NOVEL 200 - 400 Hz ACCELERATORS FOR PROTON AND CARBON THERAPY: THE CYCLINACS

Ugo Amaldi

University of Milano Bicocca and TERA Foundation

15 years of TERA: 1992-2007

TERA has proposed and produced 3 designs for the National Centre for carbon ions (and p) to be built on 3 sites: Novara (1993-1995), Milano (1996-2000) and Pavia

↓

CNAO is being completed in Pavia

by the CNAO Foundation

TERA has developed (1993-2006) a novel type of accelerator:

the "cyclinac" for protons and carbon ions

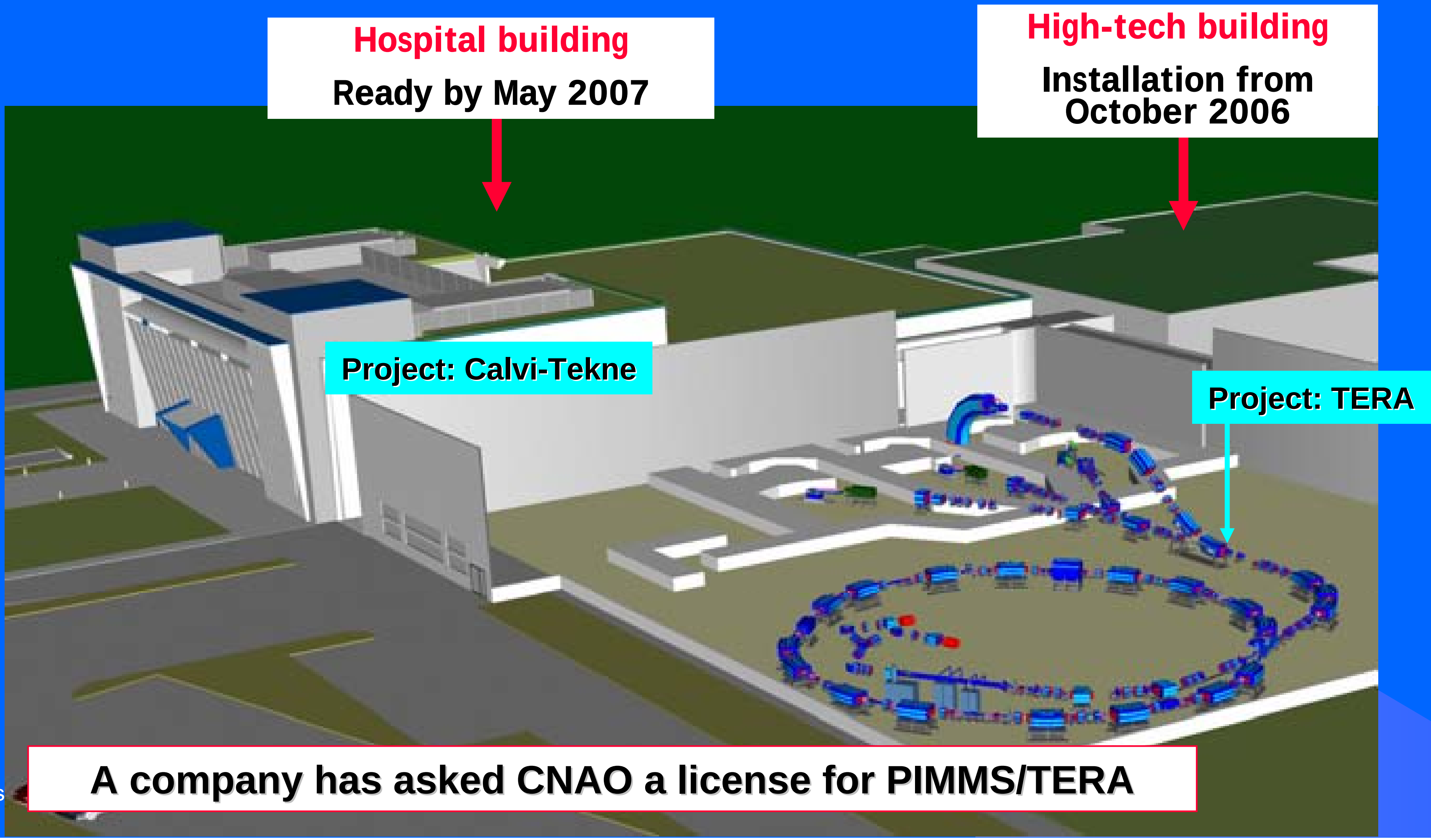
↓

2. **IDRA (2001)**
3. **CABOTO (2005)**

The National Centre in Pavia

CNAO = Centro Nazionale di Adroterapia Oncologica

CNAO Foundation created on TERA request by the Italian Health Minister in 2001:
4 Hospitals in Milan, 1 Hospital in Pavia and TERA
In 2003 TERA passed to CNAO the full design (3000 pages) and 25 people
INFN has become <u>Institutional Participant</u> in 2004 with construction responsibilities



A company has asked CNAO a license for PIMMS/TERA

The surface buildings

Main source of 90 M€:
Italian Health Ministry

First beam:
end 2007

CNAO Foundation

President:	**E. Borloni**
Medical Director:	**R. Orecchia**
Technical Director:	**S. Rossi**

The hospital building in March 2007

Emplacements of the sources, LEBT and Linac: 20 February 07

Start of sources installation: 26 march 2007

Ion source

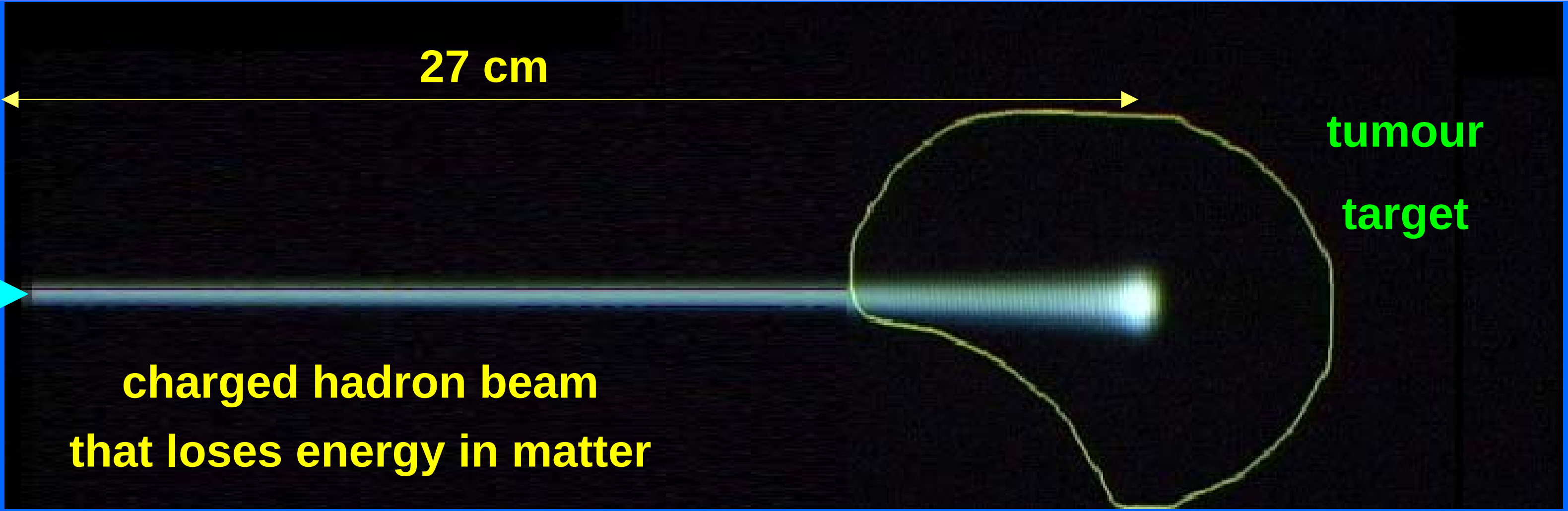
Cyclinacs

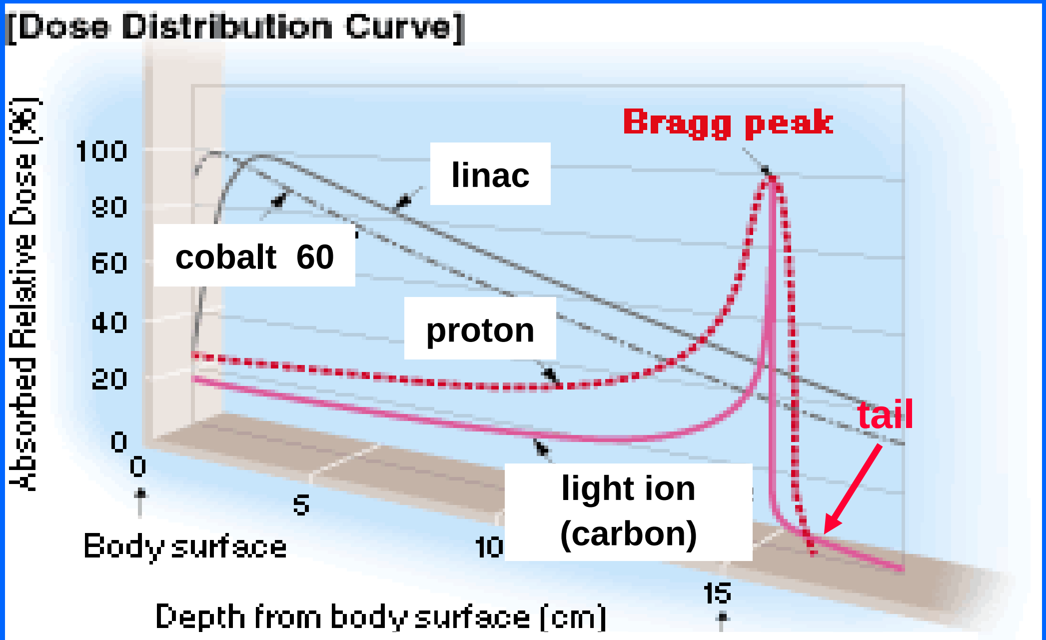
LOW currents of protons and ions spare healthy tissues

200 MeV - 1 nA!
protons

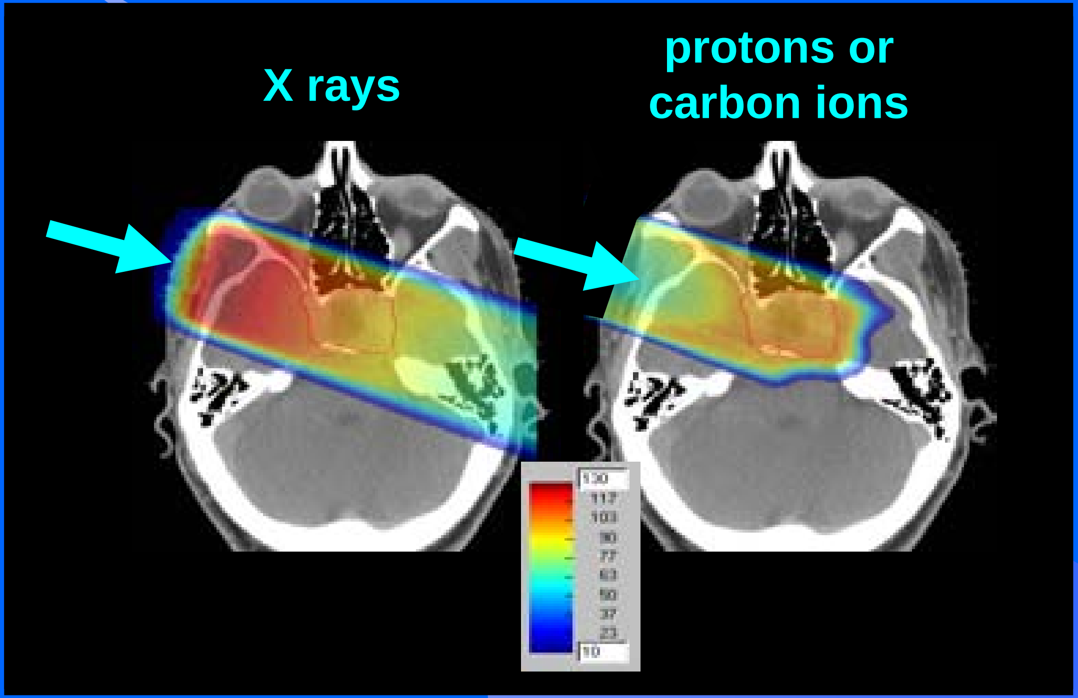
4800 MeV – 0.1 nA!
carbon ions

which can control radioresistant tumours

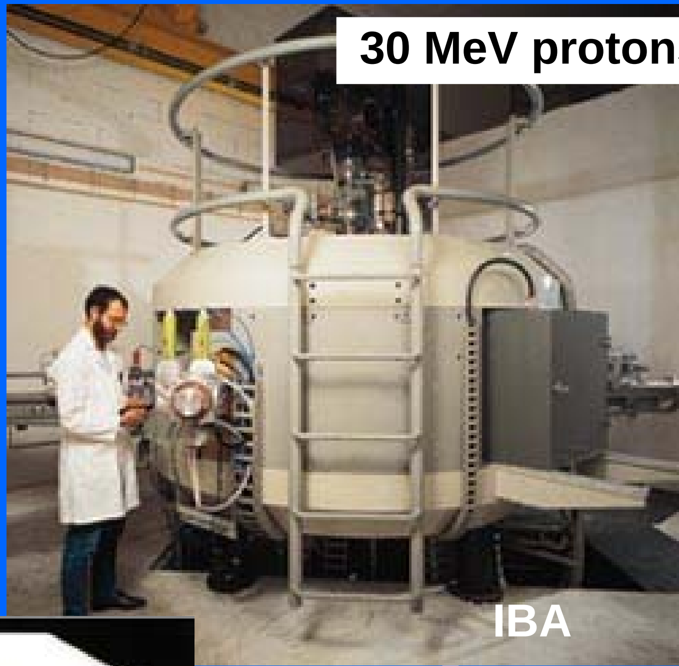


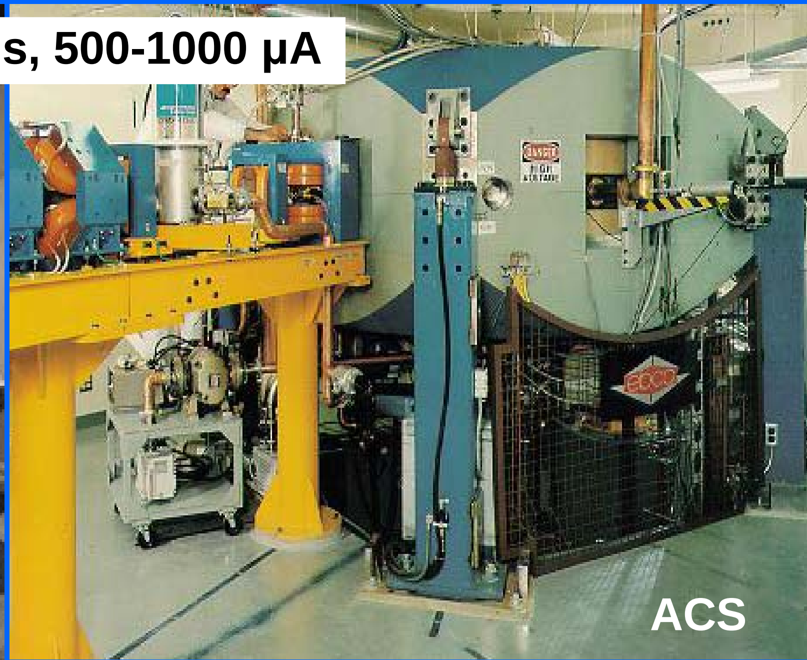


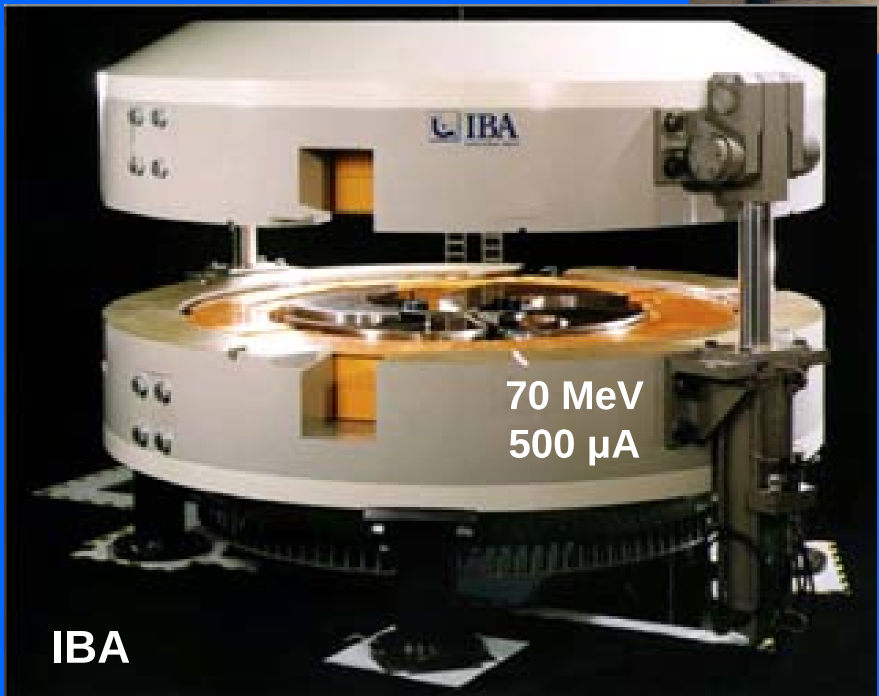
http://global.mitsubishielectric.com/bu/particlebeam/index_b.html

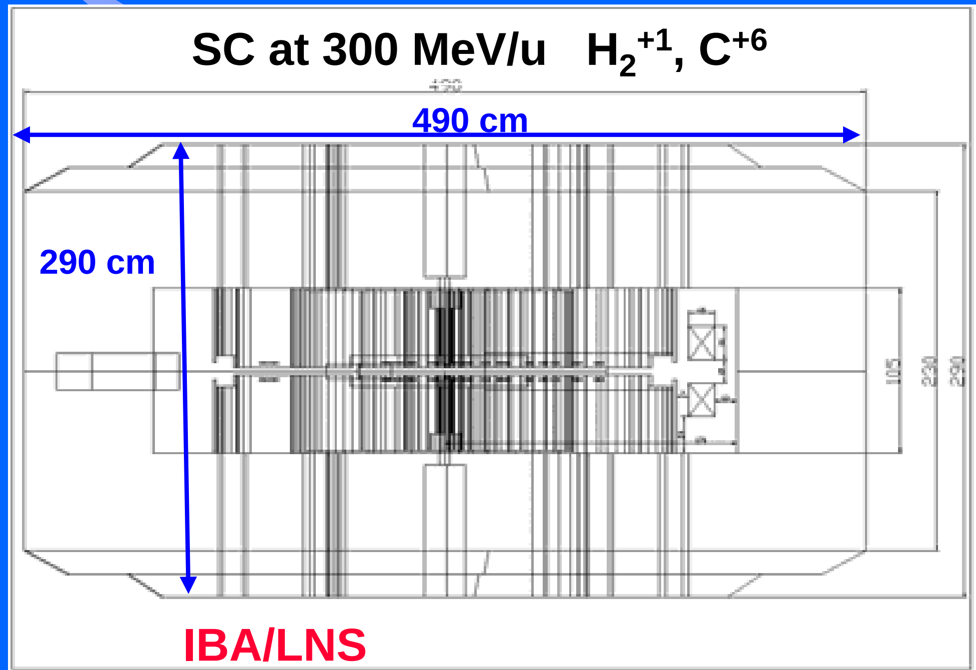


Commercial cyclotrons









The new concept introduced by TERA: the "cyclinac"

cyclotron + linac = cyclinac

The linac used in conventional radiotherapy is f = 3 GHz.
f = 3 GHz has been chosen for IDRA and CABOTO because
(i) it is an international standard,
(ii) components are relatively cheap,
(iii) it implies shorter linacs since the gradient is roughly proportional to $f^{½}$

This high frequency had never been used to accelerate protons and ions

The new concept introduced by TERA: the "cyclinac"

cyclotron + linac = cyclinac

The cyclotron is used as injector but has other <u>valuable</u> medical utilizations:

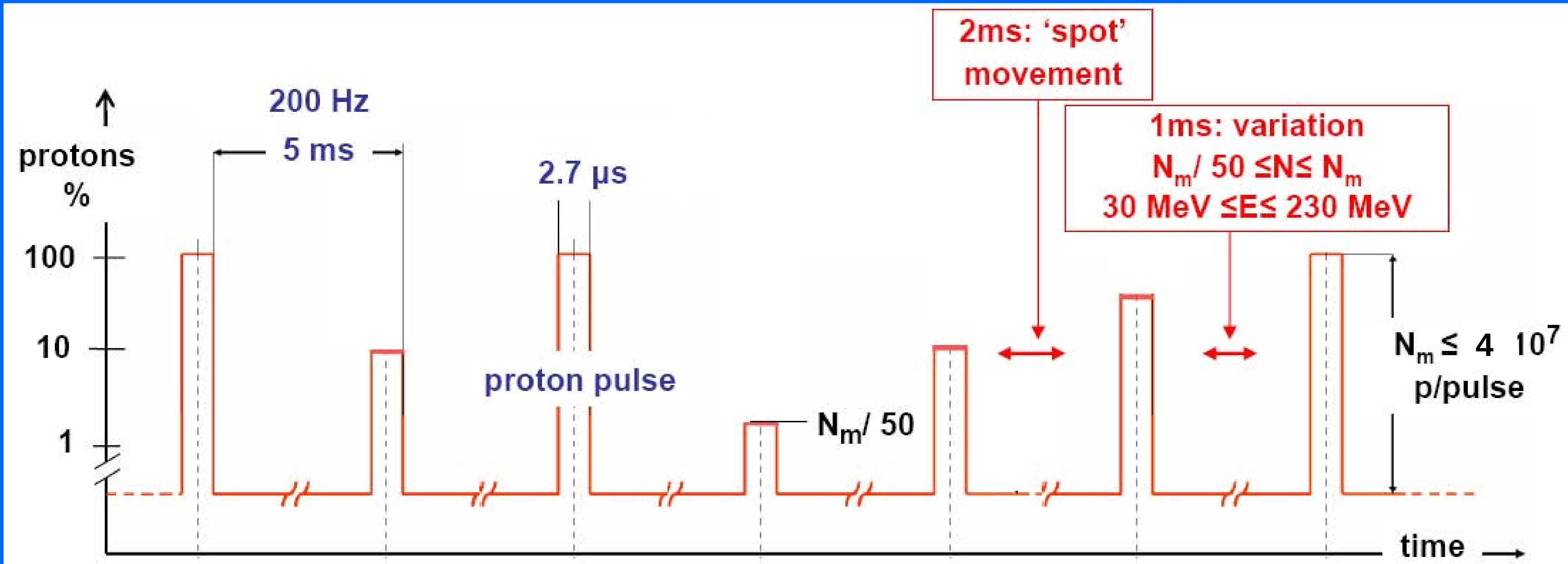
A. Production of radioisotopes for diagnostics and/or therapy — 24-30 MeV p

A. Isotopes for diagnostics and/or therapy and eye melanoma — 60-70 MeV p, 7 Mev/u He^{+2} and C^{+6}

C. Deep (shallow) therapy with protons (with carbon ions) — 230-300 MeV/u H_2^+, C^{+6}

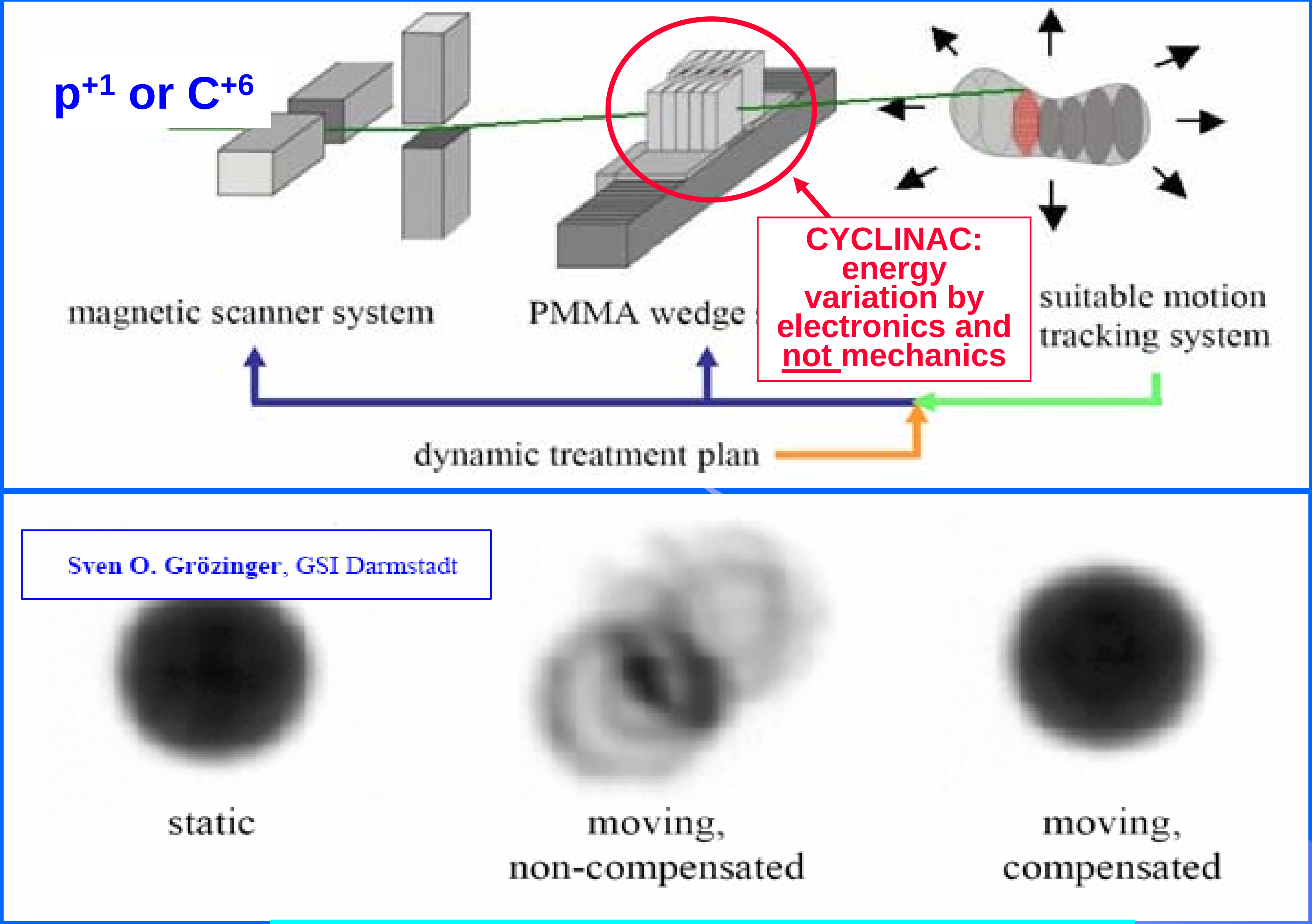
Note: TERA has deposited two patents, one for A.+B. and one for C.

Time and amplitude structure of the beam - the proton example: IDRA



4

Cyclinac uses the GSI approach to face the challenge: moving organs



4D radiotherapy is the frontier of IMRT and the future of hadrontherapy

Properties of the therapy beams

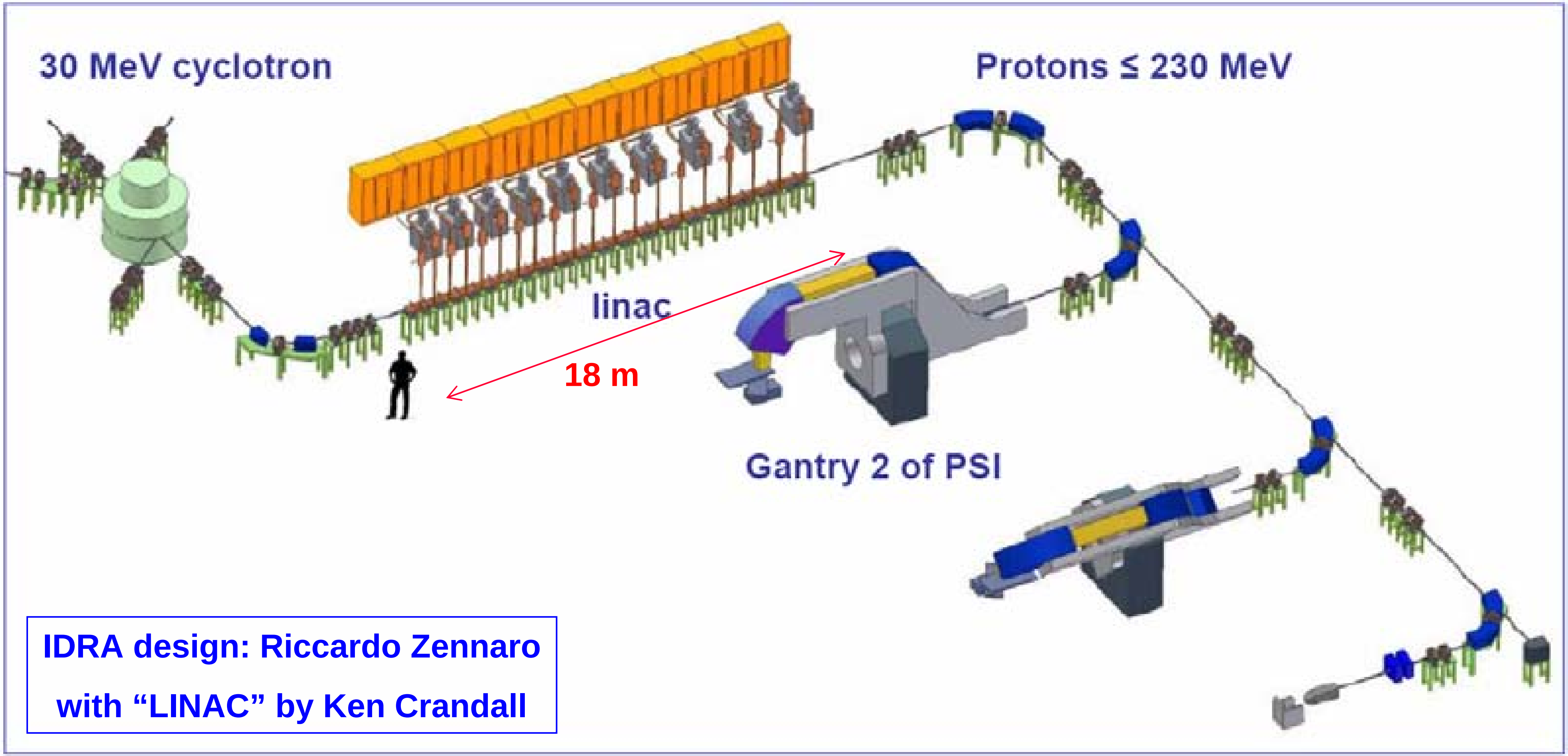
Accelerator	Beam always present during treatments	Energy variation by electronic means	Time needed for varying the energy
Cyclotron	Yes	No	30-50 ms (*)
Synchrotron	No	Yes	1 second
Cyclinac	Yes	Yes	1 millisecond

(*) With movable absorbers

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

A proton cyclinac: IDRA
Institute for Diagnostic and RAdiotherapy

IDRA, the first cyclinac, was proposed in 1993



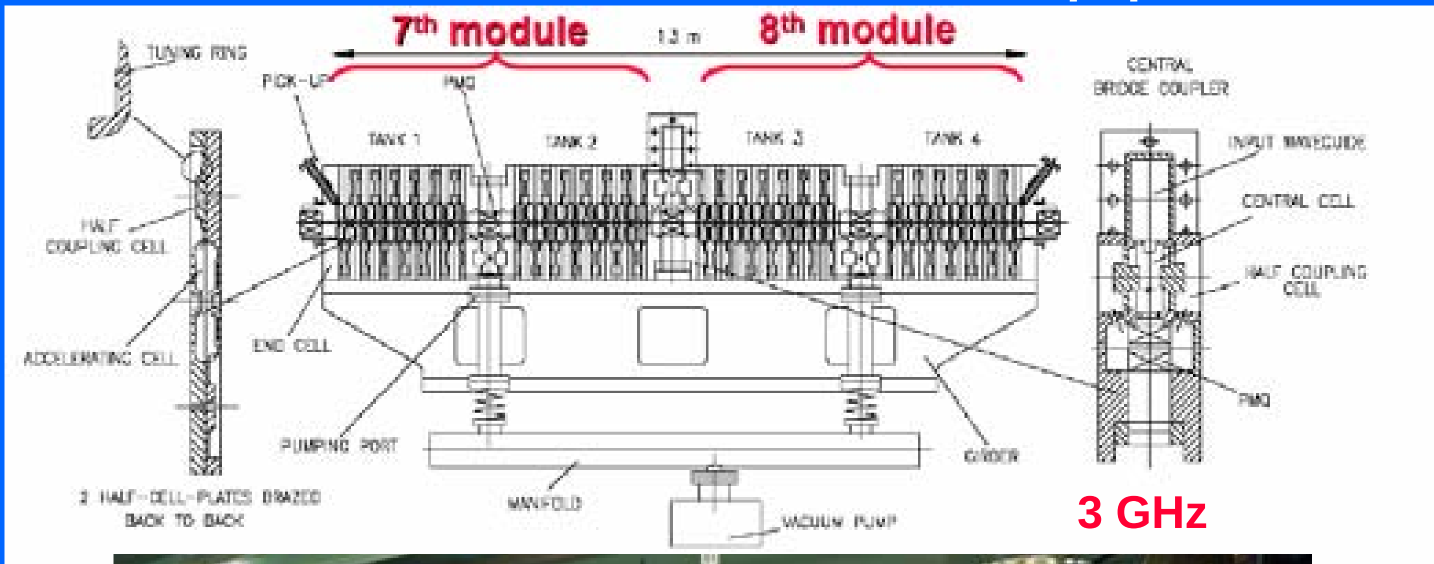
IDRA design: Riccardo Zennaro
with “LINAC” by Ken Crandall

Prototype of 2 'modules' of the CCL LIBO= LInac BOsoster (now in Microcosm-CERN)

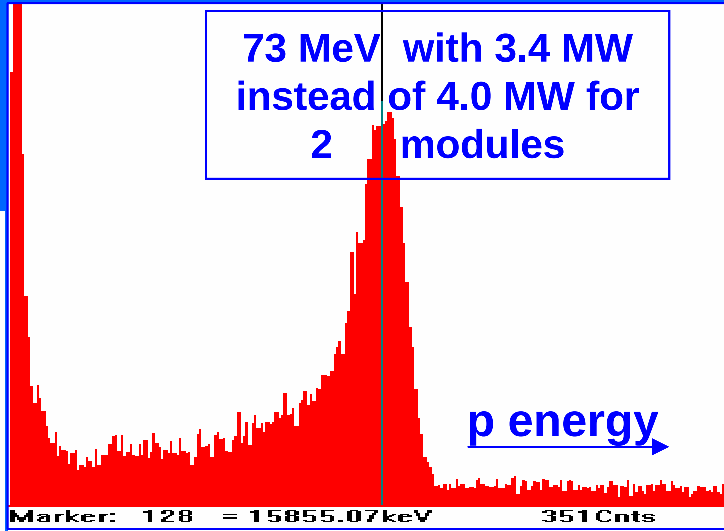
Collaboration INFN-CERN-TERA 1999-2002

Project leader: Mario Weiss

Module tested at LNS, Catania - NIM paper



3 GHz



Project value: 16 MV/m;

measured 27 MV/m with 12 MW

LIBO in LIL

NIM-A 2004

Available online at www.sciencedirect.com

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Nuclear Instruments and Methods in Physics Research A 521 (2004) 512–529

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH

Section A

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LIBO—a linac-booster for protontherapy: construction and tests of a prototype

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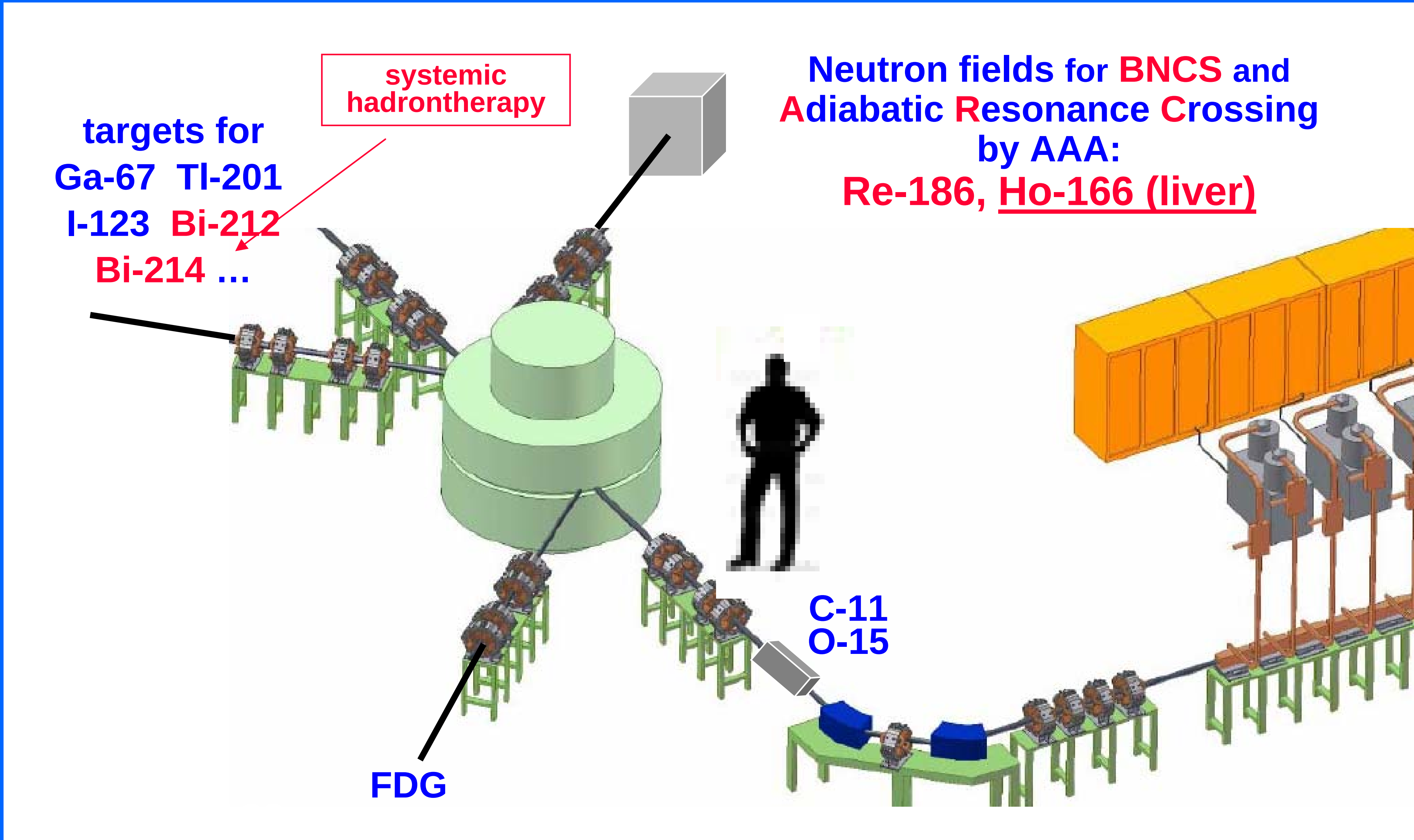
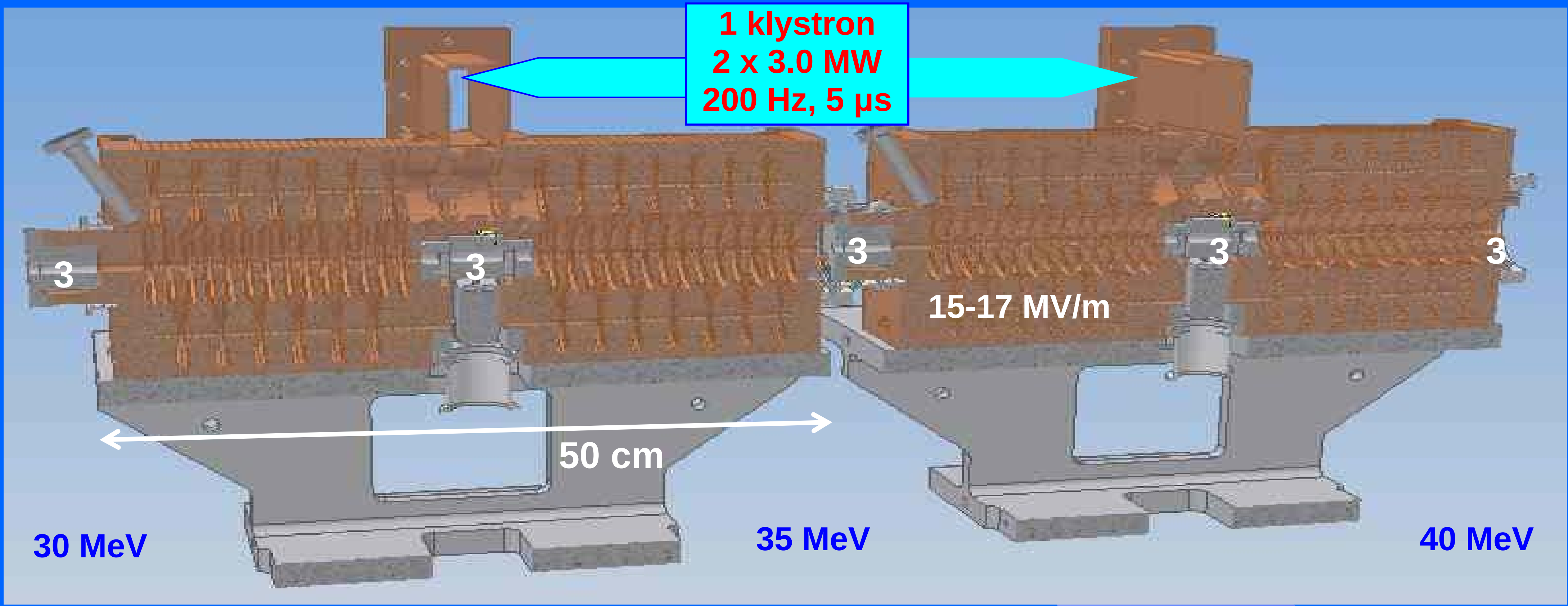
The cyclotron has 4 high-current beam lines (30 MeV, ≤ 1000 μA) to produce radioisotopes for diagnostics and endoradiotherapy

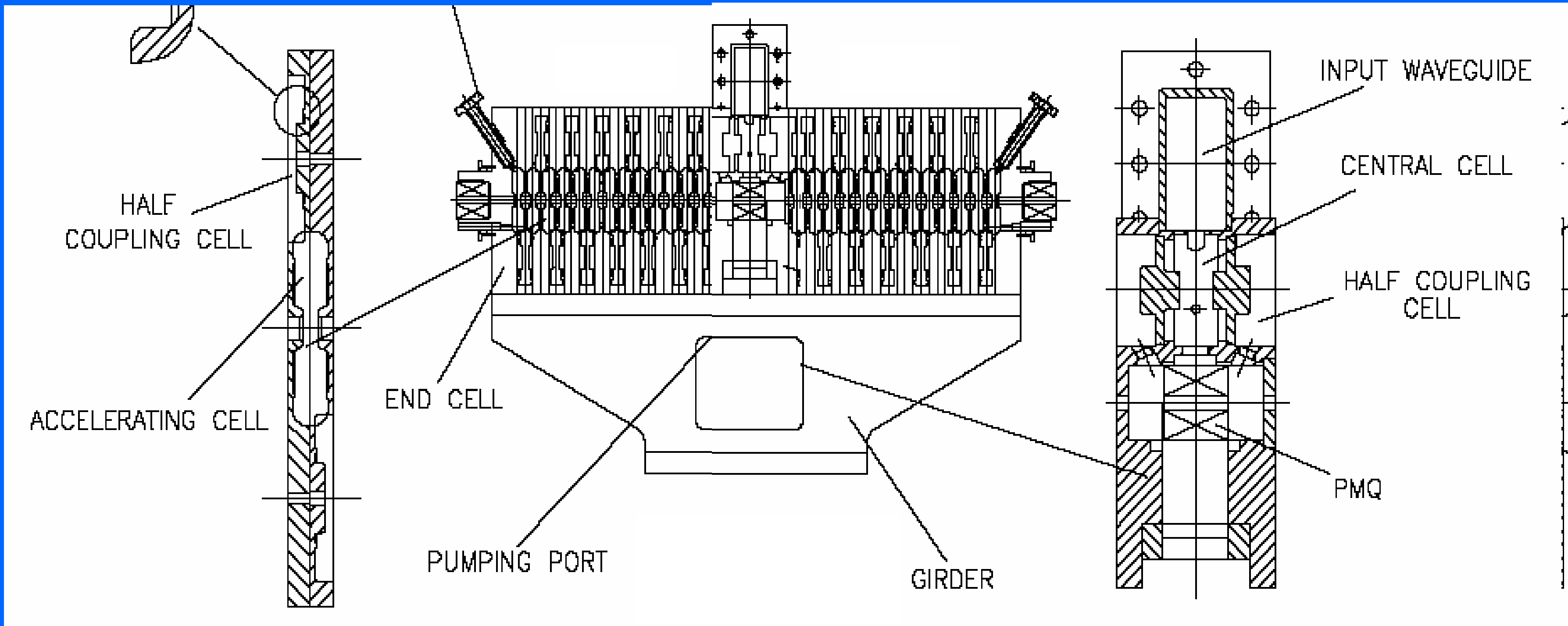


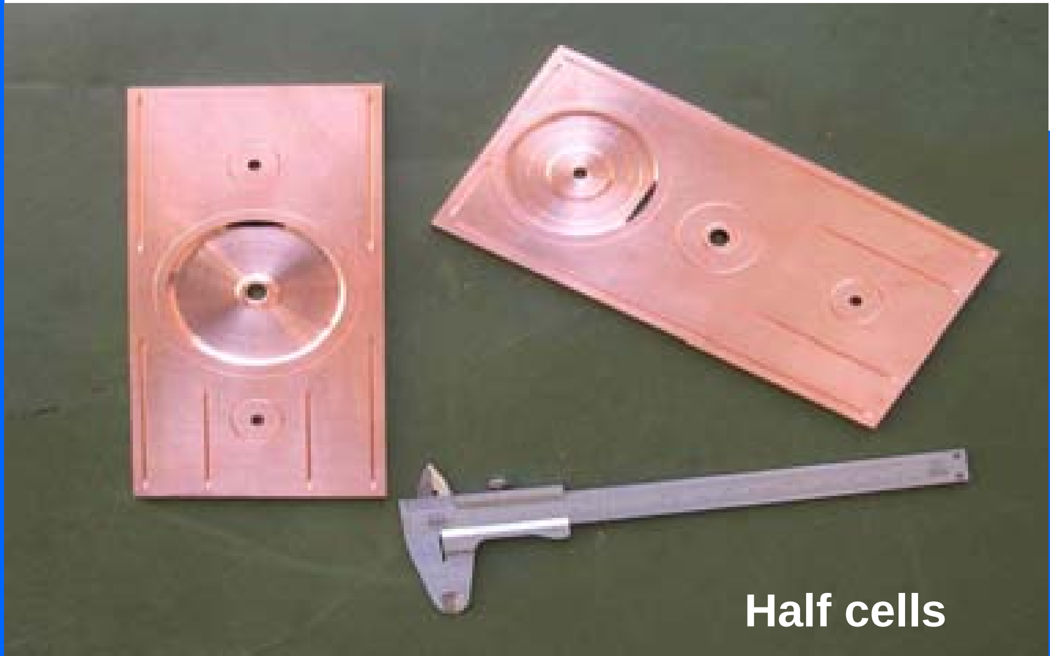
The first two modules of the linac of IDRA



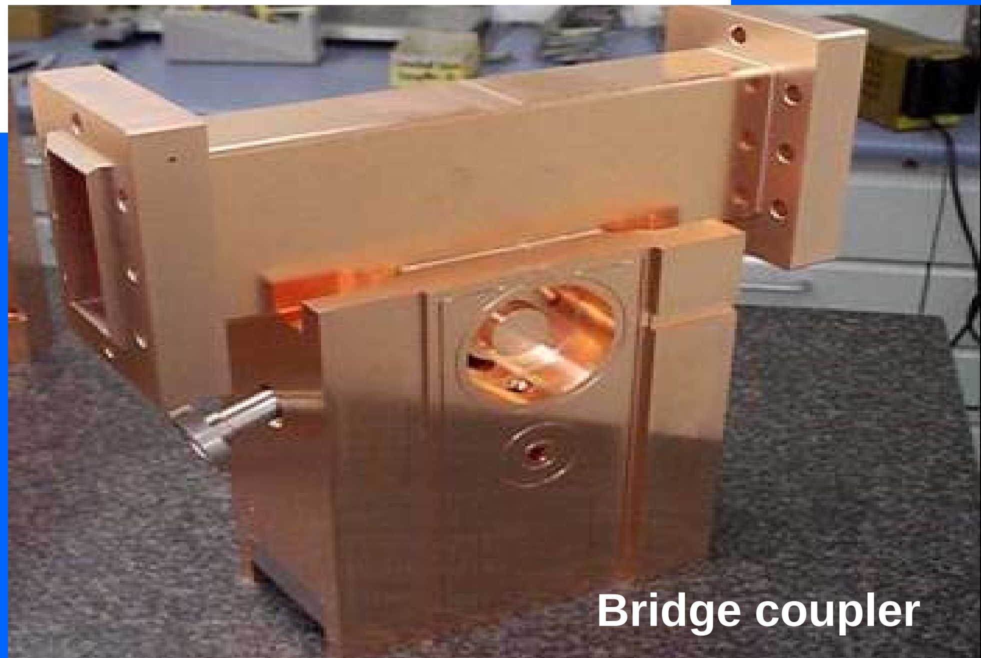
3 = locations of the permanent quadrupoles

Construction details of the first module built by industry



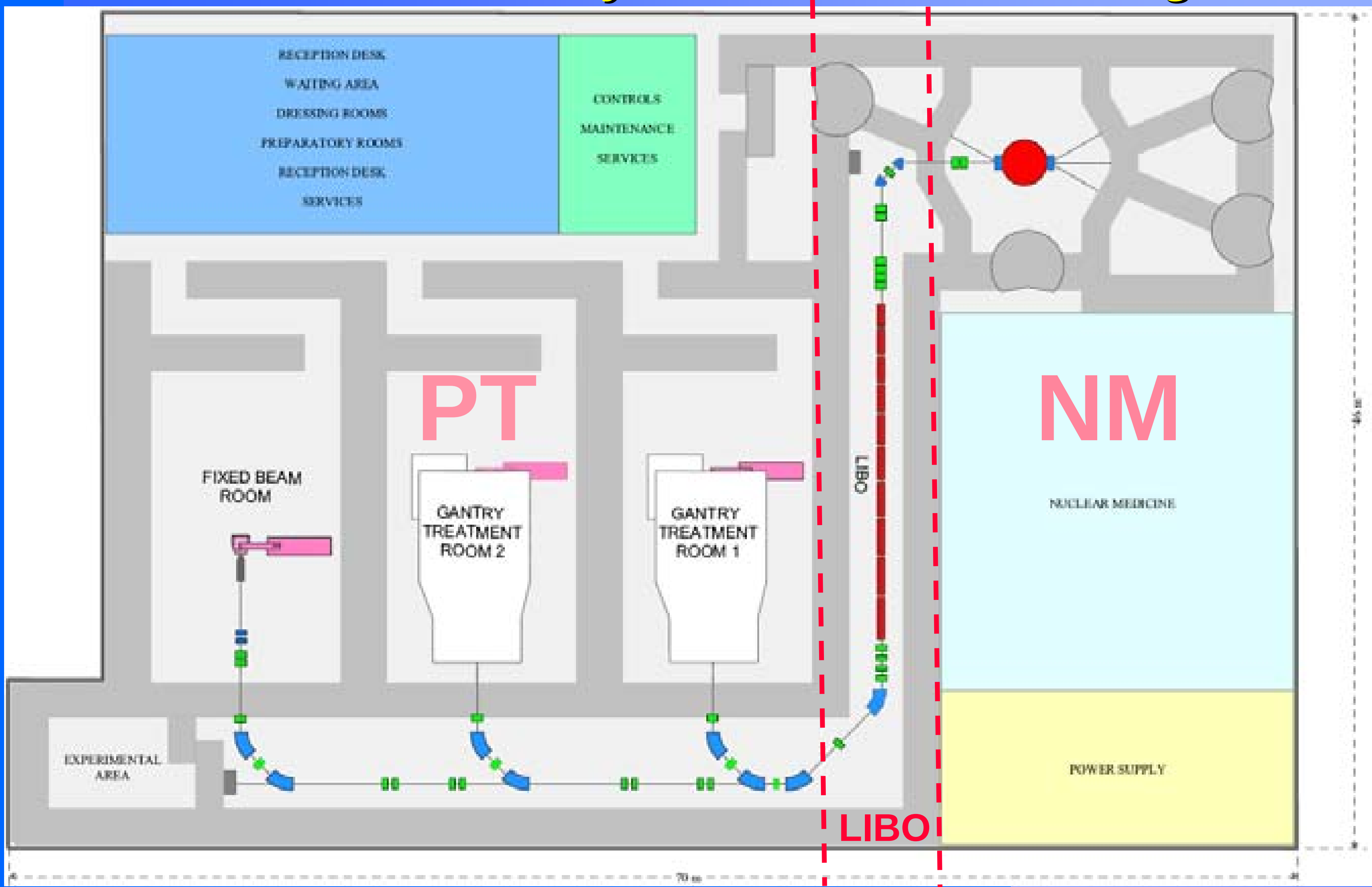


Half cells



Bridge coupler

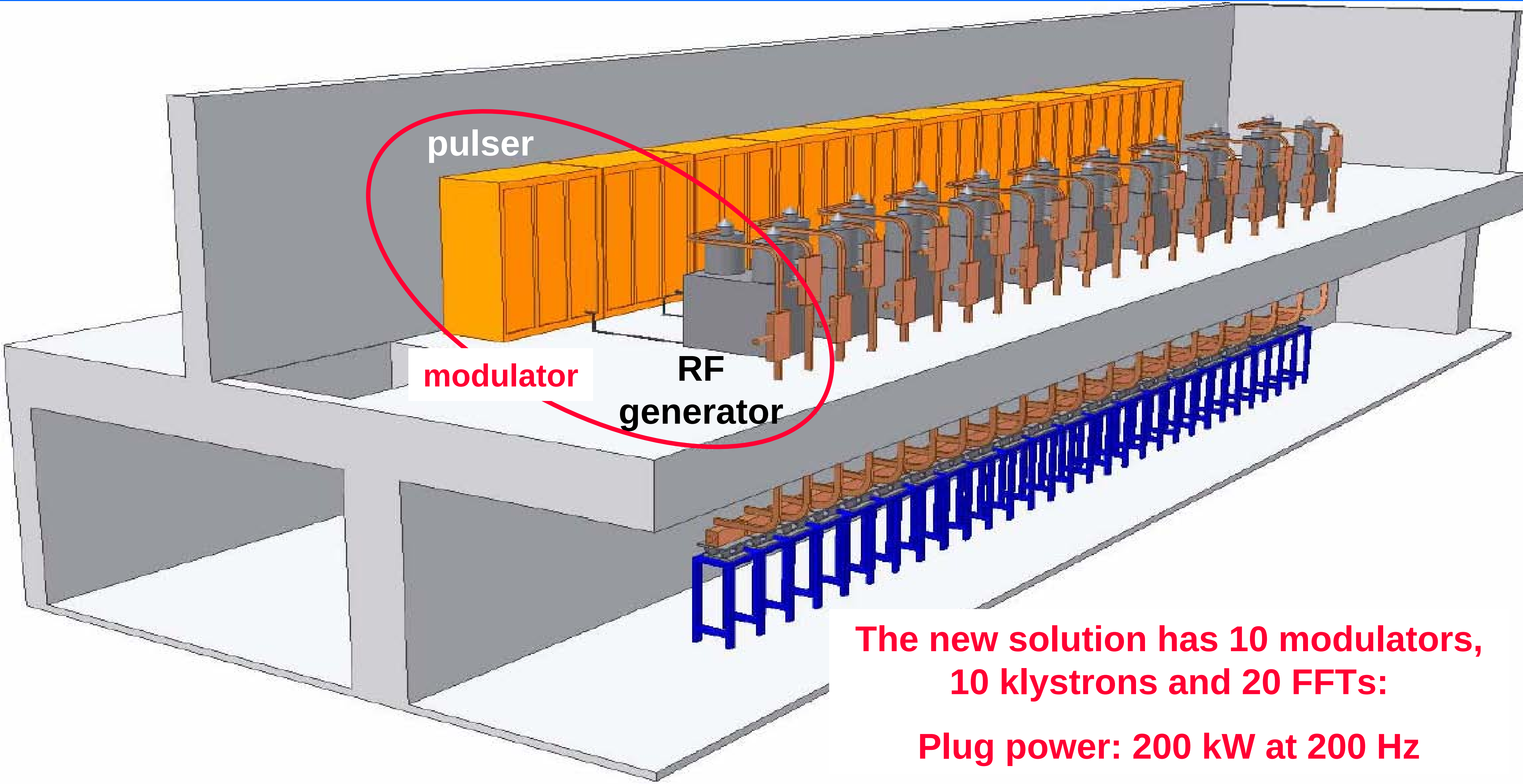
Layout of the IDRA underground floor



1[st] floor: receptions, klystron gallery , NM and PT areas

2[nd] floor: laboratories, offices and common spaces

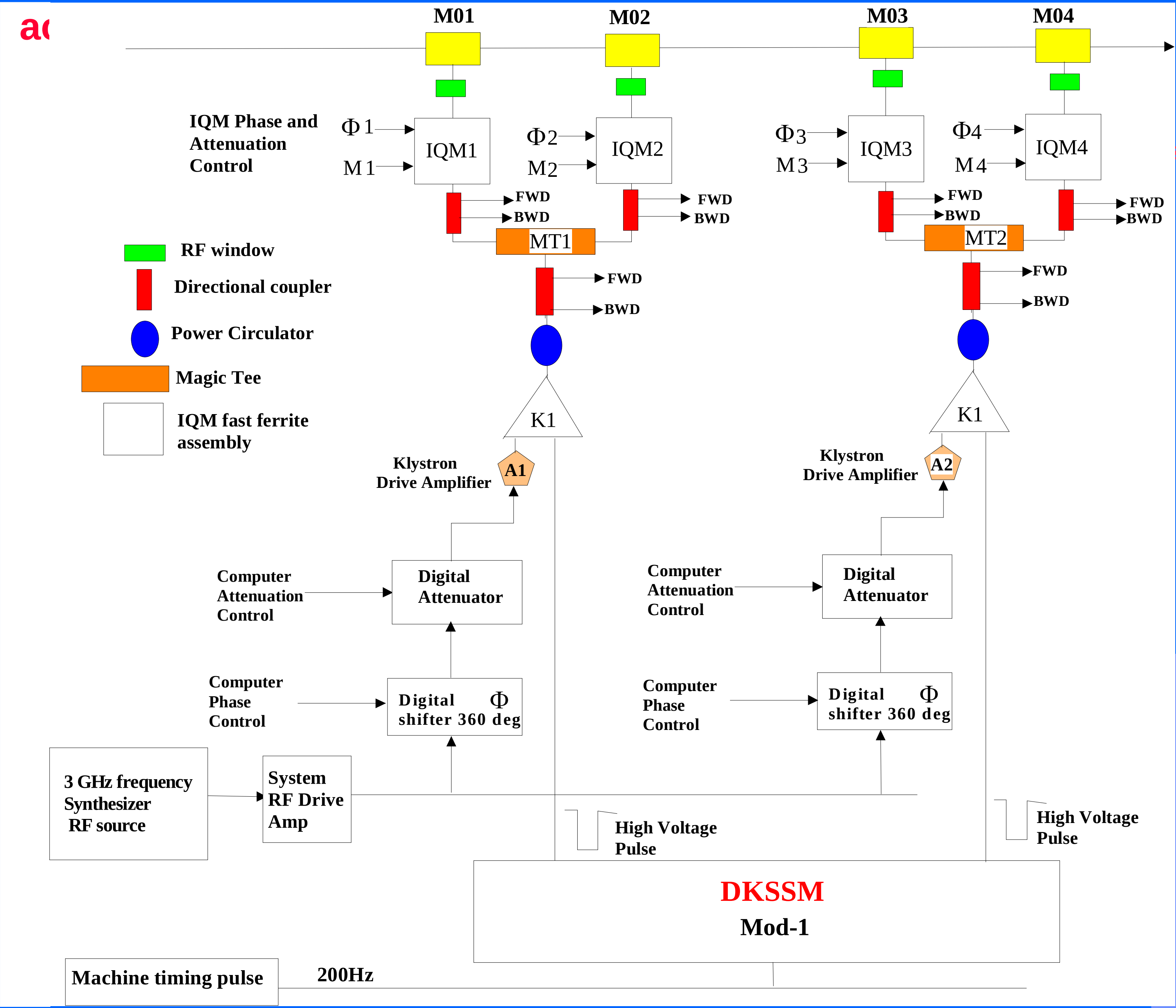
RF power distribution system with 20 klystrons



The new solution has 10 modulators, 10 klystrons and 20 FFTs:

Plug power: 200 kW at 200 Hz

10 pulsers, 10 klystrons and 20 FFTs (Peter Pearce)

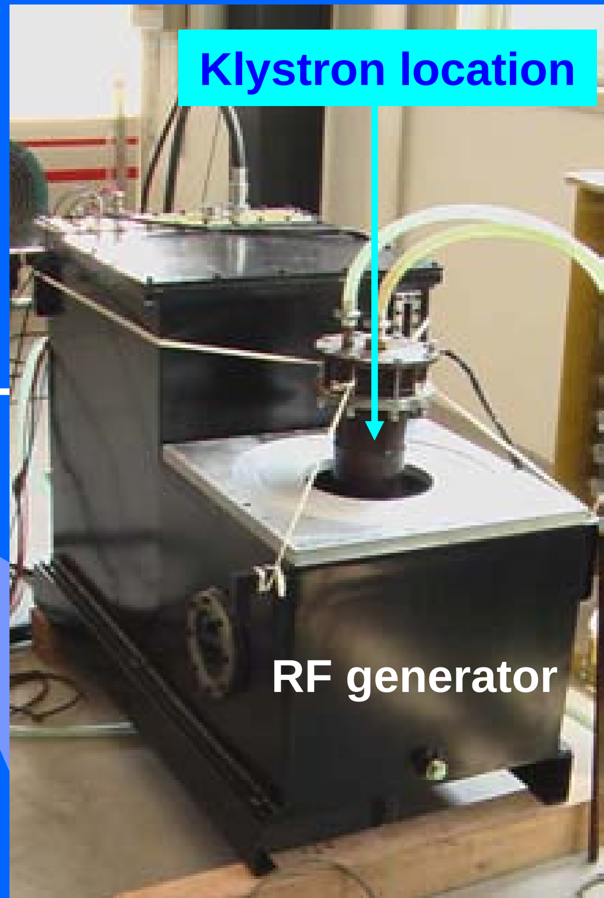


NOVEL

IQMs = FAST FERRITE TRANSFORMERS

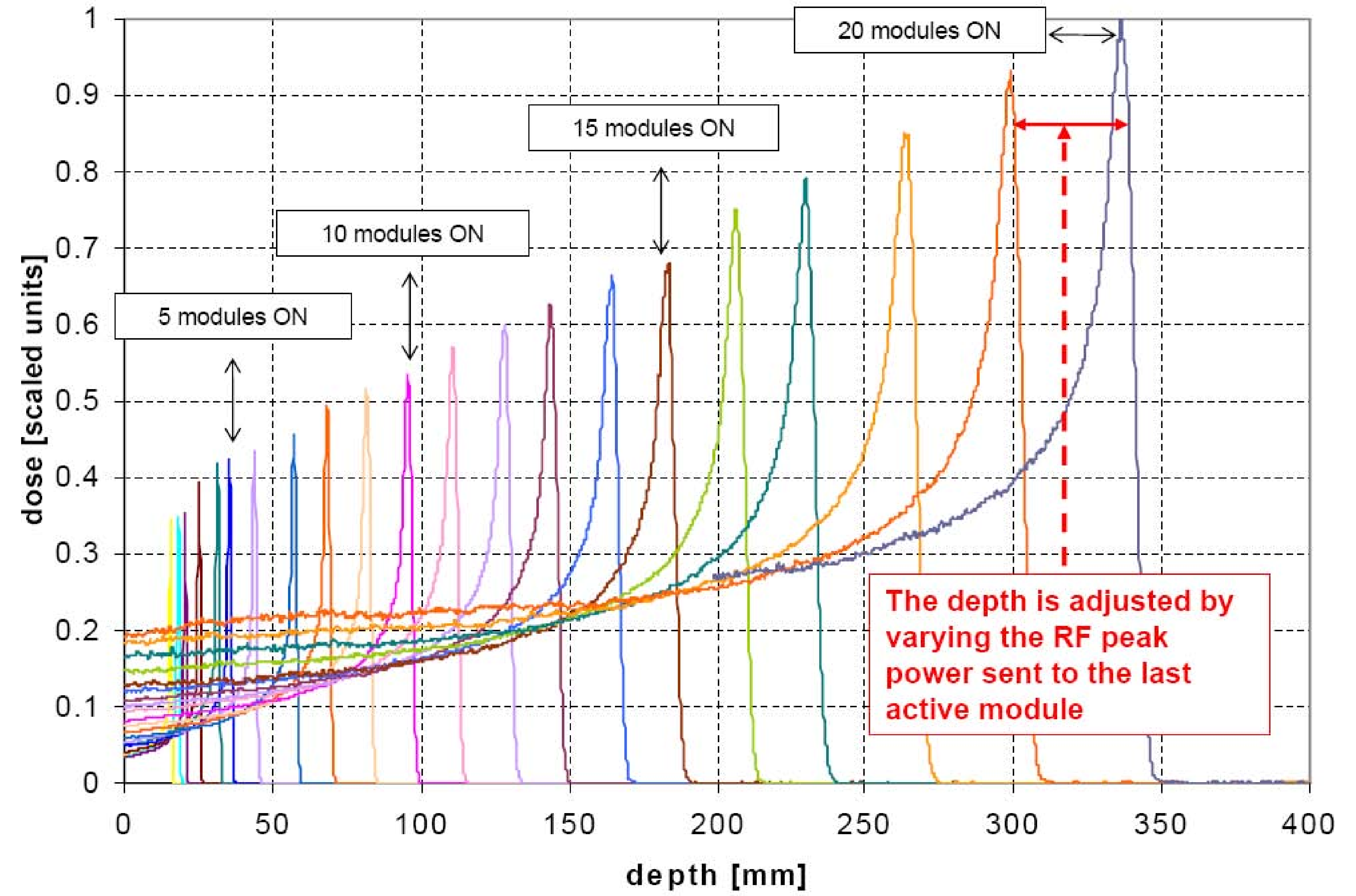
vary the power of individual modules

Cowan - China: modulator built for Physics Department Milano Bicocca

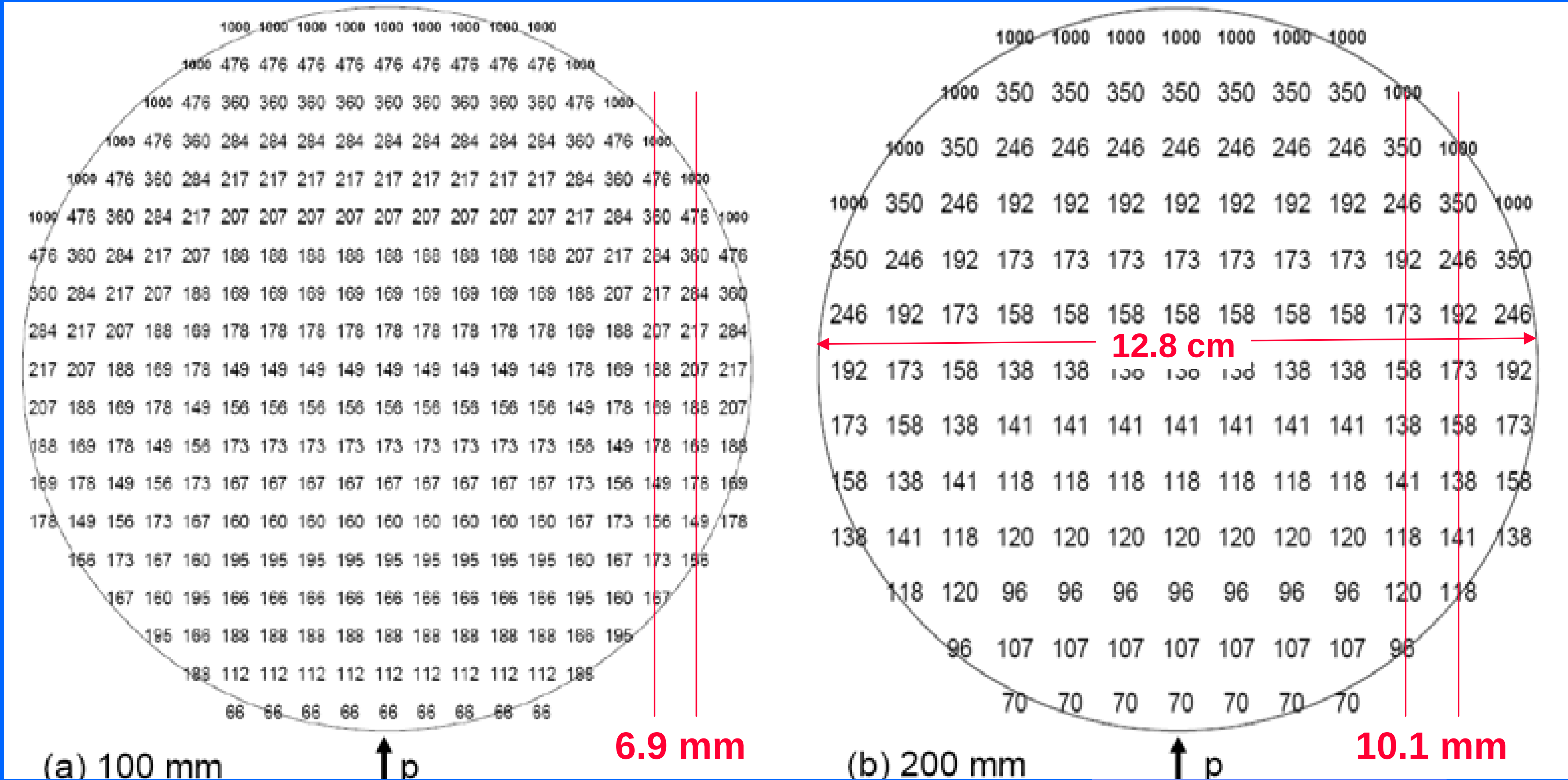


The first modulator is in-house

Bragg curves obtained by 'switching off' accelerating modules

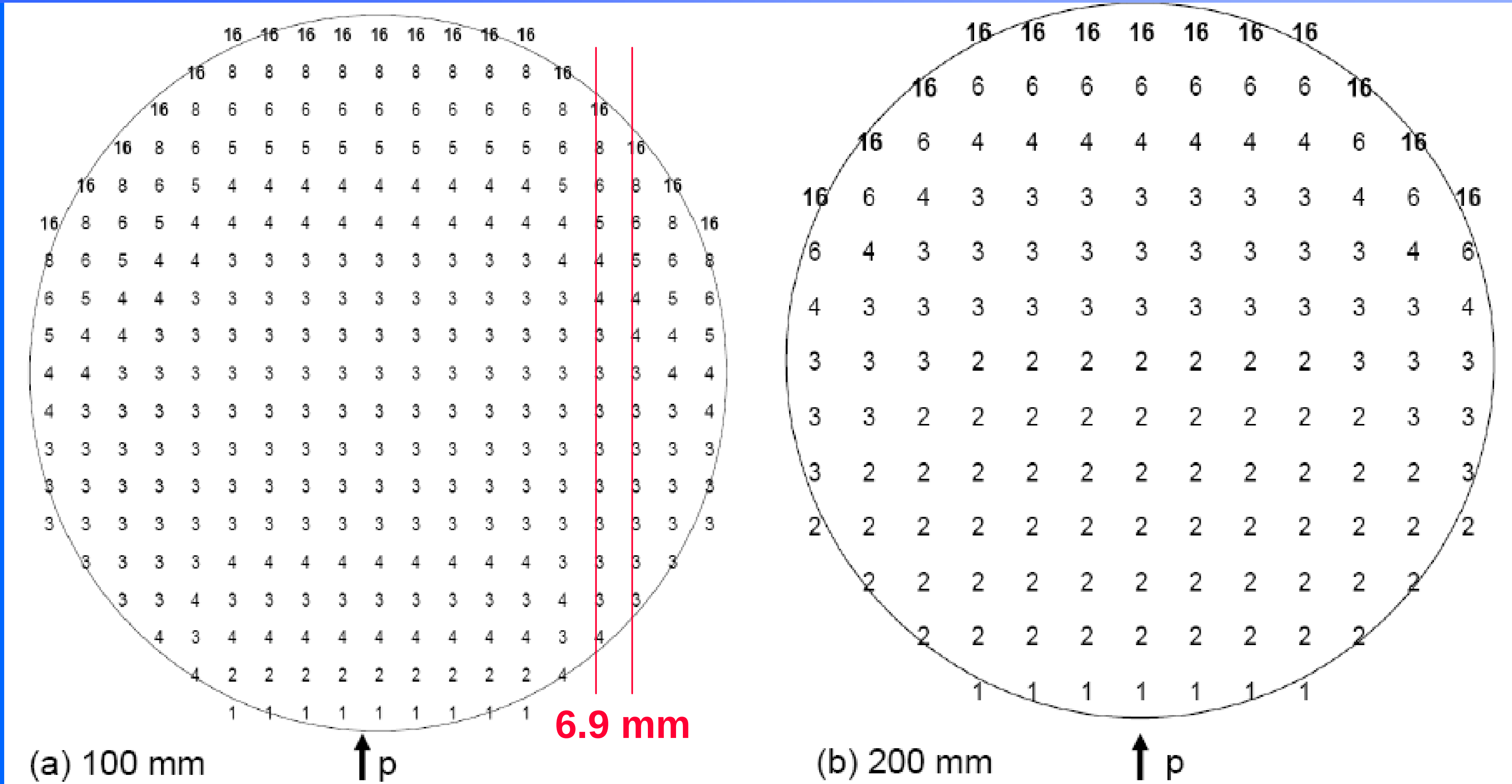


Protons at 200 Hz for 1 liter sphere at 10 and 20 cm: distance/FWHM = 0.75



Giulio Magrin and Marco Dominietto

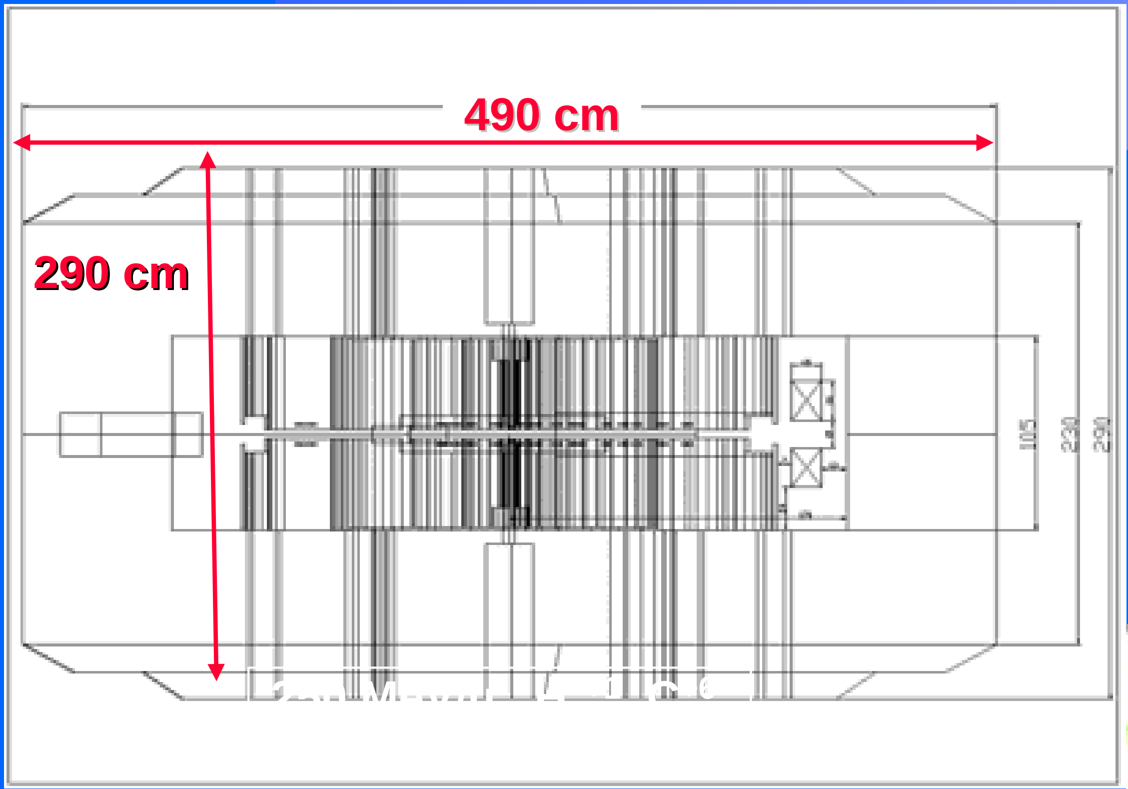
At least 16 paintings for 4 Gy l^{-1} min^{-1}: a missing spot ≤2.5%



on 19^3 = 19772 deliveries	on 13^3 = 6544 deliveries
99 (trans)+ 15 (long) = 114 s	33 (trans)+ 9 (long) = 42 s
Giulio Magrin and Marco Dominietto	[but on 19^3 107 s]

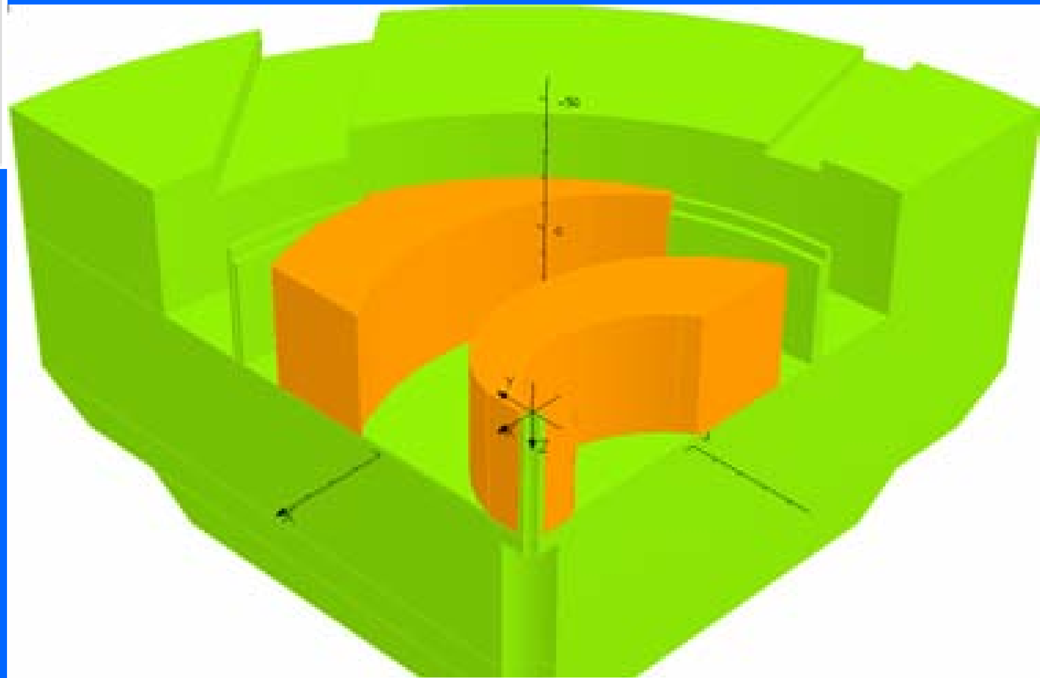
A carbon ion cyclinac: CABOTO
CArbon BOoster for Therapy in Oncology

The new IBA/LNS SC cyclotron



A side view of the cyclotron

300 MeV/u H_2^{+1}, C^{+6}



spiraled sectors highlighted in the model

The last LNS paper

Available online at www.sciencedirect.com

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Nuclear Instruments and Methods in Physics Research A 562 (2006) 1009–1012

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

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A novel superconducting cyclotron for therapy and radioisotope production

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Available online 6 March 2006

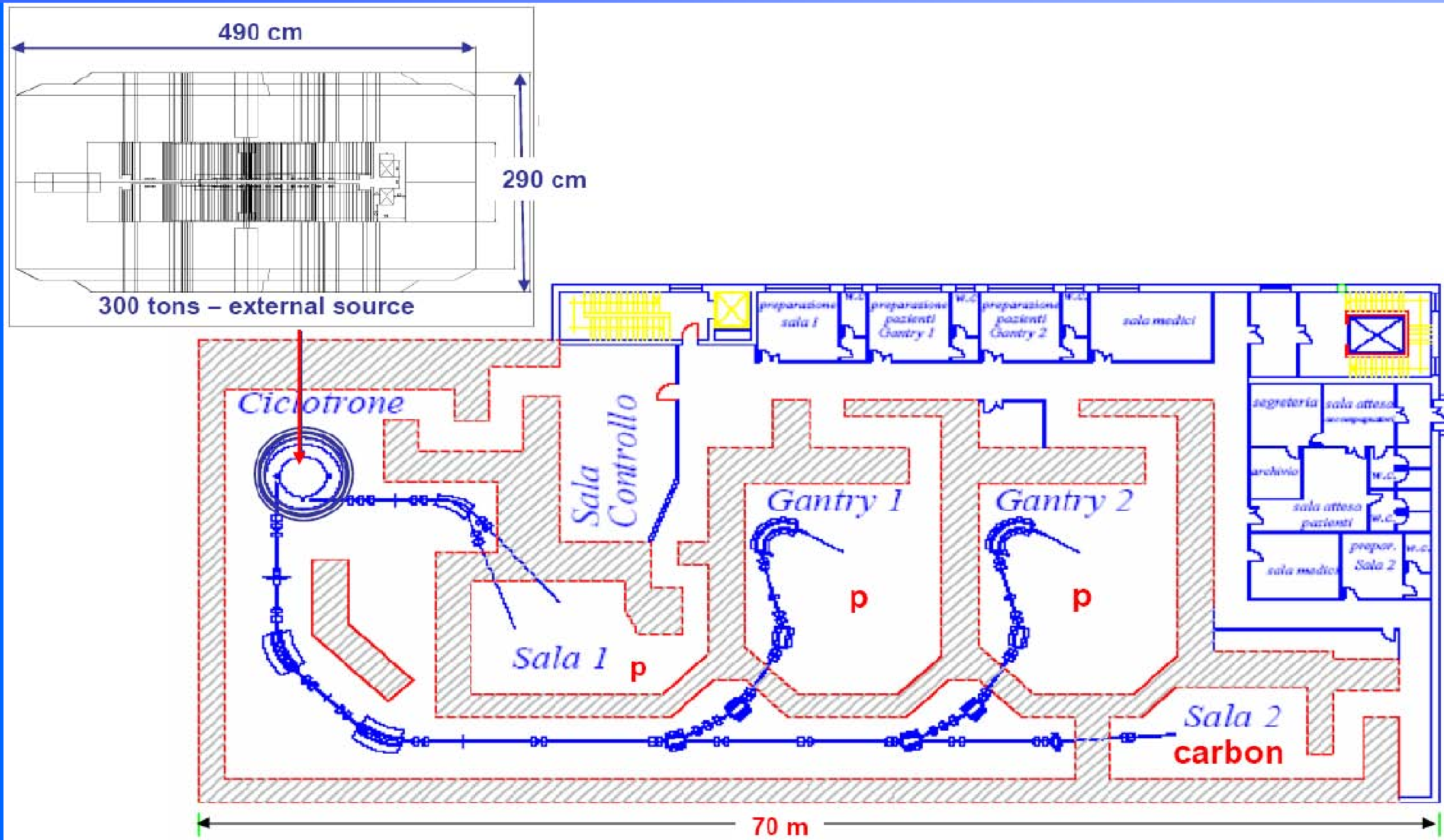
Abstract

The design of a four sector compact superconducting cyclotron, able to accelerate up to 250 A MeV light ions with charge/mass ratio 0.5, is in progress. Light ions like $^{12}C^{6+}$, $^{10}B^{5+}$, $^{6}Li^{3+}$ will be extracted by electrostatic deflectors while H_2^+ ions can be extracted also by stripping, therefore a beam power of 10 kW or more is available. This cyclotron can be used for radiotherapy with protons or carbon ions and also to drive a facility for production of unusual medical radioisotopes. The main parameters and some features of the machine are here presented.

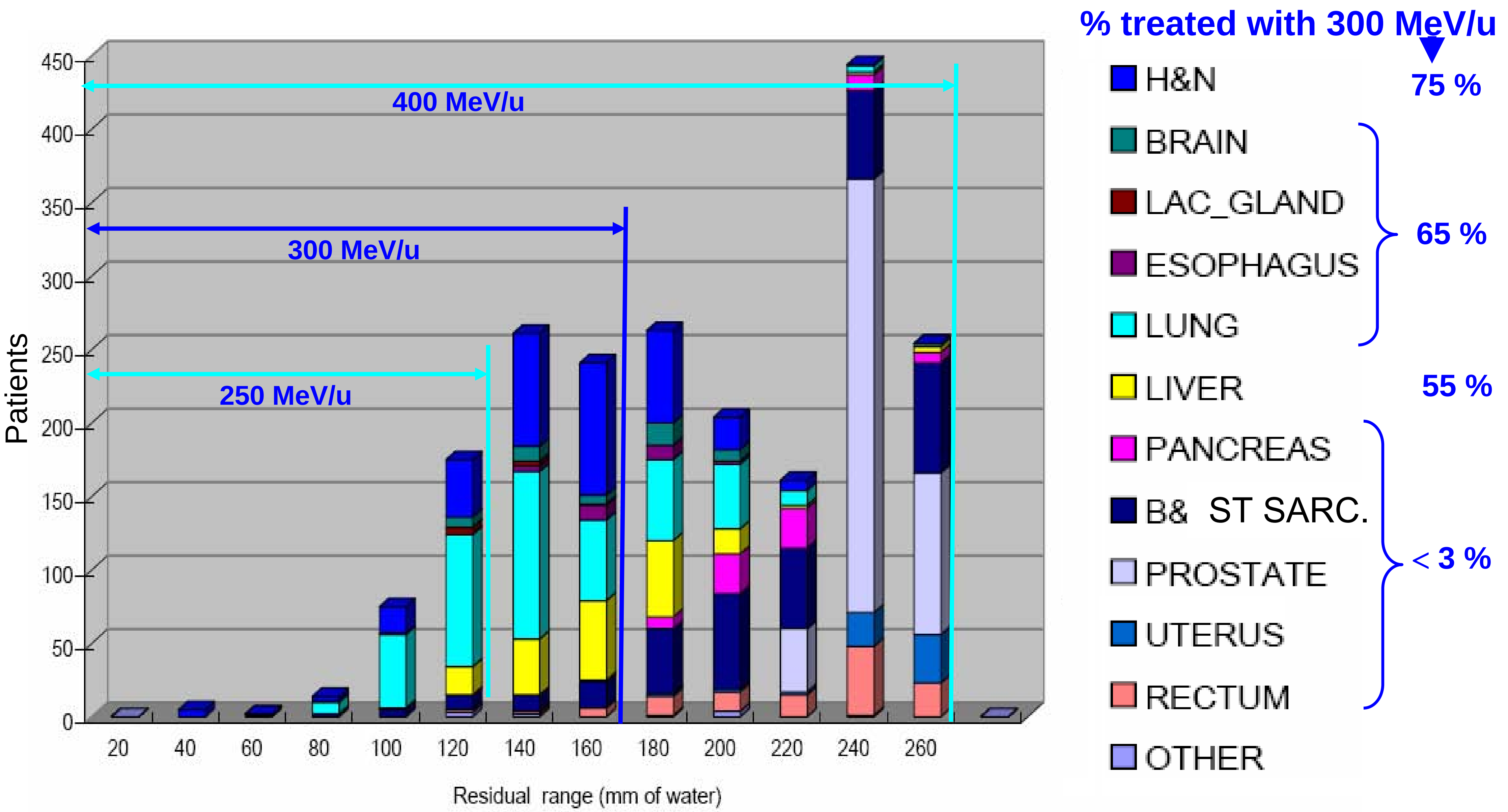
PACS: 29.20.Hm; 41.75.Ak

Keywords: Cyclotron; Carbon beam; Therapy; Radioisotope; Production

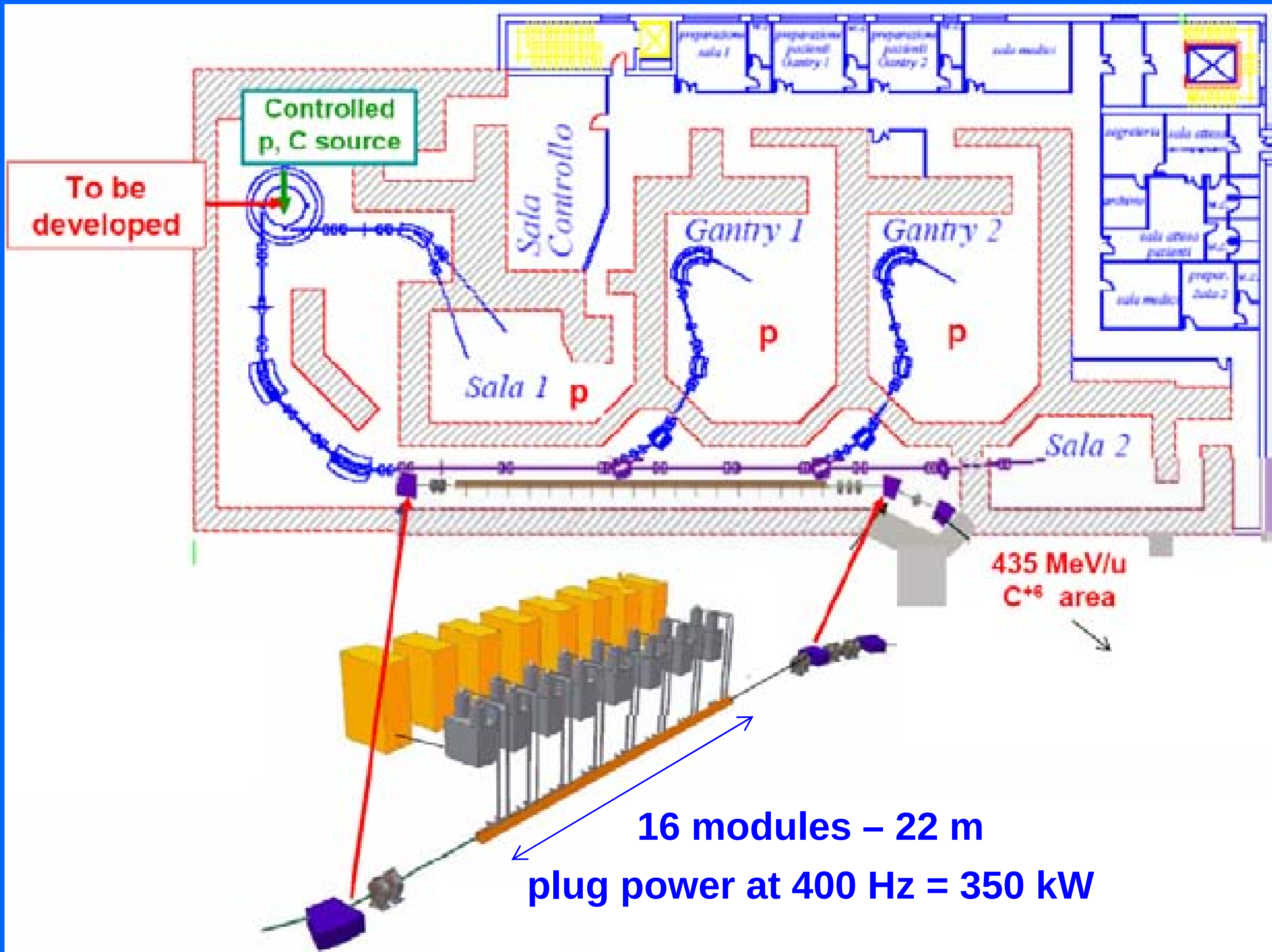
The 300 MeV/u LNS project for Cannizzaro Hospital (Catania)



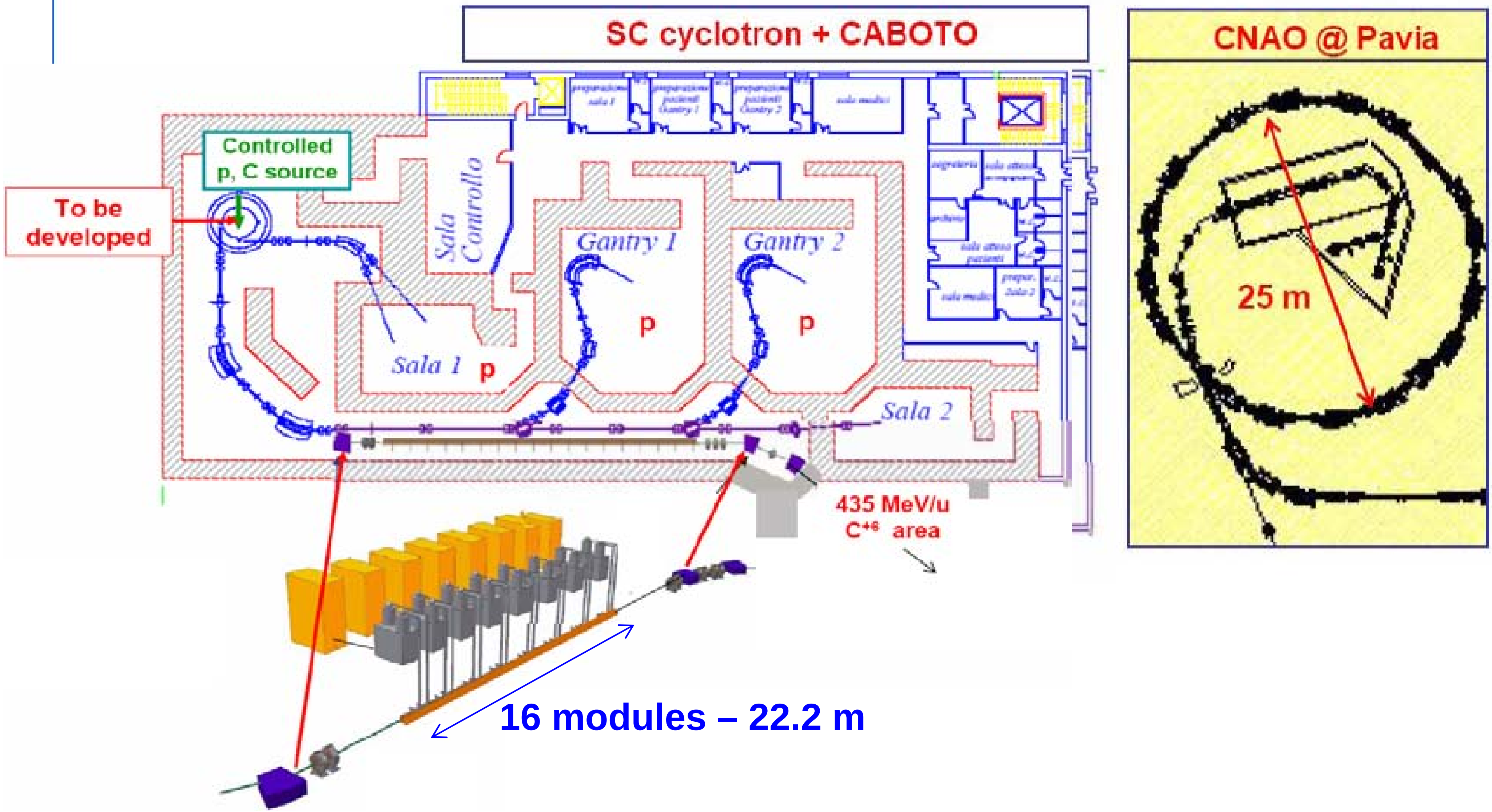
Maximum water-range used by HIMAC-NIRS on 2000 patients



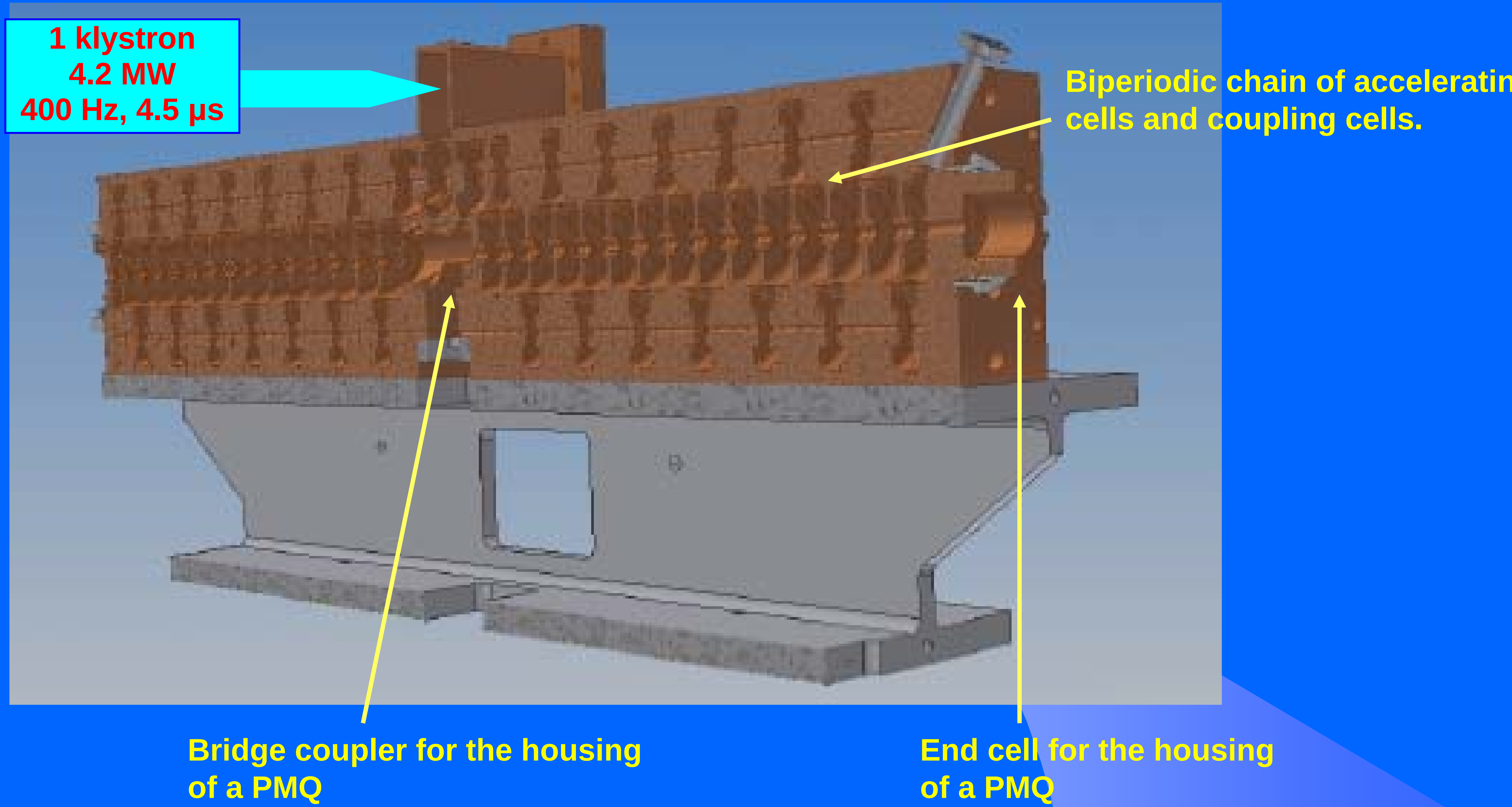
Upgrading of the SC cyclotron to 435 MeV/u with CABOTO



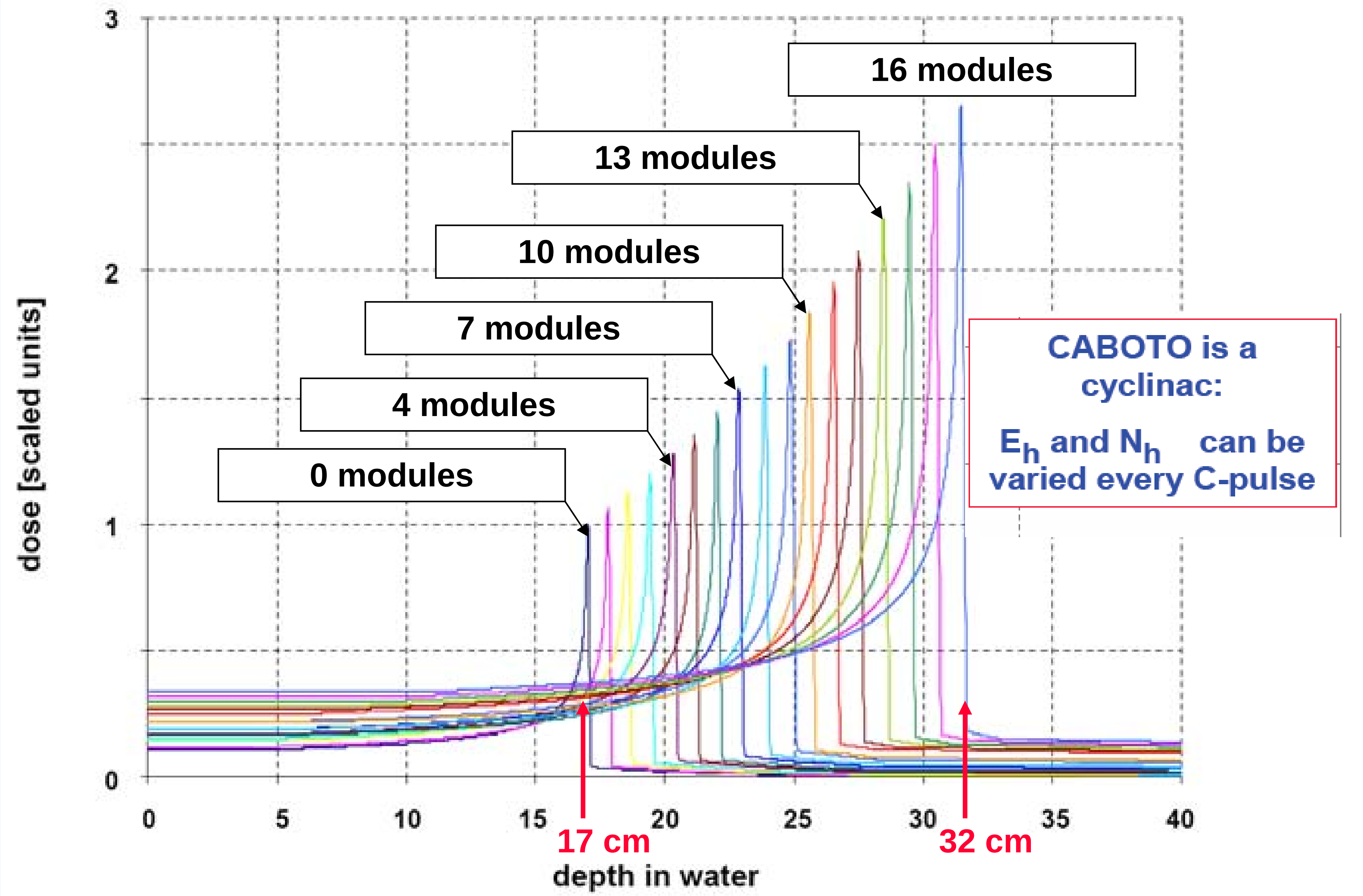
Comparison CABOTO-CNAO



The modules of CABOTO are longer than the ones of IDRA



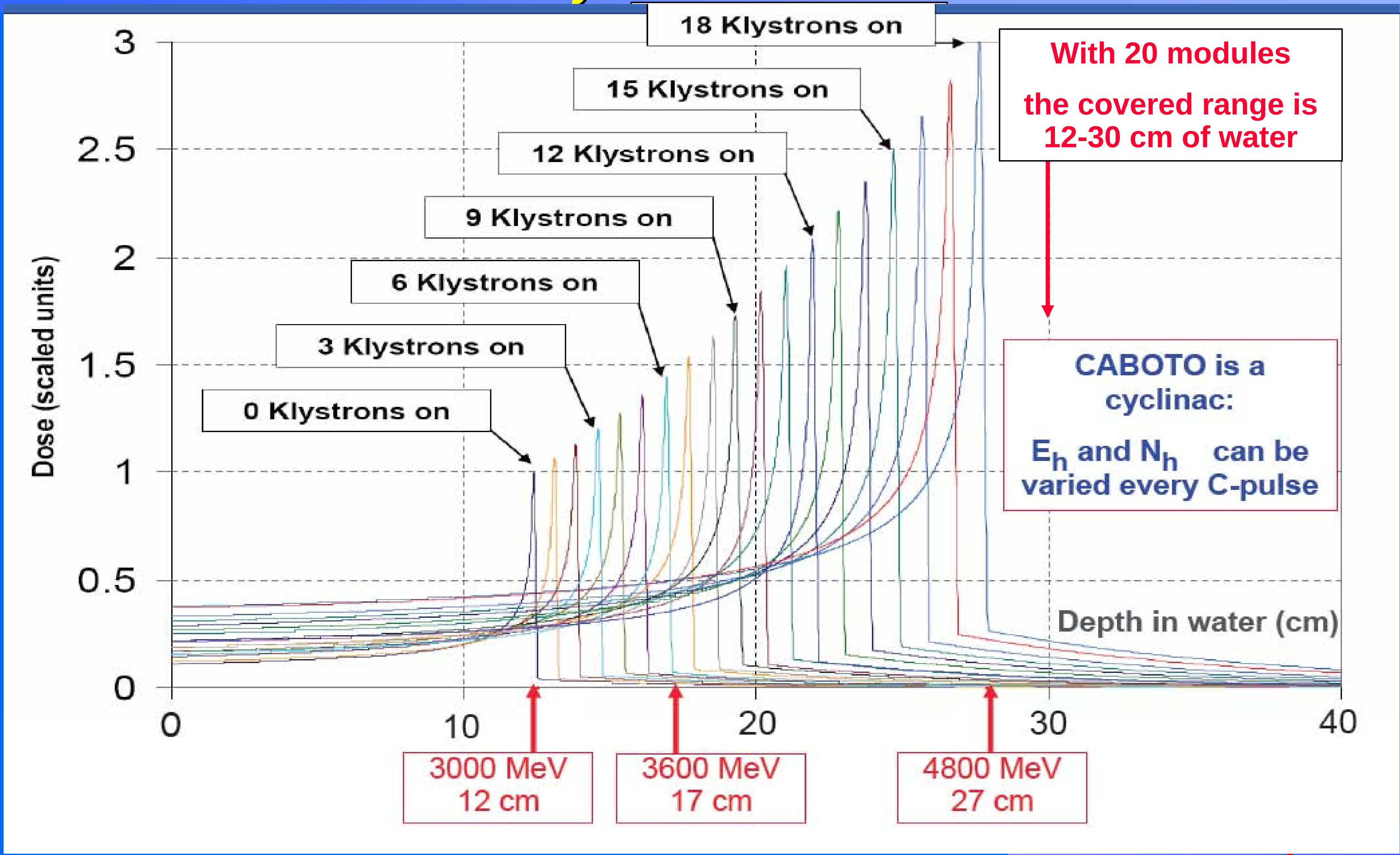
Ion Bragg curves by adjusting the klystrons: 300-435 MeV/u



CABOTO is a cyclinac:

E_h and N_h can be varied every C-pulse

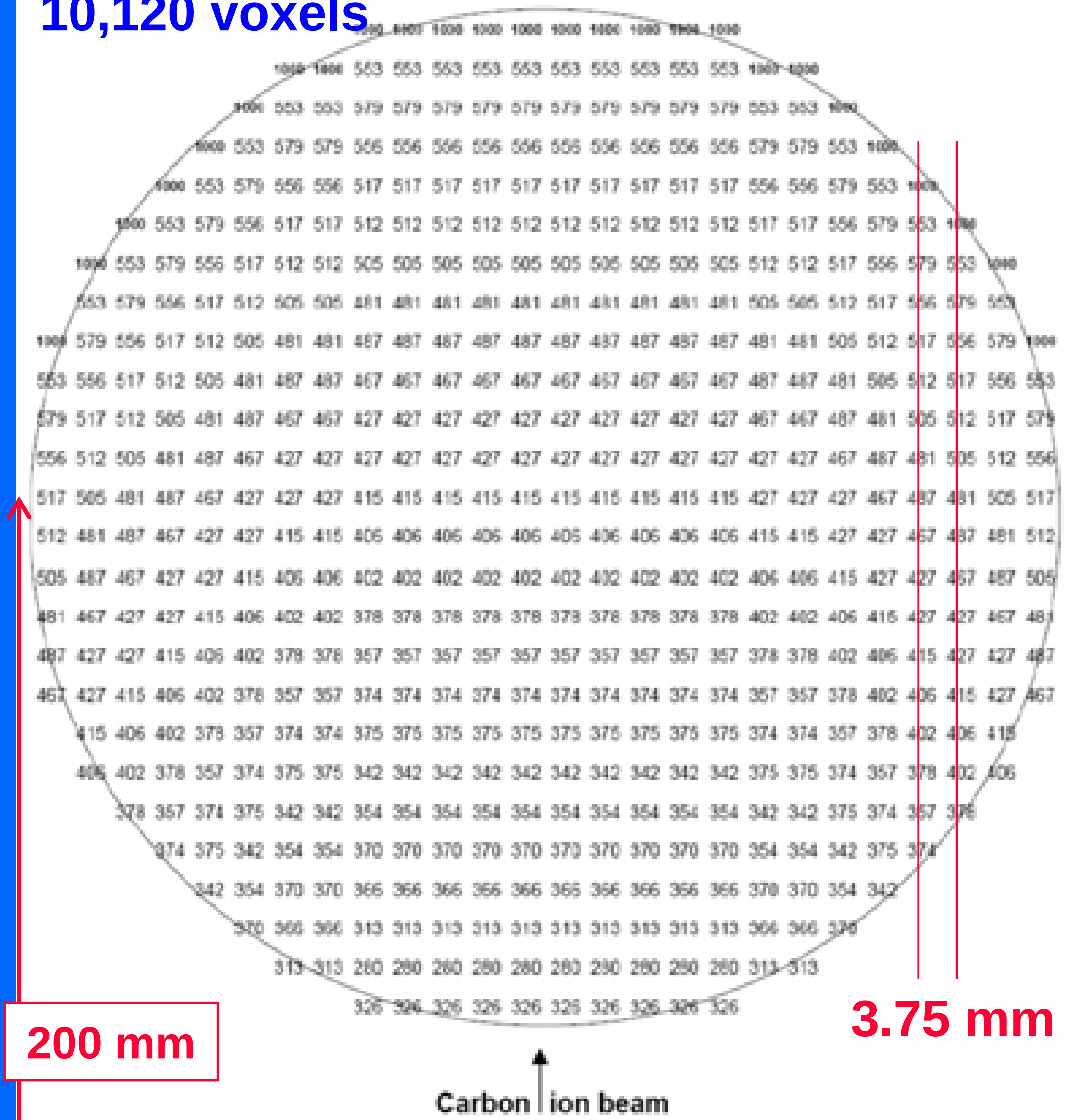
A better solution with SC cyclotron of 250 MeV/u and 20 modules

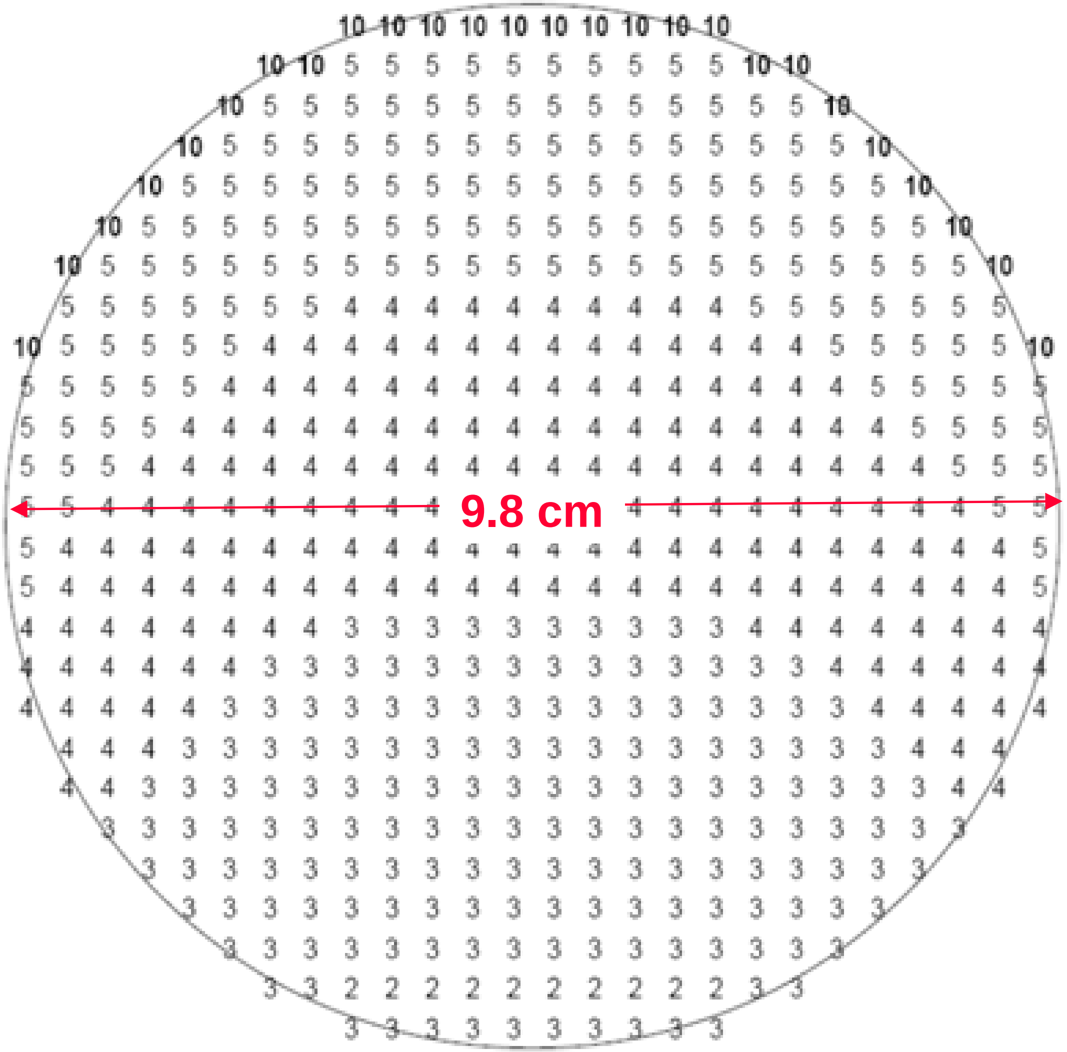


Giulio Magrin and Marco Dominietto

Carbon ions at 400 Hz with 10 paintings
FWHM = 5 mm, distance/FWHM = 0.75

10,120 voxels





42,868 visits and 163 energy steps to have at least 10 paintings

4 GyE to 0.5 liter in (107 + 16) = 123 s, i.e. 4 Gye l^{-1} min^{-1}

THE END