KYUSHU UNIVERSITY 2011
100th Anniversary

Status of FFAG Accelerator of Kyushu University

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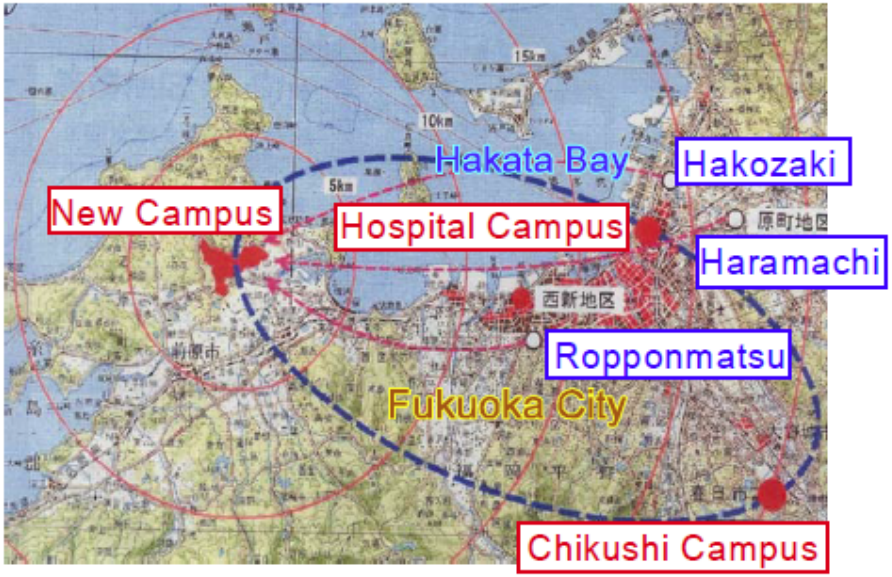
Kyushu University

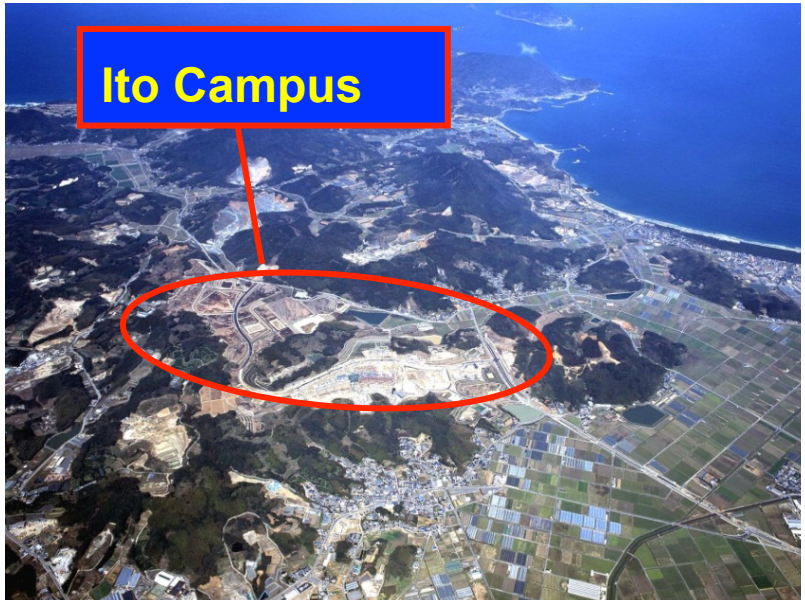
October 30,2010

KYUSHU UNIVERSITY

Contents

Movement of Kyushu University to New Campus





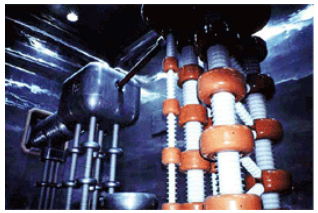
Schedule of the move

2005-6 : Faculty of Engineering

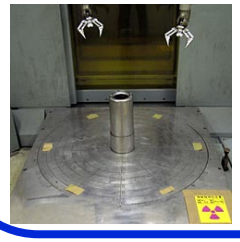
2014 - : Faculty of Sciences (planned)

1. Center for Accelerator and Applied Beam Science

1st stage (2009)



Cockcroft-Walton
Accelerator laboratory
(Faculty of Engineering)



^{60}Co gamma-source
(Institute for irradiation and
analysis of quantum radiation)

FFAG

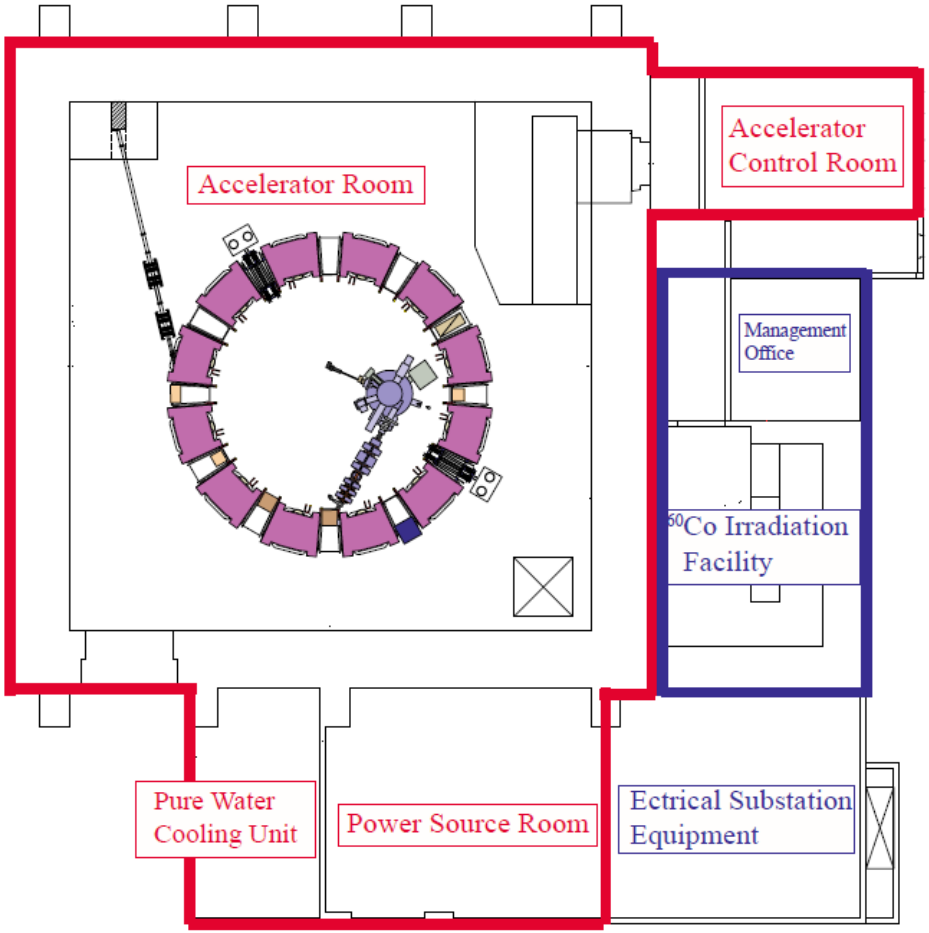
New Facility on Ito Campus

2nd stage (2013)

10 MV tandem
Accelerator laboratory
(Faculty of Science)

Nuclear science and engineering : Neutron reaction data, etc.
Medical field: Fundamentals for proton beam therapy
Accelerator science: FFAG accelerator

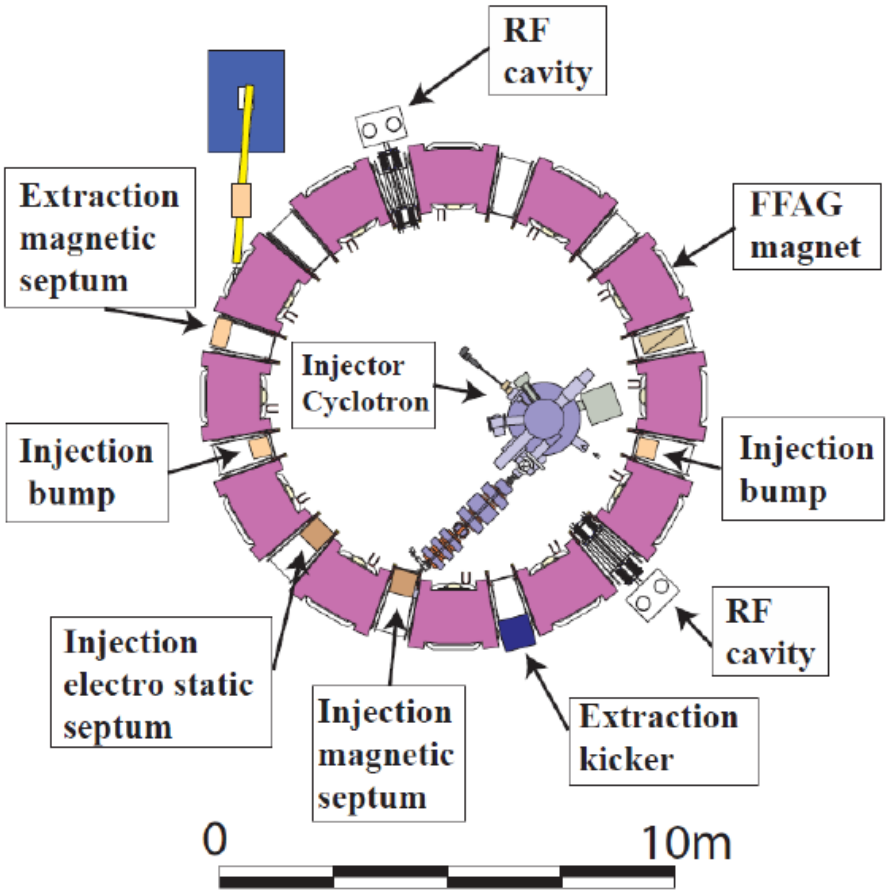
Accelerator Facility of Center for Accelerator and Beam Applied Science



Accelerator Facility (FFAG + Cyclotron)

^{60}Co gamma-ray Irradiation Facility (185 TBq)

150 MeV FFAG Accelerator



magnet	Radial sector type (DFD-triplet)
Cell	12
K-value	7.62
Beam energy	12 ⇒150 MeV (10 ⇒ 125 MeV)
Radius	4.47 ⇒ 5.20 m
Betatron tune	H: 3.69～3.80 V: 1.14～1.30
Max. field	F-field: 1.63 T
(along orbit)	D-field: 0.78 T
Circ. freq.	1.55～4.56 MHz
Repetition	100 Hz
Mean current	1.5 nA

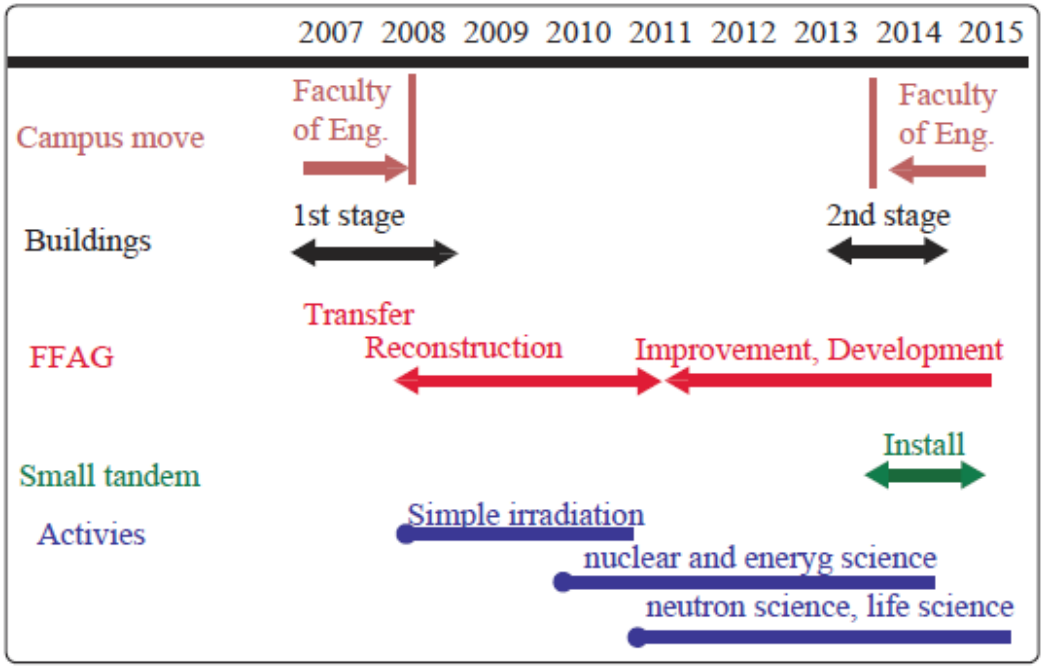
Injector Cyclotron

Main Parameters of Baby-Cyclotron

Energy	10 MeV (proton)
Type	AVF Cyclotron
Ion Source	Internal PIG (LaB6 cathode)
RF Dee Voltage	40 kV
Extraction Radius	300 mm
Magnetic field	Max. 1.54 T
RF Frequency	47 MHz (2^{nd} harmonic)
Beam Current	15 μA

JSW Baby-Cyclotron

2. Construction Plan

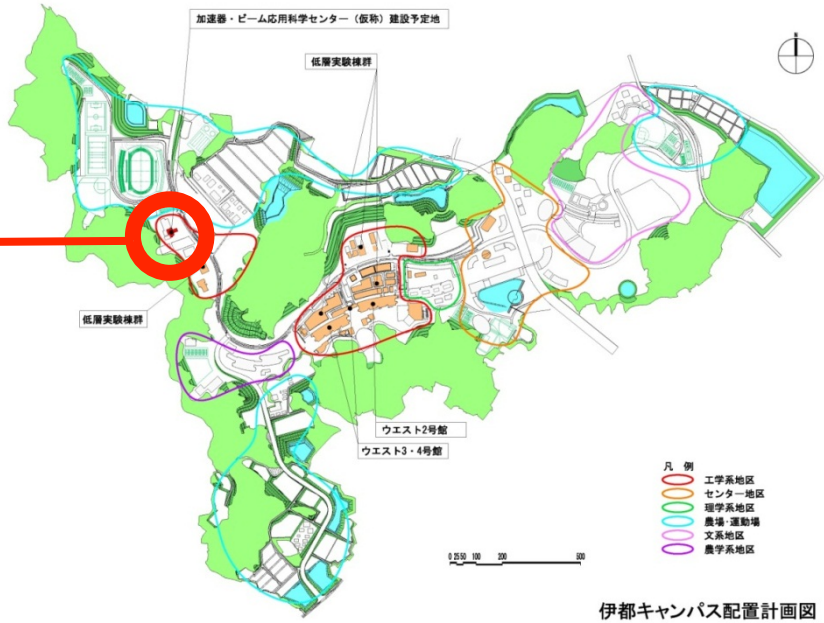


Total budget of 1st stage:
\100 M ($1.2M, €0.88M)
All equipment of FFAG, except building

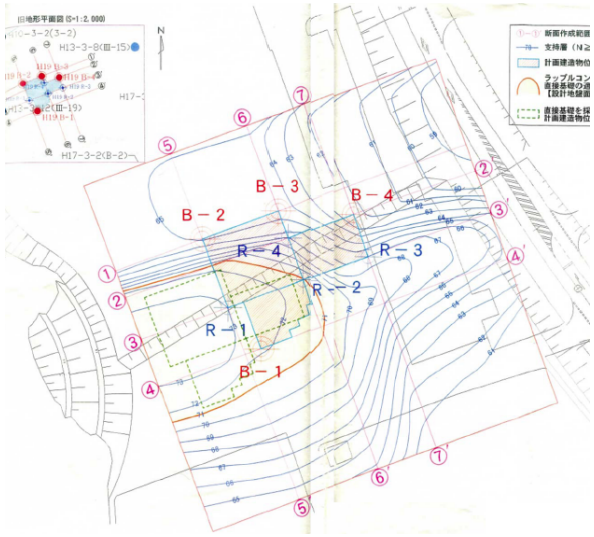
2 Staffs,
1 Technical assistant and
3 Students

Construction of 150 MeV FFAG has started in Jul. 2008.
Construction will be completed by Dec. 2010.
Beam commissioning will be started in Jan. 2011.

Construction site



伊都キャンパス配置計画図



Facility under construction (2008)

Transfer of 150 MeV FFAG

150 MeV FFAG was disassembled in June 2006

It was transported in March 2008

Construction of FFAG (1)

1. Assembling Water Cooling Unit (Jul 2008)

2. Repair and commissioning of Injector cyclotron (Sep - Dec 2008)

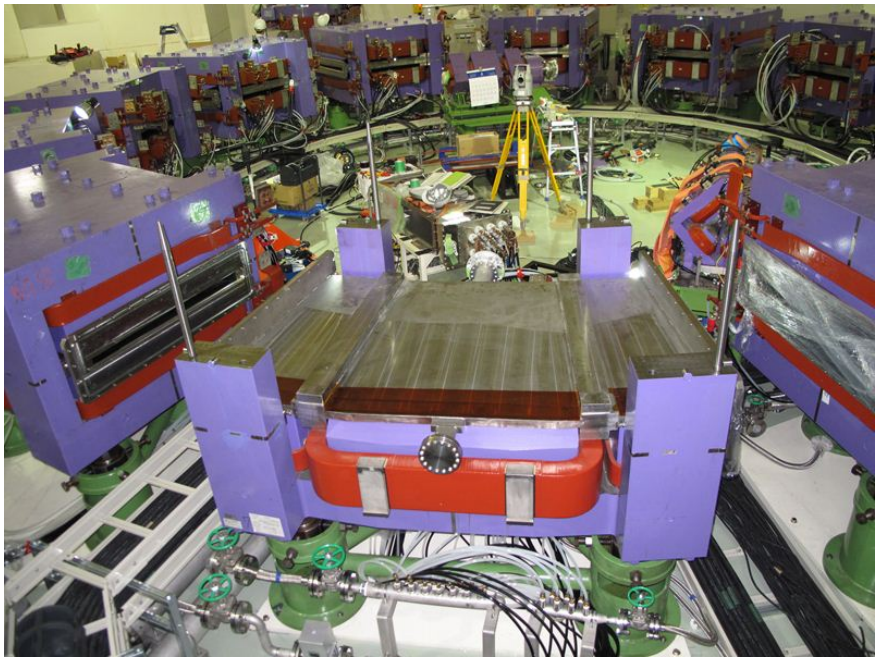
Construction of FFAG (2)

3. Setting up Monuments for Alignment
(Mar – May 2009)

4. Alignment of the main ring
(Jun - Dec 2009)

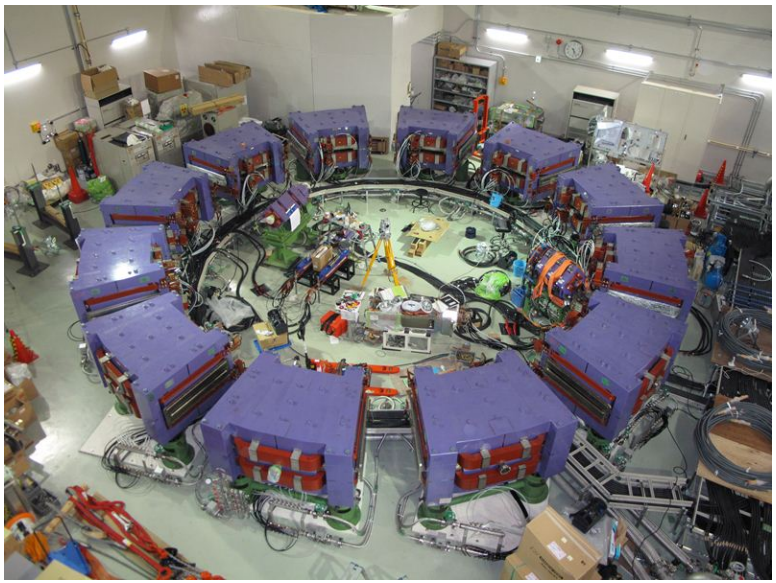
Construction of FFAG (3)

5. Connecting cooling water tube (Feb 2010)



6. Installing vacuum chambers (Apr-May 2010)

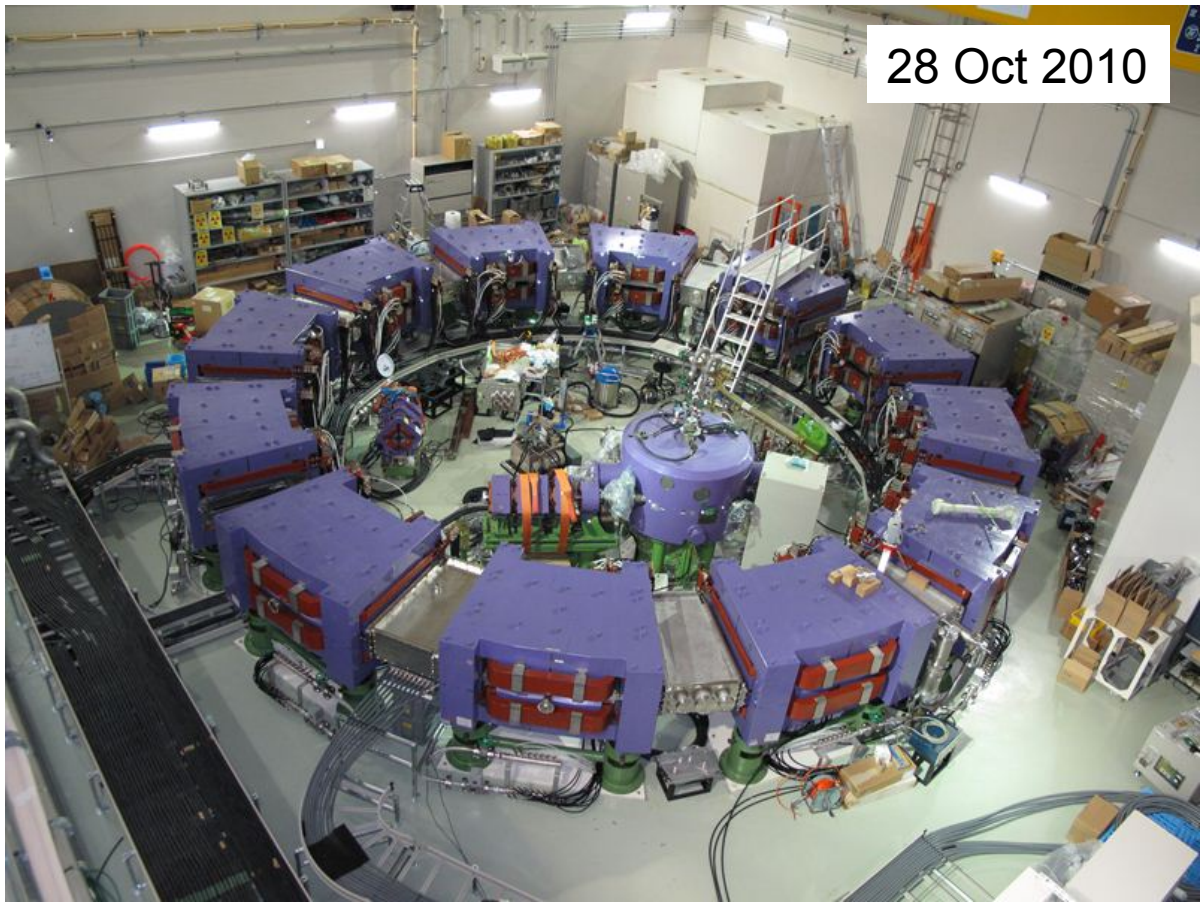
Construction of FFAG (4)



7. Cabling and Power test
(Jun-Sep 2010)

8. Construction of Beam Dump
(Sep 2010)

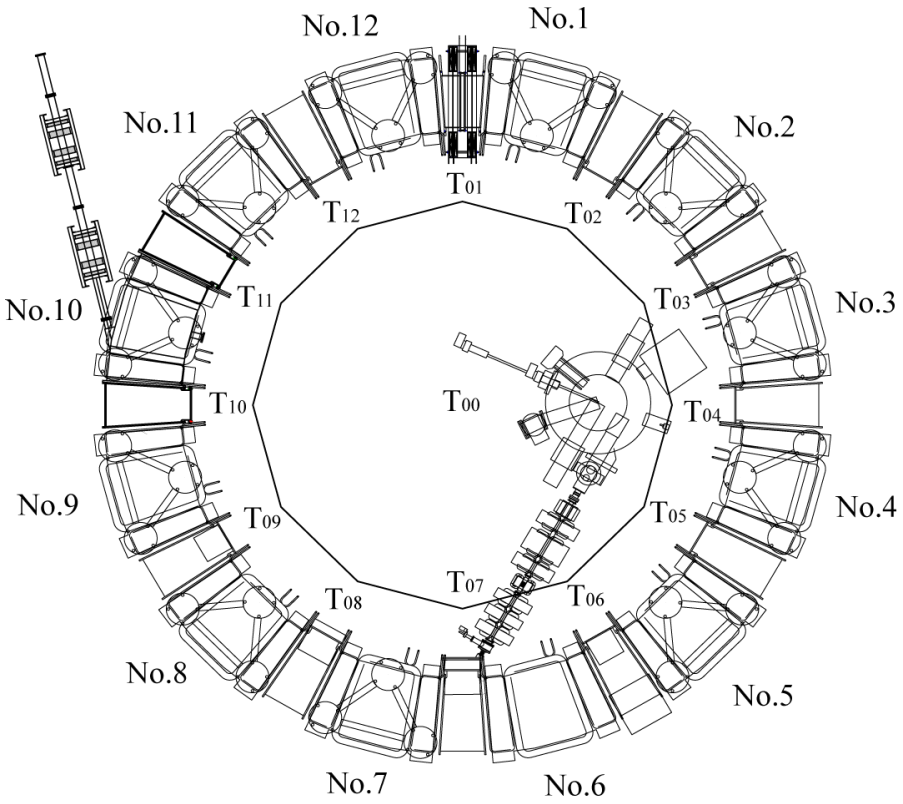
Current status

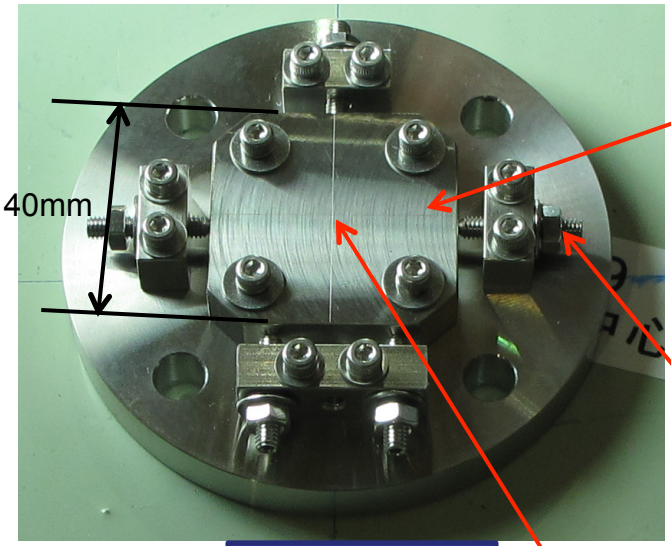


Construction of 150 MeV FFAG will be completed by Dec 2010.

3. Alignment of the main ring

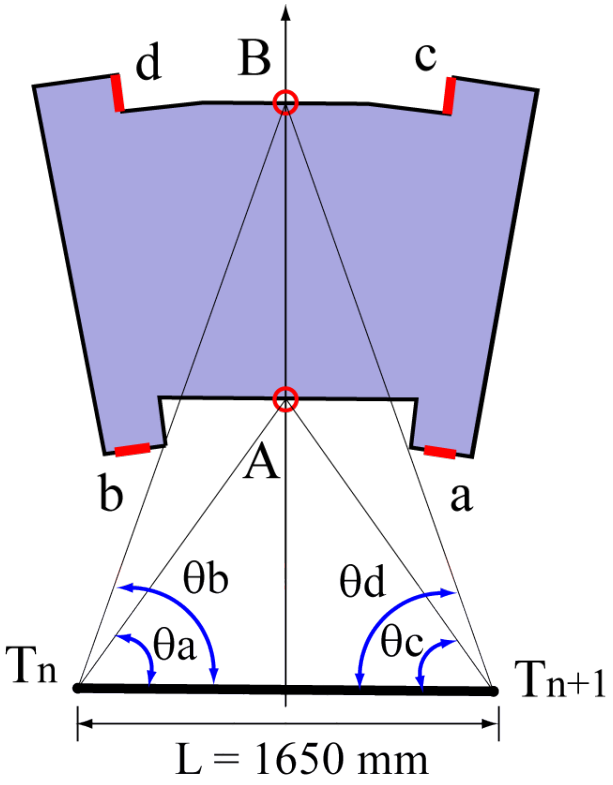
Reference Network

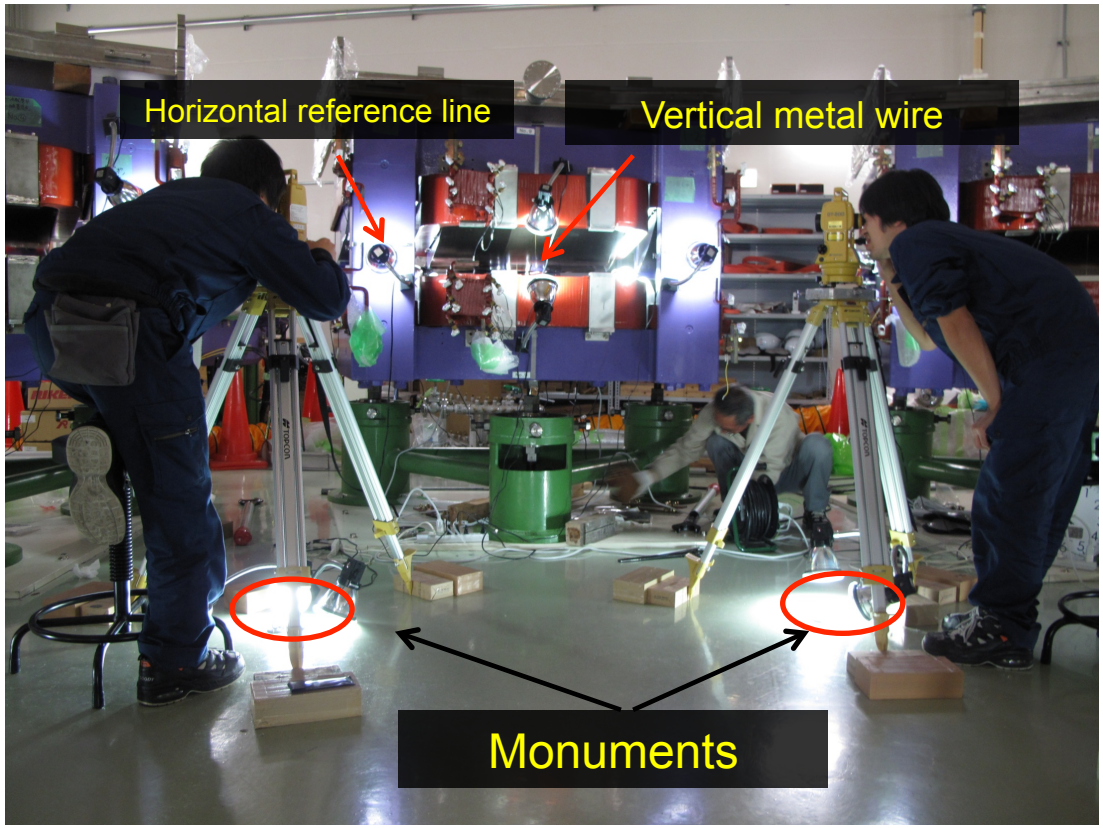




monument

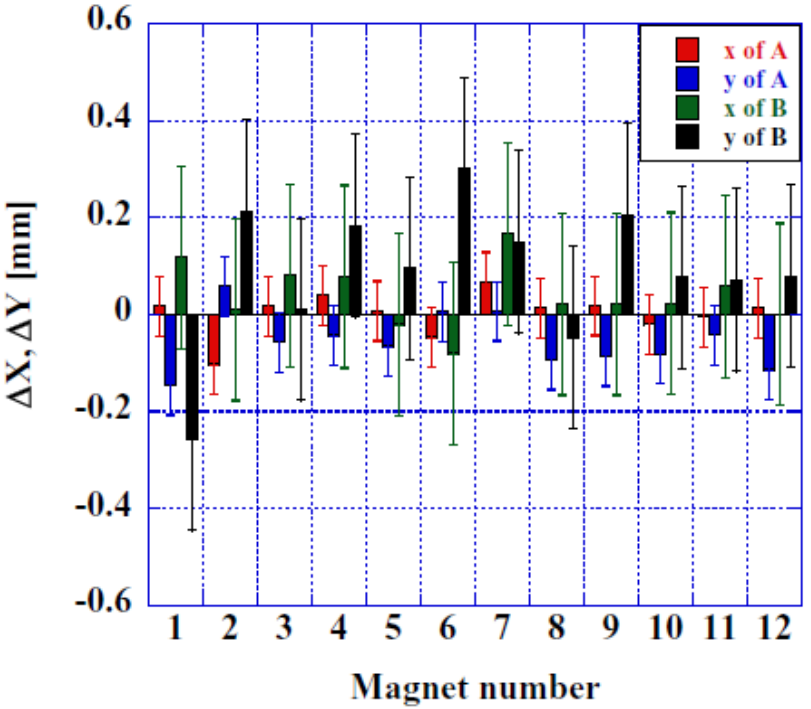
Alignment of FFAG magnets

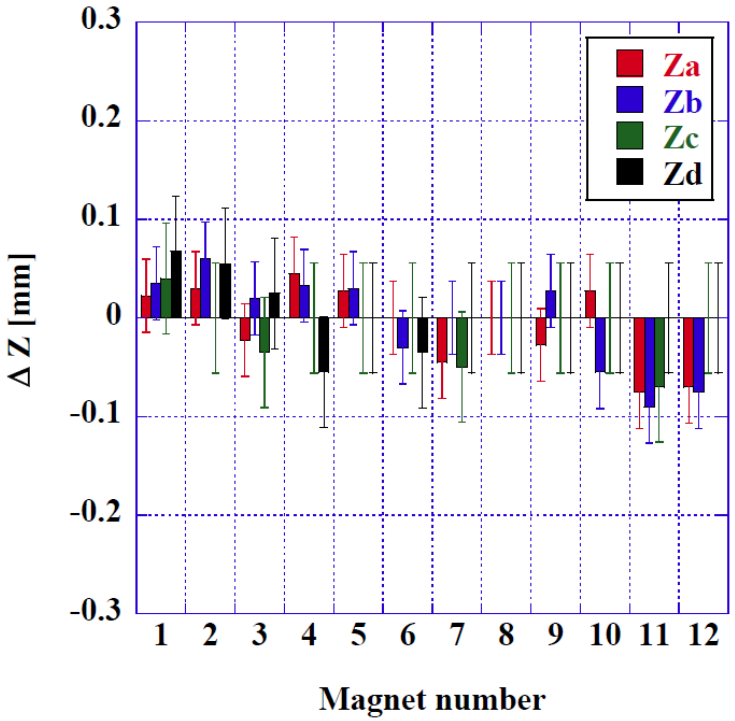




A, B : Position of vertical wire
a, b, c, d : Horizontal line (medium plane)
Tn, Tn+1 : Monuments

Result of Alignment





Horizontal misalignment
± 0.3 mm

Vertical misalignment
± 0.1 mm

4. Development of the second RF cavity

- 8.4 kV of gap voltage is required for 100Hz operation.
- In this condition, the power dissipation of the cavity is serious problems.

$$P = \frac{V^2}{2R}$$

P : power dissipation
V : gap voltage
R : shunt impedance

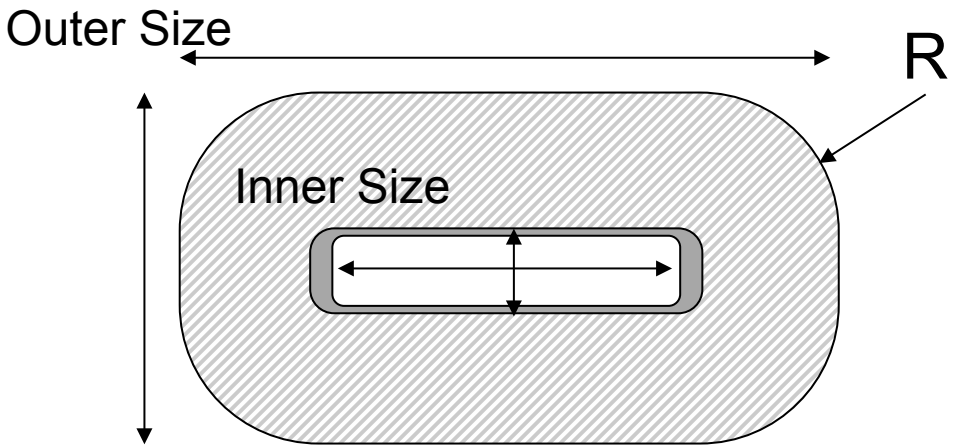
- The power dissipation reaches about 90 kW.
- The temperature of surface of the core reaches over 200 degrees.

Temperature should be under about 100 degrees in order to realize stable operation.

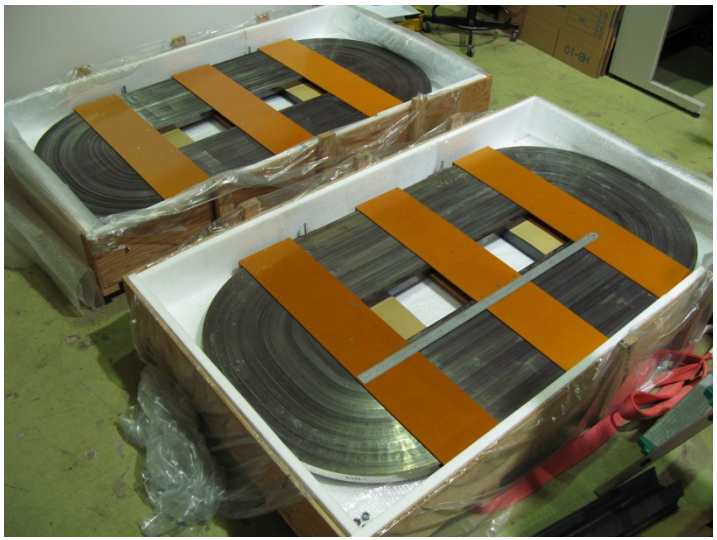
- To resolve this problem, we decided to employ two cavities.
- **A new cavity** with high-efficiency cooling system has been developed.

- Required voltage for each cavity is **4.2 kV / cavity**
- The power dissipation of the core becomes a quarter.

Development of New MA core for the 2nd cavity



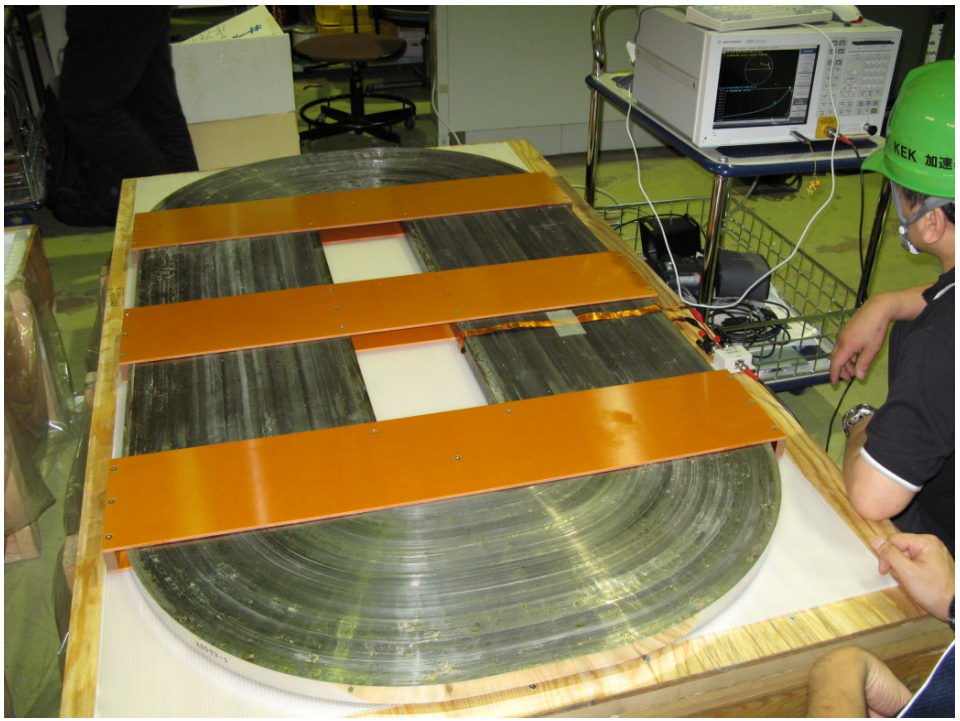
	Previous Core	New core
Outer Size	1700 × 950 mm	1780 × 950 mm
Inner Size	980 × 230 mm	1060 × 230 mm
Thickness	30 mm	30 mm
R	360 mm	310 mm
Lout	4682 mm	4928 mm
Lin	2420 mm	2580 mm



Length of outer circumference

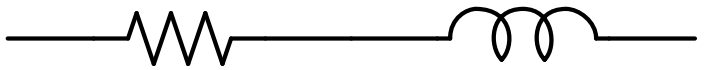
Length of inner circumference

Impedance measurements of MA core



$$Z = R_s + jX_s$$

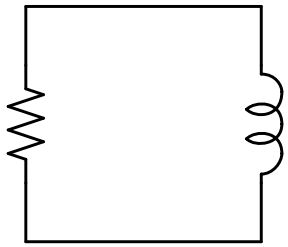
$$X_s = j\omega L - \frac{1}{j\omega c}$$



R_s X_s

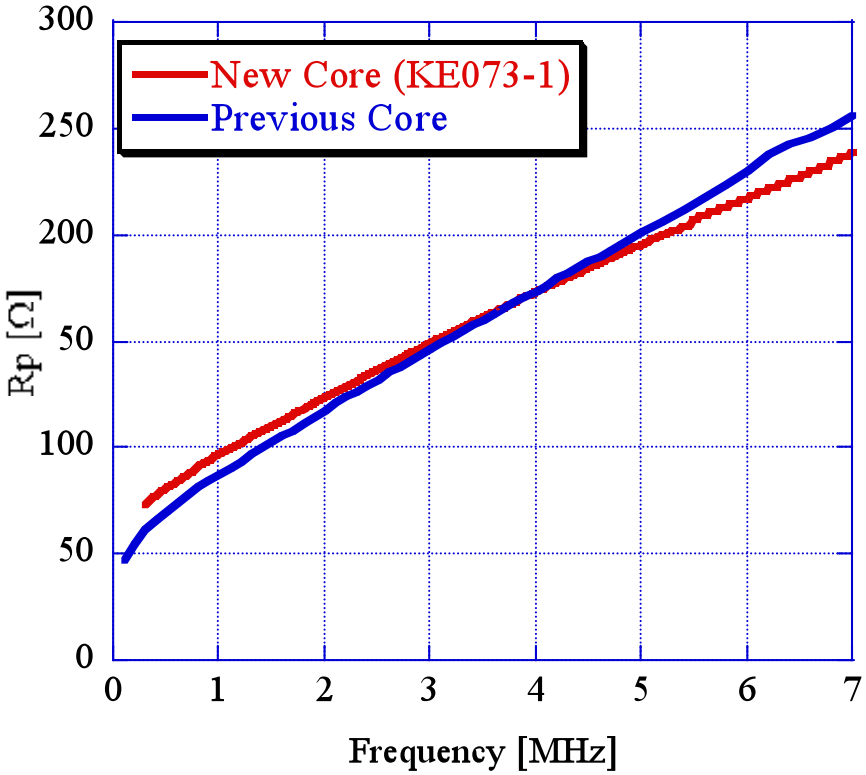
$$Q = \frac{X_s}{R_s} \qquad R_p = \left(1 + Q^2\right)R_s \;,\; X_p = \left(1 + 1/Q^2\right)X_s$$

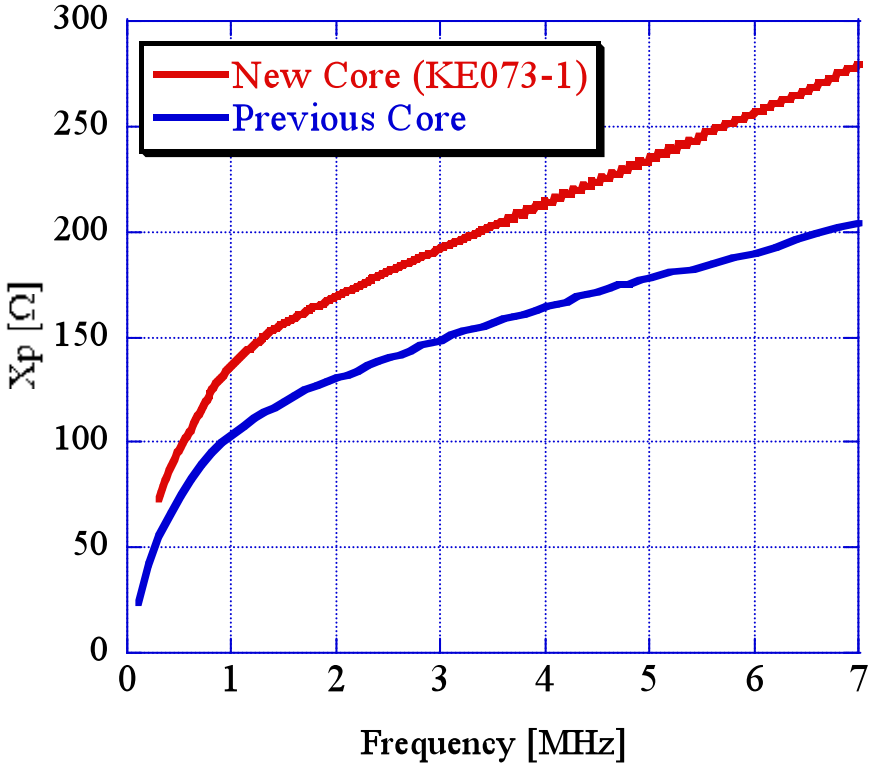
Shunt impedance R_p



X_p

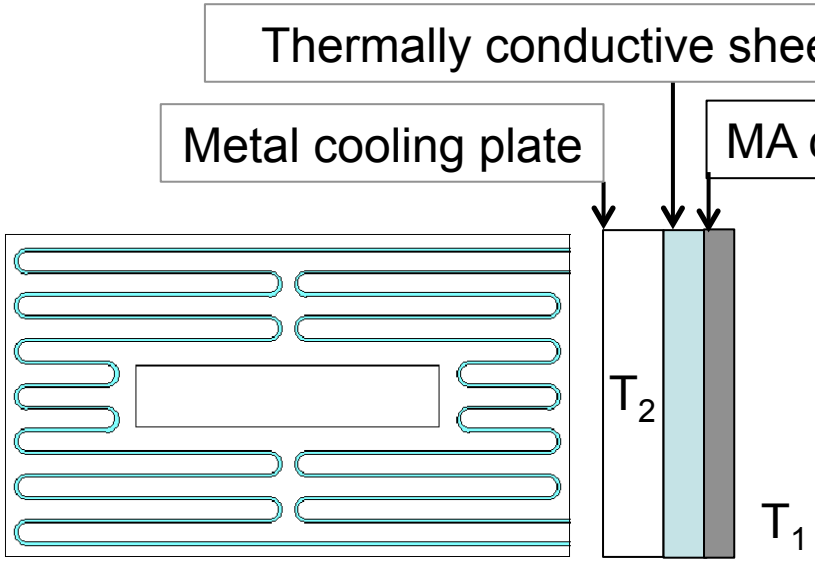
Measured impedance of new MA cores





Shunt impedance R_p of new core is similar to that of the previous core. Capacitive/Inductive components X_p is about 30% larger than that of the previous core.

Improvement of cooling plate



$$Q = k\frac{T_1 - T_2}{t}$$

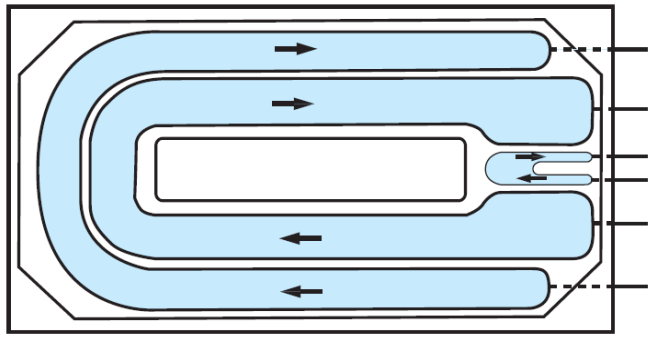
Q: Thermal Flux

T_1: Temperature of core

T_2: Temperature of cooling plate

t: thickness of thermally conductive sheet

New cooling plate

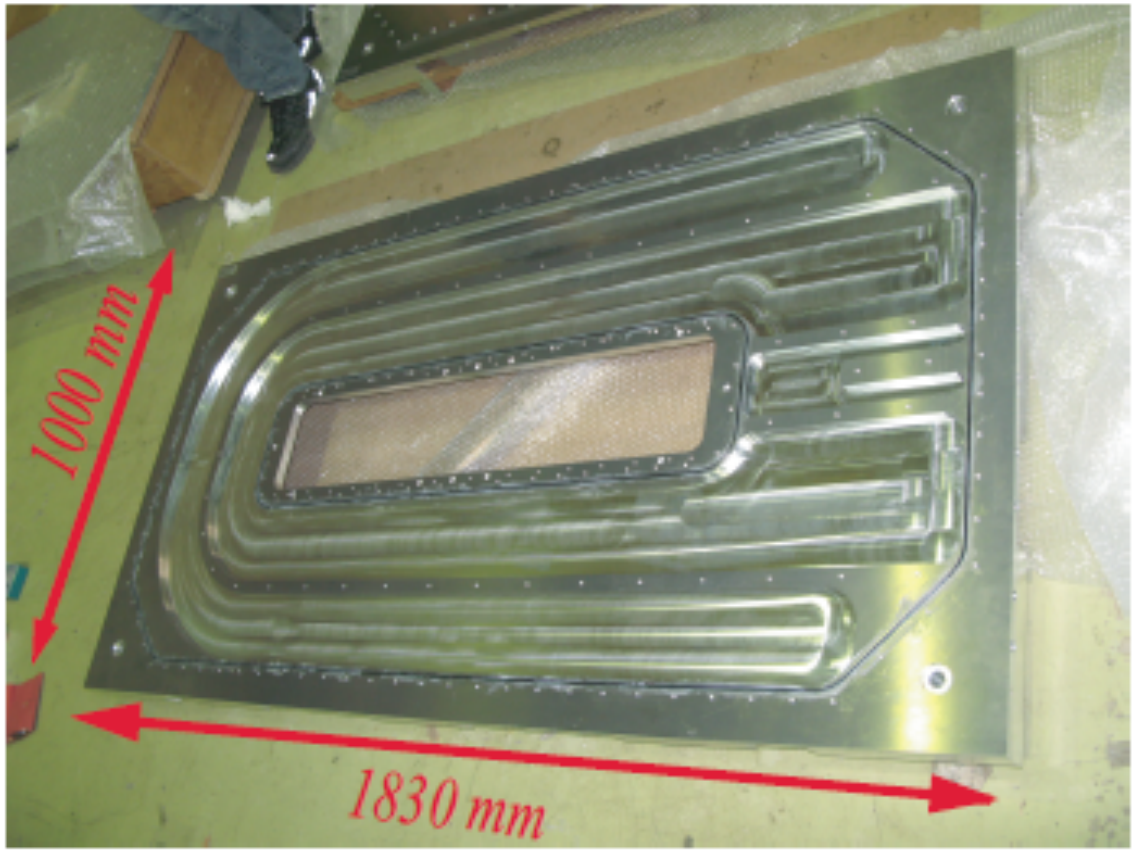


Water-jacket system & thin thrmal spacer

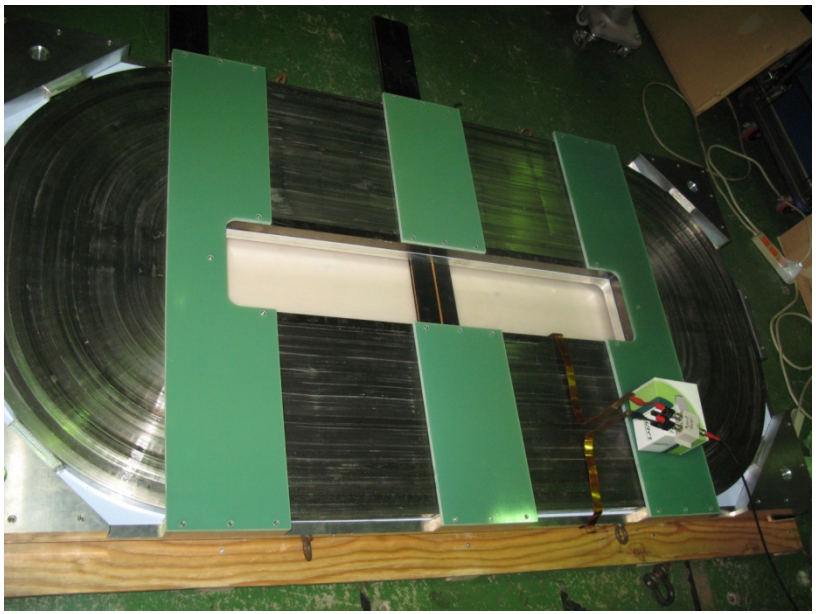
Thickness of thermal conductive spacer has been changed **from 3 mm to 1 mm**.

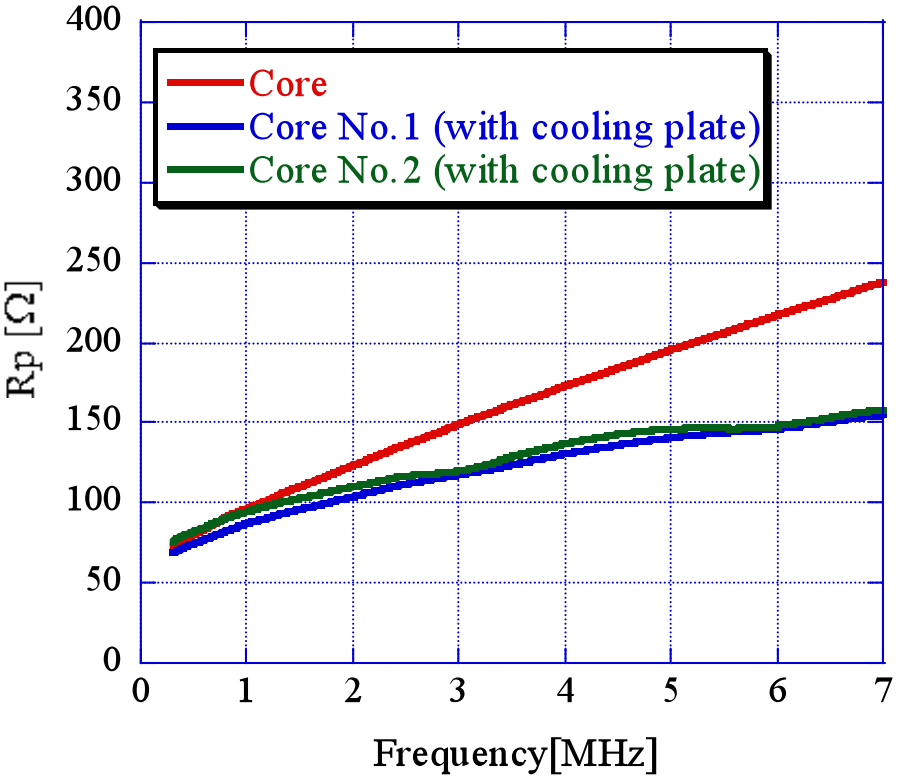
The contact area between cooling water and the core is designed to be **7 times larger** than the former cavity.

Water-jacket type cooling plate



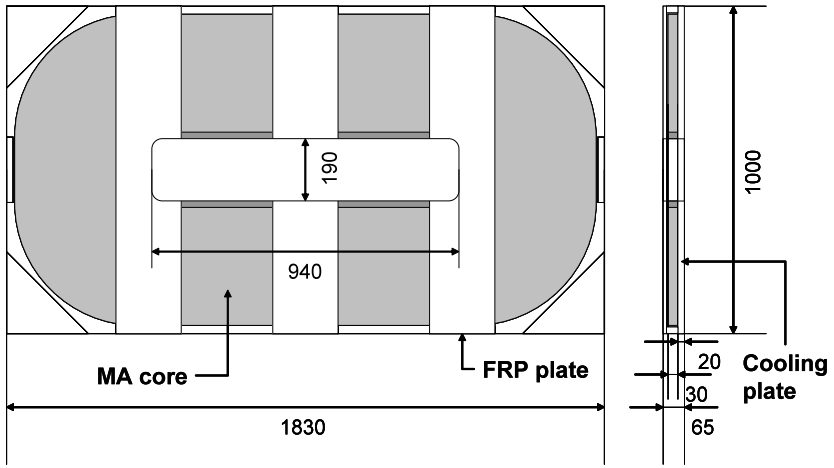
Impedance measurements of MA core with the cooling plate

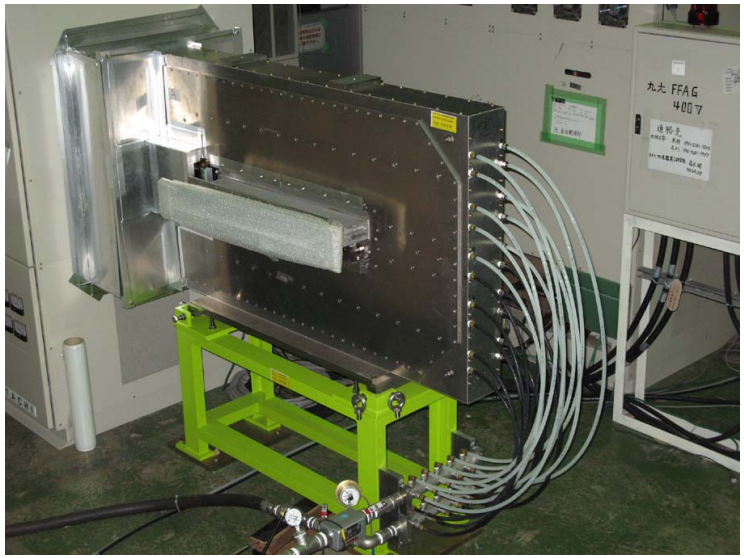


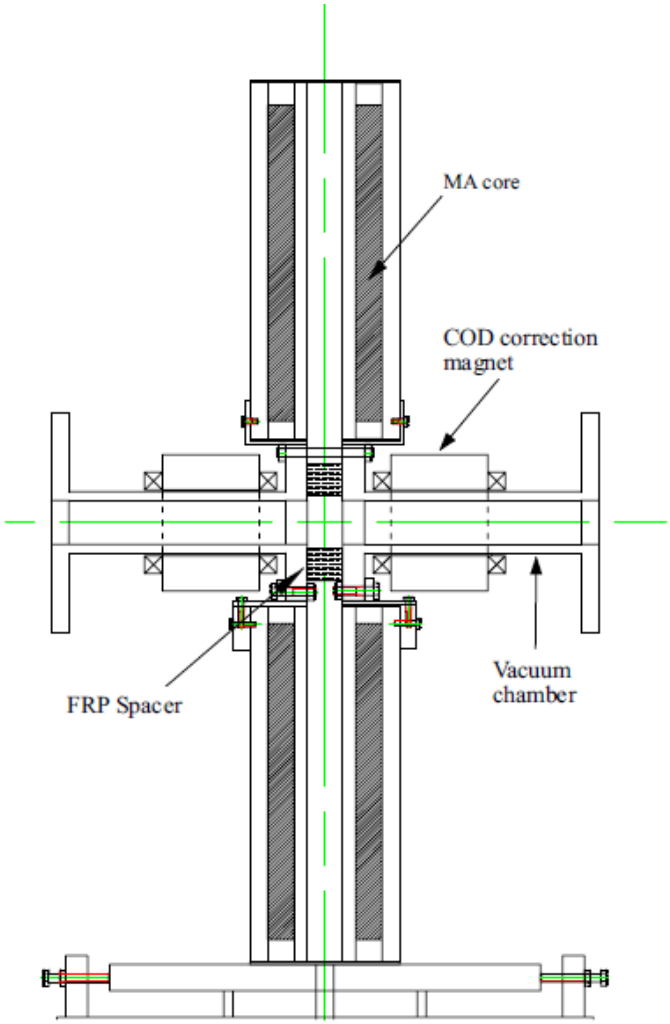


Additional capacitance between the core and the cooling plate brings about a degrease of shunt impedance.

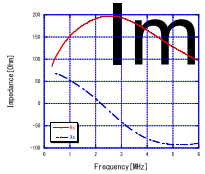
The second RF cavity

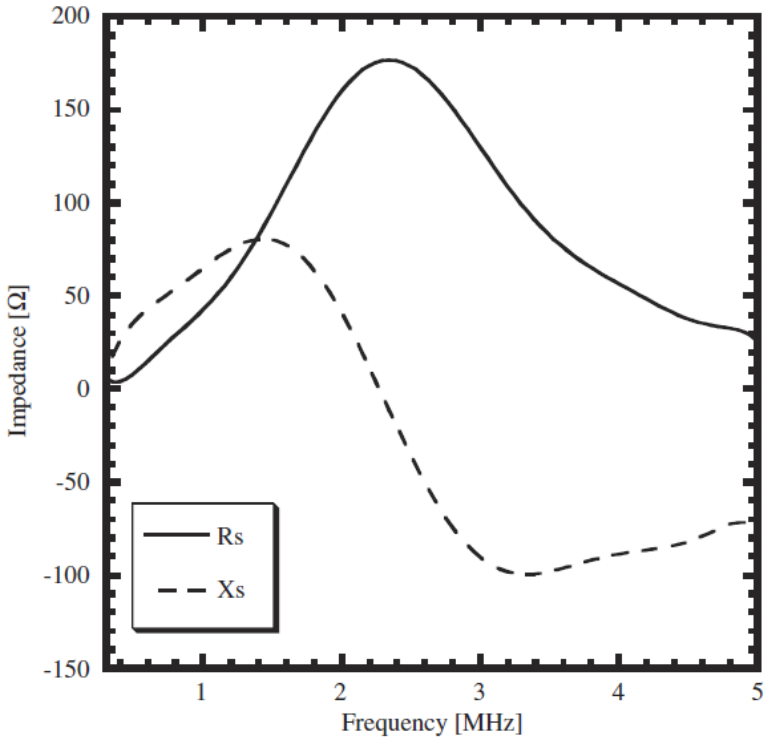






Impedance of the second RF cavity



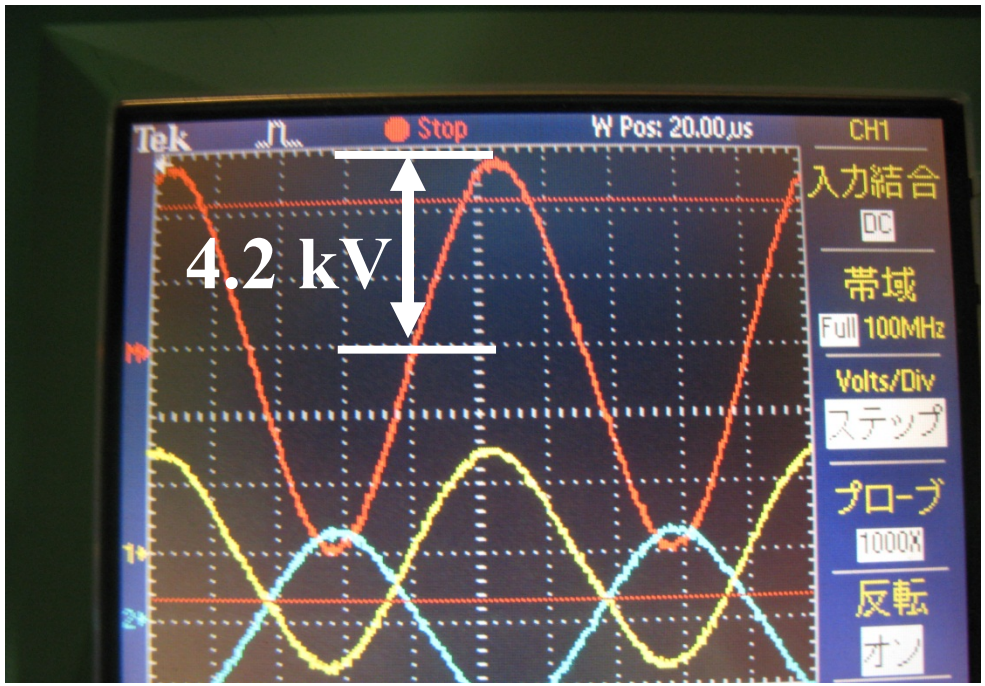


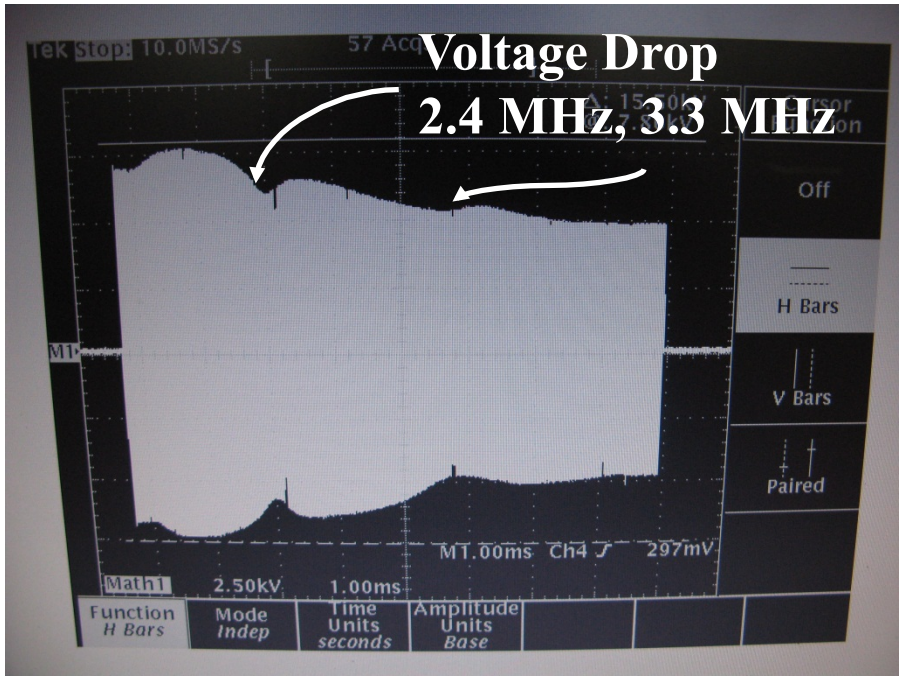
the second cavity

The first cavity

Shunt Impedance of the 2nd cavity is 20% larger than the 1st cavity.

Power Test (Low repetition rate, 20Hz)





The measured gap voltage is 4.2 kV.
High power test of 100Hz will be carried out.

Voltage drop at 2.4 MHz and 3.3 MHz are observed.
We are investigating the problem.

Summary

Construction of 150 MeV FFAG will be completed by Dec 2010.

Beam commissioning is scheduled to start in Jan. 2011.

In order to decrease power dissipation per cavity, the second cavity with new cooling plate has been developed.

Power test of the second cavity has been performed.
Gap voltage of 4.2 kV/cavity has been achieved.