Nb Material R&D at KEK

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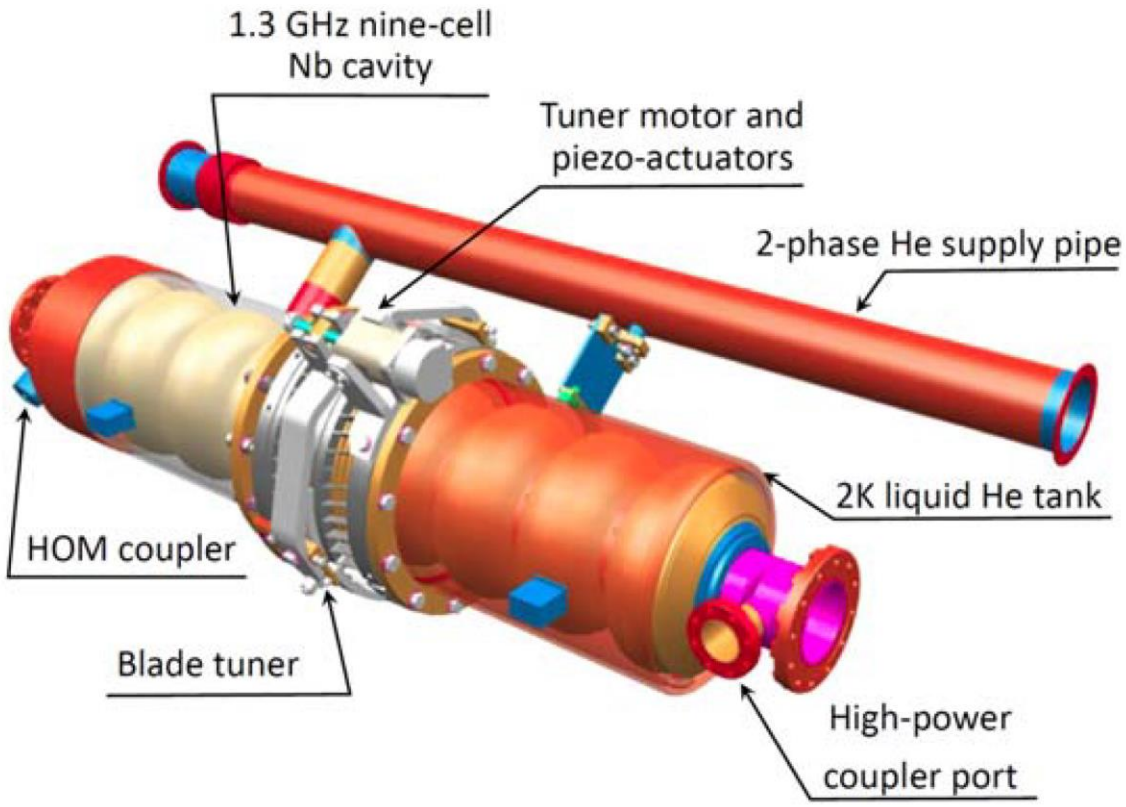
- Different Grades of Niobium
- Mechanical properties of Nb
- Performance of various cavities

1.3 GHz 9-Cell SRF Cavity Assembly



Cited from: The International Linear Collider: A Global Project, arXiv:1903.01629 [hep-ex]

Niobium SRF Cavity with its Titanium jacket is considered as a pressure vessel

↓

Design must be in accordance with high-pressure gas safety regulation (HPGS)

↓

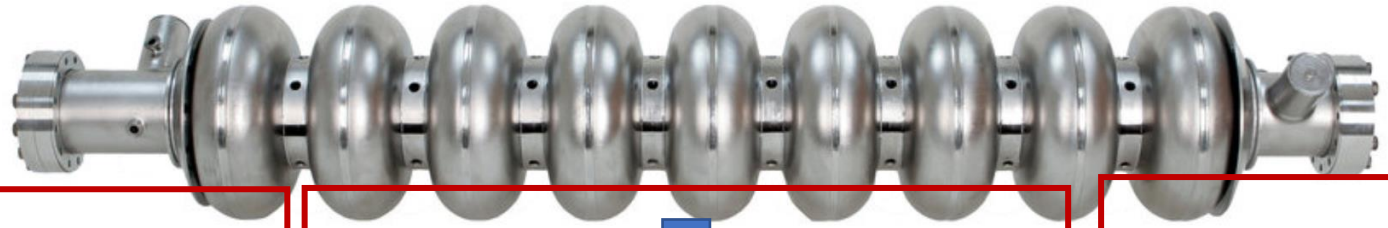
Stress due to cooldown, 0.2 MPa of pressure and tuning action

↓

Nb is not a code material, hence material characterization is necessary

Niobium for 9-Cell 1.3 GHz SRF Cavity

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 for HPGS.
- High Cost.

R & D Material

Large Grain (LG) Nb

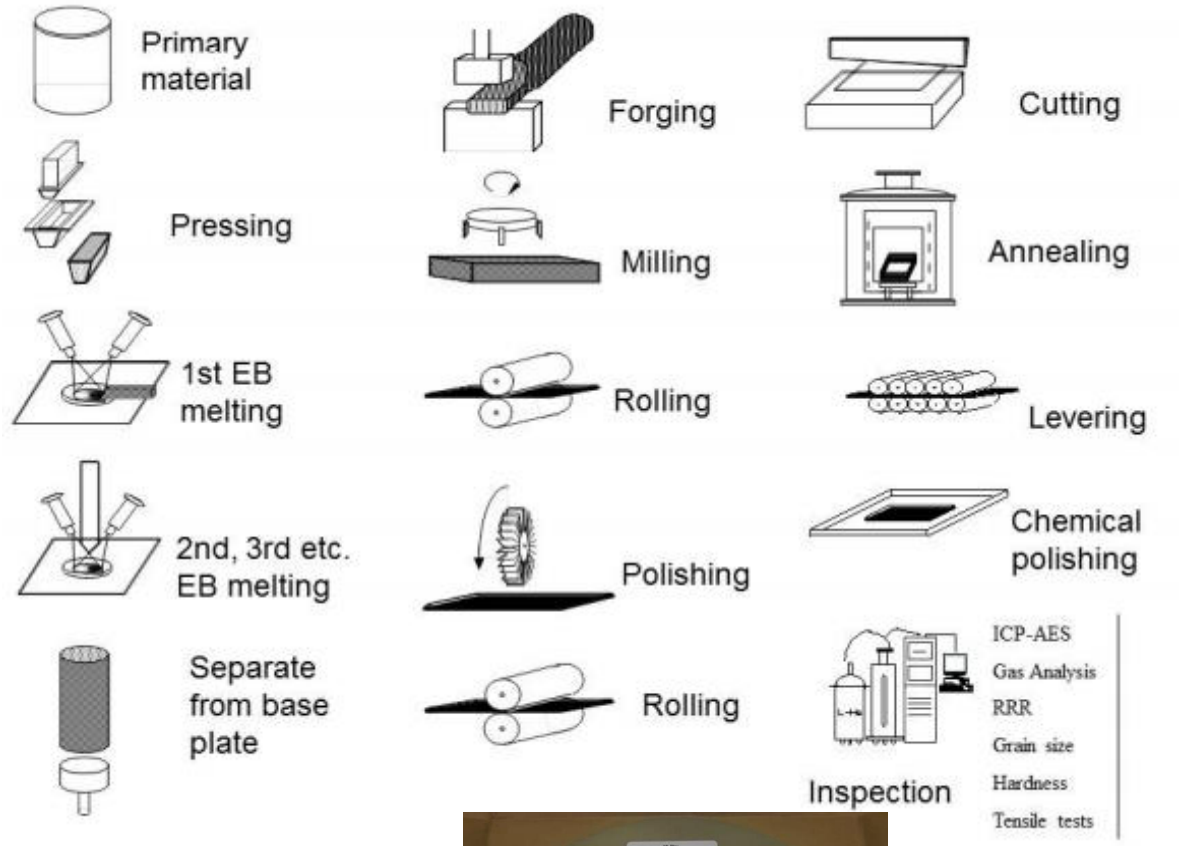
- Grain size > 1 cm.
- Anisotropic mechanical properties.
- Issue with HPGS clearance
- Low Cost.

New Material

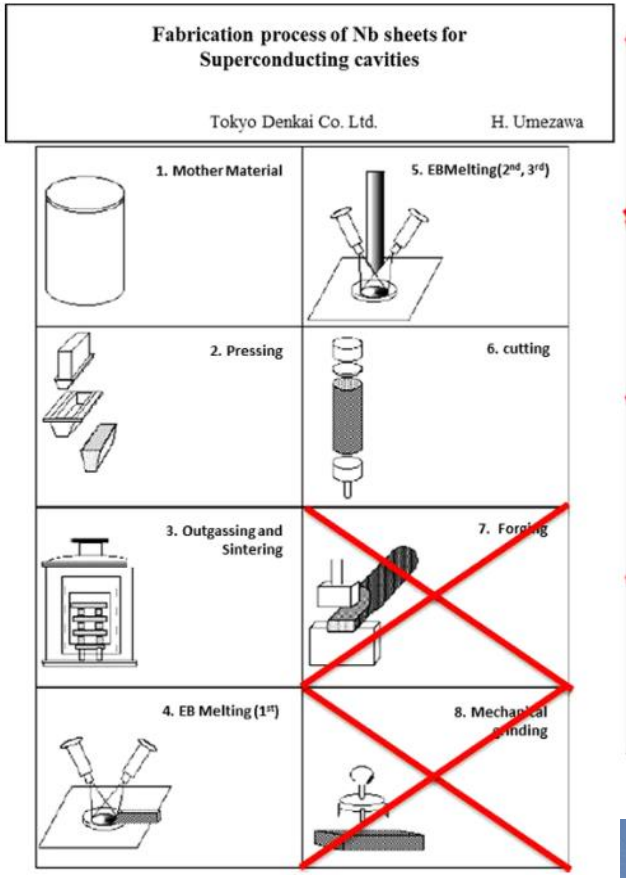
ATI Medium Grain (MG) Nb

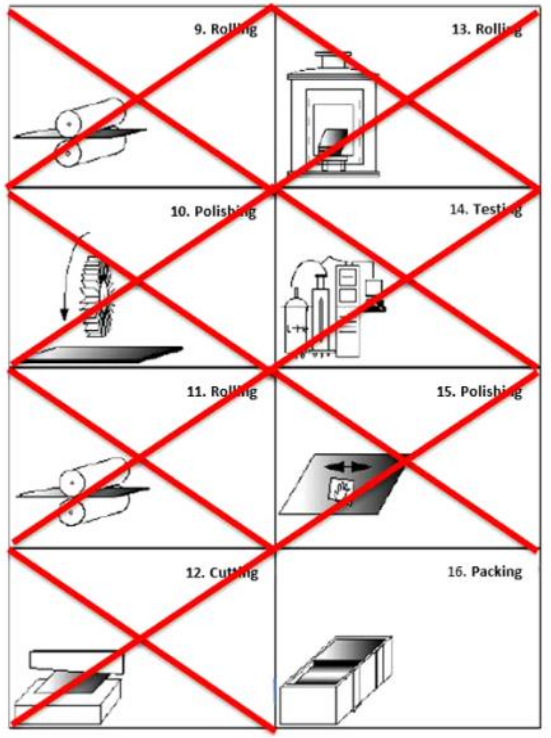
- Grain size - 200-300 µm, occasional 1-2 mm grains
- Isotropic properties?
- Viable for SRF cavity?
- Cost reduction w.r.t FG Nb

Nb Disk Manufacturing

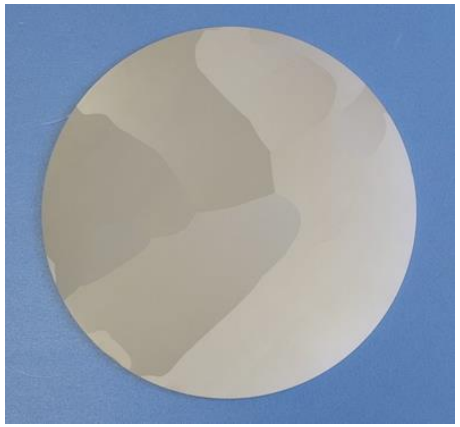


FG Nb





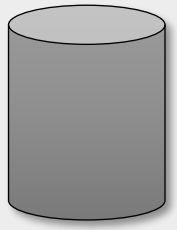
LG Nb



Cited from: Nuclear Instruments and Methods in Physics Research A 774 (2015) 133–150

Manufacturing of LG & MG Nb

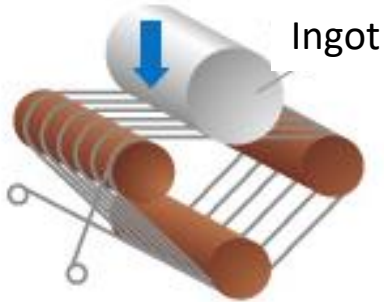
Nb melting



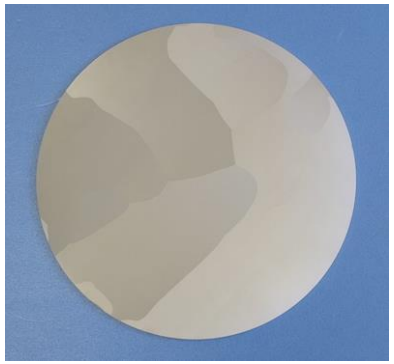
Niobium ingot
(Raw material)

Direct slice of LG ingot

Ingot, as it is



Slicing image
by wire-saw

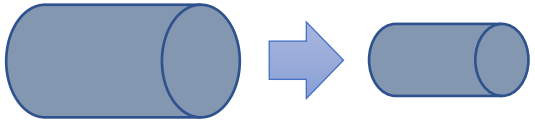


LG Nb

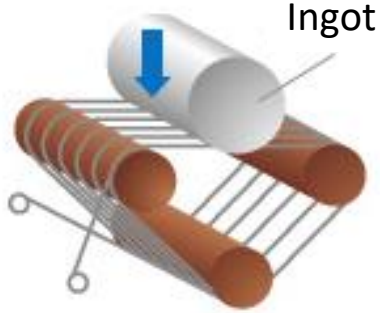
Large Grain (LG) Disc

Grain Size >> 1 cm

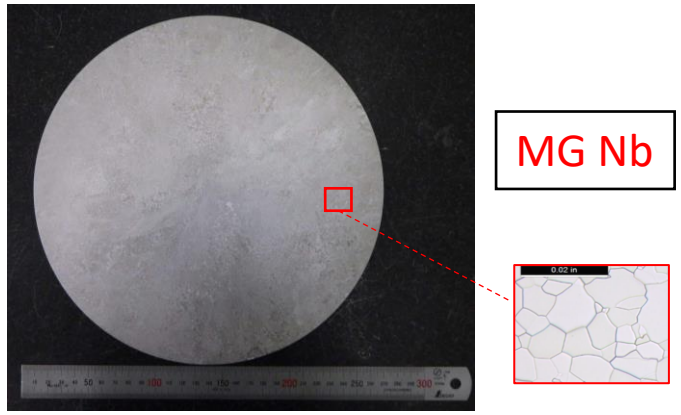
Direct slice of MG ingot



Ingot, forged
and annealed



Slicing image
by wire-saw



MG Nb

A New Approach:

Medium Grain (MG) Disc

Grain Size **< 1 mm**

2022/2/16

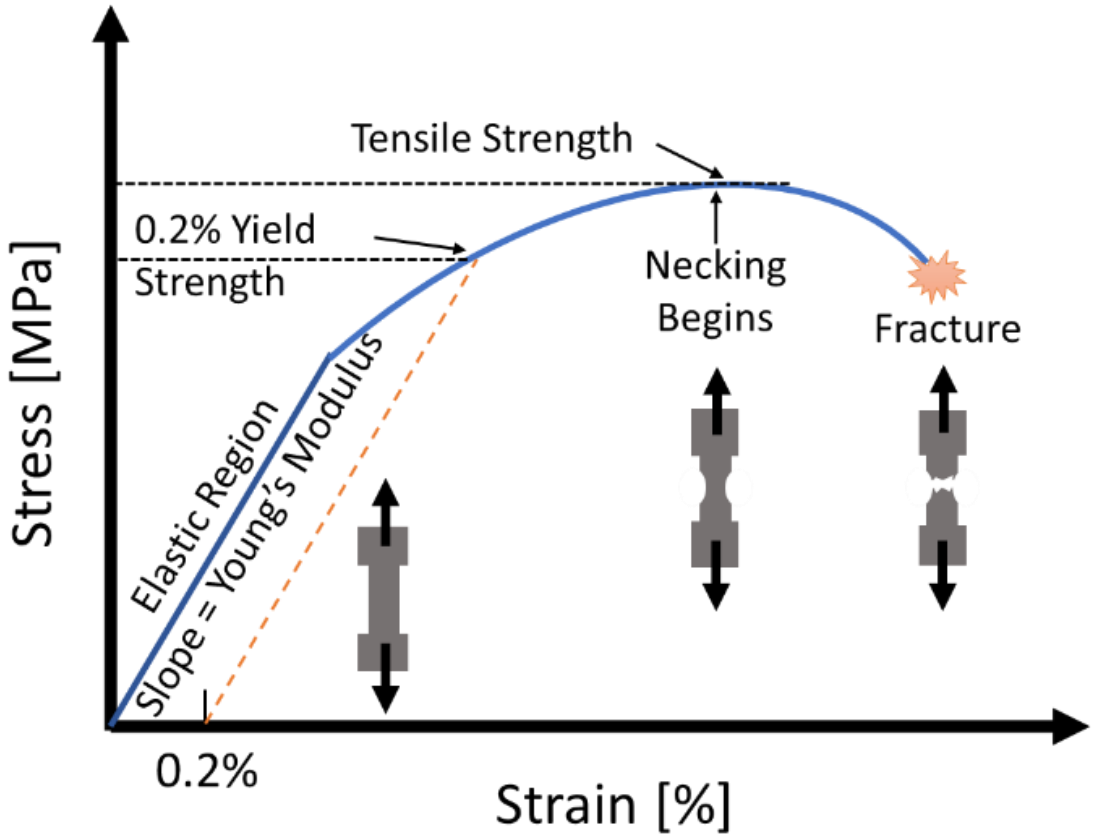
* The “Nb forged ingot” technology originated by **ATI**, and SRF (GHz) cavities planned to be fabricated and RF tested by **KEK** and **JLab**, to qualify this approach, in collaboration of **ATI, ODU/BSCE, JLab, and KEK.**

Mechanical Properties of Nb

Tensile Testing for Mechanical Properties

- Material is subjected to uni-axial tension until failure.

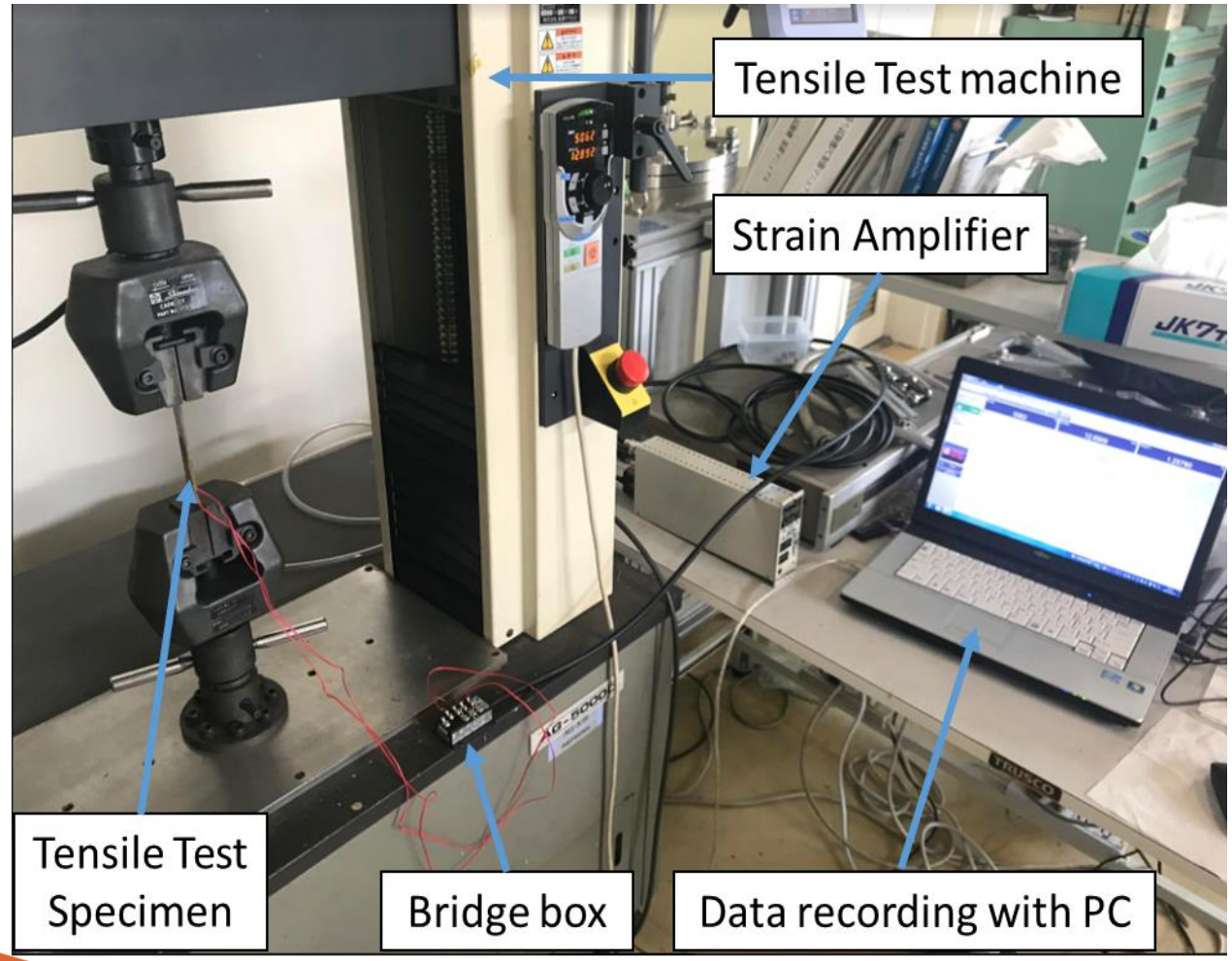
- Young's Modulus (E) – Stiffness of the material in tension
- 0.2% Proof Strength (0.2% P.S) – Stress at which strain is 0.2% after unloading
- Tensile Strength (T.S) – Maximum stress or stress before failure of the specimen
- Elongation – Measure of ductility of a material



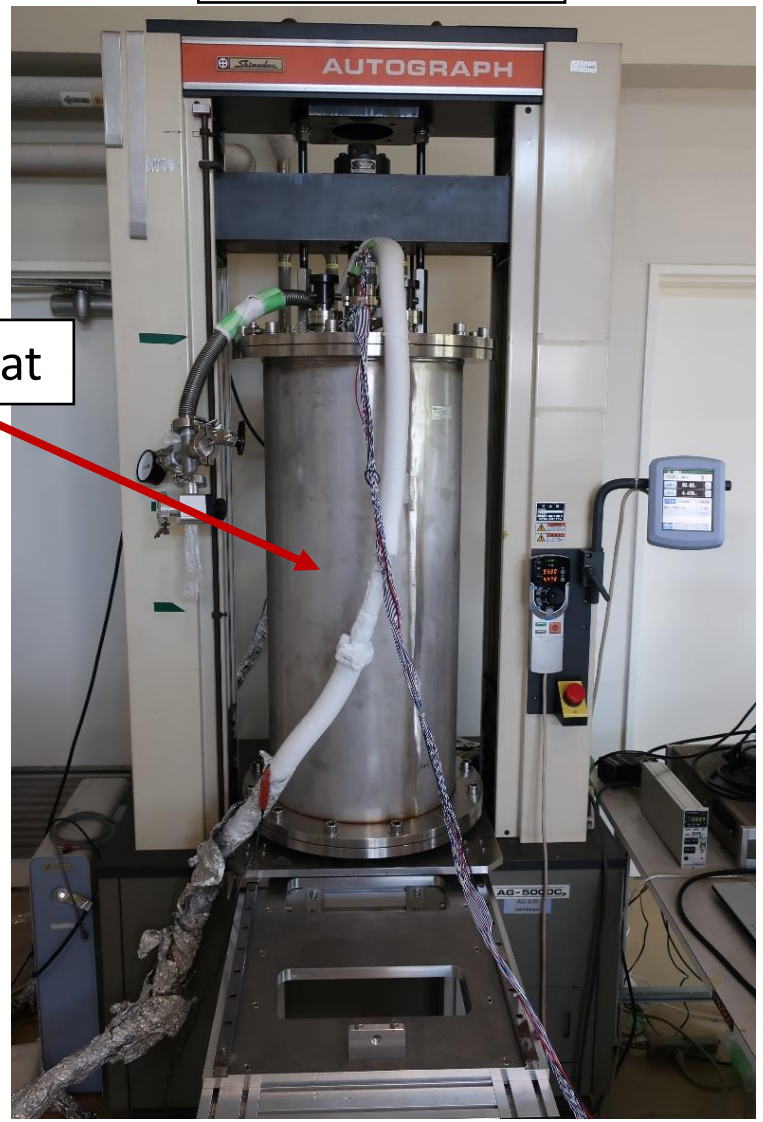
$$\text{Elongation}\ (\%) = 100 \times \Delta L_f / L$$

Tensile Testing Apparatus at KEK

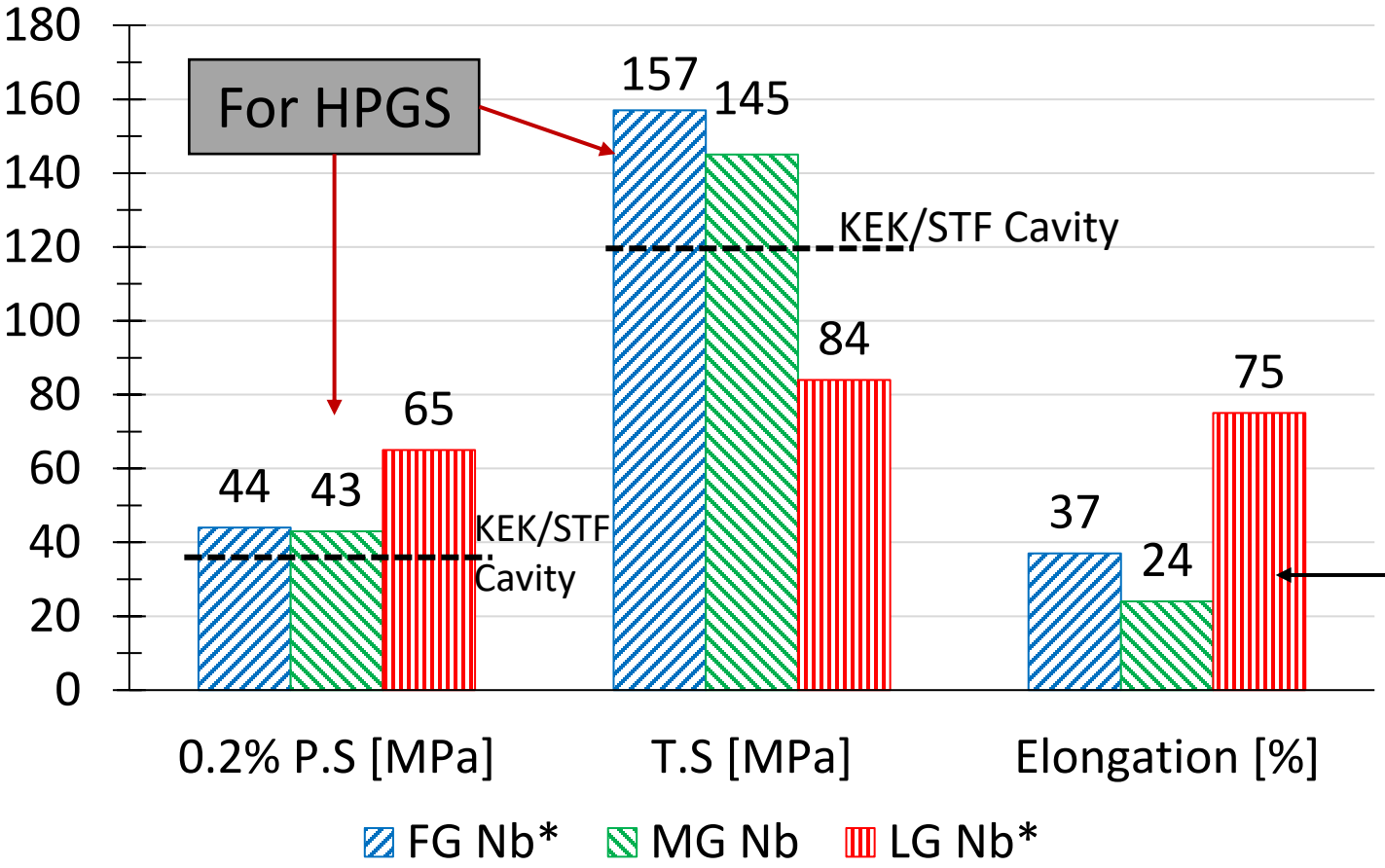
At room temperature



With Liquid He



Room temperature property Comparison



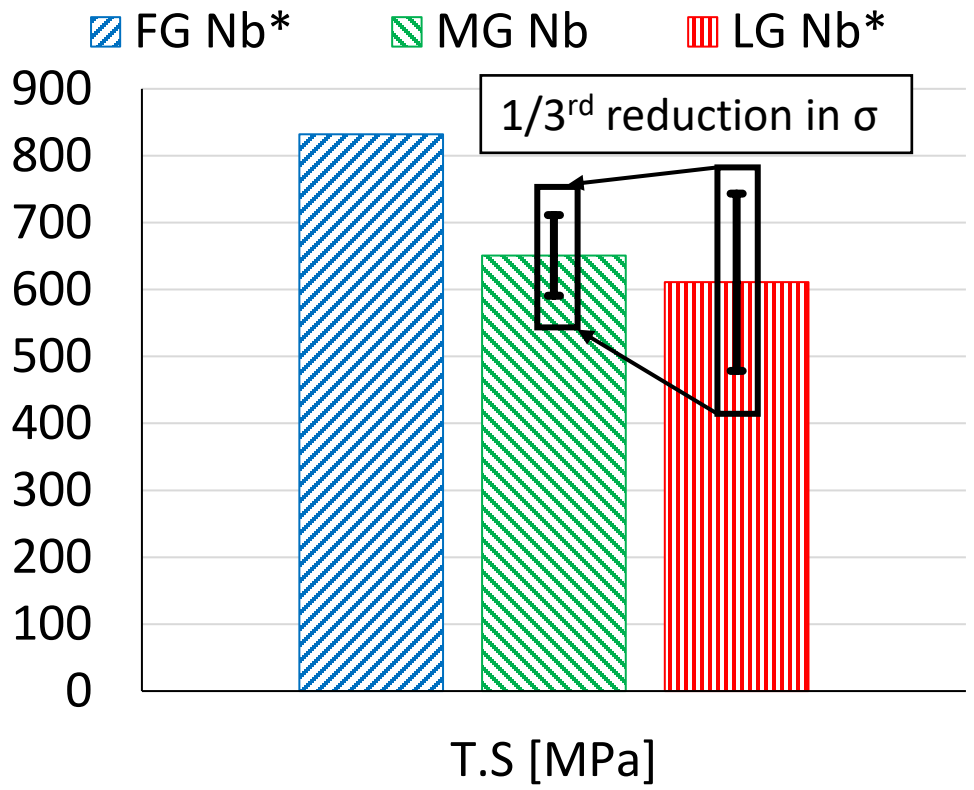
- MG Nb closer to FG Nb than LG Nb
- Elongation is lower than FG Nb but unnecessary for HPGS
- High elongation necessary for press forming of half cells.

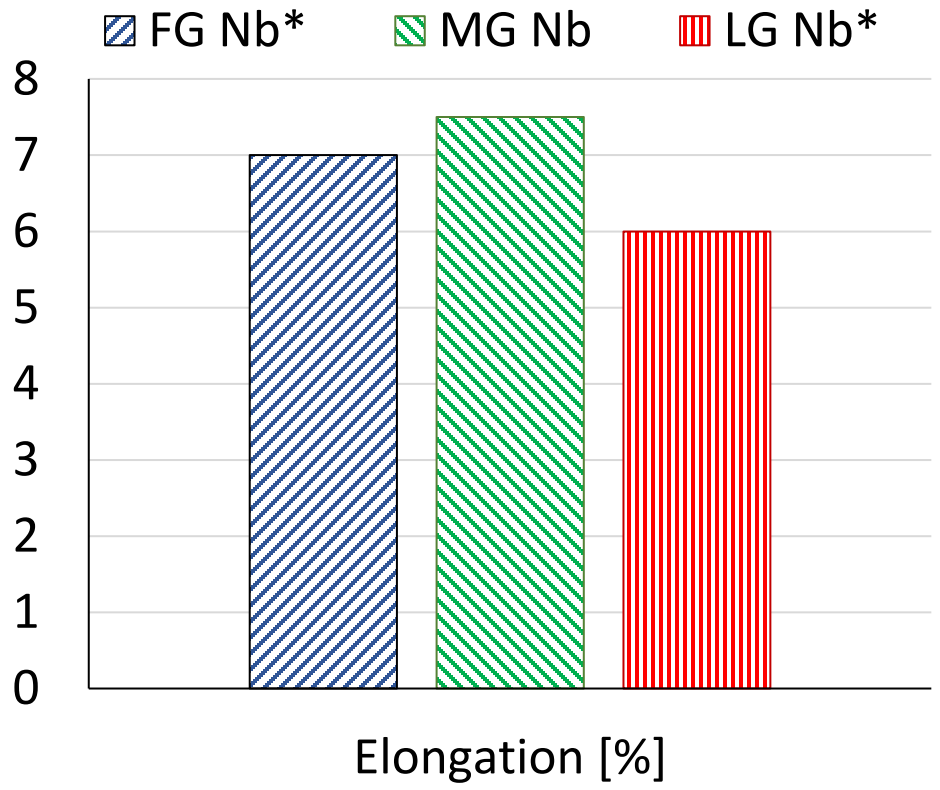
Mechanical strength of MG-Nb achieved the criteria of HPGS regulation for KEK/STF-Cavity

MG Nb data: A. Kumar et al. (July 2021), SRF2021 MOPCAV004

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

Low Temperature Property Comparison





- Tensile Strength of MG-Nb at LHe-T is better than LG-Nb.
- Brittleness and low elongation of MG-Nb are not observed at LHe-T after annealing.

* 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. (July 2021), SRF2021 MOPCAV004

Performance of LG Nb and MG Nb Cavities

Credits:

LG Nb cavity results by Hayato ARAKI

MG Nb cavity performance results by Takeshi DOHMAE

Overview of Cavities and their Performance

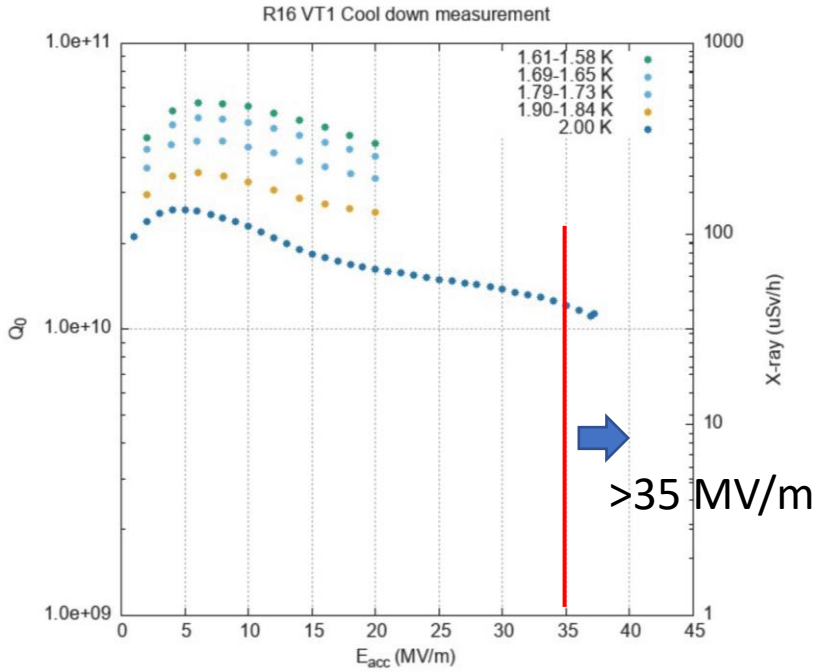
Nb Materials	Cavities	Cavities	Vertical Test Results	ILC Specification
LG Nb (Mid-RRR, High-Ta)		Two 9-Cell	E_{acc} < 35 MV/m (E_{acc} – 34 MV/m)	✕
LG Nb (High-RRR, Low-Ta)		Two 3-Cell	E_{acc} > 35 MV/m	✓
LG Nb (High-RRR, High-Ta)		Two 3-Cell (two 9-Cell under fabrication)	E_{acc} > 35 MV/m	✓
MG Nb (High-RRR, Low-Ta)		Two 1-Cell (One 9-Cell will be fabricated)	E_{acc} > 35 MV/m	✓

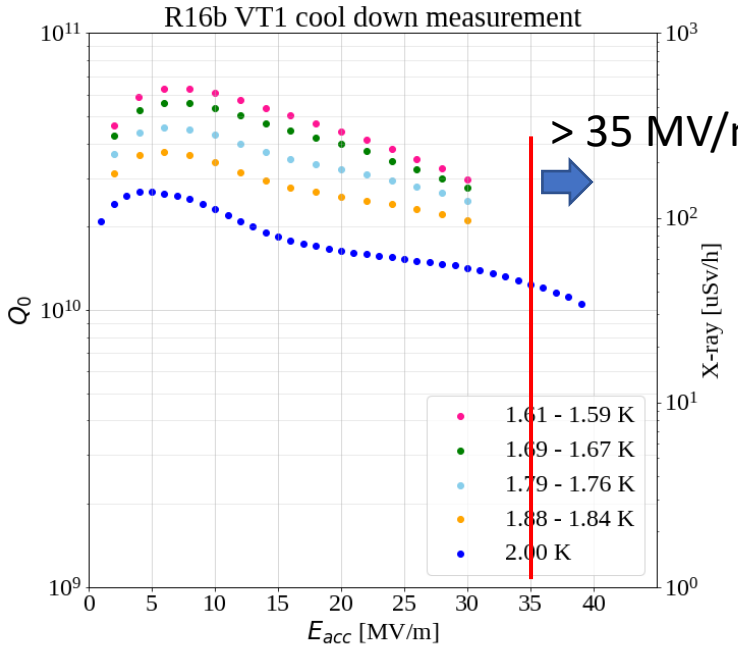
LG Nb Material (High RRR, Low Ta)

High-RRR (LG-Nb, Low-Ta) 3-cell cavities have reached > 35 MV/m.

Two 3-cell cavities

R16, R16b
High RRR, Low Ta





R-16: VT1, Eacc = 37 MV/m (Initial Eacc = 41 MV/m).
R-16b VT1, Eacc = 39 MV/m (Initial Eacc = 40 MV/m).

Focus will be on Nb material with RRR > 300.

H. Araki et al., PASJ2021 TUP037

LG Nb cavity results by Hayato ARAKI

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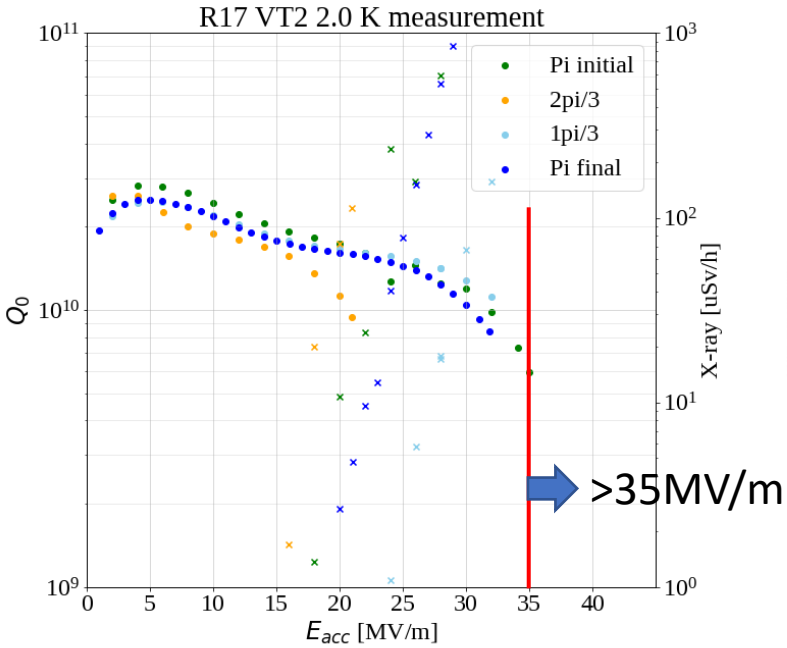
Nb Materials	Cavities	Cavities	Vertical Test Results	ILC Specification
LG Nb (Mid-RRR, High-Ta)		Two 9-Cell	E_{acc} < 35 MV/m	✕
LG Nb (High-RRR, Low-Ta)		Two 3-Cell	E_{acc} > 35 MV/m	✓
LG Nb (High-RRR, High-Ta)		Two 3-Cell (two 9-Cell under fabrication)	E_{acc} > 35 MV/m	✓
MG Nb (High-RRR, Low-Ta)		Two 1-Cell 9 (One 9-Cell will be fabricated)	E_{acc} > 35 MV/m	✓

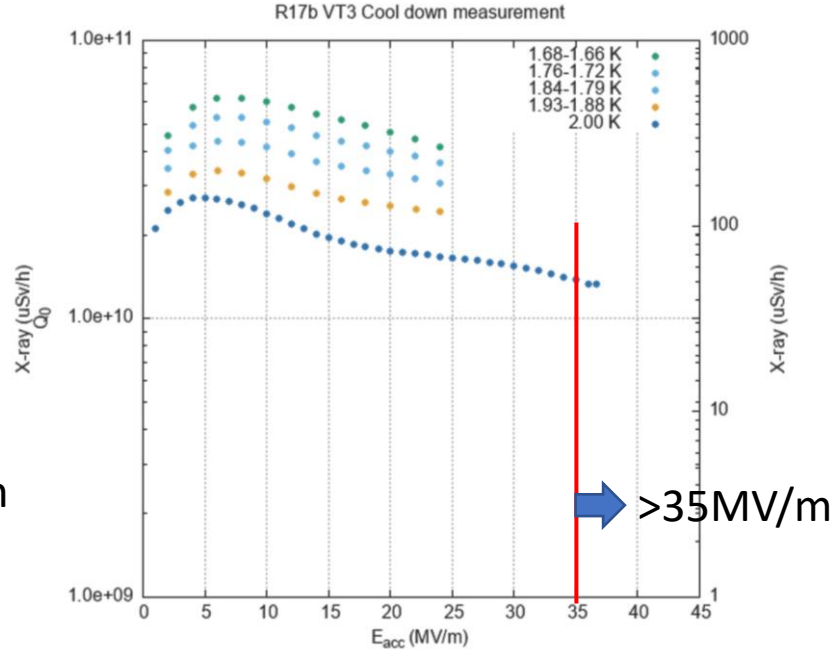
LG Nb Material (High RRR, High Ta)

High-RRR (LG-Nb, High-Ta) 3-cell cavities have reached > 35 MV/m.

Two 3-cell cavities

R17, R17b
High RRR, High Ta)



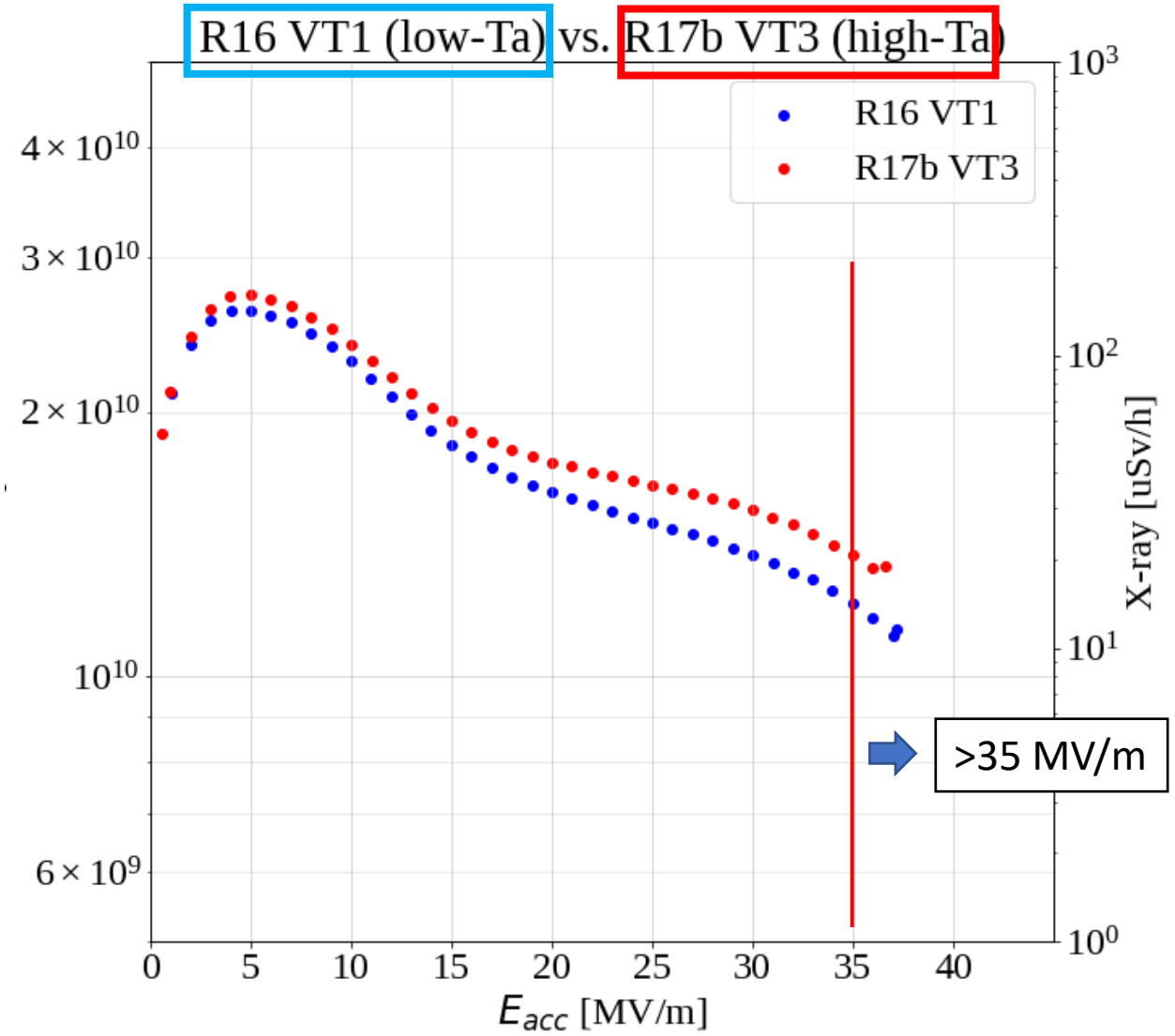


R-17: VT2, Eacc = 35 MV/m
R-17b: VT3, Eacc = 37 MV/m (Initial Eacc = 42 MV/m)

H. Araki et al., PASJ2021 TUP037

LG Nb cavity results by Hayato ARAKI

Low Ta vs High Ta (High RRR, LG Nb)



Comparison of
Low-Ta vs High-Ta

Ta-fraction is not sensitive to
the SRF performance if RRR > 300.

Difference of Q values are
within the measurement error.

H. Araki et al., PASJ2021 TUP037

LG Nb cavity results by Hayato ARAKI

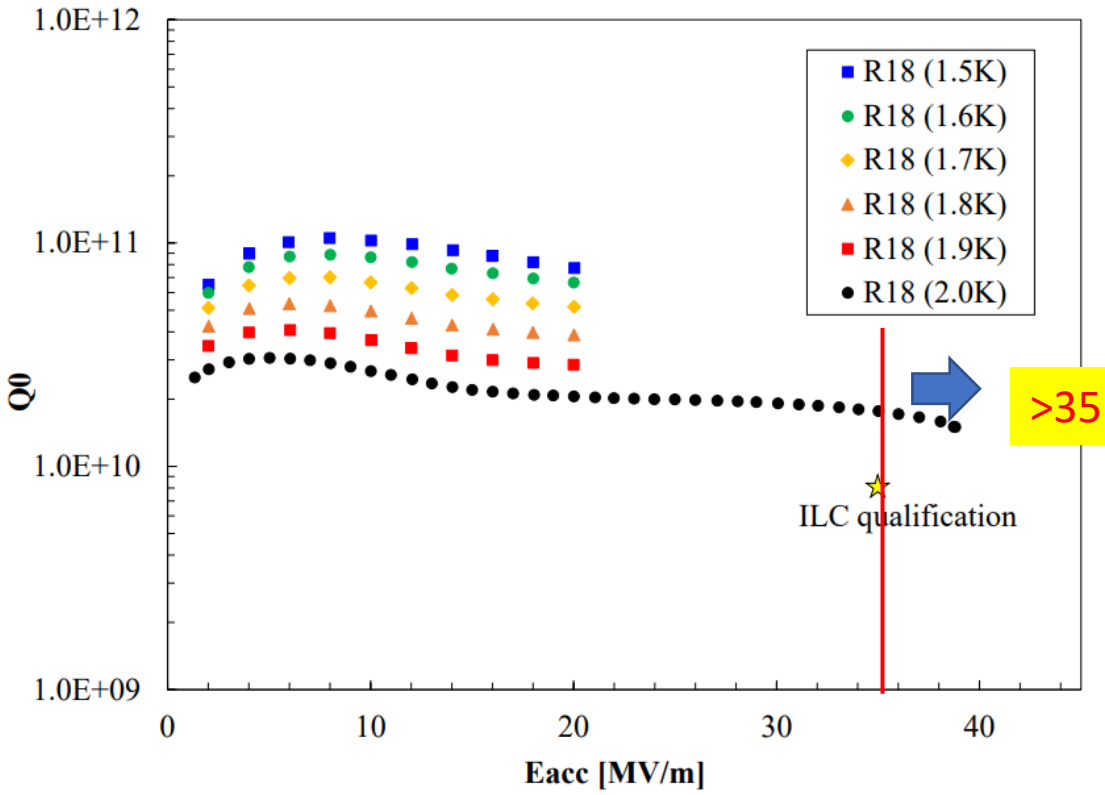
Overview of Cavities and their Performance

Nb Materials	Cavities	Cavities	Vertical Test Results	ILC Specification
LG Nb (Mid-RRR, High-Ta)		Two 9-Cell	E_{acc} < 35 MV/m	✕
LG Nb (High-RRR, Low-Ta)		Two 3-Cell	E_{acc} > 35 MV/m	✓
LG Nb (High-RRR, High-Ta)		Two 3-Cell (two 9-Cell under fabrication)	E_{acc} > 35 MV/m	✓
MG Nb (High-RRR, Low-Ta)		Two 1-Cell 9 (One 9-Cell will be fabricated)	E_{acc} > 35 MV/m	✓

MG Nb Material (High RRR, Low Ta)

Results of MG single-cell cavities.
R18, R18b (vs. R9 / FG single-cell cavity).

RF test result of R18



>35 MV/m

- R18, R18b were fabricated using MG discs
- Inner surface of R18 was mechanically polished during fabrication (R18b was not)
- VT of R18: 38.8 MV/m with $Q_0=1.5\times10^{10}$
- VT of R18b: 35.4MV/m with $Q_0=1.76\times10^{10}$

Two MG-Nb single-cell cavities have reached > 35 MV/m

R18 Results Cited From: T. Dohmae et al., SRF' 21 MOPCAV012

R18b cavity results by Takeshi DOHMAE

Summary

- LG Nb: High RRR for high SRF performance.
- LG Nb: Ta-fraction is not sensitive to the SRF performance.
- LG-Nb is cost effective and has good SRF performance, but the mechanical strength creates hurdles to pass HPGS regulation.

- MG-Nb: Cost effective and has good SRF performance (1-Cell clears ILC specification)
- Adequate Mechanical properties to pass HPGS regulation.
- MG Nb elongation improvements is anticipated for ILC mass-production (yield rate of press-forming of half-cell).

Thank You for Your Attention!