Injection and Fast eXtraction Systems for J-PARC Main Ring

AFAD 2024

Koji ISHII (on behalf of J-PARC MR)

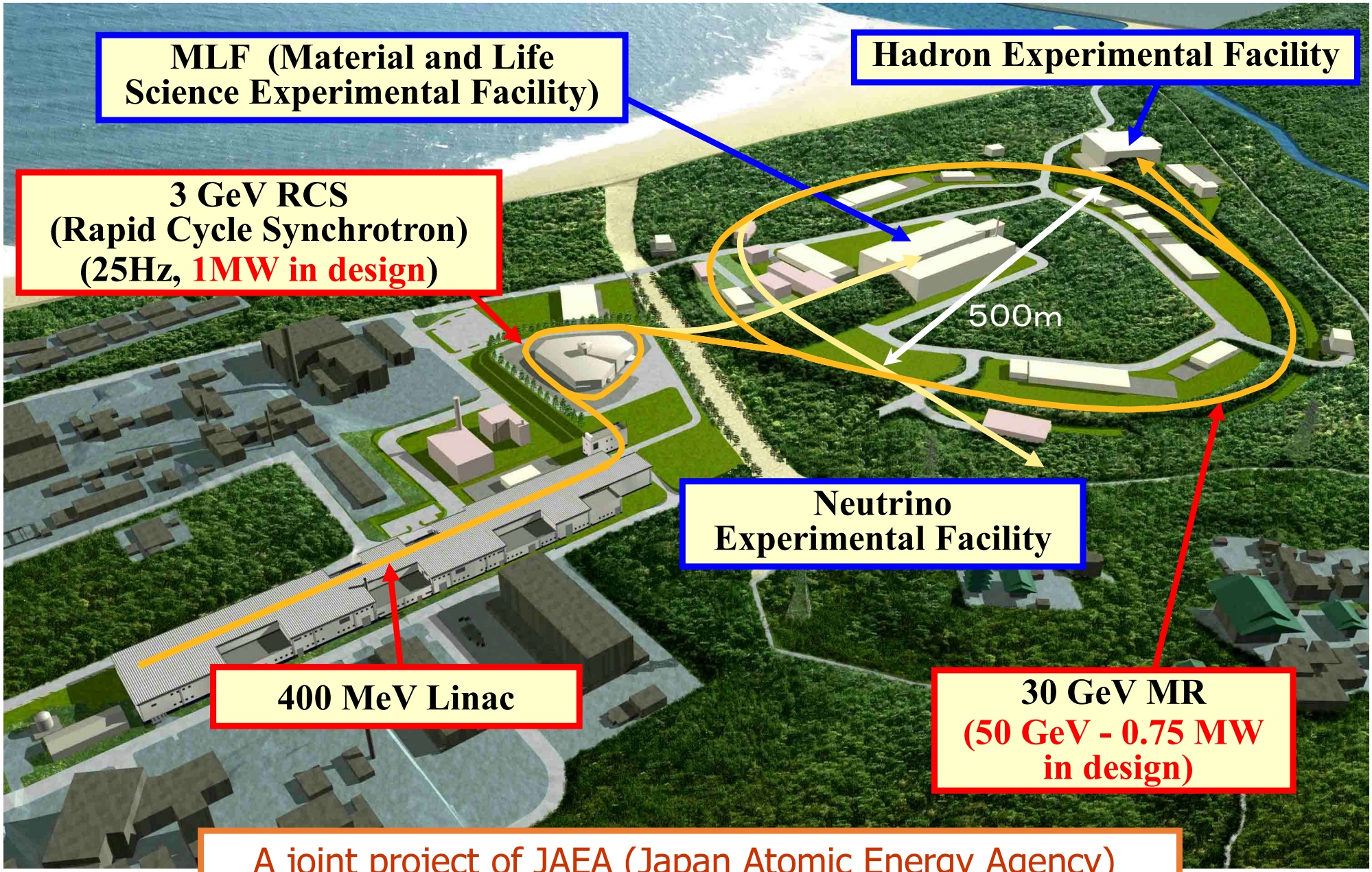
1) Power progress of J-PARC MR

2) Key technologies of the MR upgrade

3) MR kicker and septum

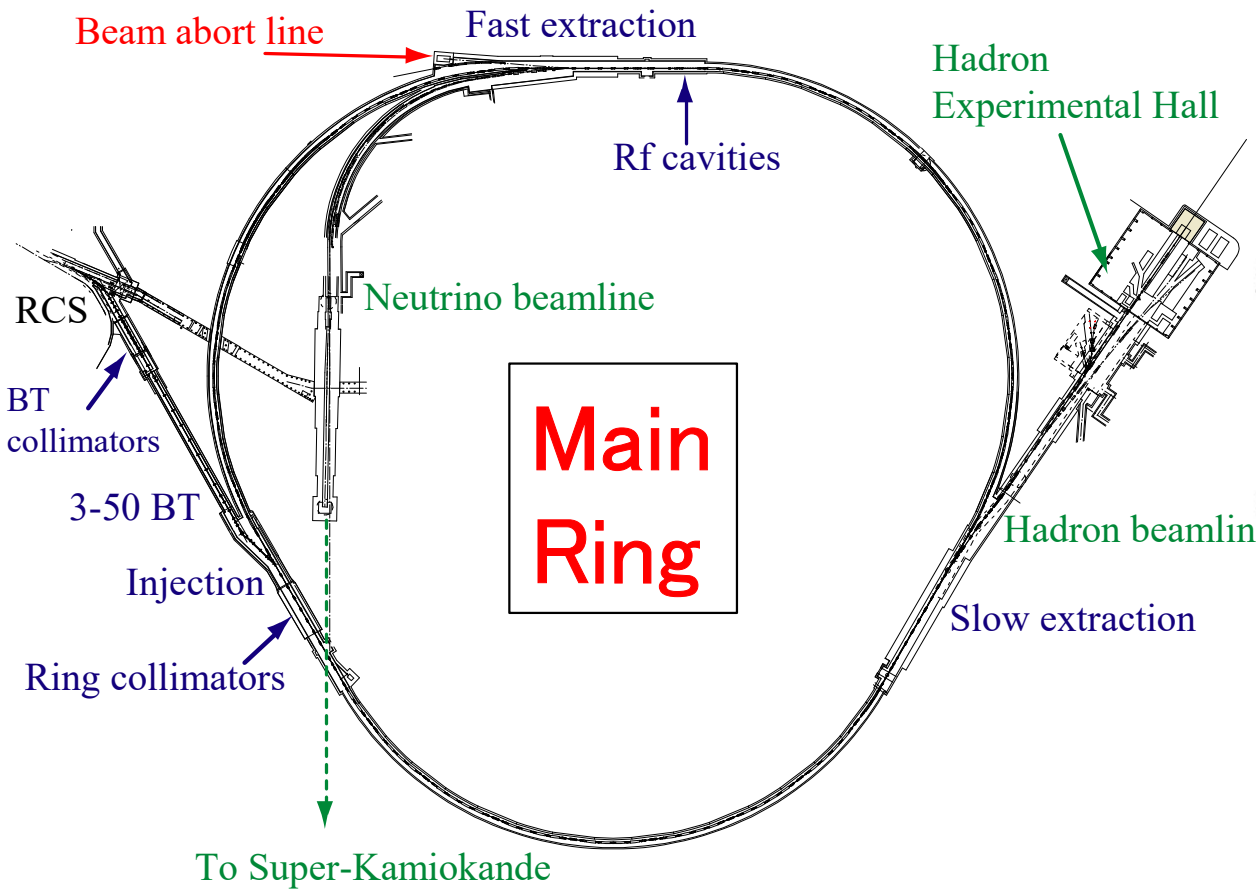
4) Future Plan

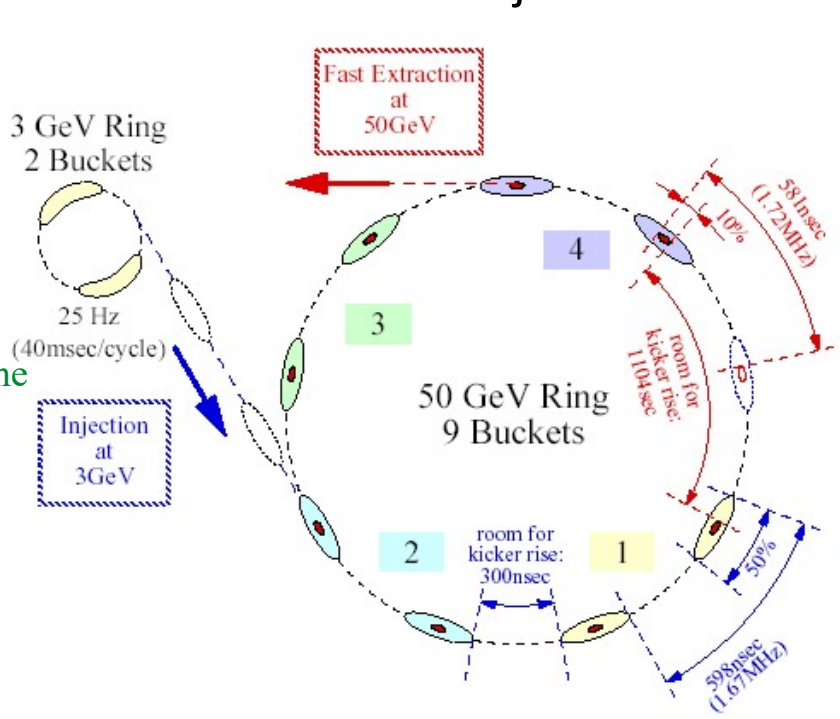
J-PARC Facilities

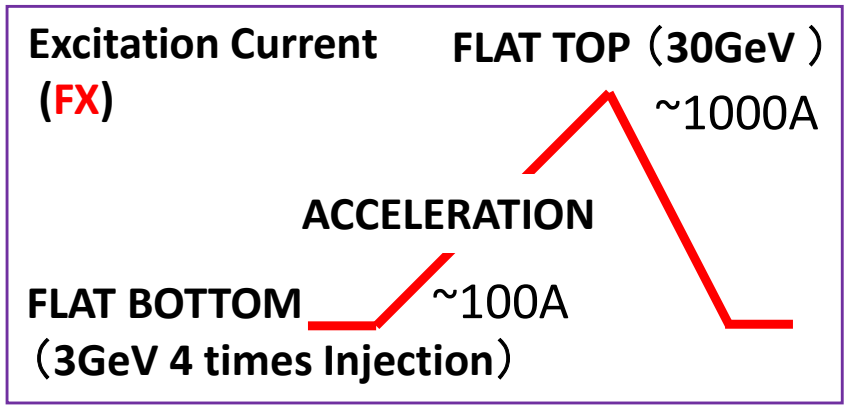


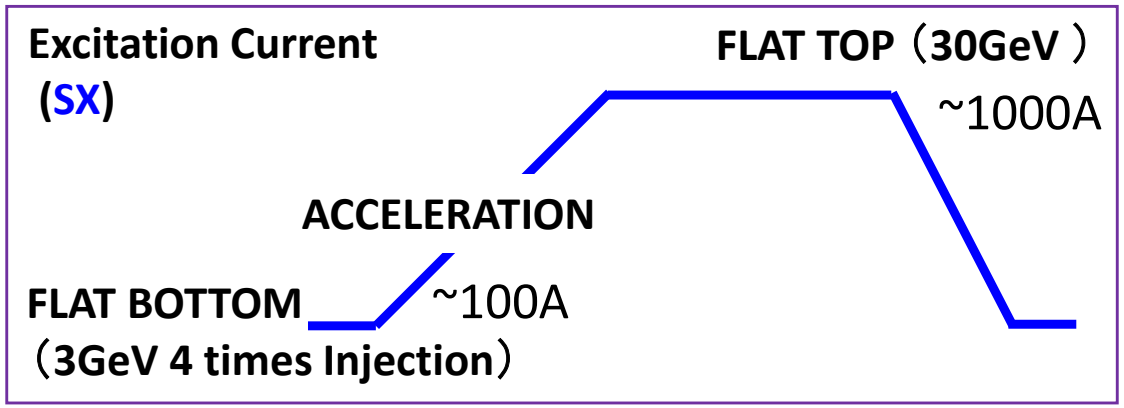
A joint project of JAEA (Japan Atomic Energy Agency) and KEK (High Energy Accelerator Research Organization)

MR Injection and eXtraction

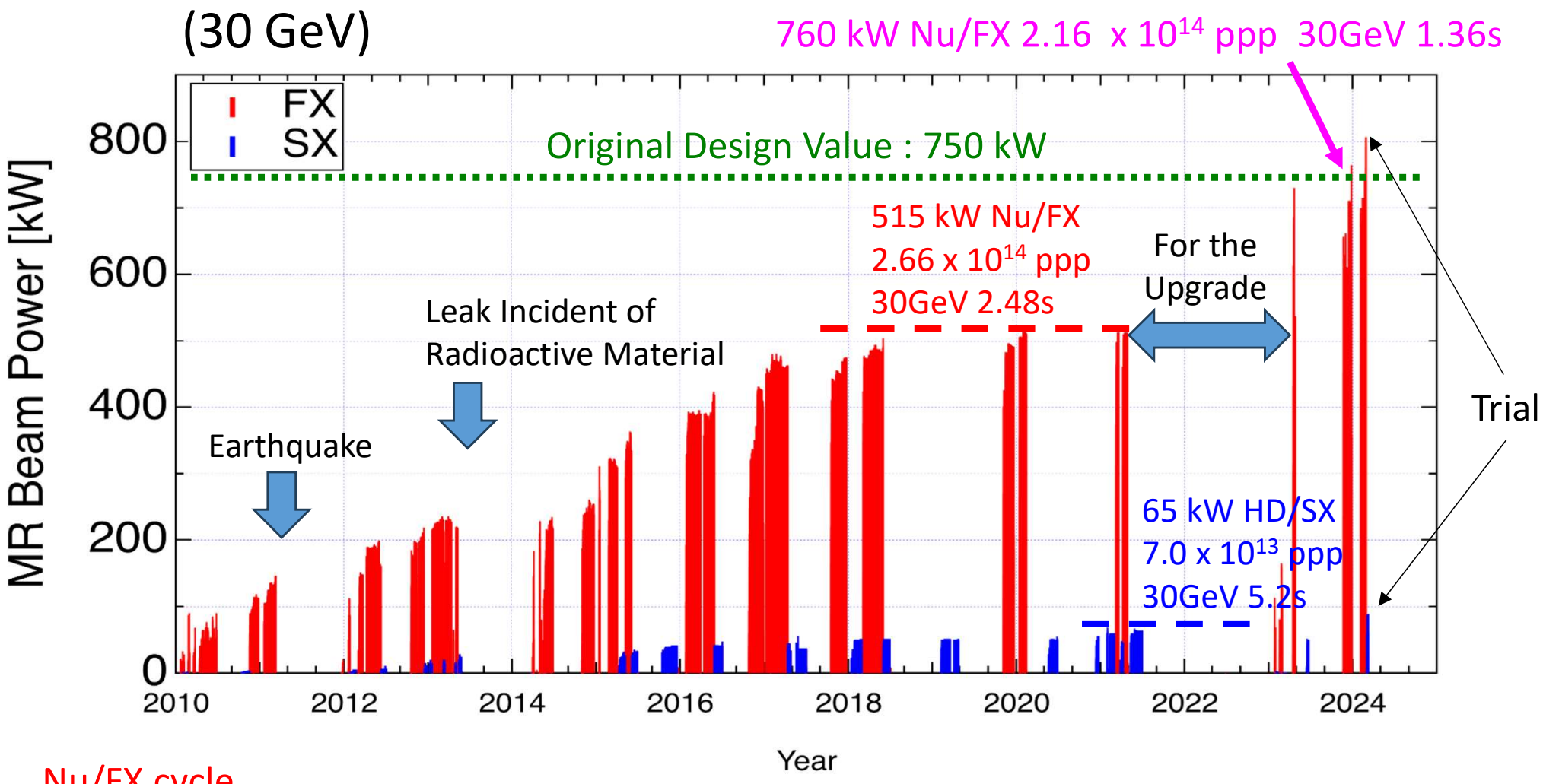








History of MR Beam Power



Nu/FX cycle

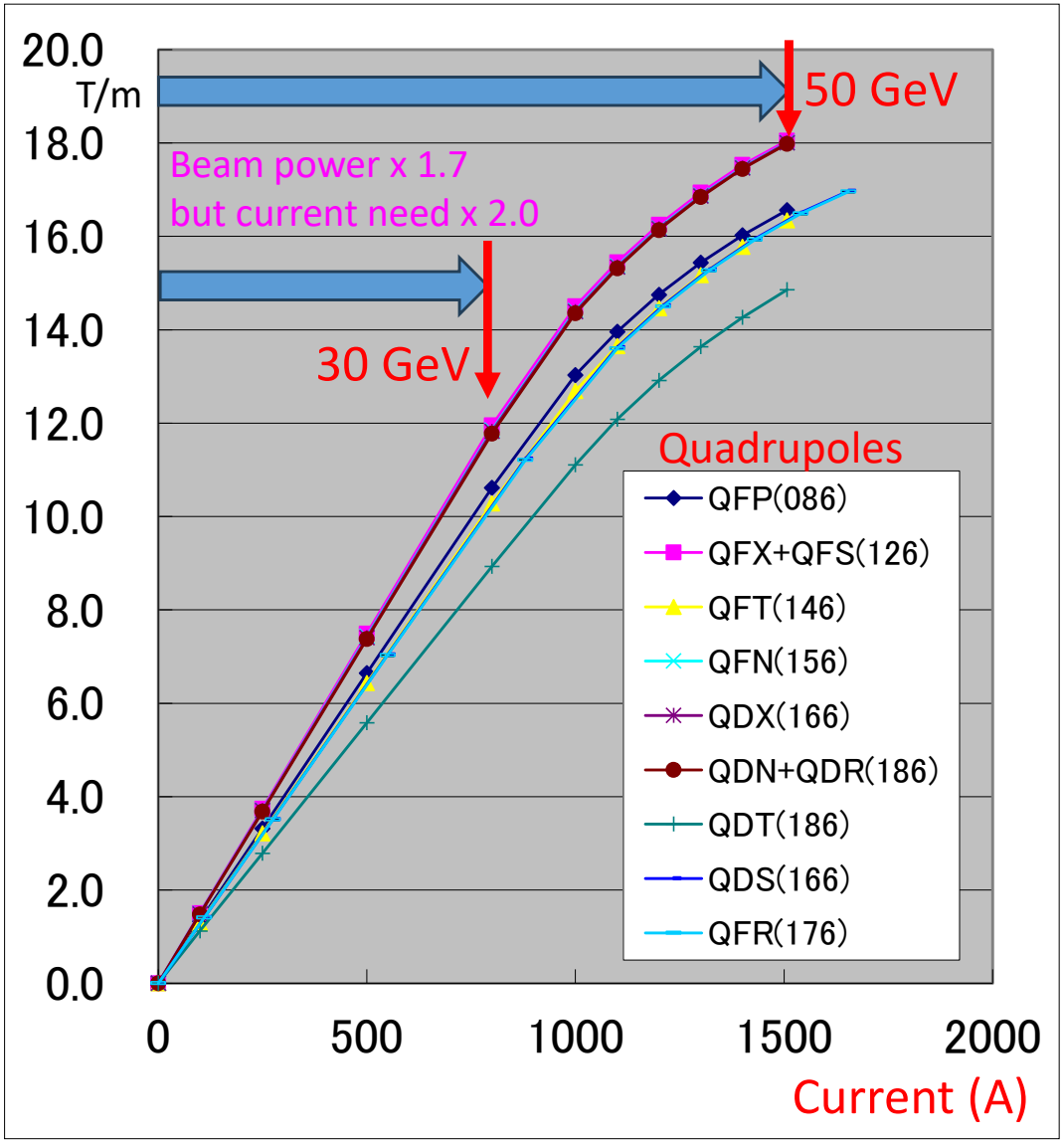
3.52s 3.04s 2.56s 2.48s → 1.36s →

HD/SX cycle

6.00s → 5.52s → 5.20s → 4.24s

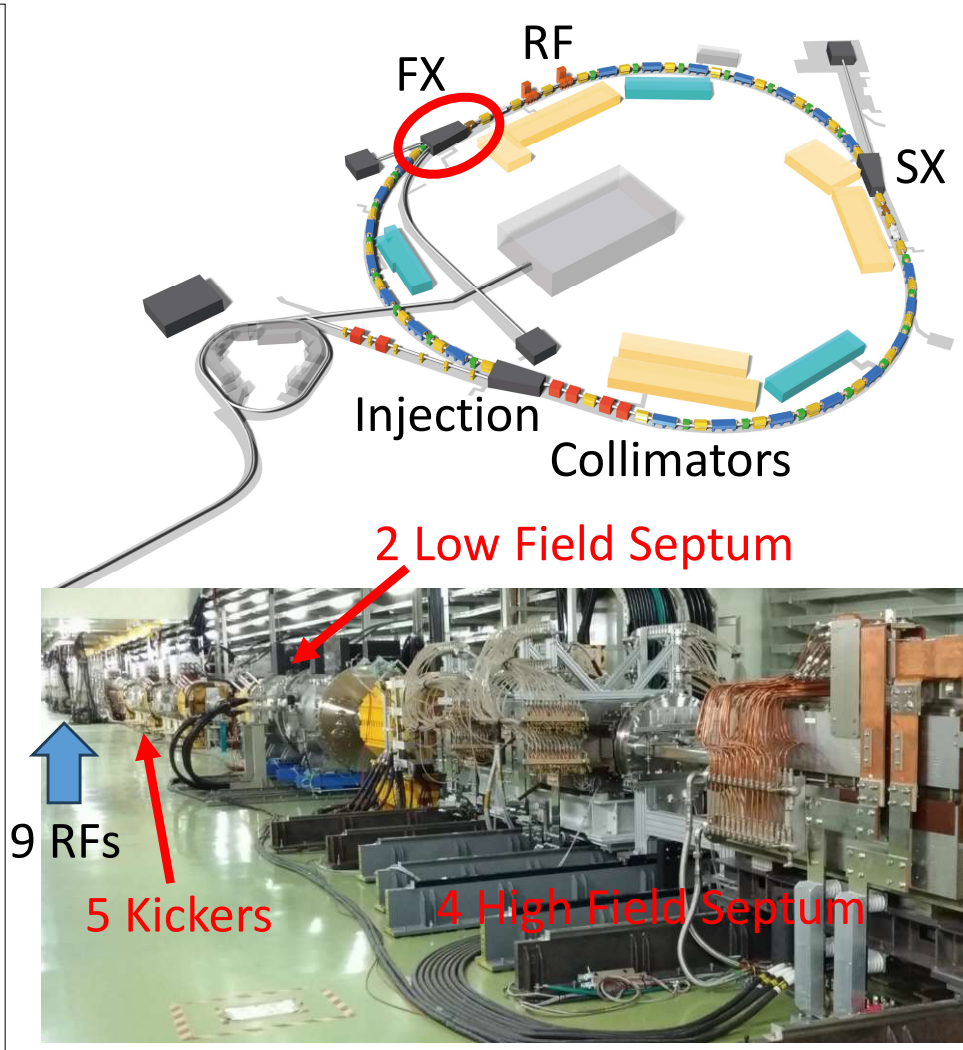
2 major problems of 50 GeV extraction

Magnet Saturation



Need more than 2 times higher current

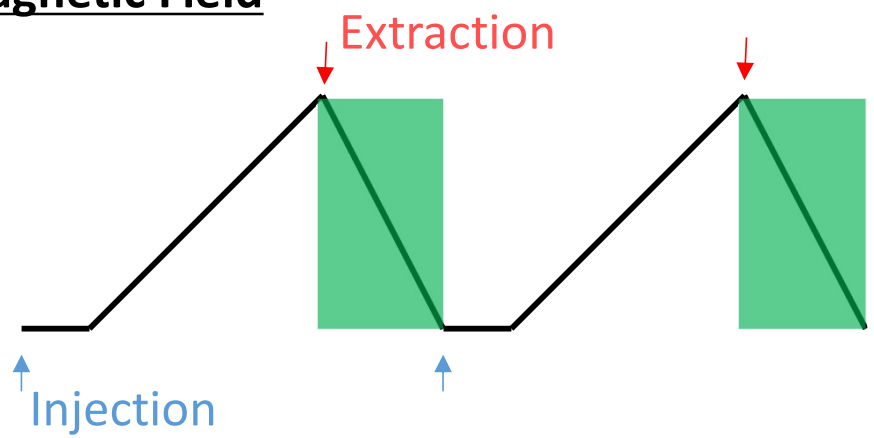
Not enough space of the extraction



Find the space
OR
Develop the powerful equipment

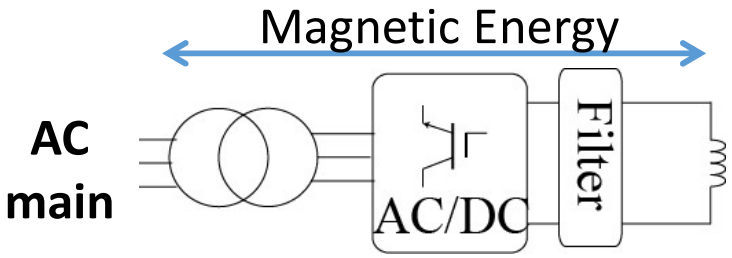
Power Variation Problem

Magnetic Field



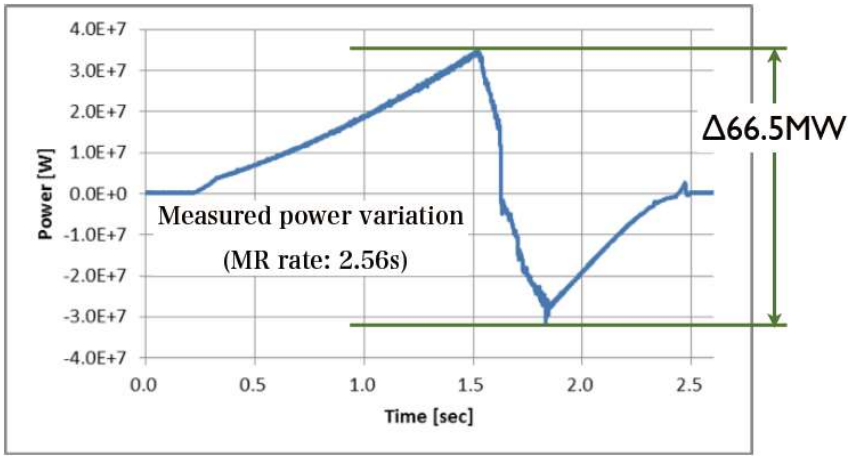
magnetic energy must be reduced for the next injection

Previous PS

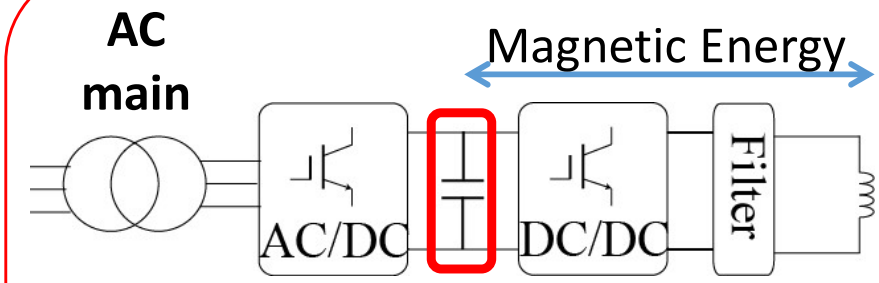


All magnetic energy are returned to the AC main grid

Previous Input Power Variation



Required to be maintained at the present level even after the upgrade by the electricity company



All magnetic energy is recovered to capacitor bank

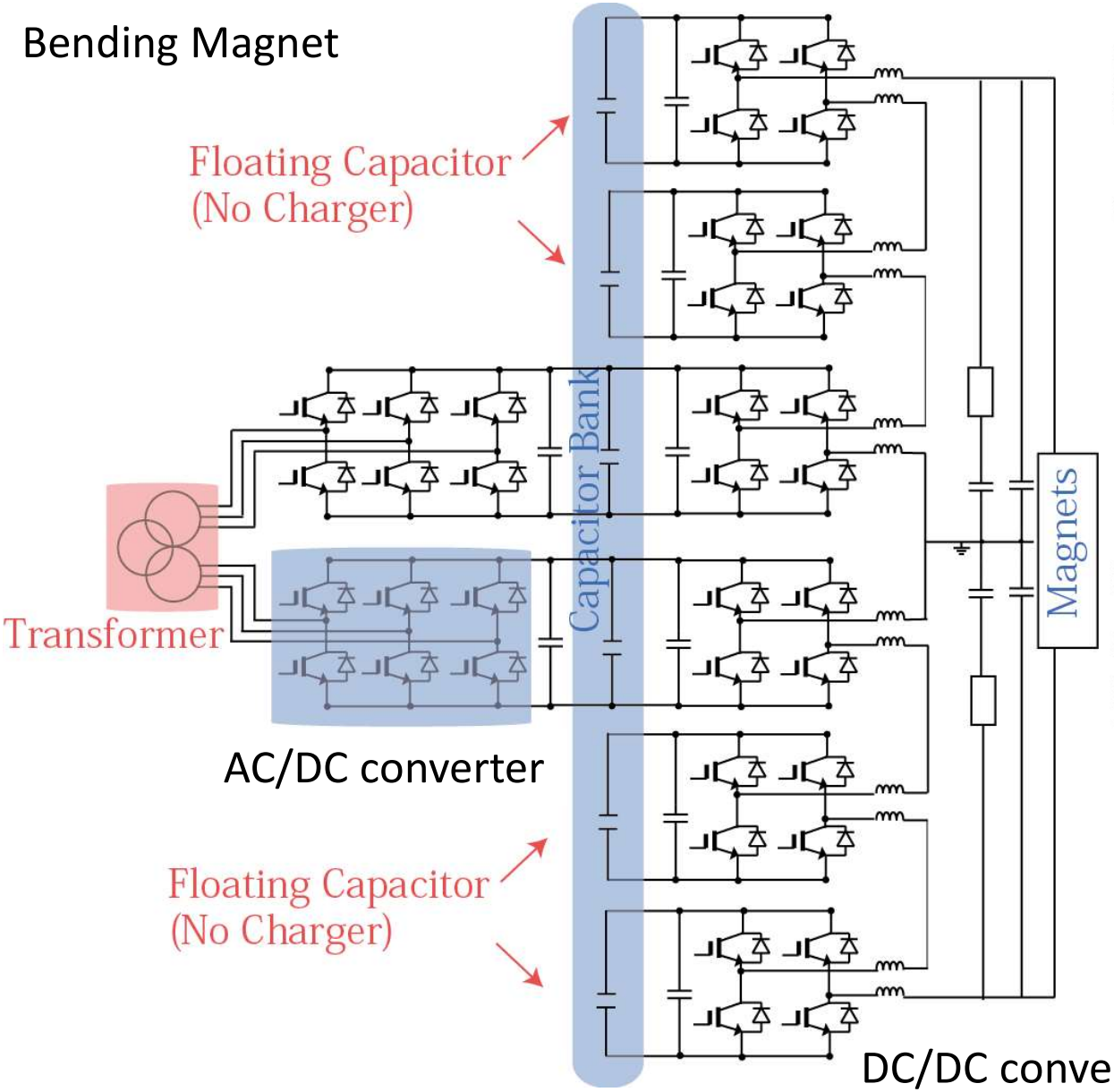
Main P.S. Group

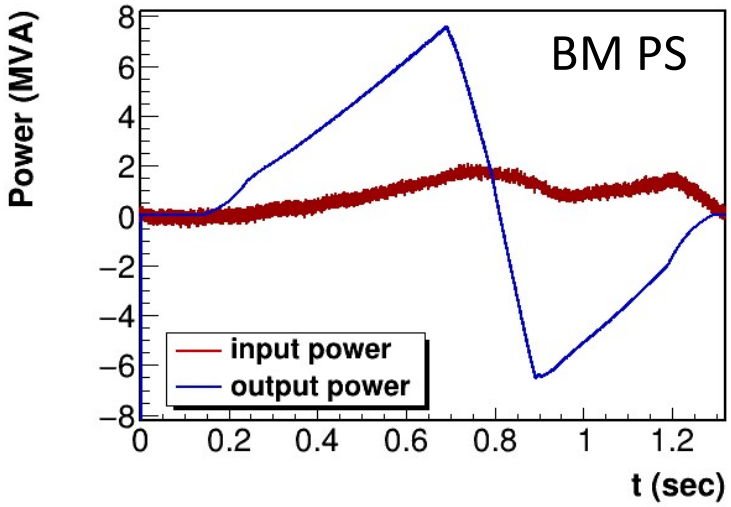
Capacitor Bank Solution

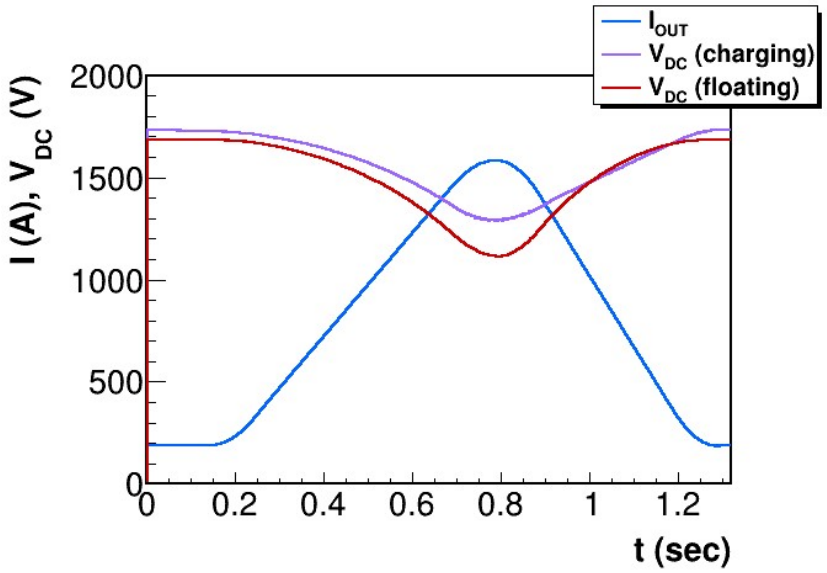
Repetition Cycle: 2.5 s ⇒ 1.2 s

$$V = L_{mag}\frac{dI_{mag}}{dt} + R_{mag}I_{mag}$$

Bending Magnet



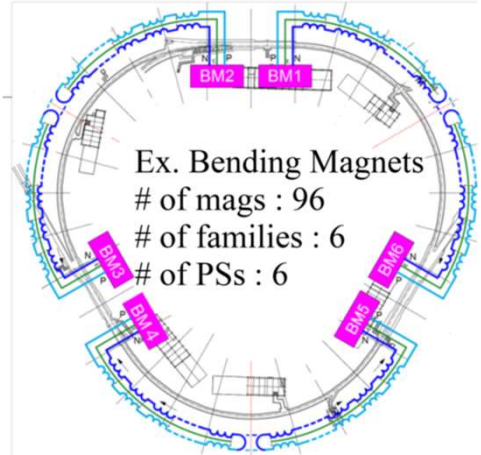




Main P.S. Group

NEW Power Supplies for 30 GeV

family	#. of family	#. of magnets / family	Magnet type	Inductance (H)	Current @ 30 GeV (A)	PS types
BM1-6	6	16 each	B	1.47	1575	NEW PSs with capacitor banks
QFN, QDN	1 each	48 each	Q	2.93, 3.46	750	
QFX	2	24 each	Q	1.2	750	Reuse of Old PSs (Family divided)
QDX	2	14, 13	Q	0.91, 0.84	750	
QFS, QFT,QDS	2	3 each	Q	0.15, 0.16,	900	
QFP	1	6	Q	0.2	900	Reuse of Old PSs
QFR	1	9	Q	0.57	850	
QDR, QDT	1	6	Q	0.44, 0.37	900	NEW PSs w/o capacitor banks
SFA, SD	1	24, 48	S	0.41, 0.82	200	



Main P.S. Group

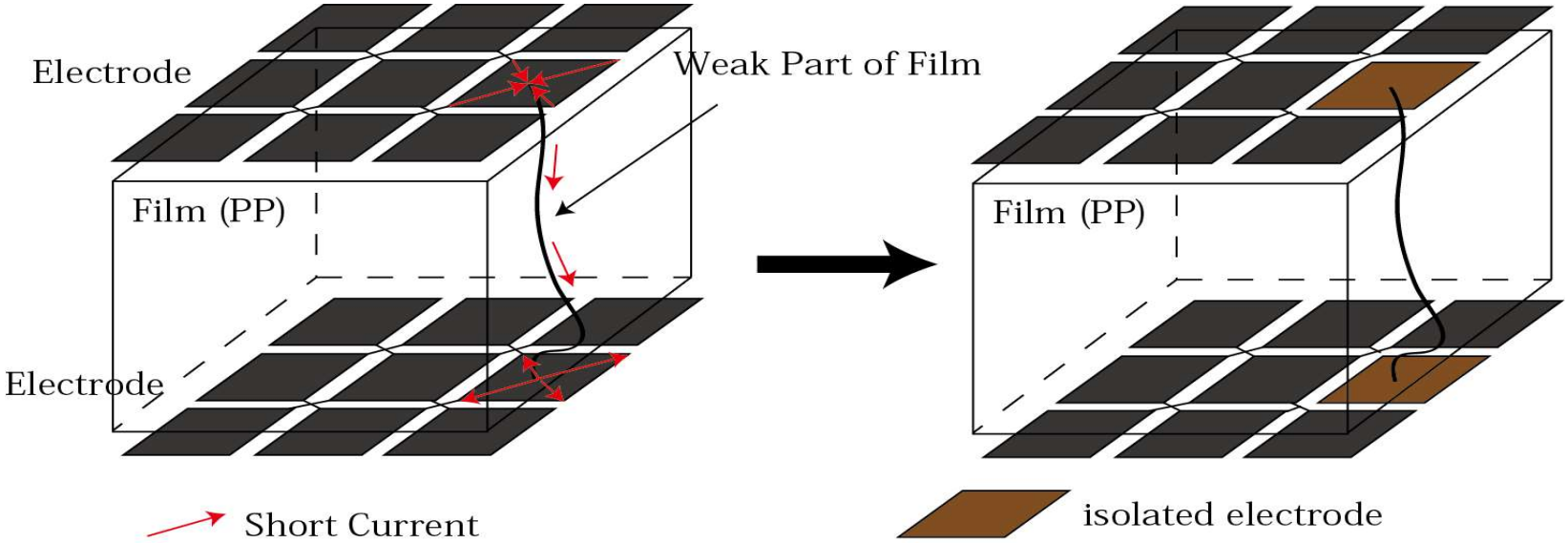
Capacitor (Technology choice)

Requirement for the capacitive energy storage

- **Long Lifetime > 10 years**
  ~10^8 charge-discharge cycles
- **No internal Short (for safety)**

Dry-type film Capacitor

Self-Healing Structure



- Many small pixel capacitors connect with each other
- A pixel capacitor with weak part is isolated by over current

Deterioration has not been observed yet.

Main P.S. Group

MR Upgrade for 1 Hz Operation

RF : Increase the RF Cavities
7 ⇒ 9 (⇒ 11 in future)

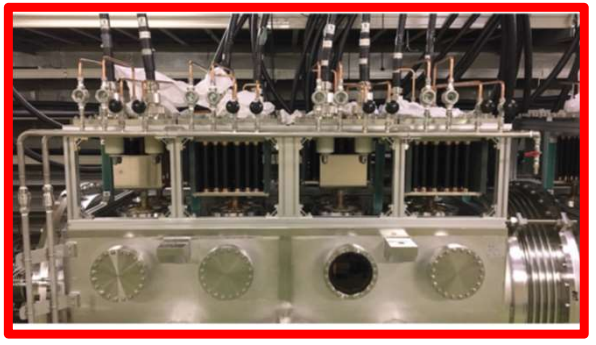
FX Septum :
(Low Field)
New System

NEW Buildings for
Power Supplies

Collimators : 4 ⇒ 7
2.0 kW ⇒ 3.5 kW

Injection Kicker :
Termination Register Upgrade

Another NEW Space for RF
(2 RF Cavities Increase)



RF Upgrade Plan

2023

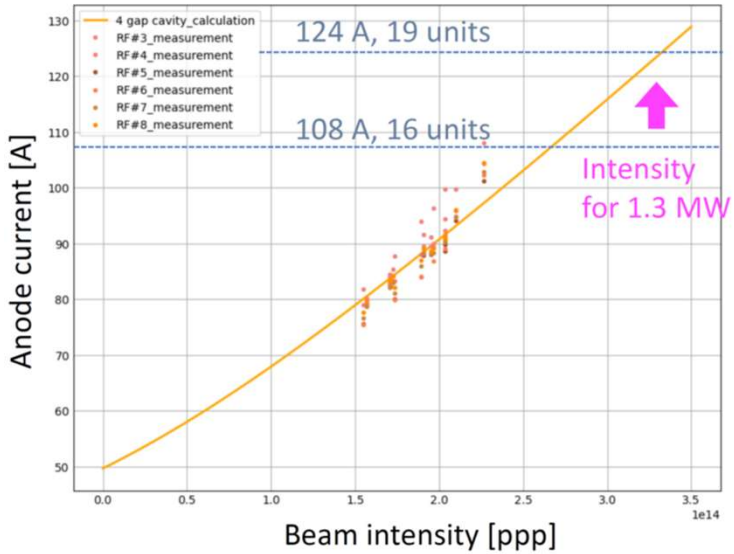
Maximum numbers from RCS

	500 kW	750 kW	1.3 MW
MR Cycle	2.48 sec	1.36 sec	1.16 sec
Intensity	2.6E14 ppp	2.1E14 ppp	3.3E14 ppp
# of Cavities	7 Fund. + 2 2nd	9 Fund. + 2 2nd	11 Fund. + 2 2nd
RF Voltage	320 kV	450 kV	550 kV
Anode Current	95 A	90 A	124 A
2nd RF Voltage	110 kV	110 kV	110 kV
2nd RF Anode_I	65 A	85 A	110 A

Added Anode Power Supplies

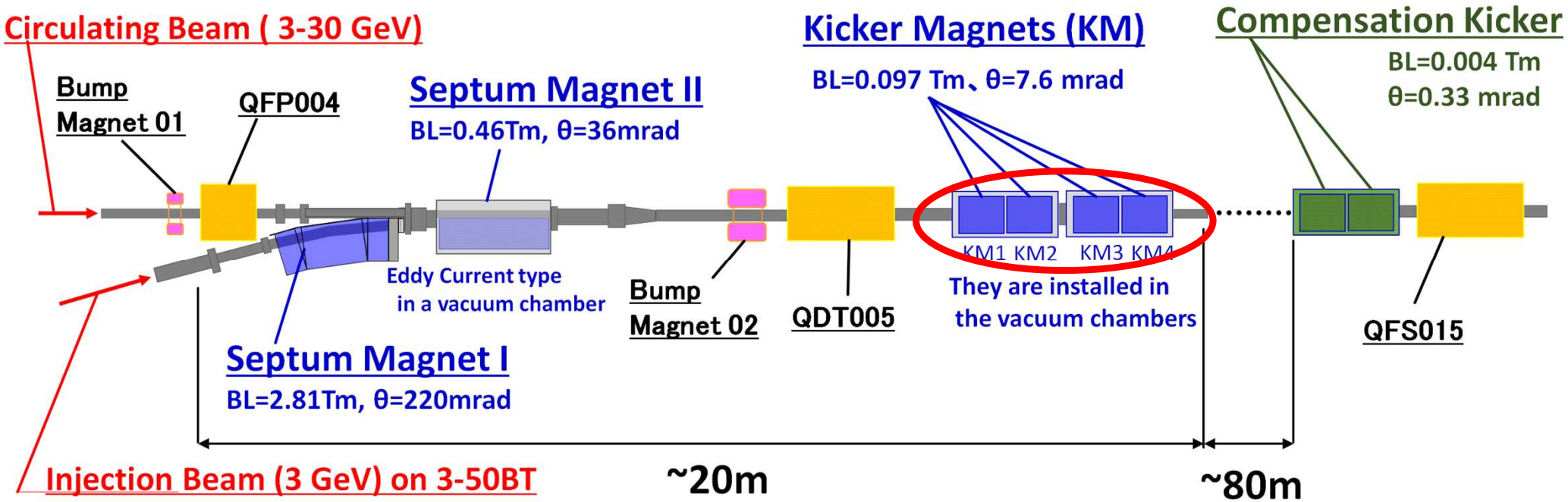
2nd Harmonics RF : Need for Dilution of Longitudinal Phase Space

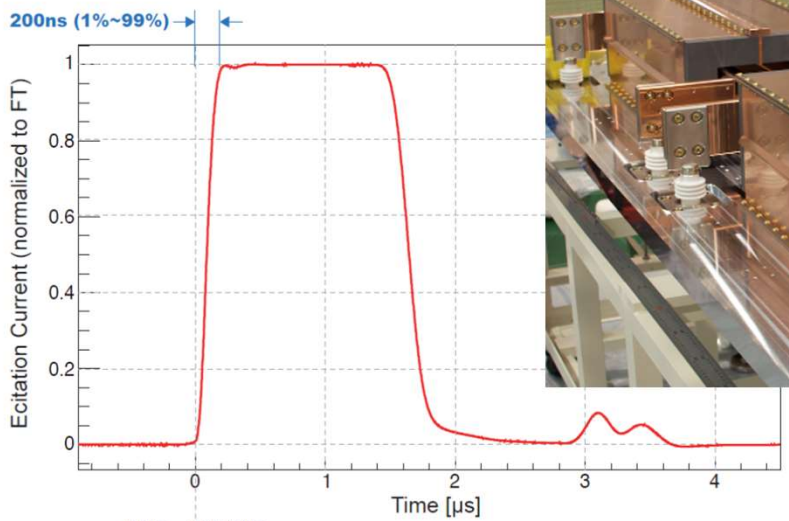
Anode Current : Need for Compensation of Beam Loading

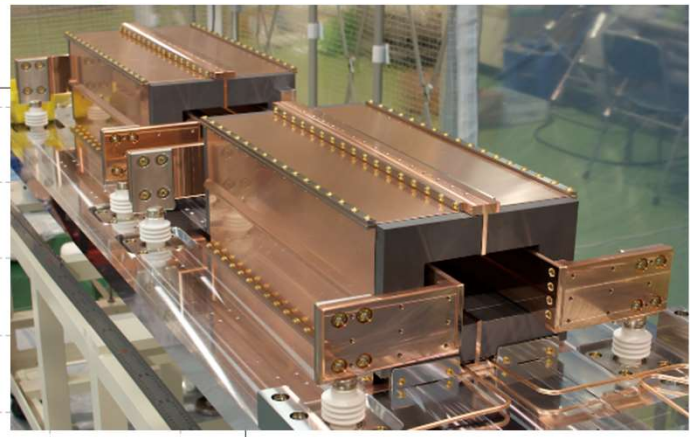


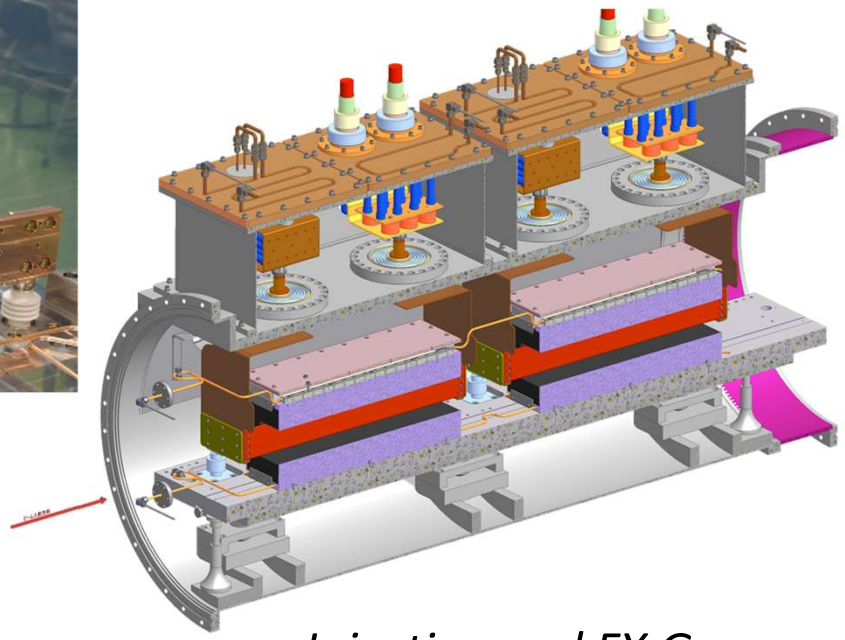
RF Group

Injection Kicker



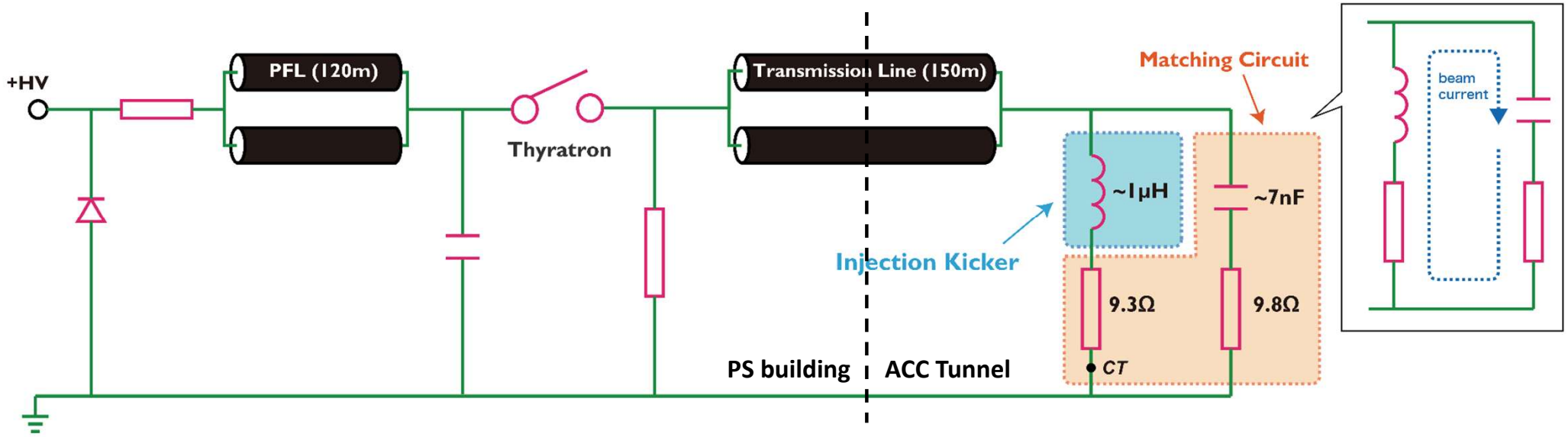




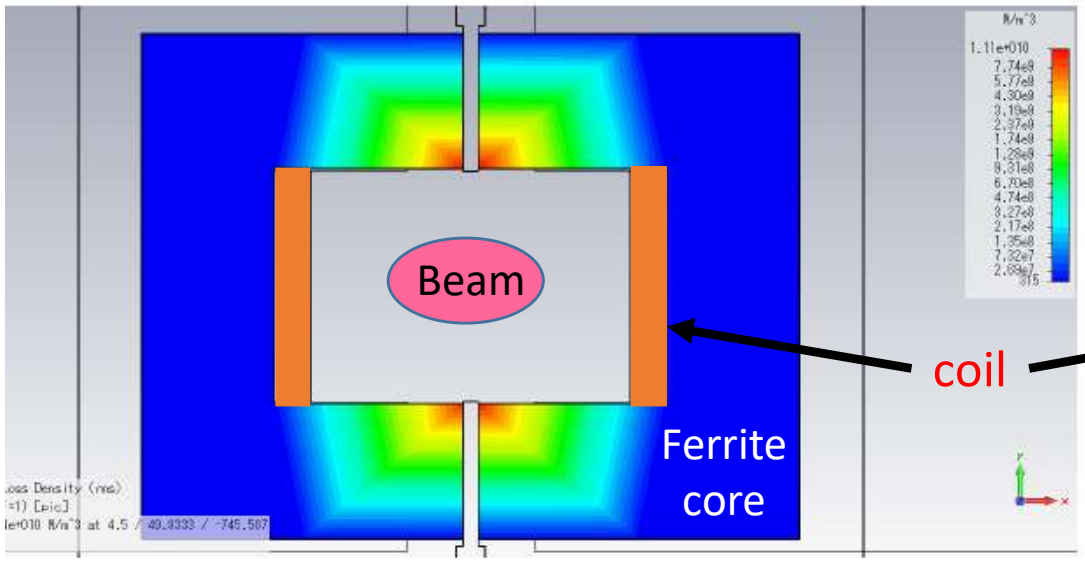


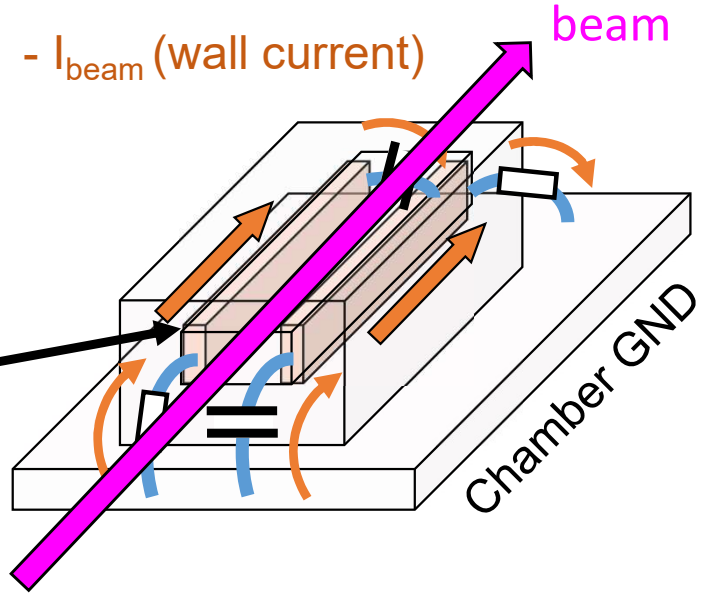
Injection and FX Group

Injection Kicker



There is no problem with 1 Hz operation itself without beam, but ・・・





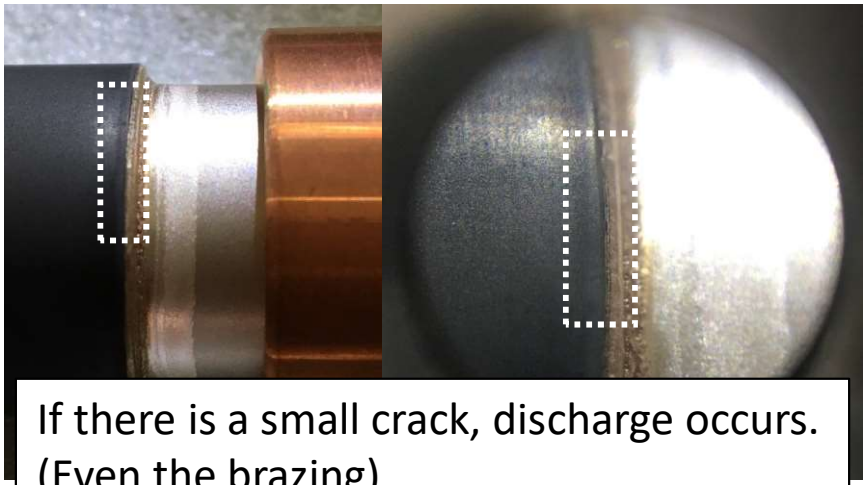
Power loss distribution caused by the coupled beam at Kicker magnet core.

Injection and FX Group

Registers Development

Discharge problem with termination resistor in 2011 (Poor contact with electrode)

Resistor development with the brazing specialist of company



If there is a small crack, discharge occurs.
(Even the brazing)

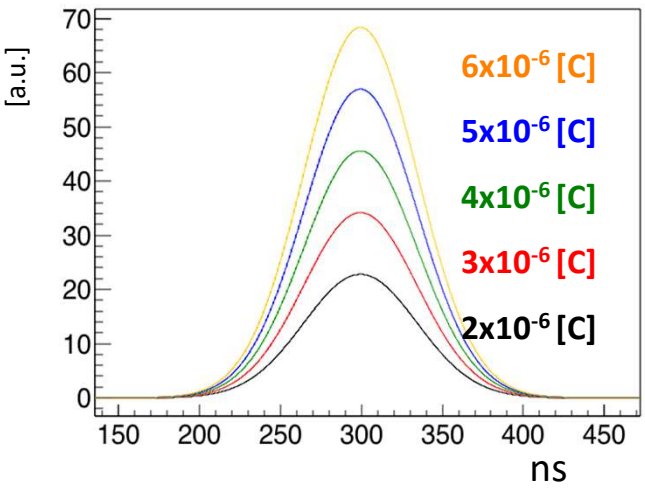
- Our developed brazing resistors have become very expensive.
- We also tried a consumer product (USA) brazed resistor, but it discharged.

Injection and FX Group

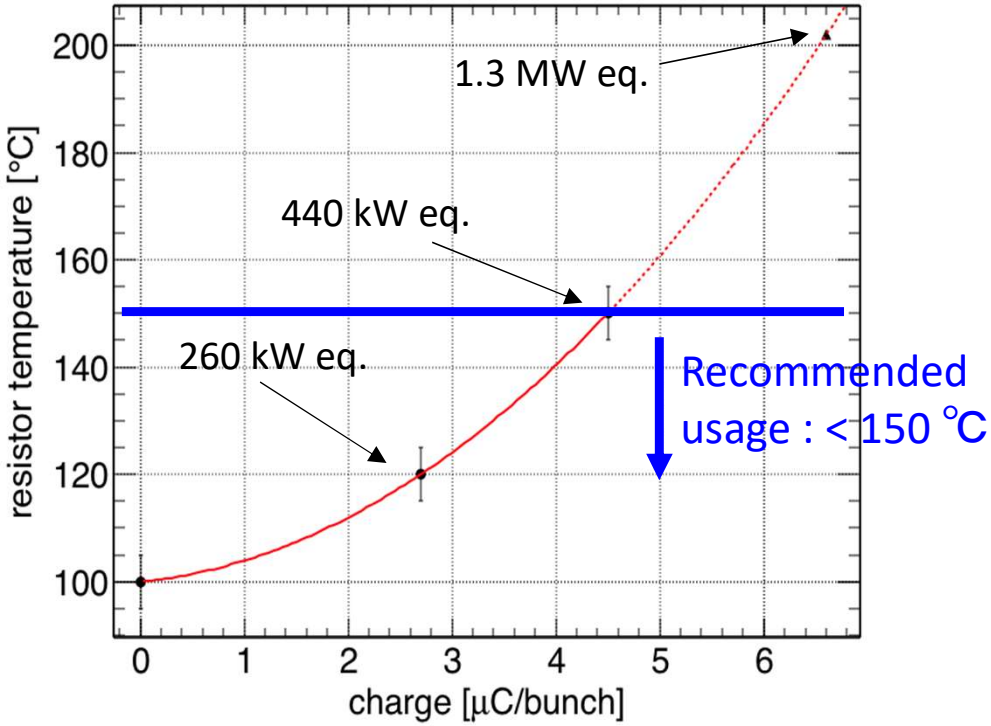
Heat Estimation of Termination Registers

Output Power	Repetition Cycle	Resistor ΔT Kicker Pulse	Charge I Beam	Resistor ΔT I beam	Resistor T (+ 30 ℃)
480 kW	2.48 s	70 ℃	4.9 μC	60 ℃	160 ℃
750 kW	1.32 s	130 ℃	4.0 μC	40 ℃	200 ℃
1.3 MW	1.16 s	220 ℃	6.7 μC	100 ℃	350 ℃

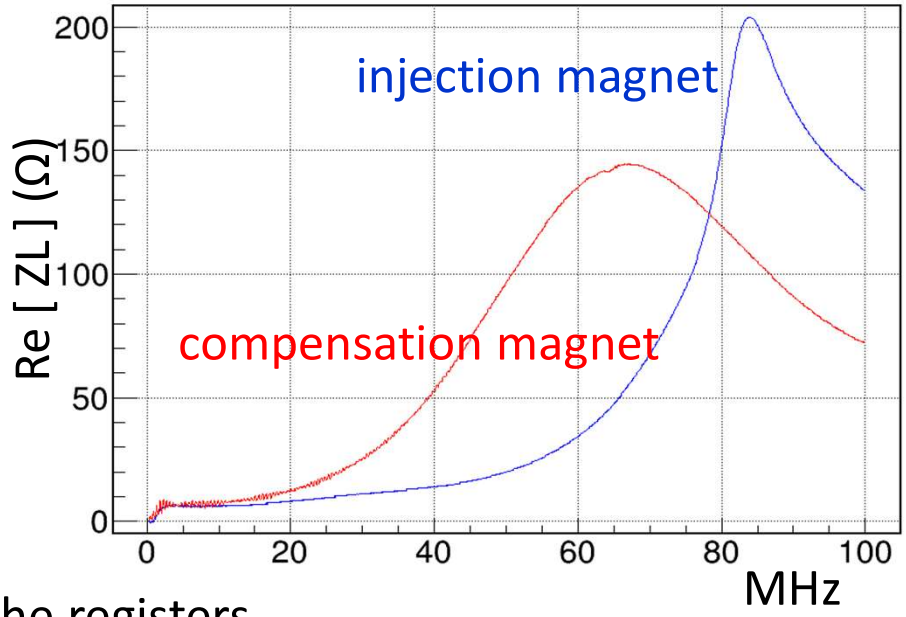
Beam shape estimation



Previous Matching Registers



Measured beam coupled impedance



We must update the matching box. (Size up the registers, Increase the numbers, Improve cooling efficiency ・・・)

Injection and FX Group

New Matching Box and Registers

Register size up :

ϕ20 - L170 ⇒ ϕ30 - L200

Register numbers increase :

15 ⇒ 30

Cooling efficient improvement :

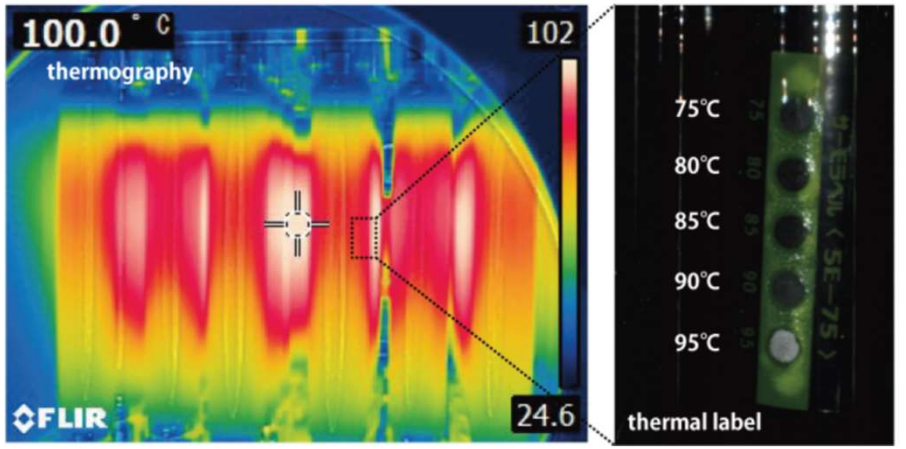
+ powerful cooling fan

+ ceramics beads

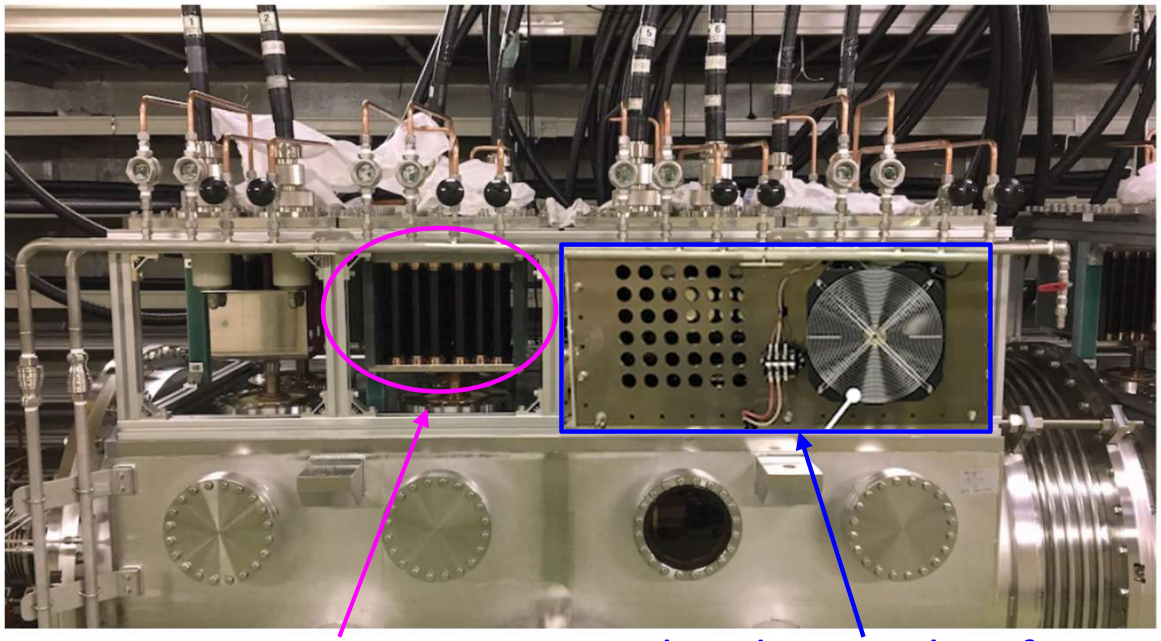
1.16 sec cycle - 3.3E14ppp (1.3 MW)

⇒ Register Temp. ～100 ℃

Fill with the ceramics beads



Measurement without beam and cooling fan
(good agreement with the simulation)

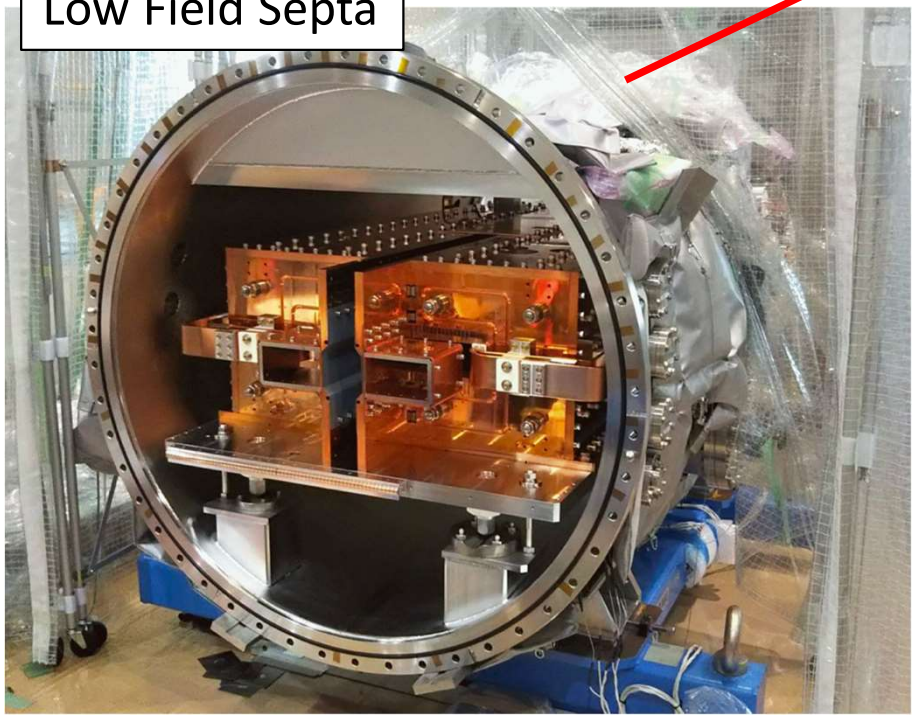


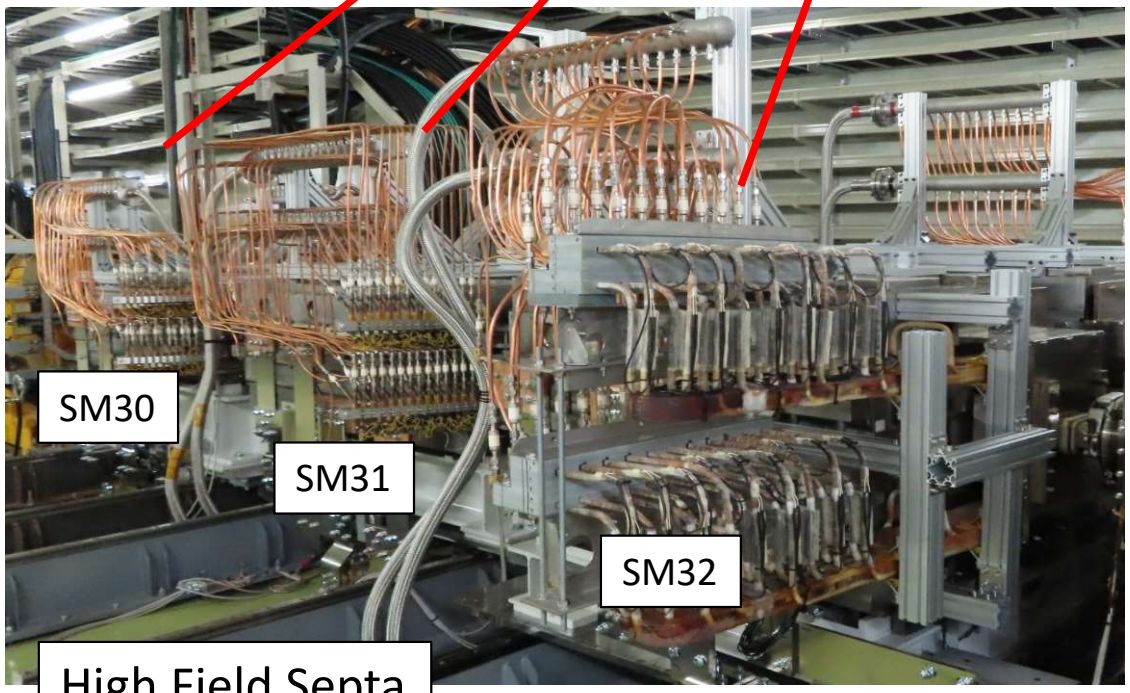
Fast eXtraction

FX Kicker (reuse)

New septum magnets for 1Hz operation
(Installed in 2021-22)

Low Field Septa





High Field Septa

Injection and FX Group

FX Low Field Septum

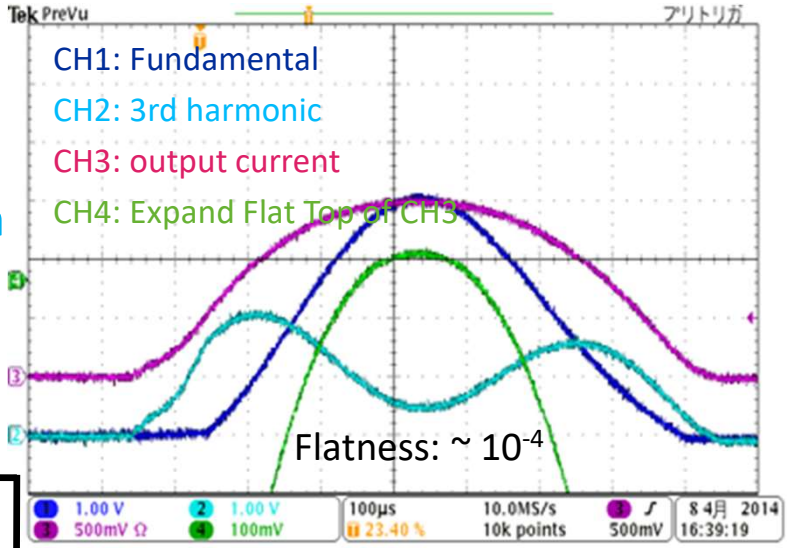
Previous Magnets
(Conventional)

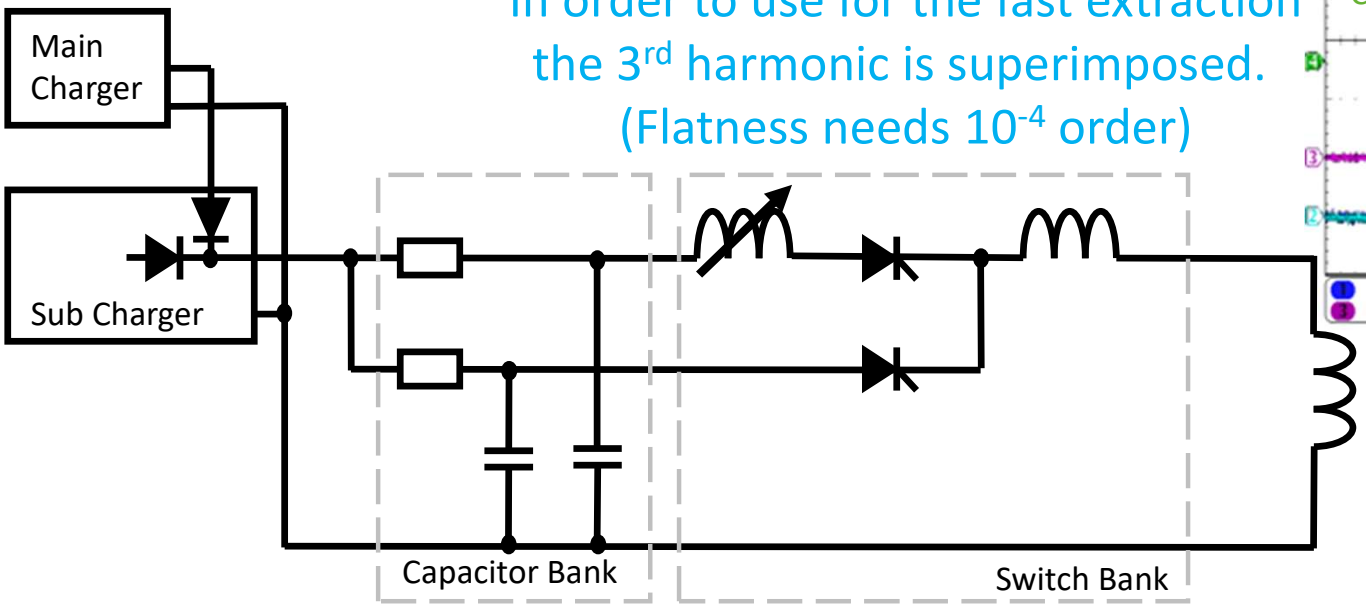
New Magnets
(EDDY Current・Pulse)

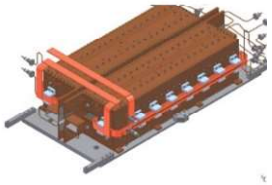
EDDY Current Type
- Low Vibration
- Small heat generation
- Higher Magnetic Field
- Low Leakage Field

Maximum Magnetic Field: 0.3 T ⇒ 0.5 T
Measured Leakage Field: ~ 0.5 mT ⇒ ~ 0.05 mT

In order to use for the fast extraction
the 3rd harmonic is superimposed.
(Flatness needs 10^{-4} order)

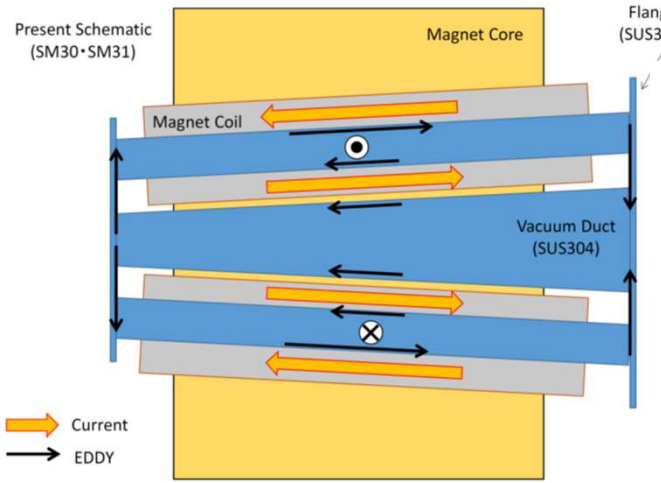




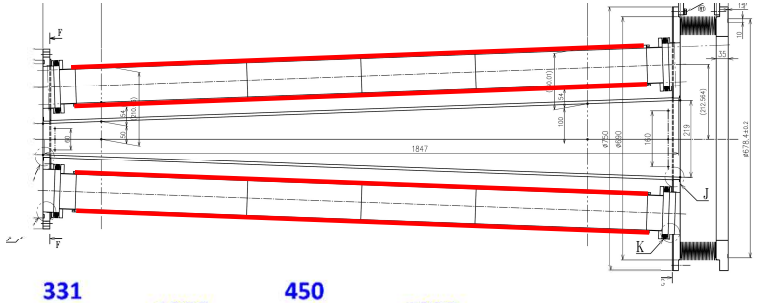


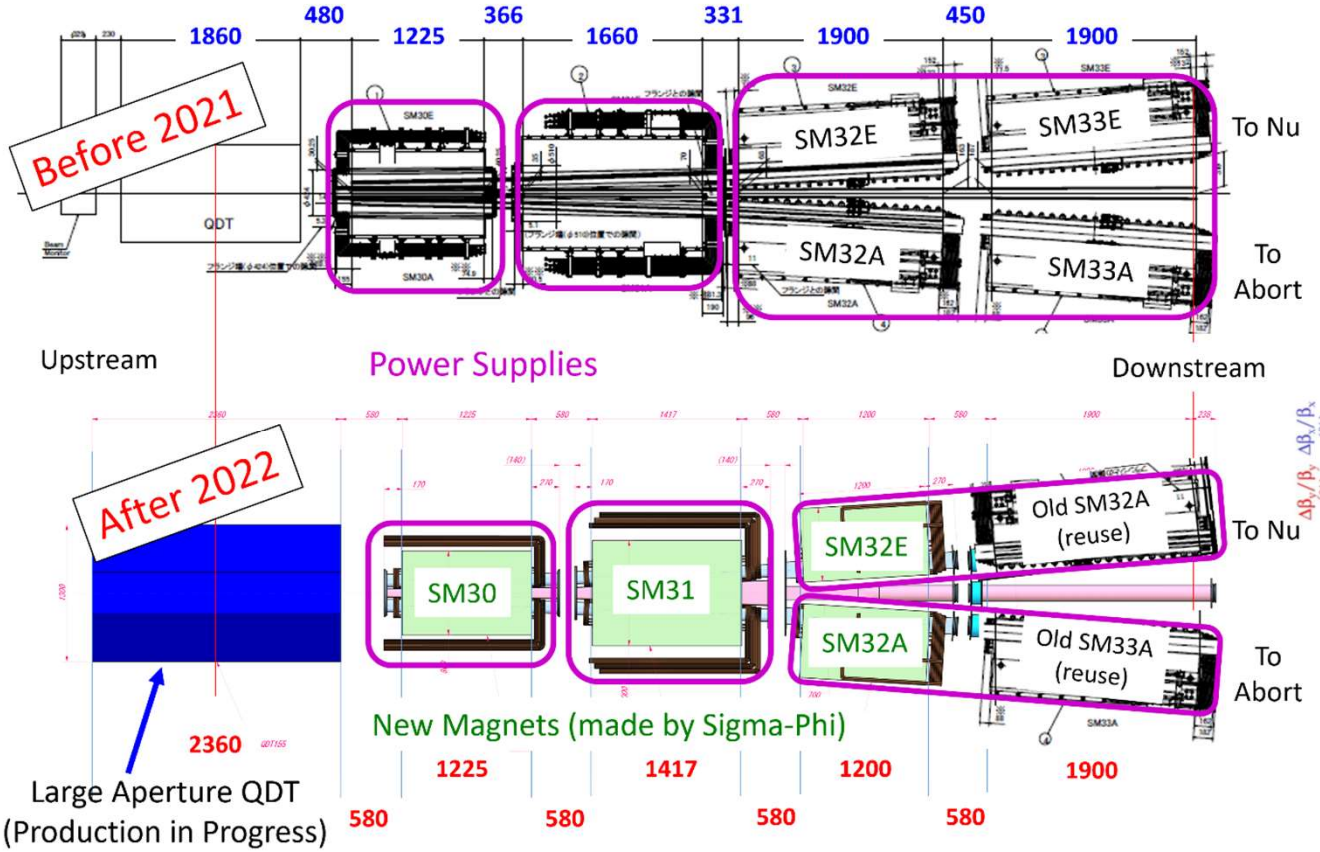
Injection and FX Group

FX High Field Septum



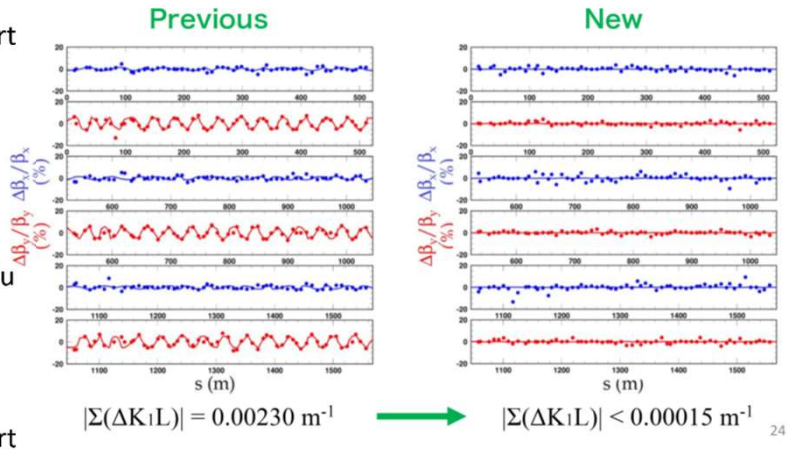
Since loop eddy currents are generated, this heat is eliminated at 1 Hz operation by using ceramic ducts.





Reduction of the Leakage Field

Small Optics Modulation



Injection and FX Group

Large Aperture QDT

FX Kicker

Kicker Magnets (KM)
BL=0.126Tm, θ=6.1mrad
They are installed to the vacuum chambers

Low Field Septum Magnets (SM)

	SM1	SM2
BL (Tm)	0.44	0.44
θ(mrad)	4.35	4.35

They are installed to the vacuum chambers

QDT155

To Neutrino Line

KM1 KM2 KM3 KM4 KM5 SM1 SM2 SM30 SM31 SM32 SM33

QFR154

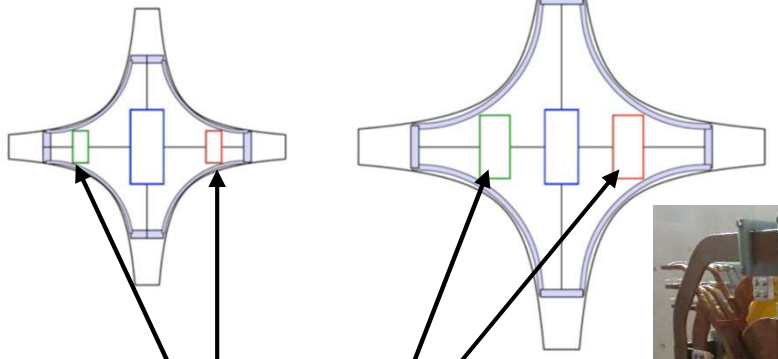
High Field Septum Magnets

To Abort Line

	SM30	SM31	SM32	SM33
BL (Tm)	1.17	1.75	1.81	1.81
θ (mrad)	11.4	17	17.6	17.6

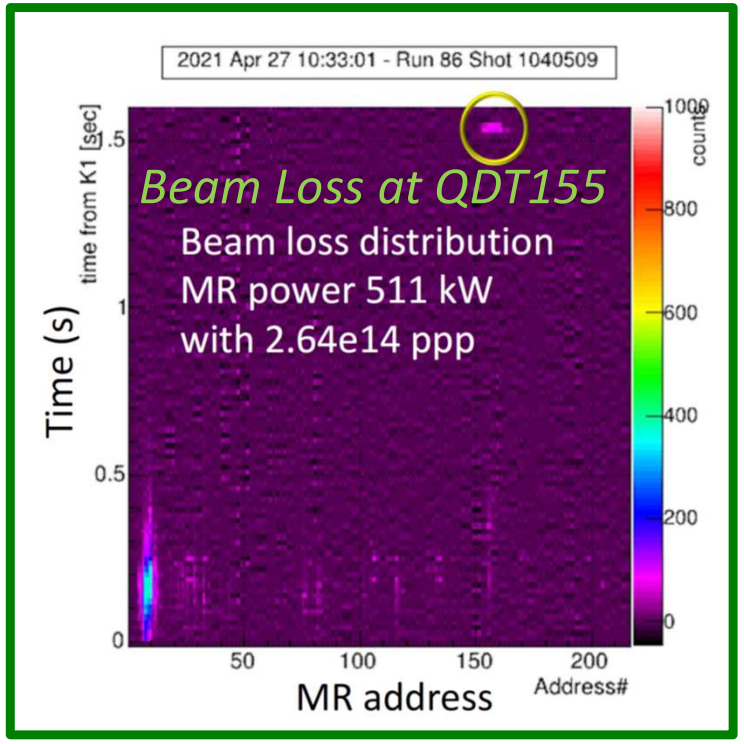
There are 5 kicker systems, but only 4 downstream magnets are effective for the beam separation.
⇒ In this summer we plan to remove the most upstream magnet to make a space for the RF cavity.

- Present QDT Magnet
  - 150 mm ϕ
- Large Aperture QDT
  - 220 mm ϕ



Extraction aperture make LARGE
Beam Size : 15π ⇒ 60π

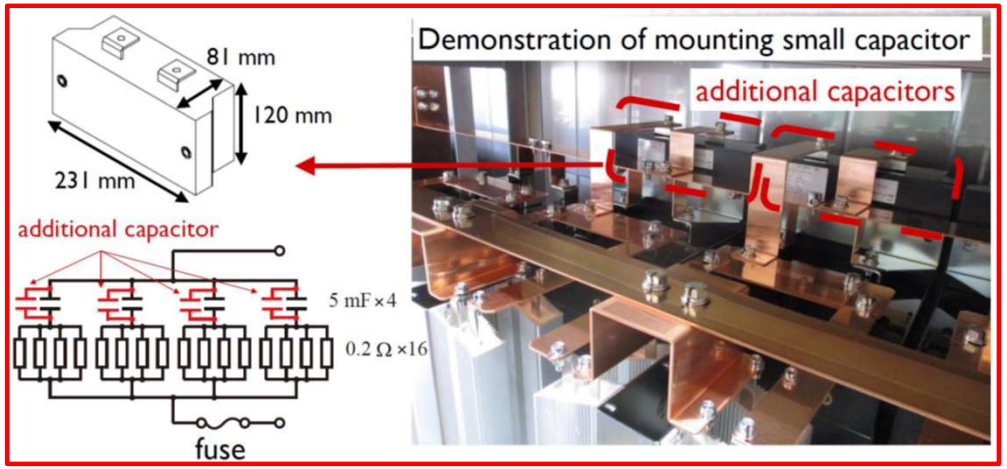
First Magnet of LA-QDT

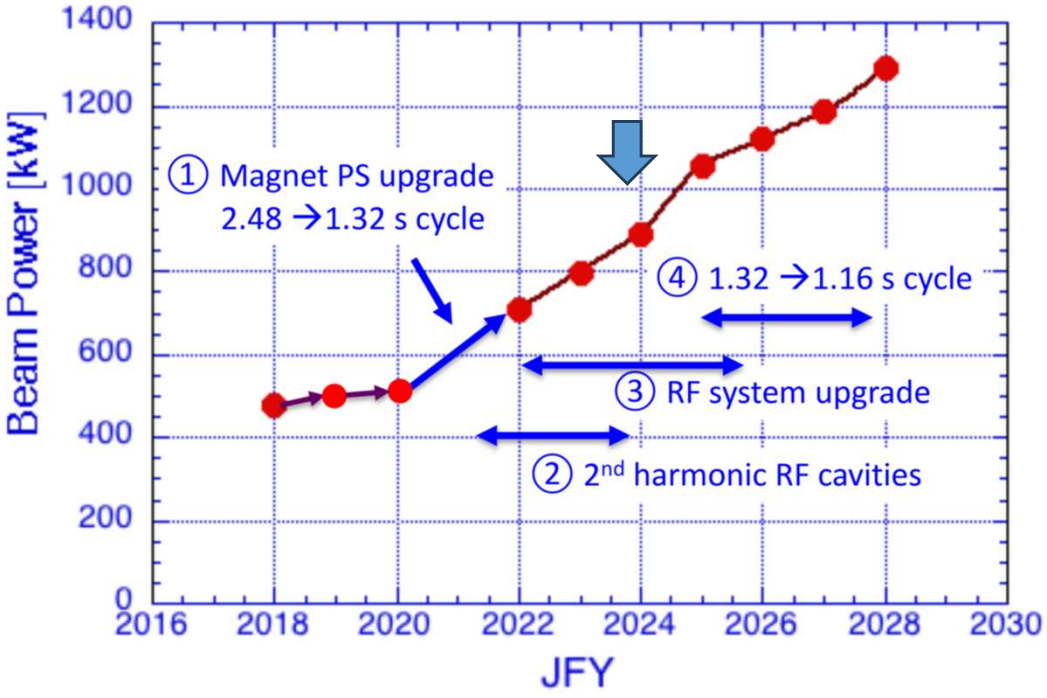


Injection and FX Group

Future Plan and Summary

① Power Supplies Upgrade : Done
② 2nd harmonic RF cavities : Done
③ RF system upgrade : Under progress
④ 1.16 s : Under preparation
(Need to increase capacitors)





Advances in fundamental technologies like resistors and capacitors are enabling output power boosts.

We will continue to develop technology and achieve to improve J-PARC output.

Correction Magnet System Upgrade
(Increase the Power Supplies 4 to 24)

H. Hotchi *et al.*, in Proc. IPAC'23, TUPM055.