Nb_3Sn R&D at Cornell University

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Outline

- Introduce Nb_3Sn program at Cornell
- Current Nb_3Sn performance
- Advances and current work
  - Quench fields
  - Surface defects
  - Layer growth dynamics
  - Surface roughness
- Conclusion/Future outlook

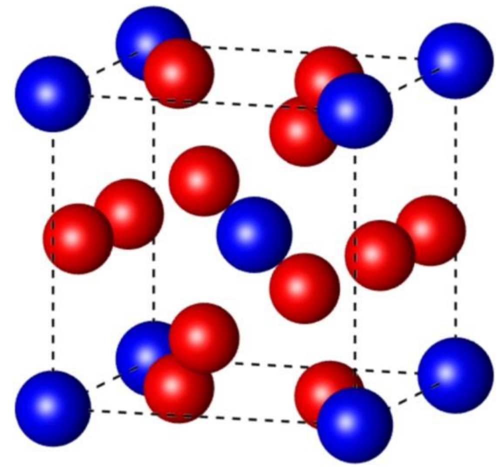
Properties of Nb_3Sn

Higher critical temperature

→ Operation at 4.2 K

Higher superheating field

→ Double the limit of niobium



Blue: tin

Red: niobium

Parameter	Niobium	Nb_3Sn
Transition temperature	**9.2 K**	**18 K**
Superheating field	**219 mT**	**425 mT**
Energy gap $\Delta/k_b T_c$	1.8	2.2
λ at T = 0 K	50 nm	111 nm
ξ at T = 0 K	22 nm	4.2 nm
GL parameter κ	2.3	26

Lower losses

Higher gradients ~90 MV/m

Cornell Nb_3Sn Program

- We have a program at Cornell for creating Nb_3Sn coatings
- Reignited Nb_3Sn interest!
- Coat Nb with 2-3 µm of Nb_3Sn
  - Vaporize tin in high temperature vacuum furnace
- Can (currently) coat:
  - samples
  - ~1.3 GHz single cells

The vapour diffusion process

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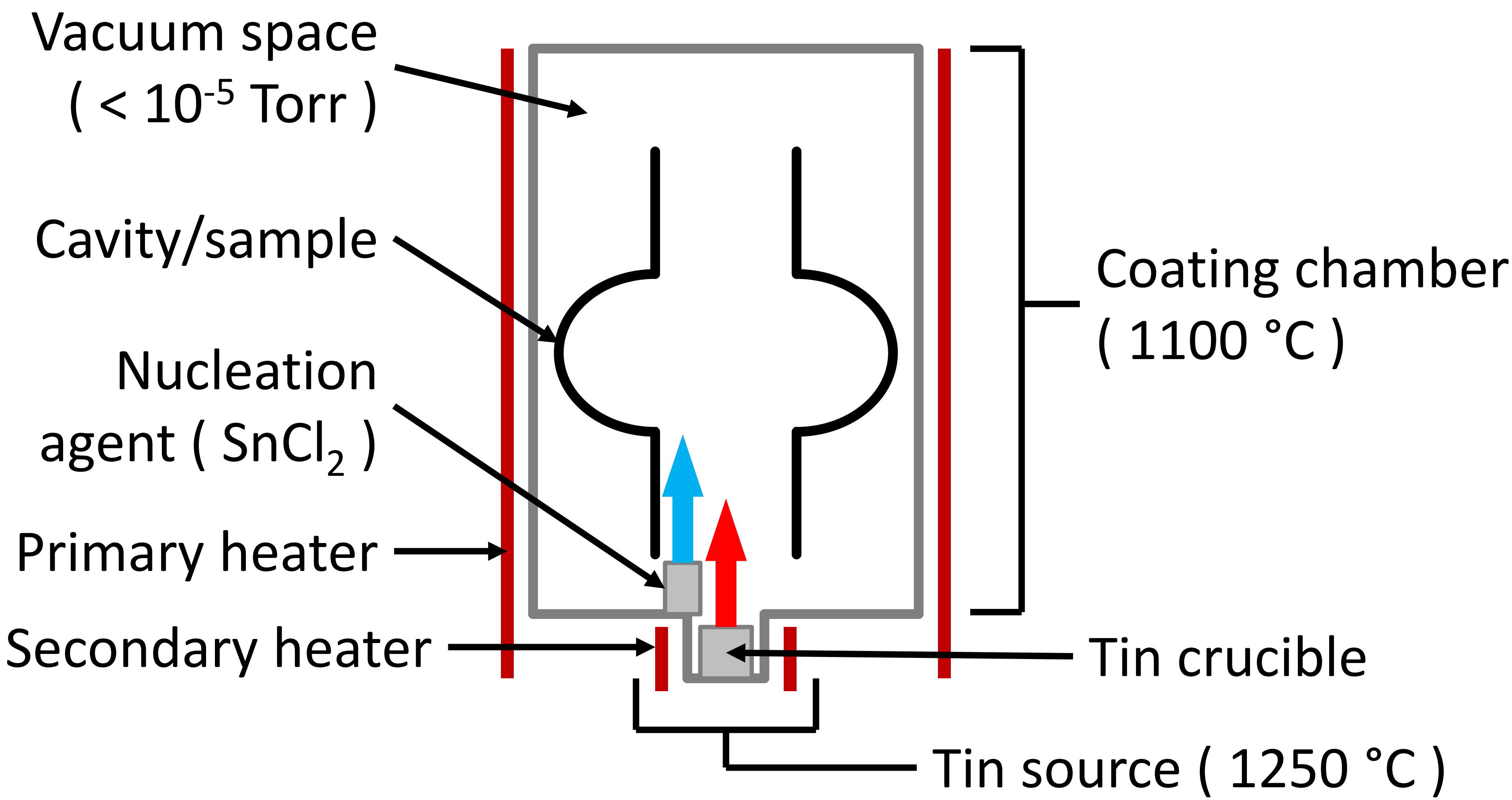
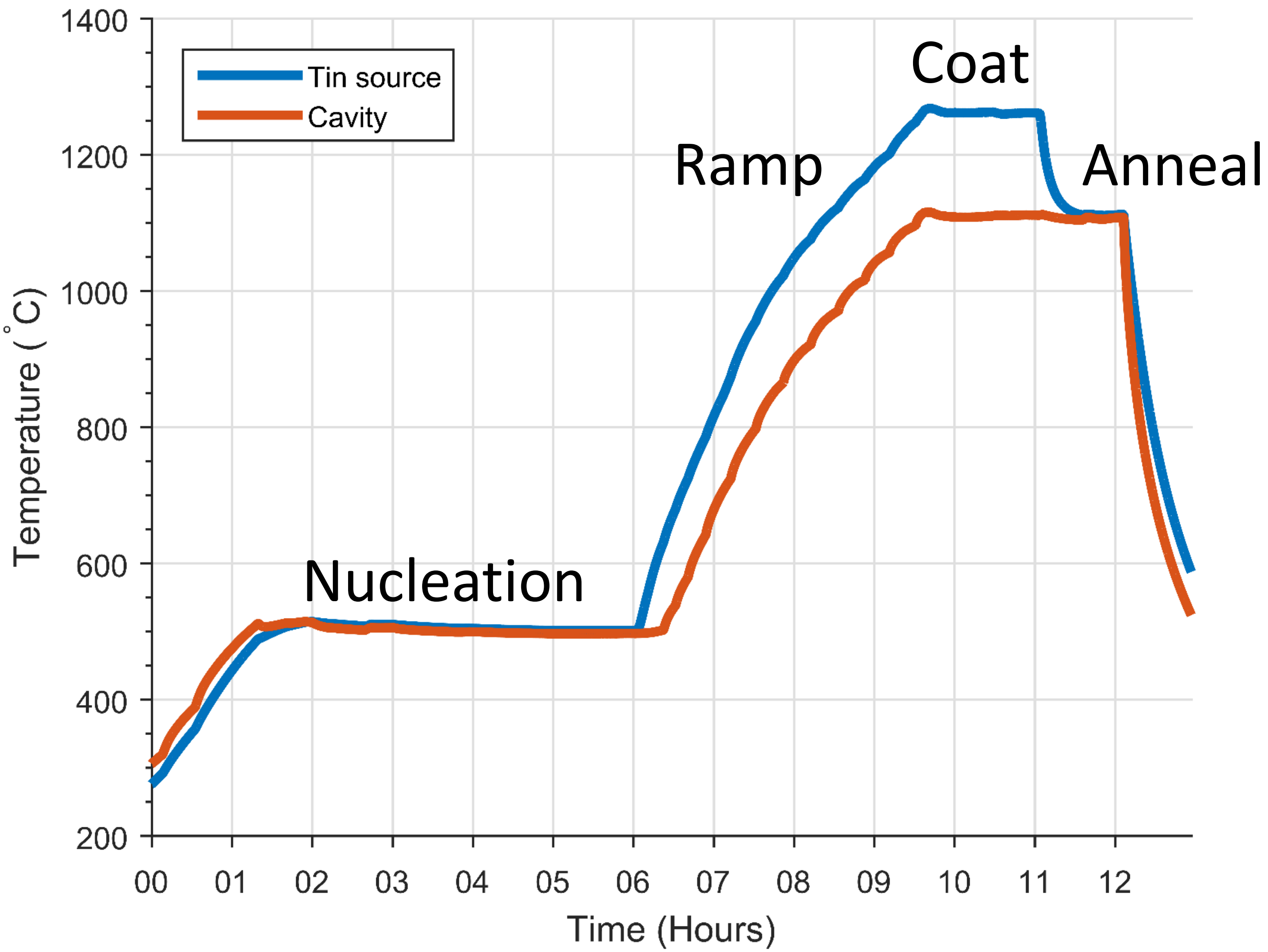
Sn vapor diffusion into Nb in high temperature vacuum furnace

– Note: separate Sn **source hot-zone**

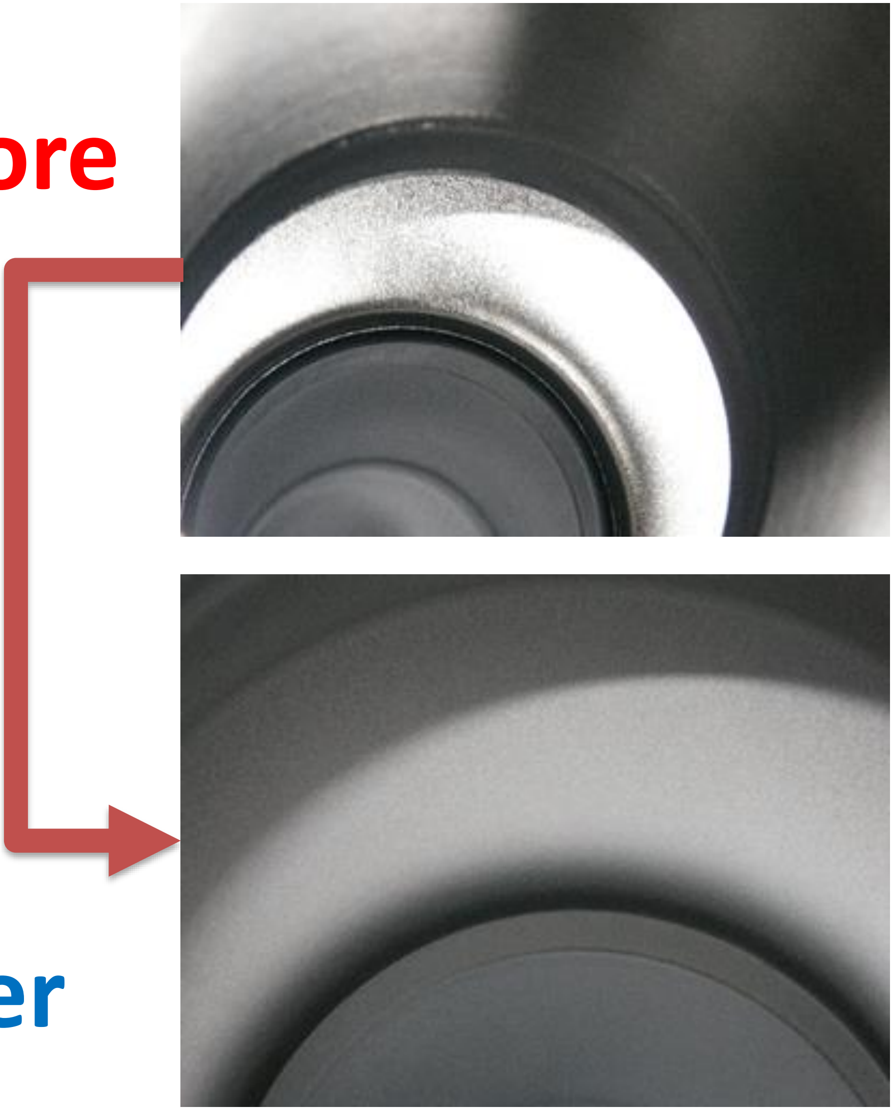


Coating Process



Before/After Coating

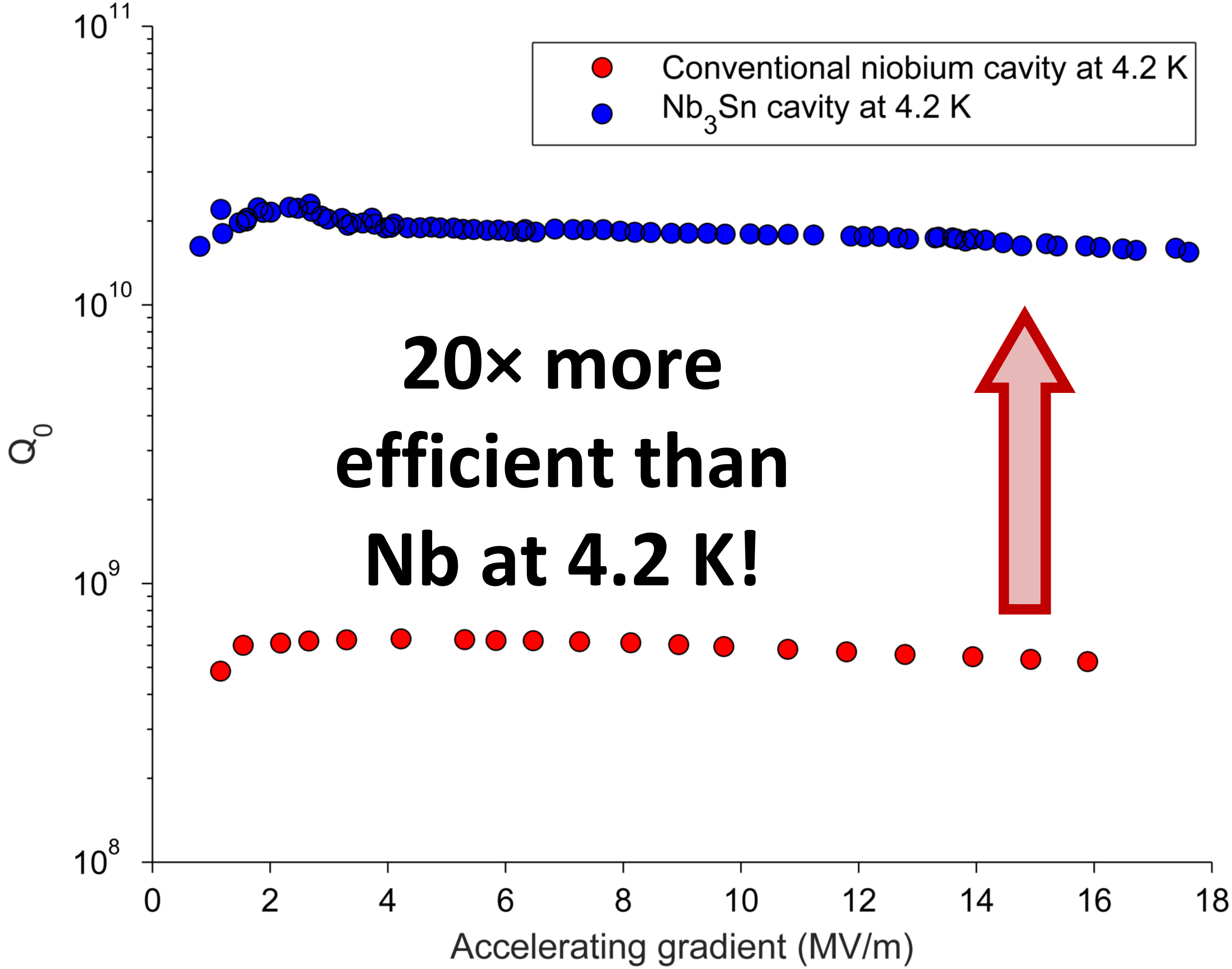
- Doesn't look that much different than before coating…



Before

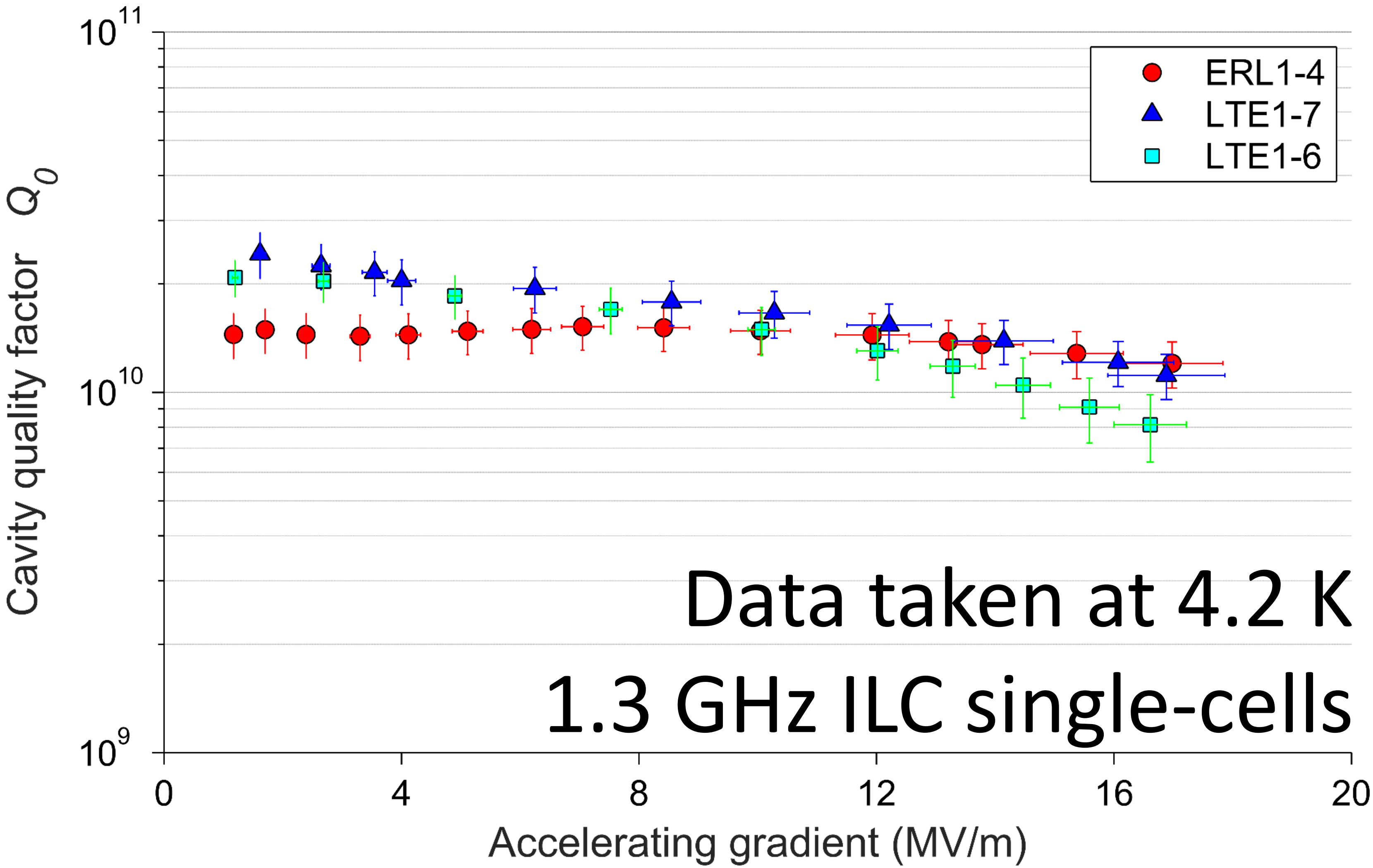
After

Comparison to niobium



Flat Q results at Cornell reignited interest in Nb_3Sn

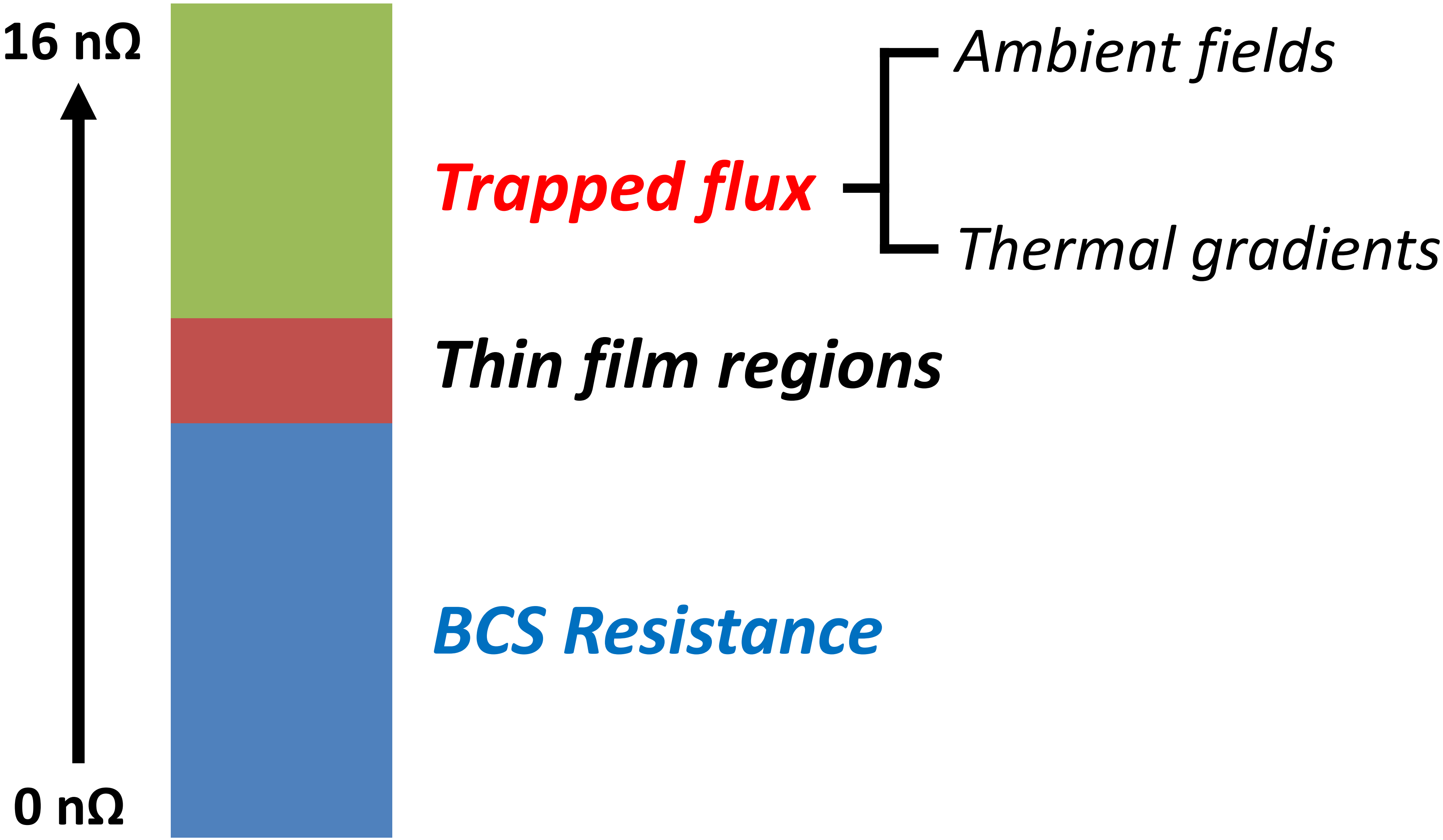
Current performance



Q could be 2-3 times higher → what is lowering it?

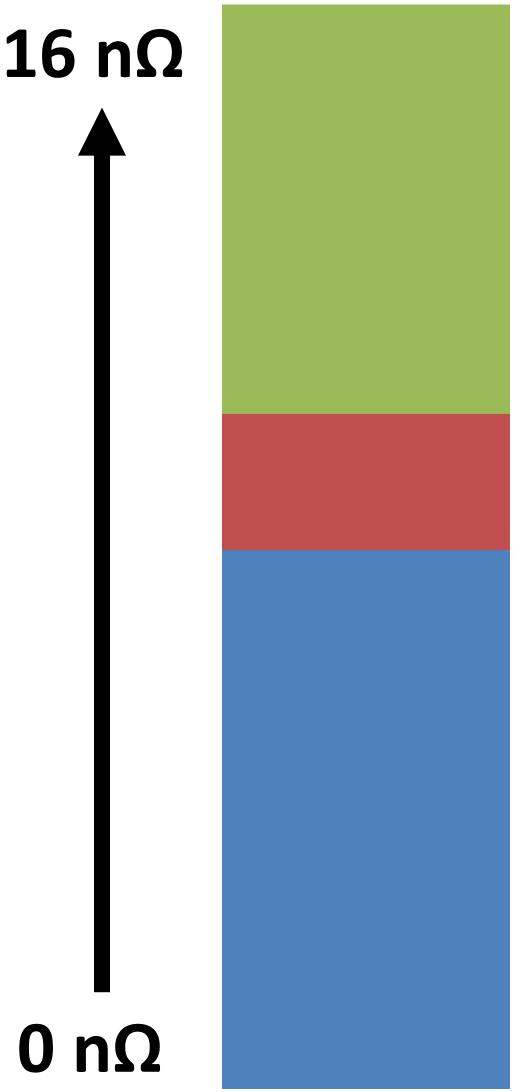
Breaking down the *Q*

Surface resistance at 4.2 K and 10 MV/m



Breaking down the *Q*

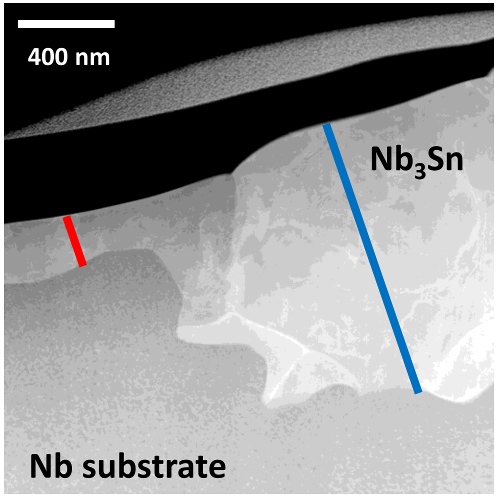
Surface resistance at 4.2 K and 10 MV/m



Trapped flux
- *Ambient fields*
- *Thermal gradients*

~~***Thin film regions***~~

BCS Resistance

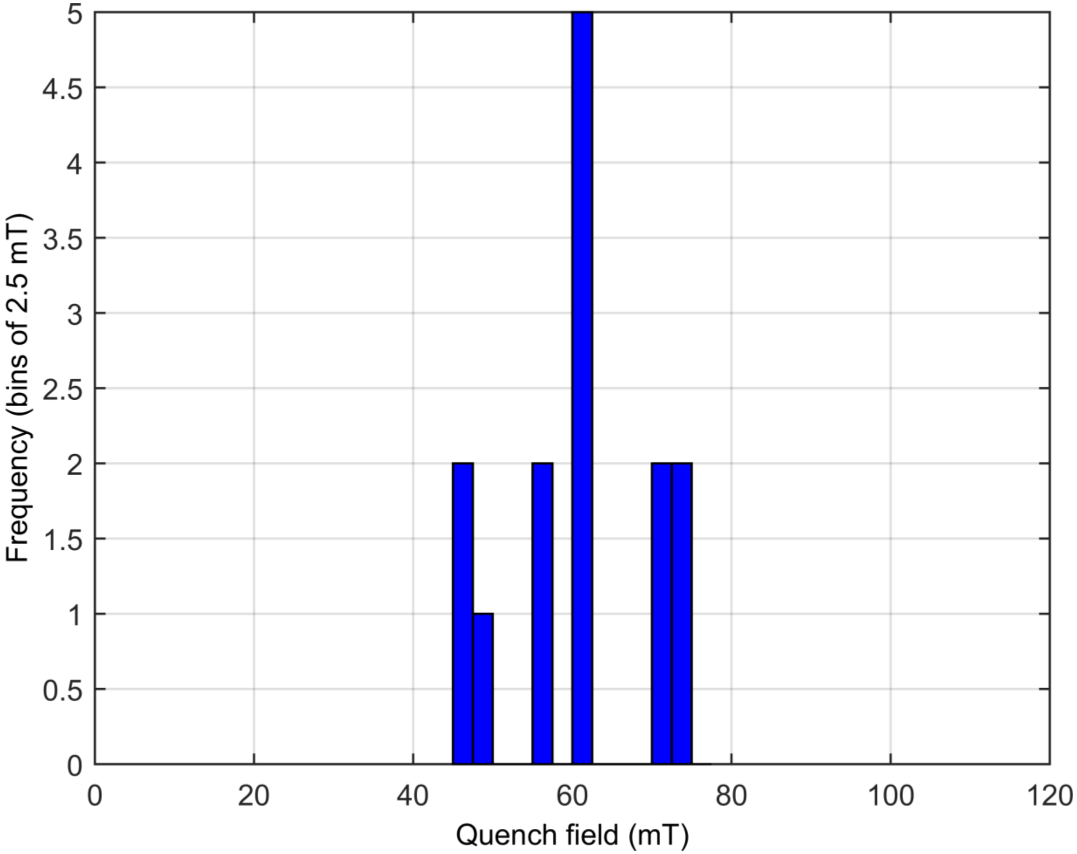


Anodizing surface before coating prevents thin regions

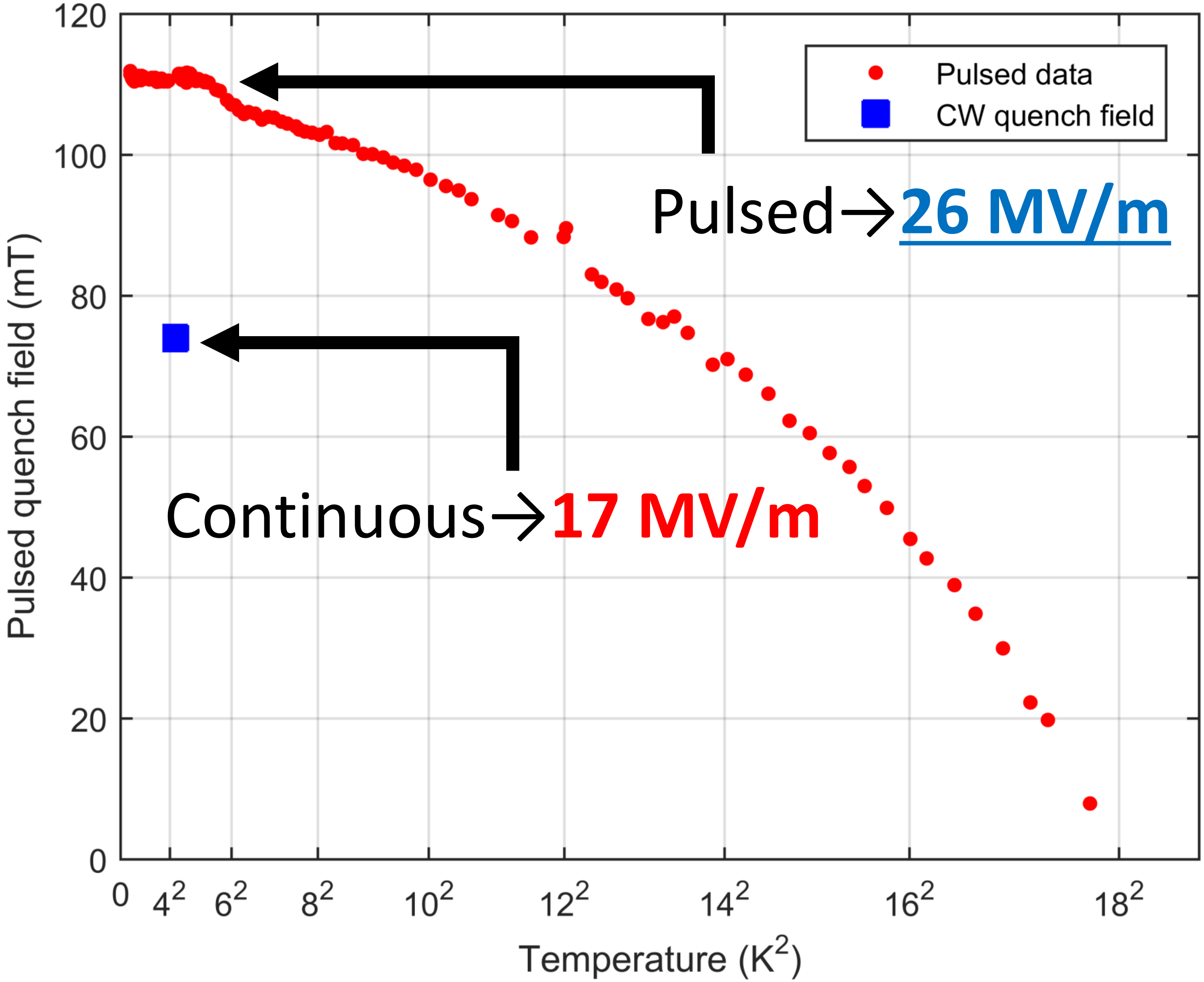
Limitations in quench field

Nb_3Sn cavities quench consistently at fields between **14 and 18 MV/m in continuous wave operation.** Only tried small changes in coating process.

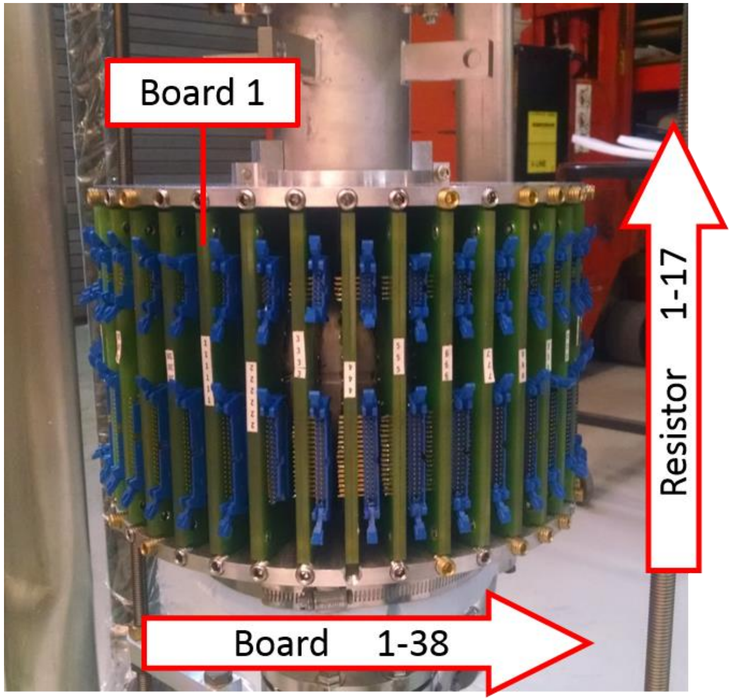
The superheating field suggests we can achieve fields up to **90 MV/m**!

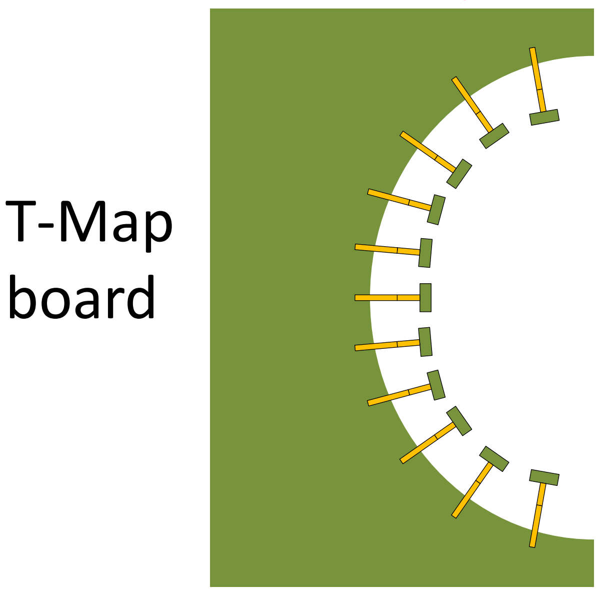


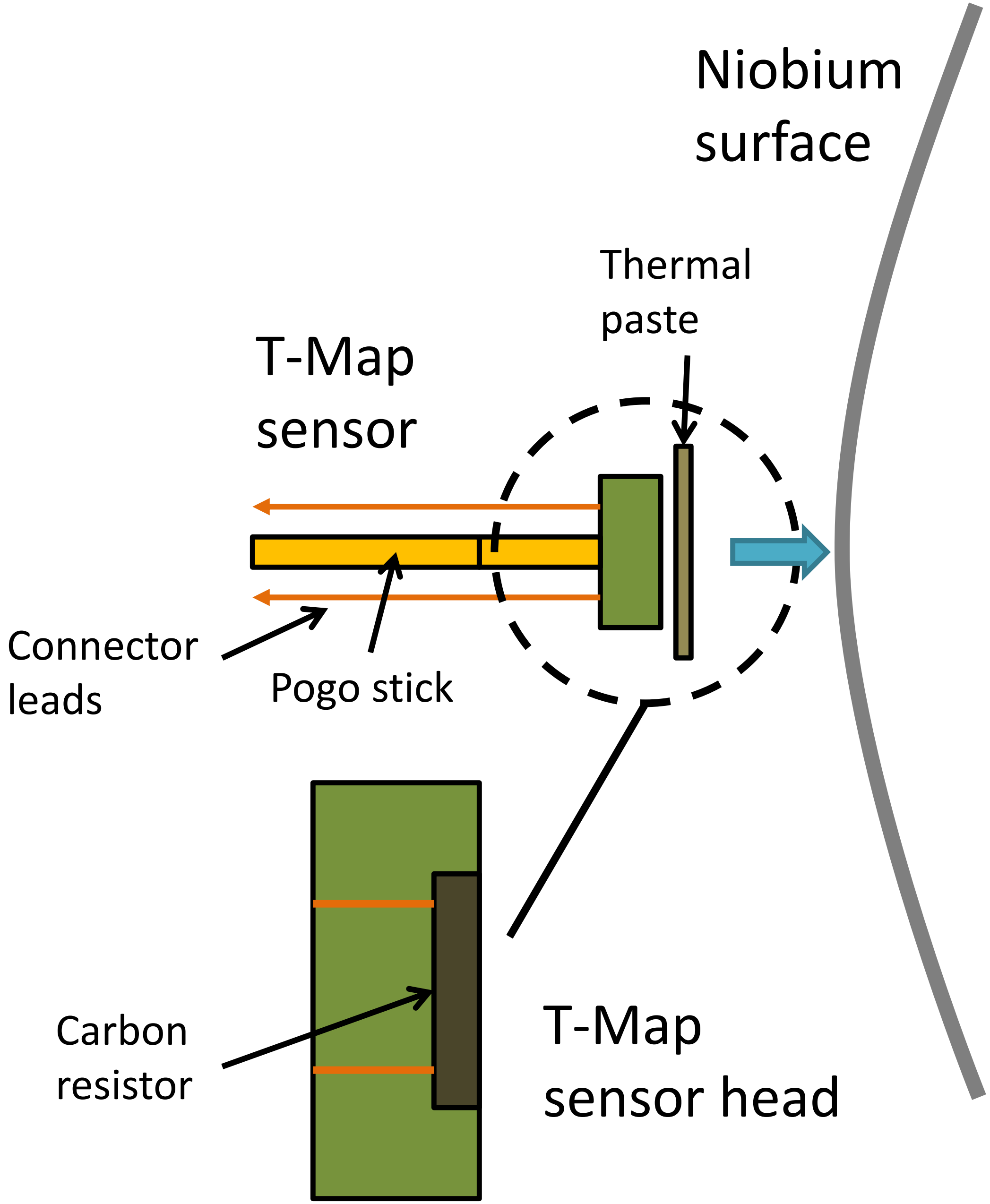
Pulsed quench field



T-Map experiment

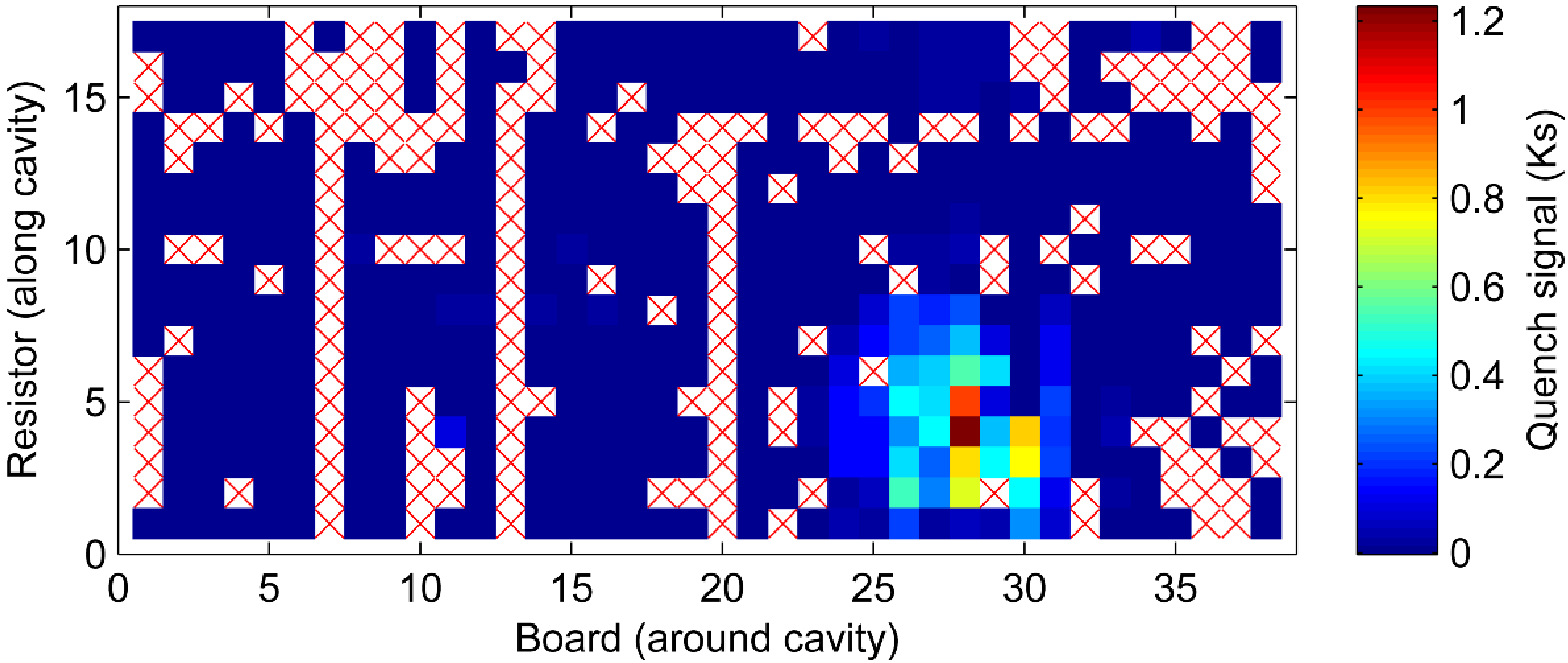






Localised quench

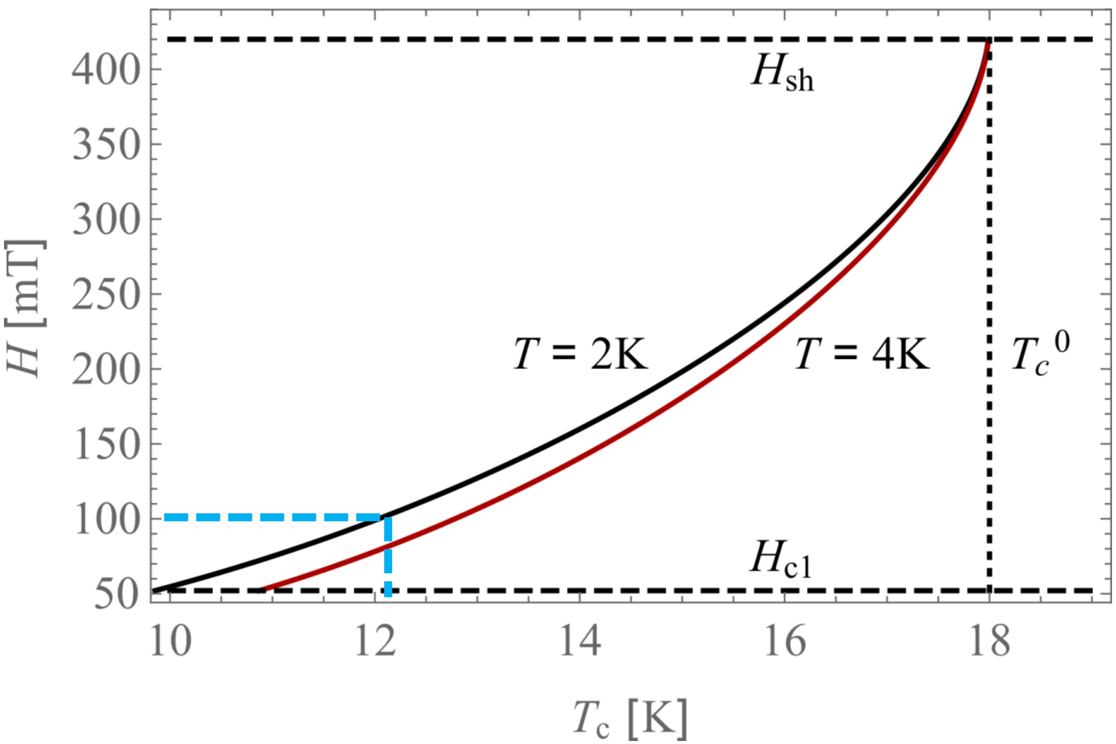
Nb_3Sn cavities are limited by a quench at a defect

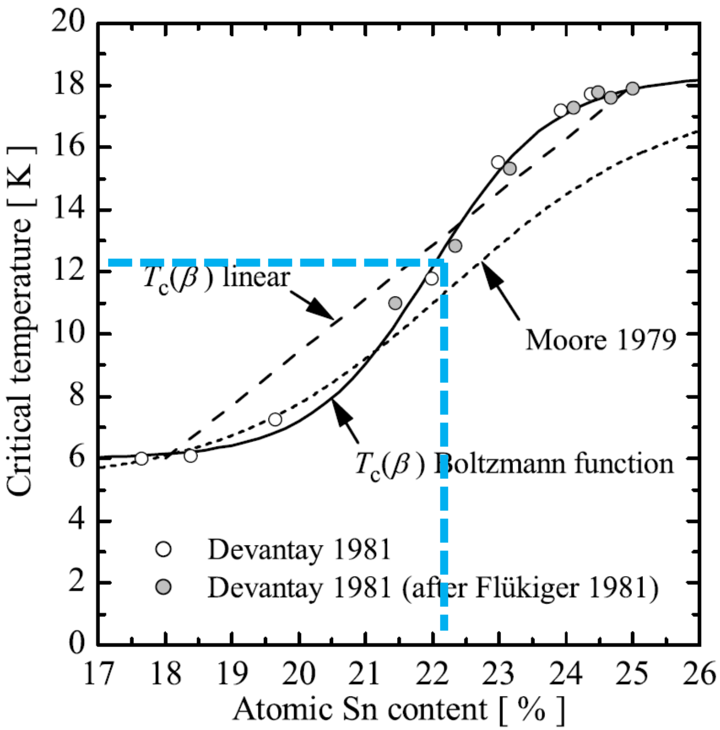


What sort of defect could be at fault?

T_c suppression

A tin depletion of only **3%** reduces H_{sh} by **75%**





Flux entry could occur at **tin-depleted surface defects**

Tin-depletion in grains

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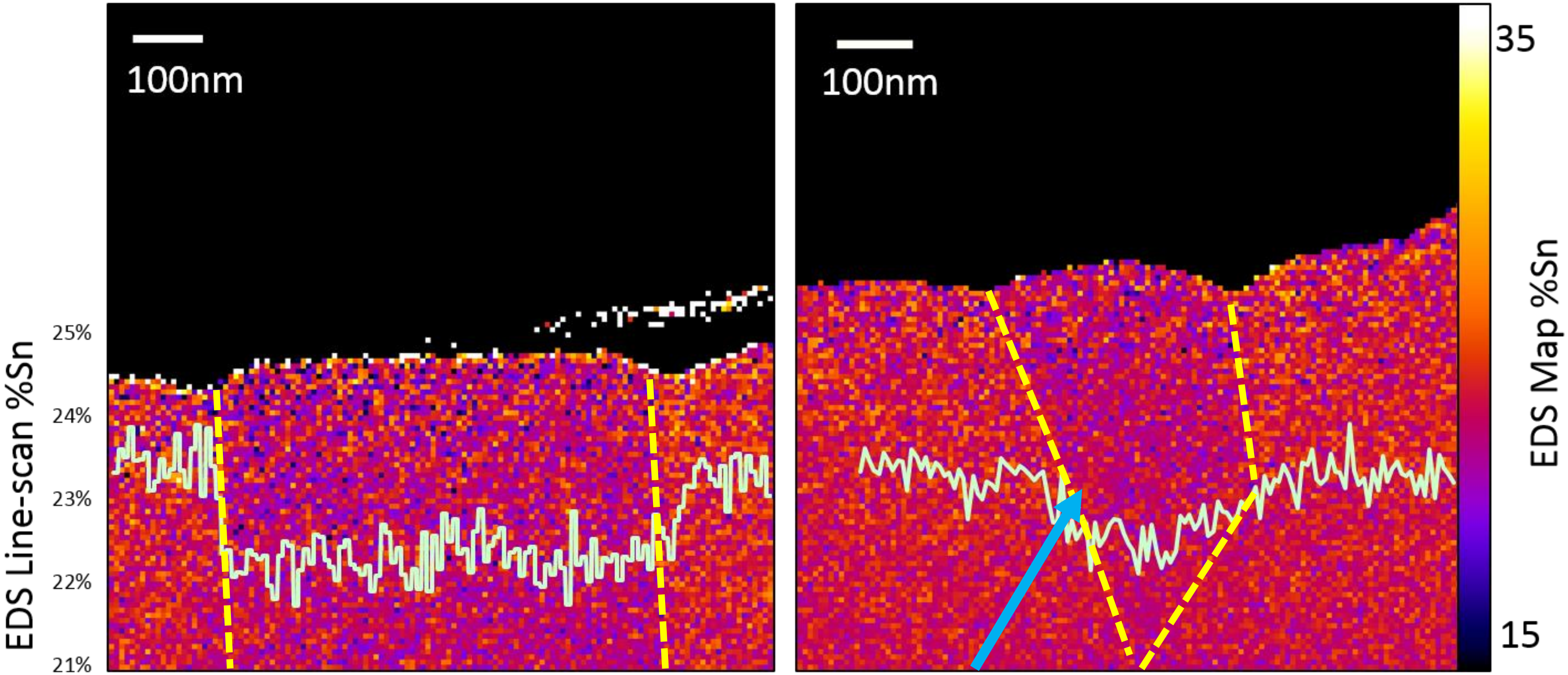
Cross-section of the Nb_3Sn RF surface

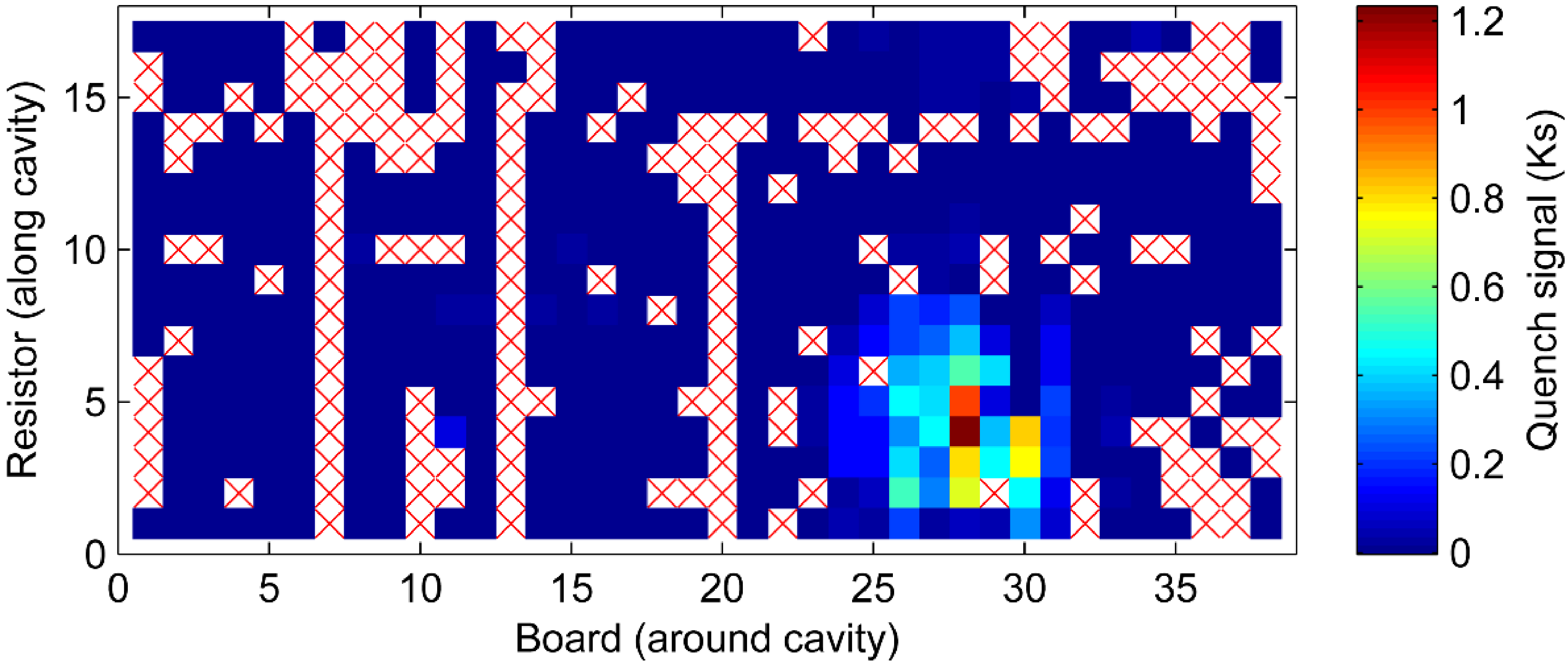


Grain boundary

Only about 1% Sn depletion seen so far. Matter of Statistics?

Localised quench

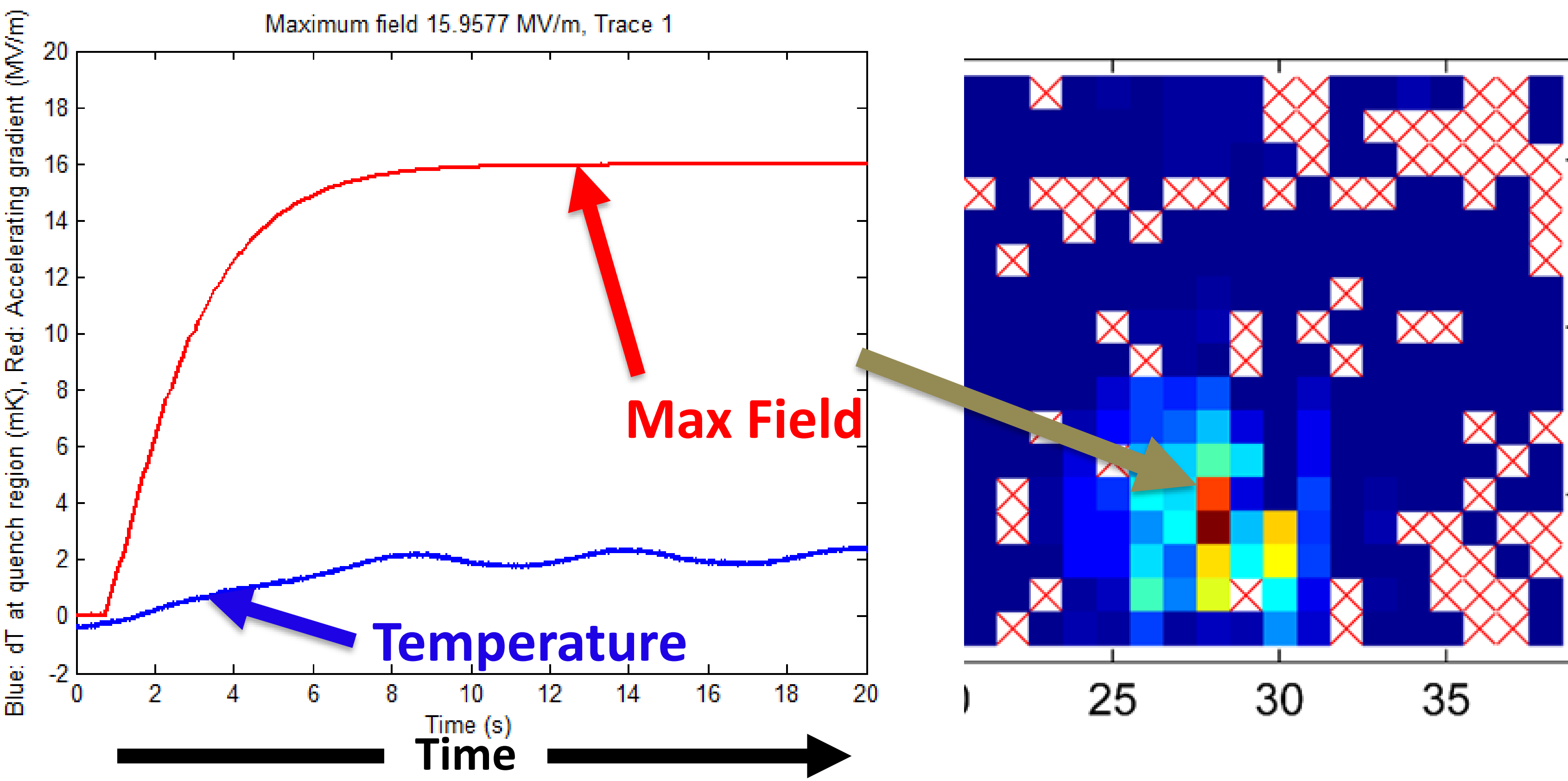
Nb_3Sn cavities are limited by a quench at a defect



What happens, thermally, right at the defect?

Near quench behavior

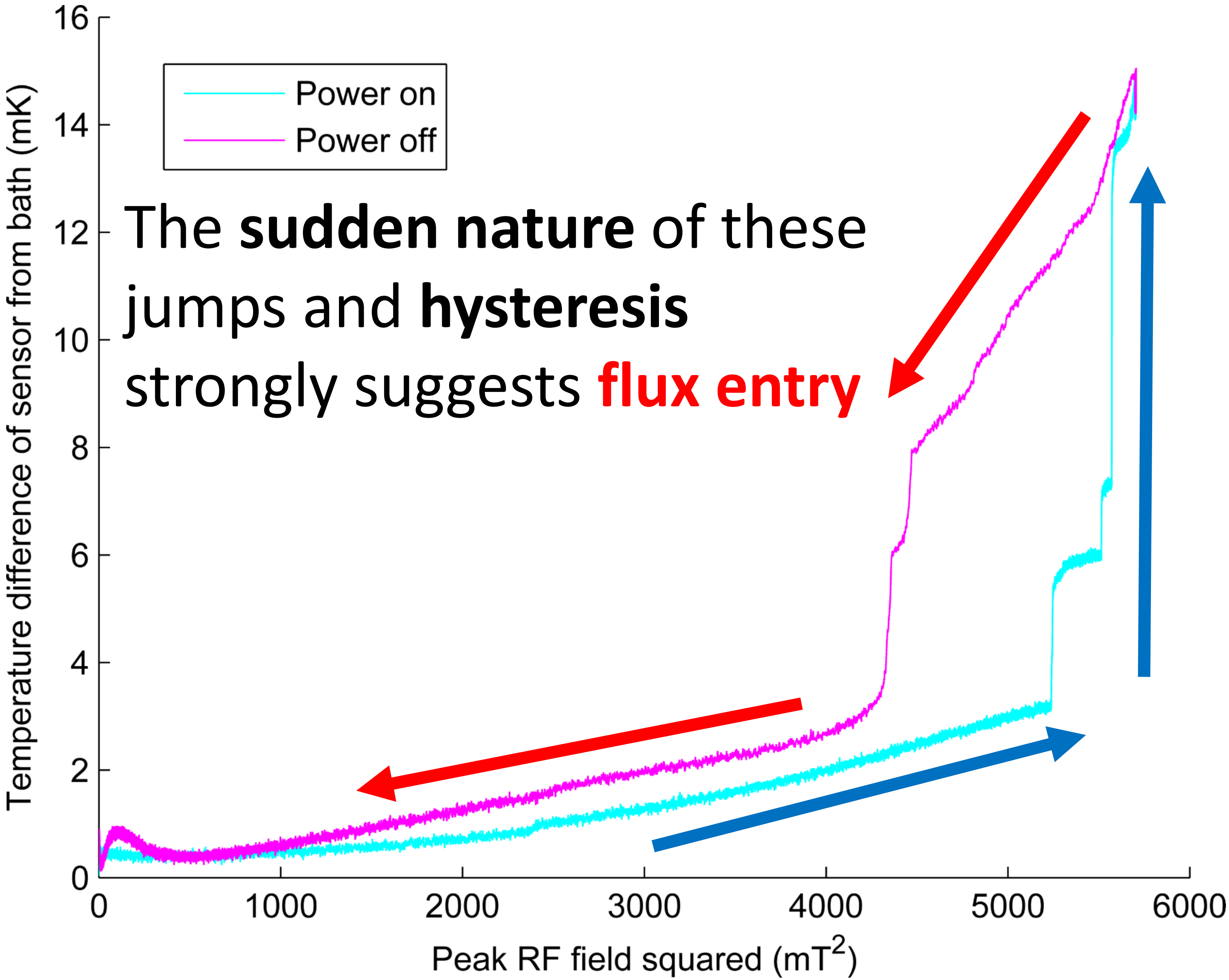
- Measure temperature of sensor near the quench point as field is increased



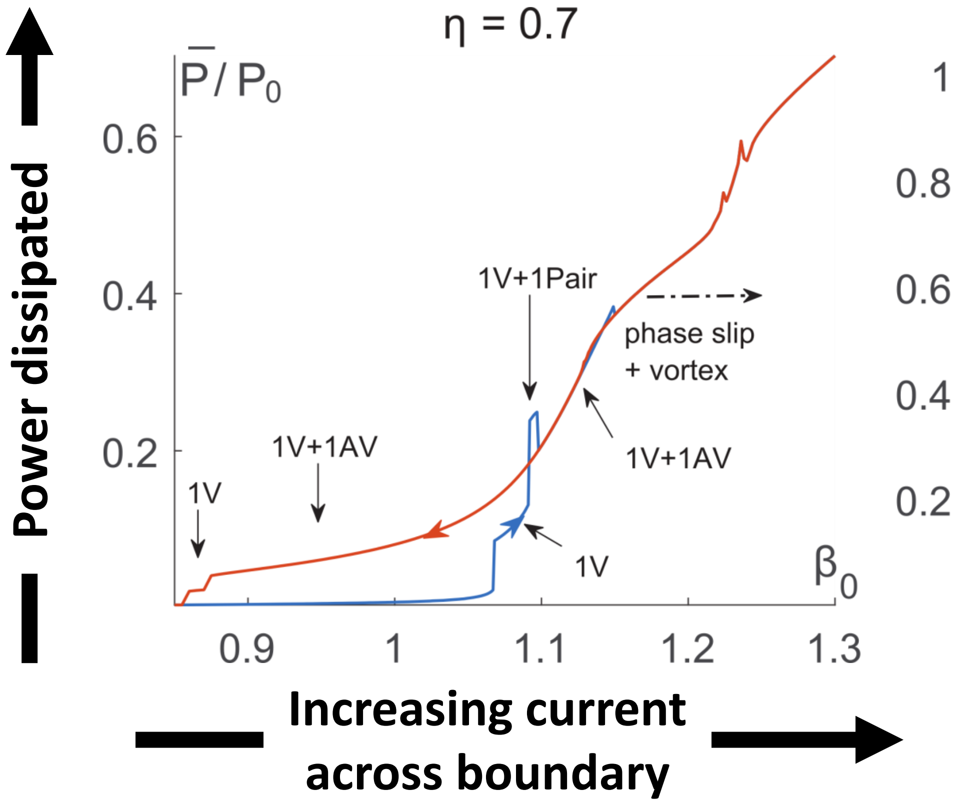
- Sudden jumps in temperature

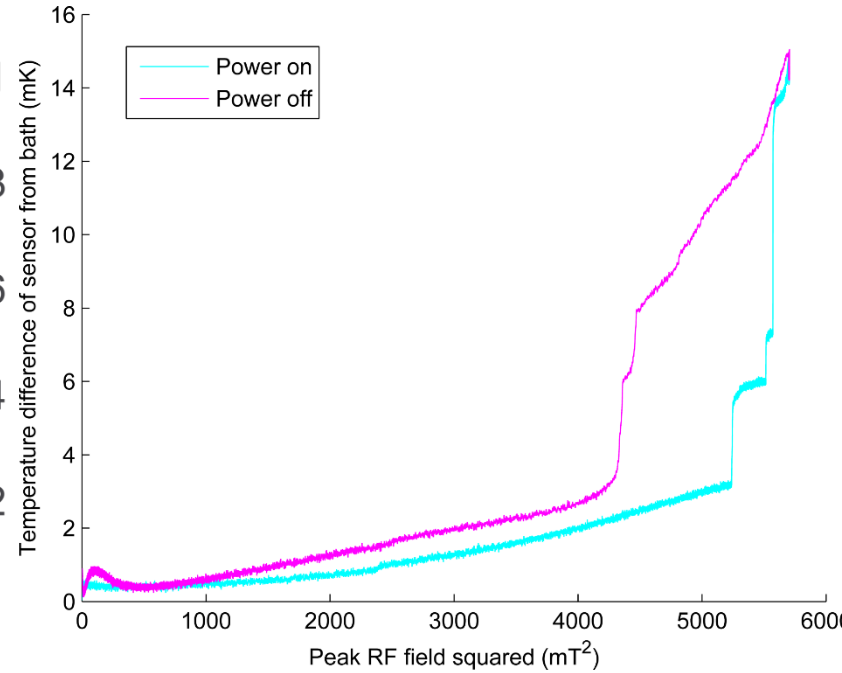
Near quench behaviour

The **sudden nature** of these jumps and **hysteresis** strongly suggests **flux entry**

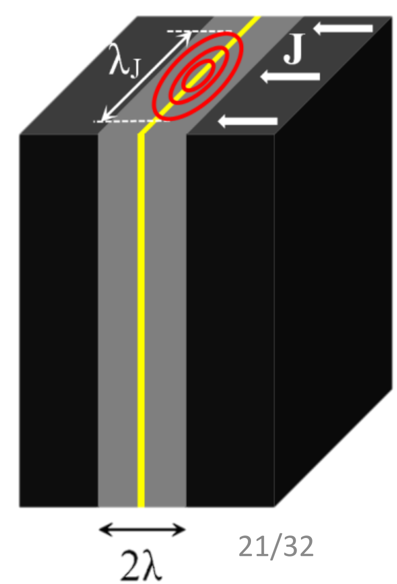


Grain boundary flux penetration





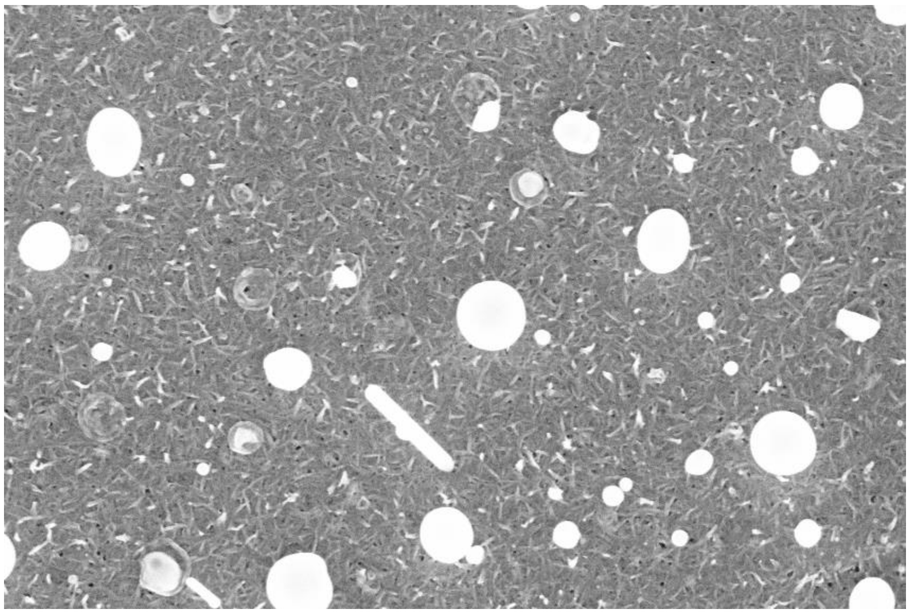
Ahmad Sheikhzada and **Alex Gurevich**
Physical Review B **95**, 214507 (2017)
arXiv:1702.02843

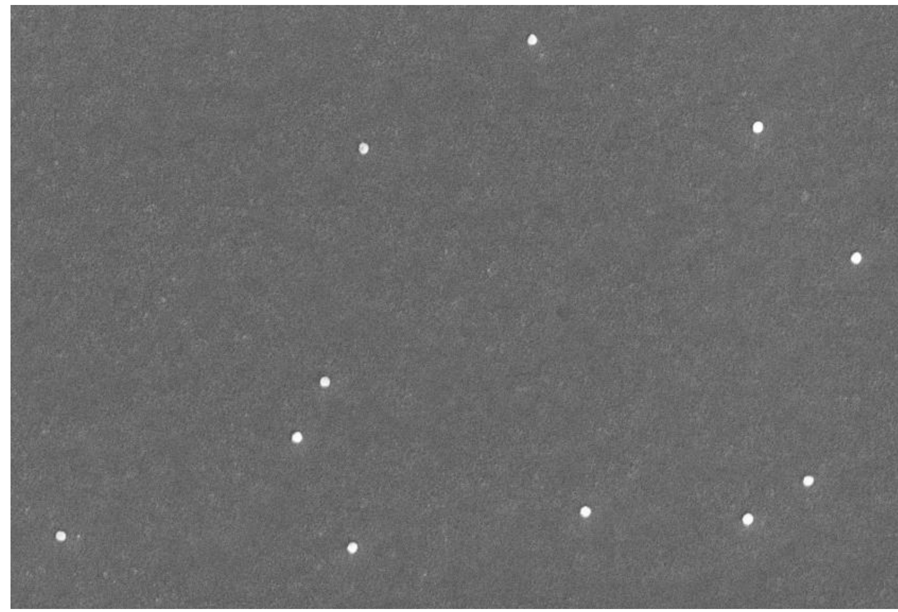


Layer growth during ramp

Pre-anodised

Not anodised



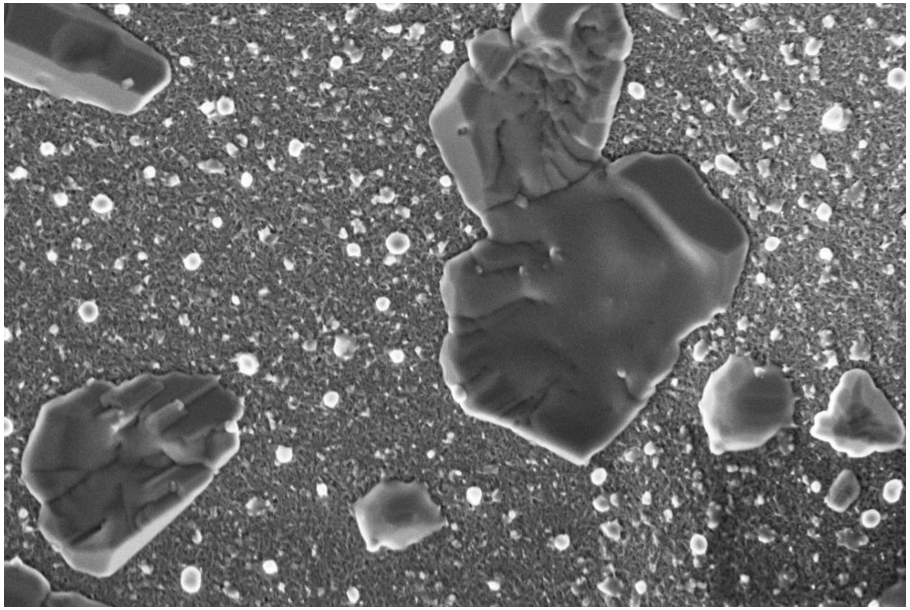


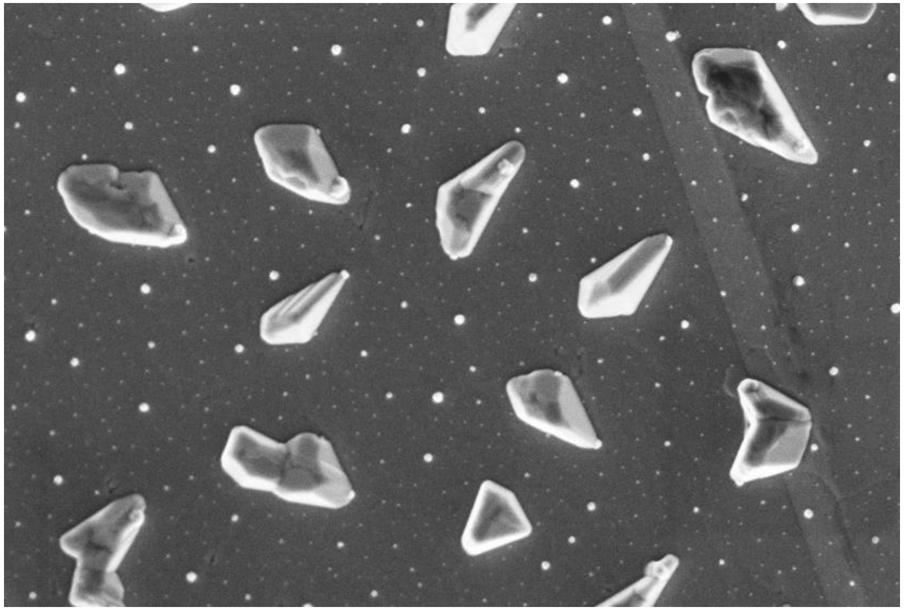
2 µm

500°C

Layer growth during ramp

Pre-anodised | **Not anodised**



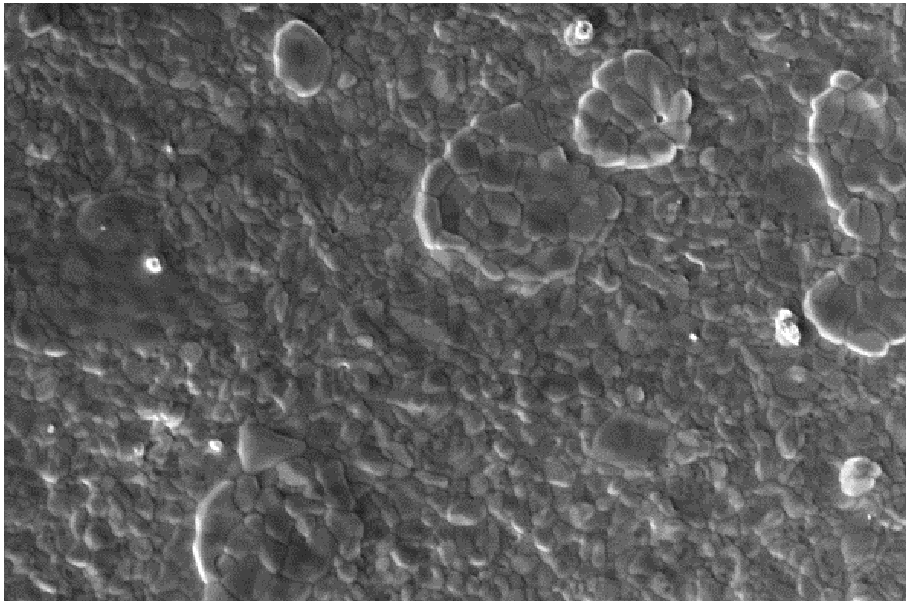


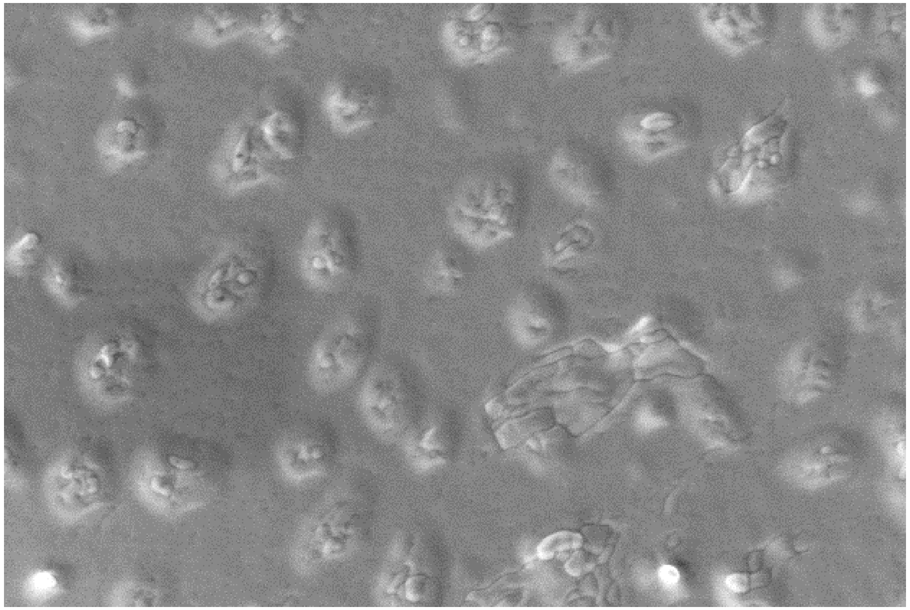
2 µm

800°C

Layer growth during ramp

Pre-anodised **Not anodised**

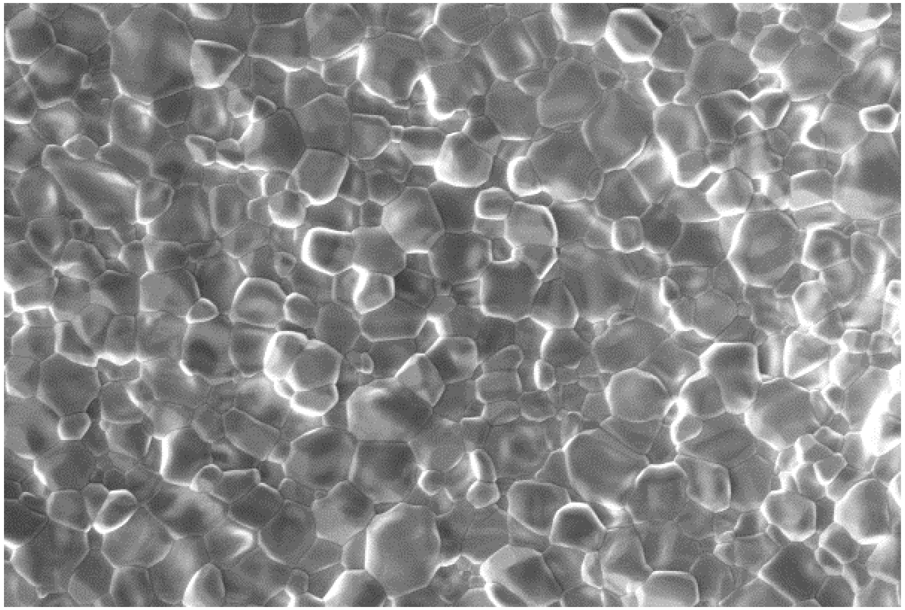


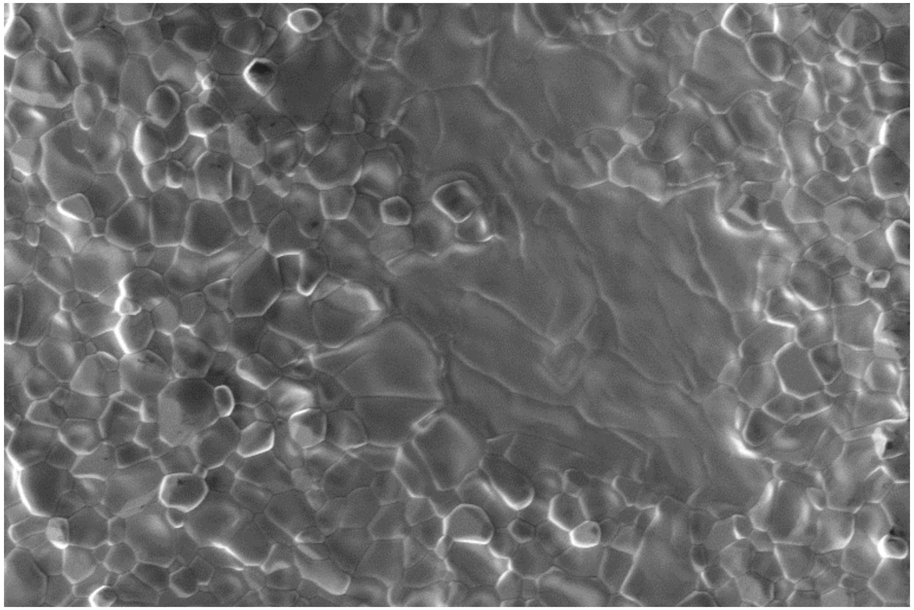


2 µm **950°C**

Layer growth during ramp

Pre-anodised | **Not anodised**

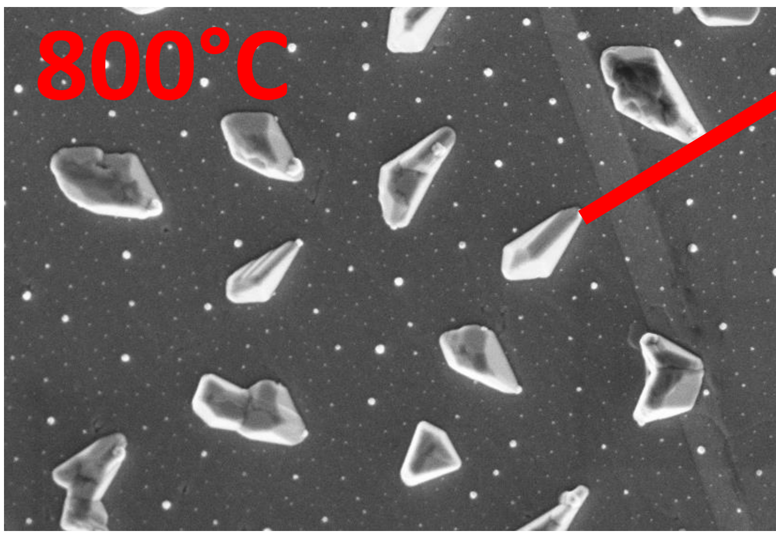


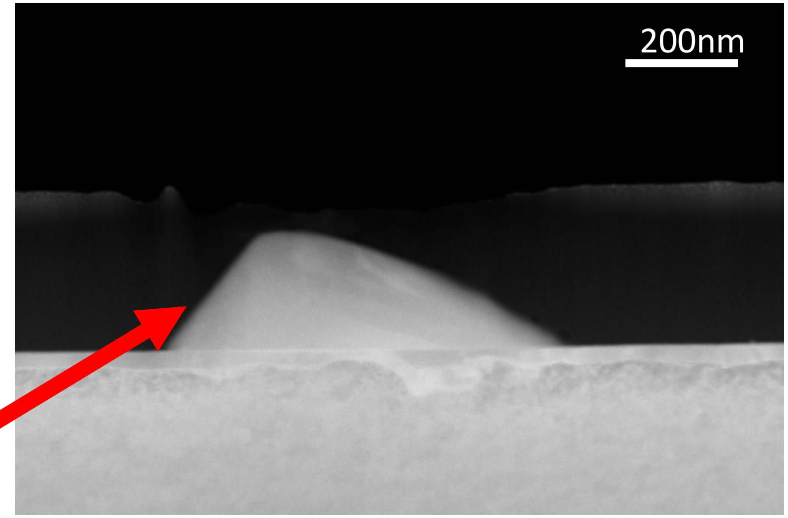


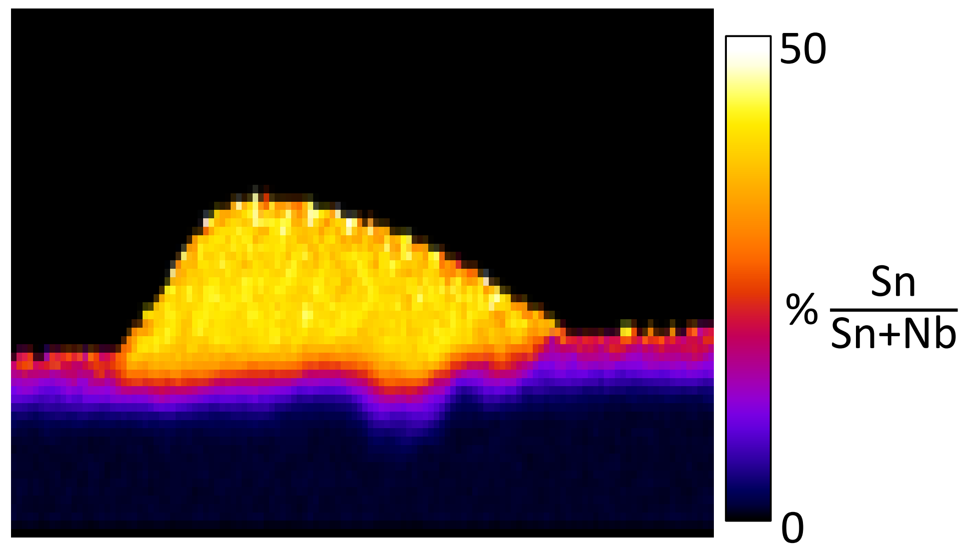
2 µm ■ **1120°C**

Layer Growth – Cross-sections

- What is the chemical composition?
  - FIB lift-outs + EDS

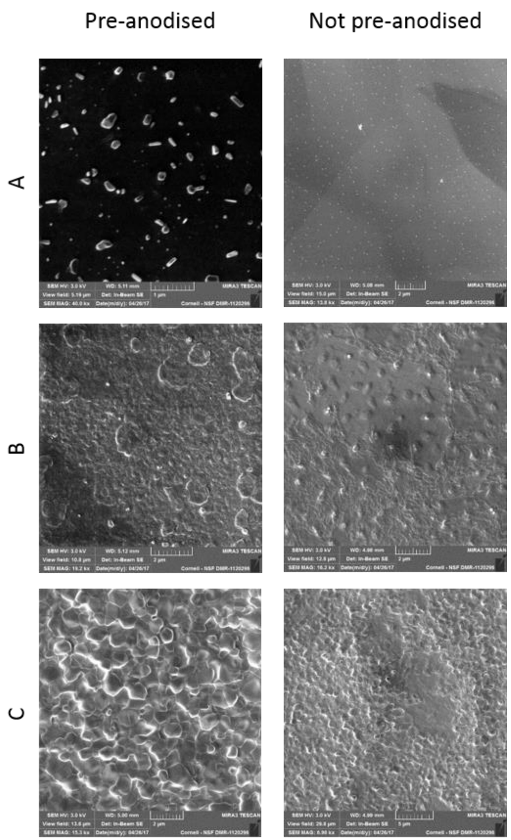






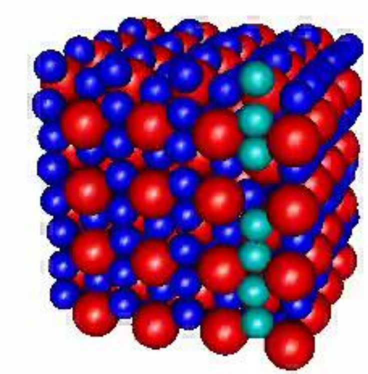
Understanding layer growth

Surface analysis of sample coupons

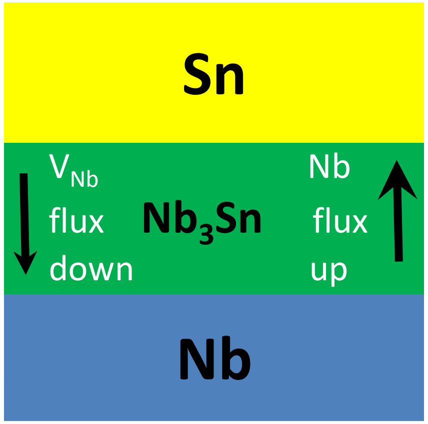


Simulations with Joint Density Functional Theory

JDFTx.org
Prof. Tomas Arias
Cornell University



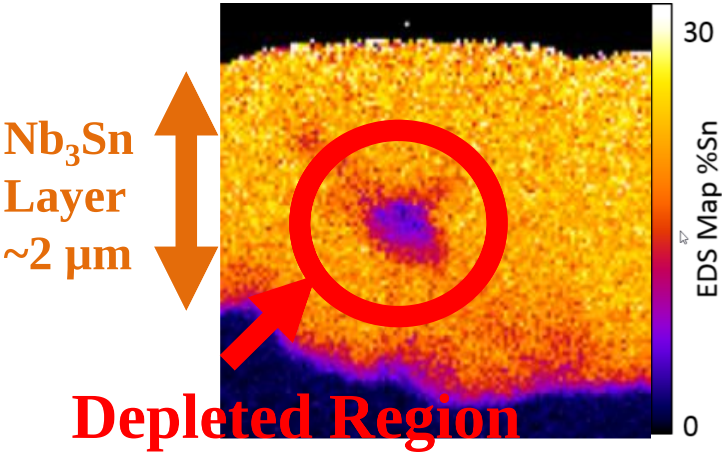
[0.1 ns runtime]



Growth simulations tell us **which dials to turn** to affect the properties of the layer's features

Layer Growth – Improvement

- Sn depleted regions form in Nb_3Sn layer

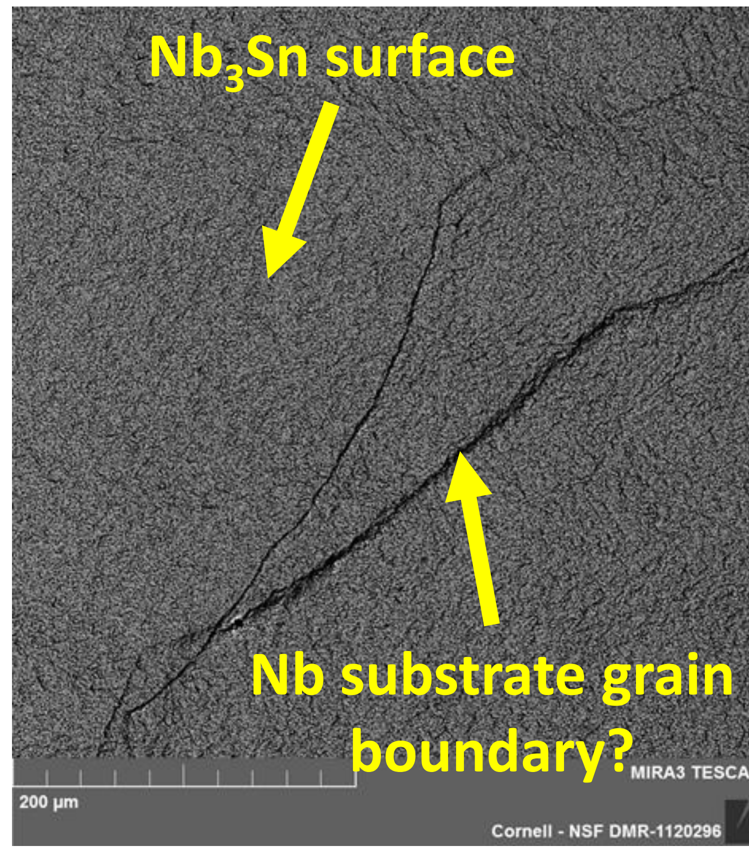


Nb_3Sn EDS Cross-section

- Theory: form due to running out of Sn during temperature ramp
  - Could prevent by adding more nucleation agent
- In process of testing!

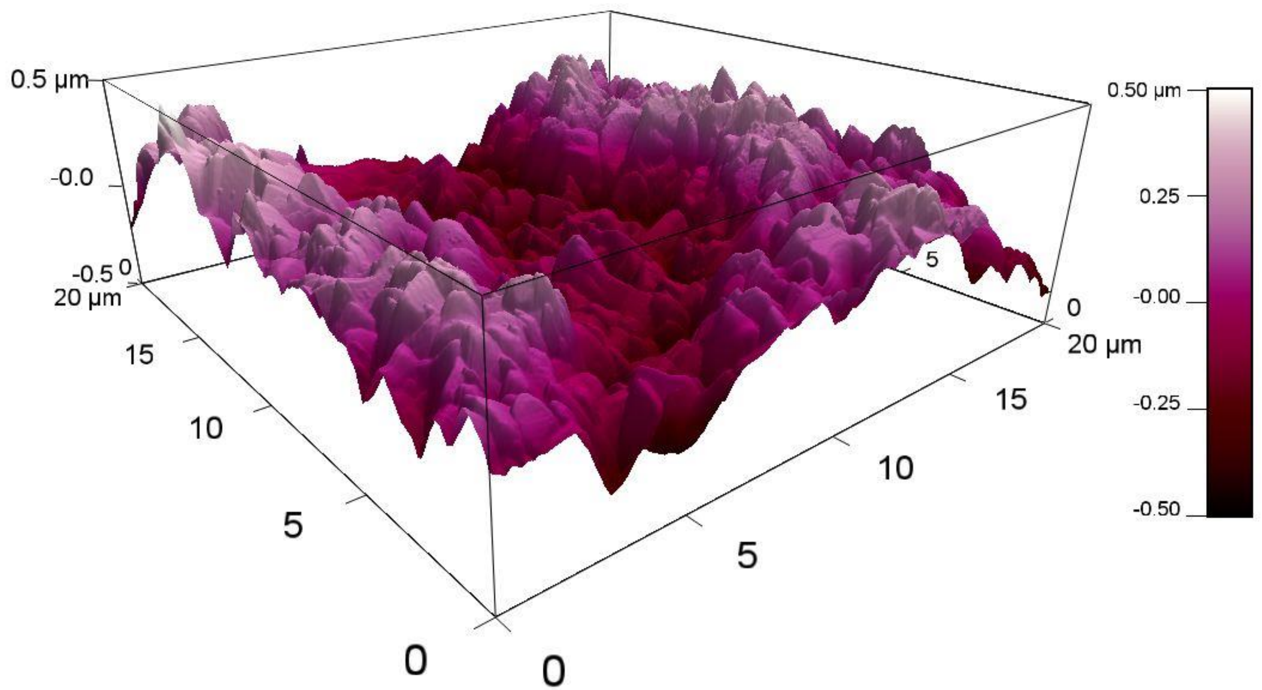
Microscopy of quench site?

- We cut out this region and examined it with microscopy
- Nothing suspicious except jump
  - Rough Surface



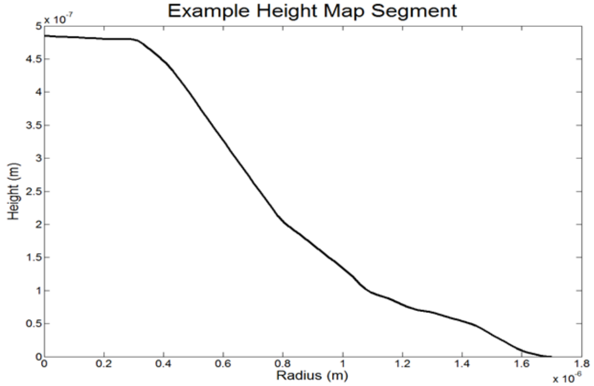
Surface Roughness

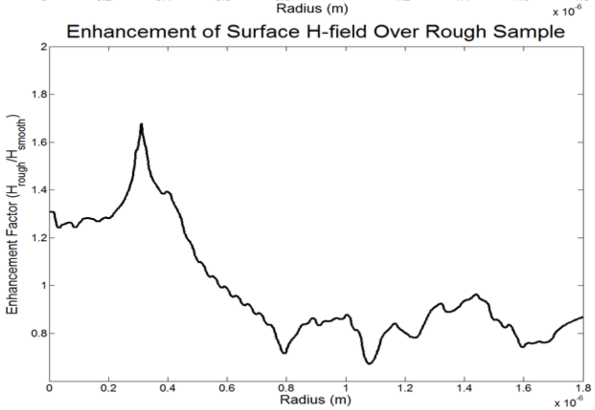
- Nb_3Sn we create is rougher than electropolished Nb
  - ~1 µm peak to peak
- This causes large enhancement of the surface magnetic field

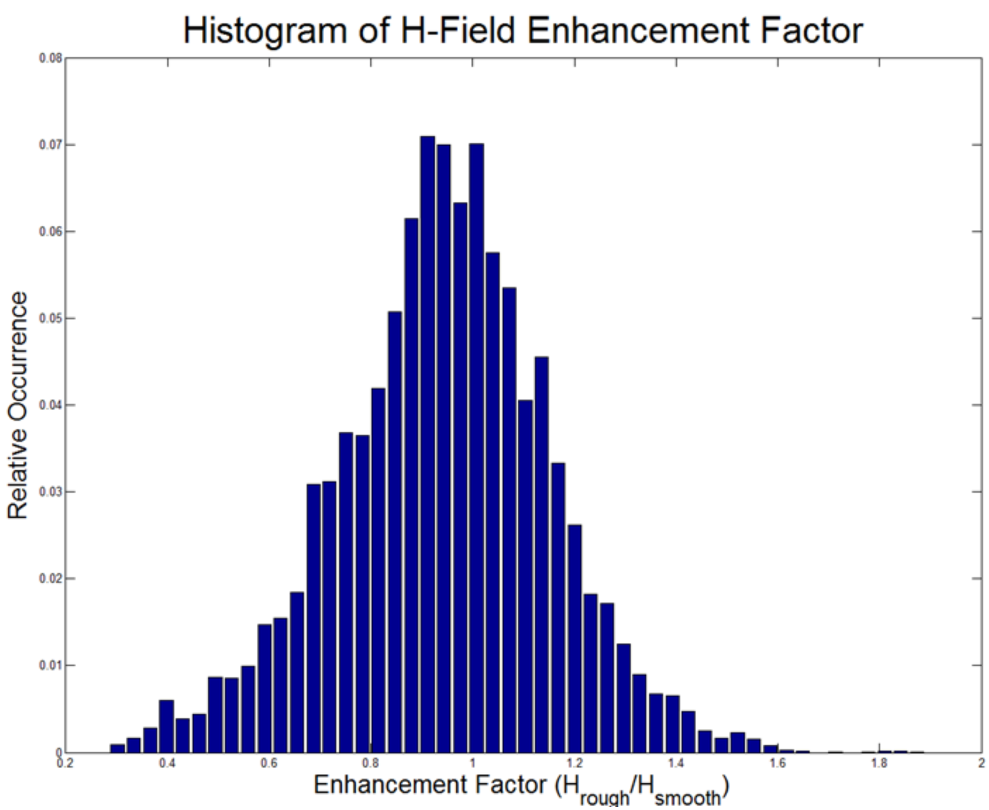


Field Enhancement

- 1% of the surface has **surface fields at least 50% higher** than for a flat surface
  - Limits maximum quench fields 60 MV/m for perfect surface
  - Lowers field before defects become an issue

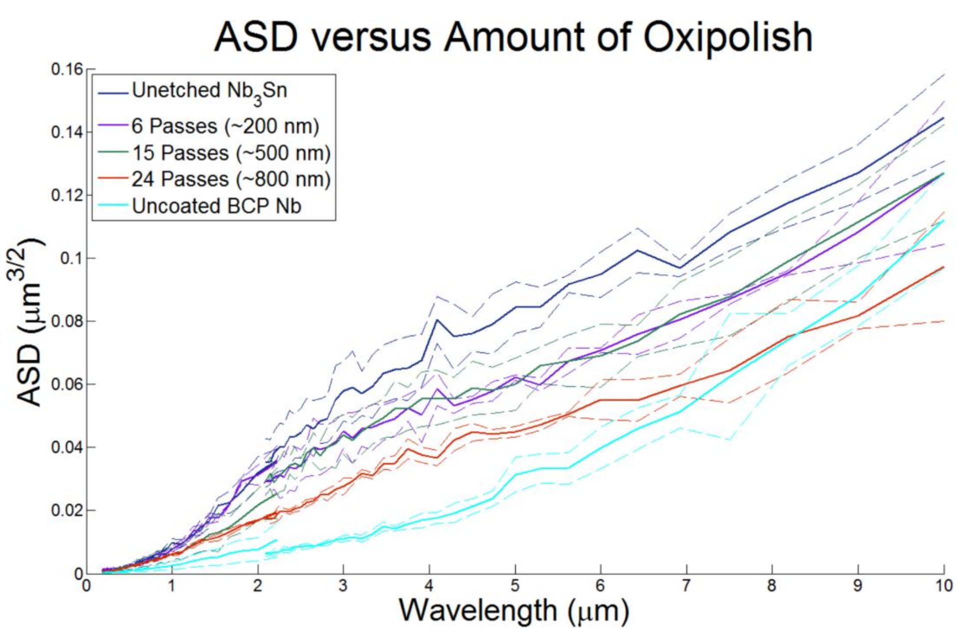


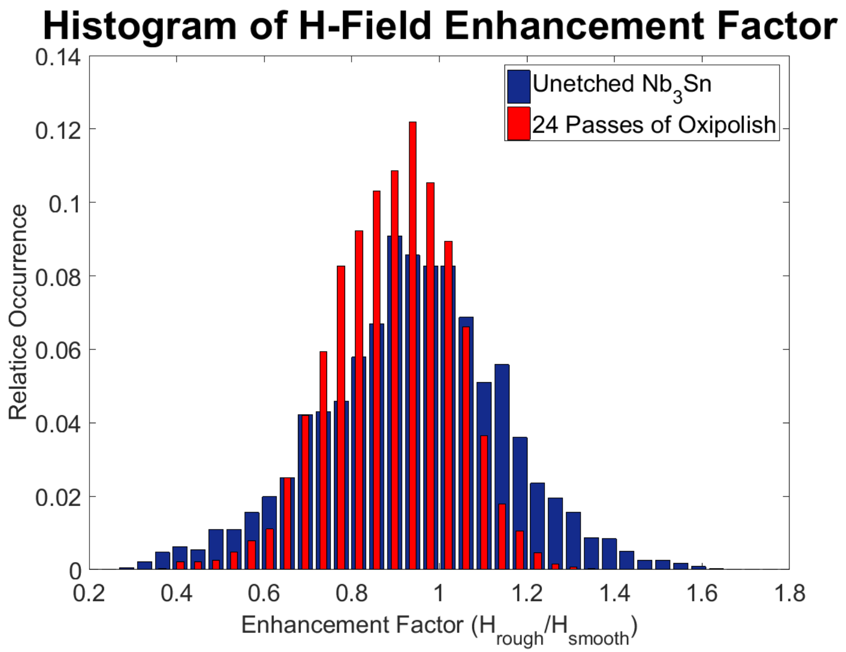




Surface Treatment

- Developing surface treatments to reduce surface roughness
- Early results found oxypolishing could **half roughness and surface field enhancement** while removing < 1 μm





Conclusions

- Can reach **$2\cdot10^{10}$ at 4.2 K**
- Achieve 16-17 MV/m in continuous mode
- Achieve **26 MV/m** in pulsed mode

- Have identified main sources of performance limitations
  - Quality Factor
    - Trapped external flux and thermal gradients
  - Quench Fields
    - Surface roughness
    - Vortex entry possibly at grain boundaries

Looking Forward

- Reducing surface roughness may gain us 50% improvement in quench fields
  - Continuous: **17 MV/m** → **25 MV/m**
  - Pulsed: **26 MV/m** → **39 MV/m**

- If we can fix grain boundaries
  - Continuous & pulsed: → **90 MV/m**?

- Improving in magnetic shielding and cooldown could **~1.5x Q** at 4.2 K

Acknowledgements

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