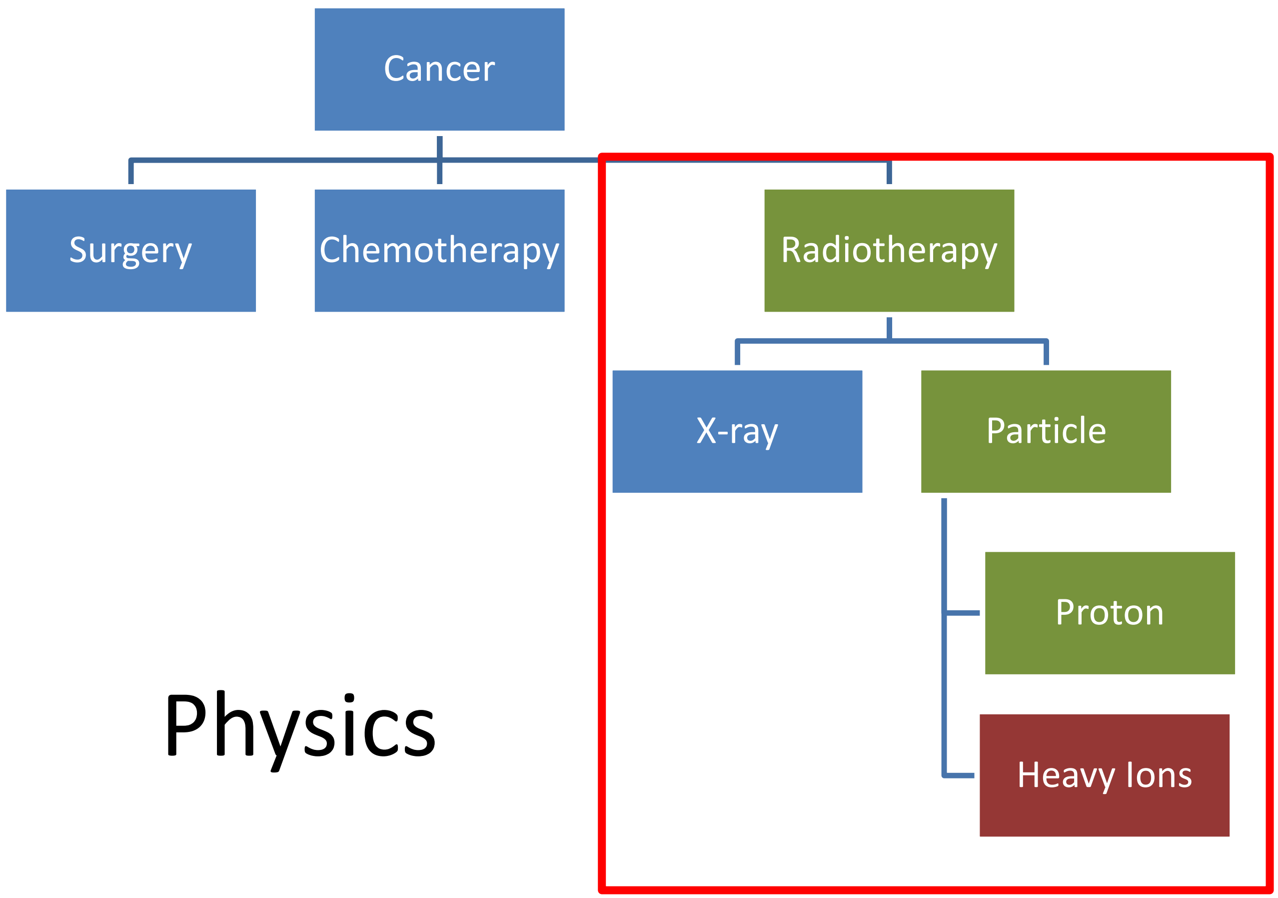


- ^{18}FDG carries the ^{18}F to areas of high metabolic activity
- 90% of PET scans are in clinical oncology
- 3D - image


ENVISION
European NoVel Imaging Systems
for ION therapy

Treatment

Cancer treatment options



Physics

Radiotherapy in 21st Century

3 "Cs" of Radiation

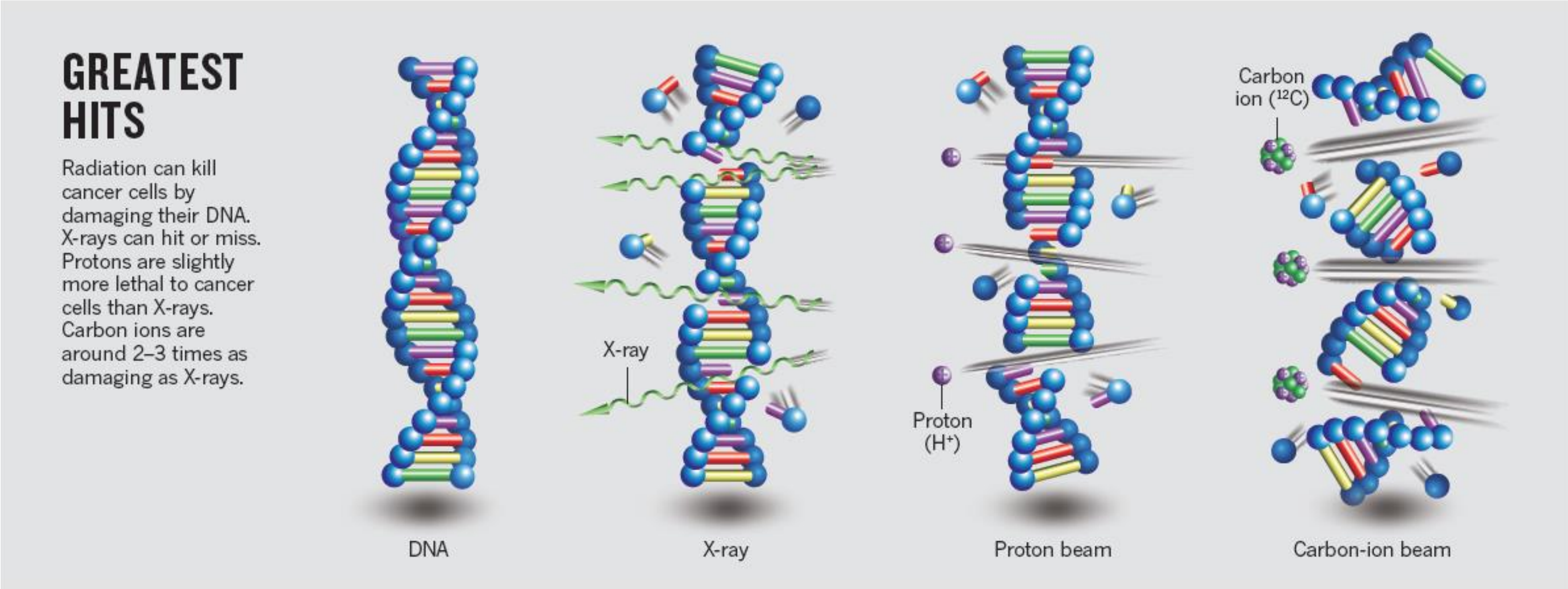
Cure (about 50% cancer cases are cured)

Conservative (non-invasive, fewer side effects)

Cheap (about 10% of total cost of cancer on radiation)

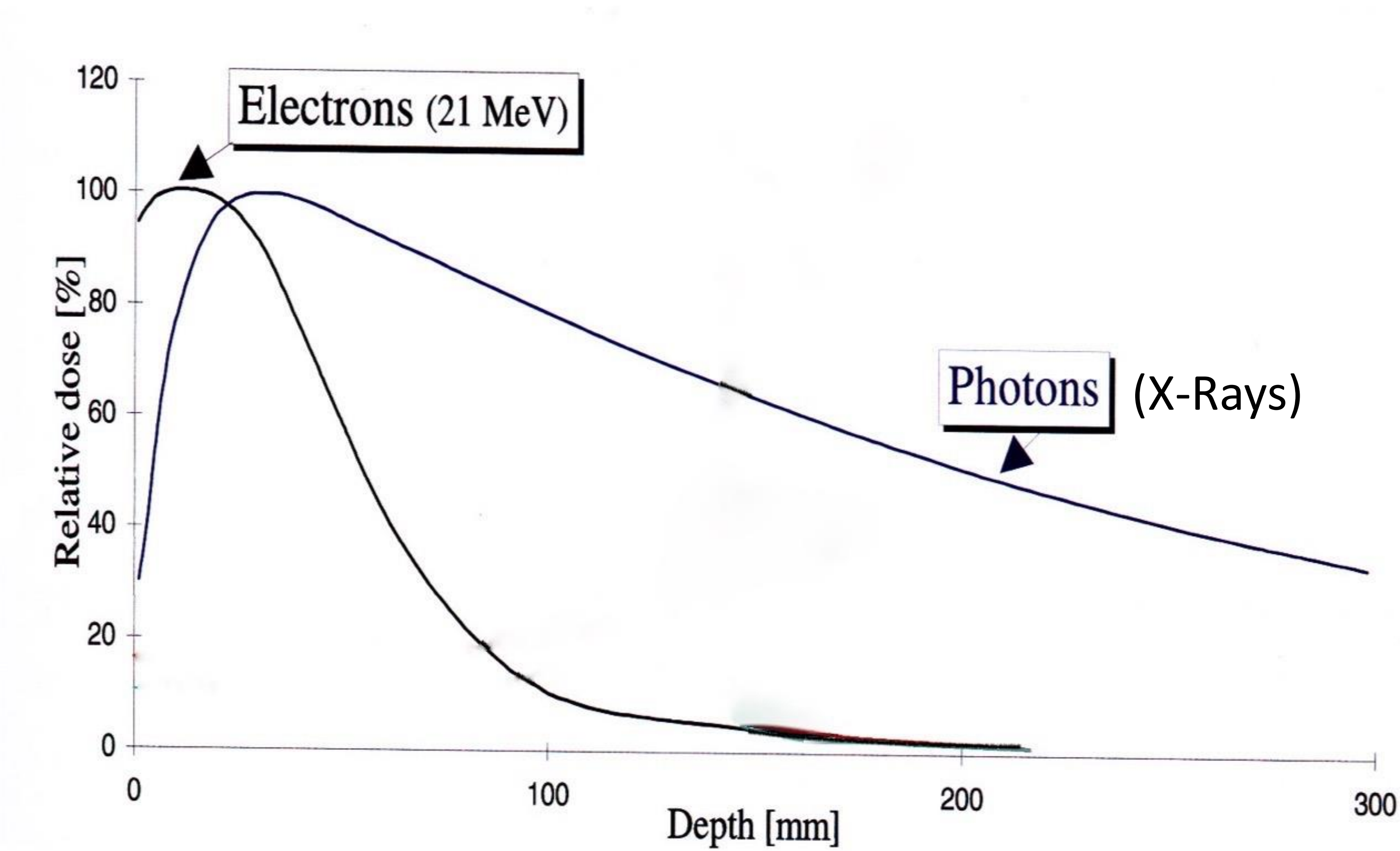
(J.P.Gérard)

DNA **X-rays** **Protons** **Carbon ions**



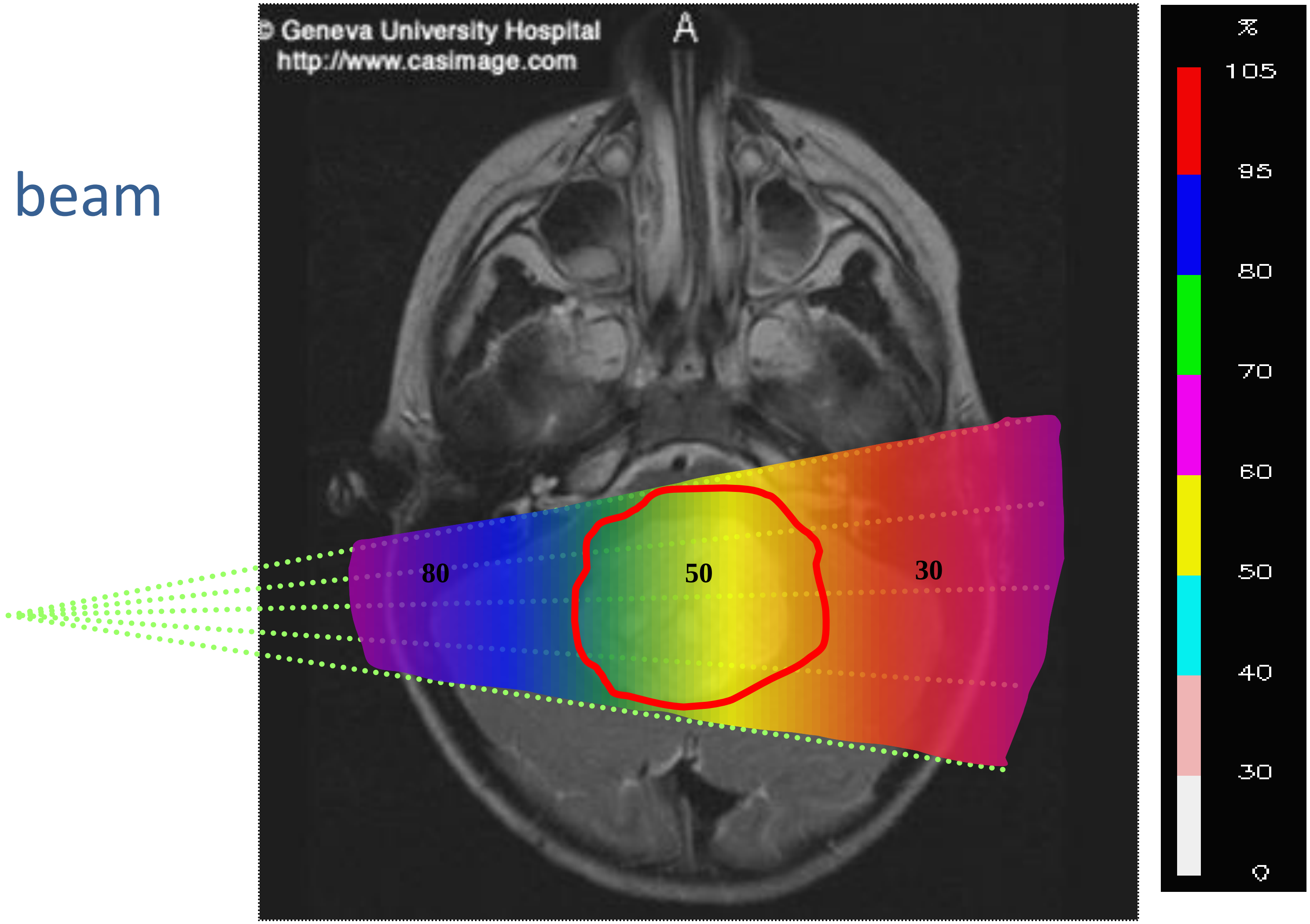
Marx, Nature, 2014

Radiation therapy



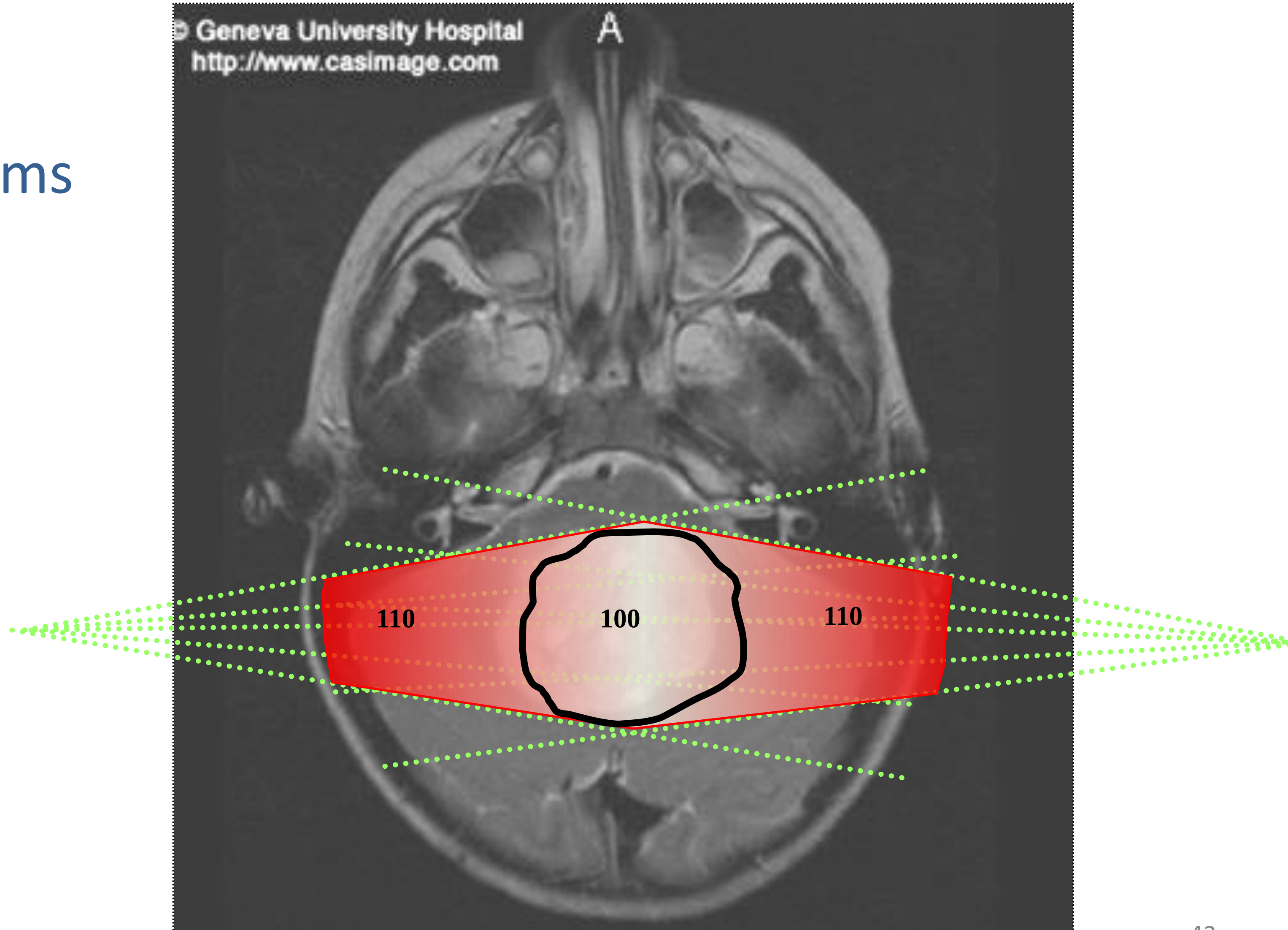
Classical Radiotherapy with X-rays

single beam

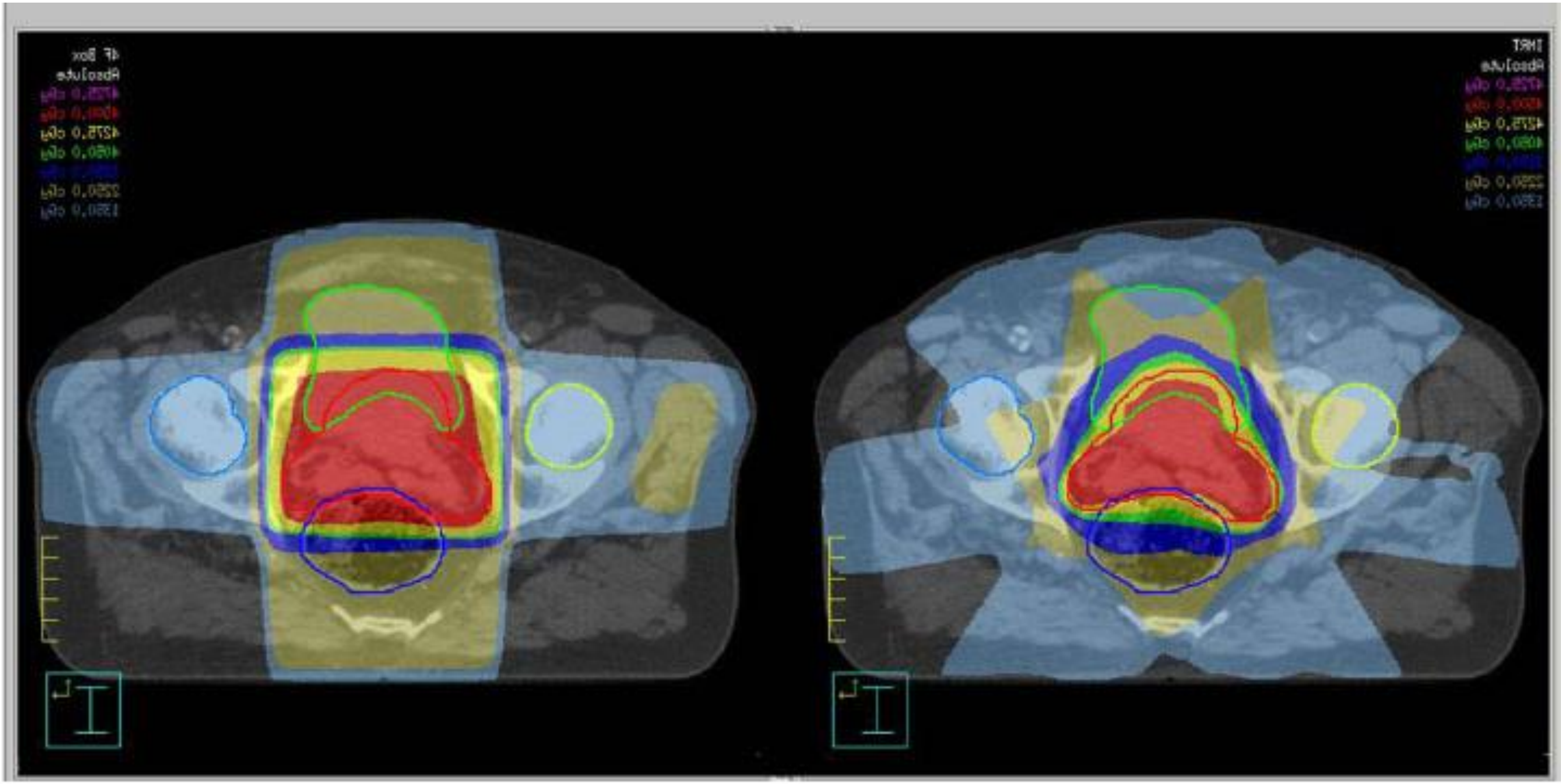


Radiotherapy with X-rays

two beams



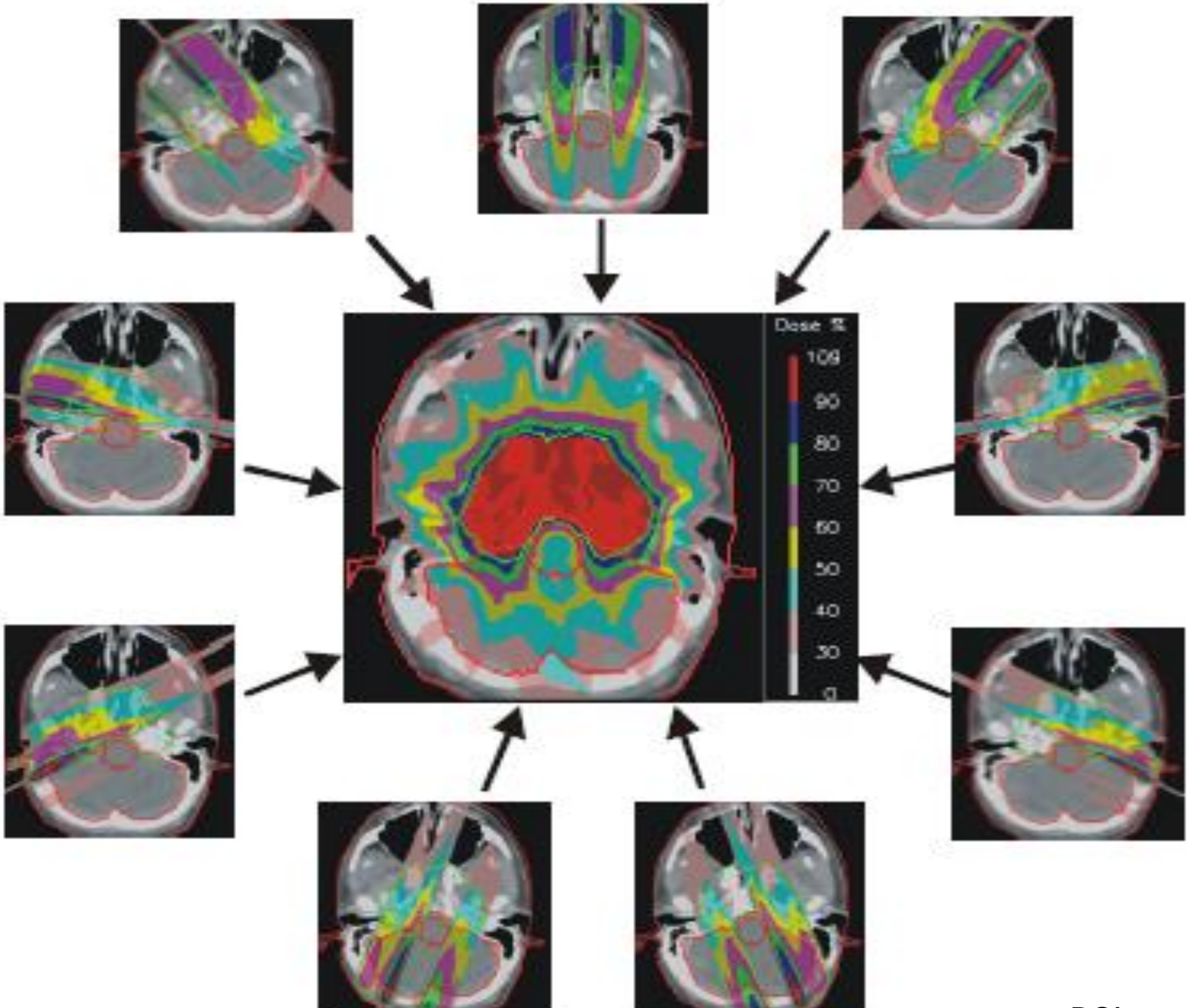
Improved Delivery



1990s: 4 beams with the same shape

Current state of RT: many beams with different shapes to target the tumour

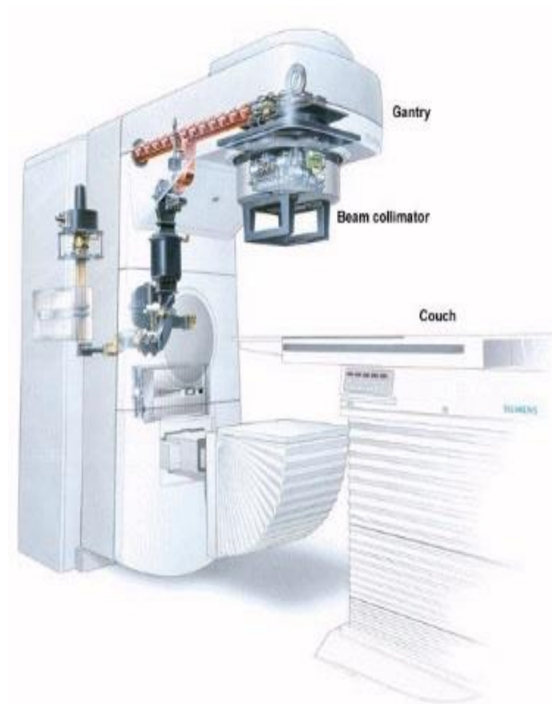
9 NON-UNIFORM FIELDS

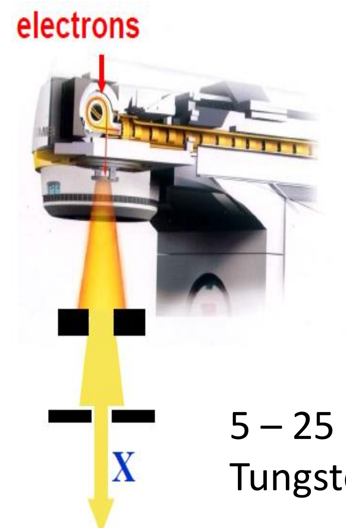


PSI

The most widespread accelerator

Electron Linac (linear accelerator) for radiotherapy (X-ray treatment of cancer)





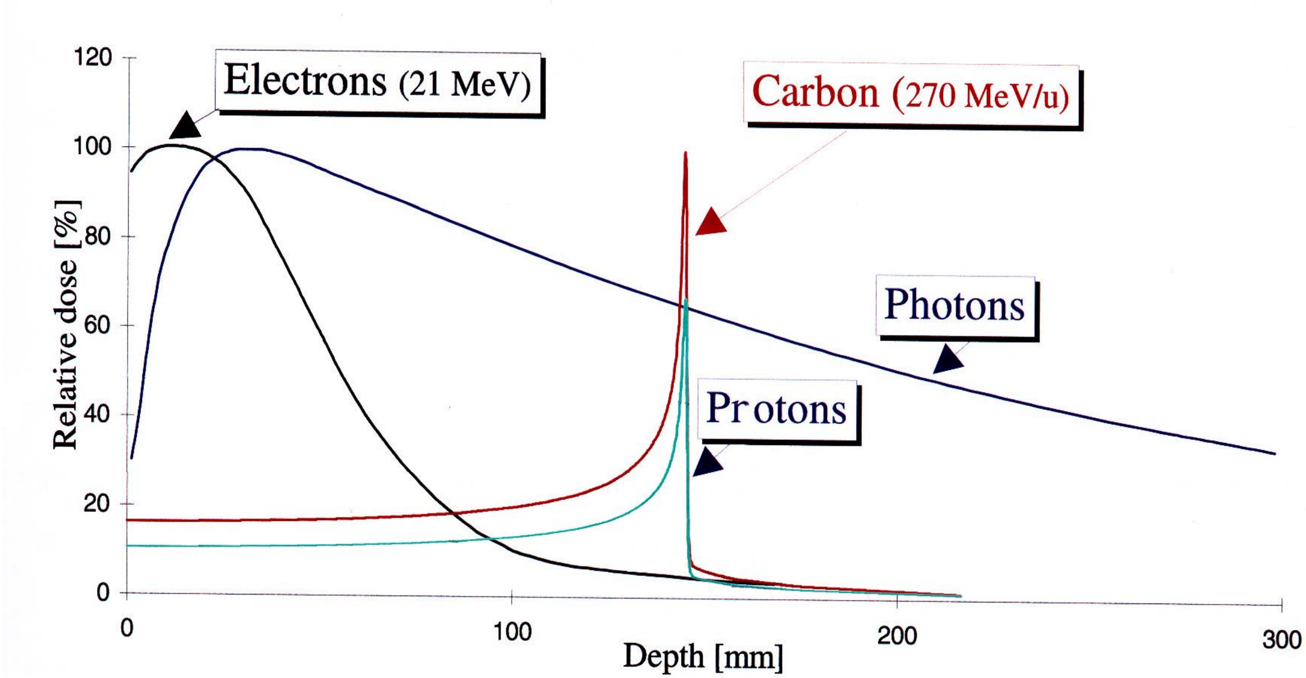
5 – 25 MeV
Tungsten target

Hadron Therapy

Why Hadron Therapy?

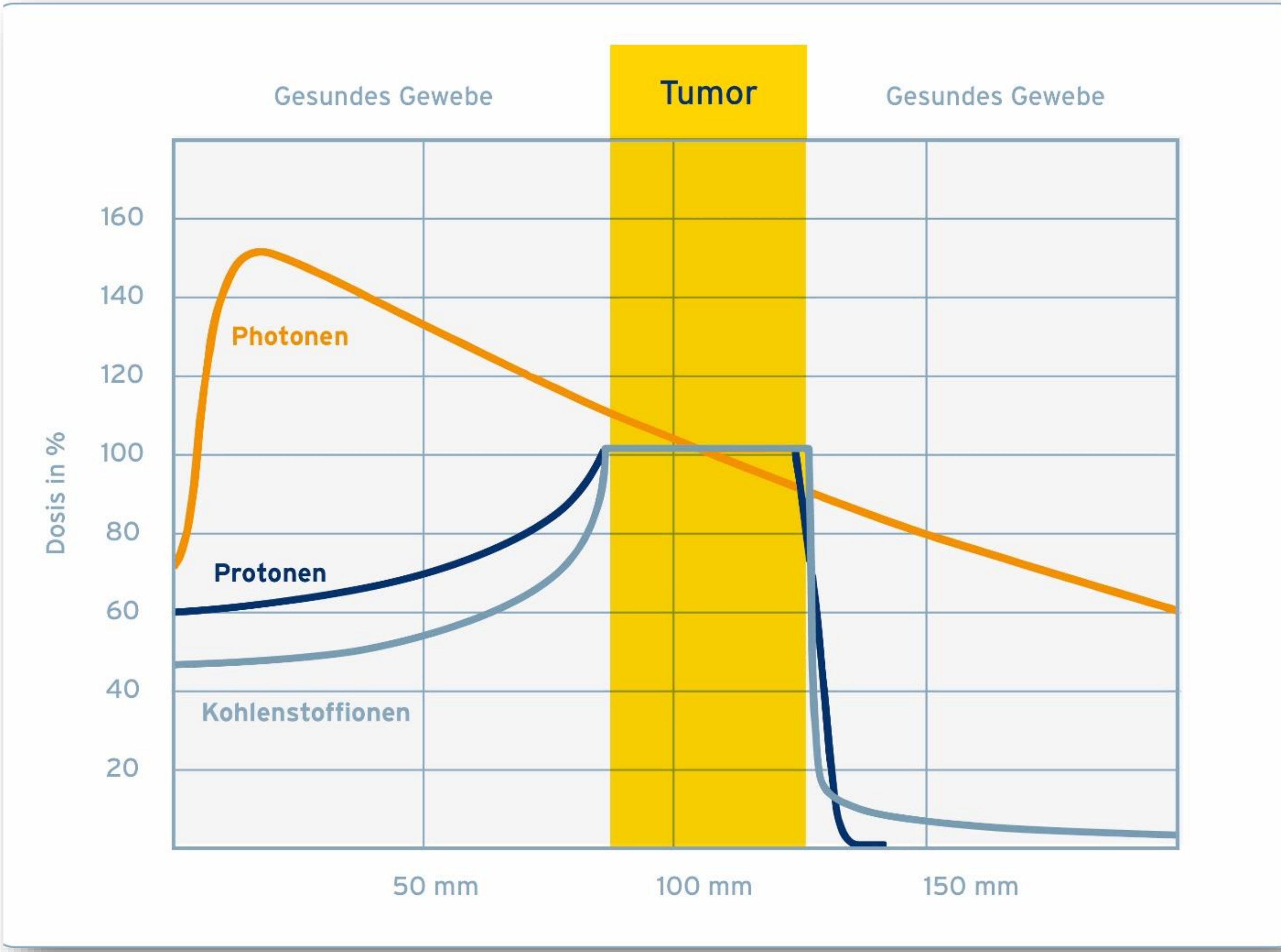
In 1946 Robert Wilson:

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



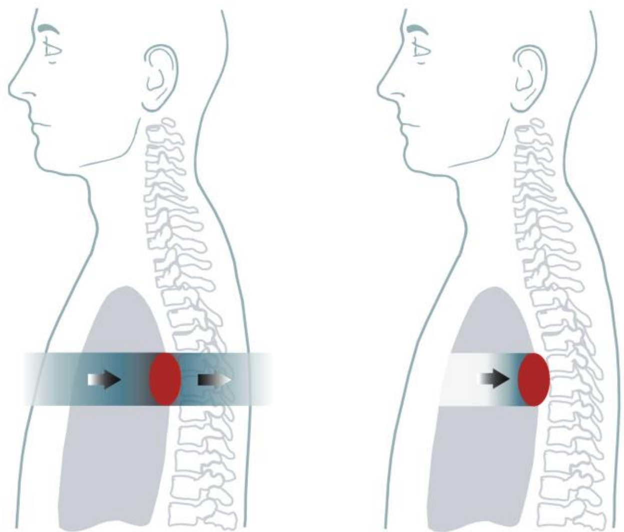
Depth in the body (mm)

Hadron Therapy

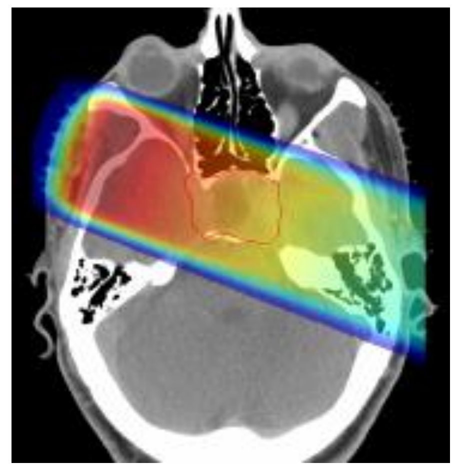


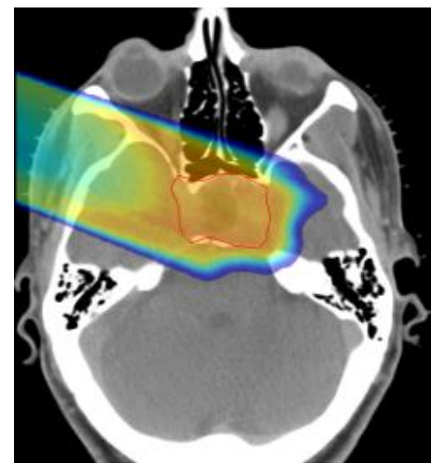
Why hadron therapy?

Image courtesy MedAustron



Conventional: X-Rays   Ion Radiation

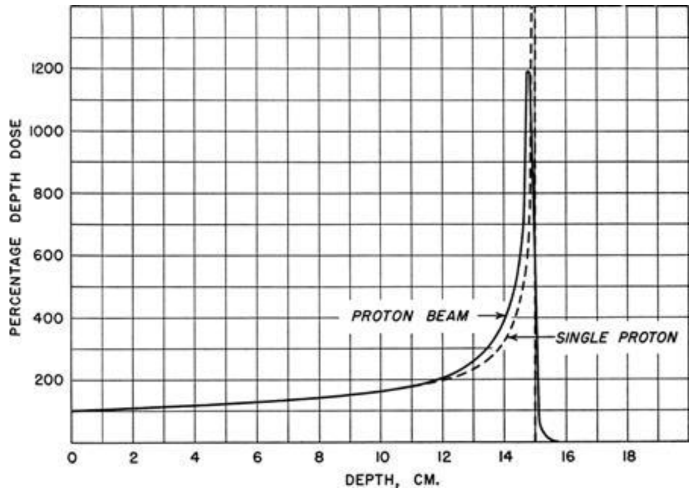




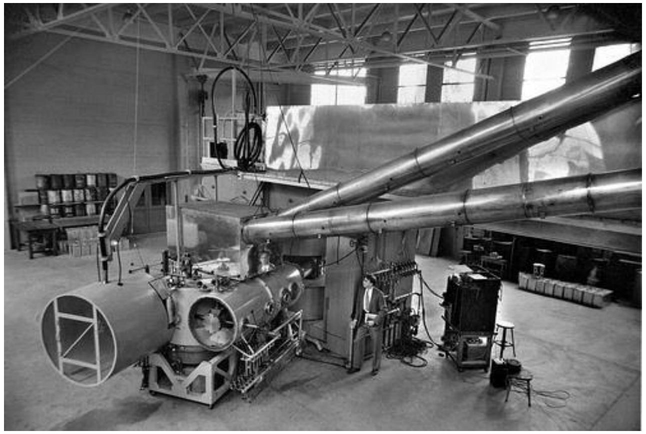
Spares normal healthy tissue

1932 - E. Lawrence First cyclotron

1946 – proton therapy proposed by R. Wilson

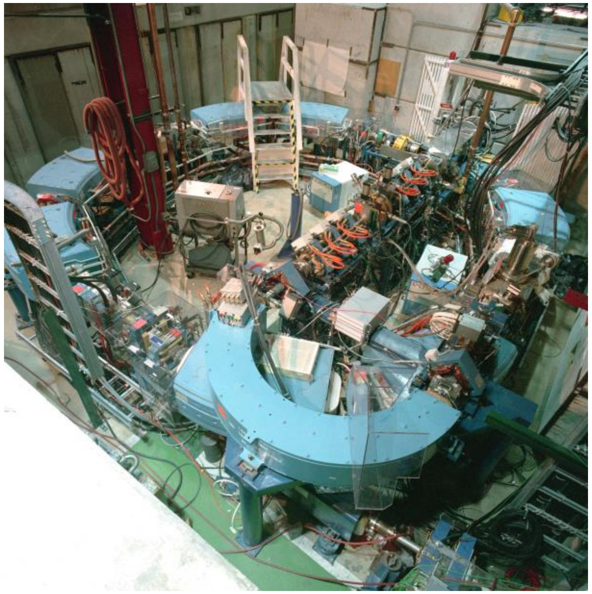


1954 – Berkeley treats the first patient



From physics……..

1993- Loma Linda USA (proton)



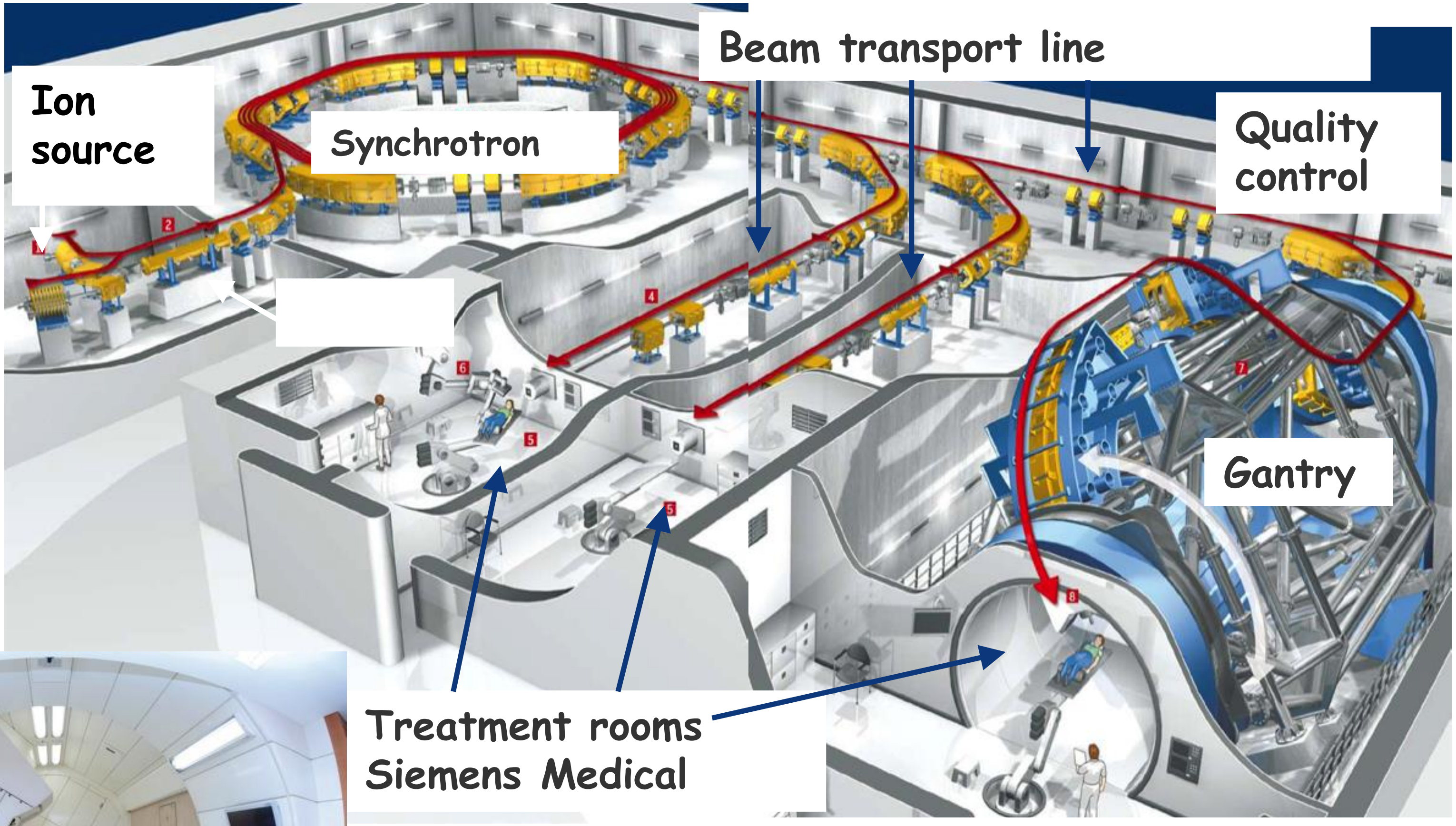
First dedicated clinical facility

1994 – HIMAC Japan (carbon)

1997 – GSI Germany (carbon)

……...to clinics

HIT - Heidelberg



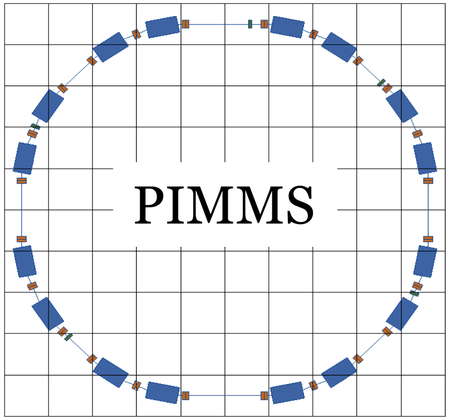
Carbon facilities in Europe: first was HIT in Heidelberg – started treating patients in 2009

PIMMS study at CERN (1996-2000)

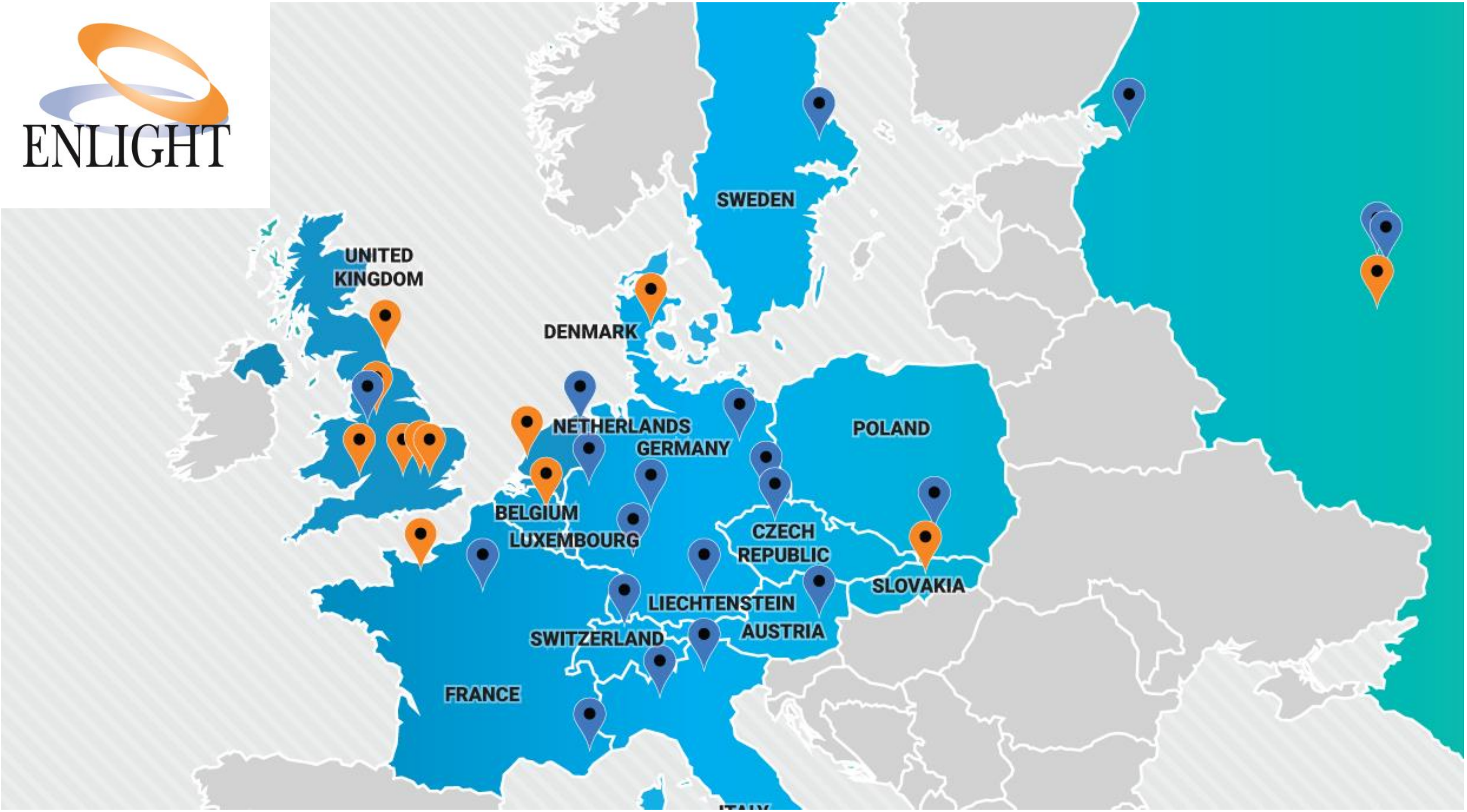
Treatment , CNAO, Italy
2011

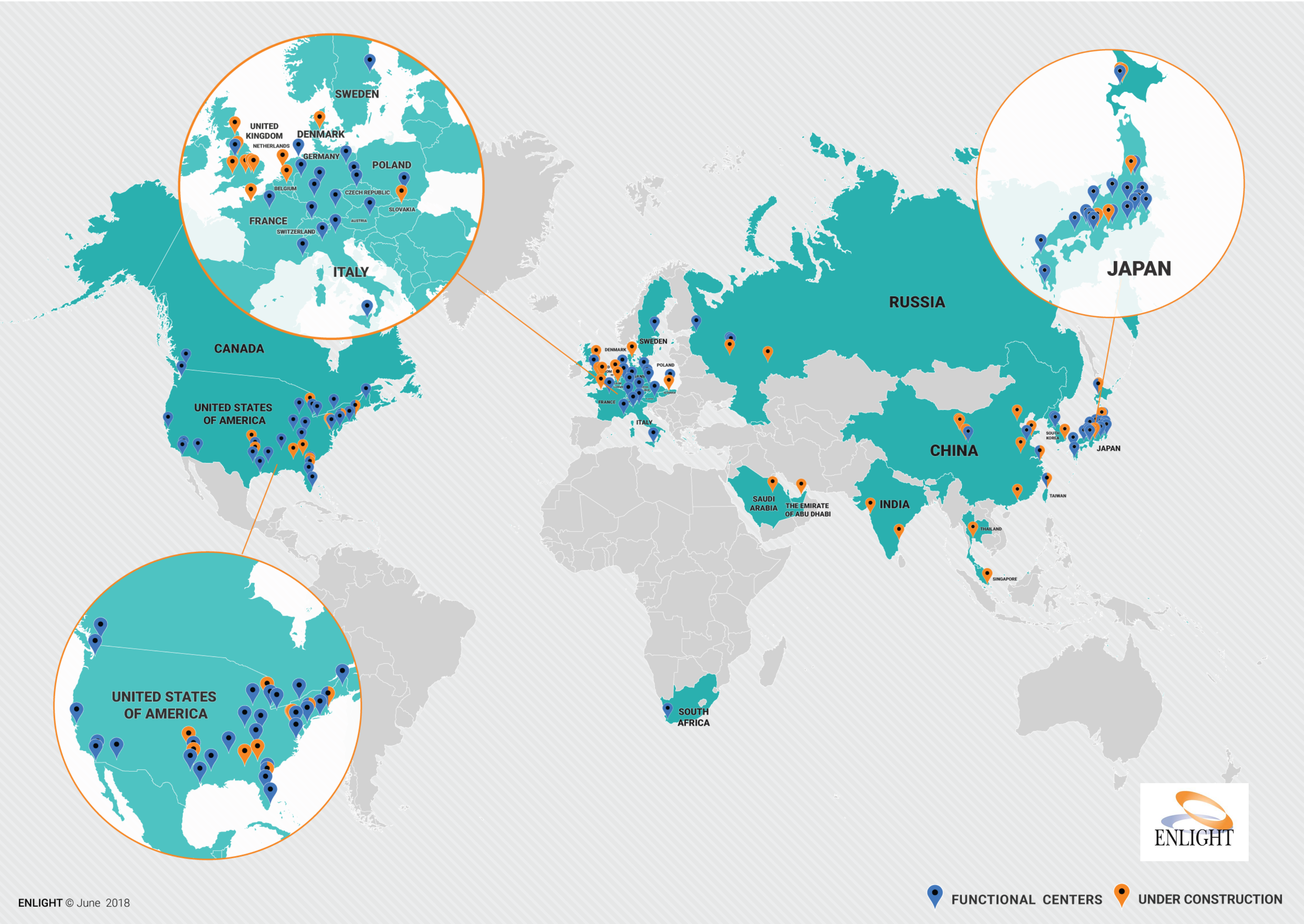
MedAustron, Austria 2016

1996-2000
PIMMS study



Facilities in operation now – Europe (2018)

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What do we need in the future?

- Treat the tumour and only the tumour

  $\Rightarrow$Even if the tumour is moving

- Cheap
- Small: Fit into every large hospital ?

New collaboration project started for a future improved facility (CERN, GSI……….)

Treating moving targets

Courtesy of Christian Graeff, GSI, Germany