

Measurements of Radiation Fields From a Ceramic Break

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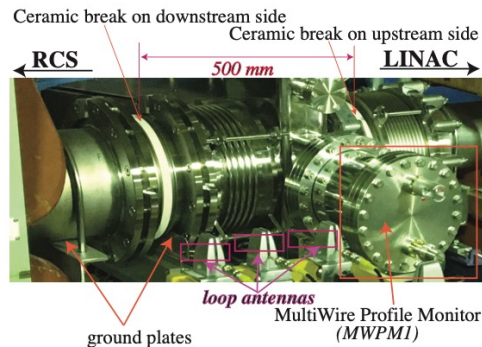
This work was supported by KAKENHI (17K05124)

◆ Outline

- Introduction
- Performance of Multi-Wire Profile Monitor, and the nearby Ceramic breaks
- Measurements of radiations and impedances from Ceramic breaks in the electromagnetic anechoic chamber, and their application for wideband monitor
- Measurements of radiations from Ceramic breaks in J-PARC
- Summary

➤ Introduction

- Seven Multi-Wire Profile Monitors are used to adjust the injection LINAC beams during the painting process to produce high-intensity beams at the RCS in J-PARC.

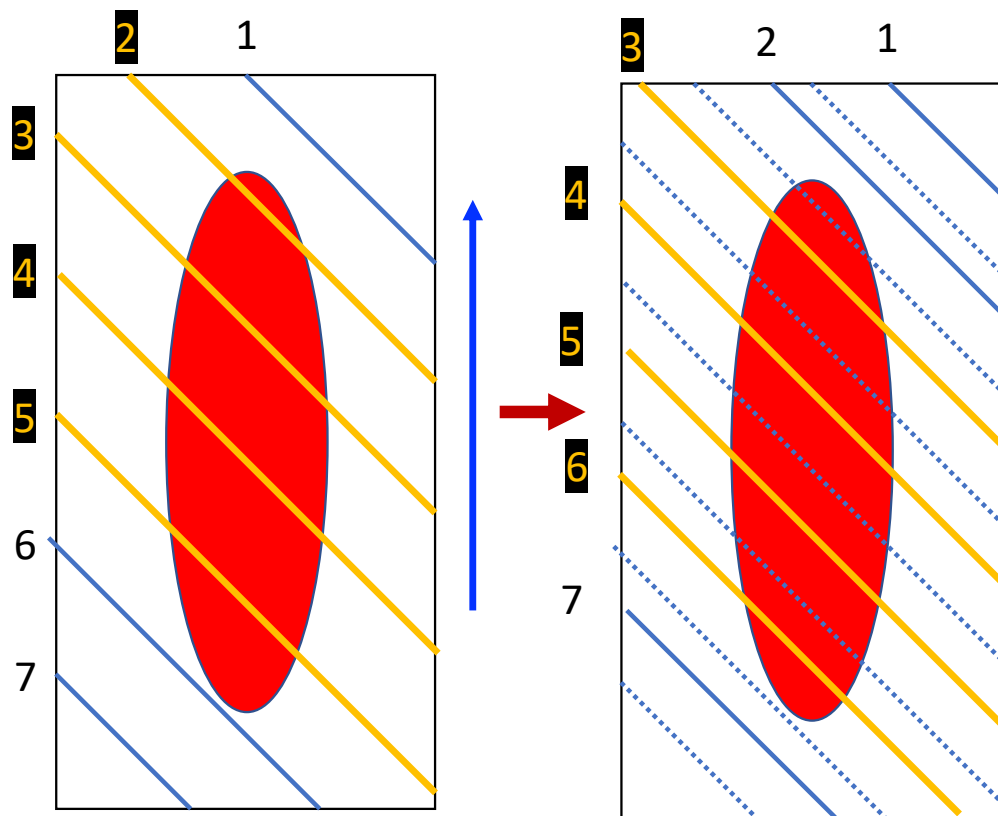


- Ceramic breaks are beneficial to electrically keep monitors durable from noises due to nearby magnets or to suppress the eddy current effects.
- To prevent wall currents from interfering with the MWPM on the injection line to the RCS, the MWPM is sandwiched by two ceramic breaks.
- Based on the design concept of RCS,
 - ❑ The ceramic breaks are not covered over capacitors.
 - ❑ neither coated with thin (~ 10 nm) TiN.

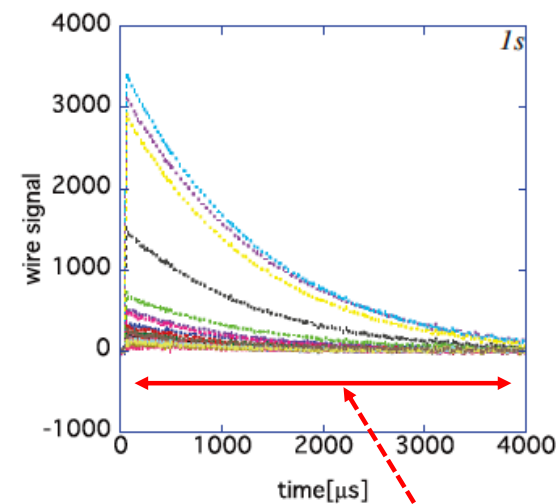
- On the other hand, the radiation fields from the ceramic breaks themselves can be another source of the noise.
 - ❑ The ceramic breaks without capacitors neither TiN coating caused a malfunction of the monitors at the very early commissioning stage of MR in J-PARC.
- Moreover, radiation from ceramic breaks is closely related to the beam coupling impedance (*Y. Shobuda et al, PRAB 10, 044403 (2007); PRAB 12, 094401 (2009); PRAB 17, 091001 (2014); PRAB23, 092801 (2020)*).
- From a beam impedance point of view, or suppressing the electron cloud build-up, it would be better
 - ❑ The ceramic breaks are covered over capacitors.
 - ❑ Coated with TiN.
- ❖ Can the ceramic breaks suppress the radiations (impedances), while eliminating the noise through the current on the chamber wall ?
- ❖ For the investigation, we use MWPM1 on the injection line with very low-intensity LINAC beams to secure a safe workplace.

➤ Performance of MWPM1, and the nearby Ceramic breaks

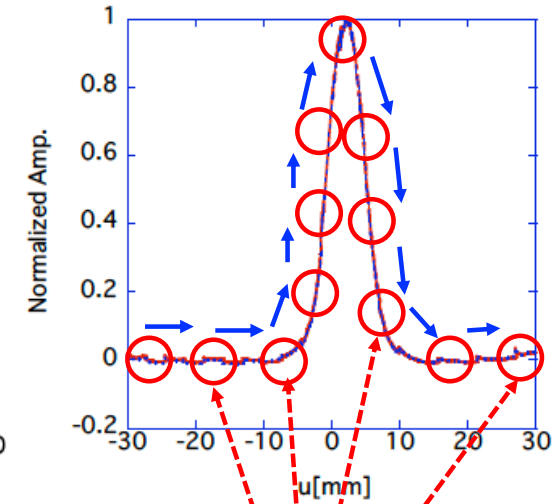
- MWPM1 consisting of 27 wires measures the transverse beam profile.
- Each wire moves 0.1 mm/s **filling the intervals of respective wires**, while 100 LINAC beams pass there with a 1 Hz repetition rate.



Respective wire-signals



Produced bunch shape

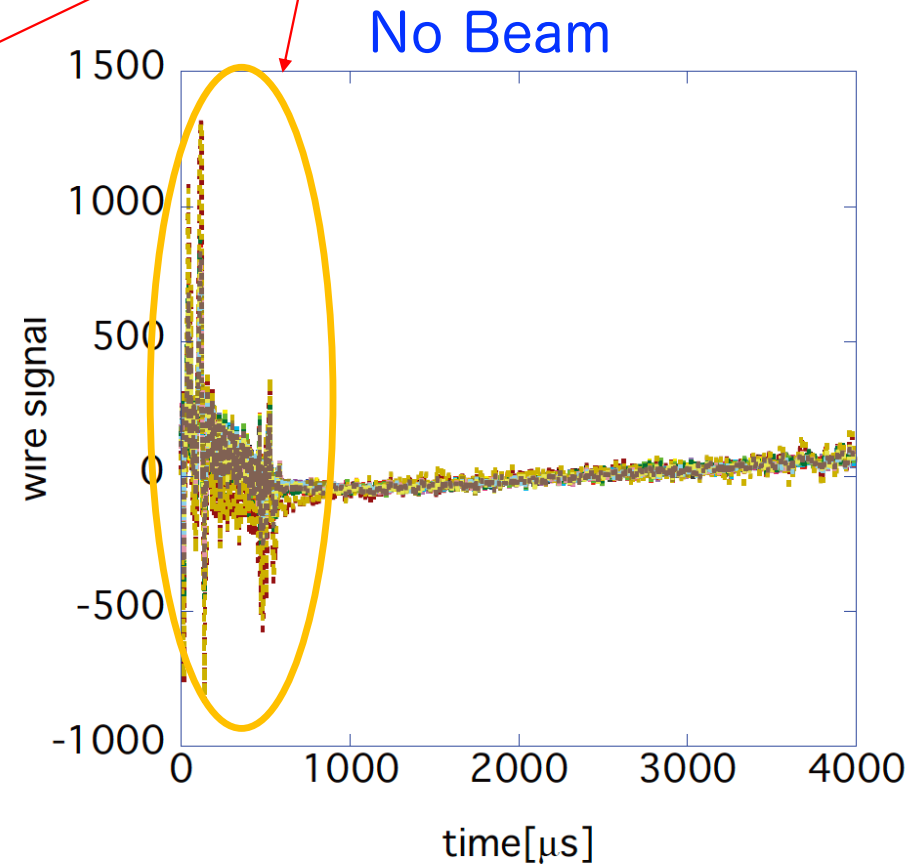
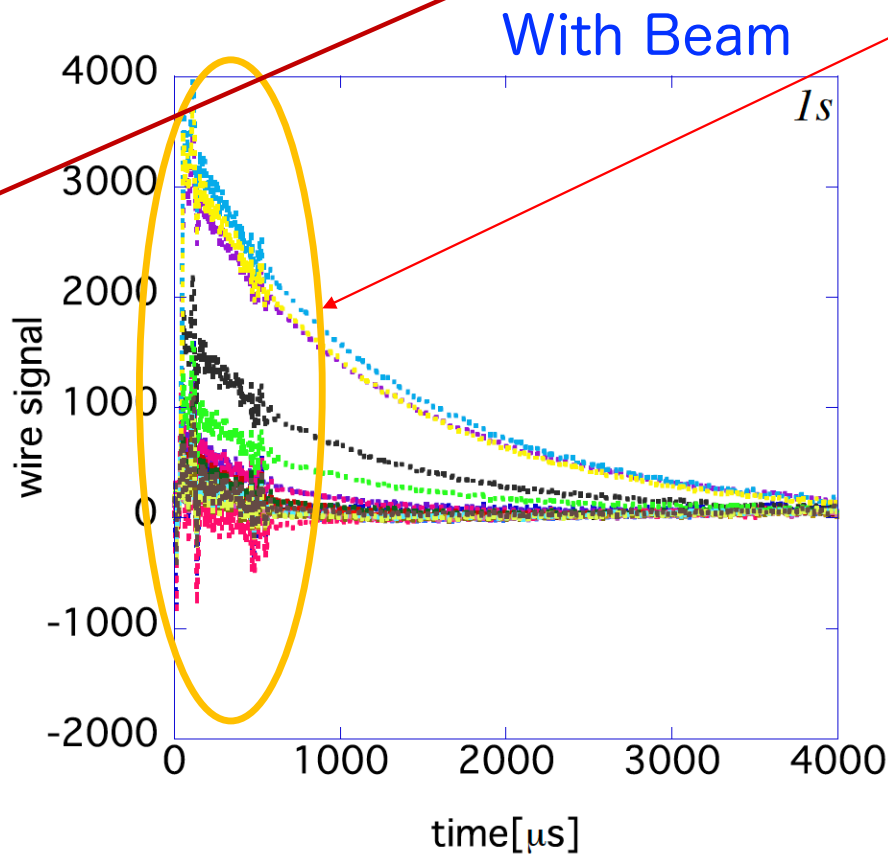
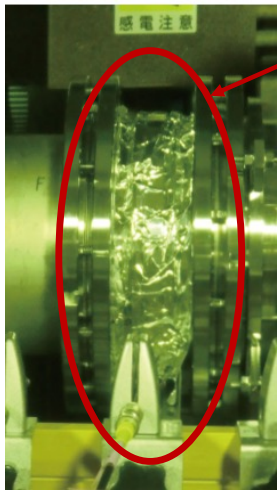


The **integration** of the respective wire-signals over **4 ms** provides the beam density at the **wire positions**.

No noise is observed.

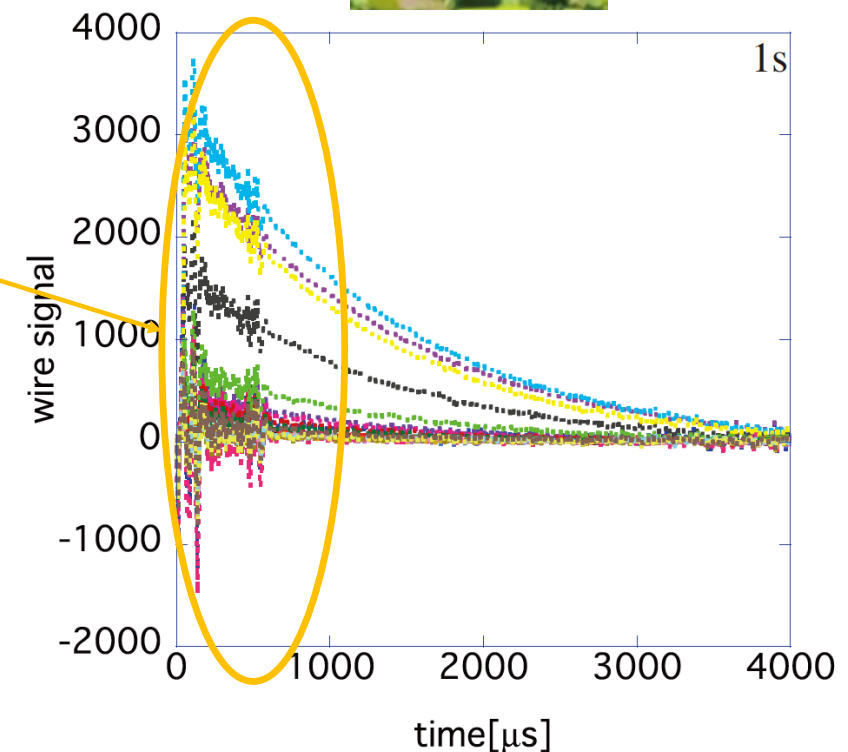
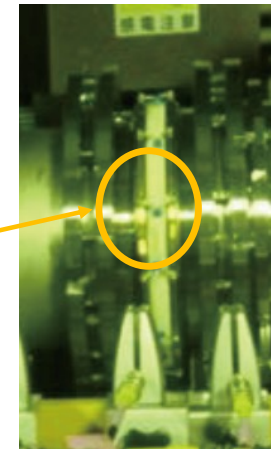
- Al sheet covered ceramic break

- When the ceramic break is covered over Al sheet, the noise emerges on the wires.
- This is not related to the beams, but due to the working of injection magnets.



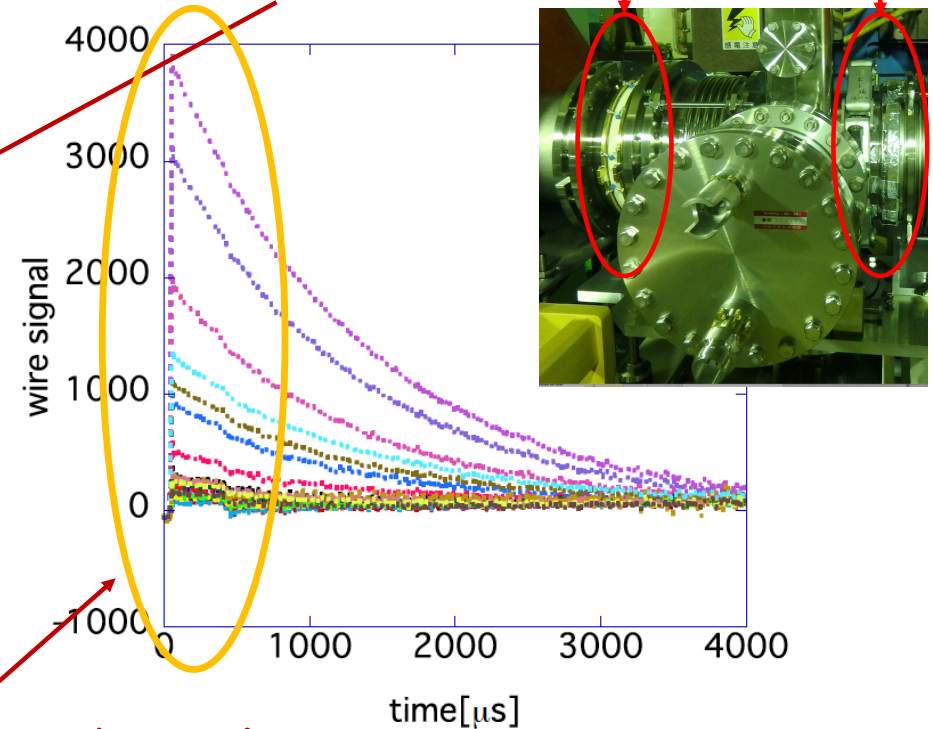
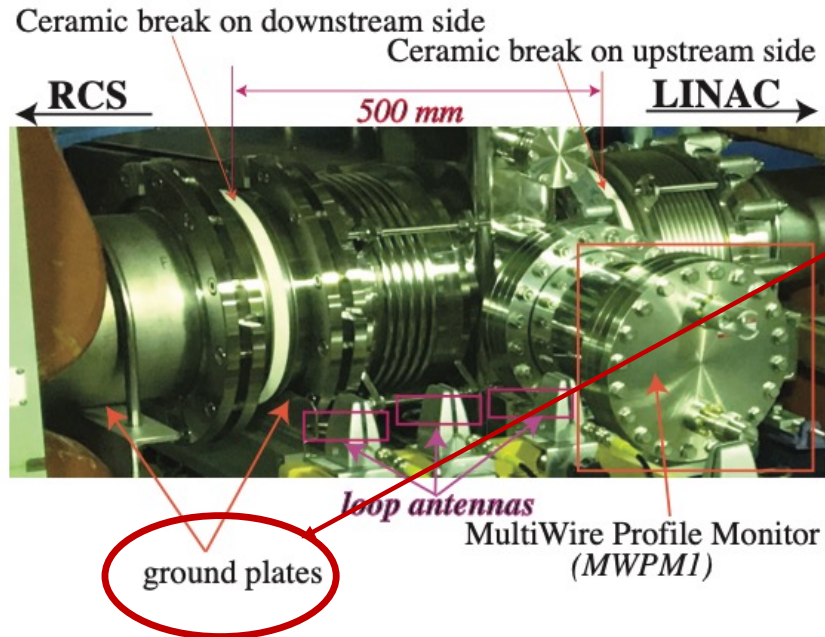
○ Capacitors covered ceramic break

- Capacitors are chosen to suppress low frequency components, referring to a typical frequency component of the machine (25 Hz at the RCS because of its repetition rate).
- Twelve $1\mu\text{F}$ capacitors still cannot eliminate the noise, because the noise has high frequency components.
- When the capacitances are made lower, the performance of suppressing impedance is degraded accordingly.
- ❖ Since it is a systematic error, the noise can be eliminated in principle (by comparing the case without beams).



- For perfect working of the capacitors

- Finally, we found the noise comes through the ground plates.

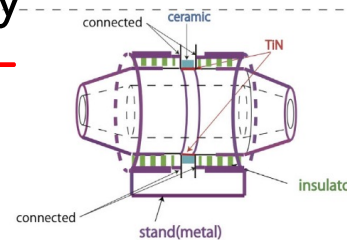
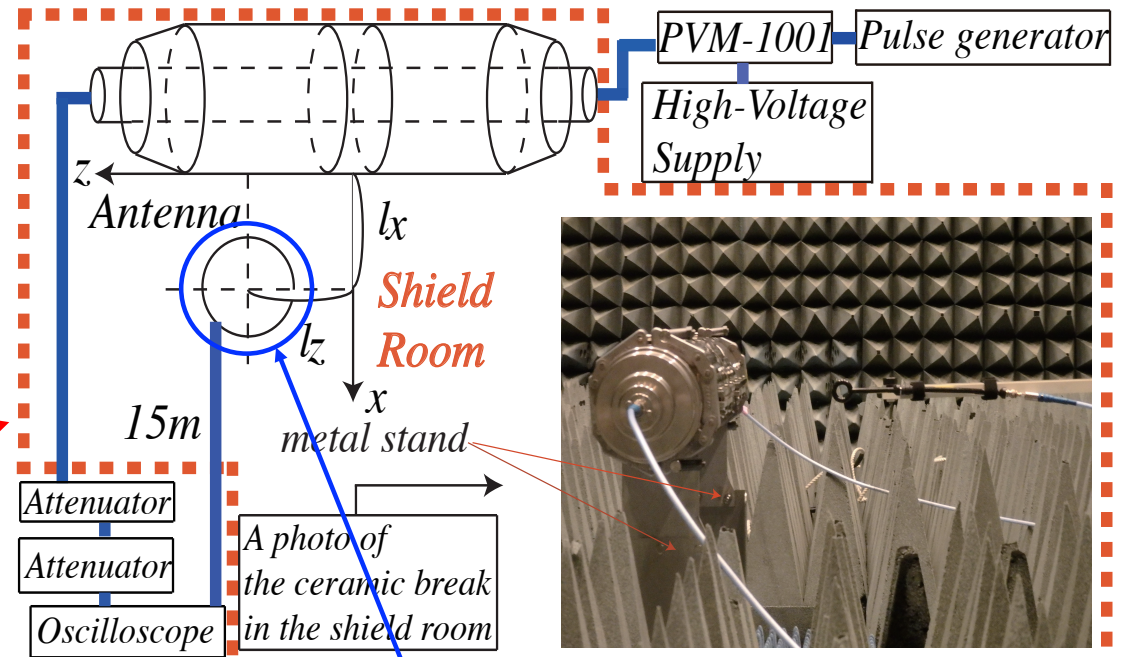


- After removing the plates, we can eliminate the noise.
- ❖ It is important to identify the noise path so that the capacitors work perfectly, because some noises have high frequency components.
- ❖ Investigate how to suppress radiations from several types of ceramic break.

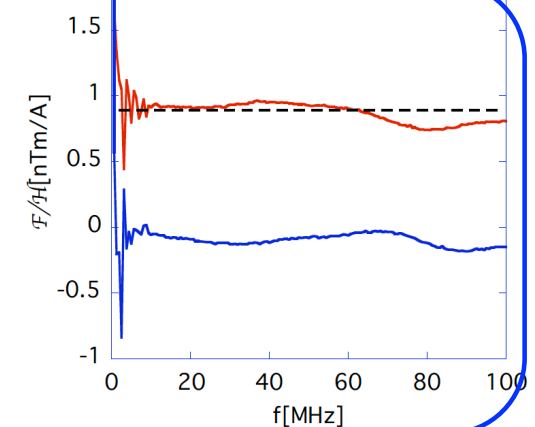
➤ Measurements of radiations and impedances from Ceramic breaks and their application for wideband monitor (by using test stand)

- Radiations are measured under the idealistic condition, i.e. **the electromagnetic anechoic chamber in JAXA.**
- The ceramics are supported by metal stand to **secure the wall-current path.**
- Ceramic breaks **with** and **without** thin 10nm **TiN coating** are investigated.

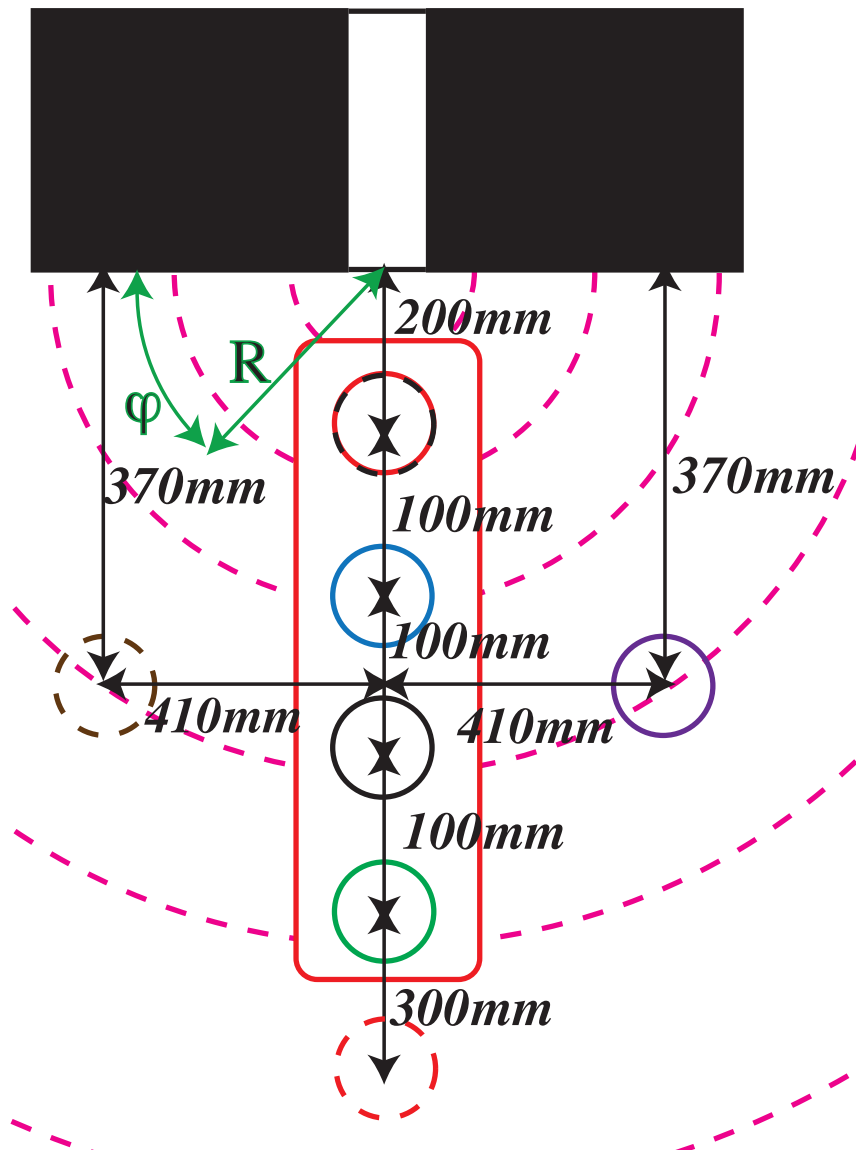
(1) Measurement setup



Measured magnetic flux divided by the magnetic field at the center of loop.



Ceramic break



□ Theoretically, H_θ in the far field region is (*PRAB 10, 044403, 2007, Y. Shobuda*) simplified as

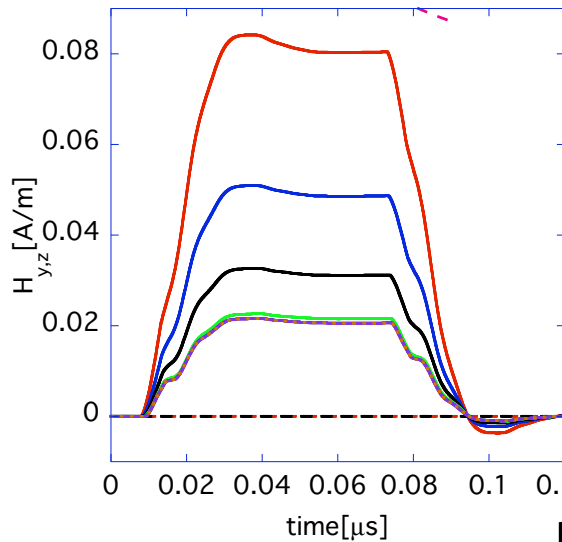
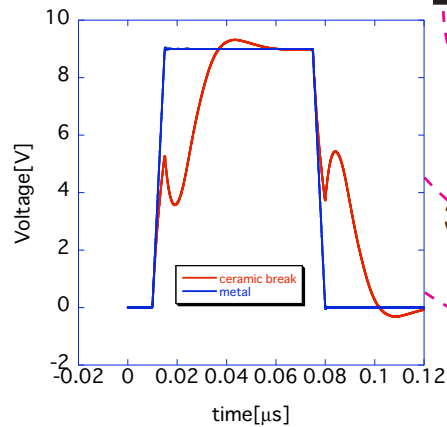
$$H_\theta(\rho, z_{\text{obs}}) \simeq j \frac{\beta c \sigma \bar{k} I_0(\bar{k} a) Z_{\text{gap} \parallel} e^{-jk\beta \bar{R}}}{2\pi \bar{R} Z_0 I_1(\bar{k} \sigma) H_0^{(2)}(k\beta a \sin\varphi) \sin\varphi},$$

relating to the longitudinal impedance.

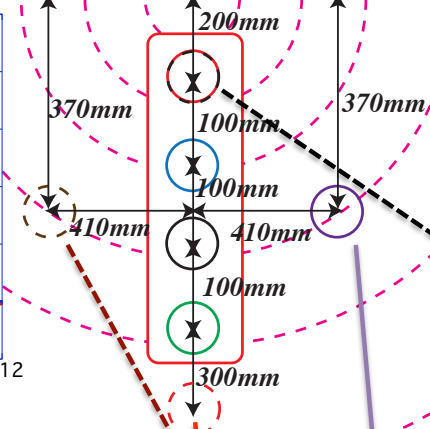
□ Characteristics

- Only H_θ is excited.
- H_θ is symmetric for the ceramic break.
- H_θ decreases inverse proportionally to R .
- TiN significantly shields the radiation by suppressing the impedance.

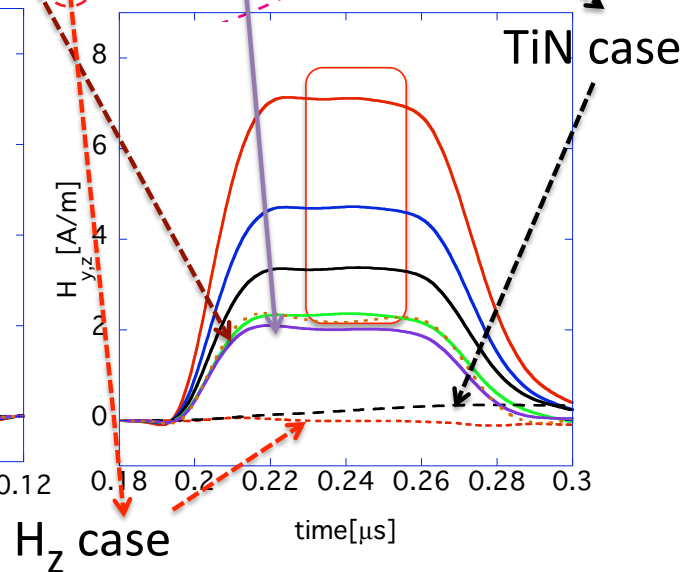
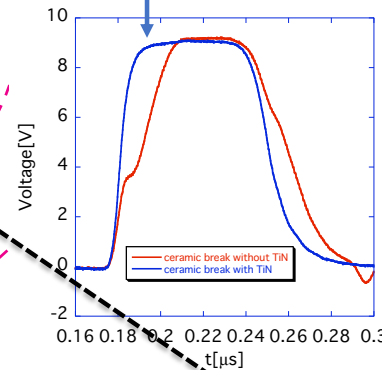
simulations



Ceramic break



measurements TiN case

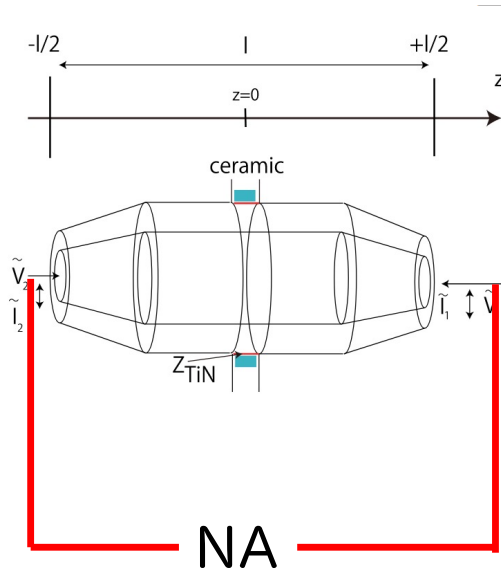


Simulations and Measurements

- ❑ 40 dB attenuator makes both results different by 2 orders.
- ❑ The impedance mismatch modulates the currents on the downstream.
- ❑ The simulations well explains the measurements (red is exception).
 - ❖ Only H_y is excited.
 - ❖ The purple and brown lines are almost identical (symmetric).
- ❑ Only 10nm TiN coating significantly shields EM.

- Measurements of the impedance of the ceramic break with TiN coating.

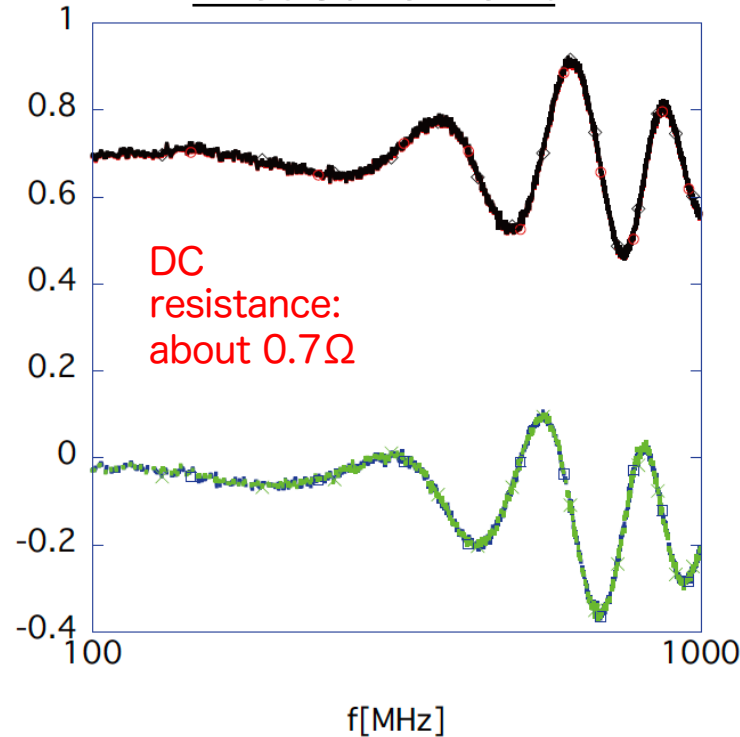
(2) Measurement setup



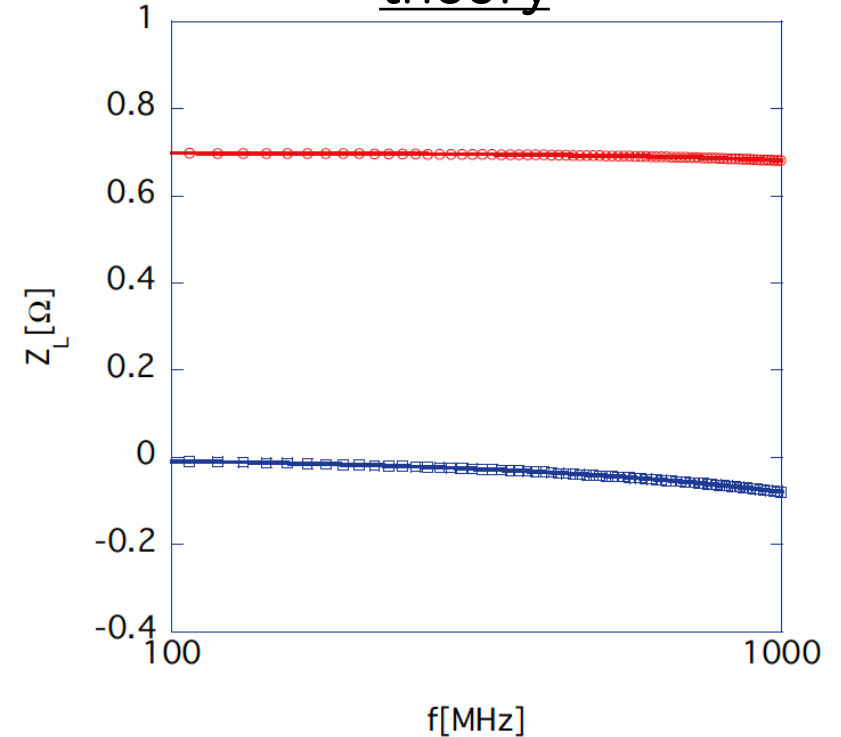
$$Z_{cerTiN,L} = -2Z_{50} \log\left[\frac{S_{12}}{S_{12}^{(ref)}}\right],$$

$$Z_{TiN} = 2Z_{50} \frac{\left(1 - \frac{S_{12}}{S_{12}^{(ref)}}\right)}{\frac{S_{12}}{S_{12}^{(ref)}}},$$

Measurement



theory

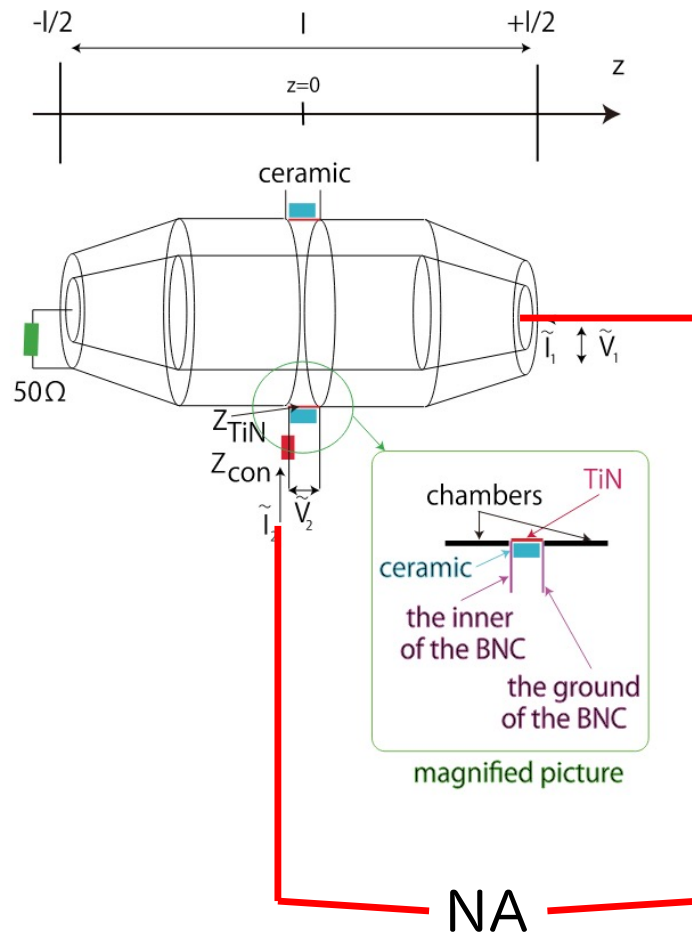


- The longitudinal impedance is suppressed with thin TiN, consistent with the measurements of radiations.
- The coupling impedance does **not depend on frequency**.
- ❖ In its application, the characteristic can be used as a **monitor with wideband**.

- Application of shielded ceramic break (Wideband monitors)

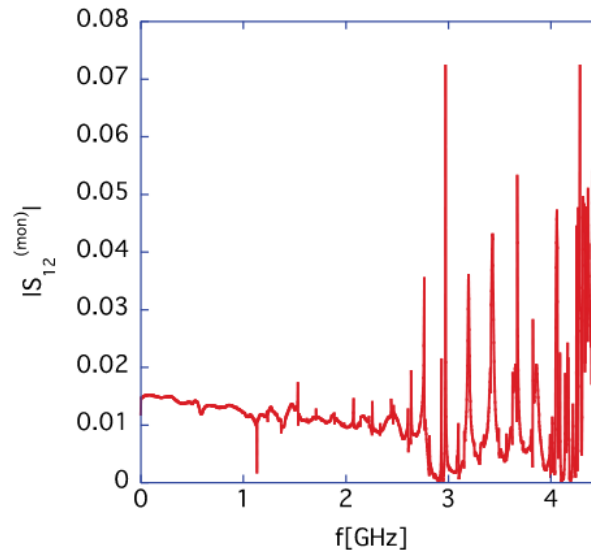
Y. Shobuda et al PRAB23, 092801 (2020).

(3) Measurement setup

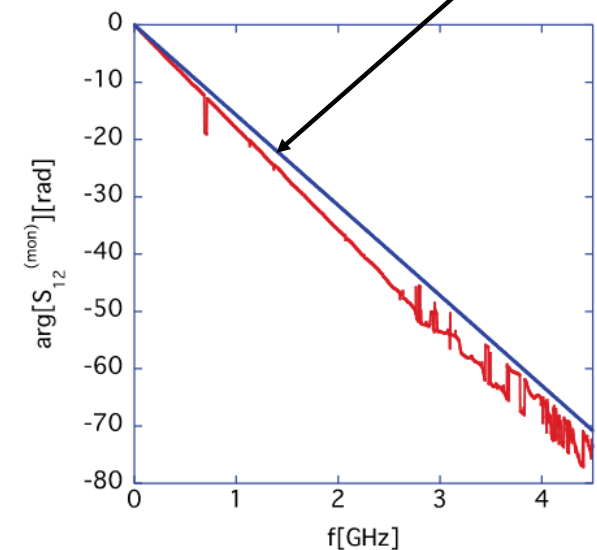


reference : $-2 \pi f v(L C) l/2$

Amplitude



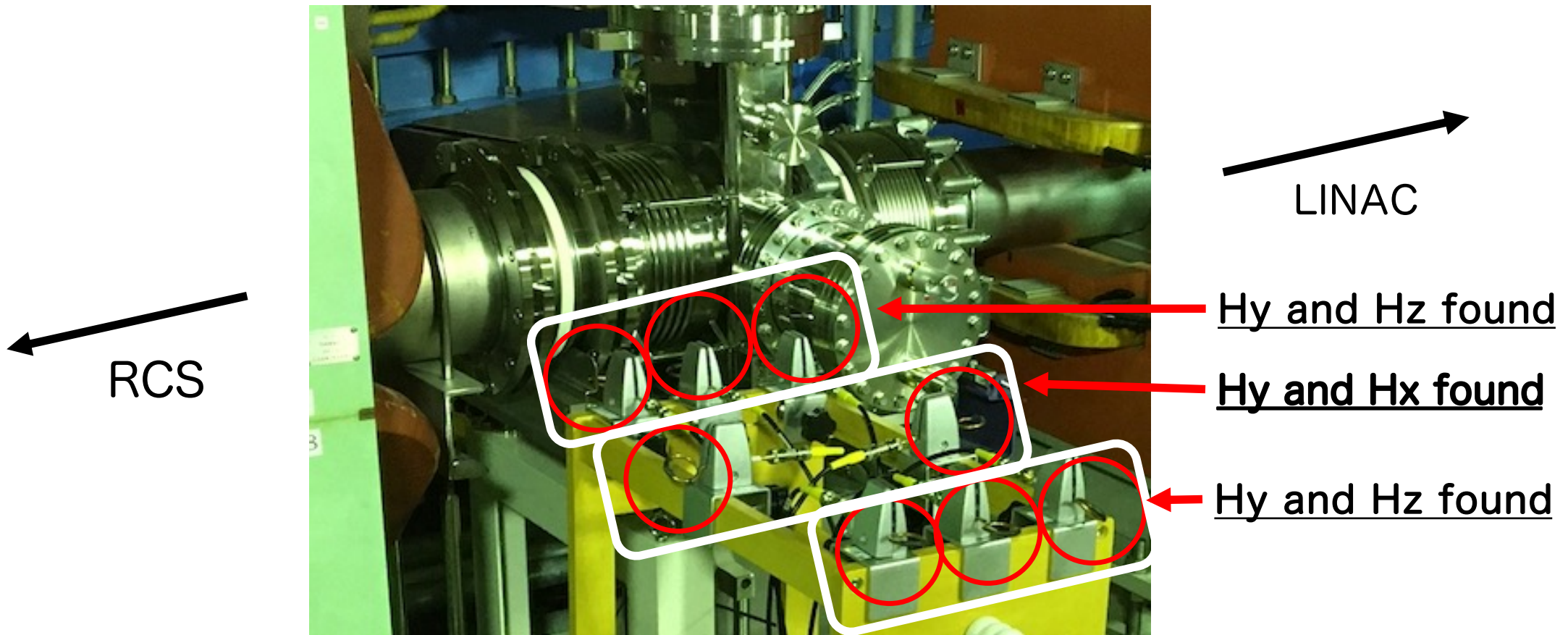
phase



- Amplitude and phase uniformity is good up to 2.5 GHz.

- ❖ The ceramic break with TiN coating not only shields EM but also can be a broadband monitor.
- ❖ Can the capacitors suppress the radiations ?

➤ Measurements of radiations from Ceramic breaks in J-PARC

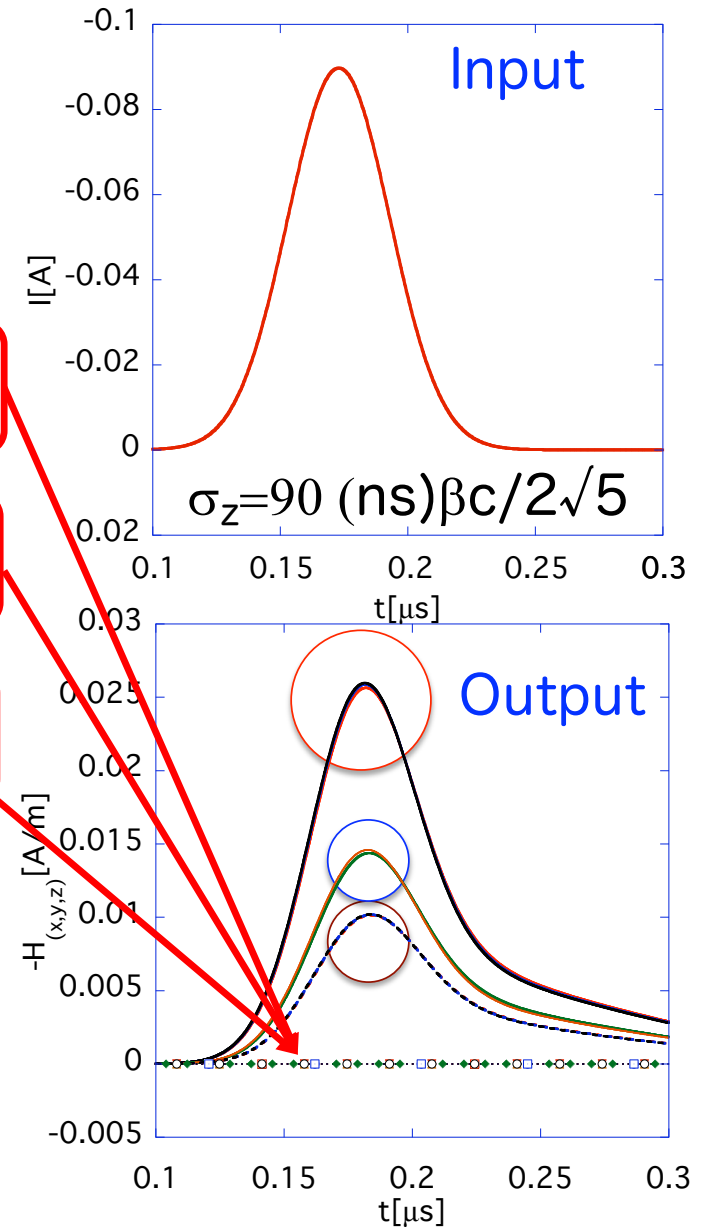
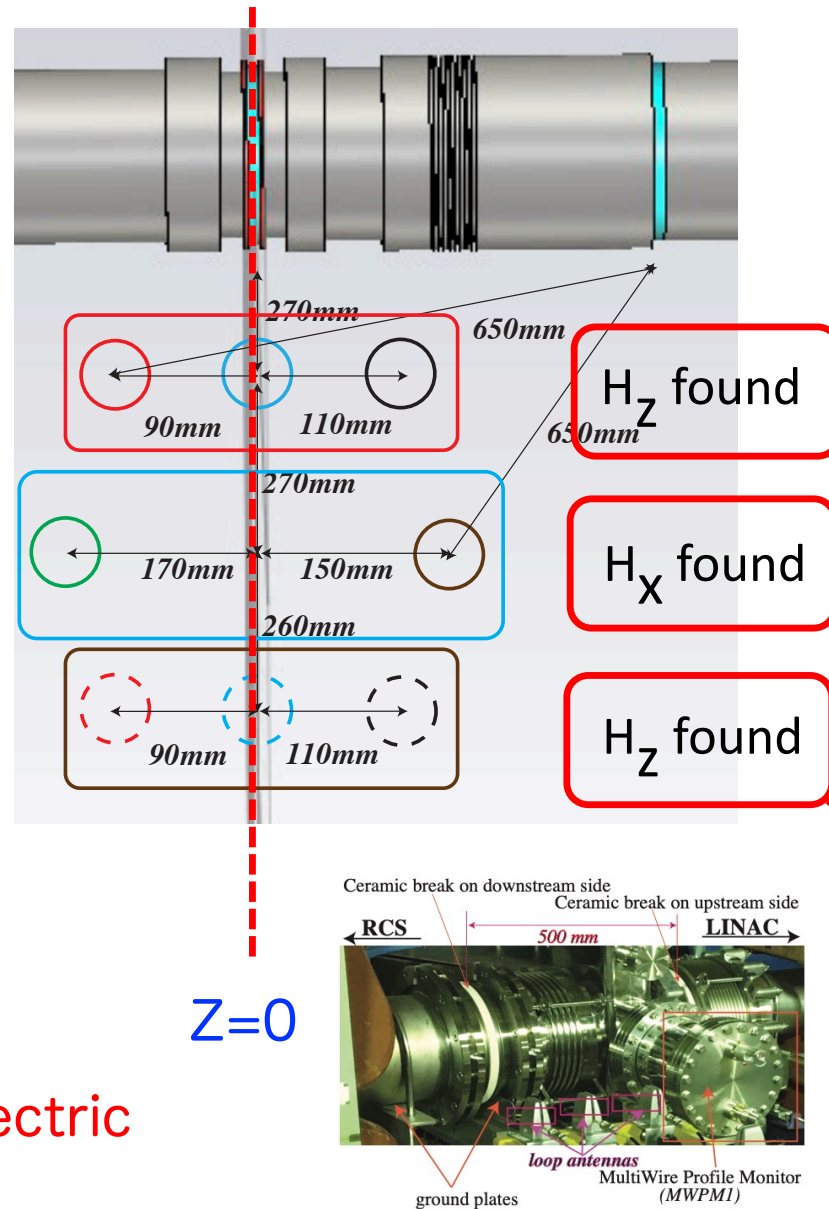


○ Simulation studies

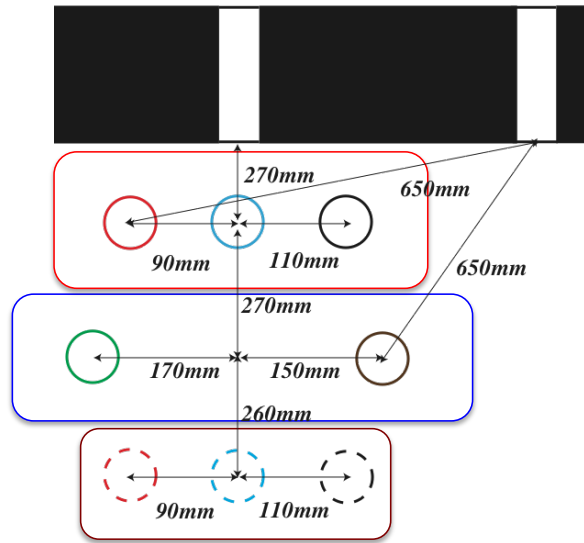
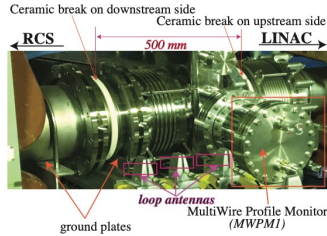
❑ The real condition is so complicated that the model is **simplified** in the simulation.

❖ Only H_y is excited, partially reflecting the longitudinal bunch shape.

❖ H_y is almost **symmetric** for the $Z=0$ plane.



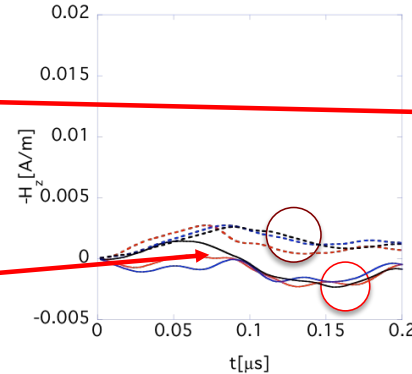
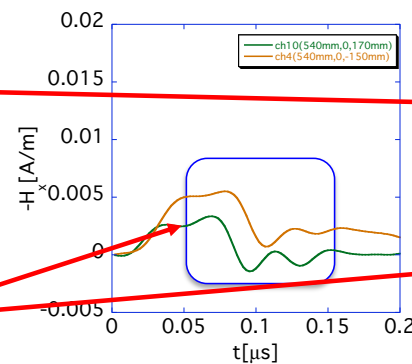
○ Measurements



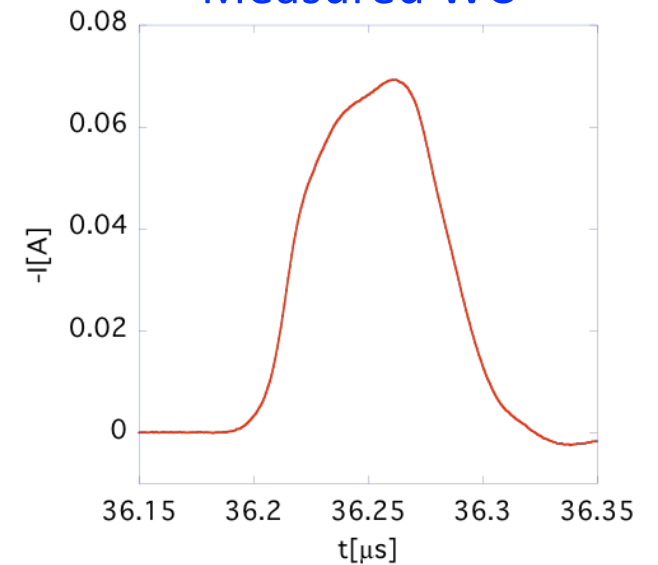
❑ Drawback : simplified simulations overestimate the measurements.

❑ Excited H_y reflects the longitudinal bunch shape.

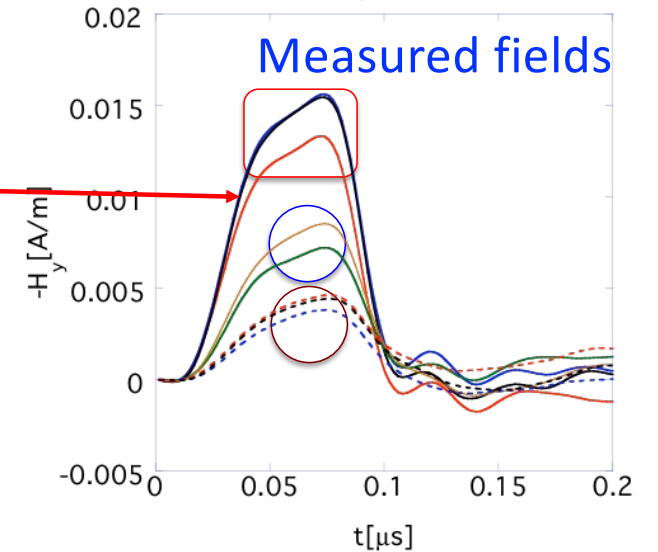
❑ $H_{x,z}$ are excited, due to the objects.



Measured WC

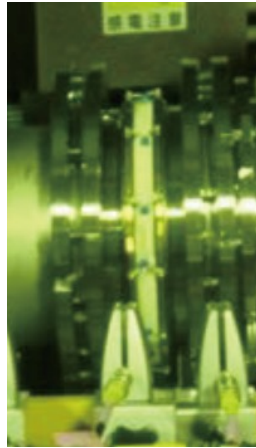


Measured fields

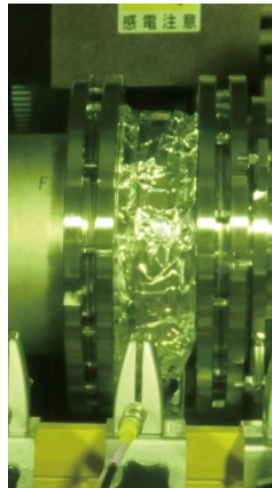


- In the case of the downstream ceramic break covered over capacitors or Al.

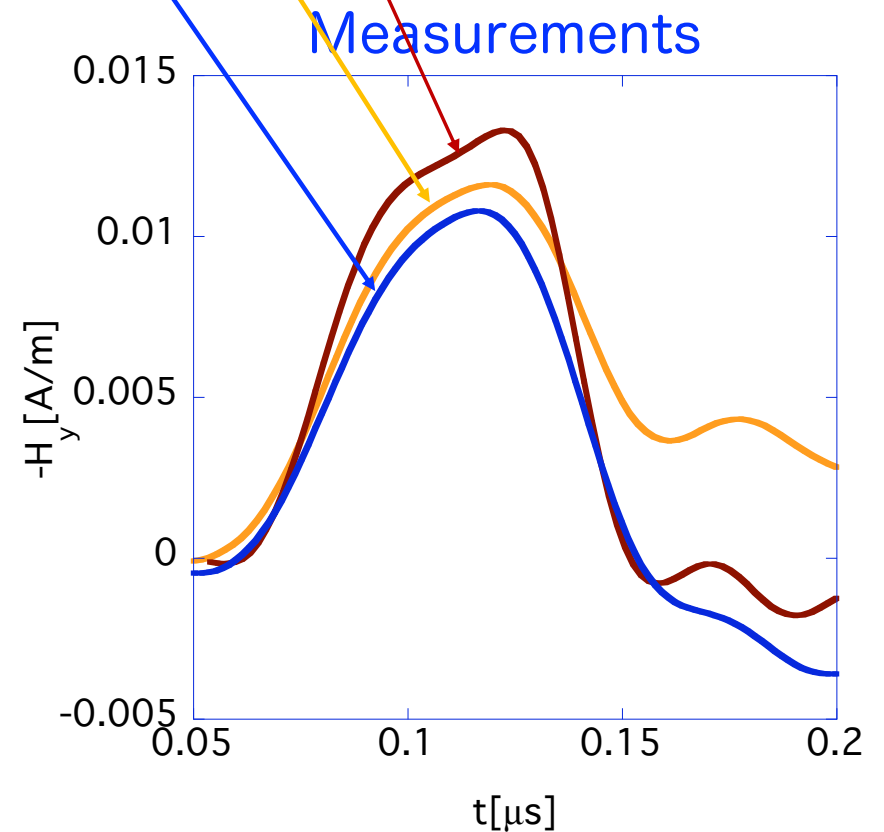
- Though the reduction effect due to the capacitors is expected to be significant, the effect is not so remarkable.



- Moreover, even when the ceramic break is covered over Al, the effect is not significant.

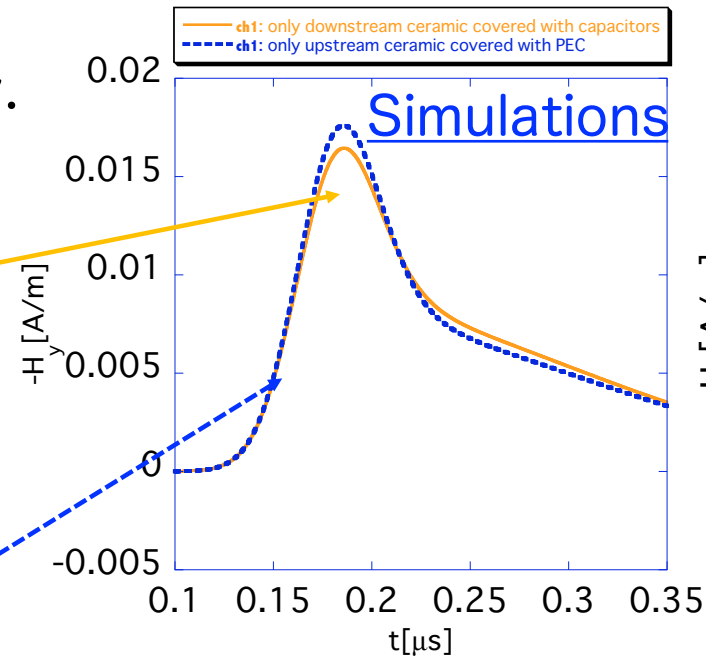
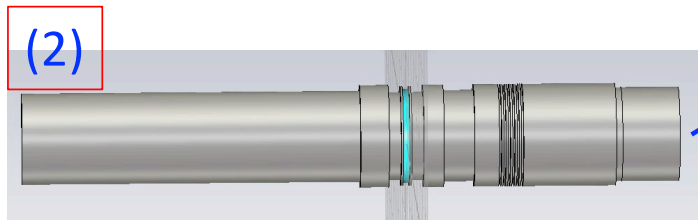
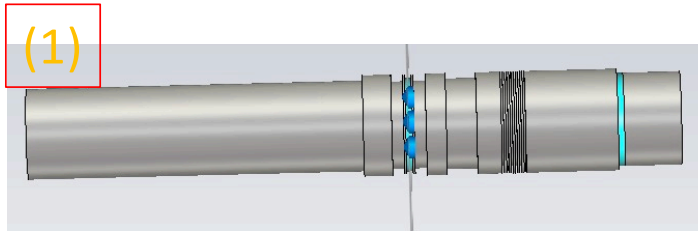


- (1) Original results.
- (2) Downstream is covered with CAP.
- (3) Downstream is covered with Al sheet.



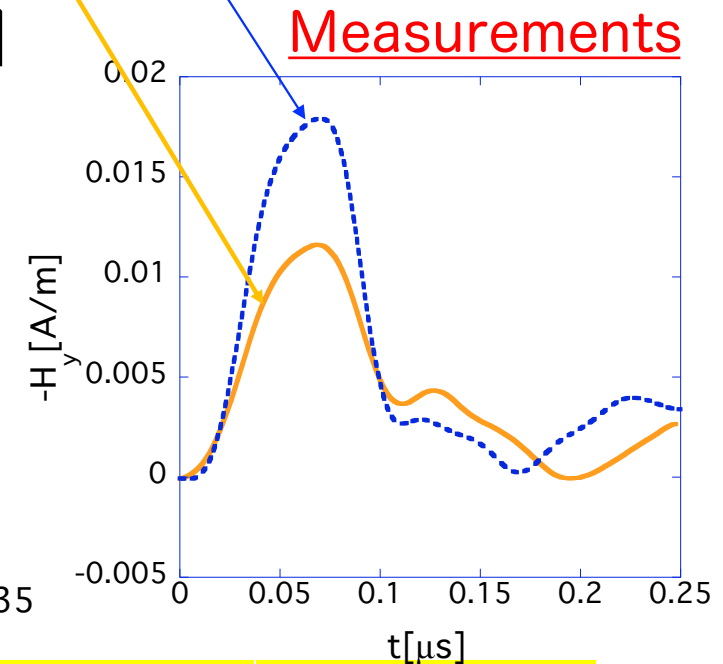
Here, let us simulate two cases where

- (1) the capacitors are attached on the downstream ceramic break only,
- (2) PEC is covered over the upstream ceramic break only.



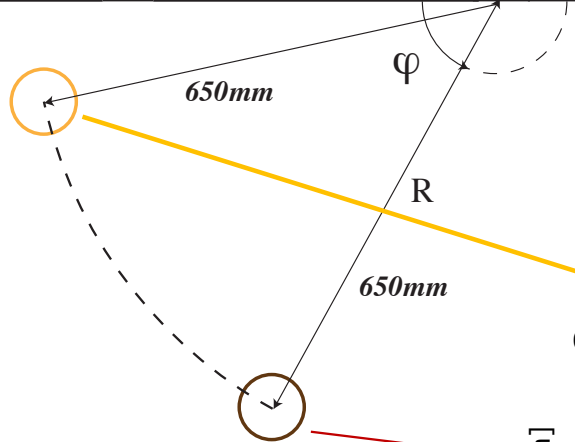
Al covers over upstream.

Capacitors covers over downstream.



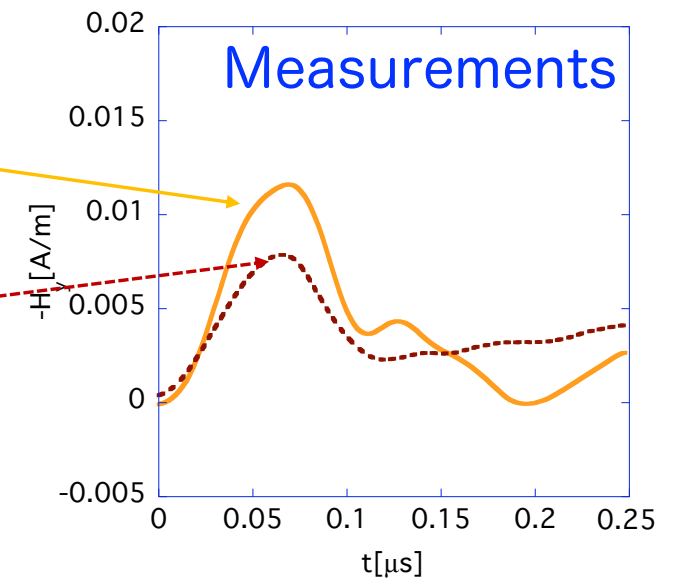
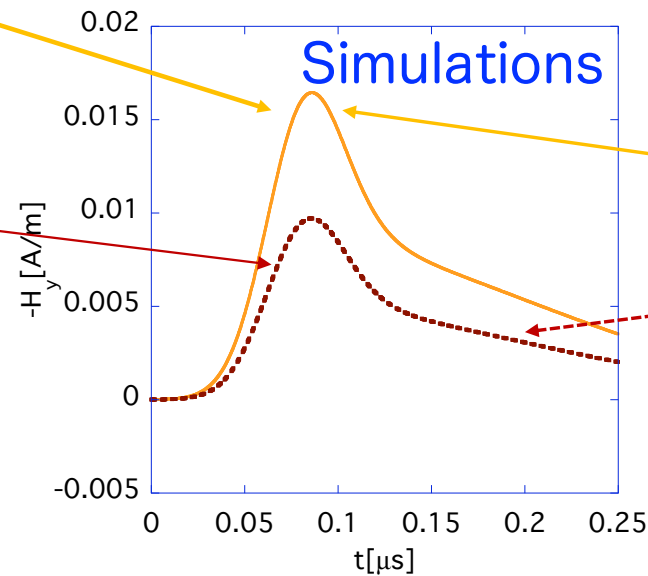
- The contribution from both ceramic break can be comparable (simulation).
- ❖ The measurement demonstrates the contribution from upstream is significant.

$$H_{\theta}(\rho, z_{\text{obs}}) \simeq j \frac{\beta c \sigma \bar{k} I_0(\bar{k} a) Z_{\text{gap}, \parallel} e^{-jk\beta \bar{R}}}{2\pi \bar{R} Z_0 I_1(\bar{k} \sigma) H_0^{(2)}(k\beta a \sin\varphi) \sin\varphi},$$



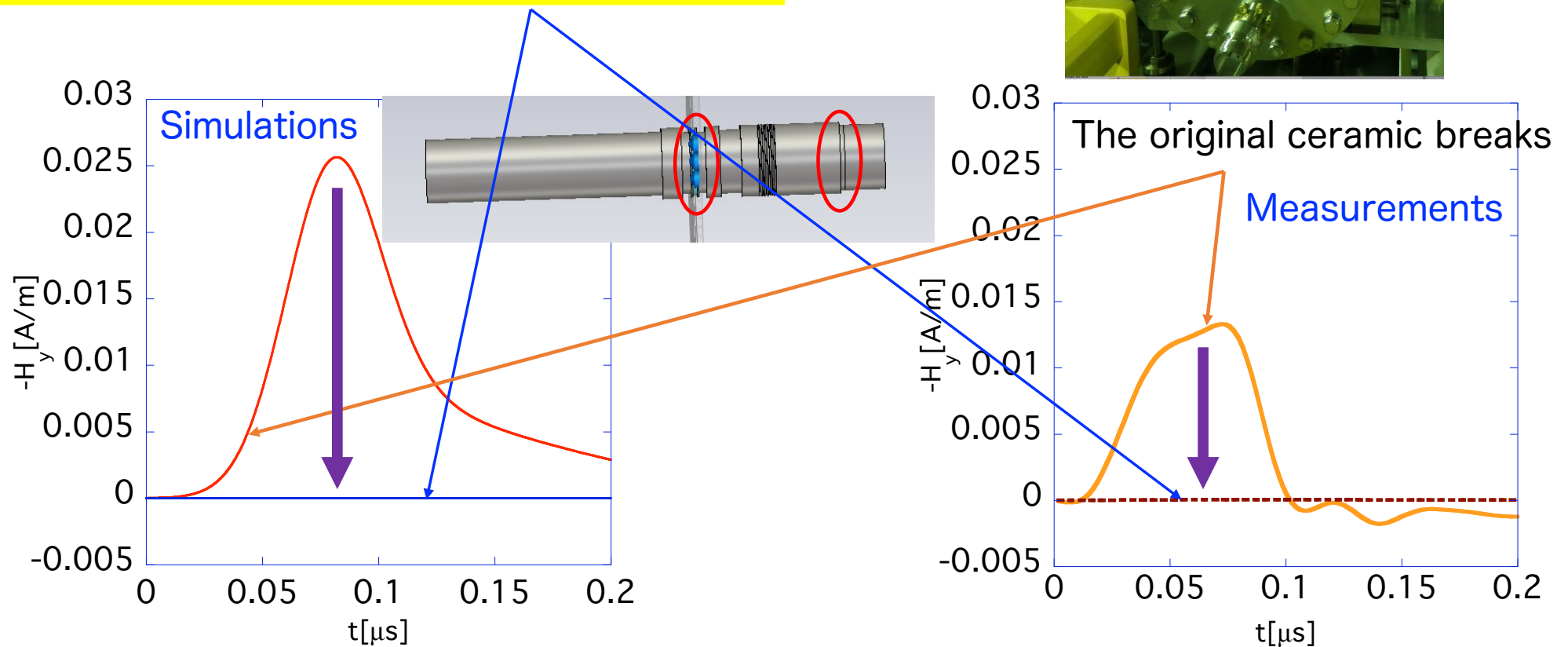
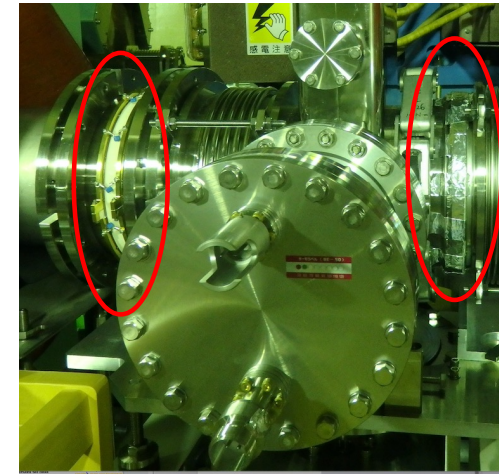
- Theoretical result suggests that the magnetic fields can be **enhanced near chamber**.
- Simplified **simulation** study **confirms** this theoretical expectation.

❖ **The enhancement is confirmed by measurements.**



- Cover not only the downstream ceramic break with capacitors,
- But also the upstream one with Al sheet.

❖ The radiations are perfectly suppressed both in simulations and measurements.



➤ Summary

- ❑ The ceramic break with 10 nm TiN coating suppresses the radiations and impedance.
- ❑ Moreover, the beam-induced voltage on the ceramic break with TiN coating can provide a broad band monitor simultaneously.
- ❑ Since the magnetic fields from the ceramic break are enhanced near the chamber wall, careful investigations are required.
 - Even a simplified simulation is a good tool to evaluate the suppression effect by the capacitors.
- ❑ The noise path through the ground would better be identified in order that the capacitors work to suppress the radiations from the ceramic breaks.