Major longitudinal impedance sources in the J-PARC main ring

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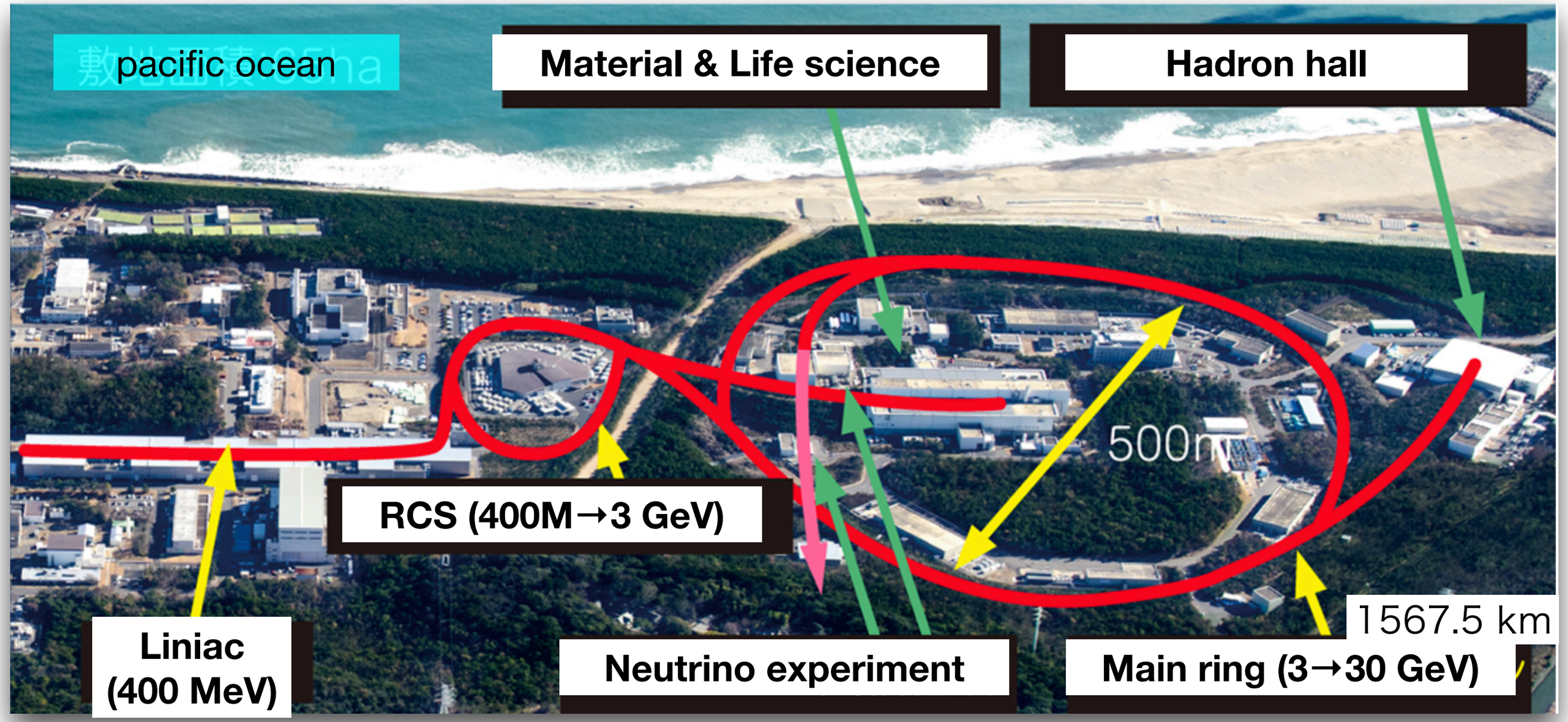
Yoshihiro Shobuda, Masahito Tomizawa, Takeshi Nakamura
and other impedance working group members

J-PARC

Japan Proton Accelerator Research Complex (J-PARC)

https://ja.wikipedia.org/wiki/



http://j-parc.jp/c/OPEN_HOUSE/2020/about.html

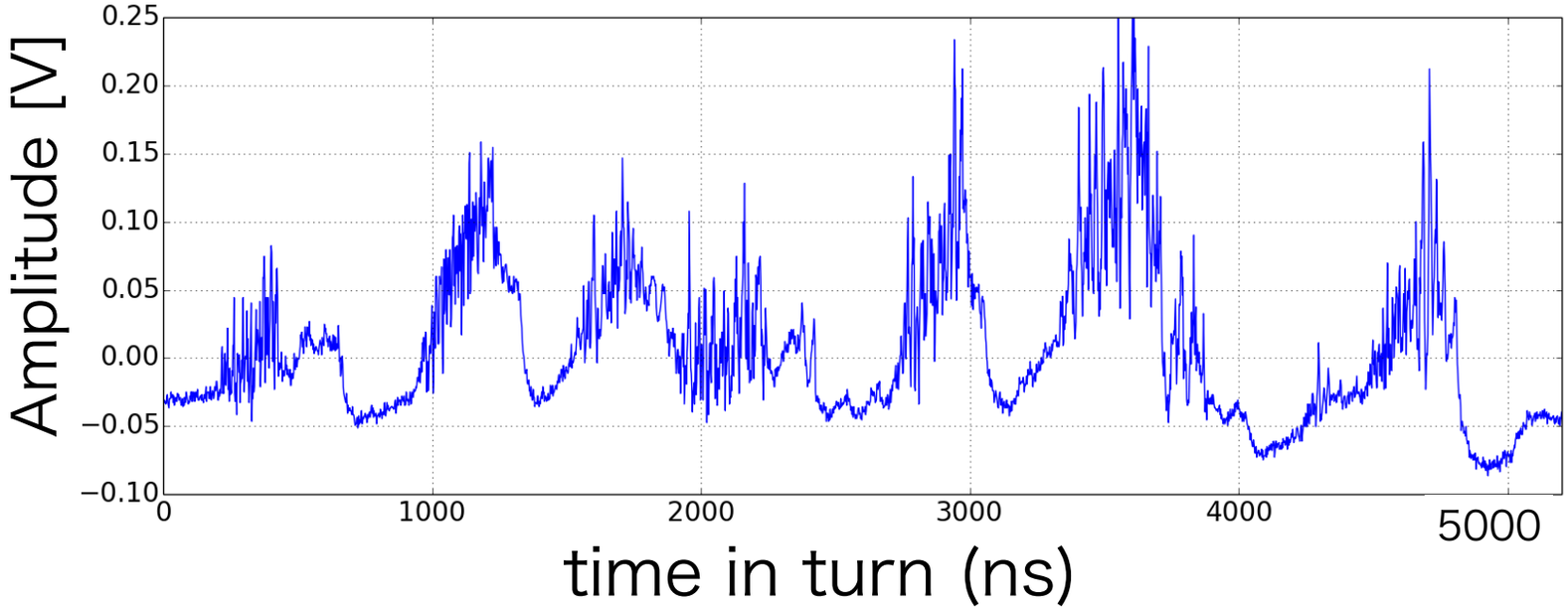
FX : T2K experiment (Tokai-to-Kamioka, neutrino)

SX : hadron experiments （multiple projects）

Issues due to longitudinal impedances

Currently, longitudinal beam instability in the debunched beam has become a problem in SX operation.

Typical microbunch structure with beam instabiliy



Wall current monitor signal at the begging of the debunch

60 ms after RF voltage off measured by Y. Sugiyama

😕 electron cloud generation and vacuum; It has been suggested that this is related to the structure of the beam tens of MHz.[1]

😕 transvserse beam instability

😕 beam loss

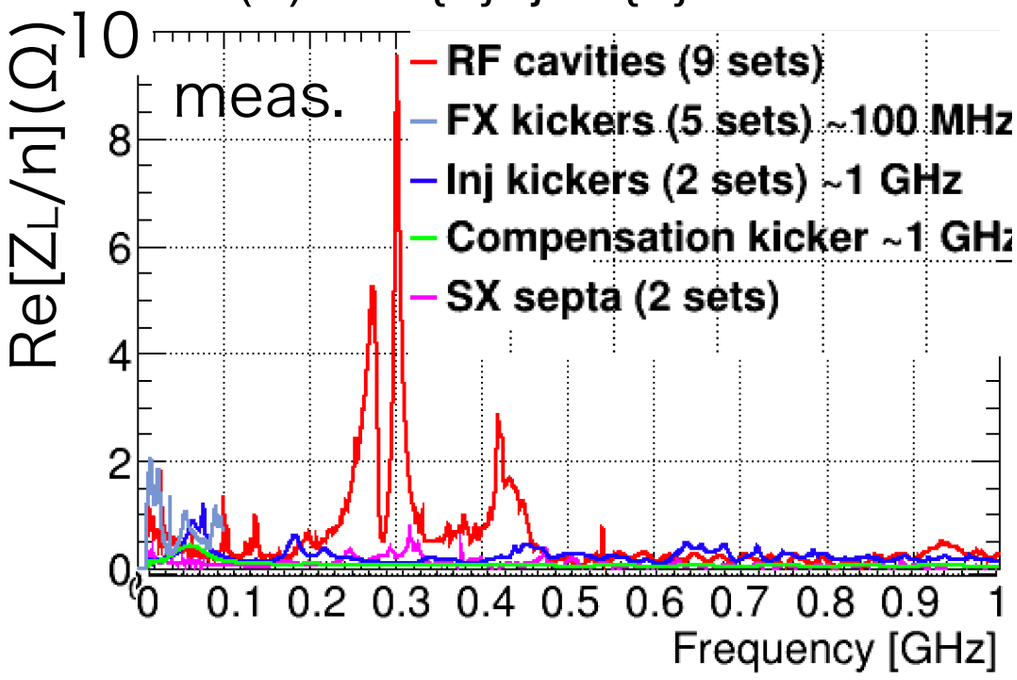
[1] B. Y. Rendon et al., IPAC2016

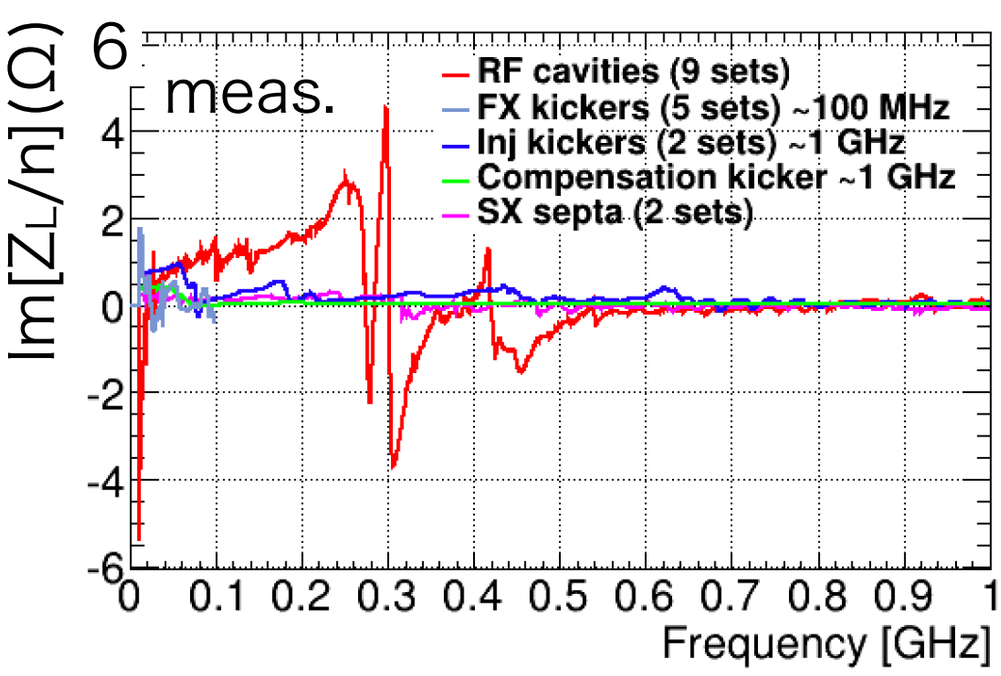
This limits the power of SX operation and could also be a problem in future FX operation candidates with time structures with lower peak currents.

Impact of impedance sources scattered in MR

$Z(\omega) = \mathrm{Re}\{Z\} + j\,\mathrm{Im}\{Z\}$

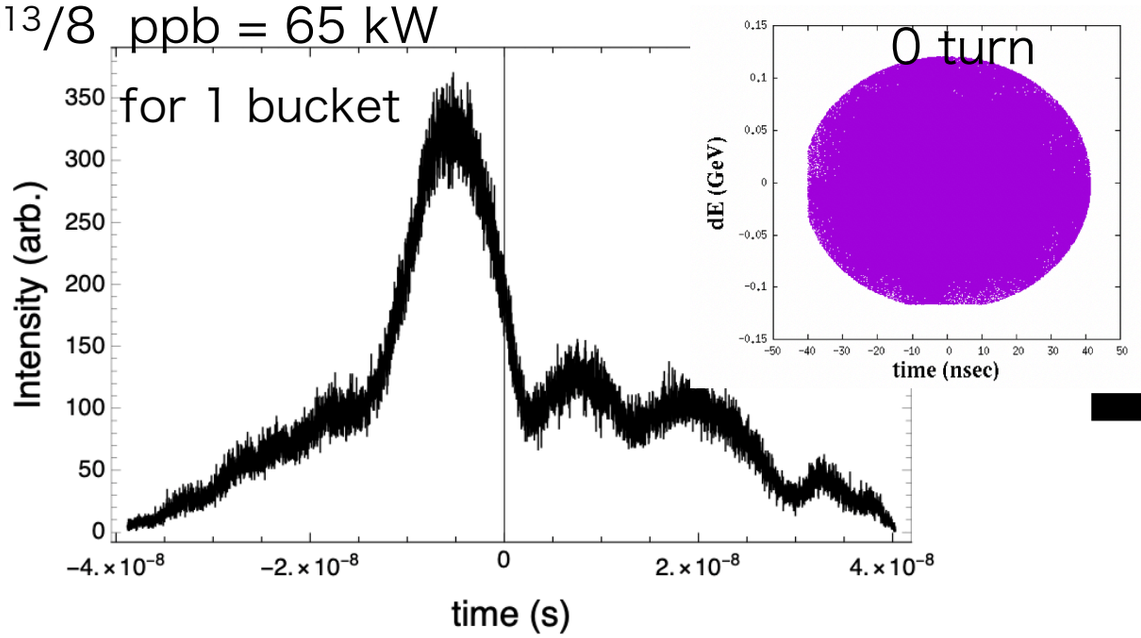
n = frecuency f/revolution frequency f_{rev}



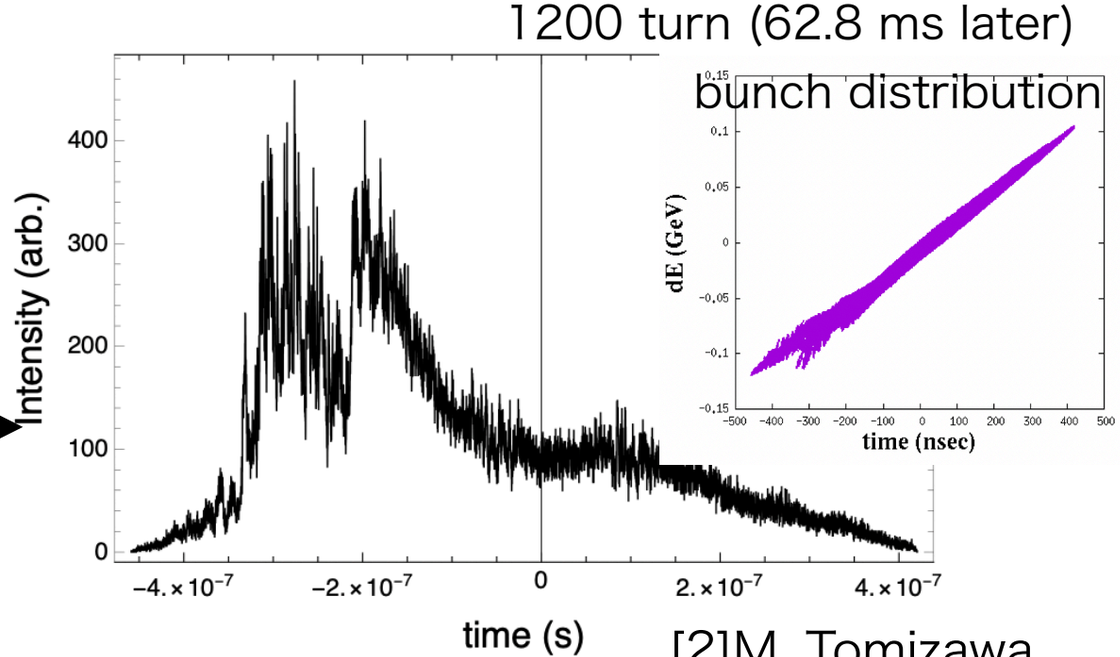


Beam simulation: Using the wall current monitor waveform measurement results as initial conditions, the impedance measurement results were used to reproduce the longitudinal micro bunch structure.[2]

$7\times10^{13}/8$ ppb = 65 kW



1200 turn (62.8 ms later)



Simulations suggest a link between the impedance of the device and the time structure of the beam

[2]M. Tomizawa, ATAC2022

How to deal with it ?

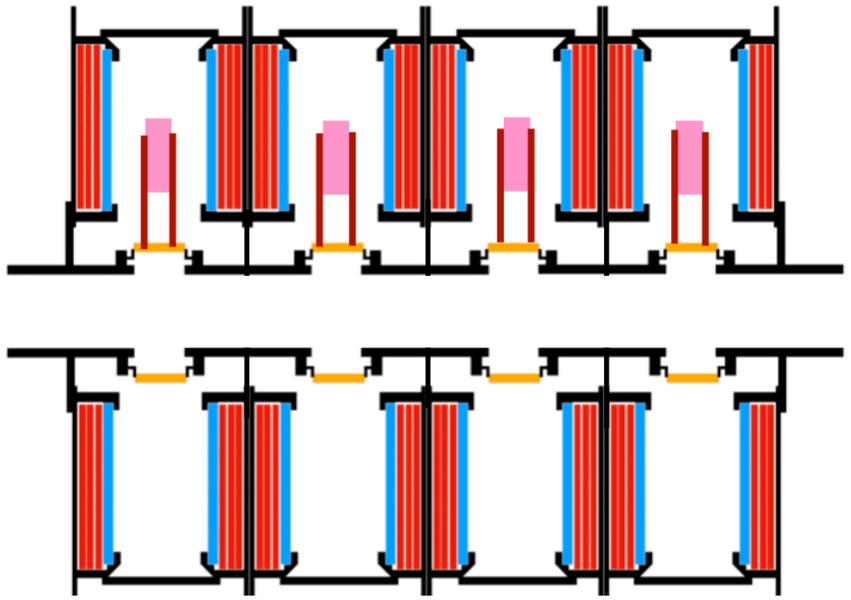
- ✓ Manipulation of beam conditions to avoid beam instabilities
  - ✓ RF gymnastics
- ✓ Identification of existing impedance sources and reduction impedance
  - ✓ modeling
  - ✓ measurement
- ✓ Investigation of impedance effects on beams
  - ✓ beam simulation
  - ✓ beam study
- ✓

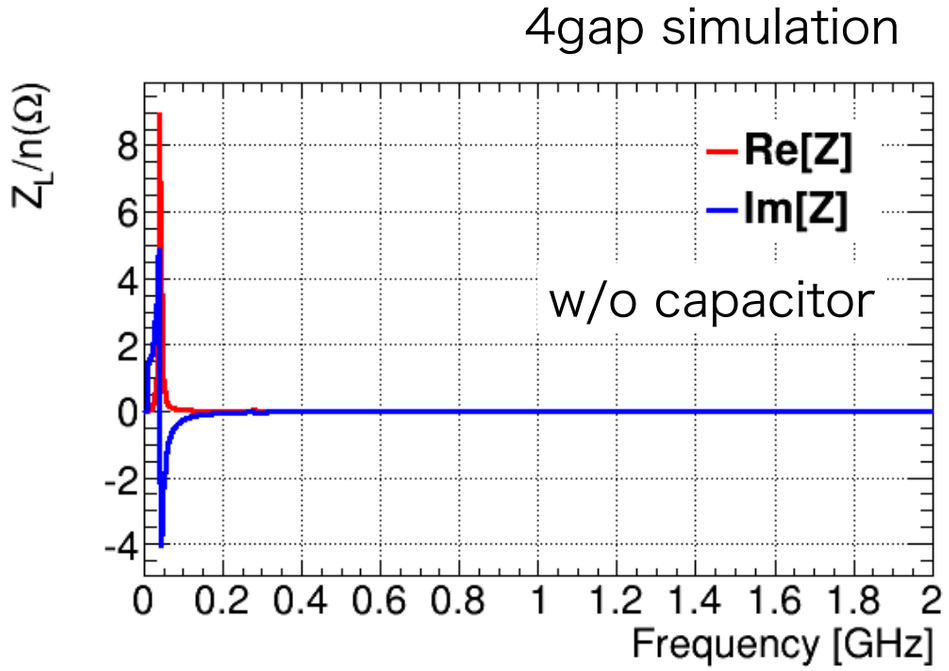
Target longitudinal impedance Z_L for instability suppression@MR : $\left|\frac{Z_L(f)}{n}\right| < 0.5\ \Omega$

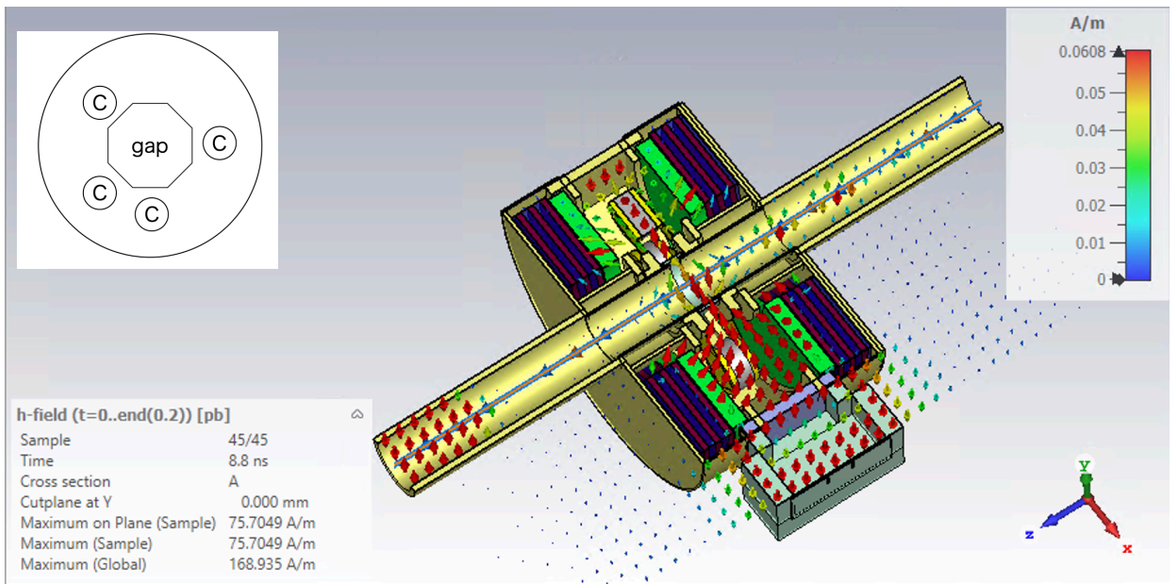
Keil - Schnell criterion and measured impedance of the device taken into account

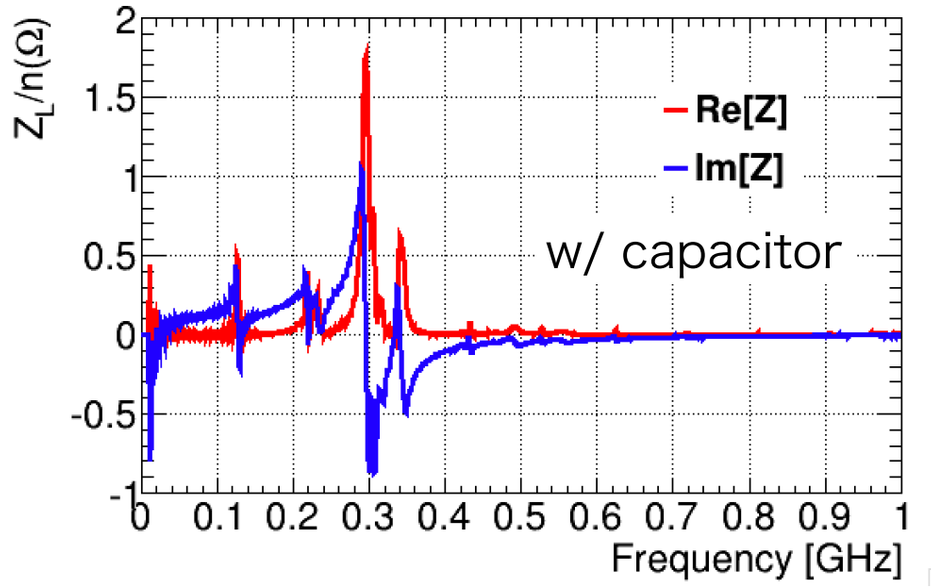
RF cavity impedance

RF cavity simulation model





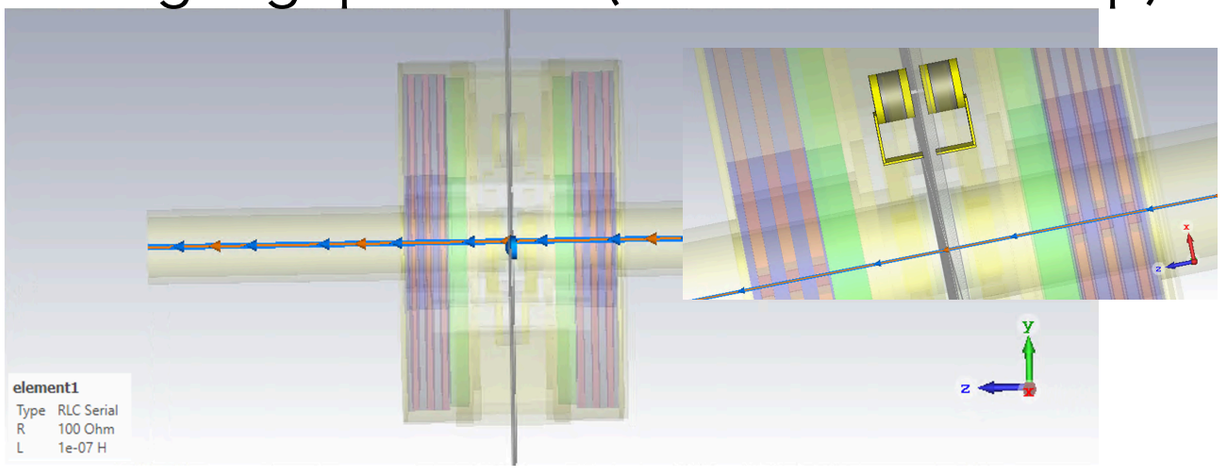


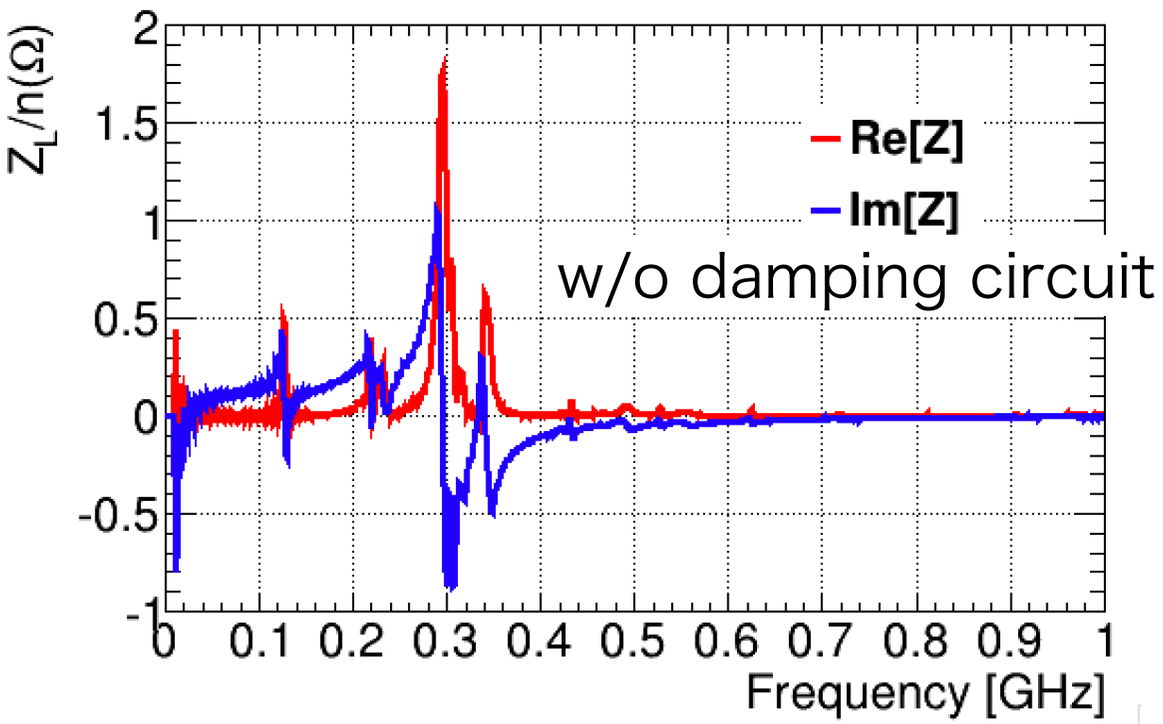


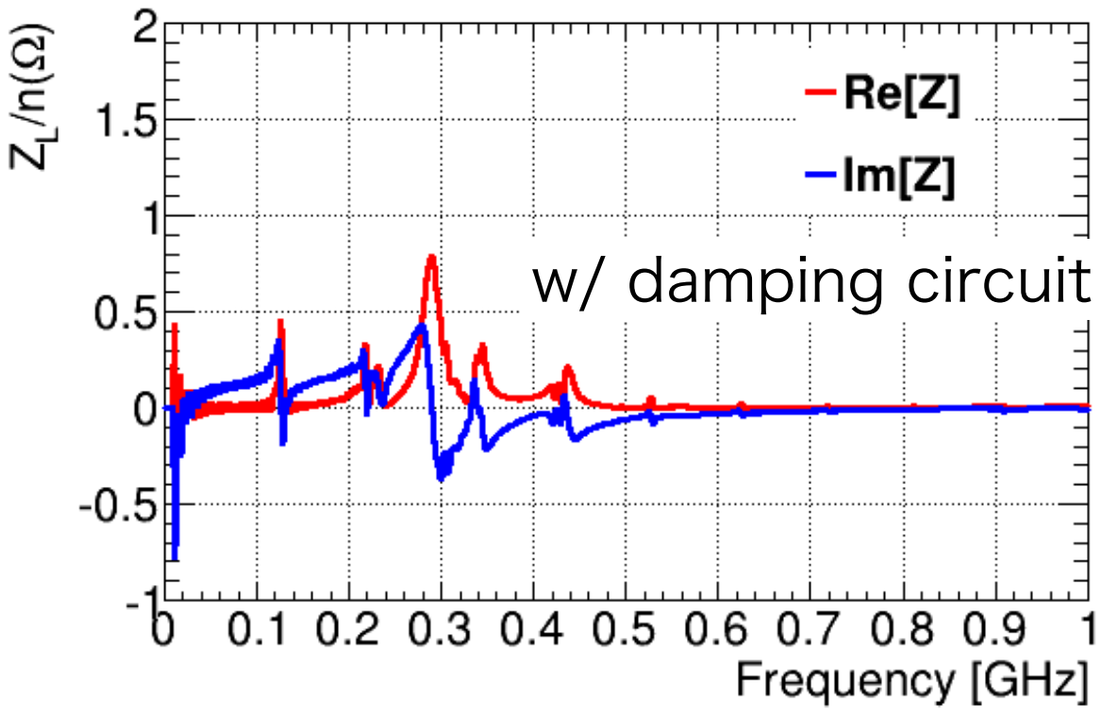
Resonance of several hundred MHz is generated by the capacitor installed in the RF cavity.

Impedance Reduction Method

single gap model (funamental setup)







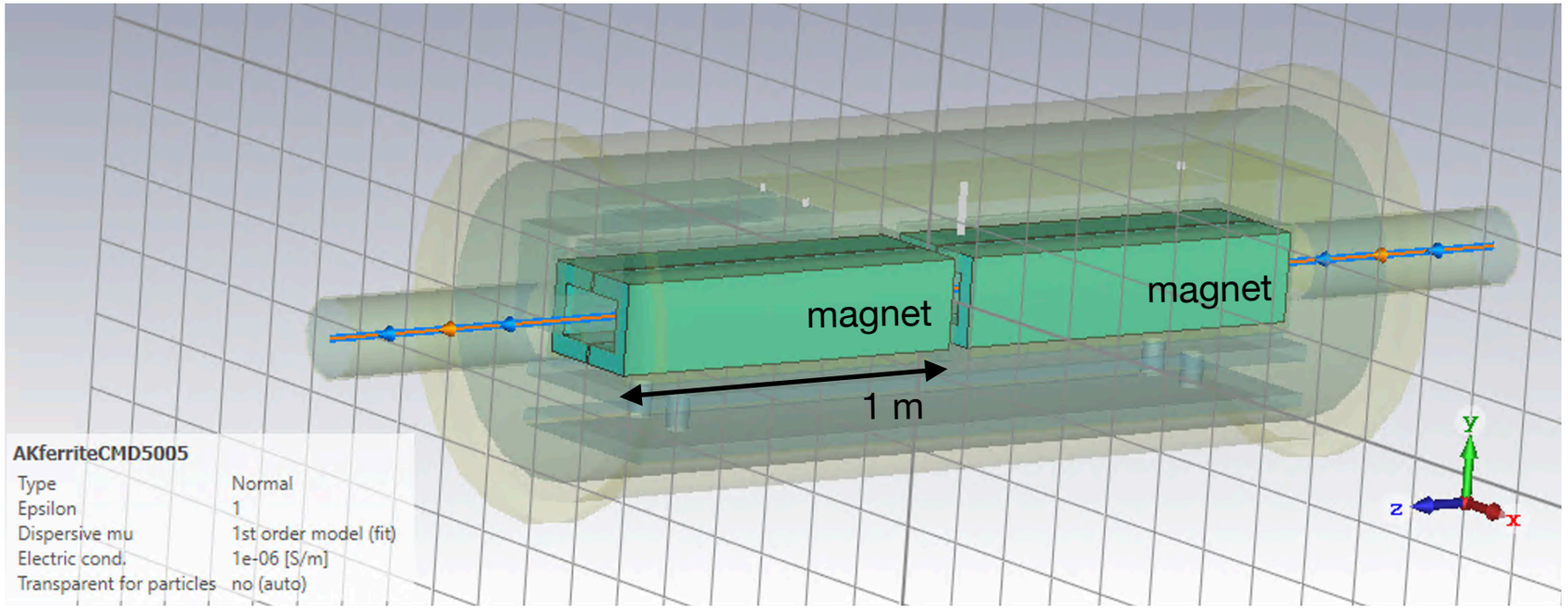
A method of dumping the resonance by installing analog resistors and coils[3] was considered, but has not yet achieved sufficient reduction.

We will consider other methods in the future.

[3] F. Tamura, internal documents.

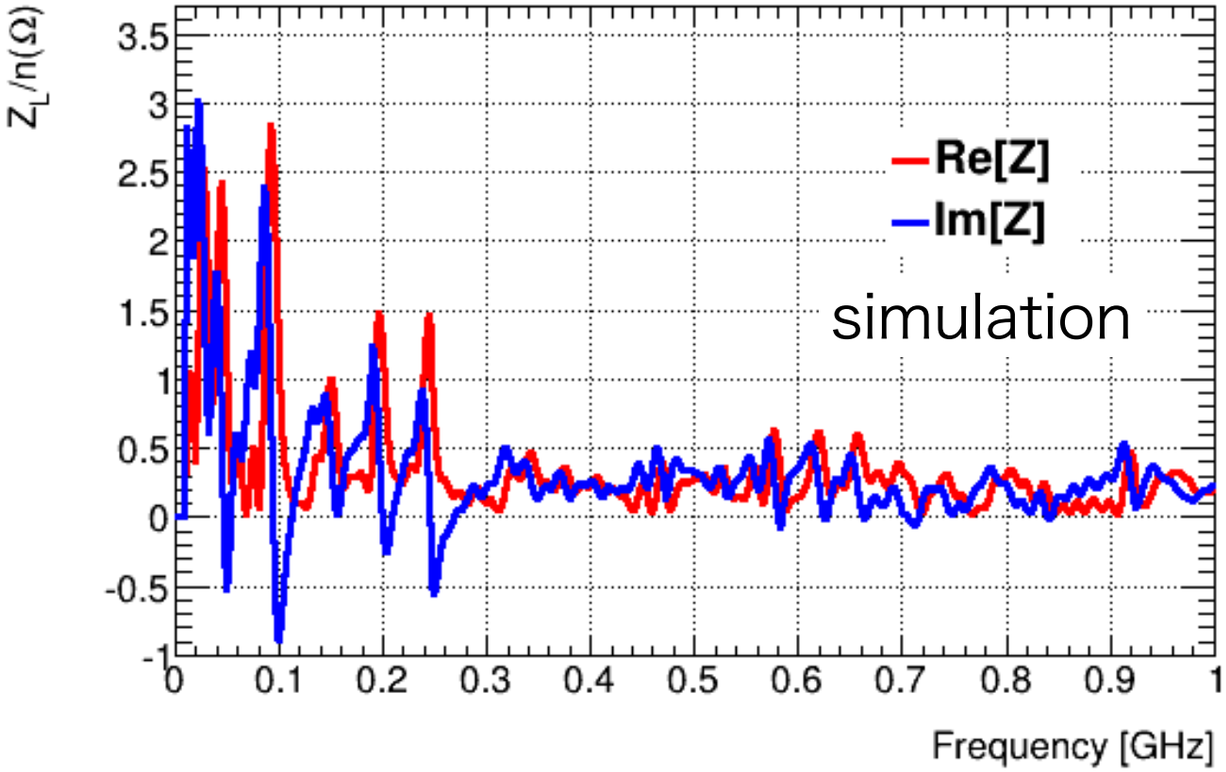
FX kicker impedance

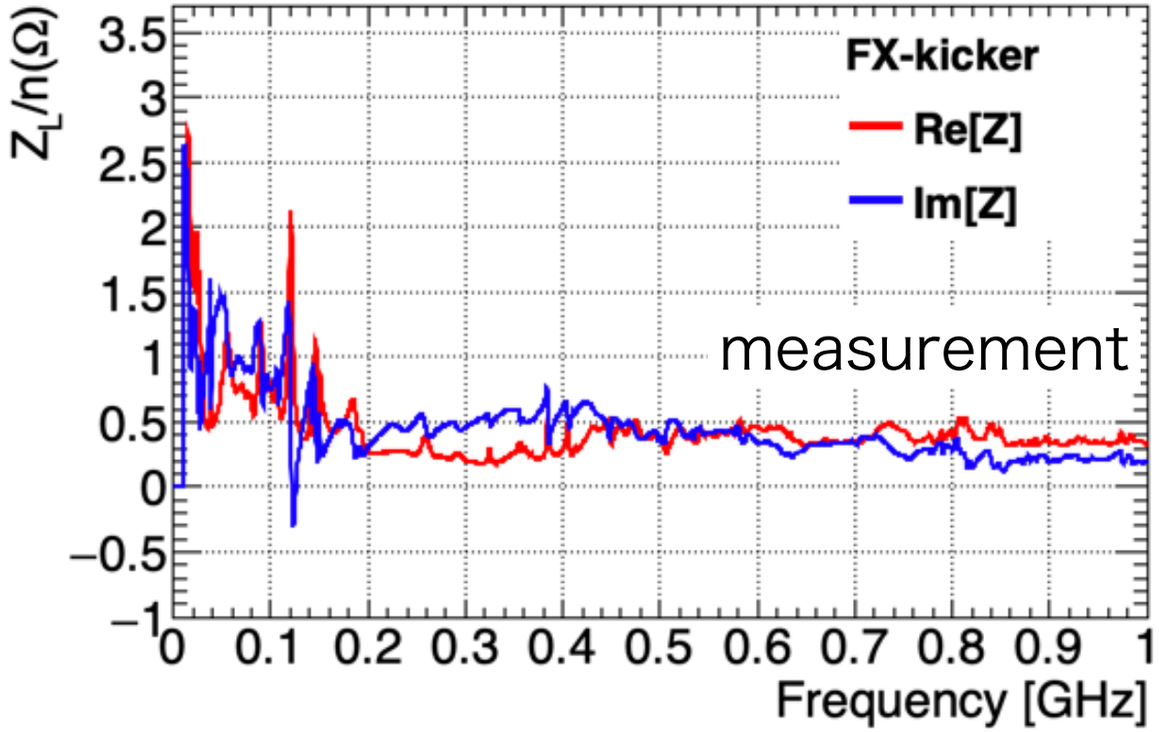
FX-kicker simulation model



× 5 sets

Ferite : CMD5005





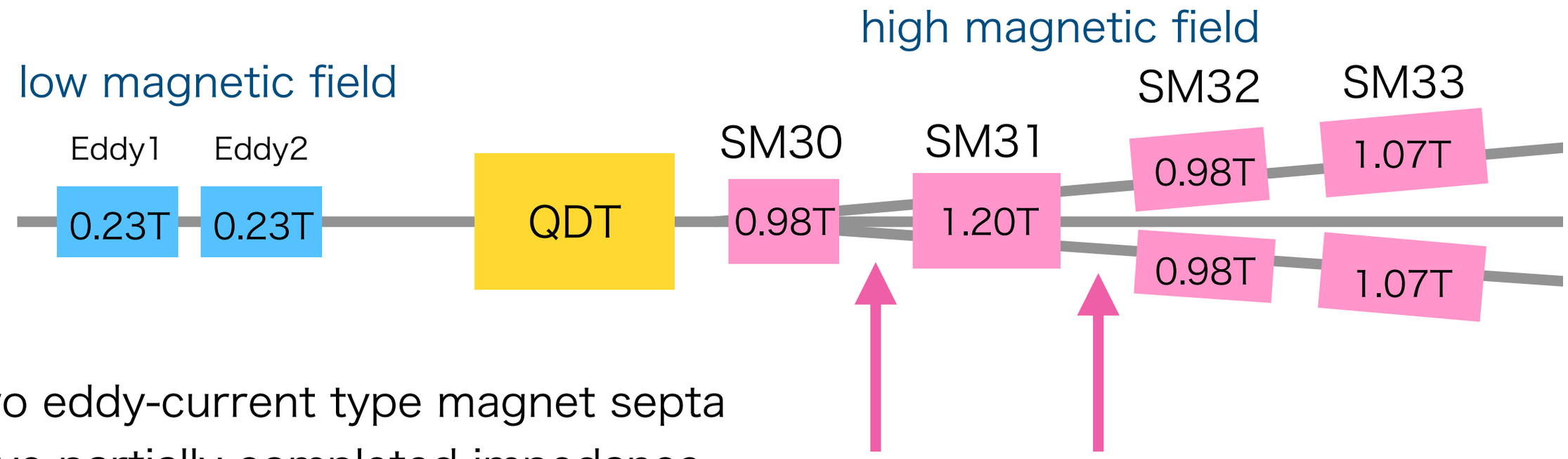
There are large multiple resonances below 300 MHz,
which is the frequency that affects the beam.

FX septum magnet impedance

FX septum magnets

FX septum magnets were updated to an improved version in 2022
to achieve higher repetition rates (1 Hz) for higher intensity FX beams.

They were found to have high impedance in the frequency band affecting the beam.



Two eddy-current type magnet septa have partially completed impedance measures.

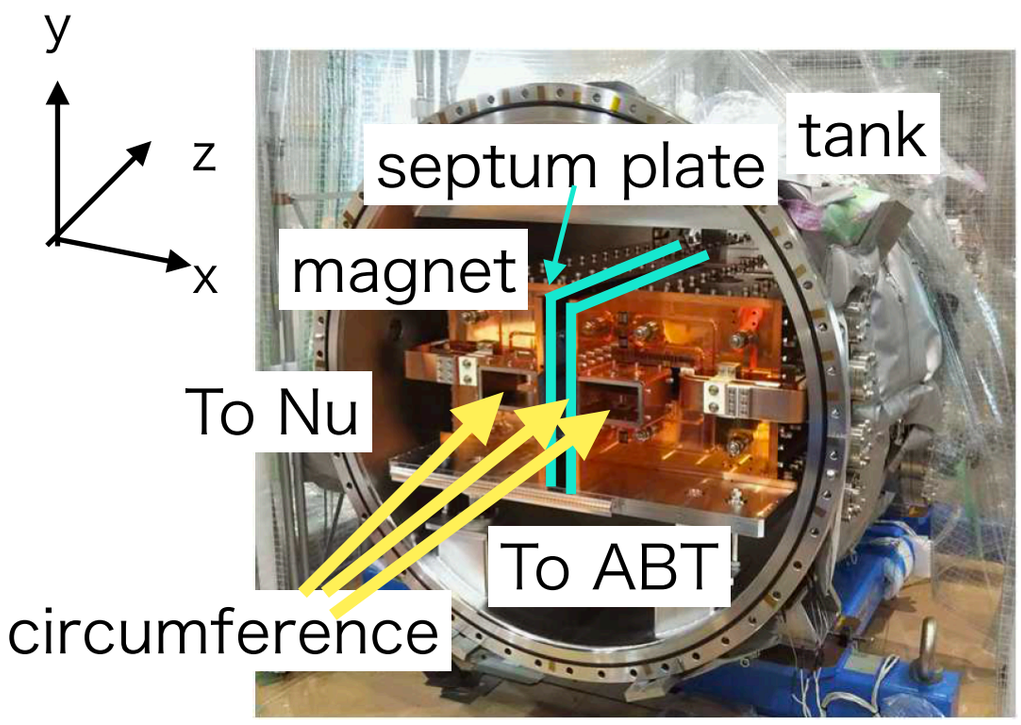
The remaining three septa have a different structure, but were found by calculation and measurement this summer to have large impedances at their connections.

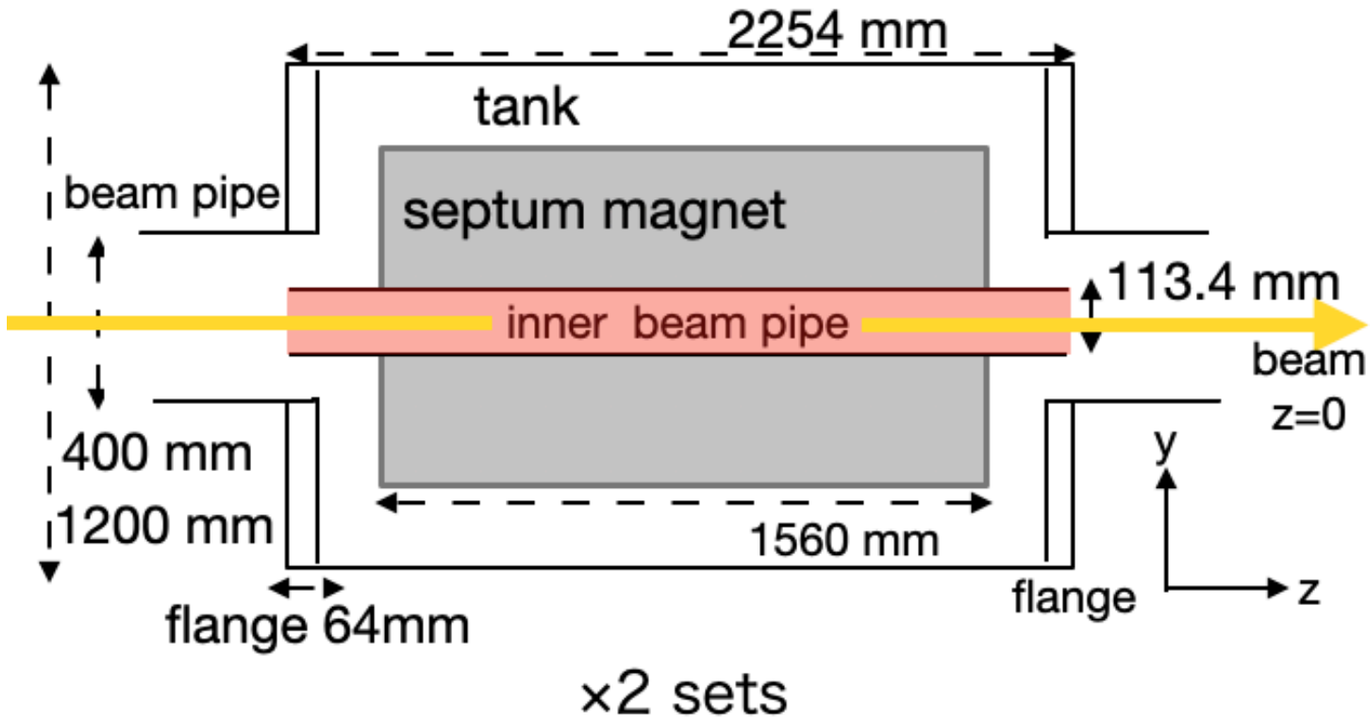
Low-field septum magnet impedance

New FX septa （FX Eddy-Current Type Septa）

Iron inner beam pipes between septum plates to reduce magnetic field leakage [4].

[4] T. Shibata et al., JPS Conf. Proc. 33, 011033 (2021)





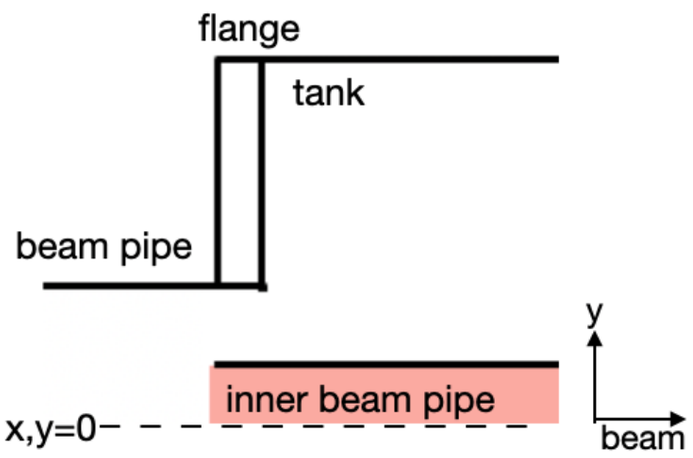
This found to have an even larger impedance by simulation, and countermeasures were taken accordingly[5].

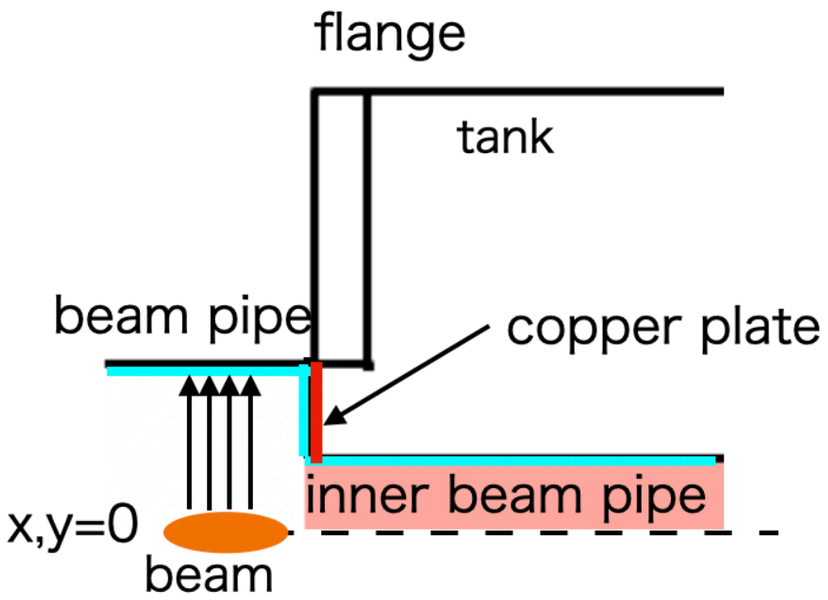
This impedance was caused as a result of the wall current not flowing smoothly into the chamber containing the septum magnets, causing resonance.

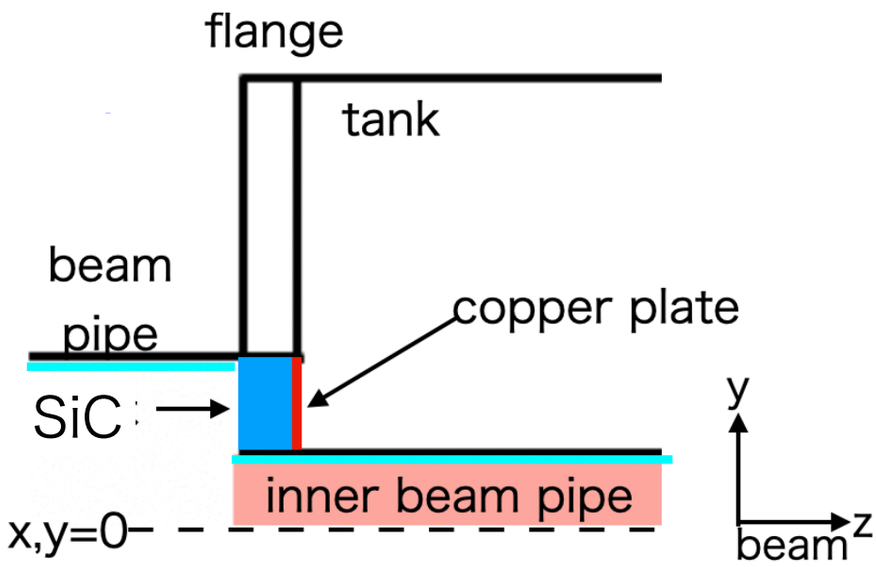
[5] A. Kobayashi et al., Nucl. Instrum. Meth. A 1031, 166515 (2022)

Impedance reduction effect by copper plate + radio wave absorber SiC

Plates are installed so that
mirror current flows smoothly

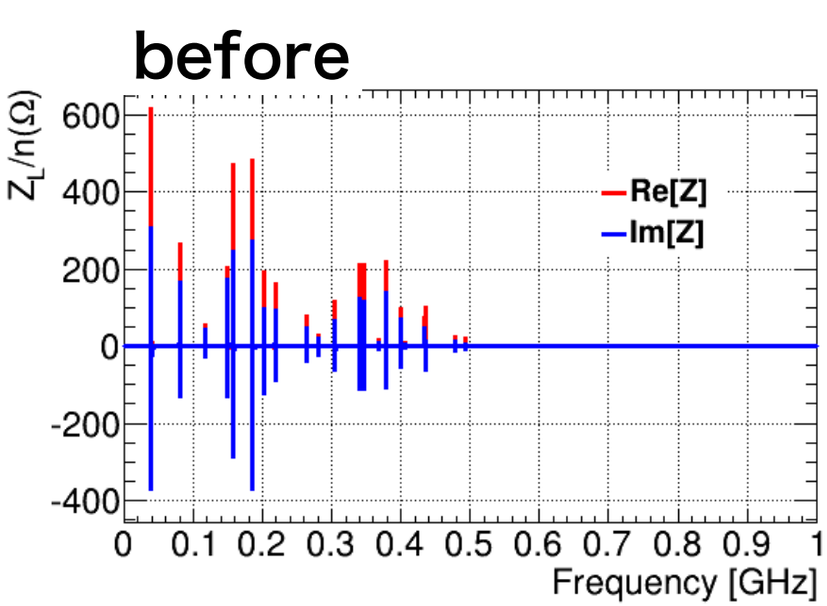


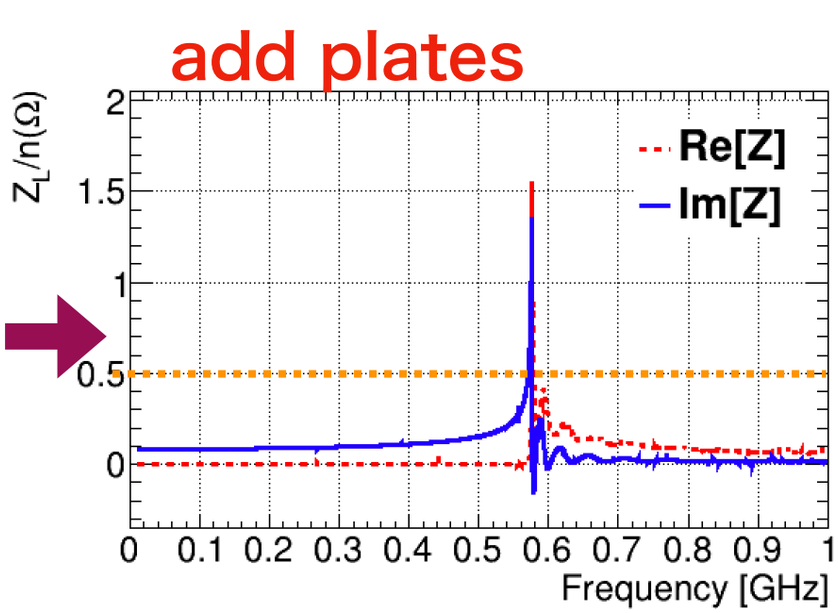


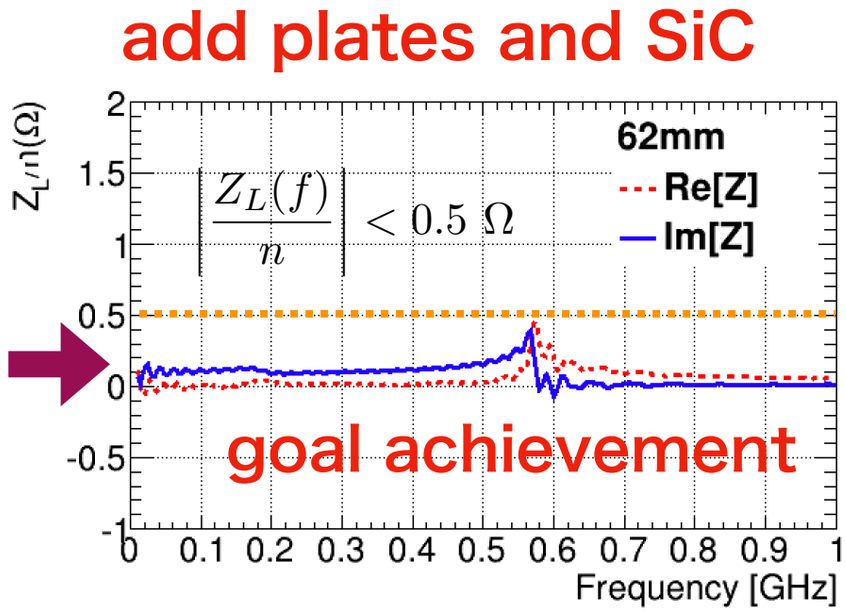


Absorbed by radio
wave absorber SiC

Electromagnetic fields build up on steps.







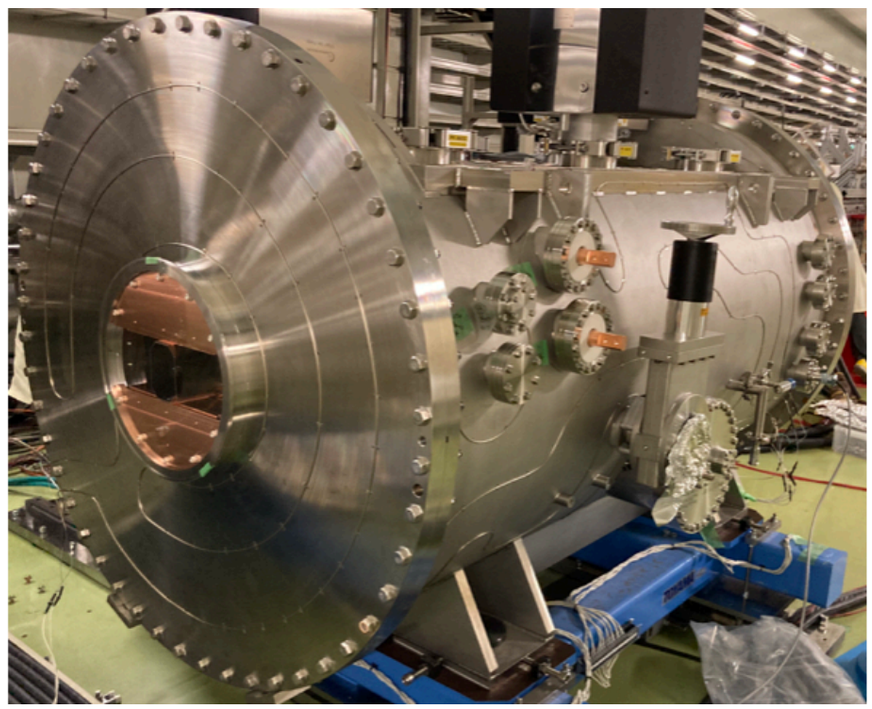
A method to significantly reduce impedance was devised and produced. [4]

[5] A. Kobayashi et al., Nucl. Instrum. Meth. A 1031, 166515 (2022)

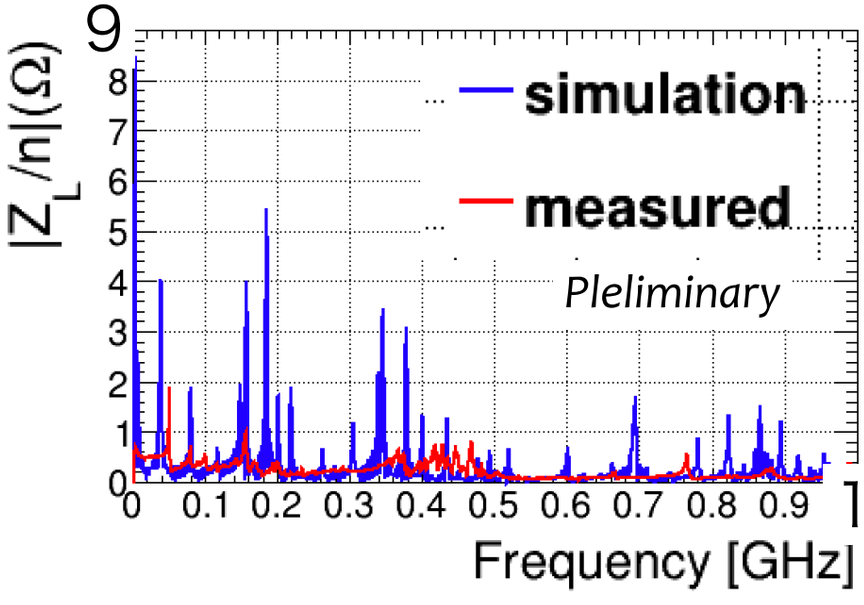
Impedance measured results

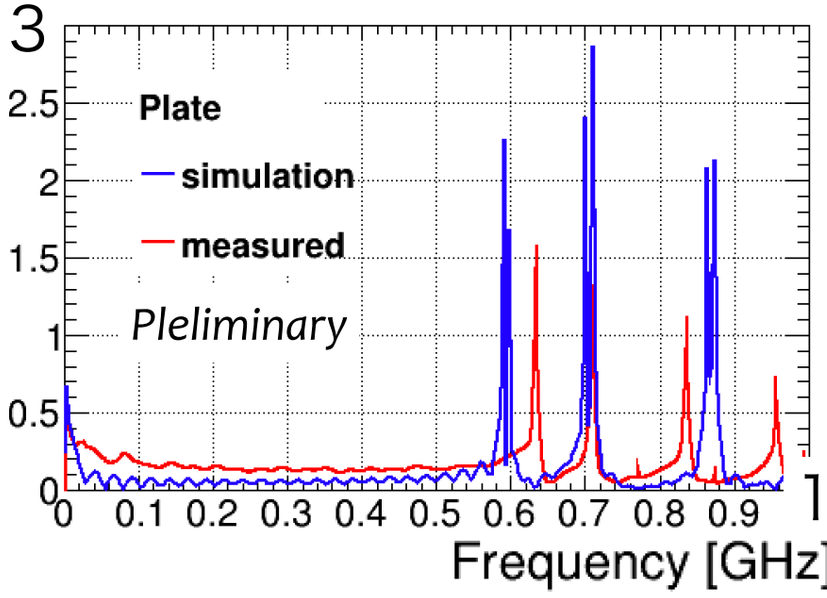
No countermeasures

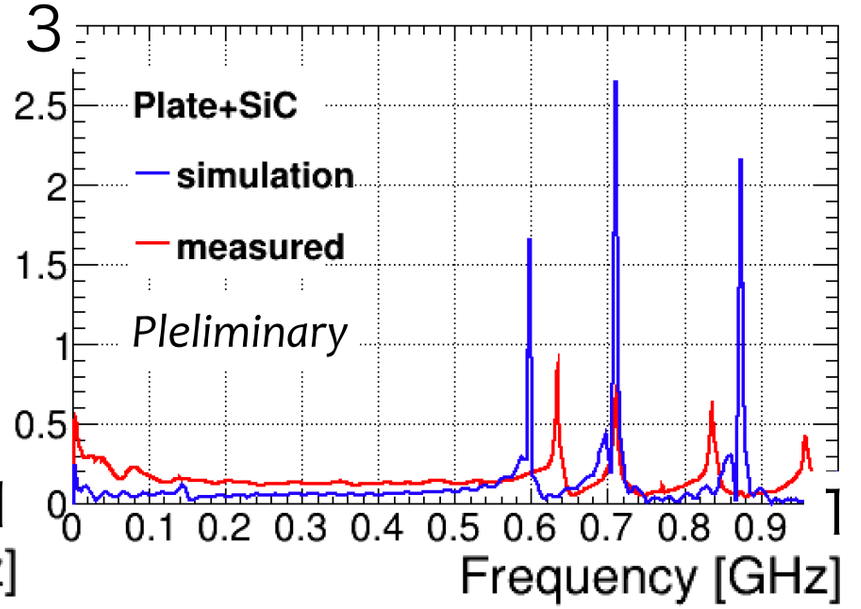
With contact



With contact and absorber (SiC)







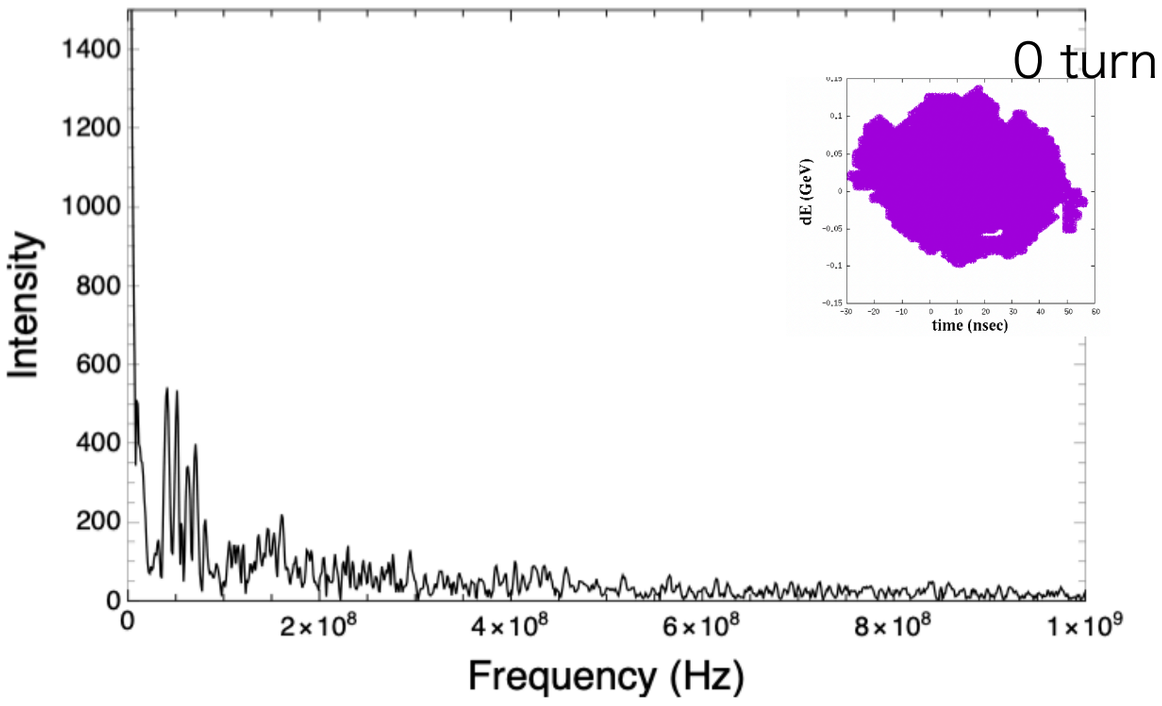
Impedance reduction effect was confirmed by measurement

Differences from the model will be pursued in the future.

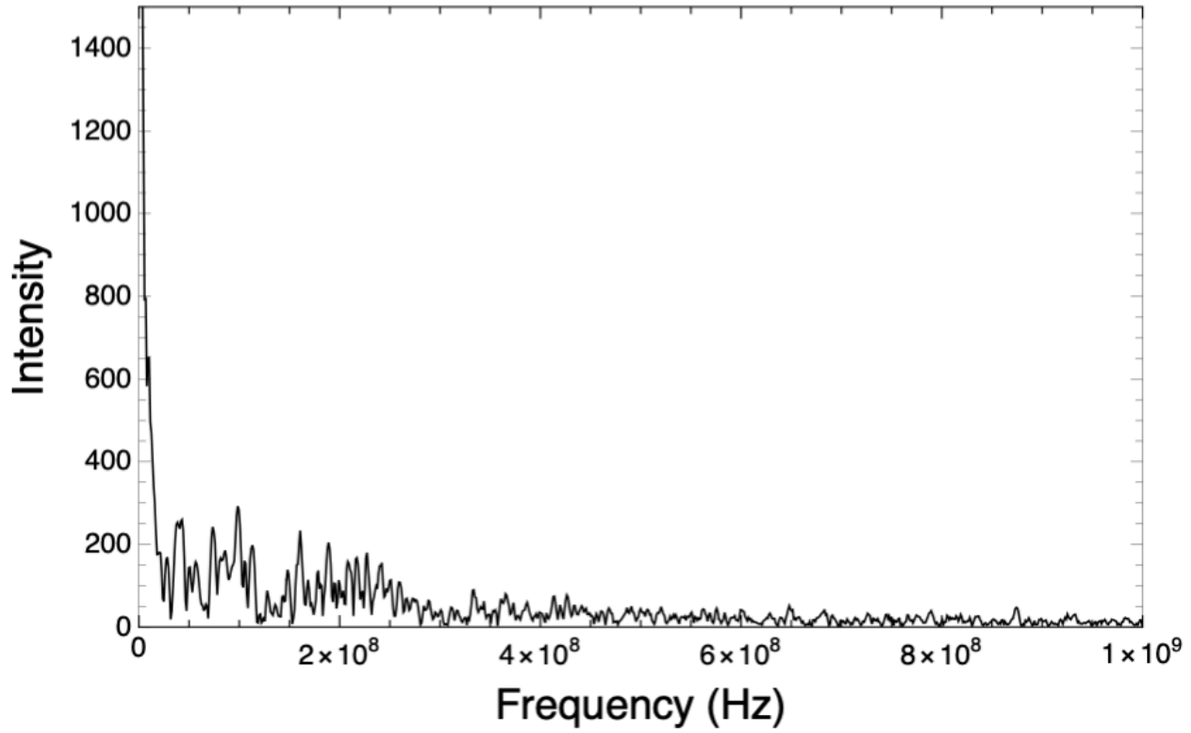
Effectiveness of countermeasures

Beam simulation [6] shows that the impedance measures for the Eddy-current type septum magnet improve the time structure of the beam.

Before impedance measures



After impedance measures(w/ contacts)

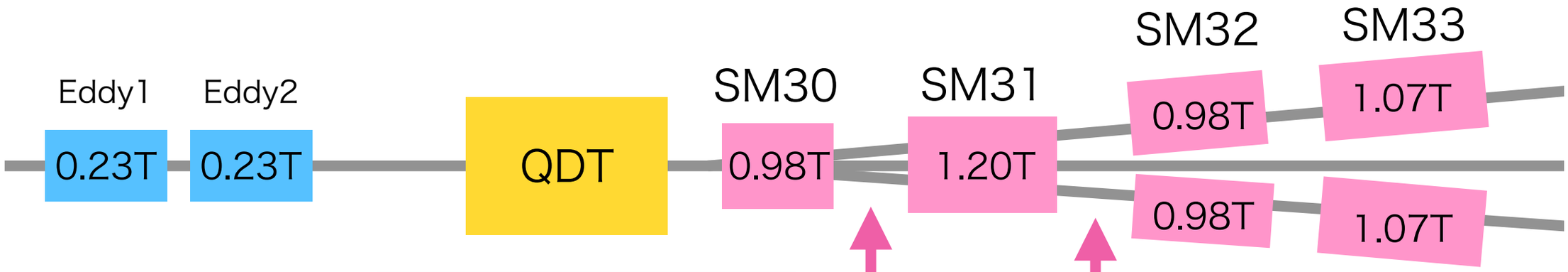


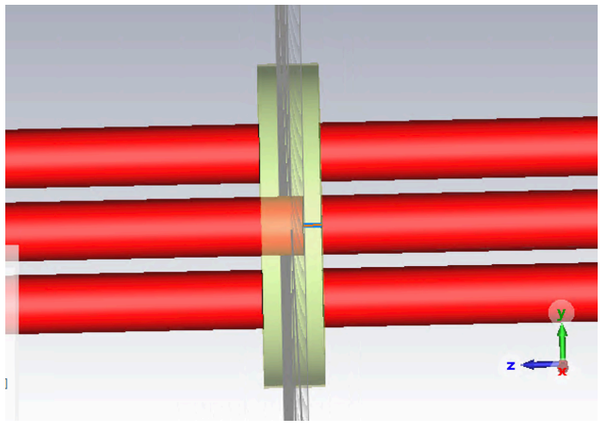
[6] Tomizawa et al., ECloud workshop 2022

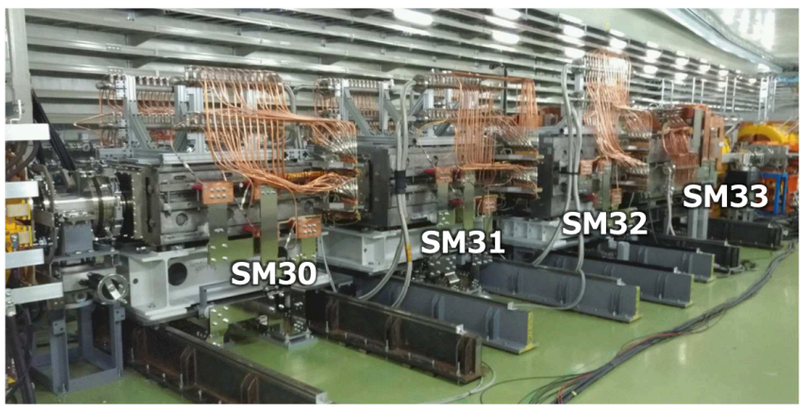
Beam instability was observed at 60 kW before the impedance countermeasure. During beam tuning in SX mode in June 2023, beam instability was not observed above that intensity, and it did not occur at least up to 75 kW, where beam tuning was performed. However, as the beam conditions and RF feedback system were improved parallelly, we did not investigate whether this is due to the impedance countermeasure alone.

High-field septa impedance

FX septam magnets

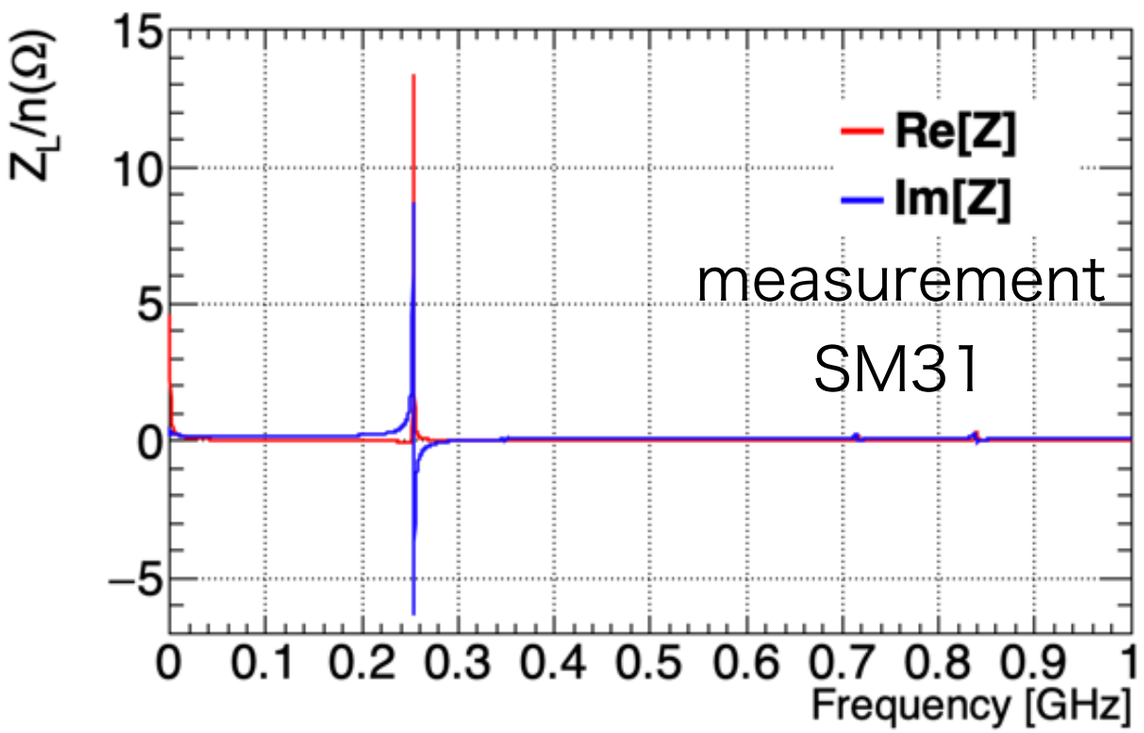






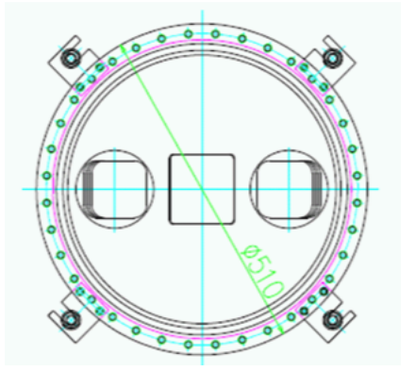
Picture from slides by T.Shibata

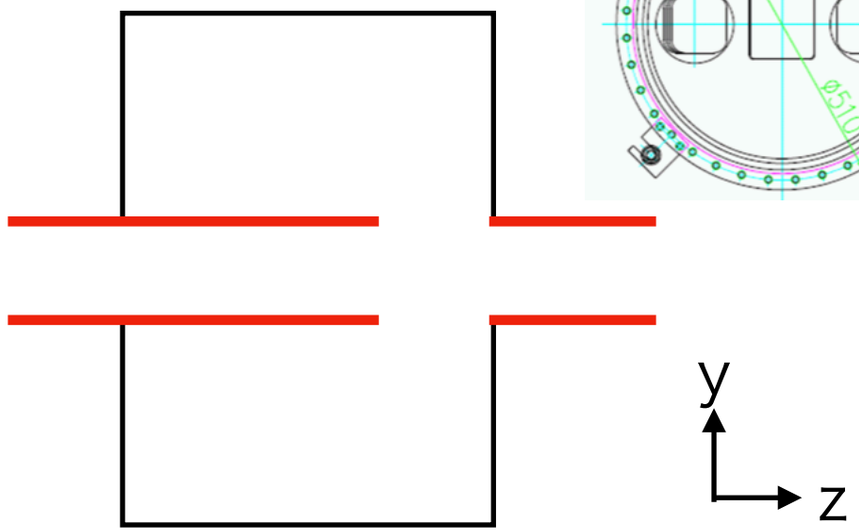
The problem is that the SM30~32 connections have a cavity-like structure and have a large impedance.



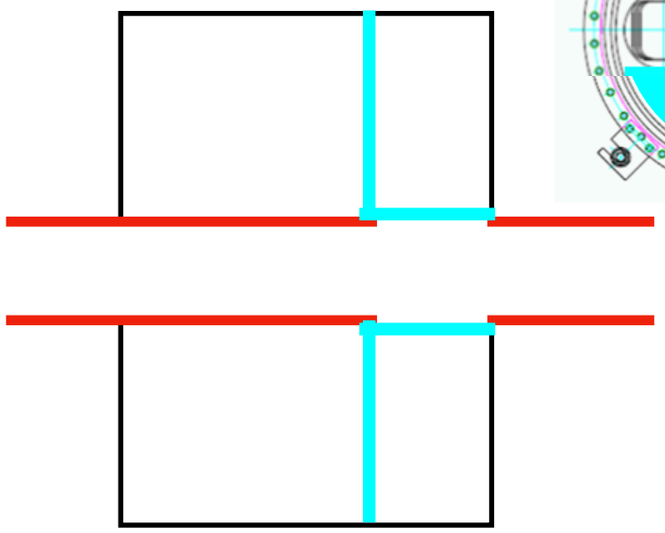
Outline of countermeasures

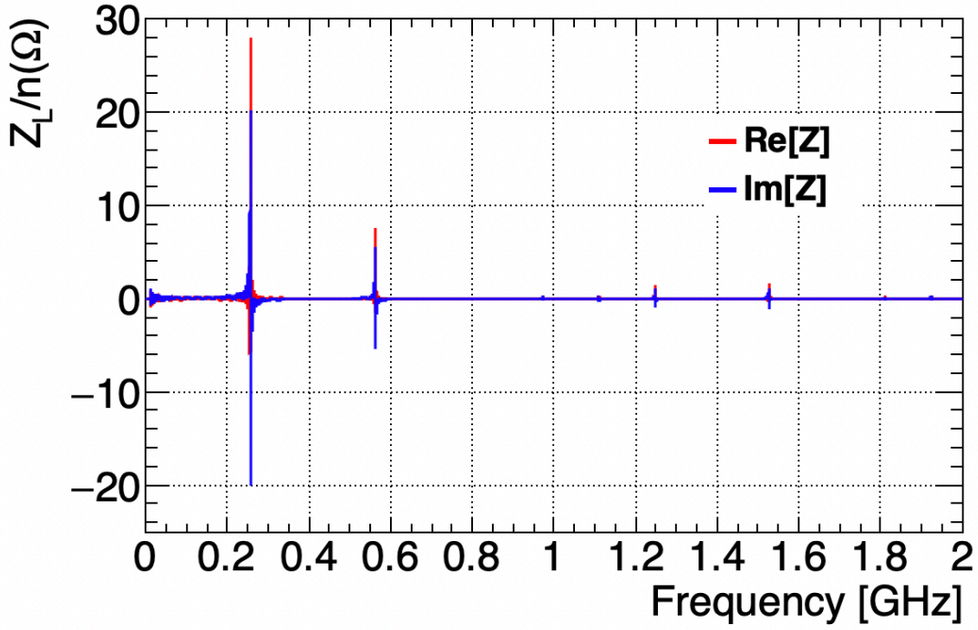
before





after





Extending the beam pipe to ensure the bellows' elasticity and maintainability is difficult, and we are considering installing contacts with copper plates to ensure a smooth flow of wall currents with measures similar to Eddy-current type.

Summary

Upgrades are ongoing at J-PARC MR for beam enhancement.
Microstructures in the high-intensity debunching process cause longitudinal beam instabilities, electron clouds, and transverse beam instabilities.
We are in the process of measuring and addressing the major impedance sources.
This report summarizes the measured and simulated impedances of the main longitudinal impedance sources, RF-cavities, FX-kickers, and FX-septa.