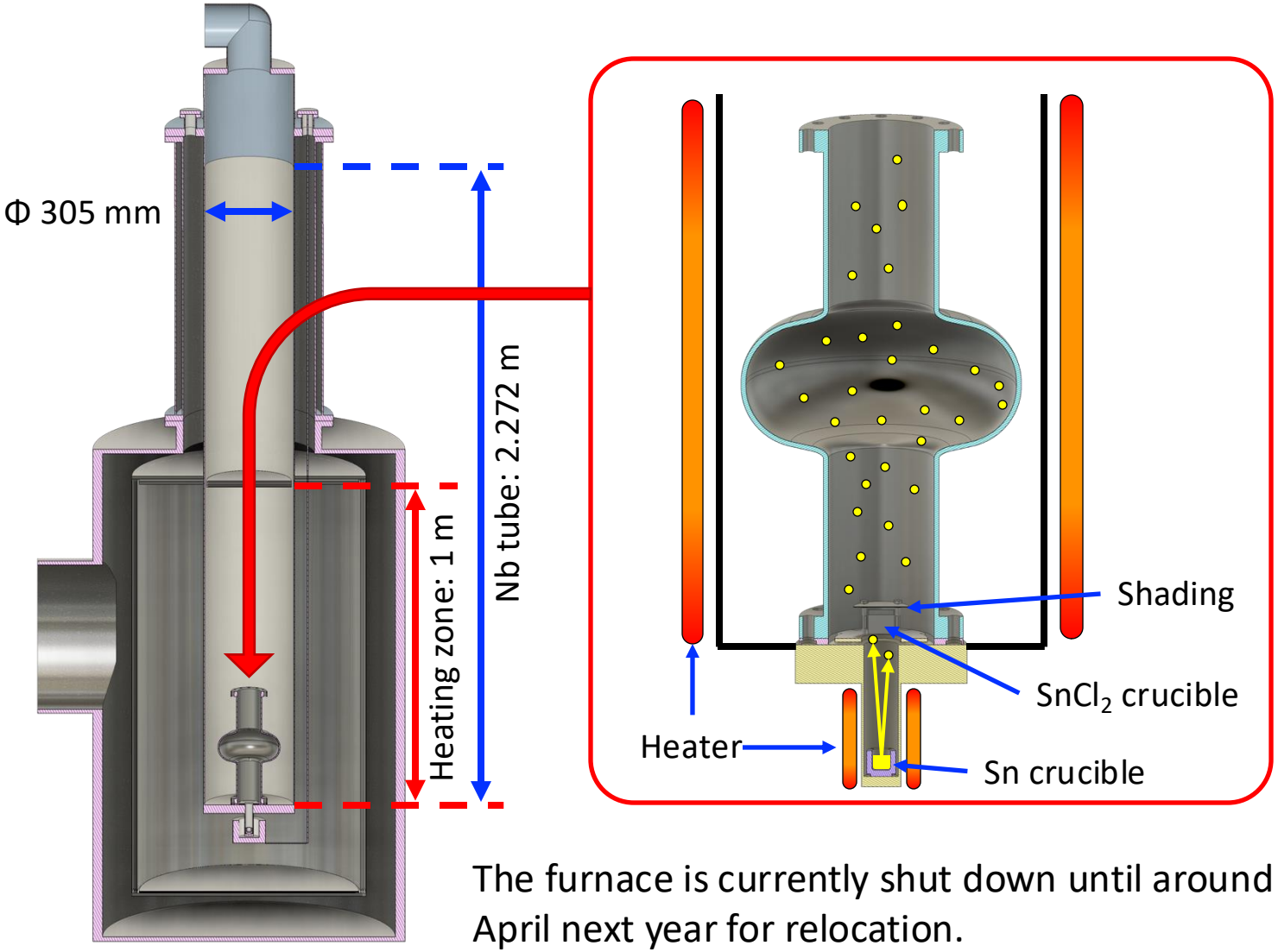
Nb_3Sn coating R&D at KEK

Hayato Ito

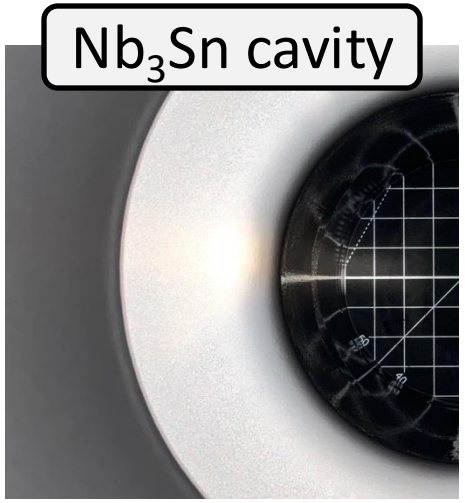
On behalf of KEK Nb_3Sn group

12th IHEP-KEK Superconducting collaboration meeting

Furnace for Nb_3Sn coating at KEK



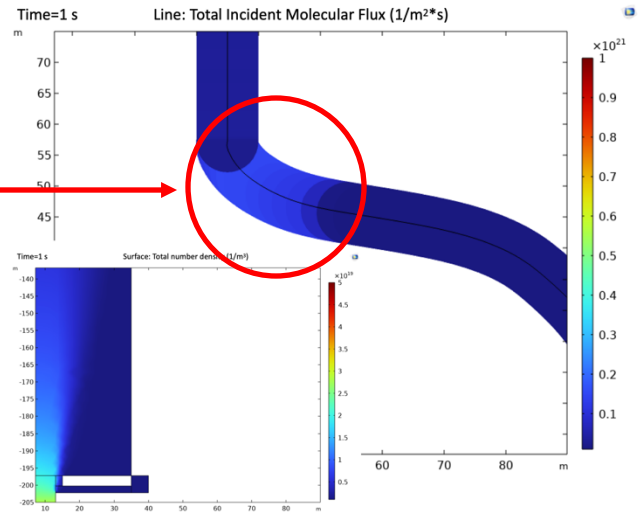
The furnace is currently shut down until around April next year for relocation.

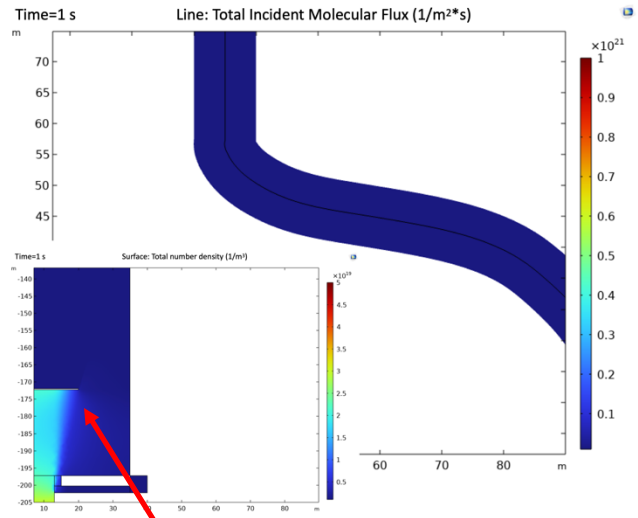


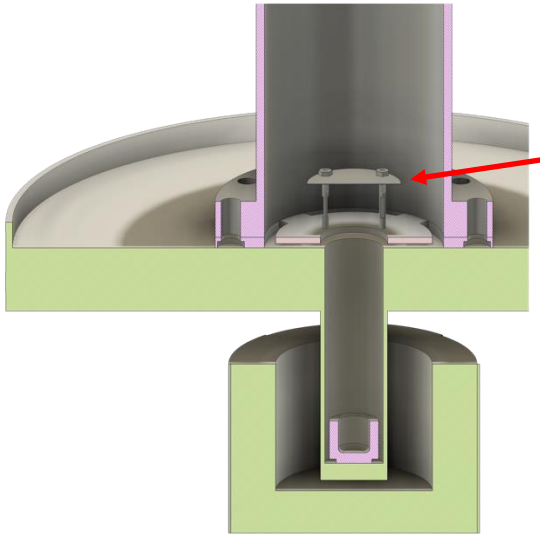
- Two independent vacuum systems
- Heaters
  - Furnace: Max 1200°C
  - Sn crucible: Max 1500°C
- Nb tube is evacuated during coating
- Shading is installed to suppress the formation of Sn droplets on the upper side

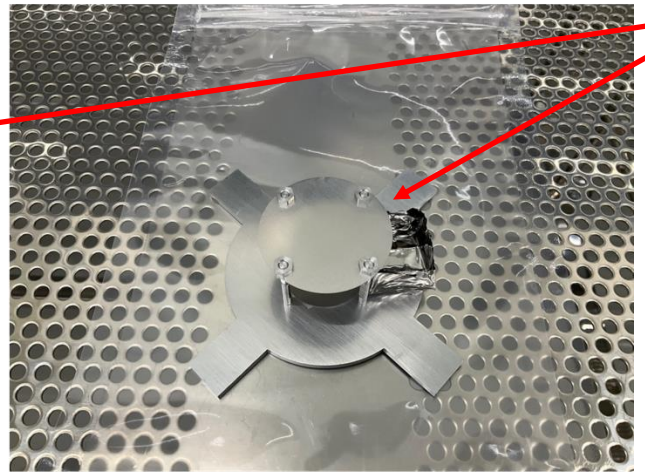
Current cavity setup

Sn dots formed









Nb shading suppresses the amount of vapor directly entering the upper side of the cavity.

Nb_3Sn coating on single-cell cavities

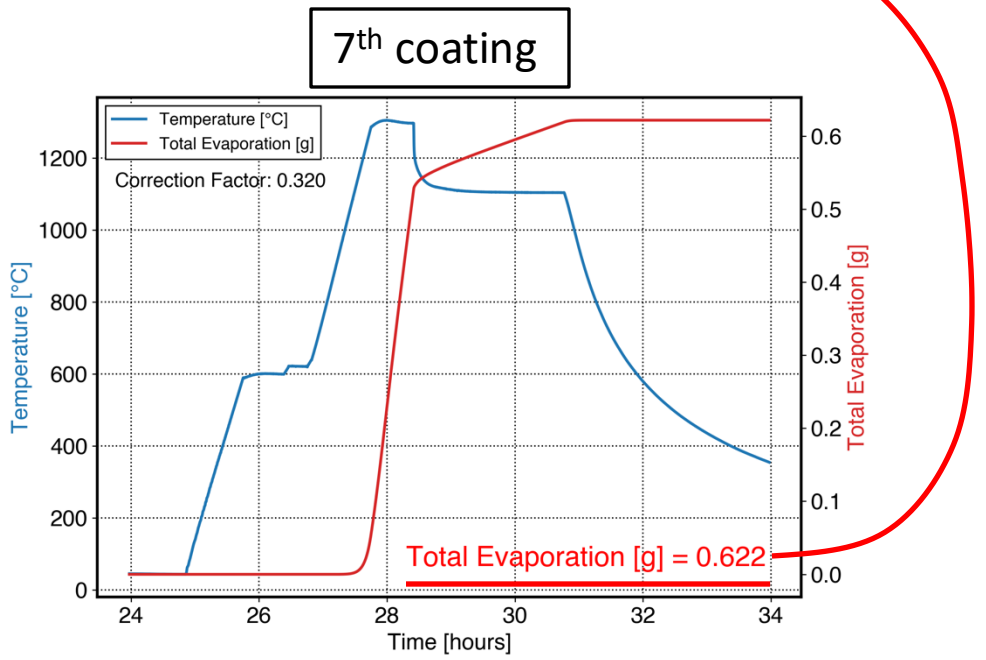
No.	Nucleation 600C	Coating Furnace / crucible 1100C / 1300C		Annealing 1100C	Amount of Sn put in [g]	Evaporated Sn [g]	Evaporation predicted from calculation [g]
4	1 h	3 h	3 h	-	1.48	1.48	2.28
5	1 h	40 min	40 min	2 h 20 min	1.51	0.57	0.59
6	1 h	2 h	2 h	1 h	0.80	0.80	1.52
7	1 h	40 min	40 min	2 h 20 min	1.51	0.64	0.62

- 8 coatings have been performed so far, varying the coating time and the amount of source
- We calculated the Sn evaporation using the following two equations
- This allows the appropriate amount of Sn to be put into the crucible

***Calculations have just started after the 7th coating.**

$$\frac{dM}{dt} = Ap_{\mathrm{v}}\sqrt{\frac{m}{2\pi k_b T}} \quad \text{Langmuir's Equation for Evaporation}$$

$$\log p_{\mathrm{v}} = A + B \cdot T^{-1} + C \log T + D \cdot T \cdot 10^{-3}$$



Amount of Sn source and evaporation

No.	Nucleation 600C	Coating Furnace / crucible 1100C / 1300C		Annealing 1100C	Amount of Sn put in [g]	Evaporated Sn [g]	Evaporation predicted from calculation [g]
4	1 h	3 h	3 h	-	1.48	1.48	2.28
5	1 h	40 min	40 min	2 h 20 min	1.51	0.57	0.59
6	1 h	2 h	2 h	1 h	0.80	0.80	1.52
7	1 h	40 min	40 min	2 h 20 min	1.51	0.64	0.62

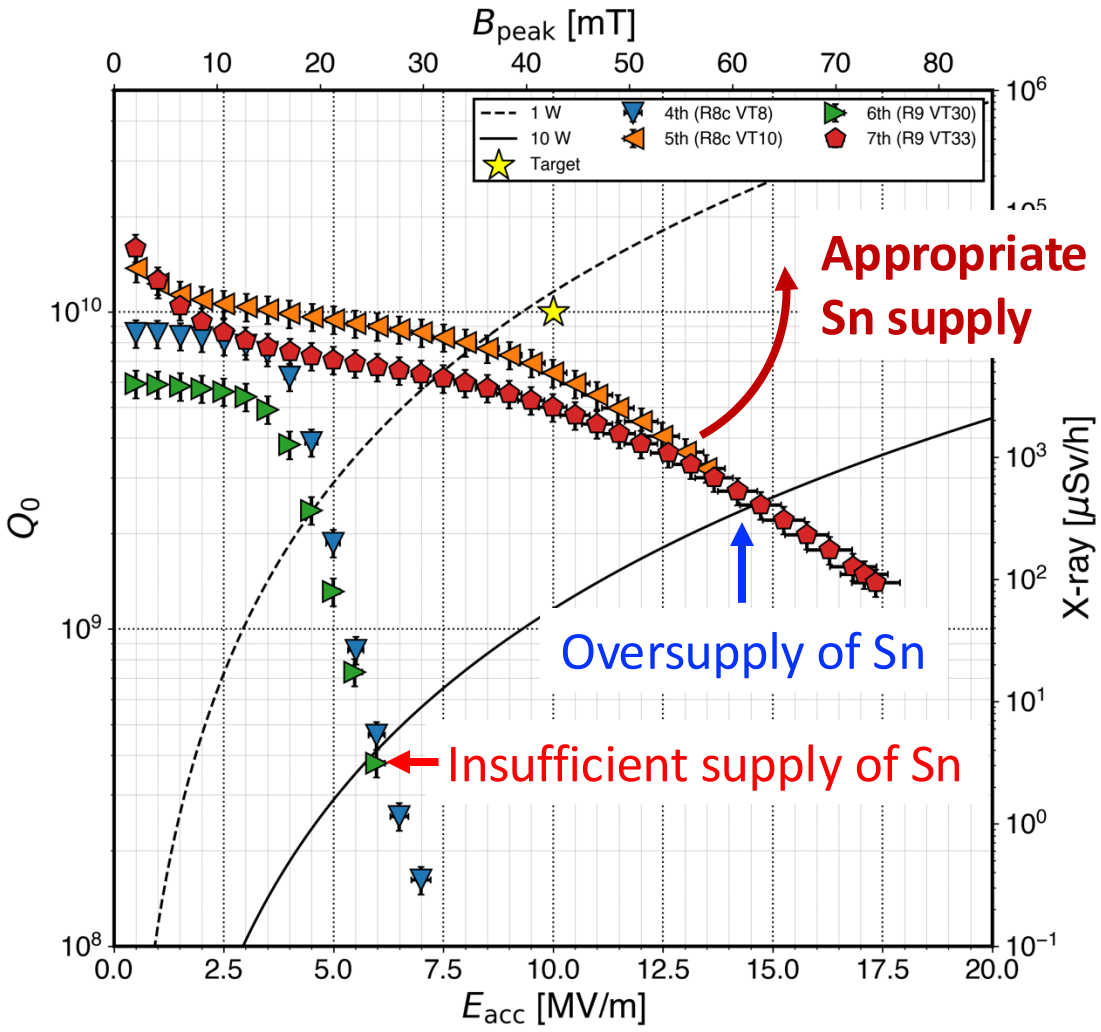
Oversupply of Sn

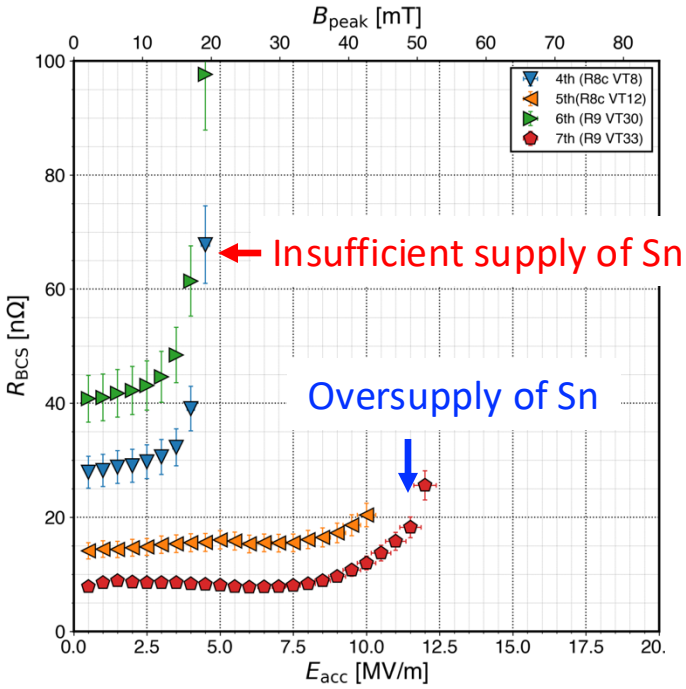
Large amounts of Sn remained.
→ Sn is also considered to remain on the inner surface of the cavity.
It can be source of RF loss.

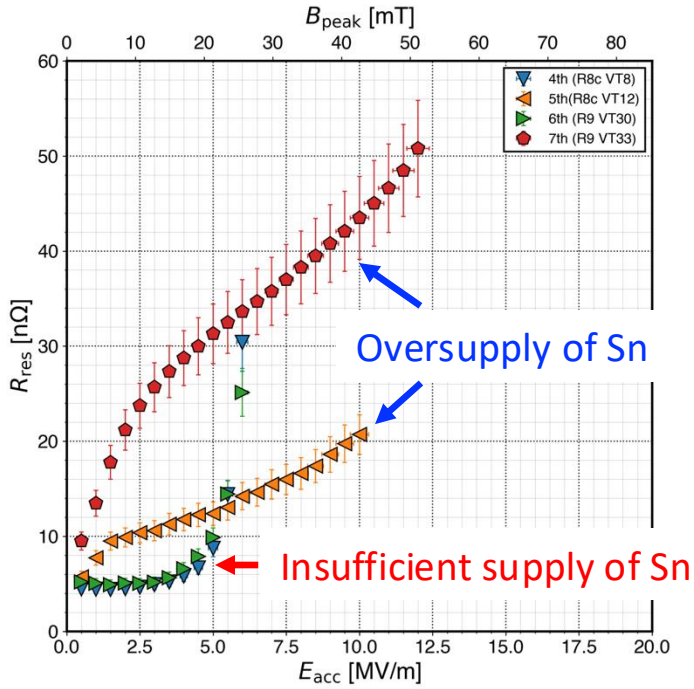
Insufficient supply of Sn

The amount of Sn put in was insufficient for the expected evaporation.
→ The supply of Sn vapor during deposition was insufficient.
Nb_3Sn film quality probably was considered poor.

Performance of KEK's Nb_3Sn cavities





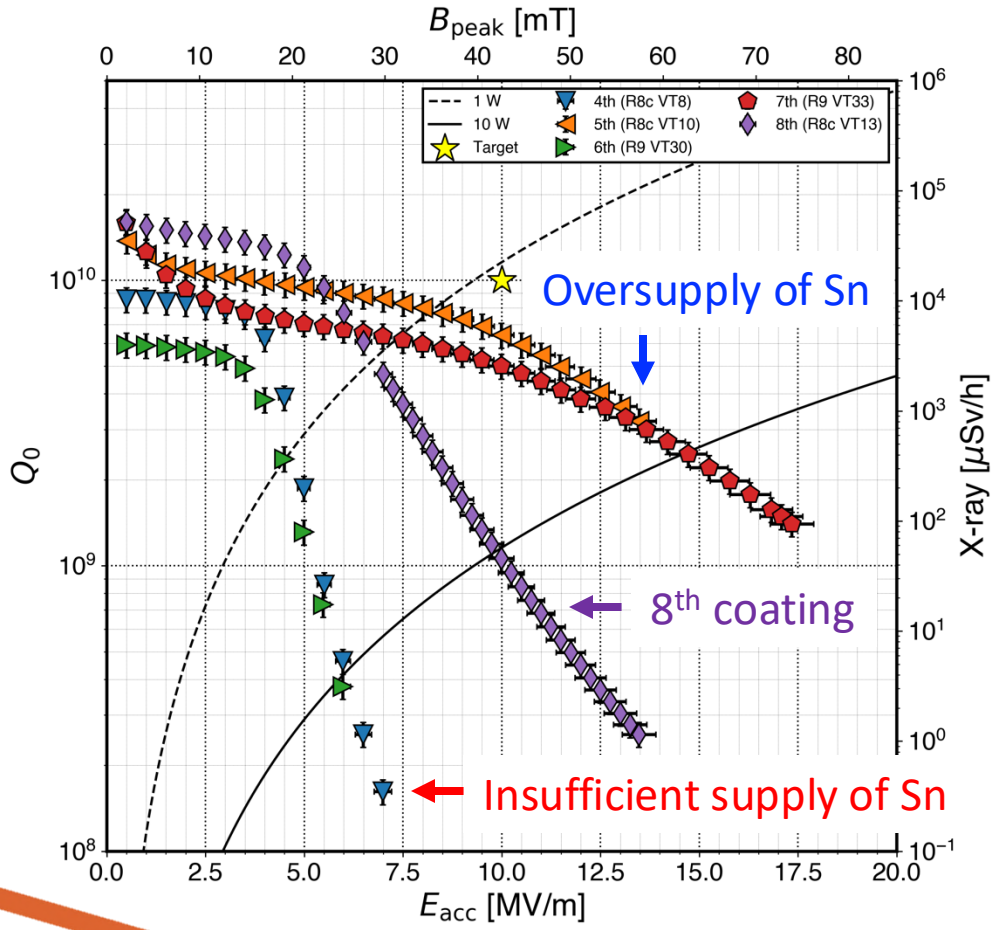


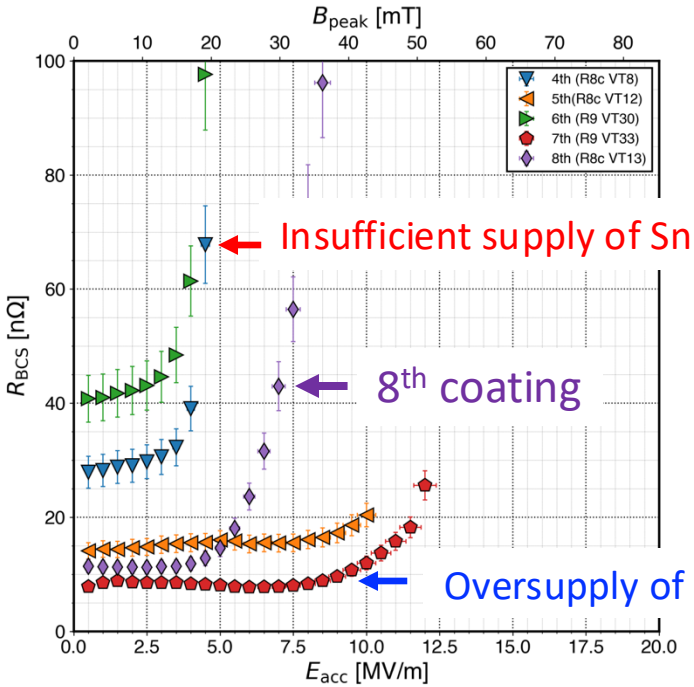
- Max E_{acc} is 17.5 MV/m, Q-slope is observed in all cavities
- Cavity performance strongly depends on the balance between Sn supply and its consumption on the inner surface
- 8th coating was carried out with the aim of supplying Sn without excesses or deficiencies

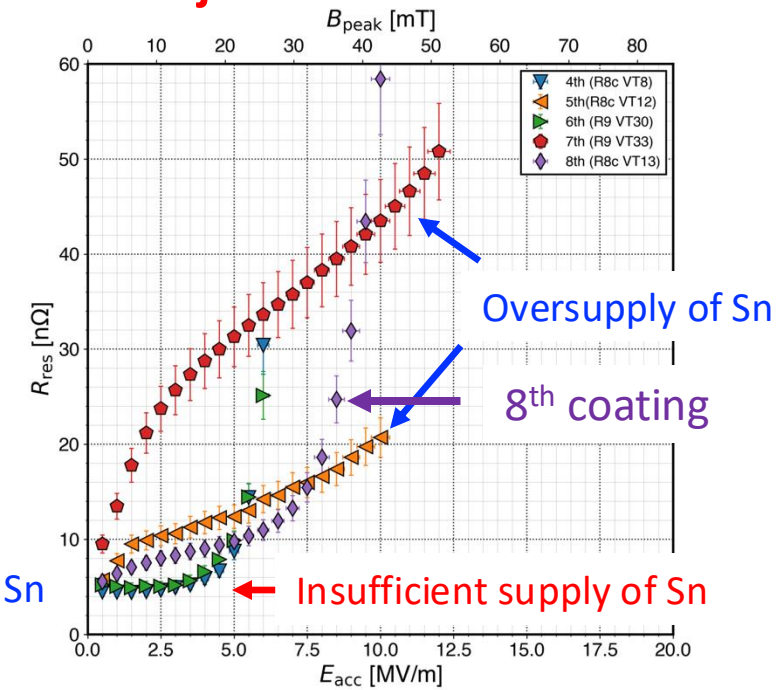
Performance of KEK's Nb_3Sn cavities

No.	Nucleation 600C	Coating Furnace / crucible 1100C / 1300C		Annealing 1100C	Amount of Sn put in [g]	Evaporated Sn [g]	Evaporation predicted from calculation [g]
8	1 h	2 h	2 h	1 h	1.55	1.47	1.52

The amount of Sn was well adjusted.



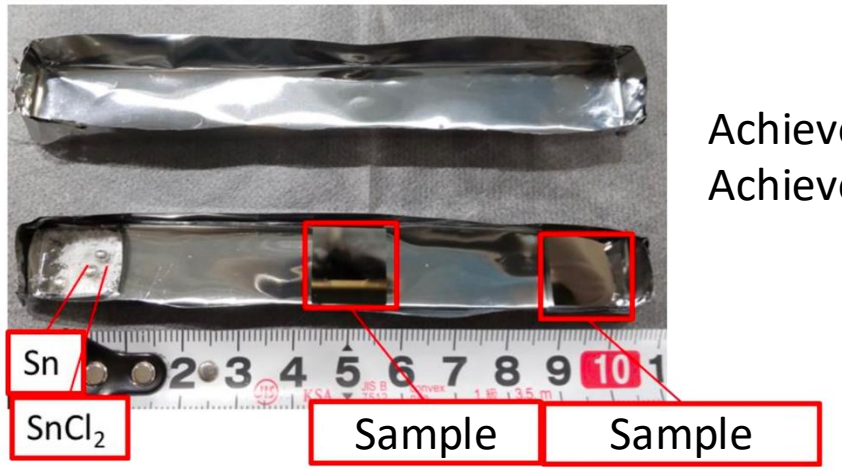




- The amount of Sn could be adjusted well, but the cavity performance is just in between them
- **Nb_3Sn film quality degraded after 1 h of annealing?**

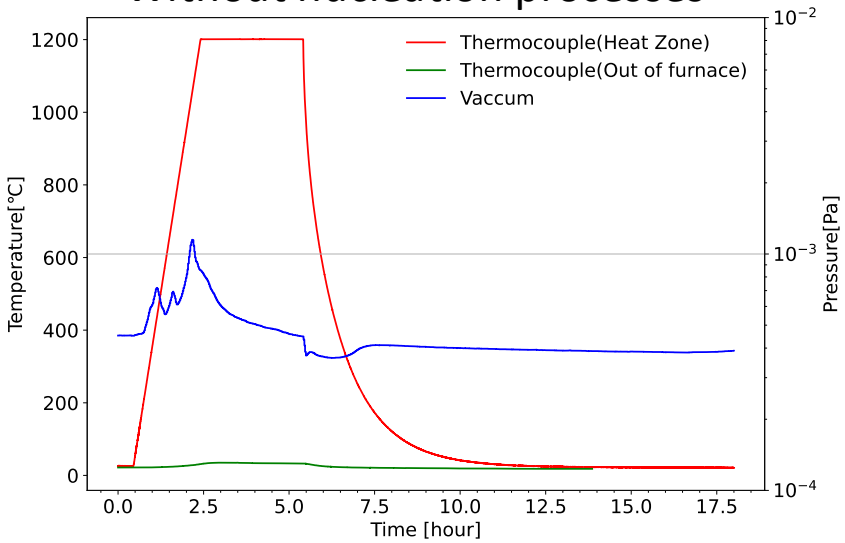
Sample studies

Start-up of small coating furnace and sample coating

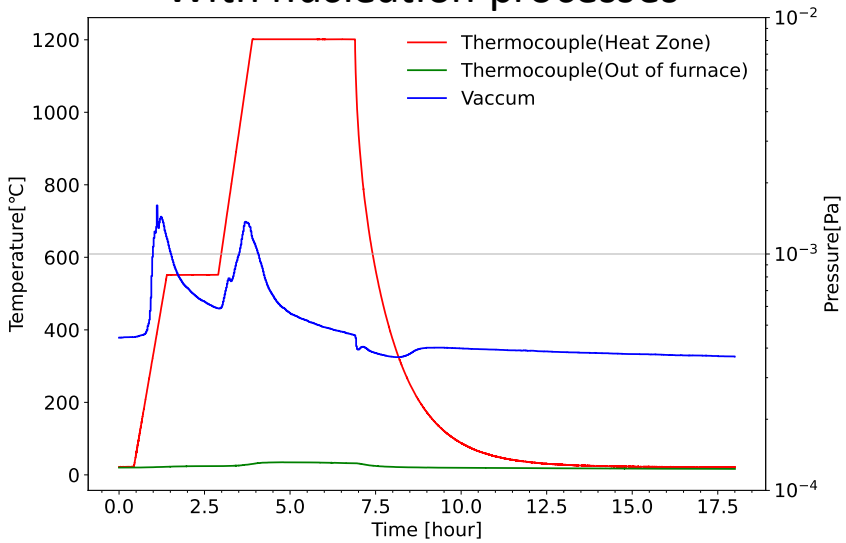


Achieved temperature: 1400C
Achieved vacuum: 5×10-4 Pa @ RT

Without nucleation processes



With nucleation processes

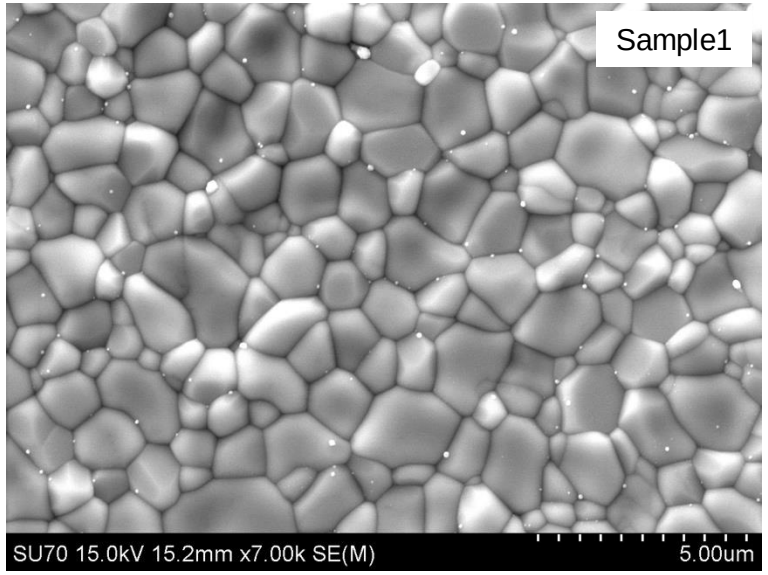


To investigate the influence of the nucleation process on the final Nb_3Sn film, a small coating furnace was set up for sample coating.
Various samples with and without $SnCl_2$ and nucleation processes were produced.

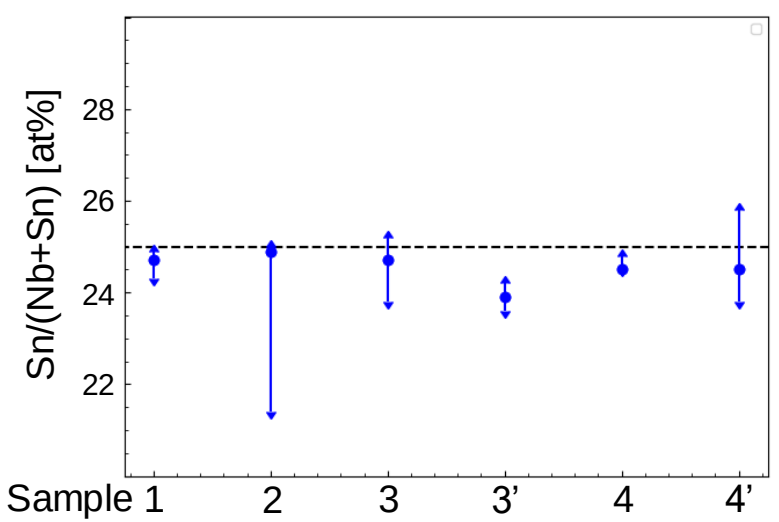
Sample analysis

Sample	$SnCl_2$ (~0.1 g)	Nucleation	Evaporated Sn [g]	Mo box	Sn composition ratio [at%]	Grain size [μm]	R_a [nm]	Film thickness [um]	T_C [K]
1	with	with	**0.138**	**1st**	24.7	**1.13**	68	-	-
2	with	without	0.181	3rd	24.9	0.95	72	-	-
3	without	without	0.183	3rd	24.7	0.98	68	1.57 ± 0.18	18.0 ± 0.2
4	with	with	0.192	3rd	24.5	1.01	71	1.65 ± 0.26	17.8 ± 0.2

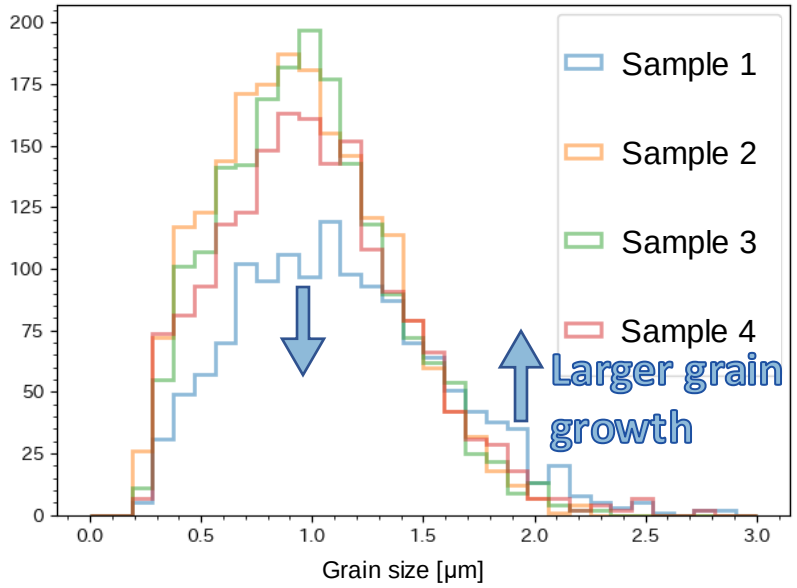
SEM/EDS



Composition analysis



Grain size distribution



- Under all conditions, the composition ratio was about 25 at%
- Only sample 1 has a larger grain growth

Sample analysis

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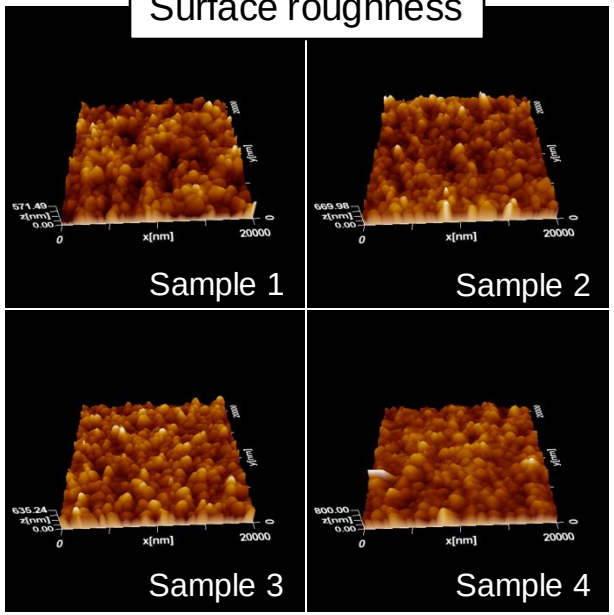
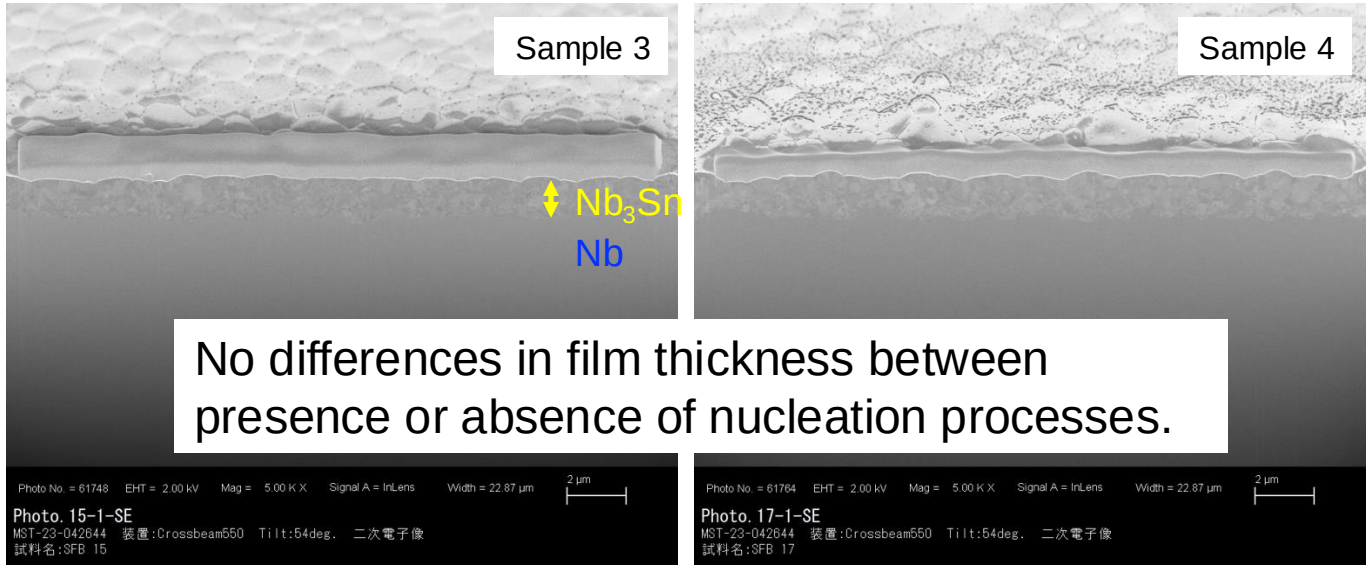
Surface roughness



FIB-SEM Cross-sectional analysis



Differences in Mo box produced differences in grain size.
← Vapor pressure differences during the deposition process are thought to have an effect.

Summary

- Cavity performance have been steadily improved
- Optimal source amount adjustment is now possible. Next step is to optimize annealing time
- A small coating furnace has been set up to carry out more efficient parameter exploration
- Some useful information has already been obtained from sample studies
- Cavity coating and sample studies will be conducted with mutual feedback in the future