Seminar
Accelerators for Therapy

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OUTLINE

1. **Introduction**

2. ***Instrumentation and treatment modalities***
   - Accelerators for hadrontherapy
   - Active and passive scanning

3. ***Future challanges in hadrontherapy***
   - Moving organs
   - Single room facilities
   - *Modern hadrontherapy gantries*

CONCLUSION

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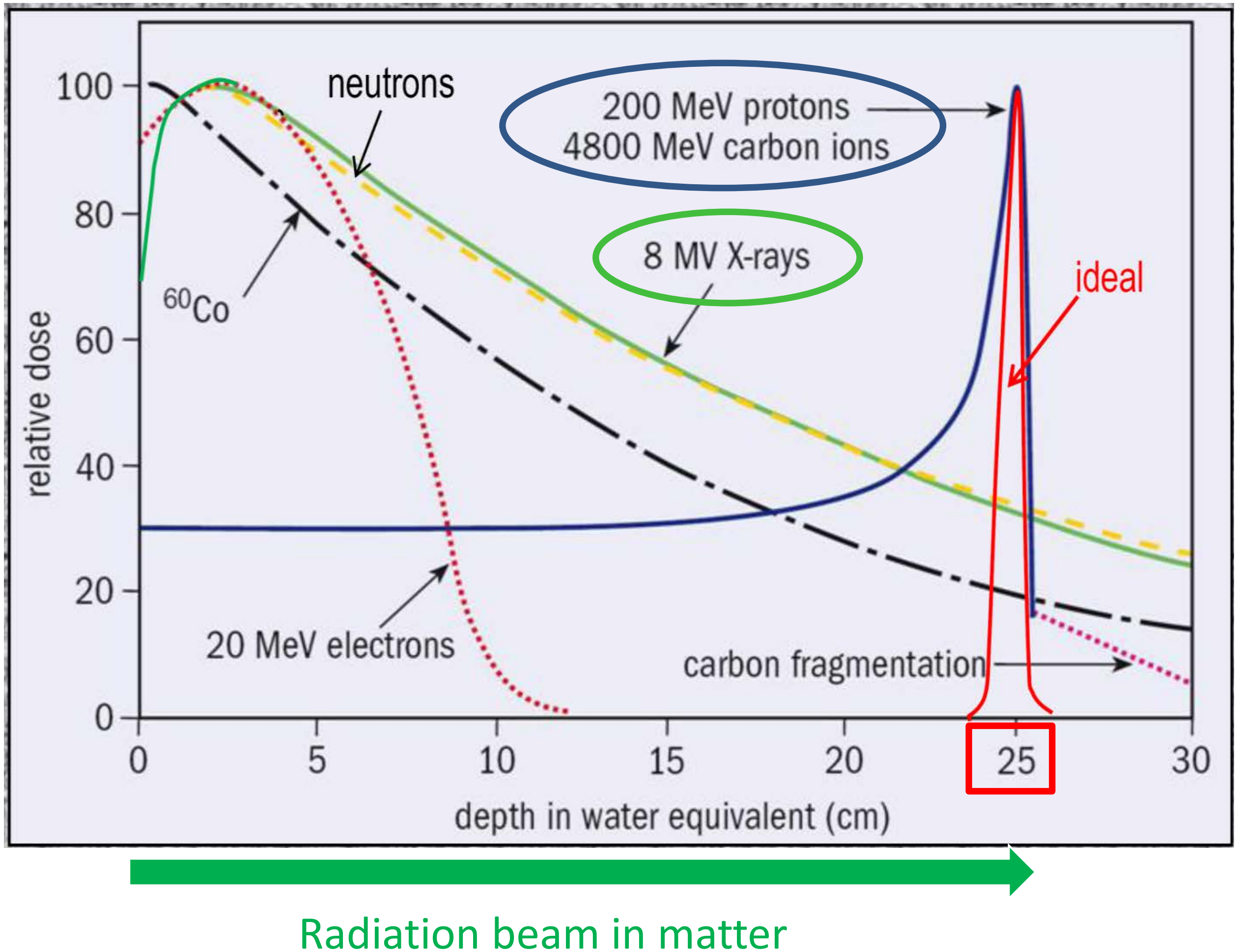
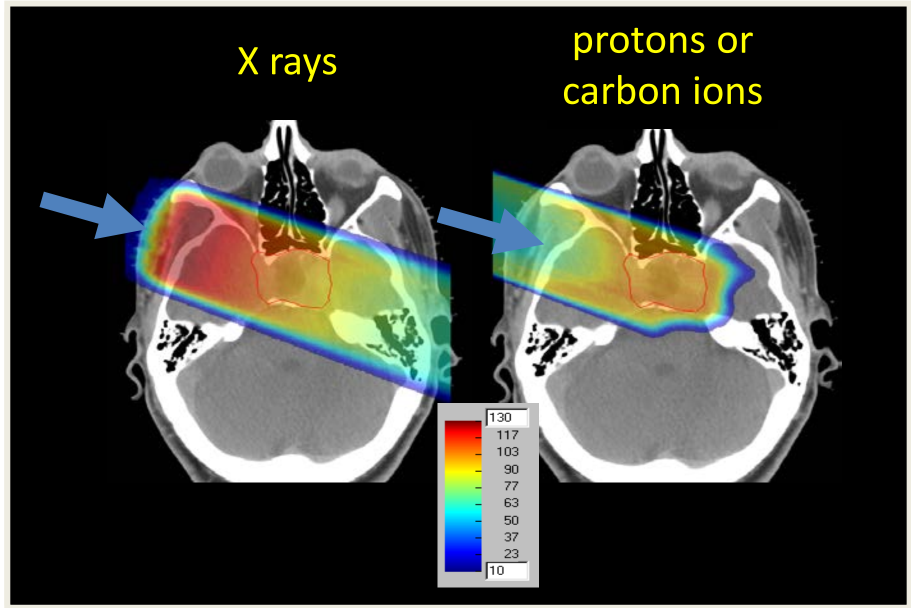
Introduction

The icon of radiation therapy with charged hadrons



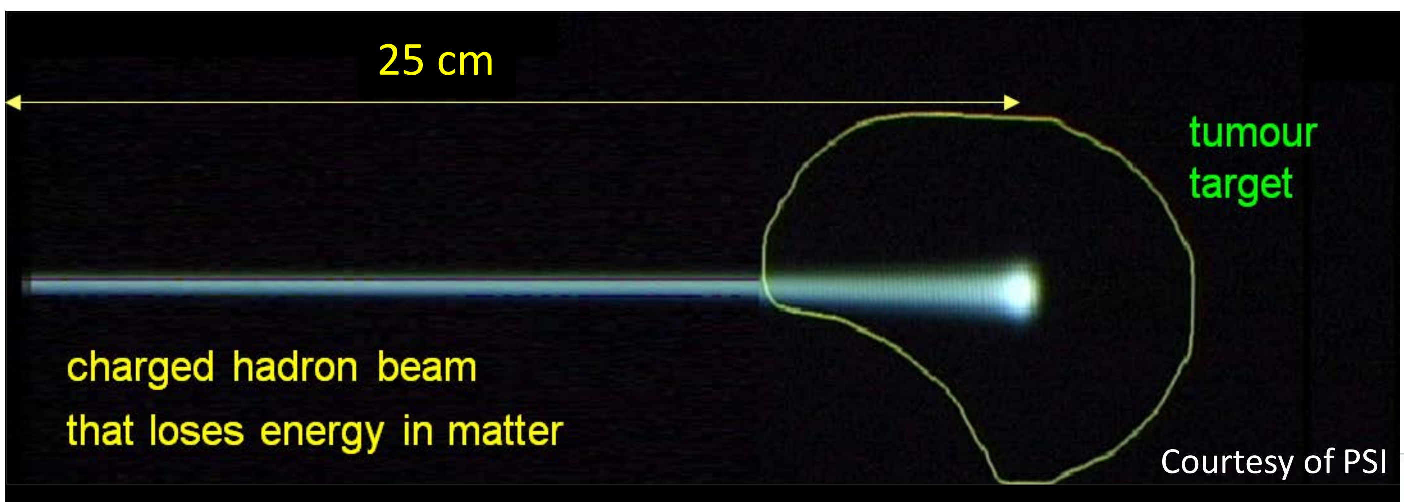
Protons and ions spare healthy tissues



200 MeV - 1 nA protons

4800 MeV – 0.1 nA carbon ions

(radioresistant tumours)



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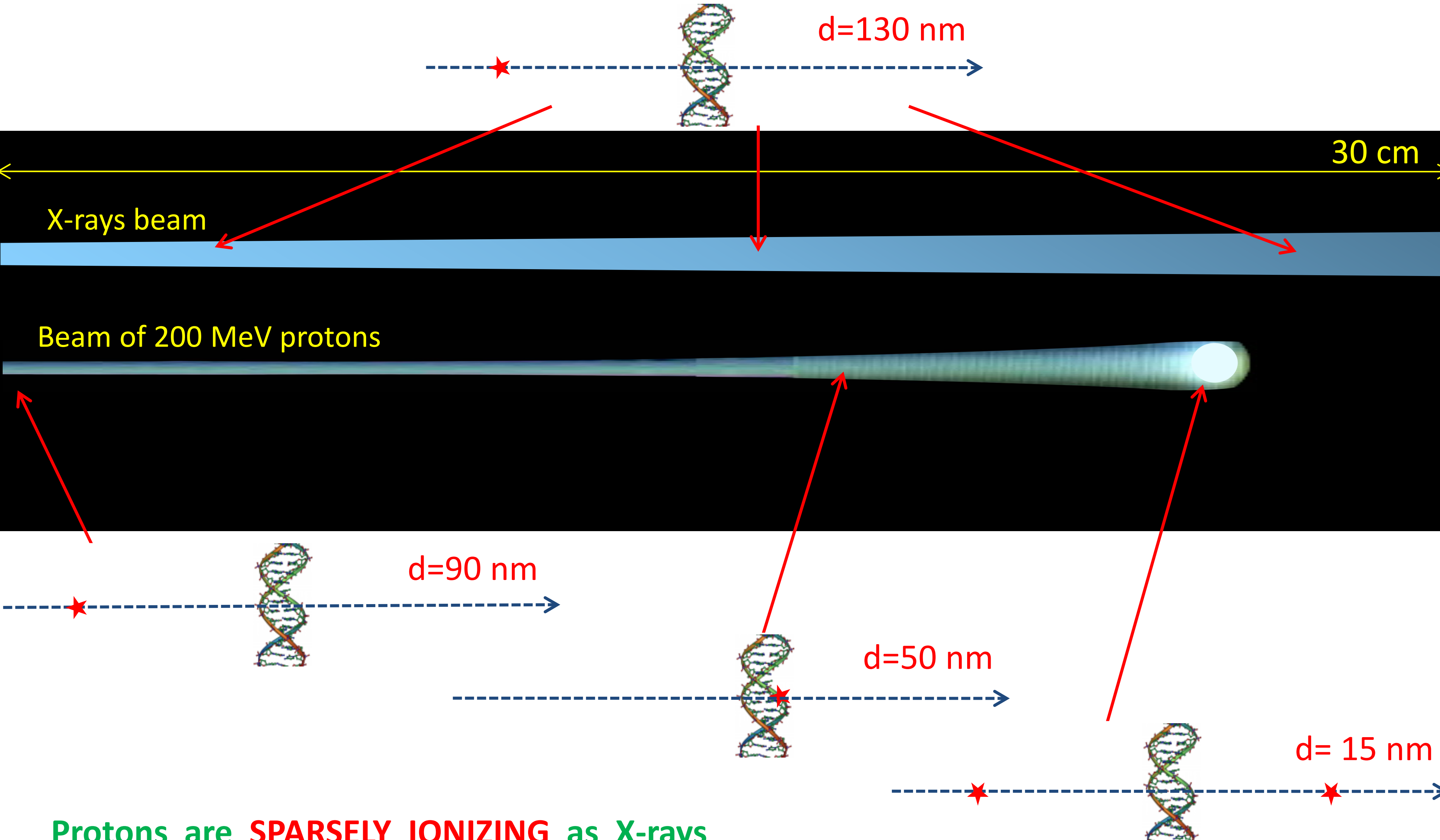
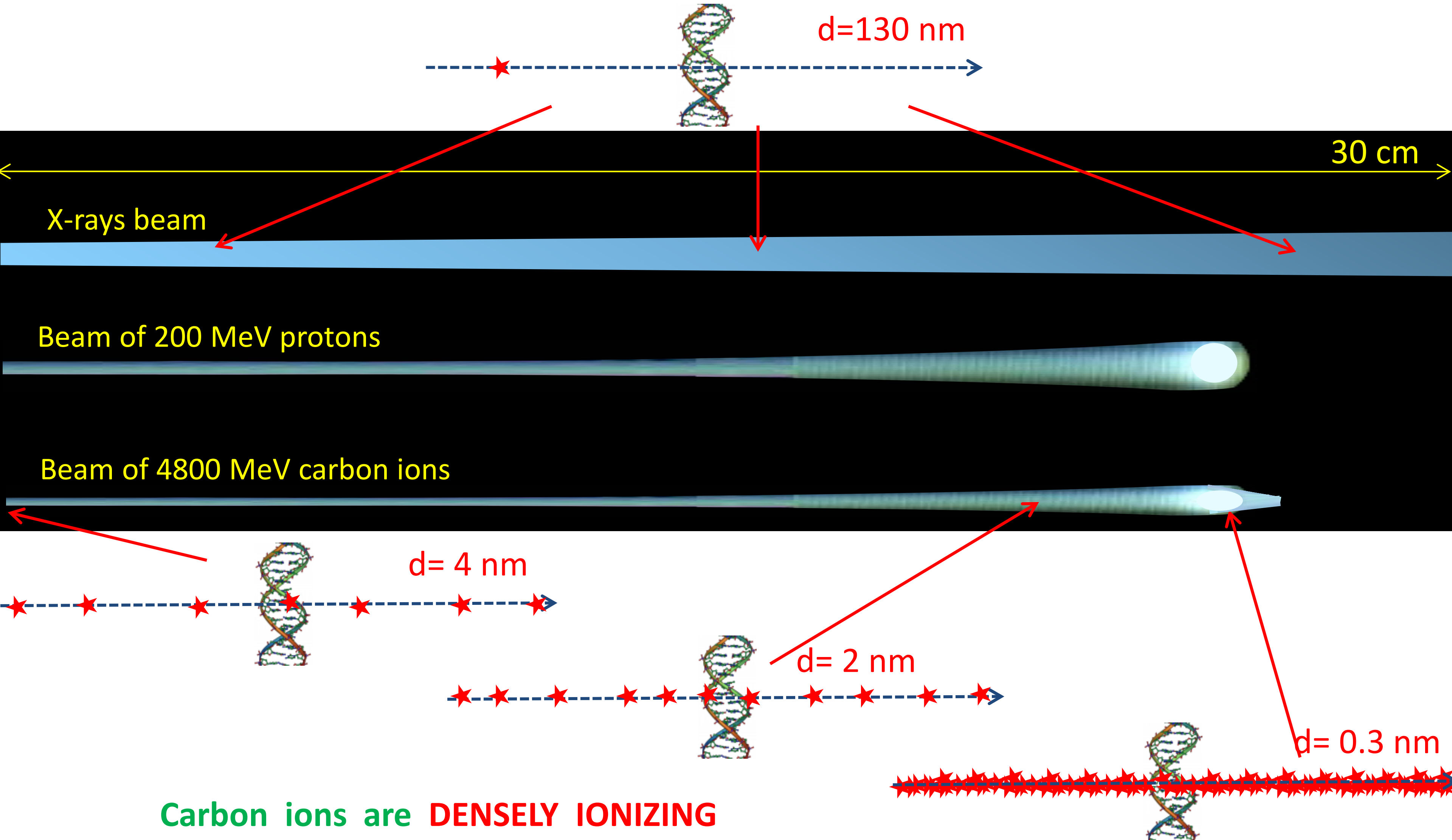
Protons: 1. more favorable dose 2. same ‘**indirect effects**’



Protons are SPARSELY IONIZING as X-rays

Carbon ions: 1. more favorable dose 2. ‘**direct effects**’



Carbon ions are DENSELY IONIZING
(higher biological effectiveness)

Numbers of potential patients (*)

- X-ray therapy

  every 10 million inhabitants: 20'000 pts/year

- Protontherapy

  12% of X-ray patients 2'400 pts/year

- Therapy with Carbon ions for radio-resistant tumour

  3% of X-ray patients 600 pts/year

TOTAL every 10 M about 3'000 pts/year

(*) Combining studies made in Austria, Germany, France and Italy in the framework of ENLIGHT - Coordinator: Manjit Dosanjh –

Projects in FP7: ULICE, PARTNER, ENVISION , ENTERVISION for a total of 22 MEuro

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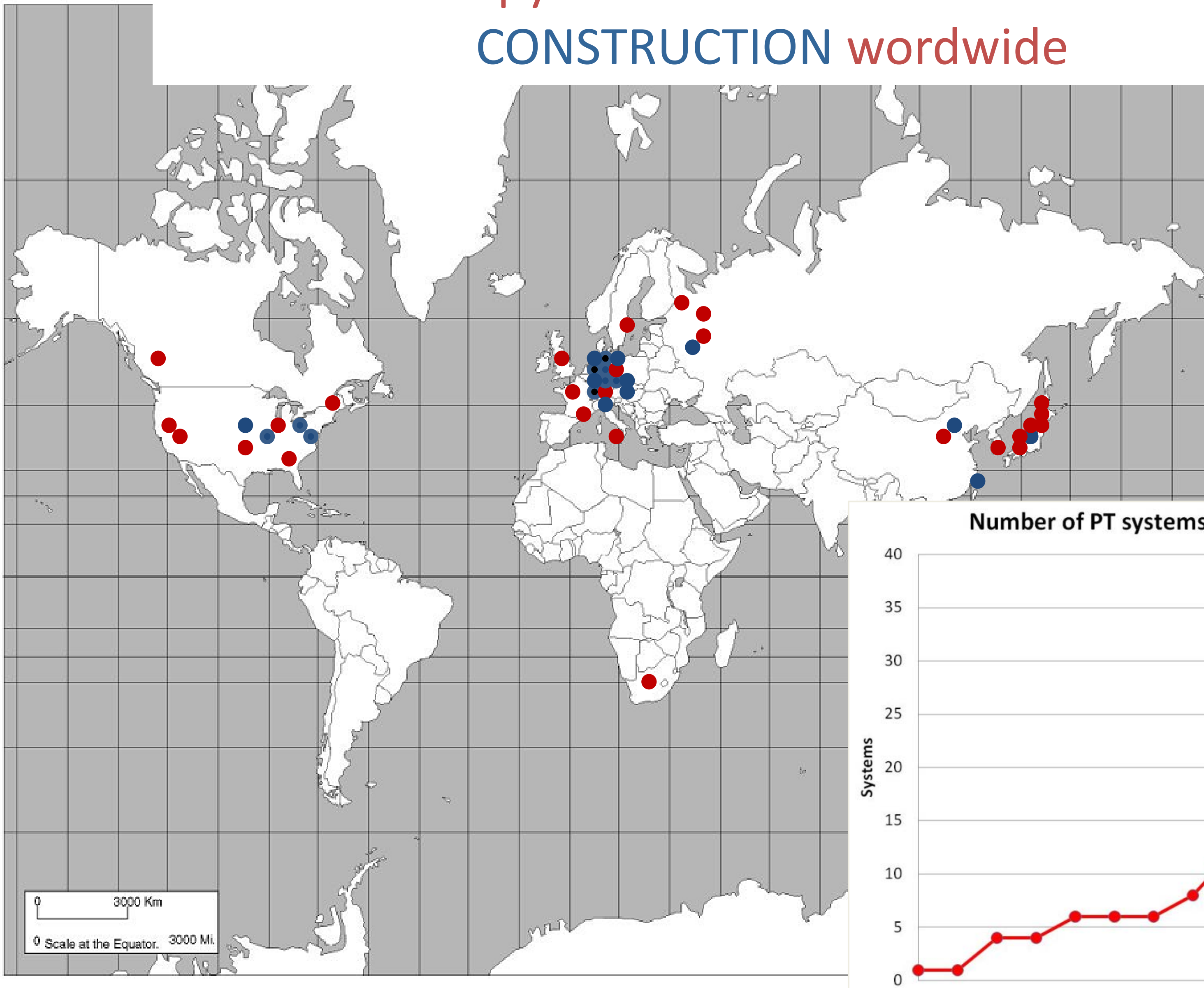
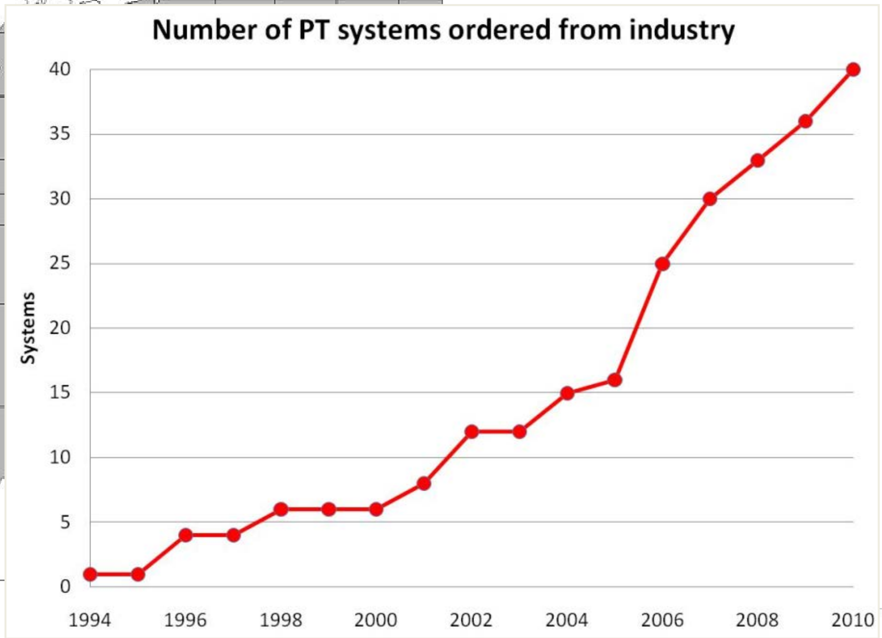
Part 2: Accelerators and technology

Accelerators for hadrontherapy

Hadrontherapy centres IN OPERATION and UNDER CONSTRUCTION wordwide



M. Dosanjh (PTCOG Data)



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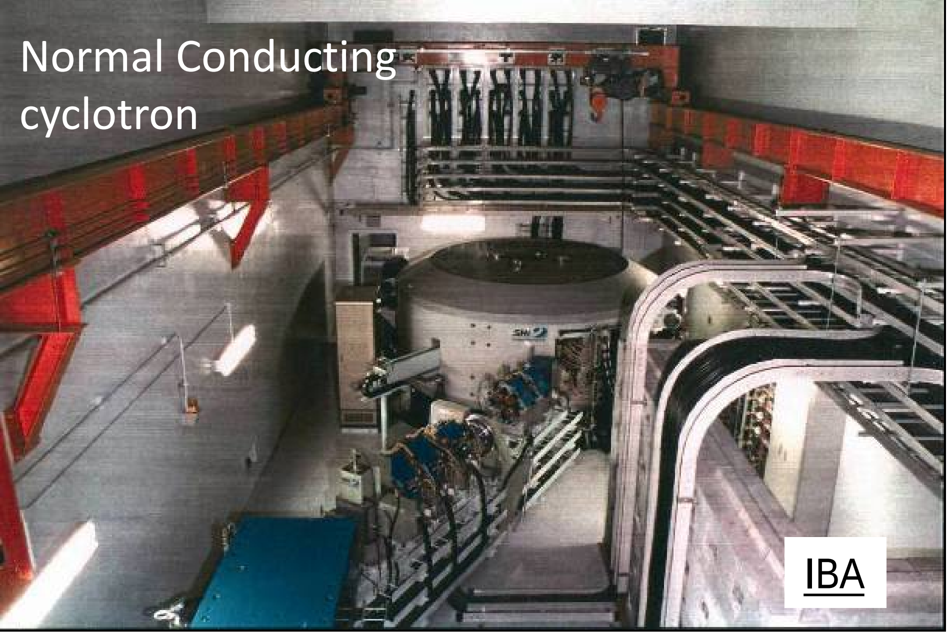
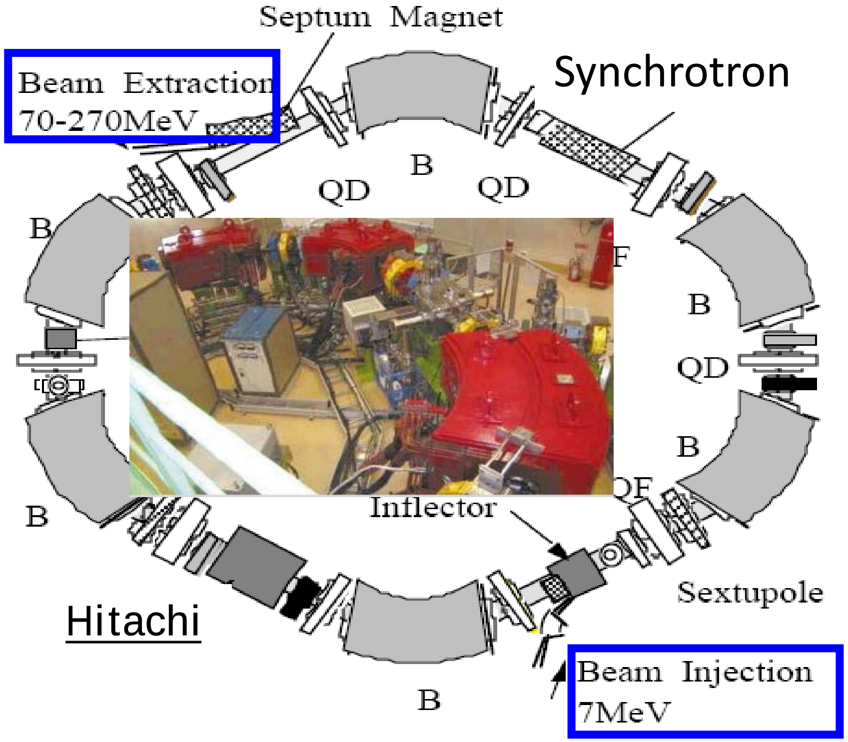
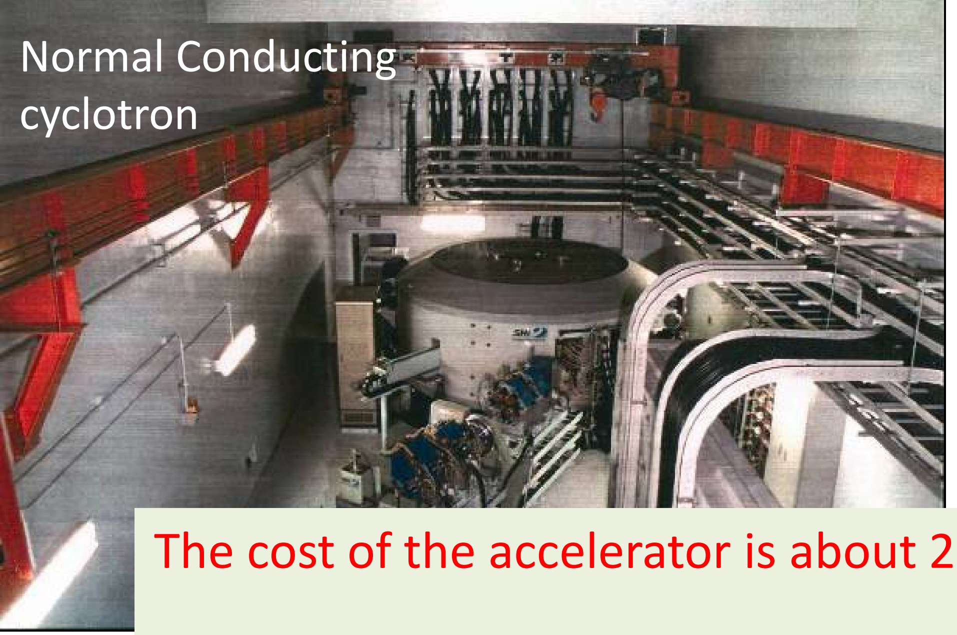
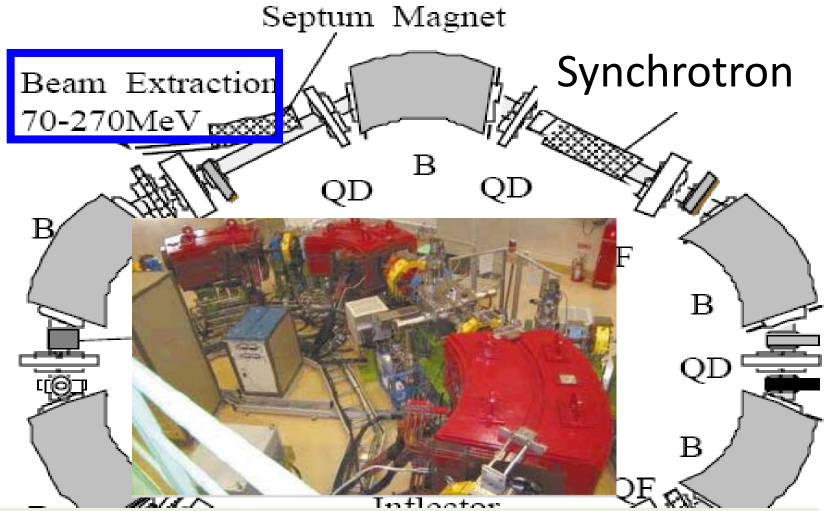
Proton accelerators





4 commercial 230-250 MeV p^+ accelerators





4 cor

The cost of the accelerator is about 20% of the cost of the centre:

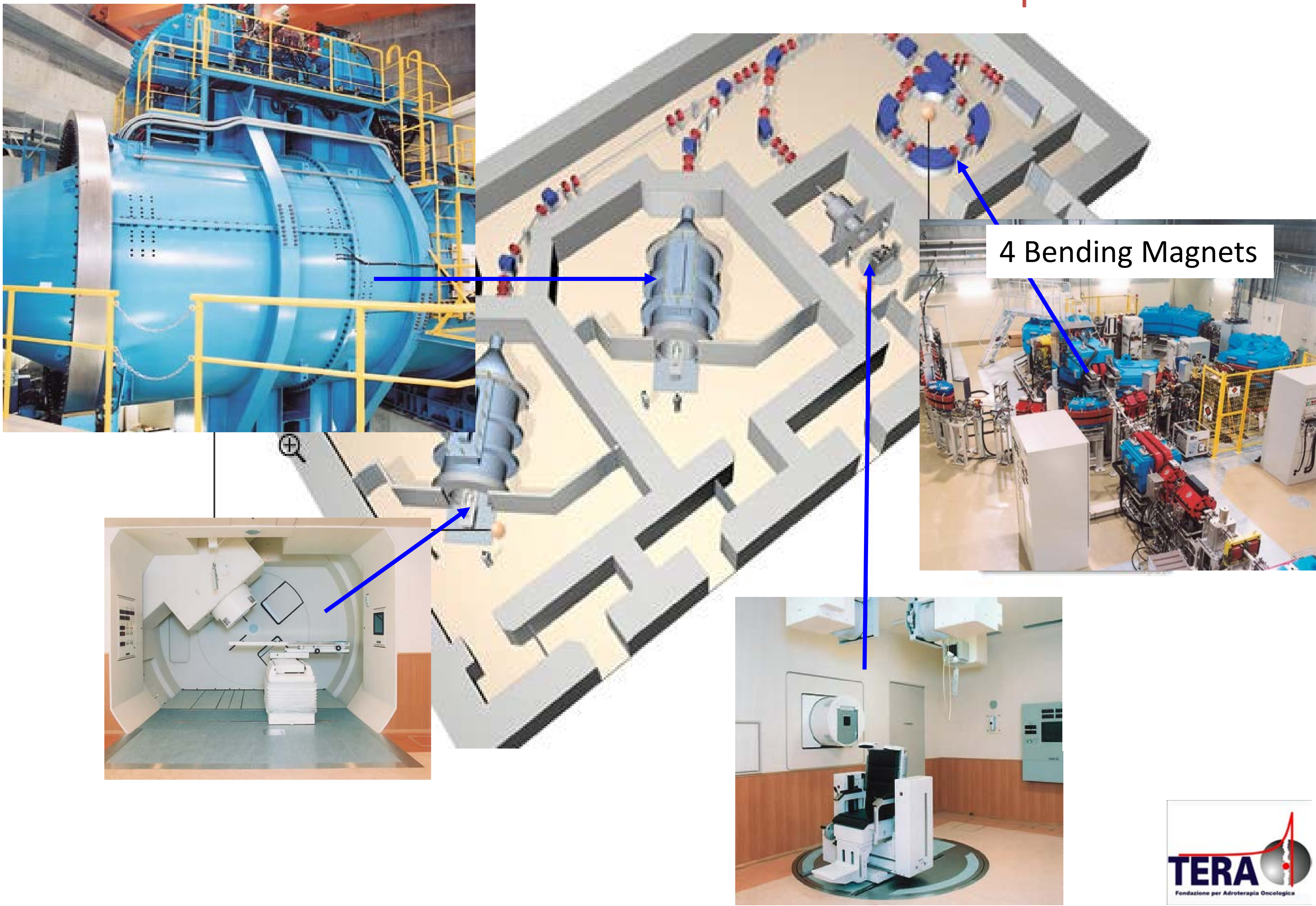
accelerator	20%	
building	20%	
3 gantries	20%	**(~30 MEuro)**

Cyclotron for protons by Ion Beam Applications - Belgium

Turn-key centres are offered for ≈150-180 M€.

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

Mitsubishi solution for Shizuoka - Japan



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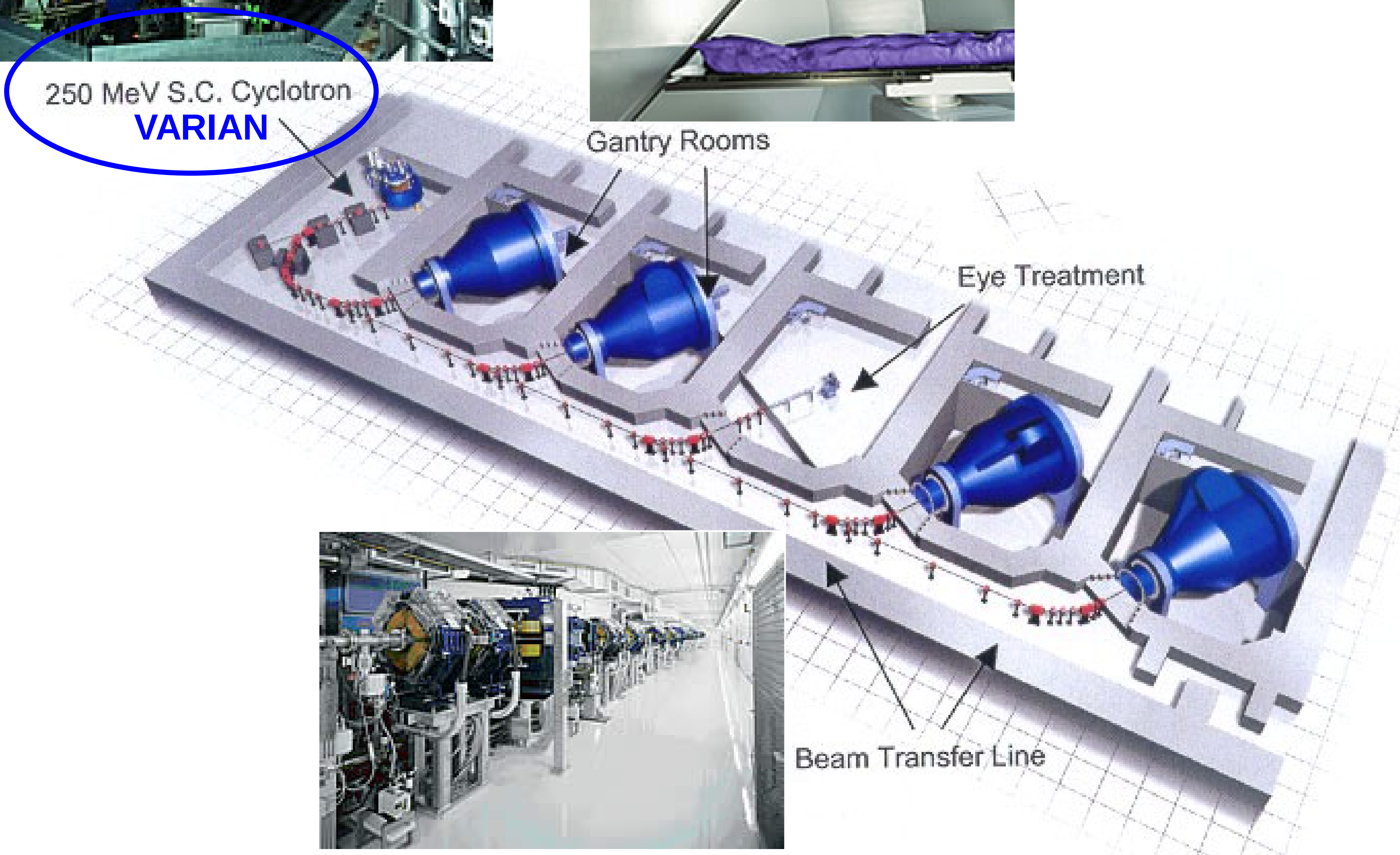
Rinecker Proton Therapy Centre Munich

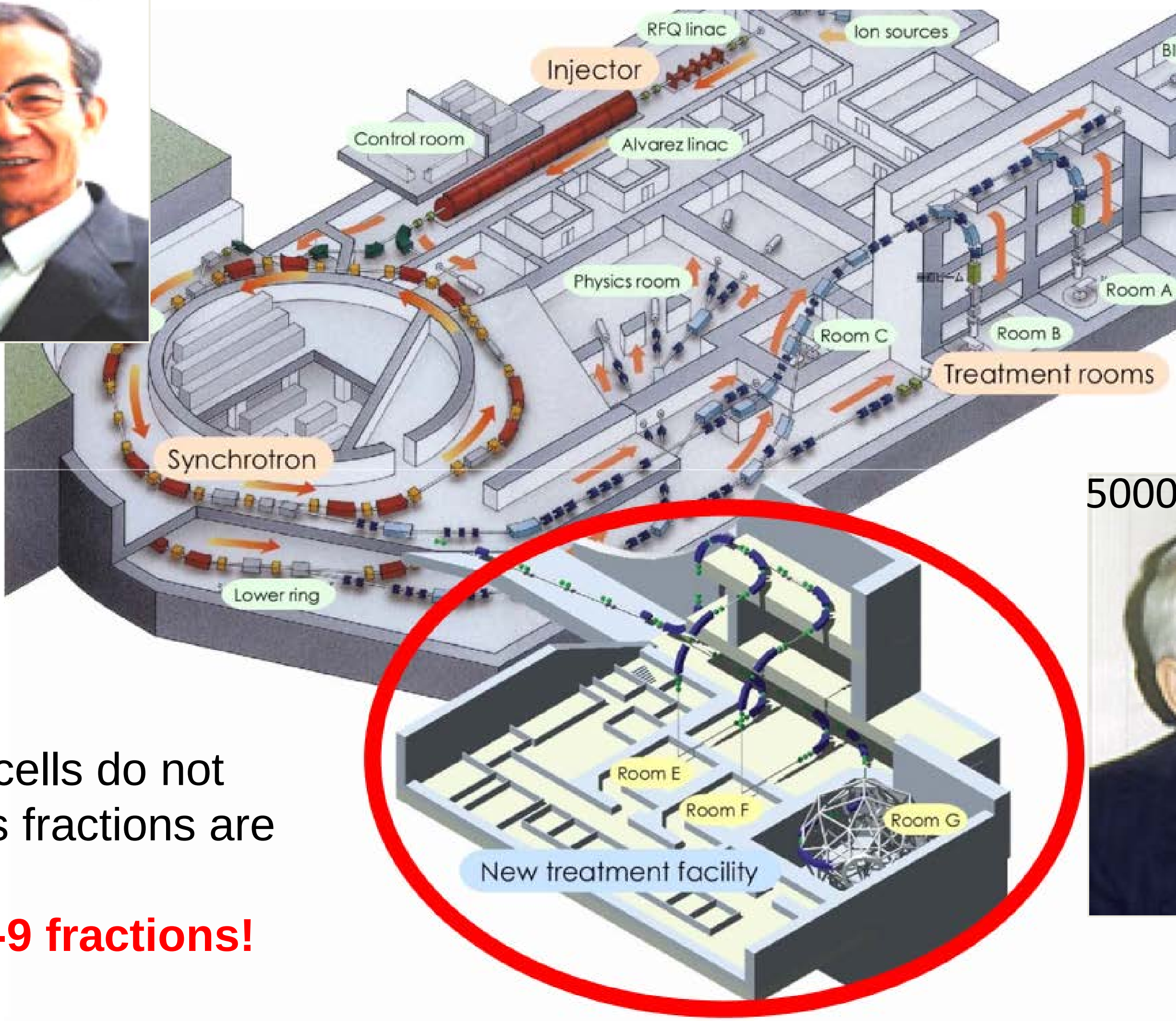


Dual centers
(p^+ / C^{6+} accelerators)

HIMAC in Chiba is the pioneer of carbon therapy

Yasuo Hirao

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



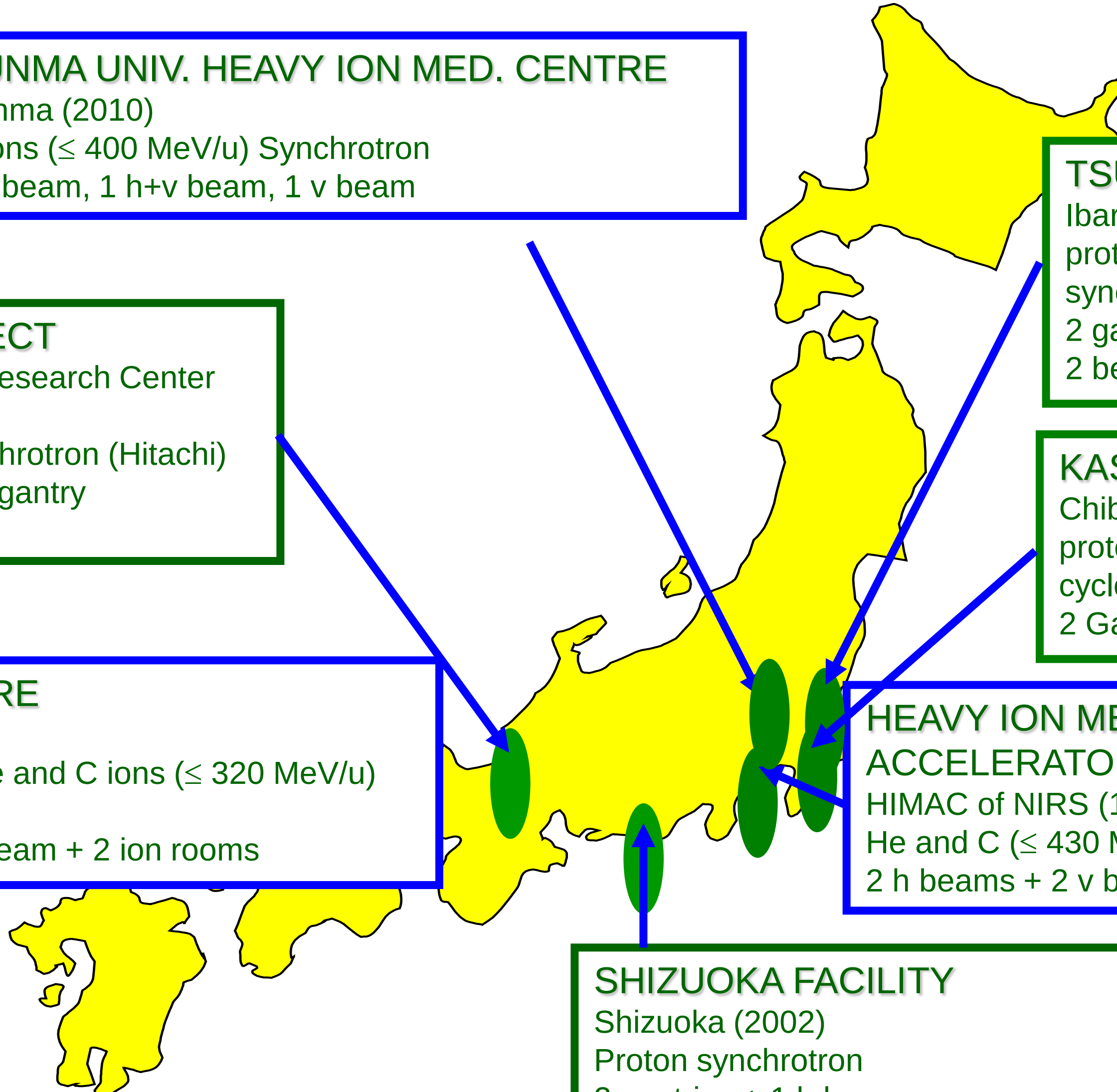
Hirohiko Tsujii

5000 pts 1994-2010

Since the cells do not repair. less fractions are possible

HIMAC: 4-9 fractions!

Japan is the best equipped region



GUNMA UNIV. HEAVY ION MED. CENTRE
Gunma (2010)
C ions (≤ 400 MeV/u) Synchrotron
1 h beam, 1 h+v beam, 1 v beam

TSUKUBA CENTRE
Ibaraki (2001)
protons (≤ 270 MeV)
synchrotron (Hitachi)
2 gantries
2 beam for research

WAKASA BAY PROJECT
by Wakasa-Bay Energy Research Center
Fukui (2002)
protons (≤ 200 MeV) synchrotron (Hitachi)
1 h beam + 1 v beam + 1 gantry

KASHIWA CENTER
Chiba (1998)
protons (≤ 235 MeV)
cyclotron (IBA – SHI)
2 Gantries + 1 hor. beam

HYOGO MED CENTRE
Hyogo (2001)
protons (≤ 230 MeV) - He and C ions (≤ 320 MeV/u)
Mitsubishi synchrotron
2 p gantries + 2 fixed p beam + 2 ion rooms

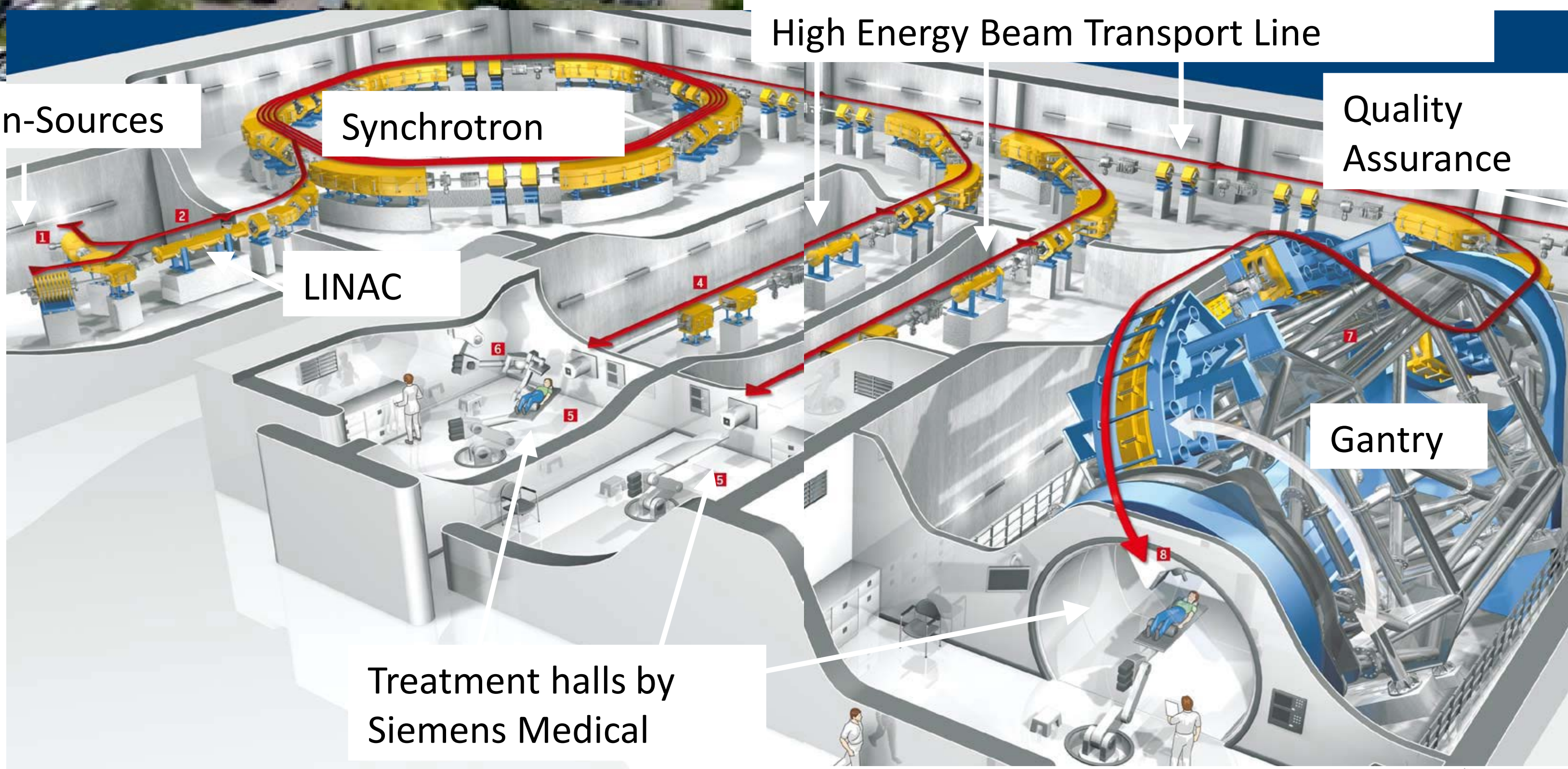
HEAVY ION MEDICAL ACCELERATOR
HIMAC of NIRS (1995)
He and C (≤ 430 MeV/u) 2 synchrotrons
2 h beams + 2 v beams

SHIZUOKA FACILITY
Shizuoka (2002)
Proton synchrotron
2 gantries + 1 h beam

HIT at Heidelberg

Medical Director: J. Debus
Technical Director: T. Haberer

First patient: September 2009
At present: about 2600 patients



CNAO: Centro Nazionale Adroterapia Oncologica at Pavia

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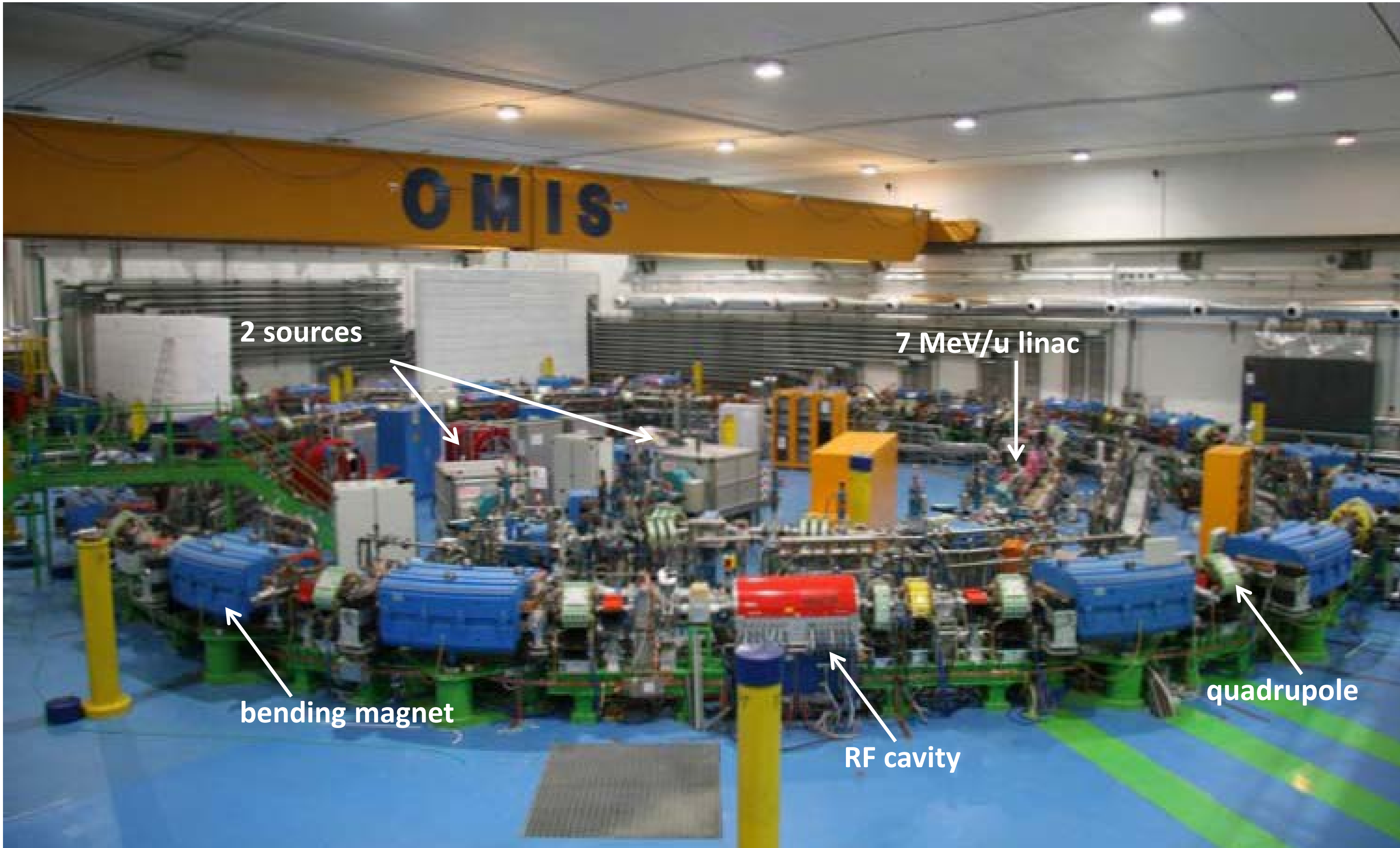
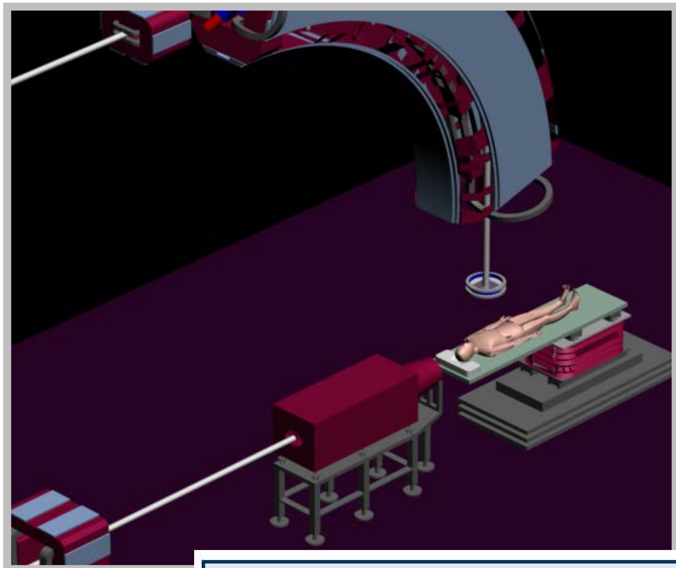
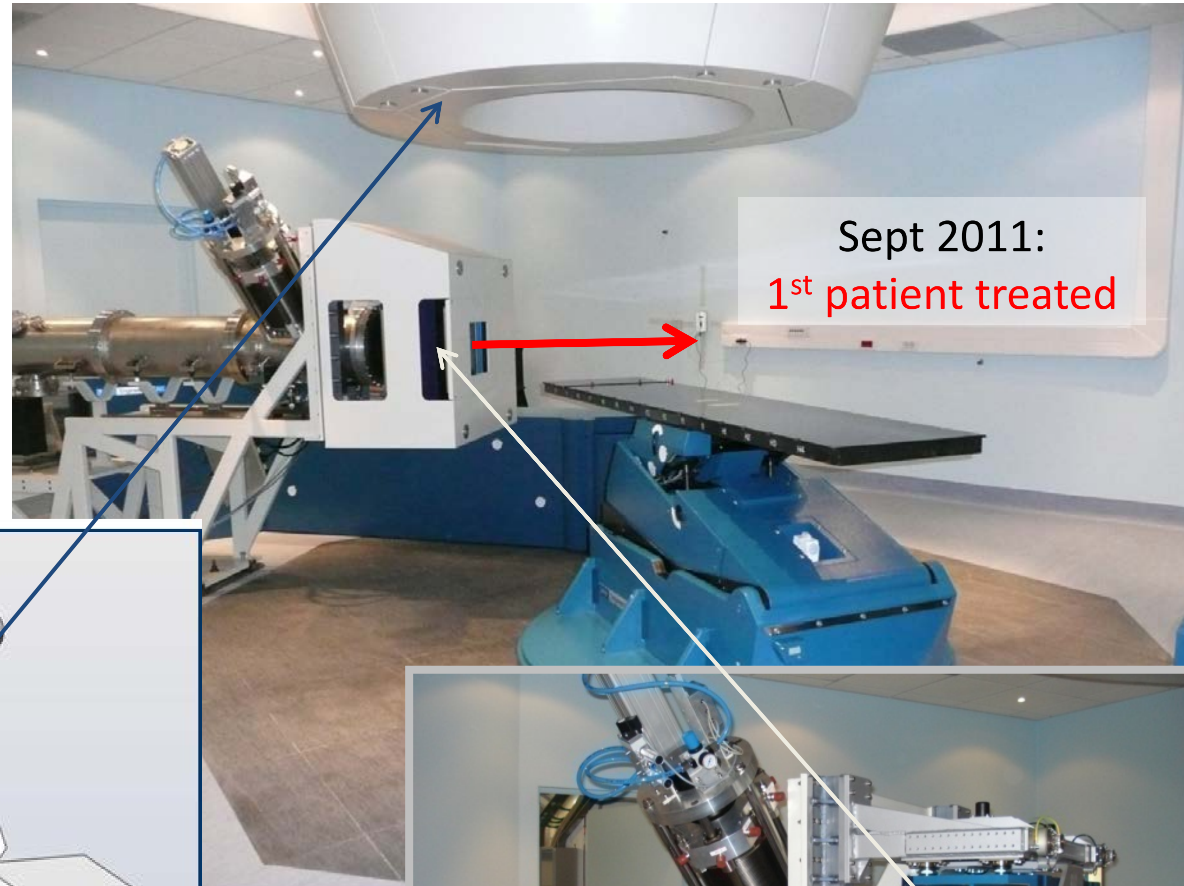
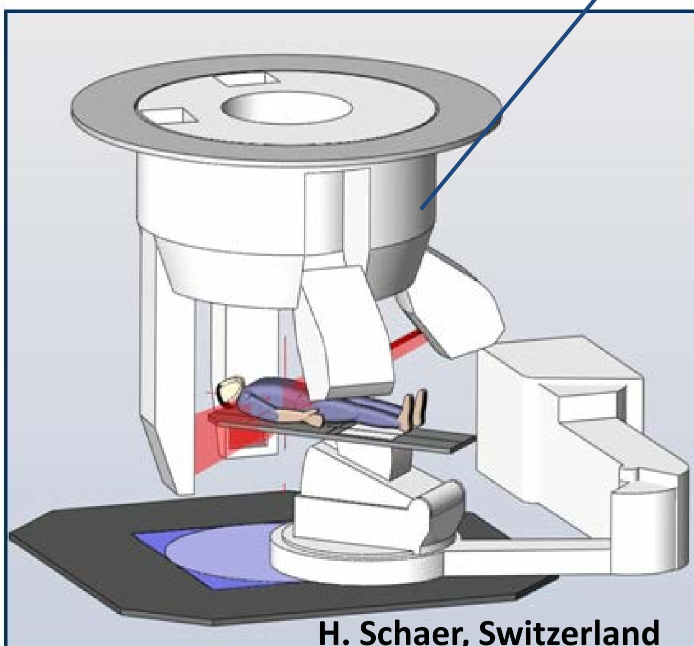
The CNAO Synchrotron for protons and carbon ions



CNAO: the treatment room

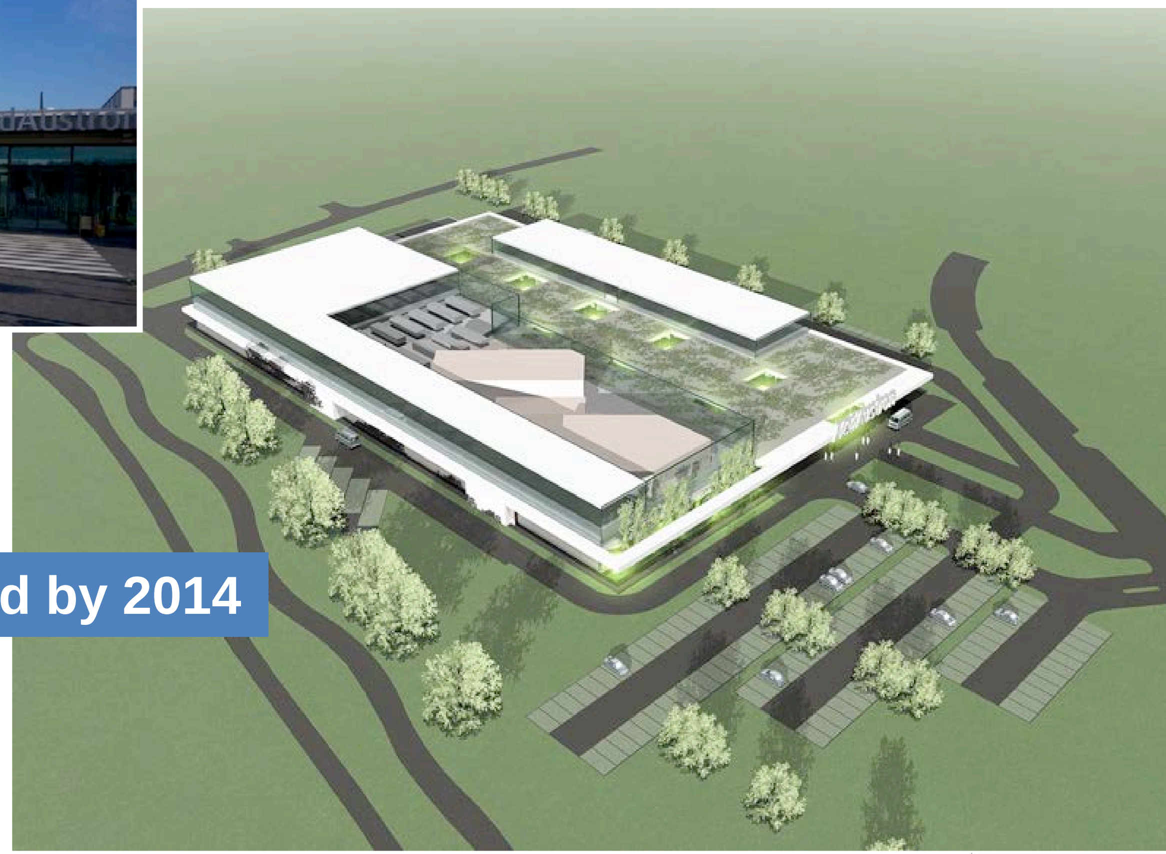






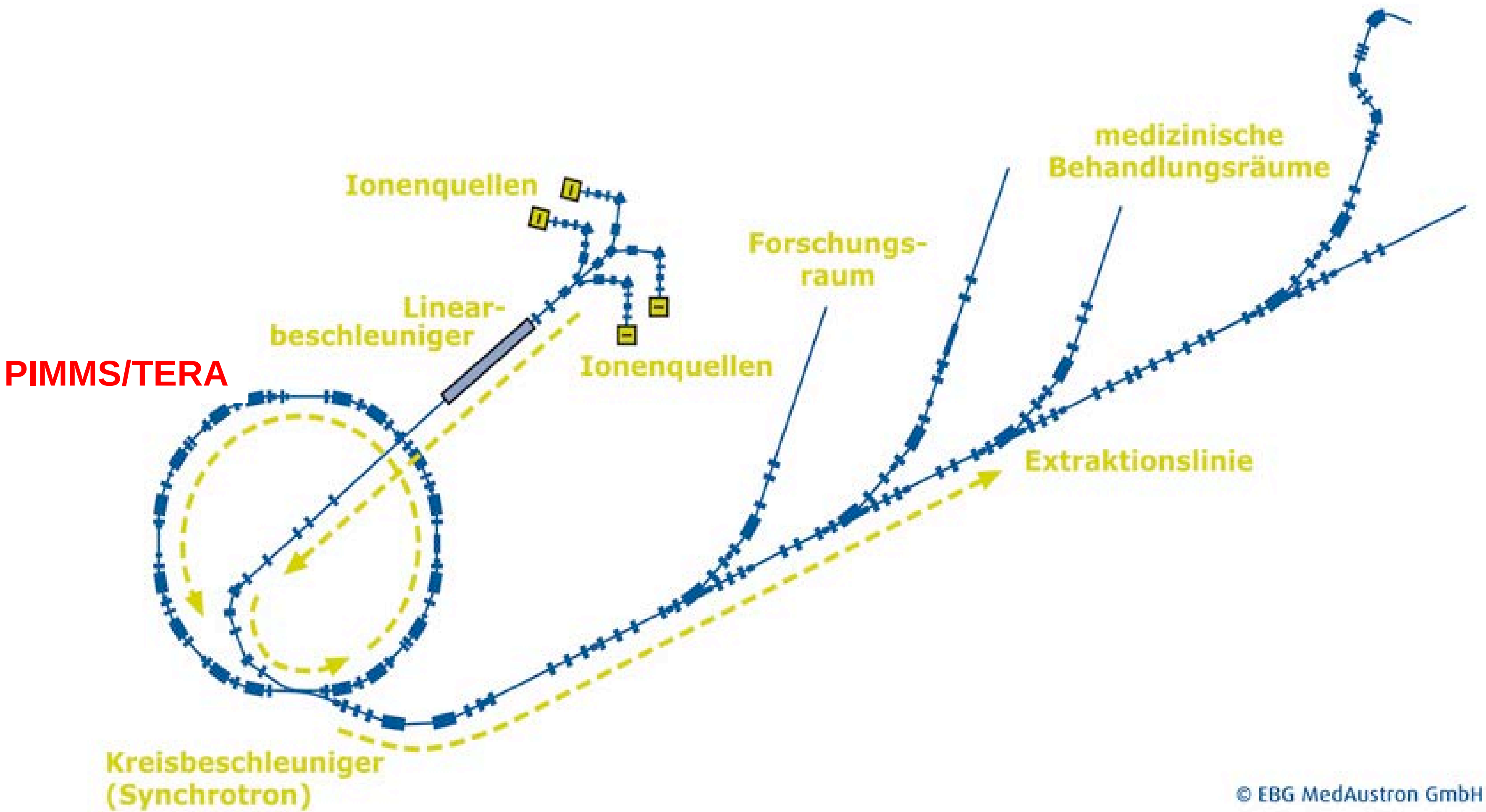
MedAustron promoted and participated in PIMMS

Meinhard Regler
Michael Benedikt



Construction completed by 2014

MedAustron participated in PIMMS



MedAustron has bought from CNAO Foundation the construction drawings for 3.2 million Euro (by agreement with CERN-CNAO-INFN)

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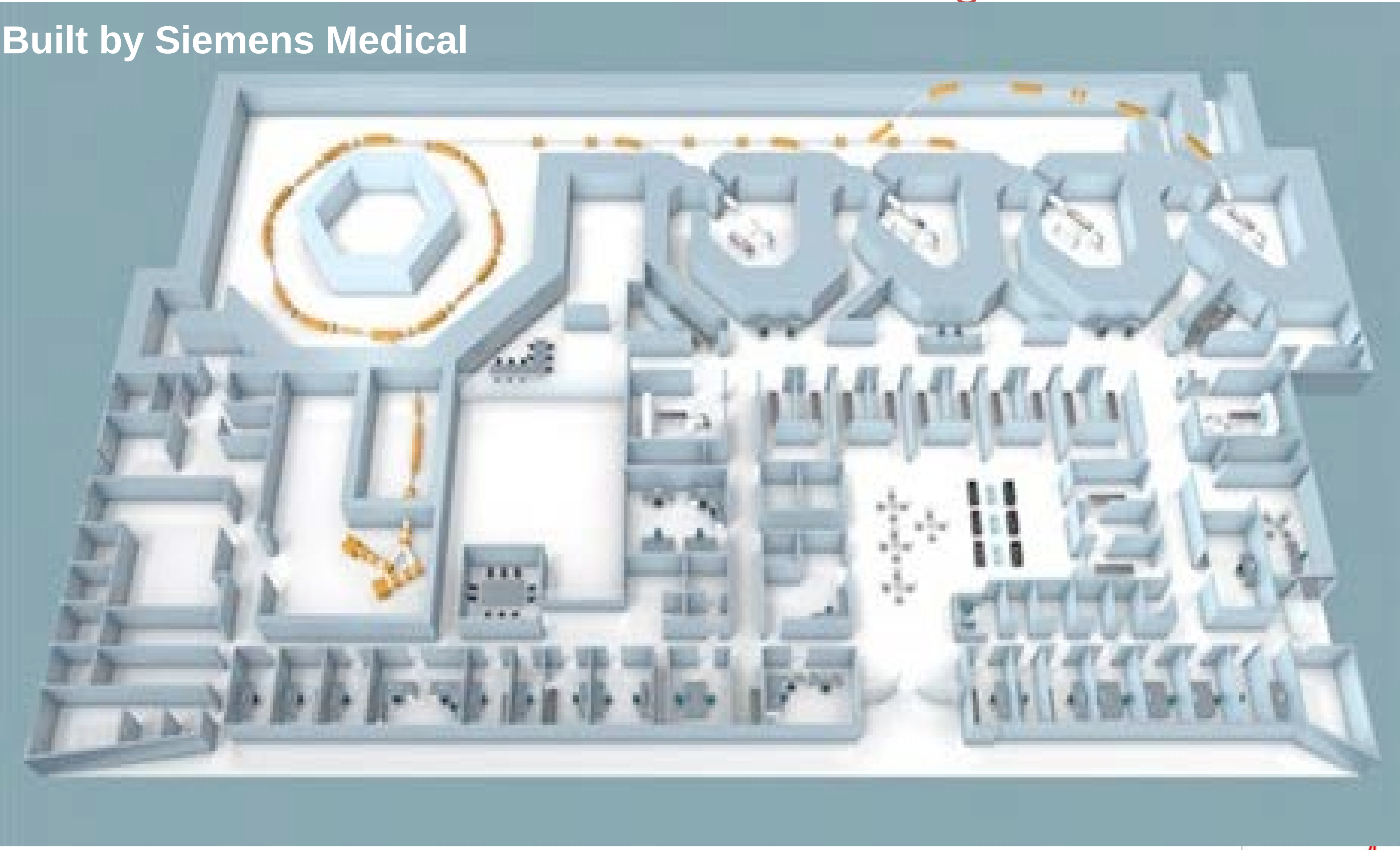
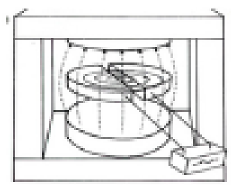
Marburg carbon ion and proton dual centre
Similar centre in Shangai

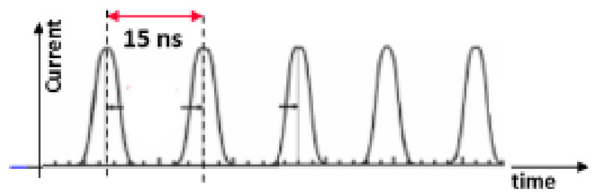


Treatment modalities

Properties of the beams of different accelerators

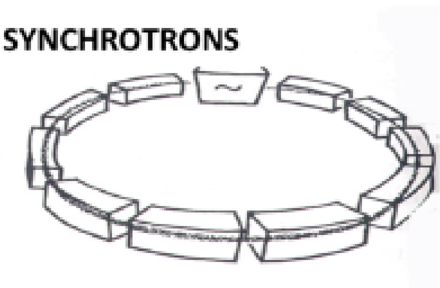
CYCLOTRONS (*) (Normal or SC)

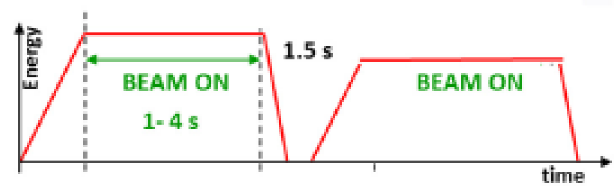




The pulsed beam of fixed energy
is always present

SYNCHROTRONS

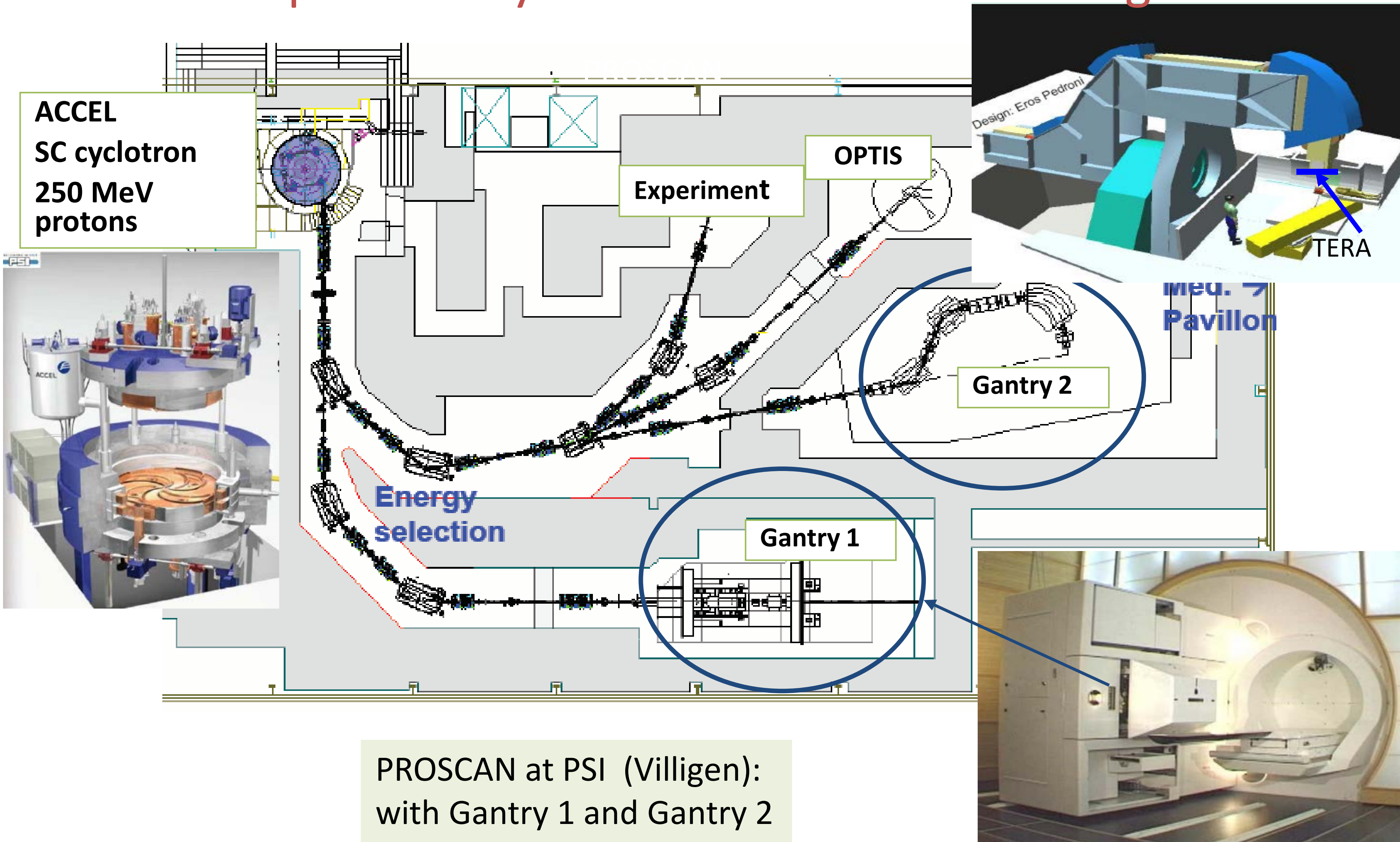




A cycling beam of variable energy
has 1 second gaps

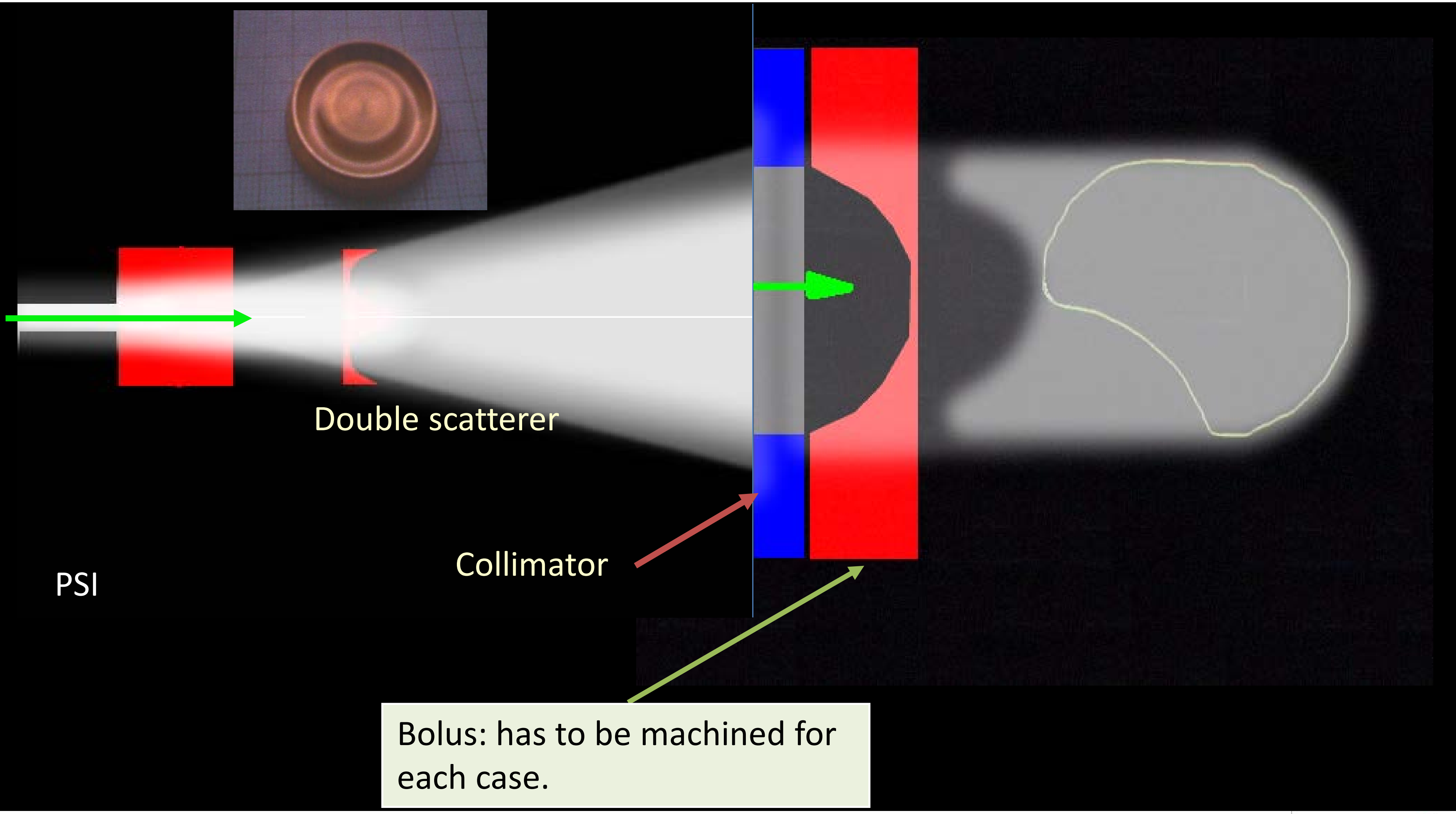
Accelerator type	Beam always present ?	Energy variation by electronic means	Time needed for varying the energy
Cyclotron	Yes (hundreds Hz)	No	80-100 ms (with abs)
Synchrotron	No	Yes	1-2 second

Two methods for imparting the dose: “passive” system and “active” scanning

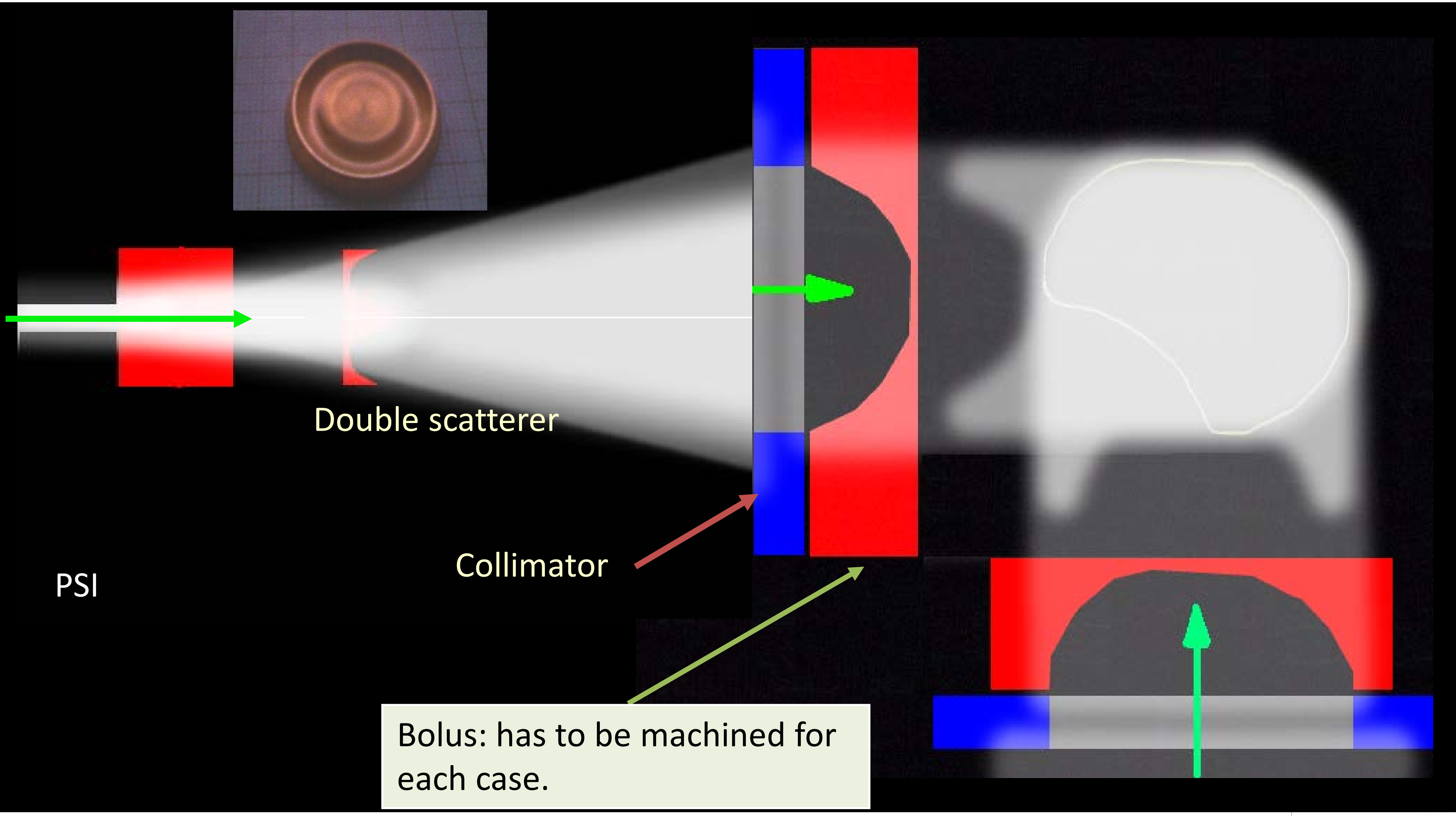


PROSCAN at PSI (Villigen):
with Gantry 1 and Gantry 2

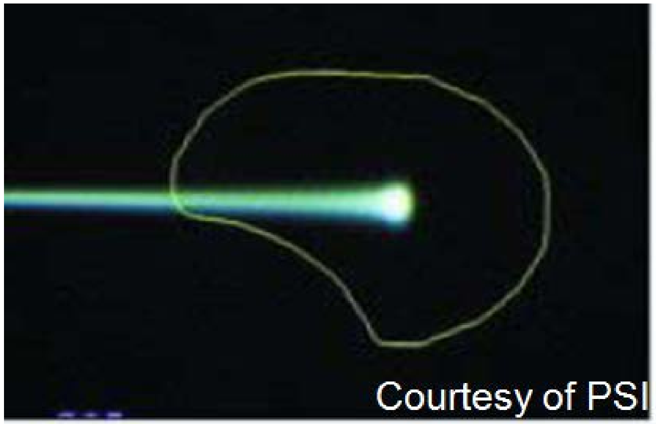
1A. Standard procedure: Passive beam spreading with respiratory gating



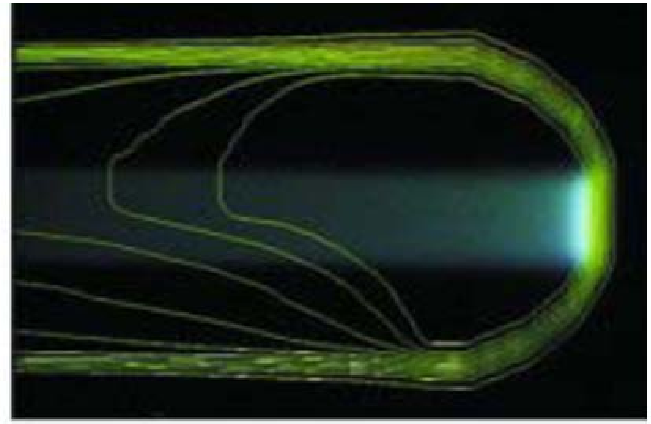
1A. Standard procedure: Passive beam spreading with respiratory gating



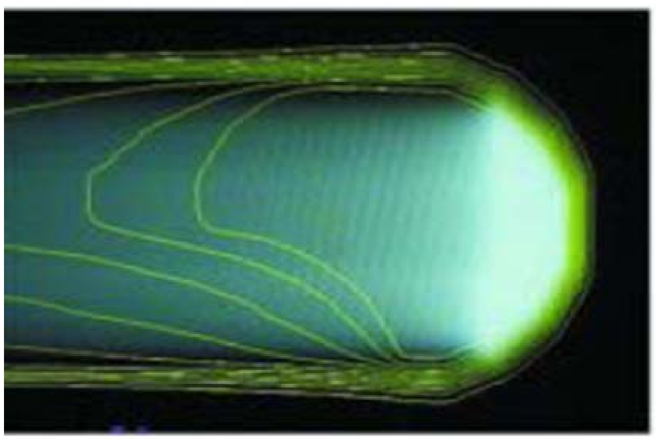
2A. Active "spot scanning" technique by PSI with respiratory gating (Villigen)



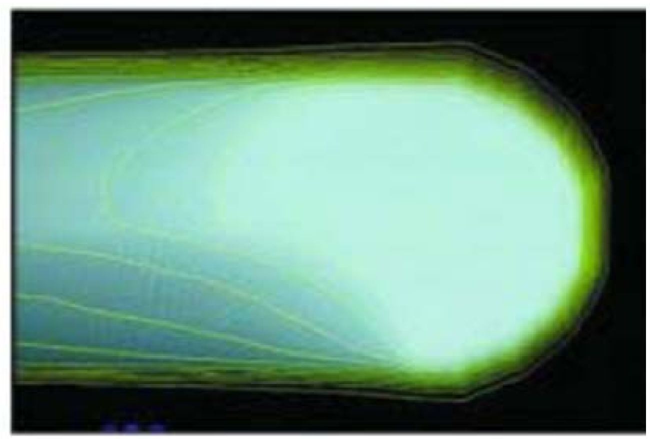
Single 'spot' pencil beam



Lateral scanning with magnets: 2 ms/step



Depth scanning: ENERGY MODULATION

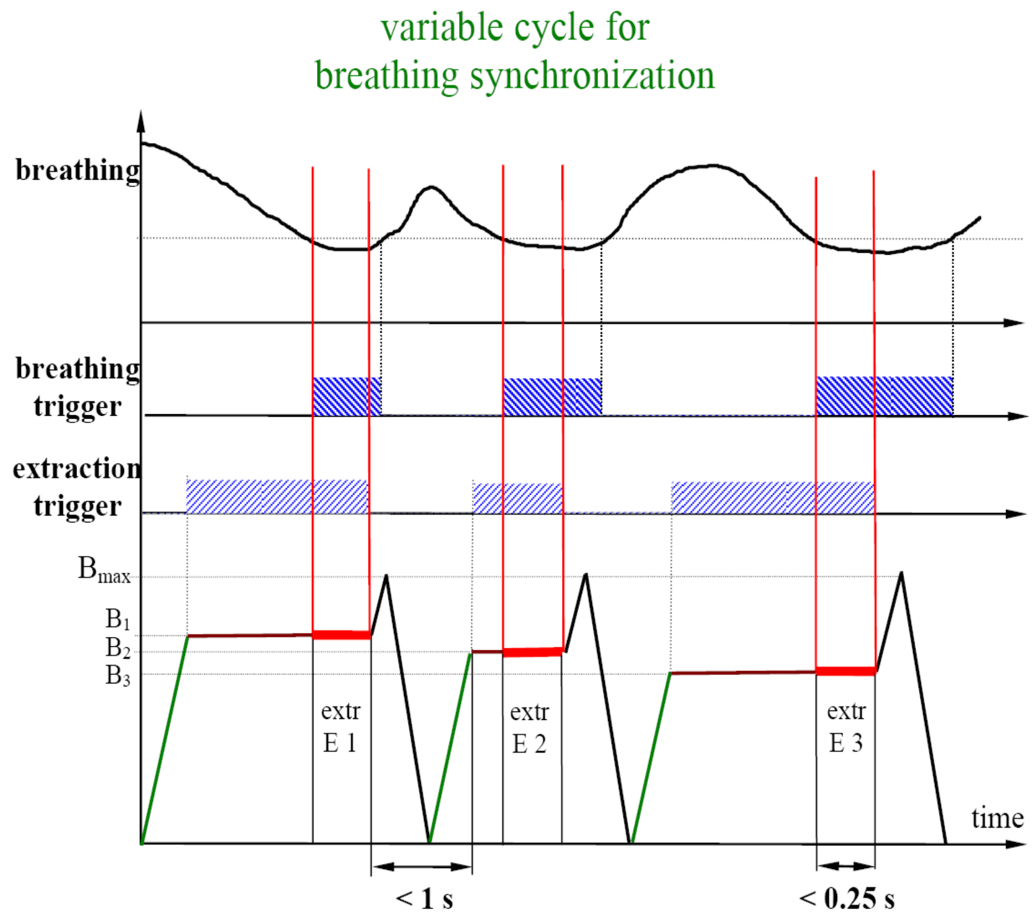


<u>3D conformal treament</u>

Future challanges in hadrontherapy:

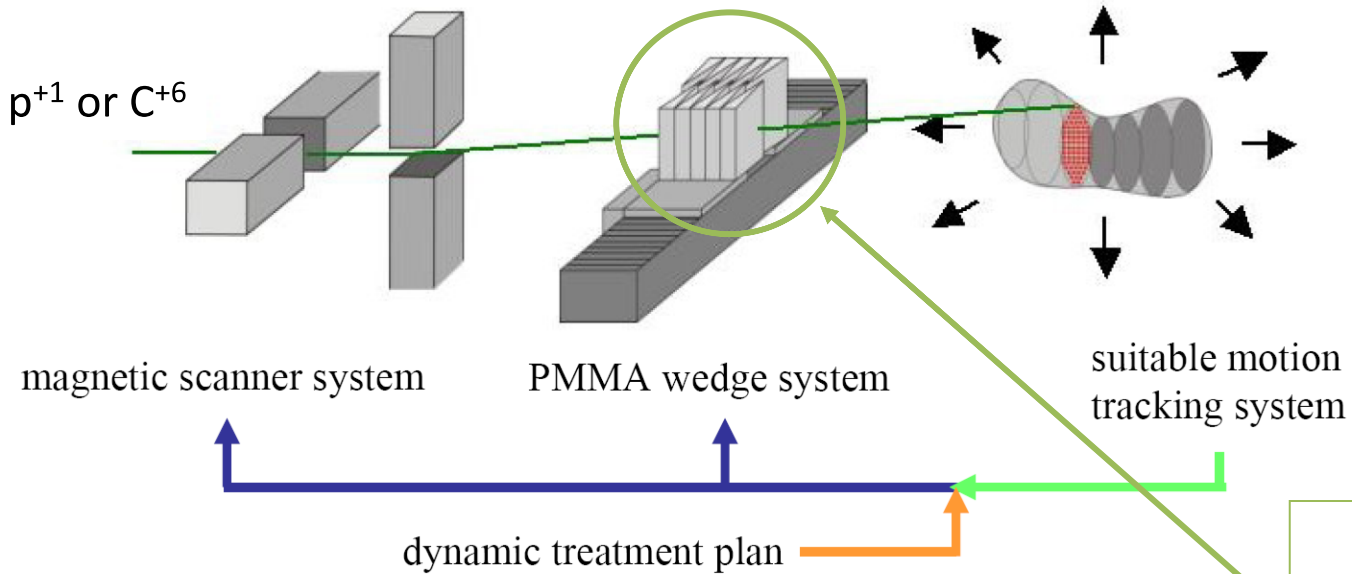
Respiratory gating with a synchrotron

- The beam reaches the patient only when the Target "gate" is ON
- Synchrotrons: synchronization of the respiration of the patient with the cycle of the accelerator
- Technique already in use in Japan (Tsukuba)



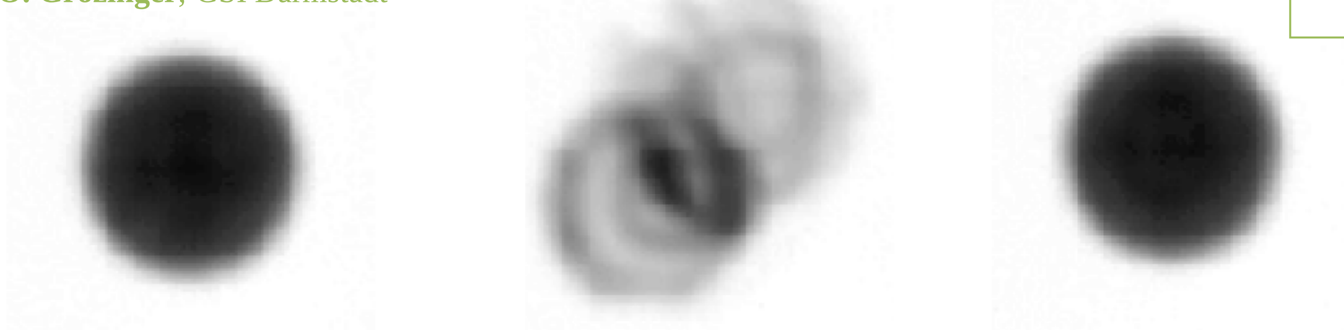
Cyclotrons are better because the beam is always present

GSI approach to treat moving organs: depth with fast absorbers



BETTER SOLUTION: energy variation by electronics and not mechanics

Sven O. Grözinger, GSI Darmstadt

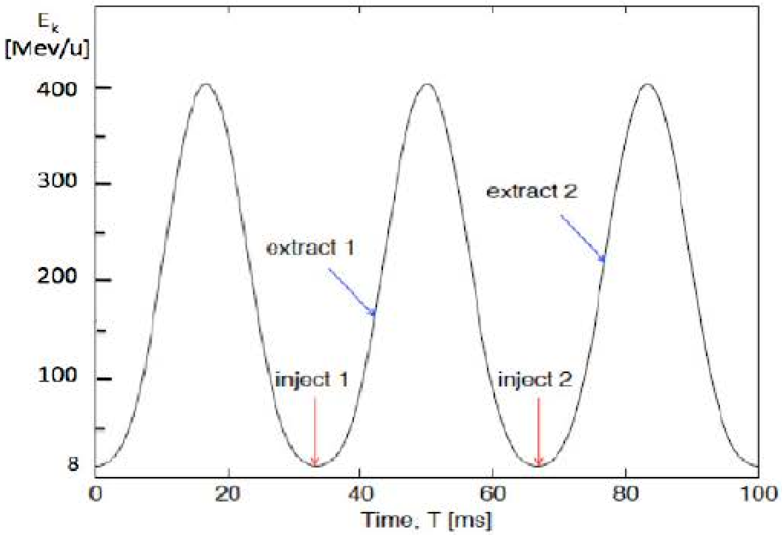


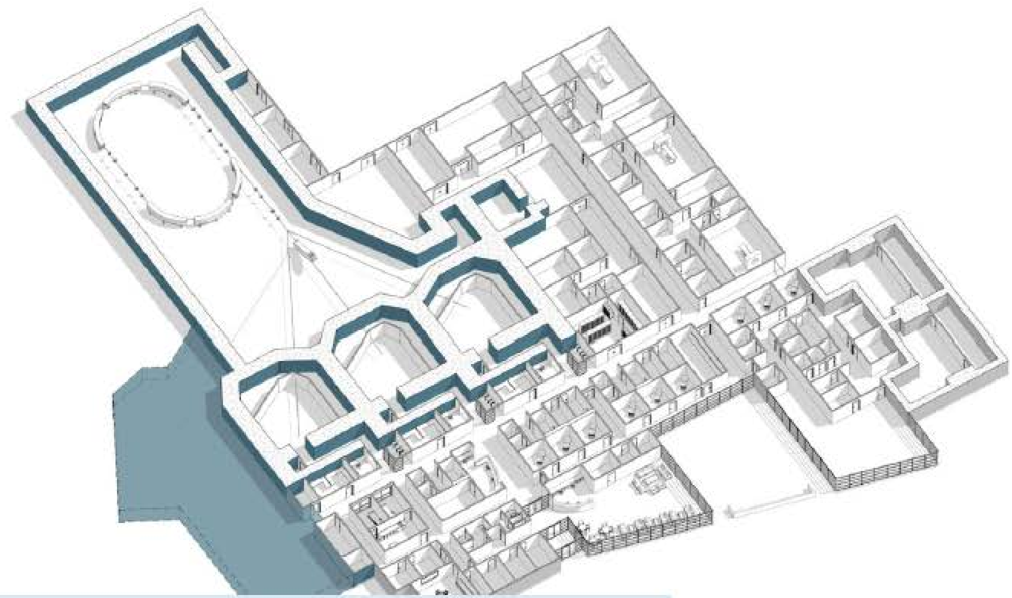
static

moving, non-compensated

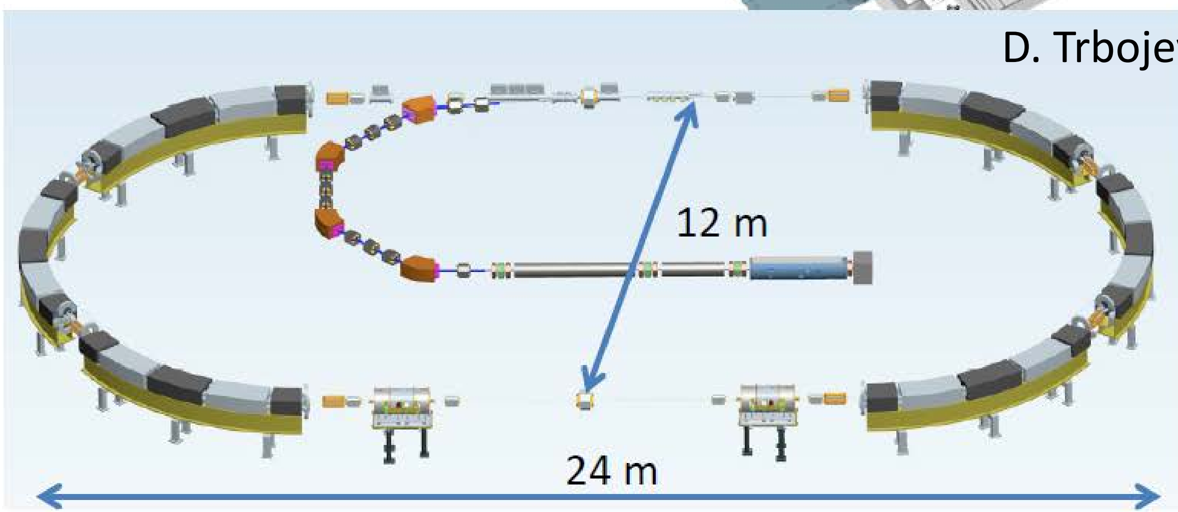
moving, compensated

ion Rapid Cycling Medical Synchrotron





D. Trbojevic et al., IPAC2011

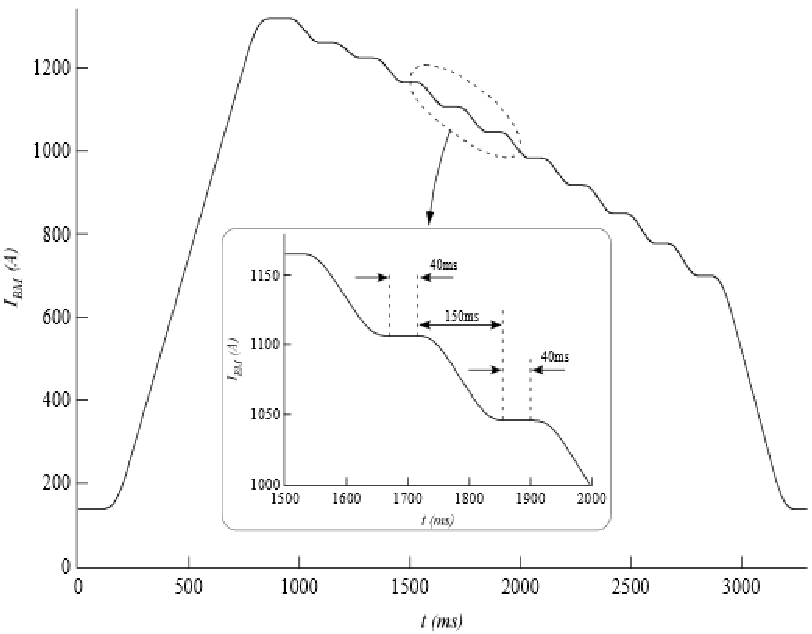


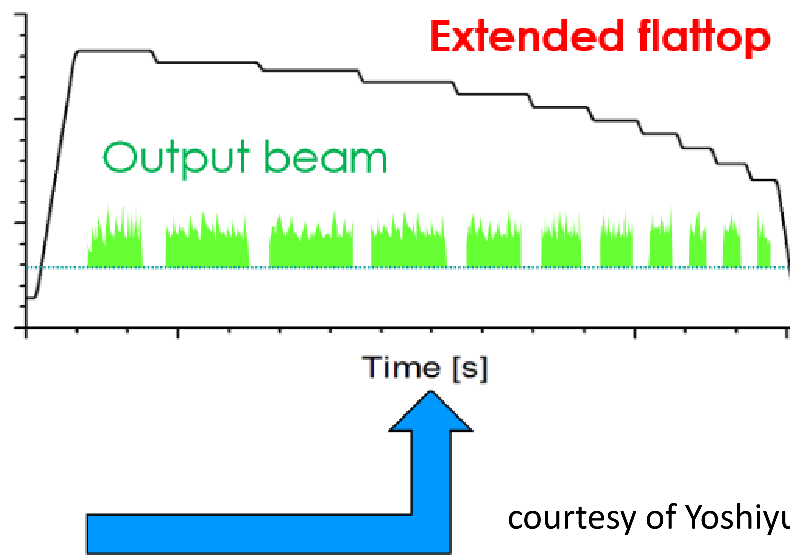
Fast energy variation with synchrotron at NIRS

NIRS
HIMAC

Multiple-flattop operation

- Operation pattern having multiple flattops
- Each flattop can be extended
- **Beams having various energies can be extracted!**





courtesy of Yoshiyuki Iwata

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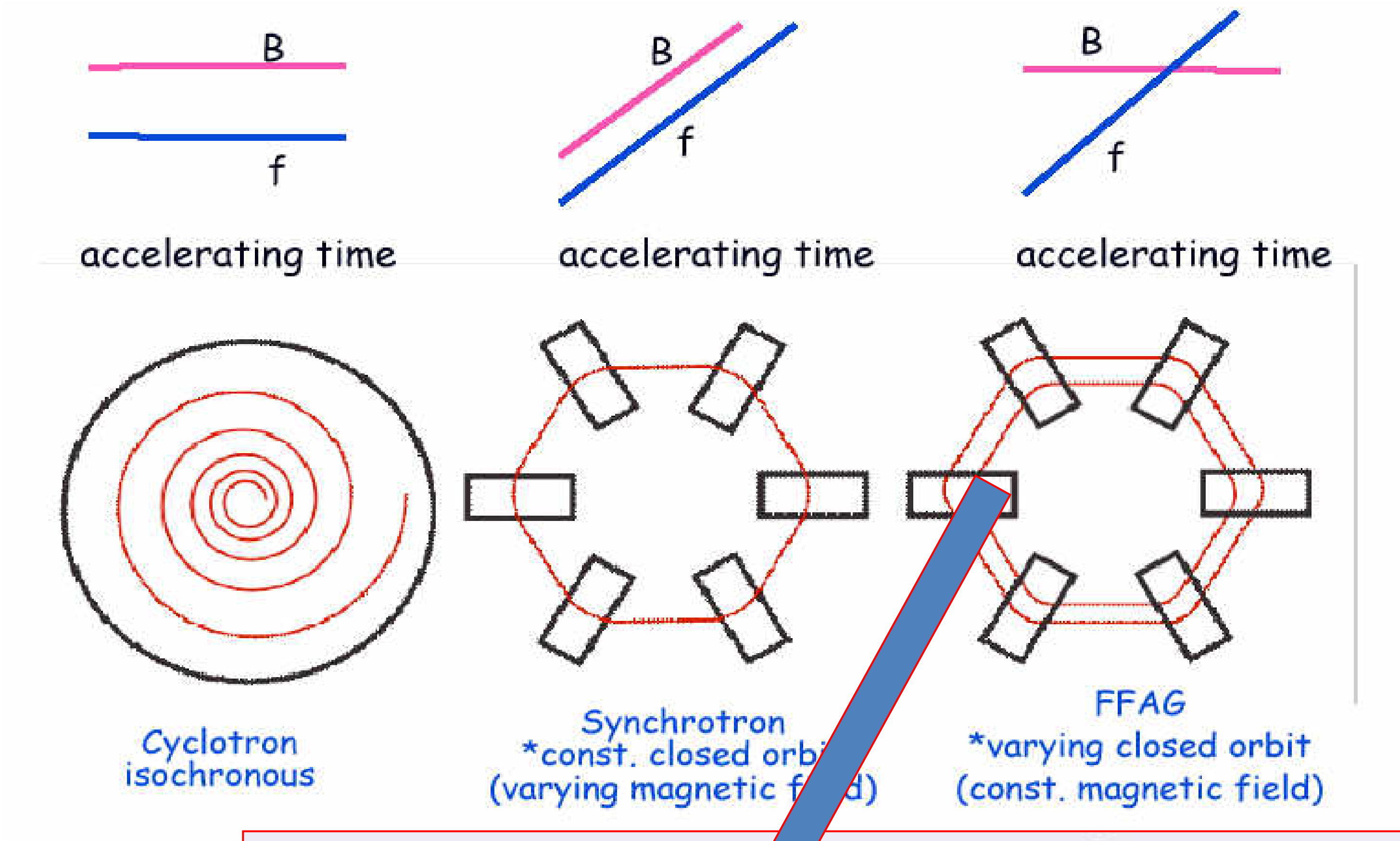
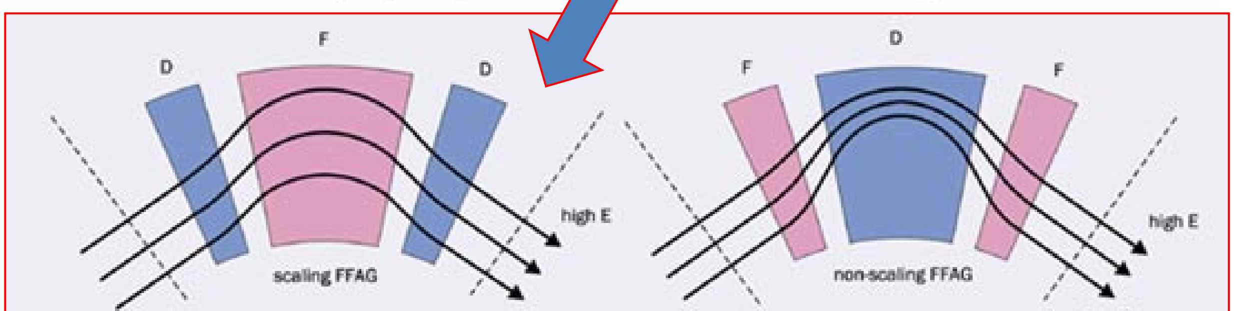
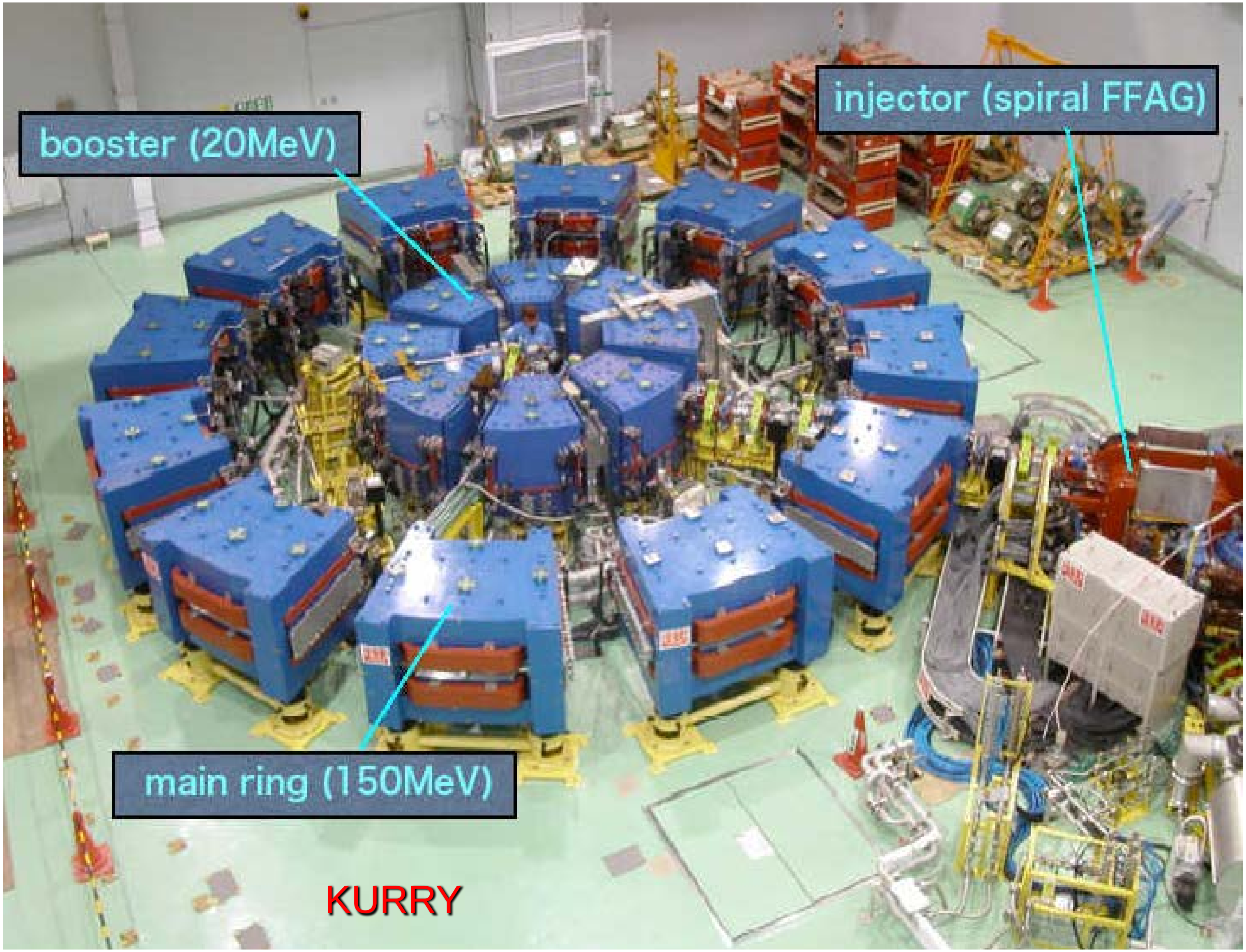
An old-new solution: Fixed Field Alternating Gradient





Scaling and Non scaling FFAG

The Japanese scaling 150 MeV proton FFAG



A non-scaling Fixed Field Alternating Gradient

DESIGN OF A NON-SCALING FFAG ACCELERATOR FOR PROTON THERAPY*

D. Trbojevic, A. G. Ruggiero, BNL, Upton, NY, USA, E Keil, CERN, Geneva, Switzerland, N. Neskovic, Vinca, Belgrade, and A. Sessler, LBL, Berkeley, CA, USA

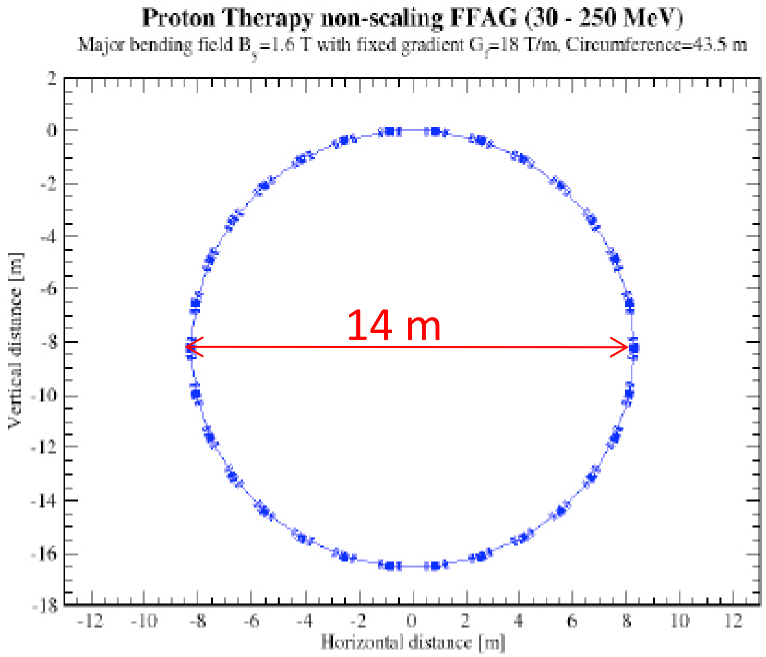


Figure 2. The whole ring of the fixed gradient lattice with 35 cells, C=43.5 m.

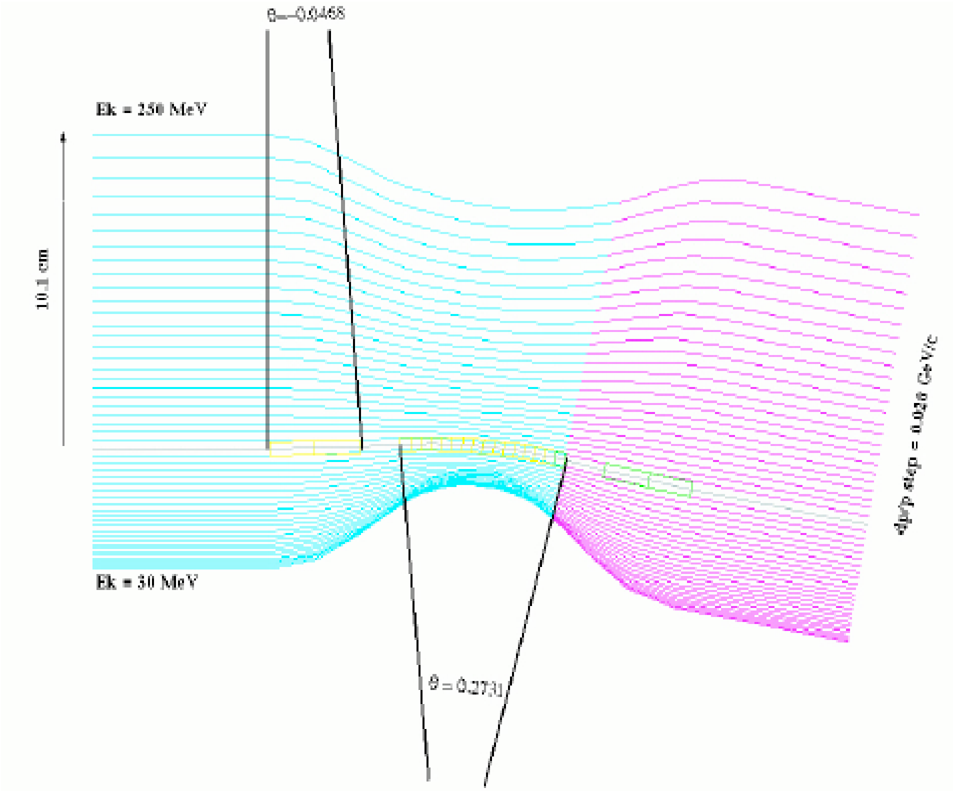


Figure 3. Orbits of particles during acceleration.

2nd challenge: proton single room-facilities

The reasons for proton single room-facilities*:

Radiation treatment	Patients per year in 10^7	Number of session per patient	Sessions/d in 1 room (d = 12 h)	Patients/y in 1 room (y=230 d)	Rooms per 10 million people (1)	Relative ratio ≈
Photons (1)	20'000	30	48	370	54	**8^2**
Protons (12%)	2'400	20	36	380	6.3	**8**
C ions (3%)	600	10	36	760	0.8	**1**

ENLIGHT results

1 Proton single-room facility
every 8 X-ray rooms
in 3-4 close-by hospitals
serving ≤2 million people

* U. Amaldi et. al, NIM A 620 (2010), 563-577

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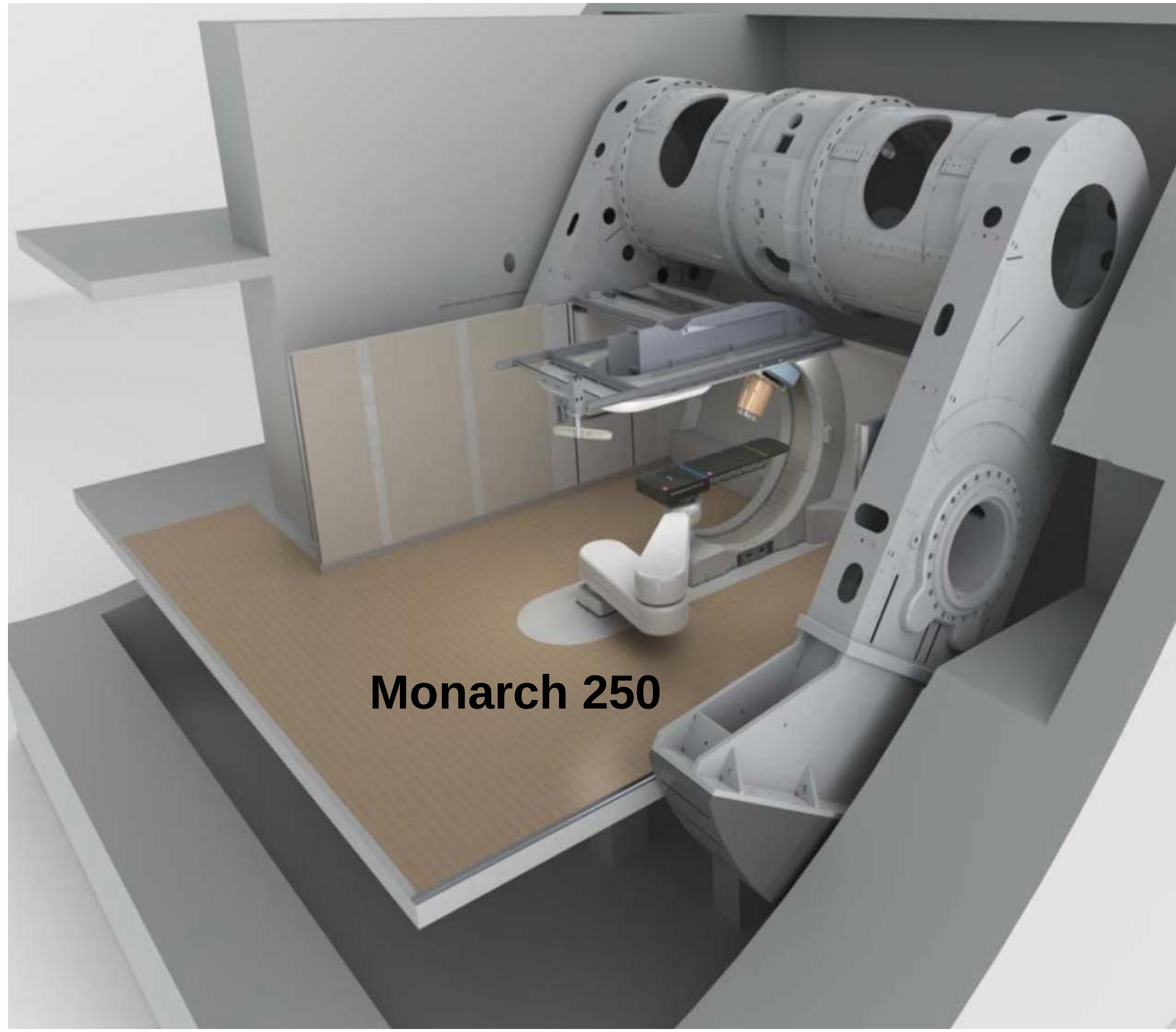
Single room facility by MeVion

9 tesla superconducting synchrocyclotron



Single-room facility by IBA (Belgium): Proteus One

PROTEUS ONE

New superconducting synchrocyclotron

WILLIS-KNIGHTON CANCER CENTER IN SHREVEPORT, LOUISIANA TO INSTALL FIRST ULTRA-COMPACT PROTON THERAPY SOLUTION FROM IBA

Louvain-La-Neuve, Belgium, Oct. 3, 2011

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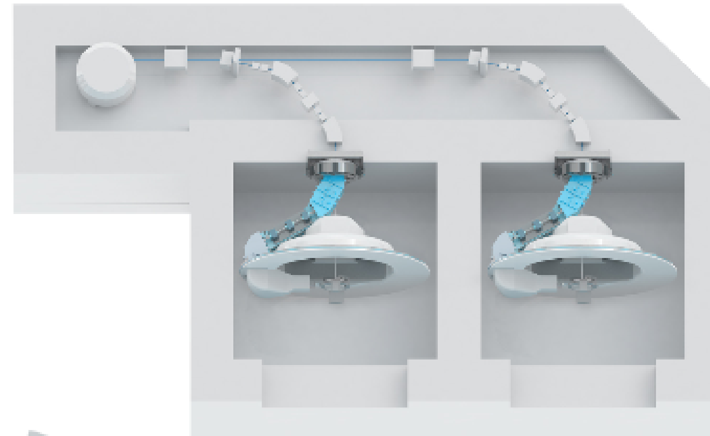
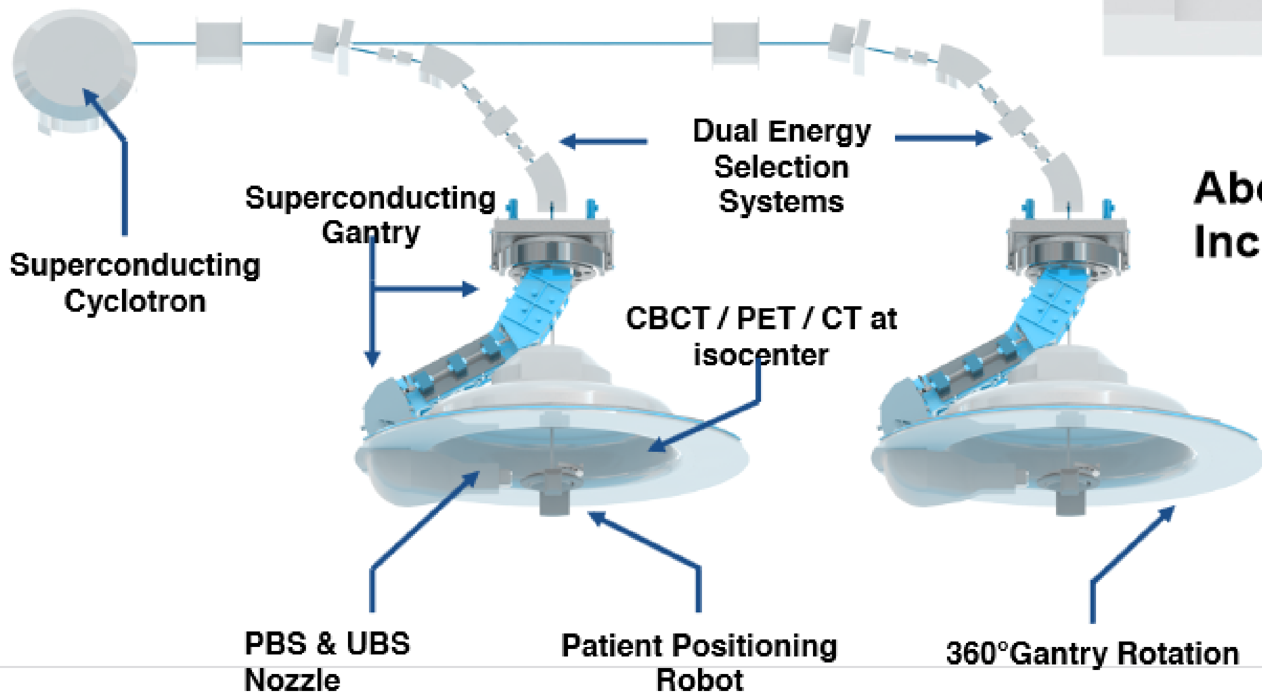
SC360 Efficient 2-Room Solution

- Superconducting gantry
- Rectangular treatment room
- Dual ESS with Rapid switching
- Permanent magnet beamline
- 3D imaging with PET





About 30 m x 19 m
Including shielding

Courtesy of
V. Derenchuk,
PRONOVA

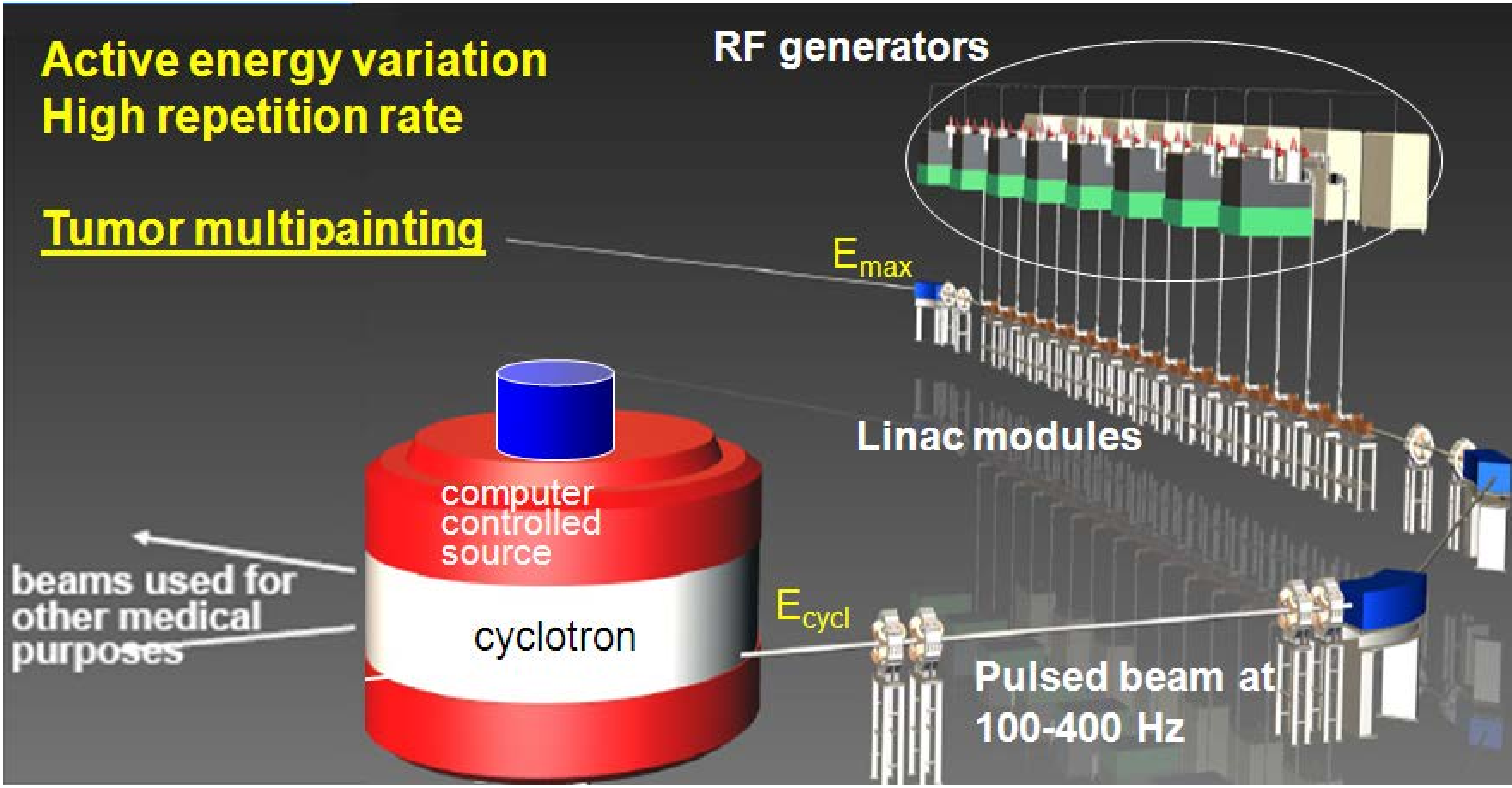
TERA approach to treat moving organs and
for single room facilities:

high-current cyclotron + fast-cycling high gradient linac

=

"cyclinac"

General concept of a Cyclinac



Beam suitable for the 4D spot scanning technique

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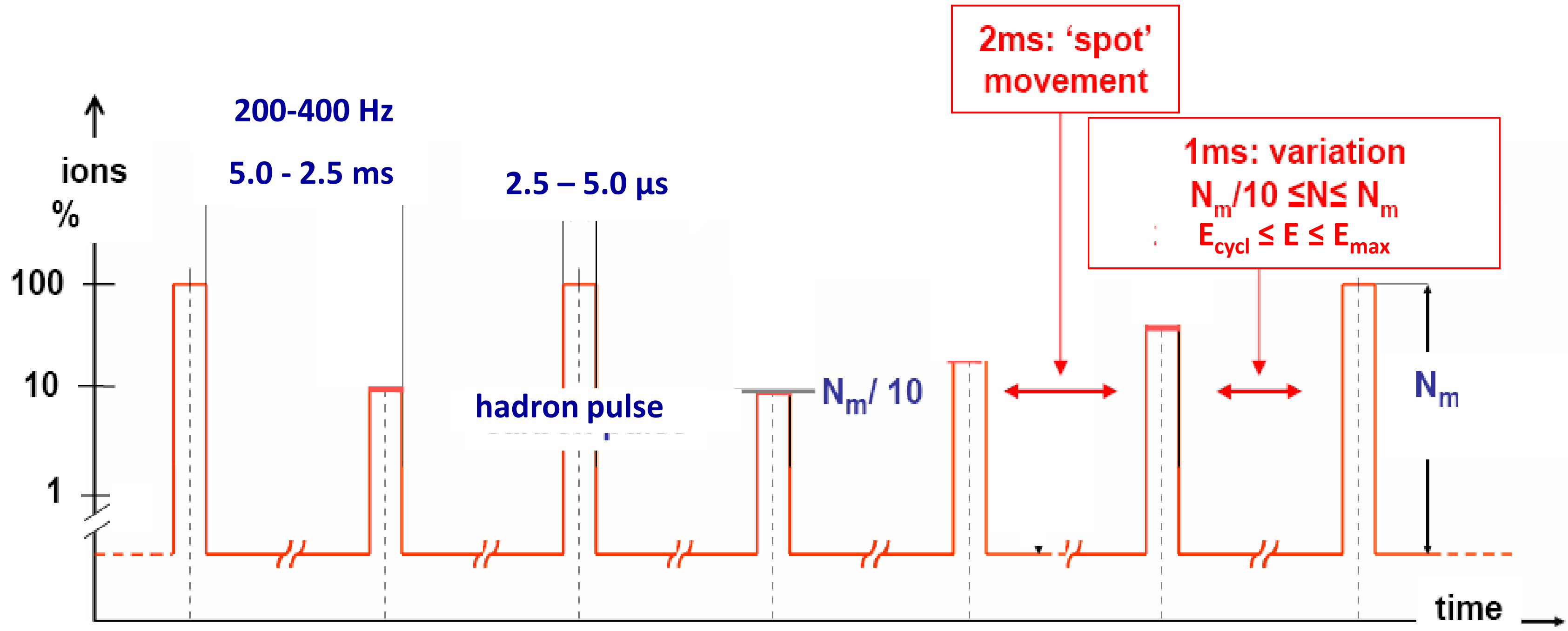
The cyclinac beam is ideal for spot-scanning with many paintings and position feedbacks



The number of hadrons N, the two transverse positions and the depth of the spot can be varied every pulse, because the linac energy E can be adjusted every 1-2 ms

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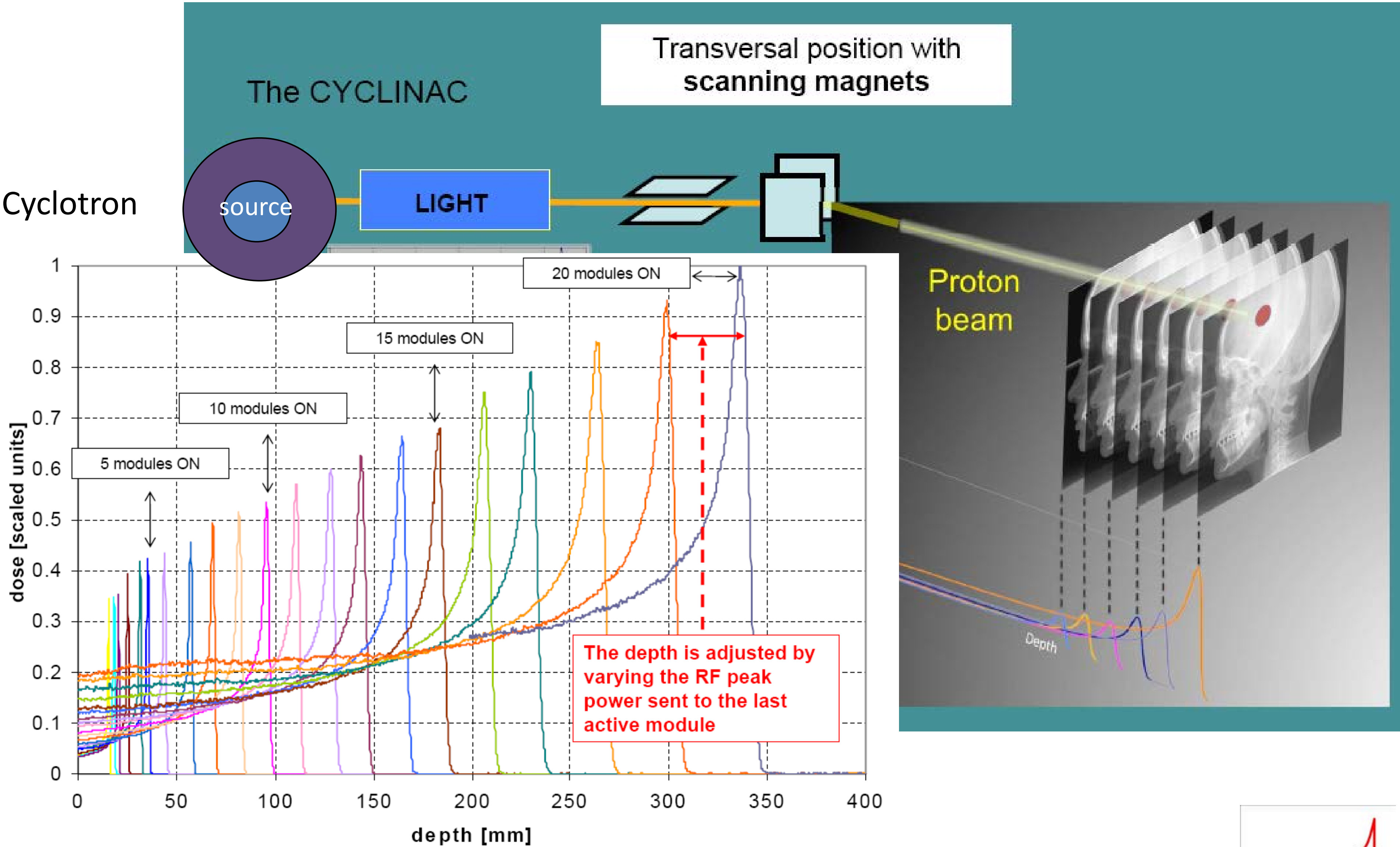
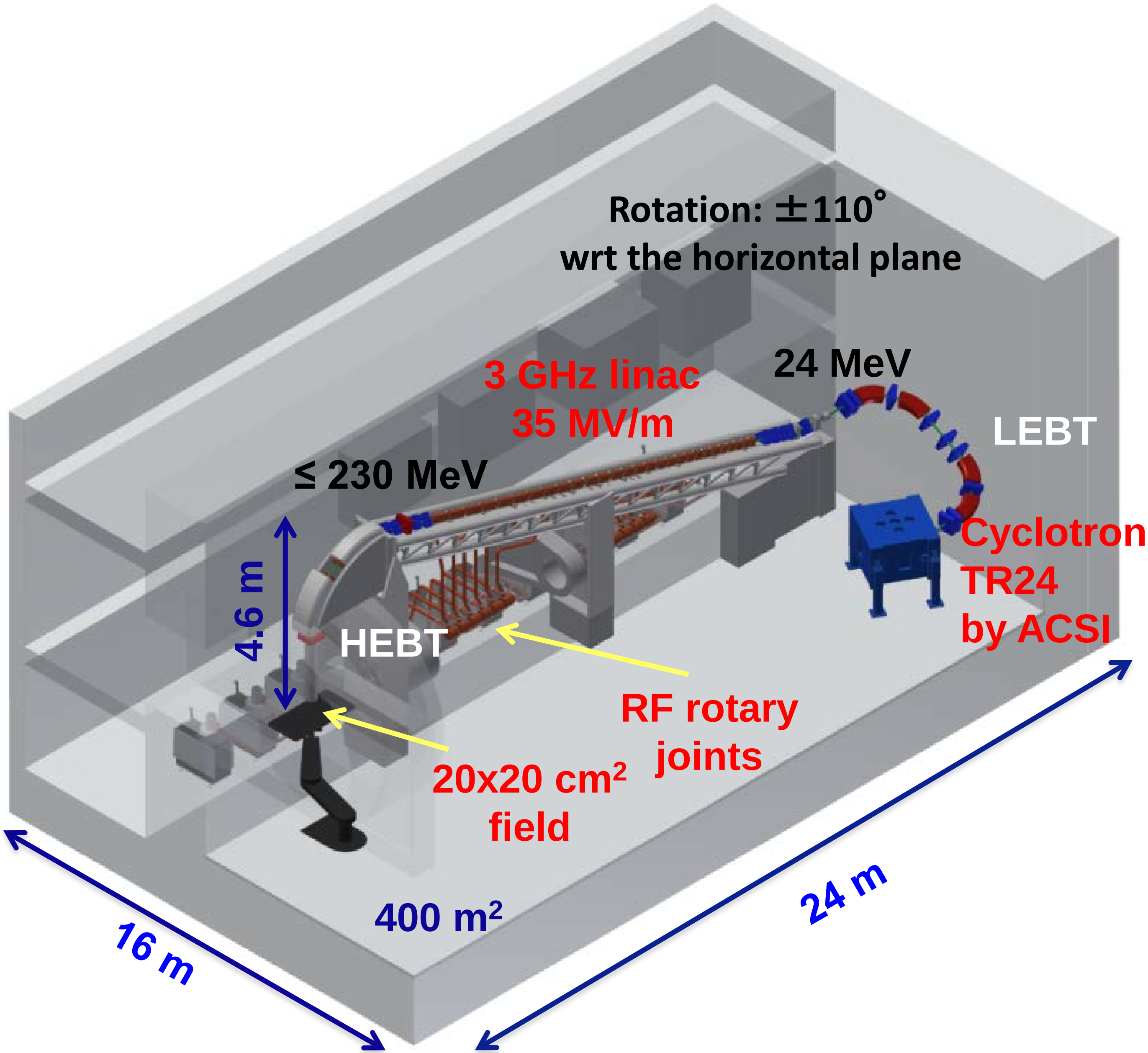
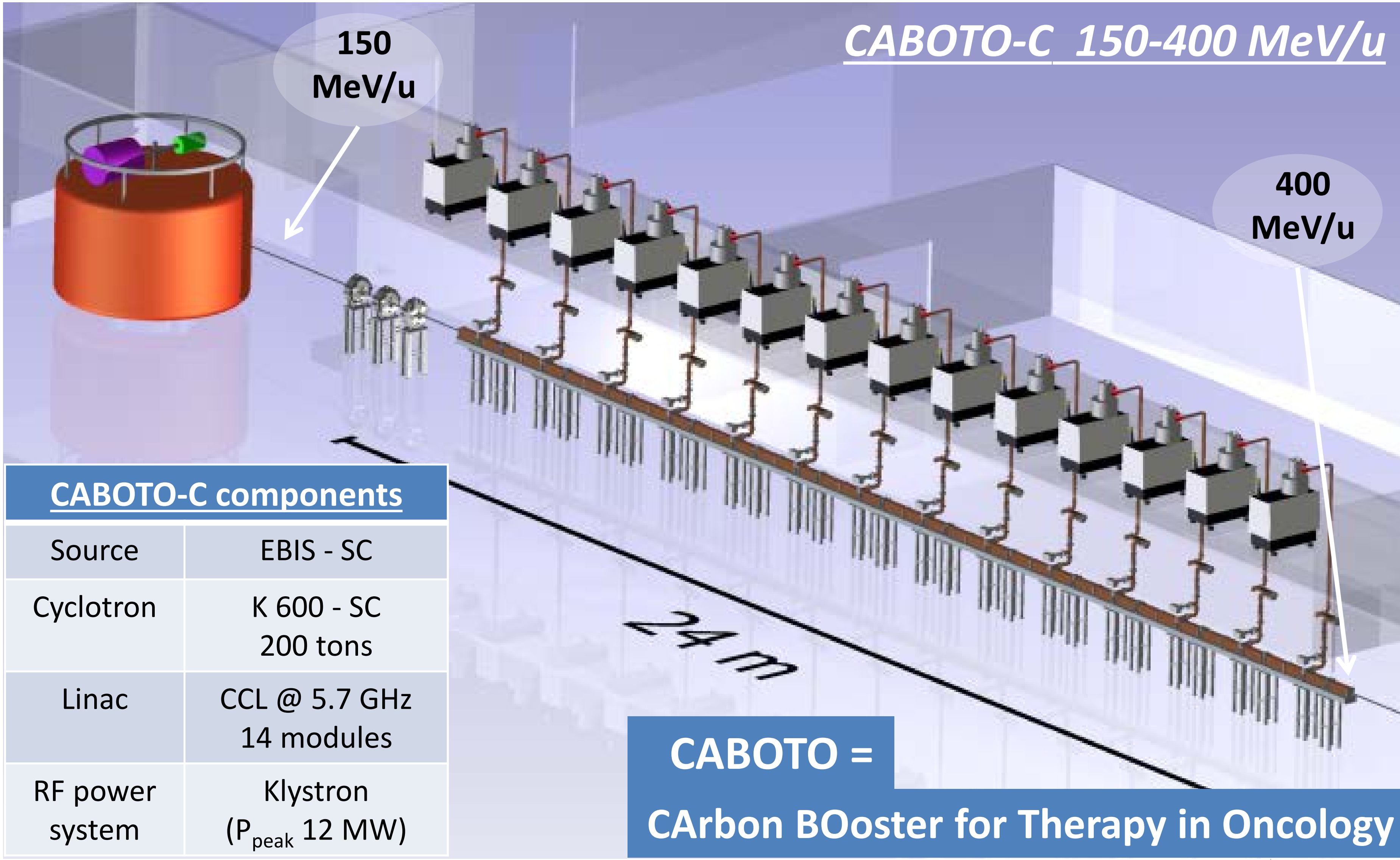
The energy of a cyclinac can be varied in 1-2 ms



TERA solution: TUrning LInac for Protontherapy (TULIP)



CABOTO-C: a cyclinac for a compact ‘dual’ machine



CABOTO-C components	
Source	EBIS - SC
Cyclotron	K 600 - SC 200 tons
Linac	CCL @ 5.7 GHz 14 modules
RF power system	Klystron (P_{peak} 12 MW)

CABOTO =

CArbon BOoster for Therapy in Oncology

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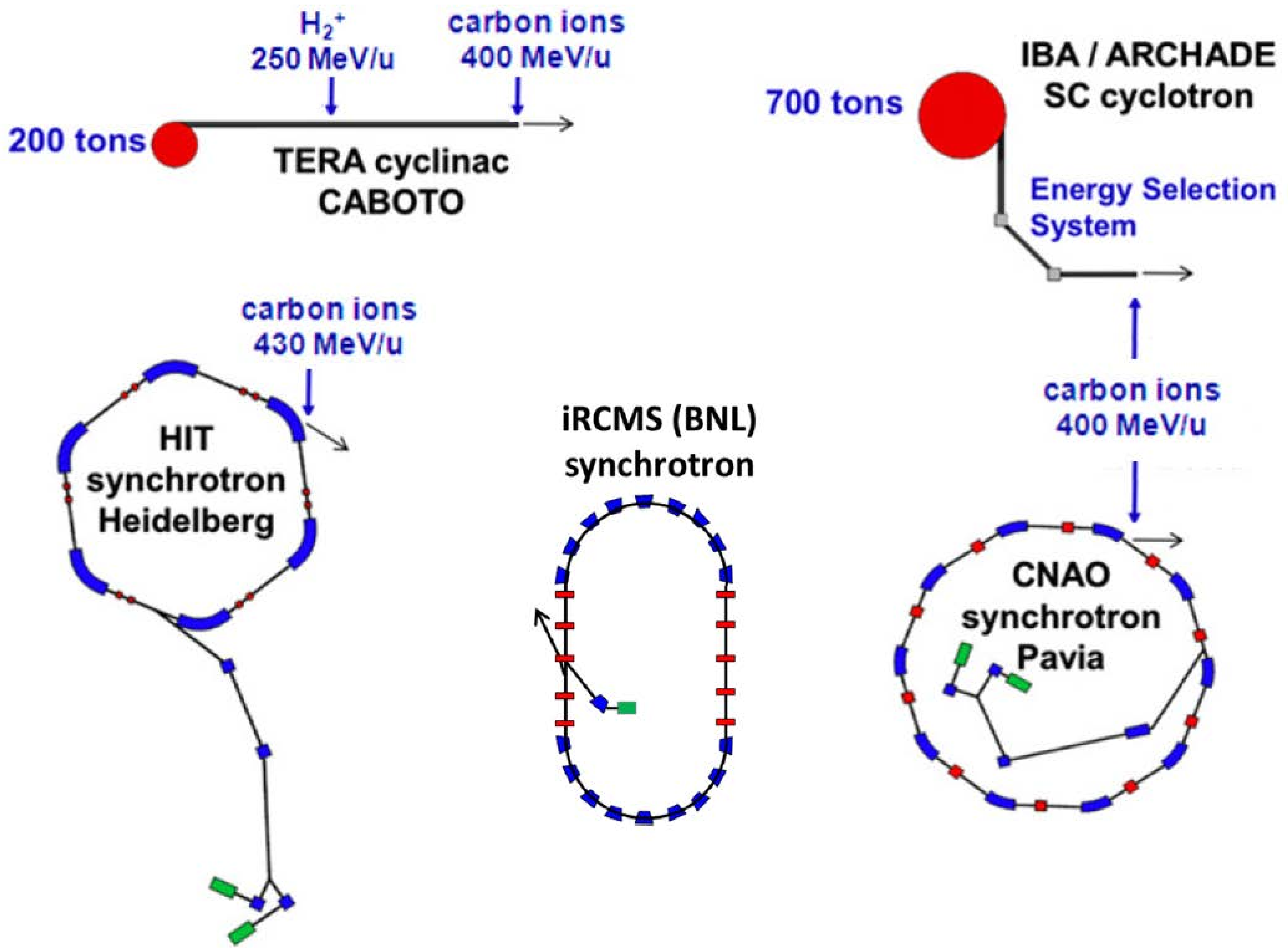
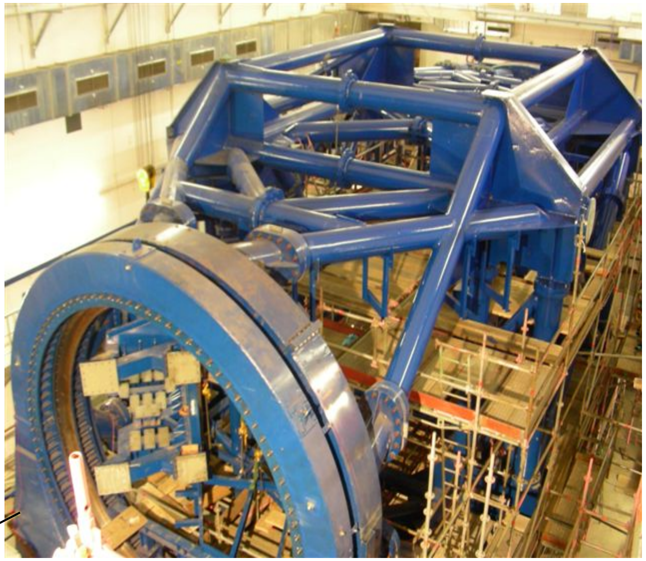
Dimensional comparison among carbon ion accelerators

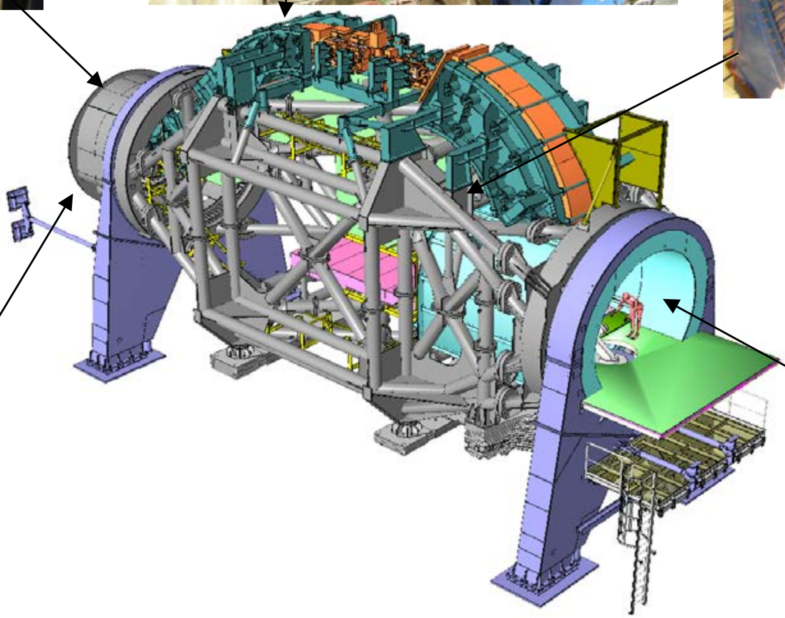


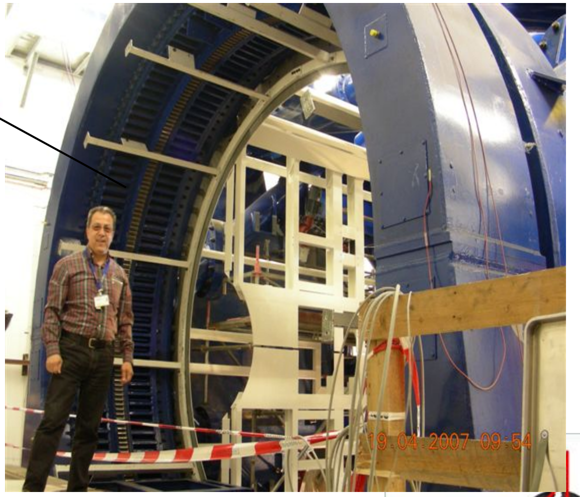
3rd challenge: compact gantries

Heidelberg ion gantry: 600 tons and 400 kW



1st Rotation at
21.04.2007





Superconducting rotating-gantry

Use of superconducting (SC) magnets

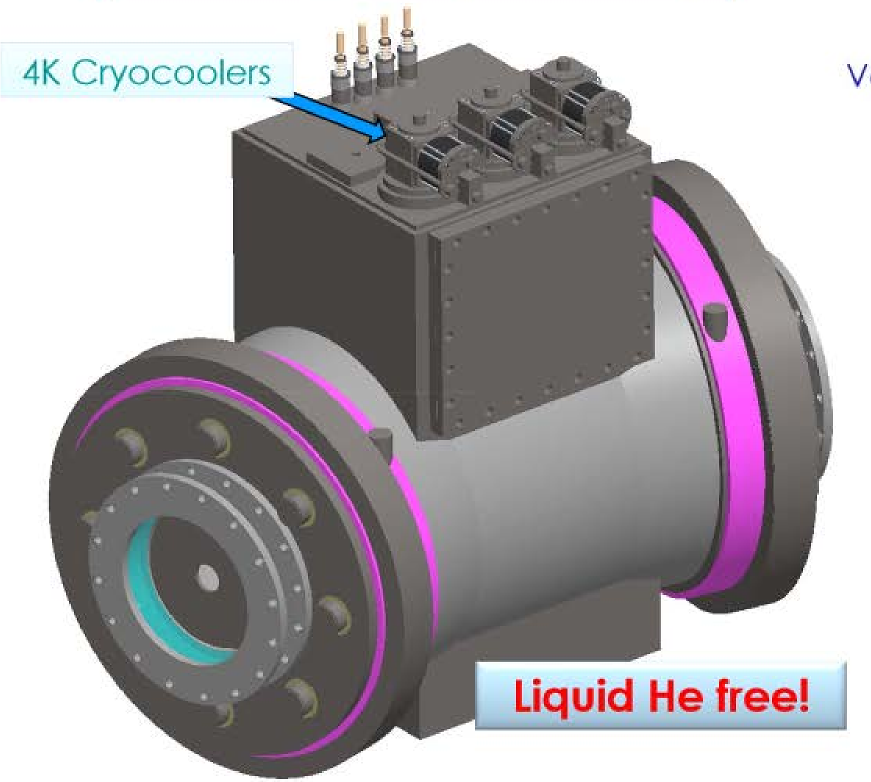
Ion kind	: ^{12}C
Irradiation method	: 3D Scanning
Beam energy	: 430 MeV/n
Maximum range	: 30 cm in water
Scan size	: □200×200 mm^2
Beam orbit radius	: 5.45 m
Length	: 13 m

The size and weight are considerably reduced

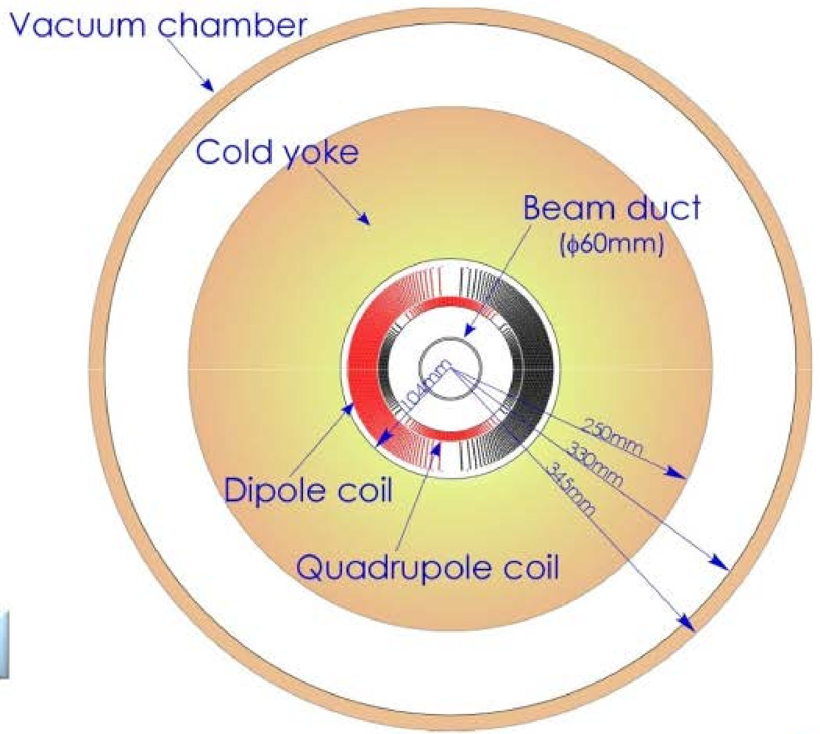
courtesy of Yoshiyuki Iwata

Development of curved SC magnets

SC magnet (BM02-05)



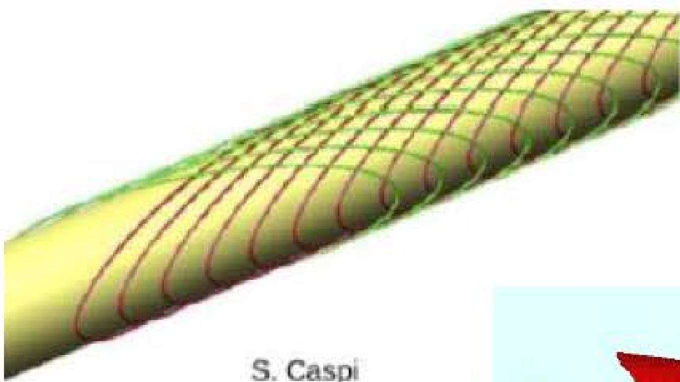
Cross-sectional view

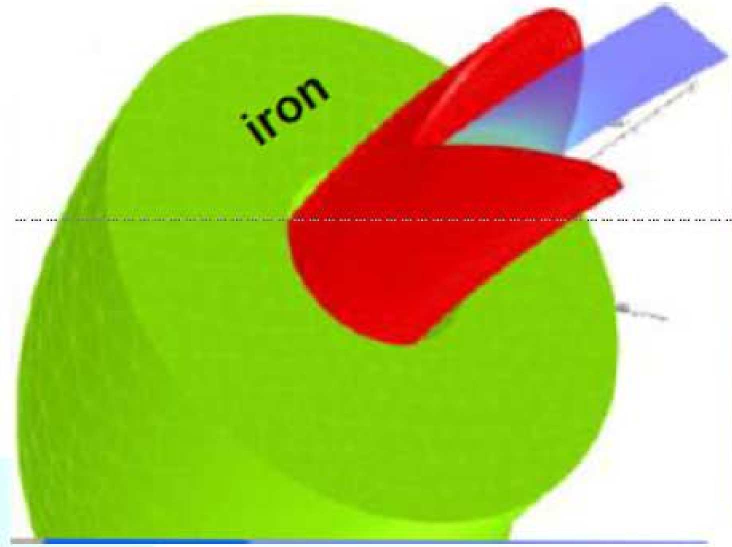


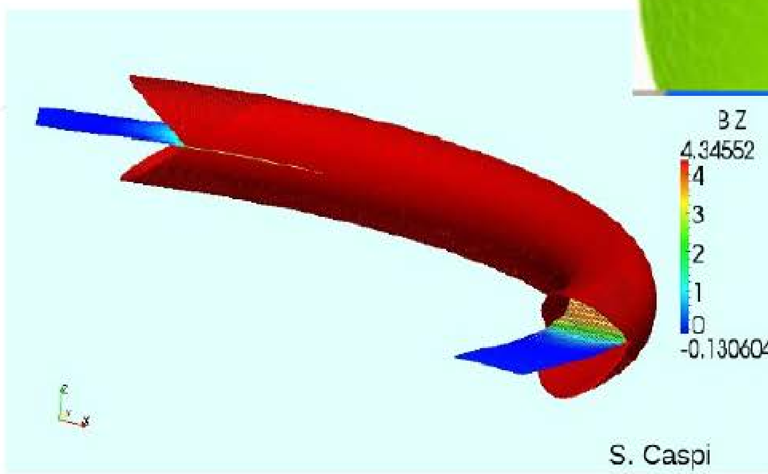
courtesy of Yoshiyuki Iwata

work in progress at LBNL - Berkeley

Two layer helical wires on a straight cylinder give a dipole field



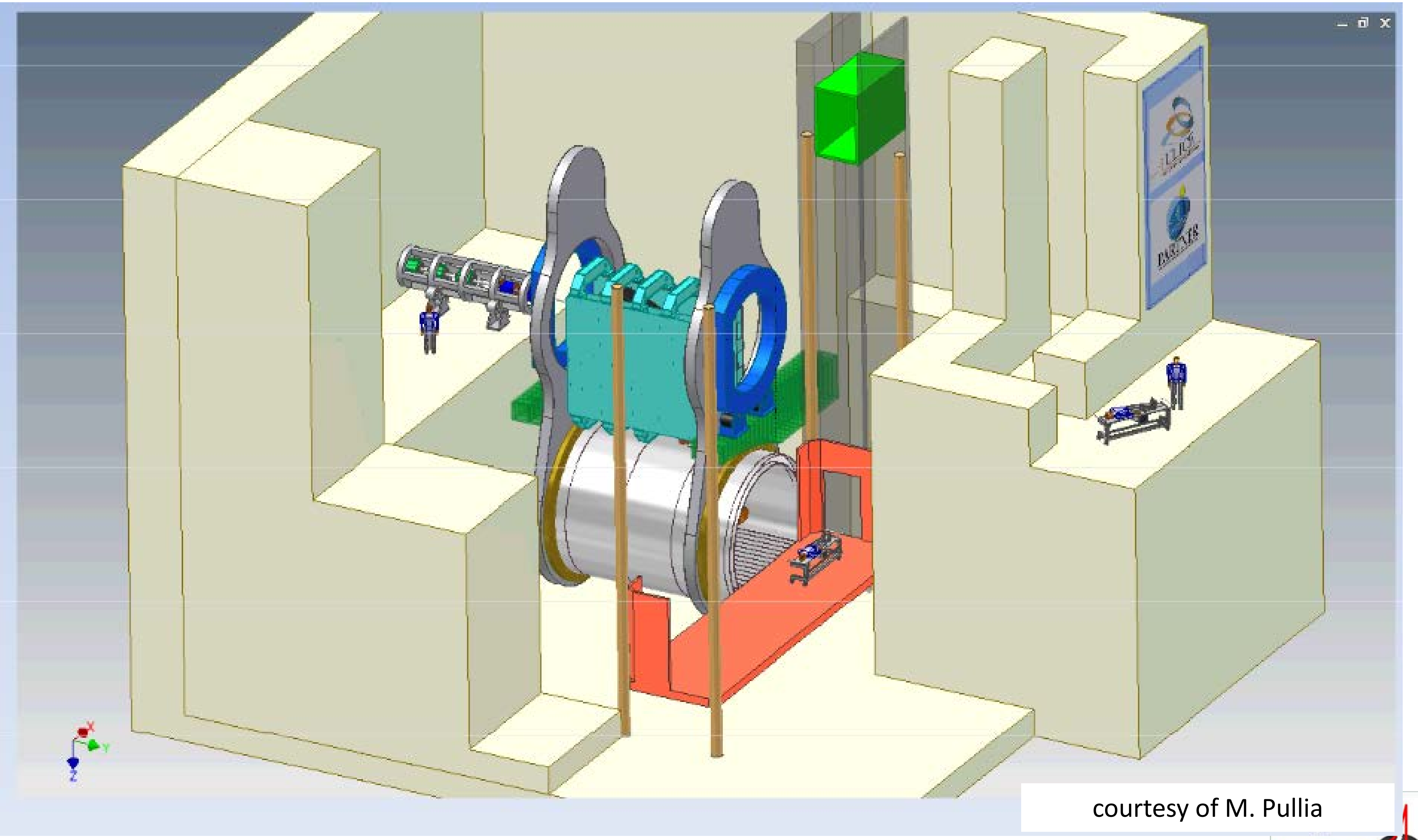




Shlomo Caspi, David Robin, Andy Sessler, Changchun Sun, Weishi Wan and Moohyun Yoon by LBNL LDRD funds

"Novel Design of Gantry Optics for Carbon Cancer Therapy Accelerator"

The ULICE gantry design



courtesy of M. Pullia

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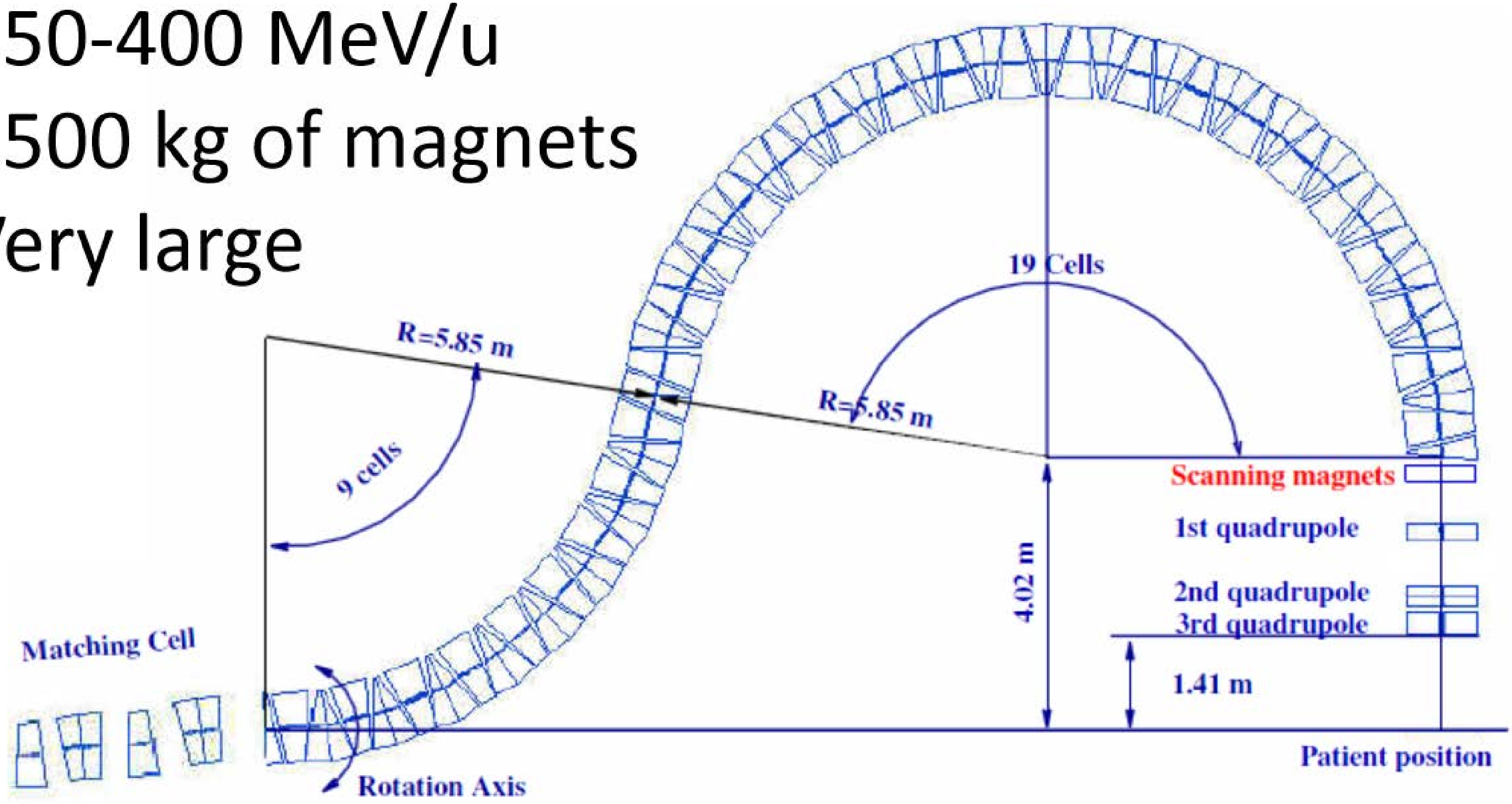
an FFAG gantry for Carbon ions

150-400 MeV/u
1500 kg of magnets
Very large



courtesy of D. Trbojevic

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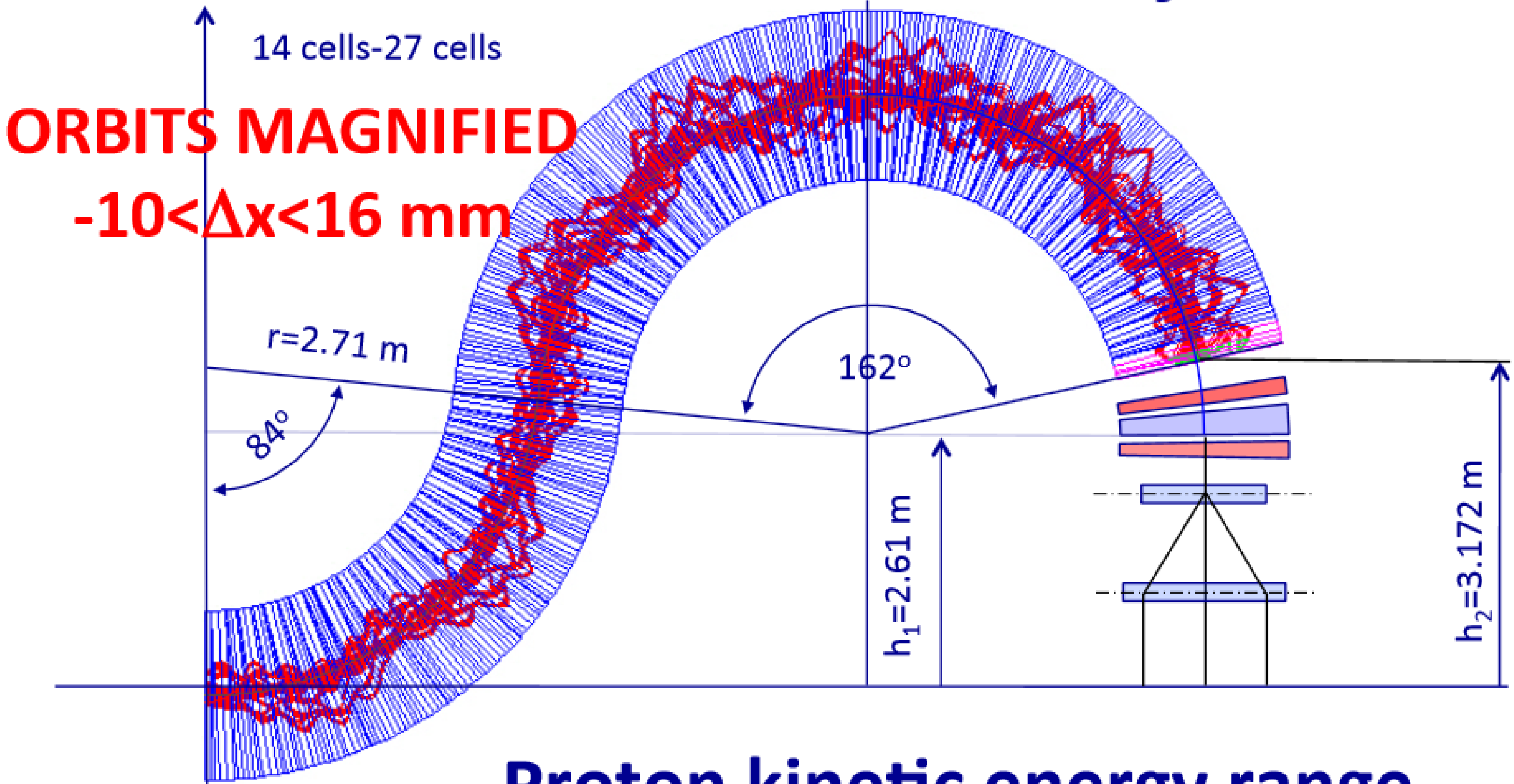
Permanent Halbach Magnet NS-FFAG Proton Gantry



Proton kinetic energy range

30 – 250 MeV

Conclusion

Accelerators and technology for hadrontherapy : Status and future perspective

- ***Hadrontherapy is booming worldwide***
  - > 50 centers in the next few years
- ***Circular machines for hadrontherapy***
  - time characteristics of the beam
  - treatment modalities (passive spreading vs. active scanning)
- ***Future challanges in hadrontherapy***
  - Treatment of moving organs
  - Cost effective machines (single room facilities)
  - Compact gantries for carbon ions
- ***Novel technolgies are under development (see ref.)***
  - Cyclinacs
  - Fixed Field Accelerating Gradients (FFAG)
  - Superconducting magnets for gantries

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