ORIGINI E SVILUPPI DELL'ADROTERAPIA (*) IN ITALIA

Ugo Amaldi

(*) Termine collettivo che copre tutte le terapie basate su particelle fatte di quark:

neutroni veloci, BNCT, pioni, protoni, ioni leggeri (C), alfa per alfa-immunotherapy, antiprotoni, …

G. Tosi:

1964 in "Energia Nucleare" , CISE

"Gli acceleratori di particelle in radioterapia“

betatrons for electrons and synchrotrons for protons.

E. Fiorini:

1974 in “Giornale di Fis. San. e Prot. delle Radiazioni”

“Nuovi mezzi strumentali per le applicazioni mediche delle particelle ad altissima energia”

Nuovi mezzi strumentali per le applicazioni mediche delle particelle ad altissima energia

E. Fiorini

Istituto di Fisica dell'Università degli Studi di Milano
Istituto Nazionale di Fisica Nucleare Sezione di Milano

Estratto da

GIORNALE DI FISICA SANITARIA E PROTEZIONE CONTRO LE RADIAZIONI

Vol. 18 - N. 4 - Pag. 151-173 (Ottobre-Dicembre 1974)

My view of the Italian developments

Discussions in the years 1988-1990 between G. Tosi and U.A. while meeting at Via Celoria when giving the courses to the students of

Scuola di Specializzazione in Fisica Sanitaria e Ospedaliera

TERA 91/ 1 GEN 1
25 Maggio 1991

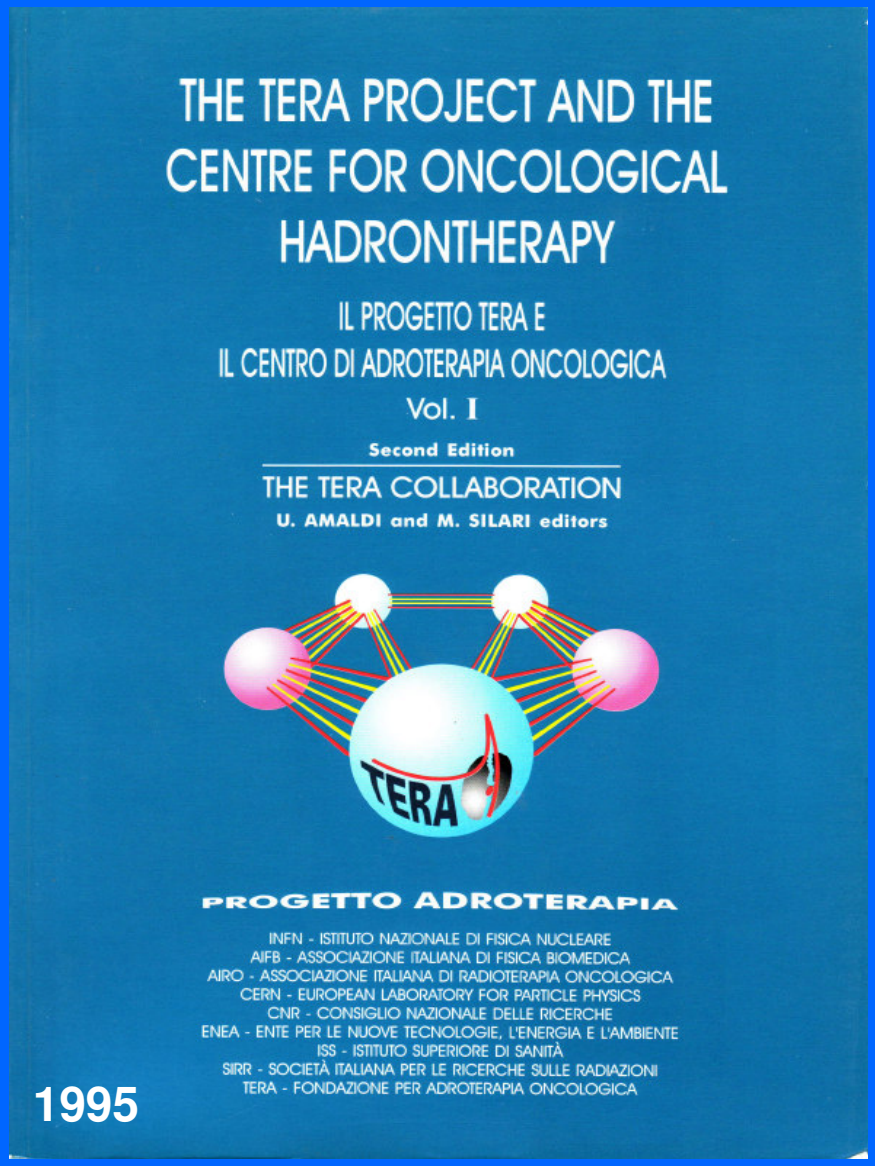
Per un Centro di
Teleterapia con Adroni

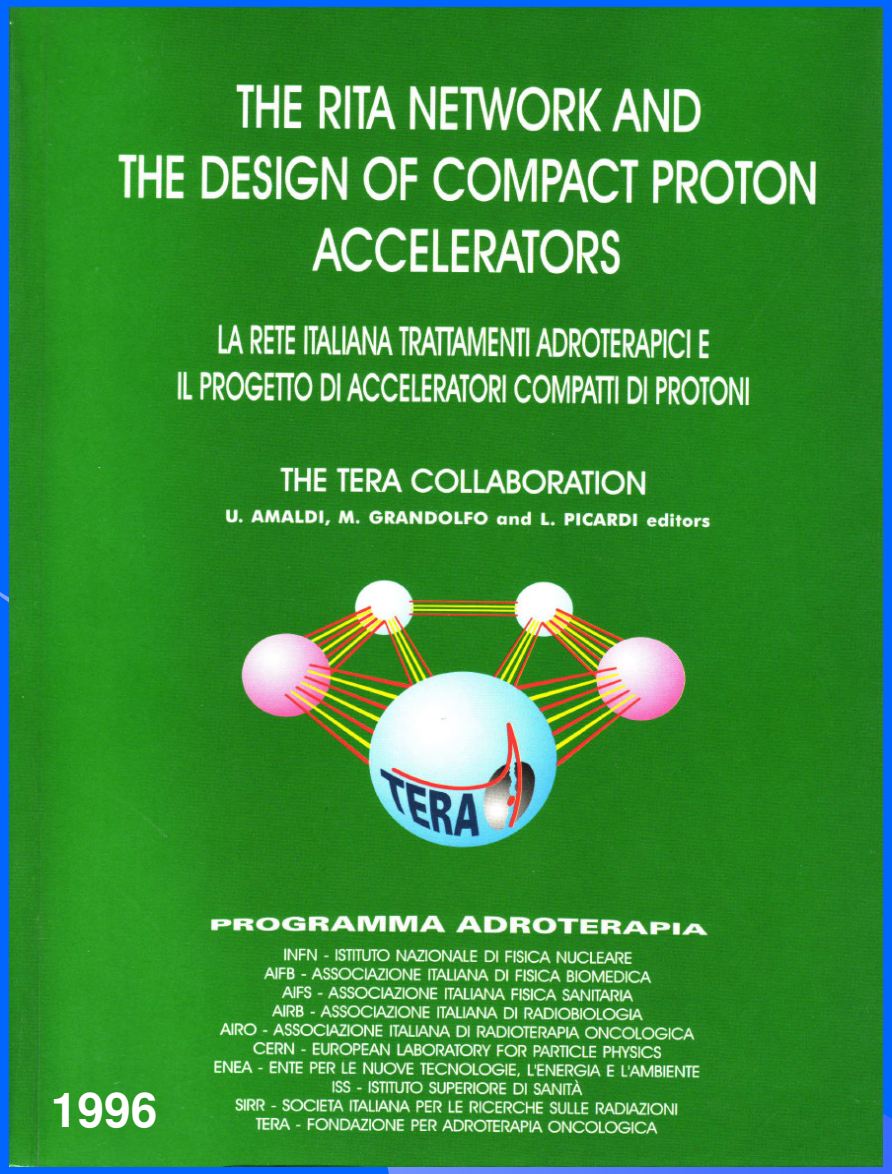
Ugo AMALDI [1] Giampiero TOSI [2]

1 CERN, 1211 Ginevra 23, Svitzerland
2 Università di Milano - Servizio di Fisica Sanitaria - Ospedale Niguarda Ca Granda - Pza Ospedale Maggiore, 3 - 20162 Milano - Italy

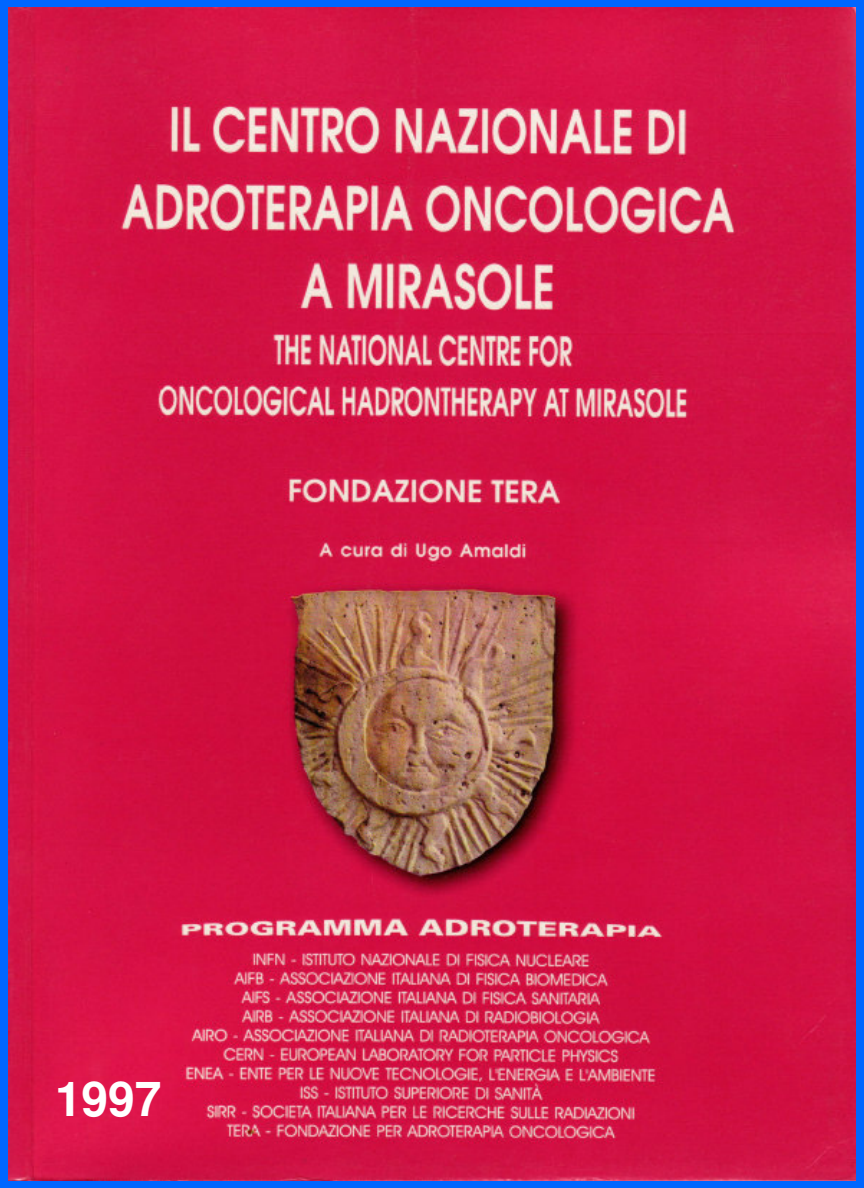
September 1991	**INFN finances ATER at INFN-Milano to design the ion accelerator**
October 1992	**Creation of TERA foundation (U.A., E. Borgonovi, G. Tosi, G. Vanolo)**
1992- 2000	**INFN finances extensions of ATER up to 12 groups in 12 Sections**

The "Blu Book" and the "Green Book"





The "Red Book" and the "White Book"

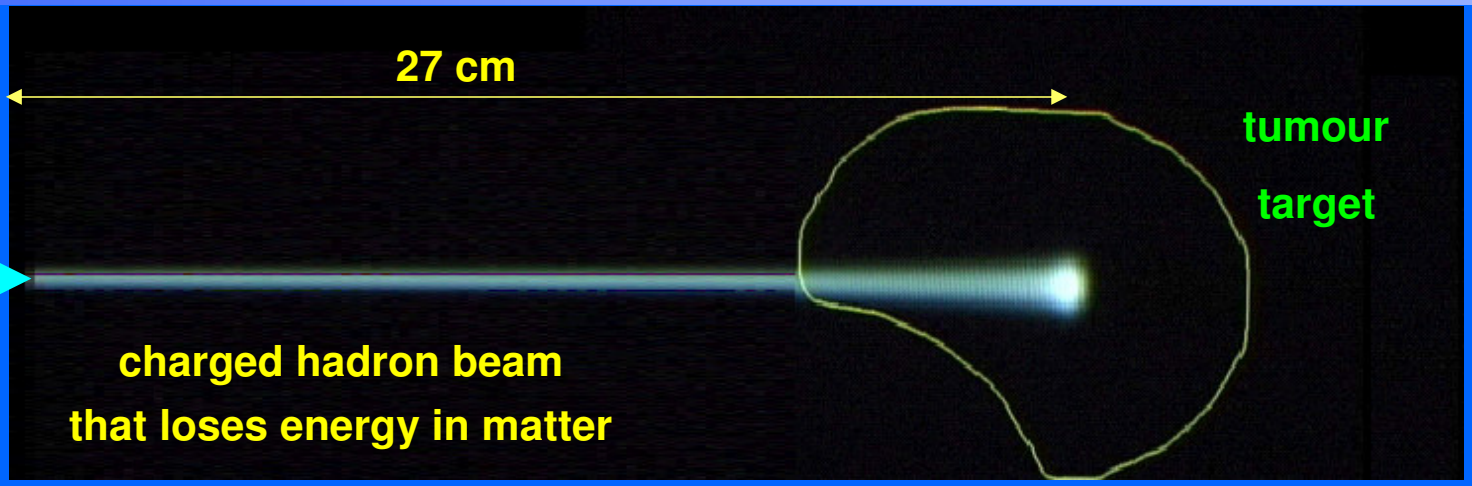


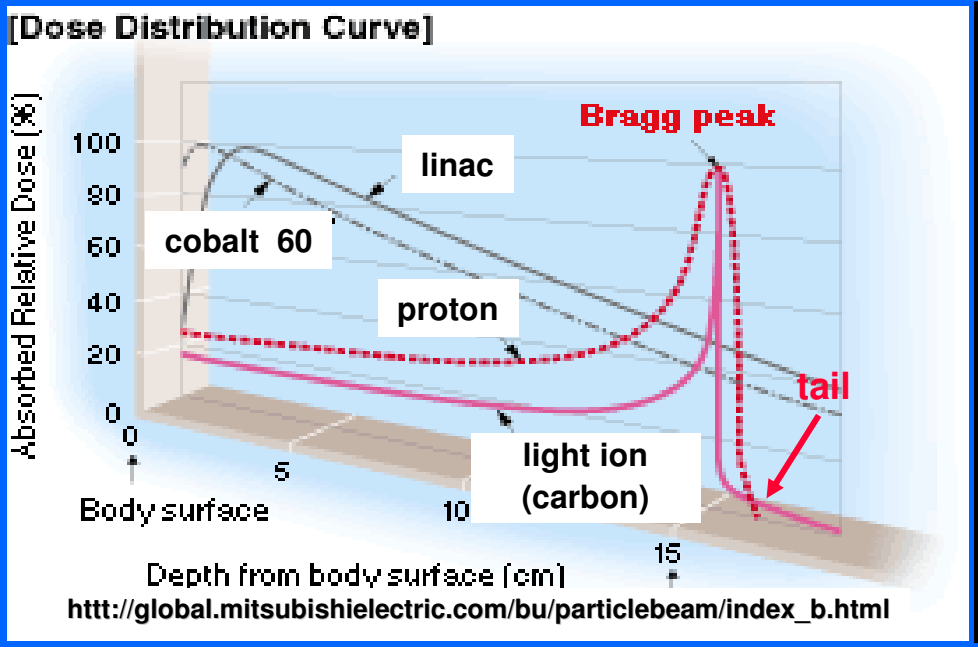
Basic facts: protons and ions spare healthy tissues

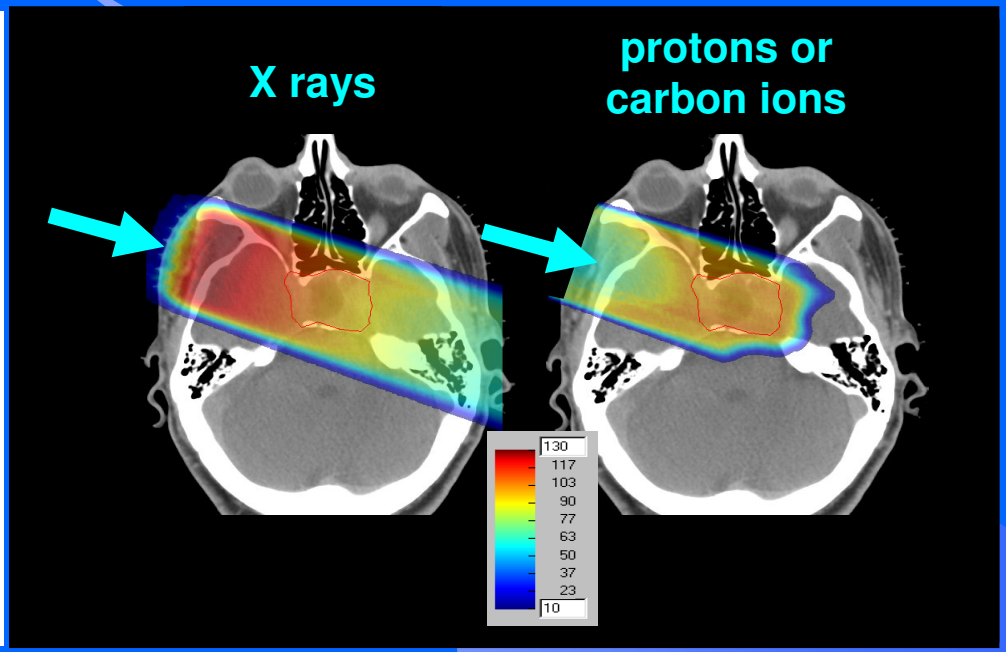
200 MeV - 1 nA protons

4800 MeV – 0.1 nA carbon ions

which can also control radioresistant tumours

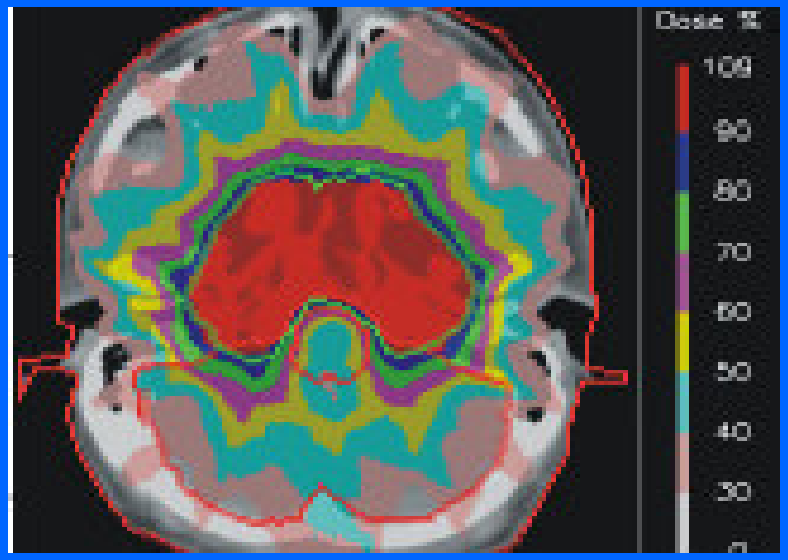




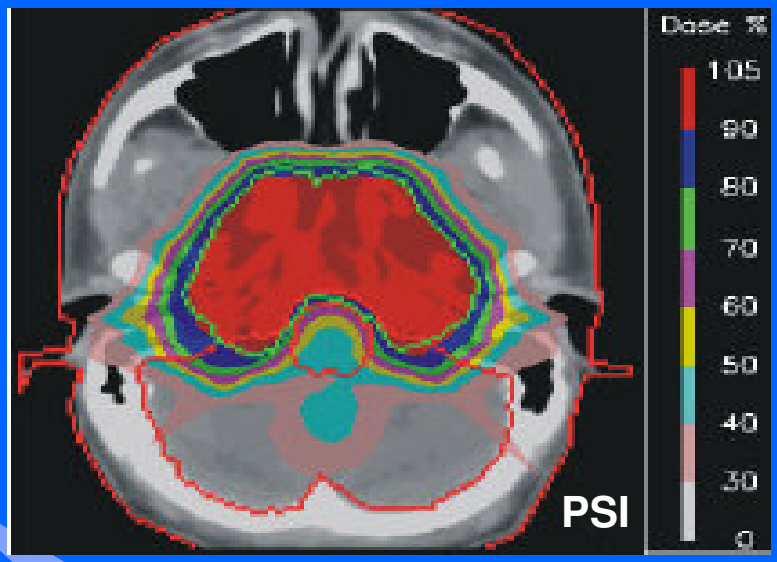


Protons are quantitatively different from X-rays

9 X-ray fields

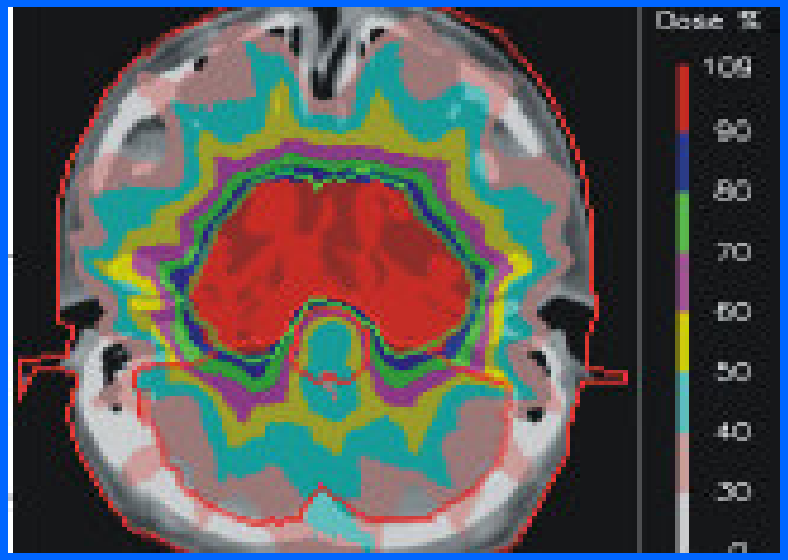


4 proton fields

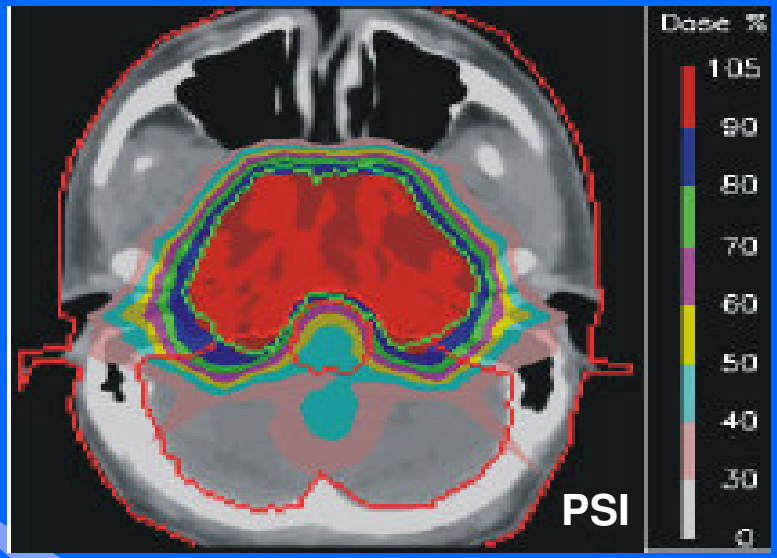


Carbon ions are qualitatively different from X-rays

9 X-ray fields



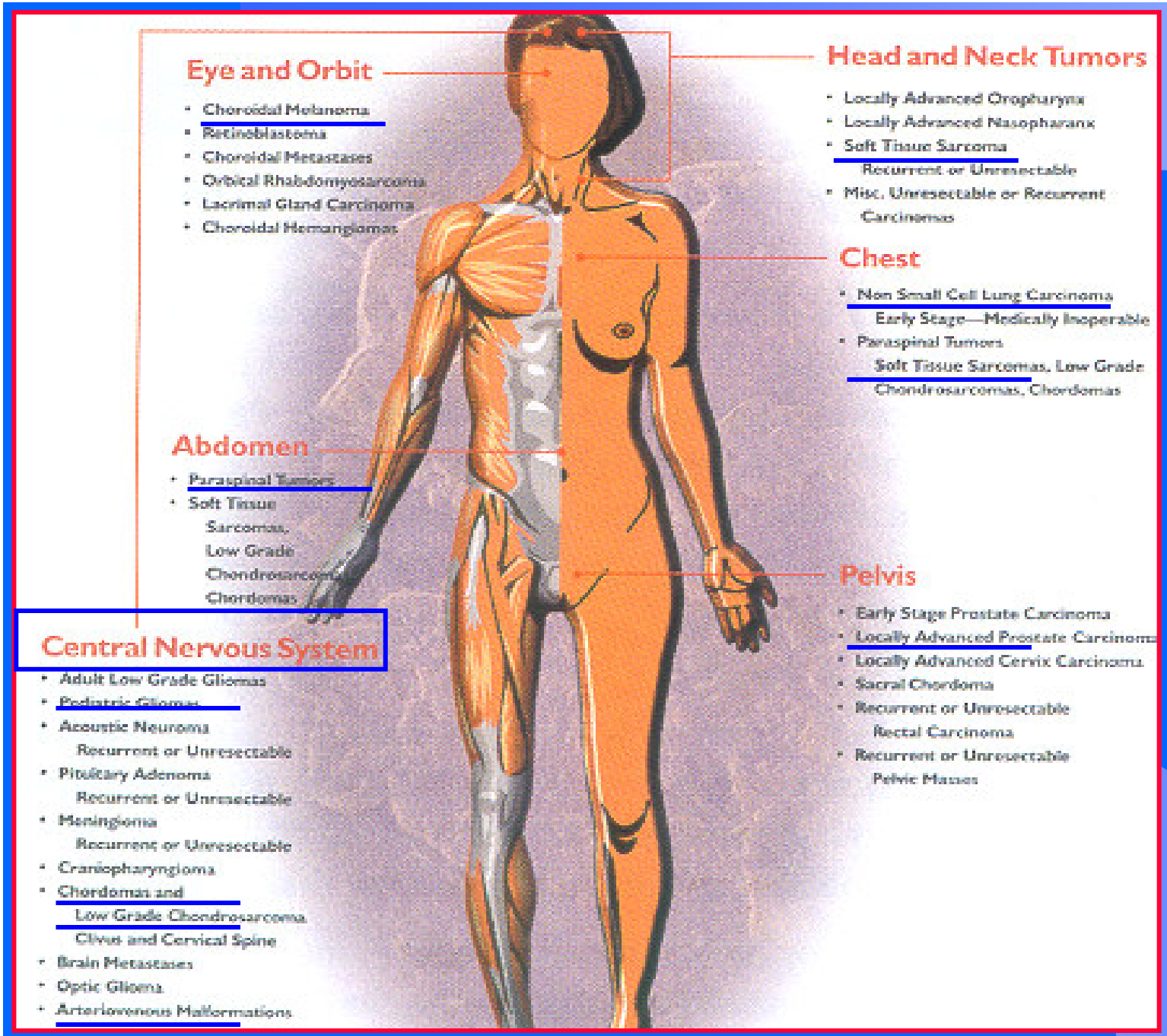
4 proton fields



Carbon ions deposit in a cell 24 times more energy than a proton producing not reparable multiple close-by double strand breaks

Carbon ions can control radio-resistant tumours

The site treated with hadrons



Today in the world

protontherapy:

50'000 patients

carbon ion therapy

3500 patients

BUT

In 1991 about 15'000 patients had been treated with p and none with C ions

Numbers of potential patients (2004)

X-ray therapy ($\geq$ 40 linacs)

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

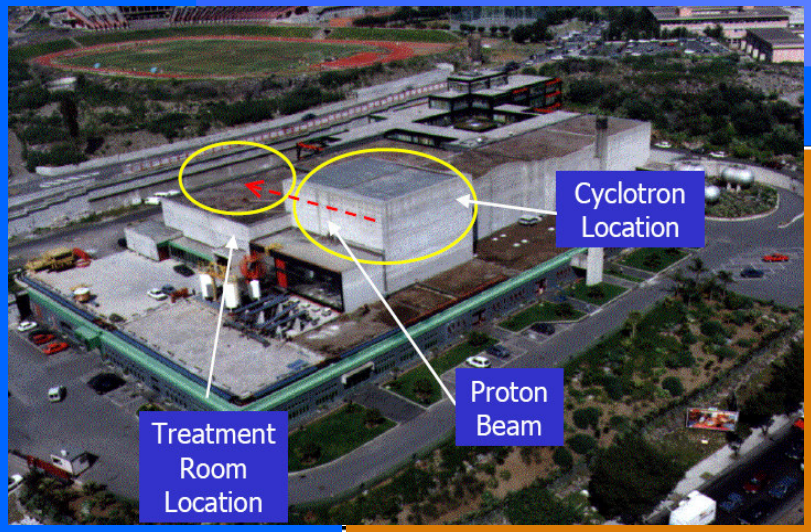
3% of X-ray patients 600 pts/year

TOTAL every 10 M **about 3'000 pts/year (*)**

(*) In Italy : 17'000 patients
5 proton centres and 1 carbon centre (AIRO-2004)

Italian activities

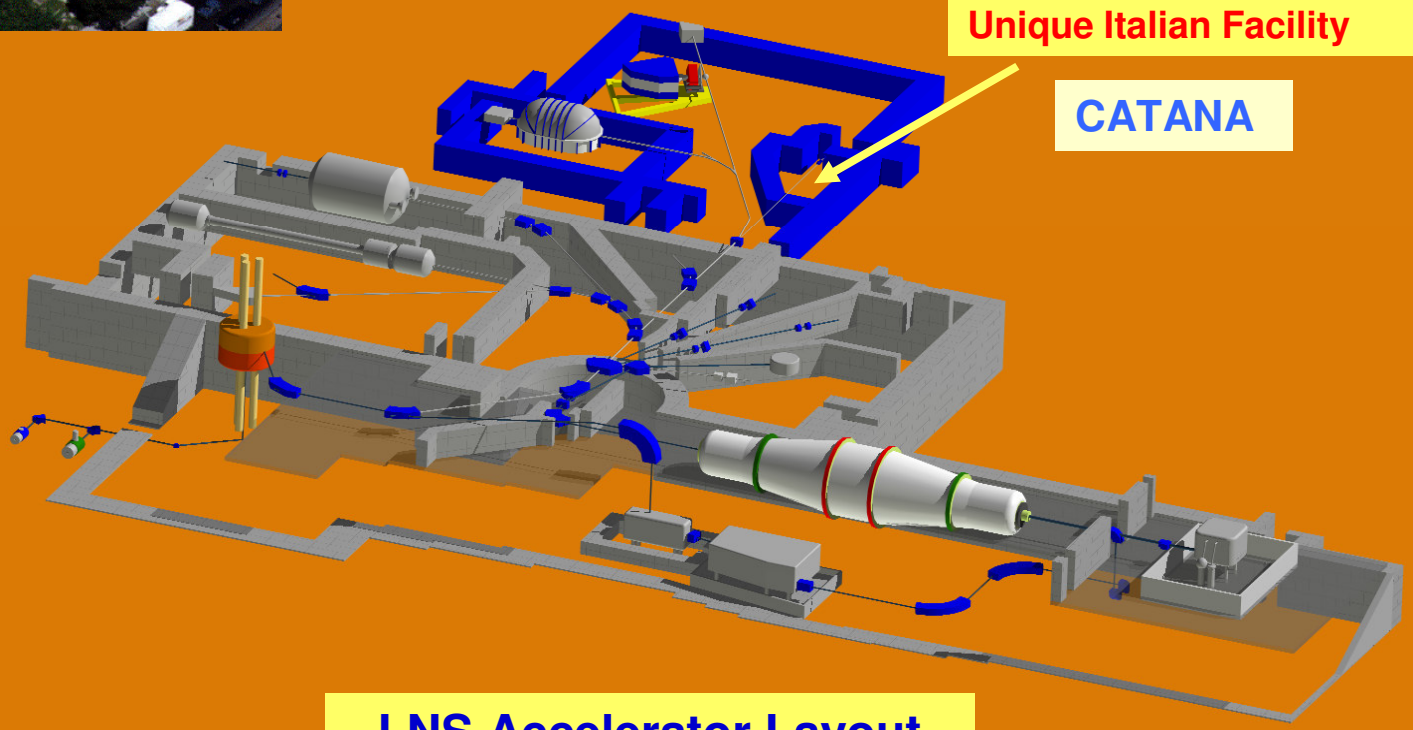
Càtana at "Laboratori Nazionali del Sud" of INFN is described by. G. Battistoni



Ocular Protontherapy

Unique Italian Facility

CATANA



LNS Accelerator Layout

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

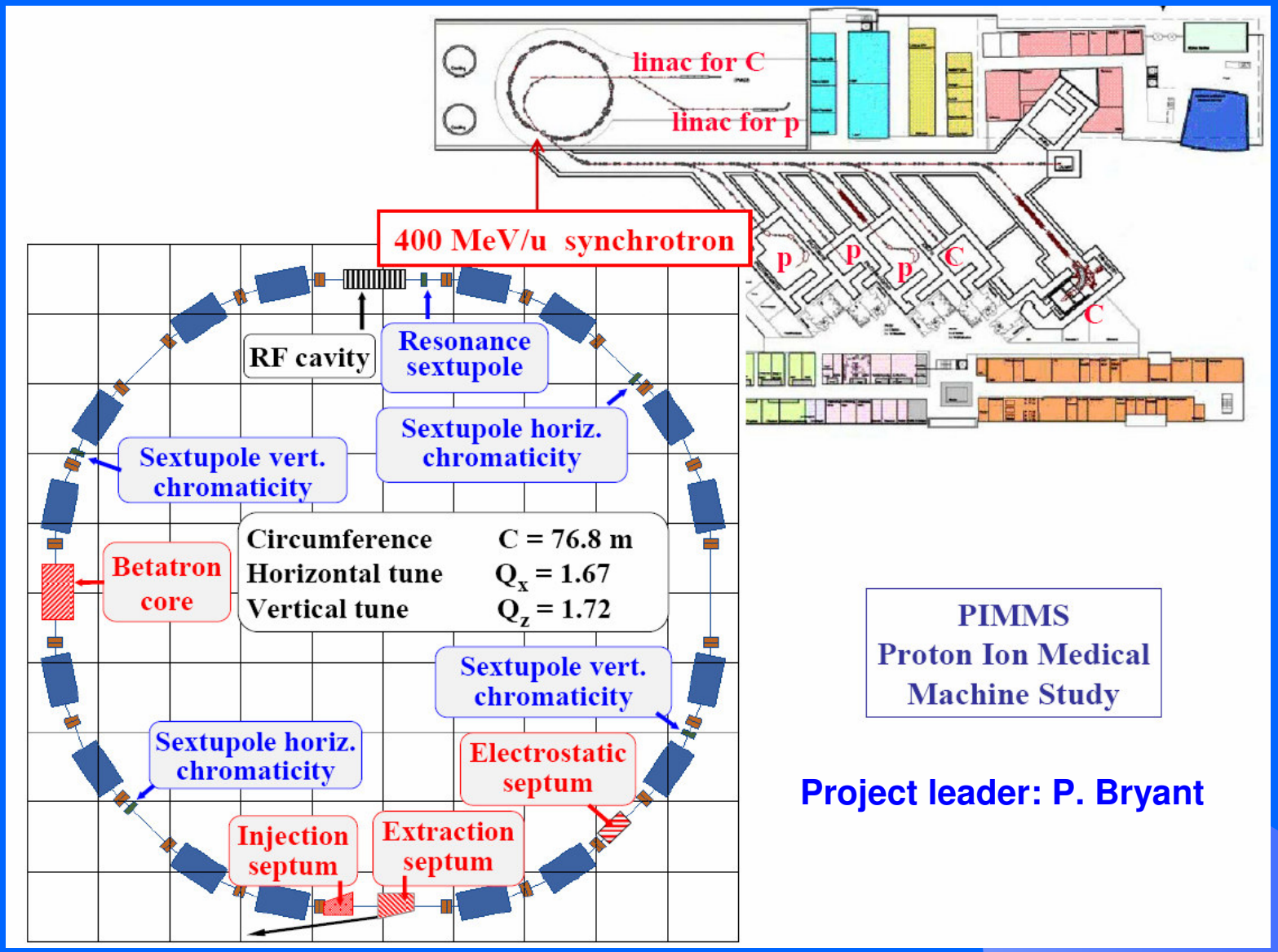
1. **CNAO is being completed in Pavia by the CNAO Foundation together with INFN**

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

the "cyclinac" for protons and carbon ions

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

Basic PIMMS design: CERN-TERA- MedAustron 1996-2000



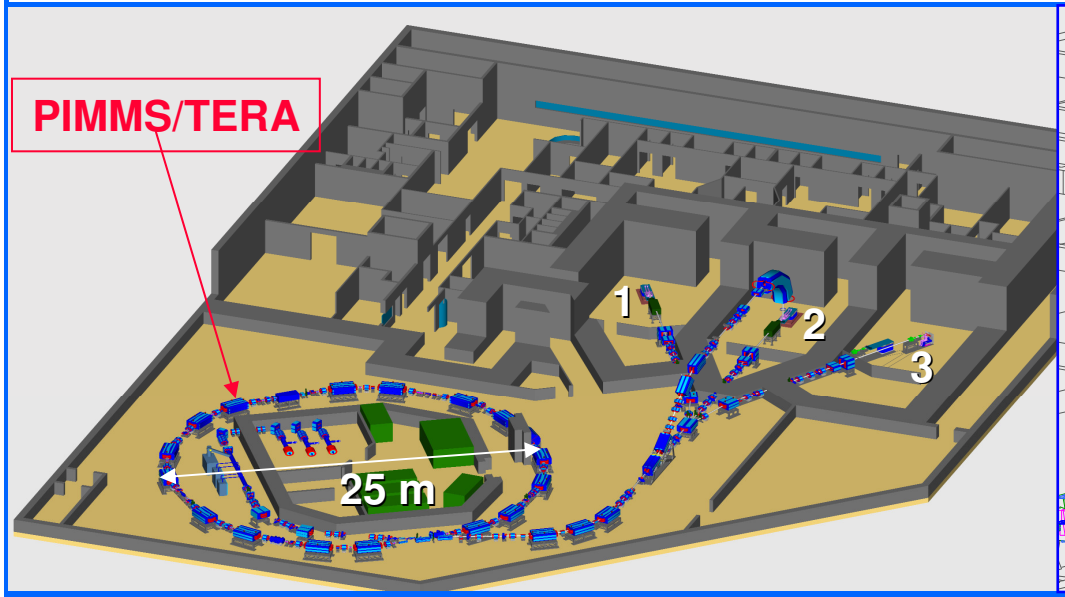
CNAO = Centro Nazionale di Adroterapia

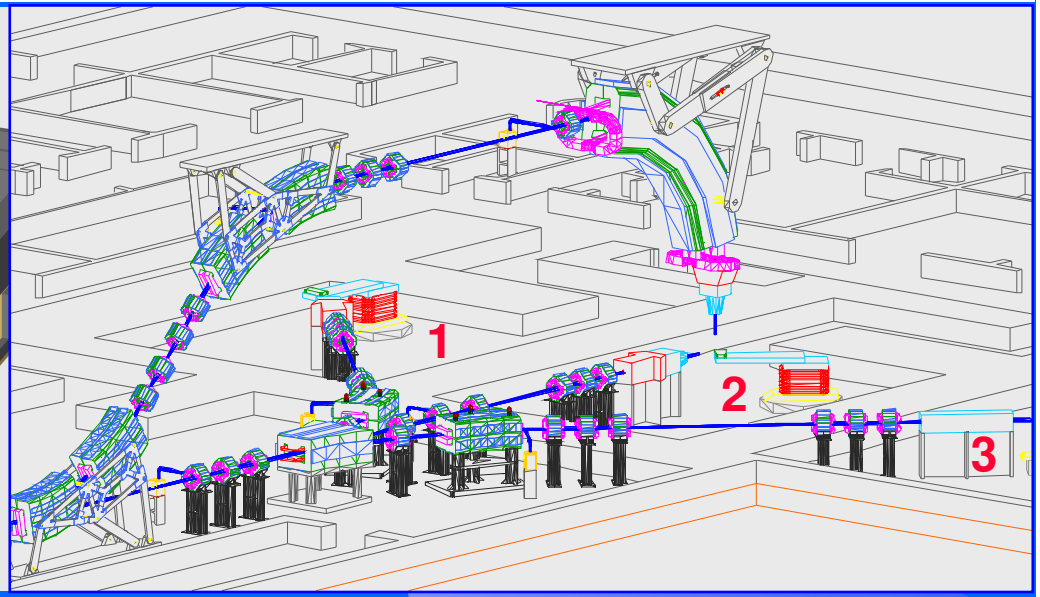
CNAO Foundation created by the Italian Government in 2001:
"to construct and manage
the 'Centro Nazionale di Adroterapia Ancologica' designed by TERA"

Founders: Osp. Maggiore, San Matteo, INT, IEO, Besta and TERA

Since 2004 INFN is Institutional Participant with construction responsabilities as described by G. Battistoni

Modifications to PIMMS: multi-turn injection, linac inside the ring, short beam lines





The surface buildings

In October 2003 TERA passed to CNAO specifications + drawings (3000 pages) and 25 people

Main source of 90 M€: Italian Health Ministry

First beam: spring 2008

Project: Calvi –TEKNE

CNAO Foundation

President: E. Borloni

Medical Director: R. Orecchia

Technical Director: S. Rossi

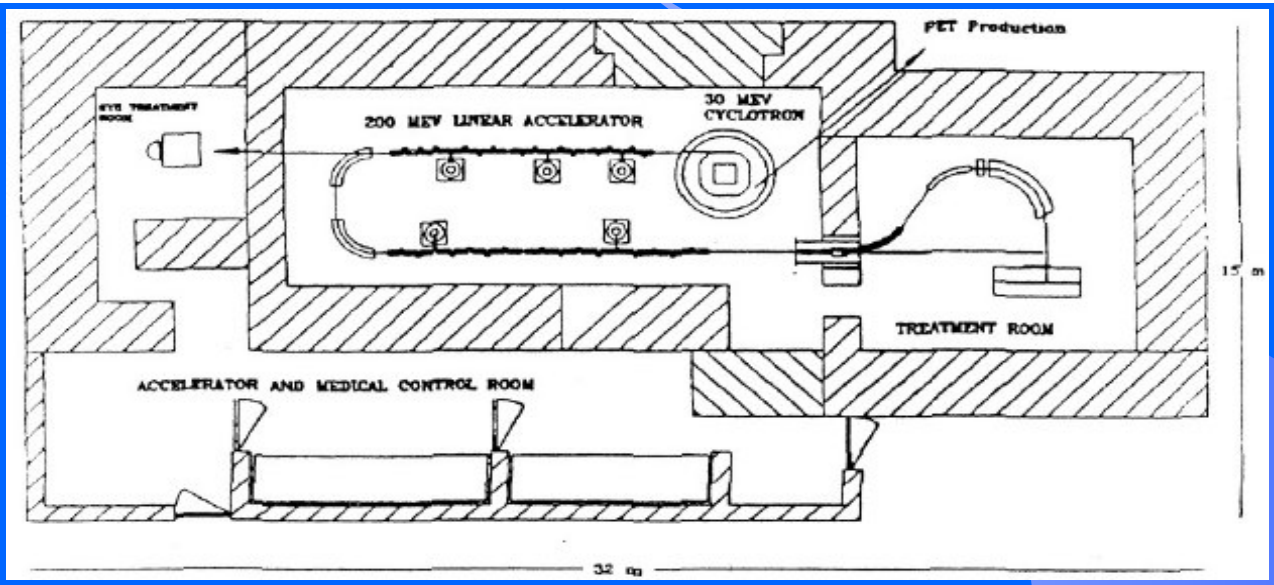
Linacs in hadrontherapy

The first proposal of the "cyclinac" accelerator: 1993

UA in :Hadrontherapy in Oncology", UA and B. Larsson eds., Elsevier, 1994

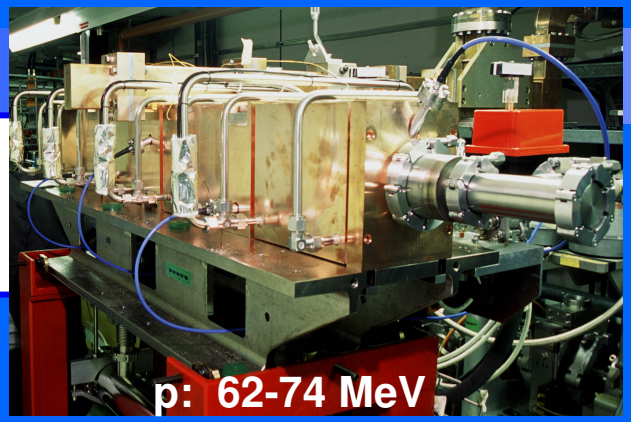
A preliminary solution foresees the use of a 30 MeV cyclotron as an injector, with other options under study.

TERA 94/13 GEN 11: "Il progetto adroterapia tre anni dopo" 25.5.1994



2 routes to light ion therapy

LIBO prototype
CERN-INFN-TERA
1998-2002



TERA "cyclinacs" for p and C

Green Book 1996

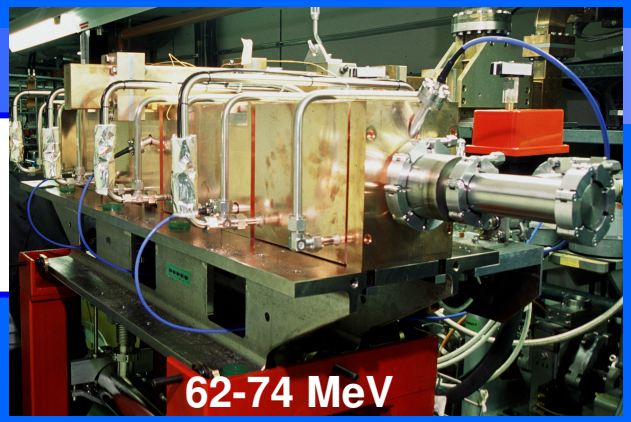
p-62 MeV — LIBO

p-30 MeV — LIBO — 230 MeV

p-C 300 MeV/u — LIBO — 435 MeV/u

2 routes to light ion therapy

LIBO prototype
CERN-INFN-TERA
1998-2002



TERA "cyclinacs" for p and C

Green Book 1996

p-62 MeV

LIBO

p-24 MeV

230 MeV

LIBO

p-C 300 MeV/u

435 MeV/u

LIBO

SCDTL

Linac: 7 MeV

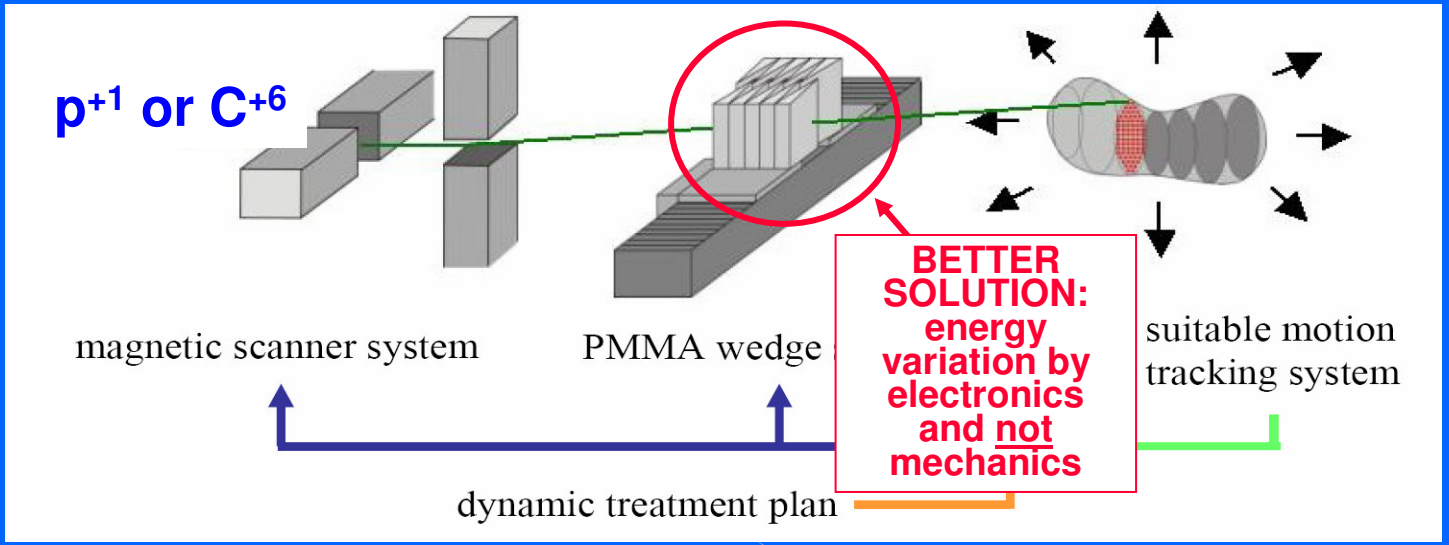
62 MeV

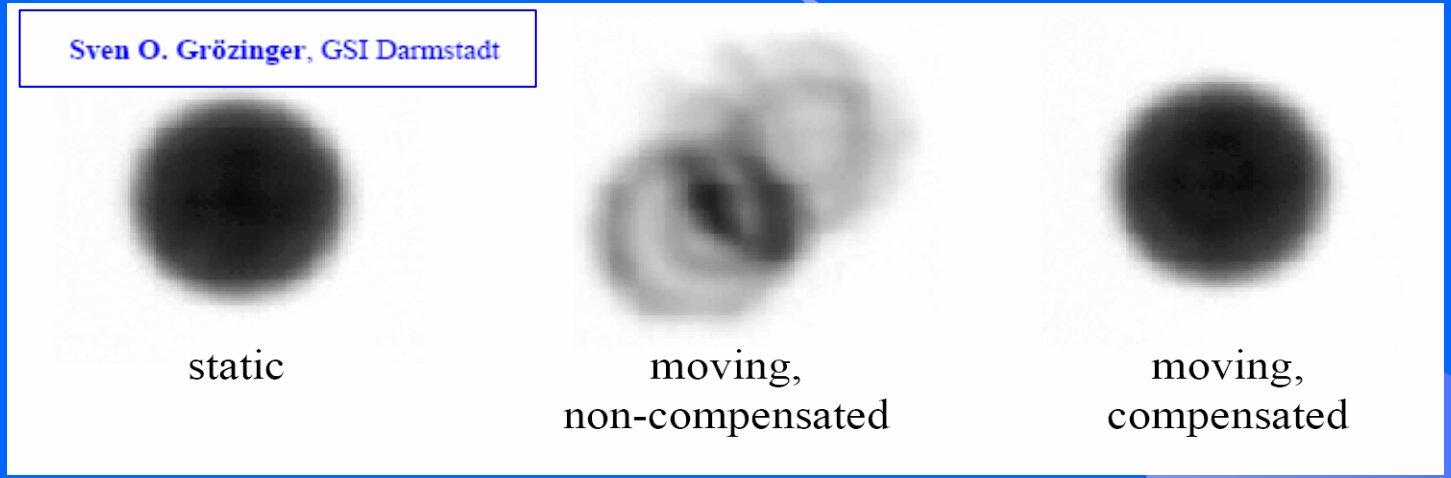
LIBO

TOP = 'Terapia Oncologica con Protoni'
ENEA and Istituto Superiore di Sanità

SCDTL prototype
G. Picardi et al
2000-2005

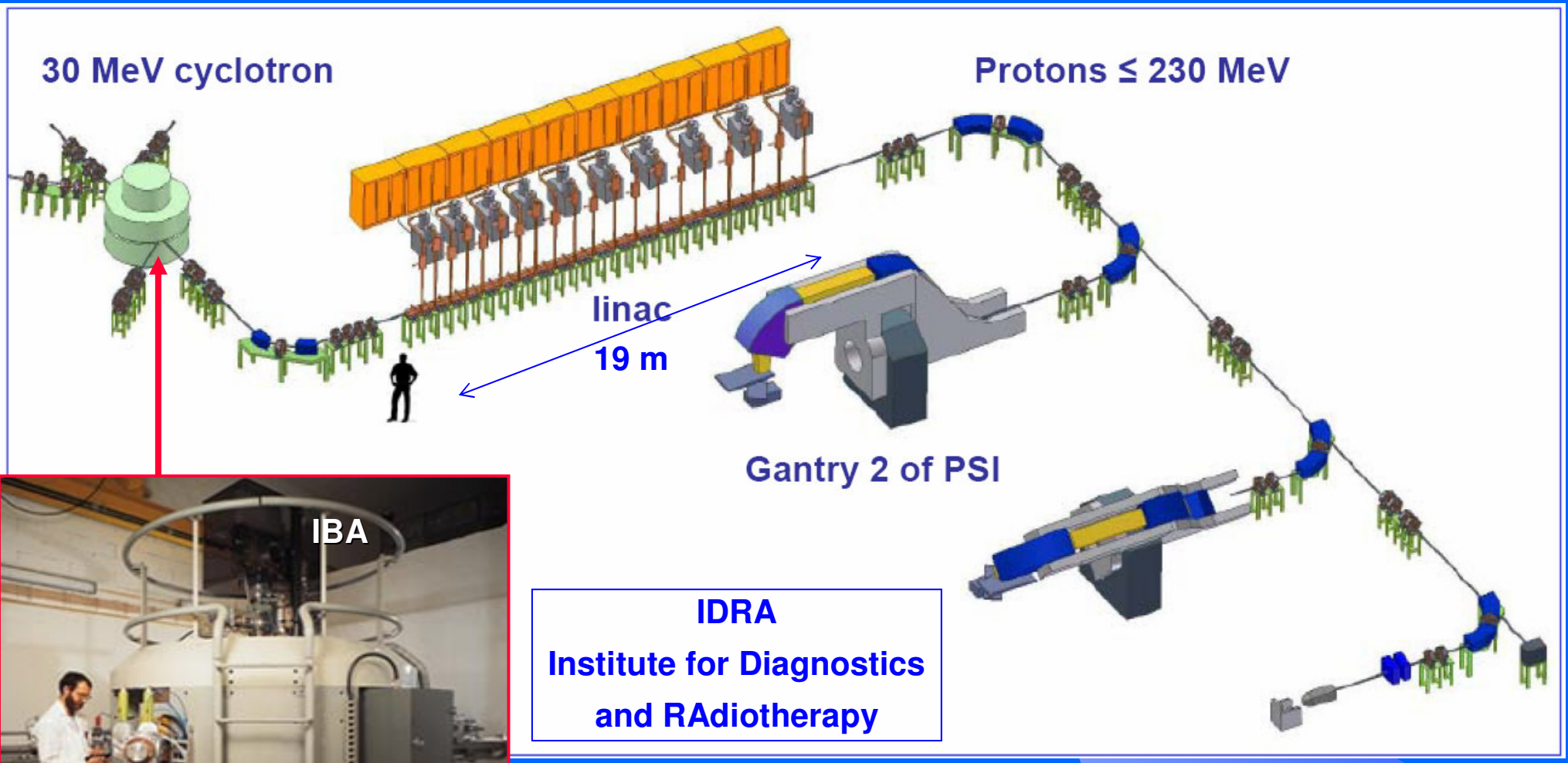
WHY? The challenge of hadrontherapy: treat moving organs





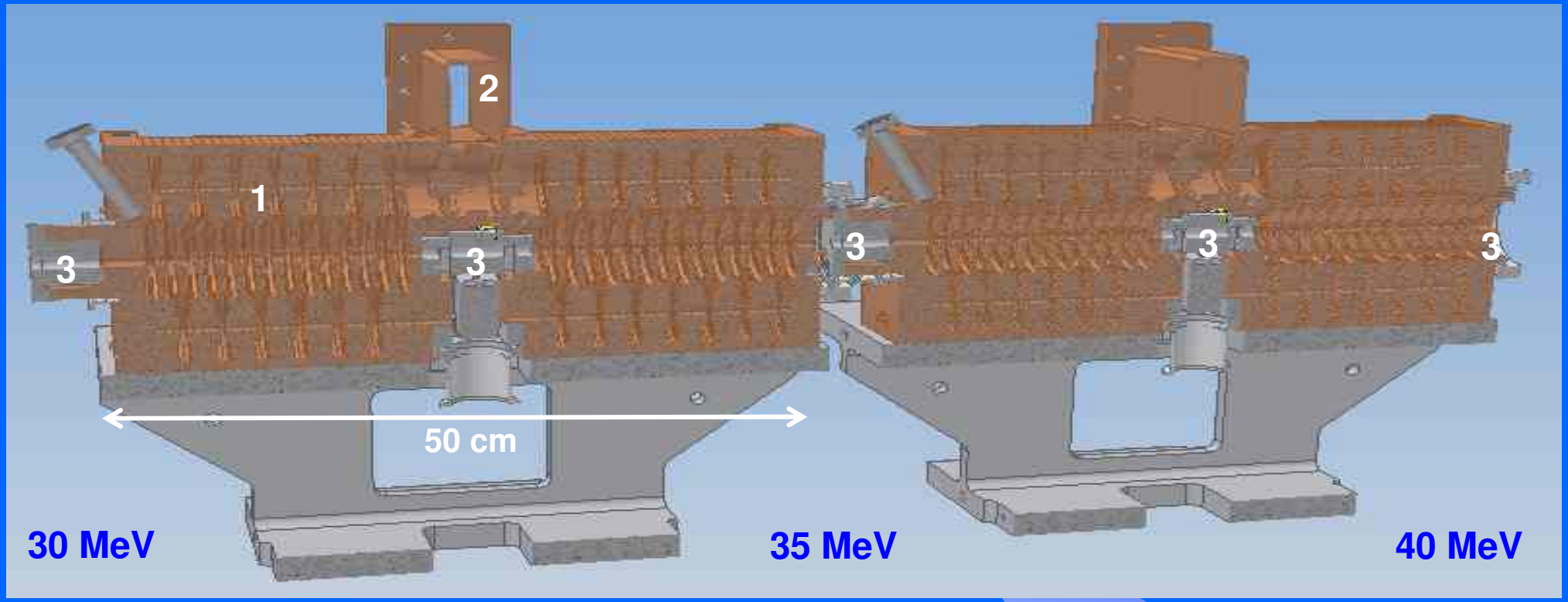
PSI and GSI approach : depth adjusted by moving absorbers

The proton 'cyclinac' concept faces the challenge : IDRA



IDRA
Institute for Diagnostics and RAdiotherapy

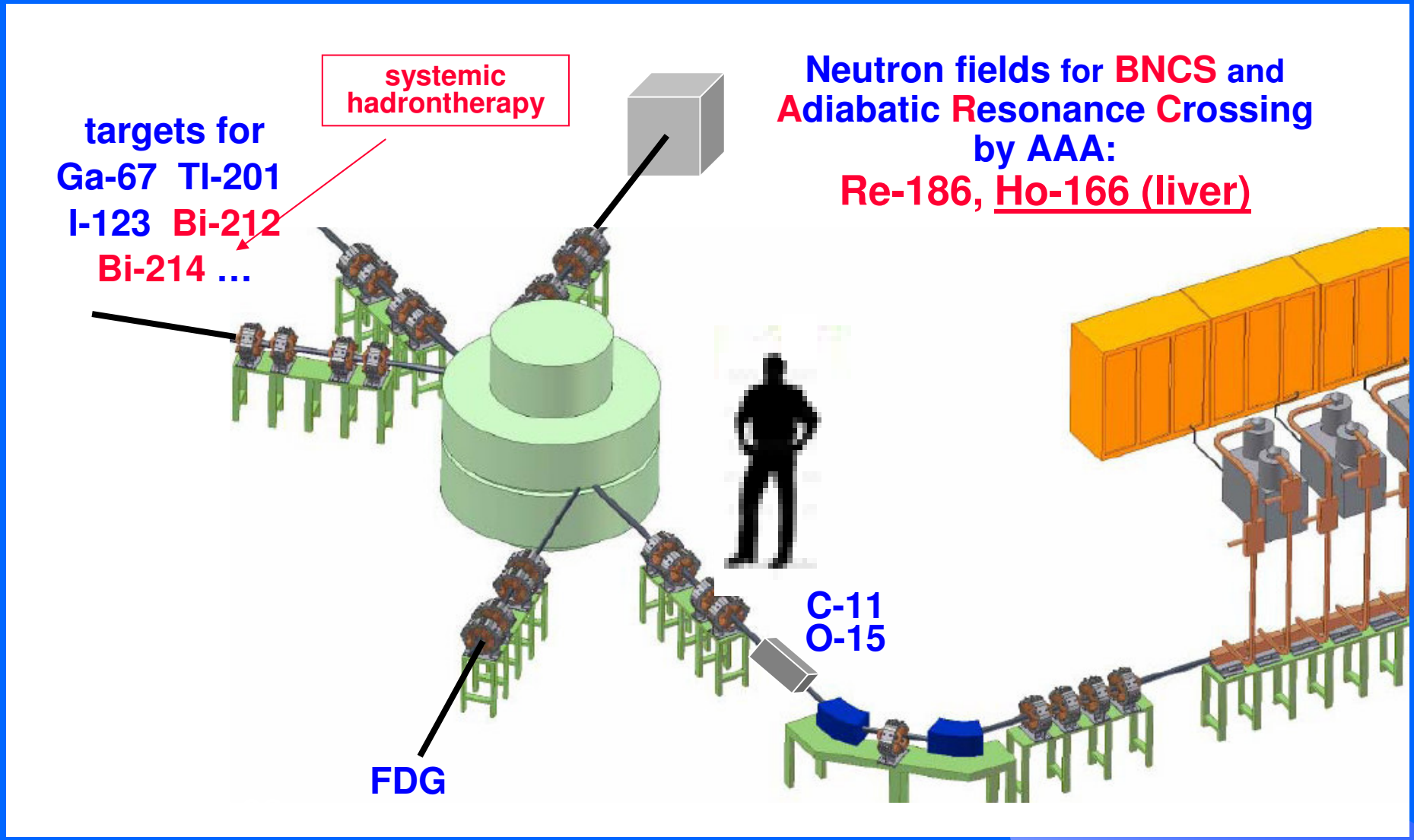
The linac is made by 20 separately powered modules



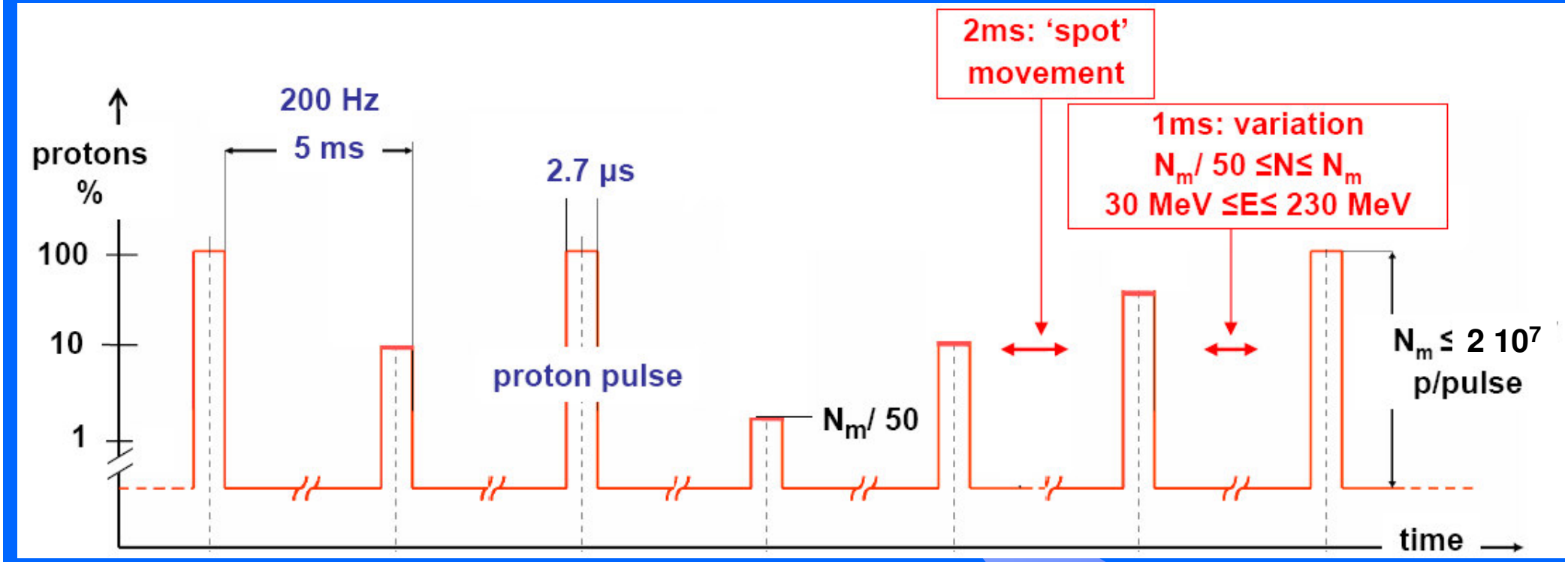
The first two modules:

3 = locations of the permanent quadrupoles

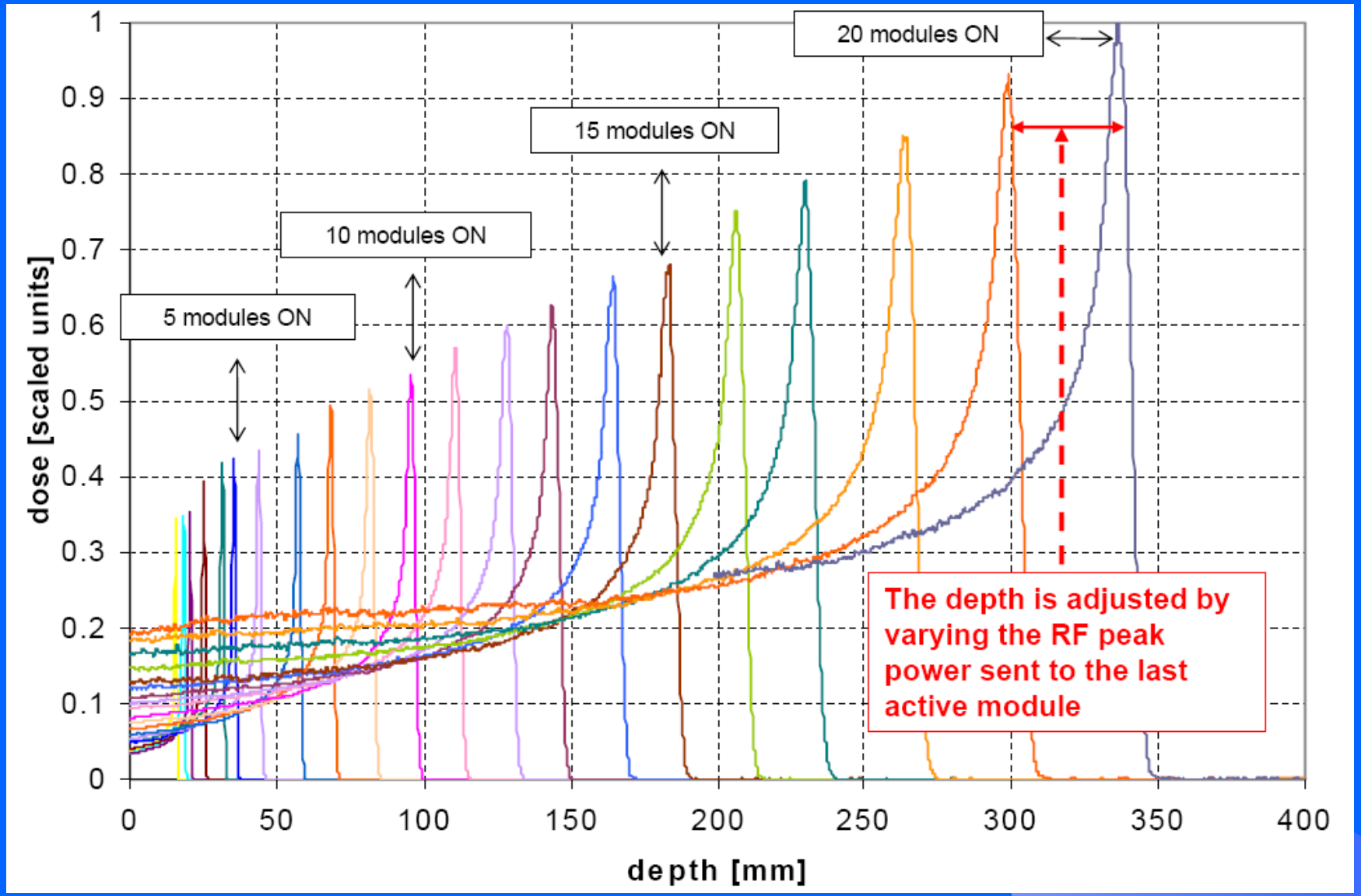
The cyclotron has 4 high-current beam lines (30 MeV, ≤ 750 μA) to produce radioisotopes for diagnostics and endotherapy



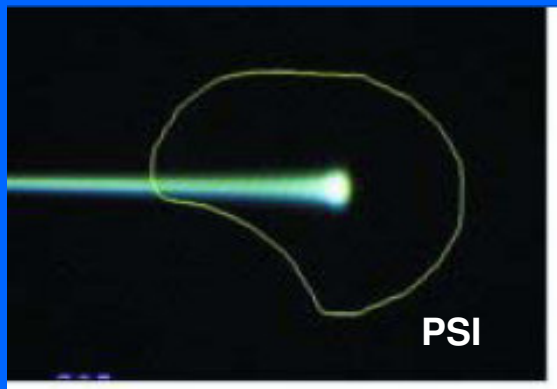
Time and amplitude structure of the IDRA beam



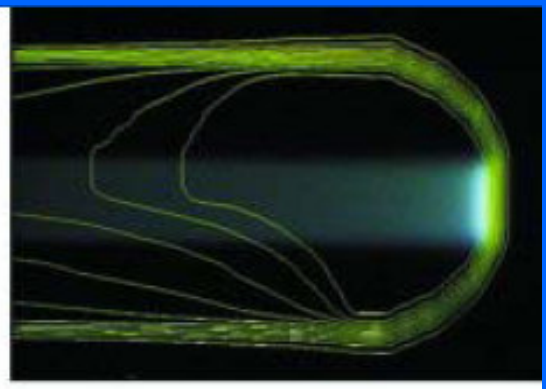
Depth as a function of the number of active klystrons



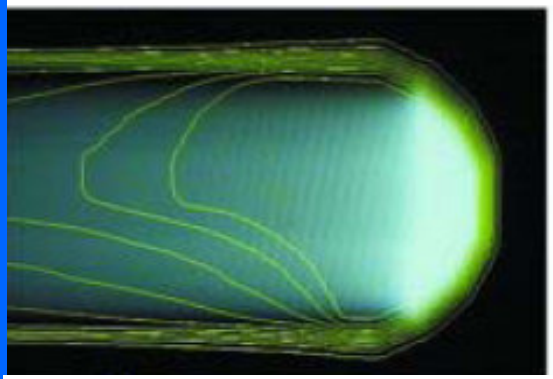
Use of the cyclinac approach with the PSI technique



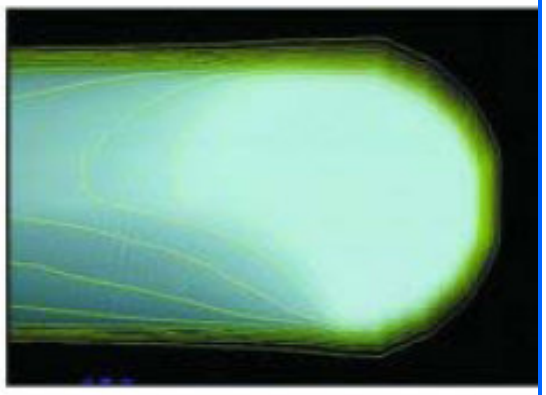
Single ‘spot’



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

Fast variation by ± 15 mm

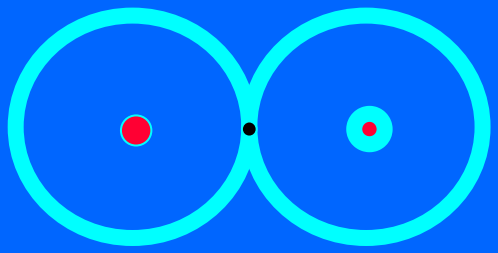
if the magnetic channel has ± 2% momentum acceptance

Cyclinac for carbon ions

For C ions the TERA solution is based on the 300 MeV/u SC cyclotron designed by LNS

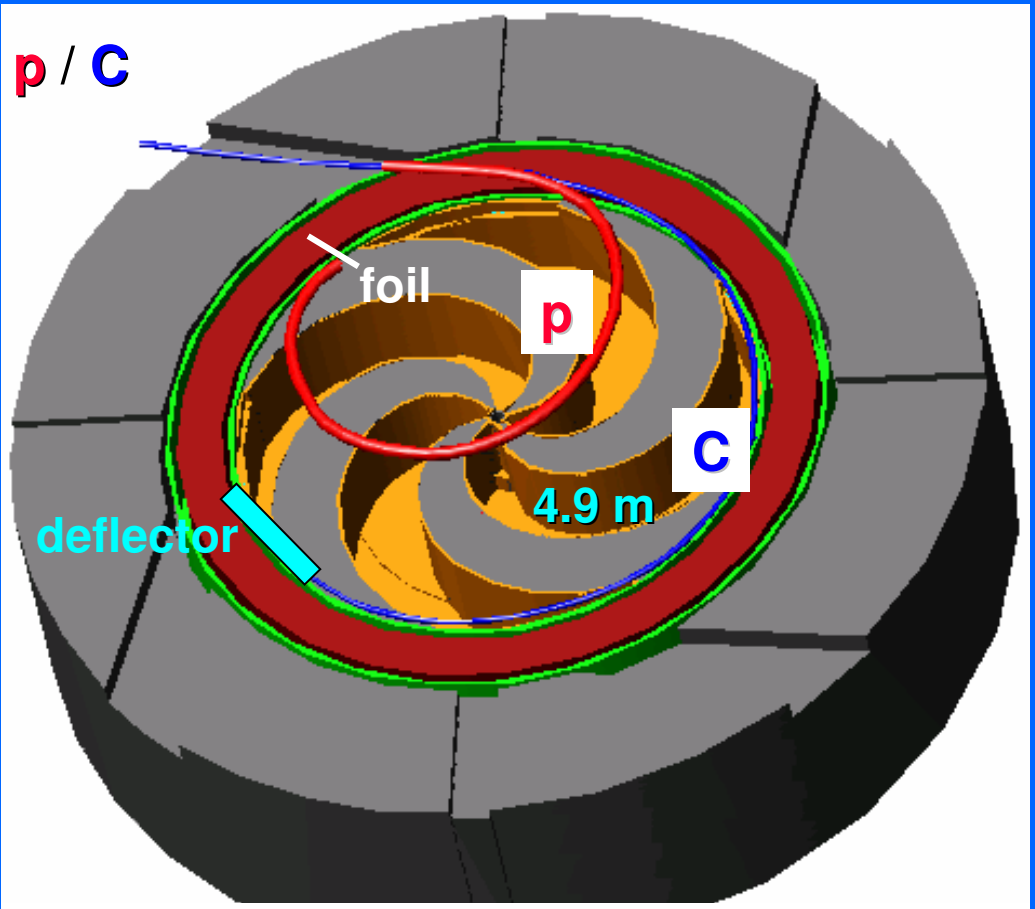
The superconducting cyclotron accelerates particles with Q/A = ½

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

H_2^+  $2p^+ + 1e^-$

Output energies:

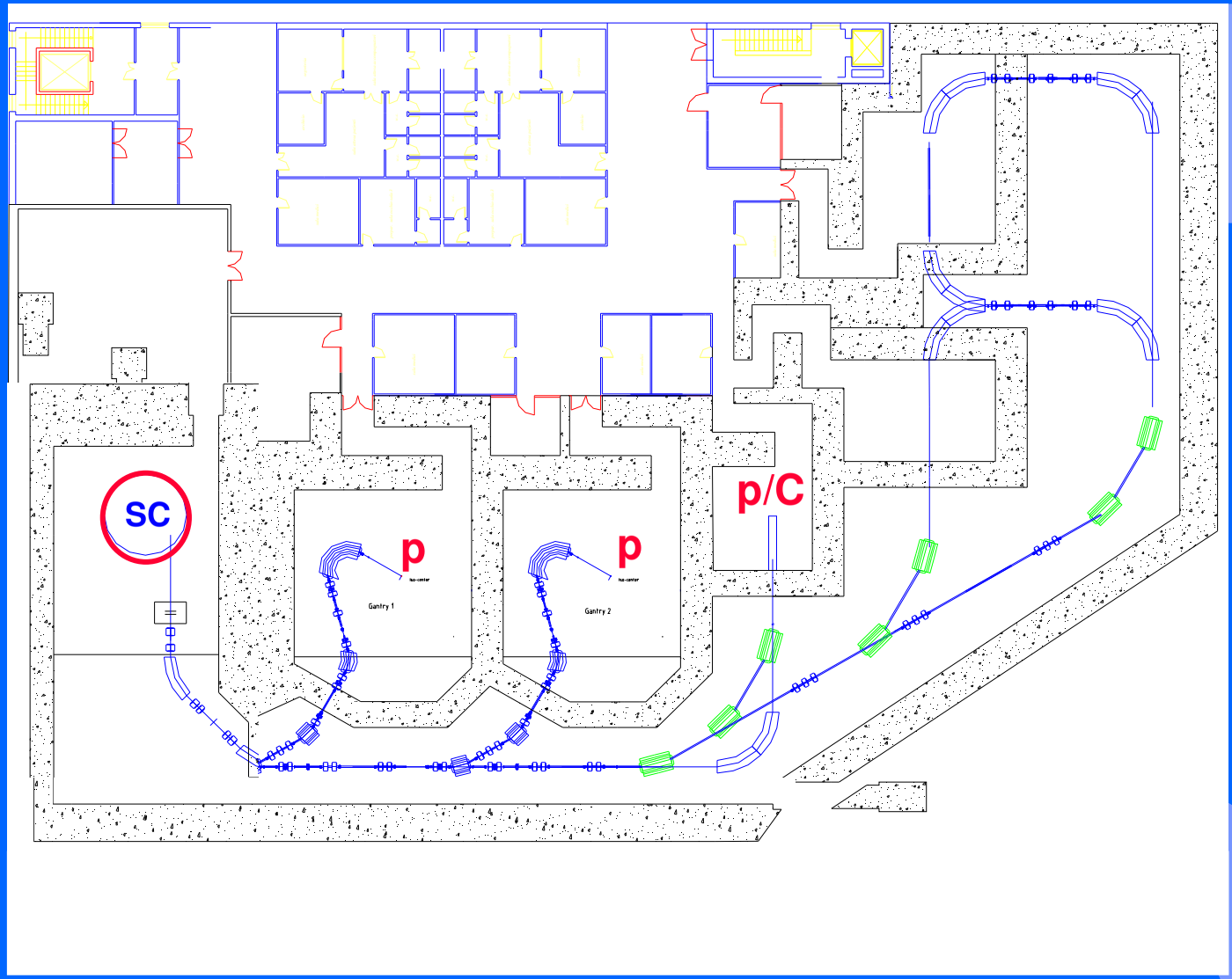
protons	300 MeV
carbon ions	3600 MeV



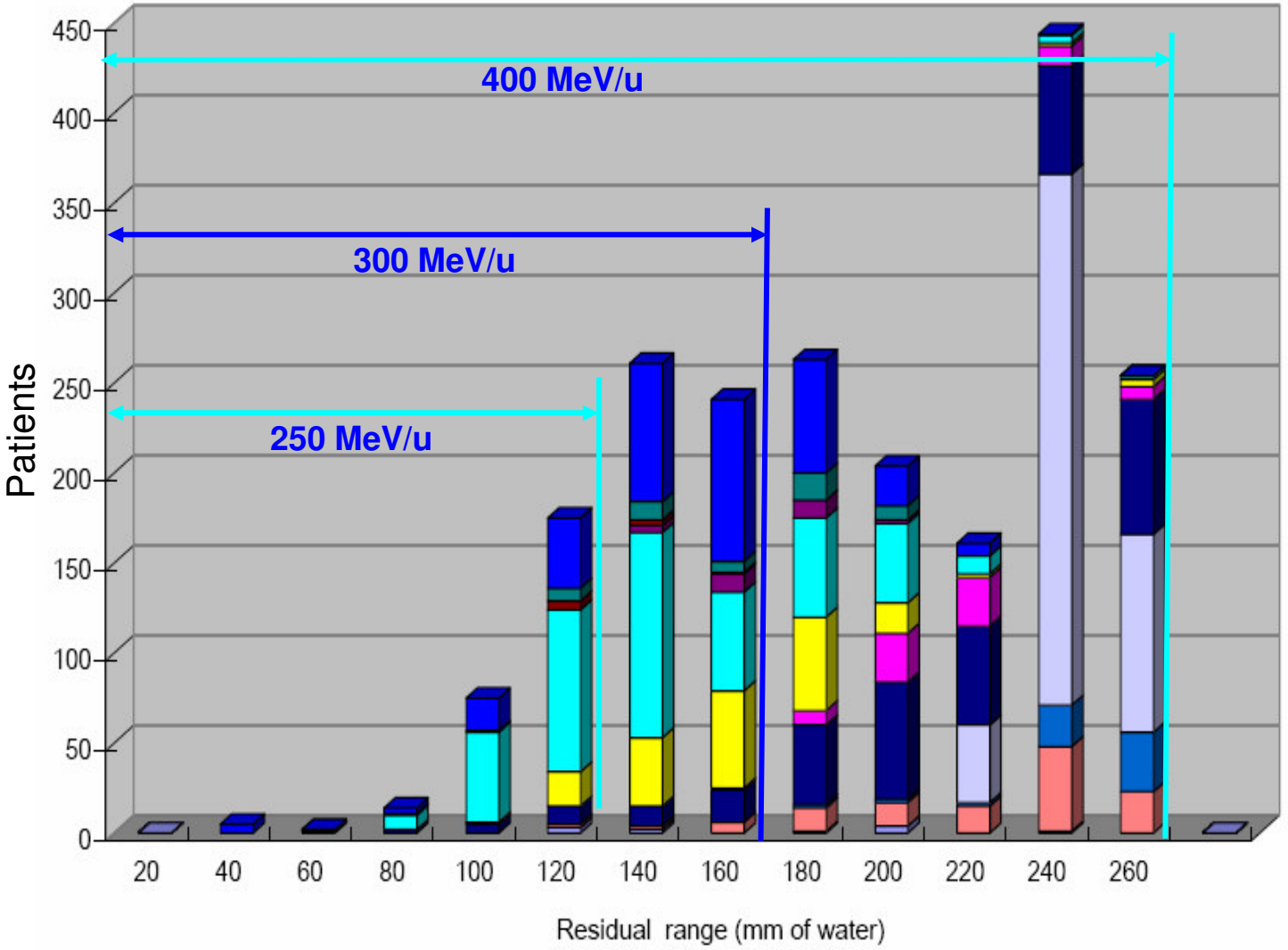
SCENT = Superconducting Cyclotron for Exotic Nuclei and Therapy

IBA (Belgium) offers today the INFN 300 MeV/u SC cyclotron

LNS project for Cannizaro Hospital in Catania



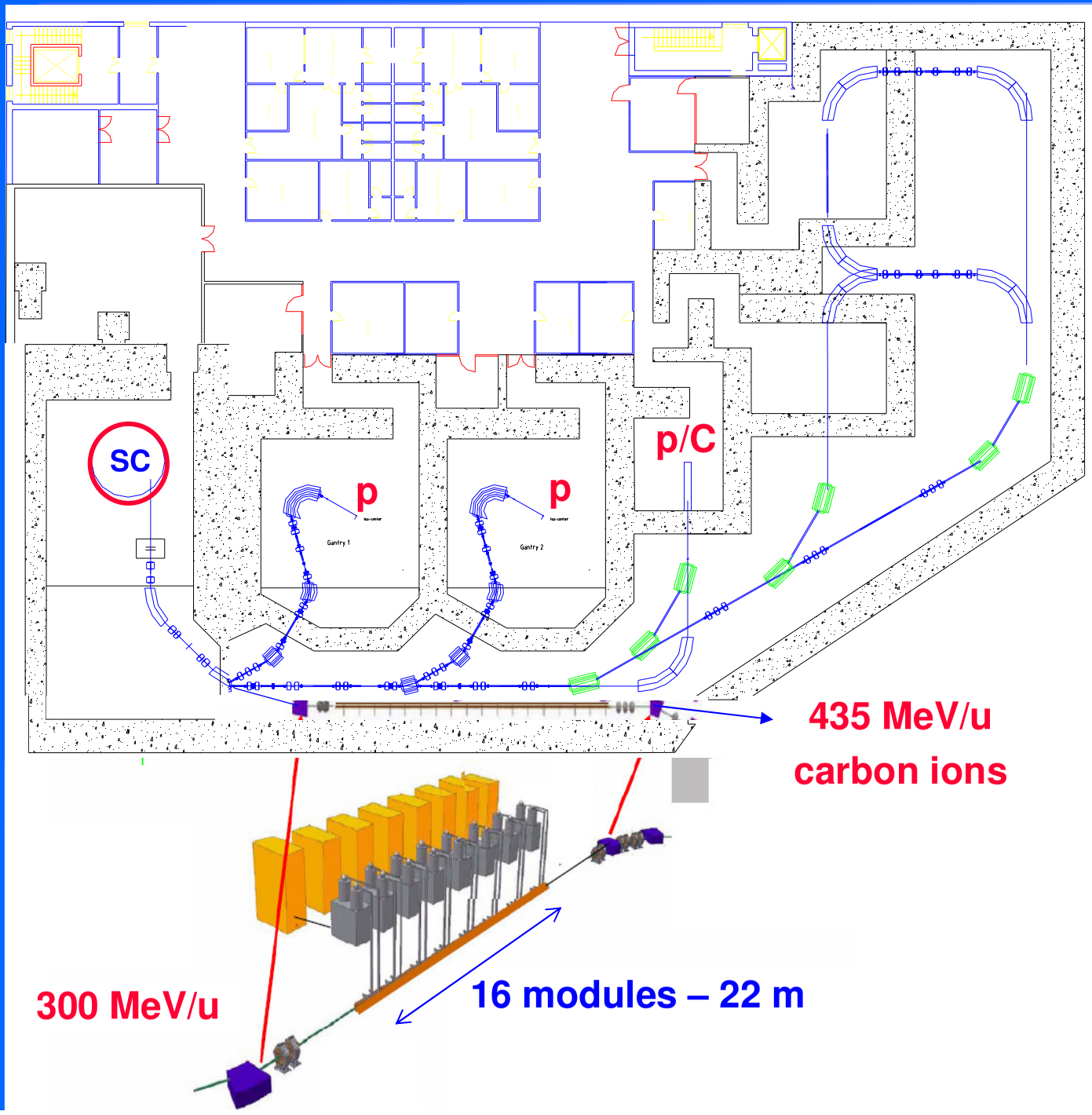
HIMAC statistics of the maximum range used per patient



% treated with 300 MeV/u

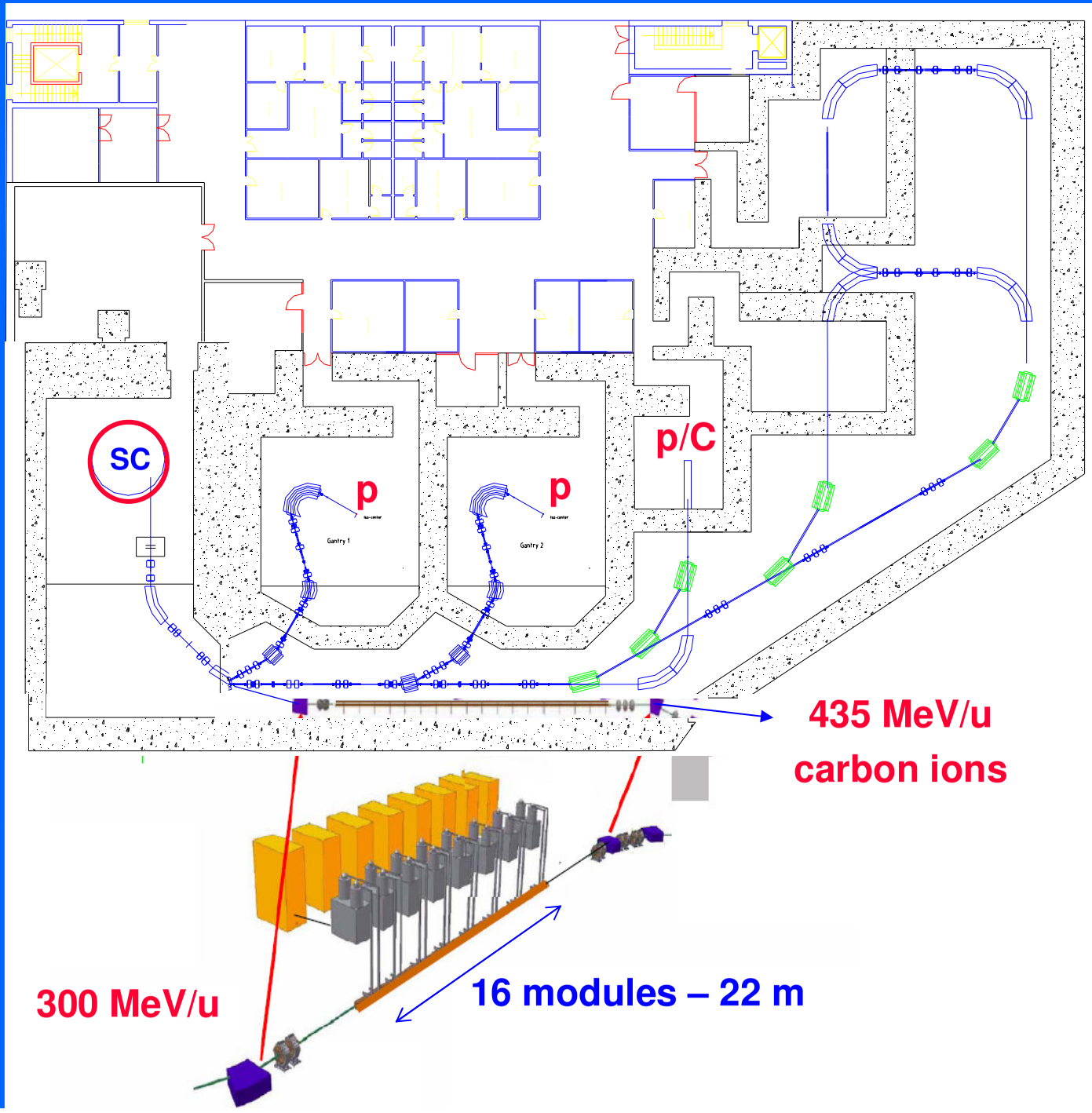
- H&N — **75 %**
- BRAIN
- LAC_GLAND
- ESOPHAGUS
- LUNG — **65 %**
- LIVER — **55 %**
- PANCREAS
- B& ST SARC.
- PROSTATE
- UTERUS
- RECTUM — **< 3 %**
- OTHER

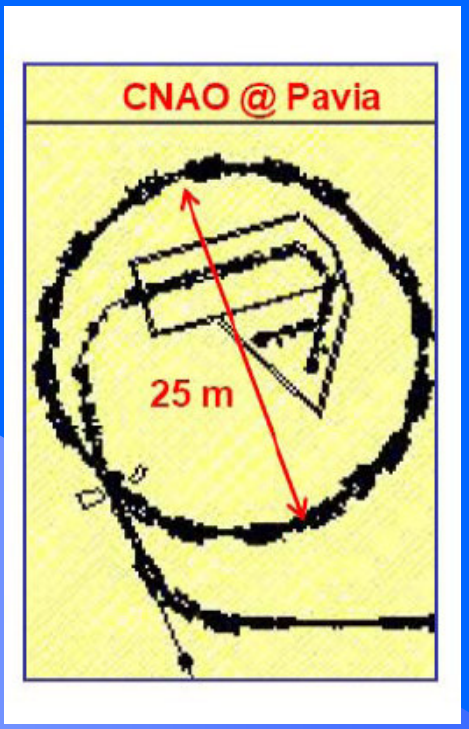
Upgrading with CABOTO = CArbon BOoster for Therapy in Oncology



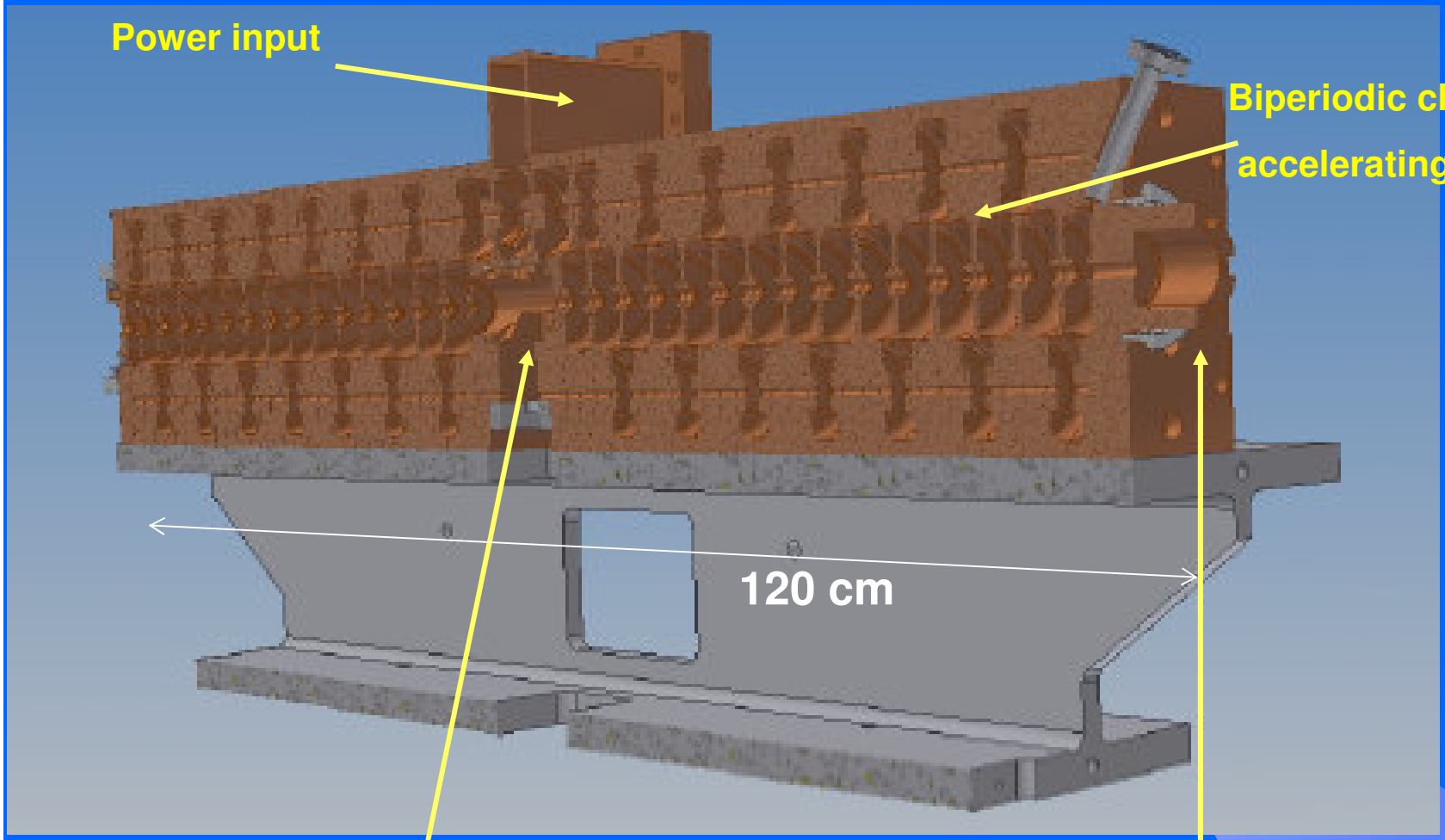
The C^{+6} source has to be developed

Comparison with CNAO synchrotron

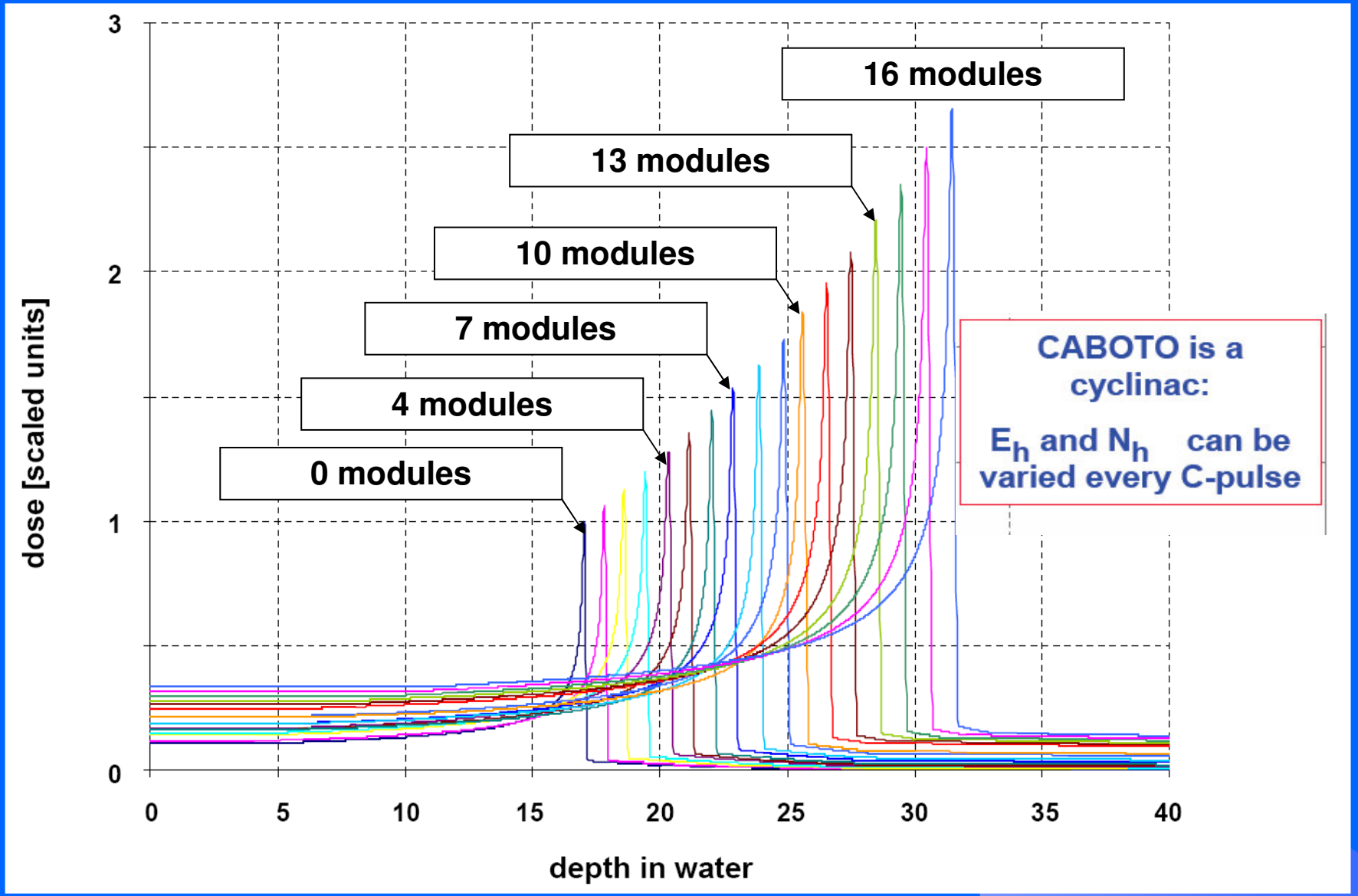




A module of CABOTO



Ion Bragg curves by adjusting the 16 powers: 300-435 MeV/u



The protonherapy Centre in Trento

Characteristics of the ATreP Centre

Centro ospedaliero finanziato dall'Assessorato e alla Ricerca ed Innovazione.

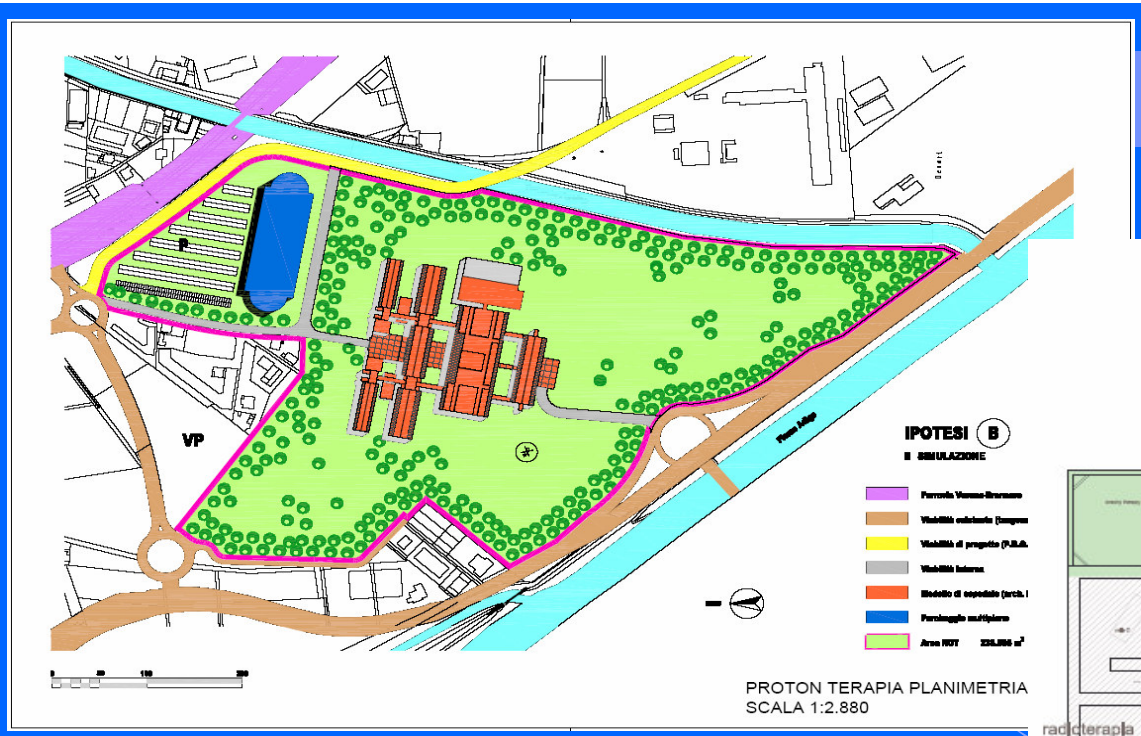
Capacità di trattamento di 600 pazienti/anno a regime.

Una testata isocentrica e una linea fissa, con la predisposizione per una seconda.

Spazzolamento attivo.

Preparazione del paziente fuori della sala di trattamento.

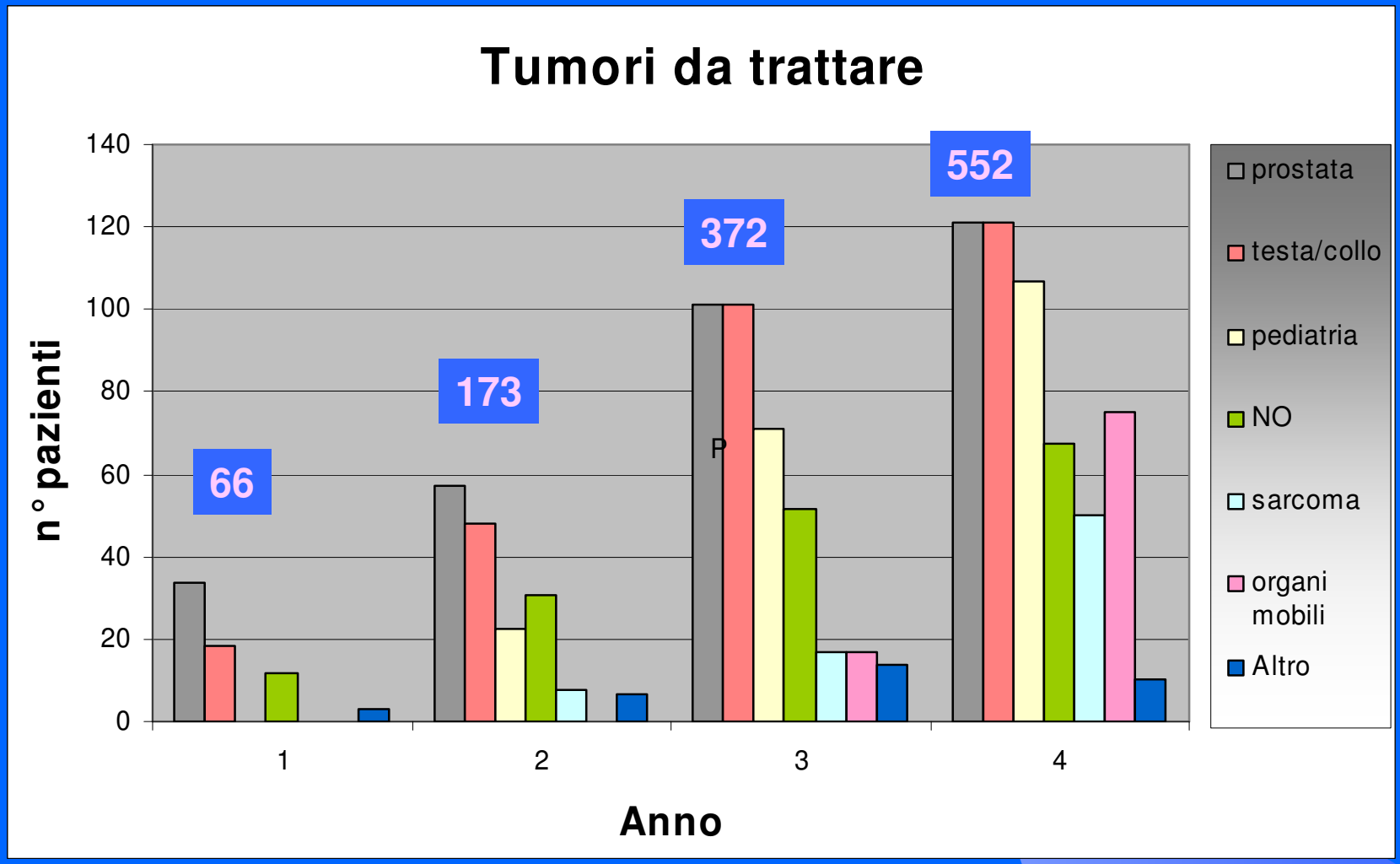
Foreseen solution



Un solo fornitore responsabile dell'intero complesso

Contratto di manutenzione e probabilmente di operazione a lungo termine.

Treated tumours in the first 4 years



THE END