Nb_3Sn Cavities: Material Characterisation and Coating Process Optimisation

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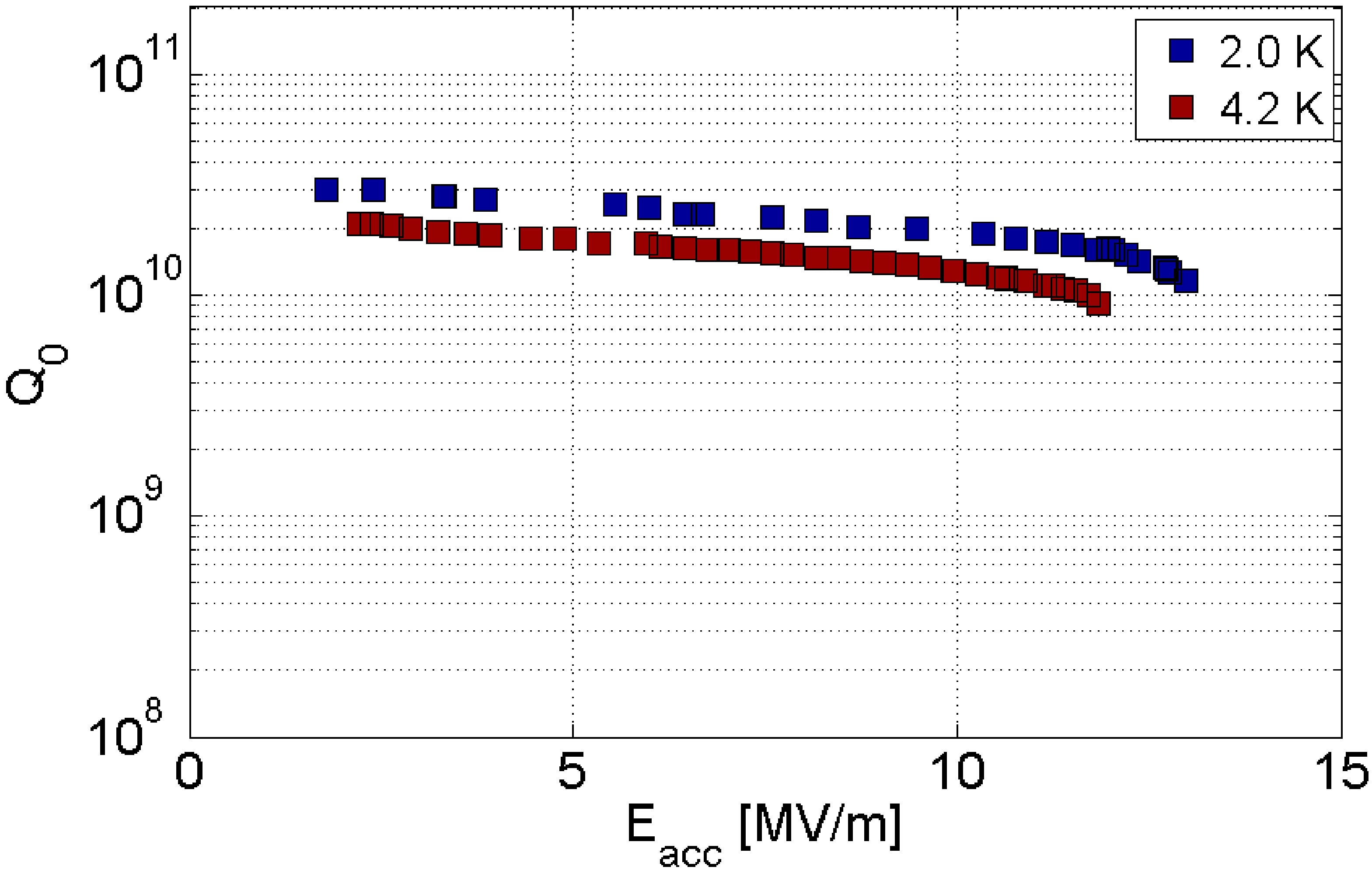
The promise of Nb_3Sn

- An intermetallic alloy of niobium and tin with a T_c of 18 K
- BCS resistance at 4.2 K is low enough to operate at cavity without pumping on the cryostat
- Superheating field of 400 mT corresponds to a peak theoretical field of 90 MV/m in ILC cavities

CLASSE facilities are operated by the Cornell Laboratory for Elementary Particle Physics (LEPP) and the Cornell High Energy Synchrotron Source (CHESS) with major support from the National Science Foundation.

This time two years ago



Data from "Understanding and Overcoming Limitation Mechanisms in Nb3Sn superconducting Cavities", Sam Posen, Cornell University, 2015

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Talk outline

- Altering the coating procedure
  - What happens to the RF performance?
- Characterising Cornell's Nb_3Sn
  - What kind of properties does it have?
- Practical use of Nb_3Sn
  - What performance can be expected for state-of-the-art Nb_3Sn cavities in a cryomodule?

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Altering the coating process

What changes?

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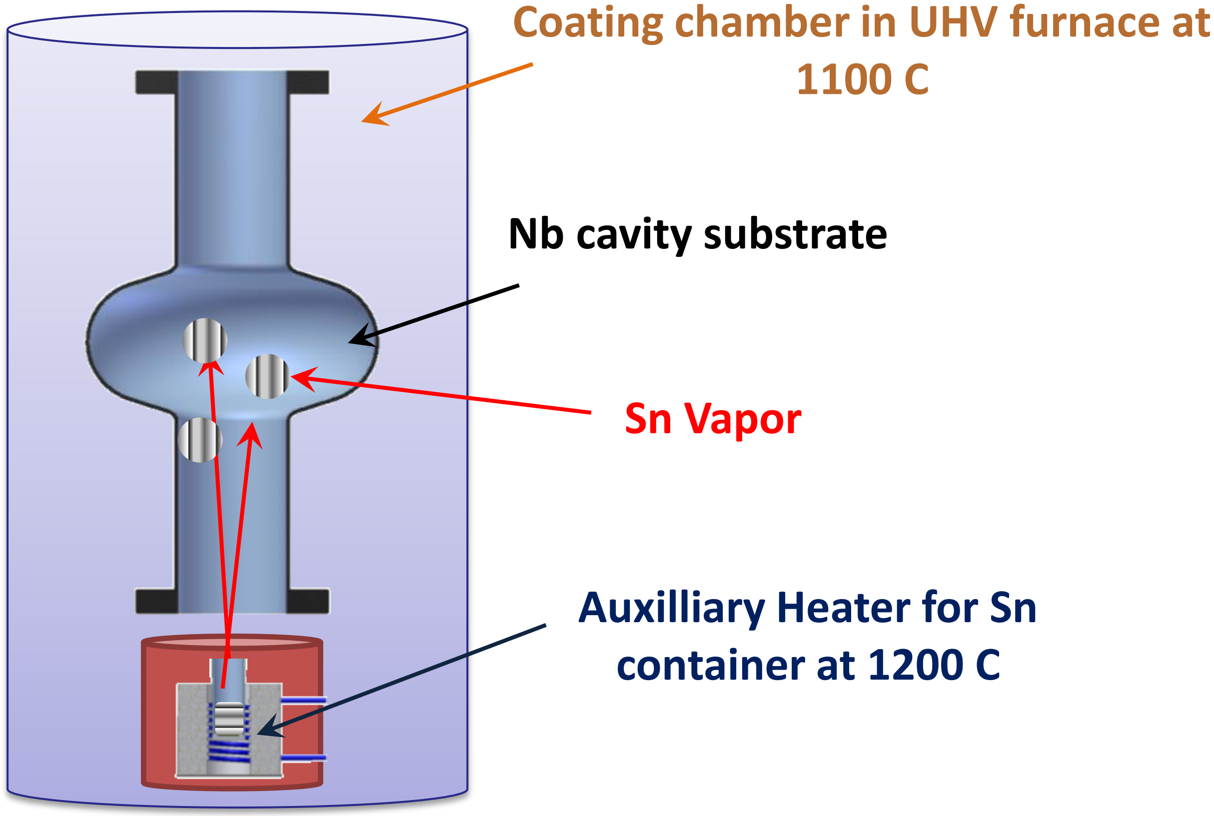
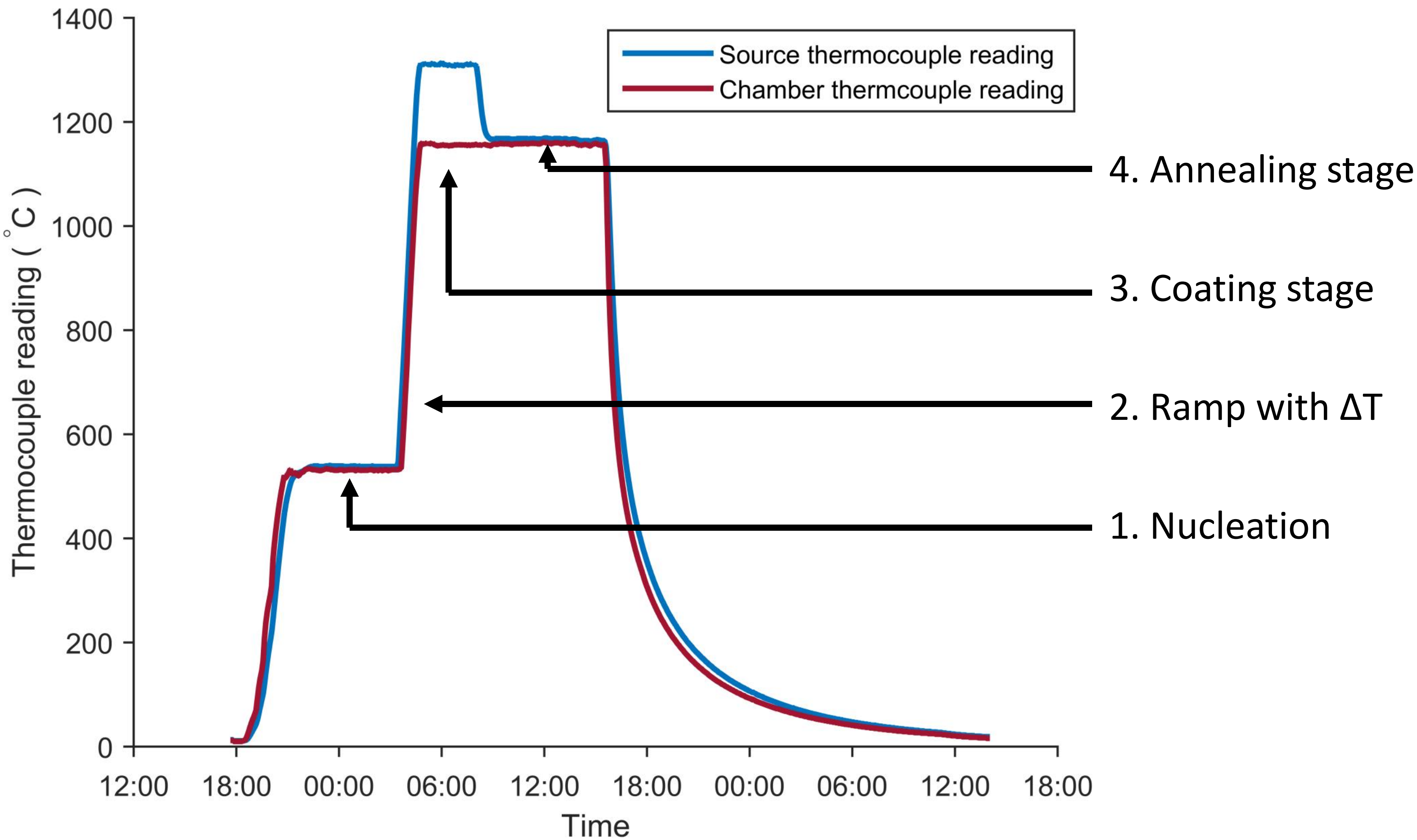
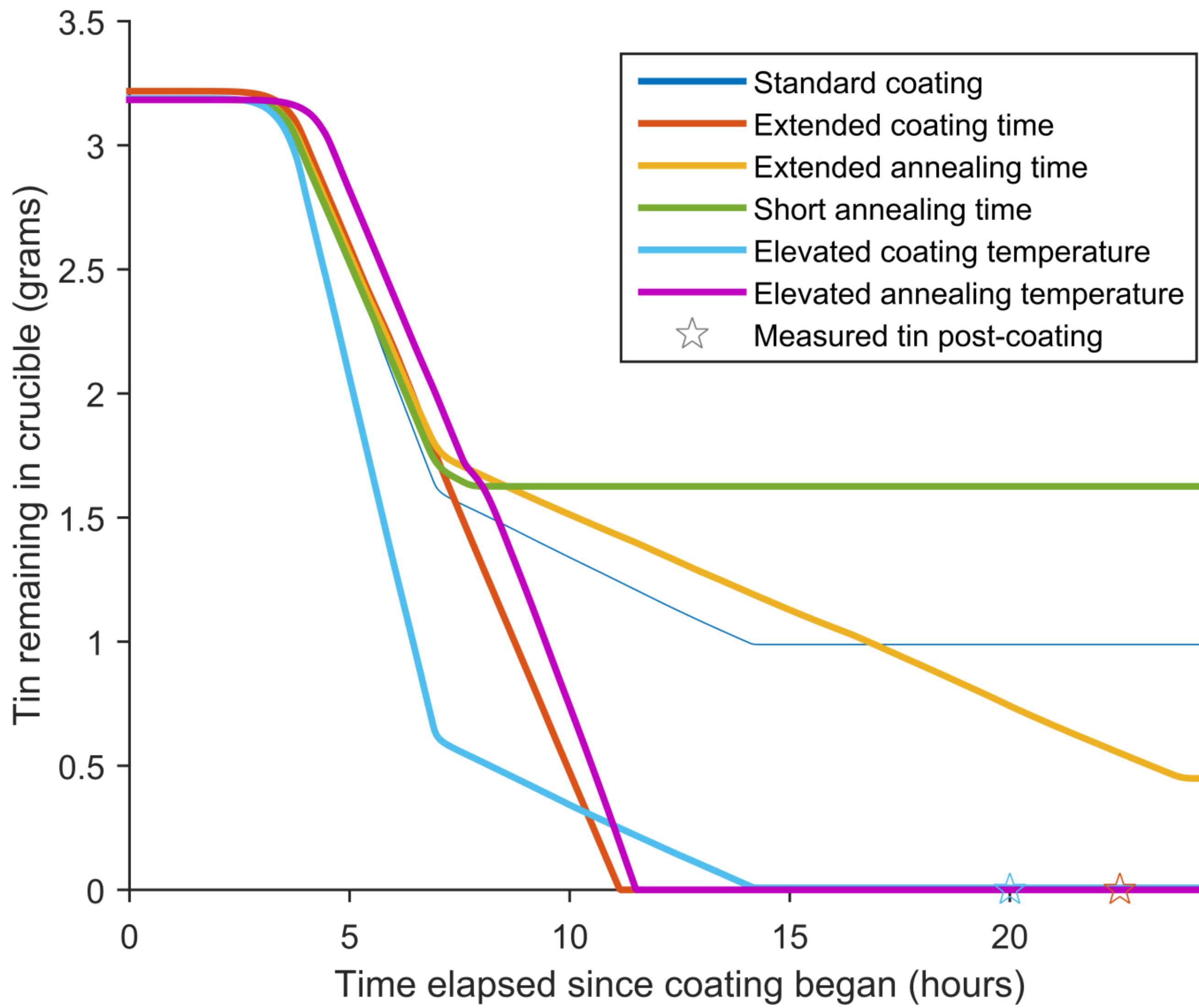
Cornell's Nb_3Sn vapour diffusion



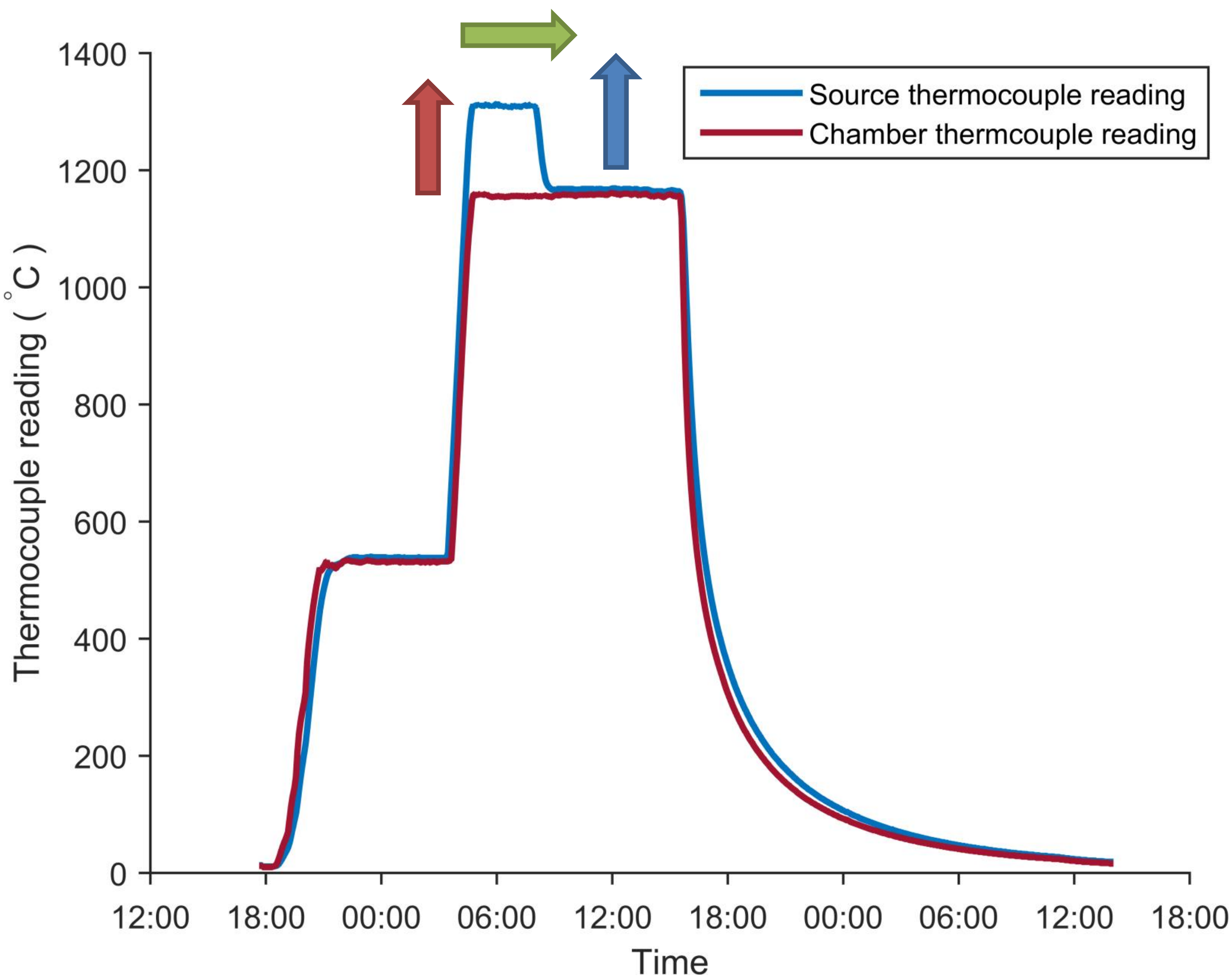
The coating process



Simulating tin usage



What was changed?



1. No change
2. Longer coating
3. Hotter coating
4. Hotter anneal

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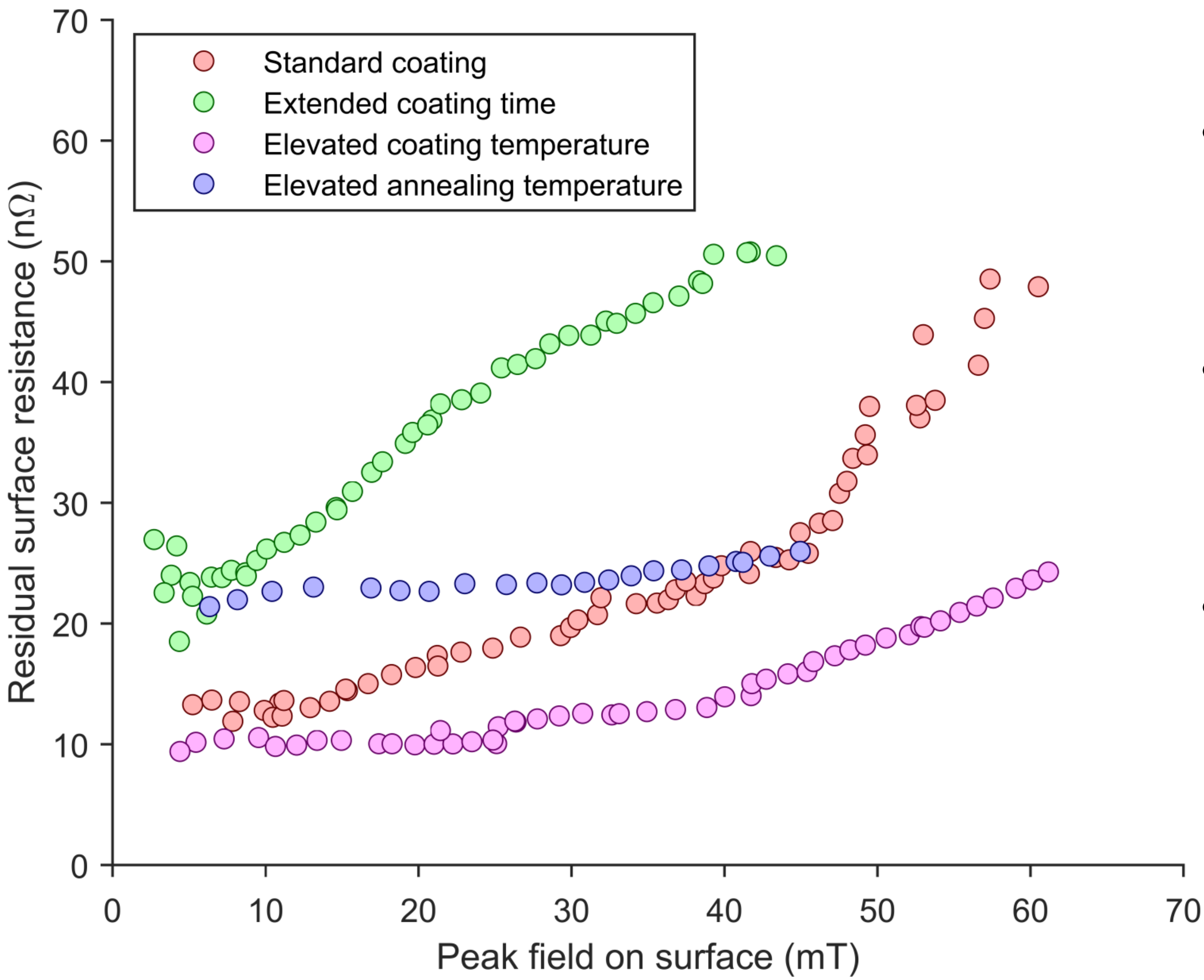
Changes in residual resistance



Initial results:

- Get tin to the surface faster
- Tin gas must have a short mean free path
- You can overdo the amount of tin you put on the surface

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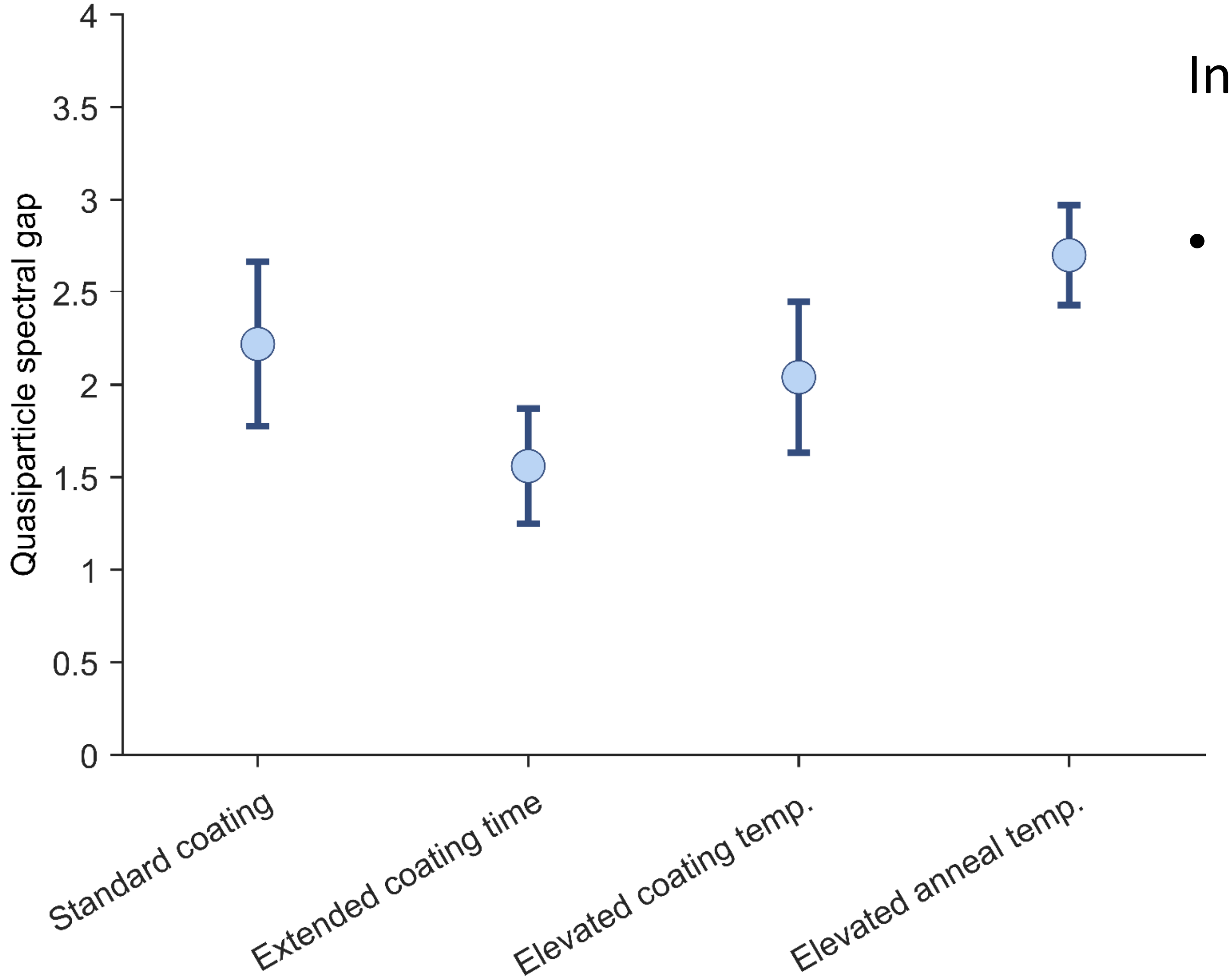
Changes in BCS performance



Initial results:

- An annealing period is necessary to produce a good BCS superconductor

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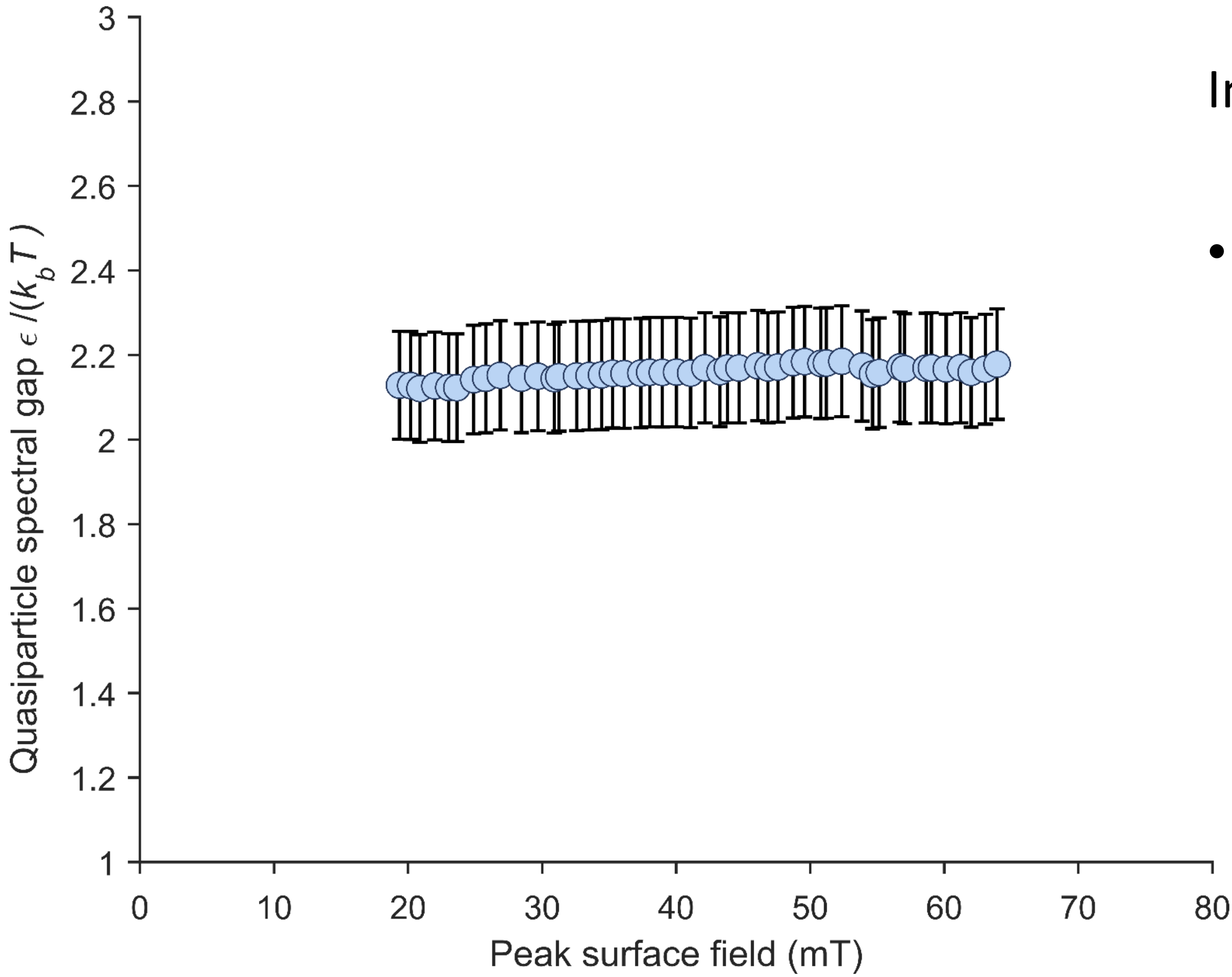
Spectral gap dependence on field



Initial results:

- No closing of the energy gap – yet?

F. Pei-Jen Lin, A. Gurevich, *Phys. Rev. B*, 2012

Where to next with the coating?

- We have begun exploring the coating parameter space

- The goal is to now lower the total surface resistance as much as possible

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Material characterisation

What have we made?

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Material characterisation

- What material characteristics are responsible for the RF performance – both Q_0 and quench field?

- Surface analysis: TEM/EDX, SEM, AFM, XRD

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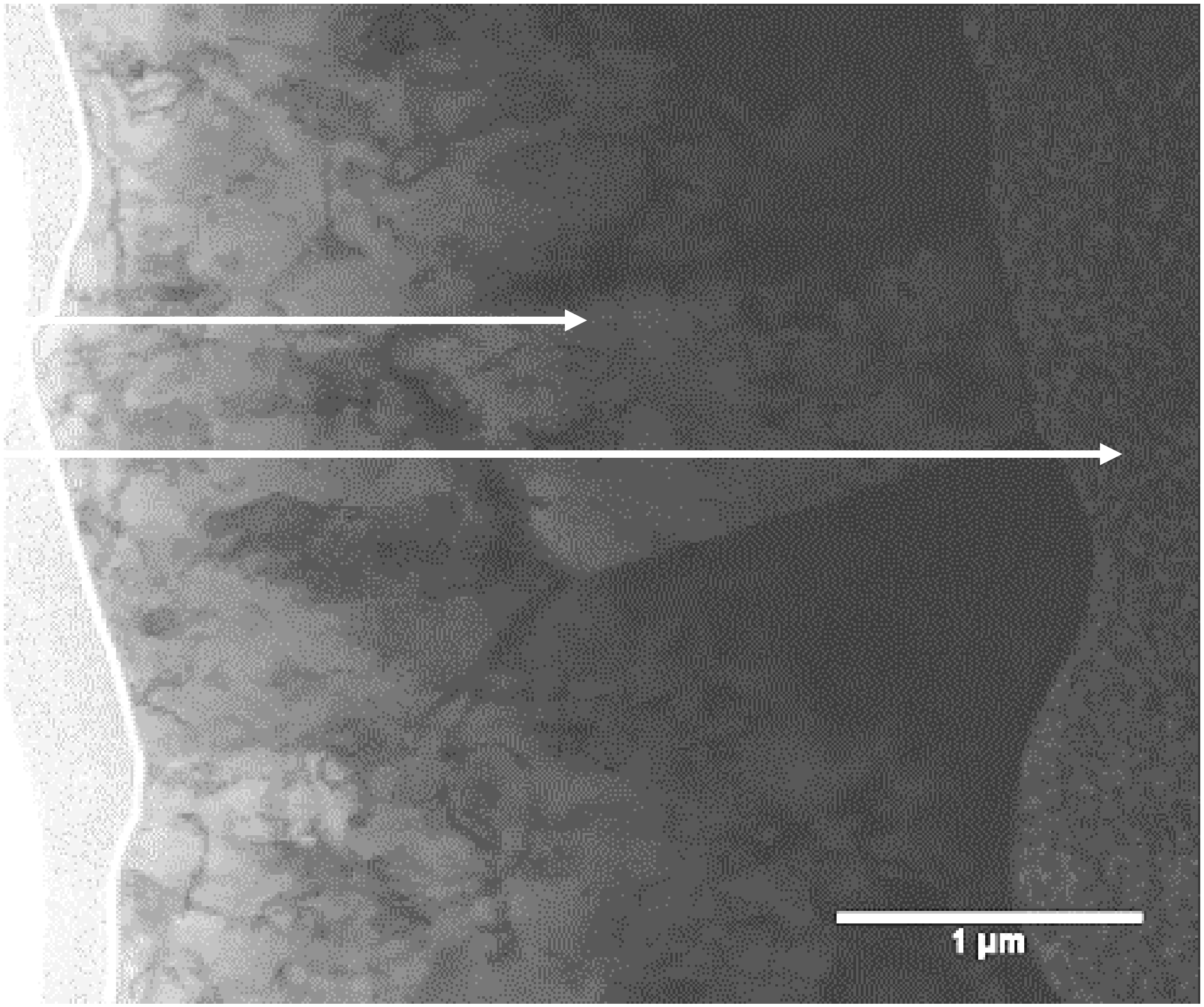
Presence of tin depleted phases



Nb$_3$Sn layer

Nb substrate

Image courtesy of Thomas Proslier, ANL

Presence of tin depleted phases

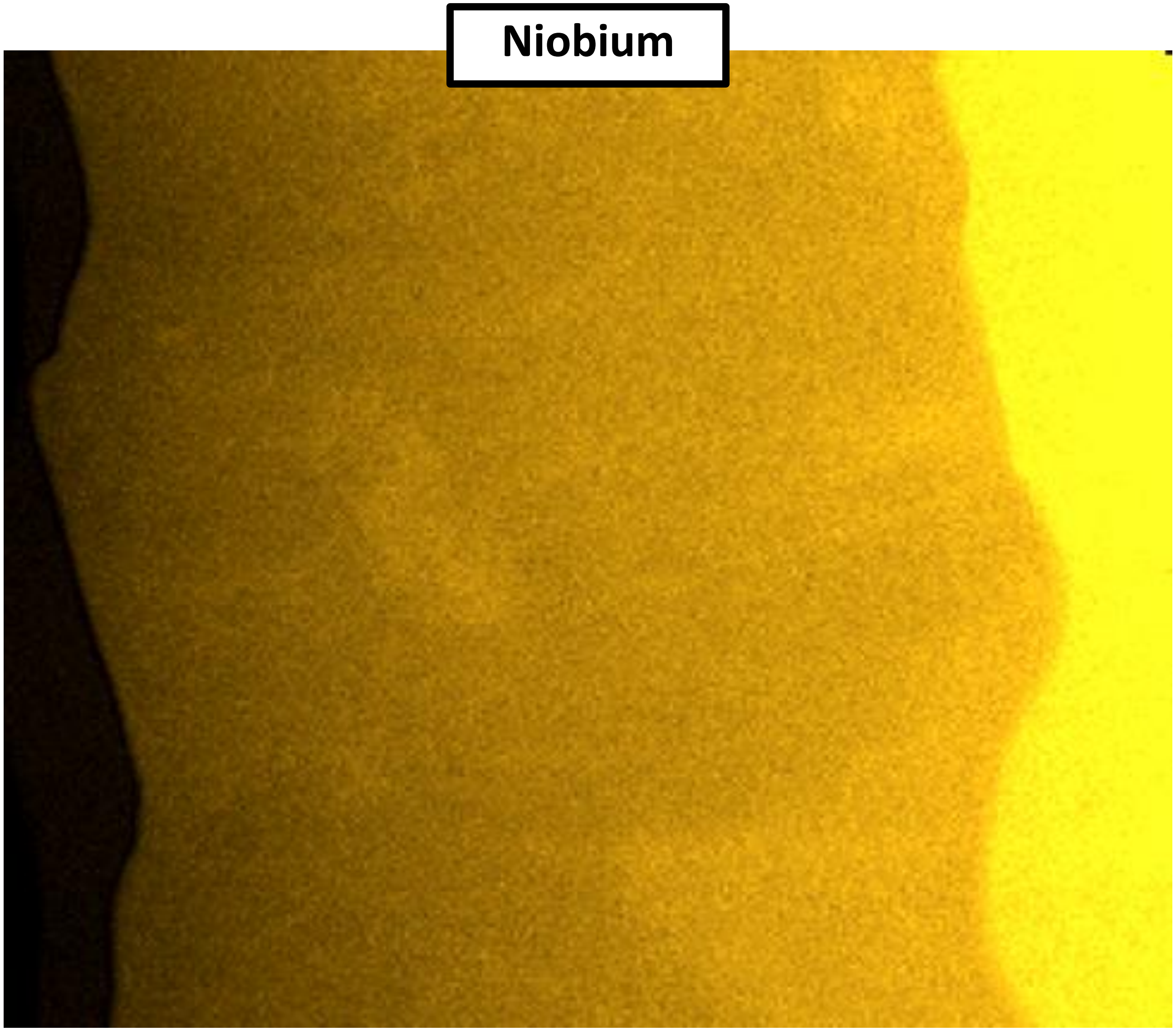


Image courtesy of Thomas Proslier, ANL

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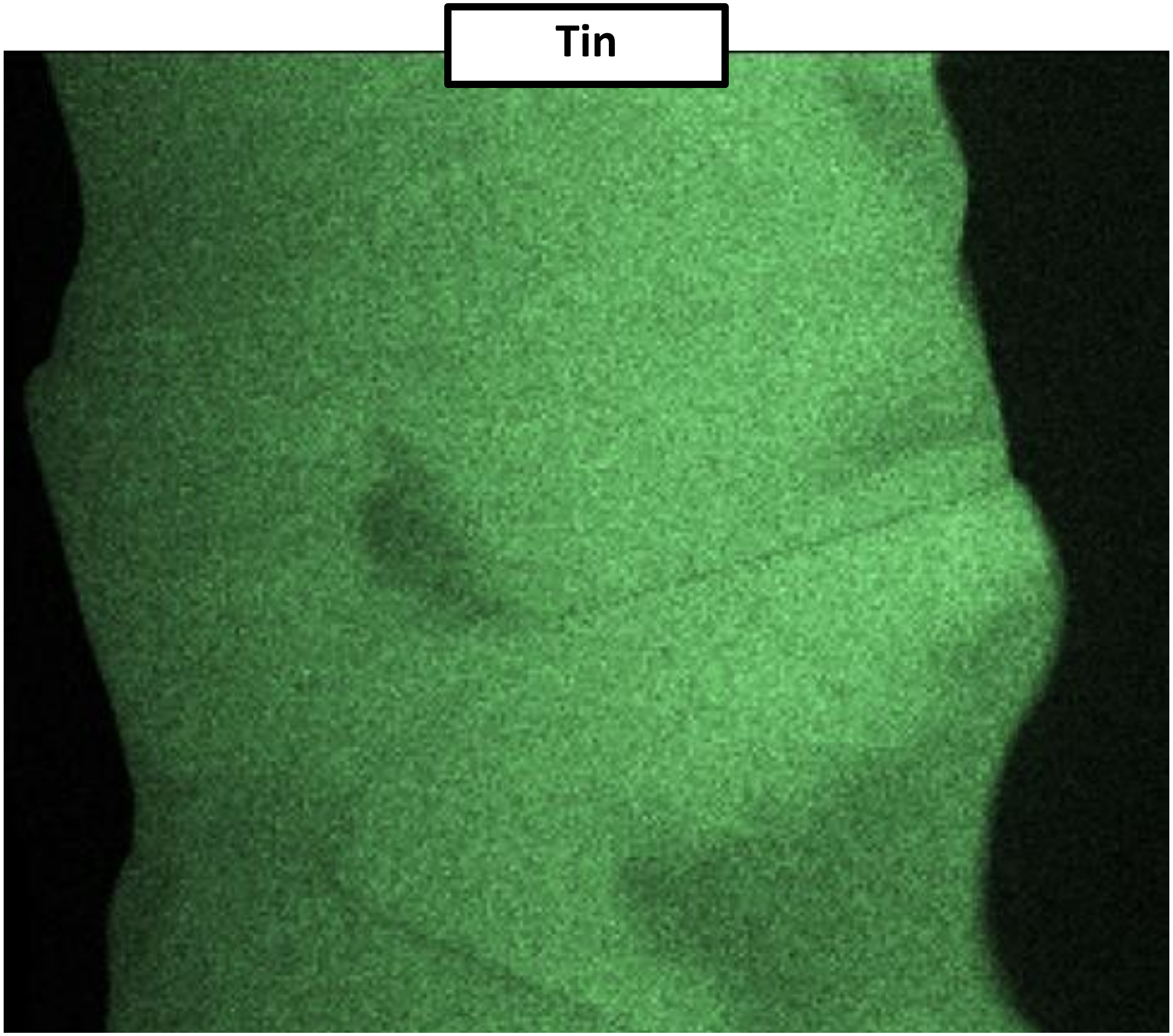

Image courtesy of Thomas Proslier, ANL

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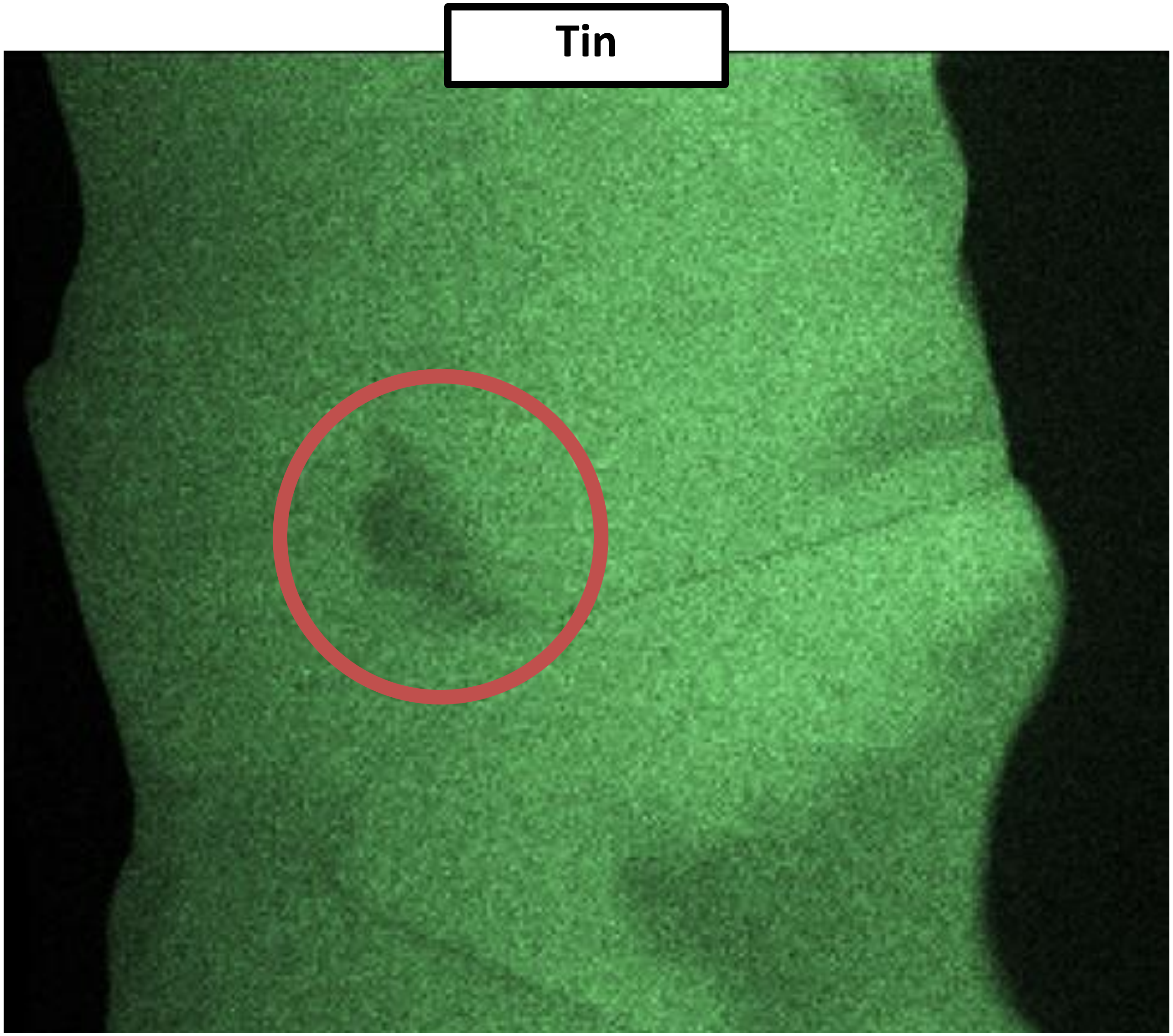

Image courtesy of Thomas Proslier, ANL

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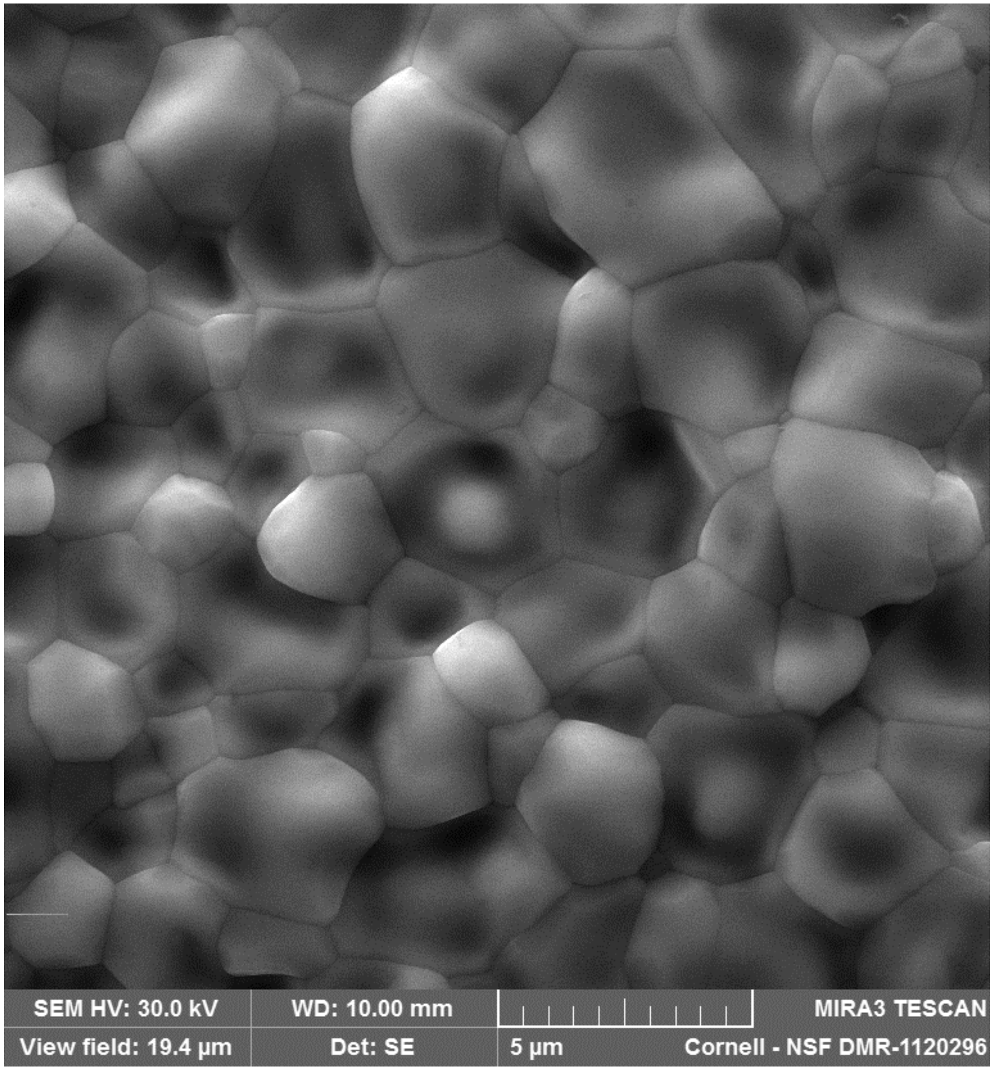
Surface uniformity



- Stoichiometric defects are on the order of 1 µm or less
- Have we seen any that are bigger than that?

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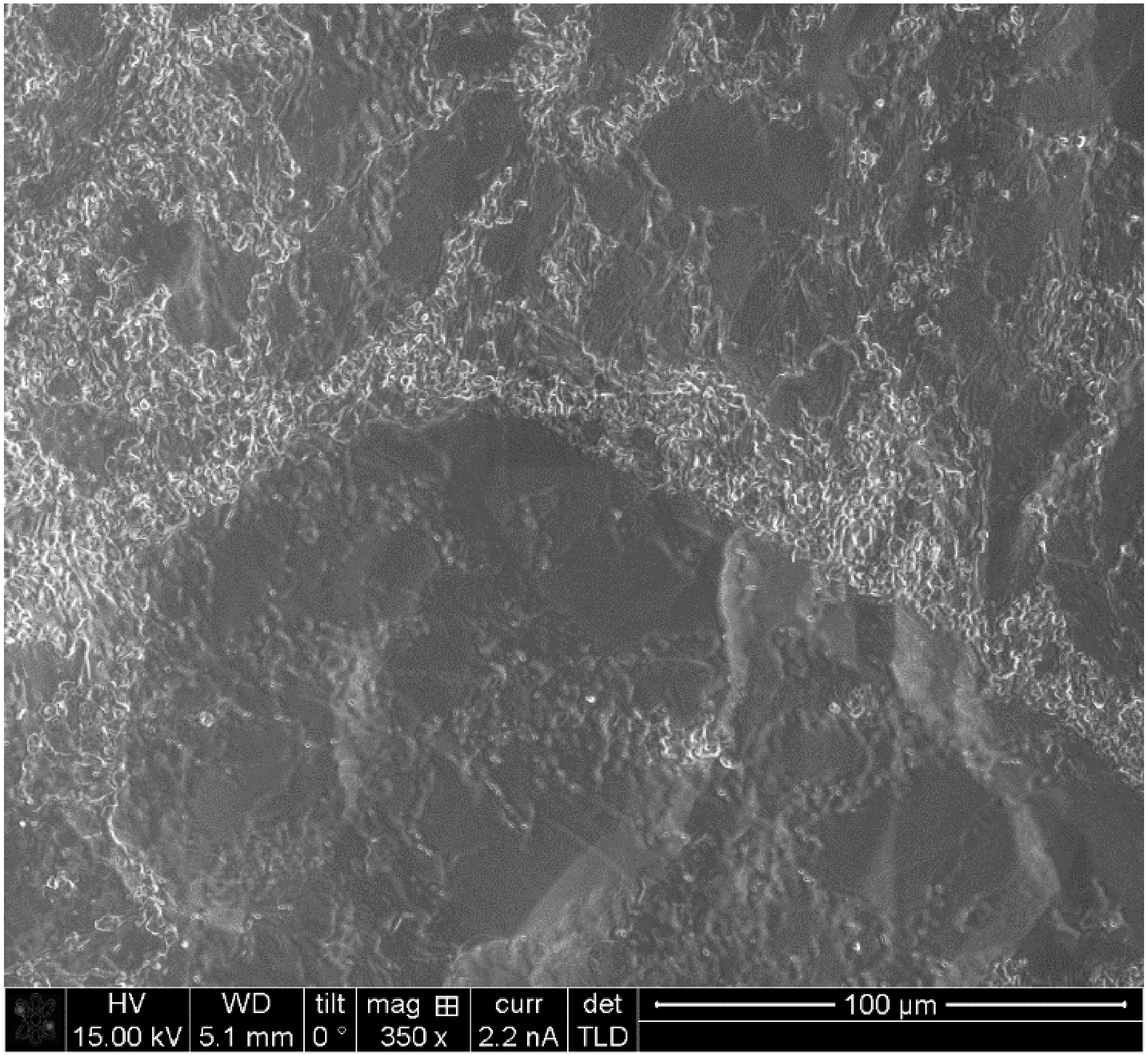
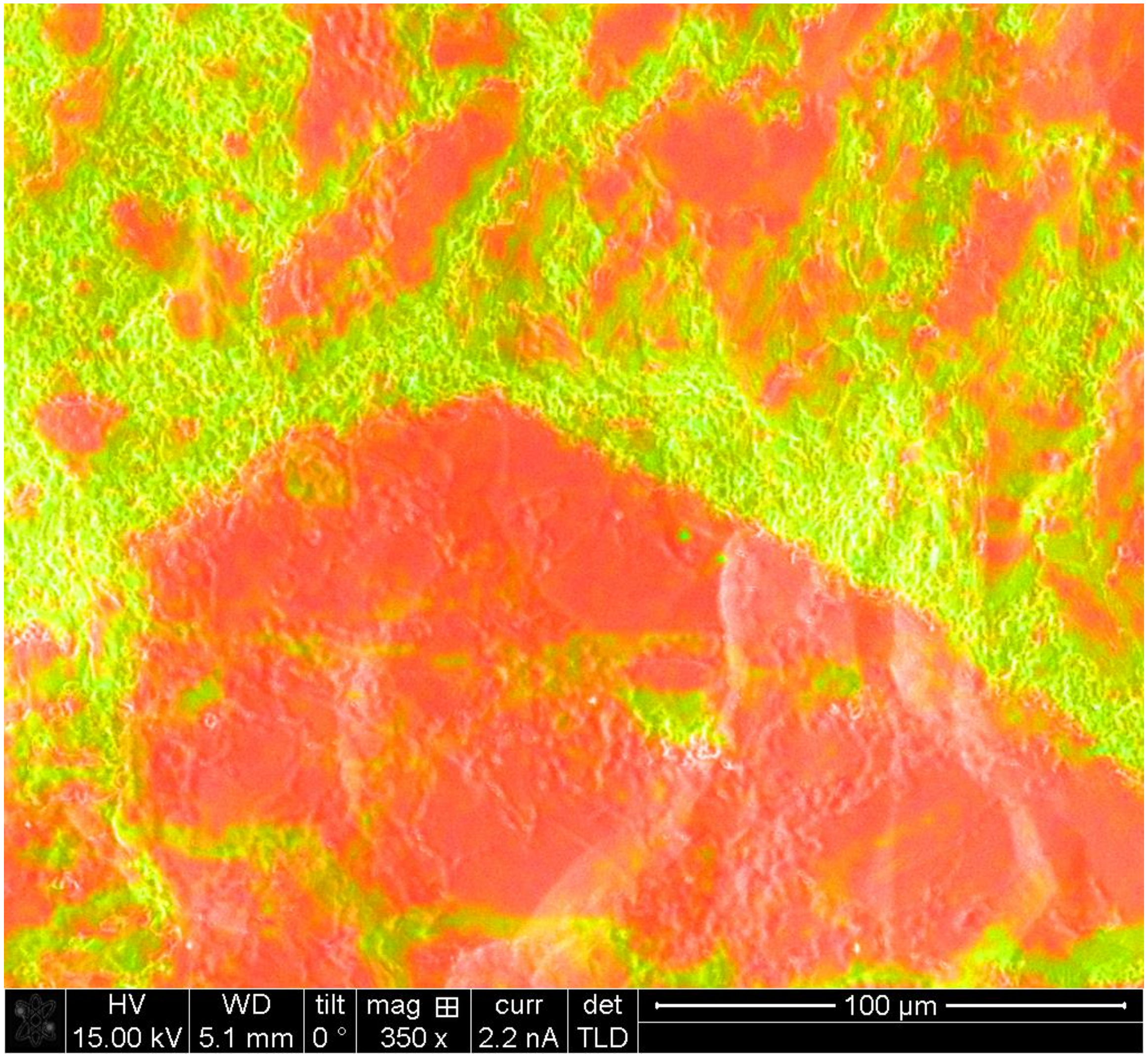
Regions of poor tin coverage



- Yes!
- But it's rare – only one example

Regions of poor tin coverage



Green – good coverage

Red – poor coverage

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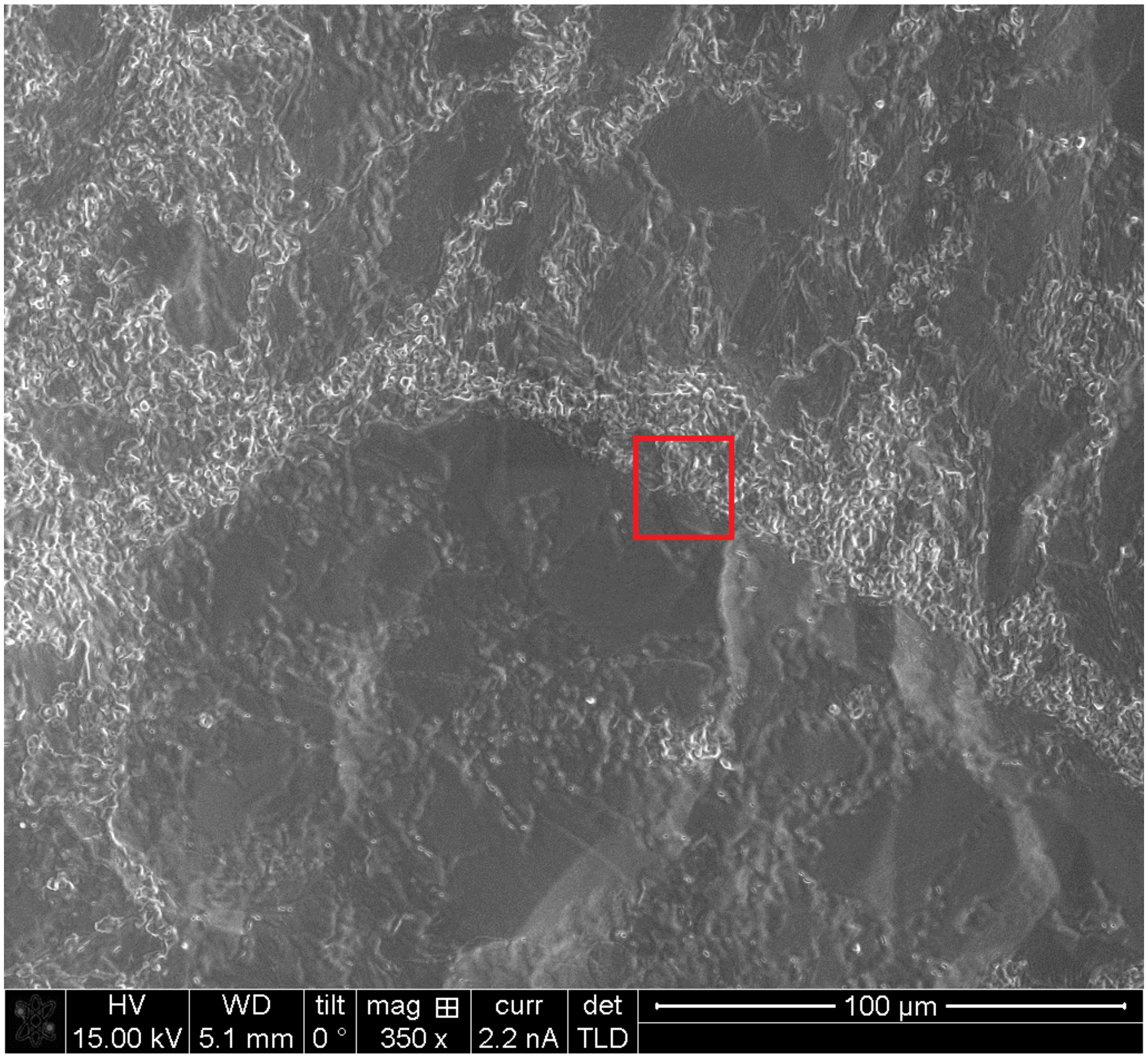
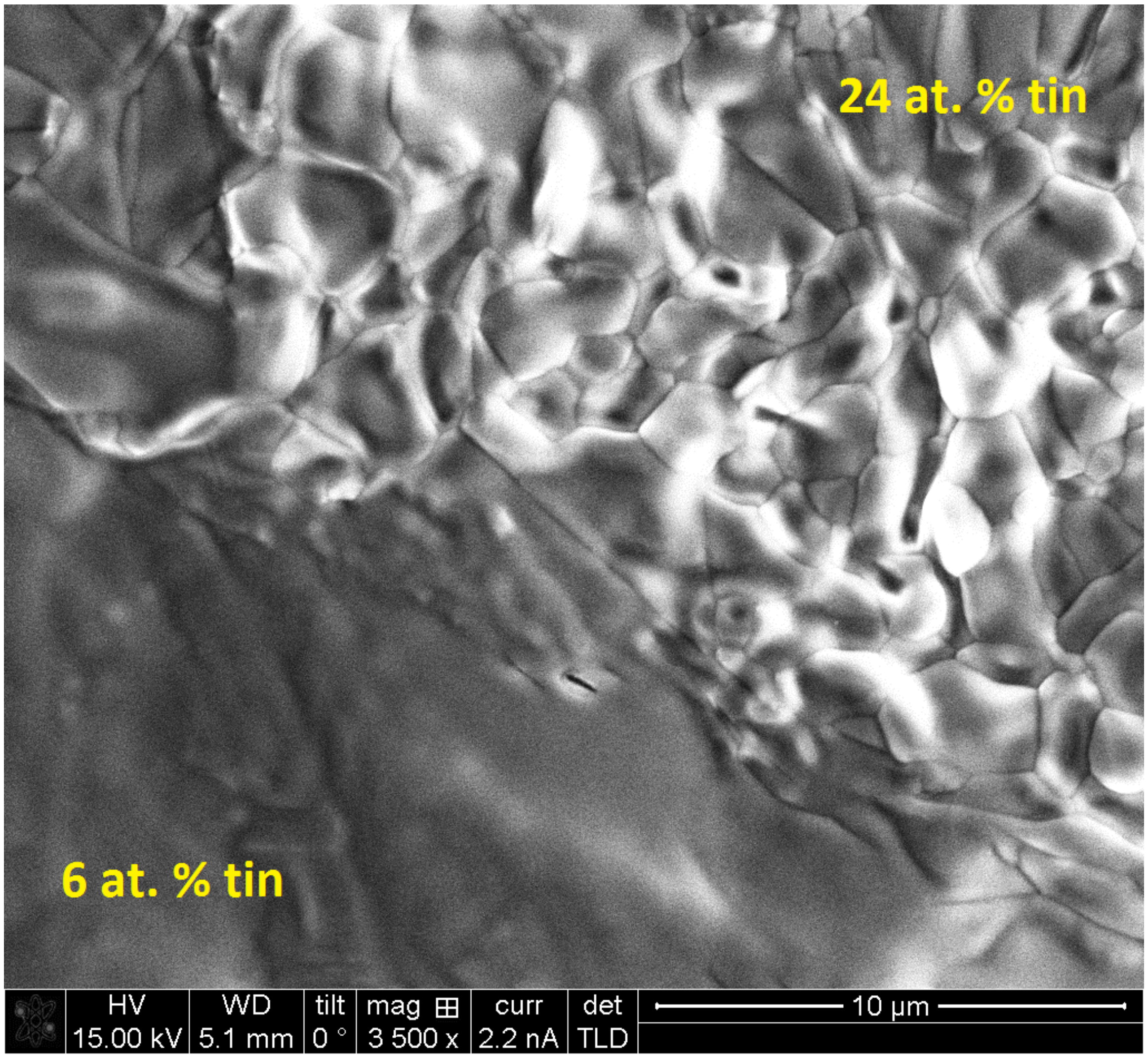
Regions of poor tin coverage



Regions of poor tin coverage



See poster this afternoon – **TUPB049**

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Why is tin-depletion bad?

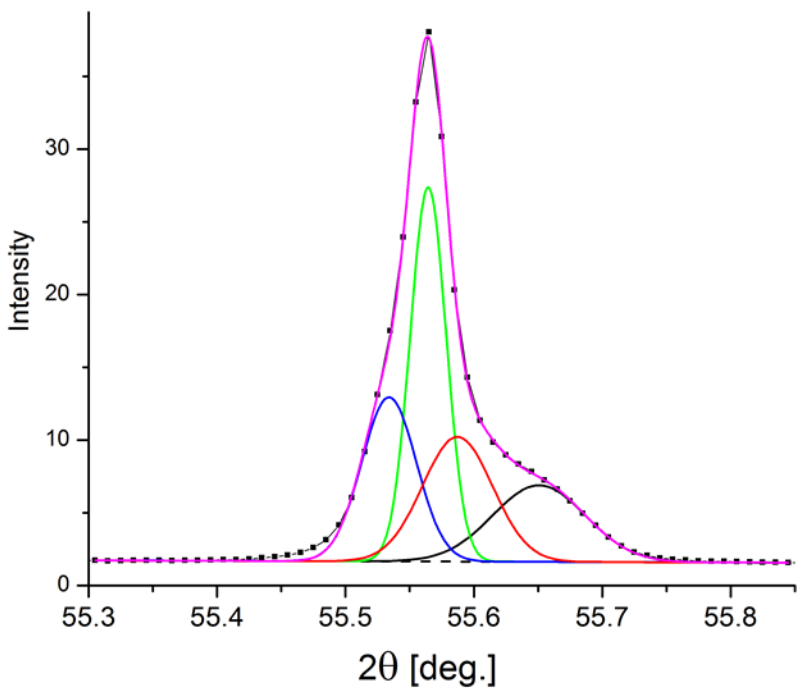
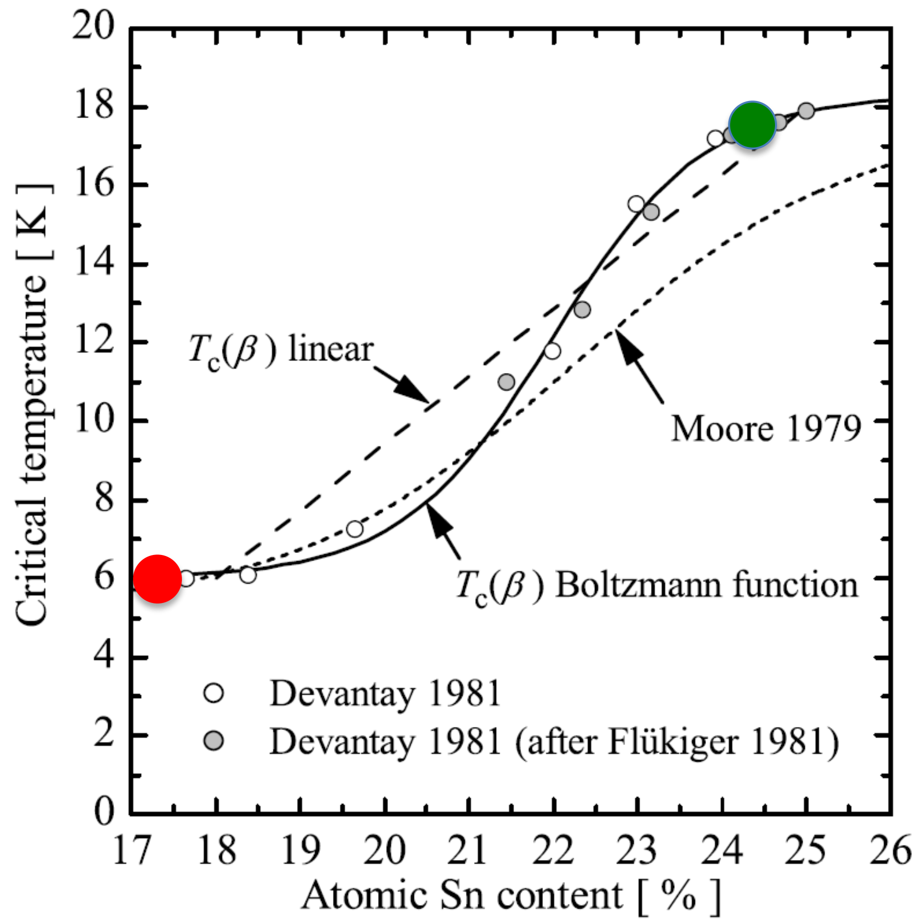


Image courtesy of Thomas Proslier, ANL



A. Godeke, Supercond. Sci. Tech, 2006

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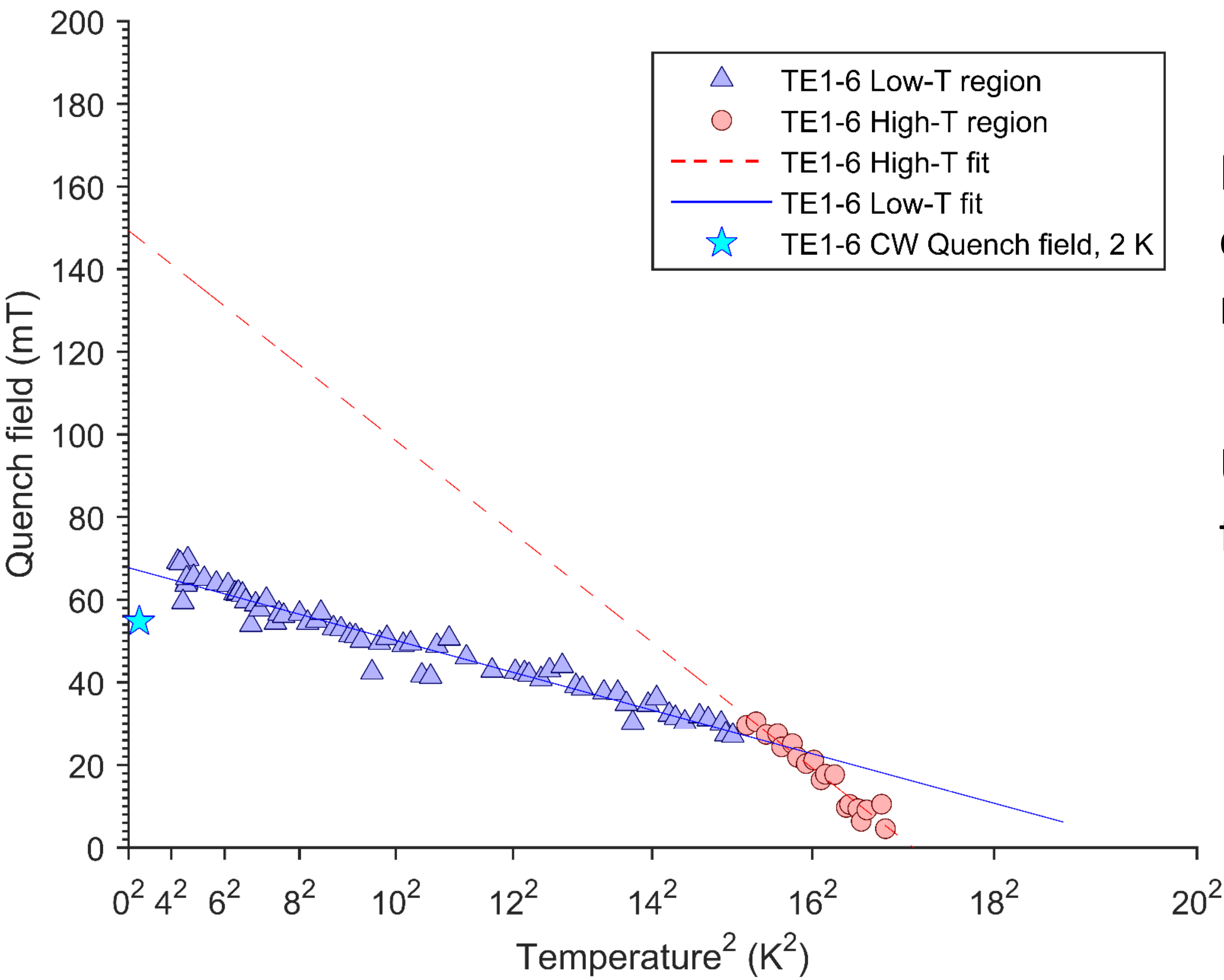
Measuring the flux-entry field



Pulsed test data shows evidence of two or more phases in play

Ultimate flux entry field is only 150 mT?

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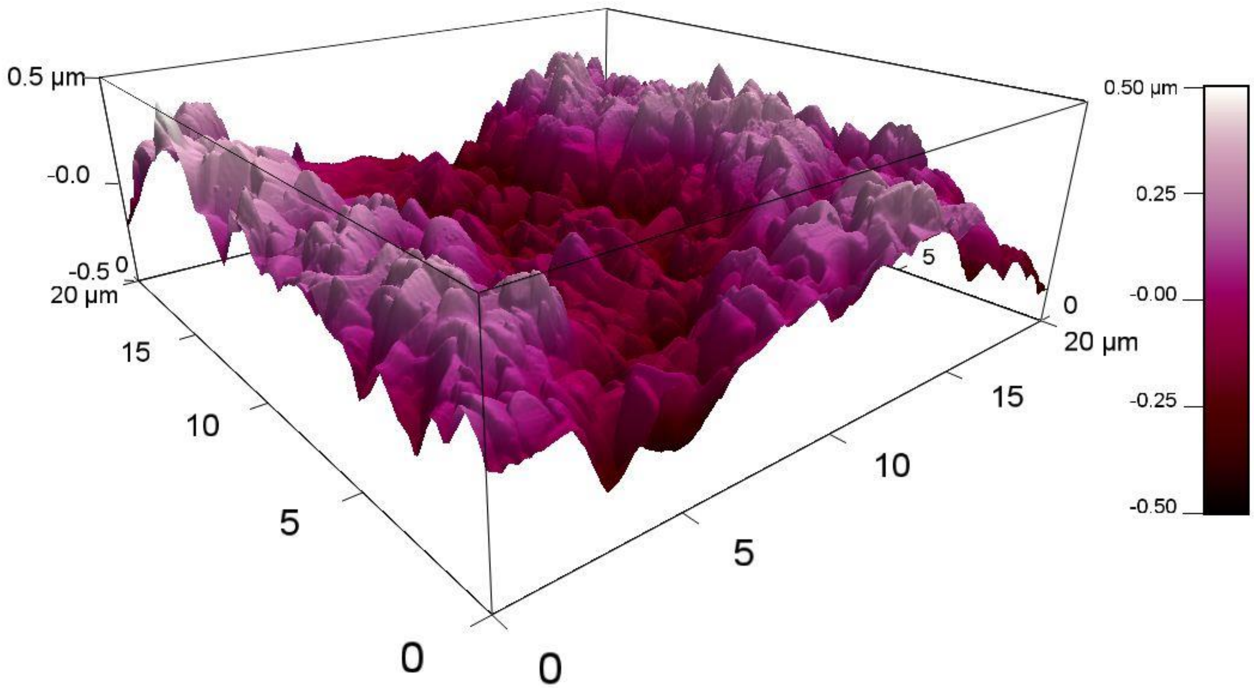
Surface roughness



Surface is rough – it will cause field enhancement

Image courtesy of James Maniscalco, Cornell University

CCMR facilities are supported by NSF grant MRSEC 1120296

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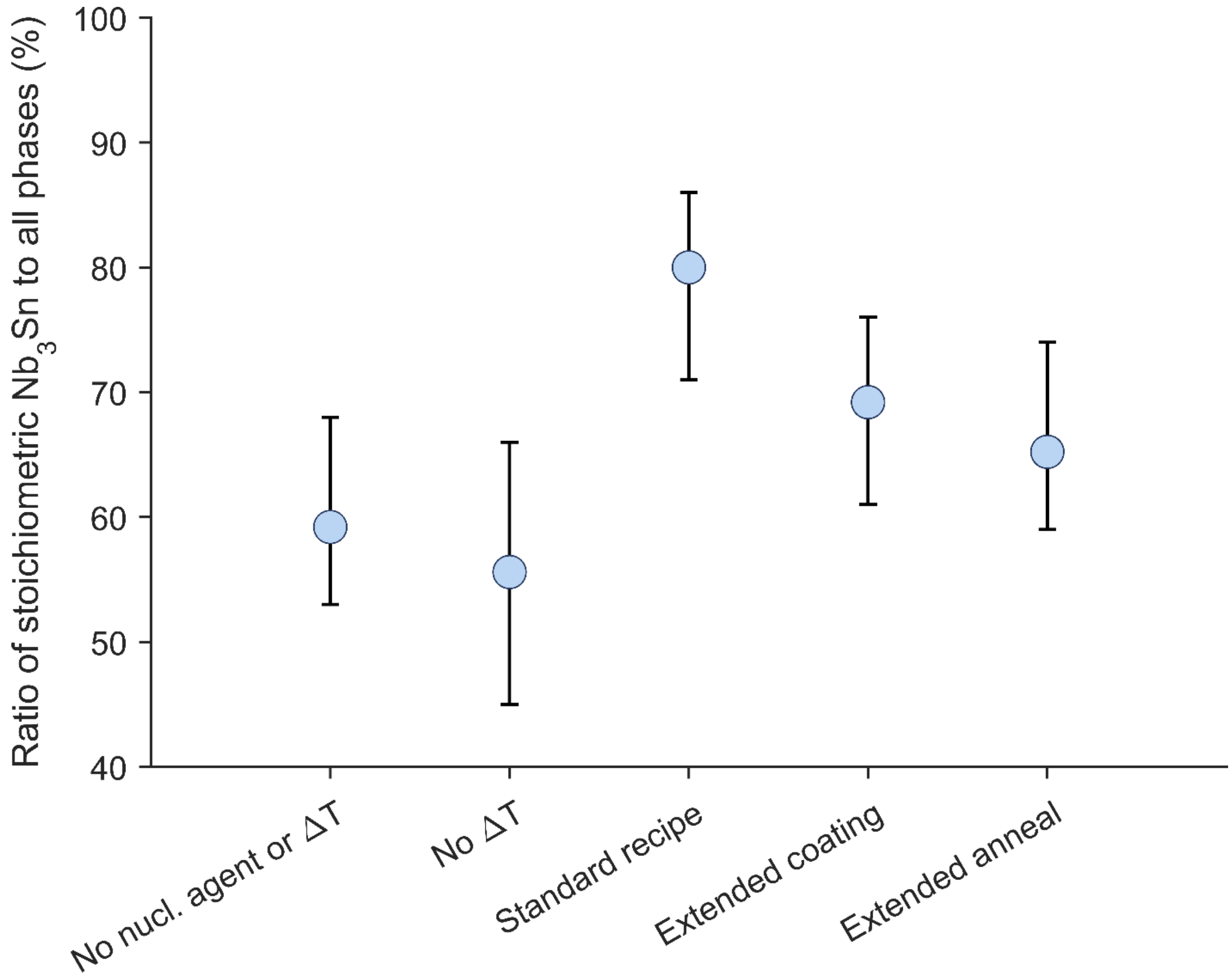
How do we avoid bad phases?



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Nb_3Sn as a practical application

- Would cryomodule designs have to be modified to accommodate Nb_3Sn cavities?
- Is Nb_3Sn approaching a state where we would consider using it in an accelerator?

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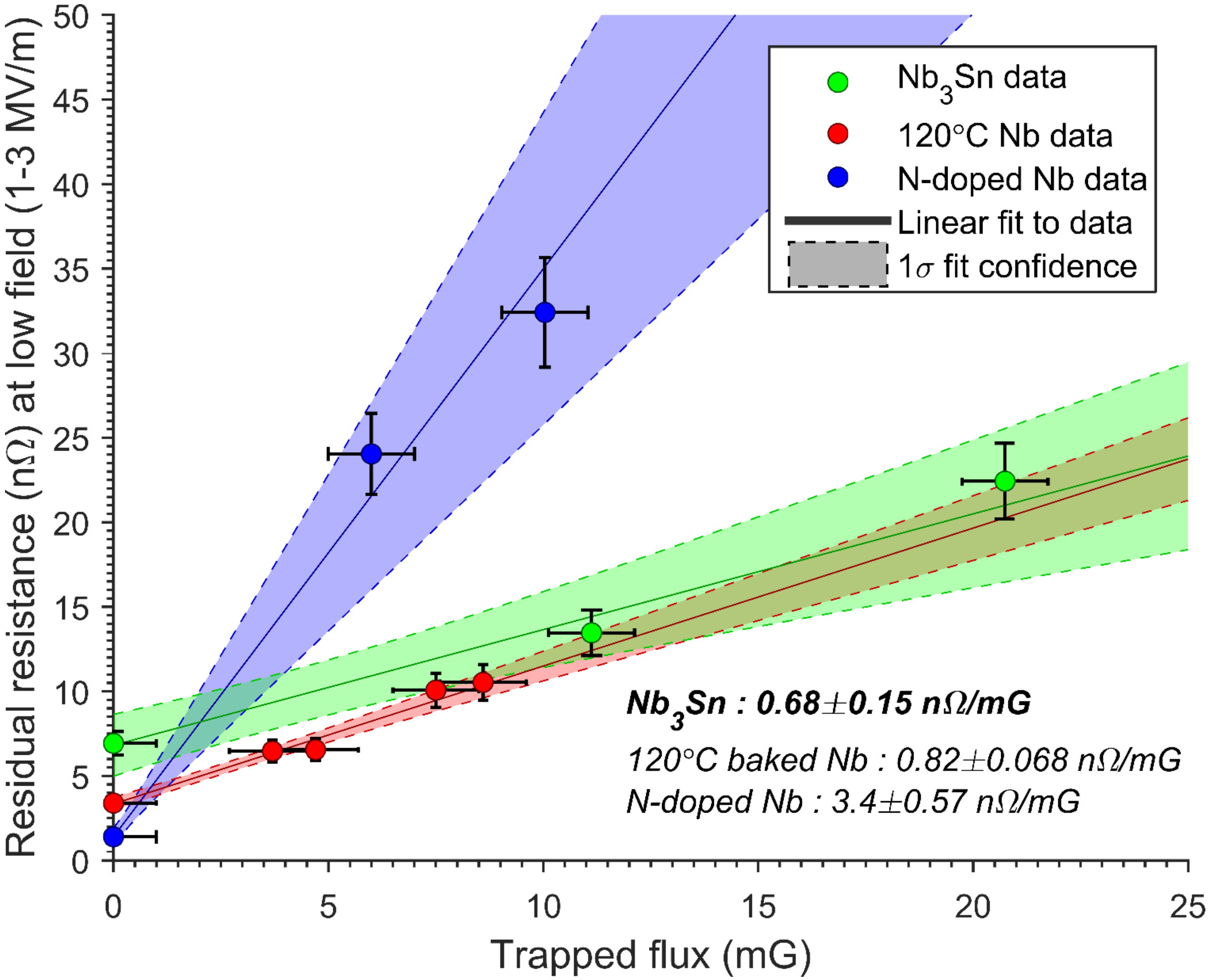
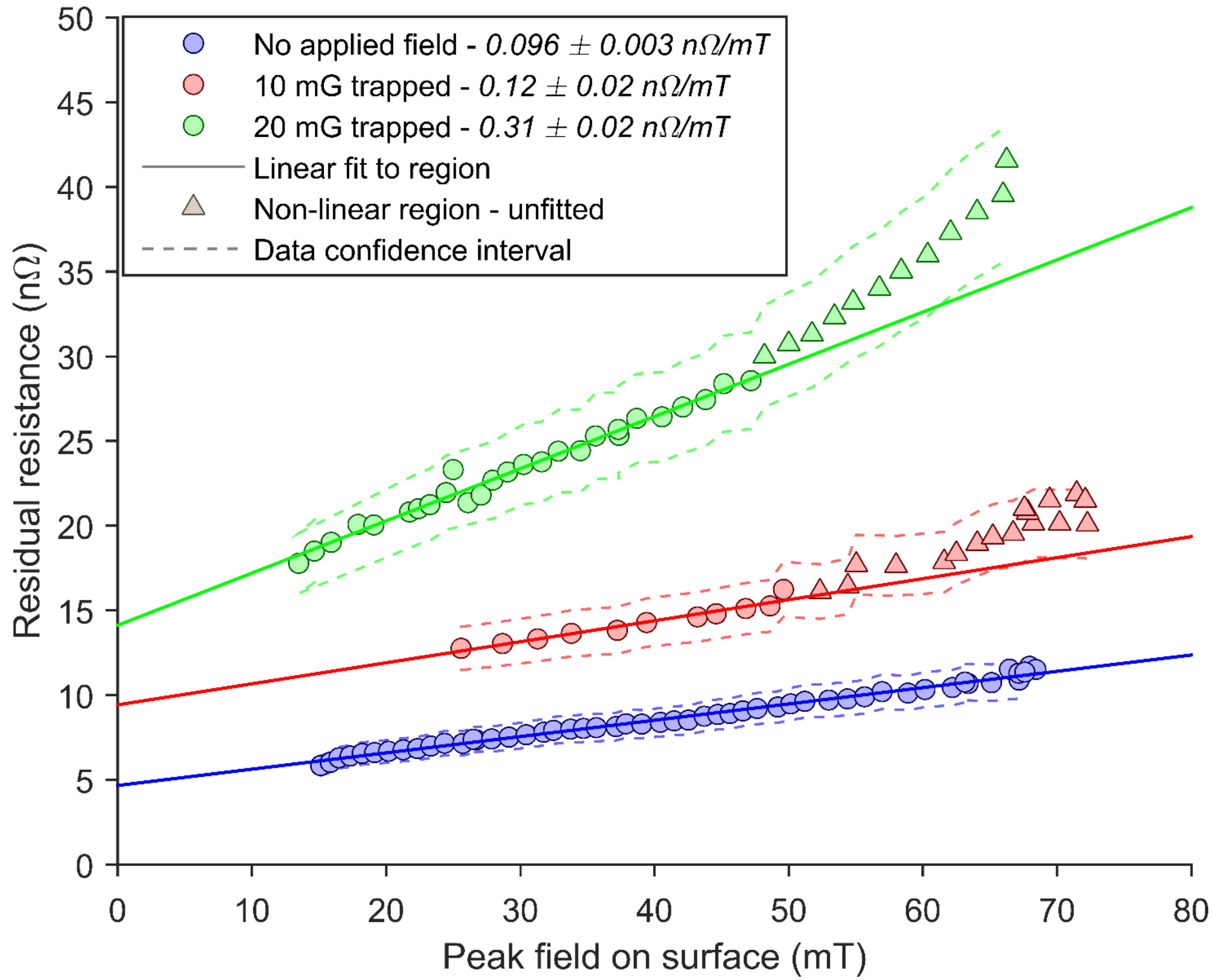
Sensitivity to trapped flux



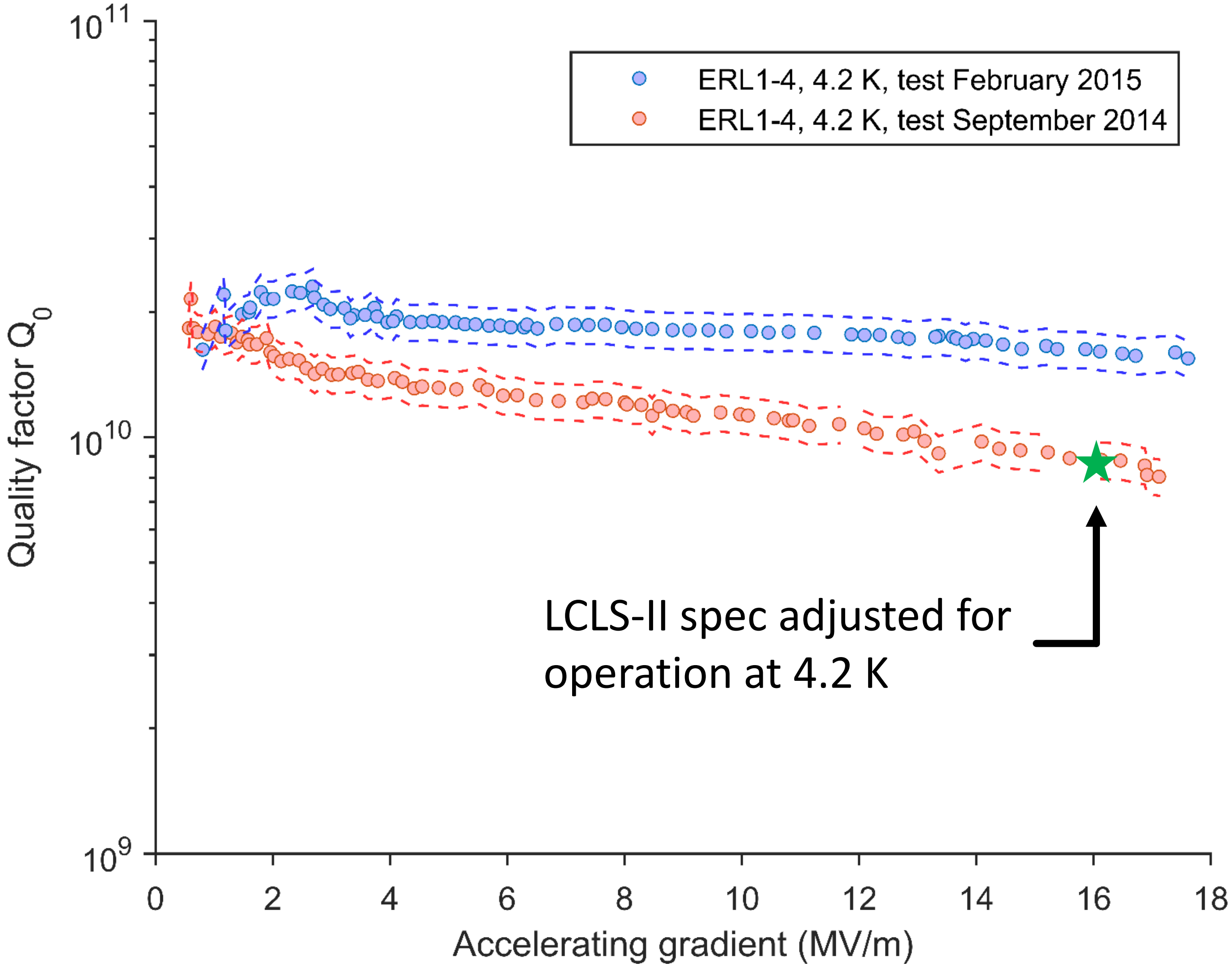
Nb_3Sn cavities have to be cooled slowly

No more sensitive to trapped flux than 120 °C baked niobium

Trapped flux and Q-slope



Impact of the cooldown procedure



Small thermal gradients give better performance

This cavity exceeds LCLS-II spec by a factor of 2

Summary and conclusions

- The current limitations of Nb_3Sn are due to its fabrication and are not fundamental to the material itself
  - Current limitation: stoichiometry, tin-depletion
- We are optimising the coating process
  - Looks promising!
- Nb_3Sn cavities are not sensitive to losses from trapped flux
- The state of the art has exceeded the LCLS-II specifications by a factor of 2

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The world's first Nb_3Sn accelerator?

LCLS IV

Stay tuned

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Acknowledgements

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Jefferson Lab

Nb_3Sn is growing!

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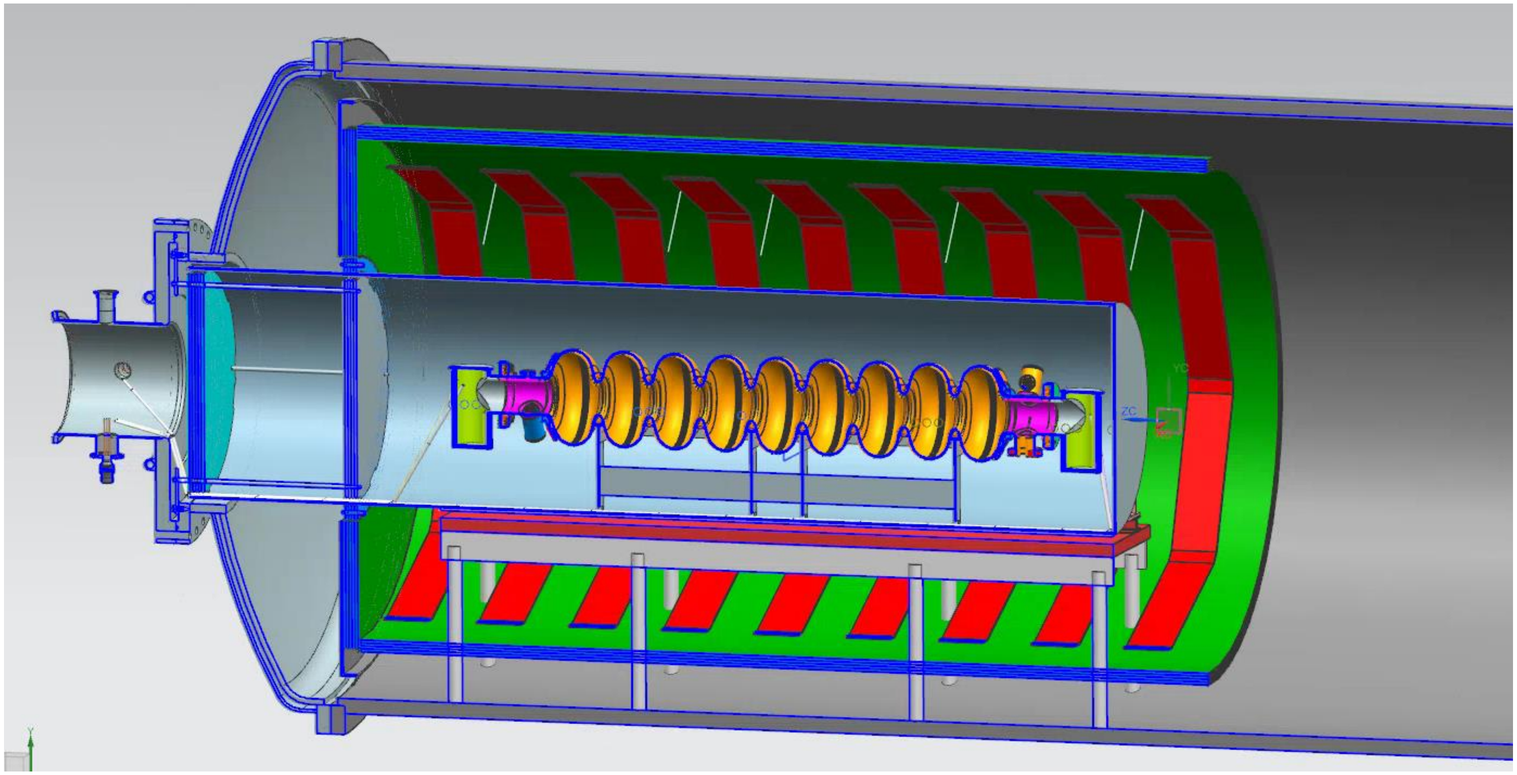
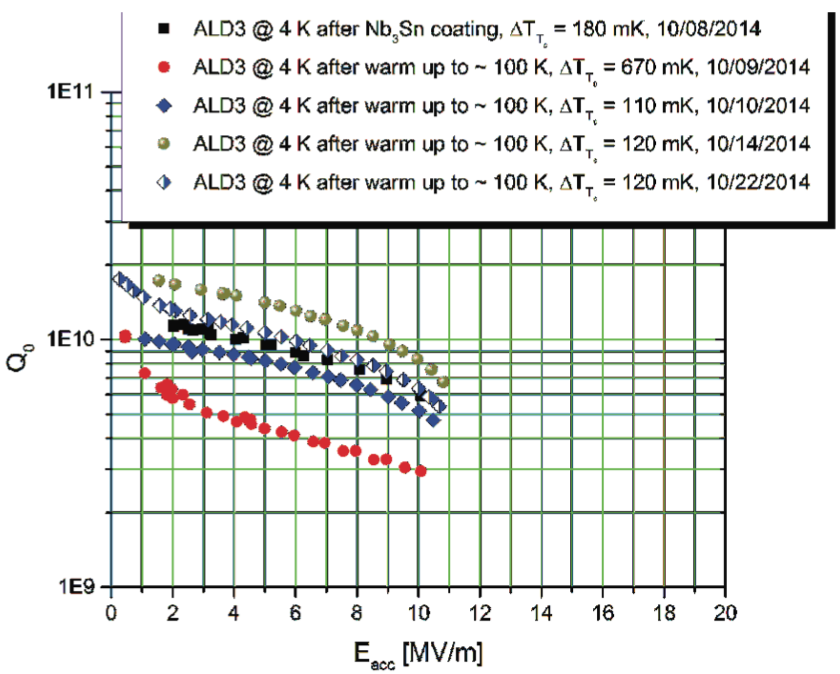
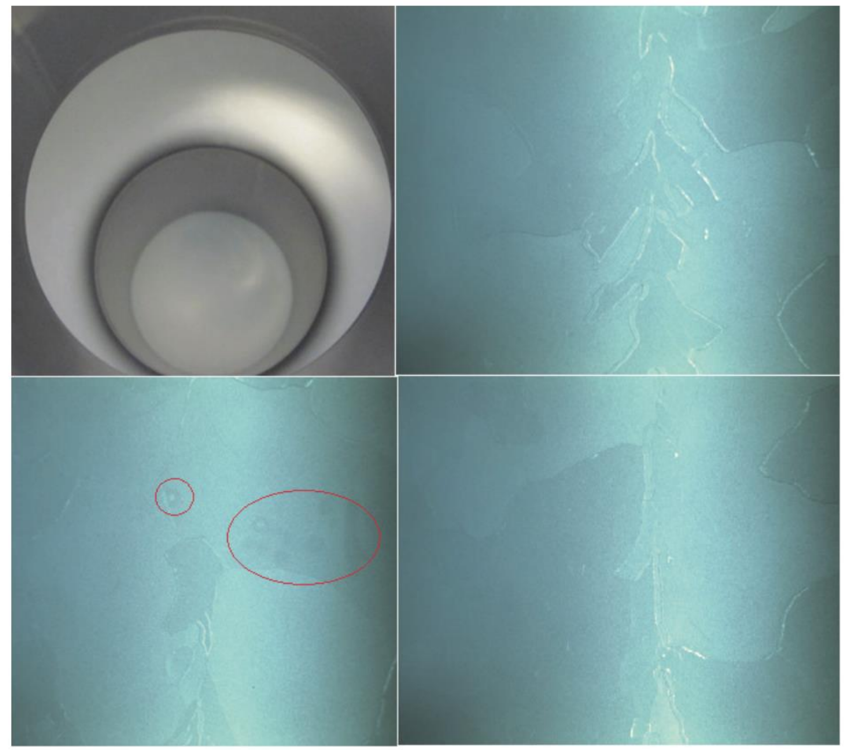
Fermilab Nb_3Sn Program

- **Fermilab**: Nb_3Sn R&D program funded by LDRD
- Will build a coating chamber large enough for TeSLA 9-cell cavities or 650 MHz 5-cells
- Continue R&D to push performance and begin proof of concept for practical applications



Jefferson Lab





Thank you for your attention