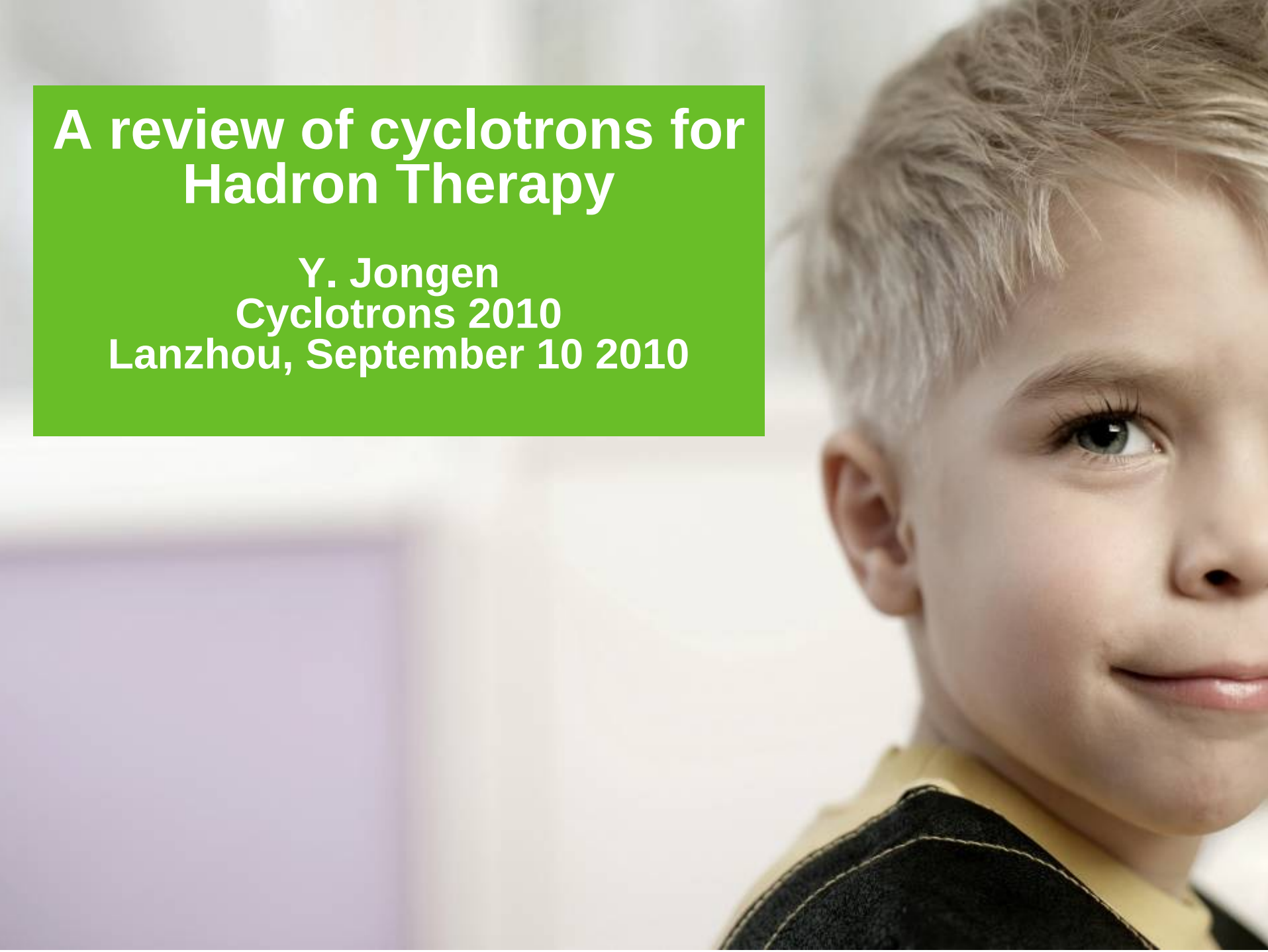
A review of cyclotrons for Hadron Therapy

Y. Jongen

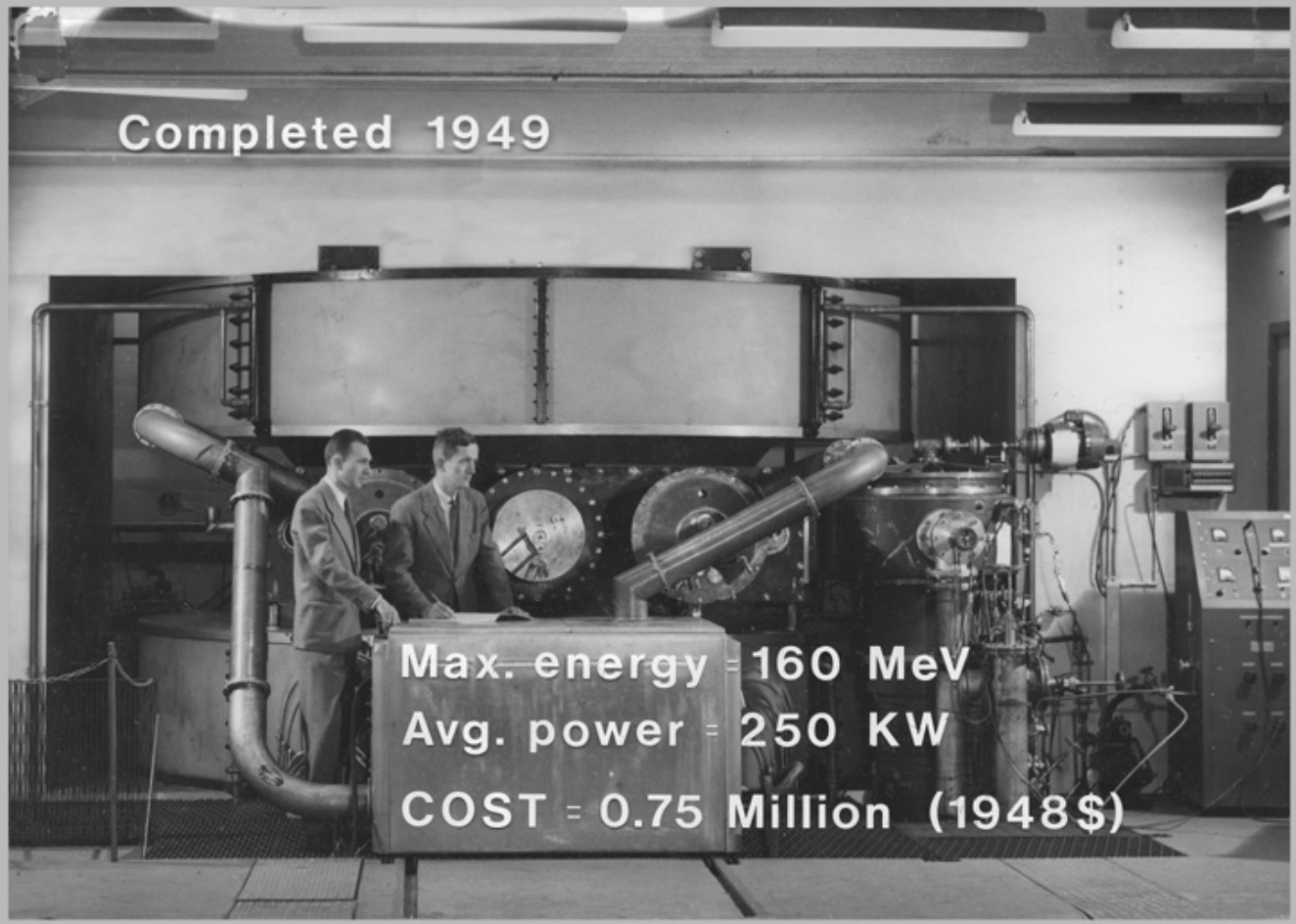
Cyclotrons 2010
Lanzhou, September 10 2010



The early days

- The possible use of the Bragg peak of high energy ions in the radiotherapy of cancer was suggested by Bob Wilson in 1946
- But it took two decades to see real clinical use of particle beam therapy in cancer treatment
- The first patient treatments took place in the late 1950's and early 1960's at LBNL in Berkeley, at Uppsala University in Sweden and at Harvard Cyclotron Laboratory (HCL)
- HCL had a specially important role in developing present day proton therapy techniques, while Berkeley developed the early steps of heavier ions therapy

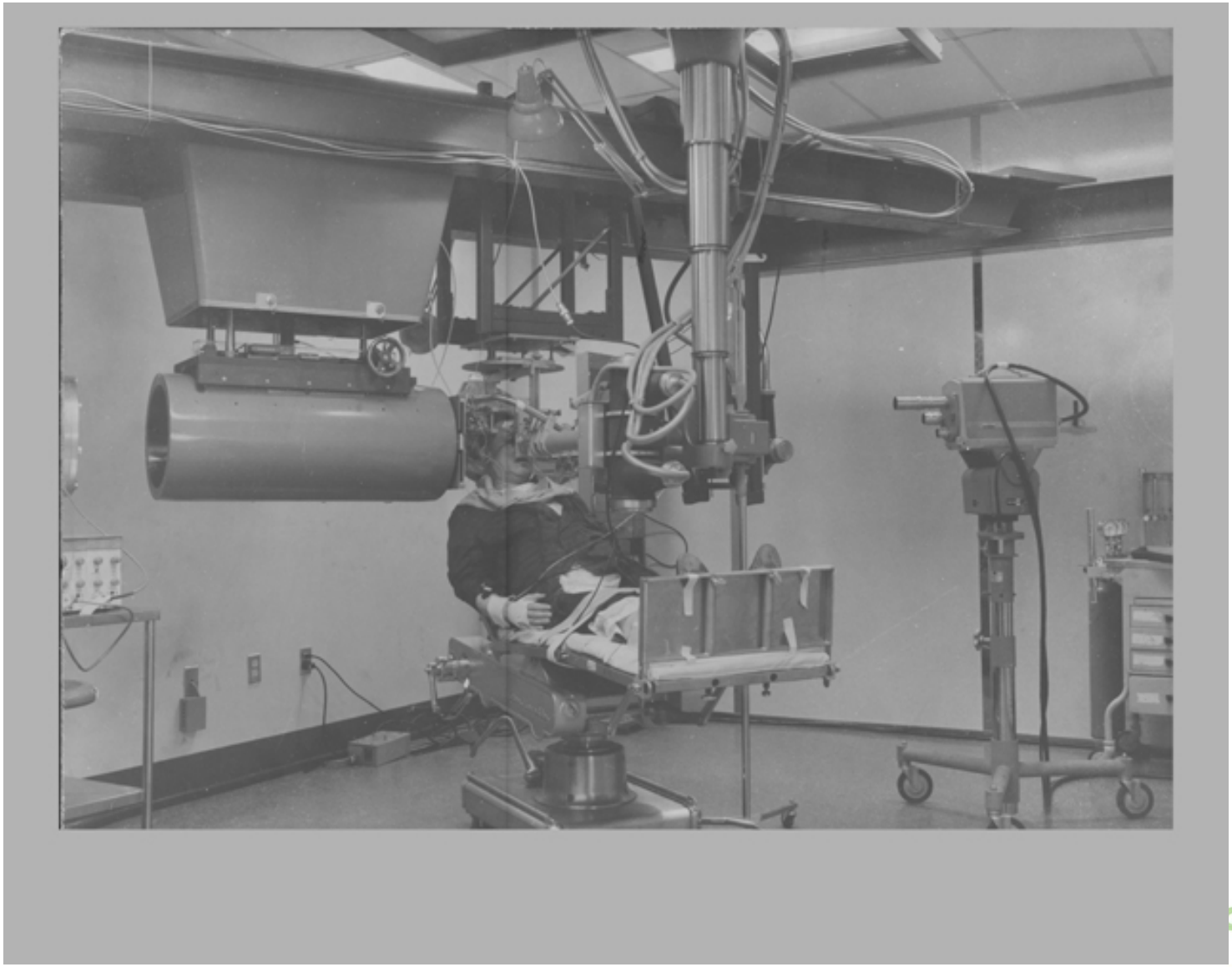
The Harvard Synchrocyclotron



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

Andy Koehler and Jason Burns in the MCR (1989)

Early proton treatments by Dr. Kjellberg



iba Advanced RadioTherapy

Hospital based facilities

- The successful experience of HCL indicated clearly that it would be better to have the proton therapy facility within the hospital, rather than in an ex-physics laboratory
- In 1983, the different laboratories developing PT got together and formed the Proton Therapy Cooperative Group (PTCoG) to develop hospital based PT facilities
- The first achievement of PTCoG was to develop a common set of specifications for an hospital based PT facility
- These specifications remain today the “bible” of proton therapy facility developers (even if the validity of some specifications are discussed today)

Loma Linda

- While most of the early development of proton therapy was made in Harvard, the group led by Pr. James (Jim) Slater at Loma Linda University Medical Center (LLUMC) was the first to be able to raise the funds needed to build a hospital based PT facility
- The development of the accelerator was subcontracted by LLUMC to a group of experienced accelerator physicists at Fermilab.
- The accelerator technology selected was a synchrotron and for a long time the synchrotron would be considered the technology of choice for PT
- The development of the gantries was subcontracted to SAIC
- A company (named Optivus today) was created by Jim Slater to do the maintenance and development of the LLUMC PT facility
- Optivus is proposing for sale a PT system closely derived from LLUMC one (but so far have not concluded a contract)

Massachusetts General Hospital (MGH) (1)

- MGH, who was leading the PT development at HCL got in 1992 from NCI and private donors the budget needed to build an in hospital PT facility. An international tender was launched
- After a first selection, 3 groups remained in the race:
  - Varian, allied with Maxwell-Brobeck was proposed a synchrotron based system
  - Siemens proposed 2 solutions. One based on a synchrotron, the other based on a superconducting isochronous (designed by Pierre Mandrillon from CERN & Nice)
  - IBA, allied with General Atomics proposed a solution based on a resistive isochronous cyclotron of 230 MeV
- Eventually, the IBA system was selected by MGH, and the contract was signed in 1994 with the goal to treat a first patient in 1998

Massachusetts General Hospital (MGH) (2)

- At the end of the MGH tender, one observer noted: « This tender may well cause the end of 3 good accelerator companies: perhaps for the companies which did not get the contract, but certainly for the company that got it ». He was very close to be entirely right
- After the contract with IBA, the Brobeck division of Maxwell was closed
- The “special projects” division of Siemens was closed too, and sold to its management. It restarted business under the name of ACCEL, and eventually came back to PT
- IBA encountered problems too. The cyclotron, beam lines and gantries came on specifications, on time and on budget. But we underestimated badly the effort and methodology needed for the software development. Finally the first patient was treated in 2001, 7 years after the contract (7 years seems to be an invariant for PT systems). The cost overrun was huge! Fortunately, IBA had other profitable activities to avoid bankruptcy

IBA 230 MeV resistive isochronous cyclotron

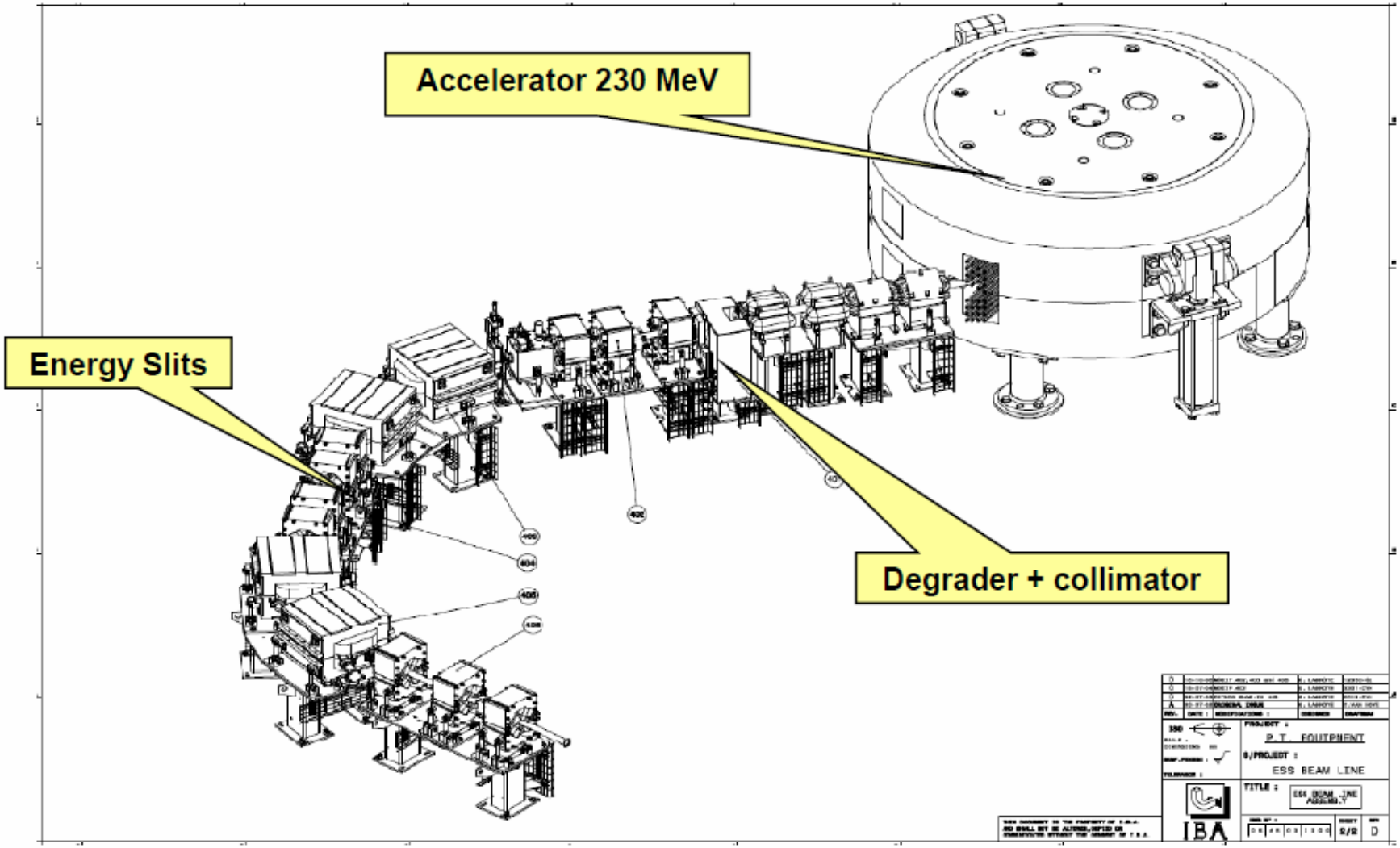
Inside the cyclotron

iba Advanced RadioTherapy

Central region

Electrostatic deflector

Energy selection system



Advanced RadioTherapy

Isocentric gantry treatment room

Advanced RadioTherapy

The sales of the IBA system

- 9 Treating Patients
  - MGH (Boston)
  - MPRI* (Bloomington, In)
  - Wanjie PTC (Zibo, China)
  - UFPTI (Jacksonville, Fl)
  - KNCC (Ilsan, Korea)
  - Procure 1 (Oklahoma City)
  - U-Penn (Philadelphia, Pa)
  - CPO (Orsay, France)
  - Hampton University (Va)
- 2 in Installation
  - WPE (Essen, Germany)
  - Procure 2 (Warrenville, Il)
- 5 in Construction
  - Procure 3 (Somerset, Il)
  - ATreP (Trento, Italy)
  - Procure 4 (Seattle, Wa)
  - PTC Prag (Prag, Czech R.)
  - PTC Krakow (Krakow, Poland)

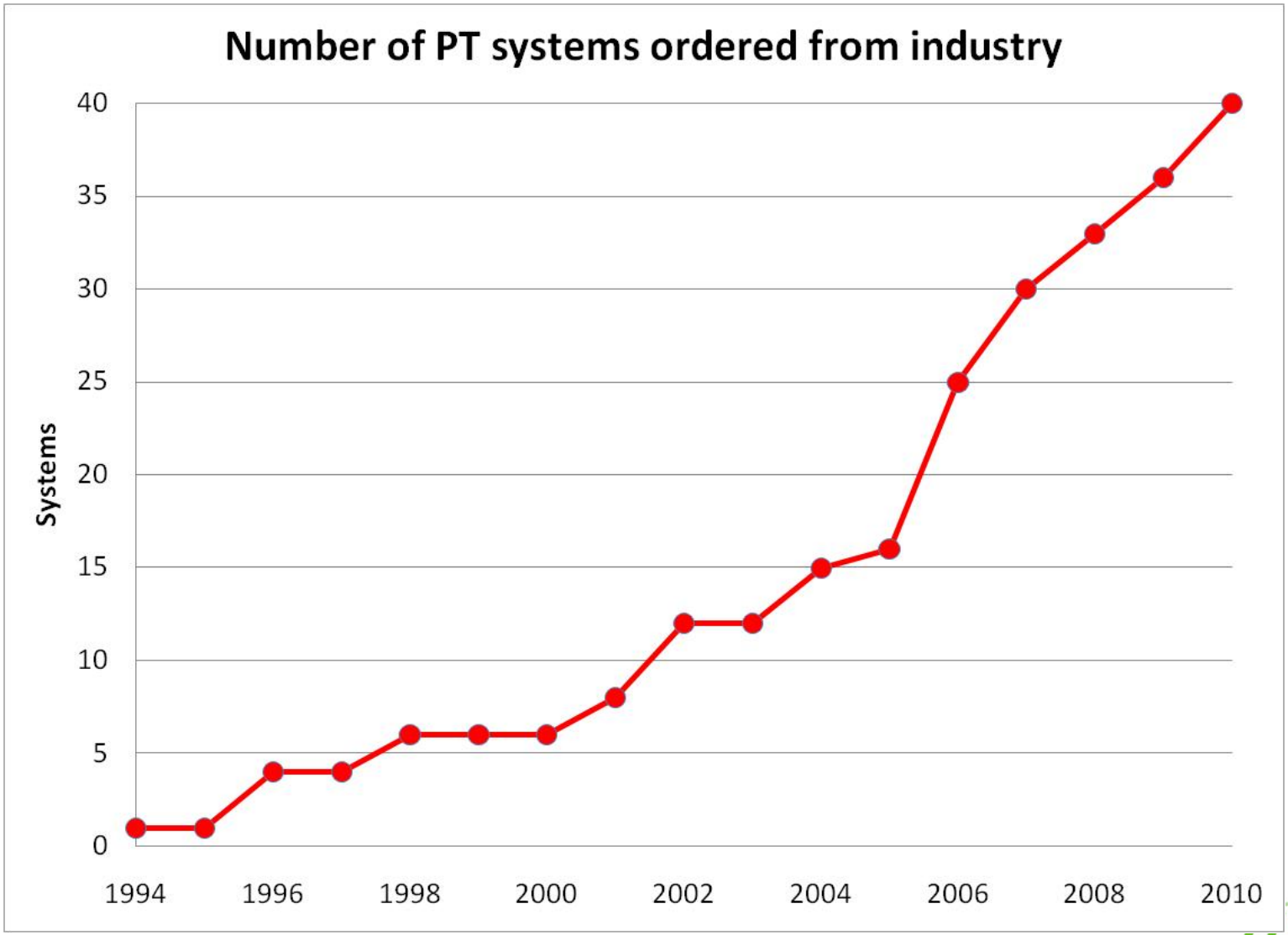
*MPRI: Gantry only

iba Advanced RadioTherapy

1995-2000: Japan leads the way

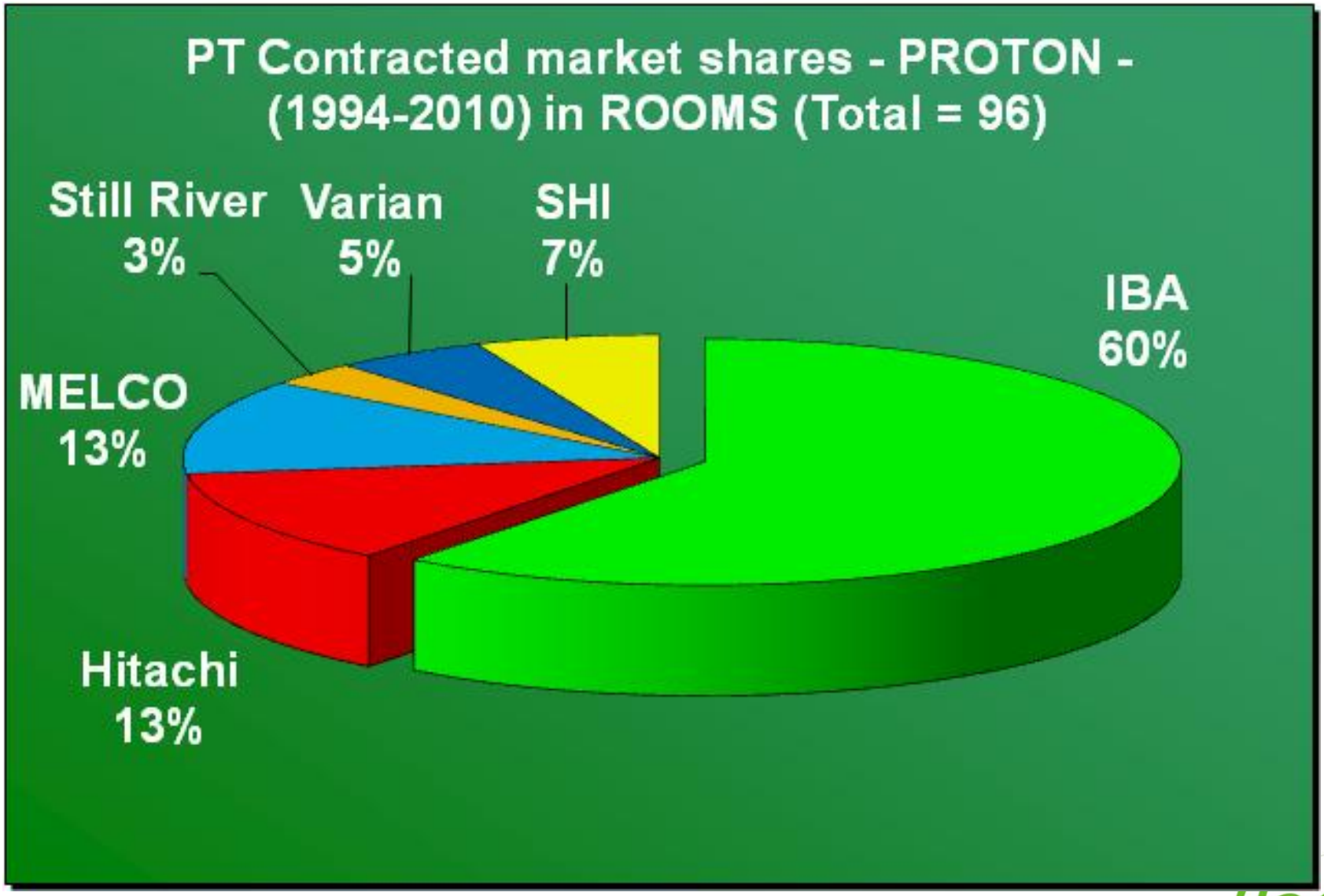
- After the MGH order, from 1995 to 2000, the construction of proton therapy facilities concentrated in Japan, where the public authorities financed the construction of 4 PT facilities and one carbon/proton facility. These facilities were built by 3 Japanese companies: Hitachi, Mitsubishi Electric Co (MELCO), and Sumitomo Heavy Industries (SHI)
- In 1991, IBA and SHI had signed a 10 years collaboration agreement to develop jointly a proton therapy system. The first system installed by SHI at NCC in Kashiwa was built in collaboration (the cyclotron magnet came from IBA).
- Knowing about the difficulties encountered by IBA at MGH with the software, SHI proposed a much simpler control system for Kashiwa. As a result, in 1998, NCC was the first PT system based on an isochronous cyclotron to treat a patient.
- After 2000, the orders of PT facilities to industry grew rapidly

Number of systems contracted to industry



Advanced RadioTherapy

PT market share (in treatment rooms): 75% cyclos

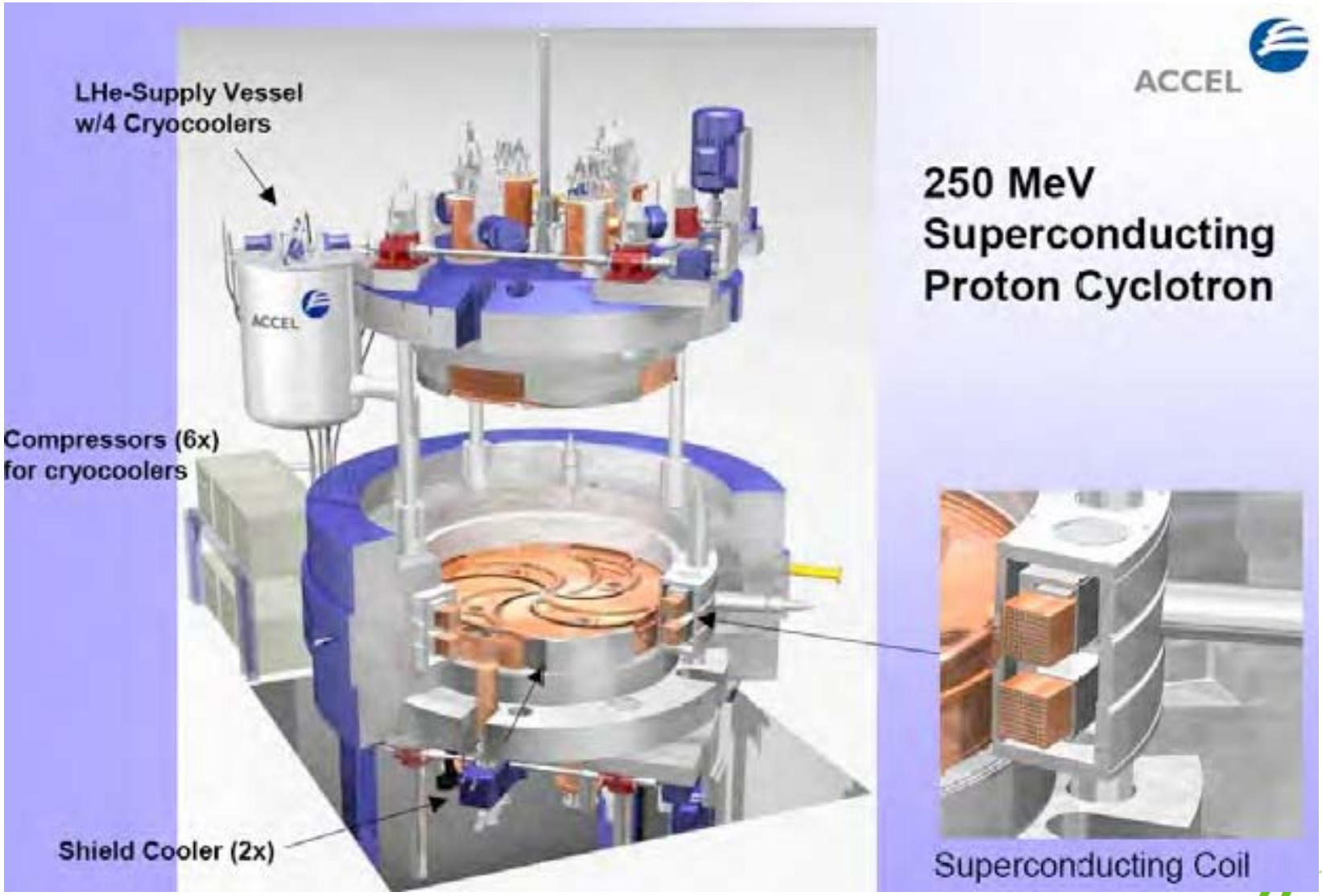


After NCC, SHI sold one system to Taiwan

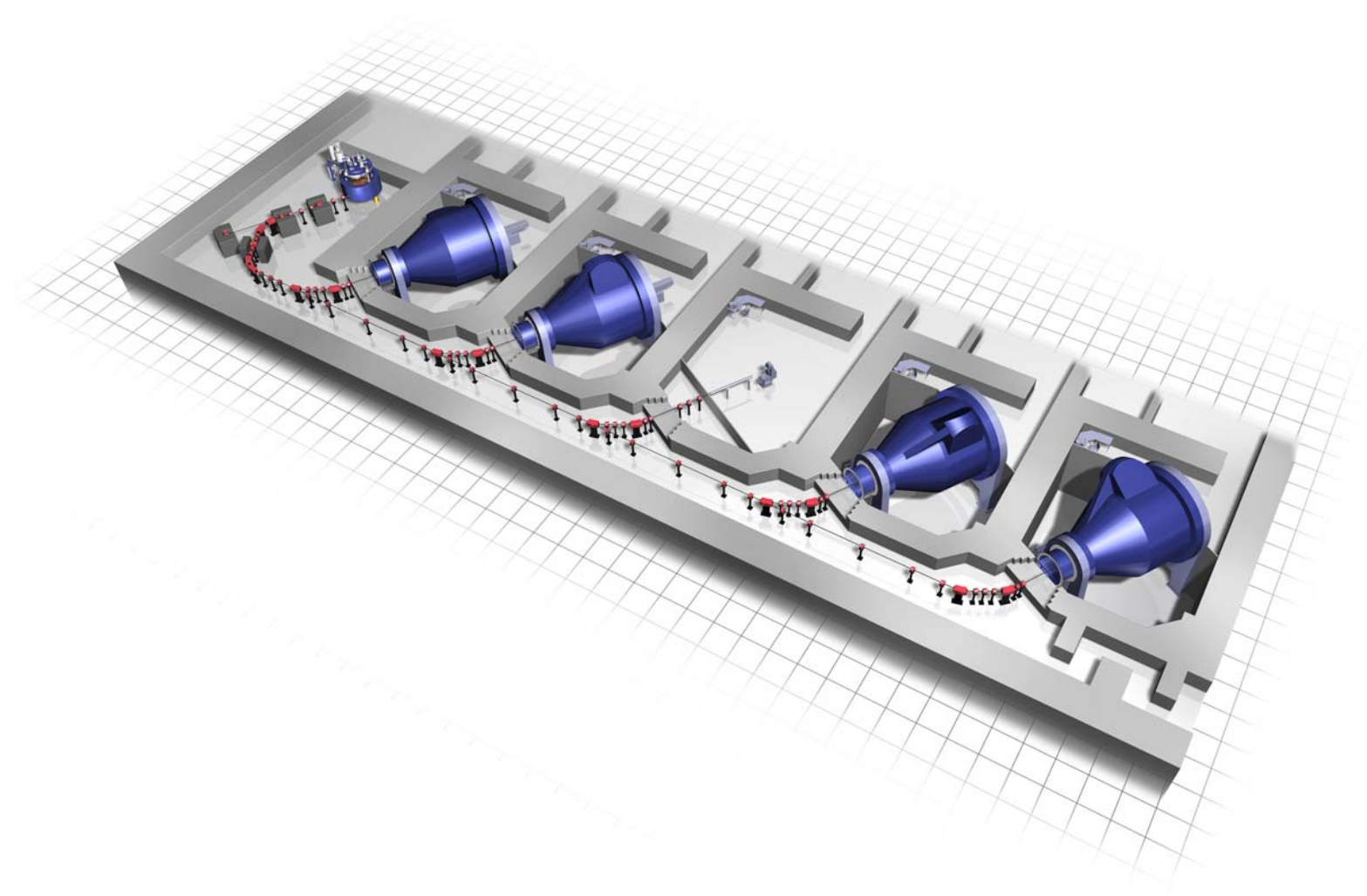
ACCEL-Varian

- Around 1995, ACCEL decided to return to the field of proton therapy, and asked Henry Blosser to design for them a high extraction efficiency, 250 MeV SC isochronous cyclotron
- The prototype of the new ACCEL cyclotron was sold to PSI for their new PT facility
- Then in 2002, ACCEL was selected to deliver a 5 treatment rooms PT facility to the clinic of Dr. Rinecker in Munich
- Like for IBA, the development and installation of the cyclotron, beam lines and isocentric gantries was more or less on schedule, but major difficulties were encountered for the development of the treatment software
- Eventually, in 2007, ACCEL was acquired by Varian, the leader in classical (photons) radiotherapy equipment
- The first patient was treated at the Rinecker PTC in 2009
- However, at this date (September 2010) the validation of the Rinecker facility is still ongoing and no new PT orders have been officially confirmed by Varian

ACCEL-Varian superconducting cyclotron



ACCEL-Varian PT facility in Munich

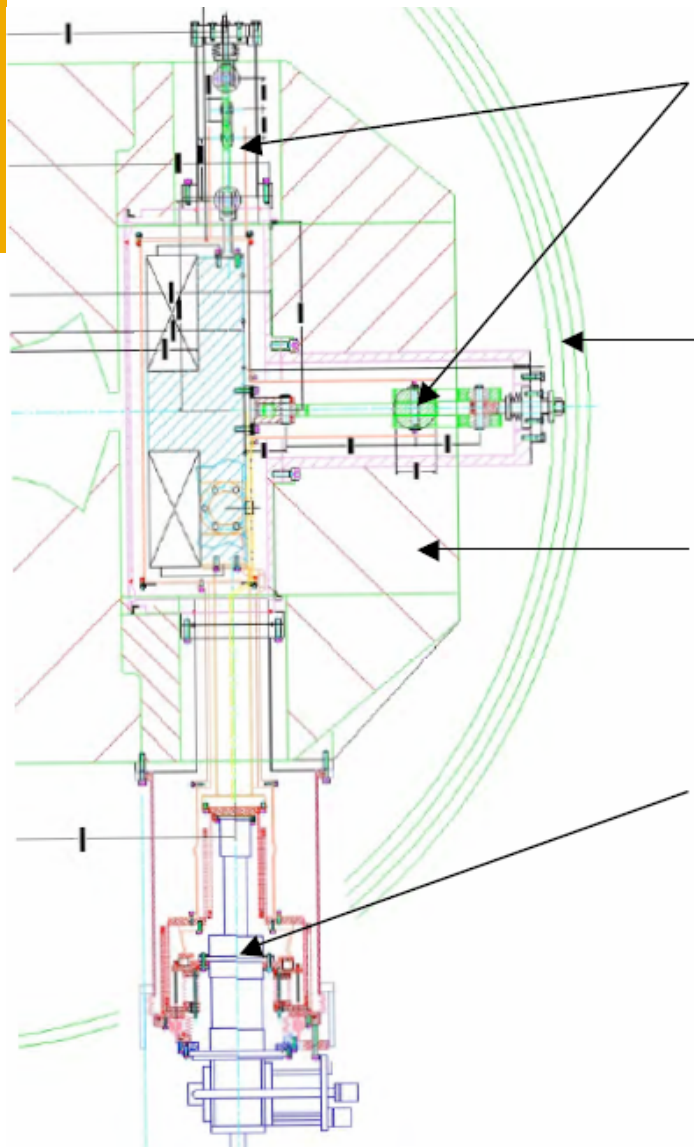


iba Advanced RadioTherapy

The compact PT system of Still River Systems

- Around 2004, the Still River Systems company was formed by medical physicists who had shared the PT experience of HCL and MGH: Ken Gall, Miles Wagner and Skip Rosenthal.
- Their goal was to design and build a one room, very compact PT system based on a very high field (9T) synchrocyclotron mounted on a gantry and rotating around the patient
- The original design of the cyclotron was made for them by Tim Antaya from MIT, but the further development of the cyclotron was made by SRS, independently from MIT
- As usually in PT, the new PT system was offered for sale despite the lack of a working prototype, and a number of “soft” commitment were obtained from prospective customers
- The development of the prototype was strongly delayed, and to a large extent by problems to reach stable operation of the cyclotron SC magnet

SRS cyclotron Nb-Sn magnet design

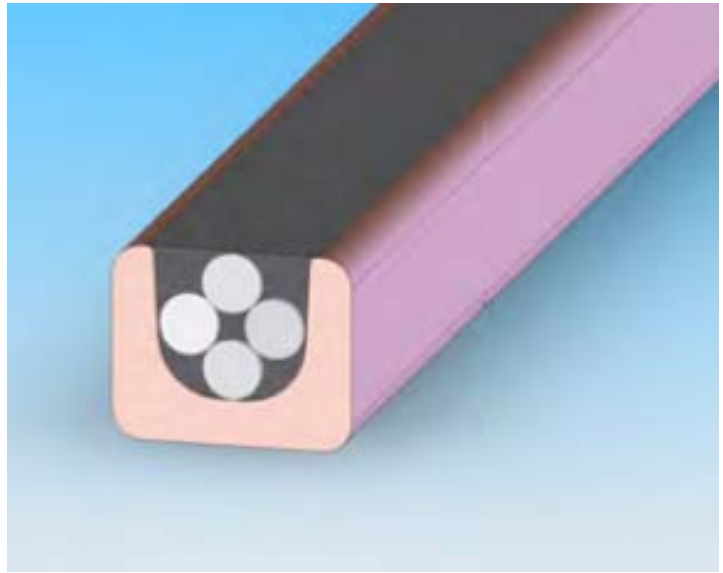


Axial and Radial Tension Links

Integral Magnetic Shield

Warm Iron

Cryo-cooler and HTS Leads

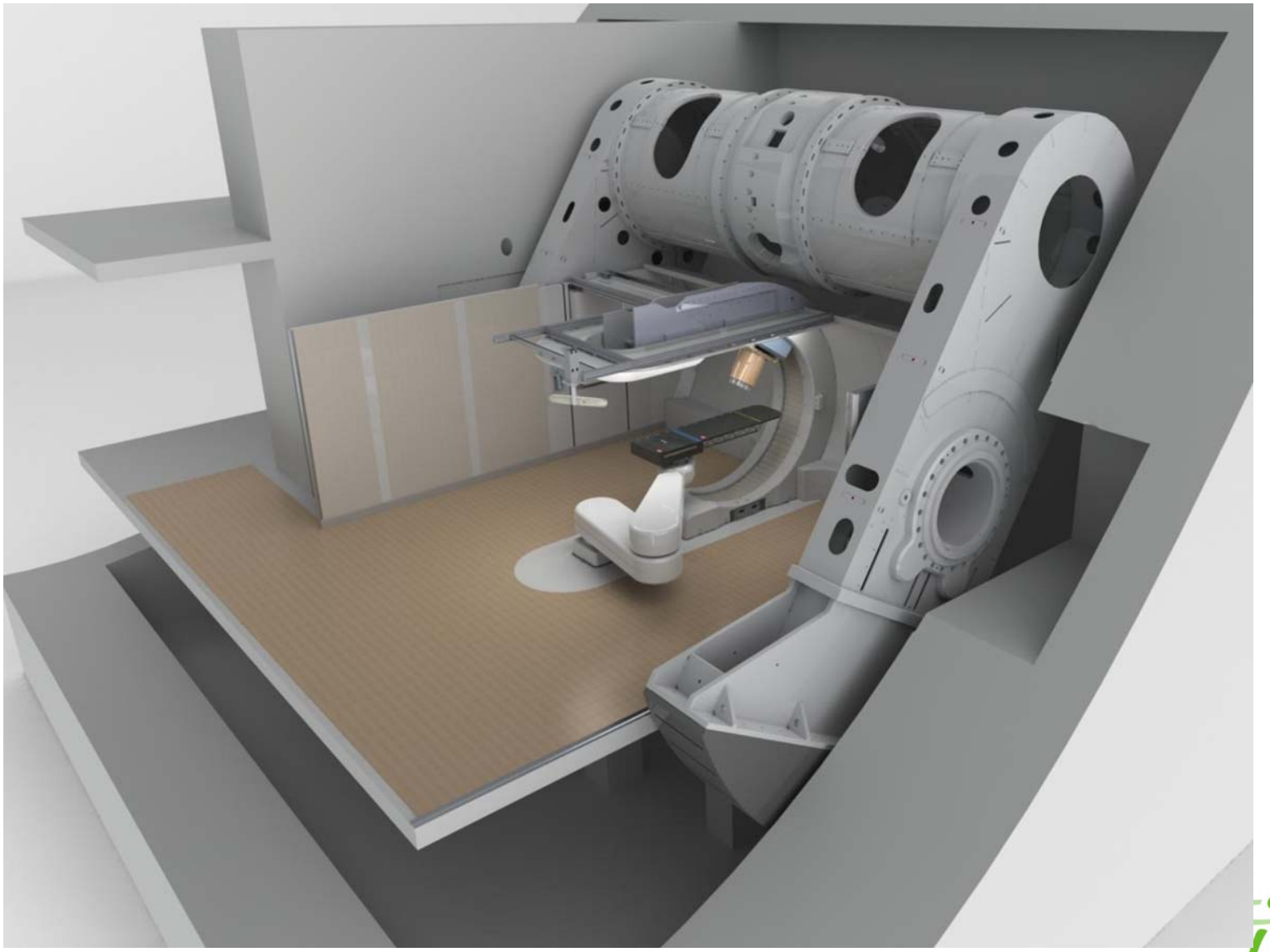


iba Advanced RadioTherapy

SRS cyclotron prototype

iba Advanced RadioTherapy

SRS PT treatment room



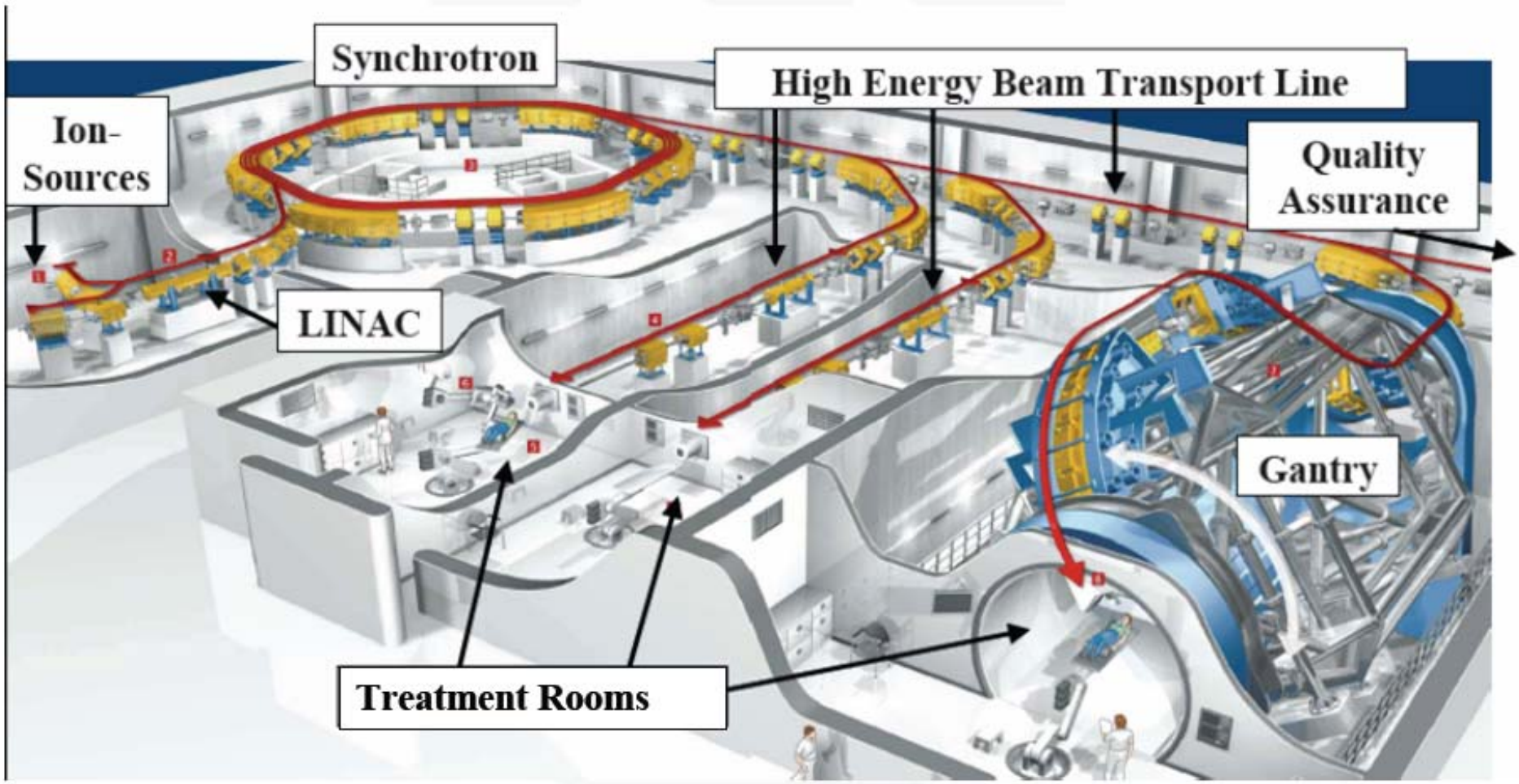
iba Advanced RadioTherapy

The SRS team after the first extracted beam!

Carbon therapy

- Like in PT, the initial research in heavier ion therapy took place in national research centers: first LBNL (Bevalac), then NIRS (Himac) then GSI.
- Realizing the limits of treating patients in a physics laboratory, GSI developed the design of a more compact, hospital based carbon therapy system. The prototype was built at the DKFZ in Heidelberg
- For carbon acceleration up to 400 MeV/u, a system made of an ECR ion source, a RFQ, a DTL and a synchrotron seemed obvious and was selected in all projects so far.
- A similar system was developed in a European collaboration led by CERN (the PIMMS design). The prototype of the PIMMS design was adapted and is being constructed in Pavia (CNAO, Italy)
- Similarly, NIRS developed the design of a compact, hospital based carbon ion facility. The prototype is installed at Gunma university and started treating patients this year. The Gunma NIRS system is available for sale from all big Japanese manufacturers

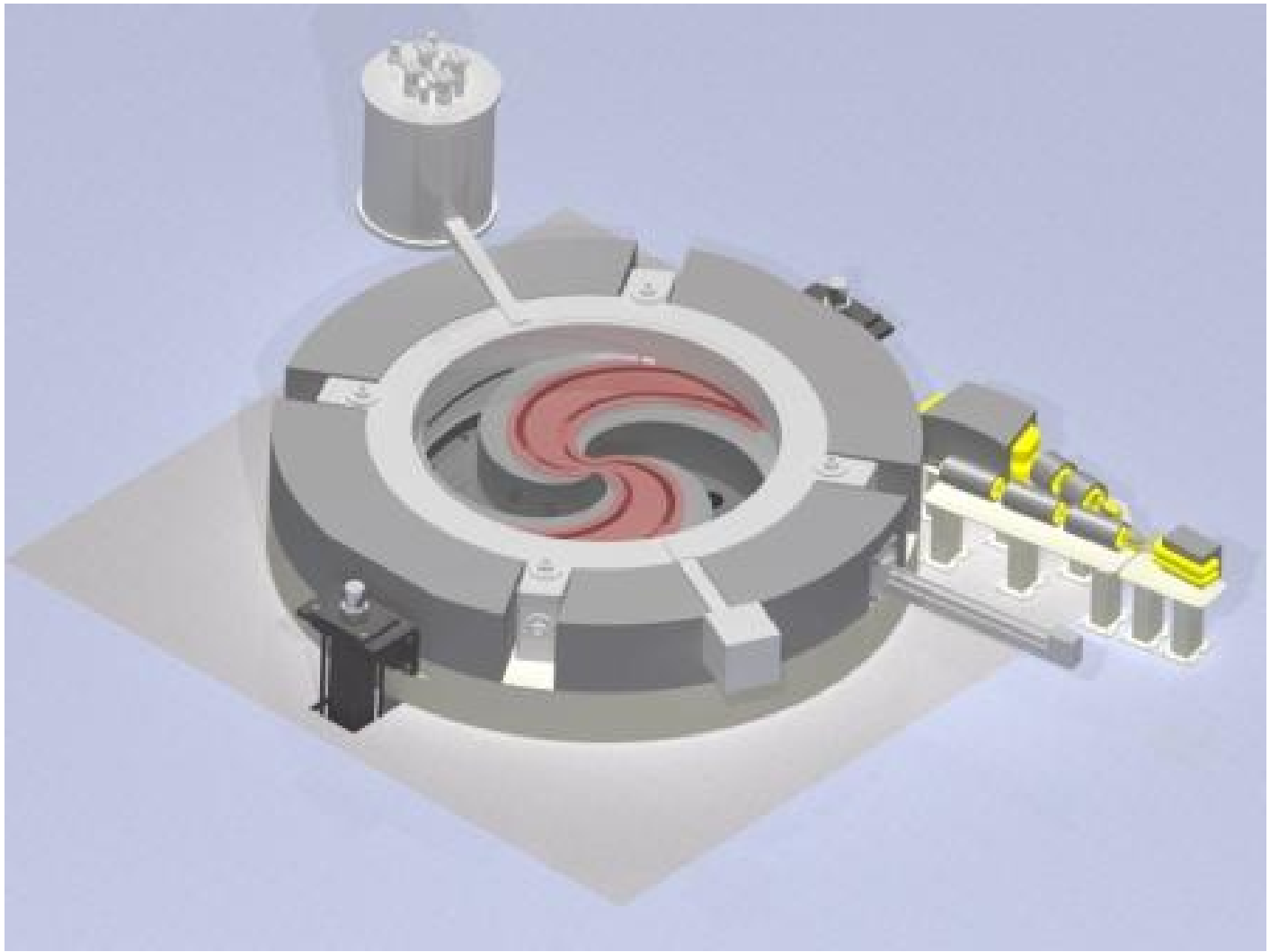
HIT: Heidelberg Ion Therapy Facility



Cyclotrons in Carbon therapy ???

- Today, the synchrotron is the natural choice of accelerator in carbon therapy. The rigidity of carbon ions at 400 MeV/u is 6.4 Tm, and synchrotrons have naturally a variable energy.
- But the same thing was said in proton therapy until 1992, when IBA introduced an effective cyclotron design for PT. Today, 75% of PT facilities are based on cyclotrons
- Can we bring the same revolution in carbon therapy? Yes we can! IBA has developed, together with a team of the JINR in Dubna the design of an isochronous cyclotron able to accelerate Q/M = ½ ions to 400 MeV/u (see the presentation of N. Morozov in this session)
- Why selecting the cyclotron?
  - The cyclotron is smaller and cheaper
  - All parameters are constant
  - You operate one accelerator, not 3 accelerators in series
  - The beam is continuous, and can be modulated rapidly in intensity

The IBA C400



iba Advanced RadioTherapy

Conclusions (1)

- The initial development of proton and carbon beam therapy took place in national research laboratories
- But since the MGH tender in 1992-1994, more than 40 proton and carbon therapy facilities were ordered to industry. Roughly half of these 40 systems have been installed and are treating patients
- These systems built by industry have treated today more than 15,000 patients
- Initially, following the development of the Loma Linda synchrotron by Fermilab scientists, synchrotron was considered the preferred accelerator technology for proton therapy

Conclusions (2)

- In 1991, IBA was the first to come with an efficient proton therapy design based on an isochronous cyclotron. Almost 20 years later, 75% of the systems installed or in construction in the world are based on cyclotrons
- Today, the synchrotron is the preferred accelerator technology for carbon beam therapy
- But IBA is presenting today a carbon therapy system based on a SC 400 MeV/u isochronous cyclotron
- We could see tomorrow cyclotrons becoming also the preferred choice for carbon beam therapy

Thank you…