Status of 150-MeV FFAG Accelerator of Kyushu University

Center for Accelerator and Beam Applied Science of Kyushu University

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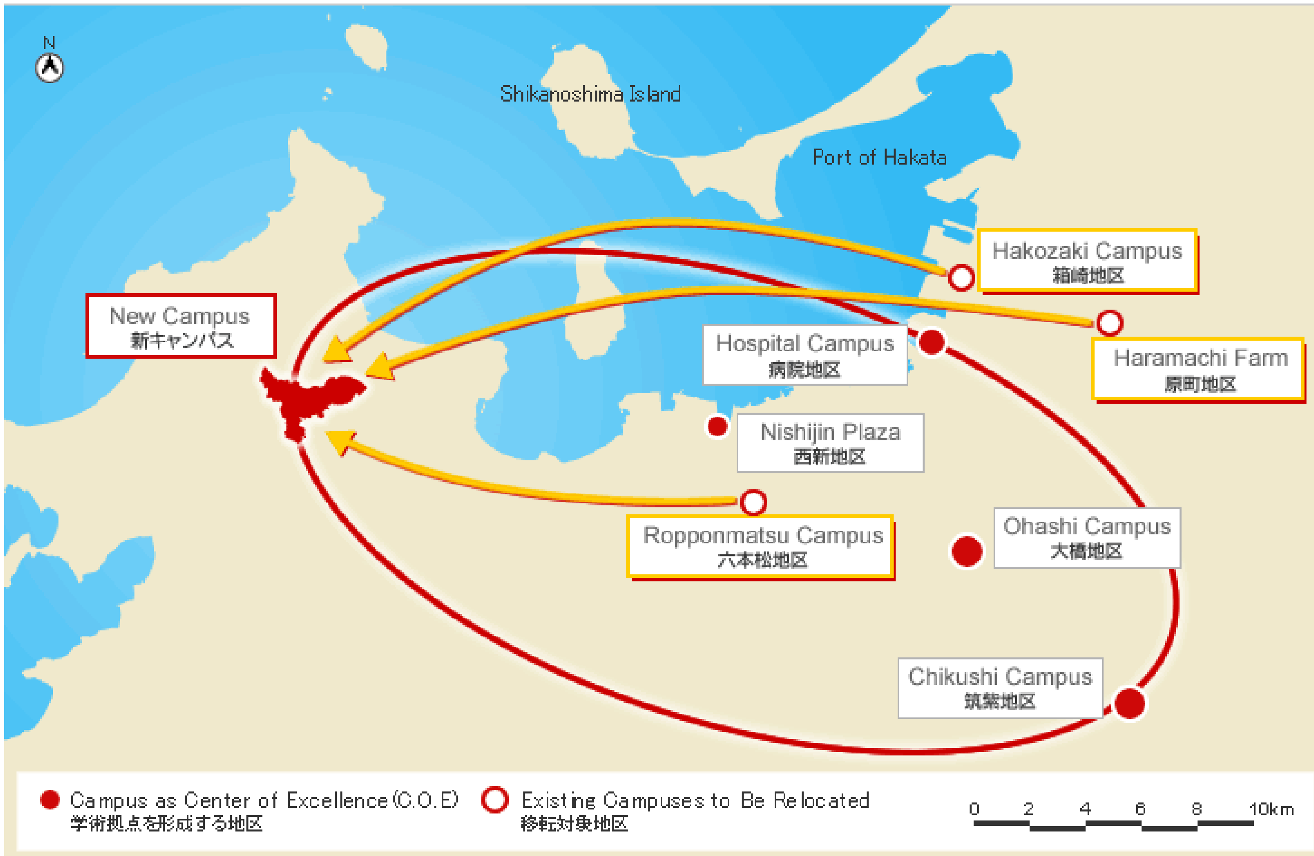
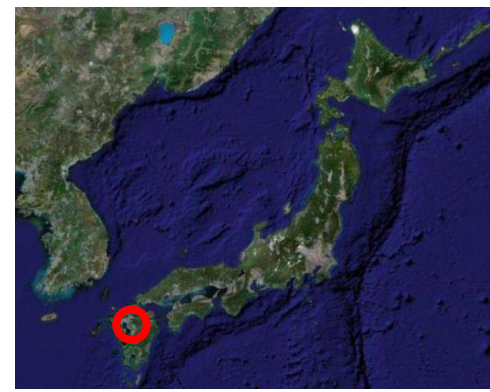
Overview of Center for Accelerator and Beam Applied Science of Kyushu University

New campus plan and construction of new accelerator facility





Fukuoka City

http://www.kyushu-u.ac.jp

Establishment of
Center for Accelerator and Beam Applied Science

Cockcroft-Walton
Accelerator Laboratory,
Faculty of Engineering

10 MV Tandem
Accelerator Laboratory,
Faculty of Science

Institute for Irradiation
and Analysis of Quantum
Radiation

Center for Accelerator and Beam Applied Science

150 MeV FFAG

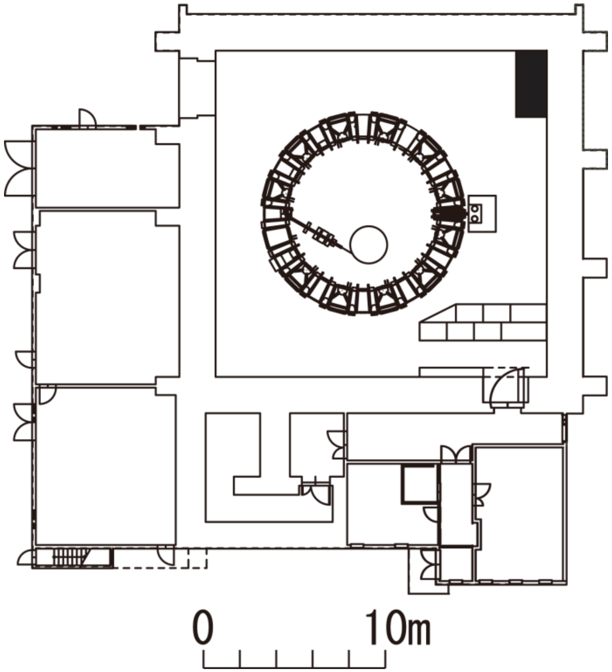
8-MV Tandem

^{60}Co gamma-source

To promote activity in nuclear science and engineering,
medical field and accelerator science at Kyushu University

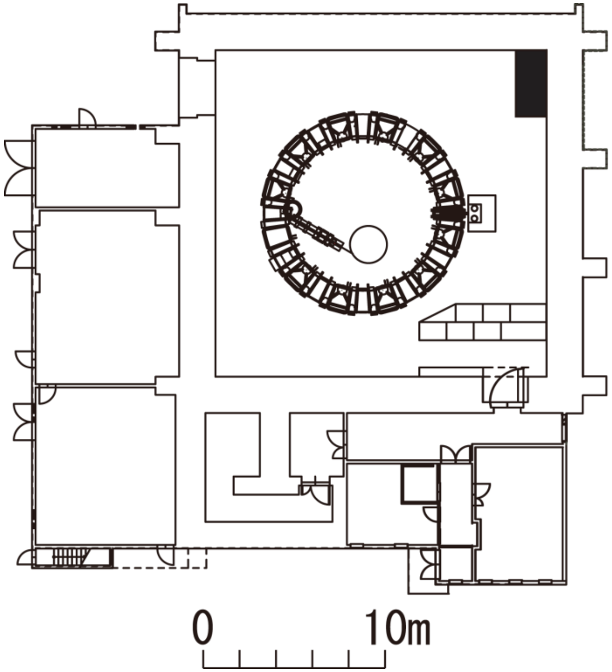
Construction History of Accelerator Facility

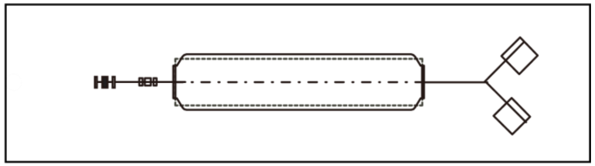
1st Stage (2008-2011)



Construction History of Accelerator Facility

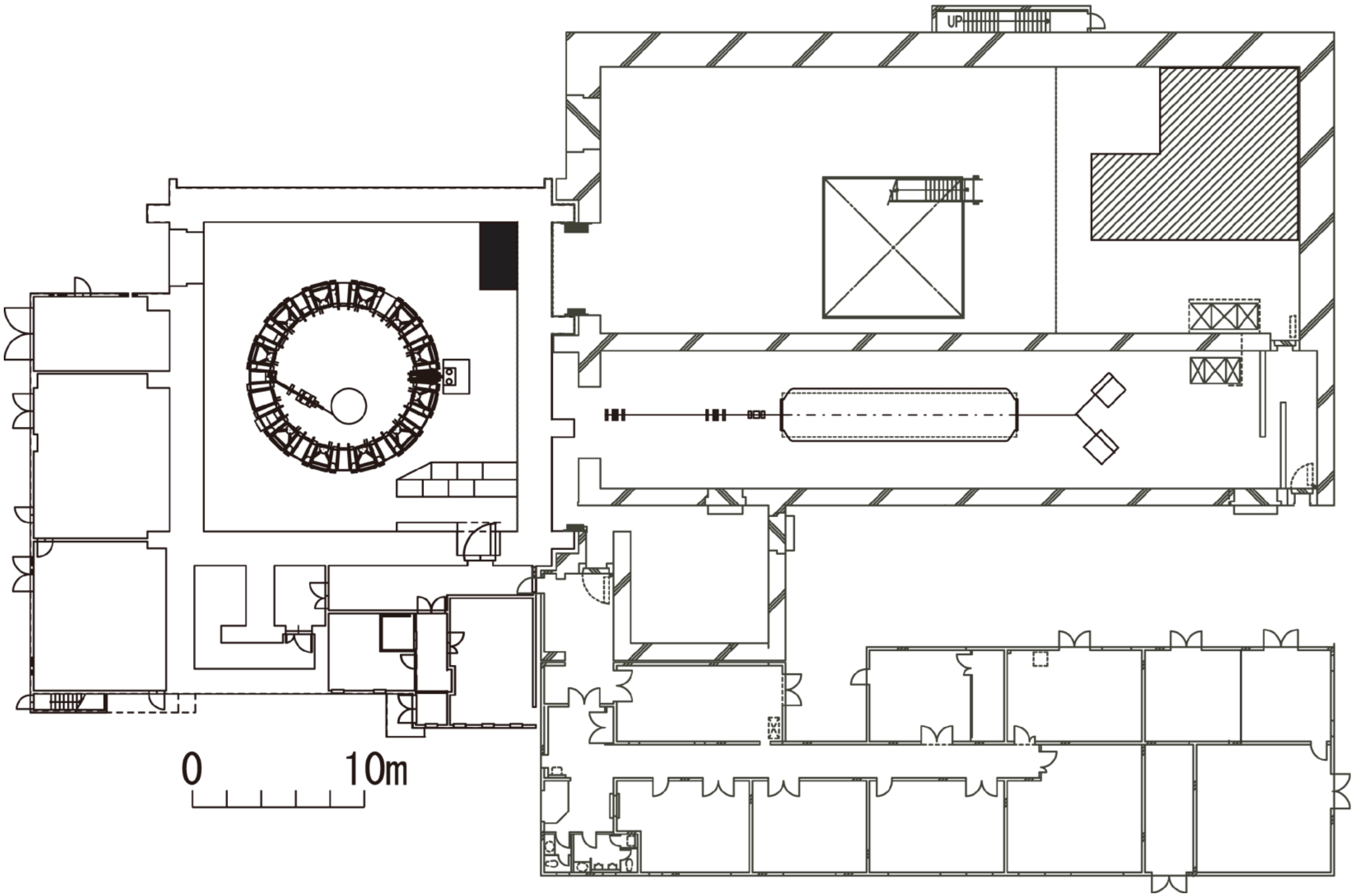
1.5st Stage (2011-2013)



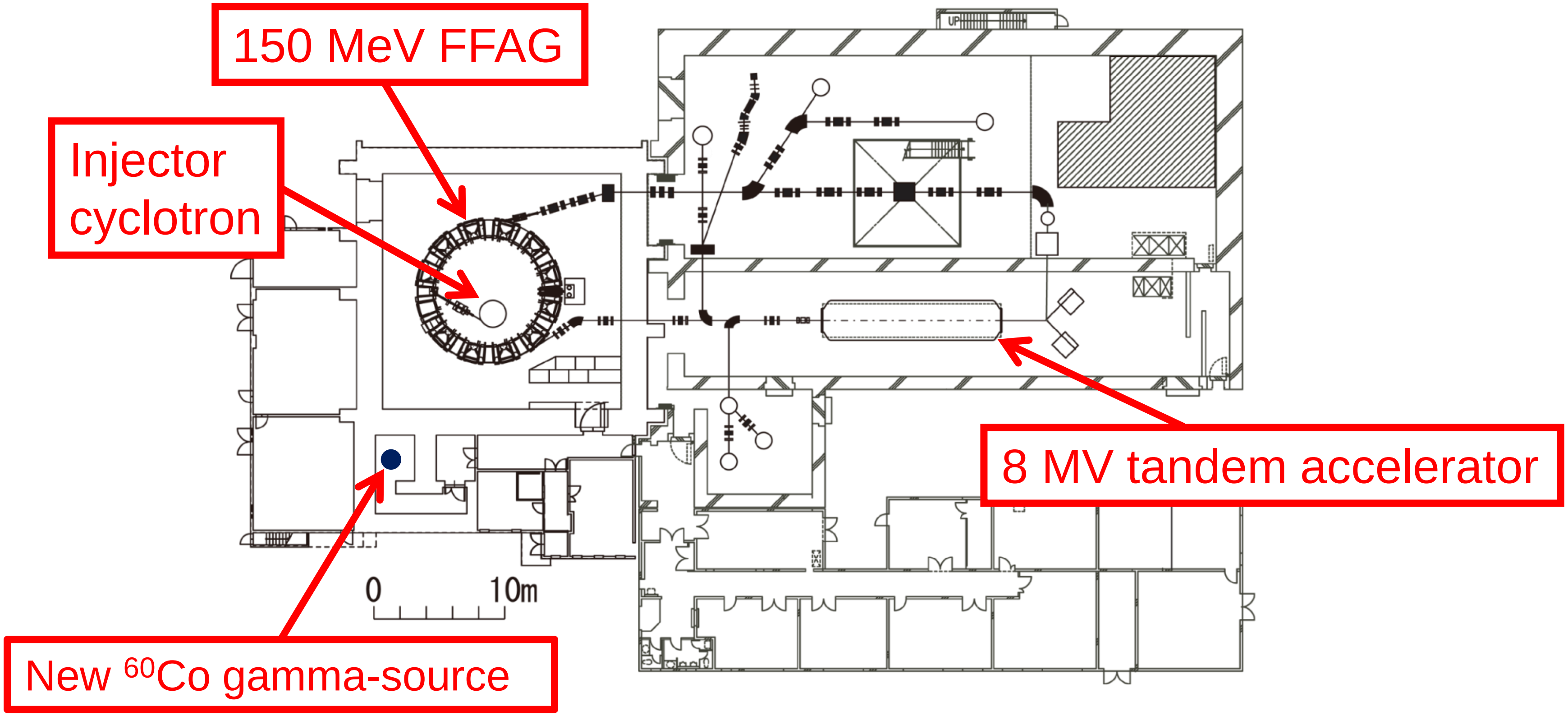


Construction History of Accelerator Facility

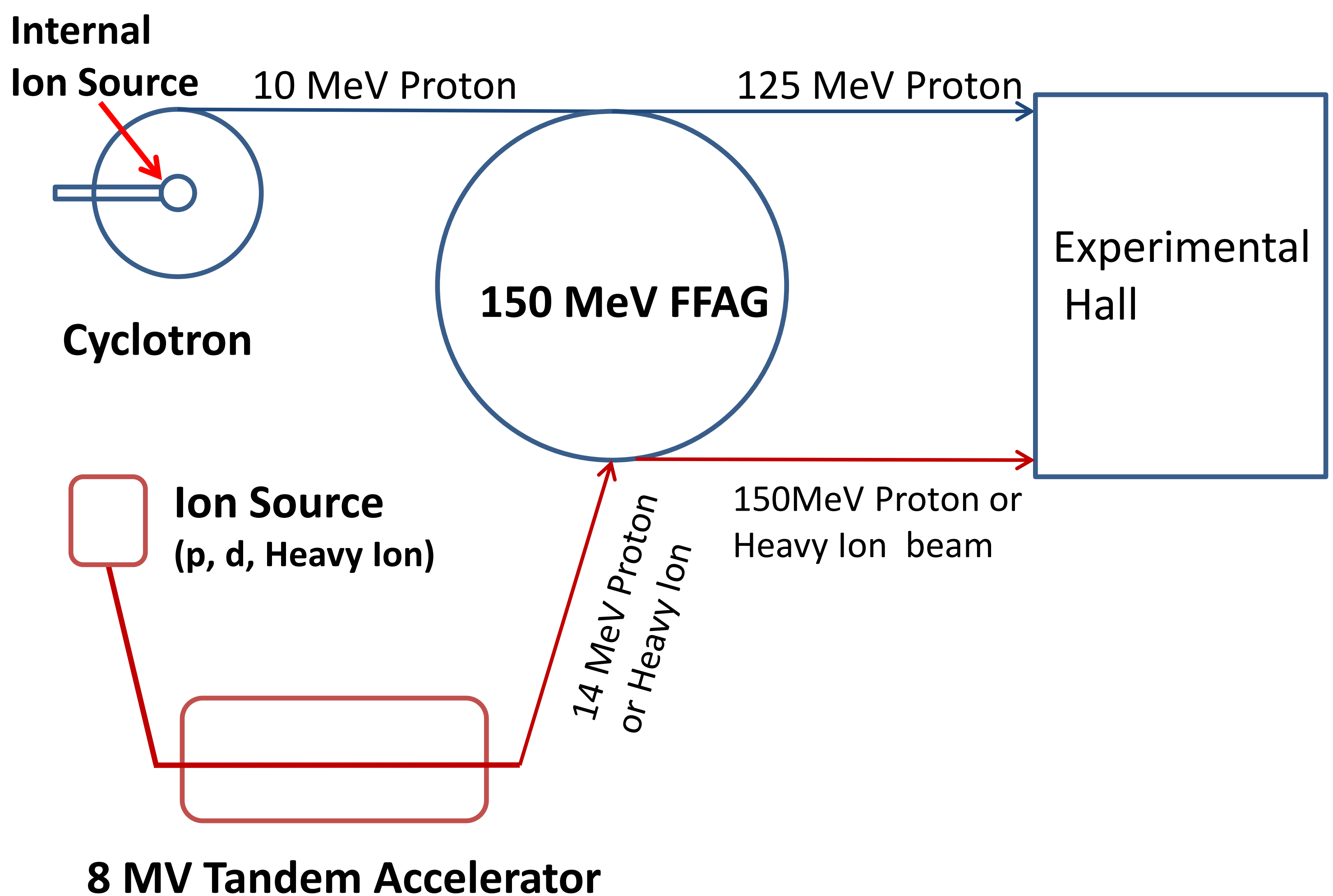
2nd Stage (2013-2014)



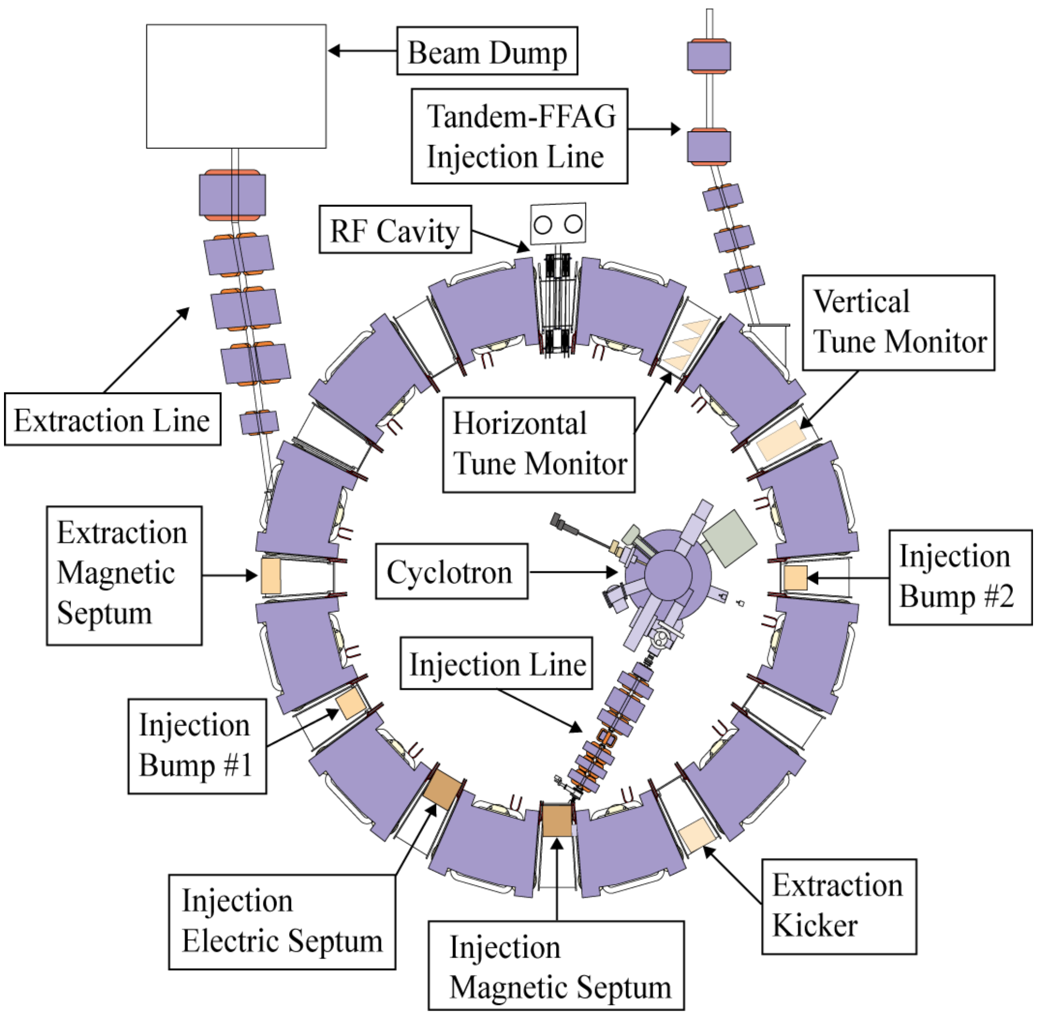
Center for Accelerator and Applied Beam Science



150 MeV FFAG accelerator and injectors

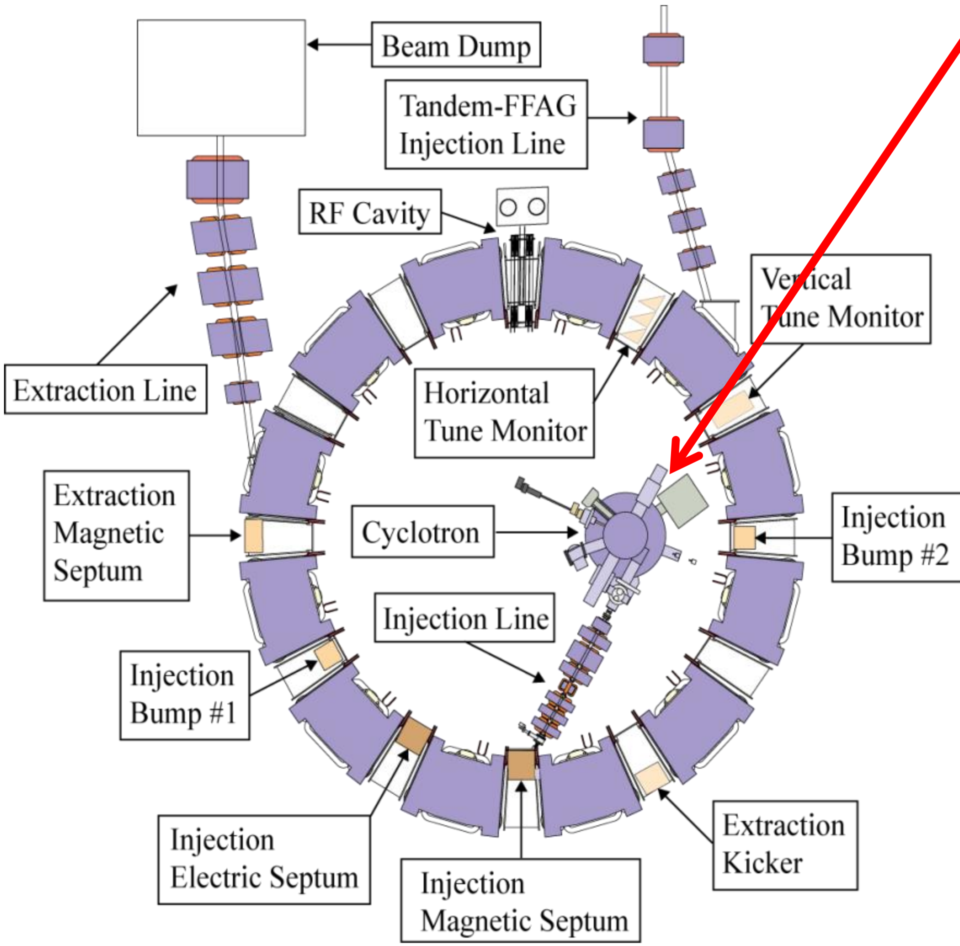


150 MeV FFAG Accelerator (2017)



magnet	Radial sector type (DFD-triplet)
Cell	12
K-value	7.62
Beam energy	10 ⇒125 MeV (12 ⇒ 150 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

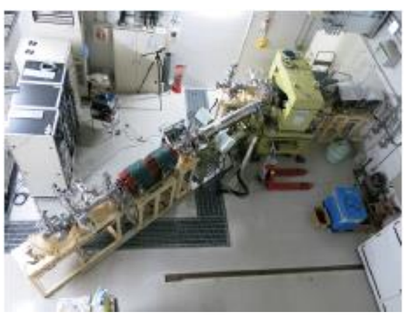
Injector cyclotron



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

8-MV tandem accelerator

Beam operation for low energy experiments has been started in 2016.



Low energy beam lines

Accelerator Type	Horizontal Tandem Van de Graaf
Model	NEC pelletron (8UDH)
Terminal Voltage	7 MV (max. 8 MV)
Accelerator Tank	Diameter: 3.0 m Length: 13.6 m
Insulation Gas	SF_6 (Pressure: 0.6 MPa)
Ion Source	Sputter Ion Source (NEC MC-SNICS) RF Ion Source (NEC Alphatross)
Injection Voltage	-70 kV
Beam	P, d, Heavy Ion
Current	1 nA (➔ 1uA)
Terminal Stripper	C Foil and N2 Gas
Charging Device	Double Pellet Chains (Current: 150 mA x 2)

Construction and Beam Commissioning Log

2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

1st stage
2008 ~ 2011


1.5 stage
2011 ~ 2013


2nd stage
2014 ~ 2017


Cyclotron

Maintenance & Reassembling (2008.9 - 2009.3)

Beam commissioning

Radiation Inspection (2014. 6)

In Operation

FFAG

Construction FFAG (2009.5 – 2012. 2)

Test of Power sources & Beam injection (2011.12 – 2012. 12)

Beam Acceleration (2013.7 – 2014. 12)

Construction of Tandem- FFAG Injection line (2015. 2 – 2015. 6)

Construction of extraction beam lines (2016.8 – 2017.9)

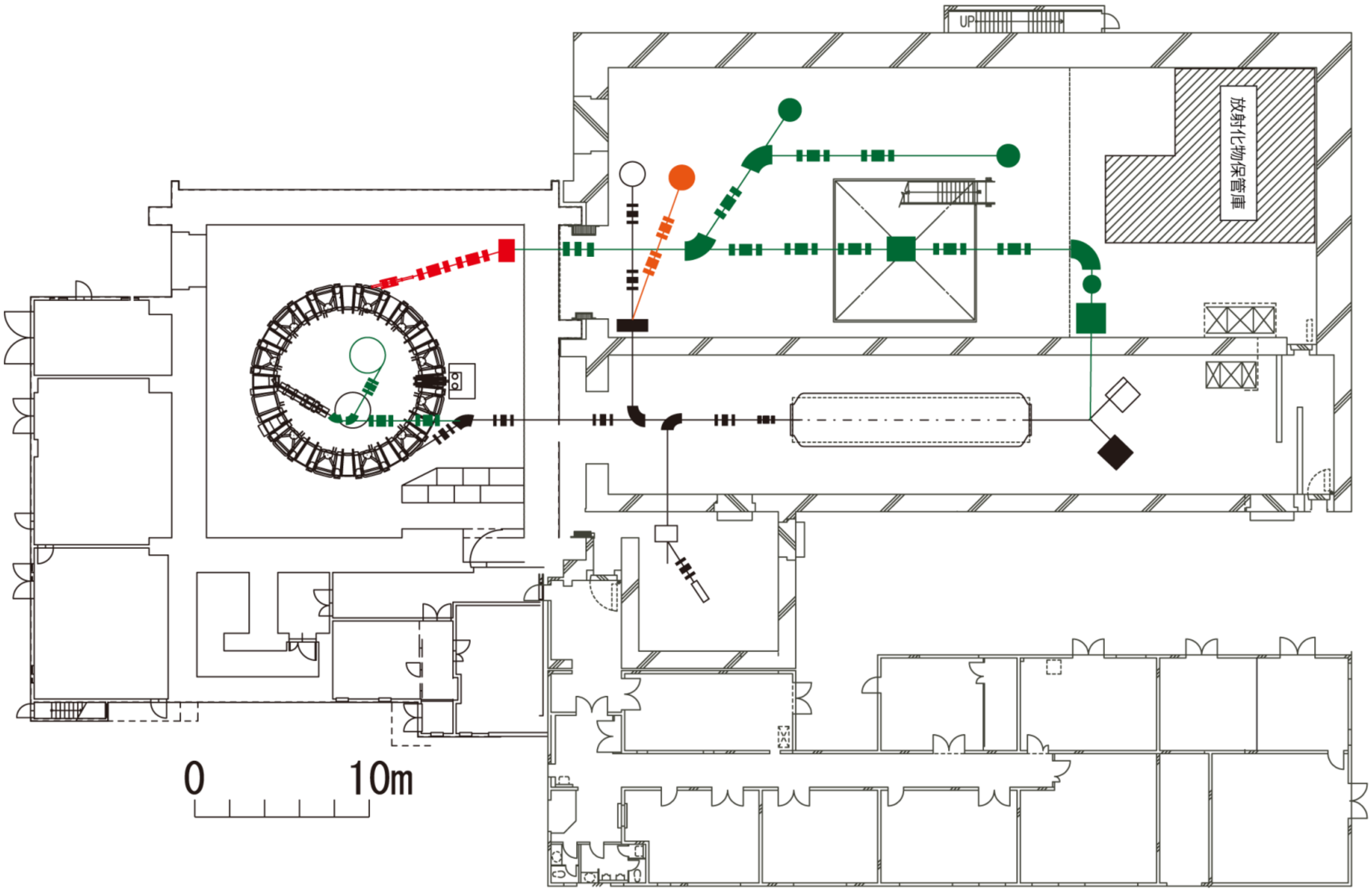
Tandem

Construction of Tandem (2011.3 – 2013. 6)

Test of ion source & Beam acceleration (2014.4 – 2015.3)

In Operation

Construction status of beam lines



Black: Construction completed
Red: Under construction
Orange: Construction will be started
Green: In the planning stage

Present Status of
150-MeV FFAG Accelerator

1. Status of beam commissioning
2. Construction of beam extraction system

Status of Beam Commissioning of 150-MeV FFAG Accelerator

Beam acceleration was demonstrated (~80MeV) in 2013.
Radiation safety inspection was passed in Jun. 2015.

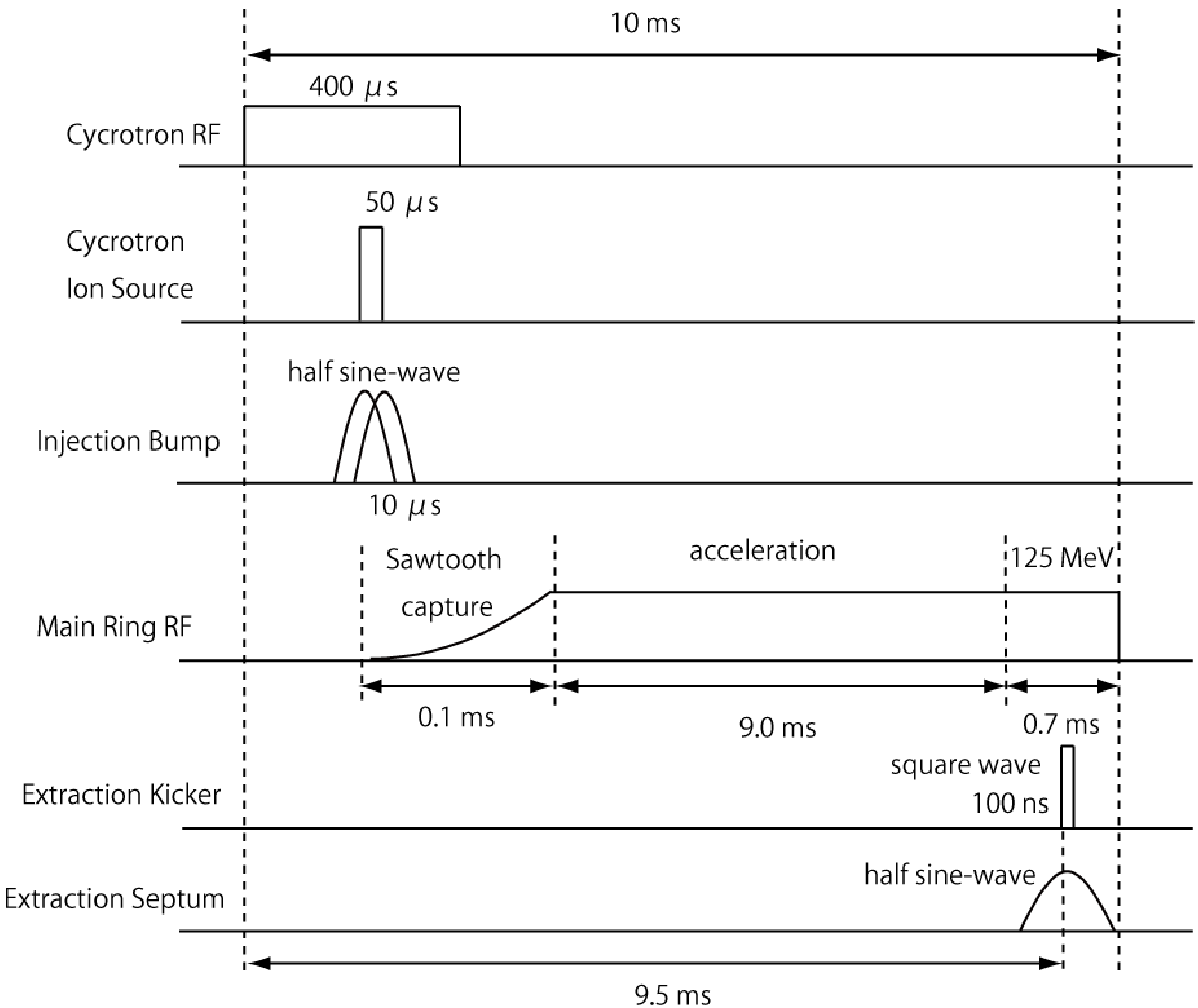
2016	Beam commissioning was suspended due to construction of extraction beam line and development of tune correction system.
2017	Oct. – Dec. Test of tune correction system will be carried out. Beam extraction will be demonstrated .

Operation time: about 200 hours / year

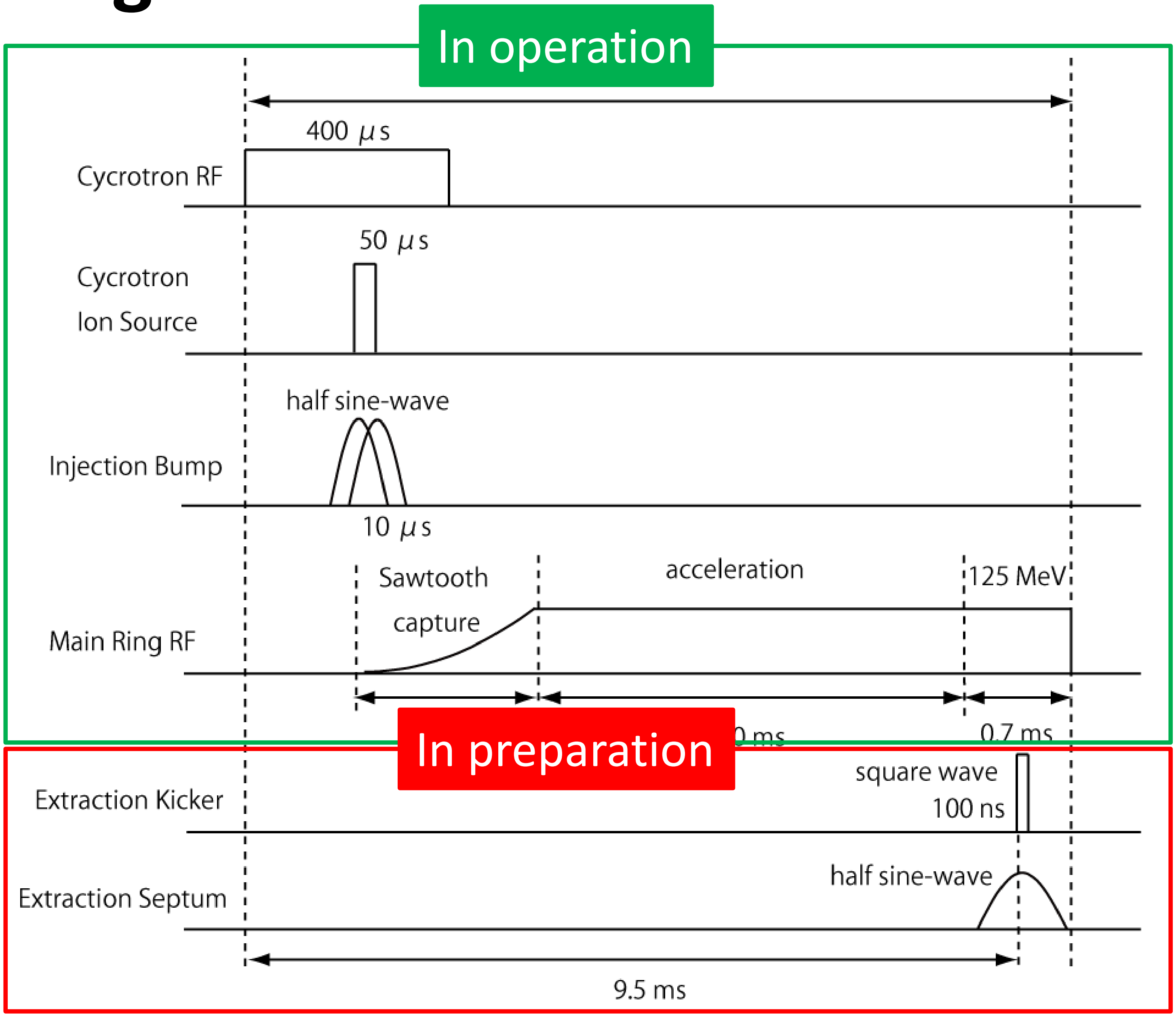
(Limitation of budget)

Timing Chart of the FFAG accelerator

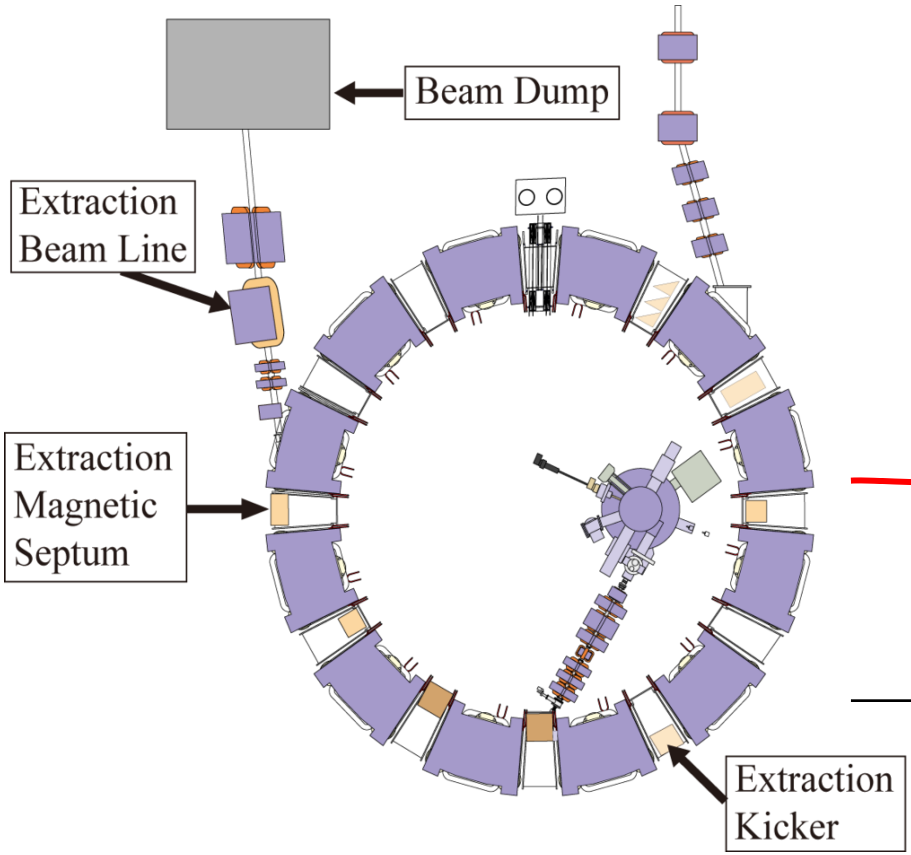
Repetition rate
100 Hz

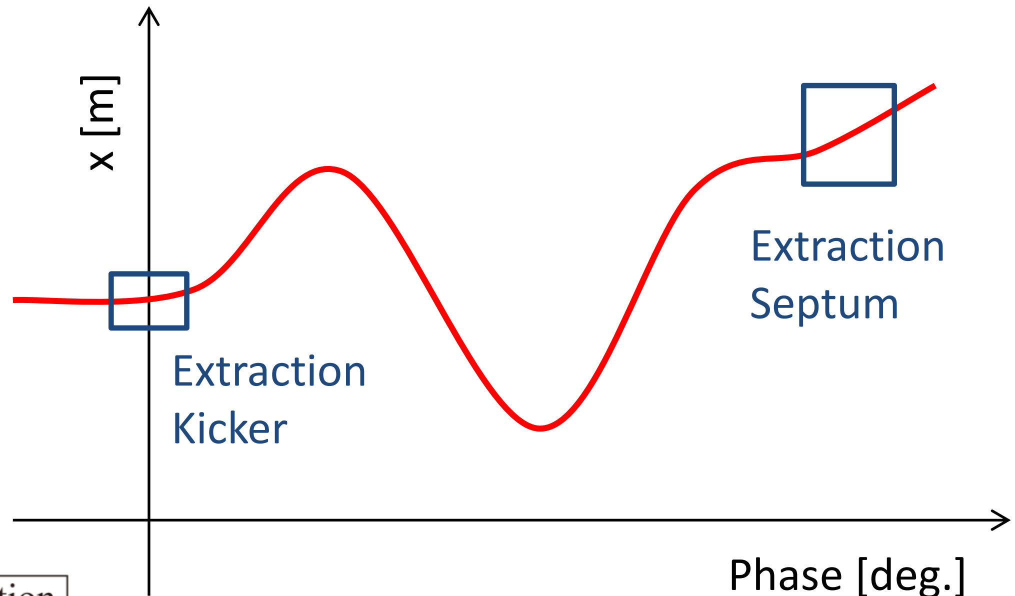


Timing Chart of 150 MeV-FFAG



Configuration of Beam Extraction System

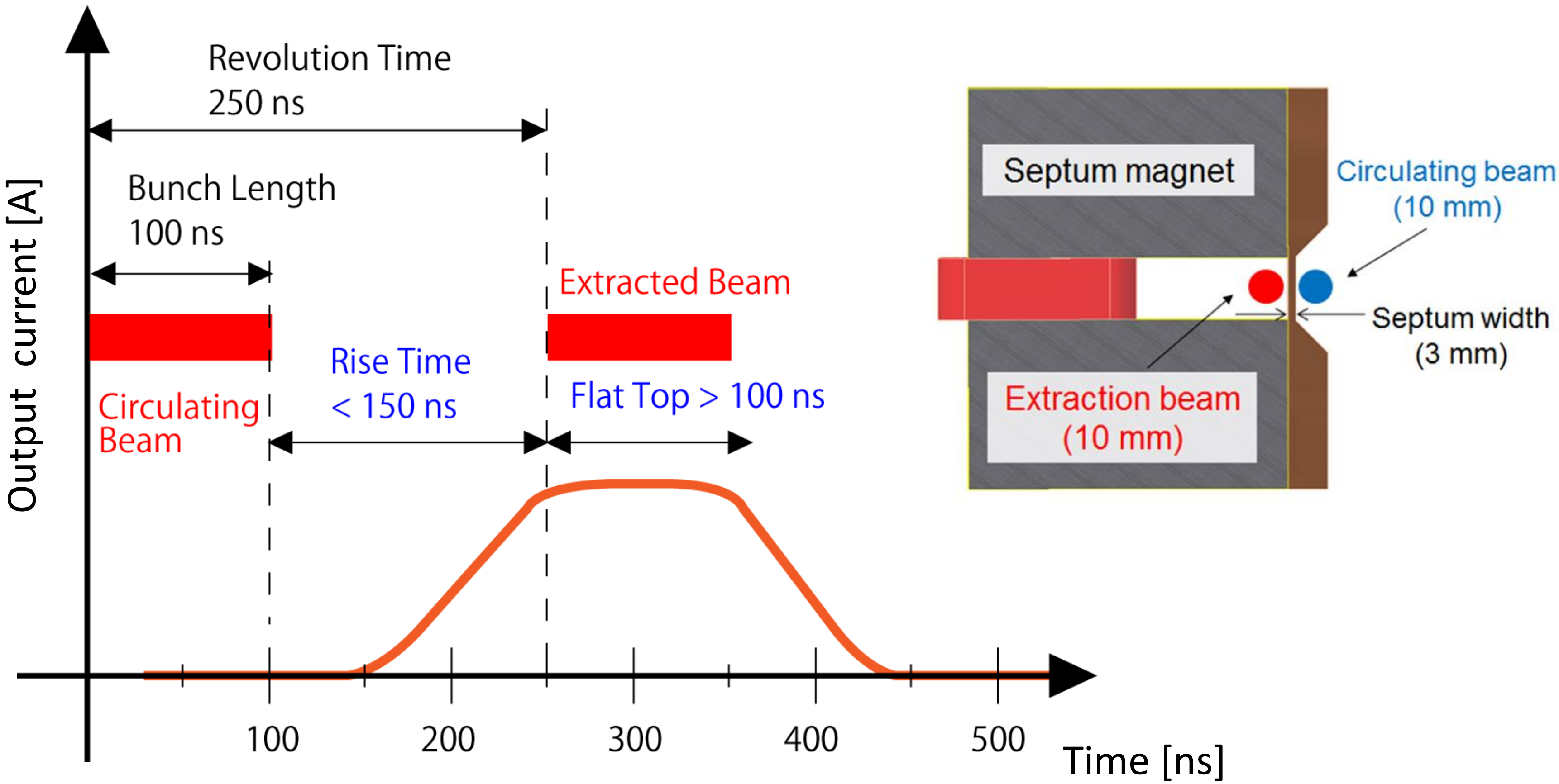




Extraction method : Fast Extraction

Phase advance between kicker and septum: 440 deg.(4 cells) $\cong 3\pi$

Requirements for Extraction kicker (1)

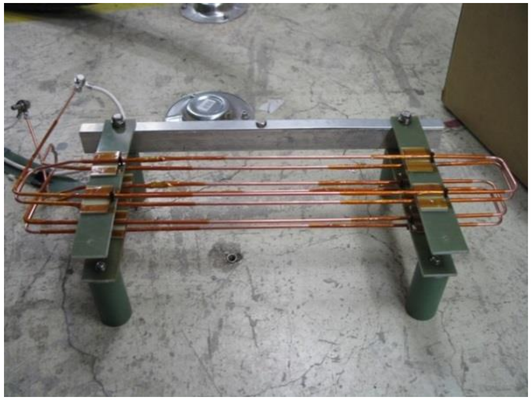


- Rise time should be less than 150 ns in order to prevent beam loss at the extraction septum.
- Time width of flat top is larger than 100 ns.
- Required beam separation is larger than 13 mm.

Requirements for Extraction kicker (2)

Kicker magnet developed at KEK in 2006

The kicker magnet consists of air core



Rise Time: 270 ns

Time width of flat top: 80 ns

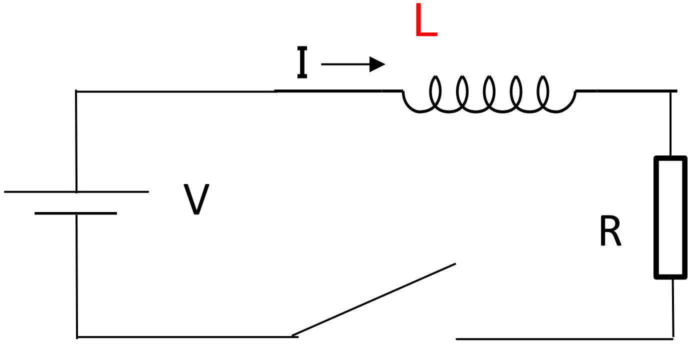
Beam loss rate was 10 %

Charge Voltage

$< 40\ kV\ (in\ air)$

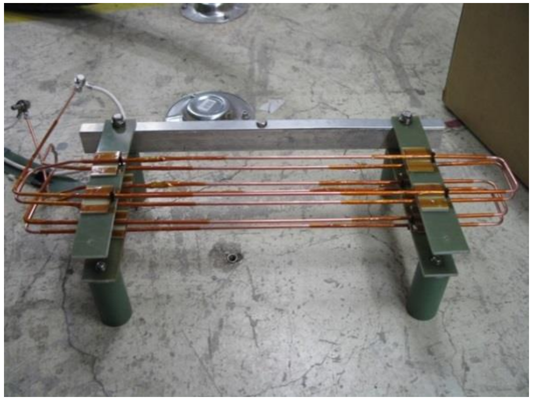
$$V = -L\frac{dI}{dt}$$

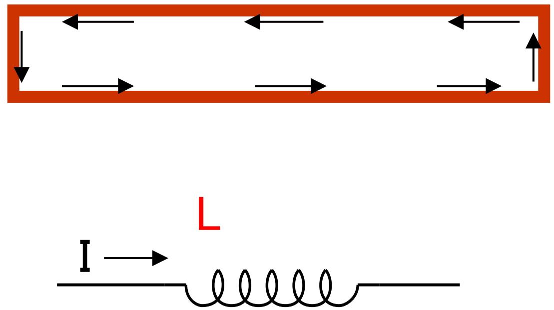
$$\frac{dI}{dt} \propto 1/(rise\ time)$$



Rise time can be decreased if inductance L is reduced.

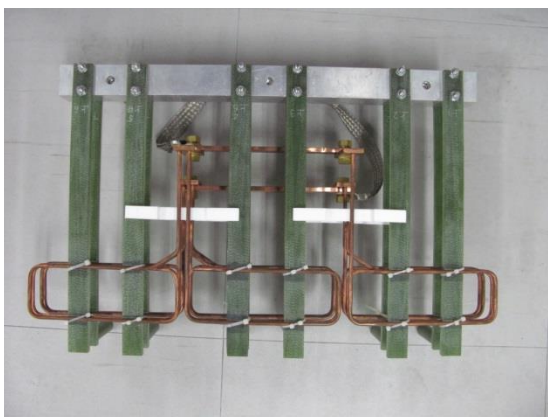
Development of new type Extraction kicker magnet



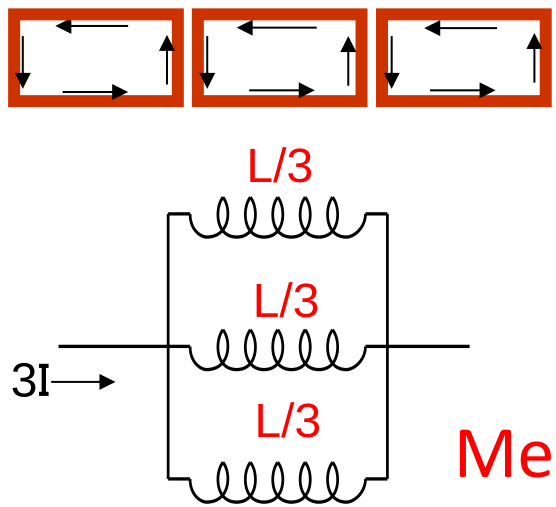


L = 6.5 uH

New type of kicker magnet with 3 coils has been developed.



600 mm x 70 mm



In ideal condition,

L' = 1/9 L

L' = 0.72 uH [1]

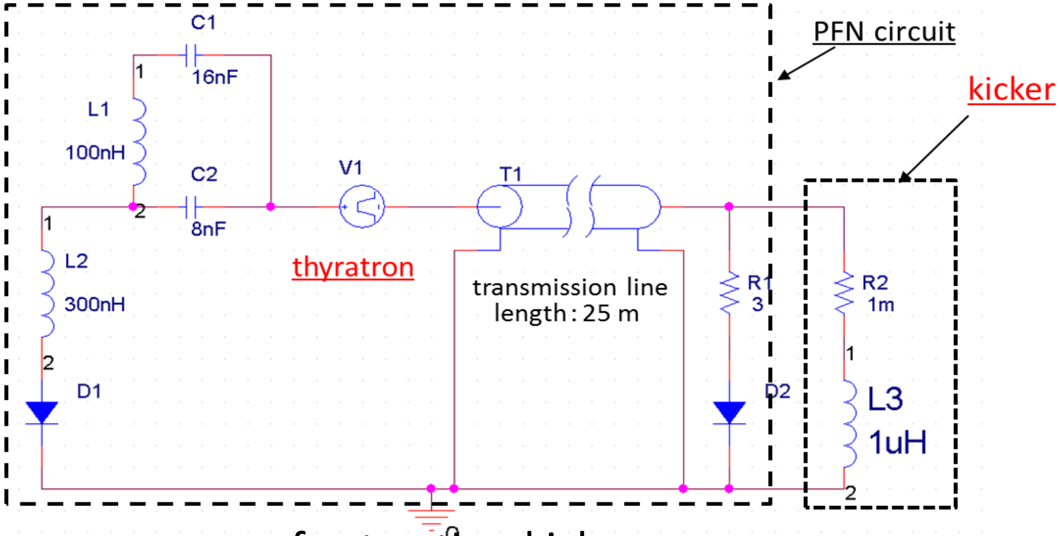
Measured L = 0. 95 uH

Development of new type of kicker magnet has been developed in 2012, however, High power test with rapid cycling operation has not been performed.

[1]. T. Matsunaga, DEVELOPMENT OF THE EXTRACTION KICKER FOR FFAG ACCELERATOR AT KYUSHU UNIVERSITY, Proceedings of the 7th Annual Meeting of Particle Accelerator Society of Japan (August 4-6, 2010, Himeji, Japan) ,593-595

Power test of Extraction Kicker (1)

The kicker coils has been installed in the main ring, and high power test has been carried out.

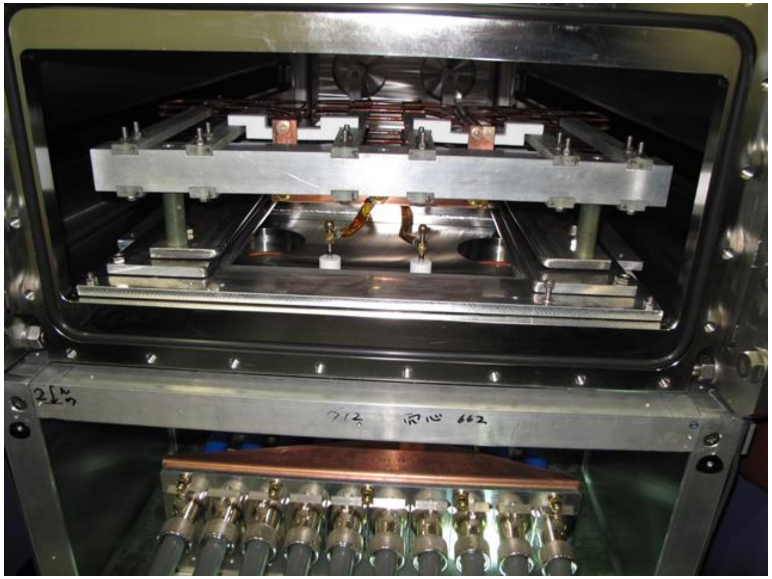


Design Parameters of power source of extraction kicker

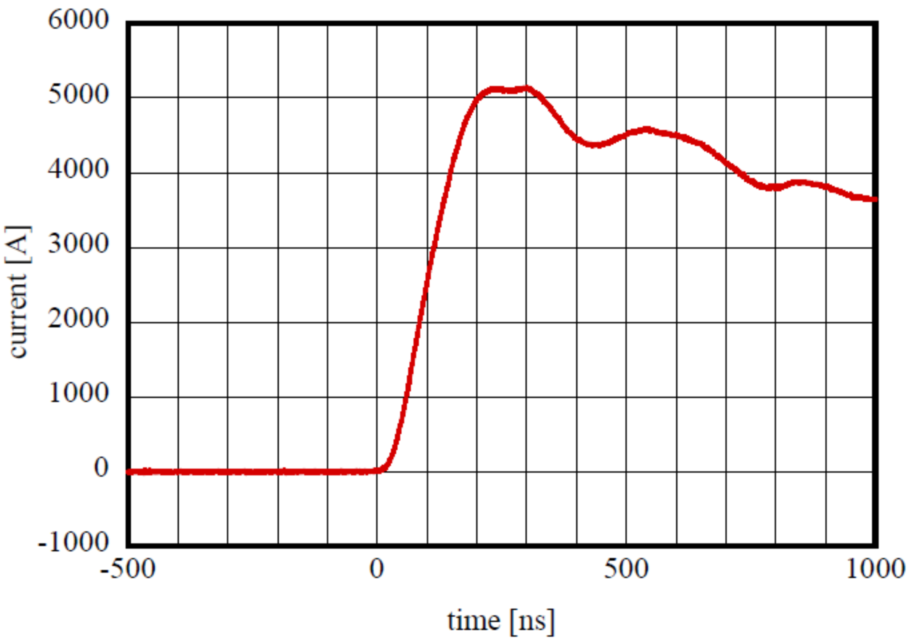
Maximum Current	5100A (1700 A /1 coil)
Charging Voltage	40 kV
Switching device	E2V CX1175
Wave form	Rectangular wave
Type of Output circuit	Pulse Forming Network

Power test of extraction kicker (2)

Power test with 100 Hz operation has been performed



Installed Kicker magnet



Measured output current

Before

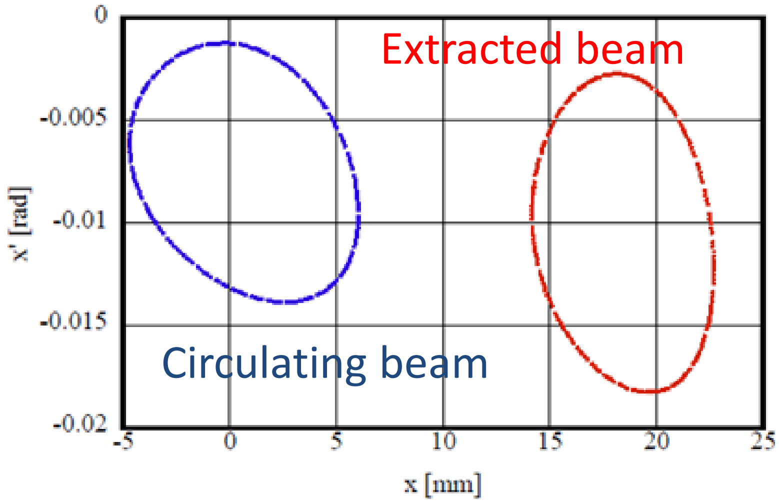
Rise Time: 270 ns
Time width of flat top: 80 ns
Peak current: 1700 A

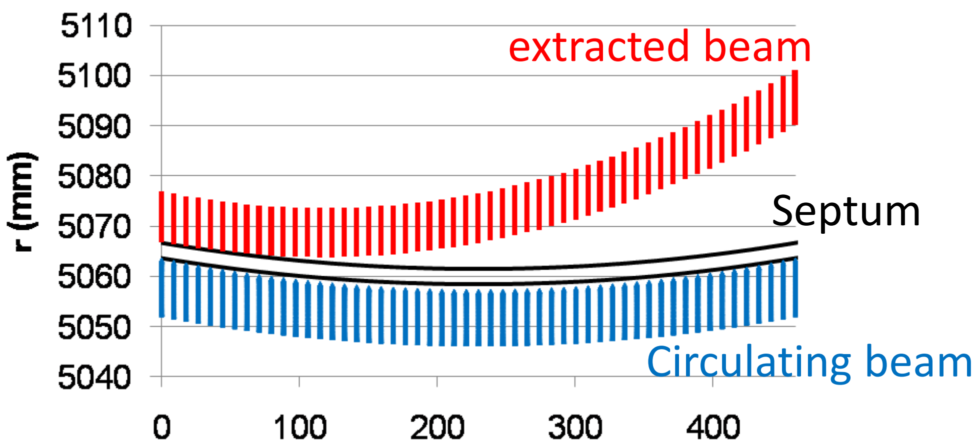
Rise Time: 160 ns
Time width of flat top: 140 ns
Peak current :5140 A = 1713 A/coil

Rise time was 7 % larger than required rise time.

Results

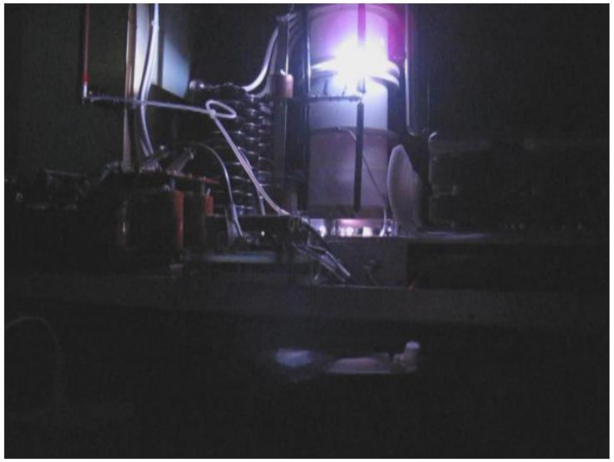
At the entrance of the septum magnet





Enough beam separation was obtained.

Technical issues



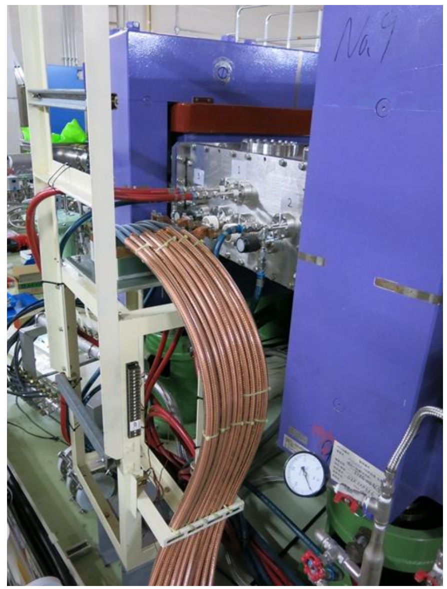
100 Hz, 42.5kV

Electric discharge around the thyratron was occurred when charging voltage was larger than 42.5 kV. (Operation voltage = 42 kV)
We are now investigating of the cause of the discharge.

Power test of extraction Septum (1)

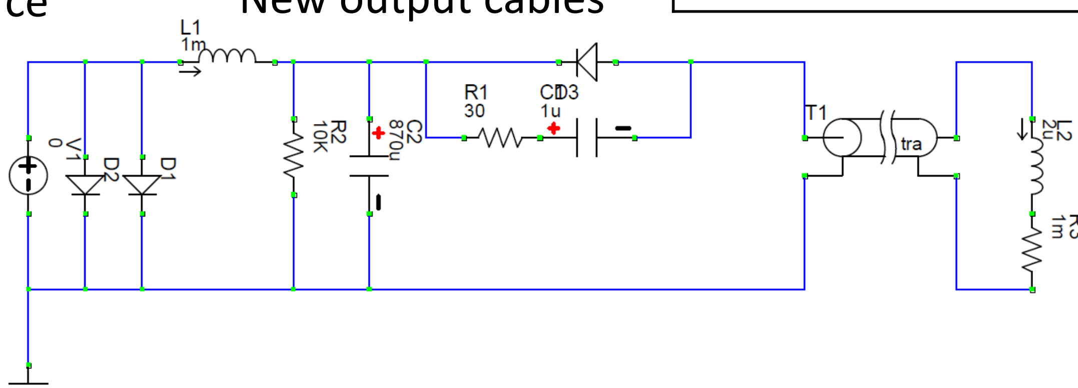
The maintenance of the power supply was carried out using the additional budget in 2016.

Power source

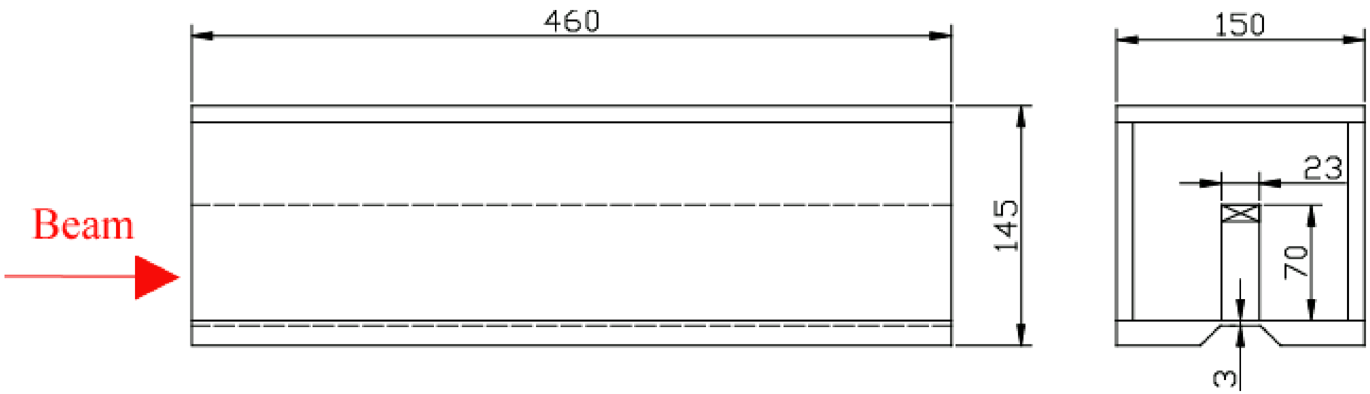


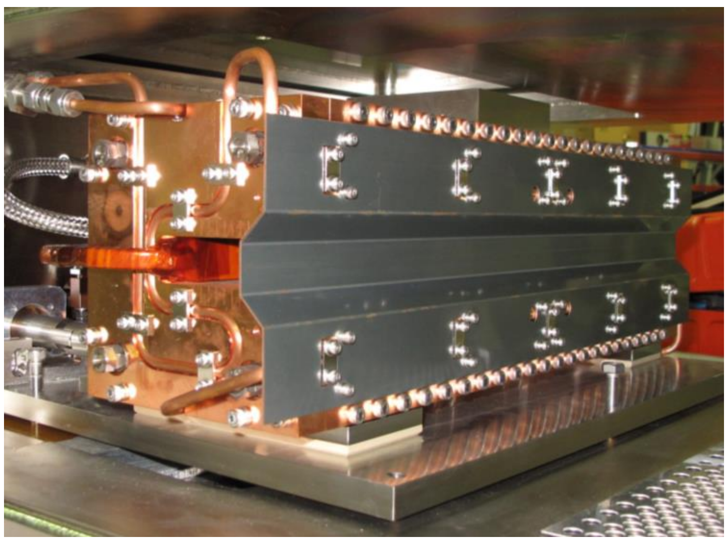
New output cables

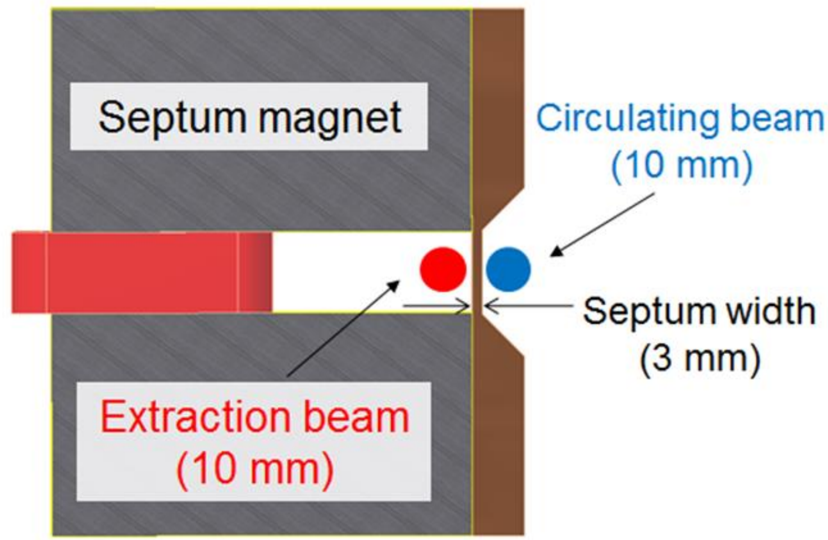
Magnet Type	Eddy current type
Output waveform	Half-sin wave
Magnet Length	460 mm
Gap width / height	70 mm / 23 mm
Switching device	Mitsubishi FT1500EY-24
Wave length	155 us
Peak current	8600 A
Charging voltage	3.7 kV



Power test of extraction septum magnets (2)



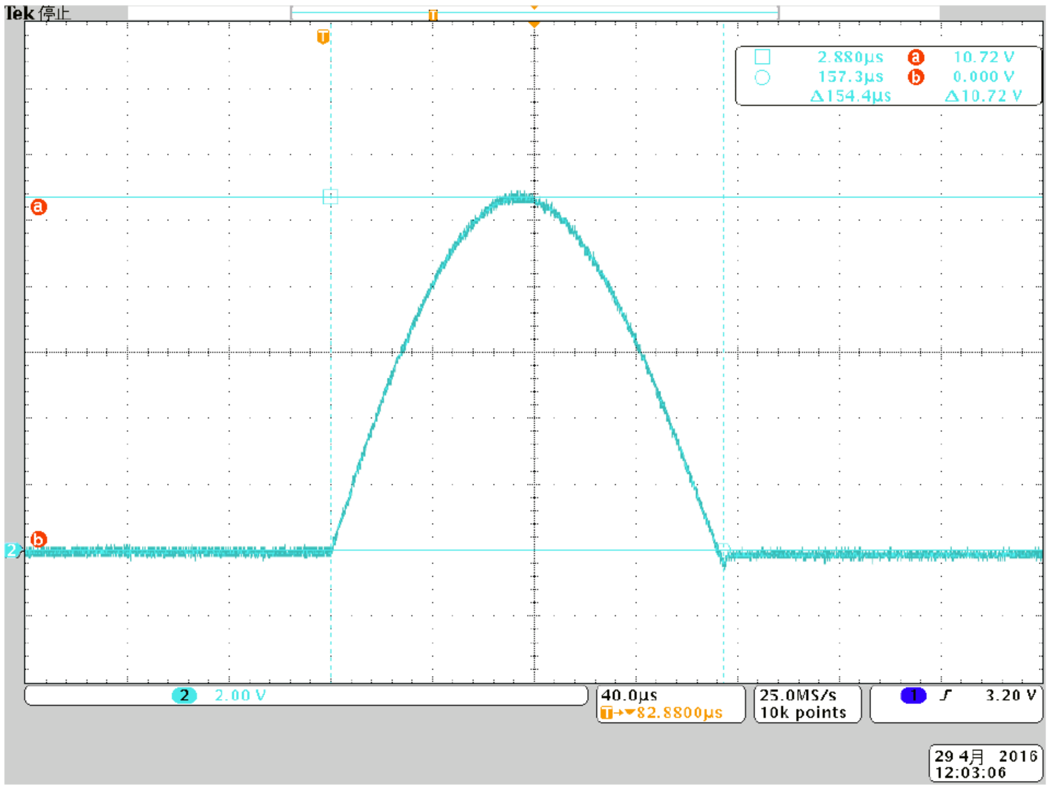




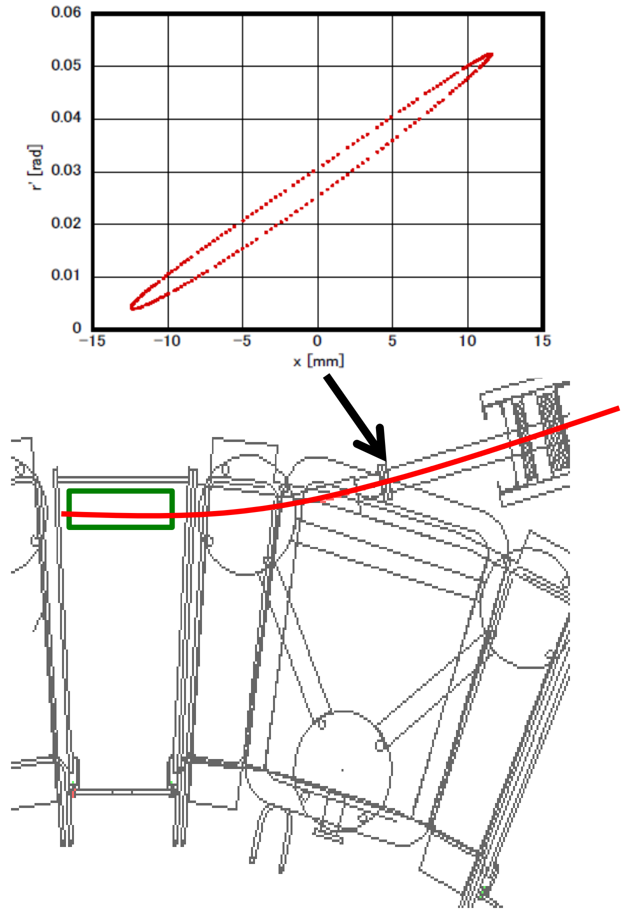
Installation into vacuum chamber and alignment has been performed.

Power test of Extraction Septum (3)

Power test with 100 Hz operation has been carried out.

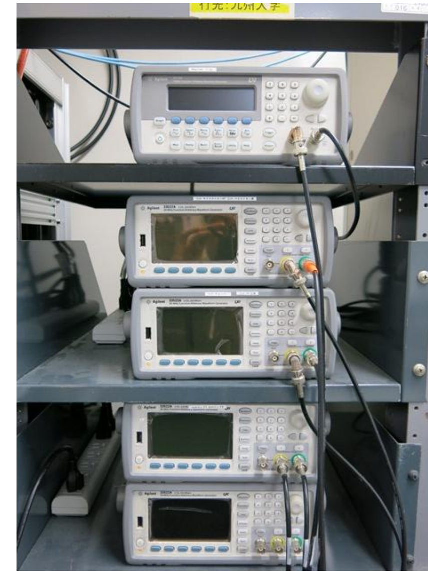


Calculated horizontal beam at the extraction port



Required current (8600A) for beam extraction was obtained.

Upgrading of Trigger system



- Agilent 33210A Function/Arbitrary Generator
  - Agilent 33522A Function/Arbitrary Generator
    - Cyclotron RF
    - Pulse Ion Source
  - Agilent 33522A Function/Arbitrary Generator
    - Beam Chopper
    - Main ring RF → Tektronix AWG 2021
  - Agilent 33522A Function/Arbitrary Generator
    - Injection Bump #1
    - Injection Bump #2
  - Agilent 33522A Function/Arbitrary Generator
    - Extraction Kicker
    - Extraction Septum

Trigger system consists of 6 function generators. Measured Time jitters are less than 4 ns. Trigger timing can be controlled arbitrary in 10 ns.

Construction of extraction beam line

Since additional construction budget was secured, construction of the extraction beam line has been started in 2016.

Reuse of old magnets in KEK

TRISTAN

Dipole magnets

Quadrupole magnets

PS Pre-injector

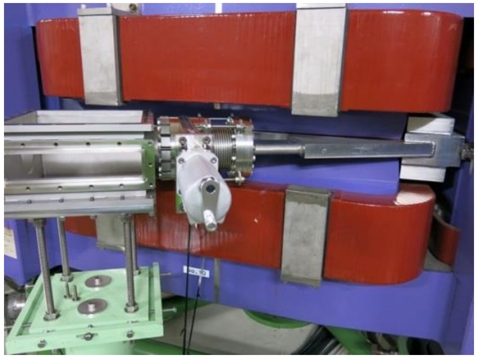
Triplet quadrupole
Dipole magnet

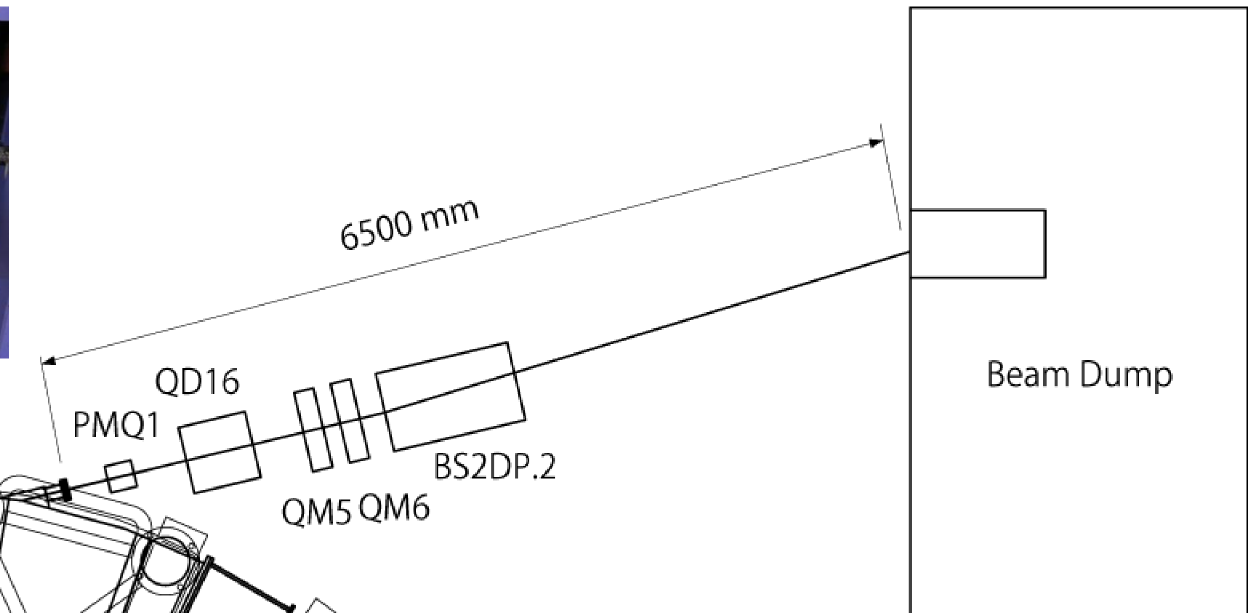
Power sources

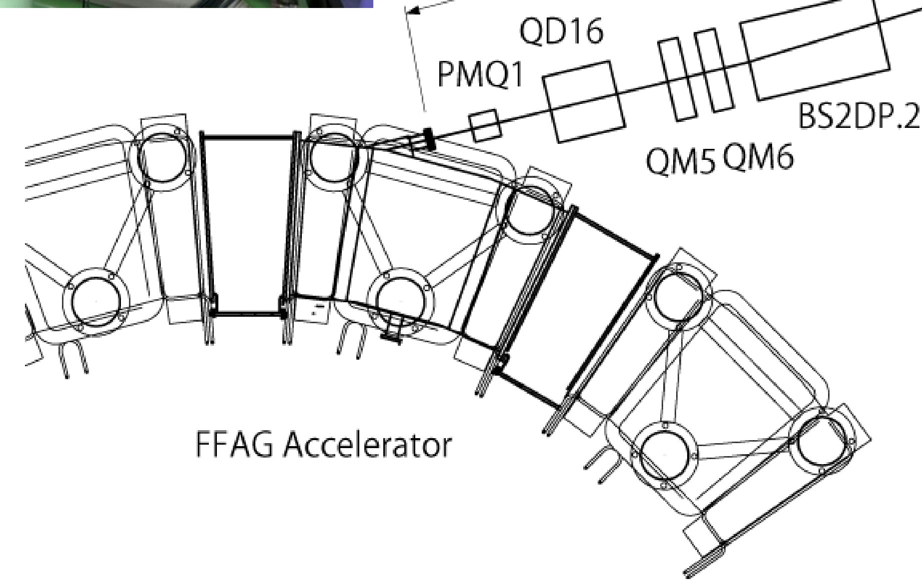
However, Because we did not get enough budget to manufacture new magnets and power sources, used magnets and power sources have been transported from KEK.

Transportation from KEK in Jan. 2016

Construction of extraction beam line







Vacuum pump and chamber are ready to install.

Construction has been almost completed. Beam commissioning for beam extraction will be started soon.

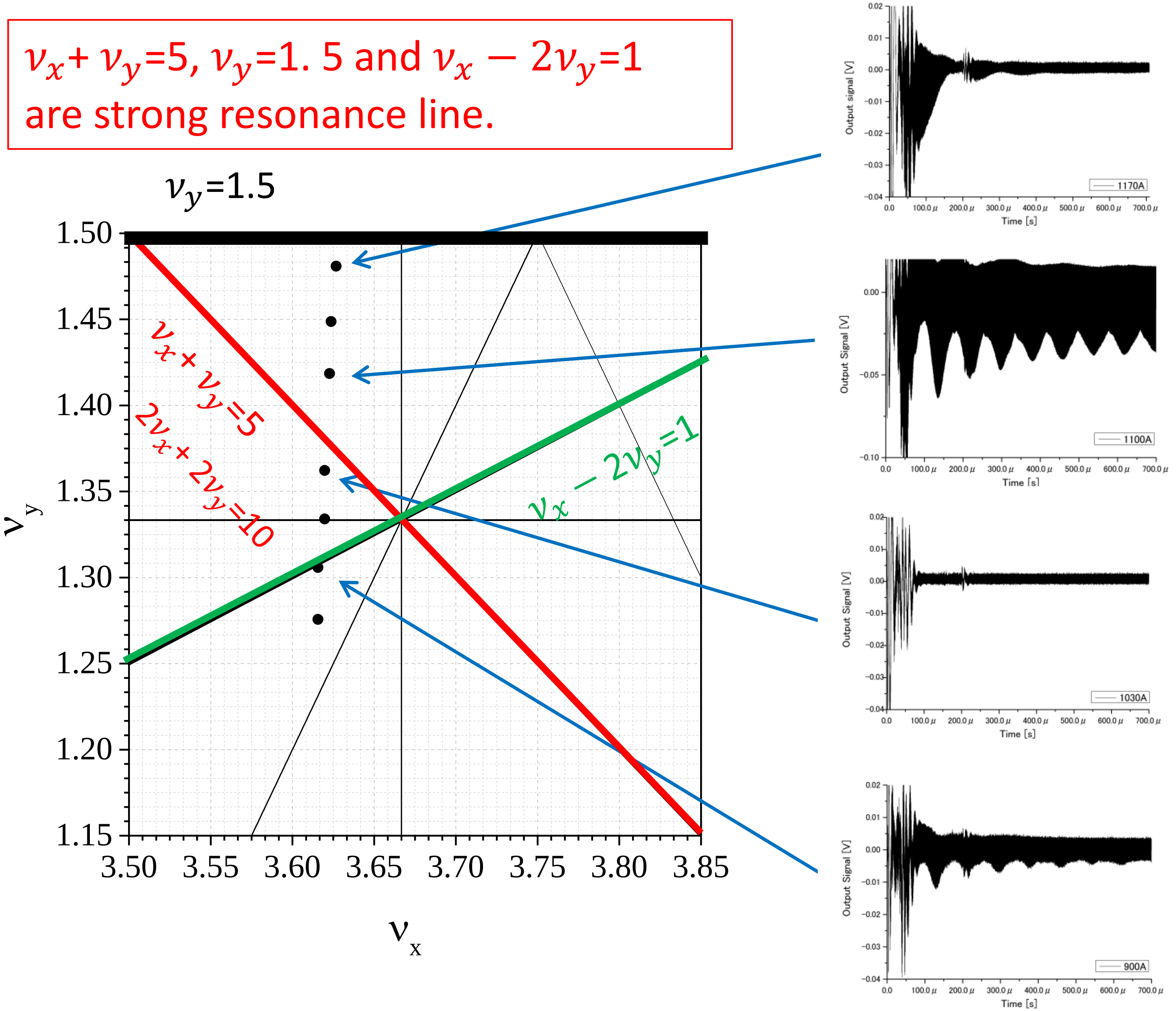
Hardware developments for 150-MeV FFAG

Tune Correction system

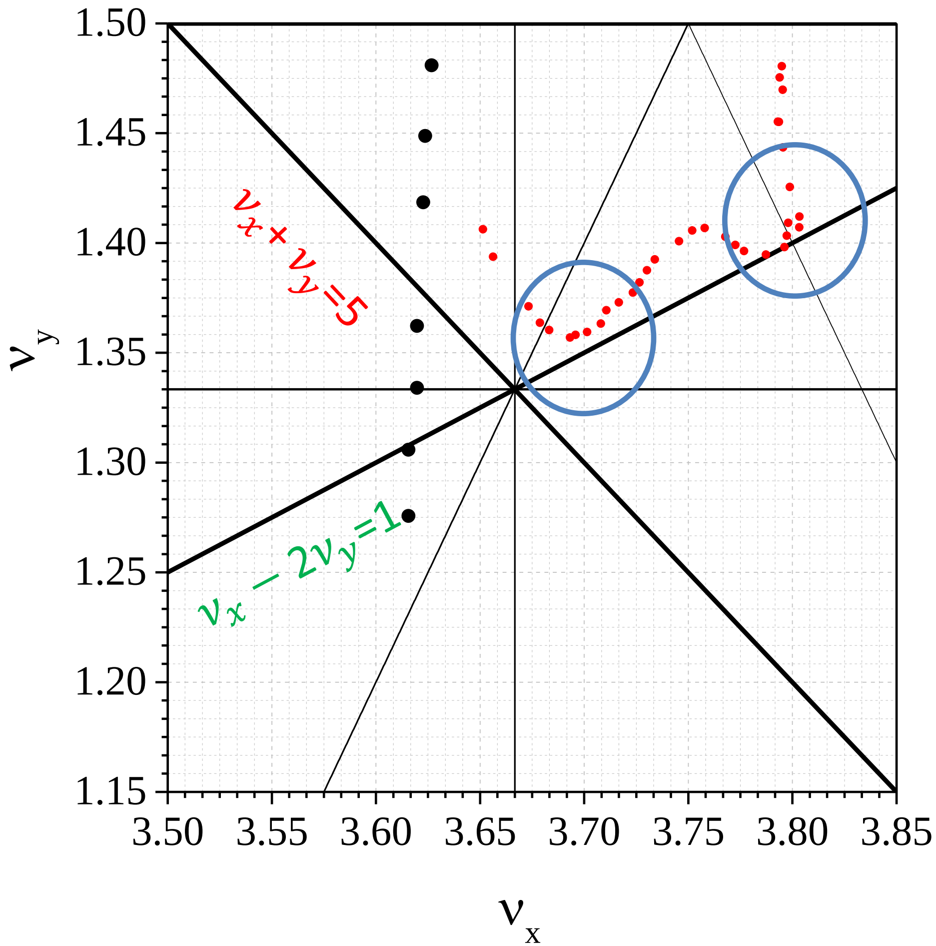
- Vertical tune correction patches
- Horizontal tune correction coils

Beam loss caused by resonances

$\nu_x + \nu_y = 5$, $\nu_y = 1.5$ and $\nu_x - 2\nu_y = 1$ are strong resonance line.

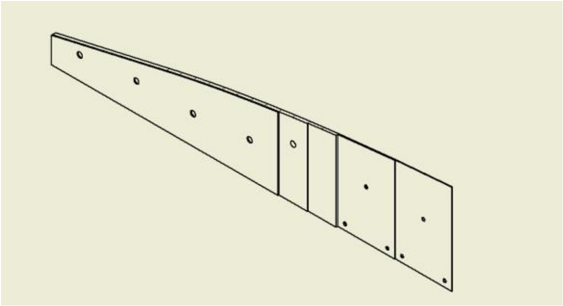


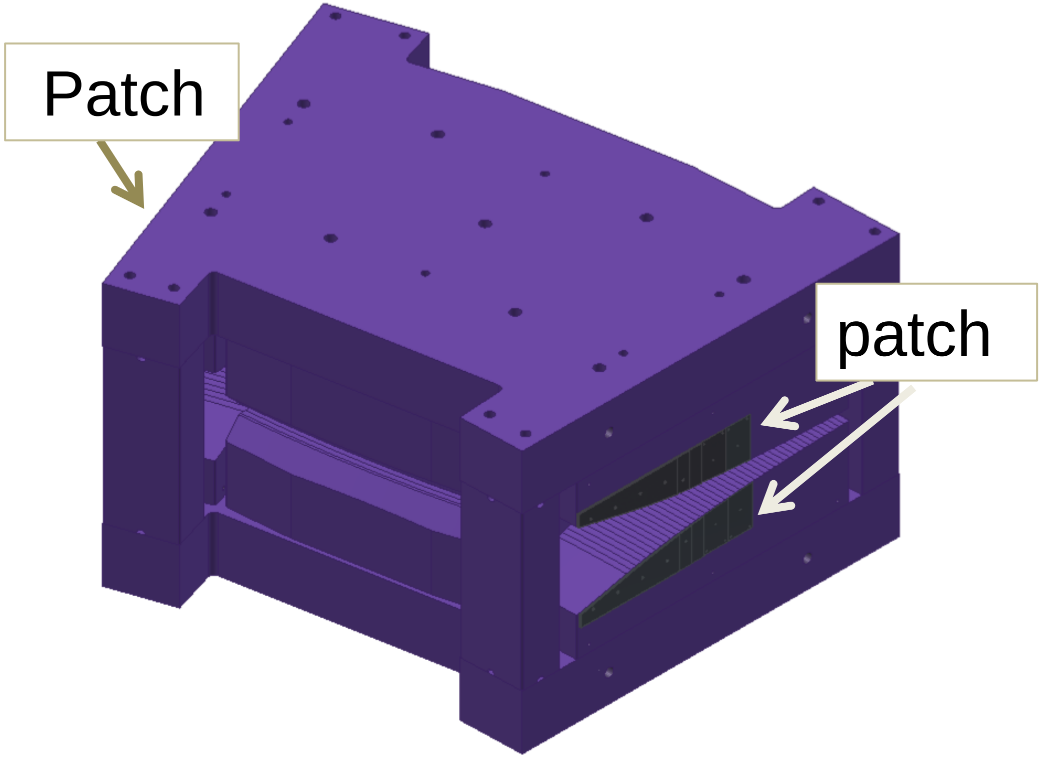
Tune variation during acceleration

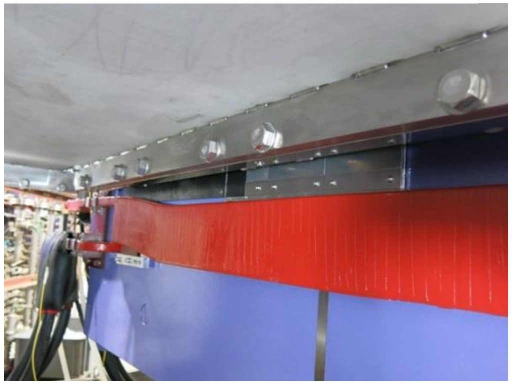


To reduce the tune variations is important in order to prevent beam loss.

Development of additional pole (patch) for vertical tune correction



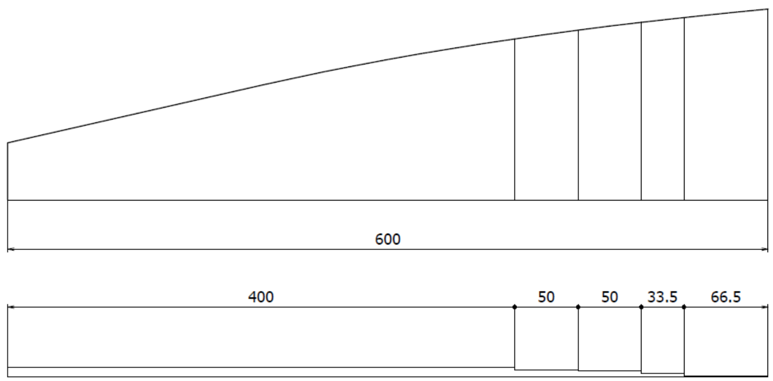




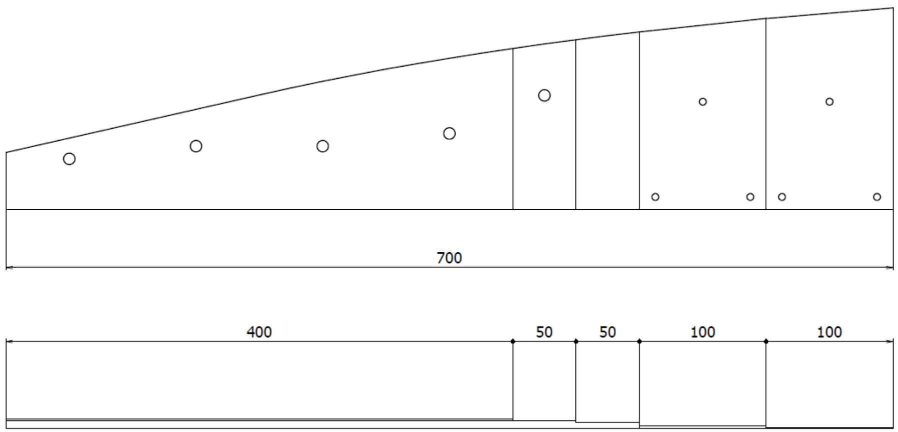
The variation of vertical tune has been decreased with the iron plate installed in both side of the magnet.

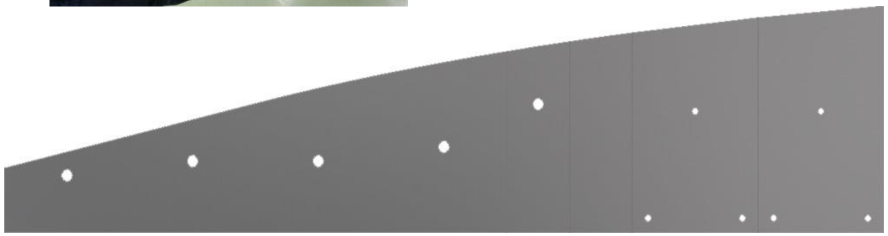
Optimization of shape of the plate with Opera 3d has been carried out by Motohashi-san in 2016.

Improvement of additional patch



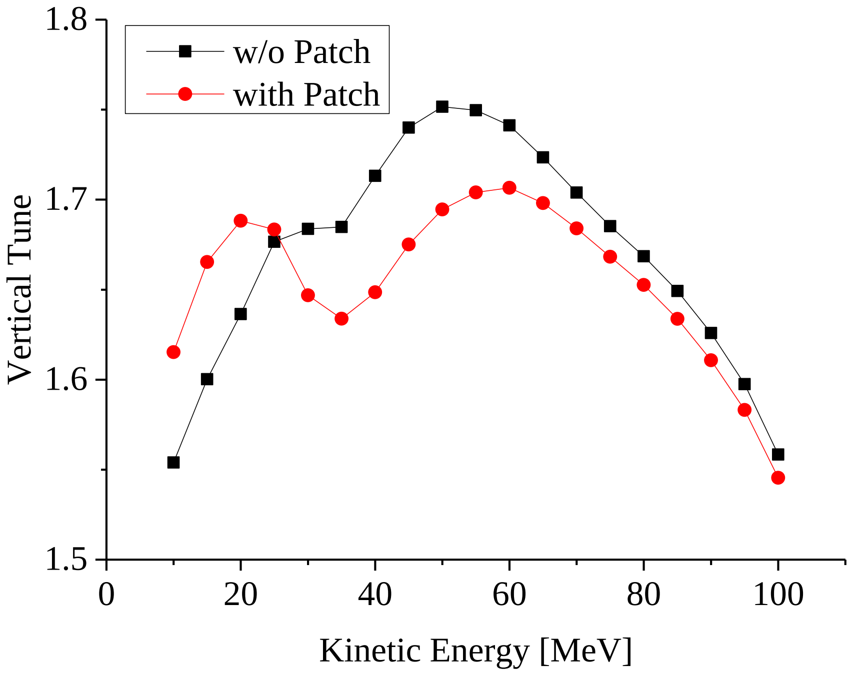
Developed pole in KEK in 2005

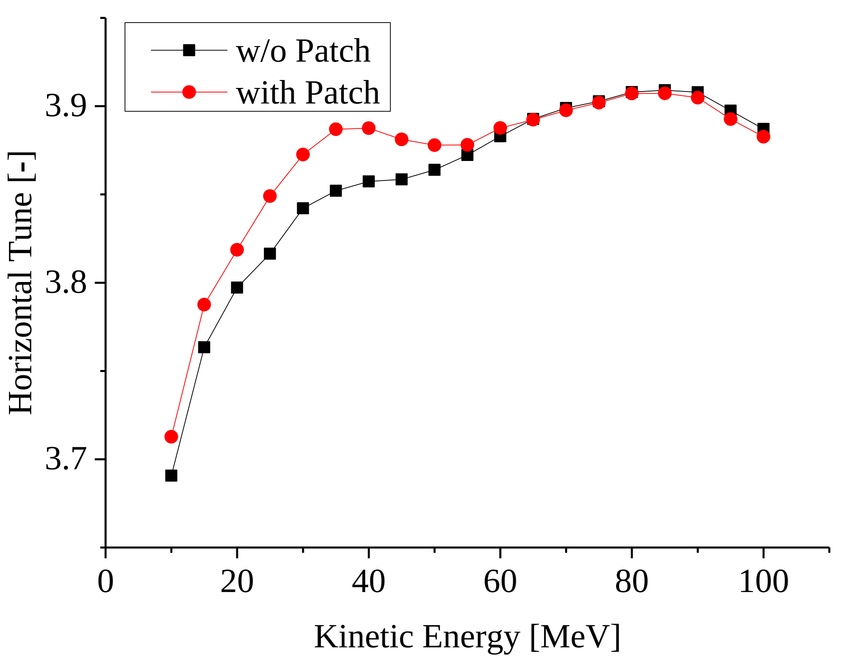




New additional pole

Calculated tune with path



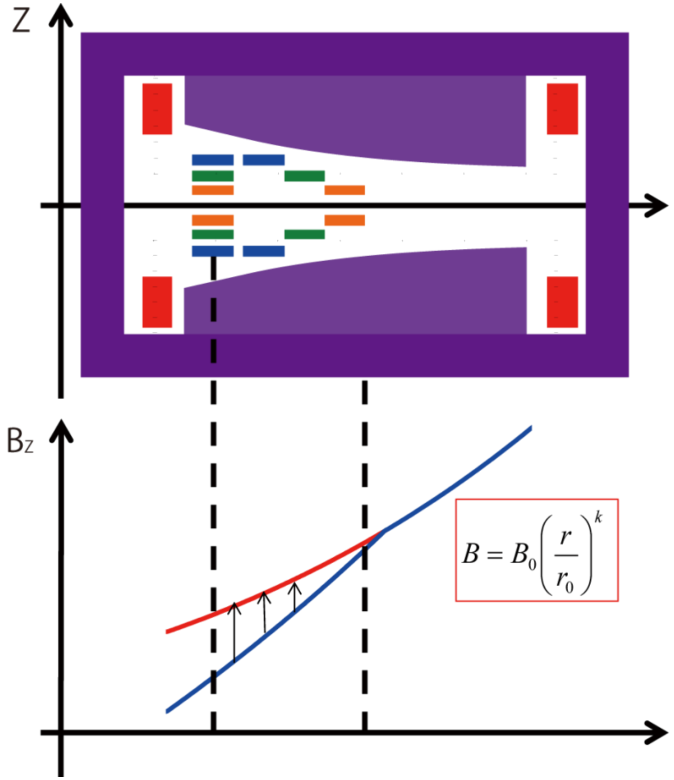


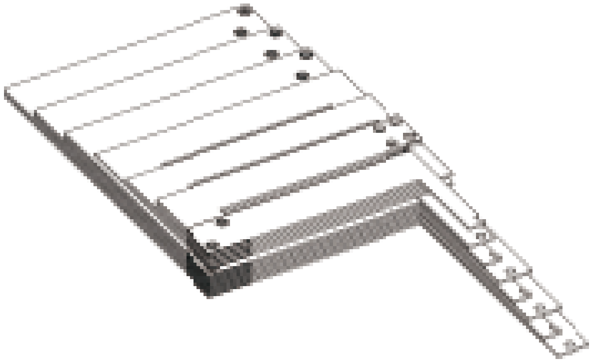
Calculation results indicates that Vertical tune variation has been reduced from 0.2 to 0.09

Tune measurements will be carried out in next beam time from Nov.

Development of horizontal tune correction coils

In order to reduce horizontal tune variation,
correction magnet with multilayered coils has been developed.





Detail of development of the correction coils and results of field measurements will be reported in Ueda-san's presentation in September 10.

Summary

- Construction status
  - Construction of beam extraction system has been completed.
  - High power test of the extraction kicker and the extraction septum has been demonstrated.
- Hardware development
  - Tune correction system has been developed successfully.

Beam commissioning for beam extraction will be stared.