

**View-points of Beam Commissioning
of J-PARC Main Ring
for Safe and Reliable Operation**

**Yoichi Sato, Shuei Yamada, Takaaki Yasui
KEK/J-PARC**

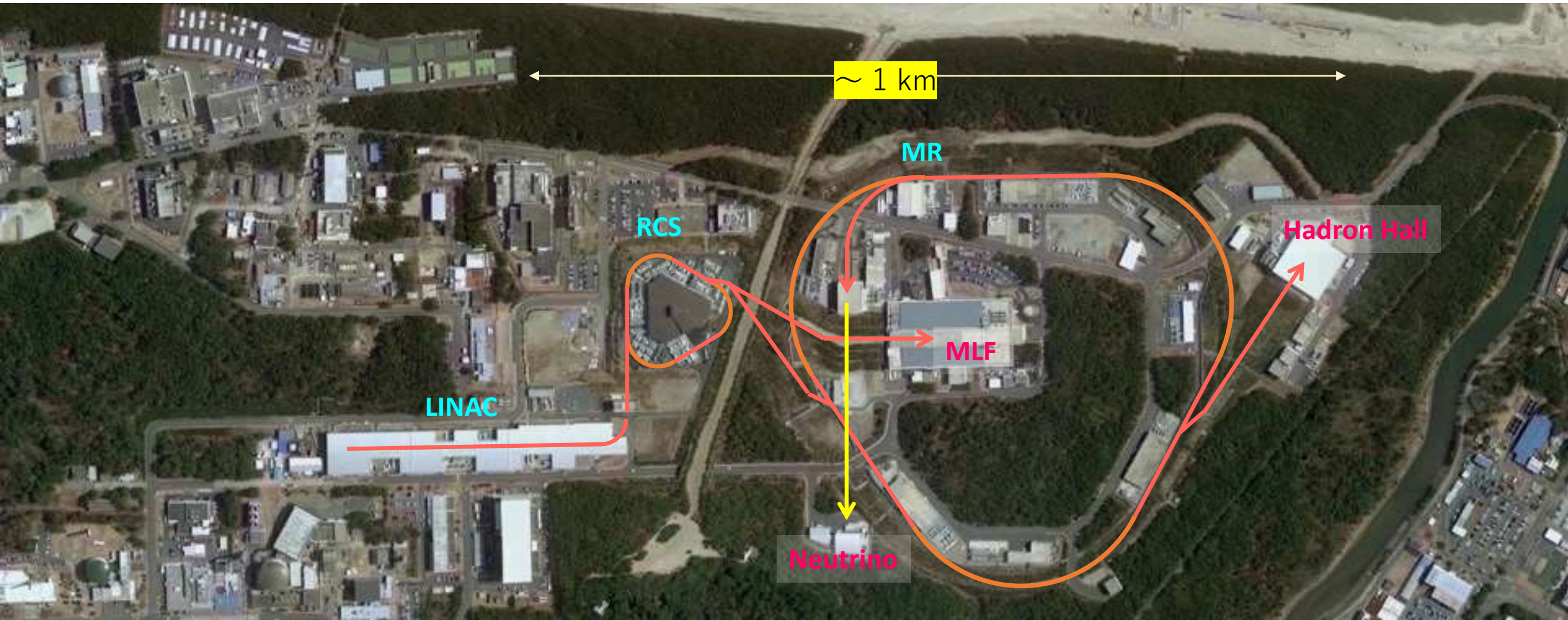
WAO2023 OR18, 2023 SEP14 09:20 – 09:40

Japan Proton Accelerator Research Complex

- Operated by Japan Atomic Energy Agency (JAEA) and High Energy Accelerator Research Organization (KEK)
- Tokai, Ibaraki (0.65 million m²)
- High Intensity Proton Accelerators
- Facilities to use the secondary beams

- LINAC (400 MeV)
- Rapid Cycling Synchrotron (RCS) (3 GeV)
 - Materials and Life Science Experimental Facility (MLF)

- Main Ring (MR) (30 GeV)
 - Hadron Exp. Facility
 - Neutrino Exp. Facility



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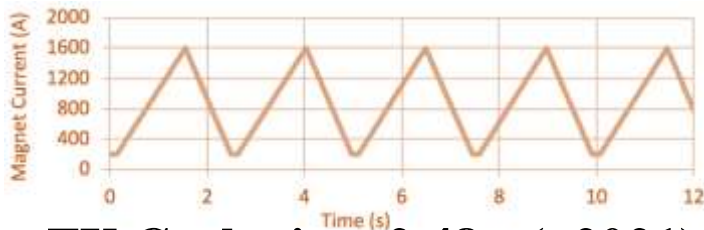
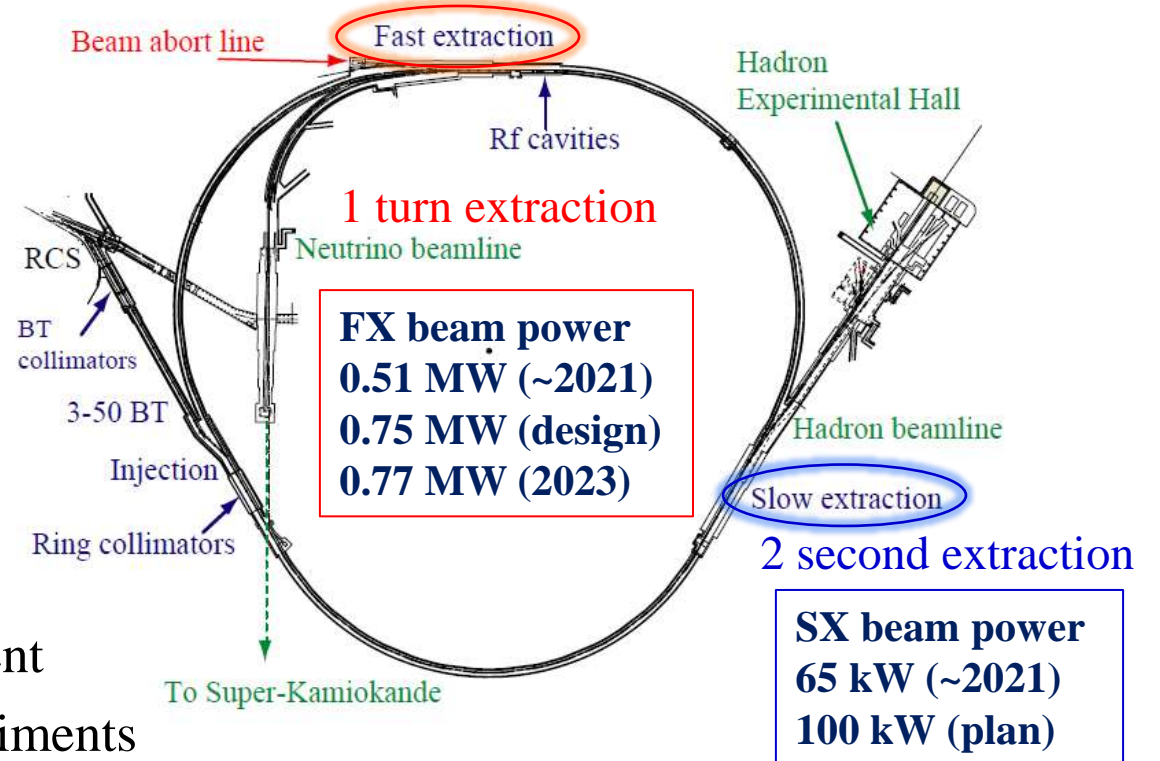


Main Parameters of MR

Circumference	1567.5 m
Injection energy	3 GeV
Extraction energy	30 GeV
Super-periodicity	3
harmonic	9
Number of bunches	8
Rf frequency	1.67 - 1.72 MHz

TWO OPERATION MODES:

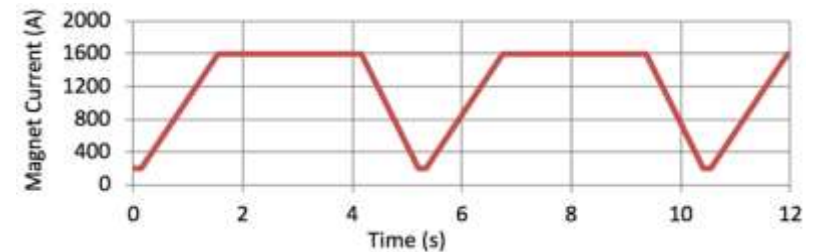
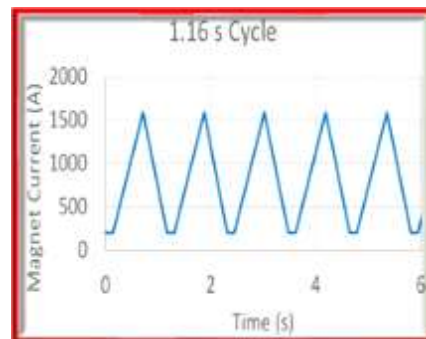
- **Fast extraction mode (FX)** for the neutrino experiment
- **Slow extraction mode (SX)** for the hadron hall experiments



FX Cycle time 2.48 s (~2021)

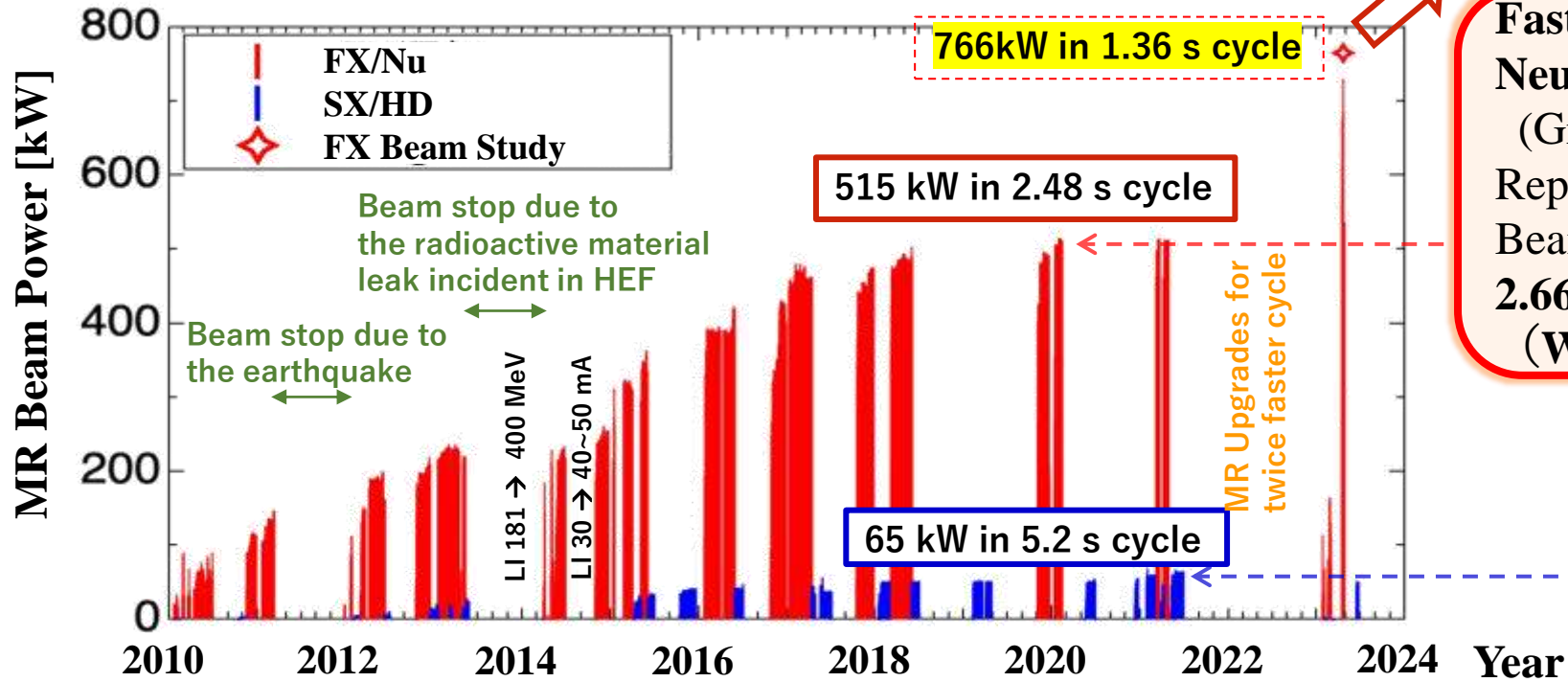
JFY2023: 1.36 s

JFY2028: ~1.16 a



SX Cycle time 5.20 s

Power Trend of MR



1.3 MW
(JFY2028)

**Fast Extraction (FX) Mode
Neutrino Exp. Facility**
 (Graphite Target)
 Repetition cycle 2.48s
 Beam Power 515 kW
2.66E14 protons per pulse
 (World record)

**Slow Extraction (SX) Mode
Hadron Exp. Hall**
 (Au Target)
 Repetition cycle 5.2 s
 Beam power 65 kW
SX Efficiency 99.5%
 (World record)

FX cycle	3.52 s	2.48 s	2.48s	→ 1.36 s
Bunch length	150 ns long	300 ~ 400 ns long		
Tune	(22.4, 20.75)	(21.35, 21.43)		

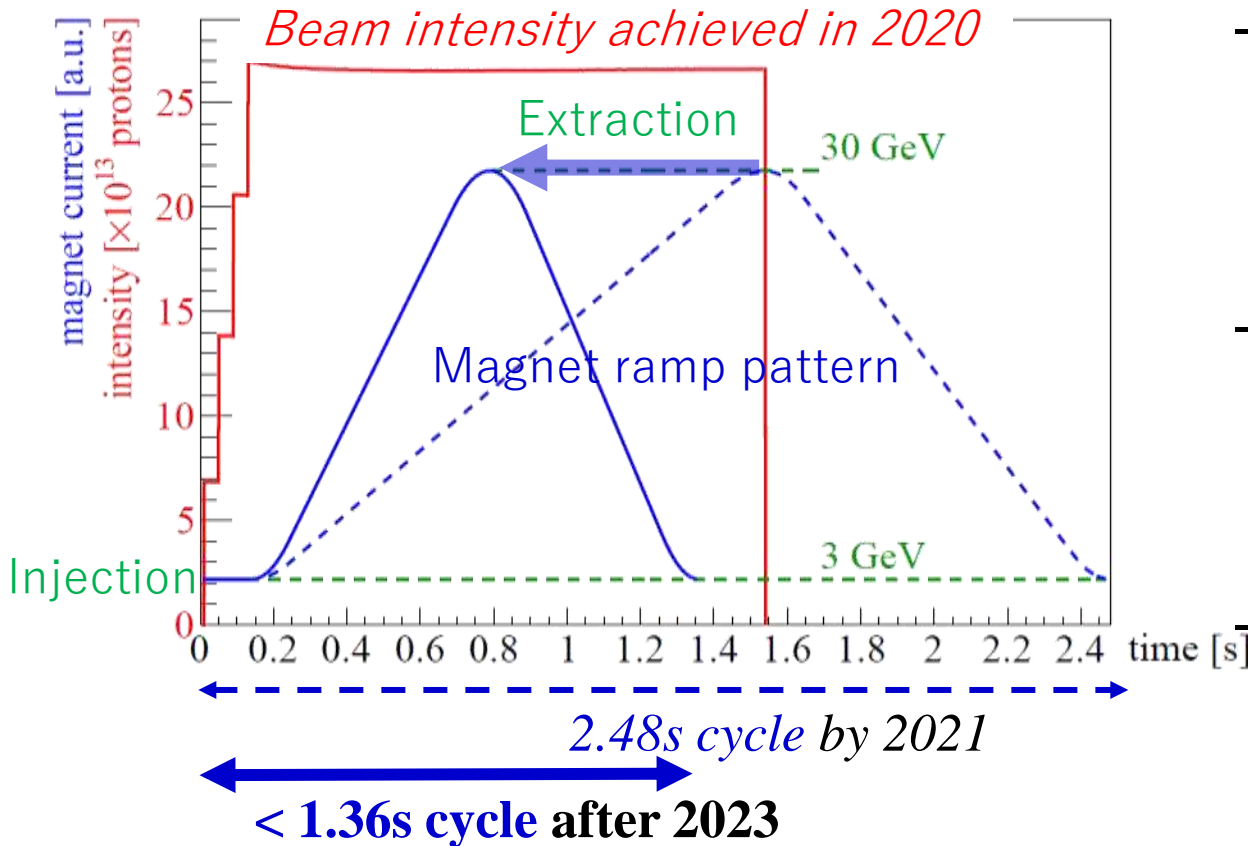
Since 2010, the beam power of MR has been increased by Faster cycle, Space charge mitigation, Optics improvements, and Hardware enhancement associated with them.

Upgrade plan of MR FX (2023~)

Beam Power \propto **Energy (30GeV)** \times **1/T_{rep}** \times **# of protons.**

JFY2021	515 kW	2.48 s	2.66E14 protons per pulse
JFY 202*	> 940 kW	<1.36 s	2.66E14 protons per pulse

of protons in a pulse extracted from synchrotron (Word Record)



- In 2021 -2022, MR major properties (RF /Magnet / Injection&FX / ...) were upgraded for **Twice Faster cycle**.
- We are in the way to reproduce *the 2021-Beam-Optics* first, and to make further upgrades.
- In 2023 beam study, we achieved **FX 766 kW eq.**
2.17E14 protons per pulse

Staffing during Beam Operation

STAFFING to be responsible for safe beam operation	Beam Study	User Operation
Accelerator Shift Leader (SL) A person assigned from ALL Researchers/Engineers in J-PARC Accelerator Division	○	○
Sub-Shift Leaders (Sub-SLs) out-sourcing members	○	○
Beam Commissioning Leaders (B-Comm.Ls) decide beam-conditions. Y. Sato & T. Yasui are for MR-B-CommLs.	○	
MR-Shift: Special shift only for MR operation Assigned only from MR section members. No special shift for Linac & RCS operation.	○	○

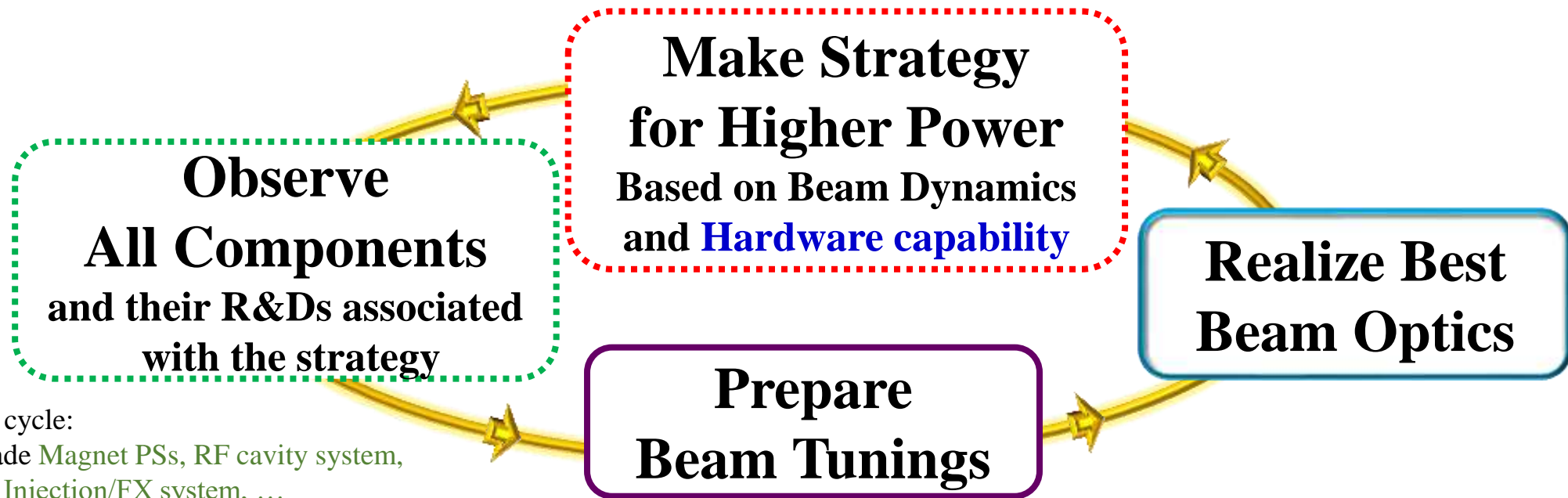
Staffing in the control center room
 during MR Beam Study

You can see the control enter room in J-PARC at
<https://www.nhk.jp/p/zero/ts/XK5VKV7V98/movie/>
 (Japan Broadcasting Corporation)

MR Beam Commissioning process

To aim higher intensity, beam loss management is important to protect facility components and their maintenance capabilities.

MR Beam Commissioning is to process the following steps iteratively



- Faster cycle:
Upgrade Magnet PSs, RF cavity system, Injection/FX system, ...
- Space charge mitigation:
Upgrade RF and Inj. Schemes for Longer beam bunch
- Optics improvements:
Use limit of Magnet PSs, Add Trim-Magnetic fields, ...

MR Beam Commissioning process

Prepare Beam Tunings

Confirm stability of all components ---Reproducibility is a key to success

Magnets, RF systems, Monitors, Control systems, Data taking...

Realize Best Beam Optics

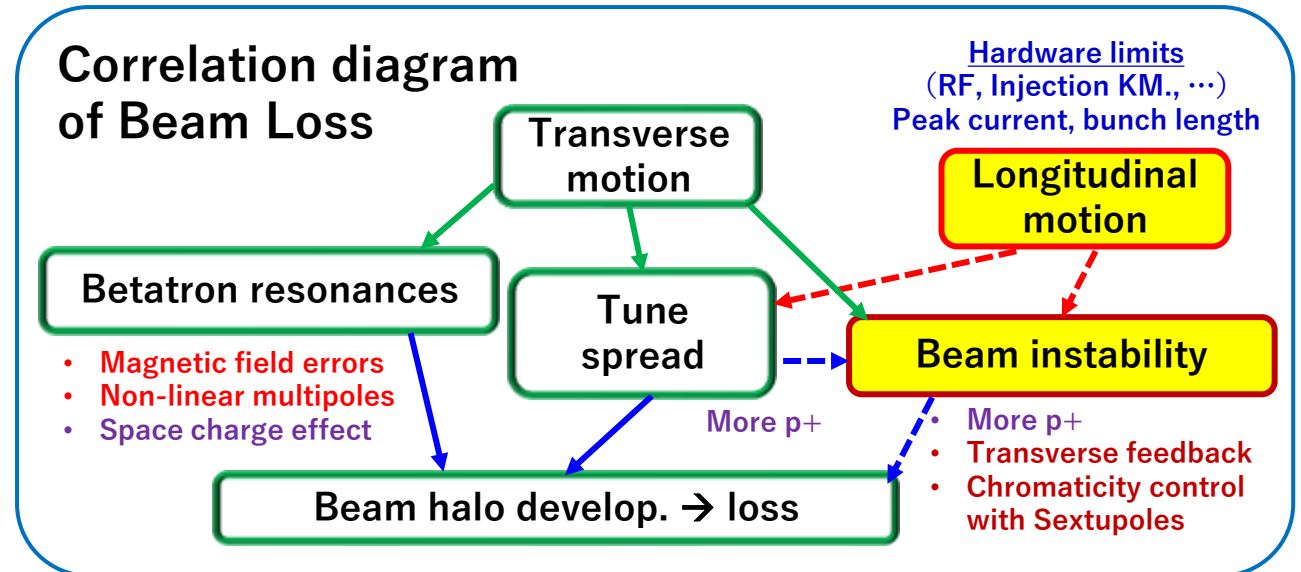
Classify the crossed relations and solve each by each

to make **Stable acceleration**

to **Suppress beam instability**

to **Focus on effects from resonance lines**

to **Manage loss distribution**



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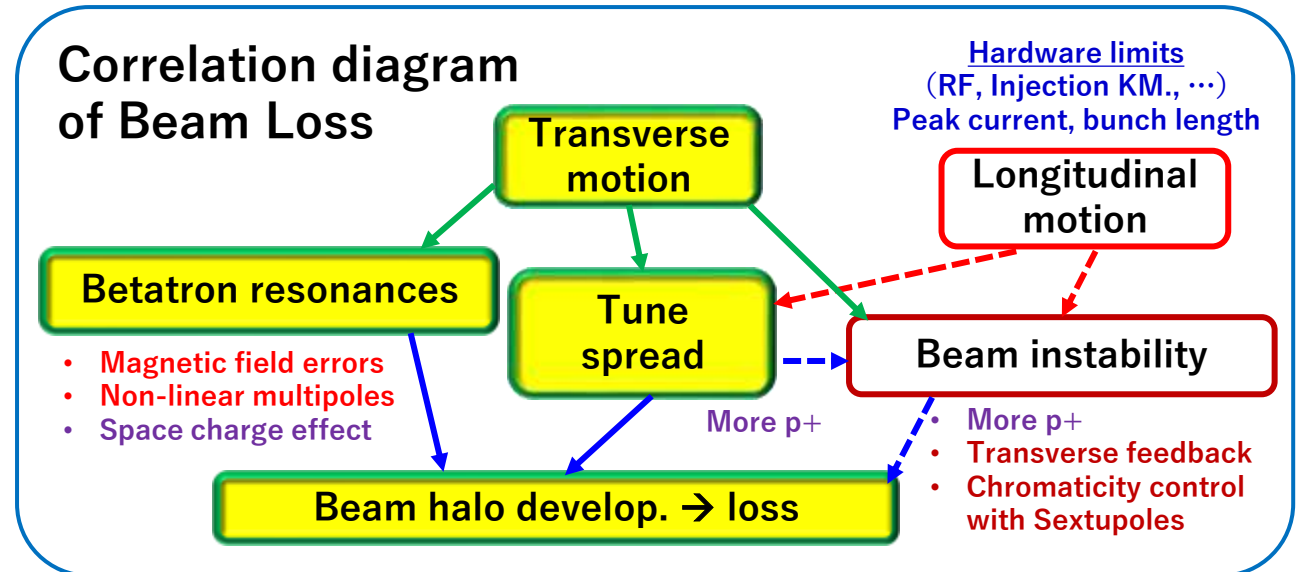
Classify the crossed relations and solve each by each

to make **Stable acceleration**

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View-Points of Beam Commissioning

Beam Study and User Operation have different view-points
Required data and their required timing are also different for each purpose.

Every shot data
required immediately

Additional data
on demand

Continuous data
- checked immediately for Alert
- checked in every 2~5 min.

Data in every 10 shots
& last 5 shots in case of beam stop

Continuous data
- checked immediately for Alert
- checked in every 2~5 min.
- Long-Term Trends

TRIGGERED with Beam Shot

No TRIGGER

MR DATA to be observed		MR Beam Study			User Operation	
		Triggered with beam shot		No trigger	Triggered with beam shot	No trigger
		Every shot	Additional data Recorded on demand	Continuous data	Every 10 shots & Last 5 shots at beam stop	Continuous data
①	BLM (3-50 BT,MR)	<input type="radio"/>	<input type="radio"/> finer time step		<input type="radio"/>	
②	DCCT	<input type="radio"/>	<input type="radio"/> backup system		<input type="radio"/>	
③	BT-orbit & inj. Error	<input type="radio"/>			<input type="radio"/>	
④	BPM (COD)	<input type="radio"/>			<input type="radio"/>	
⑤	BPM (Turn by turn)		<input type="radio"/> optics measurement			
⑥	dp/p	<input type="radio"/>			<input type="radio"/>	
⑦	Wall current monitor		<input type="radio"/> longitudinal invest.			
⑧	Mag. PS (I, dI/dt, ...)	<input type="radio"/>	<input type="radio"/> further investigation		<input type="radio"/>	
⑨	Intra-bunch oscillation	<input type="radio"/>	<input type="radio"/> control/study instability			
⑩	Beam Profile Monitors	<input type="radio"/>				
⑪	MPS (Mchn Prtct System), Alert			<input type="radio"/>		<input type="radio"/>
⑫	Vacuum Monitors			<input type="radio"/>		<input type="radio"/>
⑬	Radiation Monitors, Alert			<input type="radio"/>		<input type="radio"/>
⑭	Risk monitors, Alert			<input type="radio"/>		<input type="radio"/>
⑮	Environments			<input type="radio"/>		<input type="radio"/>

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⑮	Environments			<input type="radio"/>		

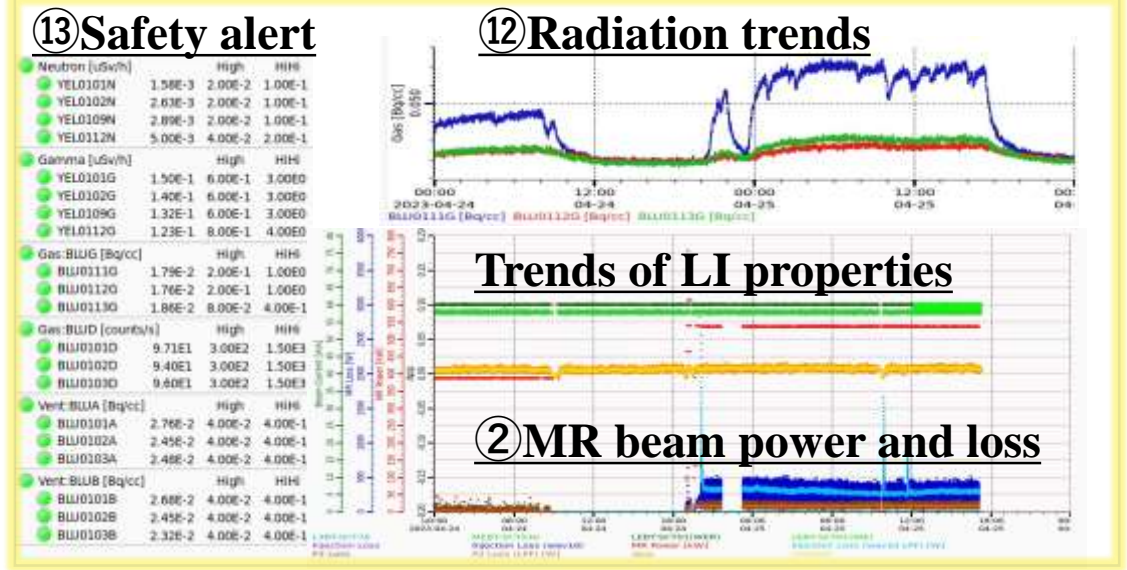
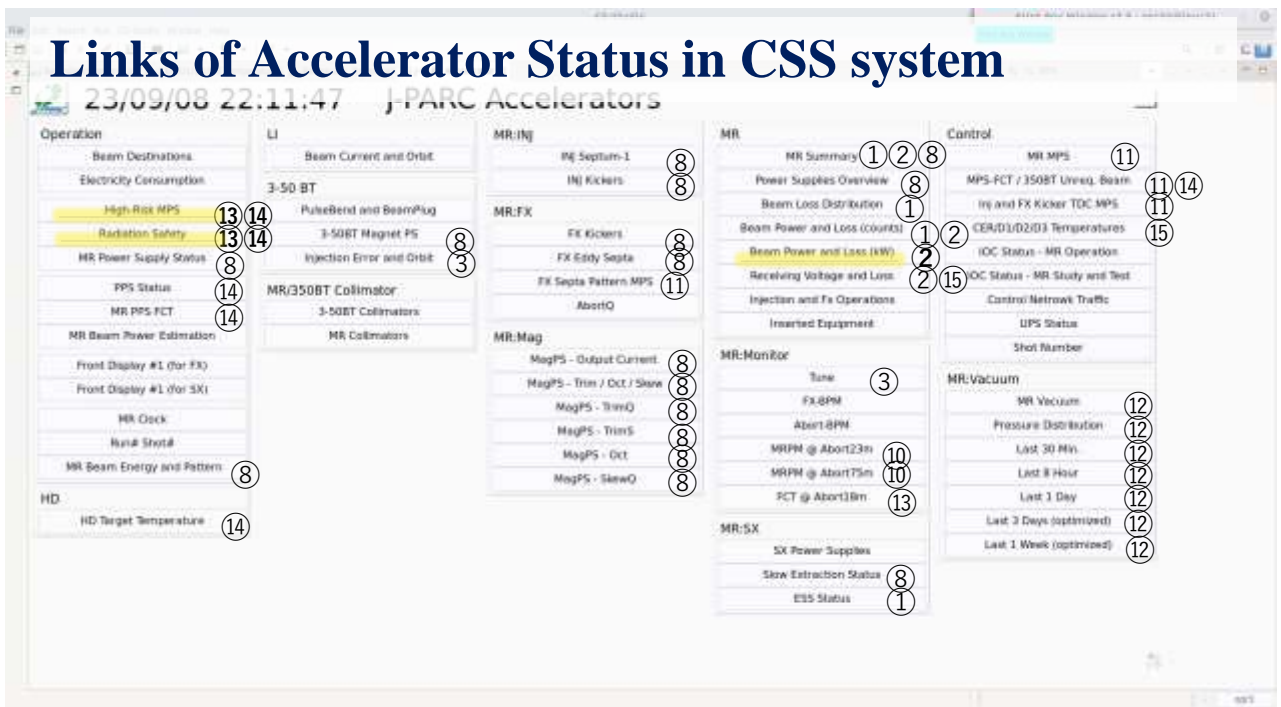
In **MR Beam Study**,
MR Beam commissioning
leaders always care

- **the basic beam properties**
- **safety/machine-protection alerts.**

Data viewing tools

- **CSS system integrates J-PARC Accelerator Status, and is good to observe**
 - ✓ Data Trends (go-back-capability) from Continuous data and their relationships.
 - ✓ Data triggered by shot (*but not stored*) to find the accelerator status immediately.
- **Archiver system** also provides data with time stamps.
- **Cadump** store data in Shot by shot (beam triggered).

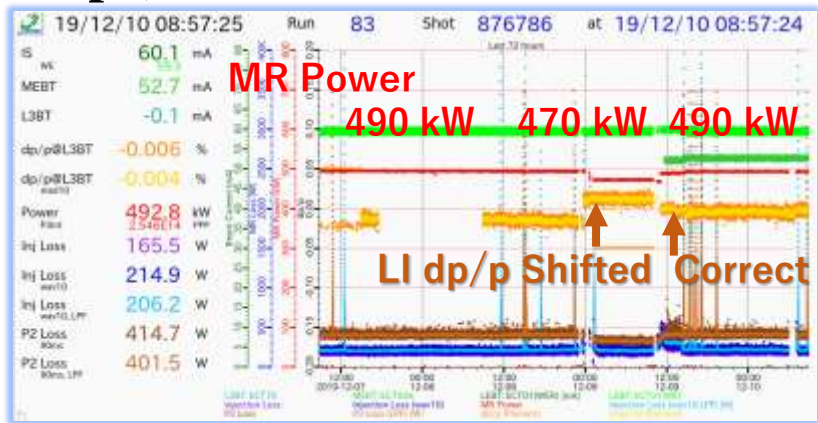
Root analysis & display are used to assemble or analyze the data via cadump



Data viewing tools

CSS system has been expanded with new items after knowing newly revealed relationships in beam properties and accel. components

Trend of MR beam power and loss attached with Linac dp/p trend, based on their empirical relationship (via chromatic tune shift in RCS)



Helped to keep high-power operation:

Sudden beam loss at BT forced us to reduce MR power.

→ Quickly found LI dp/p shift 0.03% and identified the reason came from LI klystron HV-PS#5 sudden-down

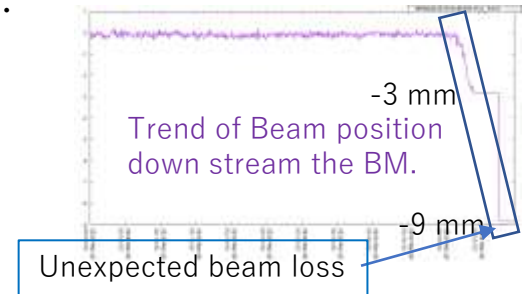
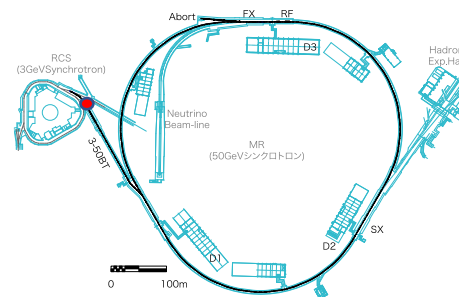
→ Apply additional prompt-tuning to correct LI dp/p

After the issue, LI member developed LI dp/p FB system

During User Op. (March 2019)

3-50BT beam orbit shifted linear in time.

→ After investigation, we found that it came from the layer-short in the coil of a bending magnet in 3-50BT.



Newly added in the CSS list

Trend of BT-orbit & inj. errors

→ Helped quick finding a damaged QM in BT with 0.7mm orbit shit in Dec. 2019.



Data viewing scene

	MR DATA to be observed
①	BLM (3-50 BT,MR)
②	DCCT
③	BT-orbit & inj. Error
④	BPM (COD)
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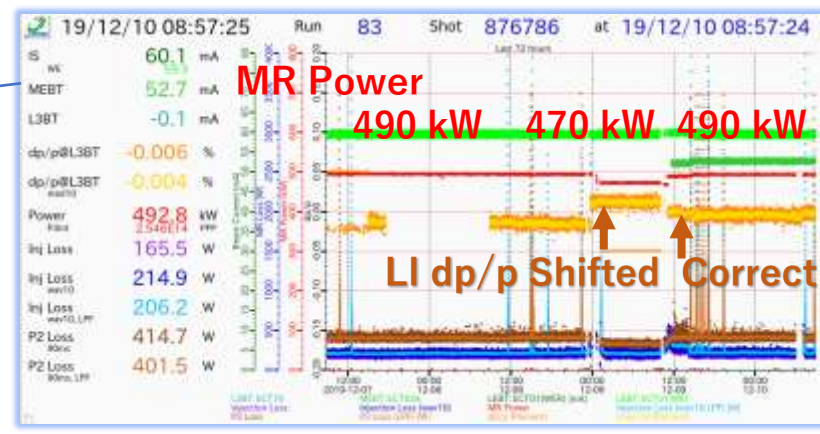
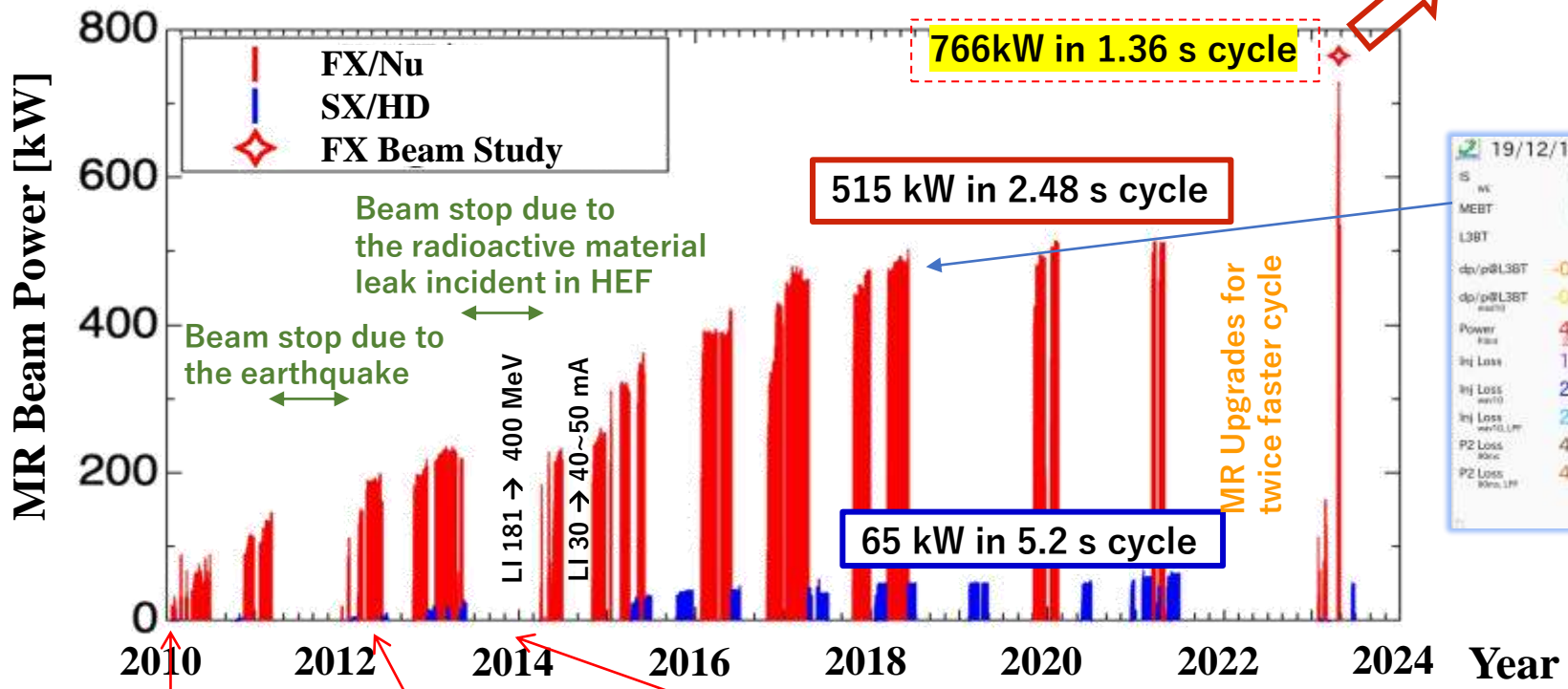
SL + sub-SLs + MR-shift observe the above during MR Operation

MR Beam Commissioning Leaders
 - observe the 2 monitors for Every Single Shot to check the basic beam properties.
 - Also check below if there is something unexpected:
 ③ Upstream/Injection status
 ⑧⑨ Instability, or miss-trigger
 ⑧,⑪-⑭ Failures in components
 ⑤⑦⑩ Further investigations

- NO ONE can see ALL data at a glance.
- Good collaboration among the Staffs is necessary to Cover ALL Monitors

Power Trend of MR

1.3 MW
(JFY2028)

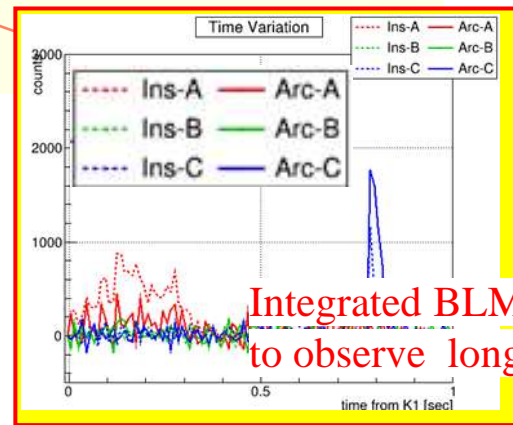
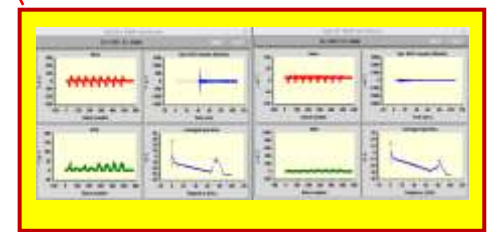
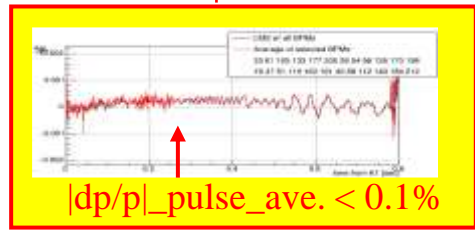


Correlation between Linac and MR

FX cycle 3.52 s → 2.48 s → 2.48s → 1.36 s

Bunch length 150 ns long → 300 ~ 400 ns long

Tune (22.4, 20.75) → (21.35, 21.43)



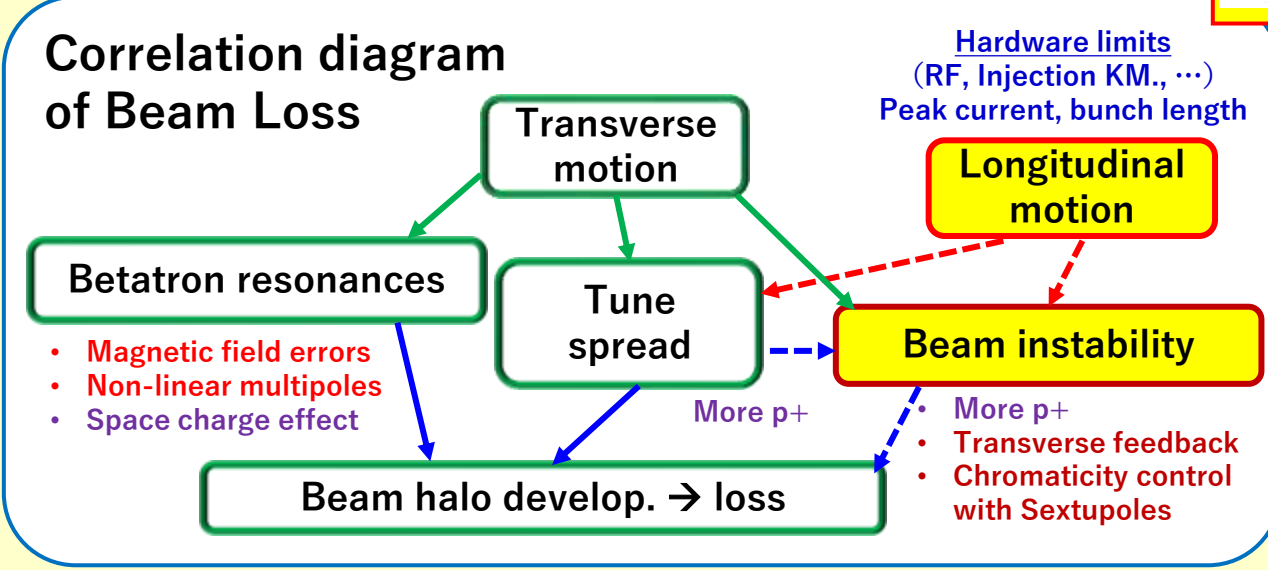
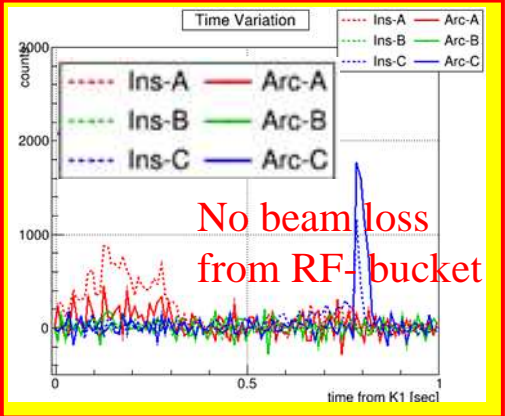
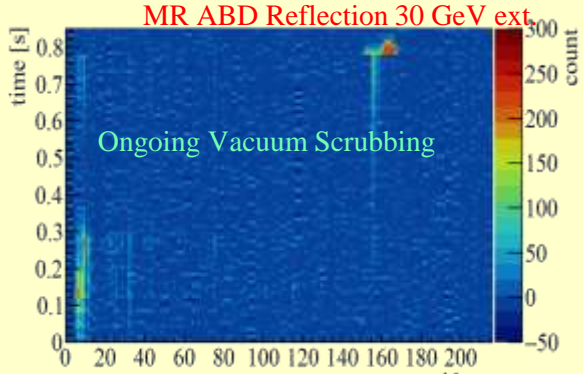
Items to Classify the crossed relations in MR Beam

Integrated BLM time development to observe longitudinal beam loss

View-Points of Beam Commissioning

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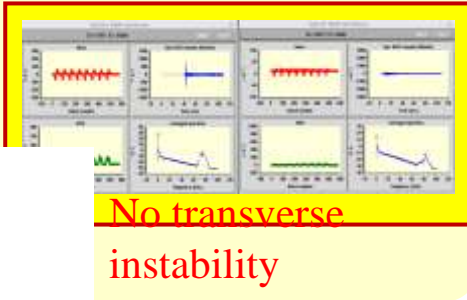
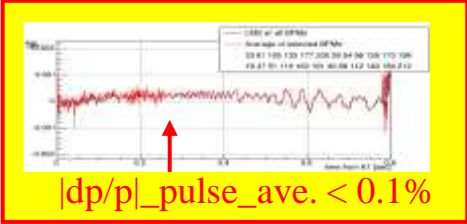
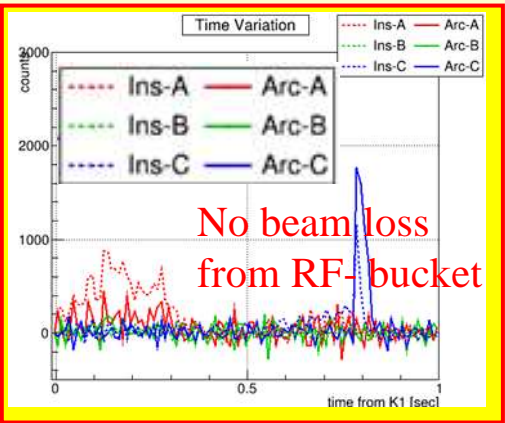
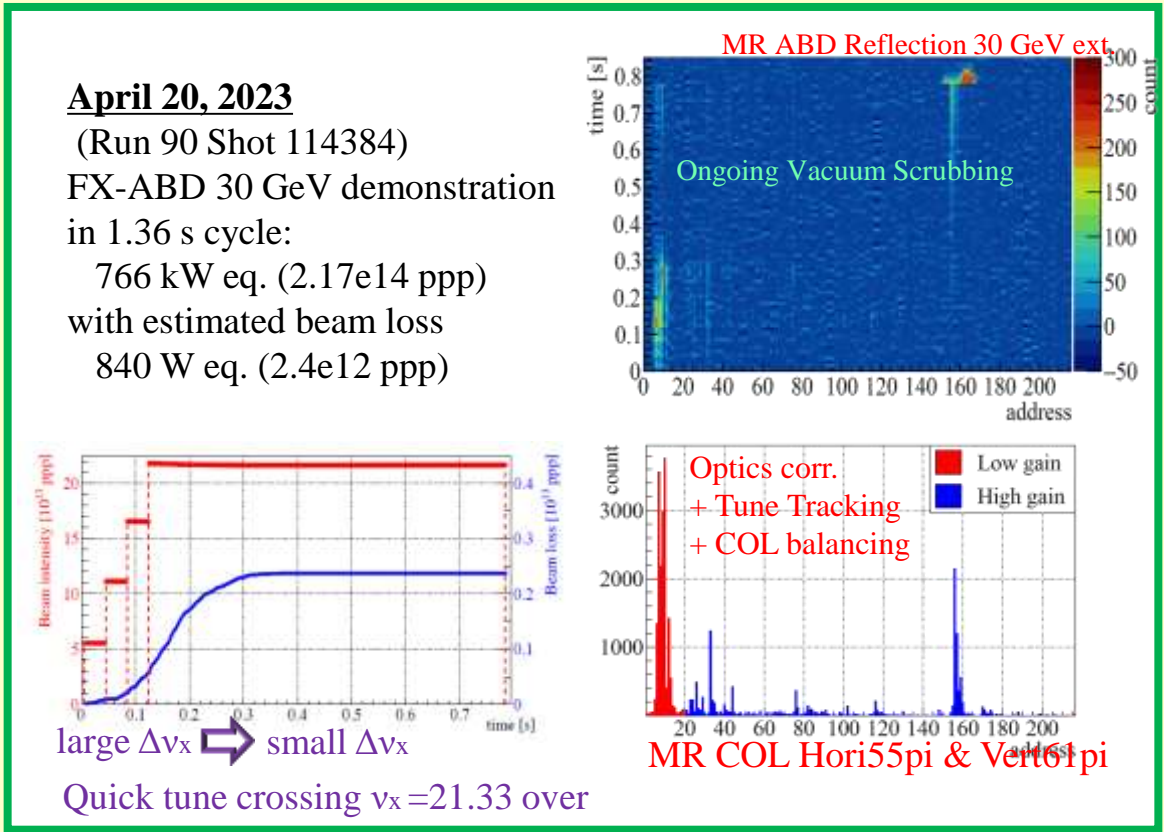
April 20, 2023
 (Run 90 Shot 114384)
 FX-ABD 30 GeV demonstration
 in 1.36 s cycle:
 766 kW eq. (2.17e14 ppp)
 with estimated beam loss
 840 W eq. (2.4e12 ppp)



**We can Classify the crossed relations,
 Only observing the basic beam properties**

View-Points of Beam Commissioning

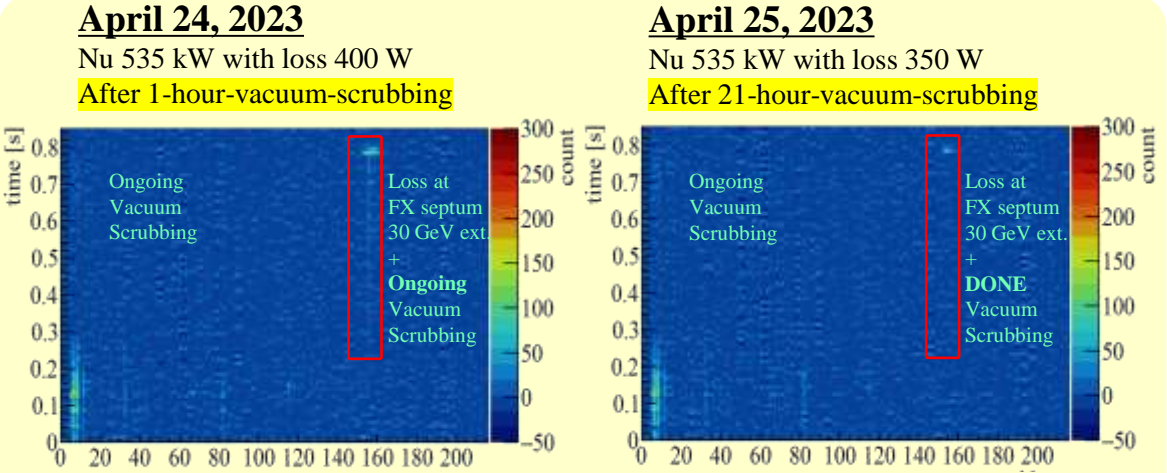
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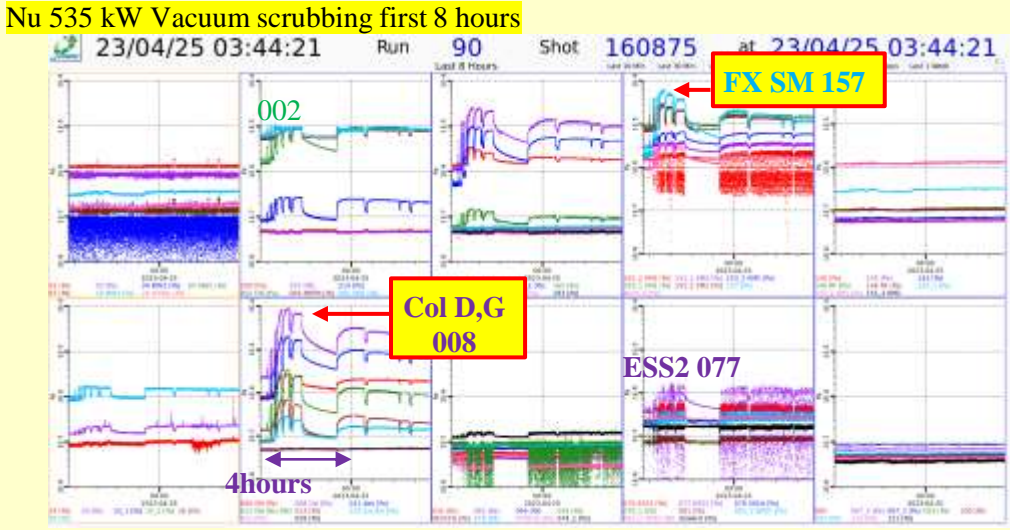
Focusing on the effects from resonance lines and managing loss distribution,
FX 766 kW eq. beam was achieved in Apr. 2023
> the max beam power 515 kW by 2021.

View-Points of Beam Commissioning

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Vacuum scrubbing suppressed beam loss > 6 GeV



The beam properties as the effects of on-going vacuum scrubbing corresponds **the newly installed components**

Summary

- ✓ In MR, beam commissioning has been carried out to increase its beam power.
- ✓ Data-viewing tools are essential to make safe and reliable judgments on the beam and equipment environments.
- ✓ We have different view-points during **Beam Study** and **User Operation**.
Required data and their required timing are also different for each purpose.
Data-viewing tools have been arranged to satisfy our demands.
 - Every shot data required immediately
 - Additional data on demand
 - Continuous data
checked in every 2~5 min. normally
 - Data in every 10 shots
& last 5 shots in case of beam stop to find
 - Continuous data
checked in every 2~5 min. normally
Long-Term Trends
- ✓ We have encountered unnoticed problems sometimes, which caused troubles and accidental beam stops. As parts of counter-measures, we have updated the data-viewing tools by adding supporting items.
- ✓ **MR beam commissioning is to realize 1.3 MW by JFY2028.**