NIRS HIMAC

Compact carbon-ion gantry development in Japan

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QST

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Outline

- Introduction
- Gantry development
  - Design
  - Construction
  - Beam commissioning
- Future plans
- Summary

Introduction

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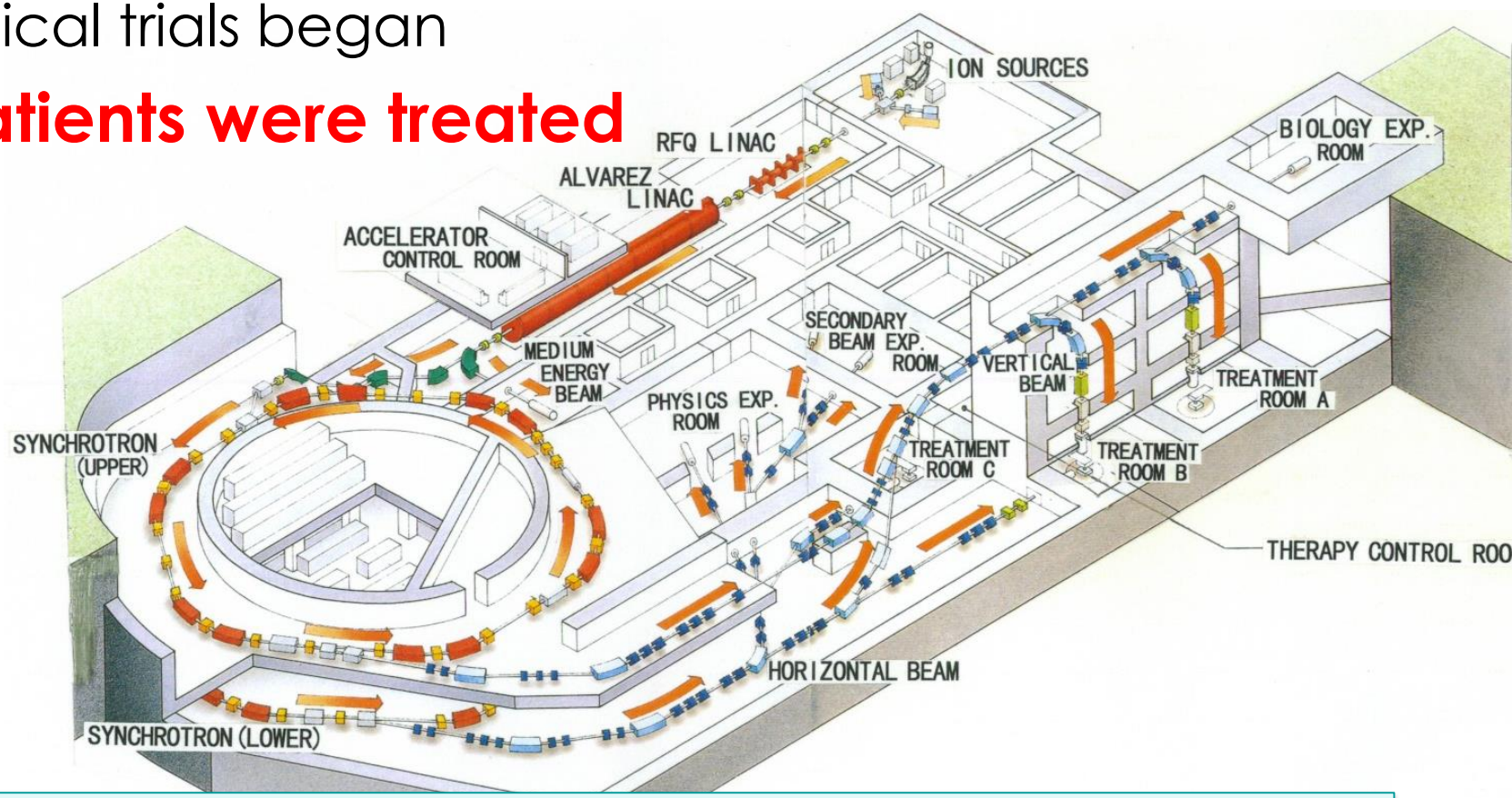
World-first heavy-ion medical accelerators

- **HIMAC (Heavy Ion Medical Accelerator in Chiba)**
  - 1987: Construction began
  - 1994: Clinical trials began
- **>11,000 patients were treated**



HIMAC can accelerate heavy ions having q/m=1/2 up to E/A=800 MeV

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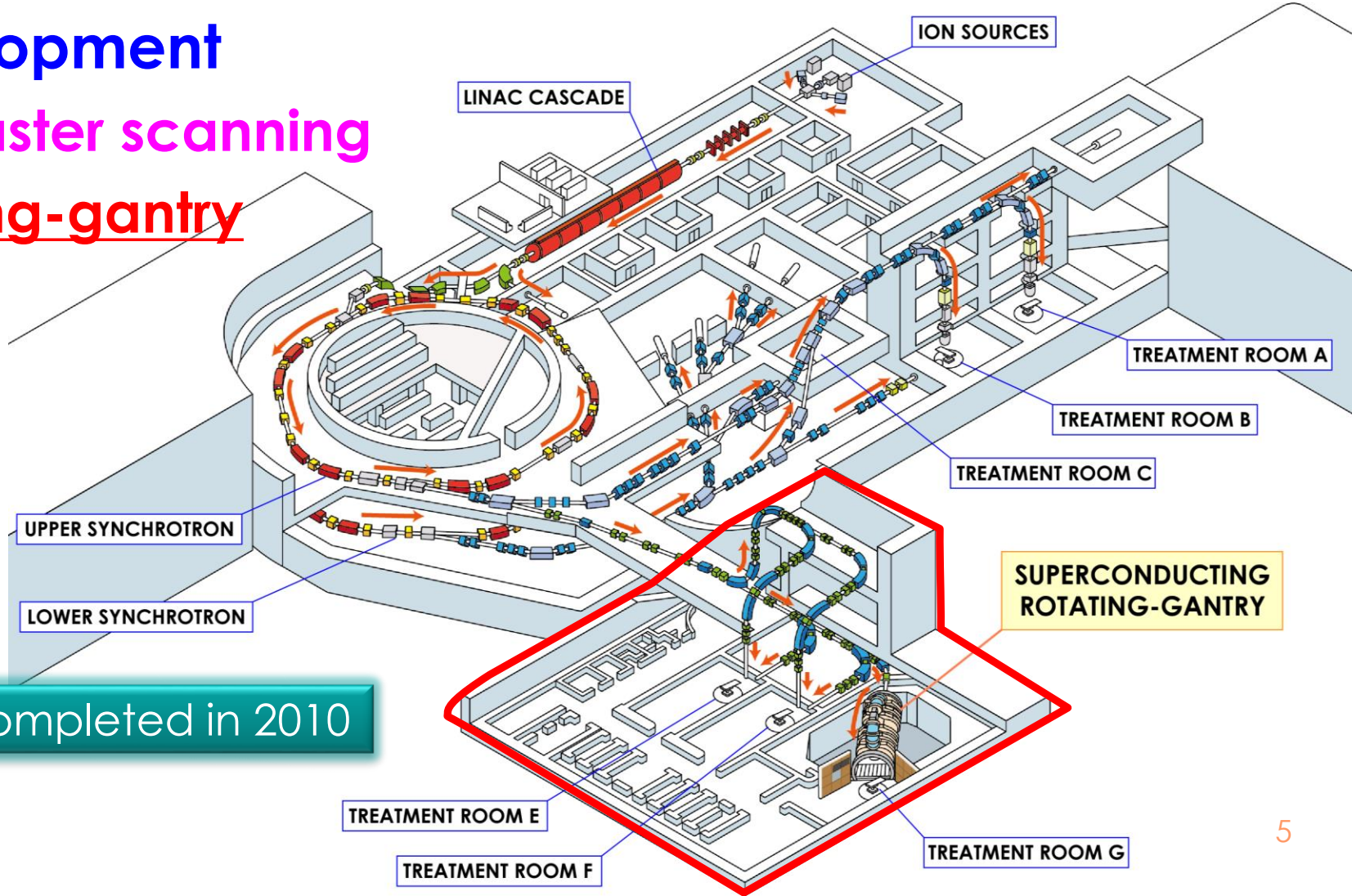
New treatment facility

- 3 treatment rooms
- New development
  - Fast 3D raster scanning
  - SC rotating-gantry



Construction completed in 2010

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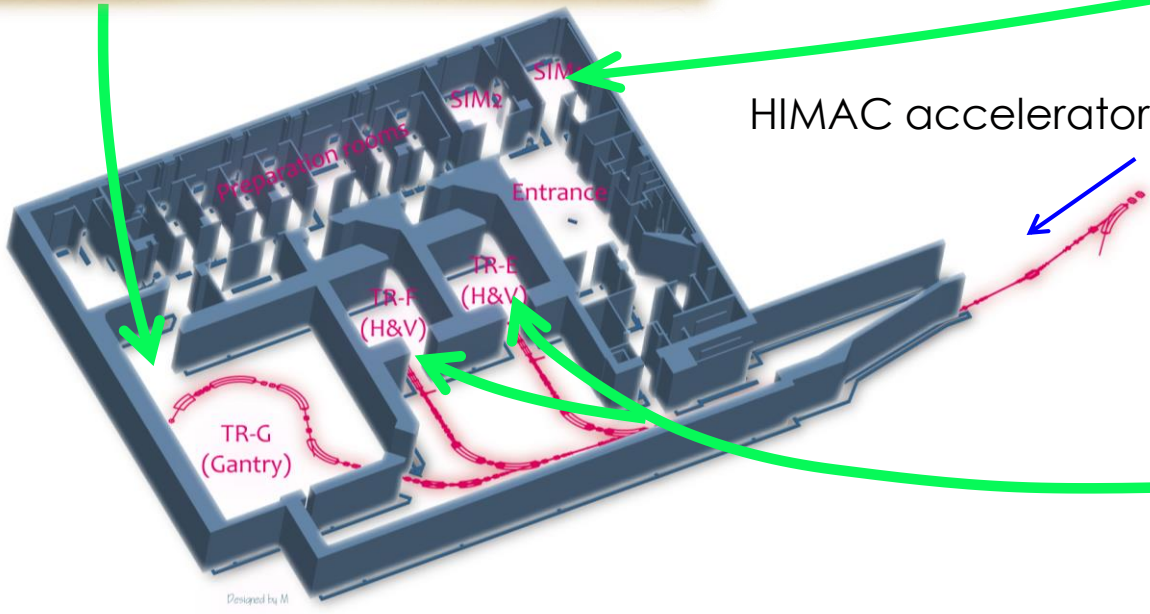
Treatment floor (B2F)

Room G

CT Simulation room



HIMAC accelerators

Room E & F

Gantry development

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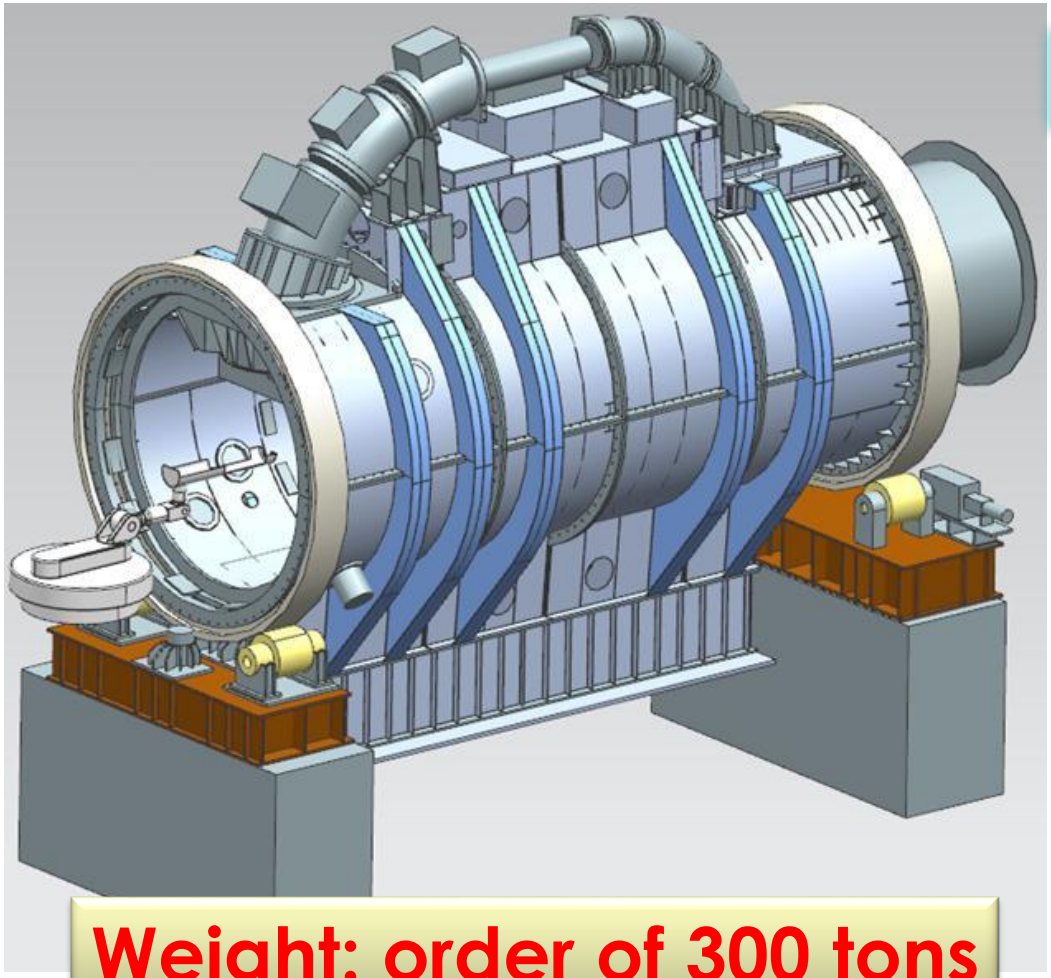
Superconducting rotating-gantry



Weight: order of 300 tons

Use of superconducting (SC) magnets

Ion kind	: ^{12}C
Irradiation method	: 3D Scanning
Beam energy	: 430 MeV/n
Maximum range	: 30 cm in water
Beam orbit radius	: 5.45 m
Length	: 13 m

The size and weight are considerably reduced

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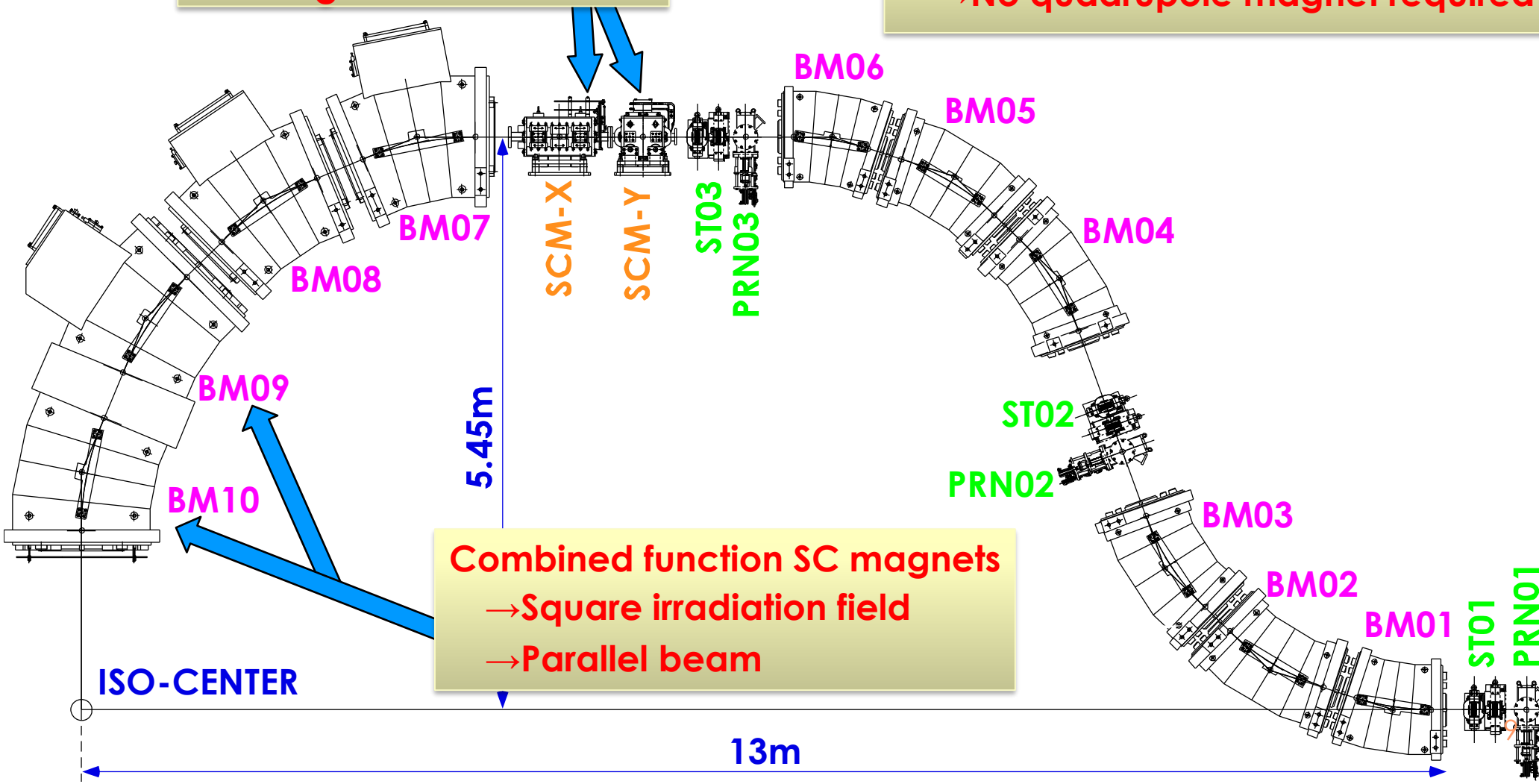
Layout of the SC gantry

Scanning magnets on top
→Large scan size

Combined function SC magnets
→No quadrupole magnet required



Combined function SC magnets
→Square irradiation field
→Parallel beam

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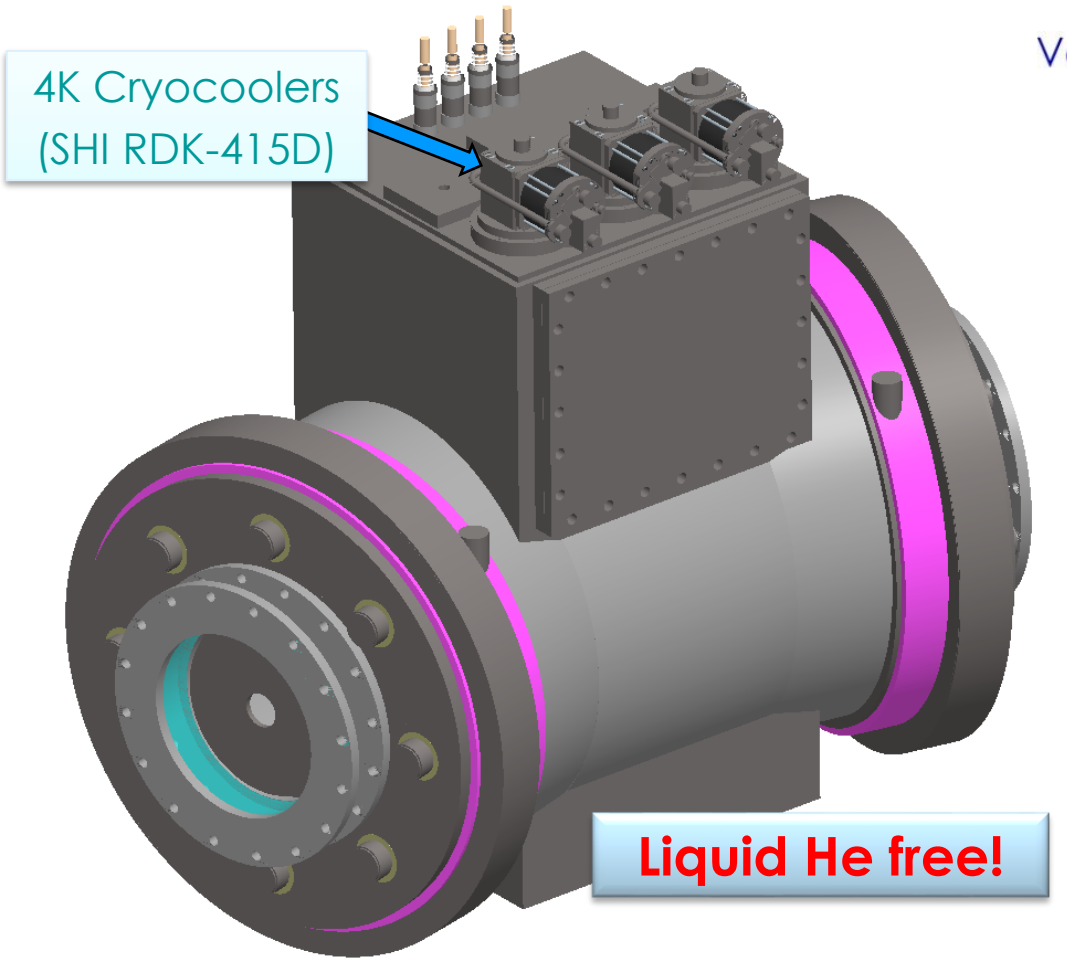
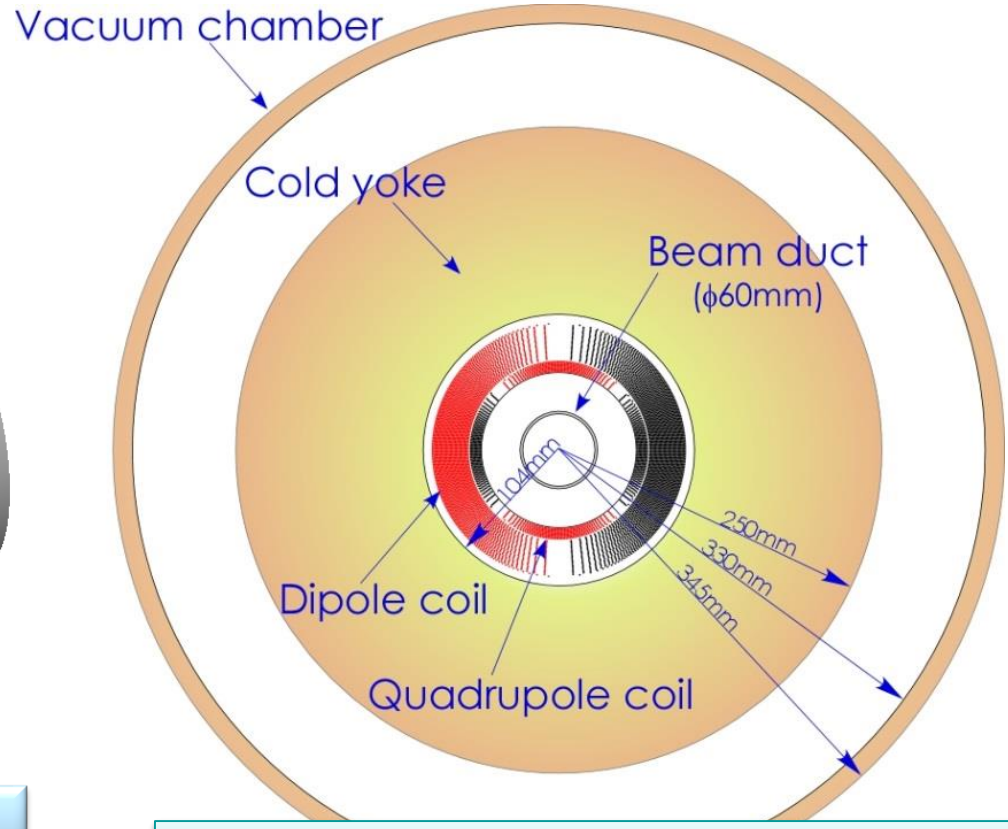
Curved SC magnets for gantry

SC magnet (BM02-05)



Liquid He free!

Cross-sectional view



Dipole and quadrupole coils can be independently excited

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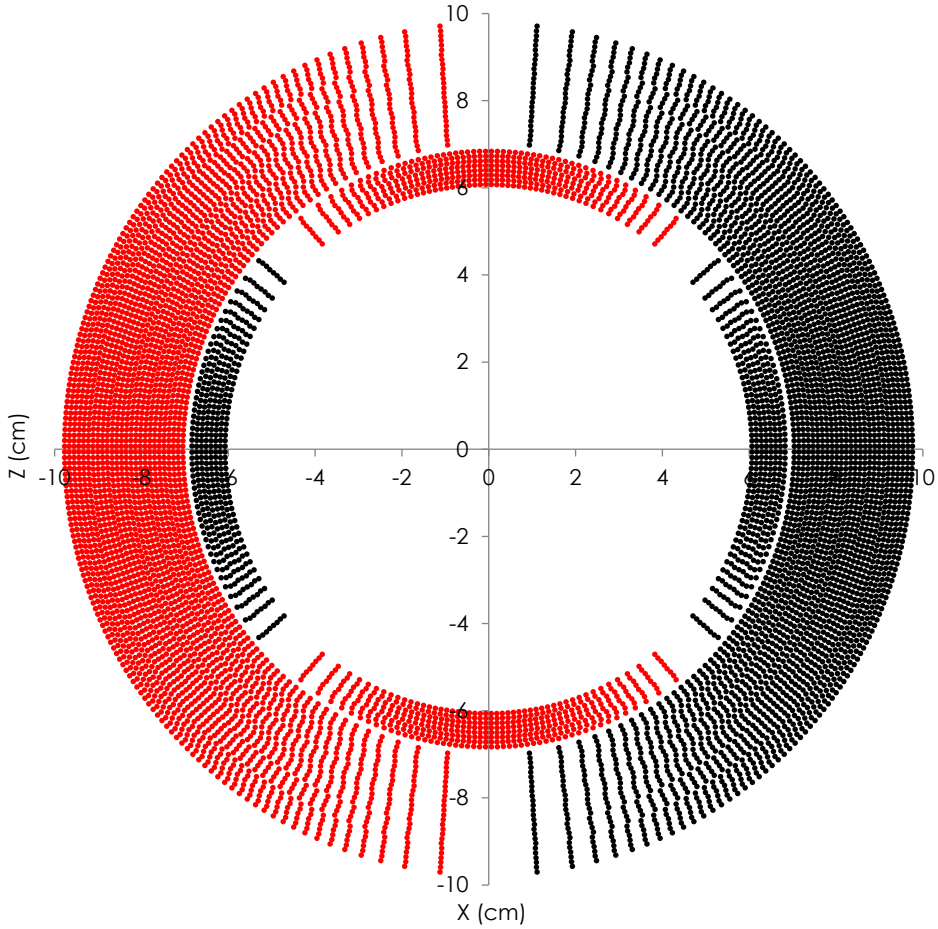
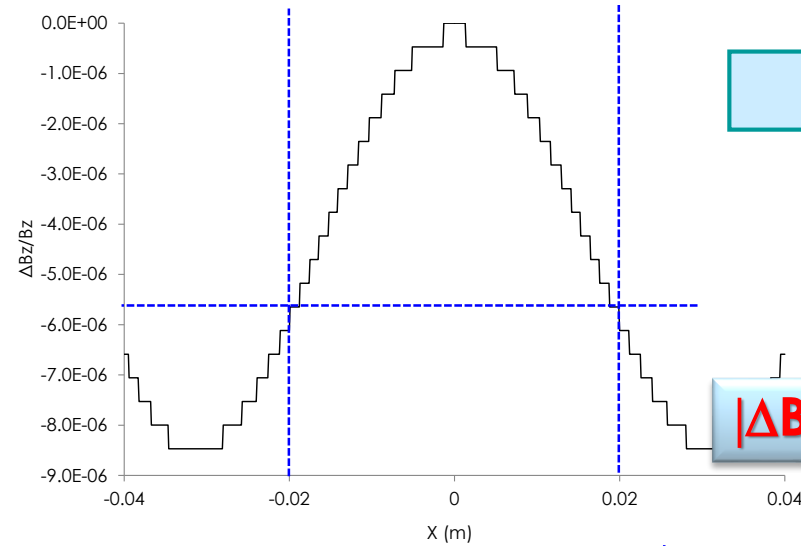
Design of SC coils

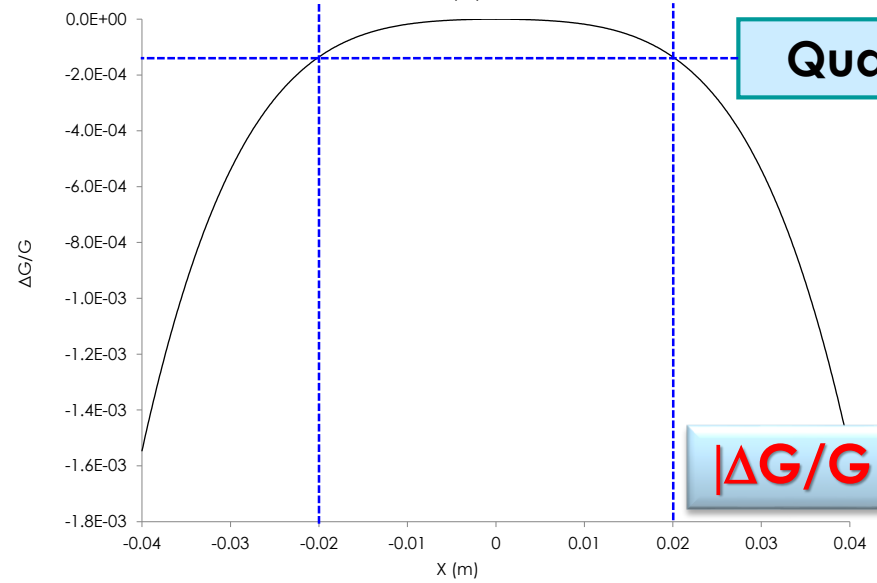
2D field calculation





Dipole

$|\Delta B/B| < 6 \times 10^{-6}$



Quadrupole

$|\Delta G/G| < 2 \times 10^{-4}$

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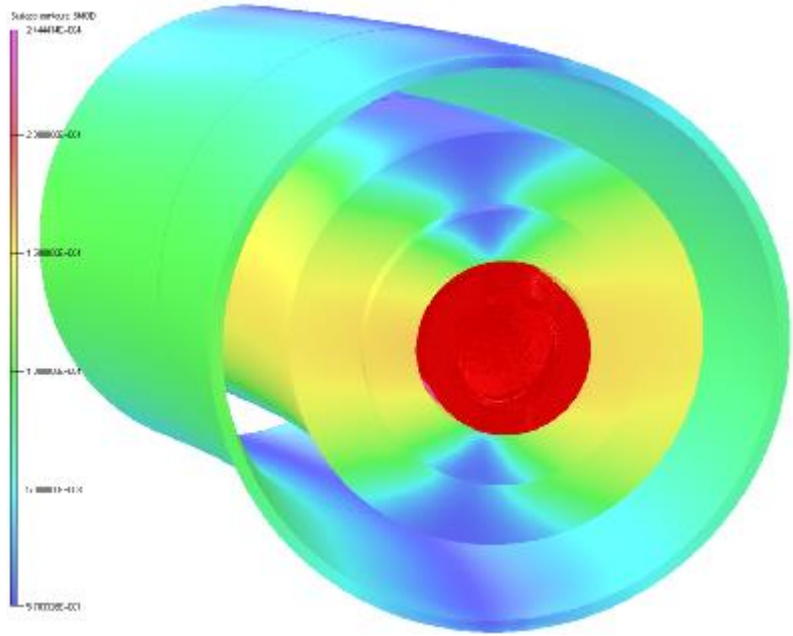
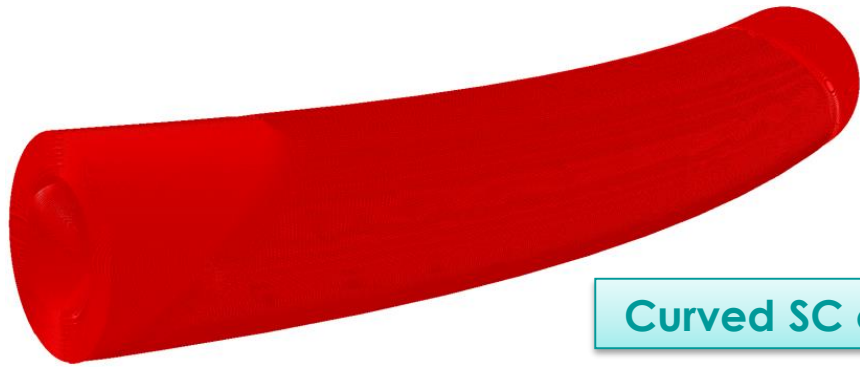
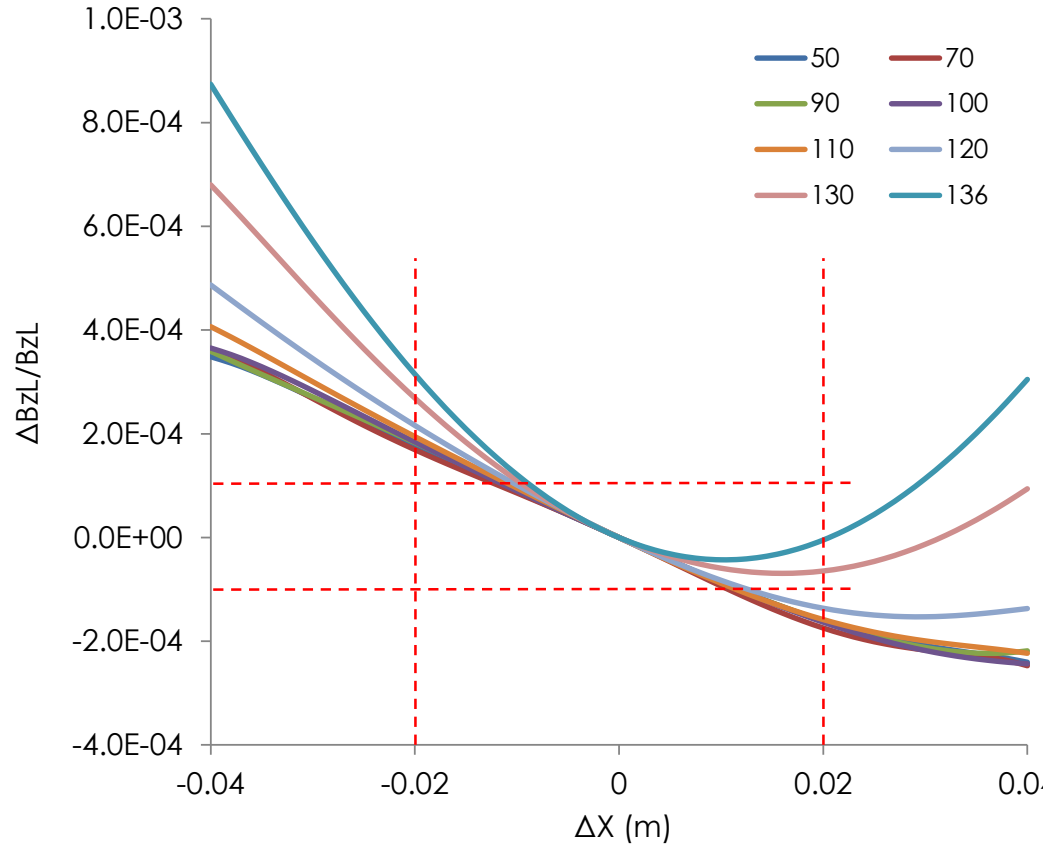
3D field calculation with Opera-3d

SC coils were precisely modelled





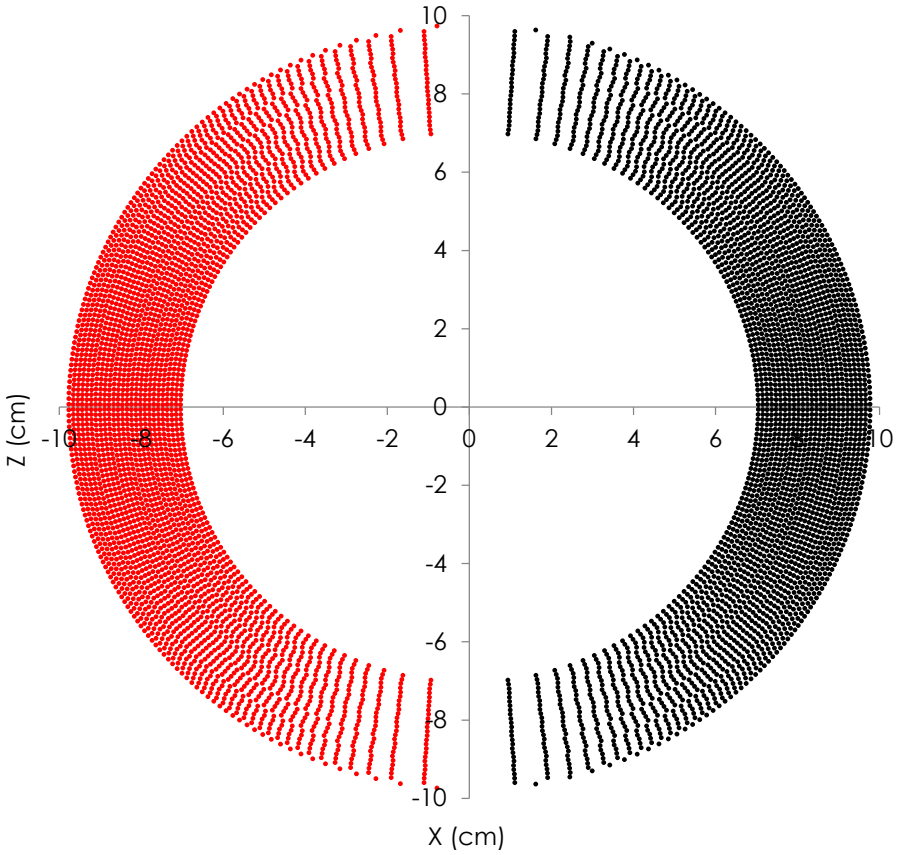
Curved SC coil



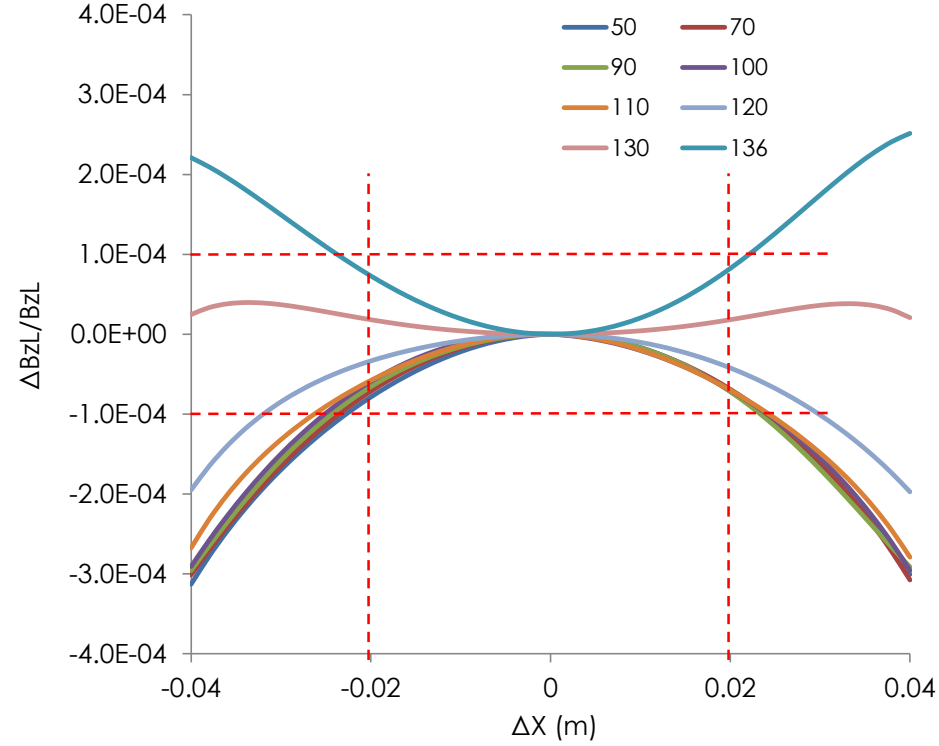
$|\Delta BL/BL| < 4\times10^{-4}$

Corrections with the outermost layer

Coil positions of the outermost layer were modified to cancel out the measured multi-pole components



Corrected uniformity



$|\Delta BL/BL| < 1 \times 10^{-4}$!

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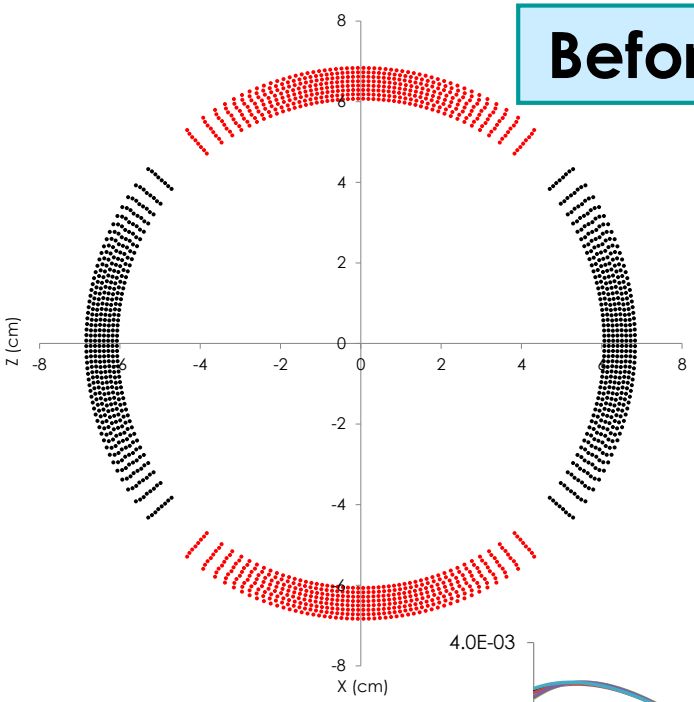
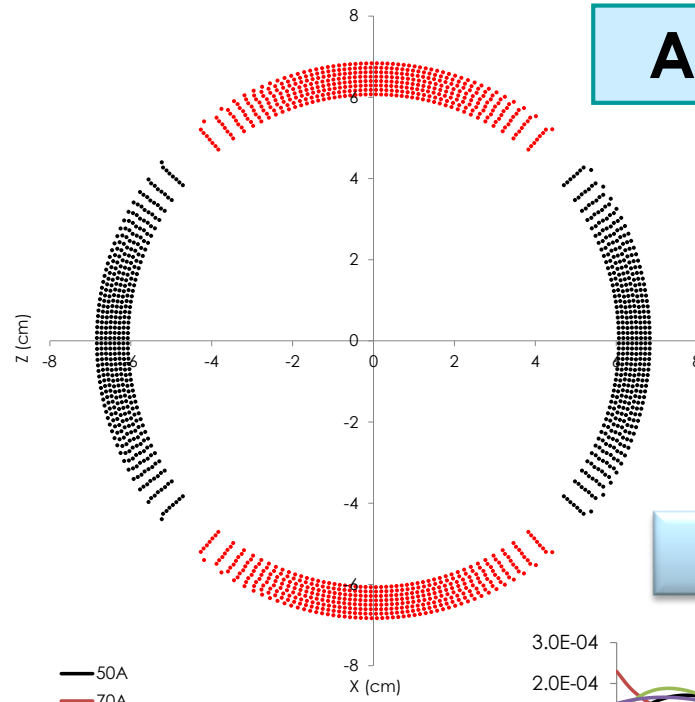
Design of the quadrupole coil

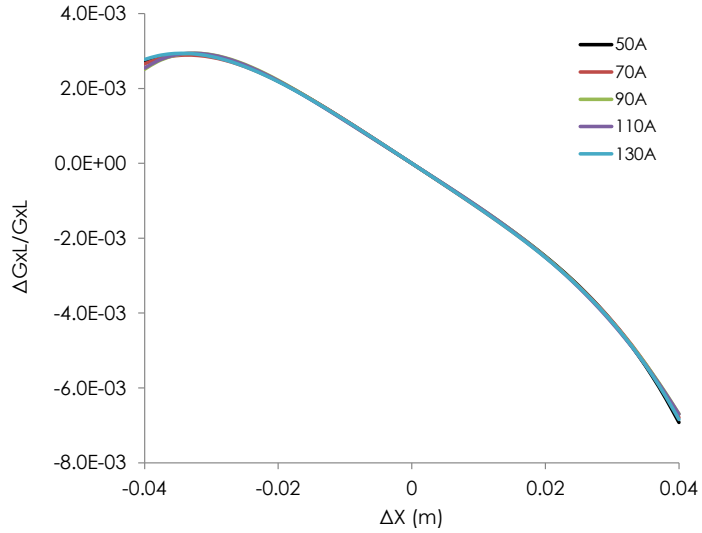
Before

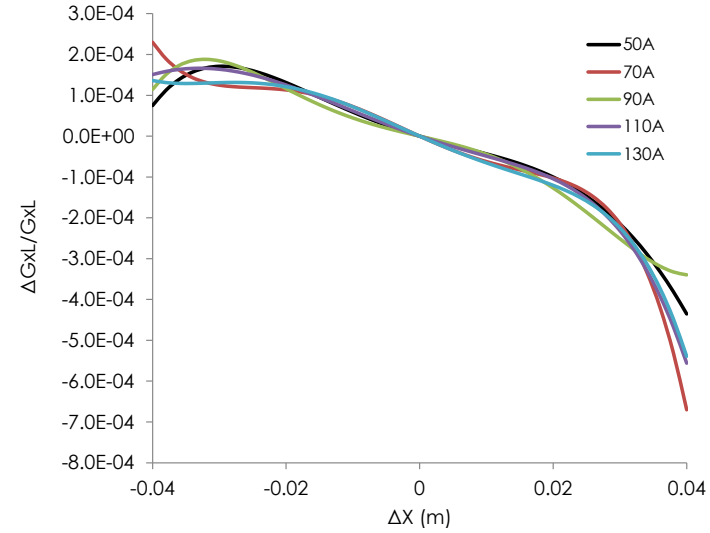


After



ΔGL/GL<2×10^{-4}!





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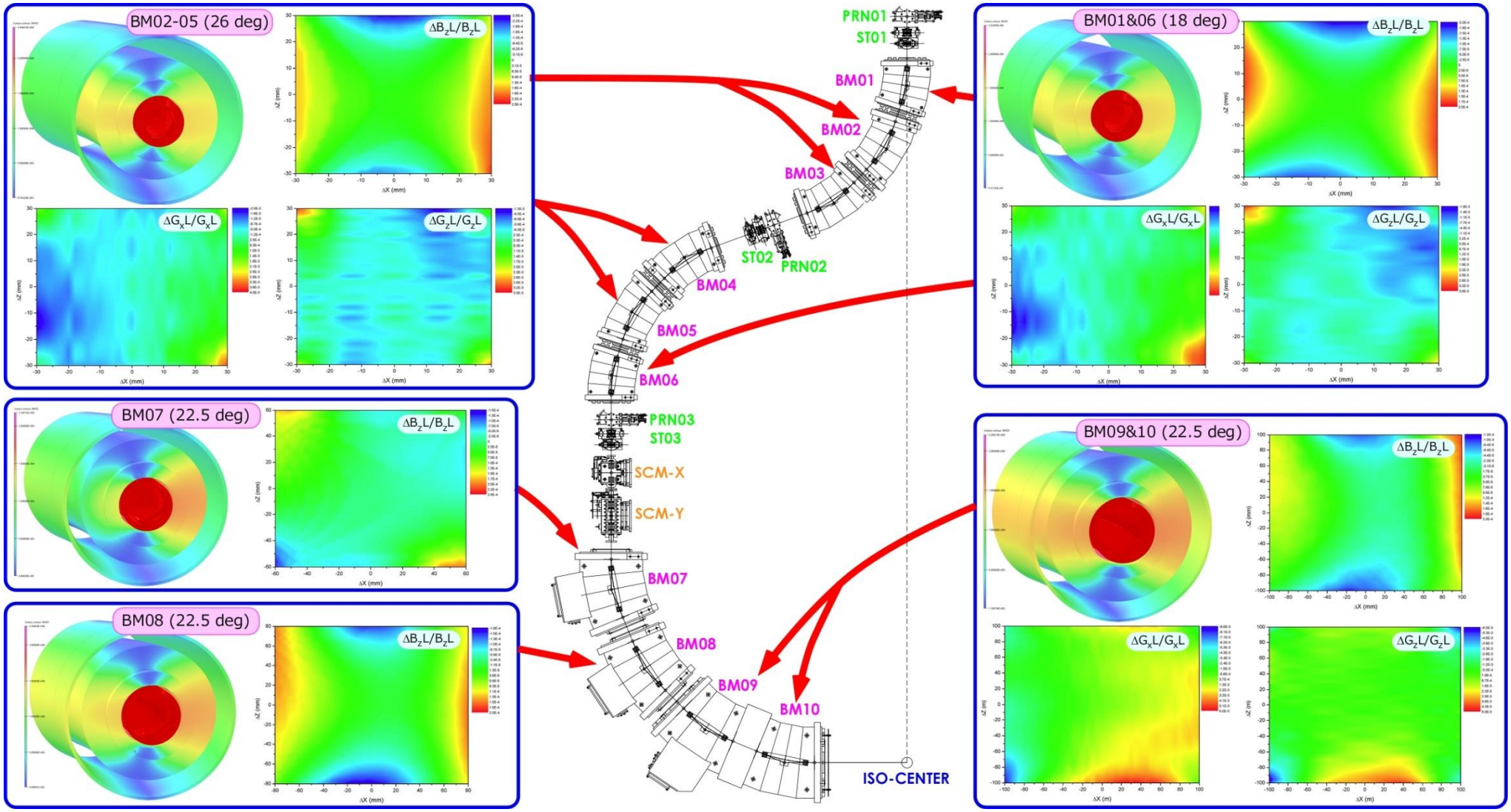
Design of SC magnets

All the SC magnets were designed by using a 3D magnetic field solver



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Specifications of SC magnets

Parameters	Symbol	Unit	BM01	BM02	BM03	BM04	BM05	BM06	BM07	BM08	BM09	BM10
Type	–	–	Superconducting sector magnet									
Coil	–	–	Dipole+Quard.						Dipole		Dipole+Quard.	
Bending angle	θ	deg	18	26				18	22.5			
Bending radius	ρ	m	2.3						2.8			
Max. field	B_{dipole}	T	2.88						2.37			
Max. field gradient	G_{max}	T/m	9.1						–		1.3	
Bore size	D_{bore}	mm	ϕ60						□122	□170	□206	
Effective radius or effective area	D_f or A_f	mm	ϕ40						□120	□160	□200	
Uniformity (dipole)	ΔBL/BL	–	$\pm 1\times10^{-4}$									
Uniformity (quad.)	ΔGL/GL	–	$\pm 1\times10^{-3}$									
Inductance (dipole)	L	H	6.2	9.1				6.2	5.2	8.9	12	
Stored Energy (dipole)	P	kJ	57	84				57	133	225	319	

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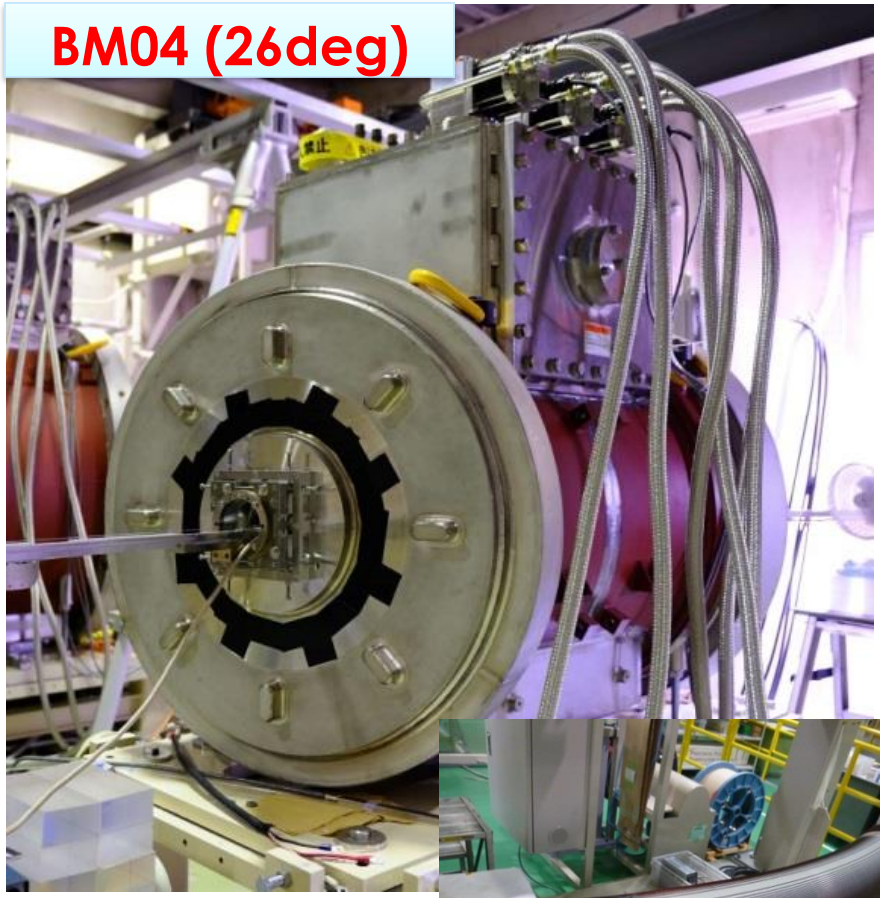
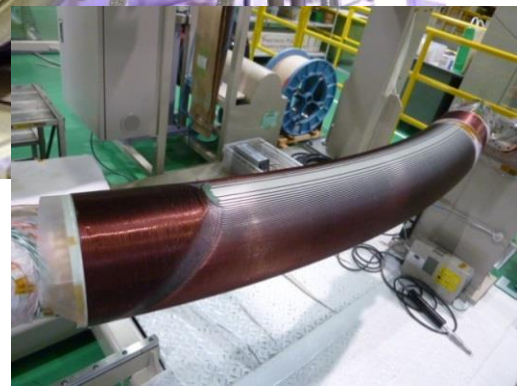
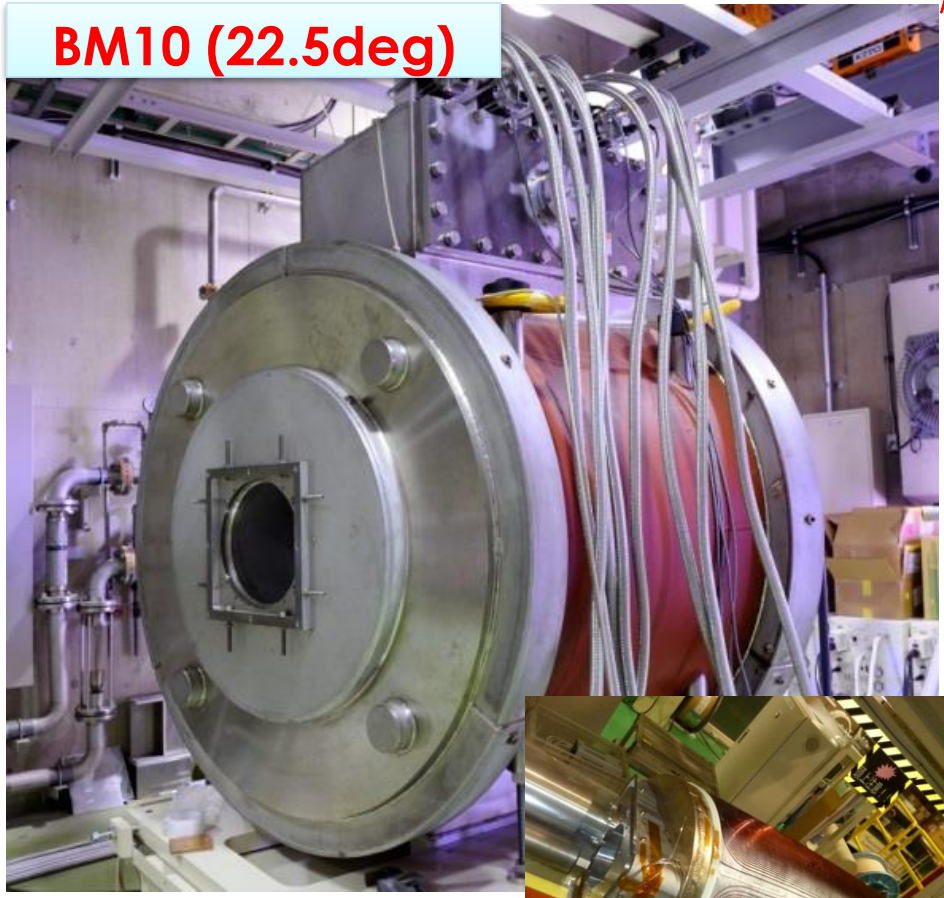
Construction of SC magnets

BM04 (26deg)





BM10 (22.5deg)



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Construction of structure

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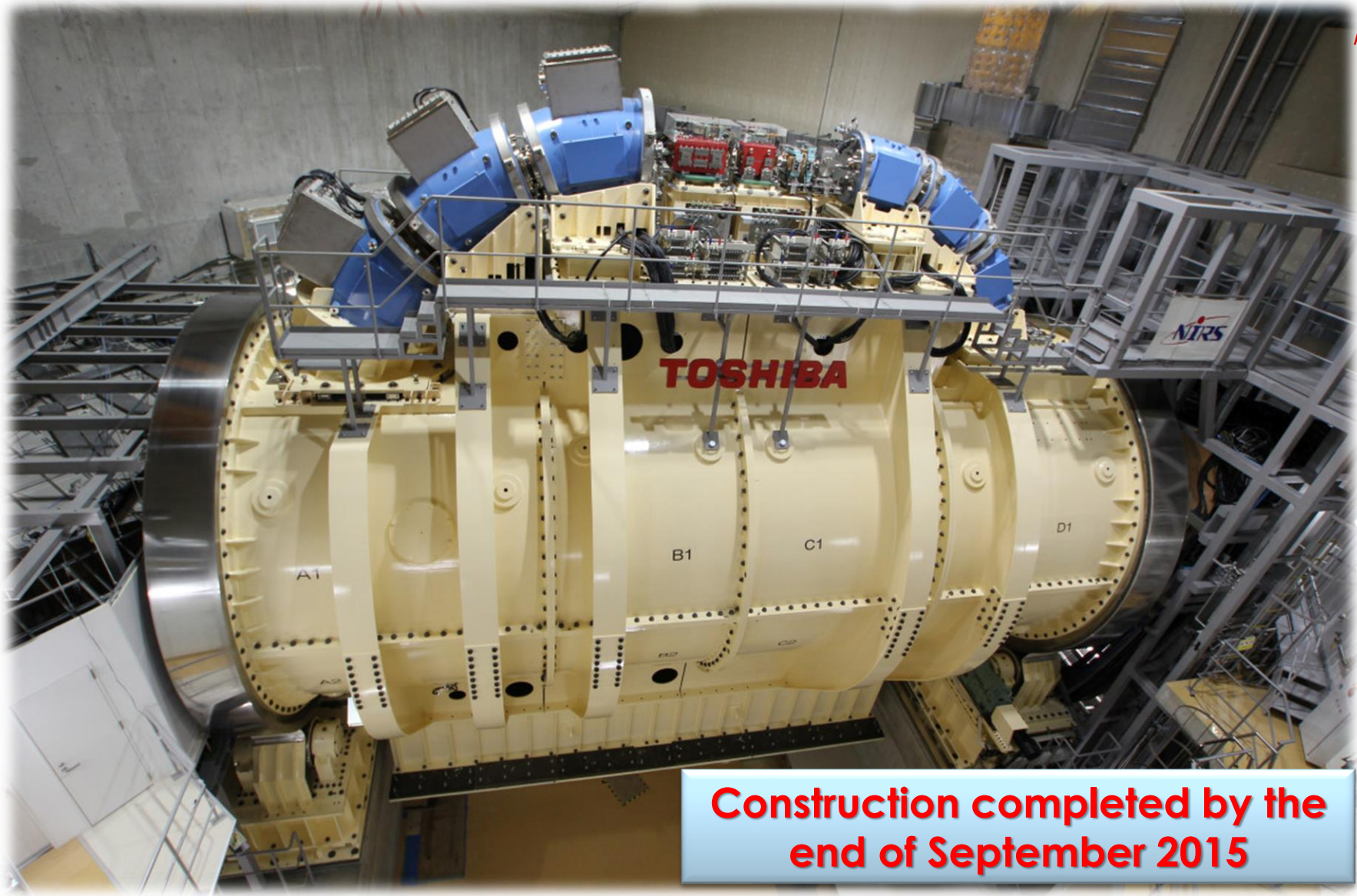
Construction at NIRS



Construction completed by the end of September 2015

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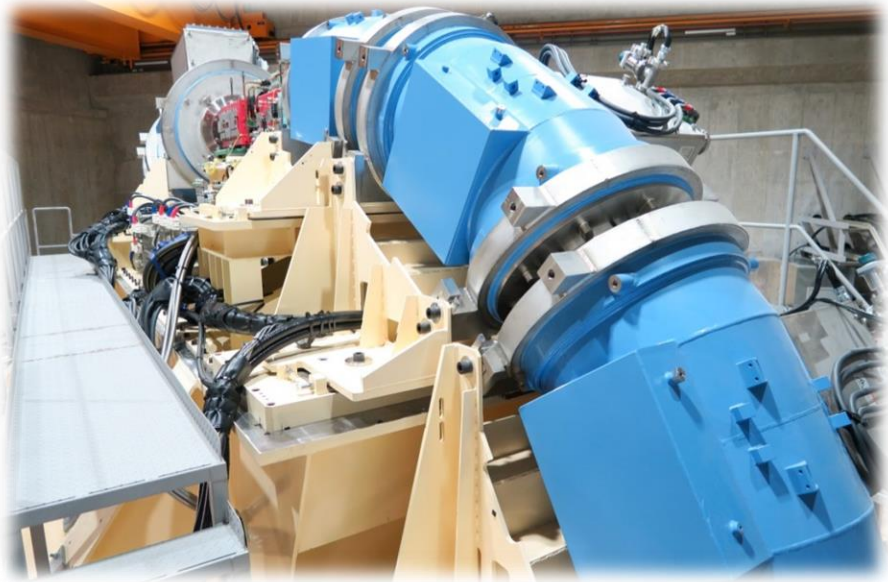
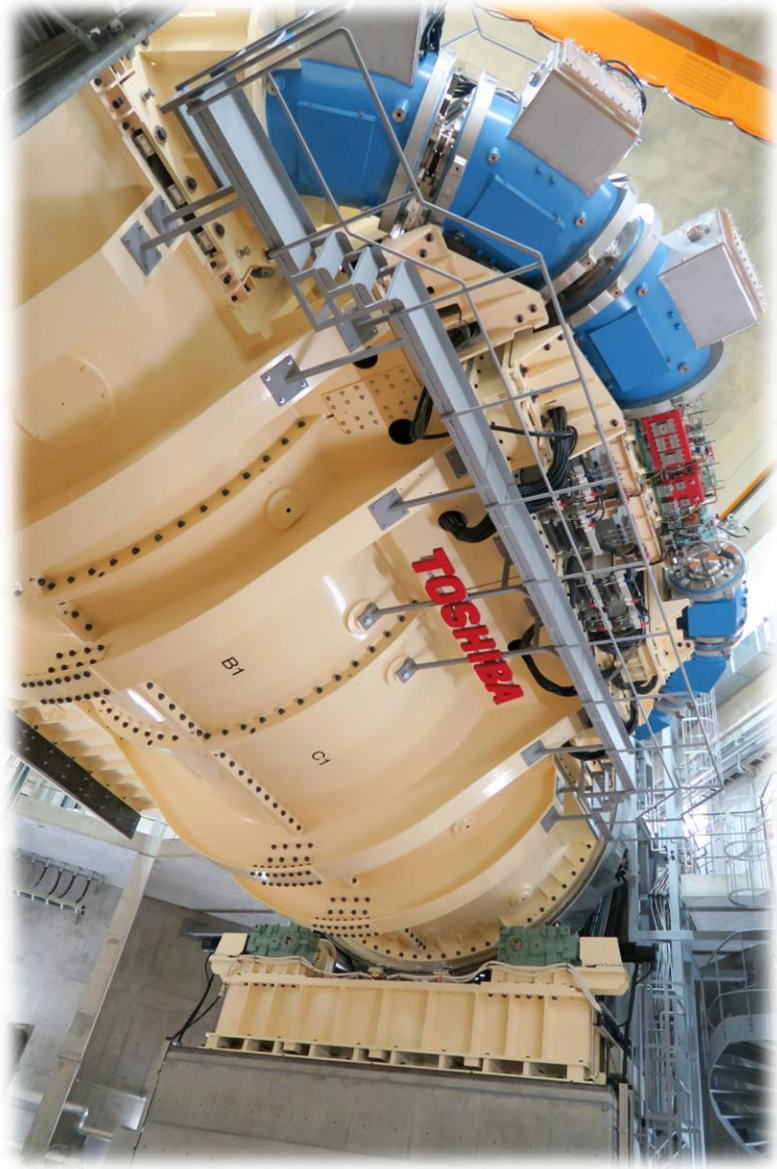
Beam commissioning began since Oct. 2015





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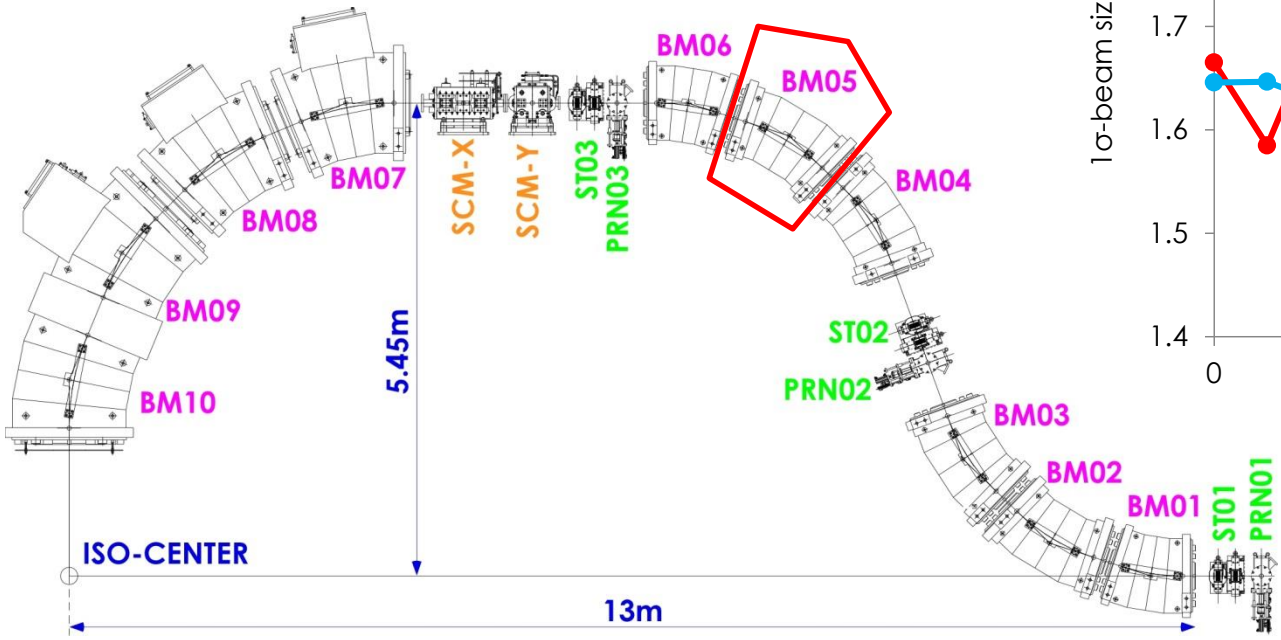
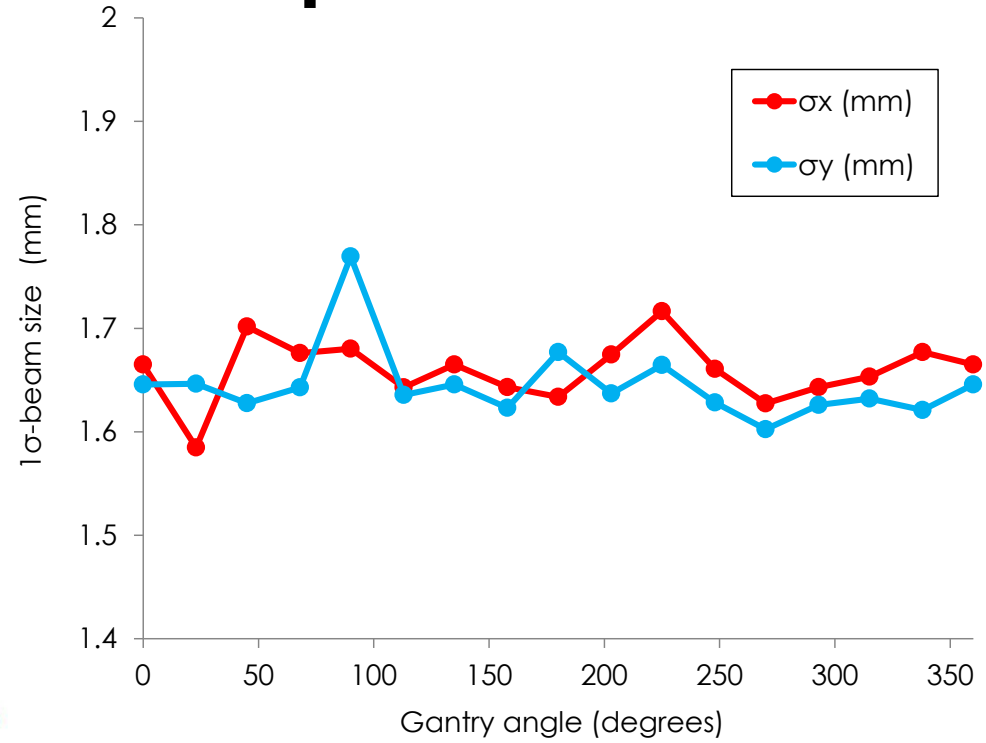
Angular dependence

- The SC quadrupole of **BM05** was finely tuned, so as to obtain circular beam spots at the isocenter.





Angular dependence of beam sizes at isocenter (E=430 MeV/u)

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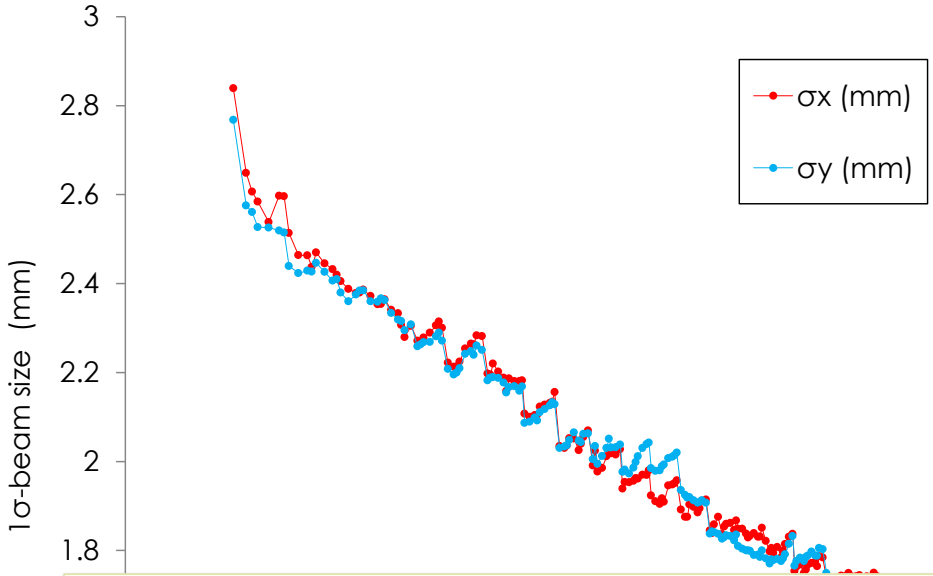
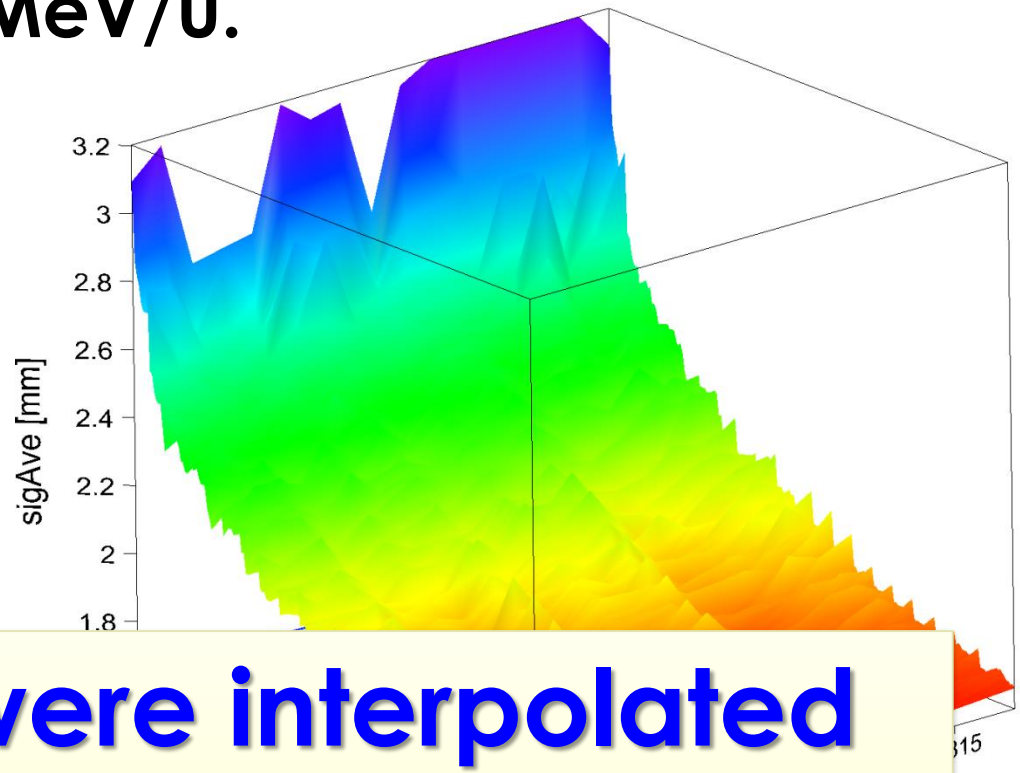
Energy dependence

- **Beam tuning was made for 201 kinds of beam energies for *E*=430~55.6 MeV/u.**





Parameter sets were interpolated to provide beams by angular step of Δθ=1 degree.

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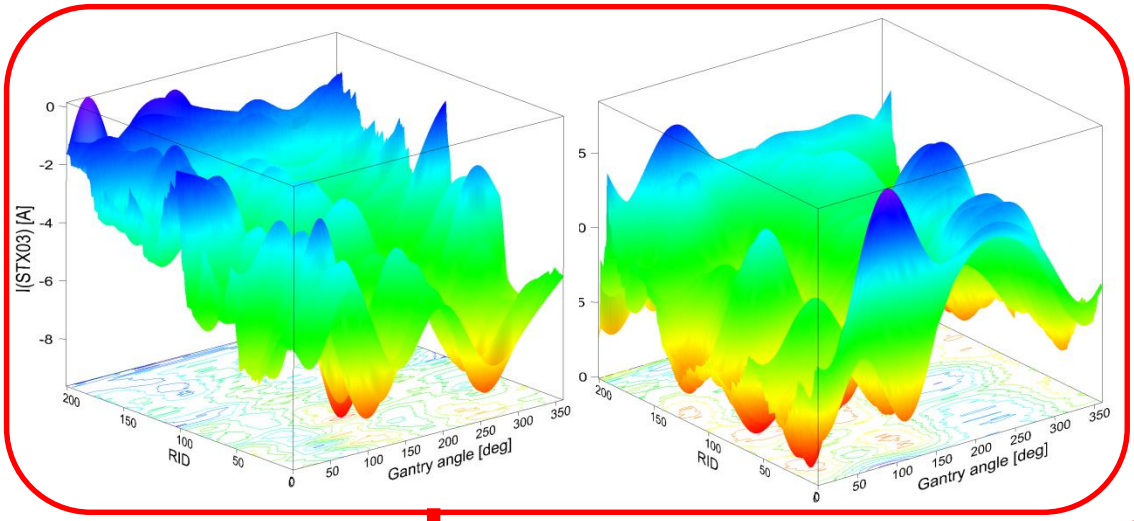
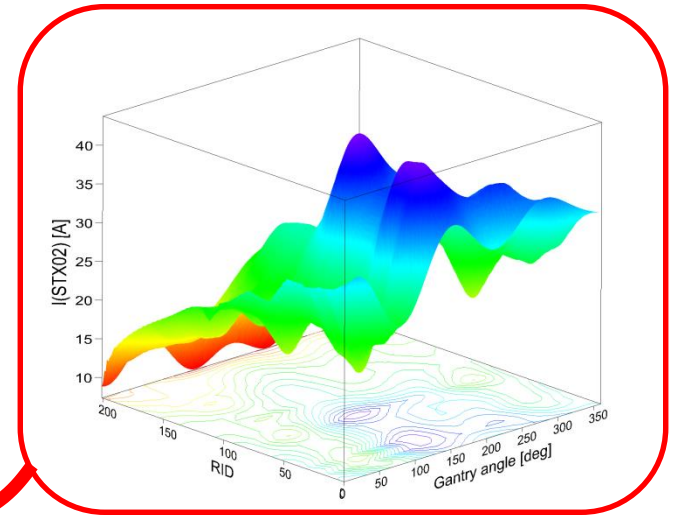
Centering beam spots





After series of beam commissioning, treatment using the gantry began since May 2017!

Future plans

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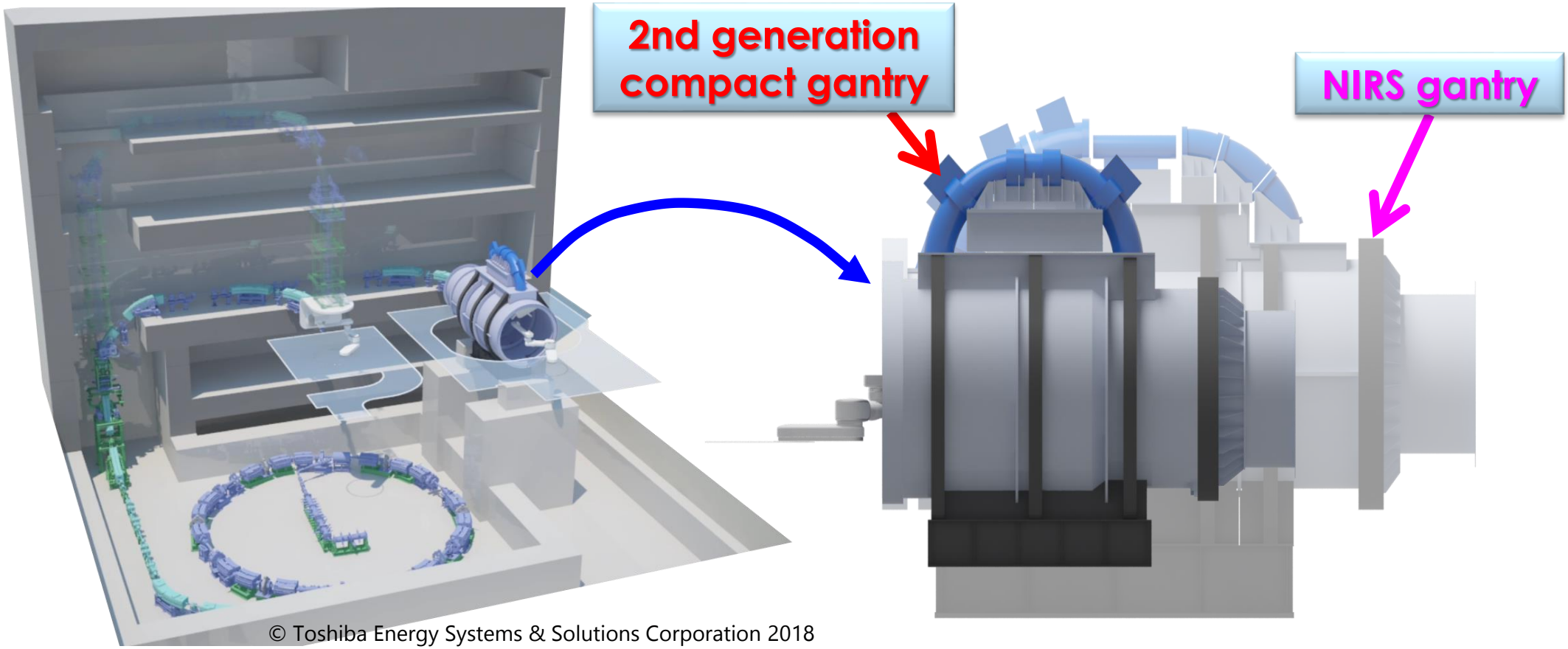
2nd-generation SC gantry

- A compact facility for CIRT is being constructed at Yamagata University.
- 2nd-generation compact gantry will be installed.



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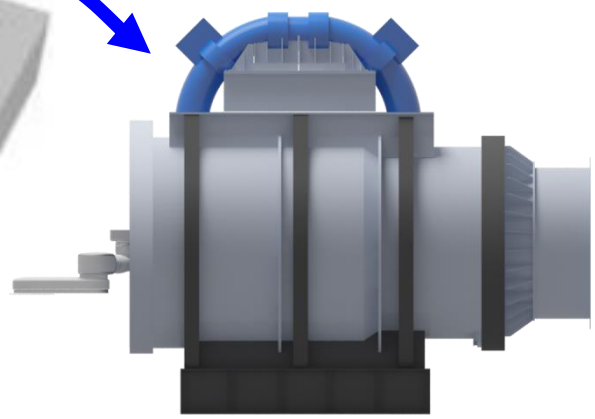
Widespread use of SC gantry

- **The 2nd-generation compact SC gantries will be constructed and installed at Yonsei University Health System in Korea.**

Compact facility for CIRT at Yonsei University Health System

2nd-generation SC gantry for CIRT



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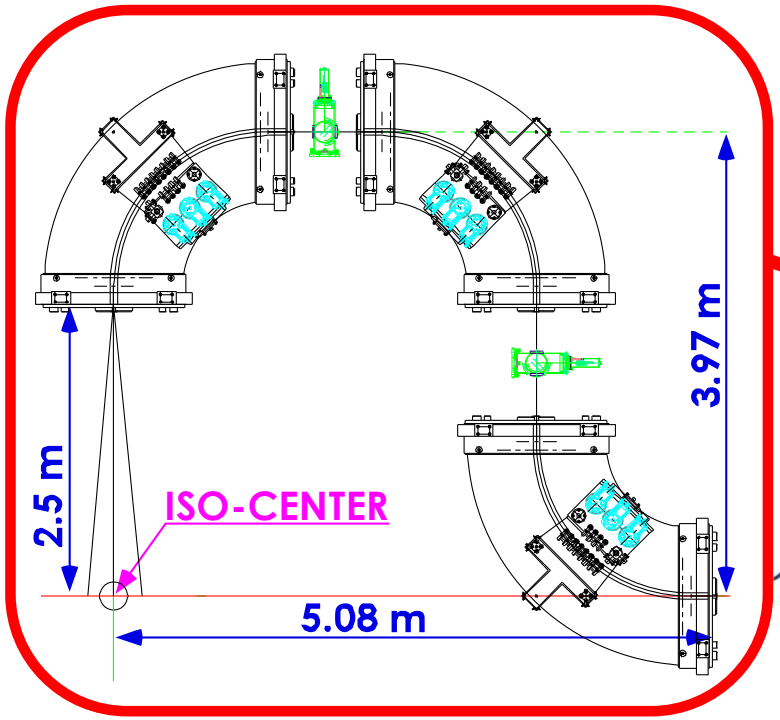
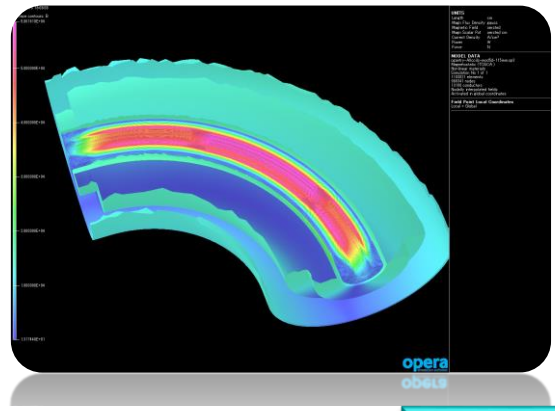
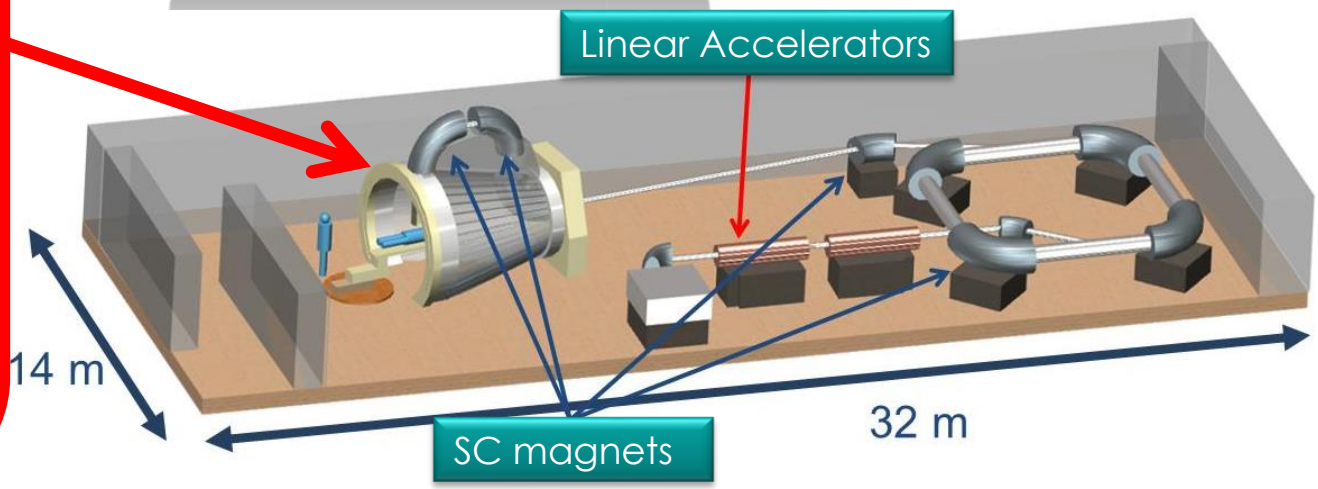
3rd-generation SC gantry

- Combined function SC magnets (B_{max}~5 Tesla)
- A size and weight will be smaller than those of proton gantries







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Summary

- CIRT using HIMAC has been performed since 1994, and more than 11,000 patients were treated at NIRS.
- The SC gantry as well as the fast 3D raster-scanning irradiation, were developed.
- After series of the commissioning works, cancer treatment using the SC gantry began since May 2017.
- The next-generation compact gantries are being developed for the future compact facilities.

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Collaborators

- T. Shirai, T. Fujita, T. Furukawa, Y. Hara, S. Matsuba, K. Mizushima, T. Murakami, K. Noda, N. Saotome, Y. Saraya, S. Sato, T. Shirai, R. Tansho (NIRS, QST)
- T. Fujimoto, H. Arai, et al. (AEC)
- T. Ogitsu (KEK)
- T. Obana (NIFS)
- N. Amemiya (Kyoto Univ.)
- T. Orikasa, S. Takayama, et al. (Toshiba Corp.)