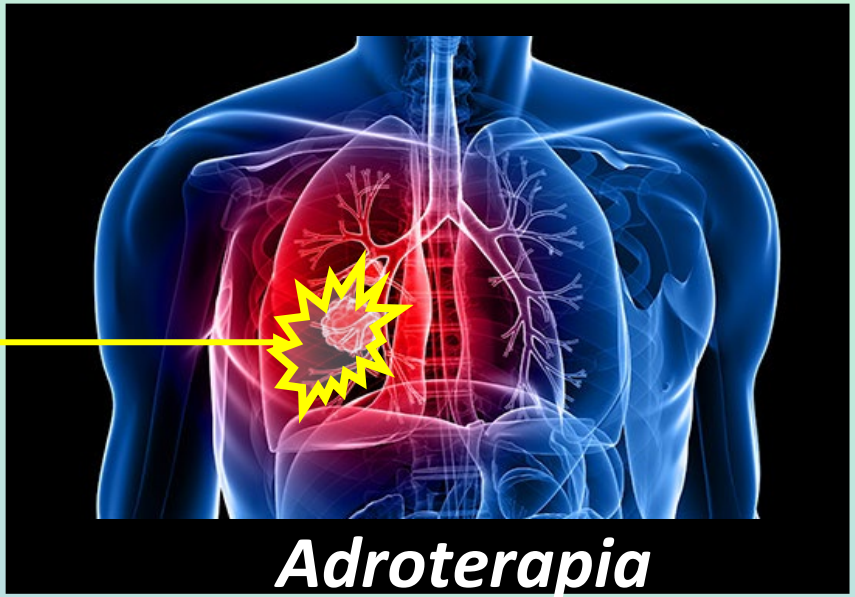
Le particelle: un'arma in più contro il tumore



Adroterapia

Bologna, 13 marzo 2025

spighi@bo.infn.it

Stefano

Roberto

Andrea

Barbara

Nicholas

INFN BOLOGNA

INTERNATIONAL MASTERCLASSES hands on particle physics

International Particle Physics Outreach Group

Elena

Particle Therapy

Riccardo

Giacomo

Matilde

Mauro

Roberto

Il Cancro nel mondo: il problema del secolo

Statisticamente: ogni anno il ~3‰ della popolazione mondiale contrae un nuovo cancro

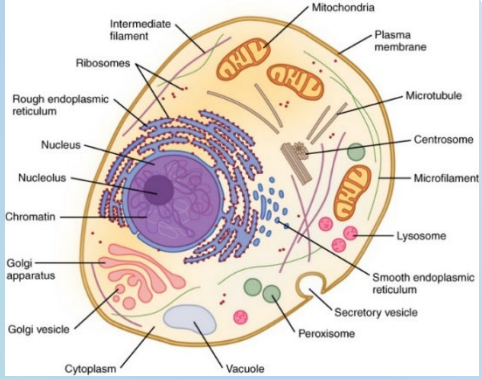
2008: nel mondo 14.1 milioni di nuovi Tumori → 8.2 hanno portato alla morte

L.A. Torre, R.L. Siegel, E.M. Ward, and A.Jemal,
Global Cancer Incidence and Mortality Rates and Trends|An Update, Cancer Epidemiol Biomarkers Prev; 25 (2016),
16 DOI: 10.1158/1055-9965.EPI-15-0578 Published January 2016

- Popolazione nel 2020:
  - 8 miliardi nel mondo
  - 24 milioni di nuovi tumori all'anno (3‰), il 50% ricorre alla radioterapia
    - **12 milioni RXT**

- Populazione nel 2010-2030
  - Persone oltre 65 anni **RADDOPPIERANNO**
  - Persone oltre 80 anni **TRIPLICHERANNO** (chirurgia ↘)

Cosa significa sconfiggere un tumore

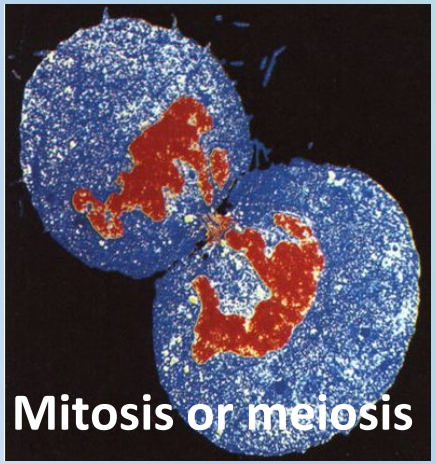


Cancro: cellula **mutata geneticamente** che si riproduce in modo incontrollato

La cellula può migrare e formare **metastasi**

Sconfiggere un cancro

Impedire la proliferazione incontrollata
non è necessario uccidere la cellula



Colpire il DNA → **Cellula perde la capacità di riprodursi indefinitamente**

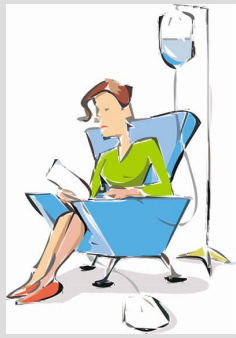
È considerata morta

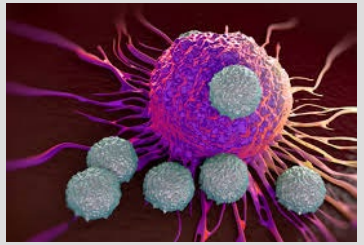
Trattamenti per i Tumori

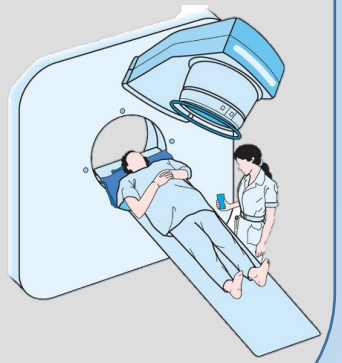
Ad oggi non sappiamo le cause per cui nasce un tumore:

- **NON POSSIAMO PREVENIRLO**
- **POSSIAMO CERCARE DI UCCIDERLO**

- **Chirurgia**
- **Chemioterapia**
- **Immunoterapia**
- **Radioterapia**
- **Adroterapia**





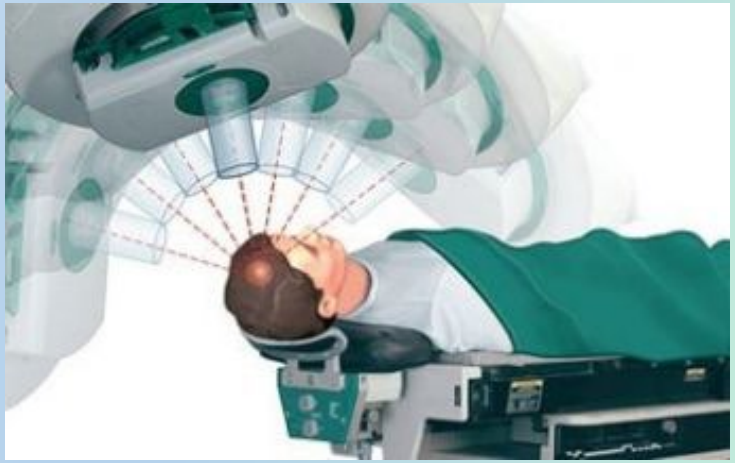


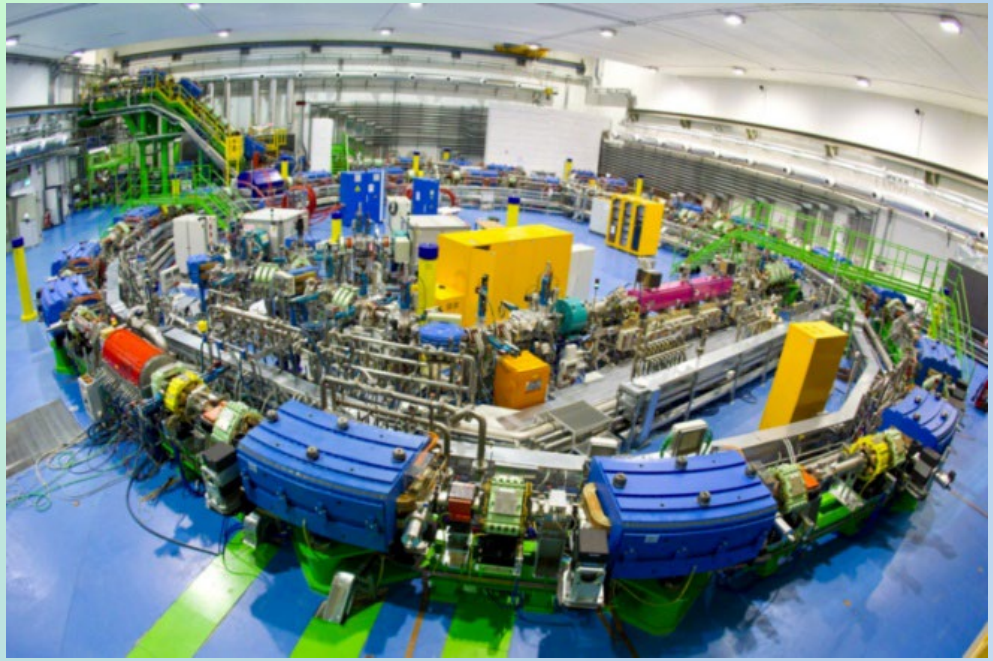
Radioterapia e Adroterapia

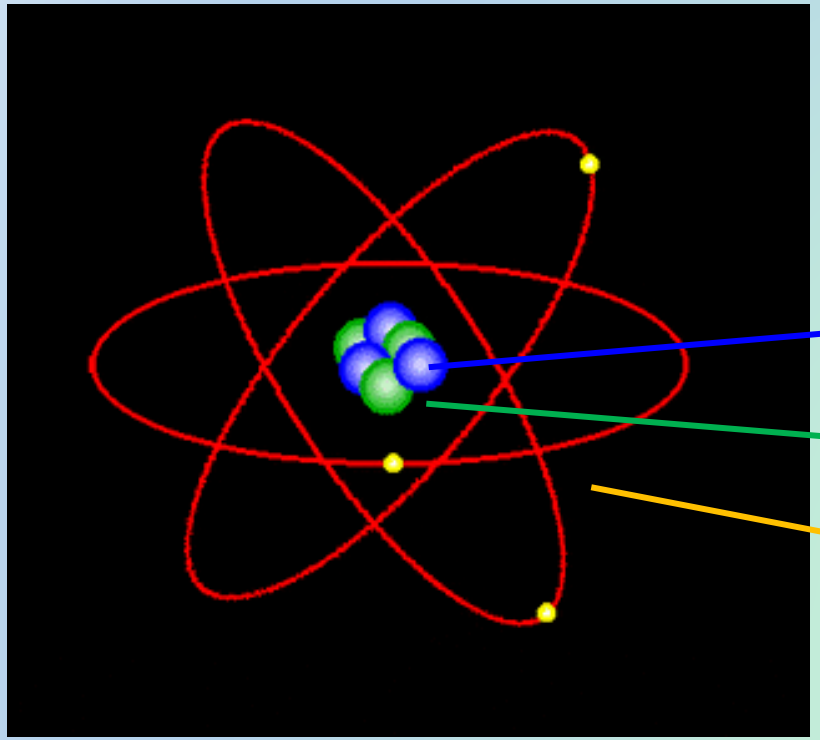
Radioterapia γ,X

Adroterapia p ^{12}C

H, C, O (>95%)



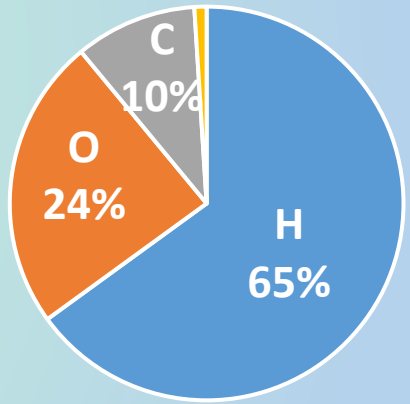




Atomo

- p protoni carica +1
- n neutroni carica 0
- e elettroni carica -1

Tutta la materia è fatta di atomi



H Protone: carica +1

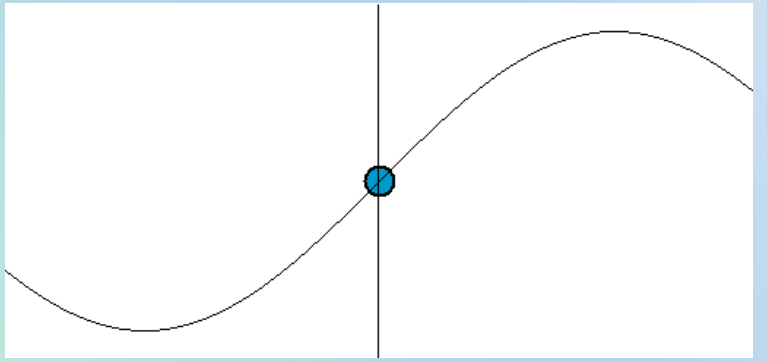
^{12}C Nucleo di Carbonio: 6p+ 6n: carica +6

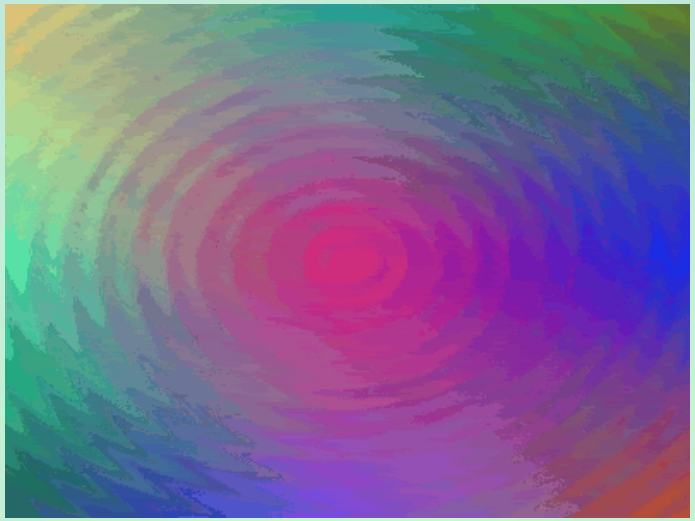
^{16}O Nucleo di Ossigeno: 8p+ 8n: carica +8

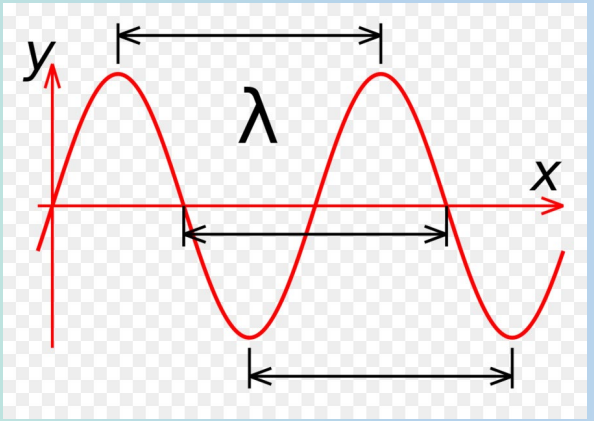
H_2O

RadioTerapia: uso di onde elettromagnetiche

Onda: perturbazione che nasce da una sorgente e si propaga, trasportando energia senza spostamento di materia.

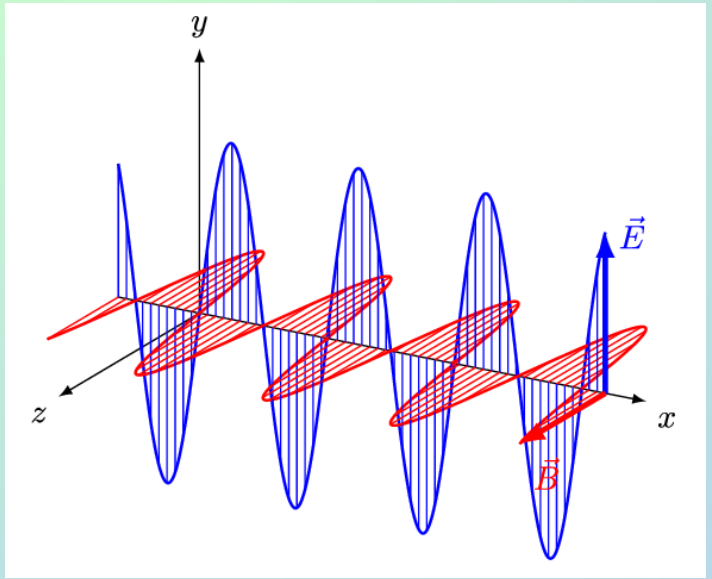






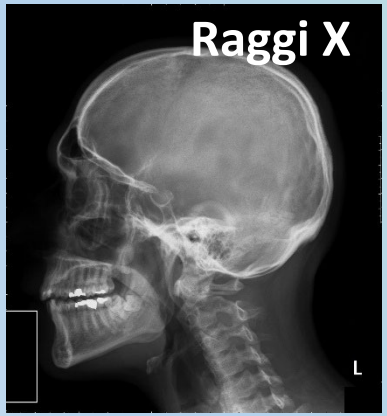
Cosa sono i raggi γ o i raggi X?

Sono onde elettromagnetiche

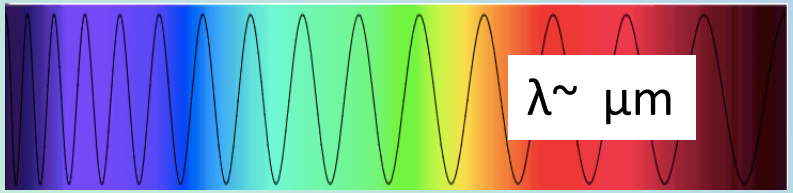


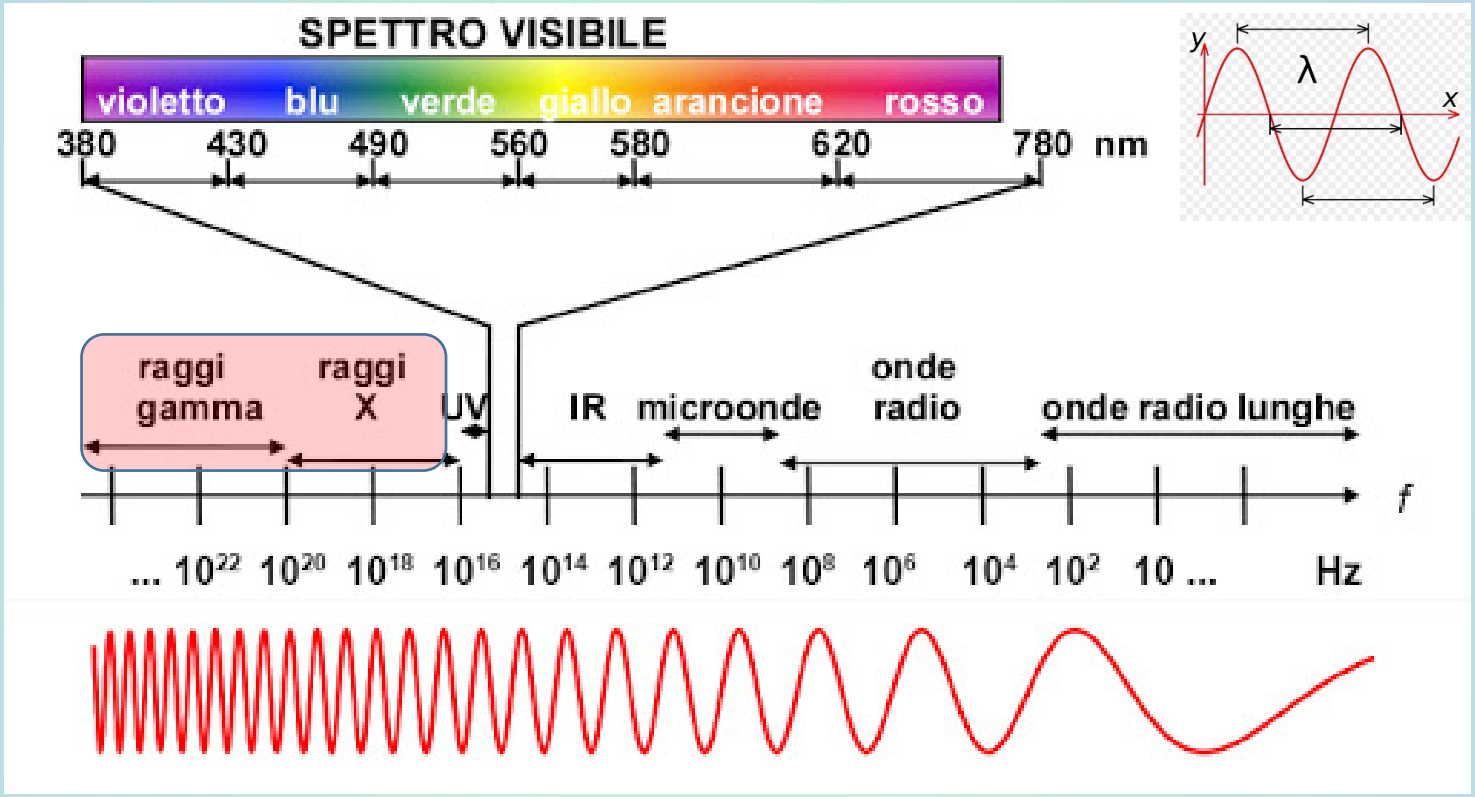
Onde elettromagnetiche

- $\lambda = 3 \cdot 10^{-14}$ m
- $\nu = 10^{22}$ Hz

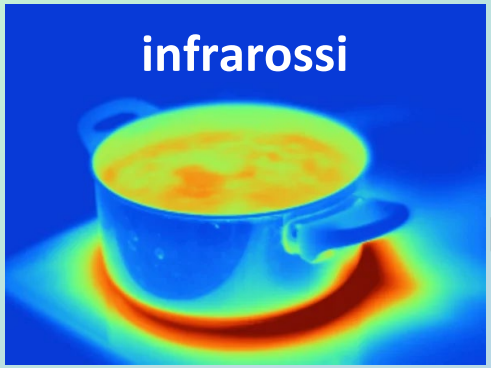


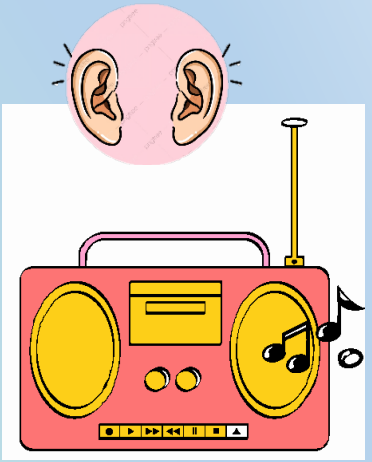
λ~ frazione di nm





Ultravioletti λ~ decina nm





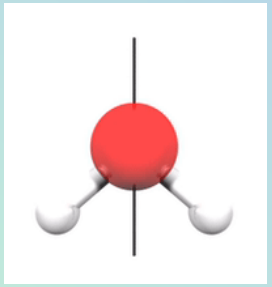
Onde Radio λ~ m-km

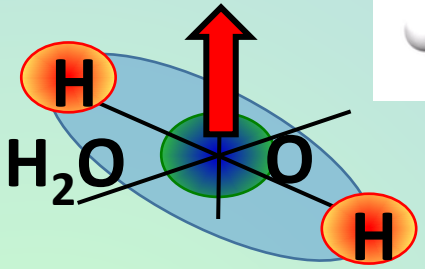
Microonde λ~ 10 cm
Frequenza GHz

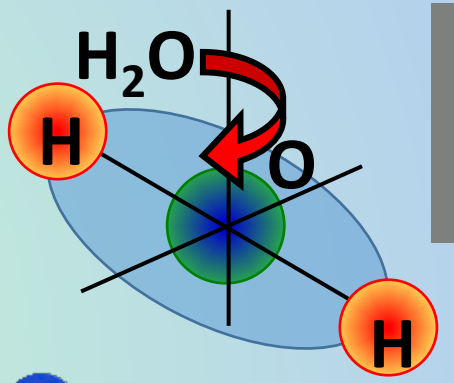
Radiazione nel nostro corpo

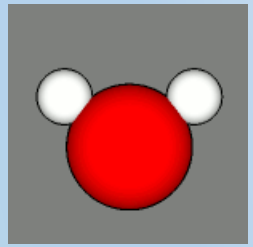
Onde em

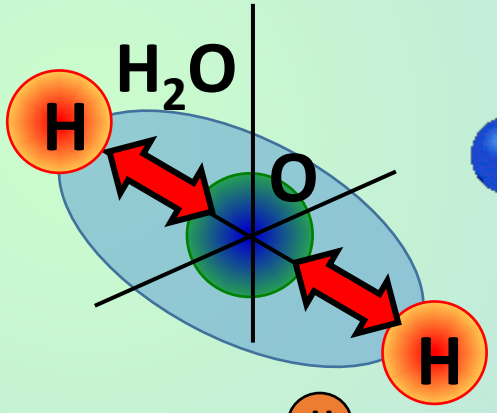
- **Radio**: λ [10 cm – 10 km]
  - interagiscono con spin dei nuclei atomici
- **Microonde**: λ [10 cm – 1 mm]
  - Inducono rotazioni nelle molecole
- **Infrarossi**: λ [1 mm – 0.1 μm]:
  - Amplificazione vibrazioni della molecola
- **Visibile** e **Ultravioletto**: λ [~ 0.1 μm – 10 nm]
  - Eccitano elettroni di valenza
- **Raggi X** e **γ** : λ [10 nm – <1 pm]
  - Strappano gli elettroni più vicini al nucleo

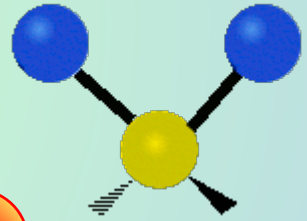


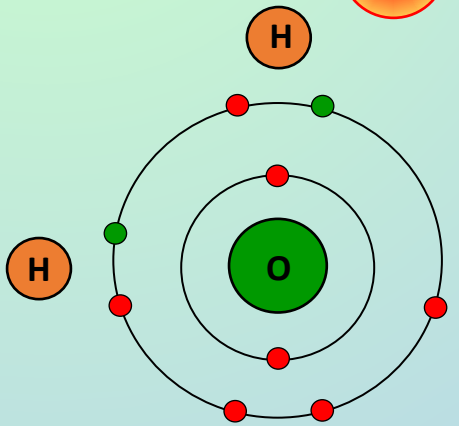


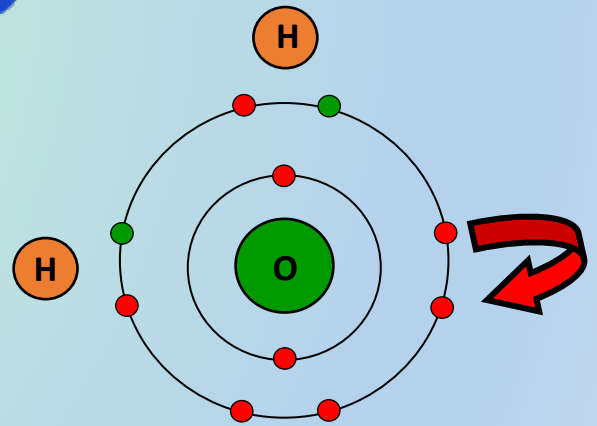






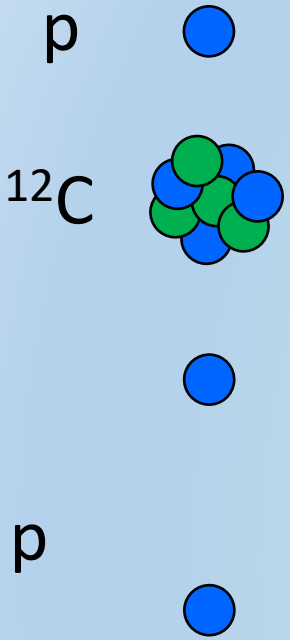


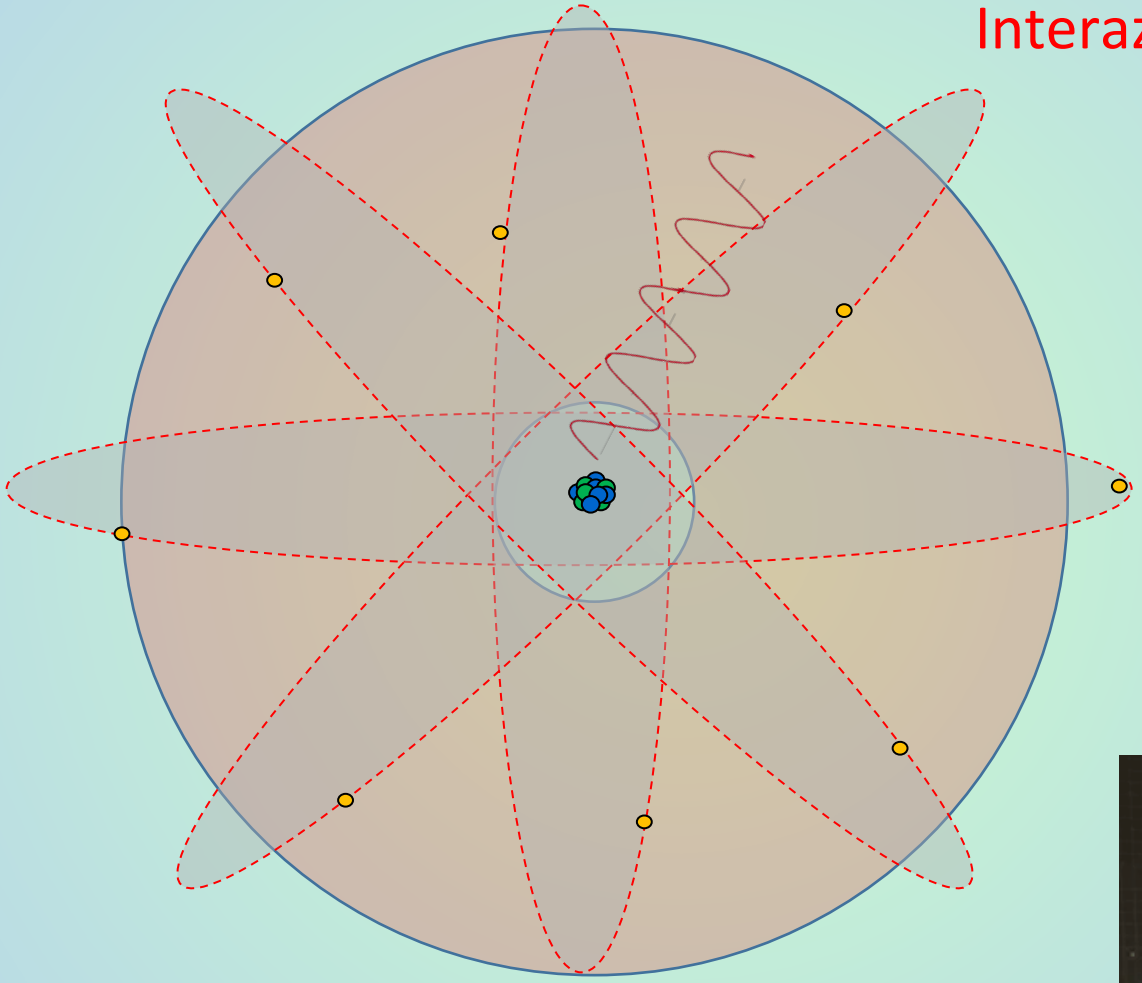




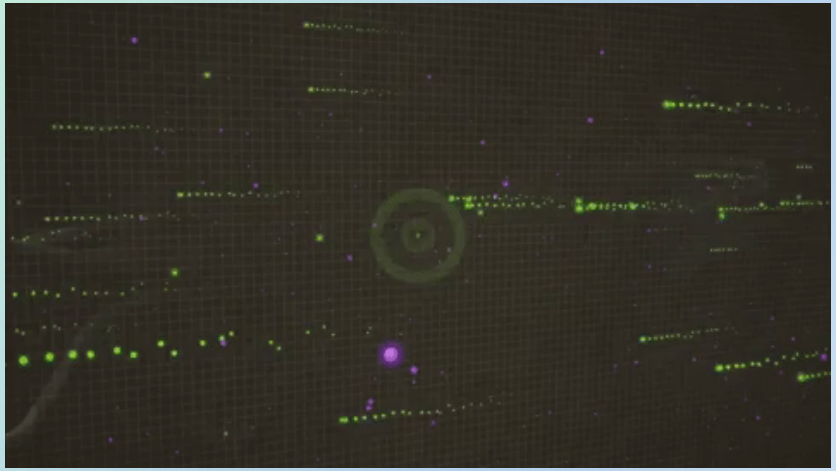
Strappano via l'elettrone

ADROTERAPIA: particelle cariche nel nostro corpo





Interazione con la nube elettronica

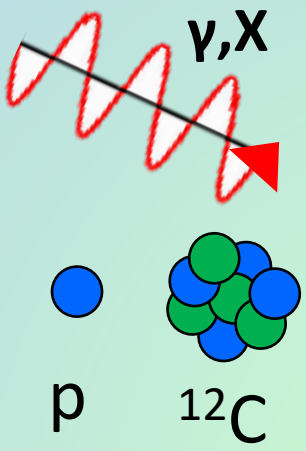


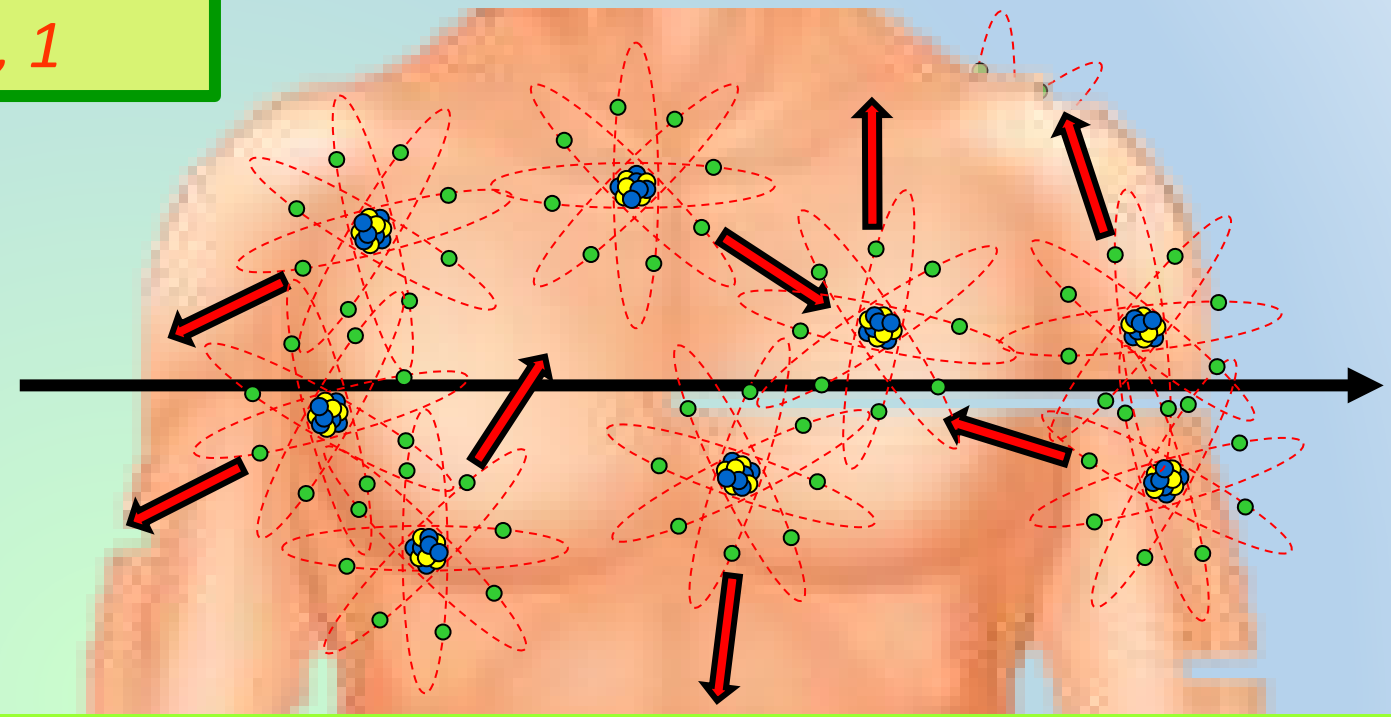
Interazione con il nucleo dell'atomo

Particelle CARICHE, raggi γ e X nel corpo, 1

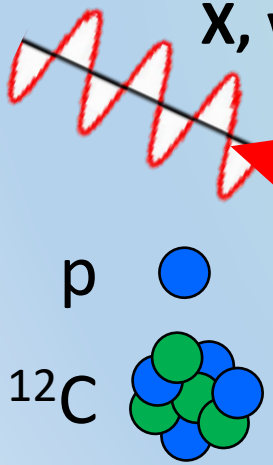
Radioterapia

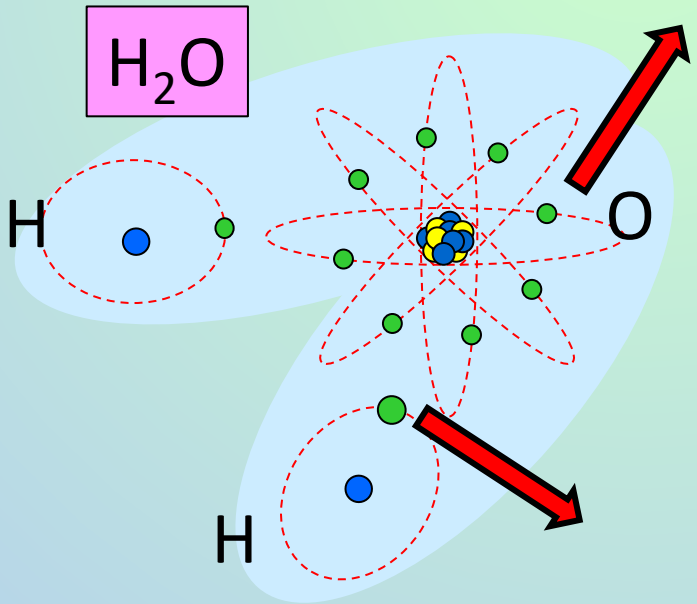
Adroterapia





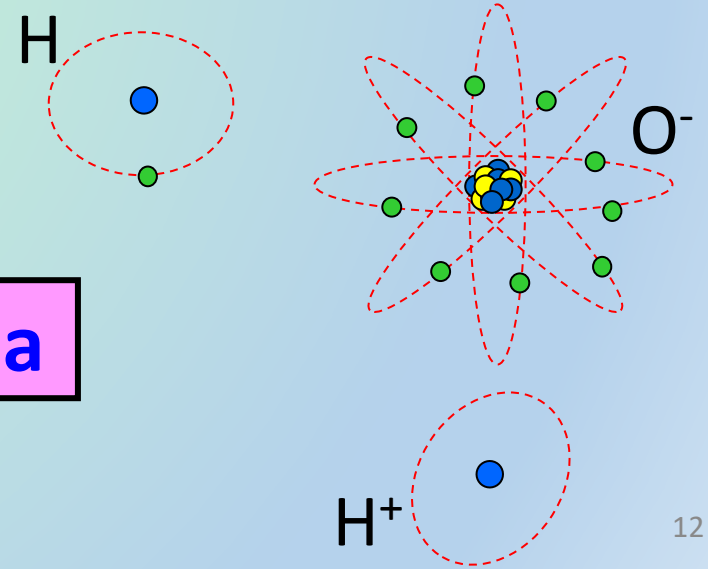
Al loro passaggio molti atomi sono ionizzati (elettroni strappati)



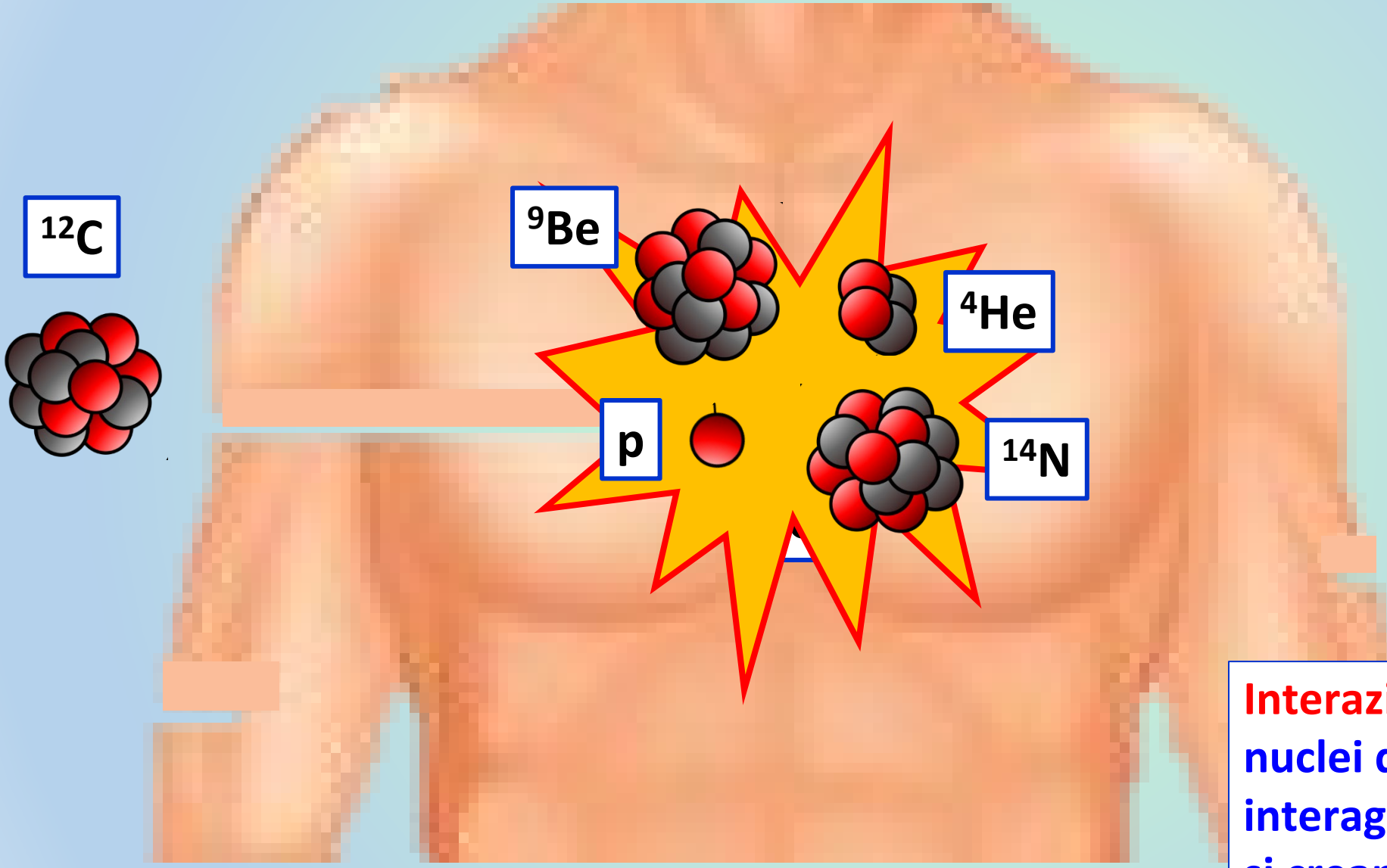


legami rotti

molecola



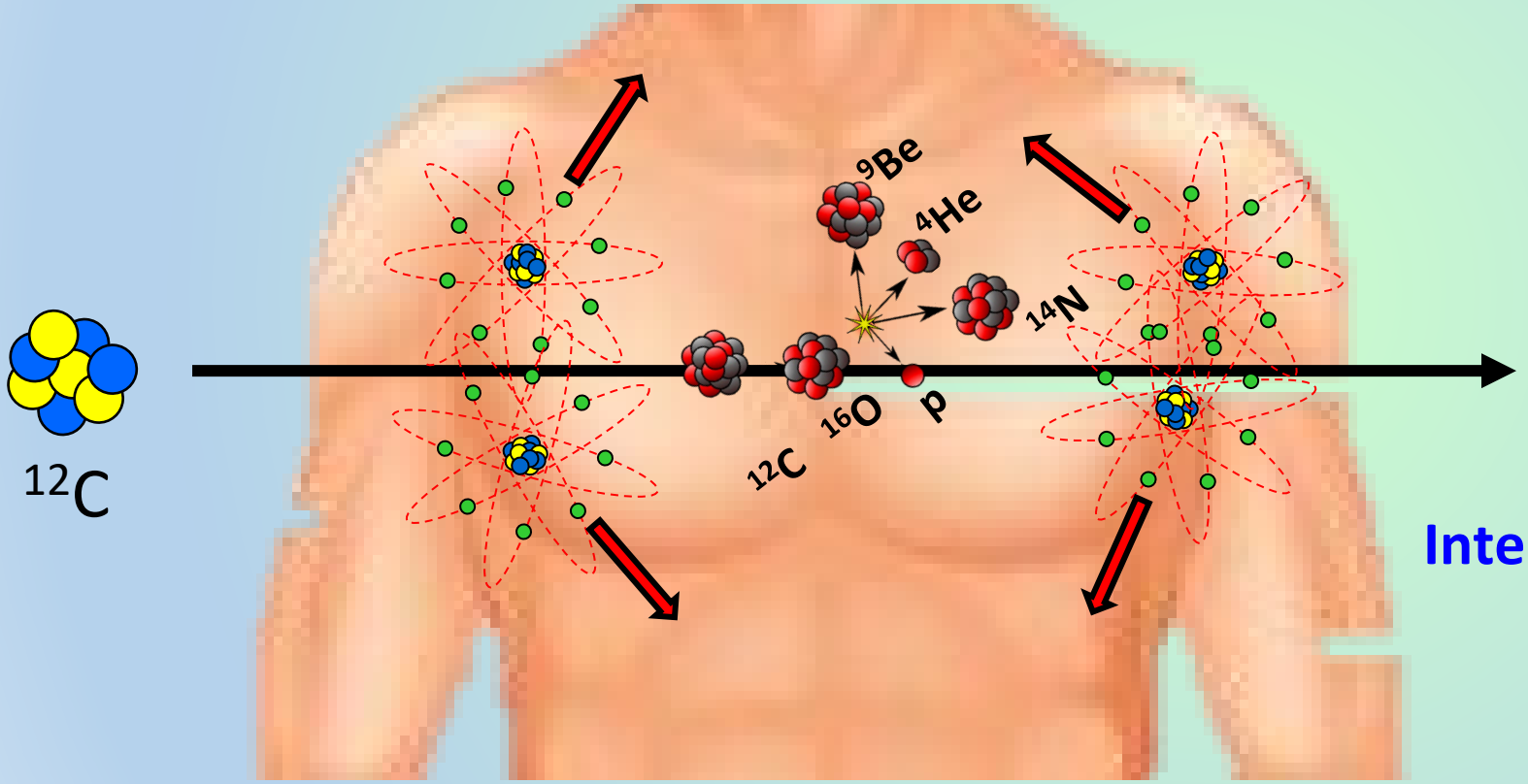
Può succedere anche qualche altra cosa



Interazioni Nucleari:, a volte i nuclei quando si avvicinano interagiscono e si spaccano → si creano altri nuclei → effetto non desiderato

Particelle CARICHE, raggi γ e X nel corpo, 2

Interazioni elettromagnetiche e nucleari



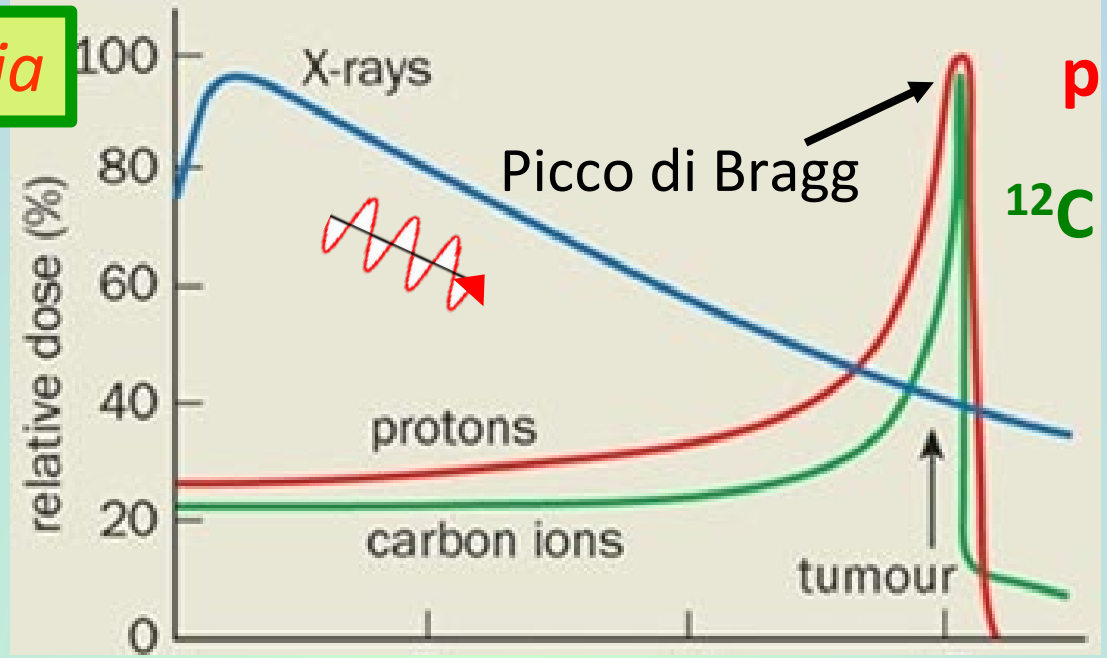
Interazioni em → sappiamo tutto

Possiamo prevedere rischi e vantaggi del trattamento

Interazioni nucleari → non tutto è noto

NON possiamo prevedere precisamente rischi e vantaggi del trattamento

Radioterapia e Adroterapia

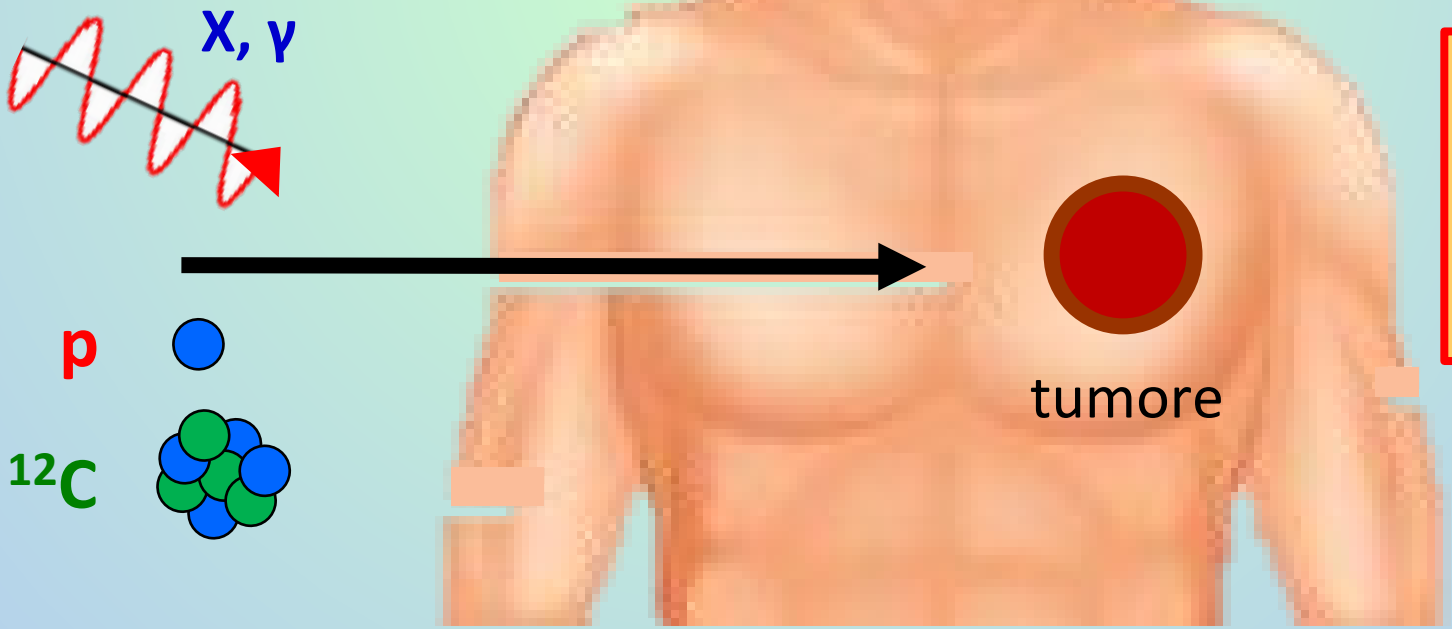


profondità di penetrazione nel corpo (cm)

ADROTERAPIA
La maggior parte del danno è creato nella zona tumorale

Radioterapia

Adroterapia



RADIOTERAPIA
La maggior parte del danno è creato nella parte iniziale

Vantaggi e svantaggi dell'Adroterapia

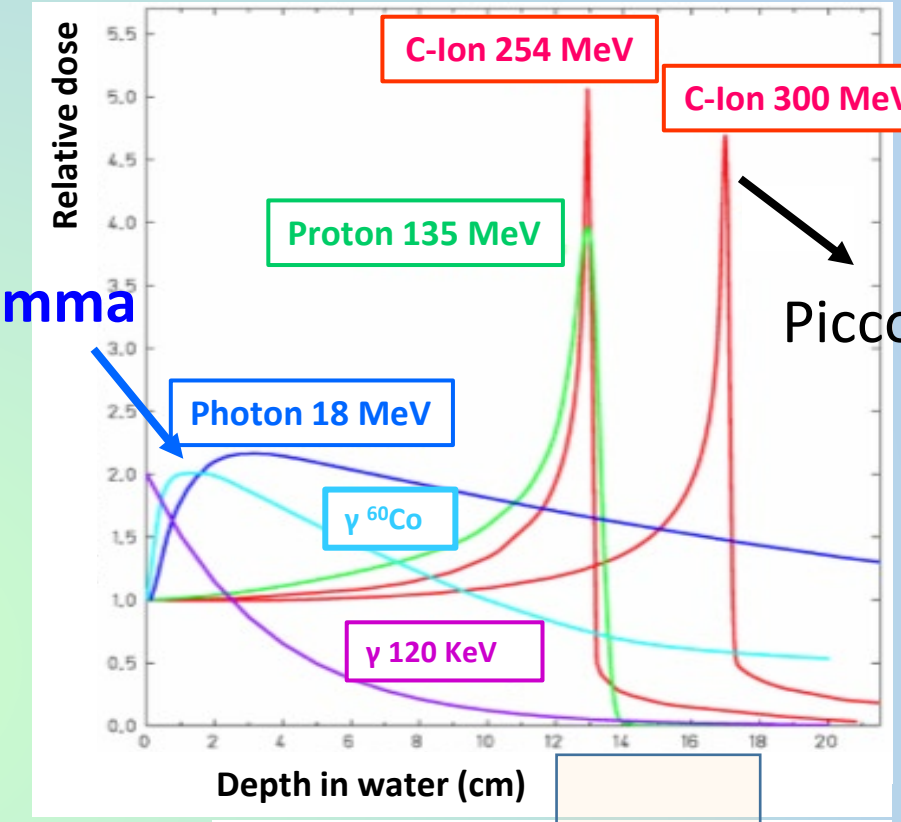
PRO

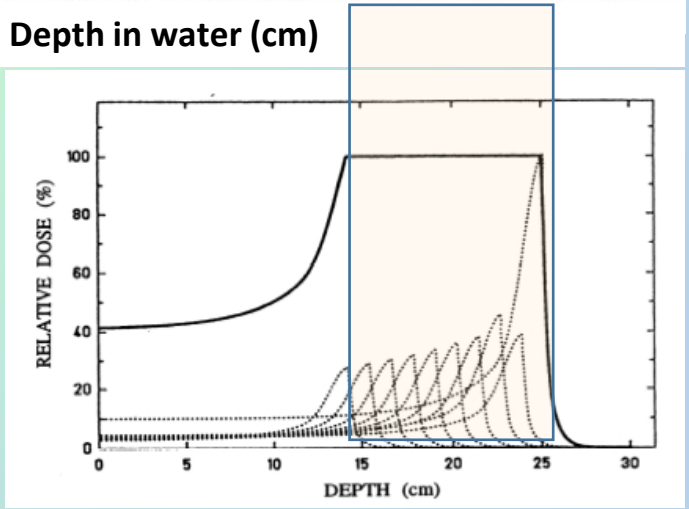
- **Massimo rilascio della dose sul tumore**
- **Profondità dipende dall'energia**

CONTRO

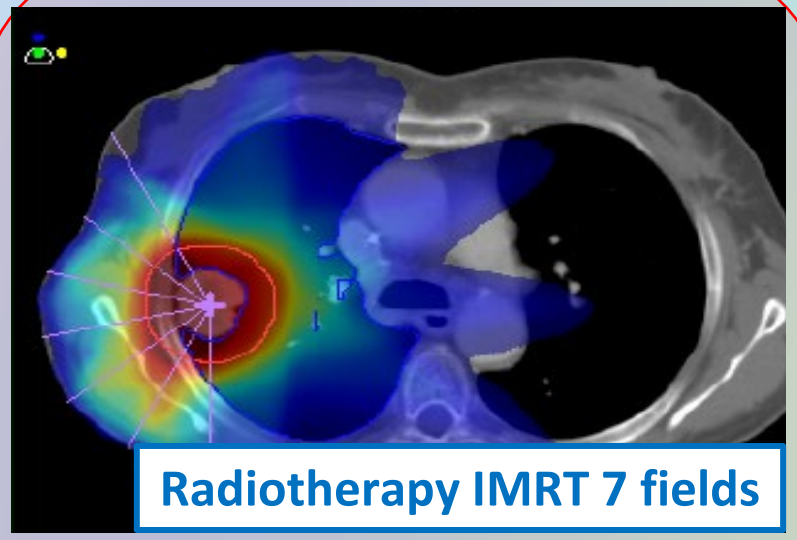
- **Più costoso**
- **effetti nucleari non misurati**

FOOT

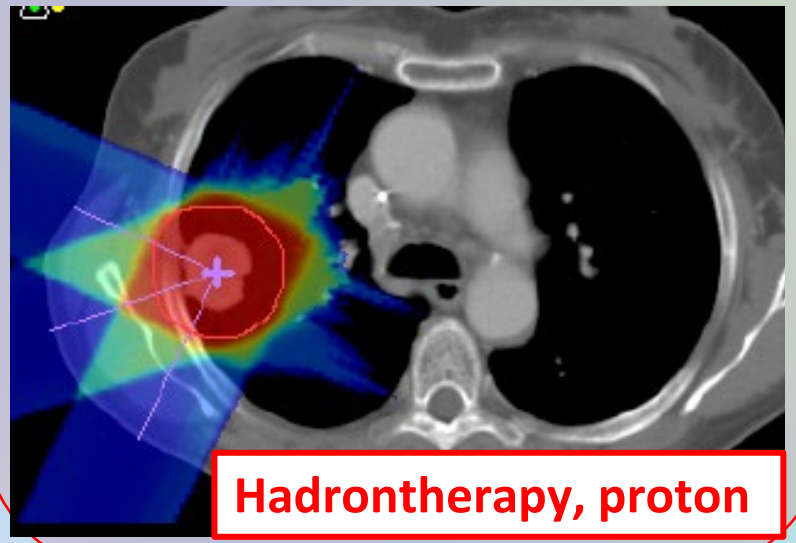




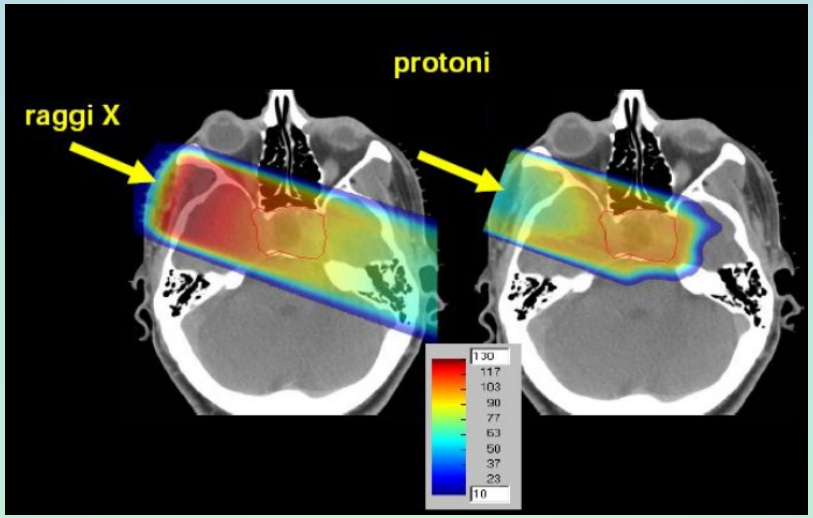
Profilo della dose

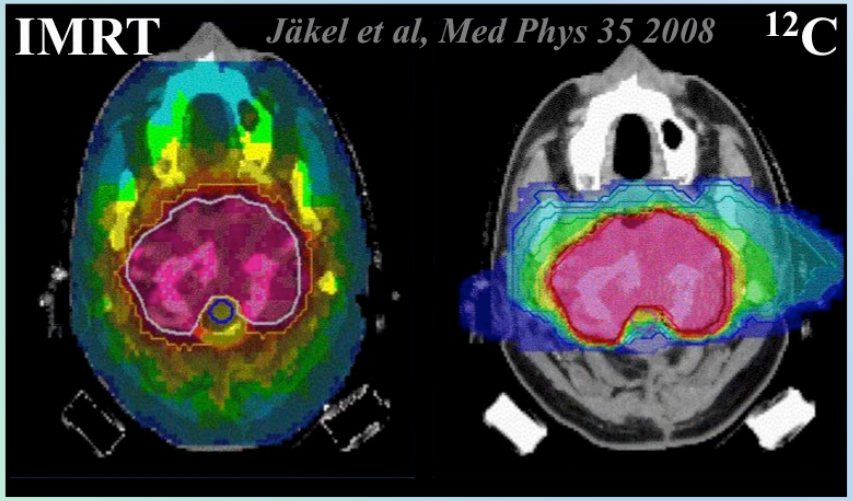


Radiotherapy IMRT 7 fields



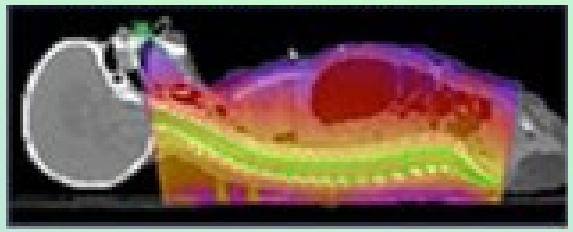
Hadrontherapy, proton

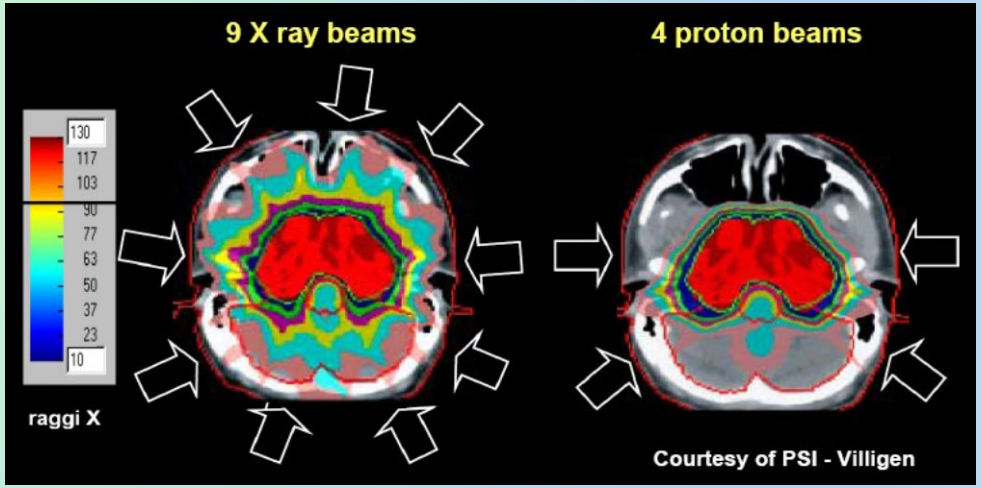




HADRONTHERAPY

CONVENTIONAL RADIOTHERAPY





Organi non coinvolti, sono maggiormente risparmiati

Colpire un tumore "è facile", difficile è risparmiare i tessuti sani

Adroterapia vs radioterapia: efficacia

Indication	End point	Results photons	Results carbon HIMAC-NIRS	Results carbon GSI
ossa	Controllo	30 – 50 %	65 %	70 %
cartilagine	Controllo	33 %	88 %	89 %
faringe	5 anni	40 -50 %	63 %	
Sist nervoso	sopravviv	12 mesi	16 mesi	
occhio	Controllo	95 %	96 % (*)	
Cavità nasale	Controllo	21 %	63 %	
pancreas	sopravviv	6.5 mesi	7.8 mesi	
fegato	5 anni	23 %	100 %	
Ghiand salivarie	Controllo	24-28 %	61 %	77 %
Tessuti soffici	5 anni	31 – 75 %	52 -83 %	

Similar to protons

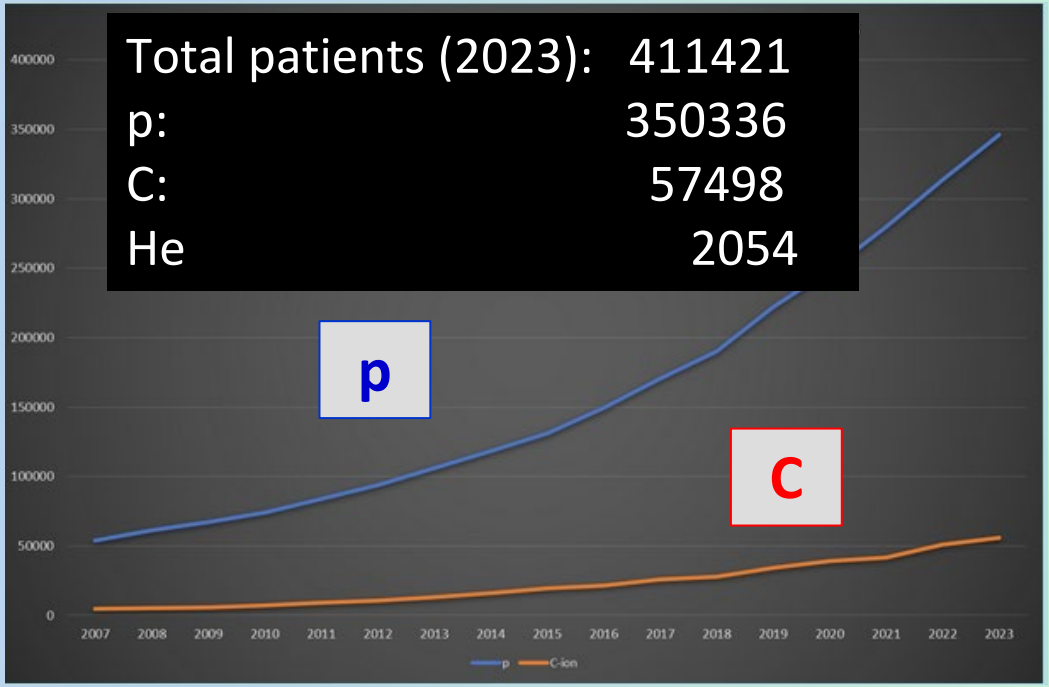
Table by G. Kraft 2007

Results of carbon ions

Geneva - 16.10.13 - UA

Adroterapia nel mondo, 1

https://www.ptcog.ch/index.php/



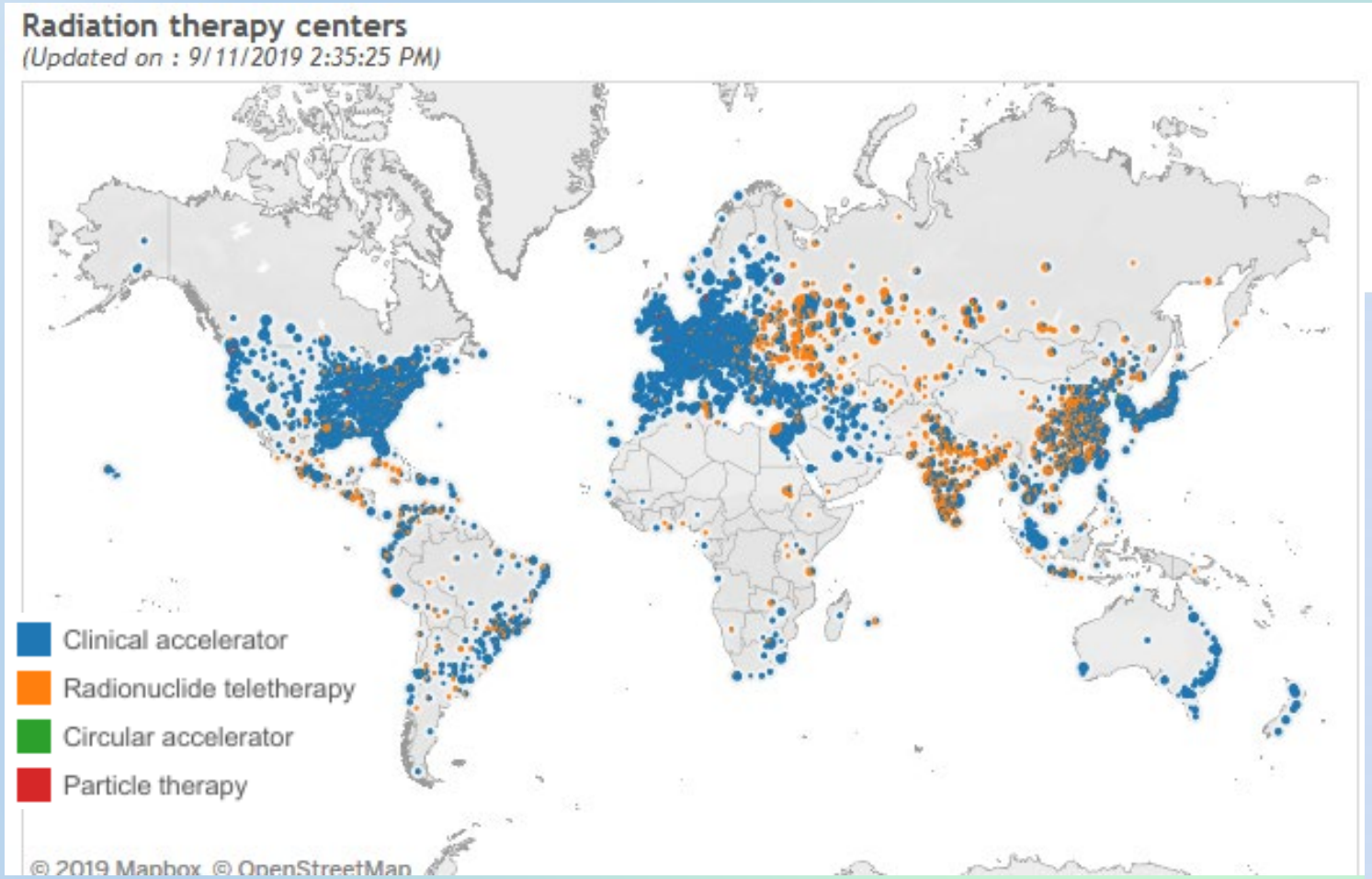
Dal 2010: 10K pazienti /anno

Radioterapia: ~ 10M pazienti /anno

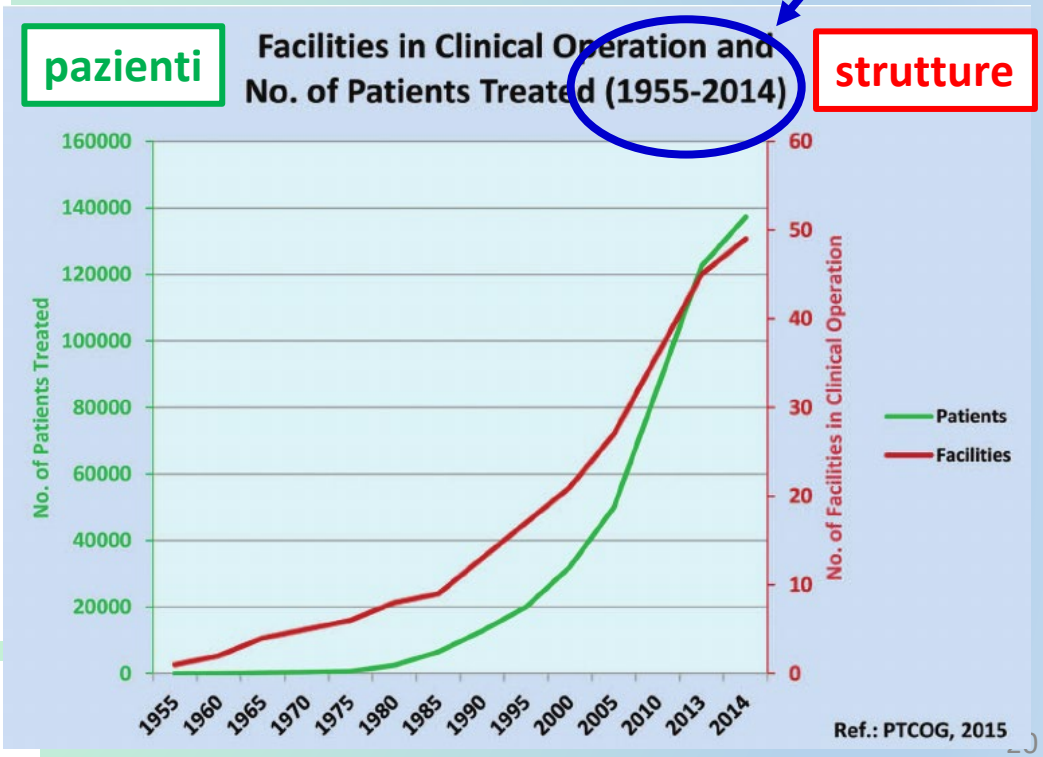
p

p & C)

Adroterapia nel mondo, 2



Non aggiornato



Countries	RT centers	Equipment	Linac	Radionuclide Therapy	Circular Accelerator	Particle Therapy
149	7477	14374	12214	2031	13	116

RT — fattore 100 → PT

Forte incremento del numero di strutture e pazienti trattati

Forte sviluppo: 31 strutture per adroterapia in costruzione

Tecniche di trattamento

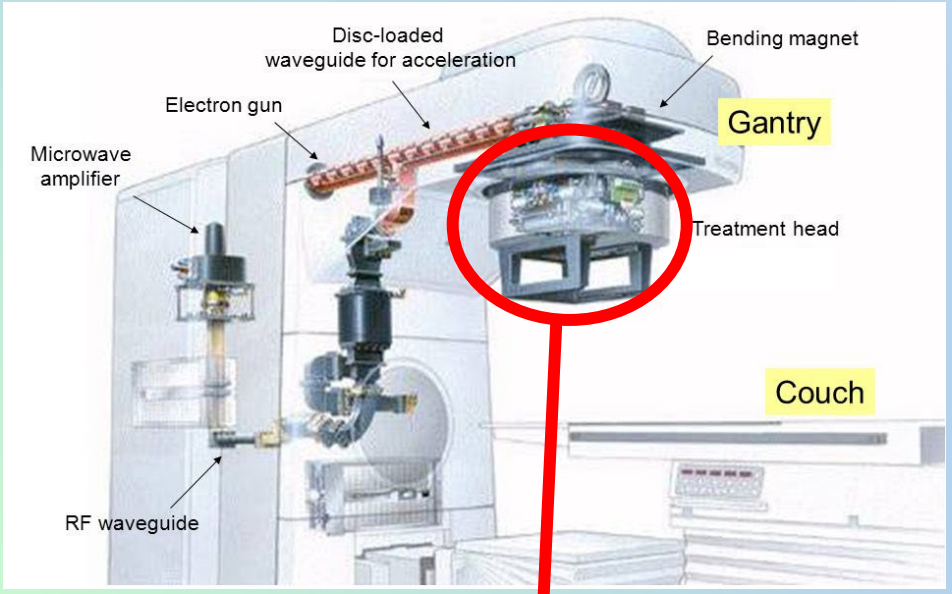
Radioterapia

- **IGRT Imaging Guided Radio Therapy**

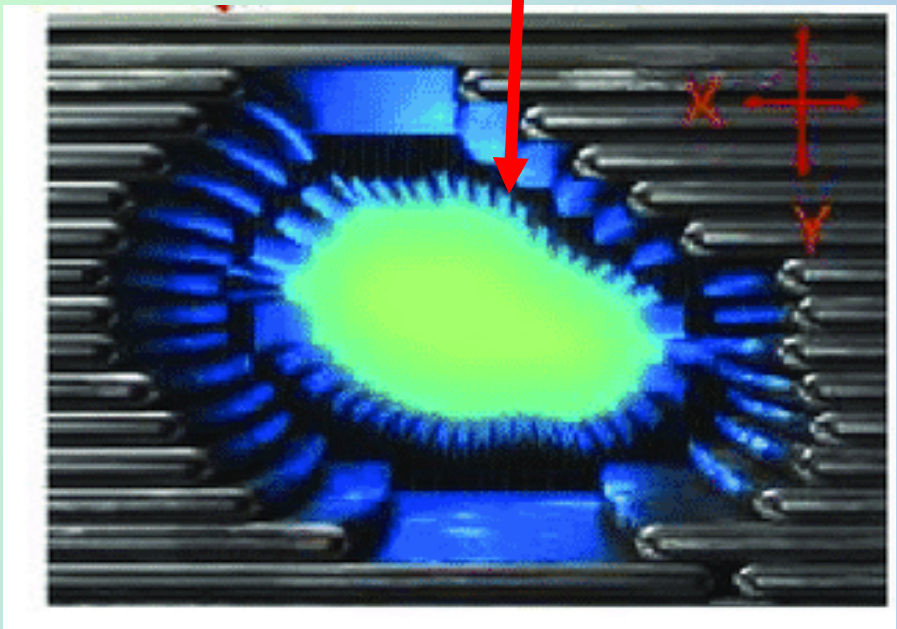
Adroterapia

- **Ciclotrone**
- **Sincrotrone**

Radioterapia: «Fuoco» sul cancro



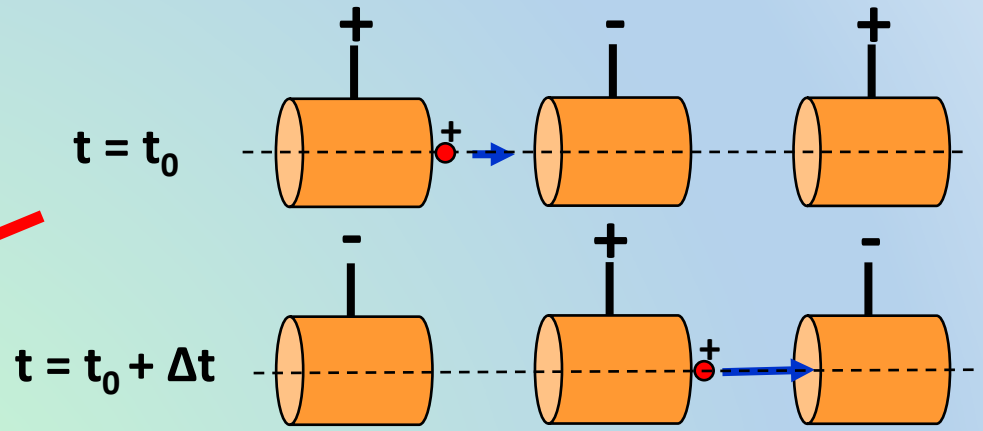
Sistema rotante (Gantry) attorno paziente

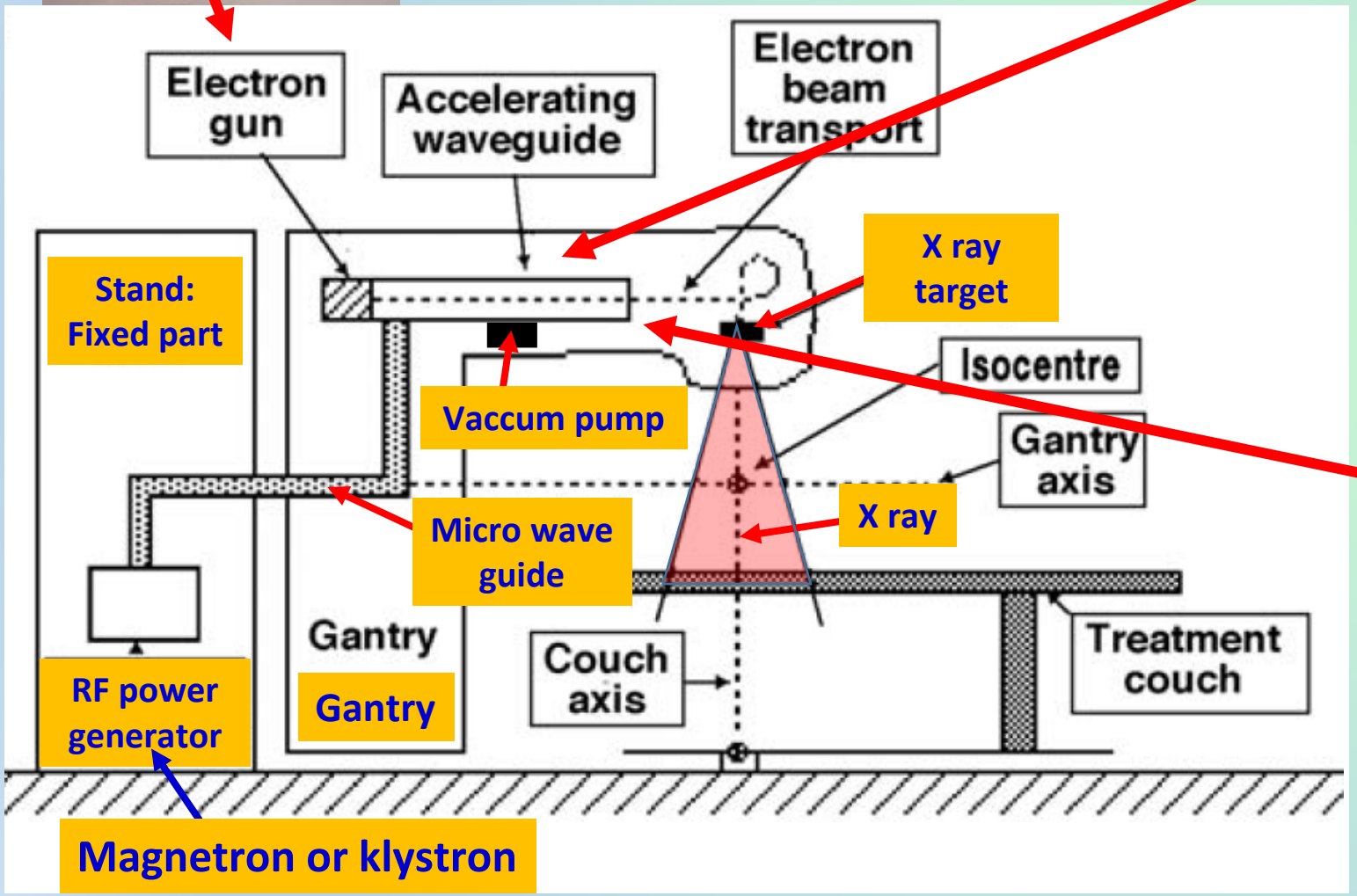


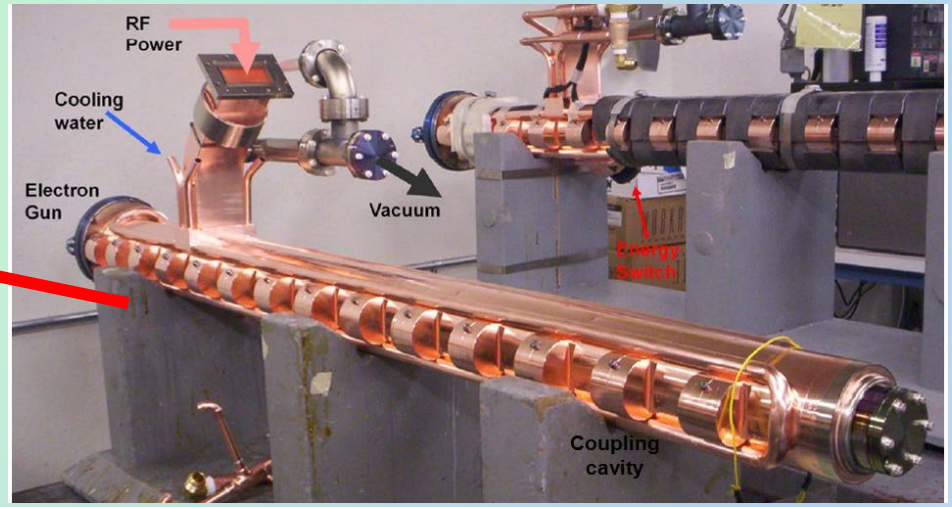
Sistema di lamelle indipendenti gestite automaticamente per modulare l'intensità di radiazione

Decine (centinaia) di lamelle indipendenti gestite dal computer per far passare più o meno radiazione

L'acceleratore lineare





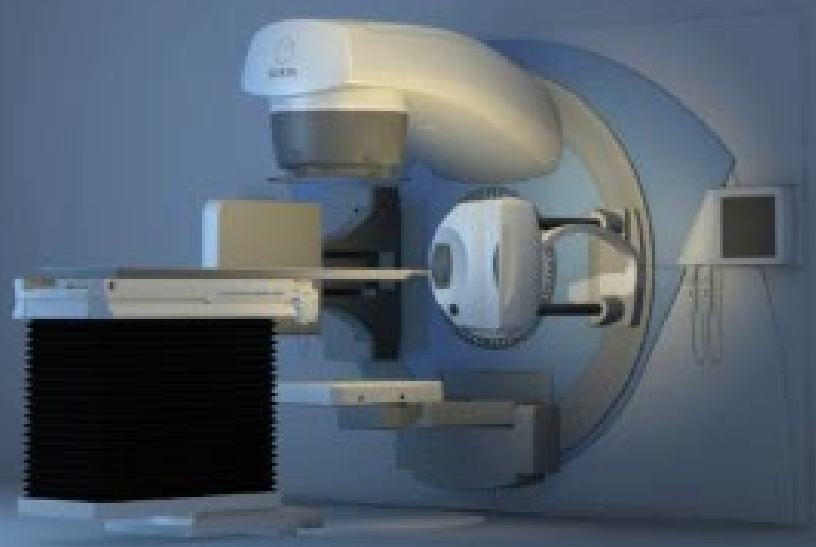


Flexibility

Confidence

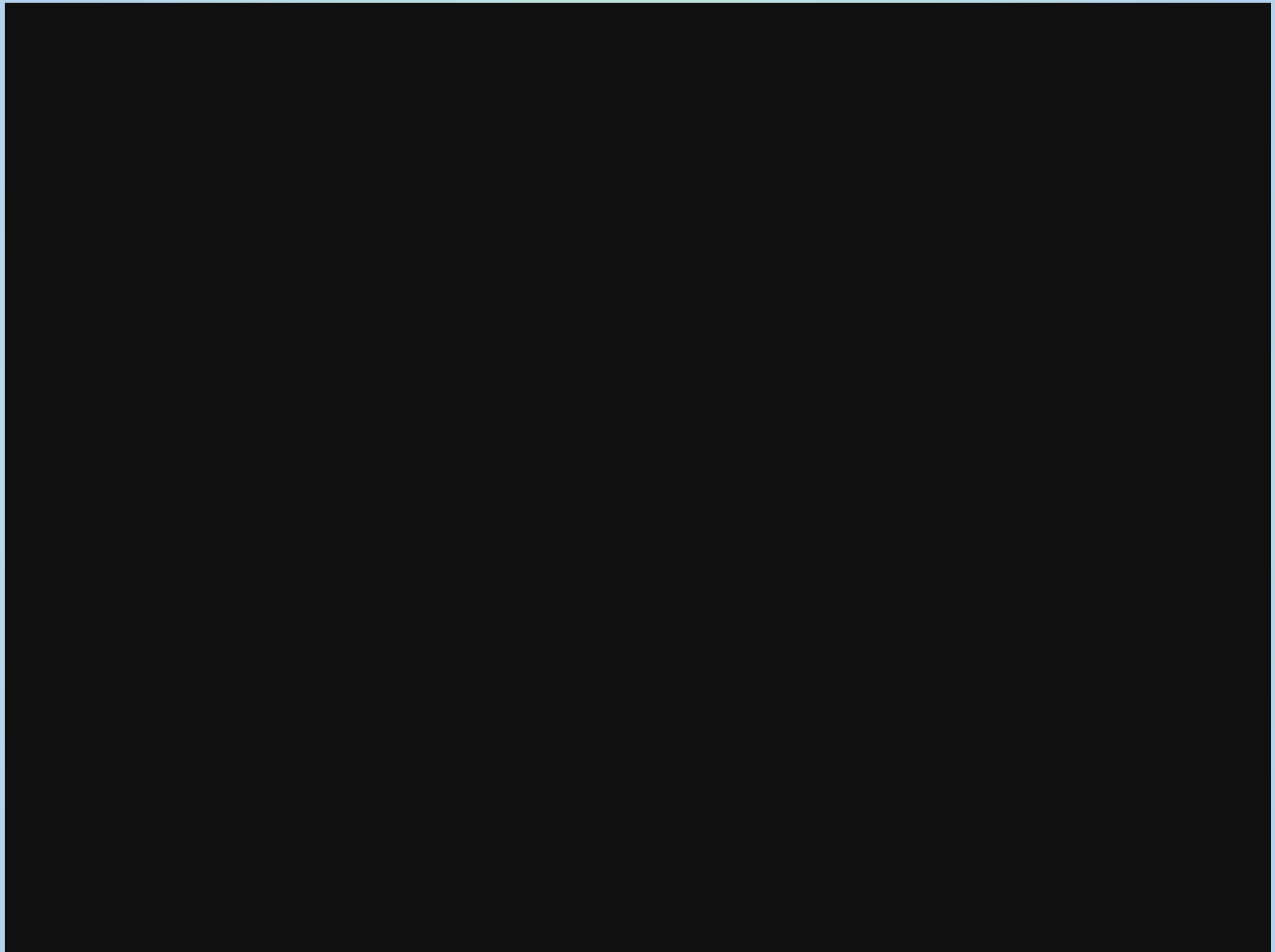
ELEKTA

Evidence

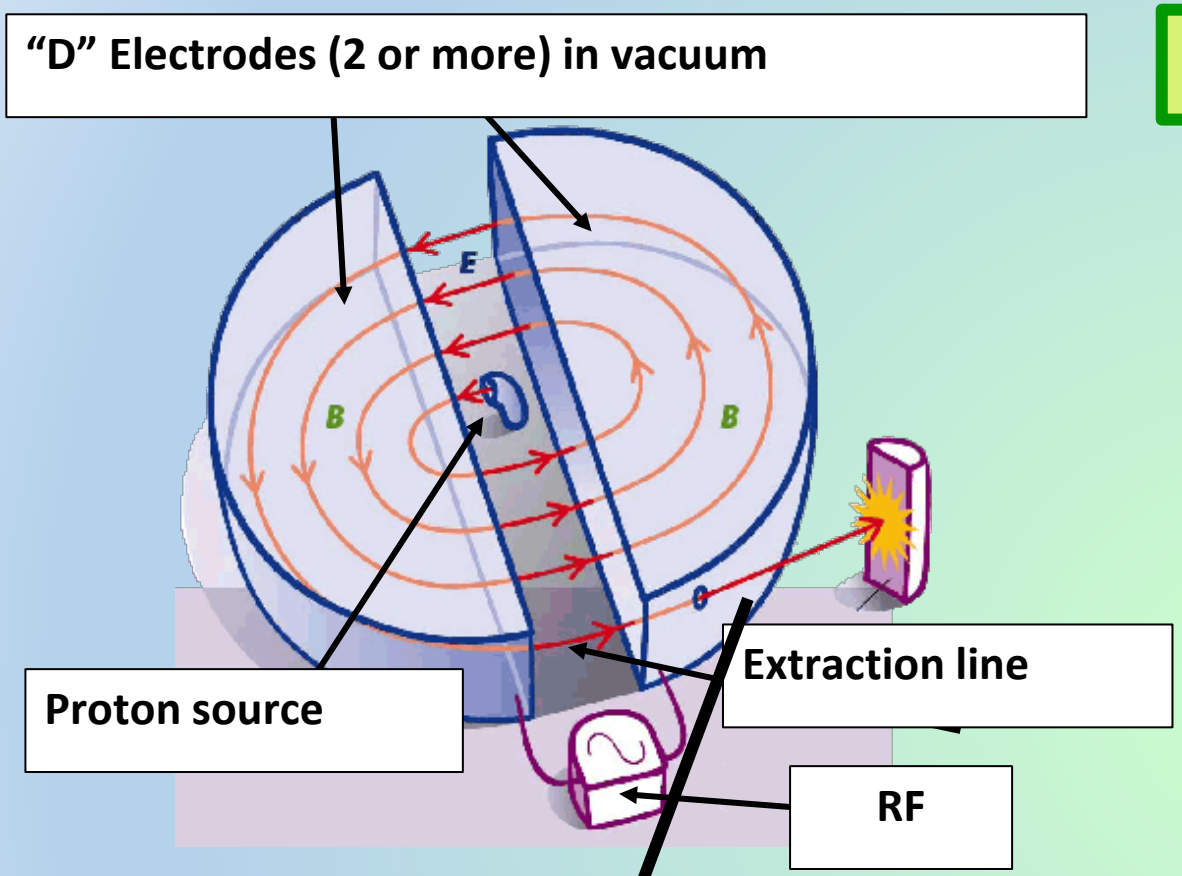


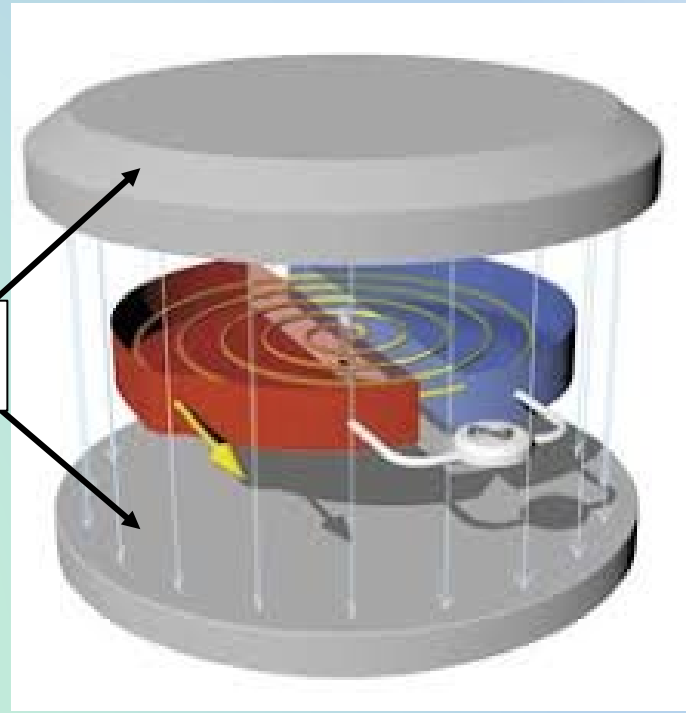
Innovation

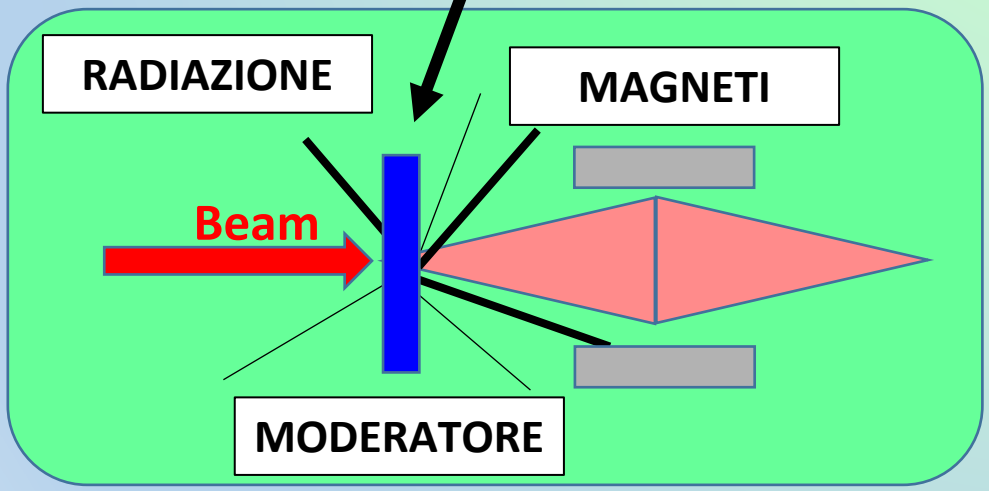
Efficiency



ciclotrone



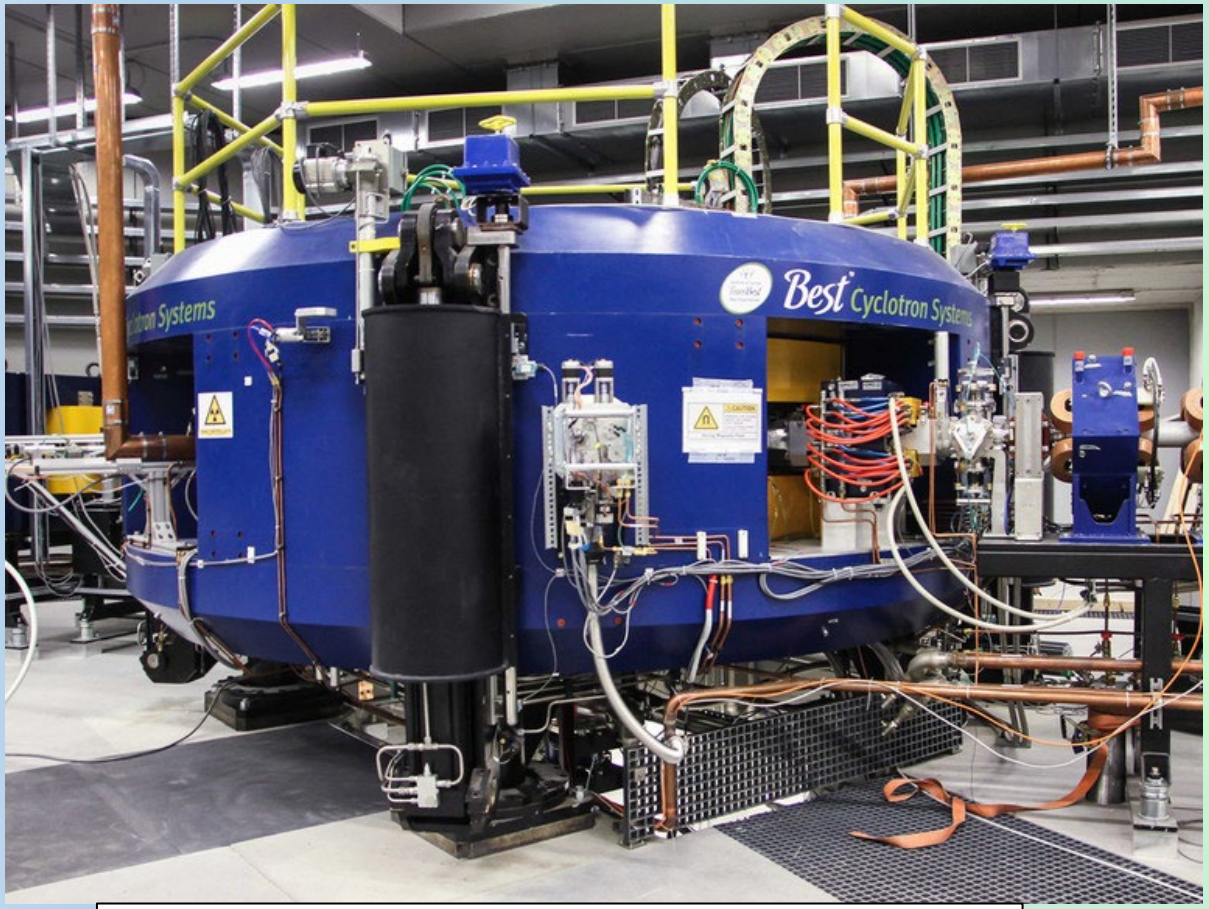




Caratteristiche principali

- Dimensioni ridotte
- Costo contenuto
- Particelle monoenergetiche
- Alta radiazione ambientale
- Bassa intensità del fascio

ciclotrone

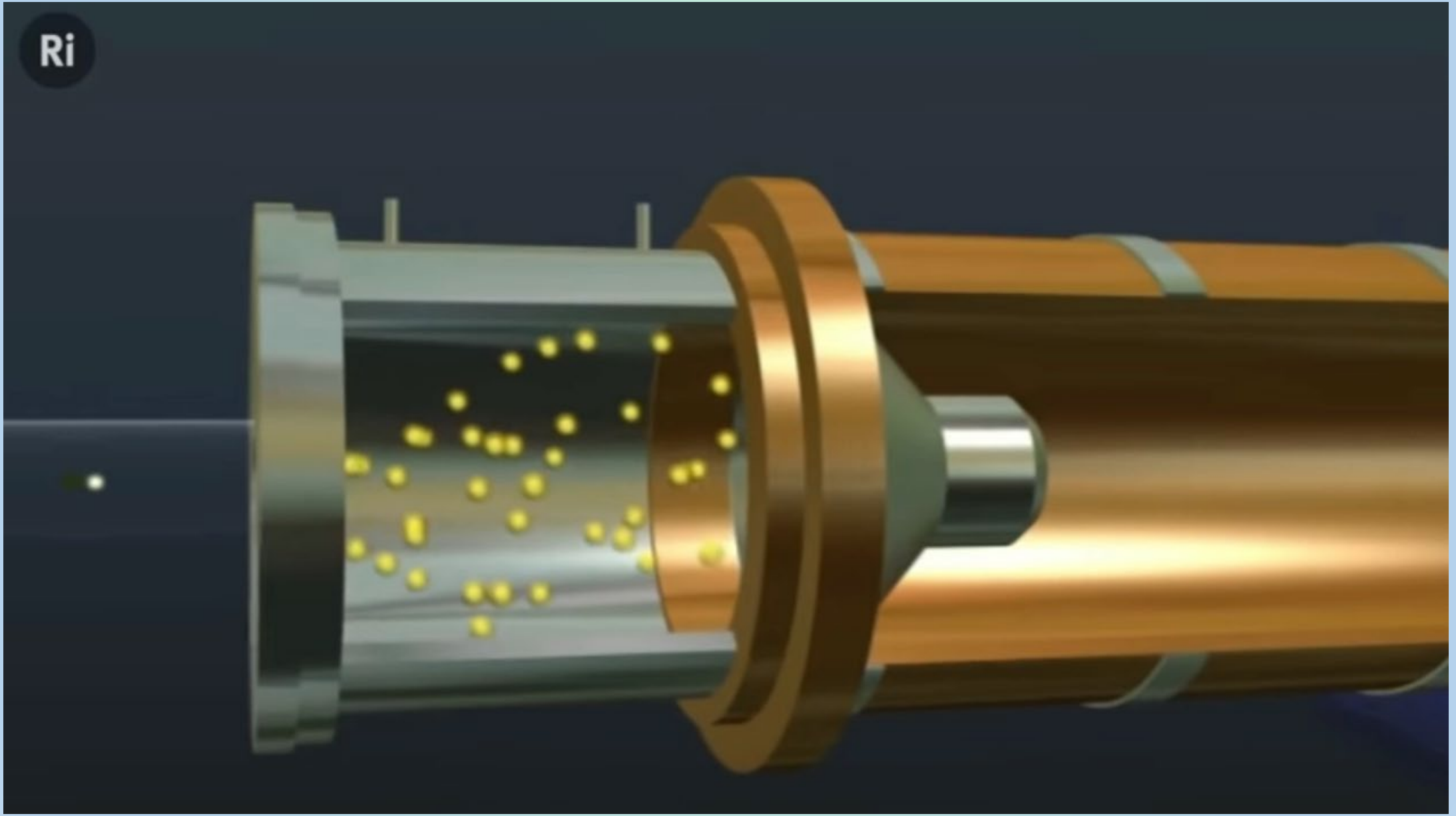


Ciclotrone al laboratorio di Legnano (PD)

CATANA superconducting cyclotron

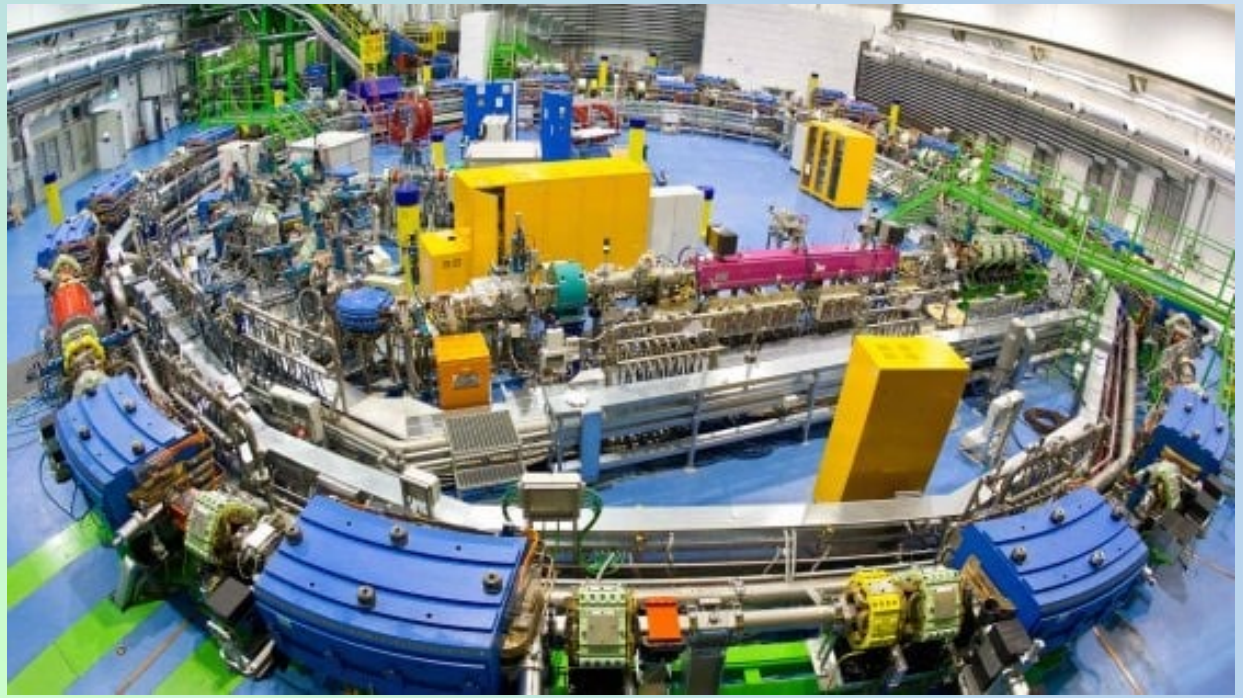
Ciclotrone del centro di protonterapia di Trento

Accelerare le particelle



Il gantry del ciclotrone del centro di protonterapia di Trento

Il sincrotrone del CNAO



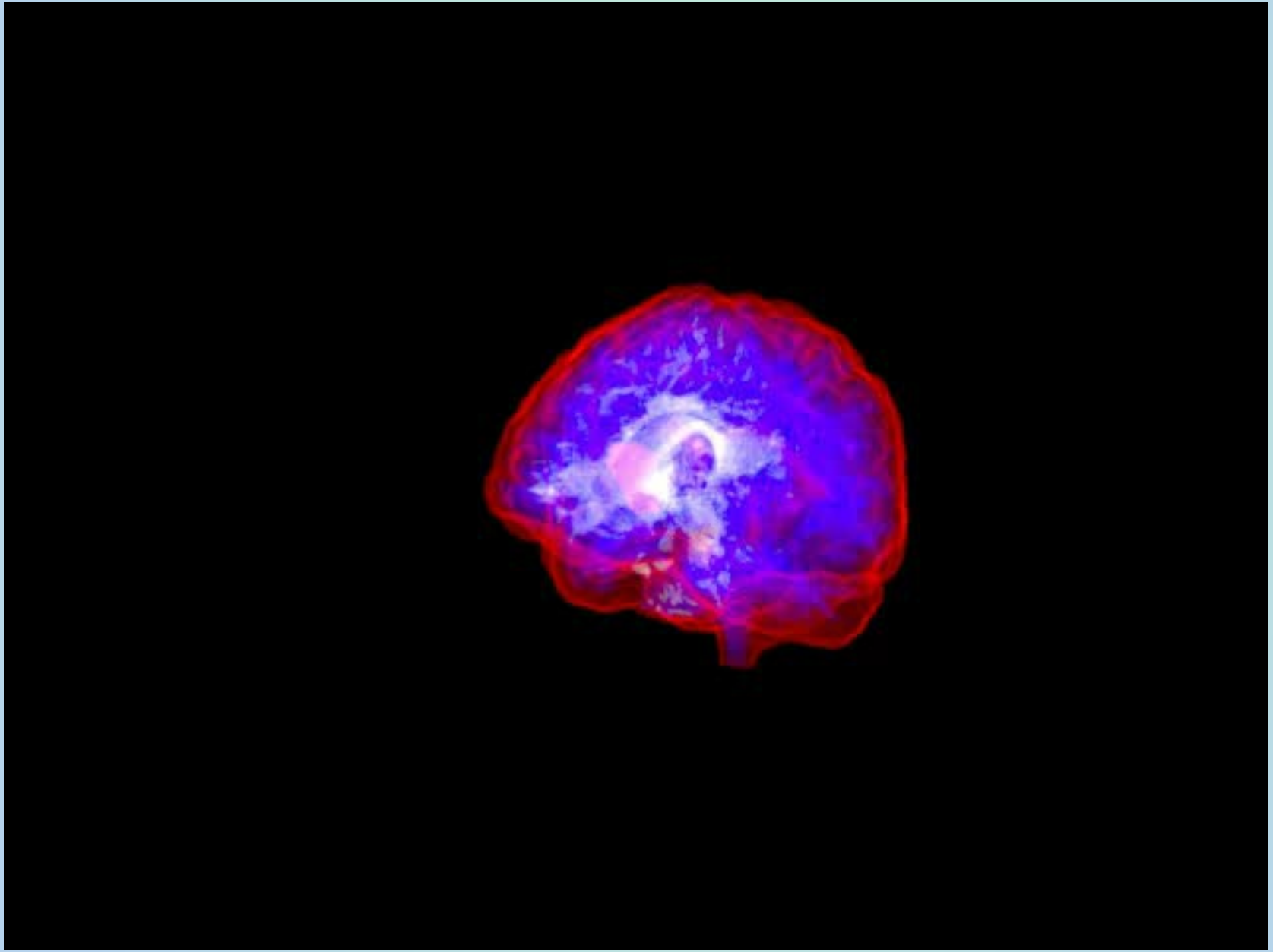
Pro

- **Accelerano anche ioni pesanti**
- **Fascio di energia desiderata**
- **Stessa intensità del fascio a qualunque energia**
- **Nessuna radiazione nell'ambiente**

Contro

- **Dimensioni maggiori (raggio ~ 10 m)**
- **Più difficili da realizzare**
- **Costosi**

Colpire il tumore con un fascio di particelle



Backup slide