MOA2C01
13th Intl. Conf. on Heavy Ion
Accelerator Technology
Sep. 7, 2015

RCNP
大阪大学 核物理研究センター

Design of a Sector Magnet for High Temperature Superconducting Injector Cyclotron

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Research Center for Nuclear Physics

Osaka University

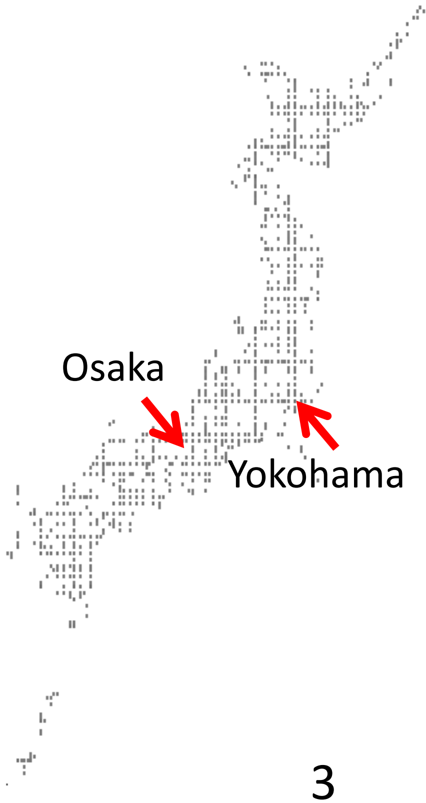
Overview

- About us
- Current status of RCNP
- Project for New Injector Cyclotron
- Sector Magnet Design
- HTS Magnets
- Summary

About Us

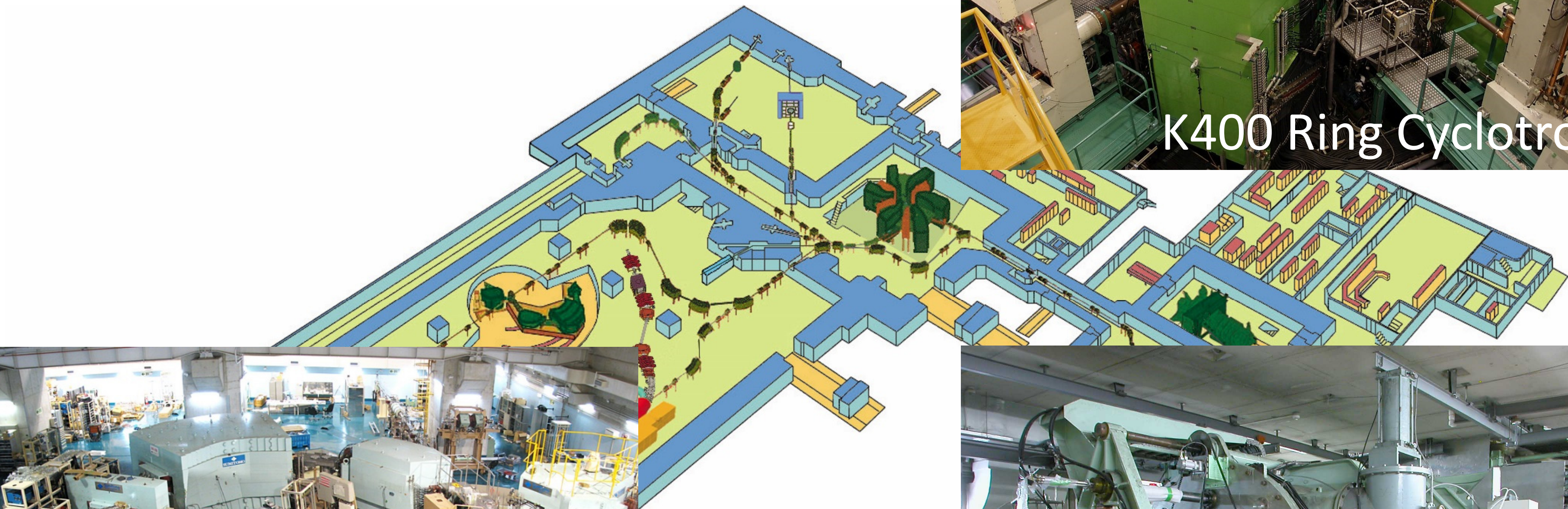
- Research Center for Nuclear Physics

大阪大学
OSAKA UNIVERSITY



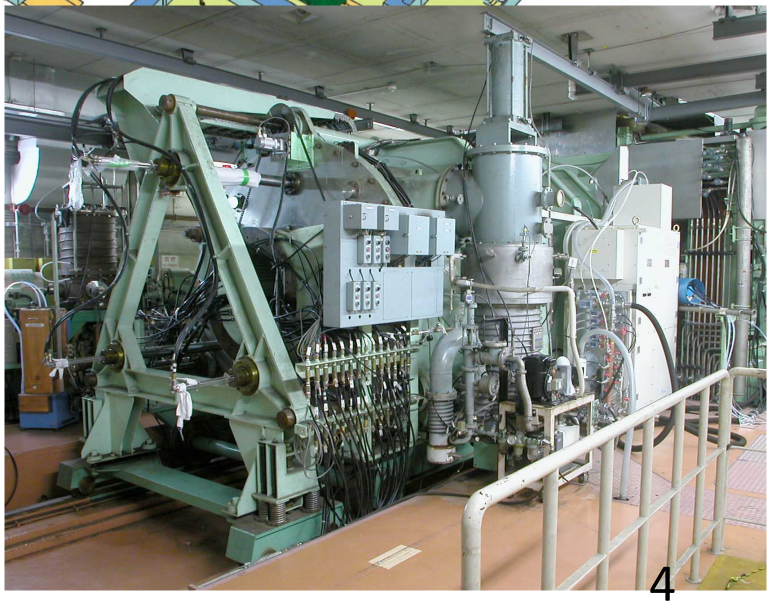
About Us

- RCNP Cyclotron Facility



K400 Ring Cyclotron


Grand Raiden Spectrometer


K140 AVF Cyclotron

Features of beam production at RCNP

- High energy resolution acceleration for precise nuclear physics experiments
- Together with Grand Raiden Spectrometer

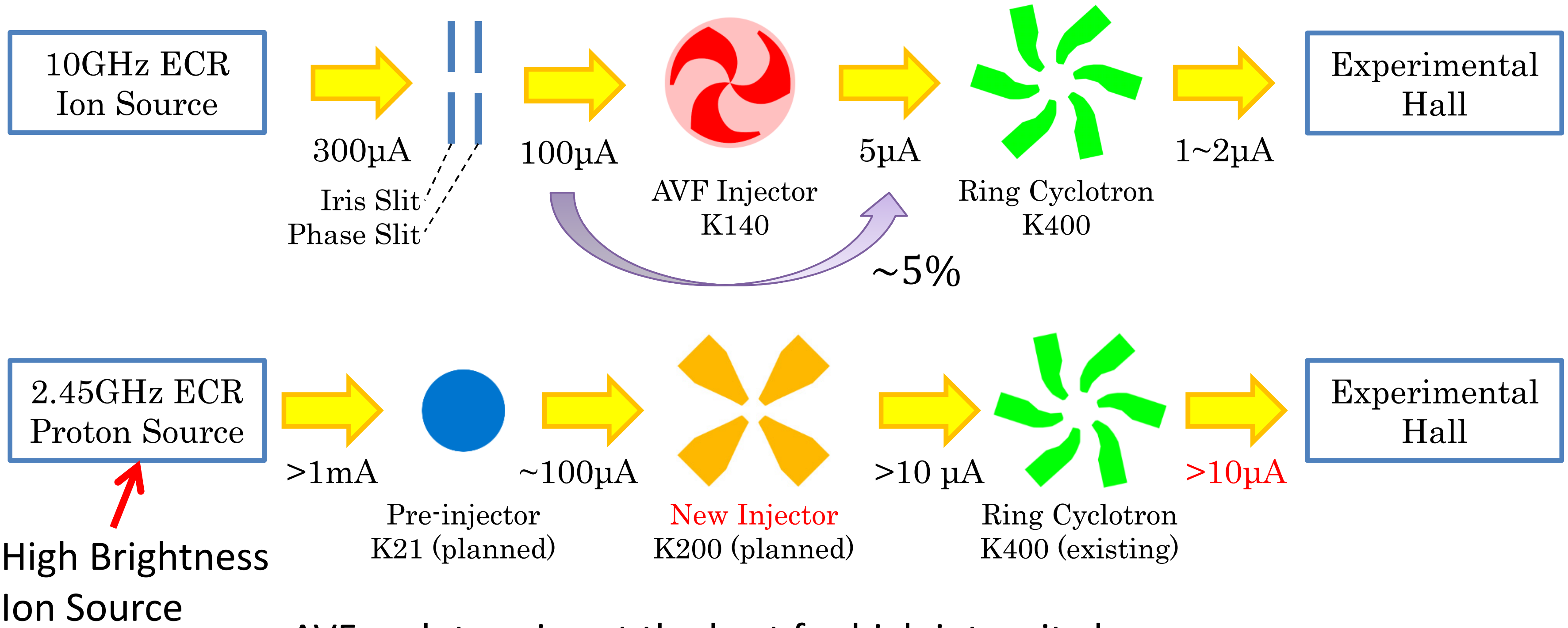
$$\frac{\Delta E}{E} \sim \frac{12.8\ \mathrm{keV}}{295\ \mathrm{MeV}} \sim 4.3 \times 10^{-5}$$

  mainly for light ions $(p, d, {}^{3}He, \alpha \ldots)$
- Intensity of the precise beam is $\sim few\ \mathrm{nA}$

- Using proton beam to produce secondary particle beam (neutrons, muons)
- Intensity limit of the primary proton beam is $\sim 1\ \mu\mathrm{A}$

Our Goal

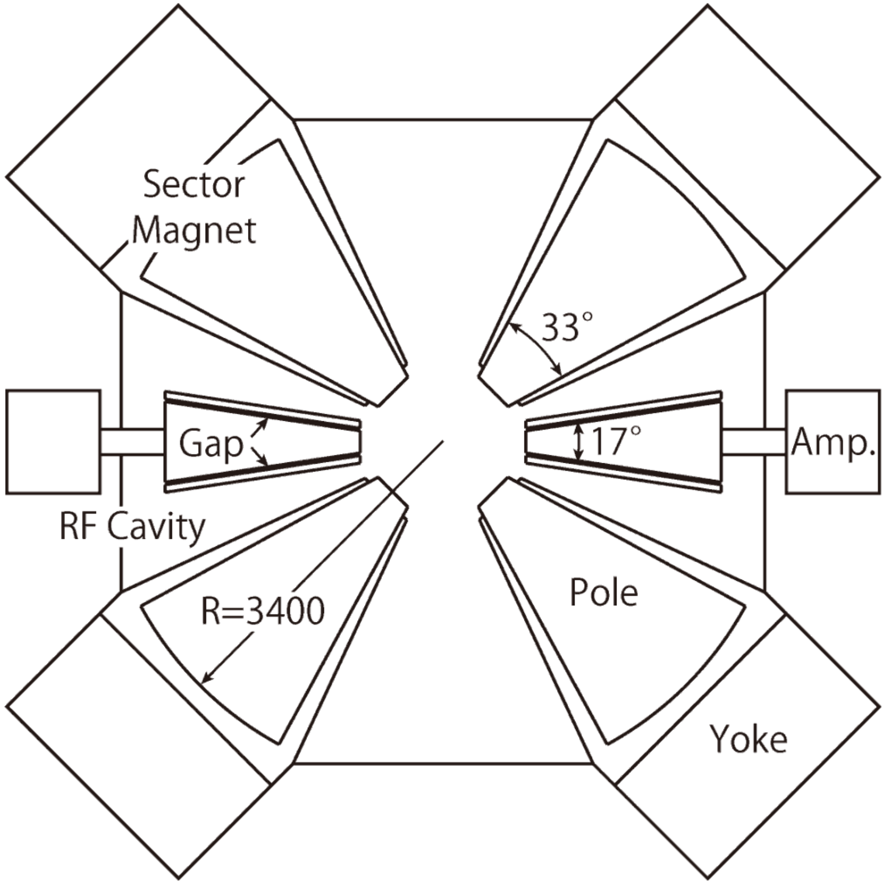
- Increase the beam current x10 for both
  - Precise ion beams (few nA → $several\ tens\ of$ nA)
  - Primary proton beam (1 μA → 10 μA)



AVF cyclotron is not the best for high intensity beam

New Injector: Conceptual Design

Parameters	
K value	200 MeV
Injection Radius	1 m
Extraction Radius	3 m
Sector Magnet	
Pole Angle	33°
No. of Sectors	4
Max. Field	1.73 T
RF Cavity	
No. of Cavities	2
No. of Gaps	2
Harmonic No.	9, 15 (RING: 6, 10)
RF Frequency	30~52 MHz
Gap Angle	17°

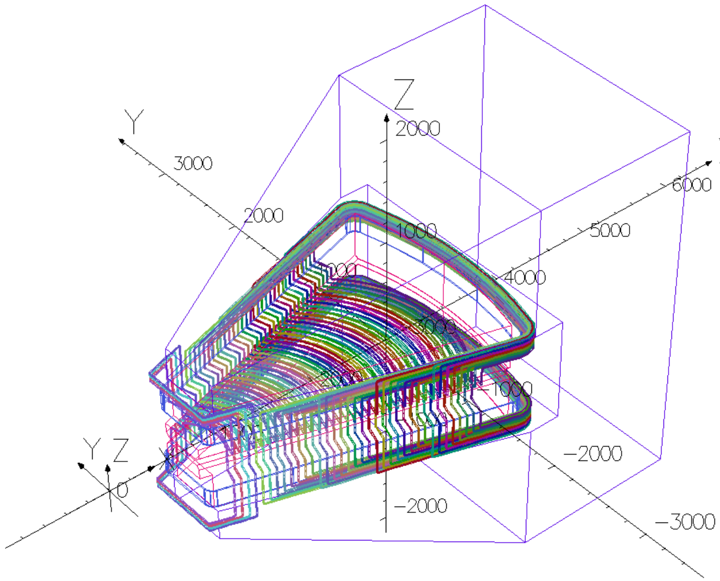


For technological development, main coil of the new injector will be implemented with HTS coils.

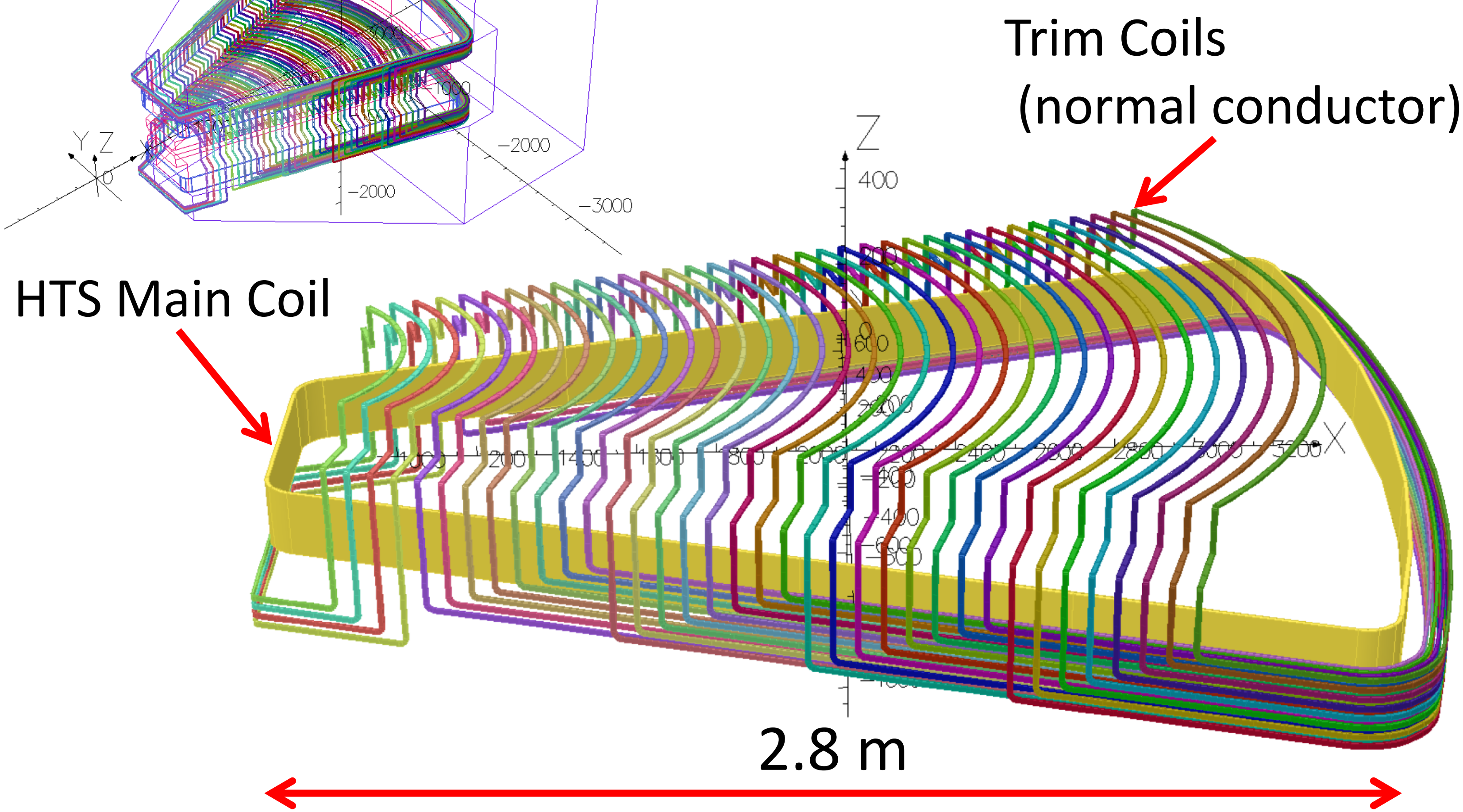
Motivations for HTS Cyclotron

- Magnets can be compact, and can generate high magnetic field
- Low power consumption
- Critical temperature is high: $T_c > 100\ \mathrm{K}$
  - No liquid helium is required
  - Operating Temperature: $T_o \sim 10\ \mathrm{K}$
  - Large margin between operating temperature and T_c
    → High stability against quenching
- Still, large scale HTS coil used for cyclotron is not available so far

New Injector: HTS Main Coil & Trim coils



- FEM model of the sector magnet.



Isochronous Field

- Design Assistant Program
  1. FEM field analysis on 3D model of sector magnet (Opera-3d, TOSCA)
     1. Main Coil
     2. 36 Trim Coils
  2. Orbit simulation on Main Coil and find equilibrium orbit by controlling particle energy (Runge-Kutta)
  3. Calculate K_B and K_r for each radius
  4. Fit isochronous field by trim coils
  5. Excite trim coils in FEM model and calculate the field

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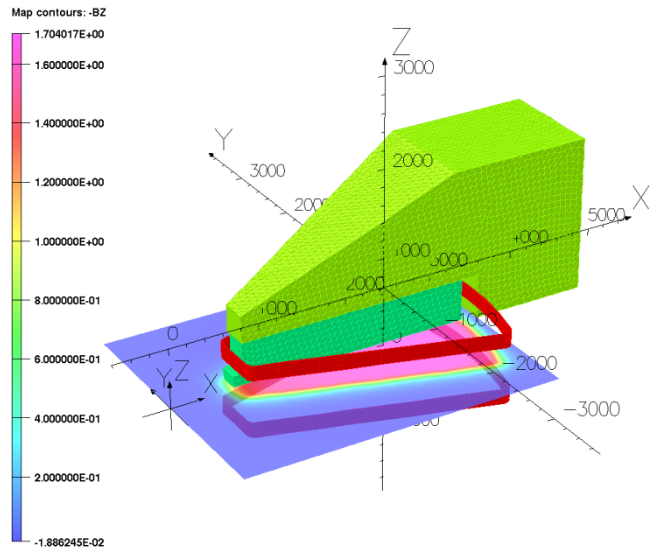

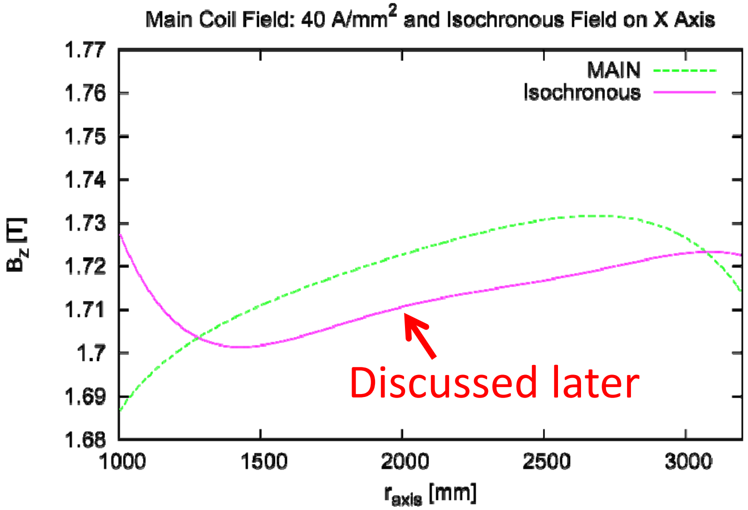

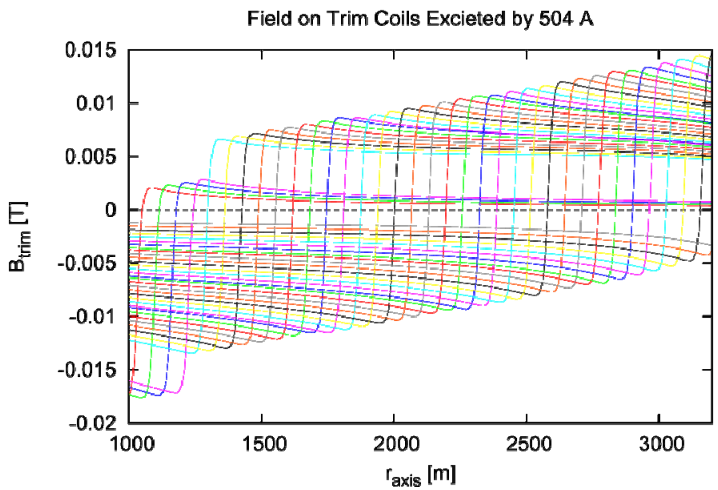

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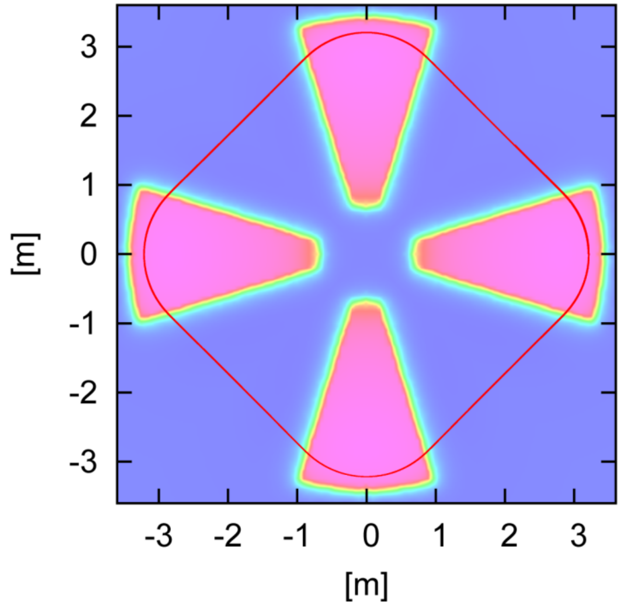


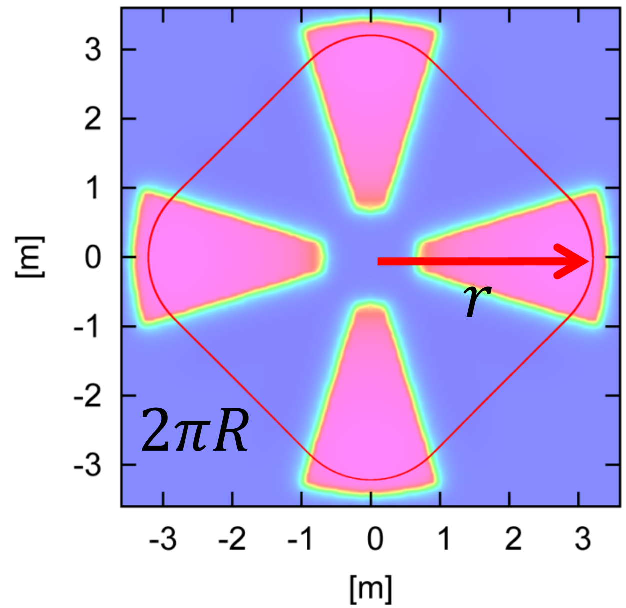
Isochronous Field

- Design Assistant Program

$$\overline{B}(R) = \gamma(R)\overline{B_0} = \overline{B_0}\sqrt{\frac{M^2}{M^2 - (Q\overline{B_0}Rc)^2}}$$

$$B_{iso}(r) = K_B\overline{B_0}\sqrt{\frac{M^2}{M^2 - (Q\overline{B_0}rc/K_r)^2}}$$

3. Calculate K_B and K_r for each radius



$$K_B = B(r)/\overline{B}(R)$$

$$K_r = r/R$$

Isochronous Field

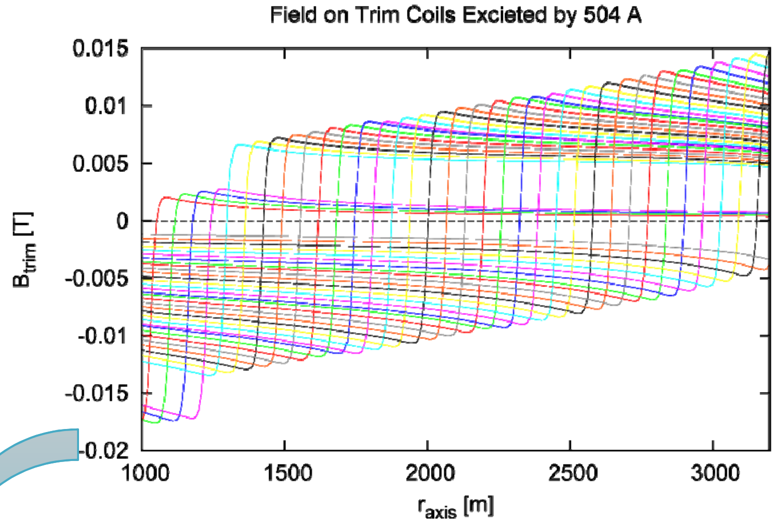
- Design Assistant Program

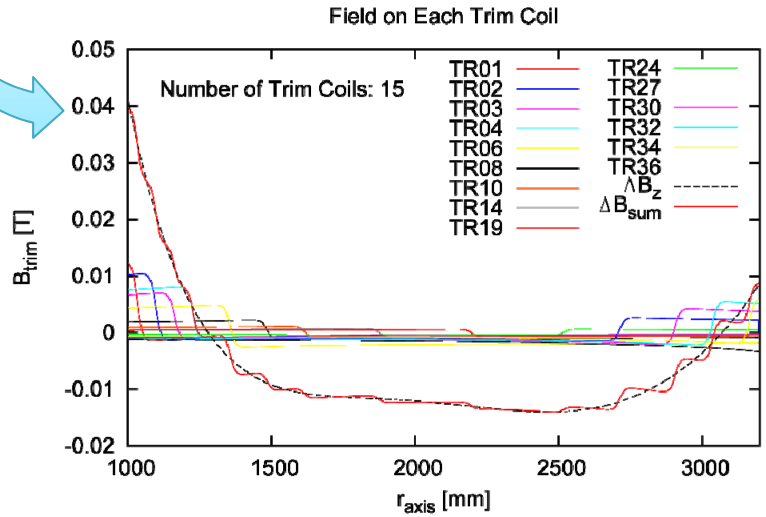
$$\Delta B(r) = B_{iso}(r) - B_{main}(r)$$

$$= \sum_{i=1}^{36} a_i B^i_{trim}(r) + \delta(r)$$

$$S = \sum_{j=1}^{N} \left\{ \Delta B(r_j) - \sum_{i=1}^{36} a_i B^i_{trim}(r_j) \right\}^2$$

Least Square Method





4. Fit isochronous field by trim coils

Isochronous Field

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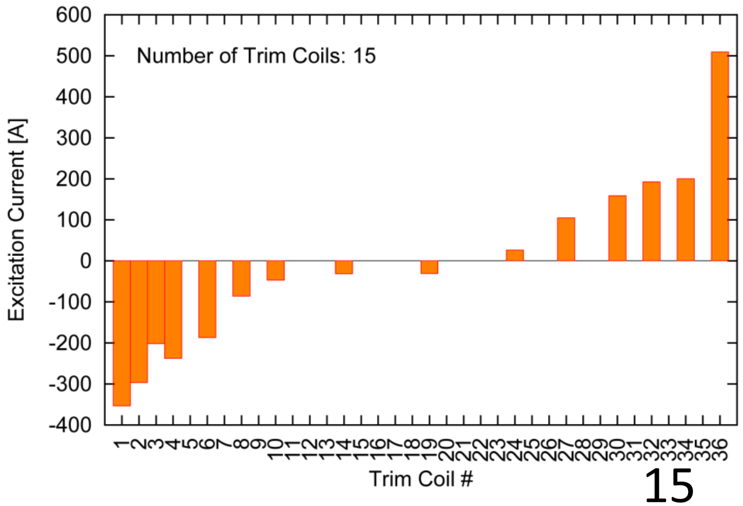
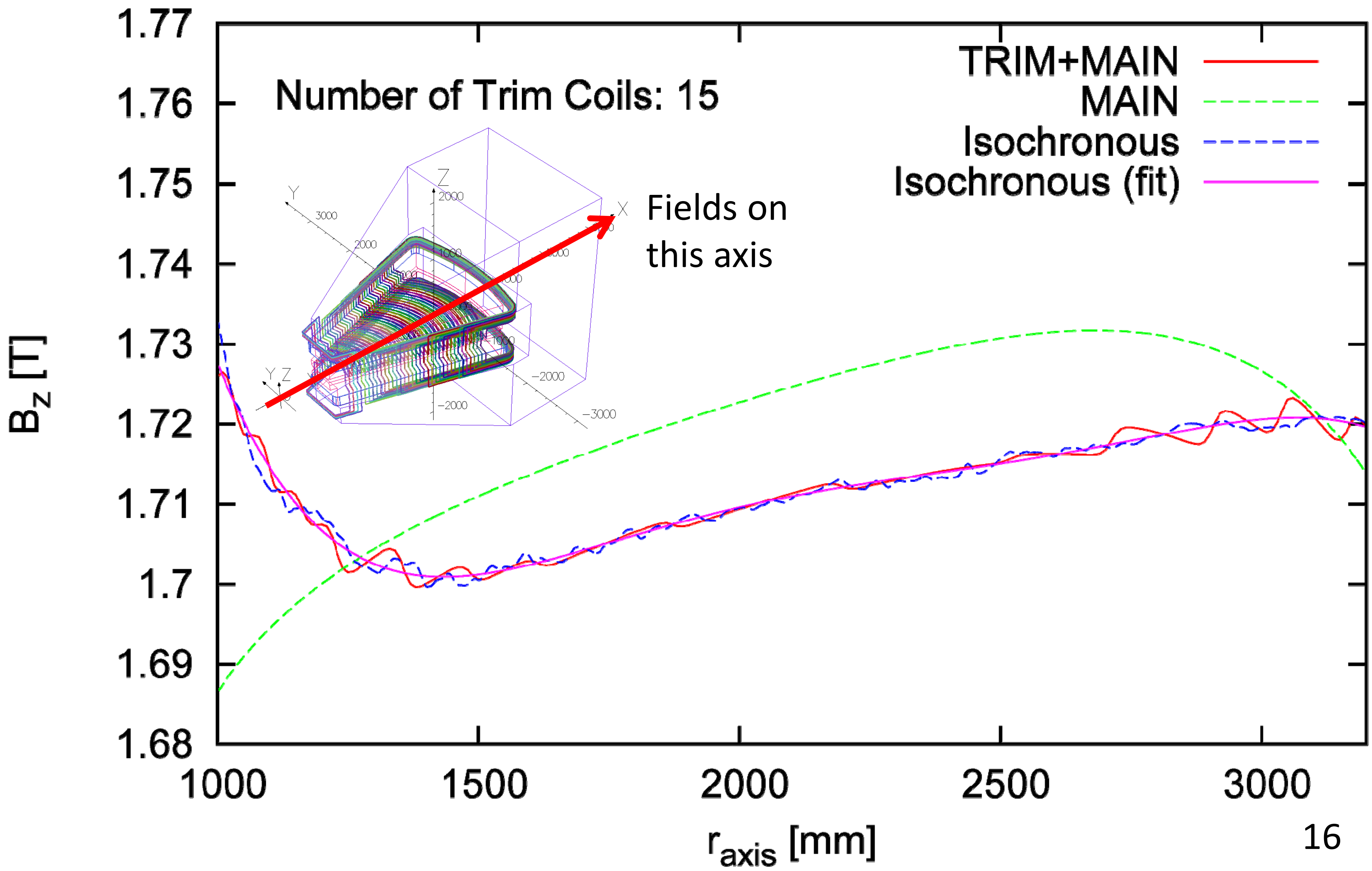
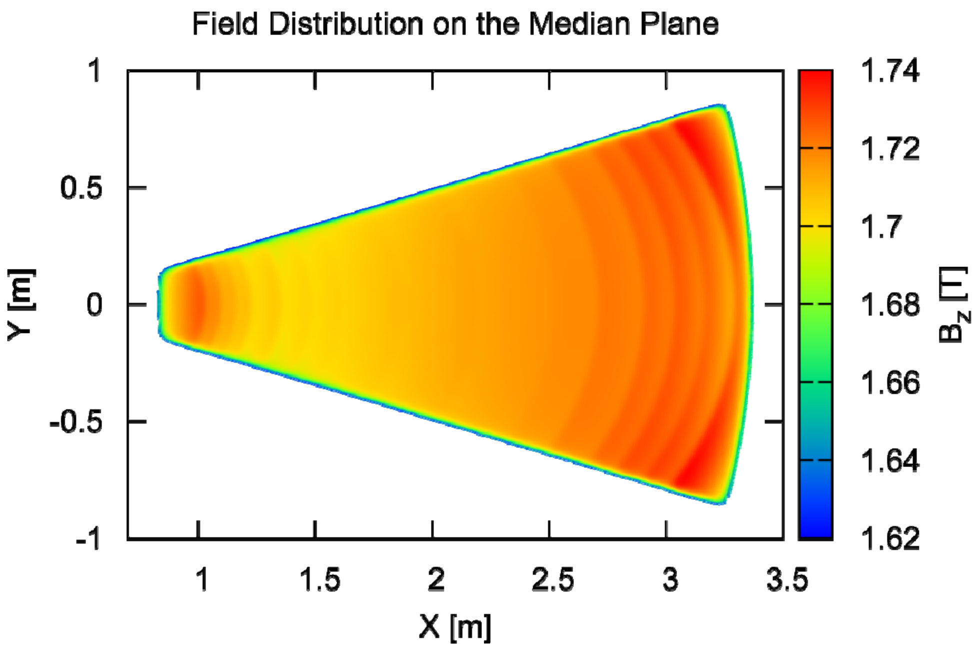


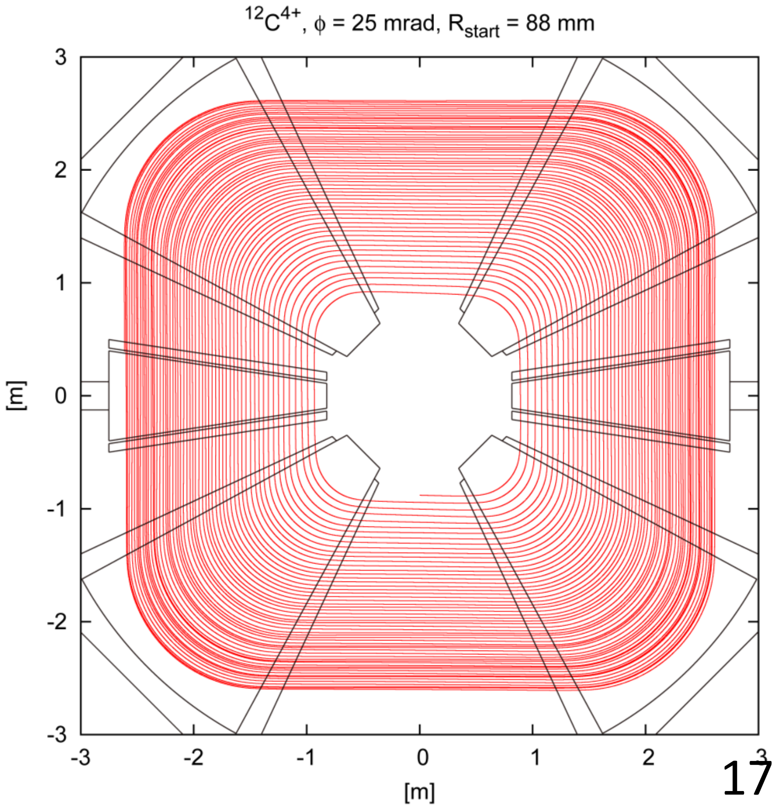
Isochronous Field



Results

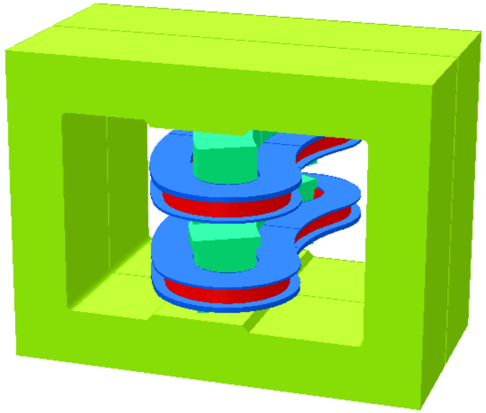
- Isochronous field has been successfully maintained by 15 trim coils.
- Orbit simulation confirmed the result.



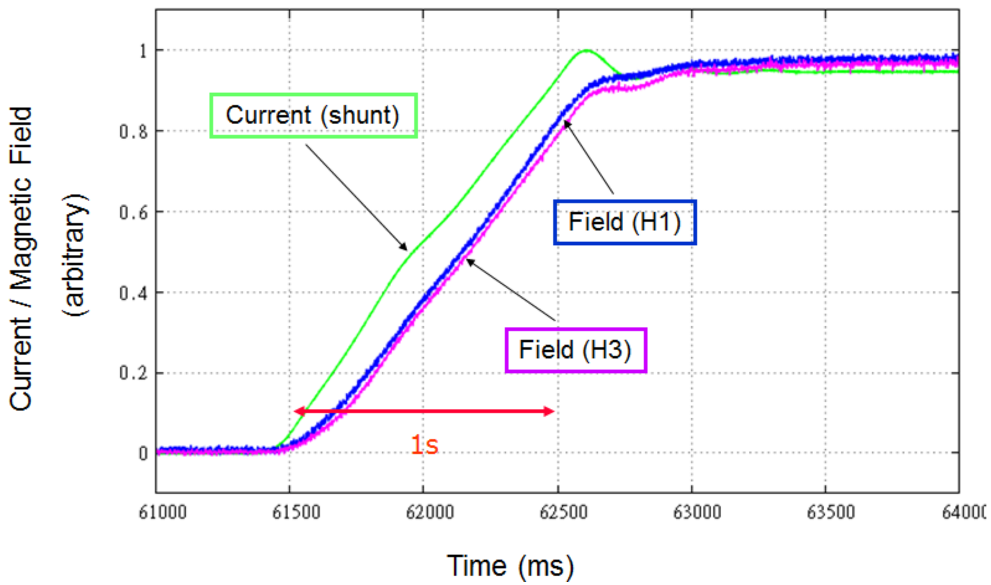


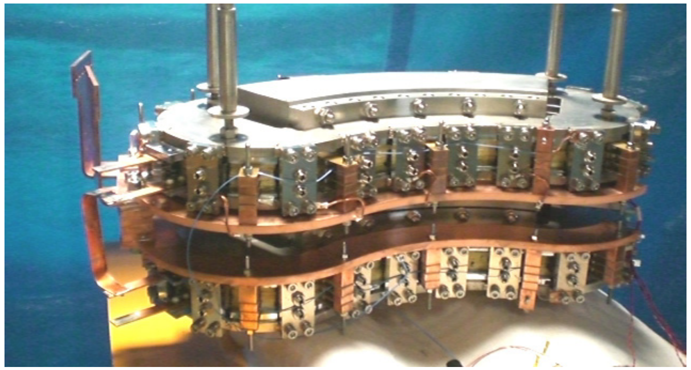
Half-meter-size HTS Magnet

- Toy model
- HTS Wire: DI-BSSCO
- Preliminary research



Excitation by pulsed current

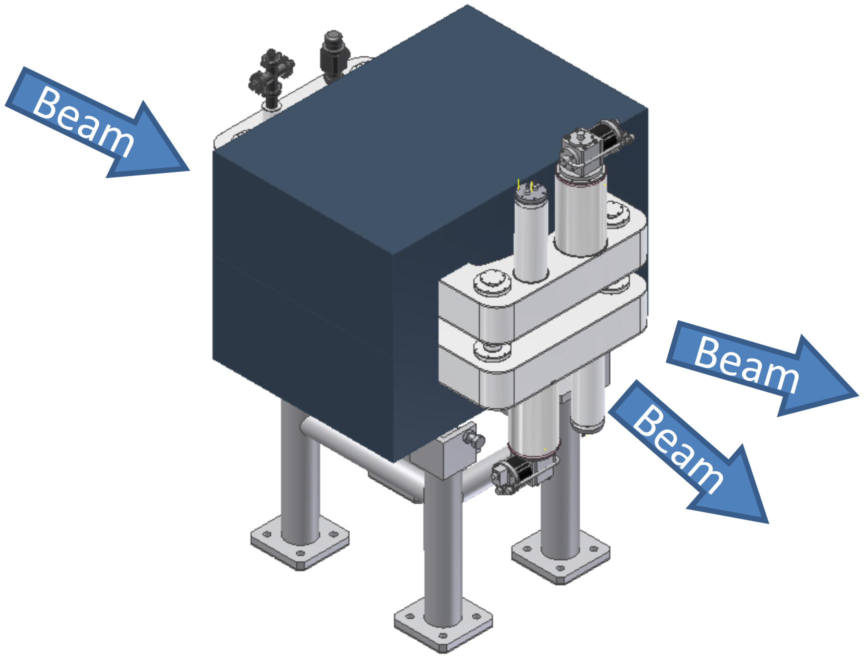




Coil	600 x 2 turns
Radius	400 mm
Deflection	60 deg.
Pole gap	30 mm

1-meter-size HTS Magnet

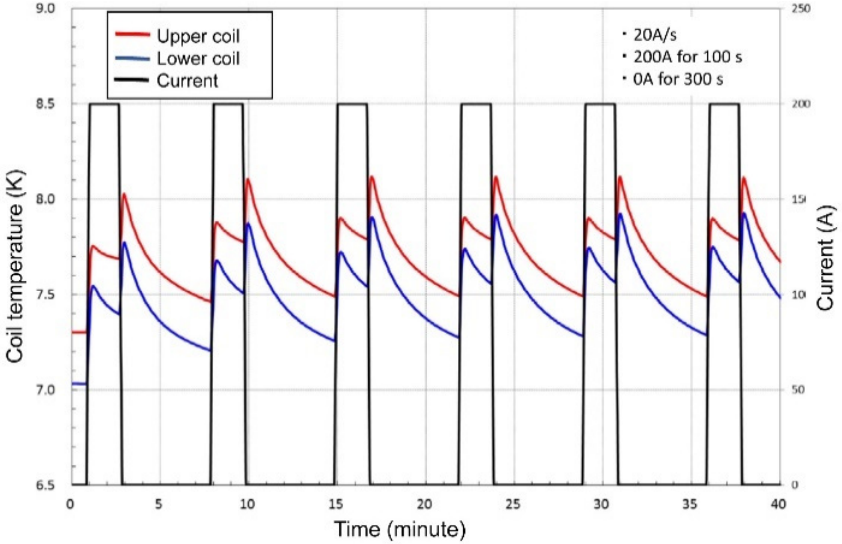
- Switching magnet for time sharing between two target rooms
- HTS Wire: BSSCO-2223
- Testing now @RCNP



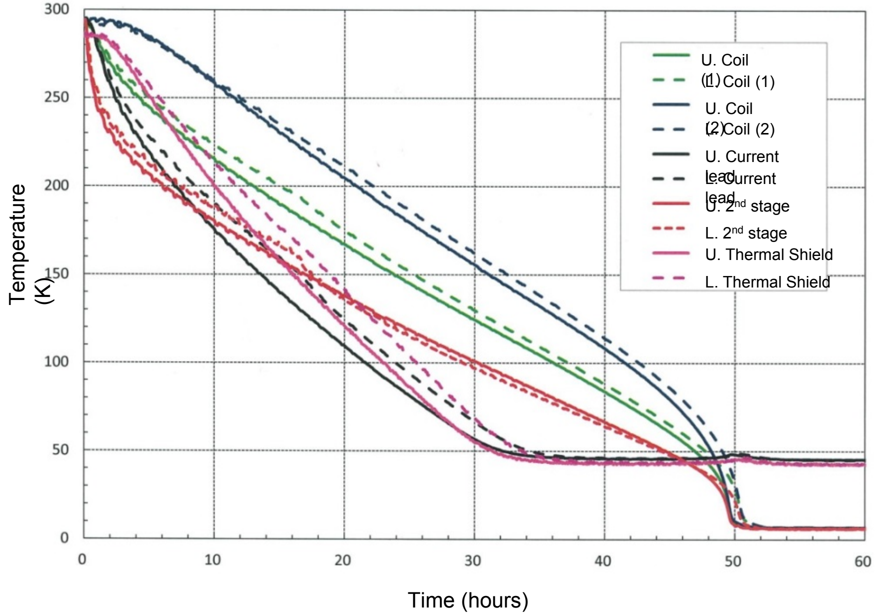
Coil	256 x 2 turns
Length	1,142 mm
Width	580 mm
Pole gap	70 mm
Current	200 A
Field	1.5 T
Ramping speed	20 A/s

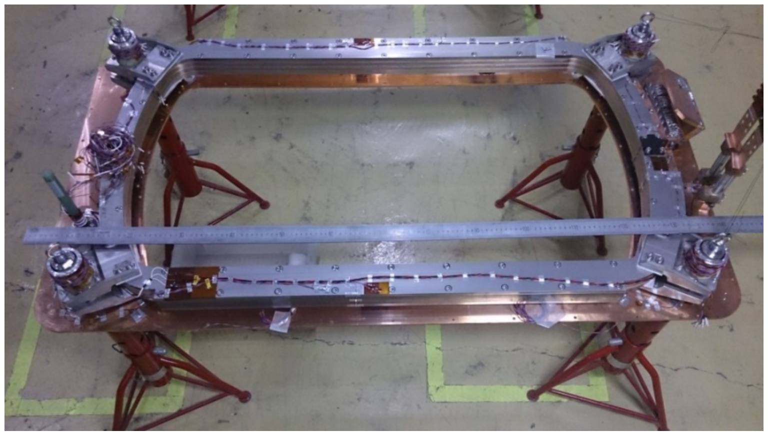
1-meter-size HTS Magnet

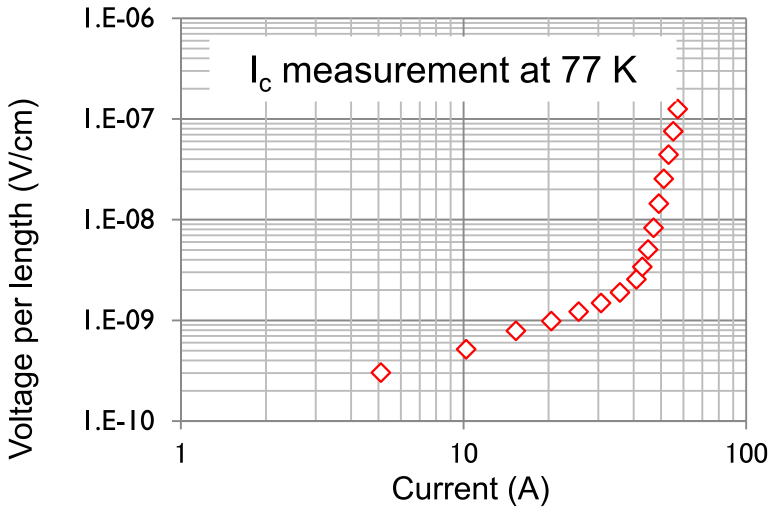
Coil temperature during a pattern operation of the switching magnet



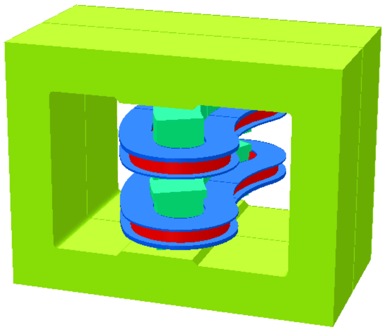
Cooling performance



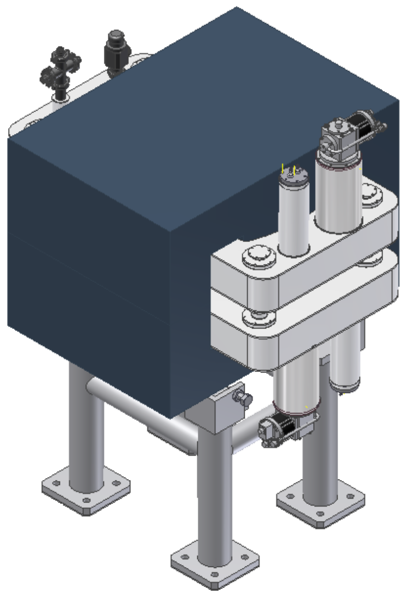




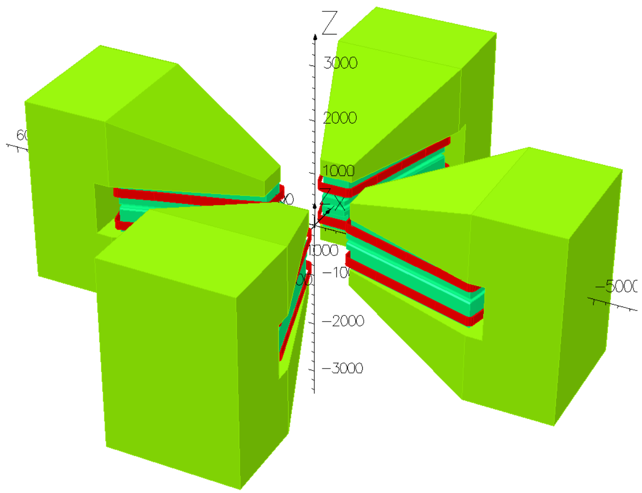
Perspective for Next-gen Cyclotron



Size: 0.4 m, Toy model



Size: 1 m, Operation: 1.5 T



Size: 2.8 m, Operation: 1.7 T

Next Generation Cyclotron
Compact & High Magnetic Field

Summary

- At RCNP, upgrading cyclotron facility has been planned to increase beam current to x10.
- HTS cyclotron is proposed for the new injector.
- Design of sector magnet is completed.
- Magnetic field and orbit simulation confirmed the design.
- Now 1-meter-size HTS magnet is being tested.
- HTS Injector Cyclotron will be the first step to the next generation cyclotrons.

Thank you for your attention

For further discussions, contact me at
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or Find me on Facebook as Keita Kamakura