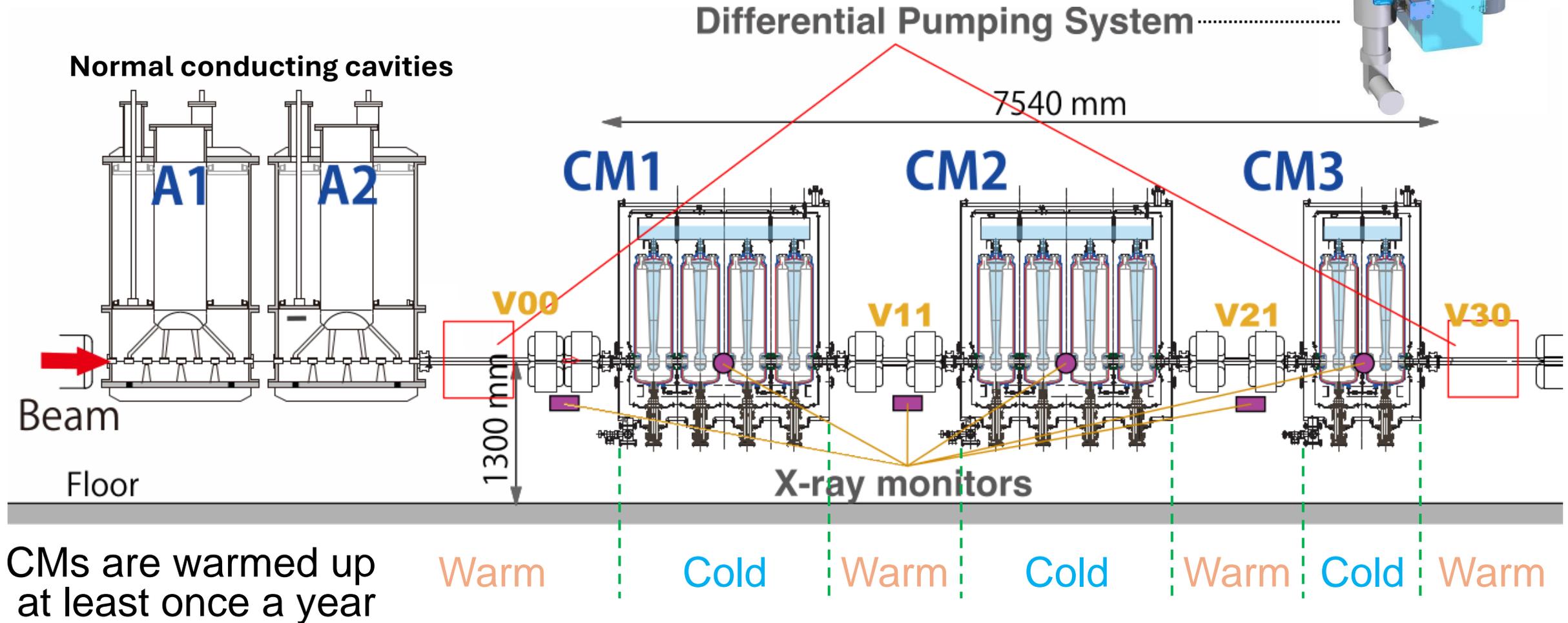


Experience with field emission at RIKEN

RIKEN Nishina Center
OZEKI, Kazutaka

General facts about SRILAC (1)

- Year built → 2019 / commissioned → 2020
- Cryomodule string layout (continuously cold, warm sections,...)



General facts about SRILAC (2)

- Particle free installation practices/protocols applied

(1) Linkage of cavities:

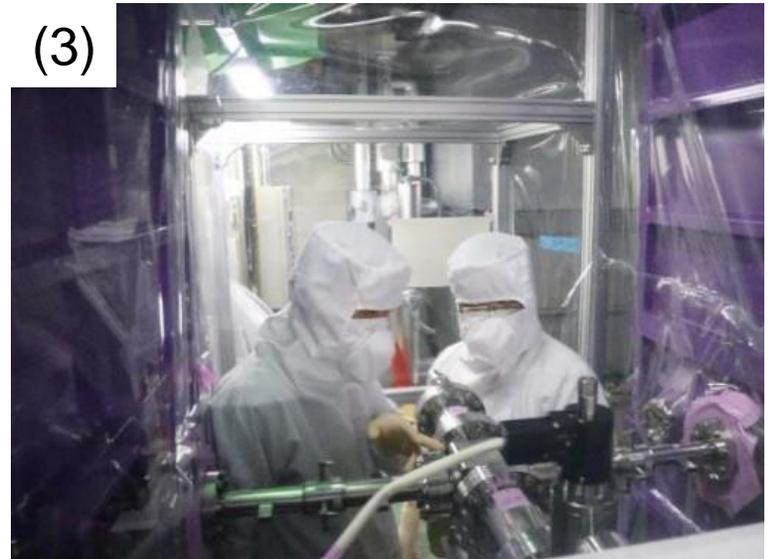
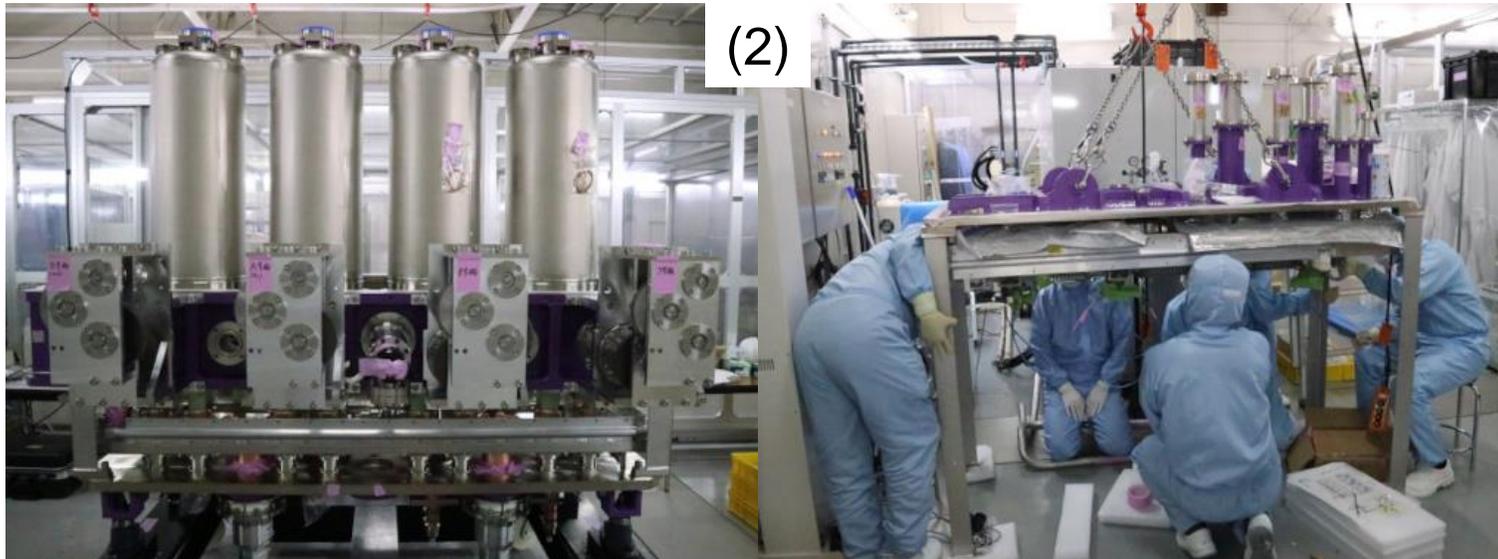
ISO class 1 clean room with gas flow

(2) Assembly of CMs other than cavities:

ISO class 7 clean room

(3) Integration of CMs into beam line:

Local clean booth (ISO class ~5 ?)



General facts about SRILAC (3)

- Peak surface field at nominal operation gradient
 → $E_{\text{acc}} = 3\text{-}4 \text{ MV/m}$ (operation voltages are set below the on-set gap voltage)
 $E_{\text{peak}}/E_{\text{acc}} = 6.2$
- Administrative/operational radiation limits (How were limits decided?)
 → [High-RF power processing \(HPP\)](#) is conducted when radiation exceeds $\sim 100 \mu\text{Sv/h}$.

Pulsed RF power is fed into cavity
 20 msec (0.5 Hz, duty 1%)



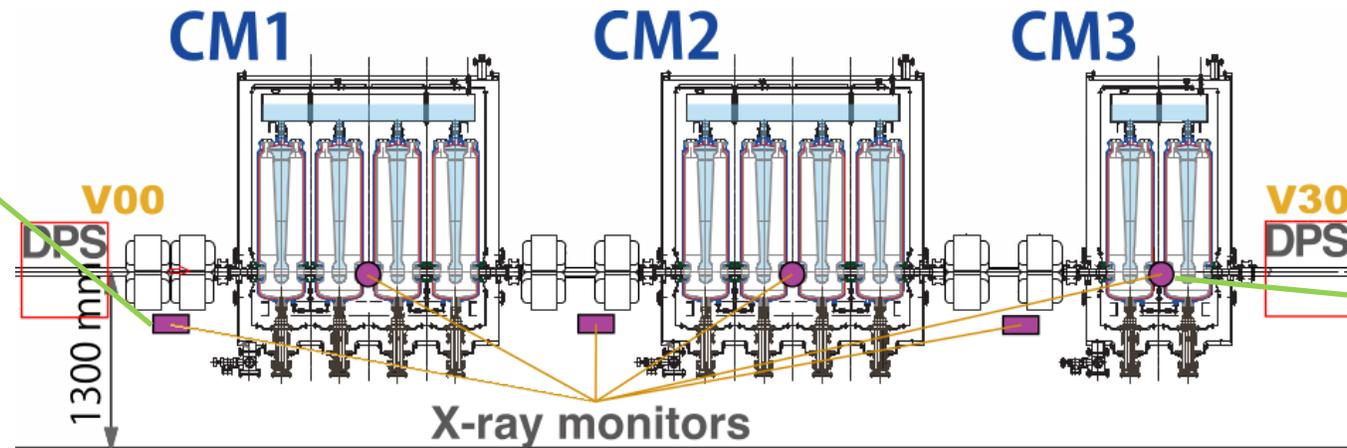
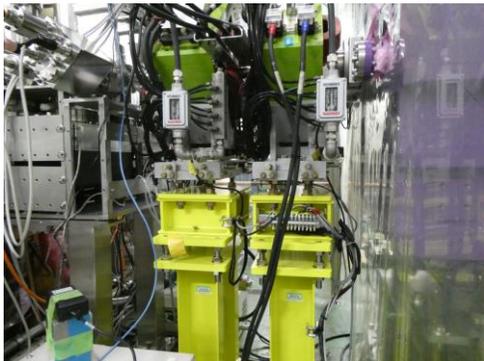
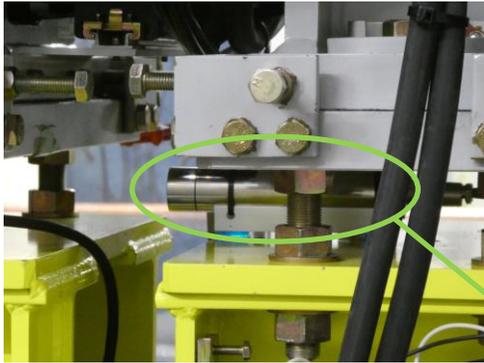
Occasional discharge
 → burn off FE sources on cavity surface



- Pulsed or CW operation? → CW operation

Instrumentation to measure/monitor radiation

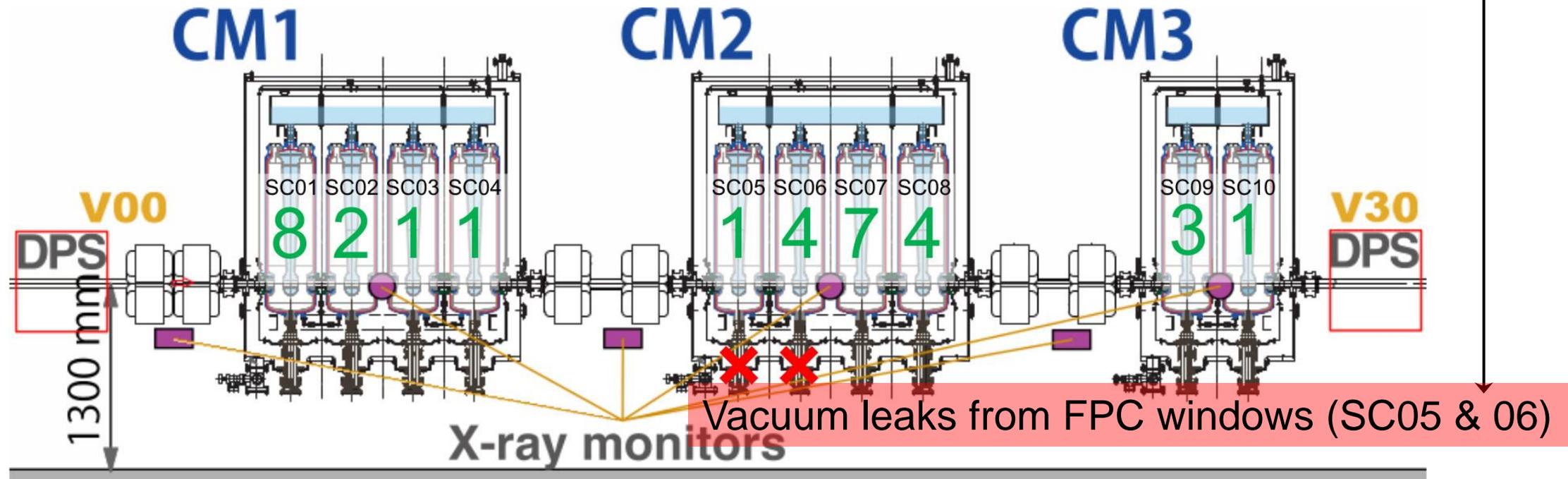
- Type of sensors
 - Si semiconductor detector (MAR-784, ALOKA)
Continuous monitoring, no energy measurement
- Locations and coverage of the machine
 - Side of each CM, between CMs, upstream of CM1
(will be installed downstream of CM3)



Evolution of field emission over lifetime of machine (1)

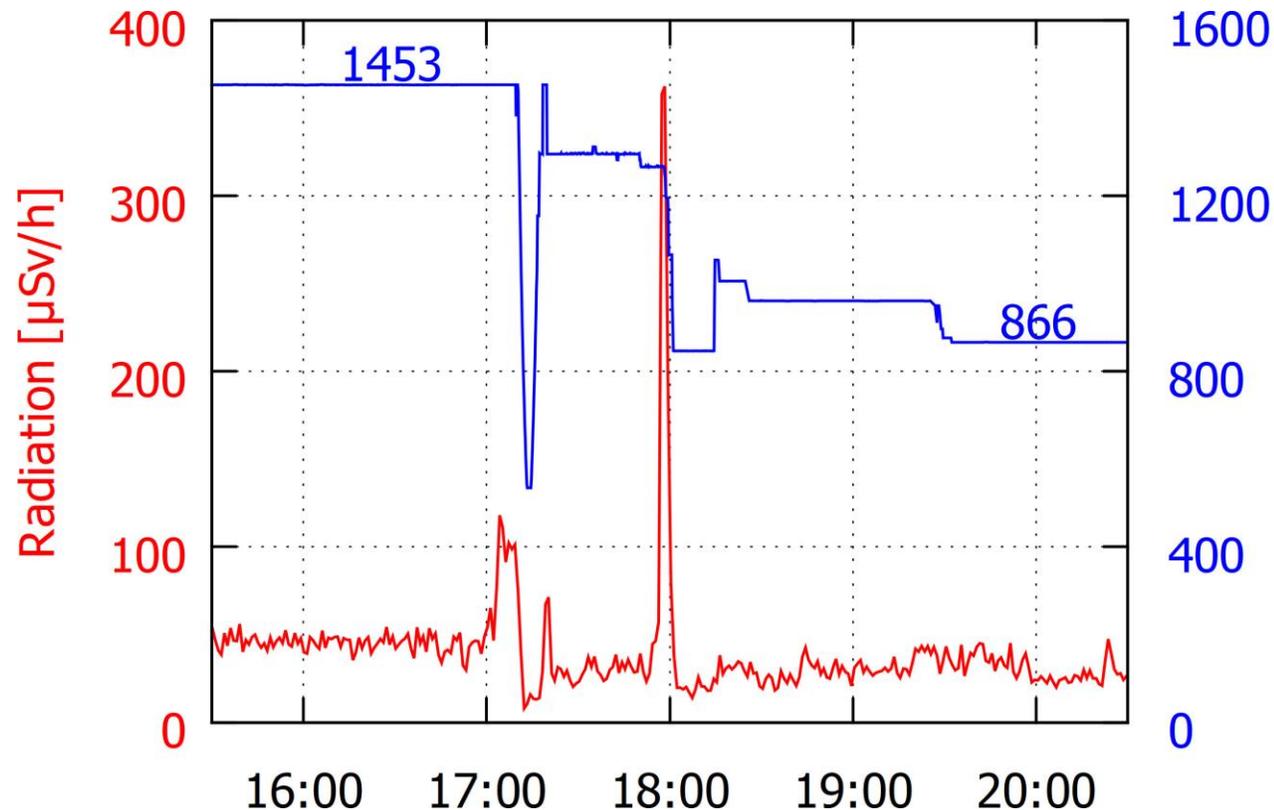
- How has field emission in the machine changed over time (**location** and magnitude)?
- Are there any **spatial patterns** observed?
- Are there **known reasons or events** this can be correlated with?

Number of times HPP conducted for each cavity



Evolution of field emission over lifetime of machine (2)⁰⁷

- How much performance has been lost due to the increase in field emission?
→ Actual case of SC02 on Jun 21, 2022
(HPP method had not been established yet...1st HPP: Nov 22, 2022)



Operation with $V_g = 1453$ kV
↓
FE increased twice in a short time
↓
 V_g was reduced to 866 kV
to keep moderate radiation level

Evolution of field emission over lifetime of machine (3)

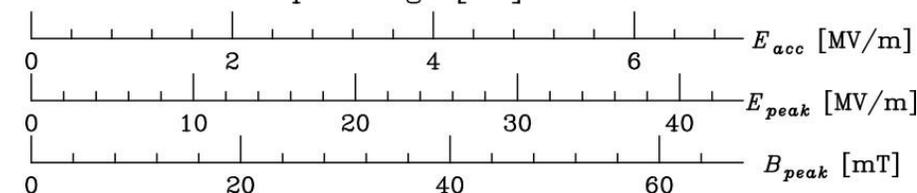
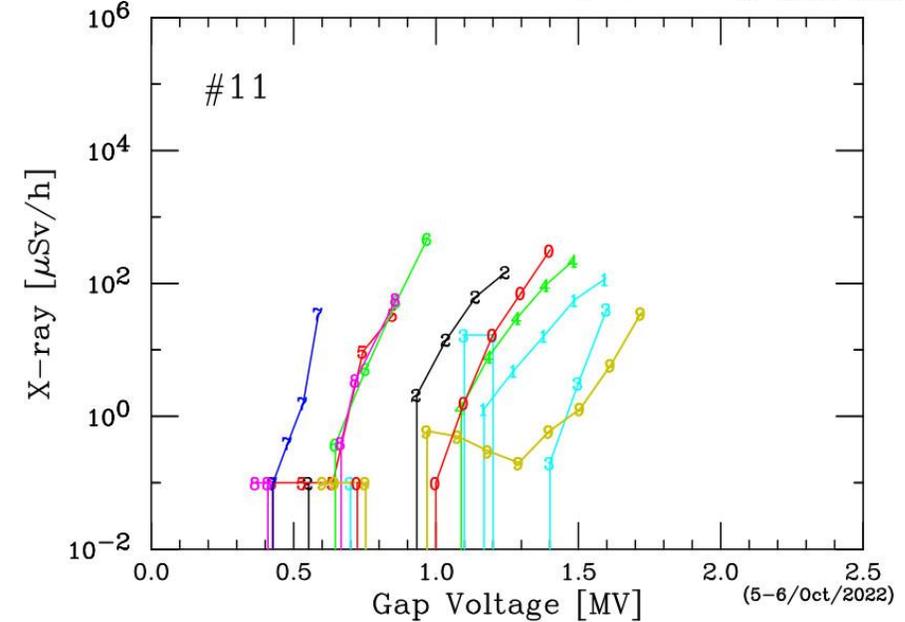
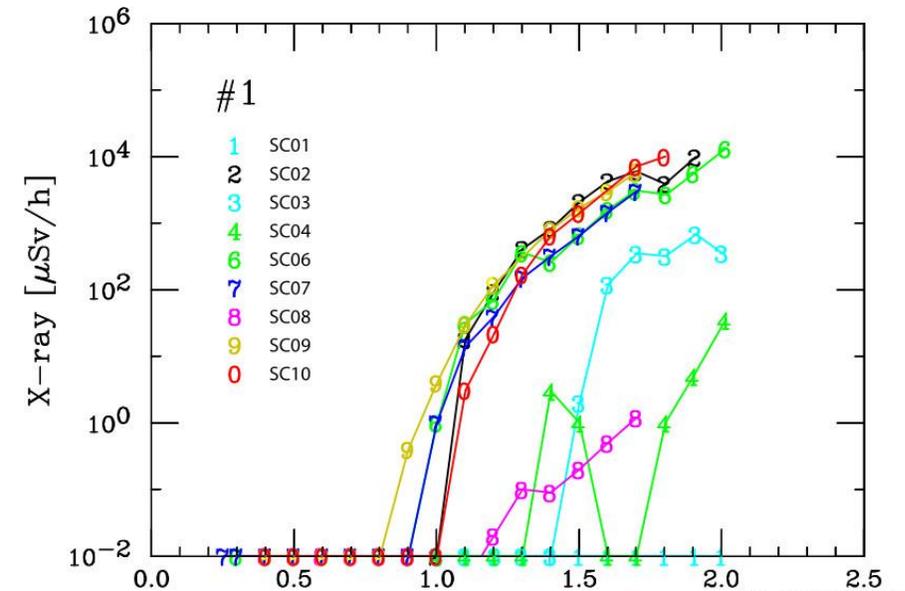
- How much performance has been lost due to the increase in field emission?
(same question with previous page)
→ Another actual case: FE measurements for each cavity (Courtesy of N. Sakamoto)

(Top) Jan 2020

- GVs of each CM had not opened yet
- CM2 had already experienced 1st vacuum leak from SC05

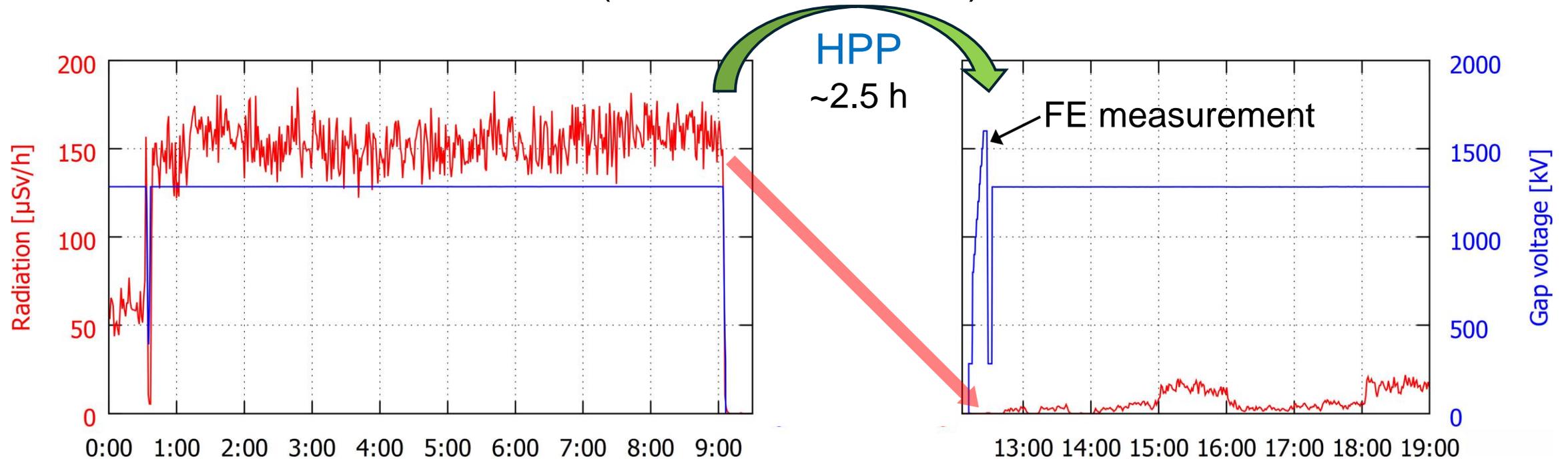
(Bottom) Oct 2022

- Just before 1st HPP
- Difficult to maintain total acceleration voltage



Field emission remediation

- Have there been attempts to decrease field emission in situ? → Yes
- If yes, what and to what level of success?
→ Actual case of the effect (SC01, Mar 1, 2024)



- If cryomodules have been removed due to field emission, has the issue resurfaced in the replacement? → CMs have not been removed yet

Summary

(From Jan 2020 to Nov 2022)

Repeated increase in FE

→ Difficult to maintain total acceleration voltage

(After Nov 2022)

HPP is conducted prior to each beam service

and each time FE increases during beam service

→ So far, FE is successfully suppressed

Details for **HPP**:

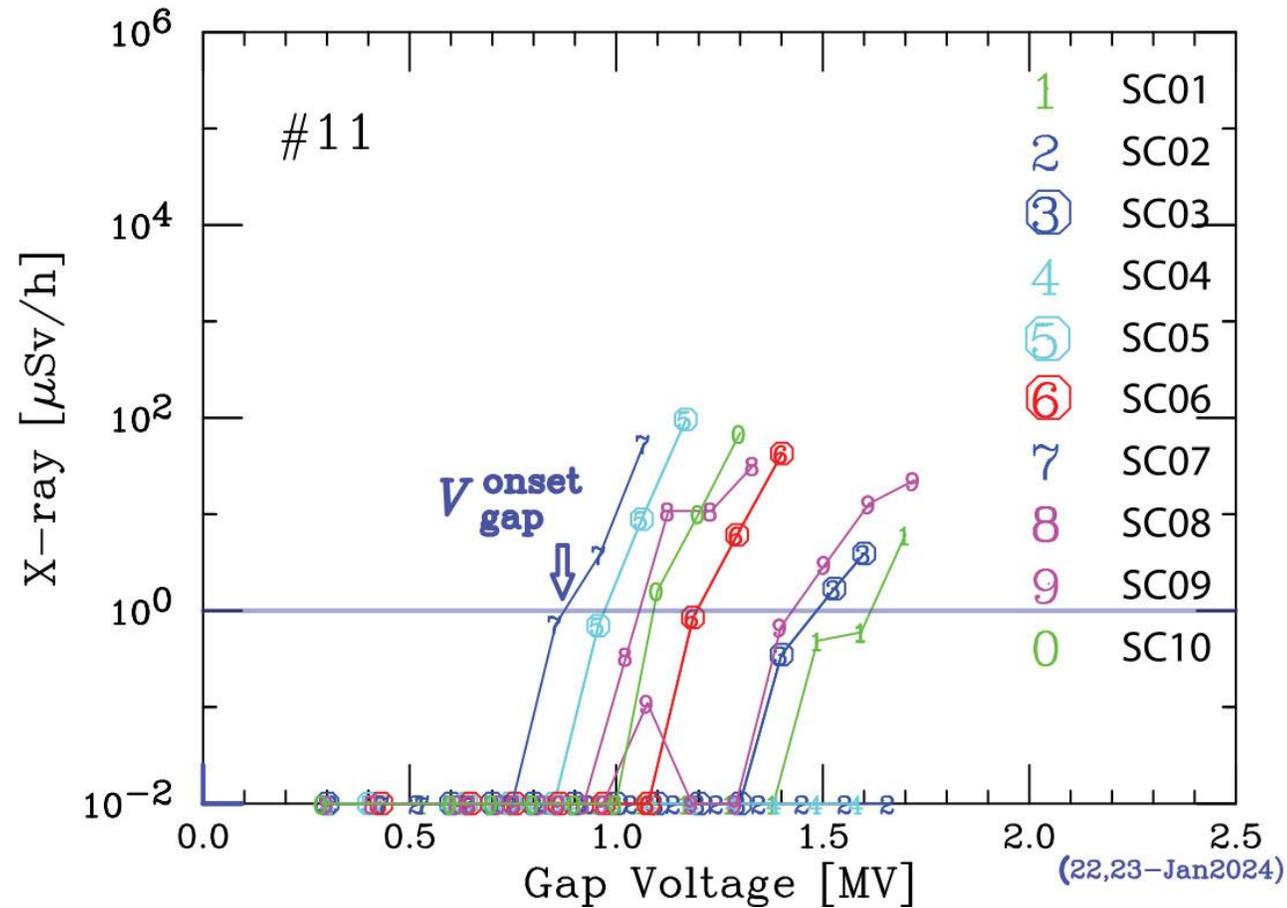
N. Sakamoto, *yesterday*

N. Sakamoto, WEPWB085, SRF2023

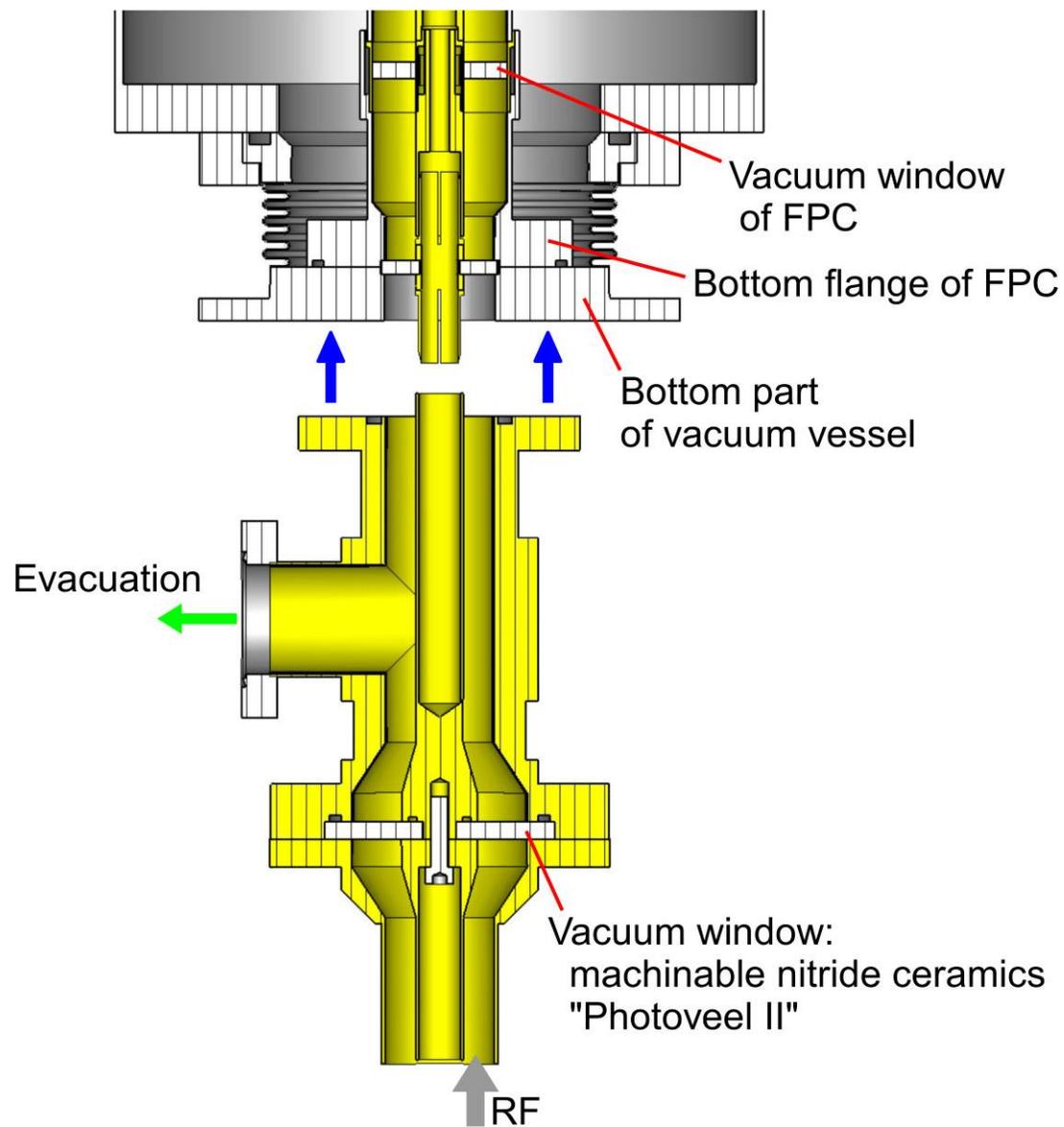
N. Sakamoto, THPB053, LINAC2024

On-set gap voltage

Definition: gap voltage at a radiation level of 1 $\mu\text{Sv/h}$



Countermeasure to vacuum leak from FPC window



Field emission situation during commissioning

- Comparison to cavity performance before installation / during acceptance testing
- Field emission situation as measured during commissioning
- Any known causes for the field emission (e.g. vacuum/gas sources, particulate sources,...)?
 - Possibility of synthesis of hydrocarbons by radiation-induced reaction between H (H in Nb?/ adsorbed water?) and C (adsorbed CO₂?) on the surface of the cavity?