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Superconducting rotating-gantry and other developments at HIMAC

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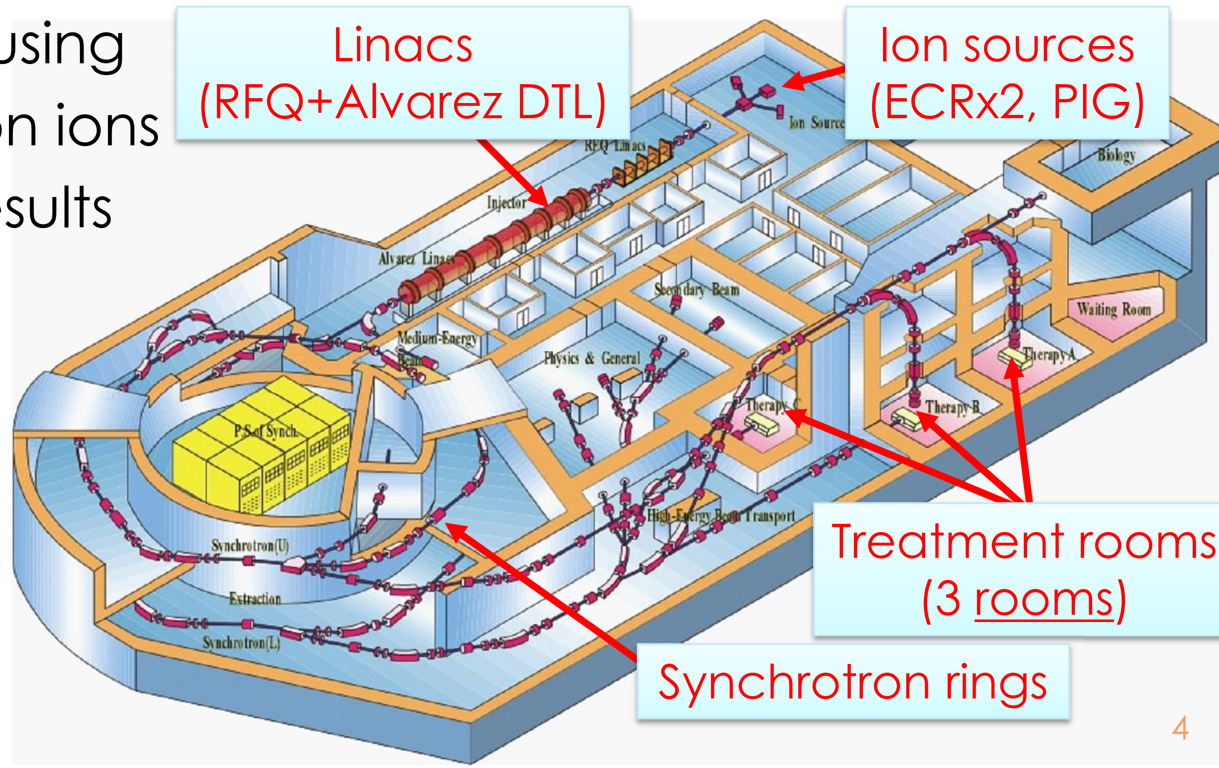
Outline

- Introduction
- Recent developments
  - Scanning irradiation
  - Multiple-flattop operation
  - Superconducting rotating-gantry
- Summary

Introduction

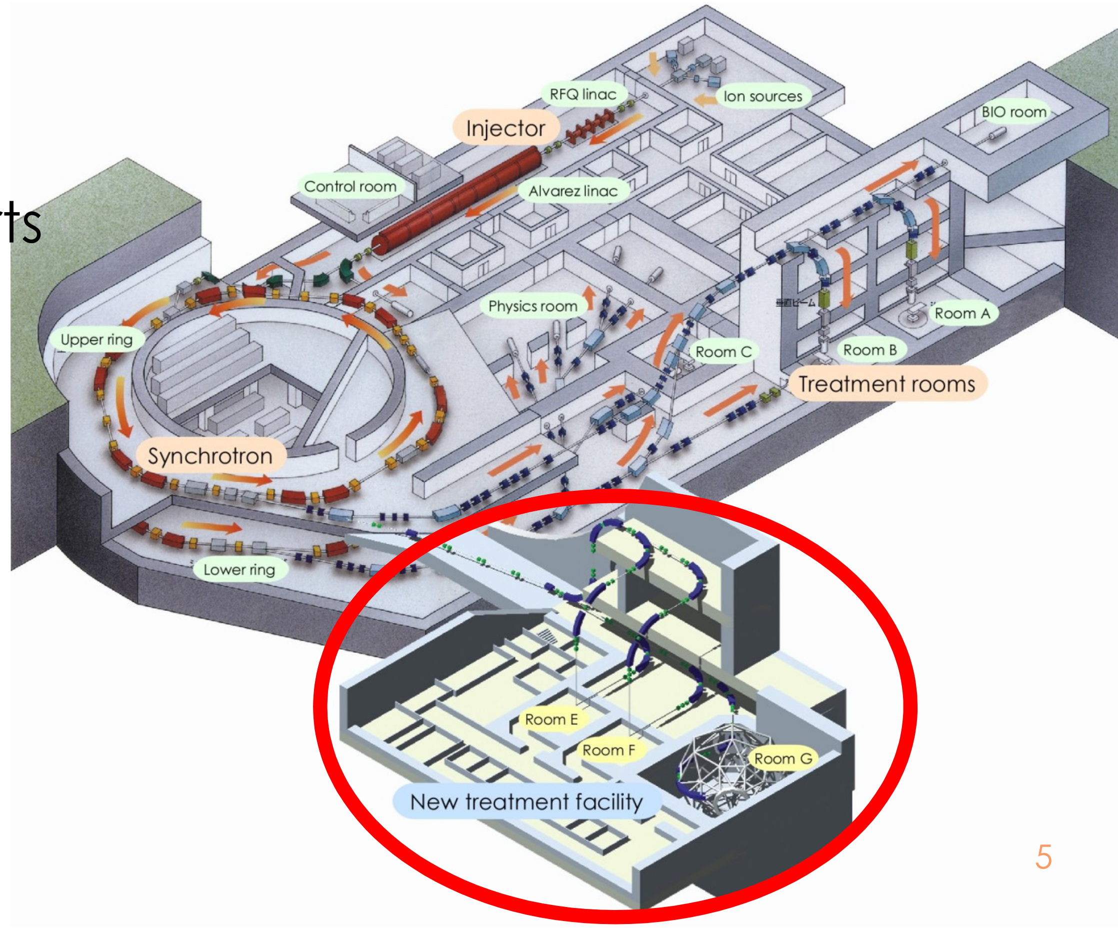
Carbon radiotherapy

- 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
- Successful clinical results
  - ✓ **~7000 patients**

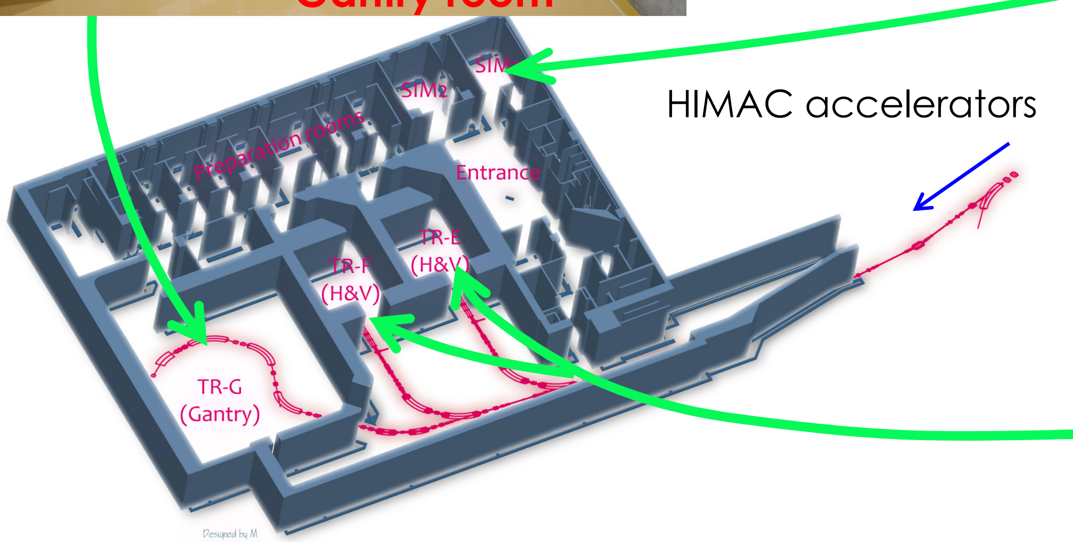


New treatment facility

- Construction completed in FY2010
- 3 treatment rooms
  - Room E & F
    Fixed H&C scanning ports
    (**in treatment operation**)
  - **Room G**
    Rotating gantry port
    (Under construction)



Treatment floor (B2F)



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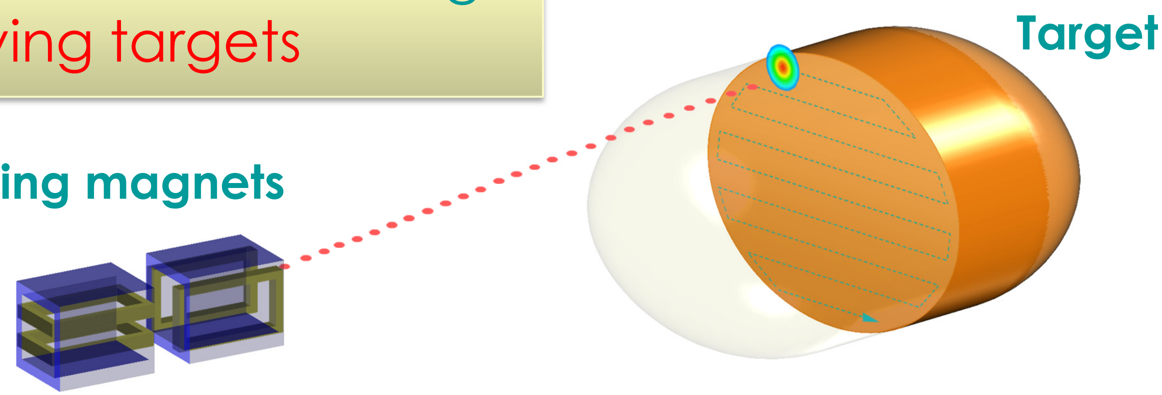
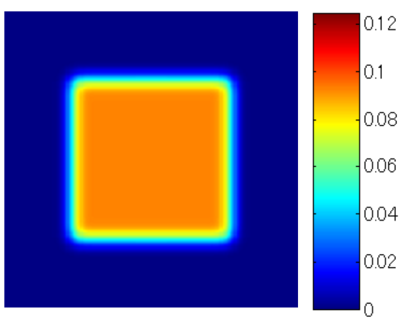
Recent developments #1 (Scanning irradiation)

3D raster-scanning irradiation

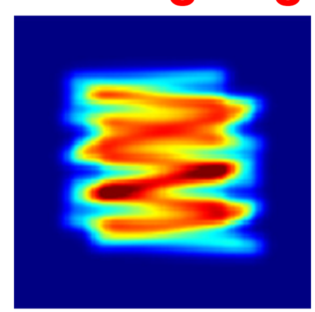
Development of 3D raster scanning-irradiation for moving targets





Dose distribution (designed)

For moving target….



Interplay observed!

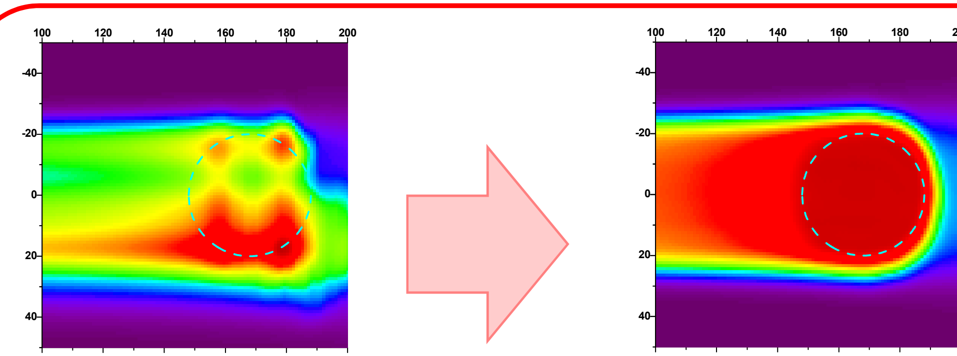
How can we fix it?

Respiration gating

Suppress target movement within ~5mm

+

Rescanning



Without gating and rescanning

With gating and rescanning

Fast rescanning
(scanning speed should be much faster than target movement)

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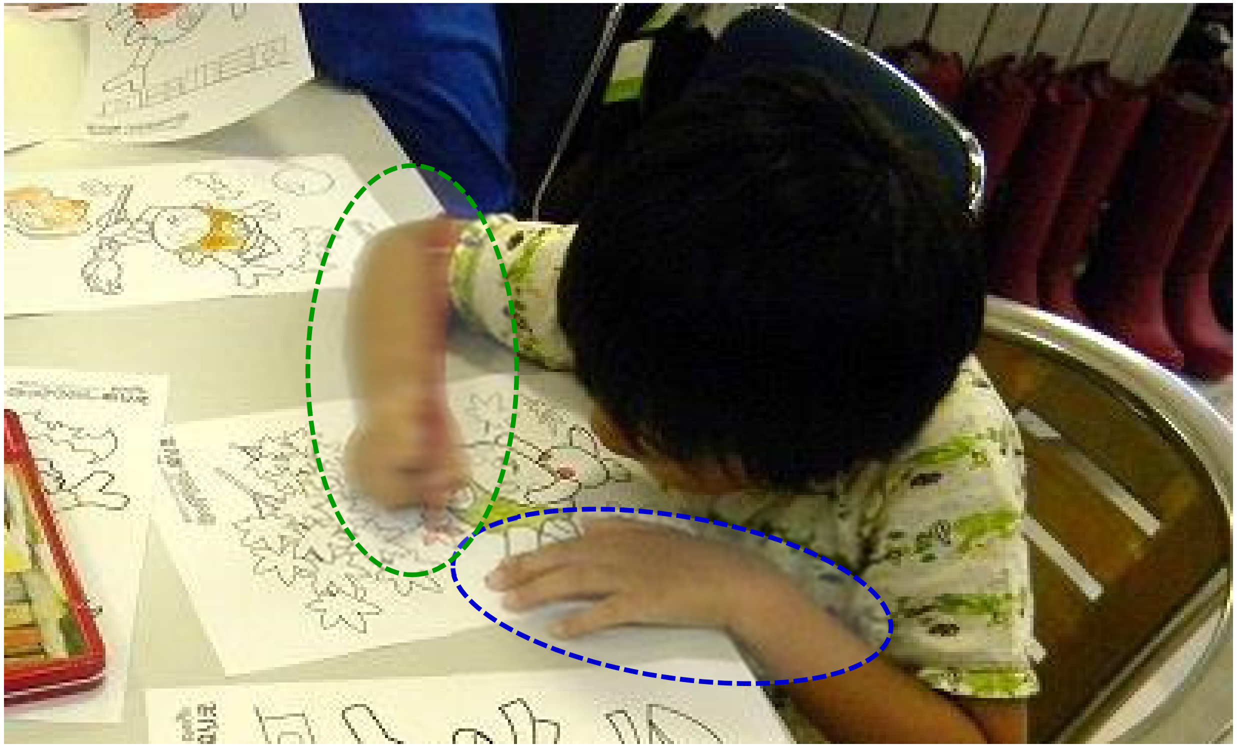
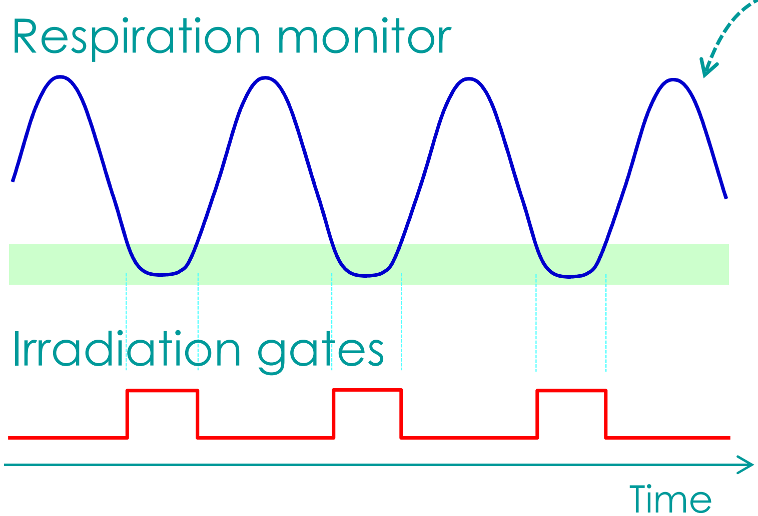
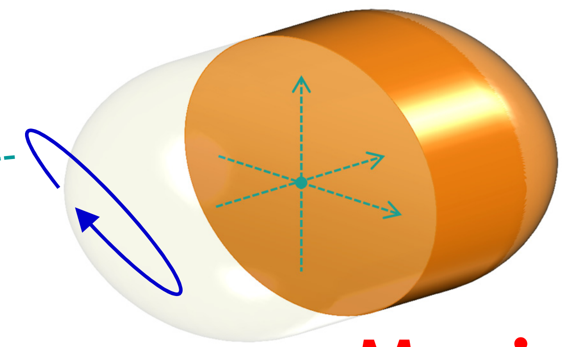
This is like…



“Respiration gating” × “Fast rescanning”

Respiration gating



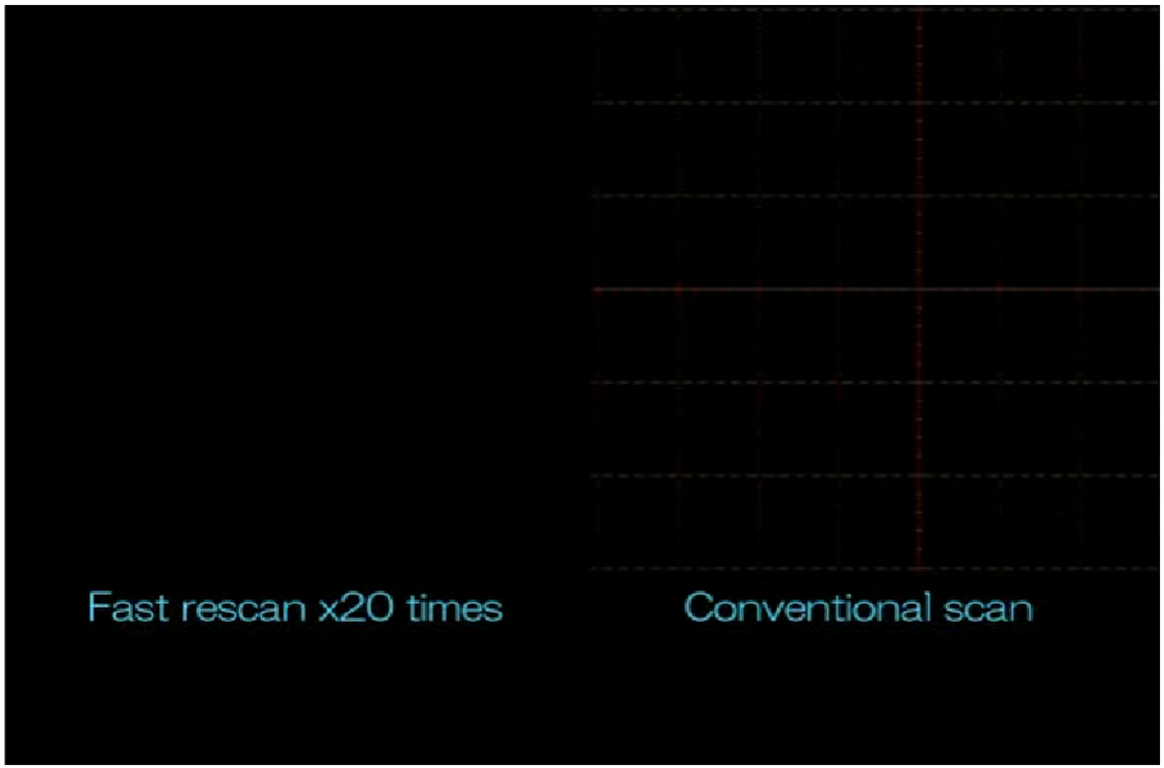


Moving target

By monitoring patient's respiration, errors in dose distribution can be reduced!

Fast rescanning

Comparison between fast rescan and conventional scanning



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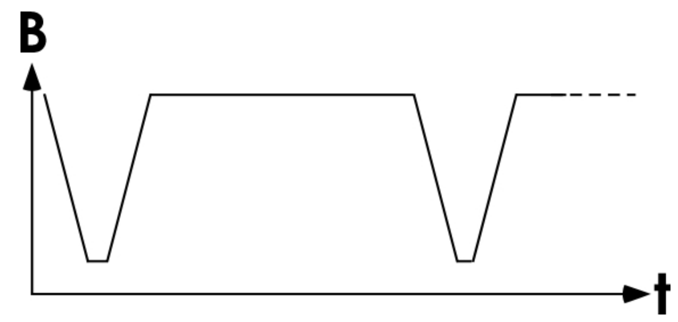
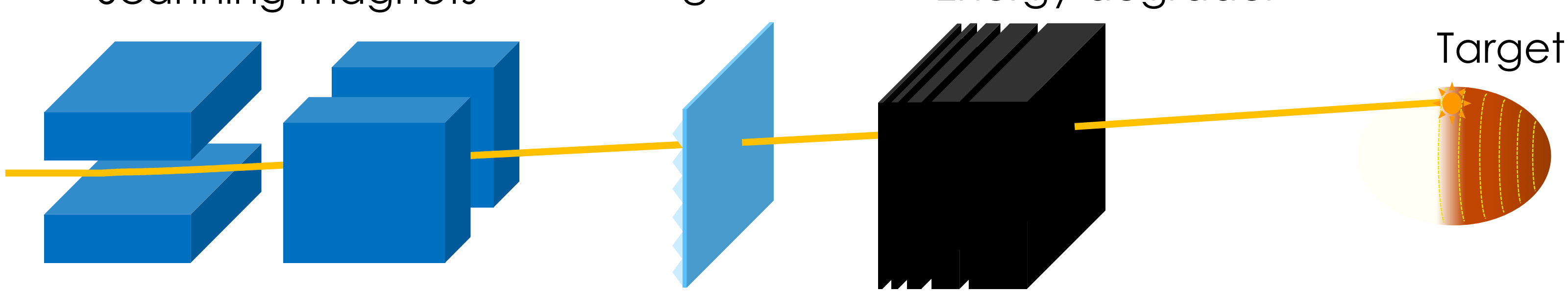
Recent developments #2 (Multiple-flattop operation)

Depth-dose distribution

- **Conventional synchrotron operation**
  - Fixed operation cycle
  - Single energy
- **Energy degrader has to be used**
  - Enlarge a size of beam spots
  - Produce fragments

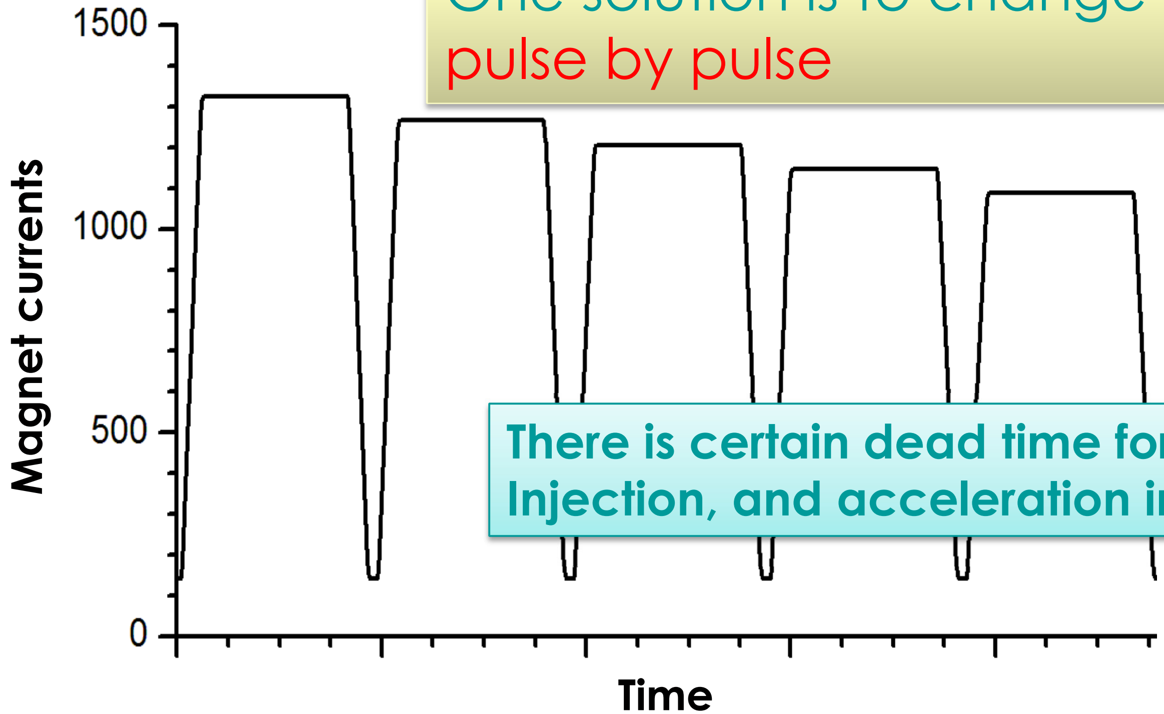




For scanning irradiation….

- **To take full advantage of the scanning irradiation,**
  - beam energy has to be changed directly from accelerators!

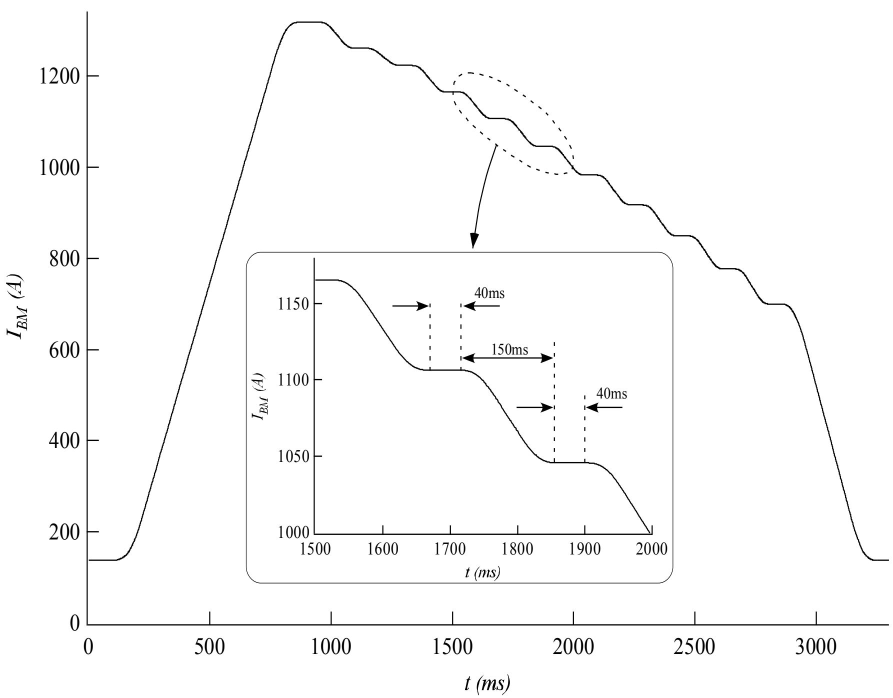
One solution is to change a pattern pulse by pulse

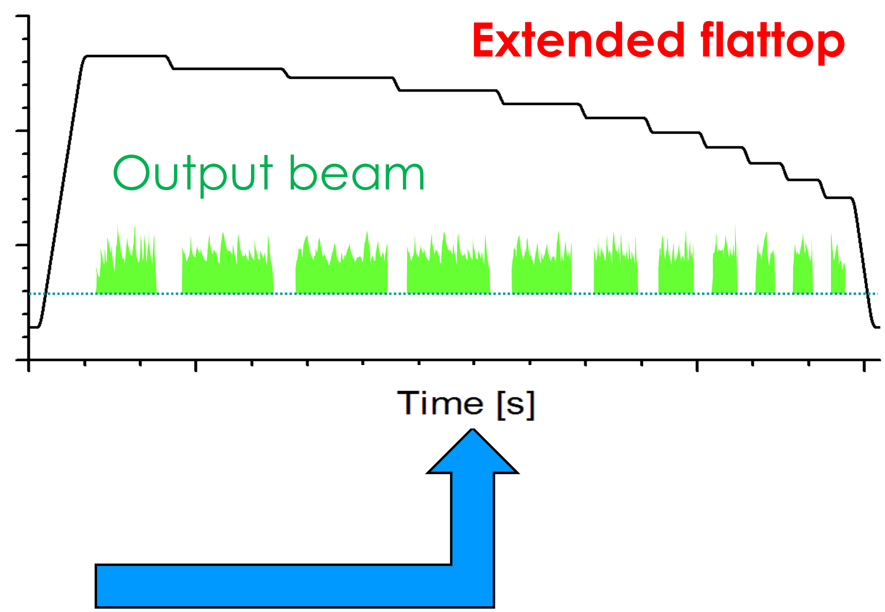


There is certain dead time for deceleration, Injection, and acceleration in each pulse.

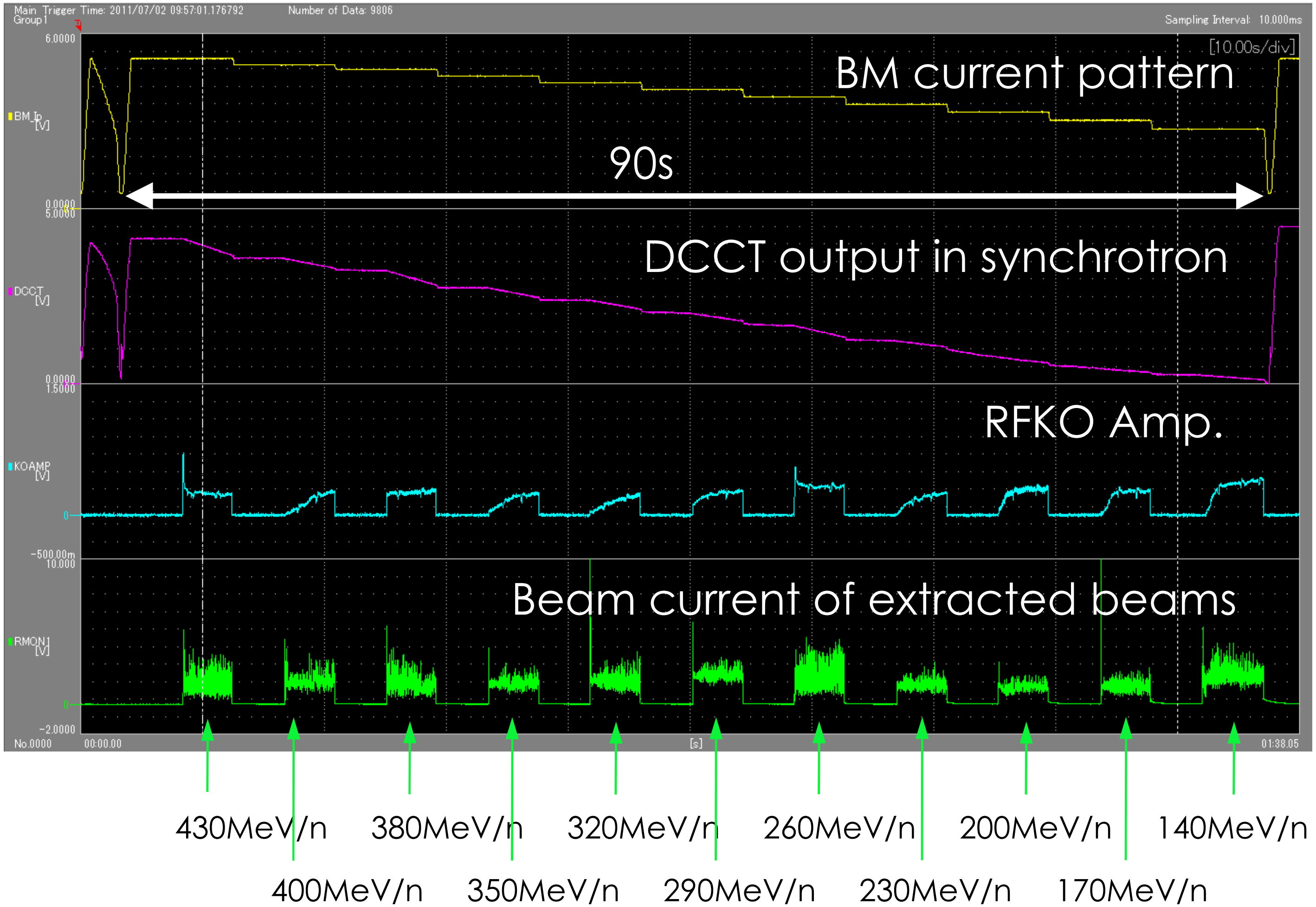
Multiple-flattop operation

- Operation pattern having multiple flattops
- Each flattop can be extended
- Beams having various energies can be extracted!

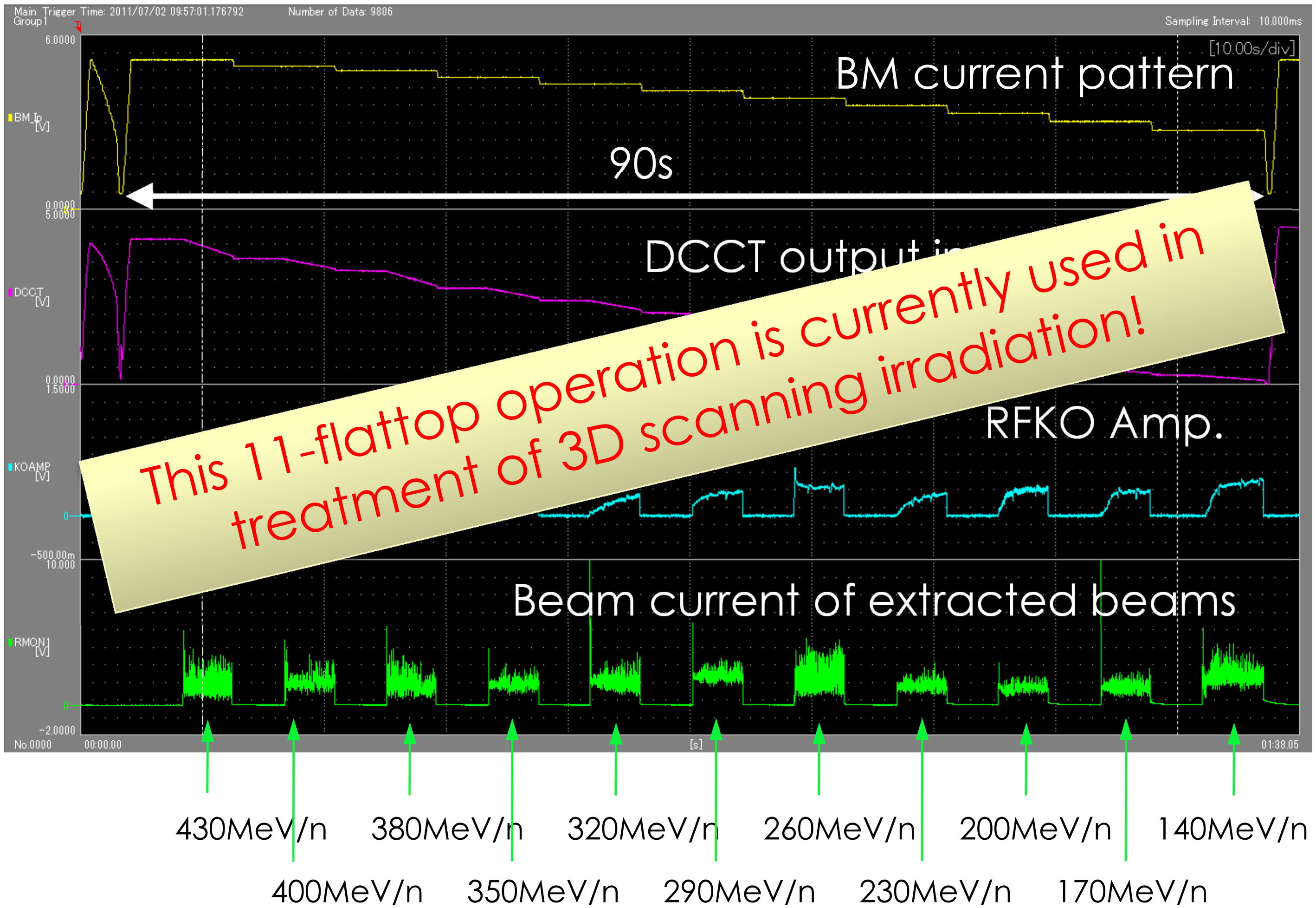




Operation with 11-flattop pattern

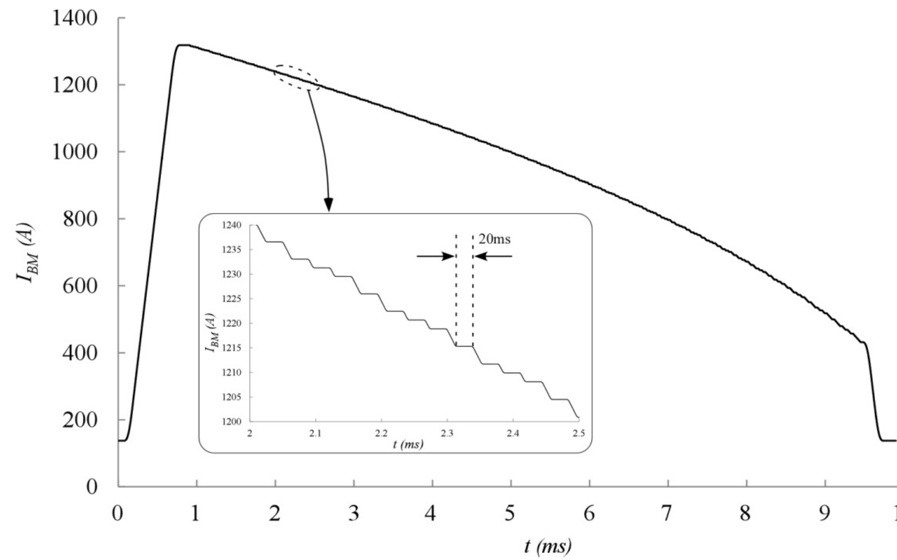


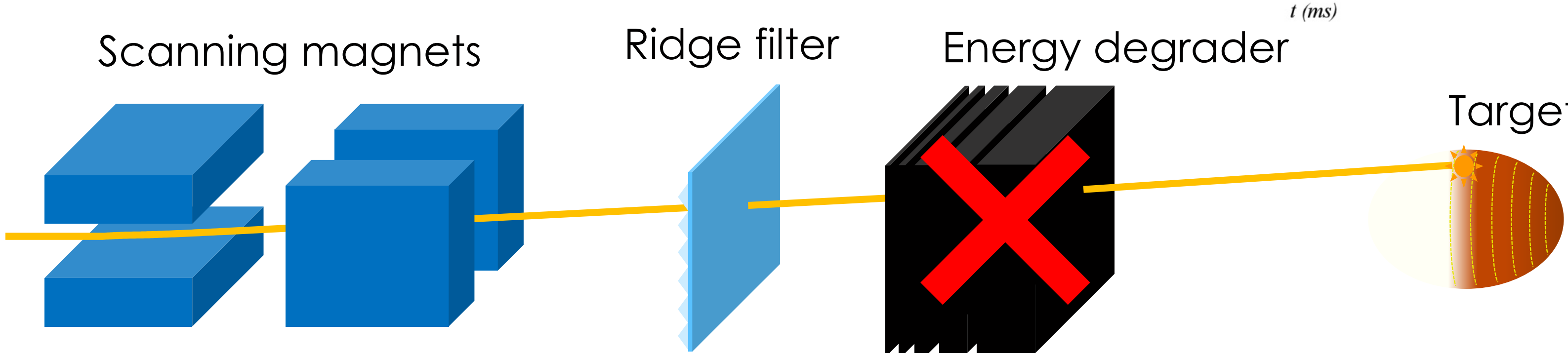
Operation with 11-flattop pattern



Full energy scanning

- **Beam energy is varied by 1 or 2 mm step in water range**
- **E=430 – 56 MeV/u**
- **201-flattop pattern**
- **No energy degrader**





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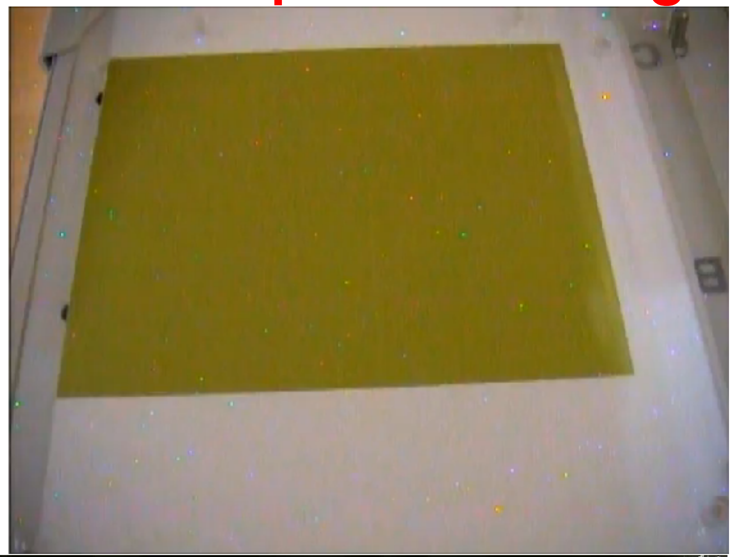
Beam acceleration and extraction tests

3mm step in water range

Lower energy

Beam direction

Higher energy



Current pattern of BM

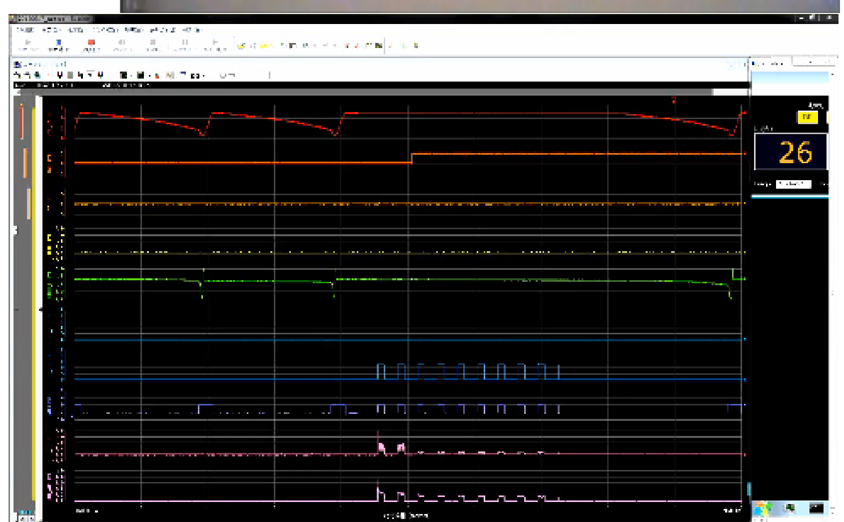
Scanning magnet (X)

Scanning magnet (Y)

Extracted beam

Beam current in ring

Irradiation gate



Energy ID

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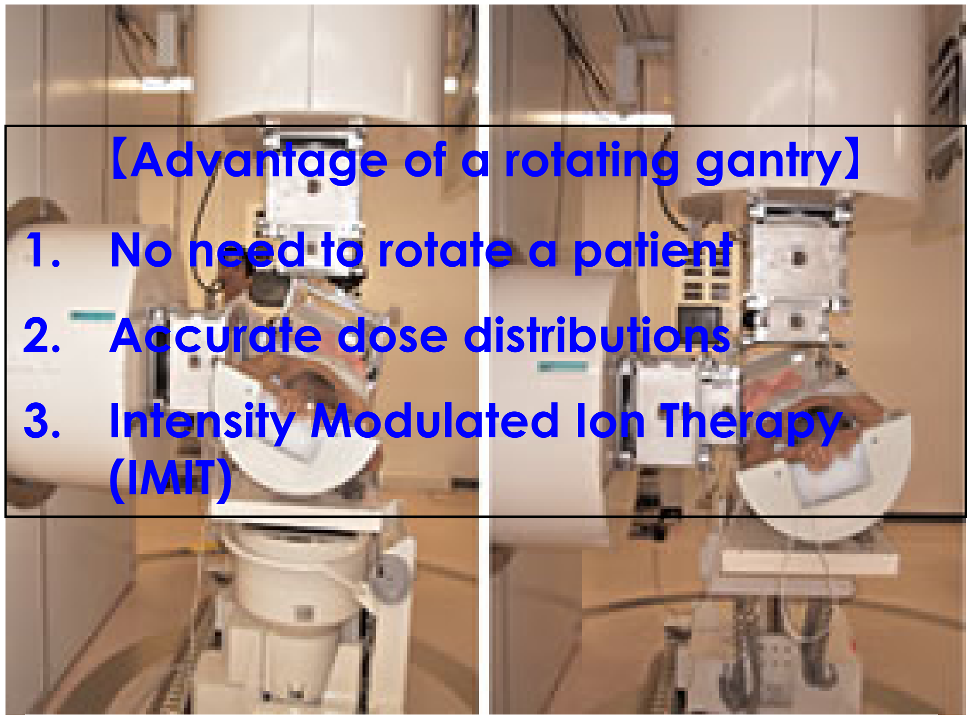
Recent developments #3 (SC rotating-gantry)

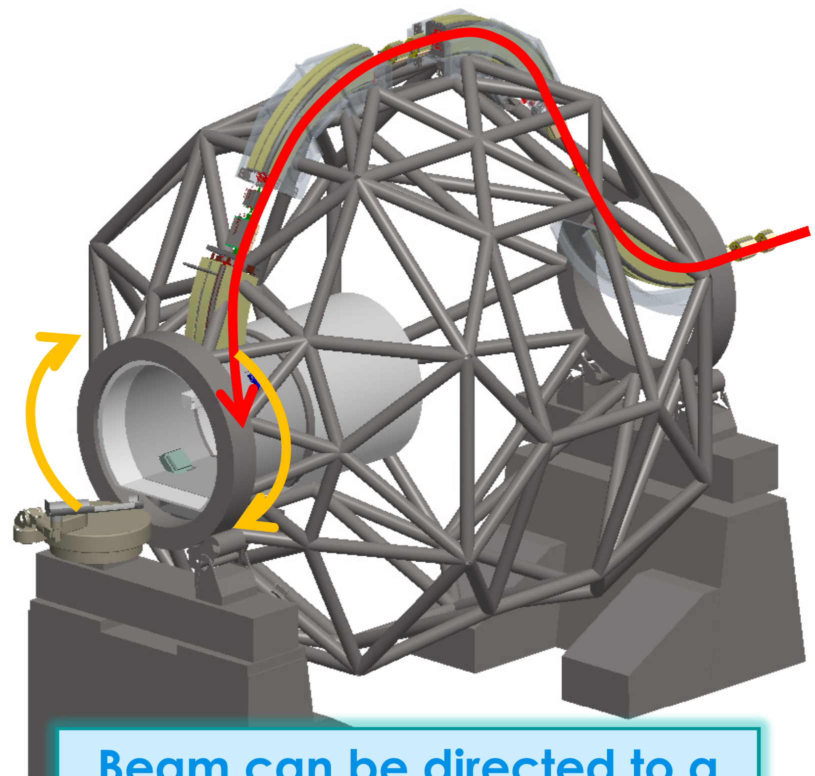
Needs for a rotating gantry



【Advantage of a rotating gantry】

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

Irradiation with the existing fixed port



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

Rotating gantry for carbon therapy

- **Only one gantry in the world**
  - Heidelberg Ion Beam Therapy Center (HIT)
- Size and weight
  - Radius: 6.5m
  - Length: 25m
  - Weight: 670t
  (Rotating part: 600t)

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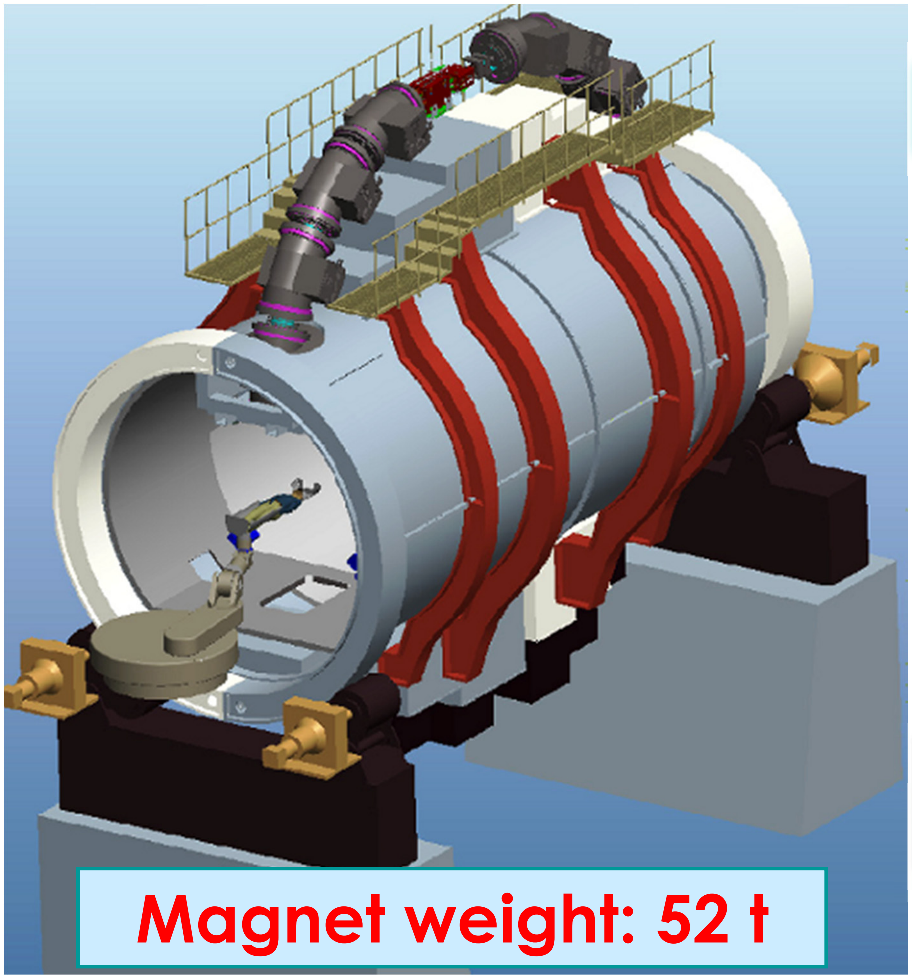
Superconducting rotating-gantry



Magnet weight: 52 t

Use of superconducting (SC) magnets

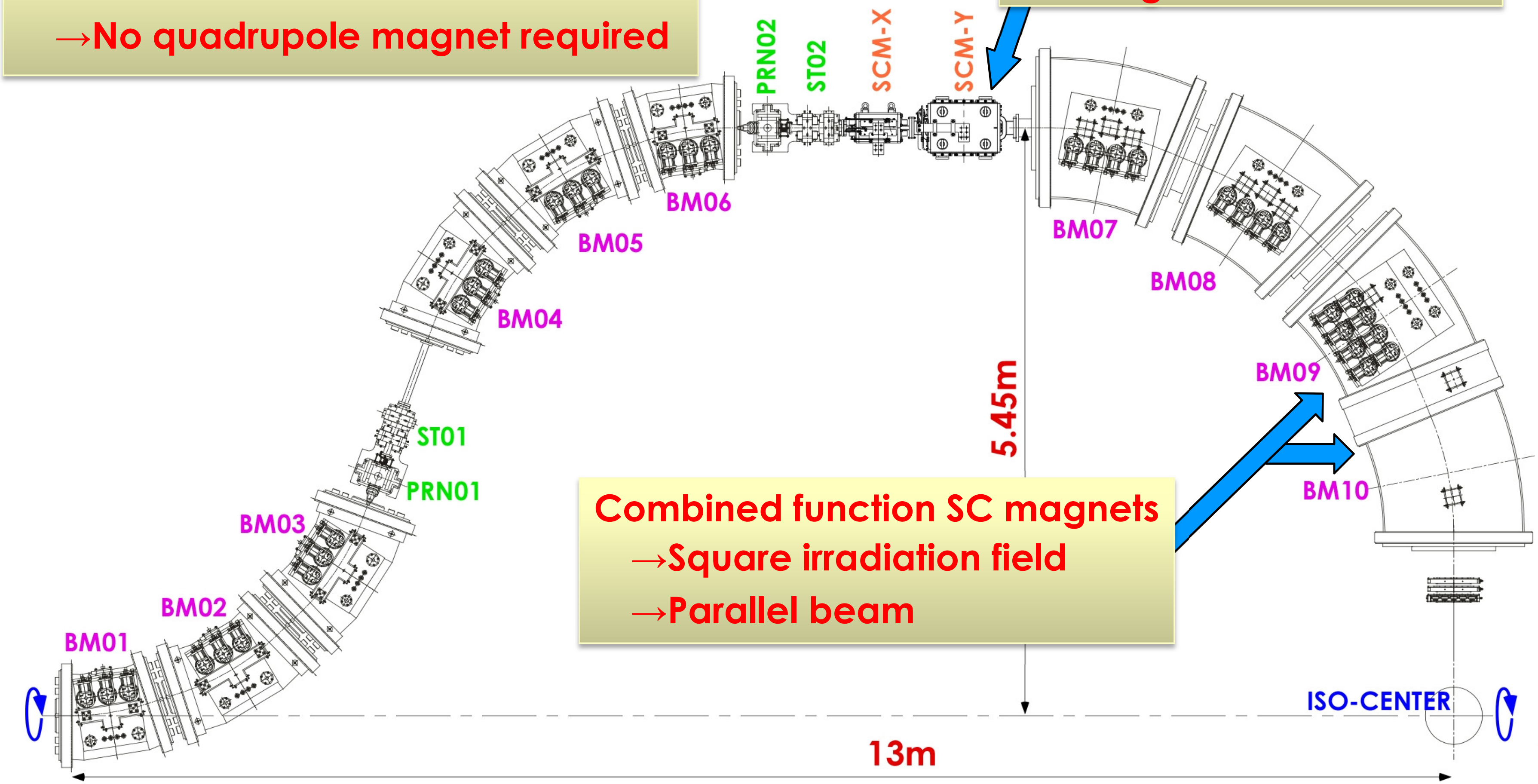
Ion kind	: ^{12}C
Irradiation method	: 3D Scanning
Beam energy	: 430 MeV/n
Maximum range	: 30 cm in water
Scan size	: □200×200 mm^2
Radius	: 5.45 m
Length	: 13 m

The size and weight are comparable to those of proton gantries!

Layout of the SC gantry

Combined function SC magnets
(BM01～BM06)
→No quadrupole magnet required

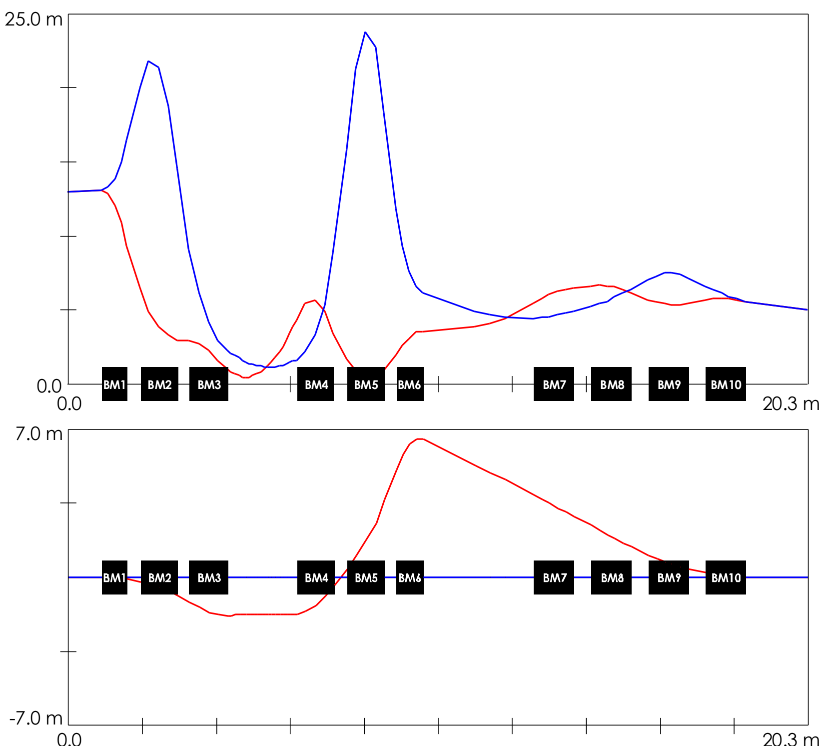
Scanning magnets on top
→Large scan size



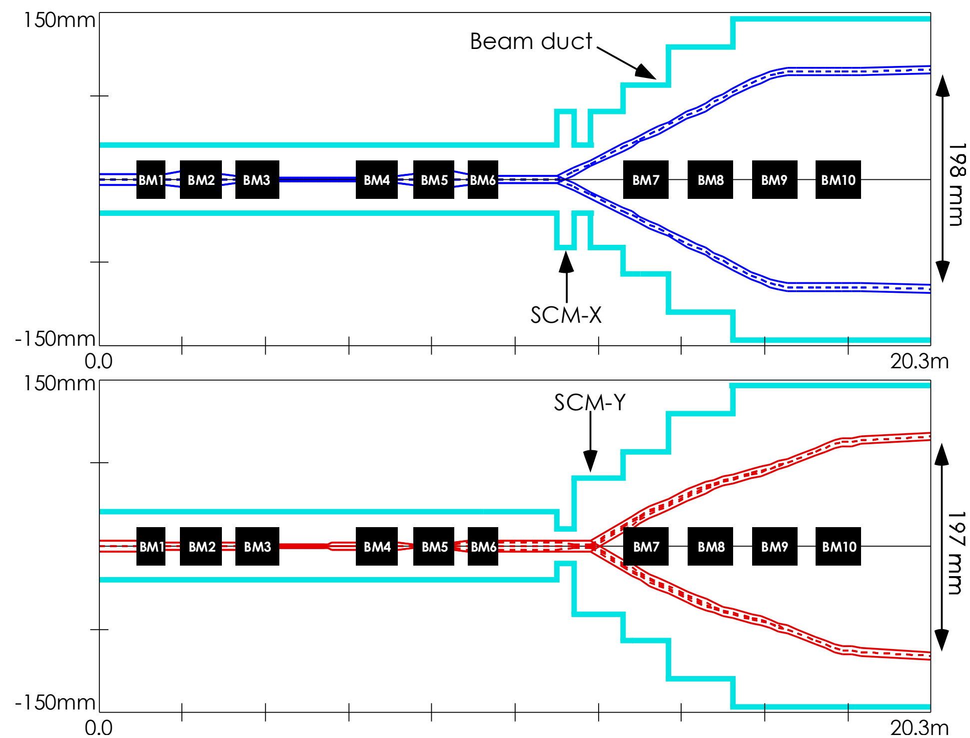
Combined function SC magnets
→Square irradiation field
→Parallel beam

Beam optics design

Beta and dispersion functions

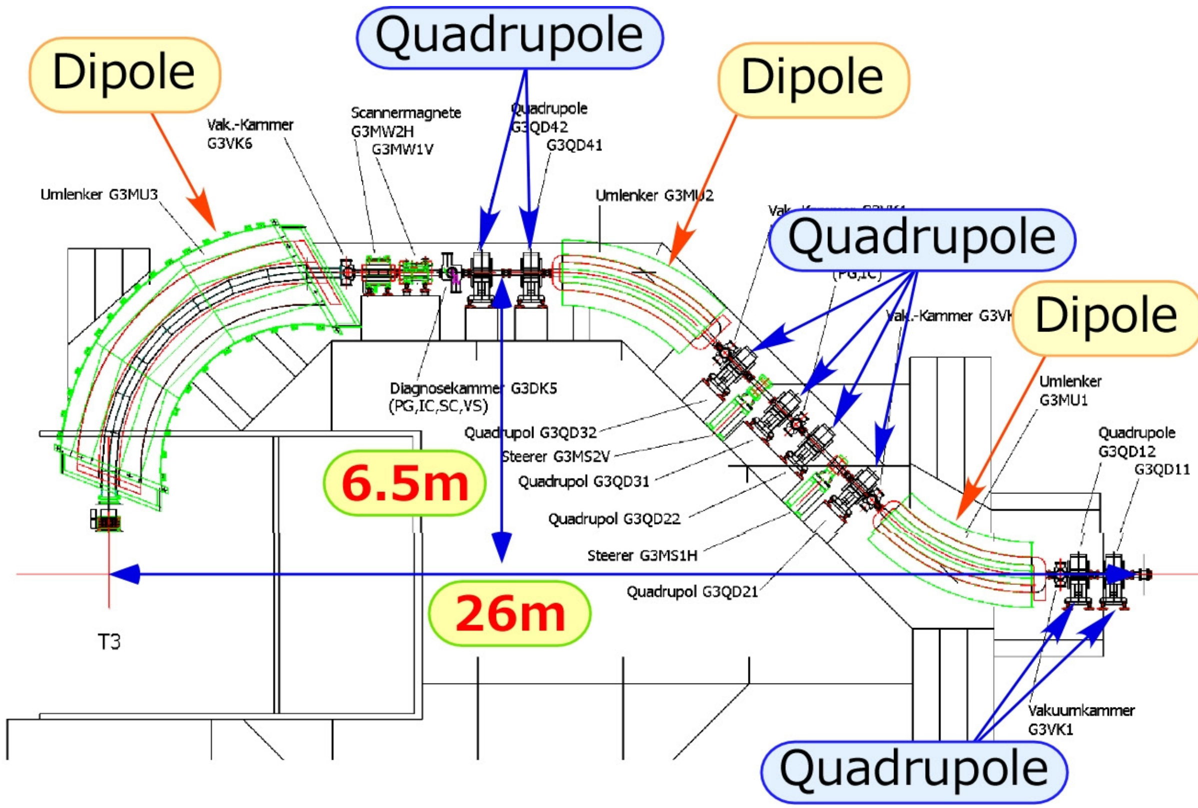


Beam envelope functions with kicks of scanning magnets

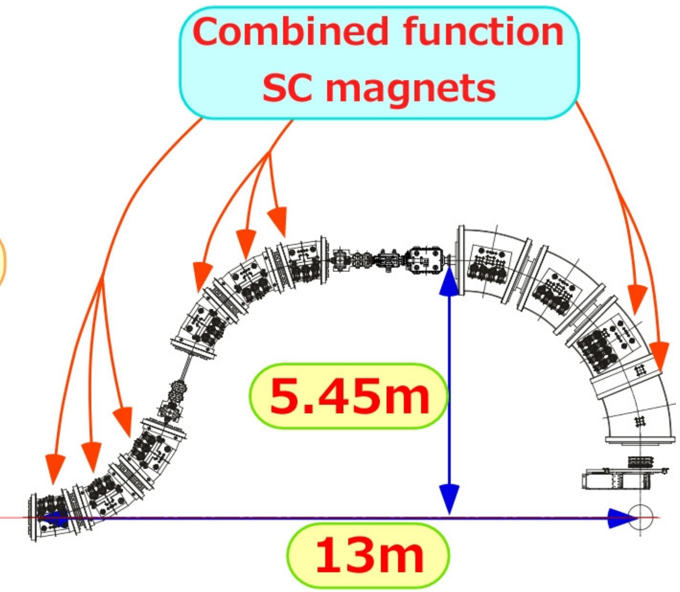


Comparison in size

HIT gantry



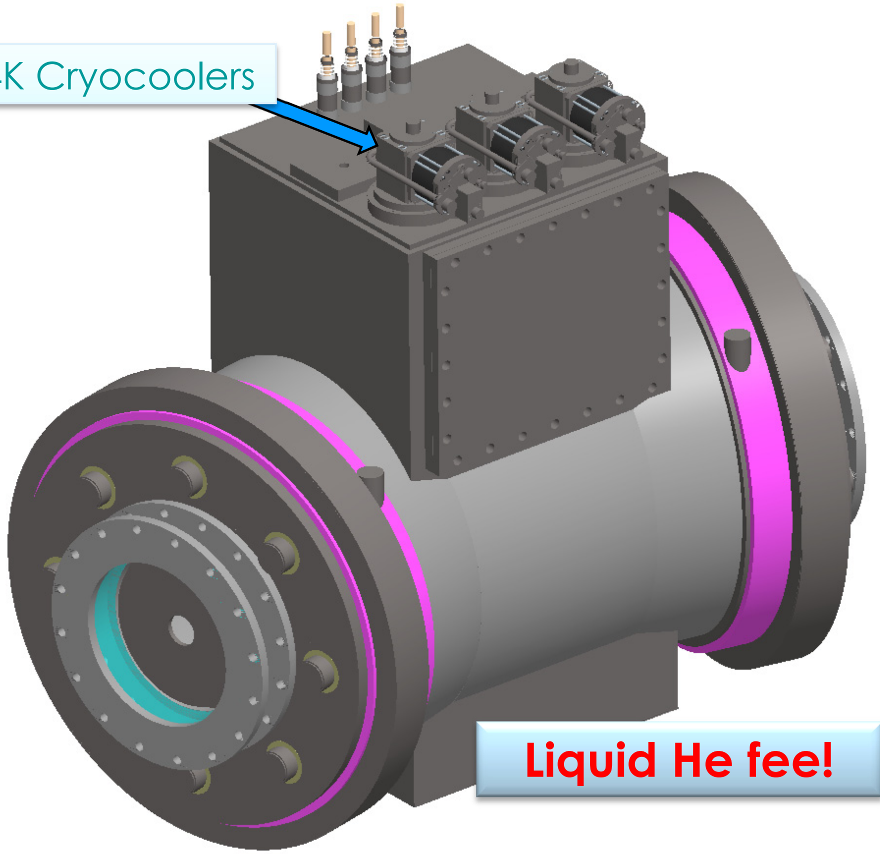
NIRS SC-gantry



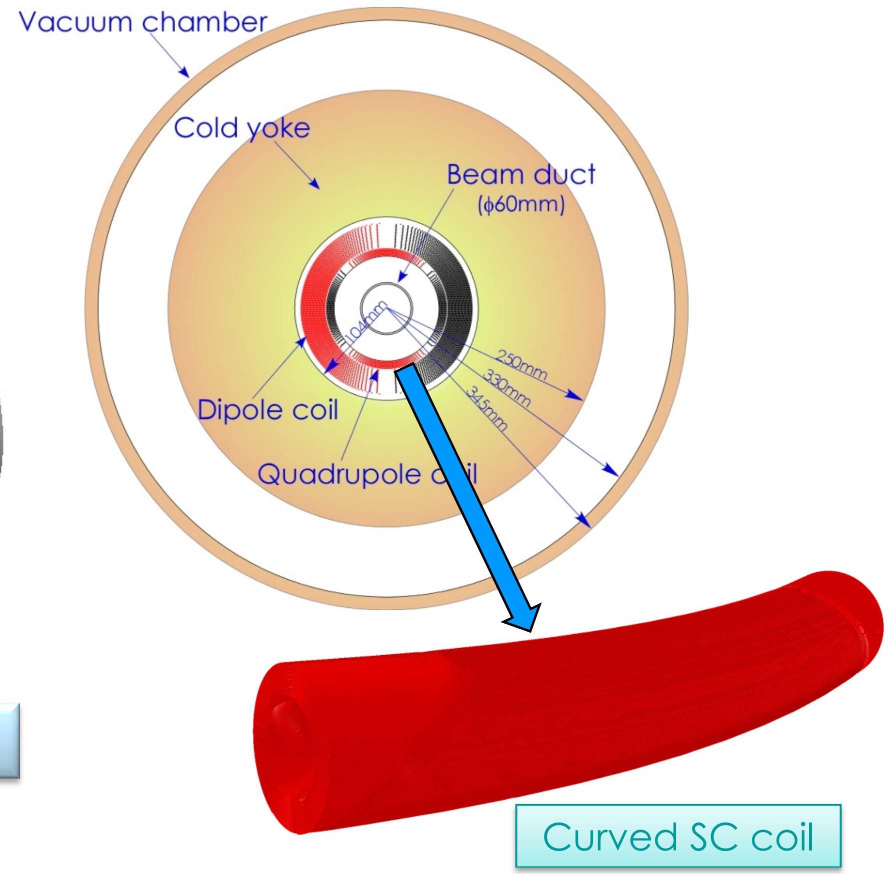
Length and weight are reduced by ~1/2

Development of curved SC magnets

SC magnet (BM02-05)

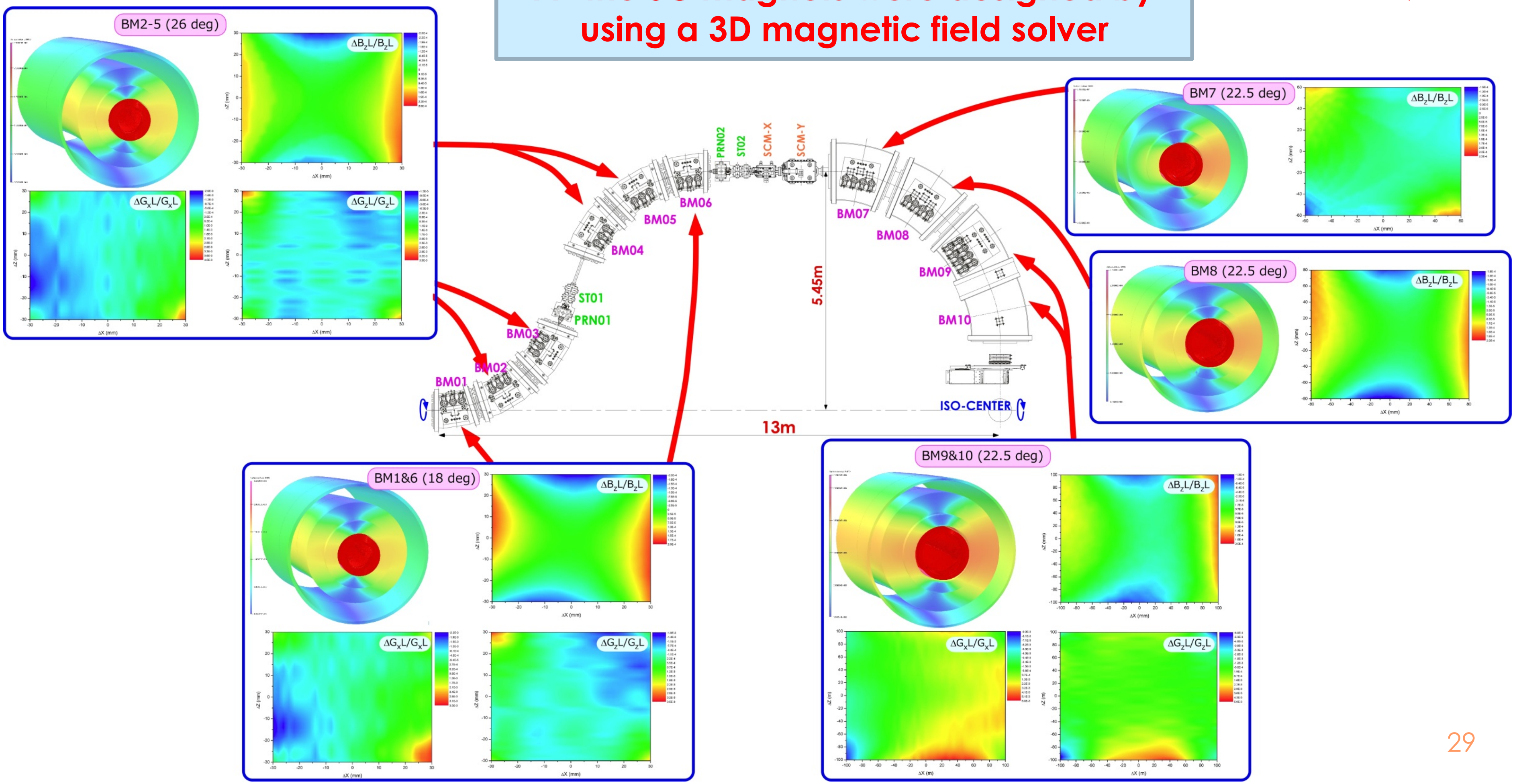


Cross-sectional view



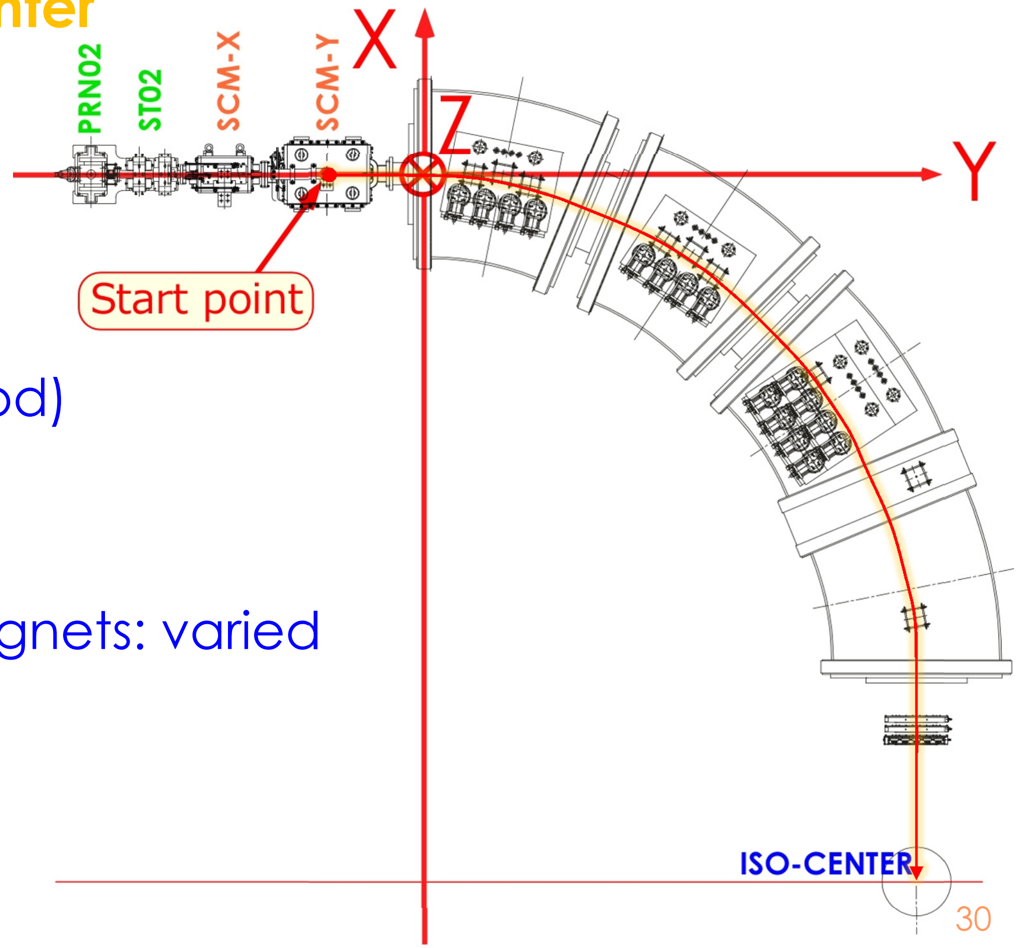
Design of SC magnets

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



Beam tracking simulations

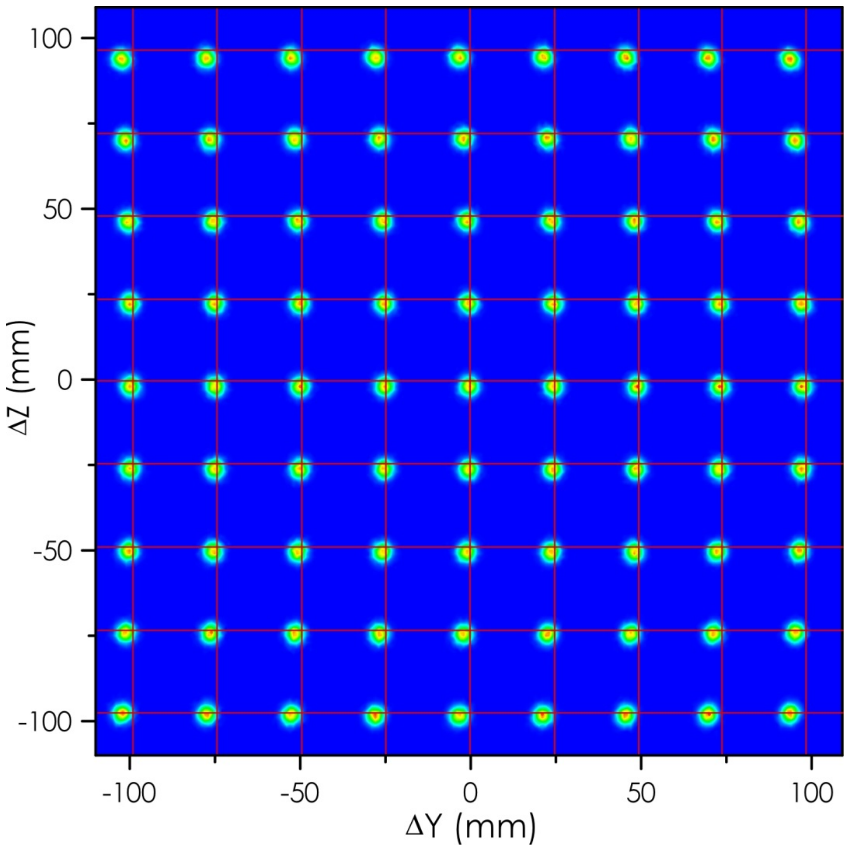
- **Beam tracking to the isocenter**
  - Field map data (from Opera-3d code)
  - Numerical integration of equation of motion (4^{th} order Runge-Kutta method)



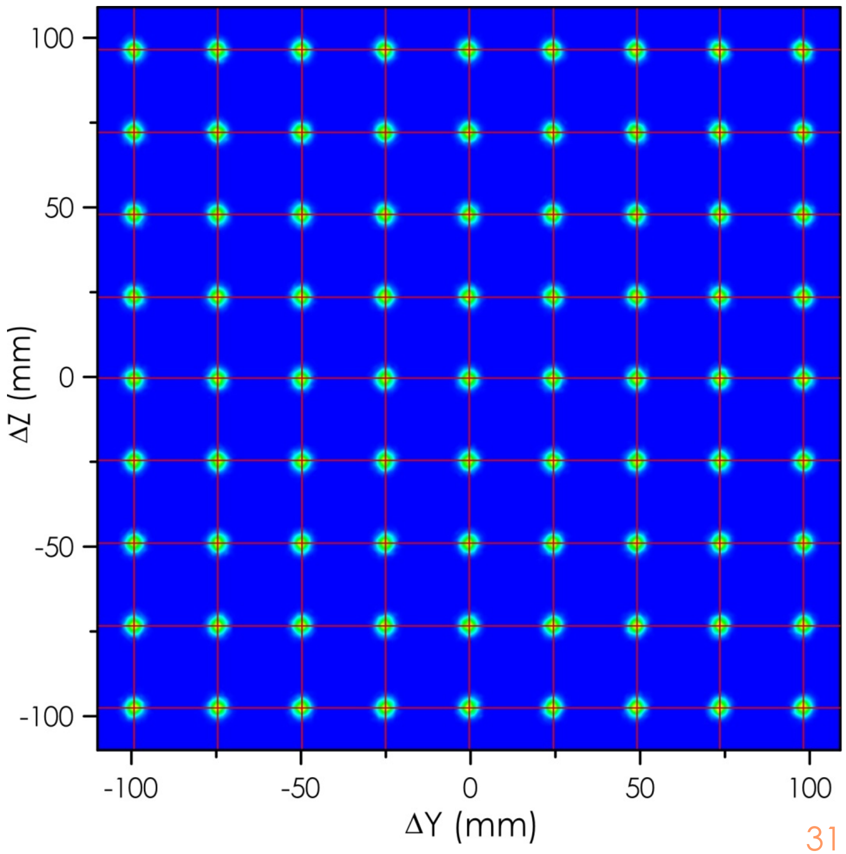
- **Beam profile at isocenter**
  - Kick angle of scanning magnets: varied
  - 81 spots at isocenter

Beam tracking simulations

Phase space distribution of three beam spots

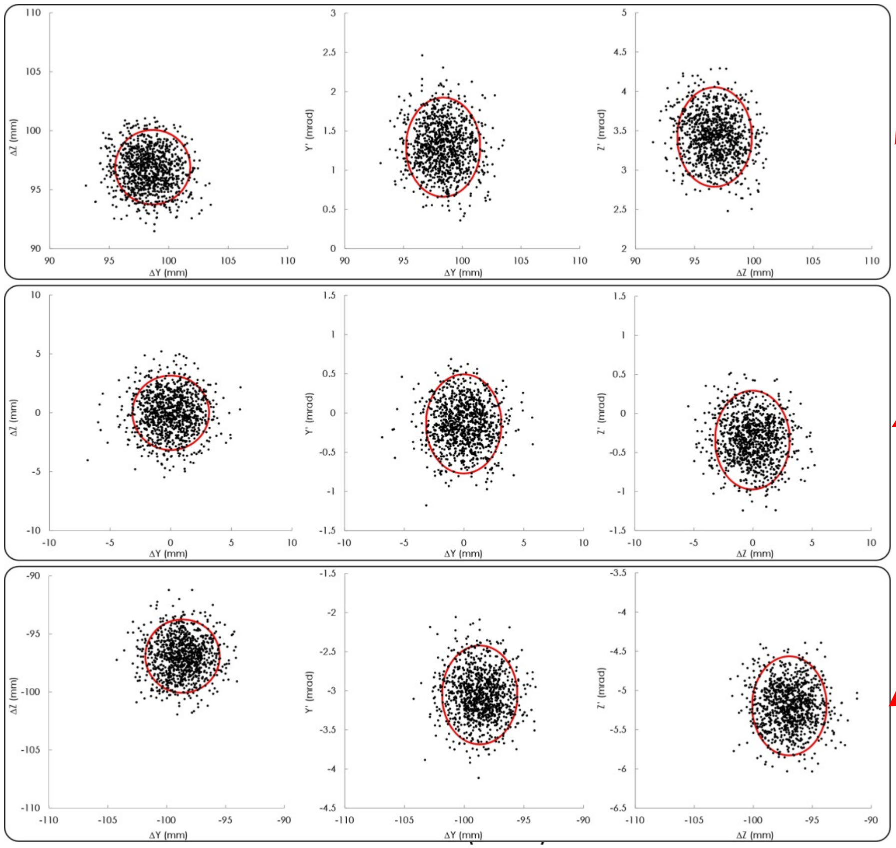


Beam profile after correction with the scanning magnets

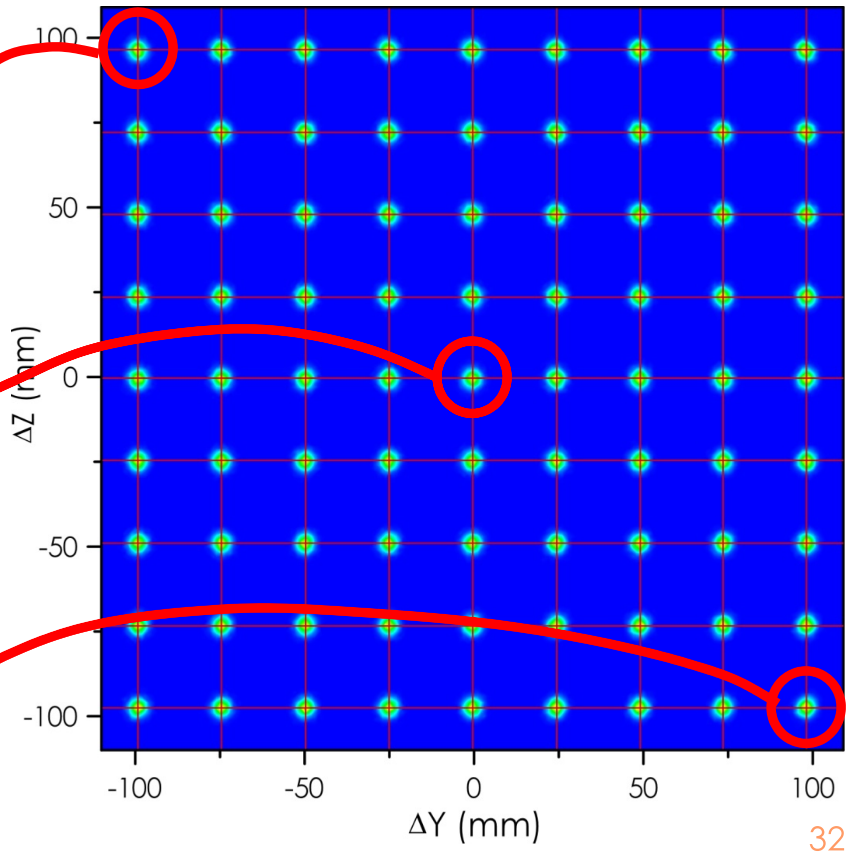


Beam tracking simulations

Phase space distribution of three beam spots



Beam profile after correction with the scanning magnets

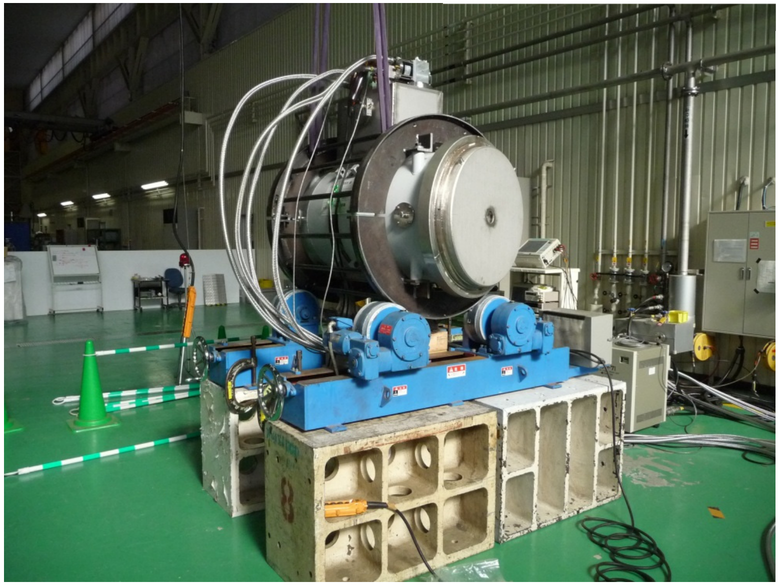


Construction and tests of SC magnets

Rotation tests

- Model SC magnet (Toshiba corp.)
- Rotation over ±180 degrees
- Appling maximum coil-current

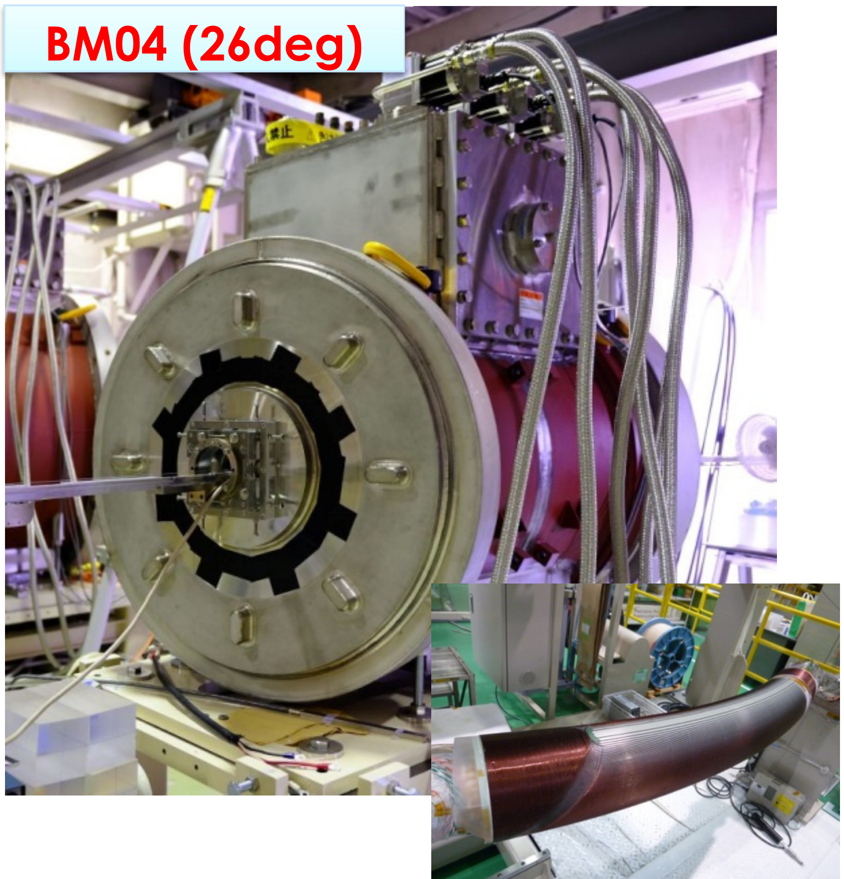
No quench observed!



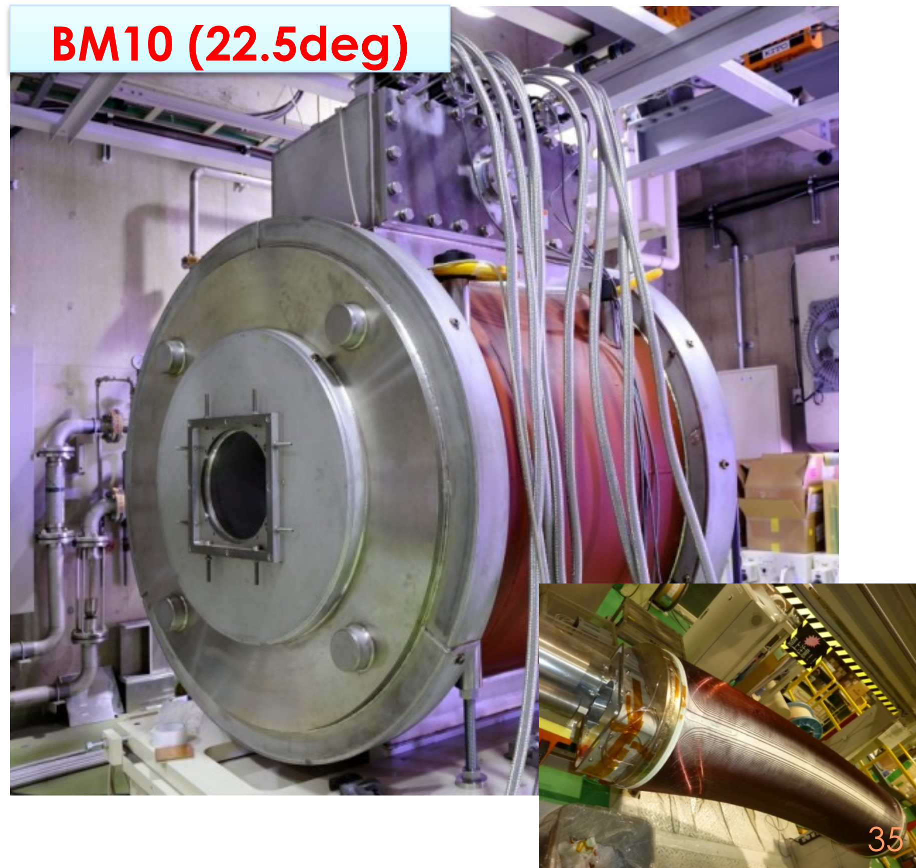
Construction of SC magnets

We have constructed 5 out of 10 SC magnets

BM04 (26deg)

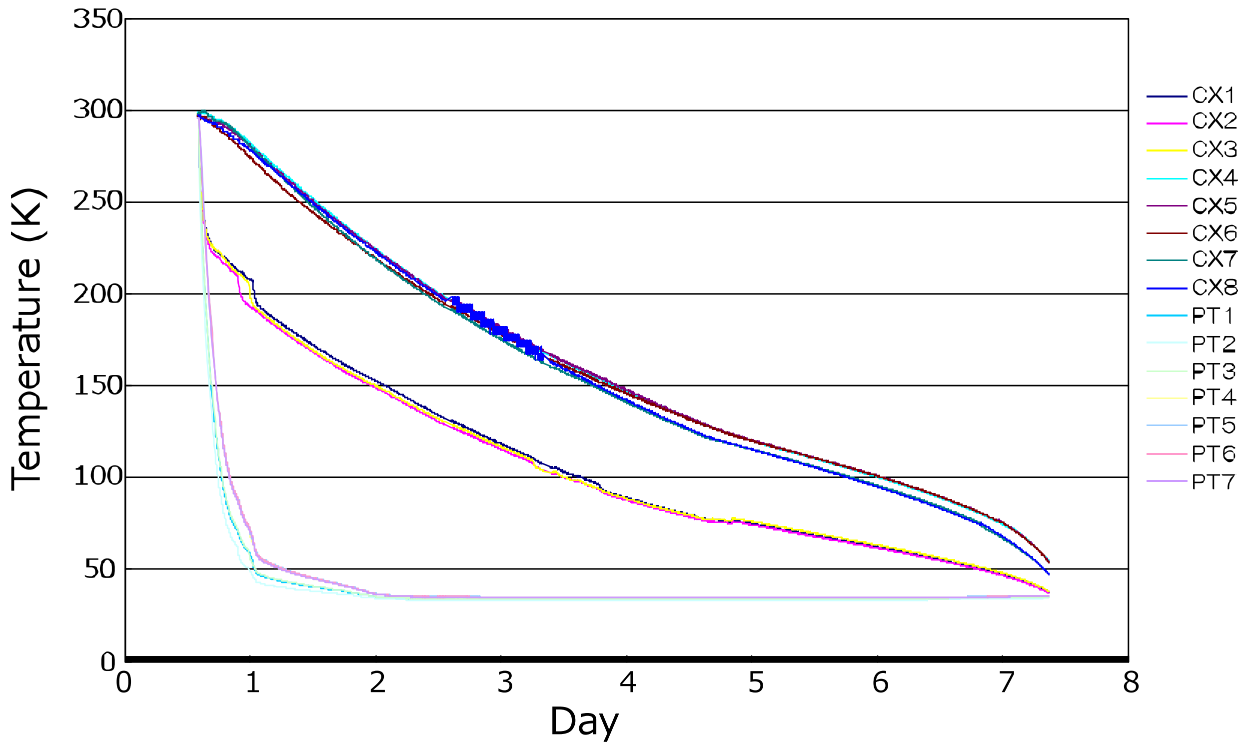


BM10 (22.5deg)



Initial cooling of SC magnet

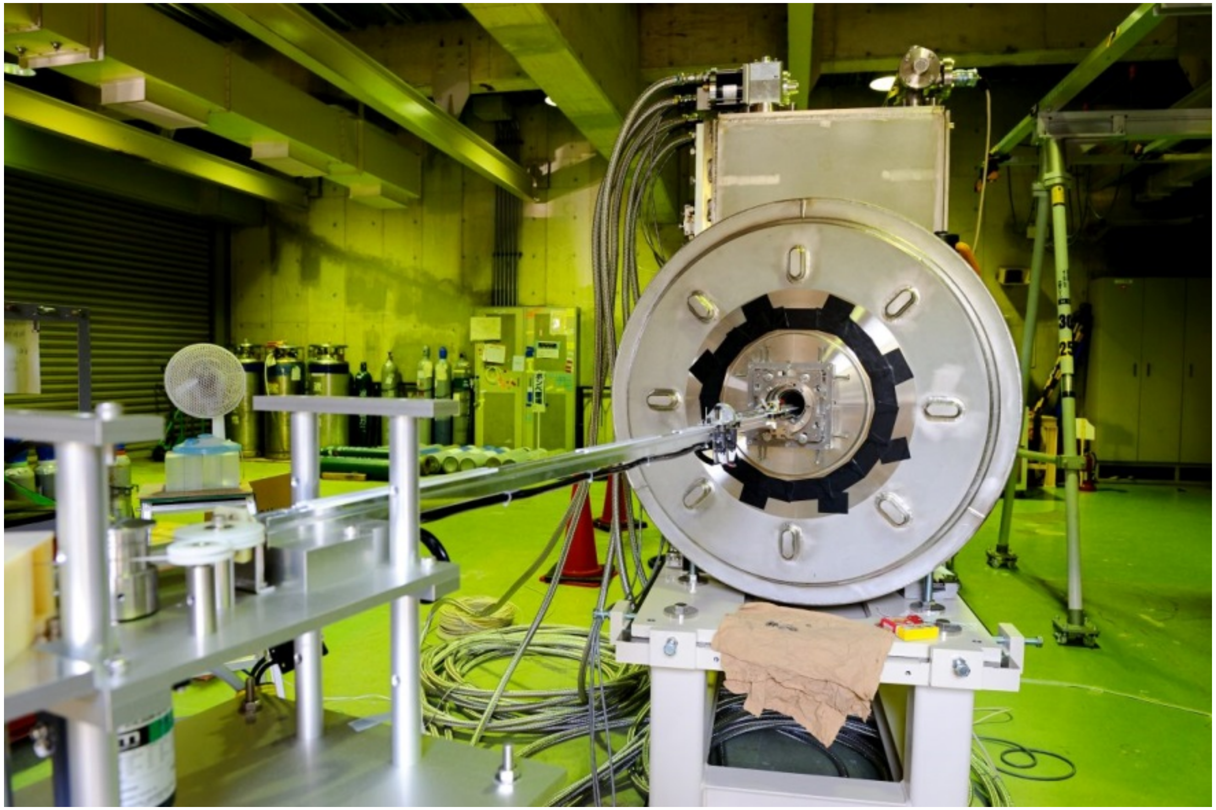
- Precool with liquid nitrogen
- It took a week to cool down by 4K



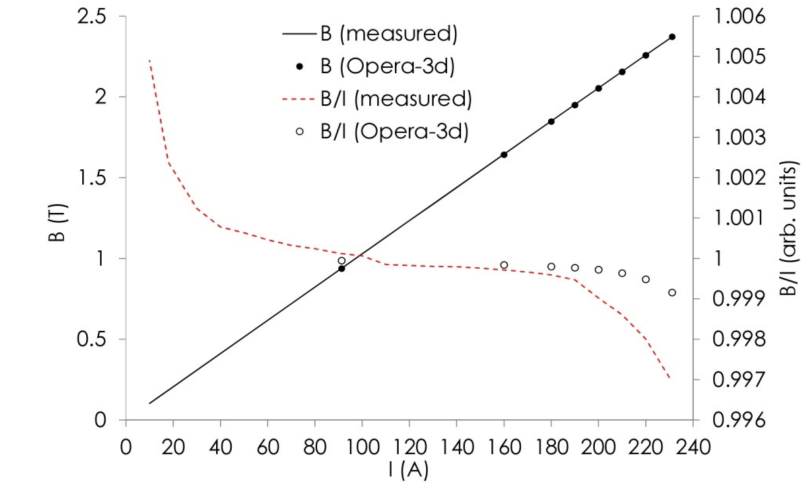
CX1: Cryocooler#1 2nd stage
CX2: Cryocooler#2 2nd stage
CX3: Cryocooler#3 2nd stage
CX4: SC coil (inner)
CX5: SC coil (middle)
CX6: SC coil (outer)
CX7: Yoke (right face)
CX8: Yoke (left face)
PT1: Cryocooler#1 1st stage
PT2: Cryocooler#2 1st stage
PT3: Cryocooler#3 1st stage
PT4: HTCPL Dipole (P)
PT5: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

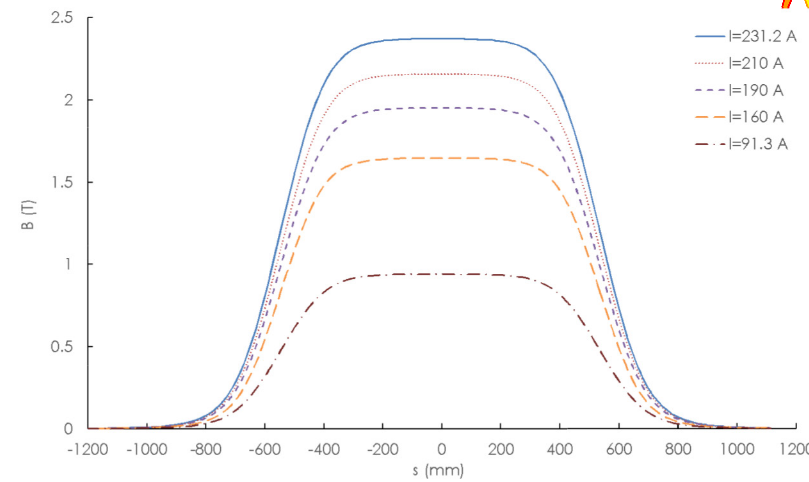
Field measurements

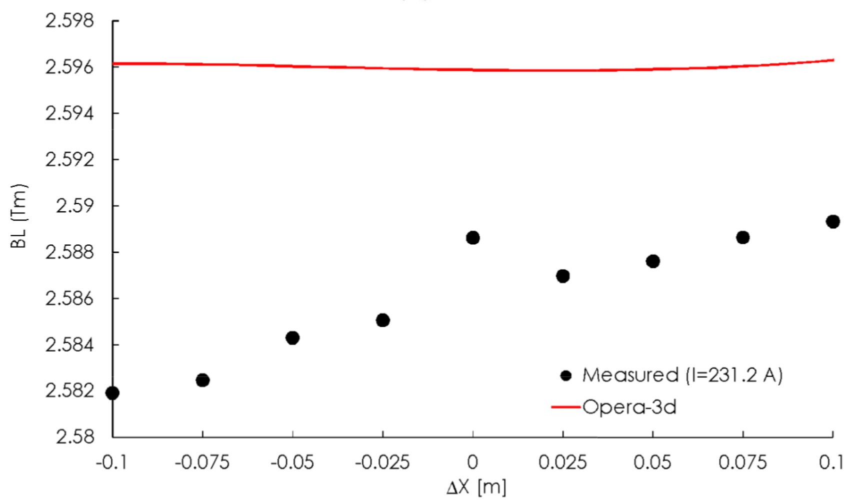
- Magnetic field measurements were performed
  - to verify the SC magnet design

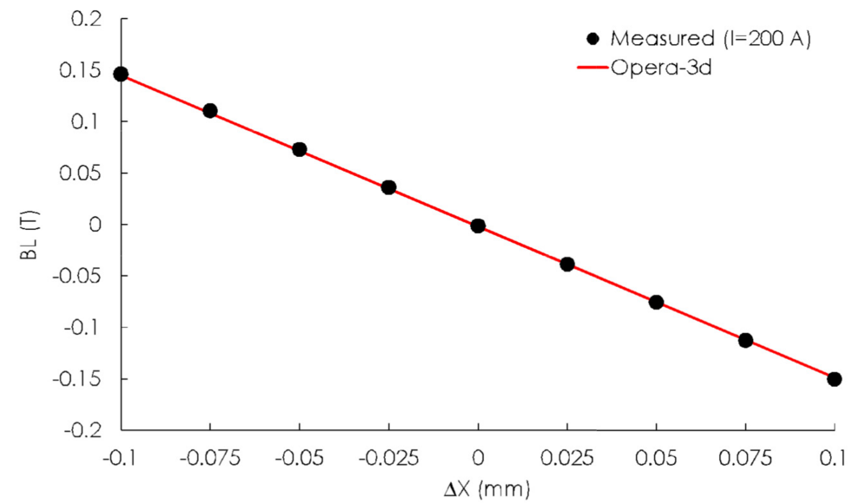


Some results for BM10





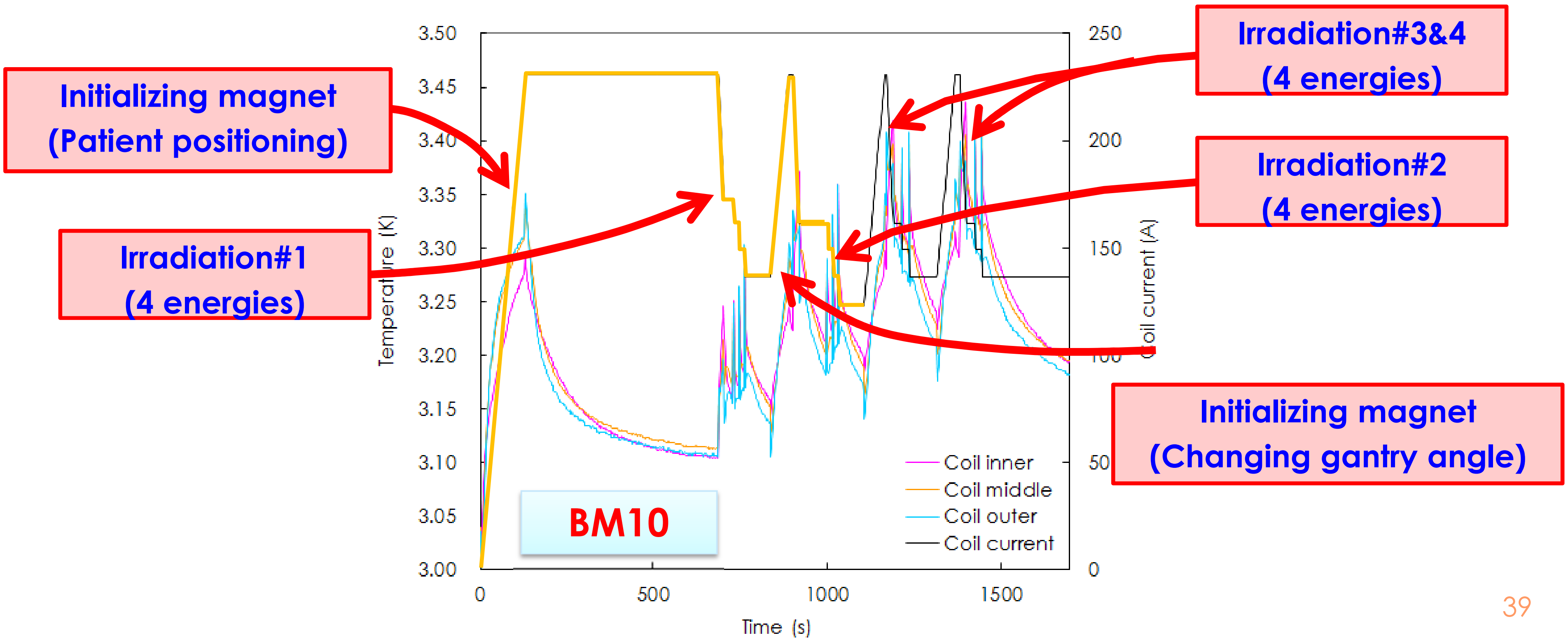




Fast slewing tests (1)

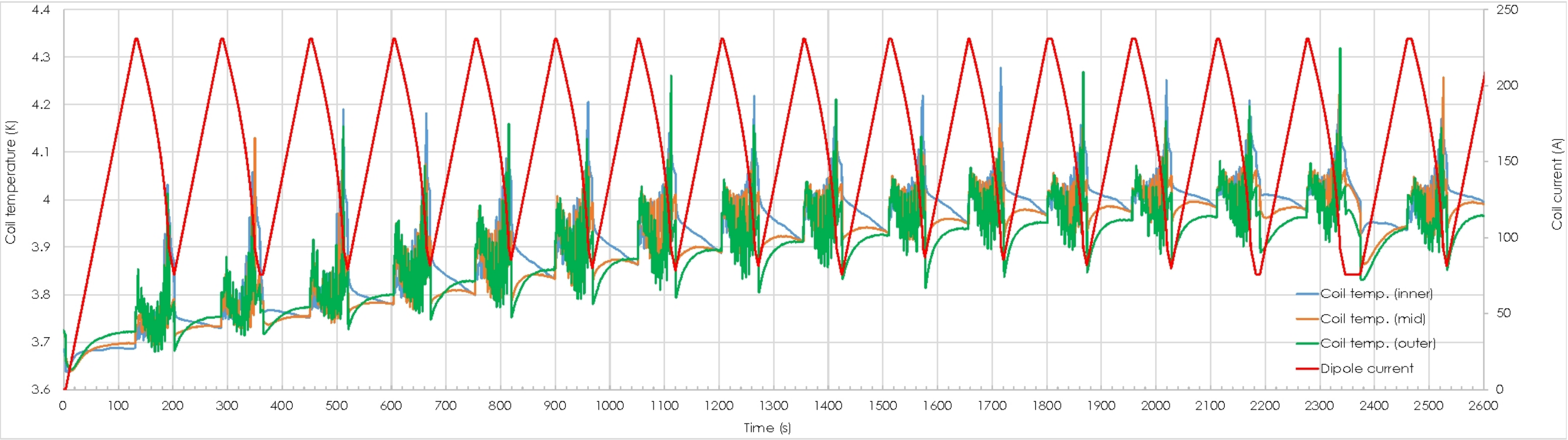
- Simulating irradiation for
  - lung cancer (4 shots), using
  - Multiple-energy operation using 11-flattop pattern

No quench observed!



Fast slewing tests (2)

- Simulate 201-flattop pattern (BM10)
- Each flattop : 300ms
- **No quench observed**
- **Average temperature converged around 4.0 K**
- **Similar results for the other SC magnets**



Summary

- 3D raster scanning irradiation
  - Fast scanning for moving target
- Multiple-flattop operation
  - 11-flattop operation: currently used in treatment
  - 201-flattop operation: tests succeeded. To be used in treatment operation

Summary (cont'd)

- Design of the SC rotating-gantry
  - Compact (~proton gantries)
  - Construction and tests of the 5 SC magnets

    → Test results agreed with those designed
- Future plan
  - All the construction and installation will be made by the end of FY2014 (March 2015)
  - Commissioning will be made in FY2015

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Collaborators

- K. Noda, T. Shirai, T. Murakami, T. Furukawa, T. Fujita, K. Shouda, S. Sato, K. Mizushima, Y. Hara, and S. Suzuki (NIRS)
- T. Fujimoto, H. Arai (AEC)
- T. Orikasa, S. Takayama, Y. Nagamoto, T. Yazawa (Toshiba)
- T. Ogitsu (KEK)
- T. Obana (NIFS)
- N. Amemiya (Kyoto Univ.)