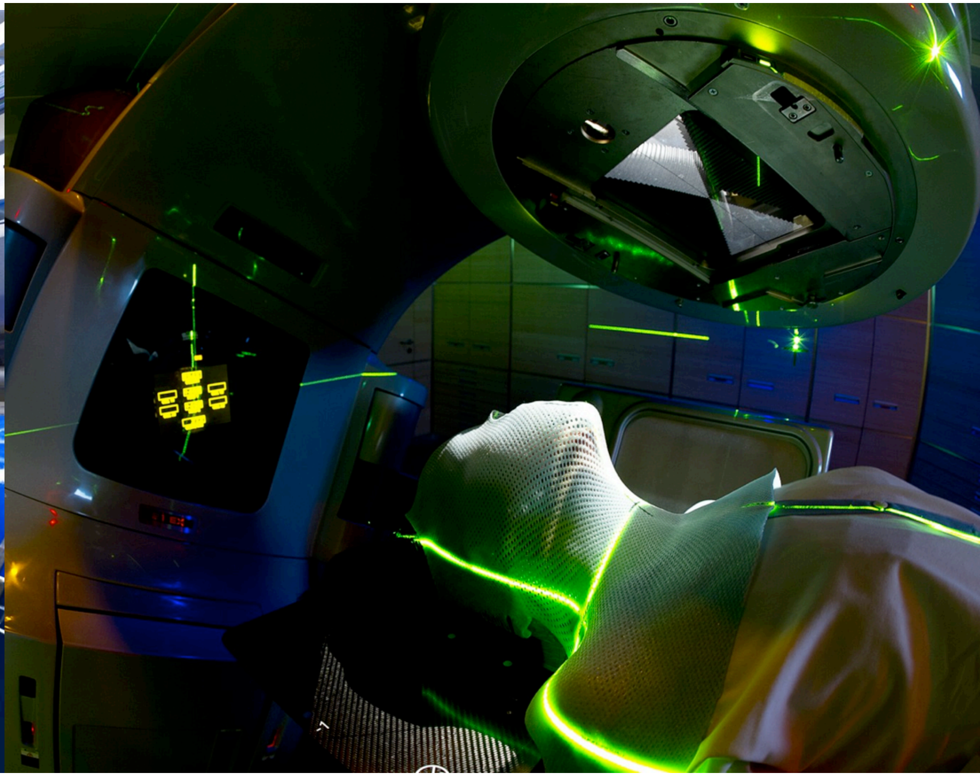
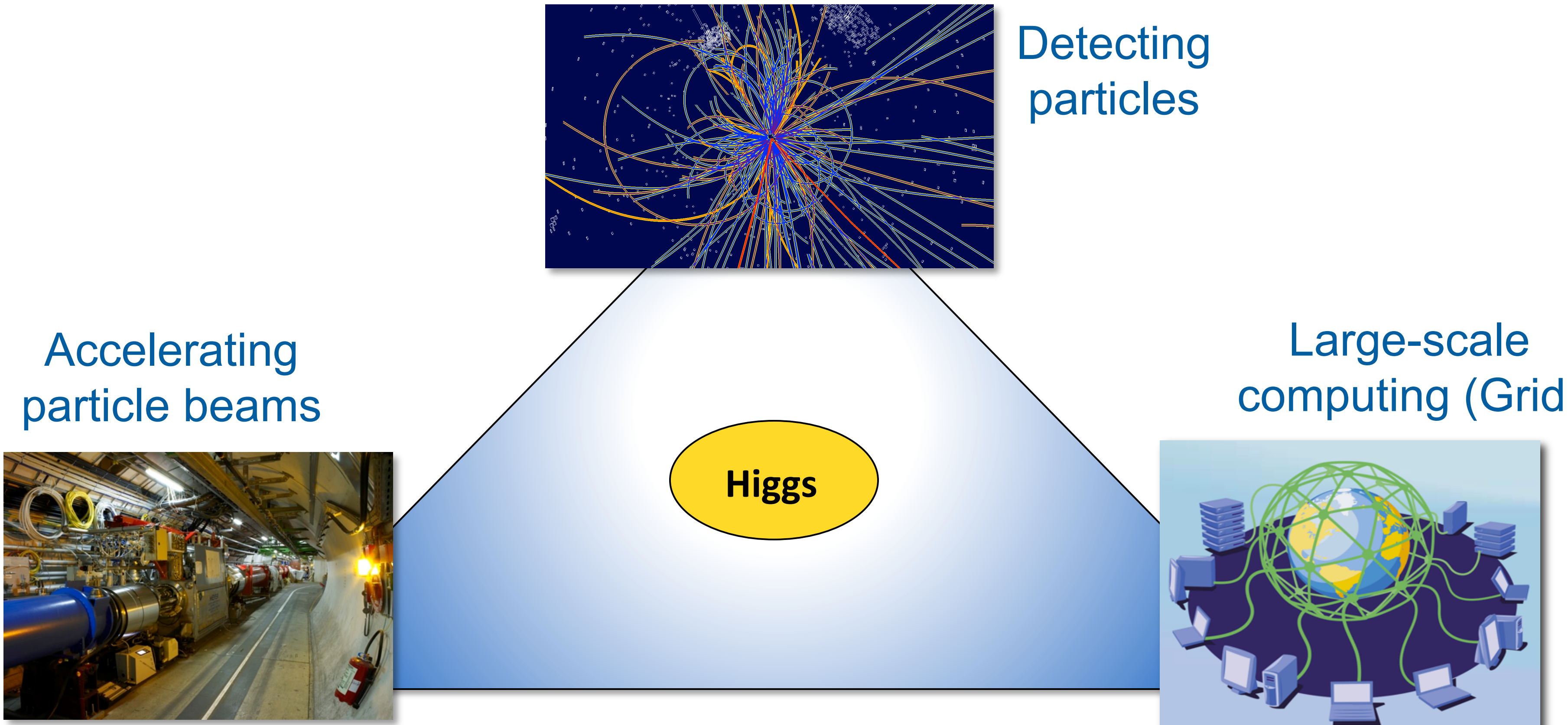
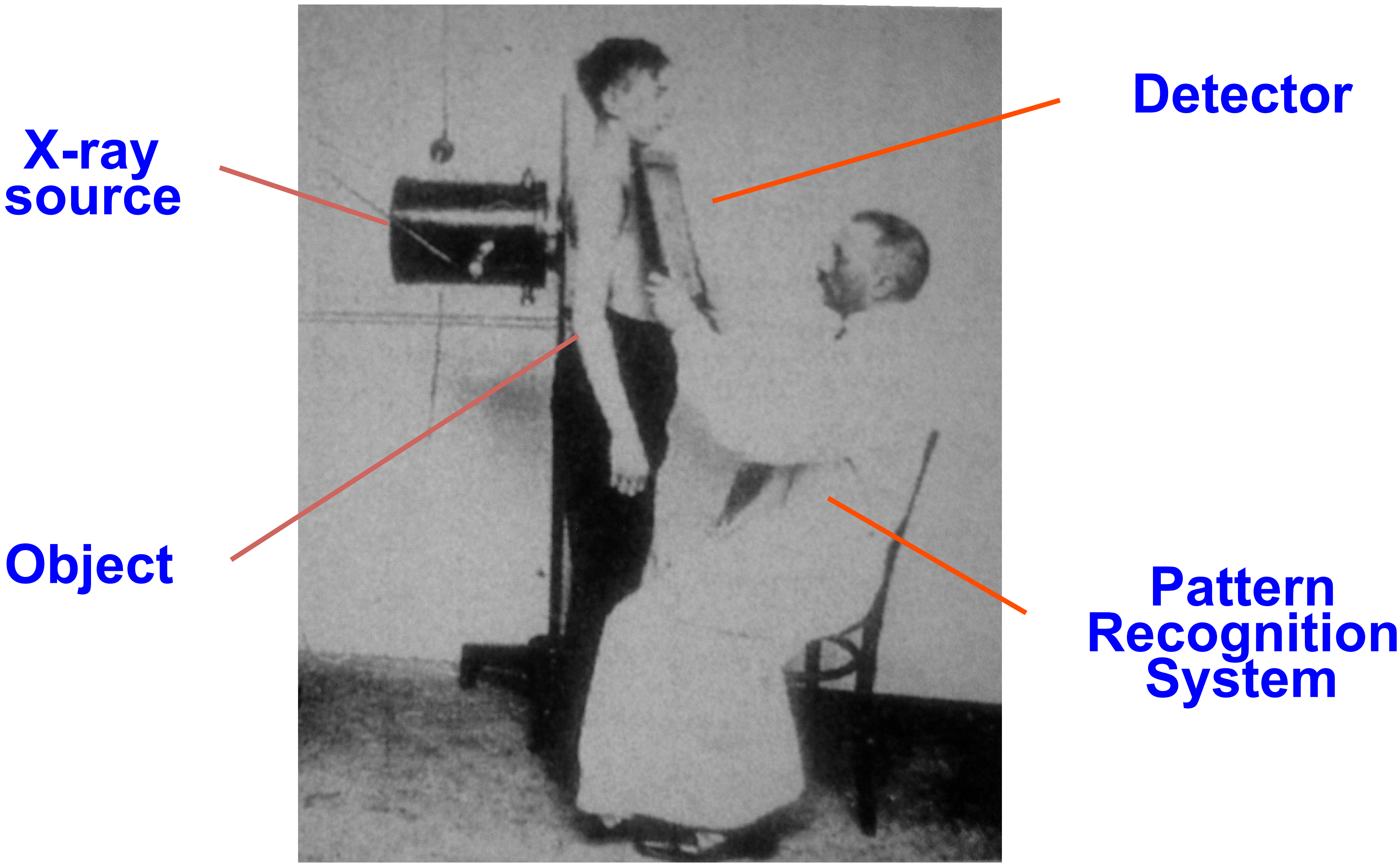
From particle physics to cancer therapy

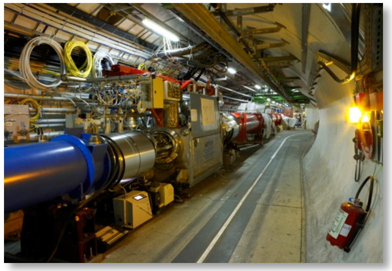


Manjit Dosanjh, CERN, October 2018

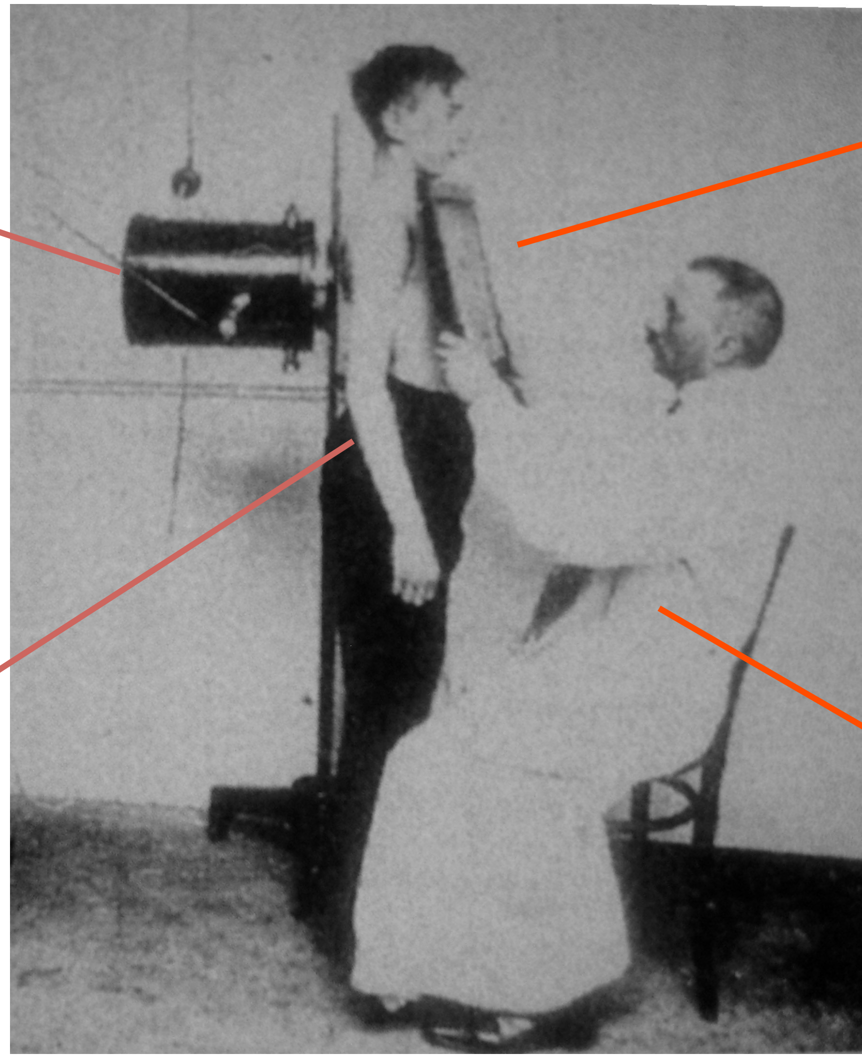
Physics Technologies



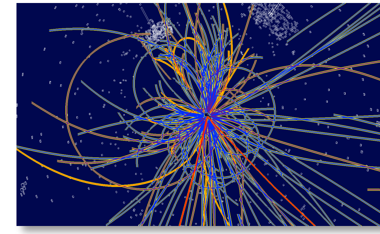

X-ray source
Detector
Object
Pattern Recognition System



X-ray source



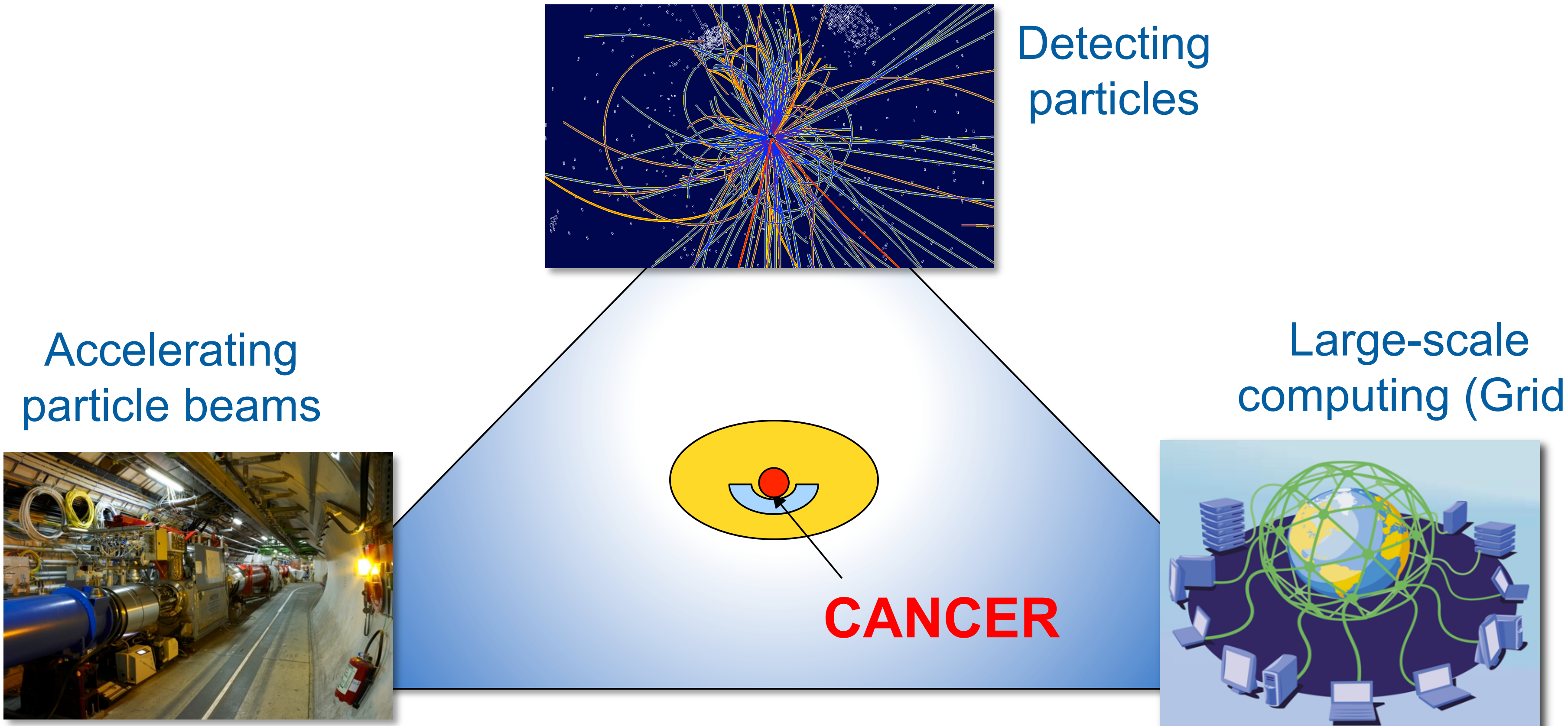
Object



Detector

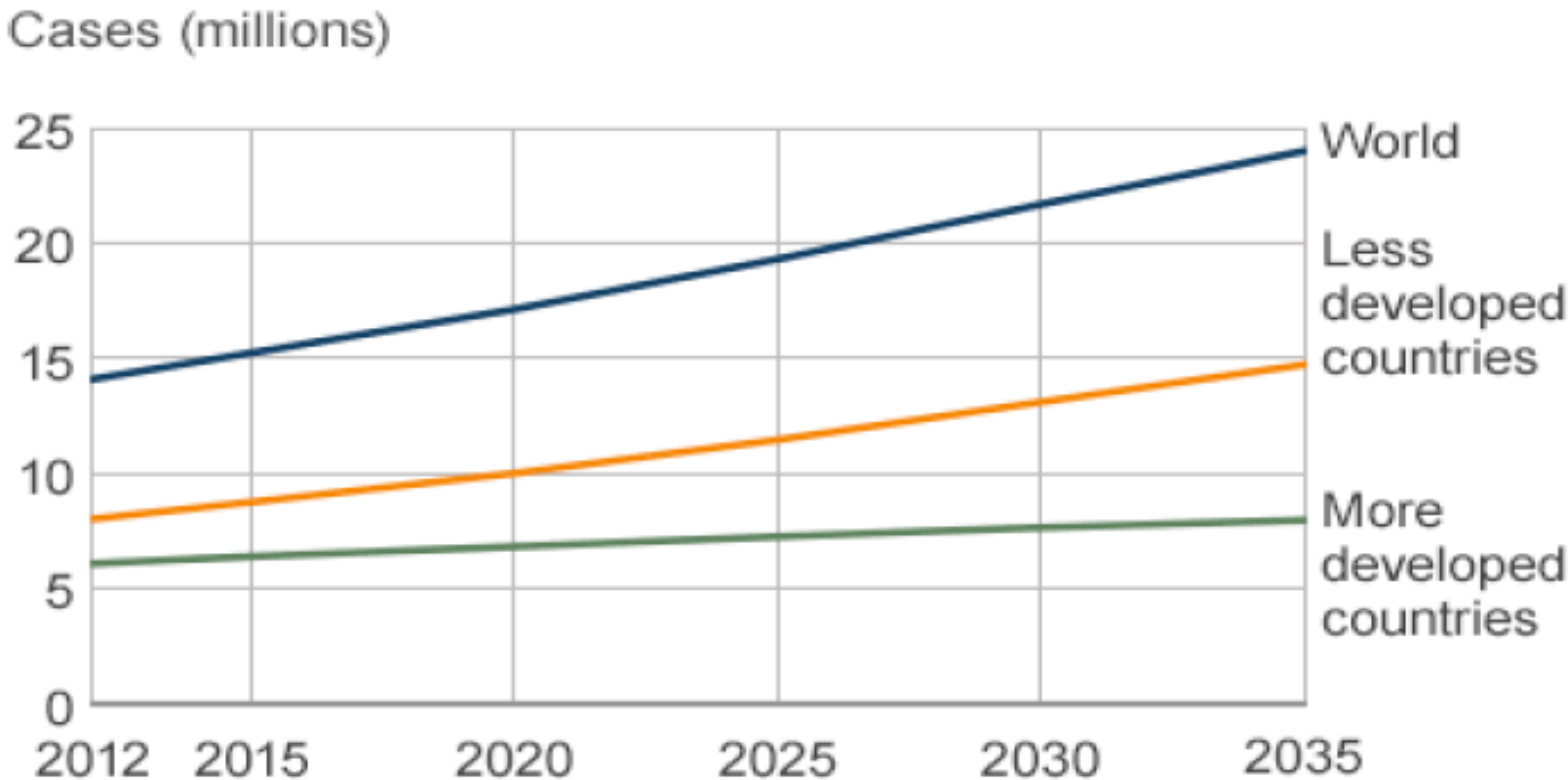
Pattern Recognition System

Physics Technologies



GLOBOCAN 2012: Estimated Cancer Incidence, Mortality and Prevalence Worldwide in 2012

Predicted Global Cancer Cases



Source: WHO GloboCan

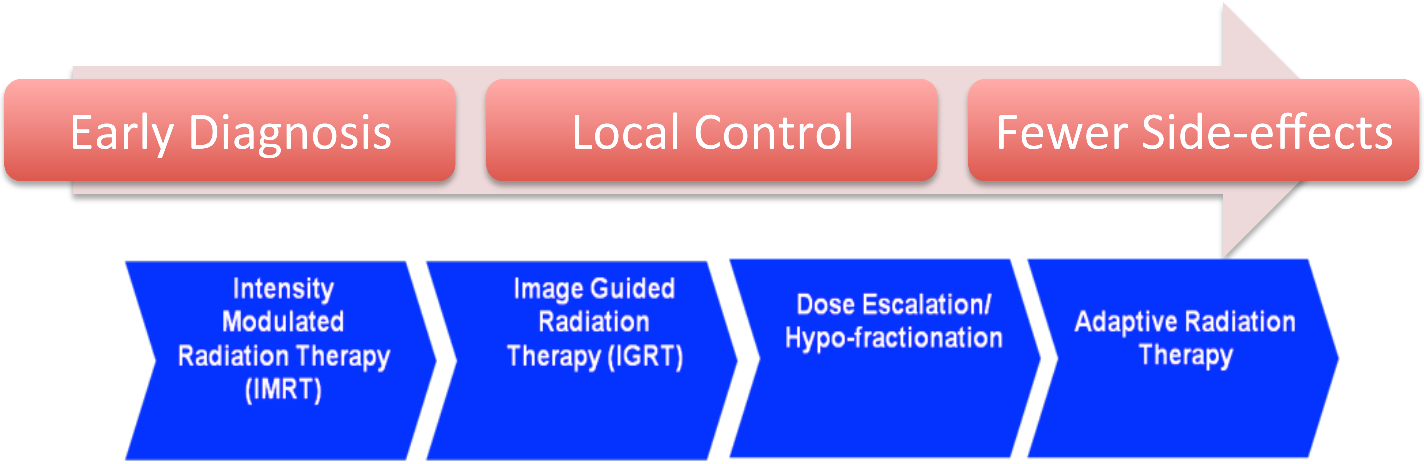
Why Cancer and Physics Technologies?

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?

Improving Cancer Outcomes



- New Technologies
- Advanced radiotherapy
- Radiobiology, Biology, Clinical
- Multi-disciplinary collaboration

The Challenge of Treatment

Ideally one needs to treat:

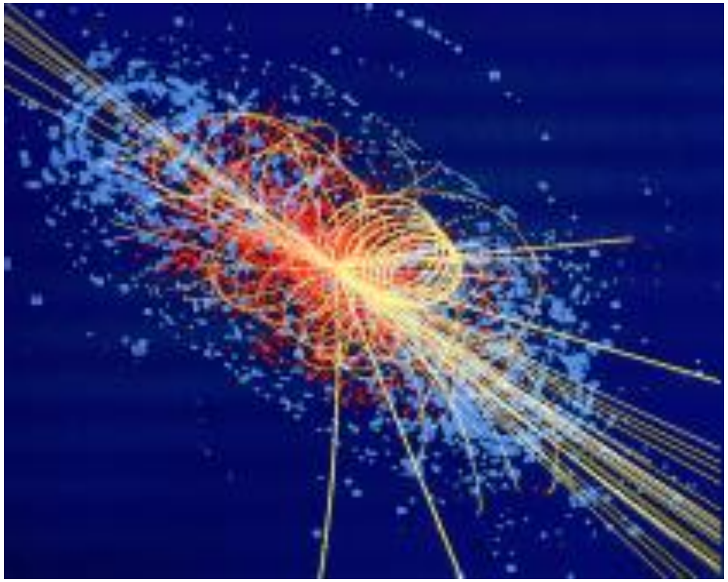
- The tumour
- The whole tumour
- And nothing **BUT** the tumour

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.

No treatment without detection!

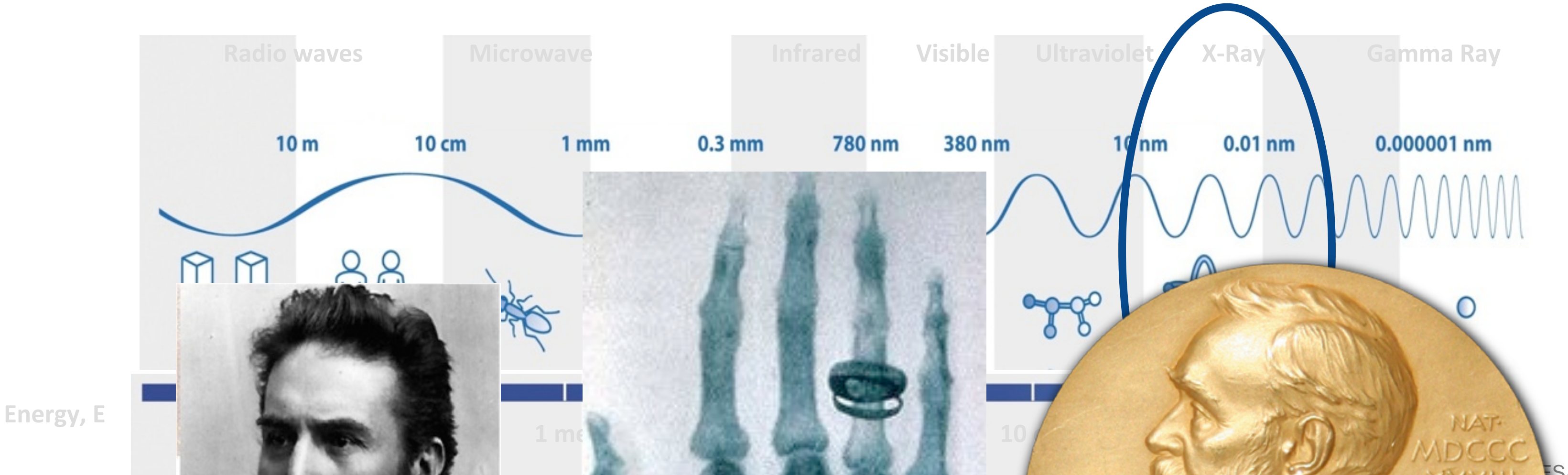
Particle Detection

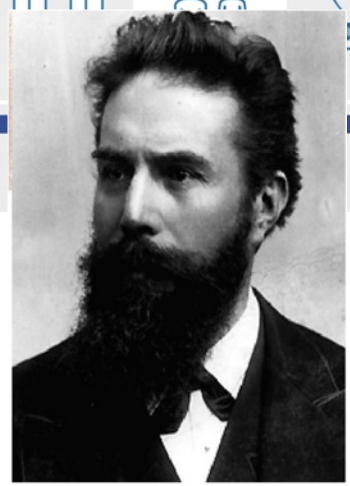


Imaging

X-ray, CT, PET, MRI

X-ray imaging



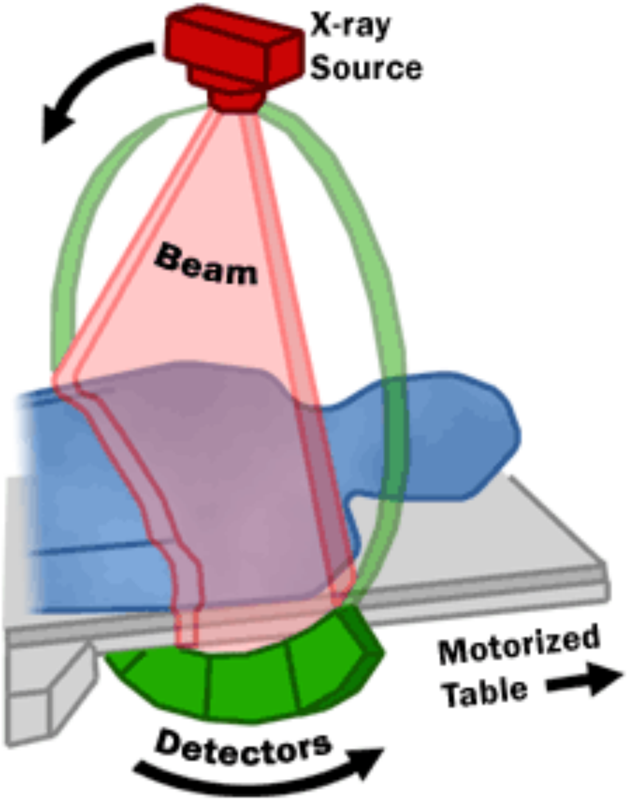


Wilhelm Röntgen

8/11/1895 — 22/12/1895 — 1901

CT – Computed Tomography

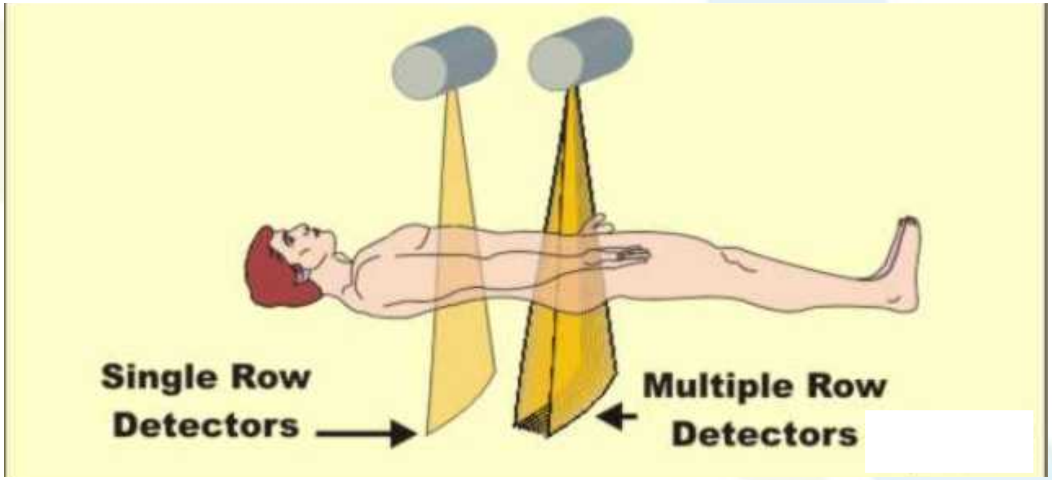
3d X-rays imaging



X-ray CT is a key driver of change

2000-2008 “CT Slices”

- *CT became very fast with small voxel / pixels*
  - 2000: acquire a single transverse slice per rotation
  - 2012: acquire up to 64-500 slices per rotation



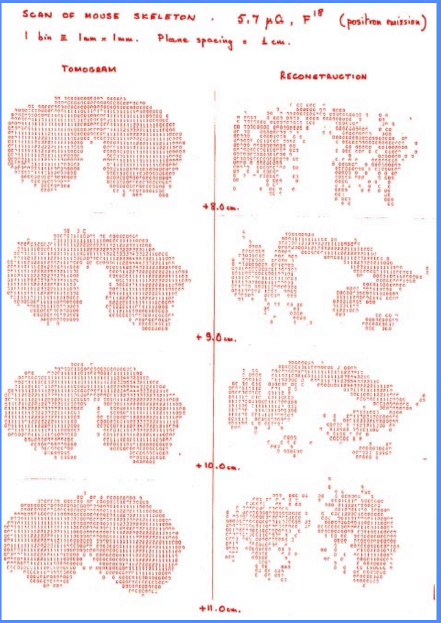
PET Imaging activities at CERN

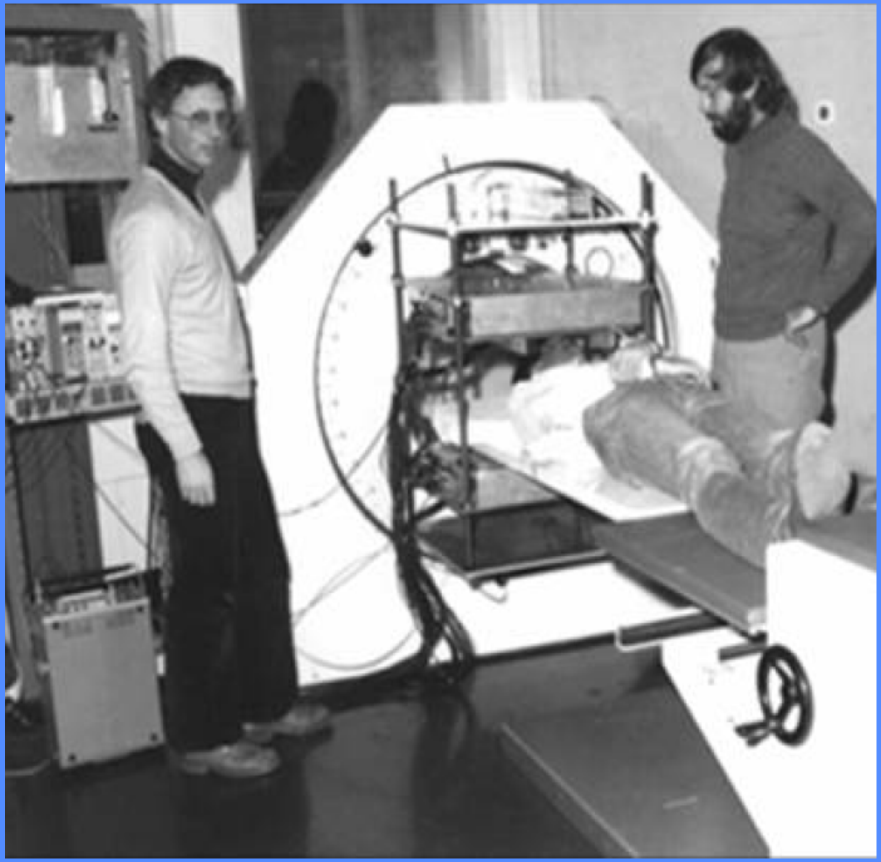
1977

Alan Jeavons and David Townsend

built and used in Geneva Hospital

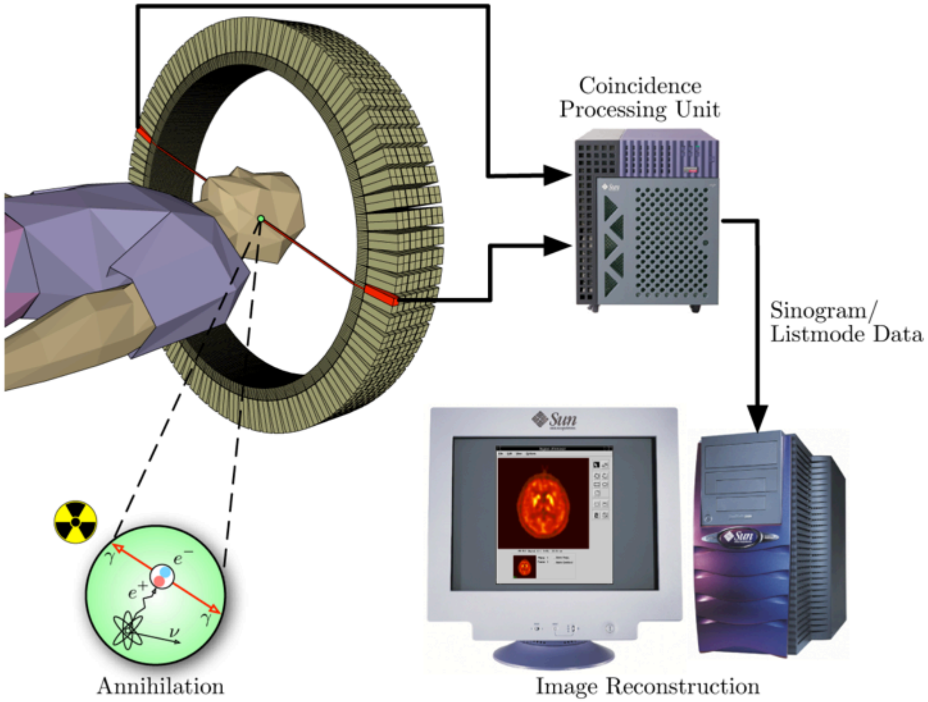
a PET system based on high-density avalanche gas chambers HIDACs

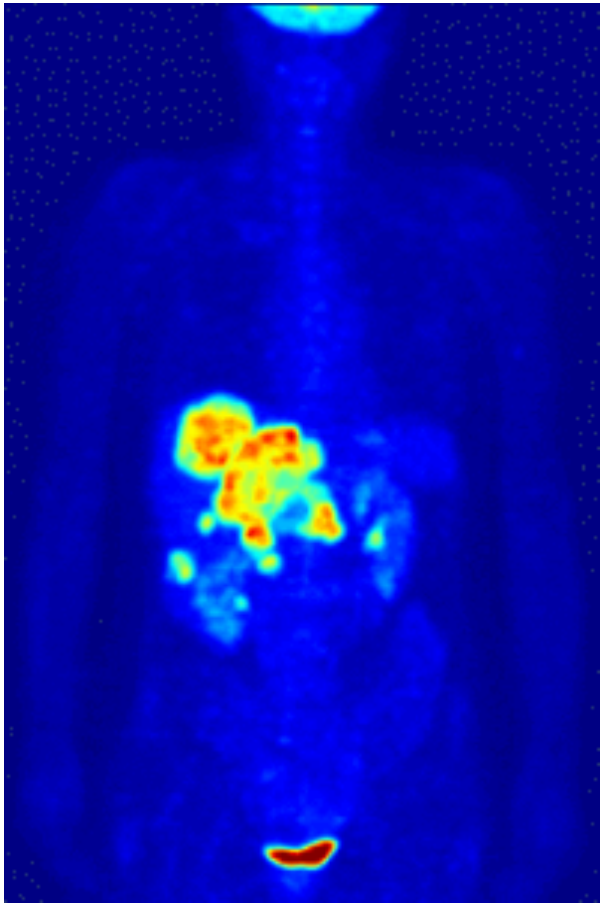




Paul Lecoq,

Positron Emission Tomography



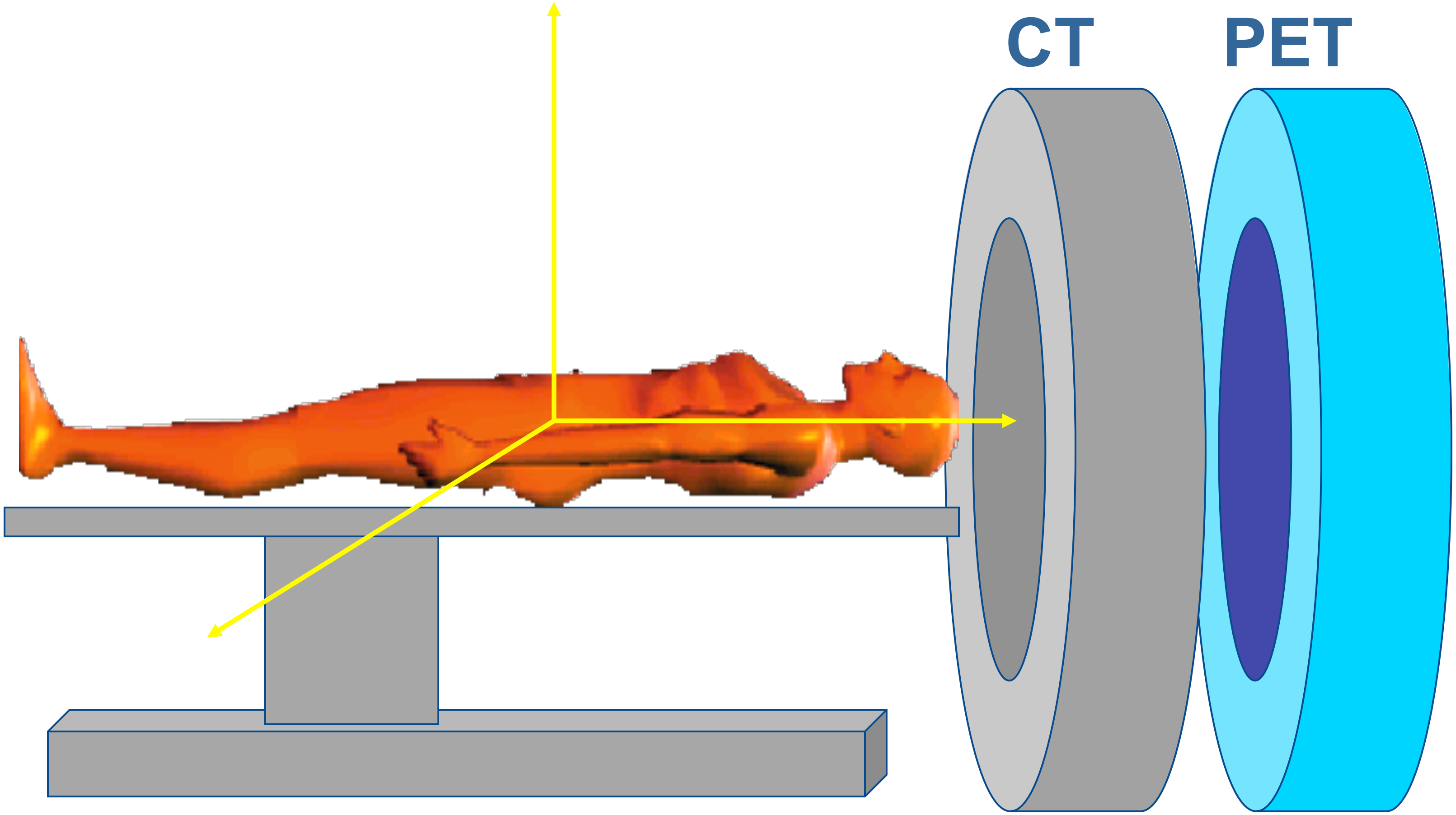


- ^{18}FDG carries the ^{18}F to areas of high metabolic activity
- 90% of PET scans are in clinical oncology

1974 the first human positron emission tomography

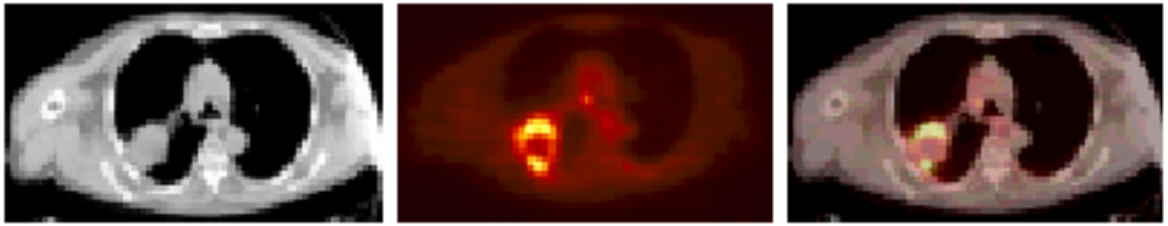
Concept of PET-CT

David Townsend



Multi-modality imaging

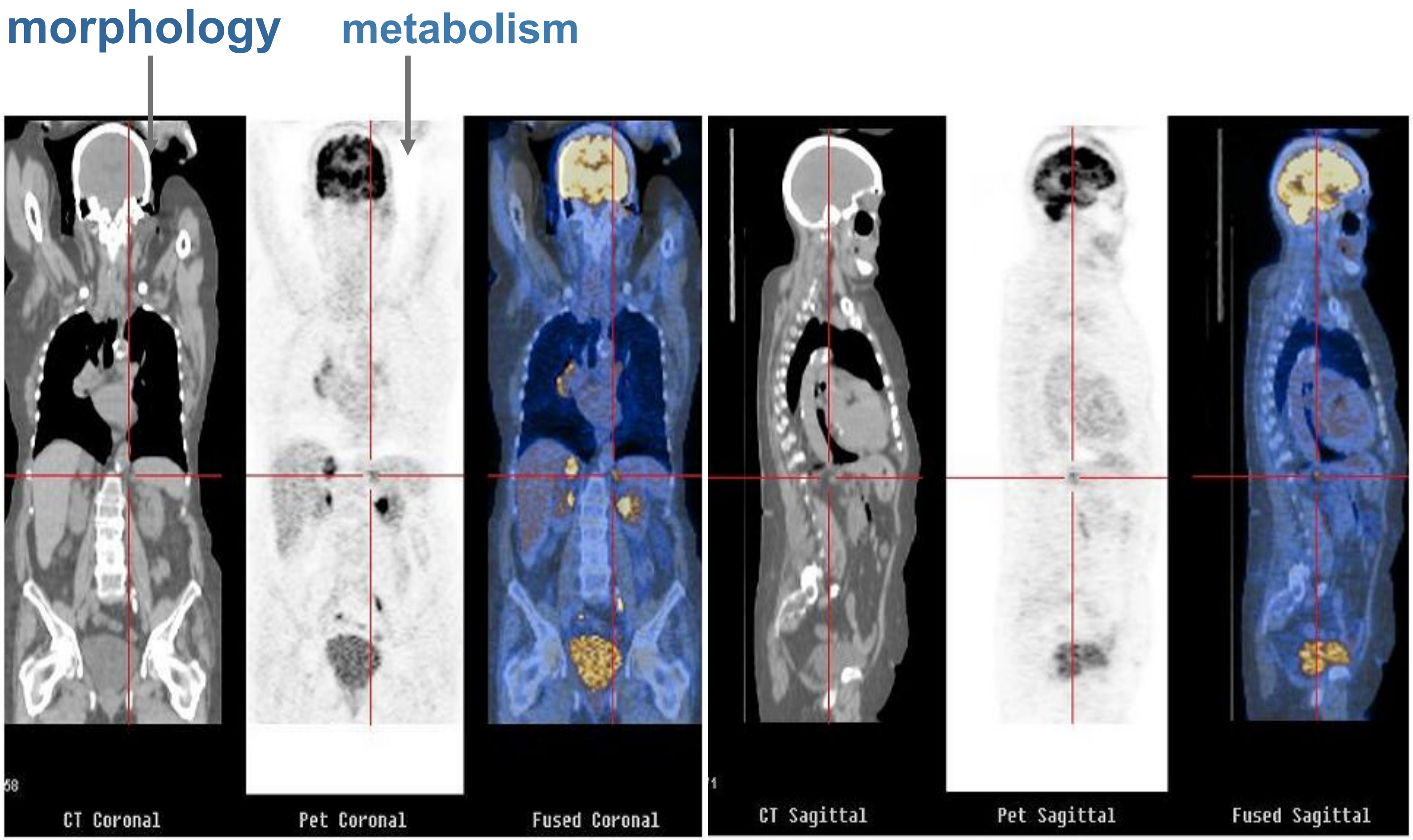
Primary lung cancer imaged with the Dual/Commercial scanner. A large lung tumor, which appears on CT as a uniformly attenuating hypodense mass, has a rim of FDG activity and a necrotic center revealed by PET.



Courtesy of David Townsend

Multimodality imaging: CT with PET

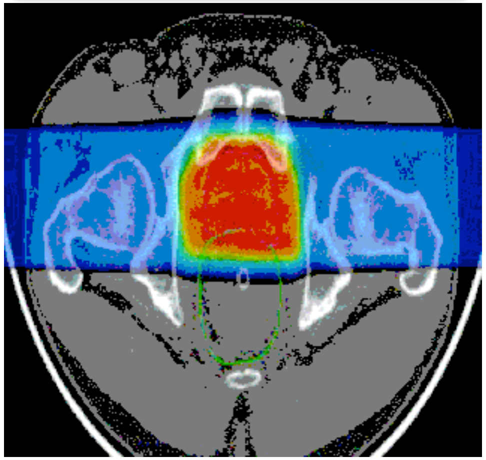
Combining anatomic and functional imaging



Treatment options

Surgery

Radiotherapy



X-ray, IMRT, Brachytherapy, Hadrontherapy

Chemotherapy (+ others)

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

AIM:
Survival, Quality of life

Radiotherapy in 21st Century

3 "Cs" of Radiation

Cure (about 50% cancer cases are cured)

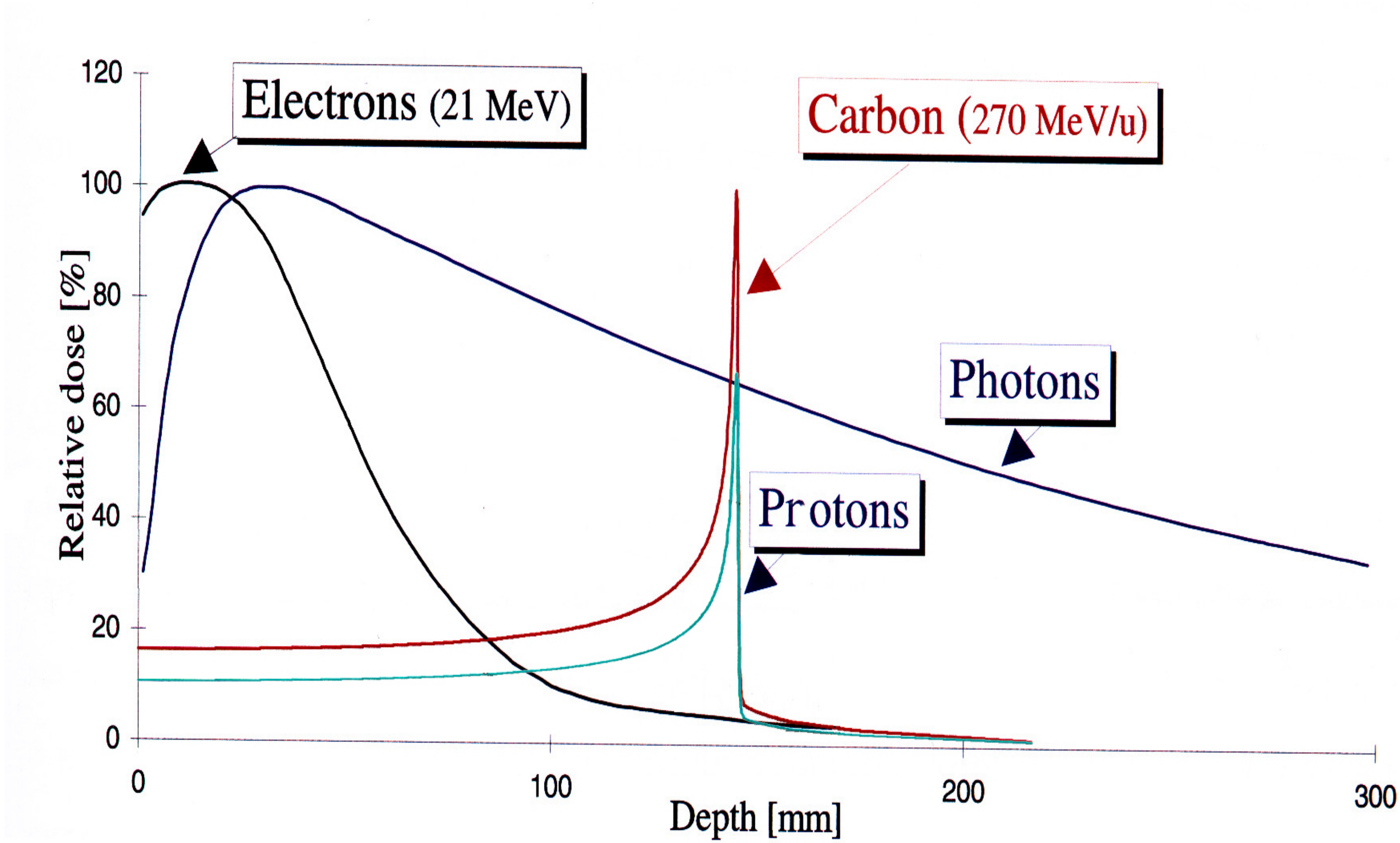
Conservative (non-invasive, fewer side effects)

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

(J.P.Gérard)

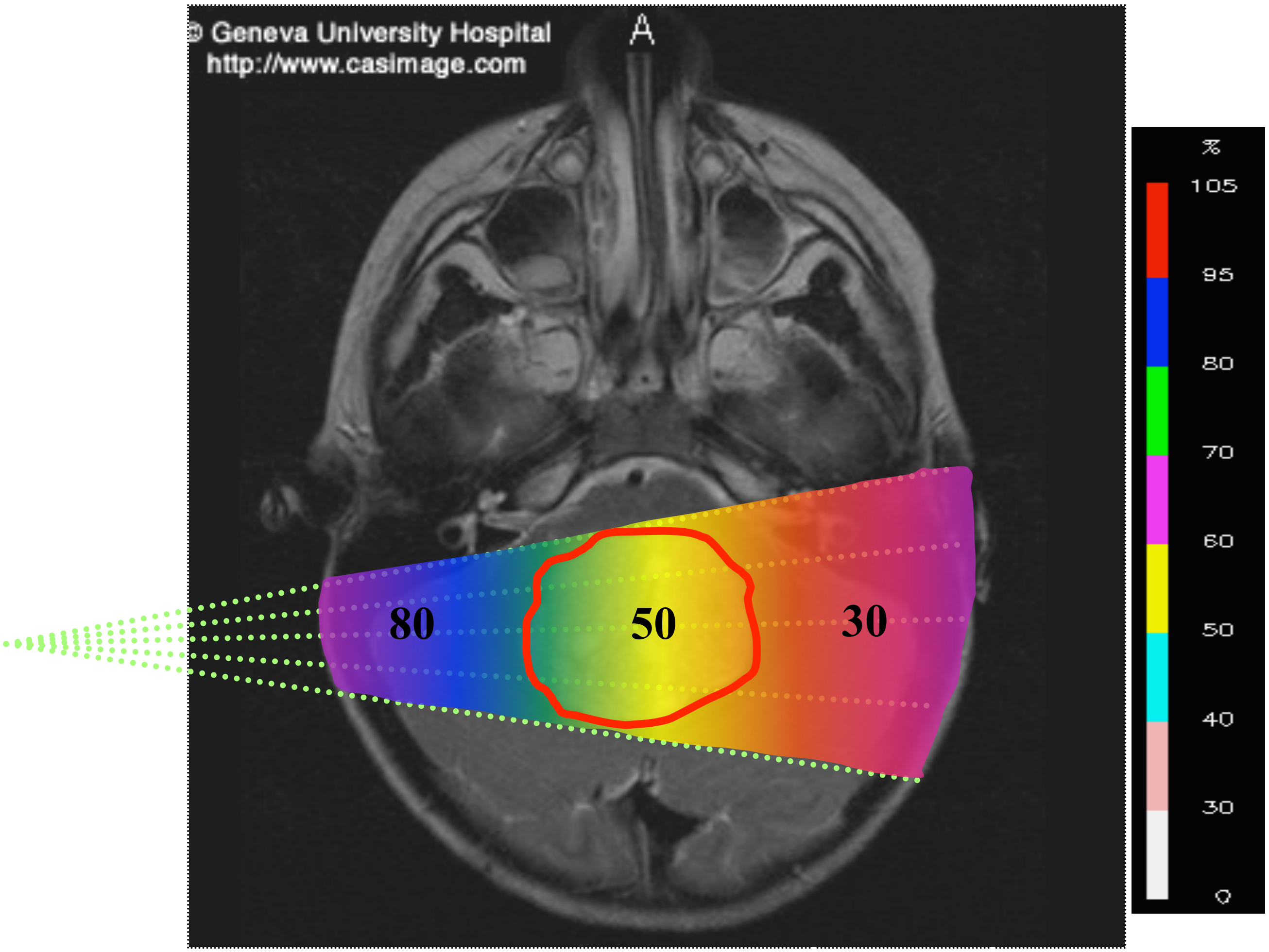
- About 50% patients should be treated with RT
- No substitute for RT in the near future
- No of patients is increasing

Radiation therapy

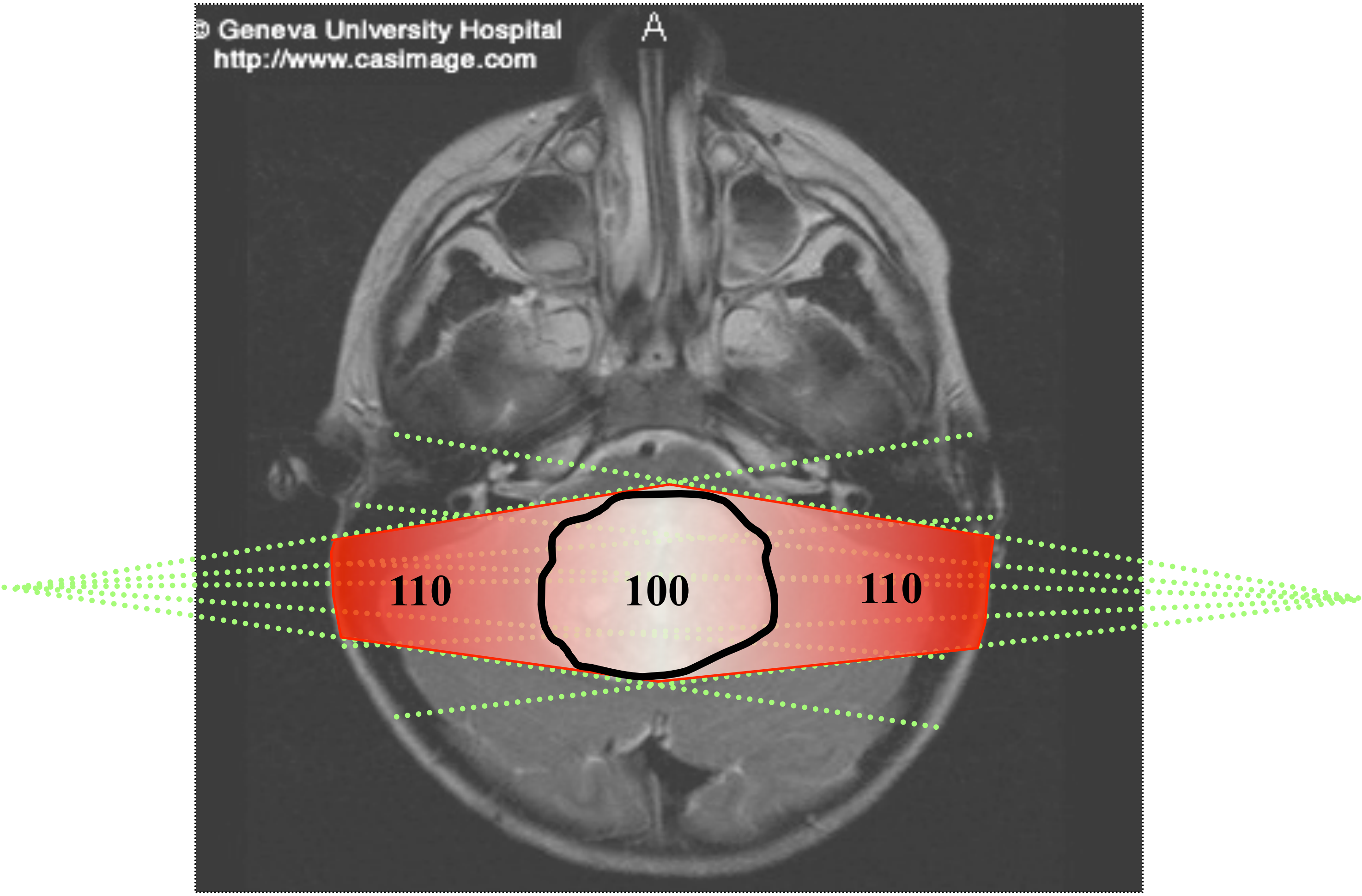


Depth in the body (mm)

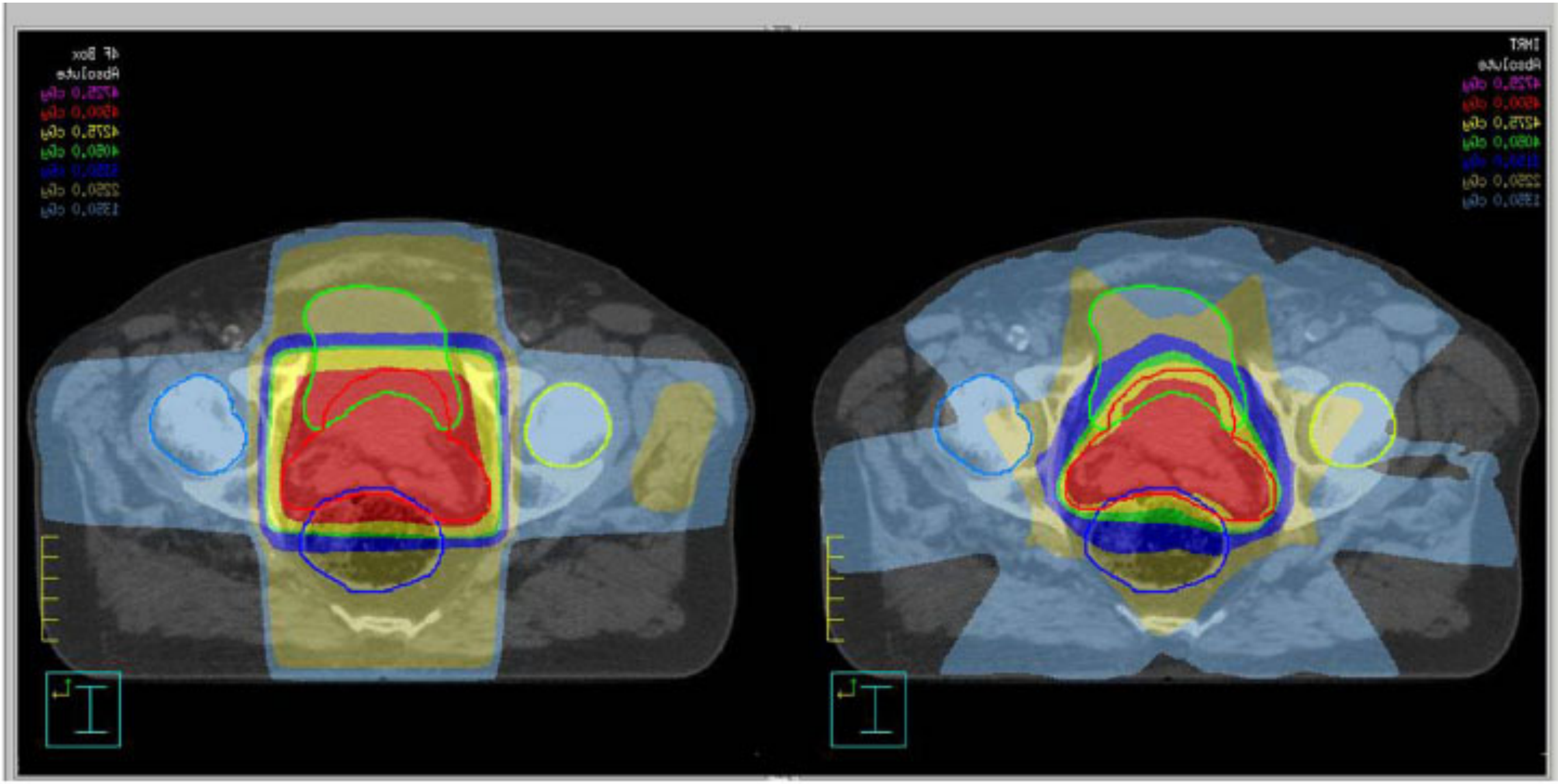
Single beam of photons



2 opposite photon beams



Improved Delivery

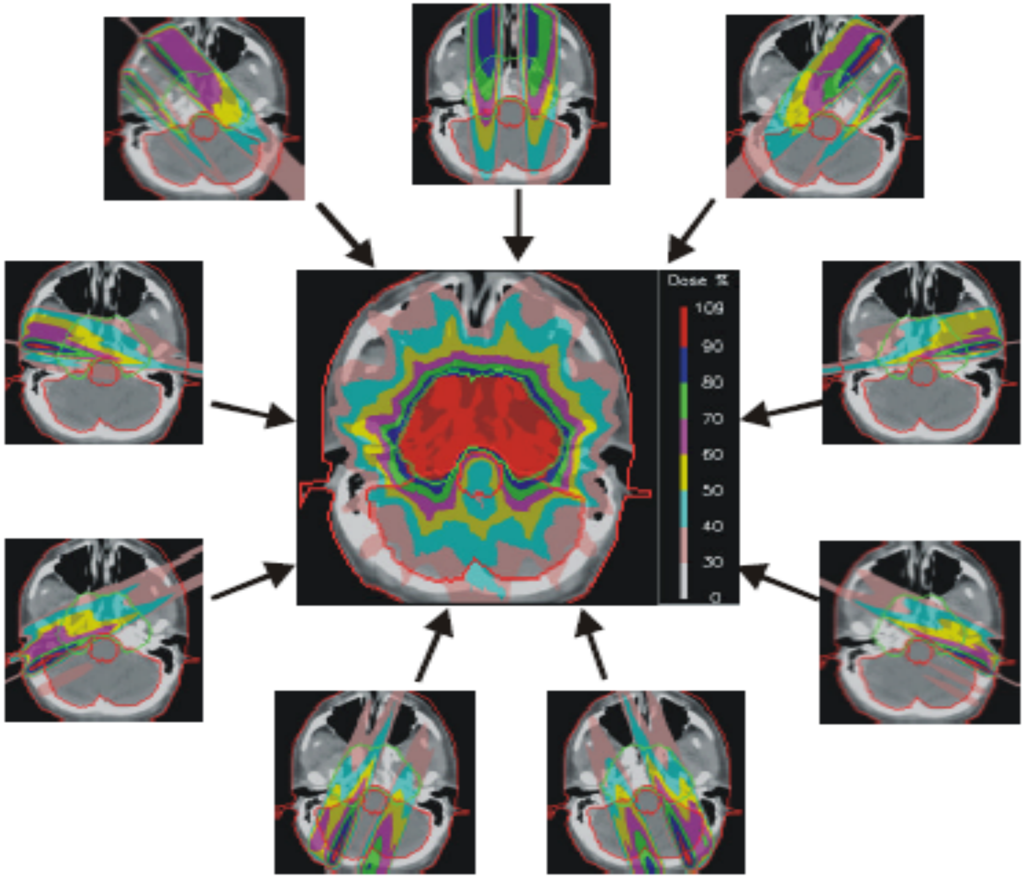


1990s: 4 constant intensity fields

Current state of RT: Intensity Modulated Radiotherapy (IMRT) – Multiple converging field with planar (2D) intensity variations

Intensity Modulated Radiation Therapy

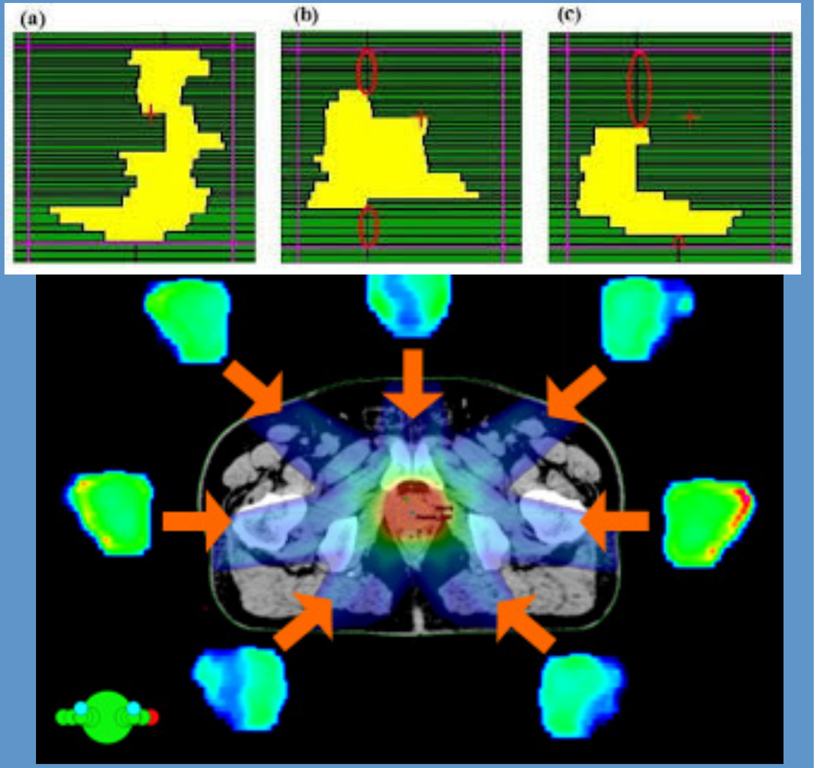
9 NON-UNIFORM FIELDS



PSI

60-75 grays (joule/kg) given in 30-35 fractions (6-7weeks)

Modern X-ray Therapy



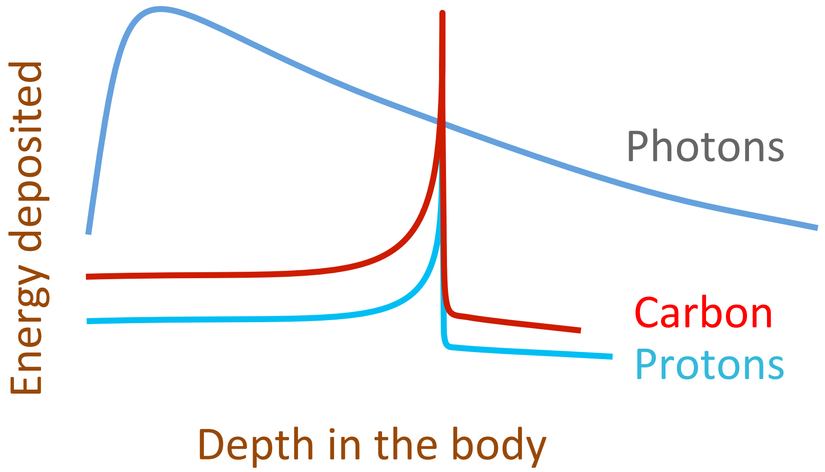
Current accelerator system with gantry, patient positioner and X-ray panels to acquire CBCT and planar X-rays.
Intensity modulation is achieved by changing the multi-leaf collimator (MLC) patterns (right), gantry rotation and dose rate. Thus, intensity modulation is achieved through mechanical (slow) means.

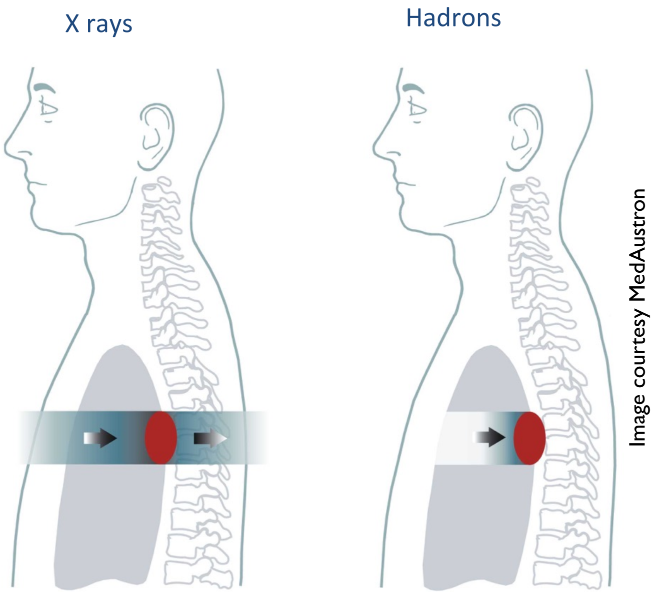
Advances in Radiation Therapy

In the past couple of decades due to:

- improvements in imaging modalities,
- powerful computers and software and delivery systems have enabled:
  - Intensity Modulated Radiotherapy (IMRT),
  - Image Guided Radiotherapy (IGRT),
  - Volumetric Arc Therapy (VMAT) and
  - Stereotactic Body Radiotherapy (SBRT)
  - New developments

Hadron therapy 1946



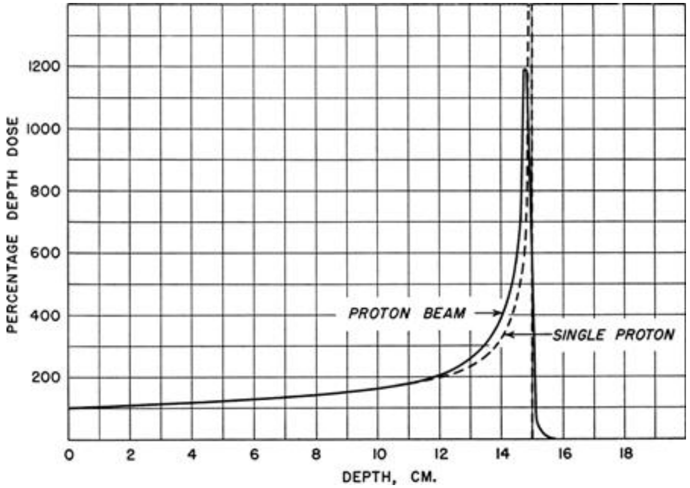


Robert Wilson in 1946:

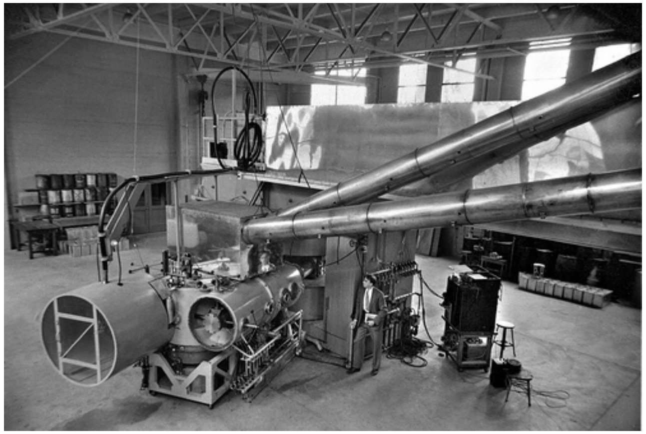
- Hadrons can be used clinically
- Accelerators are available
- Maximum radiation dose can be placed into the tumour
- Particle therapy provides sparing of normal tissues

1932 - E. Lawrence First cyclotron

1946 – proton therapy proposed by R. Wilson

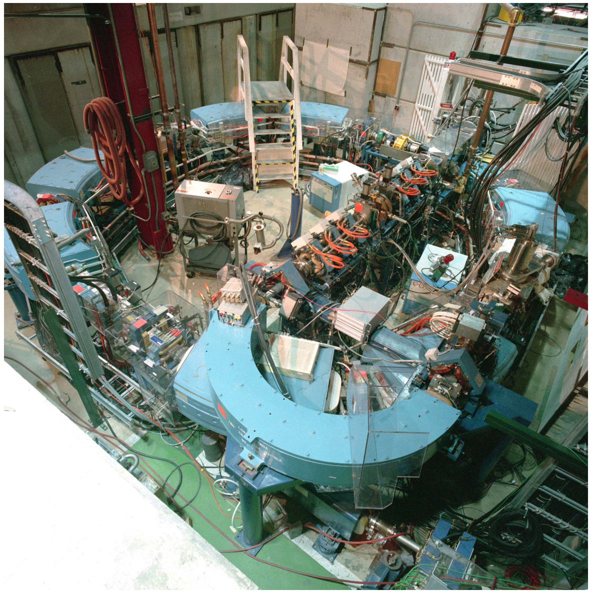


1954 – Berkeley treats the first patient



From physics……..

1993- Loma Linda USA (proton)



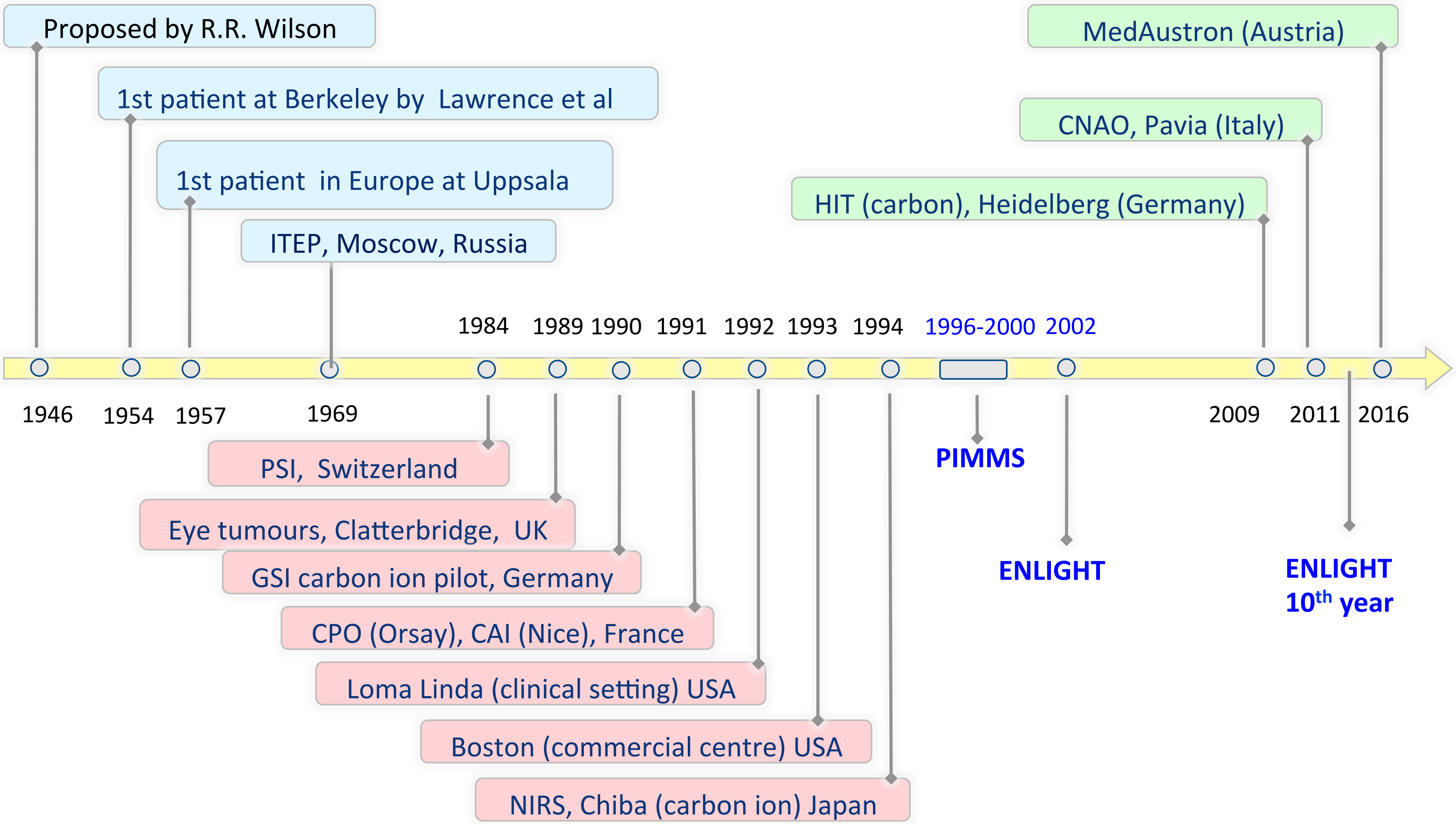
First dedicated clinical facility

1994 – HIMAC Japan (carbon)

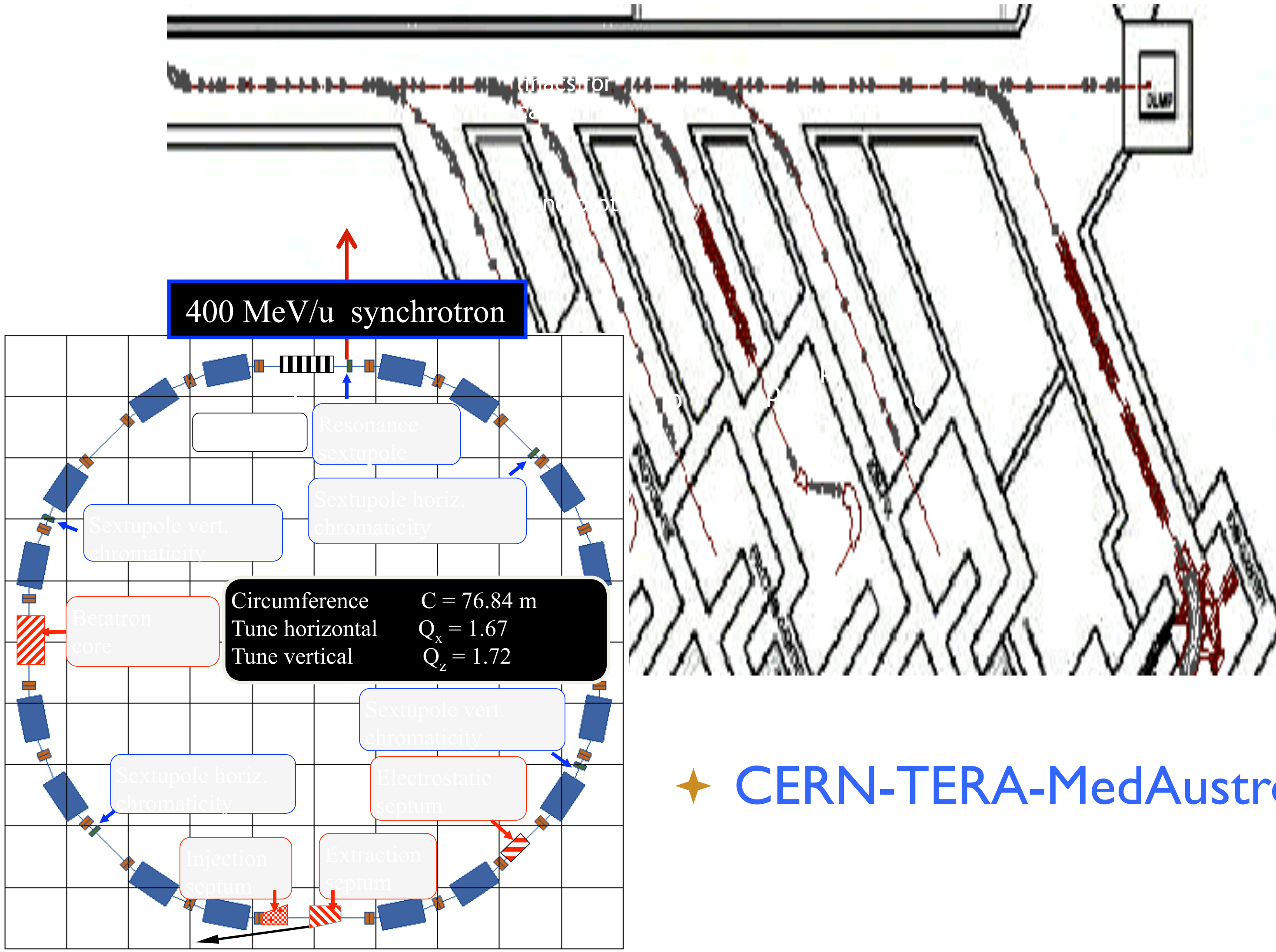
1997 – GSI Germany (carbon)

……..to clinics

Particle therapy: a short history



PIMMS at CERN (1996-2000)

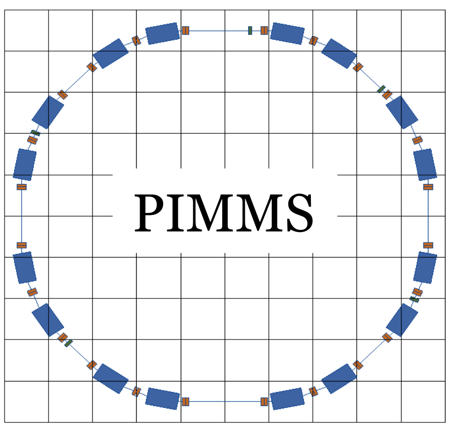


- CERN-TERA-MedAustron

PIMMS study at CERN (1996-2000)

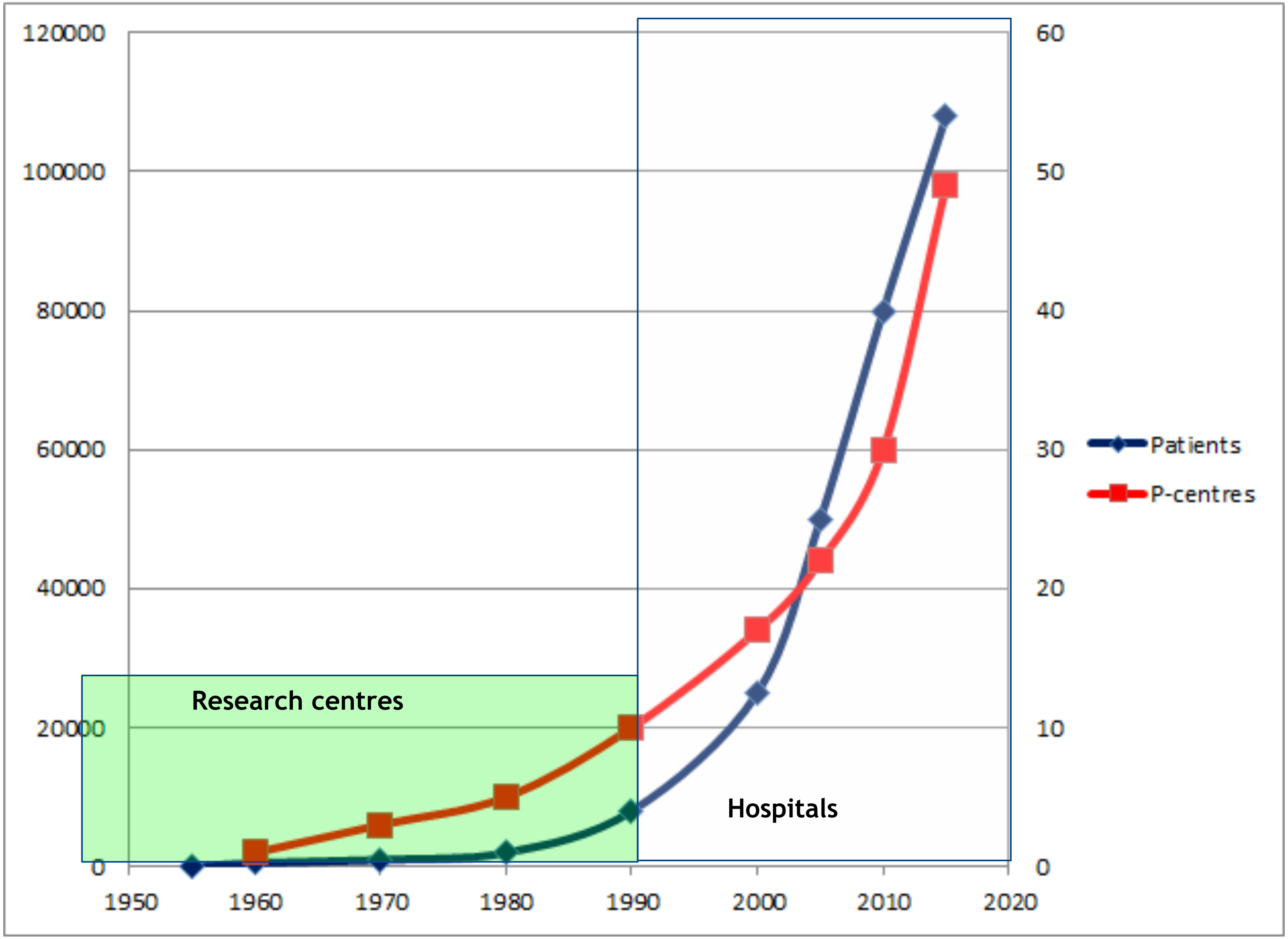
Treatment , CNAO, Italy
2011

1996-2000
PIMMS study

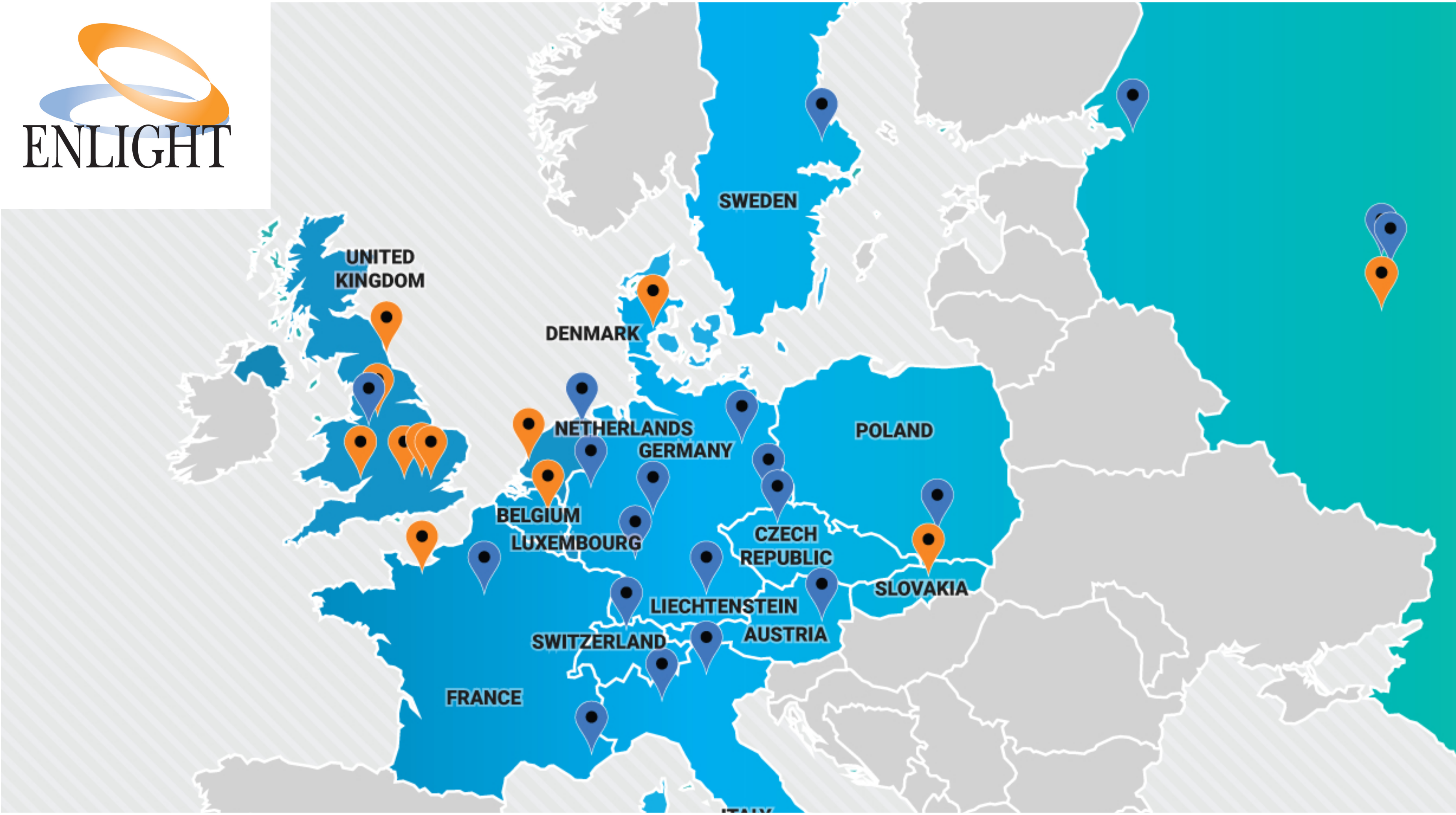


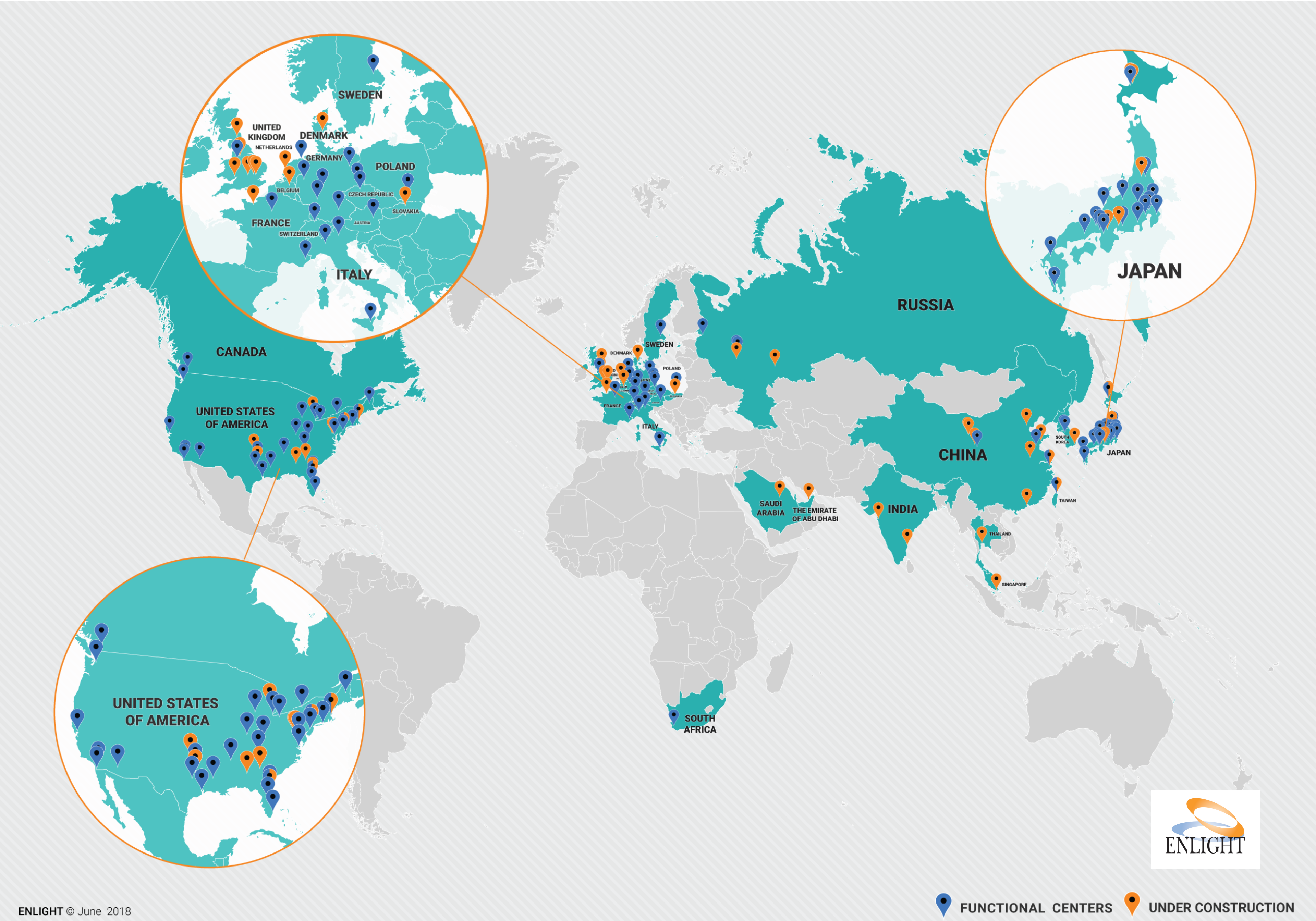
MedAustron, Austria 2016

[Data from www.ptcog.ch]



Facilities in operation now – Europe (2018)




SWEDEN
UNITED KINGDOM
DENMARK
NETHERLANDS
GERMANY
POLAND
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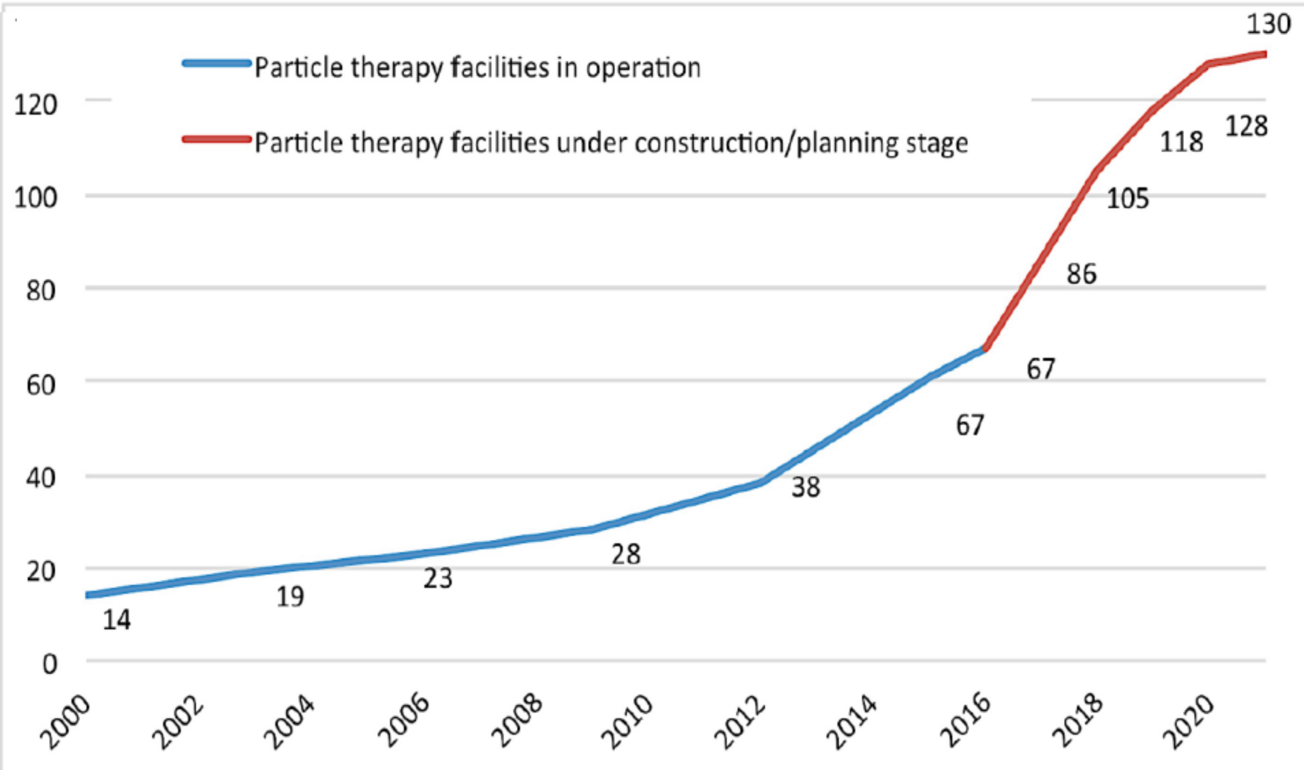
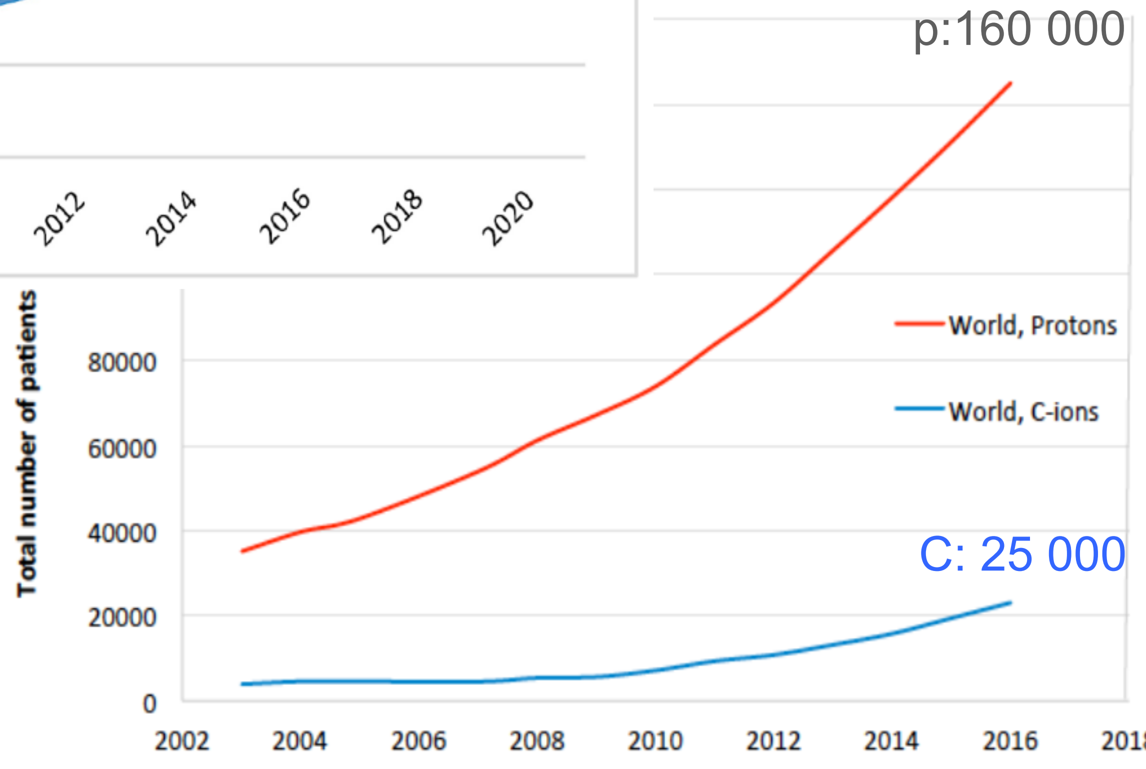
CZECH REPUBLIC
SLOVAKIA
FRANCE
AUSTRIA
SWITZERLAND
ITALY
JAPAN
RUSSIA
CANADA
UNITED STATES OF AMERICA
CHINA
SOUTH KOREA
TAIWAN
SAUDI ARABIA
THE EMIRATE OF ABU DHABI
INDIA
THAILAND
SINGAPORE
SOUTH AFRICA
UNITED STATES OF AMERICA
ENLIGHT
FUNCTIONAL CENTERS
UNDER CONSTRUCTION

Centres and patients worldwide

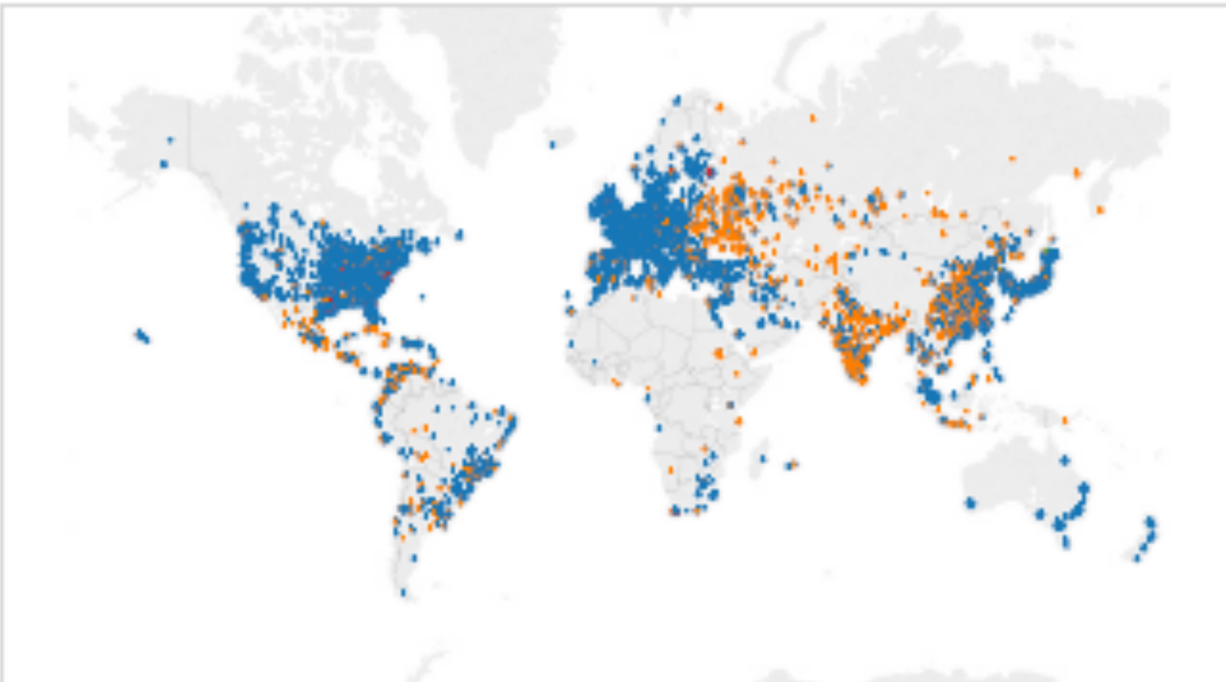




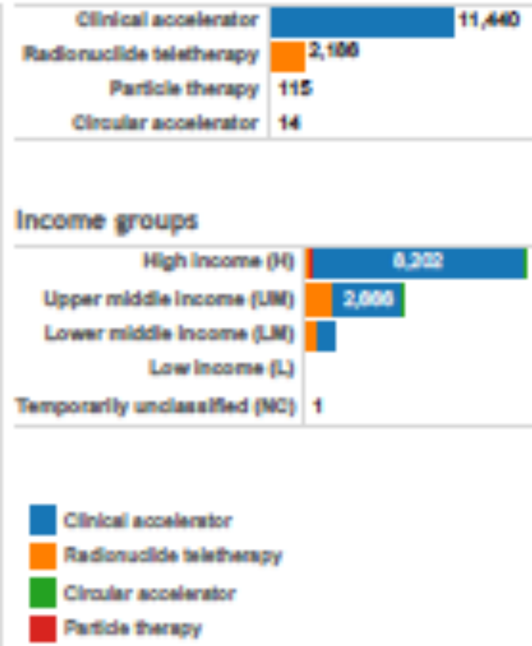
Current Challenge: how to go from no radiotherapy to high quality radiotherapy globally: Challenging Environments

World wide radiotherapy coverage

Radiation therapy centers
(Updated on : 6/1/2017 7:11:24 AM)



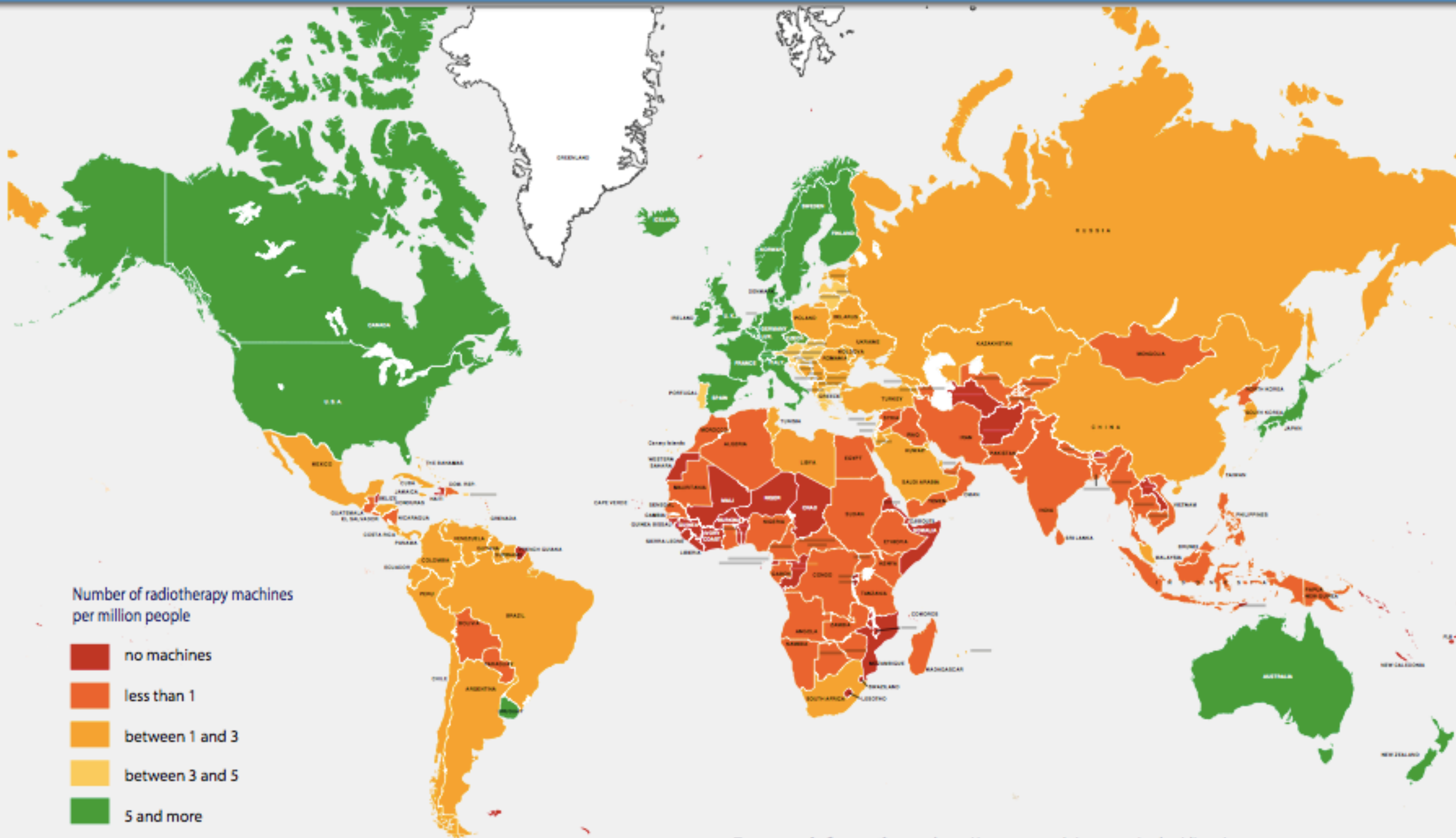
Equipment type
(Updated on : 6/1/2017 7:11:24 AM)



Countries	RT centers	Equipment	Linac	Radionuclide Therapy	Circular Accelerator	Particle Therapy
139	7041	13755	11440	2186	14	115

Availability of **RADIATION THERAPY**

Number of Radiotherapy Machines per Million People 2012



Source: *DIRAC (Directory of Radiotherapy Centres), 2012 / IAEA*

For more information: *http://www-naweb.iaea.org/nahu/dirac/*
dirac@iaea.org

Reality in numbers……

- No radiotherapy in 36 countries
- HIC (high income countries) have over 60% of all teletherapy machines and 16% of the world population
- LIC and LMIC have less than 10% of teletherapy machines which serve 50% of the world
- Around 70% cancer patients do not have access globally

Atun et al, Lancet Oncology. 2015

Needs by 2035 in LMIC

Globally 15 million cases in 2015 to 25 million in 2035:

- 12,600 megavolt-class treatment machines
- 30,000 radiation oncologists
- 22,000 medical physicists
- 80,000 radiation technologists

Massive challenge needs a sustainable solution for both near-term and long-term which covers Linacs, trained personnel and infrastructure).

Desirable features regarding LINACs designed for LICs

(Pomper MA et al. The Stanley Foundation, CNS, February 2016)

- A developing-world LINAC with modular enhancements, as capability increases: an option for LINAC companies to consider.

- Costs could be phased in by starting with a basic unit, and options could be provided for:
  - new technology,
  - remote diagnosis and adjustment,
  - a long-term maintenance contract with the vendor.

David Jaffray, ICARO 2017

Medical LINACs for challenging environments

- Design Characteristics of a Novel Linear Accelerator for Challenging Environments, November 2016, CERN
- Bridging the Gap Workshop, October 2017, CERN
    - Understanding the problem
    - Oncologists, medical physicists, accelerator physicists
    - Outcome – 5 seed-corn projects

Botswana, Ghana, Kenya, Nigeria, Tanzania, Nepal, Jordan, AFRICSIS

- Burying the Complexity Workshop, March 2018, Manchester
- Next Workshop in Botswana planned for March 2019

CERN

International Cancer Expert Corps
Partnering to transform global cancer care

Science & Technology Facilities Council

UK Research and Innovation

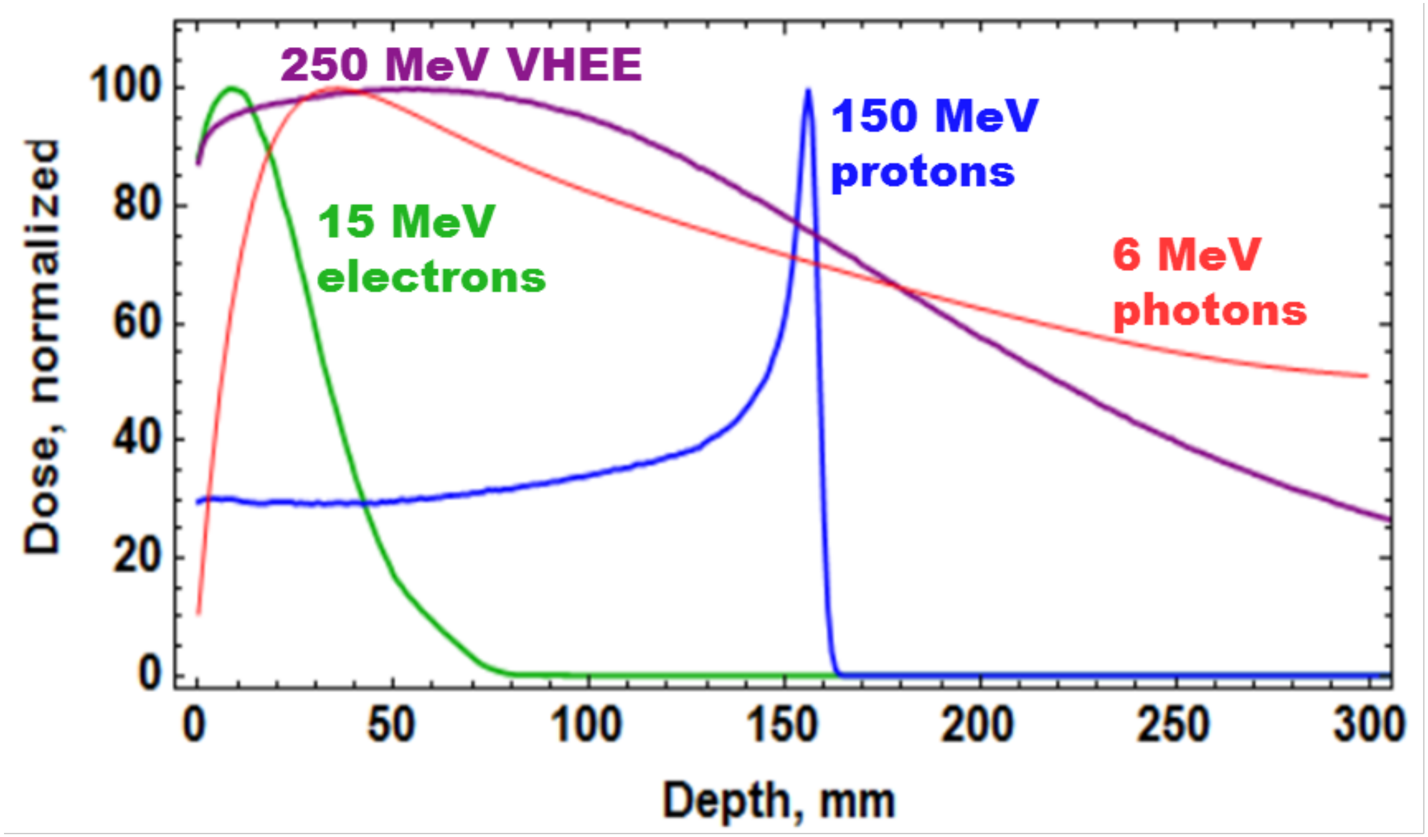
What do we need in the future?

- Treat the tumour and only the tumour
  - ⇒ Control and monitor the ideal dose to the tumour
  - ⇒ Minimal collateral radiation "outside" the tumour
  - ⇒ Minimal radiation to nearby critical organs
  - ➢ Even if the tumour is moving
- Be affordable
  - ✓ Capital cost ?
  - ✓ Operating costs ?
  - ✓ Increased number of treated patients per year ?
- Compact: Fit into every large hospital ?

- Improve patient through-put
- Increase effectiveness
- Decrease cost

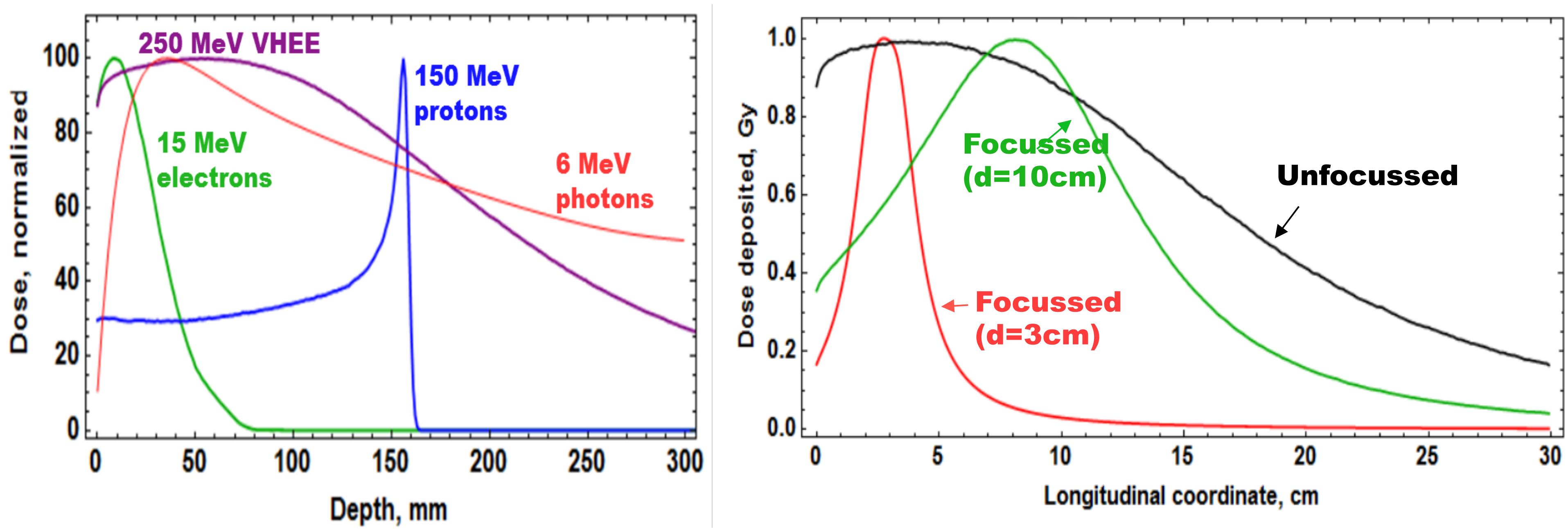
Current Hot topics: VHEE, FLASH……….

Courtesy of A. Lagzda



Dose profiles for various particle beams in water (beam widths $r = 0.5$ cm)

Courtesy of A. Lagzda



Depth Dose curve for various particle beams in water (beam widths r=0.5 cm)

FLASH - biological findings

Compared to conventional dose rate irradiation, FLASH achieves:

- Reduced normal tissue injury
  - Multiple organ systems: lung, brain, intestinal tract, skin
  - Multiple mouse strains, multiple species
- Equal or better tumor killing *in vivo*
  - Multiple tumor models

Courtesy D. Townsend

ENLIGHT: power of collaboration