Physics and Accelerators for Particle therapy

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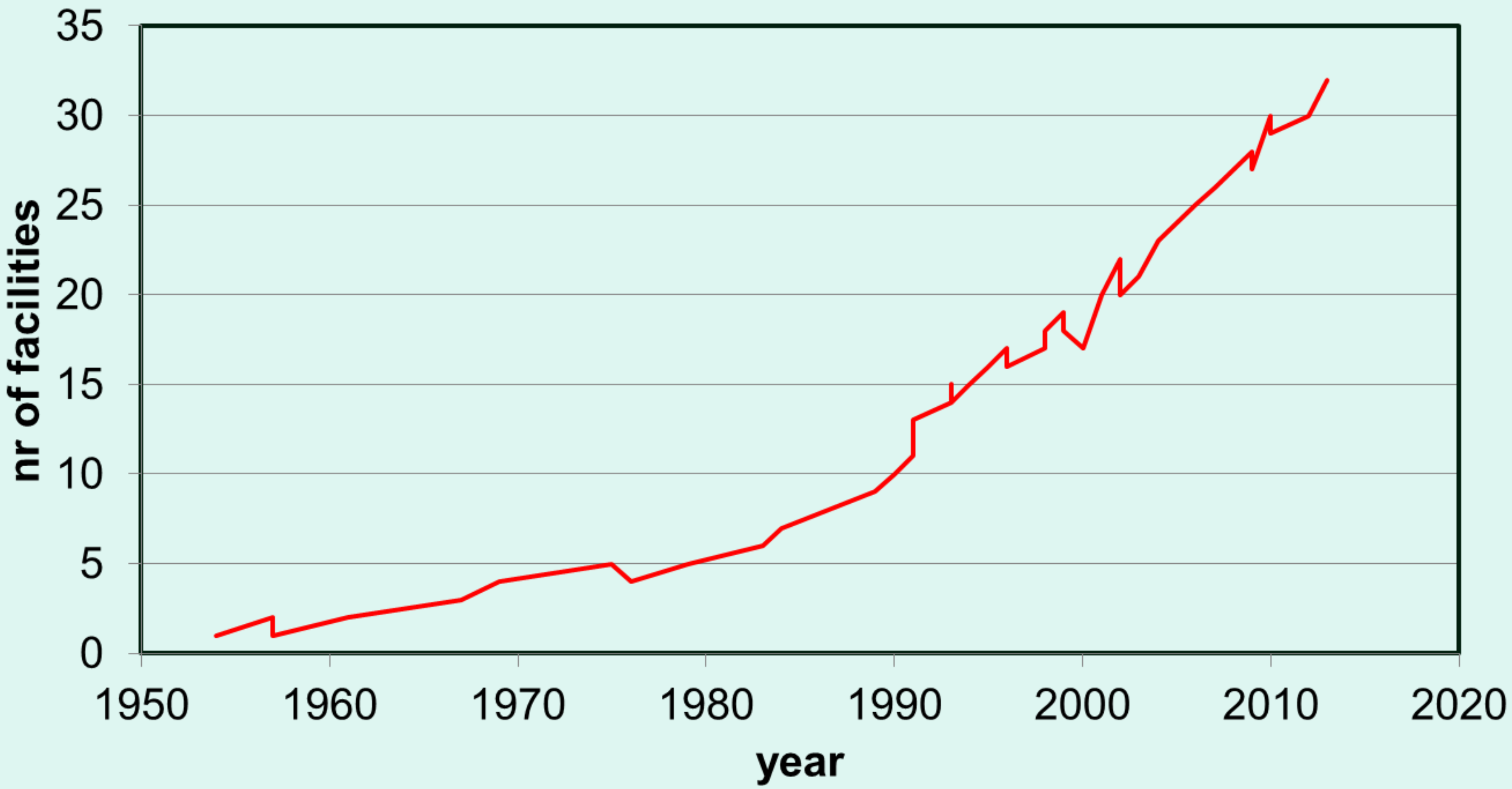
PAUL SCHERRER INSTITUT

The boost in particle therapy



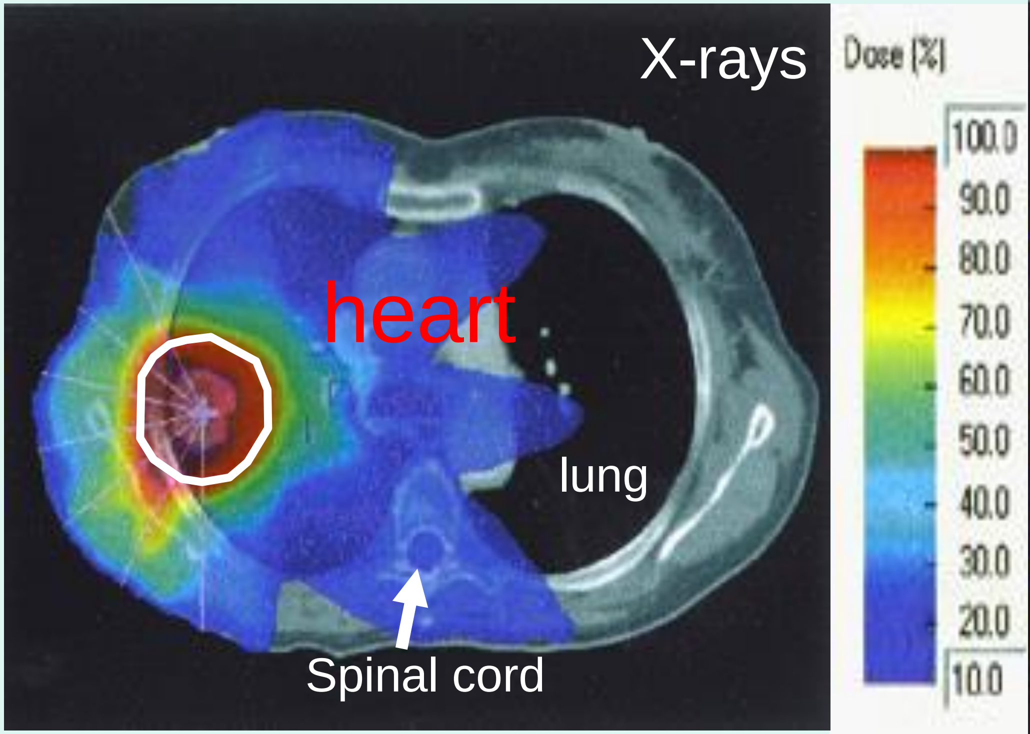
Contents

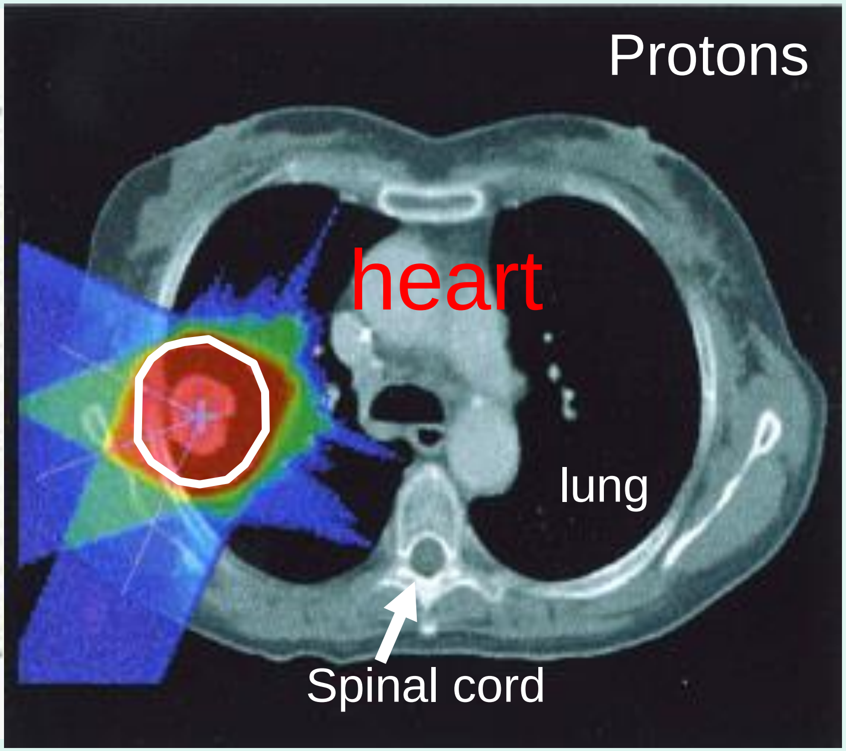
- Introduction: particle therapy
- How to apply the radiation dose
- Accelerators
  - Cyclotron
  - Synchrotron
- Treatment facilities

X-rays vs. Protons

X-ray beams (IMRT)
from 7 directions

Proton beams
from 3 directions





pictures: Medaustron

Typical Therapeutic Radiation Dose

Some orders of magnitude:

Typical dose in tumor: ~70 Gy = 70 J/kg applied in fractions of **2 Gy**

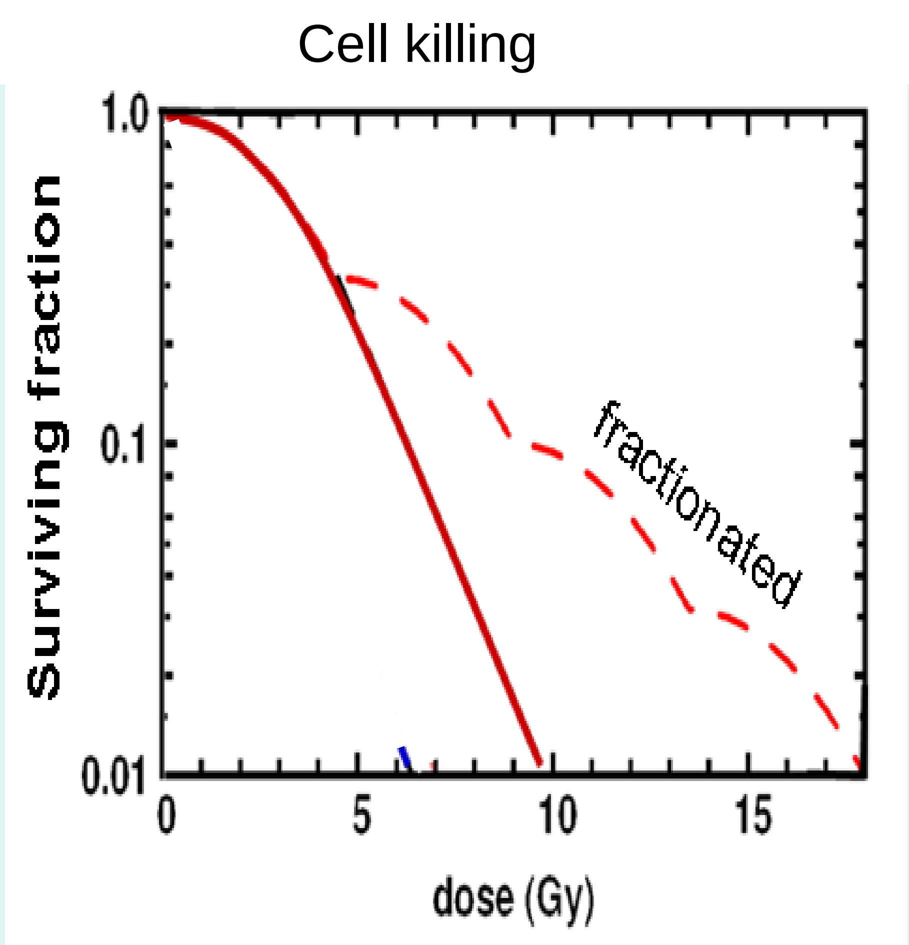
Suppose each proton loses ~100 MeV in tumor of 1 kg

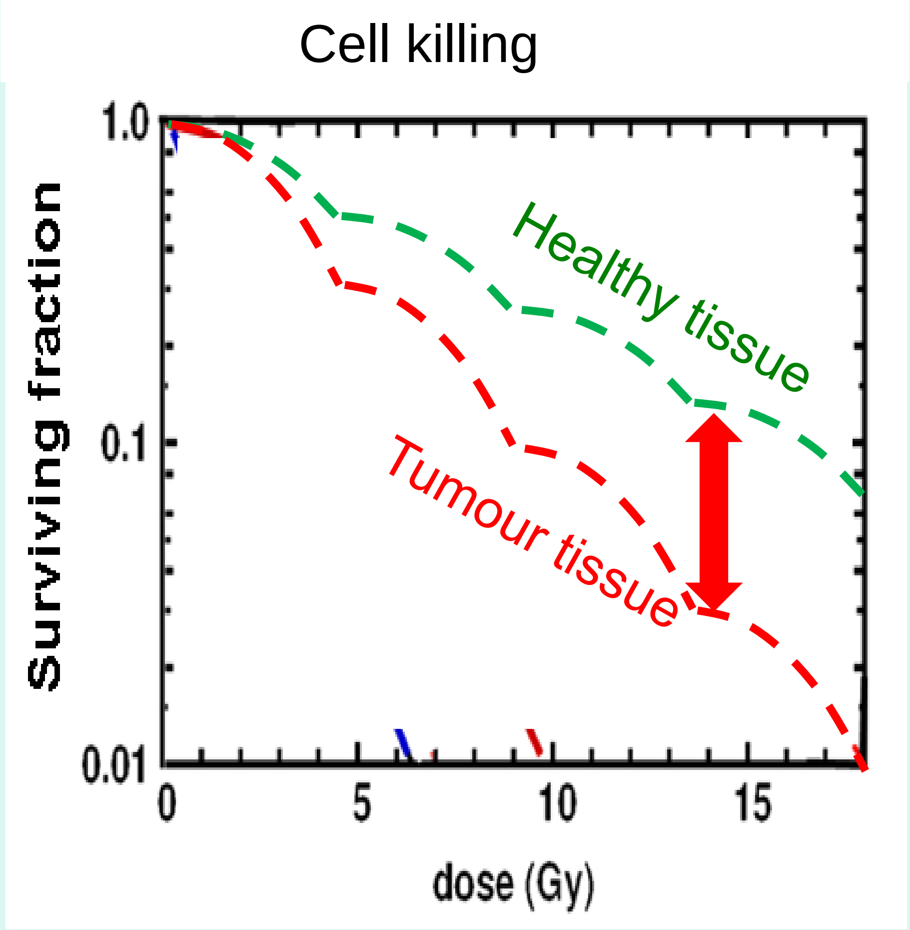
→ $\mathbf{10^{11}}$ **protons needed** $\left(\approx \frac{2}{1.6E{-}11} \right)$

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

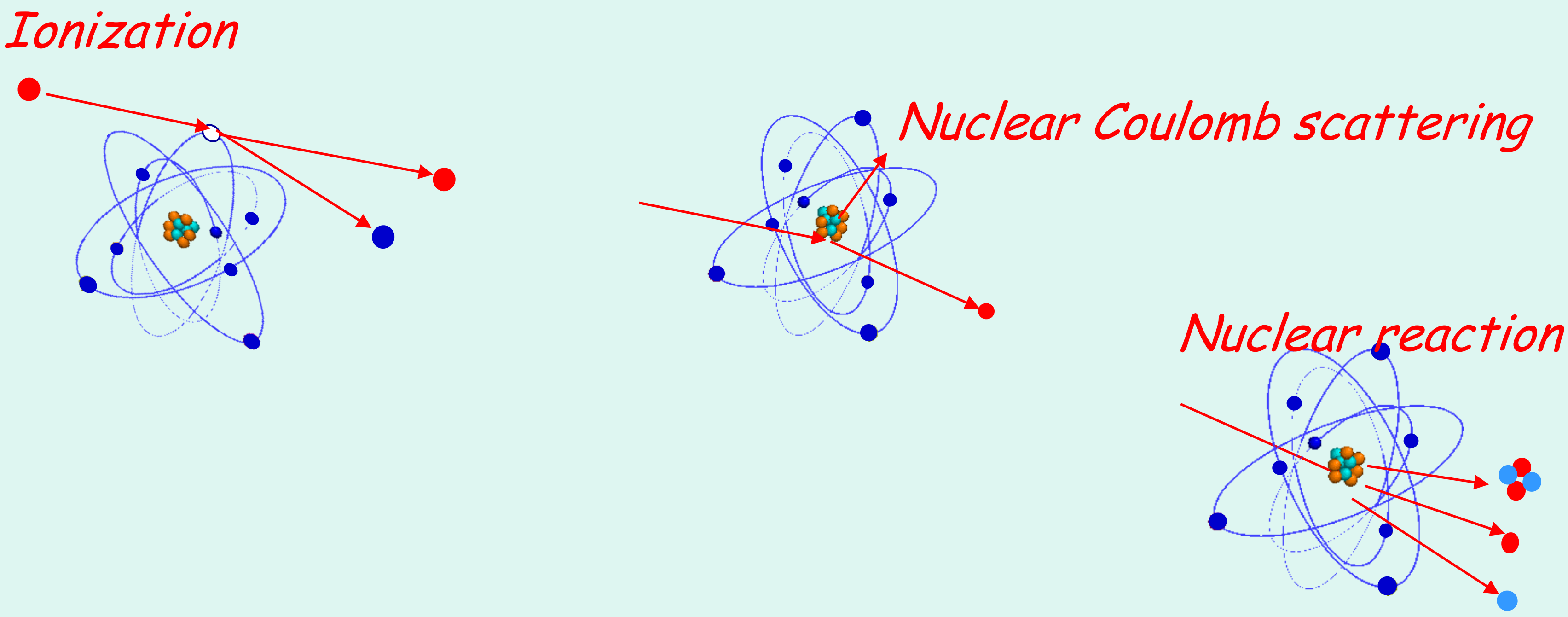
Fractionated treatment

to spare healthy tissue





Dominating proton interactions



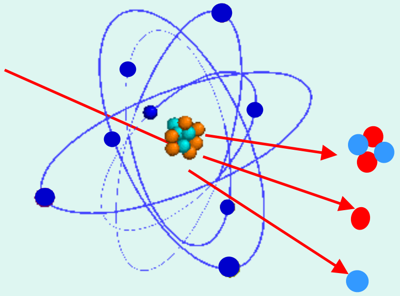
Reaction products:

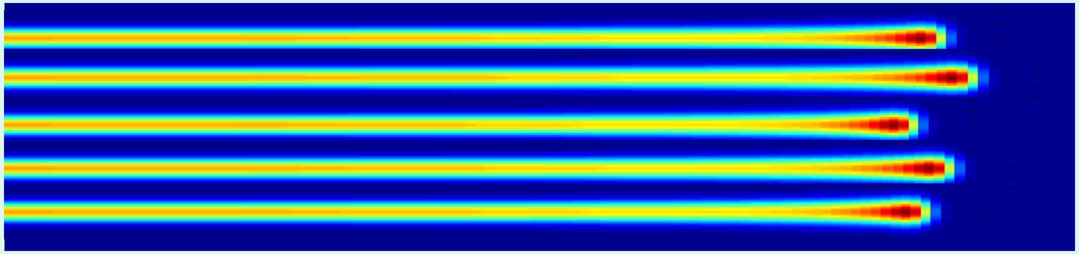
⇒ *Ionized atom* ⇒ *Chemical reaction* ⇒ *biologic effect*

⇒ *Scattered proton* ⇒ *Next interaction ……*

Proton depth-dose curve

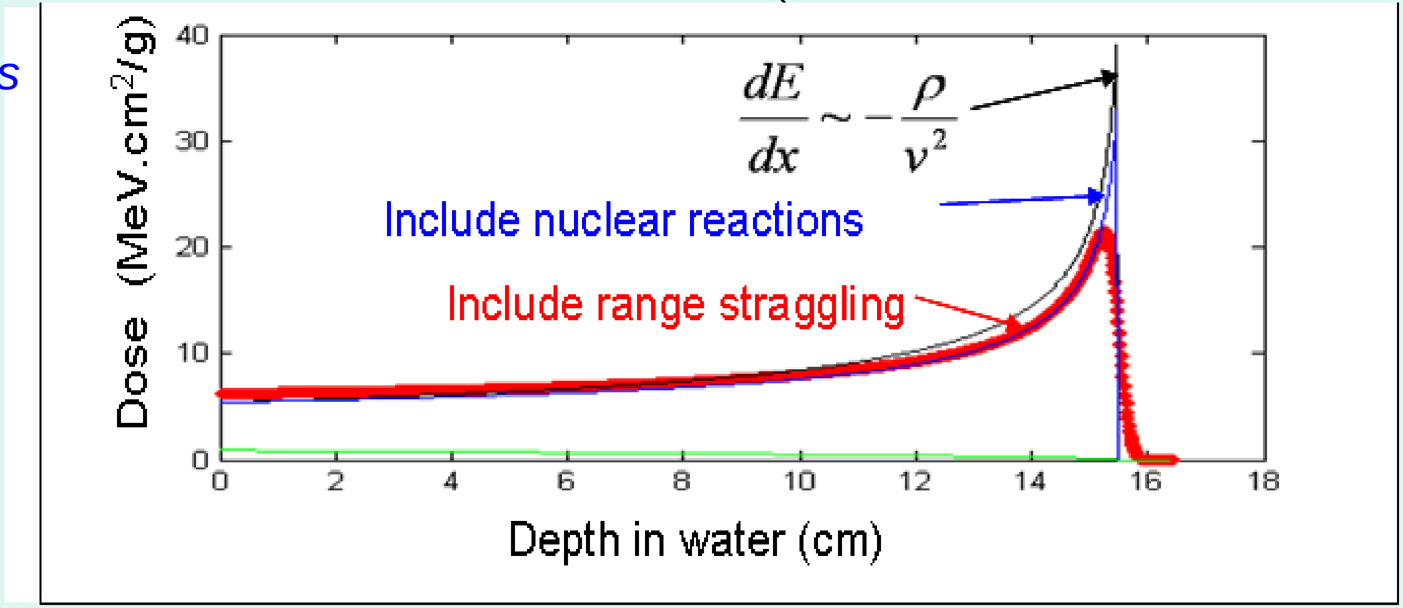
Nuclear reaction





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

- → *loss of protons*
- → *nuclear fragments*
- → *neutrons*
- → *radioactivity*

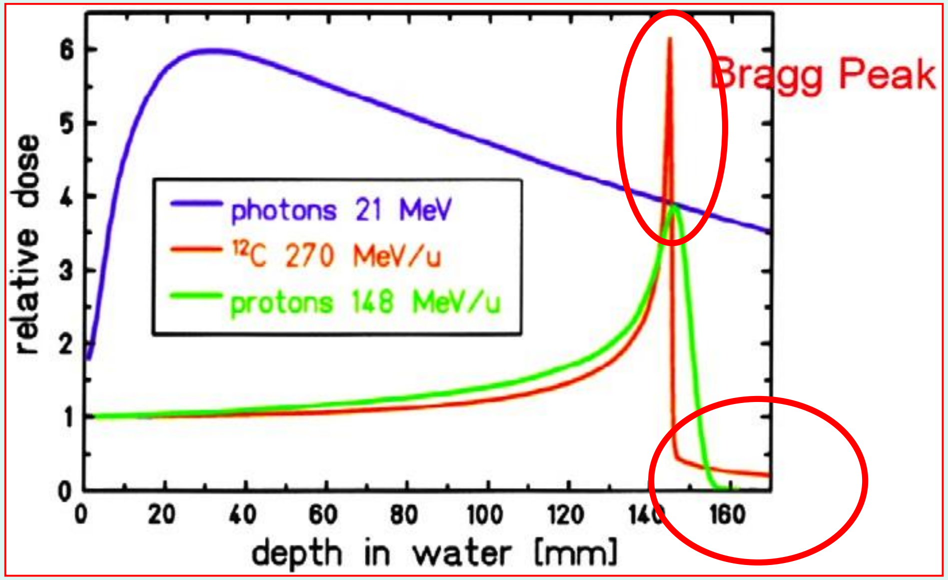


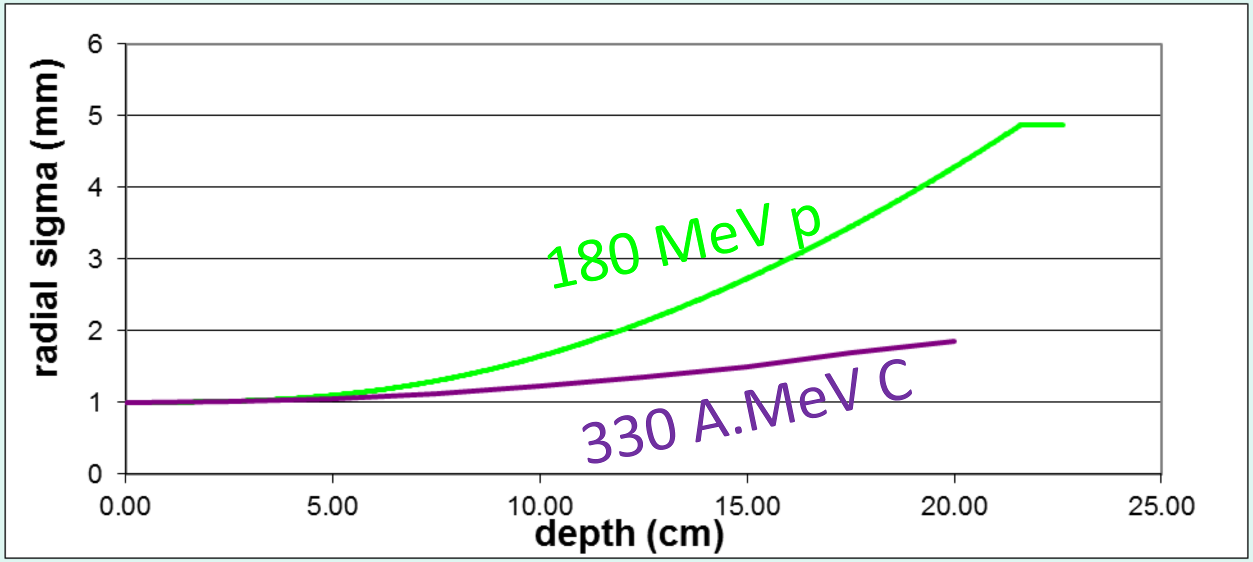
→ Additional dose from reaction products

What will Carbon ions bring?

Difference with protons:

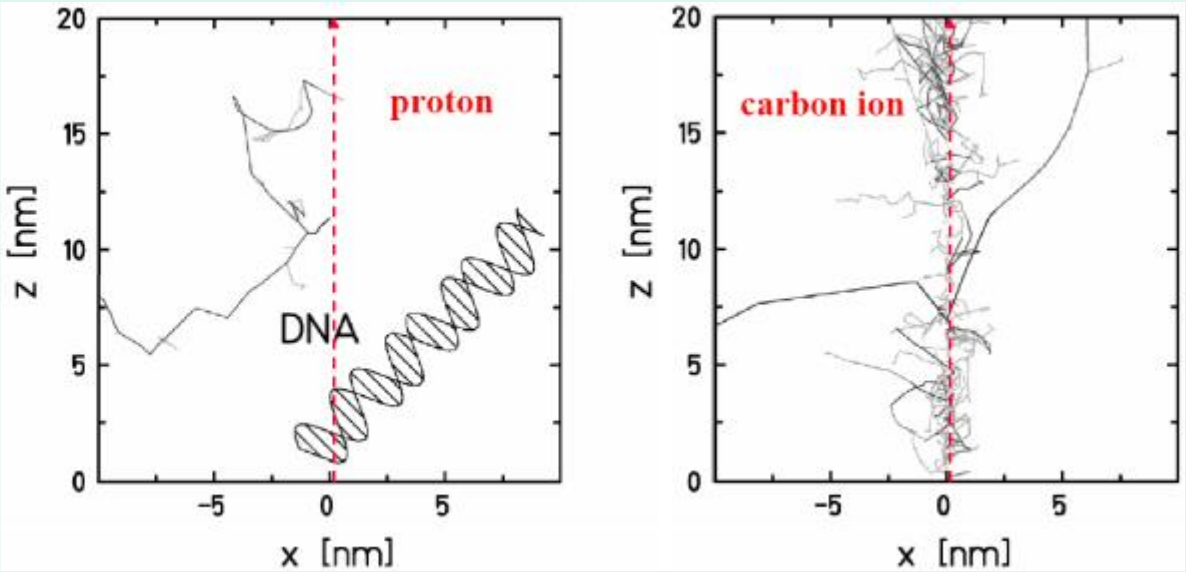
- Sharper Bragg peak
- Tail of fragments
- Less Scattering
- Larger RBE

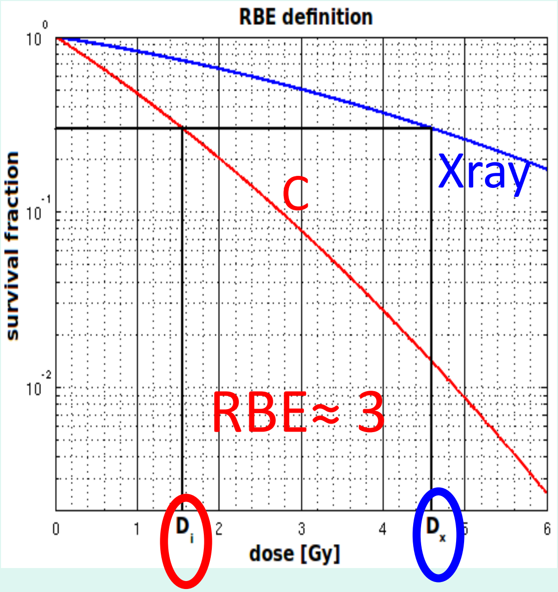




Biological effect of Carbon ions

Radio **B**iological **E**ffectiveness: **RBE** carbon= $\frac{D_{Xray}}{D_{Carbon}}$ for same cell killing.

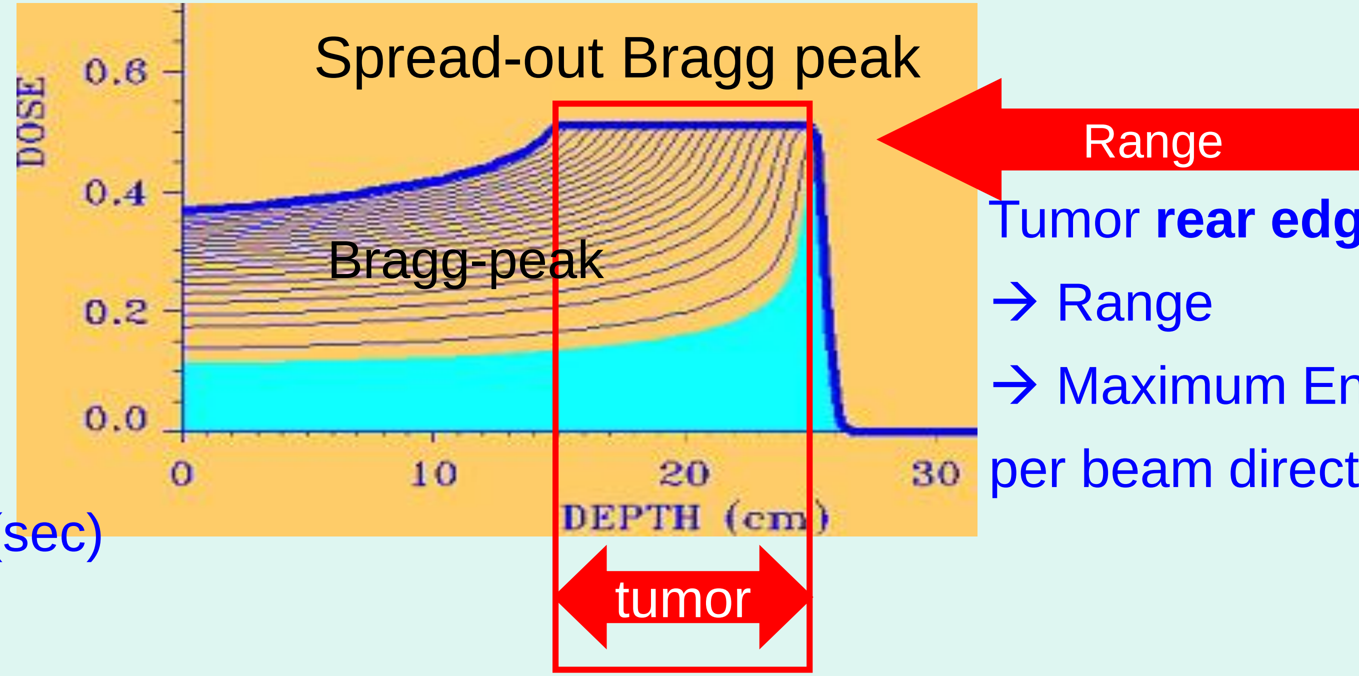




electron track (or energy) density at μm scale effects RBE (this means: RBE≠ 1)

Dose delivery techniques

Dose delivery techniques: **Depth**



Tumor **rear edge**

→ Range

→ Maximum Energy

per beam direction → „slow“ (sec)

Tumor **thickness**

→ spread-out Bragg peak

→ energy modulation

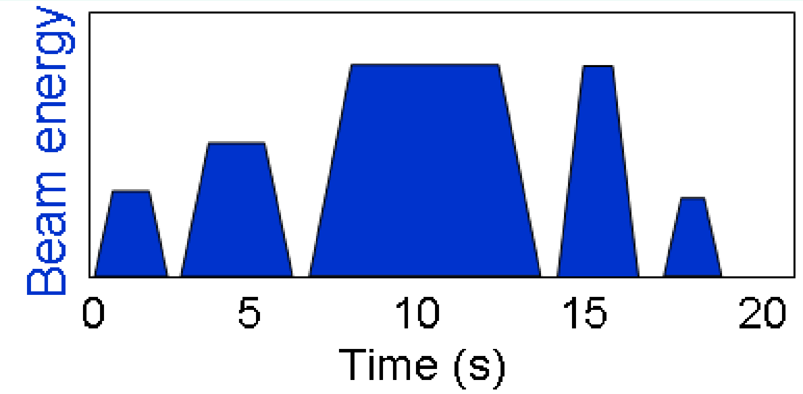
During trmt → „fast“ (<0.1-0.2 sec)

Dose delivery techniques: **Depth**

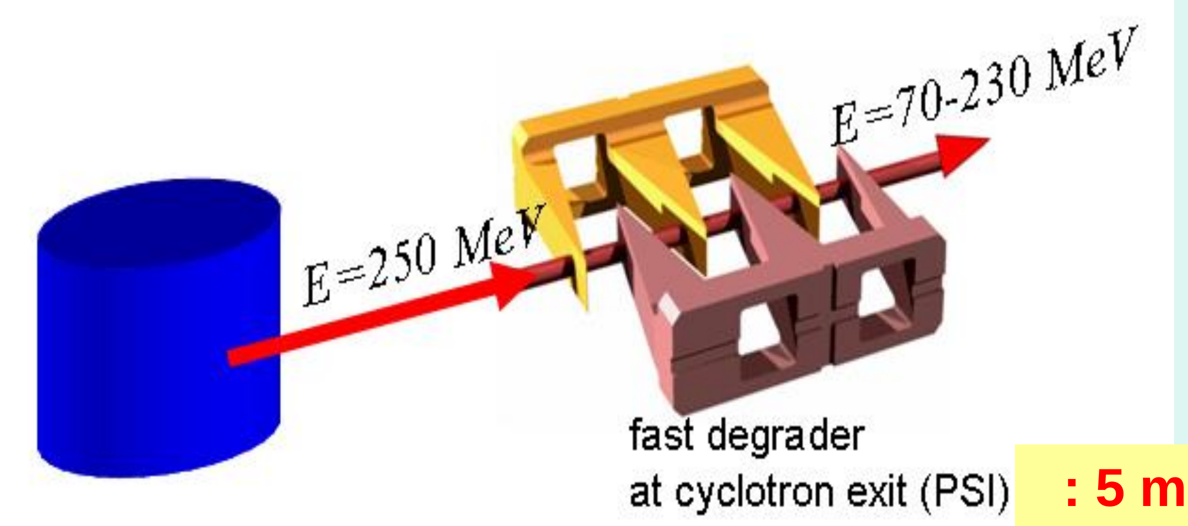
Vary energy at accelerator

Synchrotron: Set energy at each **spill:**

➔ Sets range only
➔ energy modulation in nozzle



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



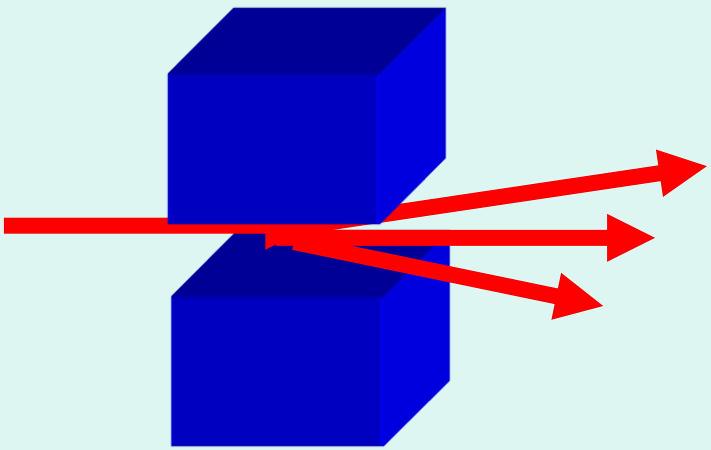
fast degrader
at cyclotron exit (PSI)

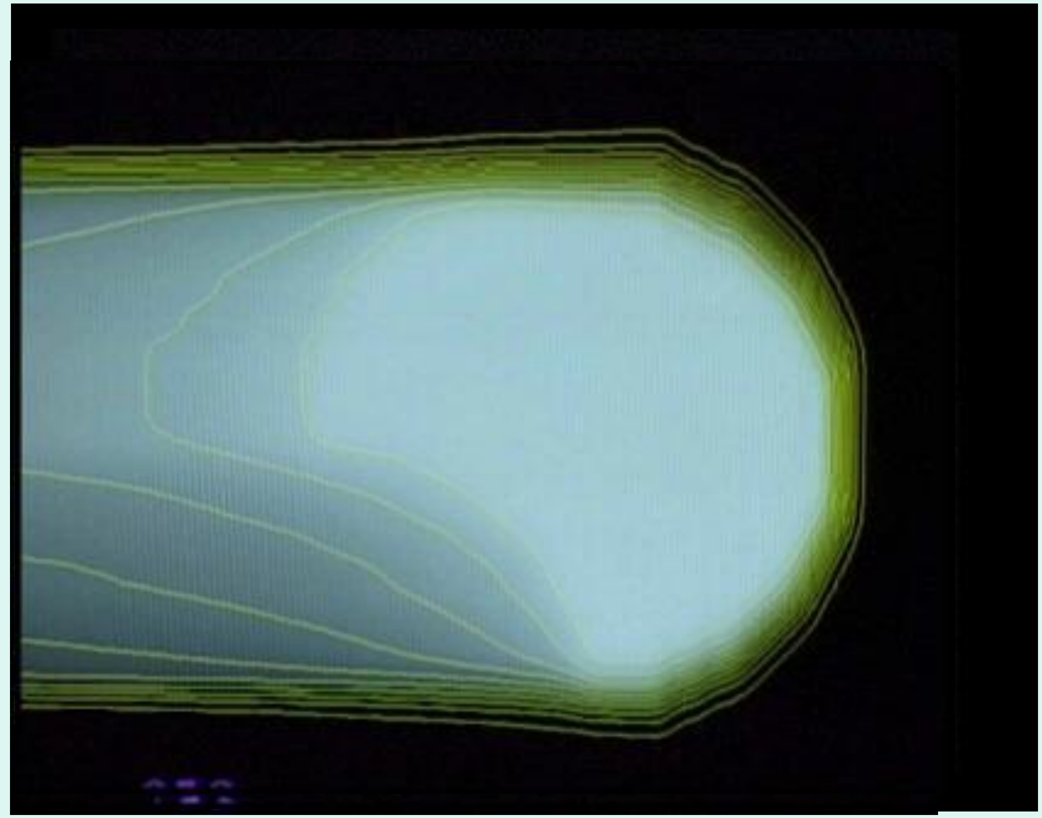
➔ Sets range
And, if fast enough
+ fast magnets:
➔ also energy modulation

: 5 mm ΔRange in 100-200 ms

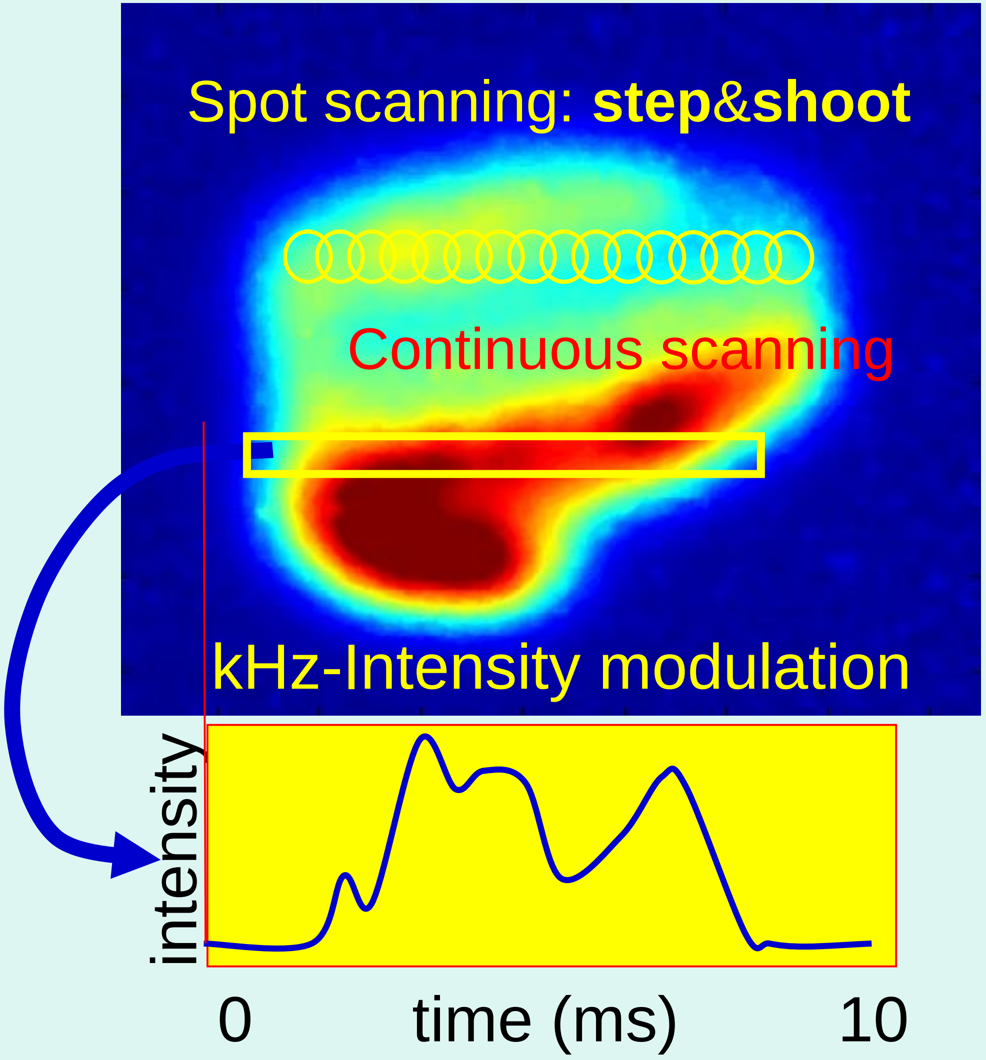
Dose delivery techniques: **lateral**

pencil-beam scanning





Pencil beam scanning



allows fast target **(re)painting**

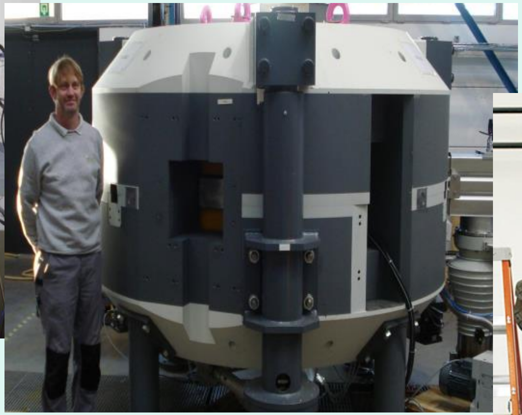
Present accelerator choice

	cyclotron	synchrotron
Protons	in use, ∅3.5-5 m	in use, ∅8-10 m
Carbon ions	in design, ∅6 m	in use, ∅25 m

Cyclotrons for proton therapy

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

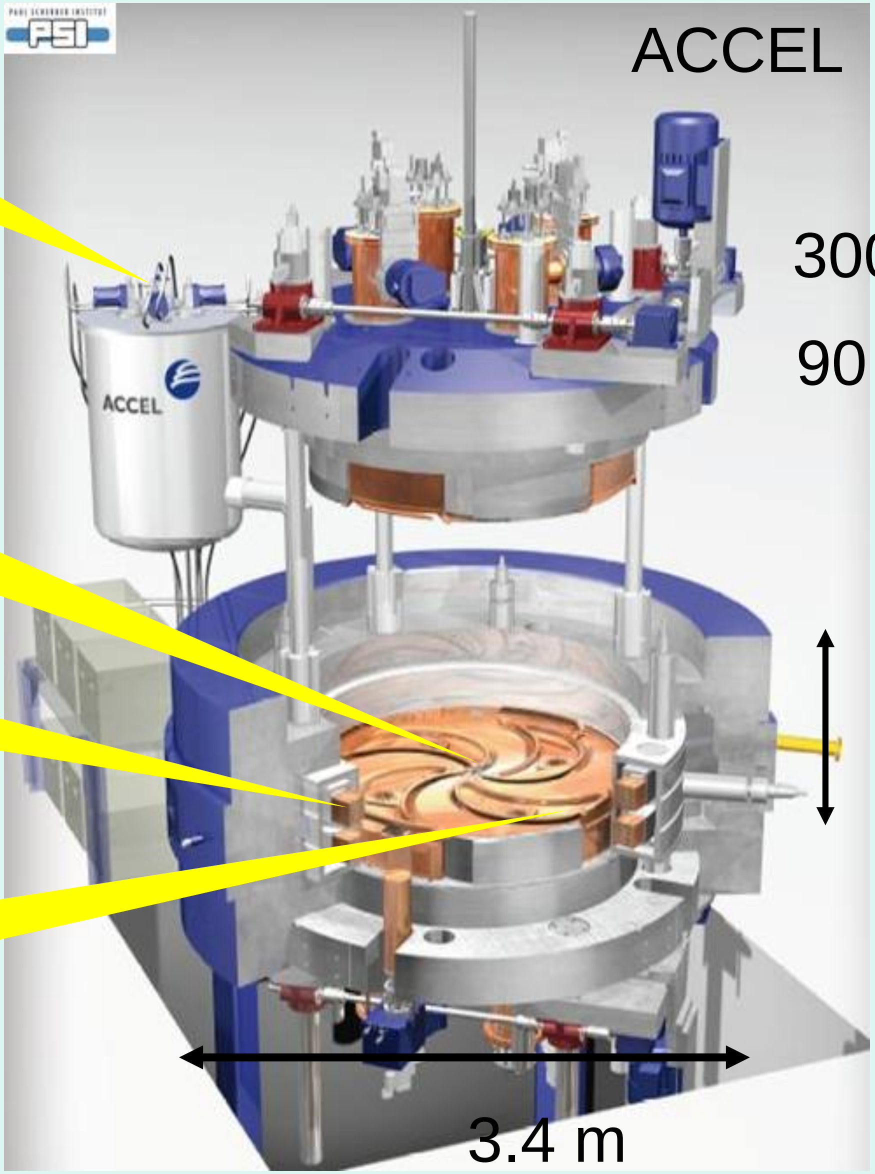
4 x 1.5 W @4K

Proton source

superconducting coils
=> 2.4 - 3.8 T

4 RF-cavities

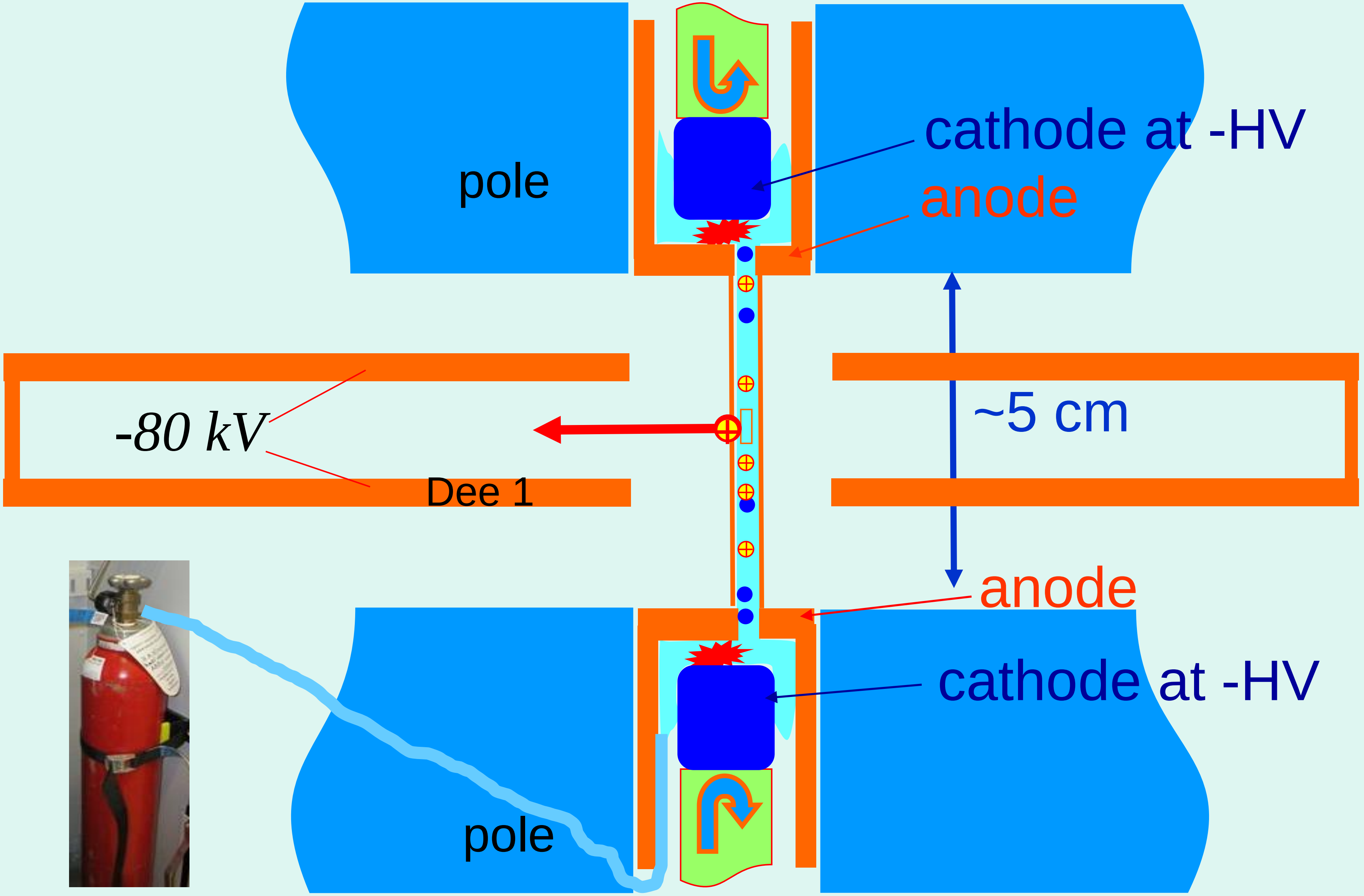
~100 kV on 4 Dees



300 kW

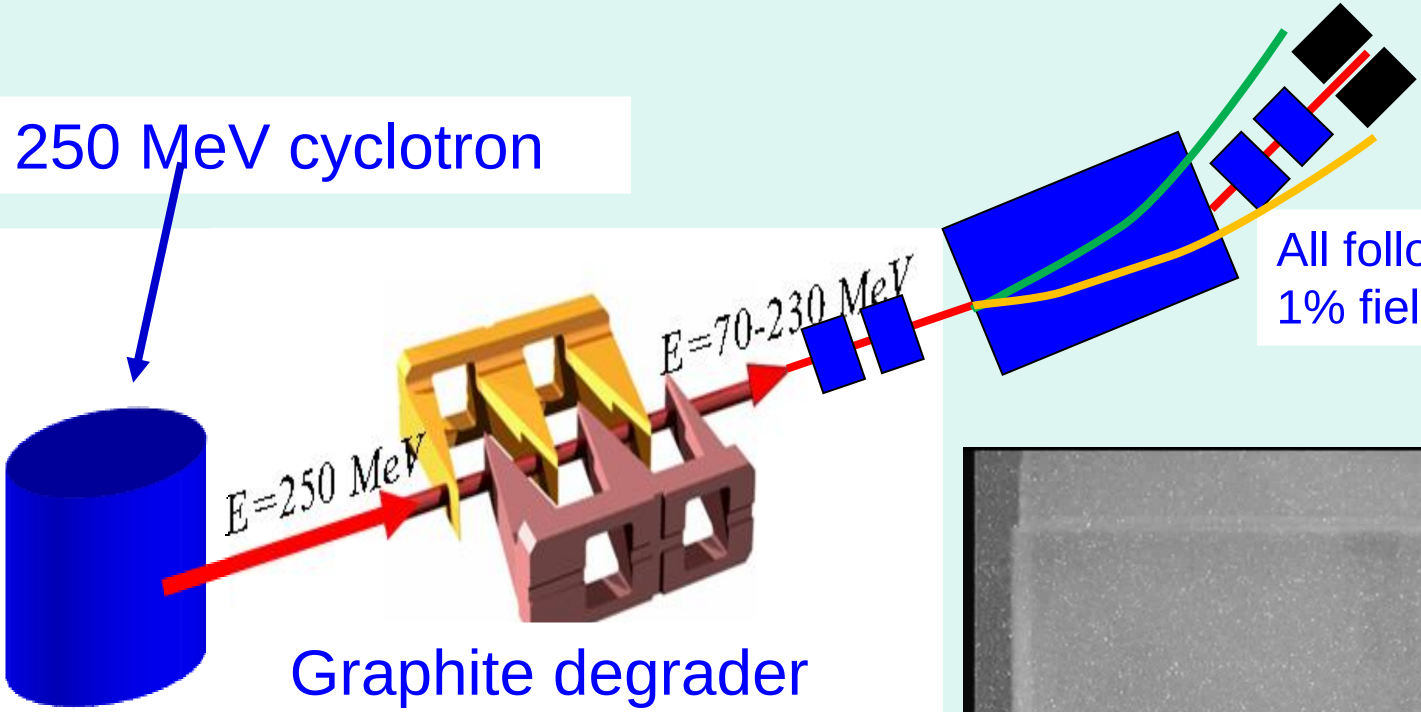
90 tons

Internal proton source



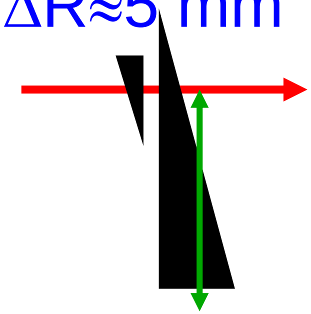
E-adjustment with cyclotron

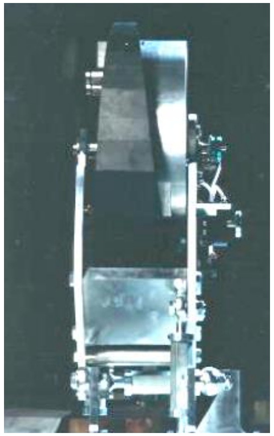
250 MeV cyclotron

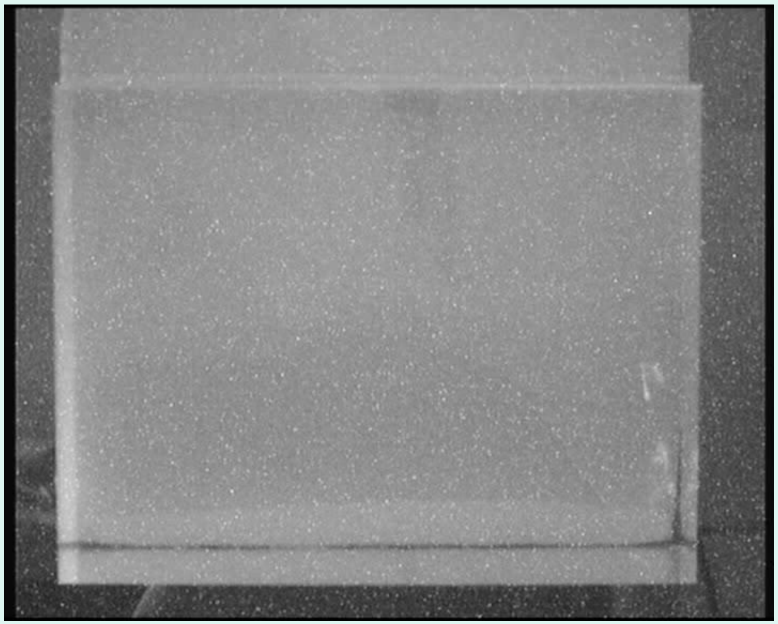


All following magnets:
1% field change

Graphite degrader
E-Steps → ΔR≈5 mm







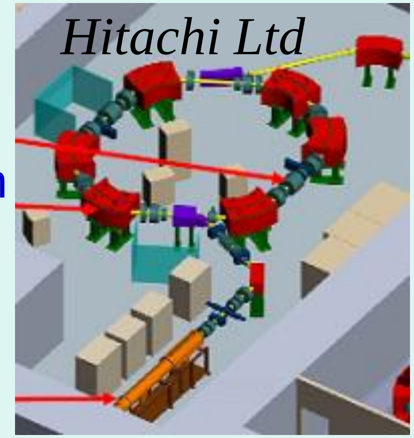
Synchrotron (1945)

Protons only:

(∅ ~8 m)

synchrotron

Proton source + injector



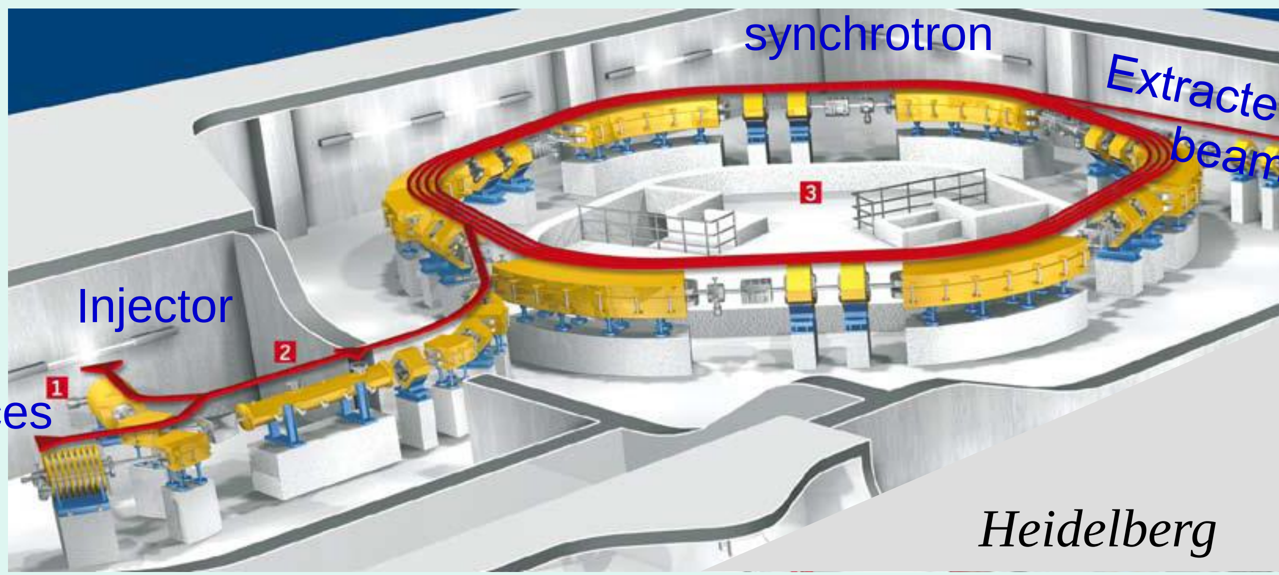
Extracted beam

Ions (p-C):

(∅ ~25 m)

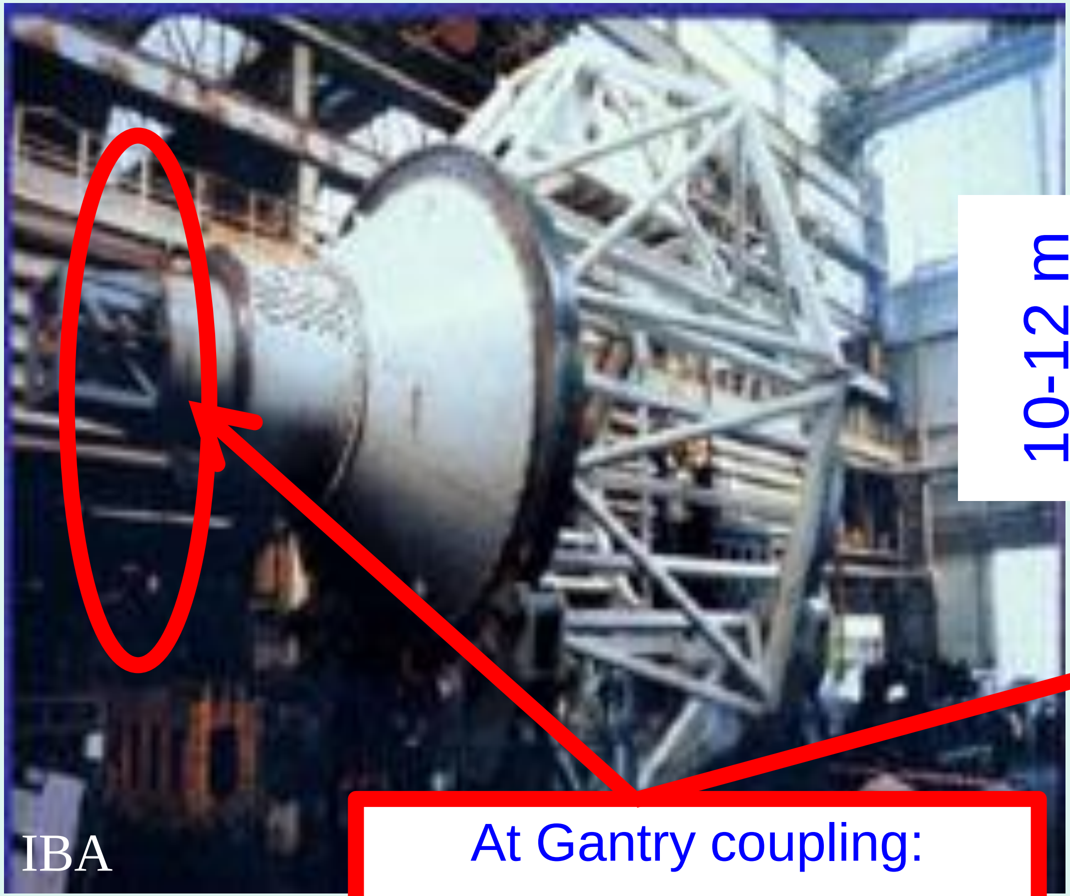
Injector

Ion sources



Gantry as seen from patient side

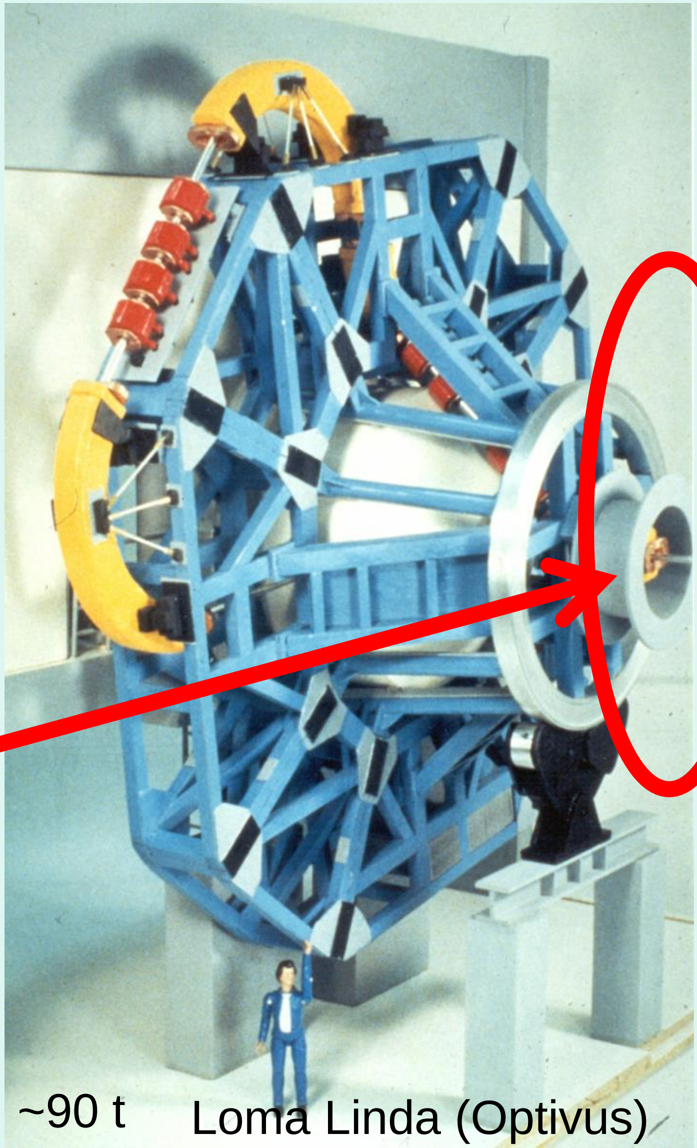
Gantries



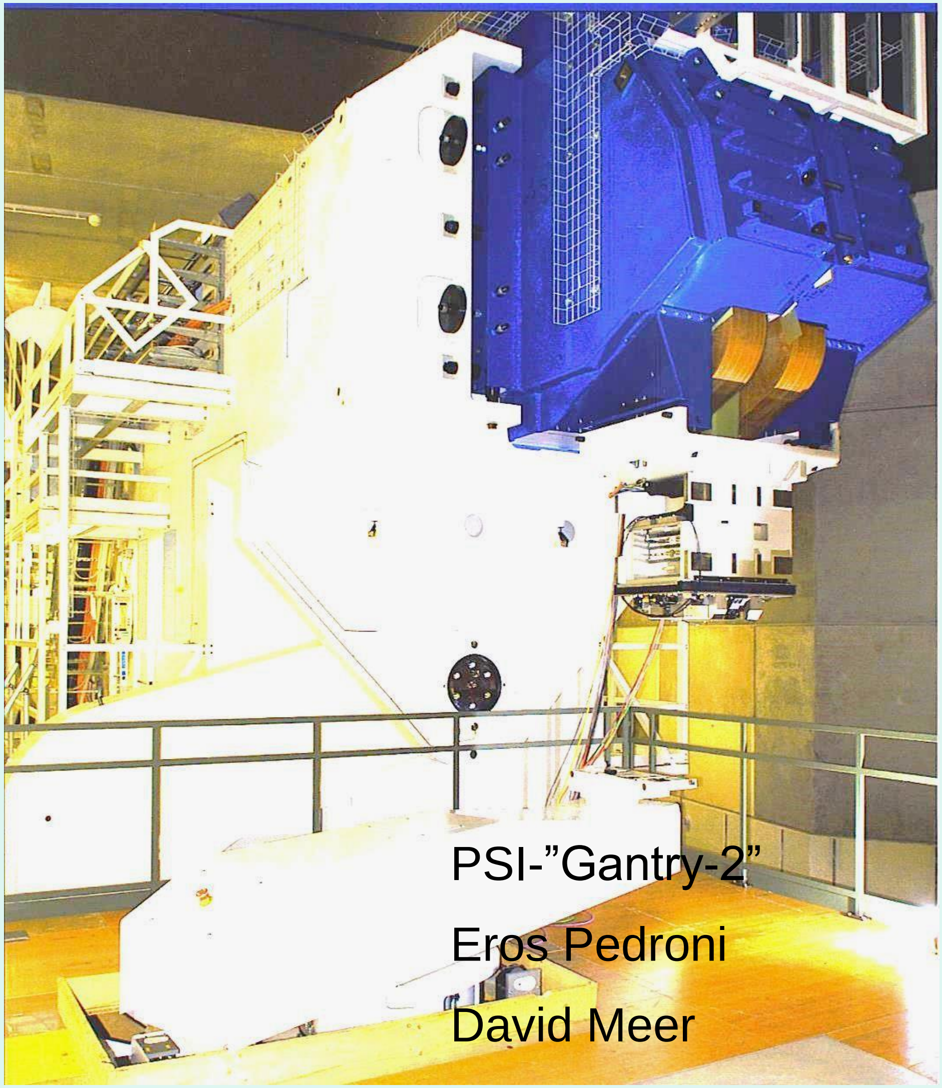
10-12 m

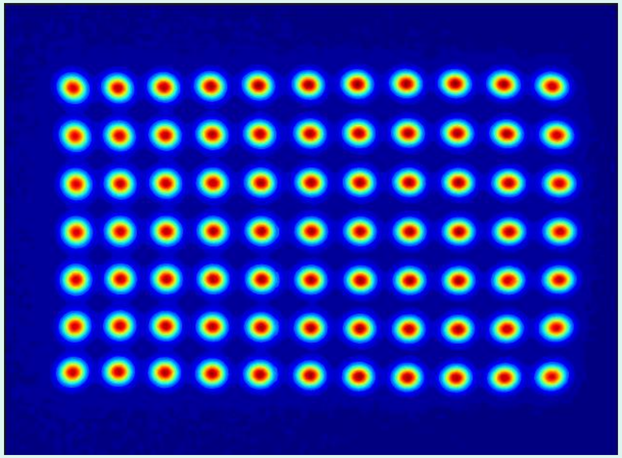
At Gantry coupling:

- Phase space symmetric
- No dispersion



PSI Gantry-2: fast 3D scanning





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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, 1996

Thank you !!

Gantry: Eros Pedroni

Tumours in kids: Beate Timmermann, Gudrun Goitein