Measurements of Radiation Fields From a Ceramic Break

Yoshihiro Shobuda(JAEA/J-PARC)
Takeshi Toyama(KEK/J-PARC)
Masahito Yoshimoto(JAEA/J-PARC)
Shuichiro Hatakeyama(JAEA/J-PARC)

Special thanks to P.K. Saha, F. Tamura, O. Takeda(NAT), and S. Ohtsu(Mitsubishi).

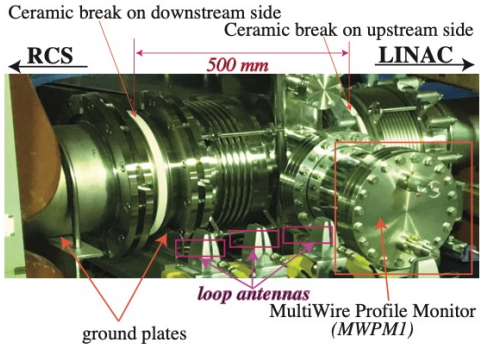
This work was supported by KAKENHI (17K05124)

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))*.

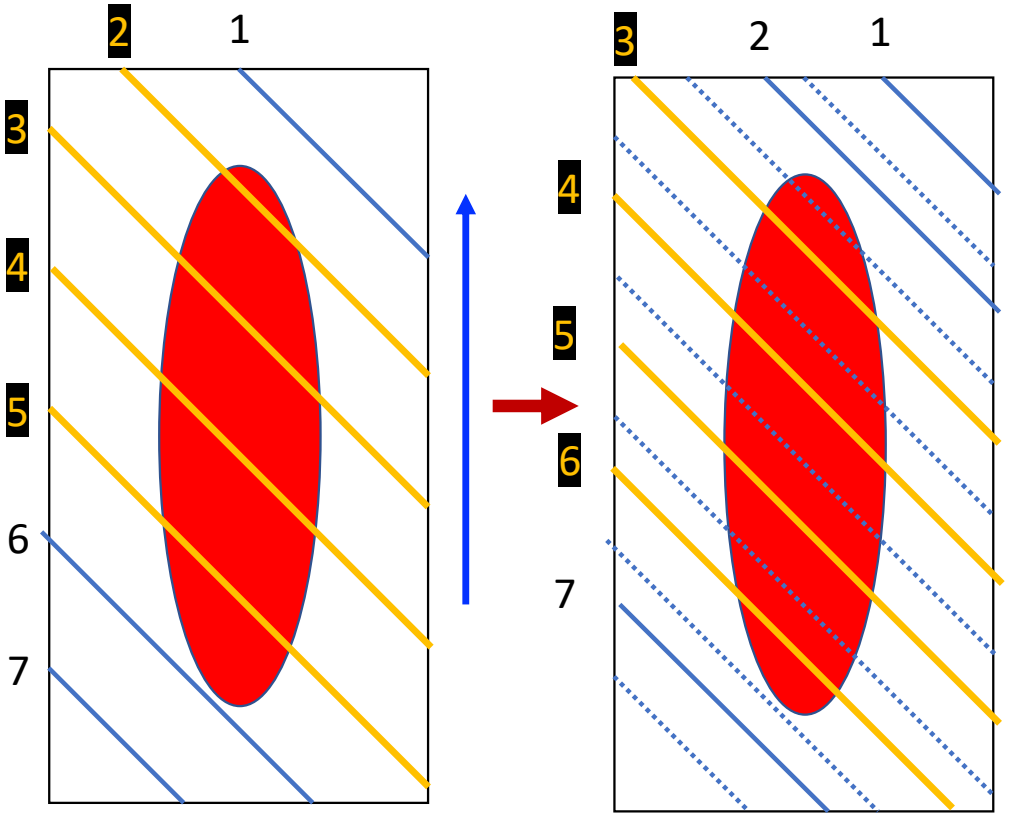
- From a beam impedance point of view, or suppressing the electron cloud build-up, it would be better
  - ❑ The ceramic breaks are covered over capacitors.
  - ❑ Coated with TiN.

❖ Can the ceramic breaks suppress the radiations (impedances), while eliminating the noise through the current on the chamber wall ?

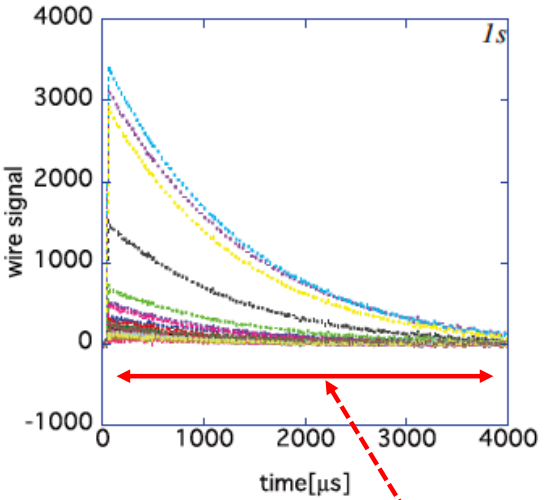
❖ For the investigation, we use MWPM1 on the injection line with very low-intensity LINAC beams to secure a safe workplace.

➢ Performance of MWPM1, and the nearby Ceramic breaks

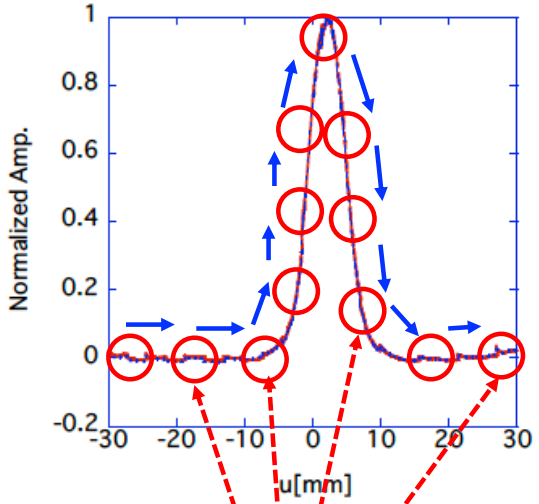
- MWPM1 consisting of 27 wires measures the transverse beam profile.
- Each wire moves 0.1 mm/s filling the intervals of respective wires, while 100 LINAC beams pass there with a 1Hz repetition rate.



Respective wire-signals



Produced bunch shape

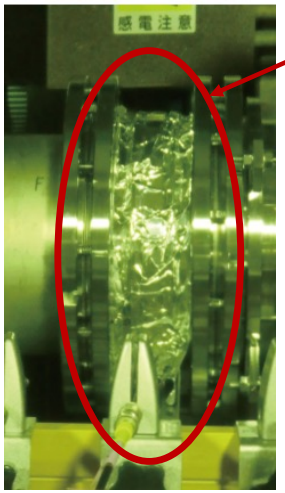


The integration of the respective wire-signals over 4 ms provides the beam density at the wire positions.

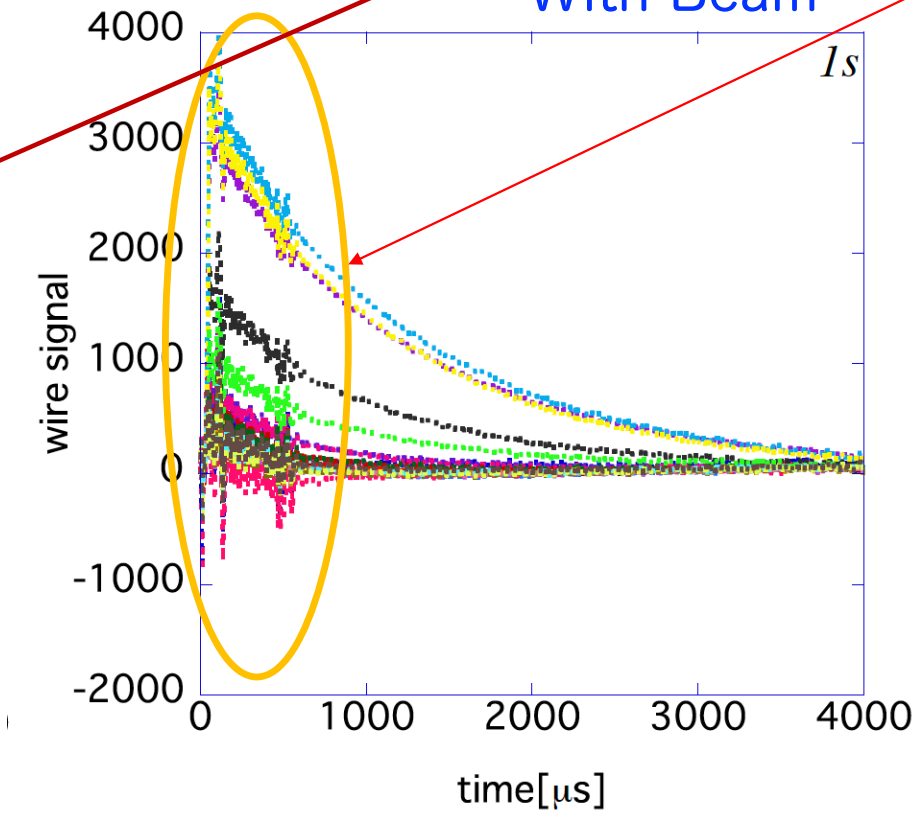
No noise is observed.

○ Al sheet covered ceramic break

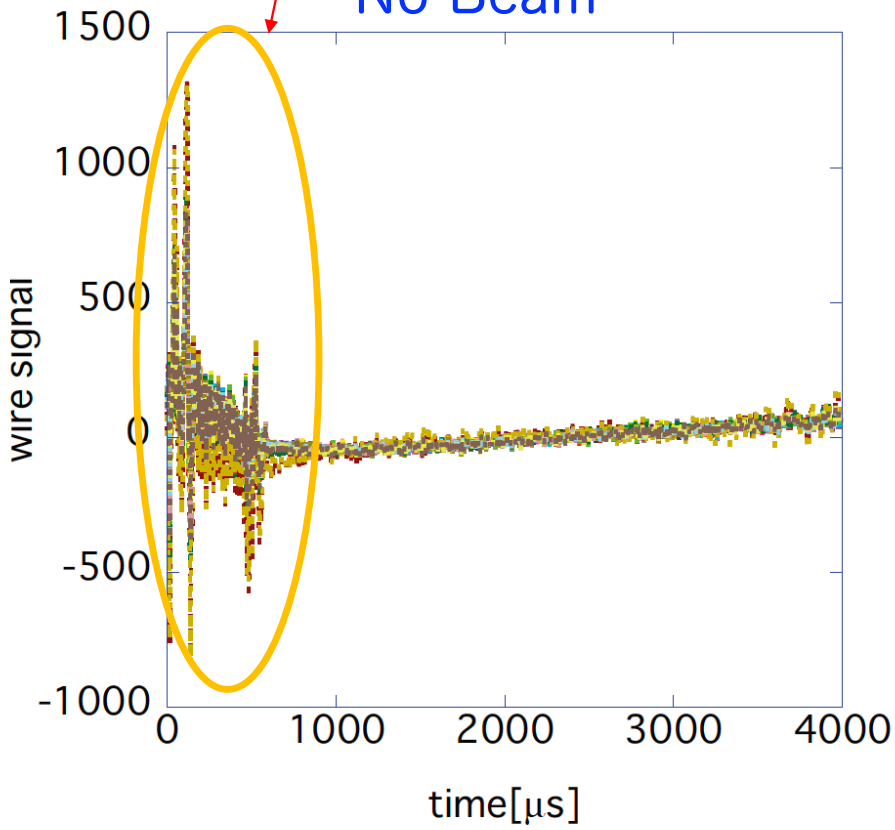
- When the ceramic break is covered over Al sheet, the noise emerges on the wires.
- This is not related to the beams, but due to the working of injection magnets.



With Beam



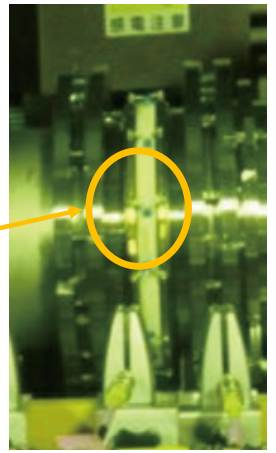
No Beam

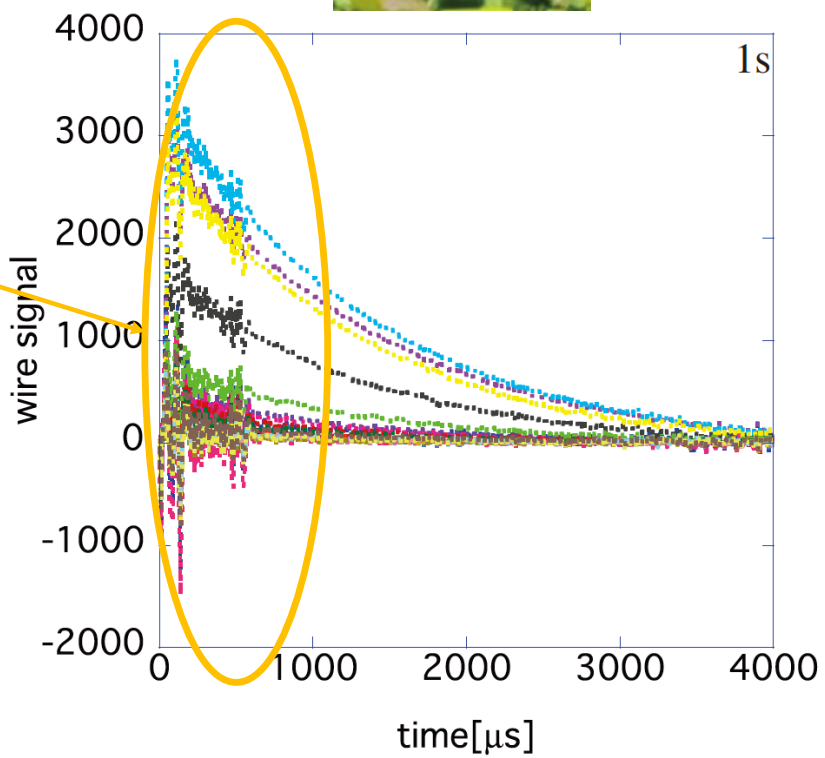


○ Capacitors covered ceramic break

- 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 1μF 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.

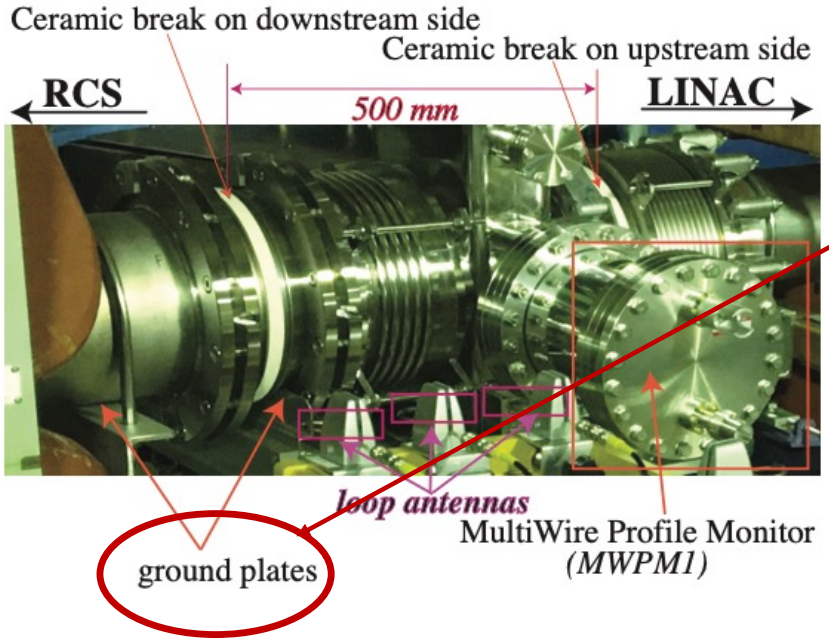
❖ Since it is a systematic error, the noise can be eliminated in principle (by comparing the case without beams).

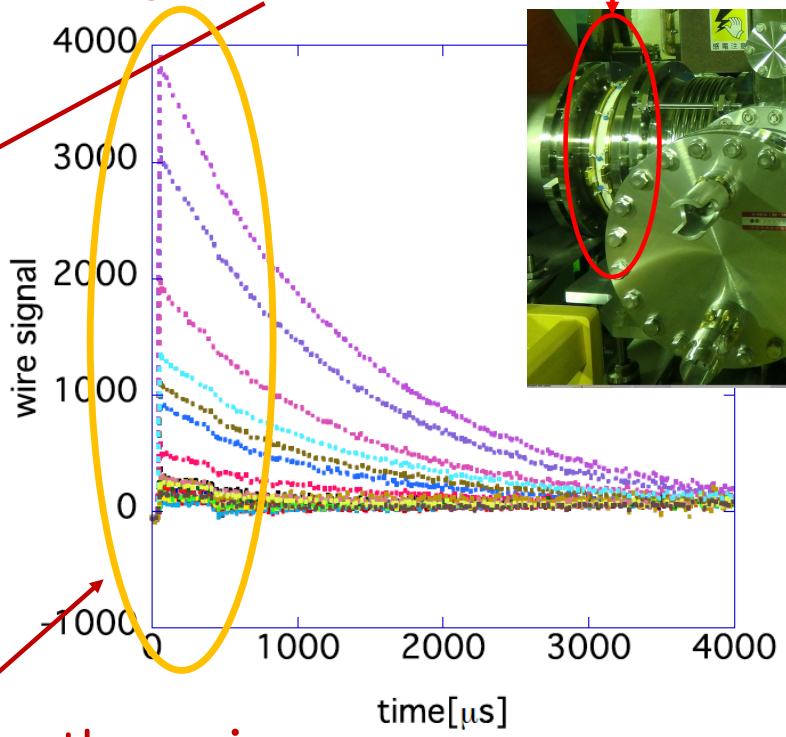




○ For perfect working of the capacitors

- 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.

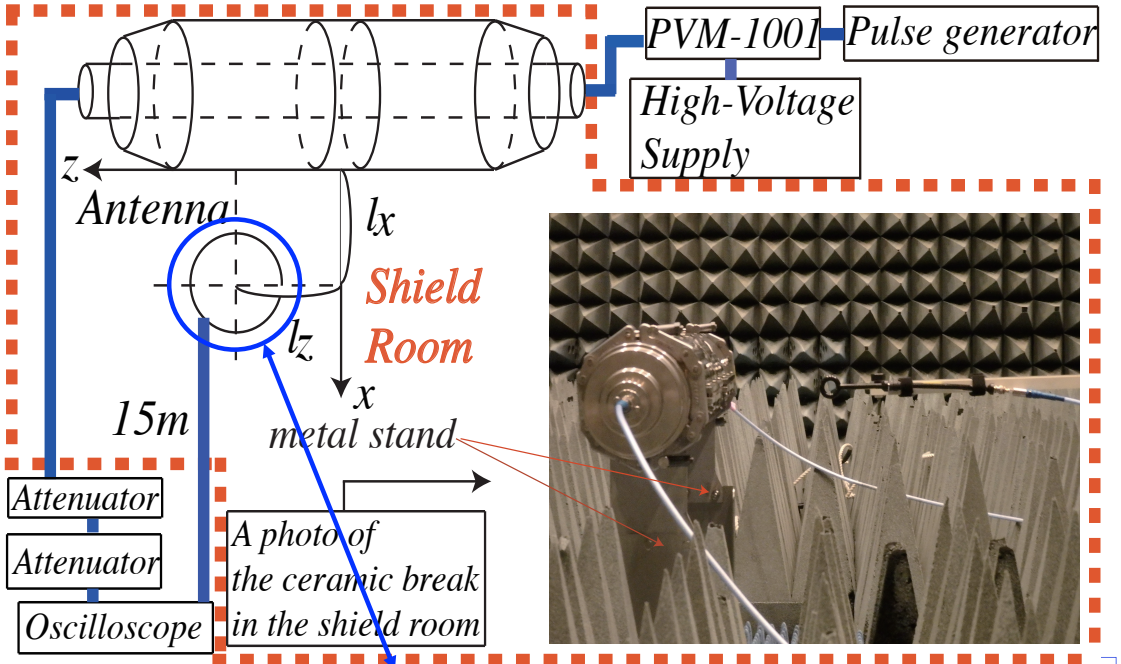
➢ Measurements of radiations and impedances from Ceramic breaks and their application for wideband monitor (by using test stand)

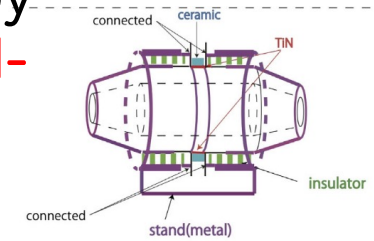
- Radiations are measured under the idealistic condition, i.e. the electromagnetic anechoic chamber in JAXA.

- The ceramics are supported by metal stand to secure the wall-current path.

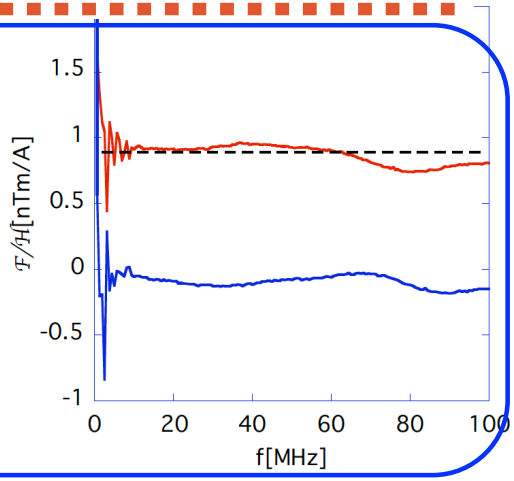
- Ceramic breaks with and without thin 10nm TiN coating are investigated.

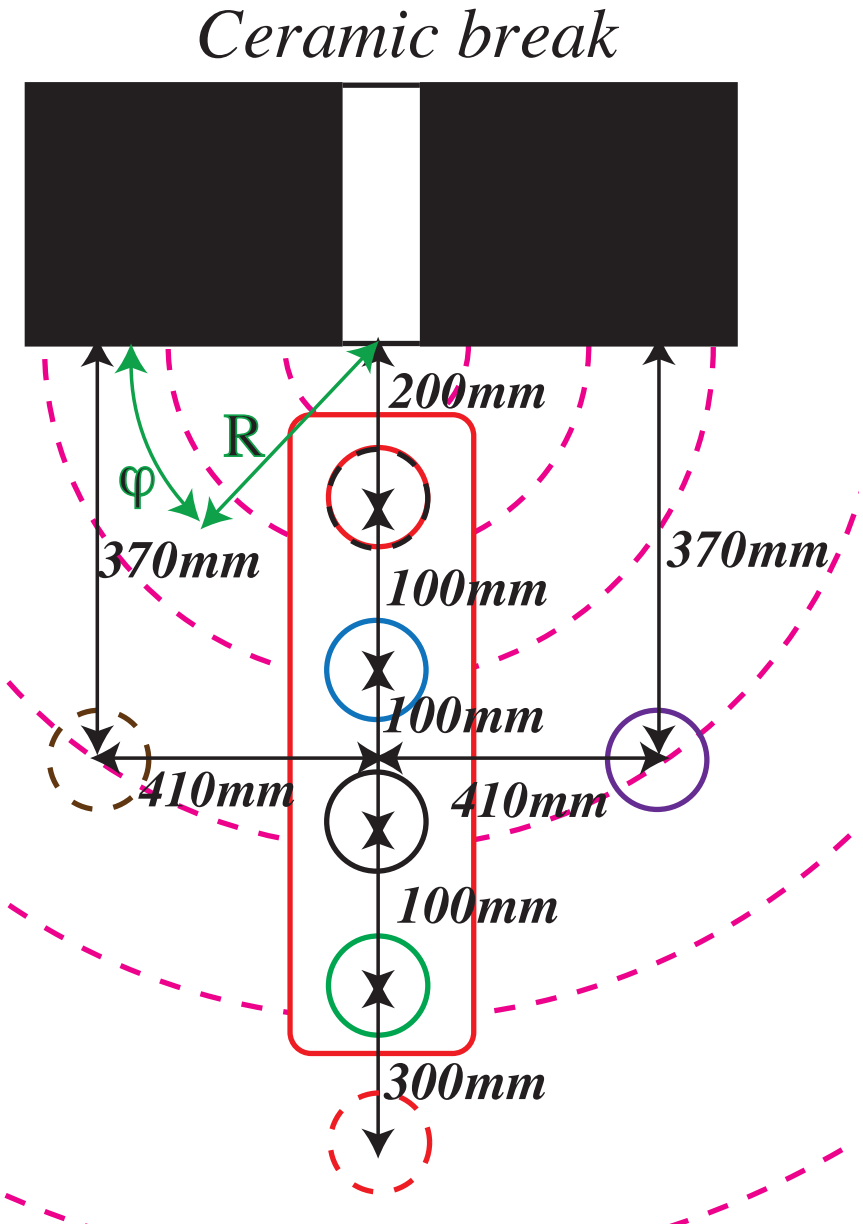
(1) Measurement setup





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





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

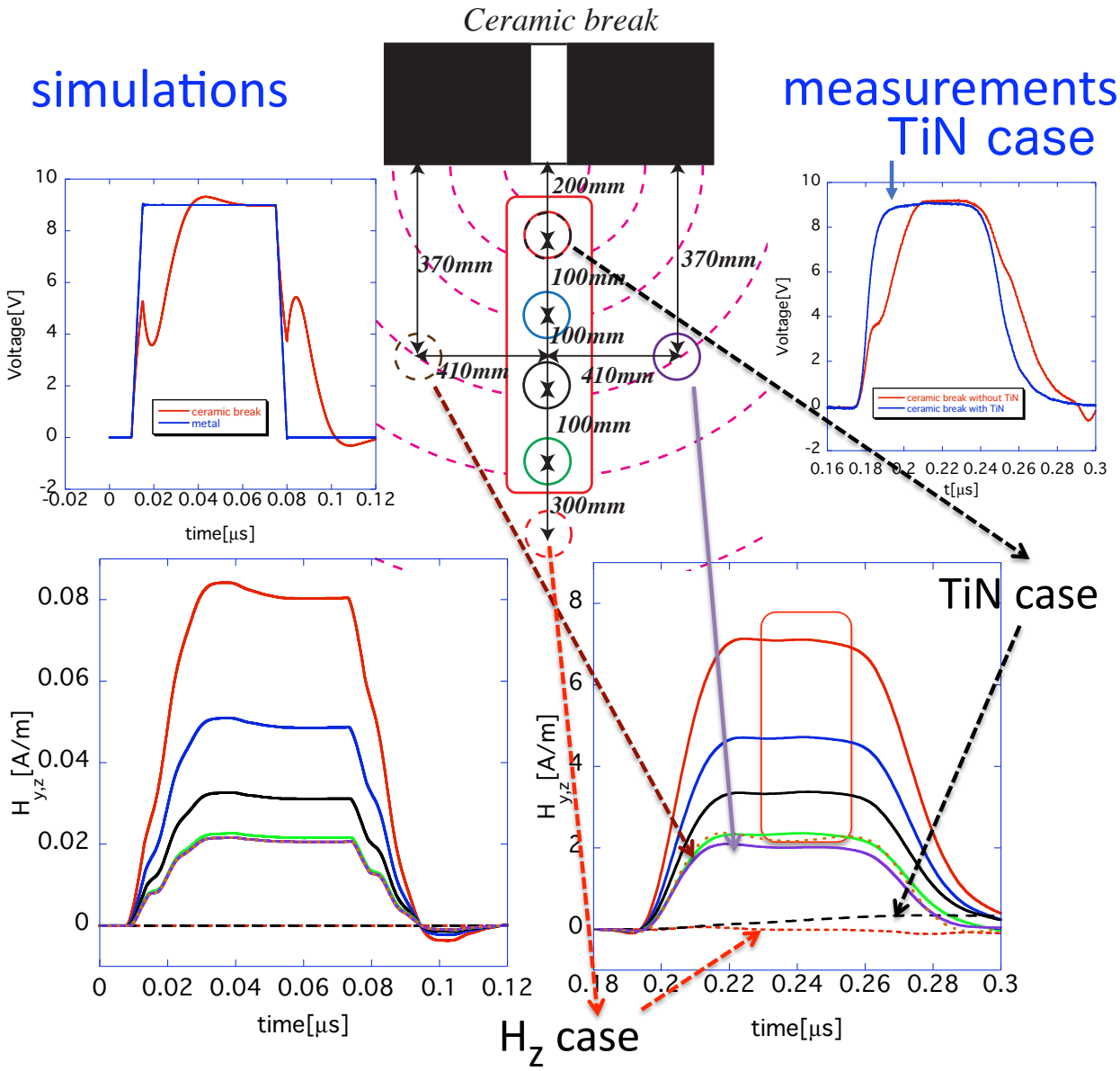
$$H_\theta(\rho, z_{\text{obs}}) \simeq j \frac{\beta c \sigma \bar{k} I_0(\bar{k}a) Z_{\text{gap}\parallel} e^{-jk\beta\bar{R}}}{2\pi \bar{R} Z_0 I_1(\bar{k}\sigma) H_0^{(2)}(k\beta a \sin\varphi) \sin\varphi},$$

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 siginficantly shields the radation by supressing the impedance.

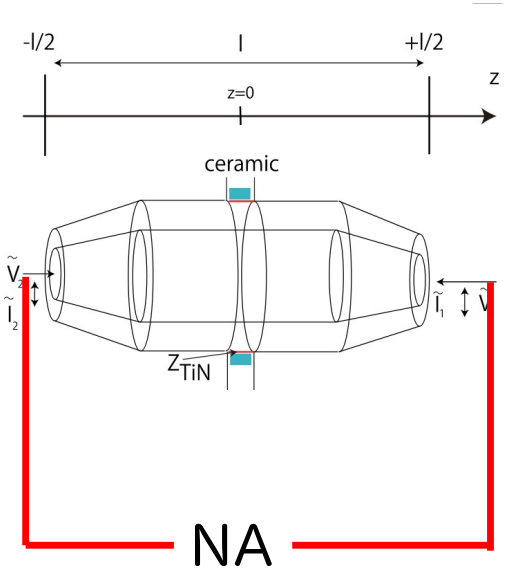
○ Simulations and Measurements

- ❑ 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 shileds EM.

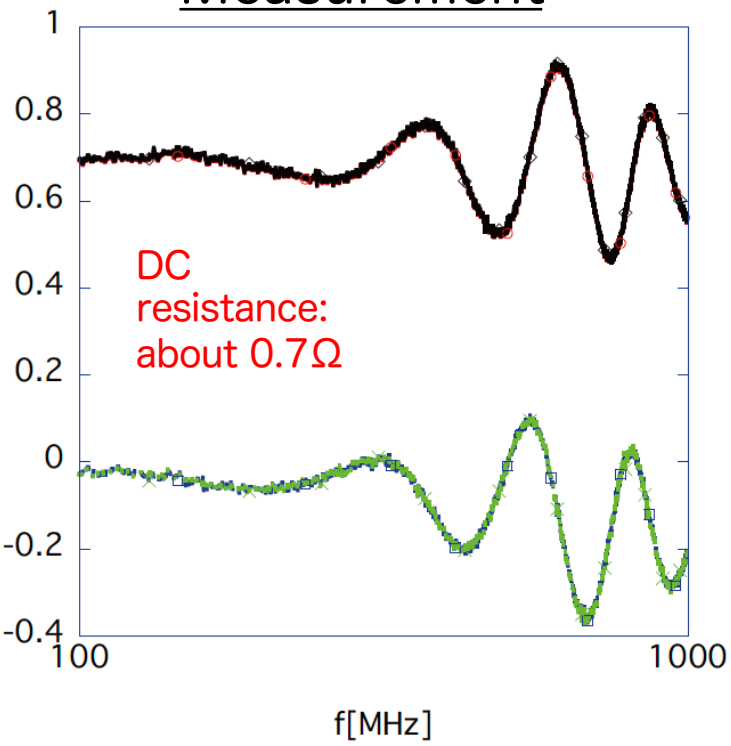


- Measurements of the impedance of the ceraic break with TiN coating.

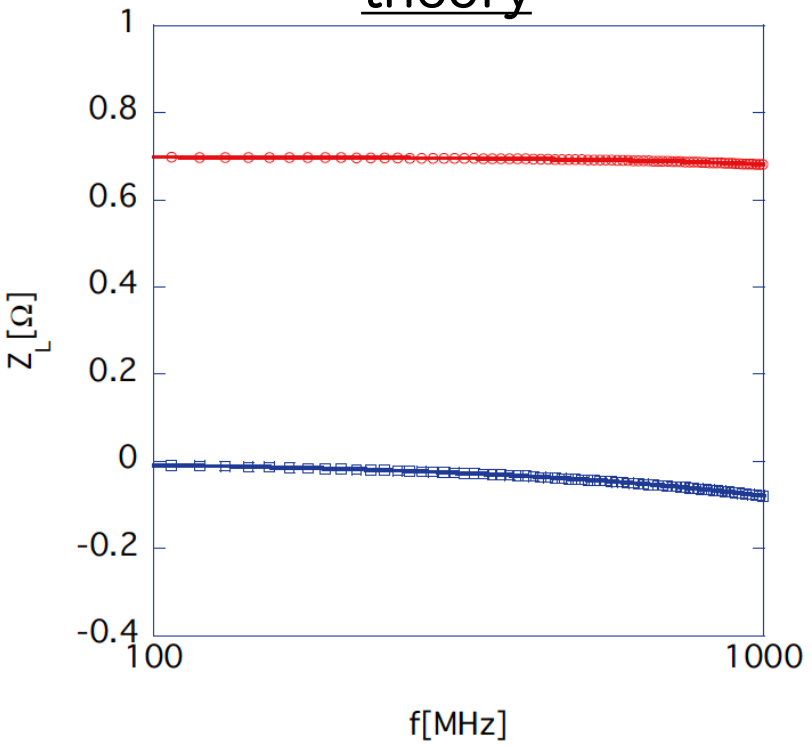
(2) Measurement setup



Measurement



theory



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

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

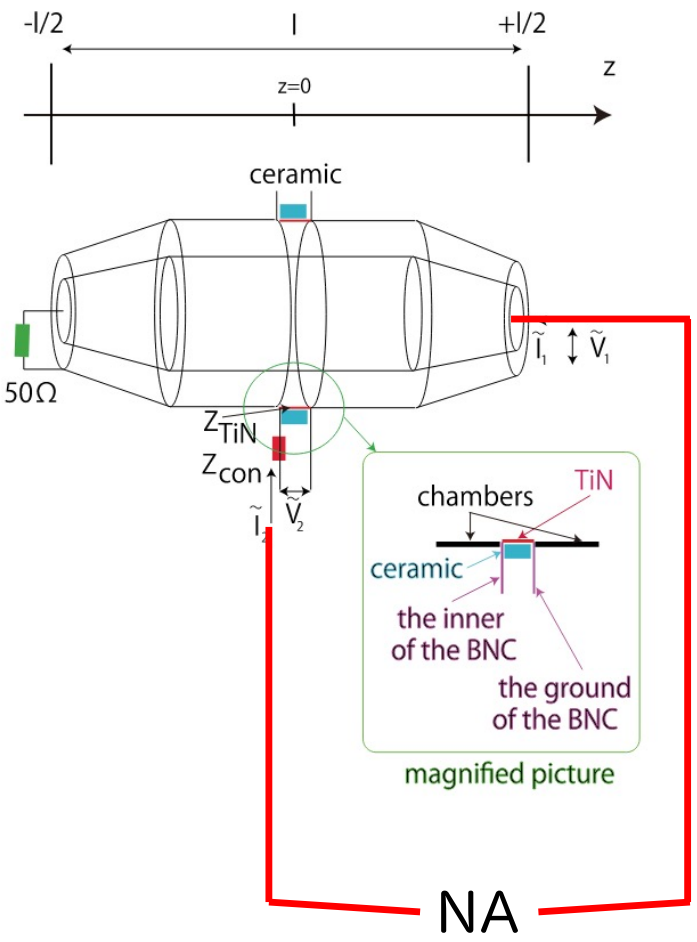
- The longitudinal impedance is suppressed with thin TiN, consistent with the measurements of radiations.
- The coupling impedance does not depend on frequency.

❖ In its application, the characteristic can be used as a monitor with wideband.

- Application of shielded ceramic break (Wideband monitors)

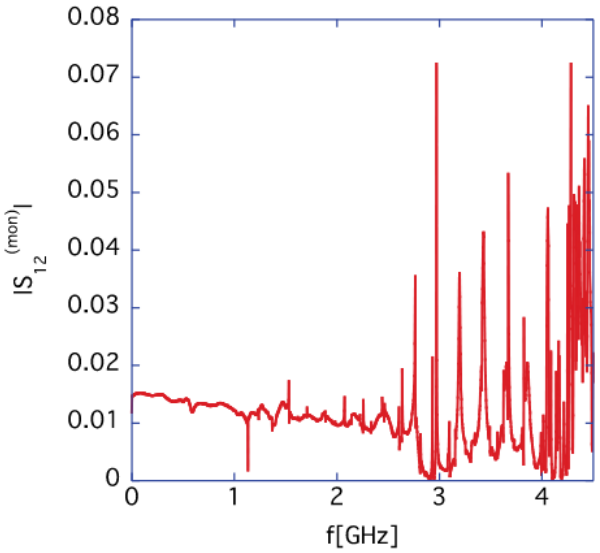
Y. Shobuda et al PRAB23, 092801 (2020)).

(3) Measurement setup

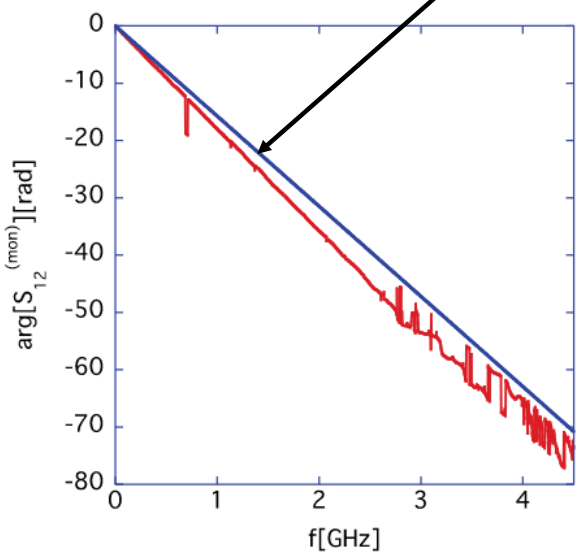


reference : $-2\pi fV(L\,C)\,l/2$

Amplitude

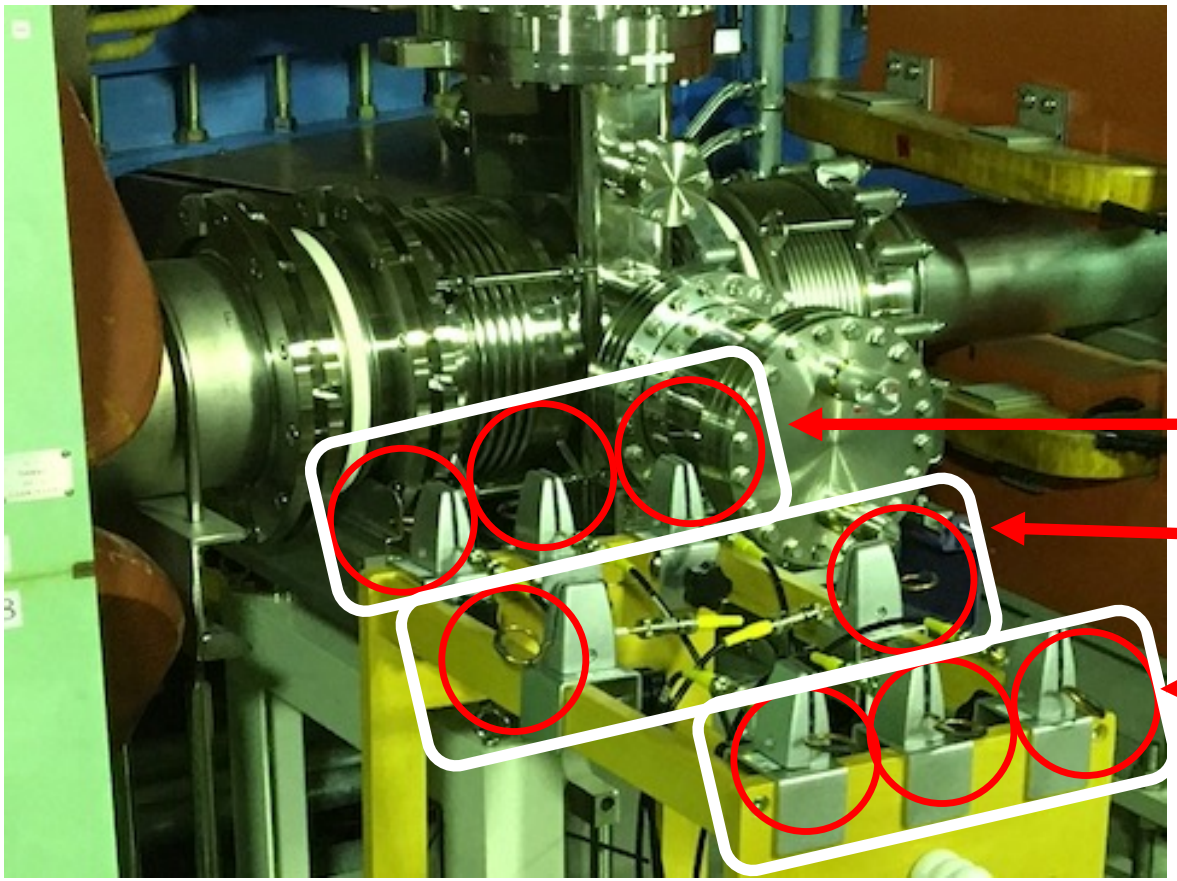


phase



- 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 capactiors suppress the radiations ?

➢ Measurements of radiations from Ceramic breaks in J-PARC



LINAC

RCS

Hy and Hz found

Hy and Hx found

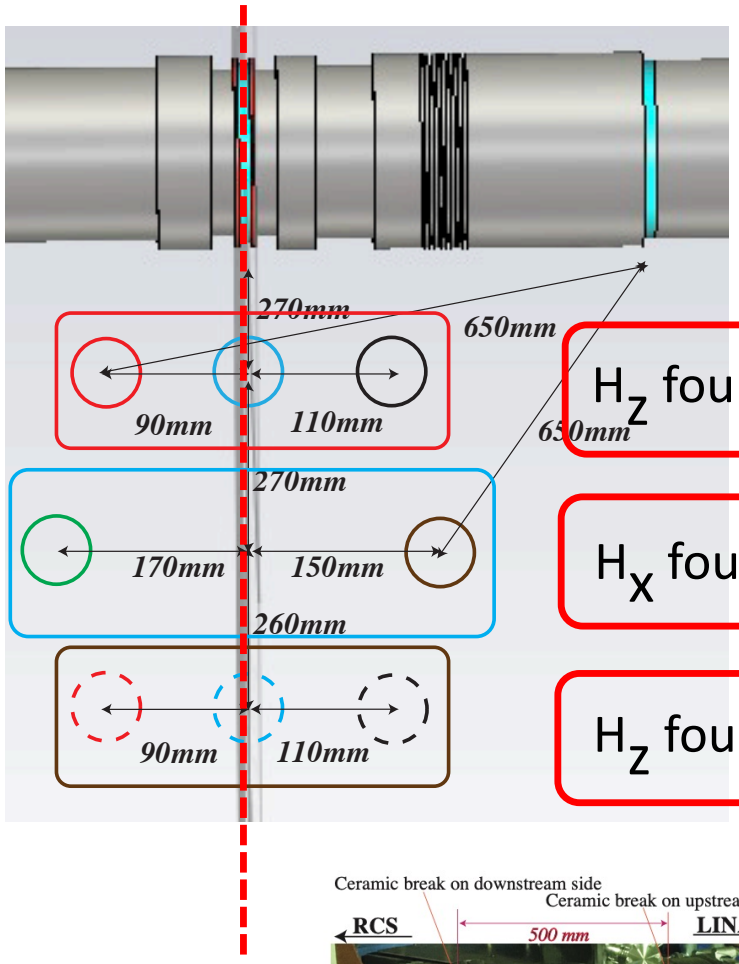
Hy and Hz found

- 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.

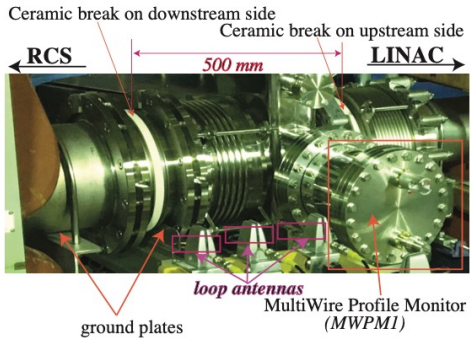
- H_y is almost symmectric for the Z=0 plane.

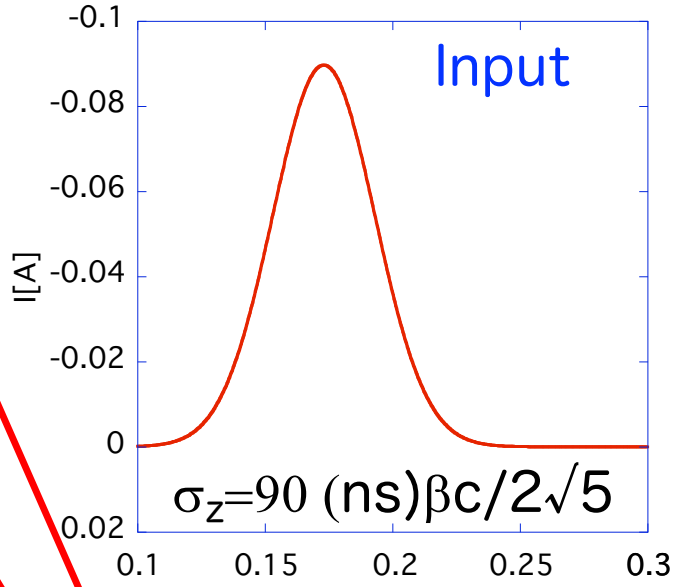


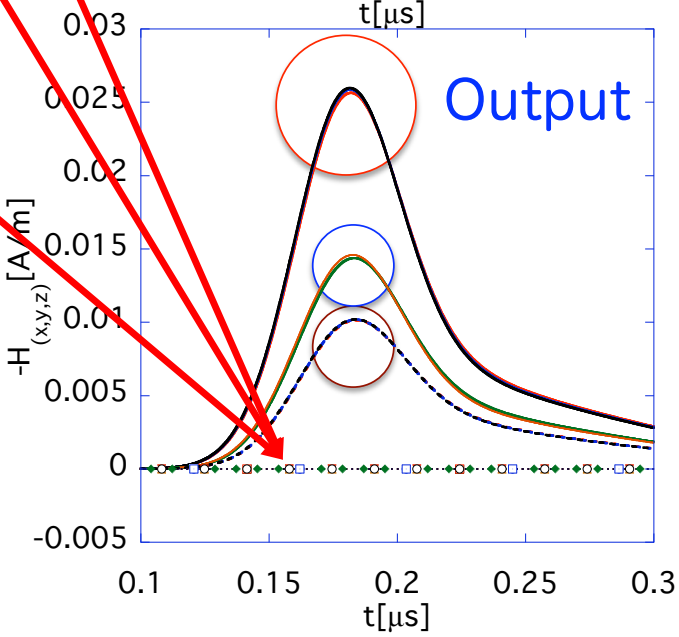
H_z found

H_x found

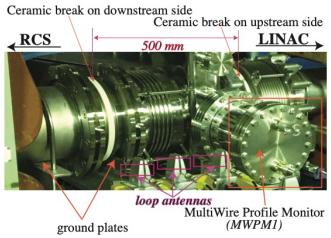
H_z found

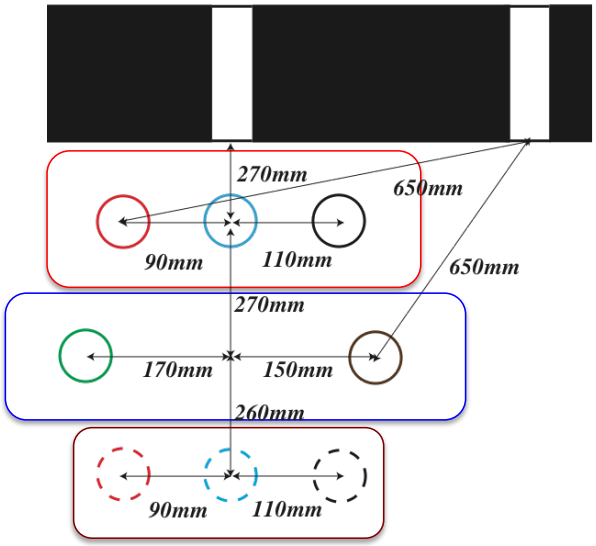




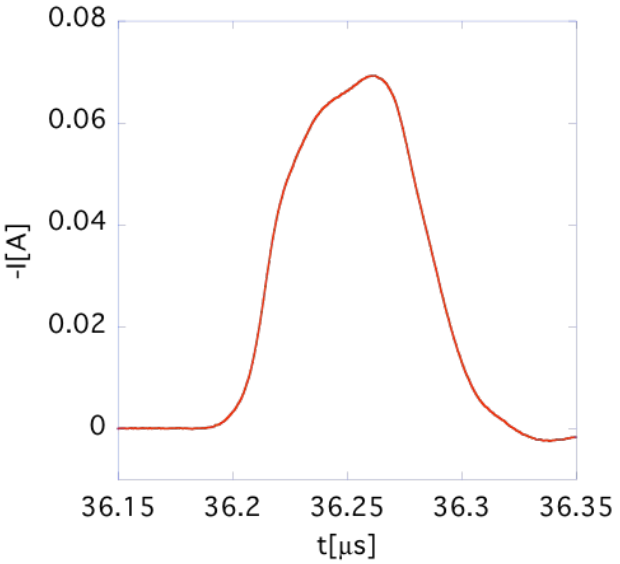


- Measurements





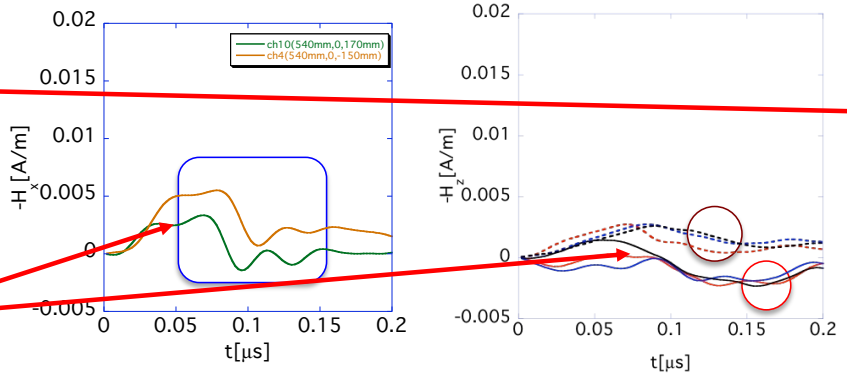
Measured WC



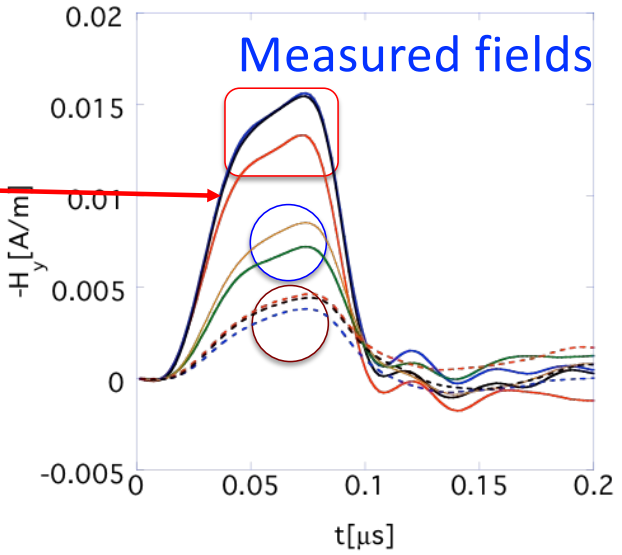
- Drawback : simplified simulations overestimate the measuremts.

- Excited H_y reflects the longitudinal bunch shape.

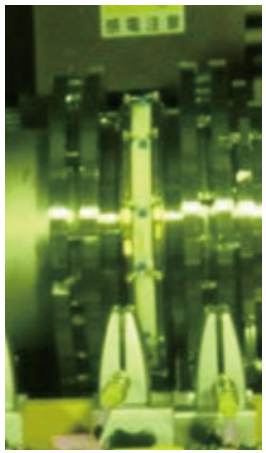
- $H_{x,z}$ are excited, due to the objects.



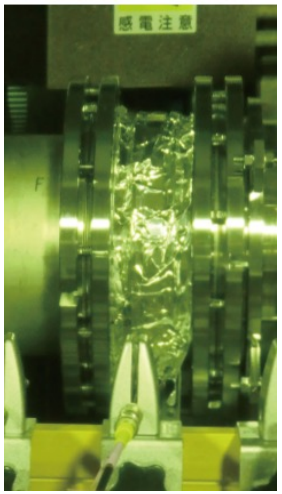
Measured fields

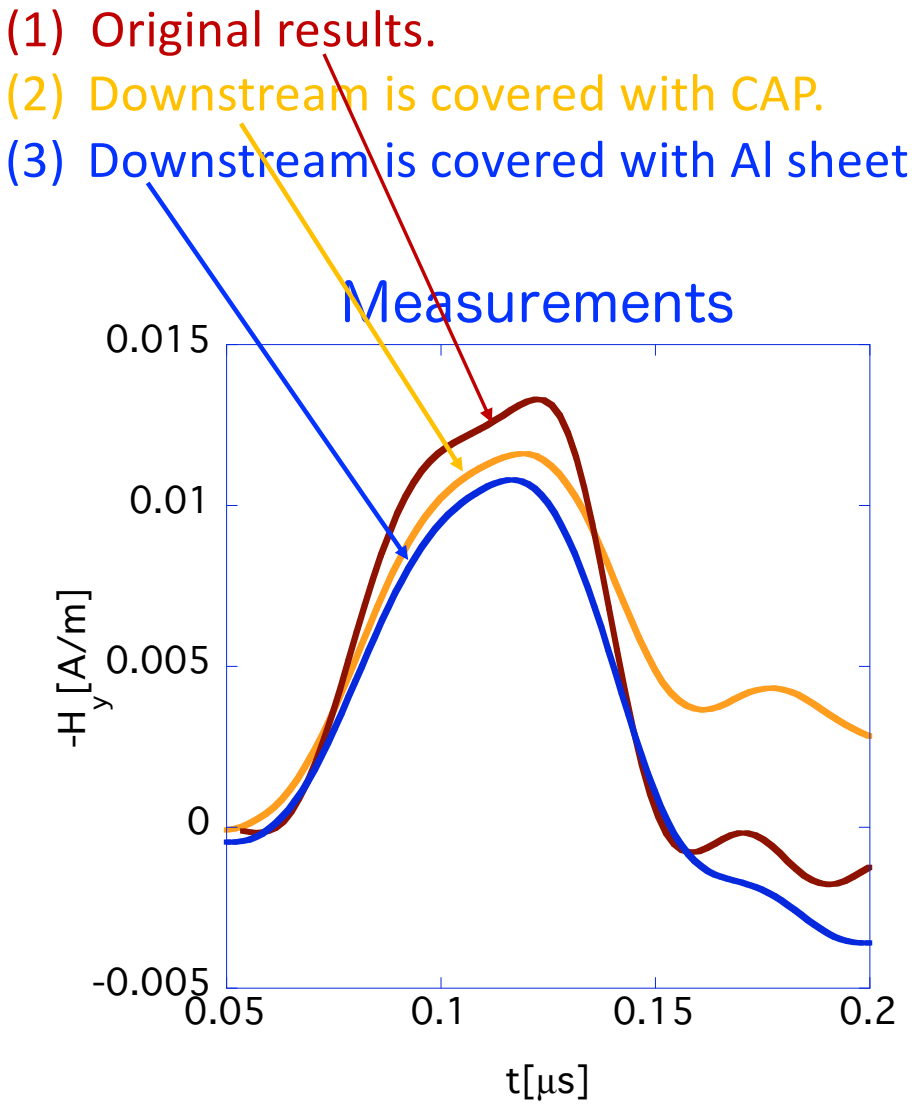


- In the case of the downstream ceramic break covered over capacitors or Al.
  - Though the reduction effect due to the capacitors is expected to be significant, the effect is not so remarkable.



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

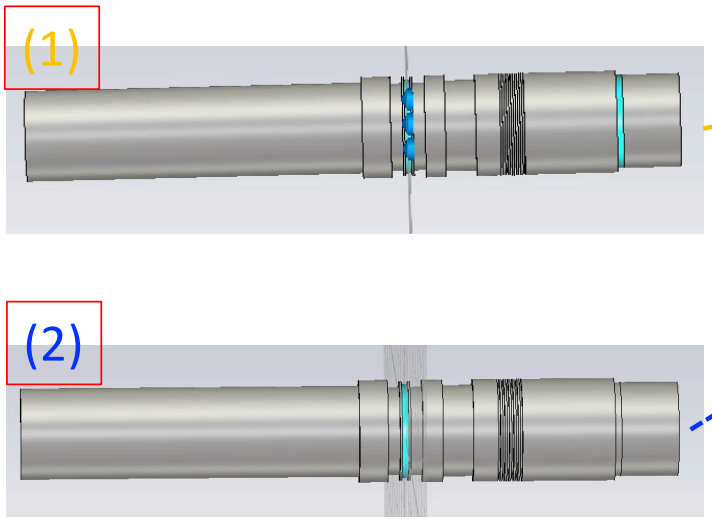


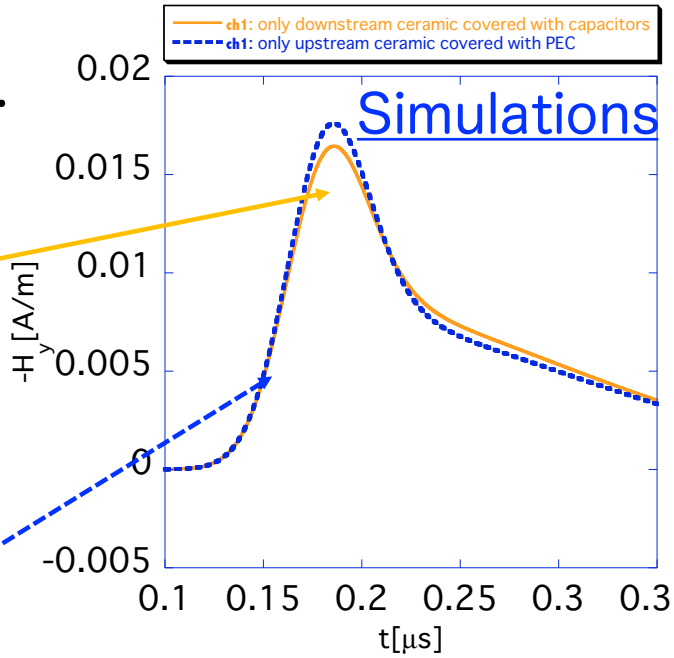


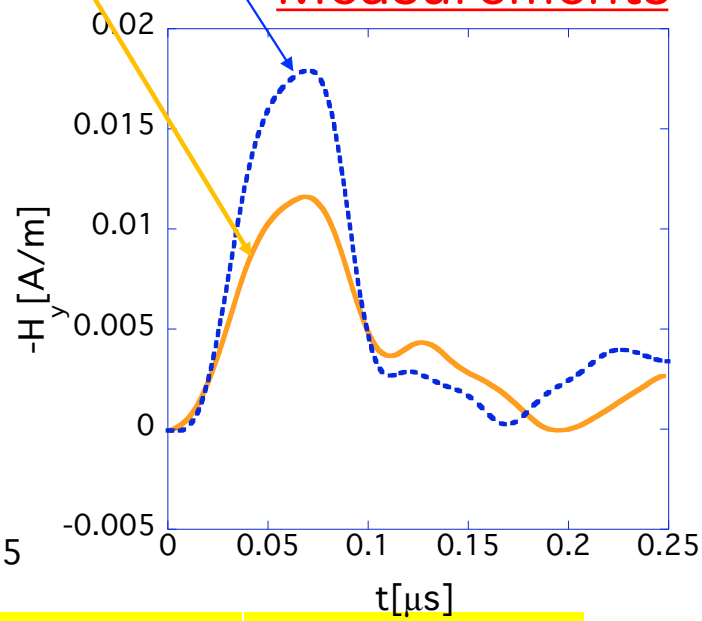
Here, let us simulate two cases where

(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.



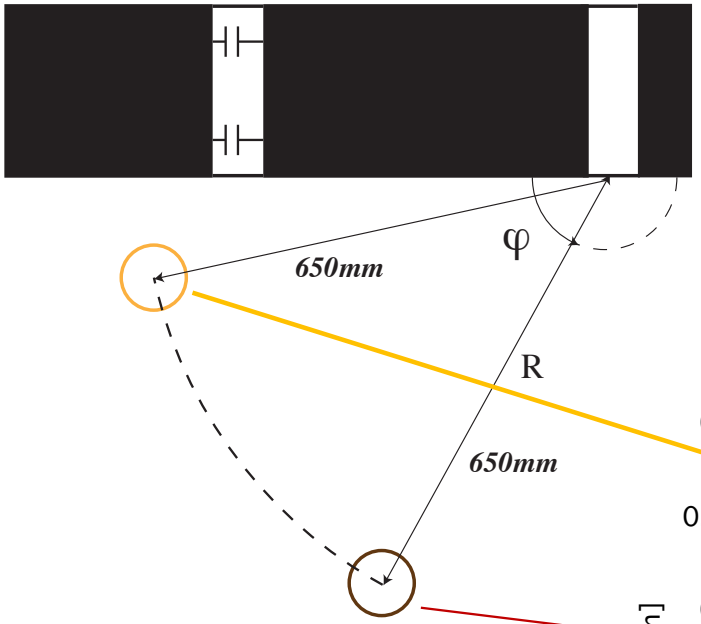




- The contribution from both ceramic break can be comparable (simulation).

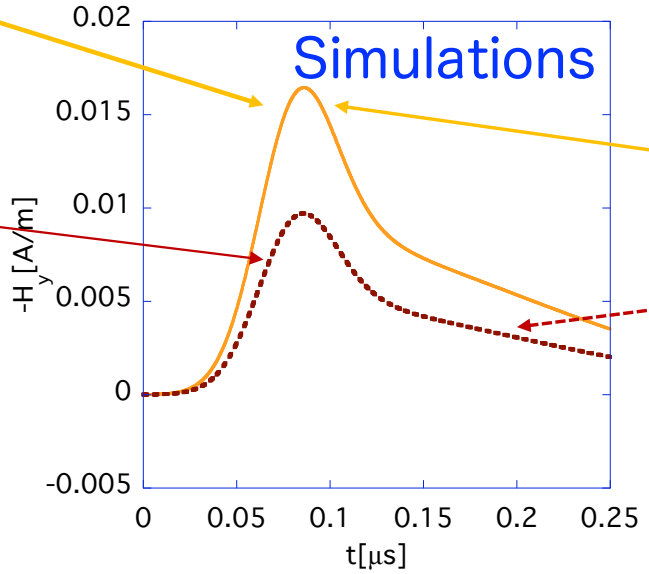
❖ The measurement demonstrates the contribution from upstream is significant.

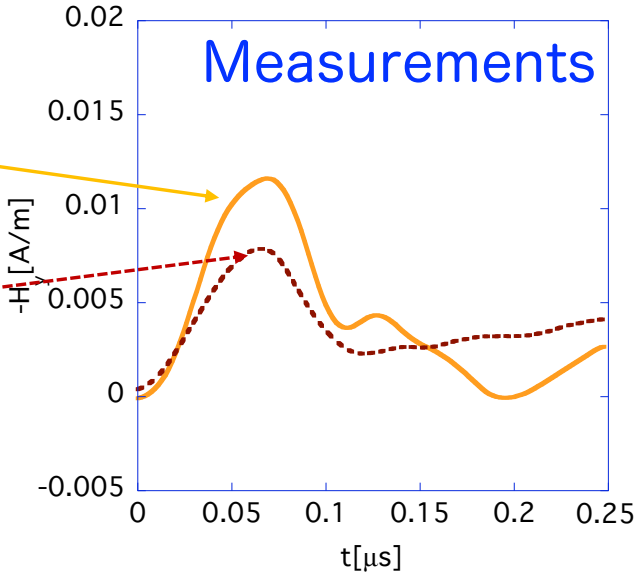
$$H_\theta(\rho, z_{\text{obs}}) \simeq j \frac{\beta c \sigma \bar{k} I_0(\bar{k}a) Z_{\text{gap},\parallel} e^{-jk\beta\bar{R}}}{2\pi \bar{R} Z_0 I_1(\bar{k}\sigma) H_0^{(2)}(k\beta a \sin\varphi)(\sin\varphi)},$$



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

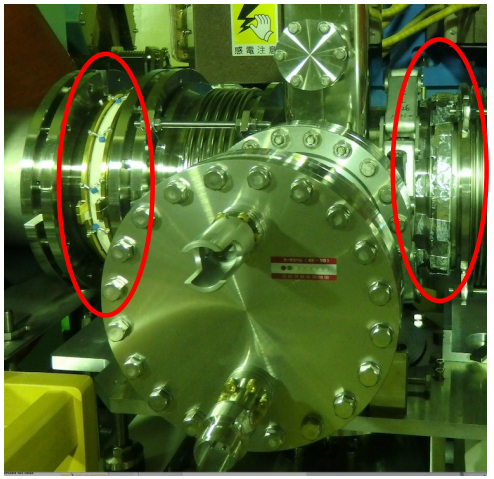
❖ The enhancement is confirmed by measurements.

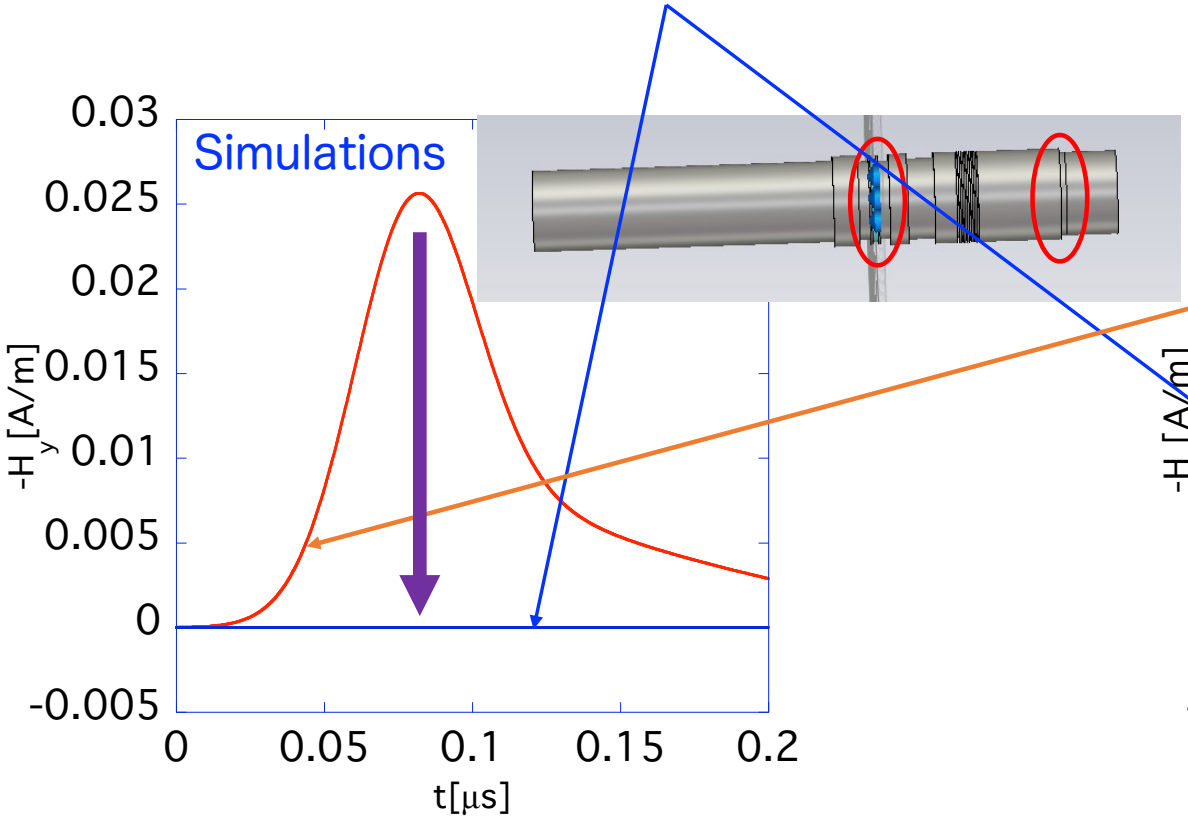


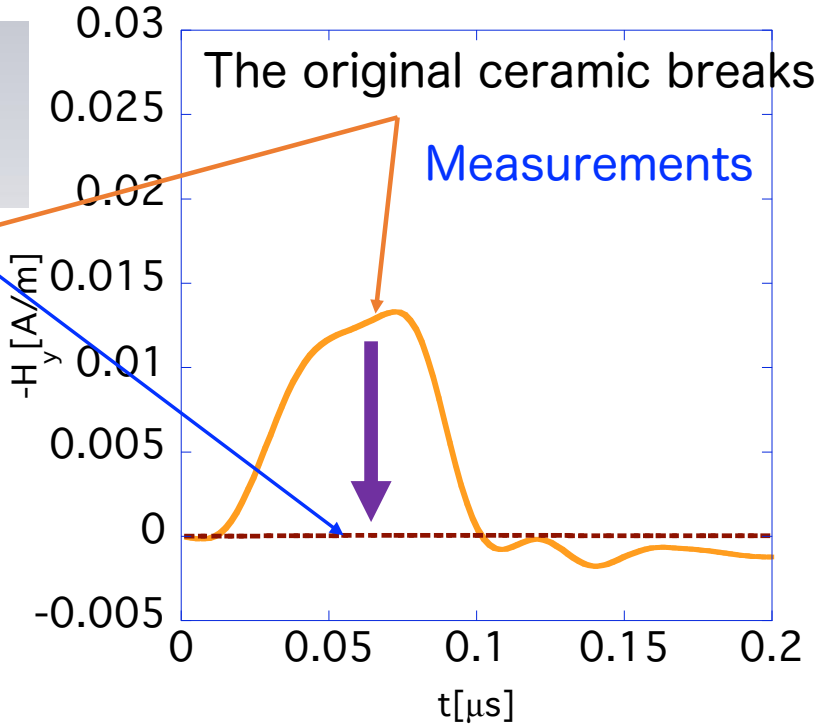


- Cover not only the downstream ceramic break with capacitors,
- But also the upstream one with Al sheet.

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







➢ 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.