Accelerators for Ion Beam Therapy

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Forschungszentrum Jülich

517th WE-Heraeus Seminar, 18 Oct 2012

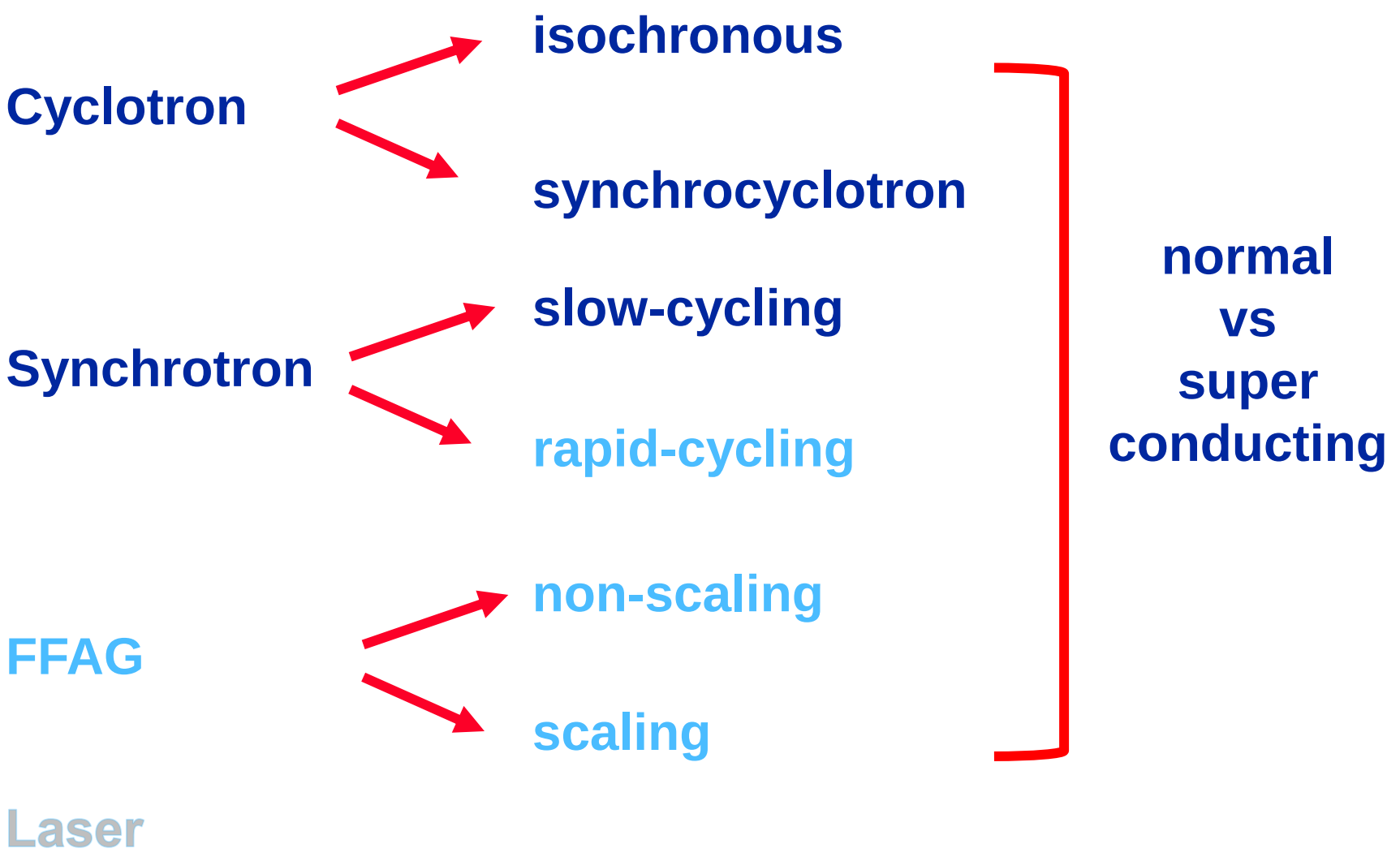
Accelerators for Ion Beam Therapy

• general requirements for IBT accelerators •

- High reliability
- Ease of operation
- Low operation cost
- Ease of maintenance
- Low maintenance cost
- Low follow-up costs

Accelerators for Ion Beam Therapy

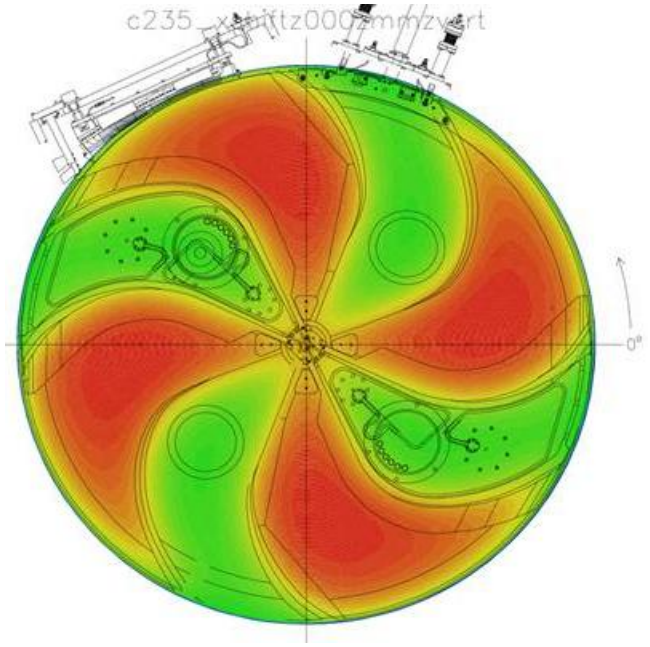
• accelerator types •



Accelerators for Ion Beam Therapy

• cyclotron: isochronous •

IBA-Proteus 235: FHBPTC, UFPTI, UPHS and 17 other locations



normal conducting

- Compact isochronous cyclotron

- 235 MeV proton energy
- 300 nA beam current, quasi-continuous
- Typical efficiency : 55 %

- Approx. weight: 220 t
- Diameter: 4.3 m

- Conventional magnet coil: 1.7 - 2.2 T
- RF Frequency: 106 MHz
- Dee voltage: 55 to 150 kV peak

Data: D. Bertrand, IBA

Accelerators for Ion Beam Therapy

• cyclotron: isochronous •

Design: H. Blosser, MSU

superconducting

Varian Probeam 250: PSI, RPTC (≥ 6 under development)

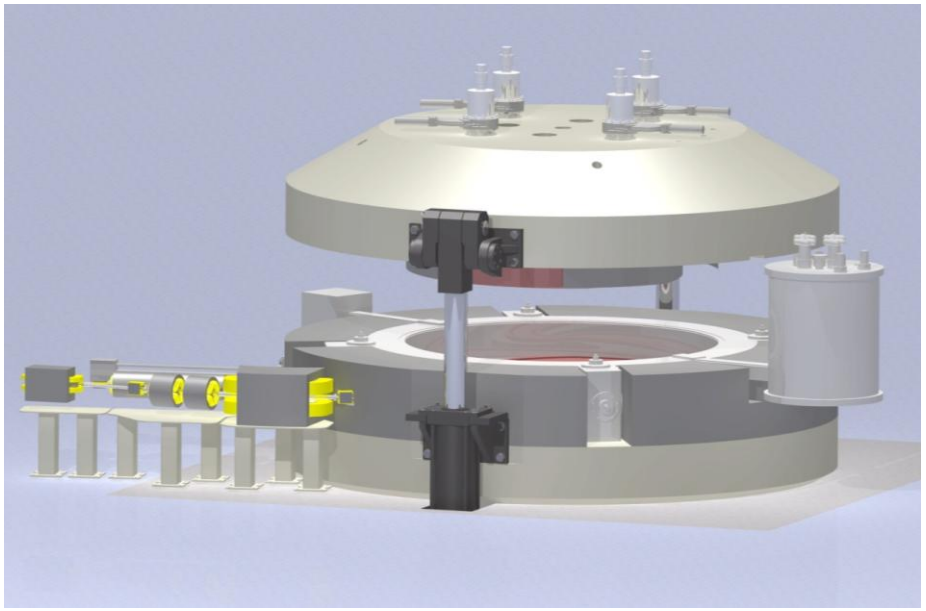
Particle	H
Energy	250 MeV
Outer diameter	3.1 m
Height	1.6 m
Weight	<90 t
Extracted current	(max)800 nA
RF power	≤115 kW
Magnetic field	2.4 (<4) T

Data: H. Röcken, Varian

Accelerators for Ion Beam Therapy

• cyclotron: isochronous •

IBA C400: ARCHADE?



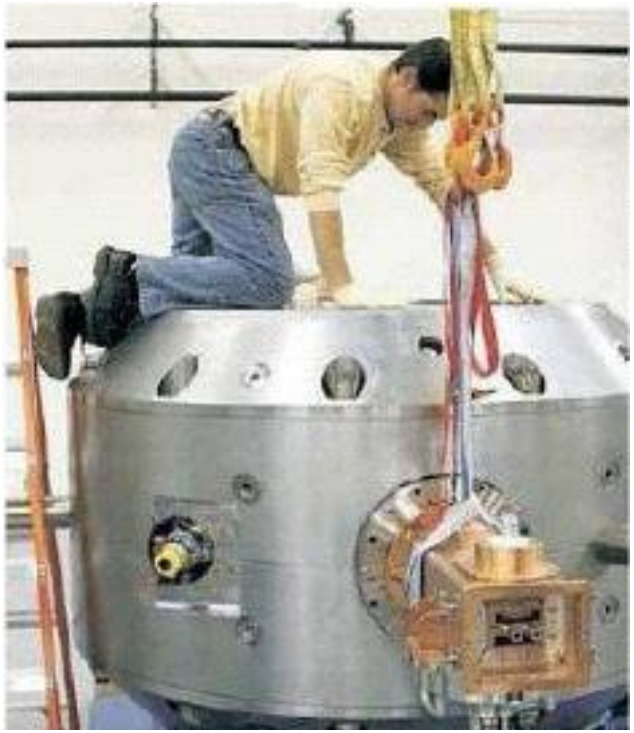
Ion	H-Ne
Energy (MeV/u)	400 (H:250)
Outer diameter (m)	6.6
Height (m)	3.4
Weight (t)	700
Extracted current (nA)	8
RF power (kW)	2x100
Magnetic field	4.5 T
RF Frequency	75 MHz

superconducting

Data: D. Bertrand, IBA and A. Olshevskiy, JINR

Accelerators for Ion Beam Therapy

• cyclotron: synchrocyclotron •

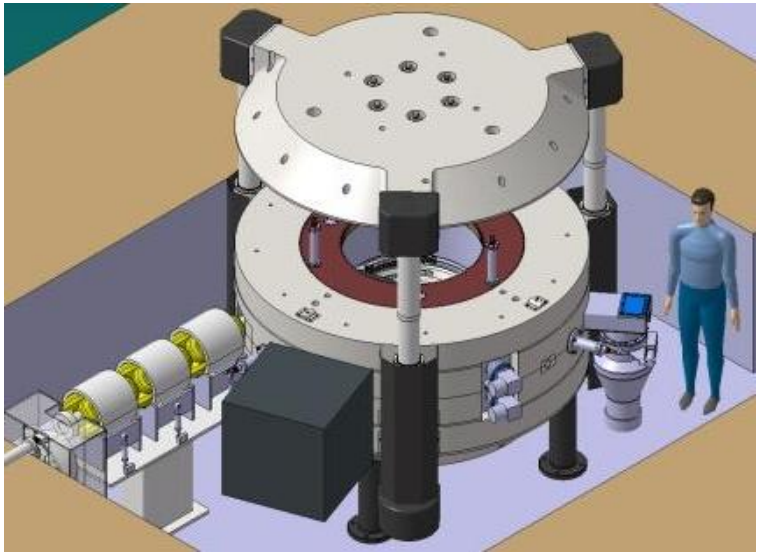


Mevion (Still River) S250

Design: T. Antaya, MIT

Ø 1.8 m, weight 20 t, 9 T, Nb3Sn coil, >10 nA at 250 MeV

super conducting



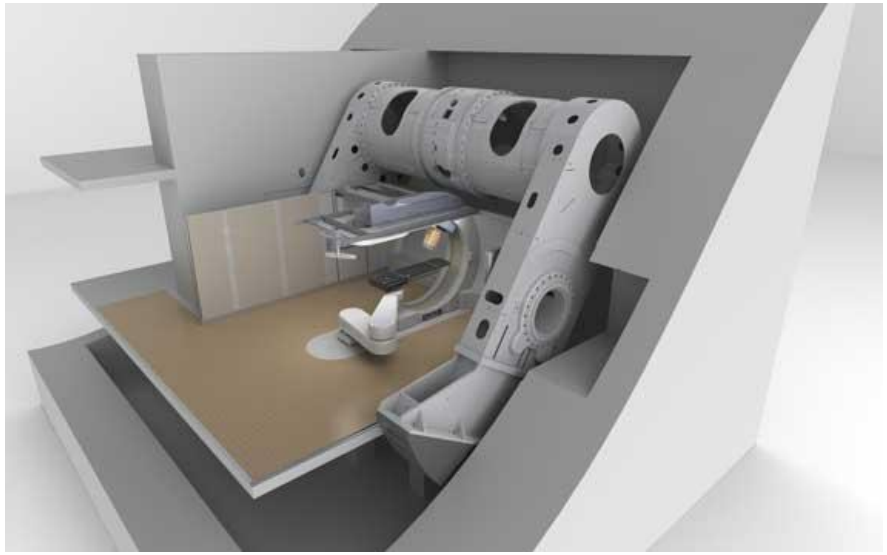
IBA S2C2

Ø 2.5 m, height 2 m, weight <50 t, 5.6 T, NbTi cryogen free coil and laminated steel operator-free system w. remote diagnostics, 20 nA average beam current at 230 MeV for PBS; Extraction efficiency >50% at 230 MeV 1 kHz beam pulse repetition rate for PBS

Accelerators for Ion Beam Therapy

• one-room facility •

180° gantry



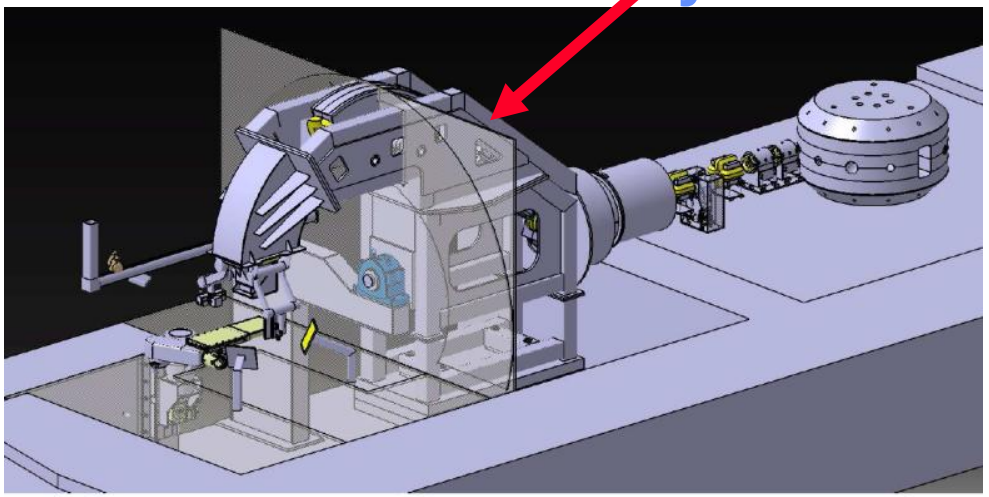
HIGH ENERGY CANCER CARE
MEVION medical systems S250

L: 14 m, H: 14 m
(scheduled for 2012)

03/12: CE certified
06/12: FDA 510(k) cleared

220° gantry

beam analysis



ProteusONE™

L: 27 m, H: 13 m
(scheduled for 2014)

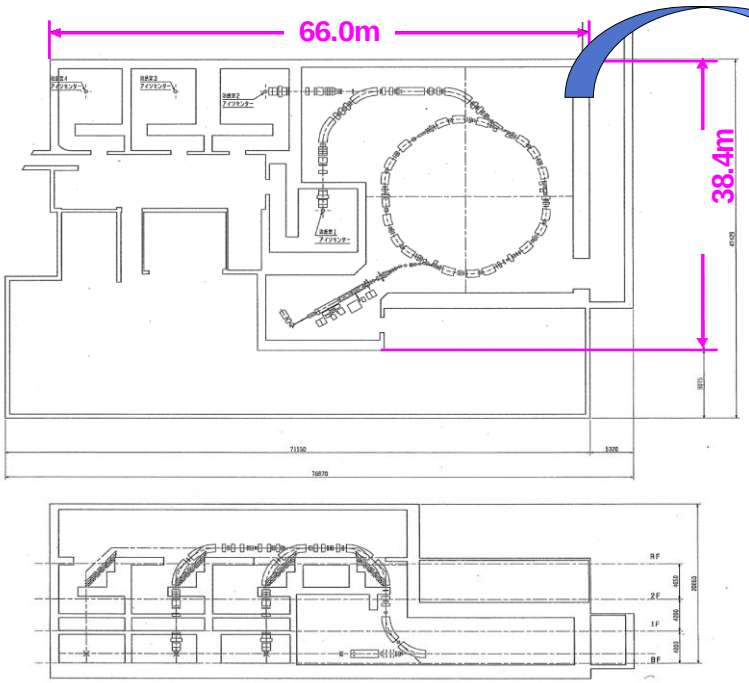
Accelerators for Ion Beam Therapy

• synchrotron: slow cycling •

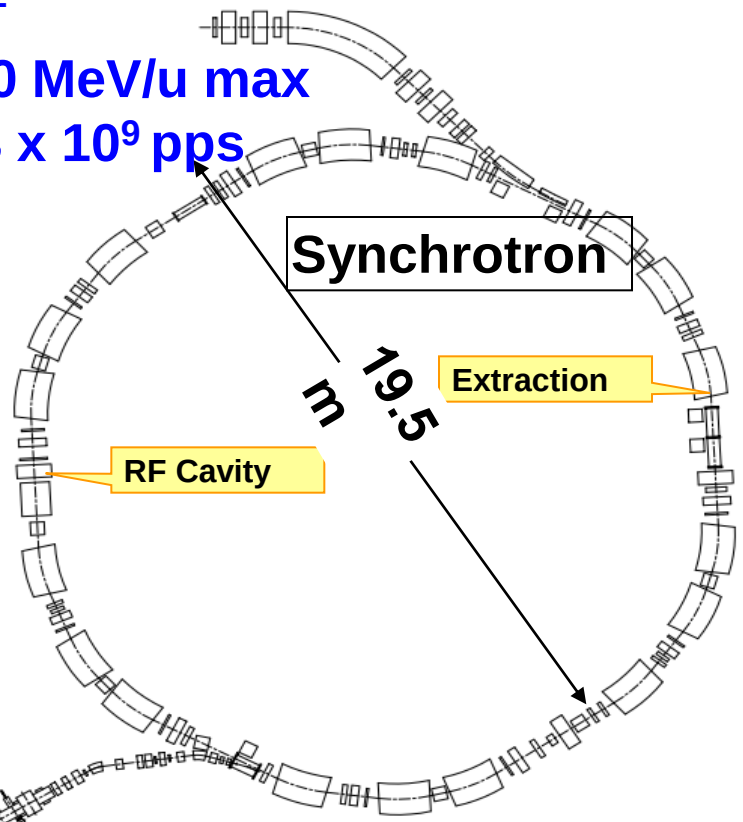
LLUMC	H	Fermi Labs
HIMAC	He-Ar	Hitachi, Toshiba
U Tsukuba, PTC-H	H	Hitachi
Shizuoka CC	H	Mitsubishi
HIT	H-O	GSI
GHMC	C	Mitsubishi
CNAO	H-C	CERN
Saga HIMAT	H-C	Mitsubishi
Shanghai	H, C	Siemens
Marburg, NRoCK	H, C	Siemens

Accelerators for Ion Beam Therapy

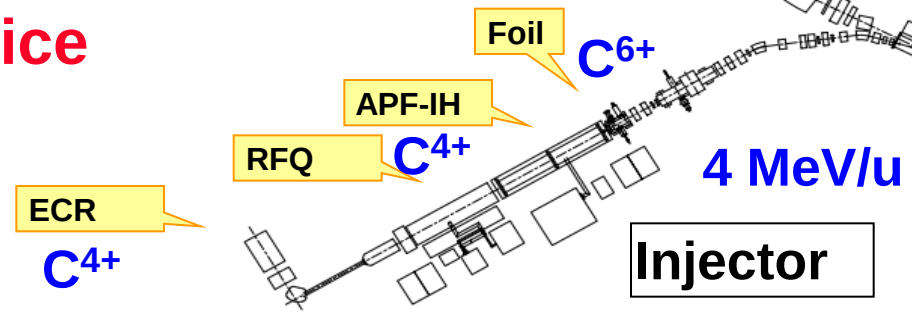
• slow-cycling synchrotron: GHMC •



C^{6+}
400 MeV/u max
1.3×10^9 pps



1/3 size and price of HIMAC



Data: T. Kanai

Accelerators for Ion Beam Therapy

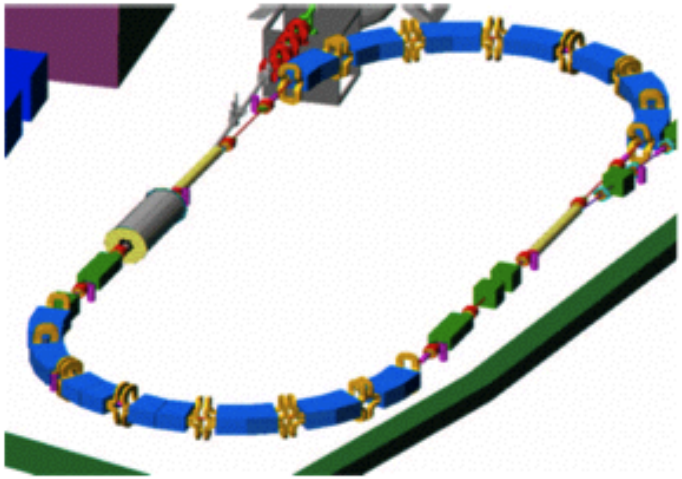
• synchrotron: rapid cycling •

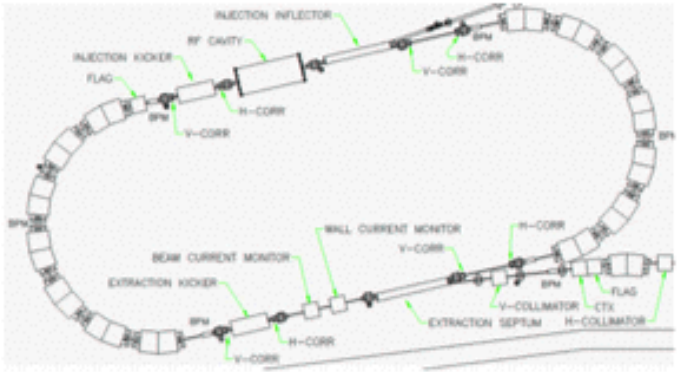
Pros	Cons
Compact construction (1-turn injection)	rapid frequency sweeps
good intensity control	high RF voltage (16 kV for H and ≤ 100 kV for C)
variable energy operation	challenging dose control
proven technology for physics applications (J-PARC, ISIS)	Eddy currents
	too costly?

Not yet realized for IBT → RCMS by BNL

Accelerators for Ion Beam Therapy

• synchrotron: rapid cycling •





Racetrack design

2 super-periods

Strong focusing minimizes the beam size

FODO/combined function mags with edge focusing

2x7.6m straight sections, zero dispersion, tune quads

Working tunes: 3.38, 3.36

Compact footprint

Circumference: 27.8 m

Area: 37 sq m

Data: S. Peggs

Accelerators for Ion Beam Therapy

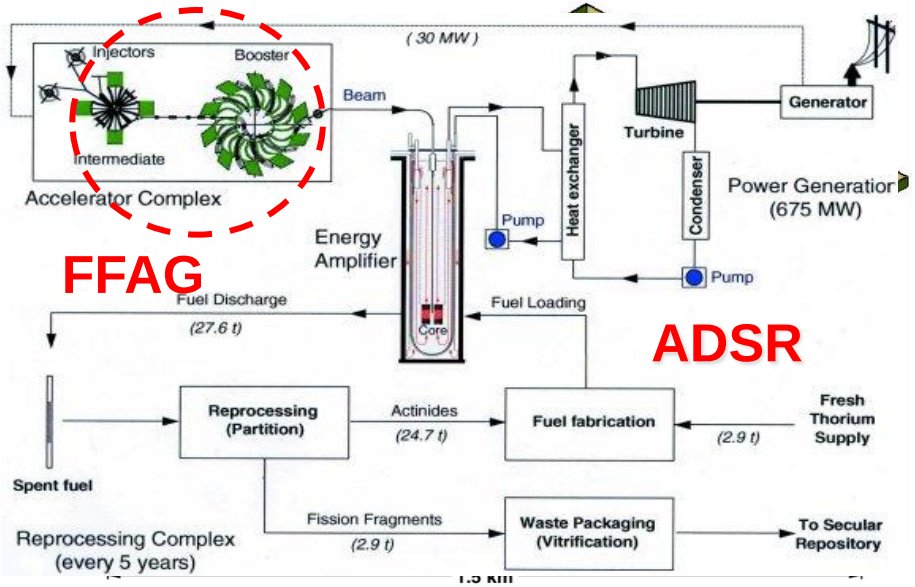
• FFAG: PAMELA •

Particle Accelerator for MEdicaL Application

Particle physics EMMA
ν-factory, muon source, proton driver

Medical PAMELA
Particle therapy, BNCT, X-ray source

Energy (PAMELA)
ADSR, Nucl. Transmutation



CONFORM (**Co**nstruction of a **N**on-scaling **F**FAG for **O**ncology, **R**esearch and **M**edicine) aims to develop the Non-scaling FFAG as a versatile accelerator.

Data: T. Yokoi/J. Pozimski

Accelerators for Ion Beam Therapy

• laser-driven proton therapy: CNRS concept •

Towards compact proton therapy ?

Scientists at CNRS and CEA have defined the characteristics of future lasers that could be applied for cancer treatment by proton therapy. The first prototype is under construction and should be operational within four years.

2010?

CNRS, 2006

Accelerators for Ion Beam Therapy

• laser-driven proton therapy: CNRS concept •

Towards compact proton therapy ?

We expect validation and demonstration of the technology within the next three to five years, at which point therapeutic deployments (including system design and clinical trials) will take place.

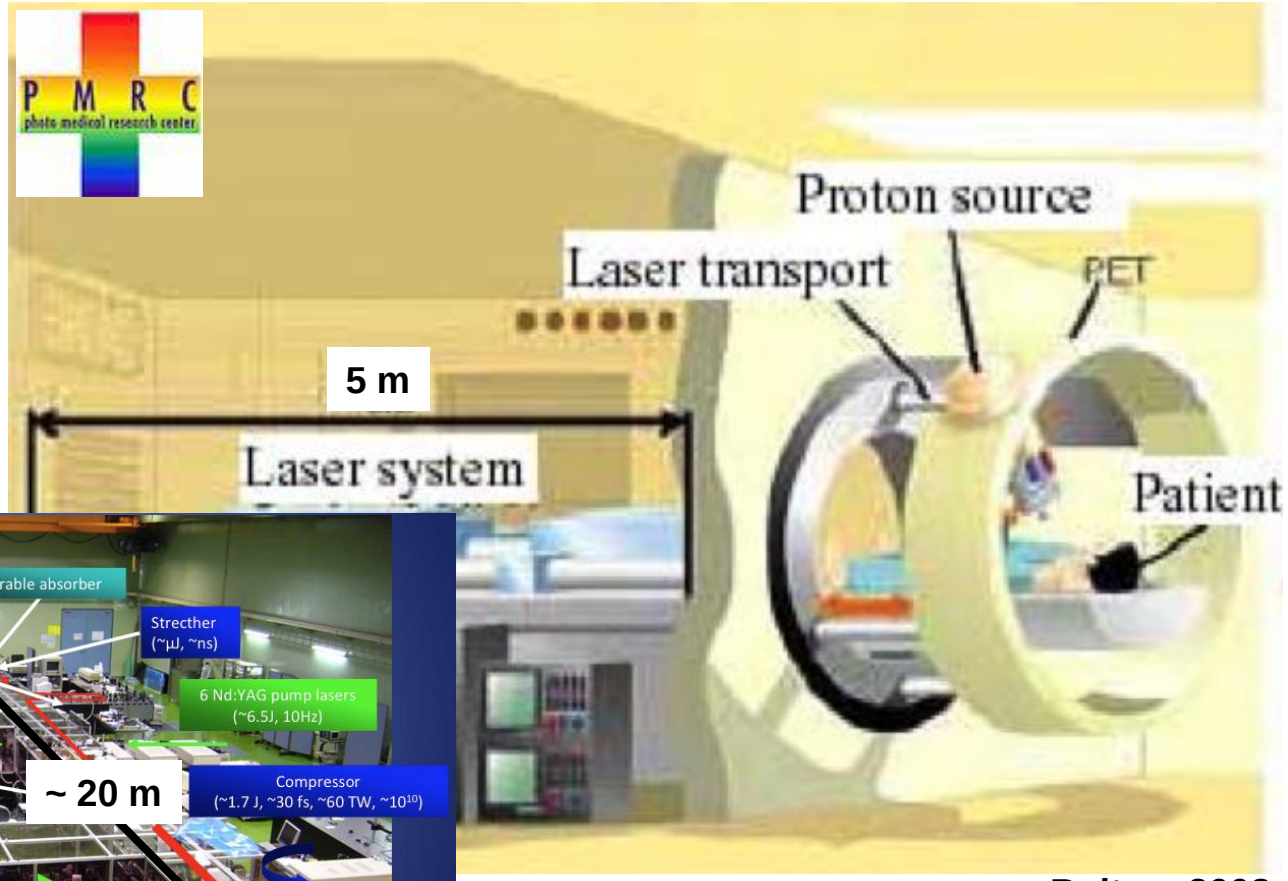
E.Mottay, CEO Amplitude, Industry partner of CEA & CNRS laser proton therapy project, **Feb 2012**, http://optics.org/news/3/2/5

CNRS, 2006

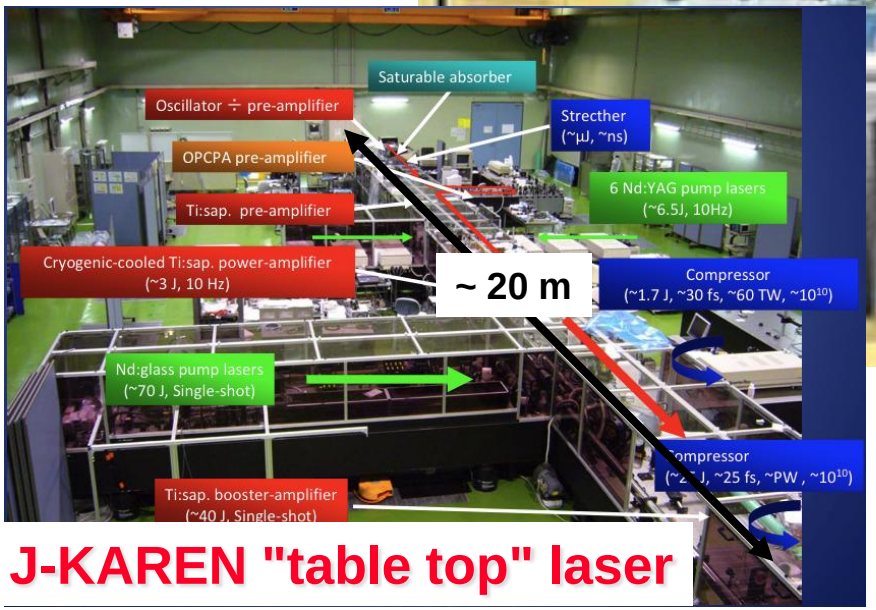
Accelerators for Ion Beam Therapy

• laser-driven proton therapy: PMRC •

"Flagship Theme"



Bolton, 2008



J-KAREN "table top" laser

Accelerators for Ion Beam Therapy

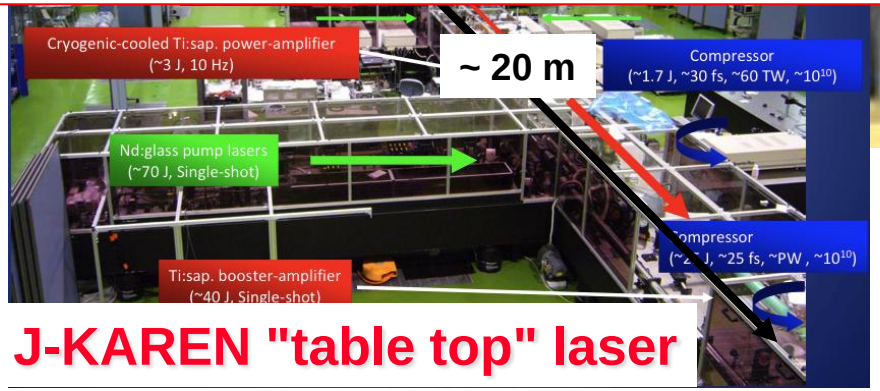
• laser-driven proton therapy: PMRC •

"Flagship Theme"

Photo-Medical Valley and the Photo-Medical Research Center

This project was ended as the result of reexamination in 2010.

http://133.188.30.80/closed/pmrc-en.html



J-KAREN "table top" laser

Bolton, 2008

Accelerators for Ion Beam Therapy

• laser-driven proton therapy: "News" •

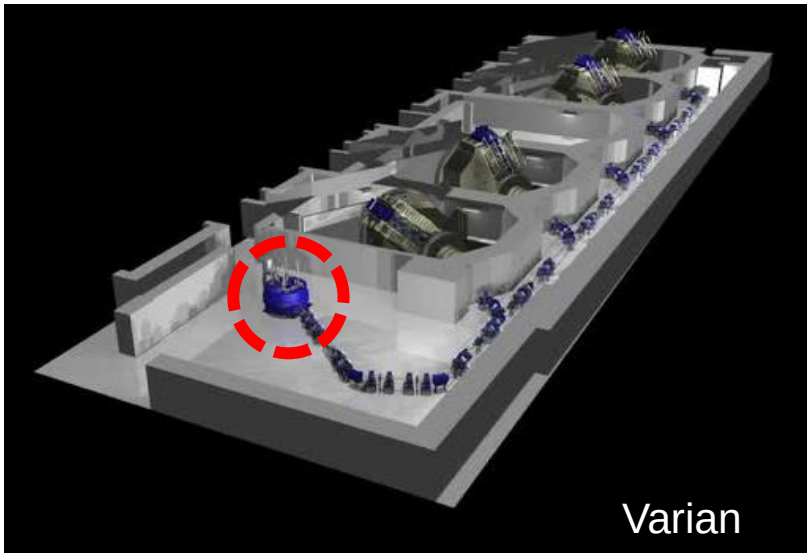
"Cyclotron accelerators are monsters. They're the size of a house," Horwitz said. "A single cyclotron takes up an entire building and costs between $150 to $250 million." What's more, the rotating gantry

"Laser acceleration promises the benefits of proton radiotherapy at a fraction of the cost and a fraction of the space," Horwitz said. "A laser accelerator might run between $5 million to $10 million and you could actually put a PET (positron emission tomography) imaging system in the room with the gantry. Clinically and financially, lasers make much more sense."

M. Martin, JNCI 101, 2009

Accelerators for Ion Beam Therapy

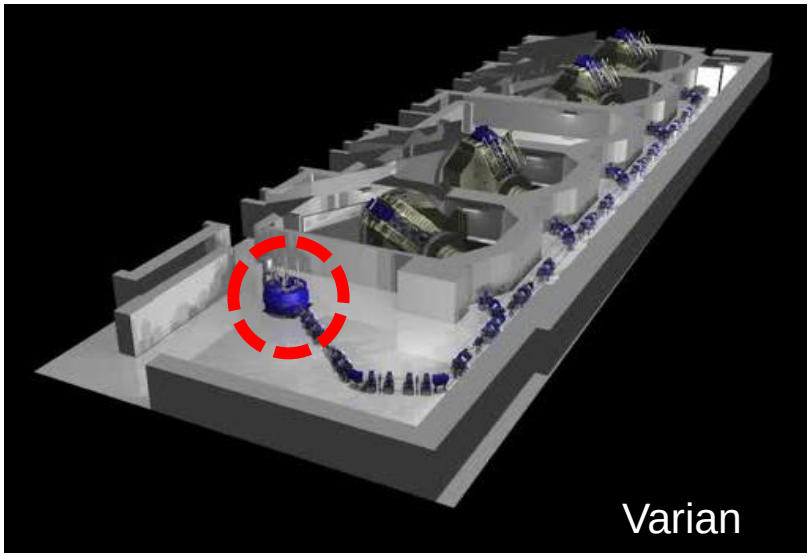
• accelerator vs facility costs •



total facility costs	80-100 MEuro
cost of equipment	30-55 MEuro
cost of accelerator	7-10 MEuro

Accelerators for Ion Beam Therapy

• accelerator vs facility costs •



total facility costs	**80-100 MEuro**
cost of equipment	**30-55 MEuro**
cost of accelerator	**7-10 MEuro**

For a multiroom PT facility,
the accelerator is NEITHER size- NOR cost-determining!

Accelerators for Ion Beam Therapy

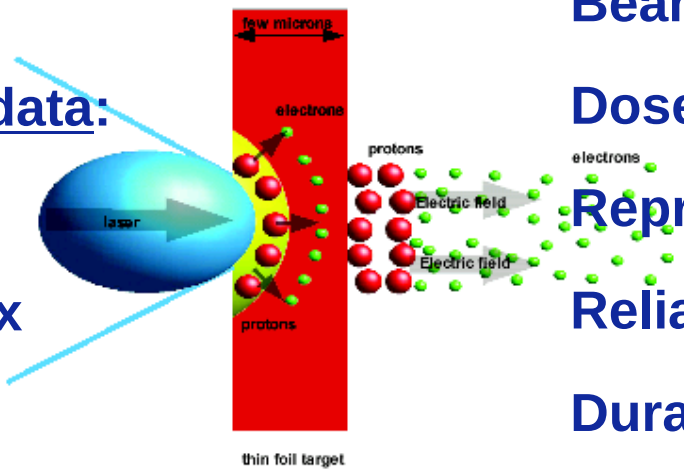
• laser-driven proton therapy: claim and reality •

Upscaling performance data:

Beam energy: 5-50x (H)

Energy variation: 10-100x

Beam intensity: ≥ 100x



Unsolved issues:

Beam control ?

Dose control ?

Reproducibility ?

Reliability ?

Durability ?

Safety ?

Cost ?

Accelerators for Ion Beam Therapy

• laser-driven proton therapy: claim and reality •

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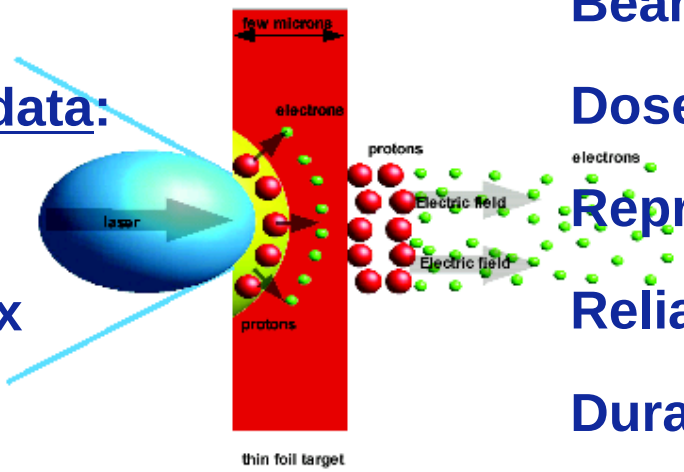


Unsolved issues:

Beam control ?

Dose control ?

Reproducibility ?

Reliability ?

Durability ?

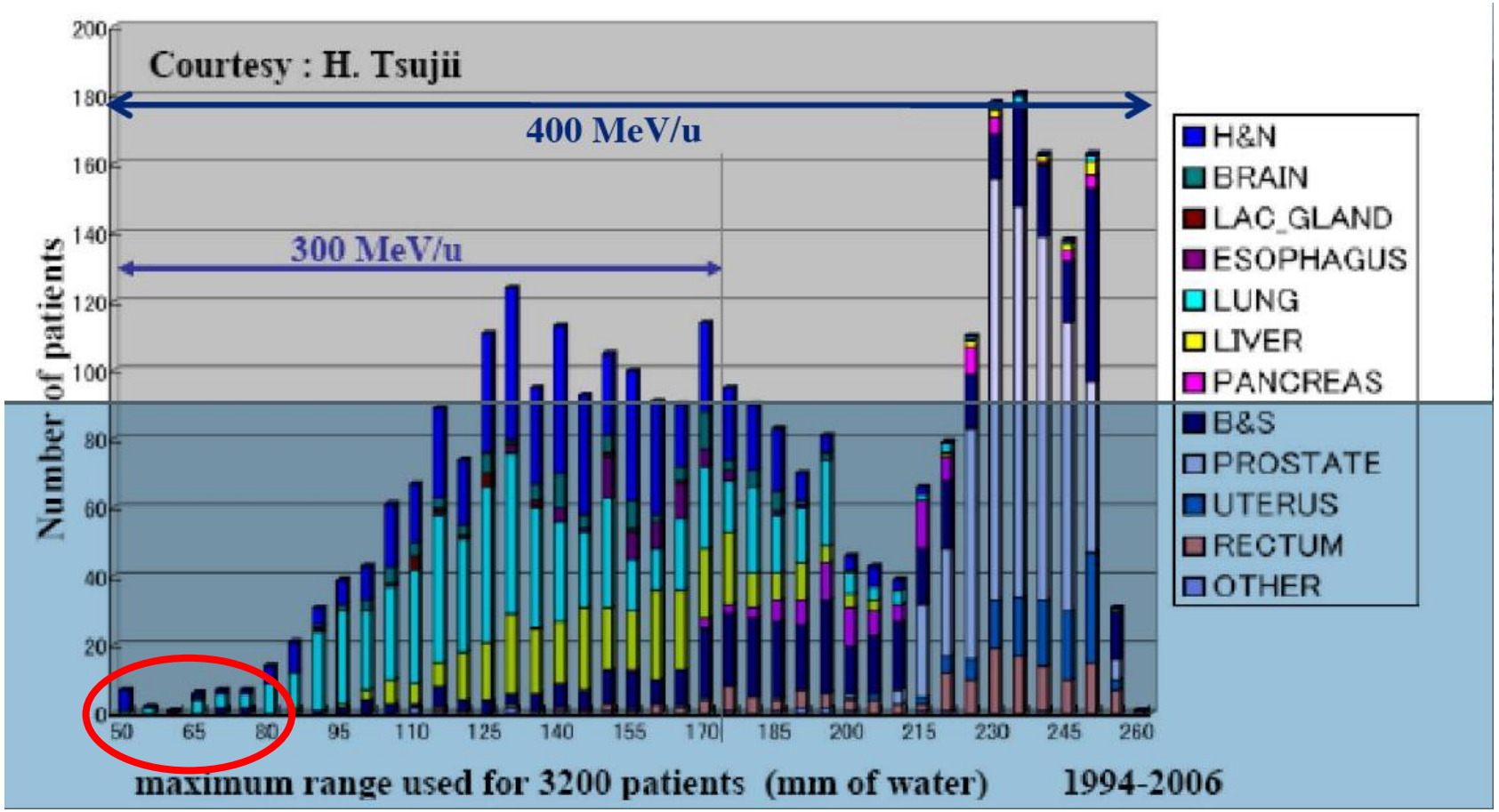
Safety ?

Cost ?

A proton beam of the proper energy is necessary but not sufficient for a proton therapy system!

Accelerators for Ion Beam Therapy

• minimum required energy •



≤ 100 MeV protons (≤ 8 cm) useful for less than 1% of tumors!

Accelerators for Ion Beam Therapy

• laser-driven proton therapy for uveal melanoma? •

Incidence: 1-8/10E6 population

Treatment options:

- radioactive plaques
- ion beam therapy
- thermo-/cryotherapy
- photocoagulation
- operation/enucleation

Example Germany: ≈ 600 patients/year → can be treated by one facility

Accelerators for Ion Beam Therap

• laser-driven proton therapy for uveal m oma? •

Incidence: 1-8/10E6 population

Treatment options:

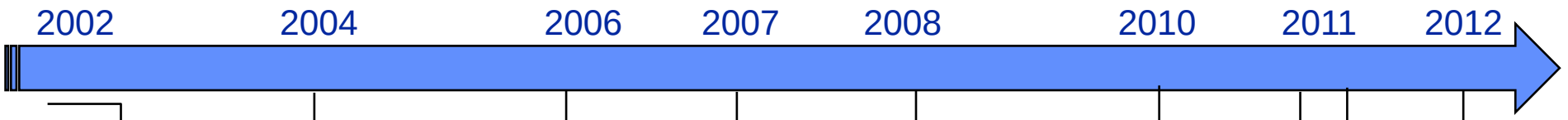
- radioactive plaques
- operation/enucleation
- ion beam therapy
- thermo-/cryoth y
- photocoa on

uveal melanoma is not a good basis for an IBT business model

Exam ermany: ≈ 600 patients/year → can be treated by one facility

Accelerators for Ion Beam Therapy

• medical device development: 1-room PT unit •



Start research on compact superconducting cyclotrons at MIT

Still River Systems
founded by
Ken Gall et al.

Clinatron 250™
First Customers:
BJH, St. Louis
Tufts MC, Boston

Timothy Antaya et al.
prototype of 9 T
synchrocyclotron

Original Marketing Goal:
Offer inexpensive
1-room proton therapy unit
The Monarch250™

Patent dispute
MIT/Still River

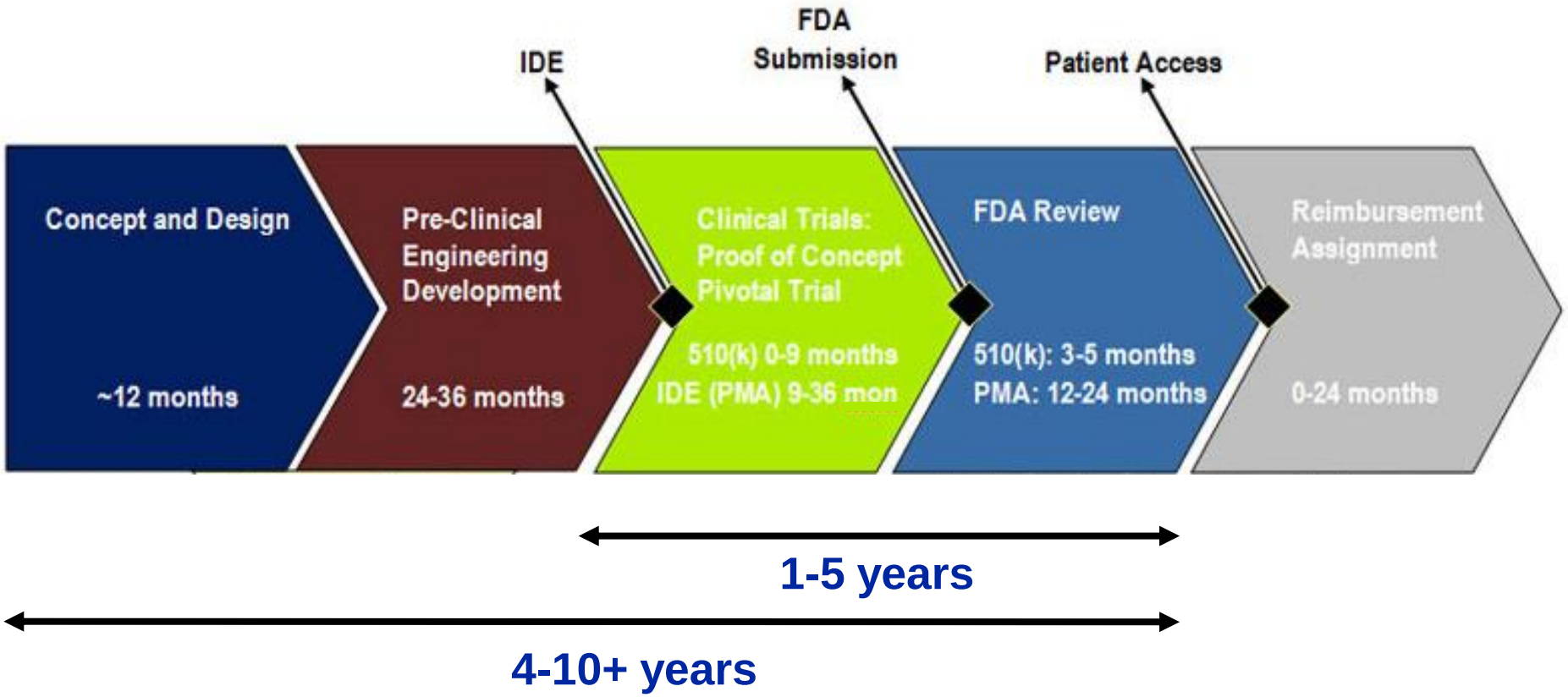
License
Agreement
MIT&Still River

Name change
HIGH ENERGY CANCER CARE
MEVION
medical systems

Mevion S250™
CE mark
FDA 510(k)
clearance

Accelerators for Ion Beam Therapy

• medical device development process •



Accelerators for Ion Beam Therapy

• laser-driven proton therapy: "News" II •

When might such laser-driven ion beams be ready for early-stage clinical studies?

As a scientist familiar with medical applications – specifically the development of carbon-ion therapy here at GSI over the past two decades – I believe that we are looking at somewhere between 10 to 20 years.

Markus Roth

Medical Physics Web, Nov 2011

Accelerators for Ion Beam Therapy

• which accelerator to choose? •

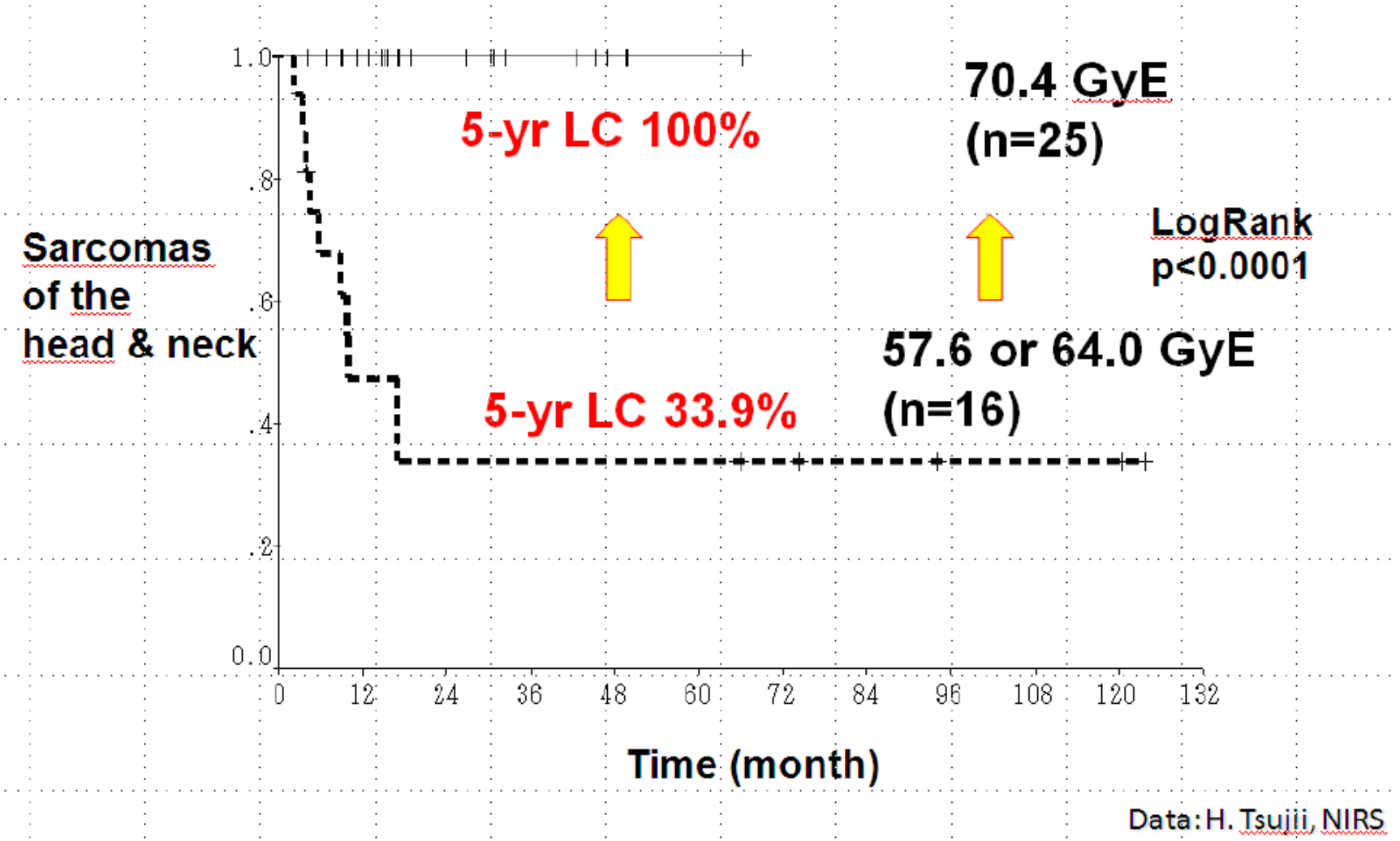
therapist's view

on the IBT system

upstream of the patient

Accelerators for Ion Beam Therapy

• the benchmark for a new IBT system •



Accelerators for Ion Beam Therapy

• which accelerator to choose? •

Simplicity, reliability, lower cost and size

IBA: iso cyclotron, nc

Smallest possible footprint and weight, less power consumption

Varian: iso cyclotron, sc

Simple, robust, low voltage, low cost, compact,...

T. Antaya, synchrocyclotron, sc

Simple, robust, small magnets, light gantry, flexible

S. Peggs, synchrotron, rapid cyc

Smaller, simpler, significantly cheaper than synchrotron

CONFORM Project: FFAG

Accelerators for Ion Beam Therapy

• which accelerator to choose? •

Health services have to be economical:

accelerator design *„unconstrained by financial and/or space limitations“* is not instrumental

Balance facility cost with patient population, patient share, e.g., max. range vs. 3rd or 4th level care unit

Balance size of accelerator with special features, e.g., single room vs. tomography option

Accelerators for Ion Beam Therapy

• clinical operation with various IBT systems •

Institution	Acc-Type	1st pt	pt # 12/2011
PTC-H	slow-cyc Sync Hitachi	May 06	3400
UFPTI	isochron Cycl IBA	Aug 06	3460

Accelerators for Ion Beam Therapy

• clinical operation with various IBT systems •

Institution	Acc-Type	1st pt	pt # 12/2011
PTC-H	slow-cyc Sync Hitachi	May 06	3400
UFPTI	isochron Cycl IBA	Aug 06	3460

Comparable patient numbers with different approaches

Accelerators for Ion Beam Therapy

• which accelerator to choose? •

Why do most PT centers use cyclotrons?

Why do most IBT centers use synchrotrons?

Why do industrial suppliers take the challenge of SC?

Accelerators for Ion Beam Therapy

• which accelerator to choose? •

Why do most PT centers use cyclotrons?

Why do most IBT centers use synchrotrons?

Why do industrial suppliers take the challenge of SC?

Antagonism between preference of clients for proven technology and the desire of developers for innovation

Accelerators for Ion Beam Therapy

• efficiency and sustainability •

Reduce weight

Reduce power consumption

Reduce neutron activation

Extend running time and service life

Save raw materials/resources

Accelerators for Ion Beam Therapy

• efficiency and sustainability •

Reduce weight

Reduce power consumption

Reduce neutron activation

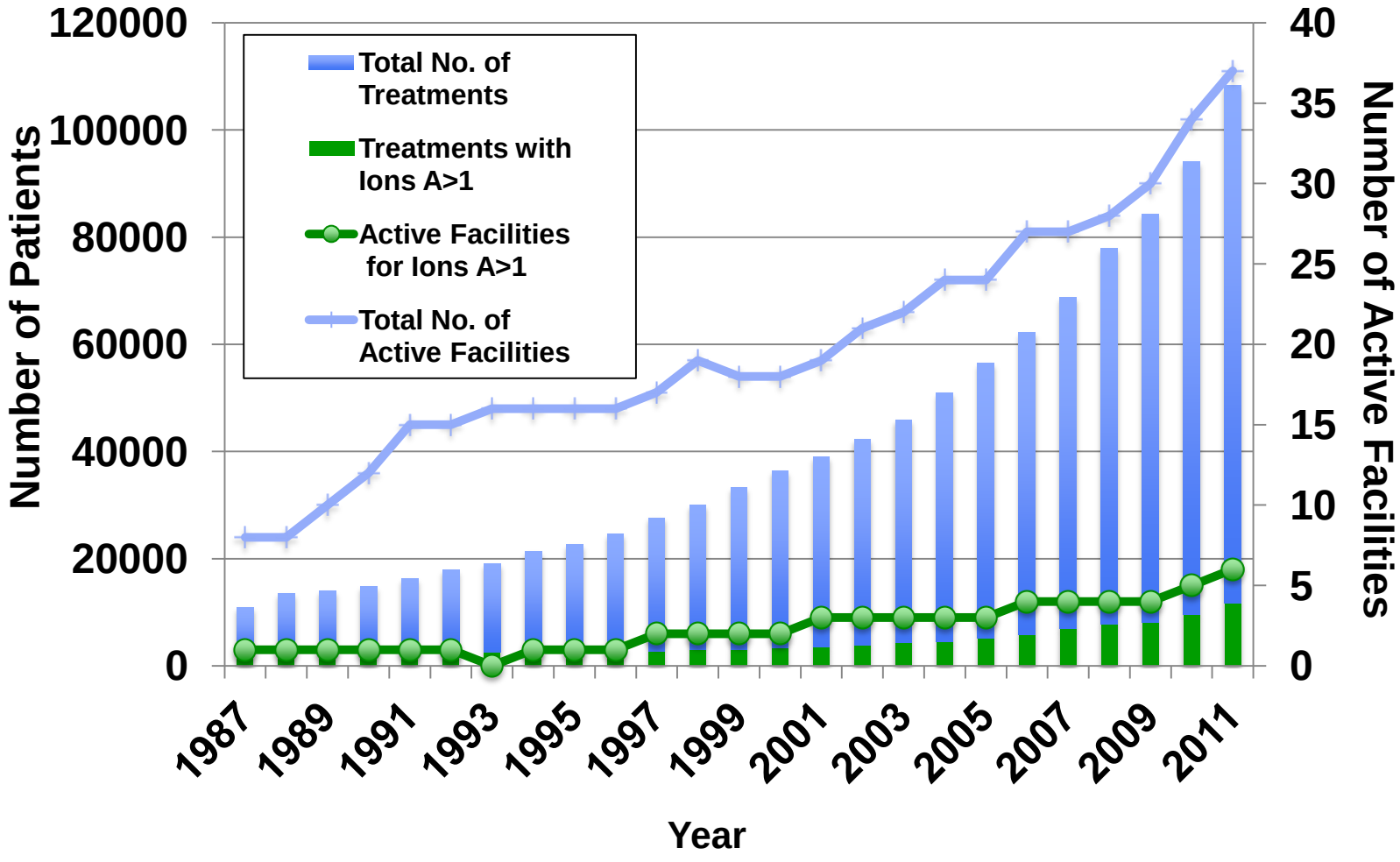
Extend running time and service life

Save raw materials/resources

Manufacturers need to give numbers on sustainability!

Accelerators for Ion Beam Therapy

• development of IBT •



Accelerators for Ion Beam Therapy

• the Blue Book •