ACCELERATORS IN CANCER THERAPY - I

Ugo Amaldi

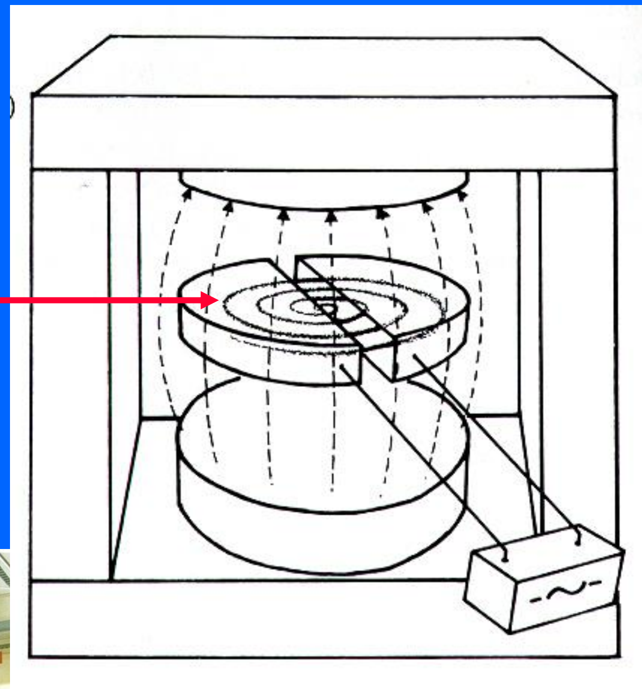
TERA Foundation and

Technische Universität München, Institute for Advanced Study

Accelerators

1930: invention of the cyclotron

Spiral tajectory of an accelerated nucleus

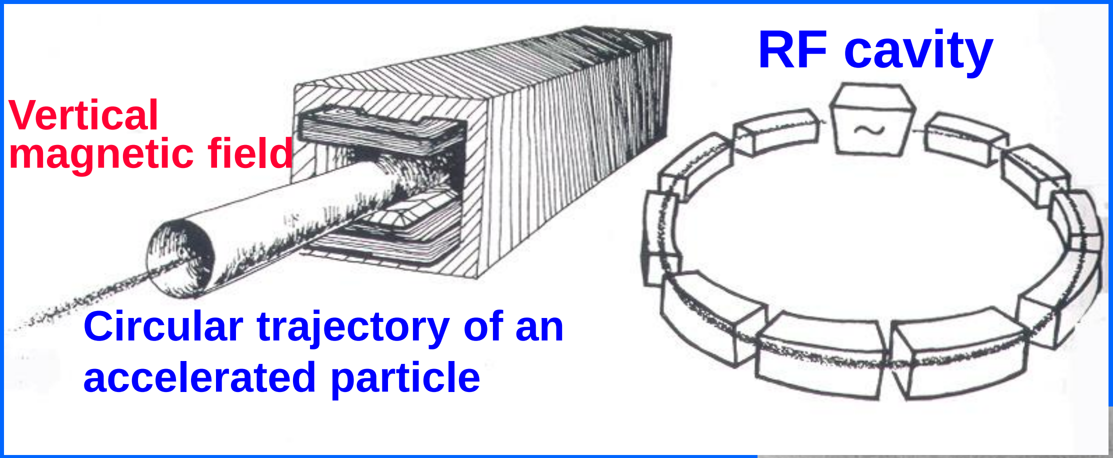


Ernest Lawrence (1901 – 1958)

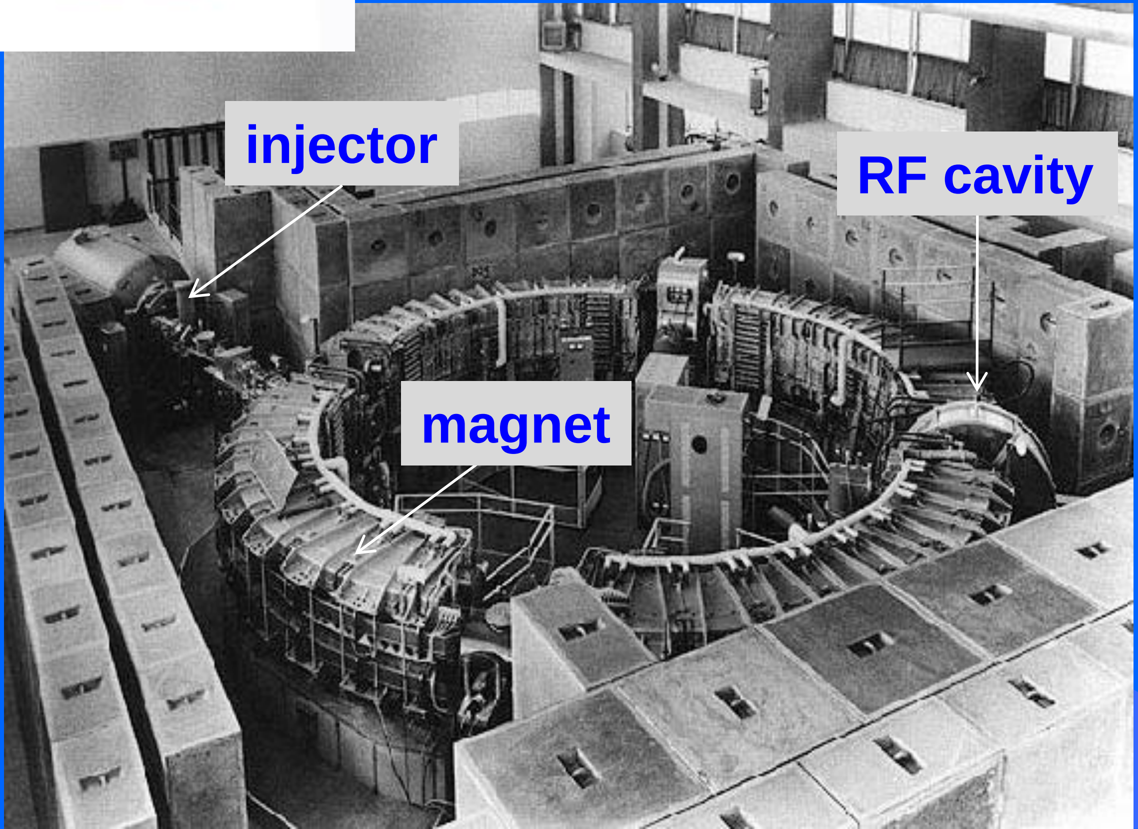
Modern 30 MeV cyclotron for radioisotope production

1944: E. McMillan and V.J.Veksler
"Phase stability principle"

The «synchrotron»



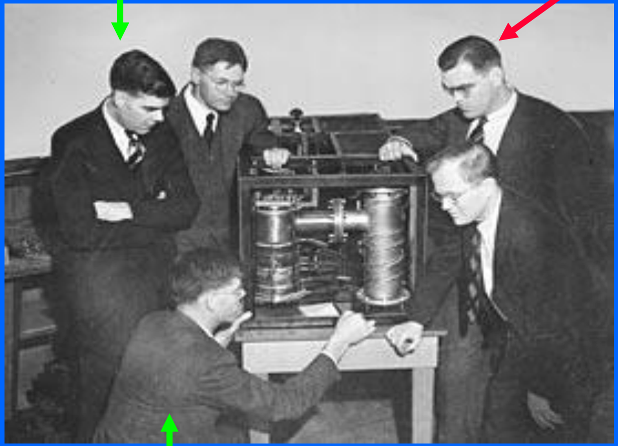
1 GeV
electron synchrotron
Frascati - INFN - 1959



The first electron linac

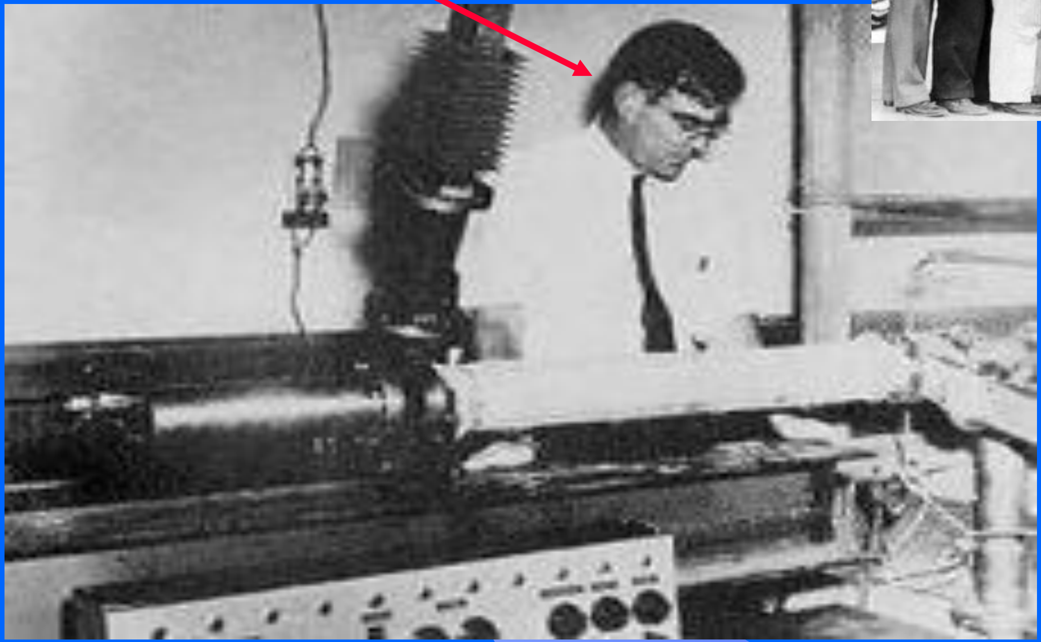
Sigmur Varian

William W. Hansen



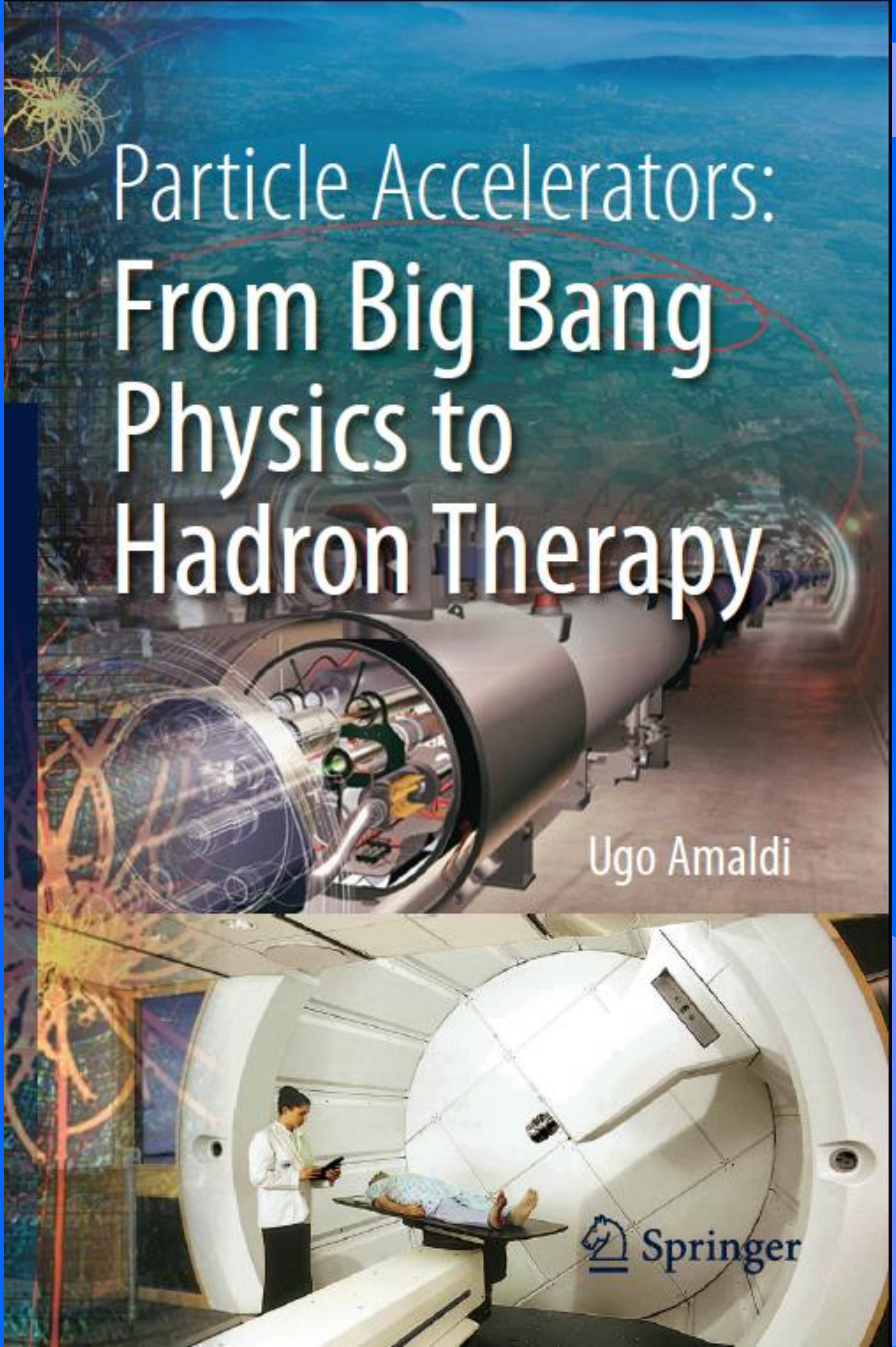
Russell Varian

1939
Invention of the klystron

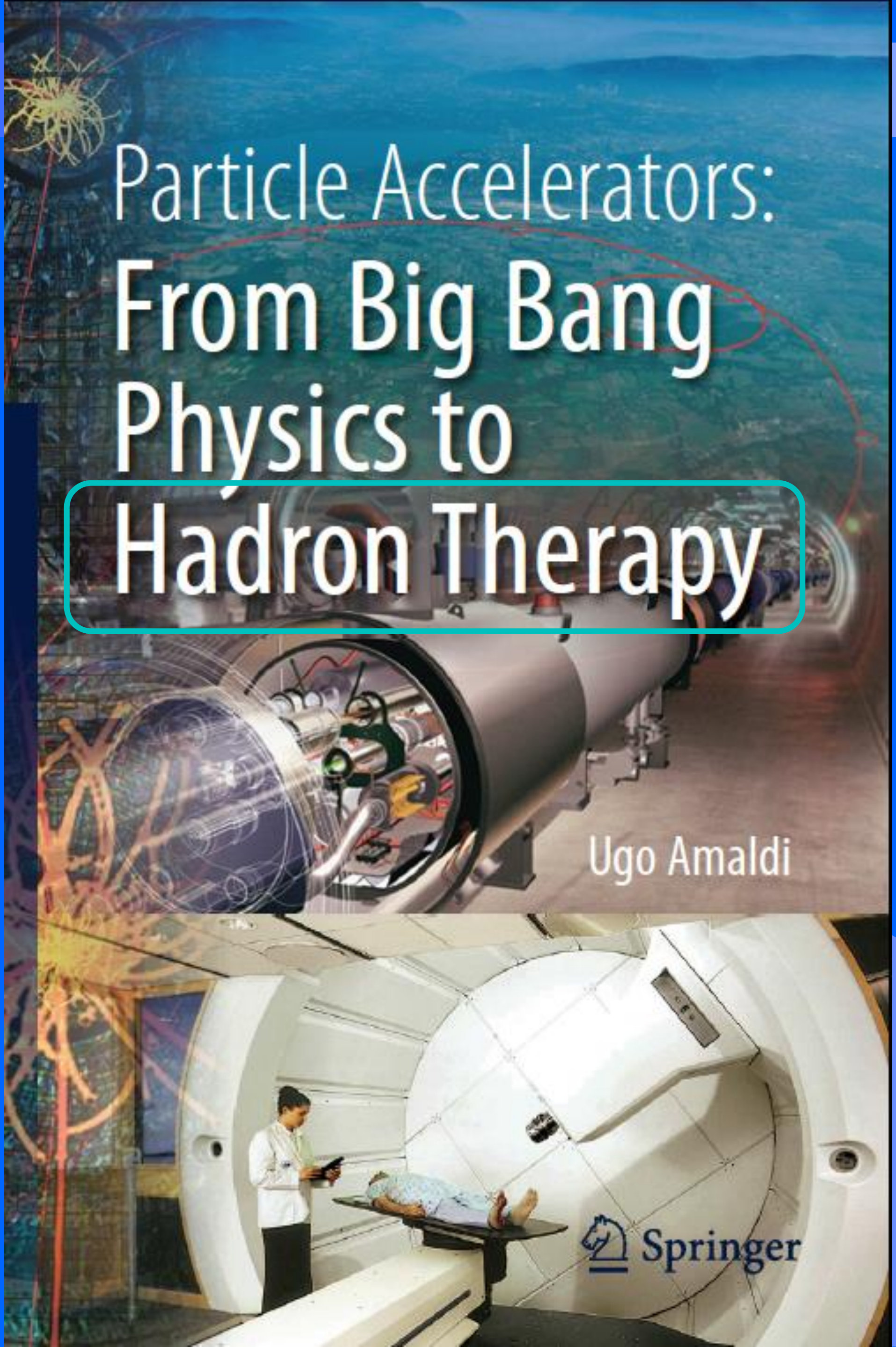


1947
linac for electrons
1.5 MeV at 3 GHz

March 2015

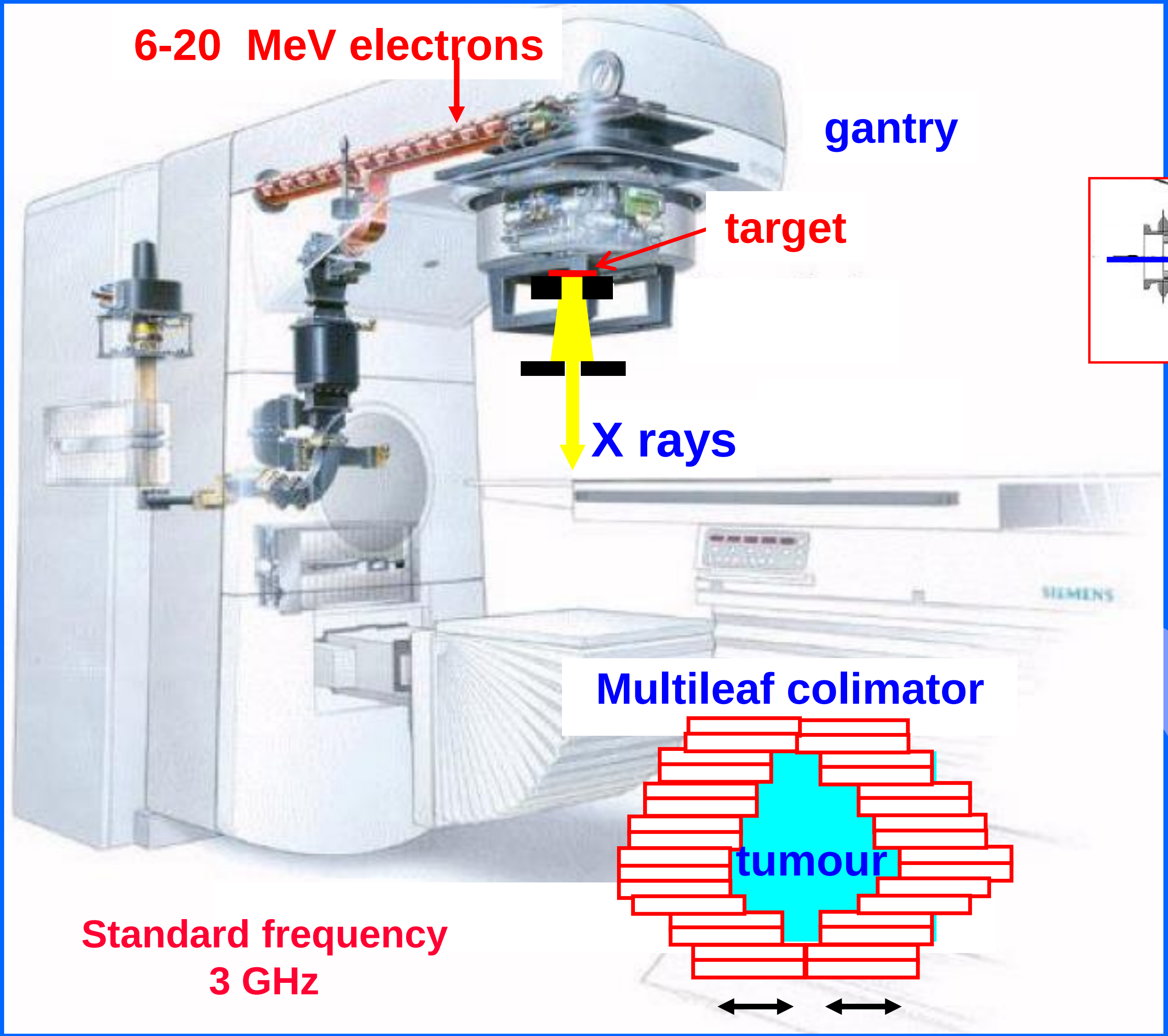

Particle Accelerators:
From Big Bang Physics to Hadron Therapy
Ugo Amaldi
Springer

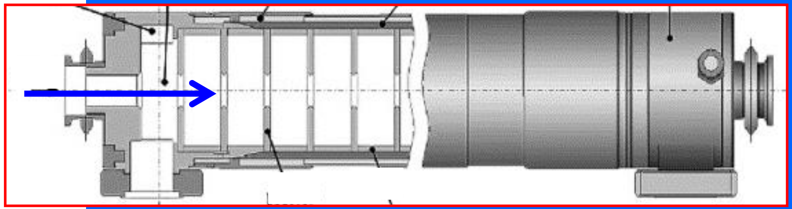
March 2015


Particle Accelerators:
From Big Bang Physics to Hadron Therapy
Ugo Amaldi
Springer

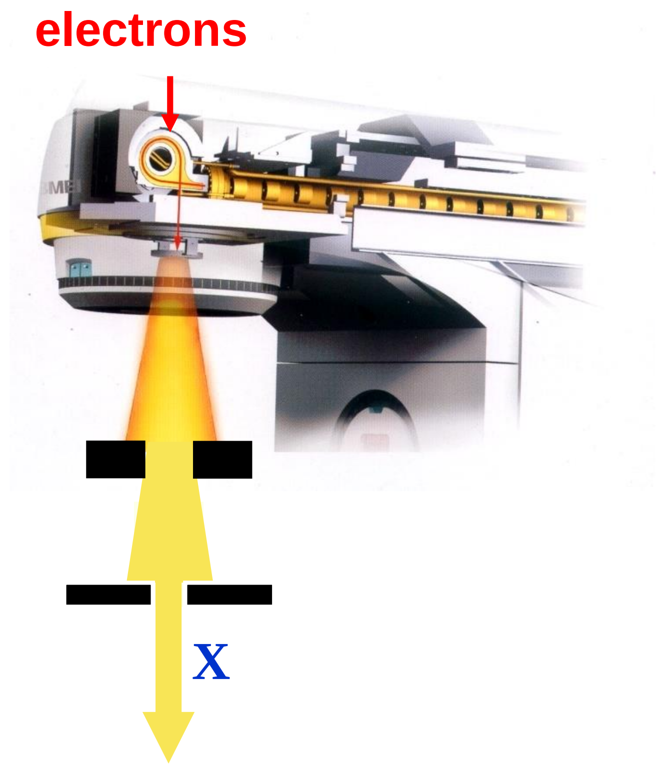
Conventional radioterapy

‘Conventional’ radiotherapy: linear accelerators dominate





‘Conventional’ radiotherapy: linear accelerators dominate

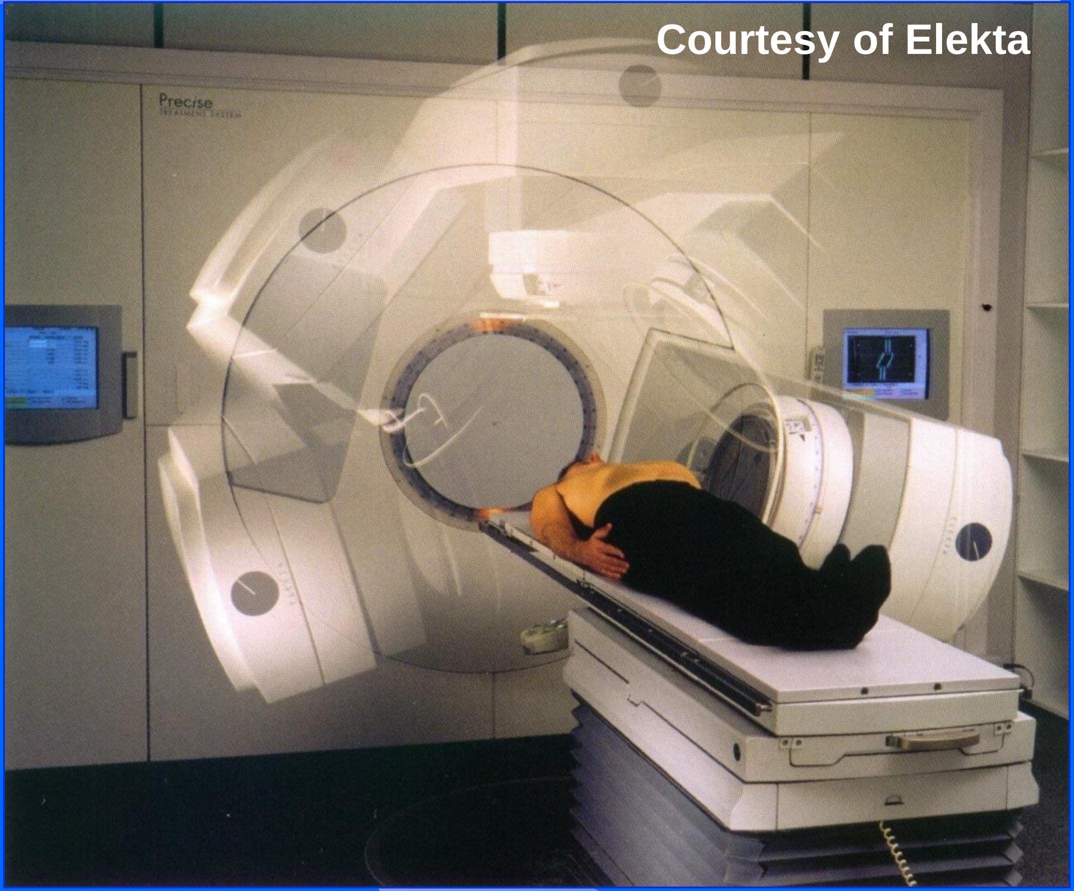


Courtesy of Elekta

2000 patients/year every 1 million inhabitants have a 30-35 session treatment of about 2 grays (Gy) (*)

(*) dose = energy / mass - measured in gray = joule / kg

‘Conventional’ radiotherapy: linear accelerators dominate



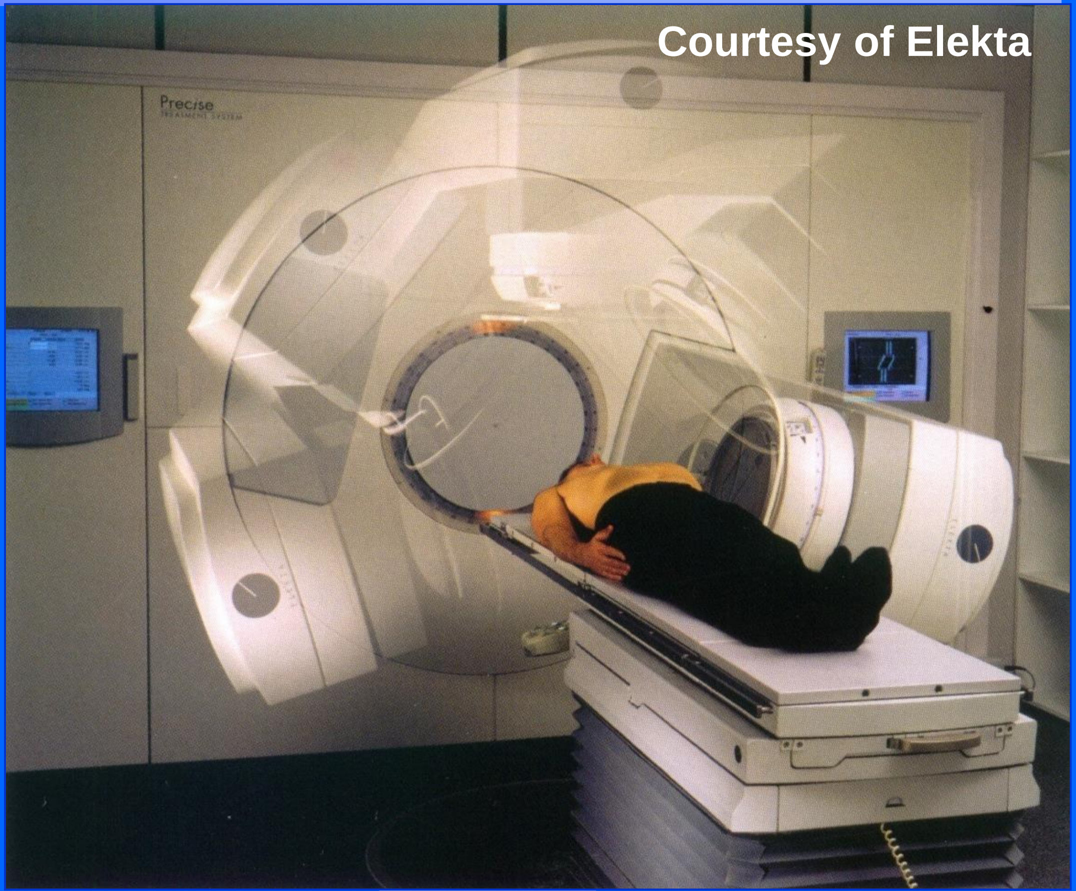
In 1 treatment room:

4 sessions/h
10 h/day
40 sessions/d
250 d/year

Maximum: 10 000 sessions/year
≤10,000/30 = 330 patients/year

6-7 X-ray treatment rooms per million inhabitants

‘Conventional’ radiotherapy: linear accelerators dominate



In 1 treatment room:

4 sessions/h
10 h/day
40 sessions/d
250 d/year

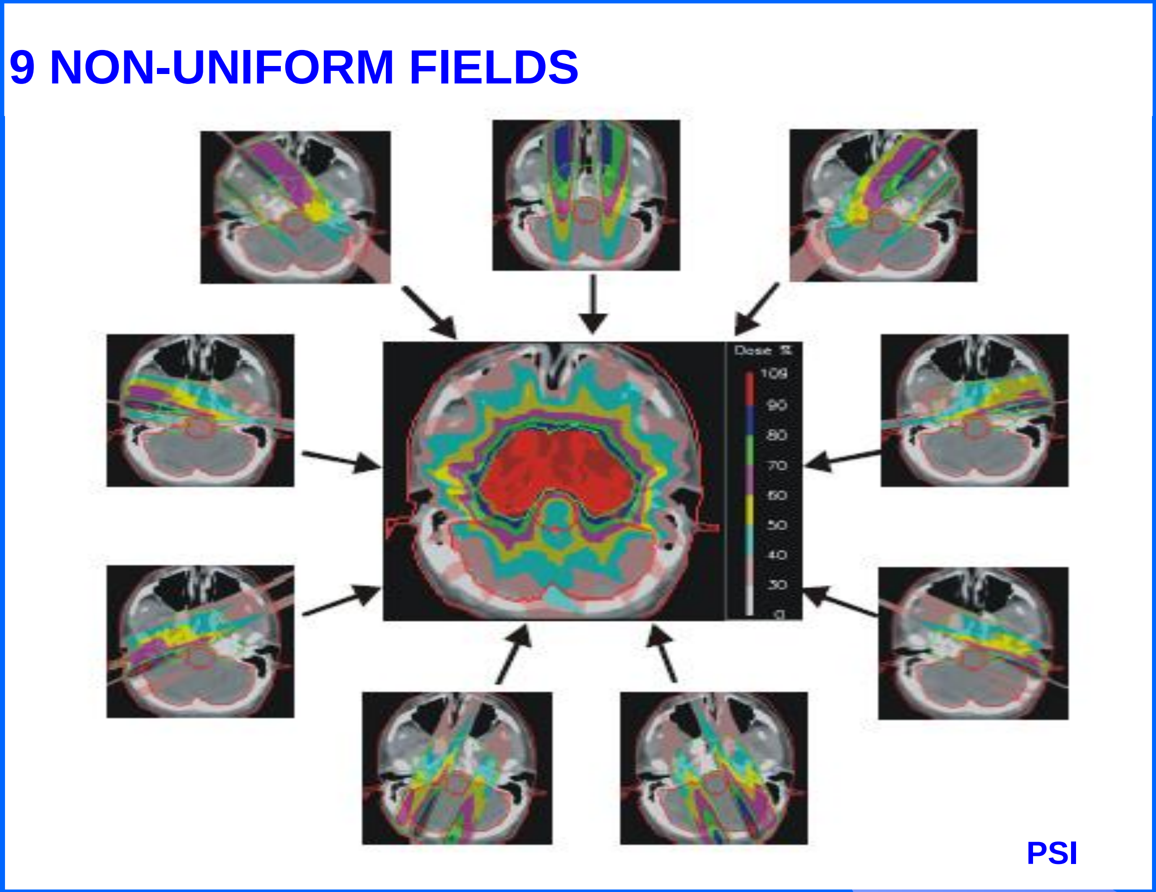
Maximum: 10 000 sessions/year
≤10,000/30 = 330 patients/year

6-7 X-ray treatment rooms
per million inhabitants

In the world radiation oncologists use 25 000 electron linacs

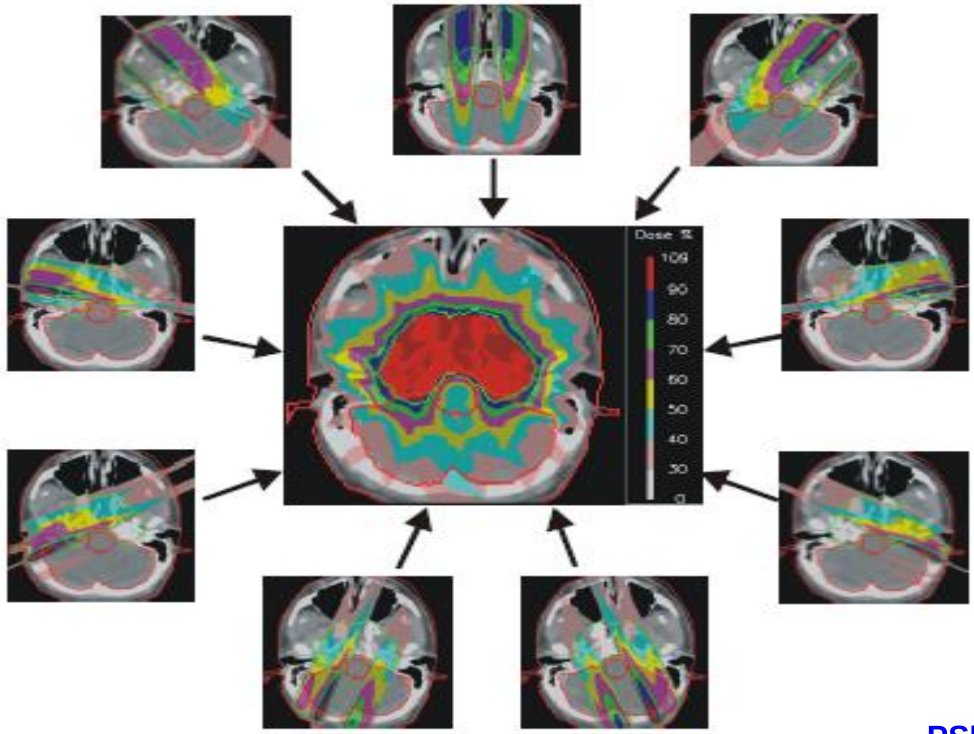
50% of all the existing accelerators above 1 MeV

IMRT = Intensity Modulated Radiation Therapy with photons



IMRT = Intensity Modulated Radiation Therapy with photons

9 NON-UNIFORM FIELDS



PSI

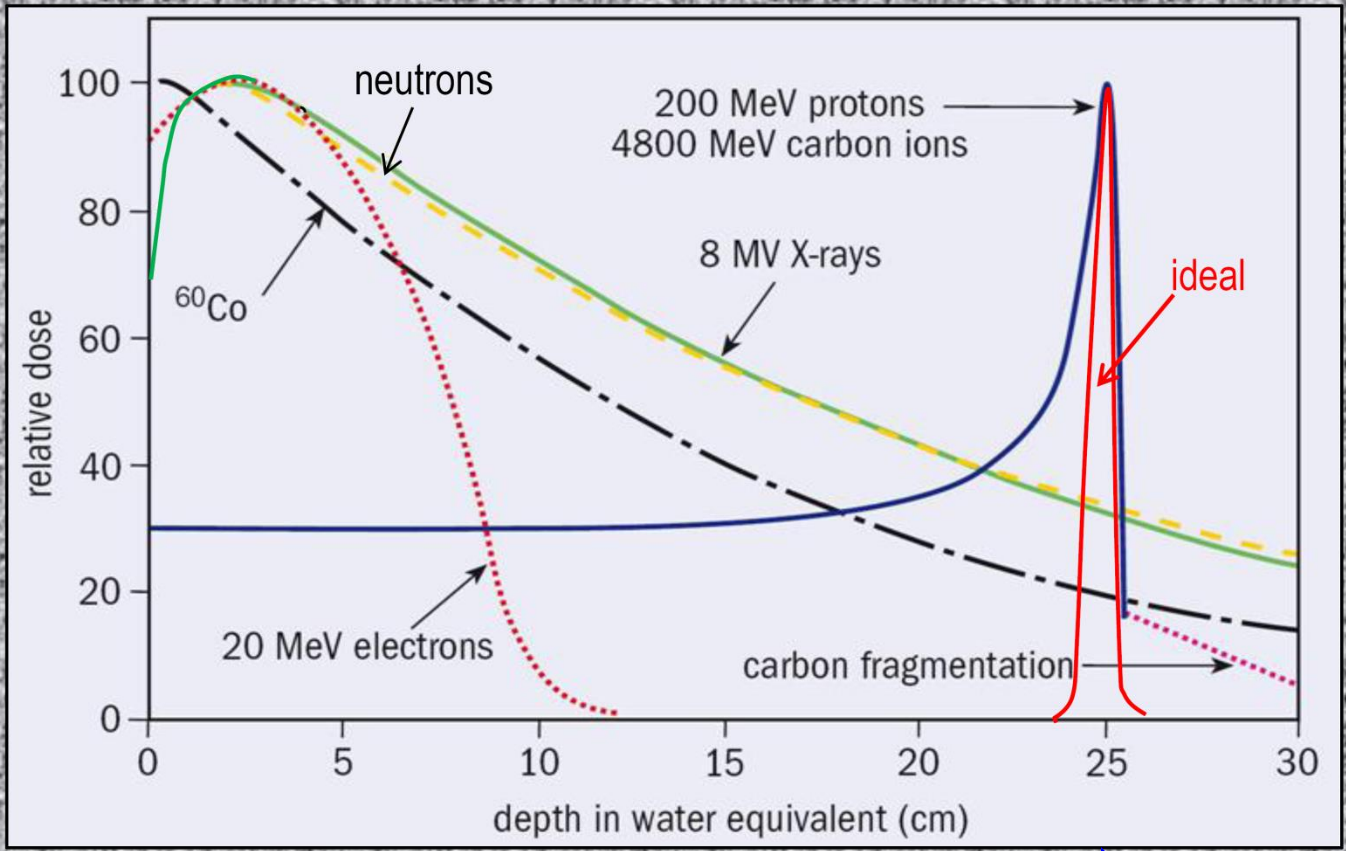
60-75 grays (joule/kg) given in 30-35 fractions (6-7weeks)

to allow healthy tissues to repair:

90% of the tumours are radiosensitive

TERA

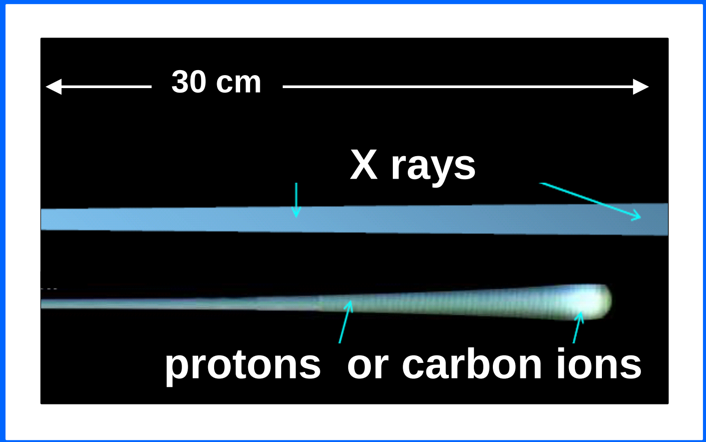
Distributions of the dose in radiation therapy



Radiation beam in matter

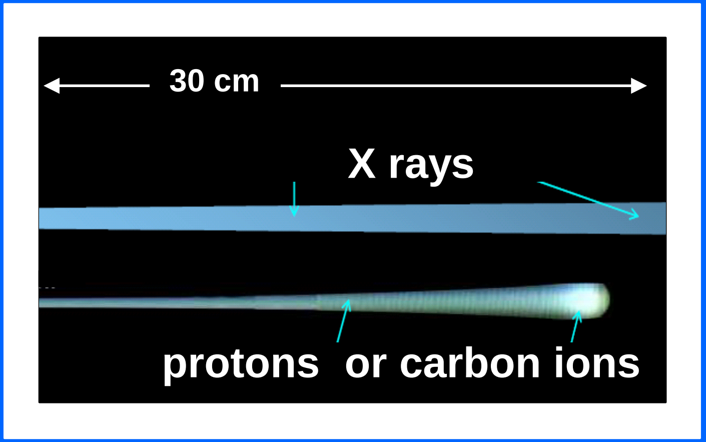
Avantages of protons and carbon ions

protons: 200 MeV
C ions : 5000 MeV



Avantages of protons and carbon ions

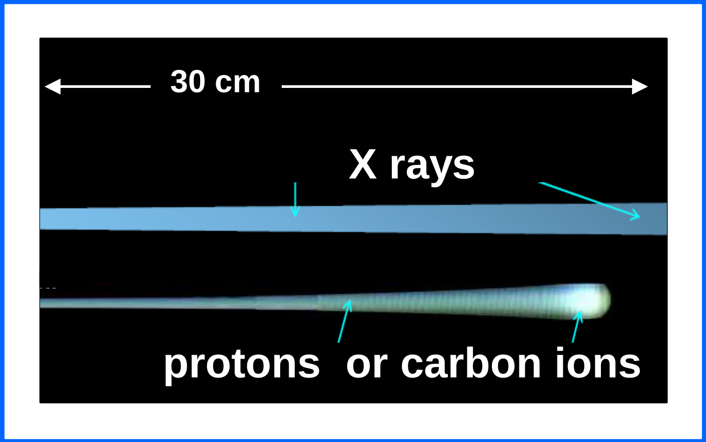
protons: 200 MeV
C ions : 5000 MeV



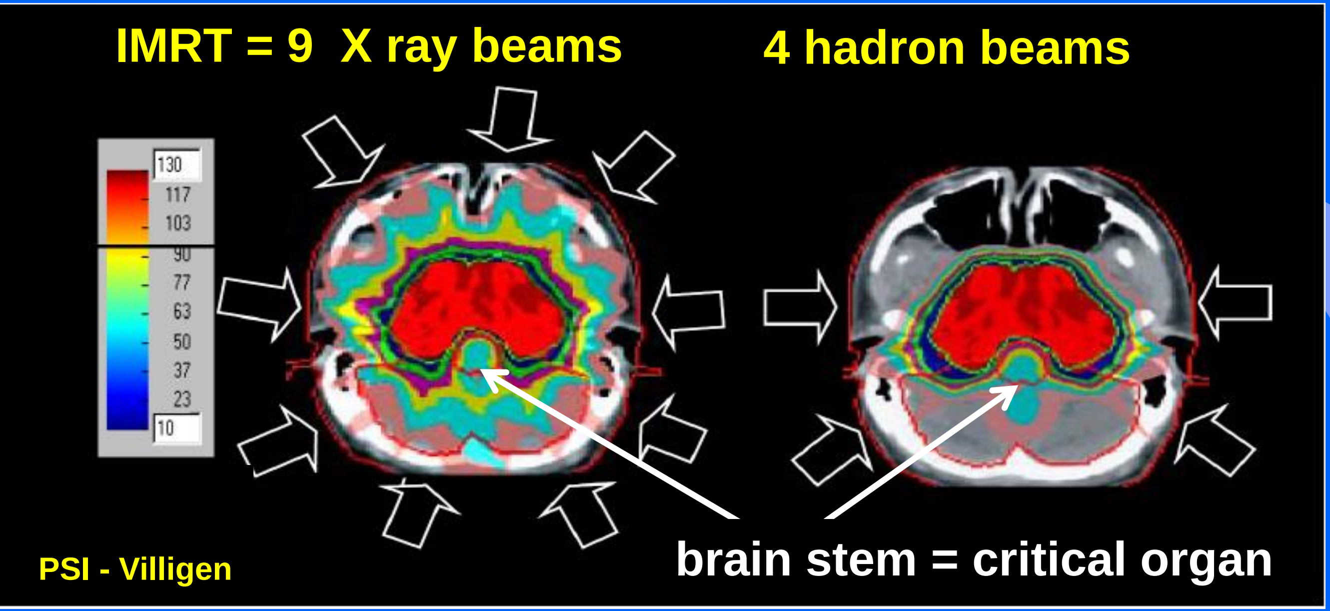
1. **Healthy tissues are spared by protons and carbon ions**

Avantages of protons and carbon ions

protons: 200 MeV
C ions : 5000 MeV

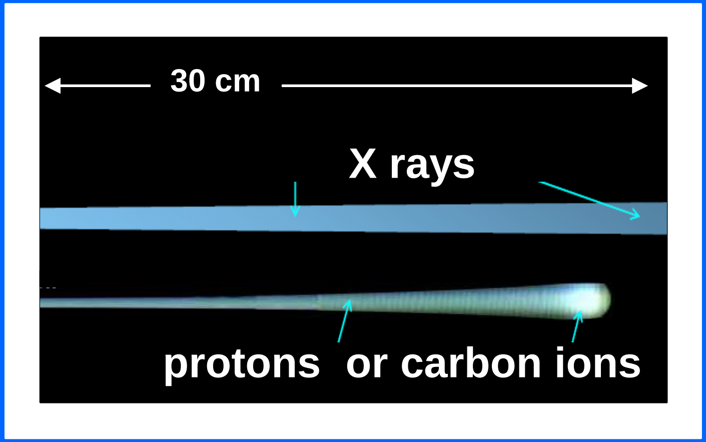


1. Healthy tissues are spared by protons and carbon ions

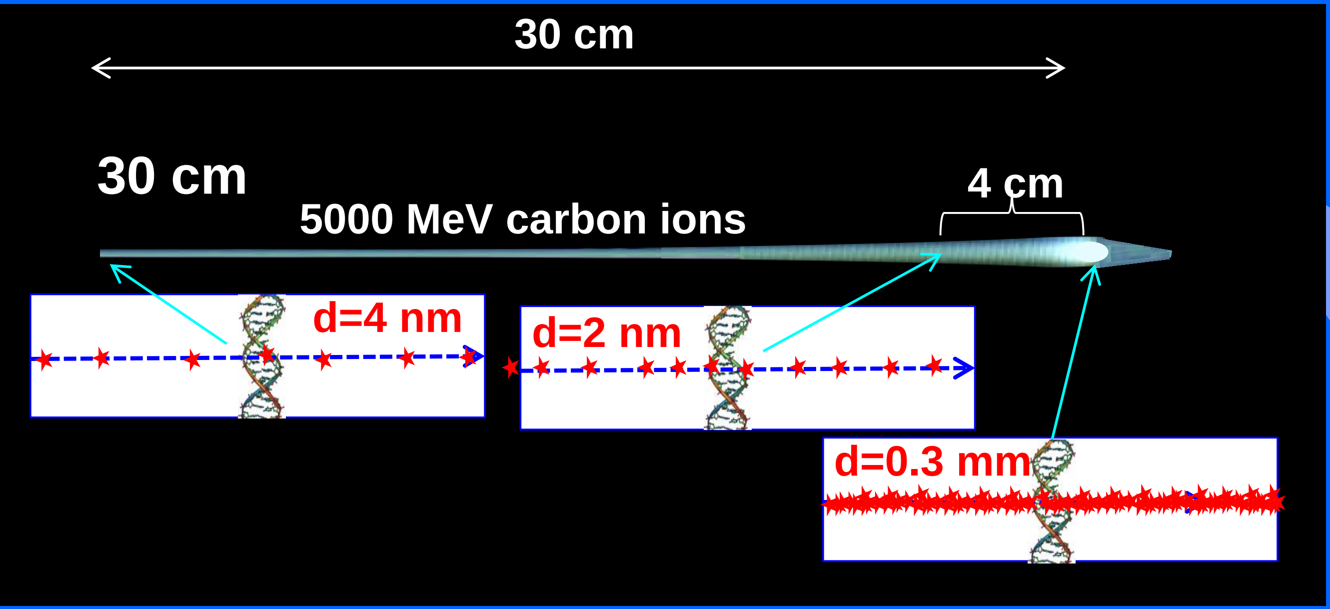


Avantages of protons and carbon ions

protons: 200 MeV
C ions : 5000 MeV

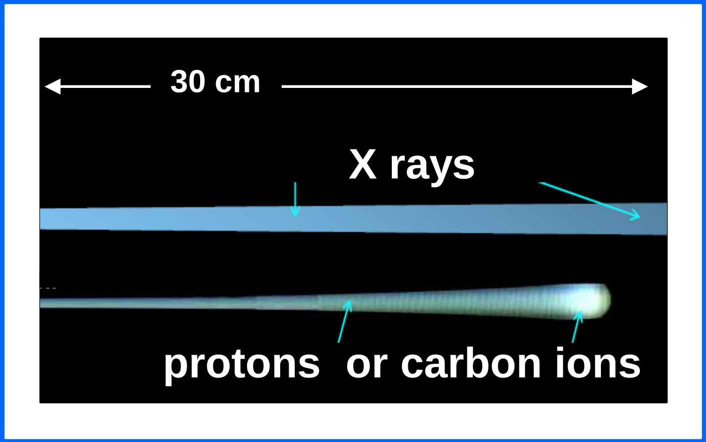


1. Healthy tissues are spared by protons and carbon ions

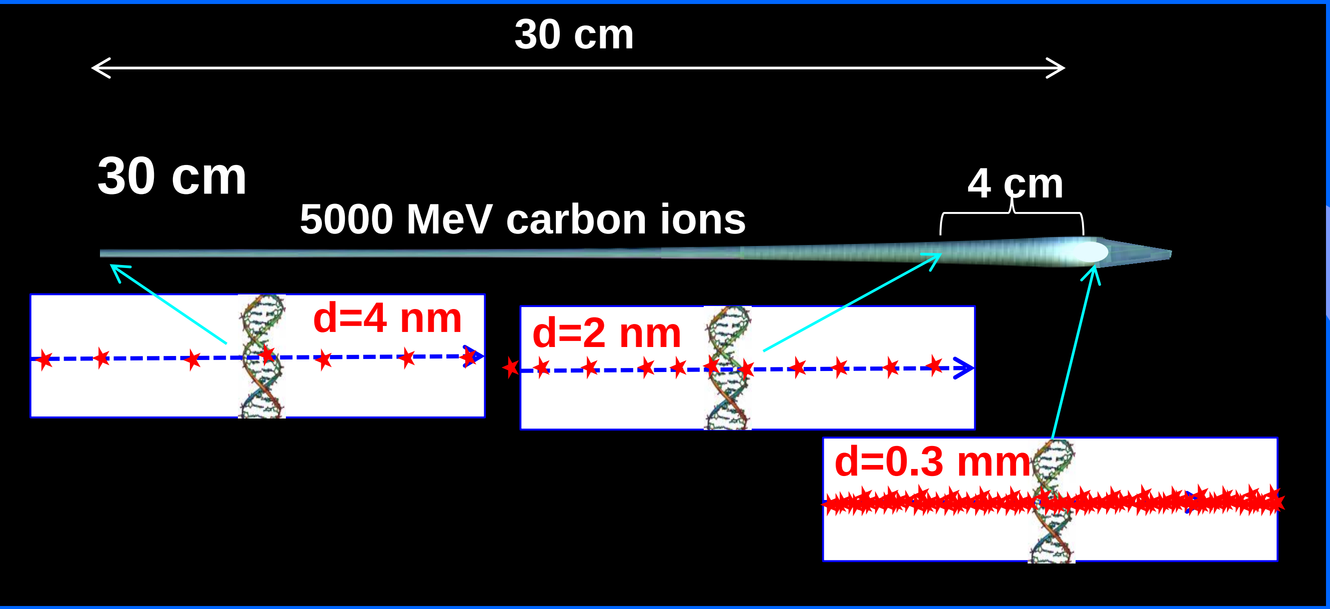


Avantages of protons and carbon ions

protons: 200 MeV
C ions : 5000 MeV

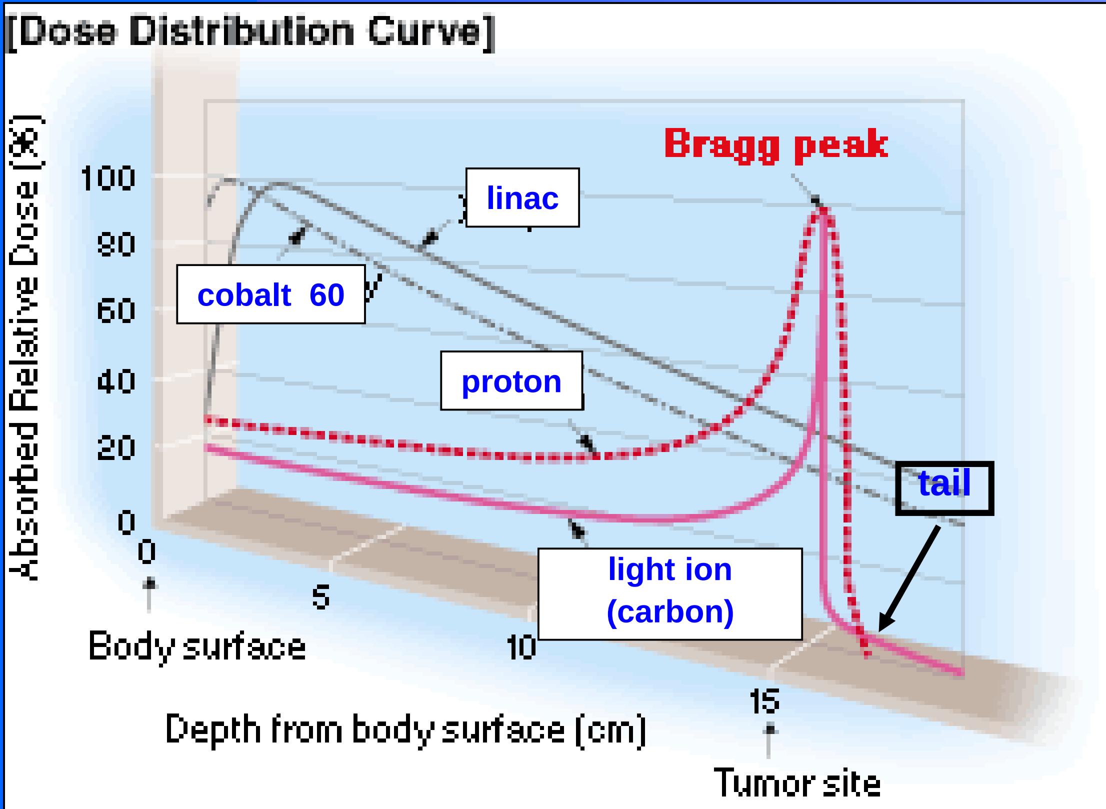


1. Healthy tissues are spared by protons and carbon ions



2. Carbon ions have charge = 6 and produce in the DNA clustered unrepairable damages thus killing at the end of the range the cells which are radioresistant to both X rays and protons.

Dose distribution techniques

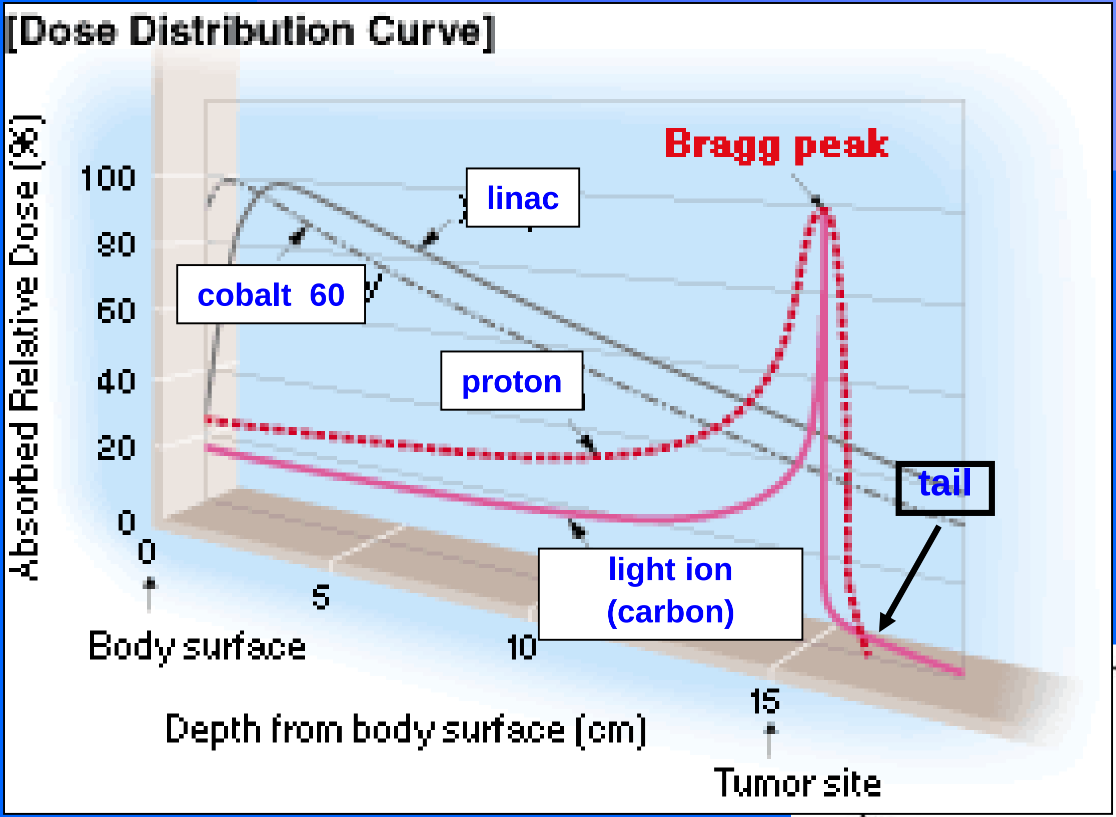


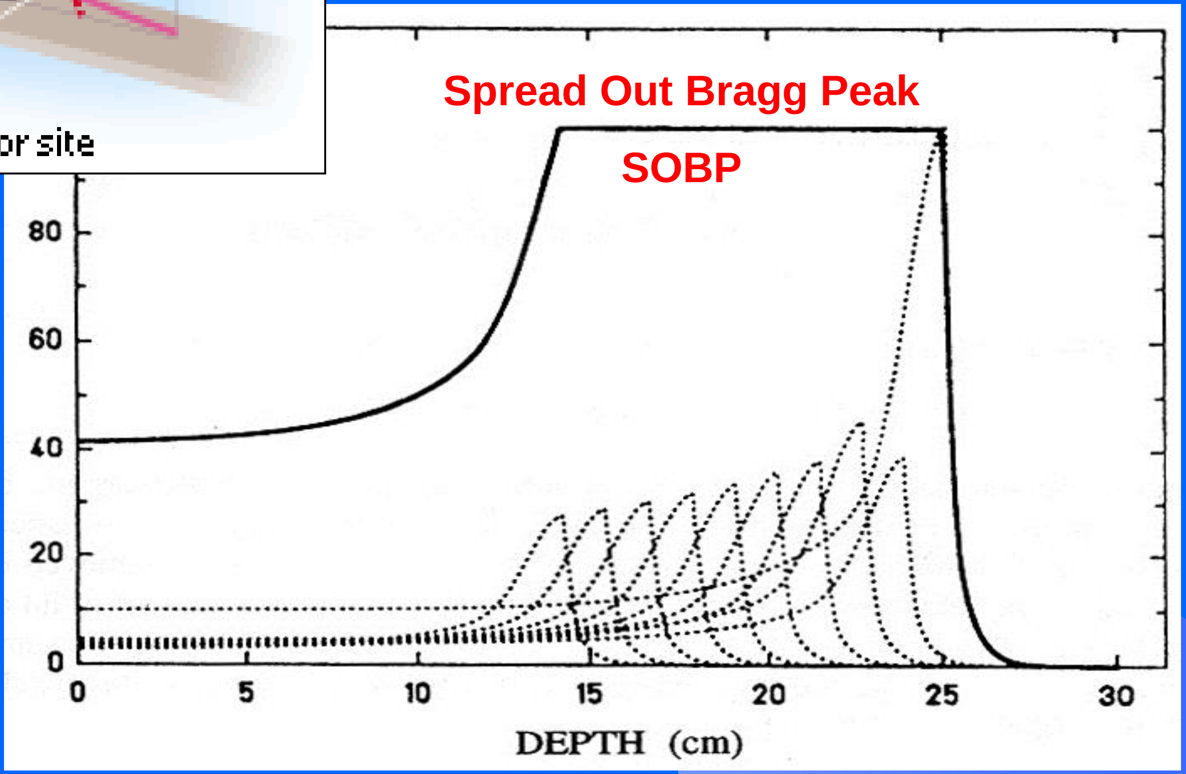
The narrow peak has to be enlarged

Longitudinally and transversally the carbon peak is about 3 times narrower than the proton peak:

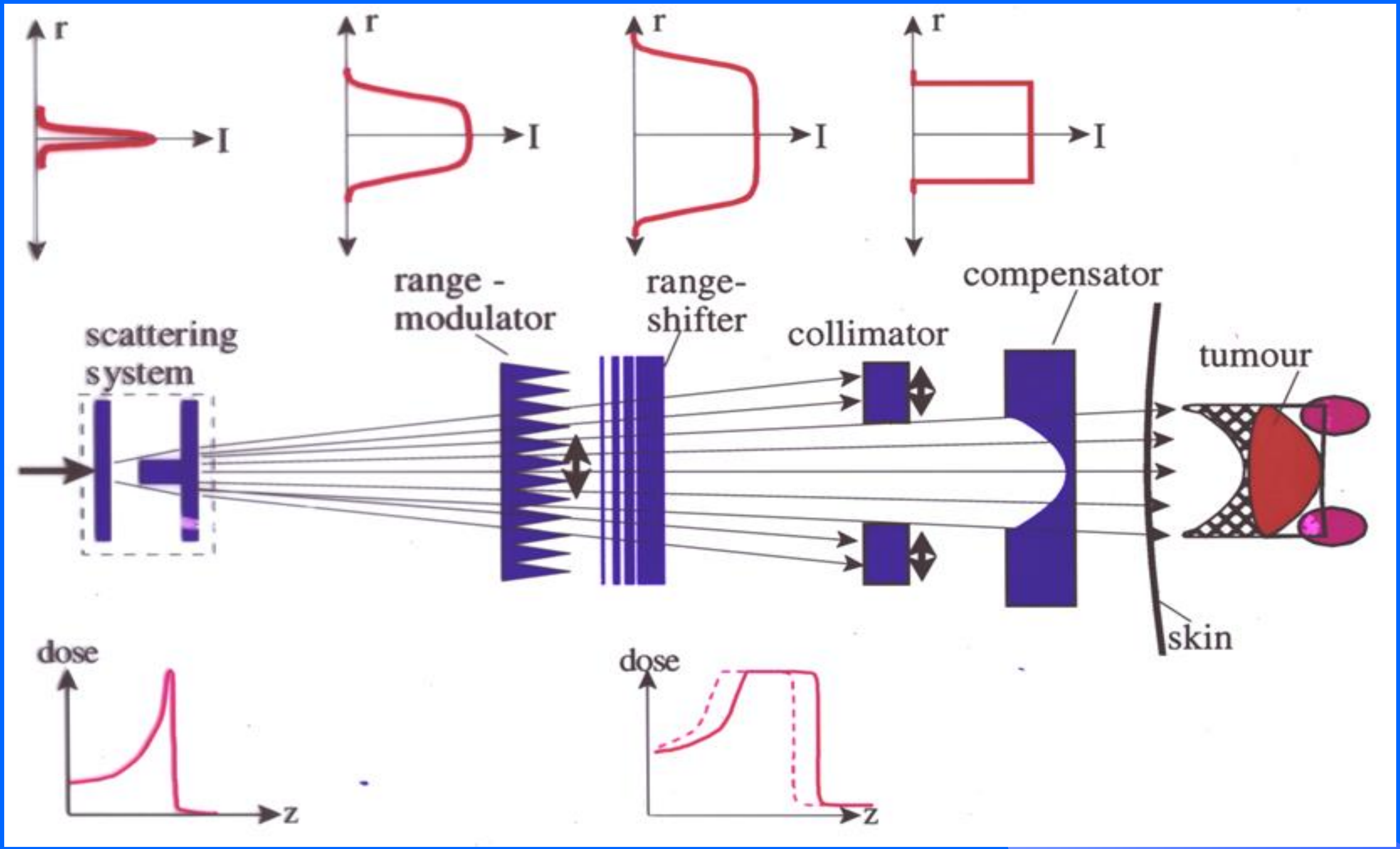
the widths are prop. to $1/\sqrt{M}$

The narrow peak has to be enlarged

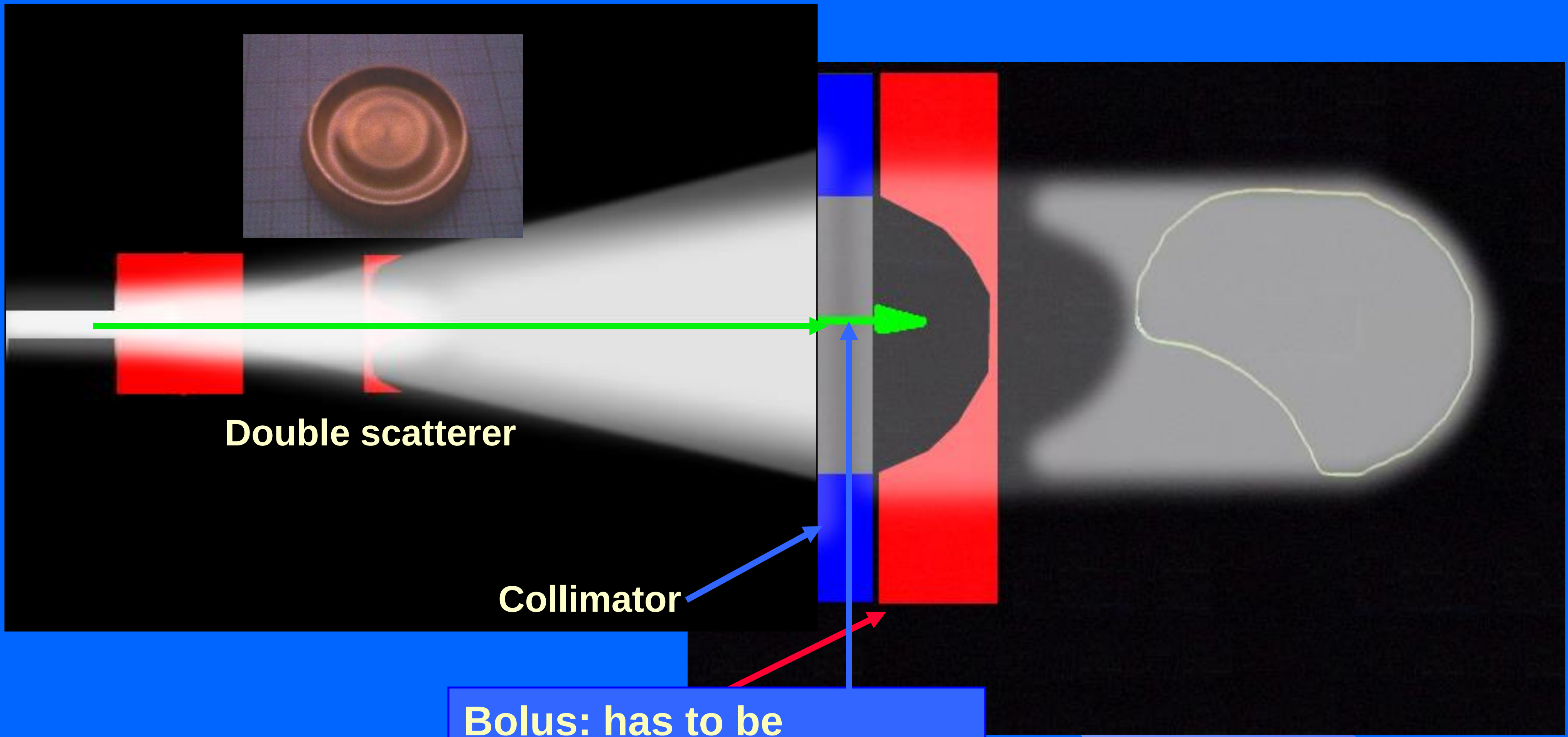




Two methods for imparting the dose:
1A. Oldest procedure: Passive beam spreading

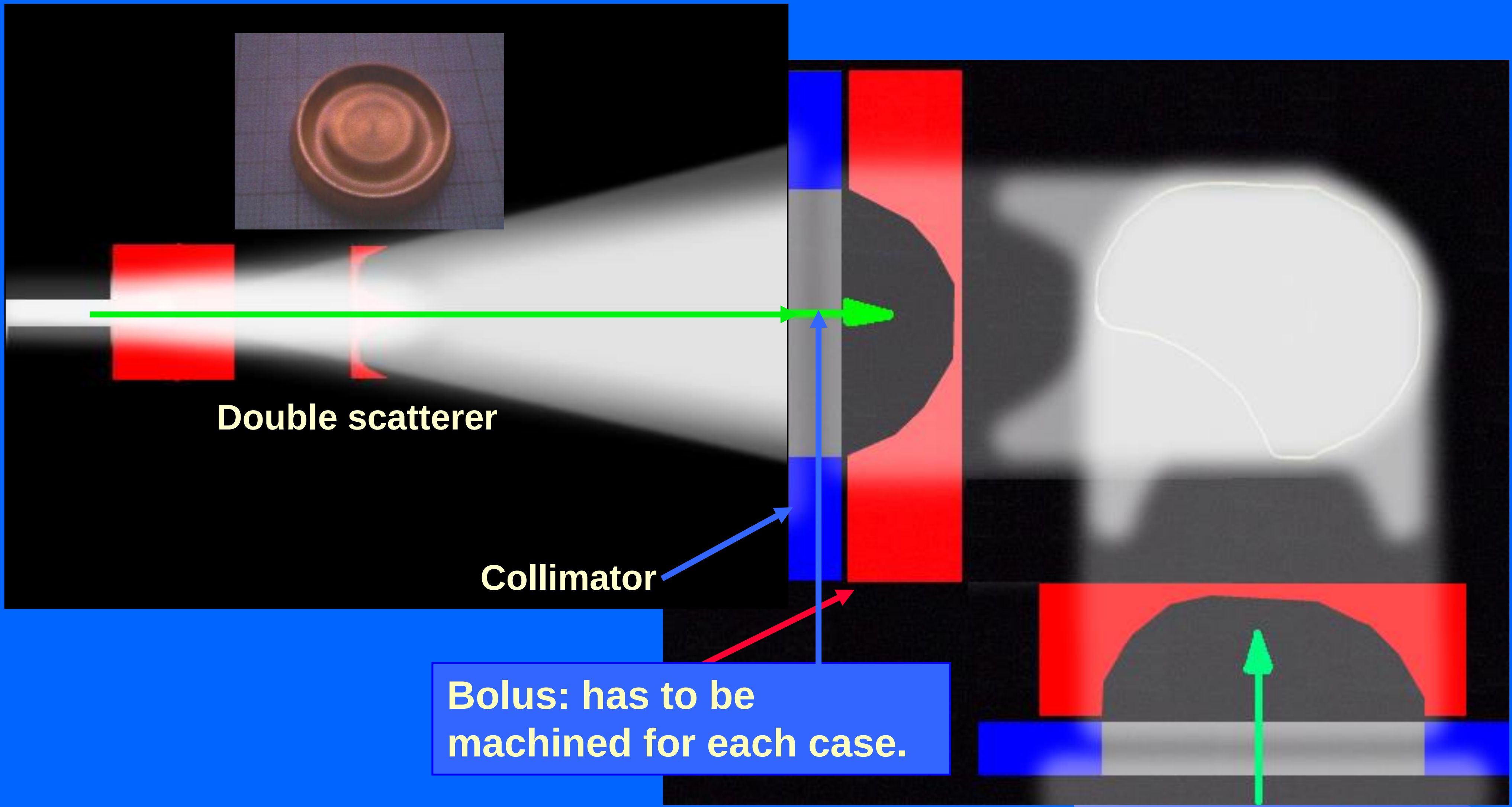


Two methods for imparting the dose:
1A. Oldest procedure: Passive beam spreading

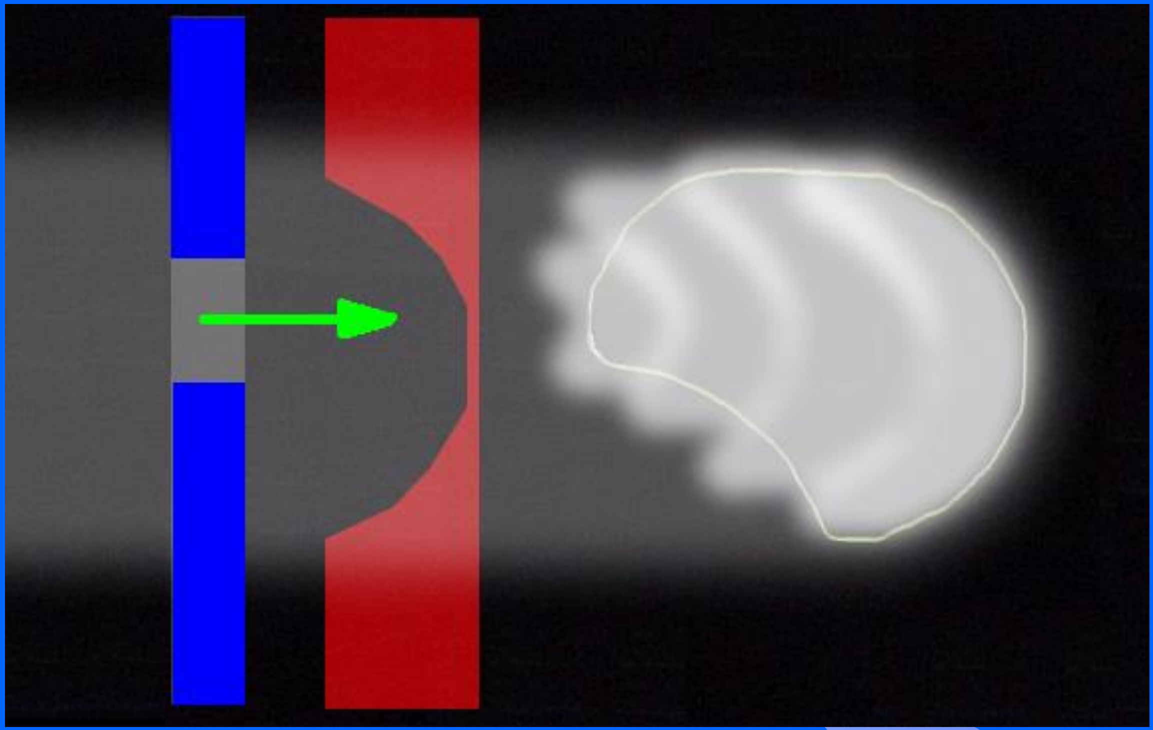


Bolus: has to be machined for each case.

Two methods for imparting the dose: 1A. Oldest procedure: Passive beam spreading

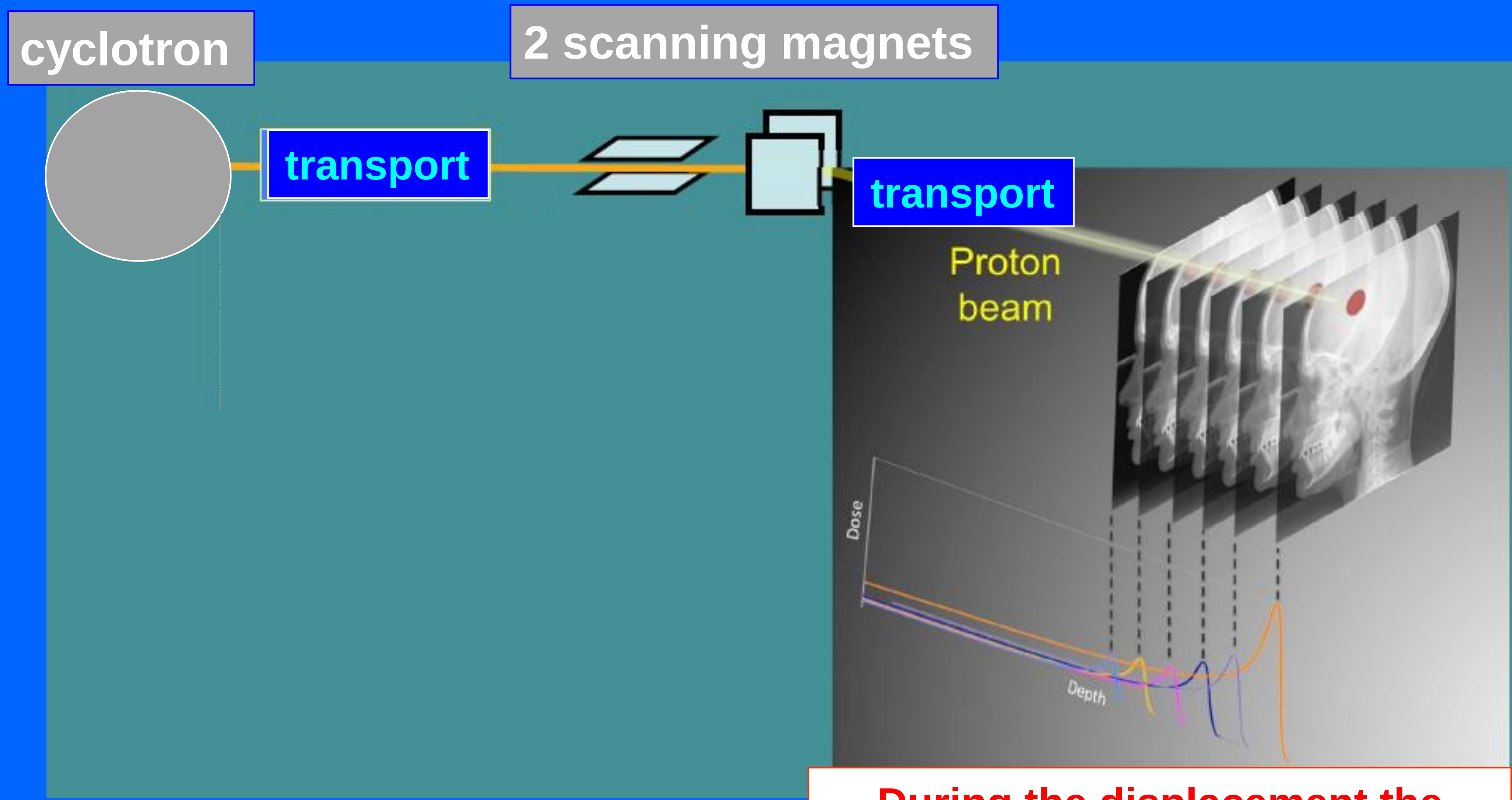


Two methods for imparting the dose:
1B Advanced procedure: layer stacking



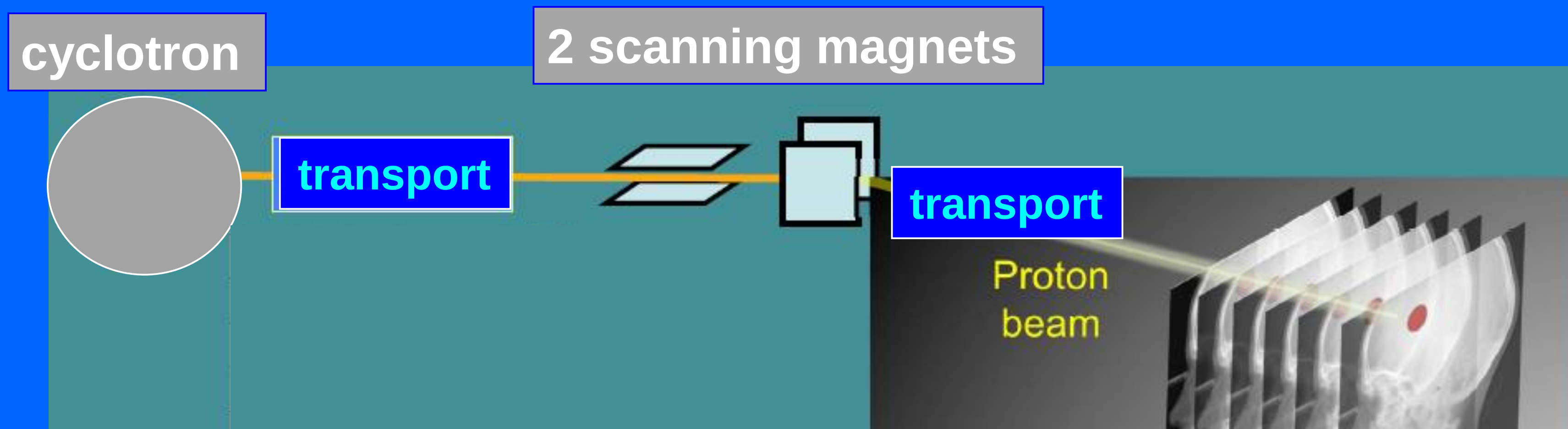
- Collimator adapted to transverse shape of each slice.

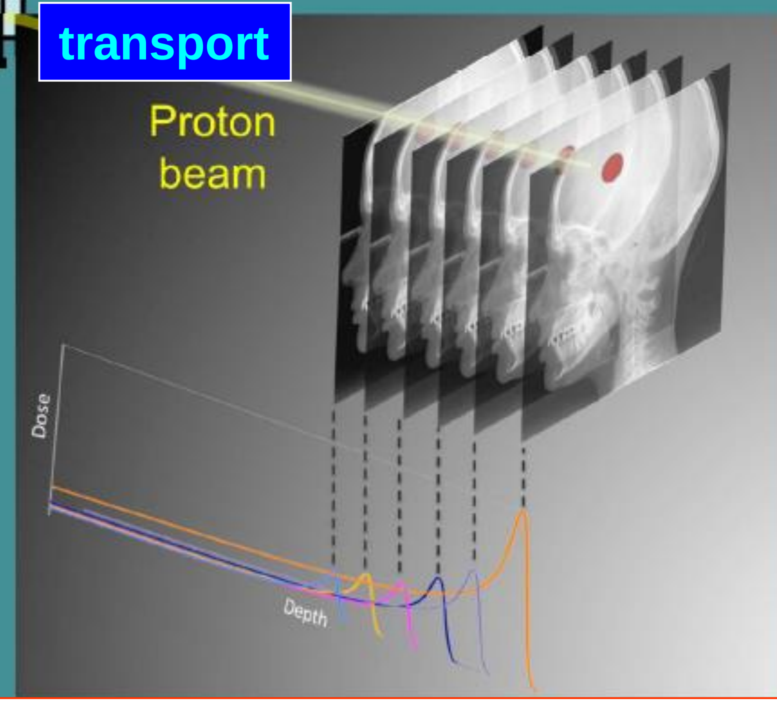
Two methods for imparting the dose:
2A. Active "spot scanning" technique by PSI (Villigen)

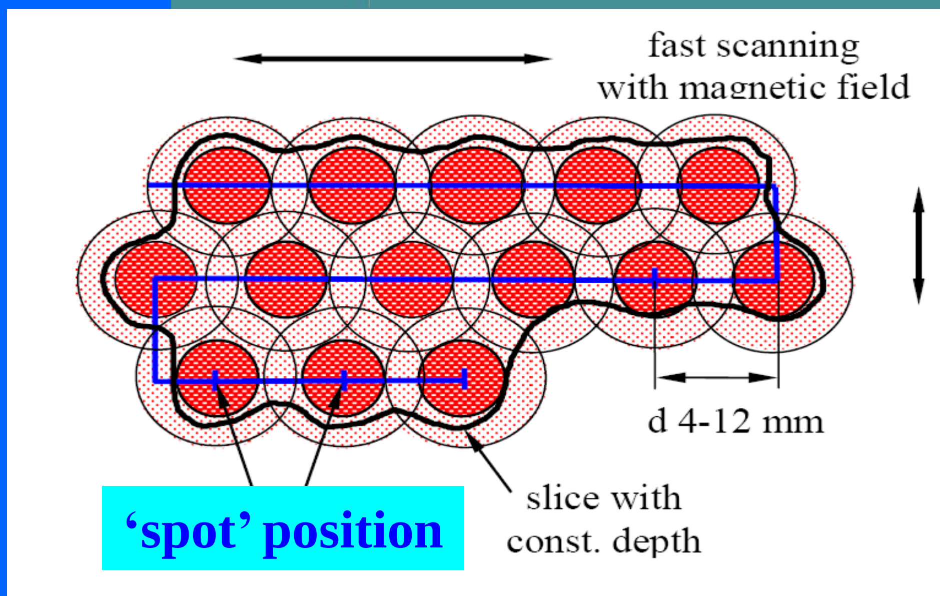


During the displacement the cyclotron beam is <u>switched off</u> for 5 ms

Two methods for imparting the dose:
2A. Active "spot scanning" technique by PSI (Villigen)



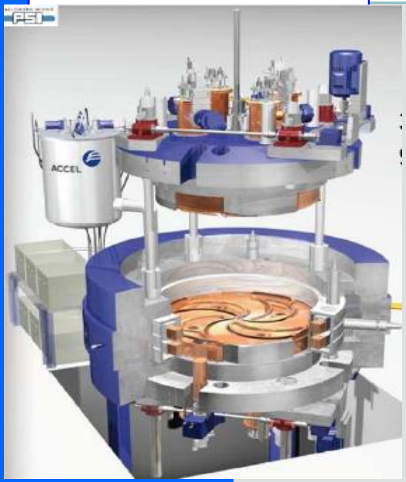


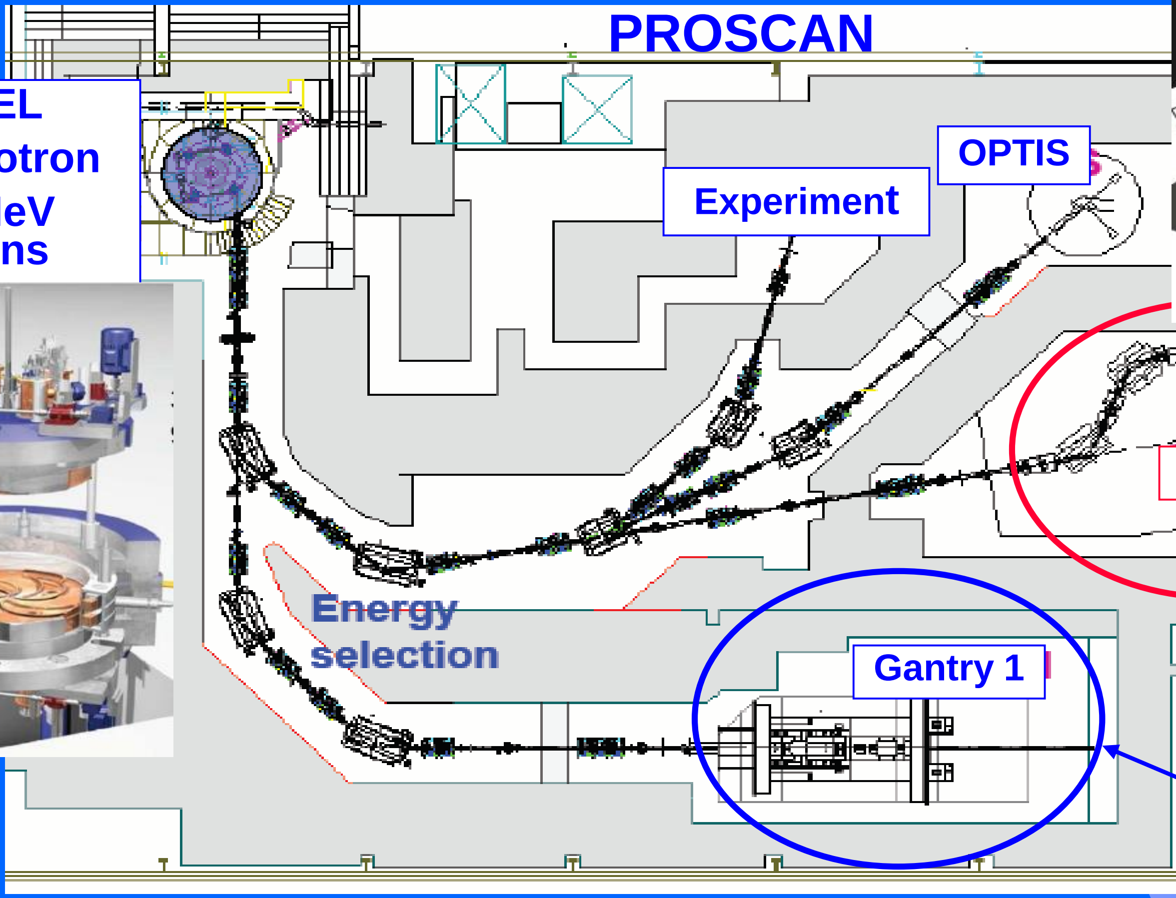


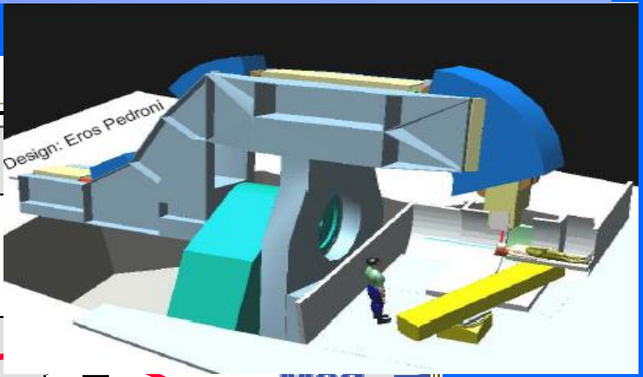
During the displacement the cyclotron beam is switched off for 5 ms

Two methods for imparting the dose:
2A. Active "spot scanning" technique by PSI (Villigen)

ACCEL
SC cyclotron
250 MeV protons





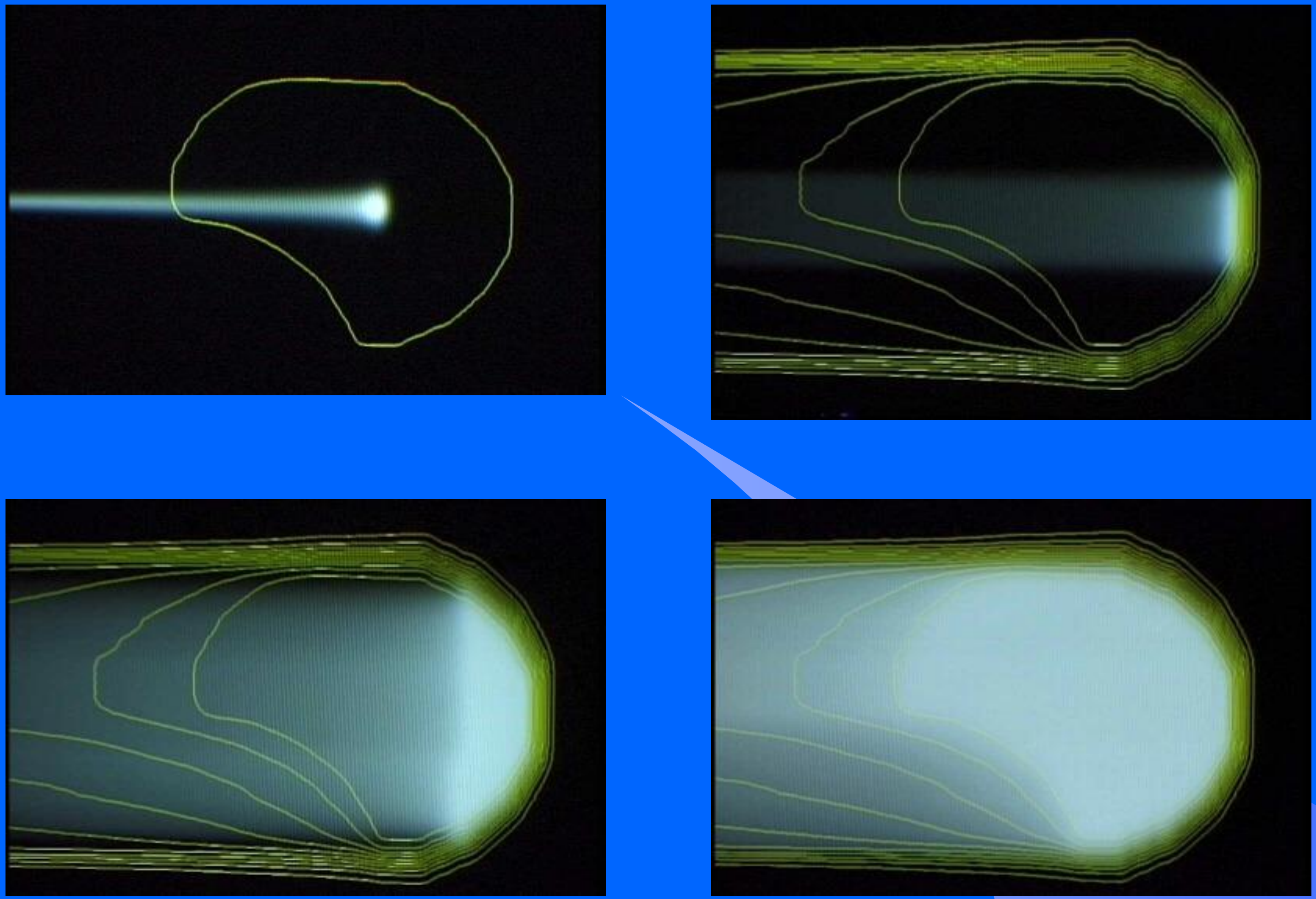


PROSCAN at PSI (Villigen):
with Gantry 1 and Gantry 2

FUTURE : « Multi-painting »

Two methods for imparting the dose:
2A. Active "spot scanning" technique by PSI (Villigen)

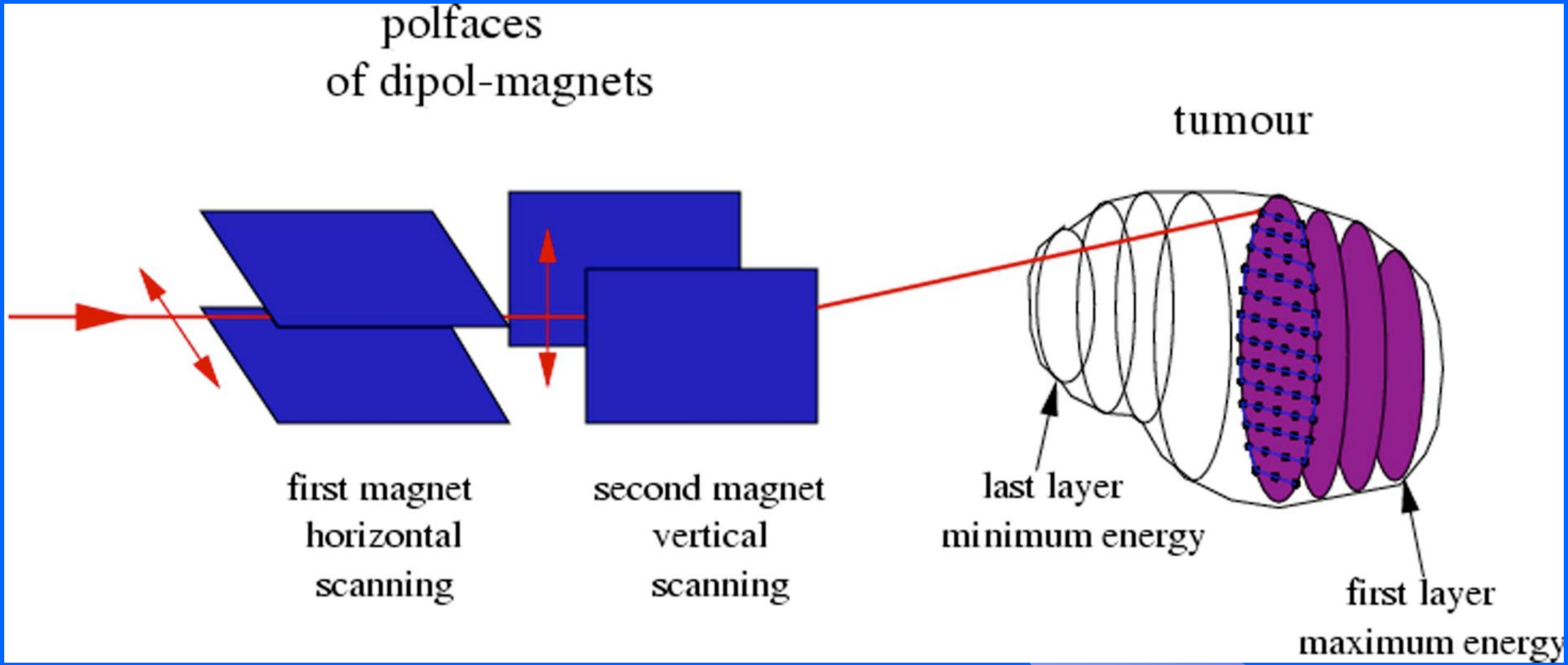
- **PROTONS**
- **Courtesy PSI**



Respiratory gating for moving organs

TERA

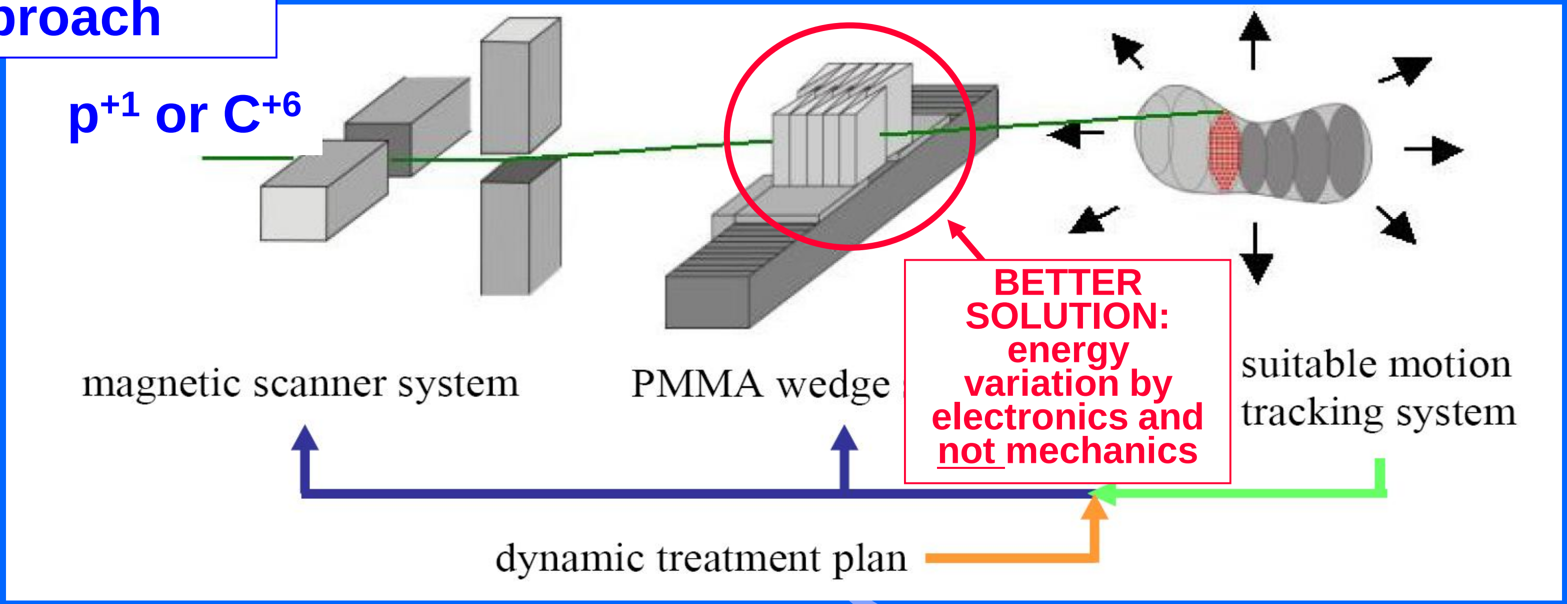
Two methods for imparting the dose: 2B. Active scanning: 'raster scanning" à la GSI

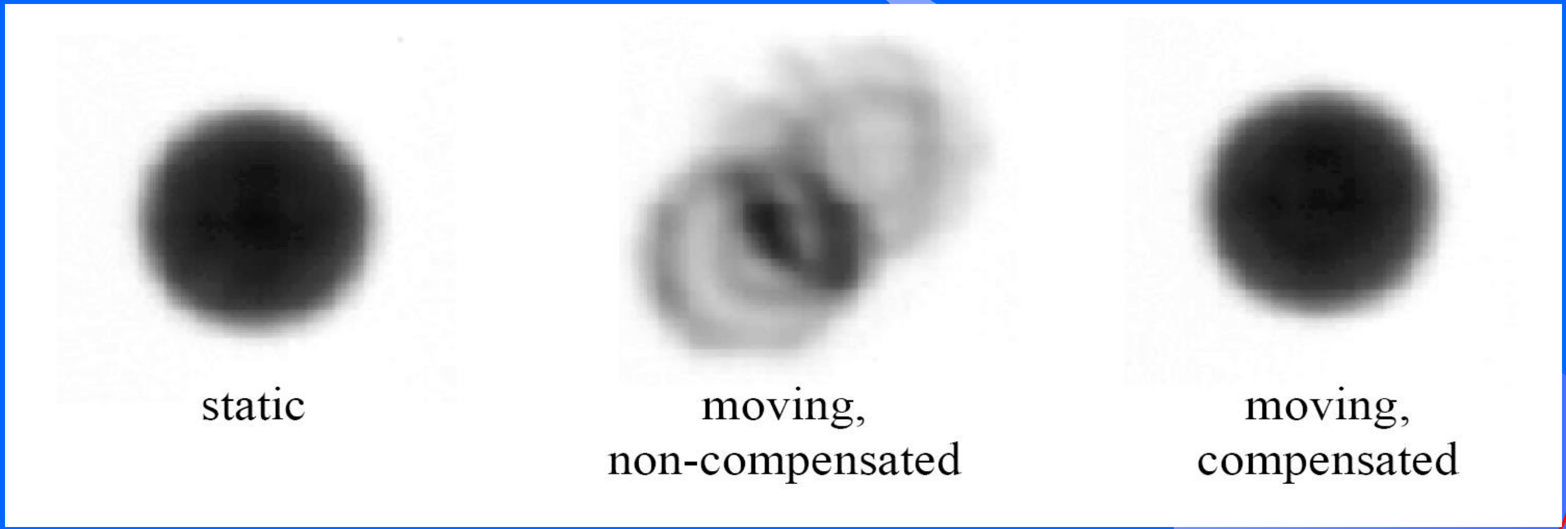


The synchrotron beam is moved <u>continuously</u>

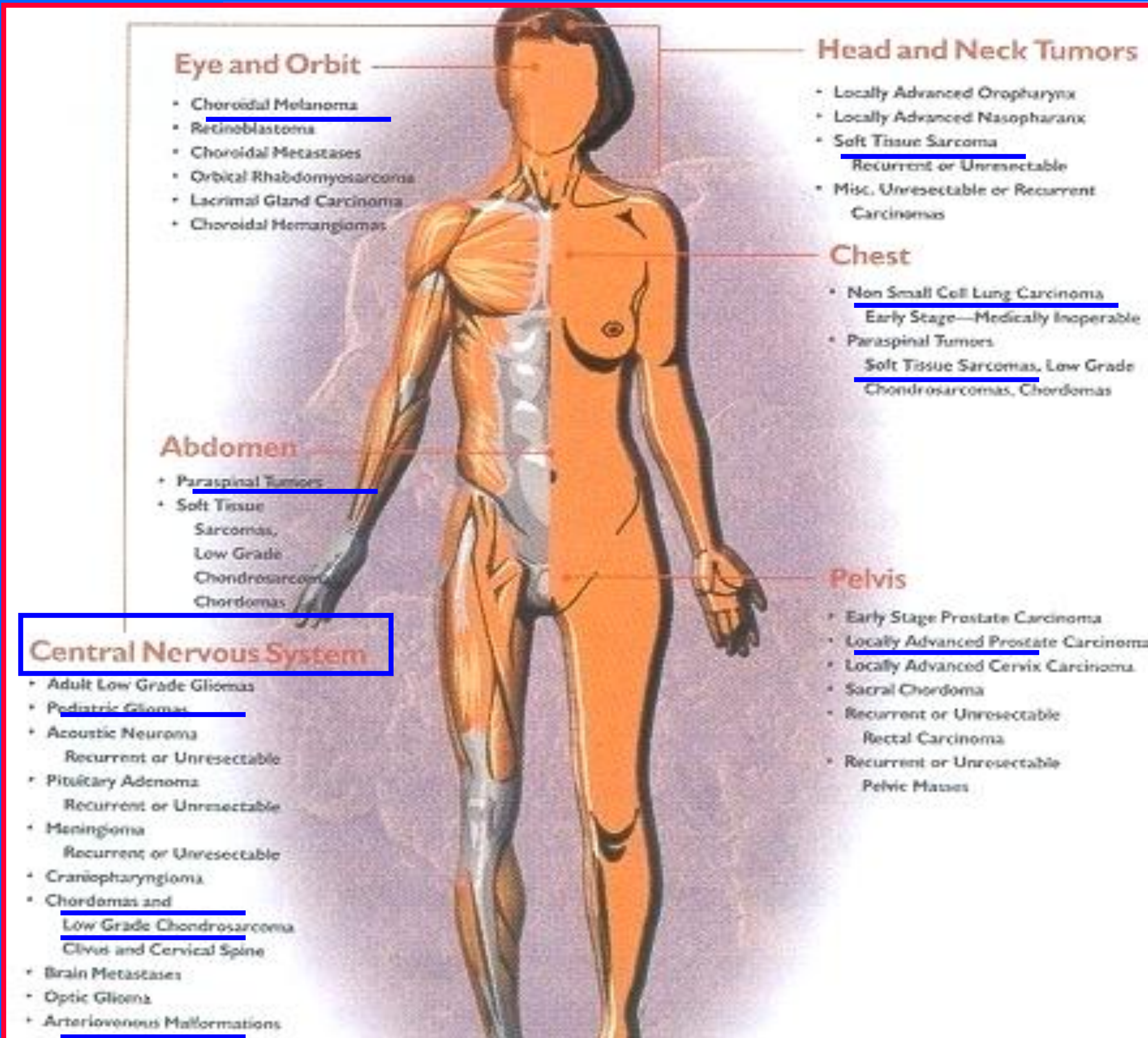
The present challenge: active scanning compensated by correcting the spot position with a feedback system

GSI approach





Patients of hadrontherapy



The site treated with hadrons

In the world

protons:

140'000 patients

(> +10% per year)

carbon ions

15’000 patients

BUT

only 5%

treated with active scanning

TERA

Indication	End point	Results photons	Results carbon HIMAC-NIRS	Results carbon GSI
Chordoma	local control rate	30 – 50 %	65 %	70 %
Chondrosarcoma	local control rate	33 %	88 %	89 %
Nasopharynx carcinoma	5 year survival	40 -50 %	63 %	
Glioblastoma	av. survival time	12 months	16 months	
Choroid melanoma	local control rate	95 %	96 % (*)	
Paranasal sinuses tumours	local control rate	21 %	63 %	
Pancreatic carcinoma	av. survival time	6.5 months	7.8 months	
Liver tumours	5 year survival	23 %	100 %	
Salivary gland tumours	local control rate	24-28 %	61 %	77 %
Soft-tissue carcinoma	5 year survival	31 – 75 %	52 -83 %	

Similar to protons

Table by G. Kraft 2007

Results of carbon ions

ENLIGHT studies: M. Ramona et al.…

RADIOTHERAPY & ONCOLOGY
JOURNAL OF THE EUROPEAN SOCIETY FOR THERAPEUTIC RADIOLOGY AND ONCOLOGY
Volume 73 Supplement 2 (2004)

Numbers of potential patients (*)

X-ray therapy

for 1 million inhabitants: 2'000 pts/year

Protontherapy

12% of X-ray patients 240 pts/year

Therapy with carbon ions for radio-resistant tumour

(blind comparisons with protontherapy are needed to define sites and protocols

3% of X-ray patients 60 pts/year

TOTAL for 1 M **300 pts/year**

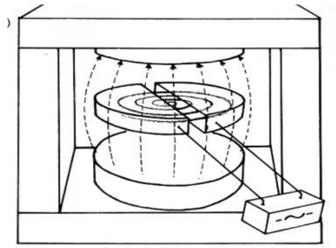
(*) European Network for Light Ion Therapy (ENLIGHT) coordinated by Manjit Dosanjh

Therapy with proton beams

The accelerators used today in hadrotherapy are "circular"

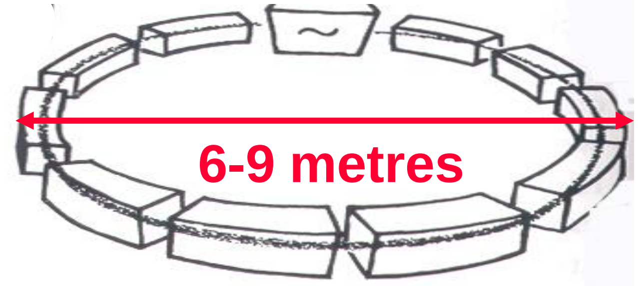
Therapy with protons (200-250 MeV)

CYCLOTRONS (*) (Normal or SC)



4-5 metres

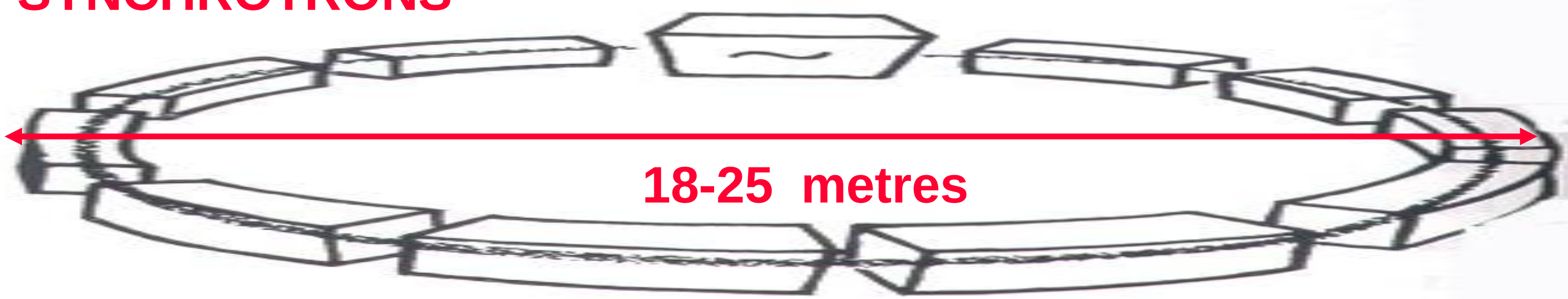
SYNCHROTRONS

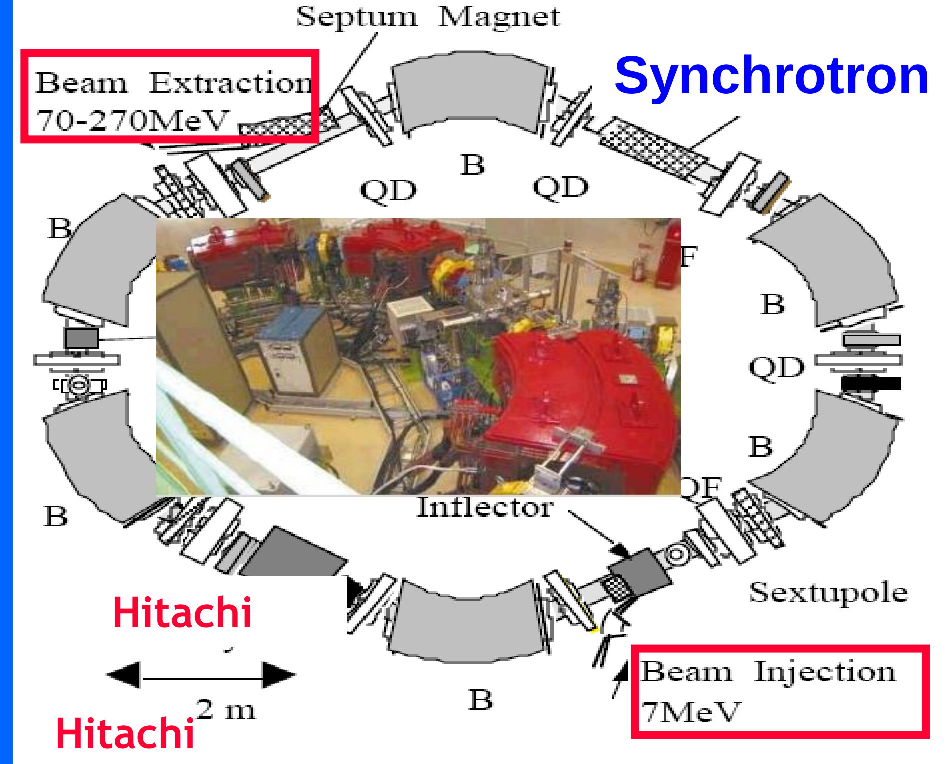


(*) also synchrocyclotrons

Therapy with carbon ions (4800 MeV = 400 MeV/u)

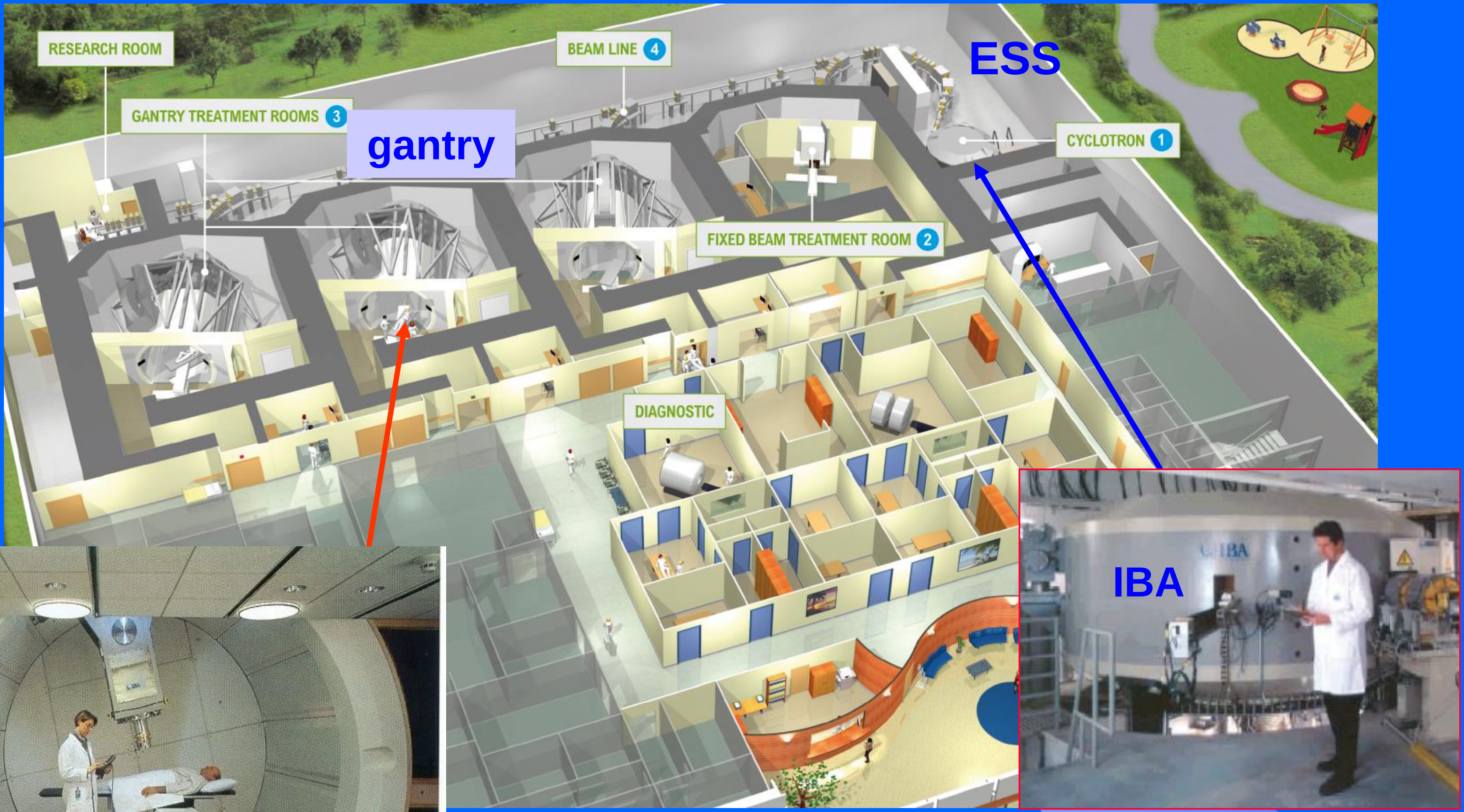
SYNCHROTRONS





4 commercial 230-250 MeV accelerators

Cyclotron solution for protons by IBA - Belgium



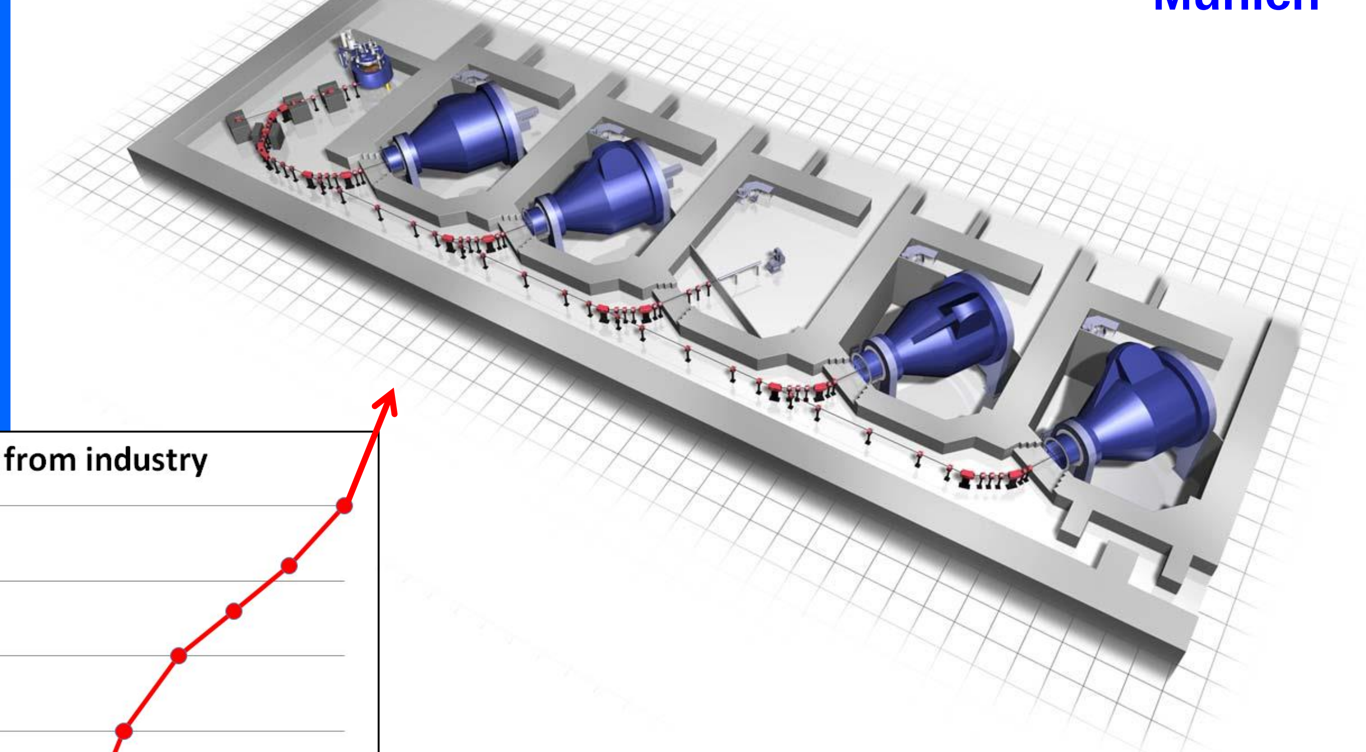
ten companies offer turn-key centres for 120-150 M€.

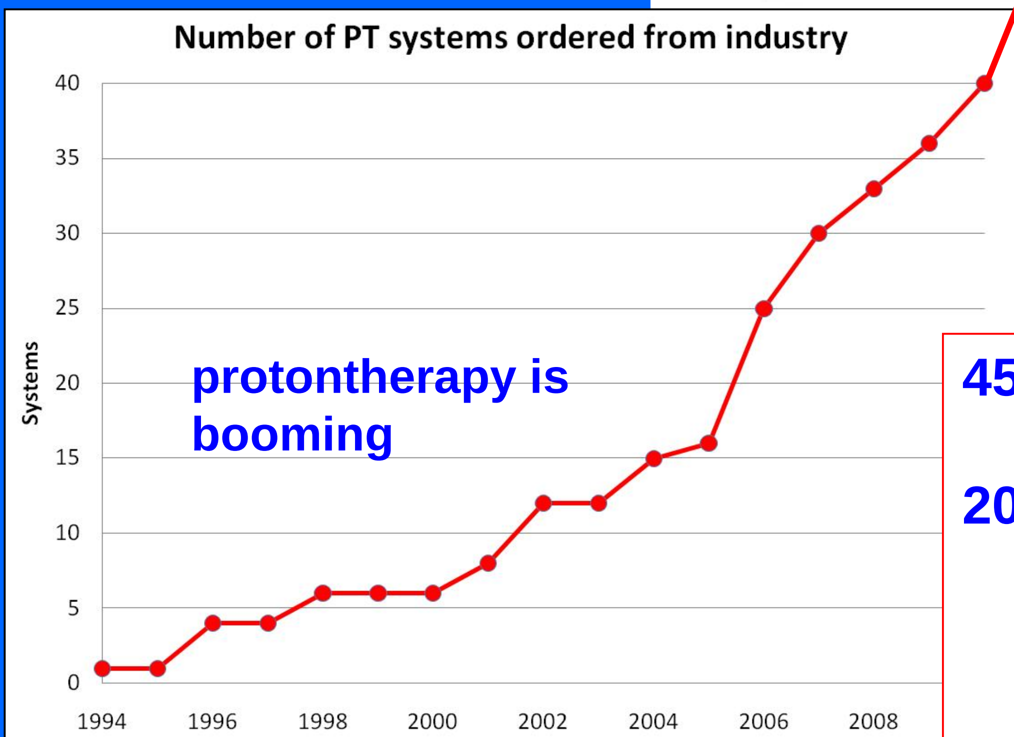
If proton accelerators were ‘small’ and ‘cheap’,
no radiation oncologist would use X rays.

Mitsubishi solution for Shizuoka - Japan

Superconducting cyclotron solution by Varian

Rinecker Proton Therapy Center (RPTC) Munich





protontherapy is booming

45 centers worldwide

20-25 sessions per patient

European cost of a full treatment:

IMRT: 8-10 k€

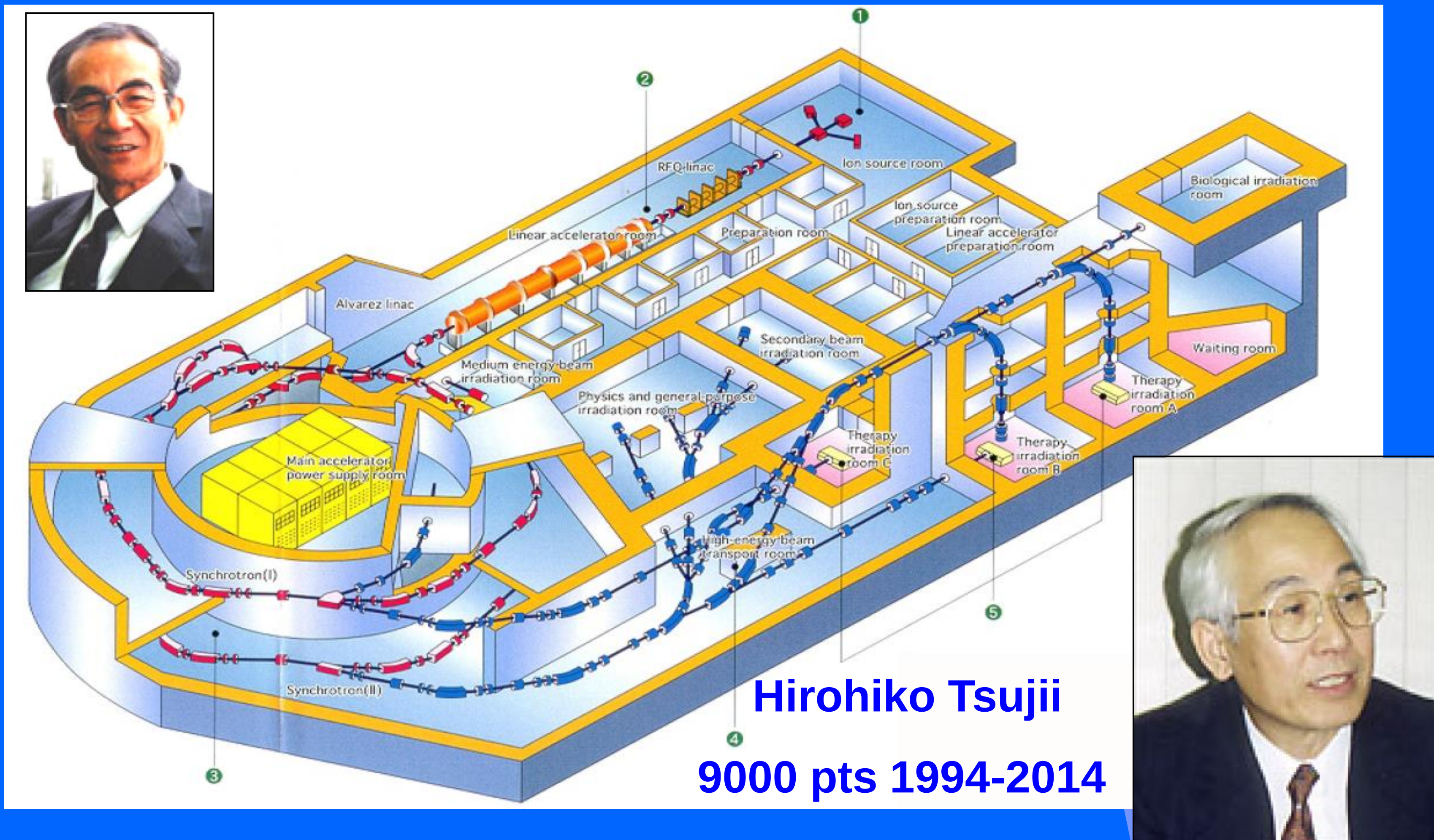
Protontherapy: 20-25 k€

Carbon ion therapy in Japan

HIMAC in Chiba is the pioner of carbon therapy (Prof H. Tsujii)

Yasuo Hirao

15 Hirao, Y. et al, "Heavy Ion Synchrotron for Medical Use: HIMAC Project at NIRS Japan" Nucl. Phys. A538, 541c (1992)



Hirohiko Tsujii

9000 pts 1994-2014

HIMAC in Chiba is the pioner of carbon therapy (Prof H. Tsujii)

Almost no repair with carbon ions:

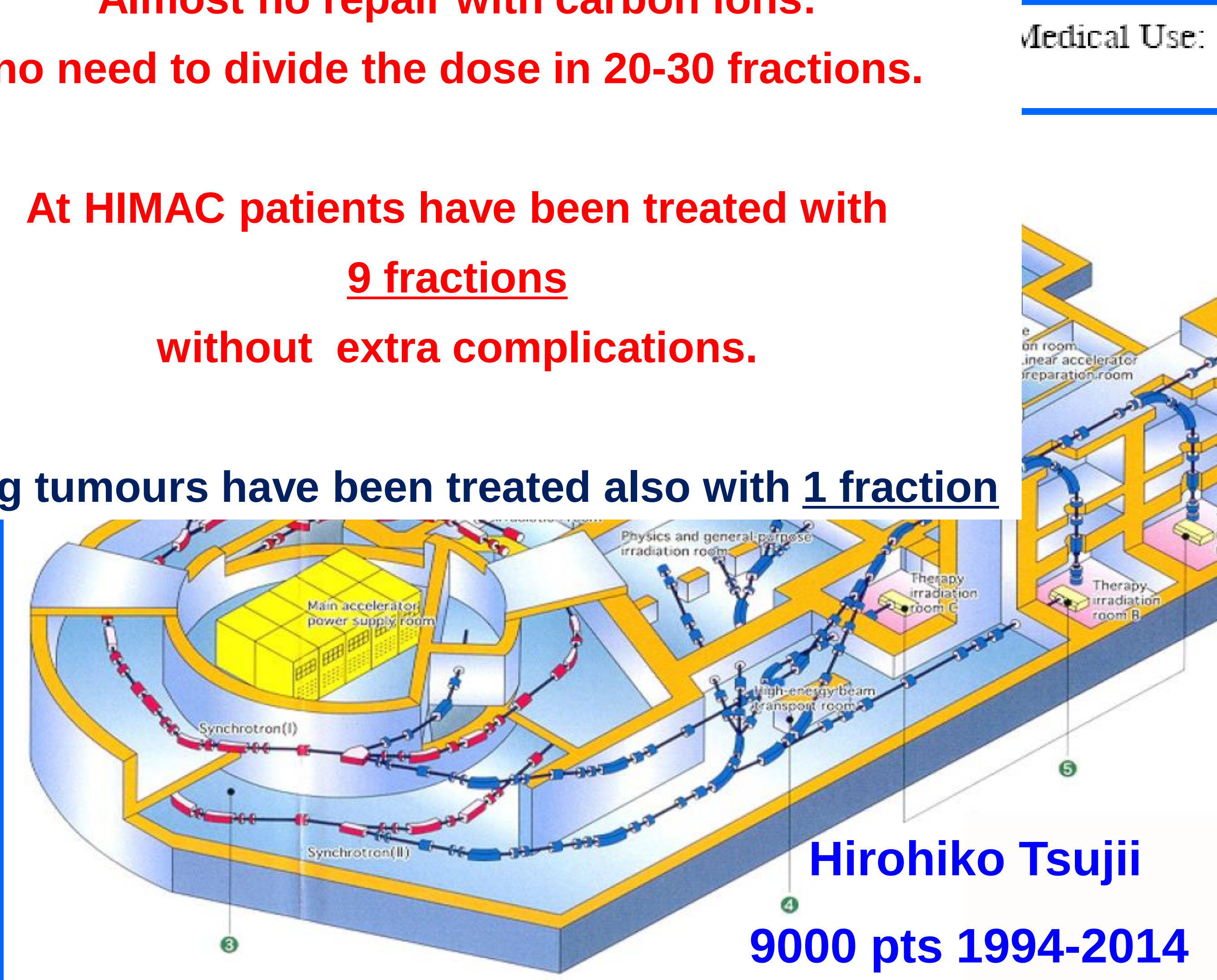
no need to divide the dose in 20-30 fractions.

At HIMAC patients have been treated with

9 fractions

without extra complications.

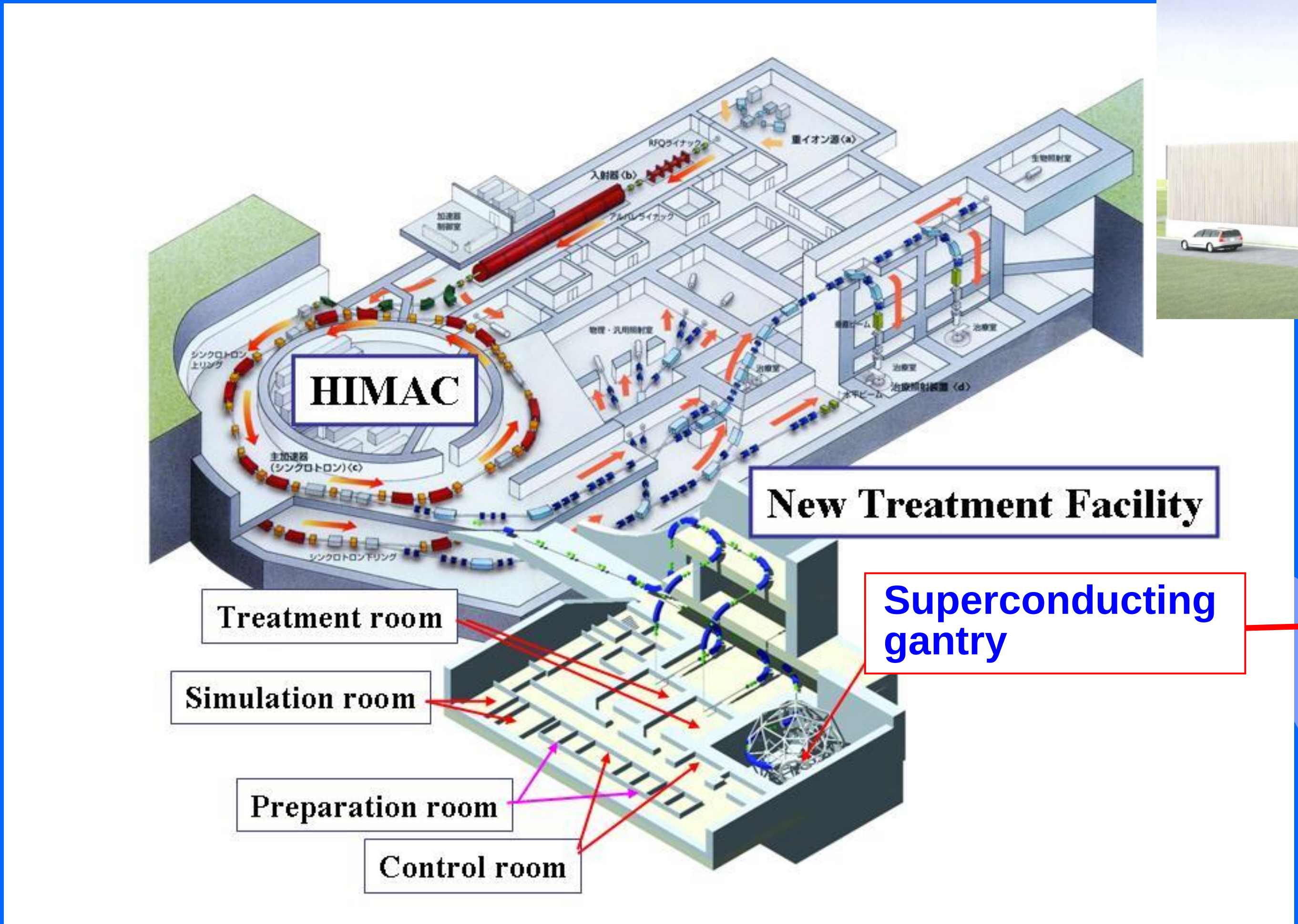
Lung tumours have been treated also with 1 fraction

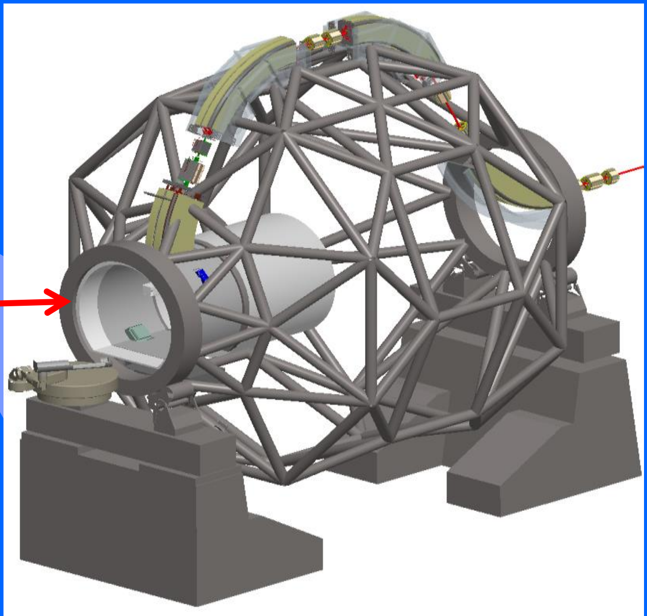


Hirohiko Tsujii

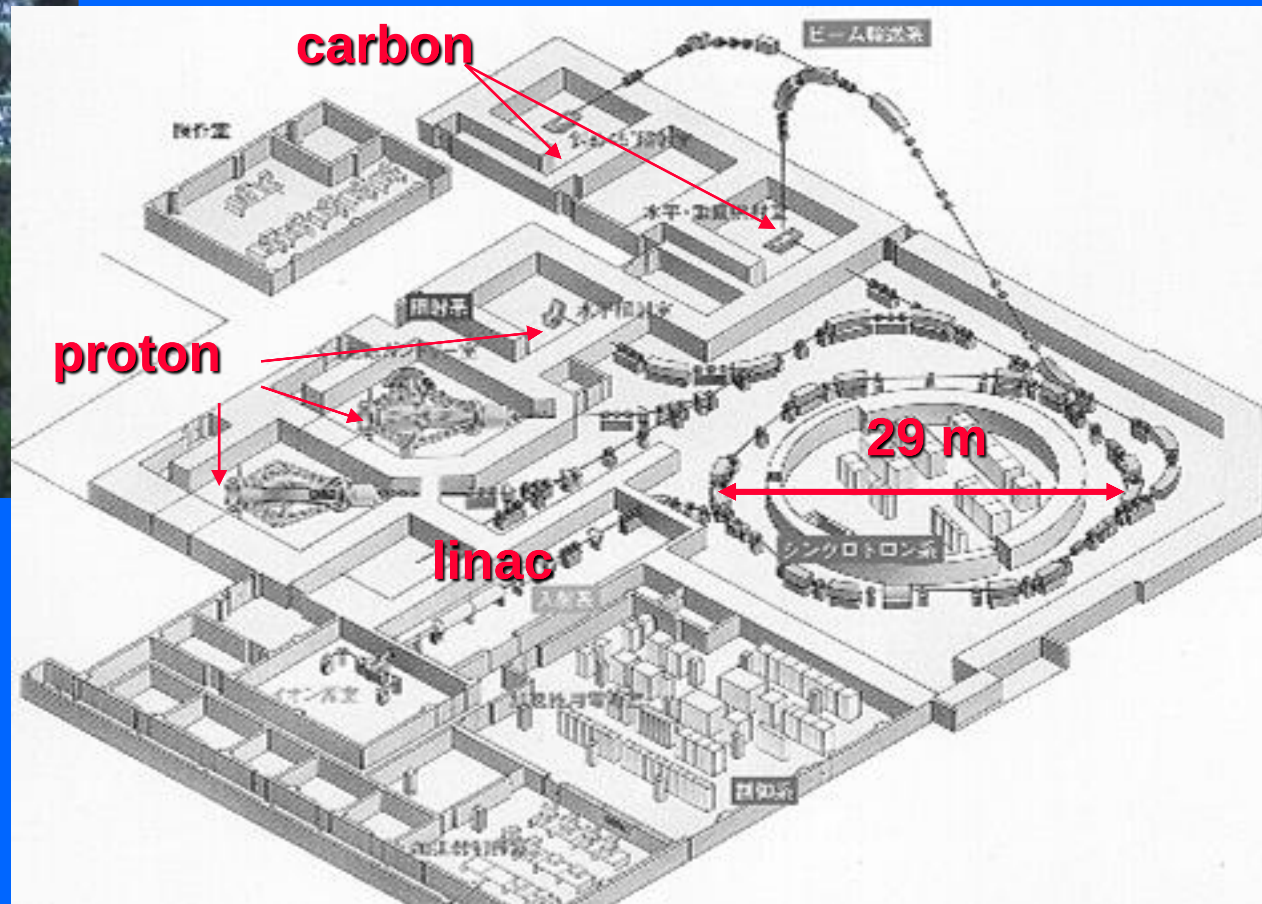
9000 pts 1994-2014

HIMAC new facility





The Hyogo 'dual' Centre



Mitsubishi: turn-key system

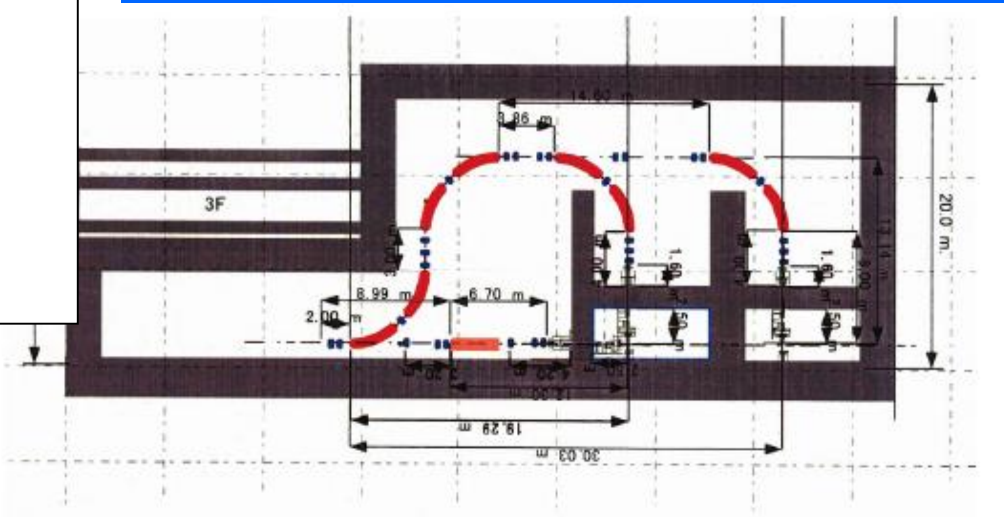
By the end of 2014:

4700 pts with p
2200 pts with C

The Gunma University dual centre

By the end of 2014:

1500 pts with C



R&D = NIRS + KEK + RIKEN

Construction: Mitsubishi

By the end of 2014:

550 pts with C

SAGA HIMAT in Tosu from 2013