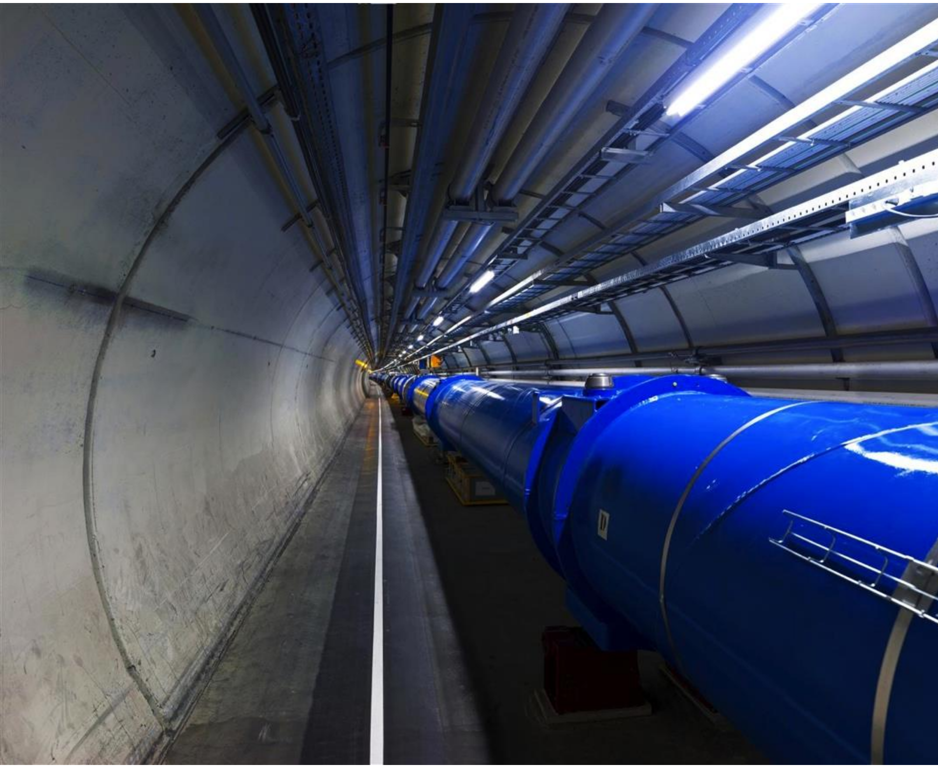
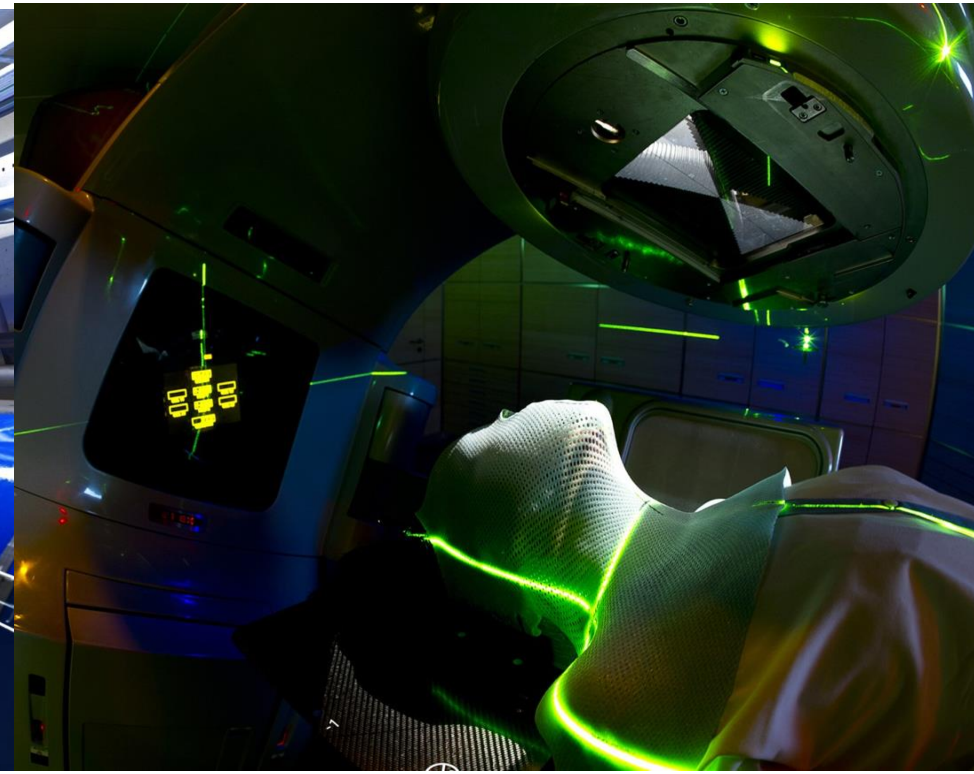
Particelle per la slaute:

dal laboratorio al paziente più velocemente e più democraticamente





Manjit Dosanjh

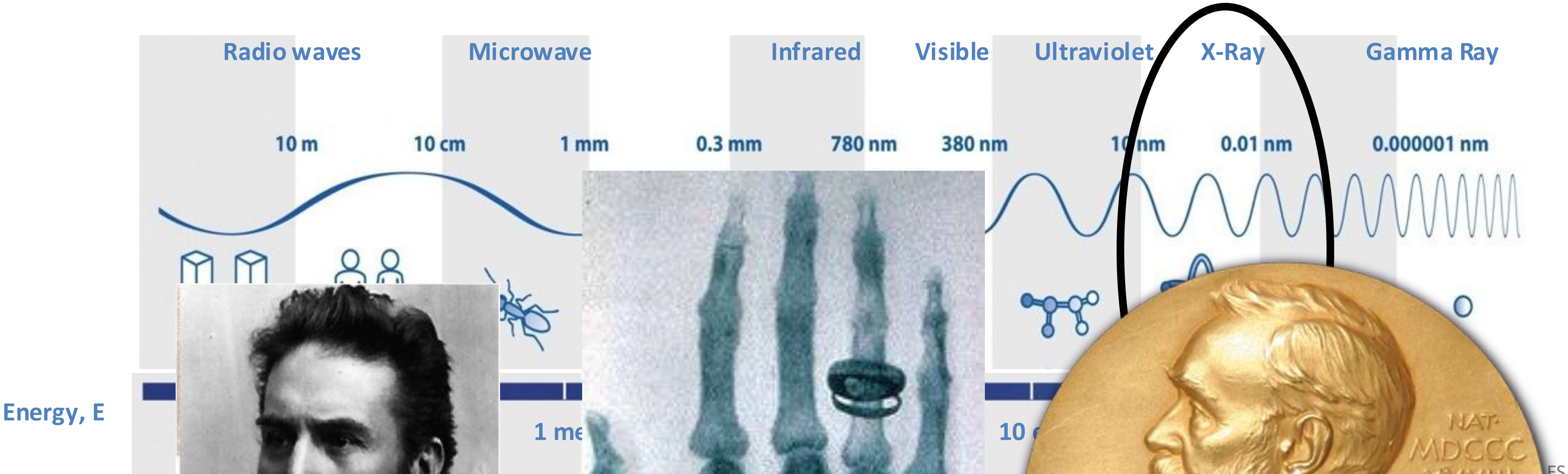
Manjit.Dosanjh@cern.ch

10.10.2024

CERN

UNIVERSITY OF OXFORD

La Fisica medica moderna…..gli inizi



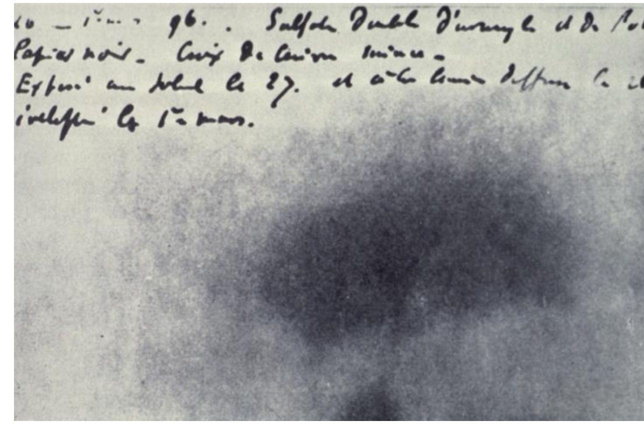
Wilhelm Röntgen

8/11/1895 — 22/12/1895 — 1901

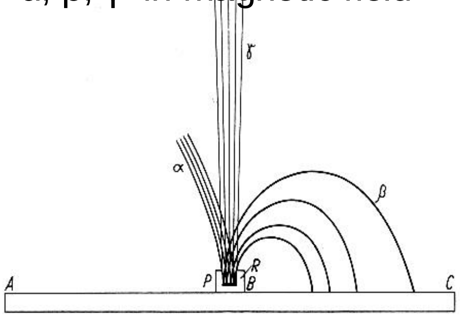
..........gli inizi

Henri Becquerel

1896:
Scoperta della radioattività naturale



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



1898: Scoperta del Radio

Immediatamente usato per la "Brachytherapy"

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

Il primo esperimento di radiobiologia

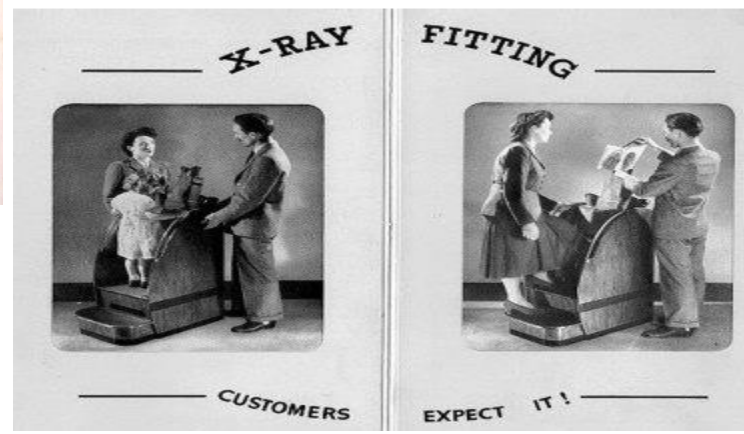
Pierre Curie and Henri Becquerel

Uso della radioattività per qualsiasi cosa….

Par Cinémagazine, 14 février 1935 — https://gallica.bnf.fr/ark:/12148/bpt6k2000628h, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=97956453

Par Radior cosmetics — sitead New York Tribune Magazine, page 12, Domaine public, https://commons.wikimedia.org/w/index.php?curid=35047170

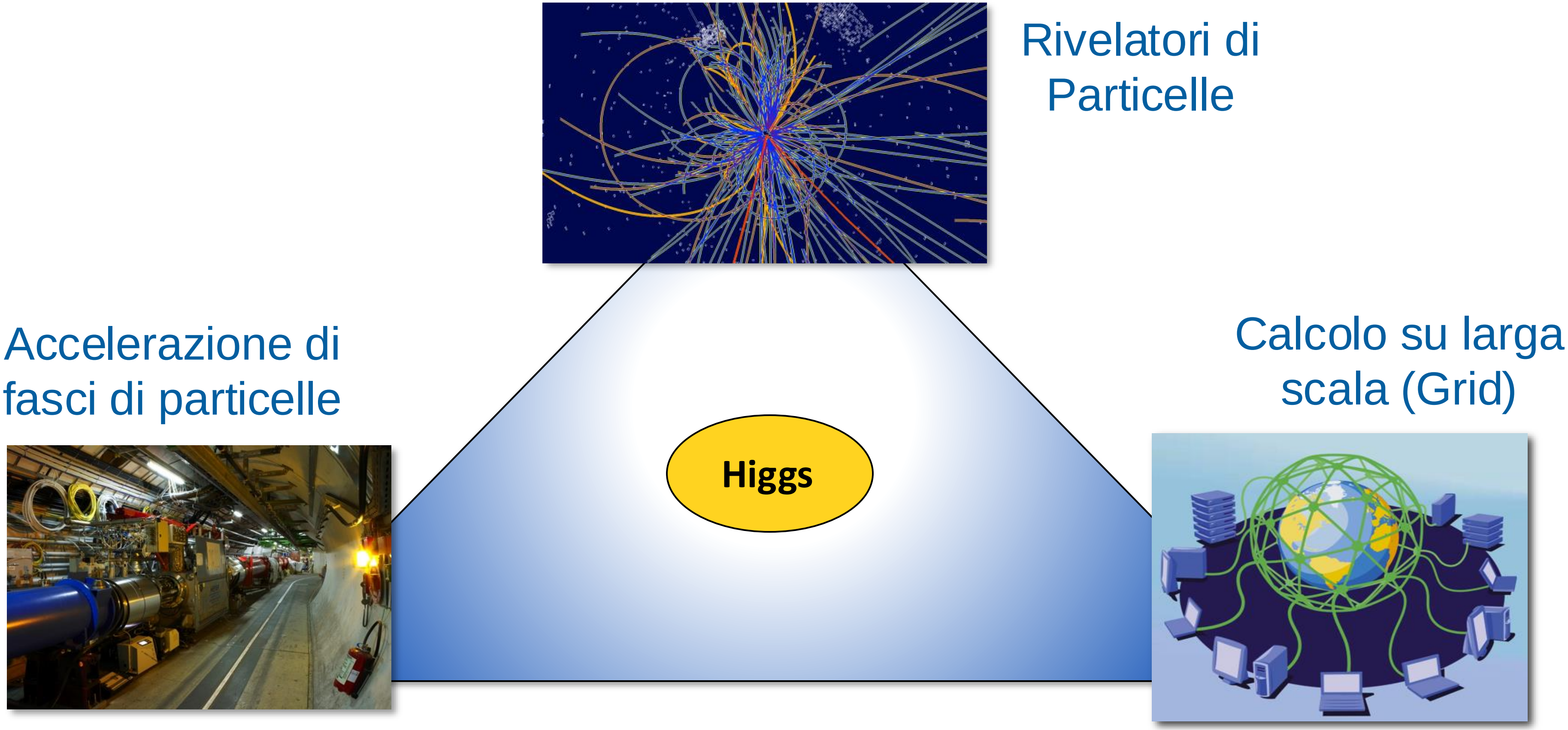
Par Sam LaRussa from United States of America — Radithor, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=57841049



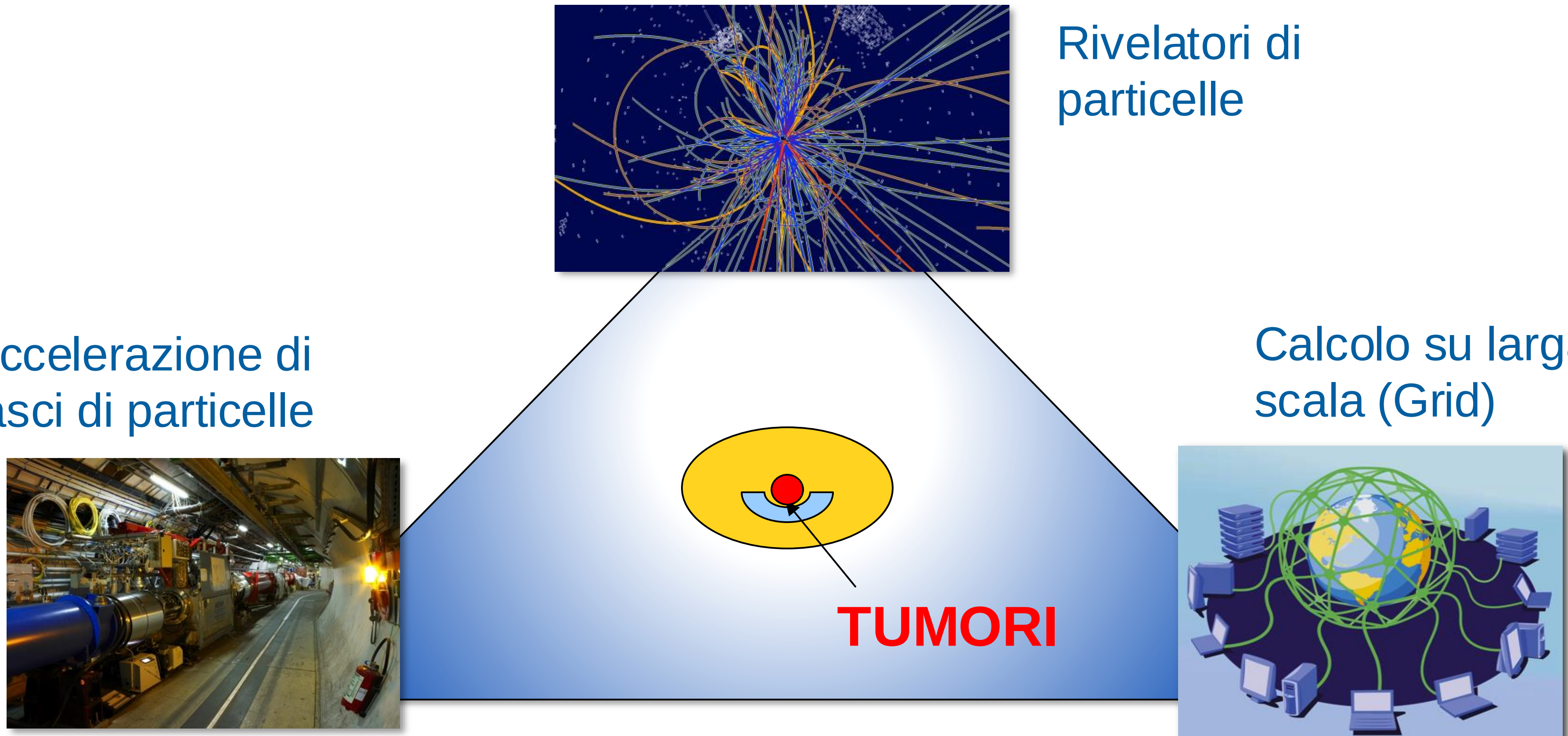
https://www.smh.com.au/national/nsw/from-the-archives-1956-ban-urged-of-x-ray-machines-at-shoe-shops-20210318-p57c1m.html

Courtesy of Manuela Cirilli

CERN e Tecnologie (tre pilastri)



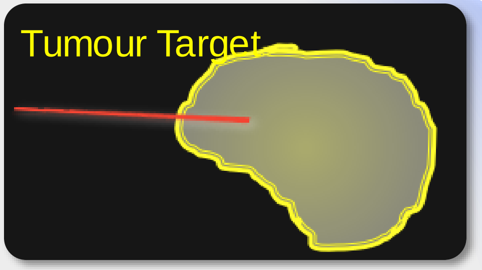
Le tecnologie della Fisica applicate alla Salute



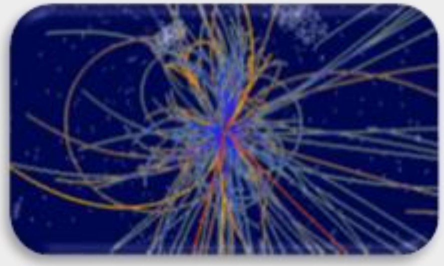
Un quarto pilastro: Catalizzare le collaborazioni

Accelerazione di particelle

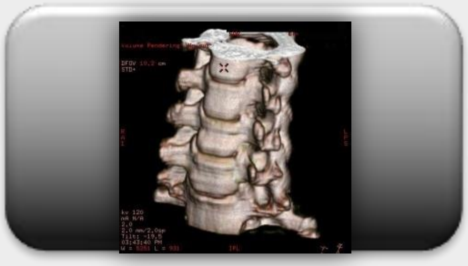
Terapia con radiazioni



Rivelazione di particelle

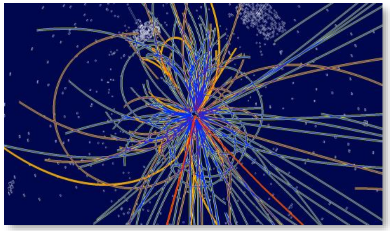


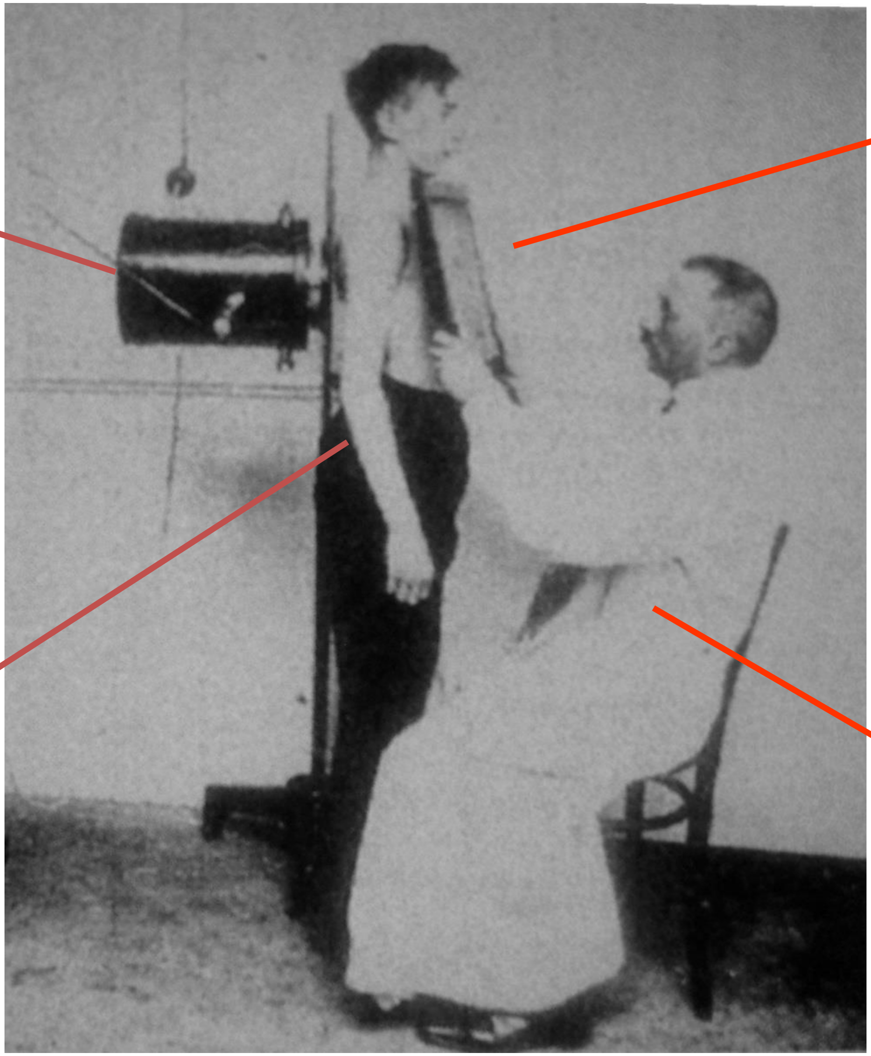
Imaging medicale



Calcolo su larga scala (Grid)

Uso del Calcolo su Grid per la gestione e l'analisi di dati medici





LHC
(Sorgente di
Raggi X)

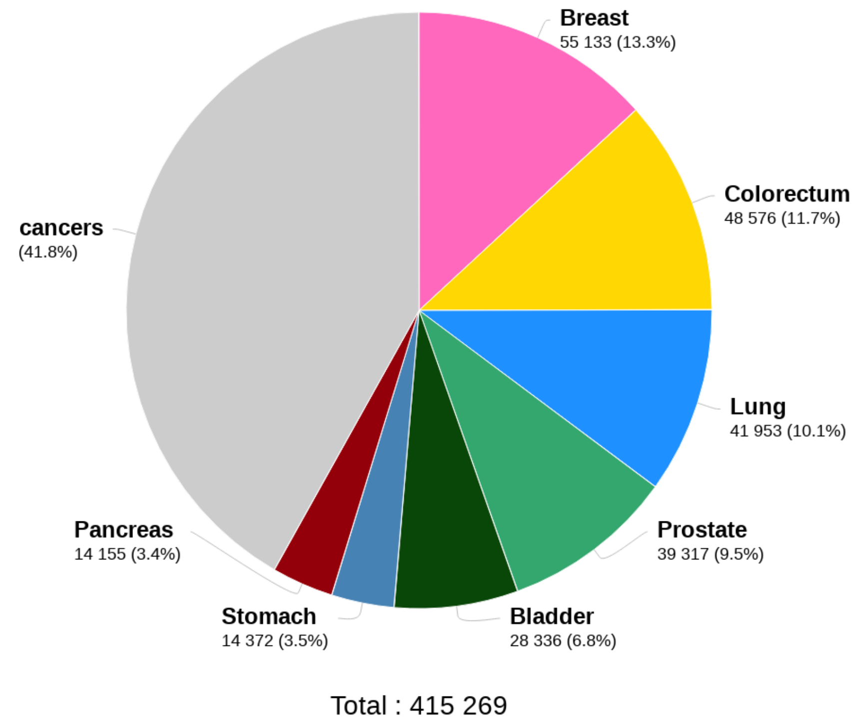
Rivelatore
(lastra raggi X)

Higgs
(Paziente)

Sistema di
riconoscimento
Immagini
(il medico)

Il Cancro è una sfida globale in continua crescita

- Globalmente **19.3** milioni di nuovi casi per anno sono diagnosticati e si sono avuti **10** milioni di morti nel **2020**
- Questo aumenterà fino a **30** milioni di nuovi casi per anno e **16** milioni di morti nel **2040**
- Adesso è la **seconda causa di morte** ma in circa 20 anni sarà la **prima causa**. ((lung, breast, colorectal, prostate)
- **>70% di queste morti hanno luogo** nelle cosiddette low-and-middle-income countries (LMICs)

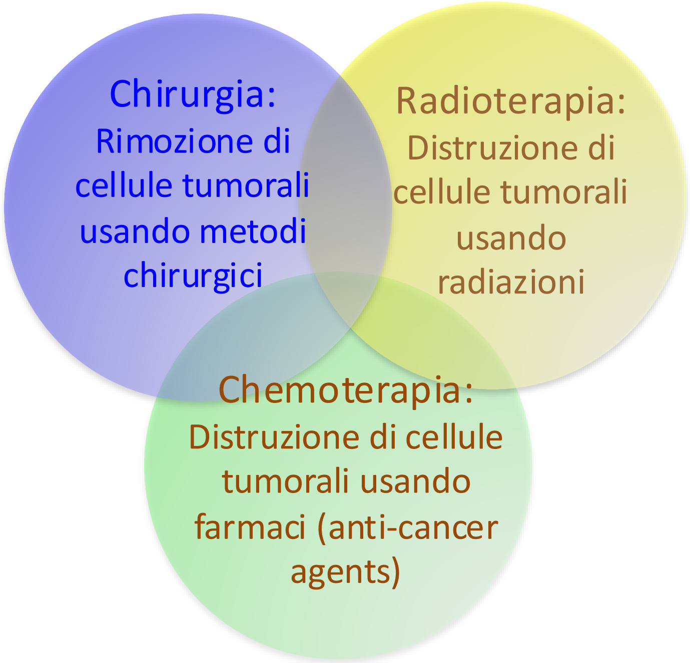


Cancer data in Italy: GLOBOSCAN 2020

- **Età** è il fattore più importante
- Più del 90% dei casi di cancro sono diagnosticati in persone dai **45 anni in su**
- Quasi un quarto dei nuovi casi sono in persone **over 70**
- **1 su 4 morti per cancro** sono causate dal **fumo**

Cosa è il Cancro?

- Tumore: che cosa è?
  - Crescita abnormale di cellule
  - Maligna: senza controllo, può diffondersi (metastasi) → cancro



Trattamento del Cancro e Miglioramento delle prospettive

Idealmente è necessario trattare:

Il tumore

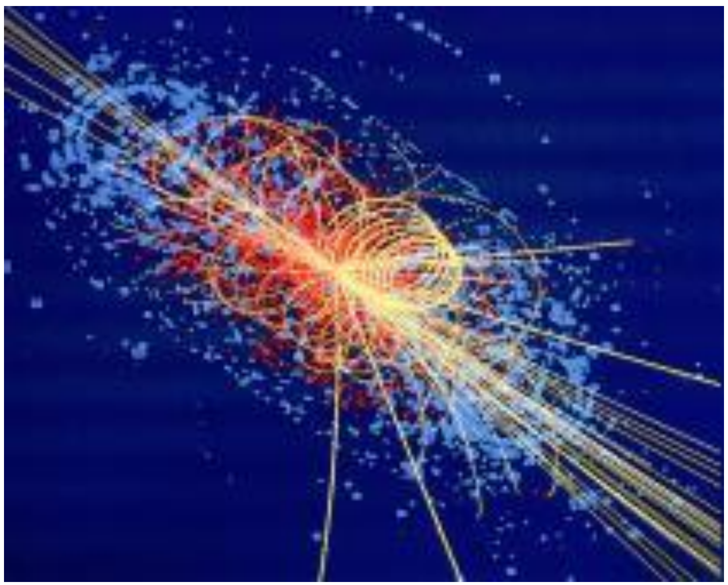
Tutto il tumore

Niente altro che il tumore

Il trattamento ha due importanti finalità: uccidere le cellule tumorali e proteggere i tessuti sani circostanti
Pertanto la chiave è "vedere" per sapere dove e "depositare" con precisione per essere certi che vada lí dove deve andare.

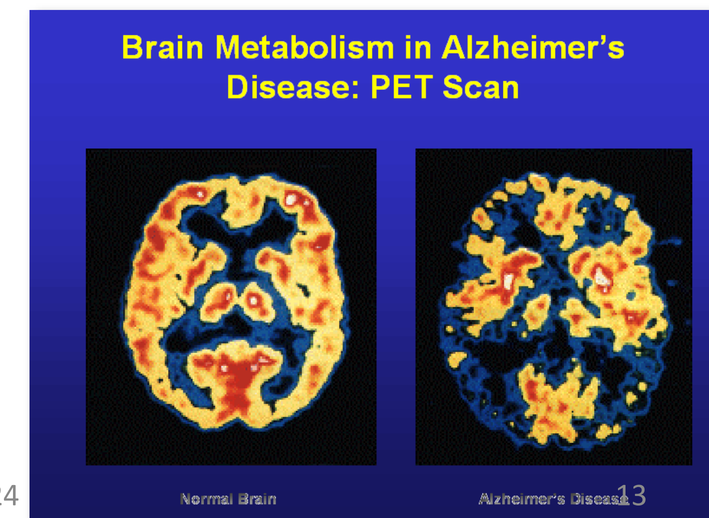
Rivelatori e l'arte di vedere………

Rivelatori di particelle



Imaging

X-ray, CT, PET, MRI



X-ray imaging

Wilhelm Röntgen

8/11/1895

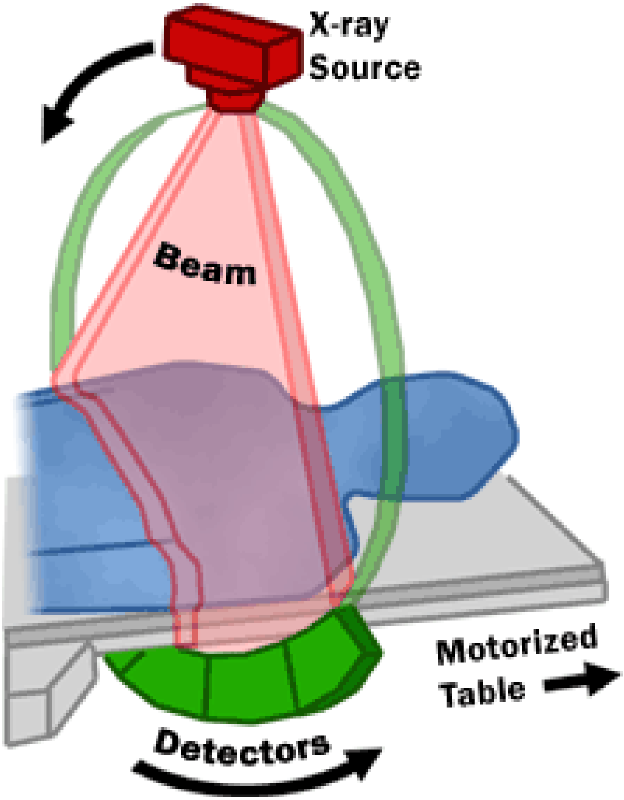
22/12/1895

1901

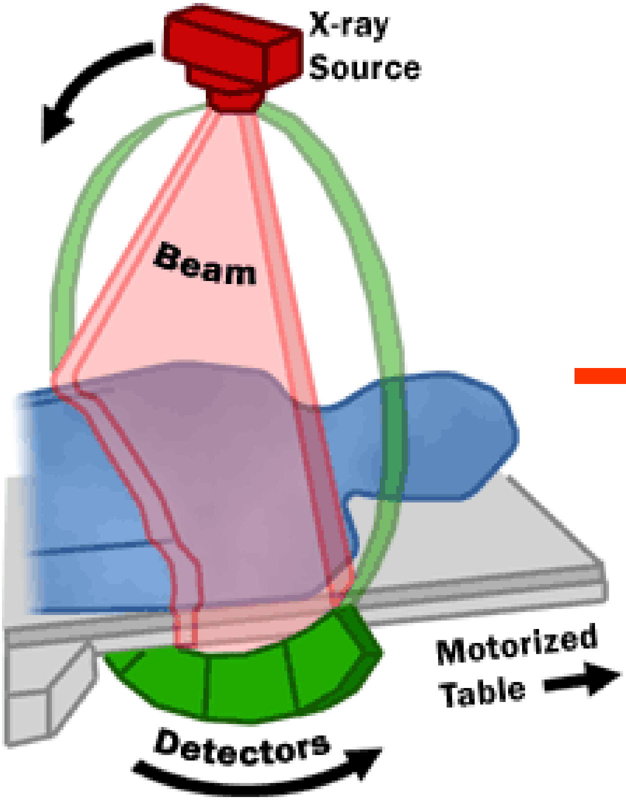
Per la prima volta si riesce a vedere sotto la pelle del paziente senza tagliarla

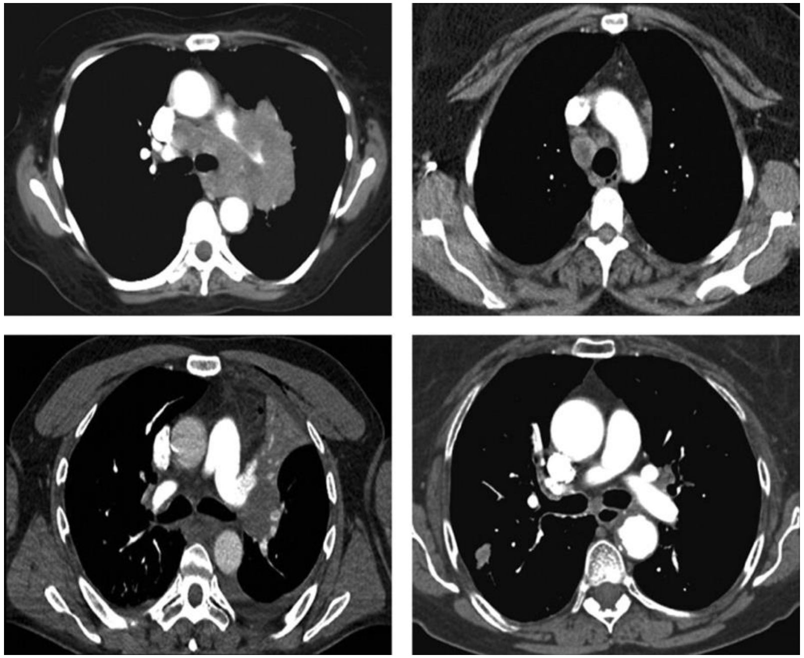
CT – Computed Tomography (TAC)

3d X-rays imaging



CT – Computed Tomography





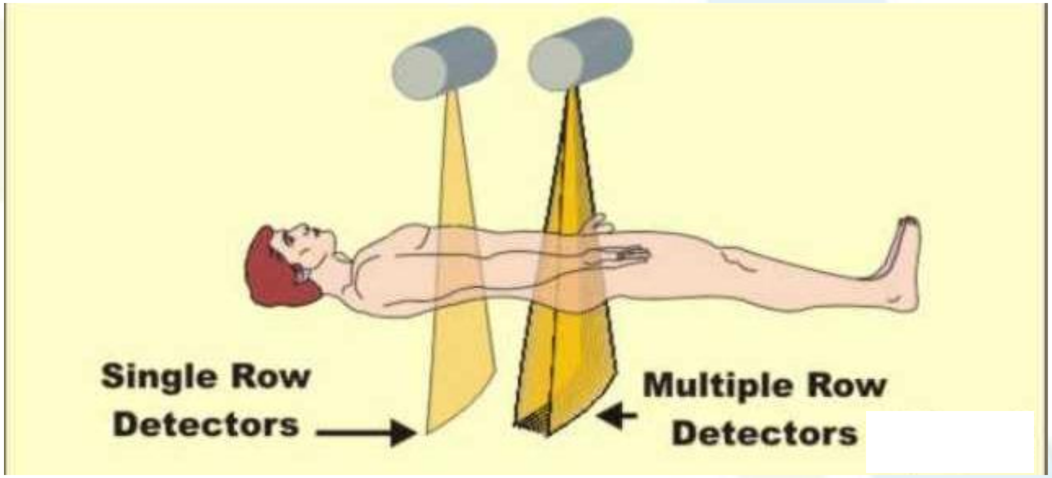
"3D-imaging"

X-ray CT ha dato il via ad un cambiamento nella diagnostica medica per immagini

2000-2008 “CT Slice War”

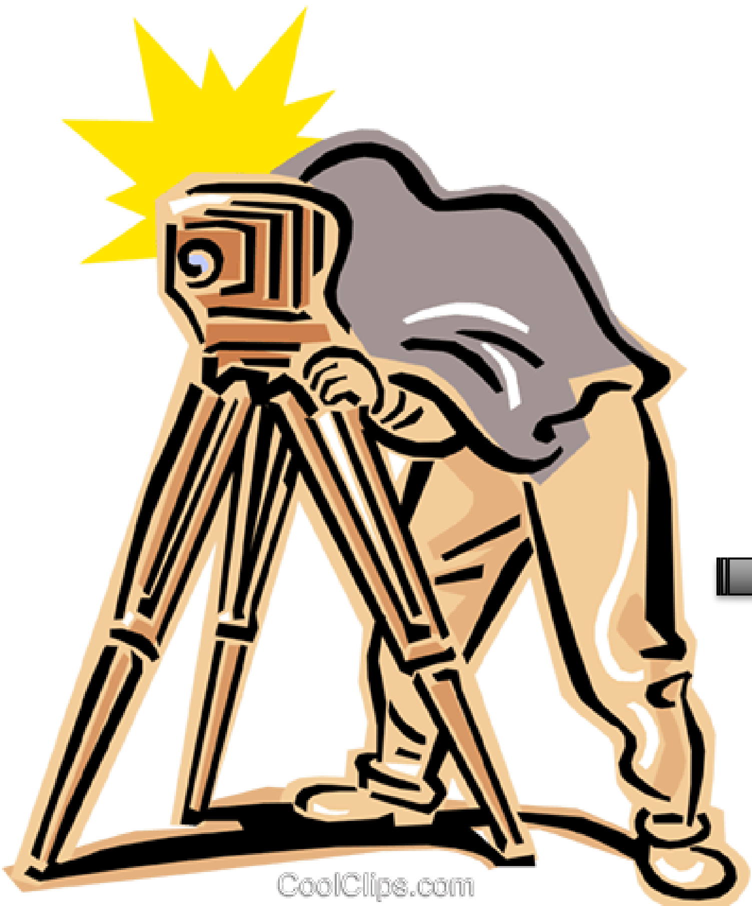
– ***CT diviene molto veloce con piccoli voxel / pixels***

- 2000: si acquisisce una singola sezione trasversa per rotazione
- 2012: si acquisiscono fino a 64-500 sezioni per rotazione



mars

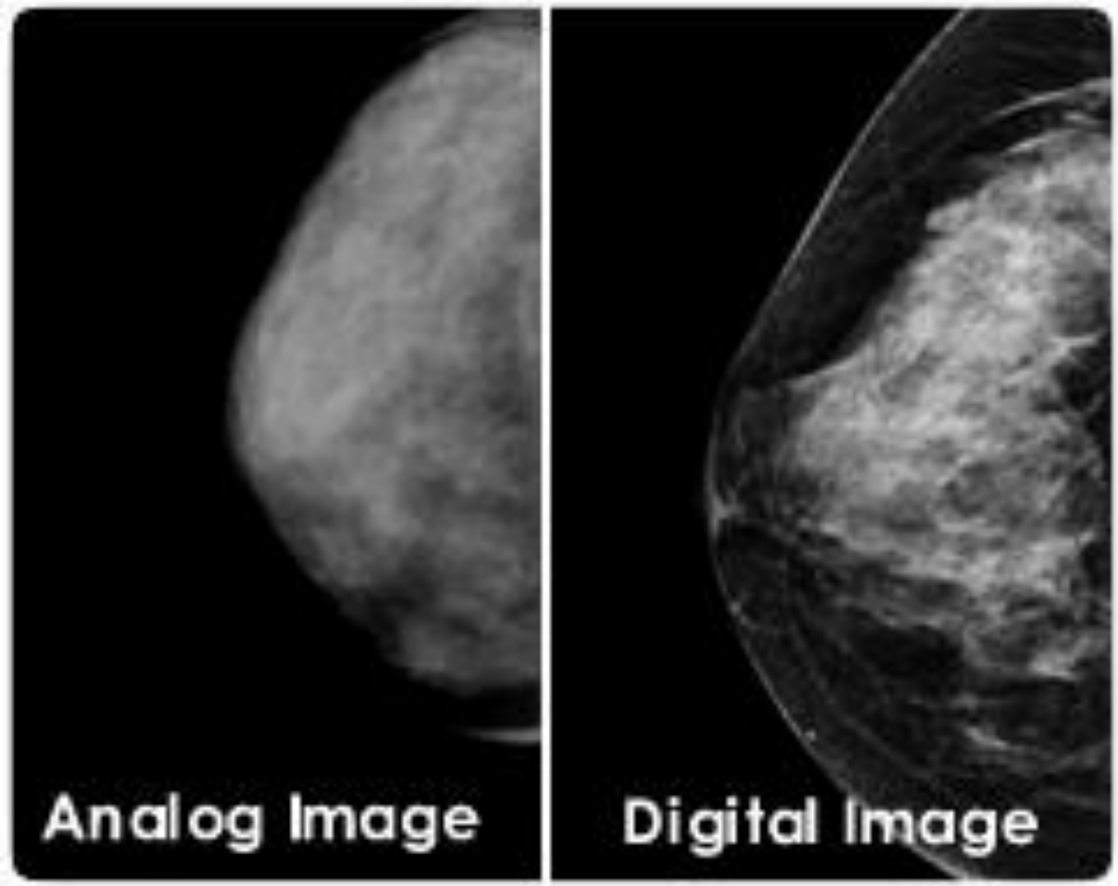
Rivoluzione nella Fotografia



Da foto in bianco e nero

Fotografia usando la tecnologia moderna

Towards digital colour x-ray imaging



Cura del cancro del seno ha subito una rivoluzione grazie al miglioramento delle immagini

Medipix

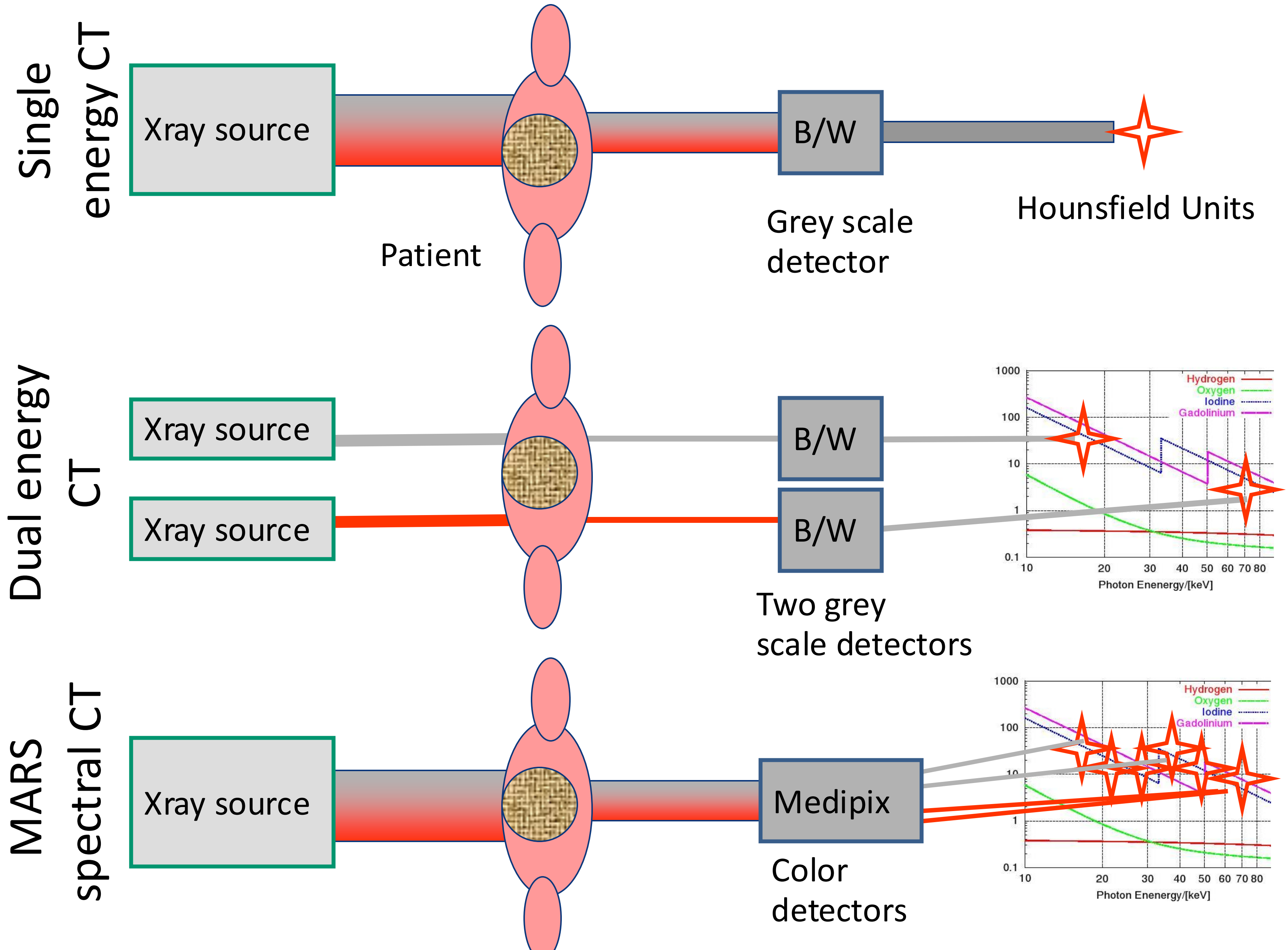
- Sviluppato per la Fisica
- delle alte energie:
  - Usato nei rivelatori di tracciamento delle particelle
  - Permette il conteggio del singolo fotone a differenza dei dispositivi tradizionali come film o CCD che integrano la carica.

Proprietà principali:

- Dispositivo totalmente digitale.
- Elevata risoluzione spaziale.
- Rapidissimo conteggio dei fotoni
- Buona efficienza di conversione per raggi-X di bassa energia


Credits: Simon Procz, University of Freiburg

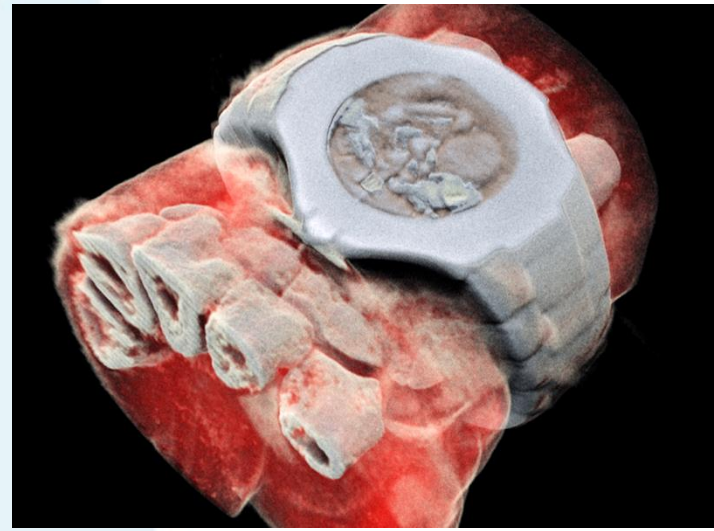
Single- , dual-, and spectral CT



Spectral CT adesso è possibile

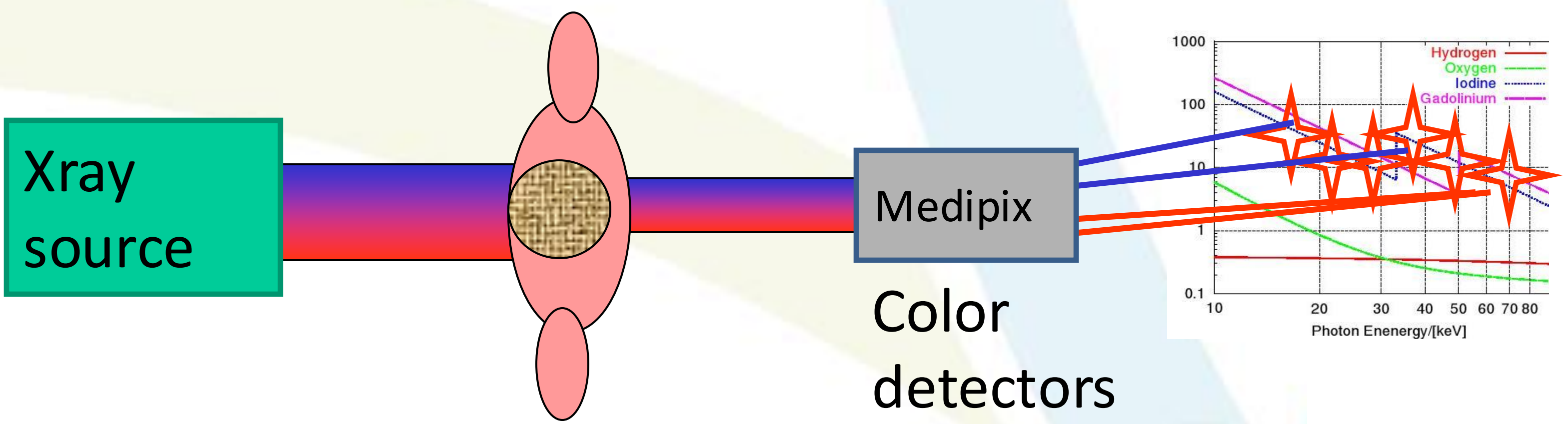
Medipix **A**ll **R**esolution **S**ystem

- **Energy resolution**
- Spatial resolution
- Temporal resolution



First 3D colour x-ray human image

MARS spectral CT



Prima immagine 3D umana a colori con raggi-X

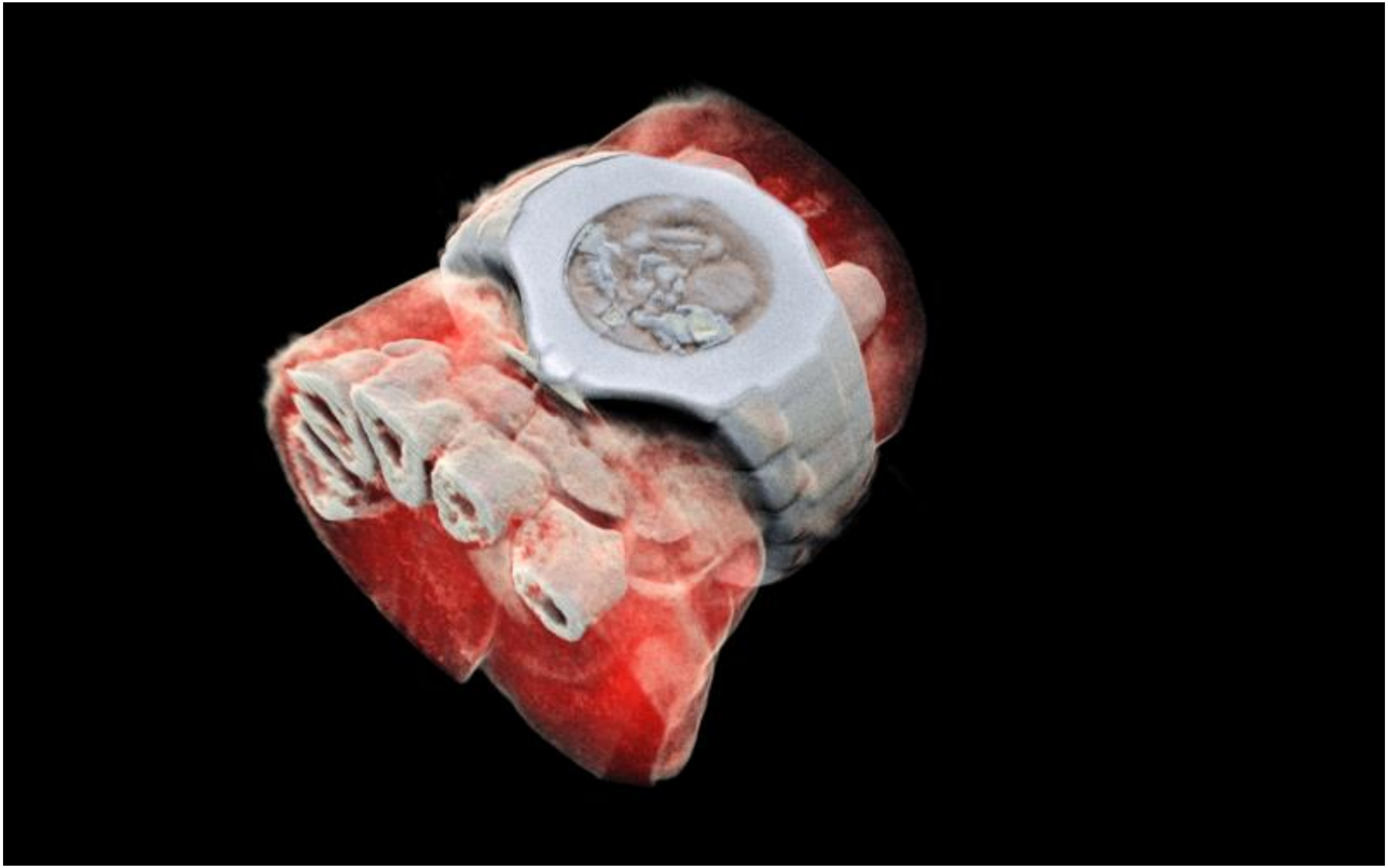
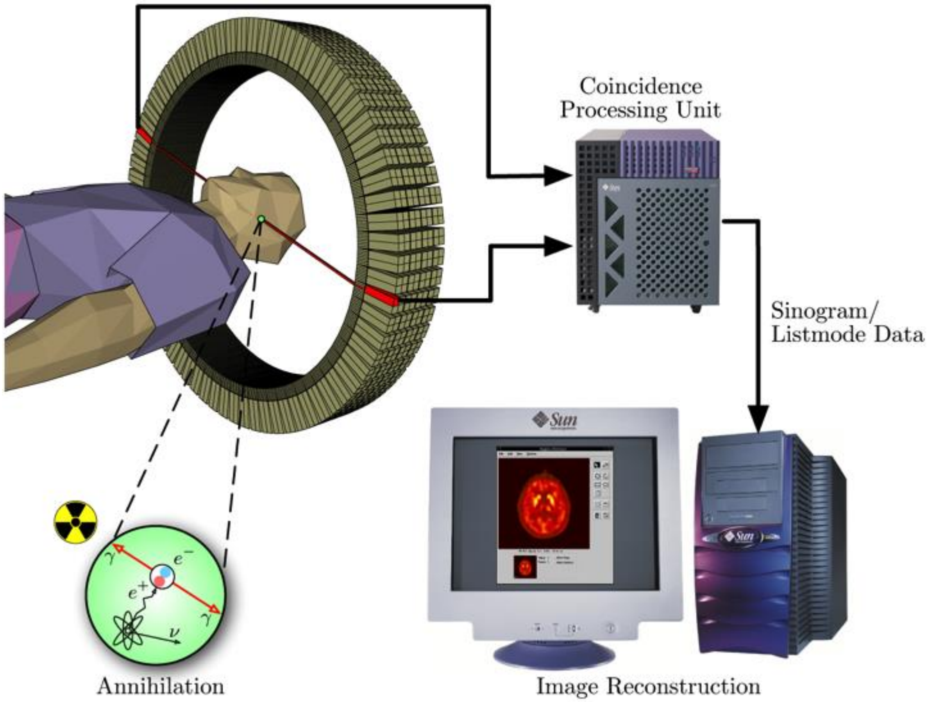
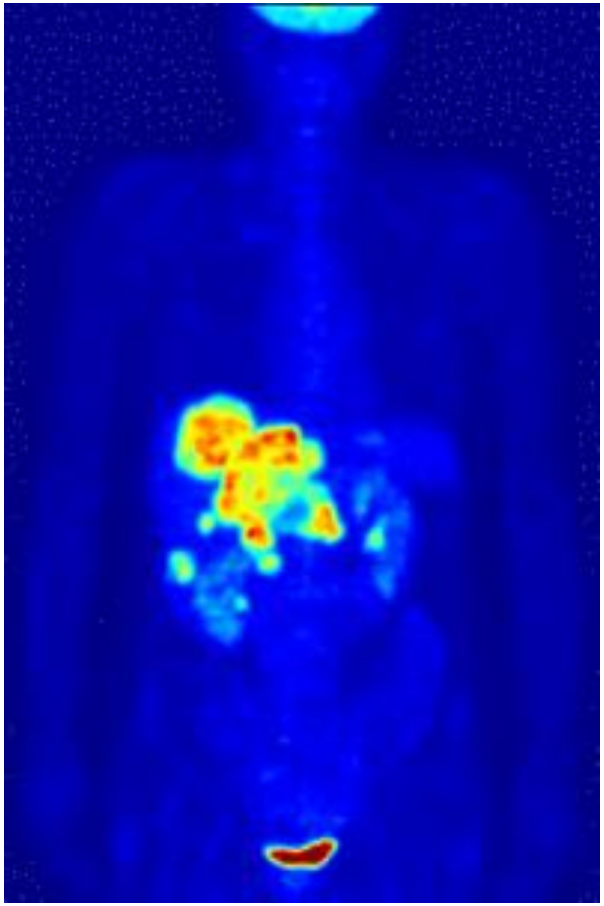


Immagine 3D di un polso con un orologio che mostra parte delle ossa delle dita in bianco e i tessuti molli in rosso. Accoppia l'informazione spettroscopica generata da Medipix3 con potenti algoritmi per generare immagini 3D. (Immagine: MARS Bioimaging Ltd)

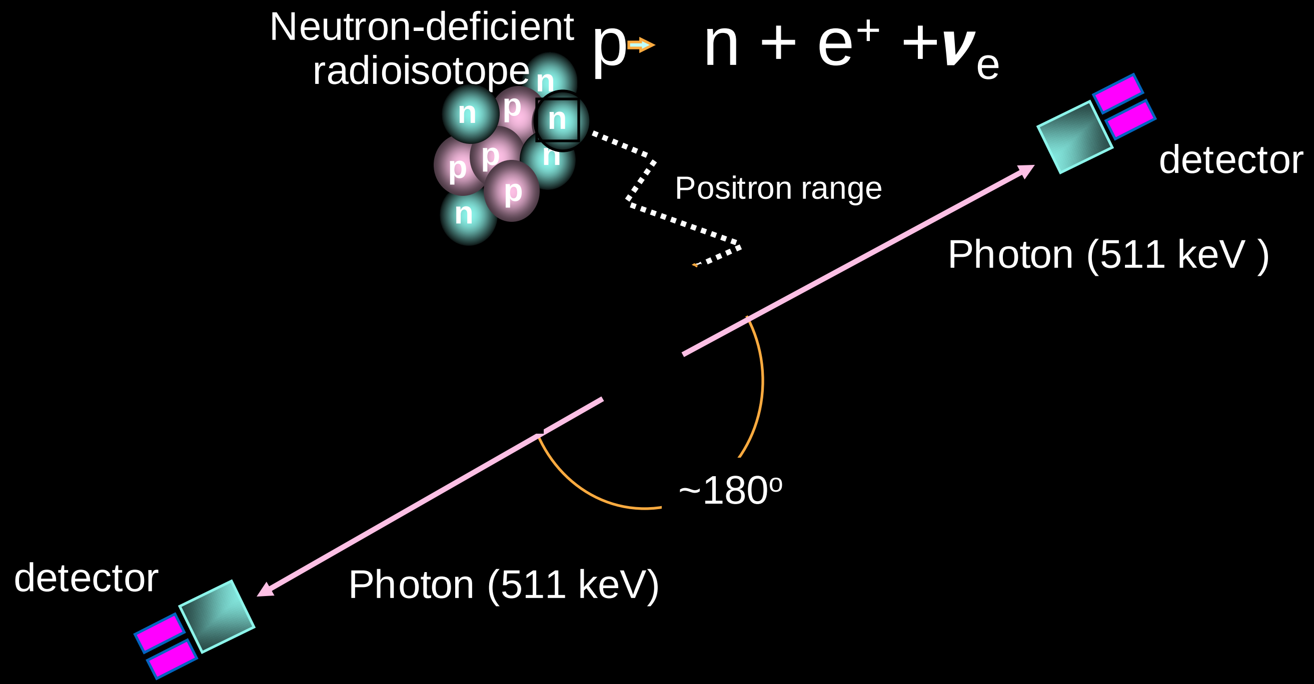
Positron Emission Tomography (Tomografia con emissione di positroni)





- ^{18}FDG trasporta il ^{18}F verso zone di alta attività metabolica
- 90% delle analisi PET sono in oncologia clinica
- 1974: prima PET eseguita su un essere umano

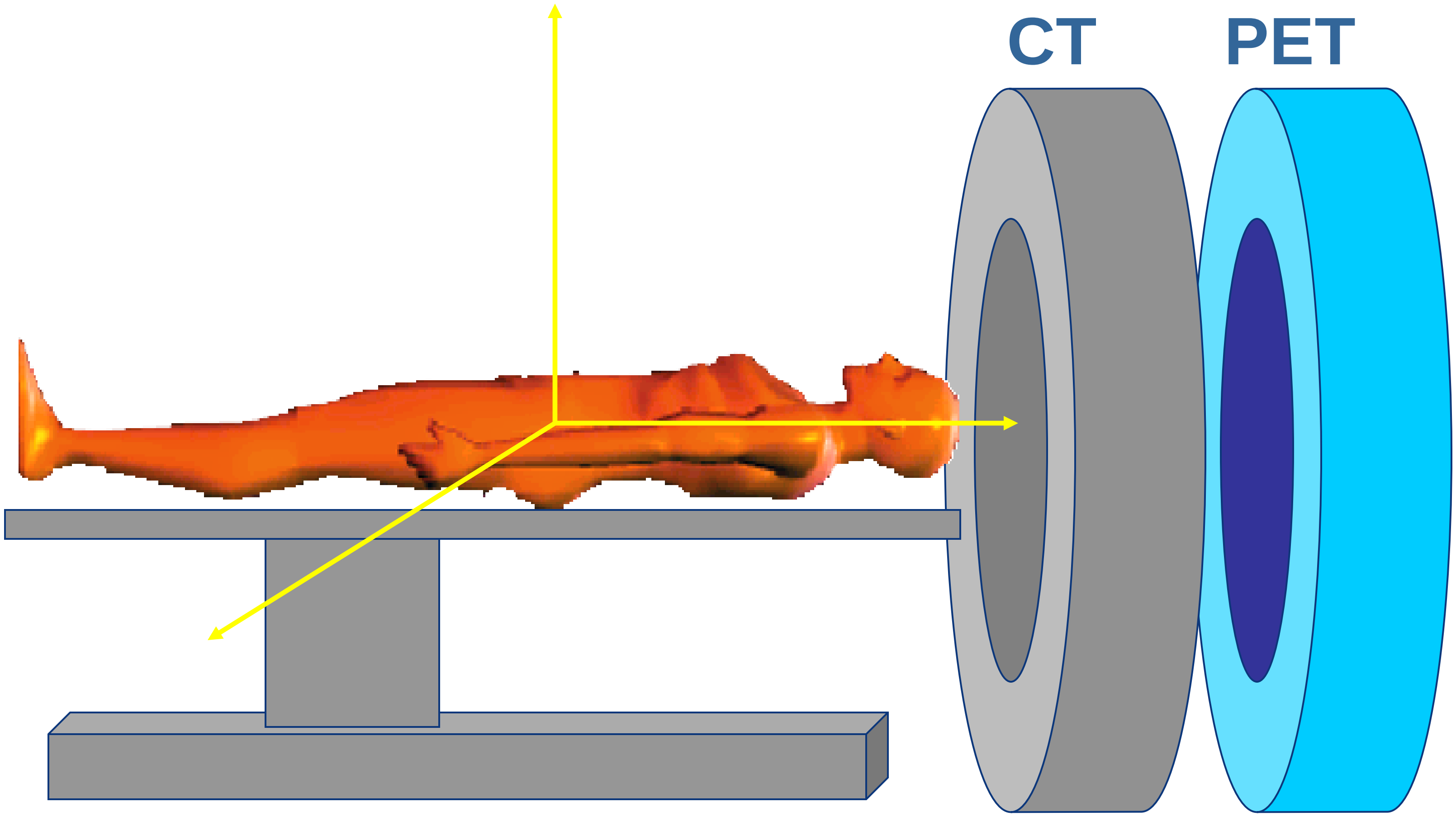
Positron Emission Tomography



PET – come funziona
http://www.nymus3d.nl/portfolio/animation/55

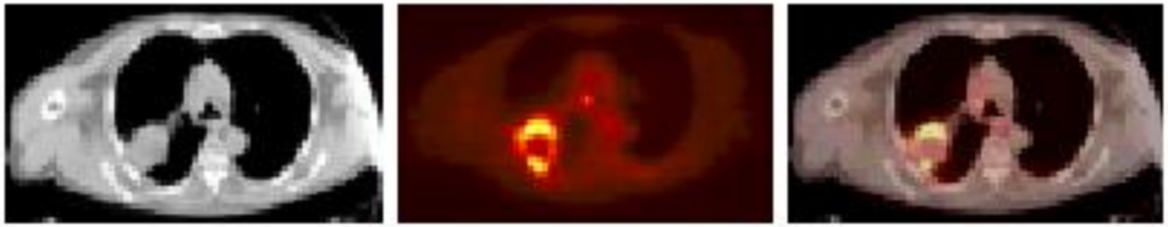
Concept of PET-CT

David Townsend



Imaging multimodale

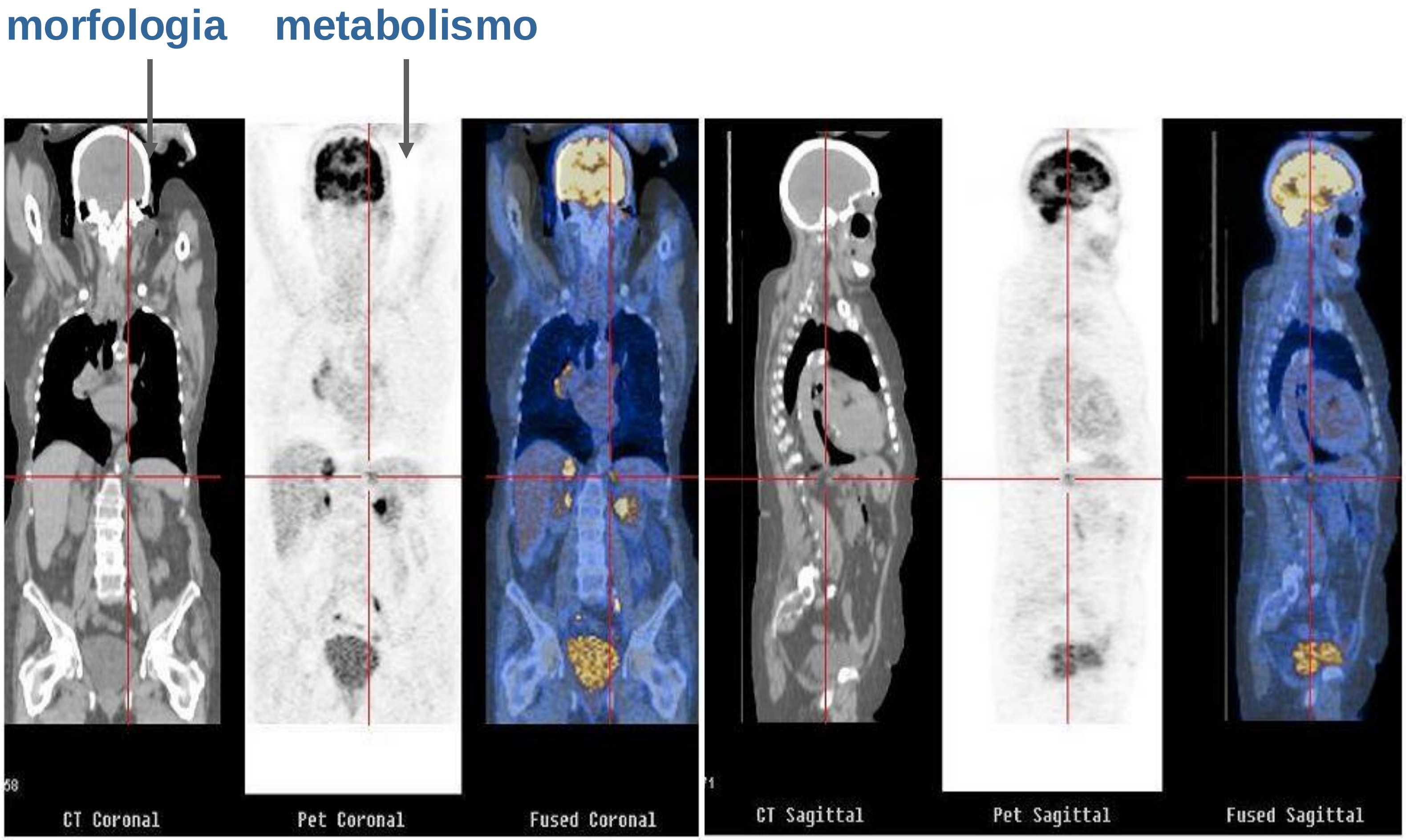
Immagine di cancro primario al polmone ottenuta con Dual/Commercial scanner. Un grosso tumore al polmone, che appare alla TAC come una massa ipodensa che si attenua uniformemente, ha un bordo di attività FDG e un centro necrotico rivelato dalla PET.



Courtesy of David Townsend

Imaging multimodale: CT e PET

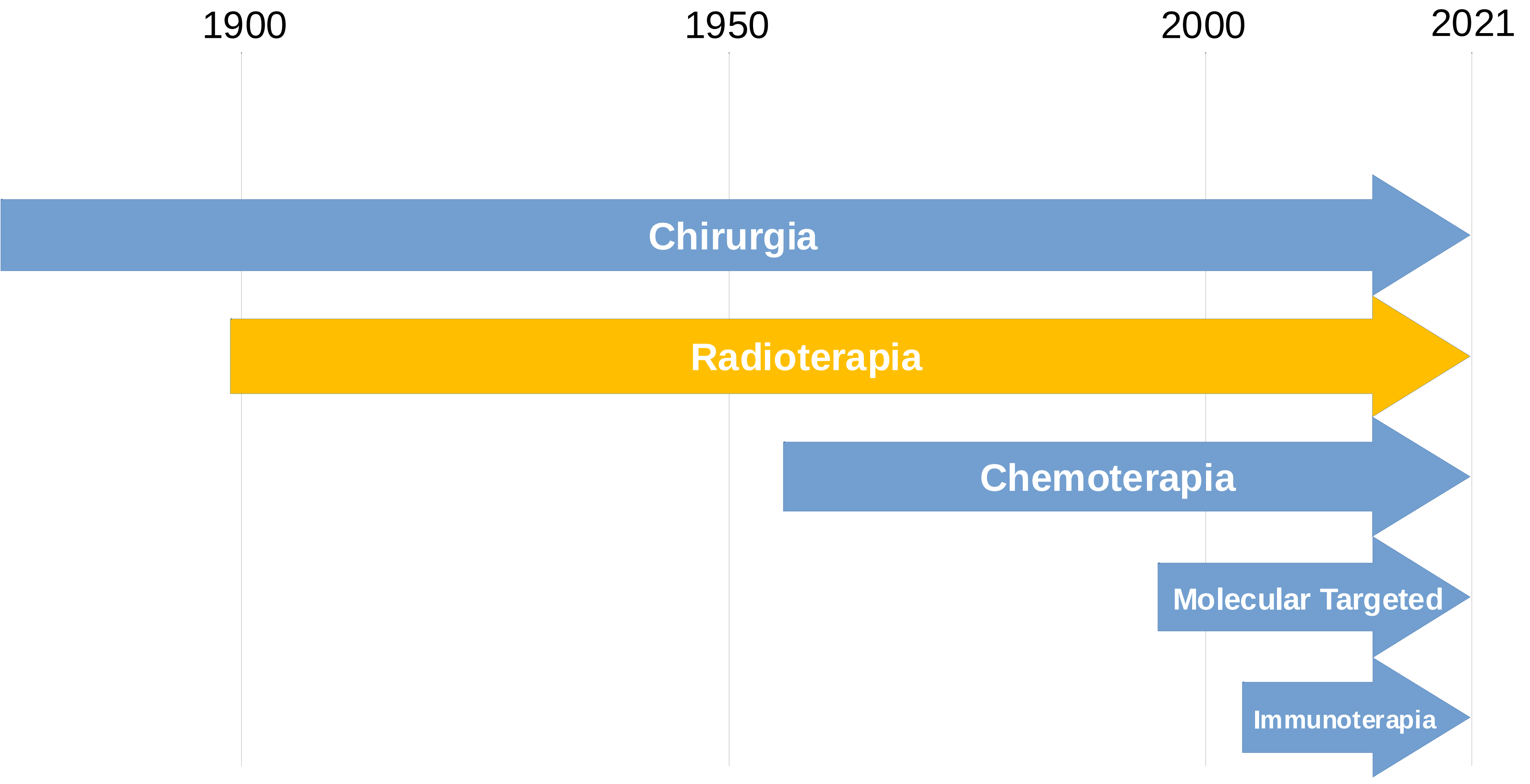
Combinare imaging anatomico e funzionale



Courtesy of David Townsend

Una volta noto dove si trova come lo curiamo?

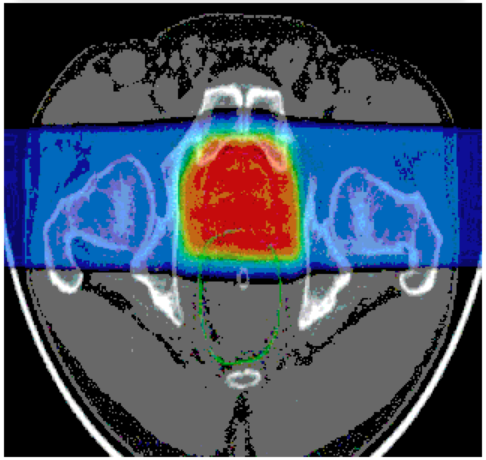
Come combattiamo il cancro?



Opzioni per il trattamento

Surgery

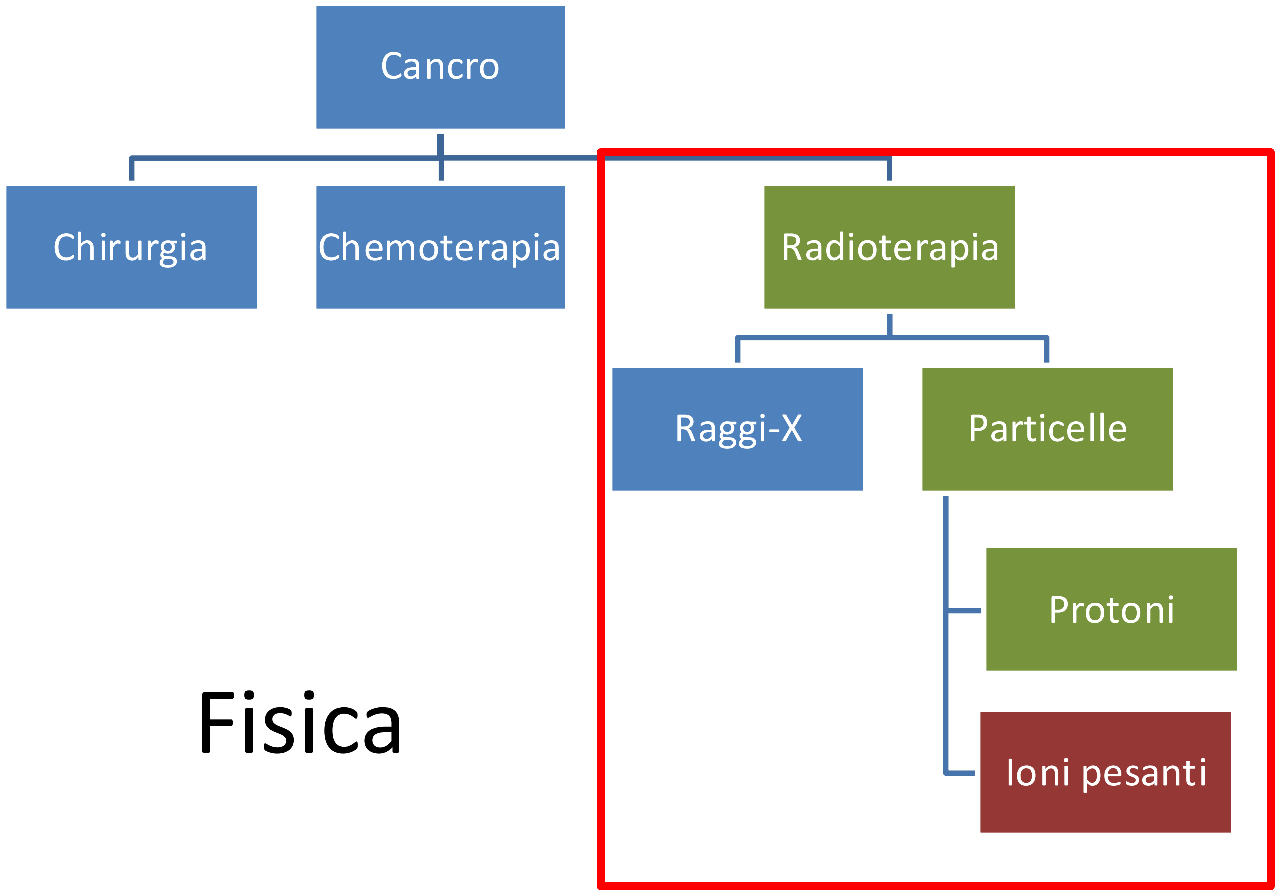
Radiotherapy



Chemotherapy (+ others)

SCOPO:
Non solo cura ma anche
Qualità di vita

Opzioni per il trattamento del cancro



Fisica

Radioterapia nel 21esimo Secolo

Le 3 "C" di Radiazione:

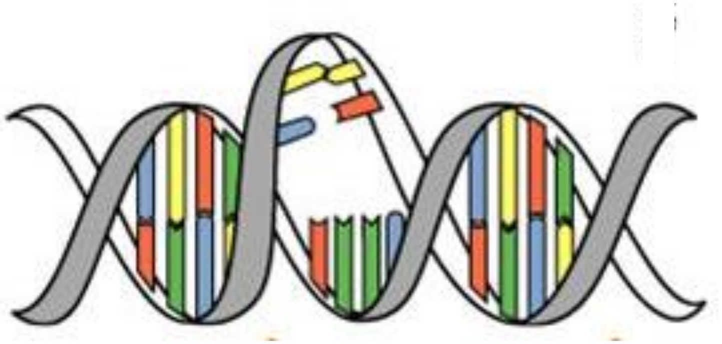
Cura (circa il 50% dei casi di cancro sono curati)

Conservativa (non-invasiva, pochi effetti collaterali)

Poco costosa(Cheap) (la radiazione costa solo circa 10% del costo totale per il trattamento del cancro)

(J.P.Gérard)

- Circa 60% dei pazienti sono trattati con RT
- Non vi è alternativa alla RT nel prossimo futuro
- Il numero di pazienti è in aumento

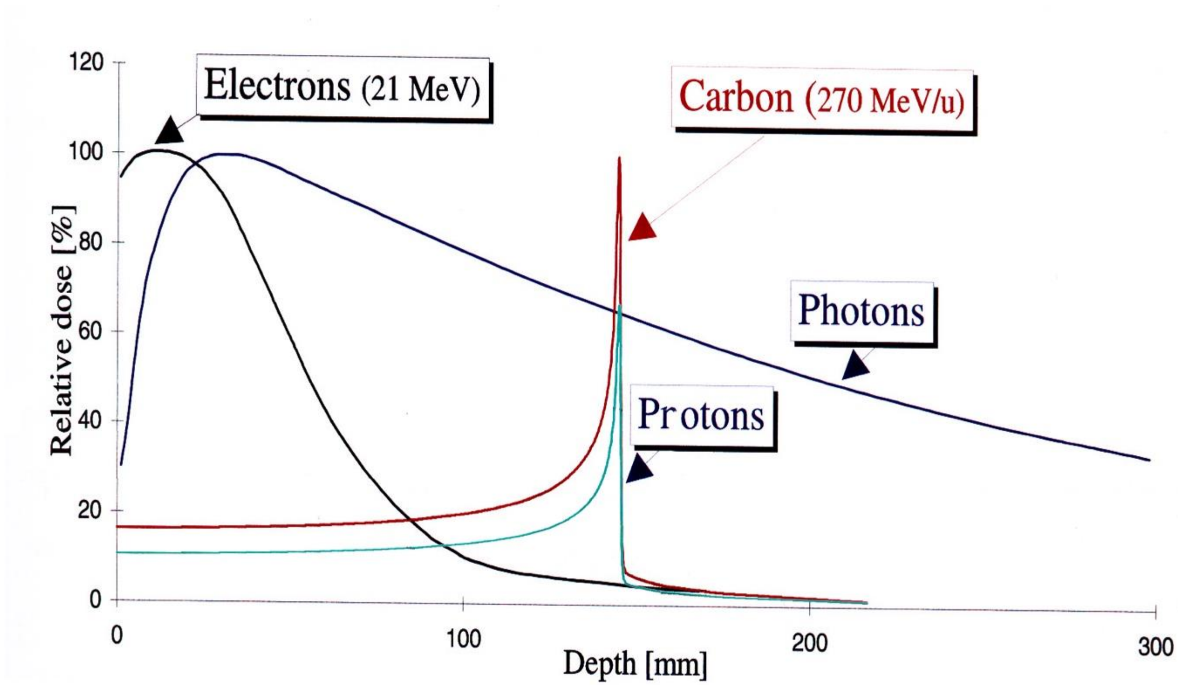


Finalità della Radioterapia:

- Irradiare il tumore con dose sufficiente a **fermare la crescita del cancro**
- **Evitare complicazioni** e **minimizzare** il danno al tessuto circostante

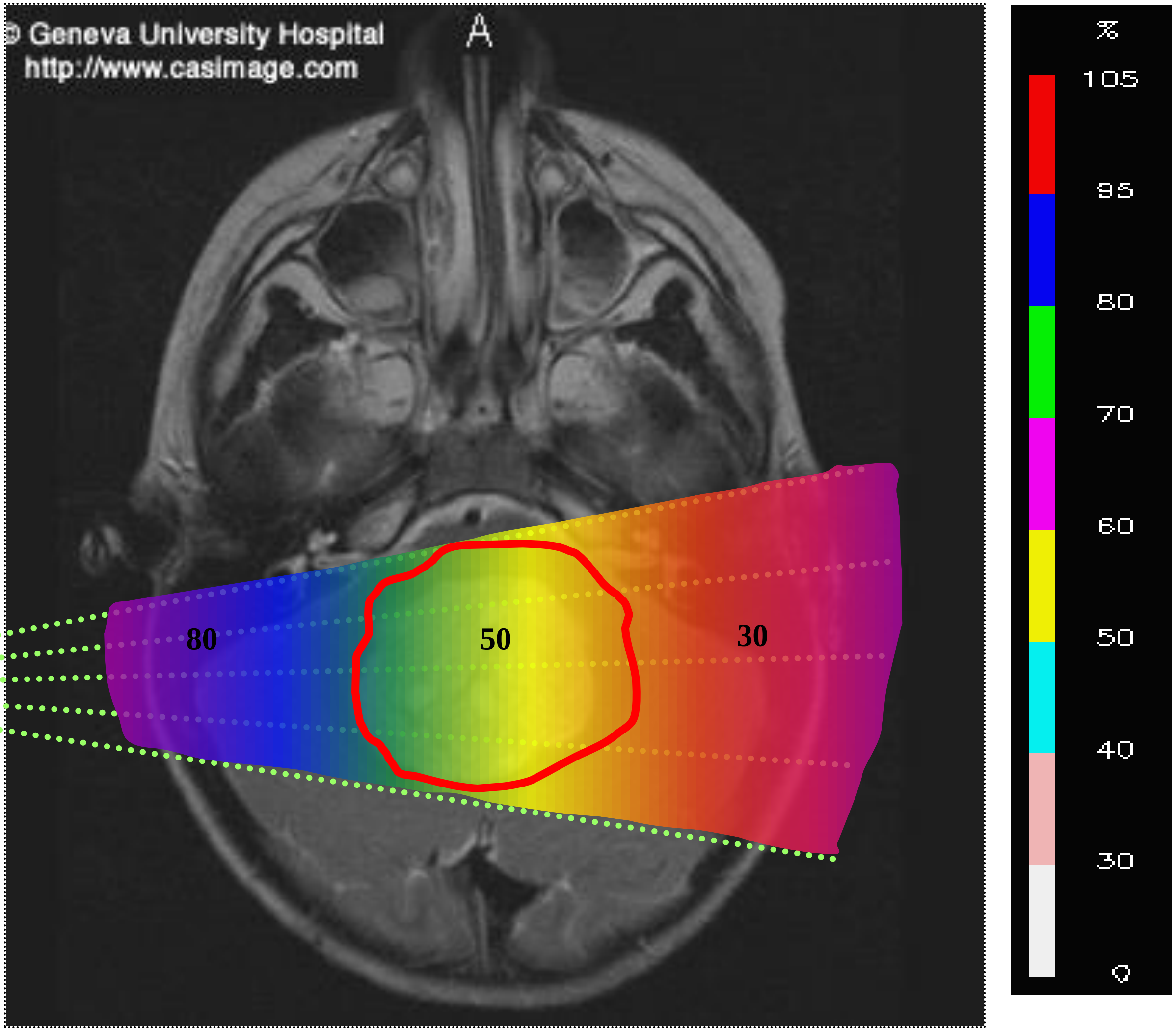
Metodi di uso corrente in radioterapia:

- 5-25 MeV fotoni
- 5 - 25 MeV elettroni
- 50 - 400 MeV/u adroni



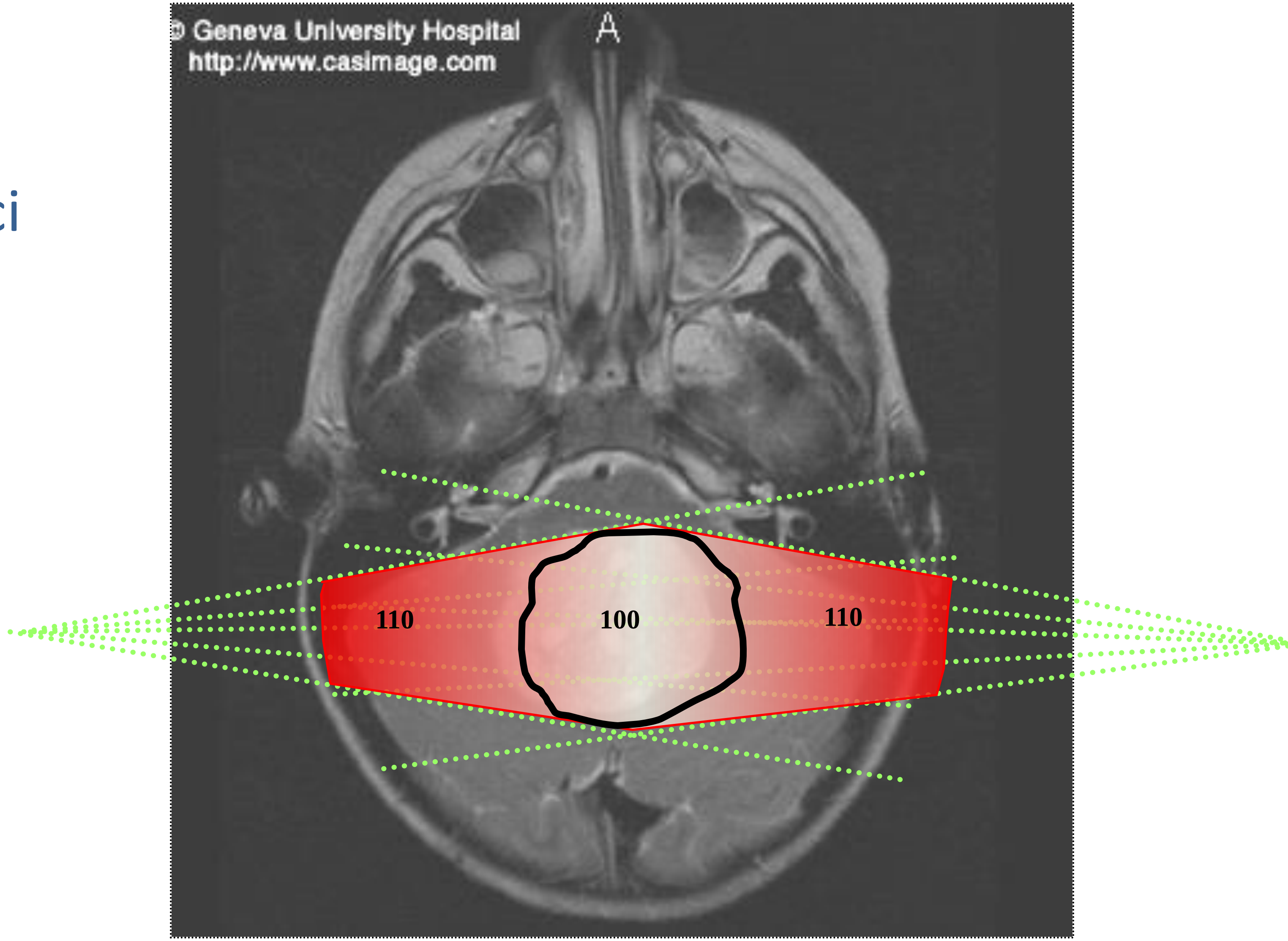
Radioterapia Classica con Raggi-X

Fascio singolo

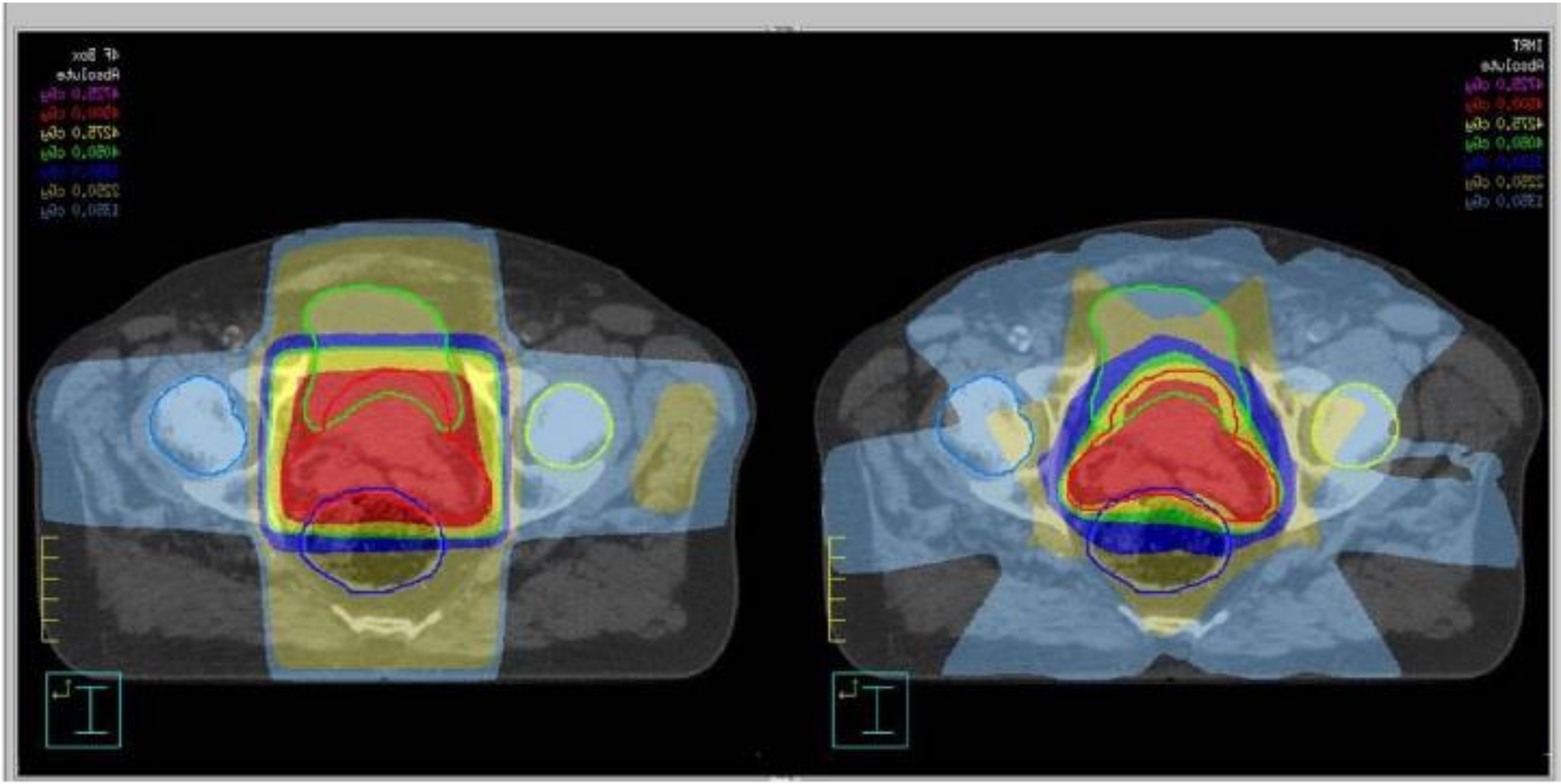


Radioterapia con Raggi-X

Due fasci



Precisione migliorata nel deposito

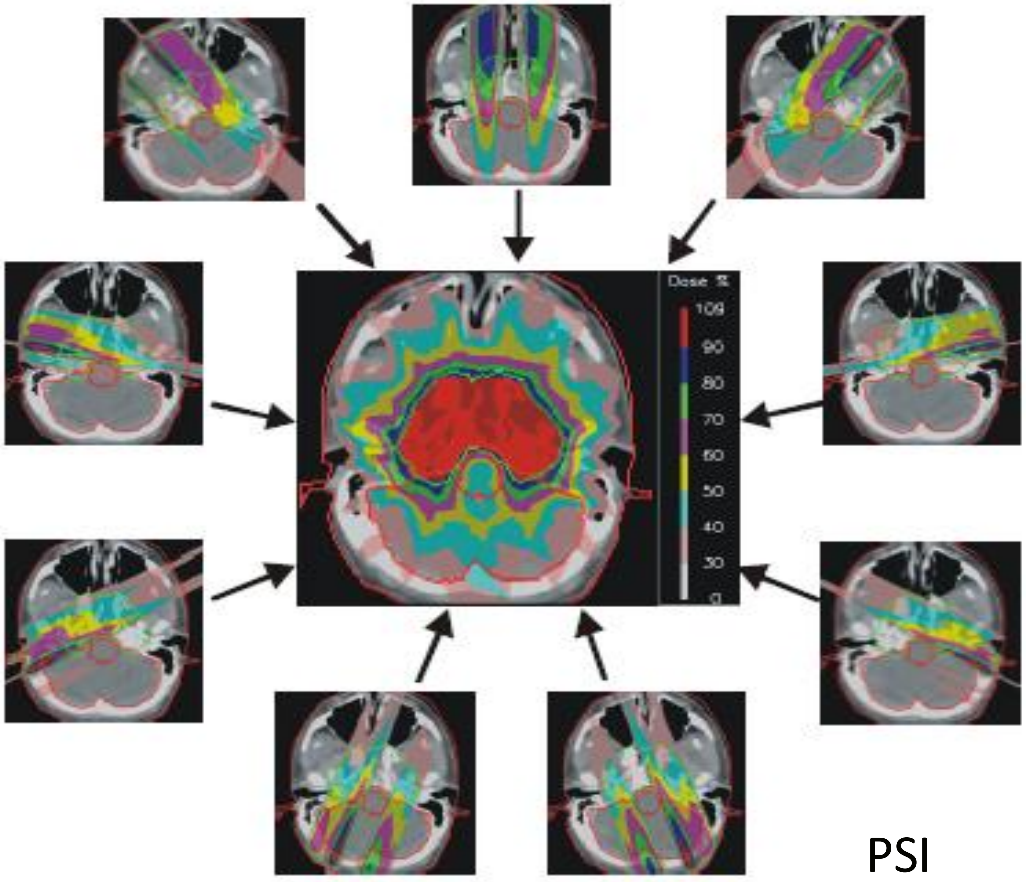


1990s: 4 campi di intensità costante

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

Intensity Modulated Radiation Therapy

9 CAMPI NON-UNIFORMI



PSI

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

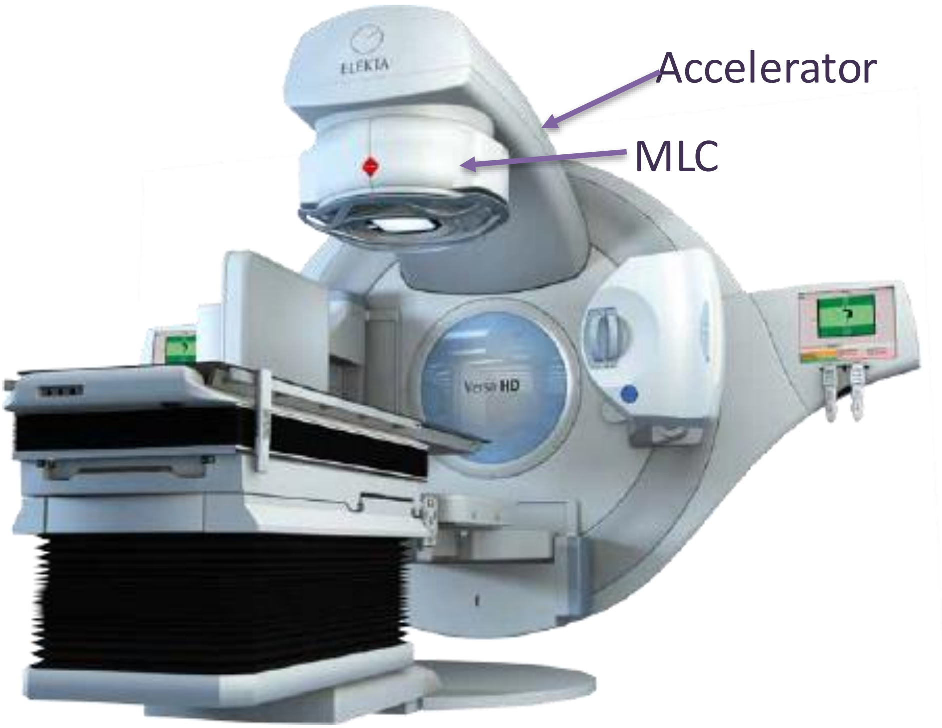
per permettere la riparazione dei tessuti sani

90% dei tumori sono <u>radiosensibili</u>

L' acceleratore più diffuso

Electron Linac (linear accelerator) for radiation therapy treatment of cancer)

around 20,000 in use



Widely available in all major hospitals in specially in high income countries (HIC)

Progressi in Radioterapia

Negli ultimi due decenni a causa di:

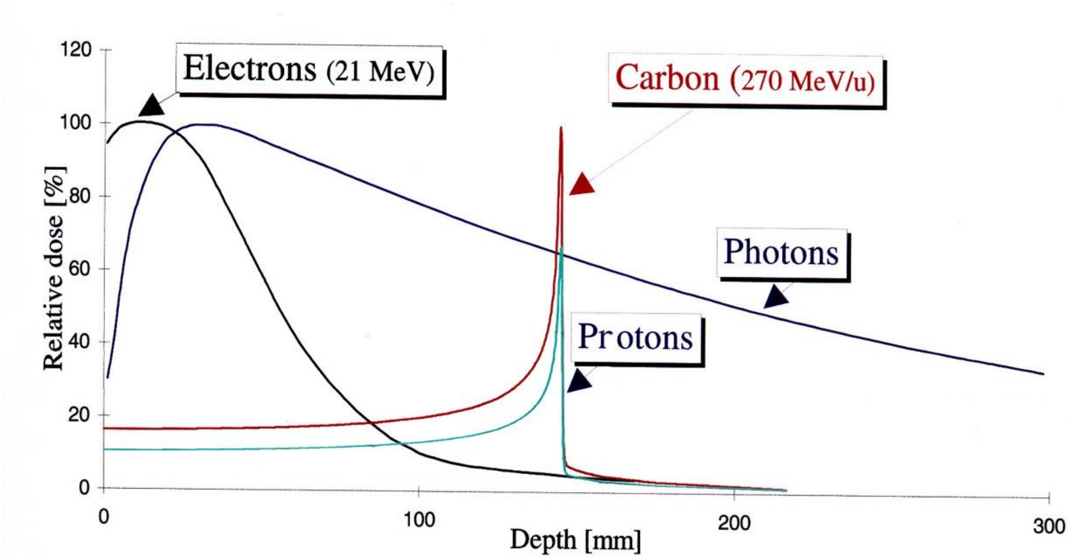
- Miglioramenti nelle modalità di imaging, multimodalità
- tecnologia, computers e software più potenti e sistemi di "delivery" hanno reso possibile:
  - Intensity Modulated Radiotherapy (IMRT),
  - Image Guided Radiotherapy (IGRT),
  - Volumetric Arc Therapy (VMAT) and
  - Stereotactic Body Radiotherapy (SBRT)
  - MRI-guided Linac therapy
- È la terapia con adroni/particelle il futuro?
- Forse è FLASH?

Hadron Therapy (Adroterapia)

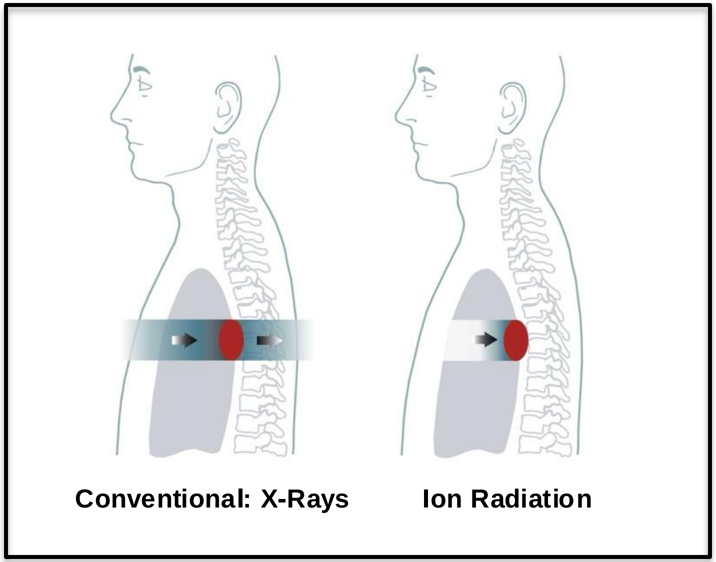
Nel 1946 Robert Wilson:

- Protoni possono essere usati clinicamente
- Acceleratori sono disponibili
- La dose massima di radiazione può essere localizzata nel tumore
- La terapia con Particelle permette di risparmiare i tessuti normali sani

Robert Wilson
Fermilab



Profondità nel corpo (mm)



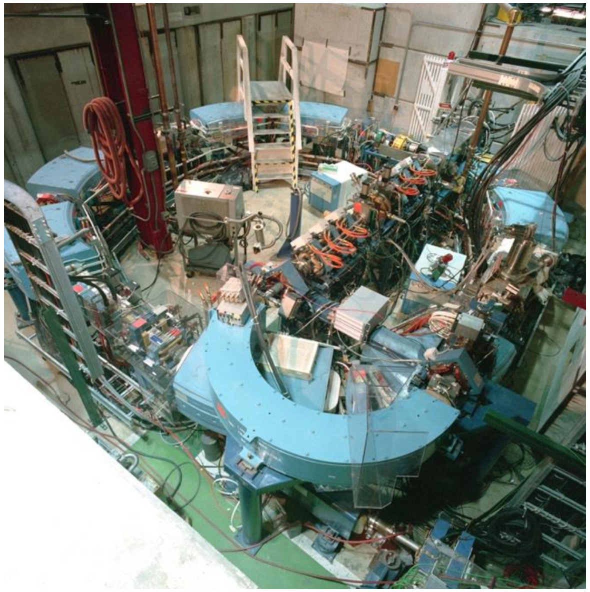
E. Lawrence
First cyclotron

Lawrence brothers
Physicist and Doctor

Sept 1954 – Berkeley
Tratta il primo paziente (CERN fondato stesso mese, anno)

Importanza della collaborazione……….

1993- Loma Linda USA (proton)



La prima struttura clinica dedicata

1994 – HIMAC/NIRS Japan (carbon)

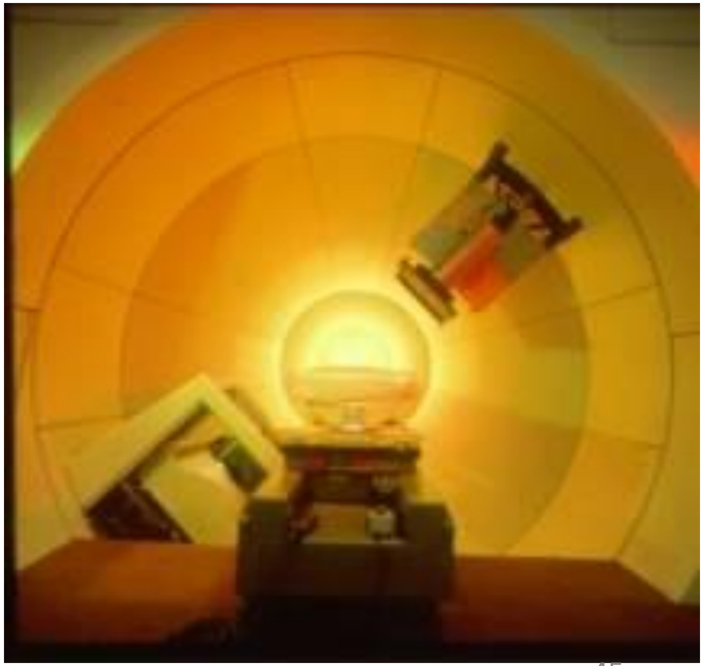
1997 – GSI Germany (carbon)

Molto tempo……. Spesso ci vuole molto tempo

Key Milestones of Hadrontherapy

1990 — First hospital based *Proton* facility
Loma Linda University Medical Center, CA, USA

360^0 Gantry



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

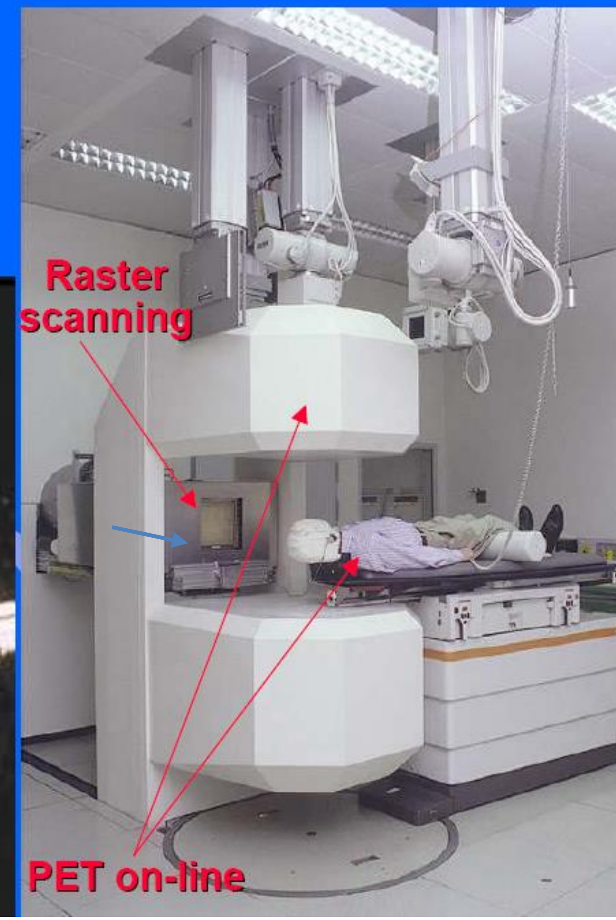
G. Kraft

J. Debus

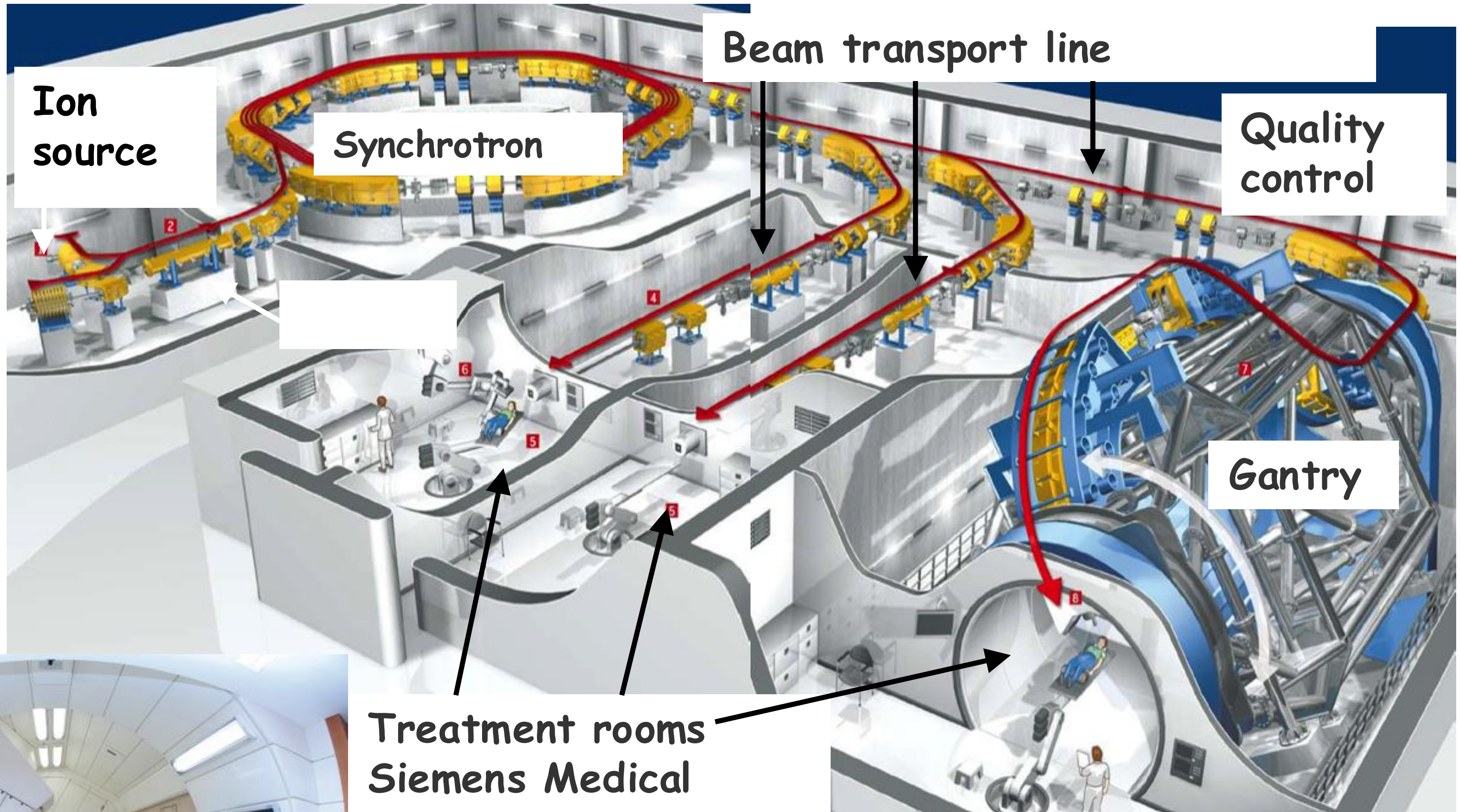
G. Kraft

450 patients treated with carbon ions

J. Debus (Heidelberg Univ.)



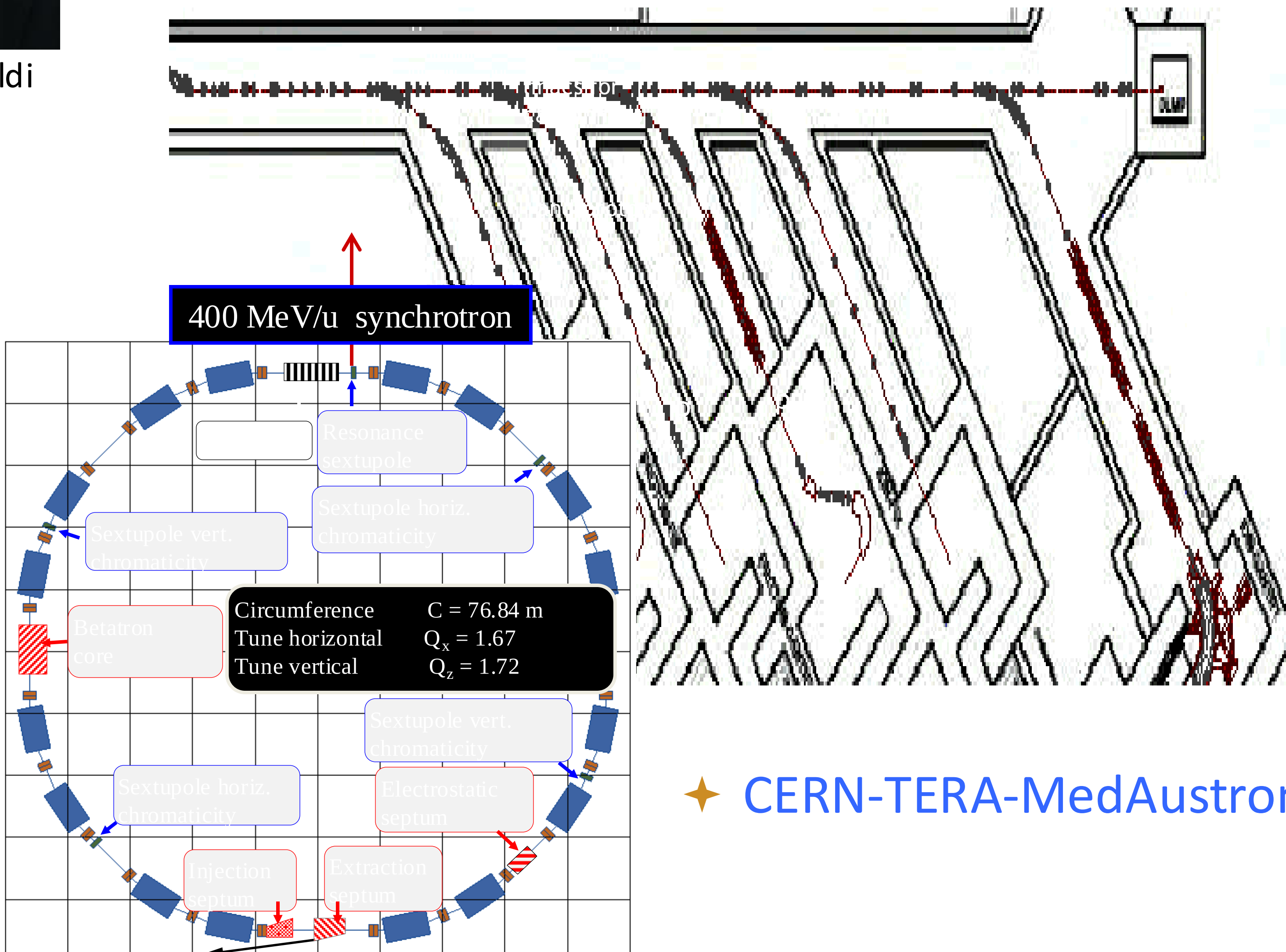
HIT - Heidelberg



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

Ugo Amaldi
TERA

PIMMS at CERN (1996-2000)



✦ CERN-TERA-MedAustron

Gli inizi di ENLIGHT

- L' idea nasce nel 2001 dopo una riunione ESTRO- Med-AUSTRON
- Nell'ottobre del 2001 una proposta per Network viene sottomessa a EC
- ENLIGHT viene inaugurato a febbraio 2002 al CERN
- Finanziamento: 1 milione di Euro nel 2002

ENLIGHT è nato per ………

- Creare una piattaforma comune multidisciplinare
- Trattamento del cancro
- Identificare le sfide
- Condividere la conoscenza
- Condividere “best practices”
- Armonizzare i dati
- Offrire formazione e istruzione
- Innovare per migliorare
- “Lobbying” per nuovi finanziamenti

La filosofia delle collaborazioni in fisica delle particelle viene portata in un ambiente medico multidisciplinare

From PIMMS study to clinical reality

TERA

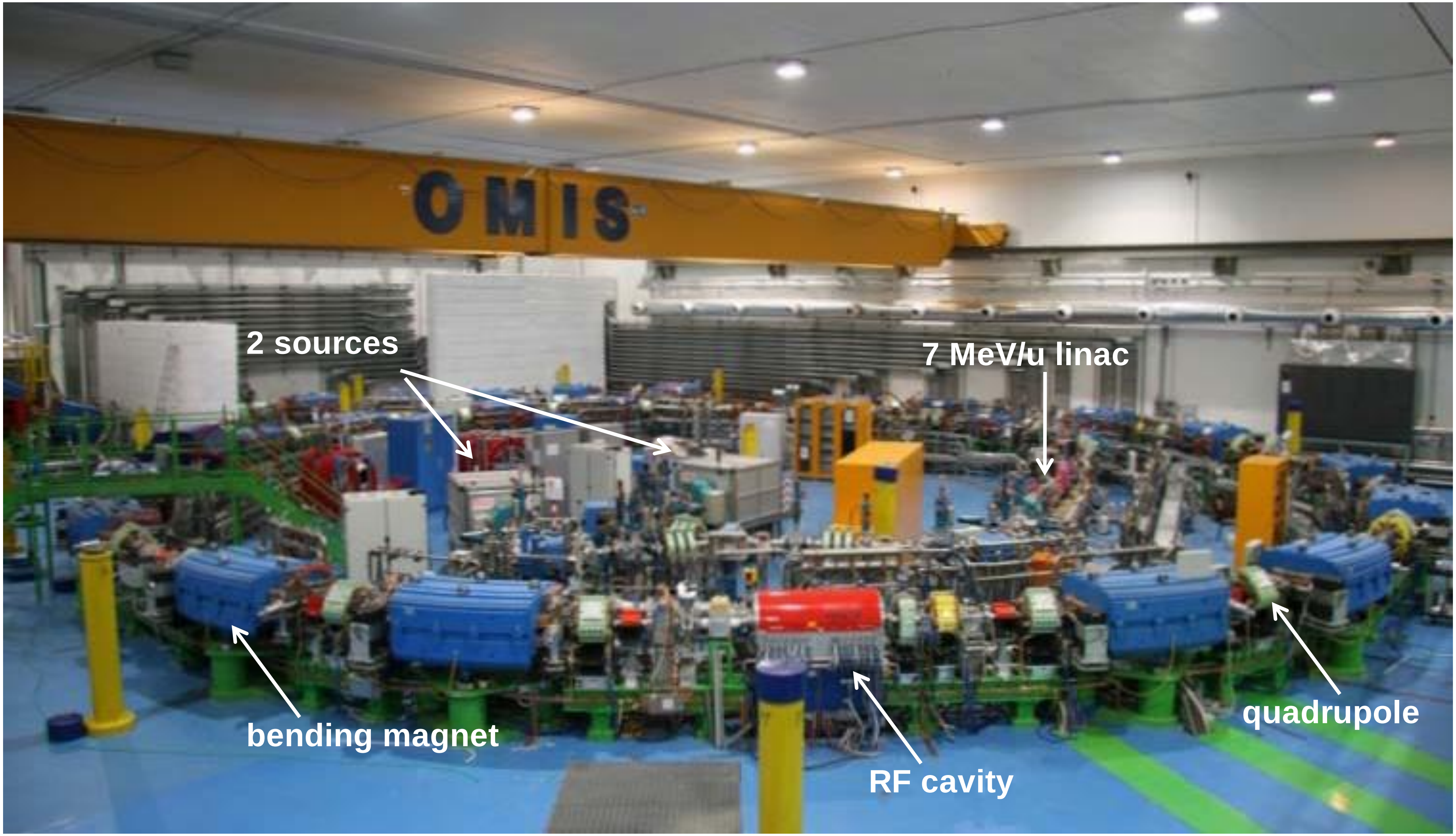
fondazione CNAO

ebg MedAustron

First patient with carbon ions Nov 2012

Treatment started in 2016

CNAO: Pavia, Italy



TERA celebrated 30 years on 16 September 2022

Particle Facilities Globally (2023)

124 facilities in total of which 110 proton facilities (in red) and 14 carbon therapy facilities (in blue).

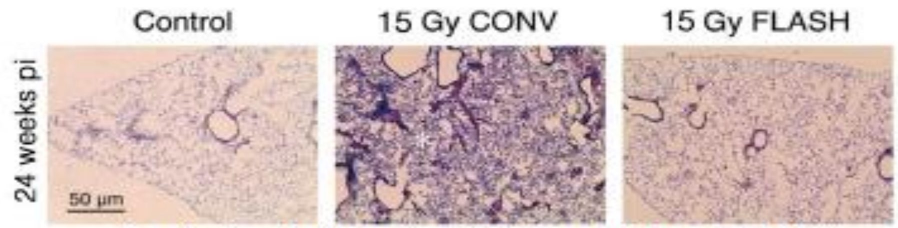
FLASH: un nuovo modo di usare Radiotherapy per il trattamento del cancro?

Primi sguardi di FLASH THERAPY - 2014

Prima dimostrazione del principio (Proof-of-Concept) con e^- di bassa energia

Sci Transl Med 6: 245ra93, 2014

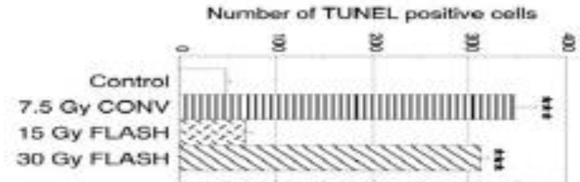
- **FLASH spared normal lung tissue** at doses known to induce fibrosis in mice exposed to conventional dose-rate irradiation (CONV).



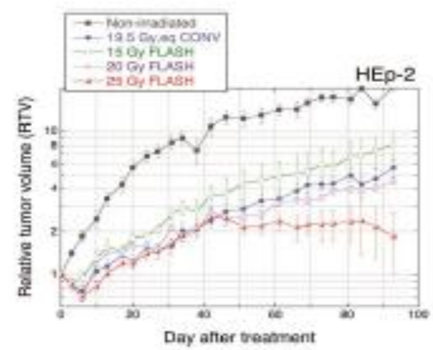
Visualisation of collagen invasion (Masson trichrome staining)

Healthy Fibrosis Healthy

- **FLASH spared smooth muscle cells** in arterioles from radio-induced apoptosis.

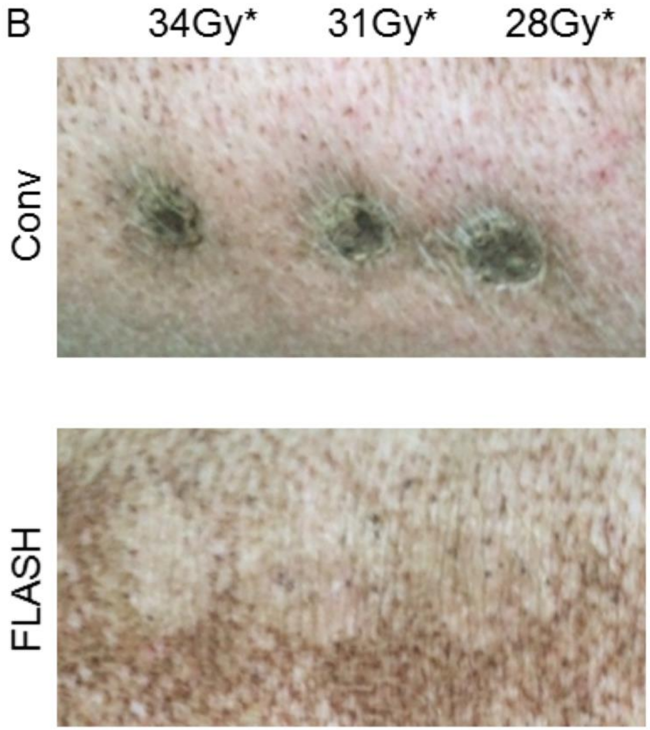


- No difference between FLASH and CONV with regard to tumor growth inhibition.
- However, **normal tissue sparing by FLASH** allowed dose escalation without complications, resulting in complete tumor cure in some xenograft models.

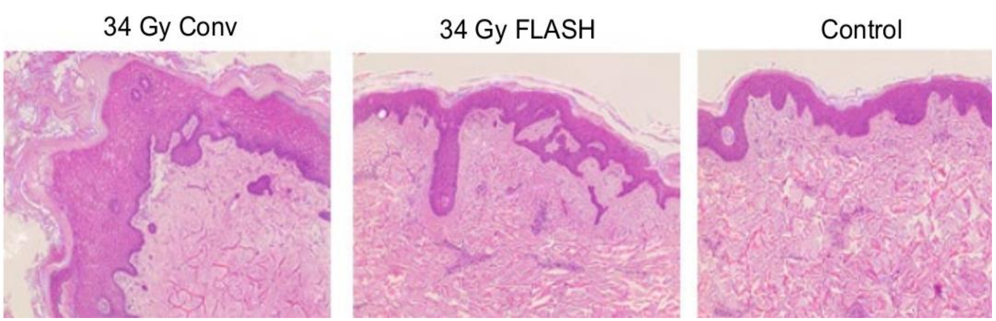


institutCurie

Effetto FLASH – riceve grande impulso



Vozenin MC, De Fornel P, Petersson K, Favaudon V, Jaccard M, Germond JF, Petit B, Burki M, Ferrand G, Patin D, Bouchaab H, Ozsahin M, Bochud F, Bailat C, Devauchelle P, Bourhis J. The Advantage of FLASH Radiotherapy Confirmed in Mini-pig and Cat-cancer Patients. Clin Cancer Res. 2019 Jan



- Apparent sparing of healthy tissue when dose is delivered at **ultrahigh dose rates (UHDR) of > 40 Gy/s.**
- Healthy tissue sparing observed in virtually all radiation modalities.
  - ✓ Majority of experiments/trials with low energy electrons and shoot-through protons.
- So far, 2 human trials:
  - Skin lymphoma with 6 MeV electrons (CHUV, 2019).
  - Bone metastases with 250 MeV (shoot-through) protons (Cincinnati, 2020). Pain relief and not curative
  - Further trials are ongoing

Il meccanismo FLASH tuttora non è compreso completamente

”Trasporto” in clinica (2019): Trattamento di un primo paziente con FLASH -radiotherapy

Contents lists available at ScienceDirect
Radiotherapy and Oncology
journal homepage: www.thegreenjournal.com

Original Article

Treatment of a first patient with FLASH-radiotherapy

Jean Bourhis [a,b,*], Wendy Jeanneret Sozzi [a], Patrik Gonçalves Jorge [a,b,c], Olivier Gaide [d], Claude Bailat [c], Fréderic Duclos [a], David Patin [a], Mahmut Ozsahin [a], François Bochud [c], Jean-François Germond [c], Raphaël Moeckli [c,1], Marie-Catherine Vozenin [a,b,1]

[a] Department of Radiation Oncology, Lausanne University Hospital and University of Lausanne; [b] Radiation Oncology Laboratory, Department of Radiation Oncology, Lausanne University Hospital and University of Lausanne; [c] Institute of Radiation Physics, Lausanne University Hospital and University of Lausanne; and [d] Department of Dermatology, Lausanne University Hospital and University of Lausanne, Switzerland

5.6 MeV linac adapted for accelerating electrons in FLASH mode

15 Gy with 10 pulses **in 90 ms**

3.5 cm diameter tumour, multiresistant cutaneous

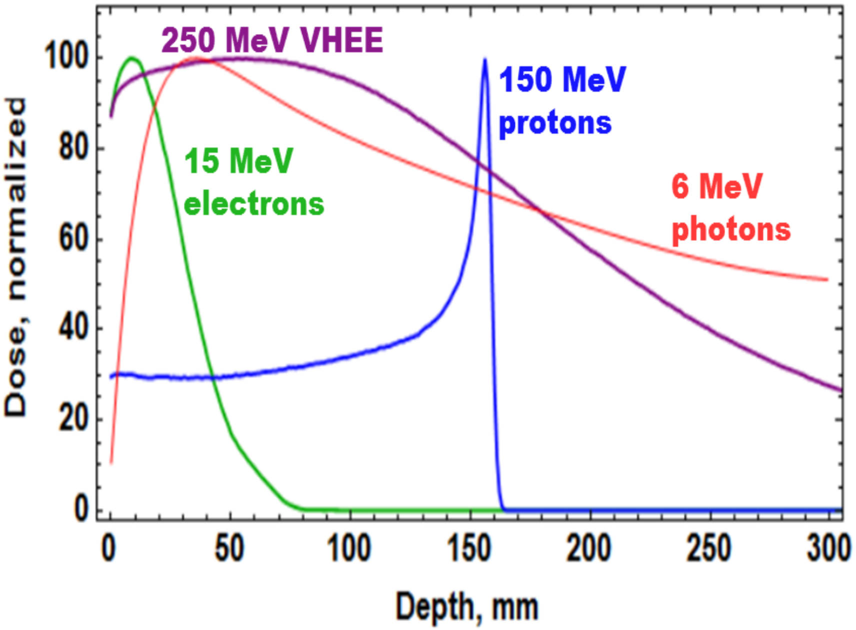
Sembra che una dose istantanea produca un consumo significativo di ossigeno e una hypoxia transitoria protettiva nei tessuti normali

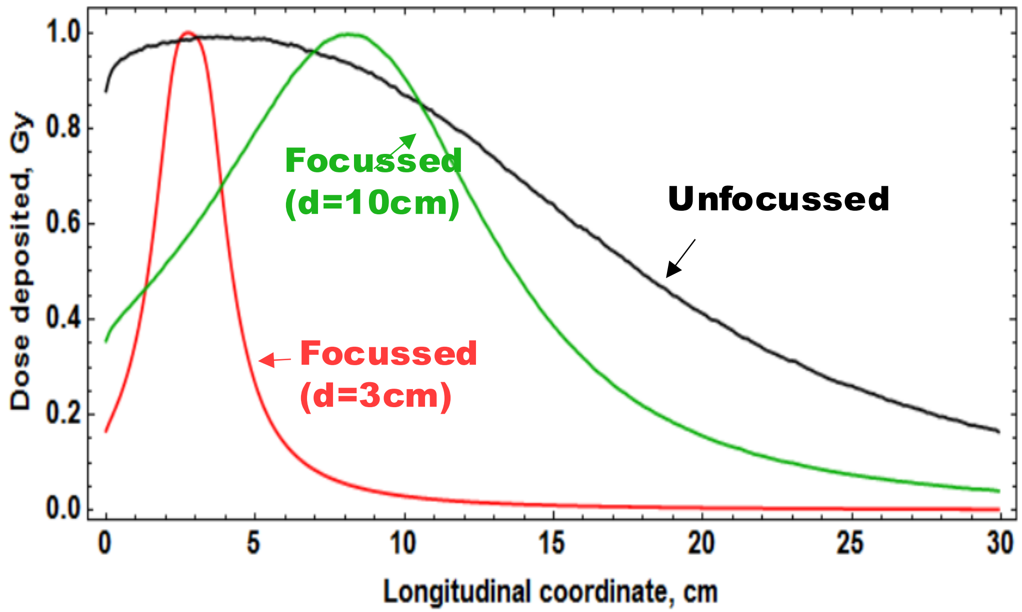
Fig. 1. Temporal evolution of the treated lesion: (a) before treatment; the limits of th PTV are delineated in black; (b) at 3 weeks, at the peak of skin reactions (grade 1 epithelitis NCI-CTCAE v 5.0); (c) at 5 months.

VHEE (Very High Energy Electrons)

VHEE

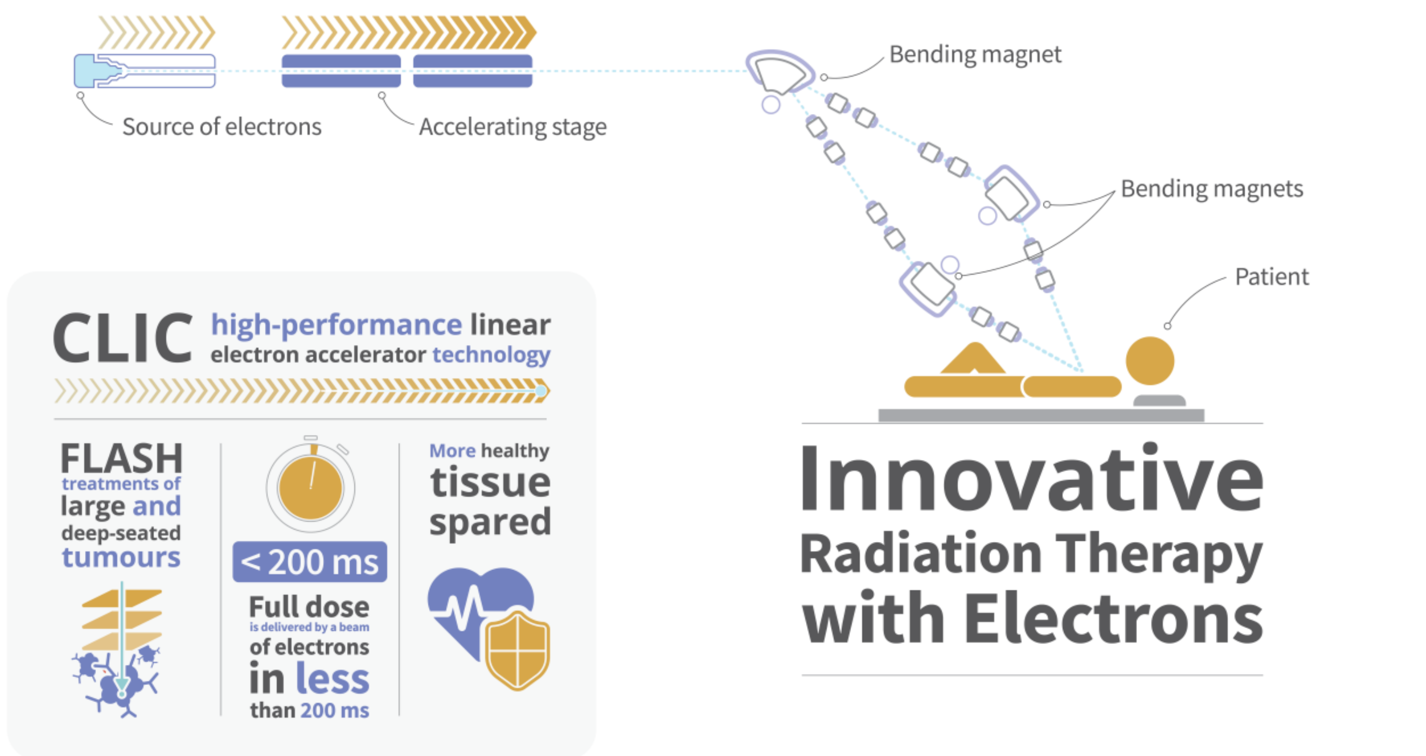
- Le loro proprietà balistiche e dosimetriche possono superare quelle dei fotoni che sono comunemente usati in RT.
- La loro posizione confrontata con i protoni deve essere valutata, tuttavia essi possono essere prodotti a costi ridotti.



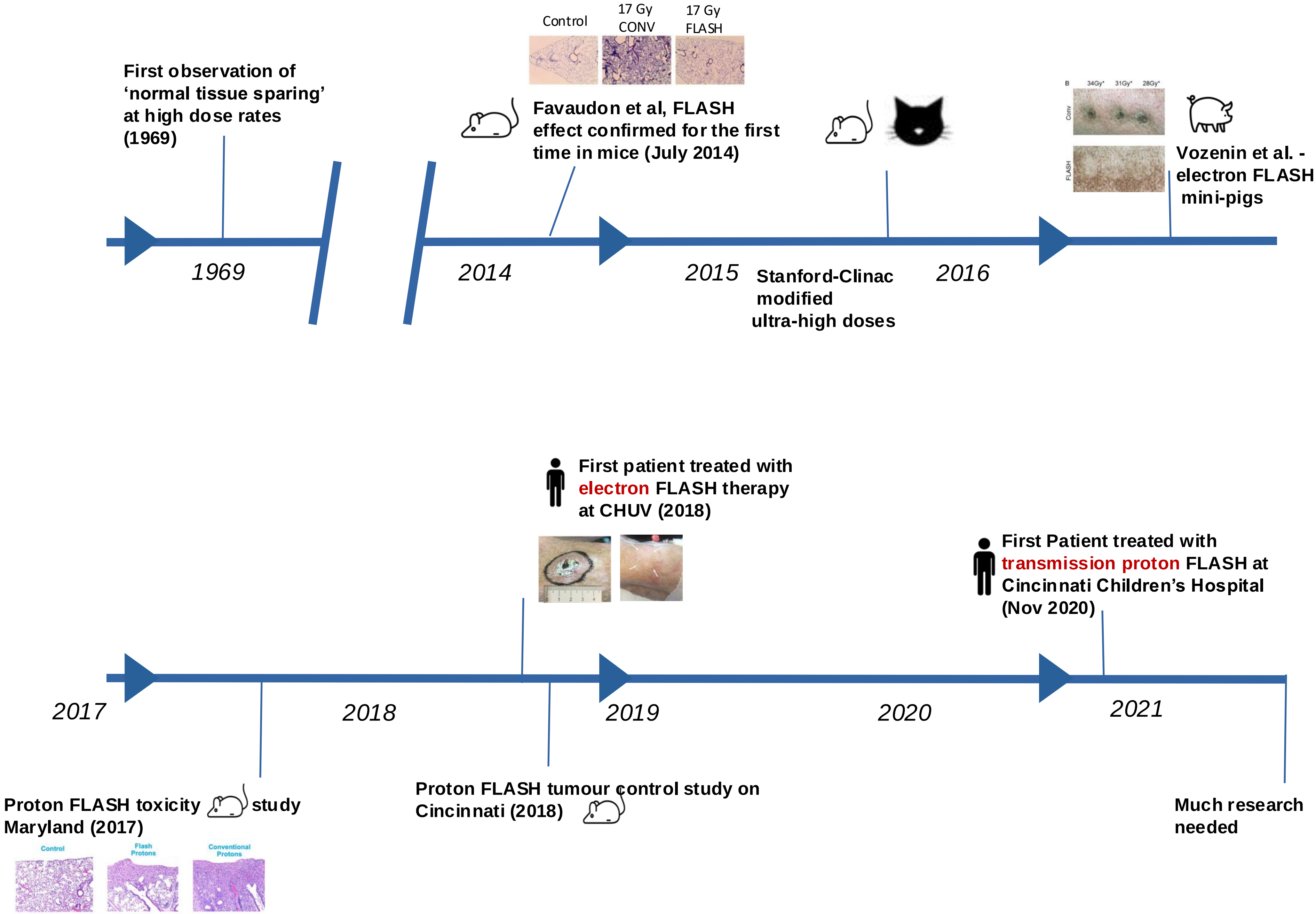


Depth Dose curve for various particle beams in water (beam widths r=0.5 cm)

CERN, CHUV and THERYQ uniscono le loro forze per la prima VHEE Facility



Produrrà fasci di elettroni di “alta” energia (VHEE) fra 100 e 200 MeV di durata inferior 100-200ms, basandosi sulla tecnologia usata per CLIC (Compact Linear Collider), permettendo il trattamento di tutti i tipi di cancro fino ad una profondità di 20 cm usando la tecnica FLASH.


First observation of
'normal tissue sparing'
at high dose rates
(1969)
1969
Control
17 Gy
CONV
17 Gy
FLASH
Favaudon et al, FLASH
effect confirmed for the first
time in mice (July 2014)
2014
2015
Stanford-Clinac
modified
ultra-high doses
2016
34Gy*
31Gy*
28Gy*
Conv
FLASH
Vozenin et al. -
electron FLASH
mini-pigs
First patient treated with
electron FLASH therapy
at CHUV (2018)
First Patient treated with
transmission proton FLASH at
Cincinnati Children's Hospital
(Nov 2020)
2017
2018
2019
2020
2021
Proton FLASH toxicity study
Maryland (2017)
Control
Flash
Protons
Conventional
Protons
Proton FLASH tumour control study on
Cincinnati (2018)
Much research
needed

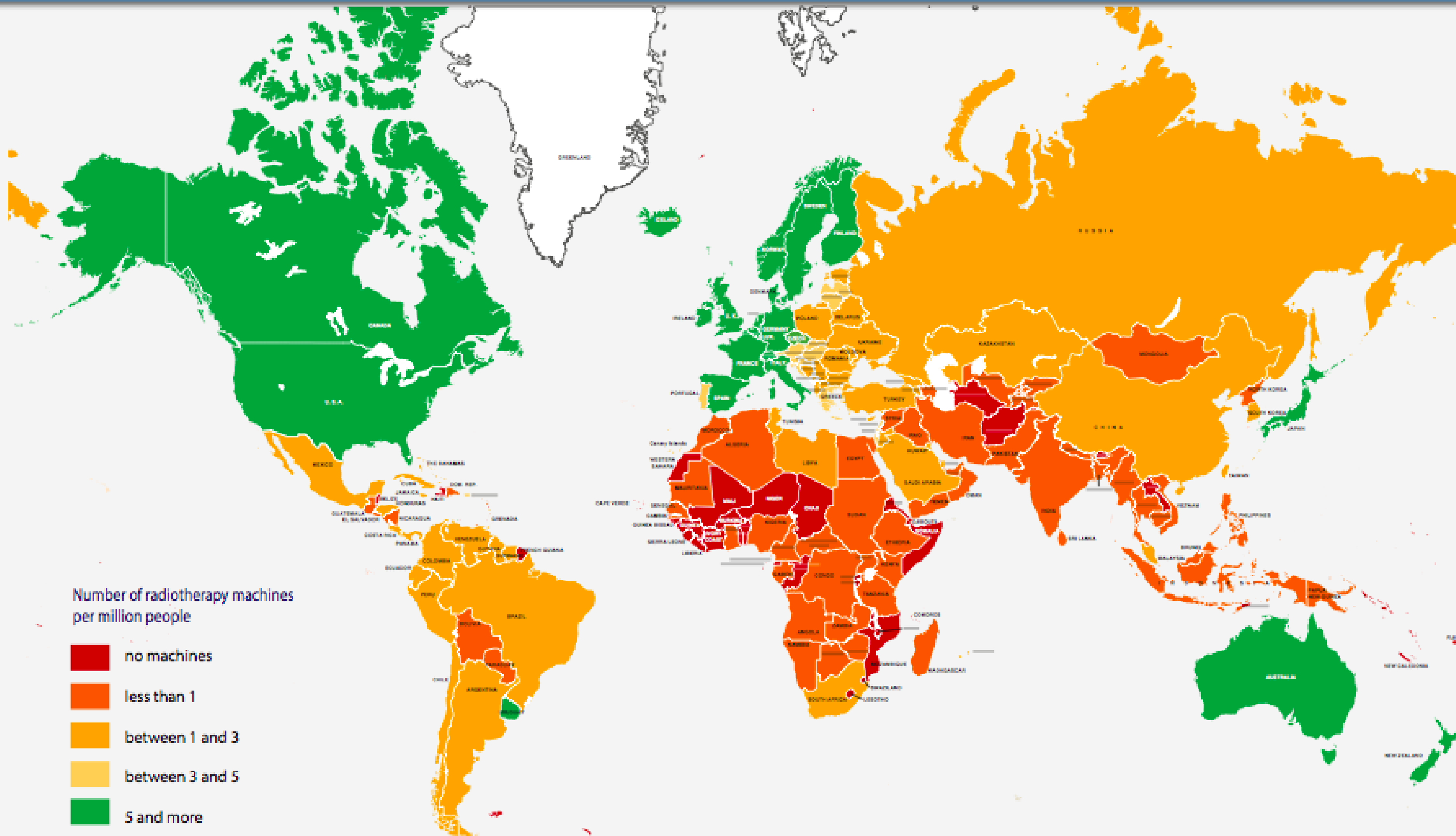
Collaborazione per lo sviluppo……

"Transforming Cancer Treatment in Low-Resource Settings" 26.09.2024

https://youtu.be/4gxQ7-e_rk4?si=qZDLnrXDqumqY5Dl

Availability of **RADIATION THERAPY**

Number of Radiotherapy Machines per Million People 2012



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

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

Manjit Dosanjh, 10 October 2024

World-wide radiotherapy coverage (2024)

Status of Radiation Therapy Equipment

156 Countries

7814 RT Centres

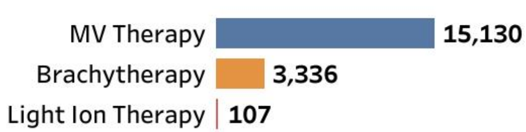
15130 MV Therapy

107 Light Ion Therapy

3336 Brachytherapy

Click on **Equipment type**, **Income groups** or **Regions** to create your own view. *Ctrl+click to select multiple items*

Equipment type
(Updated on : 3/9/2023 1:55:27 PM)



Equipment per income groups
(Updated on : 3/9/2023 1:55:27 PM)

CT Scanners Distribution per Million Population

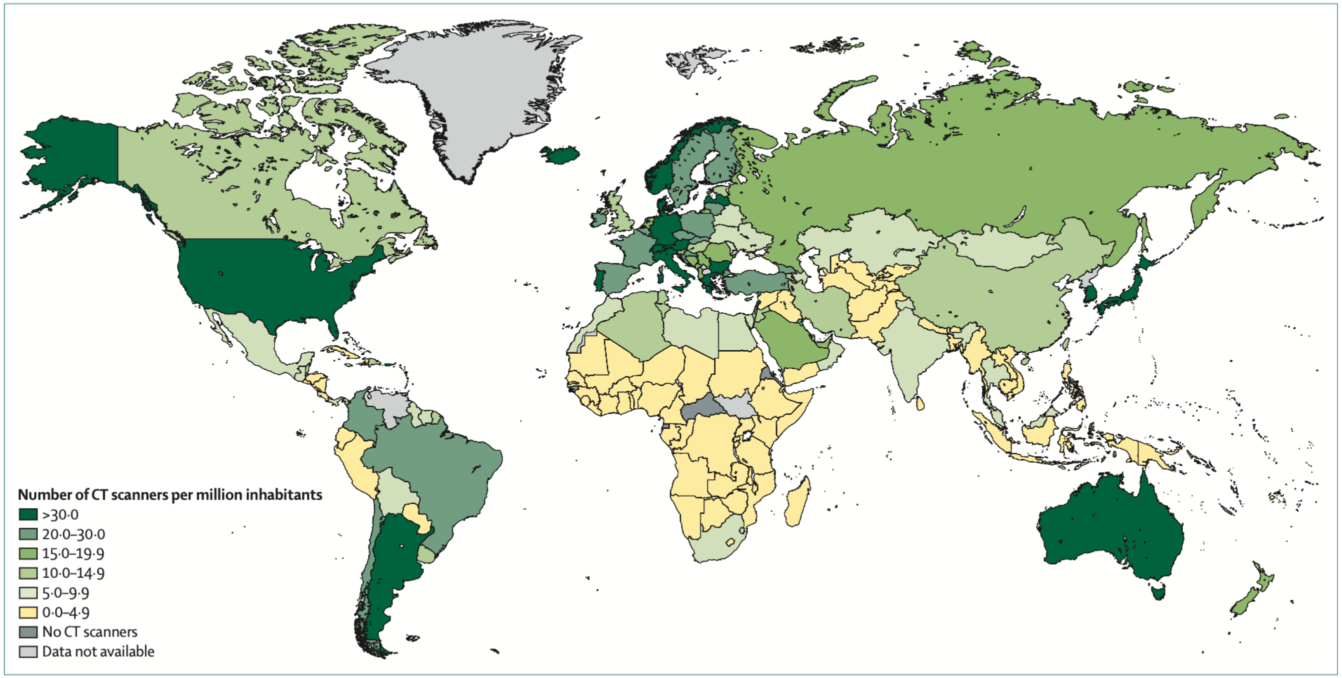
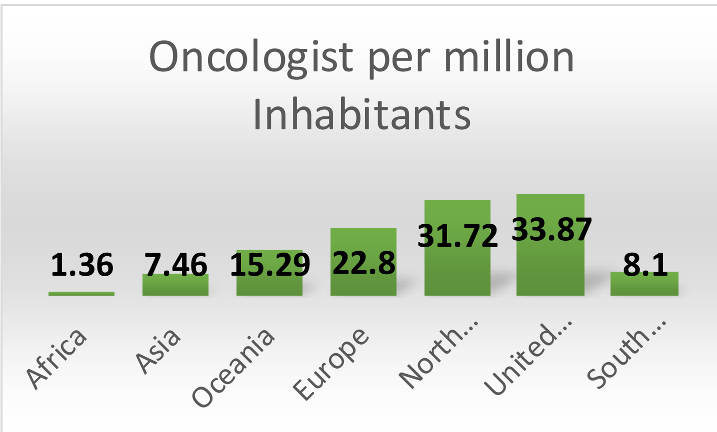


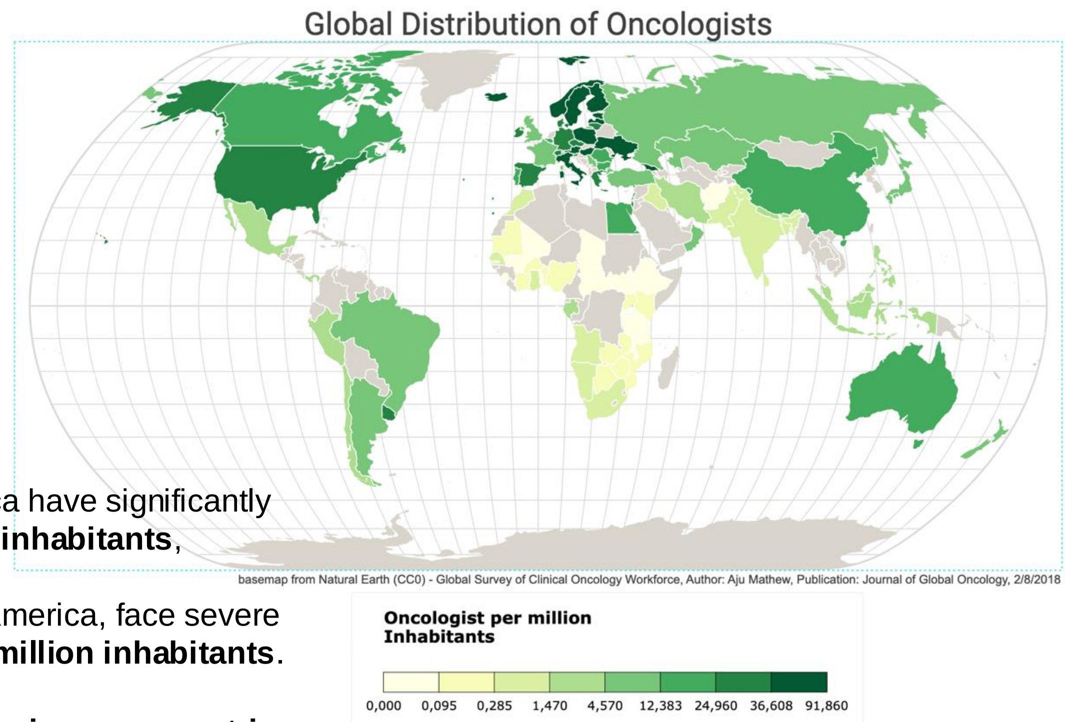
Figure 2: **Estimates of the number of CT scanners per million inhabitants**
Data are from the International Atomic Energy Agency medical imaging and nuclear medicine global resources database (IMAGINE). The map was produced by the International Atomic Energy Agency (Vienna, Austria) and is included here with permission.

CT scanners are an essential diagnostic tool in cancer care. However, high-income regions like North America and Europe have significantly higher access to CT scanners compared to LMICs.

Disparities in Access to Oncologists

The global distribution of oncologists per million inhabitants varies greatly, highlighting disparities in cancer care.





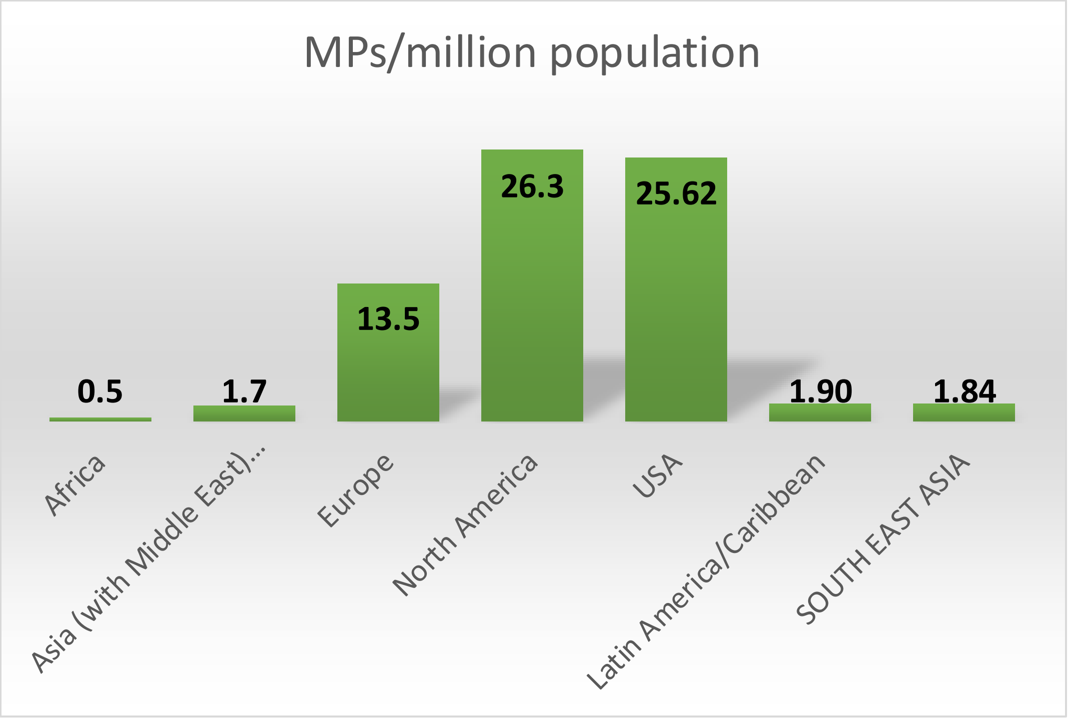
High-income regions like the US and North America have significantly more oncologists, with **33.87 and 31.72 per million inhabitants**, respectively.

Low-resource regions, such as Africa and South America, face severe shortages, with only **1.36 and 8.1 oncologists per million inhabitants**.

This imbalance means that **cancer patients in lower-income countries have far less access to specialized cancer care**, directly affecting outcomes and treatment availability.

Availability of Medical Physicists Worldwide

The distribution of MPs is also uneven, with North America having **26.3 MPs per million**, whereas **Africa lags significantly with only 0.5 MPs per million**.



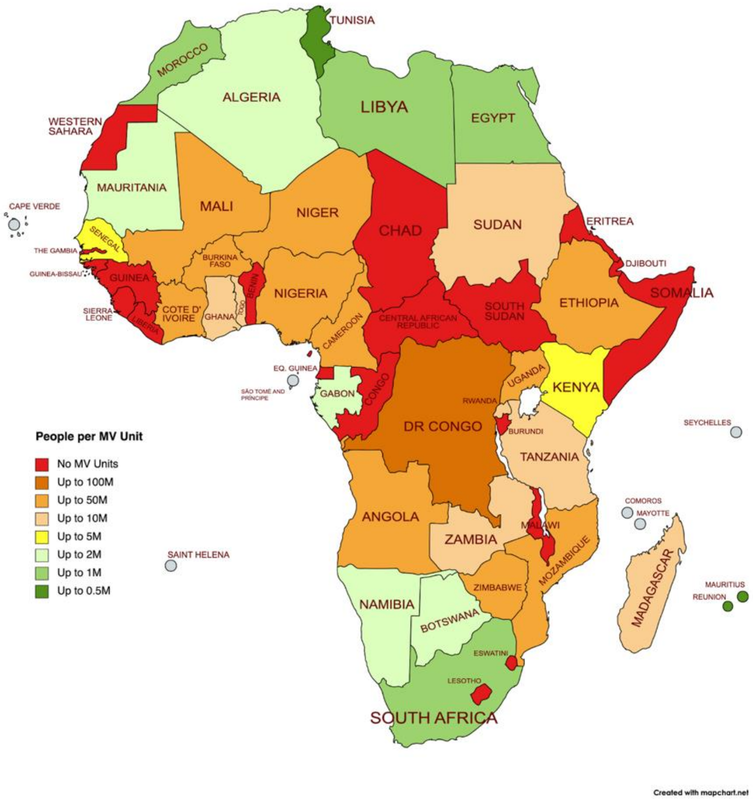
- Europe stands in between with **13.5 MPs per million**, and Southeast Asia has around **1.84 MPs per million**.
- The severe shortage of MPs in regions like Africa and parts of Asia has a profound impact on the quality and safety of radiotherapy services, which are crucial for effective cancer treatment.
- Increasing the workforce of MPs is critical for improving cancer care in these low-resource settings.

Number of people per functioning machine in countries in Africa

But there are dramatic disparities in Access

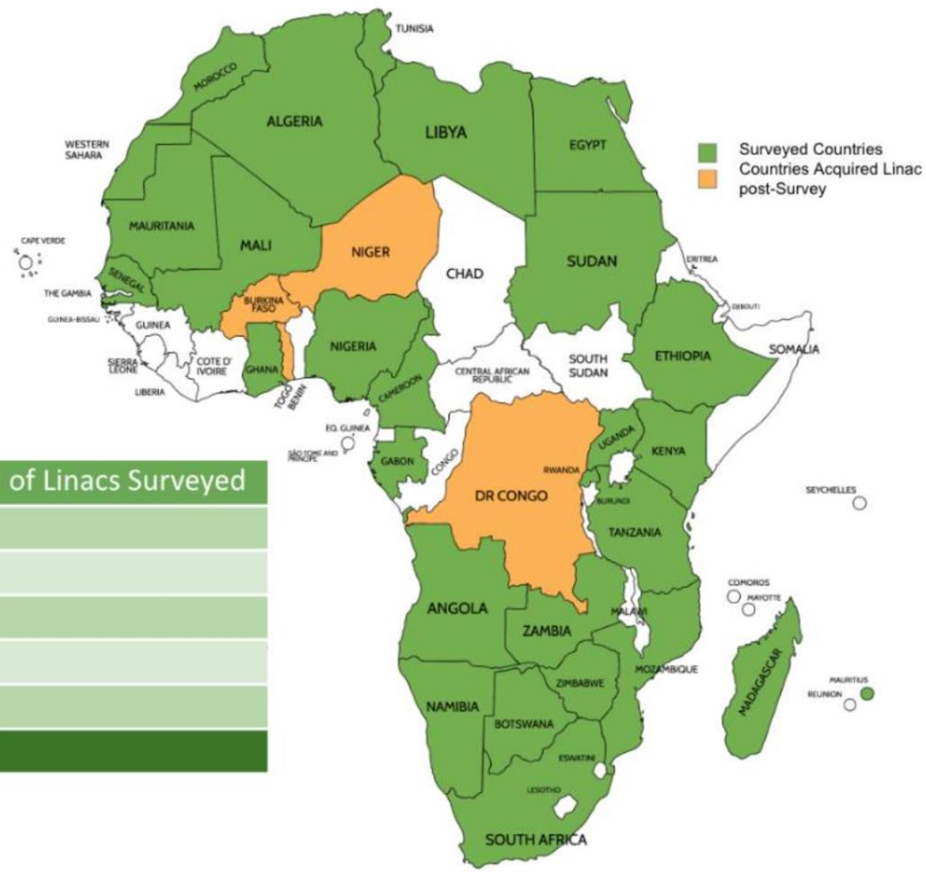
Africa: 420 MV RT units for around **1.4 billion** people
1 machine per 3.5 million people
US: **3879** MV RT units for around **340 million** people
I machine for 86, 000
UK: **357 MV RT** units for around **68** million people
1 machine per 190,000
Switzerland: 85 for **8.8** million people
1 machine for 100,000
Italy: 497 for **59** million people
1 machine for 118,000

- By 2030, there will be **1.4** million new cases of cancer and there will be **1** million cancer deaths in Africa
- In 2019 only **28** countries had RT facilities
- In 2024 there 34 countries
- Over **60% are in just 3 countries**: South Africa, Egypt and Morocco
- 20 countries have none



STELLA questionnaire for defining problem

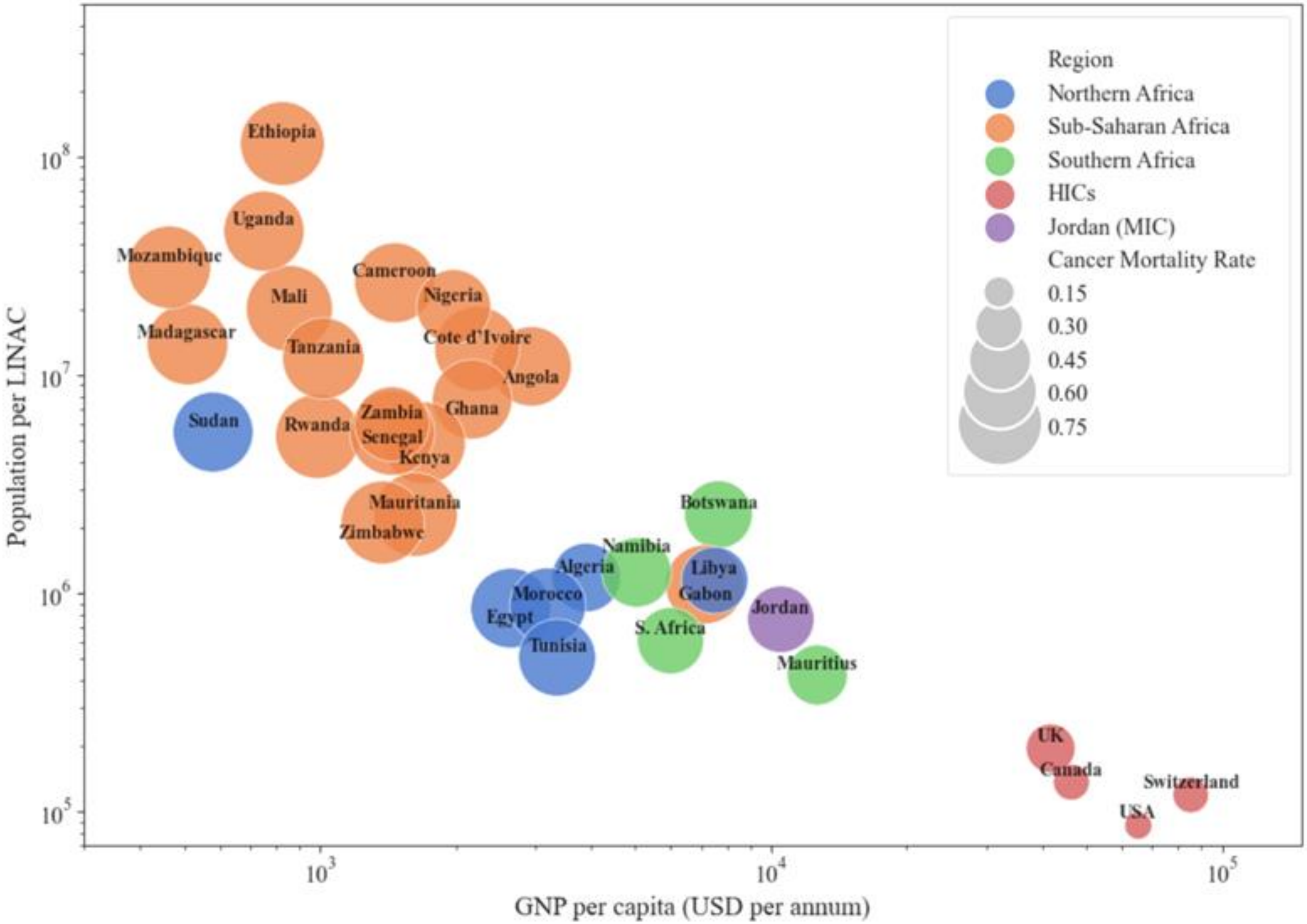
Tackling the radiotherapy shortage in Sub-Saharan Africa



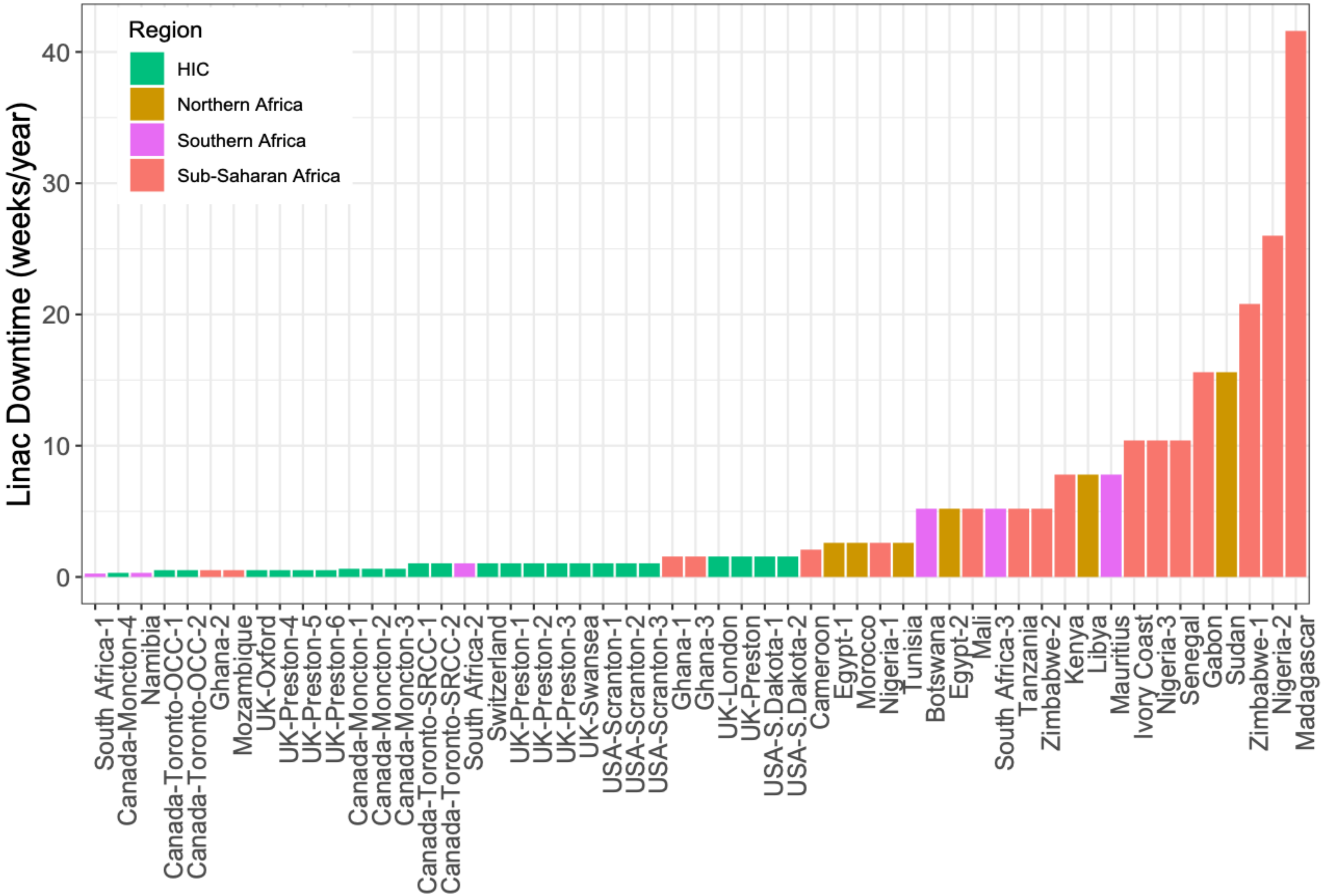
Country/Region	No. of Linacs Surveyed
UK	25
USA	14
Canada	11
Switzerland	2
Jordan	4
Africa	59

Manjit Dosanjh, Transforming Cancer, 26.09.2024

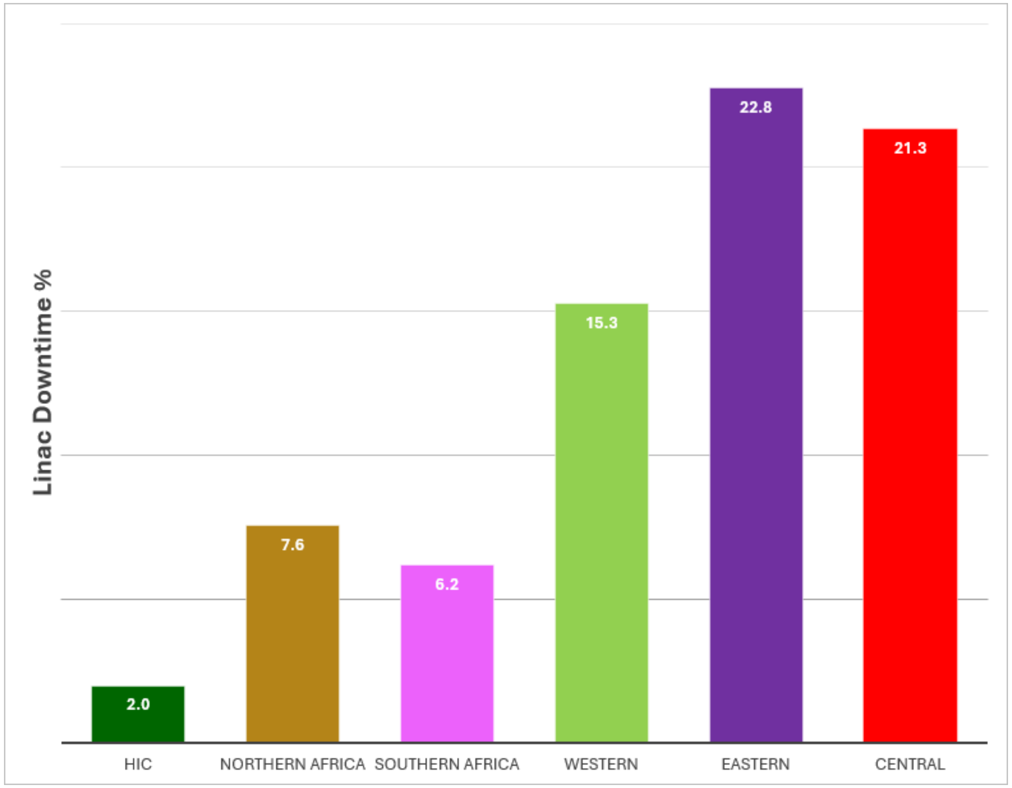
GNP per Capita and the Ratio of Inhabitants to RT Machines and Cancer Mortality Rates



Downtime in weeks comparison African and HICs



RT Machine Downtime in surveyed African Regions and HICs



May Abdel-Wahab, et al. **Radiotherapy and theranostics: a *Lancet Oncology* Commission**. September 30, 2024 https://doi.org/10.1016/S1470-2045(24)00407-8

Obiettivi Finali

- Macchine Robuste, modulari, affidabili e semplici da usare

- Che siano ”convenienti”
  - ✓ Ridurre il costo dell’investimento di capitale
  - ✓ Ridurre i costi delle operazioni
  - ✓ Ridurre i costi delle manutenzioni
  - ✓ Ridurre il numero di esperti necessari
  - ✓ Aumentare il numero di pazienti trattati per anno

- Con lo scopo di

  - ✓ Migliorare i flussi di pazienti (patient through-put)
  - ✓ Aumentare l’efficacia
  - ✓ Ridurre i costi delle operazioni, di personale e delle macchine
  - ✓ Espandere le possibilità di accesso alla Radioterapia

Grazie!!

The ambitious vision of RT for all is not possible without global partnerships and collaboration, a multi-faceted approach with all interested colleagues specially LMICs

cern.ch/virtual-hadron-therapy-centre


ENVISION
European NoVel Imaging Systems
for ION therapy

Interactive Material

- From particle physics to medicine
  www.youtube.com/watch?v=WhgDZKr9GQQ

- Transforming Cancer Treatment in Low-Resource Settings: 26.09.2024
  https://youtu.be/4gxQ7-e_rk4?si=qZDLnrXDqumqY5Dl

- Imaging and hadron therapy animation
  http://cds.cern.ch/record/1611721?ln=en
  http://cds.cern.ch/record/2002120

- FLASH An innovative electron radiotherapy technology

  https://videos.cern.ch/record/2762058

  https://videos.cern.ch/record/2295068

- PARTNER Marie Curie
  http://cds.cern.ch/record/1384426?ln=en
  http://cds.cern.ch/record/1327668

- ENERVISION Marie Curie
  http://cds.cern.ch/record/1541891

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2. Manjit Dosanjh, *et al.* **Tackling the radiotherapy shortage in Sub-Saharan Africa by gathering and using data from Lower-Middle-Income and High-Income Countries' facilities for designing a future robust radiotherapy facility.** MedicalResearch Archives, [online] 12(8).https://doi.org/10.18103/mra.v12i8.5530 (August 2024)
3. May Abdel-Wahab, et al. IAEA lead **Radiotherapy and theranostics: a *Lancet Oncology* Commission**. September 30, 2024 https://doi.org/10.1016/S1470-2045(24)00407-8
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   https://www.sciencedirect.com/science/article/pii/S0167814018301464

5\. Angal-Kalinin D, Burt G and Dosanjh M. *Linacs to narrow radiation therapy gap,* CERN Courier, December 2021 https://cerncourier.com/a/linacs-to-narrow-radiotherapy-gap/

6\. Manjit Dosanjh, Collaboration, the force that makes the impossible possible. Advances in Radiation Oncology 7(6):100966 DOI: 10.1016/j.adro.2022.100966

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- Medipix
- MARS BioImaging Ltd
- KT group at CERN