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Status of the superconducting rotating gantry for heavy-ion therapy

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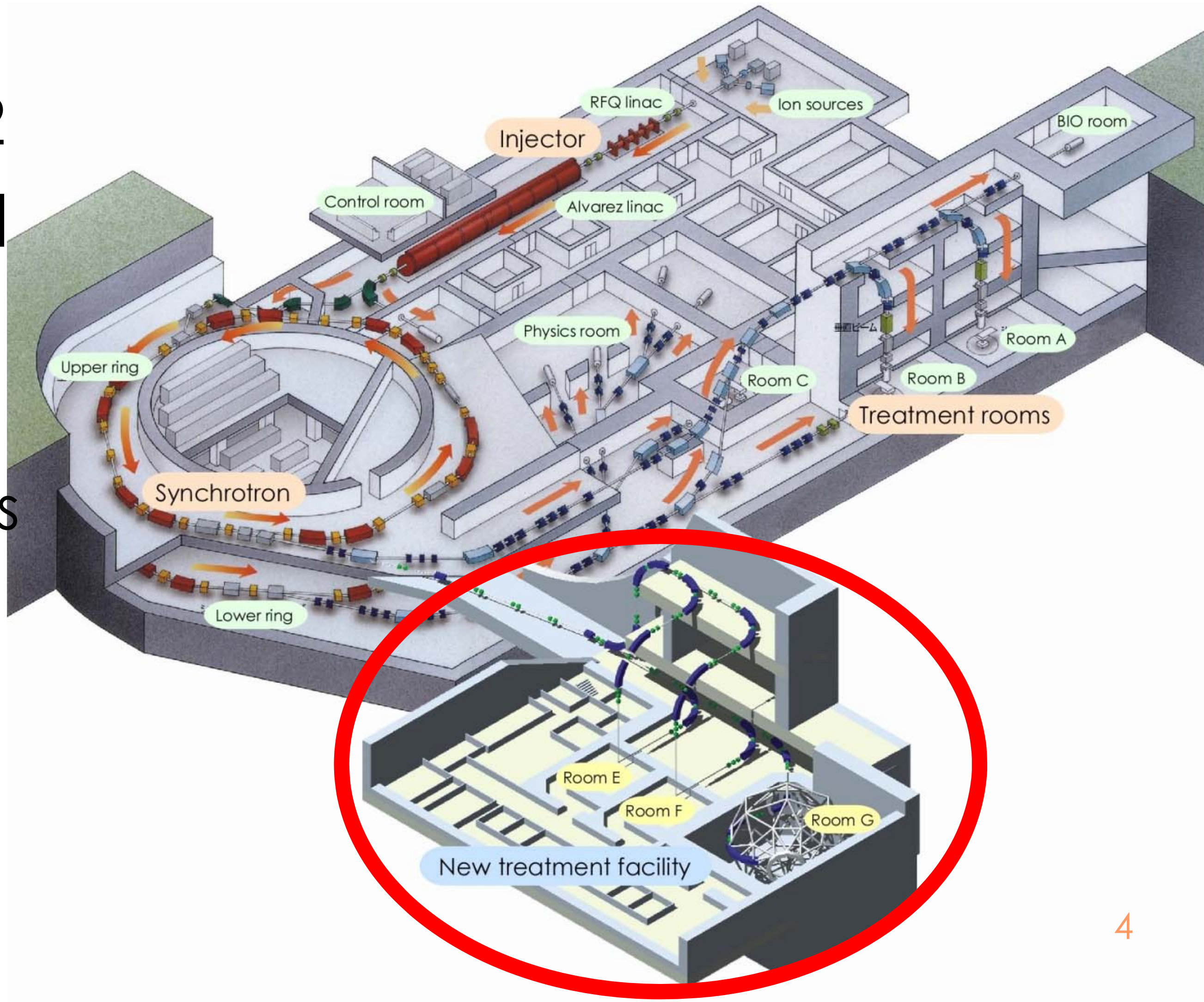
Outline

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

Introduction

Carbon radiotherapy at NIRS

- Heavy Ion Medical Accelerator in Chiba (HIMAC)
  - Ion species: p~Xe
  - E/A=800 MeV @A/Z=2
- >9000 patients treated
- New treatment facility
  - Room E & F
    Fixed H&V scanning ports
    (**in treatment operation**)
  - **Room G**
    Rotating gantry port
    (Under development)



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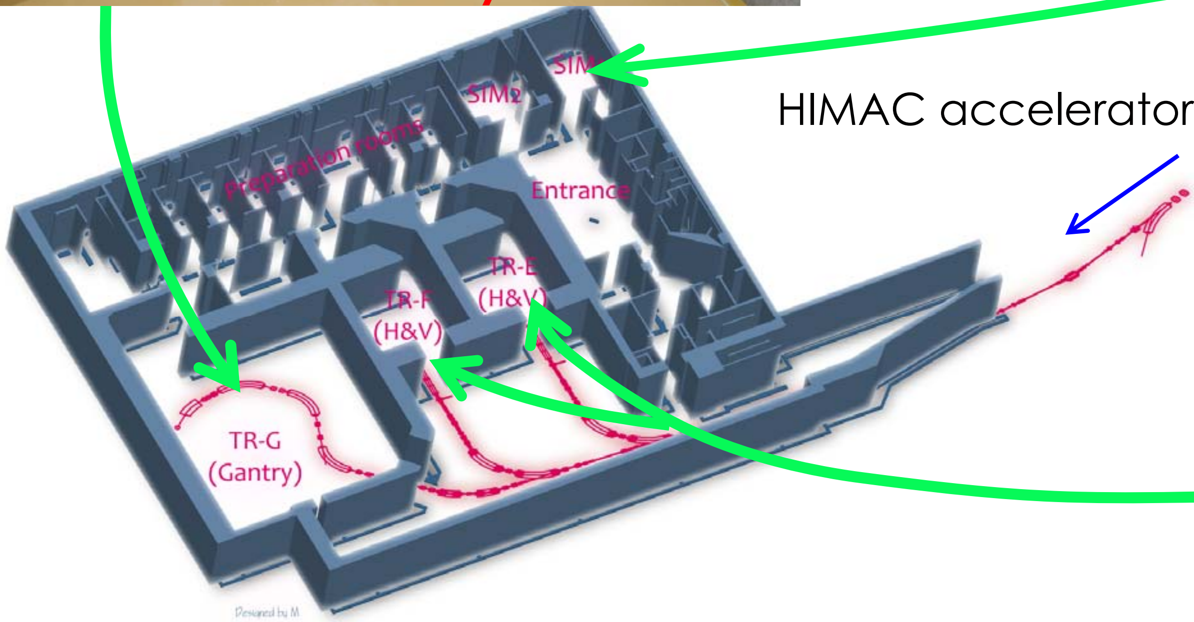
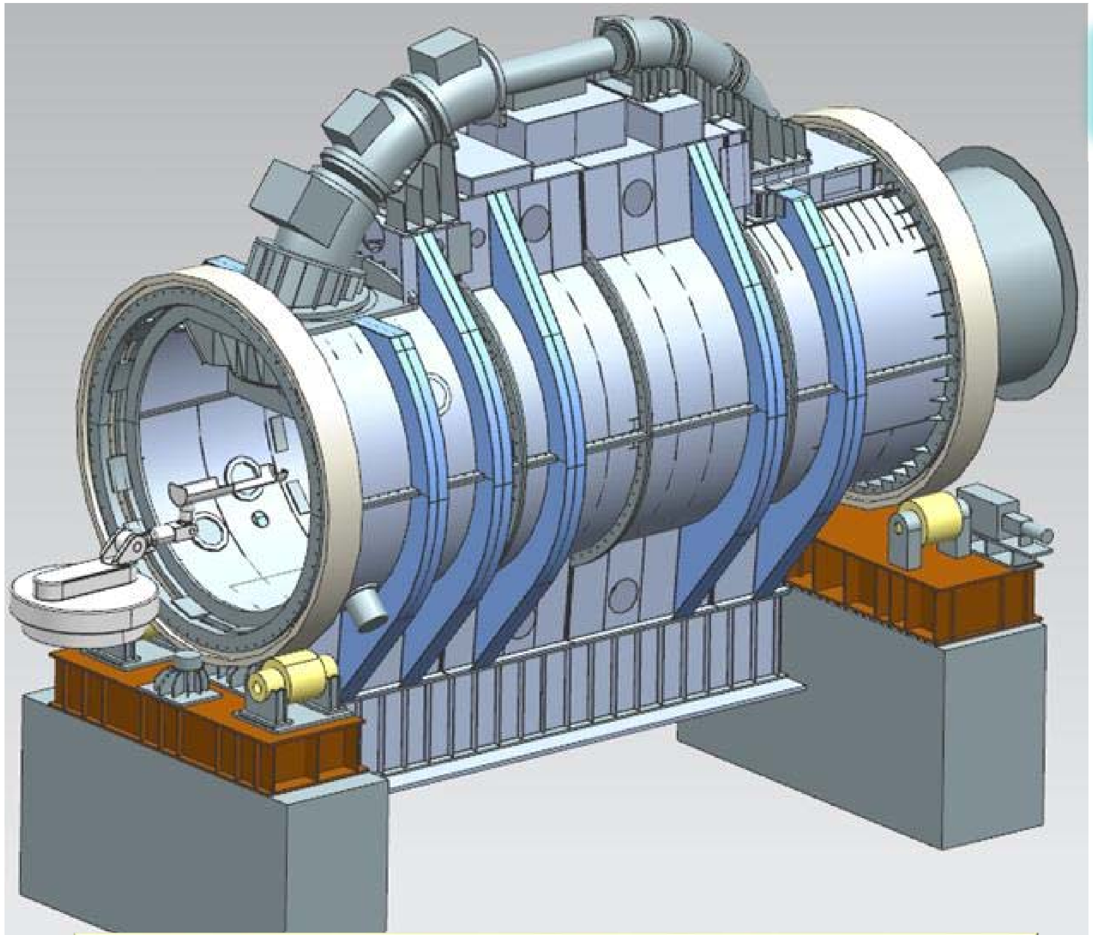
Treatment floor (B2F)



HIMAC accelerators

Superconducting rotating-gantry



Weight: order of 300 tons

Use of superconducting (SC) magnets

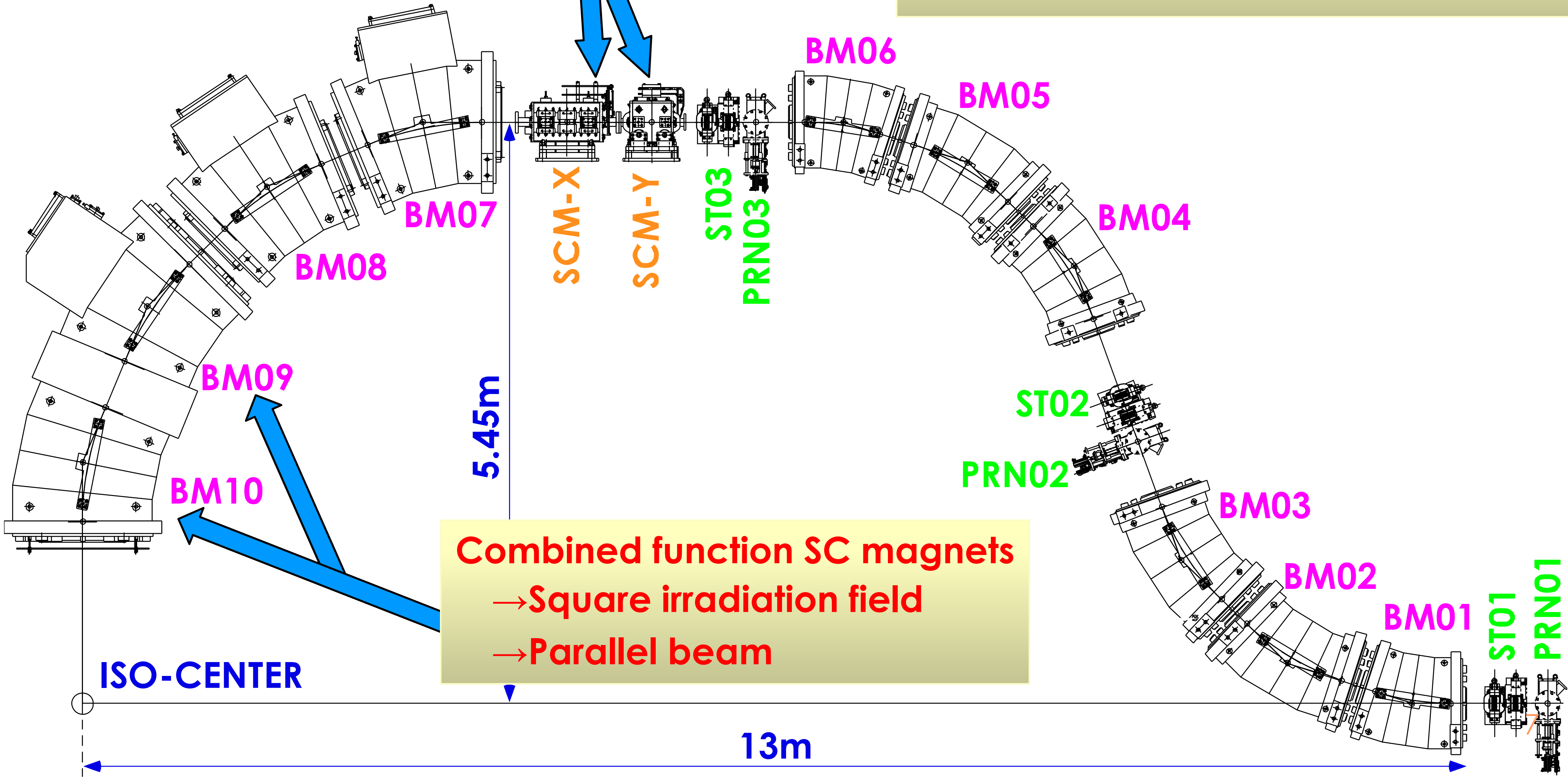
Ion kind	: ^{12}C
Irradiation method	: 3D Scanning
Beam energy	: 430 MeV/n
Maximum range	: 30 cm in water
Scan size	: □200×200 mm^2
Beam orbit radius	: 5.45 m
Length	: 13 m

The size and weight are considerably reduced

Layout of the SC gantry

Scanning magnets on top
→Large scan size

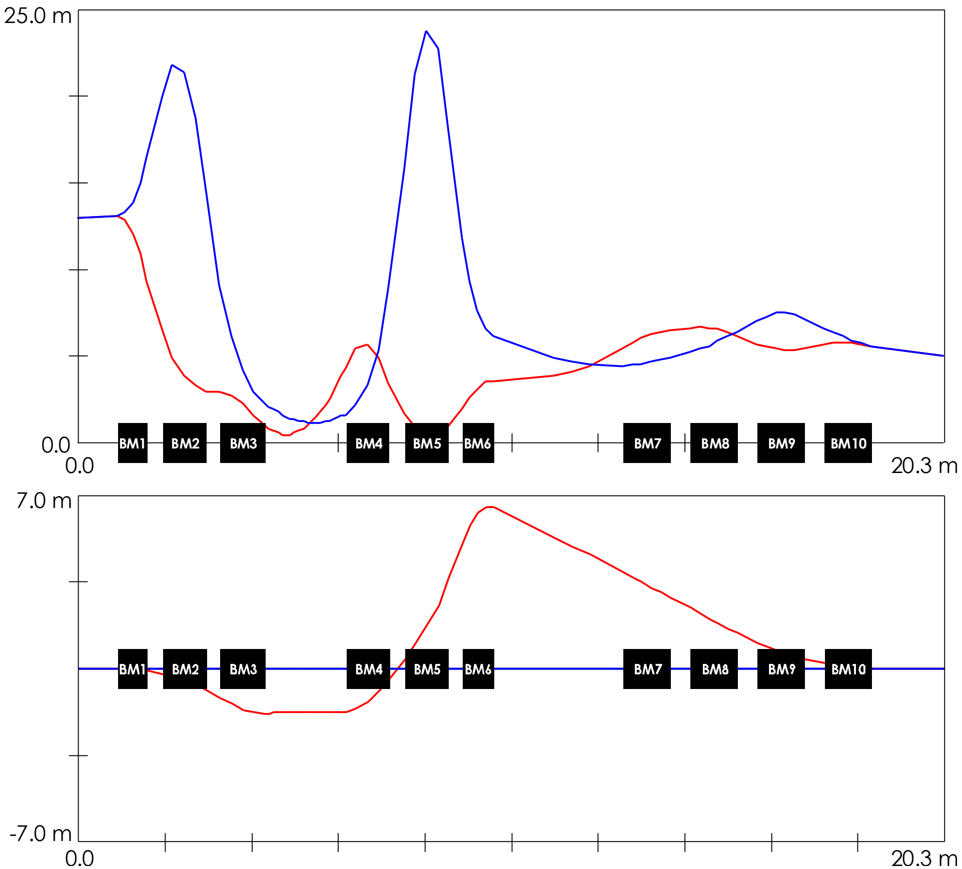
Combined function SC magnets
→No quadrupole magnet required



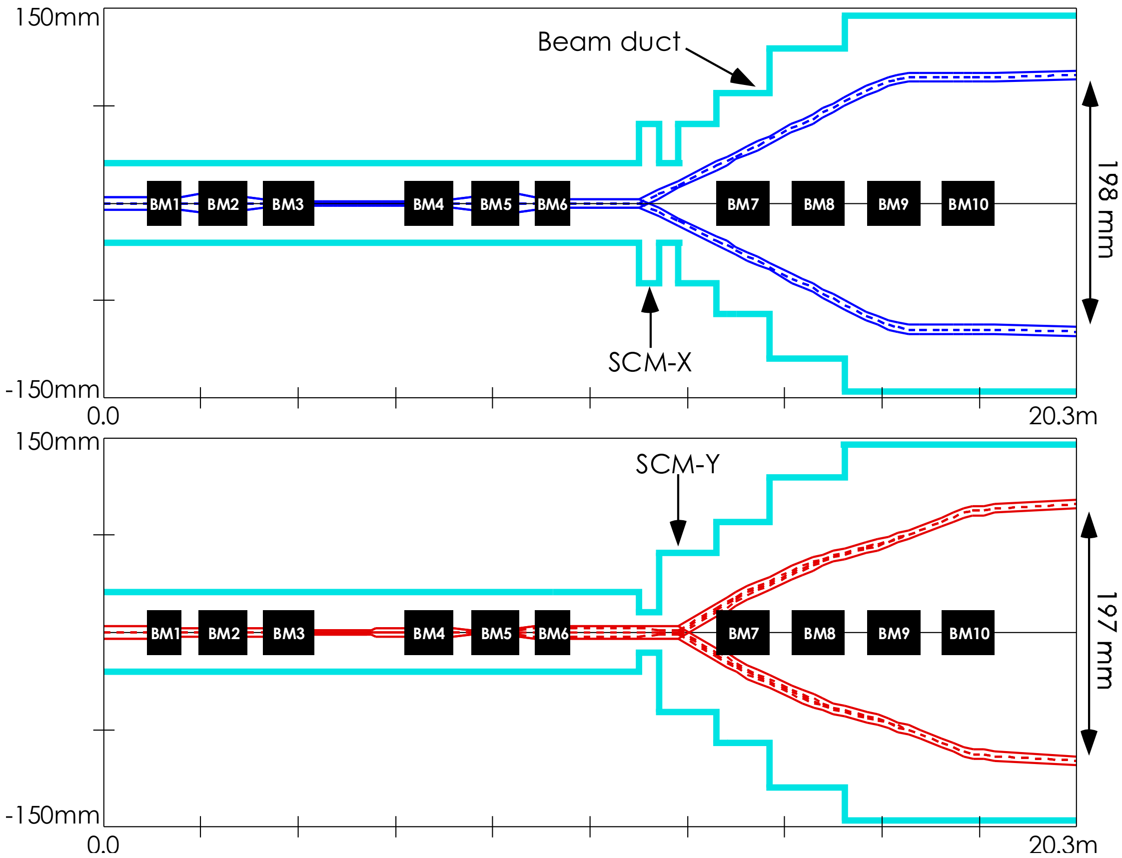
Combined function SC magnets
→Square irradiation field
→Parallel beam

Beam optics design

Beta and dispersion functions



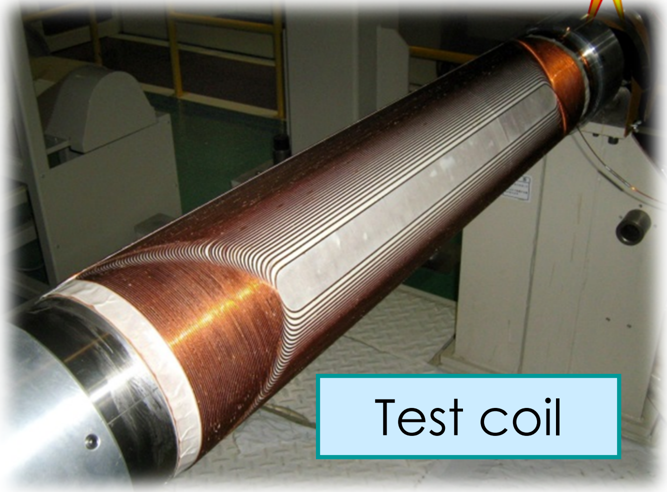
Beam envelope functions with kicks of scanning magnets

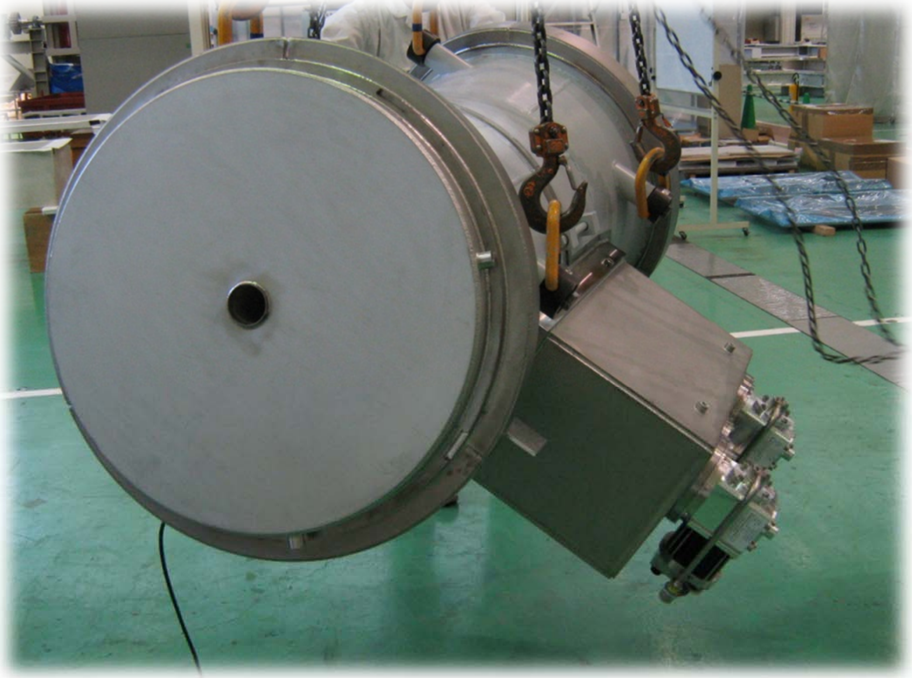


Development of superconducting magnets

SC coil and model magnet

- Superconducting test coil
- Model SC magnet
- Rotation tests
  - No quench observed
  - Displacement of coil≦±0.4mm

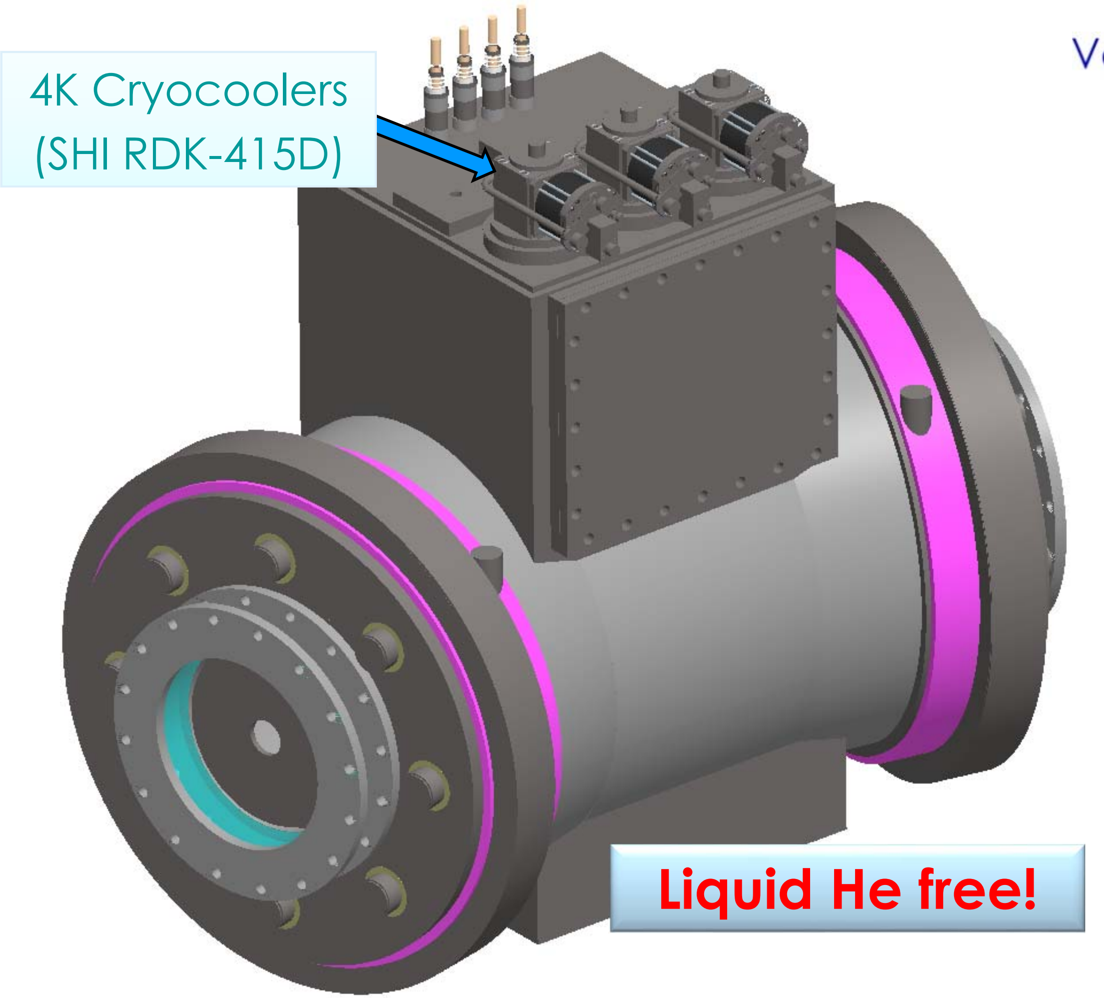


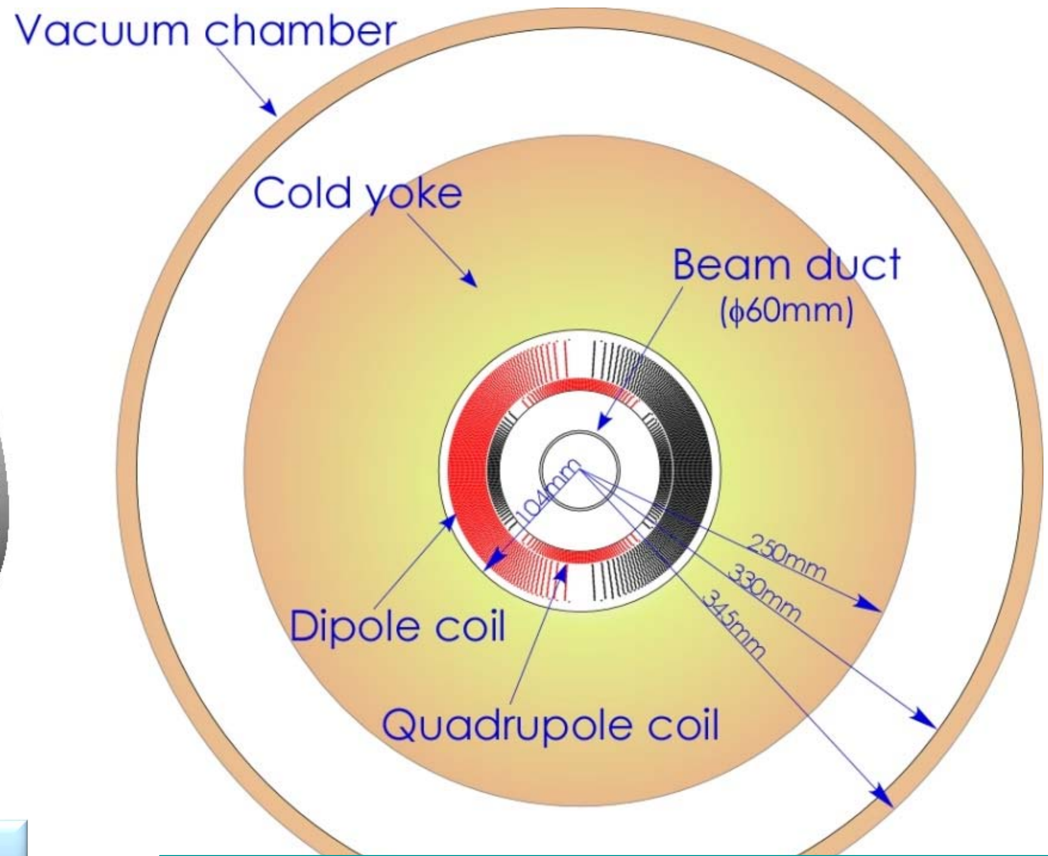


Development of curved SC magnets

SC magnet (BM02-05)

Cross-sectional view





Dipole and quadrupole coils can be independently excited

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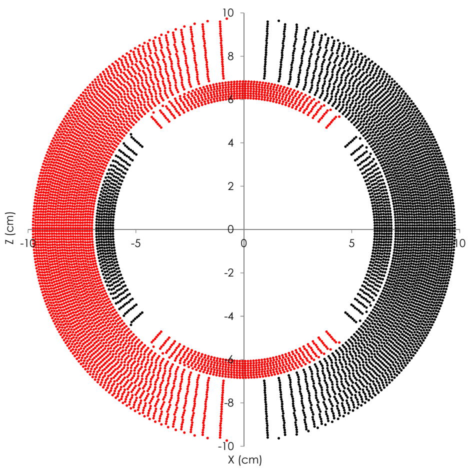
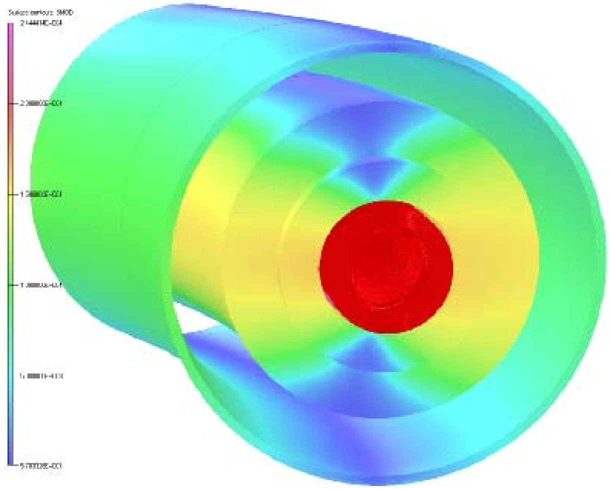
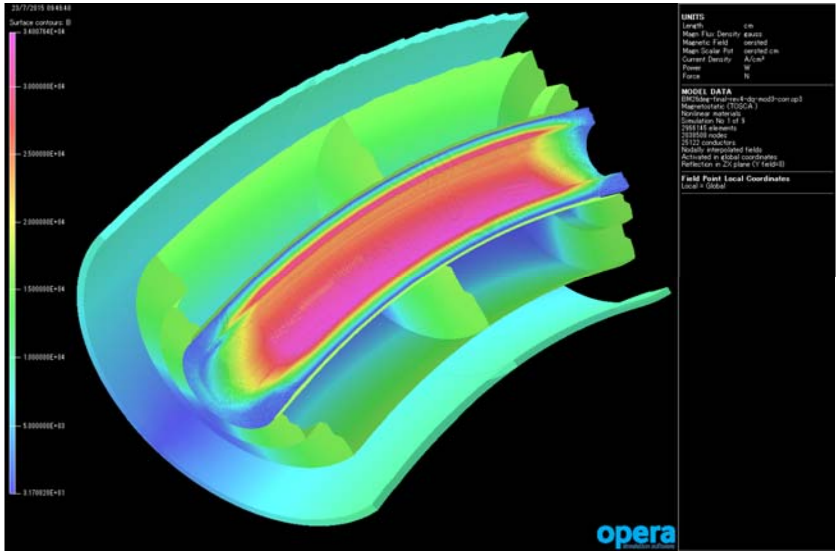
SC coil design with Opera-3d code

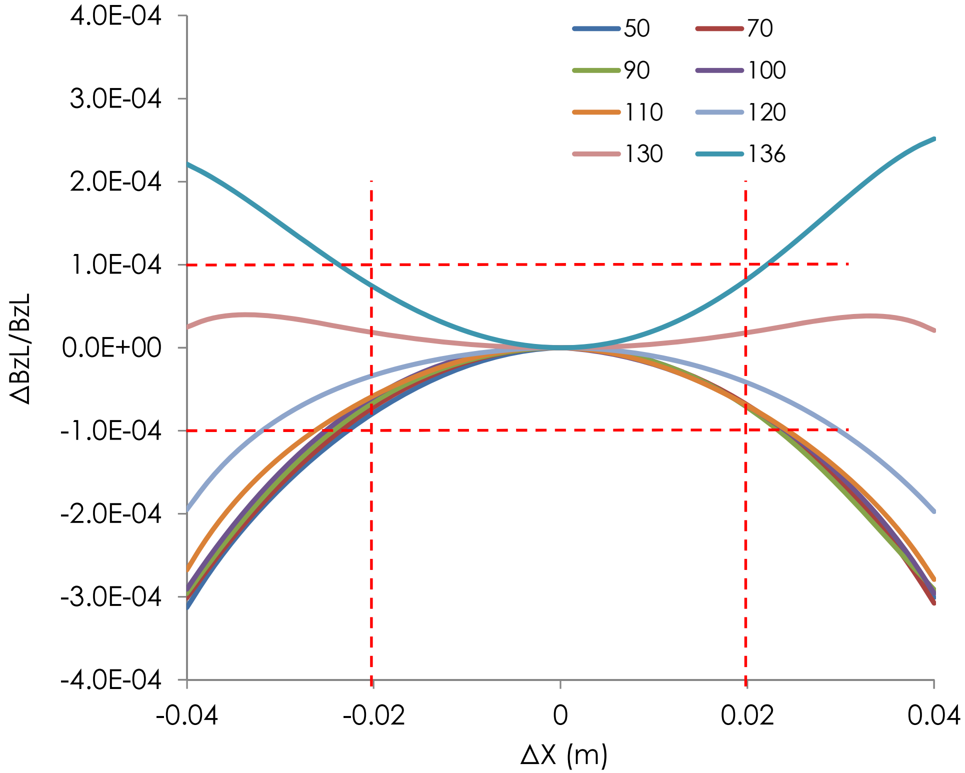
SC coils were precisely modelled







Corrected uniformity



$|\Delta BL/BL| < 1\times10^{-4}$!

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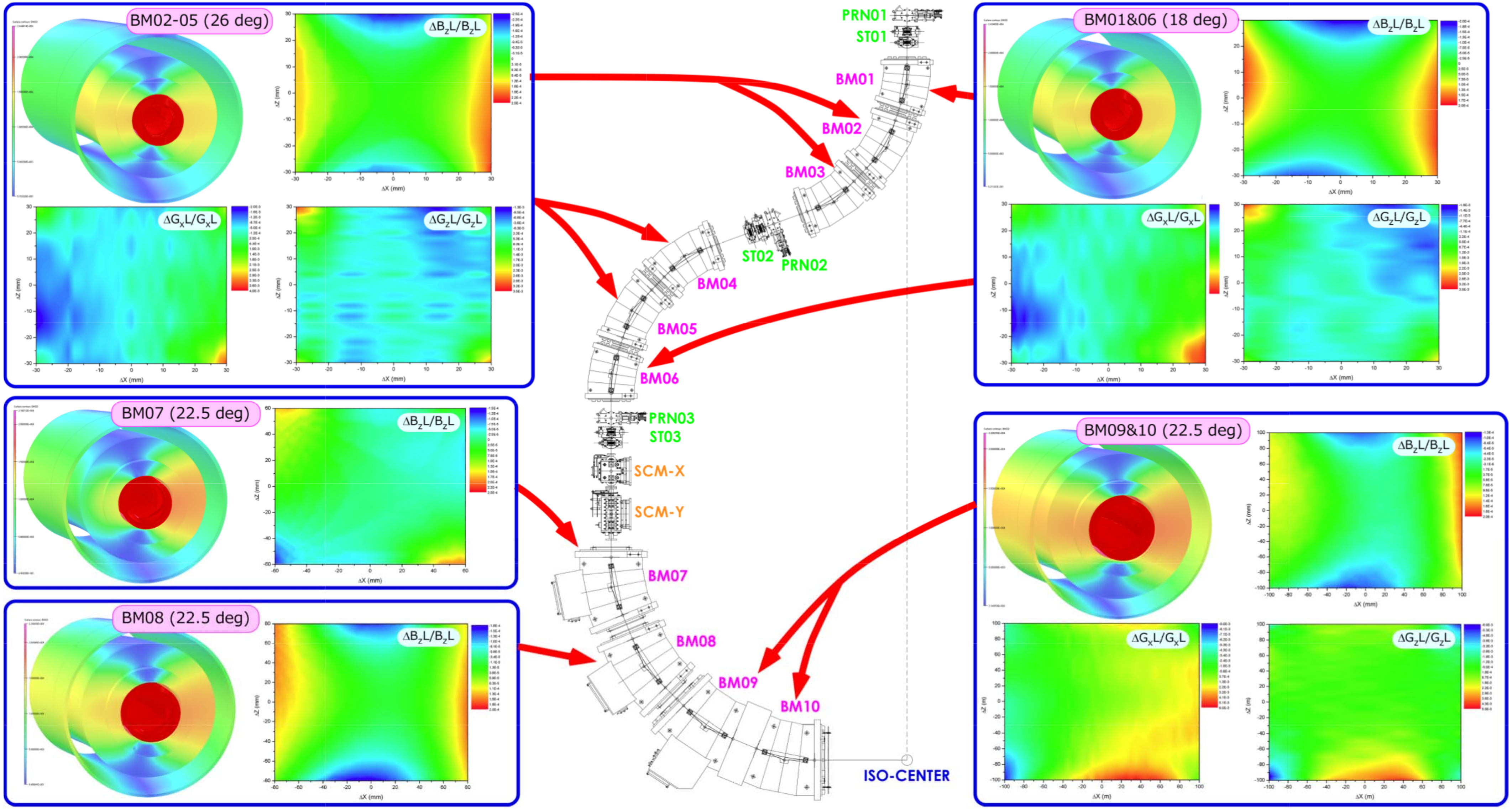
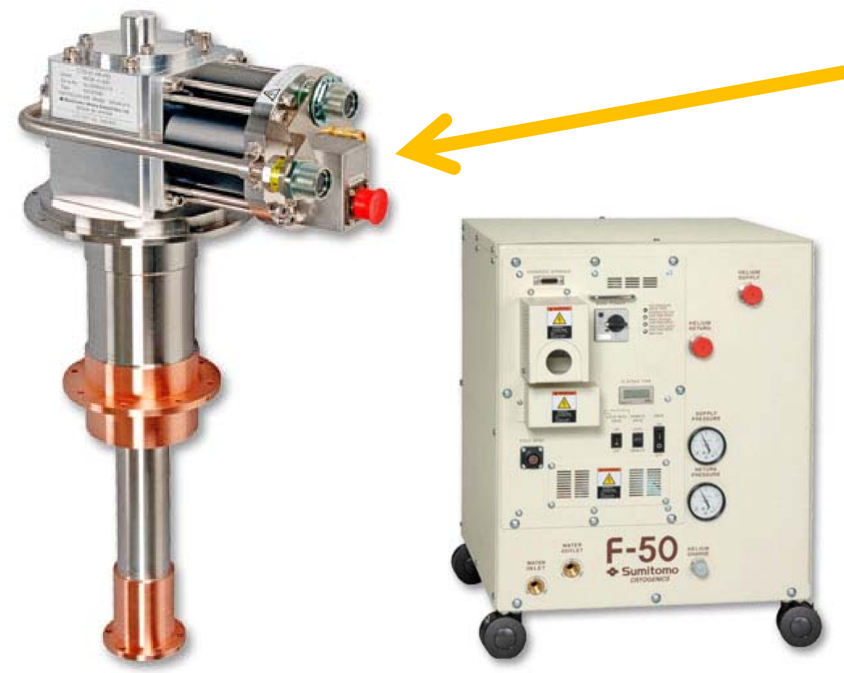
Design of SC magnets

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

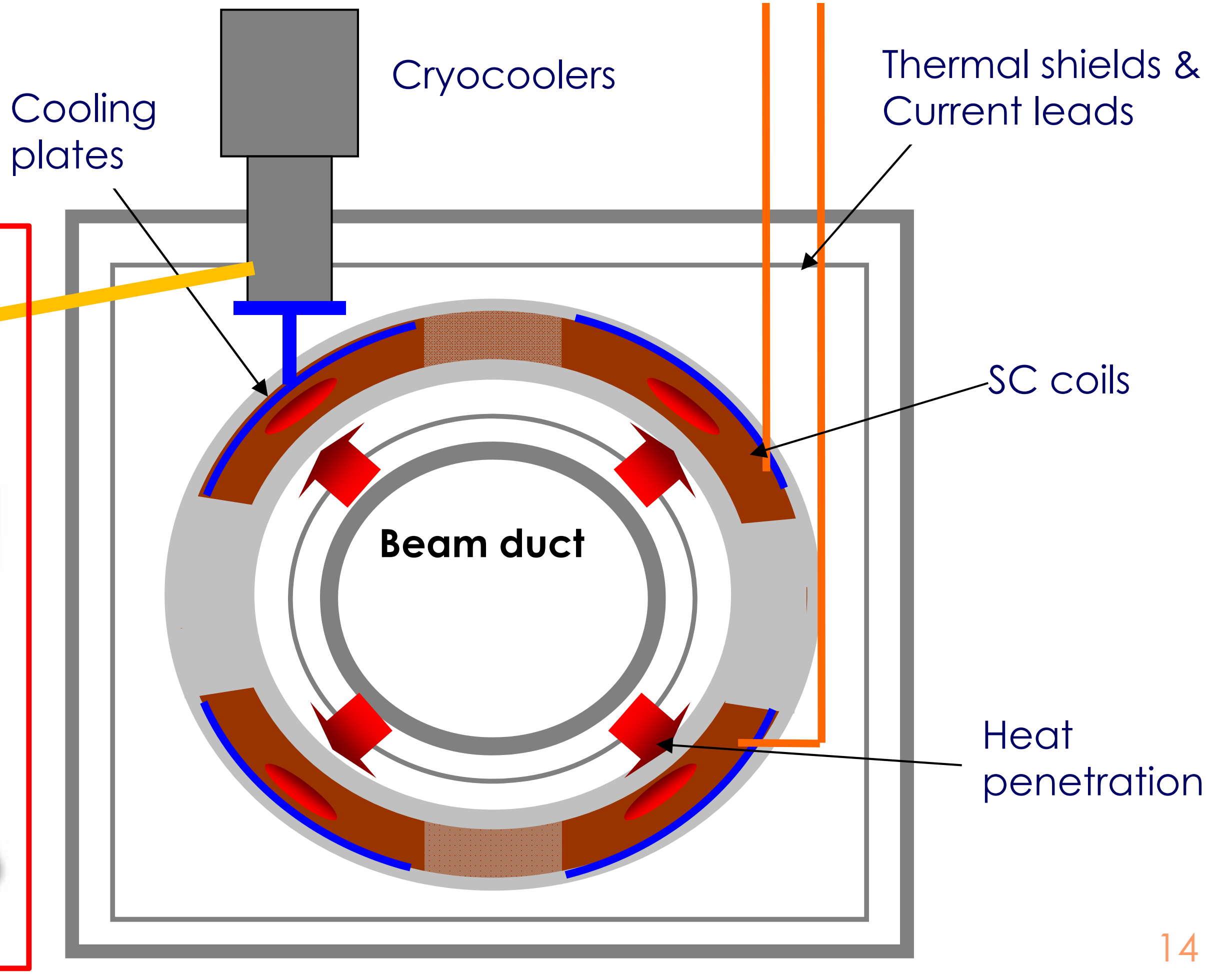


Cooling of SC magnets

- 4K GM compact cryocoolers
  - Liquid He free
  - Rotatable
    - ΔP~10%@90deg



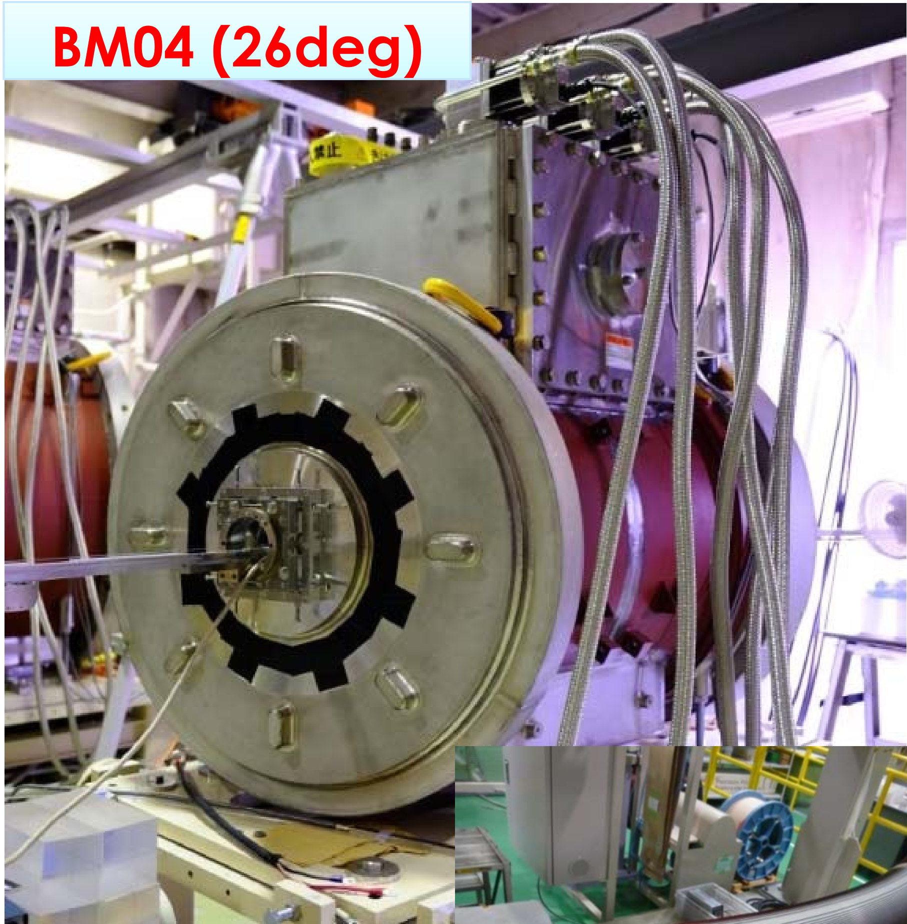
SHI cryocooler (RDK-415D)

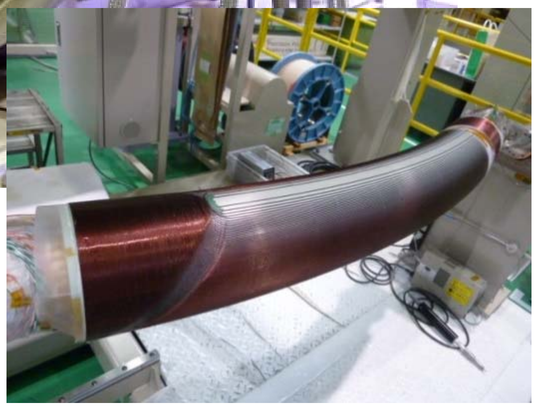


Construction and tests of the SC magnets

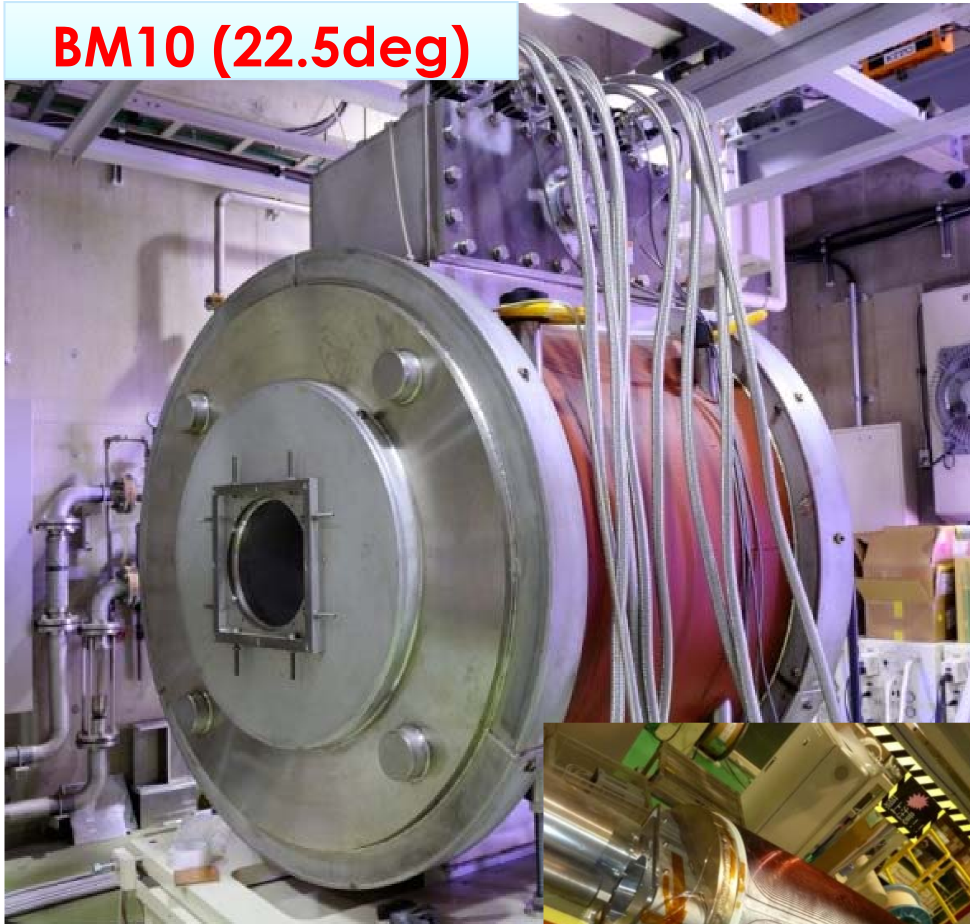
Construction of SC magnets

BM04 (26deg)



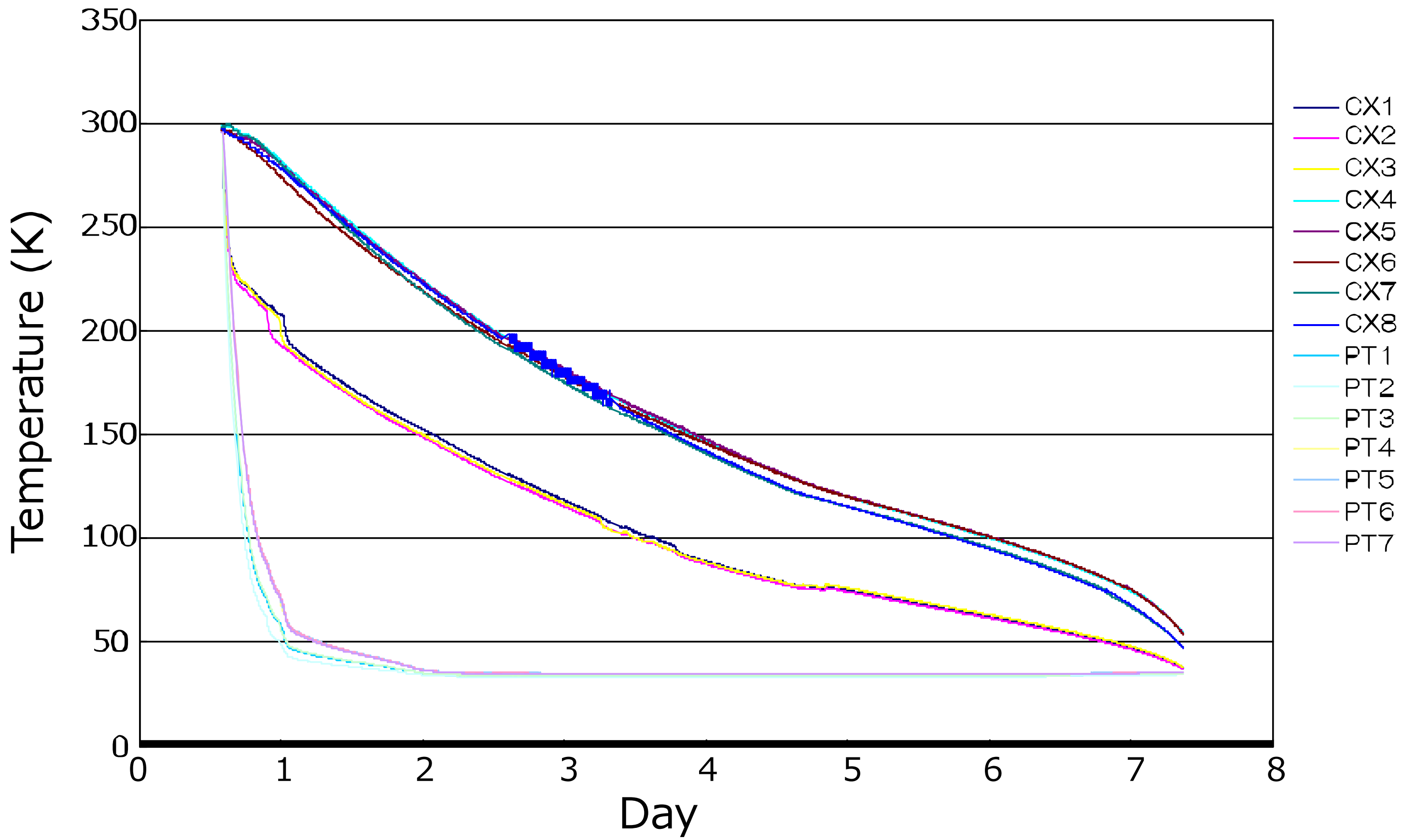


BM10 (22.5deg)



Initial cooling of SC magnet

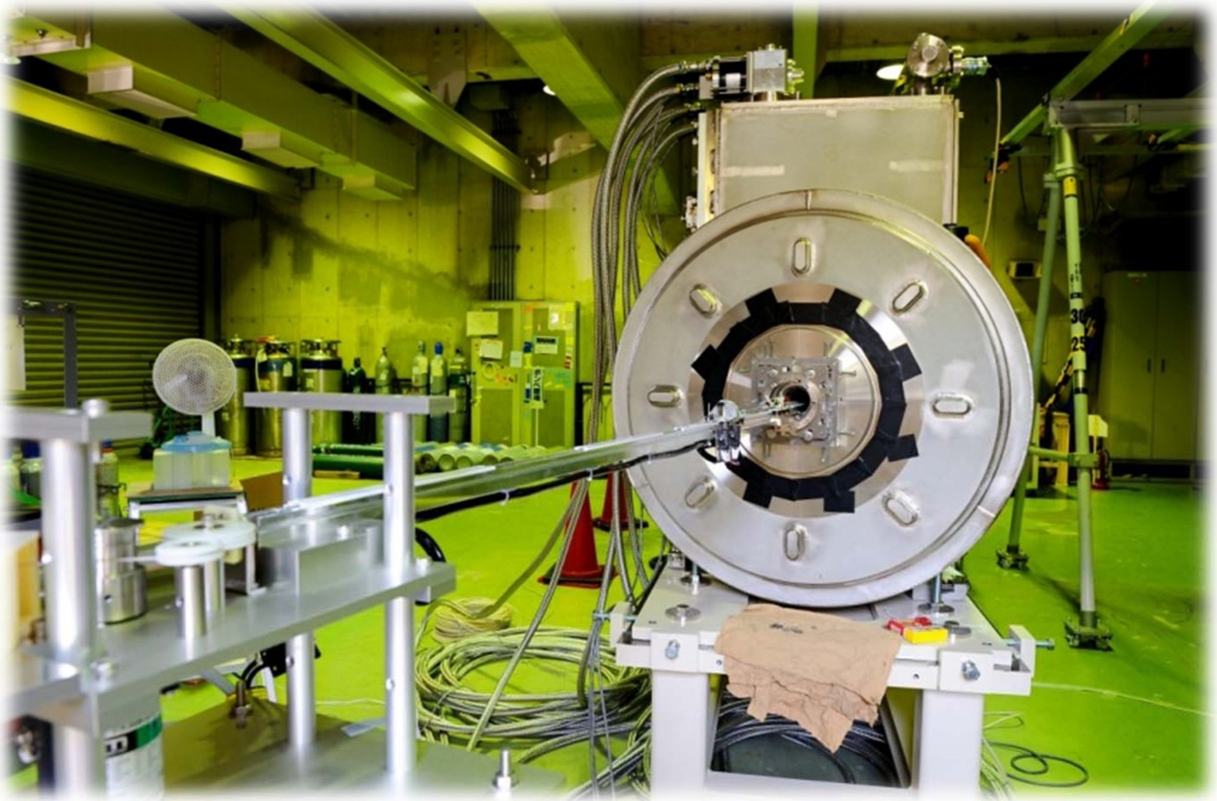
- Precool with liquid nitrogen
- It took a week to cool down by 4K

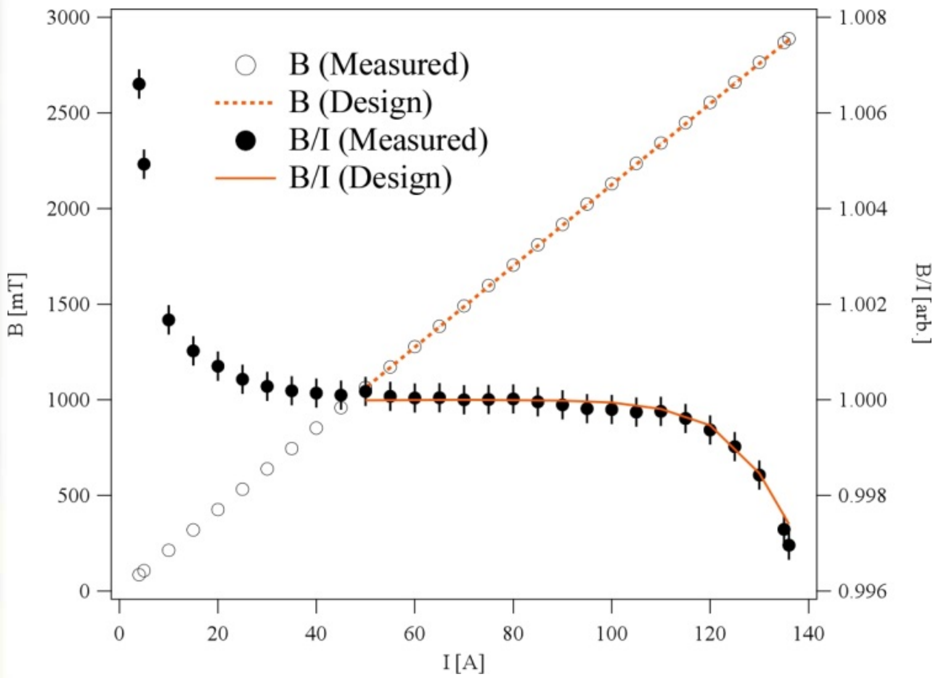


CX1: Cryocooler#1 2nd stage
CX2: Cryocooler#2 2nd stage
CX3: Cryocooler#3 2nd stage
CX4: SC coil (inner)
CX5: SC coil (middle)
CX6: SC coil (outer)
CX7: Yoke (right face)
CX8: Yoke (left face)
PT1: Cryocooler#1 1st stage
PT2: Cryocooler#2 1st stage
PT3: Cryocooler#3 1st stage
PT4: HTCPL Dipole (P)
PT5: HTCPL Dipole(N)
PT6: HTCPL Quadrupole (P)
PT7: HTCPL Quadrupole (N)

Field measurements (1)

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

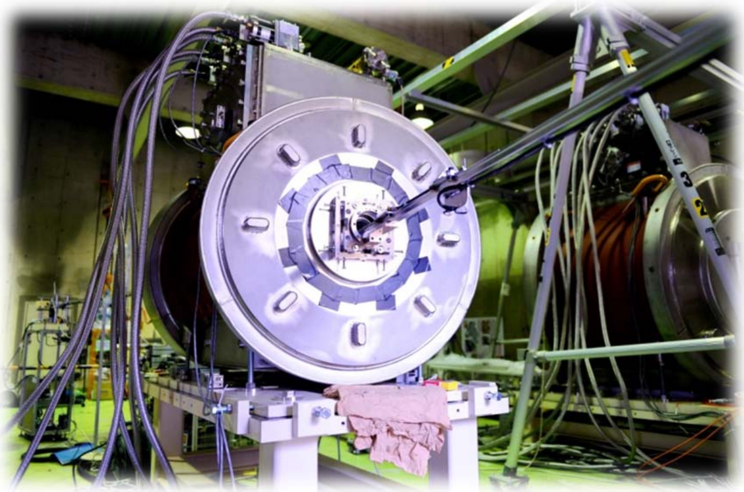


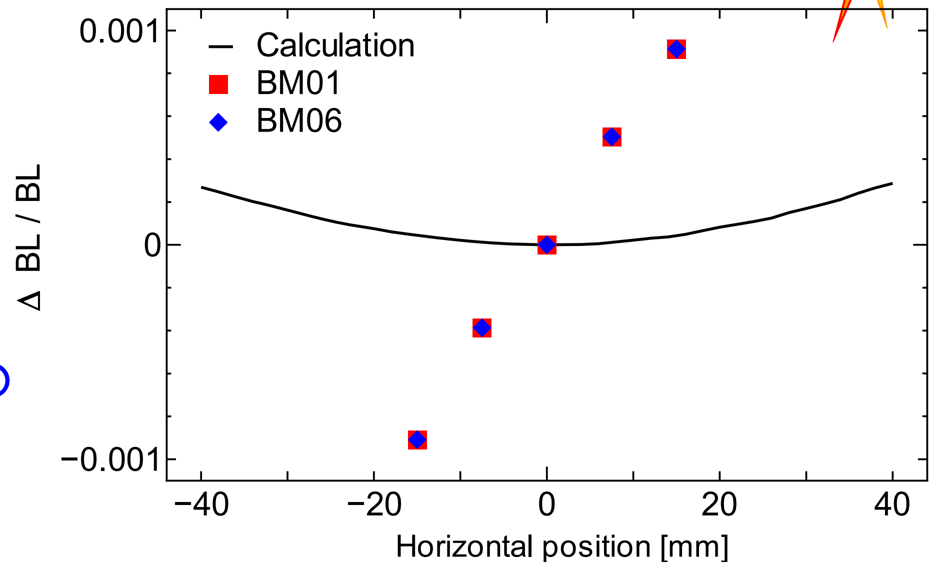


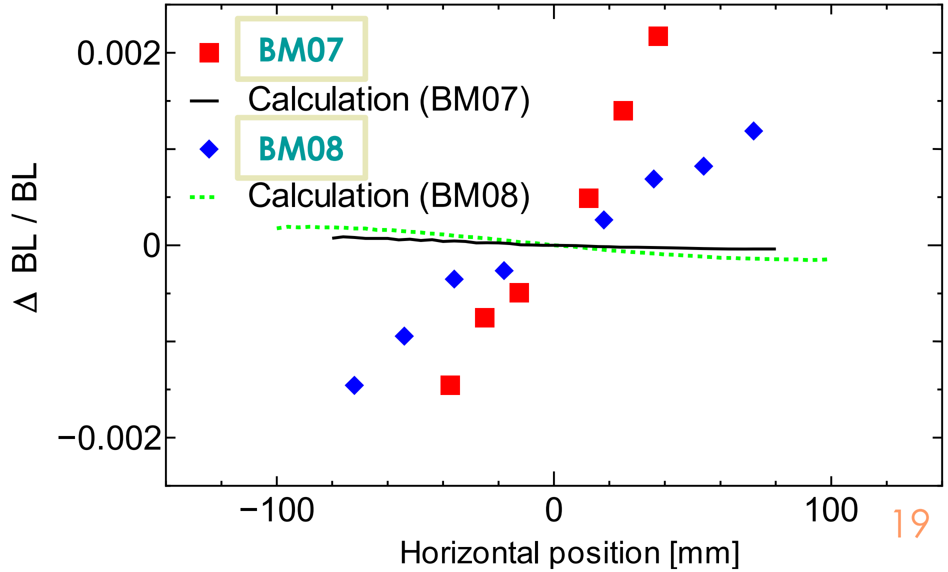
B-I measurement with NMR probes

Field measurements (2)

- Field mapping with Hall probes
- Quadrupole field observed
  - Only dipole coil excited
  - This quadrupole can be corrected by adjusting coil current, applied to the quadrupole coil
  - $\Delta GL/GL_{quard}$~0.5-0.7% (depending on magnet kind)

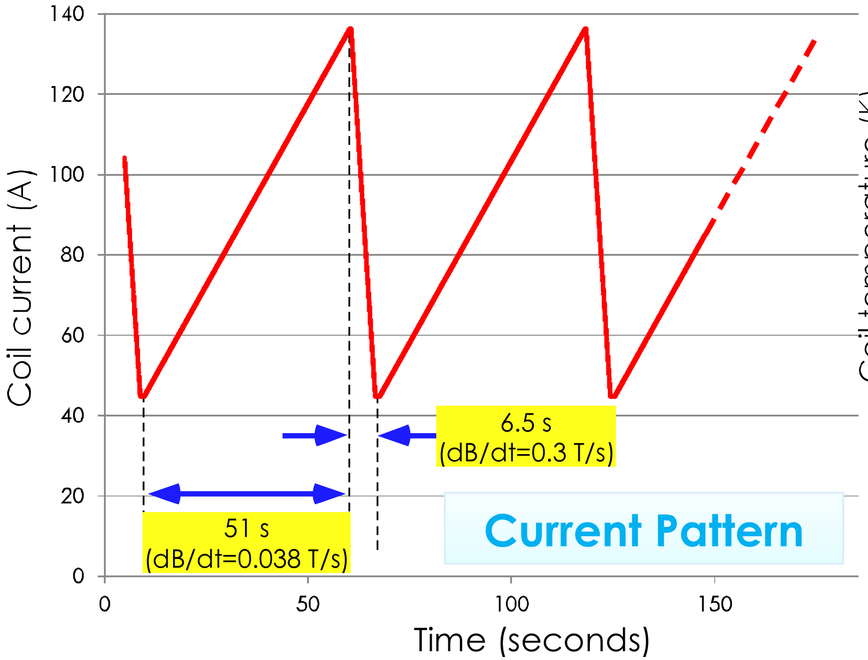


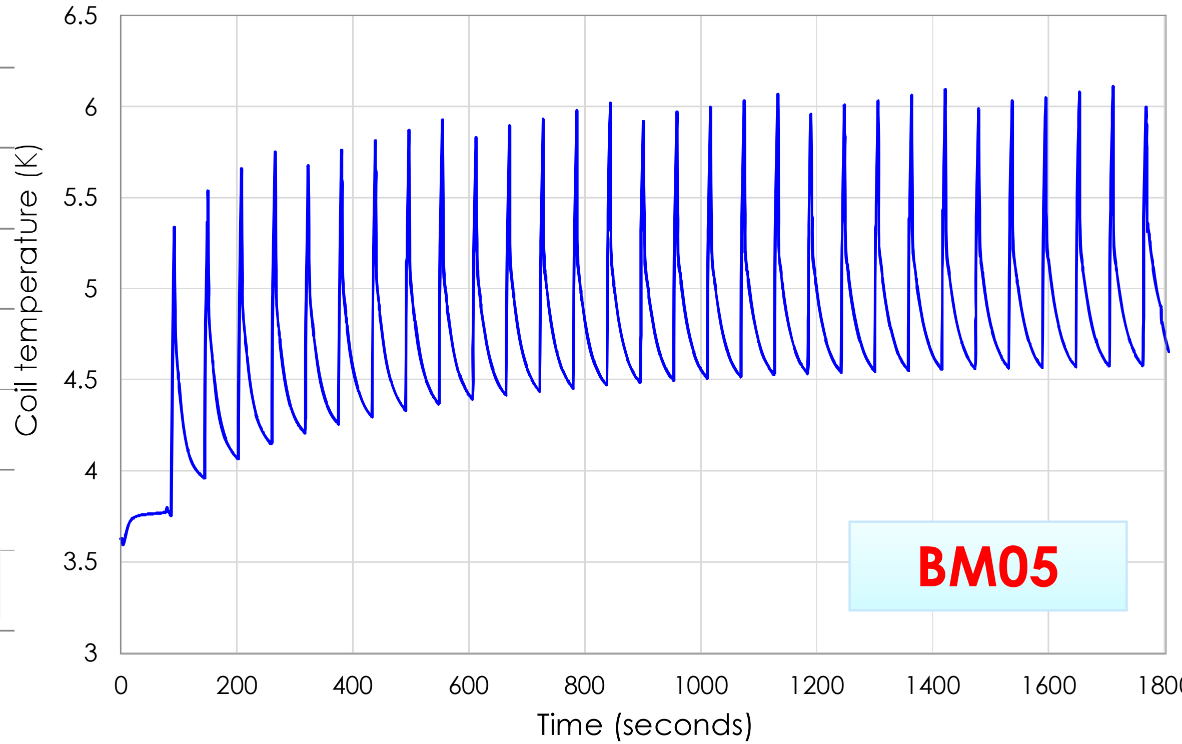




Fast slewing tests

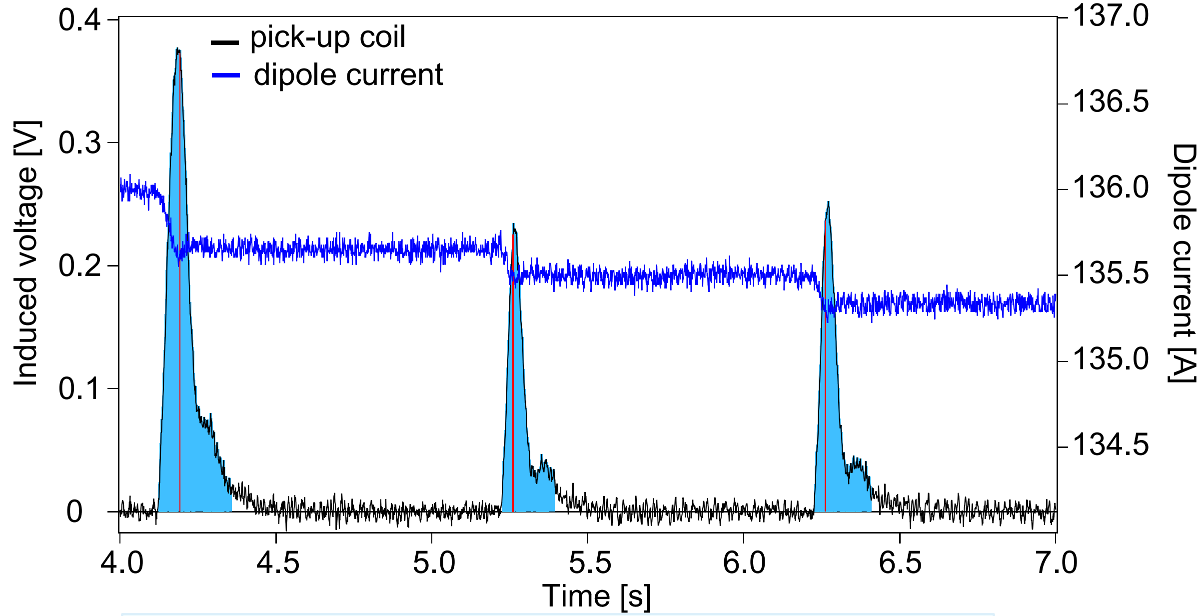
- Tests with maximum slew-rate
- I=45~136 A (E=56~430 MeV/u)
- **No quench observed**
- **Average temperature converged below Tc~6.8 K**



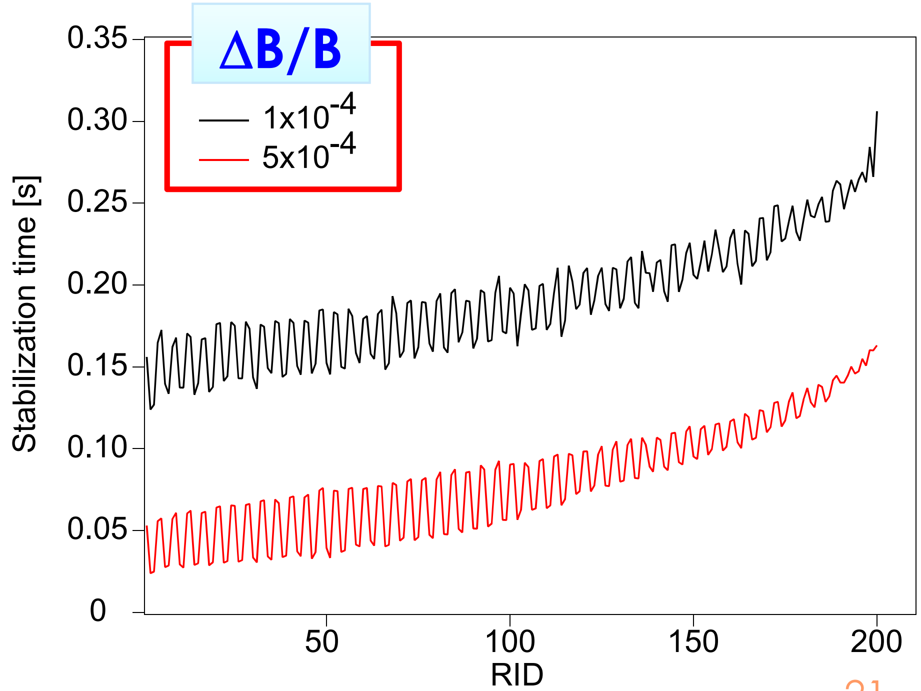


Stabilization time of dipole field

- Time to stabilize the dipole field was measured
- Pickup coil was installed in the magnet
- 202 step pattern was used
- Voltage, as excited by the field change was measured and integrated to evaluate the stabilization time



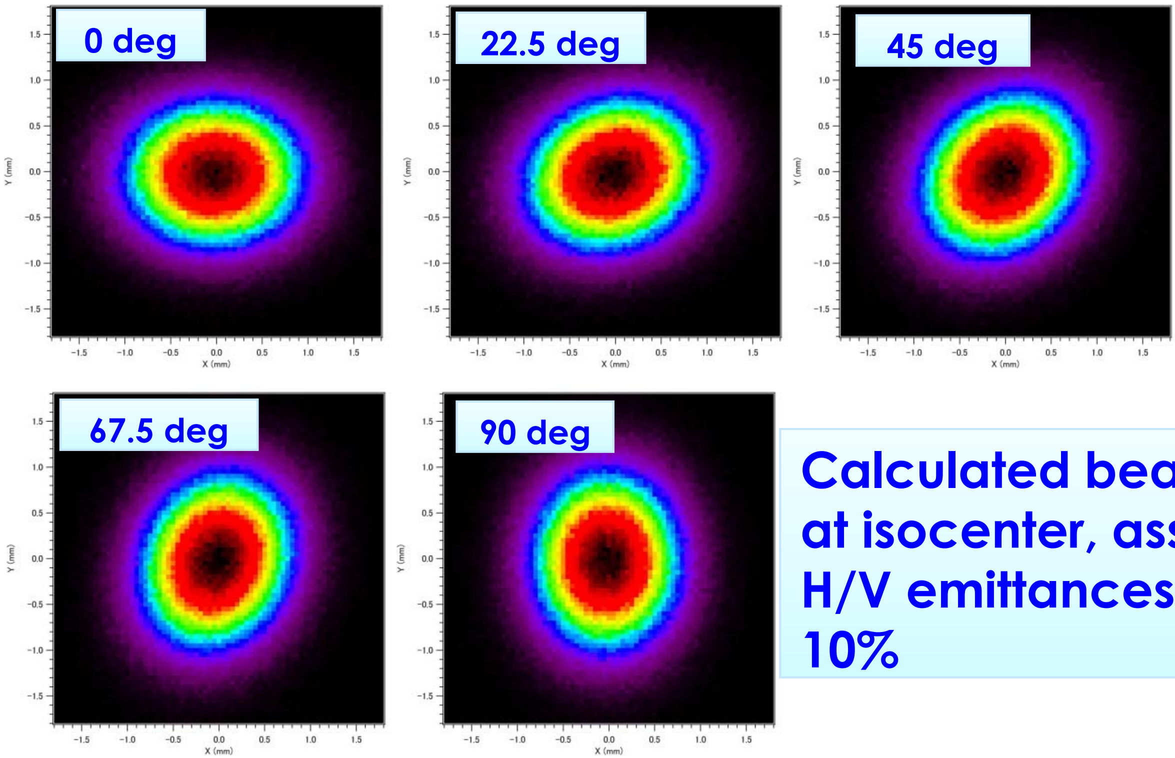
Coil current and measured voltage



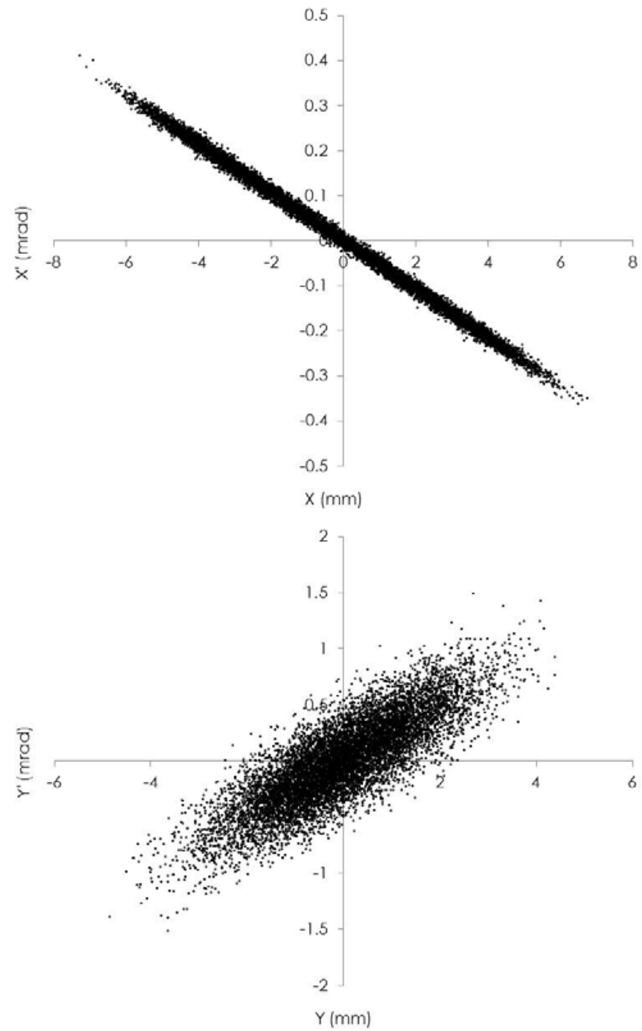
Emittance compensation

Emittance compensation (1)

- **H&V emittances are not generally equal**
  - $\varepsilon_H \sim 0.3\ \pi\mathrm{mm \cdot mrad}$, $\varepsilon_V \sim 1\ \pi\mathrm{mm \cdot mrad}$ for E=430 MeV/u
- **H&V beam coupling**



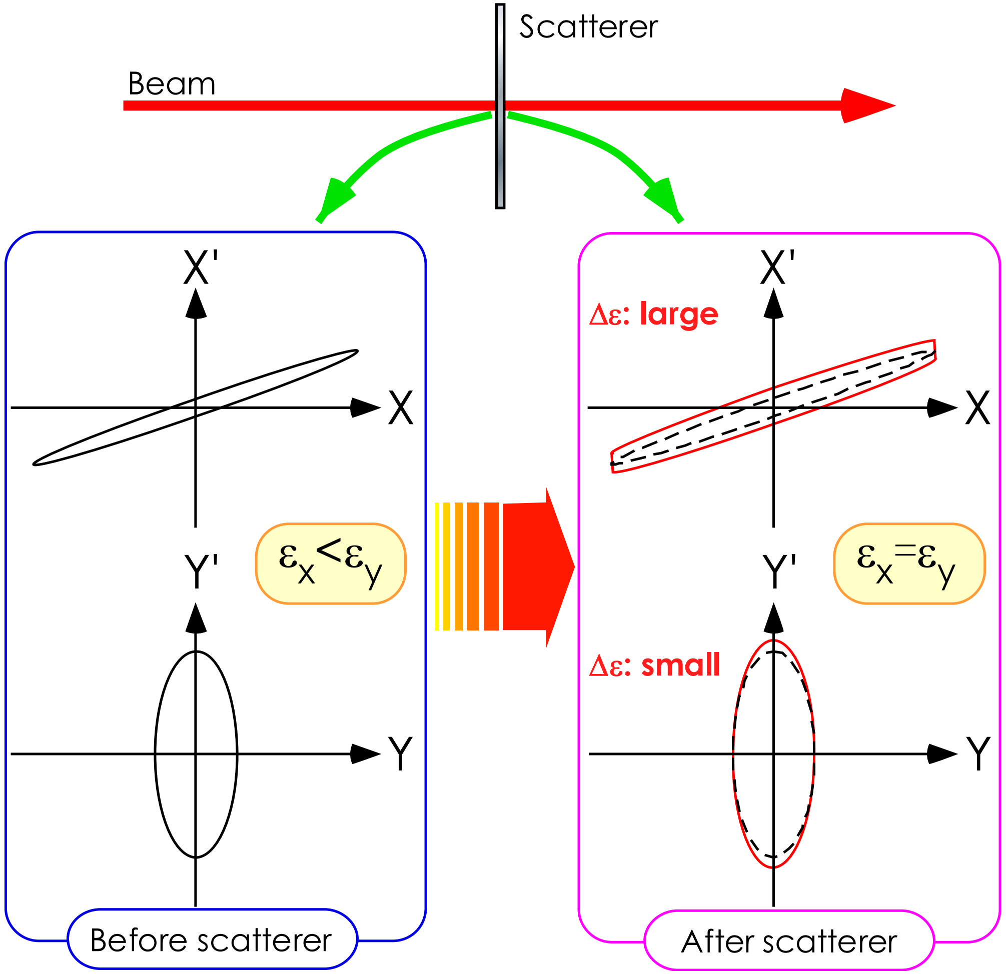
Calculated beam spot at isocenter, assuming H/V emittances differ by 10%



Phase space at extraction point

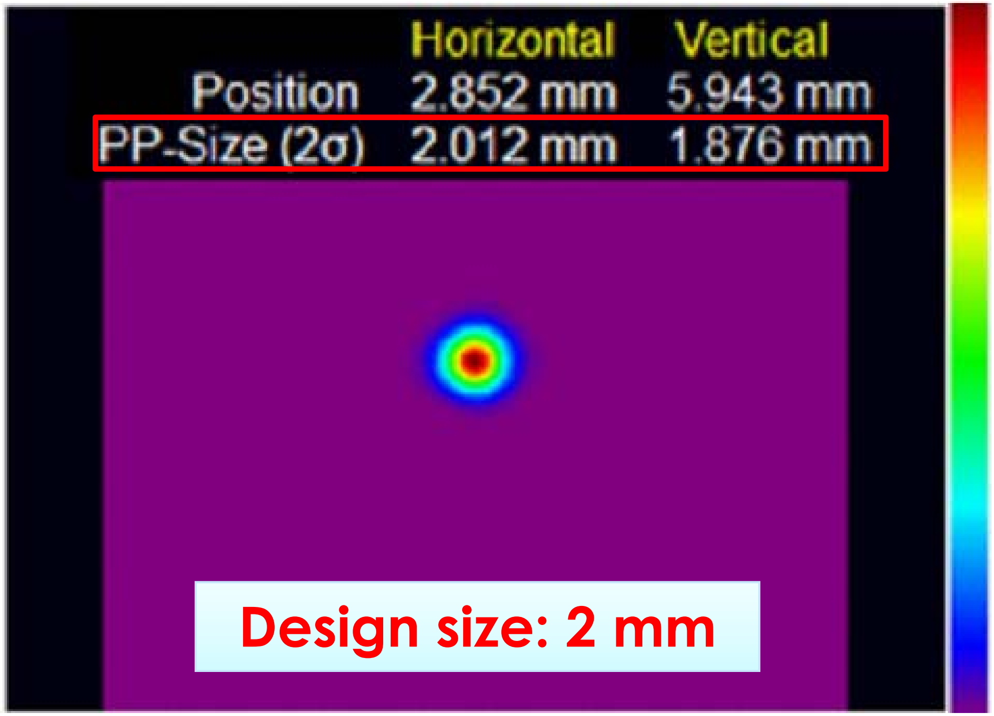
Emittance compensation (2)

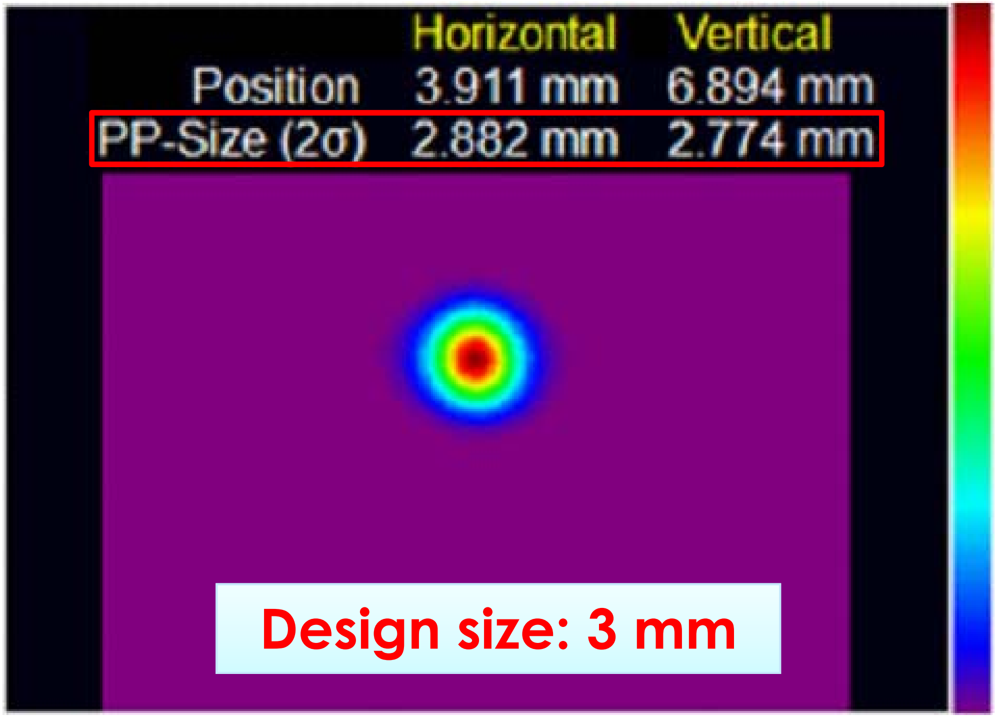
- **H&V emittances have to be matched**
  - Thin scatterer is utilized to accomplish $\varepsilon_H = \varepsilon_V$



Emittance compensation (3)

- **Beam tests at the existing beam line**
- **Design size: 2 mm and 3 mm**
  - beta's were designed to be $\beta_H=\beta_V$ at the profile monitor
- **Test results agreed with the design**





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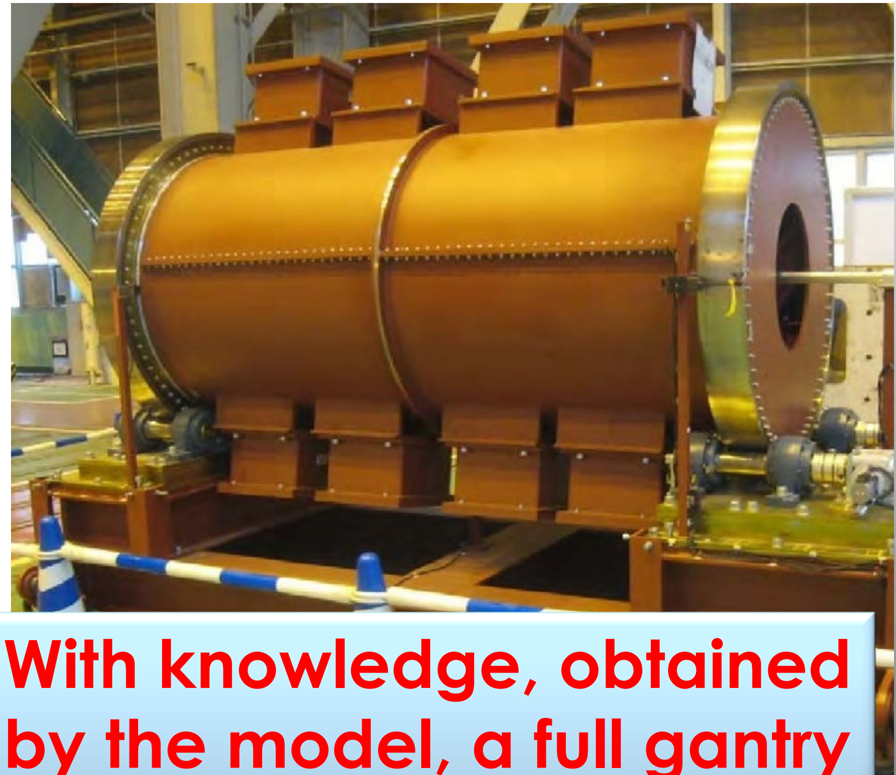
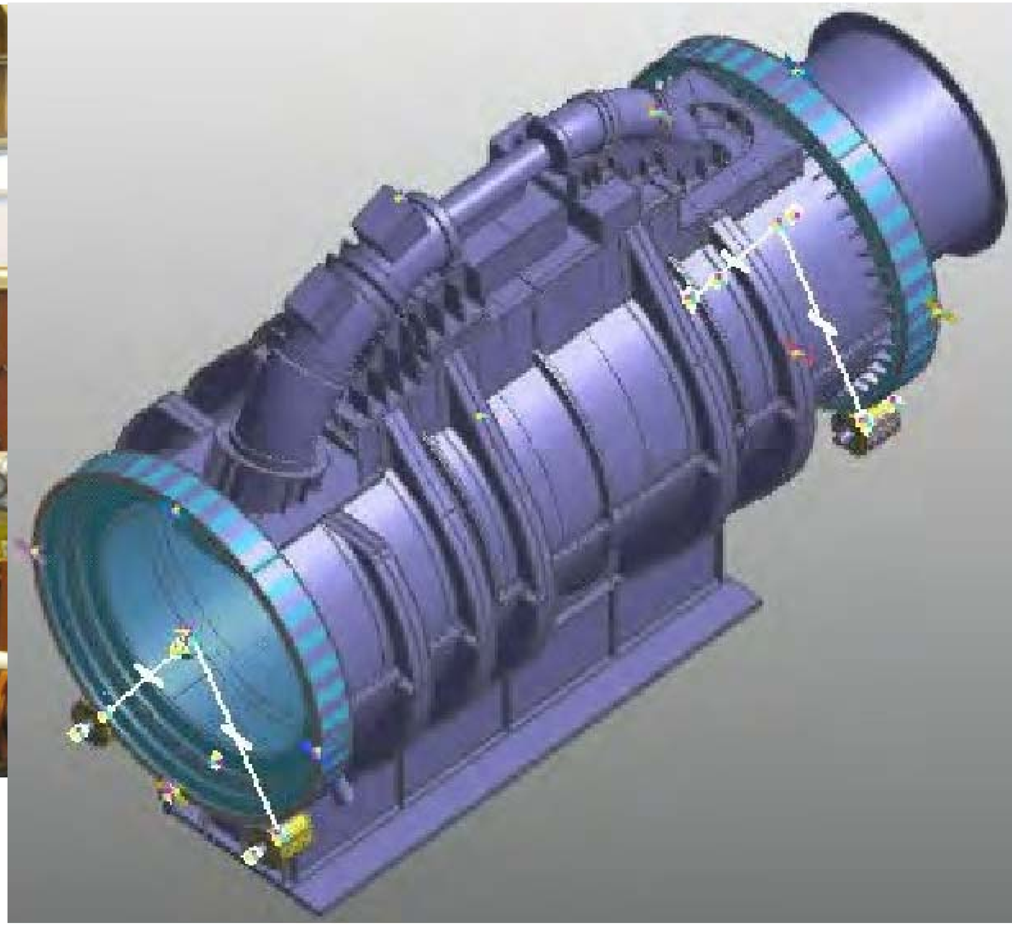
Design and construction of Gantry structure

Construction of a scale model

- 1/5 scale model
- Characteristics, compared with FEM calculations

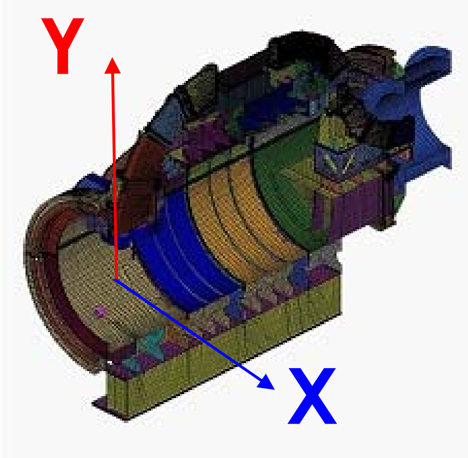


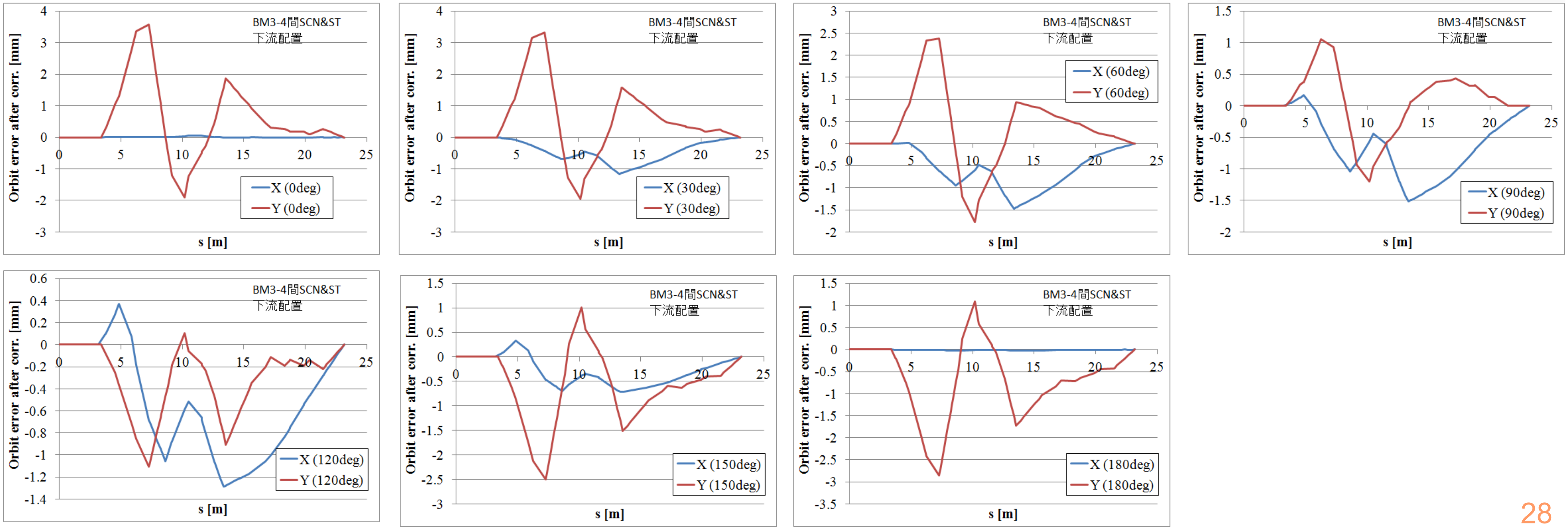


With knowledge, obtained by the model, a full gantry structure was designed!

Beam orbit corrections

- **FEM calculations**
  - Displacement of magnets≦~1mm
- **Orbit corrections with steering magnets**
  - Central beam orbit≦~3.5mm





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Construction of structure



Assembling at Toshiba

Rotation tests at Toshiba

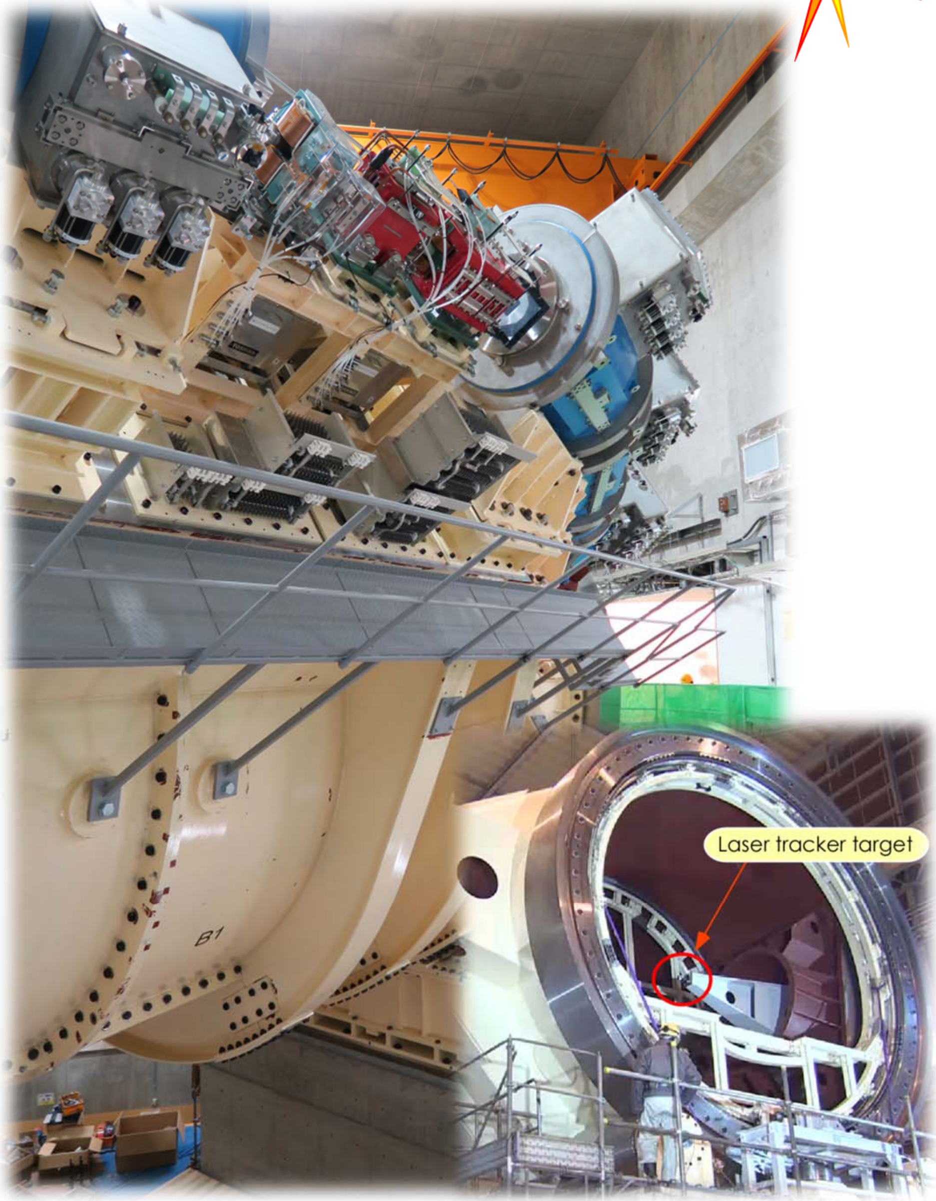
Transportation to NIRS

Installation to the gantry room

Reassembling at NIRS

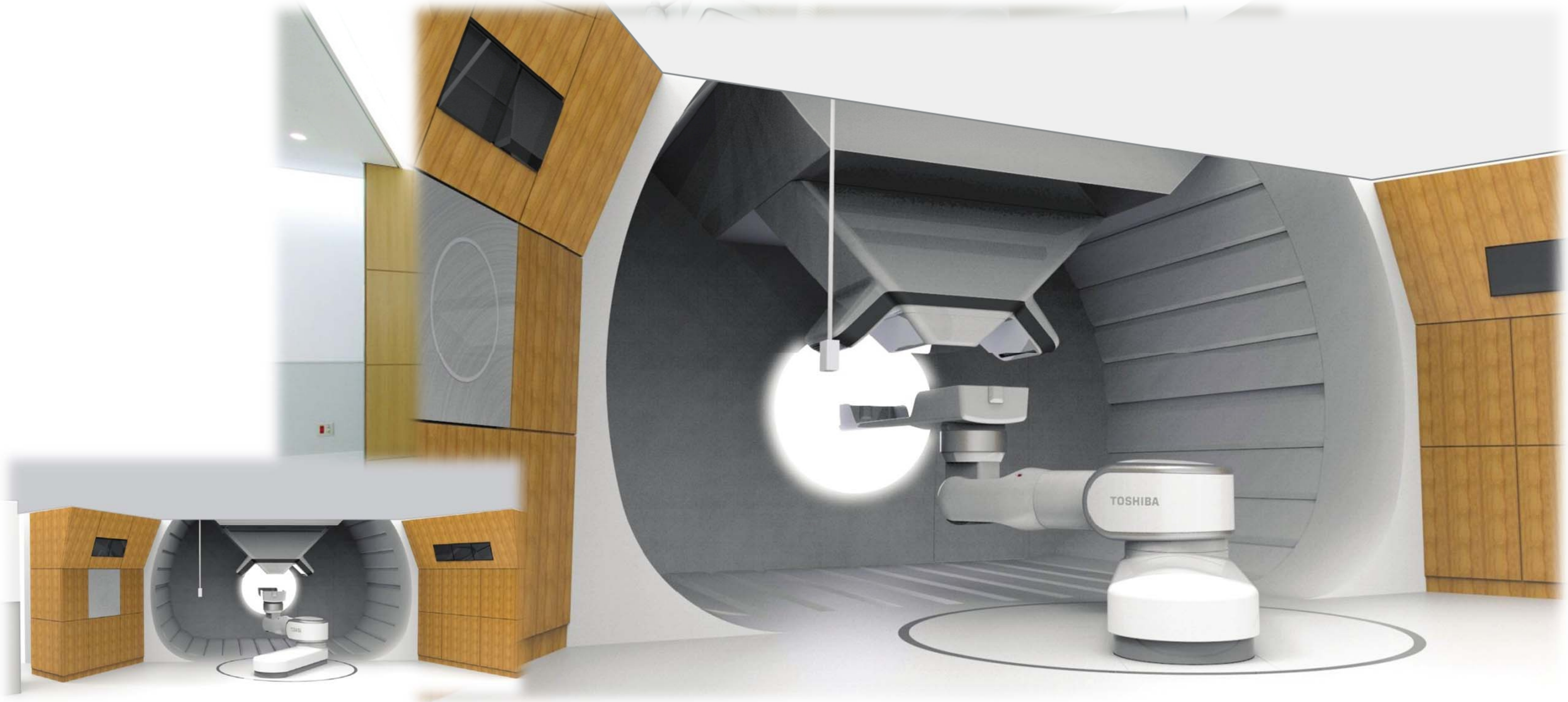
Rotation tests at NIRS

- Target of a laser tracker was placed at the isocenter
- Positions were reproduced by
  - ±0.04 mm (transverse)
  - ±0.1 mm (longitudinal)



Treatment-room design

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



Summary

- Development of the superconducting rotating-gantry
  - Compact
  - Construction will be completed by the end of this month
- Future plan
  - Commissioning will be made from this October
  - Treatment will be planned in 2016

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)