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Logo upgrade!

Nb_3Sn SRF Coatings at Fermilab

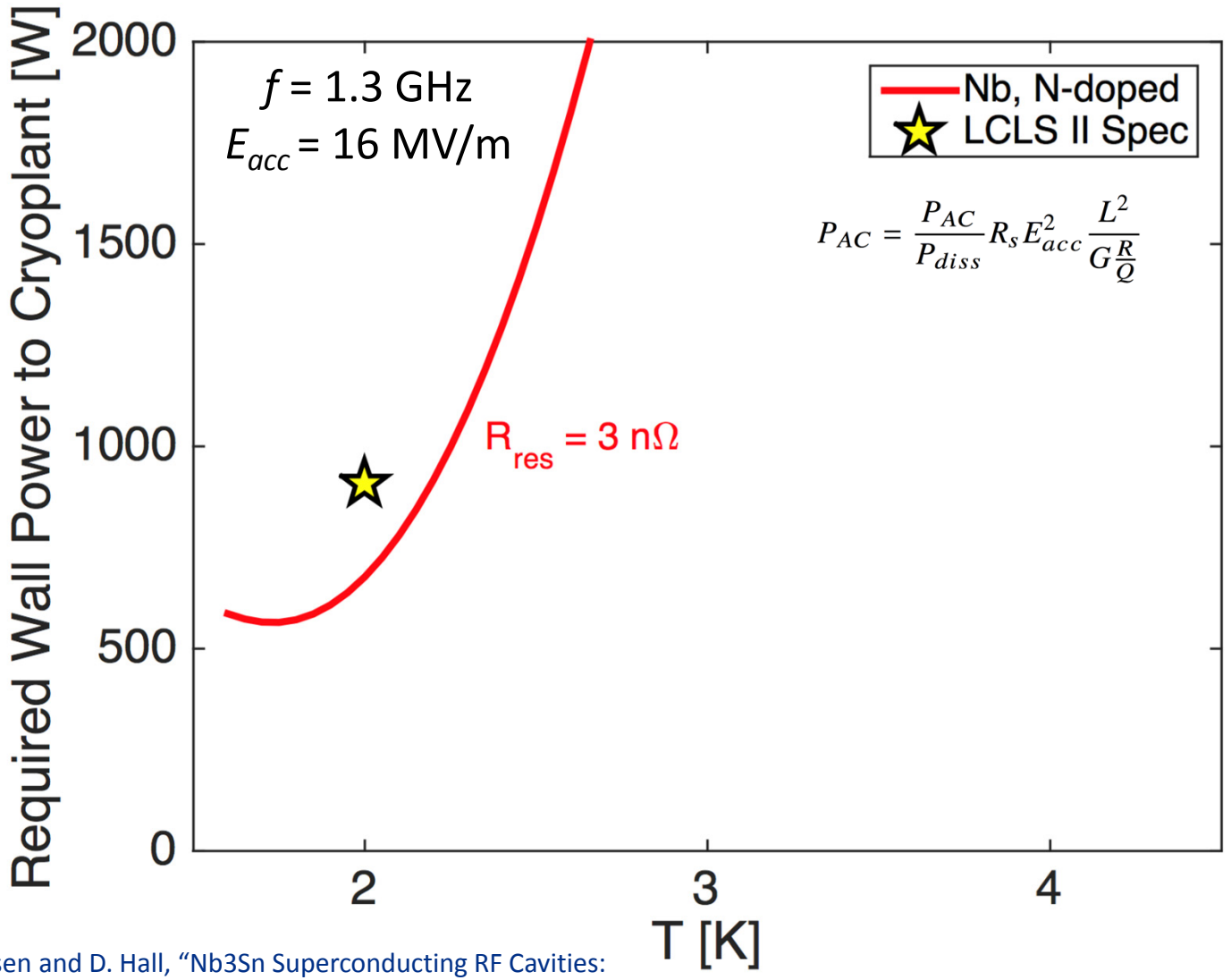
Sam Posen

Collaborators: Saravan Chandrasekaran, Daniel Hall, Matthias Liepe, Margherita Merio, Alexander Romanenko, Yulia Trenikhina

North American Particle Accelerator Conference 2016

1. Motivation: Nb_3Sn SRF Cavities versus Traditional Niobium

Power Required to Cryoplant for Each 1.3 GHz Cell



Details in: S. Posen and D. Hall, "Nb3Sn Superconducting RF Cavities: Fabrication, Results, Properties, and Prospects," submitted to *SuST,* Focus on Superconducting RF for Accelerators

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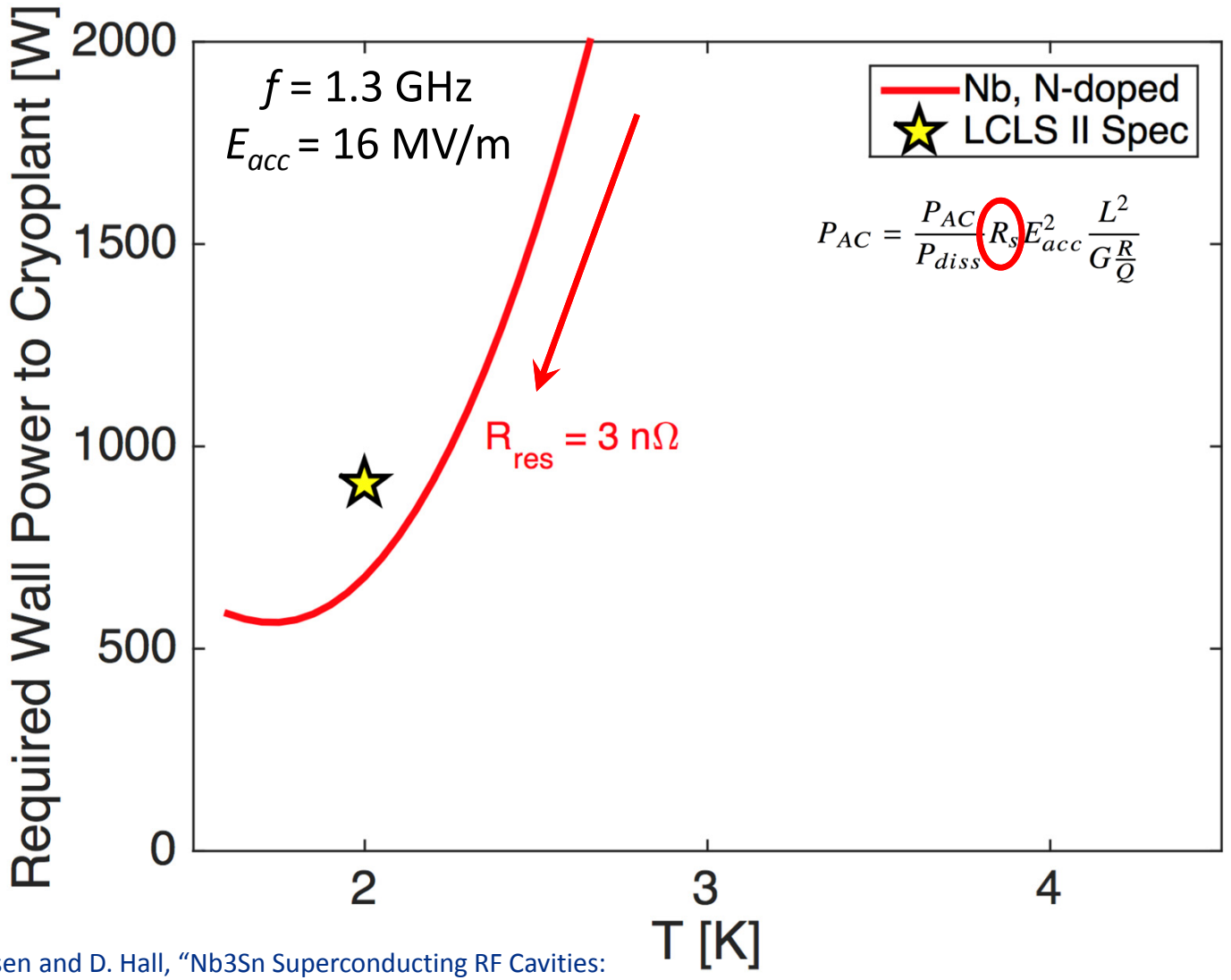

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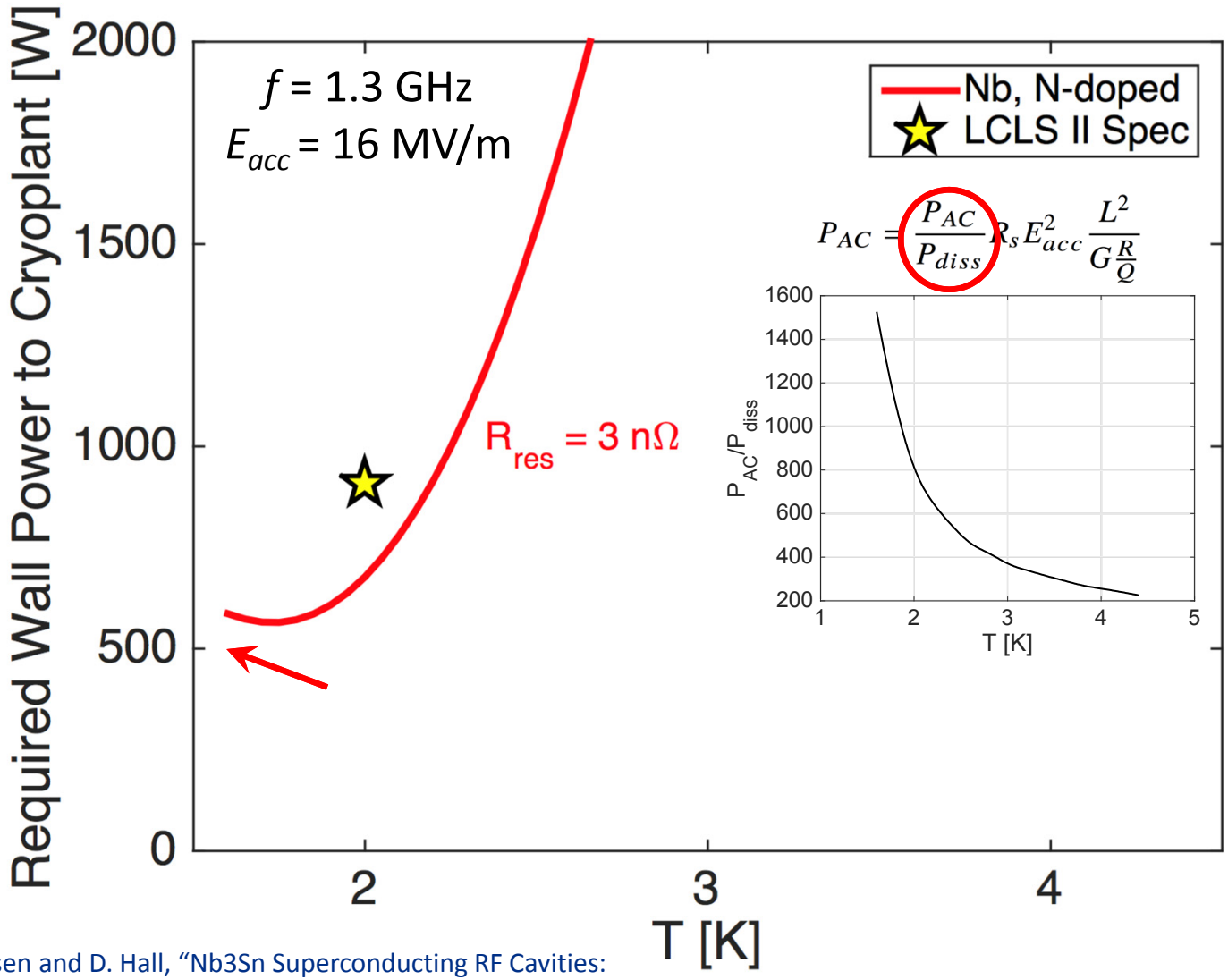

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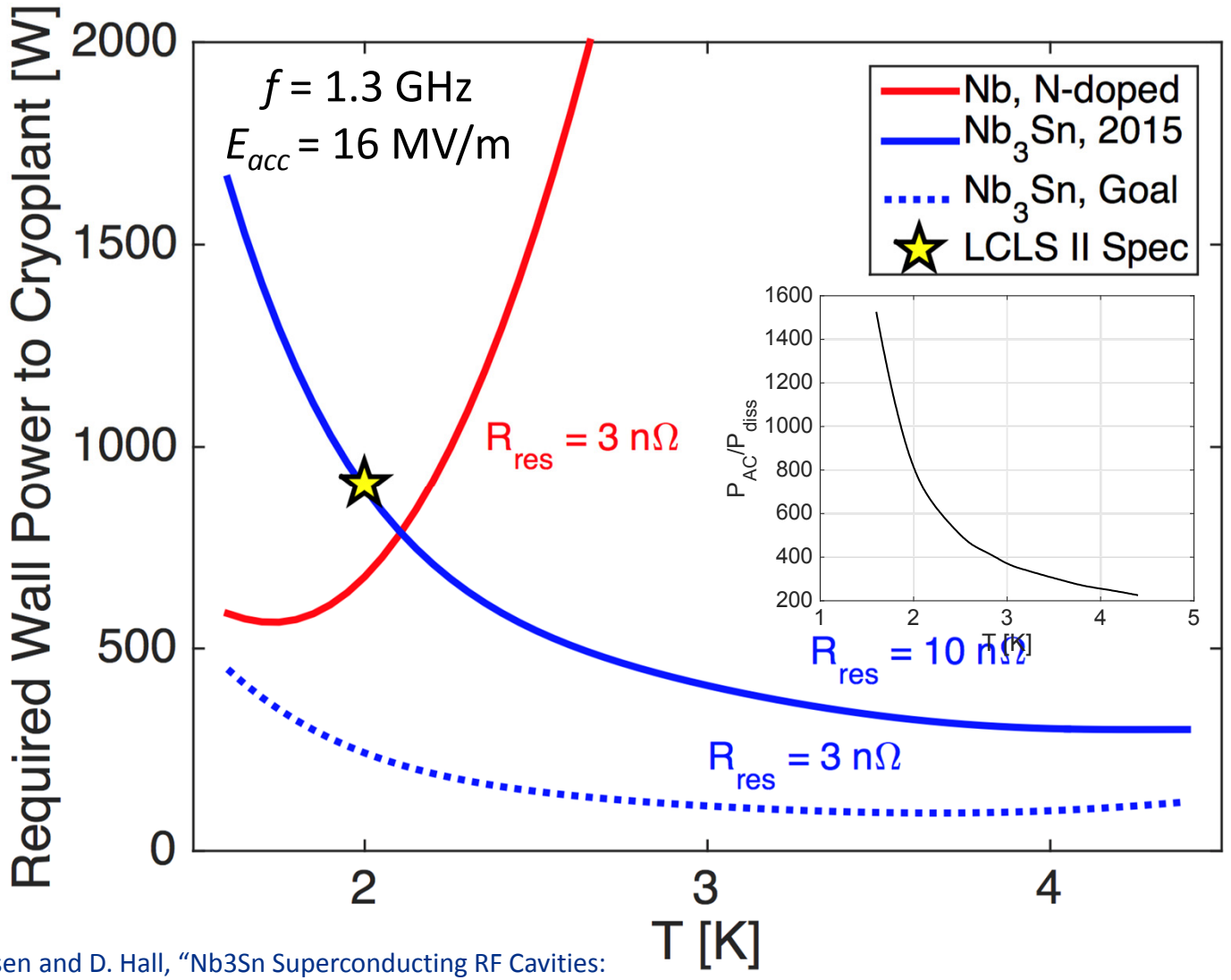

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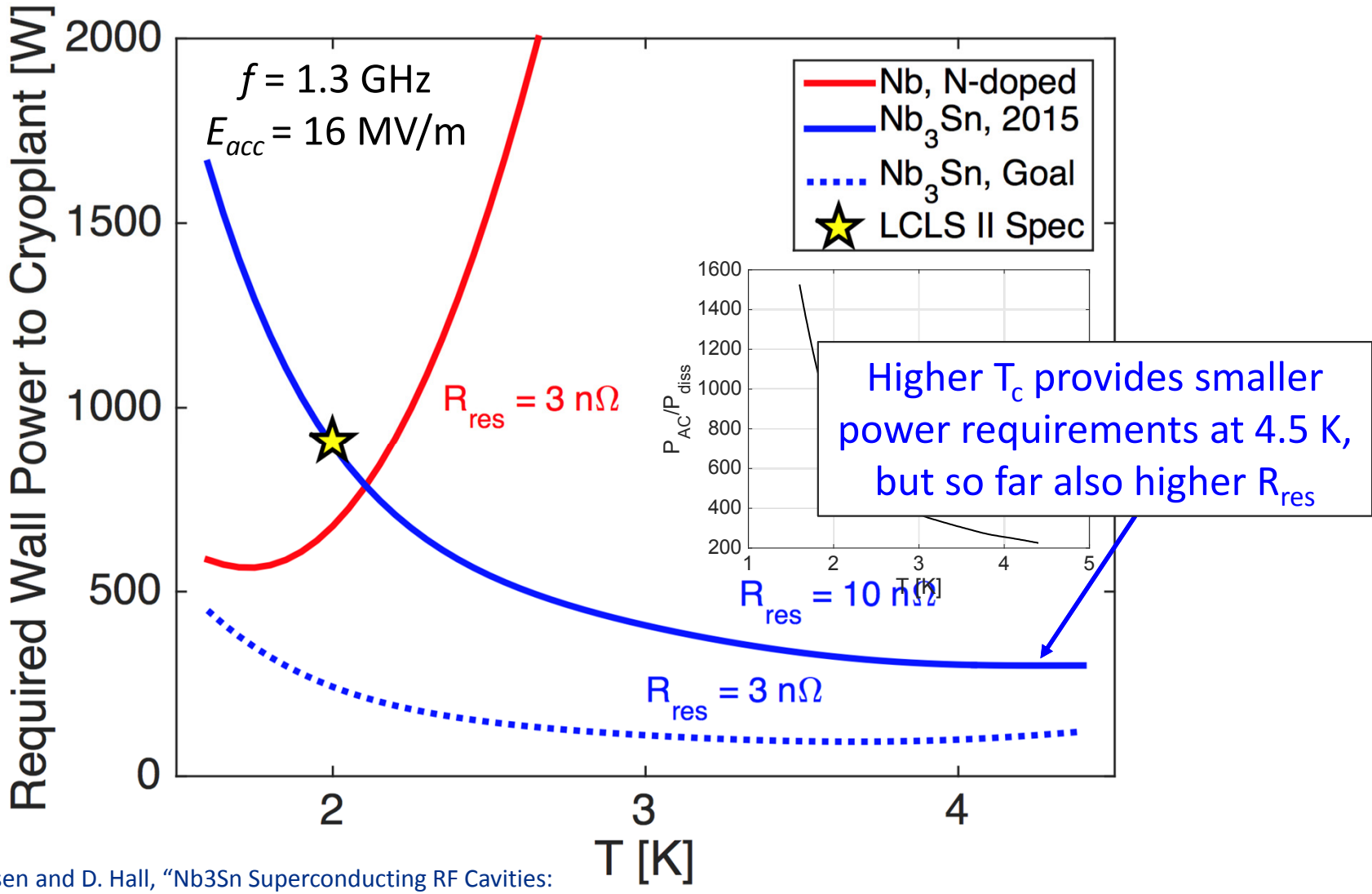

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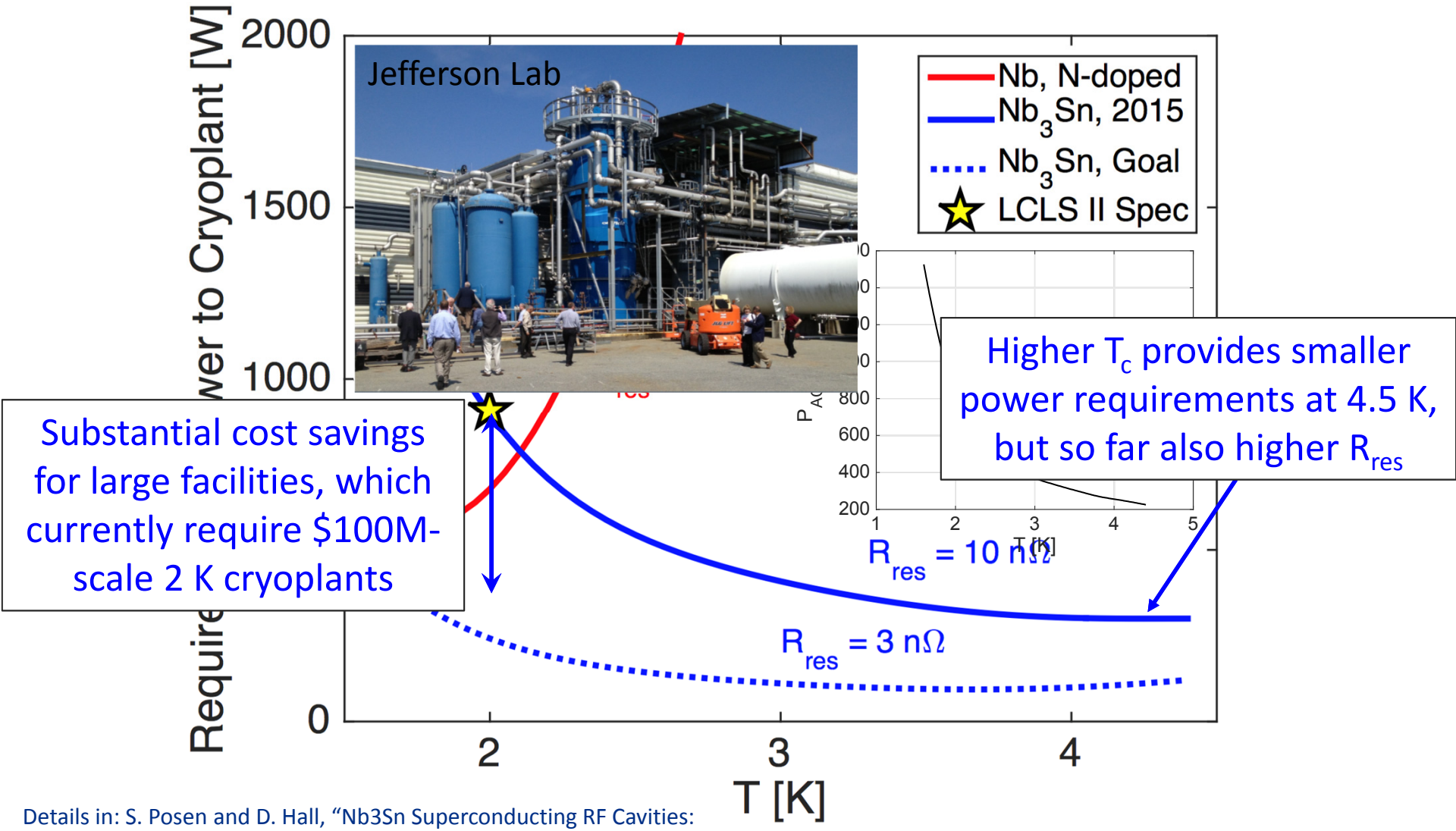

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Power Required to Cryoplant for Each 1.3 GHz Cell

Substantial cost savings for large facilities, which currently require $100M-scale 2 K cryoplants

Higher T_c provides smaller power requirements at 4.5 K, but so far also higher R_{res}

4K GM-JT CRYOCOOLER SERIES

Sumitomo

Performance Specifications

Model Number	CG304SC	CG308SC	CG310SC
3rd Stage Capacity* Watts @ 4.3 K (50/60 Hz)	1.0/1.2	3.0/3.5	4.2/5.0
Electrical Supply 50/60 Hz	3 phase, 200 V		
Power Consumption 50/60 Hz	4.5/5.4	5.1/6.4	5.1/6.4
Cooling Water L/min. (gal./min.)	5.5-6.5 (1.5-1.7)	8.0-10.0 (2.1-2.6)	8.0-10.0 (2.1-2.6)
Refrigeration Unit Weight kg (lbs.)	18.0 (39.7)	35.0 (77.2)	50.0 (110.2)
Compressor Weight kg (lbs.)	205 (452)	220 (485)	220 (485)
Maintenance Hours	10,000		

Standard Scope of Supply

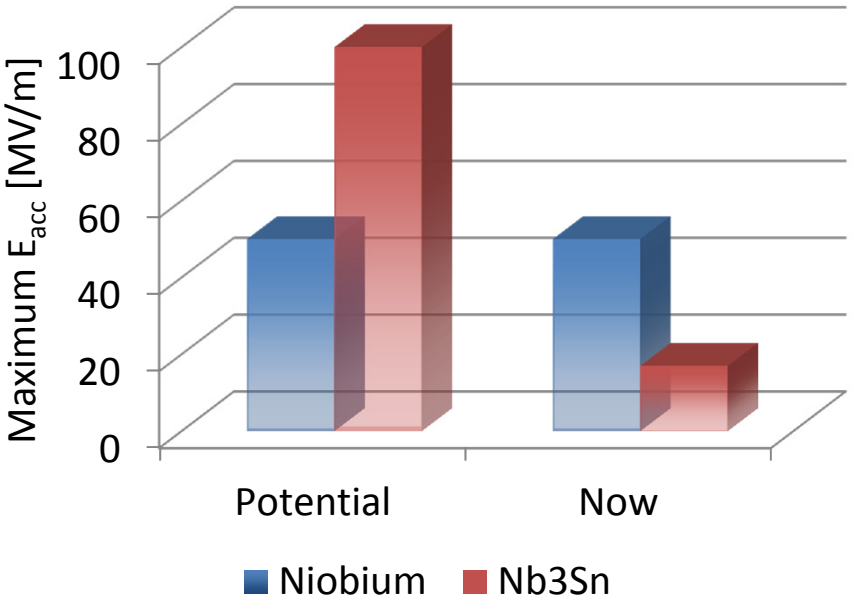
- V304SC, V308SC or V316SC Cold Head
- U304CWA or U308CWA Compressor
- Helium Vapor Gauge (with CG308SC and CG310SC models)
- Hydrogen Vapor Gauge
- 6 m (20 ft.) Helium Gas Lines
- 6 m (20 ft.) Valve Motor Cable
- Tool Kit

9-cell cavity 4.5 K dissipation at 10 MV within reach of commercial 5 W cryocooler—could enable new industrial accelerator applications

Details in: S. Posen and D. Hall, Fabrication, Results, Properties

Maximum Accelerating Field

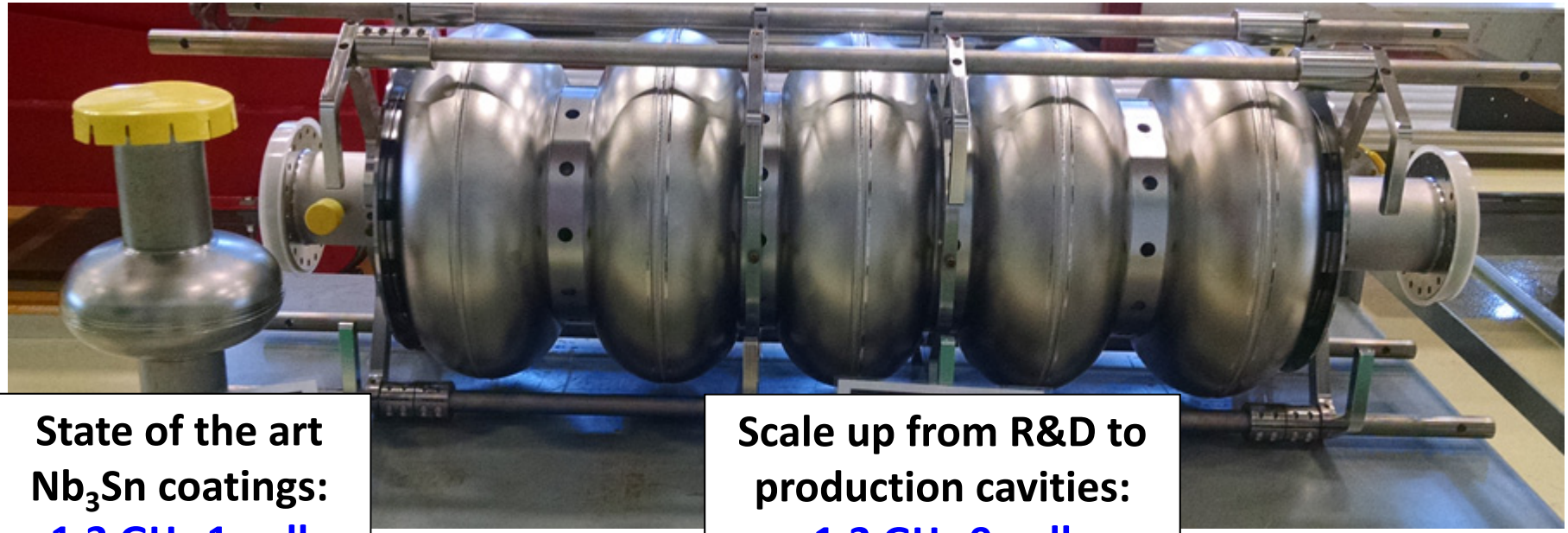
- For high gradient applications, the superheating field of Nb_3Sn is predicted to be twice that of niobium, potentially providing twice as large acceleration per unit length
- This is significantly beyond current performance levels
- R&D to avoid microstructural inhomogeneities may improve maximum fields



2. Fermilab Nb_3Sn Cavity Coating Infrastructure

Fermilab Nb_3Sn SRF Program

- Goals of program:
  - Increase maximum E_{acc}
  - Push to even higher Q_0
  - Scale up from R&D-style cavities to production-style cavities
- Funded by 2016 DOE Early Career Award



State of the art Nb_3Sn coatings:
1.3 GHz 1-cell

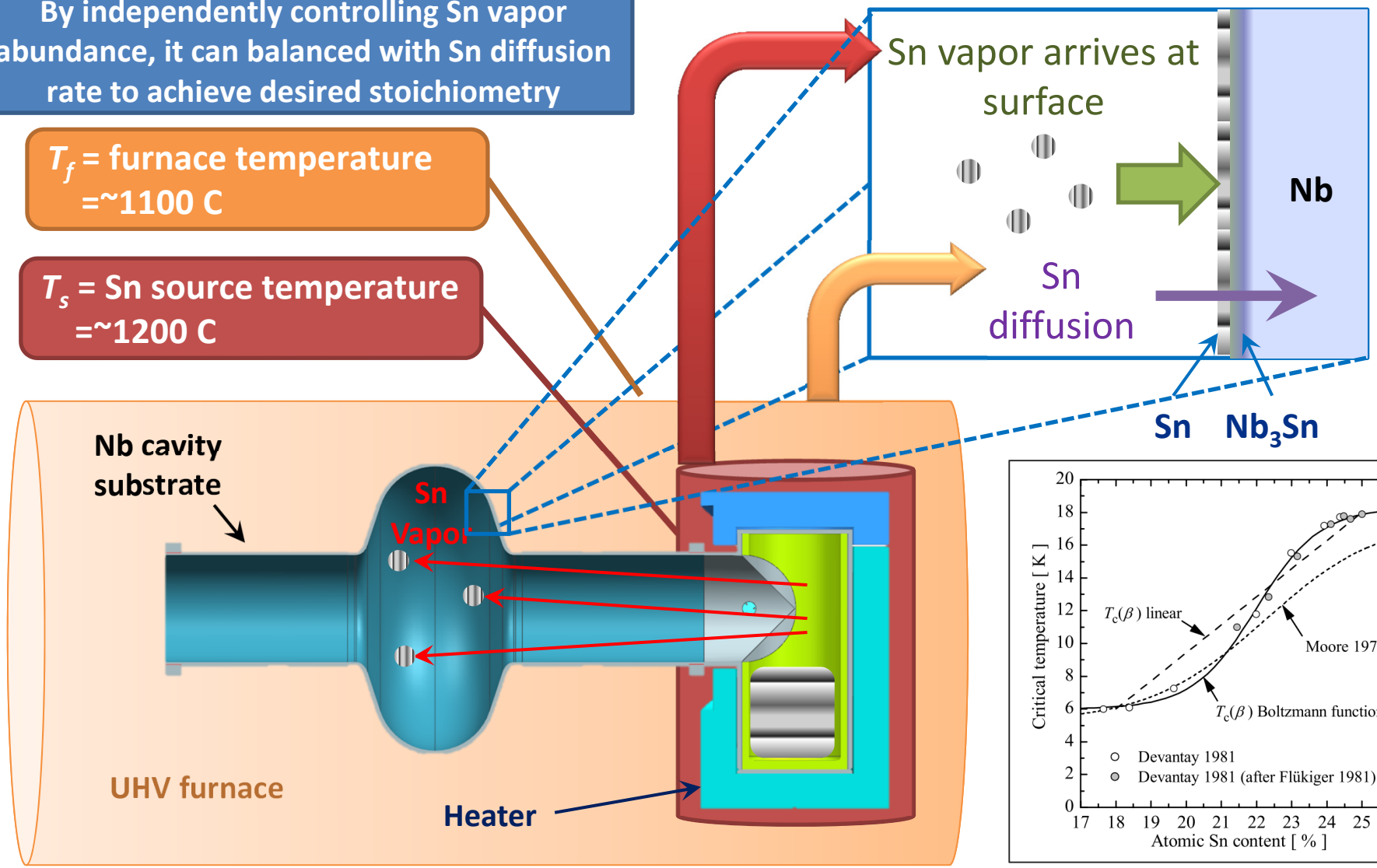
Scale up from R&D to production cavities:
1.3 GHz 9-cell
650 MHz 5-cell (above)

Coating Mechanism: Vapor Diffusion

By independently controlling Sn vapor abundance, it can balanced with Sn diffusion rate to achieve desired stoichiometry

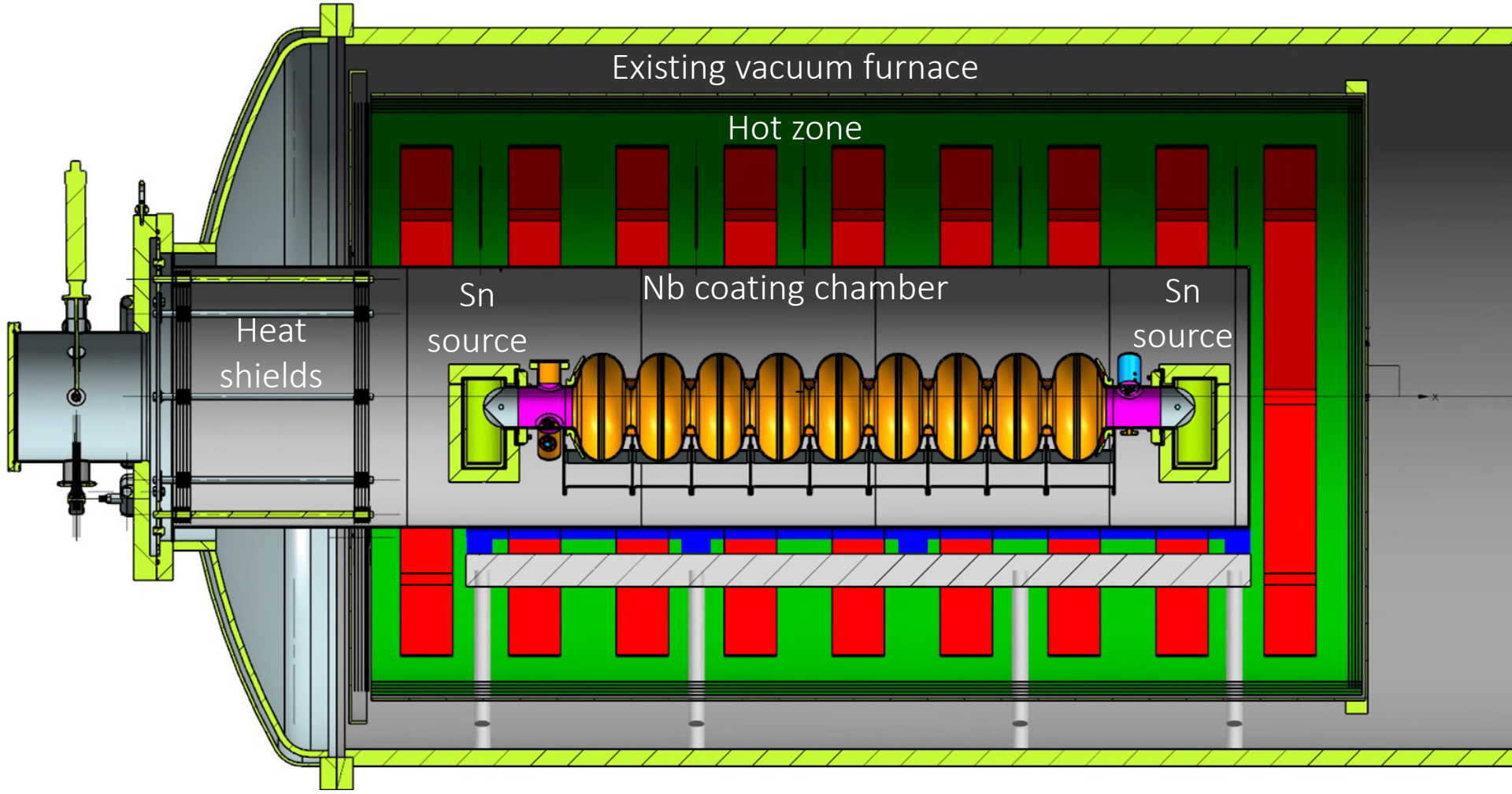
T_f = furnace temperature =~1100 C

T_s = Sn source temperature =~1200 C



Technique development: Saur and Wurm, Die Naturwissenchaften 1962, Hillenbrand et al. IEEE Transactions on Magnetics 1977, Peiniger et al, SRF'88.

Fermilab Nb_3Sn Coating Apparatus



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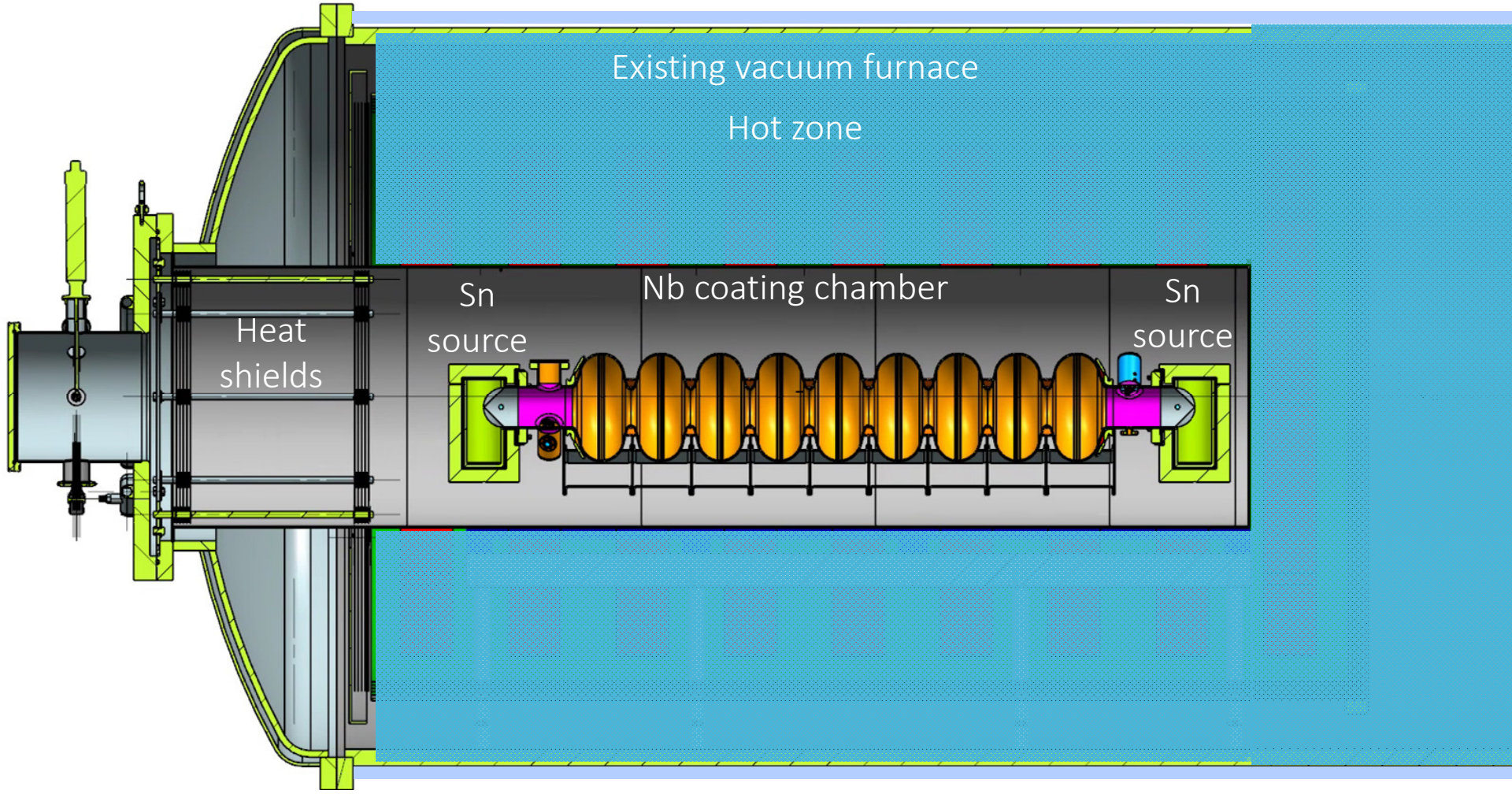
Fermilab Nb_3Sn Coating Apparatus



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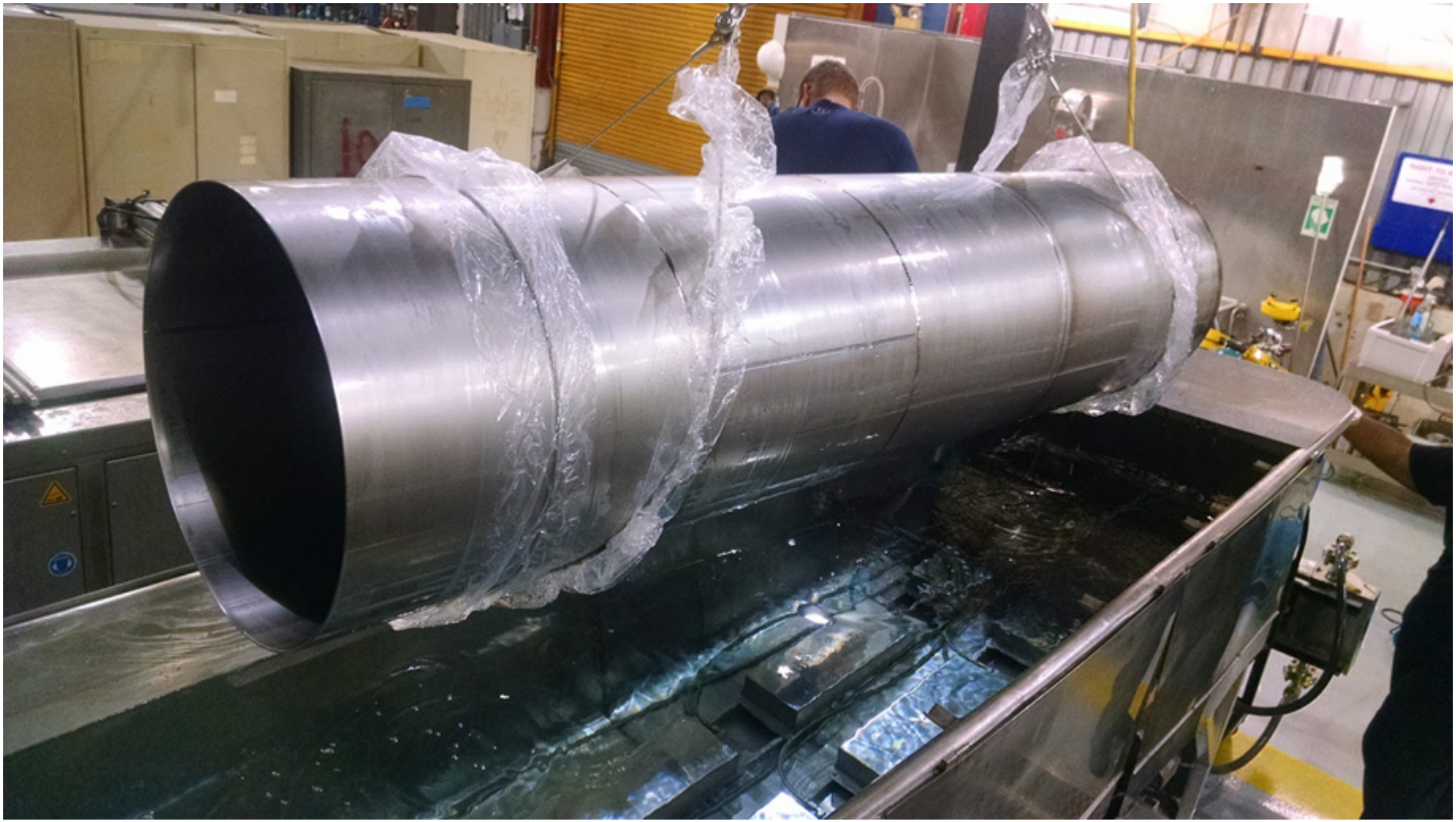
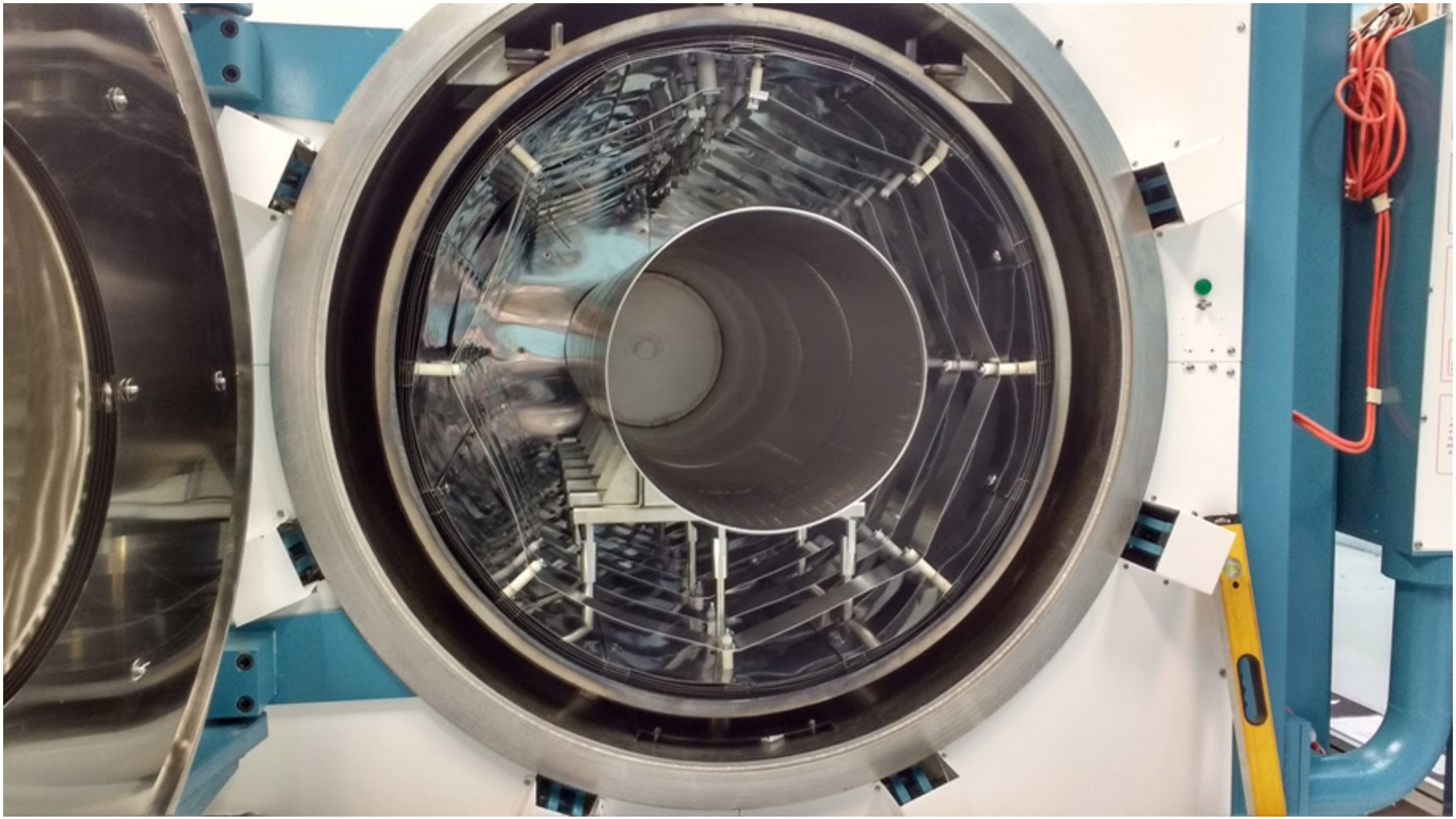
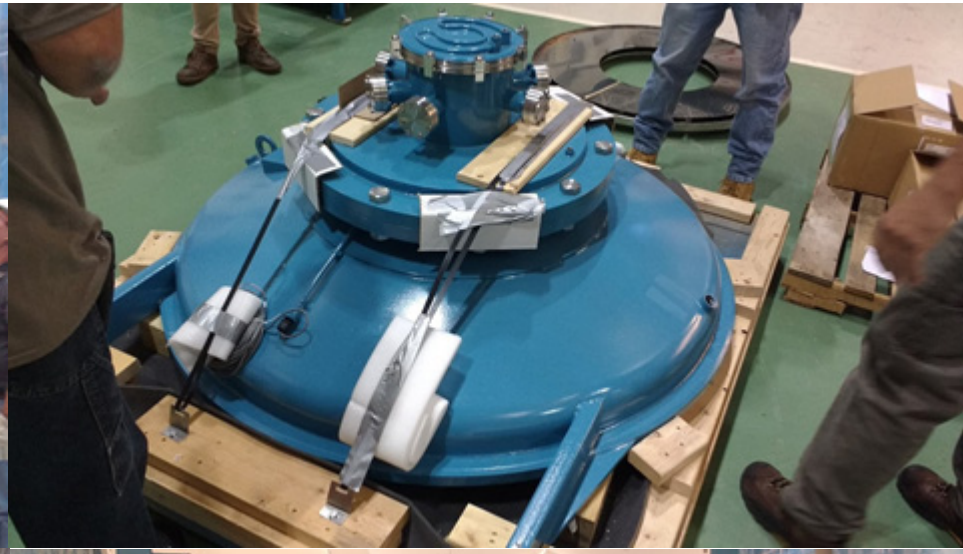
Nb Coating Chamber (protects furnace from Sn)

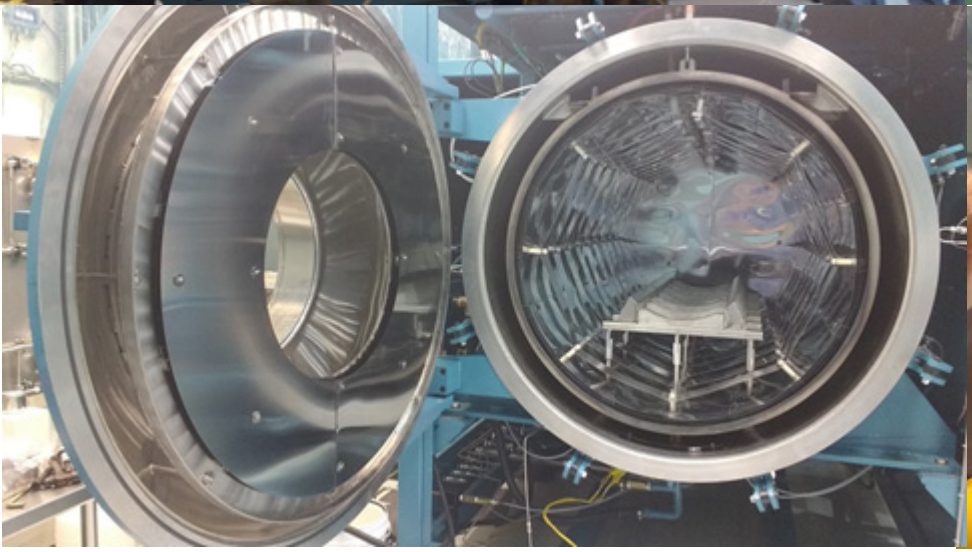


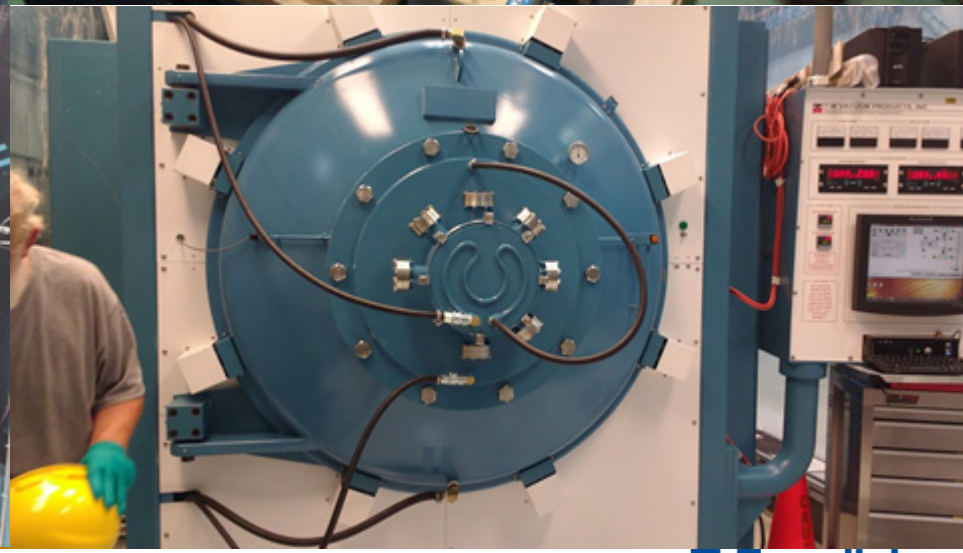
Chamber Protrudes Beyond Heat Shields



Installation of New Door







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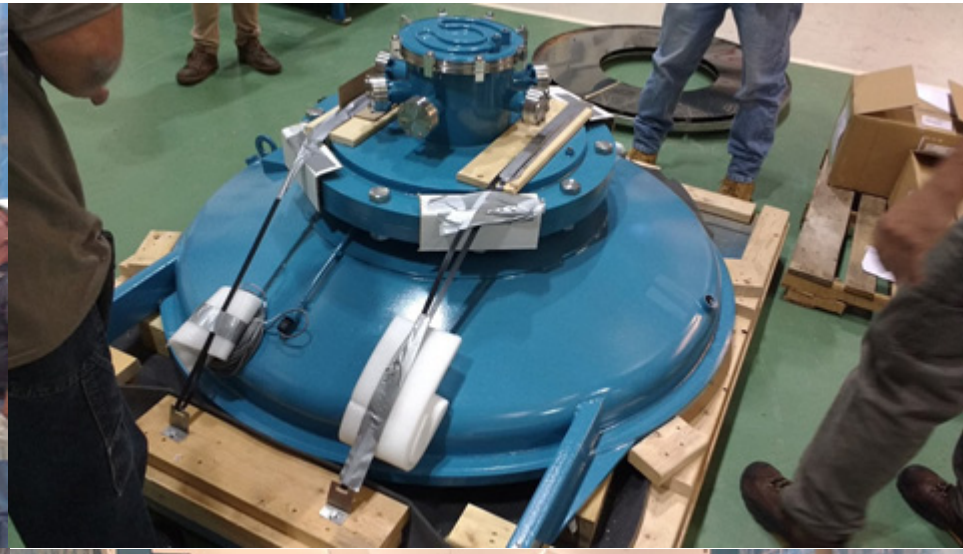

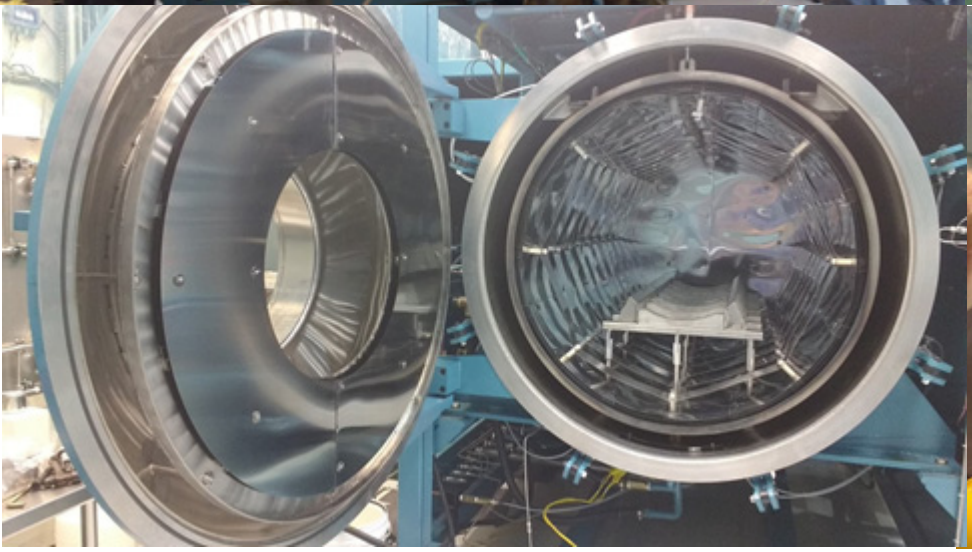

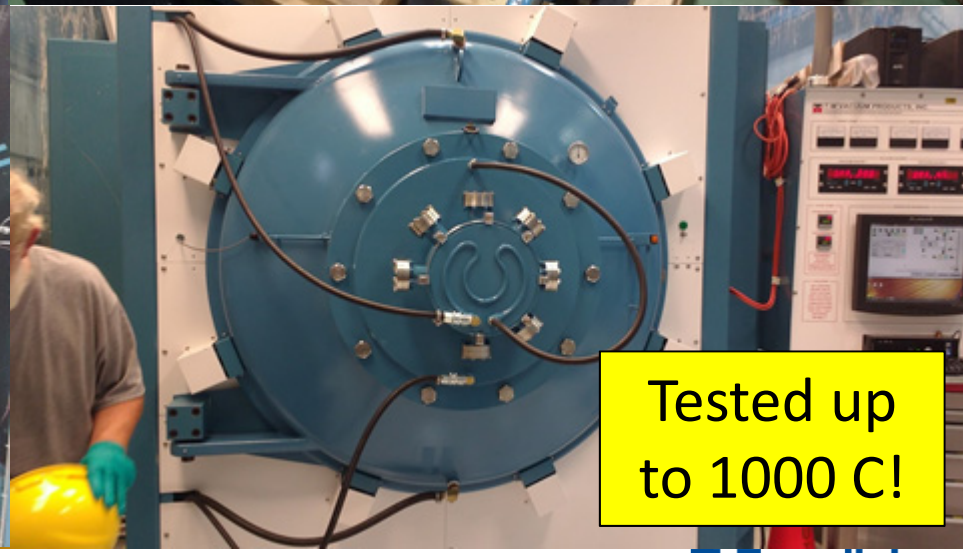

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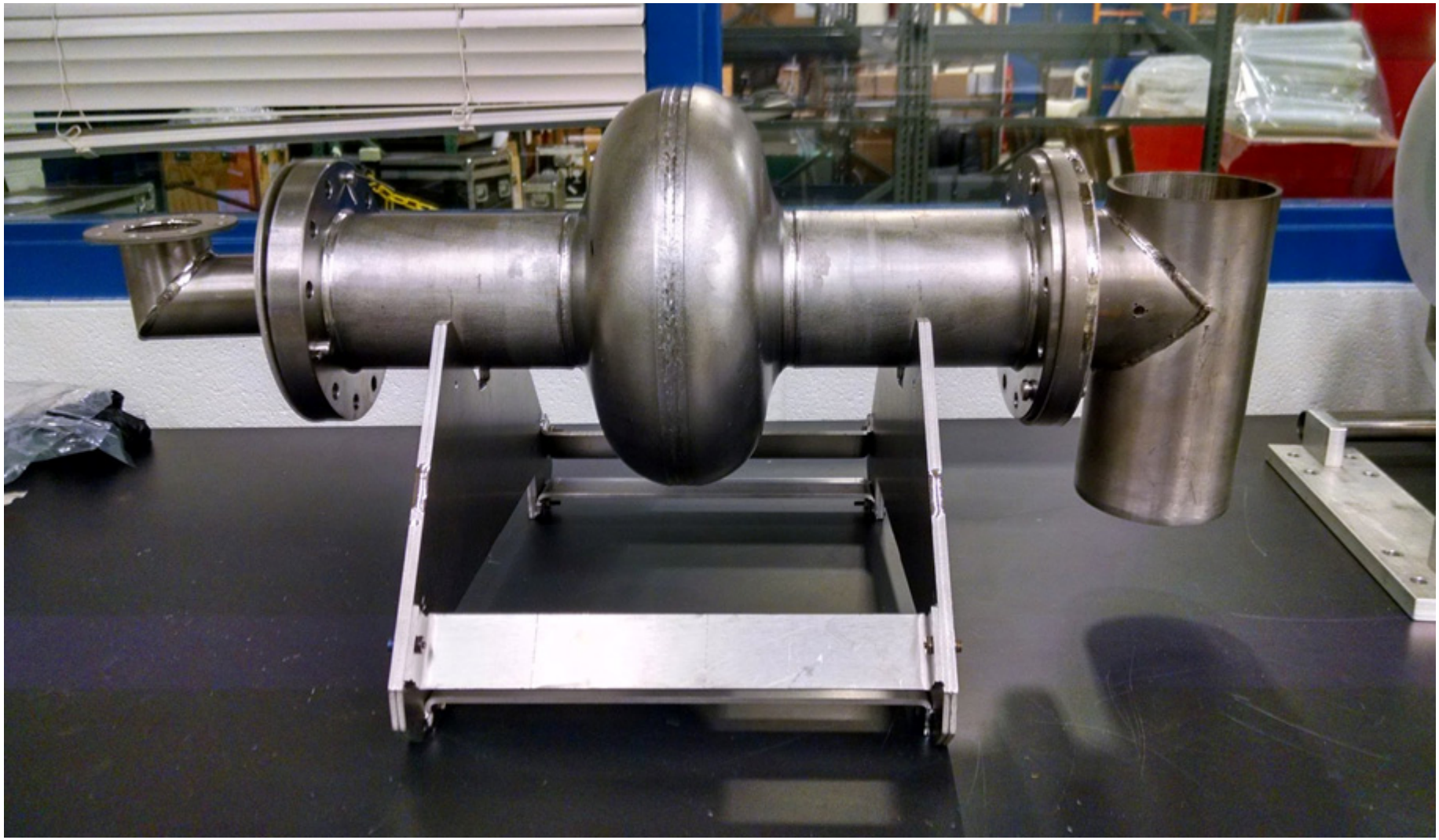
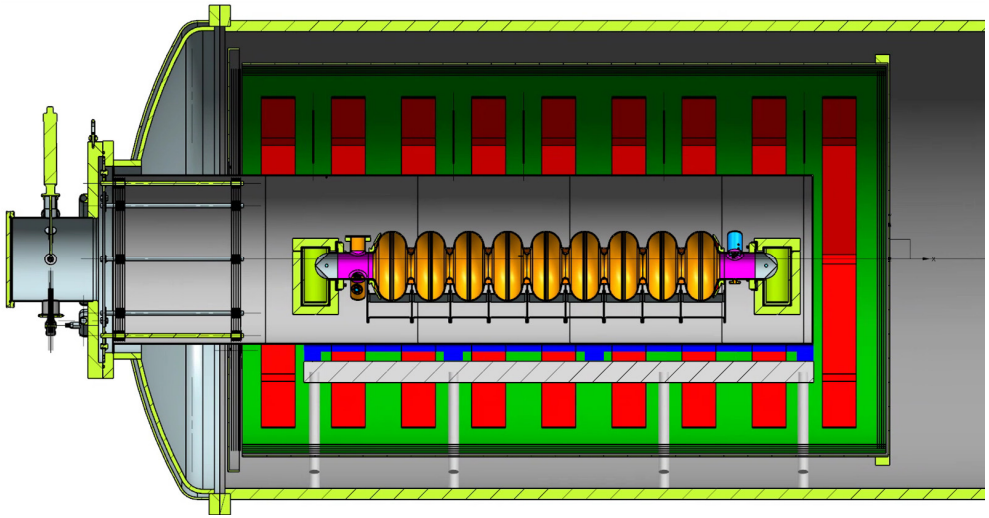
Single Cell Coating Setup



Outlook for Nb_3Sn Coatings at Fermilab

- Continued commissioning over next weeks: thermocouple calibration, tin heater power, installation of long-reach positioning forklift, slow pumpdown system, operational readiness clearance
- Coating of first samples, microscopic analysis, measure T_c and critical fields
- In early cavities, aim for performance equal to state of the art



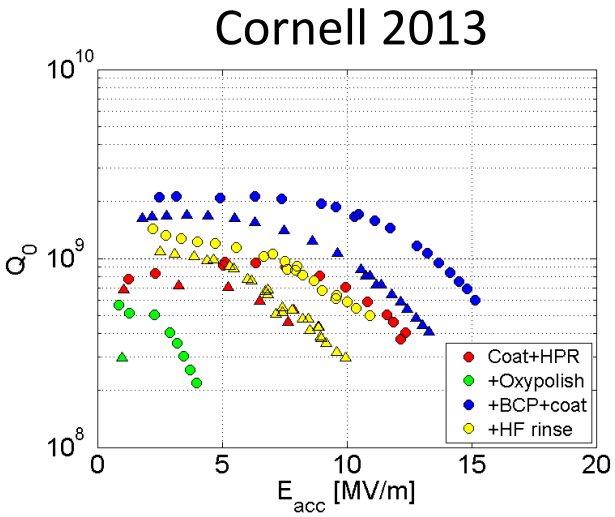
3. Analysis of Microstructure of Nb_3Sn Coatings

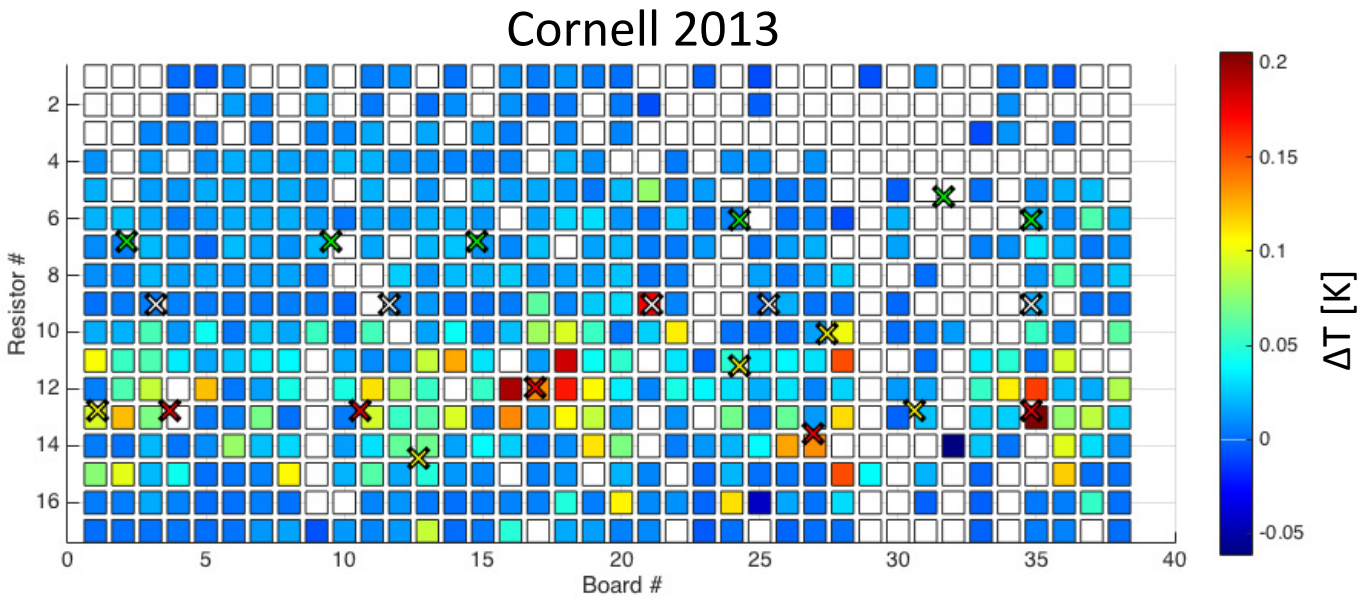
Nb_3Sn Microscopic Analysis

- While building up infrastructure, have been performing microscopic studies on Nb_3Sn-coated samples from Cornell
- Goals:
  - Understand root cause of poor performance in cavity coated at Cornell in 2013 to prevent similar problems in future coatings
  - Improved understanding of growth of Nb_3Sn grains during coating process
- Fermilab microscopy by Yulia Trenikhina:

Coupons from Poorly Performing Cavity

- Poorly performing cavity coated in 2013
- In collaboration with Cornell, both labs retested it and cut out coupons from regions that showed high R_s and low R_s (hot spots and cold spots)





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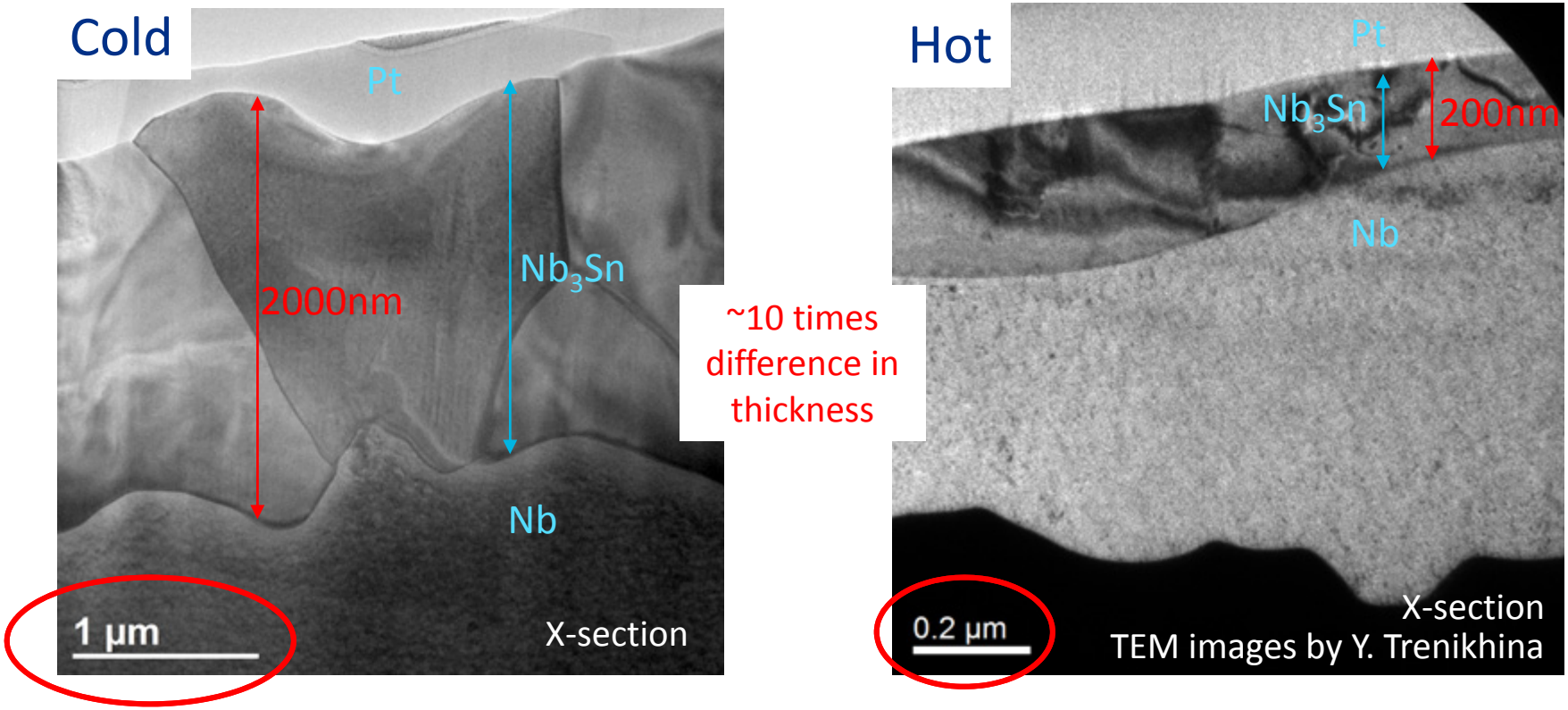
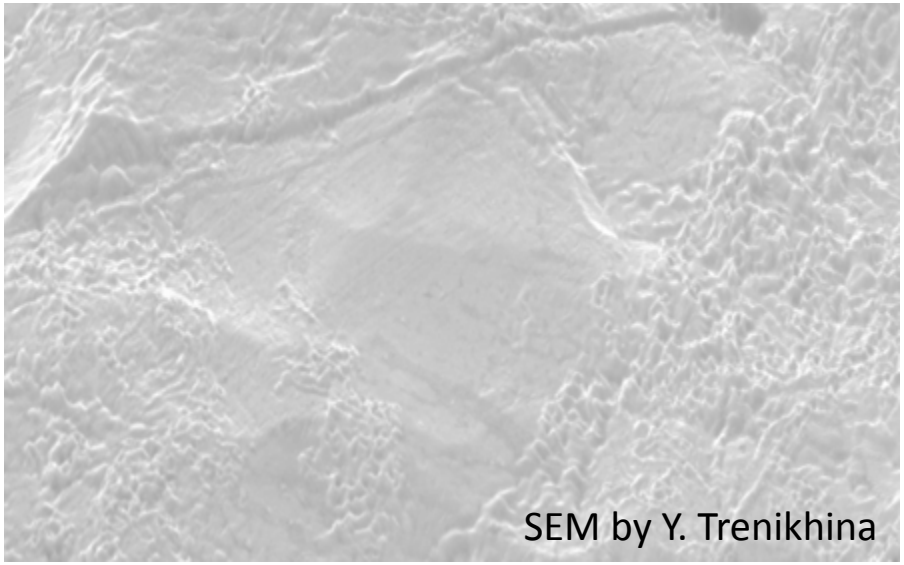
Thin Coatings in High Dissipation Hot Spots

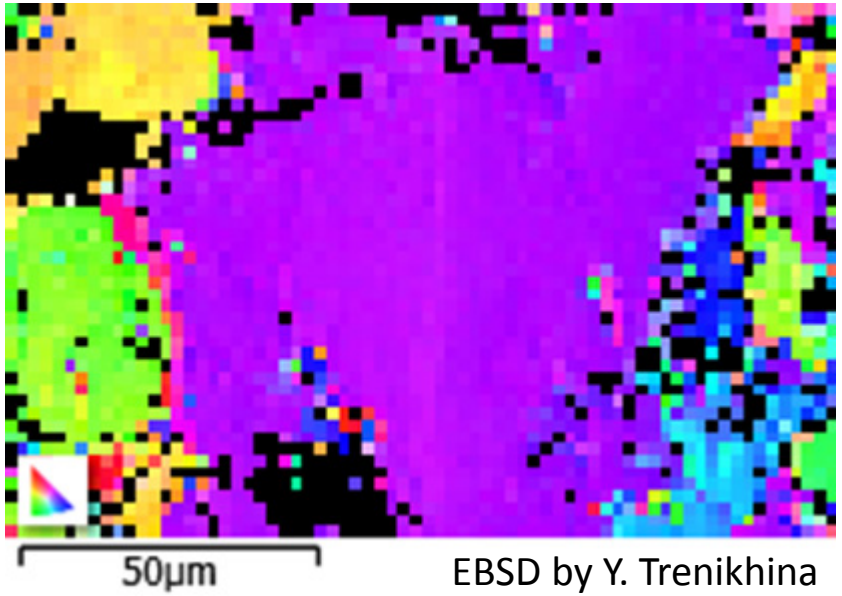


- Regions with highest dissipation show very thin coatings, not thick enough to fully screen RF currents from Nb and intermediate Nb-Sn phases below Nb_3Sn layer

Thin Regions are Unusually Large Grains

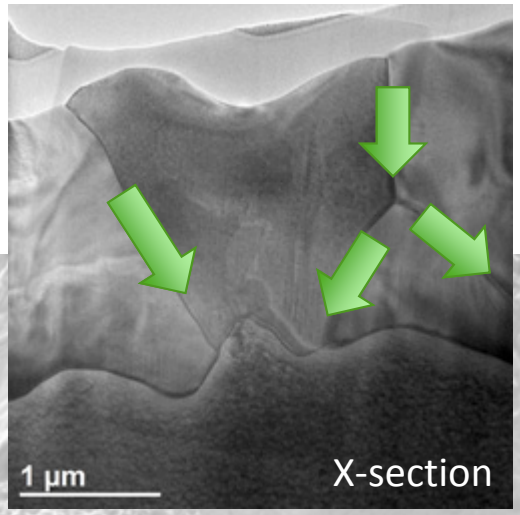
- EBSD analysis of grain orientation reveals that the thin regions in the hot spots are in fact large grains, with diameter ~100 microns vs ~1 micron for standard Nb_3Sn grains

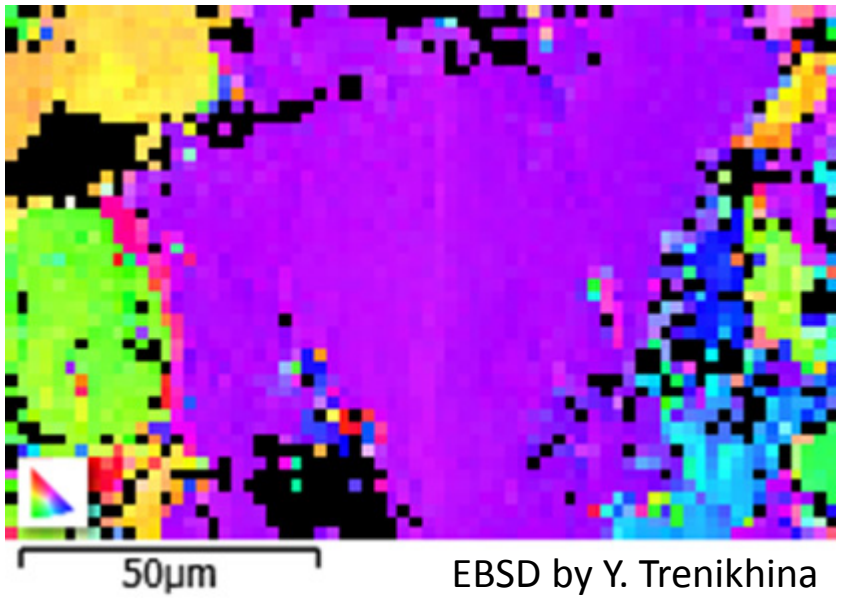




Thin Regions are Unusually Large Grains

- EBSD analysis of grain orientation reveals that the thin regions in the hot spots are in fact large grains, with diameter ~100 microns vs ~1 micron for standard Nb_3Sn grains
  - This is consistent with mechanism for growth of grains: diffusion of tin to interface via grain boundaries

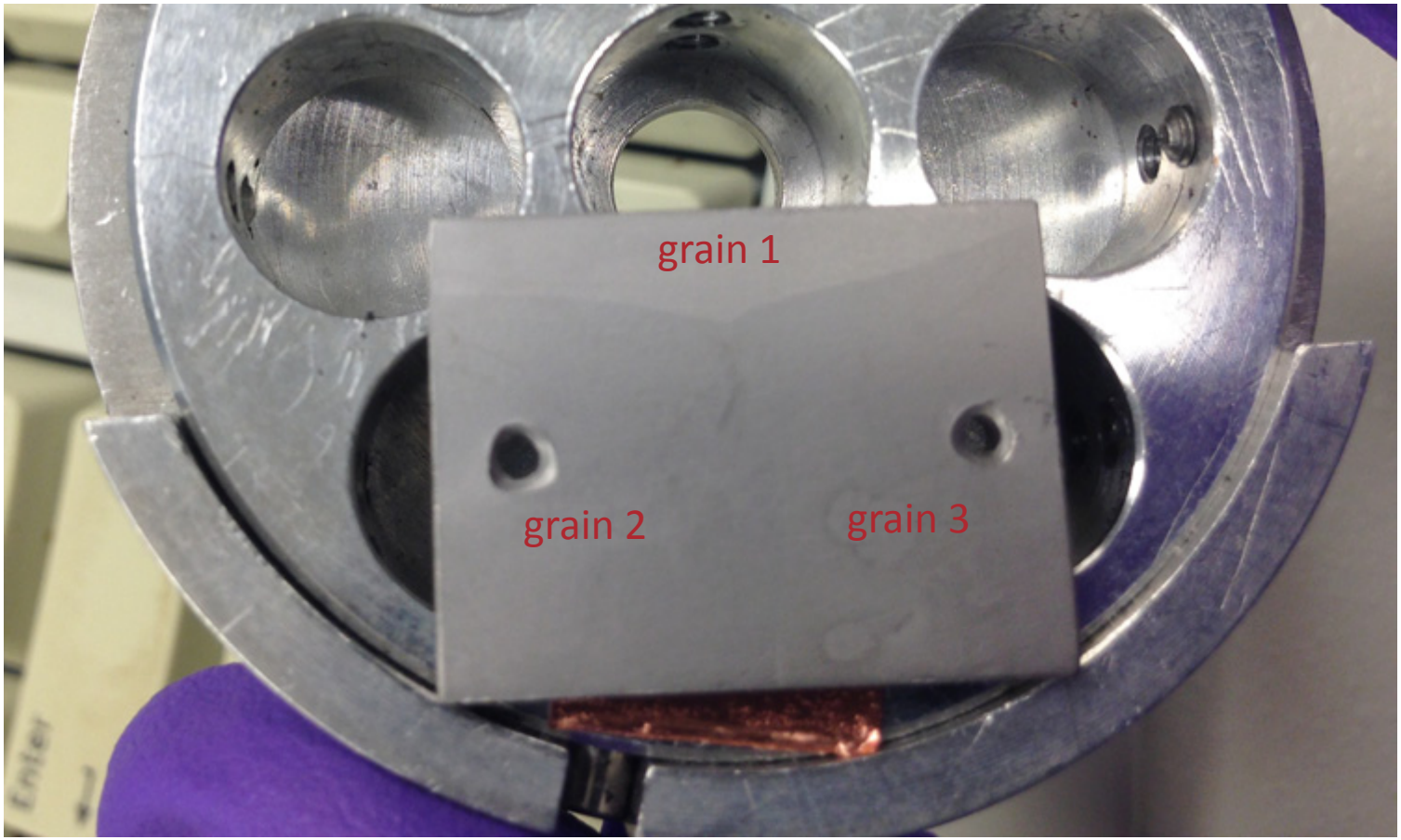




EBSD by Y. Trenikhina

Nb3Sn-Coated Large Grain Nb Sample From Cornell

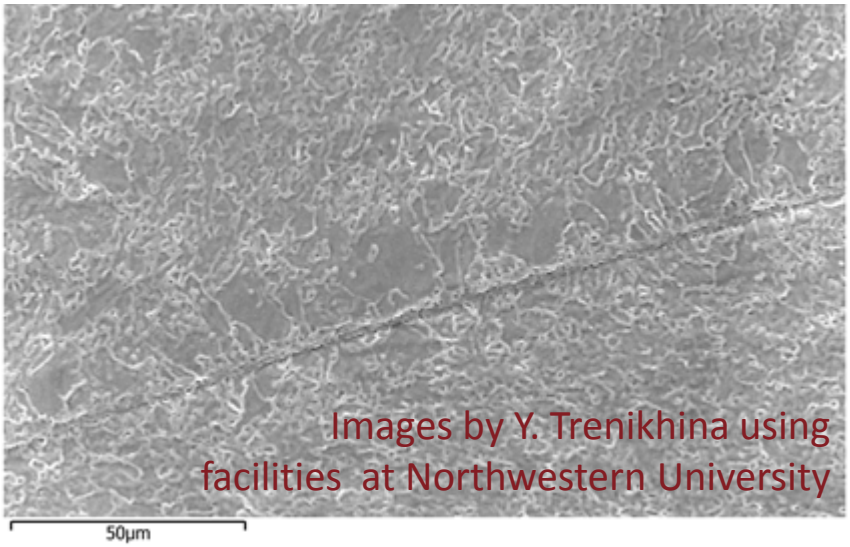
Note: nucleation step skipped during coating



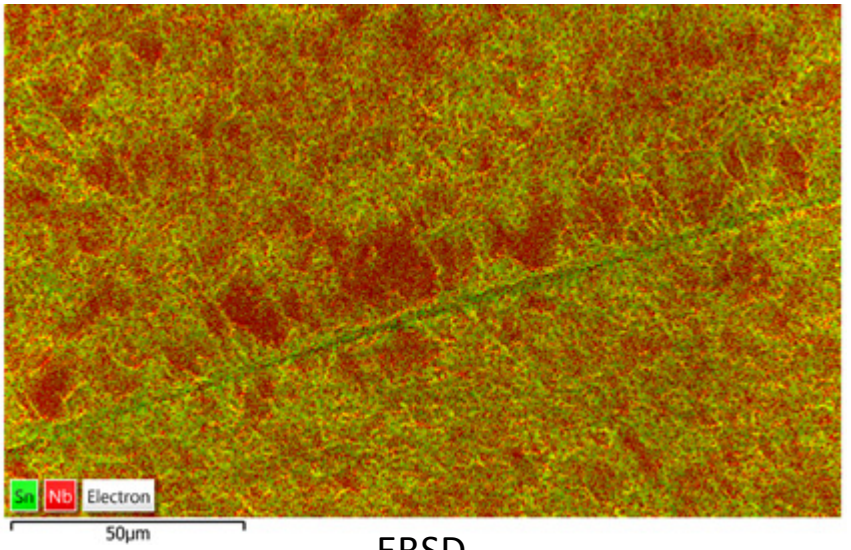
Nb grains visible under the Nb_3Sn coating

EDS Nb3Sn coating on large grains Nb

SEM

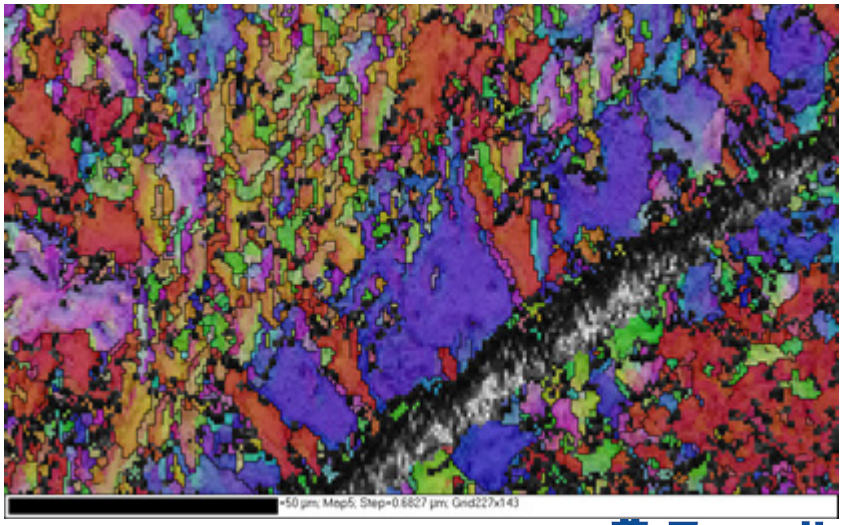


EDS



- EBSD shows similar grain orientations in thin regions
- Possible indications of influence from niobium substrate on Nb_3Sn grain structure – further study needed

EBSD



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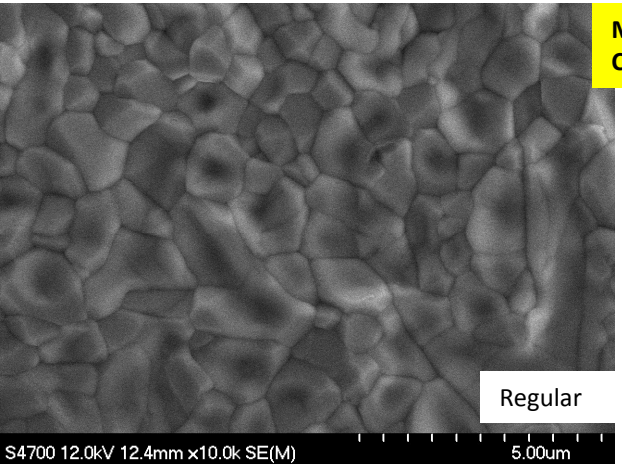
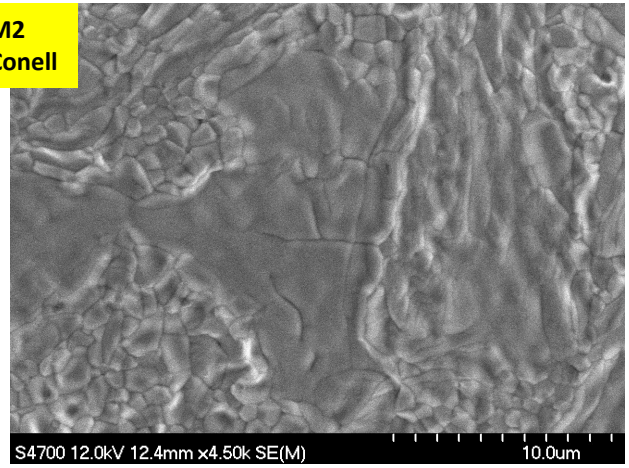
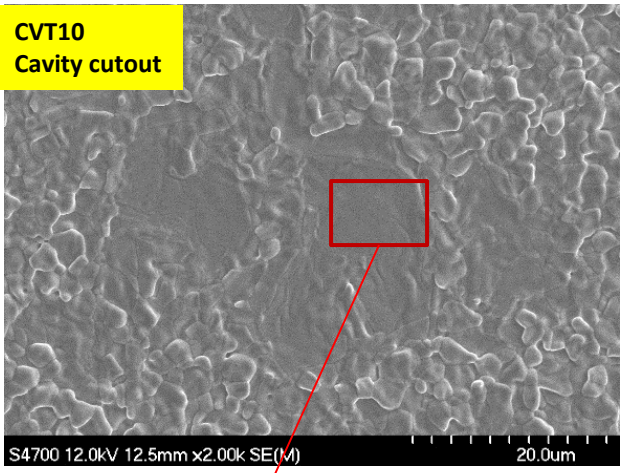
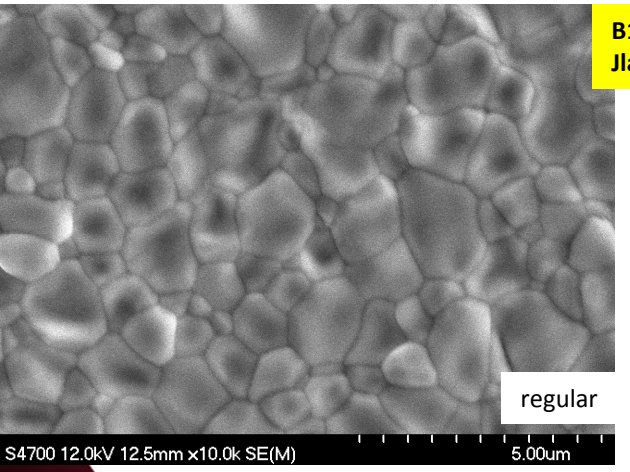
Slide courtesy Uttar Pudasaini and Grigory Eremeev, see also Uttar's talk: WEB1CO02

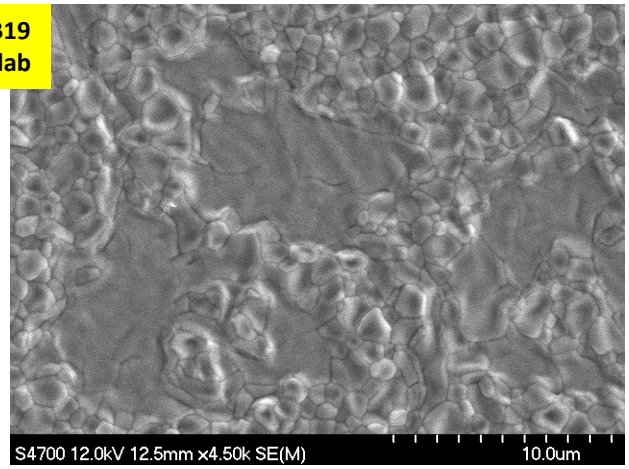
Patchy Areas in Nb_3Sn Coated Samples

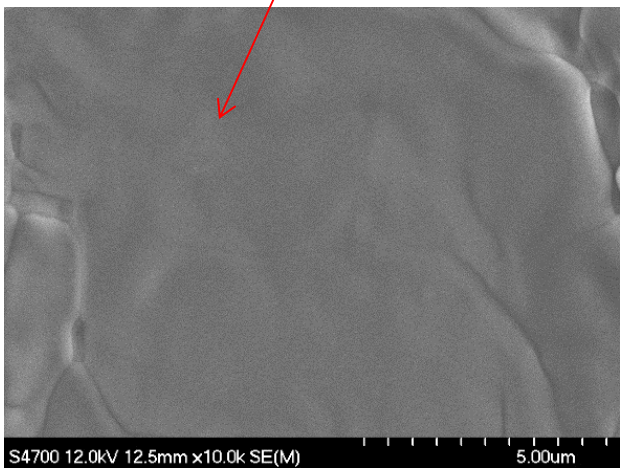










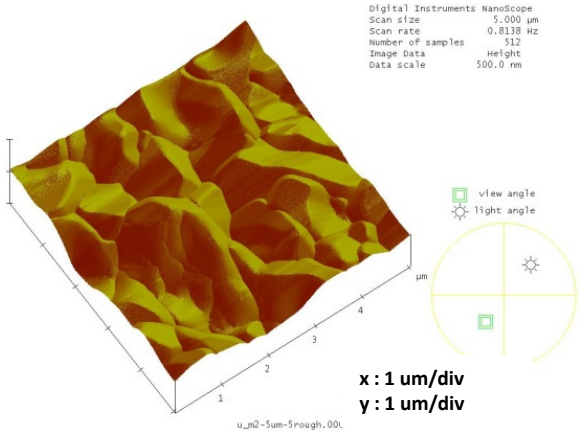


- Low tin content compared to regular areas of the same sample .
- Large grains with less pronounced GB.

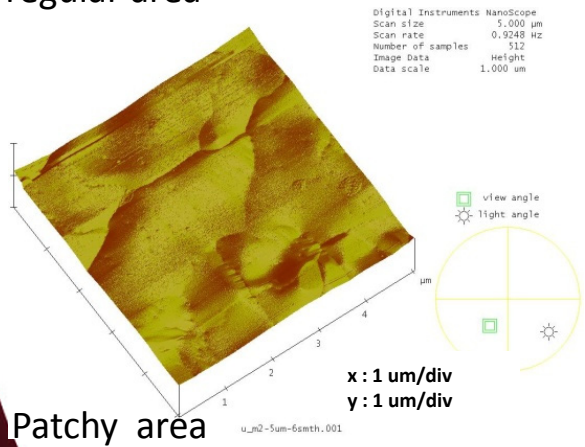
M2 : coated at Cornell, courtesy of Matthias Liepe and Daniel Hall.

Slide courtesy Uttar Pudasaini and Grigory Eremeev, see also Uttar's talk: WEB1CO02

Topography and Cross-section of Patchy Area

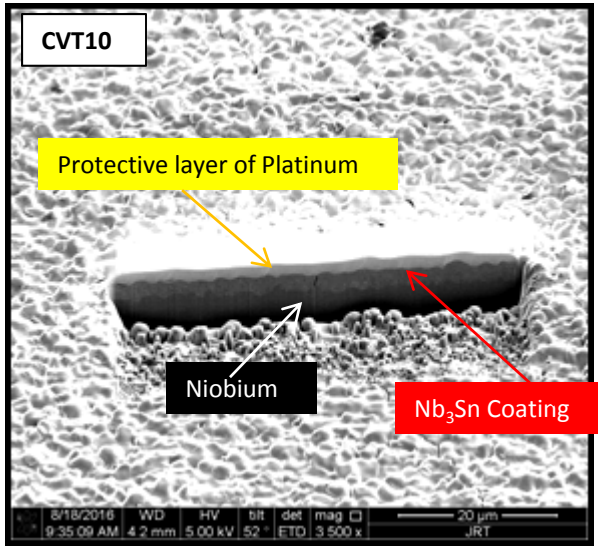


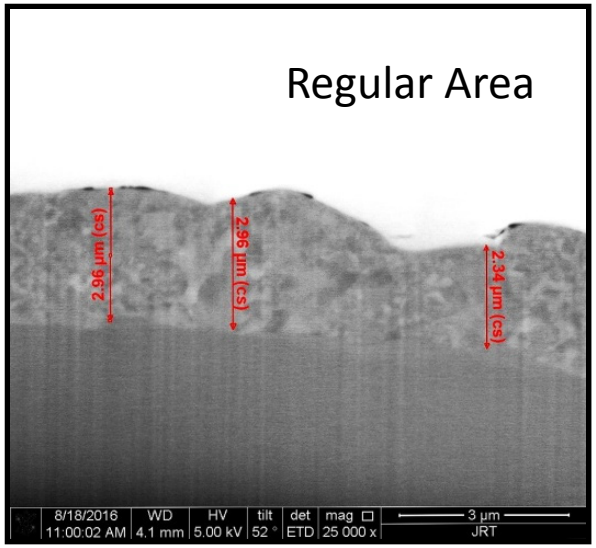
regular area

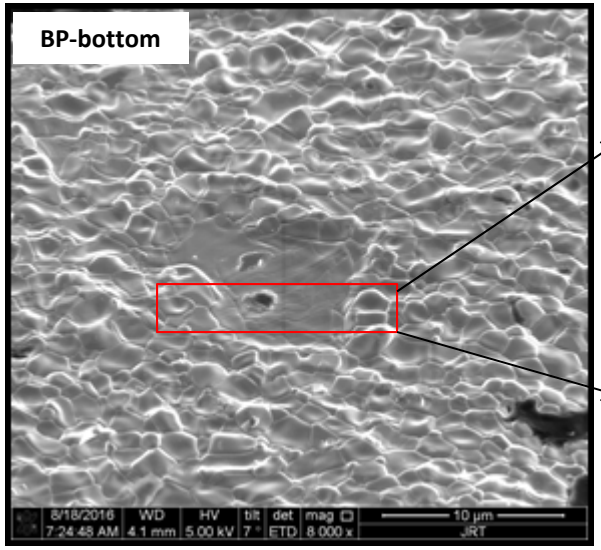


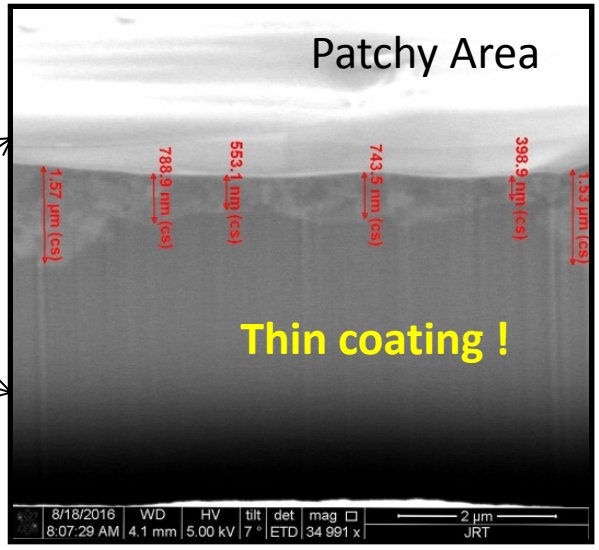
Patchy area

Smoother !









EBSD analysis of patchy area cross-section is in progress.

Microscopic Analysis Outlook

- Thin, large grains appear in coatings both at Cornell and Jefferson Lab – regions are so thin that RF may penetrate through
- Understanding how to avoid forming these regions will be especially important as we look to larger production-style cavities with less uniform conditions, more substrates
- New Fermilab collaboration with David Seidman, Professor of Materials Science and Engineering at Northwestern University
- Continued collaboration with Nb_3Sn SRF researchers at Cornell (including participation in new Center for Bright Beams) and Jefferson Lab
- Looking forward to analyzing first coatings made at Fermilab soon!