HITRI plus
Heavy Ion Therapy Research Integration

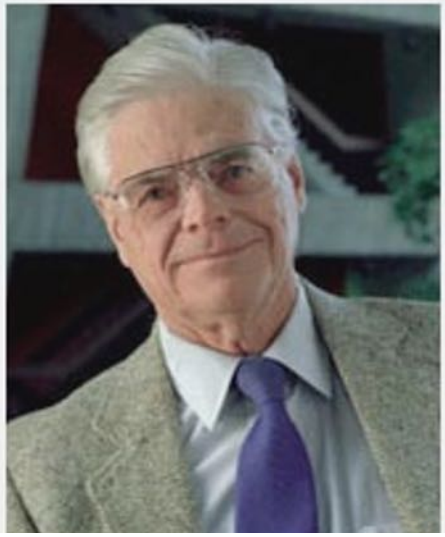
ACCELERATORS FOR HADRON THERAPY

UGO AMALDI – TERA FOUNDATION

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008548

The Berkeley times

The first steps with charged hadrons at the Berkeley laboratory



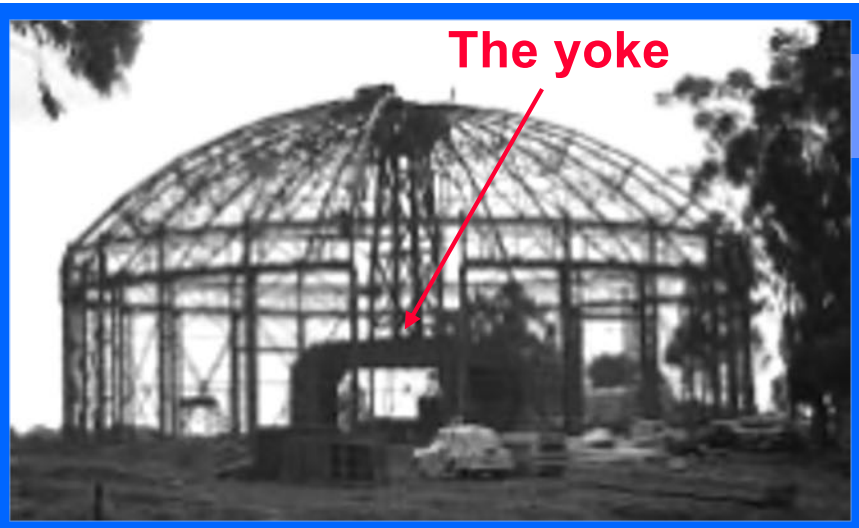
Founder and first director of Fermilab

In 1946 Robert Rathbun Wilson wrote that (*):

- **Protons can be used clinically to spare normal tissues**
- **Modulator wheels can spread narrow Bragg peak**
- **Helium and Carbon ions can also be used**

(*) Wilson, R.R. (1946), "Radiological use of fast protons, Radiology 47, 487.

The 184-inch cyclotron - 1946



Cornelius Tobias

1918-2000

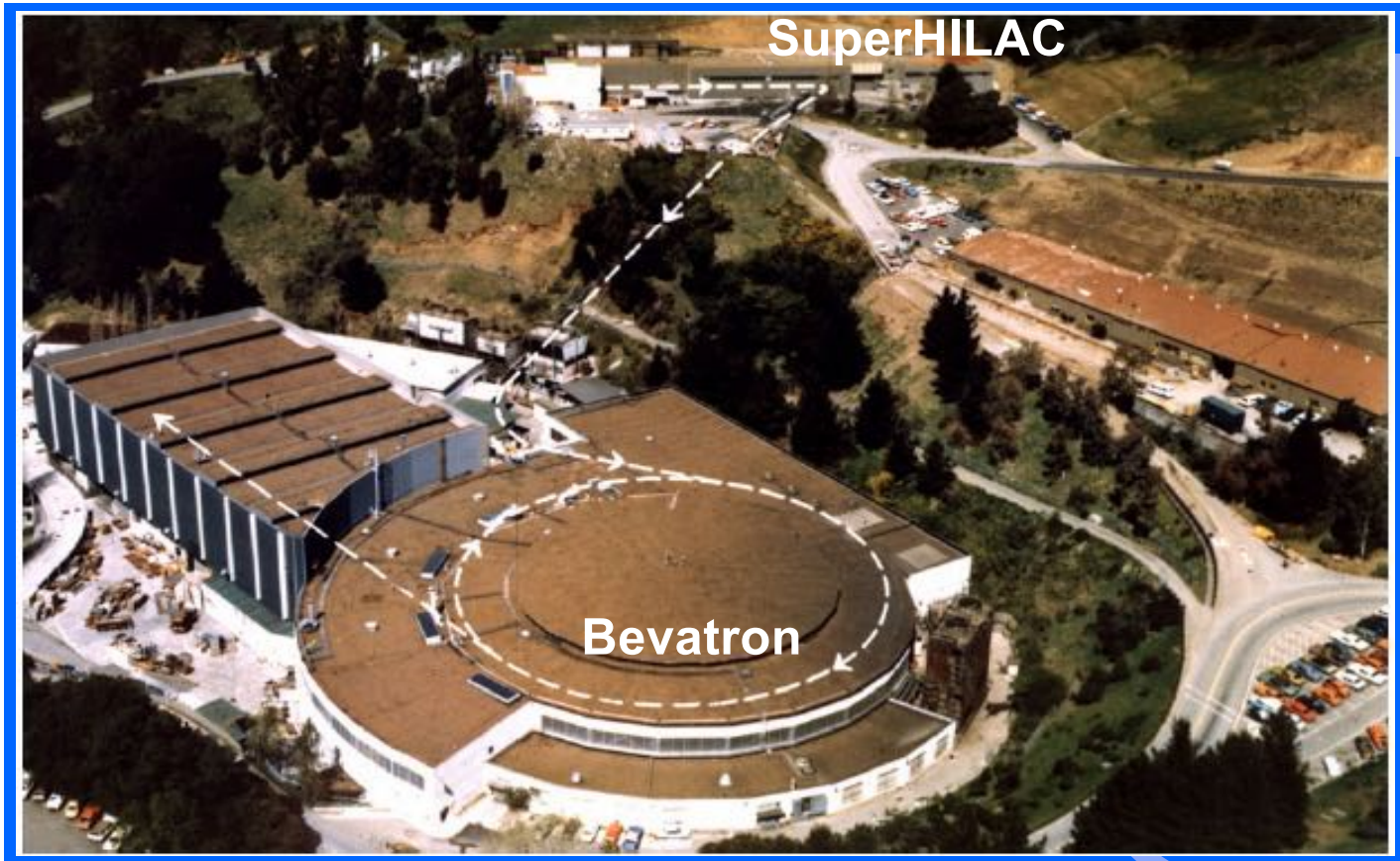
At the Berkeley Laboratory

First treatment of pituitary glands: 1954

Treatment of pituitary tumors: 1956

1000 patients treated with protons by the end of the program 1974

THIS COURSE: Start of Biophysics in Hadron Therapy and LBL
Speaker: Eleanor Blakely (LBNL)



Bevalac - 1974

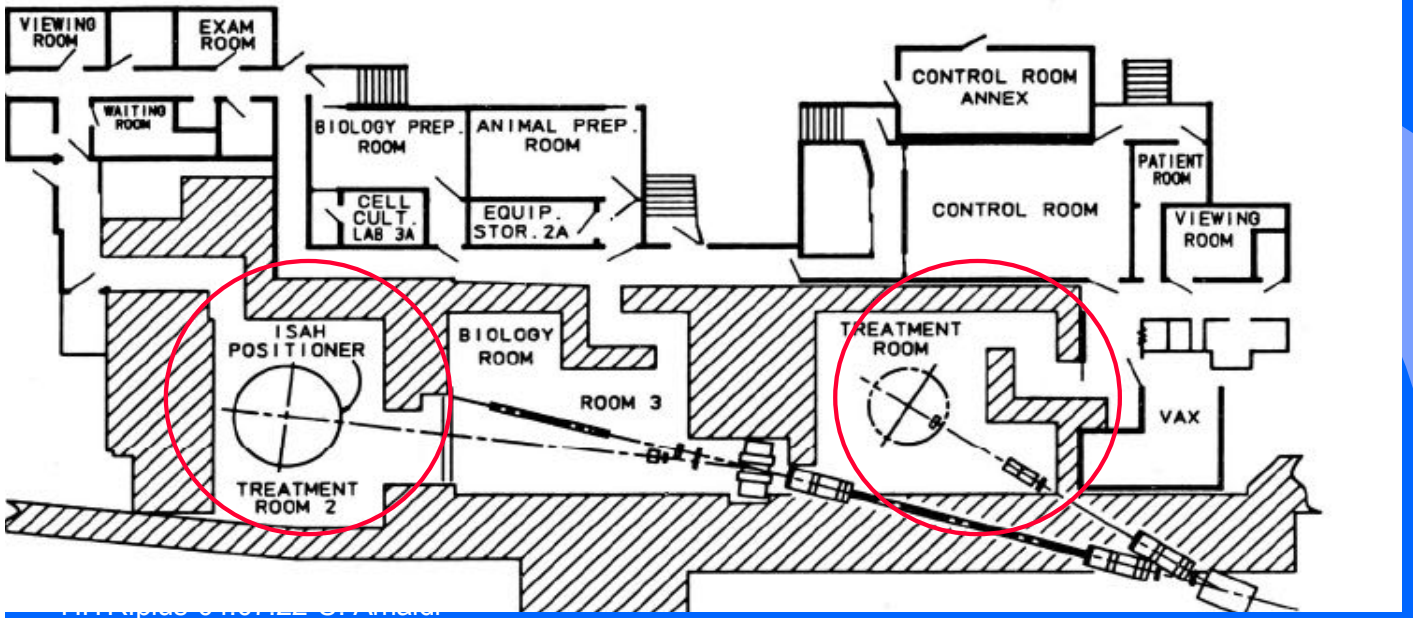
Helium: 2000 patients

Neon: 500 patients

1992

Clinical treatments ended with the closure of the Bevatron

At Berkeley more than 2,500 patients had been treated

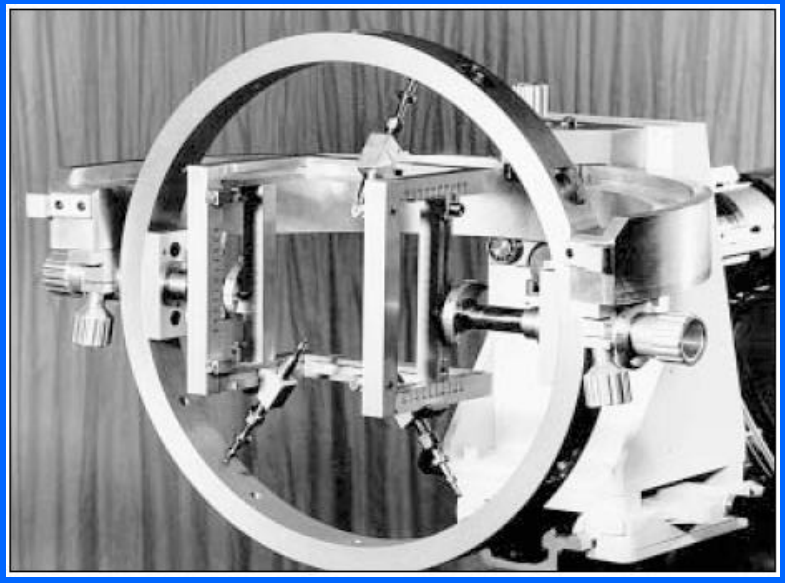


The pioneering years

Uppsala – protontherapy

1957

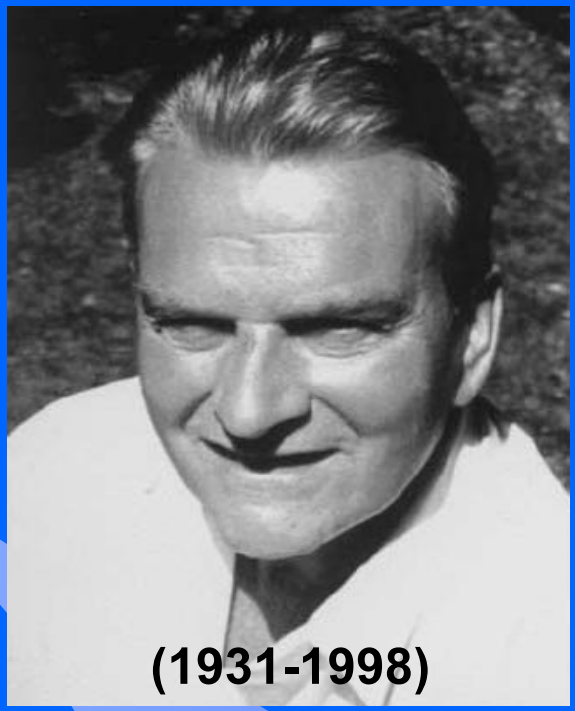
The modified synchrocyclotron



Alignment system

Bőrje Larsson

Doctoral dissertation - 1962



(1931-1998)

“On the Application of a 185 MeV Proton Beam to Experimental Cancer Therapy and Neurosurgery: a Biophysical Study”

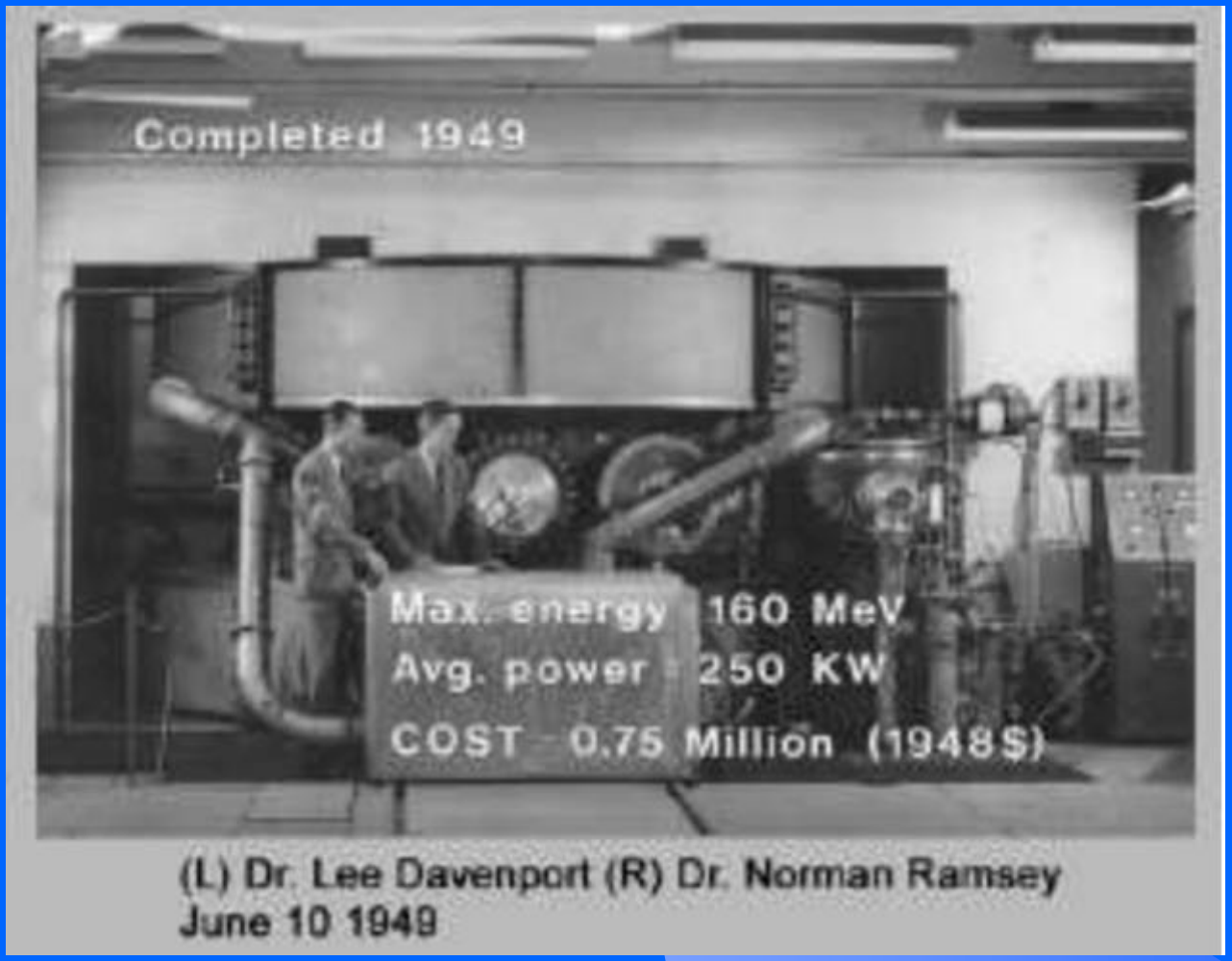
30 years of pioneering proton therapy in physics labs

Lawrence Berkeley Laboratory	USA	1954
Uppsala	Sweden	1957
Harvard Cyclotron Laboratory (*)	USA	1961
Dubna	Russia	1967
Moscow	Russia	1969
St. Petersburg	Russia	1975
Chiba	Japan	1979
Tsukuba	Japan	1983
Paul Scherrer Institute	Switzerland	1984

The Harvard 160 MeV cyclotron

I945 ‘

Bob’ Wilson - a Lawrence student – became Associate professor at Harvard and designed a new160 MeV cyclotron



(L) Dr. Lee Davenport (R) Dr. Norman Ramsey
June 10 1949

The three programs at the Harvard cyclotron (9116 pts)

Neurosurgery fot intercranial) lesions (AVMs)

(3,687 patients)

Neurosurgery Dept. of MGH

Raymond N. Kjilberg, Bernard Kliman

Eye tumors

(2,979 patients)

Massachusetts Eye and Ear Hospital.

Ian Constable, Evangelos Gragoudas

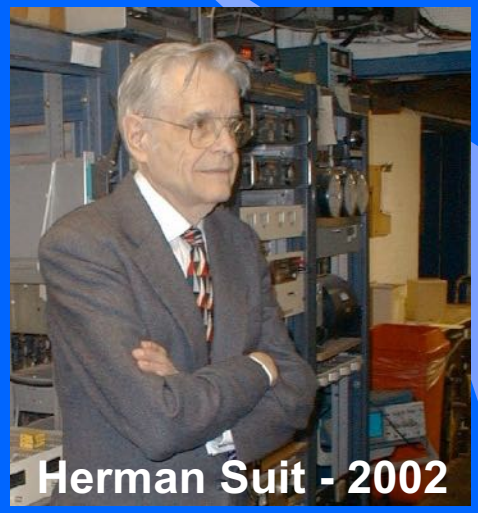
Larger tumors

(2,449 patients)

Radiation Medicine Dept of MGH

Herman Suit, Michael Goitein,
Joel Tepper, Lynn Verhey

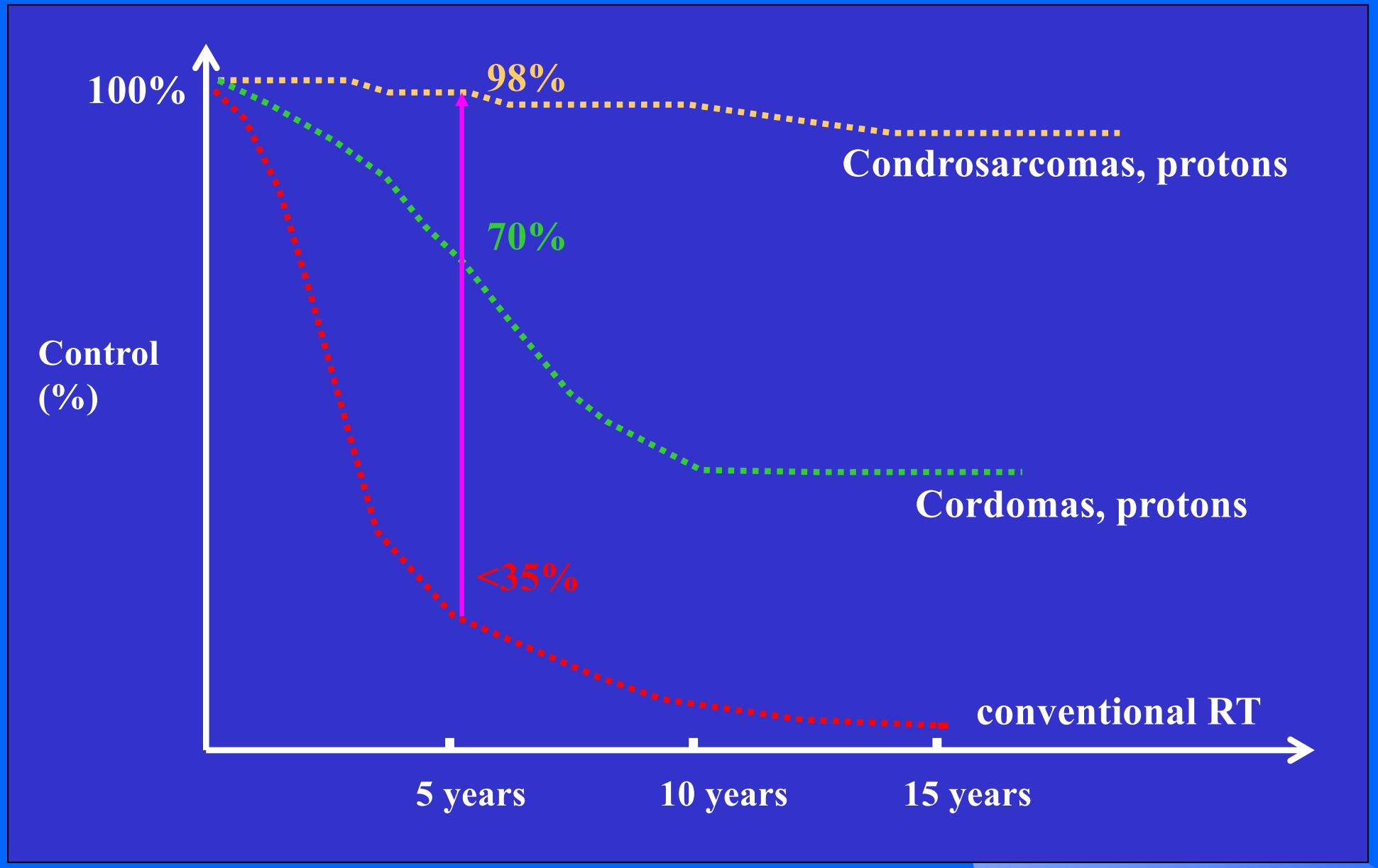

Raymond Kjilberg


Herman Suit - 2002

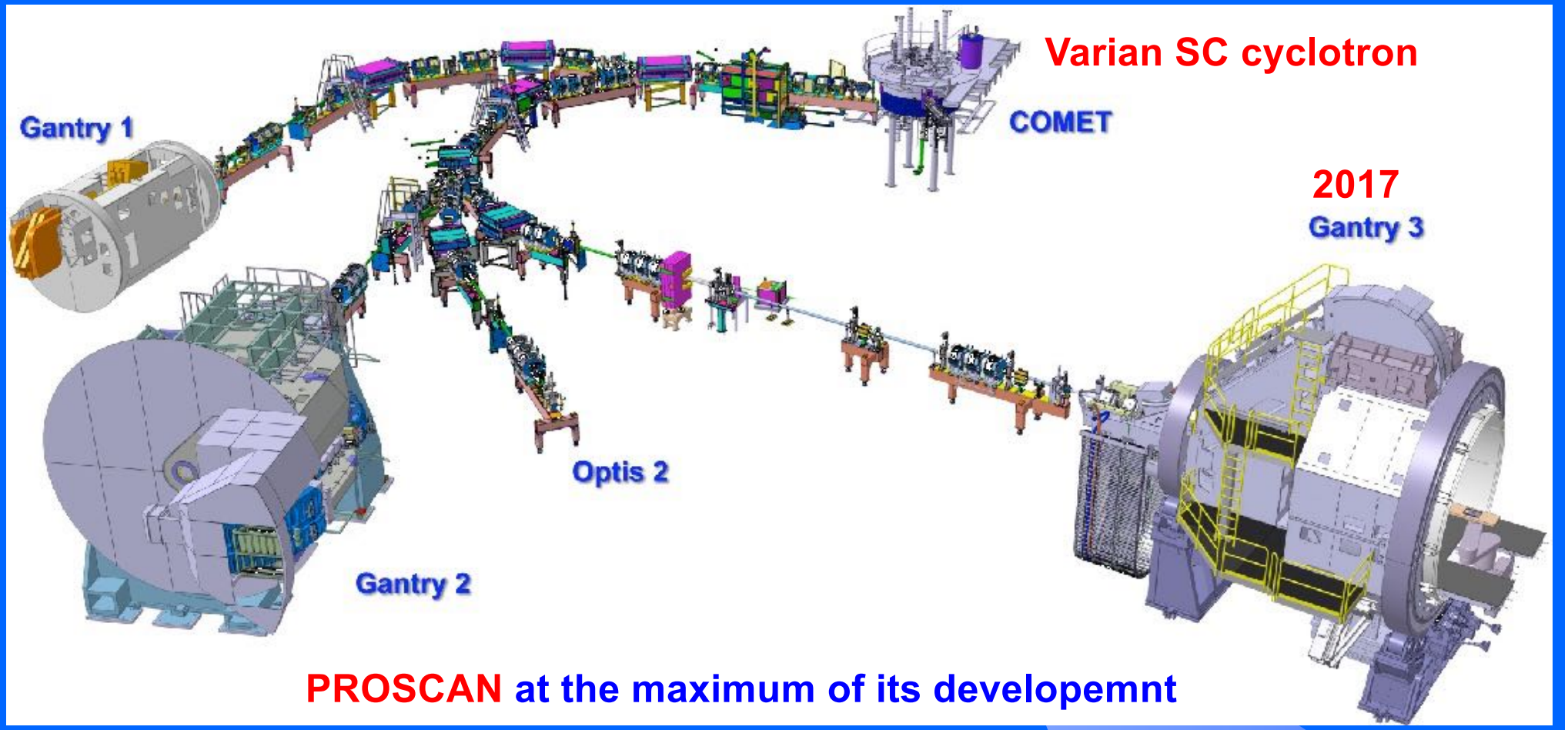

Michael Goitein

TERA

First important results obtained at MGH-Harvard



Protontherapy has been developed at PSI for 30 years



PROSCAN at the maximum of its developemnt

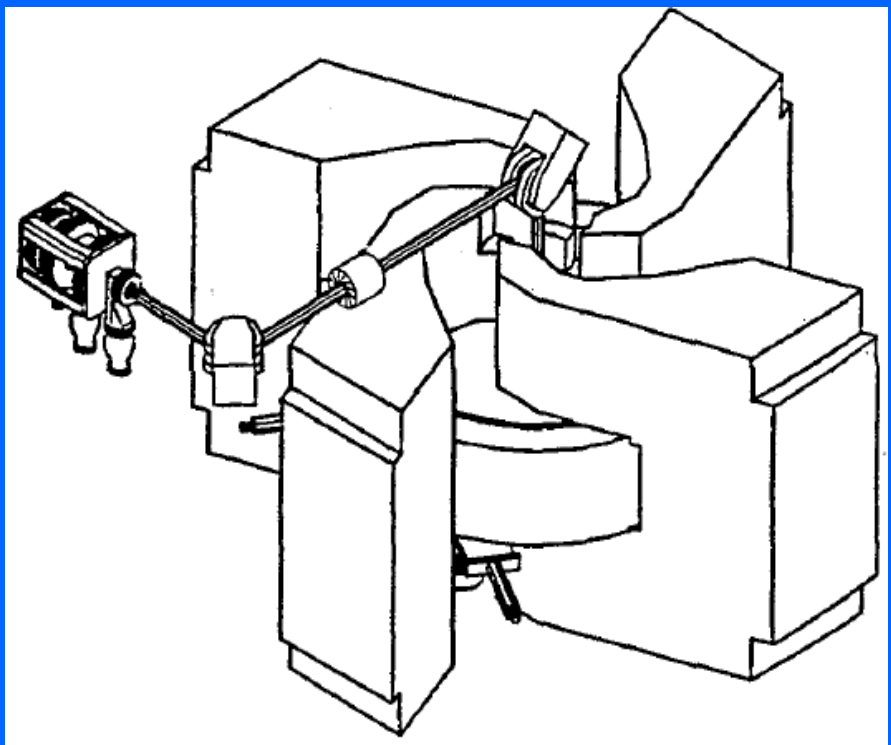
Medical physicists: Eros Pedroni
Tony Lomax

1988

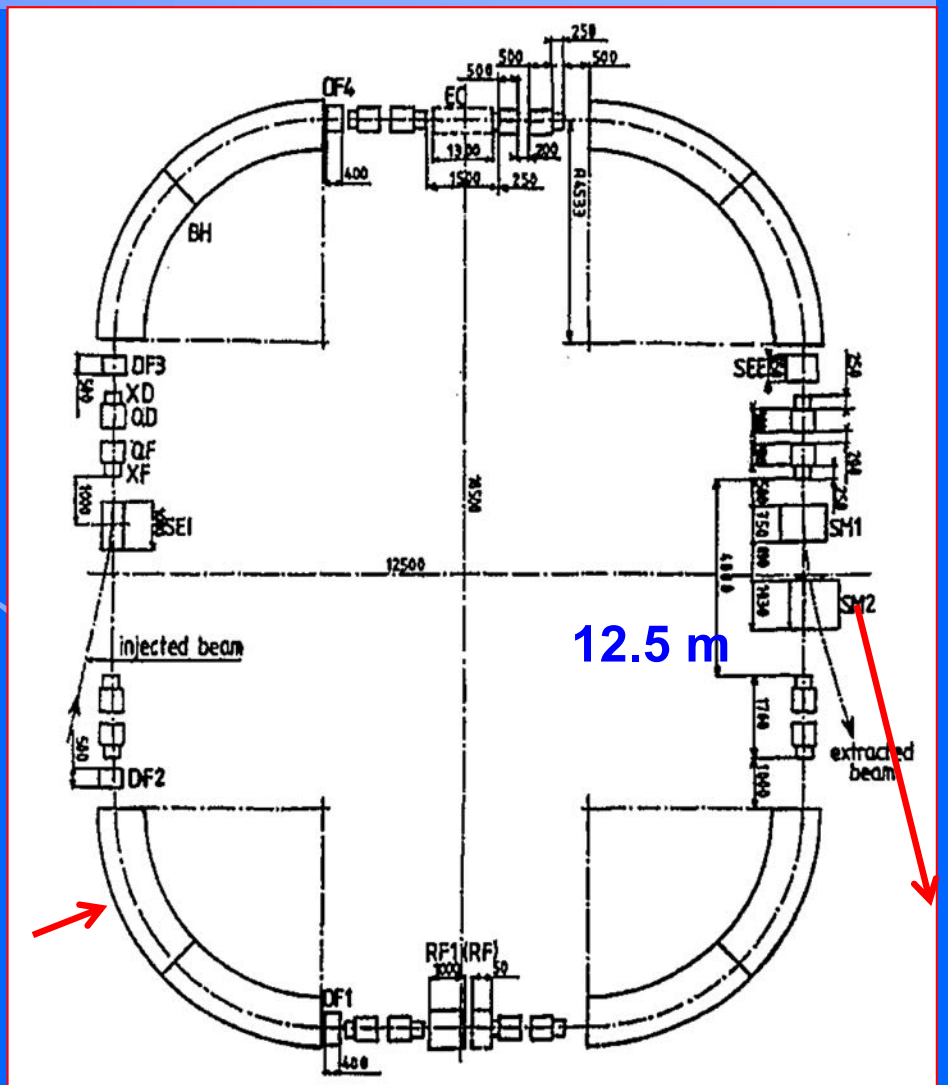
Pierre Mandrillon, Pierre Lefèvre et al : EULIMA enter CERN

European Light Ion

Medical Accelerator



superconducting cyclotron
P. Mandrillon e al



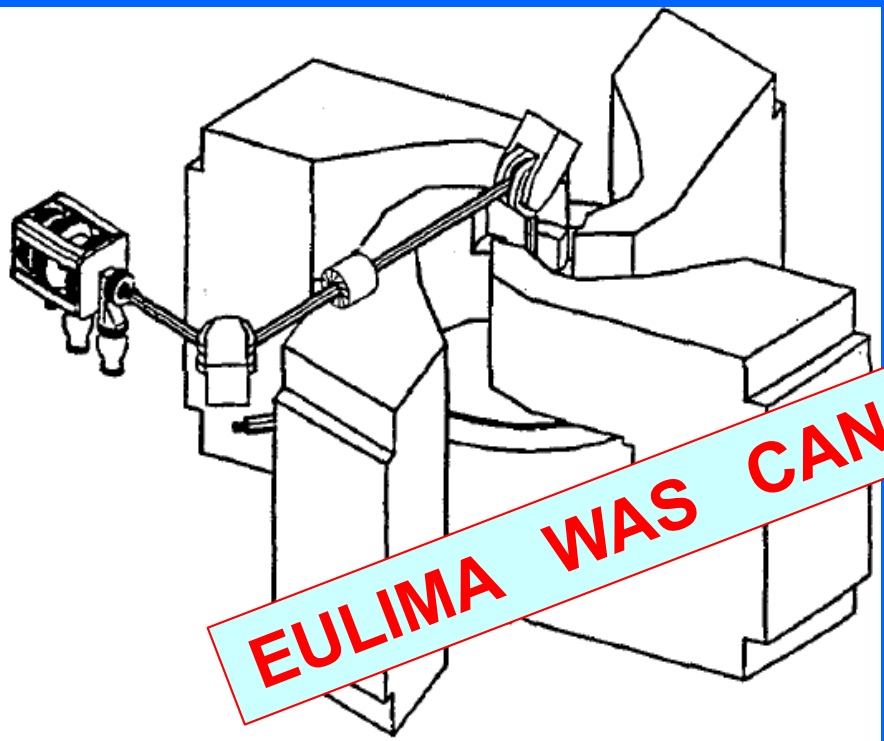
Synchrotron – similar to LEAR
P. Lefevre et al

1988

Pierre Mandrillon, Pierre Lefèvre et al : EULIMA enter CERN

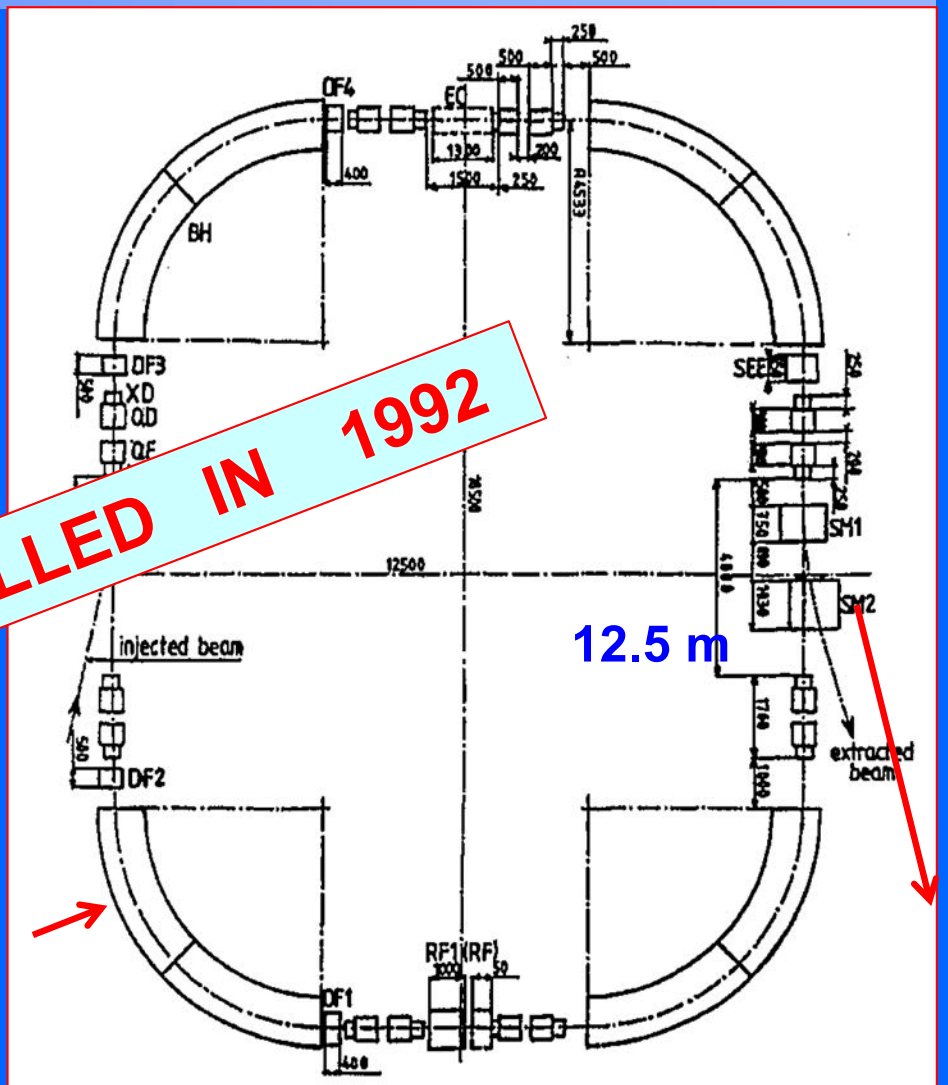
European Light Ion

Medical Accelerator



superconducting cyclotron
P. Mandrillon e al

EULIMA WAS CANCELLED IN 1992

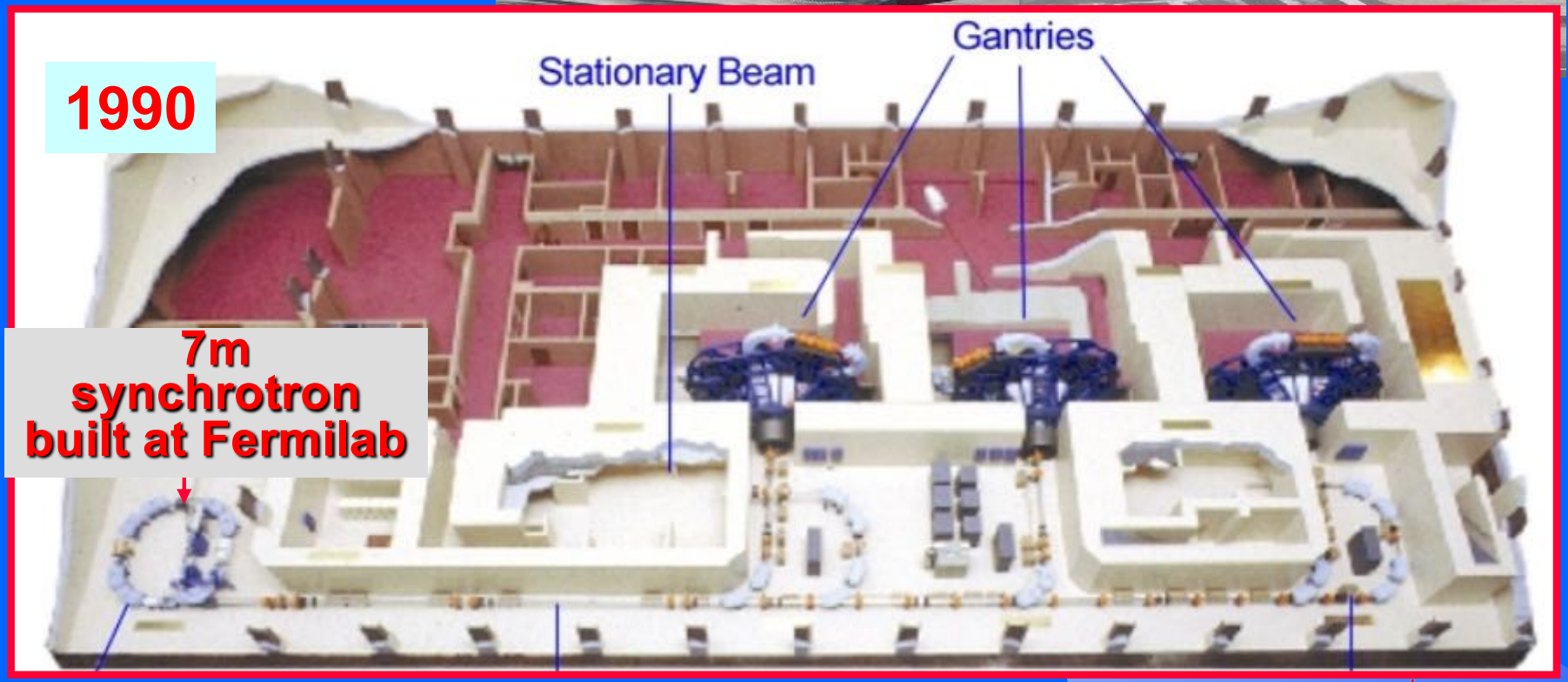


12.5 m

Synchrotron – similar to LEAR
P. Lefevre et al

First hospital centre: Loma Linda University Medical Center

- Dr. James Slater MD



1992-1994: the turning years

1992: Loma Linda treats first patient with protons

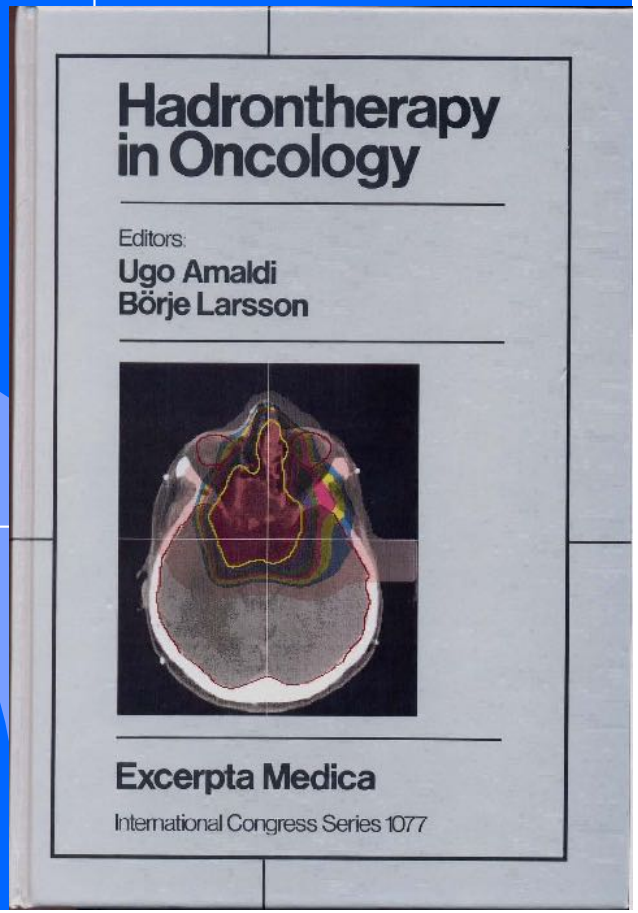
1993: MGH selects IBA for first commercial p-centre

1993: At GSI the 'pilot project' is approuved

1994: HIMAC treats the first patient with C ions

1993 Como, Italy

First International Symposium on Hadrontherapy



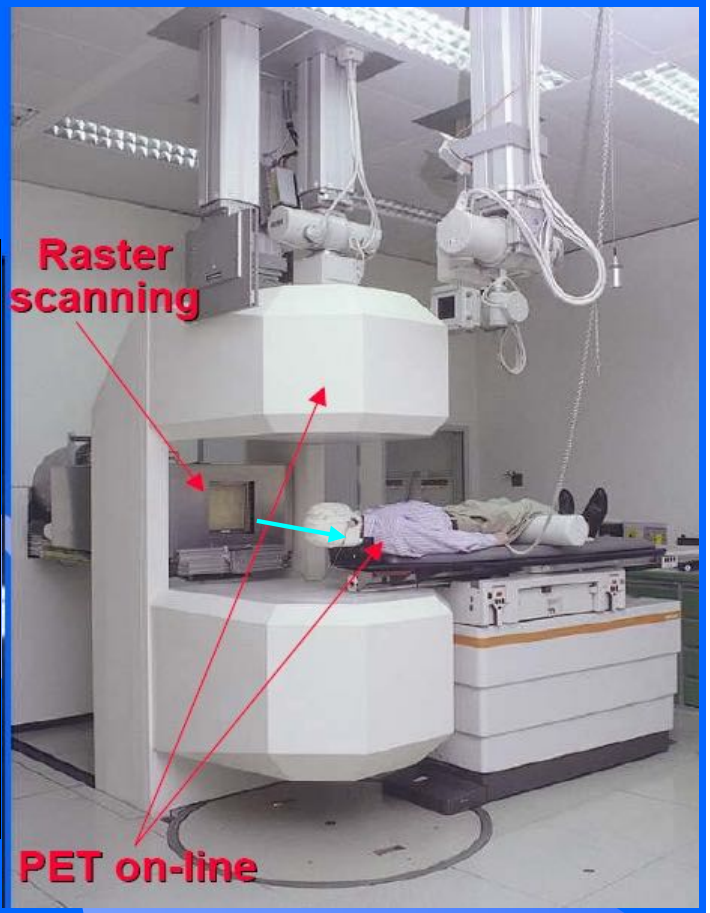
The GSI 'pilot project' (1997-2008)


Gerhard Kraft


J. Debus

500 patients treated with carbon ions


GSI - Darmstadt



Heavy Ion Medical Accelerator at Chiba first patient in 1994

QST hospital

of the National Institute for Quantum Science and Tecnologies

Yasuo Hirao

Medical Director:
Hirohiko Tsujii

15 000 pts 1994-2021

Current challenges for proton therapy aycceleratorss:

A. Compactness

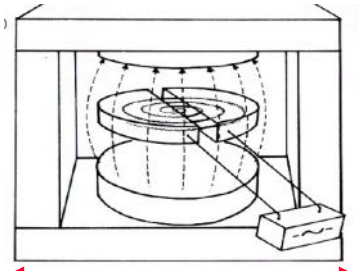
B. FLASH radiotherapy

(C. Multi-ion treatments)

The accelerators used today in hadrotherapy are "circular"

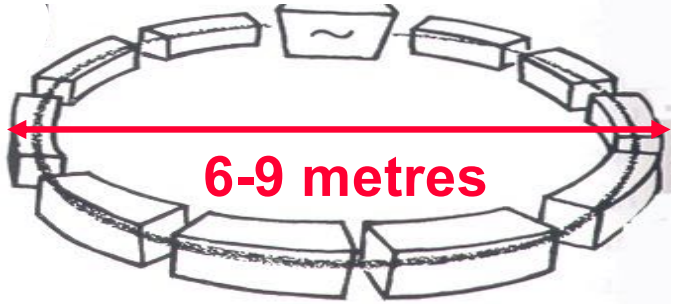
Therapy with protons (200-250 MeV)

CYCLOTRONS (*) (Normal or SC)



4-5 metres

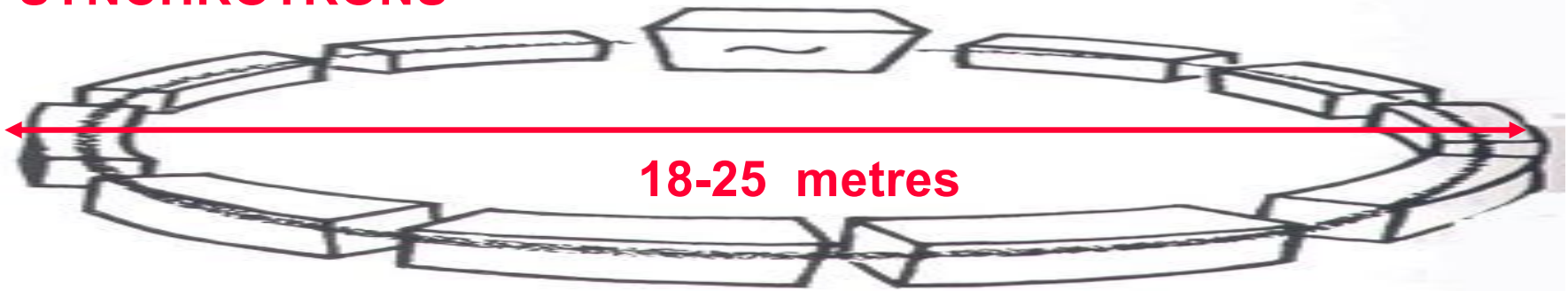
SYNCHROTRONS



(*) recently synchrocyclotrons

Therapy with carbon ions (4800 MeV = 400 MeV/u)

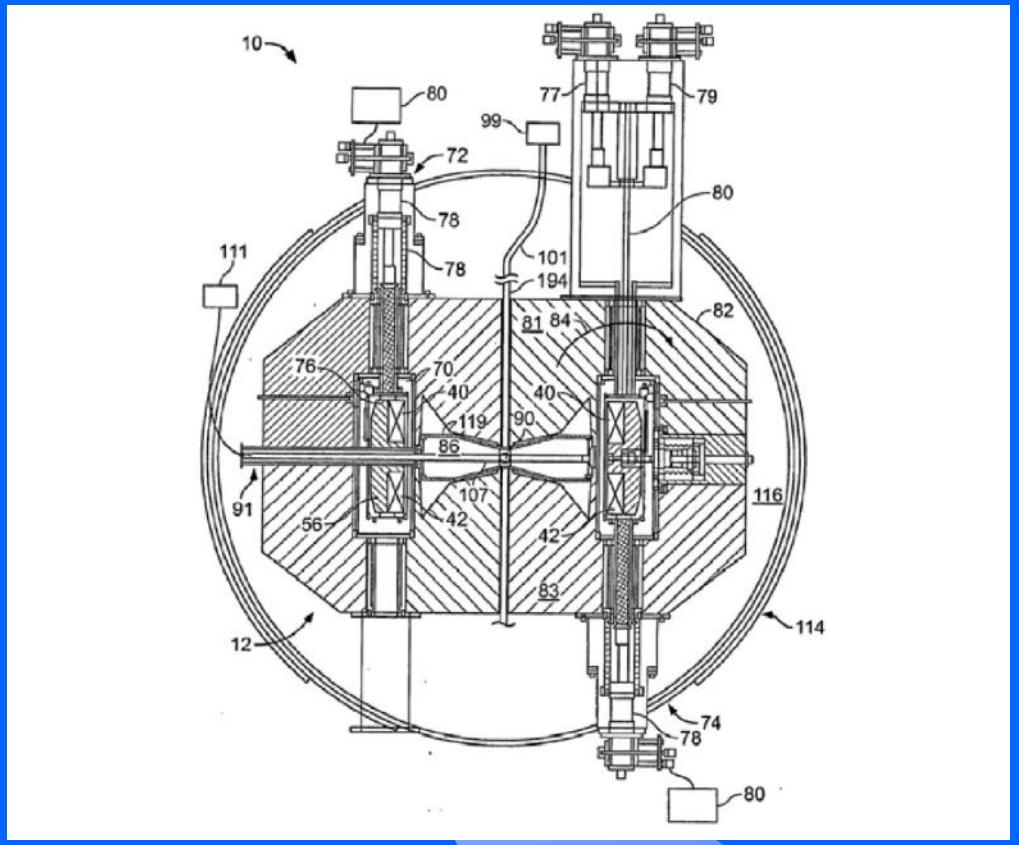
SYNCHROTRONS



At the beginnig: multi-room facilities: IBA market leader

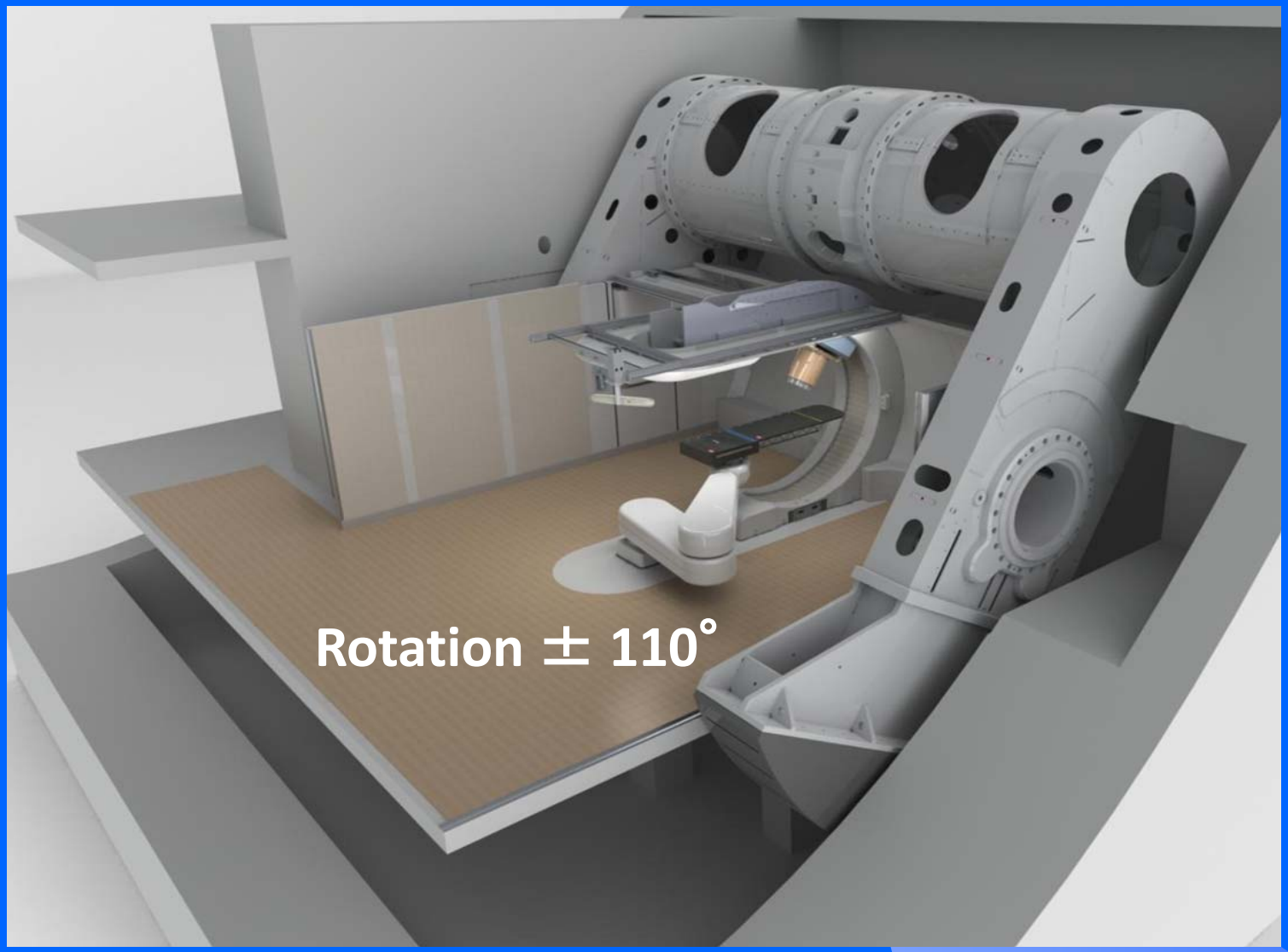
ROOM-TEMPERATURE CYCLOTRON

1. Single-room facility by MeVion



9 tesla superconducting synchrocyclotron

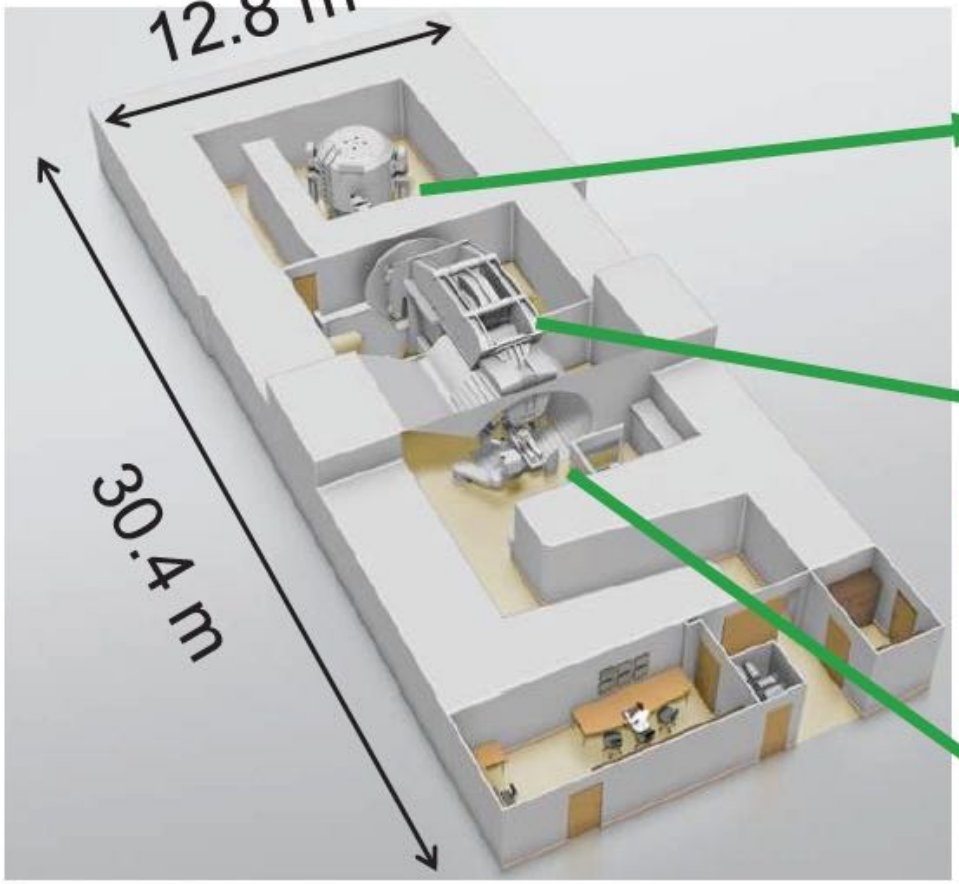
1. Single-room facility by MeVion



SYNCROCYCLOTRON

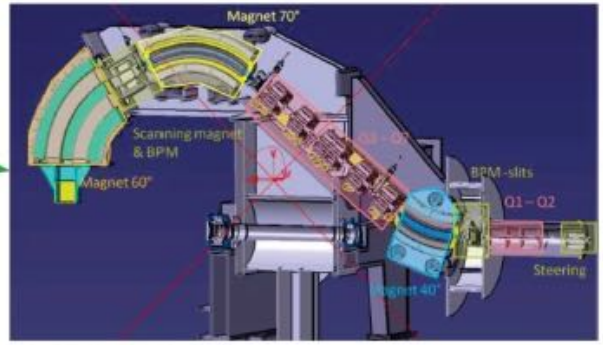
2. Single-room facility by IBA

Superconducting. SC



Synchrocyclotron with superconducting coil: S2C2

New Compact Gantry for pencil beam scanning



Patient treatment room

Protect, Enhance and Save Lives - 3 -

WILLIS-KNIGHTON CANCER CENTER IN SHREVEPORT, LOUISIANA

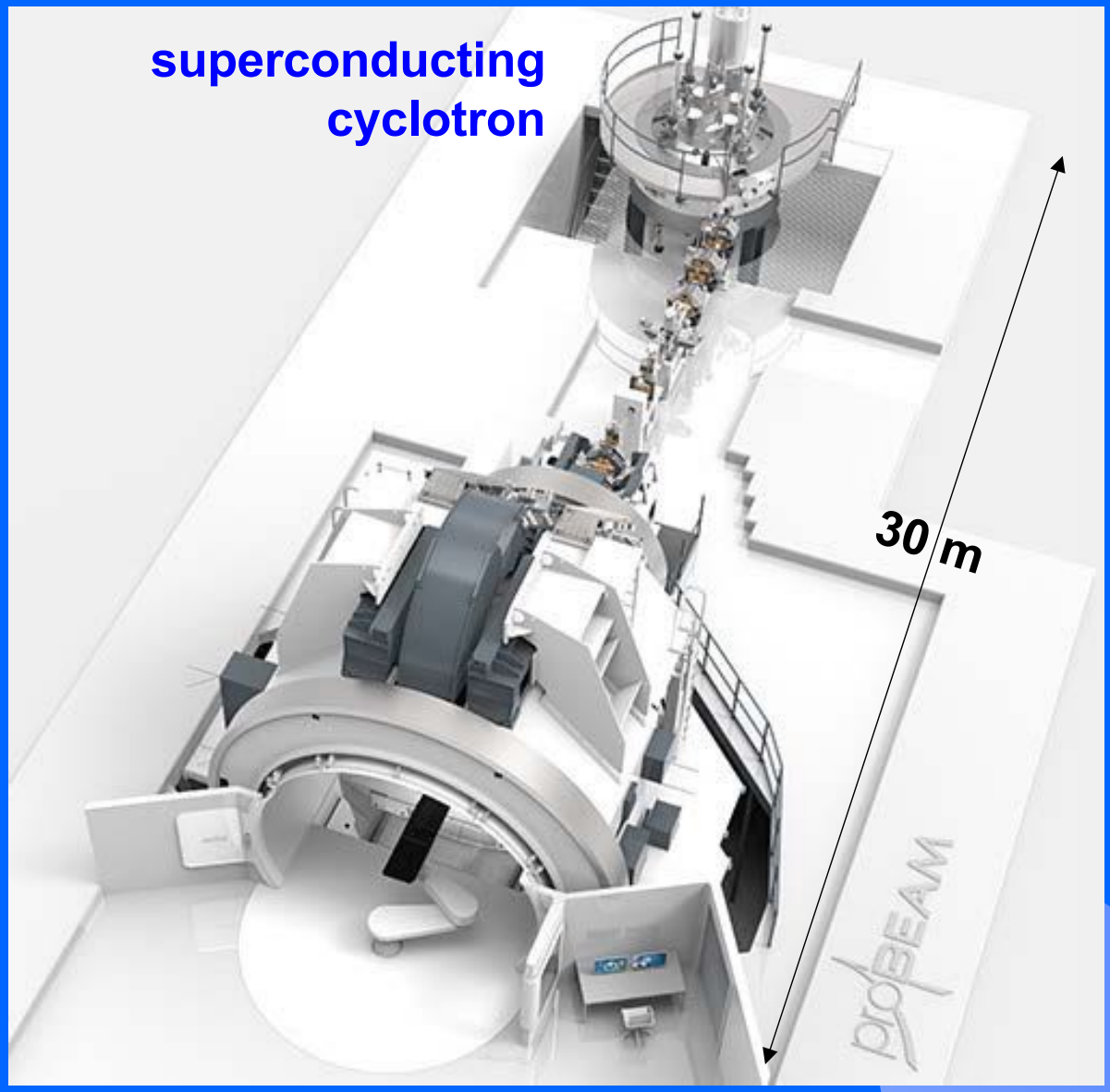
3. Single room facility by SUMITOMO (Japan)

Corkscrew gantry

Footprint:
16m x 20 m

‘Cockscrew’ gantry

4. Single room facility by Varian: ProBeam



5. Single-room facility by Hitachi

Room temperature synchrotron

Field: 30 cm x 40 cm

5. Single-room facility by ProTom

Radiance 330:
Room temperature synchrotron at MGH

Mounted with a compact gantry in two standard vaults for photon radiotherapy

TERA

Proton therapy: B. the challenge of FLASH therapy (typically: 200 ms instead than 200 s delivery time)

Time structure of the therapy beams

CYCLOTONS: Beam always present with 50-100 MHZ RF structure

SYNCROCYCLOTRONS: Pulsed beam every 0.1 ms (1000 Hz) with 50-100 MHz structure

SYNCROTRONS: Pulsed beam every 2-5 seconds (0.2- 0,5 Hz) with or without RF structure ; no beam for about 1 second

LINACS: Pulsed beam every 5 ms for afor 2-5 microseconds every 5 ms (200

FLASH therapy requires 100-1000 higher dose rates

CYCLOTONS: Beam always present with 50-100 MHZ RF structure

EASY

SYNCROCYCLOTRONS: Pulsed beam every 0.1 ms (1000 Hz) with 50-100 MHz structure

MEDIUM

SYNCROTRONS: Pulsed beam every 2-5 seconds (0.2- 0,5 Hz) with or without RF structure ; no beam for about 1 second

DIFFICULT

LINACS: Pulsed beam every 5 ms for afor 2-5 microseconds every 5 ms (200

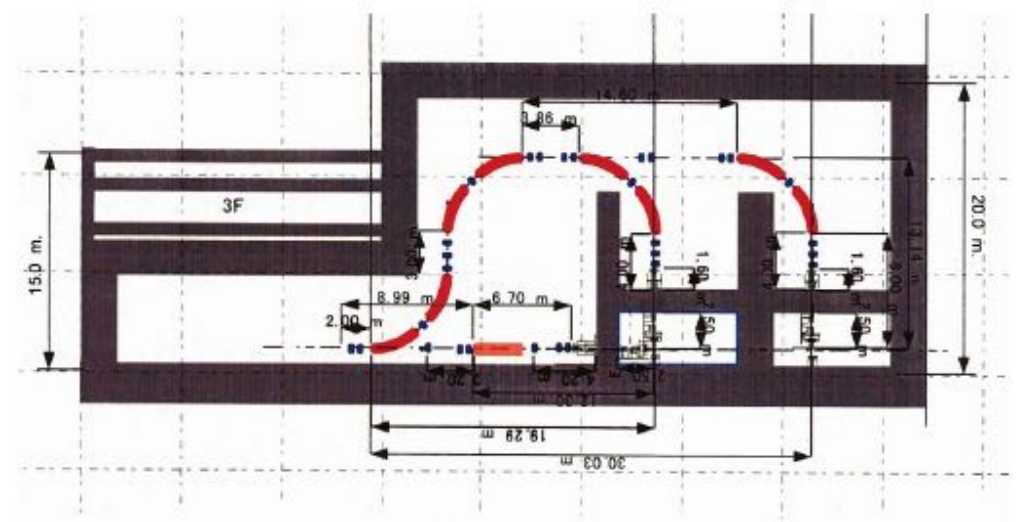
MEDIUM

Status of light ion therapy centres in Japan and Europe

In Japan six carbon ion facilities

Leader: Nat. Inst. for Quantum Sciences and Technologies

Construction: Mitsubishi



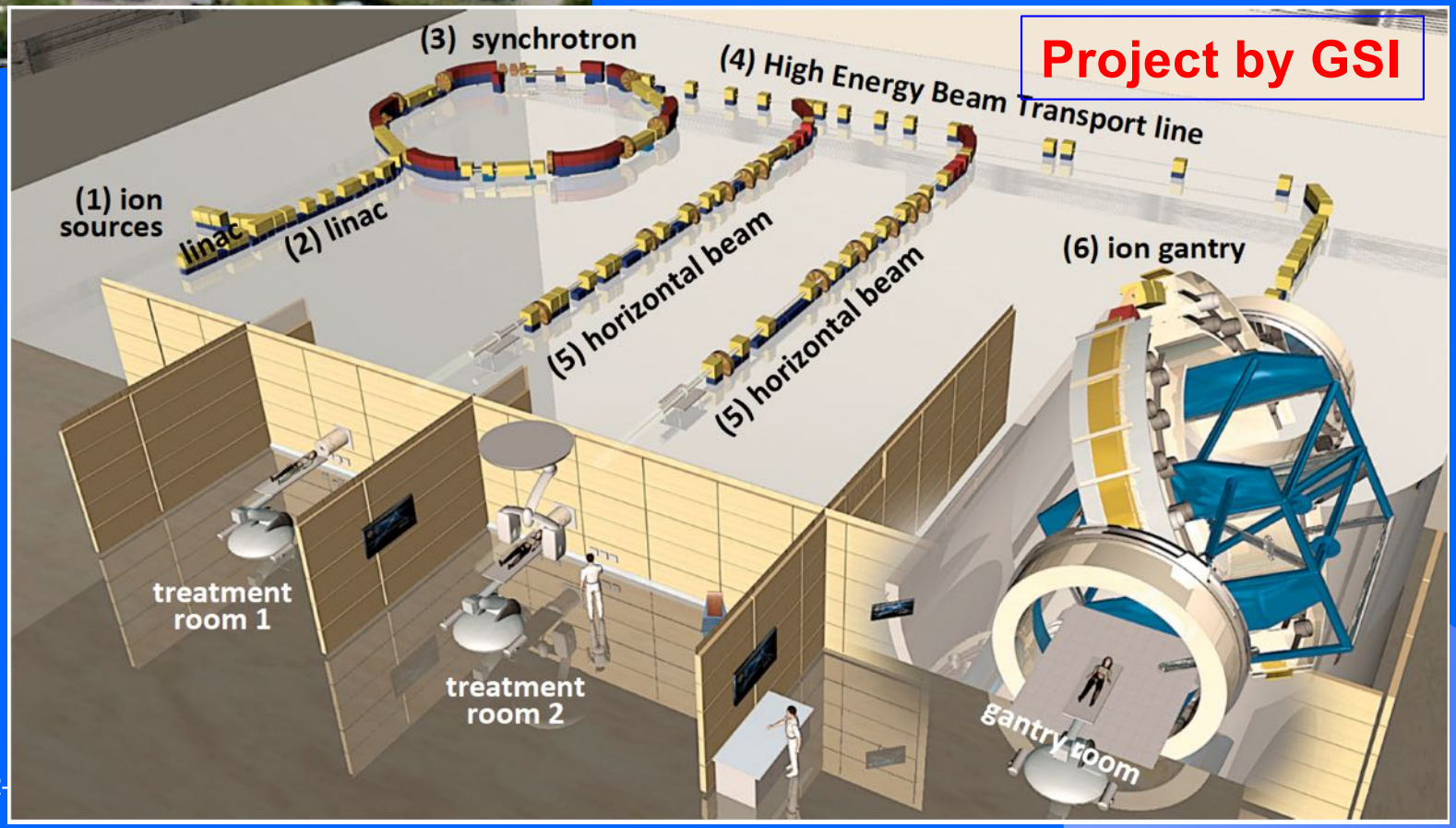
STRICT COLLABORATIONS WITH COMPANIES MITSUBISHI, HITACHI, TOSHIBA

- Heavy ion radiotherapy is under operation at Gunma University
- Heavy Ion Medical Center, Hyogo Ion Beam Medical Center
- Kyushu International Heavy Ion therapy Center
- Ion Beam Therapy Center, Kanagawa Cancer Center, Osaka
- Heavy Ion Therapy Center, Saga

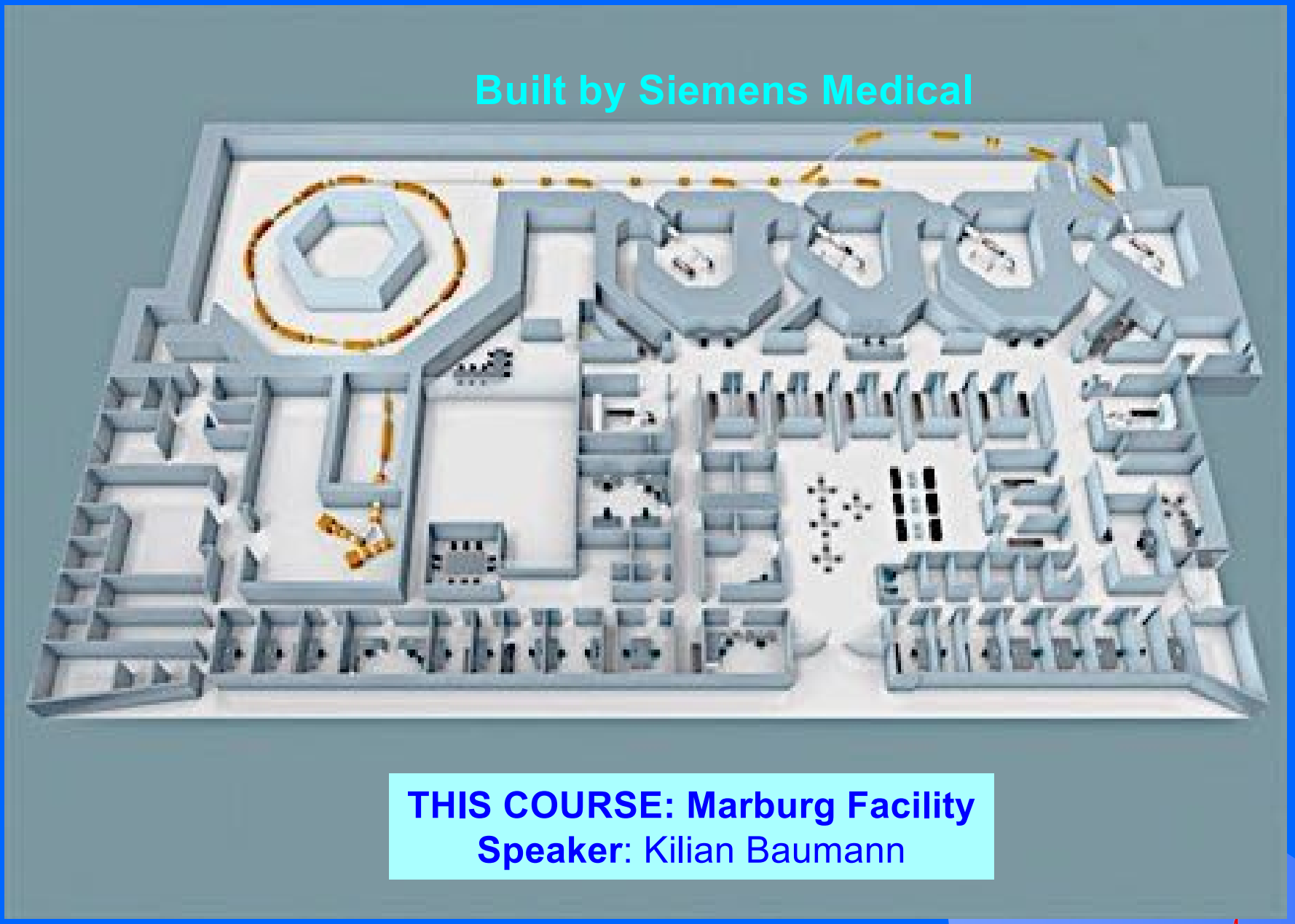
HIT at Heidelberg University Hospital

Medical Director: Jürgen Debus

Technical director: Thomas Haberer



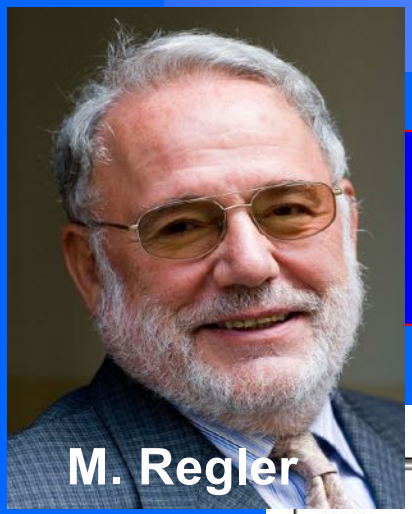
MIT-Marburg carbon ion and proton dual cen



THIS COURSE: Marburg Facility
Speaker: Kilian Baumann

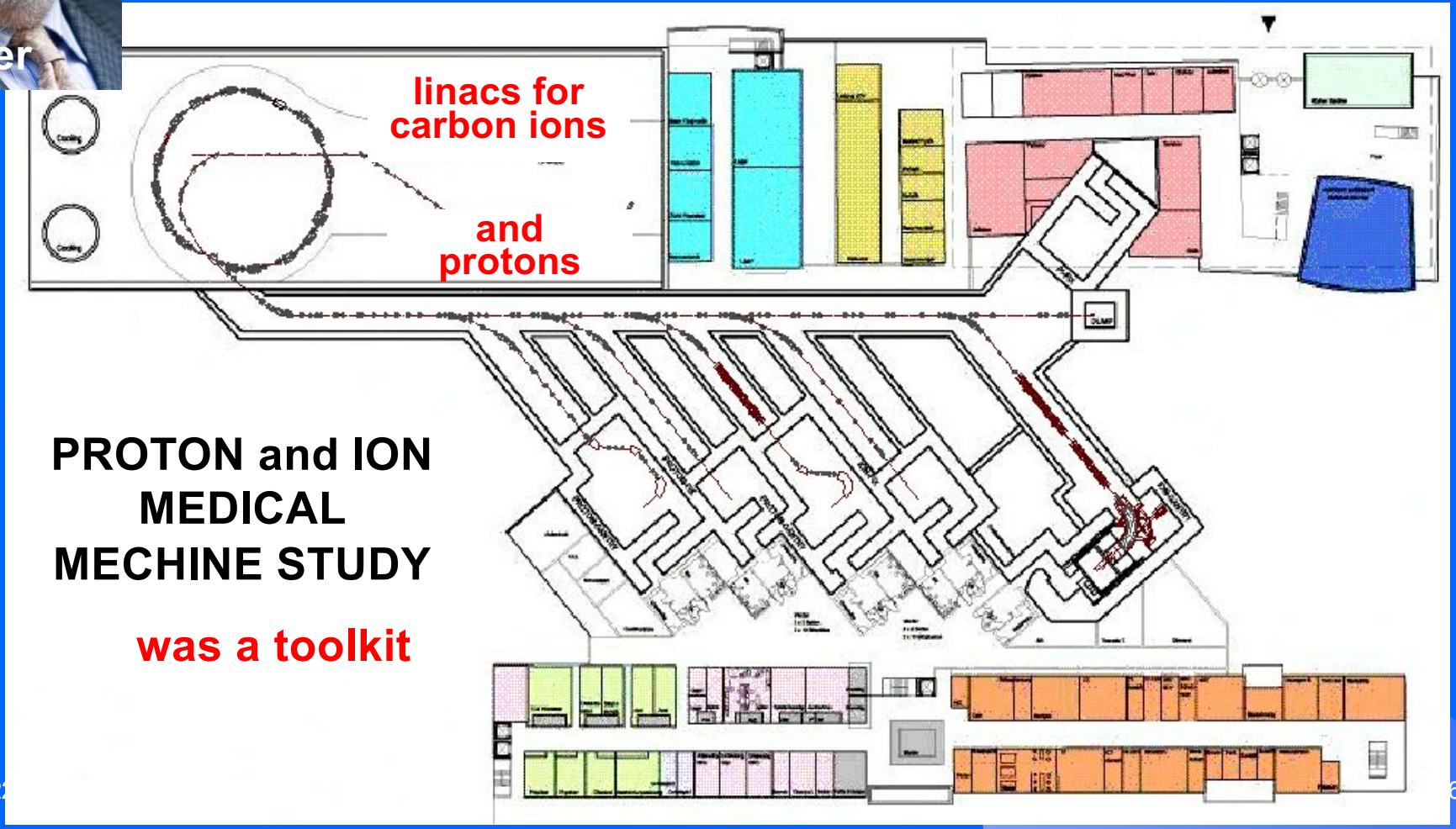
1995

In 1995 UA – P. Bryant – M. Regler convinced CERN to start Proton Ion Medical Machine Study, PIMMS



PL: Phil Bryant - PAC chair: Giorgio Brianti

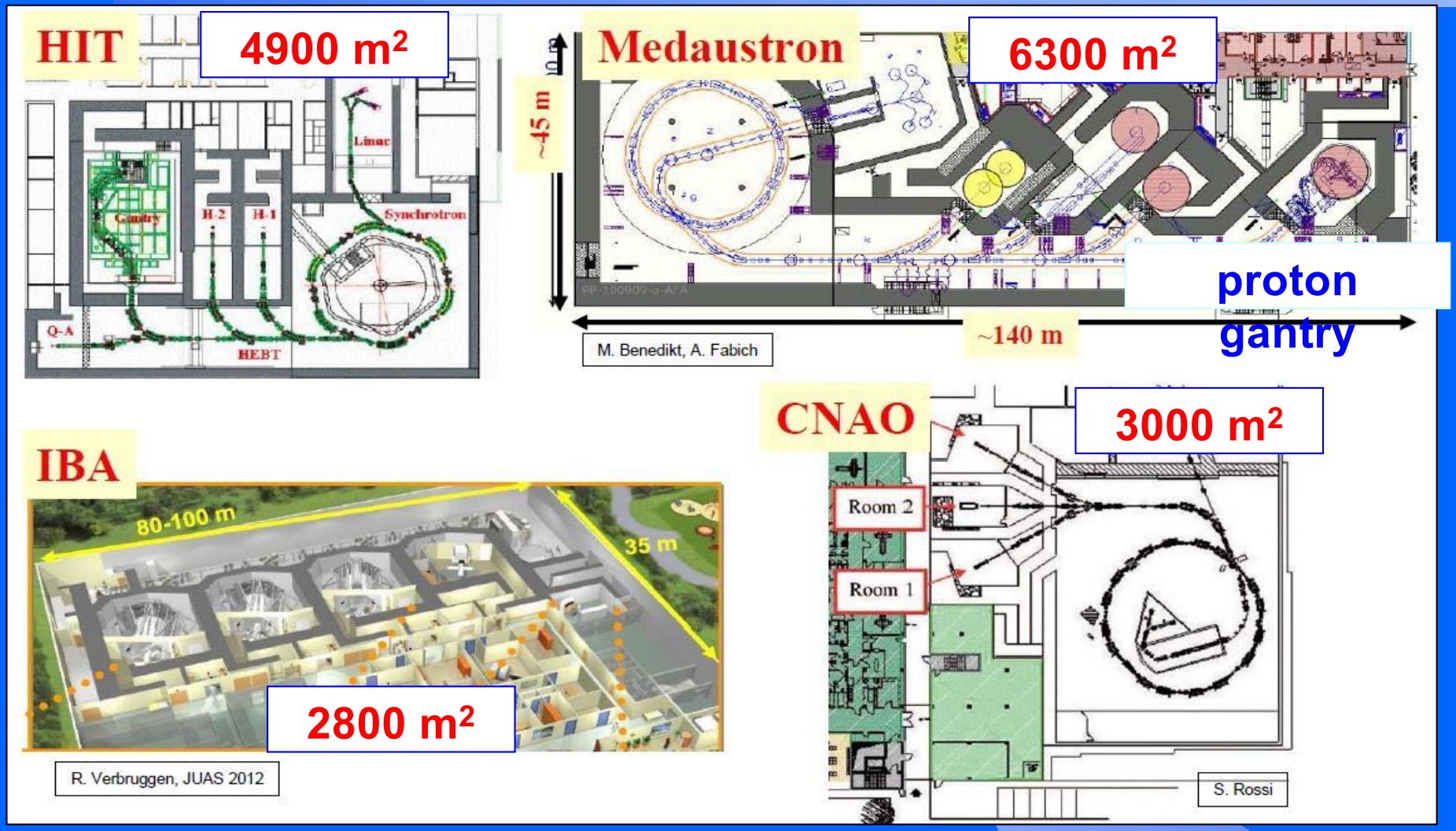
Contributors: CERN -TERA Foundation - MedAustron



PROTON and ION MEDICAL MECHINE STUDY

was a toolkit

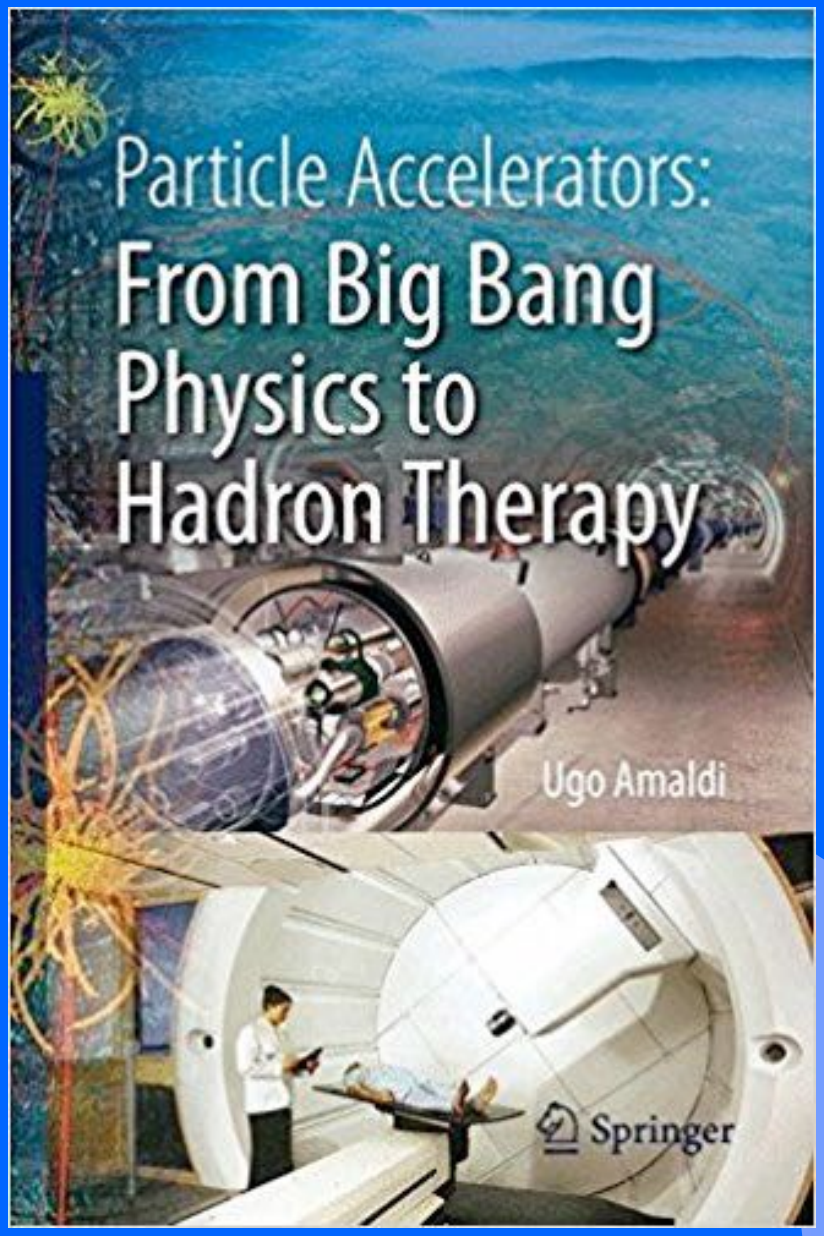
From PIMMS: CNAO and Medaustron



Thomas Haberer: comparison of four facilities

THIS COURSE: Introduction to MedAustron facility
Speaker: Dr Thomas Schreiner (MedAustron)

To know more about the history of hadron therapy



Current challenges of light ion therapy

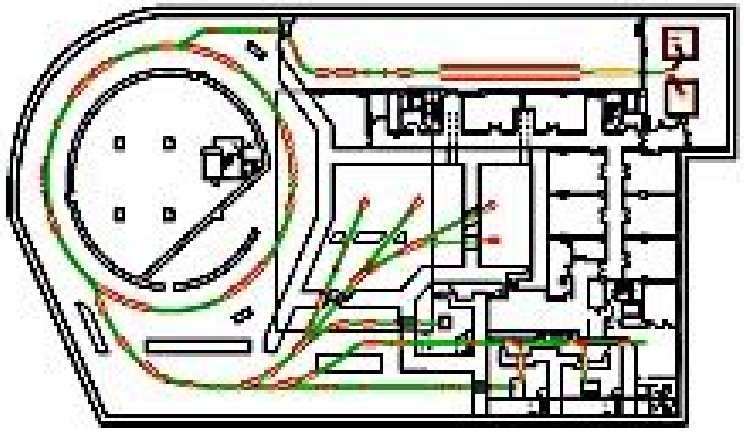
A. Compactnes: superconducting magnets, as for p

B. FLASH Radiotherapy

(C. Multi-ion treatments)

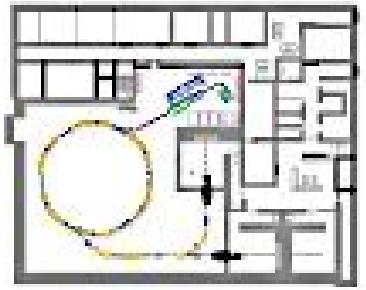
The Quantum Scalpel Project of QST

The 1st generation



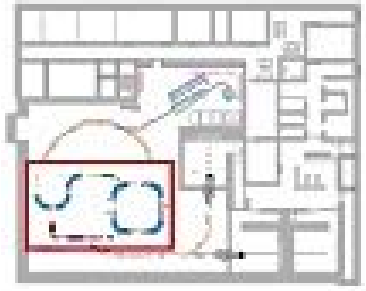
NIRS in 1994
120×65m

The 2nd & 3rd generation



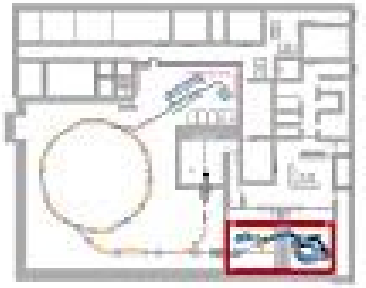
Gunma Univ. in 2010
60×50m(1/3)

The 4th generation



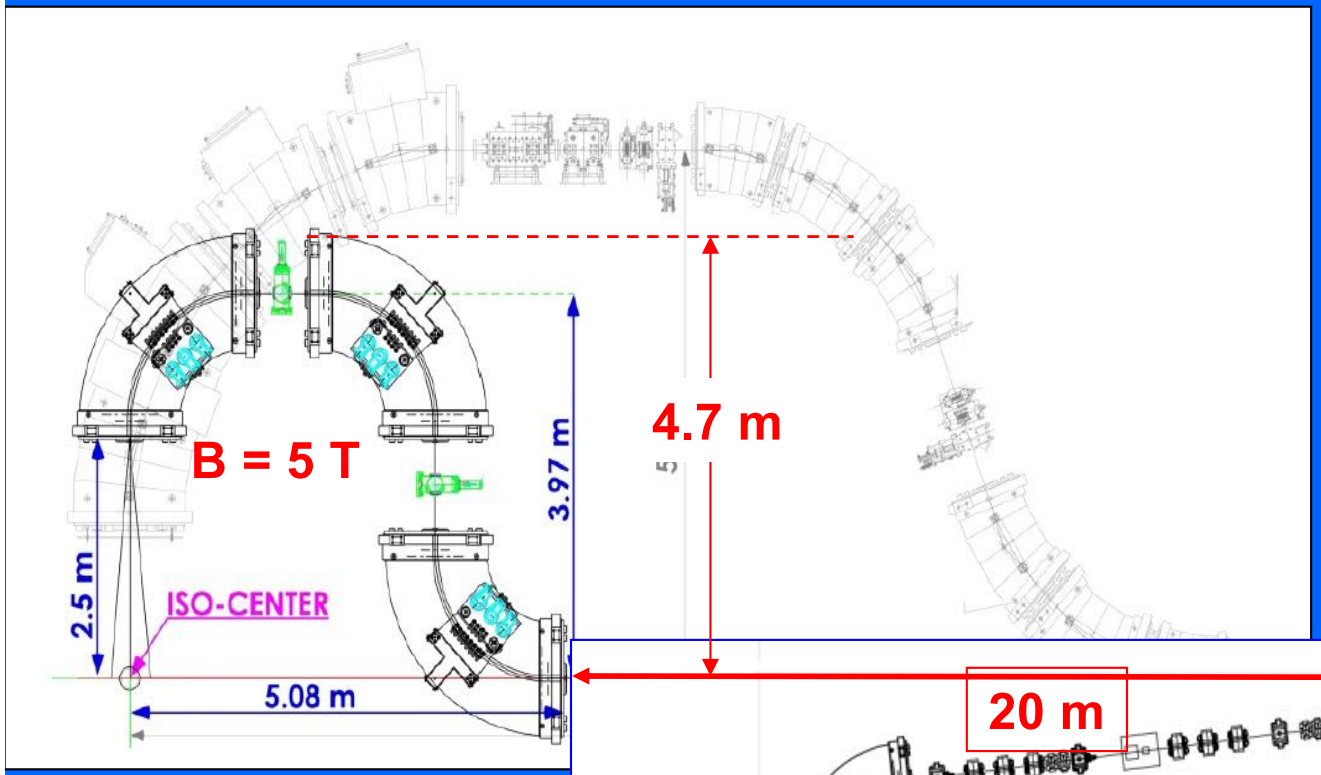
smaller
25×14m(approximately 1/20)

The 5th generation



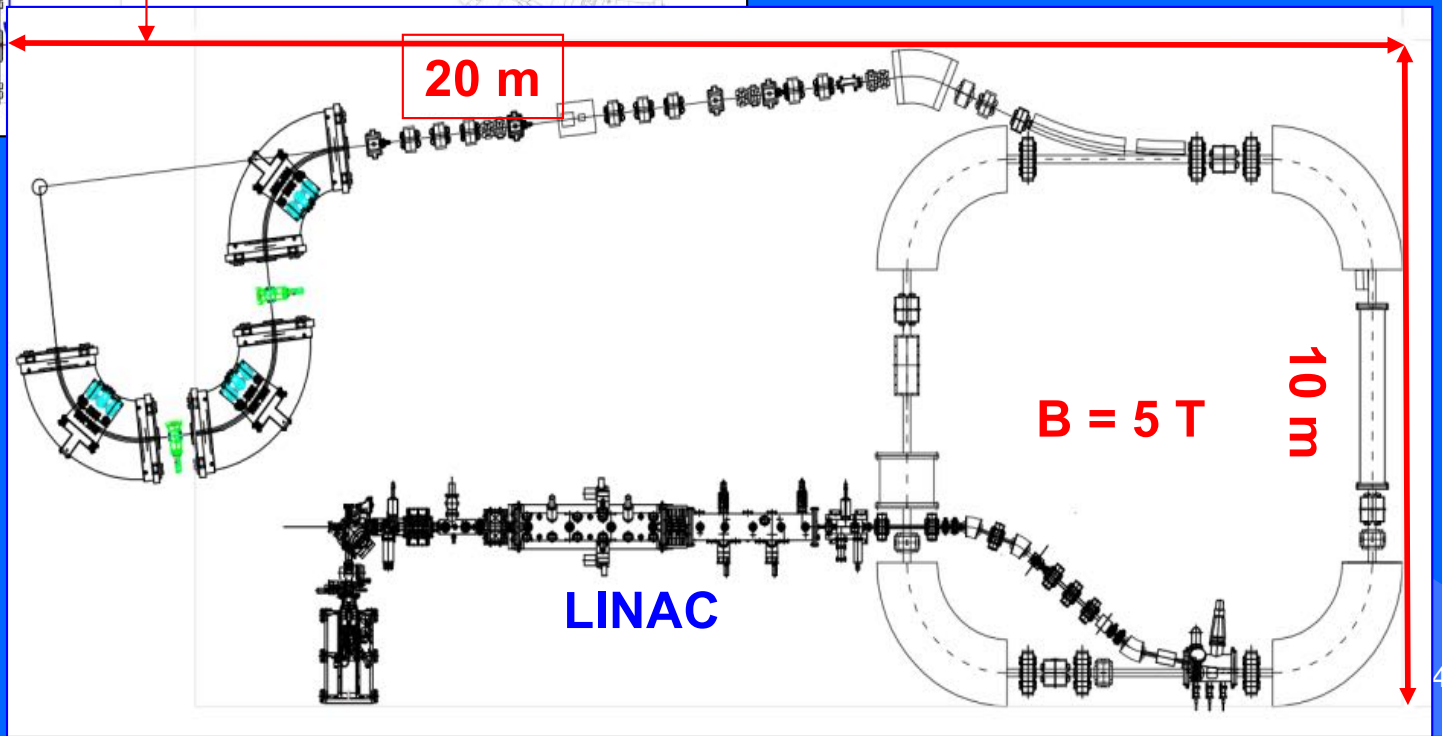
smaller and smaller
10×20m(approximately1/40)

The Quantum Scalpel project



4th generation heavy-ion therapy machine

Ongoing

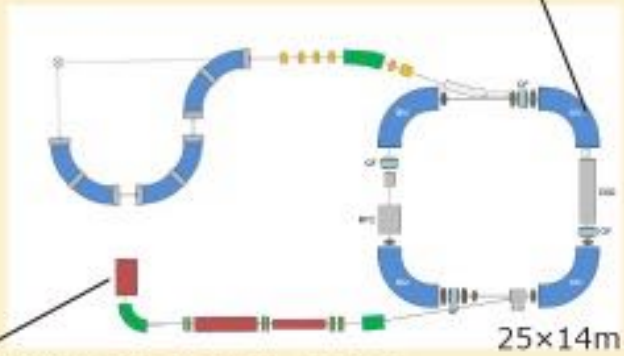


End of the program: 2030

Worldwide !
Whenever,
Wherever, Whoever

The 4th generation

①Superconducting syncrotoron

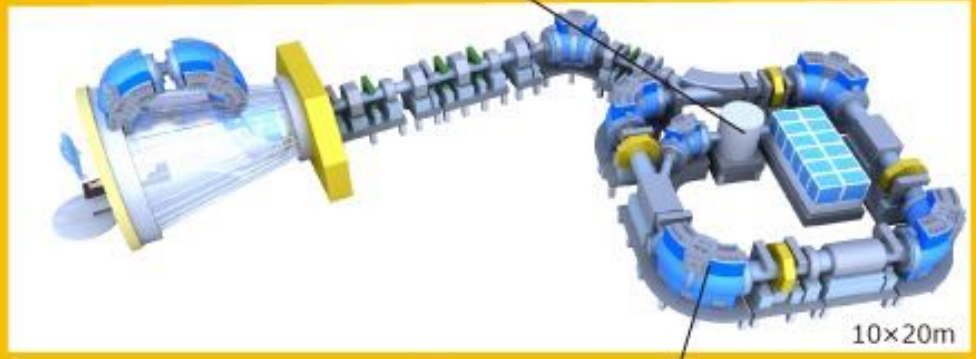


②Multi-ion irradiation system

Upgrading
from
the 4th generation

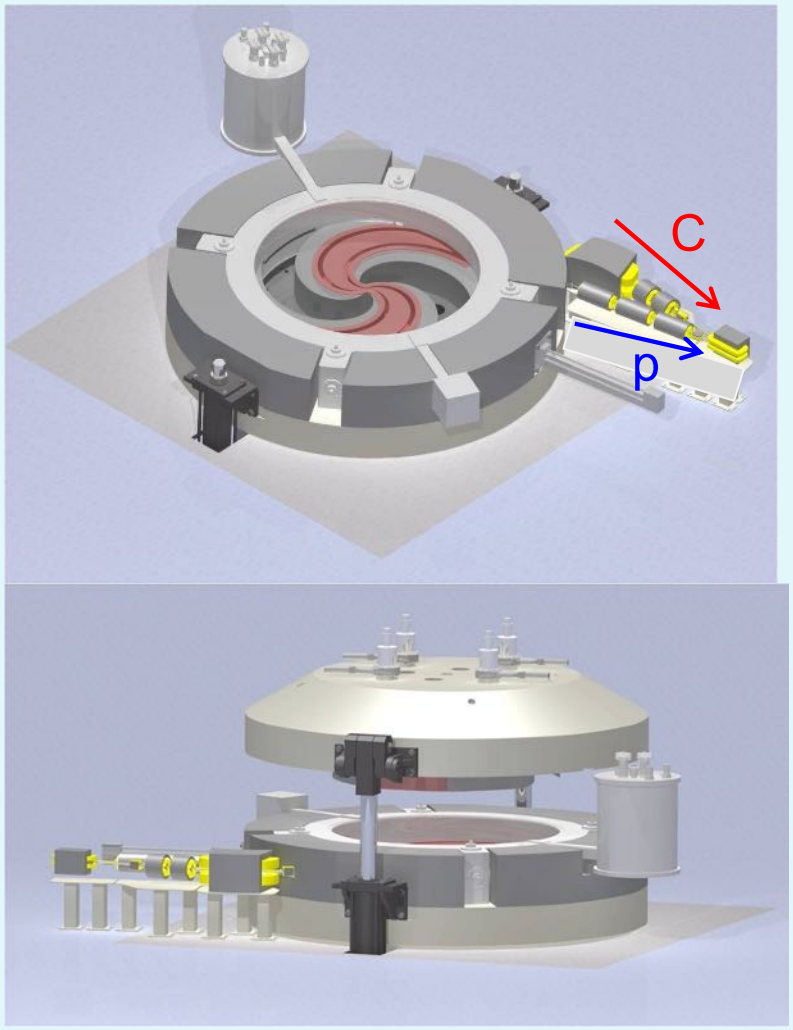
The 5th generation

②Multi-ion irradiation system
+
③Injector with laser acceleration technology

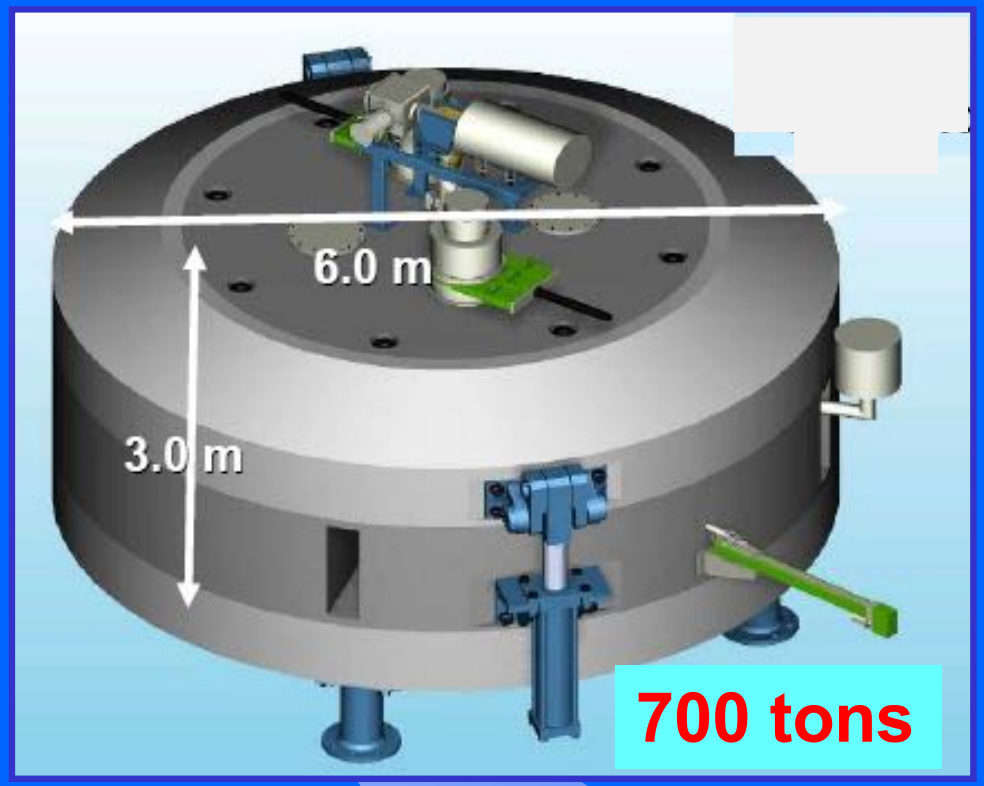


①Superconducting syncrotoron

In Europe: IBA Superconducting cyclotron for carbon ions, helium ions and protons

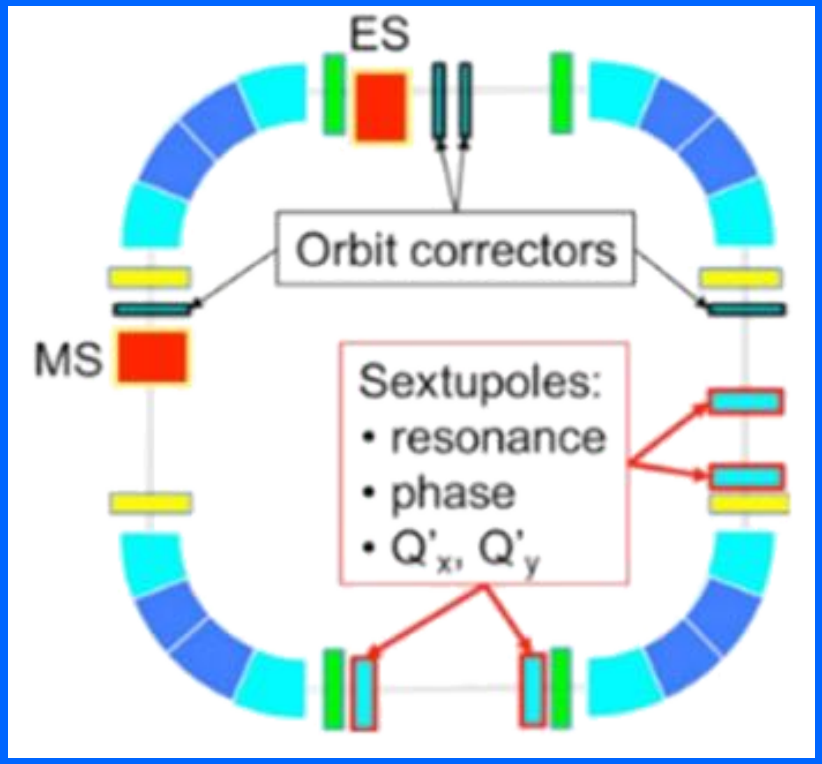


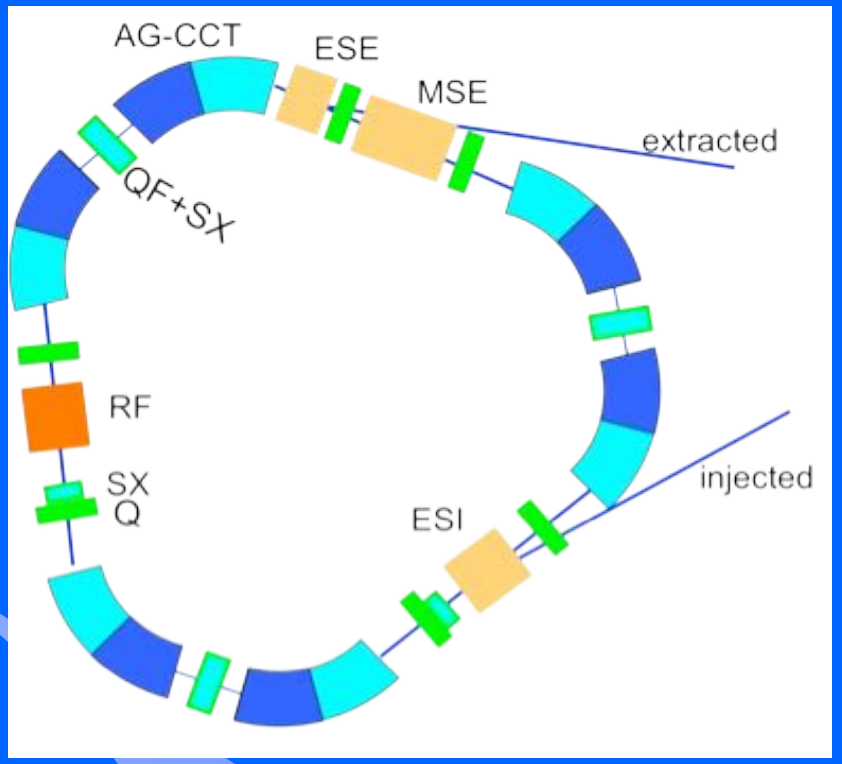
IBA C400 Cyclotron :
400MeV/u carbon , 265 MeV p
(B_c = 4.5 T)



ARCHADE project in Caen, France

In Europe: NIMMS (M. Vretenar) at the centre of many new developments, in particular SEEIIST





Two layouts of superconductin ion synchrotrons + superconducting gantries

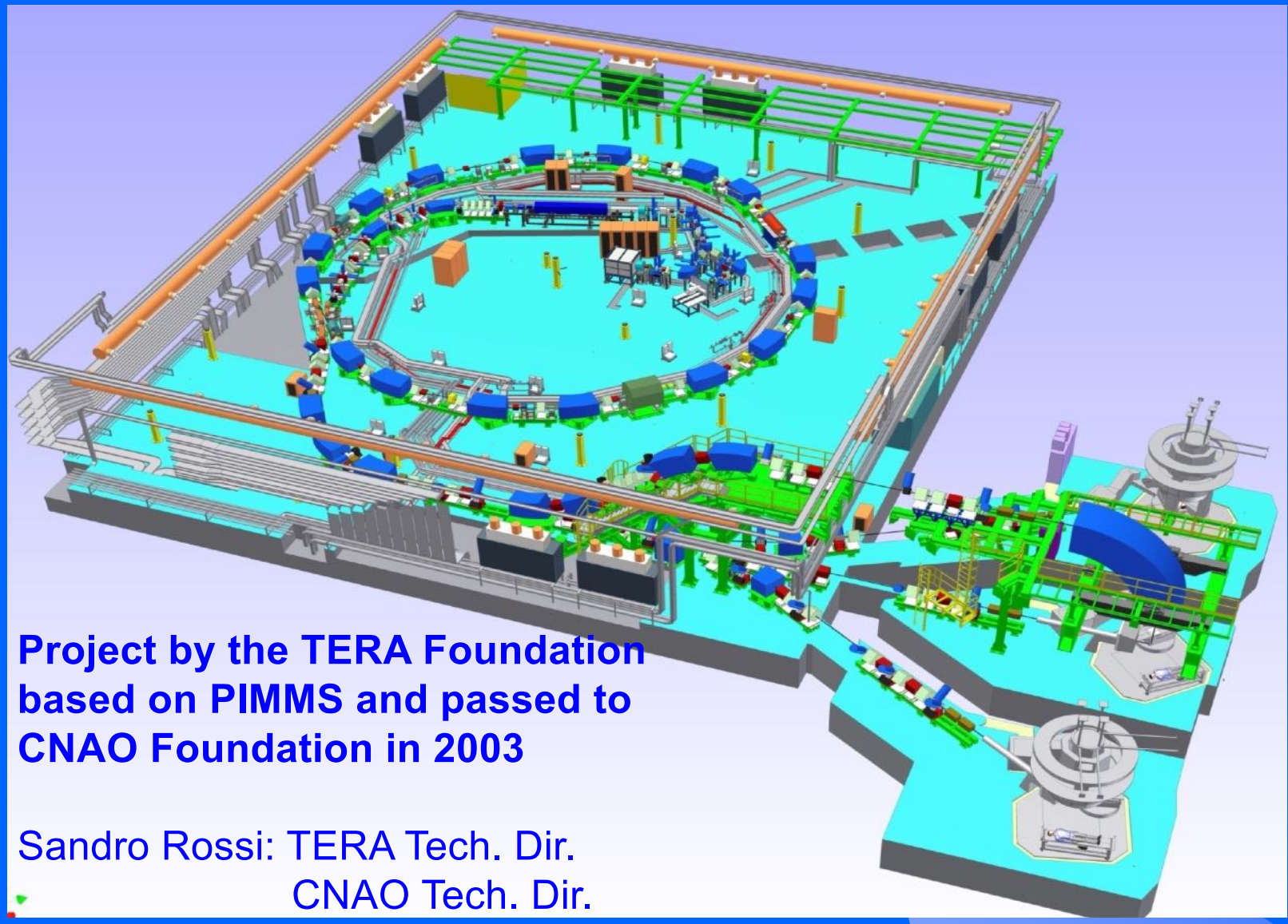
THIS COURSE: NIMMS-SEEIIST Design
Speakers: Elena Benedetto (SEEIIST Association (CH))
Mariusz Sapinski (Paul Scherrer Institute (CH))

The three offsprings of TERA Founndation (born in Novara on September 15,1992)

The three offsprings of TERA Founndation
(created in Novara on September 15,1992)

Symposiun for the 30 years of TERA
CERN Council Chamber
15 September 2022

1. Present layout of CNAO (Pavia)



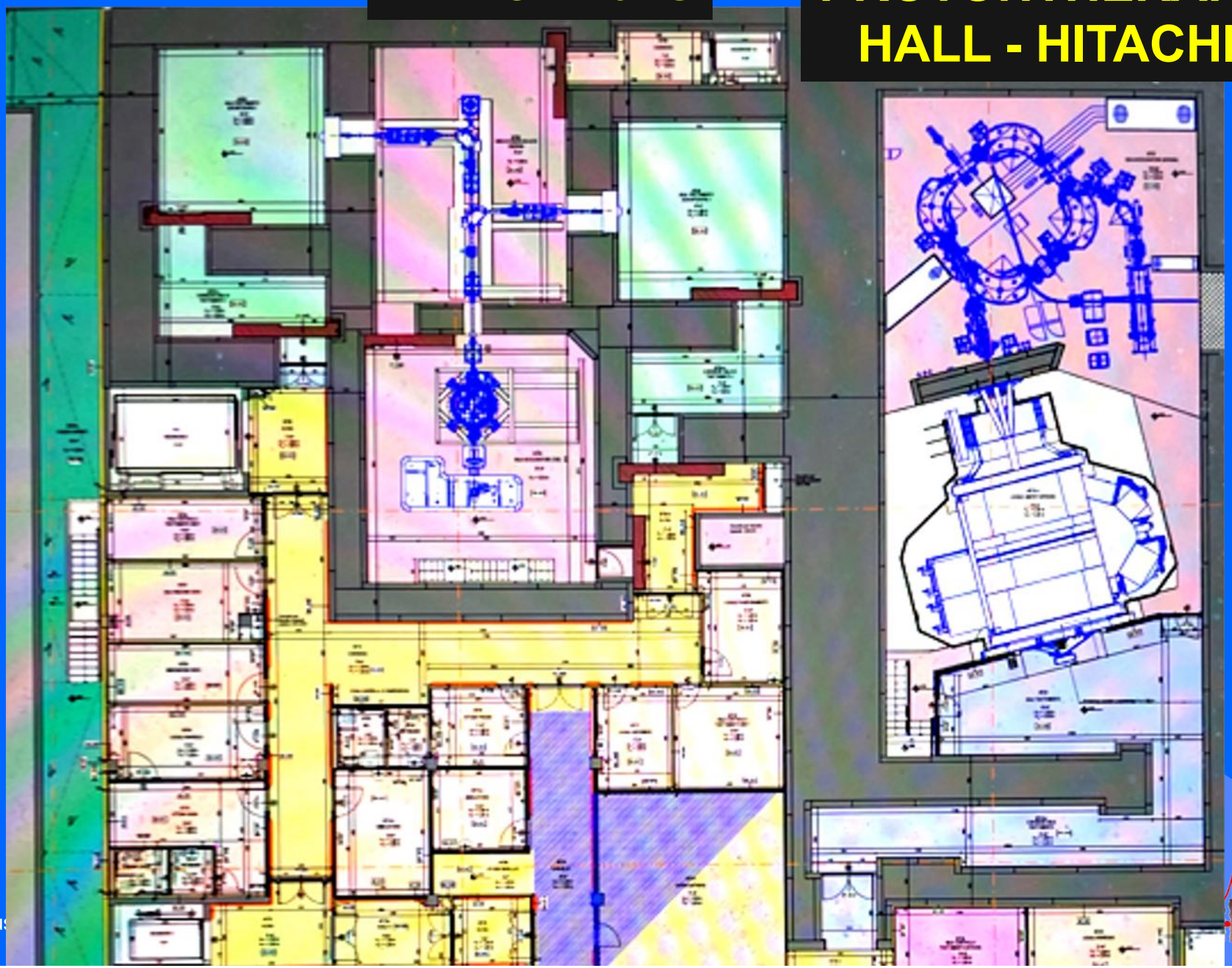
Project by the TERA Foundation based on PIMMS and passed to CNAO Foundation in 2003

Sandro Rossi: TERA Tech. Dir.
CNAO Tech. Dir.

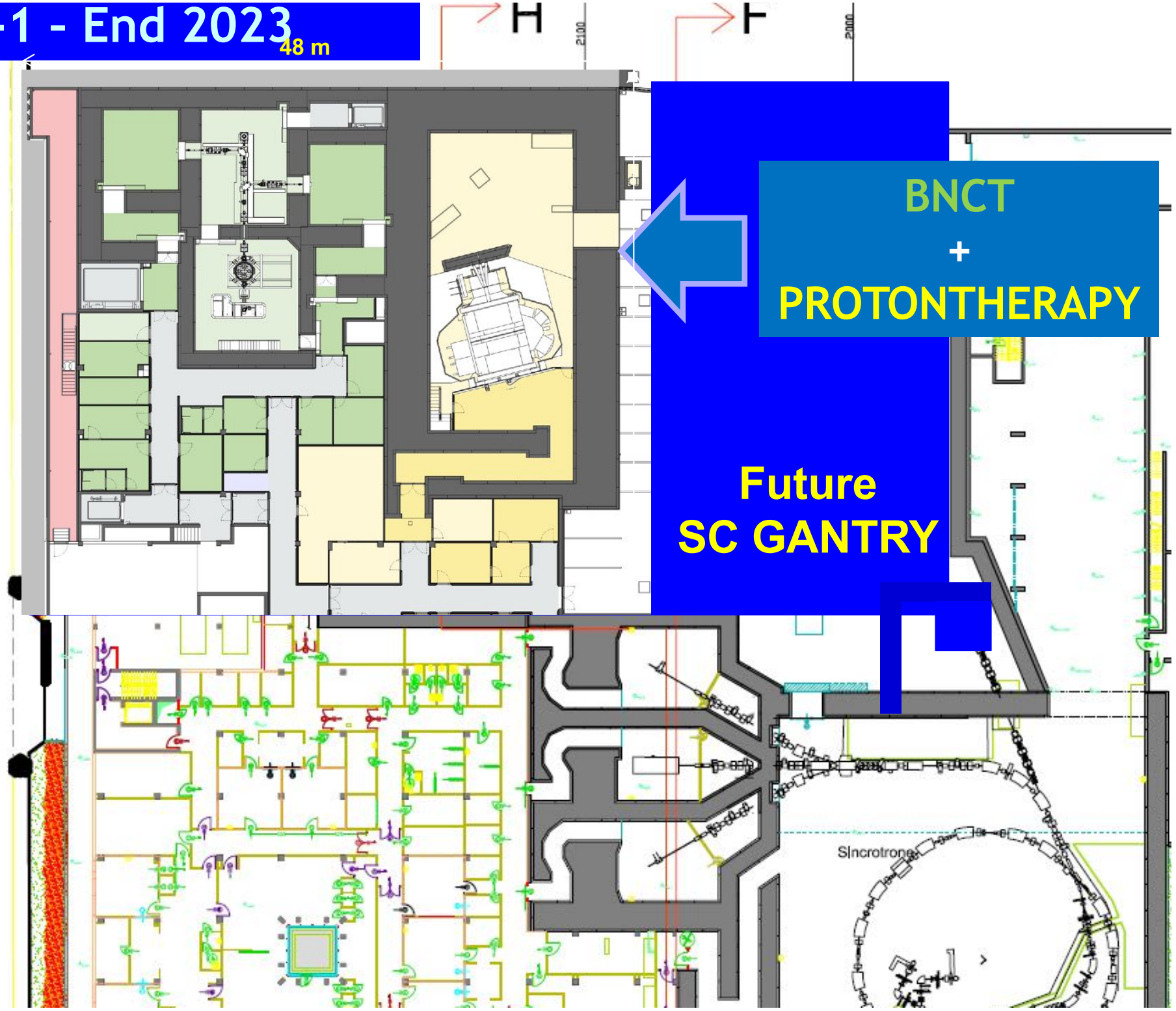
THIS COURSE: CNAO virtual visit - physics-biology
Speakers: Dr Angelica Facoetti (CNAO),
Dr Marco Pullia (CNAO)

CNAO EXTENSION - ongoing

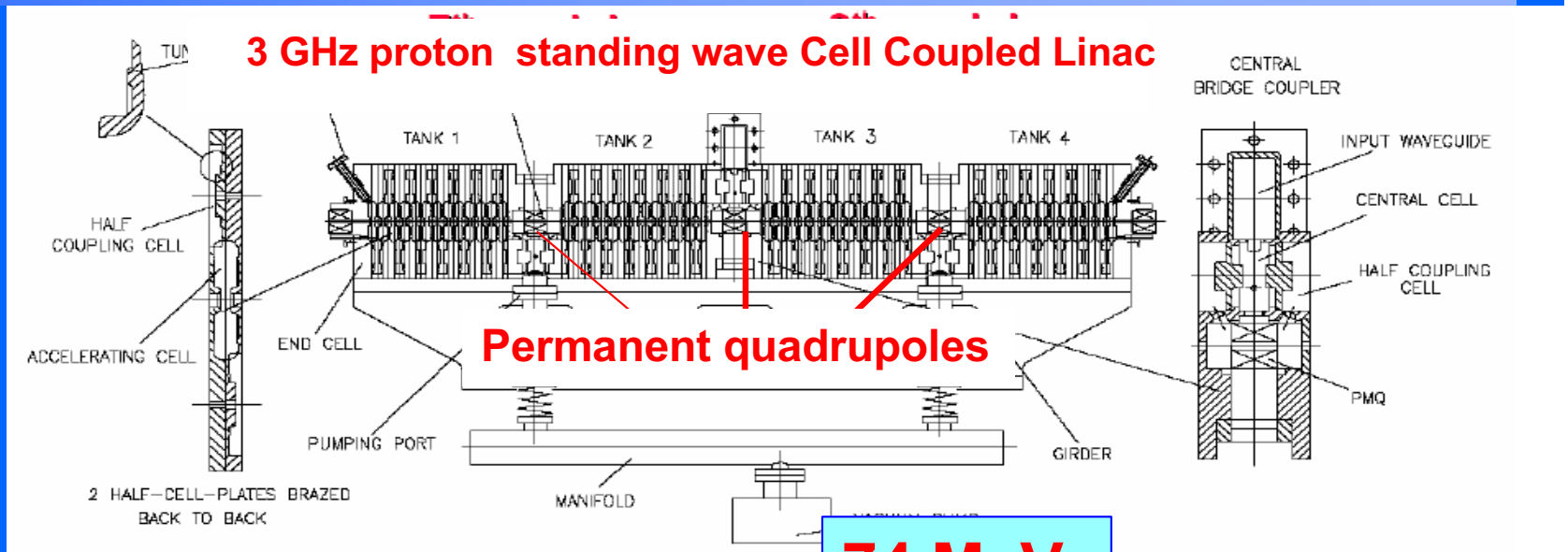
Extension program of CNAO



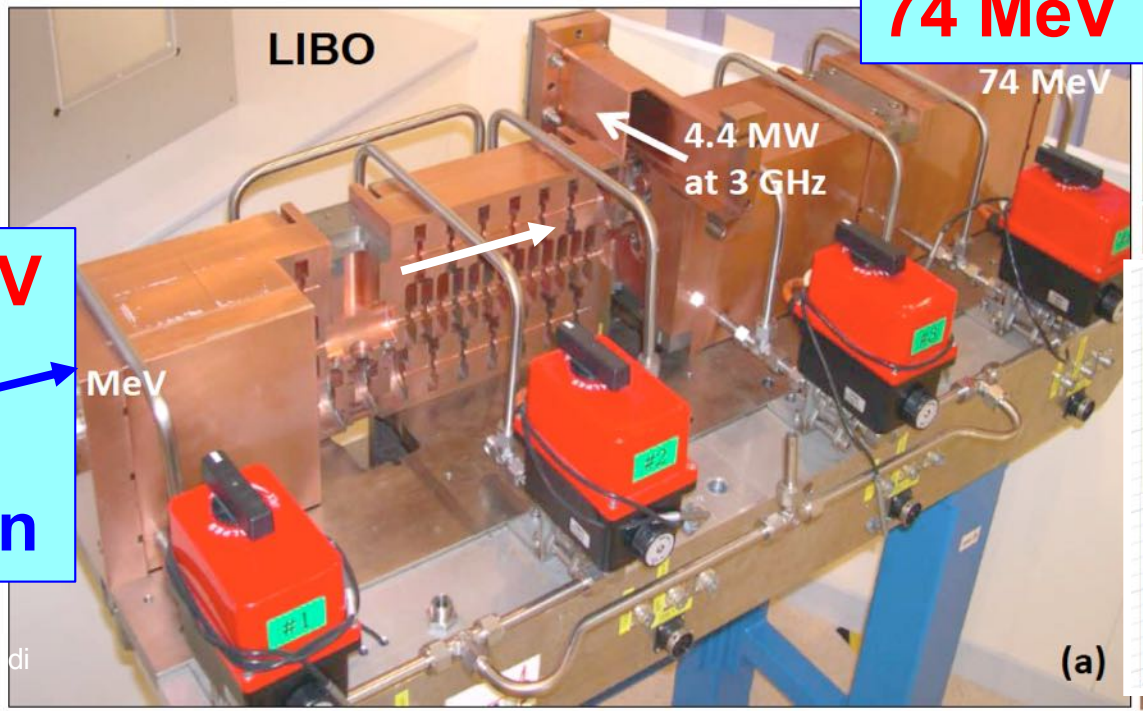
Level -1 - End 2023



LIBO=Scientific prototype built and beam tested by TERA-CERN-INFN – The first "cyc-linac"



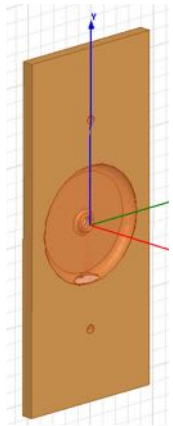
74 MeV



62 MeV

Catania

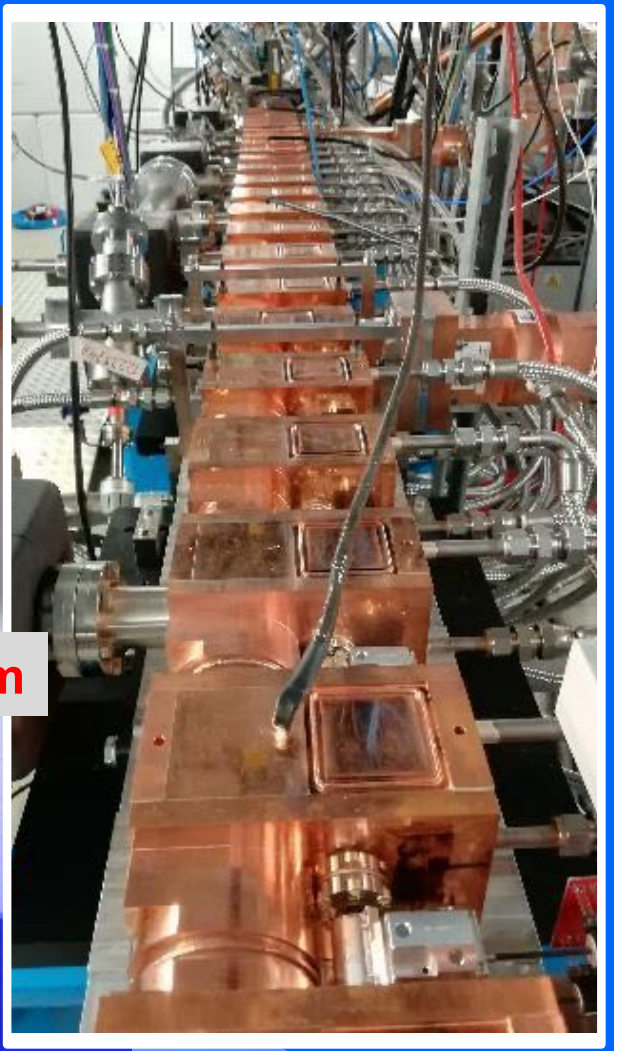
SC cyclotron



Basic unit: half-cell

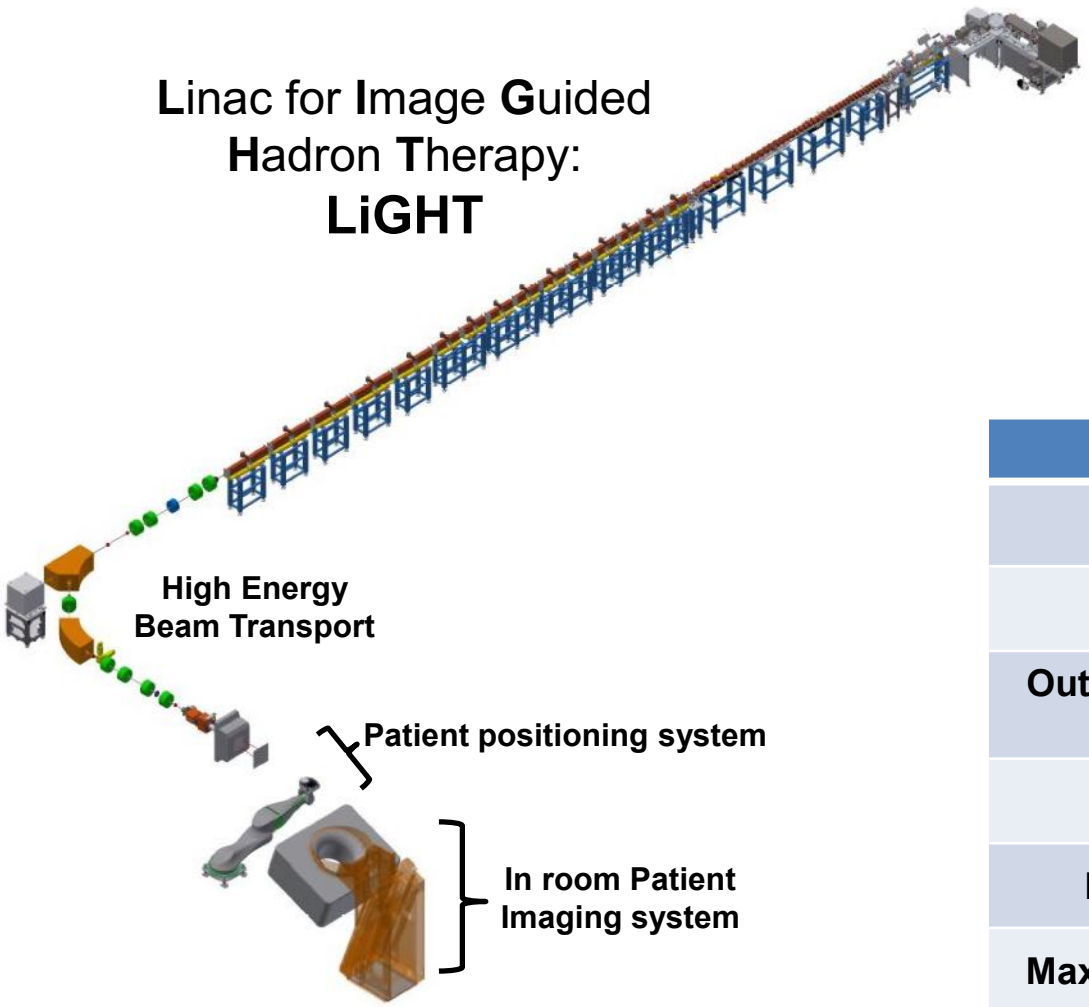
ADAM start-up created in 2008 and bought by AVO in 2013

In a CERN bunker AVO-ADAM has accelerated protons to 52 MeV



Integration:	Source	RFQ	SCDTL1	SCDTL 2	SCDTL3	SCDTL4	CCL1-2
B. energy:	40 keV	5 MeV	7.5 MeV	16 MeV	26.5 MeV	37.5 MeV	52 MeV

ADAM start-up created in 2008 and bought by AVO in 2013



Parameter	Value	Unit
Length	~25	m
Max. Energy	230	MeV
Output Peak Current (at the end)	0.3 - 40	μA
Pulse Length	0.5-2	μs
RF Frequency	2997.92	MHz
Max. Repetition Rate	200	Hz

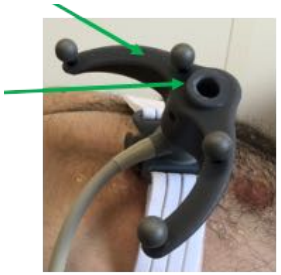
THIS COURSE: ADAM and LIGHT
Speaker: Alberto Degiovanni (ADAM)

3. EBA-Med: start-up for proton therapy of cardiac arrhythmias

EBA-Med develops Cardio-kit to enable non-invasive heart motion ultrasound imaging and real-time synchronization of the proton therapeutic beam produced by commercial.proton therapy systems.

3. EBA-Med: start-up for proton therapy of cardiac arrhythmias

EBA-Med develops Cardio-kit to enable non-invasive heart motion ultrasound imaging and real-time synchronization of the proton therapeutic beam produced by commercial.proton therapy systems.



External Beam Ablation will substitute the invasive catheter ablation technique

THIS COURSE: External Beam Ablation Medical Devices
Speaker: Adriano Garonna (EBAMed)


CNAO at Pavia
PHYSICS IS BEAUTIFUL AND USEFUL
Physik ist schön und nützlich
La physique est belle et utile
La fisica è bella e utile

This material was prepared and presented within the HITRIplus **Specialised Course on Heavy Ion Therapy Research,** and it is intended for personal educational purposes to help students; people interested in using any of the material for any other purposes (such as other lectures, courses etc.) are requested to please contact the authors

Ugo Amaldi – ugo.amaldi@cern.ch