NIRS HIMAC

Present status of a superconducting rotating gantry for carbon therapy

Yoshiyuki Iwata

National Institute of Radiological Sciences (NIRS)

NIRS

2015/9/11

NIRS

HIMAC

Outline

- Introduction
- Gantry developments
  - Superconducting magnets
  - Construction of gantry structure
- Summary

NIRS

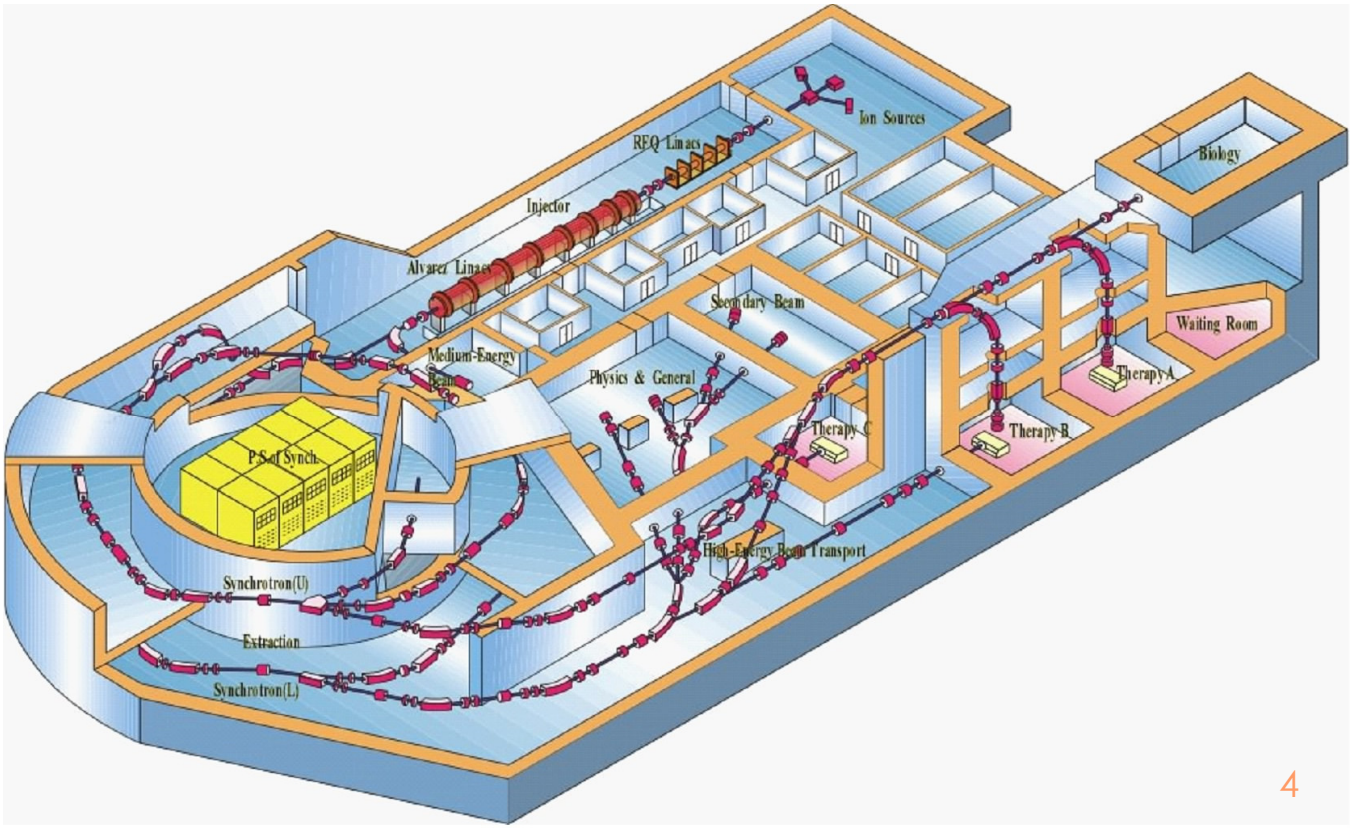
HIMAC

Introduction

NIRS

HIMAC

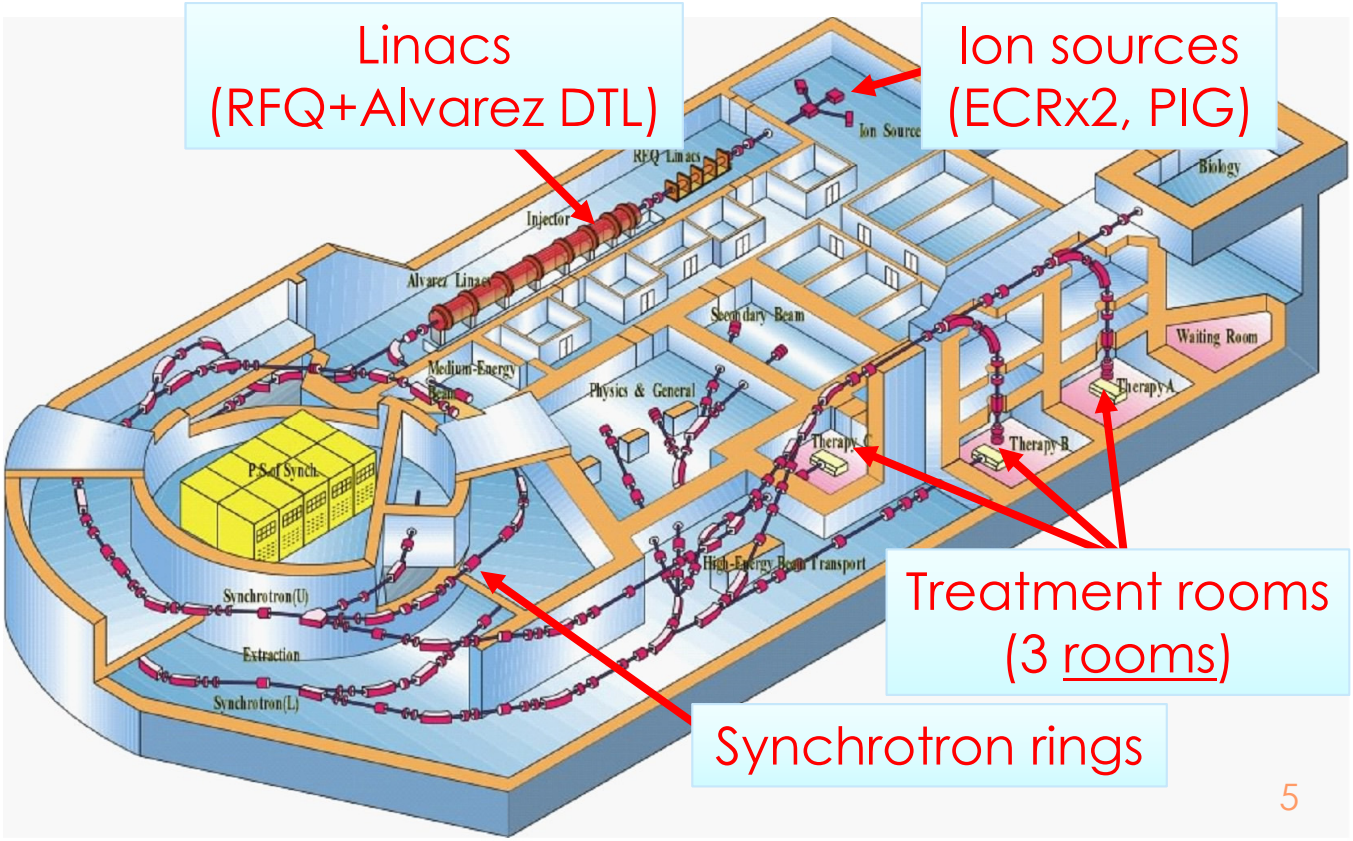
Carbon radiotherapy



NIRS

HIMAC

Carbon radiotherapy

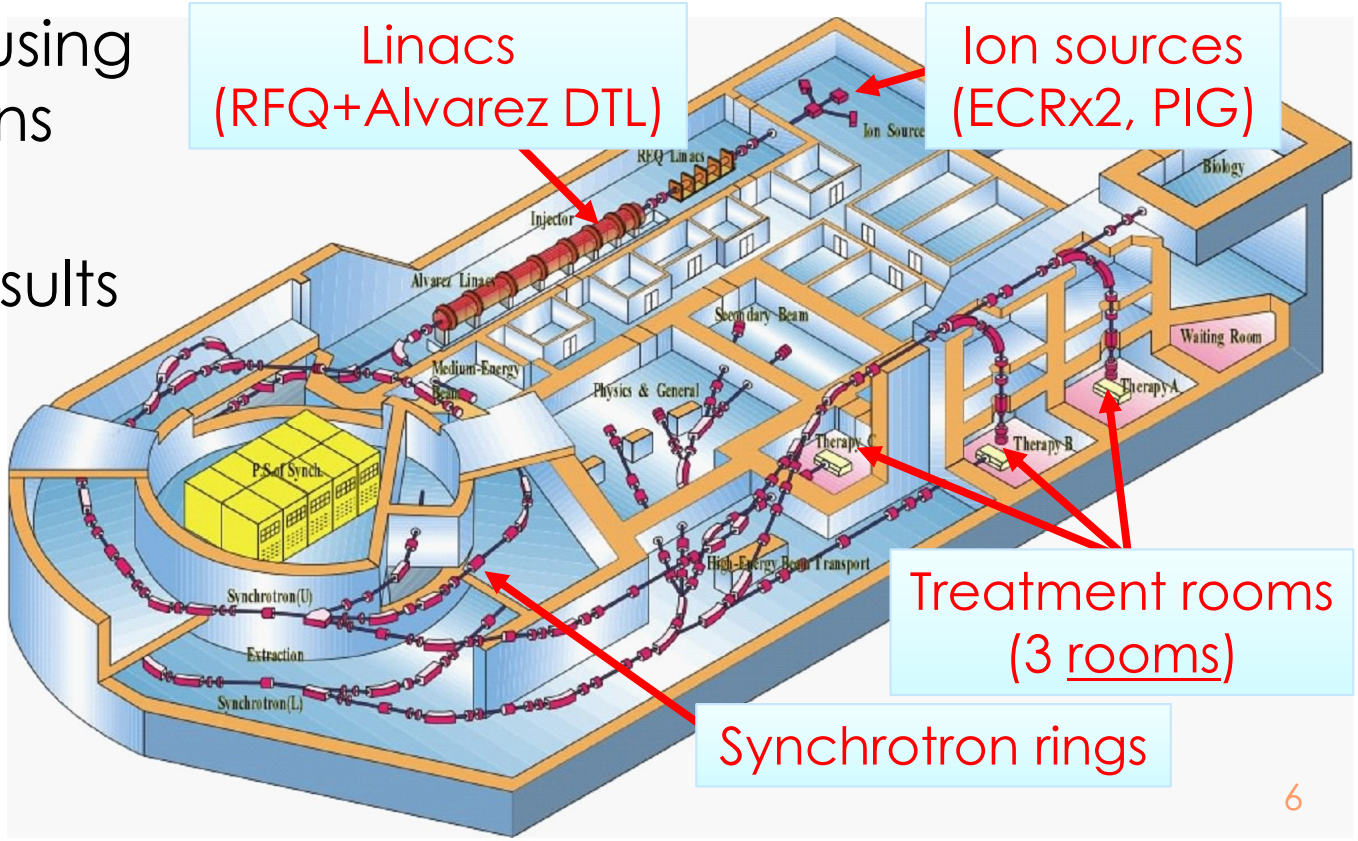


NIRS

HIMAC

Carbon radiotherapy

- Heavy Ion Medical Accelerator in Chiba (HIMAC)
- Ion species: p ~ Xe
- E/A=800 MeV for q/m=1/2
- Cancer treatments using energetic carbon ions since 1994
- Successful clinical results
  ~9000 patients



New treatment facility

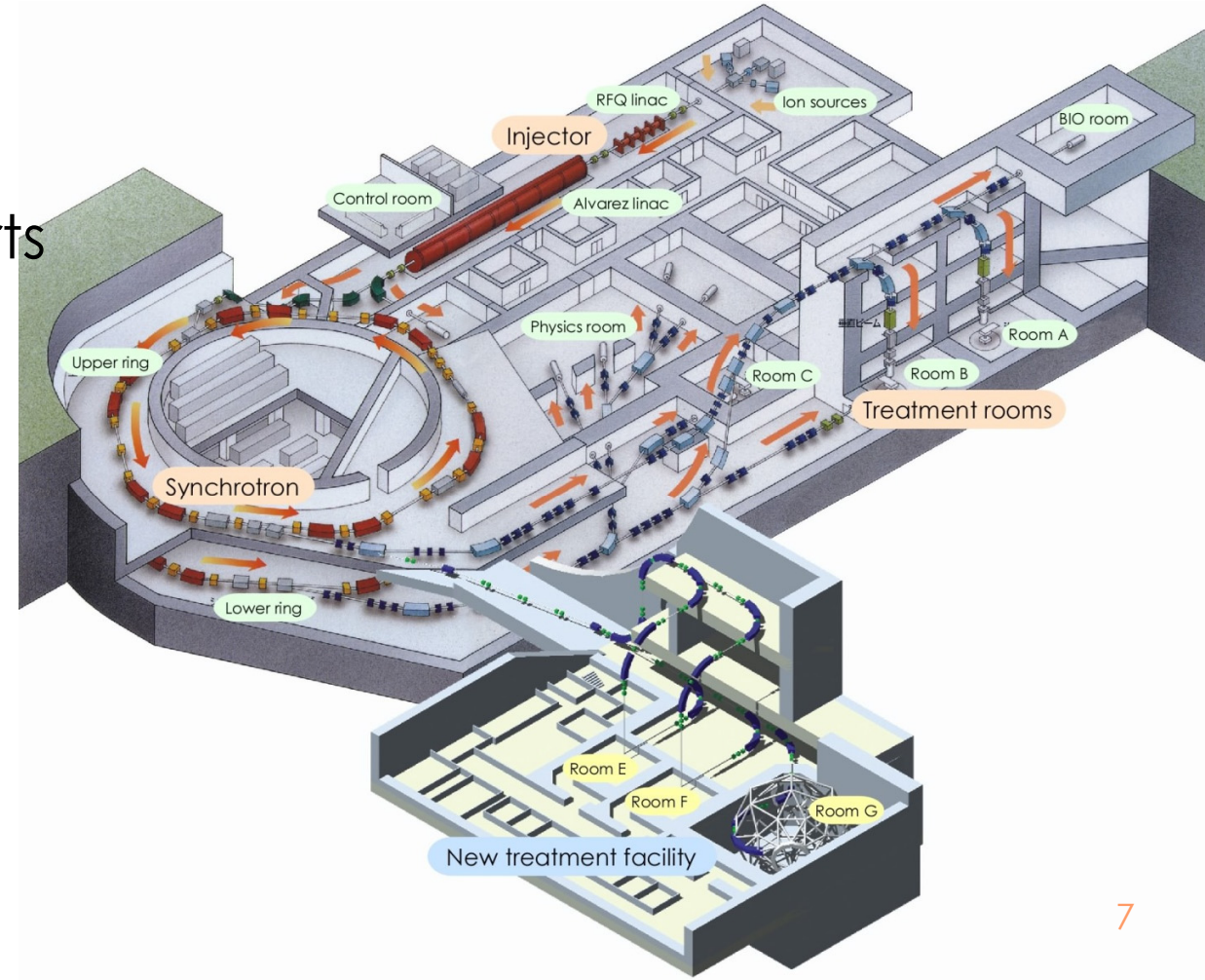
- Construction completed in FY2010
- 3 treatment rooms
  - Room E & F

    Fixed H&V scanning ports

    (**in treatment operation**)
  - **Room G**

    Rotating gantry port

    (Under construction)



NIRS

HIMAC

New treatment facility

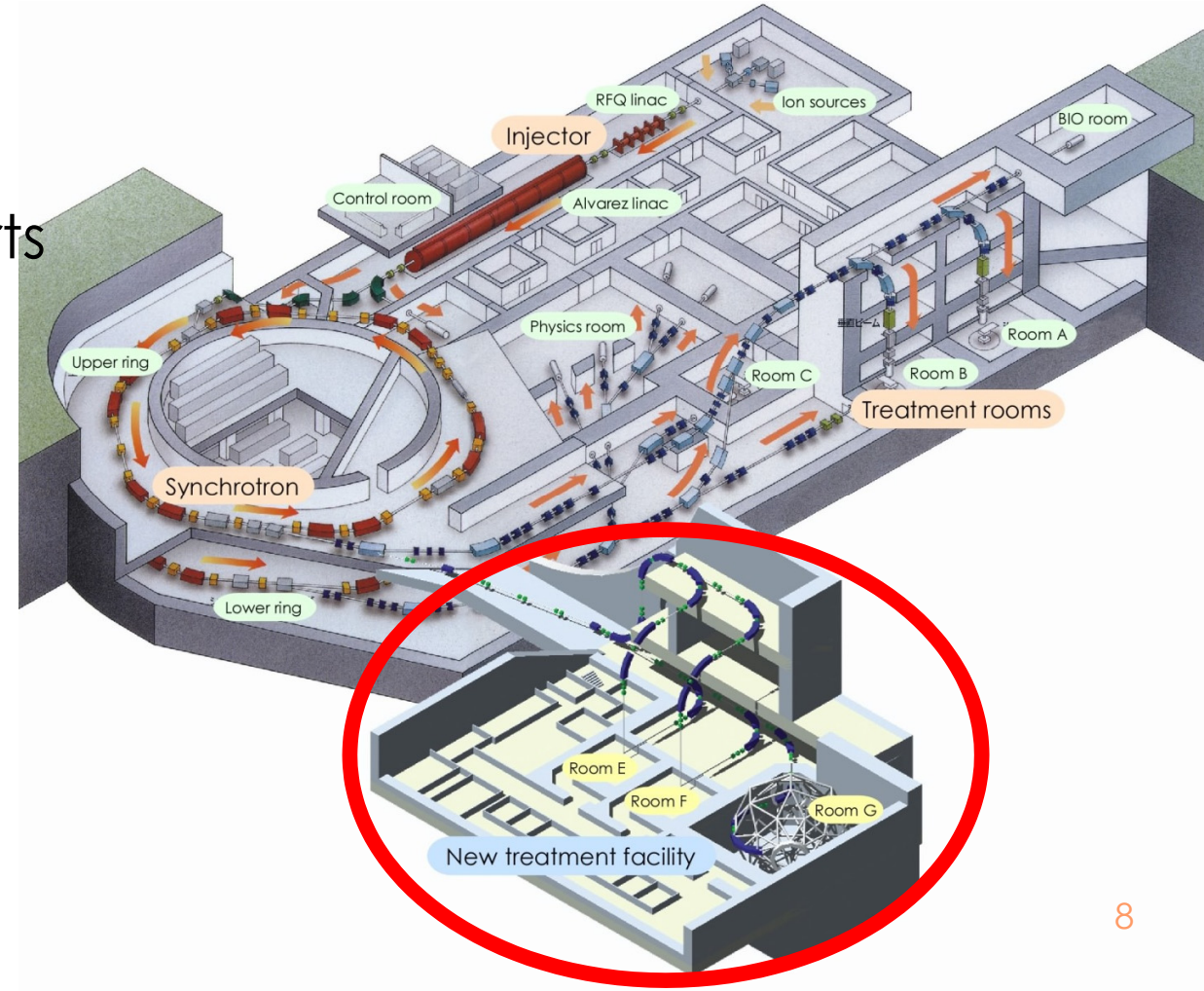
- Construction completed in FY2010
- 3 treatment rooms
  - Room E & F

    Fixed H&V scanning ports

    (**in treatment operation**)
  - **Room G**

    Rotating gantry port

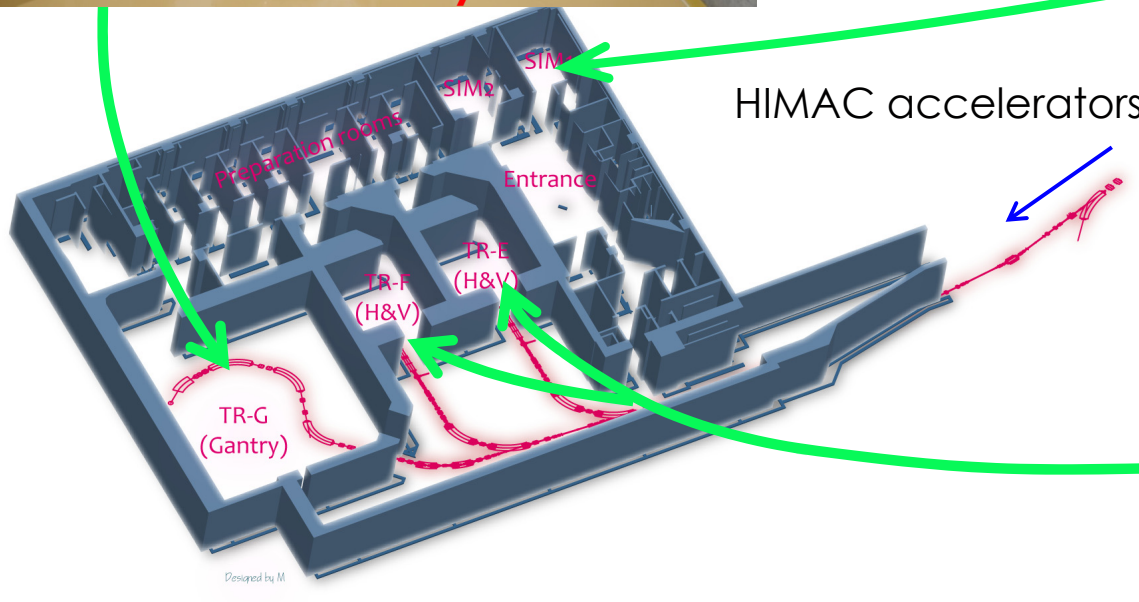
    (Under construction)



NIRS

HIMAC

Treatment floor (B2F)



HIMAC accelerators

NIRS

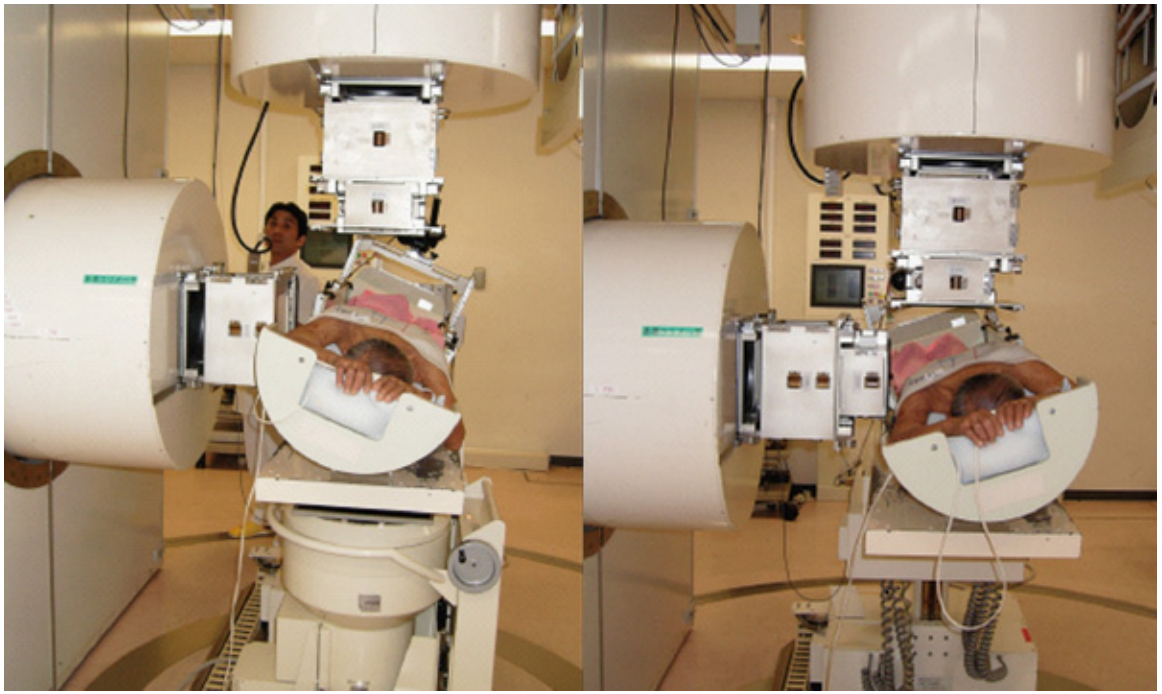
HIMAC

Rotating gantry in hadron radiotherapy

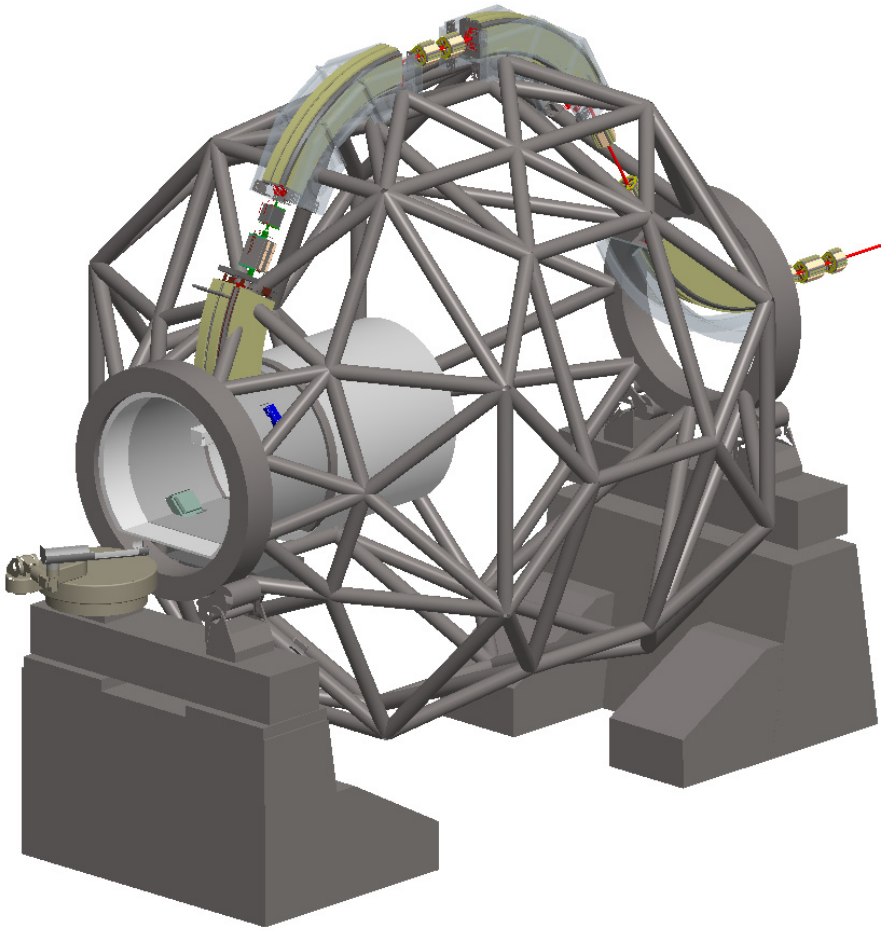
NIRS

HIMAC

Needs for a rotating gantry



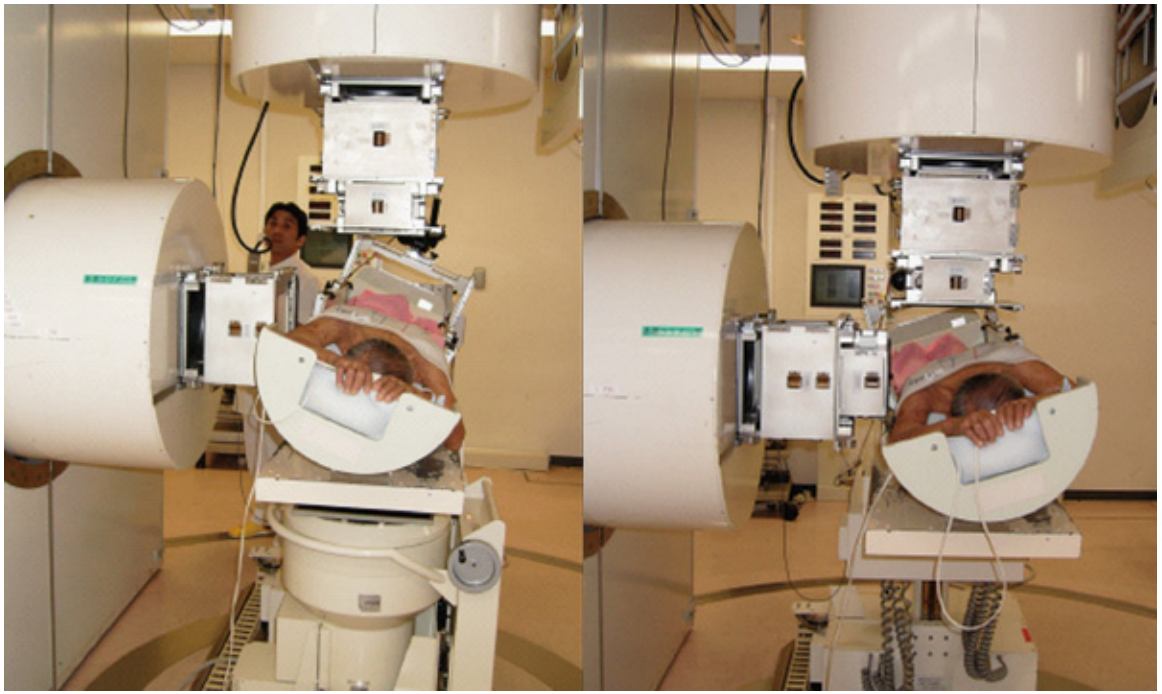
Irradiation with the existing fixed port



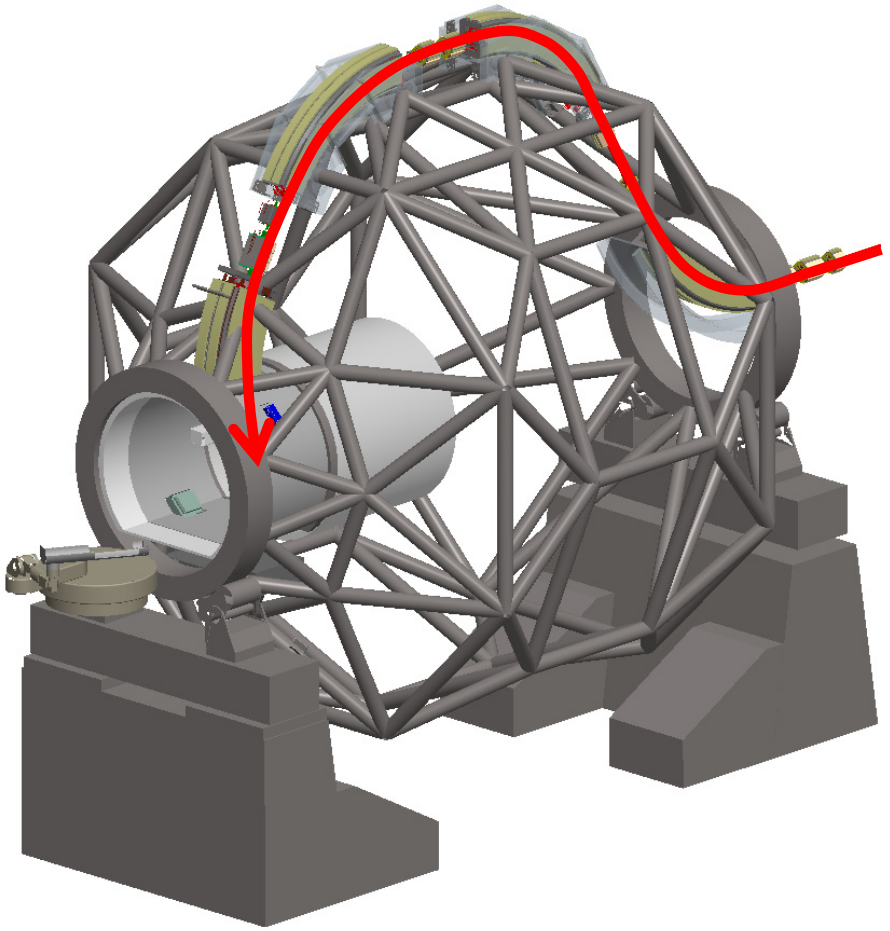
NIRS

HIMAC

Needs for a rotating gantry



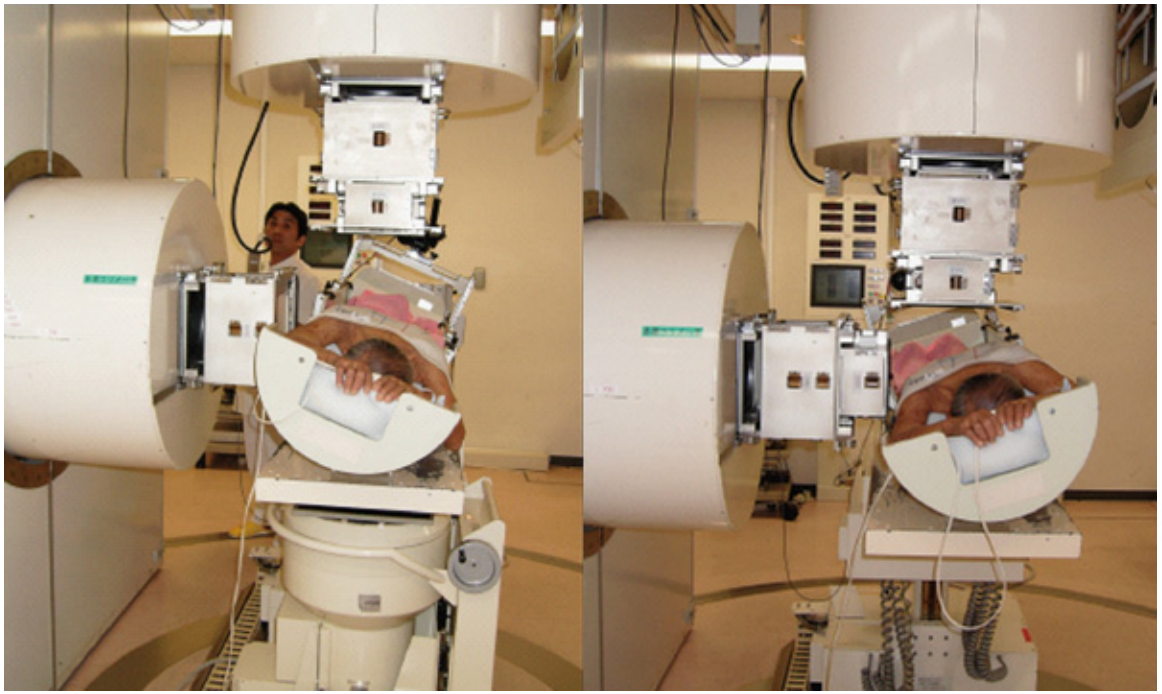
Irradiation with the existing fixed port



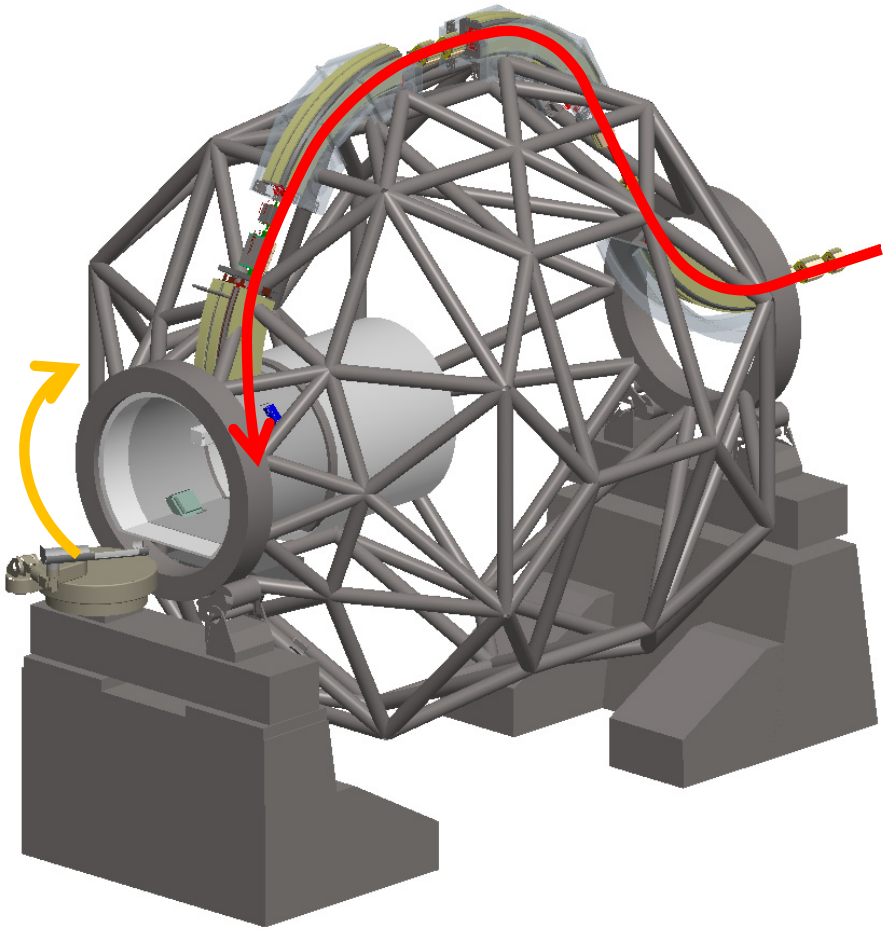
NIRS

HIMAC

Needs for a rotating gantry



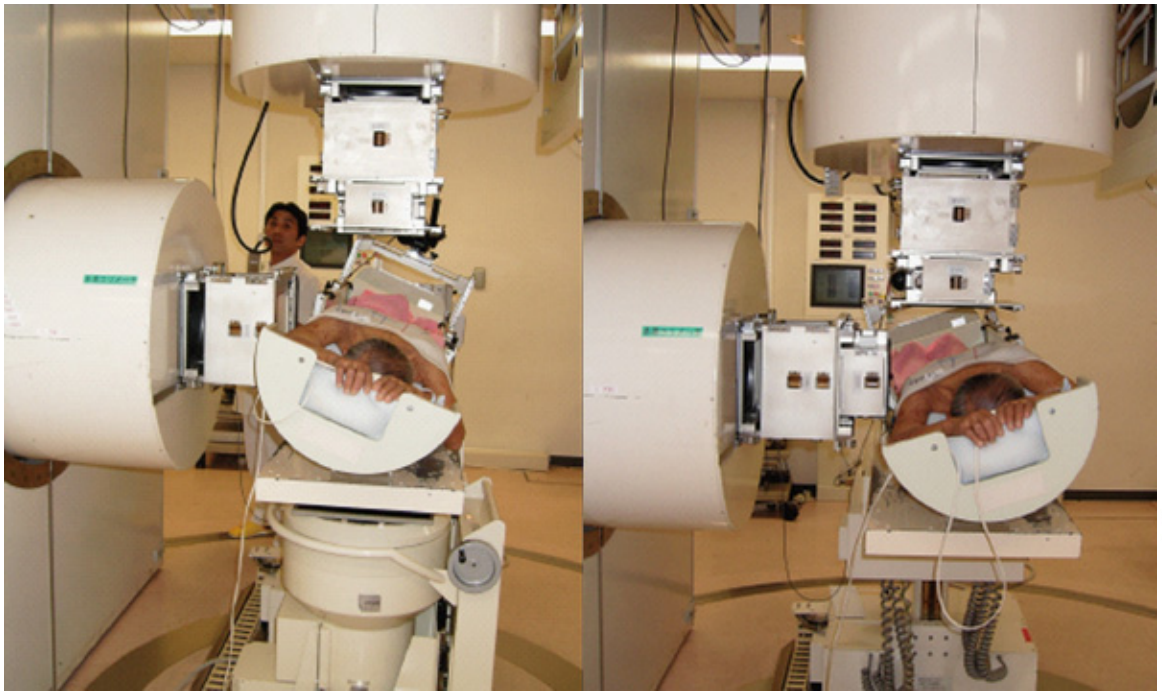
Irradiation with the existing fixed port



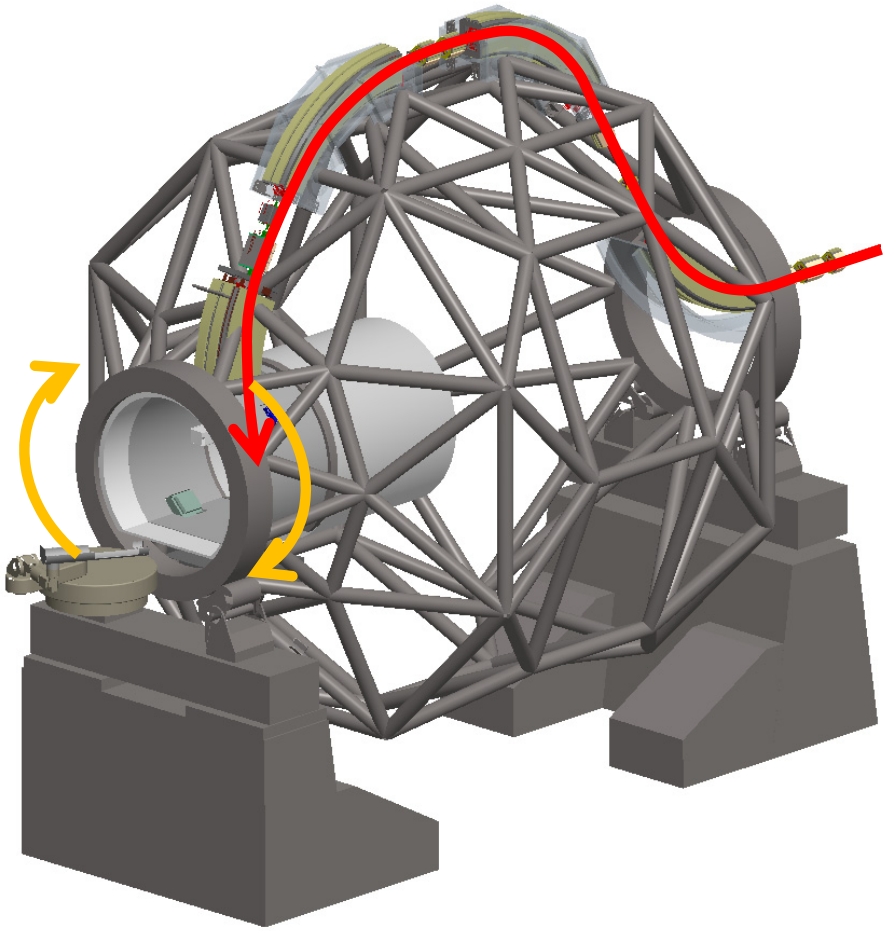
NIRS

HIMAC

Needs for a rotating gantry



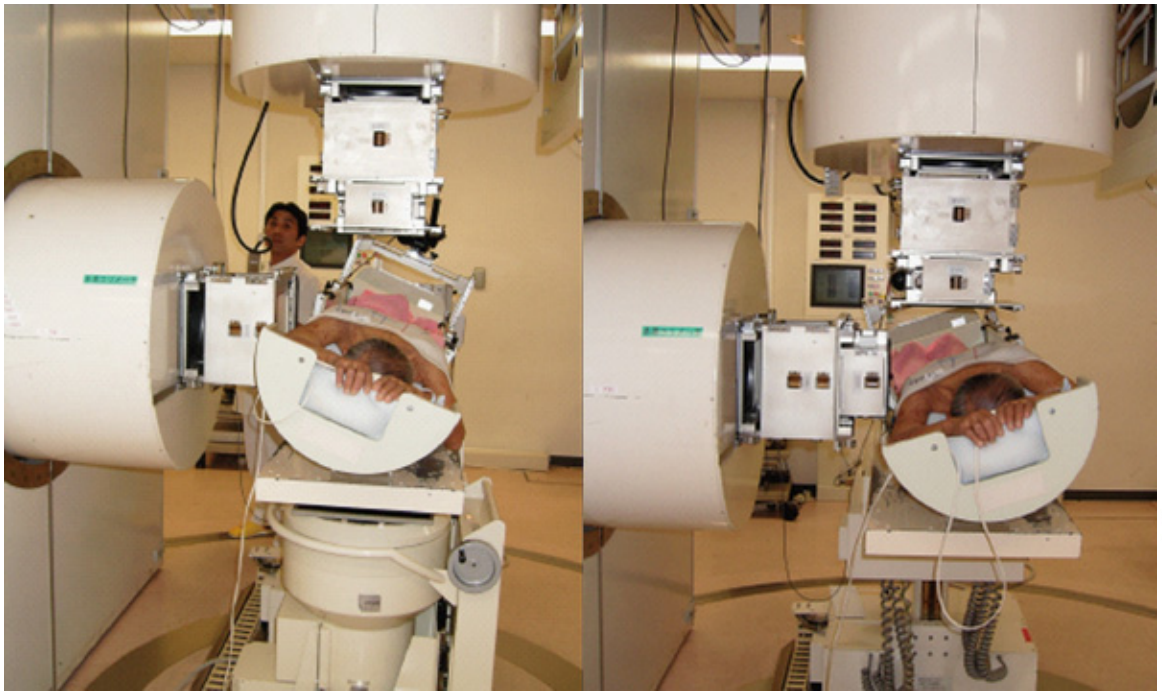
Irradiation with the existing fixed port



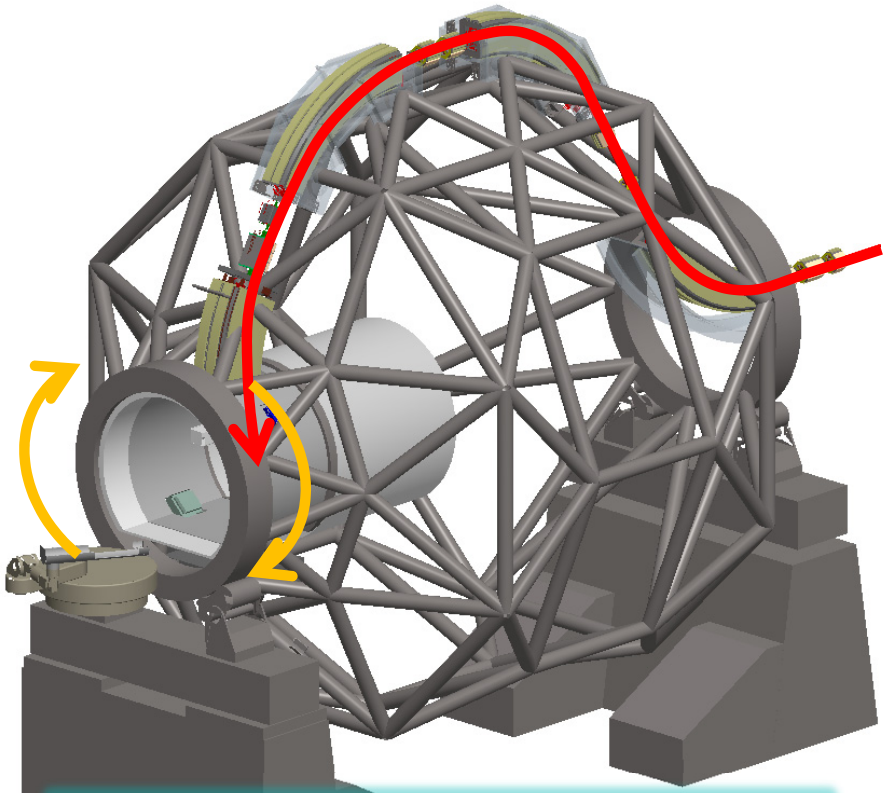
NIRS

HIMAC

Needs for a rotating gantry



Irradiation with the existing fixed port

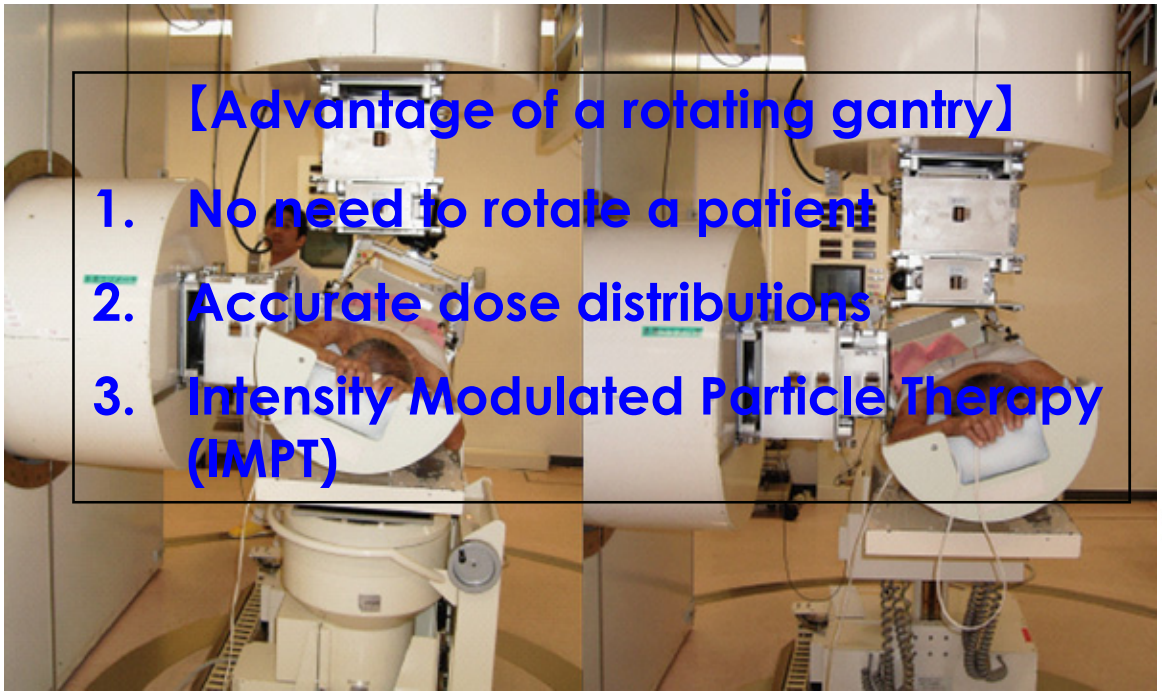


Beam can be directed to a target from any of medically desirable angles

NIRS

HIMAC

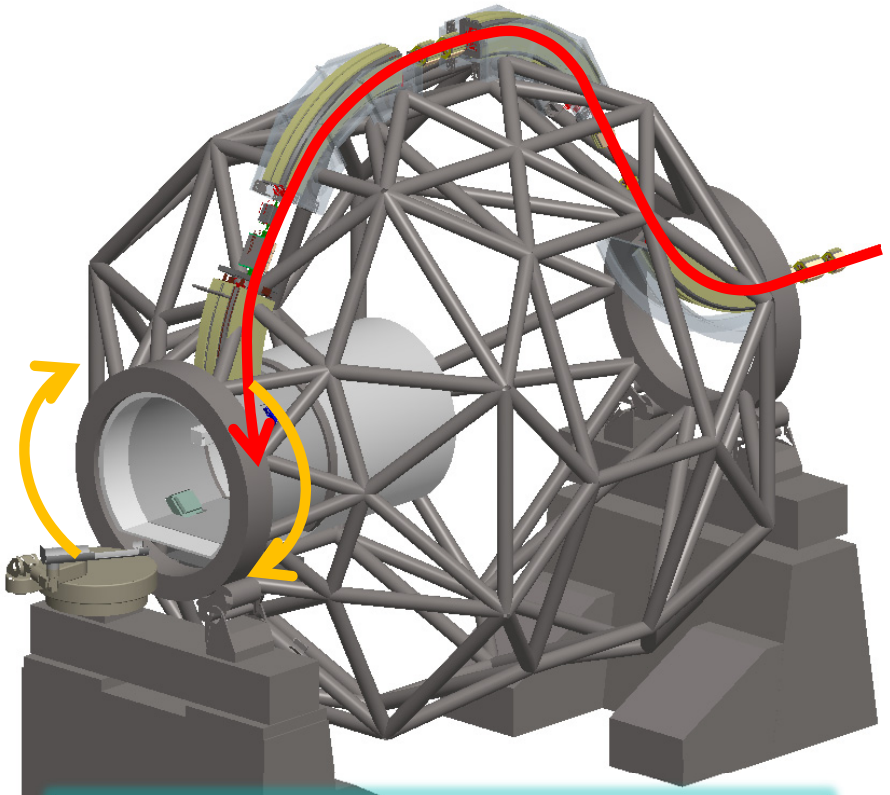
Needs for a rotating gantry



【Advantage of a rotating gantry】

1. No need to rotate a patient
2. Accurate dose distributions
3. Intensity Modulated Particle Therapy (IMPT)

Irradiation with the existing fixed port



Beam can be directed to a target from any of medically desirable angles

NIRS

HIMAC

Rotating gantry for hadron therapy

- **Proton therapy**
  - Gantries are commonly used
  - Commercially available
- **Carbon therapy**
  - Required Bρ is 3 times higher
    - Magnets will be very large and heavy
  - Difficult to
    - Design
    - Construct

NIRS

HIMAC

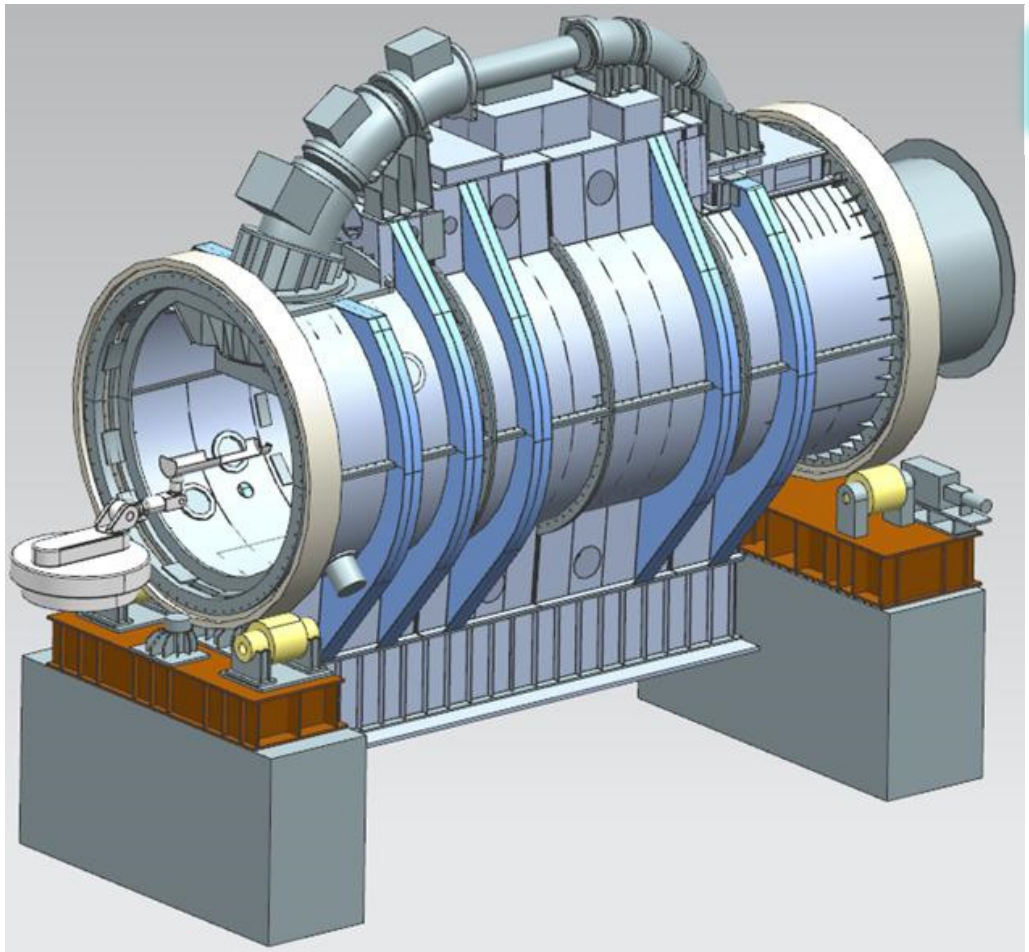
Rotating gantry for carbon therapy

- **Only one gantry in the world**
  - Heidelberg Ion Beam Therapy Center (HIT)
  - World first carbon-gantry
  - Clinical use since November 2012
  - Weight: 600 tons (rotating part)

NIRS

HIMAC

Superconducting rotating-gantry



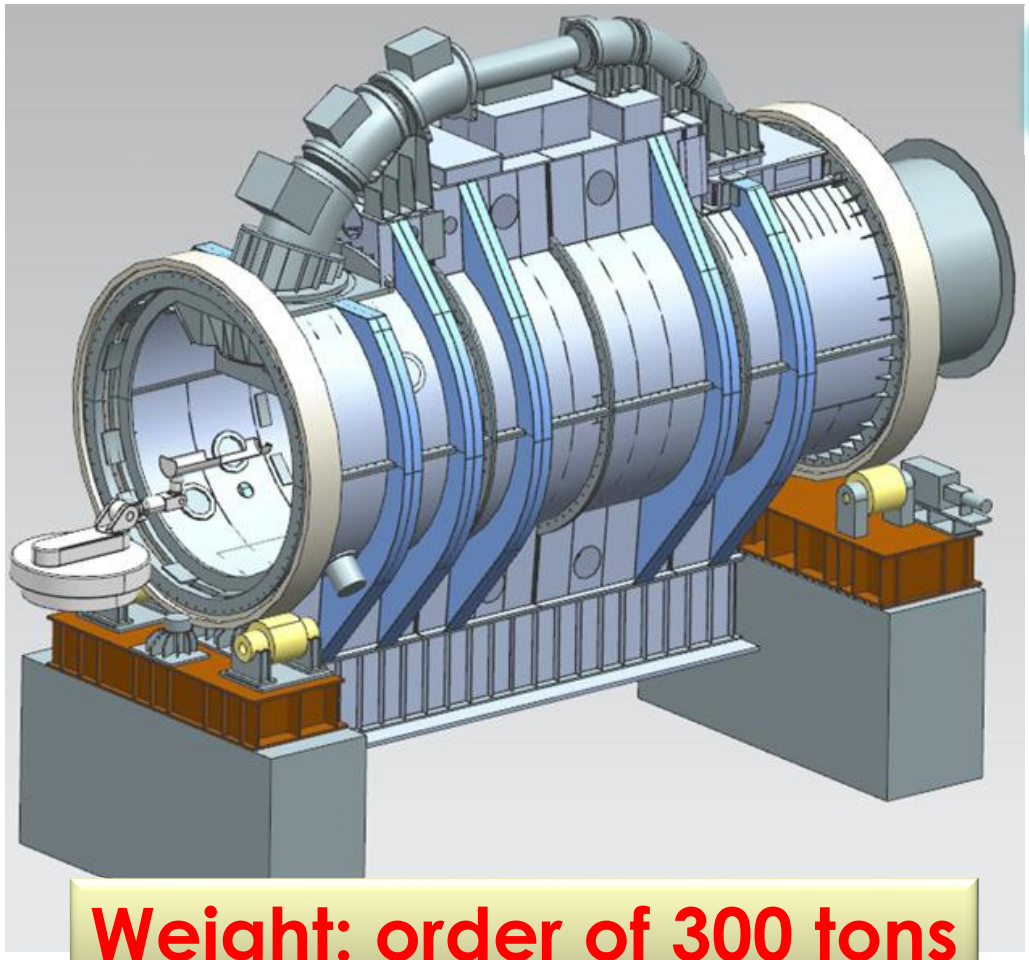
Use of superconducting (SC) magnets

Ion kind	: ^{12}C
Irradiation method	: 3D Scanning
Beam energy	: 430 MeV/n
Maximum range	: 30 cm in water
Scan size	: □200×200 mm^2
Beam orbit radius	: 5.45 m
Length	: 13 m

NIRS

HIMAC

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
Scan size	: □200×200 mm^2
Beam orbit radius	: 5.45 m
Length	: 13 m

The size and weight are considerably reduced

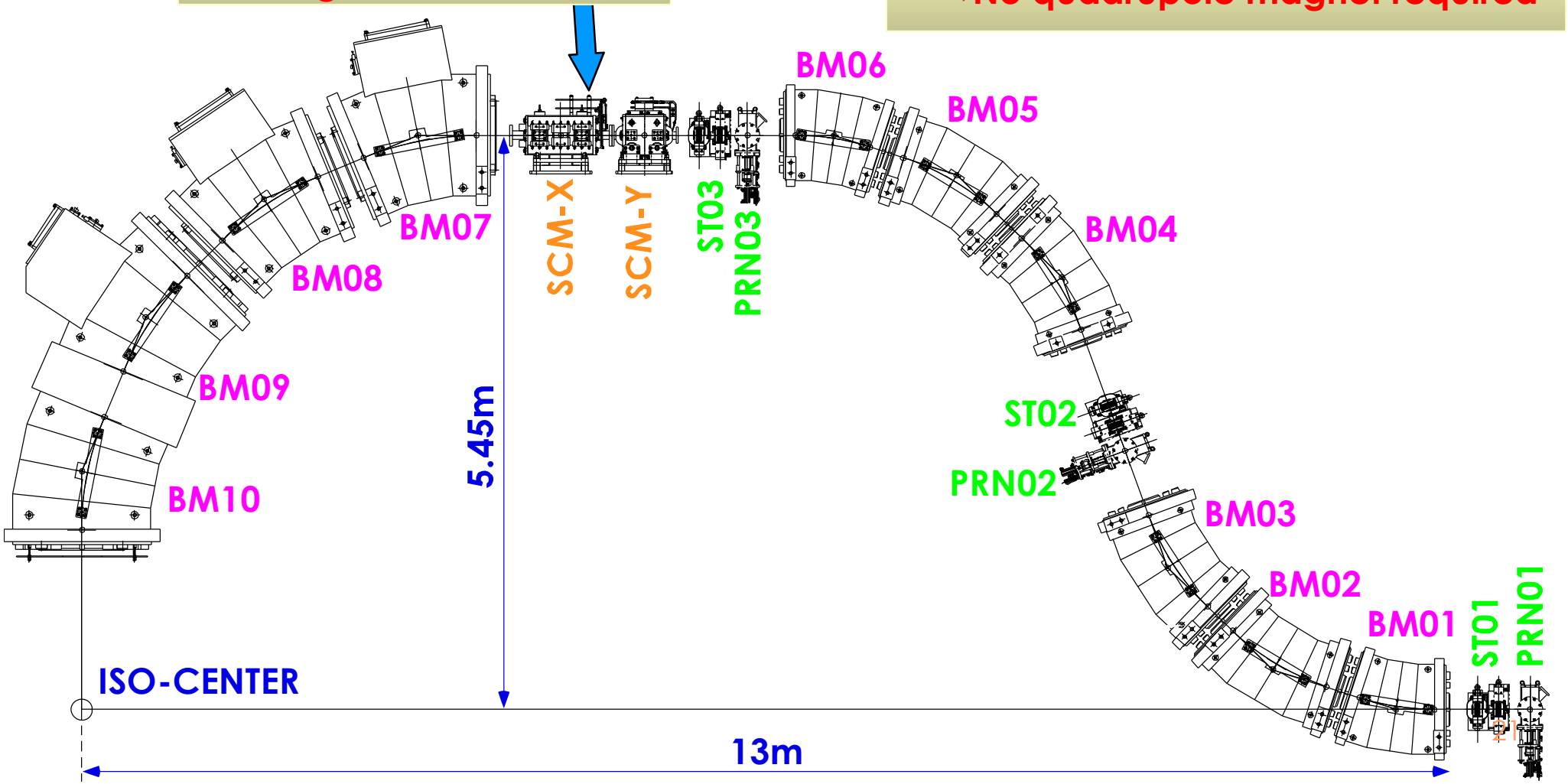
NIRS

HIMAC

Layout of the SC gantry

Scanning magnets on top
→Large scan size

Combined function SC magnets
→No quadrupole magnet required



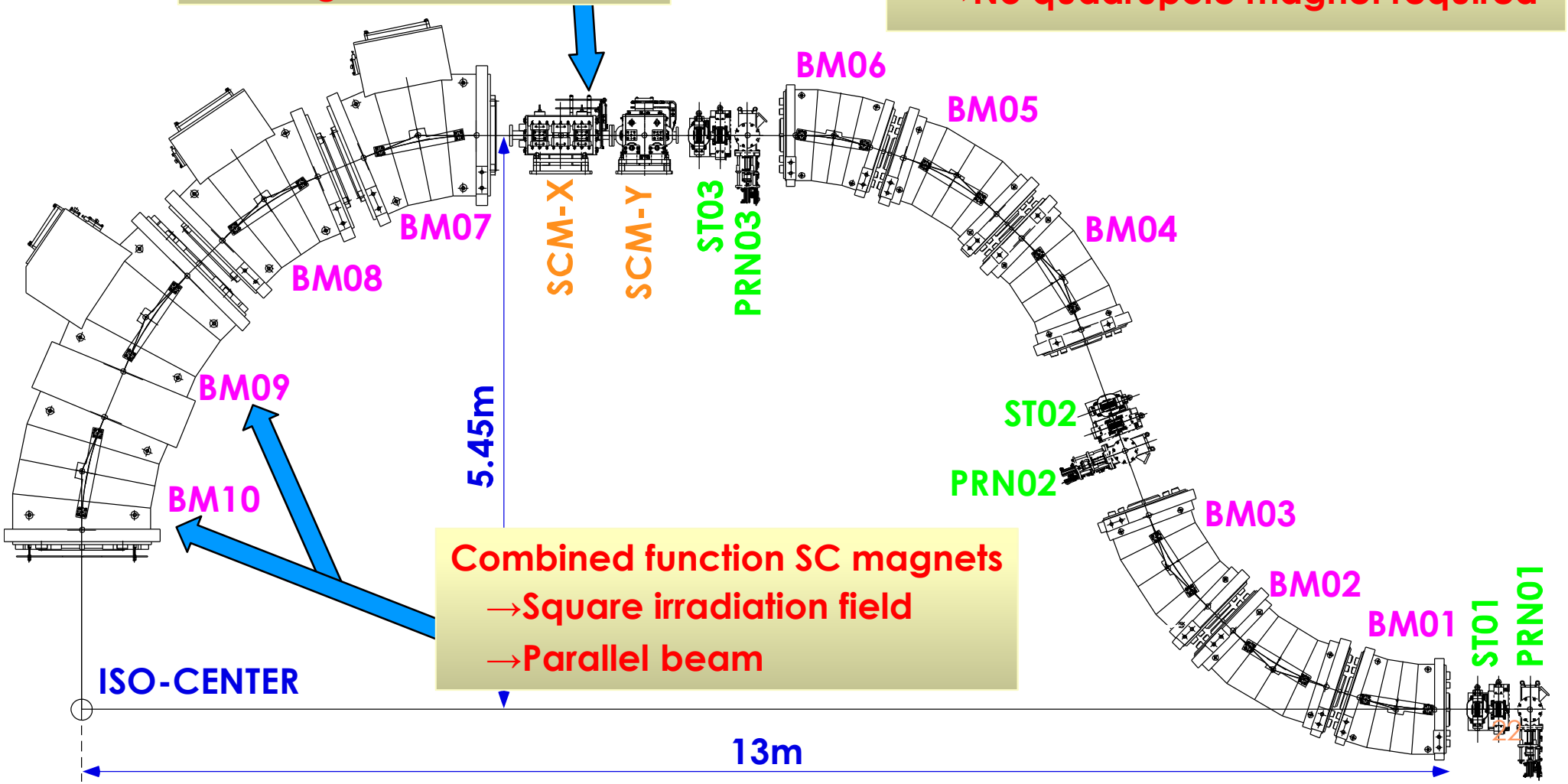
NIRS

HIMAC

Layout of the SC gantry

Scanning magnets on top
→Large scan size

Combined function SC magnets
→No quadrupole magnet required



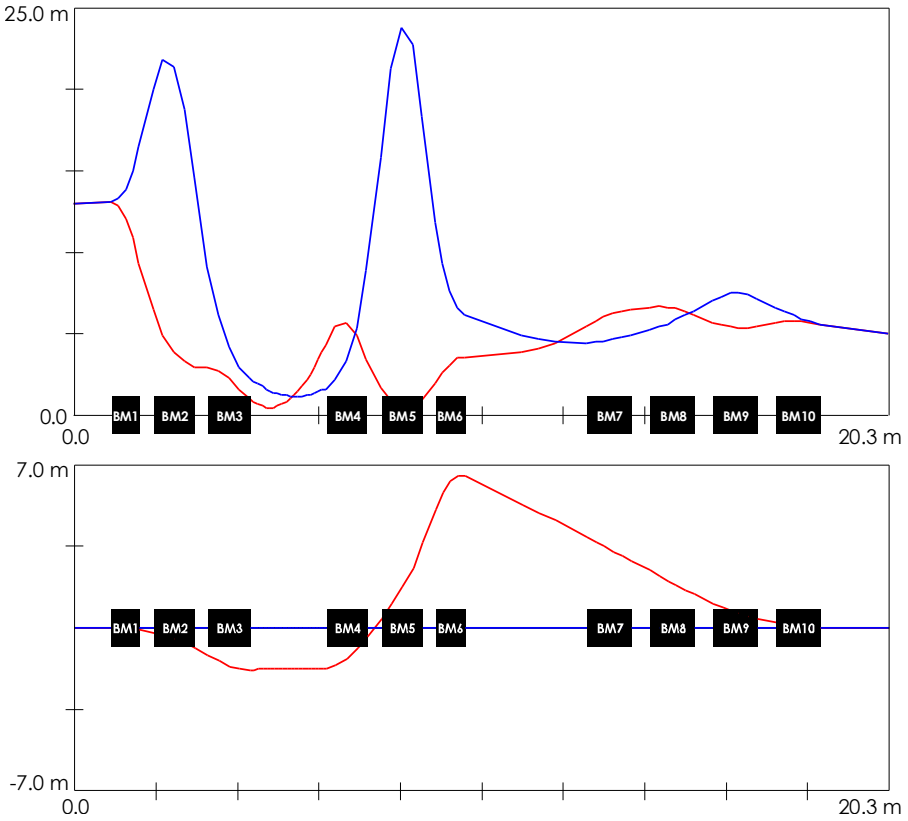
Combined function SC magnets
→Square irradiation field
→Parallel beam

NIRS

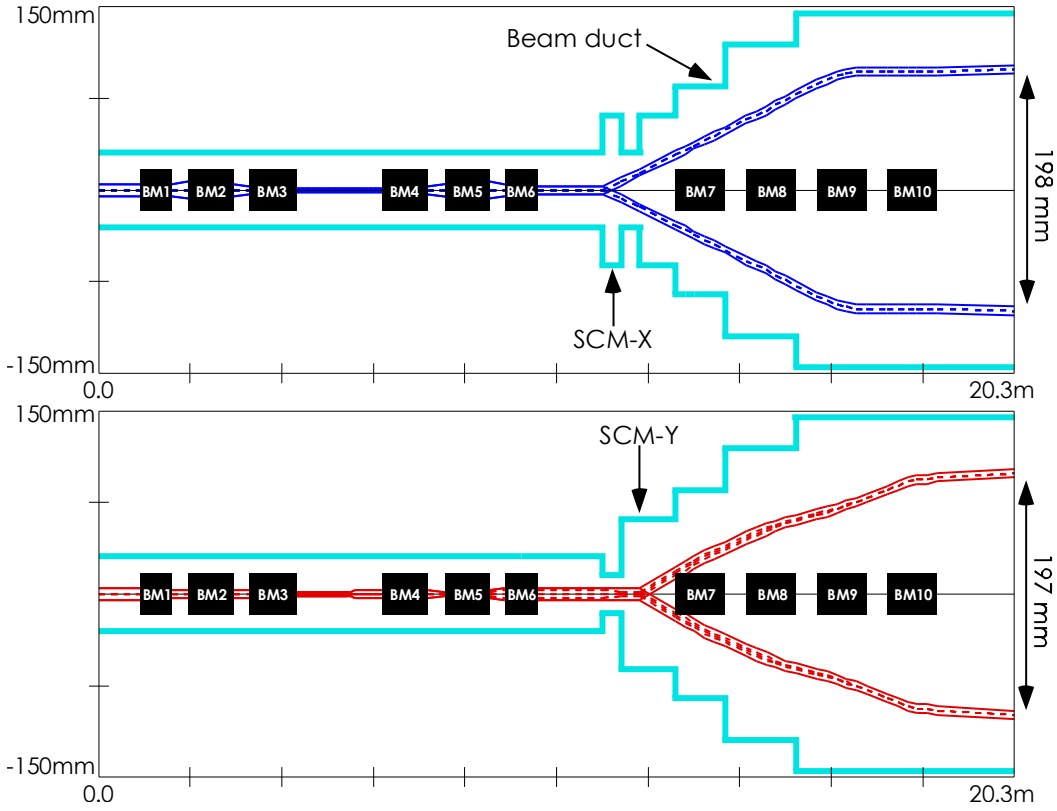
HIMAC

Beam optics design

Beta and dispersion functions



Beam envelope functions with kicks of scanning magnets



NIRS

HIMAC

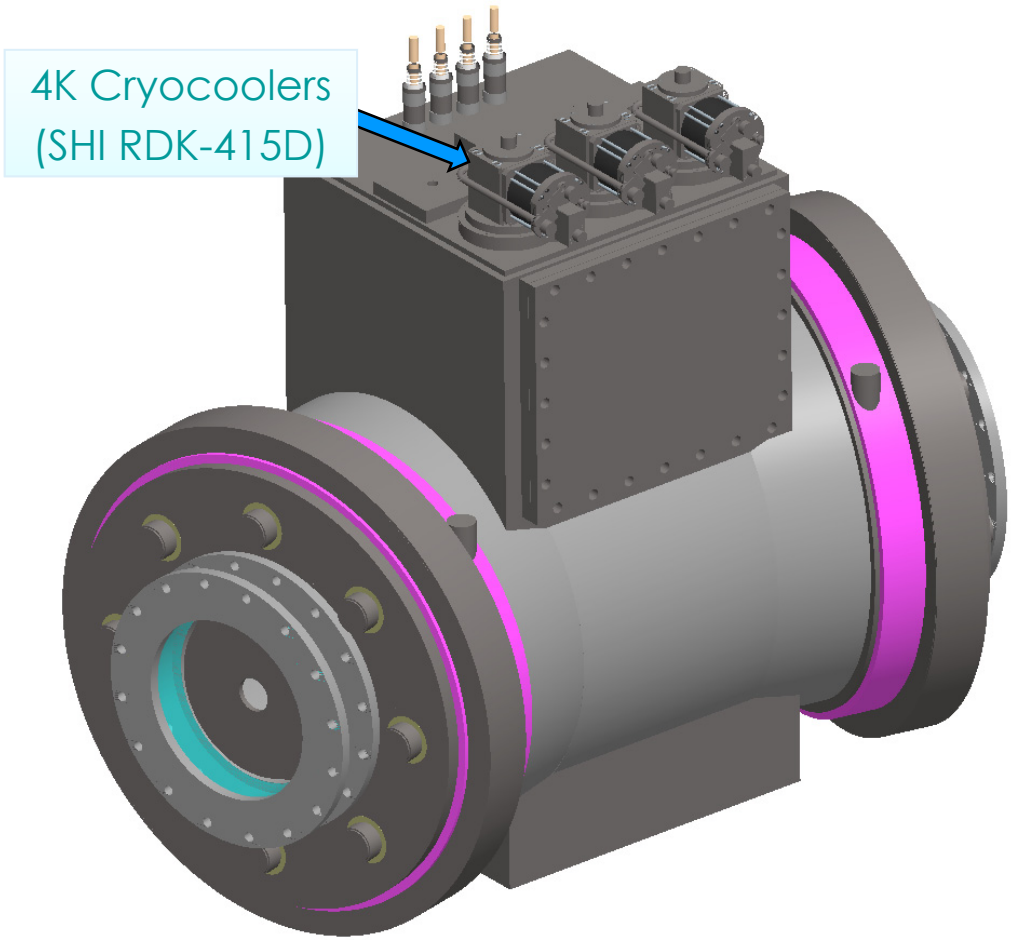
Development of superconducting magnets

NIRS

HIMAC

Development of curved SC magnets

SC magnet (BM02-05)

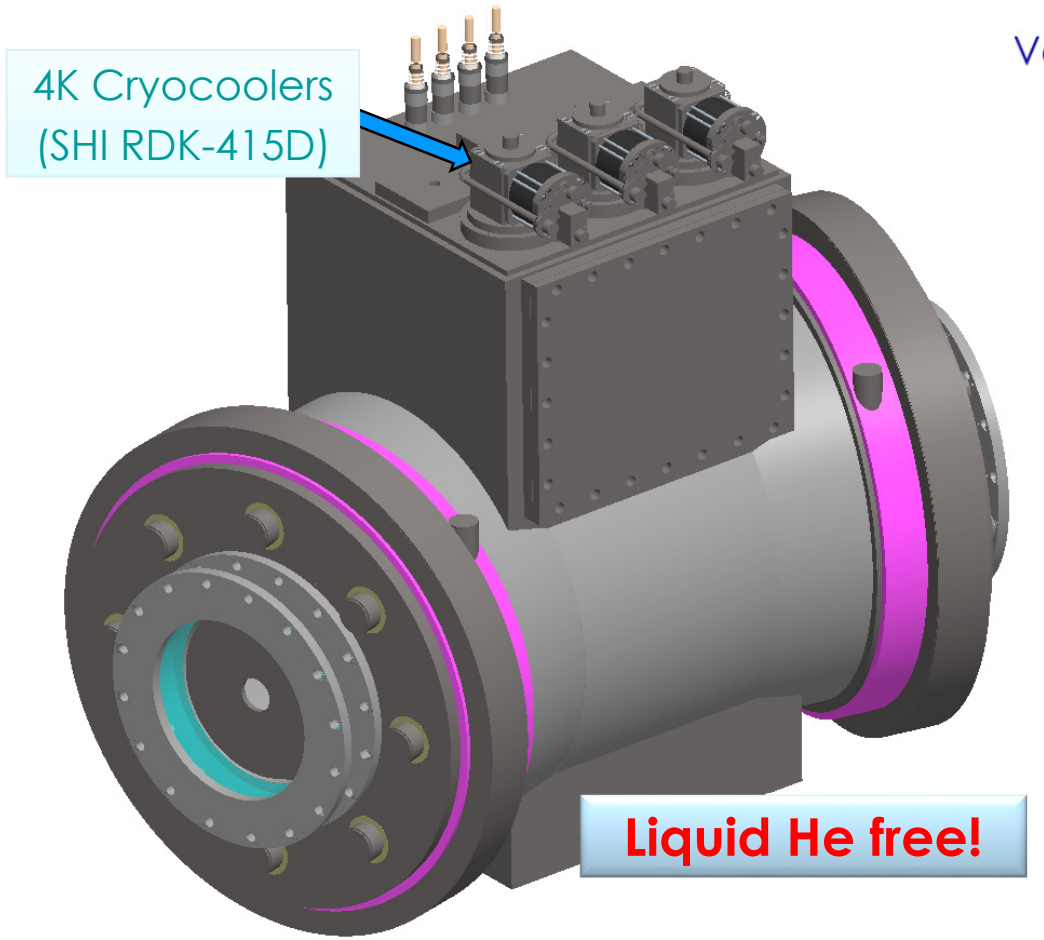


NIRS

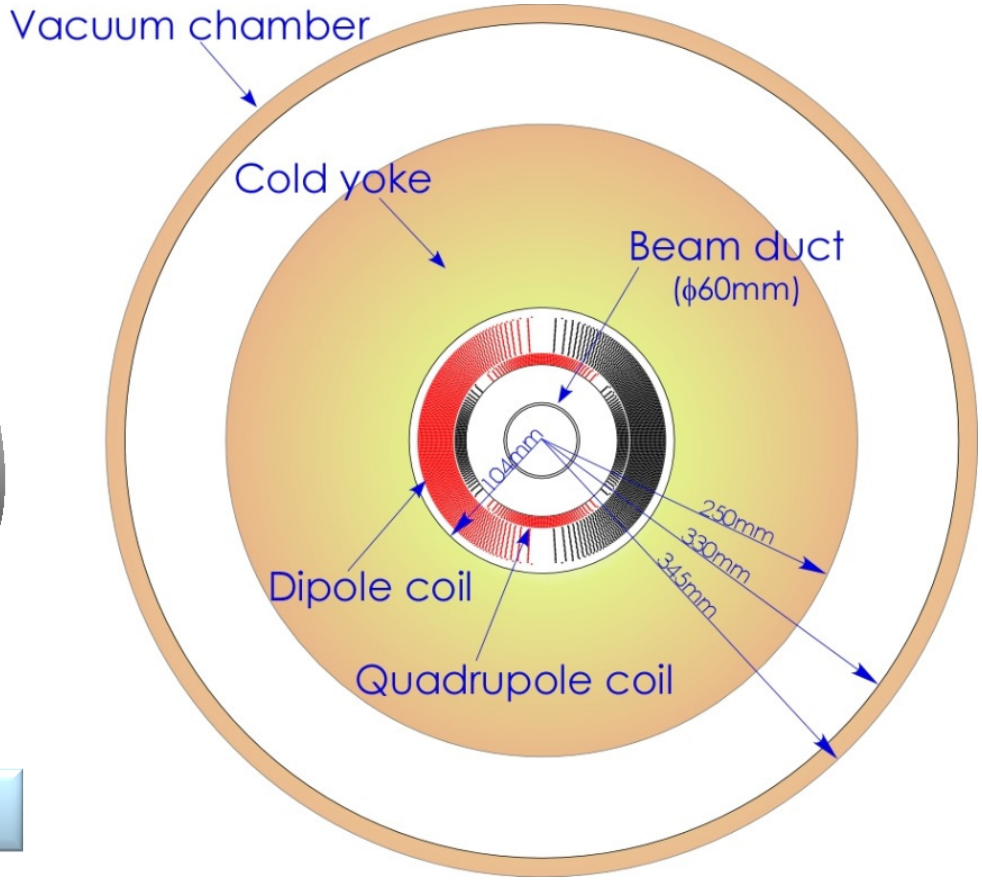
HIMAC

Development of curved SC magnets

SC magnet (BM02-05)



Cross-sectional view

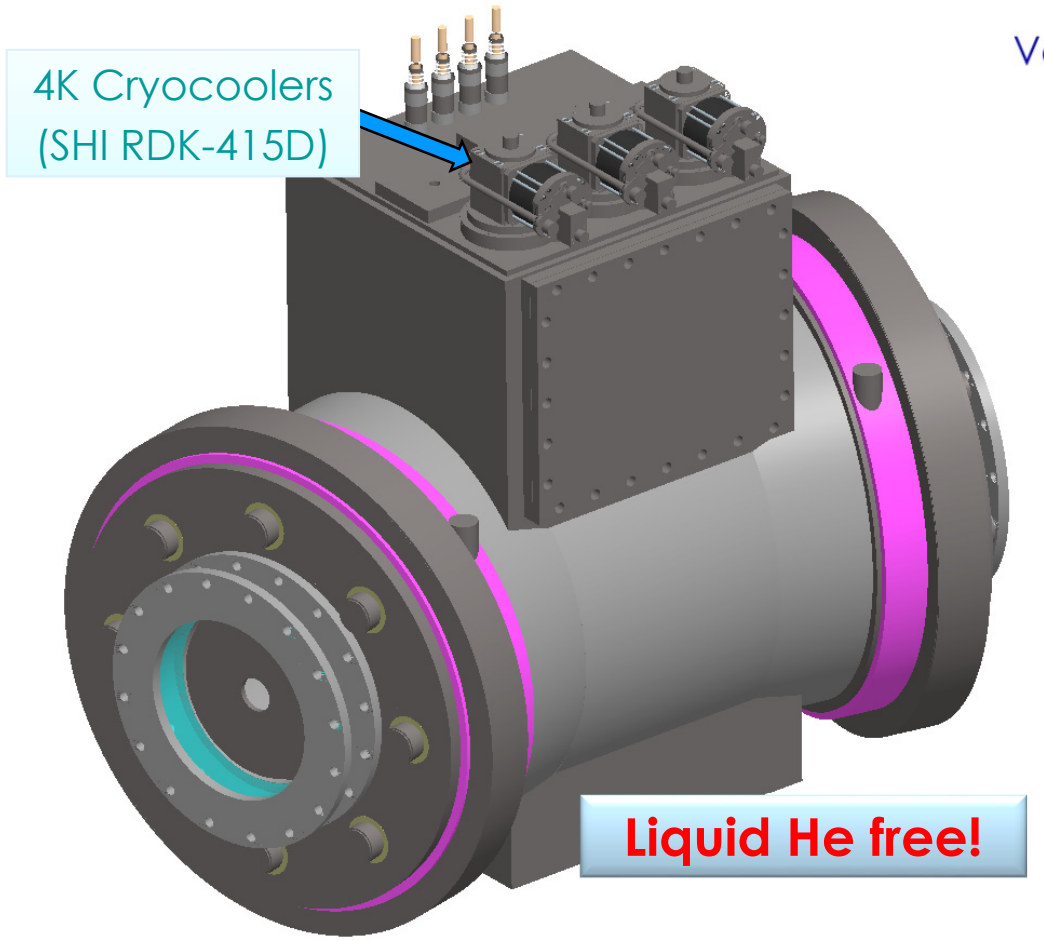


NIRS

HIMAC

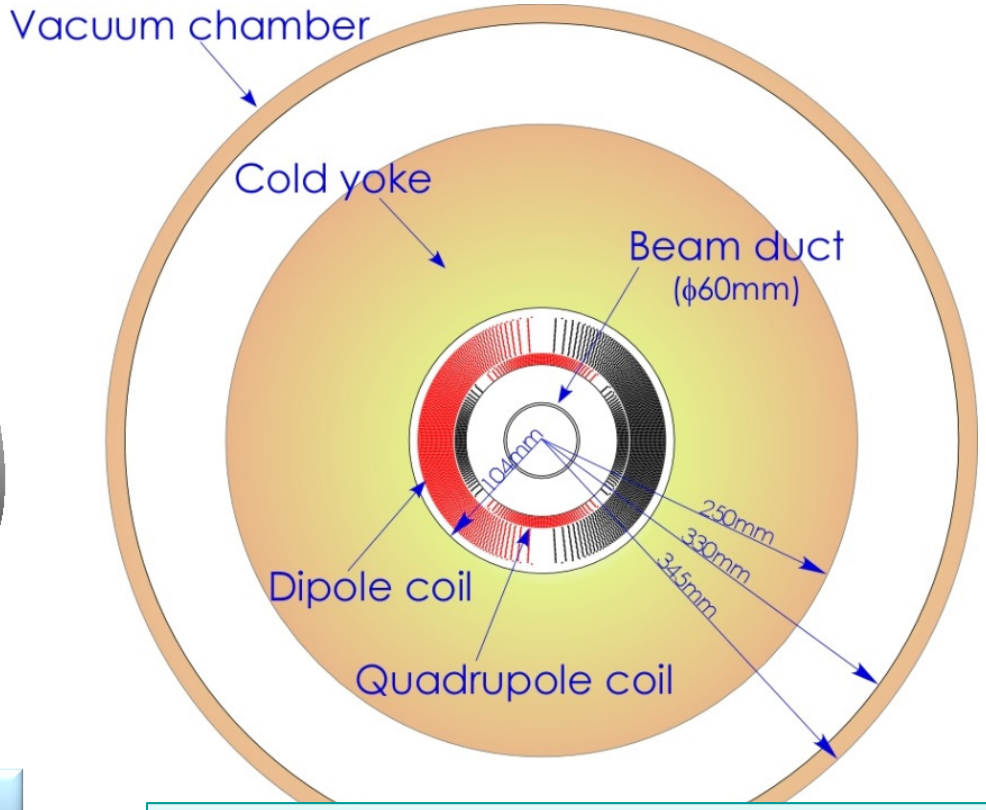
Development of curved SC magnets

SC magnet (BM02-05)



Liquid He free!

Cross-sectional view



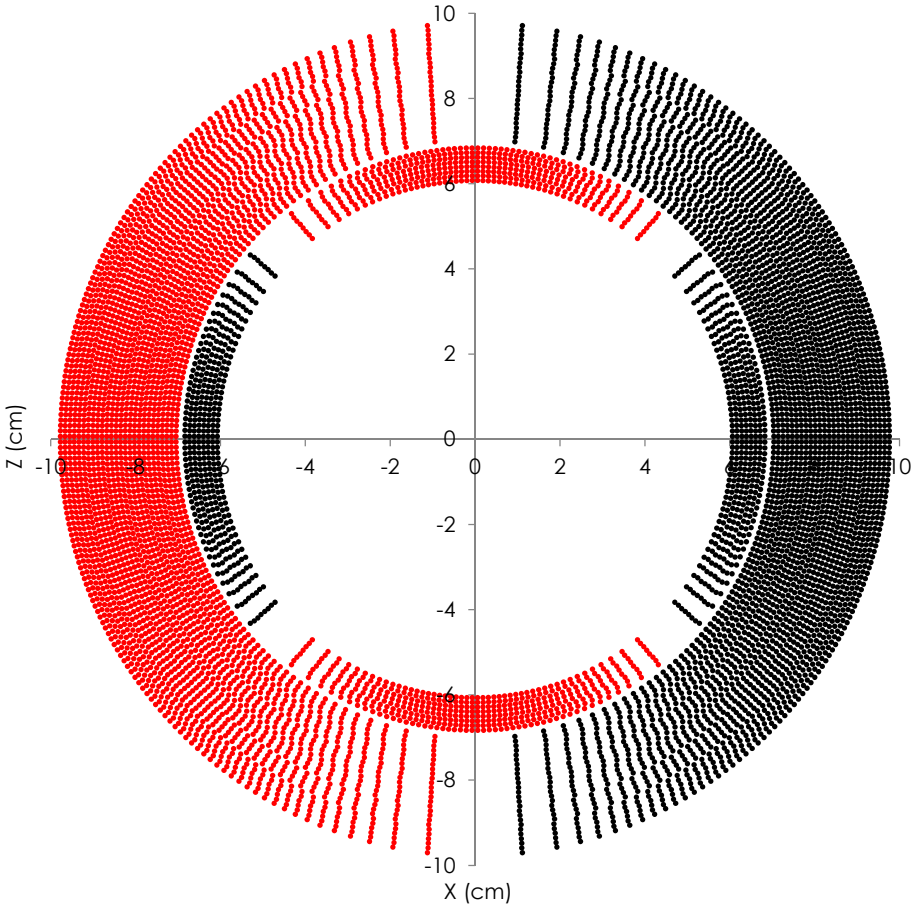
Dipole and quadrupole coils can be independently excited

NIRS

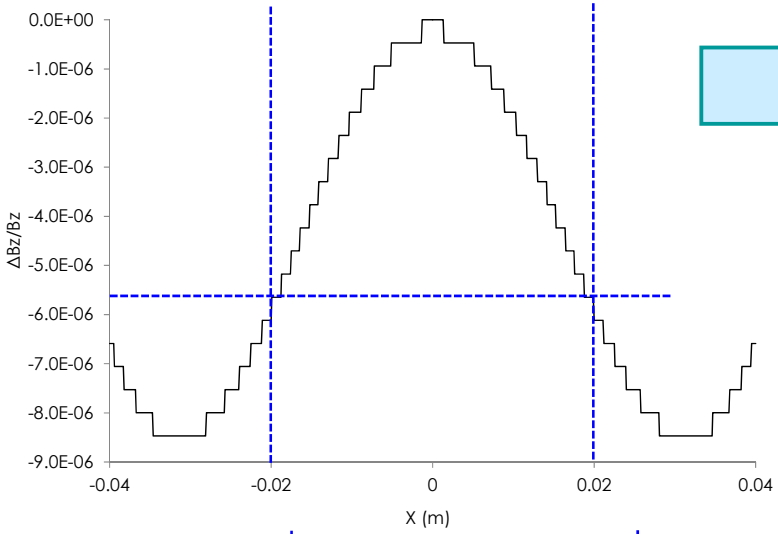
HIMAC

Design of superconducting coils

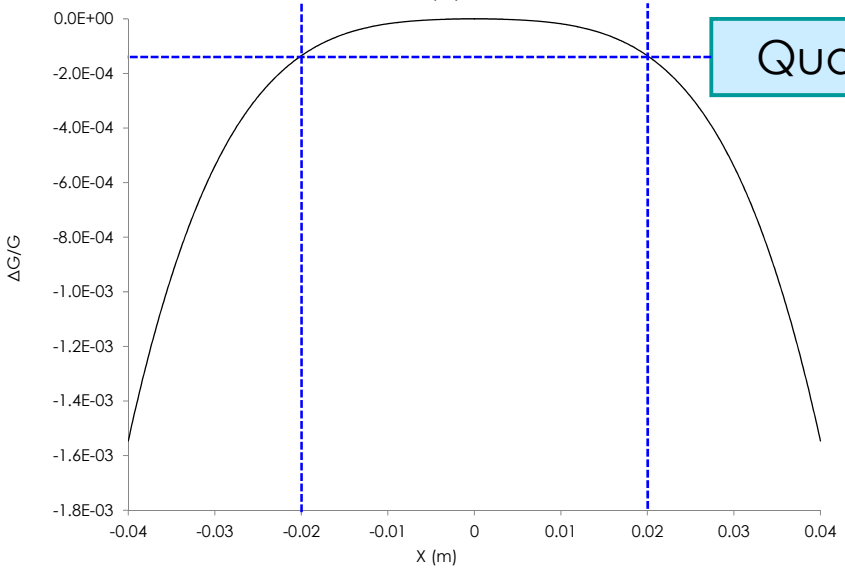
2D field calculation (BM02-BM05)



Dipole



Quardupole

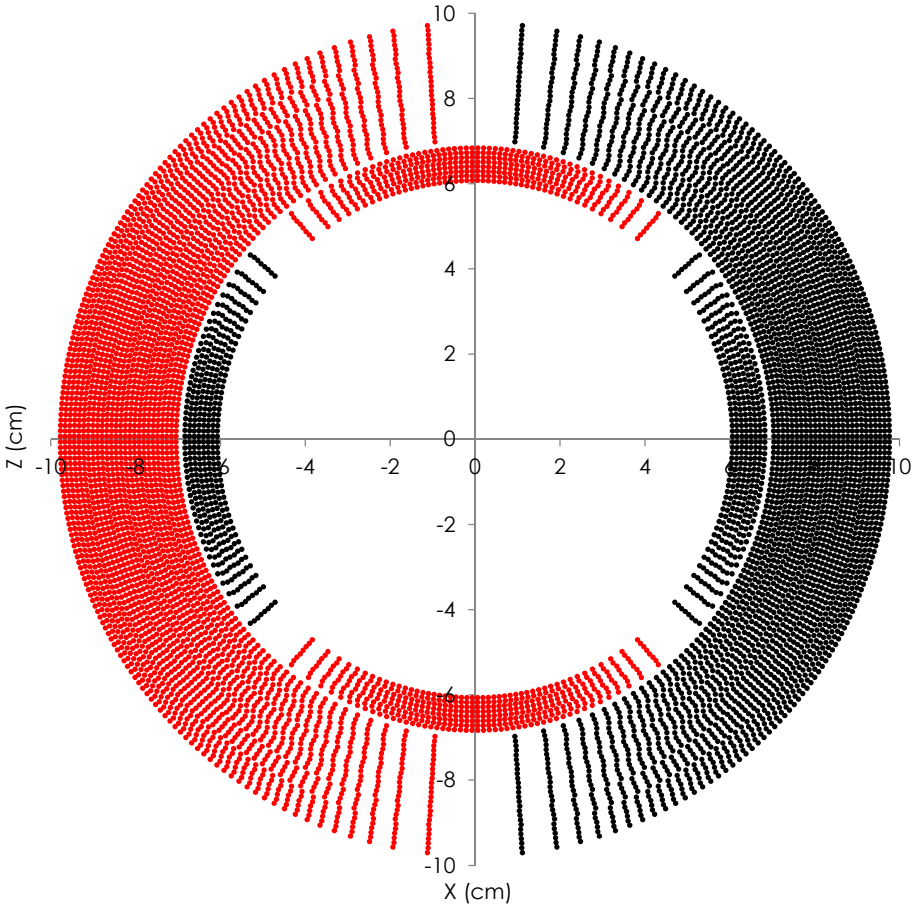


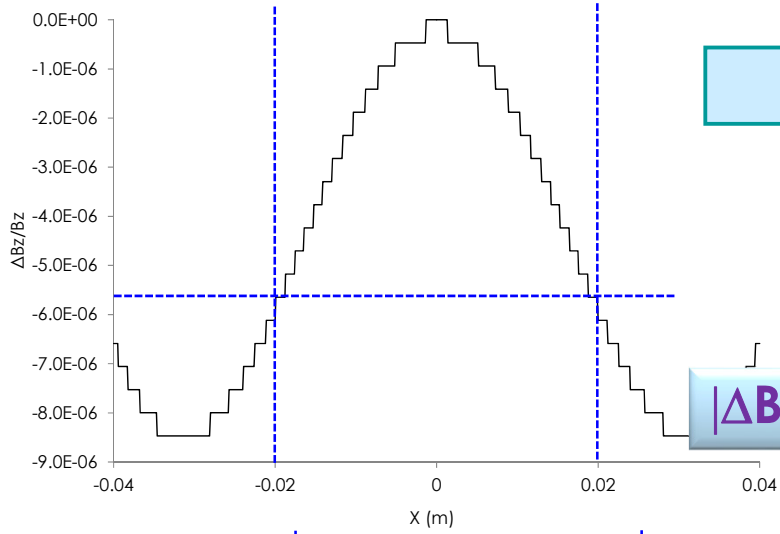
NIRS

HIMAC

Design of superconducting coils

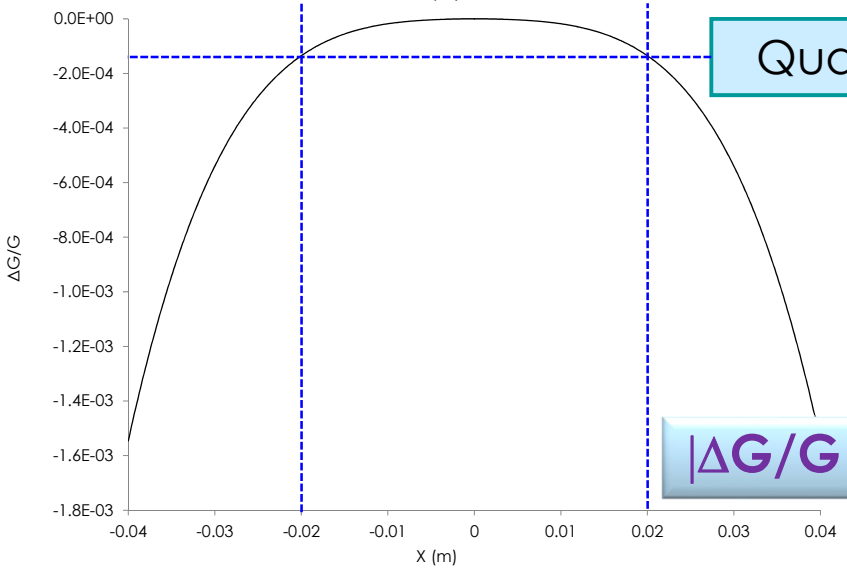
2D field calculation (BM02-BM05)





Dipole

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



Quardupole

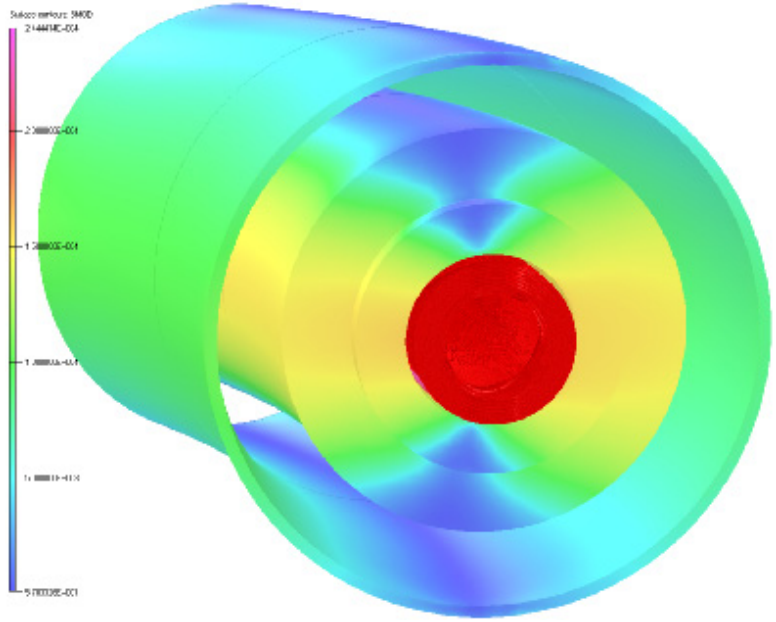
$|\Delta G/G| < 2 \times 10^{-4}$

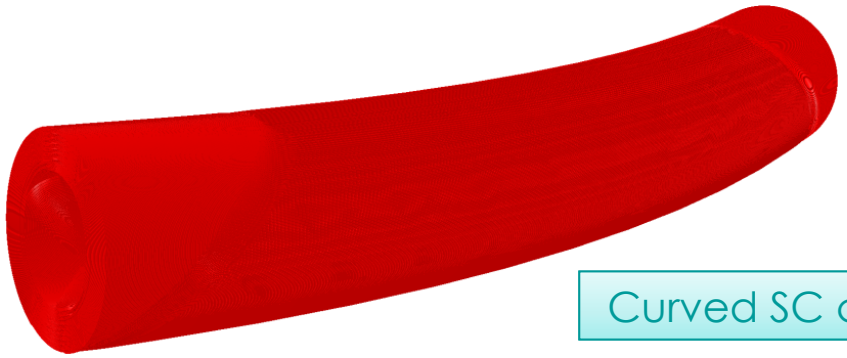
NIRS

HIMAC

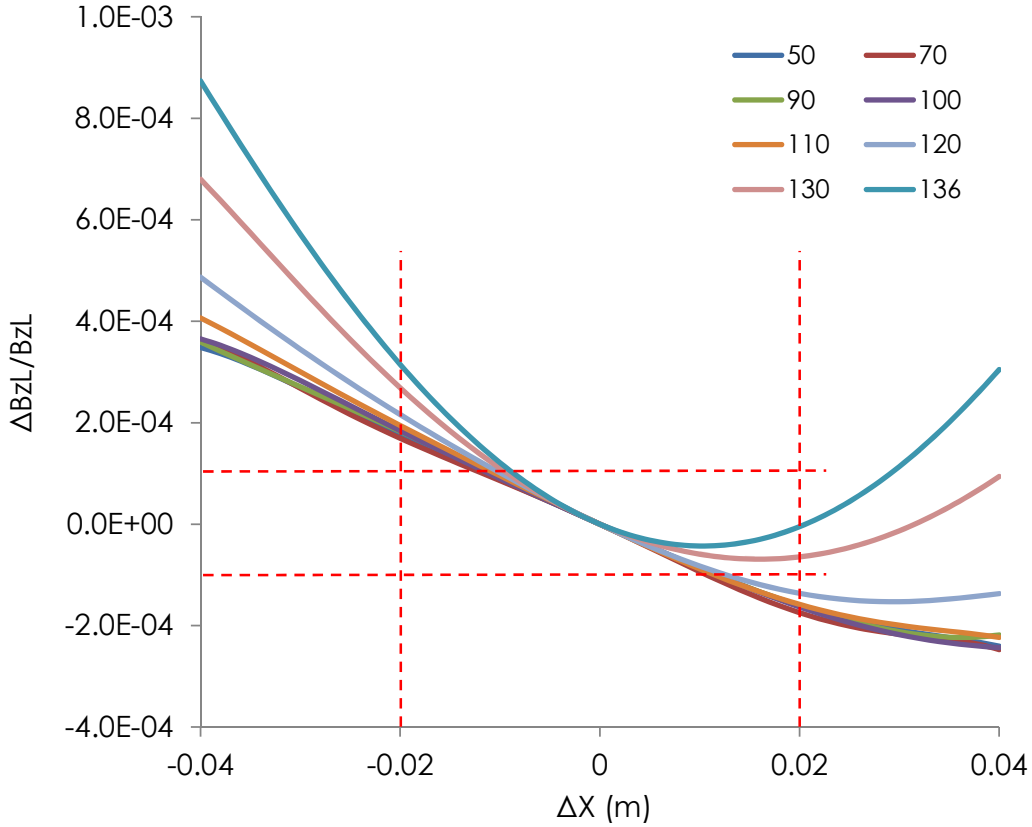
3D field calculation with Opera-3d

SC coils were precisely modelled





Curved SC coil



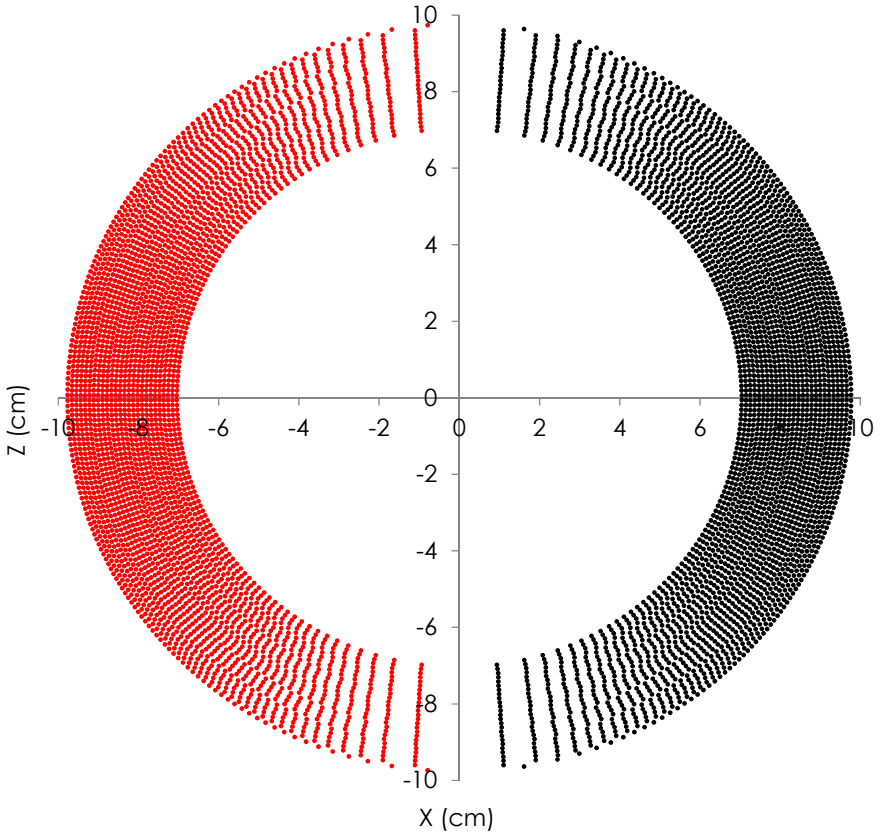
$|\Delta BL/BL| < 4 \times 10^{-4}$

NIRS

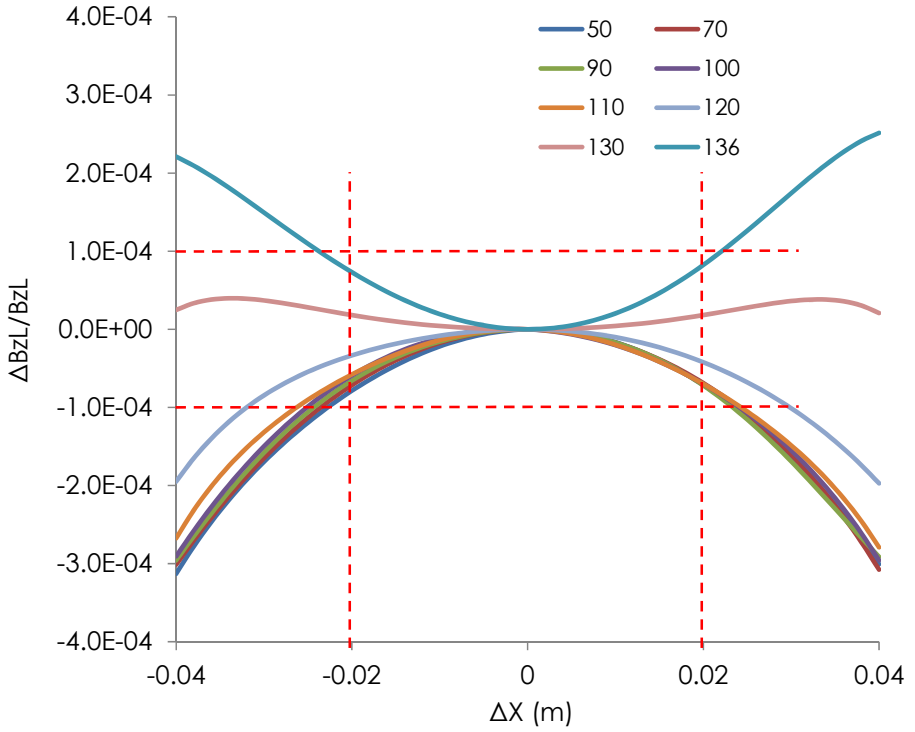
HIMAC

Corrections with the outermost layer

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



Corrected uniformity



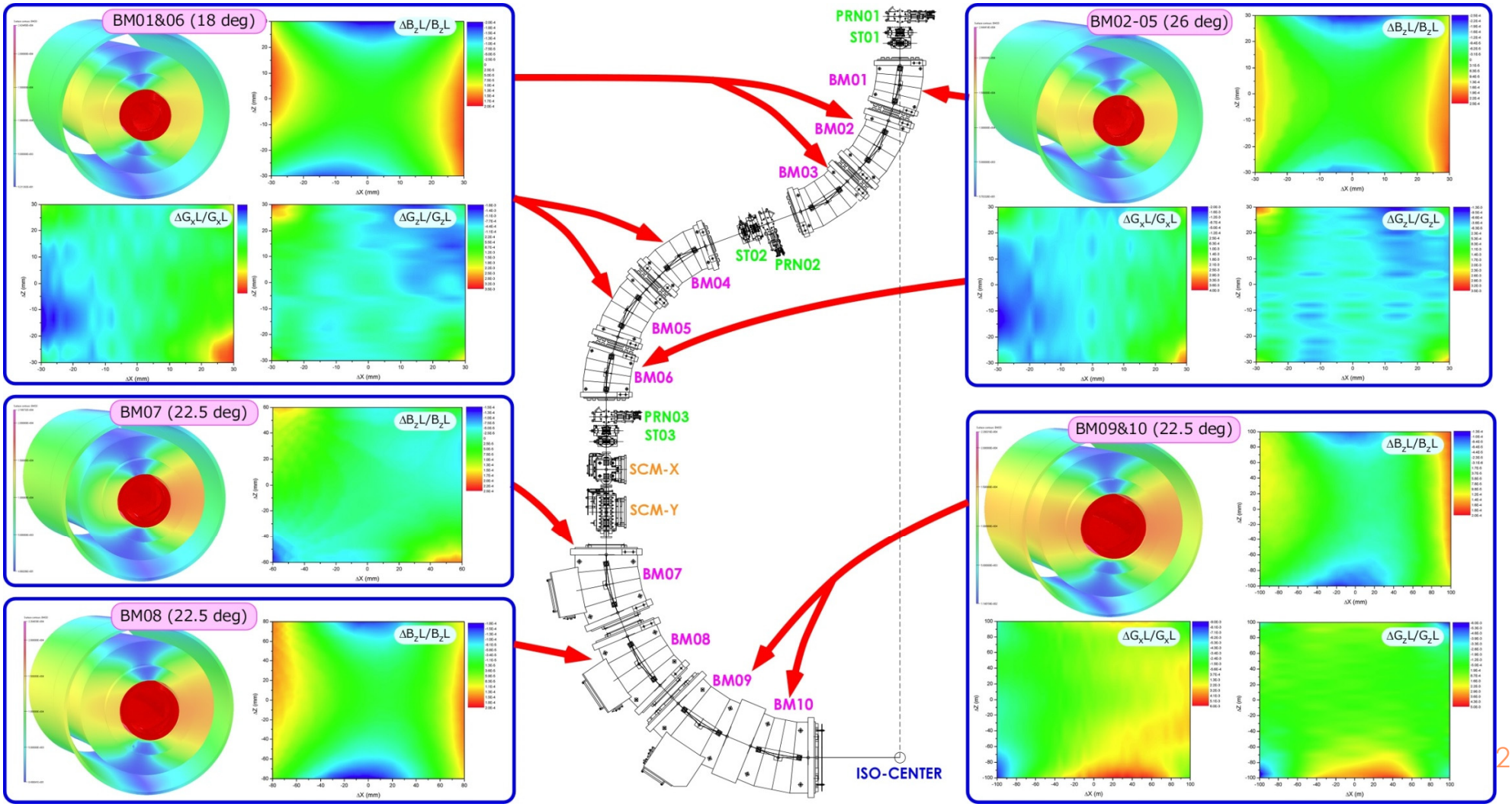
$|\Delta BL/BL| < 1 \times 10^{-4}$!

NIRS

HIMAC

Design of SC magnets

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

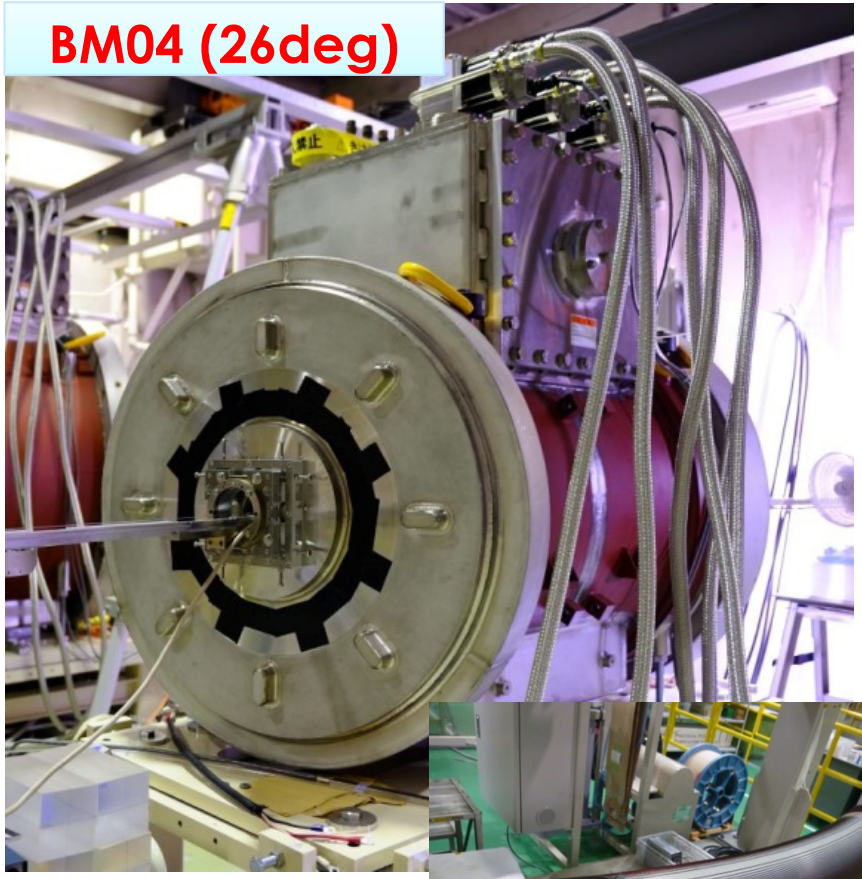


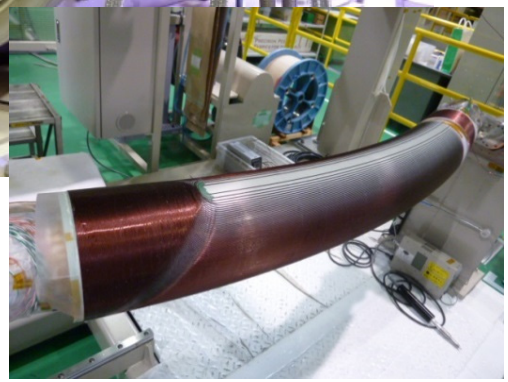
NIRS

HIMAC

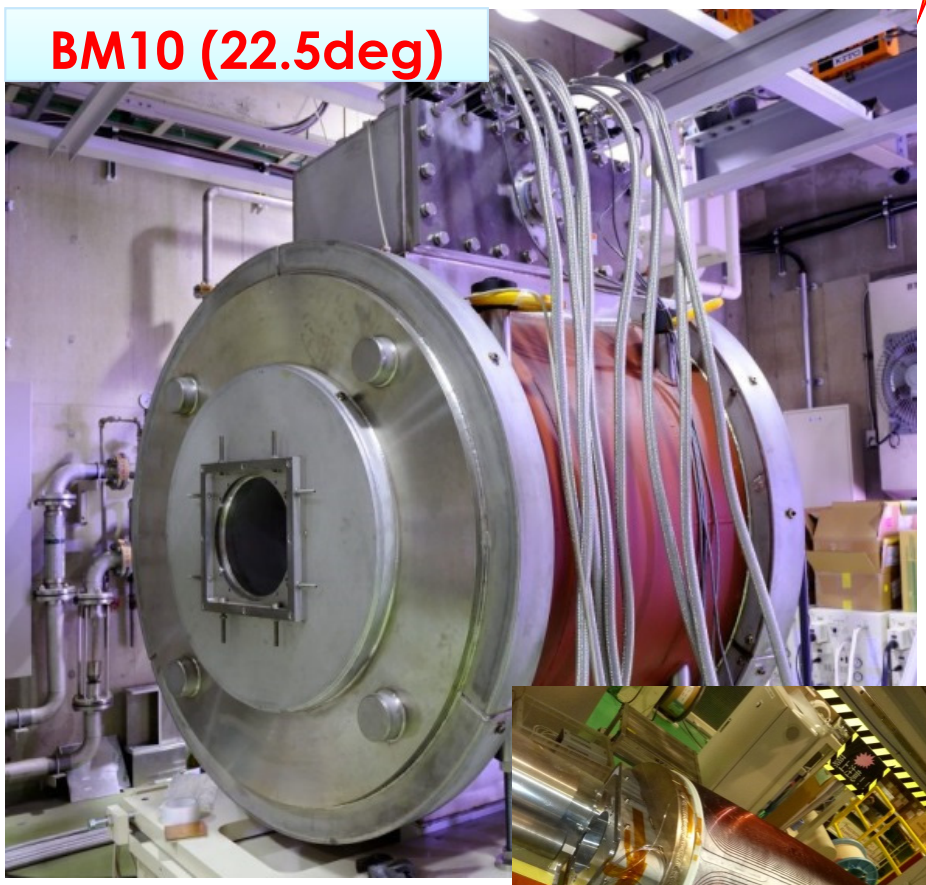
Construction of SC magnets

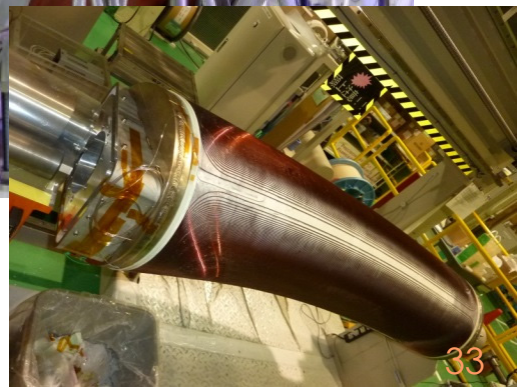
BM04 (26deg)





BM10 (22.5deg)



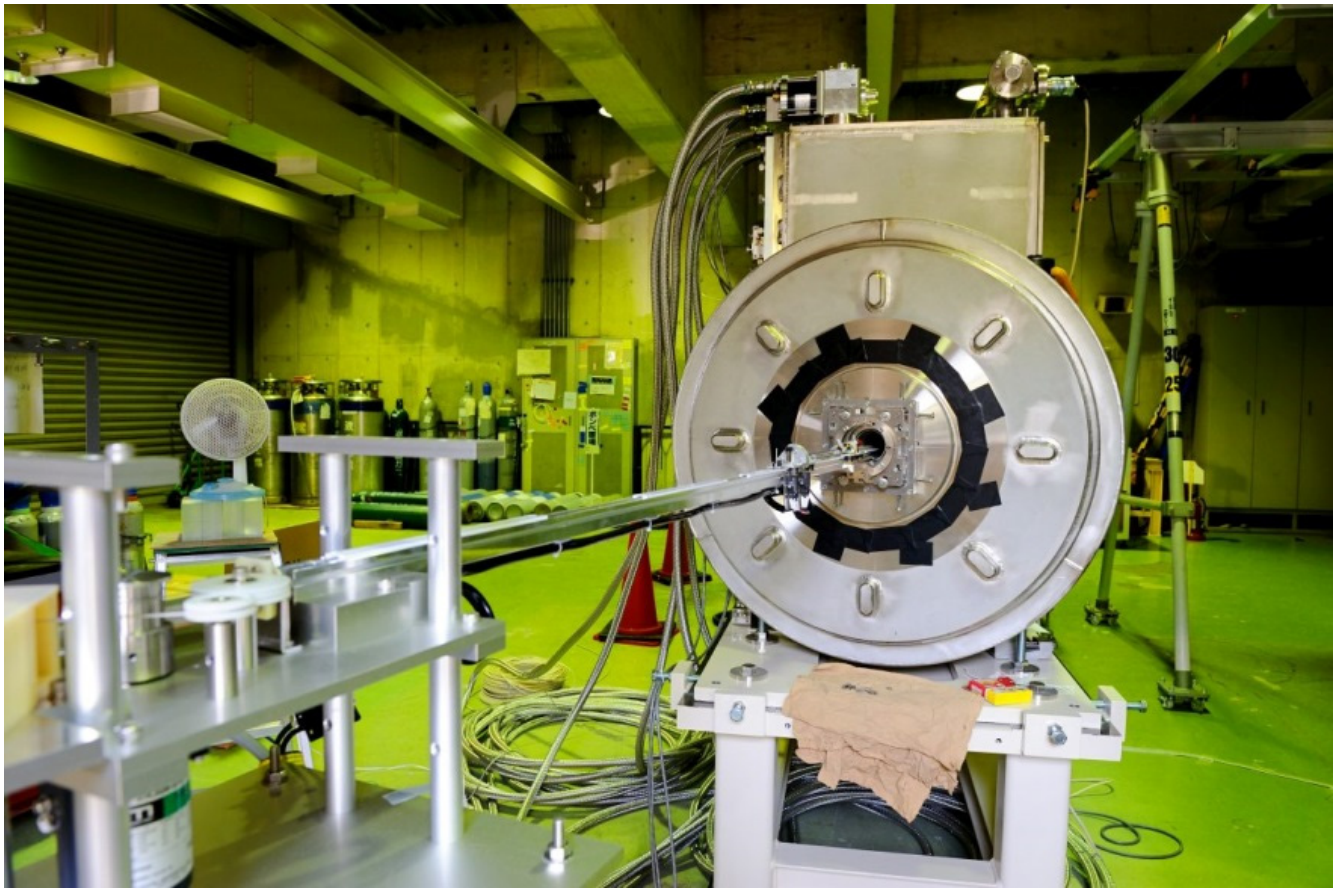


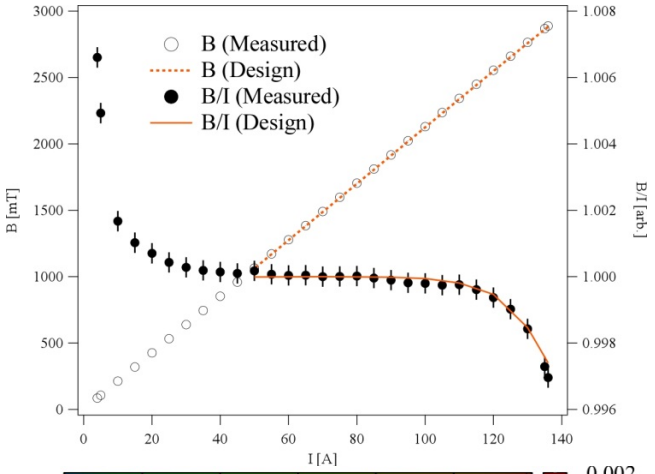
NIRS

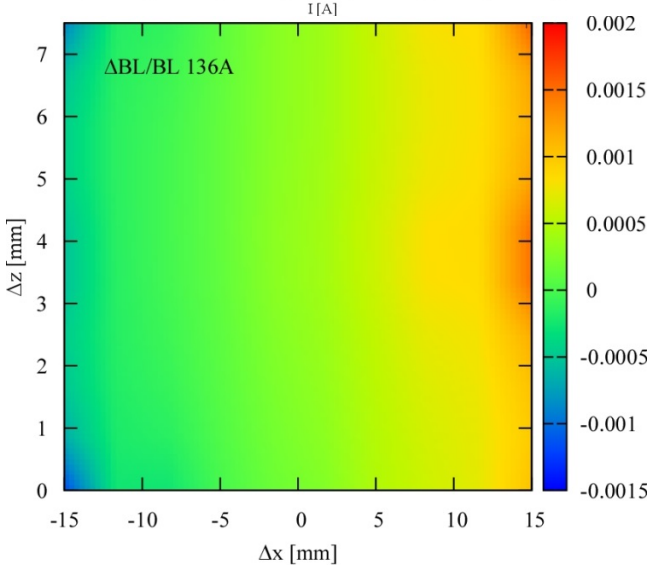
HIMAC

Field measurements

- Magnetic field measurements were performed
  - to verify the SC magnet design







Construction of the gantry structure

NIRS

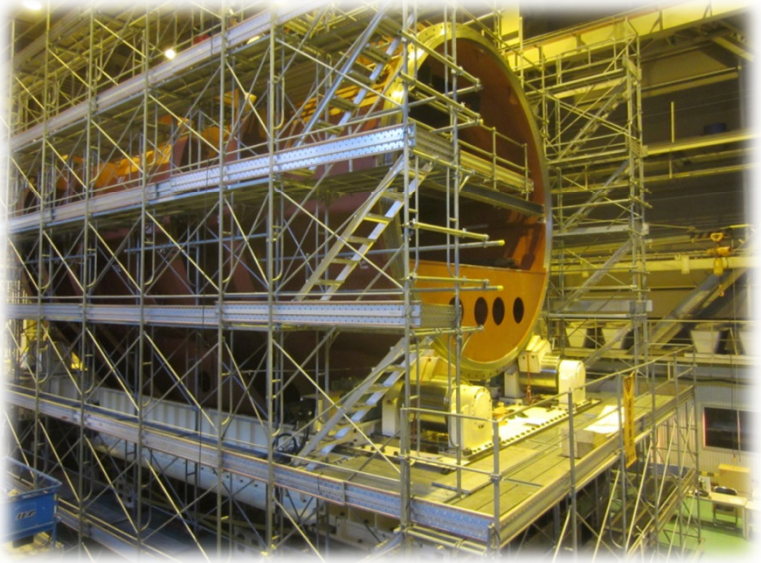
HIMAC

Construction of structure

NIRS

HIMAC

Assembling at Toshiba



NIRS

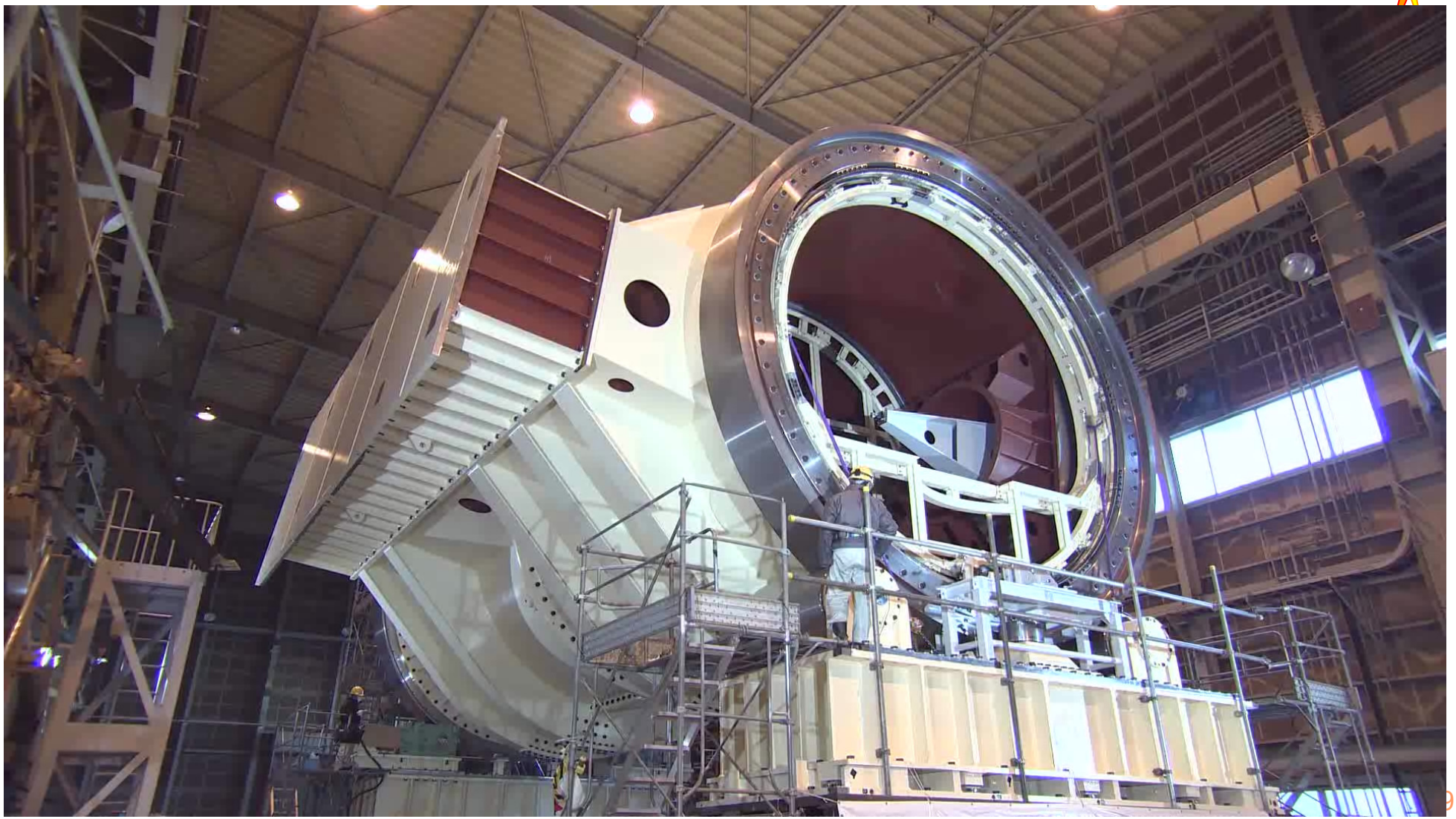
HIMAC

Assembling at Toshiba

NIRS

HIMAC

Rotation tests at Toshiba



NIRS

HIMAC

Transportation to NIRS

NIRS

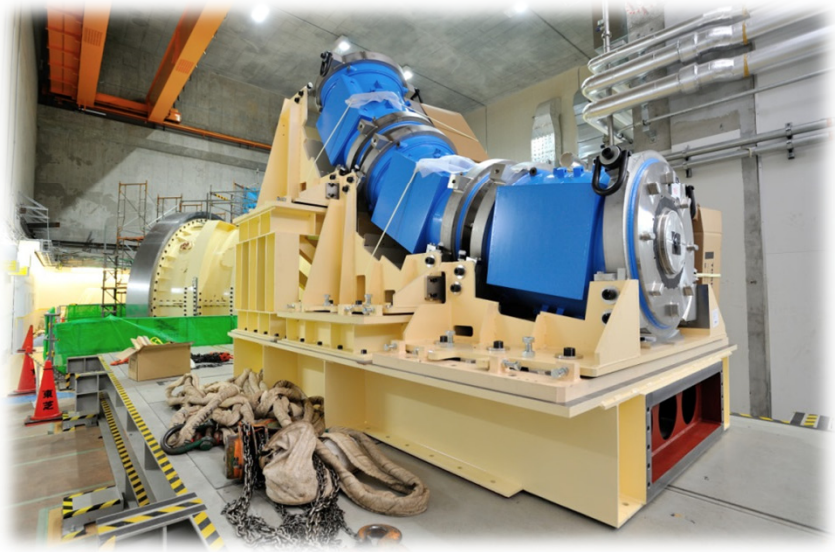
HIMAC

Installation to the gantry room

NIRS

HIMAC

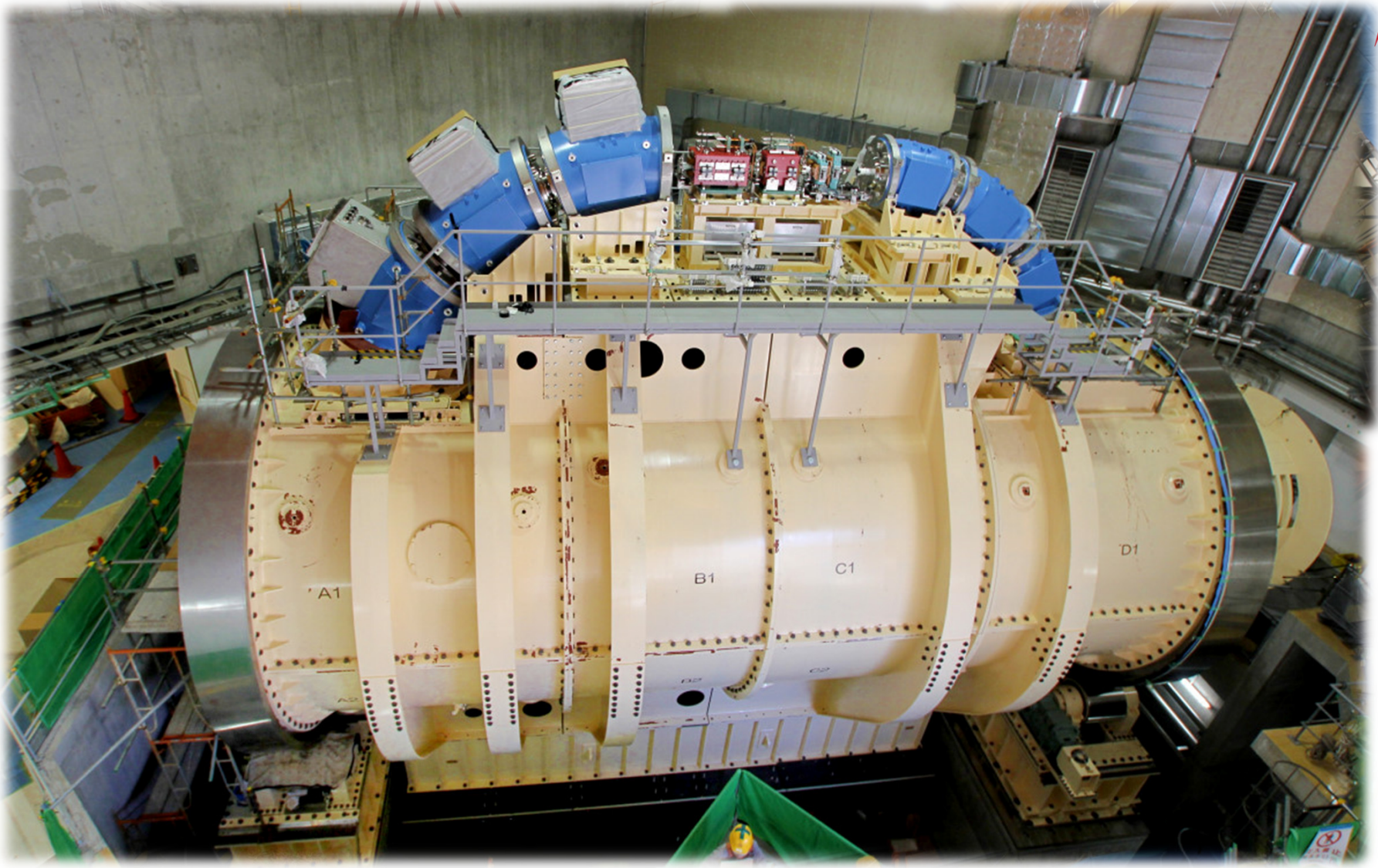
Reassembling at NIRS



NIRS

HIMAC

Reassembling at NIRS



NIRS

HIMAC

Treatment-room design

- The treatment room for the gantry is designed, based on the existing room E & F

Treatment room E and F

NIRS

HIMAC

Treatment-room design

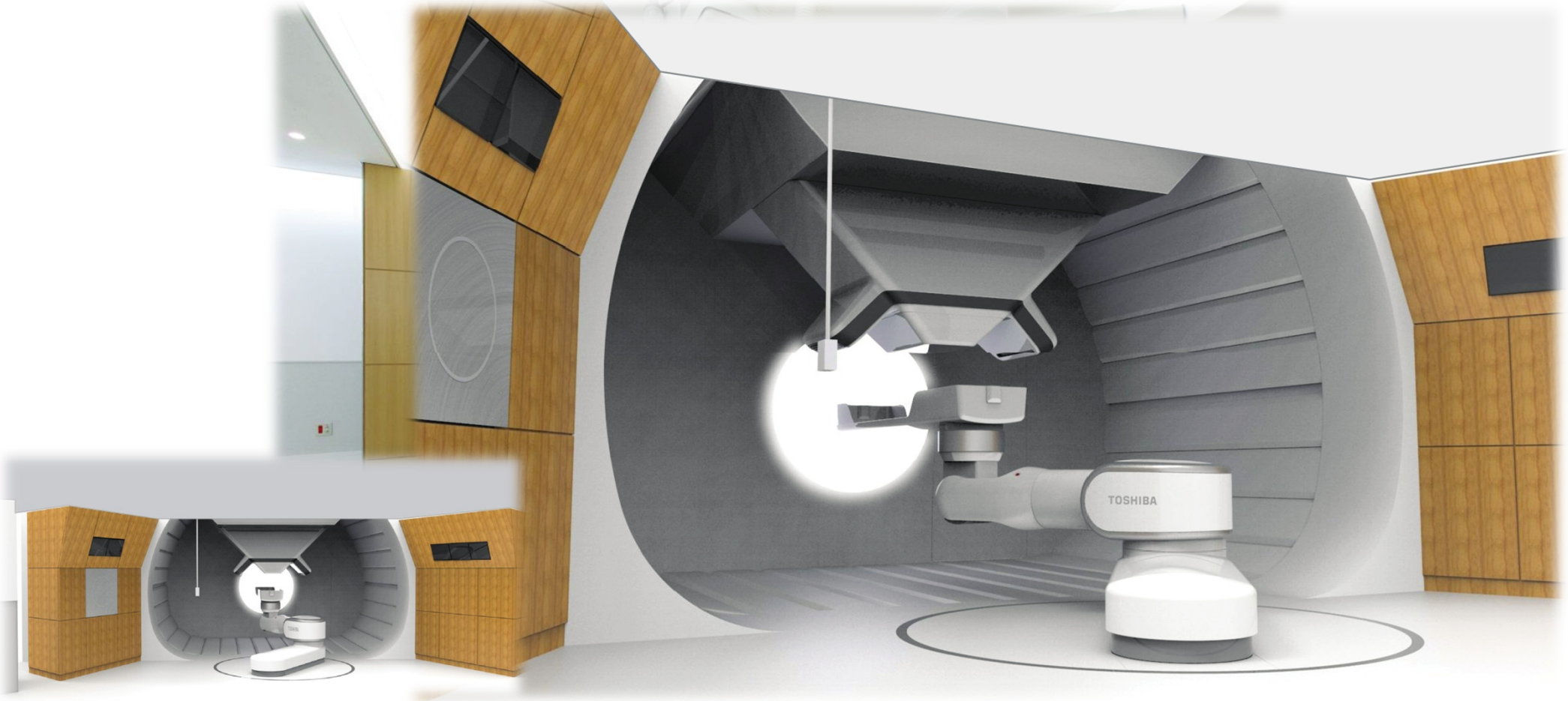
- The treatment room for the gantry is designed, based on the existing room E & F

NIRS

HIMAC

Treatment-room design

- The treatment room for the gantry is designed, based on the existing room E & F



NIRS

HIMAC

Summary

- Design of the superconducting rotating-gantry
  - Compact (~proton gantries)
  - Construction will be completed by the end of this month
- Future plan
  - Commissioning will be made from this October
  - Treatment will be made in 2016

NIRS

HIMAC

Collaborators

- K. Noda, T. Shirai, T. Fujita, T. Furukawa, K. Mizushima, Y. Hara, Y. Saraya, R. Tansho, S. Matsuba, S. Mori, S. Sato, K. Shoda (NIRS)
- T. Fujimoto, H. Arai (AEC)
- T. Ogitsu (KEK)
- N. Amemiya (Kyoto Univ.)
- Y. Nagamoto, T. Orikasa, S. Takayama, (Toshiba)

NIRS

HIMAC

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			
Maximum field	B_{dipole}	T	2.88						2.37			
Maximum field gradient	G_{max}	T/m	10						–		1.3	
Bore size	D_{bore}	mm	ϕ60						□122	□170	□206	
Effective radius or area	D_f or A_f	mm	ϕ40						□120	□160	□200	
Uniformity (dipole)	ΔBL/BL	–	$\pm 1\times10^{-4}$									
Uniformity (quadrupole)	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	