HISTORY OF HADRON THERAPY IN EUROPE

Ugo Amaldi

TERA Foundation

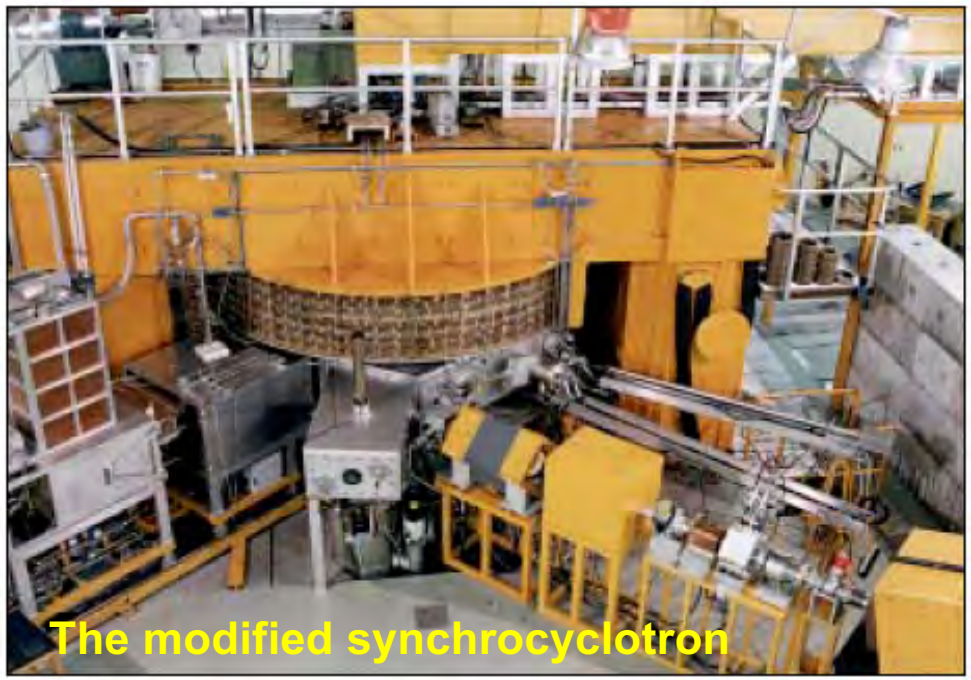
The beginnings of European proton therapy

30 years of pioneering protontherapy in physics labs

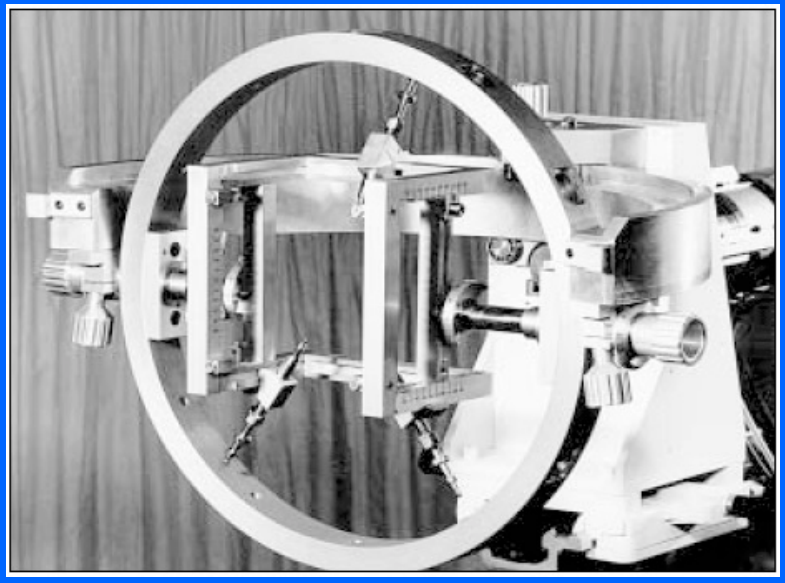
Lawrence Berkeley Laboratory	USA	1954
Uppsala	Sweden	1957
Harvard Cyclotron Laboratory (*)	USA	1961
Dubna	Russia	1964
Moscow	Russia	1969
St. Petersburg	Russia	1975
Chiba	Japan	1979
Tsukuba	Japan	1983
Paul Scherrer Institute	Switzerland	1984

(*) 9,115 patients were treated with protons before the laboratory closed in 2002

Uppsala - 1957



The modified synchrocyclotron



Alignment system for the treatment with 185 MeV protons

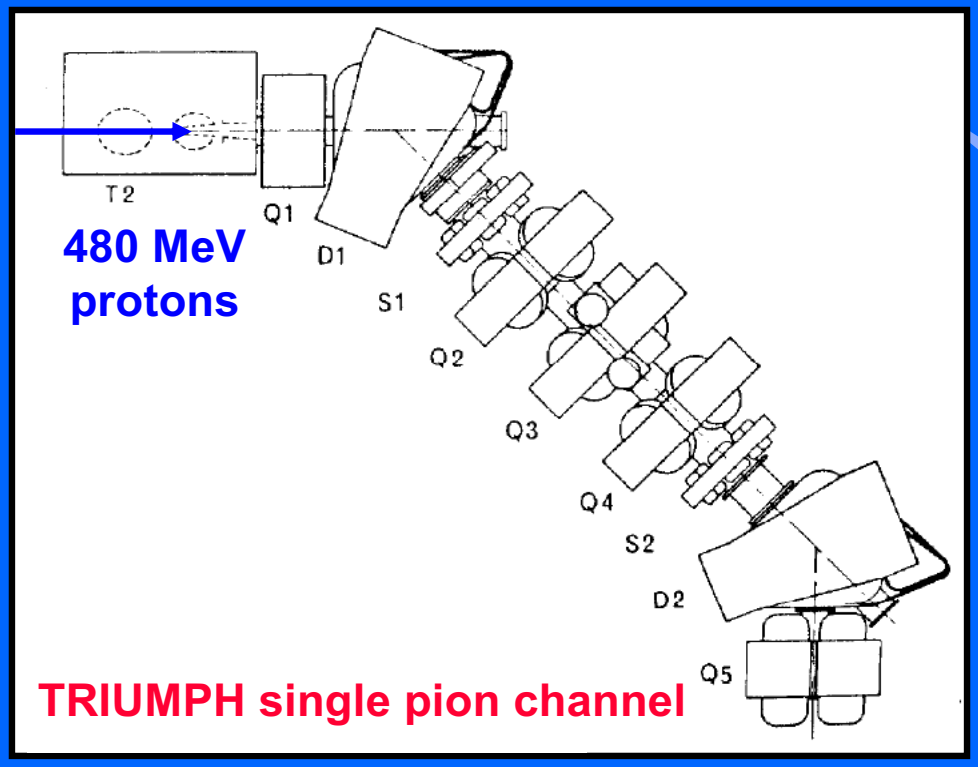
Bőrje Larsson

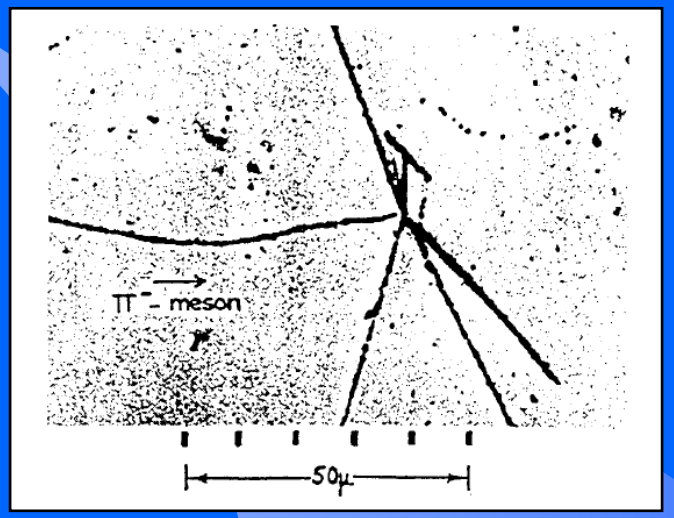
"On the Application of a 185 MeV Proton Beam to Experimental Cancer Therapy and Neurosurgery: a Biophysical Study" Doctoral dissertation - 1962

(1931-1998)

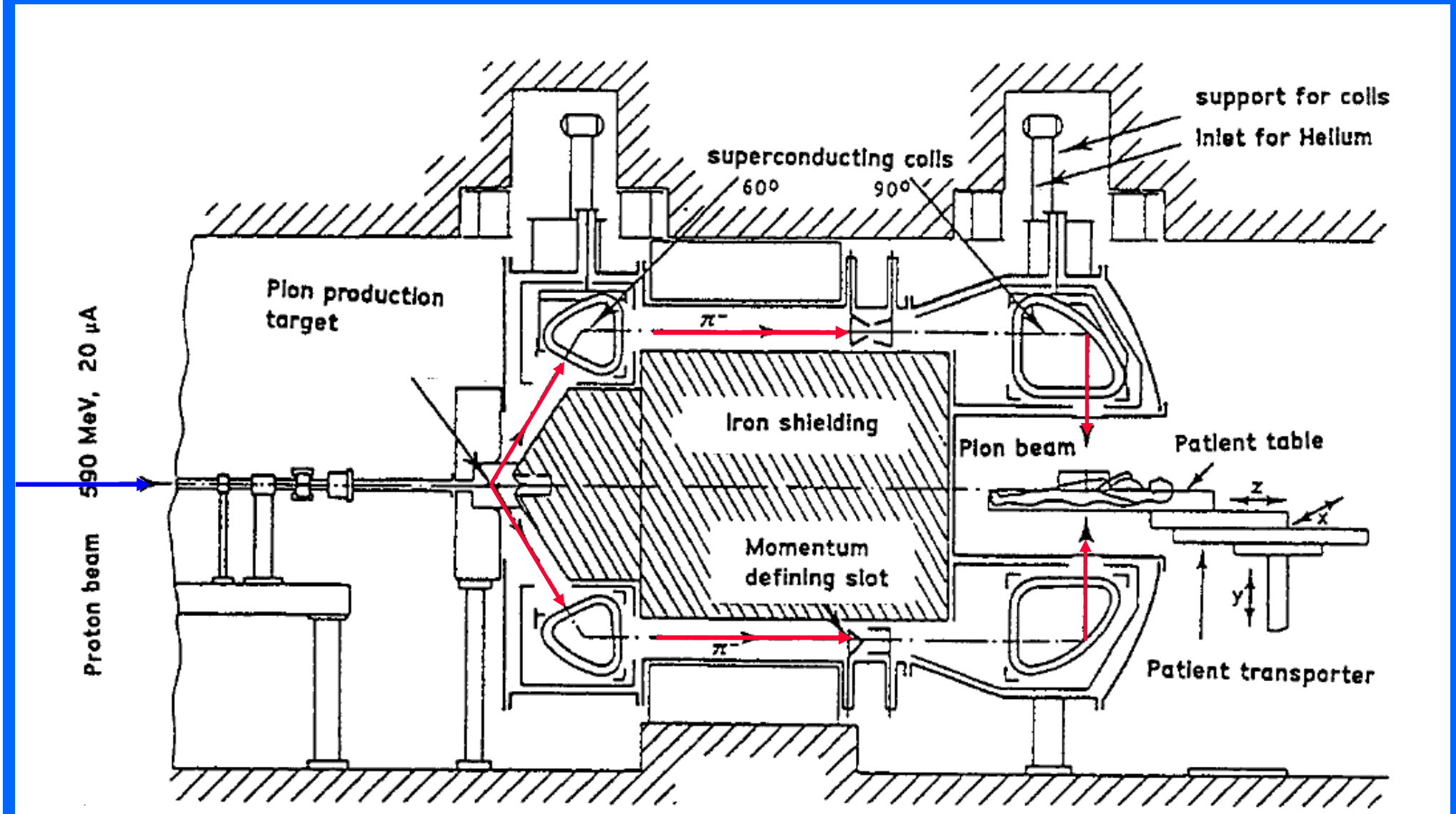
Pion facilities

Los Alamos Meson Physics Facility (LAMPF)	209 pts	1974-1982
TRIUMPH at Vancouver	350 pts	1979-1994
PIOTRON at SIN (now PSI)	506 pts	1981-1993





“Orange Peel” spectrometer of the PIOTRON



1992-1994: Hadron therapy turning point:

Three crucial years

In the years 1992-1994 the rate of progress changed rapidly:

1992 Loma Linda and Tsukuba complete the commissioning of their proton beams.

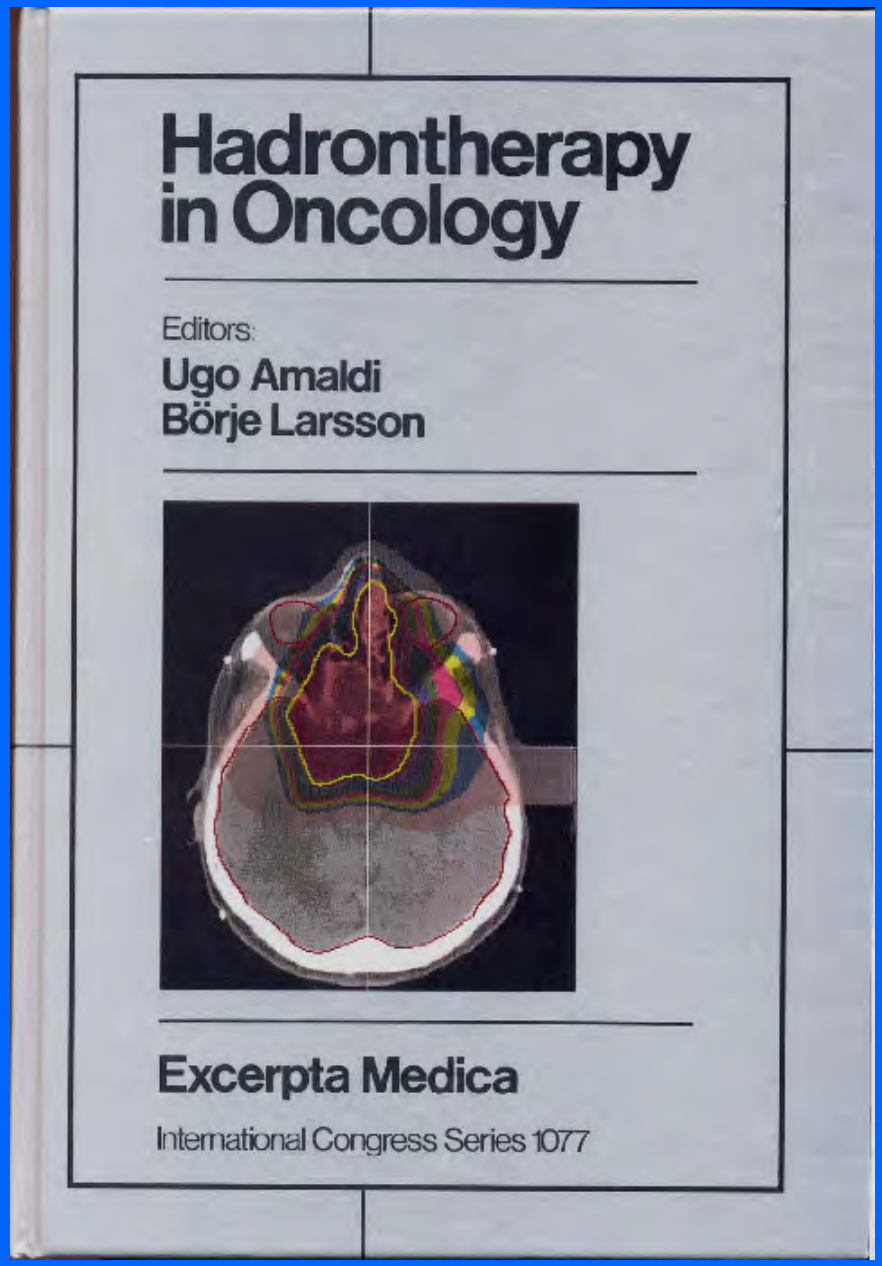
1993 The carbon ‘pilot project’ is launched by G. Kraft at GSI;

1993 MGH launches the tender for the first commercial proton facility;

1994 The last pion facility was stopped.

1994 The first patient is treated with a carbon beam at HIMAC;

First International Symposium on Hadrontherapy

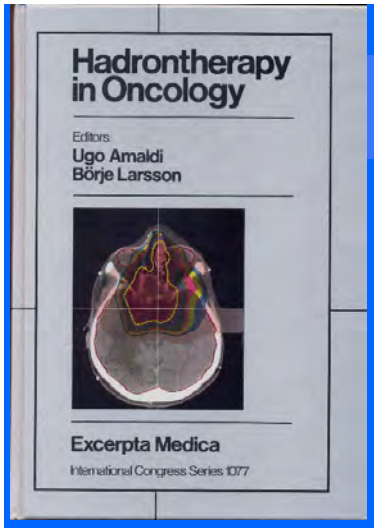


Como, Italy

September 1993

All the world actors presented their work and their ideas

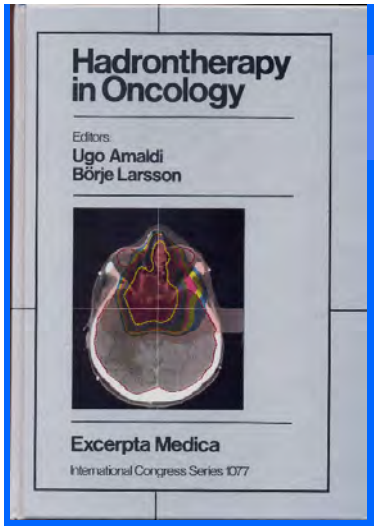
700 pages



Conclusions on pion therapy

- 1000 patients treated at 3 facilities on 20 years
- The conformation to the tumour was not as expected
- The dose due to neutrons and low LET particles was not negligible
- The RBE was never larger than 1.5-2.0
- H. Blattmann (PSI) in 1993 at the Como Hadrontherapy Conference:

  "The initial hope to implement pions successfully in a hospital environment has definitely been given up"



Detailed specifications of IBA cyclotron

Cyclotron-based protontherapy system including a new design of large throw gantries

Y. Jongen[1], W. Beeckman[1], A. Laisné[1], J.P. Dufour[1], S. Zaremba[1], D. Vandeplassche[1], H. Marie[1], R. Verbruggen[1], T. Satoh[2], N. Tachikawa[2], M. Sano[2], K. Ishii[2] and K. Ohtomo[2]

[1]*Ion Beam Applications, Chem* ... *itomo Heavy Industries, Niihama-city, Japan*

Table 1. Beam characteristics

Energy of the extracted beam	235 MeV
Energy spread (one sigma, optimal tuning)	350 keV
Energy reproducibility (one sigma)	350 keV
Maximum extracted current (continuous)	
— when intentionally hardware-limited	300 nA
— when hardware limits are removed	1500 nA
Turn on/off time by ion source (20–80%)	15 μs
Transit time from ion source to patient	30 μs
Turn off time by RF interlocks	10 ms
Turn off time by mechanical beam stopper	600 ms
Extracted monoenergetic beam emittance	
— in the horizontal plane (calculated)	0.8 mm·mrad
— in the vertical plane (calculated)	0.2 mm·mrad

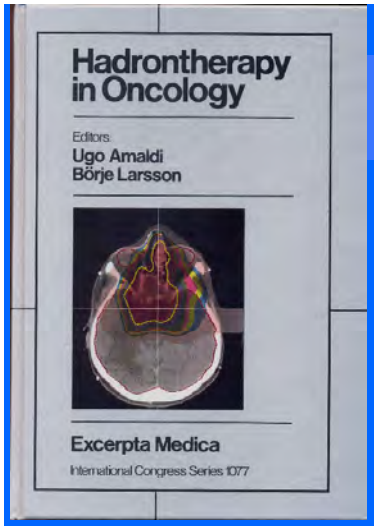
Table 2. Magnet system

Number of sectors	4
Sector angle at the center	32°
Sector angle at the extraction	62°
Maximum gap height	96 mm
Maximum hill field	2.9 T
Valley field	0.9 T
Average field at extraction	2.1888 T
Average field at center	1.76 T
Spiral angle at center	0°
Spiral angle at extraction radius	58°
Magnetic induction	5.324 10^5 At
Apparent current density in coils	155 A/cm^2
Power per coil	97 kW
External magnet diameter	430 cm
Total magnet height	210 cm
Total weight	220 tons
Electrical power consumption	
— full beam extracted	420 kW
— vacuum on stand-by condition	8 kW

Ten years of tenders: from 1994 to 2004

IBA
50% of the maarket

Year	Customer	Provider
1995	MGH, Boston MA, USA	IBA
1996	NCC, Kashiwa, Japan	SHI-IBA
1996-99	Tsukuba University	Hitachi
	Wakasa Wan Energy Research Center	Hitachi
	Shizuoka Prefecture	Mitsubishi
2001	PSI – Villigen, Switzerland	ACCEL
	Wanjie Tumor Hospital – Zibo, China	IBA
	Chang An PMC – Beijing, China	IBA
2002	Rinecker PTC – Munchen, Germany	ACCEL
	Korean NCC - Seoul	IBA
	IUCF (MPRI), Bloomington IN, USA	IBA
	M.D. Anderson CC, Houston TX, USA	Hitachi
2004	University of Florida, Jacksonville FL, USA	IBA



MGH special tendering procedure

M. Goitein:

The specifications of the proton beam

and

of the treatment field

were given

WITHOUT

defining the type of accelerator

IBA 3-room Centre

First IBA Single Room Facility

THE RITA NETWORK AND
THE DESIGN OF COMPACT PROTON
ACCELERATORS

LA RETE ITALIANA TRATTAMENTI ADROTERAPICI E
IL PROGETTO DI ACCELERATORI COMPATTI DI PROTONI

THE TERA COLLABORATION

U. AMALDI, M. GRANDOLFO and L. PICARDI editors

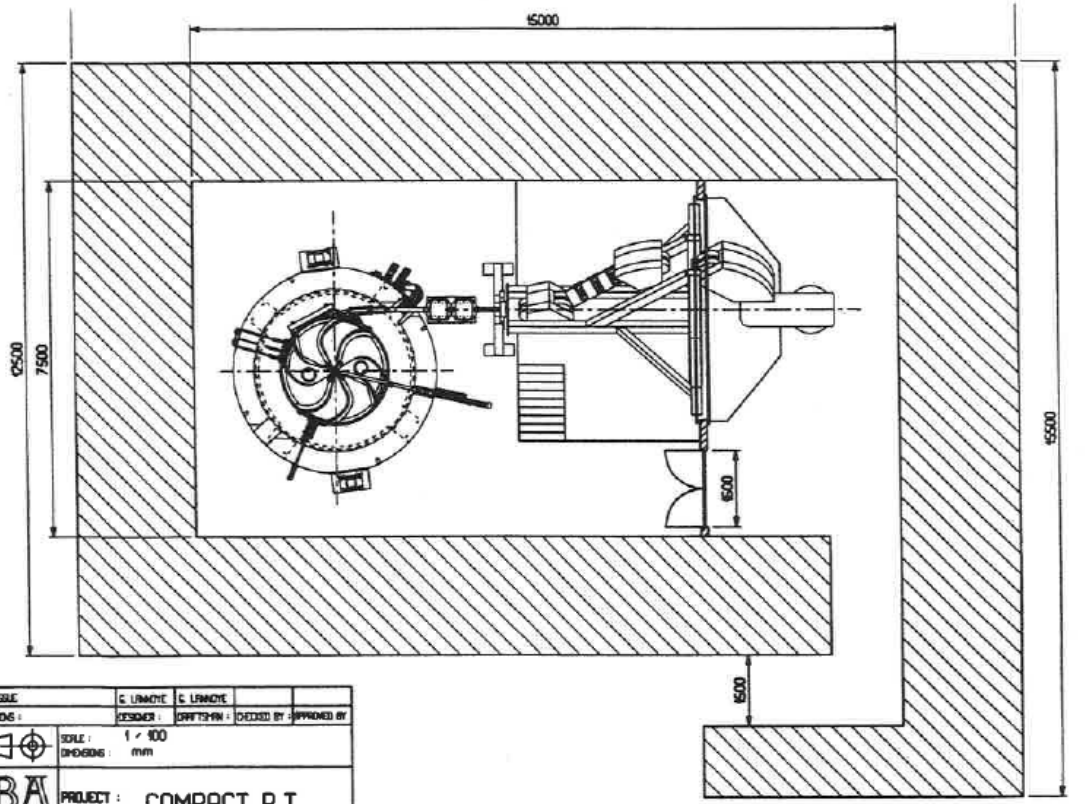
1996

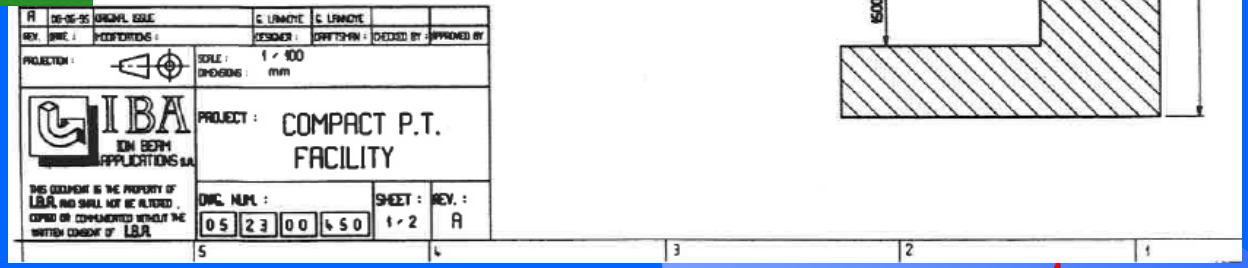
PROGRAMMA ADROTERAPIA

INFN - ISTITUTO NAZIONALE DI FISICA NUCLEARE
AIFB - ASSOCIAZIONE ITALIANA DI FISICA BIOMEDICA
AIFS - ASSOCIAZIONE ITALIANA FISICA SANITARIA
AIRB - ASSOCIAZIONE ITALIANA DI RADIOBIOLOGIA
AIRO - ASSOCIAZIONE ITALIANA DI RADIOTERAPIA ONCOLOGICA
CERN - EUROPEAN LABORATORY FOR PARTICLE PHYSICS
ENEA - ENTE PER LE NUOVE TECNOLOGIE, L'ENERGIA E L'AMBIENTE
ISS - ISTITUTO SUPERIORE DI SANITÀ
SIRR - SOCIETA ITALIANA PER LE RICERCHE SULLE RADIAZIONI
TERA - FONDAZIONE PER ADROTERAPIA ONCOLOGICA

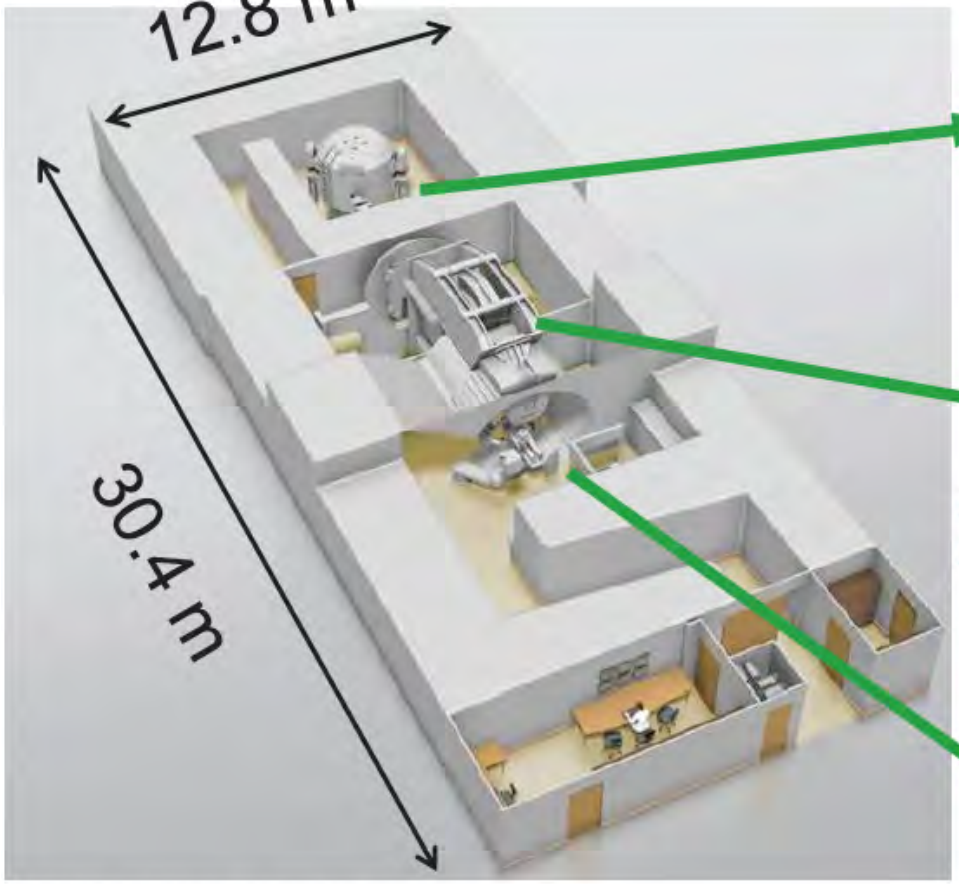
THE IBA CYCLOTRON–BASED SYSTEM

P.Cohilis[1], Y. Jongen[1],

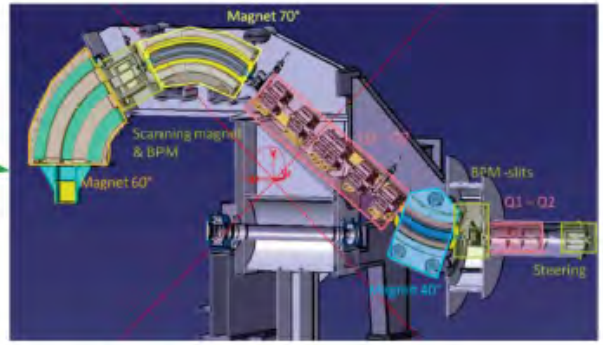




Single-room facility by IBA (Belgium): Proteus One



Synchrocyclotron with superconducting coil: S2C2



New Compact Gantry for pencil beam scanning

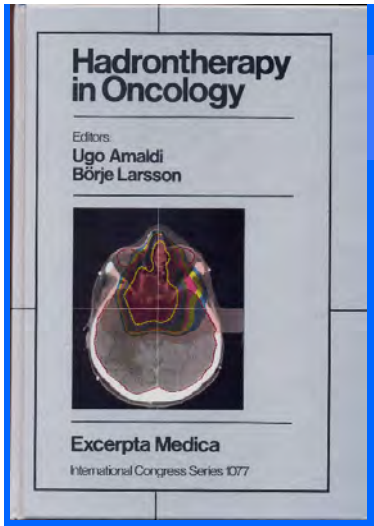
Patient treatment room

iba

Protect, Enhance and Save Lives - 3 -

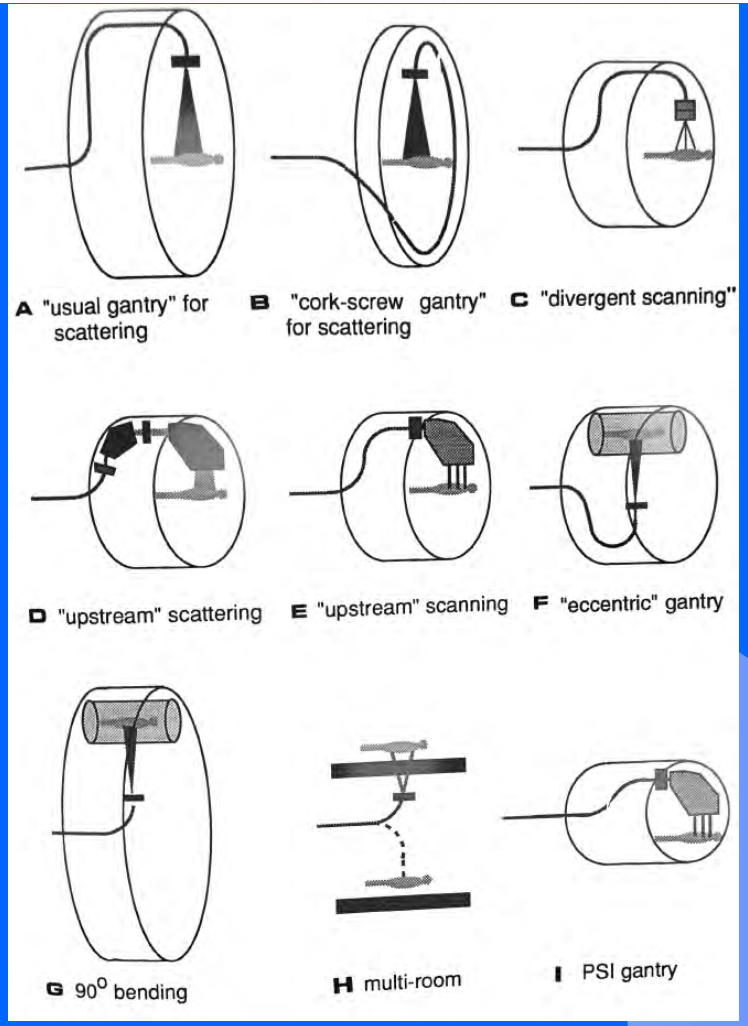
WILLIS-KNIGHTON CANCER CENTER IN SHREVEPORT, LOUISIANA

Seminal contribution of Eros Pedroni on gantries

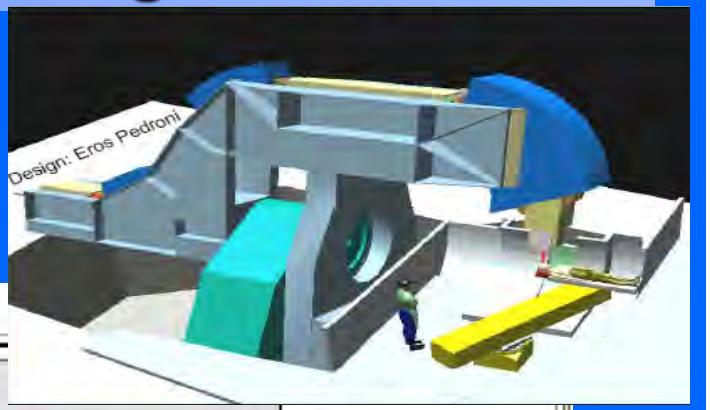


Beam delivery

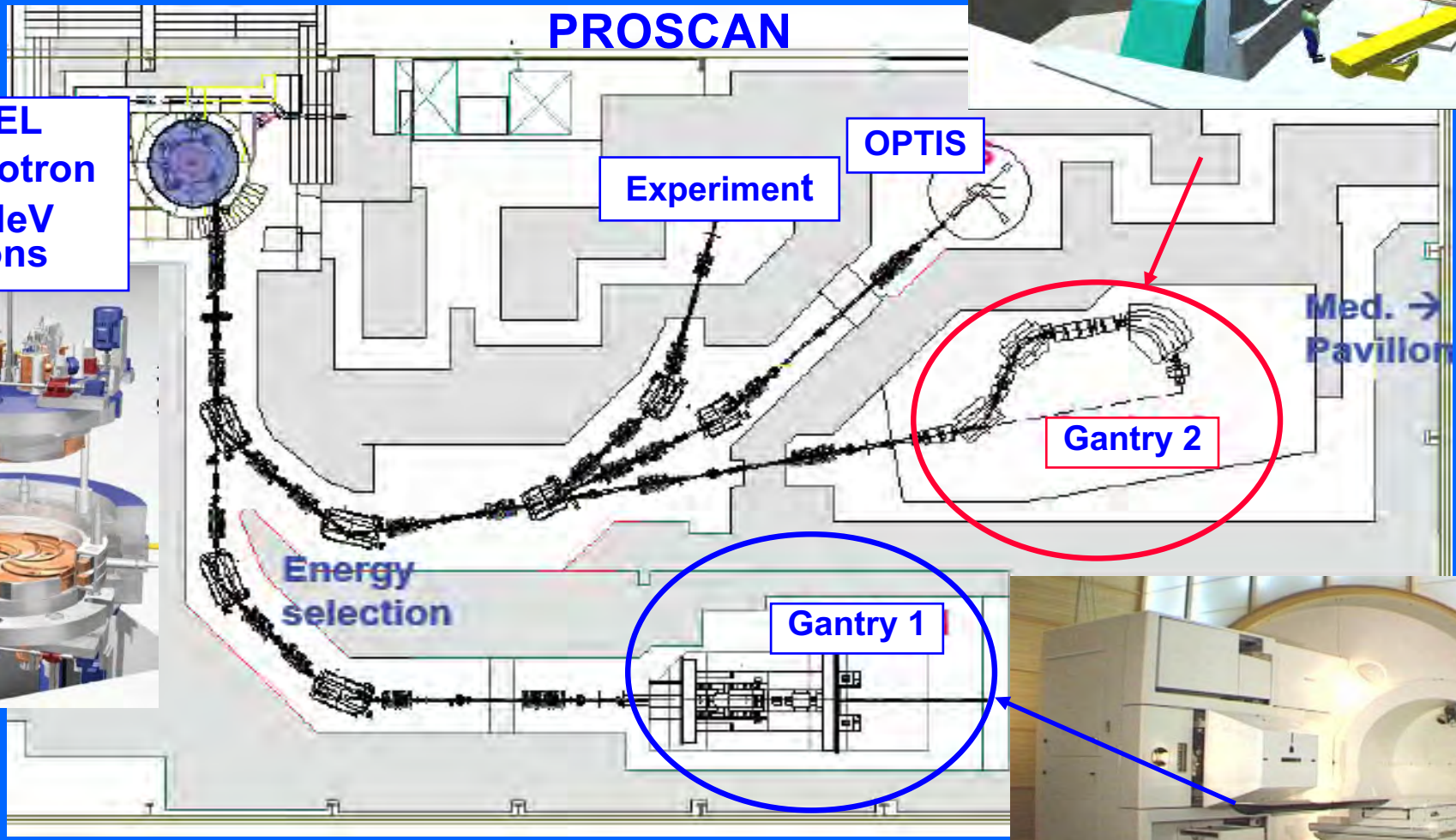
E. Pedroni
Department of Radiation Medicine, Paul Scherrer Institute, Villigen, Switzerland



Pedroni's gantries for PSI



ACCEL
SC cyclotron
250 MeV protons



The beginnings of European carbon ion therapy

Heavy Ion Medical Accelerator at Chiba – first patient in 1994

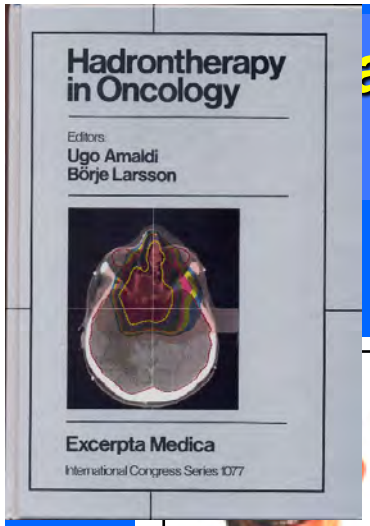
Yasuo Hirao

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

Hirohiko Tsujii

4000 pts 1994-2007

avy Ion Medical Accelerator at Chiba – first patient in 1994



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

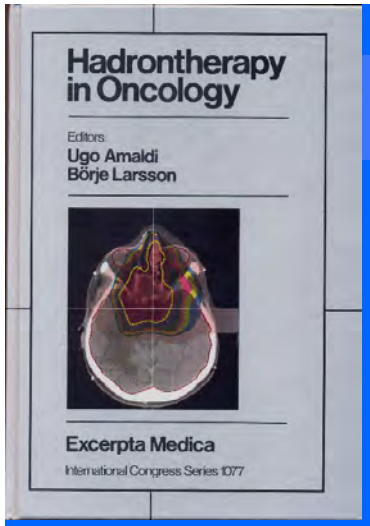
Heavy ion medical accelerator facility in Japan

Kiyomitsu Kawachi, Satoru Yamada, Kenji Sato, Hirotsugu Ogawa, Fumio Soga, Tatsuaki Kanai, Masahiro Endo and Yasuo Hirao

National Institute of Radiological Sciences (NIRS), Chiba-shi 263, Japan

Hirohiko Tsujii

4000 pts 1994-2007



GSI programs presented at the Como Conference

The Darmstadt Program HITAG: heavy ion therapy at GSI

G. Kraft, W. Becher, K. Blasche, D. Böhne, B. Franczak, Th. Haberer, W. Kraft-Weyrather, M. Krämer, B. Langenbeck, G. Lenz, S. Ritter, M. Scholz, D. Schardt, H. Stelzer, P. Strehl and U. Weber
GSI, Darmstadt, Germany

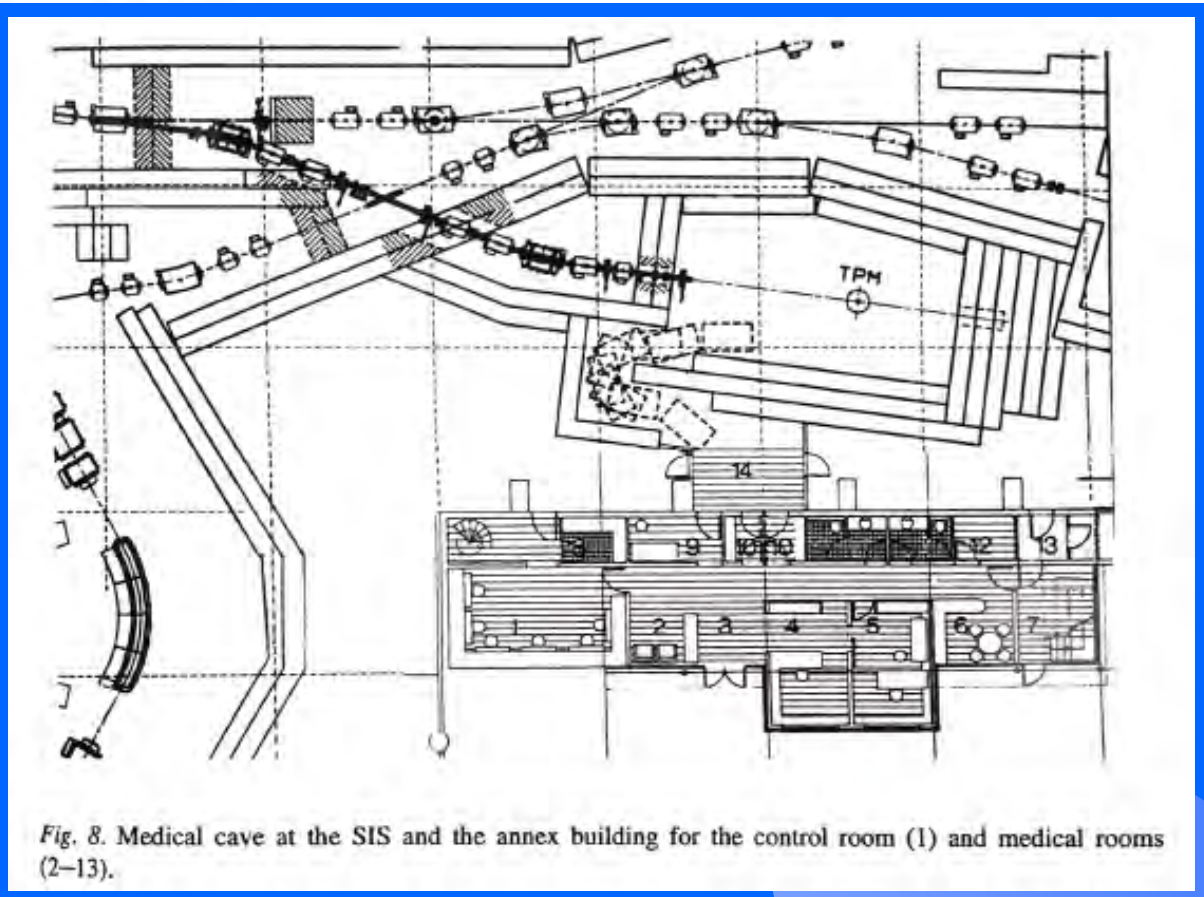
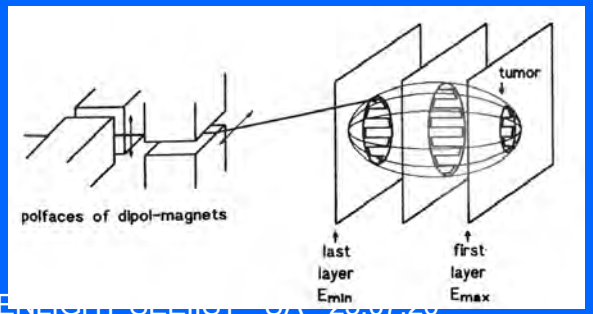


Fig. 8. Medical cave at the SIS and the annex building for the control room (1) and medical rooms (2–13).



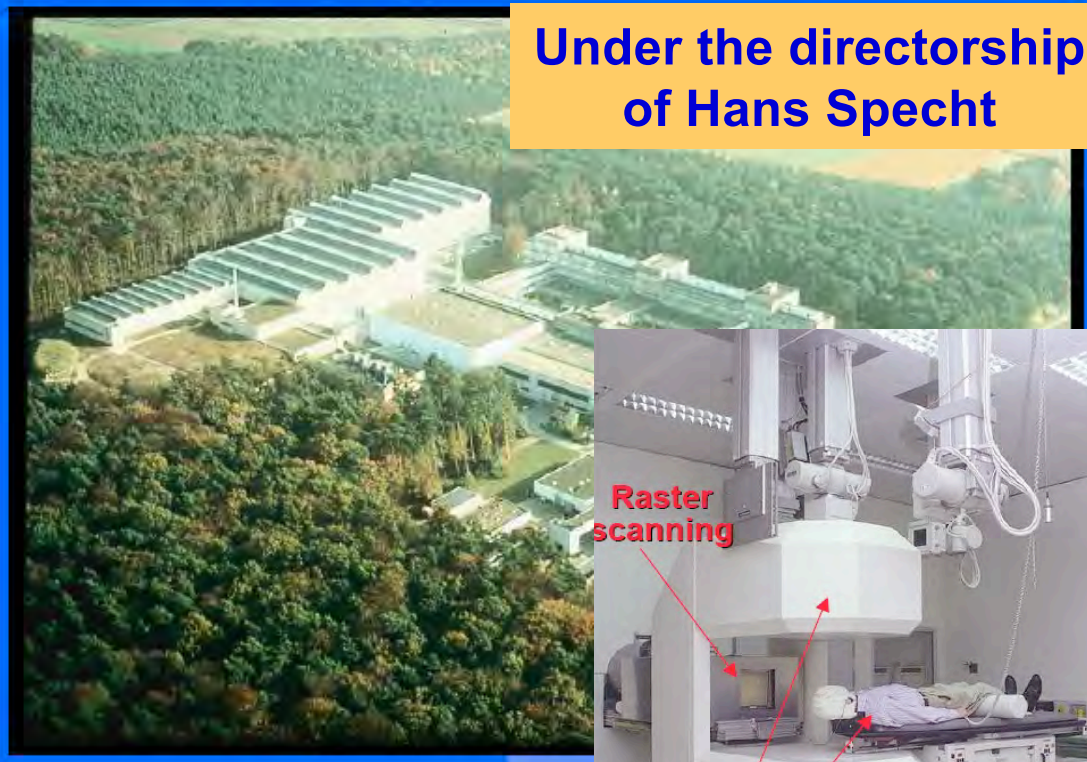
The GSI pilot project : 1997-2008

Gerhard Kraft

450 patients treated
with carbon ions
J. Debus (Heidelberg Univ.)

J. Debus

Under the directorship
of Hans Specht

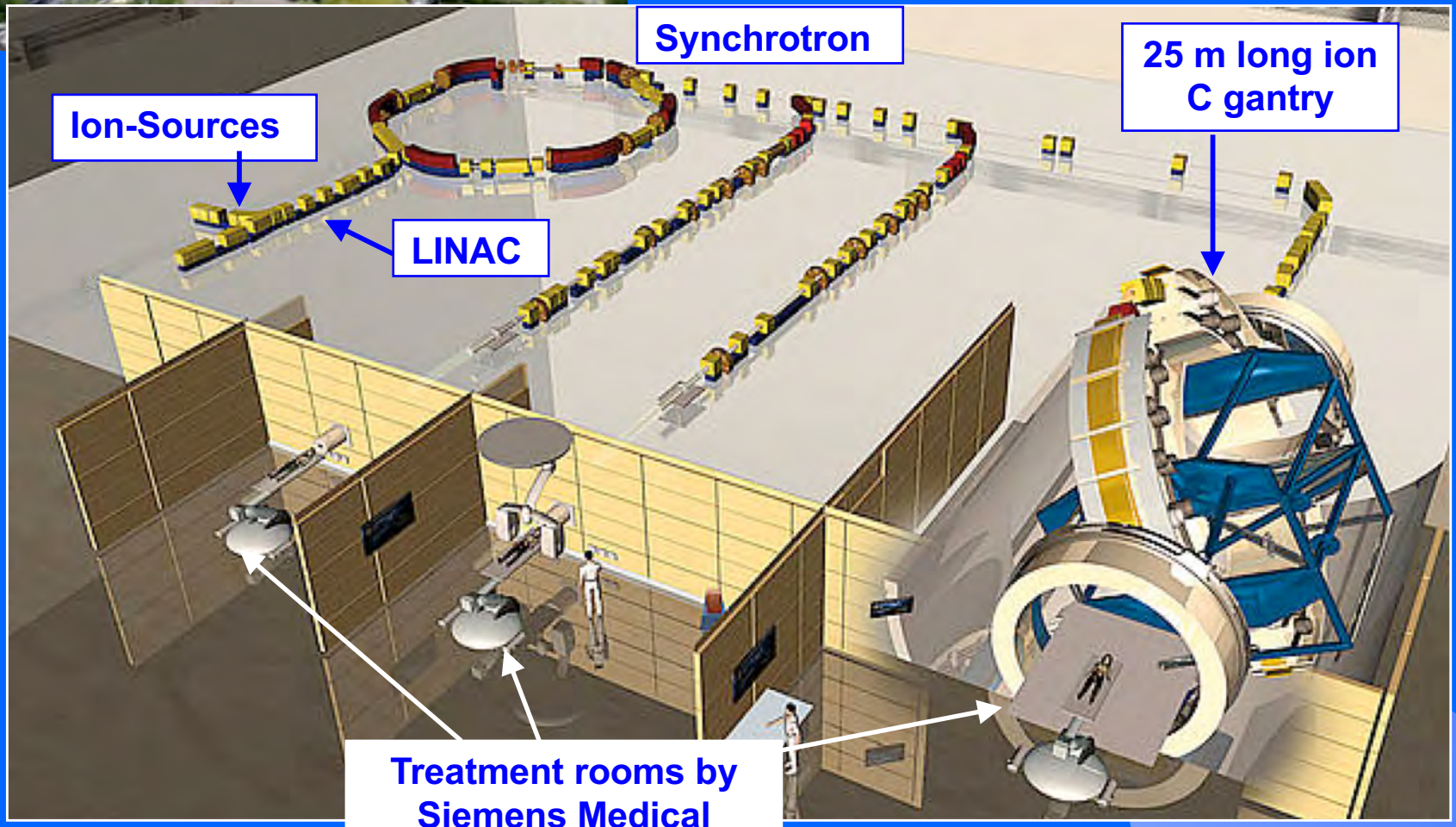


Availability for clinical applications
3 beam time blocks / year
20 days each

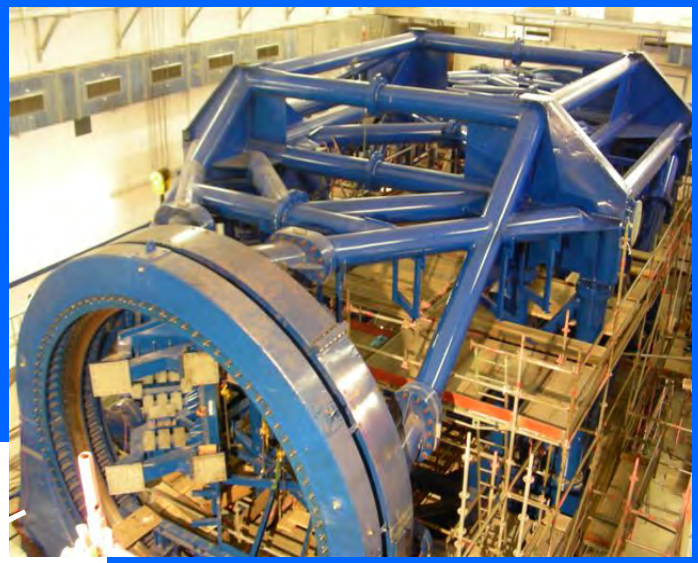
HIT at Heidelberg

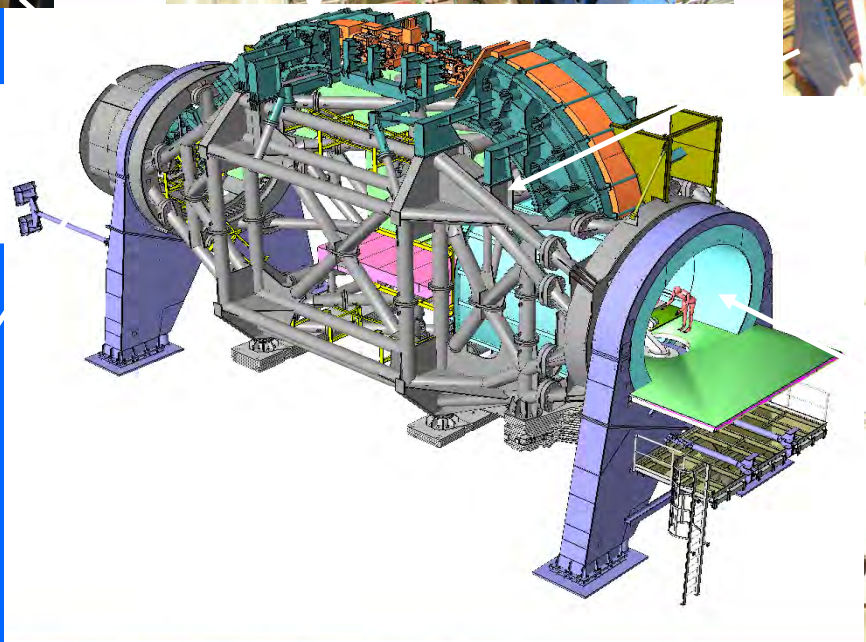
First patient: September 2009

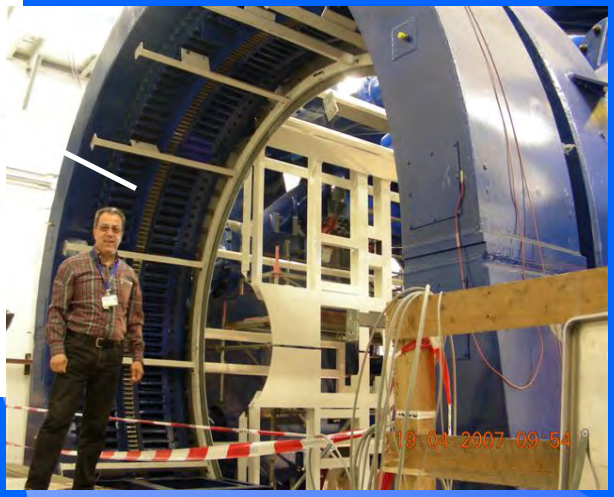
December 2019: 6500 patients (50% c-ions)



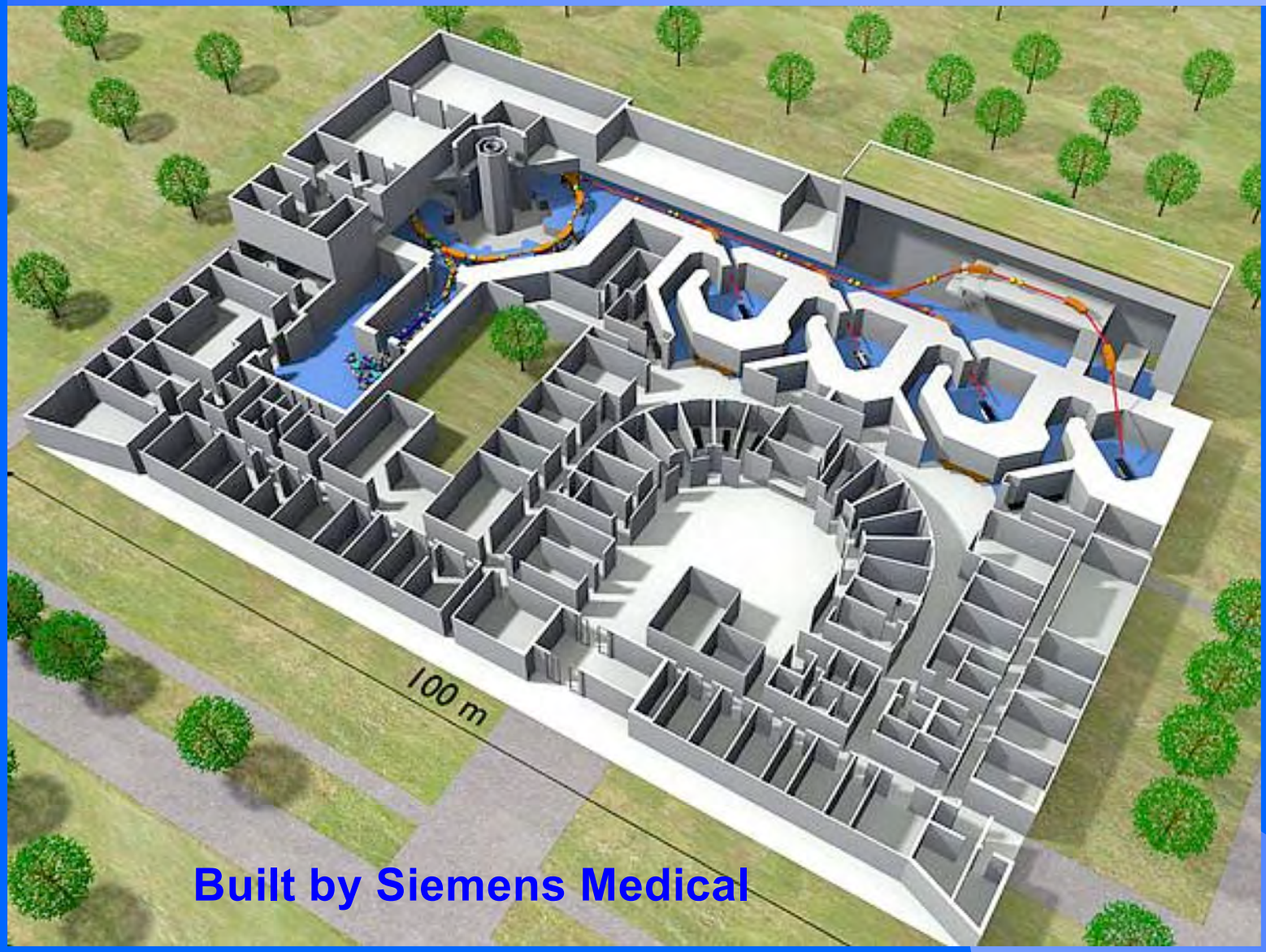
First carbon gantry in the world: 600 tons – 400 kW



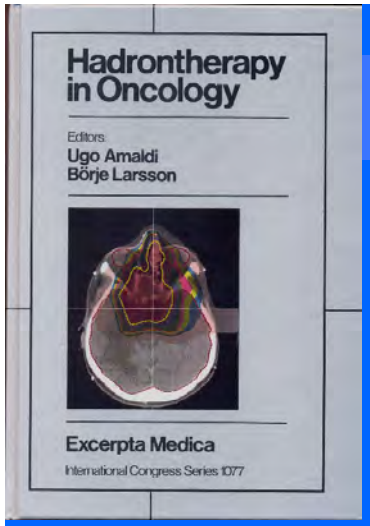




Marburg carbon ion and proton dual centre
Similar centre in Shangai



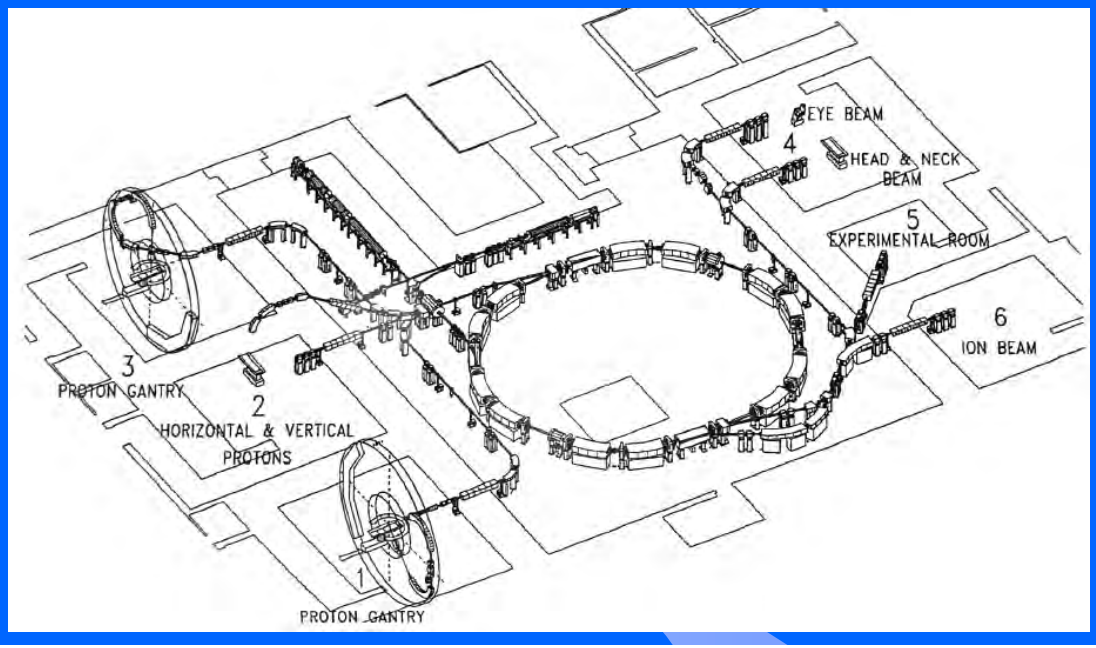
Built by Siemens Medical



TERA presantations at the Como Conference

The Italian Hadrontherapy Project

Ugo Amaldi
CERN, Geneva, Switzerland; II Science Faculty, Milan University, Como Seat, Italy

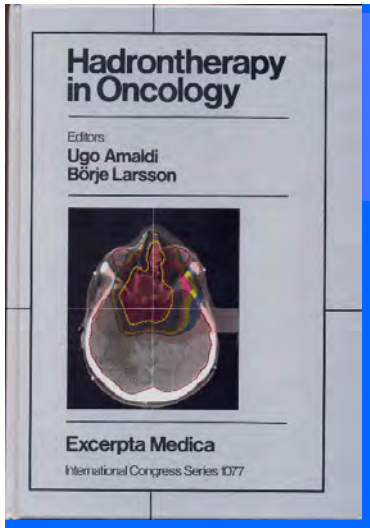


A hospital-based hadrontherapy facility for Italy

U. Amaldi[1,2], G. Arduini[3], R. Cambria[4], D. Campi[1], C. Canzi[5], F. Gerardi[6], F. Gramatica[4], R. Leone[6], G. Manfredi[7], M. Nonis[8], G. Petrucci[1], S. Rossi[4], L. Sangaletti[6], M. Silari[7], G. Tosi[9], L. Vecchi[6] and M. Weiss[1]

The Italian hadrontherapy accelerator complex

G. Arduini[1], R. Leone[2], R.L. Martin[3], S. Rossi[4] and M. Silari[5]



MedAustron presantations at the Como Conference

Ion cancer therapy research as part of the AUSTRON project

Ph. Bryant[1], H.D. Kogelnik[2], M. Pavlovic[3], R. Pötter[4], M. Regler[5] and H. Schönauer[6]

[1]CERN, Geneva, Switzerland (AUSTRON Planning group); [2]Institut für Radiotherapie und Radio-Onkologie, LKA Salzburg, Austria; [3]AUSTRON Planning group (on leave from the Slovak Technical University); [4]Universitätsklinik für Strahlentherapie und Strahlenbiologie, AKH Wien, Austria; [5]AUSTRON Planning group (partially on leave from the Austrian Academy of Sciences); [6]CERN, Geneva, Switzerland

In 1995 U.A. and M. Regler convinced CERN to start Proton Ion Medical Machine Study, PIMMS

Optimized synchrotron for therapy

Project Leader: Phil Bryant

Chair of PAC: Giorgio Brianti

1996-2000

The design was conceived as a"toolkit" from which to take the parts of interest for building a particular centre

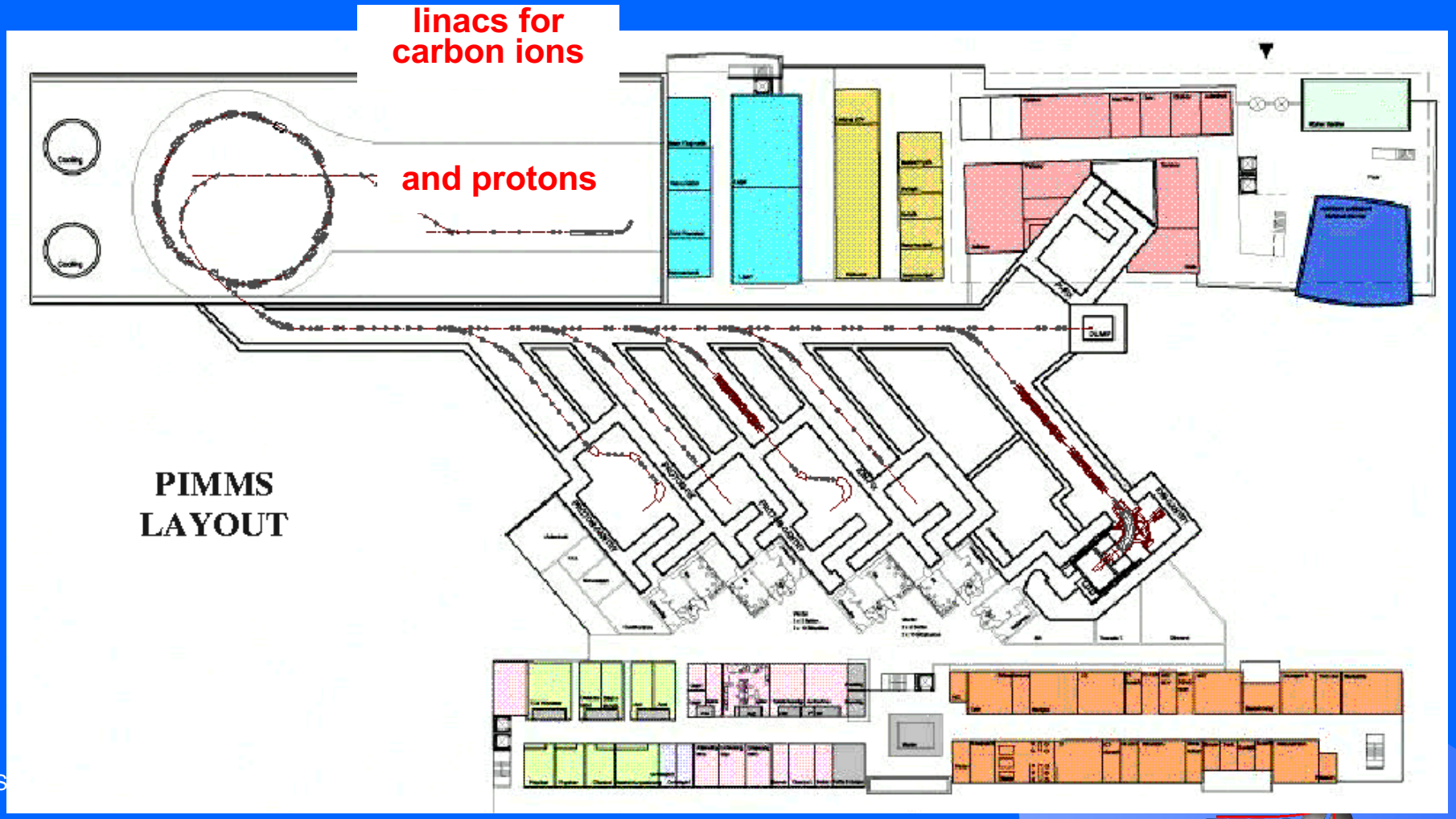
M. Regler

TERA

In 1995 U.A. and M. Regler convinced CERN to start Proton Ion Medical Machine Study, PIMMS

Contributors: CERN

TERA Foundation (Italy); MedAustron Project (Austria)

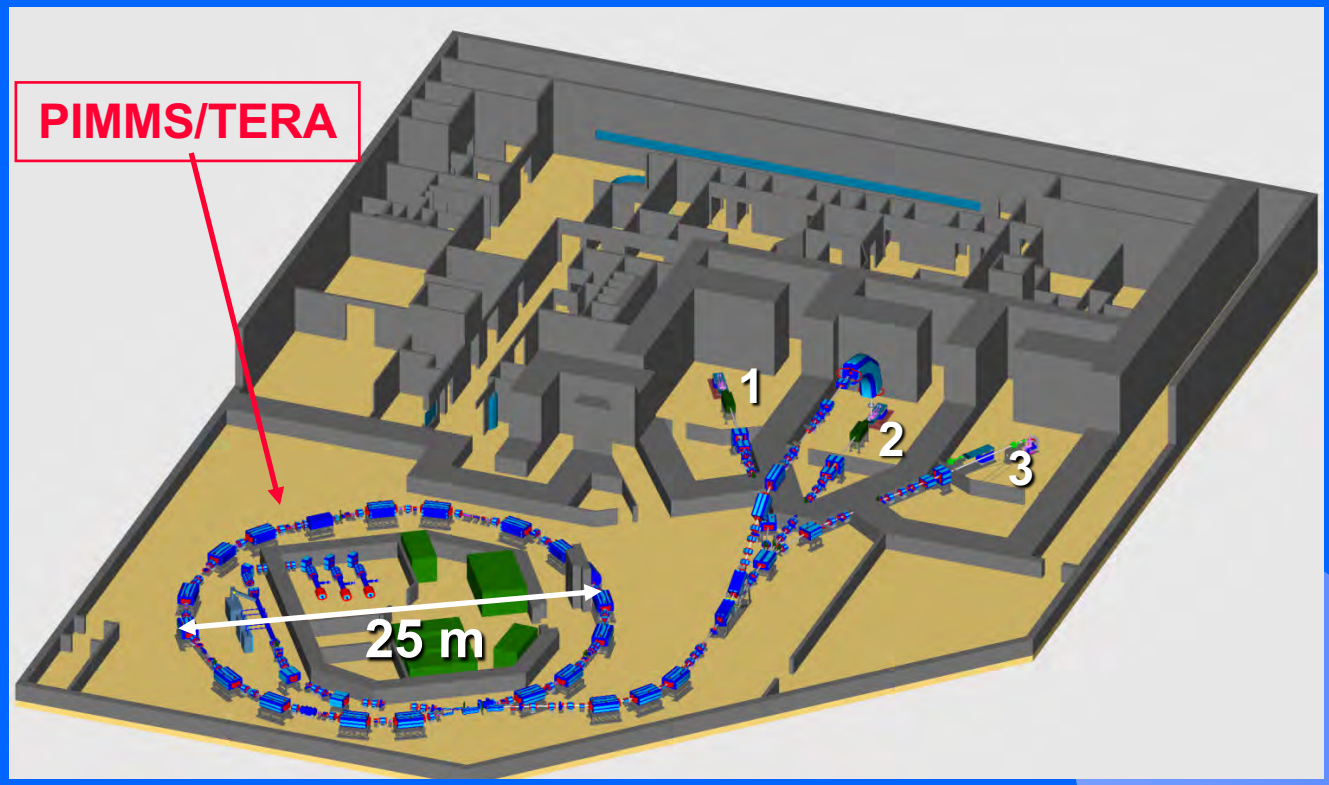


TERA

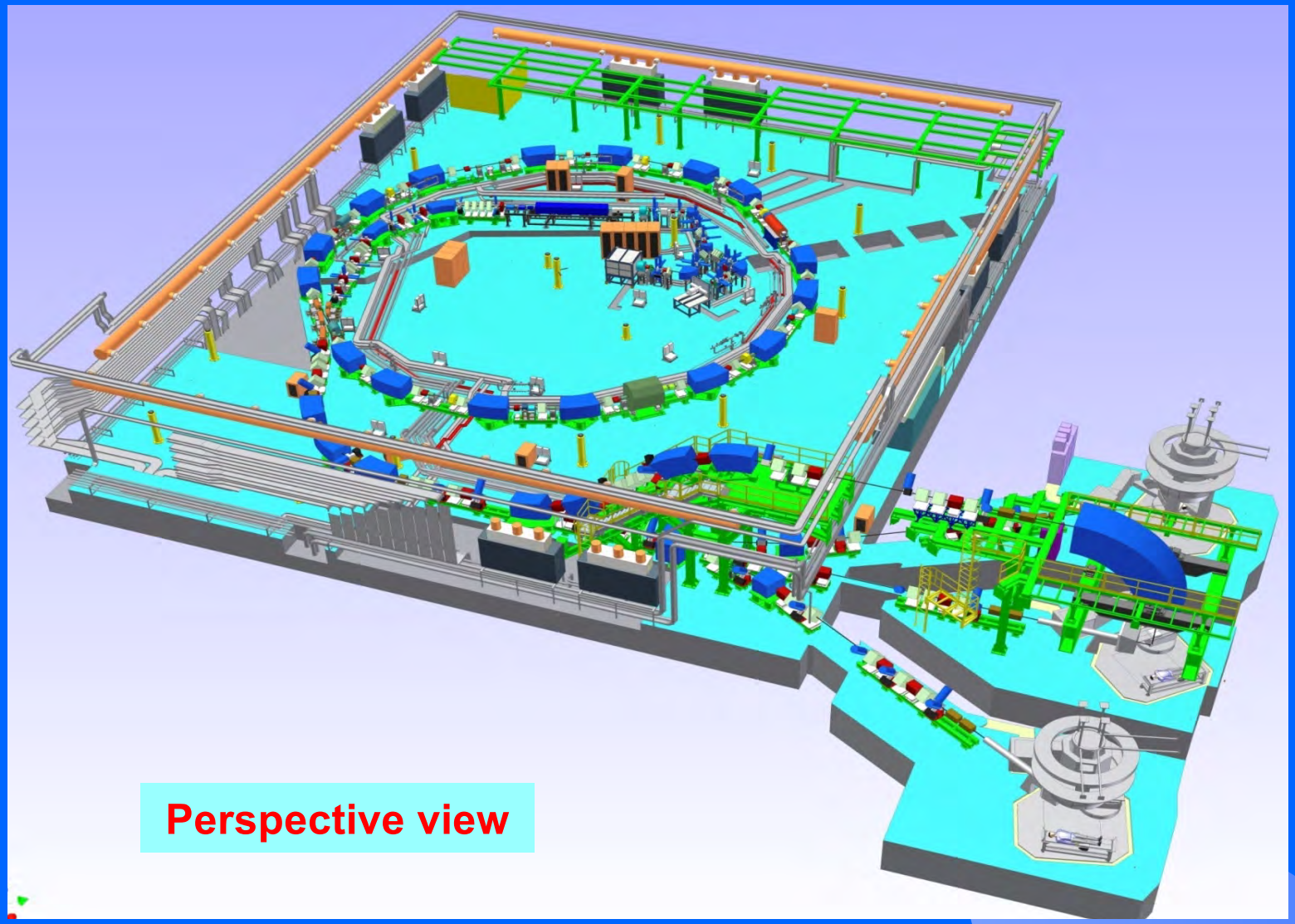
CNAO = Centro Nazionale di Adroterapia Oncologica

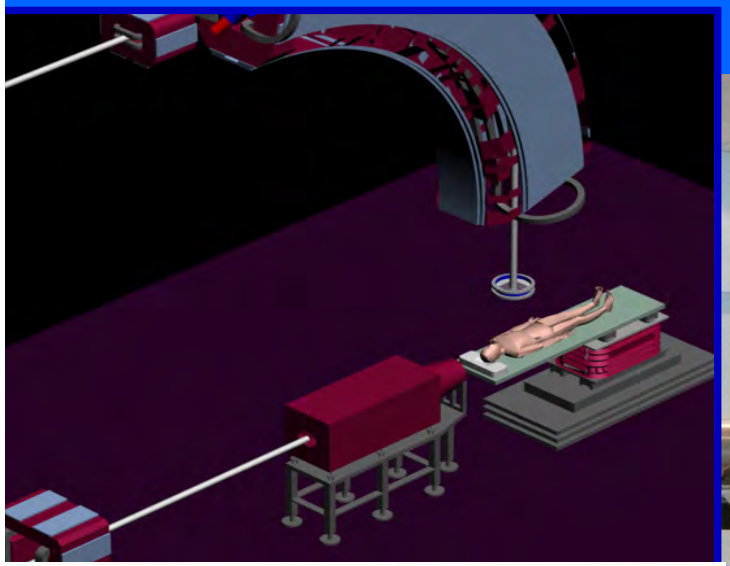
CNAO Foundation created by the Italian Government in 2002:
4 Hospitals in Milan, 1 Hospital in Pavia and TERA

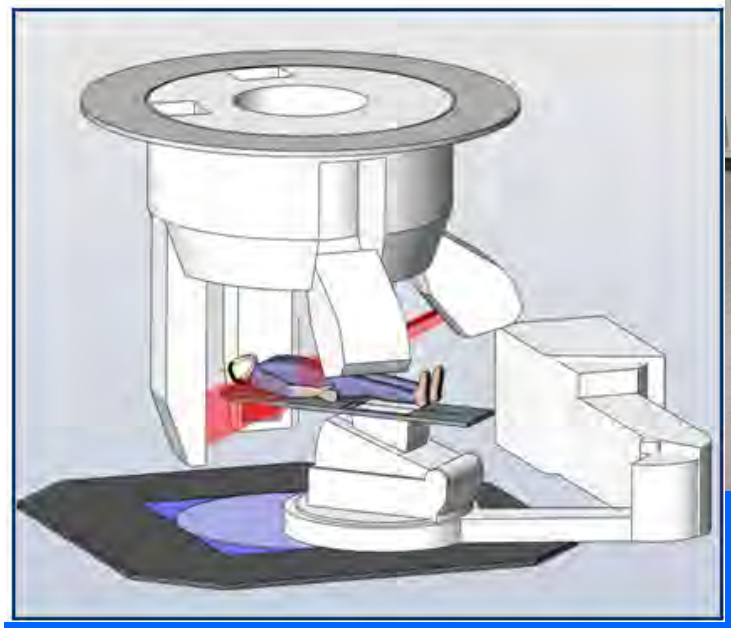
In October 2003 TERA passed to CNAO
the design of CNAO (2000 pages) and 25 people

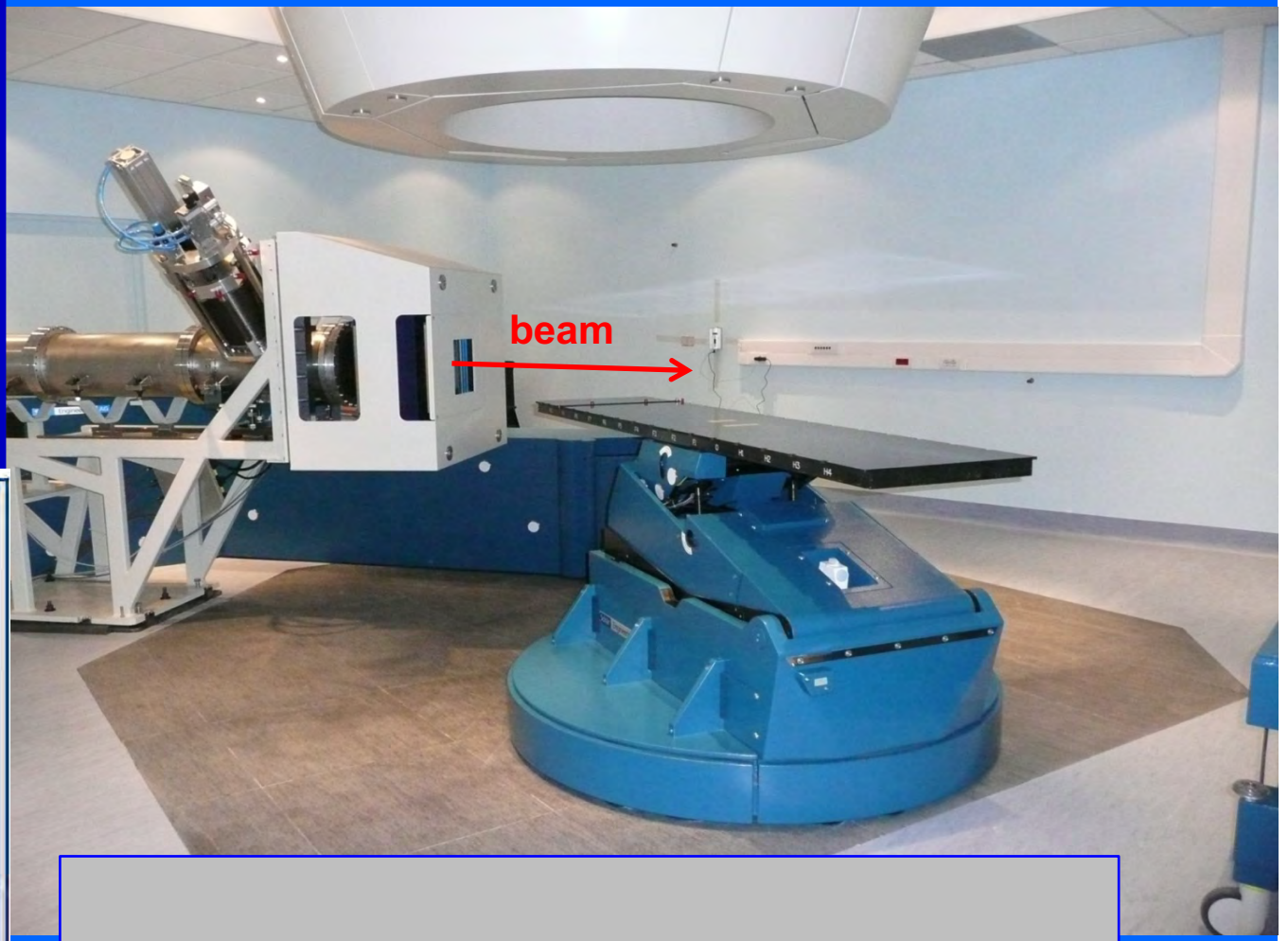


CNAO at Pavia









December 2019: 2100 patients treated

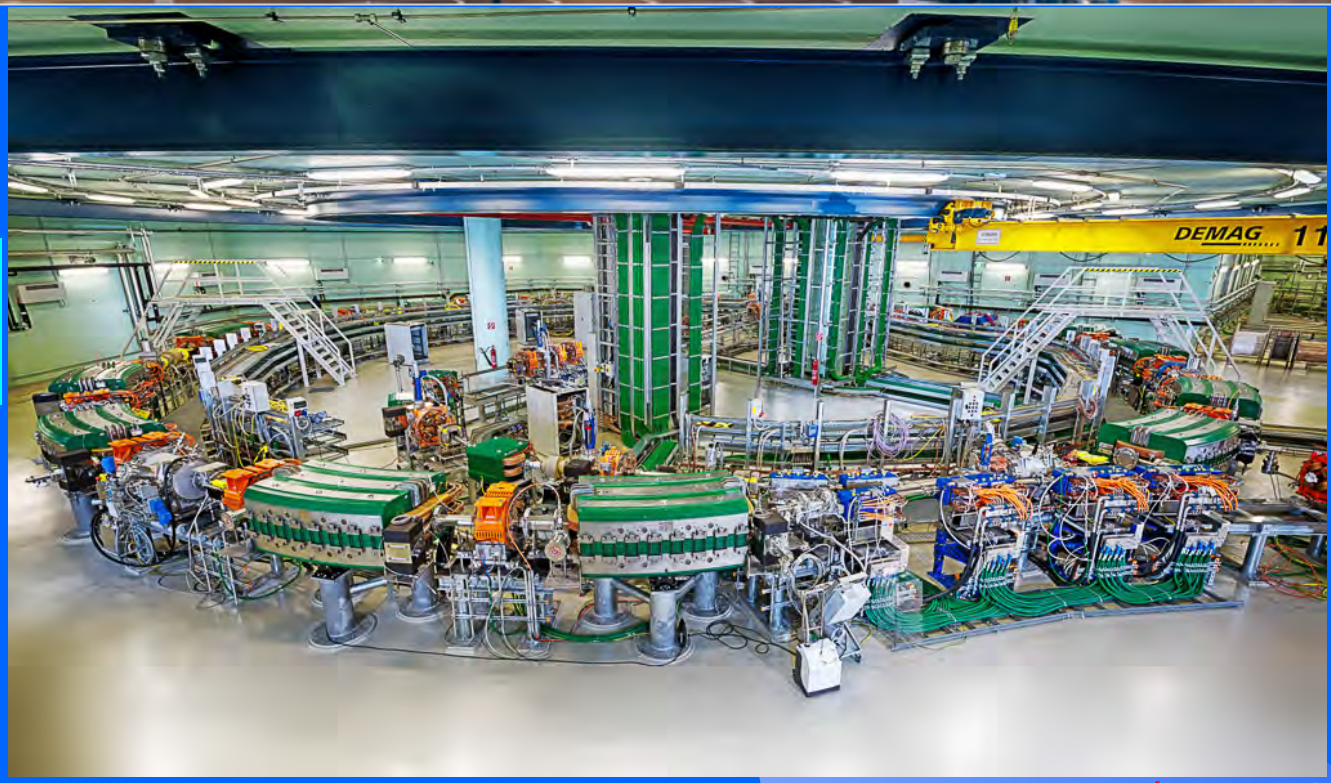
(60% wth carbon ions)

The layout of MedAustron is similar to the one of PIMMS

The layout of MedAustron is similar to the one of PIMMS

First patient in 2016

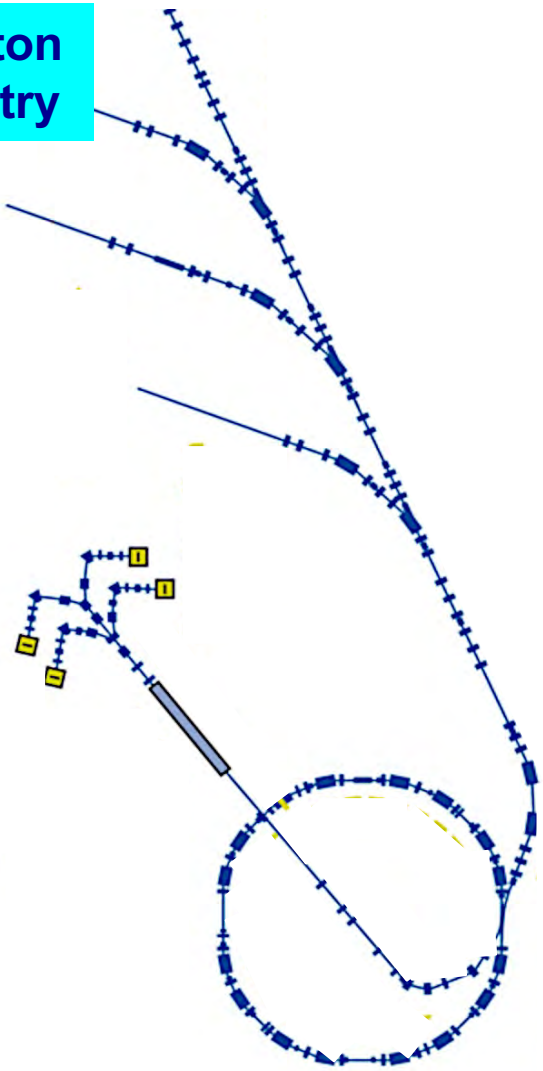
By the end on 2019: 500 pts

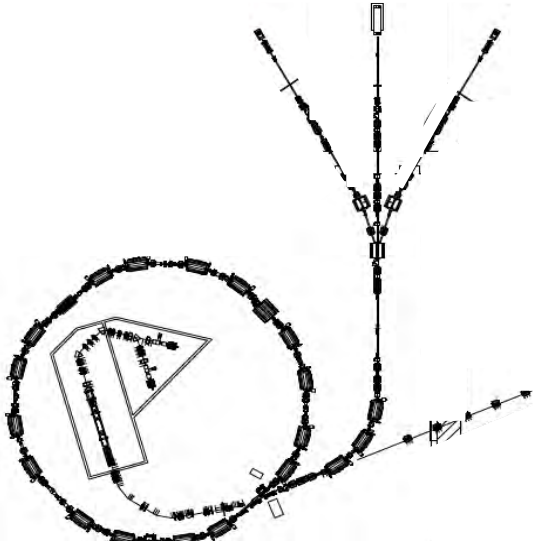


Footprints of MedAustron and CNAO

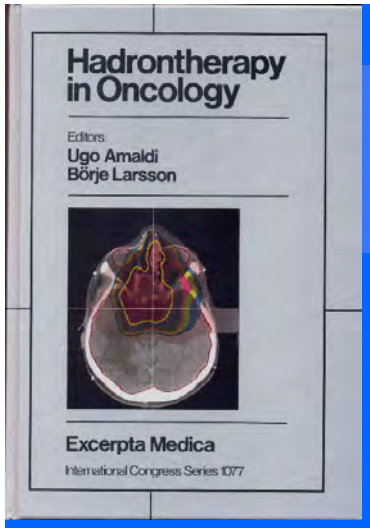
MedAustron	CNAO
has built PIMMS	has used PIMMS as a toolkit to reduce the footprint

proton gantry





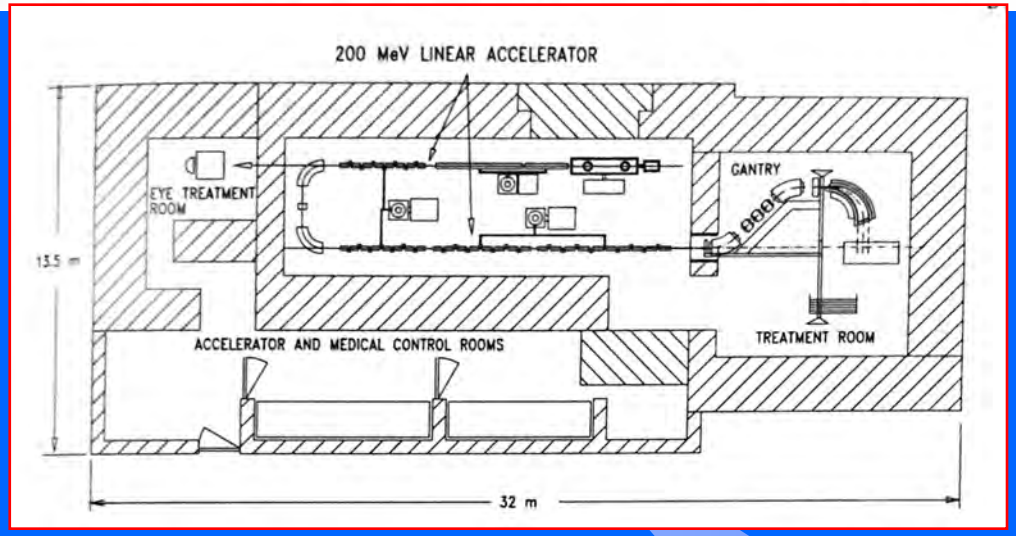
Proton linacs for therapy

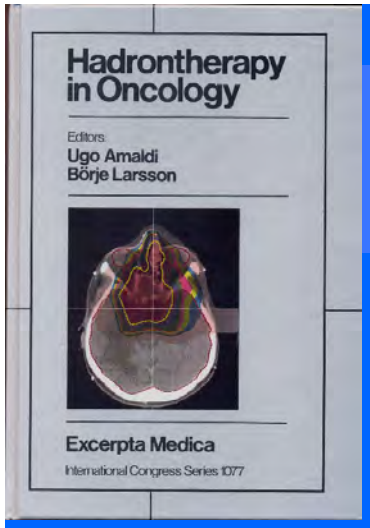


Linac Unit built and beam tested with protons by TERA-CERN-INFN in 2002

The Italian Hadrontherapy Project

Ugo Amaldi
CERN, Geneva, Switzerland; II Science Faculty, Milan University, Como Seat, Italy





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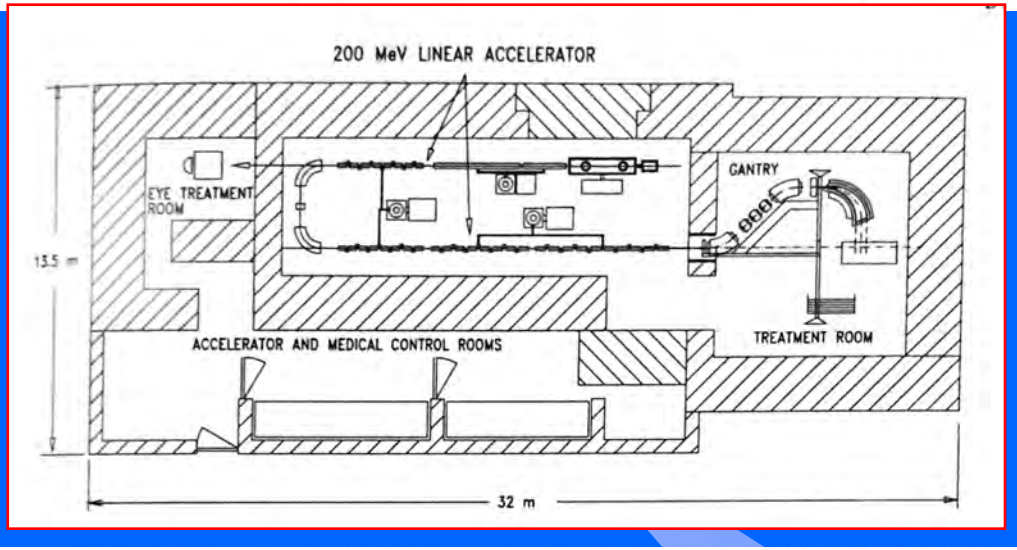
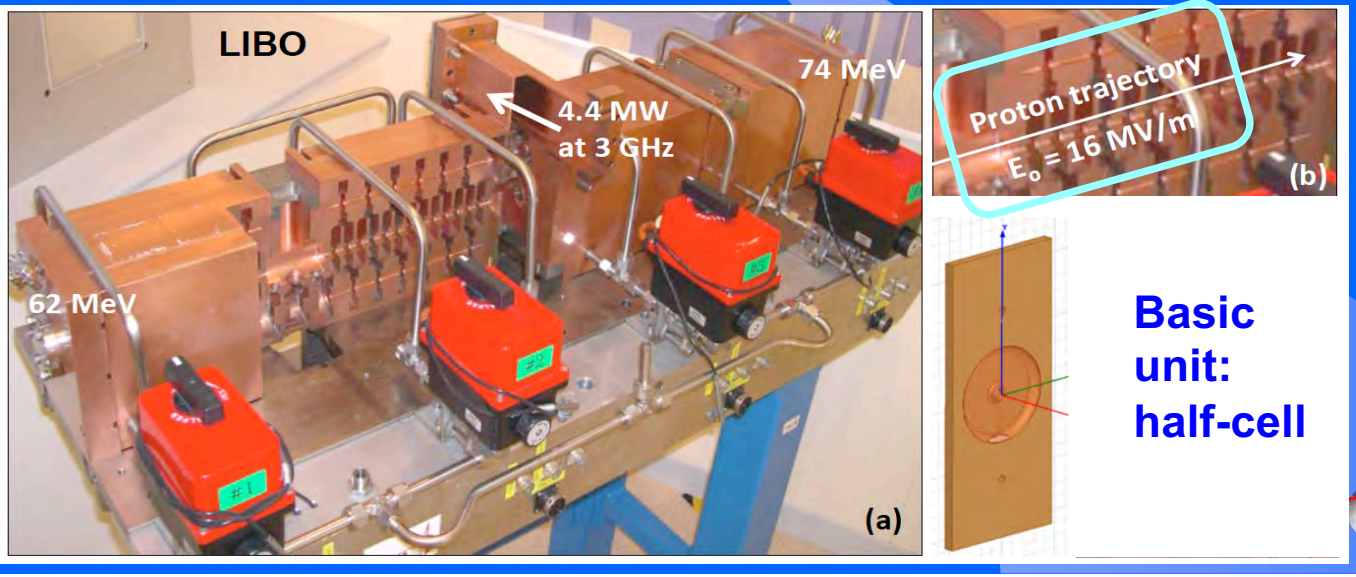


Luigi Picardi
ENEA



Basic unit: half-cell

AVO- ADAM
(see https://www.avoplc.com/en-gb/)

Built a linac prototype in a CERN bunker
That accelerated protons to 120 MeV

(Energy change in 5 ms has been tested)

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Now constructing the first medical unit in Daresbury

for two sites

one in London and the second in Cyprus


CNAO @ Pavia
The End