Design Study of a Superconducting AVF Cyclotron for Proton Therapy

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Sumitomo Heavy Industries, Ltd., Japan

Cyclotrons 2013 , Vancouver, Sep. 16, 2013

1. Introduction

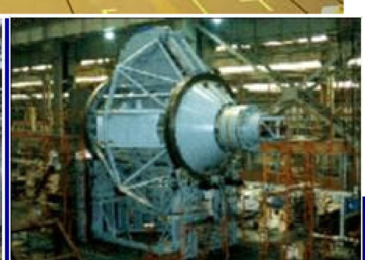
2. Superconducting cyclotron design

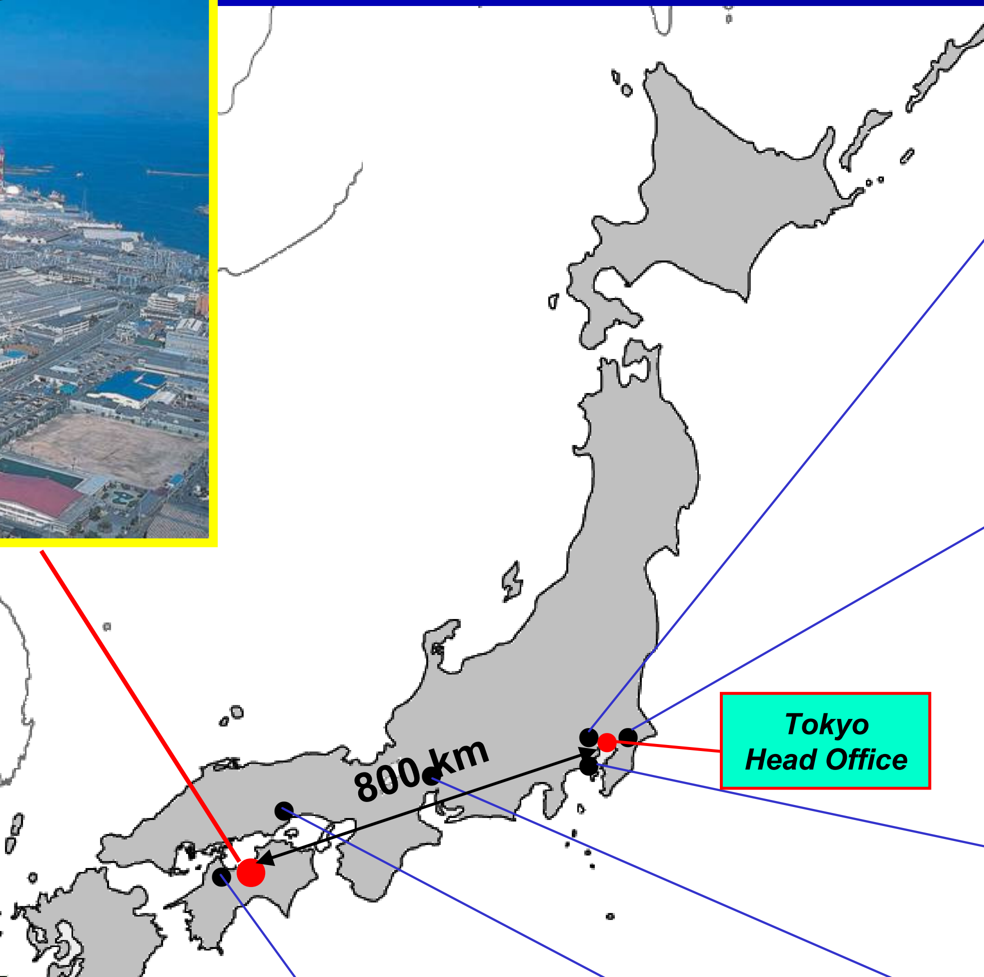
3. Summary

Factories of Sumitomo in Japan

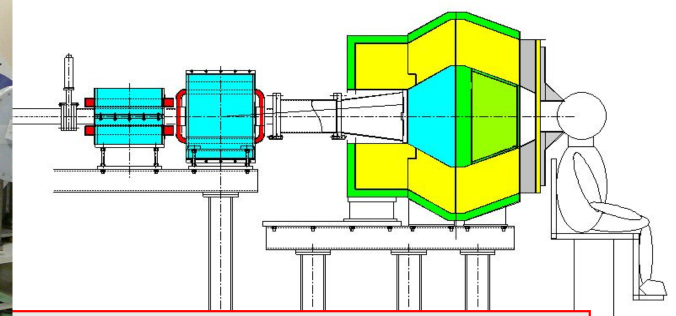
Niihama Factory

Accelerator Work Shop



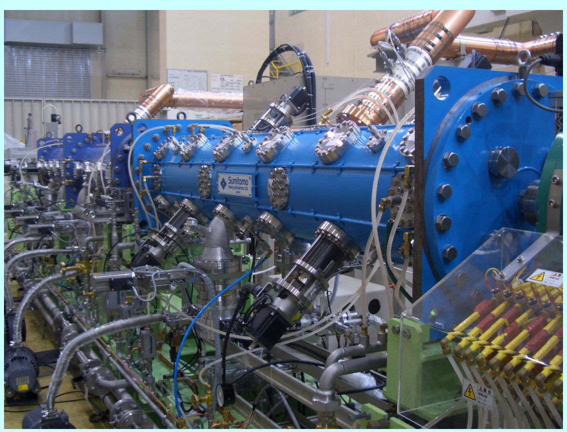


Accelerators for medical applications

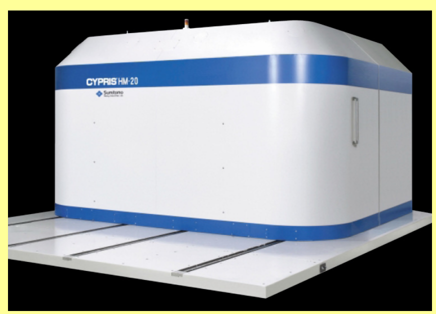


World First Cyclotron-based BNCT
(Boron Neutron Capture Therapy)

Proton Therapy System
(230MeV Cyclotron)



RFQ & APF-IH Linacs for Heavy Ion Therapy

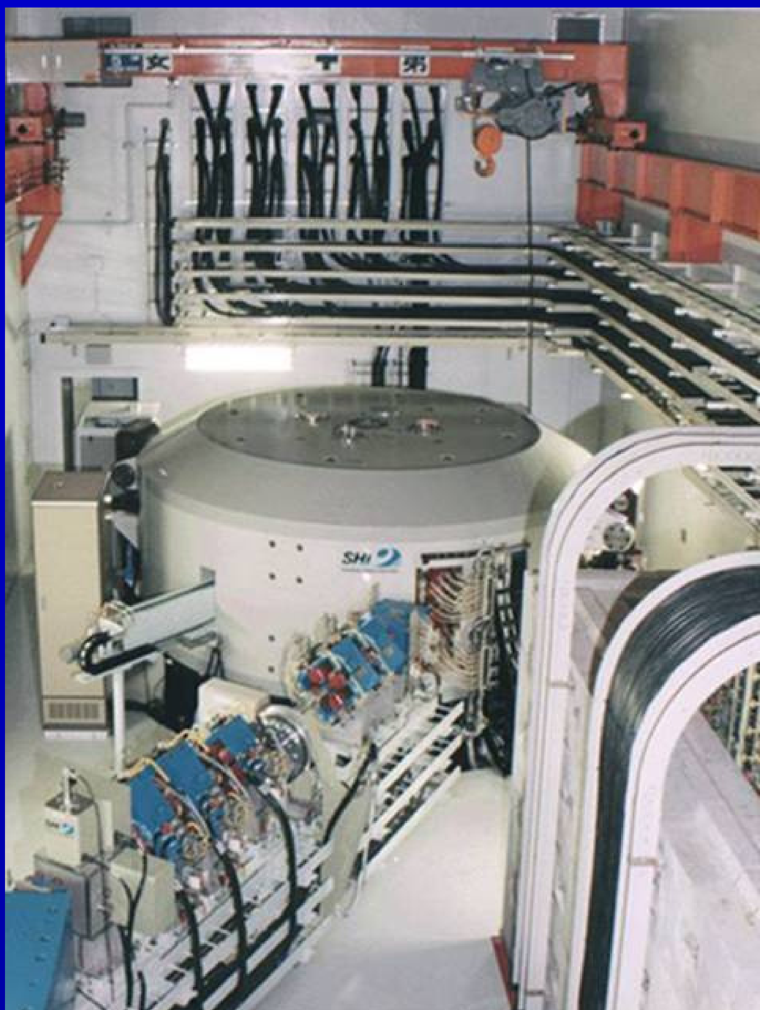


PET Cyclotron (7~20MeV)

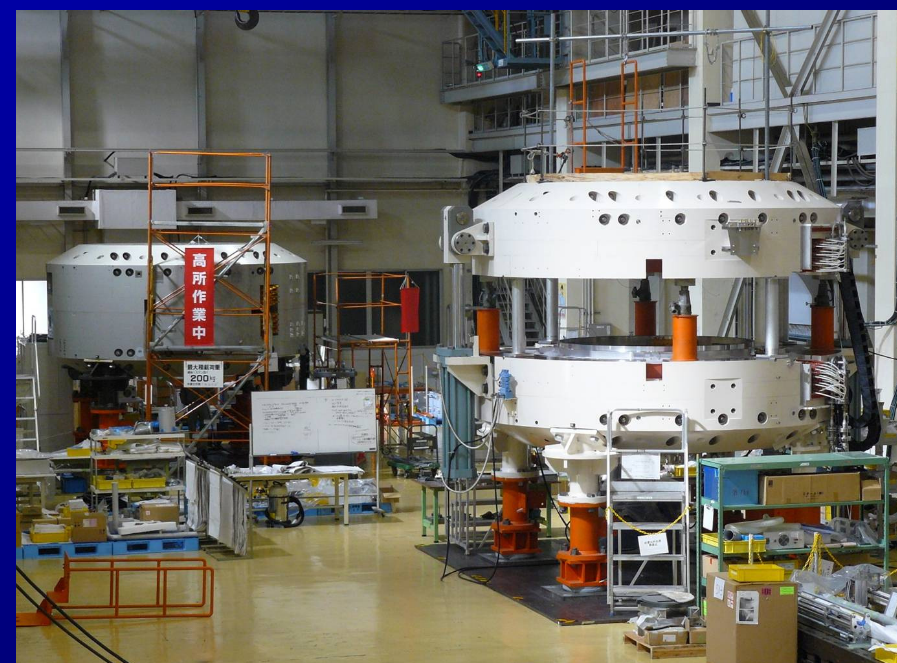
SPECT Cyclotron (30~70MeV)

230 MeV proton cyclotron (P235)

- Normal conducting (~2T)
- Weight ~200 t
- Diameter ~4.4 m



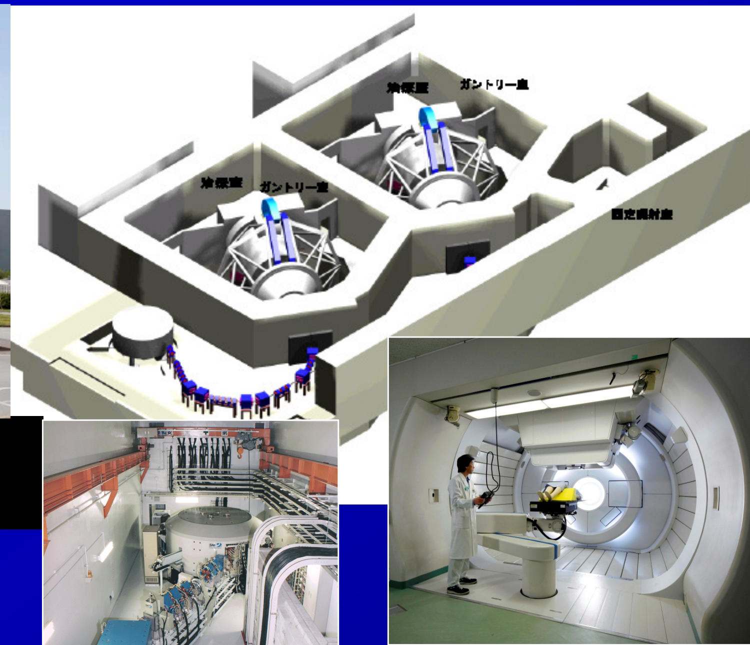
P235 cyclotron in National Cancer Center in Japan (1998~)

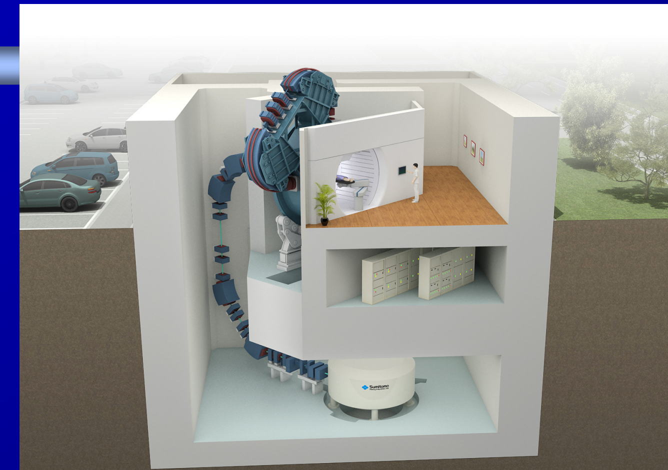


P235 cyclotrons manufactured and beam tested in Sumitomo Niihama Factory

Proton therapy systems by Sumitomo

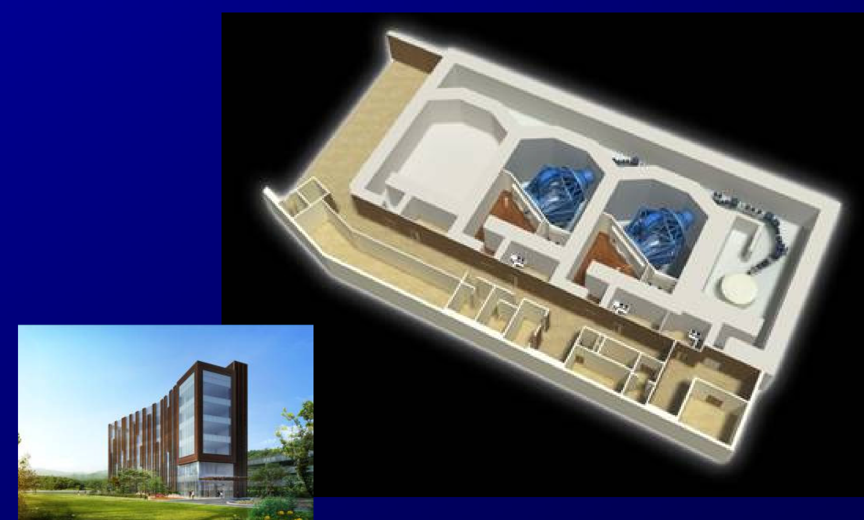
National Cancer Center Hospital (Japan)





Aizawa Hospital (Japan)

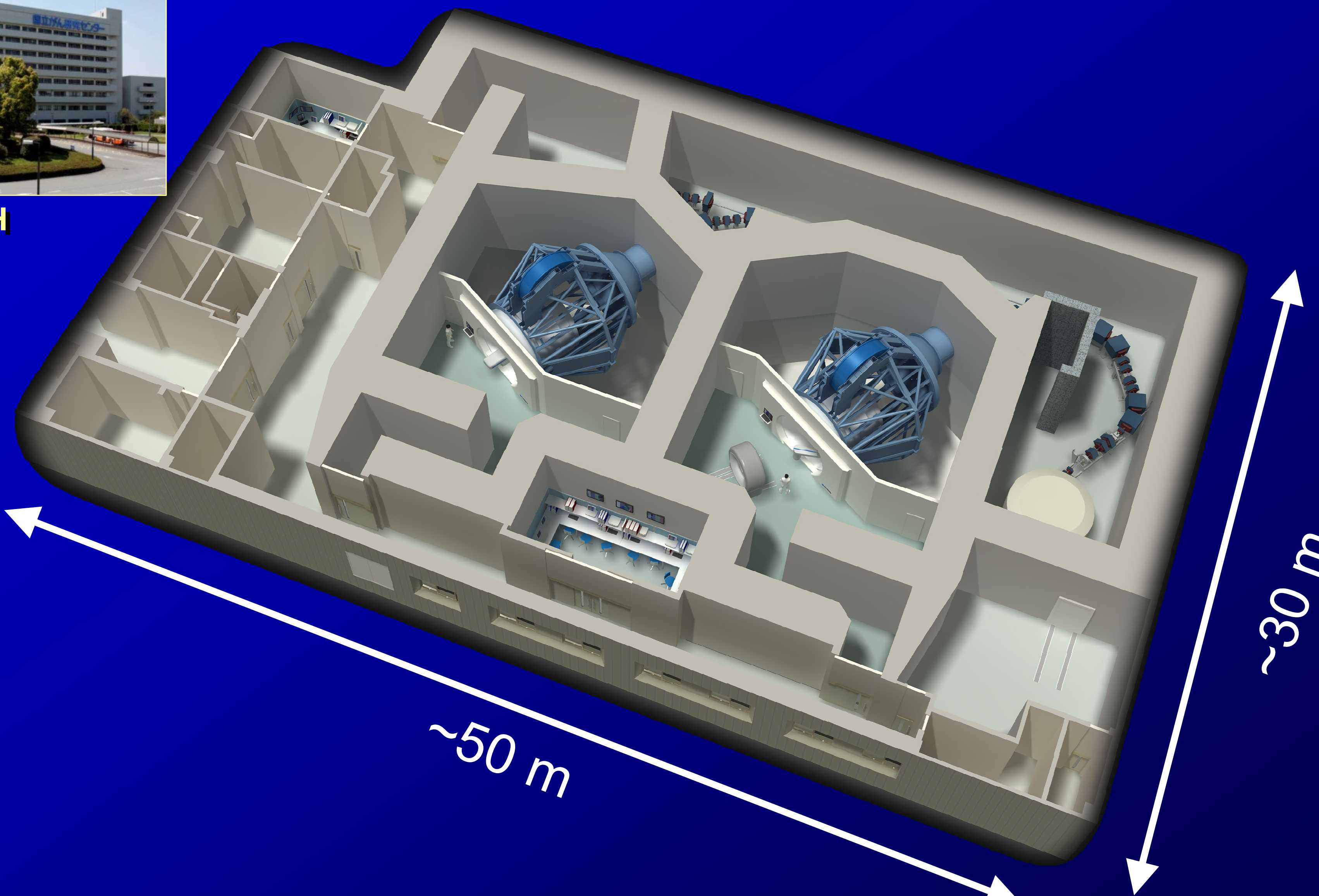
Chang Gung Memorial Hospital (Taiwan)



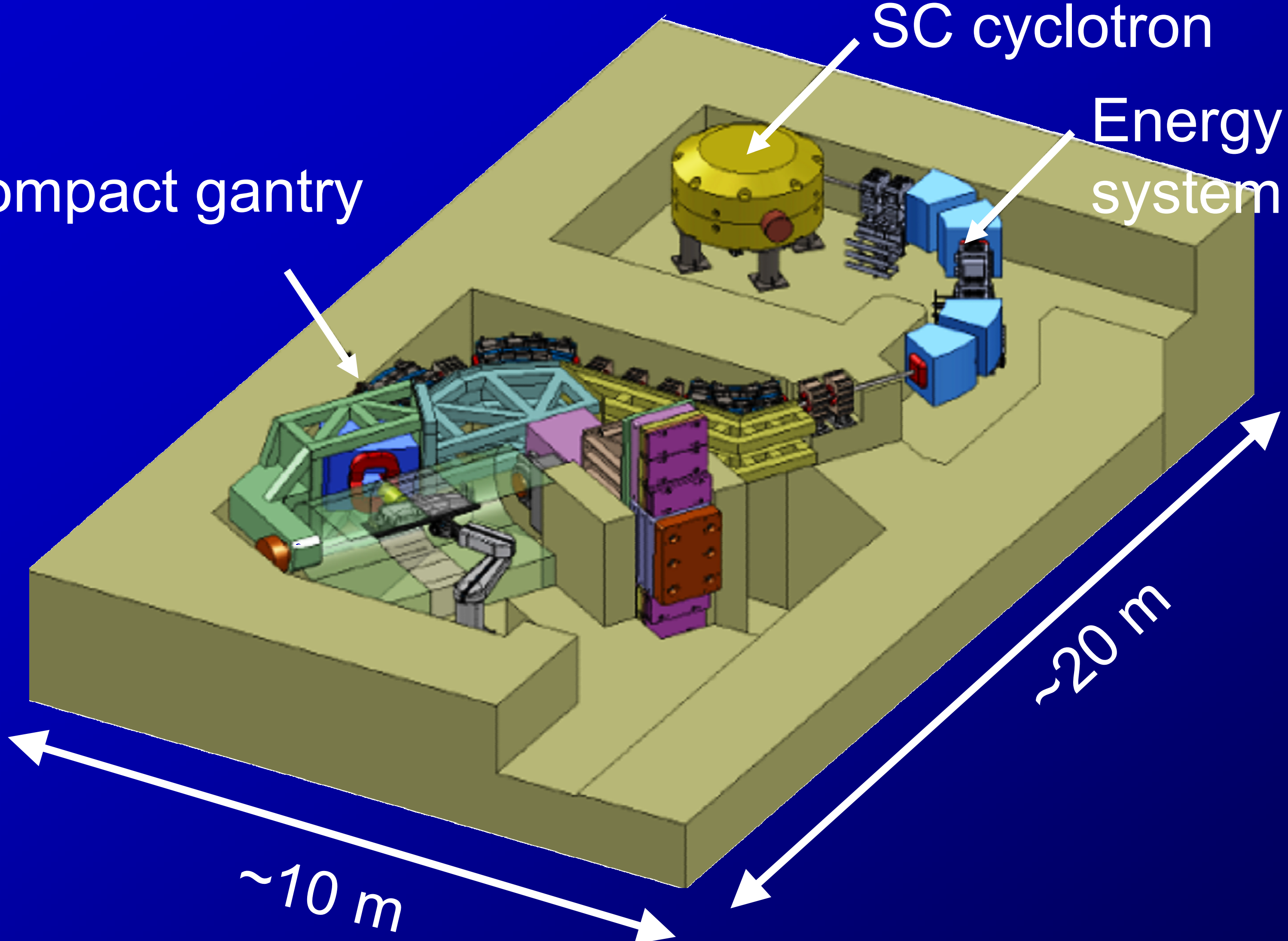
Samsung Medical Center (Korea)

Typical size of proton therapy facility

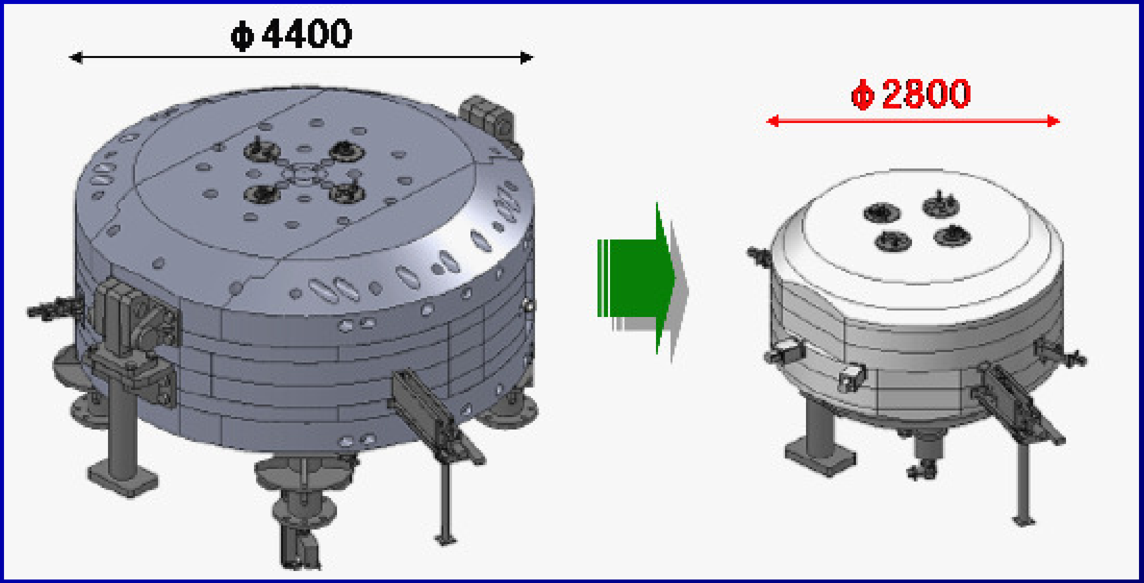
NCCH



A compact proton therapy system



P235 and SC cyclotrons



	Normal (P235)	Superconducting
Size	ϕ4.4 m×2.1 m	ϕ2.8 m×1.7 m
Yoke weight	200 t	55 t
Peak consumption power	440 kW	200 kW (RF) + 40 kW (cryocooler)

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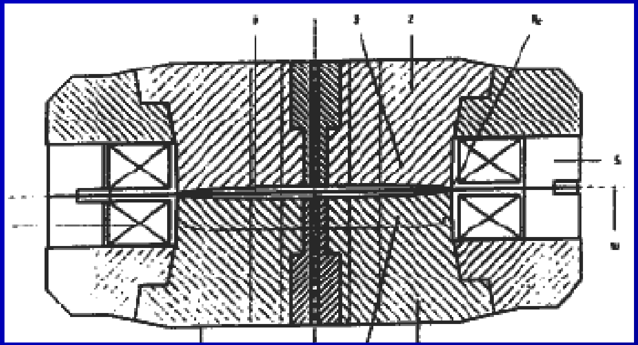
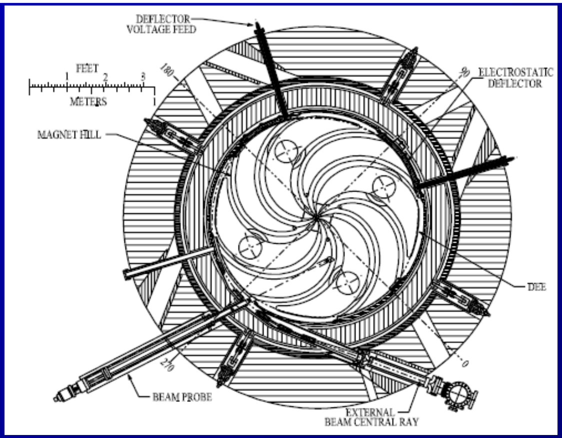
Some basic parameters

SHI

Beam	Particle species	proton
	Energy	230 MeV
	Current	> 300 nA
	Emittance	~3 π mm-mrad
	Momentum spread	±0.2 %
	Extraction efficiency	> 60 %
	Circulating frequency	48.15 MHz
Magnet	Yoke size	ϕ2.8 m × 1.7 m
	Yoke weight	55 t
	Beam extraction radius	0.6 m
	Average B at extraction radius	4 T
	Average B in center region	3.2 T
	Number of sectors	4

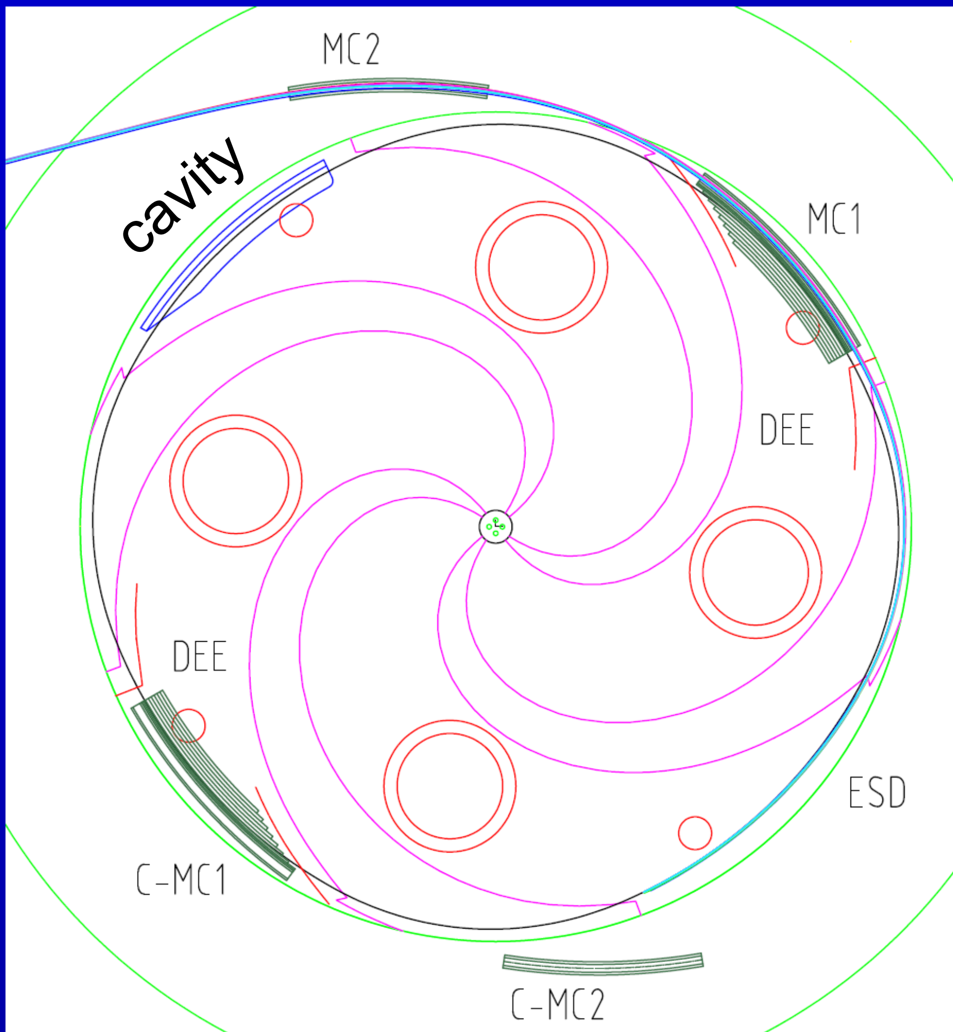
Two possible way to design a cyclotron





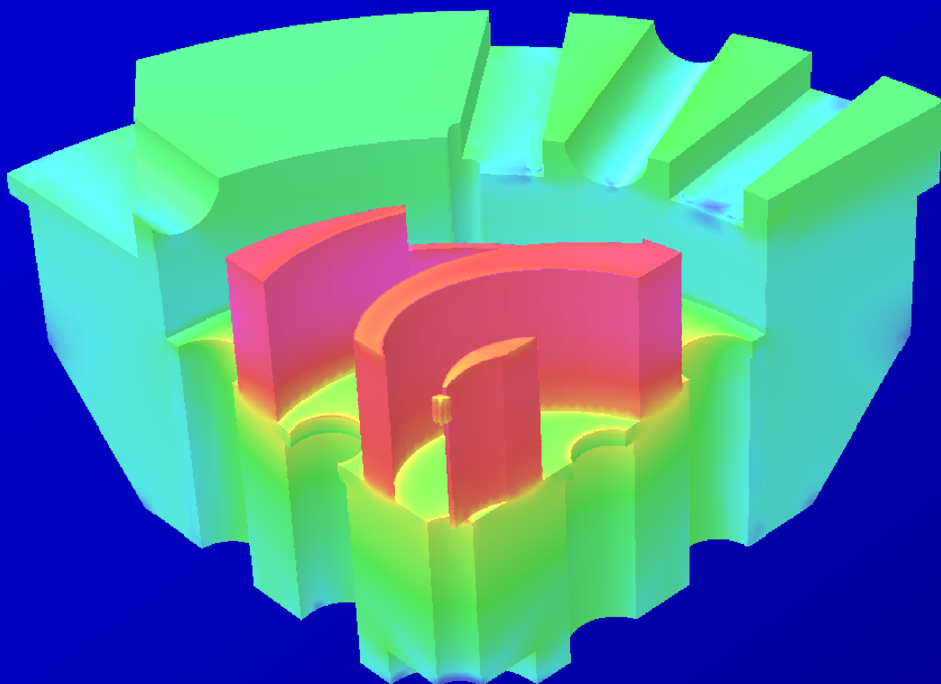
	I. Yongen	H. Blosser
Hill gap	Narrow (~10 mm)	Wide (> 60 mm)
Advantages	Compact Low magnetic field in extraction beam line	Enough space to set extraction components in hill gap
Example	P235 / C235 (SHI / IBA)	MSU K500, K1200

Features of our design

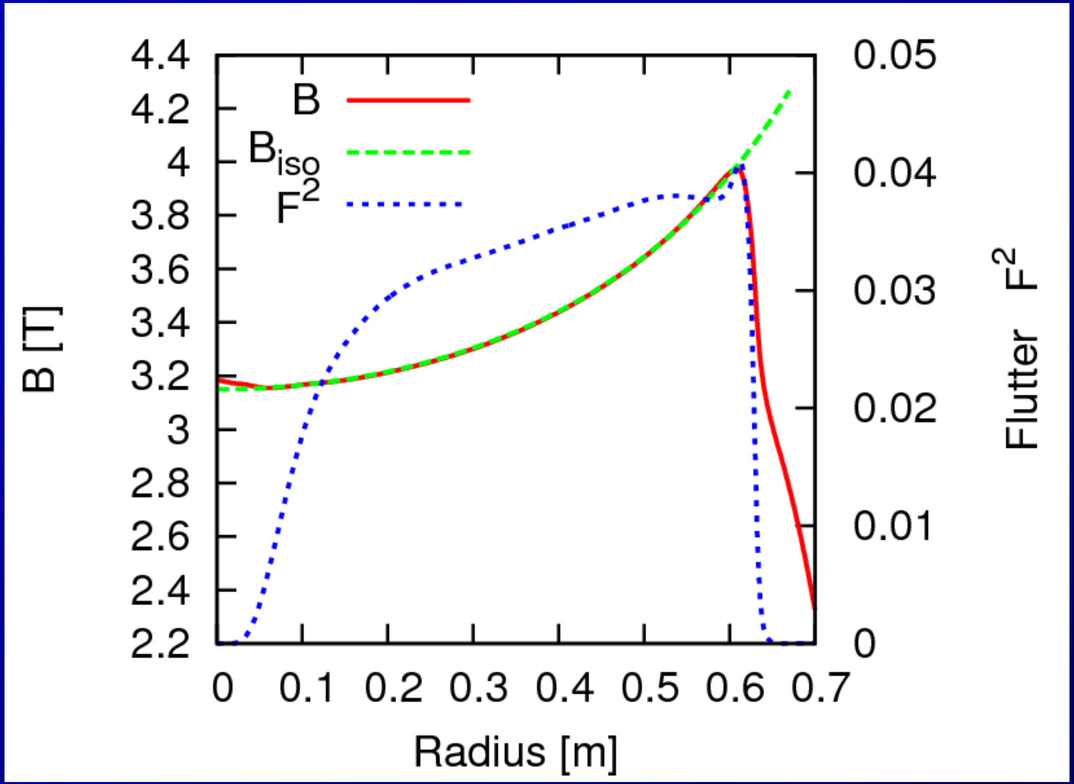


- Narrow hill gap
- 2 dees (H=2) for acceleration
- Another cavity (H=4) for beam extraction
- 1 ESD + 2 MC's for extraction
- MC1 in a dee electrode
- 2-fold rotational symmetry of magnetic field distribution

Isochronous magnetic field calculation



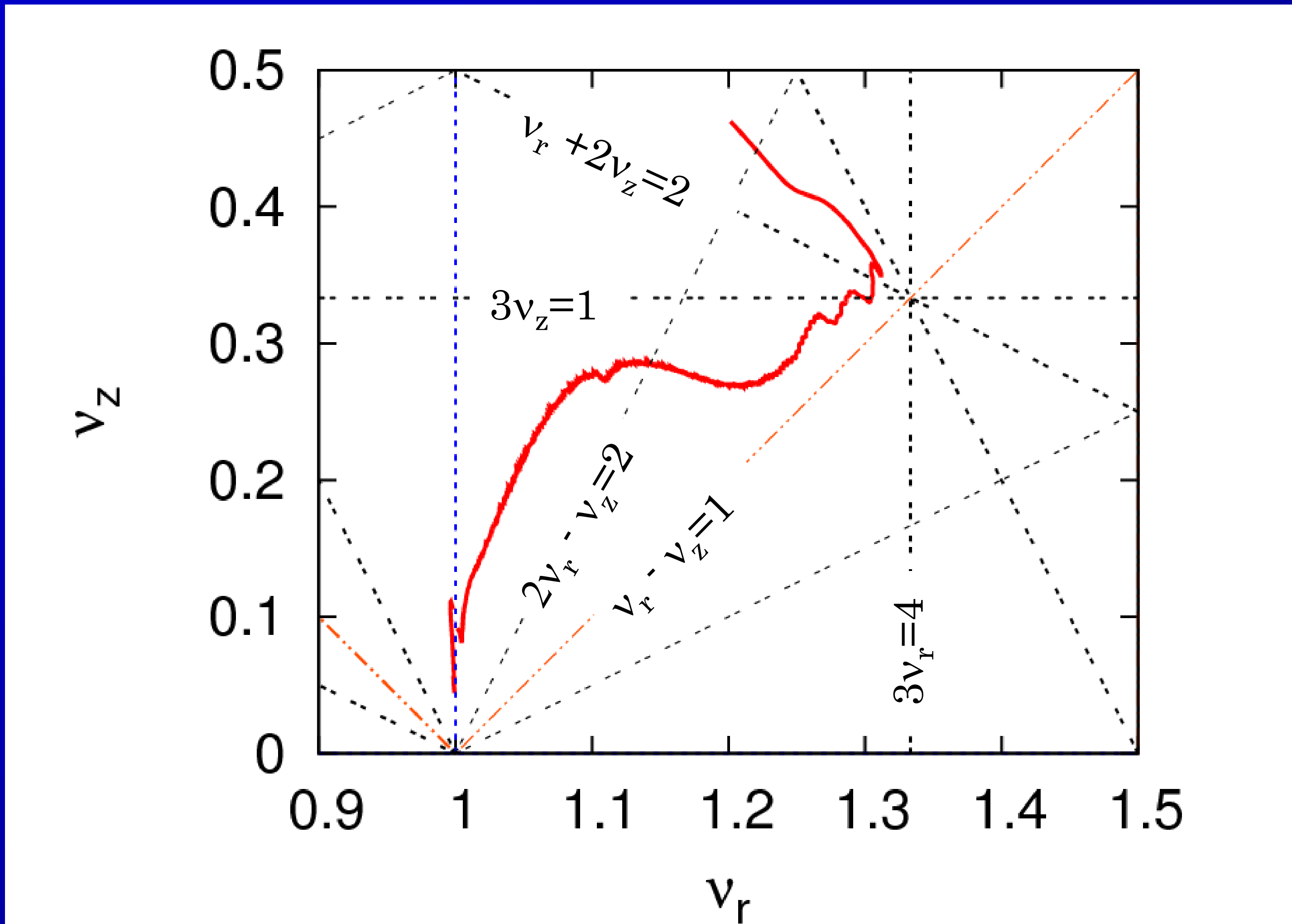
3D magnetic field calculation by Opera-3d



Average magnetic field and flutter

Isochronism and vertical beam stability have been obtained, by iteration of 3D magnetic field calculation and beam optics analysis

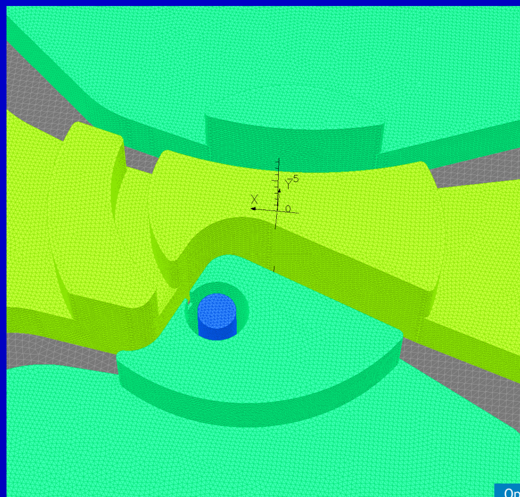
Tune diagram



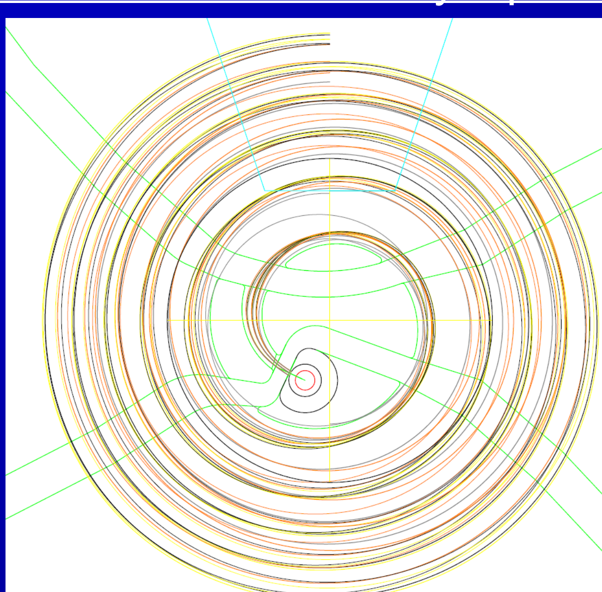
No crossing of $\nu_r - \nu_z = 1$ resonance

Extraction at $\nu_r = 1.1 \sim 1.2$

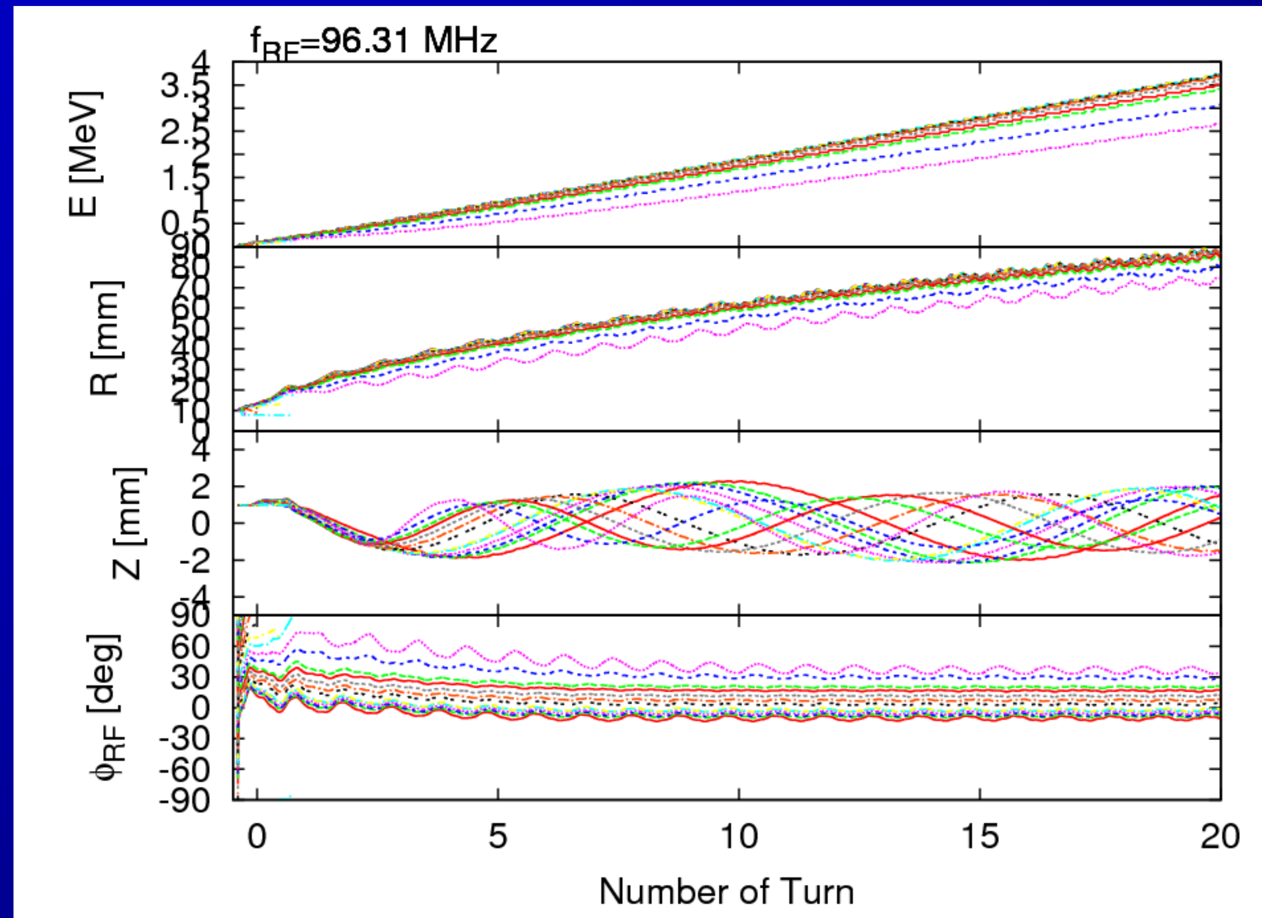
Center region



Electric field calculation by Opera-3d



Beam tracking from ion source

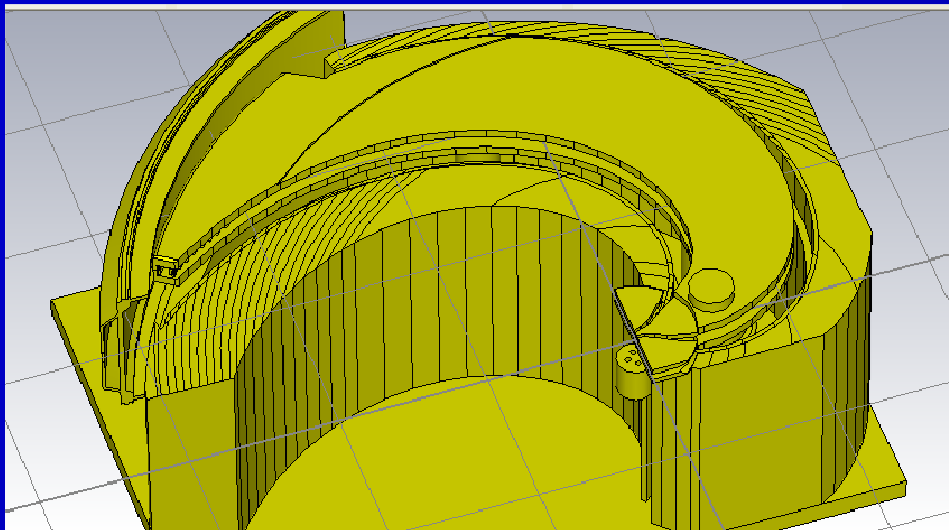


Beam tracking

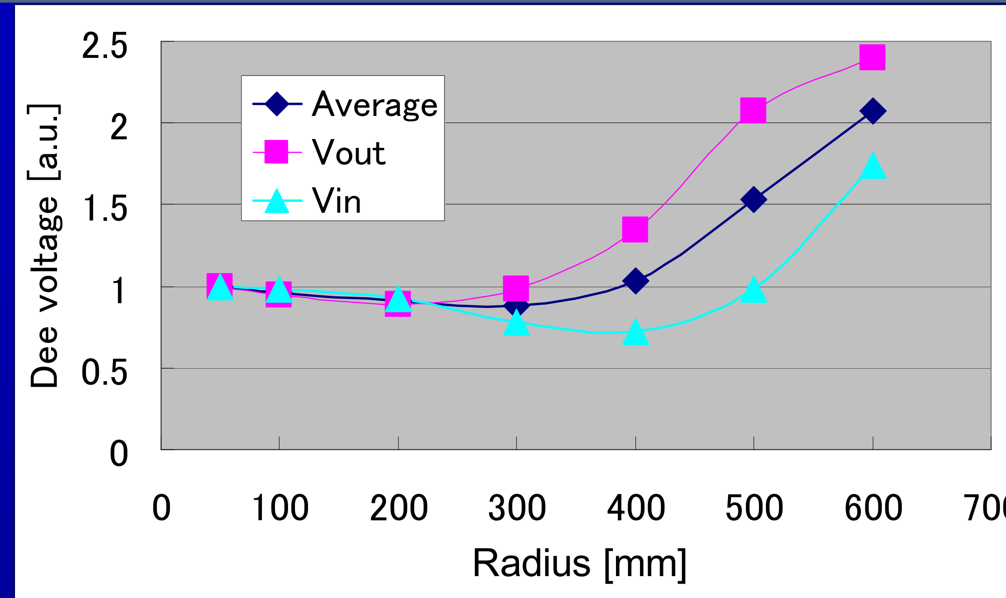
Dee voltage: 50kV

RF frequency: 96 MHz (H=2)

RF cavity



Electromagnetic field calculation by MWS

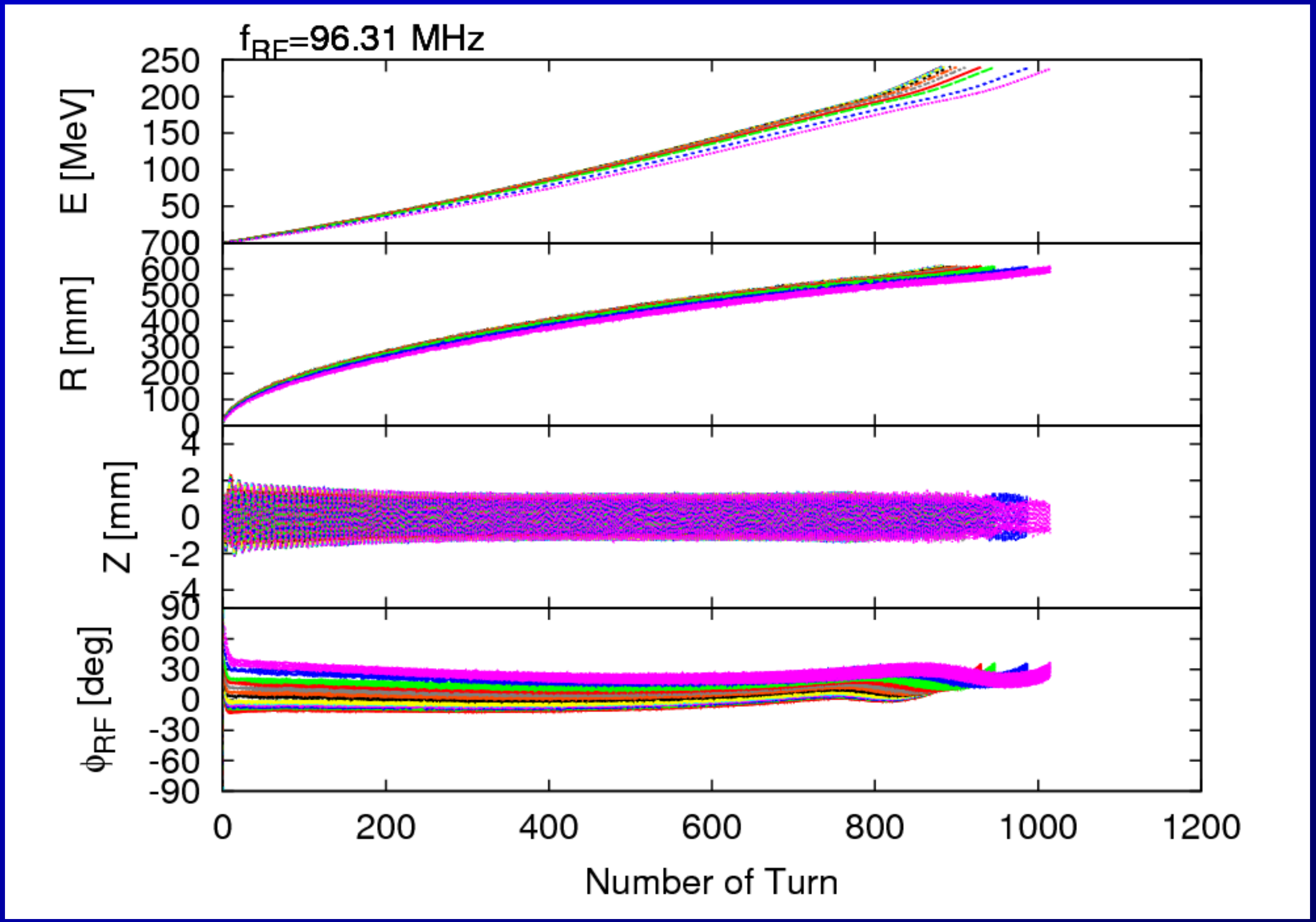


Normalized dee voltage vs. radius

One RF cavity (H=4) may be added for obtaining high beam extraction efficiency

	cavity 1, 2	cavity 3
RF frequency	96.3 MHz (H=2)	192.6 MHz (H=4)
Dee voltage	50~100kV	180kV
Wall loss (80%Q)	40 kW/cavity	40 kW

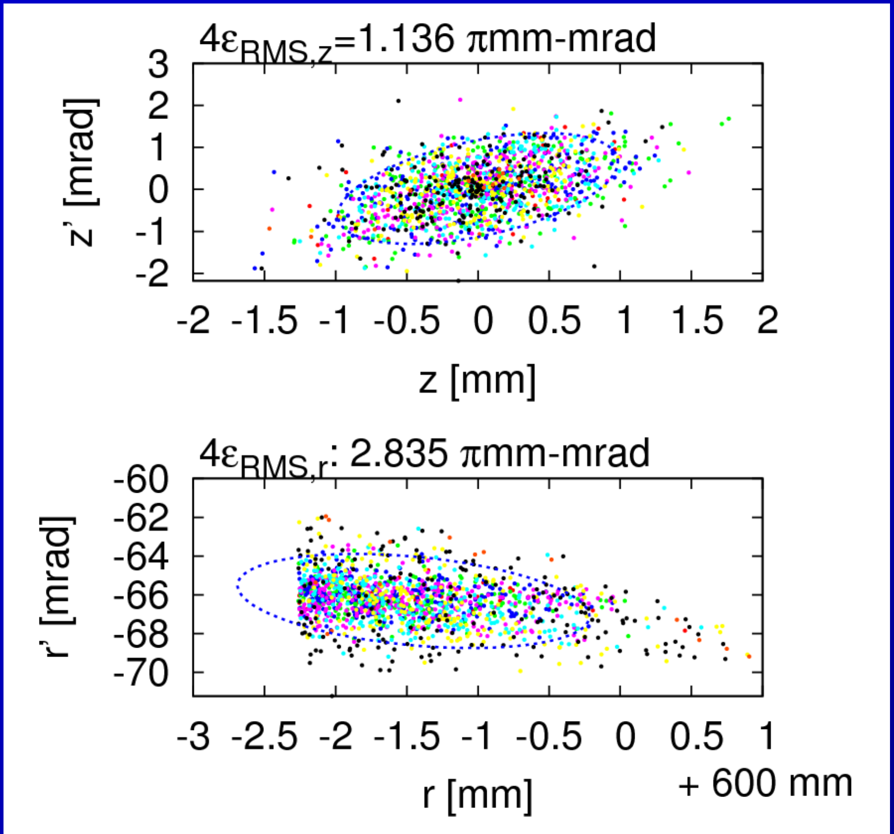
Beam dynamics during acceleration



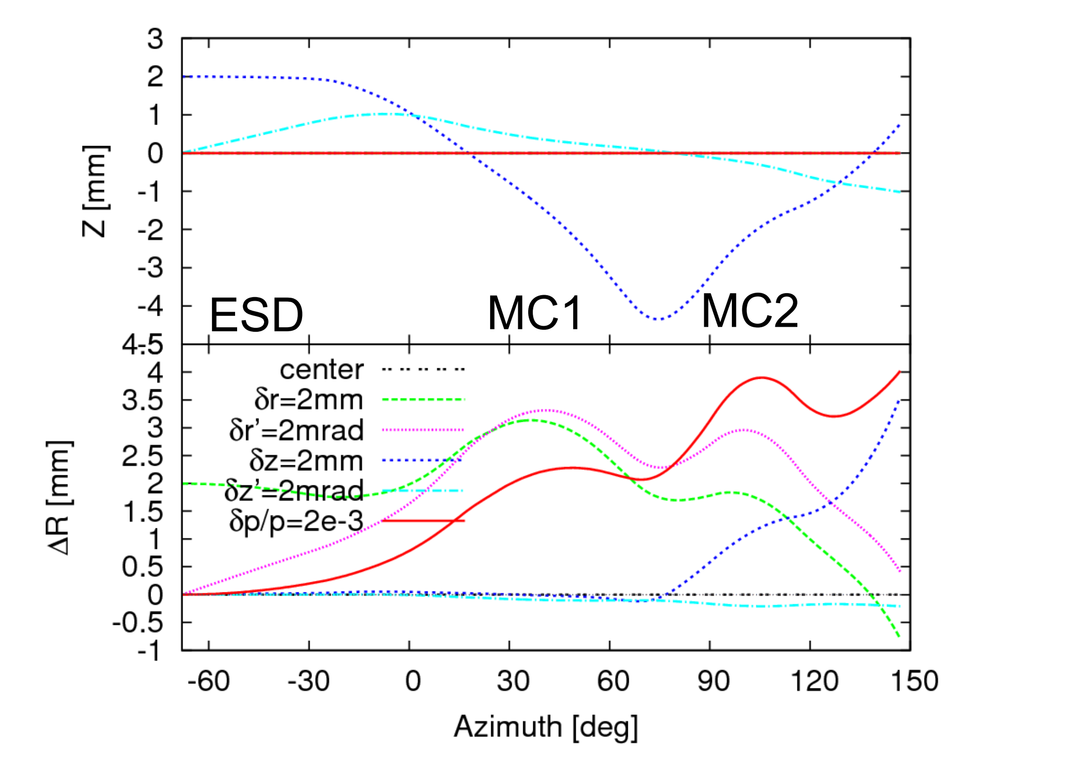
Beam tracking

No significant beam oscillation is excited by adding additional cavity

Beam extraction



Extracted beam distribution at ESD

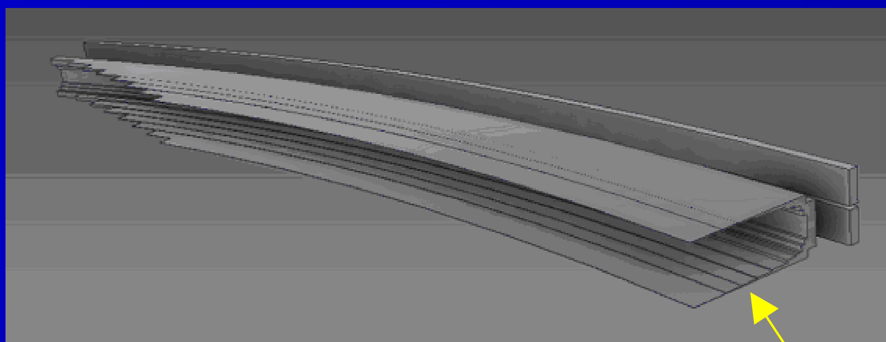


Beam tracking from ESD

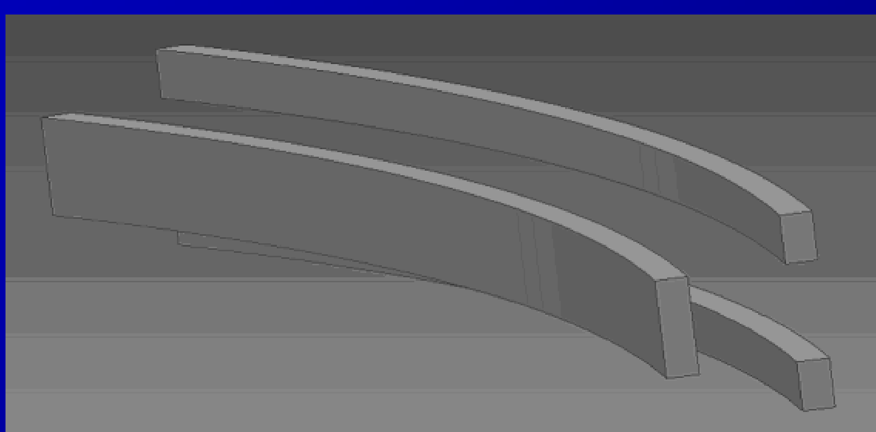
- Extraction efficiency : 60 ~ 80 %
- Emittance: ~ 3 π mm-mrad
- ESD + 2 MC's to extract the beam

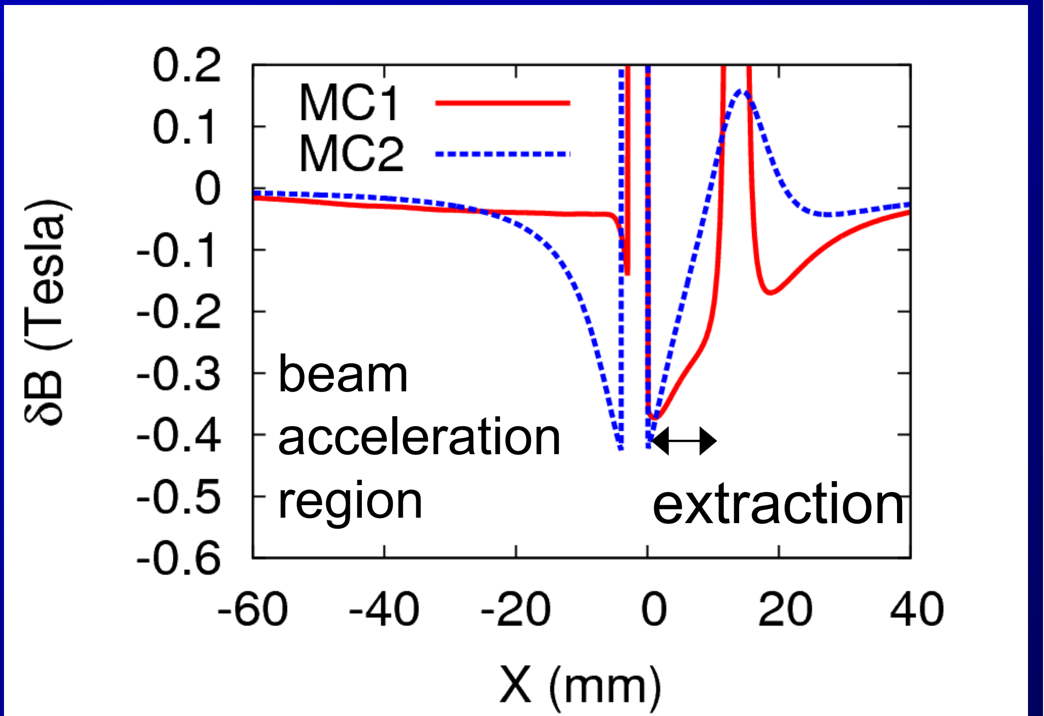
Magnetic channels (MC1, MC2)

MC1



MC2

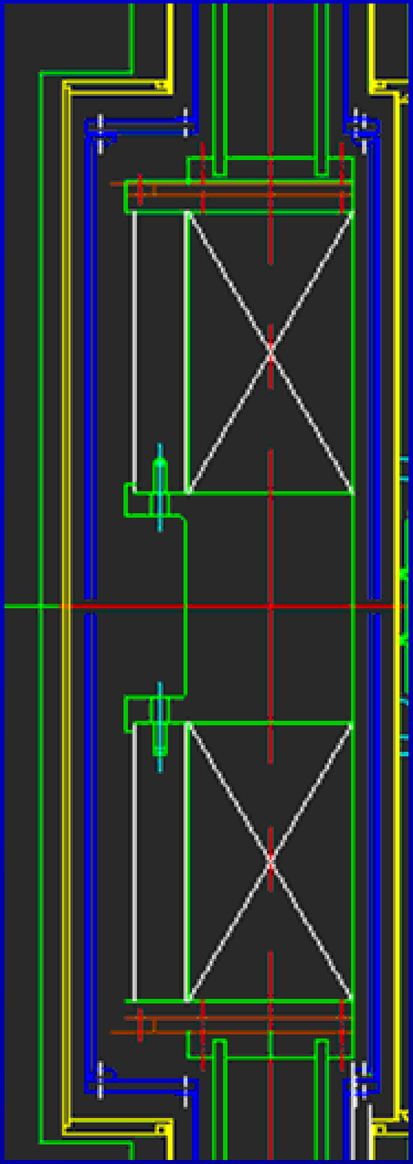




field distribution

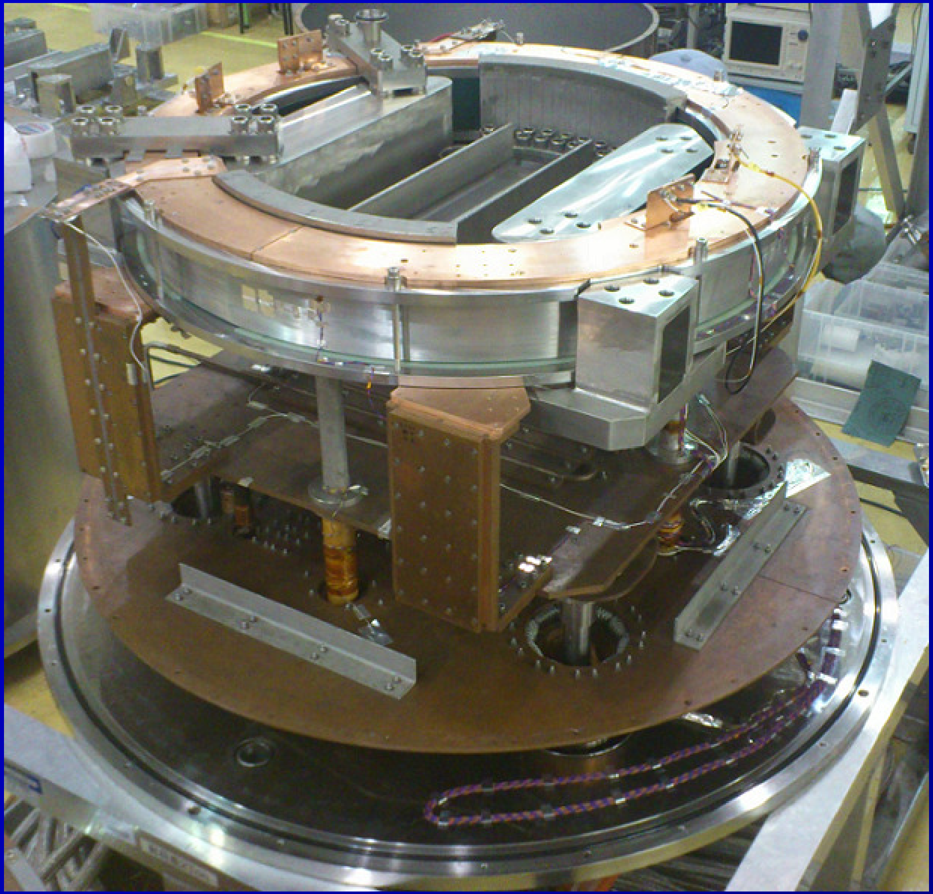
Thin iron plates reduce field nonlinearity in the beam acceleration region

Superconducting coil

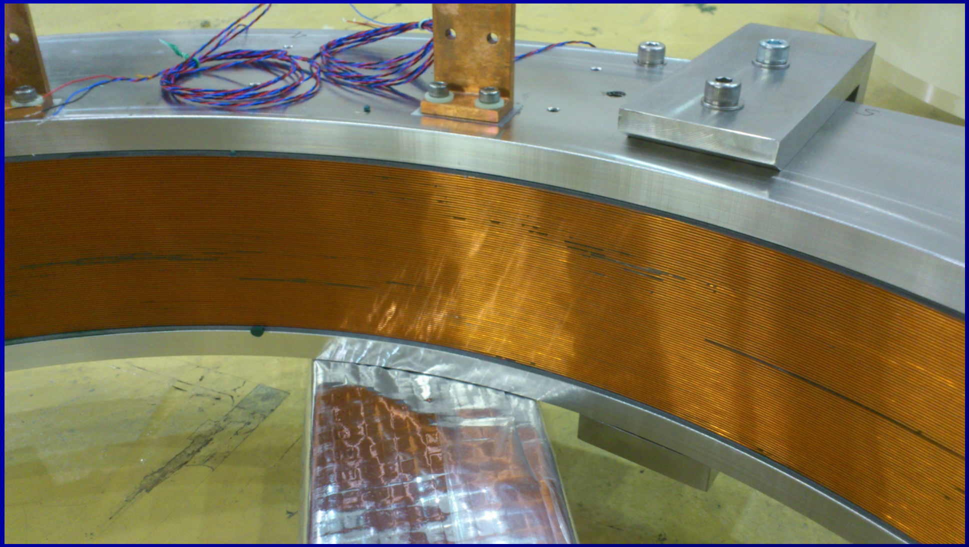


Conductor	Monolith NbTi/Cu
Cu/NbTi ratio	2.4
Maximum B in coil	4.4 T
Current density	59 A/mm^2
Cooling method	Conduction cooling (liquid helium free)
Cryocoolers	Four 4K GM cryocoolers
Current lead	HTS Bi-2223
Ramping up time	30~60 minutes

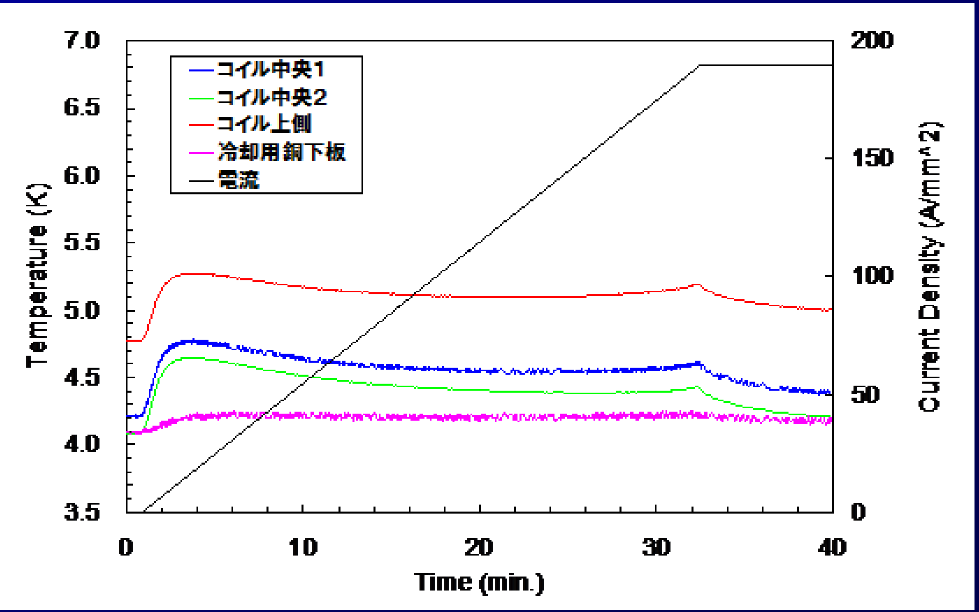
Superconducting coil prototype



SC coil



SC coil / mechanical support



Summary

- A compact SC AVF cyclotron has been designed for proton therapy
- Its performance is enough for this purpose
- It can be manufactured in the existing technology

Thank you for your attention!