APPLICATIONS OF ACCELERATORS TO TUMOUR THERAPY - 3

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The challenges of Hadrontherapy:
1. Treatment of moving organs

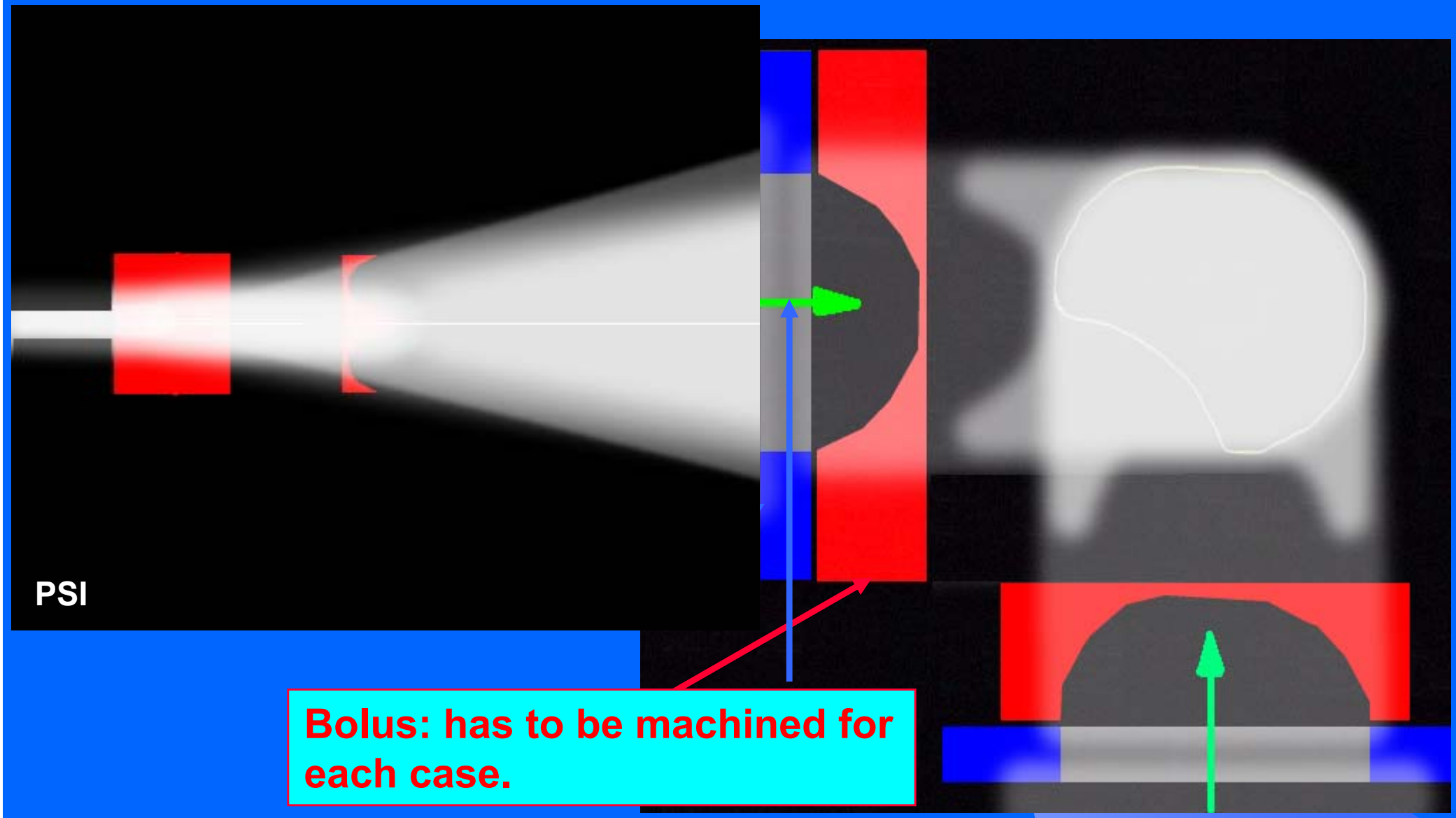
IGRT = Image Guided Radiation Therapy

X ray Therapy:

'Computer Tomography' before the treatment and 'cone imaging' during the treatment

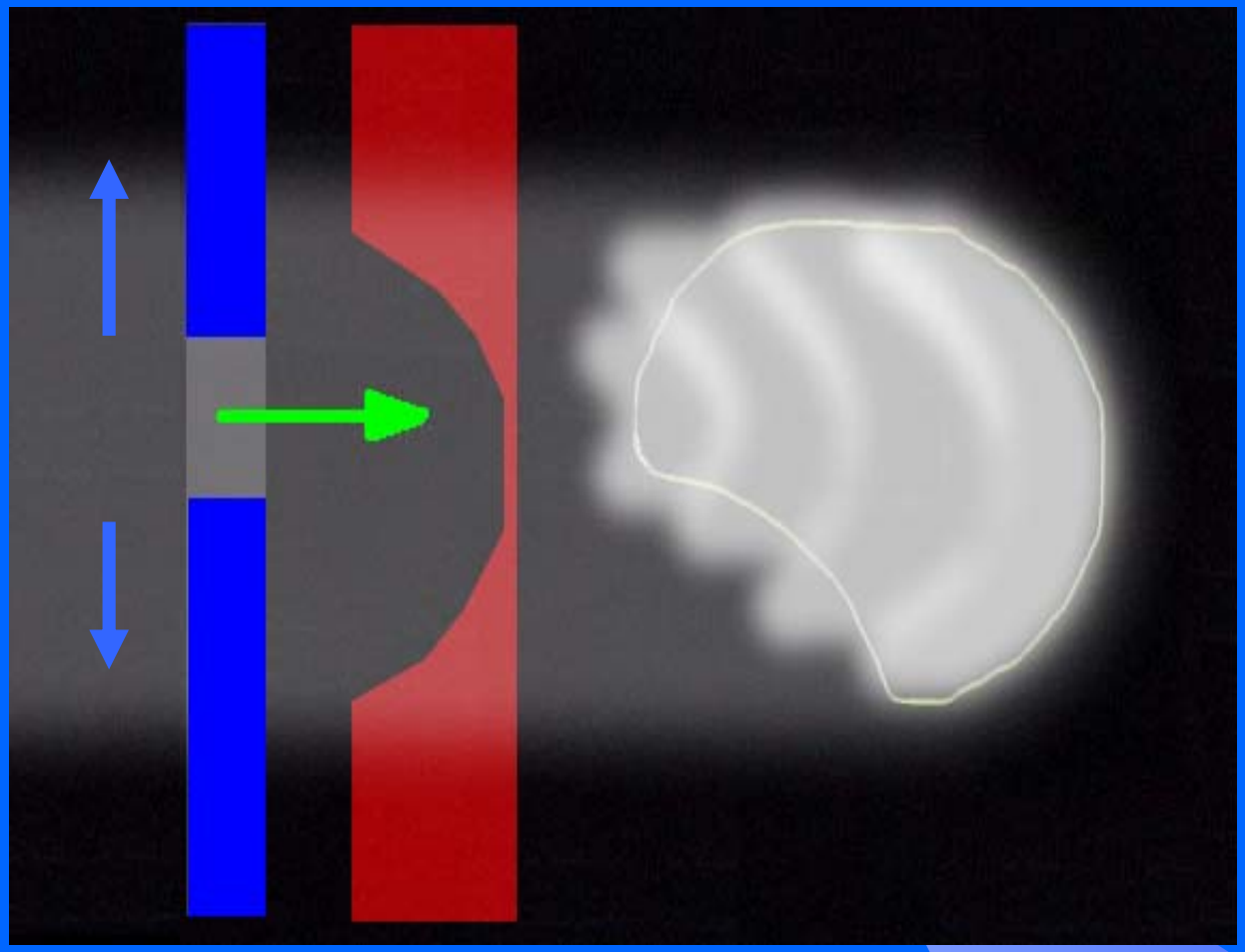
Hadrontherapy has to compete with the rapid advances of '4D' X ray therapy

Standard procedure of HT: 'Passive' beam spreading with respiratory gating



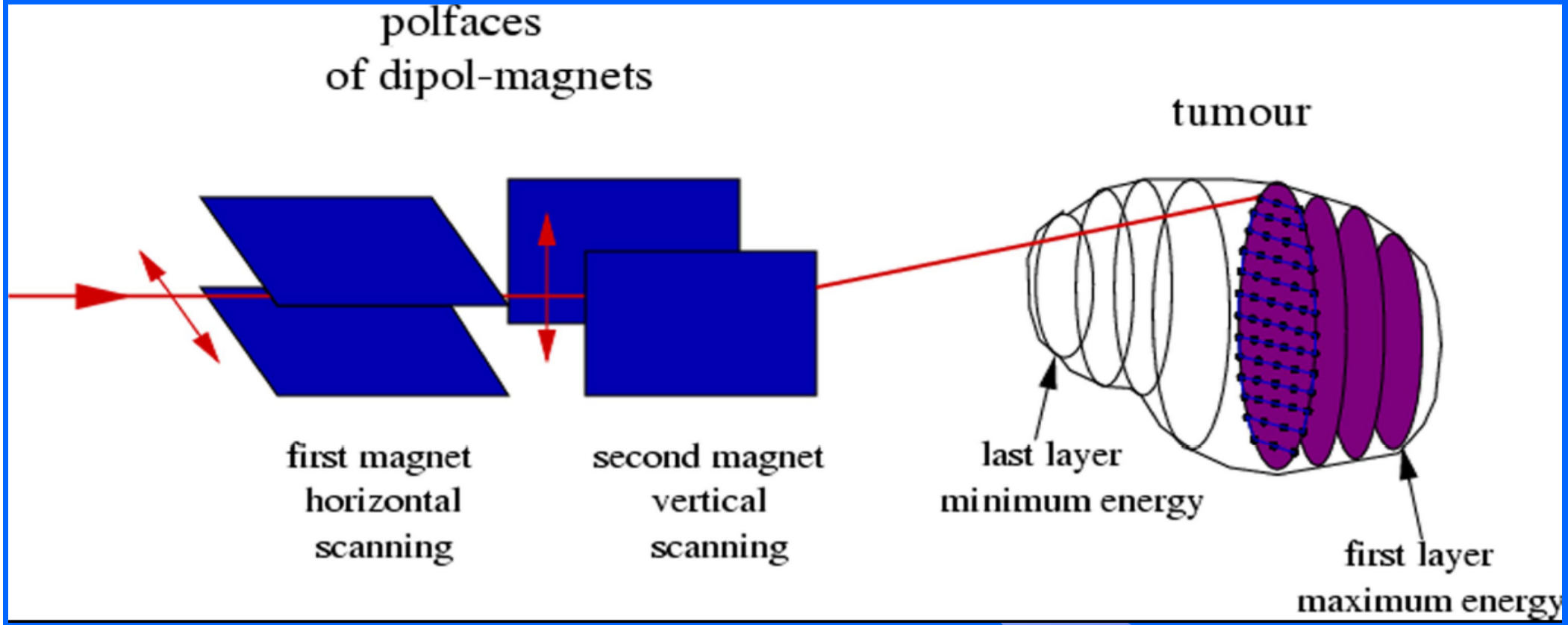
Bolus: has to be machined for each case.

Advanced procedure used at HIMAC: Layer stacking with respiratory gating



- The collimator is adapted to transverse shape of each slice.

‘Active’ dose delivery used by GSI: Raster scanning with respiratory gating

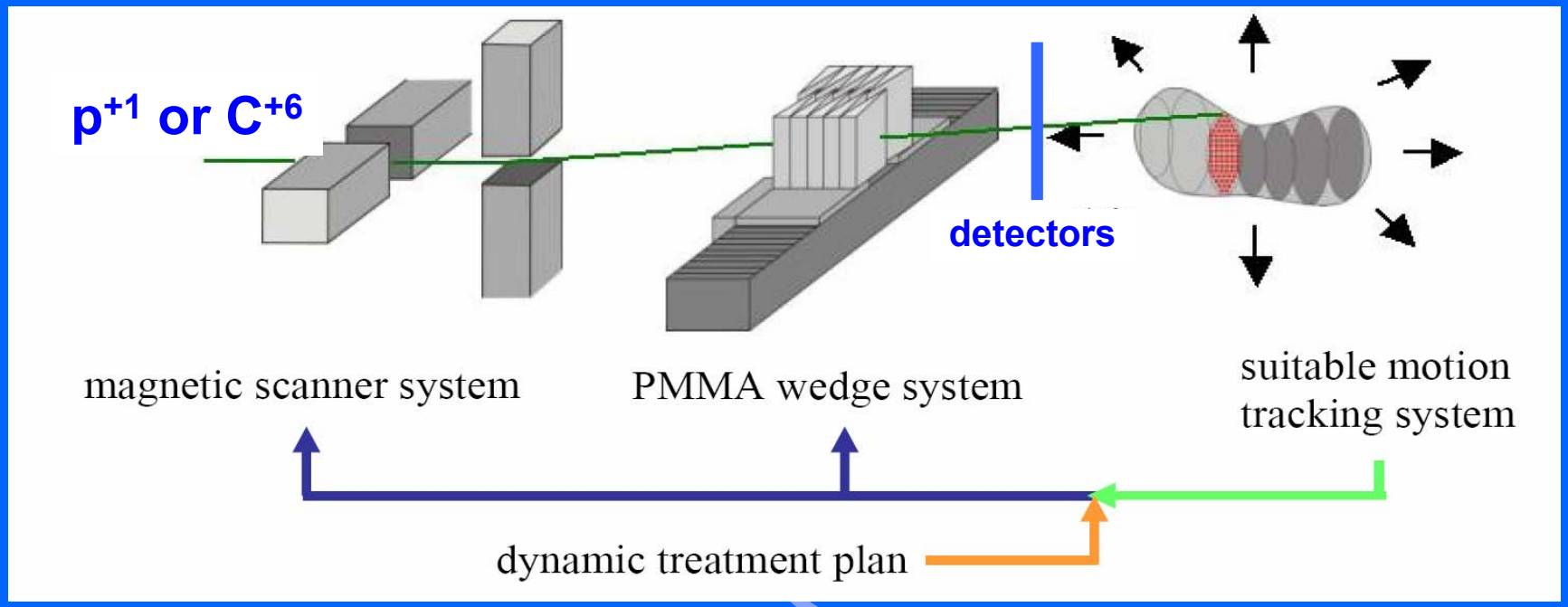


- PSI ‘spot scanning’ GSI ‘raster scanning’

  make use of the fact

  that hadrons, being charged, can be directed in the form of pencil beams

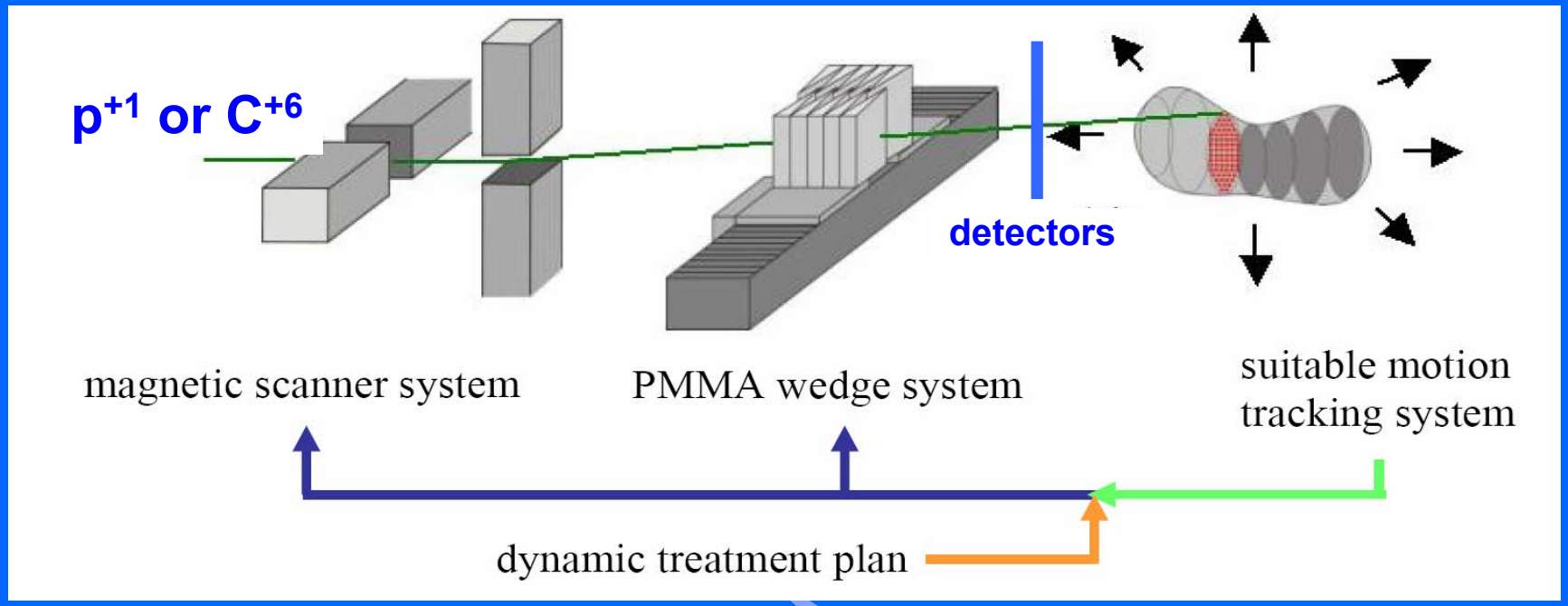
GSI approach to the irradiation of moving organs

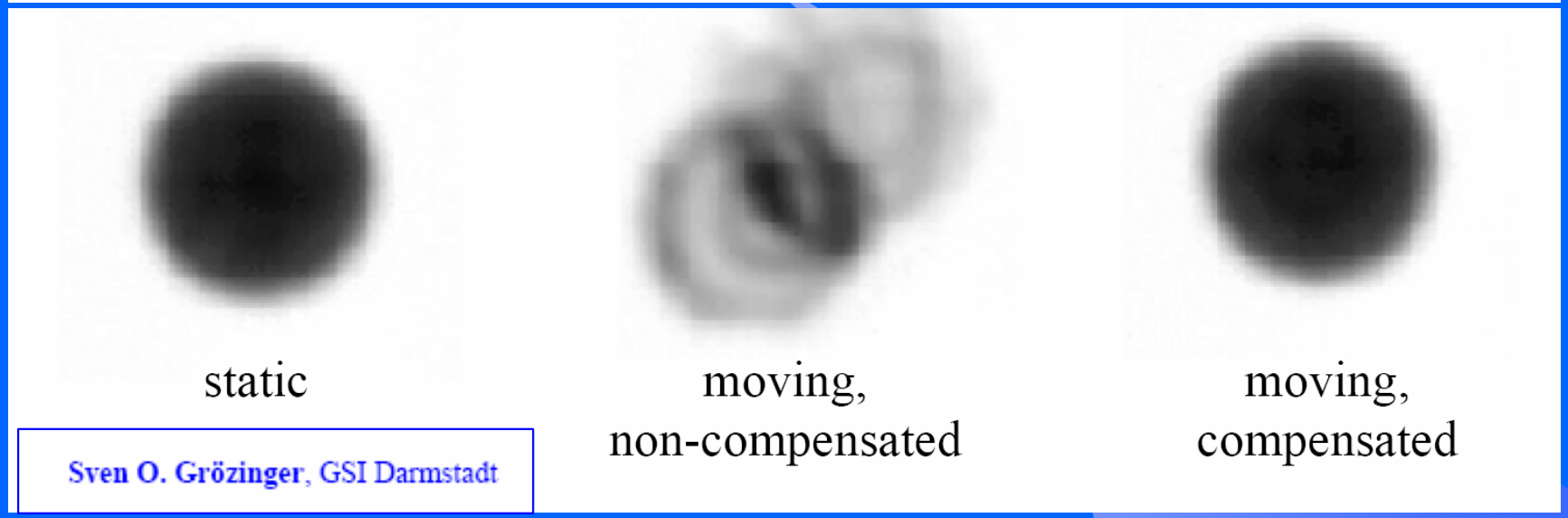


Requirements:

- instruments to follow the tumour (X rays, ultrasounds, external markers + calculations …)
- a Treatment Planning System (TPS) which contains the RBEs of various tissues (radiobiology) and can be dynamically modified
- an on-line feedback system on the three coordinates of the spot

GSI approach to the irradiation of moving organs





Beam delivery methods for treating moving organs

Three methods, which can also be combined:

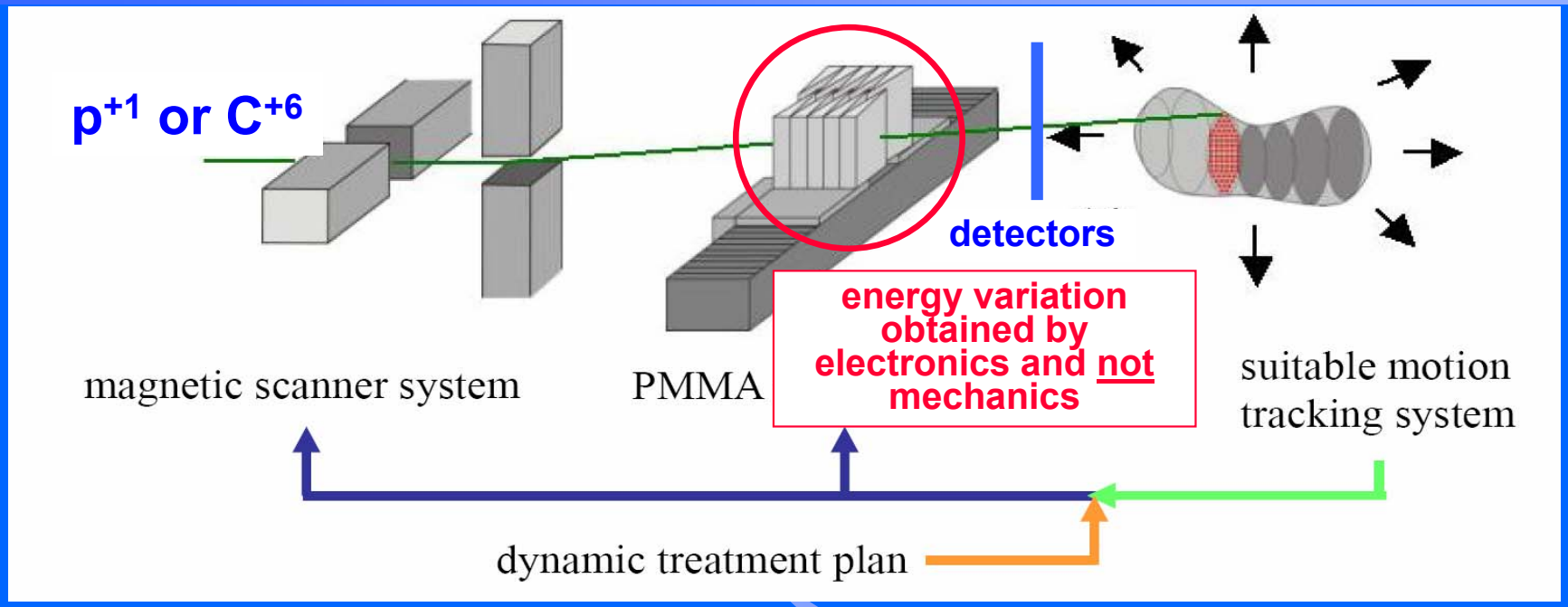
(1) Respiratory gating

(2) One-painting of the tumour with 3D feedbacks (GSI approach)

(3) Multi-painting of the tumour with 3D feedback (PSI approach)

so to correct possible 'hot' and 'cold' spots

Advantages of novel fast-cycling variable-energy accelerators

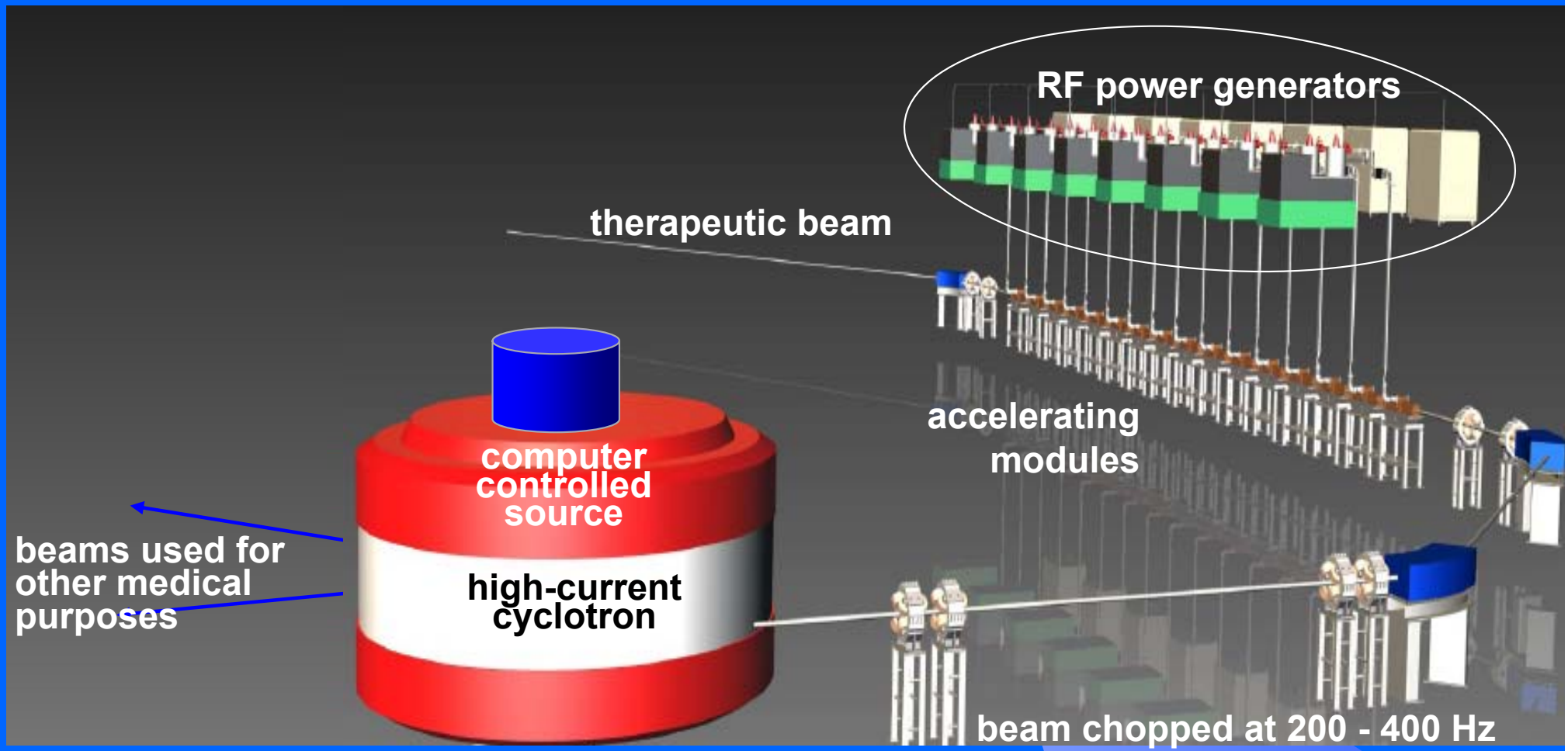


Two candidates for 4D hadrontherapy:

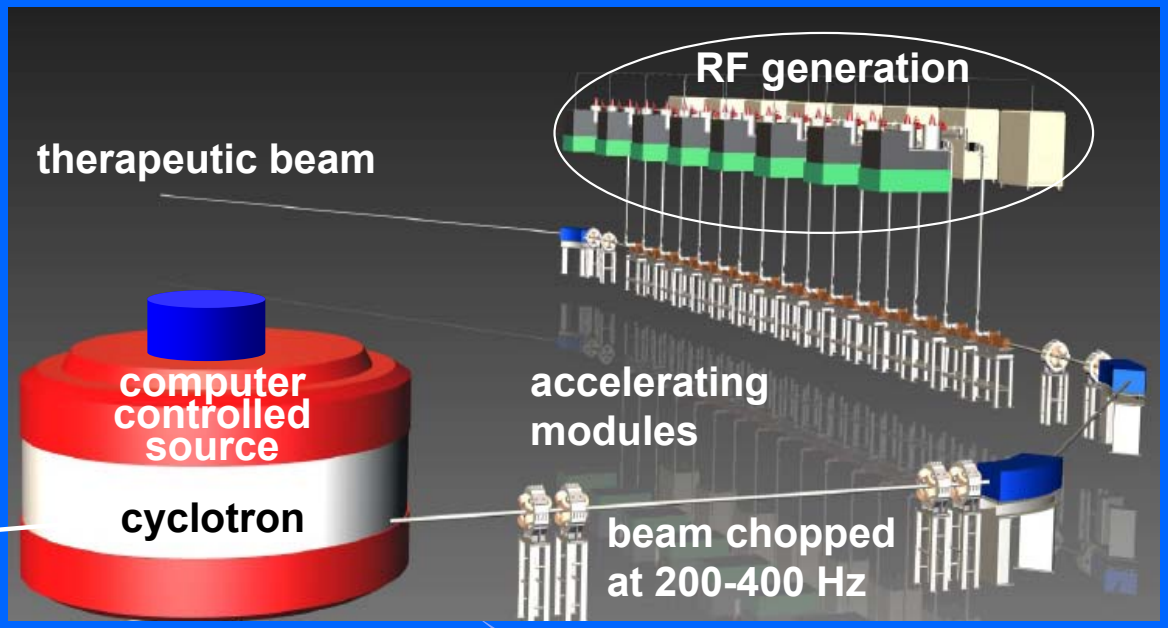
Cyclinacs

FFAGs

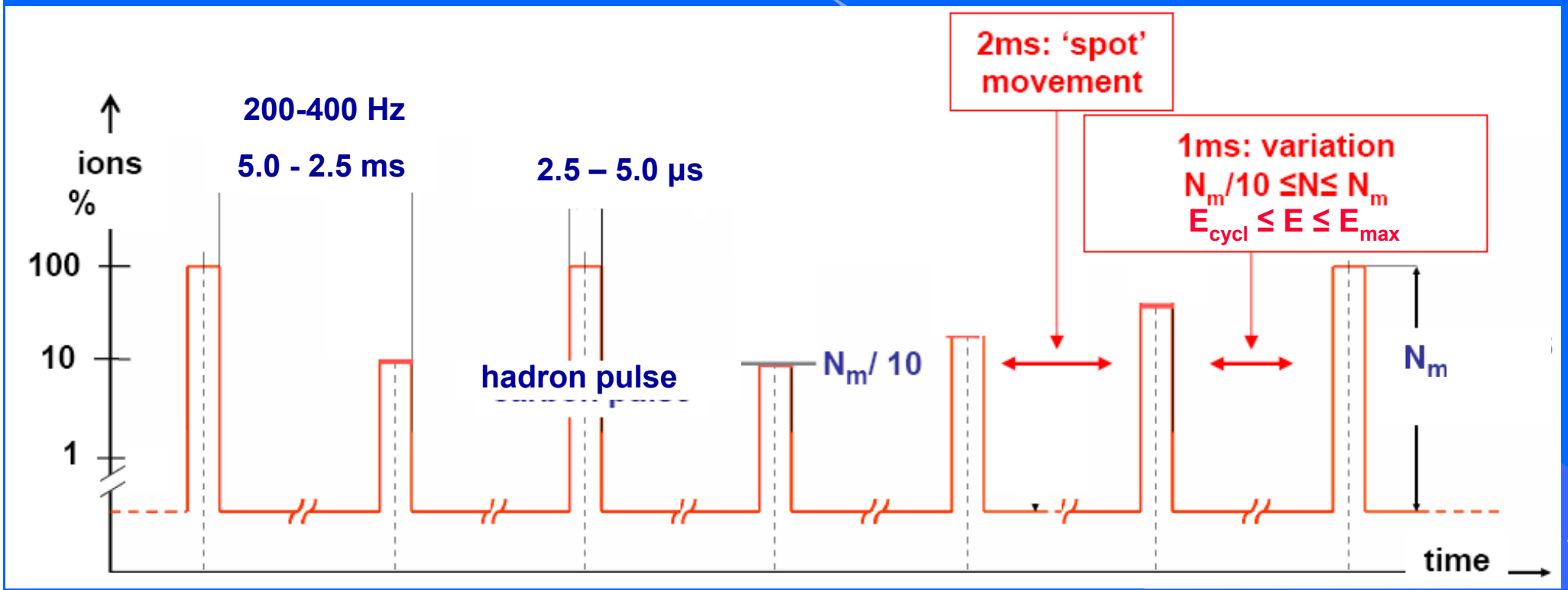
Cyclinacs: new fast-cycling accelerators conceived and designed by TERA



Properties of the cyclinac beams

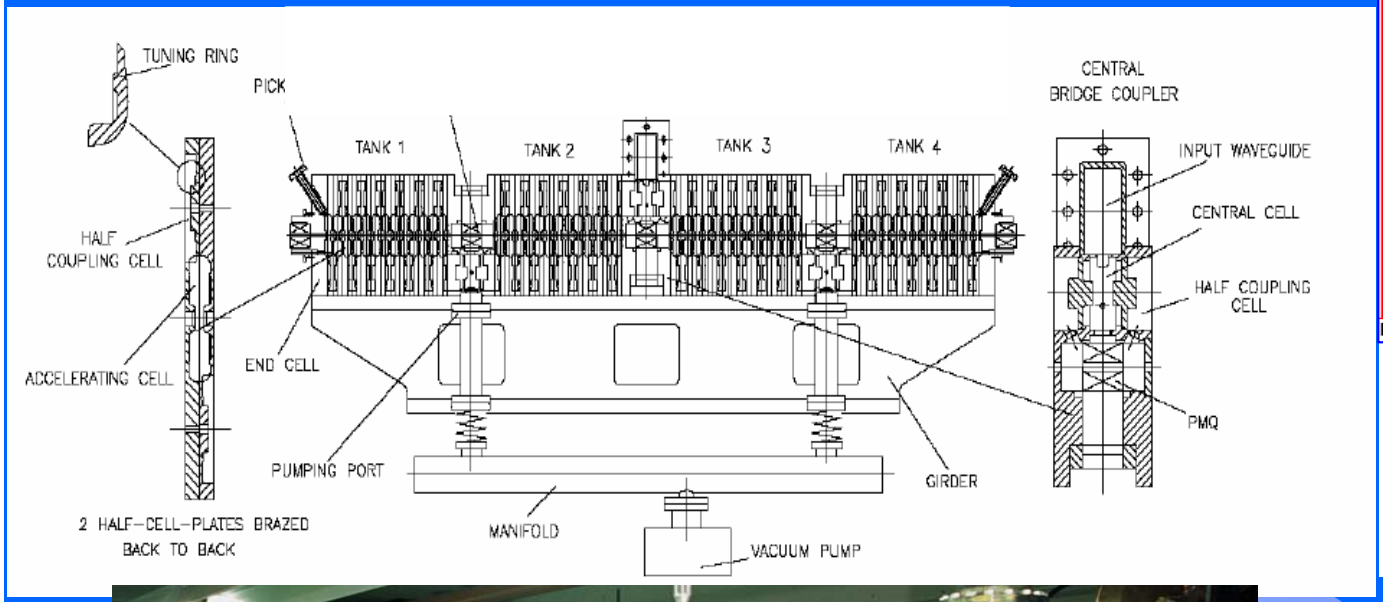


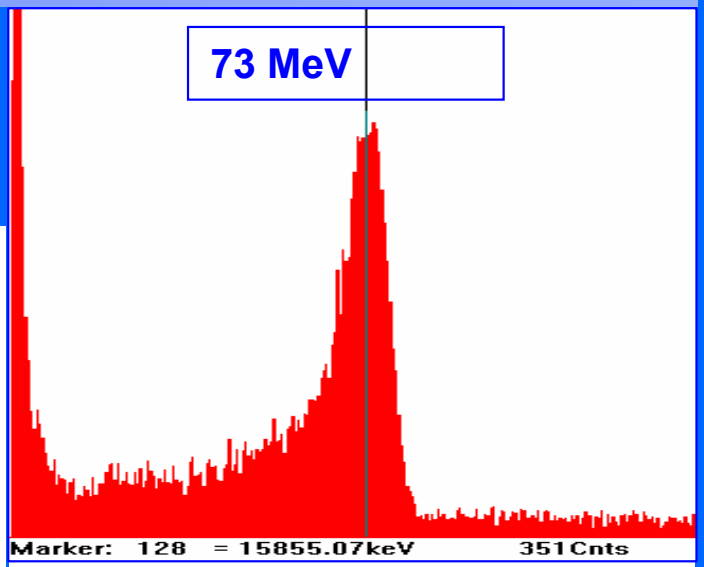
beam(s) used for other purposes



Prototype of linac at 3 GHz (LIBO = LInac BOoster)

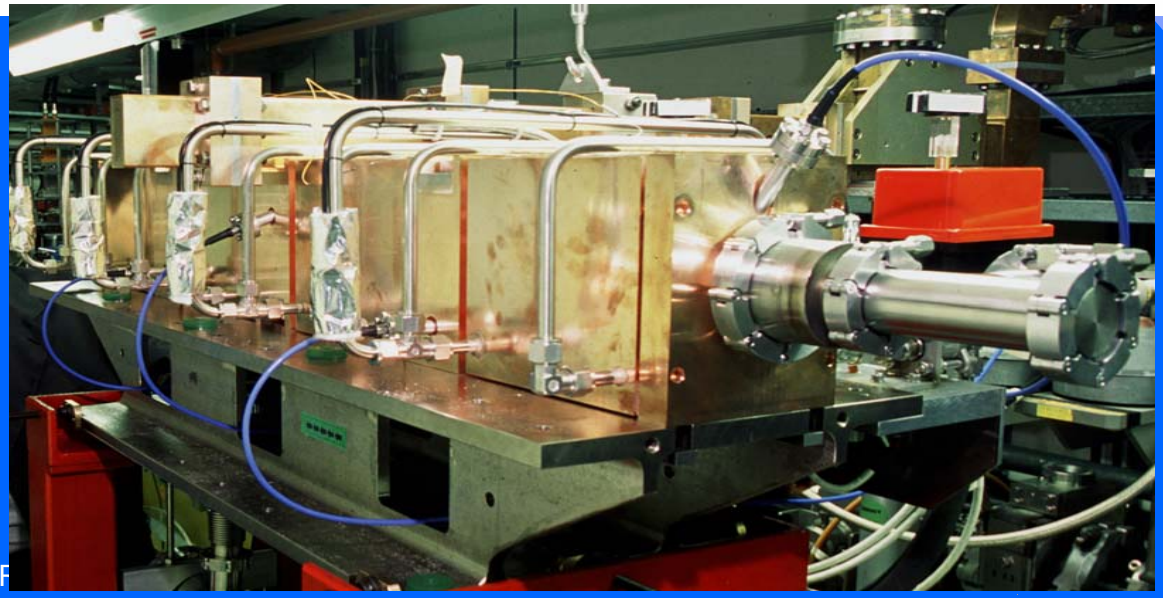
Module tested at LNS, Catania - NIM paper





Project value 15.7 MV/m;

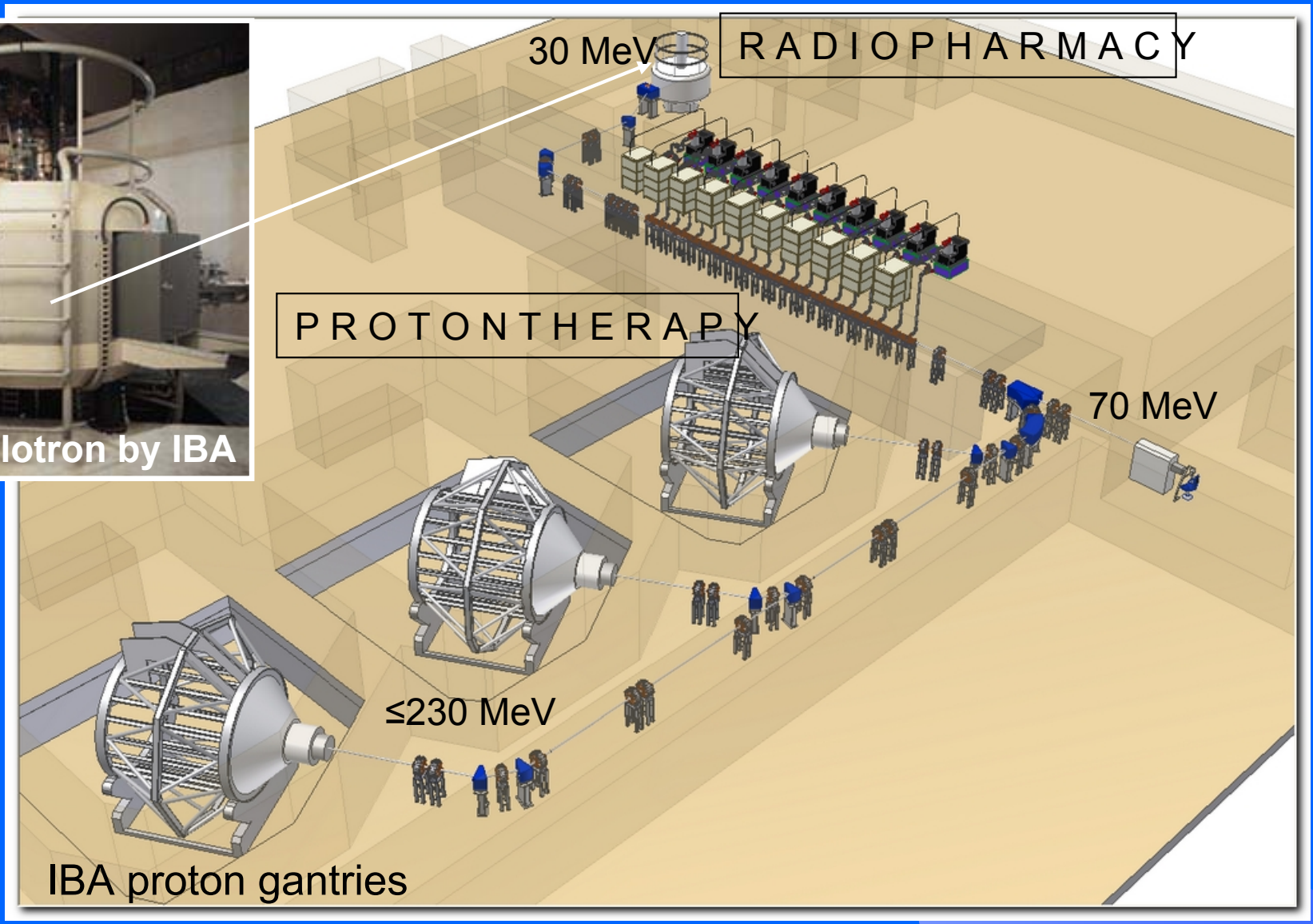
measured 27 MV/m



Collaboration 1998-2002
CERN-INFN-TERA:

CERN – E. Rosso et al
Milan – C. De Martinis et al
Naples – V. Vaccaro et al
TERA – M.Weiss et al

The proton cyclinac IDRA produces radiopharmaceuticals



IDRA = Institute for Diagnostics and RAdiotherapy

Purposes of IDRA as a 'physical and cultural' space

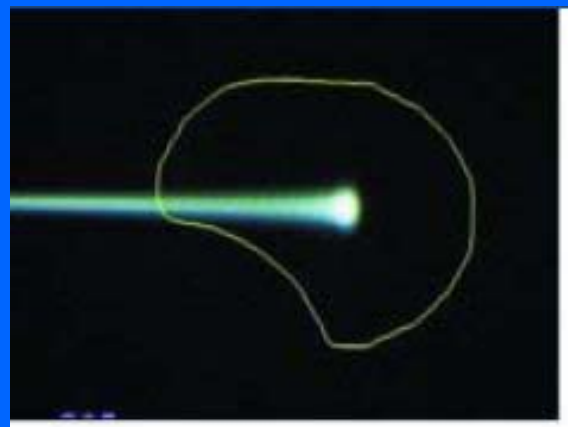
1. Precise diagnostics with PET and SPECT isotopes

2. Treatment of moving organs with teletherapy (4D-therapy)

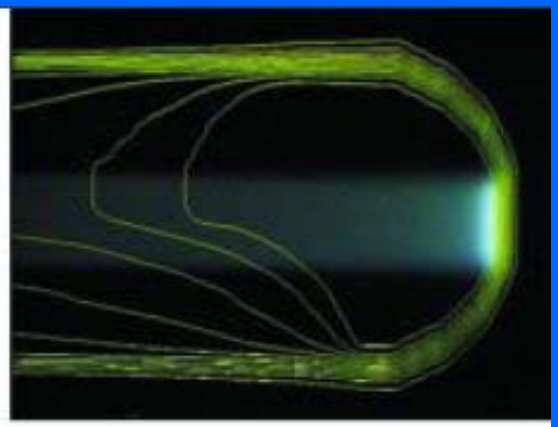
3. Treatments of metastases with endotherapy

4. Treatment of systemic tumours with endotherpy

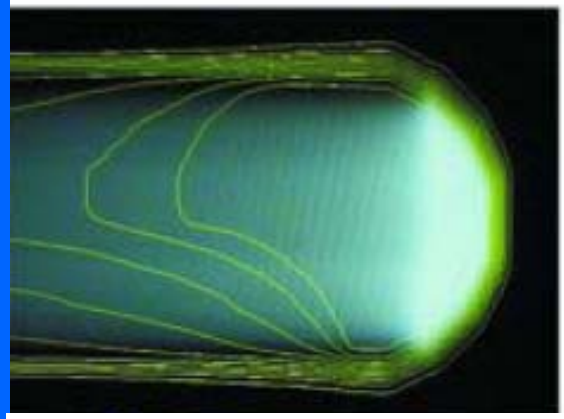
Cyclinac approach to the use of spot scanning



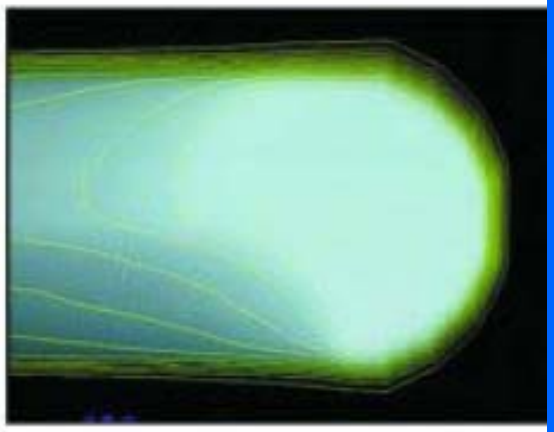
Single ‘spot’



Lateral scanning with magnet: 2 ms/step



Depth scanning: vary the power to the 20 accelerating modules

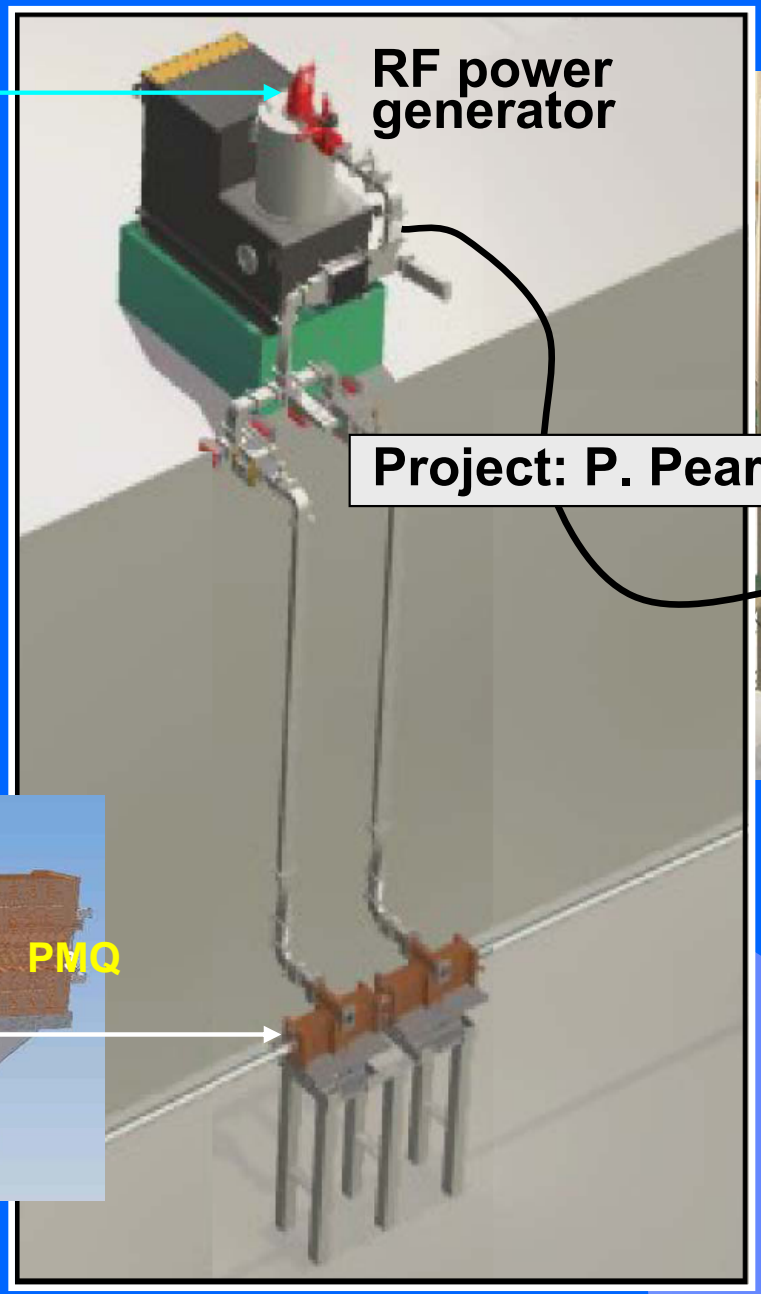


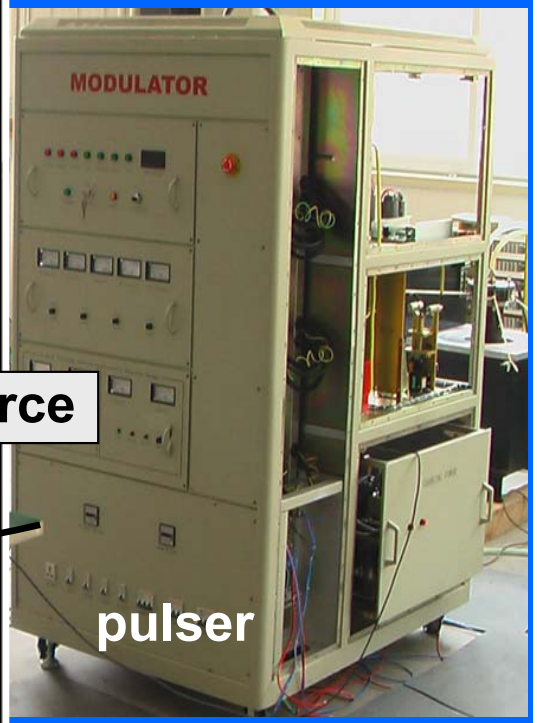
Third scanning by a bending magnet and movable bed

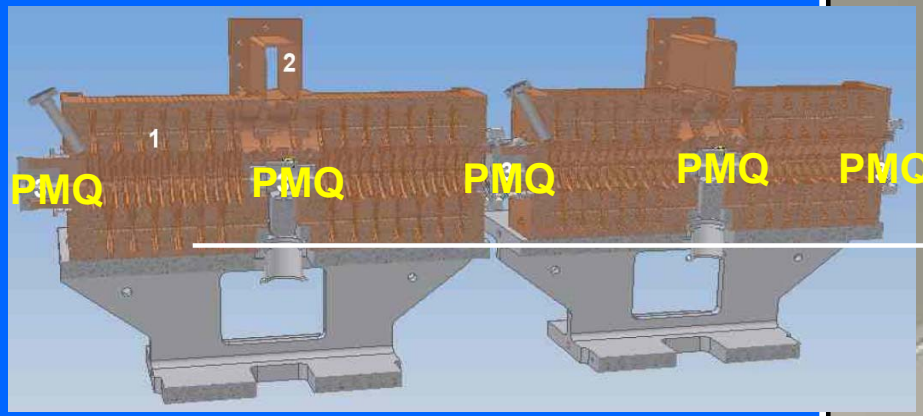
Variation of ± 10 mm with a ± 1.5% momentum acceptance of the magnetic channel

Basic unit of IDRA = 2 accelerating modules

a 3 GHz klystron without solenoid







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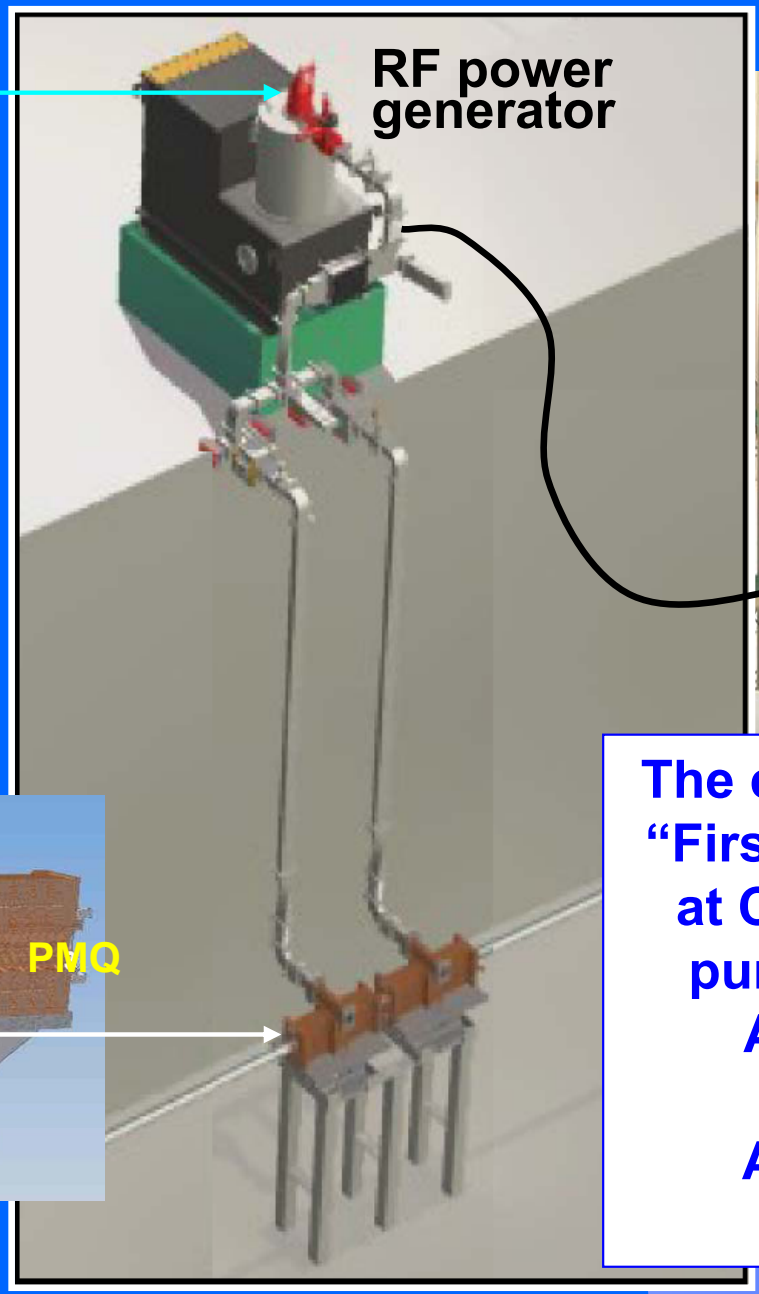
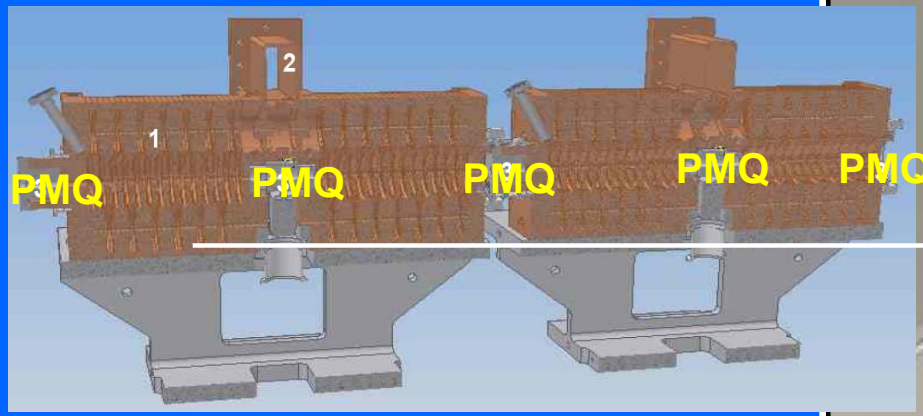




The construction of the "First Unit" and its test at CERN is the initial purpose of ADAM = Applications of Detectors and Accelerators to Medicine

The carbon ion cyclinac starts from the LNS-IBA SC cyclotron

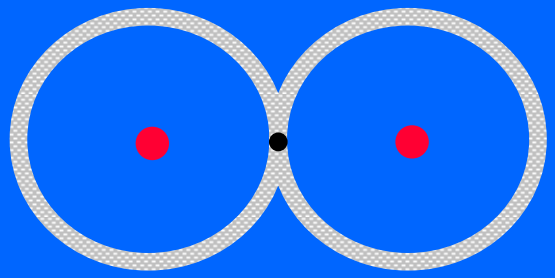
The superconducting cyclotron SCENT accelerates particles with

Q/A = ½

$^{12}C^{6+}$

$6p^+ + 6n$

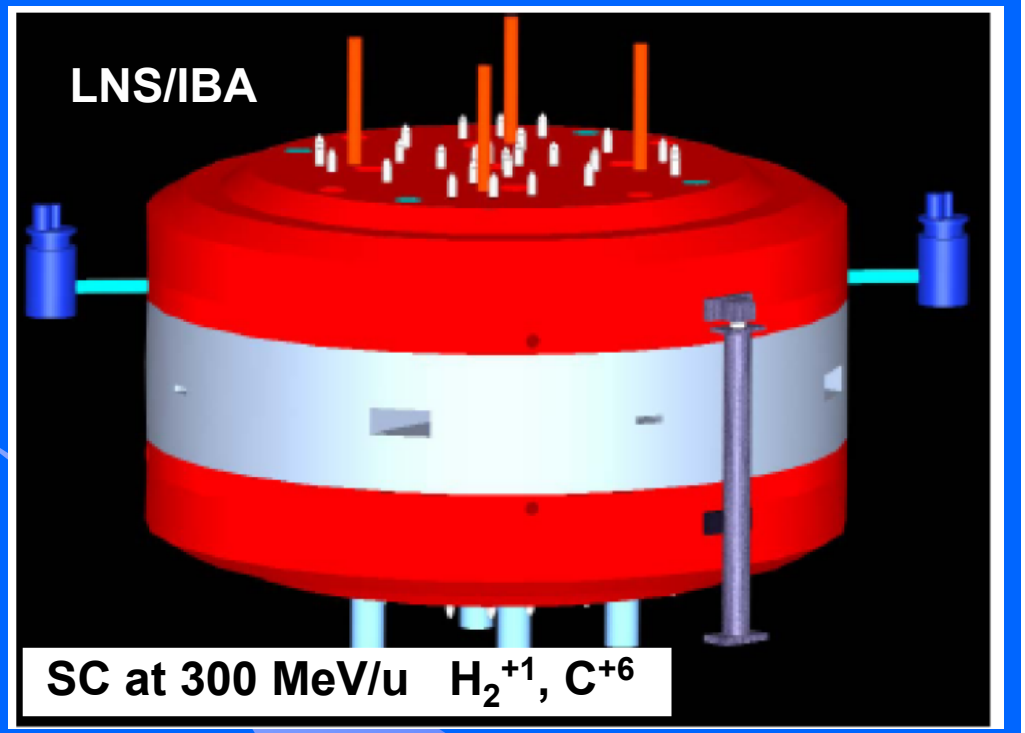
H_2^+



$2p^+ + 1e^-$

Output energies:

protons	250 MeV
carbon ions	300 MeV/u = 3600 MeV

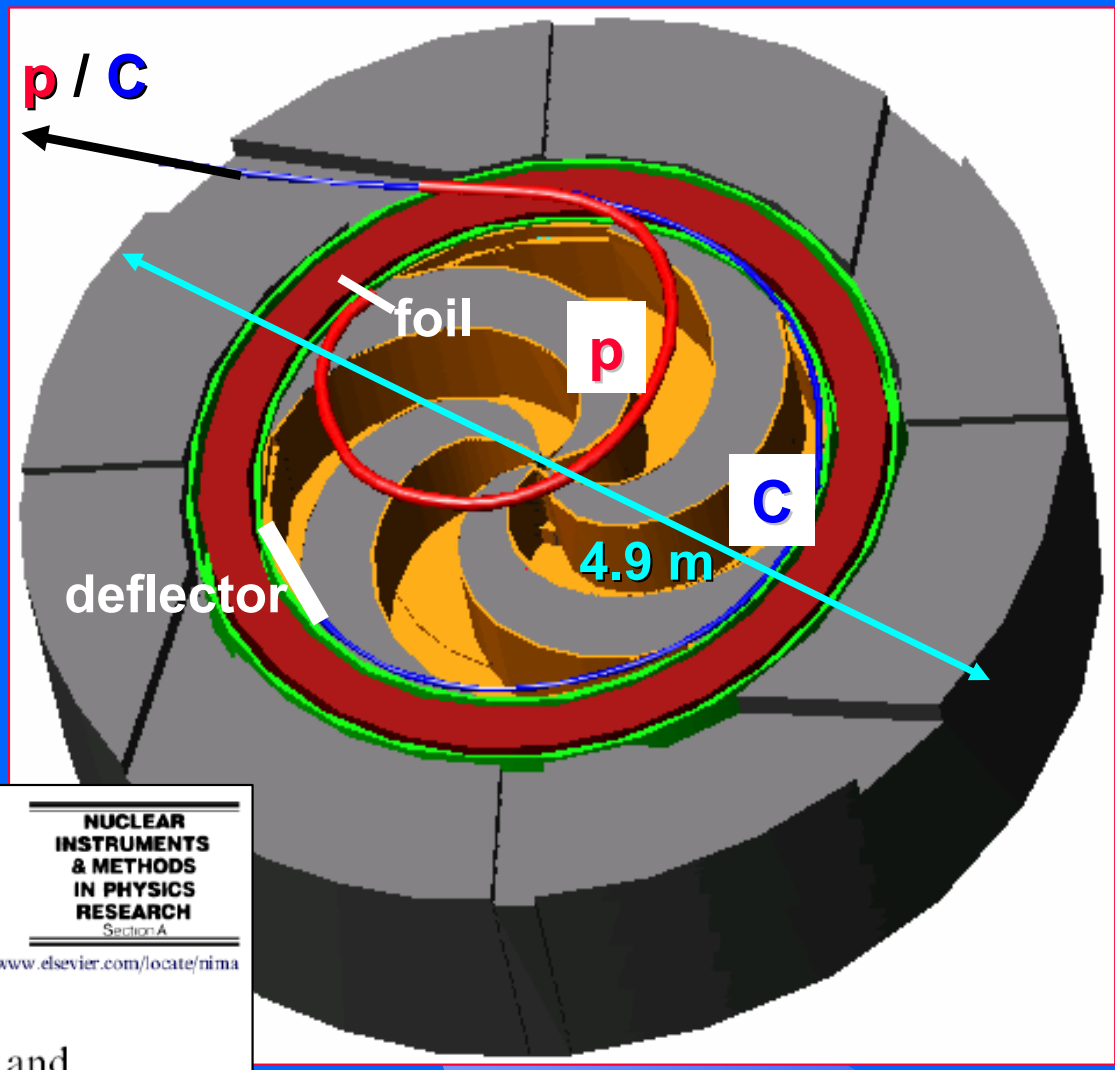


LNS = Laboratori Nazionali del Sud - INFN

IBA commercialises the 300 MeV/u cyclotron

Main Parameters

Max. Energy C	300 AMeV
Protons	250 MeV
Sectors	4
R_{pole}	132 cm
B_o	3.2 T
B_{max}	4.3 T
Hill gap	50 mm
Valley height	105 cm
RF frequency	99 MHz
Outer Diameter	4900 mm
Weight	≈ 350 tons



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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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A novel superconducting cyclotron for therapy and radioisotope production

Luciano Calabretta[a,*], Giacomo Cuttone[a], Mario Maggiore[a,b], Maurizio Re[a], Danilo Rifuggiato[a]

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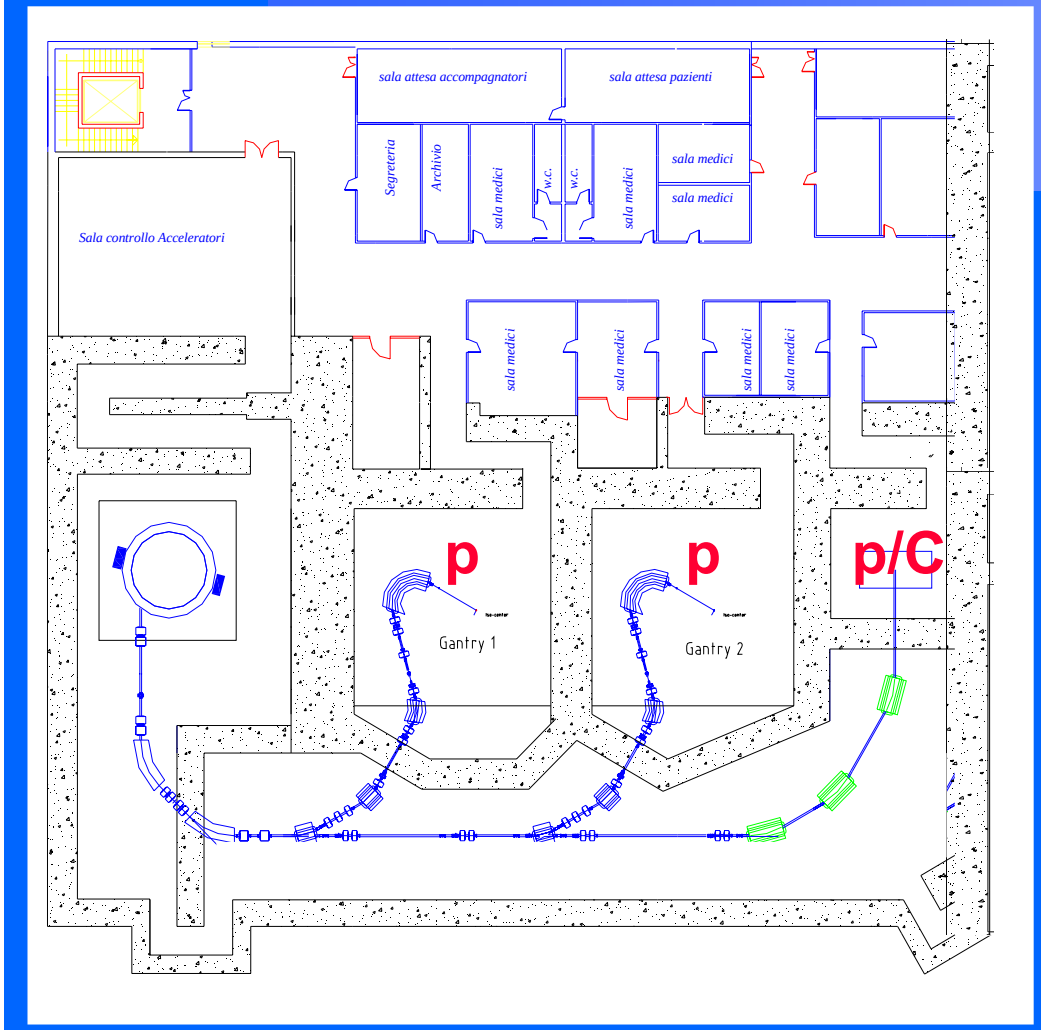
Available online 6 March 2006

TERA

The Centre designed for Cannizzaro Hospital in Catania

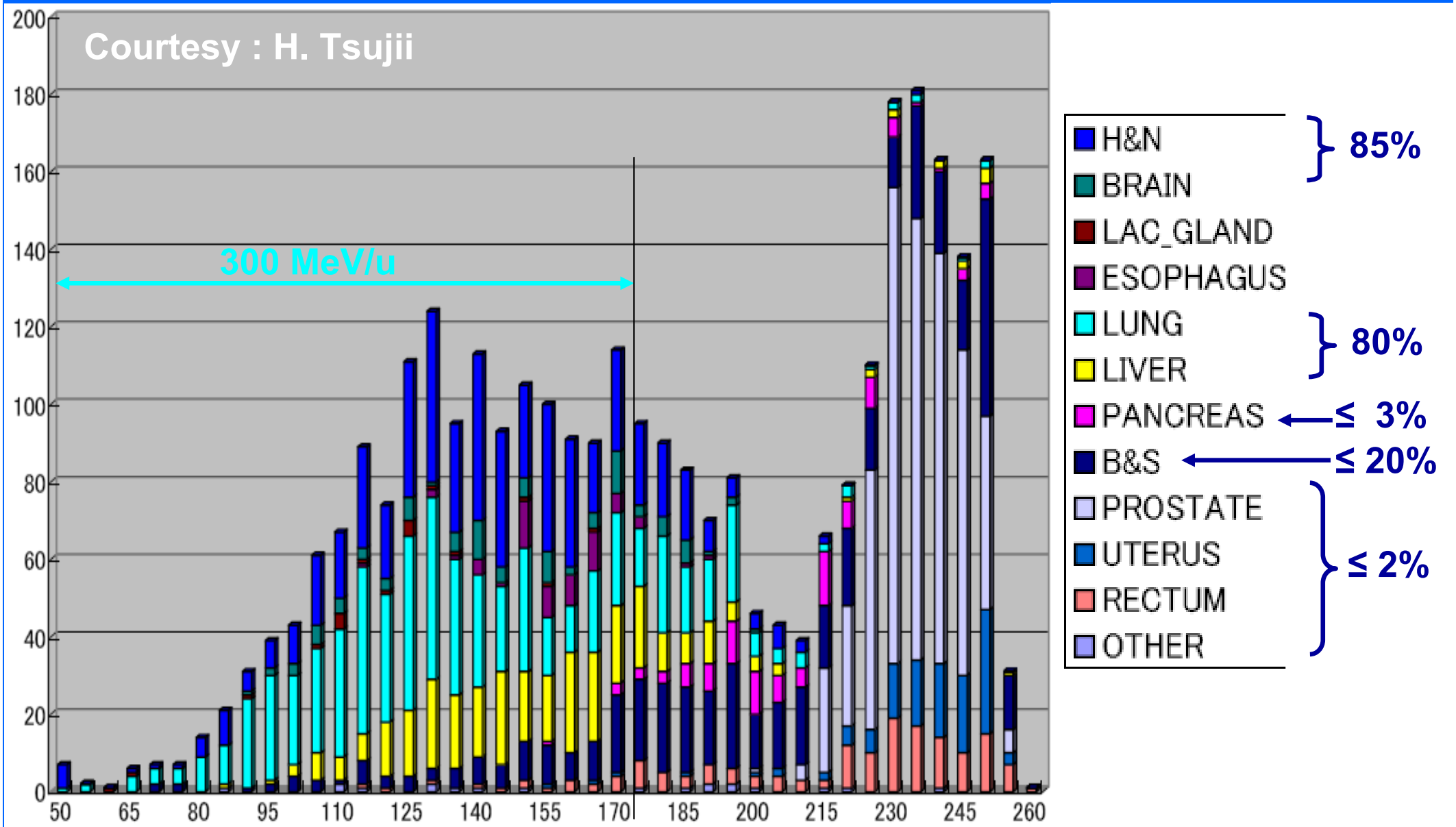


Giacomo Cuttone

Luciano Calabretta

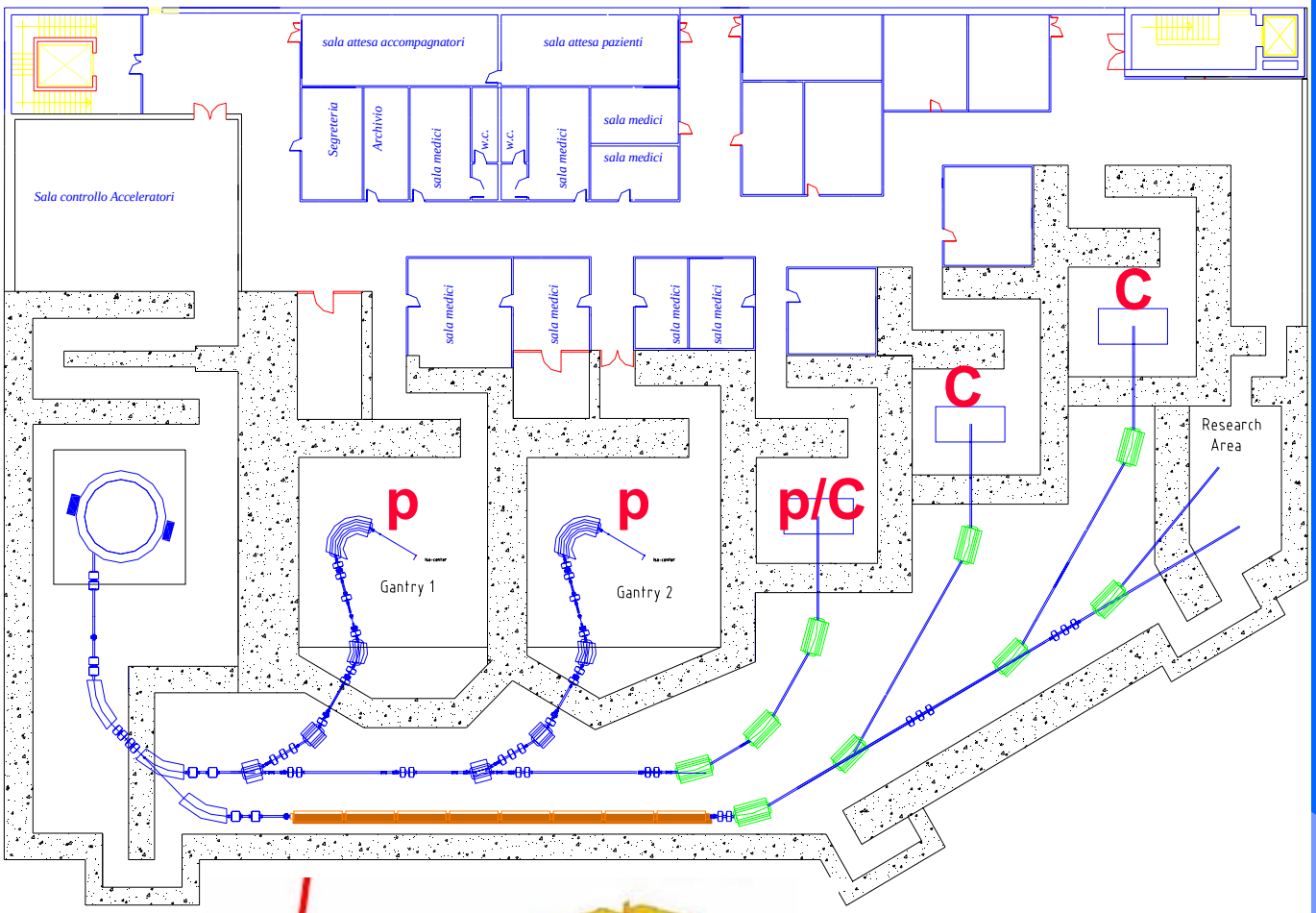
of LNS

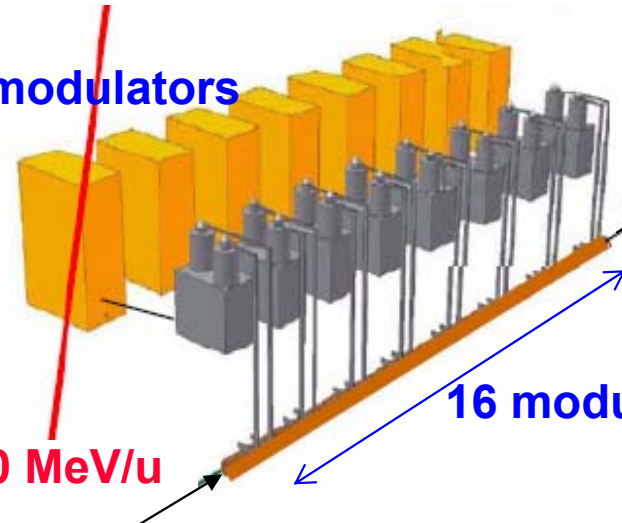
Fraction of tumours treatable with 300 MeV/u



maximum range used for 3200 patients (mm of water) 1994-

CABOTO = CArbon BOster for Therapy in Oncology



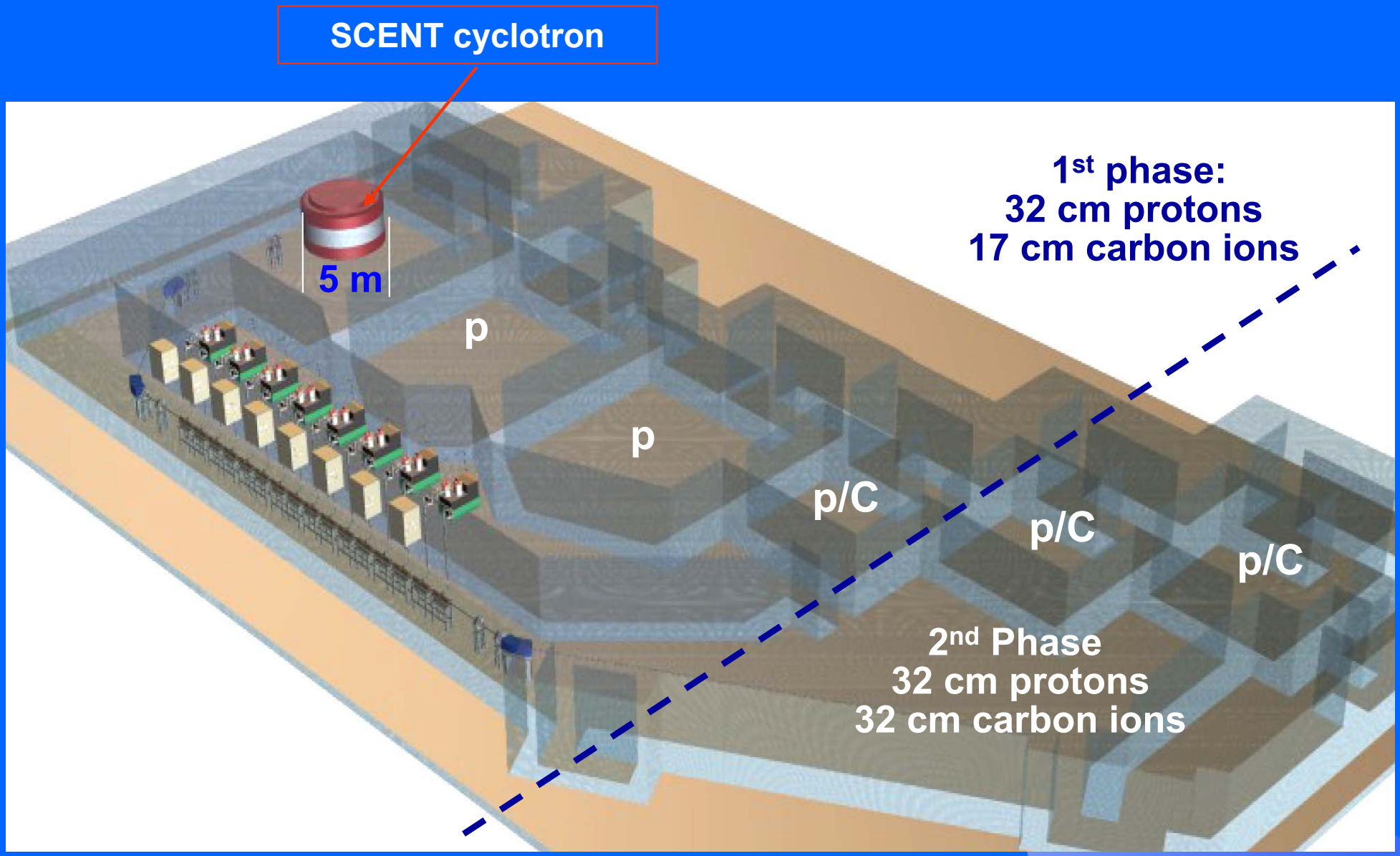


Proposed for the LNS project in Catania

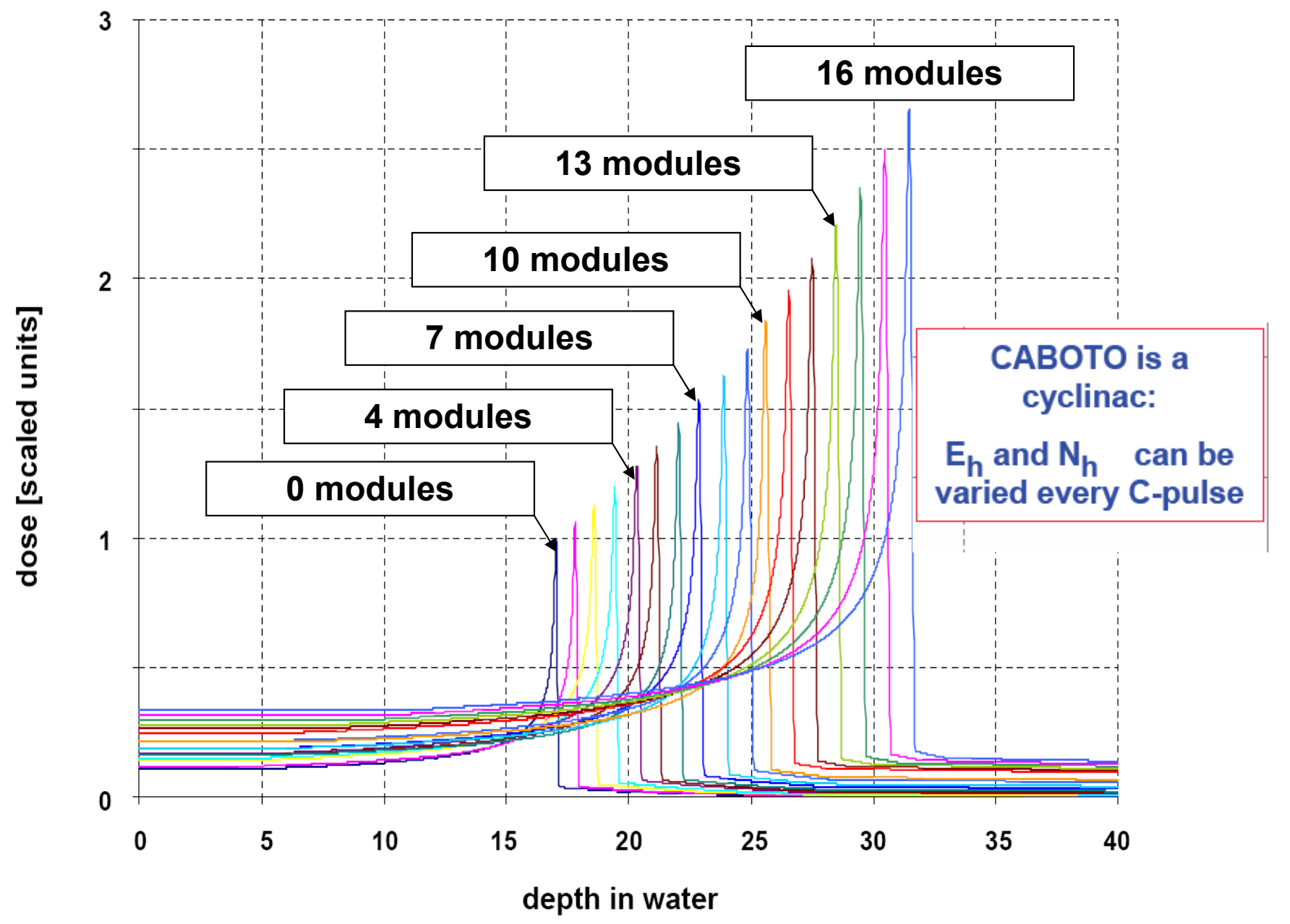
and elsewhere

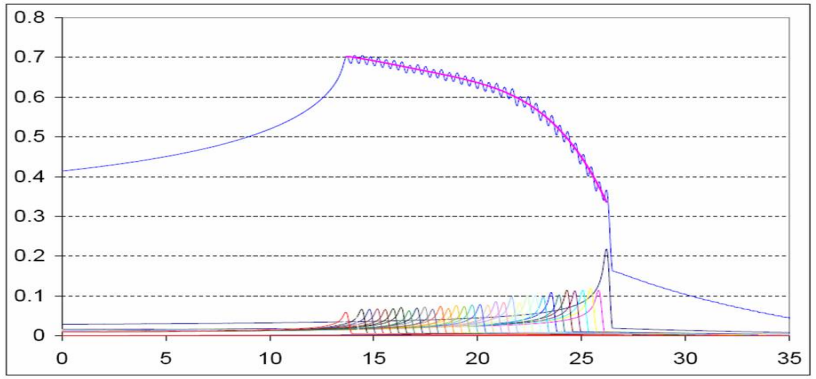
as an up-gradable dual centre

CABOTO = CArbon BOster for Therapy in Oncology



Ion Bragg curves by adjusting the powers: 300-435 MeV/u



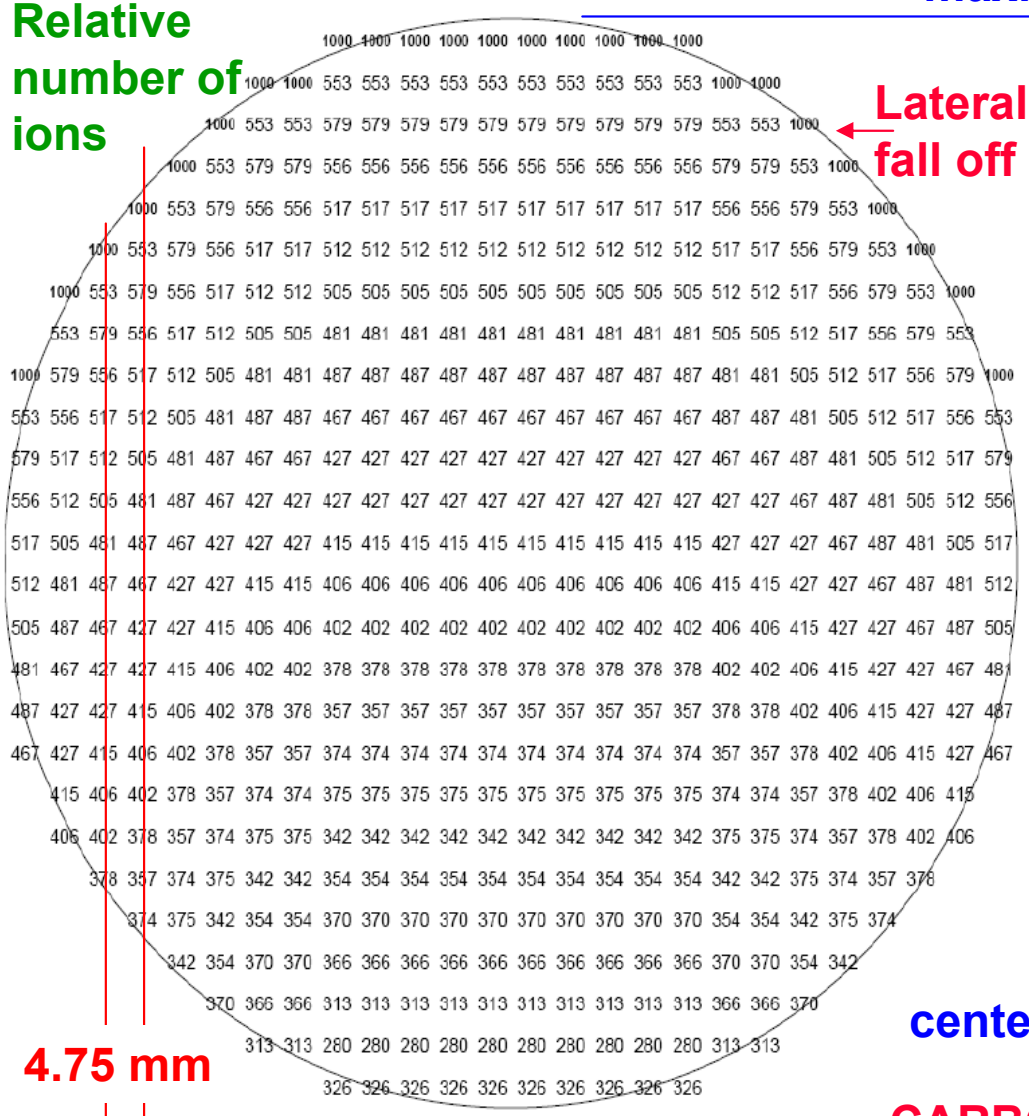


1 Liter volume contains 10 120 vox.

42 868 'visits' and 163 'energy steps' give ≥ 10 paintings in 123 s with a spot having FWHM = 6.3 mm, σ = 2.7 mm

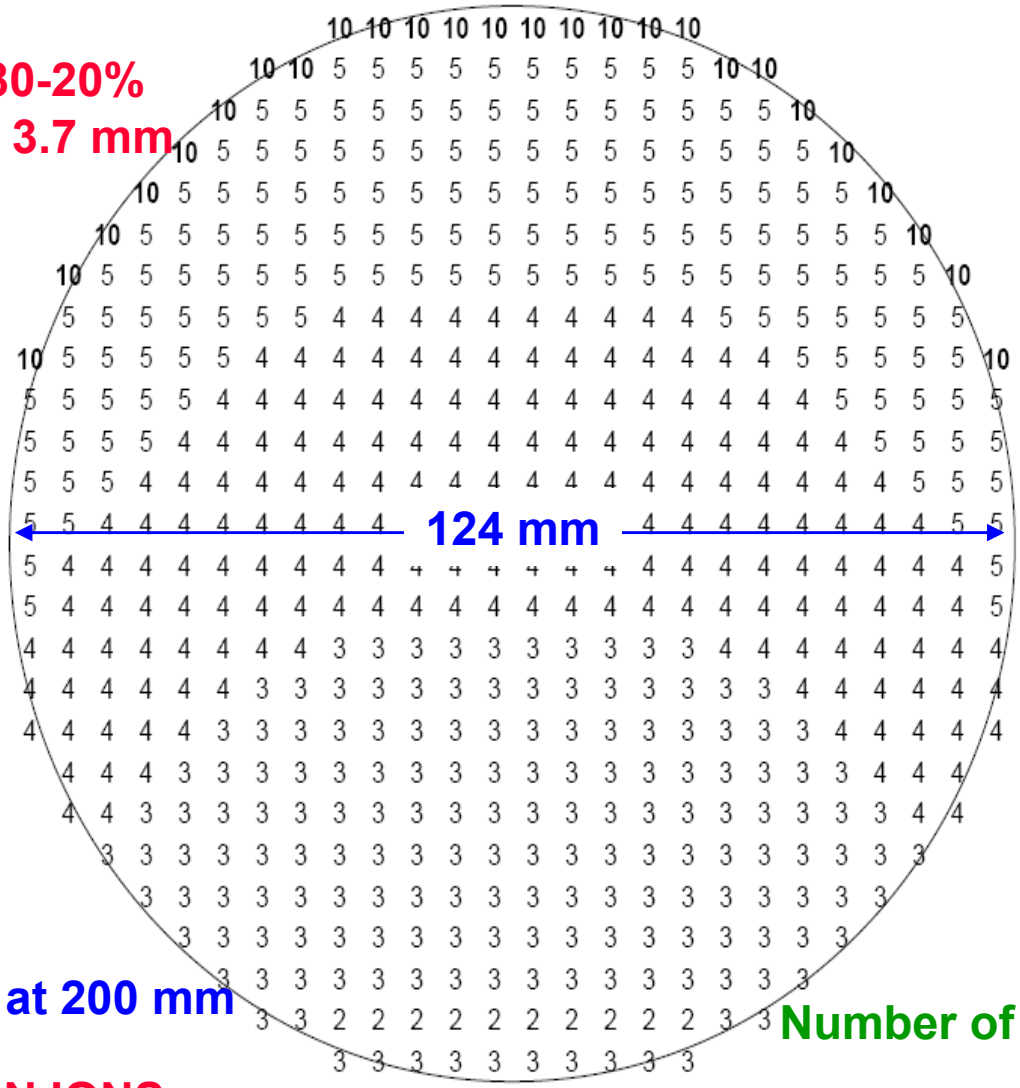
maximum depth = 262 mm, reached with 390 MeV/u

Relative number of ions



Lateral 80-20% fall off = 3.7 mm

4.75 mm



124 mm

center at 200 mm

CARBON IONS

Number of 'visits per voxel

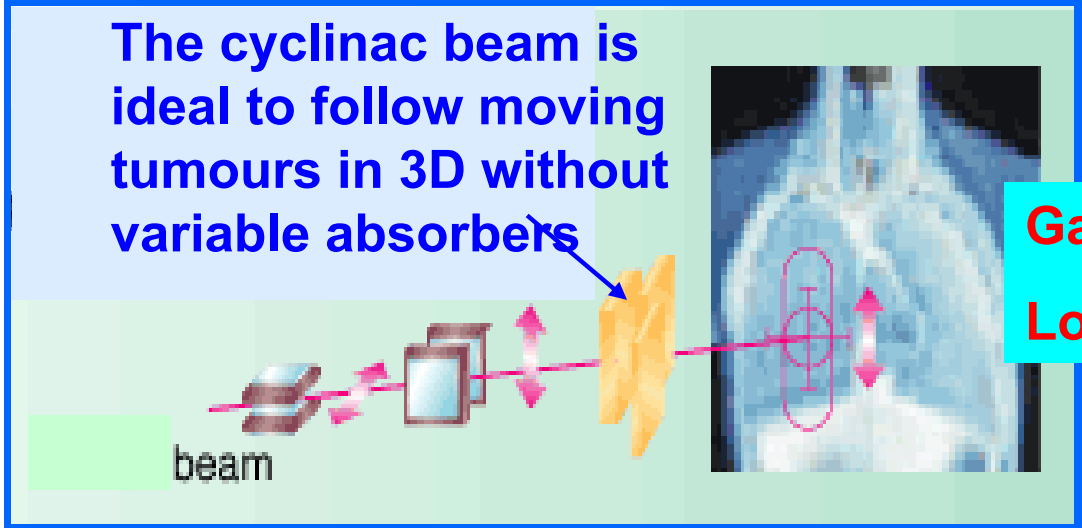
Properties of the beams of different accelerators

Accelerator	Beam always present during treatments	Energy variation by electronic means	Time needed for varying the energy
Cyclotron	Yes	No	50 ms (*)
Synchrotron	No	Yes	1 second
Cyclinac	Yes	Yes	1 millisecond

(*) With advanced movable absorbers

The energy is varied by adjusting the RF pulses to the modules

The cyclinac beam is ideal to follow moving tumours in 3D without variable absorbers

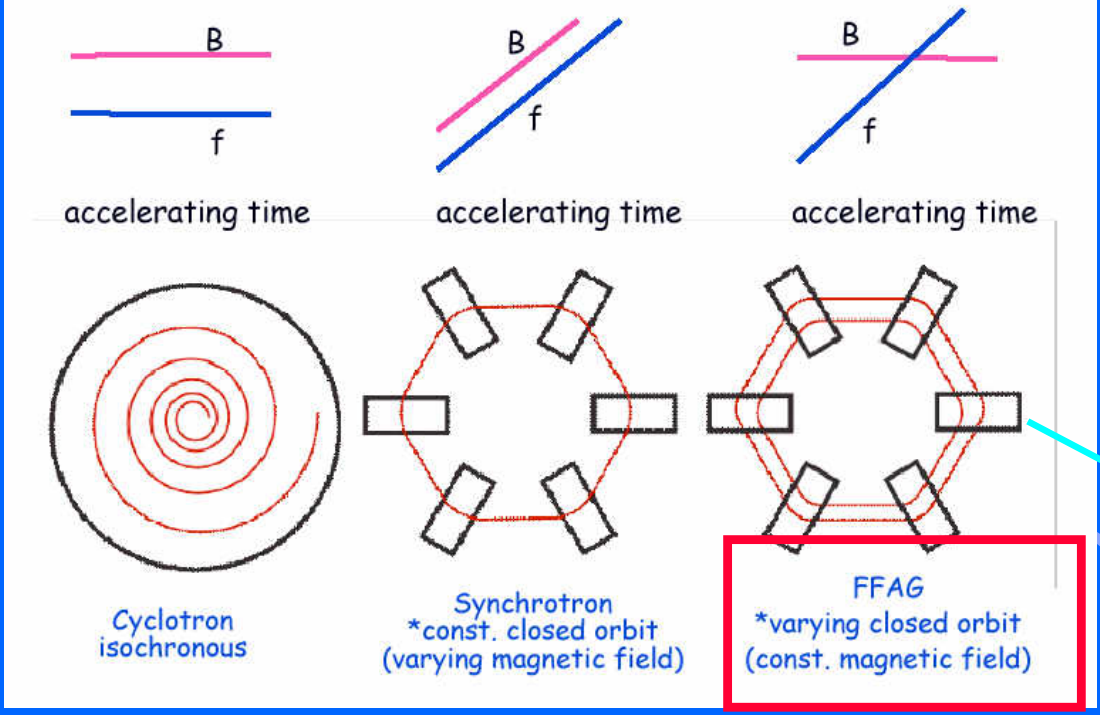


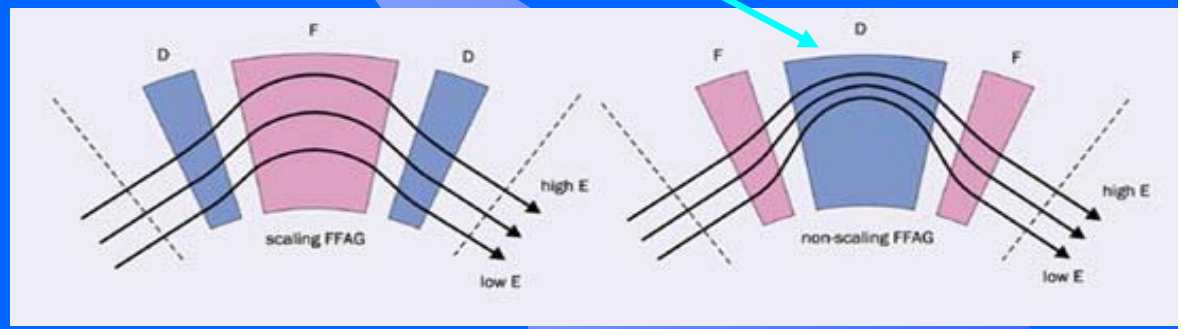
Gantry momentum acceptance: ± 1.5%

Longitudinal displacement: ± 10 mm

A medium term possibility: Fixed Field Alternating Gradient

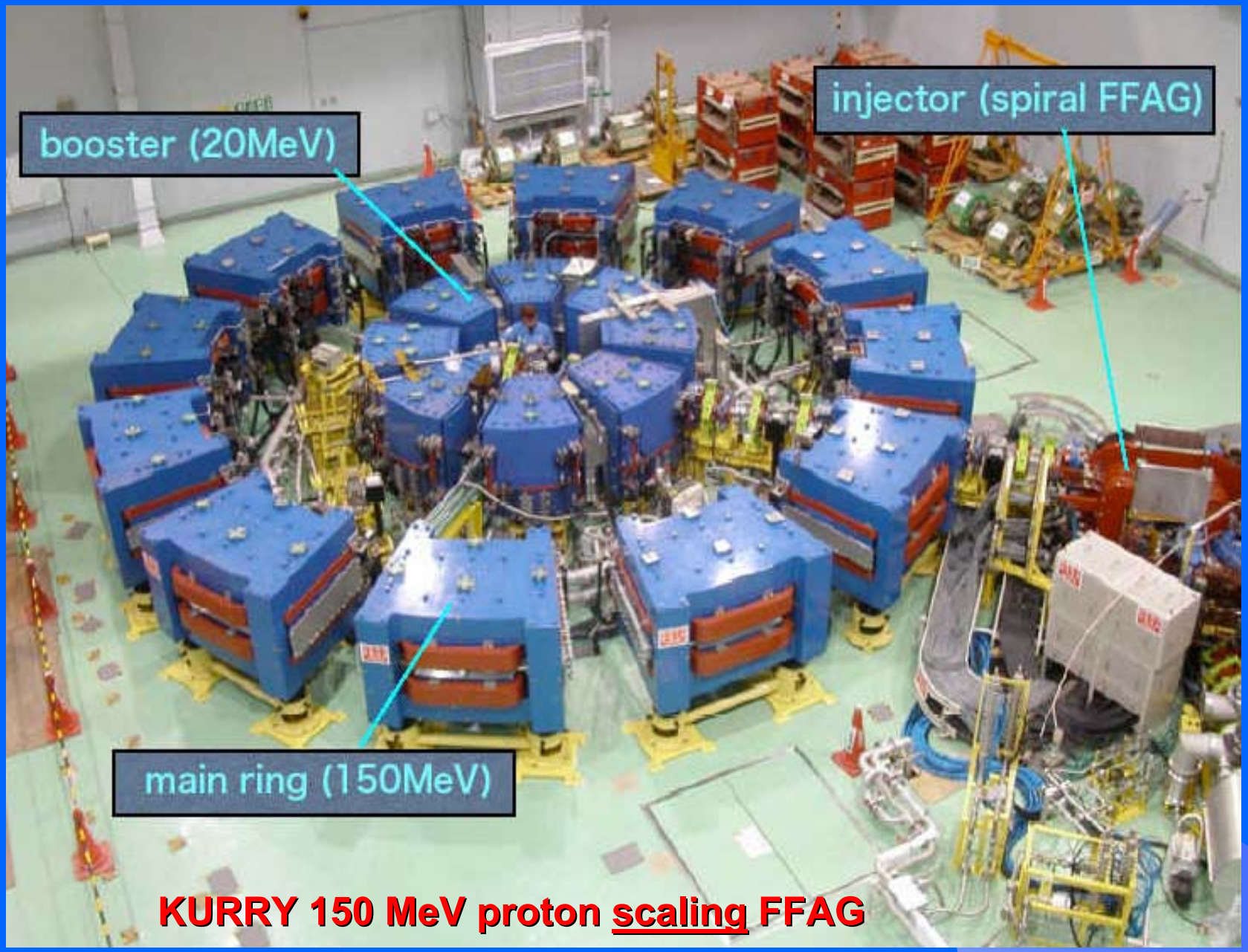
Revival of an old idea: FFAGs





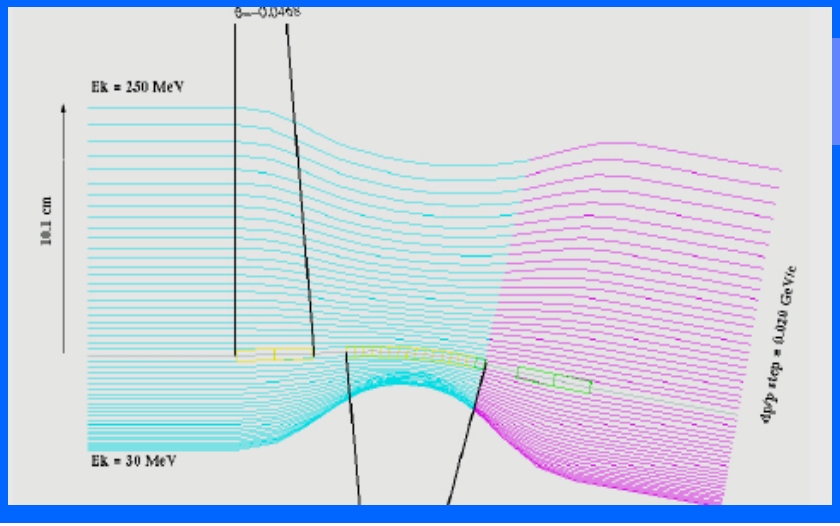
Scaling and non scaling FFAG

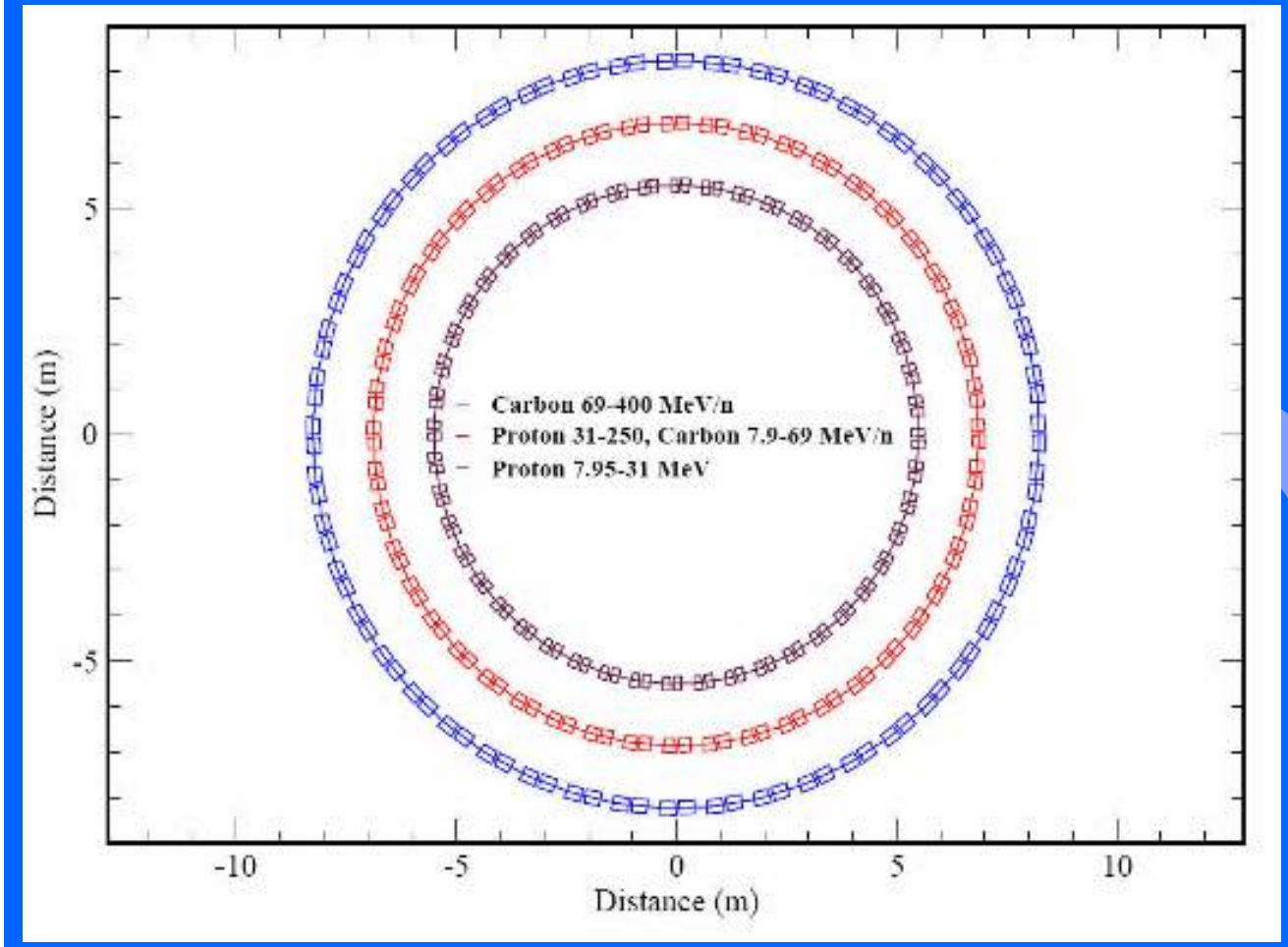
Proof of the scaling technique in Japan



KURRY 150 MeV proton <u>scaling</u> FFAG

Non scaling FFAG





E. Keil, A.M. Sessler et al.

Fast extraction

at 500 Hz?

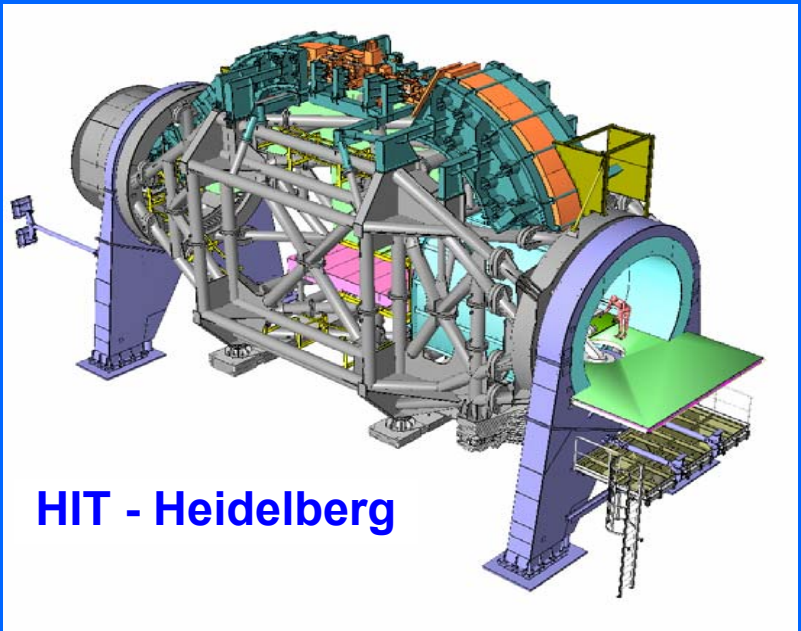
EMMA @ Oxford

is an important

electron test bed

The challenges of Hadrontherapy:
2. Construction of viable carbon ion gantries

Optimize the ion delivery with gantries



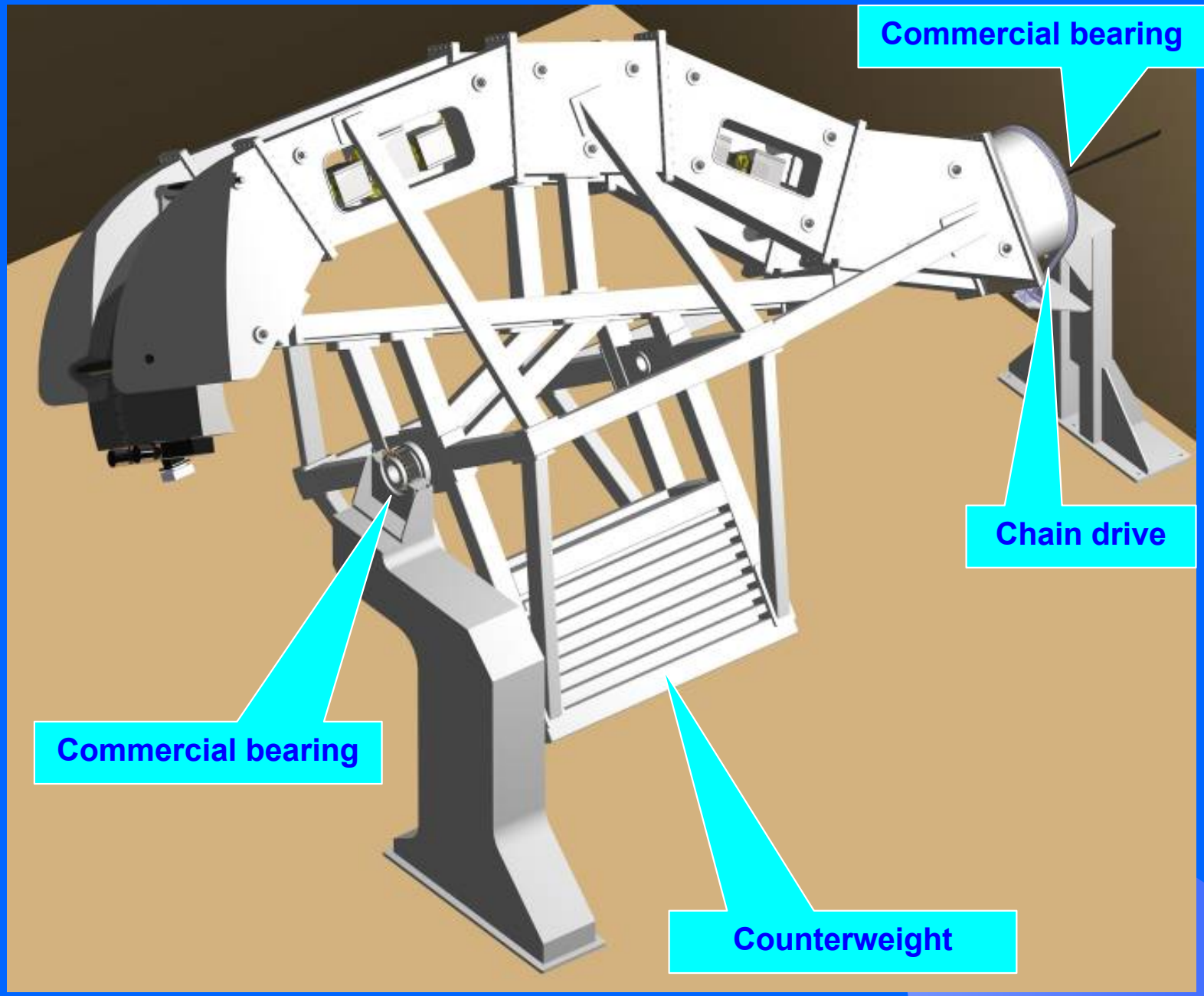
An ion gantry is costly and complicated, but allows a better sparing of healthy tissues.

Only HIT (Heidelberg) has one

Heavy-ion Gantry

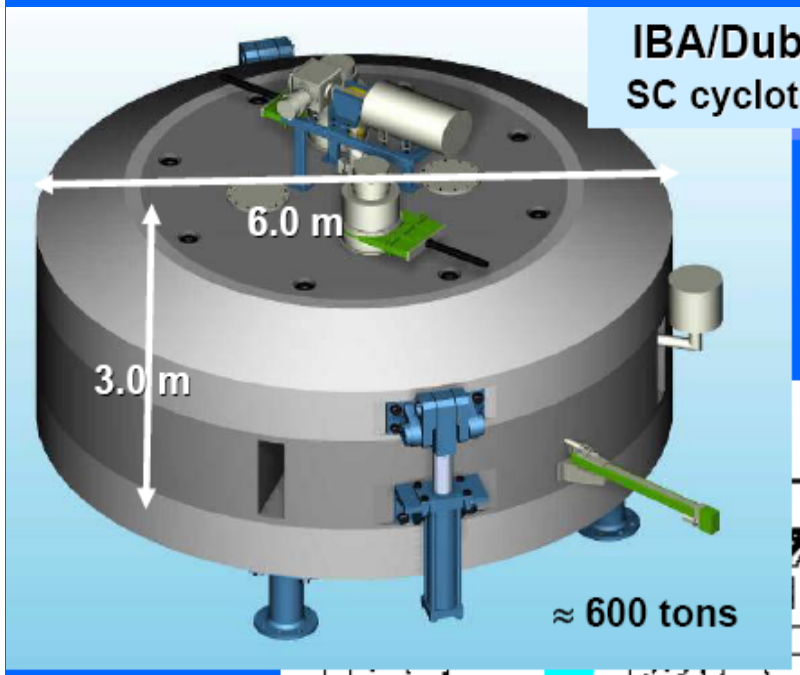
Weight: 600 t
25 m long
13 m diameter
Deformation < 0.5 mm

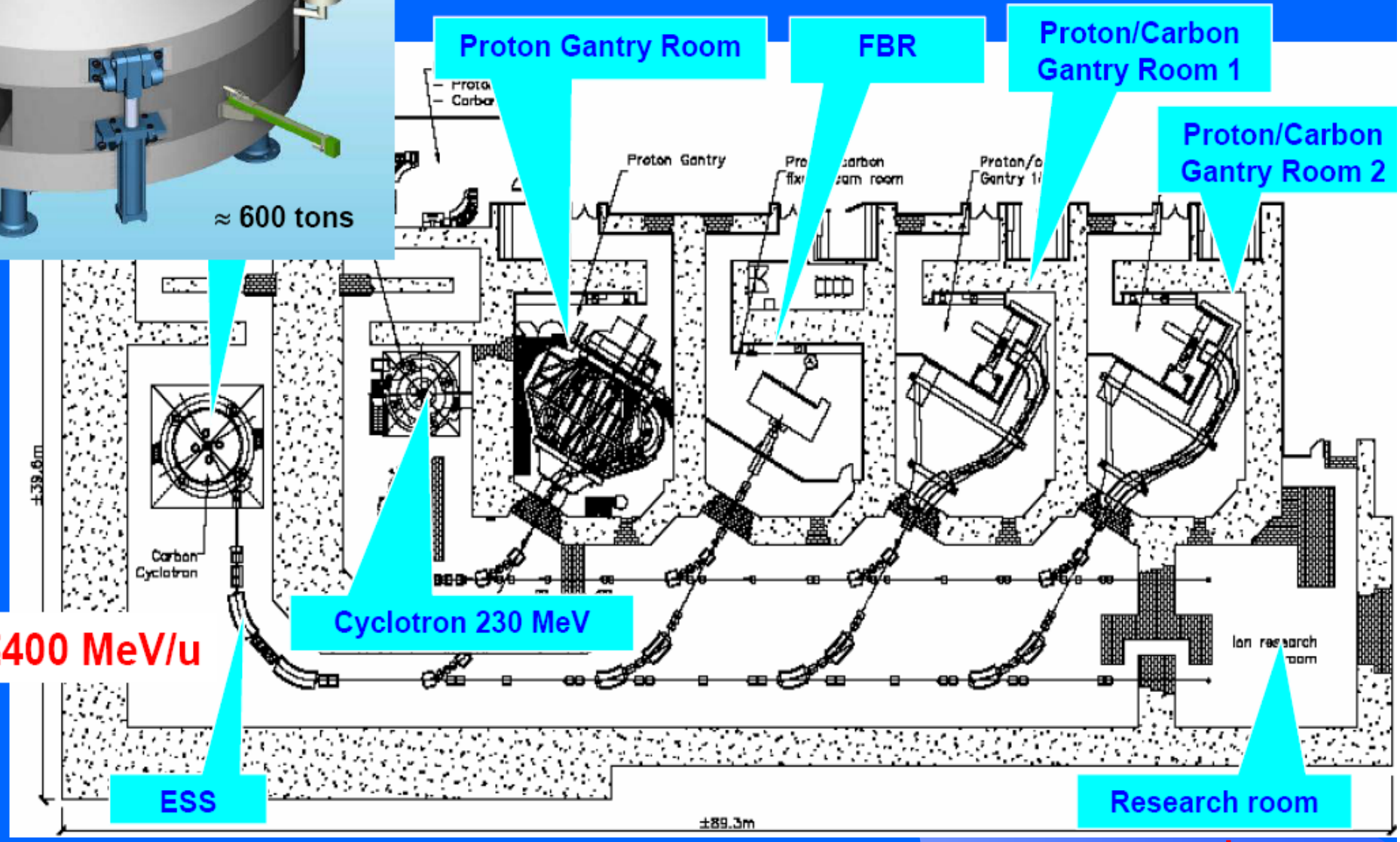
Mechanical structure of the IBA carbon ion SC gantry



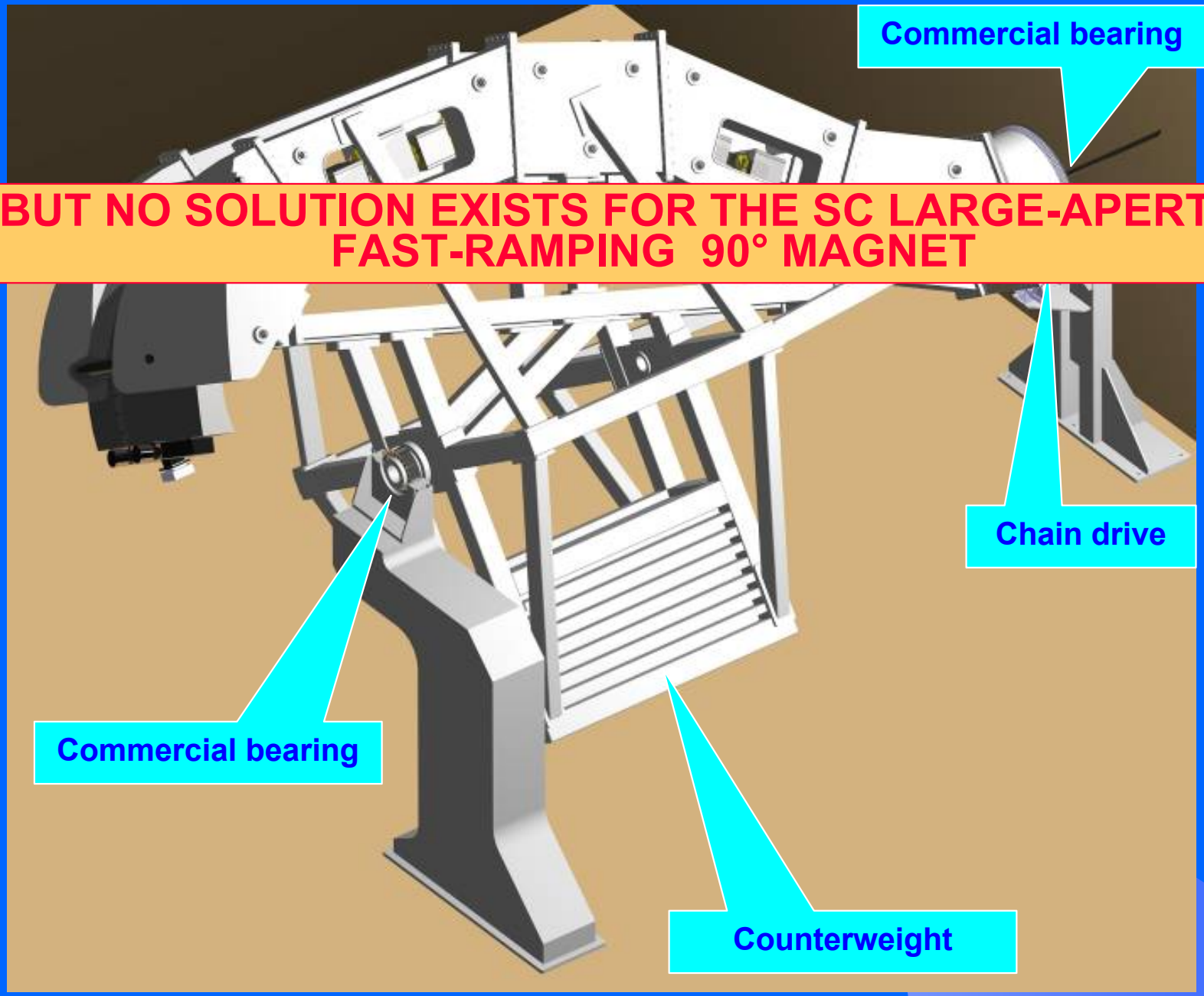
The new IBA 400 MeV/u dual facility

features two such gantries





Mechanical structure of the IBA carbon ion SC gantry



BUT NO SOLUTION EXISTS FOR THE SC LARGE-APERTURE FAST-RAMPING 90° MAGNET

ULICE = Union of Light Ion Centre in Europe

GOOD NEWS

In the proposal being prepared for the end of February a Working Package (co-ordinator: Marco Pullia – CNAO) will study SC gantries for ions

The WP will be centered at CERN

The challenges of Hadrontherapy: 3. “single-room facilities”

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**

8 Treatment rooms are found in 1 large and 2-3 small departments serving 1.5-2 million inhabitants

One single room attached to one hospital is what is needed

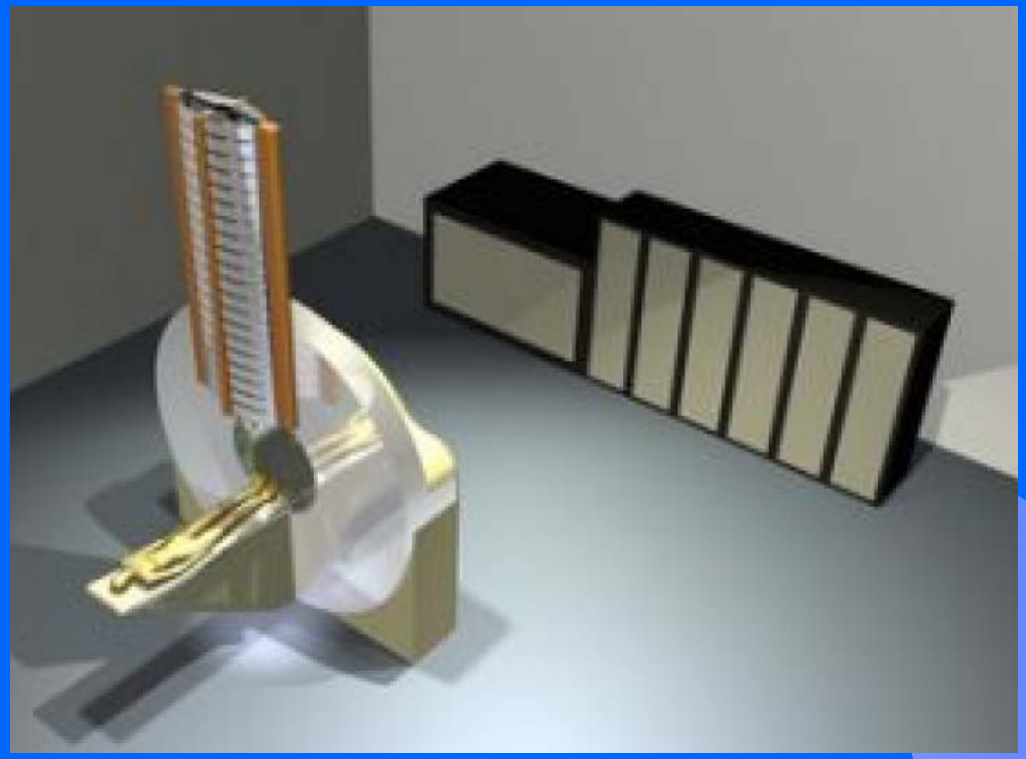
At present:

Still River builds a high-field SC synchrocyclotron mounted on a gantry

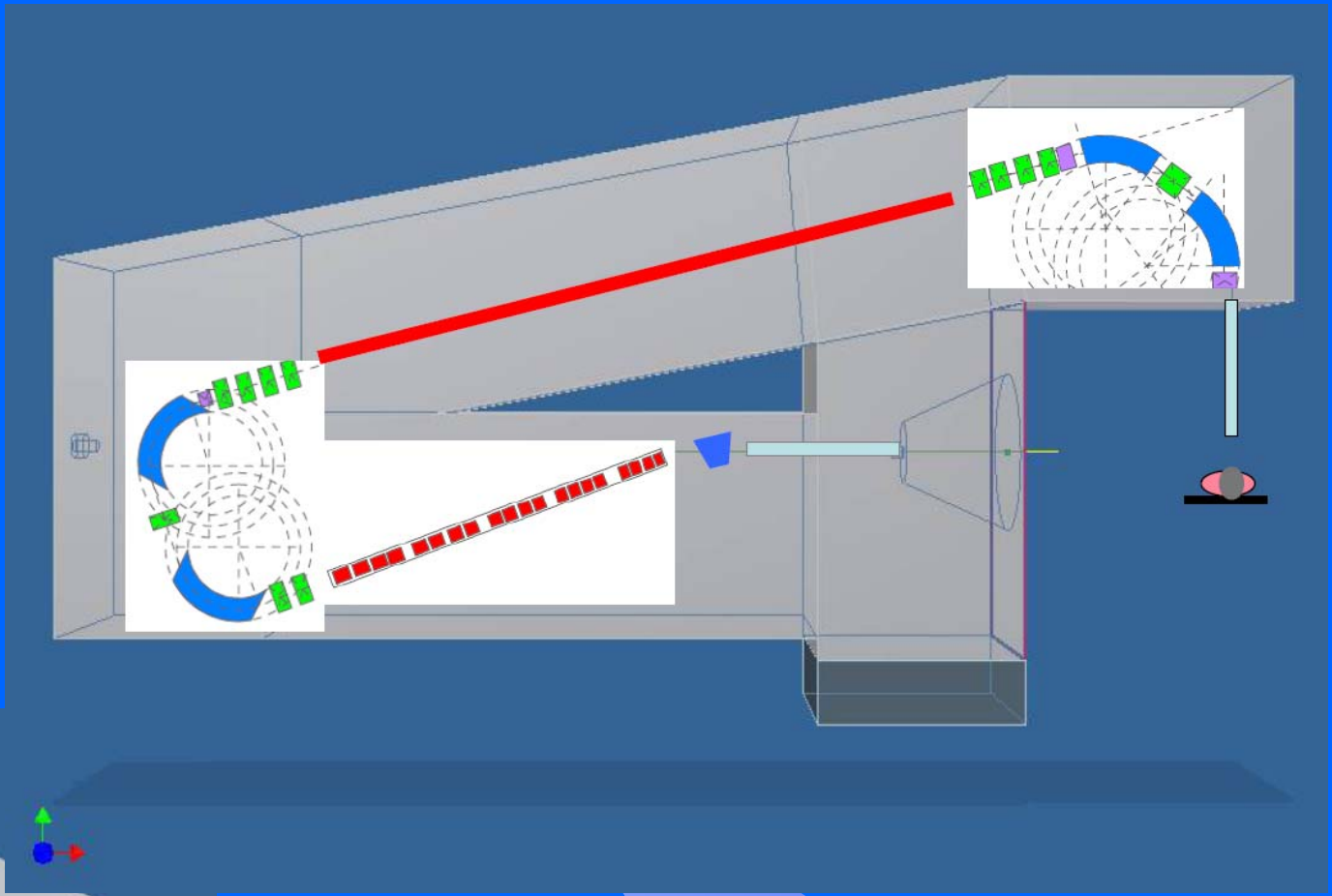
Dielectric Wall Accelerator = DWA

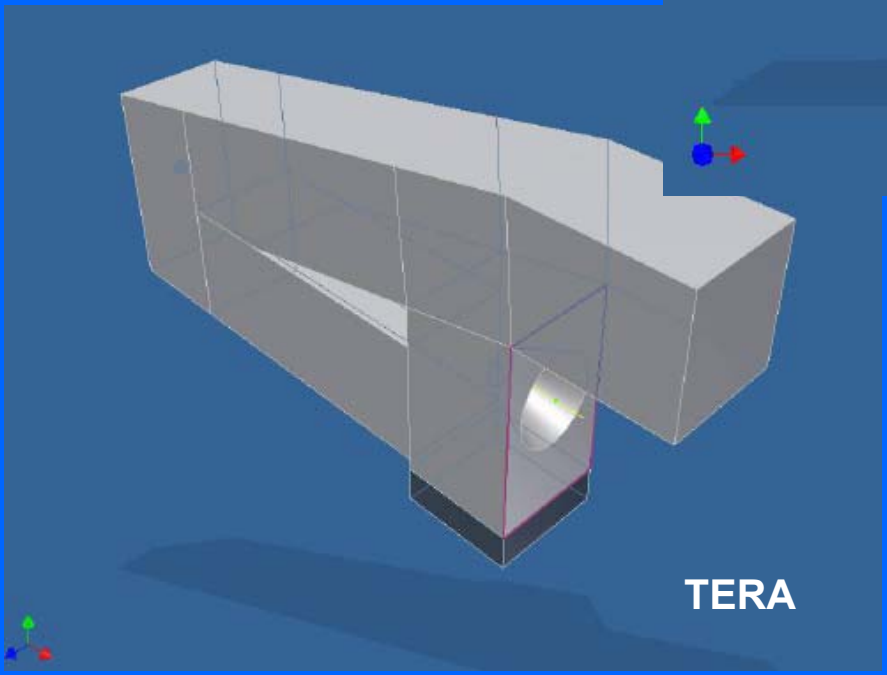
LLNL , UC Davis and TomoTherapy develop a proton accelerator outgrowth of the Los Alamos weapons research

The LLNL team is led by George Caporaso



First design of TULIP = TUrning Linac for Particle-therapy





Conclusions

Protontherapy is on the market and the number of centres and patients increases exponentially

Carbon ion therapy is delivering the promised results for radioresistant tumours but many clinical studies are still needed

As far as dual centres are concerned Europe is doing very well:
Heidelberg, Pavia are almost finished, Margburg will start in 2010
Wiener Neustadt and Lyon are coming next

The main challenge is the treatment of moving organs
- and cyclinacs promise to be the best adapted accelerators -
together with the construction of more compact carbon gantries

THE END