

Status of High-Q/G R&D at KEK

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IHPE-KEK meeting

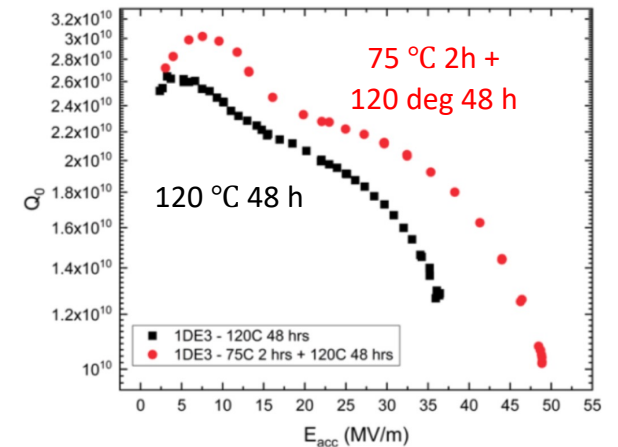
2023.11.20

Outline

- **Introduction**
- Surface heat treatment
- VT Result
- Summary

Introduction

- KEK has investigated the effects to enhance the cavity performance of SRF niobium cavities for various surfaces treatments.
- This presentation focus on the analysis result of the combination of cold EP (air cooling) and 2-step bake.
- The correspondent results at KEK were already reported in TTC2022 [1].
- However, it is found that there was ambiguity due to temperature sensors and the amount of trapped flux during the vertical test (→ next slide).
- In this presentation, we report on the analysis result considering the above mentioned ambiguity.



Comparison of Q-E curves between the case for 120 °C 48 h and that for 75 °C 2 h + 120 °C 48 h. The above figure are cited from “Accelerating fields up to 49 MV/m in TESLA-shape superconducting RF niobium cavities via 75°C vacuum bake”, arxiv 1806.09824.

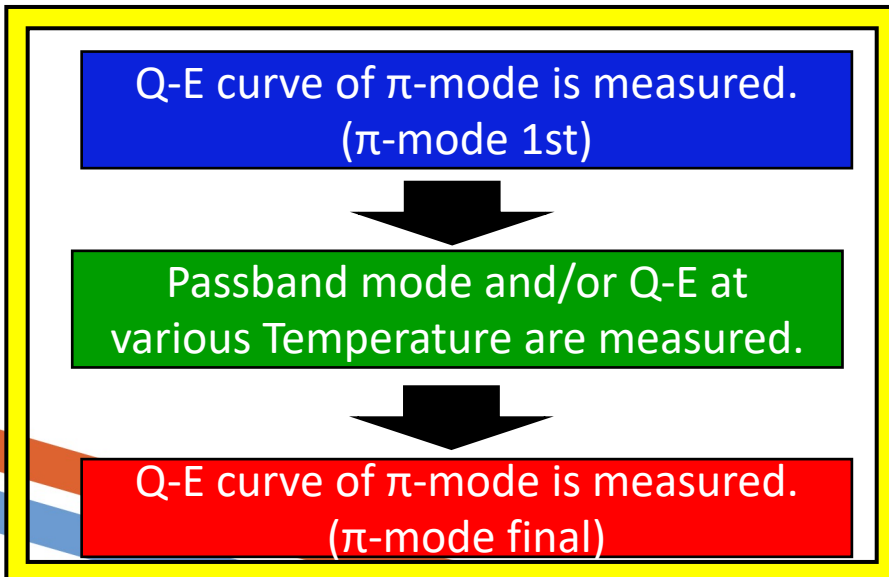
(Reference) [1] Ryo katayama, “2-step baking & mid-T baking of 9-cell SRF cavities”, TTC meeting 2022, 10, Nov, 2022, Aomori, Japan.

New Analysis Strategy

Temp sensor used in KEK

Sensor	Si	Cernox
Temp at 2 K	2.06-2.07 K	2.0 K
Period	Till beginning of 2020	Since middle of 2020

Typical VT flow at KEK



- [Strategy1]
 - KEK starts to the study of “cold EP + 2-step bake” since 2019.
 - KEK has adopted two type temperature sensors, Si and Cernox sensors.
 - Si sensor: until the beginning of 2020.
 - Cernox sensor: since the middle of 2020.
 - We found that Si sensor overestimated the observed temperature by 60-70 mK , whereas Cernox sensor is not so.
- → In this analysis, if necessary, we compare experimental data so that temperature is corrected by 70mK by the surface resistance: $R_s(T)$.
- [Strategy2]
 - For reference, the typical flow of VT at KEK is shown in the left figure.
 - Traditionally, KEK evaluate the result from the data of **π-mode final** .
 - However, in this situation, Q-value is dependent on how many quenches occur during VT, which cause an ambiguity.
- → In this analysis, we evaluate the result using the data of **π-mode 1st**.

SRF cavities used in this study



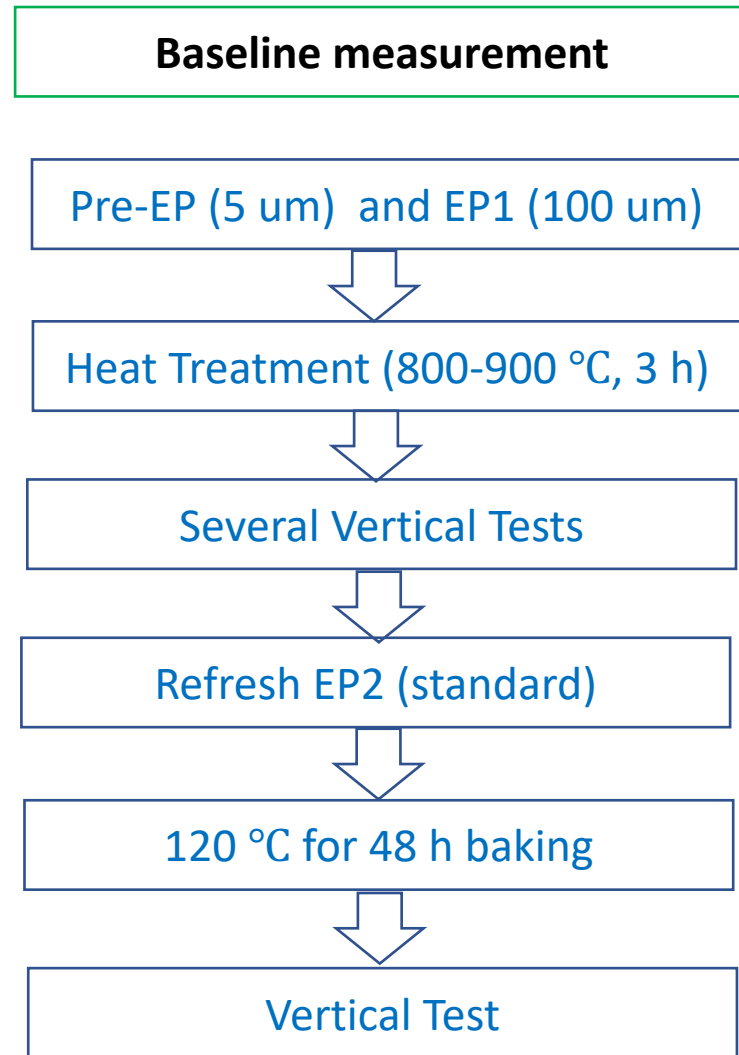
- We used the following cavities for the purpose of the High-Q/G R&D of SRF cavity using the combination of cold EP and 2-step bake.

	MT-5	MT-6	R-8
Maker	Mitsubishi Heavy Industry	Mitsubishi Heavy Industry	KEK CFF
RRR	>300 (Tokyo Denkai)	>300 (Tokyo Denkai)	>300 (Tokyo Denkai)
Shape	TESLA 9-cell	TESLA 9-cell	TESLA-like 1-cell
Heat Treatment	900 °C 3h	900 °C 3h	800 °C 3h
Grain Size	Fine	Fine	Fine

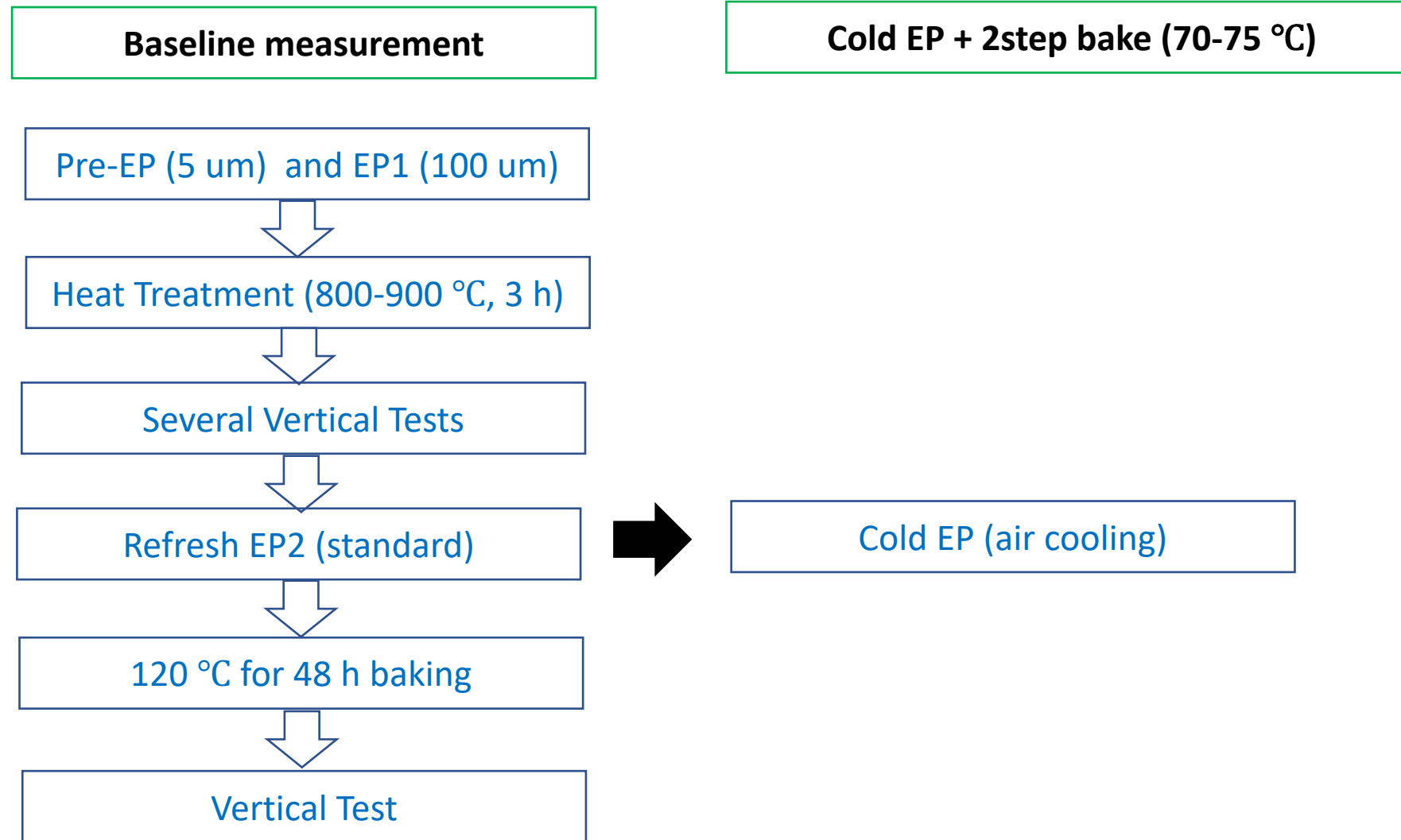
Outline

- Introduction
- **Surface heat treatment**
- VT Result
- Summary

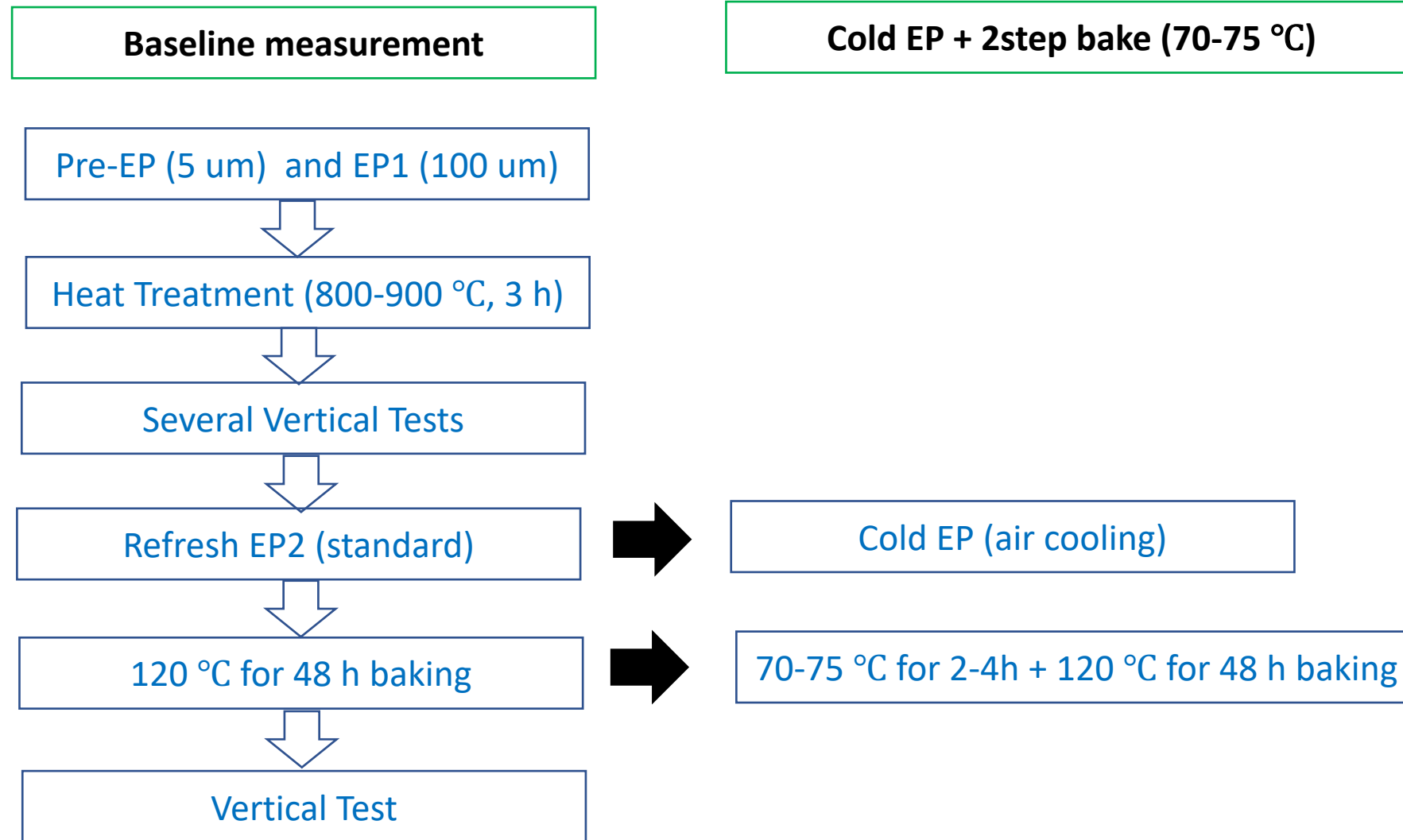
Flow chart of Surface treatment flow used in this study



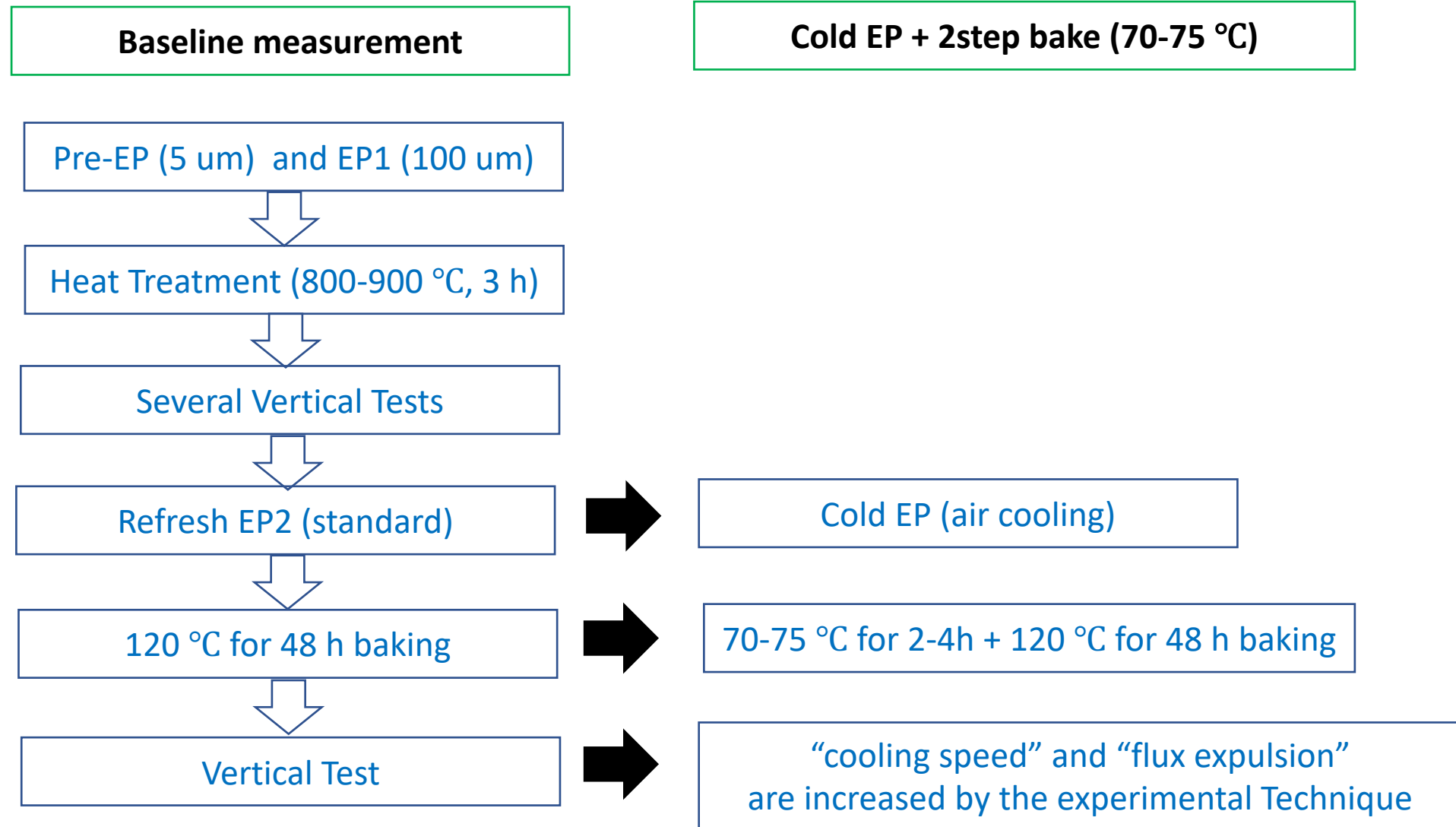
Flow chart of Surface treatment flow used in this study



Flow chart of Surface treatment flow used in this study



Flow chart of Surface treatment flow used in this study



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- Surface heat treatment
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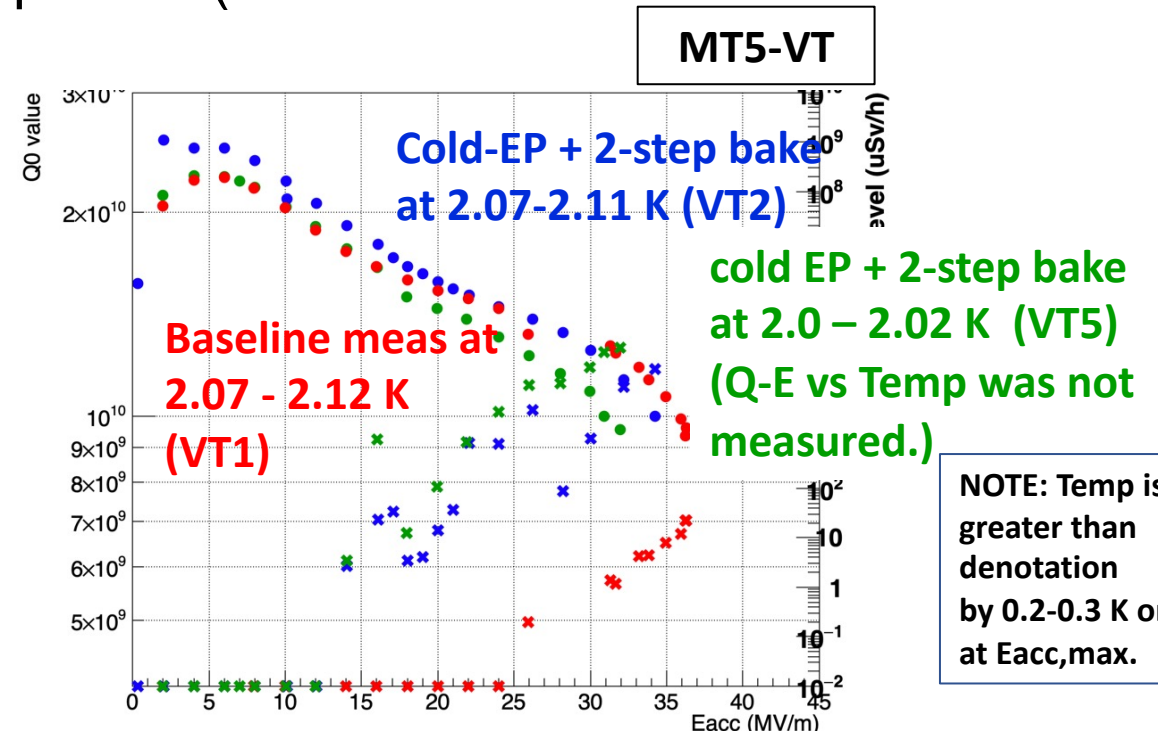
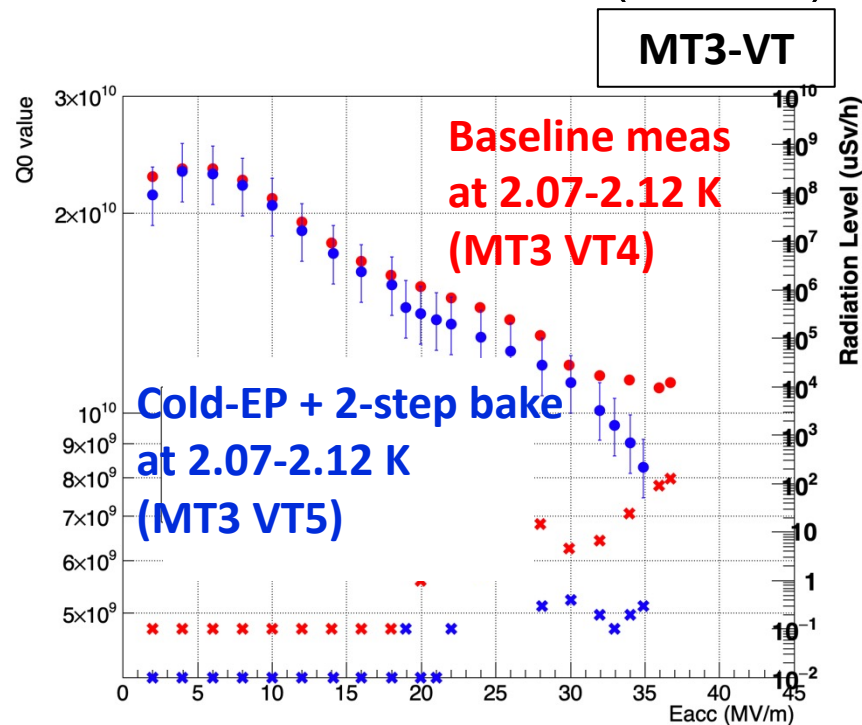
VT Result

- **75°C bake**
- **70°C bake**



Result of cold-EP + 2-step bake (75°C 2-4 h) at KEK

- The case for “cold EP + 2-step bake” is shown below.
 - Red:** KEK STD EP (25-30 °C) + STD bake (120 °C 48 h bake).
 - Blue, Green:** Cold EP (~14°C) + 2-step bake (75 °C 2-4 h bake + 120 °C 48 h bake).



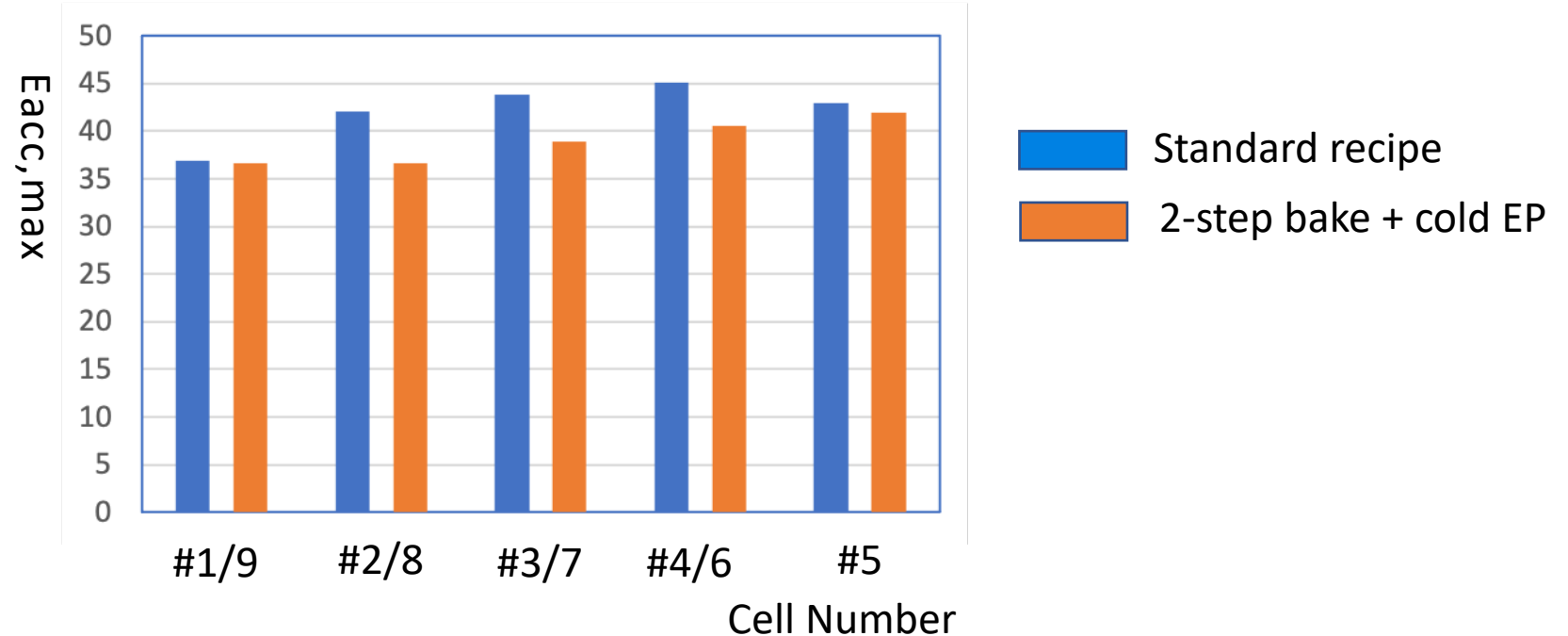
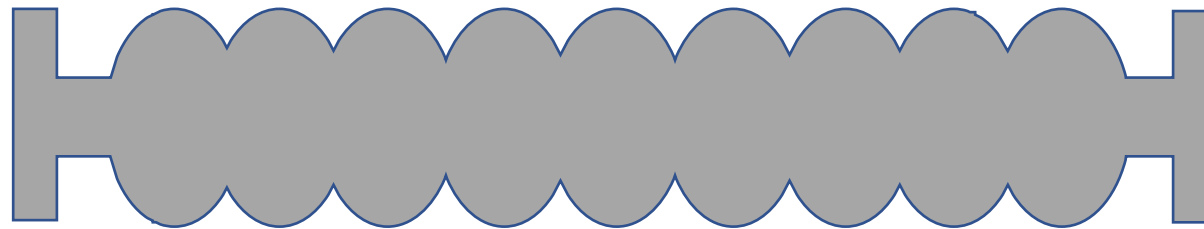
NOTE: Temp is greater than denotation by 0.2-0.3 K only at Eacc,max.

Q-value was deteriorated in the probability of 2/3.



Result of cold-EP + 2-step bake (75°C 2-4 h) at KEK

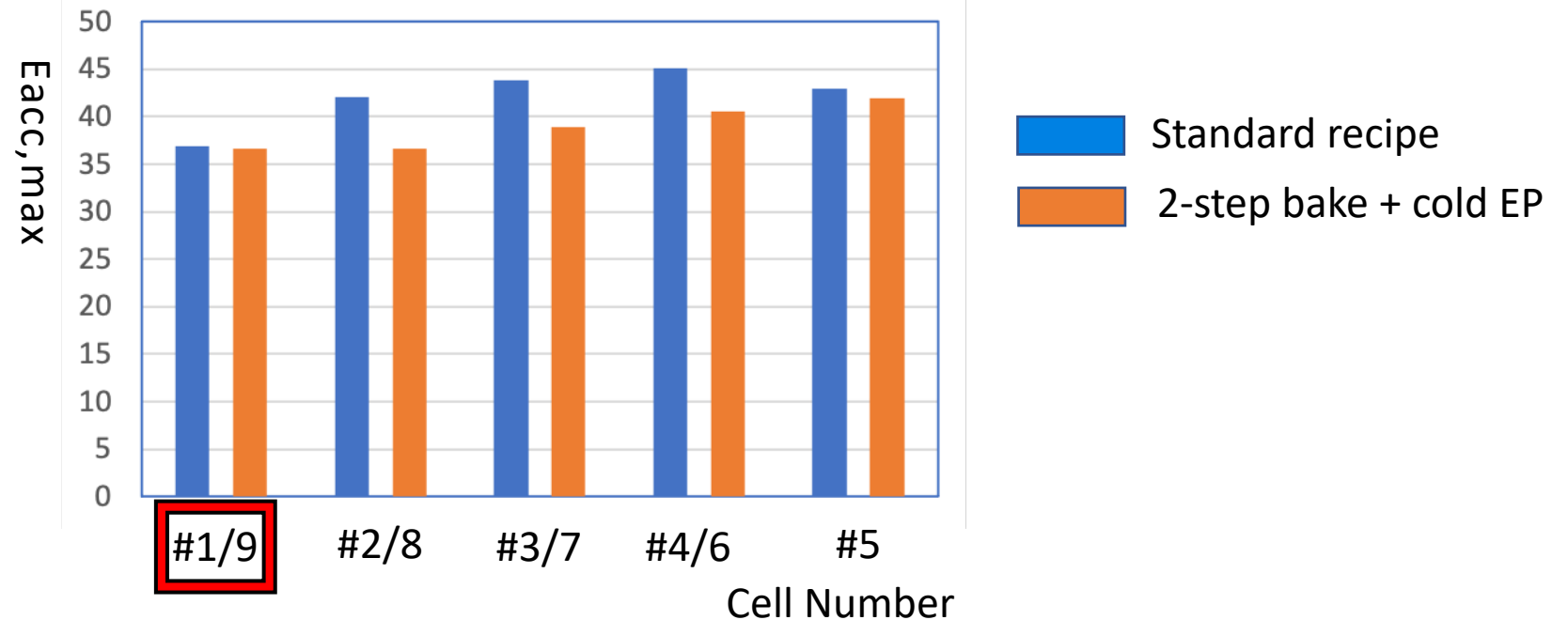
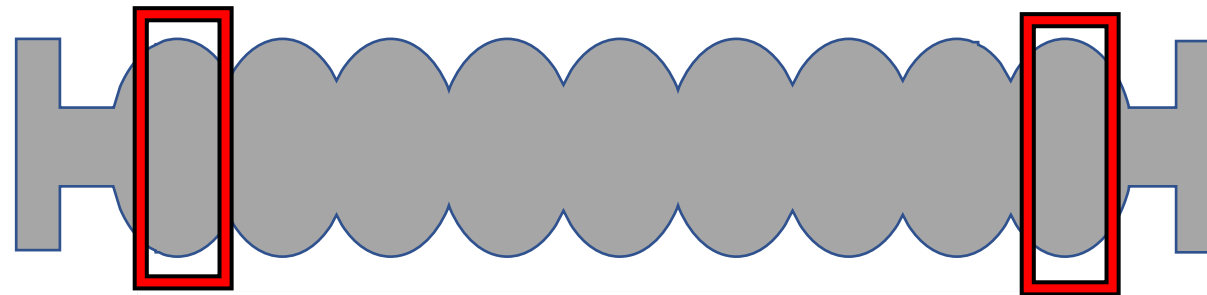
- Passband mode analyses to evaluate $E_{acc,max}$ per cell were shown in the following histograms.





Result of cold-EP + 2-step bake (75°C 2-4 h) at KEK

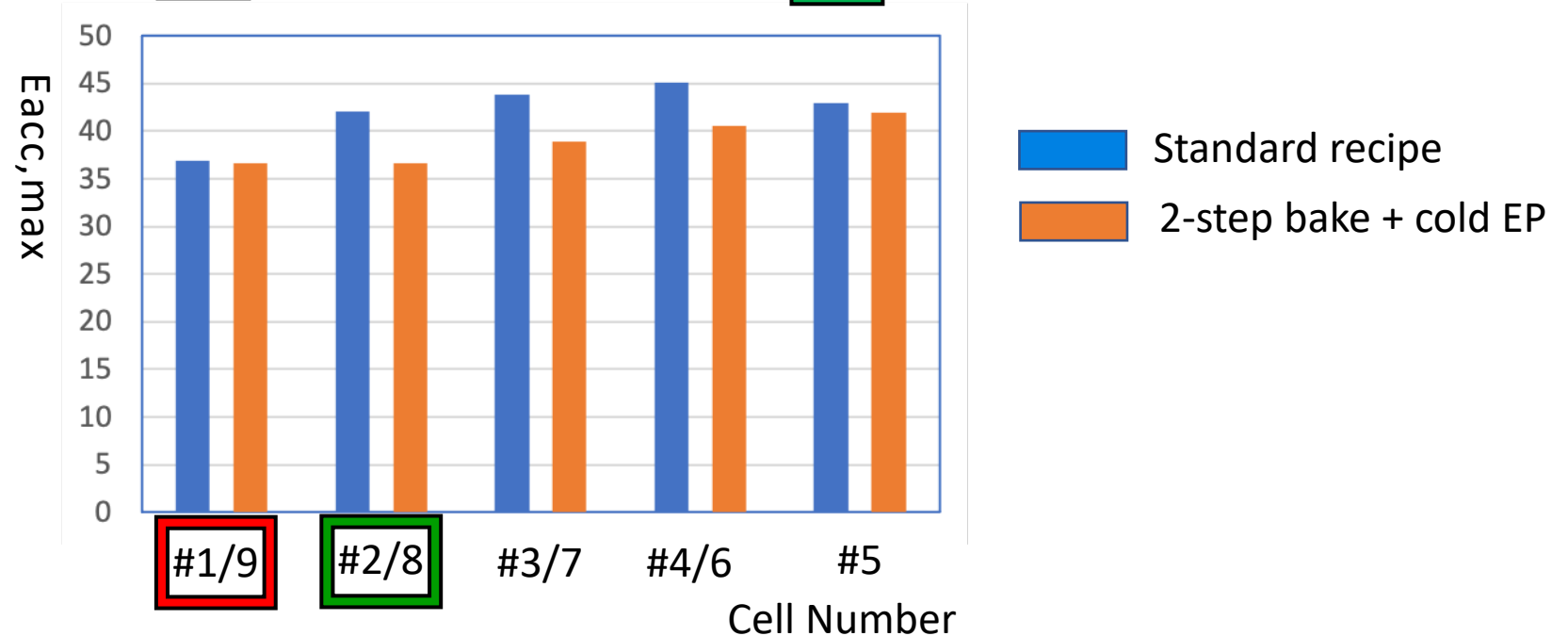
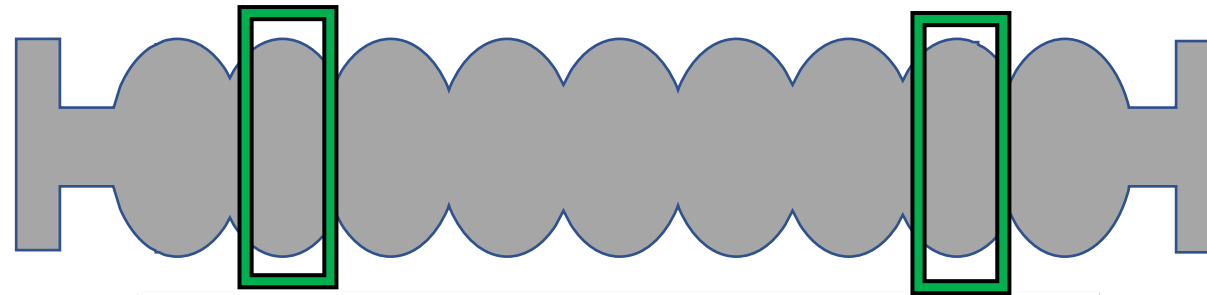
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Result of cold-EP + 2-step bake (75°C 2-4 h) at KEK

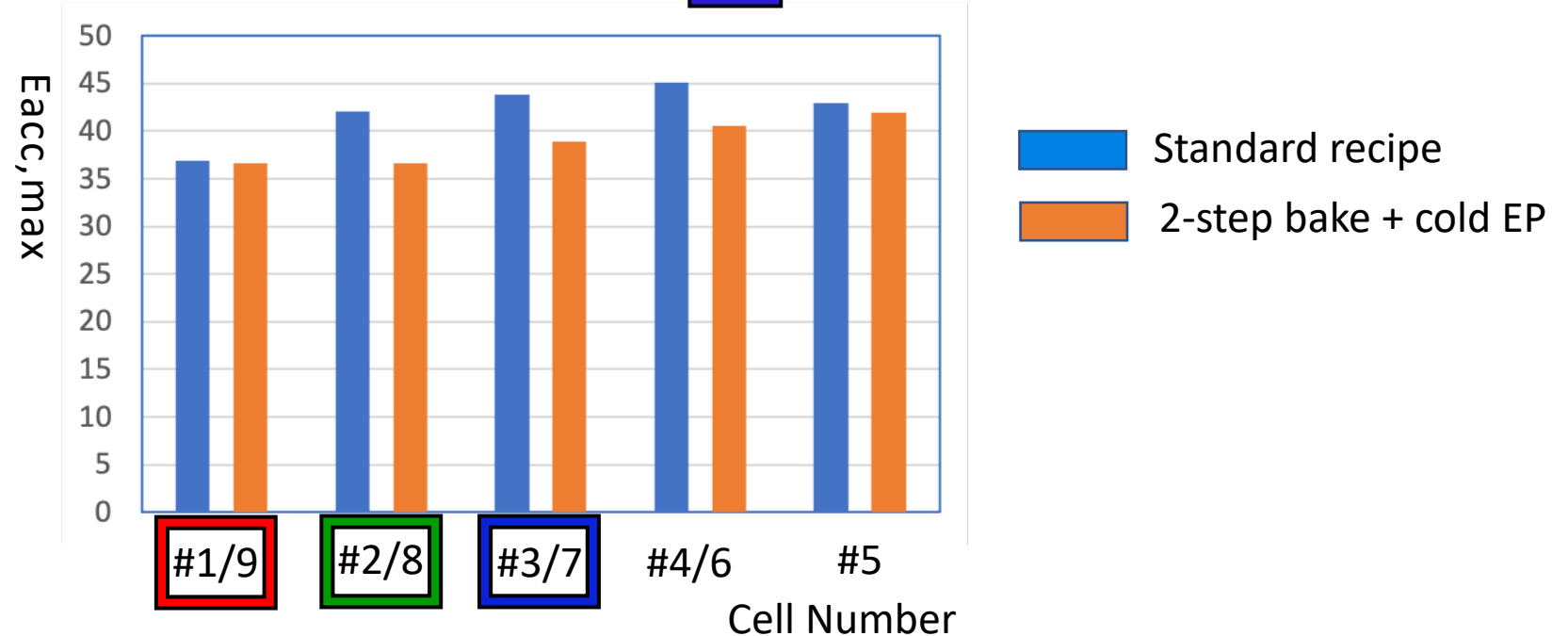
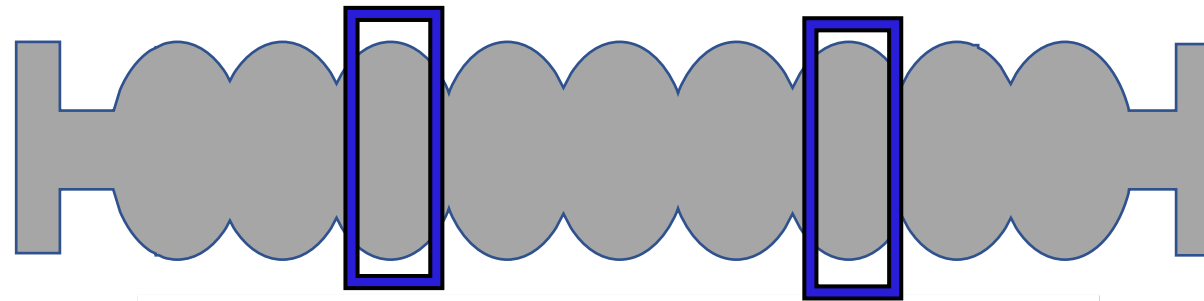
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Result of cold-EP + 2-step bake (75°C 2-4 h) at KEK

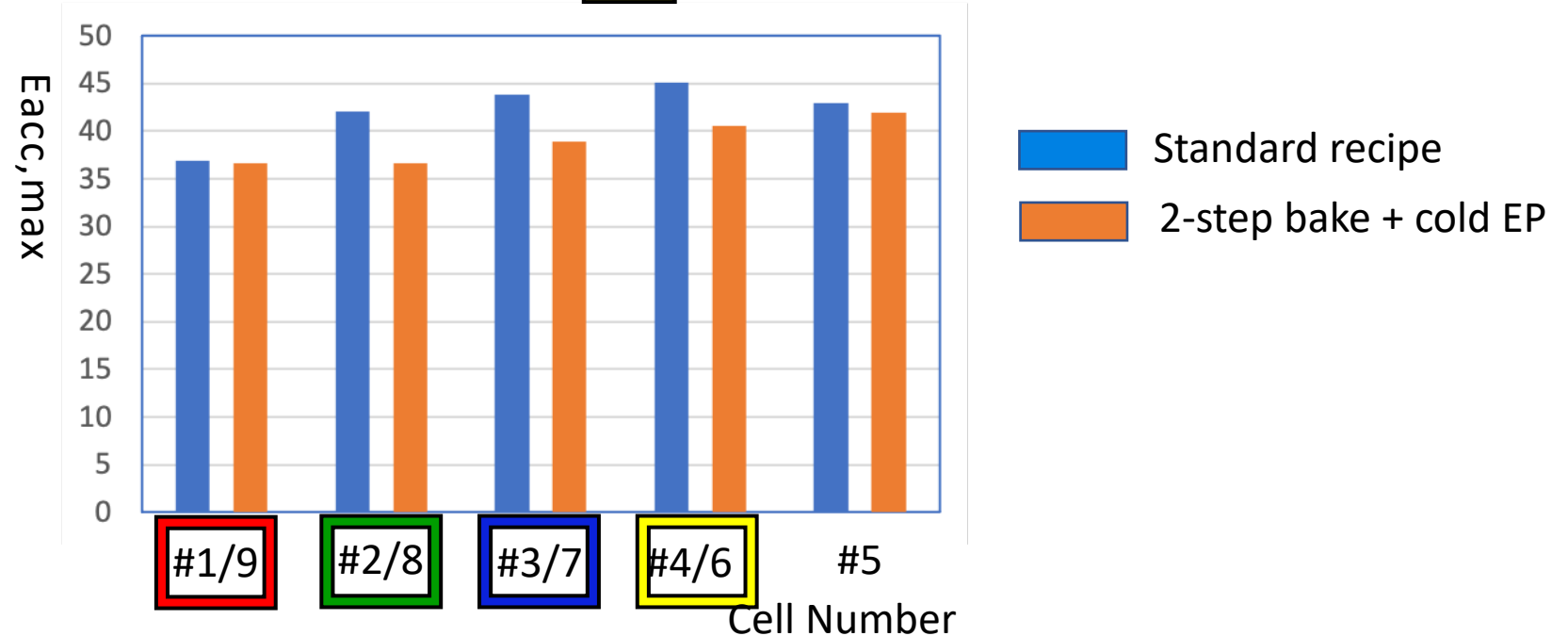
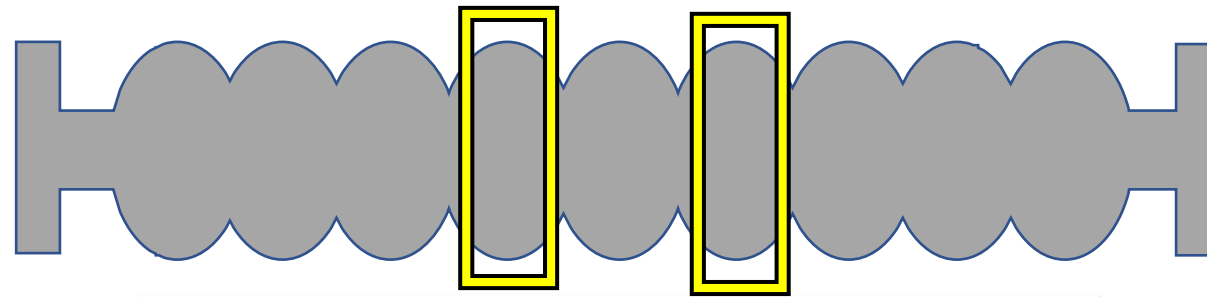
- passband mode analyses to evaluate $E_{acc,max}$ per cell were shown in the following histograms.





Result of cold-EP + 2-step bake (75°C 2-4 h) at KEK

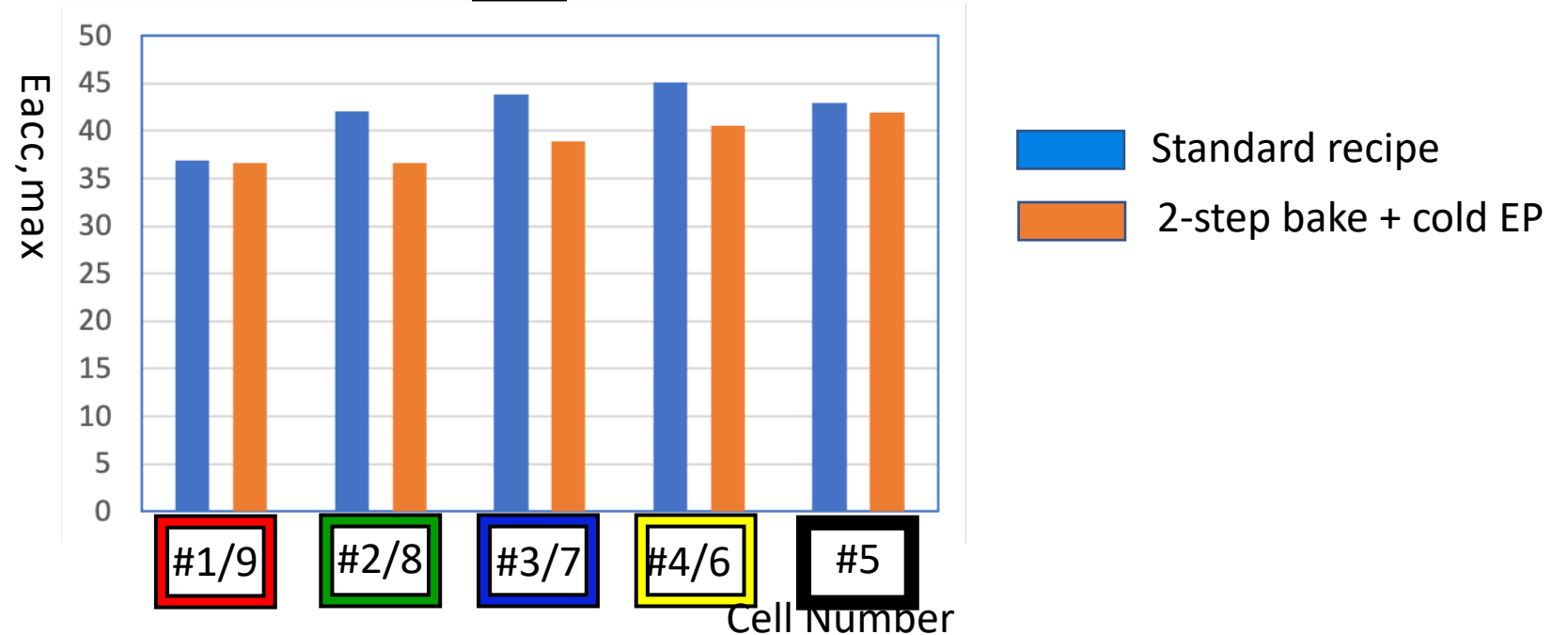
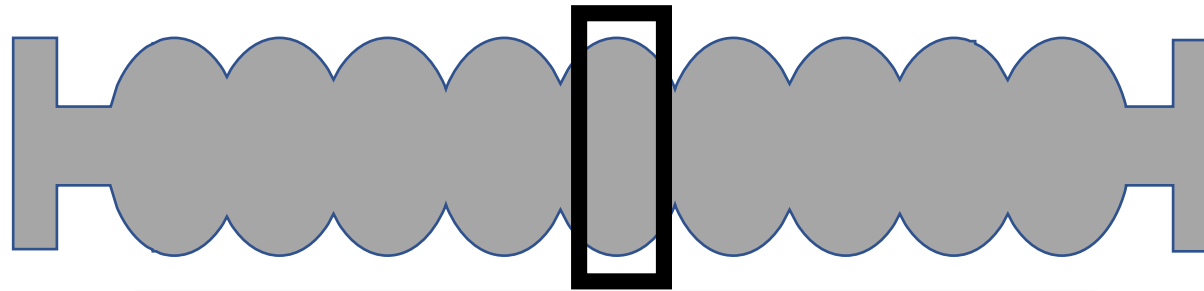
- passband mode analyses to evaluate $E_{acc,max}$ per cell were shown in the following histograms.





Result of cold-EP + 2-step bake (75°C 2-4 h) at KEK

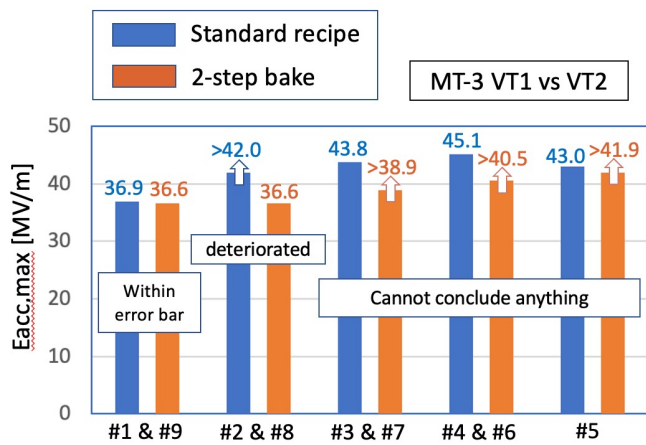
- passband mode analyses to evaluate $E_{acc,max}$ per cell were shown in the following histograms.



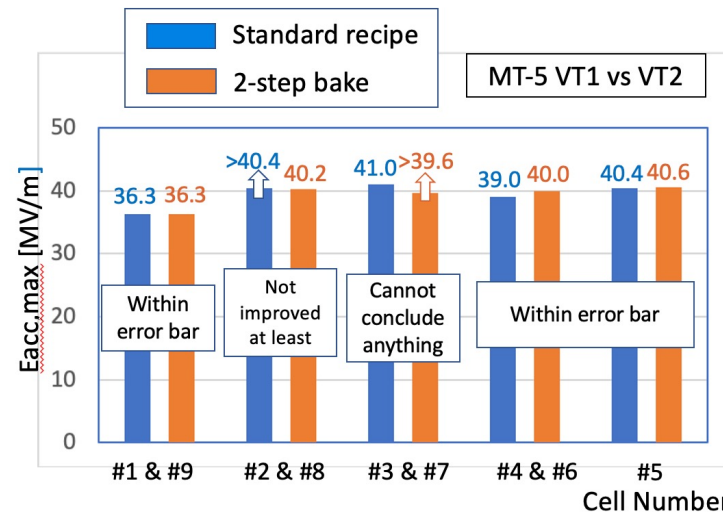


Result of cold-EP + 2-step bake (75°C 2-4 h) at KEK

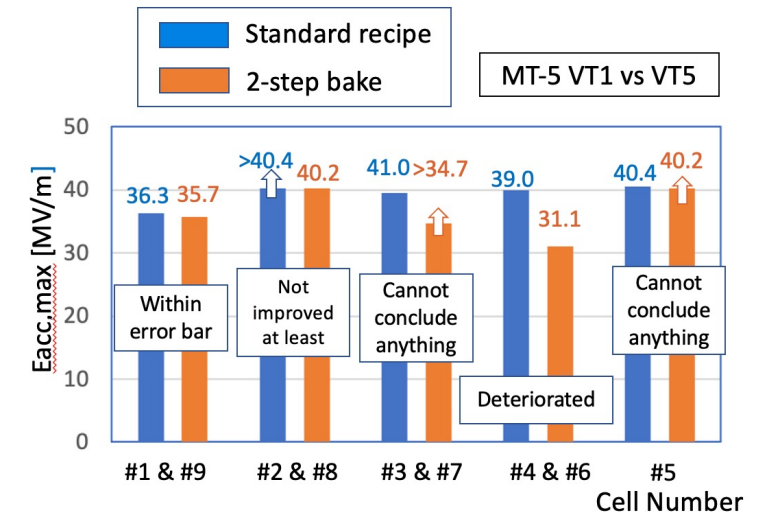
- passband mode analyses to evaluate $E_{acc,max}$ per cell were shown in the following histograms.



No improved	Deteriorate	No information
1	1	3



No improved	Deteriorate	No information
4	0	1



No improved	Deteriorate	No information
2	1	2

E_{acc,max} was not improved in any case.

VT Result

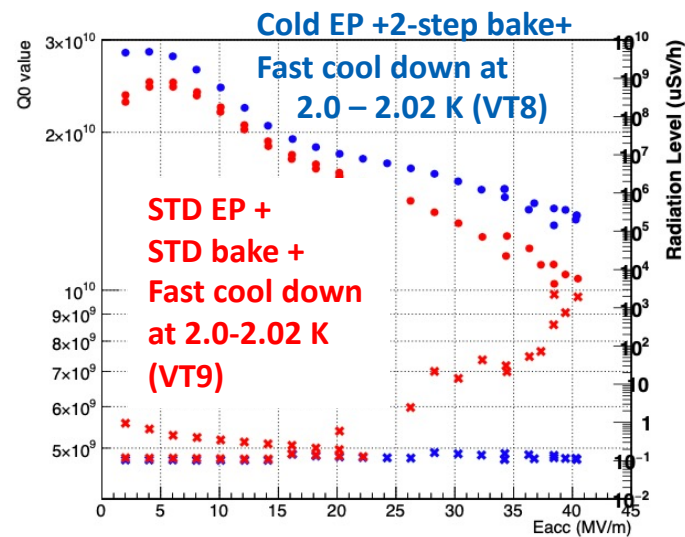
- 75°C bake
- **70°C bake**



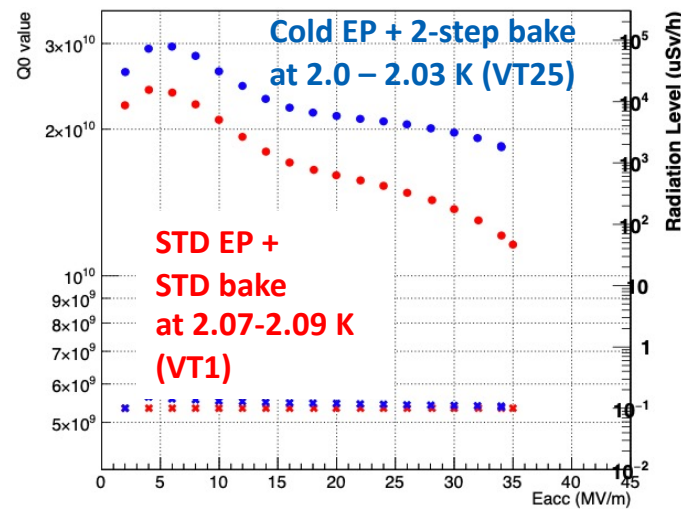
Result of cold-EP + 2-step bake (70 °C 4 h) at KEK

- Comparison of Q-E between “STD EP + bake” and “cold EP + 2-step bake” is shown below.
 - **Red**: KEK STD EP (25-30 °C) + STD bake (120 °C 48 h bake).
 - **Blue**: Cold EP (~14°C) + 2-step bake (70 °C 4 h bake + 120 °C 48 h bake).

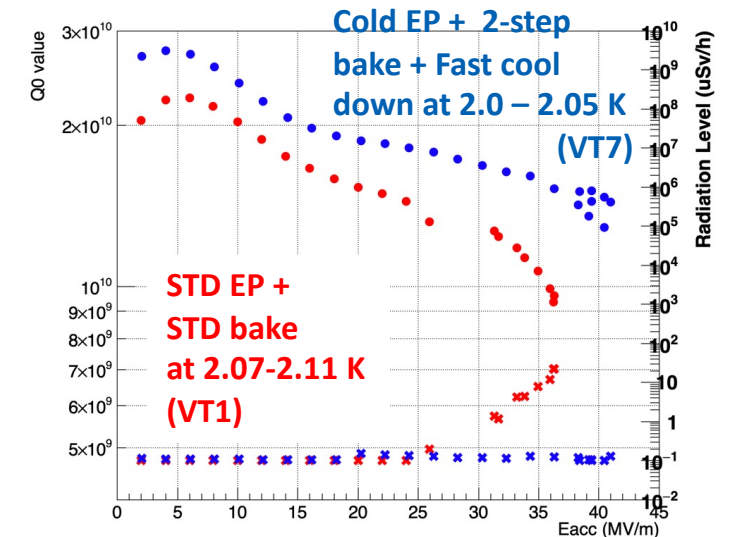
VT results for MT6
(9cell, Fine Grain Nb)



VT results for R8
(1-cell, Fine Grain Nb)



VT results for MT5
(9cell, Fine Grain Nb)



	Baseline	High-Q/G
Bake	120°C	2-step
EP	STD	cold
Fast cool	✓	✓

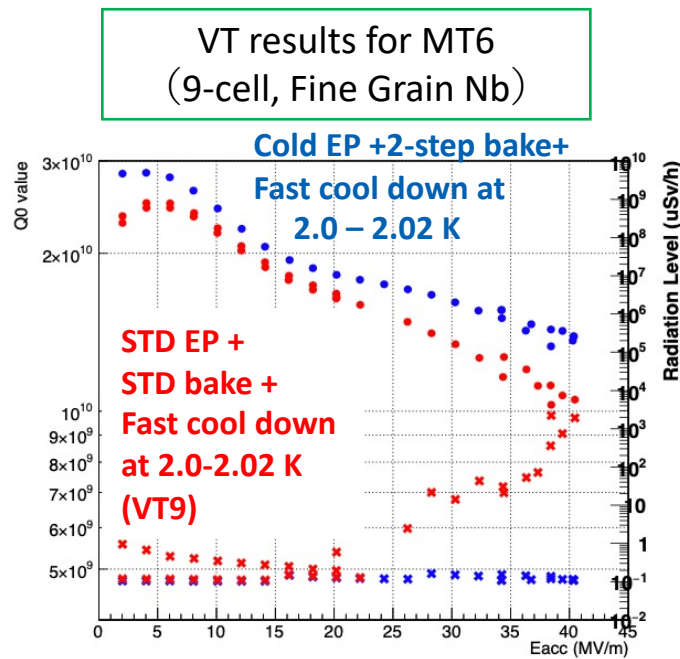
	Baseline	High-Q/G
Bake	120°C	2-step
EP	STD	cold
Fast cool		

	Baseline	High-Q/G
Bake	120°C	2-step
EP	STD	cold
Fast cool		✓

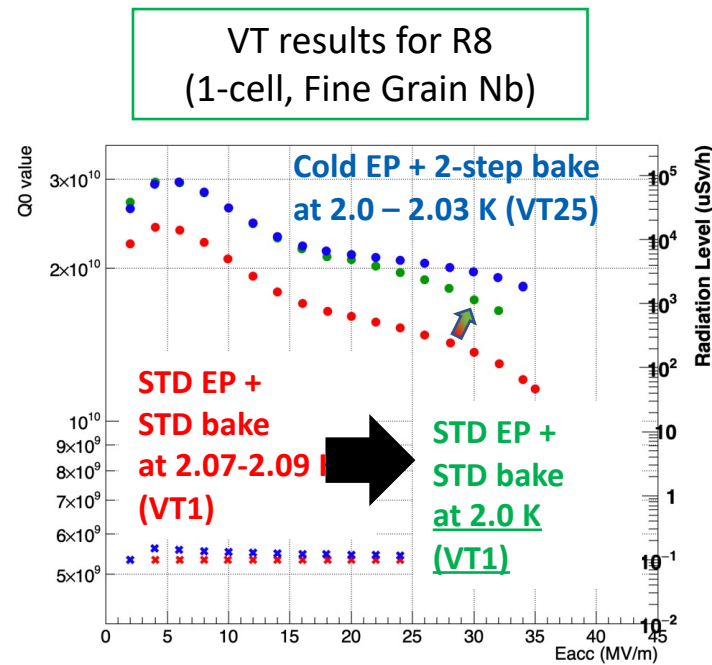


Result of cold-EP + 2-step bake (70 °C 4 h) at KEK

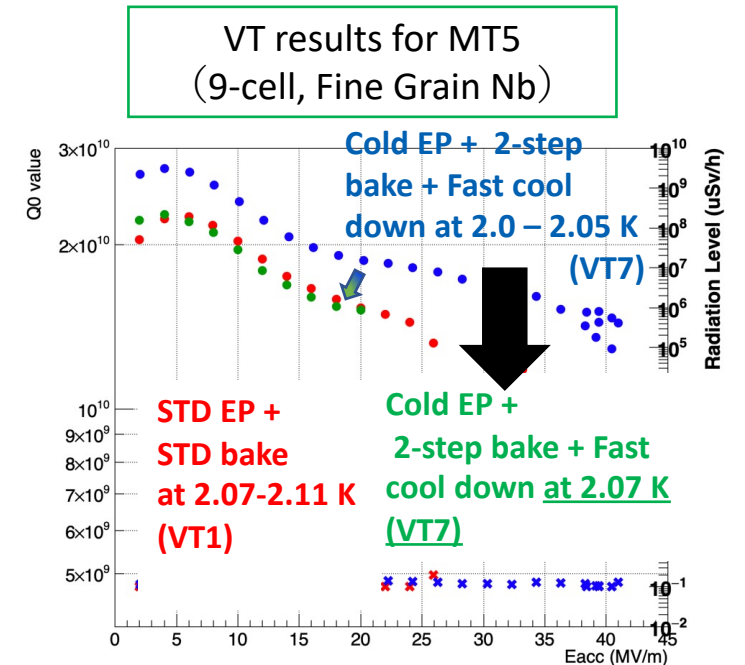
- Comparison of Q-E between “STD EP + bake” and “cold EP + 2-step bake” is shown below.
 - **Red:** KEK STD EP (25-30 °C) + STD bake (120 °C 48 h bake).
 - **Blue:** Cold EP (~14°C) + 2-step bake (70 °C 4 h bake + 120 °C 48 h bake).



Eacc improvement	Q improvement
No	YES



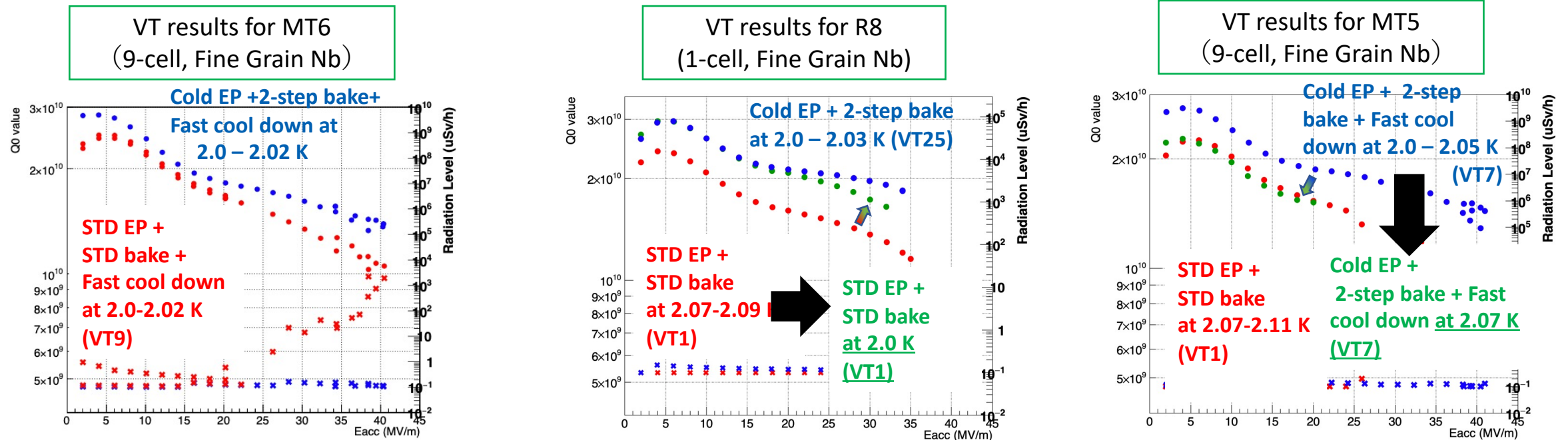
Eacc improvement	Q improvement
No	YES



Eacc improvement	Q improvement
YES	No (only low Field)

Result of cold-EP + 2-step bake (70 °C 4 h) at KEK

- Comparison of Q-E between “STD EP + bake” and “cold EP + 2-step bake” is shown below.
 - **Red:** KEK STD EP (25-30 °C) + STD bake (120 °C 48 h bake).
 - **Blue:** Cold EP (~14°C) + 2-step bake (70 °C 4 h bake + 120 °C 48 h bake).



1. Q-value was improved in the probability of 2/3.
2. Eacc,max values were not enhanced every time.

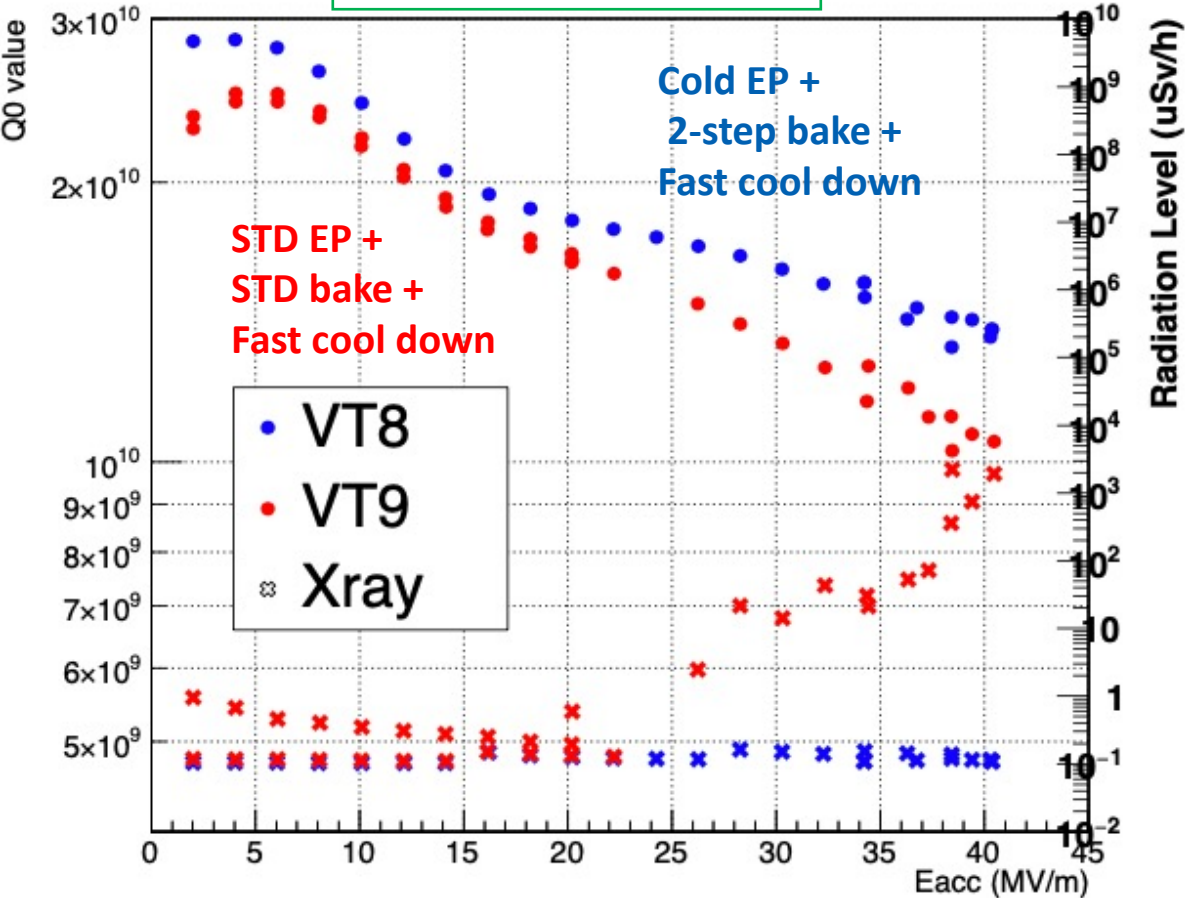


Next step:
Low-Temp bake using the oven

Discussion Point

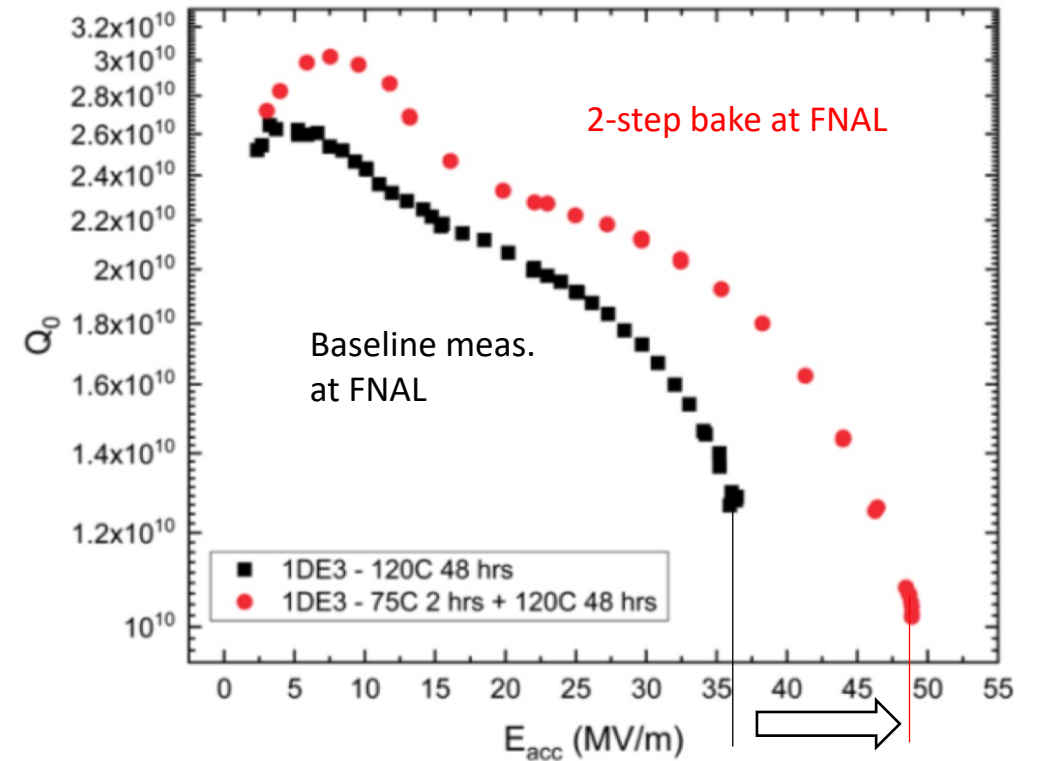


VT results for MT6
(9cell, Fine Grain Nb)



VT results at FNAL
(1cell, Fine Grain Nb)

(Ref) "Accelerating fields up to 49 MV/m in TESLA-shape superconducting RF niobium cavities via 75°C vacuum bake", arxiv 1806.09824.

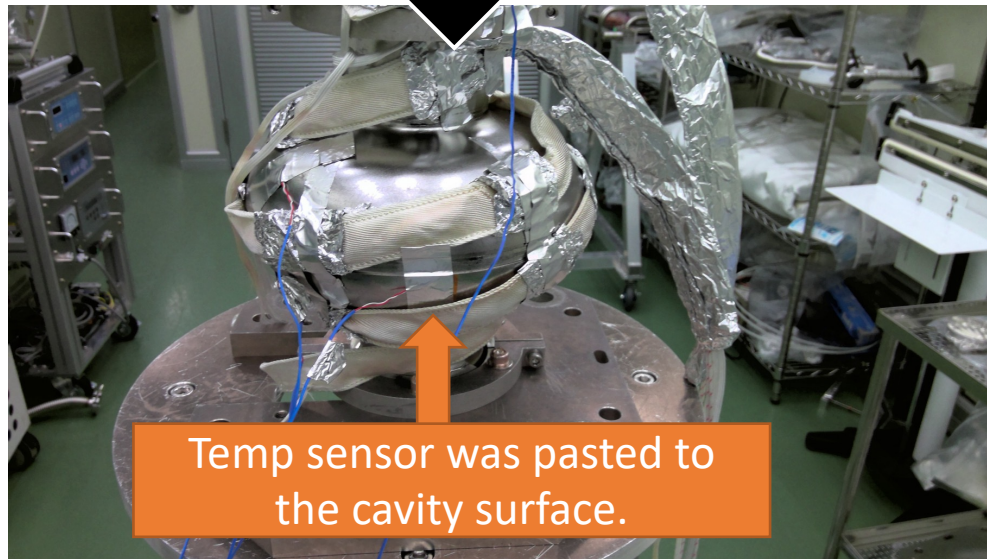


Q. why 2-step bake applied at KEK did not improve quench field ?

A. There is the possibility that temperature non-uniformity during low-Temp bake.

Photograph of baking setup at KEK

The cavity is wrapped around a ribbon heater.



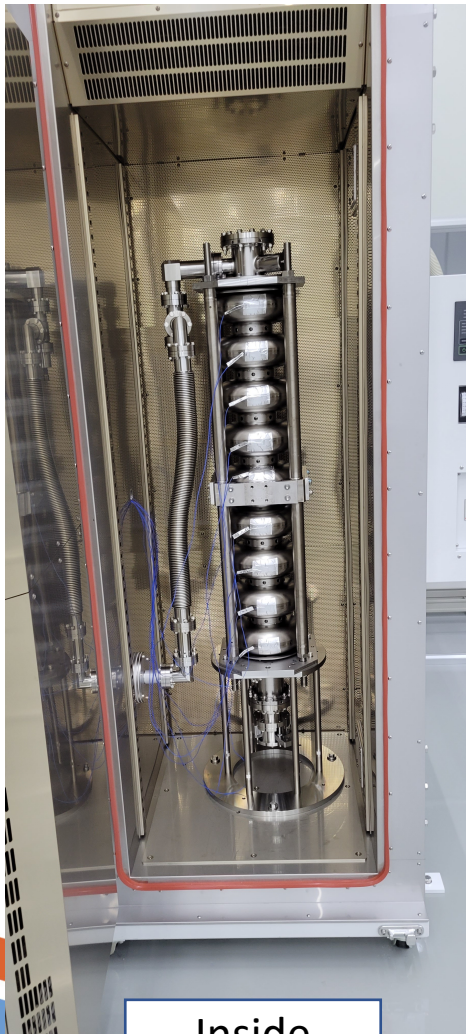
Additionally, 9-cell cavity wear a heater jacket.



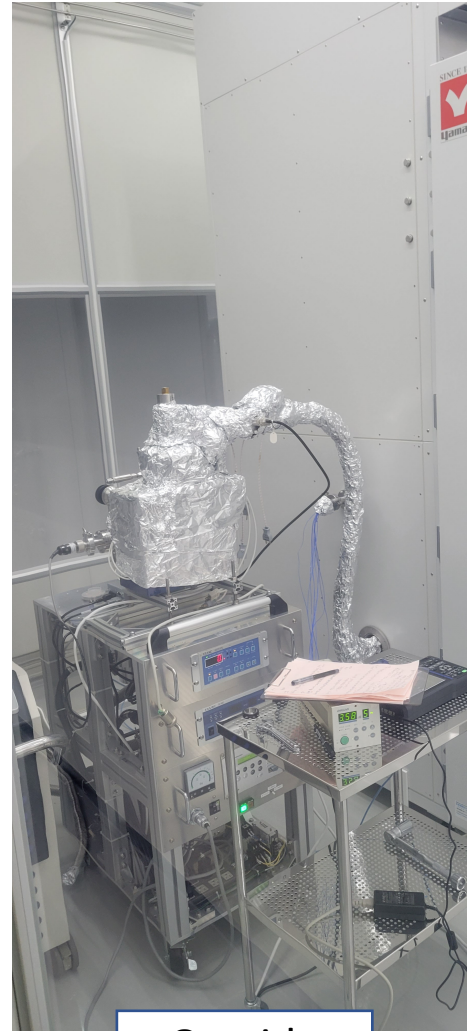
There is a possibility that temperature just behind the ribbon heater and/or heater jacket may be deviated from the temperature indicated by sensors.

The reason why pre-baking temperature was modified by -5 °C is to prevent overheating.

Introduction of the oven for low-Temp Bake



Inside

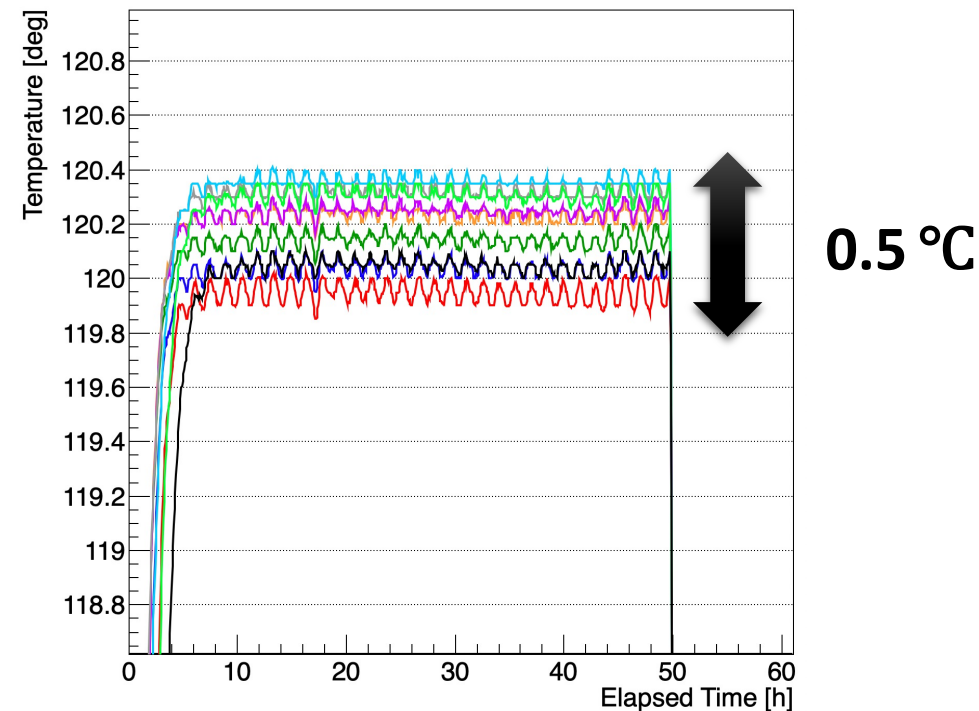
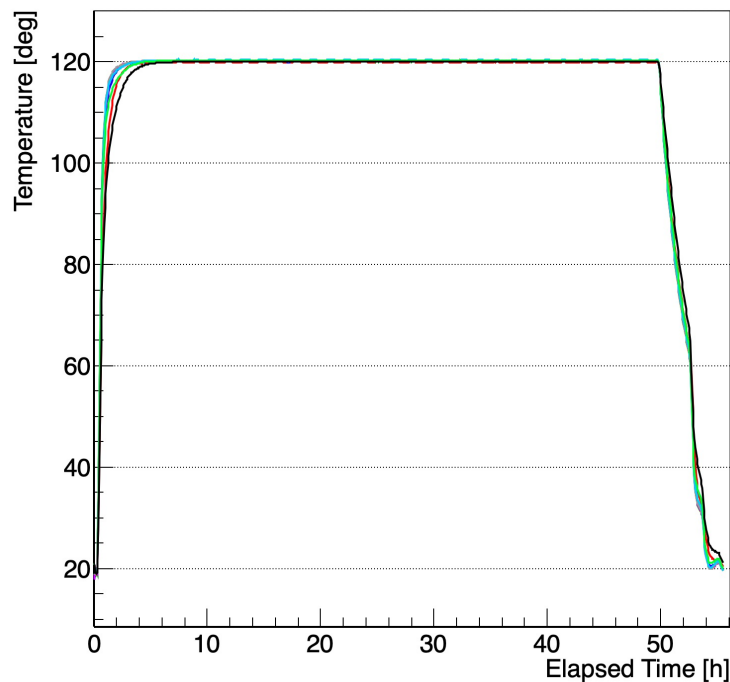
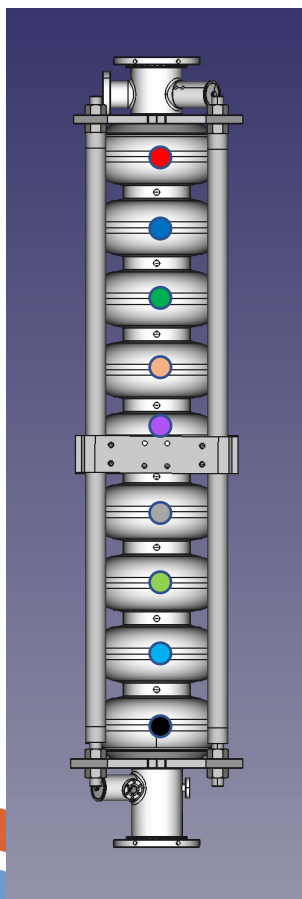


Outside

- Thus, KEK recently introduced the oven in order to uniformly warm the whole of 9-cell cavity during the low temp-bake process.
- Yamato-Kagaku inc, provide the apparatus to KEK.

120 °C bake result using clean oven

Sensor Positions



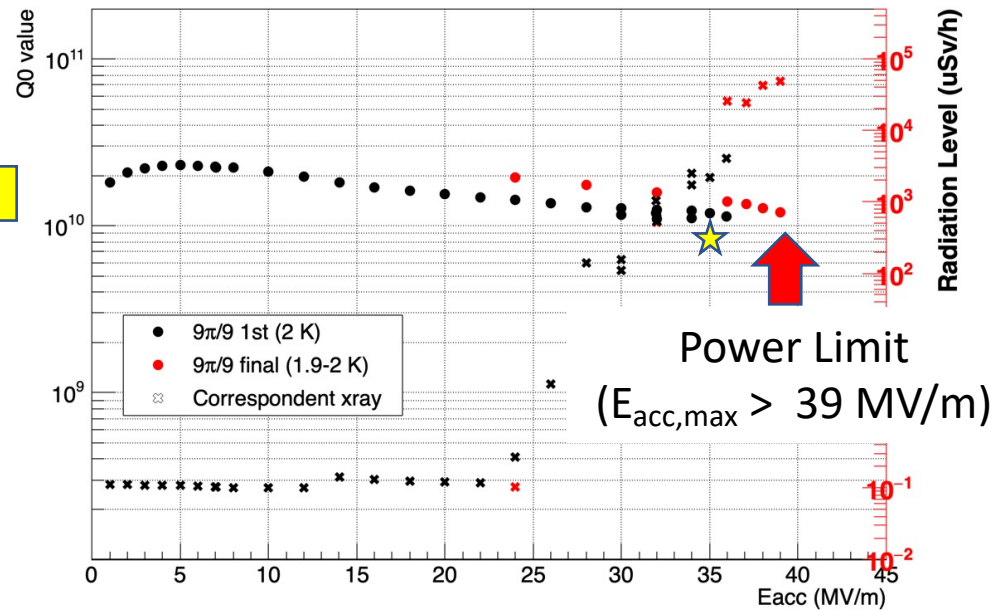
- 120 °C bake was successfully performed.
- Temp deviation was suppressed in the range 0.5 °C.



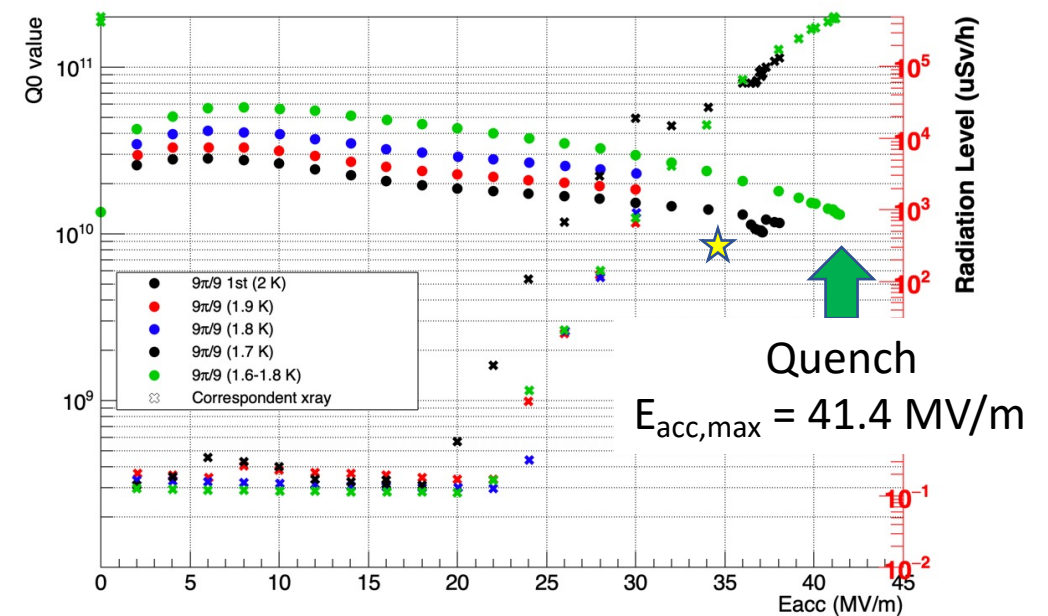
VT result of low-temp bake by oven

- 120 °C for 48 h bake by oven was applied to LCLS-257 and KEK-6
- Q-E curves for pi mode about two cavities are shown below.

LCLS-257 VT4 (9-cell, Fine Grain Nb)



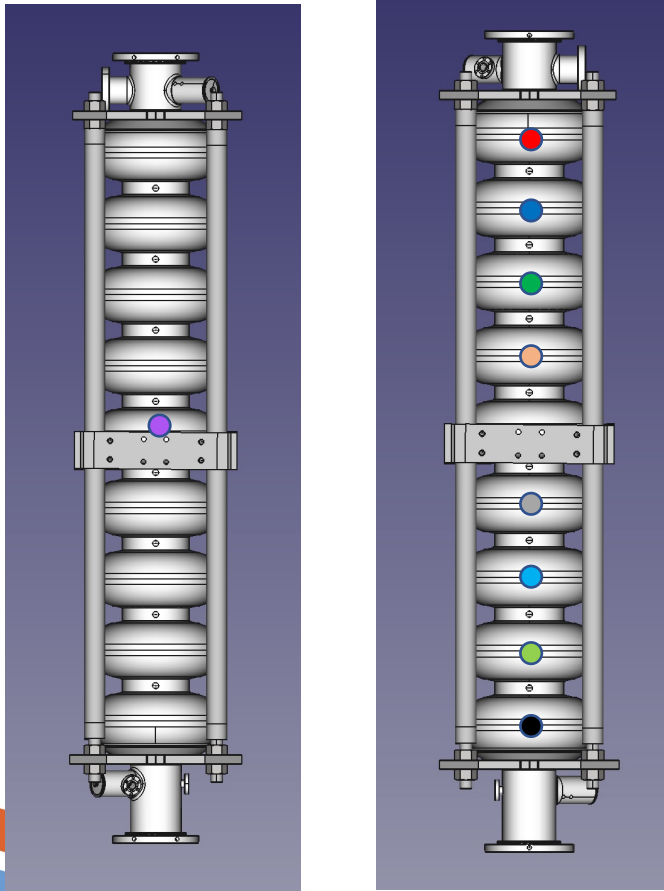
KEK6 VT3 (9-cell, Fine Grain Nb)



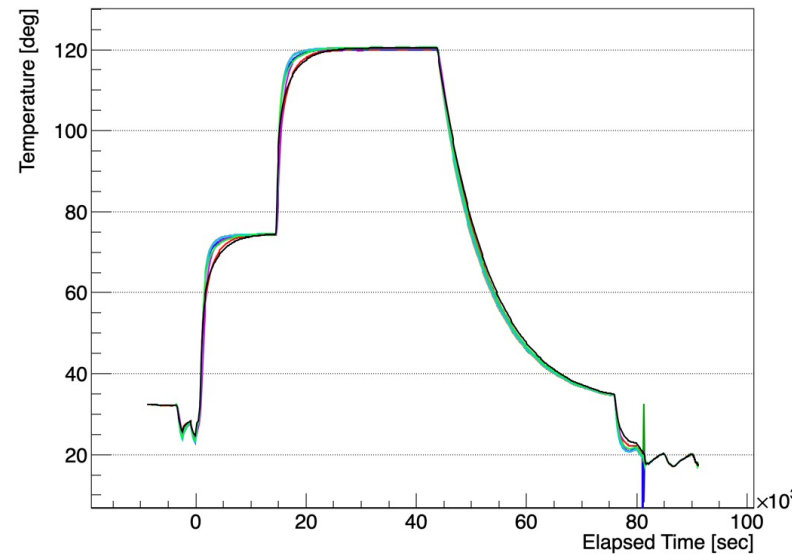
E_{acc,max} > 39 MV/m (LCLS-257) and 41.4 MV/m (KEK-6) can be obtained, and Q-value at 2 K and 35 MV/m were greater than 1e10 in both cavities.

2-step bake result using oven (only temperature test)

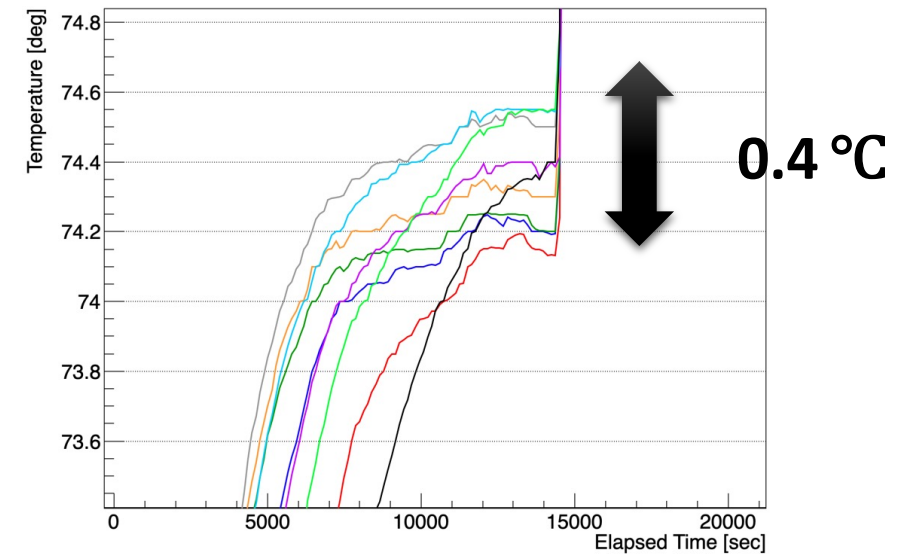
Sensor Positions



2-step bake (Sensor Back)



2-step bake (Sensor Back)



- 2-step bake (75 °C +120°C) was successfully performed.
- Temp deviation was suppressed in the range 0.4 °C.

Summary

- Combination of Cold EP (air cooling), 2-step bake (70 - 75°C 4h + 120°C 48 h) were applied to several 9-cell and single cell SRF cavities at KEK.
- 2-step bake at 75 °C did not effectively improve the cavity performance.
- Cold EP and 2-step bake at 70 °C tend to improve Q-value by ~10 %, whereas quench field was not improved in every time.



Thank you for your attention

