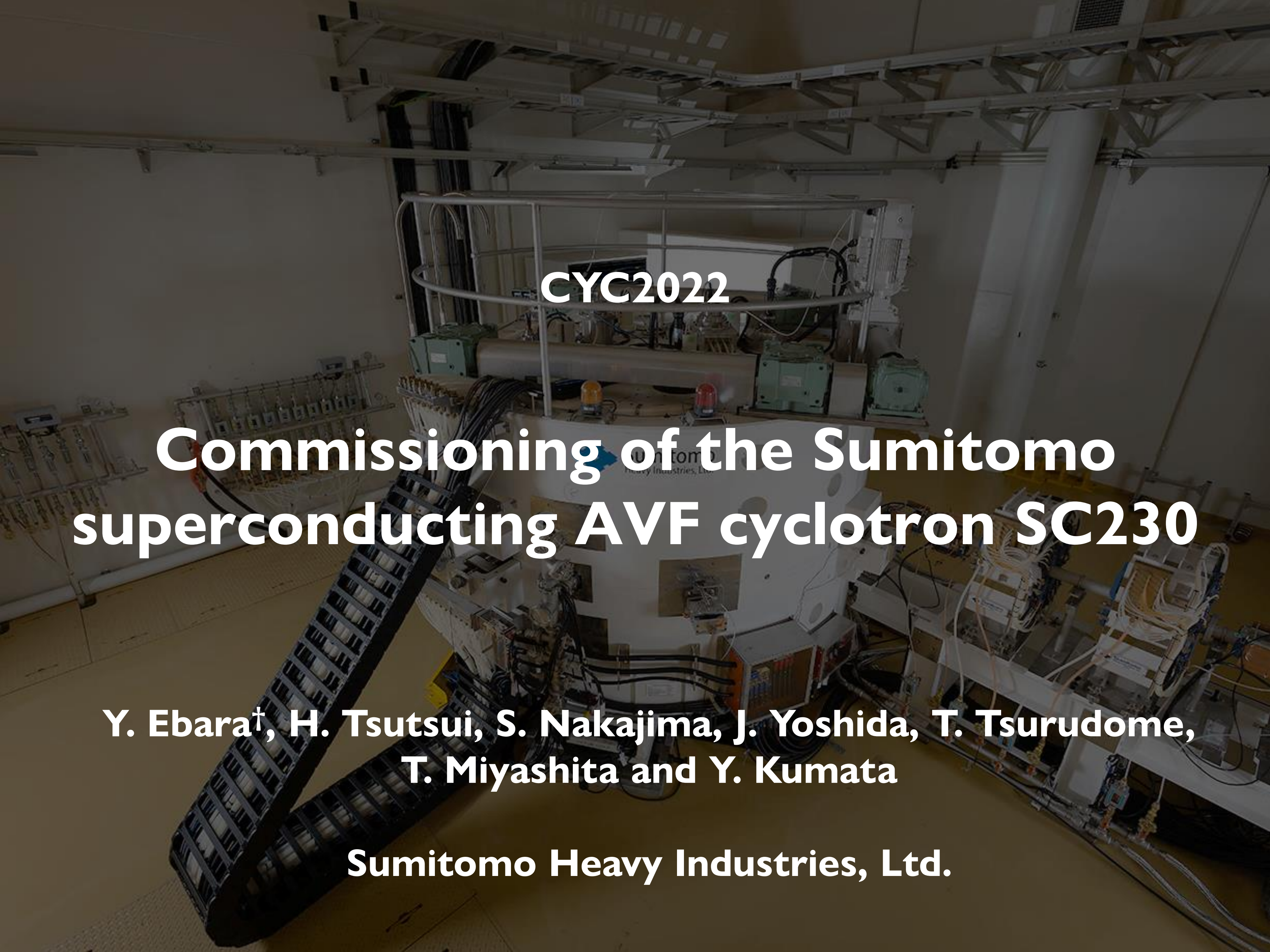


CYC2022

Commissioning of the Sumitomo superconducting AVF cyclotron SC230

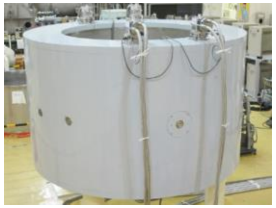
Y. Ebara†, H. Tsutsui, S. Nakajima, J. Yoshida, T. Tsurudome, T. Miyashita and Y. Kumata

Sumitomo Heavy Industries, Ltd.

Sumitomo Heavy Industries, Ltd.

Accelerators

Cryocoolers



Superconducting magnets

- Accelerator manufacturing for 50 years

  1972- Research accelerator

  1981- PET cyclotron

  1988- Injector for heavy ion radiotherapy

  1996- Proton therapy system

  2009- BNCT system

K140 AVF cyclotron （RCNP, Osaka Univ.）

Medical accelerators

PET

Linac for heavy ion radiotherapy

BNCT

Radionuclide therapy

Proton therapy

Outline

Sumitomo Heavy Industries, Ltd.

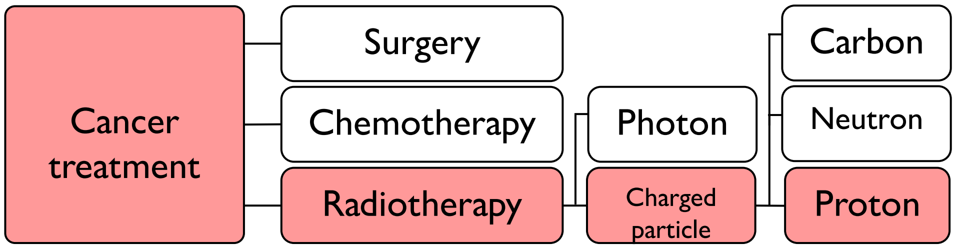
- **Introduction**
  - Proton therapy, PT system
- **SC230 : Sumitomo superconducting AVF cyclotron**
  - Concepts of SC230
  - Fabricating of components
- **Commissioning**
  - Central region, Isochronous region, Extraction region
  - Beam status
- **Conclusion**

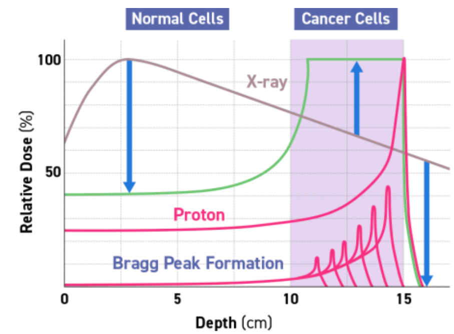
Proton therapy (PT)

Sumitomo Heavy Industries, Ltd.

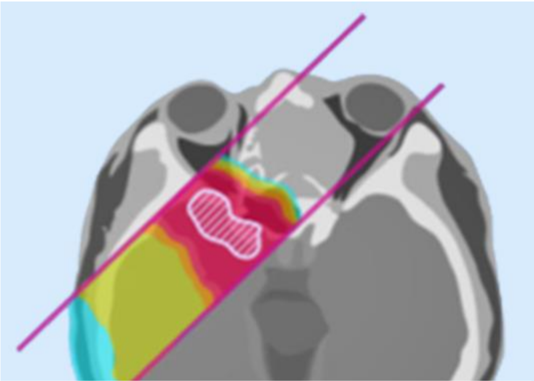
QOL ; Quality Of Life

- PT is a cancer treatment that maintains the patient's QOL



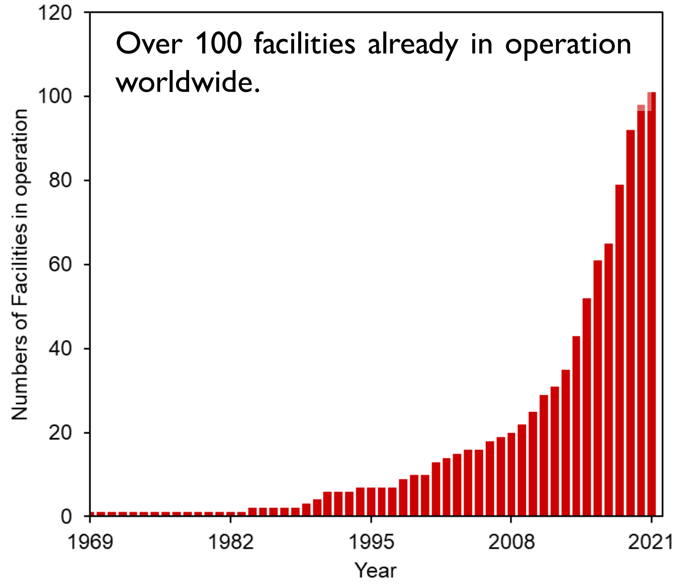


Dose distribution with PT



PT requires no incision and minimizes damage to normal cells owing to the proton depth dose distribution with the Bragg peak.

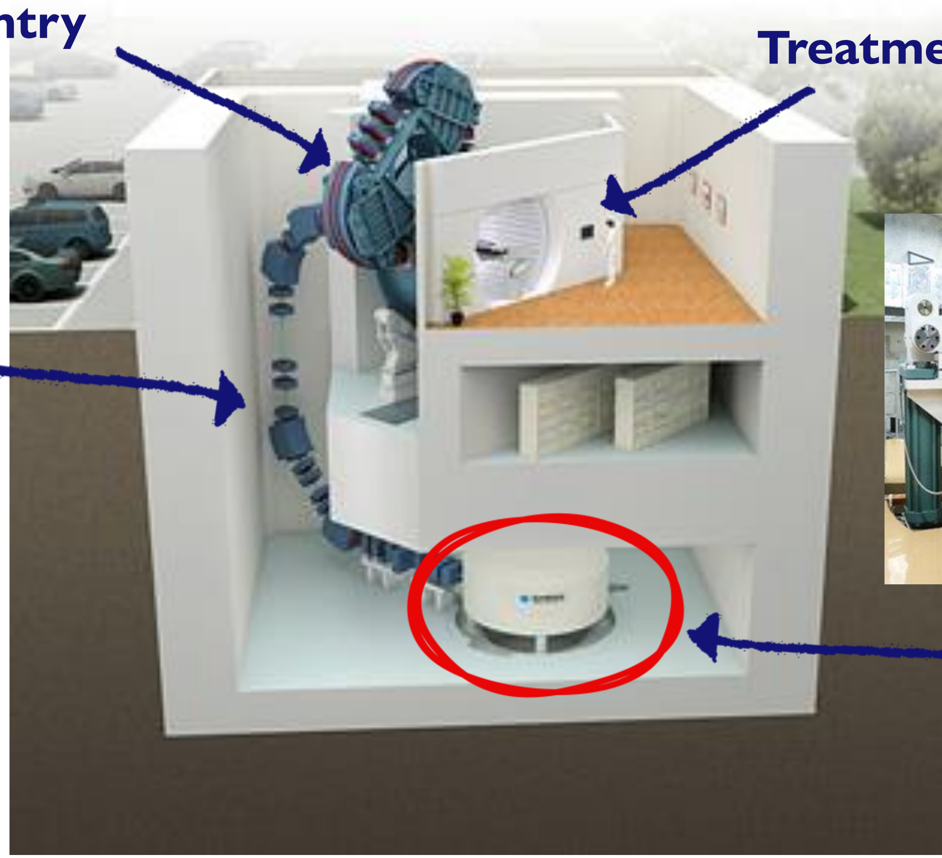
PT facilities



Recently, PT has gained prevalence in cancer treatment.

PT system

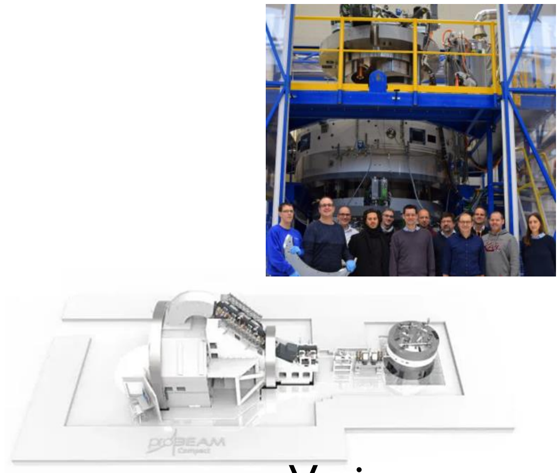
SHI's PT system



The large device size limits its use in hospitals.
Manufacturers have been miniaturized components in recent years.

Commercial SC cyclotrons for PT

- Commercial superconducting(SC) cyclotrons for PT

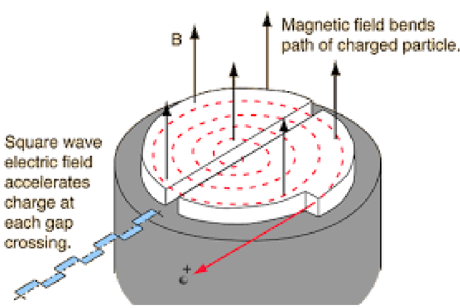


Varian

Mevion

IBA

- A high field by a SC magnet makes the accelerator compact.



$$\rho = \frac{mv}{qB}$$

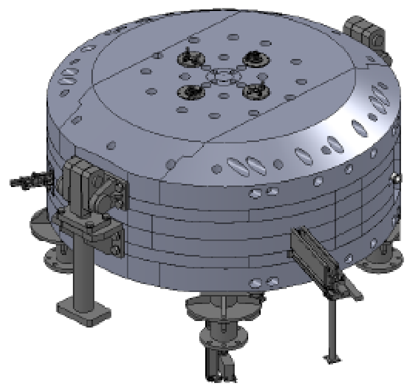
ρ : Radius
B : Magnetic field
m : Mass of particle
v : Velocity
q : Charge

Commercial SC accelerators for PT have successfully developed.

Our new cyclotron SC230

Sumitomo Heavy Industries, Ltd.

- SC230 : Superconducting AVF cyclotron for PT



Conventional model
(P235)

Developed model
(SC230)

Parameters	P235	SC230	Ratio
Weight	220 t	65 t	× 0.3
Power consumption	330 kW	< 200 kW	× 0.6
Maximum beam current	300 nA	1000 nA	× 3.3

SC230 has the characteristics of
“Compact size”, “Energy saving”, “High beam current"

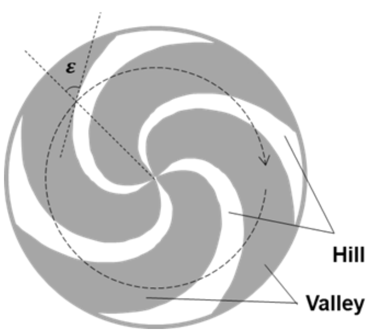
Design of SC230

H. Tsutsui, et al. (2013)

Parameters	Specifications
Type	AVF cyclotron
Particle species	Proton
Beam energy	233 - 238 MeV (Fixed)
Maximum beam current	1000 nA
Beam structure	CW
Extraction radius	0.6 m
Yoke size	Diameter: 2.8m Hight: 1.7 m
Yoke weight	65 t
RF frequency	95.3 MHz (h = 2)
Dee voltage	50 kV (Inside) 75 kV (Outside)
Number of dees	2
RF power	< 70 kW
Total power consumption	< 200 kW

- 4 sectors
  with large spiral angles of max. ~70 degrees.
  with small hill gap of min. ±6mm

$$\nu_z^2 \cong -\frac{r}{B_z}\left(\frac{\partial r}{\partial B_z}\right) + F^2(1+2\tan^2\varepsilon), \qquad F^2 = \frac{(B_h-\bar{B})(\bar{B}-B_v)}{\bar{B}^2}$$



Aiming to realize these concepts,
the design and fabrication of the components proceeded.

Design of SC230

Sumitomo Heavy Industries, Ltd.

H. Tsutsui, et al. (2013)

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Total power consumption	< 200 kW

- RF cavities
  with only two dee
  with low dee voltage of 50-75 kV
- Beam extraction
  using the precessional extraction method (using resonance of $\nu_r = 1$)

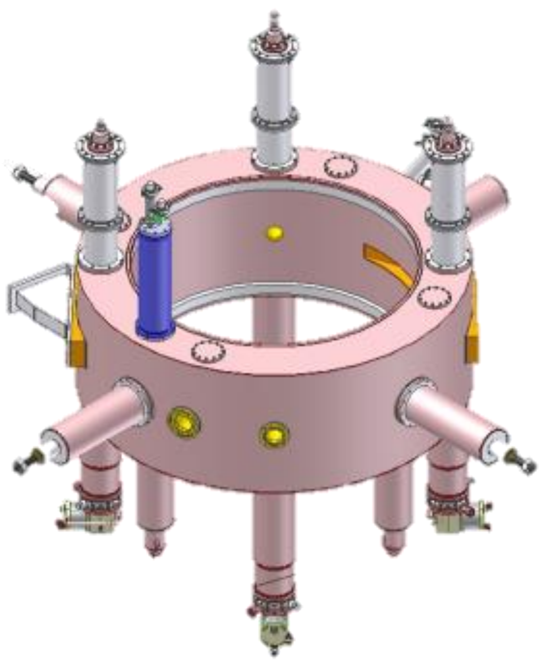
Aiming to realize these concepts,
the design and fabrication of the components proceeded.

Fabricating of components

J. Yoshida, et al. (2019)

- **Cryogen-free NbTi superconducting magnet**

  using conduction cooling method by four 4K-GM cryocoolers



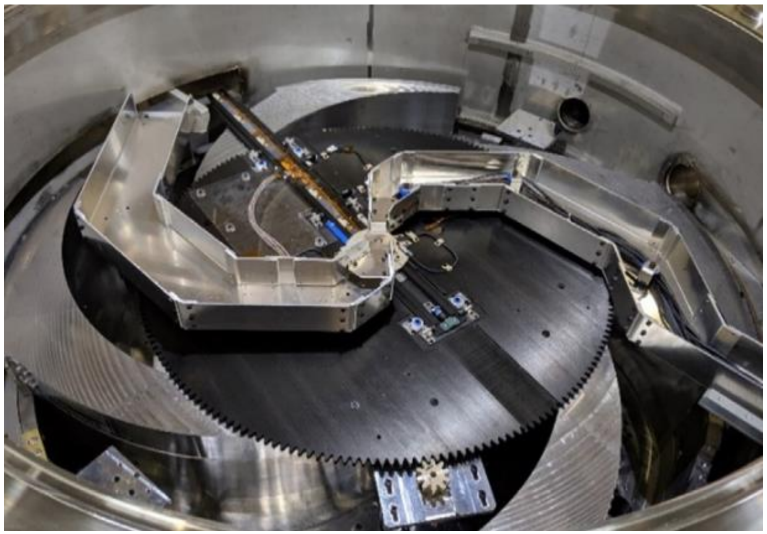
Parameters		Specifications
SC wire 	Material	NbTi/OFC
	Thickness	2.10 mm
	Width	3.40 mm
Coil	Configuration	Two circular coils with axial gap
	Number of turns	2208 Turns/Coil
Coil cooling	method	Conduction cooling
	cryocooler	Four 4K-GM cryocoolers
Coil current		~ 440 A (Max. 488 A)
Coil temperature		4 K
Cooling time from RT		14 days
Stored energy		5.3 MJ
Recovery time from quench		17 hours

A SC magnet with high safety and maintainability has been developed.

Fabricating of components

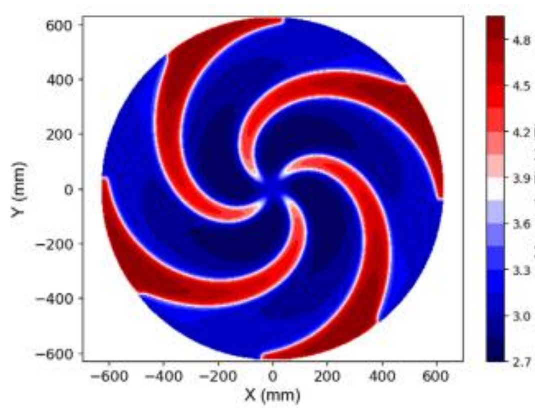
Y. Ebara, et al. (2020)

- **Mapping and field adjustment**

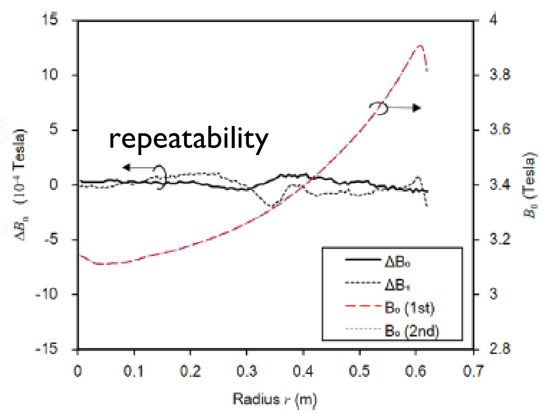


Parameters	Specifications
Sensor type	Hall probes
Number of sensors	6
Type of stages	Linier and rotate stages
Material of stage	CFRP
Actuators	USMs
Measurement points	~52 000
Measurement area	ϕ1,260 mm
Measurement time	2.5 hours
Adjustment methods	Pole machining Shimming Coil centering

Measured field



Isochronous field



Required magnetic field was formed by mapping and adjustment.

Fabricating of components

- **Other components** (Ion source, RF cavity, extraction components, etc.)

Photo of the inside of the SC230

Parameters	Specifications
Type	Hot-cathode PIG
RF cavity	2
RF frequency	95.2 MHz (h=2)
Dee voltage	50 kV (Inside) 75 kV (Outside)
RF power consumption	<70 kW
Extraction components	EHCs, ESD, MCs
Extraction method	Precessional extraction
ESD electric field	1×10^{7} V/m
Pressure	$< 1\times10^{-2}$ Pa

Each components were designed and fabricated under material and space constraints. The required performances were Achieved.

Commissioning

- New test site was constructed.
- Transportation and assembly of SC230 were completed in 2020.
- Commissioning was started at the end of 2020.

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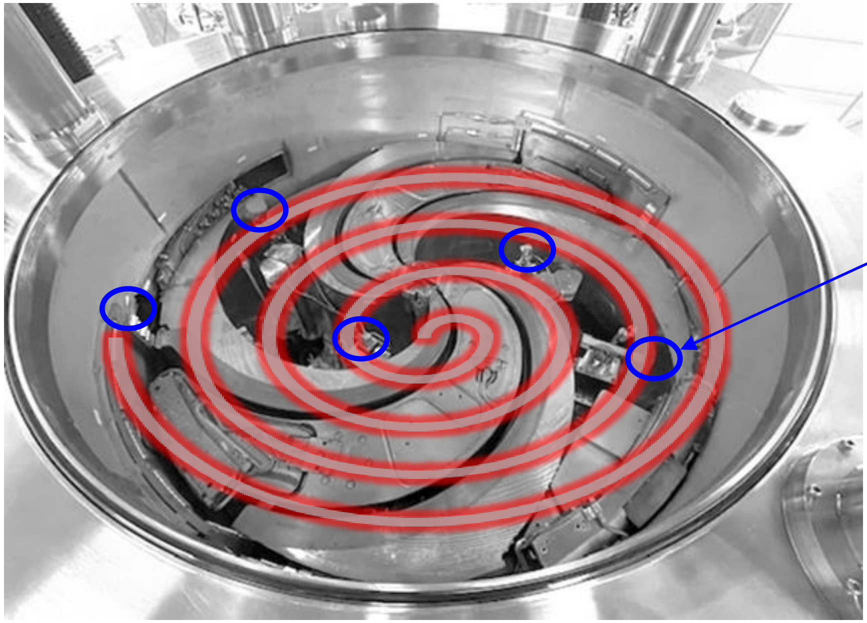
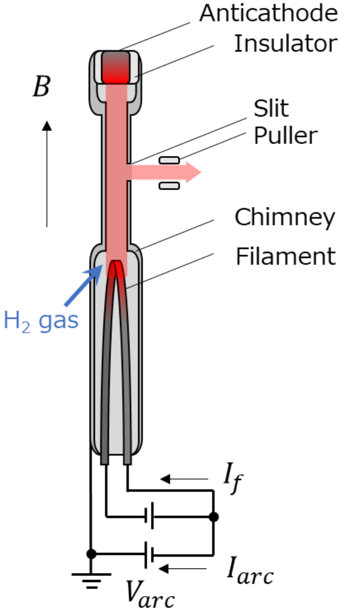
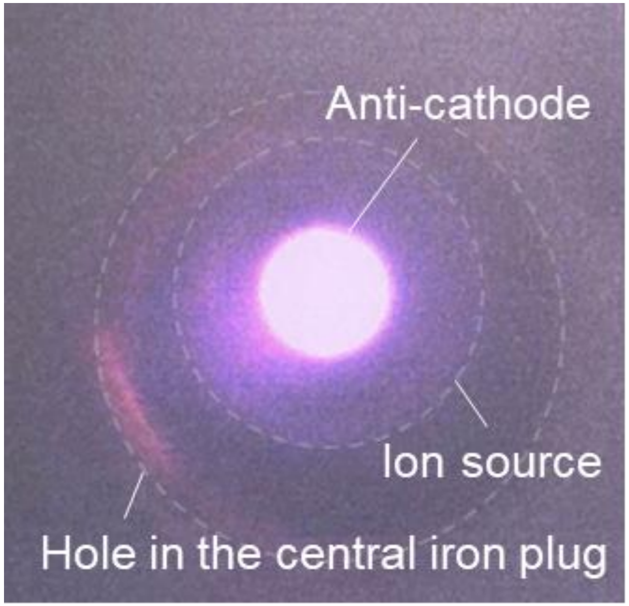


During commissioning, probes installed at each radius were used to check beam conditions, and parameters were adjusted.

Commissioning : “Central region”



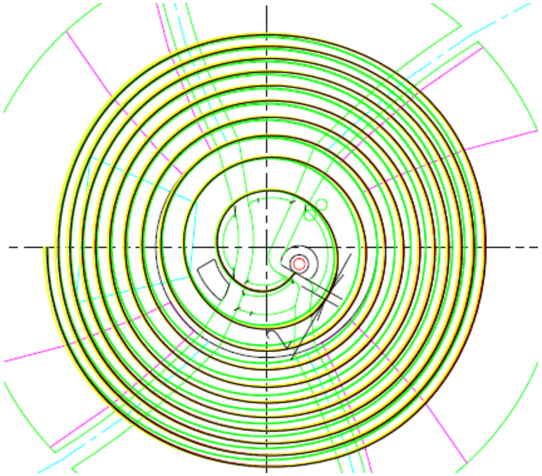


Parameters of the ion source were adjusted.

Commissioning : "Central region"

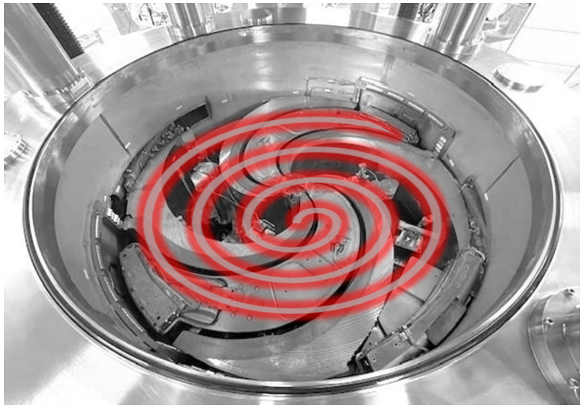
Beam mark
on the center electrode

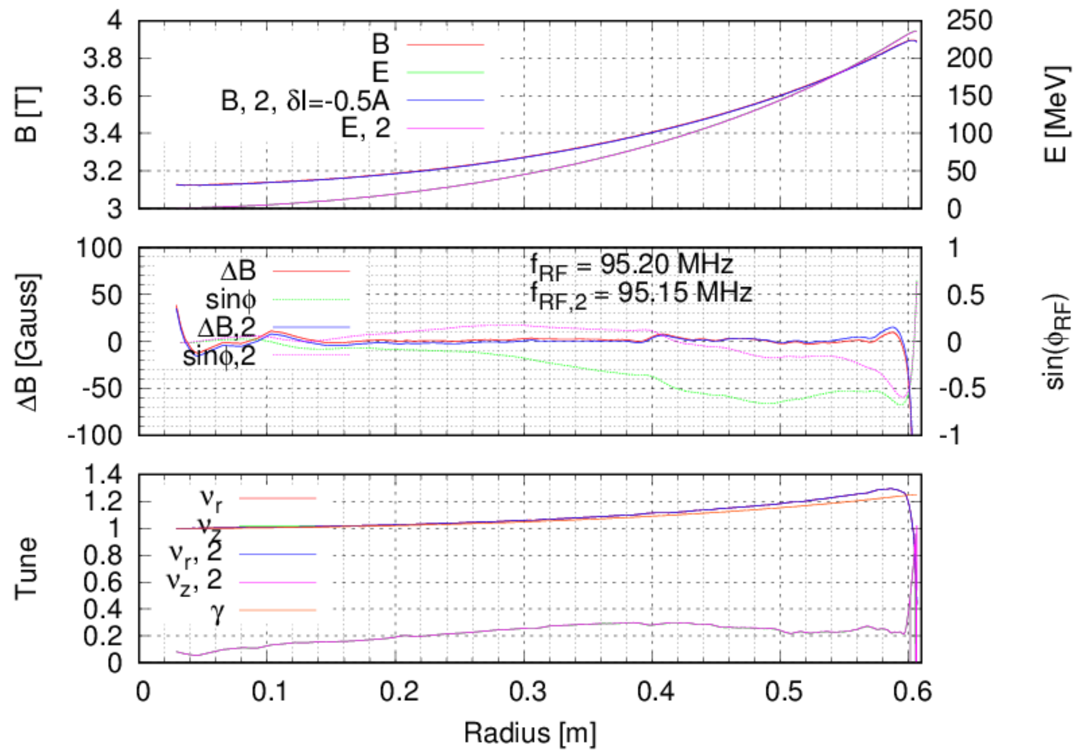
Calculated trajectory
of the central region



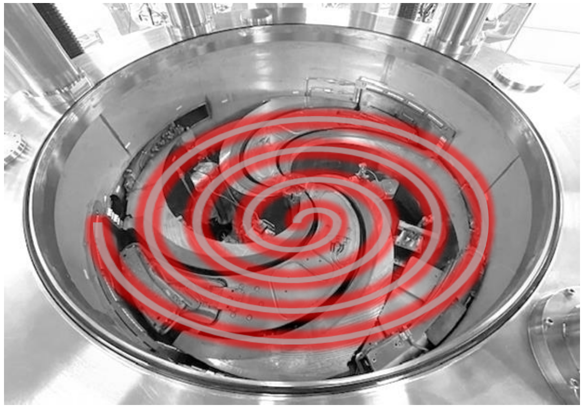
Parameters of the ion source were adjusted.

Commissioning : "Isochronous region"



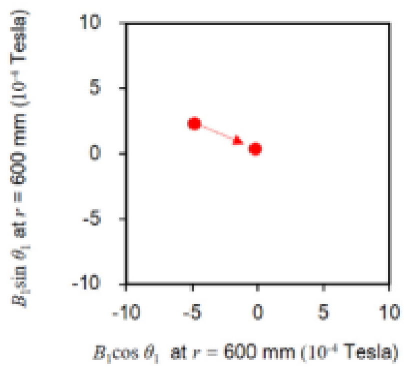


Fortunately, it was confirmed to pass through the isochronous region without any adjustment.



B_{z1} tuning

Coil centering



EHCs tuning

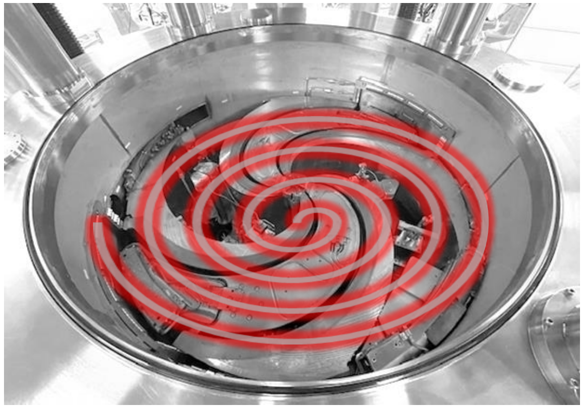
X-EHCs current (A) / Y-EHCs current (A)

Y \ X	-40	-20	0	20	40
-40			0.90	0.94	
-20			0.95	0.94	0.88
0	0.87	0.87	0.94	1.00	0.92
20	0.81	0.84	0.95	0.94	0.94
40	0.83	0.81	0.97	0.94	0.91

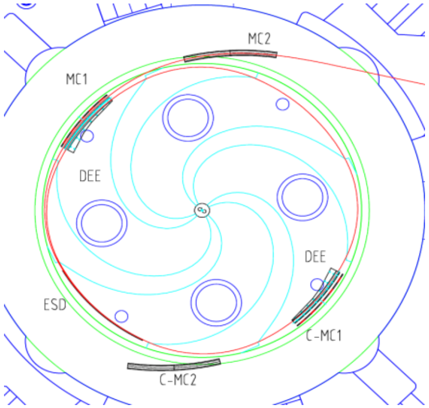
The beam was extracted by adjusting
Coil position, CHCs, EHCs, Deflector etc.

Commissioning : "Extraction region"

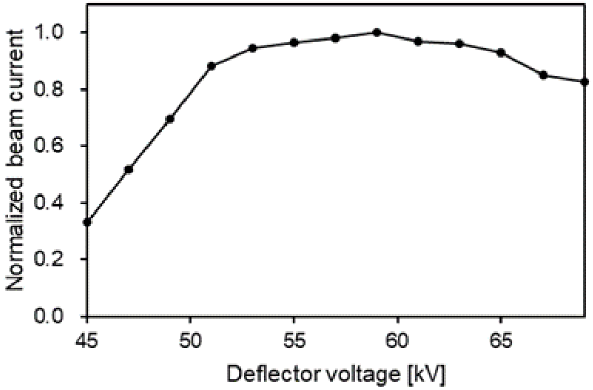
Sumitomo Heavy Industries, Ltd.



Beam extraction components



Deflector tuning

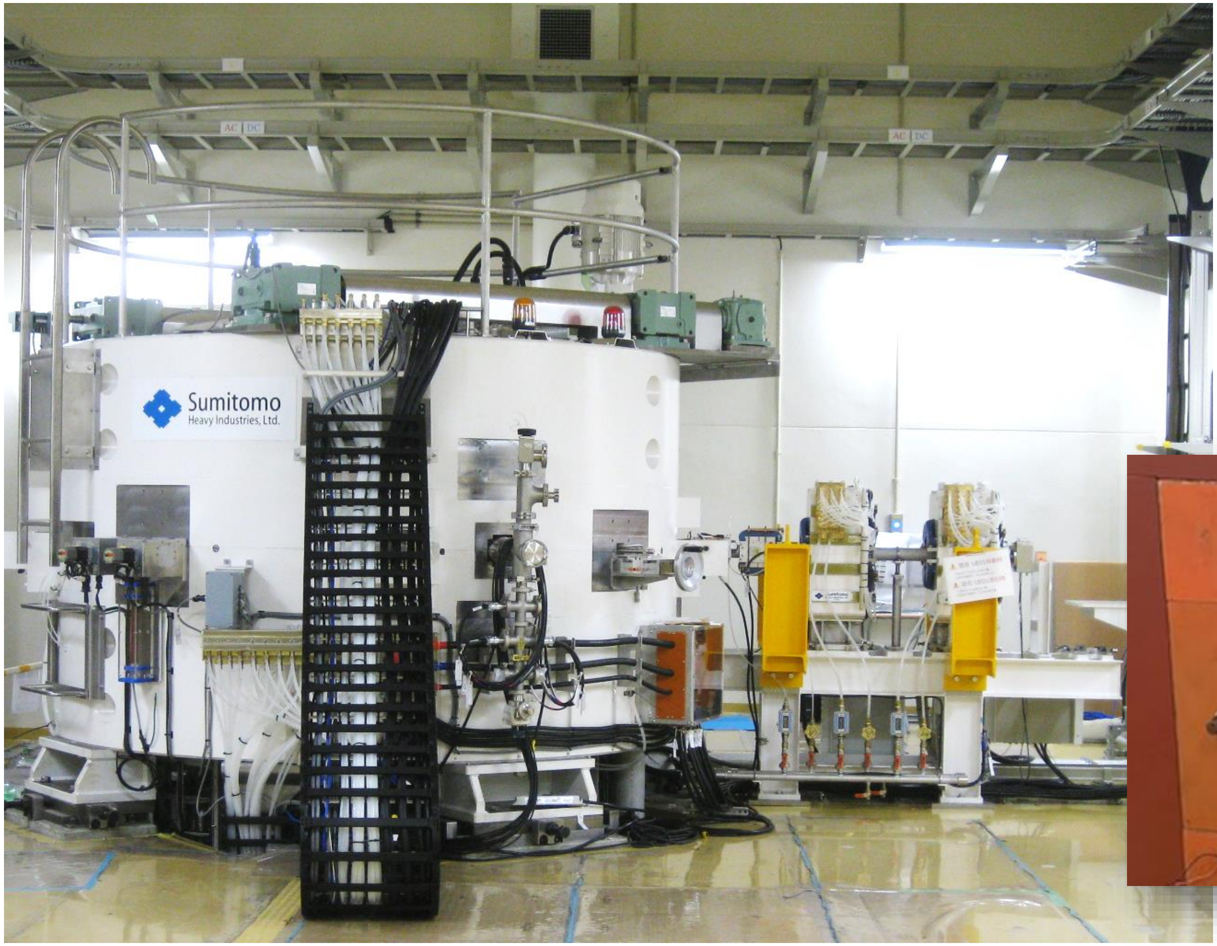


The beam was extracted by adjusting Coil position, CHCs, EHCs, Deflector etc.

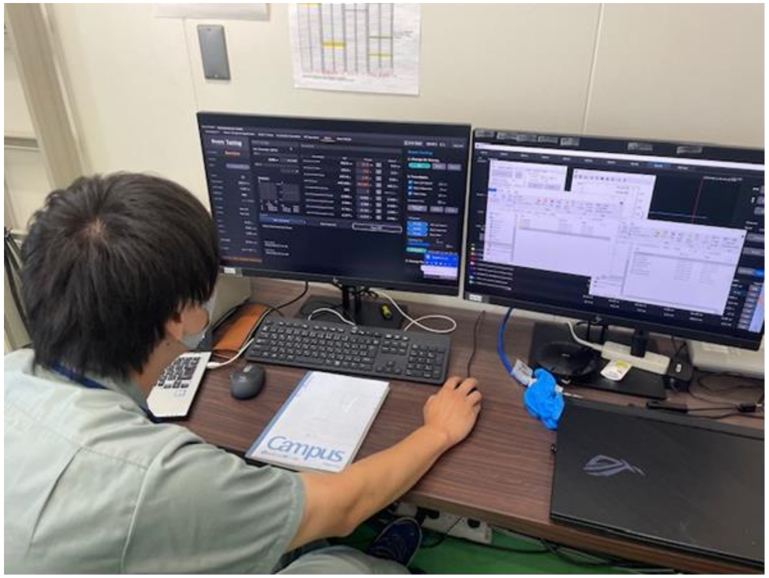
Commissioning : First beam observation

Sumitomo Heavy Industries, Ltd.

- **First beam was observed in Jul. 2021.**



Commissioning



Commissioning : Beam status

Sumitomo Heavy Industries, Ltd.

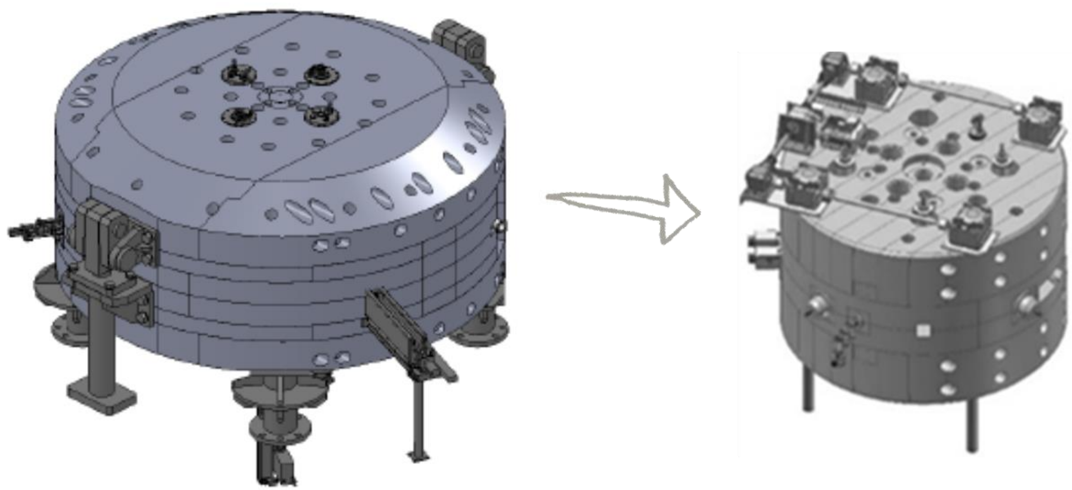
- **A parameter set that satisfies the required beam was found.**

Parameters	Specifications	Pass/Fail
Max. beam current	1000 nA	✓ Pass
Beam energy	233-238 MeV	✓ Pass
Energy repeatability	< 0.2 MeV	✓ Pass
Extraction efficiency	≥ 60%	✓ Pass
Min. controllable beam current	< 1 nA	✓ Pass
Ripple current	≦ 2 % (1σ)	✓ Pass
Beam current stability	≦ 1 % (1σ) for 2 min.	✓ Pass
Beam responsivity	≦ 50 μsec	✓ Pass
Beam position stability	< ±0.1 mm for 2 min.	✓ Pass
RMS emittance	< 2.2 μm (x) < 1.4 μm (y)	✓ Pass
Total power consumption in operation	< 200 kW	✓ Pass

A beam that satisfies all required specifications was obtained.

Commissioning

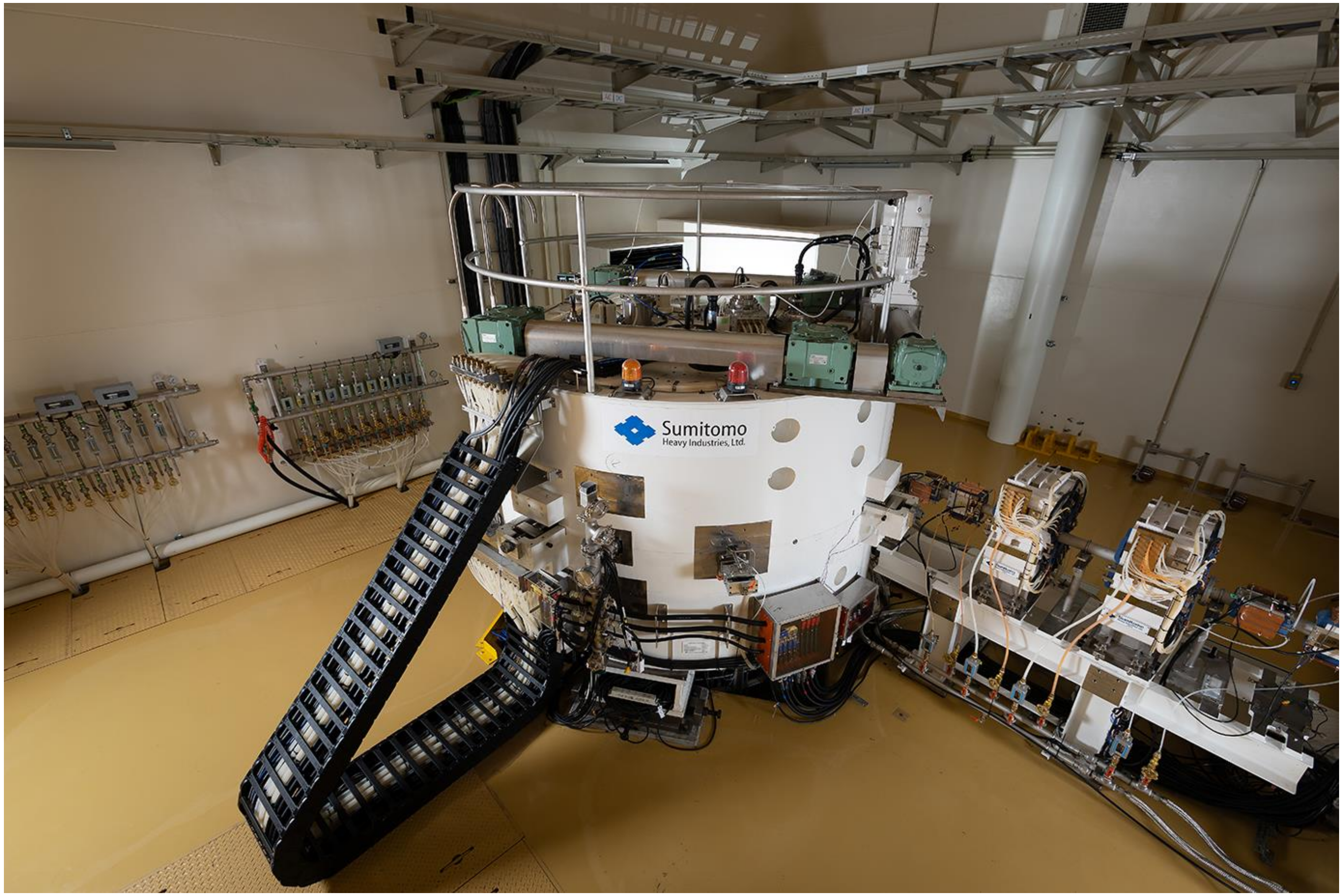
- **Commissioning completed in Nov. 2021.**



Parameters	P235	SC230	Ratio	Pass/Fail
Weight	220 t	65 t	× 0.3	✓ Pass
Power consumption	330 kW	< 200 kW	× 0.6	✓ Pass
Maximum beam current	300 nA	1000 nA	× 3.3	✓ Pass

Commissioning

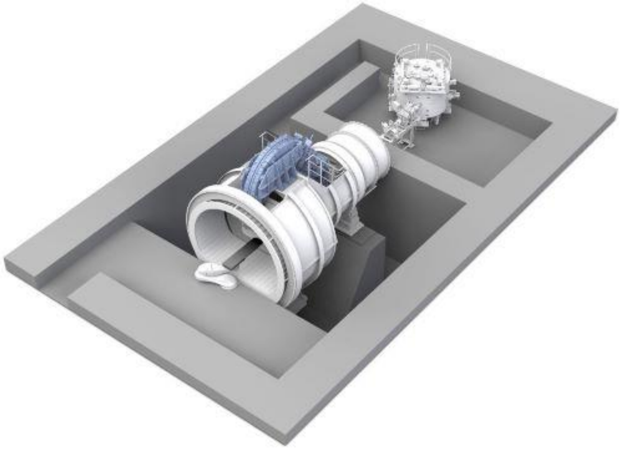
- Commissioning completed in Nov. 2021.



Conclusion

- SC230 is a superconducting AVF cyclotron, which features the compact size weighing 65 tons, high current beam of 1μA, low energy consumption less than 200 kW.
- It was developed and the commissioning was completed in 2021.

Next-generation proton beam therapy system using SC230



SC AVF cyclotron SC230 for PT has been developed.
It is expected to contribute to PT in the near future.

➢ Press release on December 1, 2022

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News

TOP > News - Fiscal 2022 > SHI receives first order for next-generation proton therapy system from Taichung Veterans General Hospital

Products

SHI receives first order for next-generation proton therapy system from Taichung Veterans General Hospital

December 01, 2022

Share tweet

Sumitomo Heavy Industries, Ltd. (head office: Shinagawa City, Tokyo; President and CEO: Shinji Shimomura; hereinafter "SHI") has received an order from Taichung Veterans General Hospital (Taiwan) for a next-generation proton therapy system (*). The next-generation system will be installed at a new proton therapy center to be established in Taichung City, Taiwan, and proton therapy is scheduled to begin in 2026. This is the first order for SHI's next-generation system.
With the aim of realizing societies where people can live long and healthy, SHI will continue to contribute to cancer treatment in the East Asian region, including Taiwan.

[Taichung Veterans General Hospital]
Taichung Veterans General Hospital is a national hospital located in central Taiwan and provides safe and high-quality medical services with new medical technologies and outstanding talents. Taichung Veterans General Hospital plans to conduct research on new treatment technologies, such as FLASH, in collaboration with SHI.

[Next-generation proton therapy system]
The next-generation proton therapy system to be introduced is a multi-room type and will accommodate two treatment rooms equipped with rotating gantries and one

Thank you