

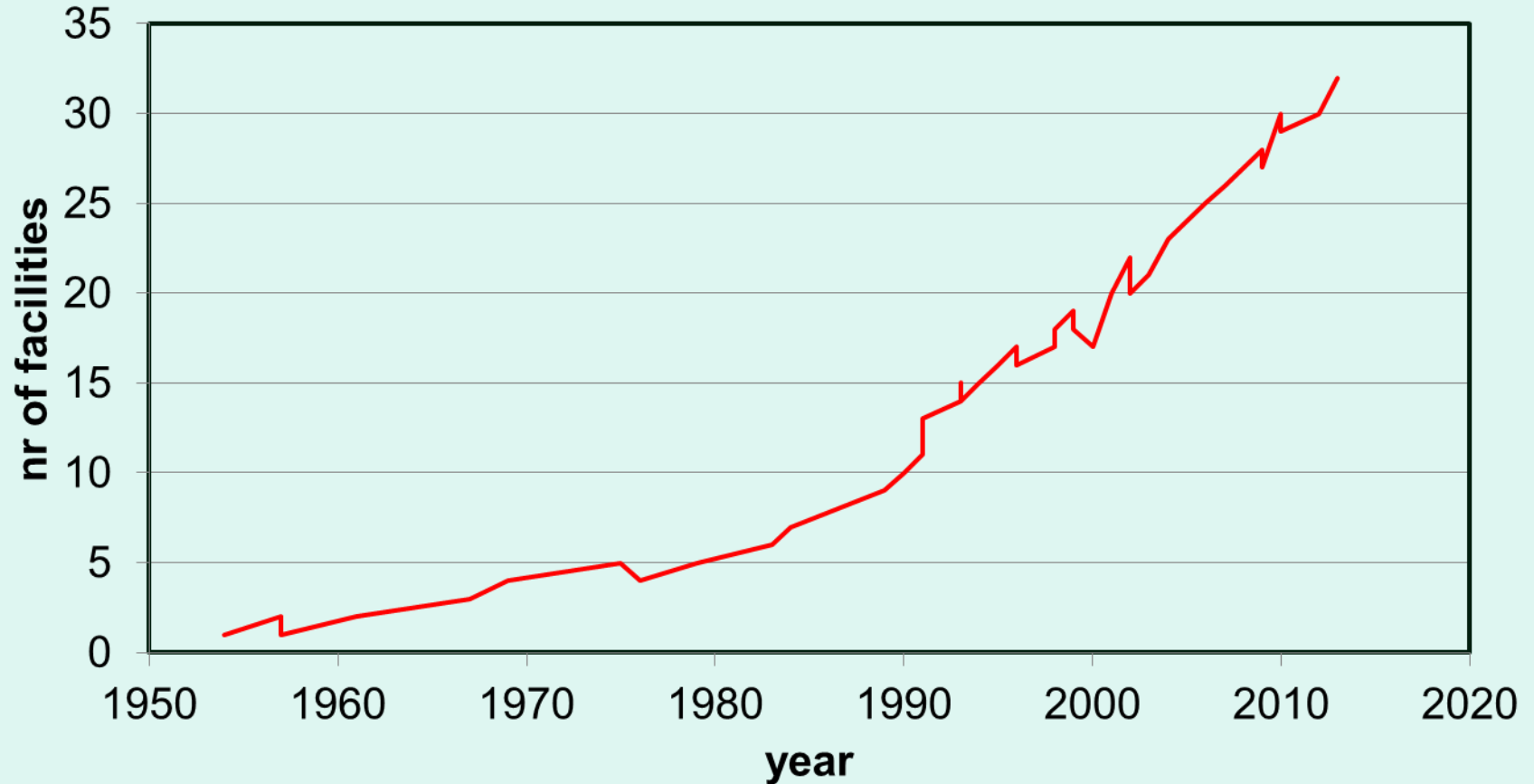


Physics and Accelerators for Particle therapy

Marco Schippers



The boost in particle therapy



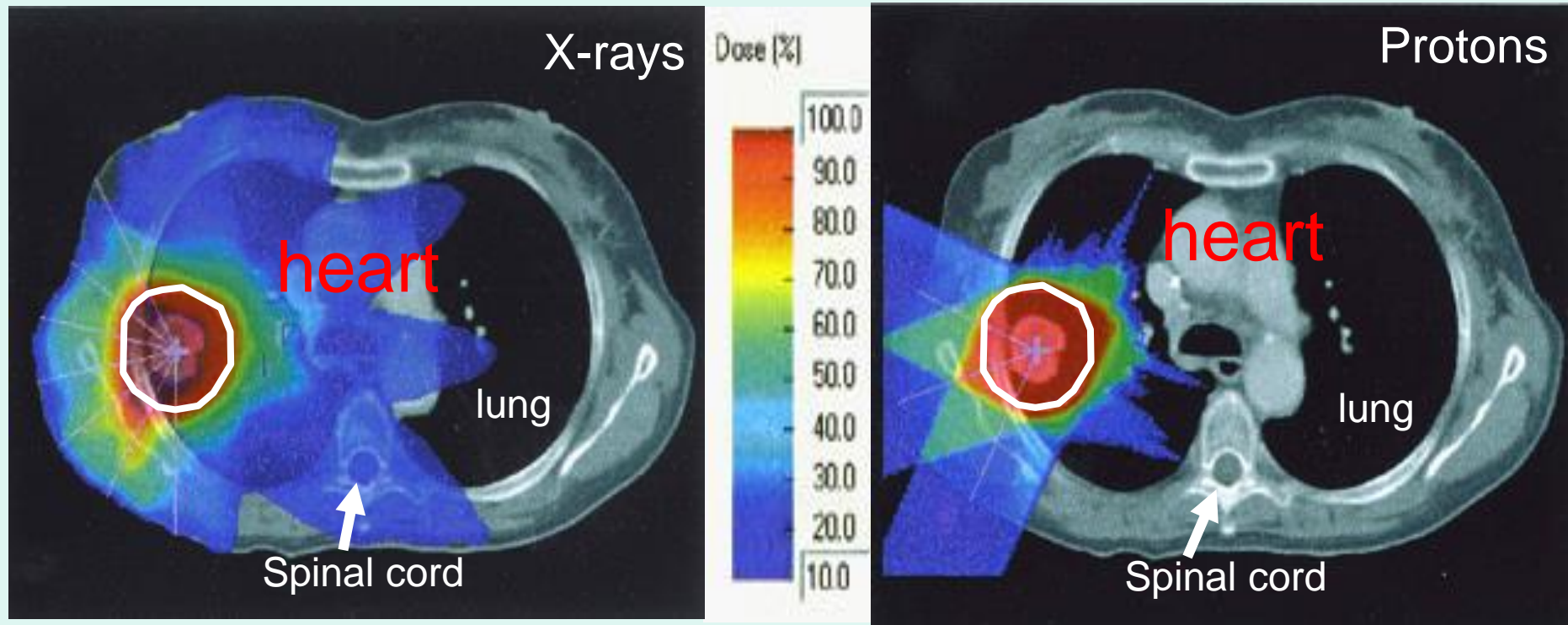
Contents

- Introduction: particle therapy
- How to apply the radiation dose
- Accelerators
 - Cyclotron
 - Synchrotron
- Treatment facilities

X-rays vs. Protons

X-ray beams (IMRT)
from 7 directions

Proton beams
from 3 directions



pictures: MedAustron

Some orders of magnitude:

Typical dose in tumor: $\sim 70 \text{ Gy} = 70 \text{ J/kg}$ applied in fractions of **2 Gy**

Suppose each proton loses $\sim 100 \text{ MeV}$ in tumor of 1 kg

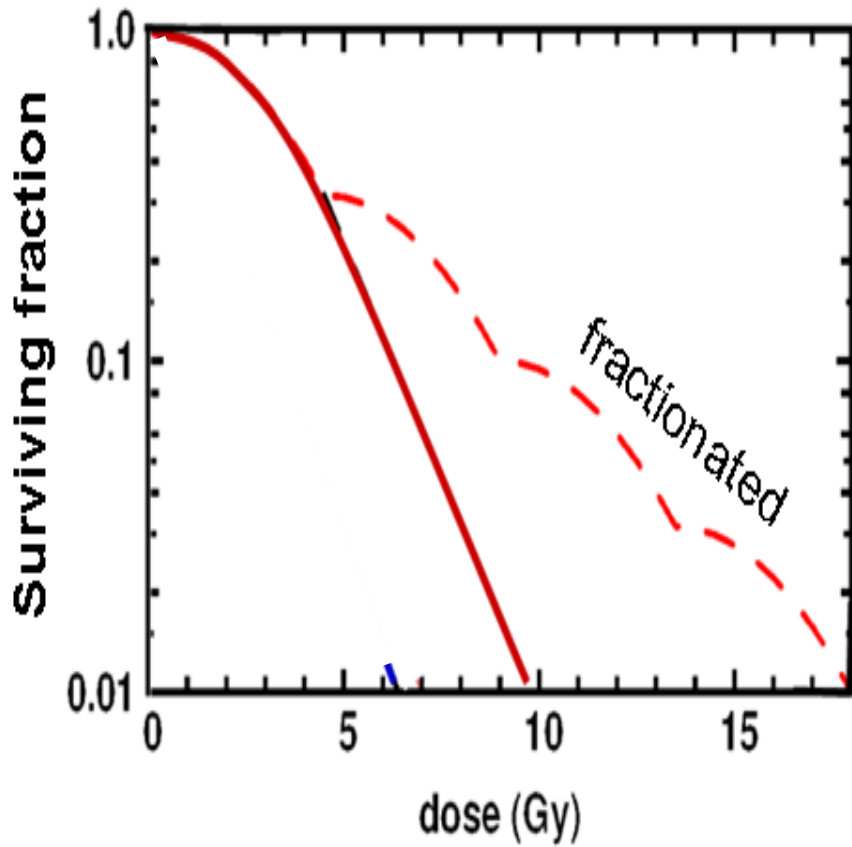
→ **10^{11} protons needed** $\left(\approx \frac{2}{1.6E-11} \right)$

Irradiation time: 1 min → beam intensity **0.25 nA**

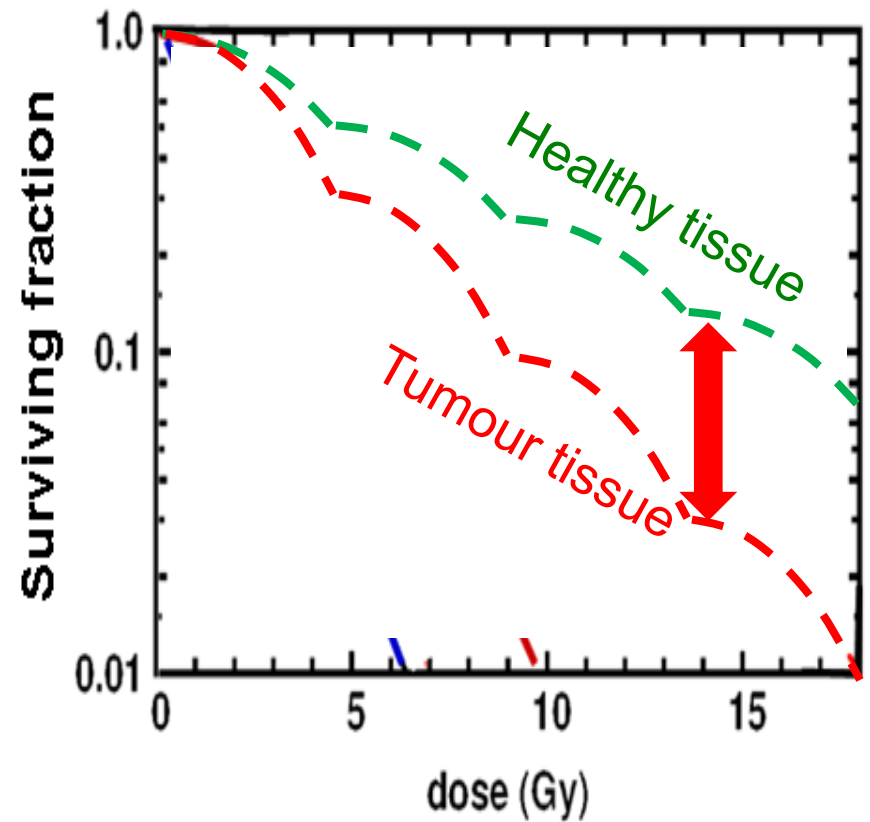
Fractionated treatment

to spare healthy tissue

Cell killing

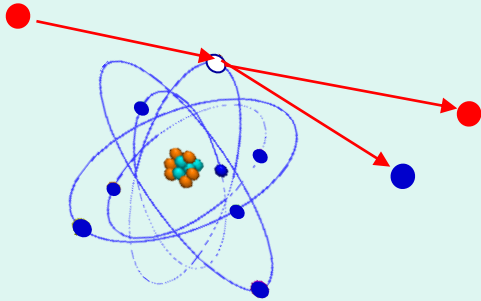


Cell killing

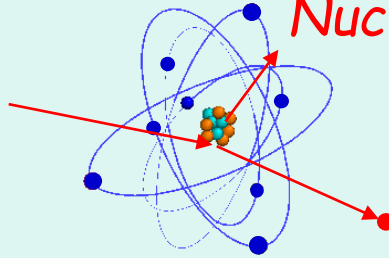


Dominating proton interactions

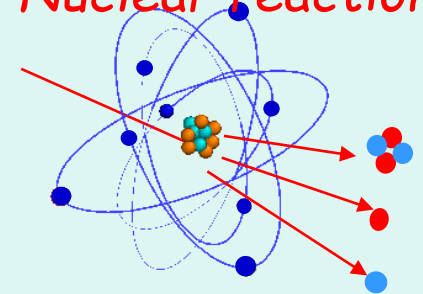
Ionization



Nuclear Coulomb scattering



Nuclear reaction

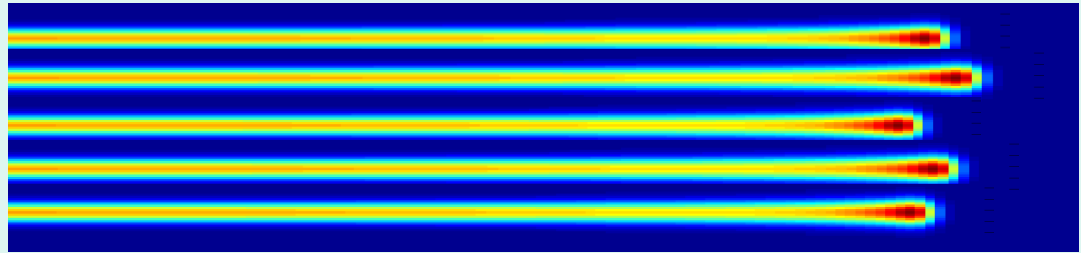
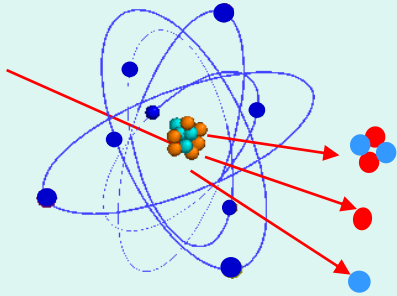


Reaction products:

⇒ Ionized atom ⇒ Chemical reaction ⇒ biologic effect
 ⇒ Scattered proton ⇒ Next interaction

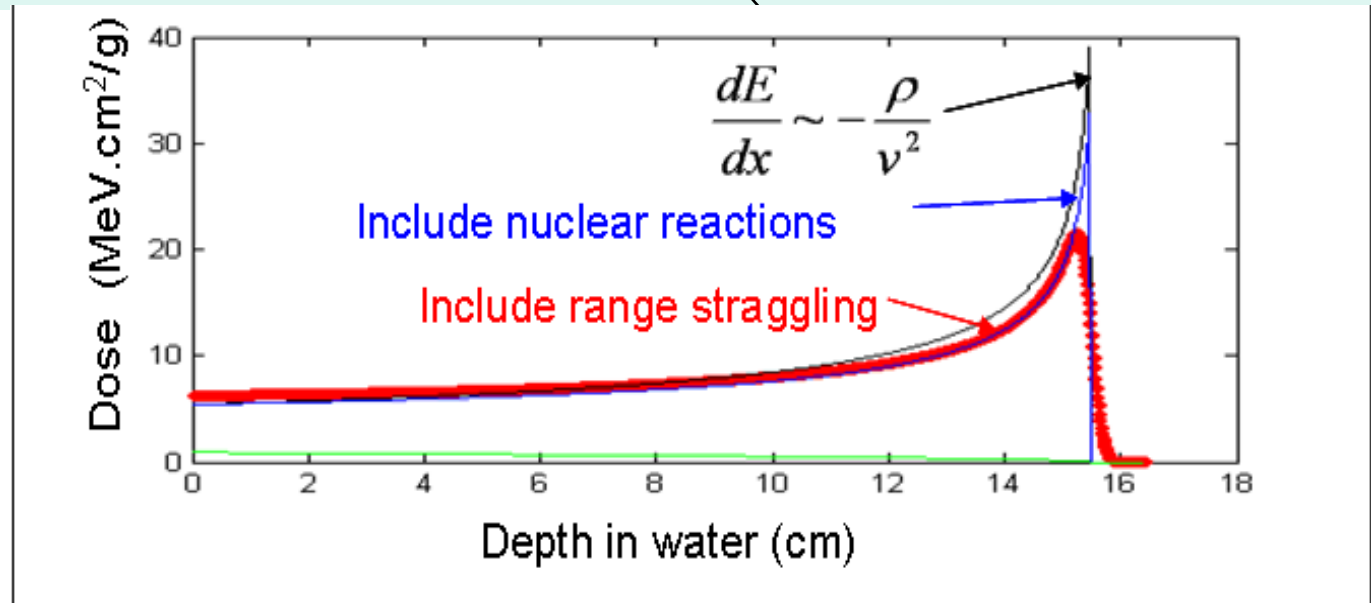
Proton depth-dose curve

Nuclear reaction



- loss of protons
- nuclear fragments
- neutrons
- radioactivity

$$\text{Bethe-Bloch: } \frac{dE}{dx} \sim -\rho \frac{Z}{A} \cdot \frac{1}{v^2}$$

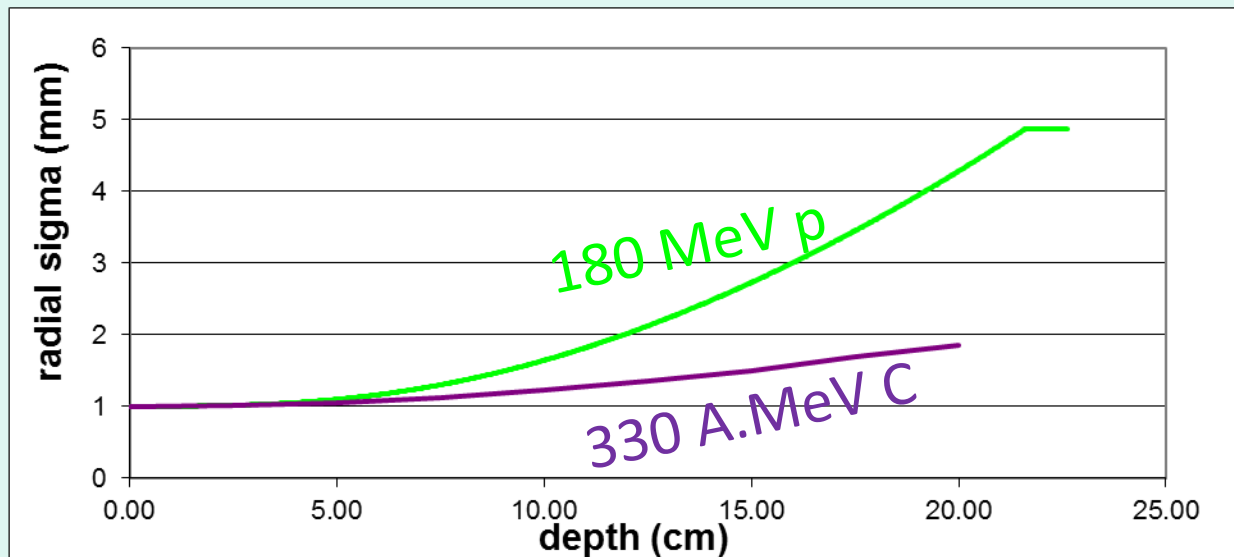
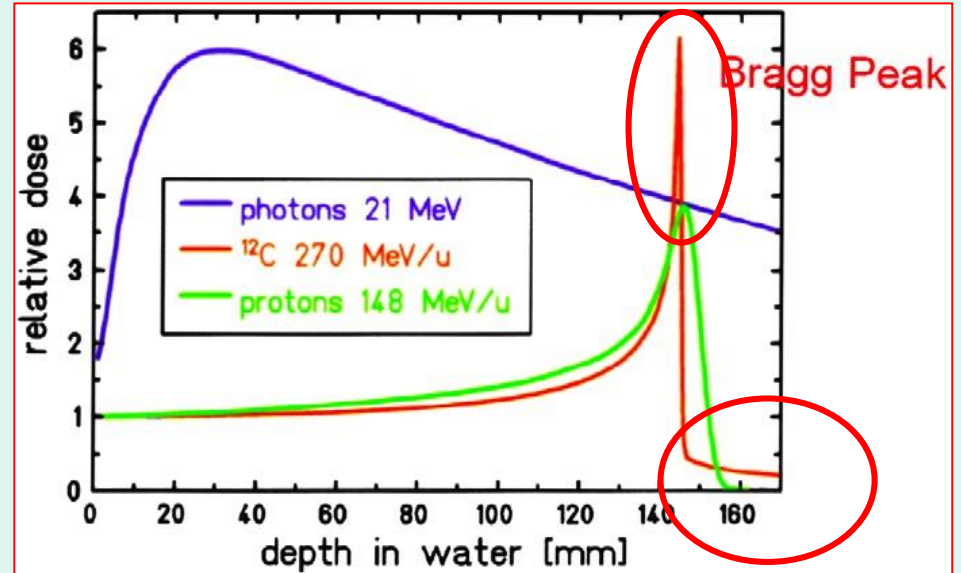


→ Additional dose from reaction products

What will Carbon ions bring?

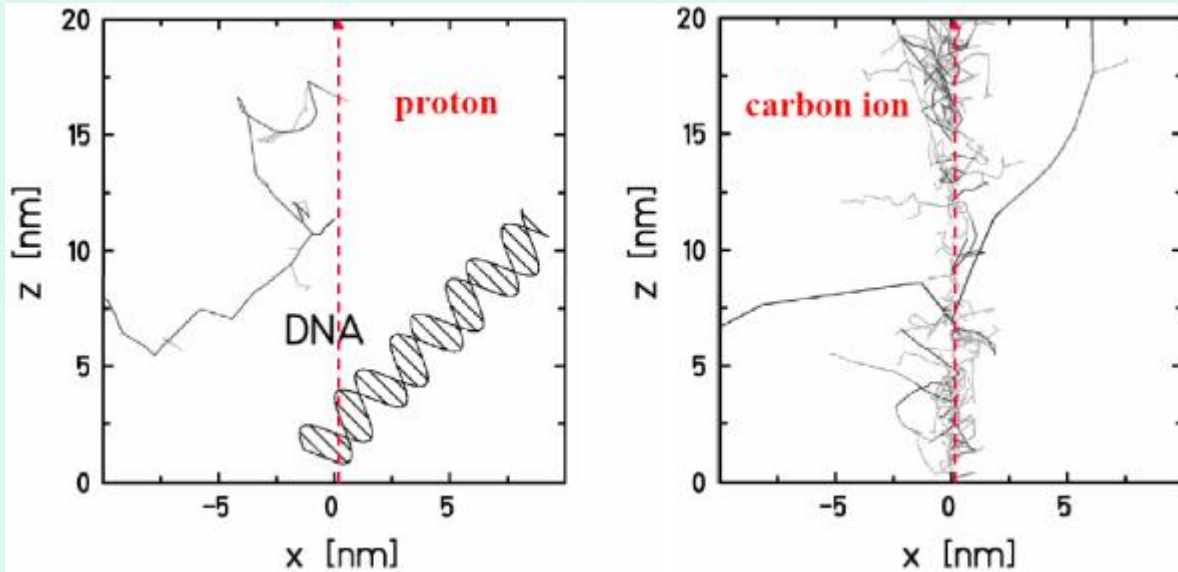
Difference with protons:

- Sharper Bragg peak
- Tail of fragments
- Less Scattering
- Larger RBE

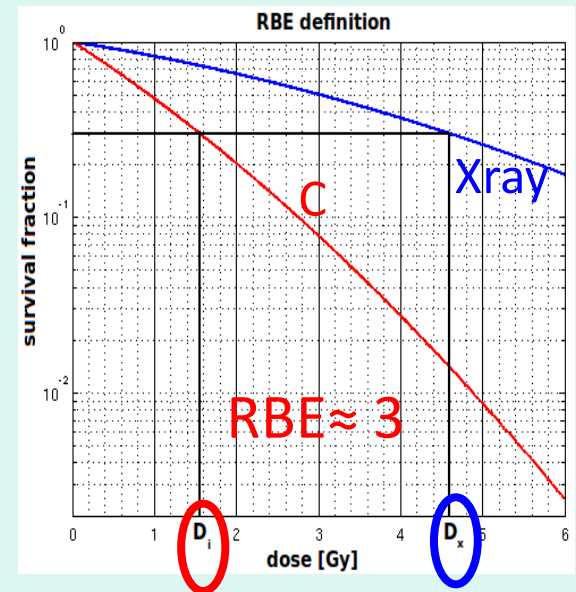


Biological effect of Carbon ions

Radio Biological Effectiveness: $RBE_{\text{carbon}} = \frac{D_{\text{Xray}}}{D_{\text{Carbon}}}$ for same cell killing.



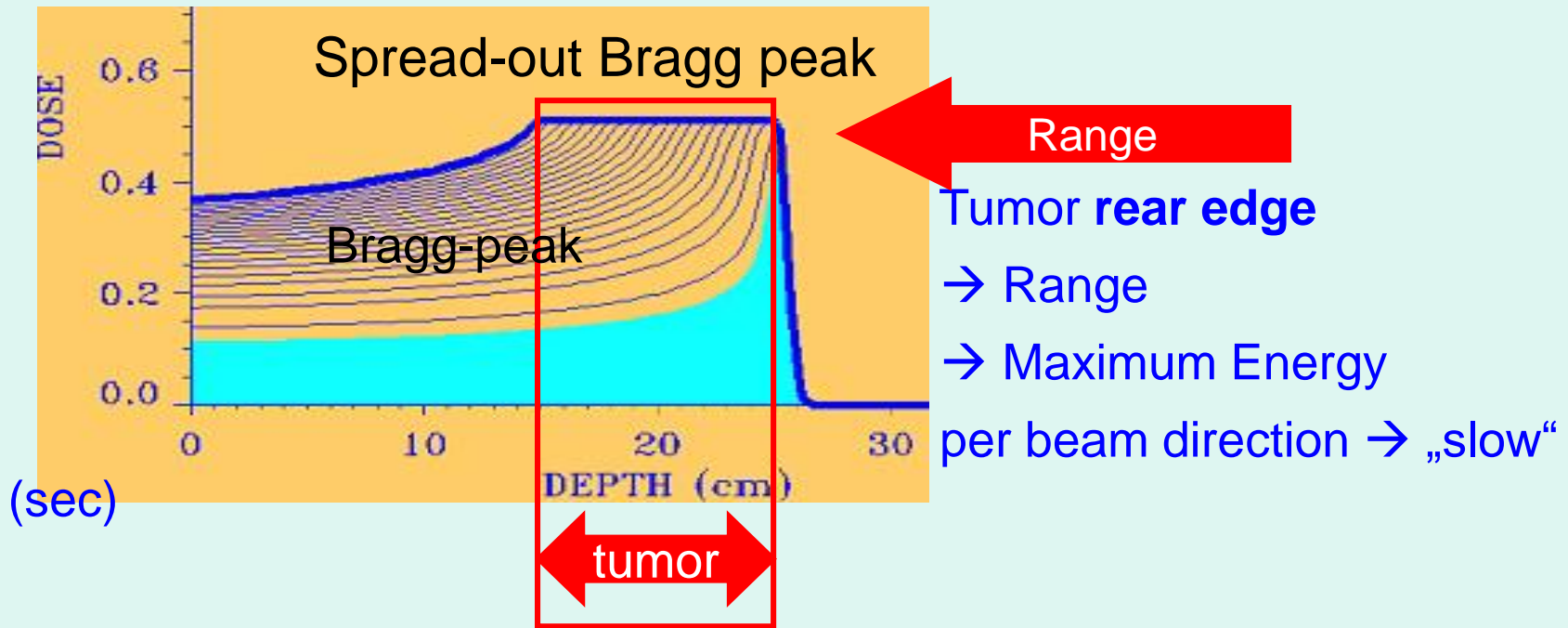
electron track (or energy) density at μm scale effects RBE (this means: $RBE \neq 1$)



Dose delivery techniques



Dose delivery techniques: **Depth**



Tumor **thickness**

→ spread-out Bragg peak

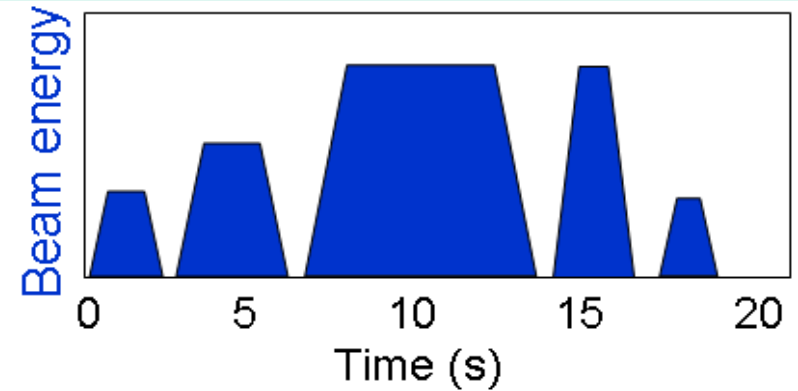
→ energy modulation

During trmt → „fast“ (<0.1-0.2 sec)

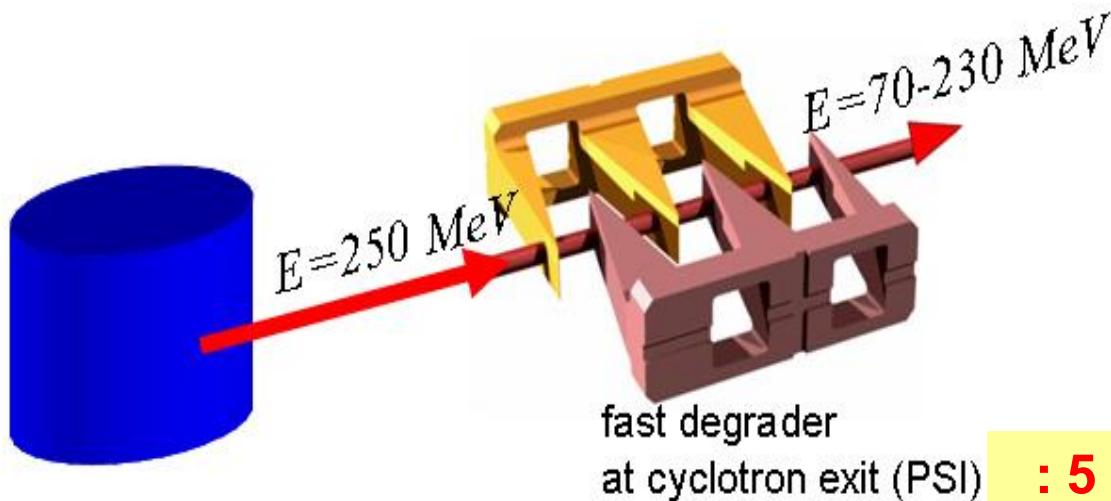
Vary energy at accelerator

Synchrotron: Set energy at each spill:

- Sets range only
- energy modulation in nozzle



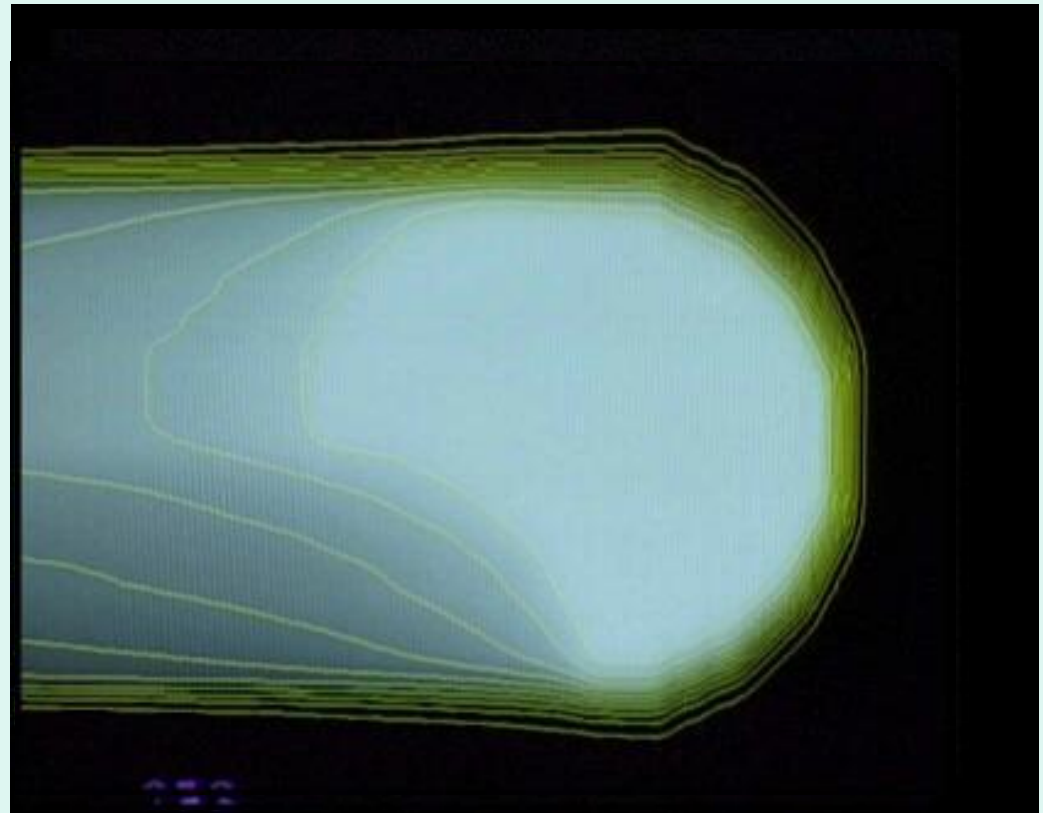
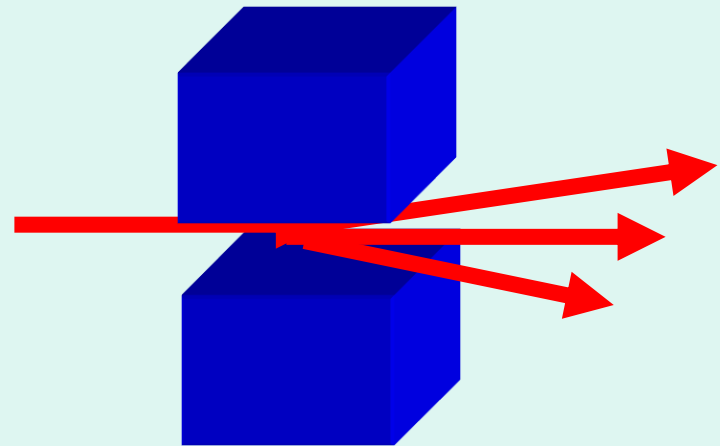
Cyclotron has fixed energy => slow down (degrade) to desired energy



- Sets range
- And, if fast enough + fast magnets:**
- also energy modulation

: 5 mm Δ Range in 100-200 ms

pencil-beam scanning



Pencil beam scanning

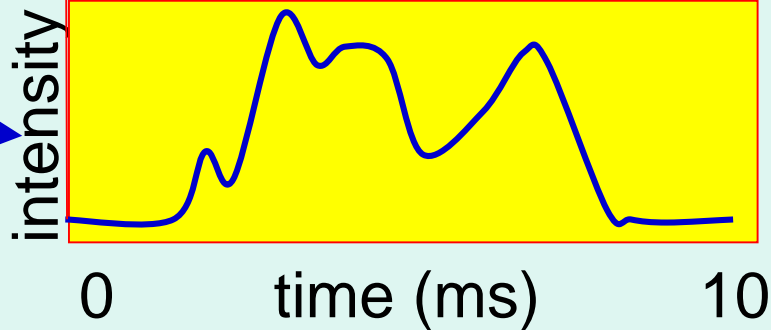
Spot scanning: **step&shoot**



Continuous scanning



kHz-Intensity modulation



allows fast treatments

→ Helps to deal with organ motion

Present accelerator choice



cyclotron

synchrotron

Protons

in use, \varnothing 3.5-5 m

in use, \varnothing 8-10 m

Carbon ions

in design, \varnothing 6 m

in use, \varnothing 25 m

Cyclotrons for proton therapy

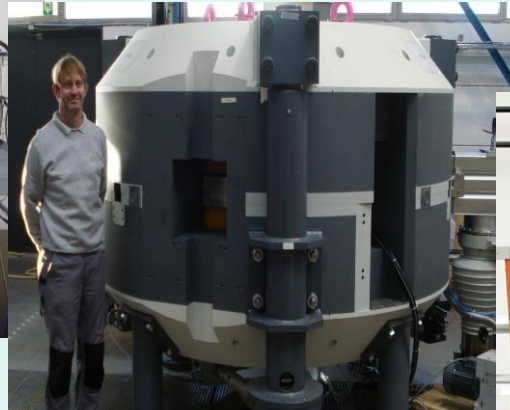
superconducting Coils



IBA – 250 Ton
Isochronous
Cyclotron



Varian – 90 Ton
Isochronous
Cyclotron



IBA – 60 Ton
Synchrocyclotron



MEVION – 15 Ton
Synchrocyclotron

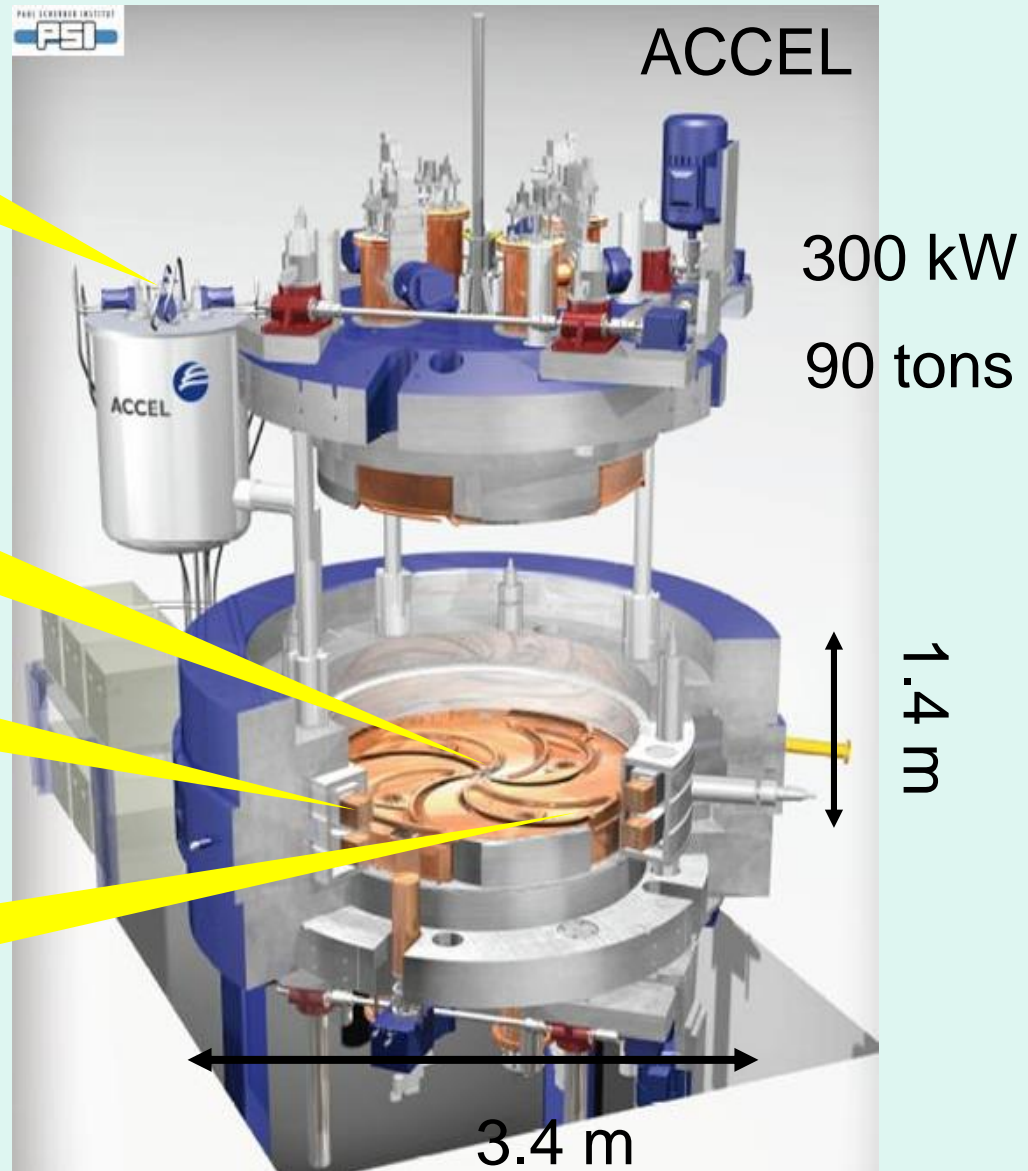
250 MeV proton cyclotron (Varian)

Closed He system
4 x 1.5 W @4K

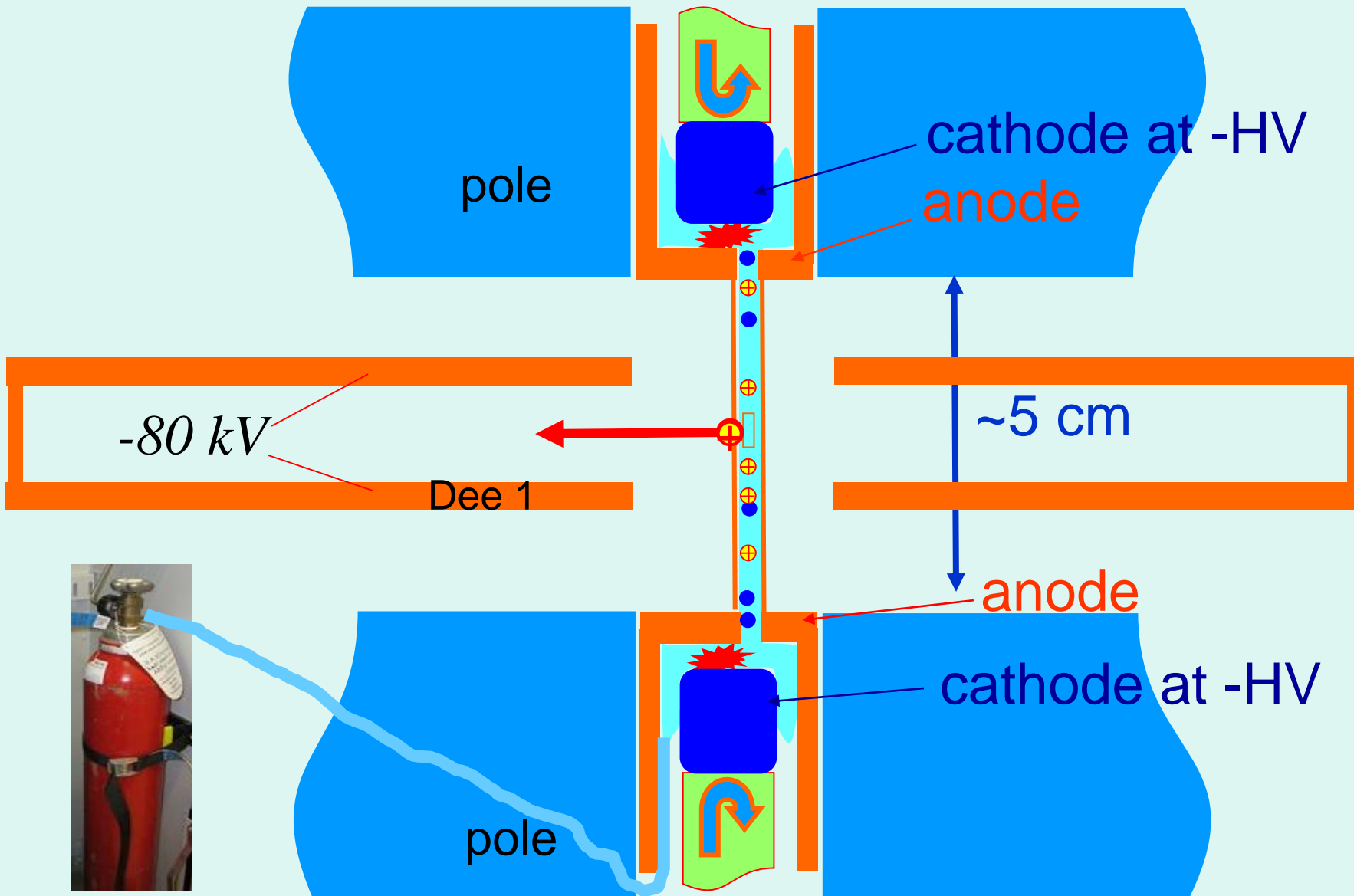
Proton source

superconducting coils
=> 2.4 - 3.8 T

4 RF-cavities
~100 kV on 4 Dees

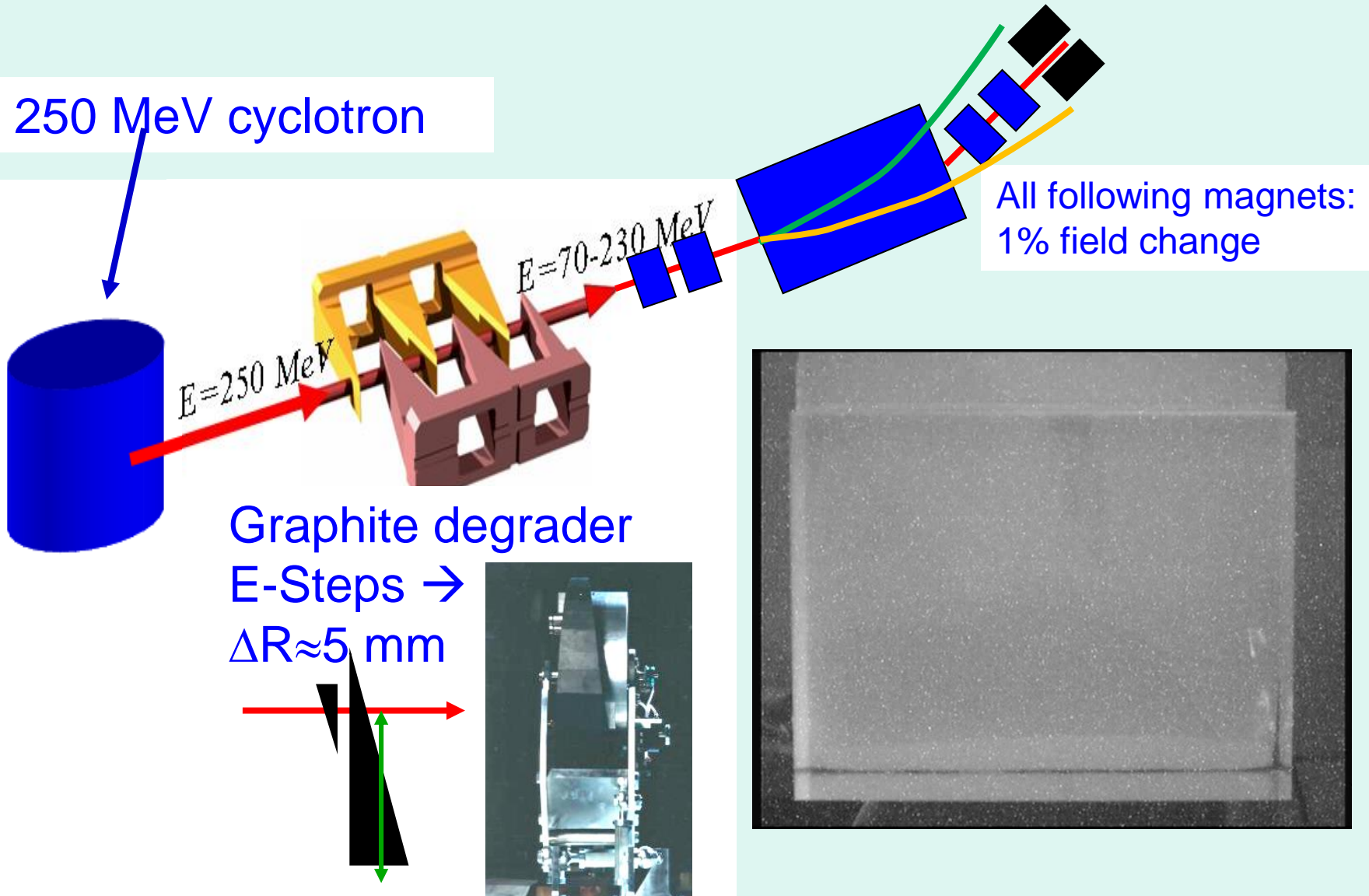


Internal proton source



E-adjustment with cyclotron

250 MeV cyclotron



Synchrotron (1945)

Protons only:

(\varnothing ~8 m)

synchrotron

Proton source + injector

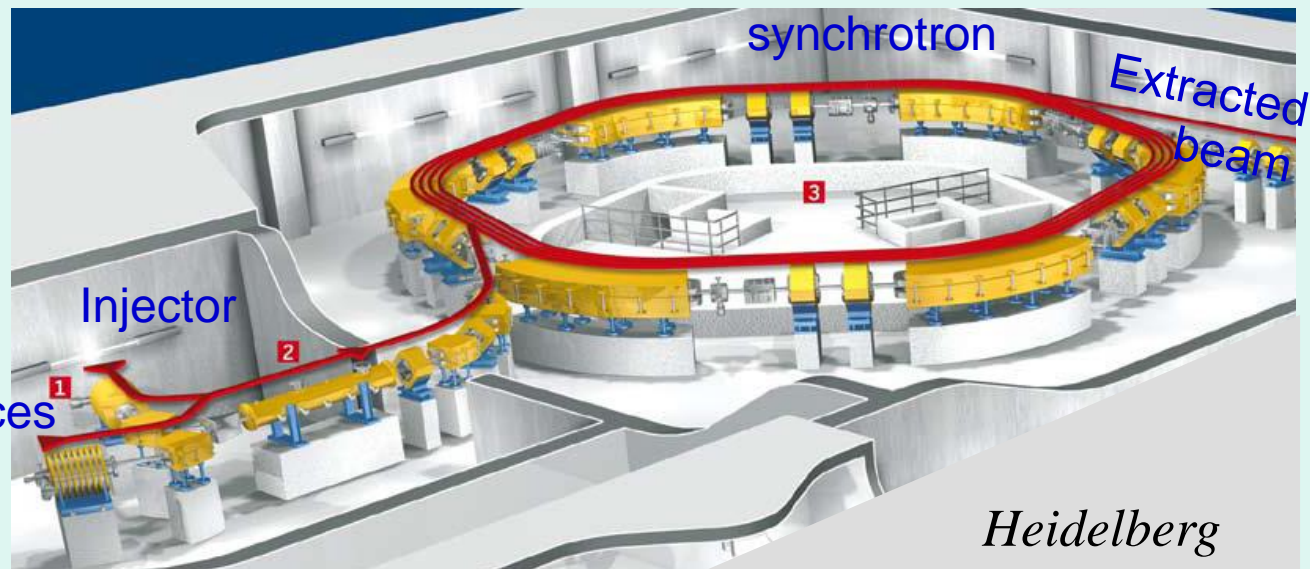


Extracted beam

Ions (p-C):

(\varnothing ~25 m)

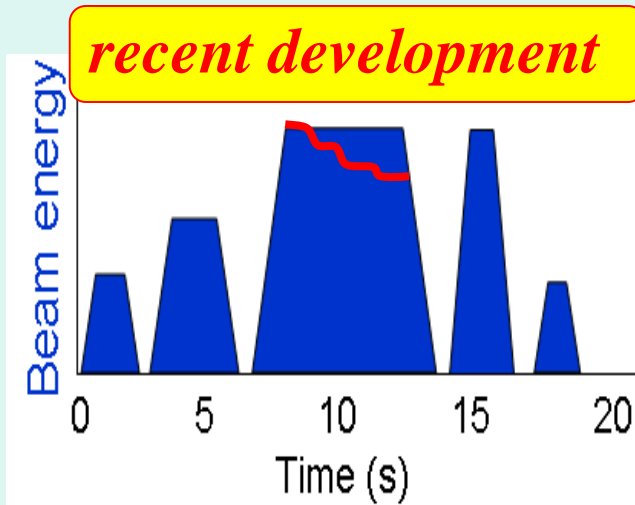
Ion sources



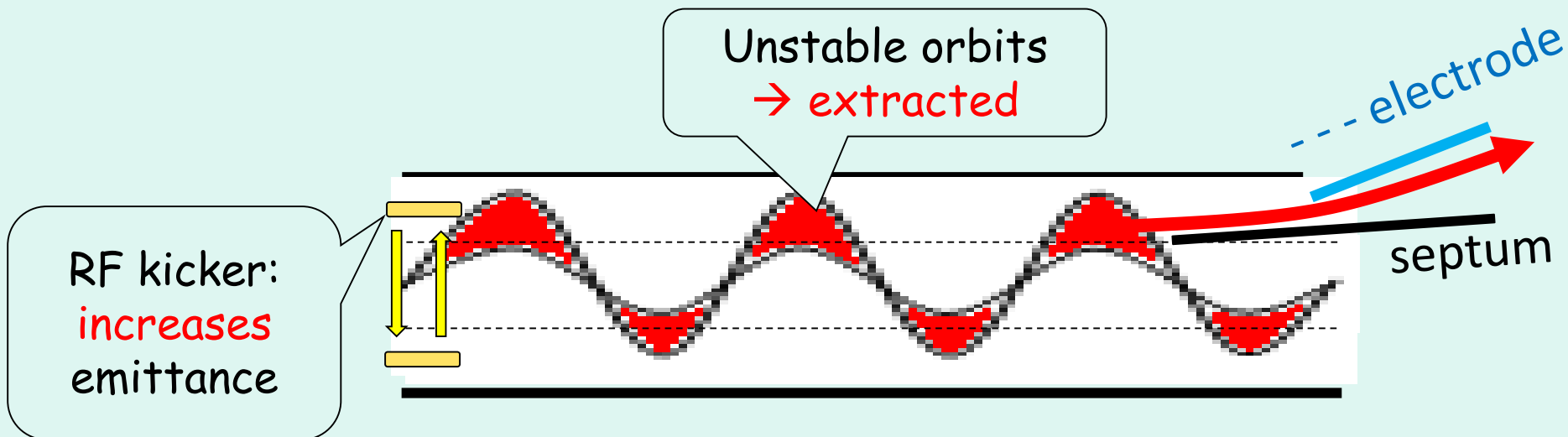
Beam extraction from synchrotron

One “spill” :

- fill ring with $\sim 10^9$ - 10^{11} particles
- accelerate to desired energy
- extract slowly during 1-10 sec
- decelerate and dump unused particles



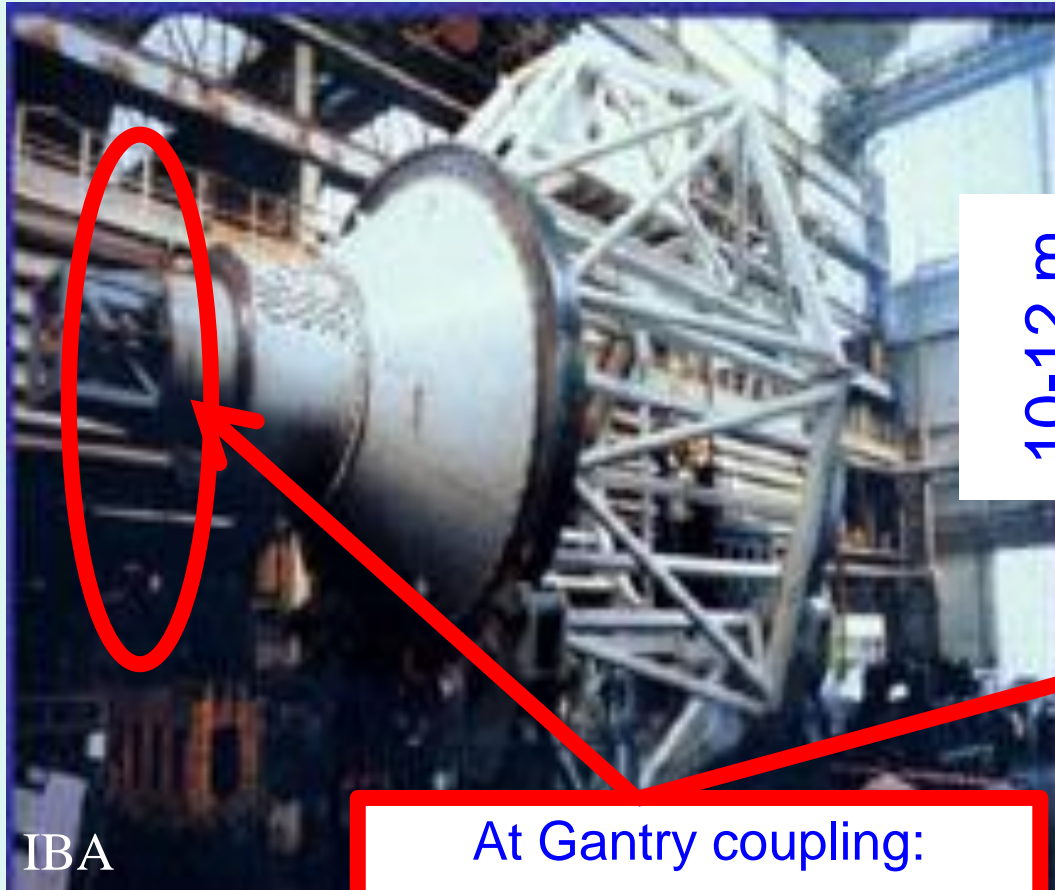
Beam extraction with RF-Knock Out



Gantry as seen from patient side



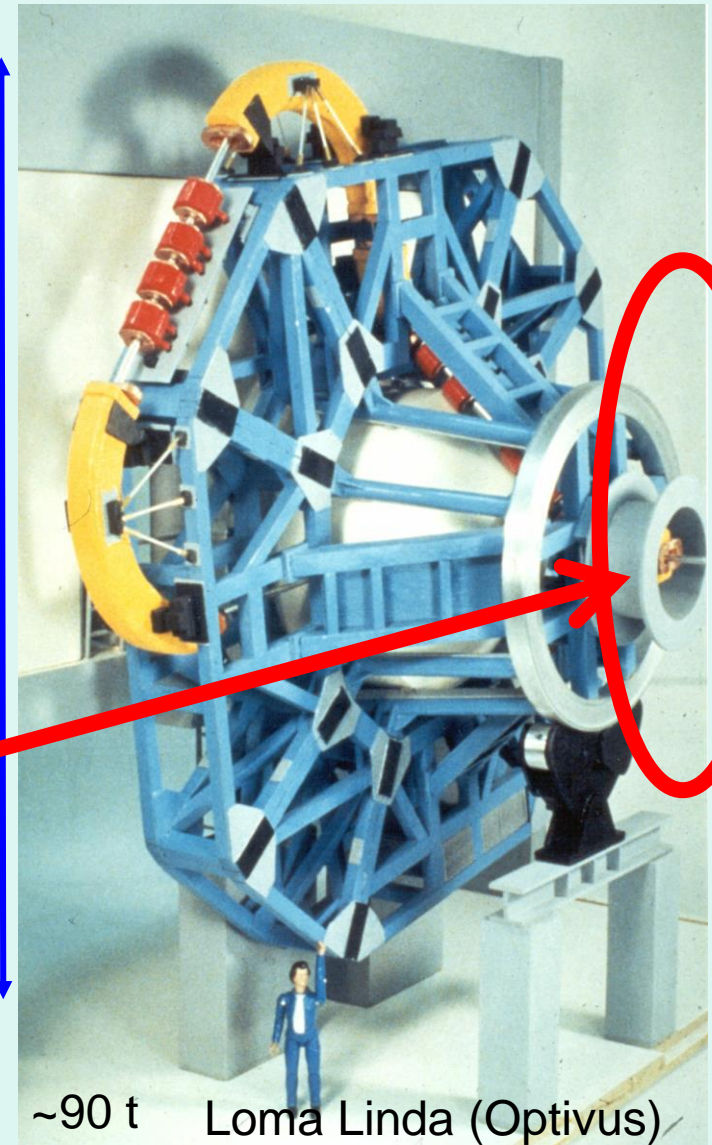
Gantries



IBA

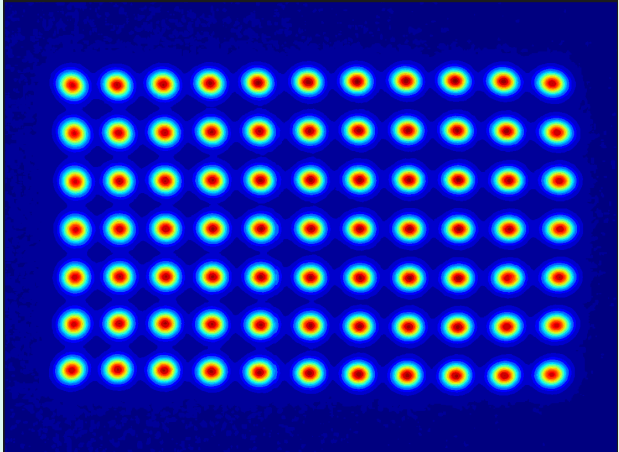
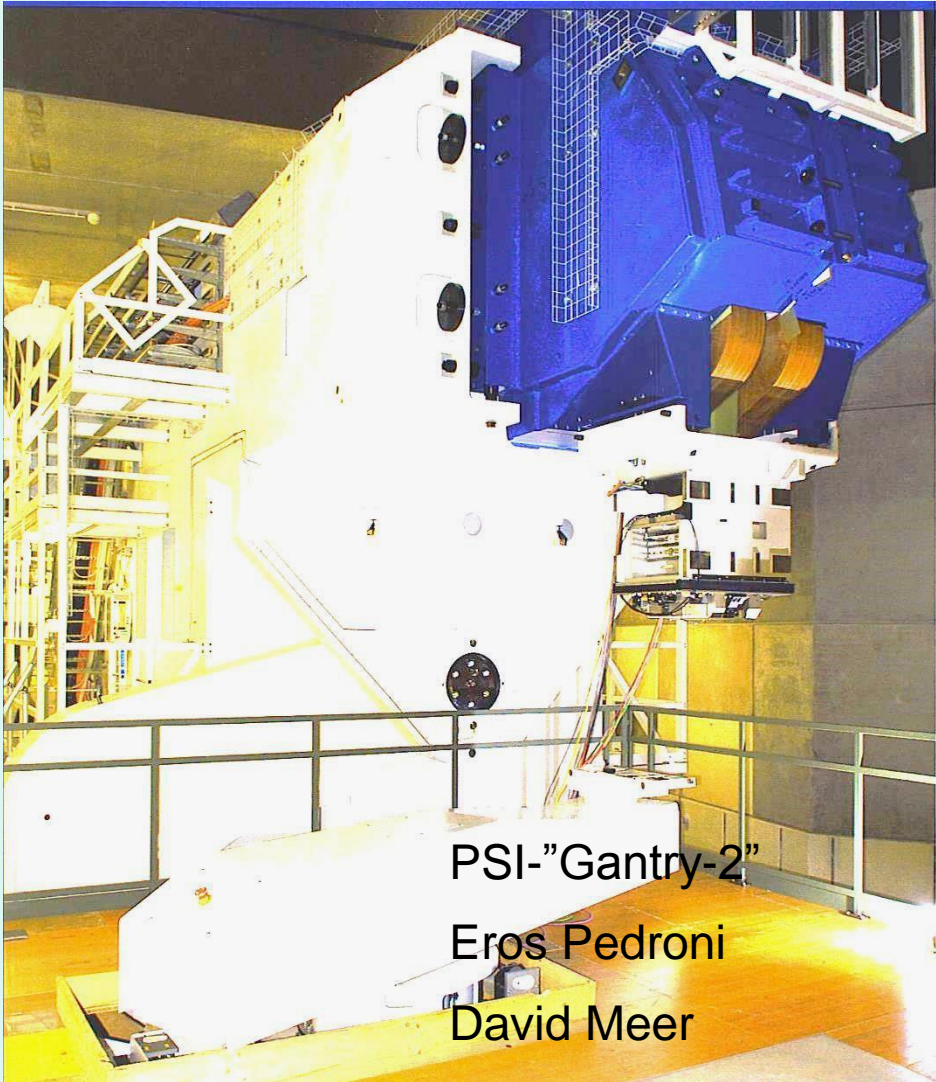
10-12 m

- At Gantry coupling:
- Phase space symmetric
 - No dispersion



~90 t Loma Linda (Optivus)

PSI Gantry-2: fast 3D scanning



SUMMARY

- Dose:
 - **finite range**
 - **maximum dose at end of track**
- Dose application: Scattering or **Scanning**
- Accelerators for Medical Application:
 - Cyclotron
 - Synchrotron
- Facilities: **Gantry** aims the beam from all directions

first scanning gantry : PSI, 1990



Gantry: Eros Pedroni

Tumours in kids: Beate Timmermann, Gudrun Goitein