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# High Performance Next-Generation $\text{Nb}_3\text{Sn}$ Cavities for Future High Efficiency SRF LINACs

**Ryan Porter**

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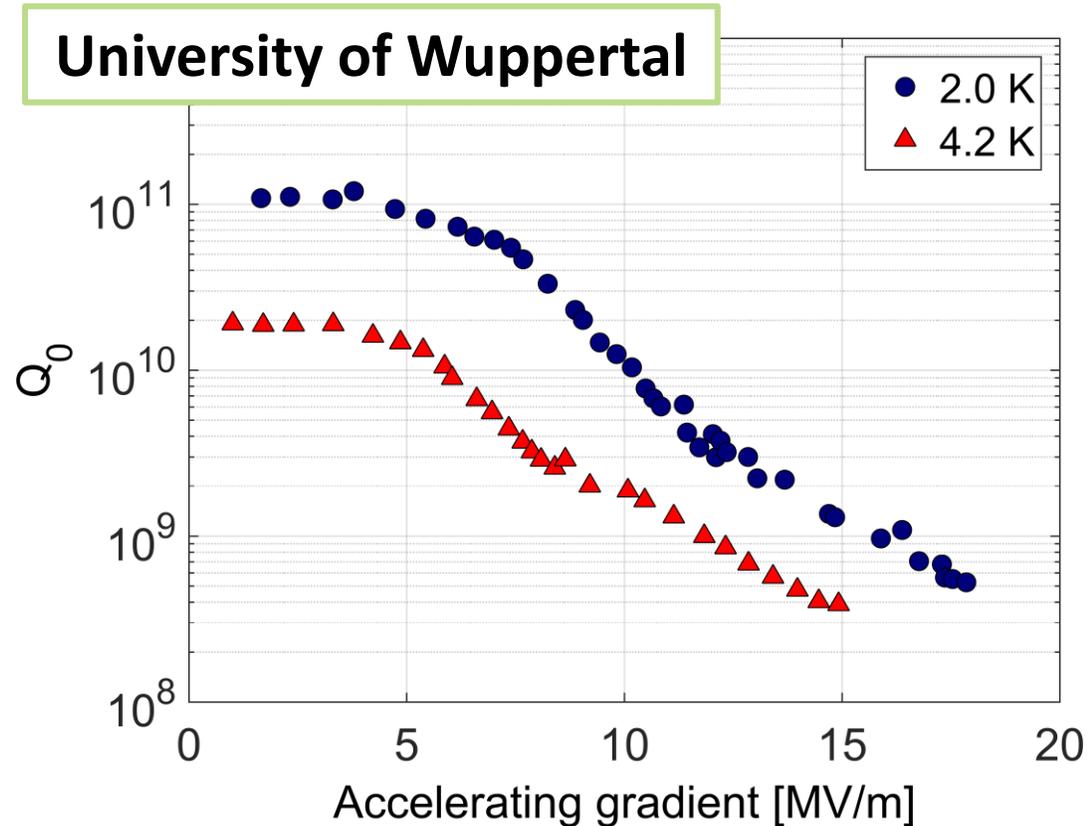
# The Promise of Nb<sub>3</sub>Sn

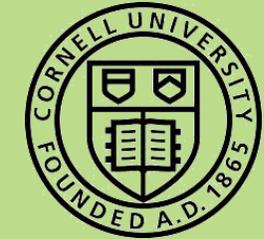
**Nb<sub>3</sub>Sn : a promising alternative material for use in SRF cavities with the potential for**

- ⇒ Higher quench fields
- ⇒ Greater cavity efficiency
- ⇒ Operation at 4.2 K

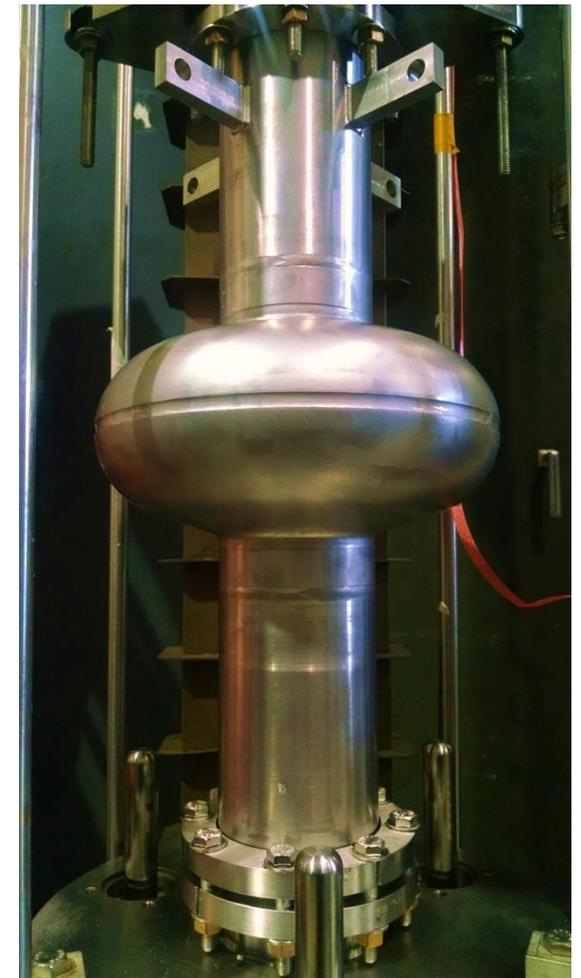
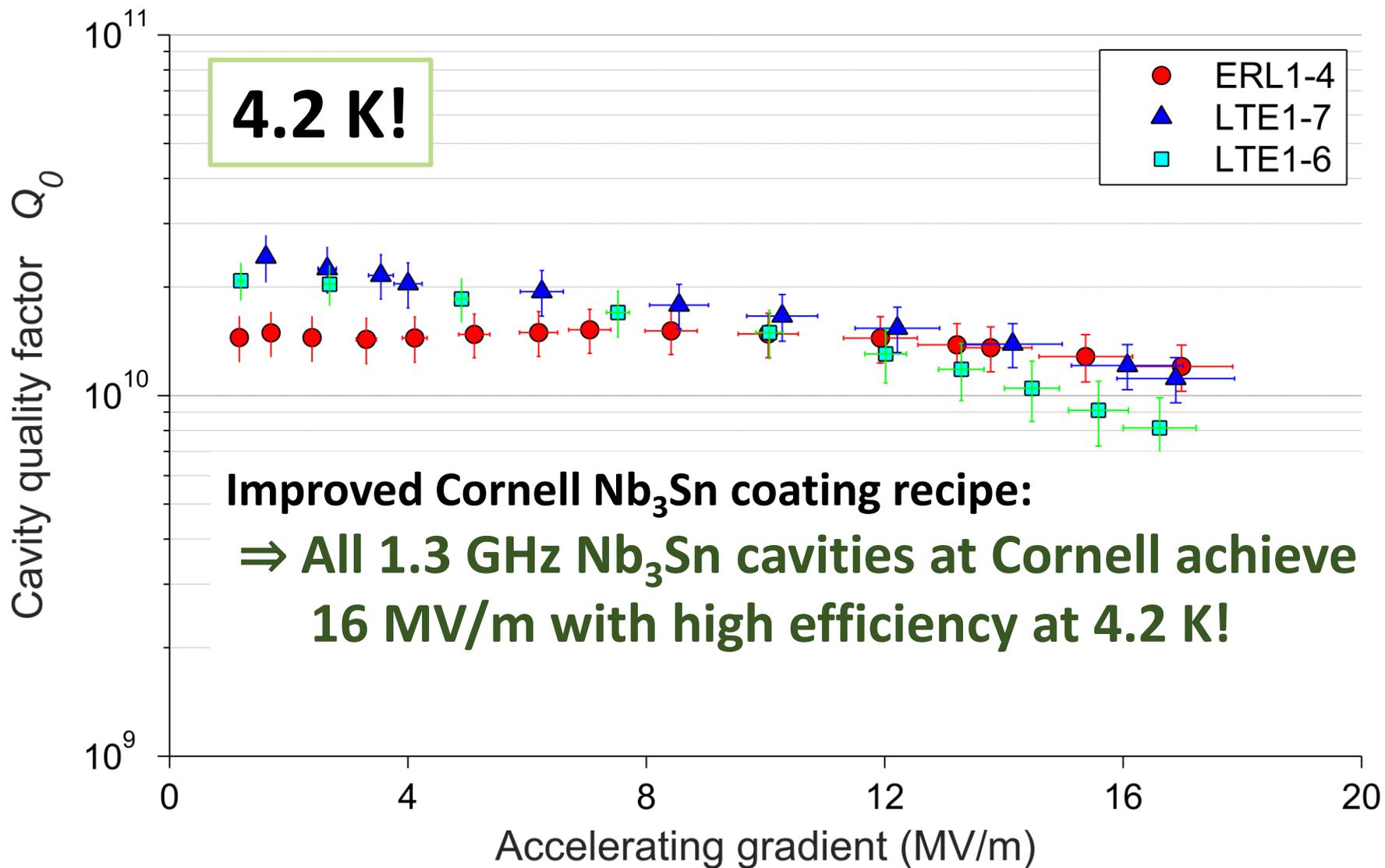
**Previous cavities limited by severe Q-slope**

Parameter	Niobium	Nb <sub>3</sub> Sn
Transition temperature	9.2 K	18 K
Superheating field	219 mT	425 mT



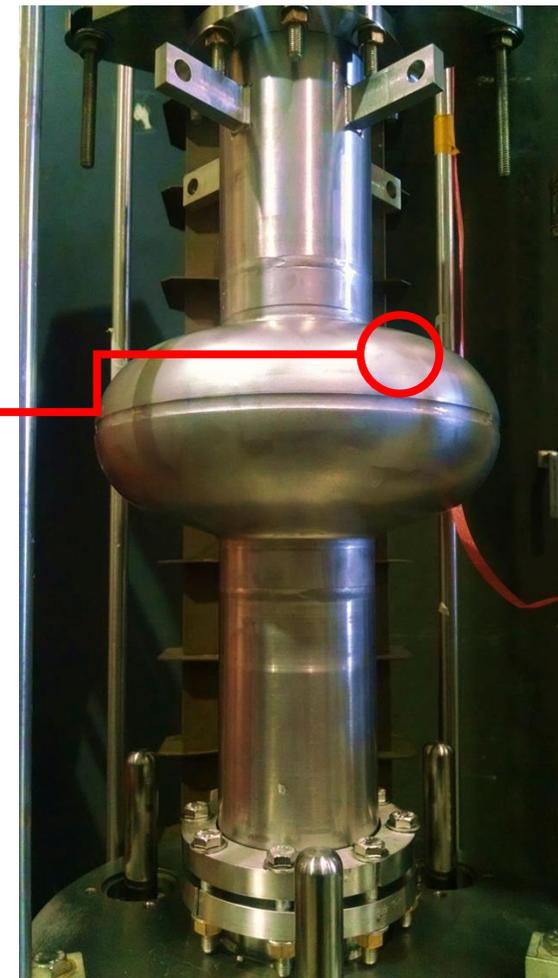
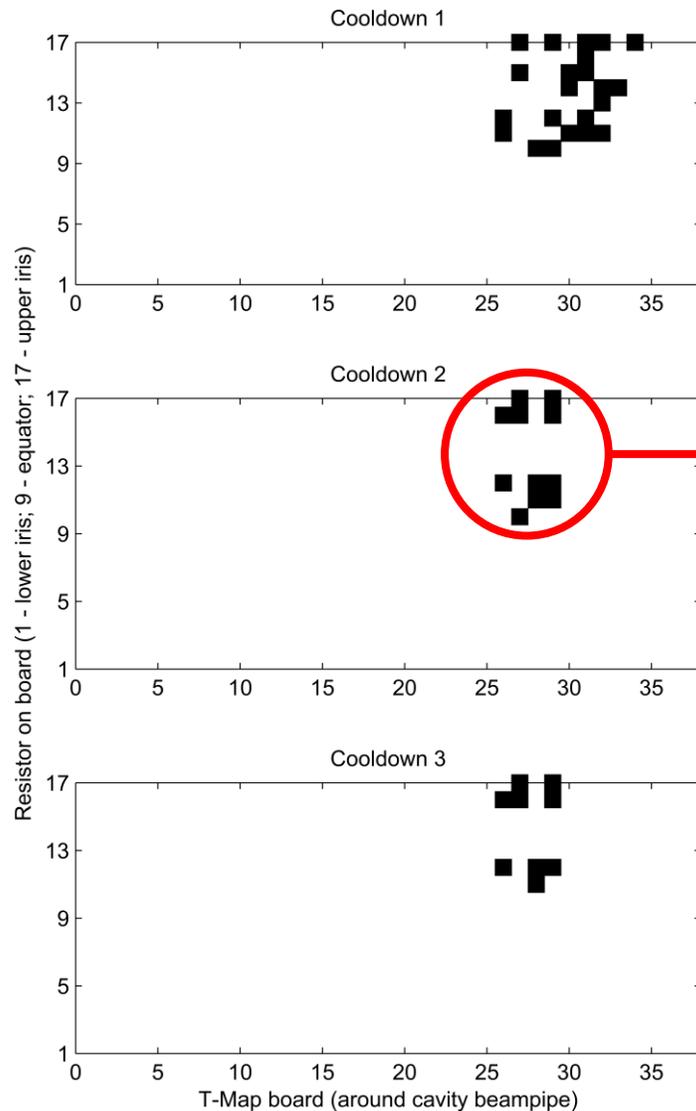
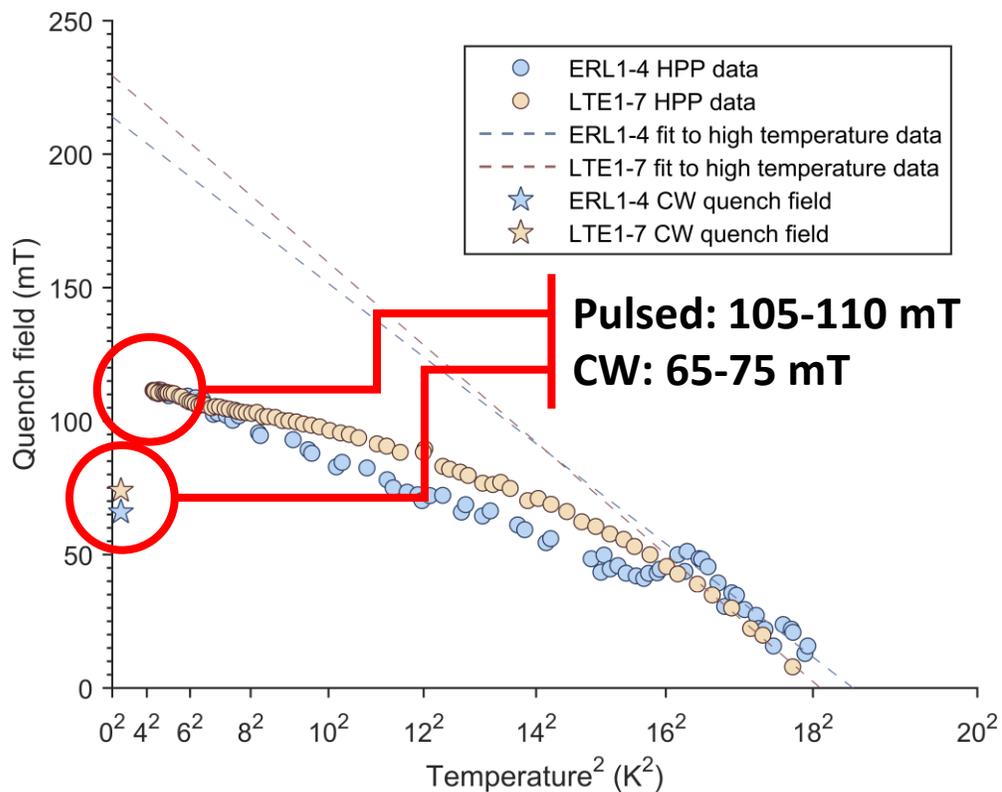


# Cornell Nb<sub>3</sub>Sn Cavity Performance



Higher fields achieved during pulsed power tests

⇒ Limited by local defect

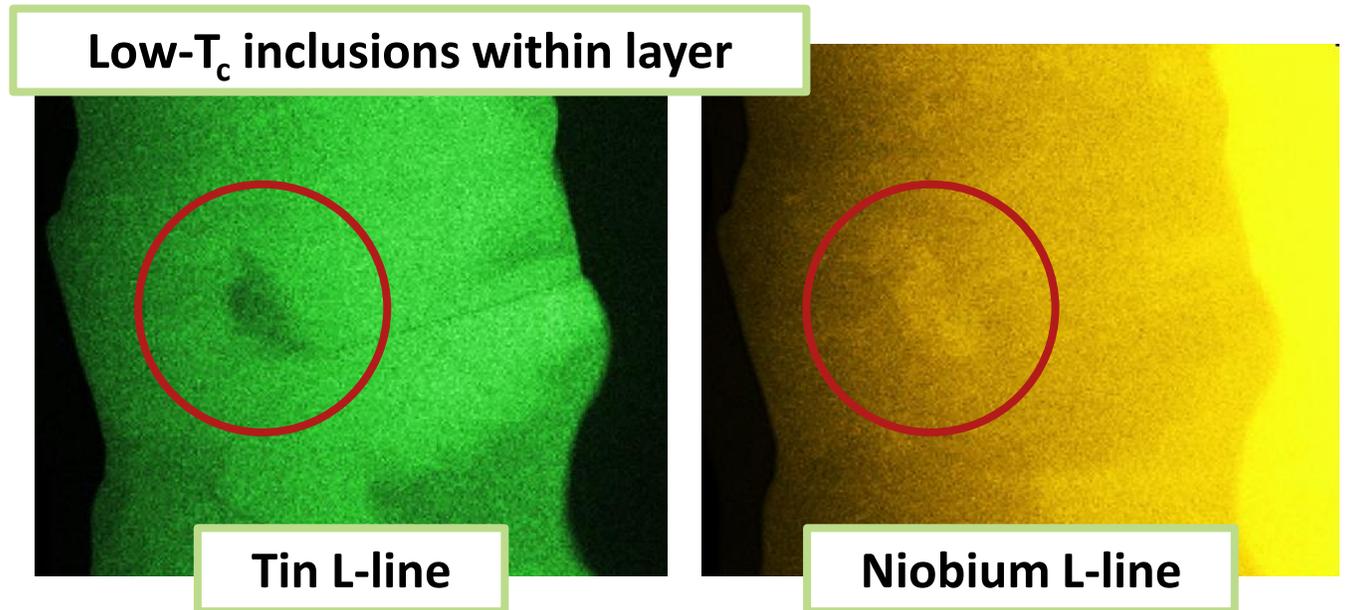


Regions of thin film – insufficient thickness to screen bulk from RF



⇒ Solution: Pre-anodising substrate before coating suppresses formation of these thin-film regions!

Tin-depleted regions with  $T_c \approx 6$  K – quench due to thermal runaway?



*Cross-section EDS maps courtesy of Thomas Proslie, ANL*

⇒ Work in progress – theoretical modelling of the growth of these regions is underway using ab initio Joint Density Functional Theory

## High Performance Next-Generation Nb<sub>3</sub>Sn Cavities for Future High Efficiency SRF LINACs

D.L. Hall\*, J.J. Kaufman, M. Liepe, J.T. Maniscalco, R.D. Porter

### Introduction

The A15 superconductor Nb<sub>3</sub>Sn shows considerable promise for replacing niobium in high-efficiency SRF cavity applications. With a superheating field of approximately 400 mT the theoretical peak achievable gradient is 90 MV/m in an ILC-style 1.3 GHz cavity, twice that of niobium.

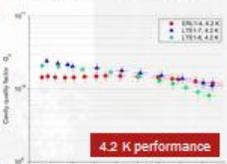
Current efforts are focused on two fronts: improving the quality factor of the cavity and identifying the reasons behind the cavity quench at fields below the superheating field.



**Nb<sub>3</sub>Sn offers the potential for a high gradient machine operating at 4.2 K**

### Repeatable cavity performance

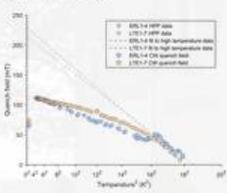
- With the improvement of the coating recipe, all 1.3 GHz single-cell cavities coated at Cornell achieve accelerating gradients of  $\geq 16$  MV/m
- More single-cell cavities have been fabricated to further improve statistics



**4.2 K performance**

### Peak achievable fields

- In high pulsed power testing, cavities achieve fields higher than those seen in the CW tests
- Extrapolation from high temperature data yields critical flux entry fields consistent with a superheating field value that is reduced by field enhancement effects



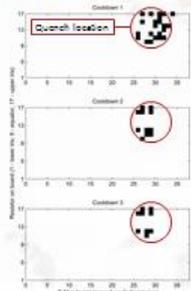
**Cavities achieve surface peak fields >100 mT in pulsed power tests**

### Potential quench mechanisms

- Quench maps of a cavity show that the quench is localized in nature
- The quench location is independent of the cavity cooldown

Right: Cavity quench map. Black squares indicate regions of the cavity where fast heating was detected during a quench event

Below: Red regions indicate areas that possess too thin a coating to effectively screen the bulk from the RF field



Right: Cross-section EDS maps of a Nb<sub>3</sub>Sn layer showing tin-depleted regions with lower transition temperature (circled in red)



**Cavity quench is likely caused by identifiable localized defects in the coated layer**

### Conclusion and further work

Single cell cavities coated with Nb<sub>3</sub>Sn reliably achieve gradients of  $\sim 17$  MV/m, with higher fields achievable in pulsed power tests; however, the quench fields still fall short of the maximum gradient predicted by the superheating field.

Work is underway to conclusively identify the exact source of cavity quench in a cavity test using high resolution thermometry mapping



## Surface Roughness Effect on the Performance of Nb<sub>3</sub>Sn Cavities

R. Porter, D. L. Hall, M. Liepe, J. T. Maniscalco

### Introduction

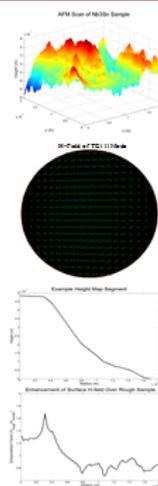
Nb<sub>3</sub>Sn cavities produced at Cornell have rougher surfaces than conventional Niobium cavities. Previous simulations and calculations have shown that both bumps and pits in the surface of a cavity can cause local enhancement of the surface magnetic field. If the magnetic field is sufficiently enhanced over a large enough area it could lower the quench field of the cavity. The increased surface area and changes in local magnetic field could also impact the quality (Q) factor of the cavities. When analyzing experimental data the Q-factor is usually assumed to be identical to a smooth cavity, so any significant difference could impact previous analysis of Nb<sub>3</sub>Sn cavities.

Here we present electromagnetic simulations of the impact of the observed surface roughness of Nb<sub>3</sub>Sn cavities on the enhancement of surface magnetic fields and Q-factors.

### Method

Short ( $\sim 2.5$   $\mu$ m) line segments were taken from Atomic Force Microscope scans of Nb<sub>3</sub>Sn coated samples. This segment of real height data was used in an electromagnetic simulation. In the model, the line segment was placed in center (contained within 6% of the center) of a flat end of a cylindrical pill box cavity. The line segment was rotated to create an azimuthally symmetric cavity (required by SLANS2).

The electromagnetic field was solved for in the TE<sub>111</sub> mode using SLANS2 (Superlans). The surface magnetic field parallel to the line segment was compared to the simulation results of a flat cavity and the magnetic field enhancement and change in Q-factor was calculated.



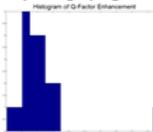
### Superheating Field

Klystron high pulsed power measurements near T<sub>c</sub> (Hall, 2016) suggest the superheating field in our Nb<sub>3</sub>Sn cavities is  $\sim 230$  mT (at 0 K). This is significantly lower than theoretical calculations that predict superheating fields of  $\sim 400$  mT (at 0 K). Not including field enhancement from surface roughness effects is likely the cause of the lower experiment results.

### Results

The histogram on the right shows the relative distribution of field enhancement ( $H_{rough}/H_{smooth}$ ) over the rough region. The mean of the distribution is  $(0.958 \pm 0.011)$  (stat). 10% of the points are over 1.2, 5% of the points are above 1.29 and **1% of the points are above 1.45**.

A 50% increase in mesh density increased the enhancement by approximately 0.01 on some of the short samples. So actual enhancement may be slightly higher.



The histogram on the left shows the ratio of the quality factors over the rough region ( $Q_{rough}/Q_{smooth}$ ). The mean of the distribution is  $(1.038 \pm 0.010)$  (stat). **The Q-factor is increased but is almost the same.**

### Conclusion

**Field enhancement due to surface roughness must be accounted for when determining the superheating field from high pulsed measurements.** Assuming (roughly) that 1% of the cavity being normal conducting is enough to cause a quench, Cornell klystron experiments suggest of superheating field of  $1.45 \times 230$  mT = 330 mT. This brings measurements much closer to the theoretical prediction.

It is not, however, important to consider surface roughness when calculating Q-factors from experimental data, as the **roughness causes almost no change in Q-factor.**

# TUPRC031

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# MOPRC027

Surface Roughness Effect on the Performance of Nb<sub>3</sub>Sn Cavities