Current Status of Sumitomo's Superconducting Cyclotron Development for Proton Therapy

H. Tsutsui, Y. Arakawa, Y. Ebara, A. Hashimoto, M. Hirabayashi, T. Hirayama, N. Kamiguchi, J. Kanakura, Y. Kumata, Y. Mikami, H. Mitsubori, T. Miyashita, T. Morie, H. Murata, H. Oda, H. Ookubo, T. Sakemi, M. Sano, T. Tachikawa, N. Takahashi, K. Taki, T. Tsurudome, T. Watanabe, J. Yoshida,

Sumitomo Heavy Industries, Ltd.

Sep. 27, 2019, Cape Town, Cyclotrons 2019

Outline

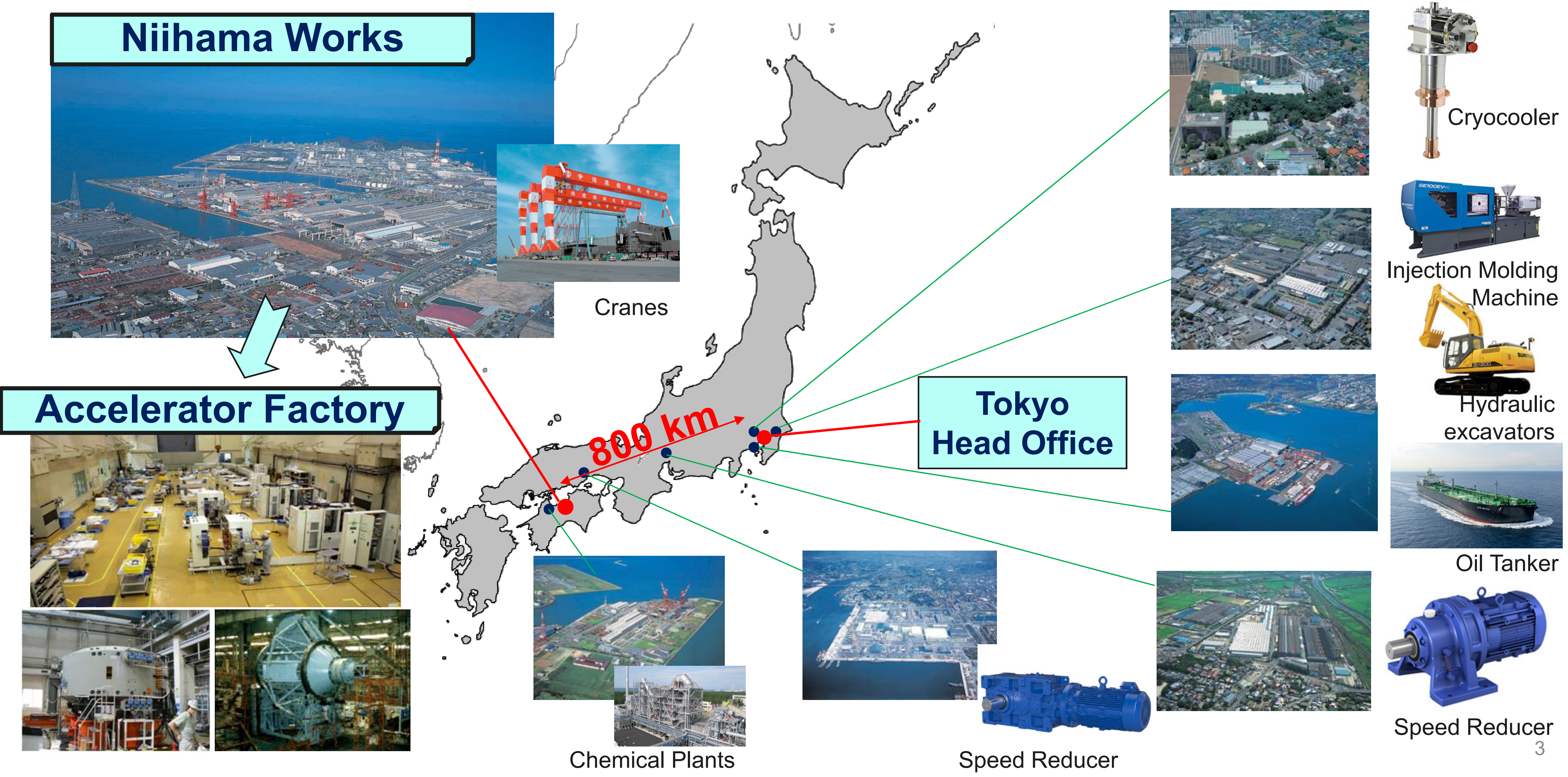
1. Introduction

2. Cyclotron Components

3. Beam Dynamics

4. Summary

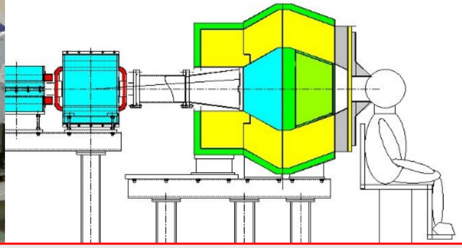
Sumitomo Heavy Industries in Japan



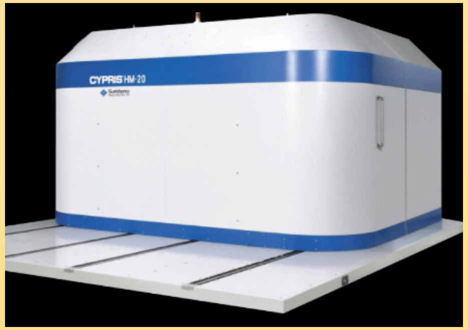
Accelerators Systems for Medical Use

Cancer Therapy

Diagnosis

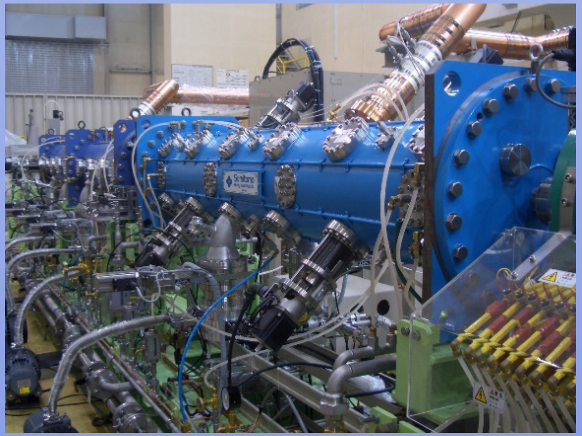


Cyclotron-based BNCT
(Boron Neutron Capture Therapy)

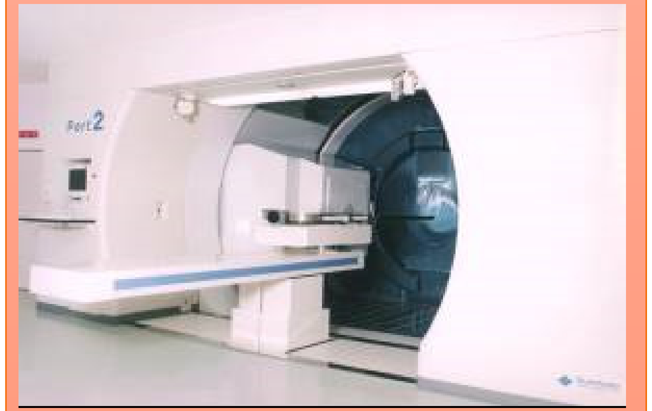


PET Cyclotron (7~20MeV)

SPECT Cyclotron (30~70MeV)



RFQ & APF-IH Linacs for Heavy Ion Therapy



Proton Therapy System
(230MeV Cyclotron)

MP-30 Cyclotron for Radio Isotope Production

Sumitomo Heavy Industries, Ltd.

MP-30 cyclotron installed in Fukushima Medical University

HM-20 cyclotron

		MP-30	**HM-20**
Proton	Energy	15 - 30 MeV	20 MeV
	Current	100 μA	150 μA
Deuteron	Energy	15 MeV	10 MeV
	Current	50 μA	50 μA
Alpha	Energy	32 MeV	N/A
	Current	30 eμA	N/A
Radio Isotopes		+ ^{62}Zn/^{68}Ge/^{111}In/^{123}I/^{201}Pb ^{177}Lu/^{211}At	^{18}F/^{15}O/^{13}N/^{11}C/^{64}Cu/^{89}Zr ^{67}Ga/^{76}Br/^{99m}Tc/^{111}In/^{124}I

Results of RI Production Tests by MP-30

Sumitomo Heavy Industries, Ltd.

	$^{62}Zn(\rightarrow {}^{62}Cu)$	$^{68}Ge(\rightarrow {}^{68}Ga)$	^{99m}Tc	^{177}Lu	^{211}At
Purpose	PET	PET	SPECT	Therapy β-emitter	Therapy α-emitter
Decay mode	EC+β^+/EC+β^+	EC/EC+β^+	IT	β^-	α, EC
Half life	9.2 h / 9.7 min	271 d / 68 min	6.0 h	6.6 d	7.2 h
Production reaction	$^{63}Cu(p,2n)$	$^{Nat.}Ga(p,2n)$	$^{100}Mo(p,2n)$	$^{176}Yb(d,x)$	$^{209}Bi(\alpha,2n)$
Target	Cu foil	Natural Ga_2O_3	$^{100}Mo\text{-}MoO_3$	$^{176}Yb\text{-}Yb_2O_3$	Natural Bi
Beam energy	p 25 MeV	p 28 MeV	p 19 MeV	d 15 MeV	α 28 MeV
Irradiation	20μA × 60min	20μA × 10min	20μA × 10min	20μA × 20min	20μA × 60min
EOB yield	1,204 MBq	0.53 MBq	180 MBq	6.0 MBq	112 MBq

Sumitomo Particle Therapy Systems in Asia

Sumitomo Heavy Industries, Ltd.

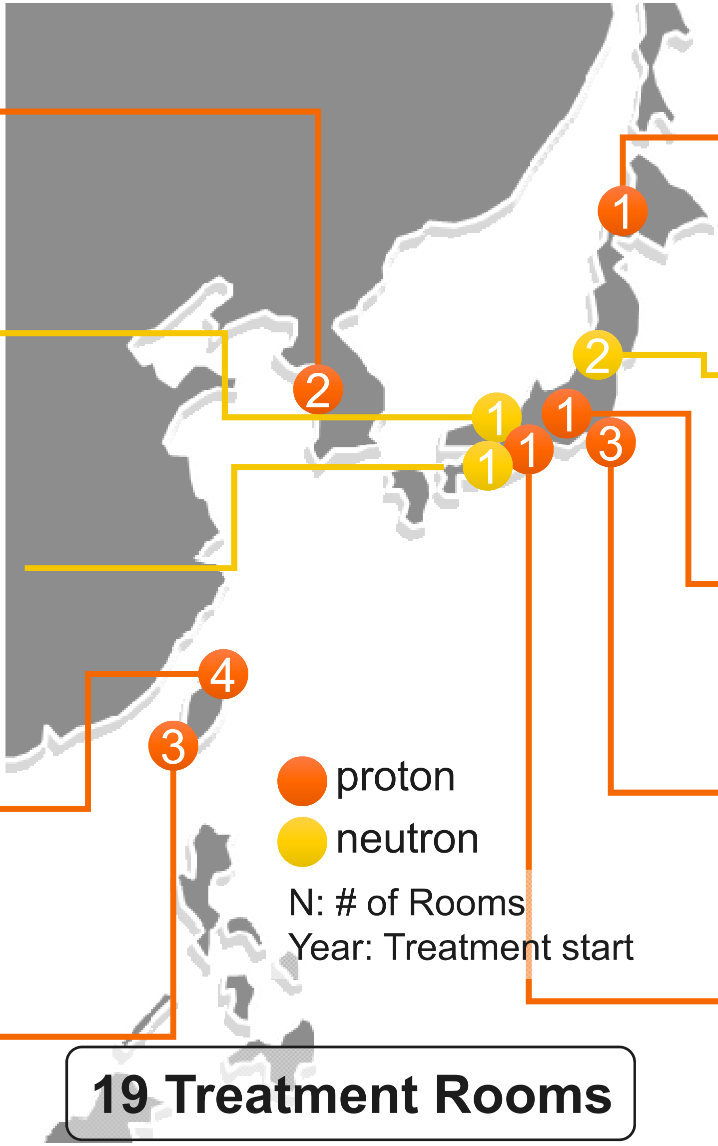
Samsung Medical Center
(Seoul, 2015)

Osaka Medical College
(Takatsuki, 2018)

Kyoto University
(Kumatori, 2013)

Chang Gung Memorial Hospital, Linkou
(Linkou, 2015)

Chang Gung Memorial Hospital, Kaohsiung
(Kaohsiung, 2018)



Sapporo Teishinkai Hospital
(Sapporo, 2016)

Southern Tohoku General Hospital
(Koriyama, 2016)

Aizawa Hospital
(Matsumoto, 2014)

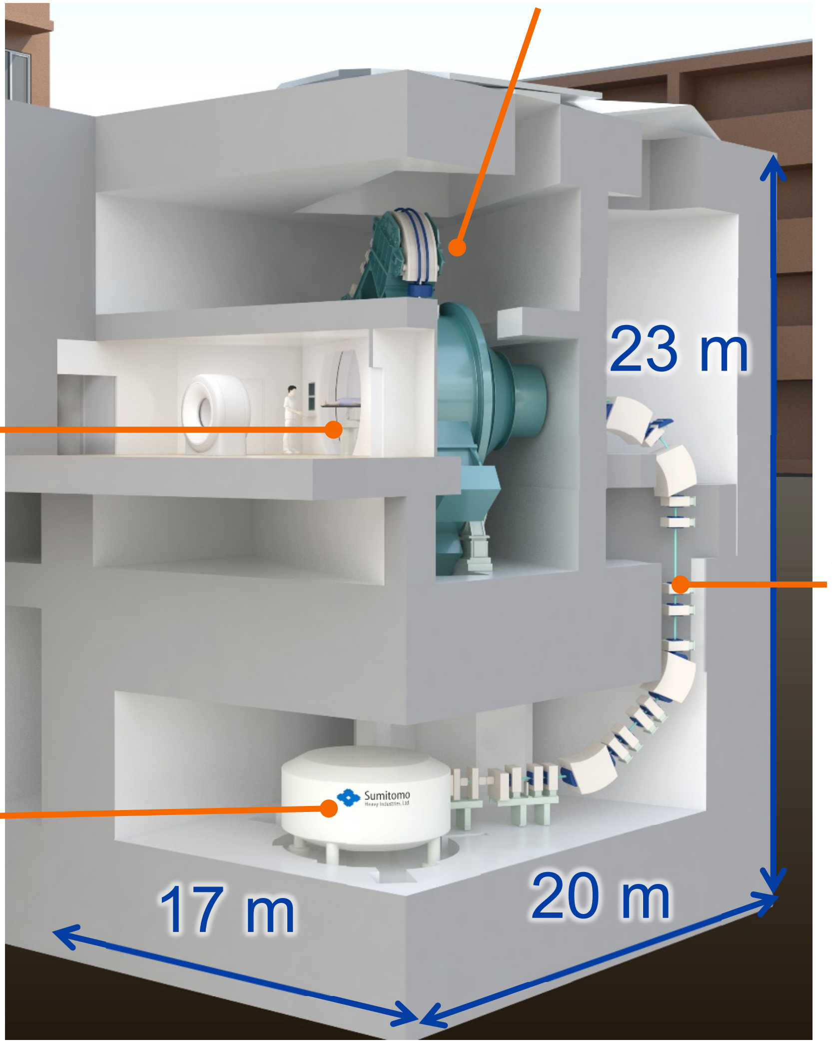
National Cancer Center
(Kashiwa, 1998)

Takai Hospital
(Tenri, 2018)

Single-Room Proton Therapy Solution

IMPT Nozzle
with Various Options

360deg Compact Gantry

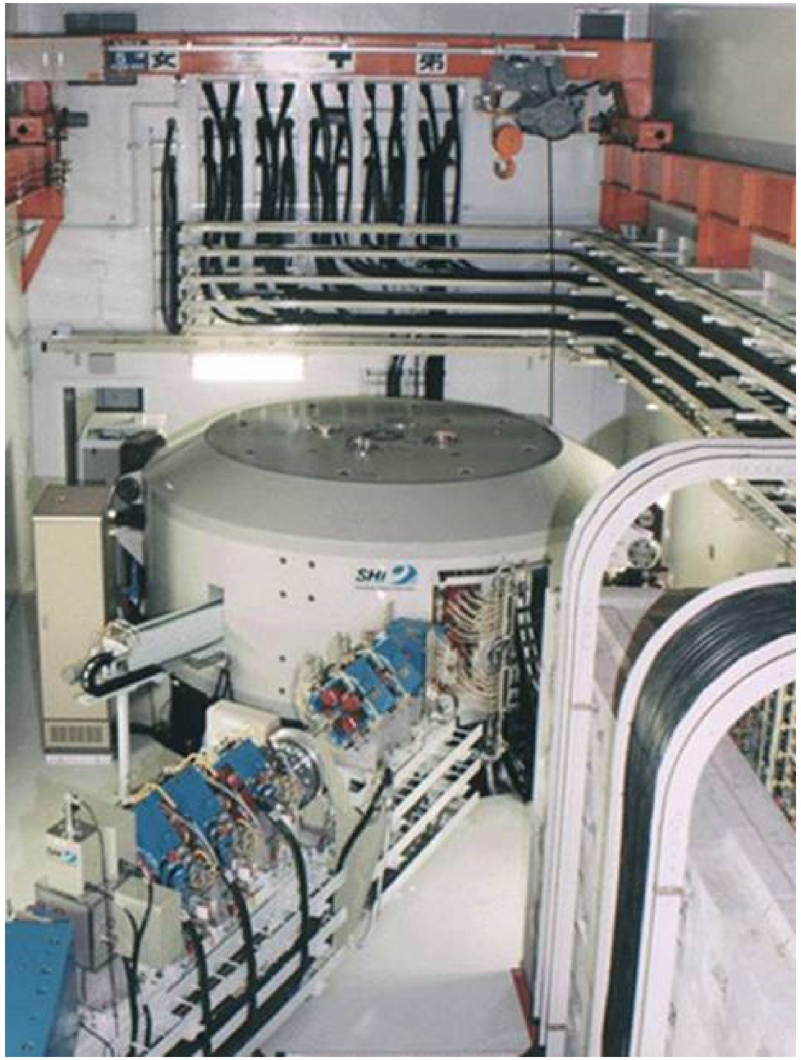


Cyclotron Underneath

Vertical ESS and Beamline

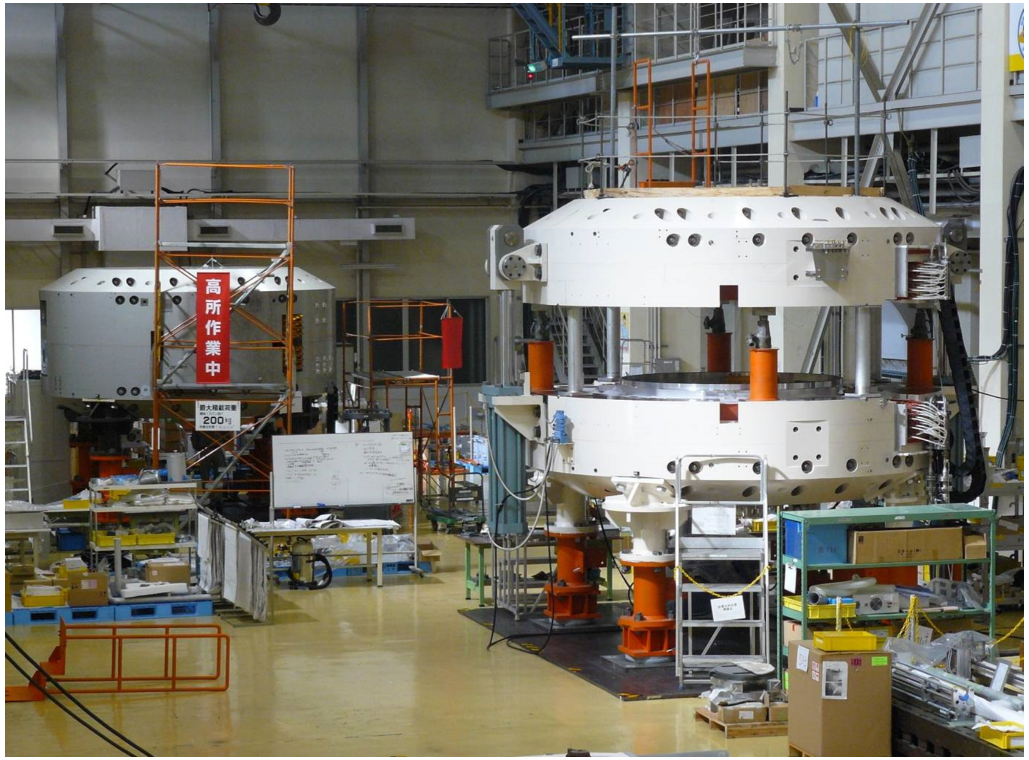
230 MeV Cyclotron P235 for Proton Therapy

Sumitomo Heavy Industries, Ltd.



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

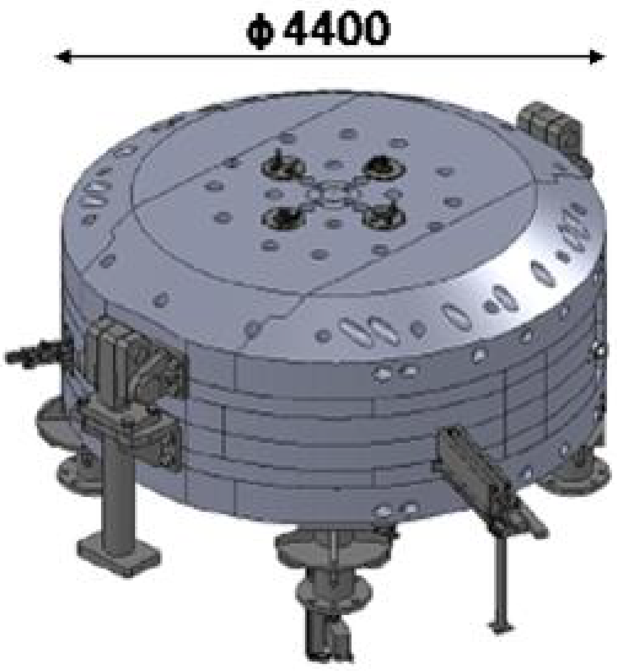
- Normal conducting (~2T)
- Weight ~220 t
- Diameter ~4.4 m

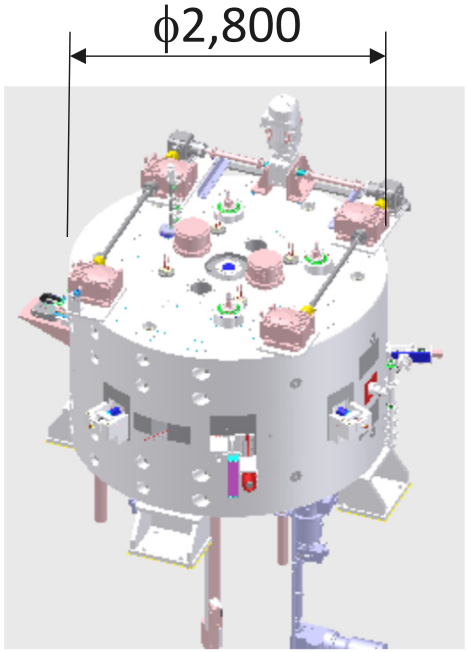


P235 cyclotrons manufactured in Sumitomo Niihama Works

P235 and New Superconducting Cyclotron

Sumitomo Heavy Industries, Ltd.





P235 (Yoke Weight ~ 220 ton)		SC230 (Yoke Weight ~ 65 ton)	
Maximum Beam Current: 300 nA		Maximum Beam Current: 1,000 nA	
Power Consumption:	400 kW	Power Consumption:	200 kW
Transport pieces:	more than 20	Transport pieces:	2 to 3
Installation Period :	30 days	Installation Period:	7 days

Design Parameters

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Beam	Particle species	Proton
	Energy	> 230 MeV
	Beam current	max. 1000 nA
	RMS emittance	~1 π mm-mrad
	RMS momentum spread	< 0.1 %
	Extraction efficiency	> 70 %
Magnet	Yoke size	ϕ2.8 m × 1.7 m
	Yoke weight	65 t
	Beam extraction radius	0.6 m
	Average B @ center / extraction	3.1 T / 3.9 T
	Number of sectors	4
RF	Frequency	95.2 MHz (h=2)
	Number of dees	2
	Dee voltage @ center / extraction	50 kV / 75 kV
	Cavity wall loss	< 100 kW

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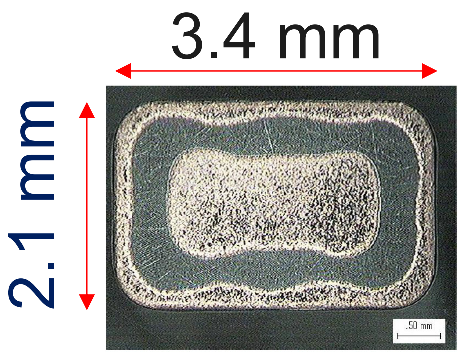
SC Coil and Cryostat

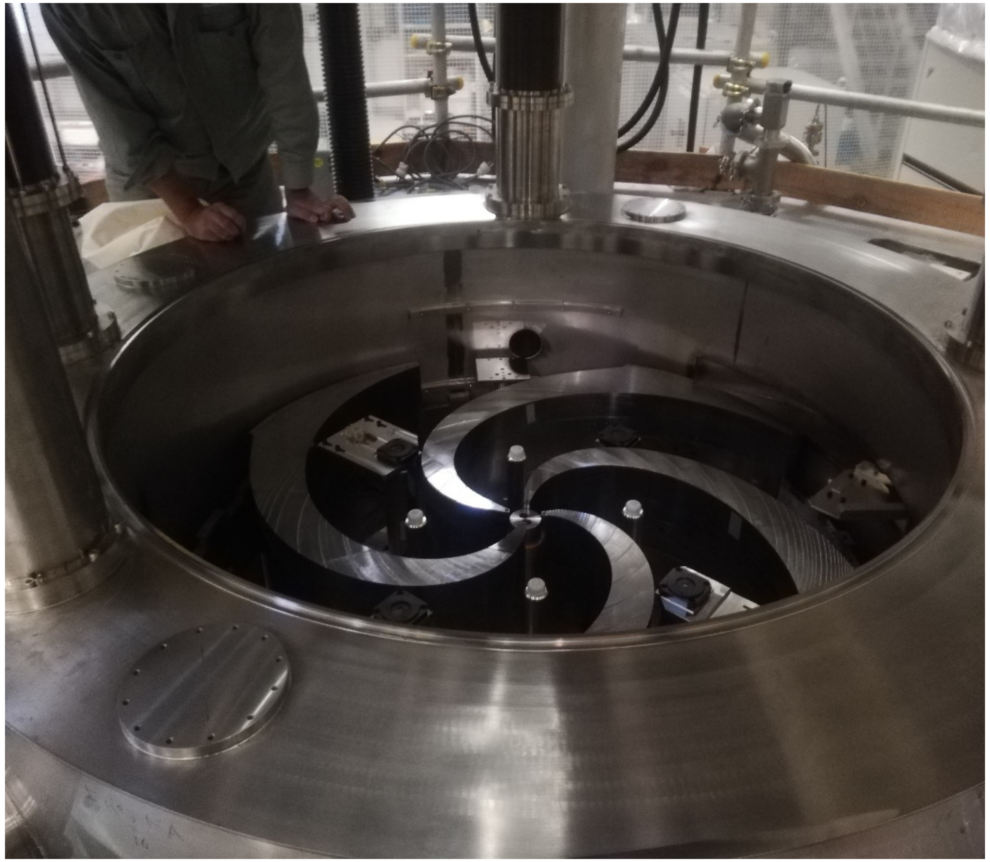
NbTi wire



Conductor	Wire material	Monolith NbTi/OFC
	Size	2.1 mm ×3.4 mm
Coil	Configuration	Two solenoids
	# of Turn	2208 Turn/coil
Cooling	Method	Conduction cooling
	Cryocooler	Four 4 K-GM coolers
Operating current		442 A
Maximum current		488 A
Peak B in coil @Imax		4.4 T
Critical temp. @ Imax		7.4 K
Nominal temperature		4.7 K
Initial cooling time		14 d

J. Yoshida et al., in Proc. MT26, 2019.
T. Tsurudome et al., in EUCAS 2019.

Cryostat in Cyclotron



Cryostat Cooling Test

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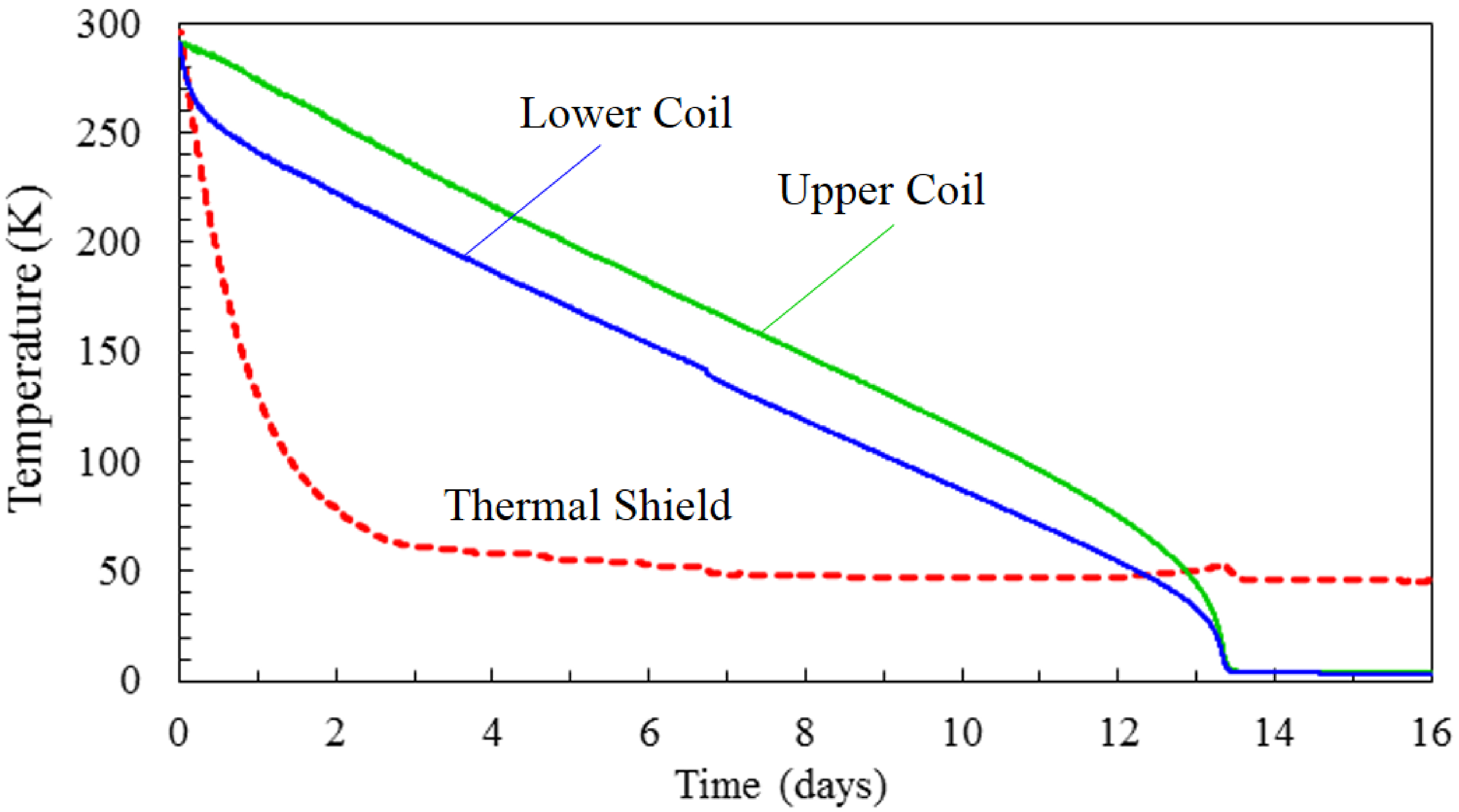
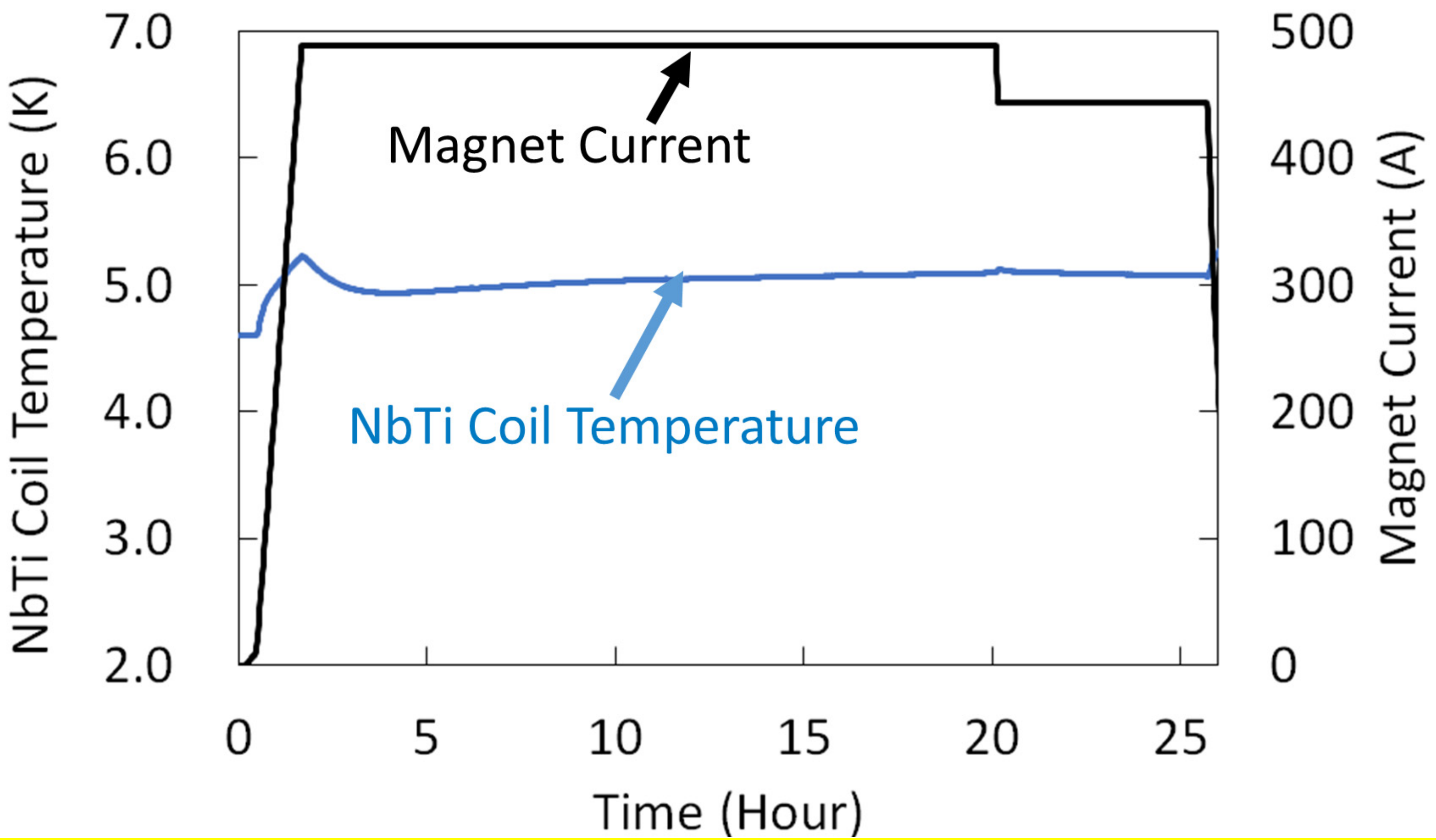


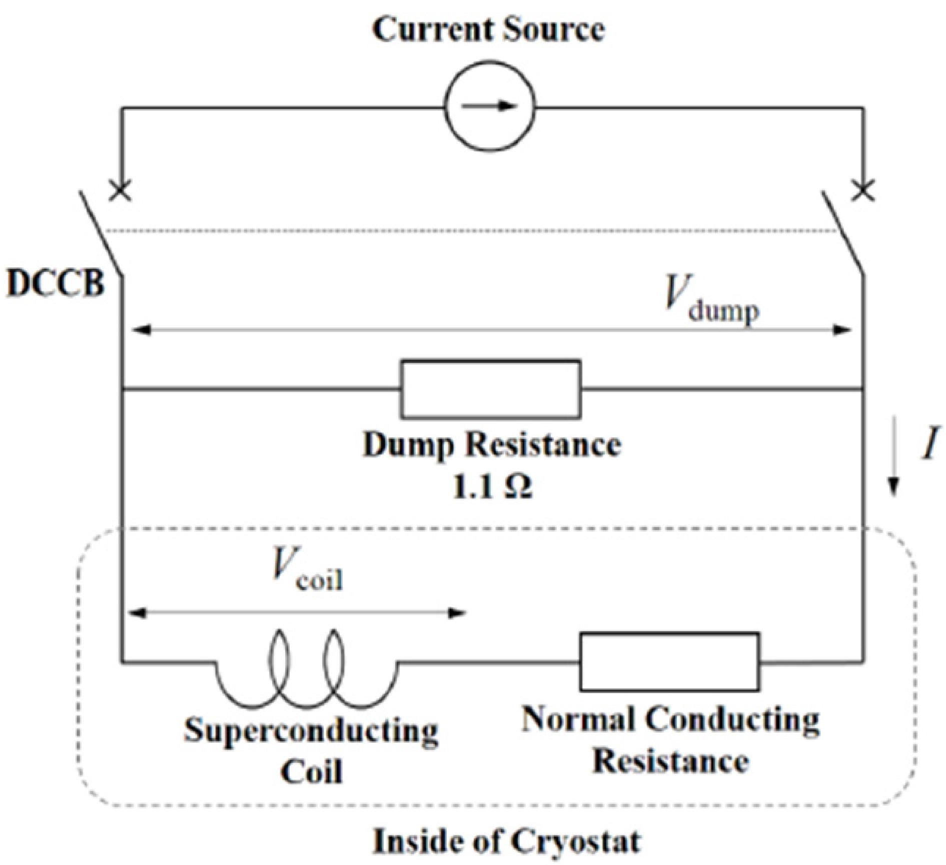
Initial cooling time was 14 days

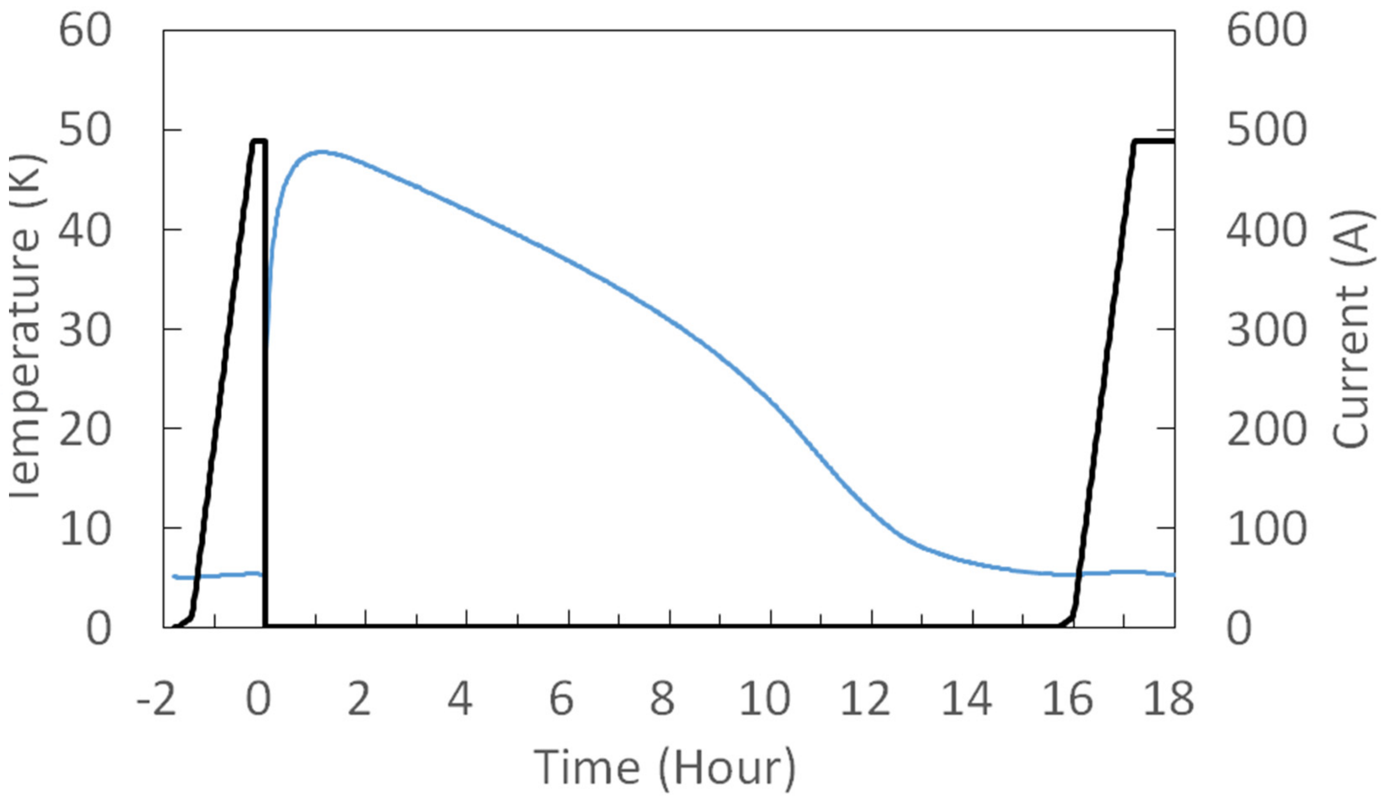
Coil Excitation Test



- Ramp up time from 0 A to 488 A was 1.5 h.
- We have not experienced a quench except during scheduled quench tests.

Quench Recovery Test

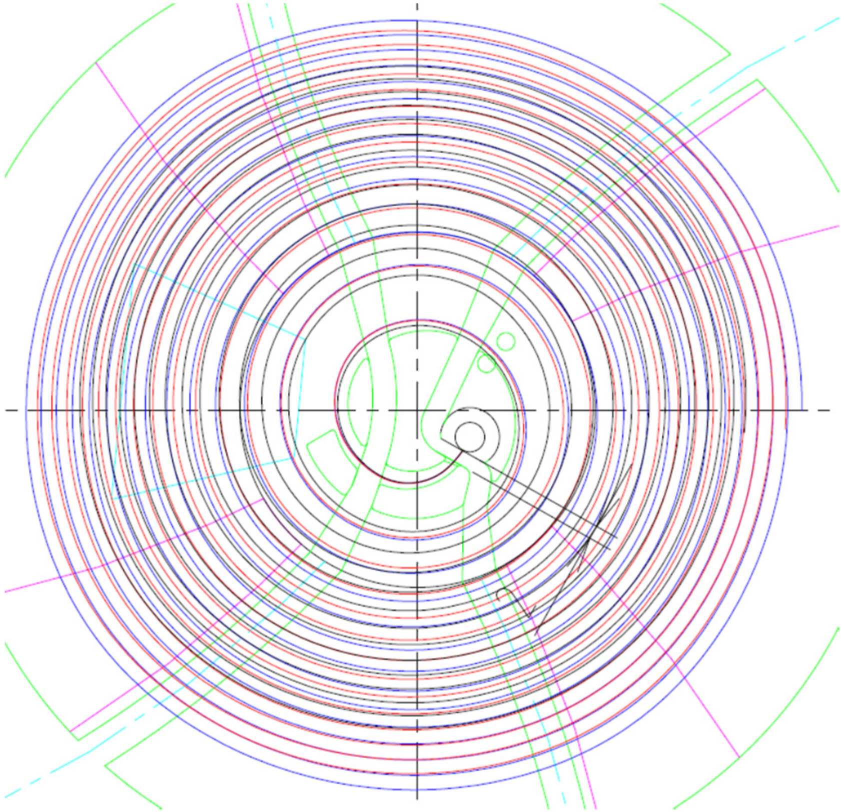


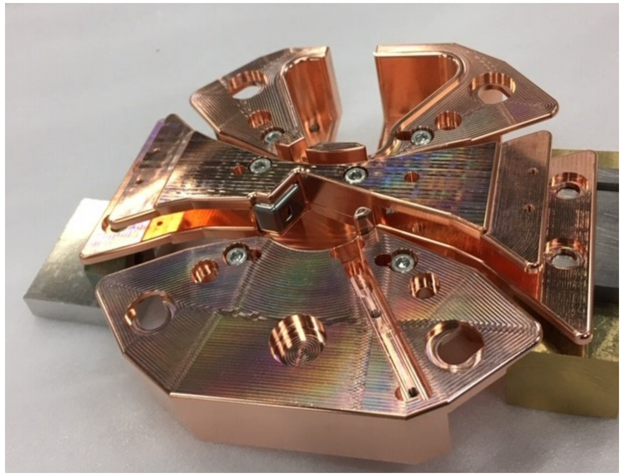


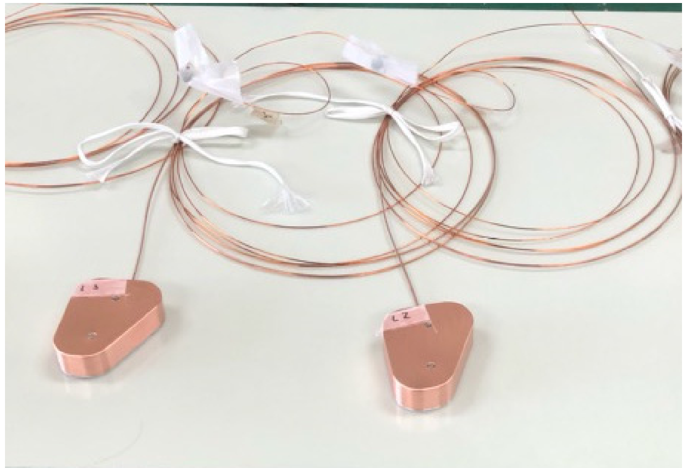
- Stored energy(=5 MJ) was consumed by SC coil and dump resistor.
- Quench recovery time was 17 h.

Ion Source and Center Region

N. Kamiguchi et al., in Cyclotrons 2019







- Vertical chopper for fast beam switch on/off (< 50 us).
- Harmonic coils for beam centering.

RF System

Type	Solid state
Frequency	95.2 MHz
Max. output power	120 kW
Size of Power Amp.	W3,704 x H2,000 x D1,110

- RF cavities are being fabricated.
- 120 kW RF power amplifier is being tested.

Beam Extraction

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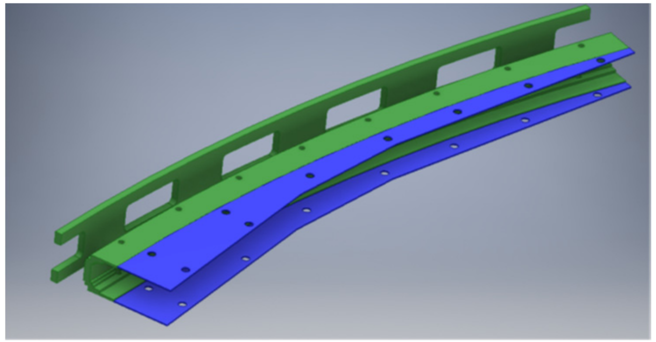
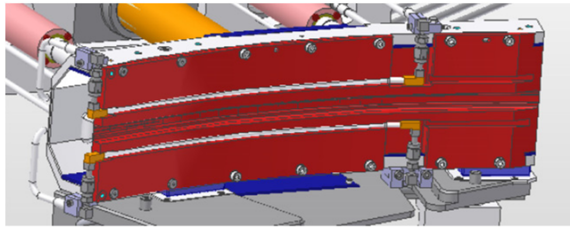
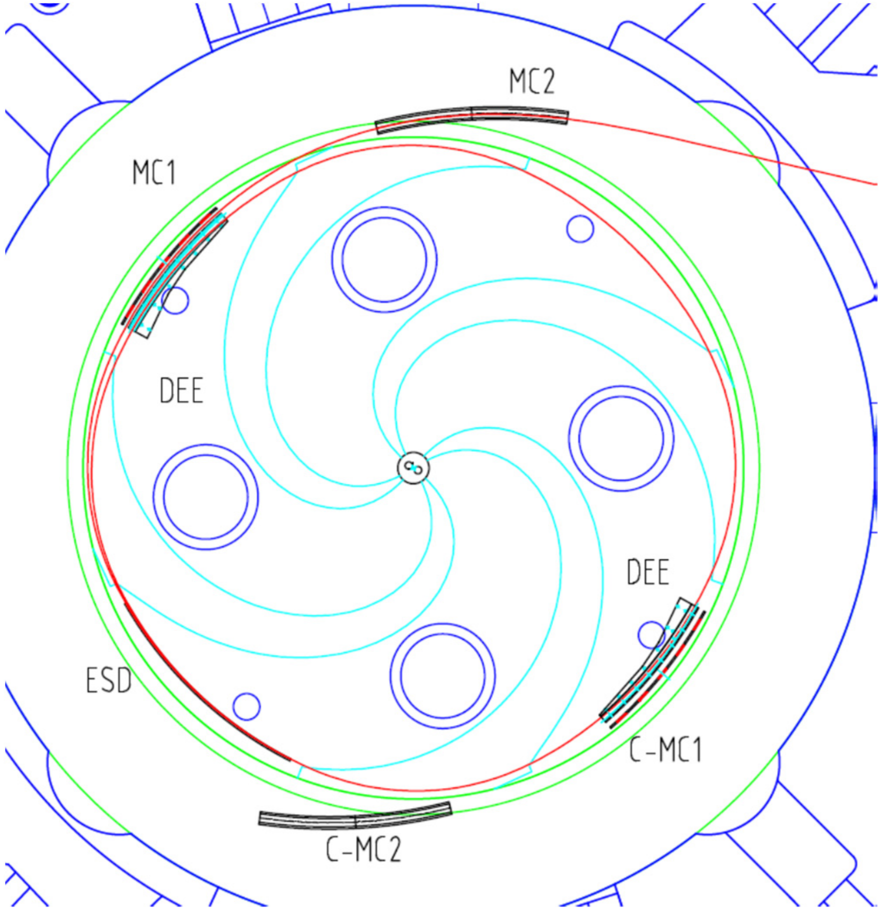
MC1

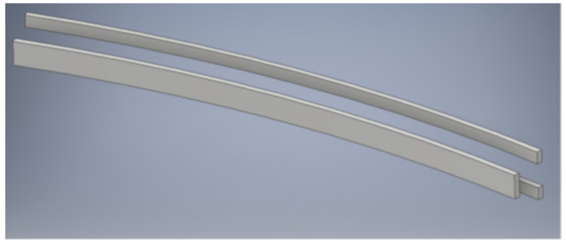


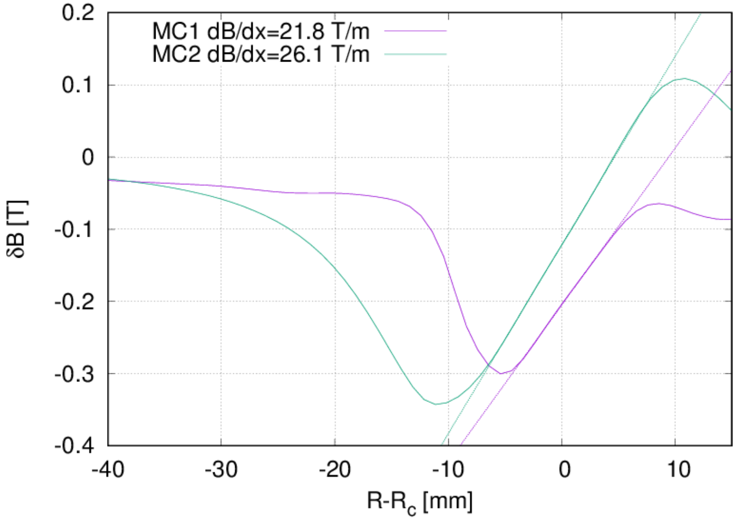
ESD -54 kV, 4 mm gap





MC2





- Beam extraction is made by ESD + MC1 + MC2
- C-MC1, C-MC2 for reducing B1 component.
- Harmonic coils for B1 control.

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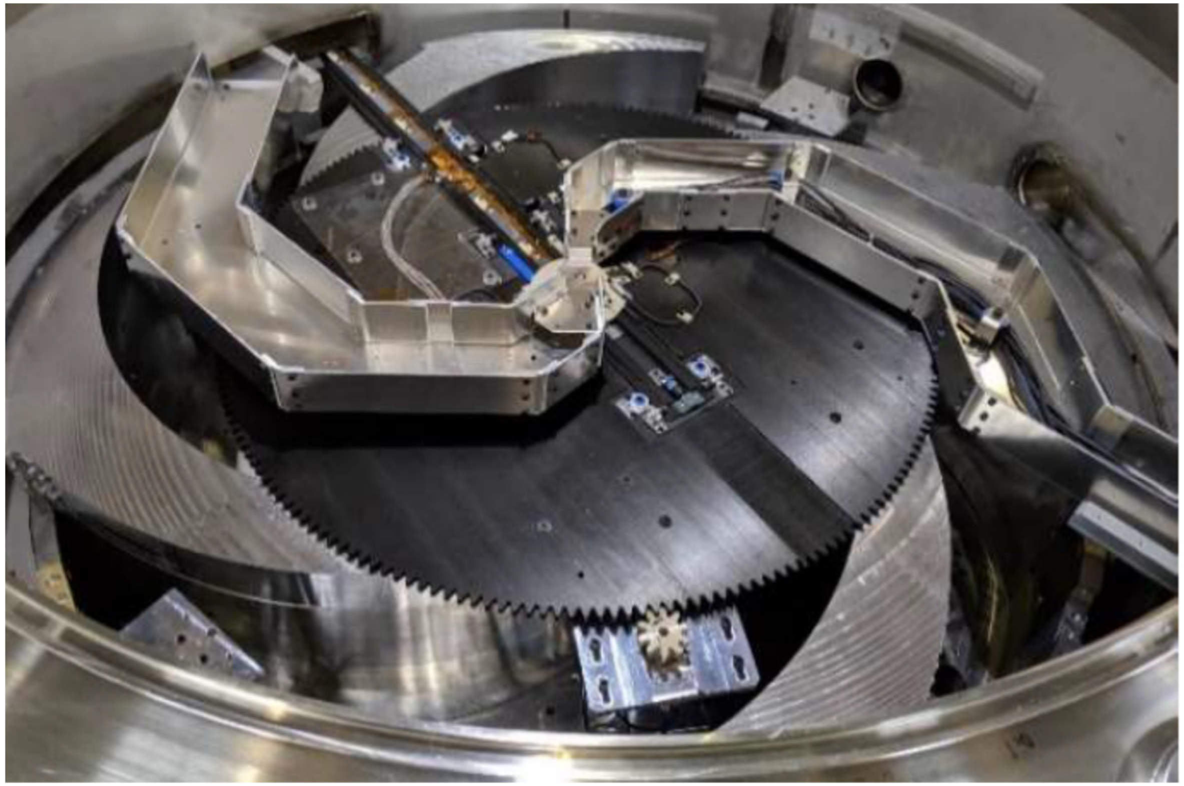
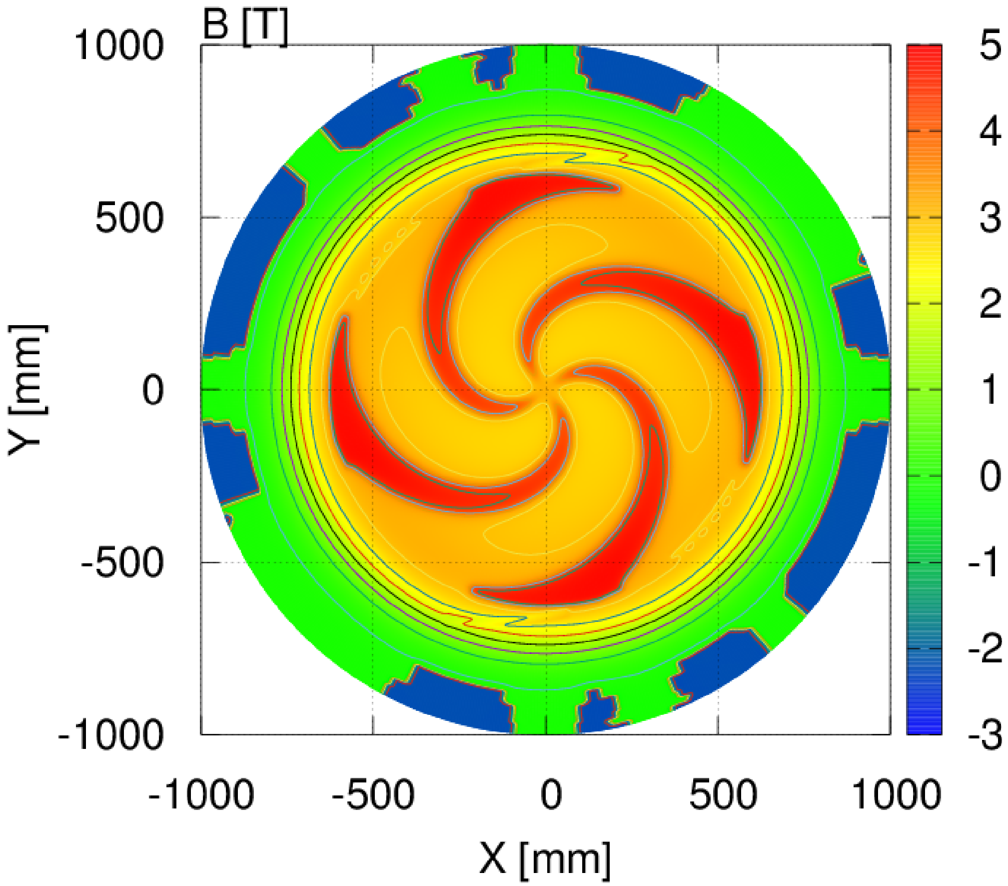
Field Mapping System

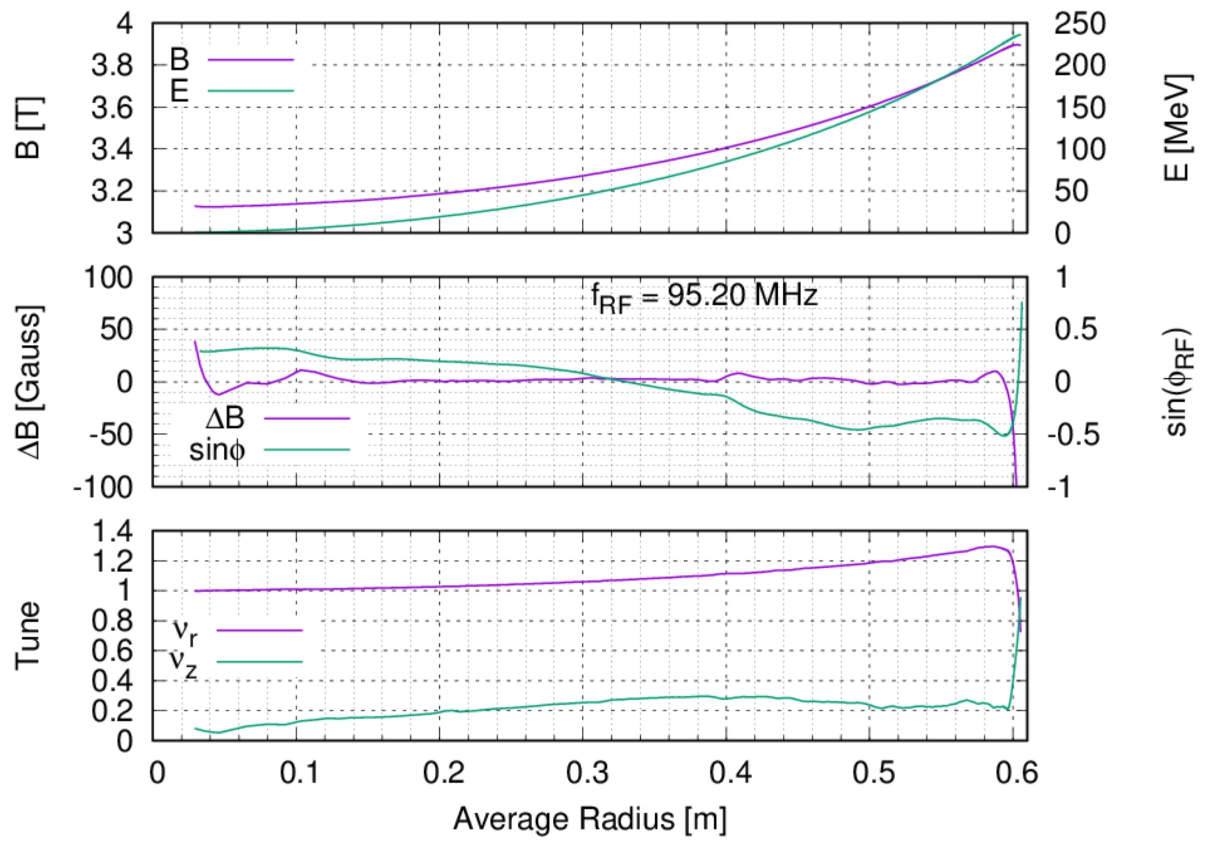
Y. Ebara et al., in Cyclotrons 2019

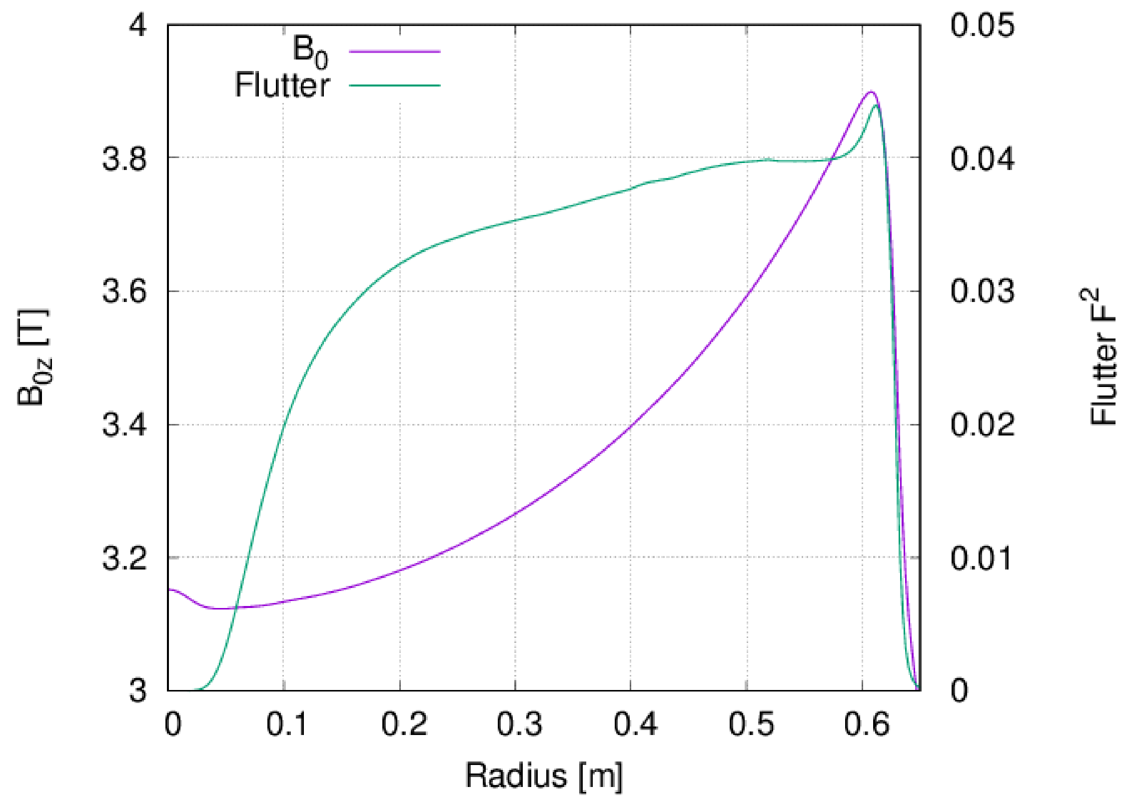




- It took 2.5 h to obtain a full field map by 6 Hall probes

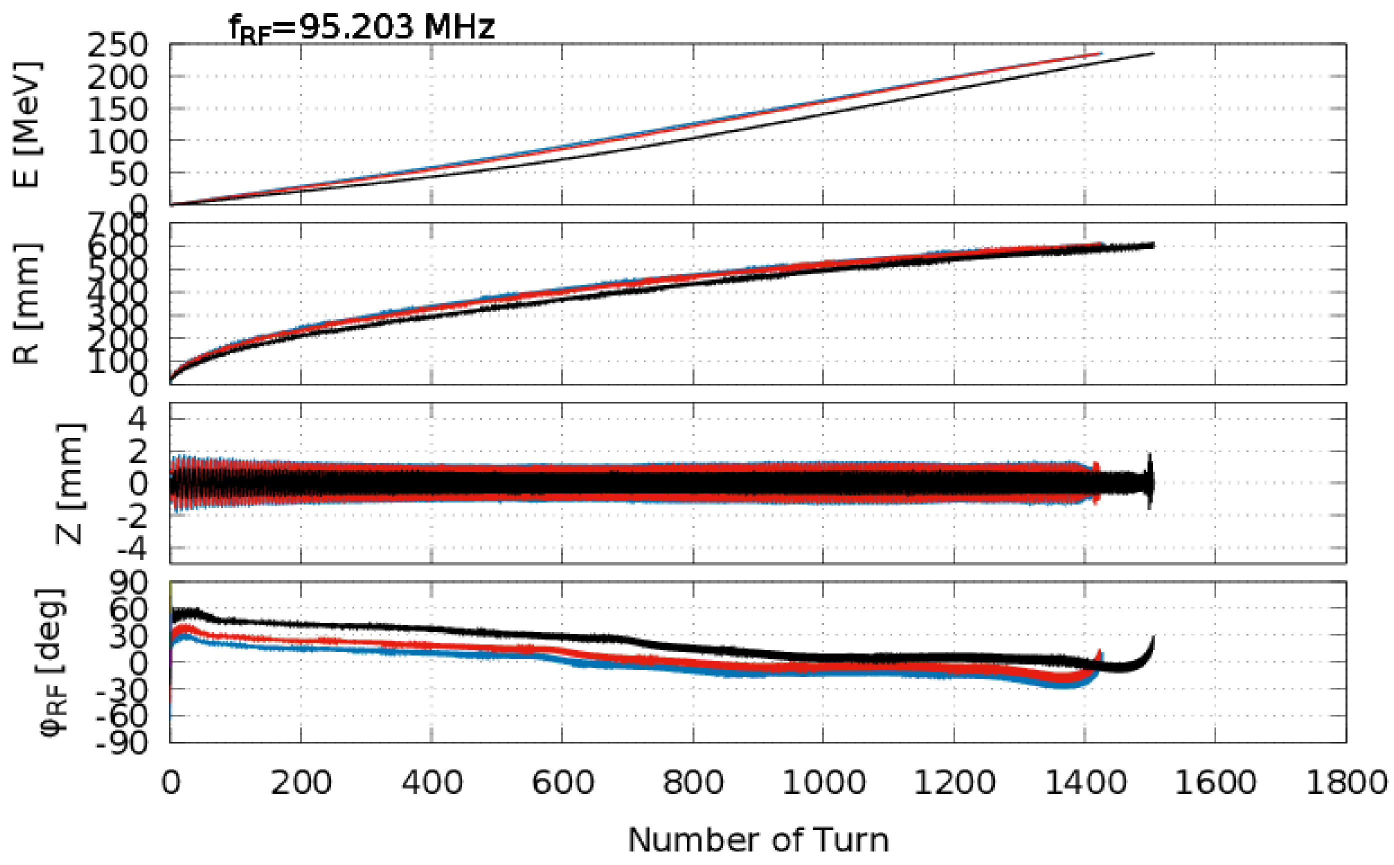
Isochronous Field

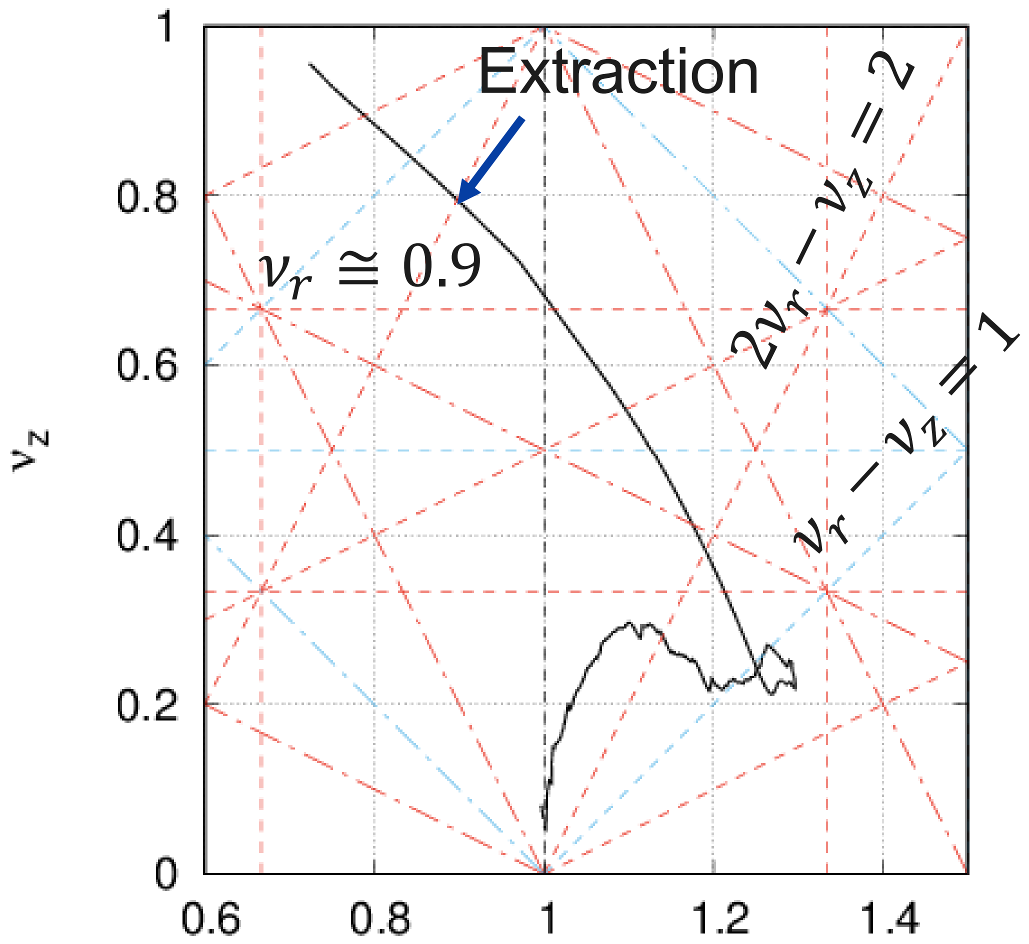




- Sectors were machined three times to obtain isochronous field

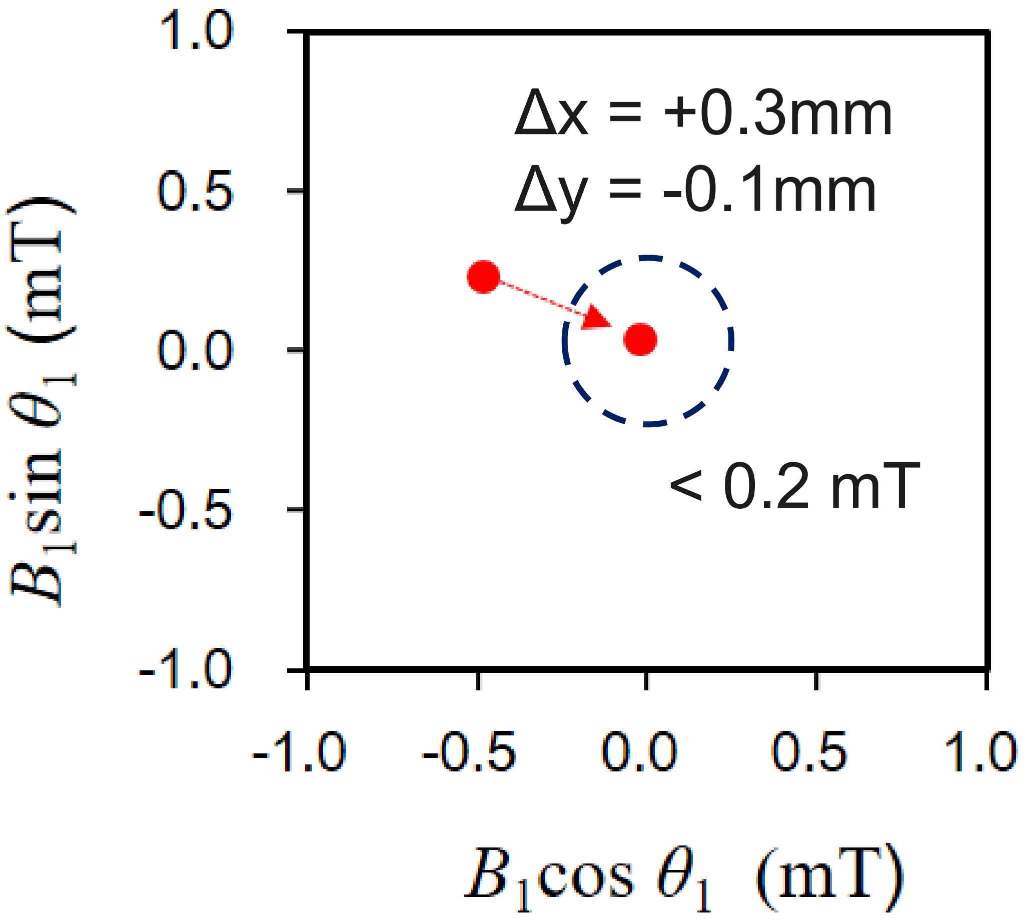
Beam Acceleration Simulation





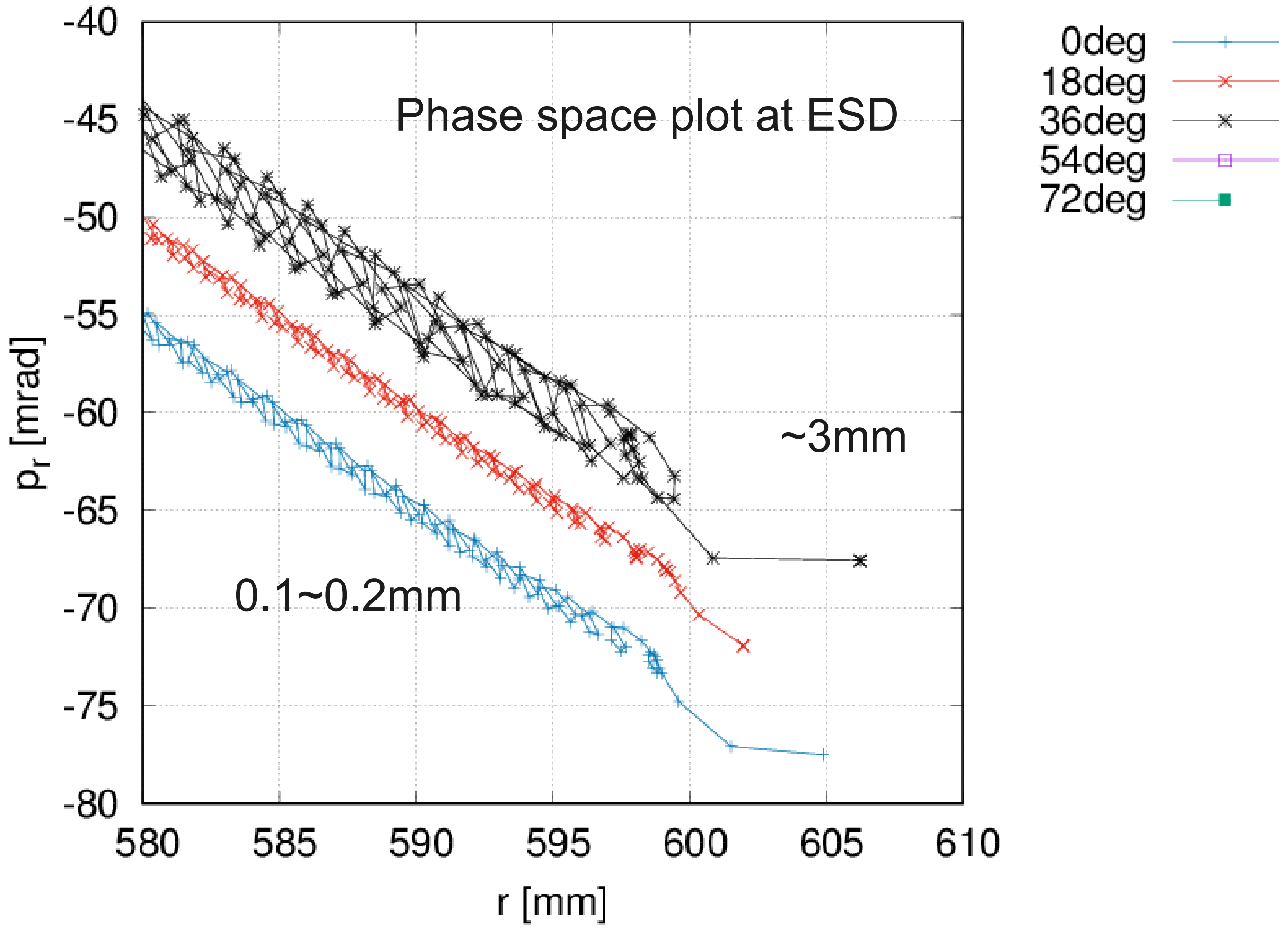
- No apparent beam blowup during acceleration.
- Precessional extraction is used to get large turn separation.

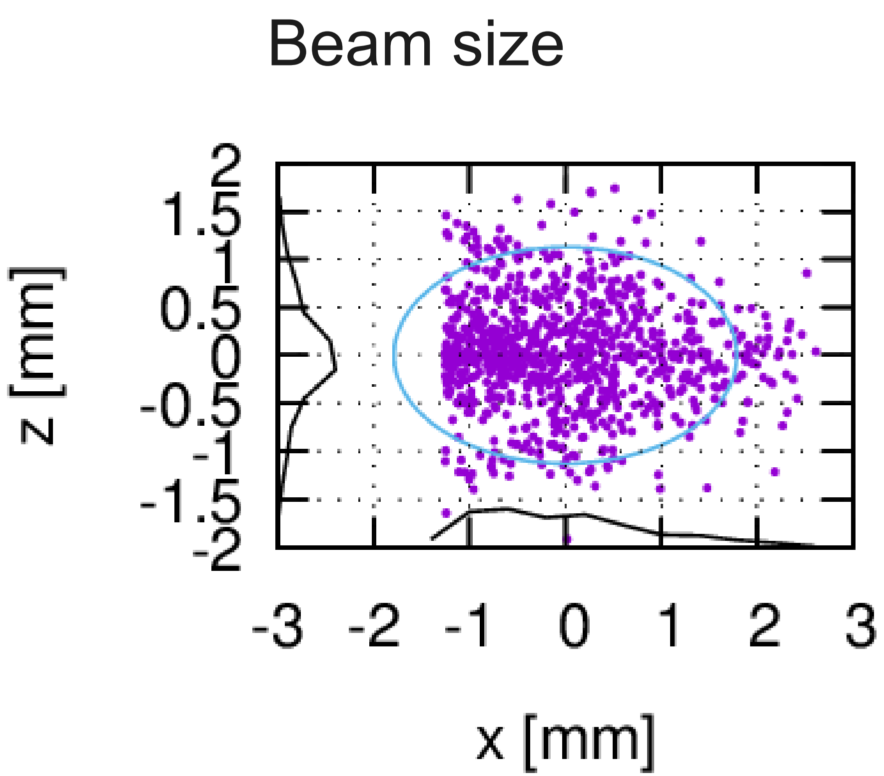
B1 Correction



- To obtain optimum turn separation at ESD, B1 should be under control.
- B1 at R=600 was corrected by adjusting horizontal position of SC coil.

Turn Separation around Extraction Radius





By adjusting harmonic coils, large turn separation was obtained.

Beam Emittance at Cyclotron Exit

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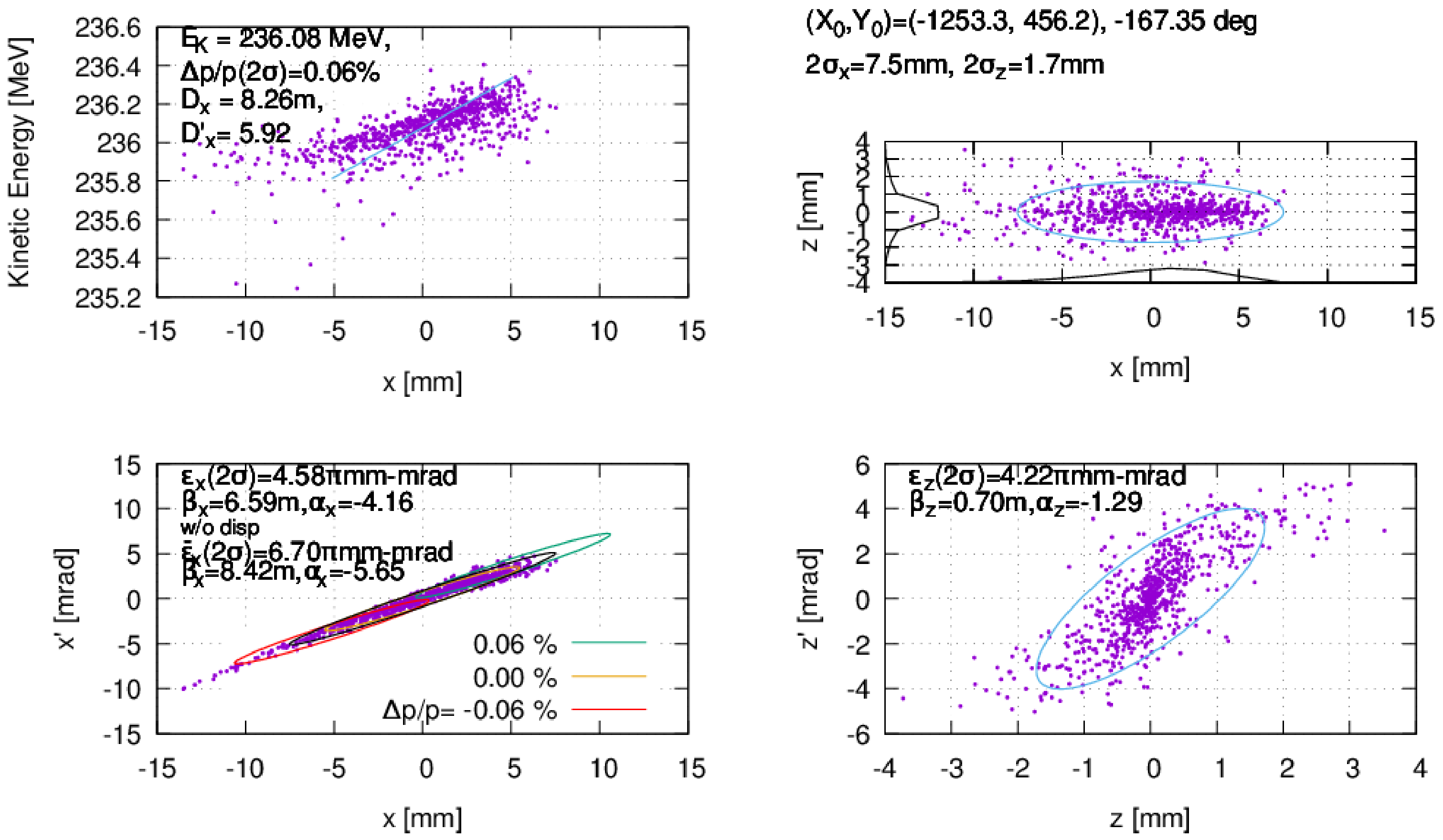

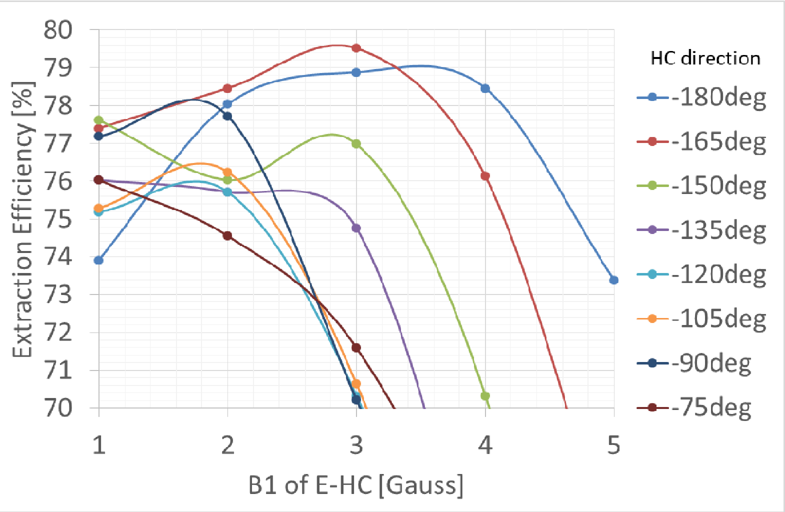

- Optimized beam extraction efficiency was larger than 70 %
- At cyclotron exit , 2σ emittance will be around 4 πmm-mrad.

Summary

- Most SC cyclotron components have been designed and are being built.
- SC magnet was built and specified magnetic field was excited.
- Isochronous field was obtained by pole machining.
- In the simulation, the optimized extraction efficiency was larger than 70 %.
- A new building in Saijo plant is under construction for cyclotron beam test. SC cyclotron will be tested at the new site in FY 2020.

Thank you for your kind attention!