High Q – High G Studies on single cell Medium Grain Nb cavities

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- Introduction – refresher on MG Nb material.
- Performance of 1.3 GHz 1-Cell HRRR MG Nb SRF Cavity for High Q – High G surface treatments.
- Flux Expulsion improvement of MG Nb cavity with high temperature annealing

Introduction

- Medium Grain (MG) Nb is cost effective compared to FG Nb due to its manufacturing process.
- At KEK, two 1-cell MG Nb cavities were manufactured and are being tested for various High Q - High G surface treatments.
- MG Nb 1-Cell cavities have significant orange peel effect on its surface.
- In this presentation, the performance of MG Nb 1-Cell cavities are summarized and compared with FG Nb 1-Cell cavity.

Niobium for 9-Cell 1.3 GHz SRF Cavity

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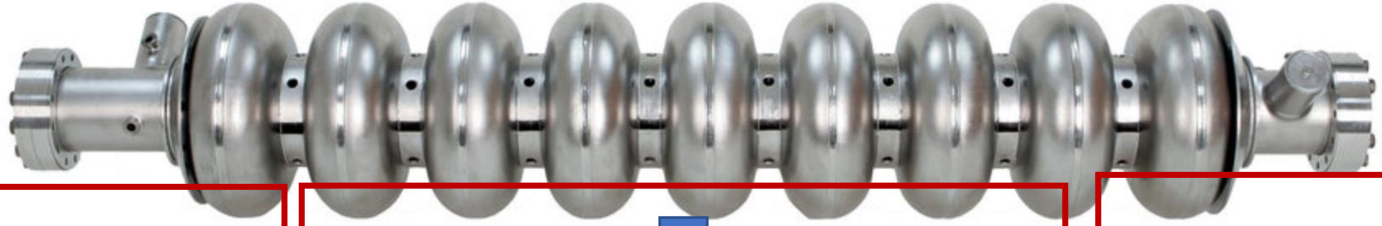
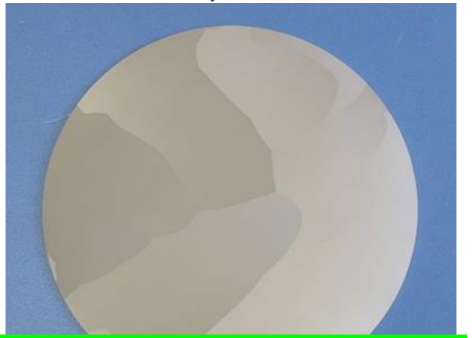
9-Cell 1.3 GHz Nb SRF Cavity



Conventional Material

Fine Grain (FG) Nb

- Grain size < 50 µm
- Isotropic mechanical properties.
- Uniform and adequate properties.
- High Cost.



R & D Material

Large Grain (LG) Nb

- Grain size > 1 cm.
- Anisotropic mechanical properties.
- Issue with HPGS clearance
- Low Cost.

New Material

ATI Medium Grain (MG) Nb

- Grain size - 200-300 µm, occasional 1-2 mm grains
- Isotropic mechanical properties, clears HPGS.
- Cost reduction w.r.t FG Nb

Performance of 1-Cell MG Nb Cavities for High Q – High G Surface Treatments

VT Parameters for HRRR MG Nb Cavity

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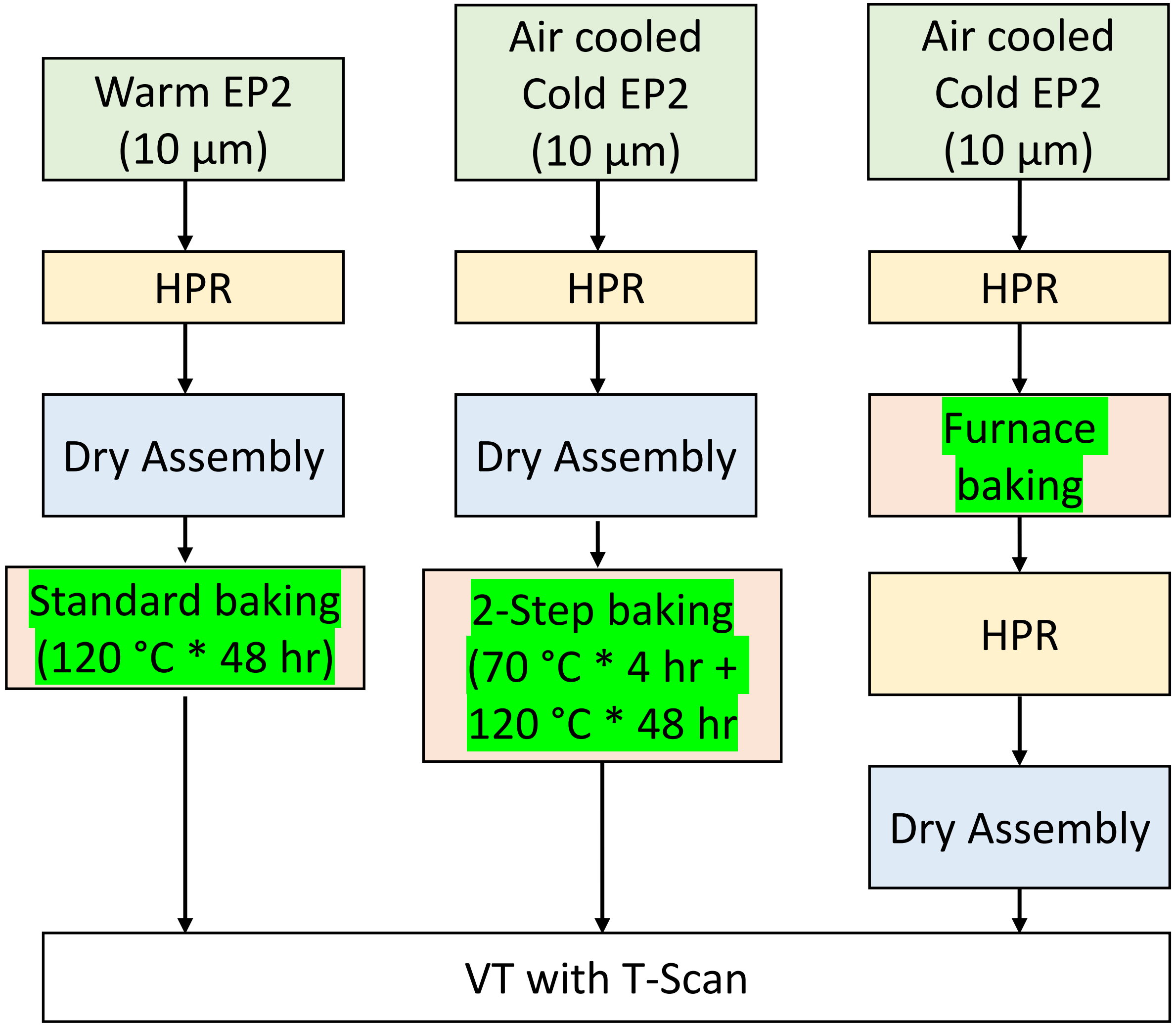
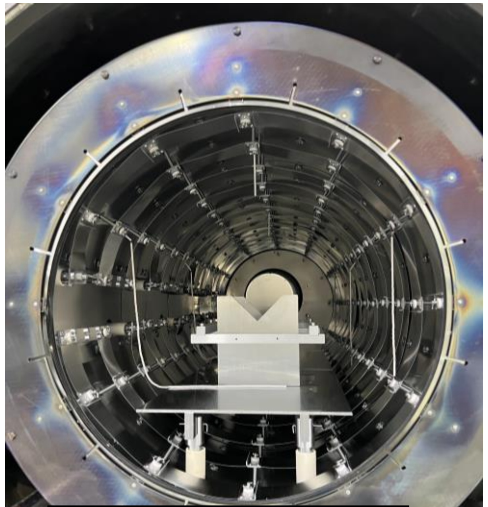


- For Flux sensitivity studies, 20 mG of flux is trapped using a solenoid coil.

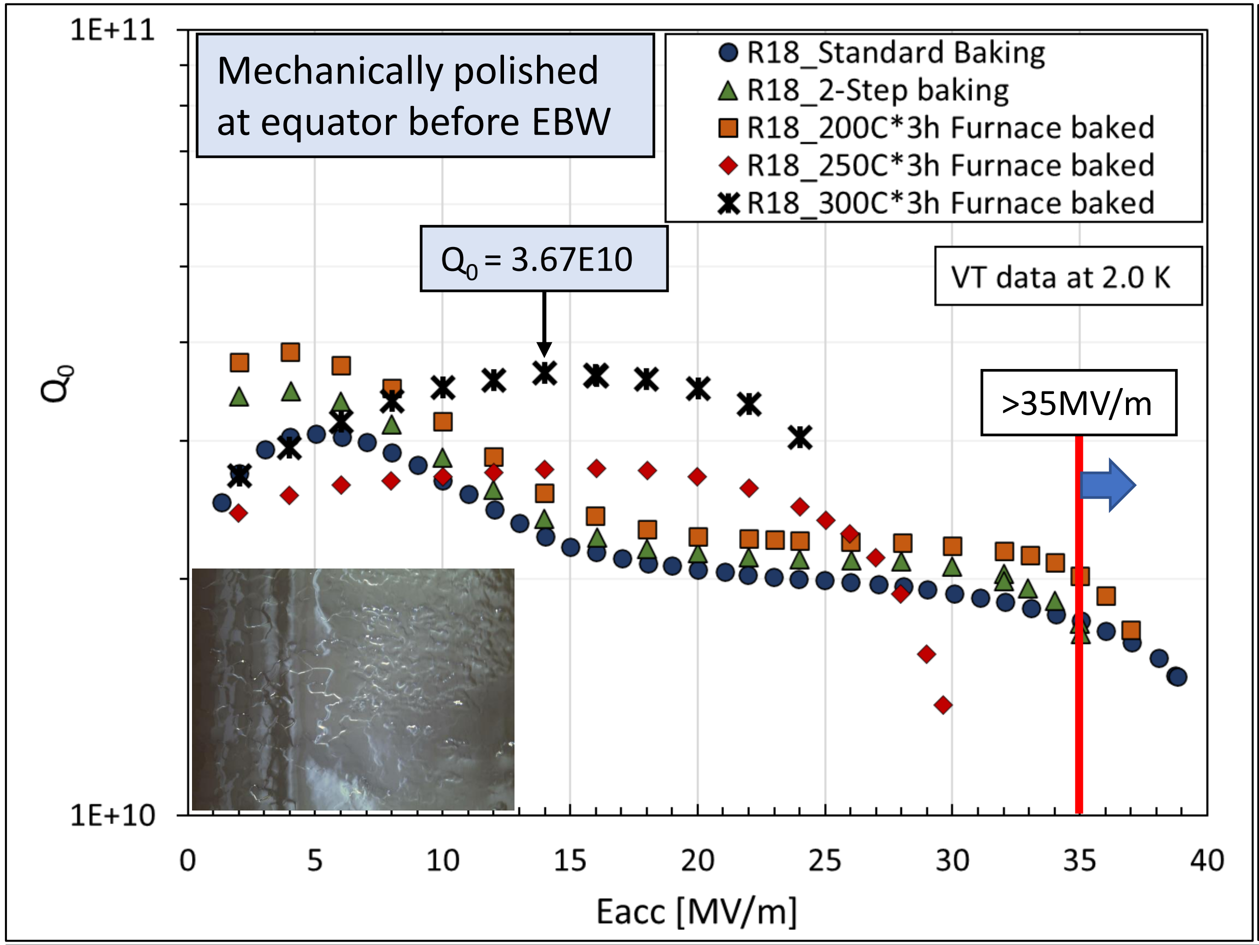
R18 & R18b HRRR MG Nb Tesla cavity manufactured at KEK-CFF

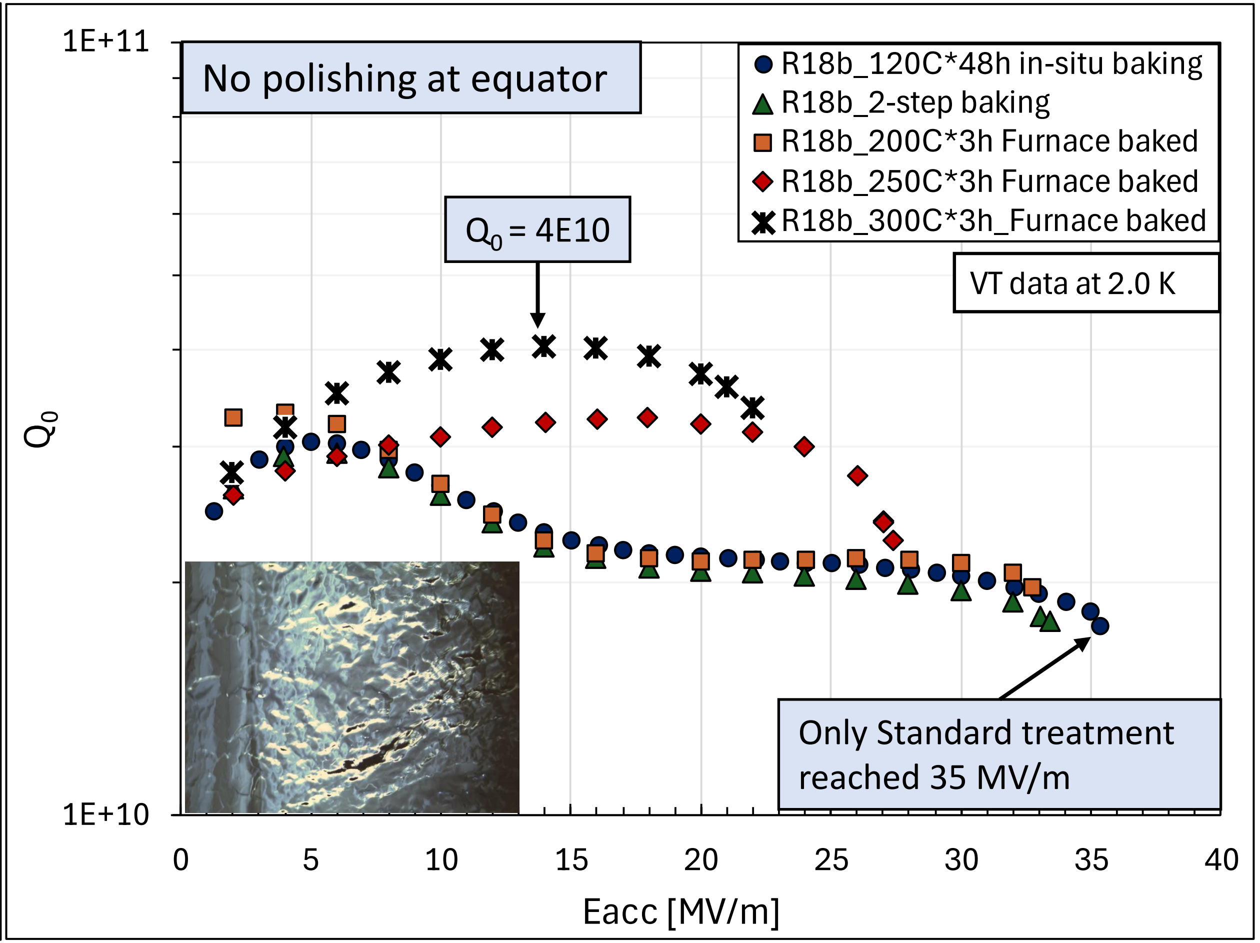
Standard or 2-step Baking



Furnace Baking

High Q – High G VT Results for MG Nb 1-Cell Cavity

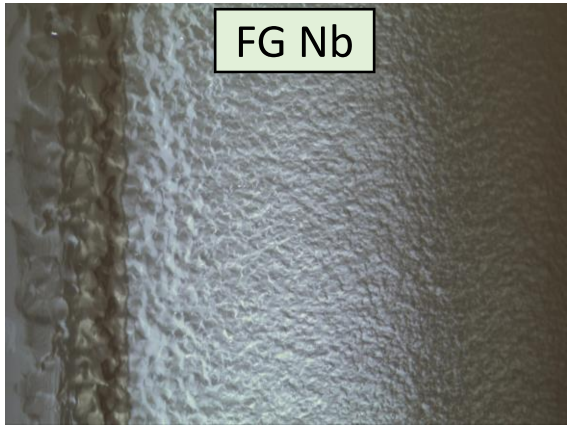


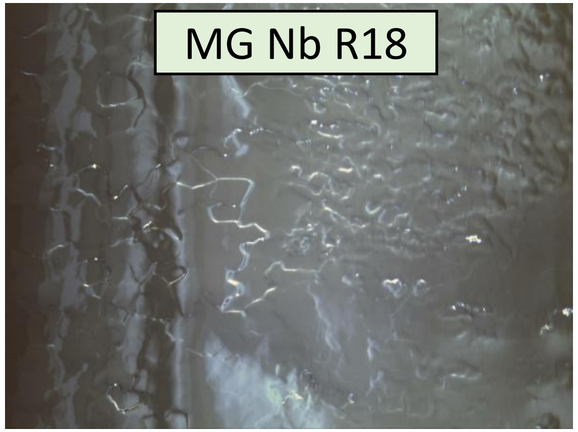


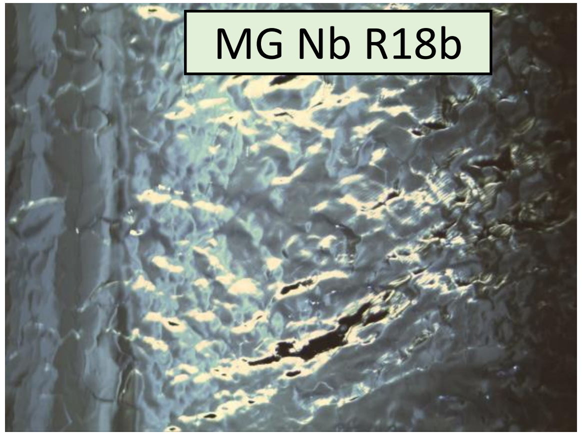
- No degradation in Eacc after quenching, degradation in Q_0 expected due to trapped flux.
- R18 maximum Eacc is > 35 MV/m for all High G surface treatments.
- R18b Eacc > 35 MV/m achieved only for Standard treatment, but Q_0 was higher for high Q treatments w.r.t R18.

MG Nb 1-Cell Cavity High Q-High G comparison with FG Nb

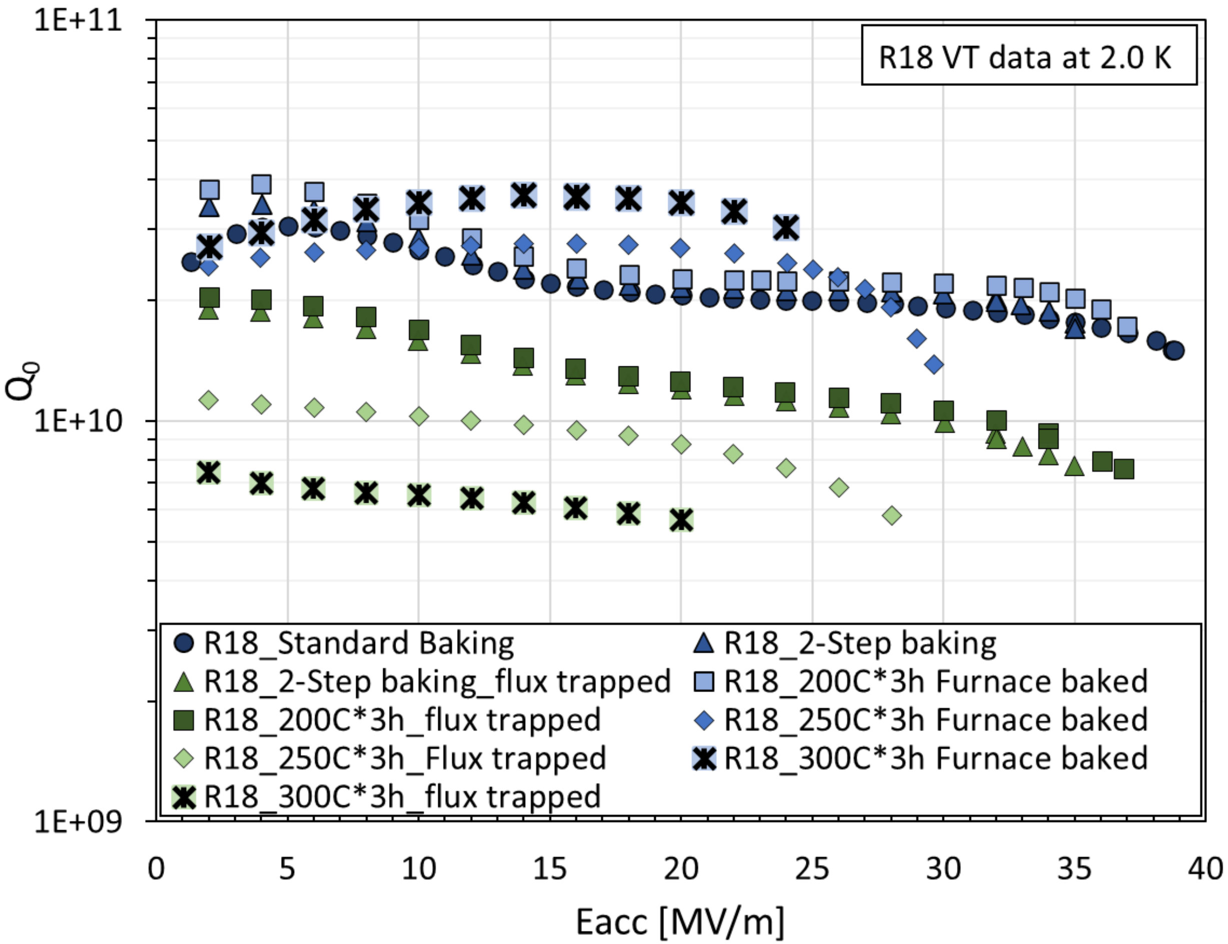
Parameters @ 2.0 K	MG Nb R18 E_{acc} max [MV/m]	MG Nb R18b E_{acc} max [MV/m]	FG Nb E_{acc} max [MV/m]	MG Nb R18 Q_0 @ E_{acc} = 35 MV/m	MG Nb R18b Q_0 @ E_{acc} = 35 MV/m	FG Nb Q_0 @ E_{acc} = 35 MV/m	MG Nb R18 Q_0 max	MG Nb R18b Q_0 max	FG Nb Q_0 max
Standard Treatment (120 °C 48h)	38.8	35.4	> 35	1.75E+10		~ 2E10	-	-	-
2-step baking (70°C 4h + 120°C 48h)	35.0	33.5	> 35	1.77E+10	1.78E+10 (@ 33.5 MV/m)	~ 2E10	-	-	-
Furnace baking (200 °C * 3hrs)	37.0	32.7	38.0	1.87E+10	1.97E+10 (@ 32.7 MV/m)	2.25E+10	-	-	-
Furnace baking (250 °C * 3hrs)	29.6	27.5	31.0	-	-	-	2.76E+10	3.27E+10	3.67E+10
Furnace baking (800 °C) (300 °C * 3hrs)	24.0	22.0	-	-	-	-	3.65E+10	4.04E+10	-





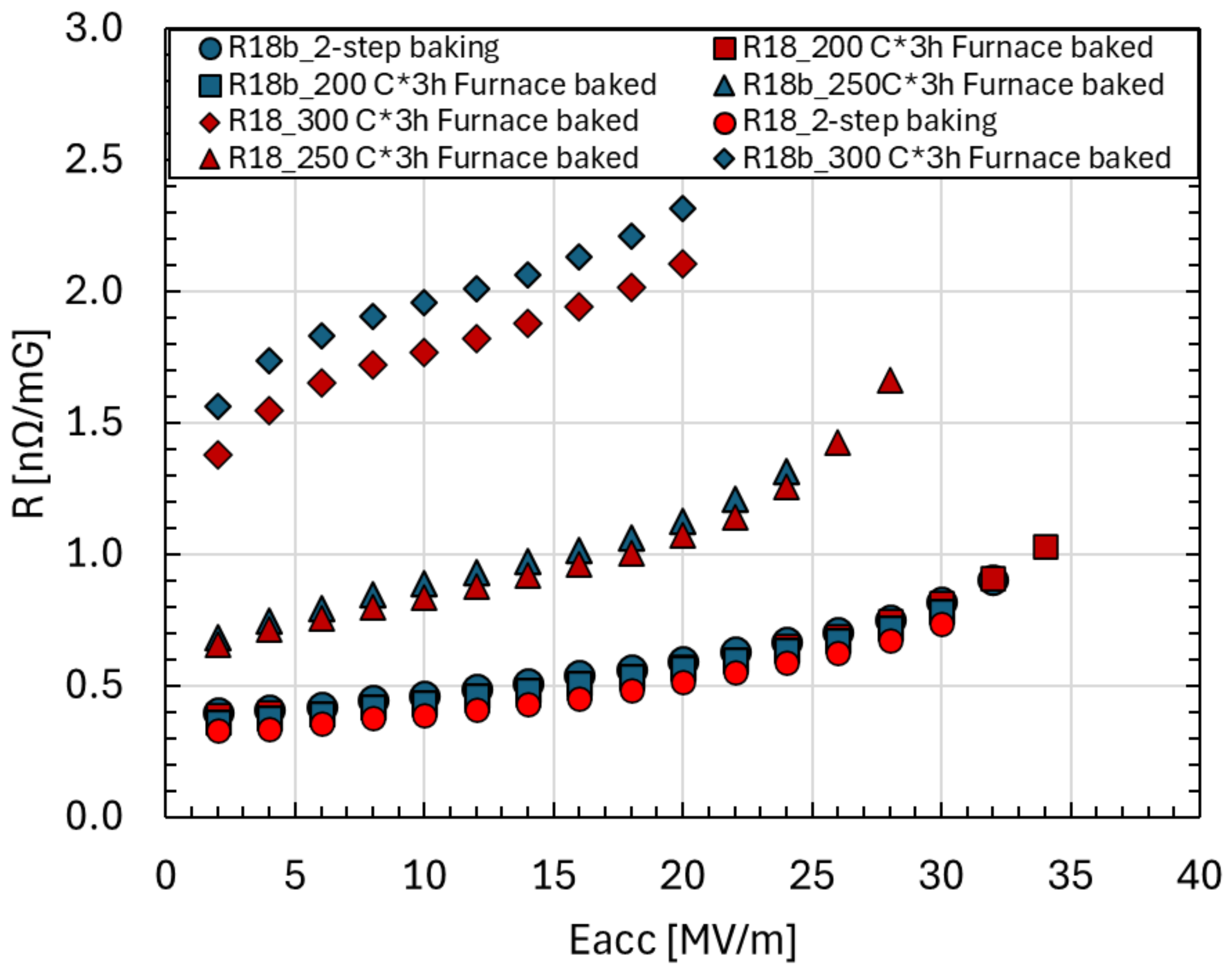


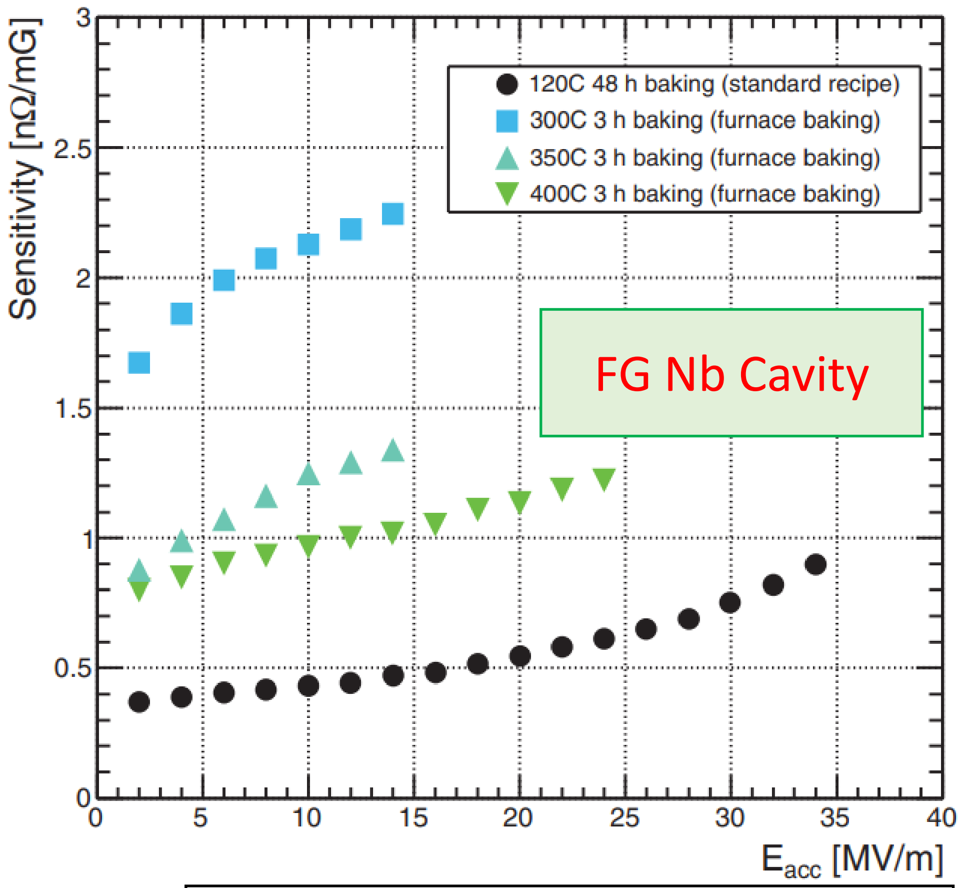
MG Nb VT results with and without Trapped Flux



- Flux trapped measurement was taken by applying 20 mG of magnetic flux with Solenoid Coil during superconducting transition.
- No degradation in Eacc due to trapped flux.
- Degradation in Q_0 expected due trapped flux.
- Q_0 degradation is highest with 300 °C*3h Furnace baking.
- Q_0 degradation due trapped flux in high G recipes like 200 °C furnace and 2-step baking was the least.

Flux Sensitivity for MG Nb



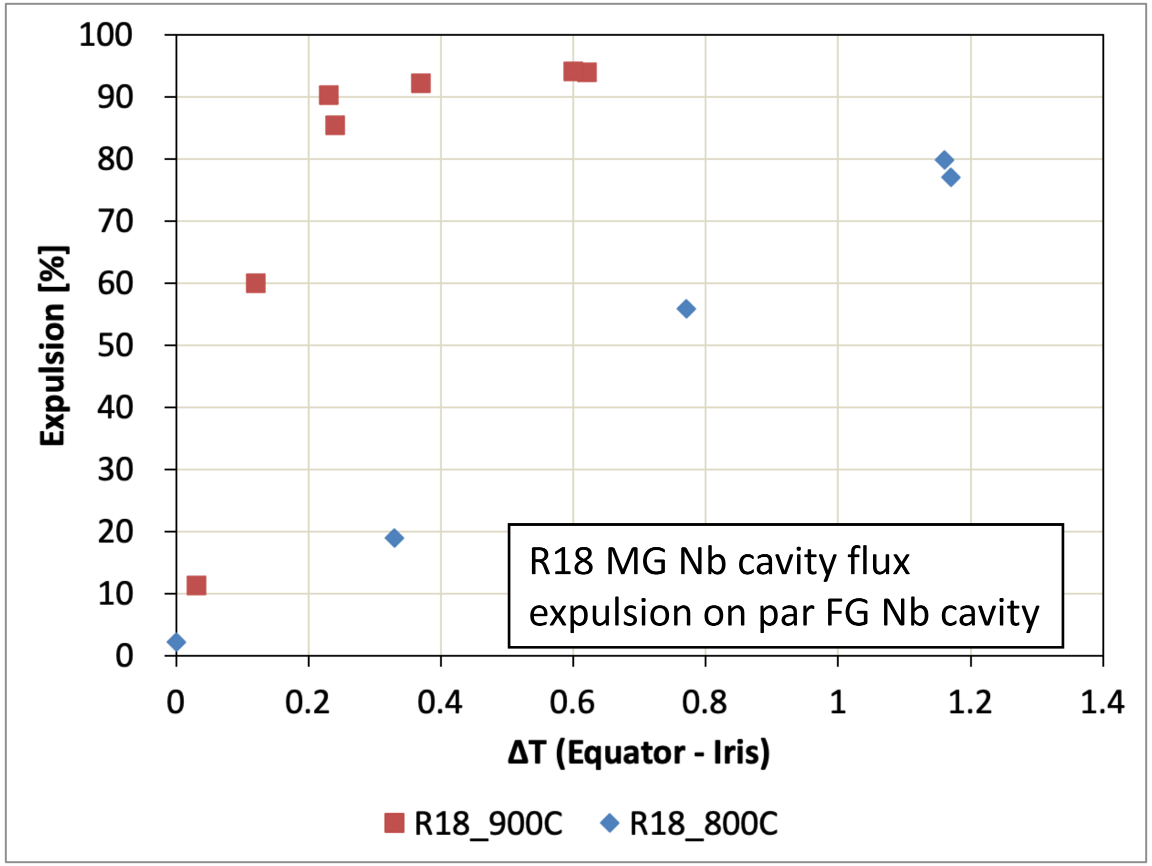


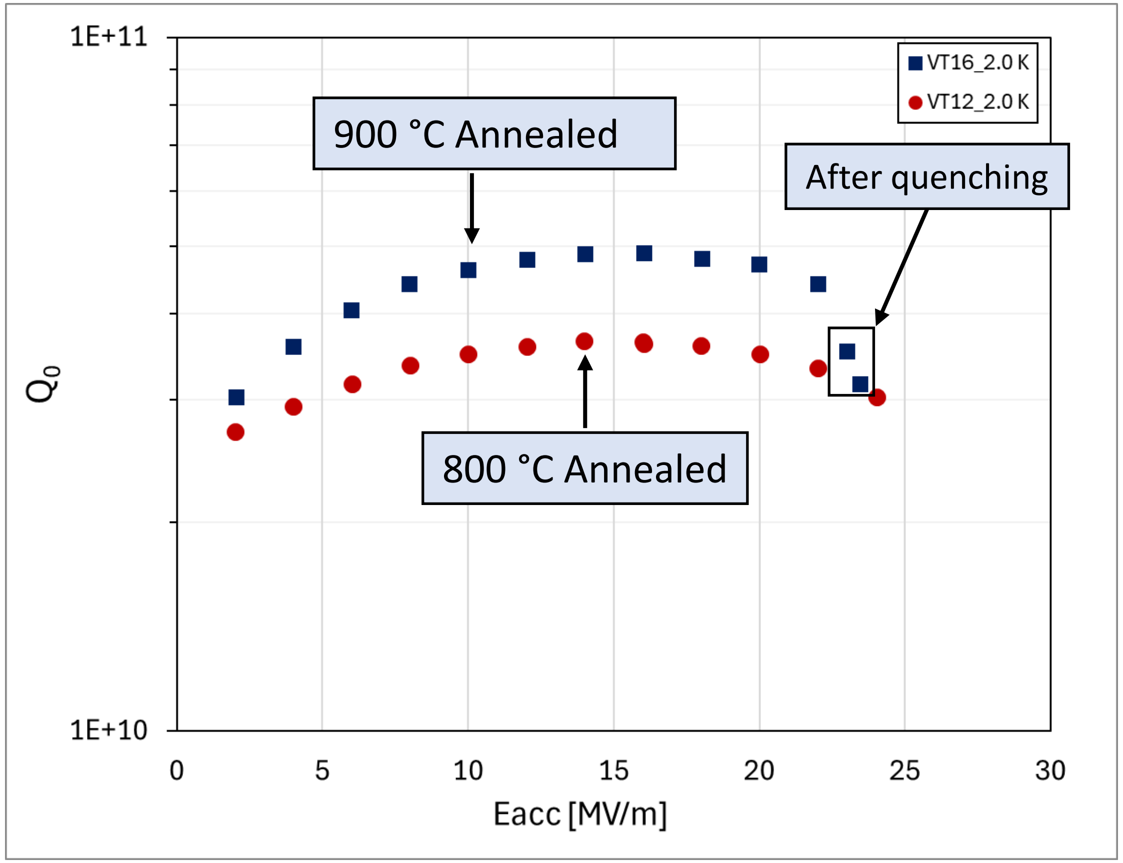
Cited from: H. Ito, Prog. Theor. Exp. Phys. 2021, 071G01

- Flux sensitivity of 1-Cell MG Nb cavity is similar to 1-Cell FG Nb standard baked cavity.

Performance Improvement of 1-Cell MG Nb Cavities with 900 °C annealing

800 and 900 °C Annealing Performance Comparison





- Comparison of 300 °C furnace baking with same VT procedure
- Significant improvement in maximum Q_0 from 3.6E10 -> 4.9E10 at Eacc = 16 MV/m, Eacc remained same.

Resistance Deconvolution

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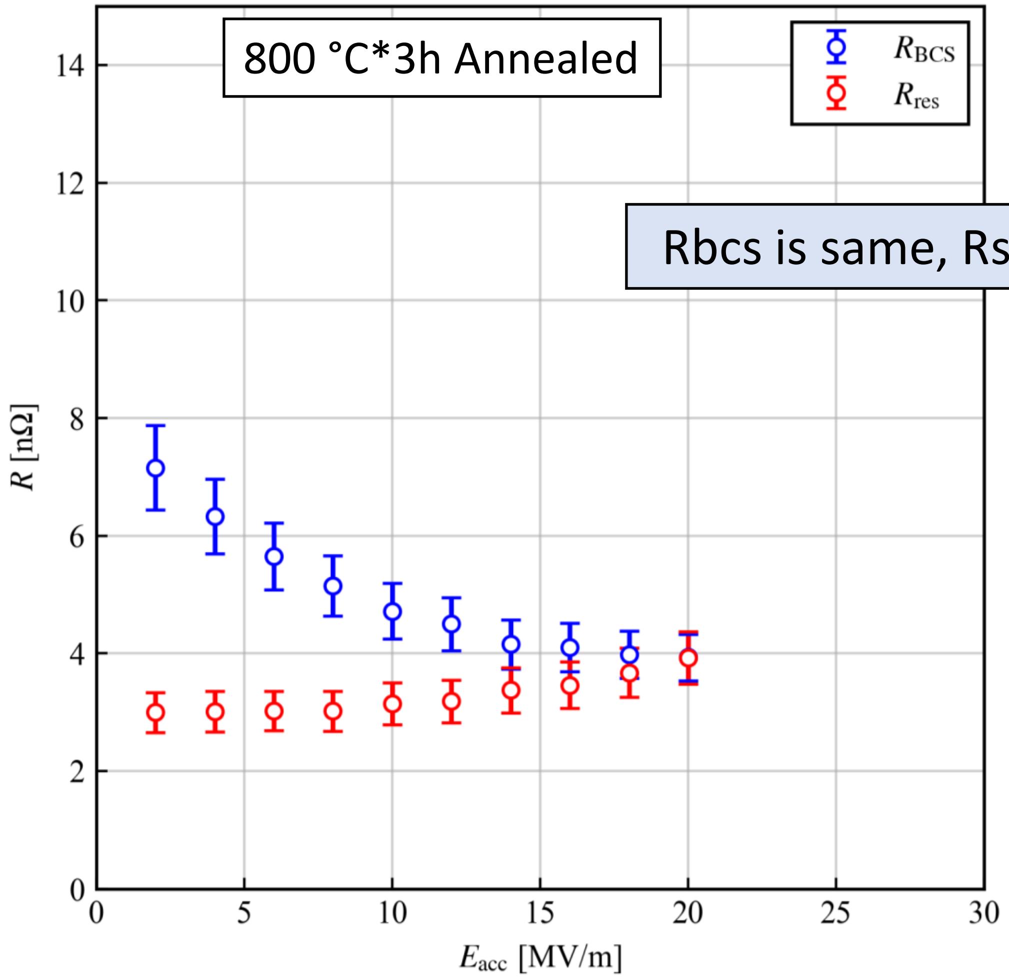
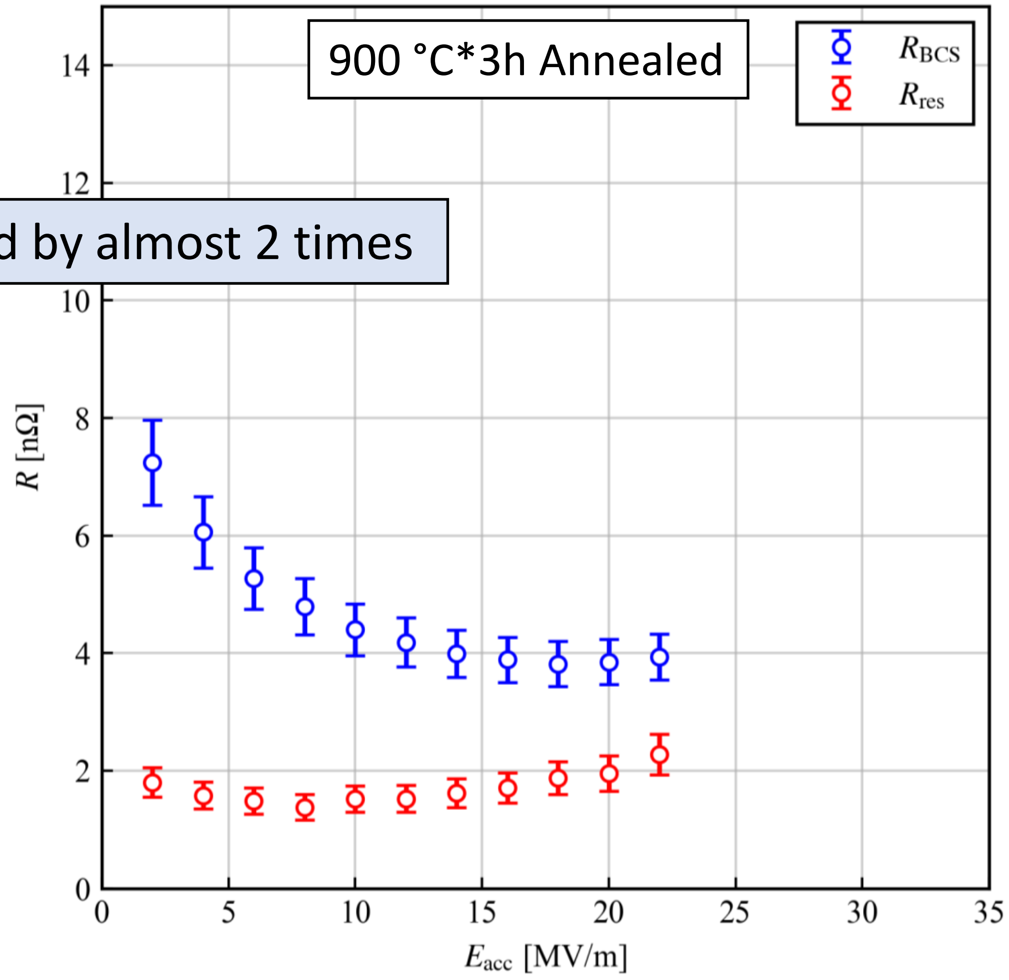
R18_VT12_300C 3h



R18_VT16_300C 3h



Rbcs is same, Rs reduced by almost 2 times

MG Nb 1-Cell Cavity High Q-High G comparison with FG Nb

Parameters @ 2.0 K	MG Nb R18 E_{acc} max [MV/m]	MG Nb R18b E_{acc} max [MV/m]	FG Nb E_{acc} max [MV/m]	MG Nb R18 Q_0 @ E_{acc} = 35 MV/m	MG Nb R18b Q_0 @ E_{acc} = 35 MV/m	FG Nb Q_0 @ E_{acc} = 35 MV/m	MG Nb R18 Q_0 max	MG Nb R18b Q_0 max	FG Nb Q_0 max
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2-step baking (70°C 4h + 120°C 48h)	35.0	33.5	> 35	1.77E+10	1.78E+10 (@ 33.5 MV/m)	~ 2E10	-	-	-
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Furnace baking (250 °C * 3hrs)	29.6	27.5	31.0	-	-	-	2.76E+10	3.27E+10	3.67E+10
Furnace baking (800 °C) (300 °C * 3hrs)	24.0	22.0	-	-	-	-	3.65E+10	4.04E+10	-
Furnace baking (900 °C) (300 °C * 3hrs)	23.5	TBC	25.0	-	-	-	4.9E+10		5.1E+10

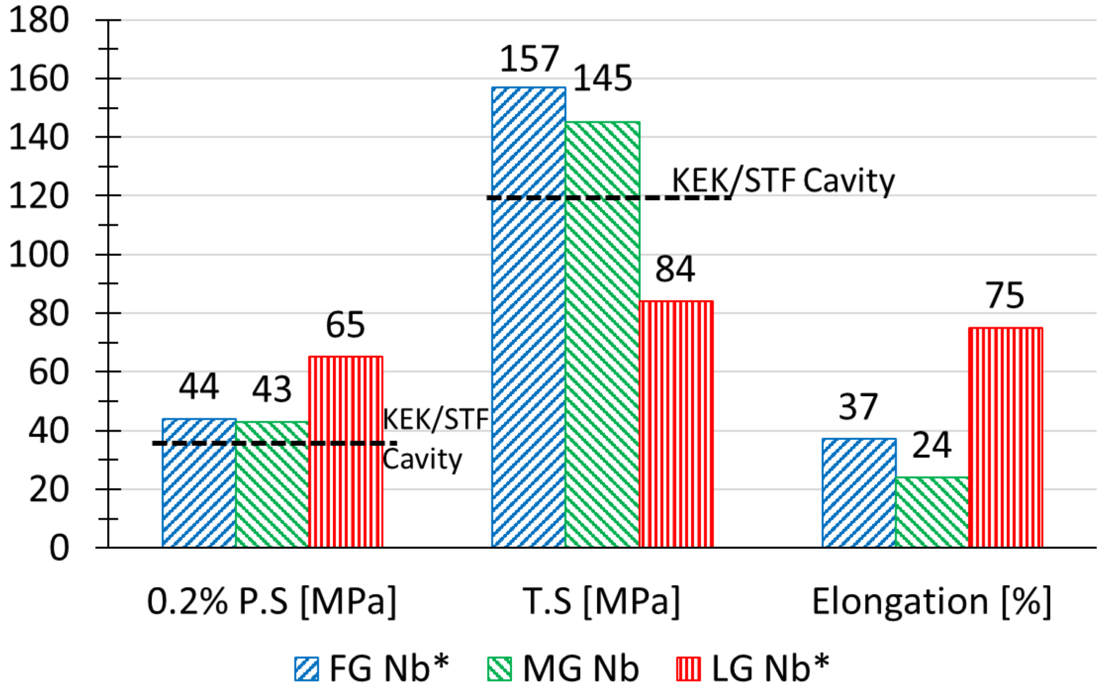
Summary

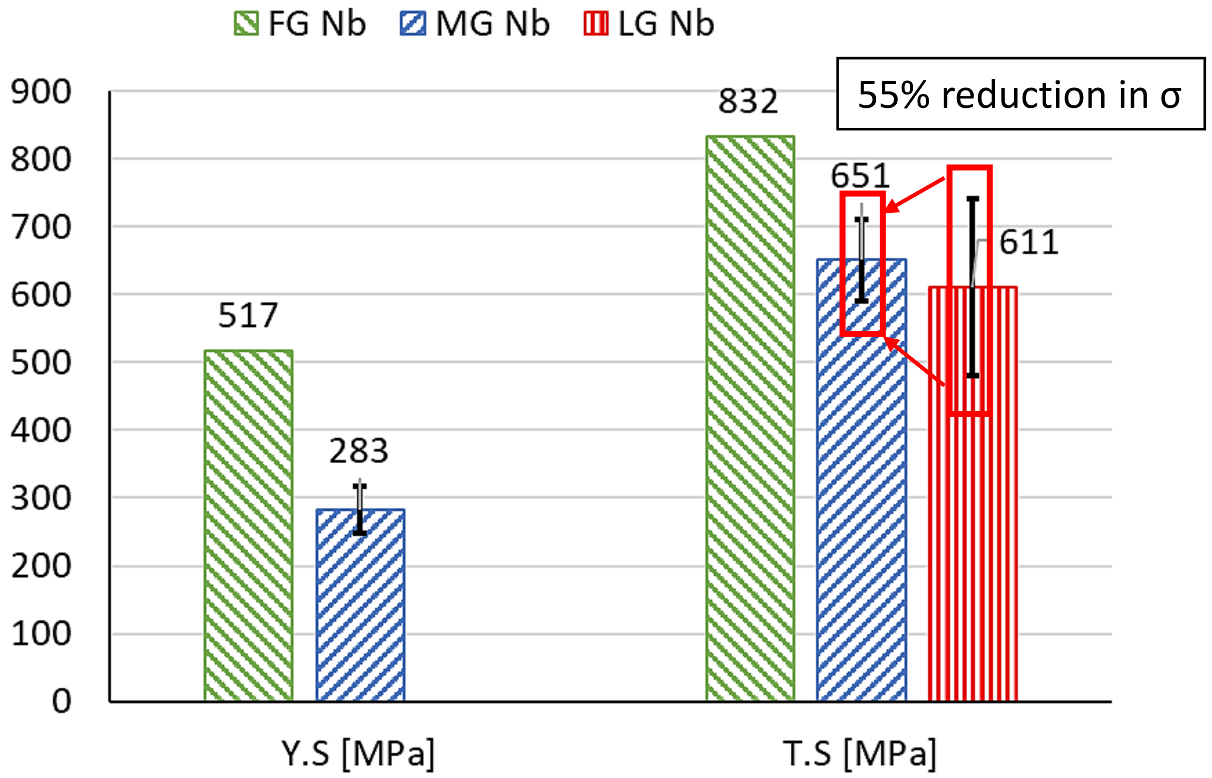
- MG Nb is a cost-effective material with isotropic mechanical properties and its 1-Cell cavity performance clears ILC specification.
- Even with orange peel effect, the performance of the 1-Cell MG Nb cavity is on par with FG Nb cavity.
- Moreover, the flux expulsion of MG Nb cavity is comparable to FG Nb material and improves drastically with 900 C*3 hr annealing.
- For surface treatments highly sensitive to trapped flux, 900 C*3 hr annealing improves the Q_0 of MG Nb cavity drastically.

Thank You for Your Attention!

Appendix

Mechanical Property of MG Nb





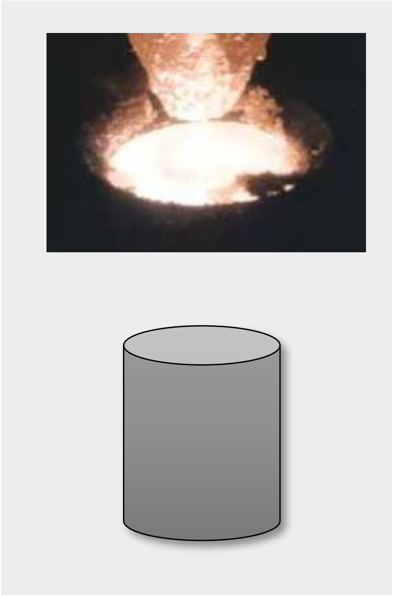
Mechanical strength of MG-Nb achieved the criteria of HPGS regulation for KEK/STF-Cavity

* FG Nb and LG Nb data is for middle RRR annealed material (M. Yamanaka et al., SRF'21 WEPFDV005.

MG Nb data: A. Kumar et al., SRF2021 MOPCAV004

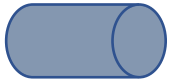
Manufacturing of LG & MG Nb

Nb melting

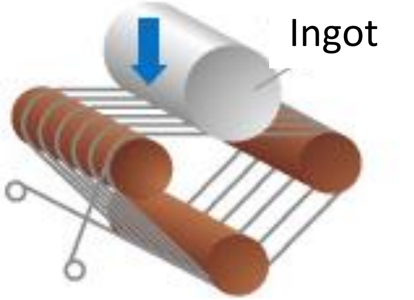


Niobium ingot
(Raw material)

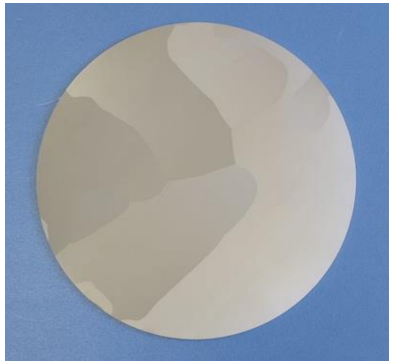
Direct slice of LG ingot



Ingot, as it is



Slicing image
by wire-saw

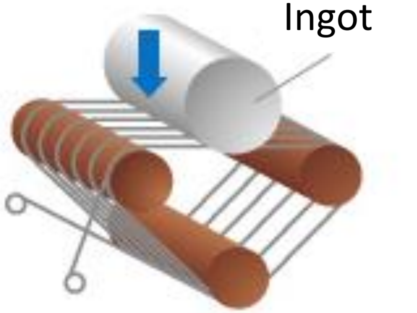


LG Nb

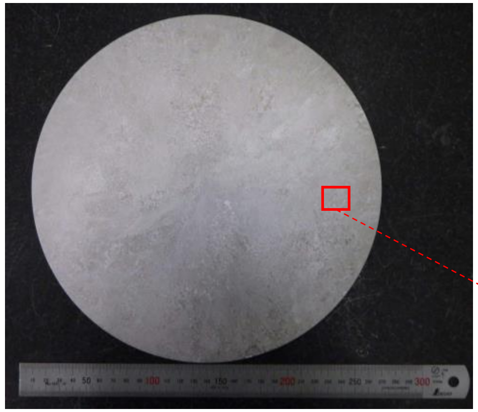
Large Grain (LG) Disc
Grain Size >> 1 cm

Direct slice of MG ingot

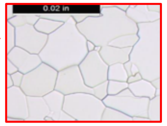
Ingot, forged
and annealed



Slicing image
by wire-saw

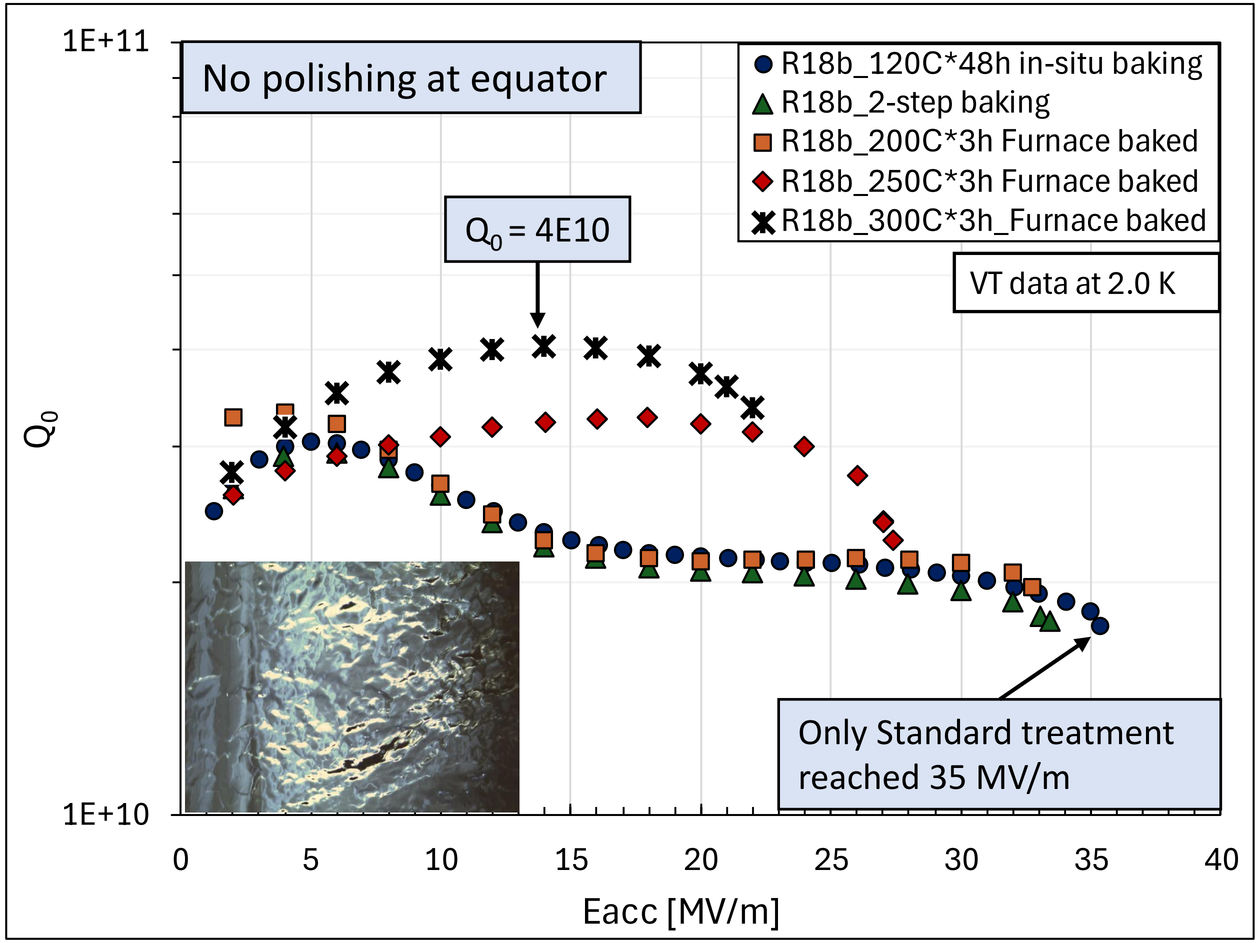


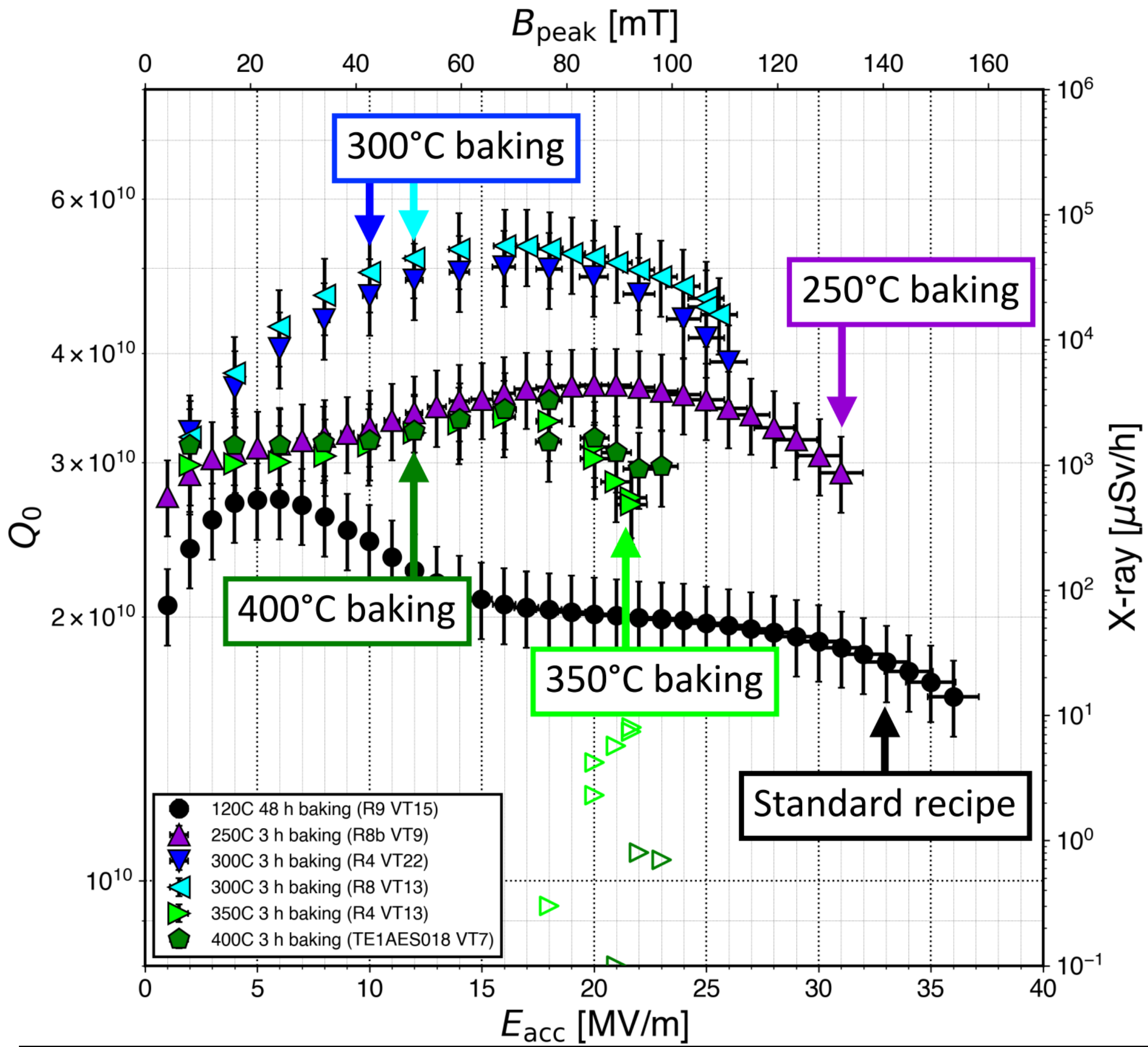
MG Nb



* The "Nb forged ingot" technology originated by **ATI**, and SRF (GHz) cavities planned to be fabricated and RF tested by **KEK** and **JLab**, to qualify this approach, in collaboration of **ATI, ODU/BSCE, JLab, and KEK.**

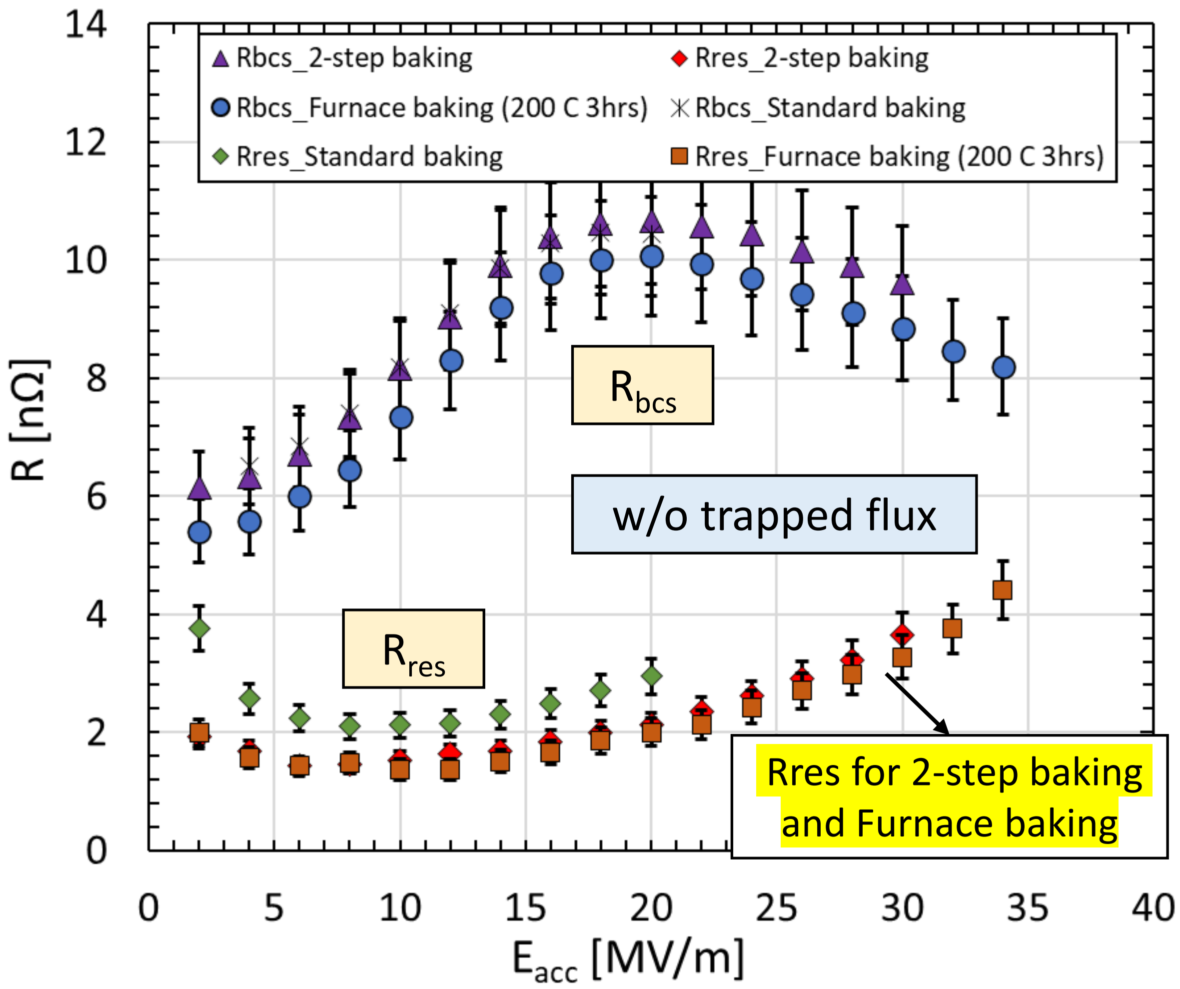
MG Nb R18b v/s R8 at 2.0 K





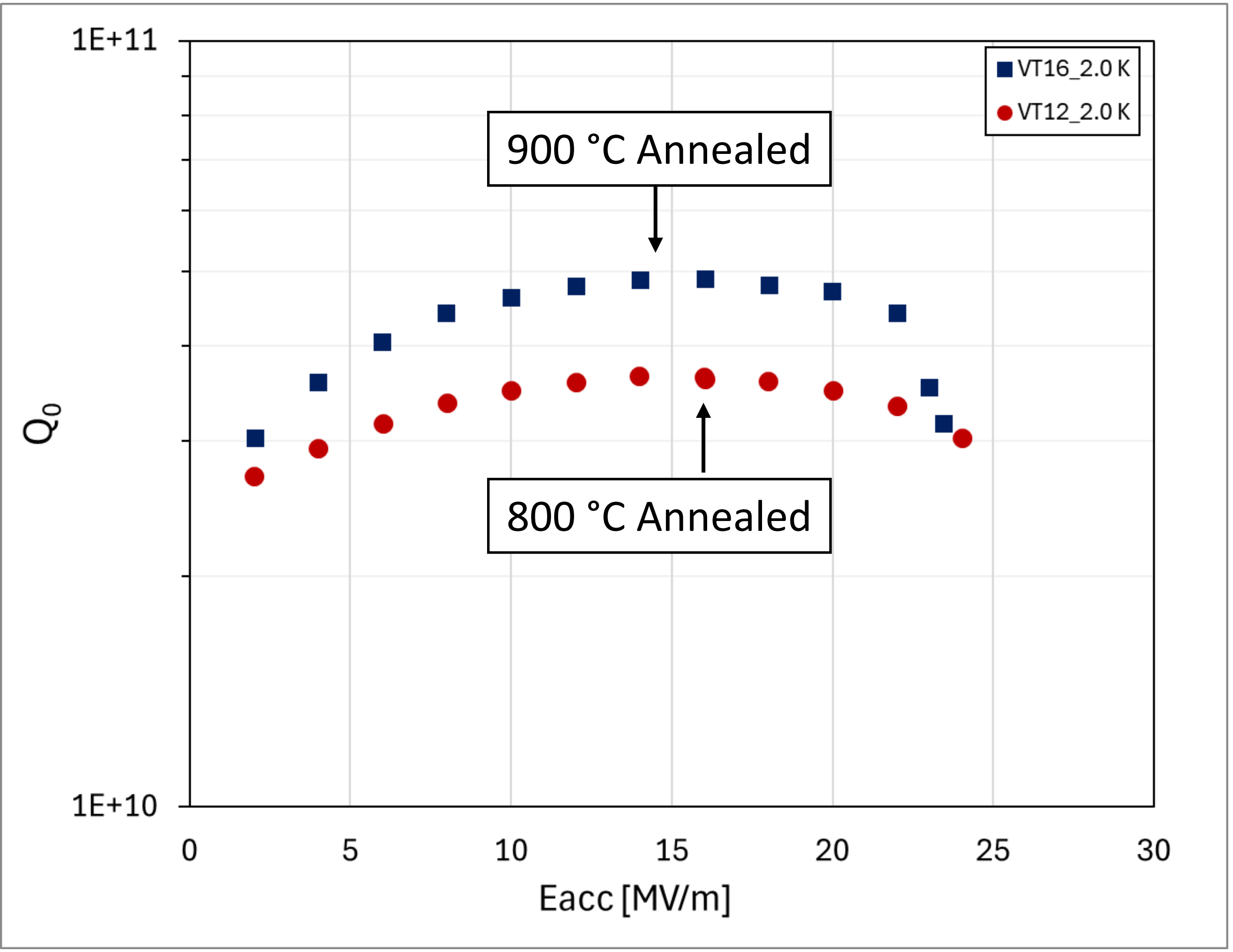
H. Ito, H. Araki, and K. Umemori, "Surface Resistance and Trapped Flux Sensitivity as Function of Baking Temperature", presented at the 21th Int. Conf. RF Supercond. (SRF'23), Grand Rapids, MI, USA, Jun. 2023, paper TUIXA03

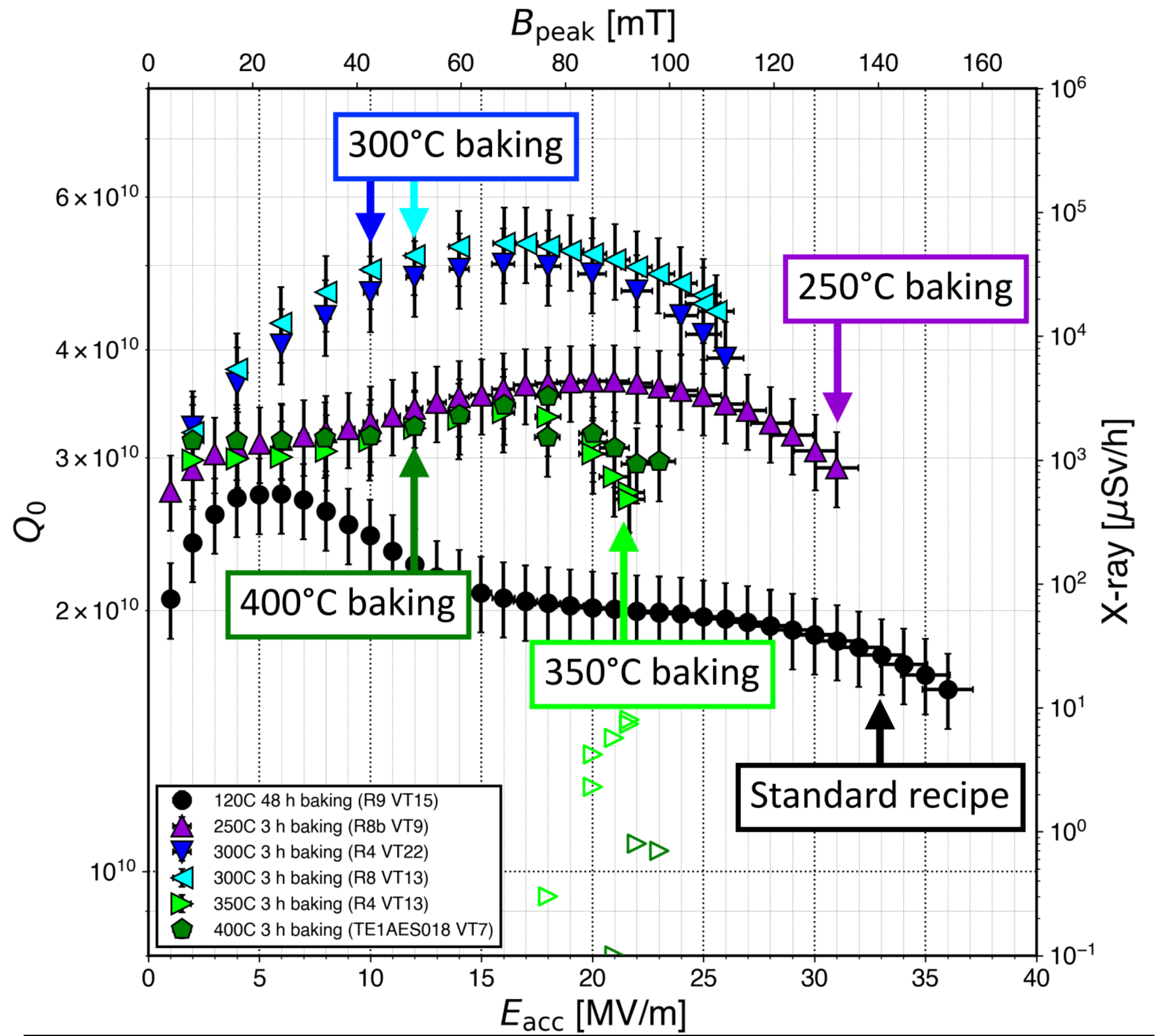
Resistance Deconvolution



- Rres lowest and same for 2-step and Furnace baking

Comparison of R18 and R8 at 2.0 K for 300C Furnace baking





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