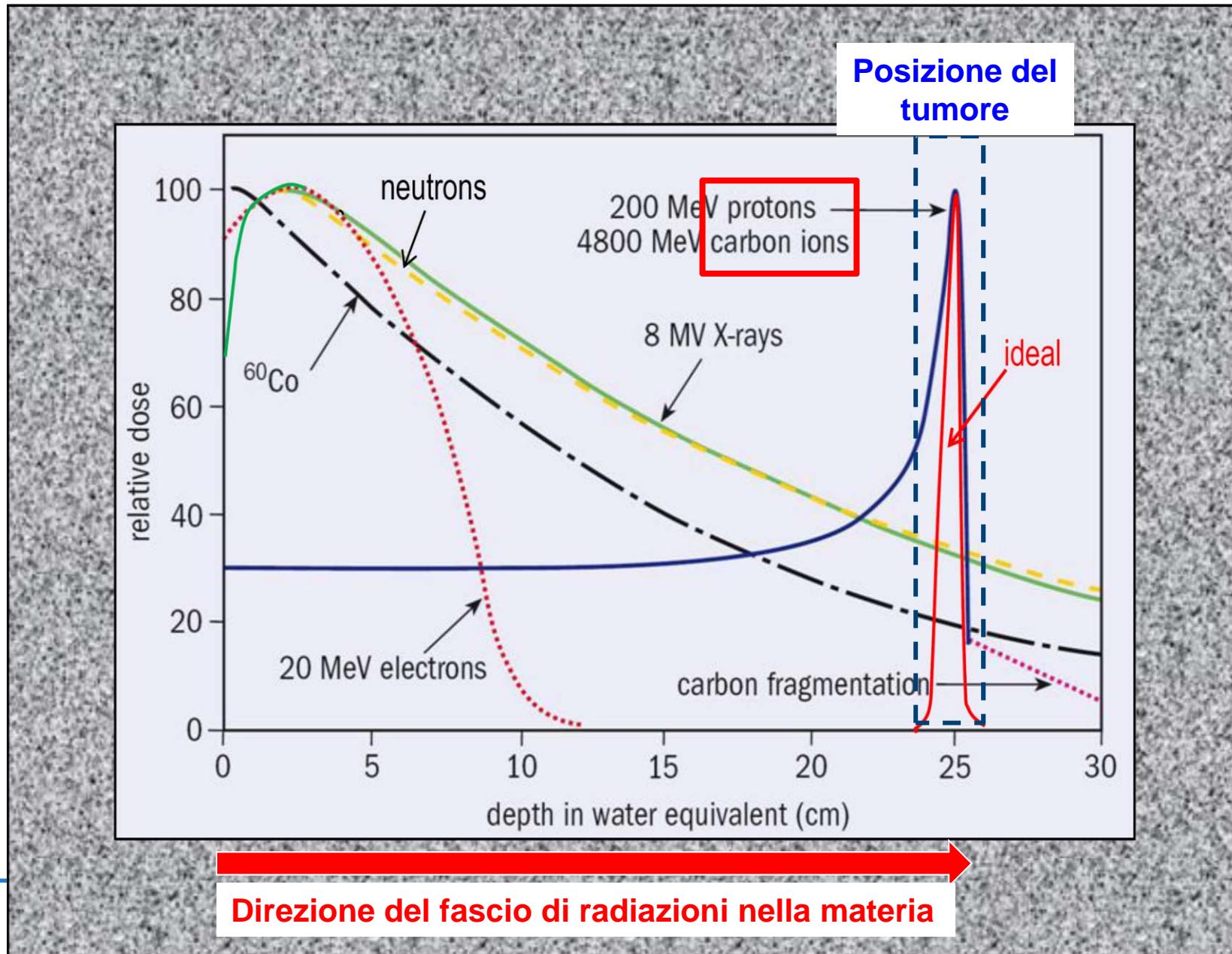




Centro Nazionale di Adroterapia Oncologica

Adroterapia

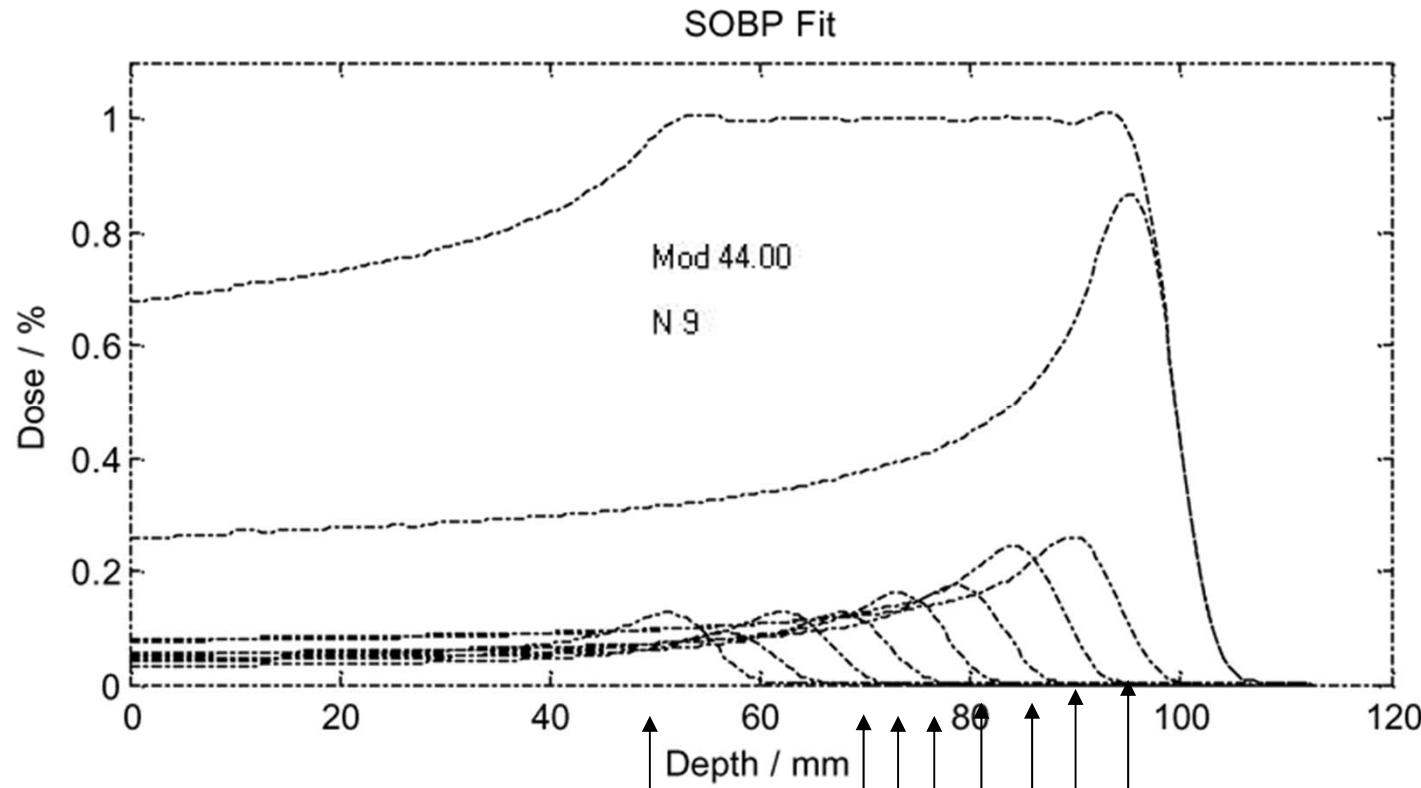
Precisione dell'adroterapia



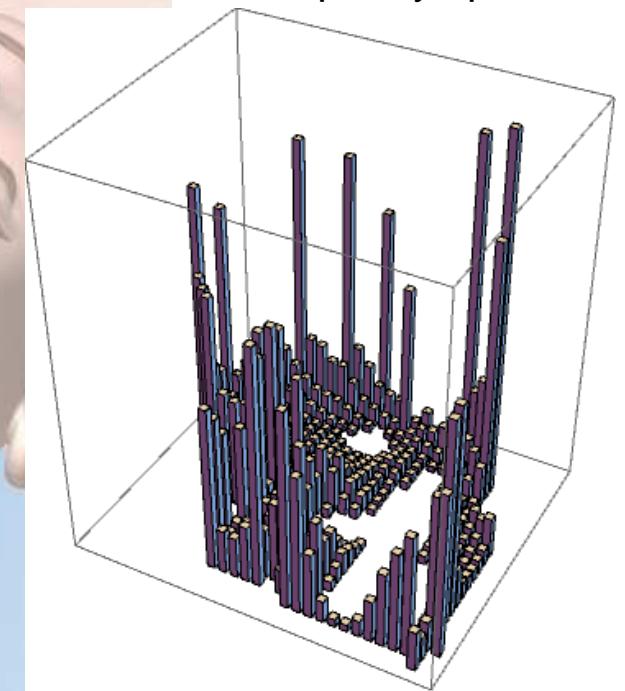
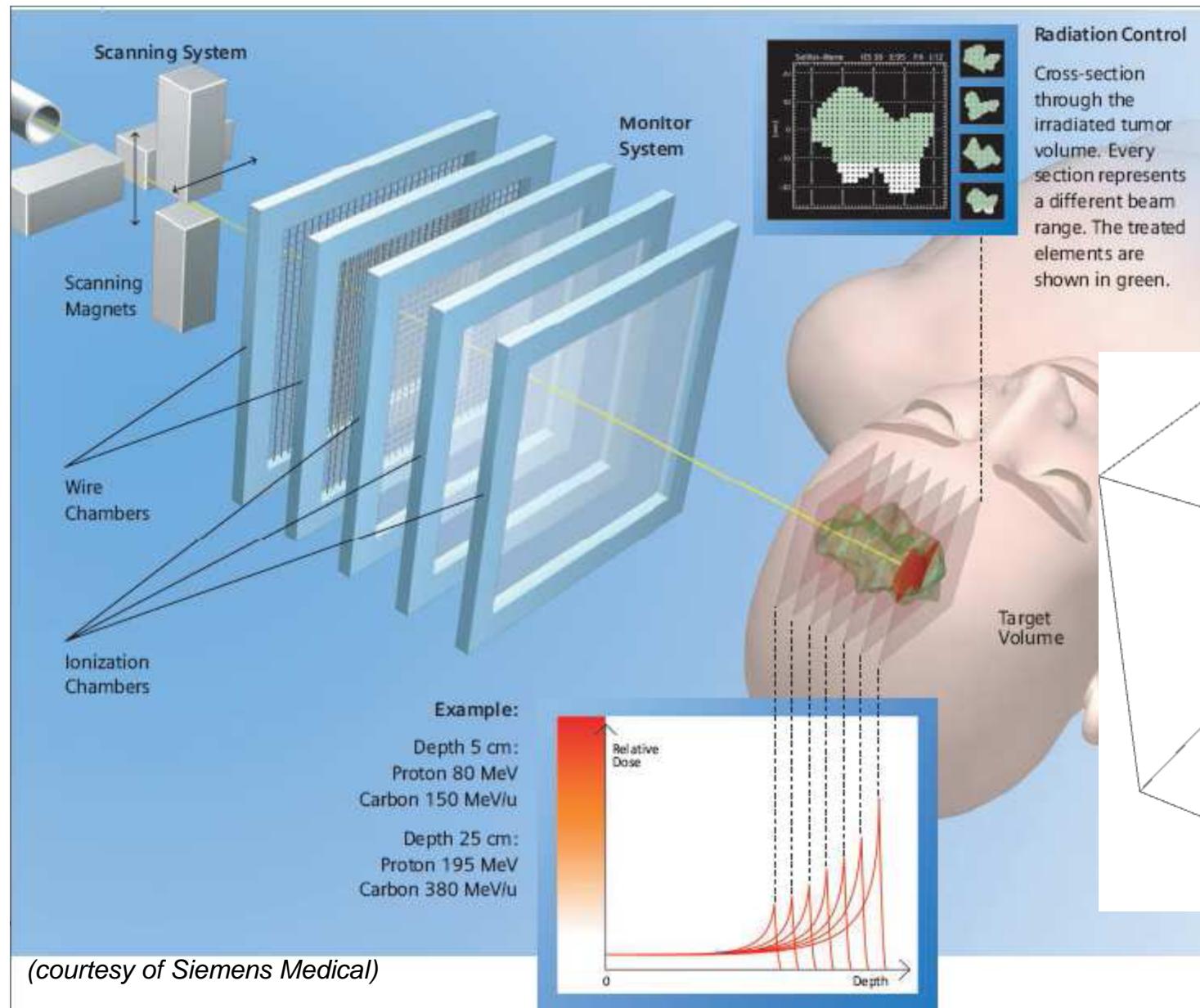
Spread Out Bragg Peak

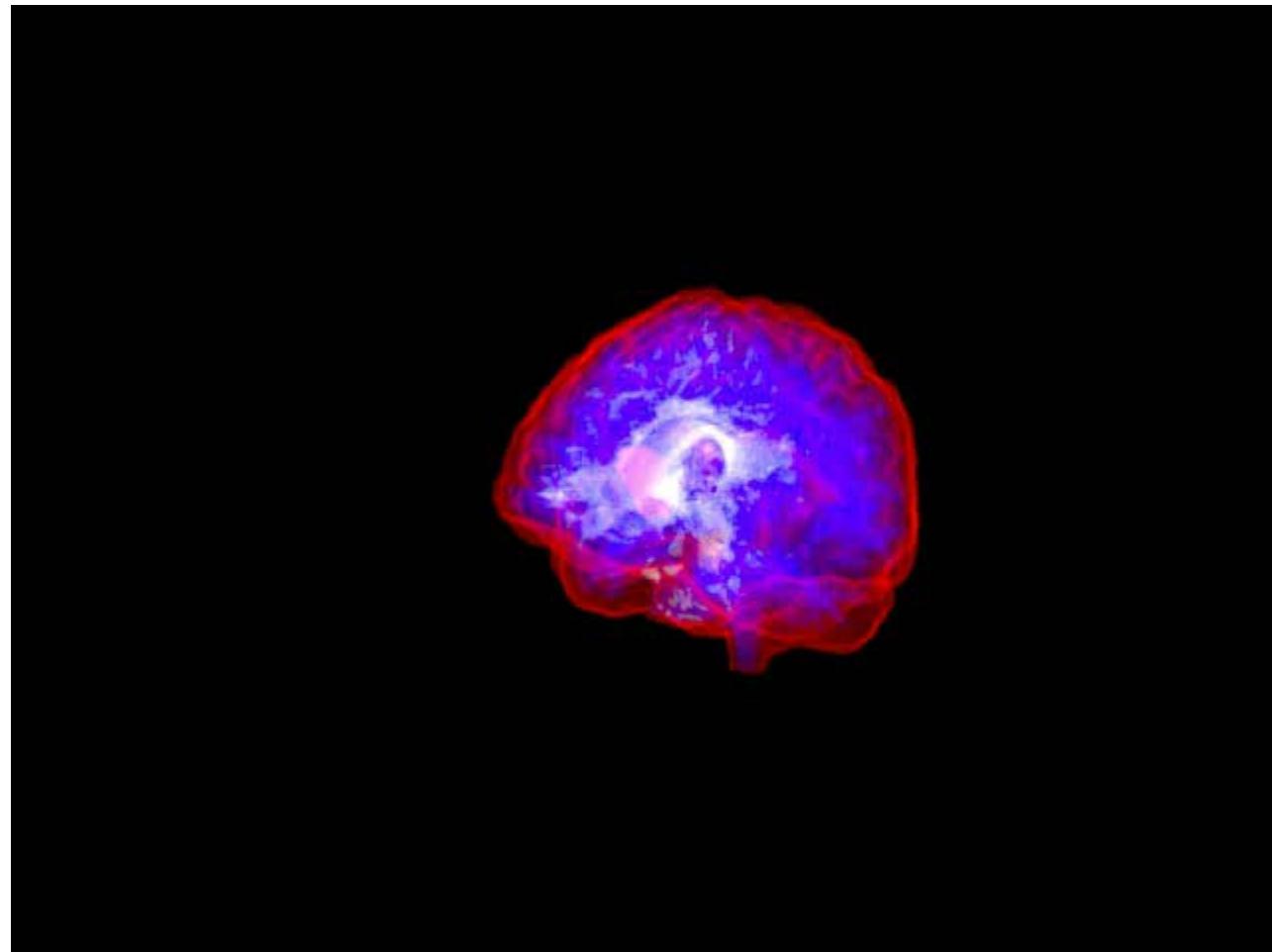
Per coprire un tumore di qualche cm bisogna sommare molti picchi stretti:

- Ciò si ottiene variando l'energia del fascio di adroni carichi riducendola in piccoli passi (**SOBP = Spread Out Bragg Peak**)
- Con tecniche di modulazione del fascio si allarga il picco (tumore a dose uniforme pur con aumento dose nel pianerottolo)

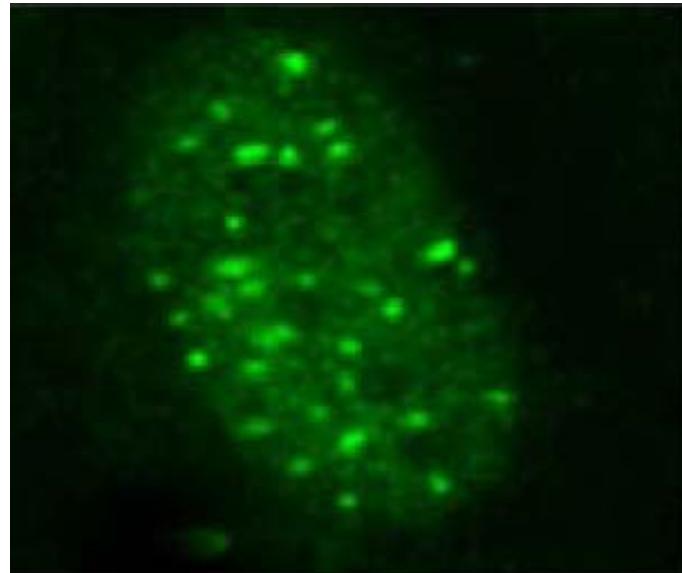
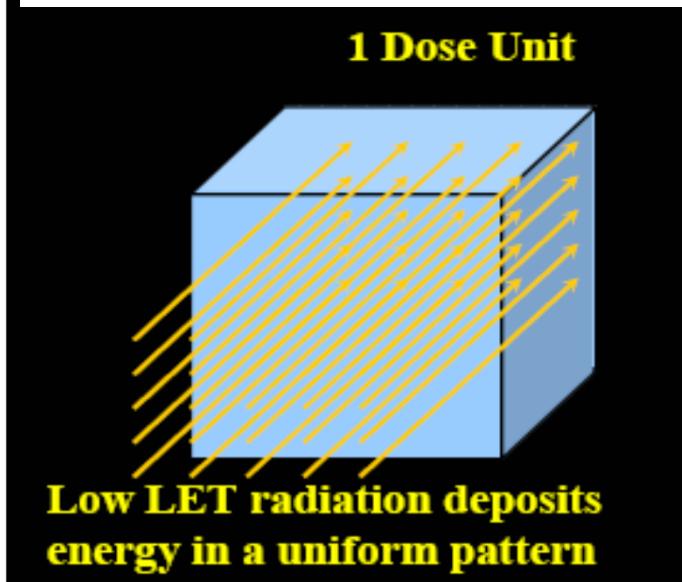


Scansione attiva

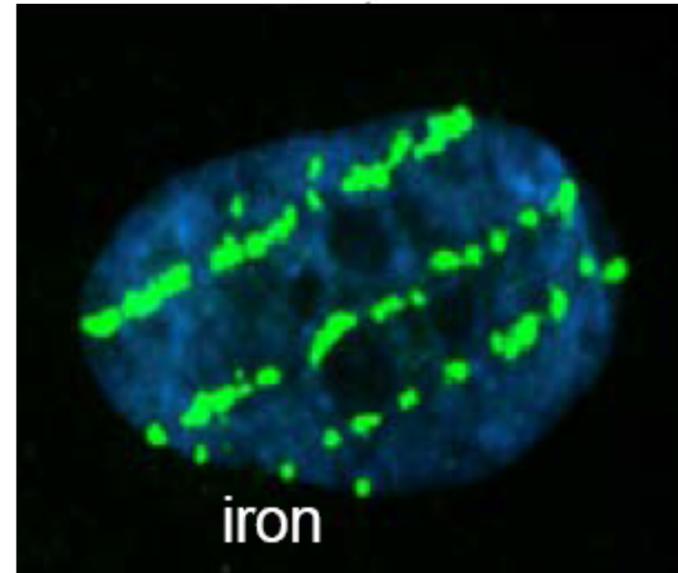
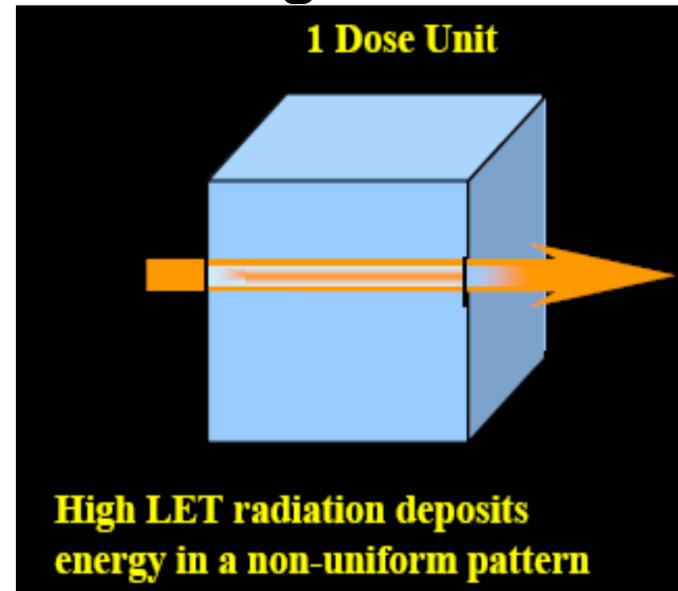




Low LET

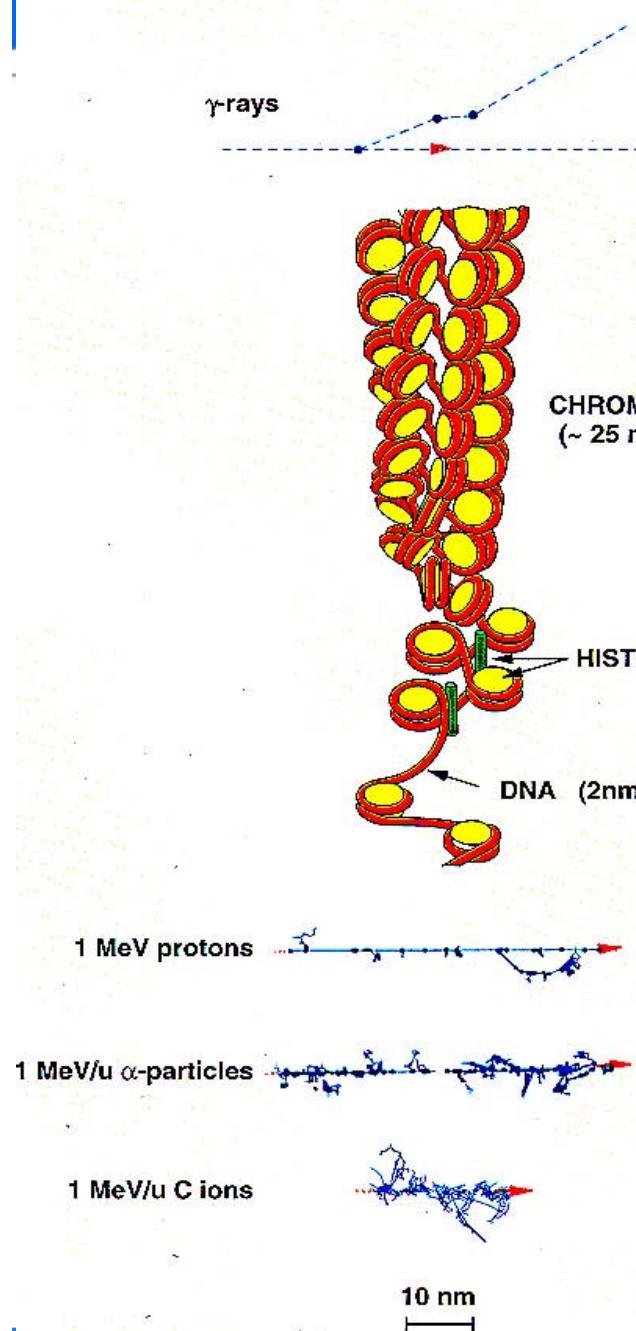


High LET

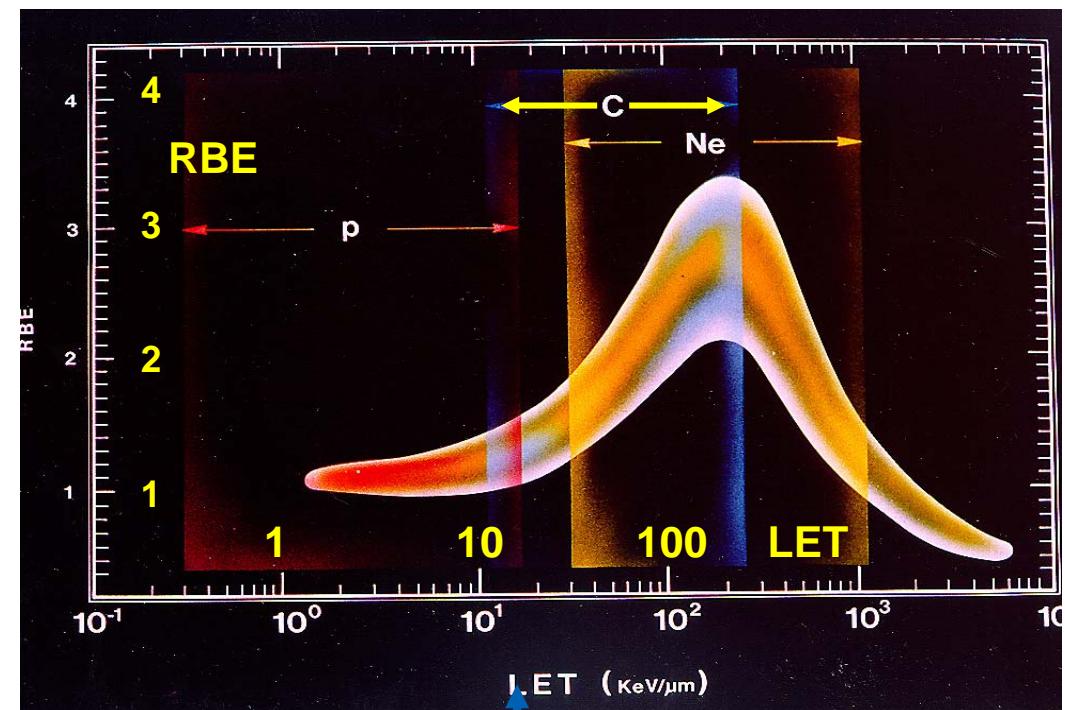


Formation of fluorescent g-H2AX clusters in irradiated human fibroblasts at 10 min postirradiation with 2 Gy of gamma rays or 0.5 Gy of 176 keV/mm iron ions

Modificato da: JAEA R&D, 2007; Cucinotta and Durante, 2006



Ioni Carbonio: Efficacia Biologica



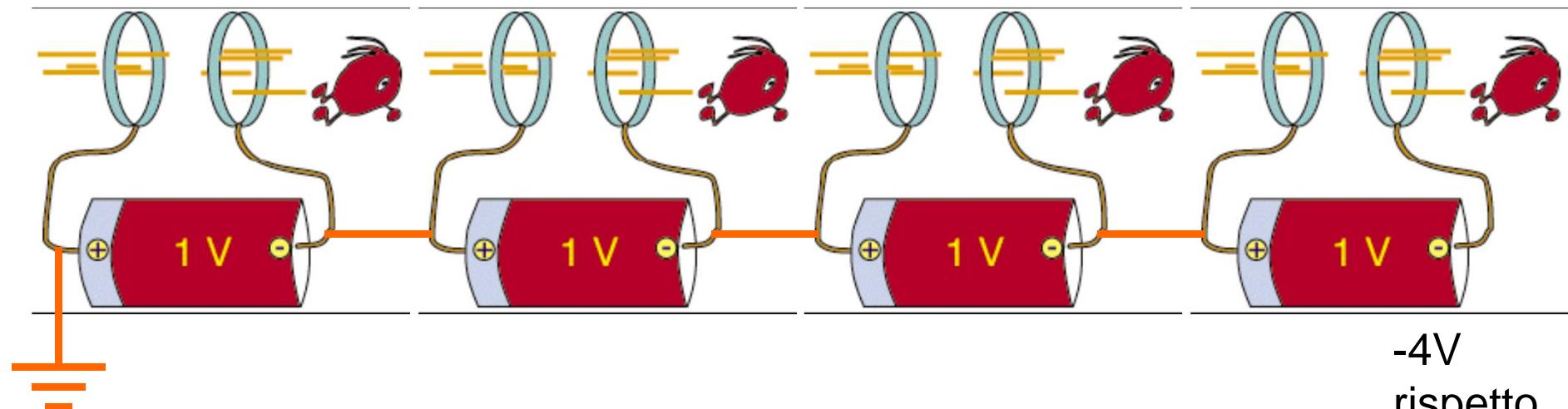
$$10 - 20 \text{ keV}/\mu\text{m} = 100 - 200 \text{ MeV}/\text{cm} =$$

$$20 - 40 \text{ eV}/(2 \text{ nm})$$

Ridotta dipendenza da presenza di ossigeno

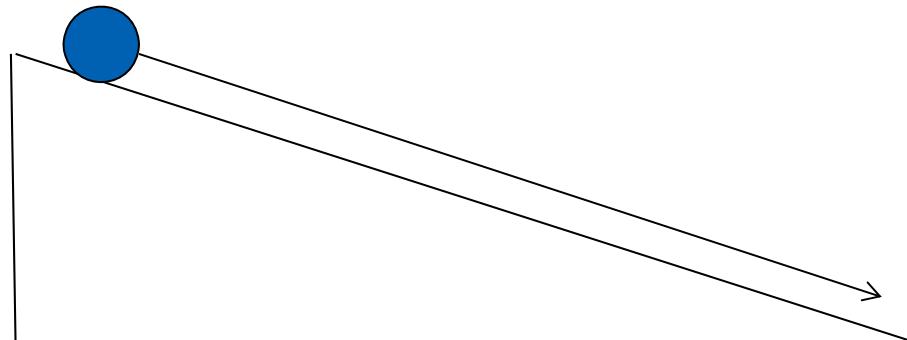
Acceleratori di particelle

Acceleratori elettrostatici



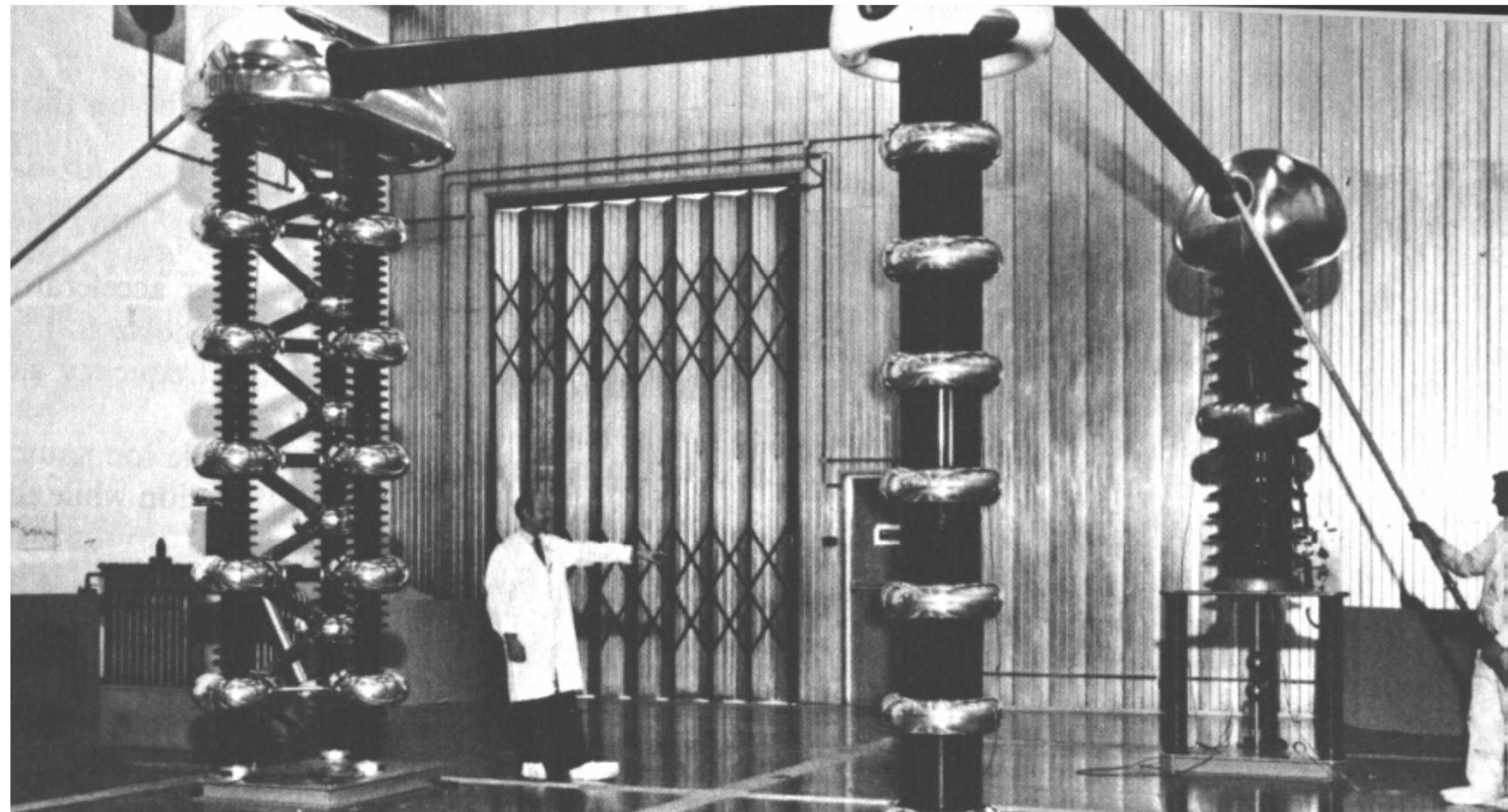
Limiti di campo elettrico ~ 10 MV/m

-4V
rispetto
a terra



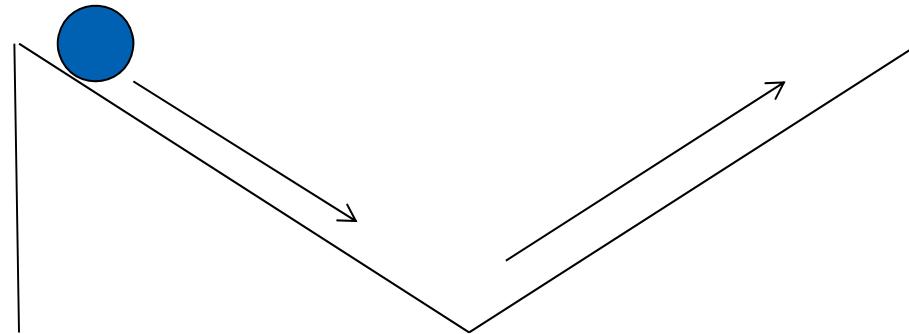
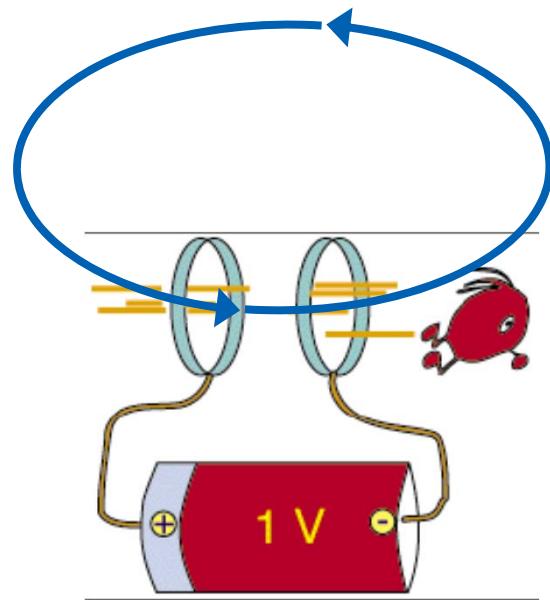
Limitati in energia

Acceleratori elettrostatici



70 MeV Cockcroft-Walton generator supplying the ion source which injected protons into NIMROD, the 7 GeV synchrotron at Rutherford laboratory.

Acceleratori circolari

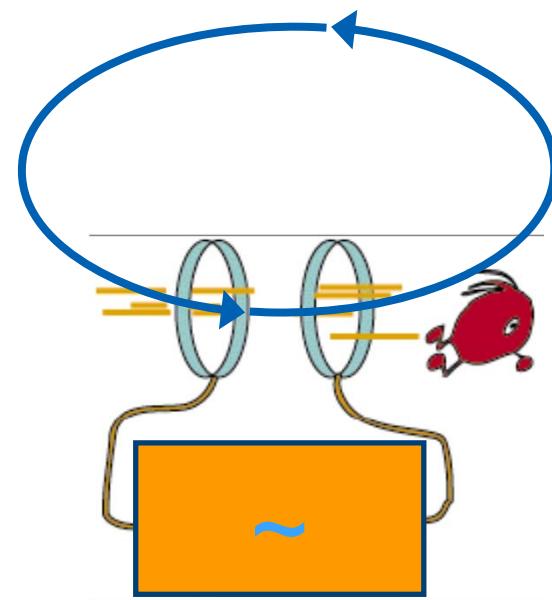
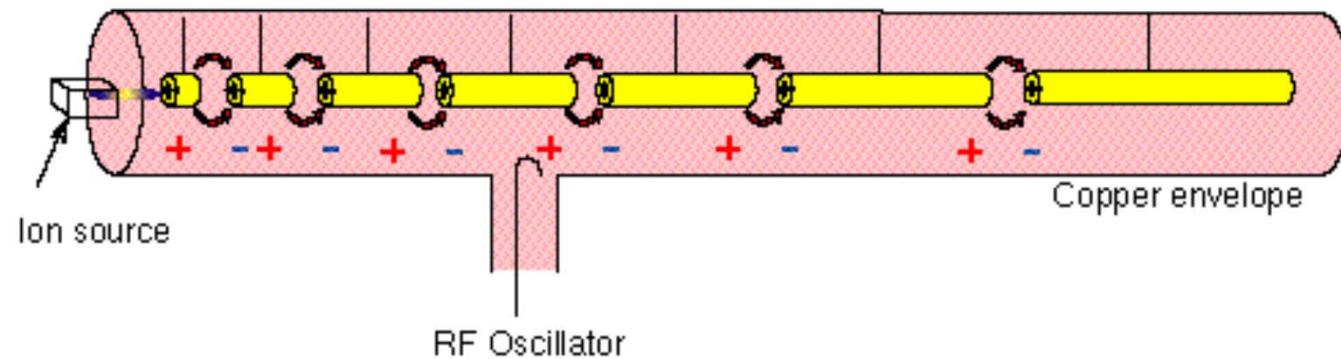


Il campo elettrostatico è conservativo, quindi un acceleratore circolare elettrostatico
NON FUNZIONA

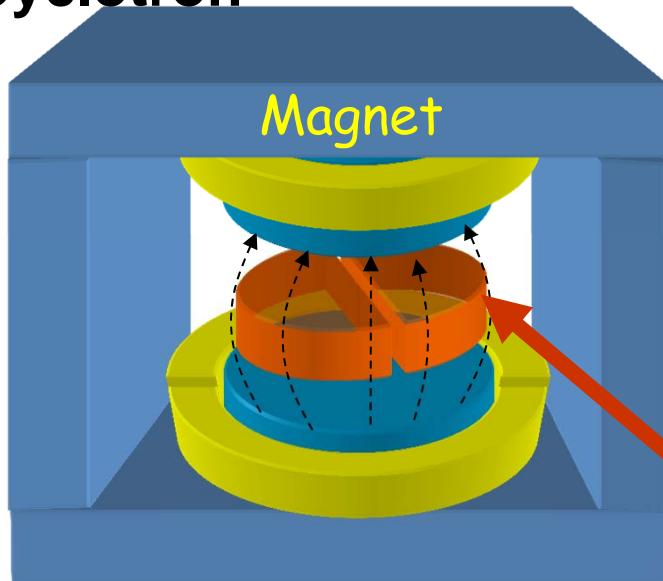
L'idea giusta

- 1924 Ising proposes **time-varying fields** across drift tubes. This is a ‘true’ accelerator that can achieve energies above that given by the highest voltage in the system.
- 1928 Wideröe demonstrates Ising’s principle with a 1 MHz, 25 kV oscillator to make 50 keV potassium ions; the first linac.

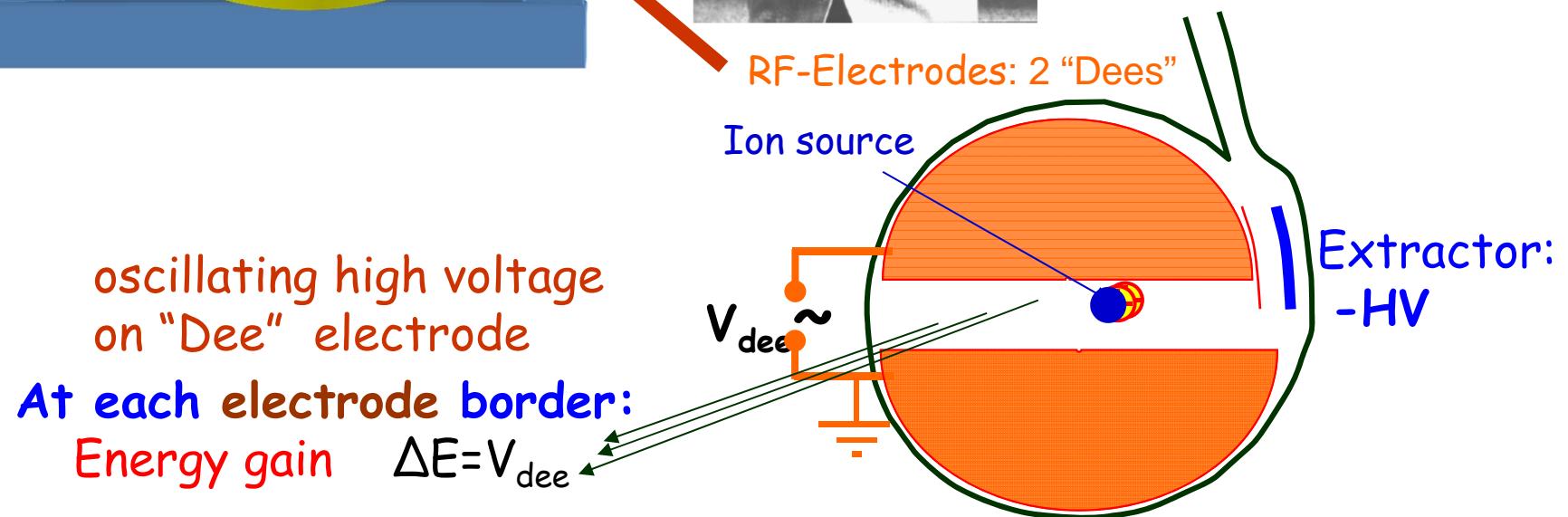
Acceleratori RF



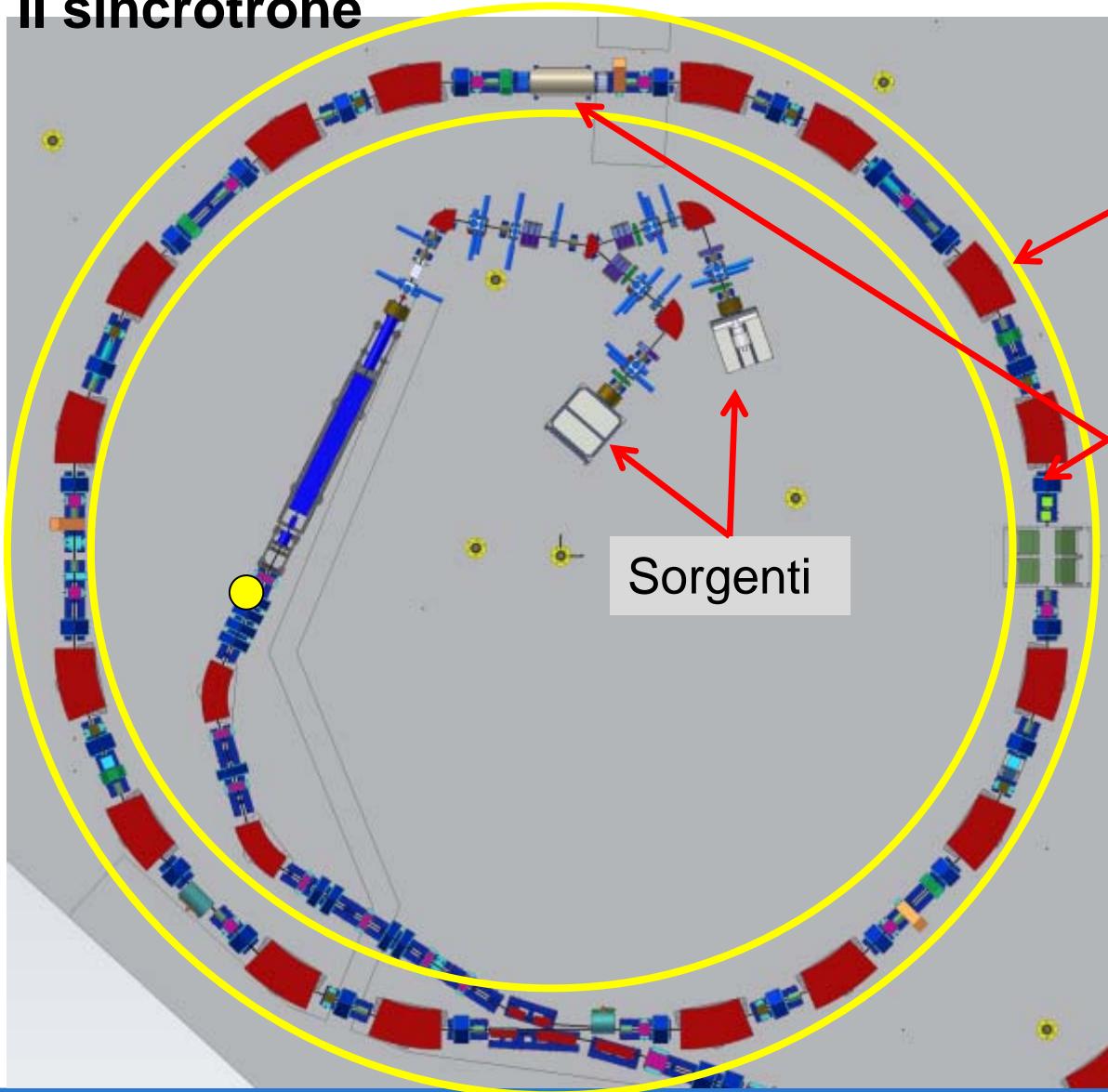
Cyclotron



Ernest Lawrence
(1901-1958)



Il sincrotrone



Dipoli (deflessione)

Quadrupoli
(focaggio, 80 000 km!)

RF Cavity
(accelerazione)

R fisso

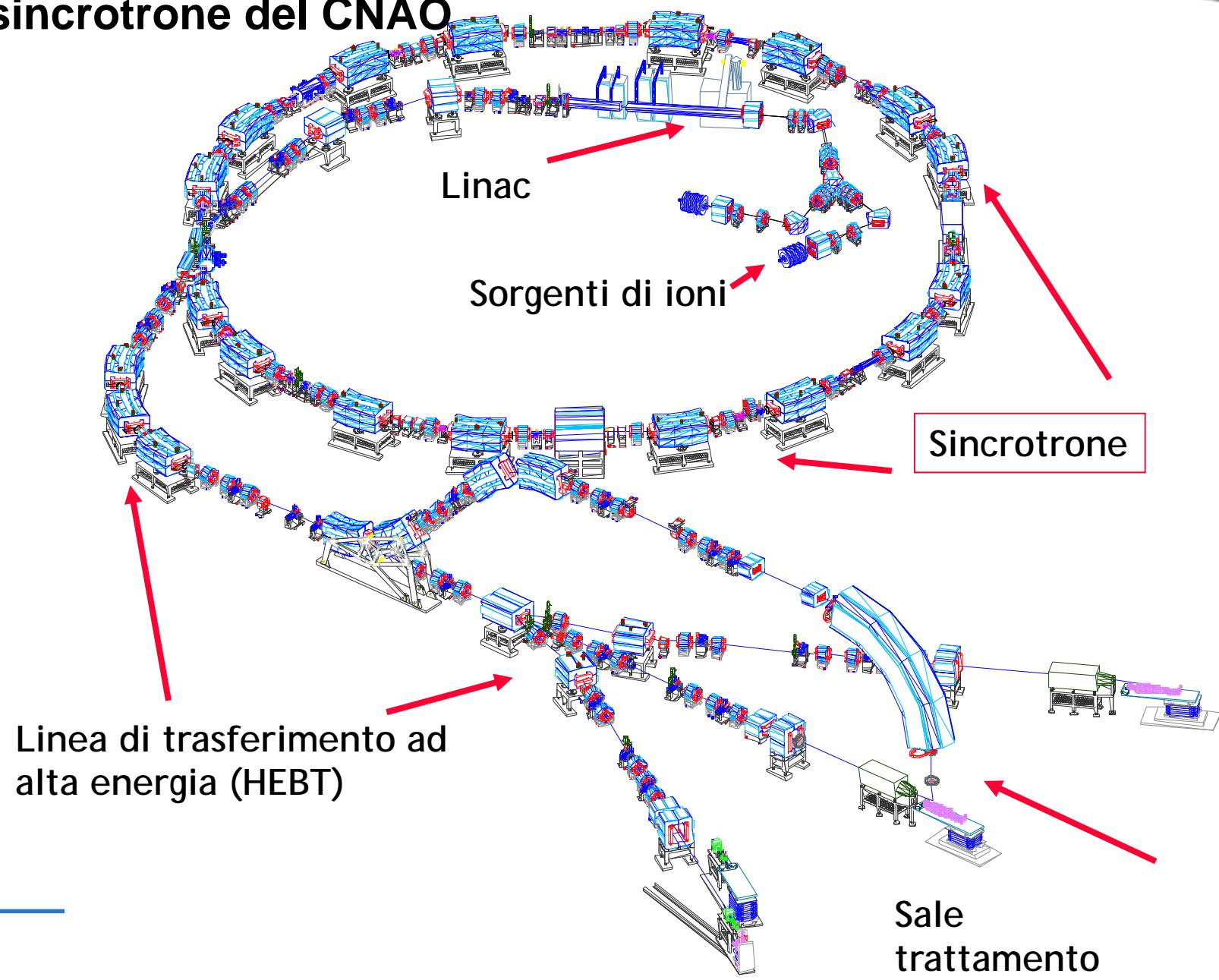
E aumenta

F aumenta

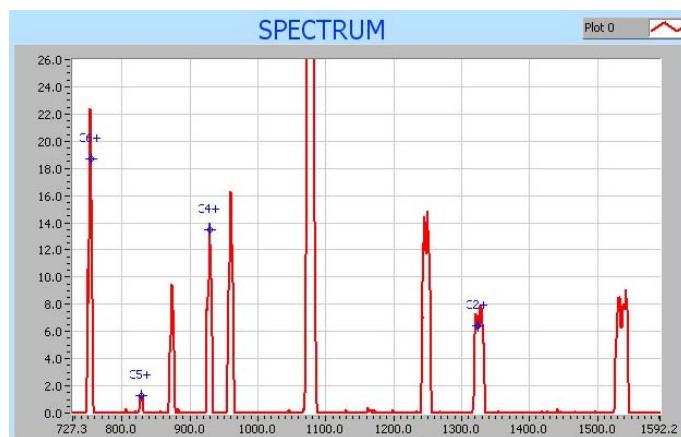
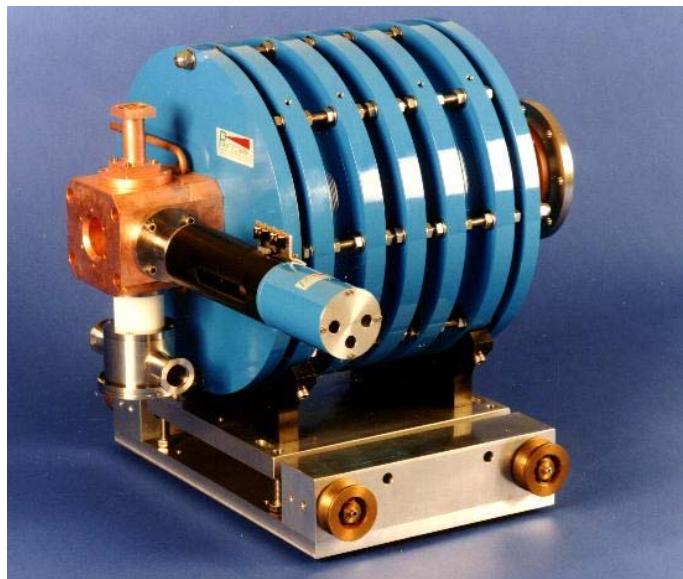
B aumenta

L'acceleratore del CNAO

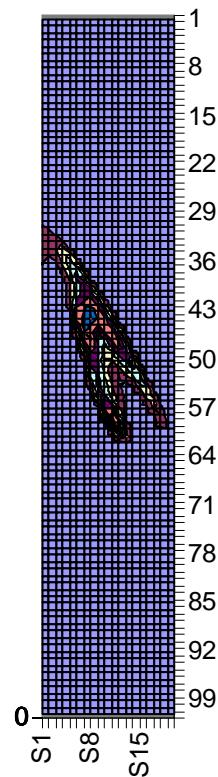
Il sincrotrone del CNAO



Sources

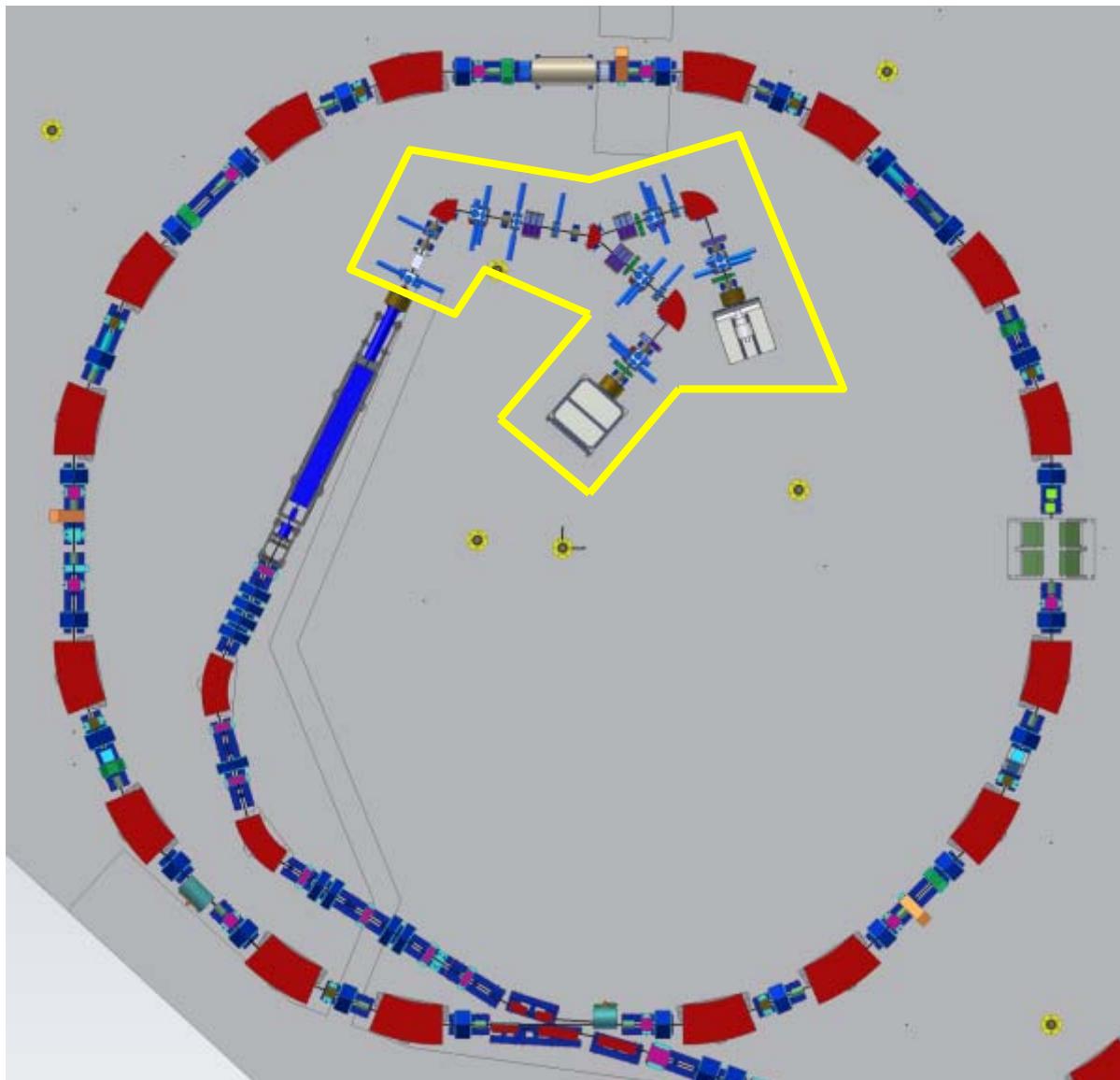


ECR, always on



$$I_{\text{tot}} = 250 \mu\text{A}$$

$$I_{180\pi} = 85\% I_{\text{tot}}$$



LEBT

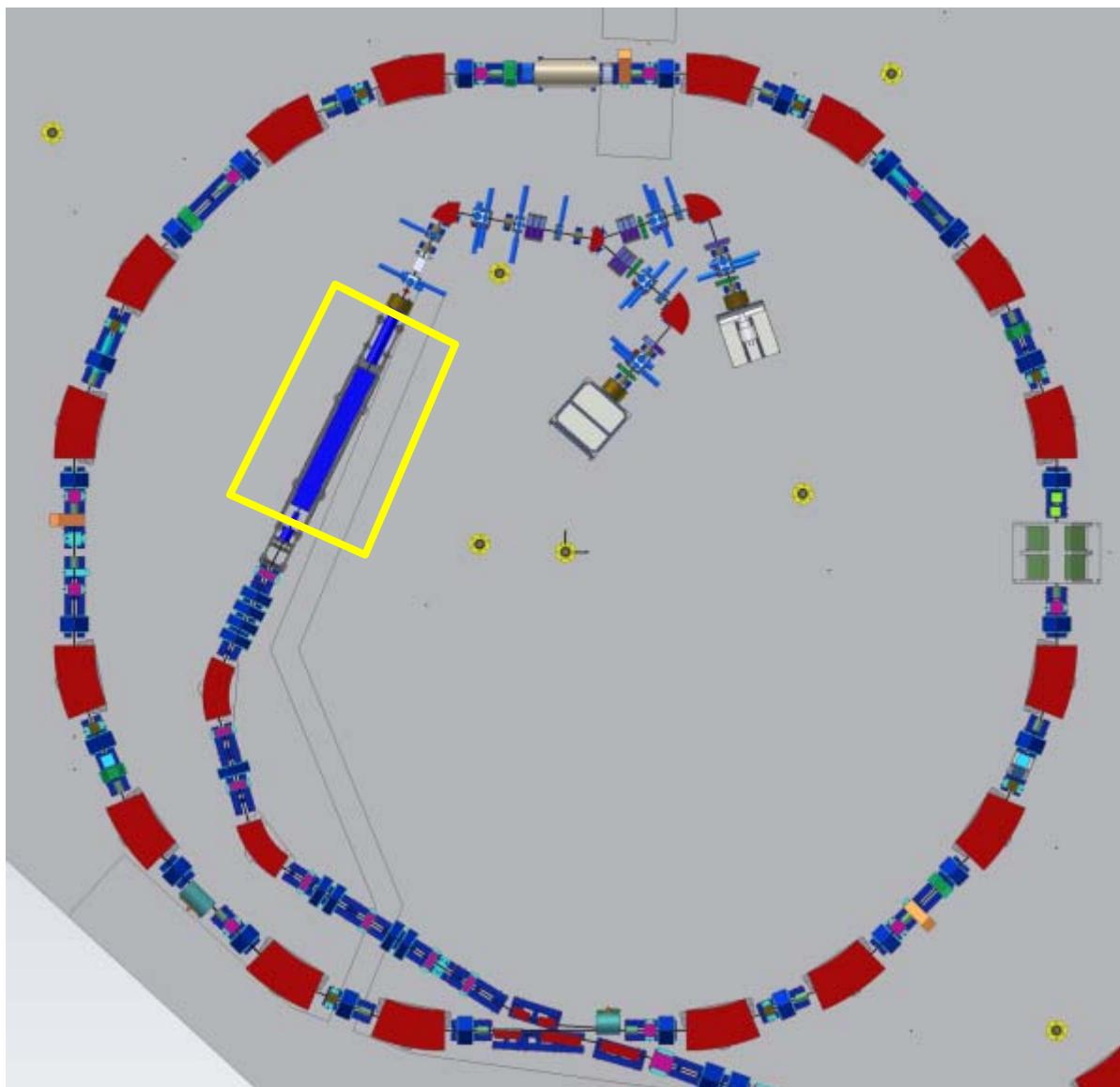
0.008 MeV/u H_3^+
0.008 MeV/u C^{4+}

$I \sim 0.7 \text{ mA } (H_3^+)$
 $I \sim 0.2 \text{ mA } (C^{4+})$

Two sources

Continuous beam

LEBT Chopper



RFQ-LINAC

217 MHz

RFQ

0.008-0.4 MeV/u H³⁺
0.008-0.4 MeV/u C⁴⁺

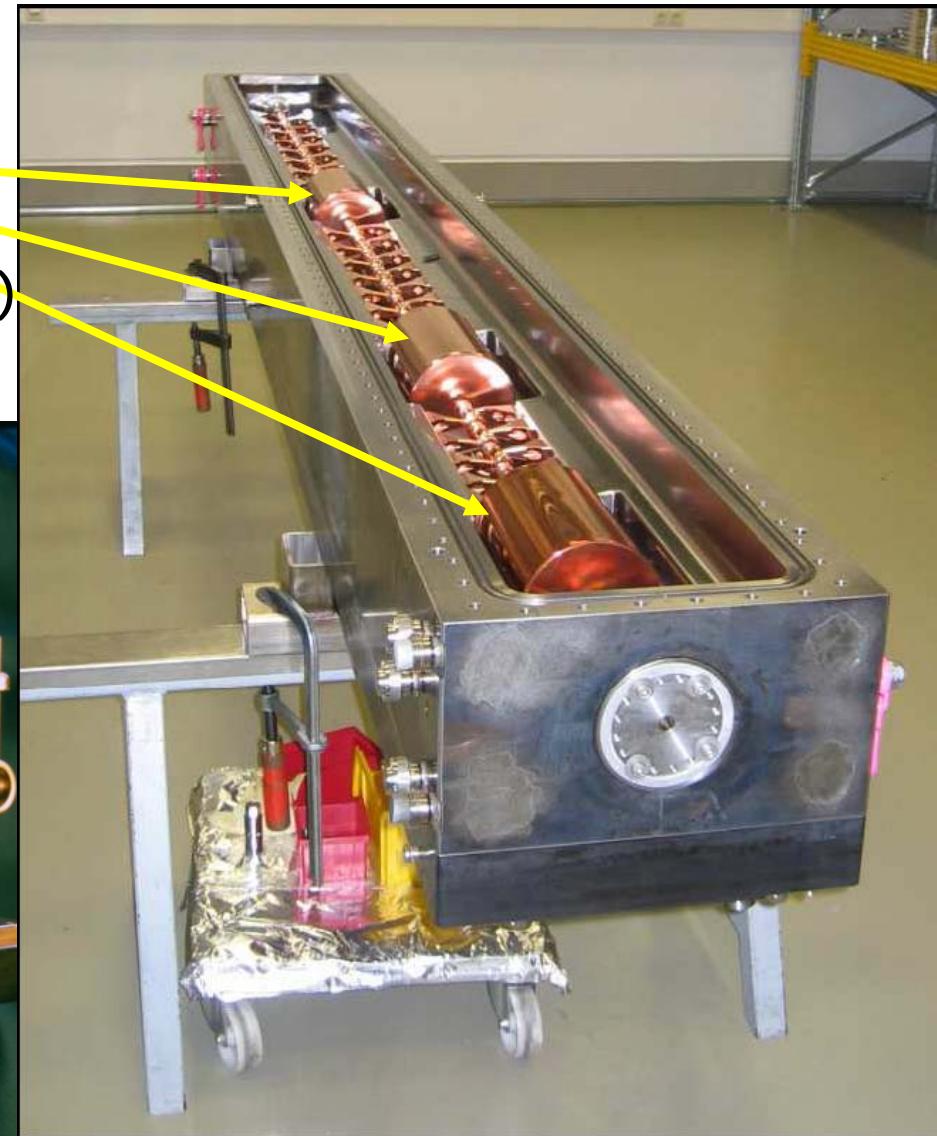
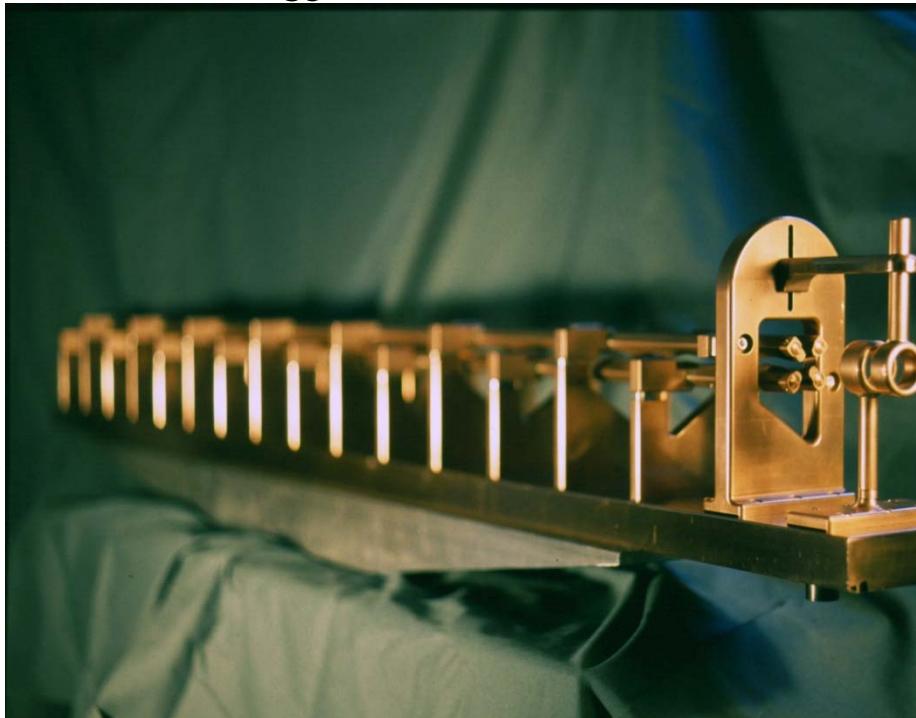
LINAC

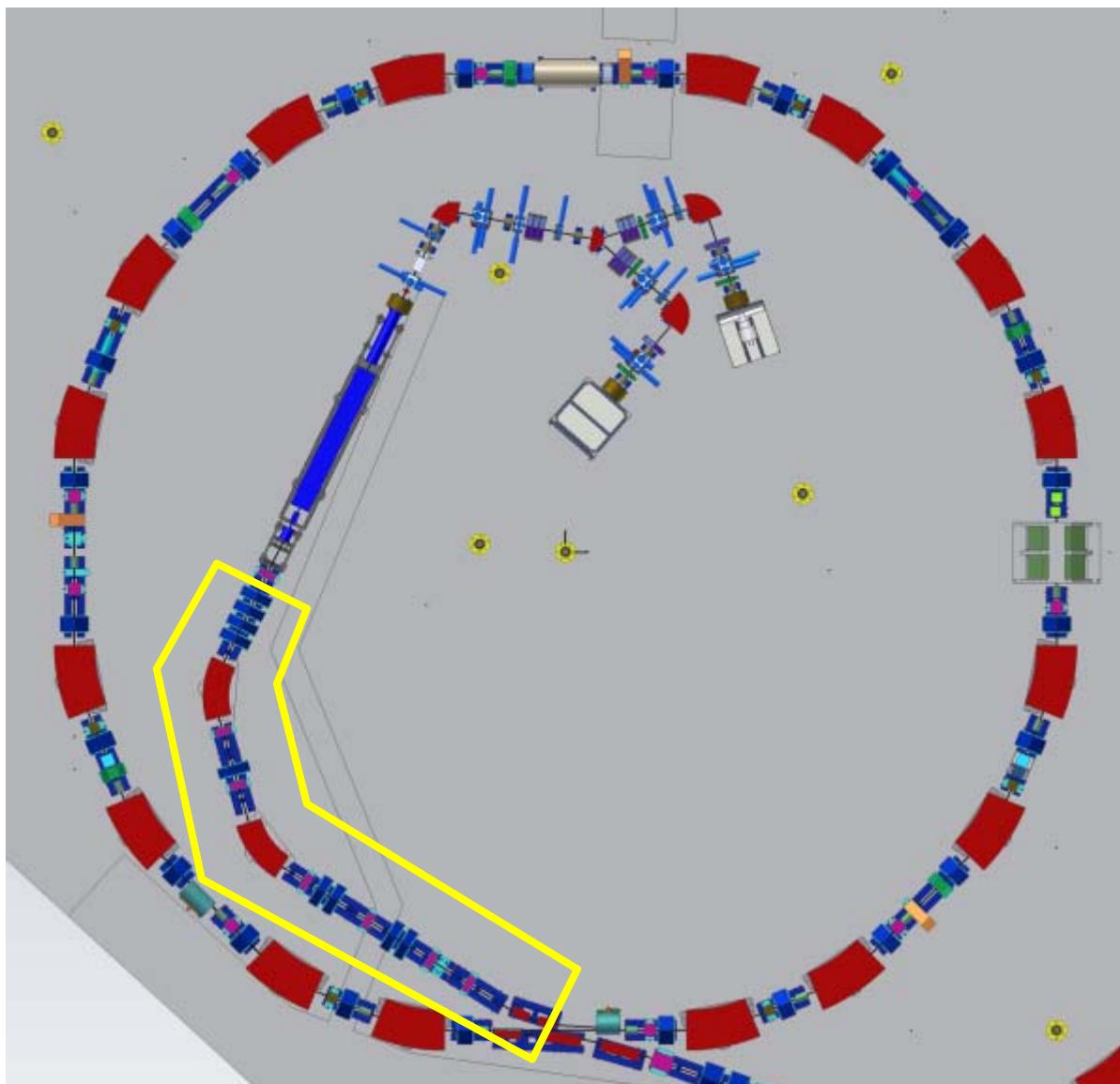
0.4-7 MeV/u H³⁺
0.4-7 MeV/u C⁴⁺

Pulse for temperature

LINAC

Triplets
RFQ+IH structures, compact (6.2 m)
Final energy 7 MeV/u





MEBT

**7 MeV p
7 MeV/u C⁶⁺**

**I ~ 0.7 mA (p)
I ~ 0.15 mA (C⁶⁺)**

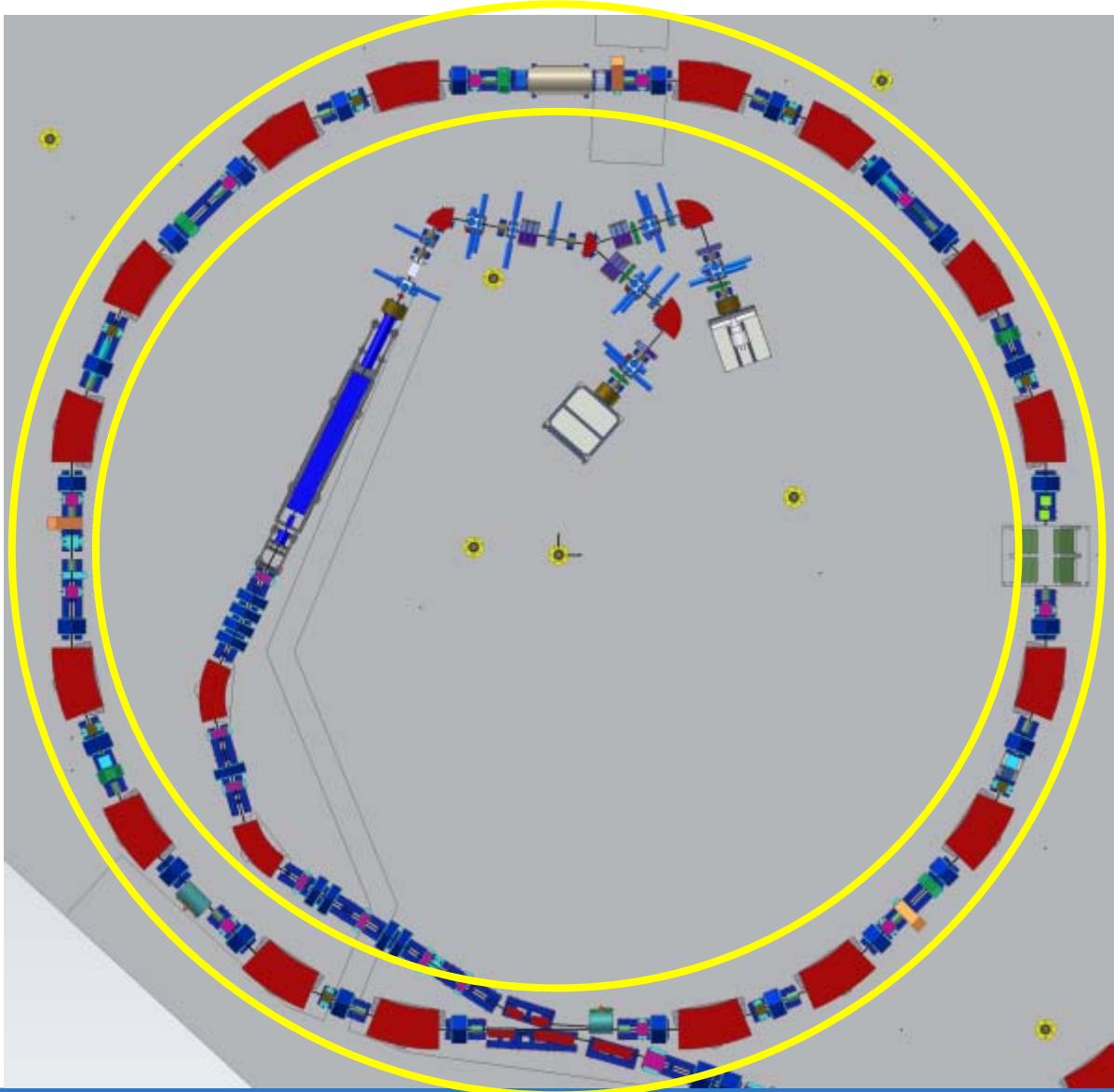
(x,x')_{Inj}

Stripping foil

Current selection

Debuncher

Emittance dilution

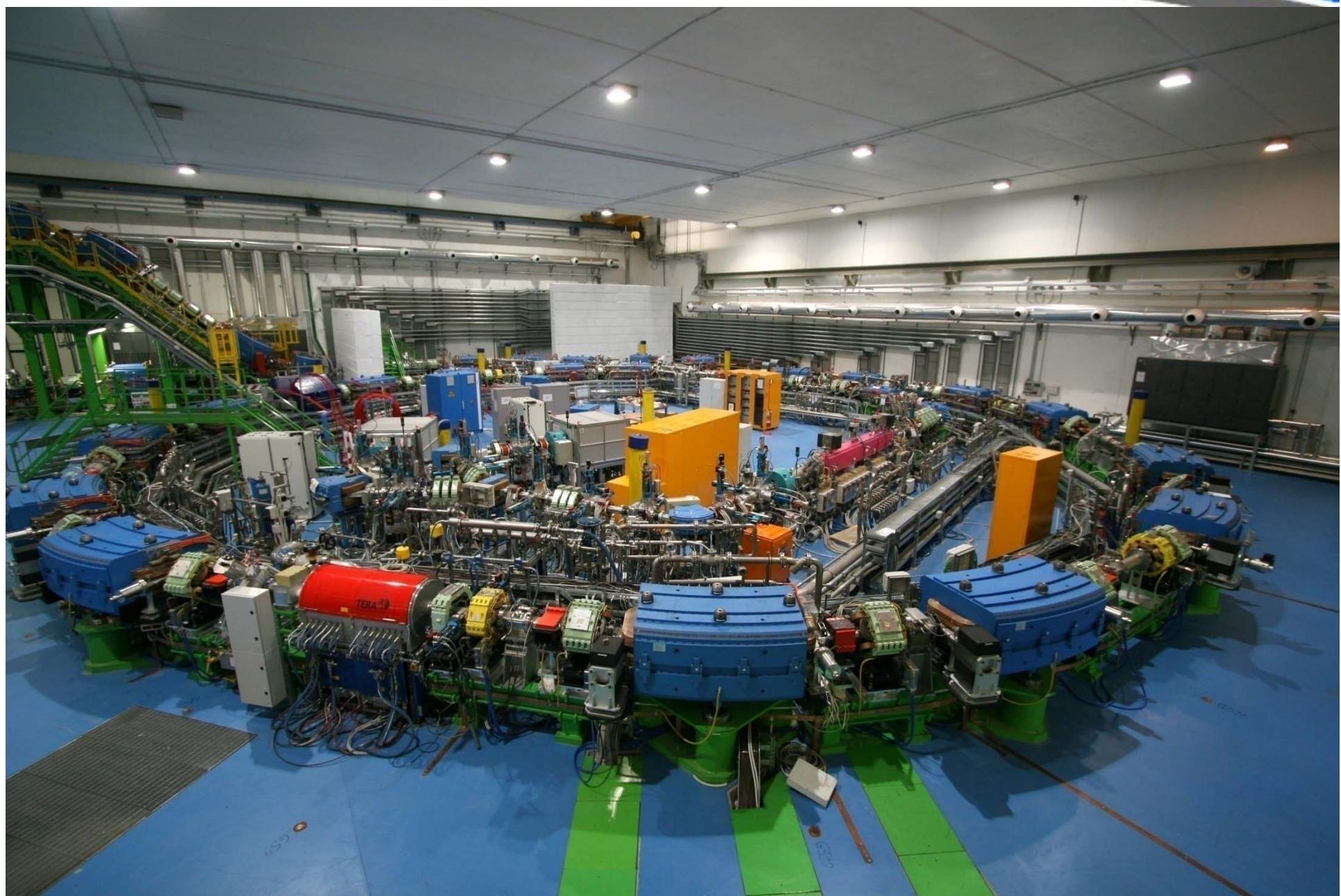


Synchrotron

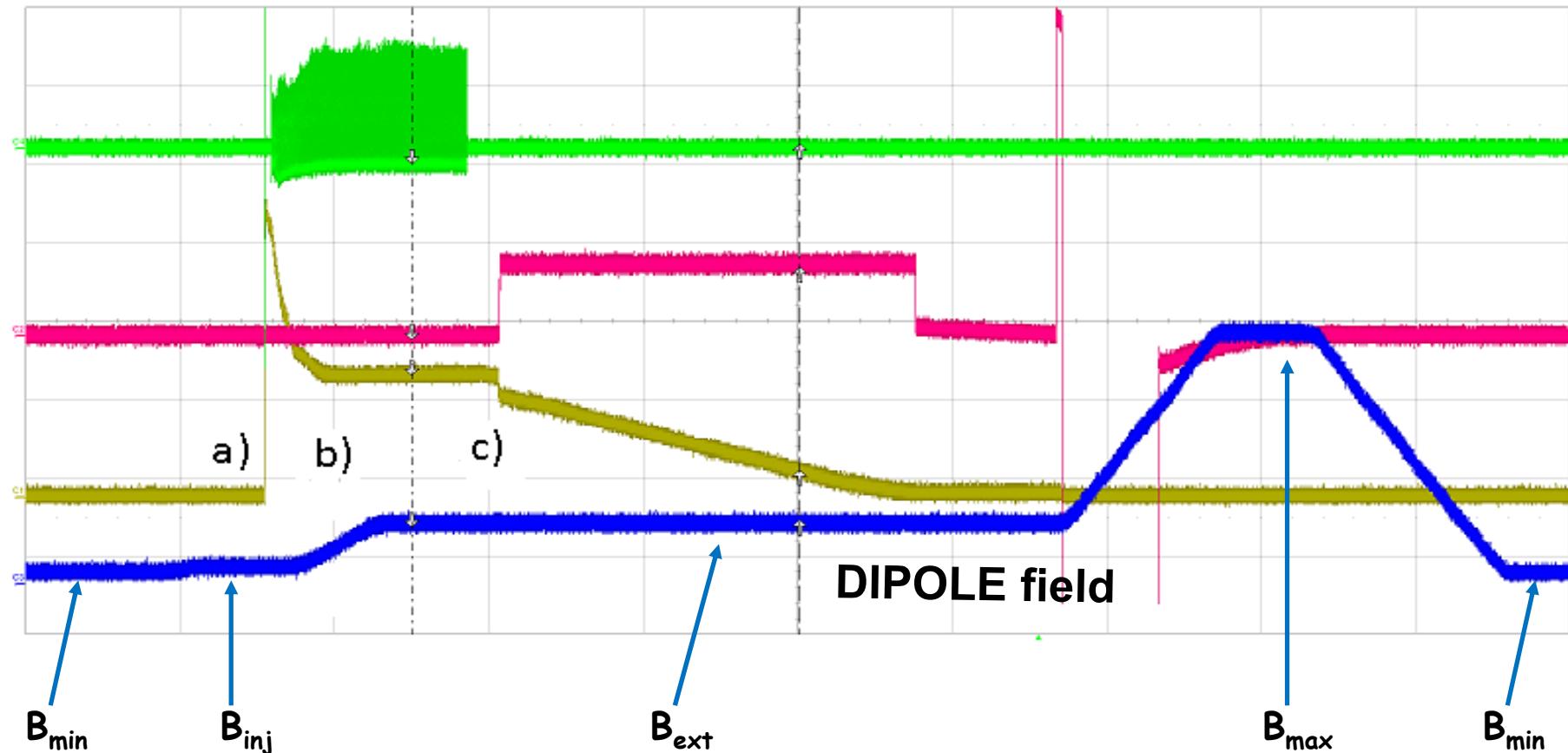
**7-250 MeV p
7-400 MeV/u C**

**$I \sim 0.1\text{-}6 \text{ mA (p)}$
 $I \sim 0.03\text{-}1.5 \text{ mA (C)}$**

Synchrotron hall (webcam)



Ciclo magnetico – ciclo di accelerazione



Estrazione

- Bisogna distribuire il fascio sul tumore
- Il fascio in macchina è un “pacchetto” che “dura” meno di 1 μ s (0.000001 s)
- Come se avessimo una mela da distribuire su un percorso di 10 m

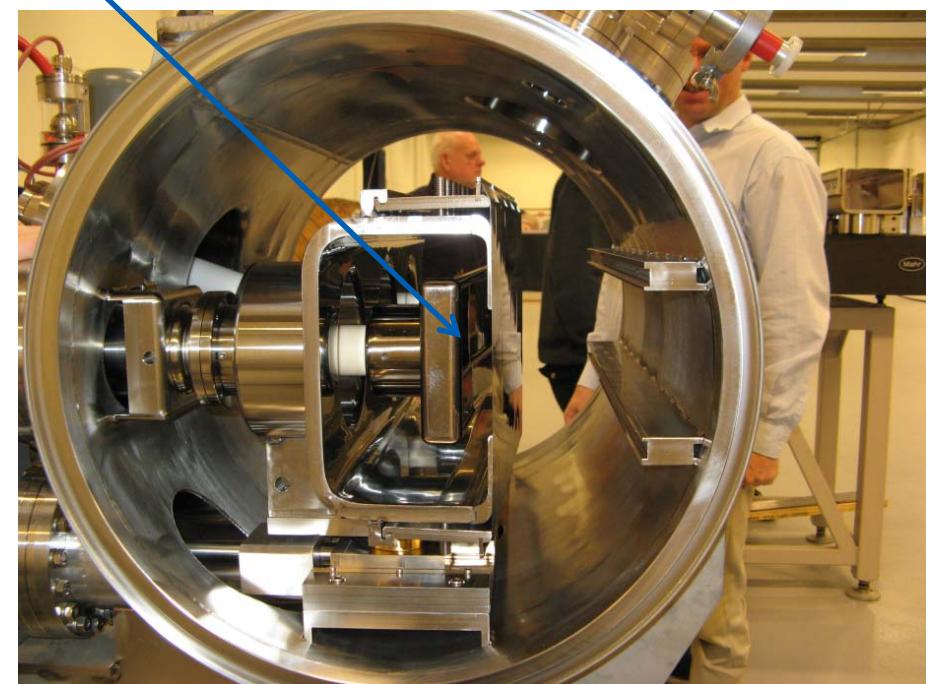
Estrazione

- Il fascio bisogna “sbucciarlo”



Fascio

Risonanza + Setto elettrostatico

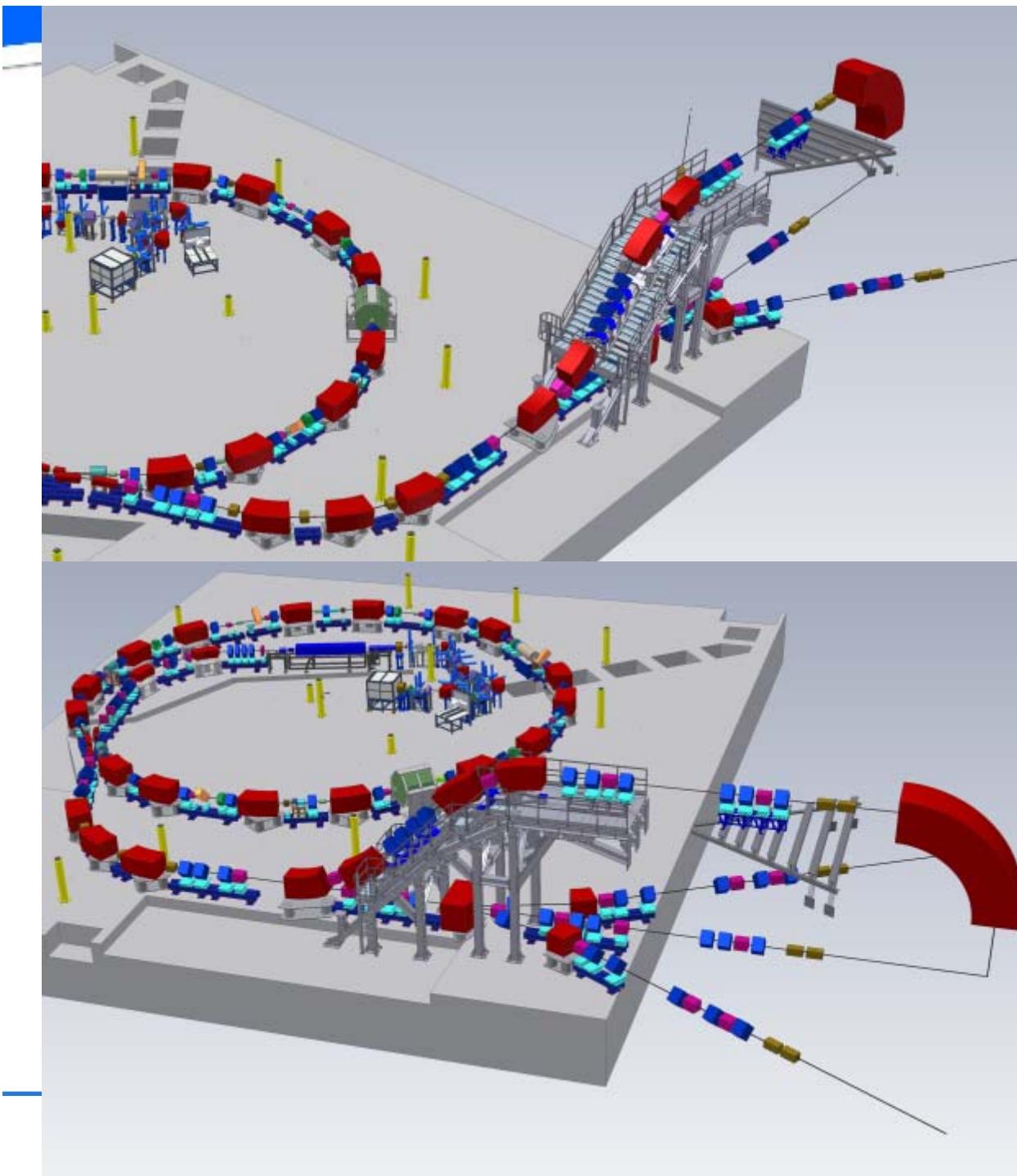


HEBT

**60-250 MeV p
120-400 MeV/u C
 10^{10} p/spill (~2nA)
 $4 \cdot 10^8$ C/spill (~0.4nA)**

different settings for

- Treatment Line
- Beam size
- Particle
- Extraction energy



HEBT

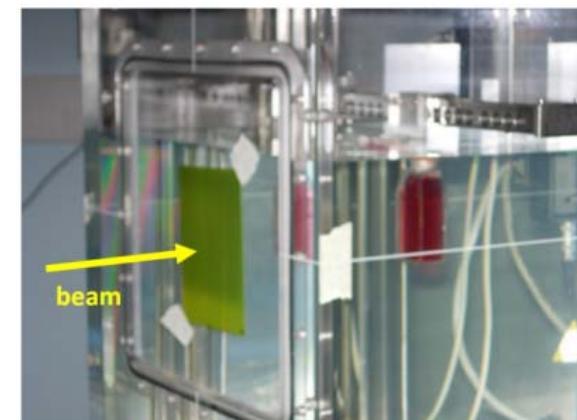
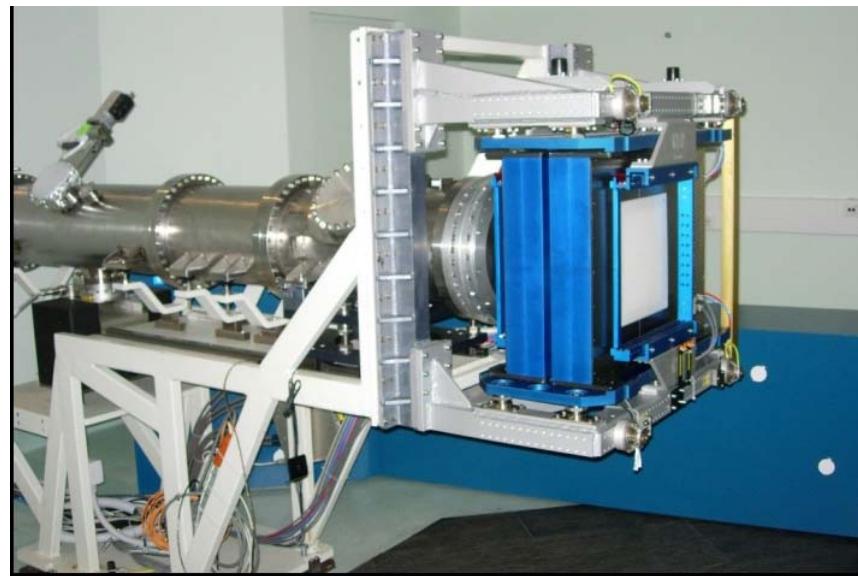
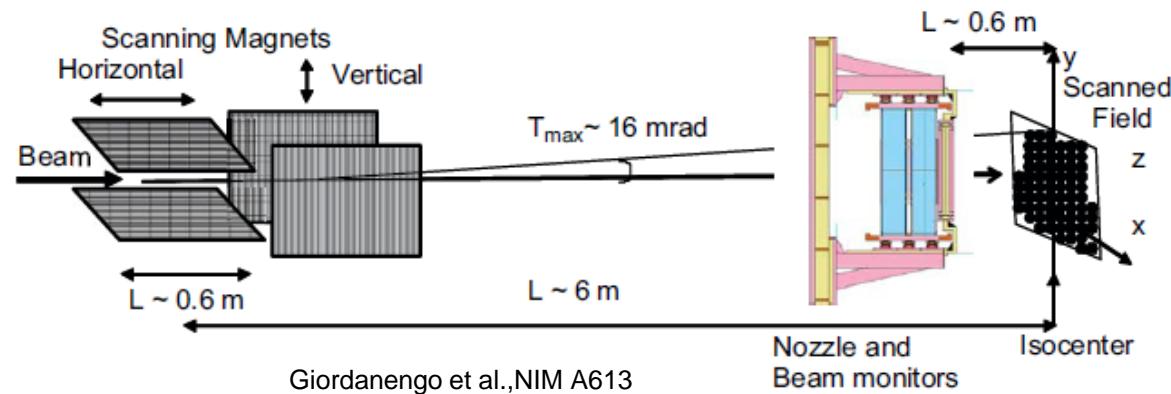
Magnete selezione sala

Salita linea verticale

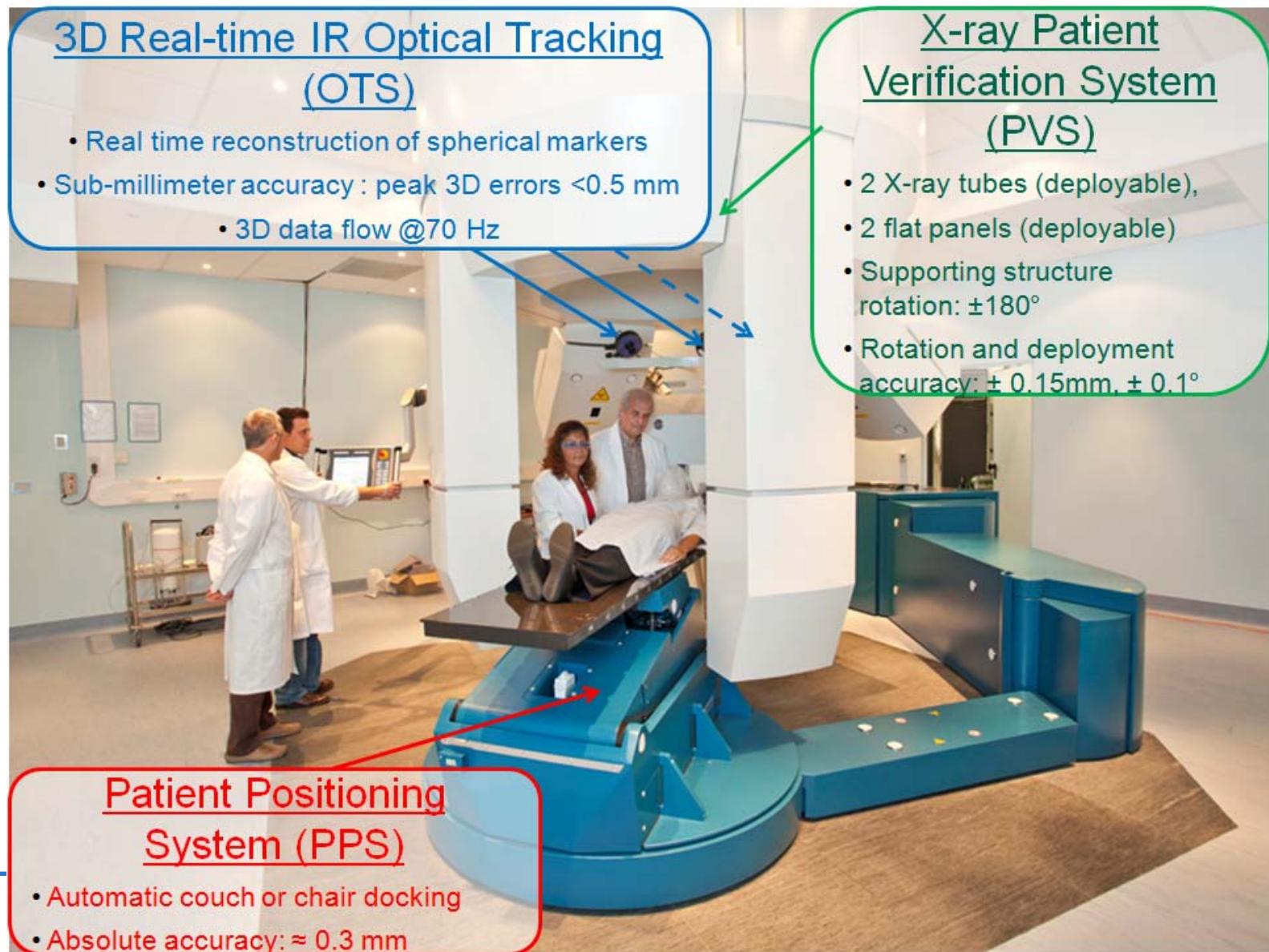


WEBCAM

Dose delivery



Sistema di posizionamento e verifica; sistema robotizzato, raggi X e dispositivo di localizzazione a Infra Rossi (IR)



Posizionamento di precisione

Maschera

Robot

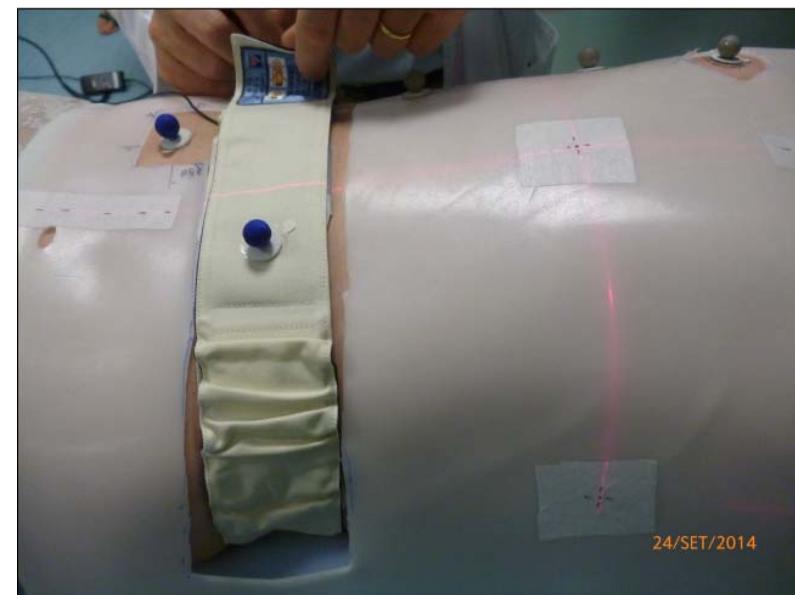
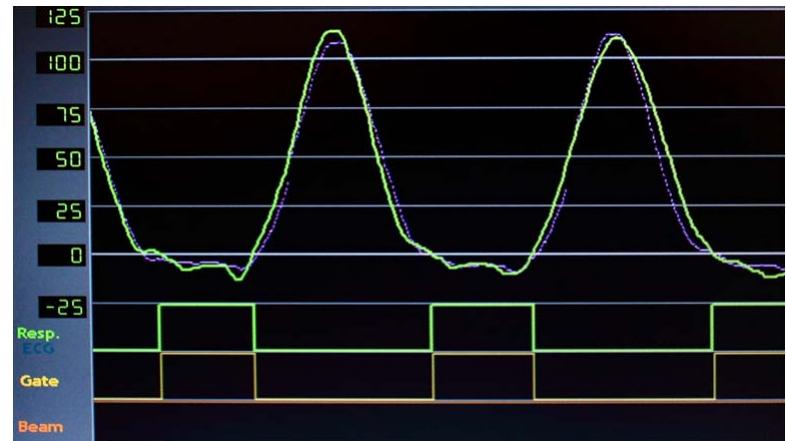
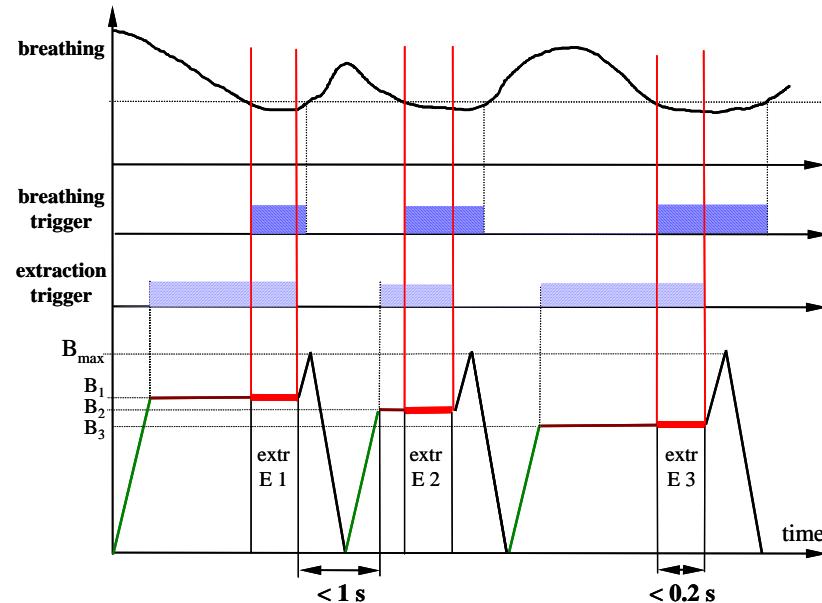
Laser

OTS

XRAY



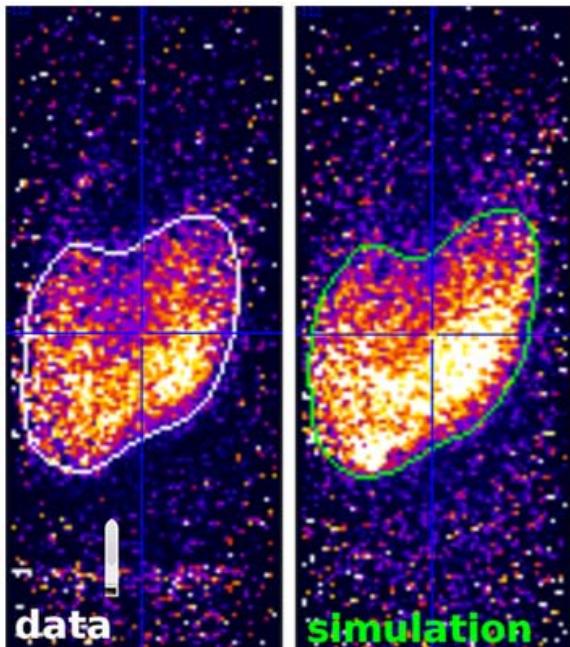
Gating + rescanning



- Resp. motion reduction (down to 5 mm) using thermo-plastic mask or pneumatic compression belt
- Multiple beams (2-3) and multi-fractionation
- Gating (ref. phase: end-exhale; ANZAI system or OTS) plus rescanning (N=5)

The INSIDE Project

INnovative Solutions for In-beam DosimEtry
in particle therapy

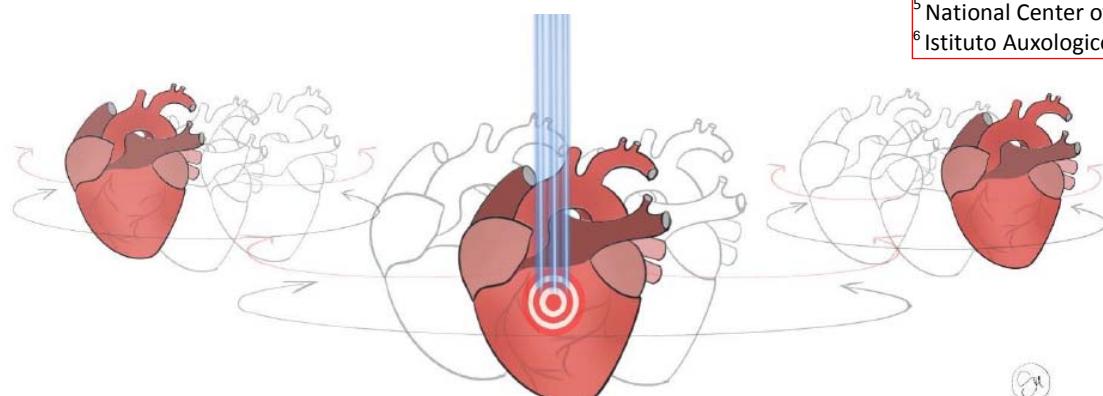
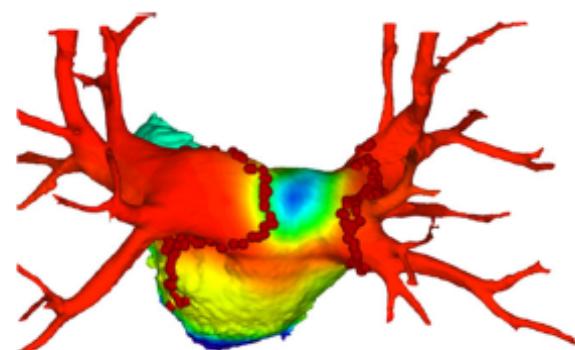


CNAQ

InSide
fondazione CNAQ
Centro Nazionale di Adroterapia Oncologica

Sistema Sanitario Regione Lombardia

Non oncological application: ventricular arrhythmia



In press on:
European Journal of Heart Failure

Non-invasive Proton Radiotherapy for Refractory Ventricular Tachycardia in advanced heart failure: first in-man case.

Veronica Dusi^{1,2}, MD, PhD; Viviana Vitolo⁵, MD; Laura Frigerio^{1,3}, MD; Rossana Totaro^{1,3}, MD;
Adele Valentini⁴, MD; Amelia Barcellini⁵, MD; Alfredo Mirandola⁵, PhD; Giovanni Battista Perego⁶,
MD; Michela Coccia³, MD; Alessandra Greco³, MD; Stefano Ghio³, MD; Massimiliano Gnechi^{1,2},
MD, PhD; Luigi Oltrona Visconti³, MD; Roberto Rordorff^{1,3}, MD.

¹ Cardiac Intensive Care Unit, Arrhythmia and Electrophysiology and Experimental Cardiology,
Fondazione IRCCS Policlinico San Matteo, Pavia, Italy

² Department of Molecular Medicine, Section of Cardiology, University of Pavia, Pavia, Italy

³ Department of Cardiology, IRCCS Fondazione Policlinico S. Matteo, Pavia, Italy

⁴ Department of Radiology, IRCCS Fondazione Policlinico S. Matteo, Pavia, Italy

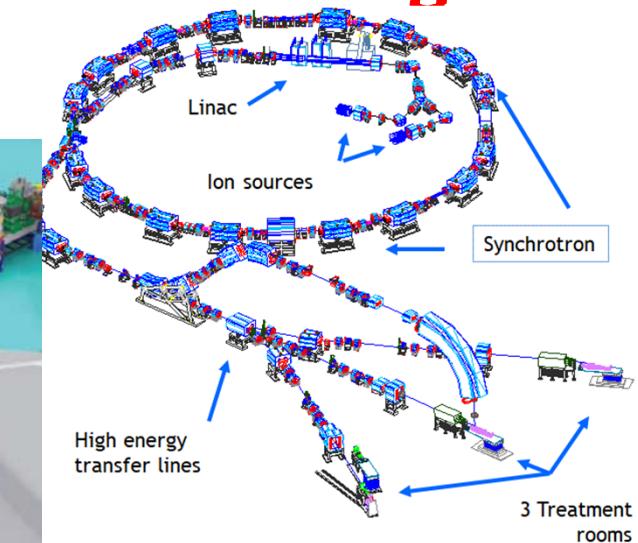
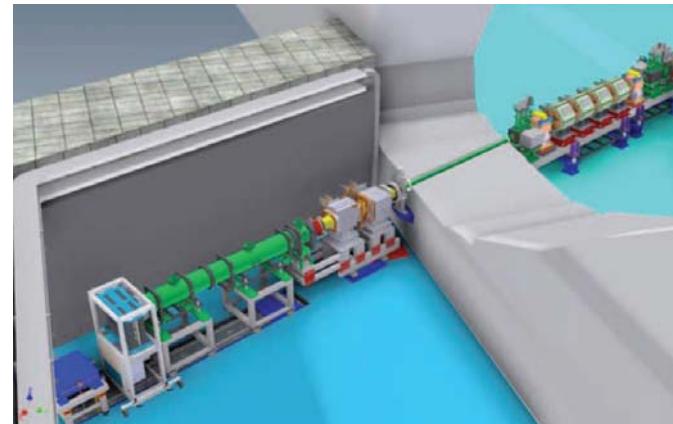
⁵ National Center of Oncological Hadrontherapy (Fondazione CNAO), Pavia, Italy.

⁶ Istituto Auxologico Italiano, Ospedale San Luca, Milan, Italy.



Sala dedicata alla ricerca + Lab radiobiologia

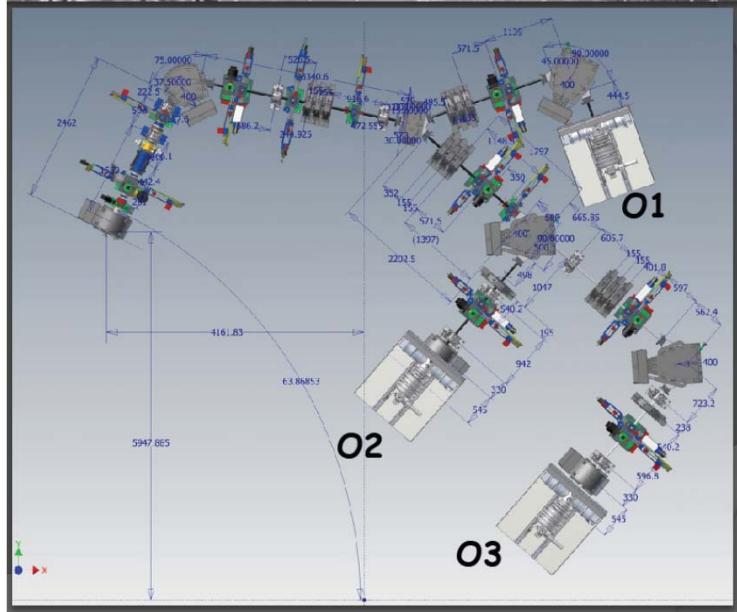
Realizzata in collaborazione con INFN



Futuro e ricerca



INSpIRIT: nuova sorgente



Collaboration CNAO-INFN-HiFuture

A facility INnovativa di irraggiamento con Sorgente per Ioni per Ricerca e studi di radiation hardness con applicazioni IndusTriali e cliniche INSpIRIT - ID 1161908

Call HUB ricerca e Innovazione - EU/Regional funds

Upgrade
Dossier Tecnico
CNAO

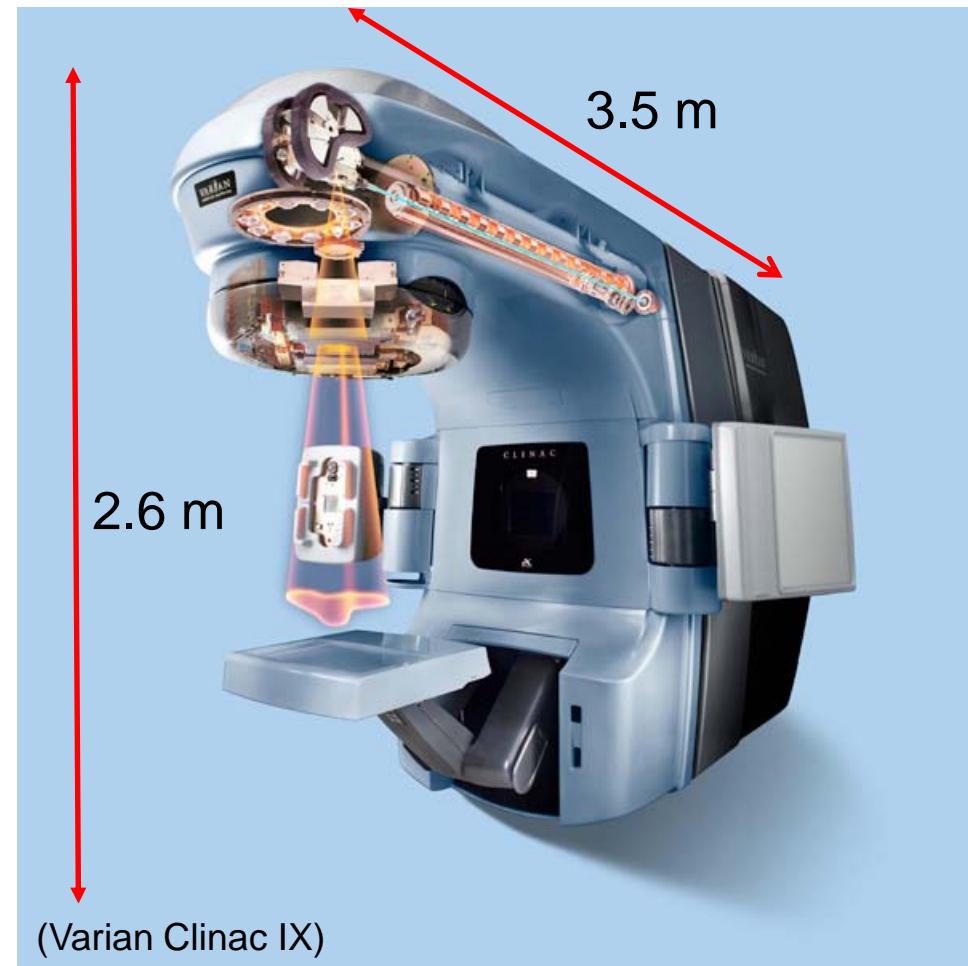
Expected currents

Ion	Supernanogan (14 GHz)	AISHa (18 GHz + TFH)
H^+	2000	4000
H_2^+	1200	2000
H_3^+	1000	1500
$^3He^+$	800	2000
$^{12}C^{4+}$	250	800
$^{6}Li^{2+} - ^{7}Li^{2+}$	//	800
$^{10}B^{3+} - ^{11}B^{3+}$	//	600
$^{18}O^{6+}$	400	1000
$^{21}Ne^{7+}$	120	500
$^{36}Ar^{12+}$	20	150

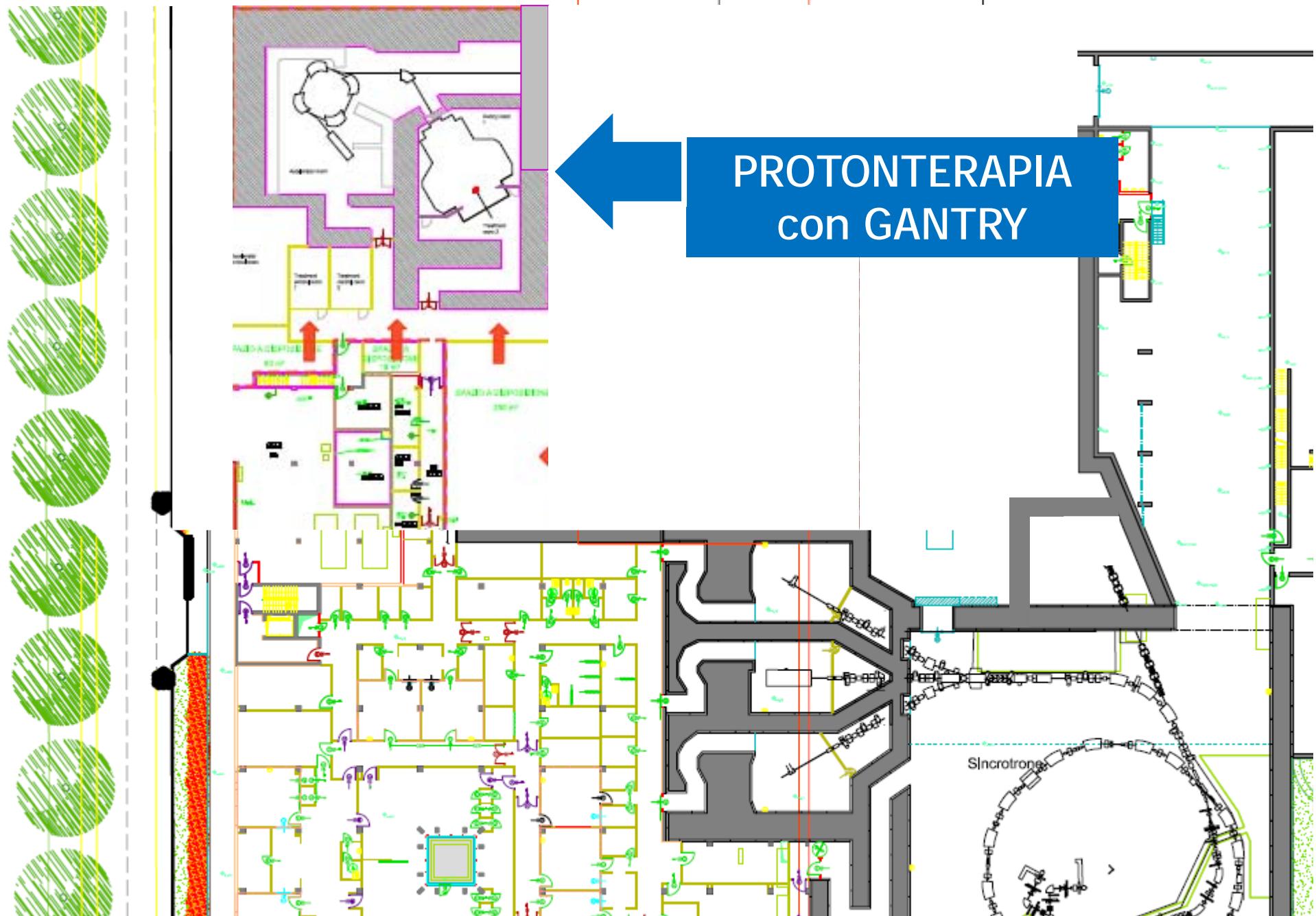
Ion beam production (e μ A)

Gantry in conventional radiotherapy

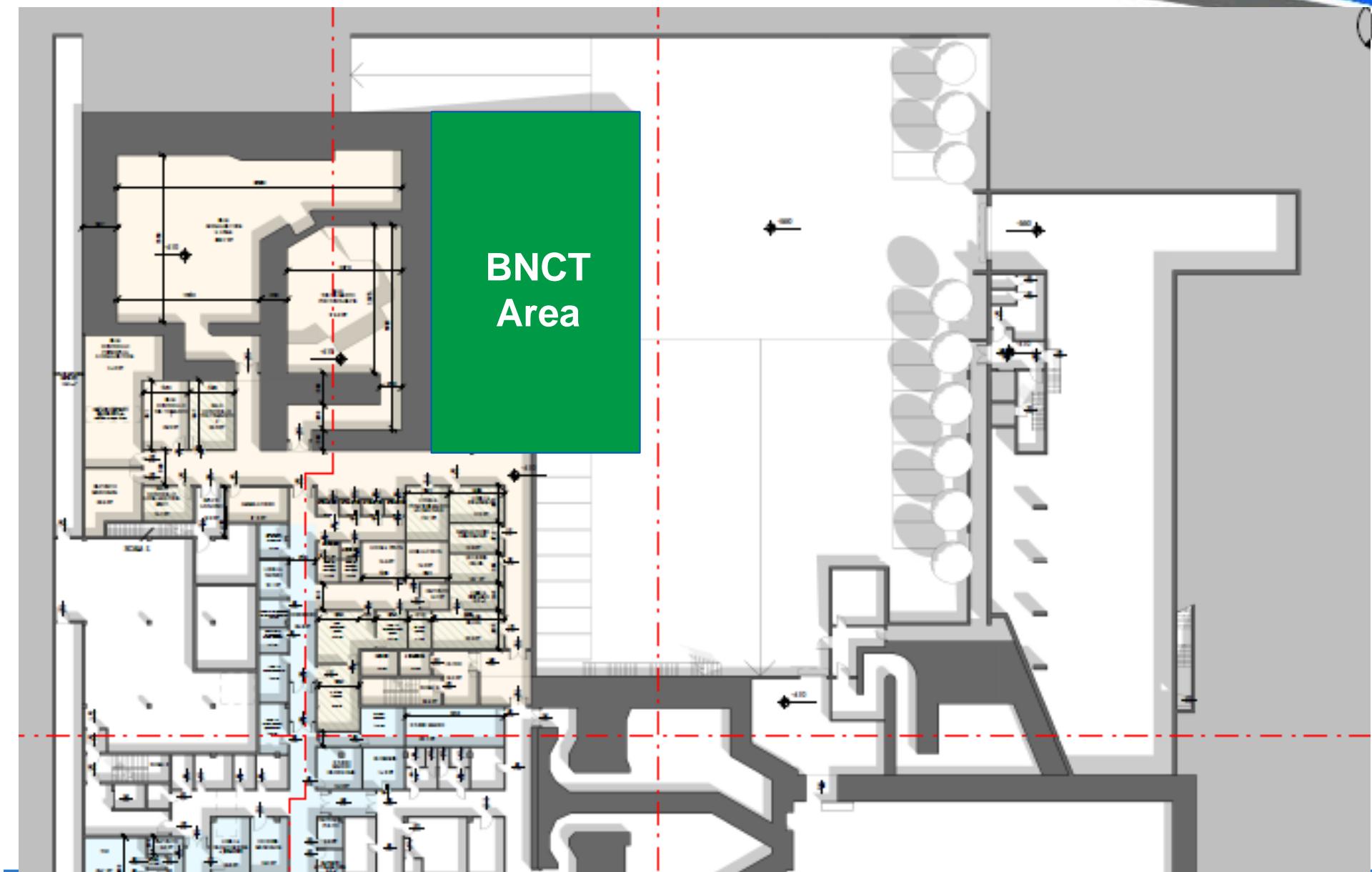
- The whole linac is inside the gantry
- The gantry head can pass between patient and floor for irradiation from below



Espansione Area A

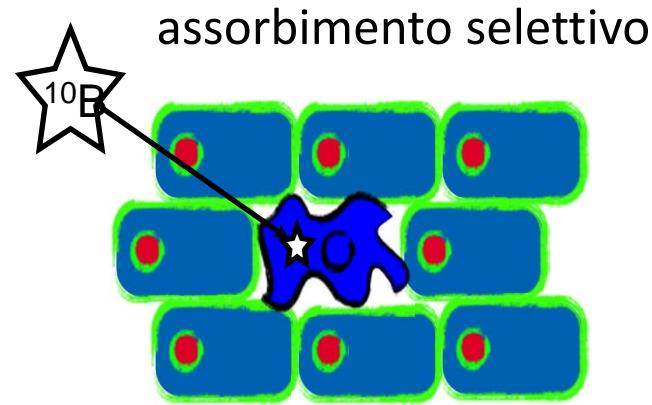


Espansione Area A: BNCT

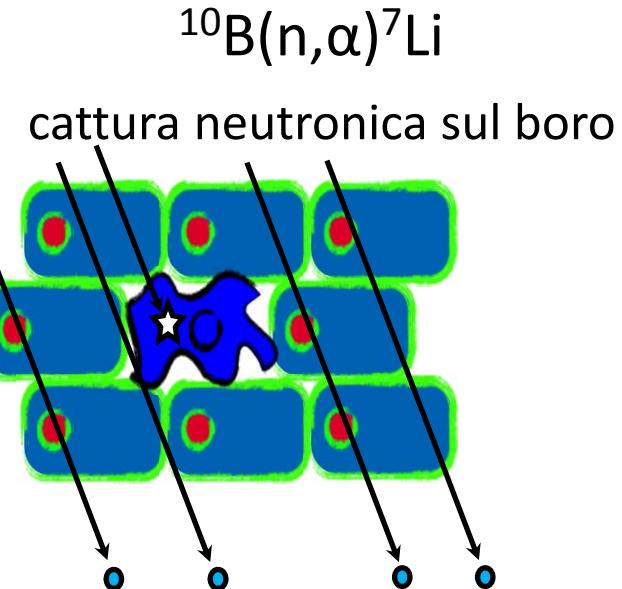
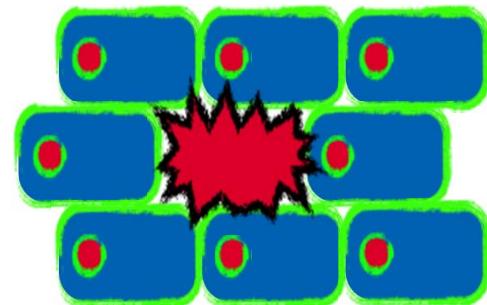


BNCT: Boron Neutron Capture Therapy (Terapia con cattura neutronica del boro)

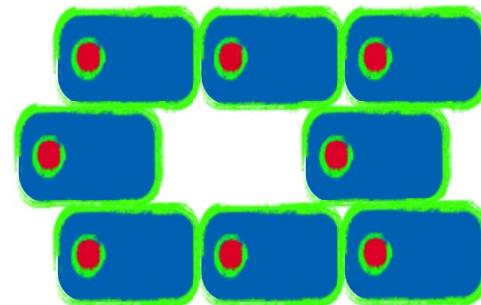
La BNCT: speranza per i tumori metastatici



cellula danneggiata muore

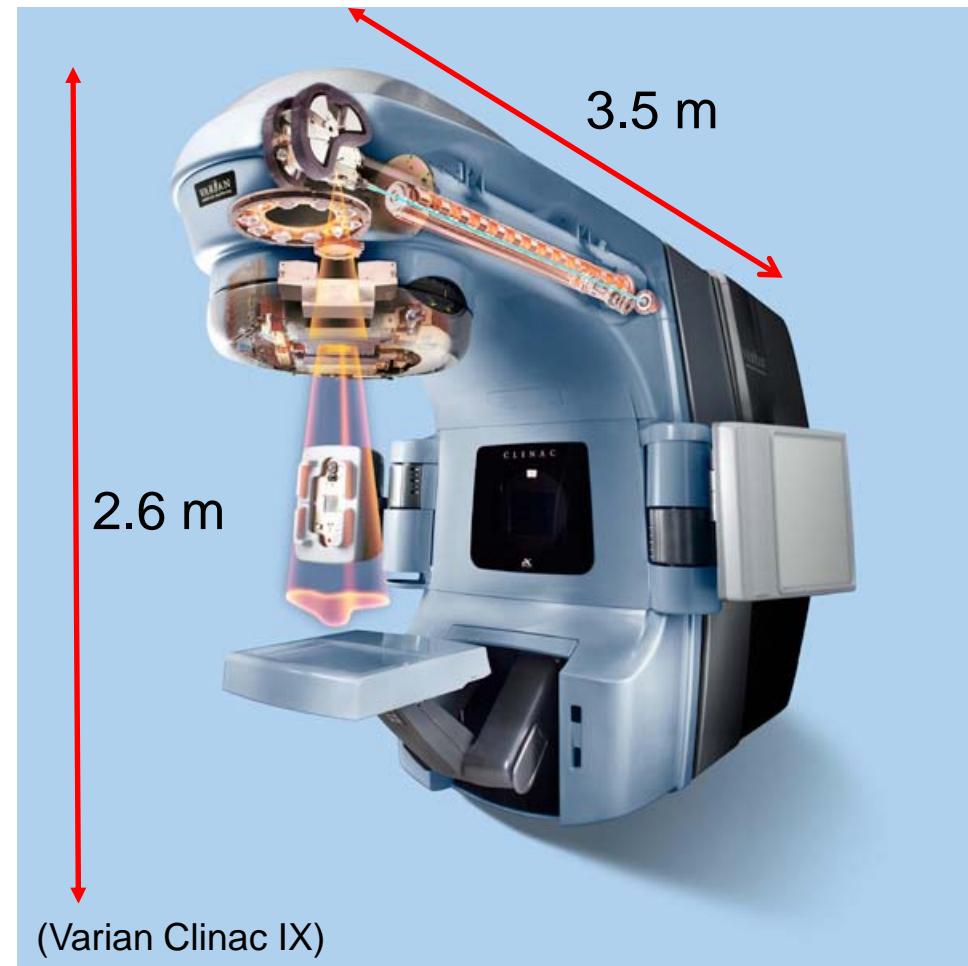


tessuto sano conservato



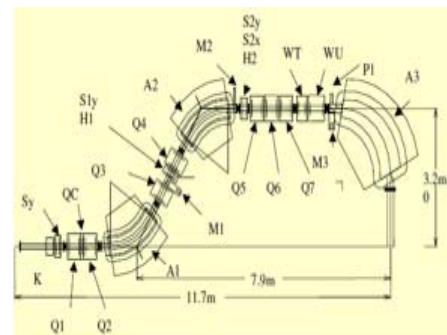
Gantry in conventional radiotherapy

- The whole linac is inside the gantry
- The gantry head can pass between patient and floor for irradiation from below



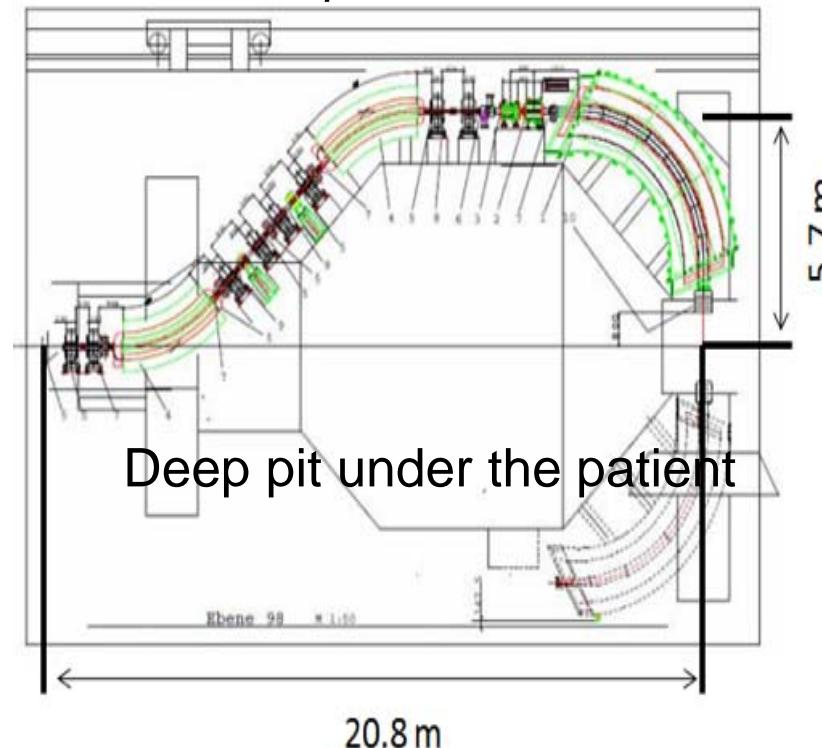
Size and magnetic rigidity

Conventional RT



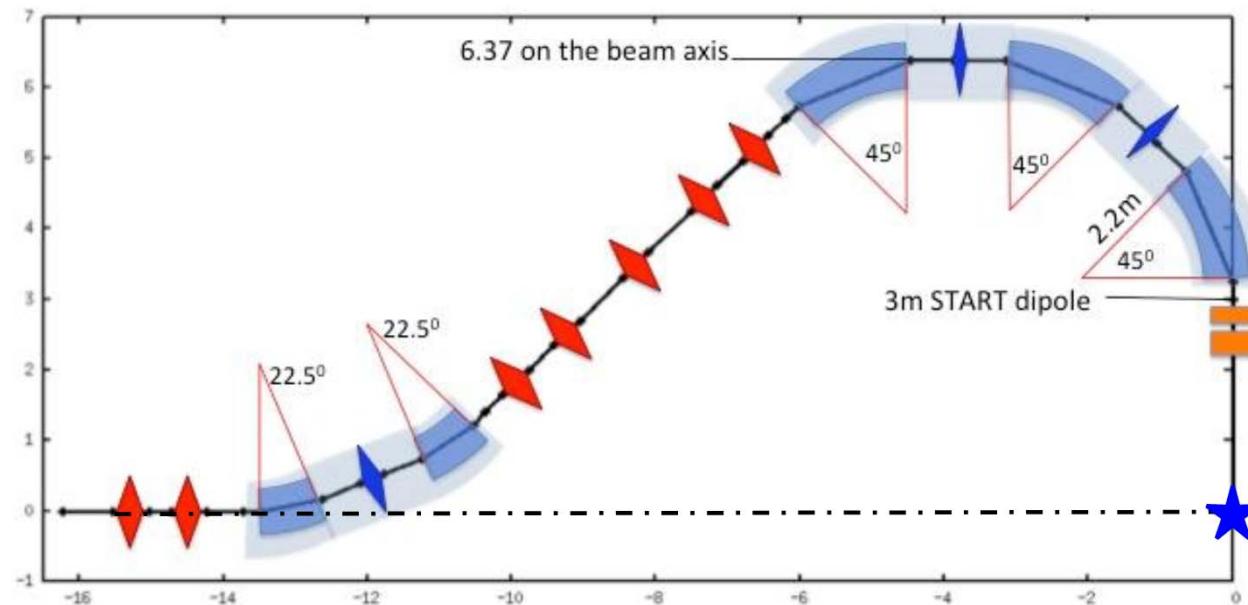
Proton Gantry
 $B\rho < 2.4 \text{ Tm}$

Carbon Ion Gantry
 $B\rho < 6.4 \text{ Tm}$



C Gantry

Studio in corso per gantry C superconduttore



(courtesy of E. Benedetto)

- **Tanti ambiti di ricerca per migliorare i trattamenti**
 - Misure di frammentazione per calcolo dose
 - Micro dosimetria
 - Verifica range/deposizione online
 - Trattamenti 4D
 - ...
- **La ricerca (& sviluppo) è fondamentale per mantenere all'avanguardia un grande investimento**



Grazie dell'attenzione

“Physics is like sex: sure, it may give some practical results, but that's not why we do it.”
R. Feynmann