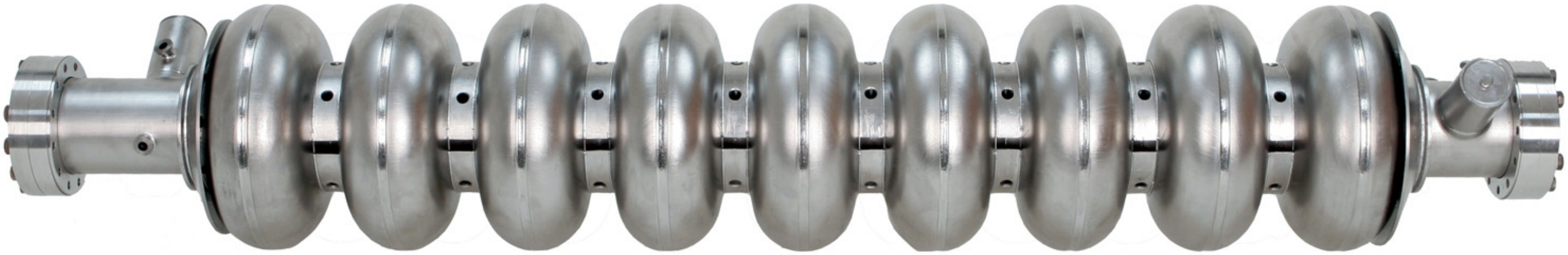
# First Results from New Single-Cell $Nb_3Sn$ Cavities Coated at Cornell University

Daniel Hall

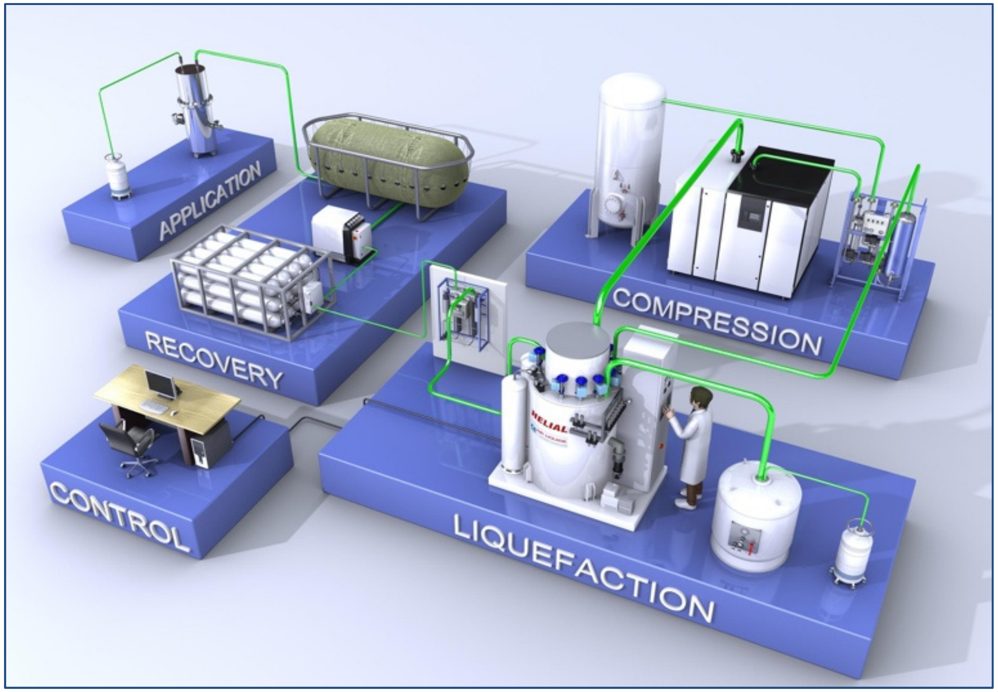
Matthias Liepe

# Superconducting RF

## Continuous bright beams with low emittance



However, the cryogenics plant is costly to build and maintain



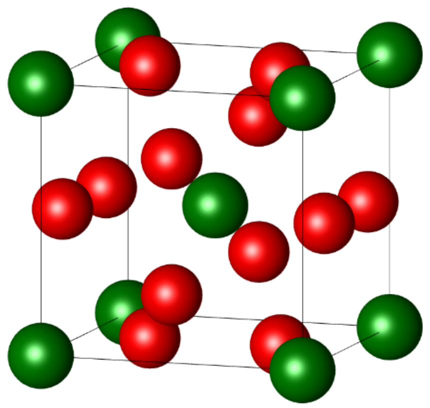
# The case for $Nb_3Sn$

**Higher critical temperature**

→ Operation at 4.2 K

**Higher superheating field**

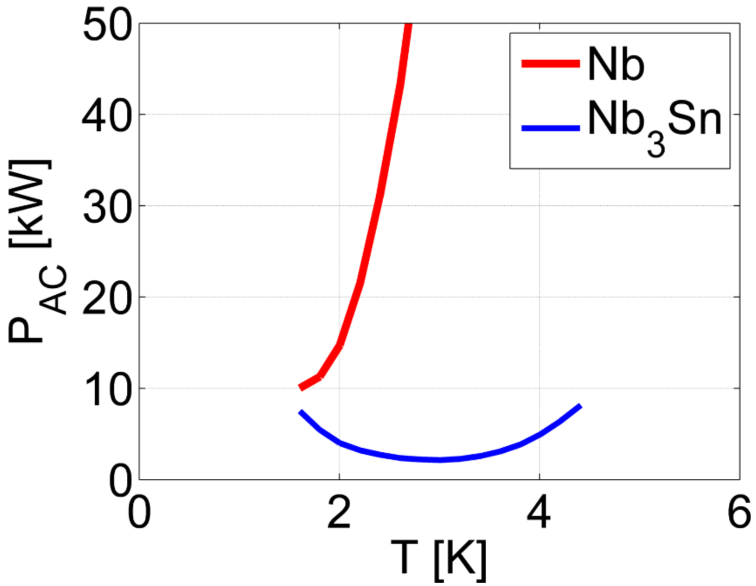
→ Double the limit of niobium



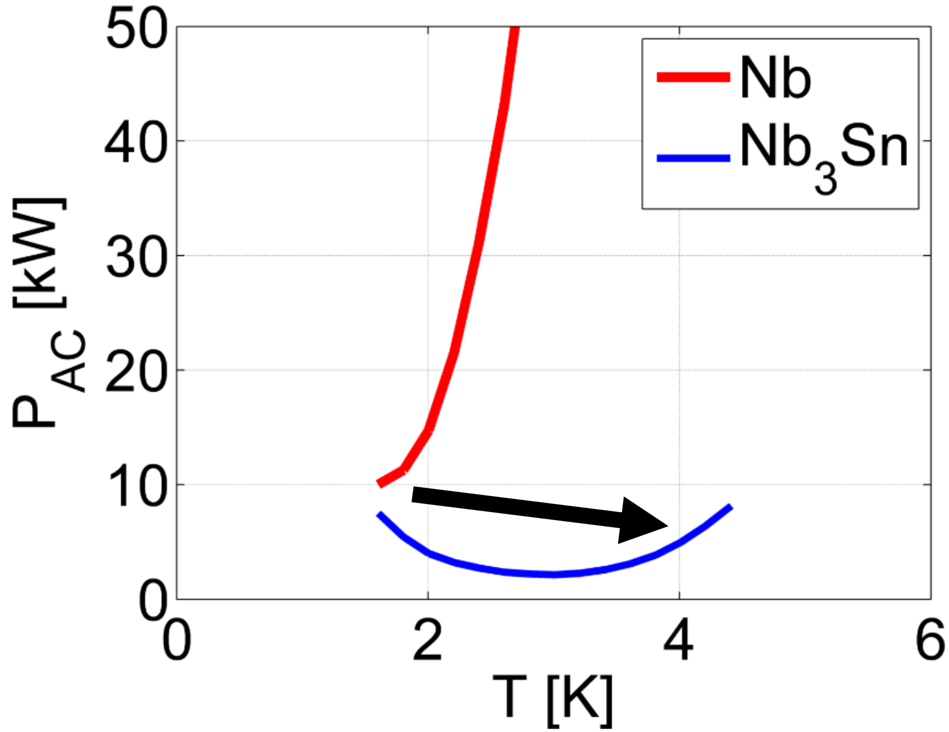
**Green: tin**

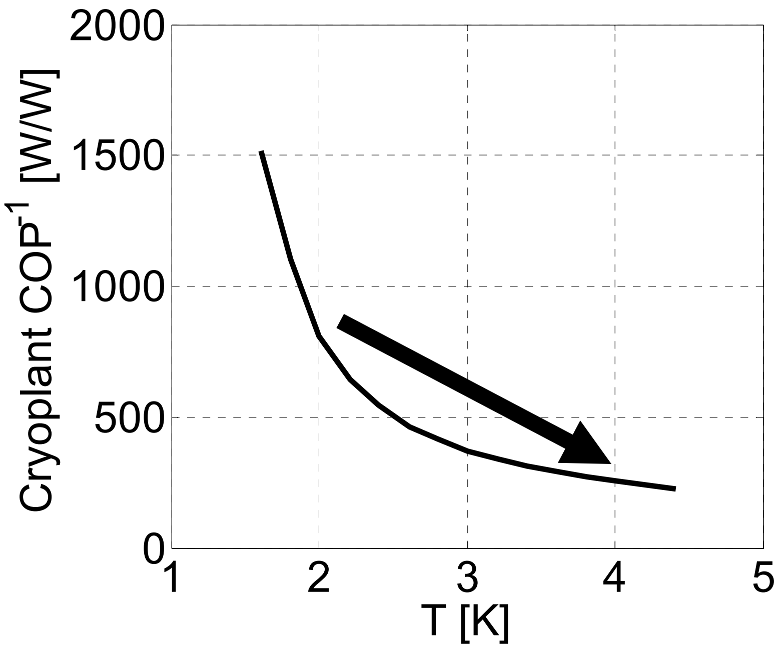
**Red: niobium**

| Parameter | Niobium | $Nb_3Sn$ |
|---|---|---|
| **Transition temperature** | **9.2 K** | **18 K** |
| **Superheating field** | **219 mT** | **425 mT** |
| Energy gap $\Delta/k_bT_c$ | 1.8 | 2.2 |
| $\lambda$ at T = 0 K | 50 nm | 111 nm |
| $\xi$ at T = 0 K | 22 nm | 4.2 nm |
| GL parameter $\kappa$ | 2.3 | 26 |

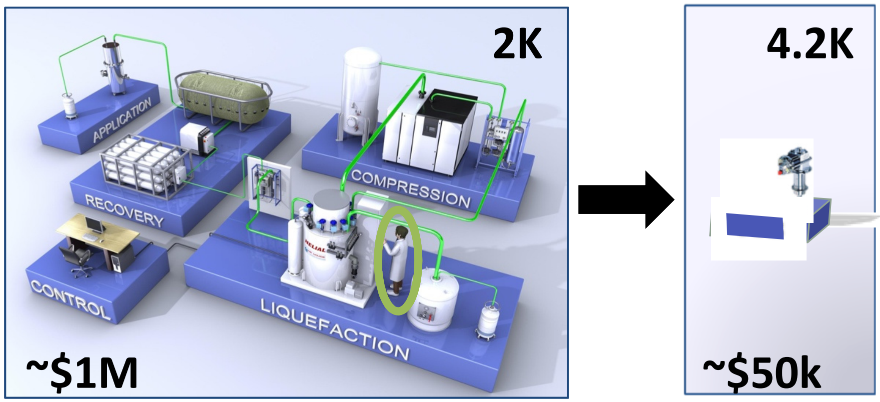


# Operation at 4.2 K



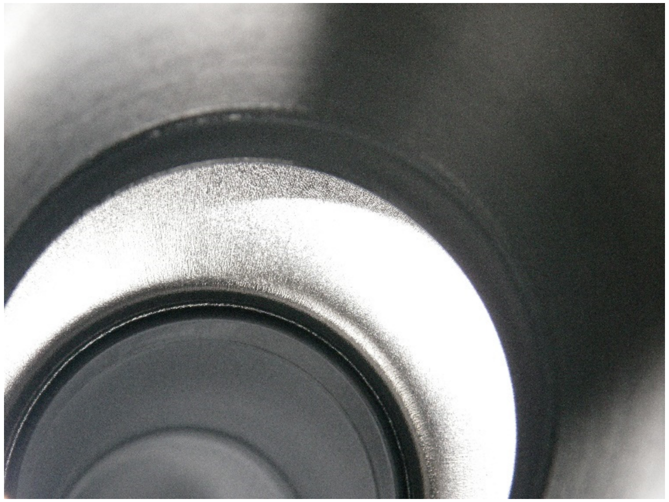



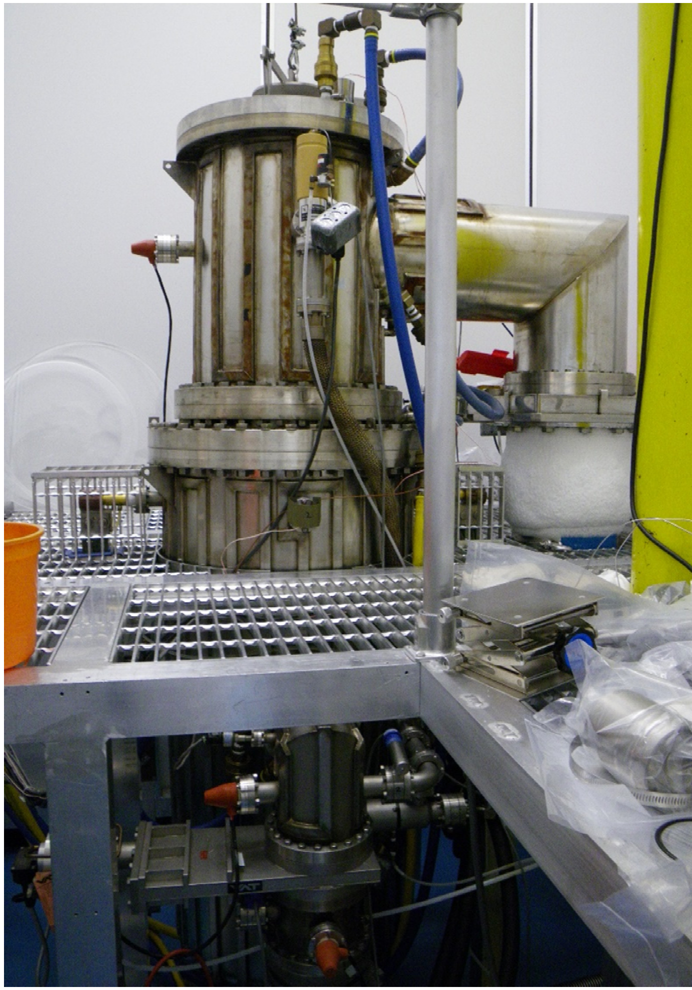

Going to 4.2 K reduces cryogenic cost and complexity



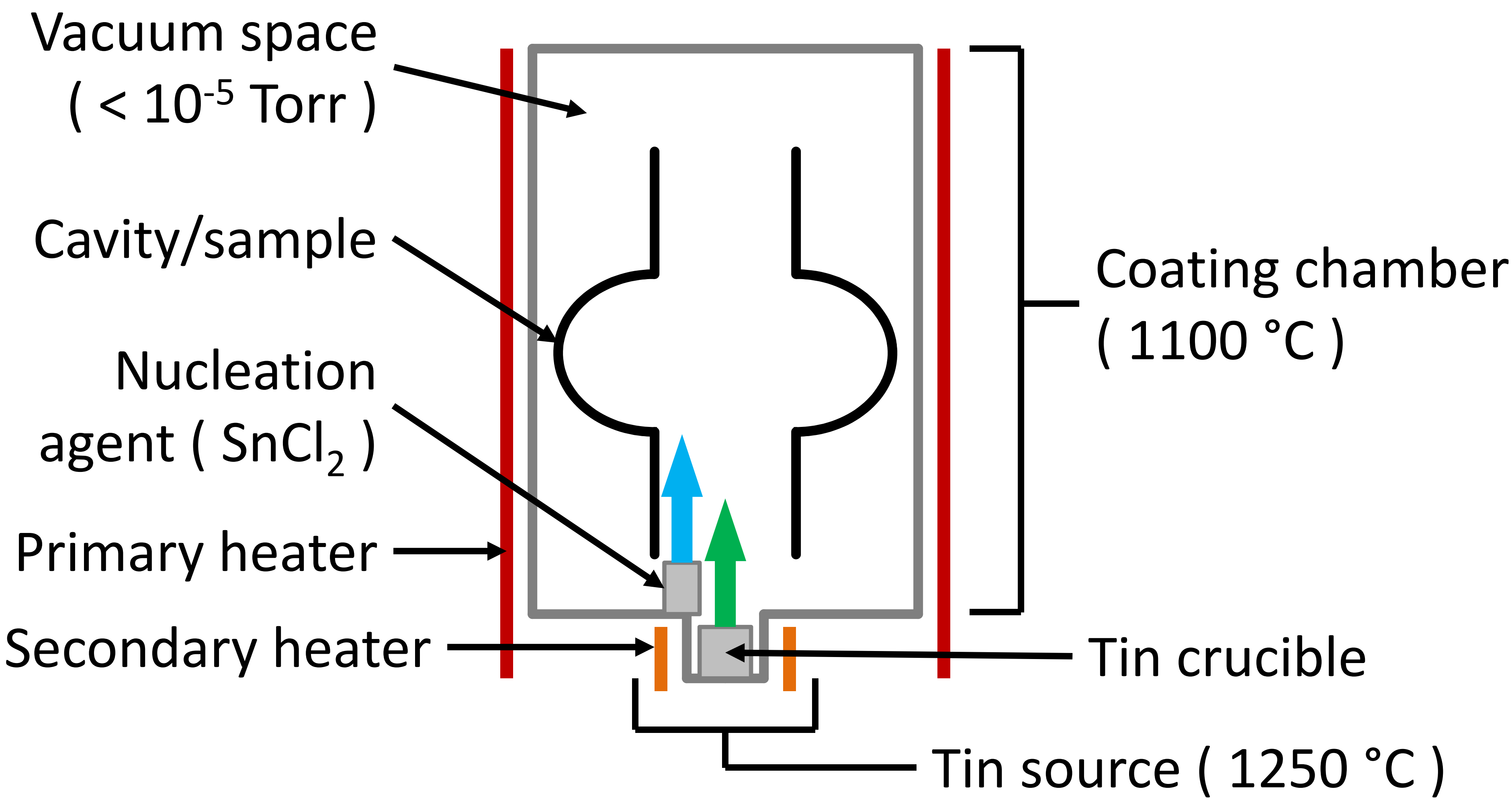
# Fabricating an $Nb_3Sn$ cavity

## A 1.3 GHz single-cell is placed into the furnace



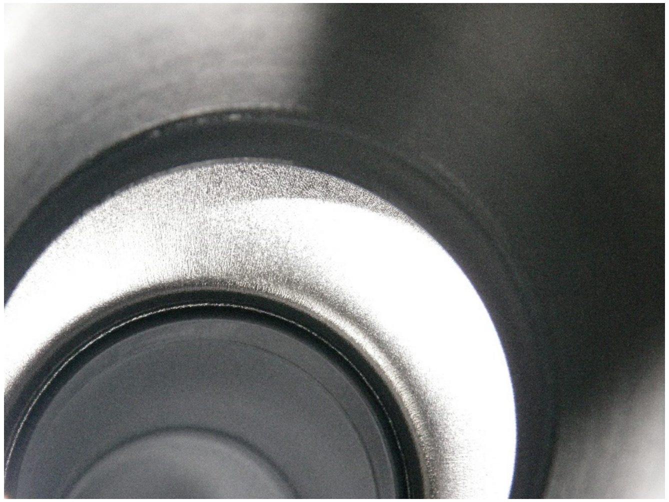


# Coating method



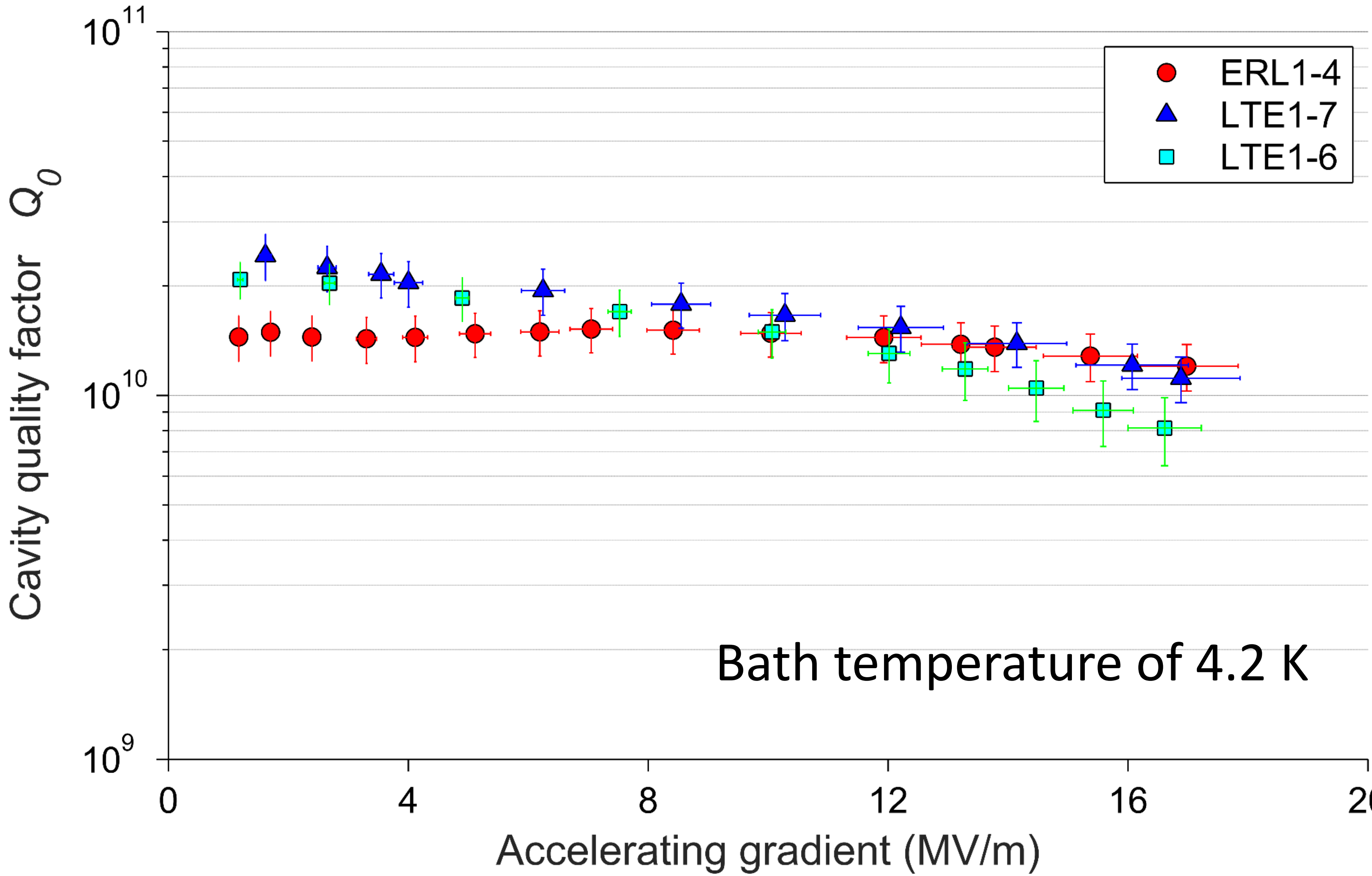
# Post coating

A coated cavity doesn't look very different

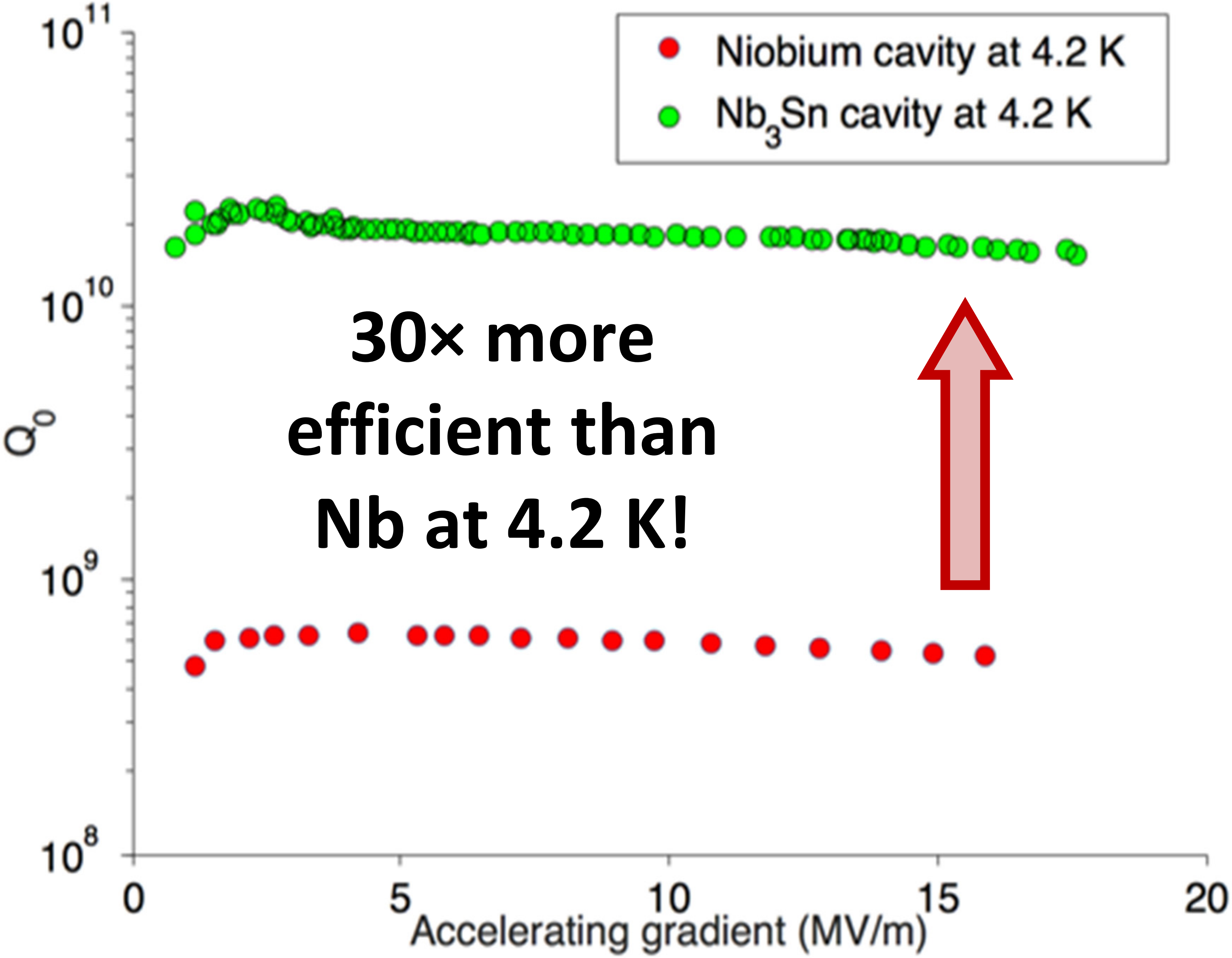


# Exemplary cavities

## But the difference in performance is significant



# Comparison to niobium




**30× more efficient than Nb at 4.2 K!**

# Pushing performance further

Great performance! But theory predicts we can do even better

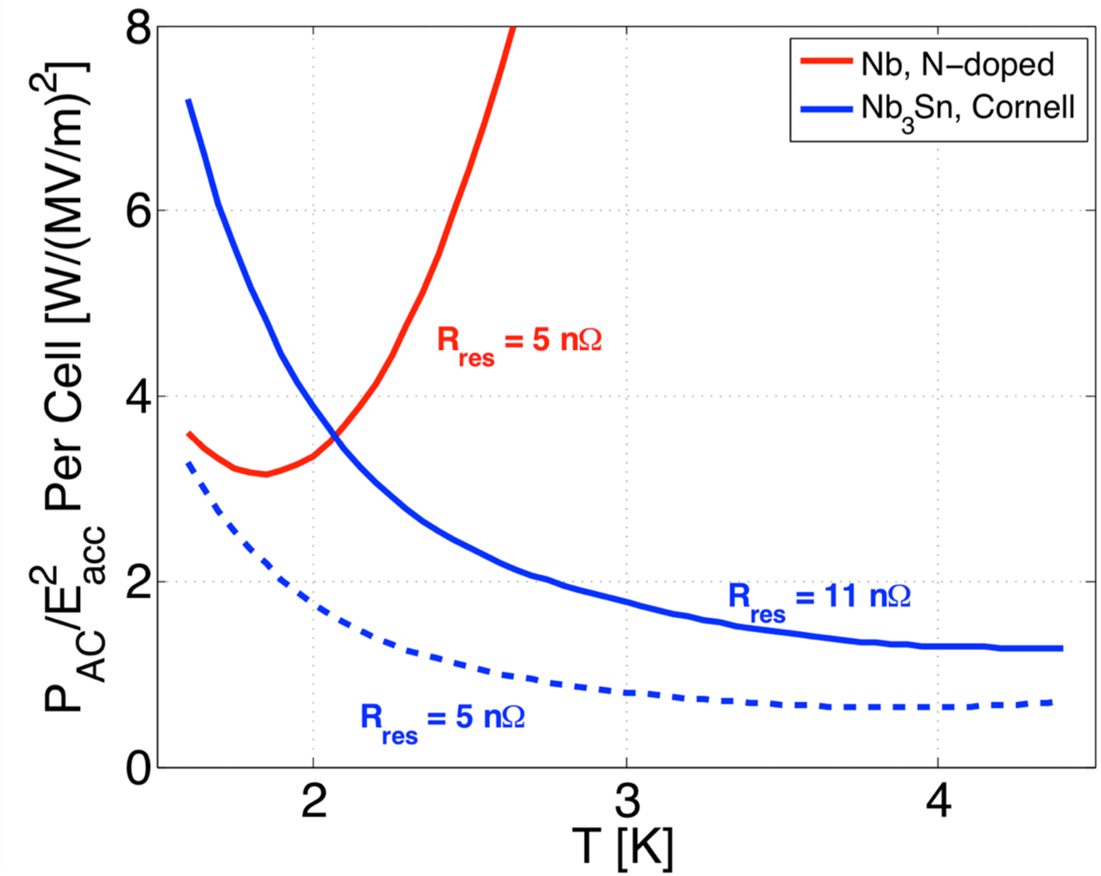
- Pushing to the maximum achievable **cavity efficiency**
- Understanding the limitations on **accelerating gradient**

# Maximising efficiency

Surface resistance = $R_{BCS}$ + $R_{Residual}$

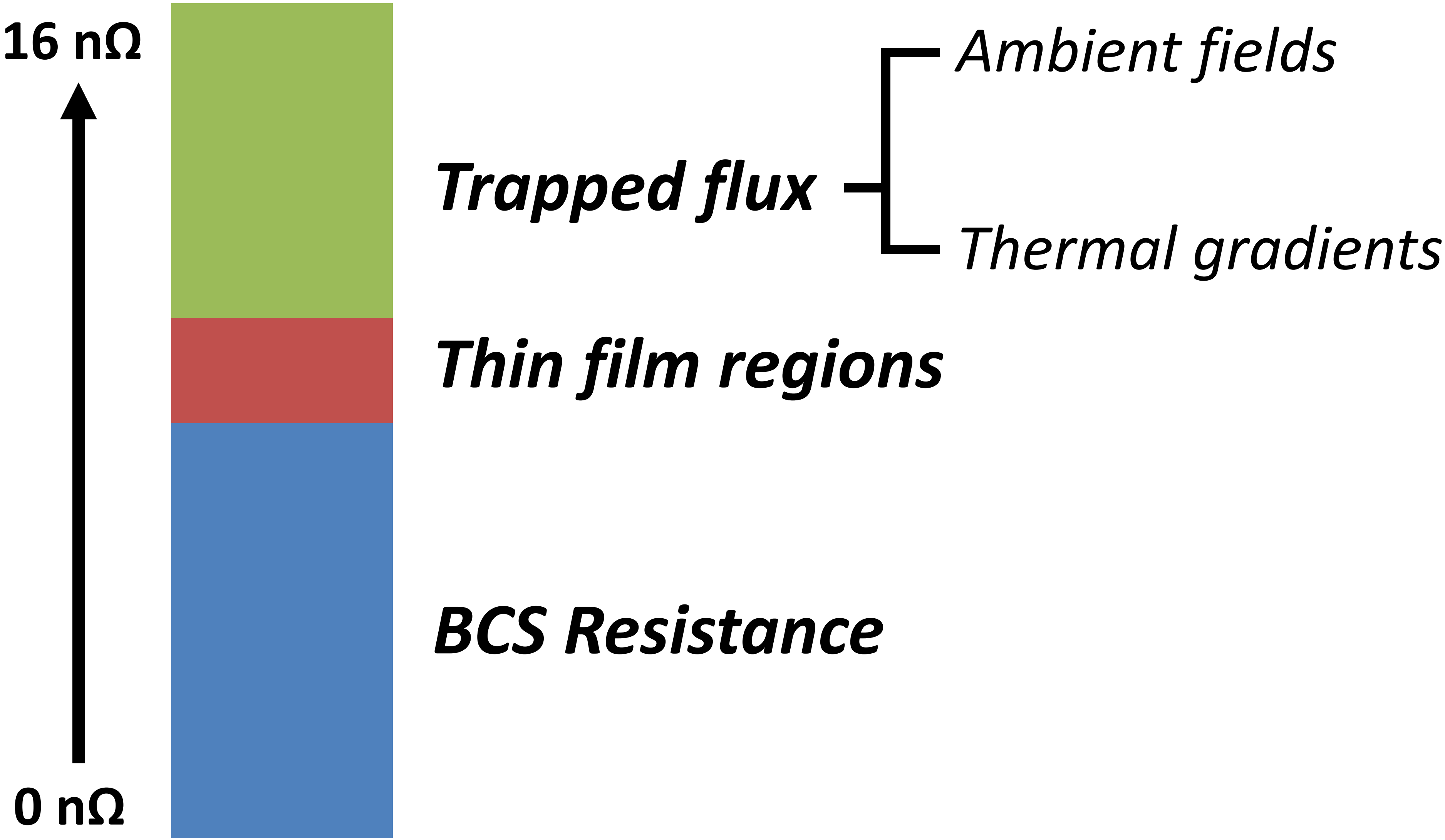
Low for $Nb_3Sn$ at 4.2 K

**Must be minimised!**



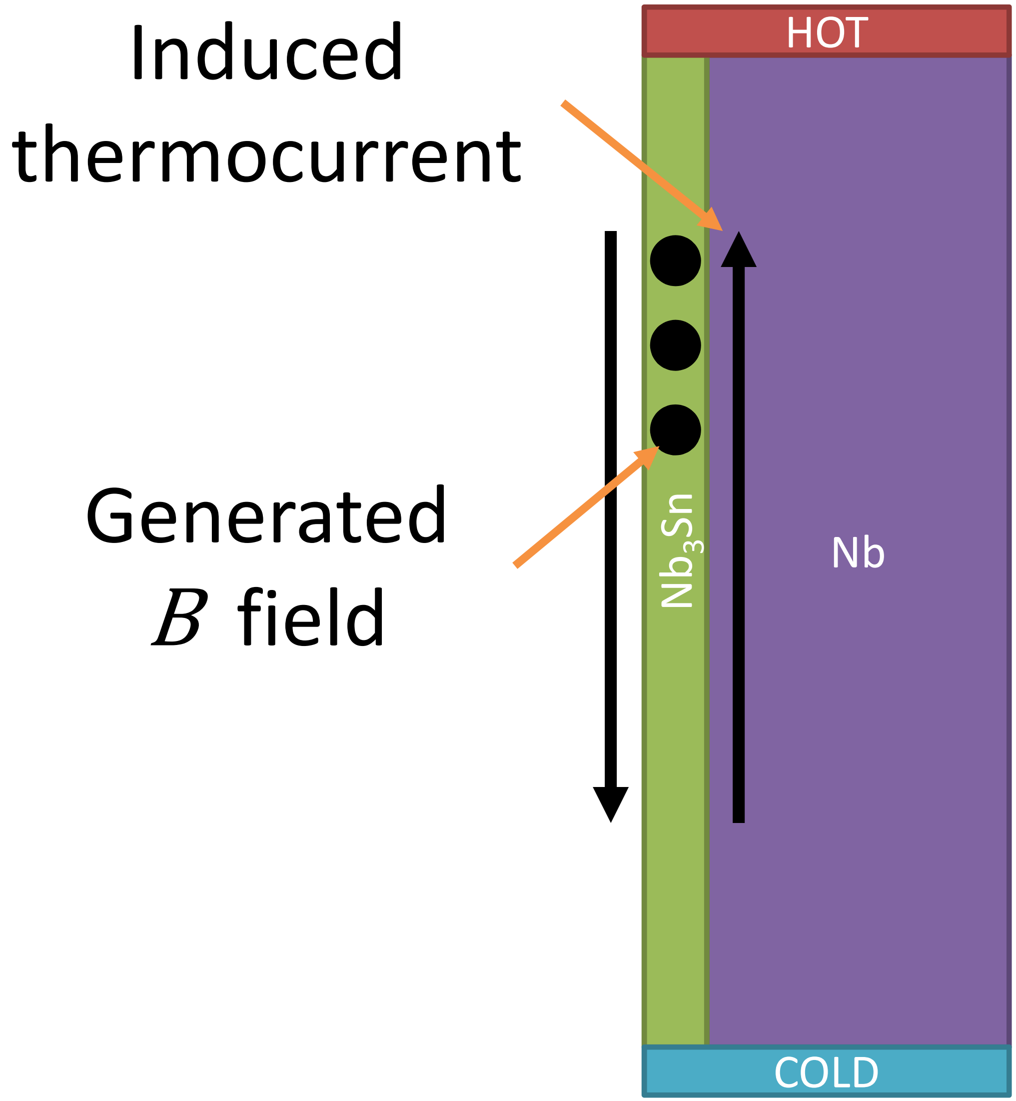

Even 3-5 nΩ can make a big impact

# Loss mechanisms



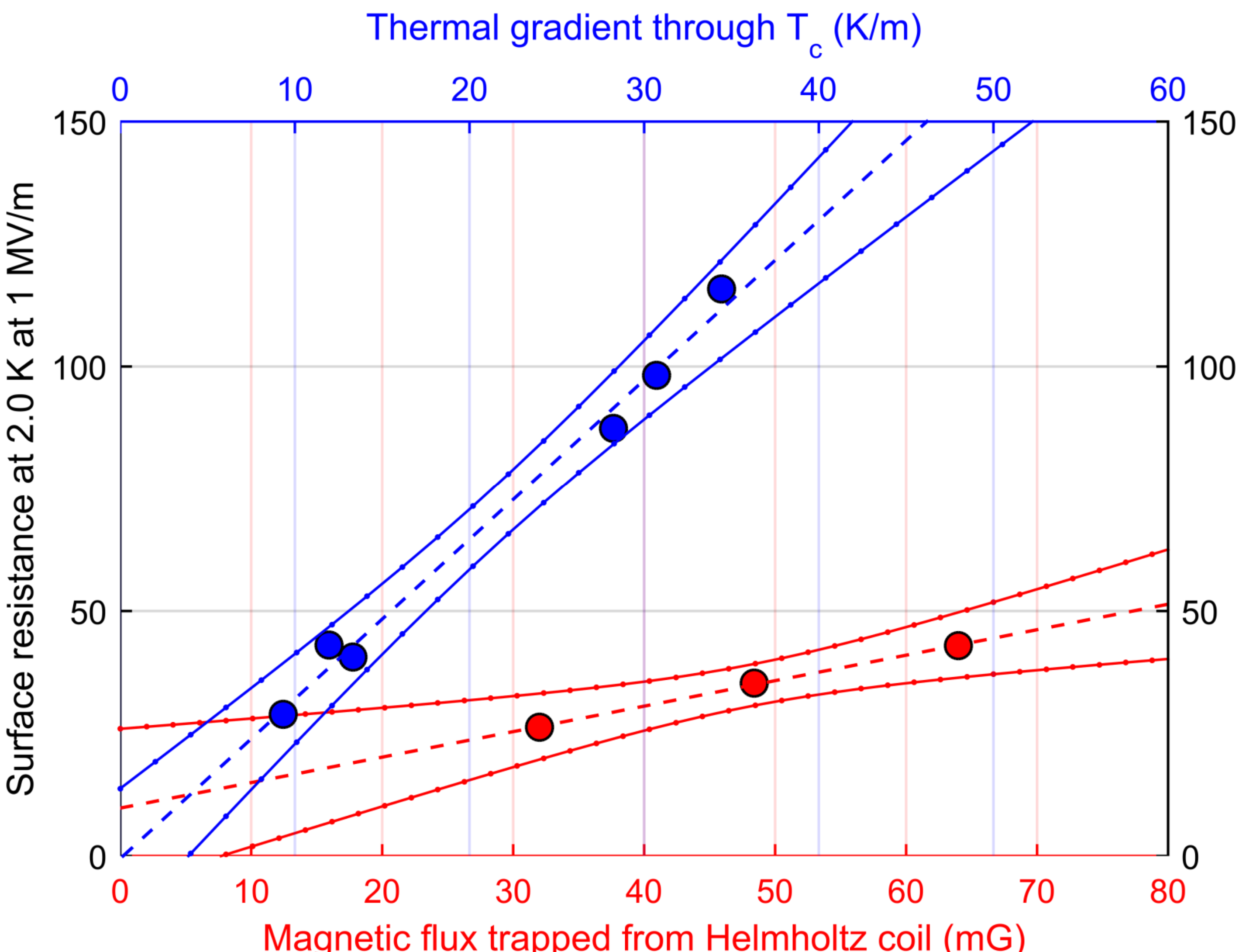
# Generation of thermal currents

Thermal gradients → Thermal currents → Magnetic flux



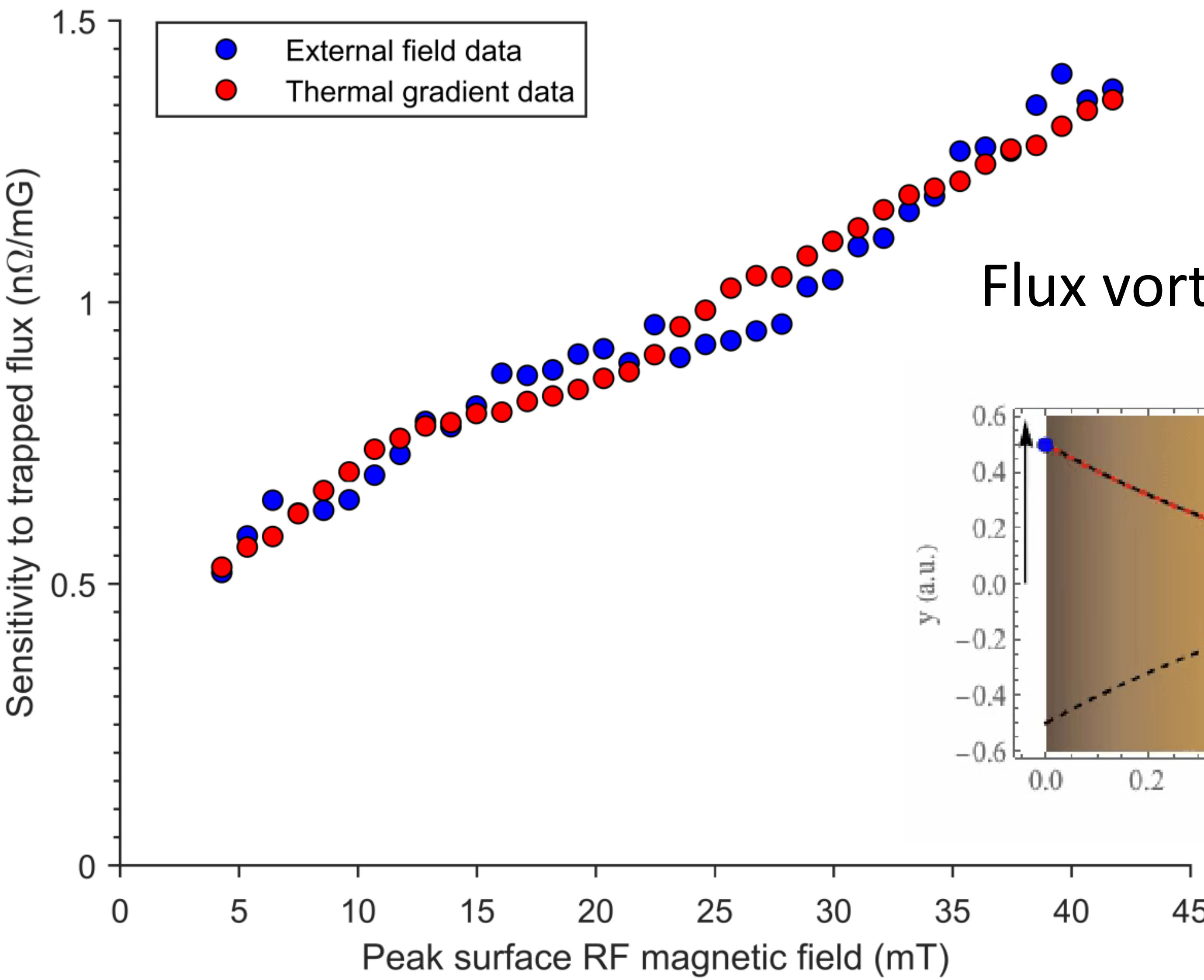
# Sensitivity to trapped flux

## The performance of $Nb_3Sn$ is degraded by thermal gradients and ambient magnetic field

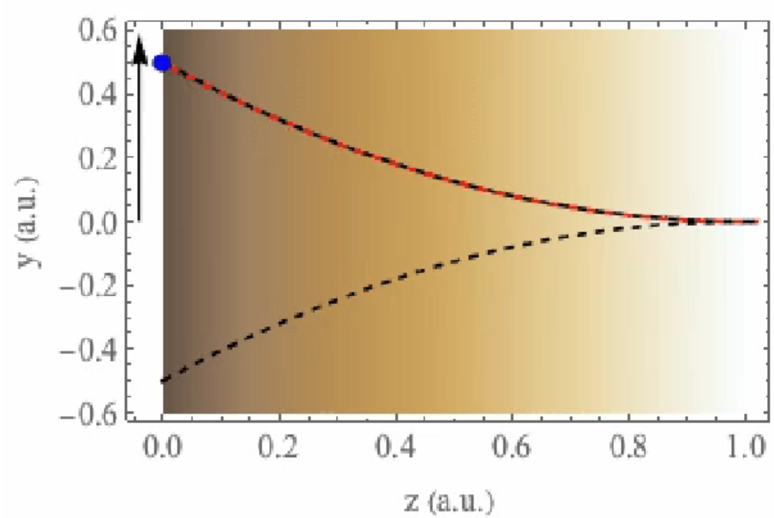


# Field dependent sensitivity

## $Nb_3Sn$ behaves like a weak pinning superconductor

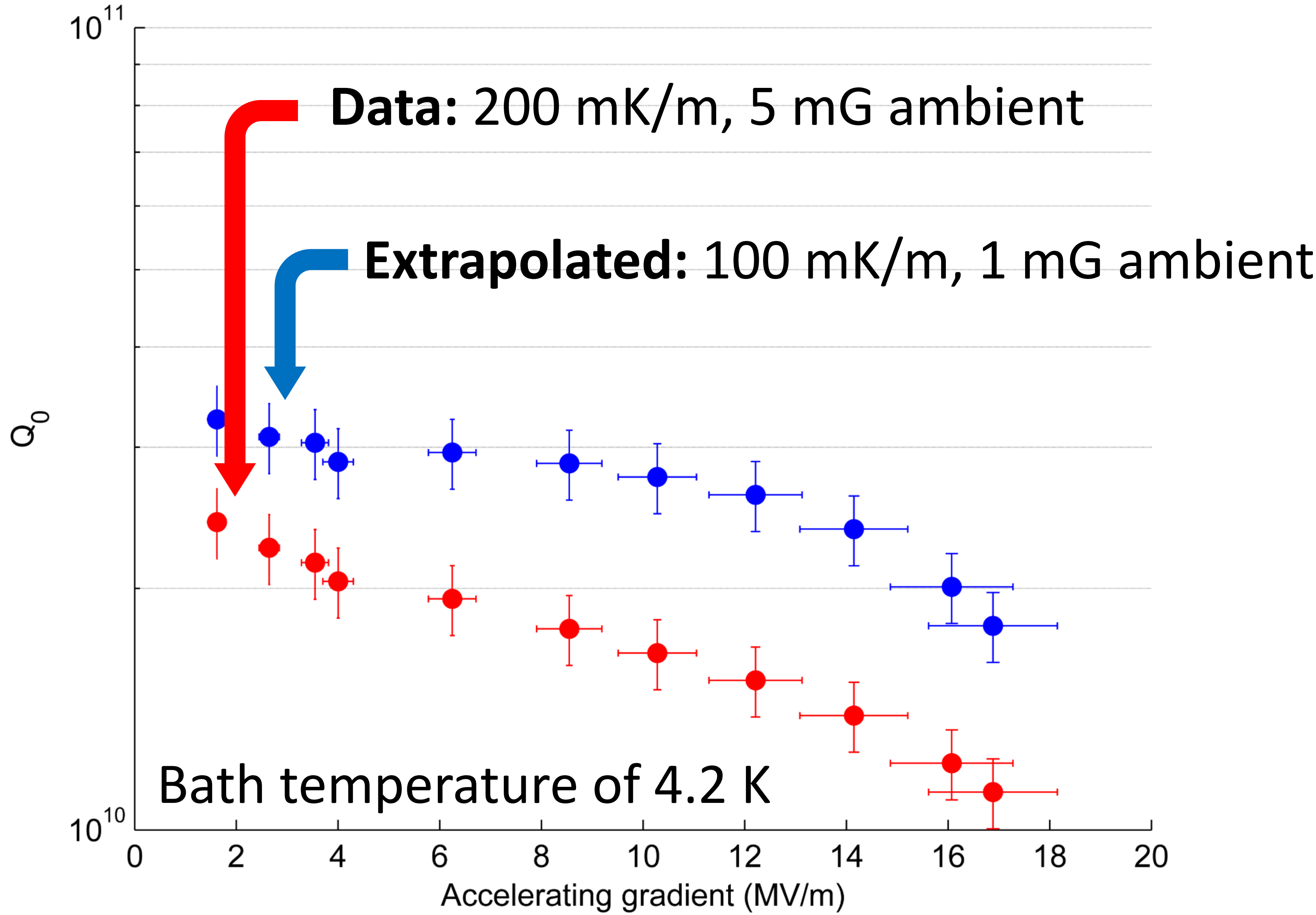



Flux vortex oscillating

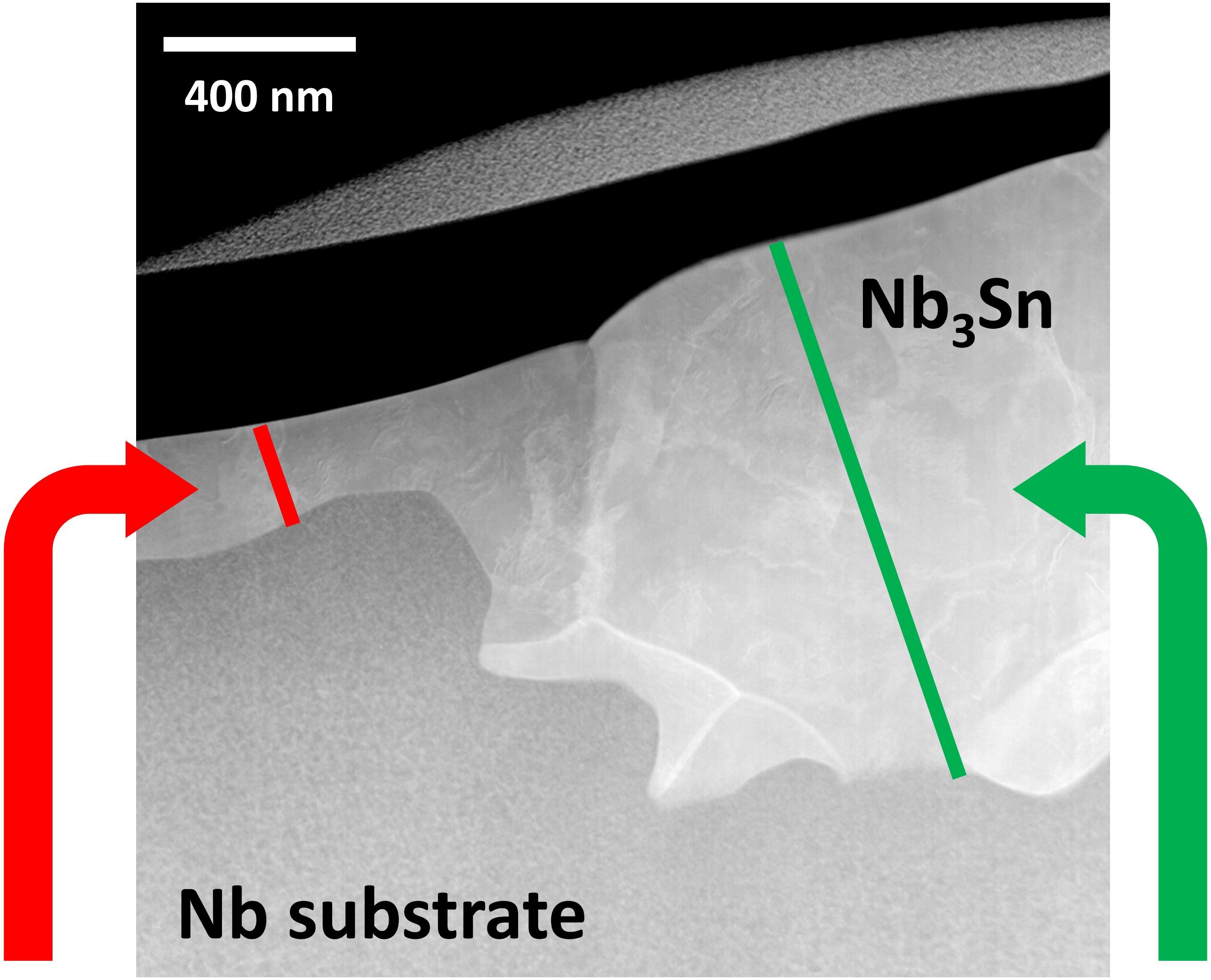


# Improving cool-down

## Optimising cool-down ensures great performance



# Thin film regions



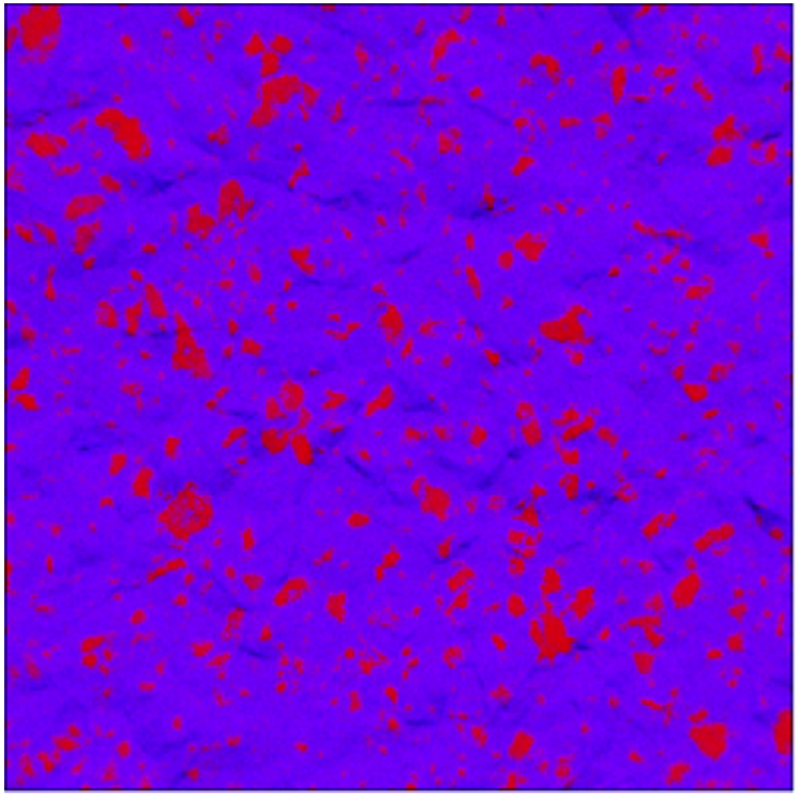

Too thin

Sufficiently thick

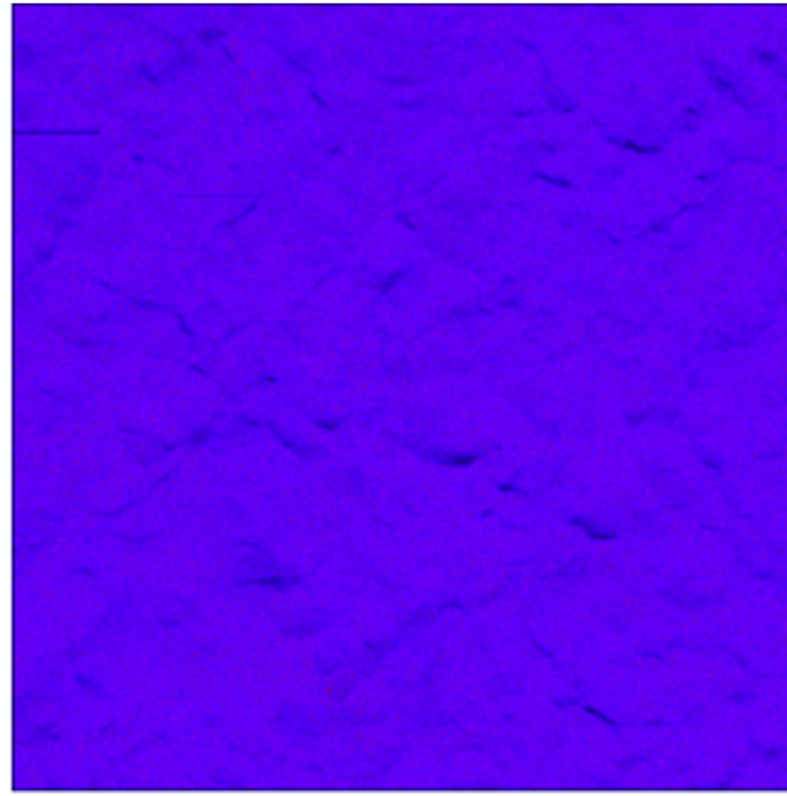
These thin film regions lead to increased losses

# Suppressing thin film regions

Growing the substrate oxide prior to coating suppresses the formation of thin film regions



**Not pre-anodised**

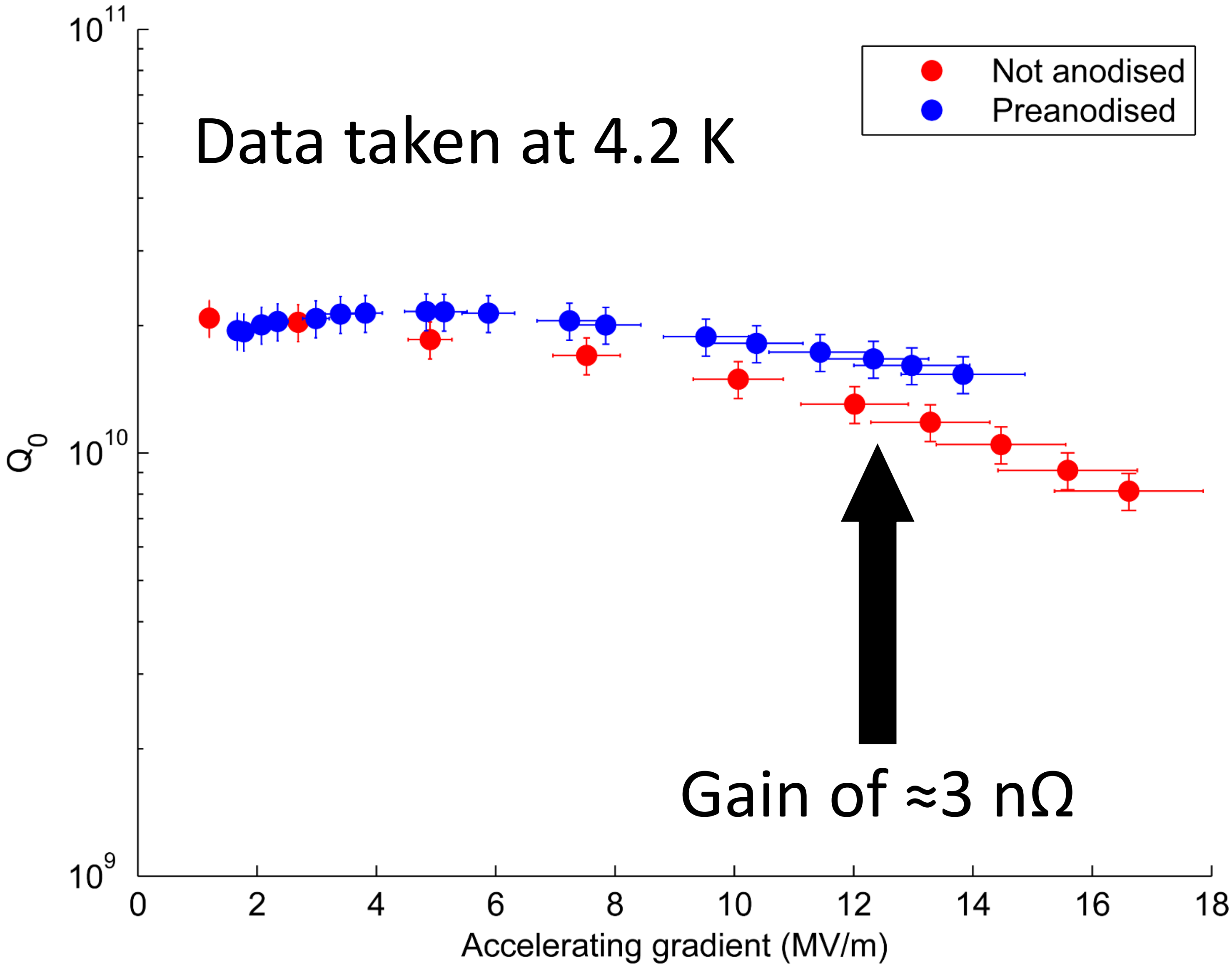


**Pre-anodised substrate**

**Red**: too thin

**Blue**: sufficiently thick

# Performance improvement



# Accelerating gradient

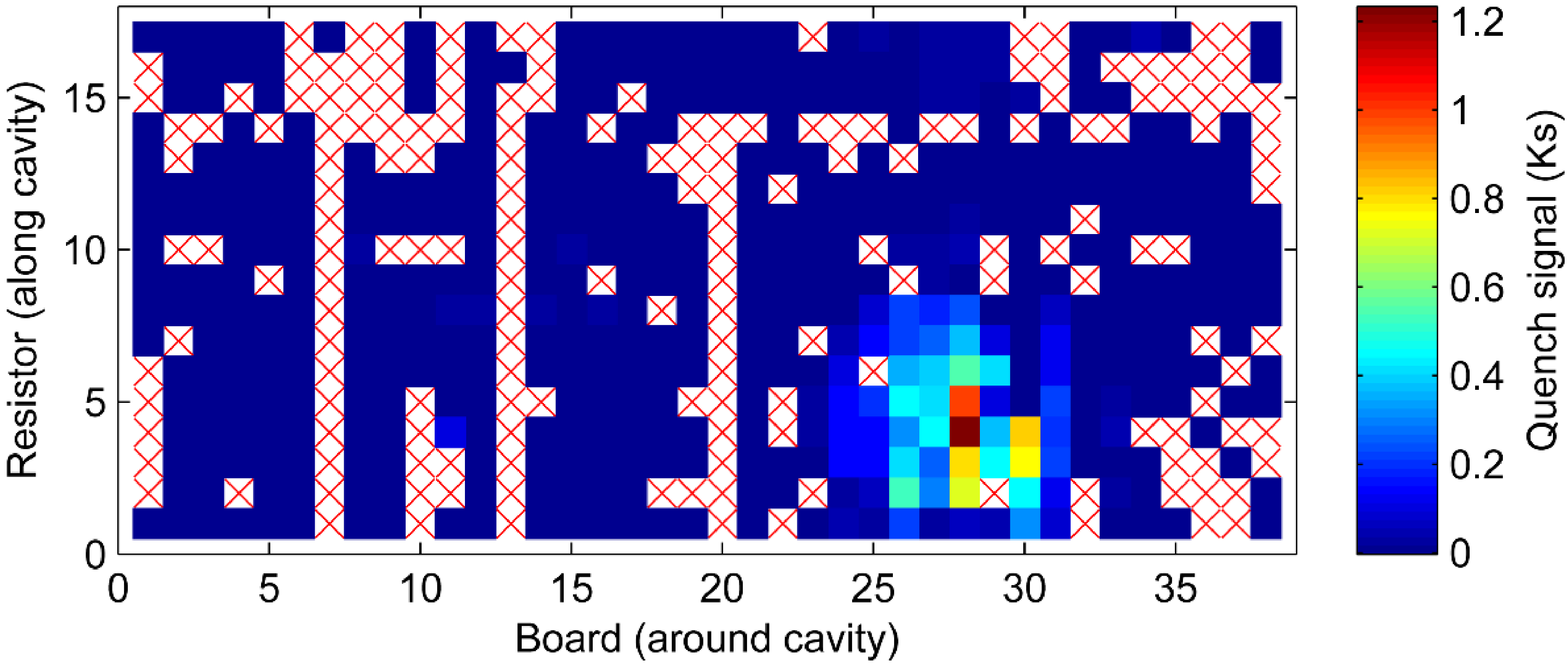
- The **ultimate gradient** of a cavity is determined by the **superheating field**, at which flux enters and quenches superconductivity

- In $Nb_3Sn$, this field is 400 mT, or **90 MV/m in an ILC cavity**

- We are currently limited to **14-17 MV/m**

# Investigating quench dynamics

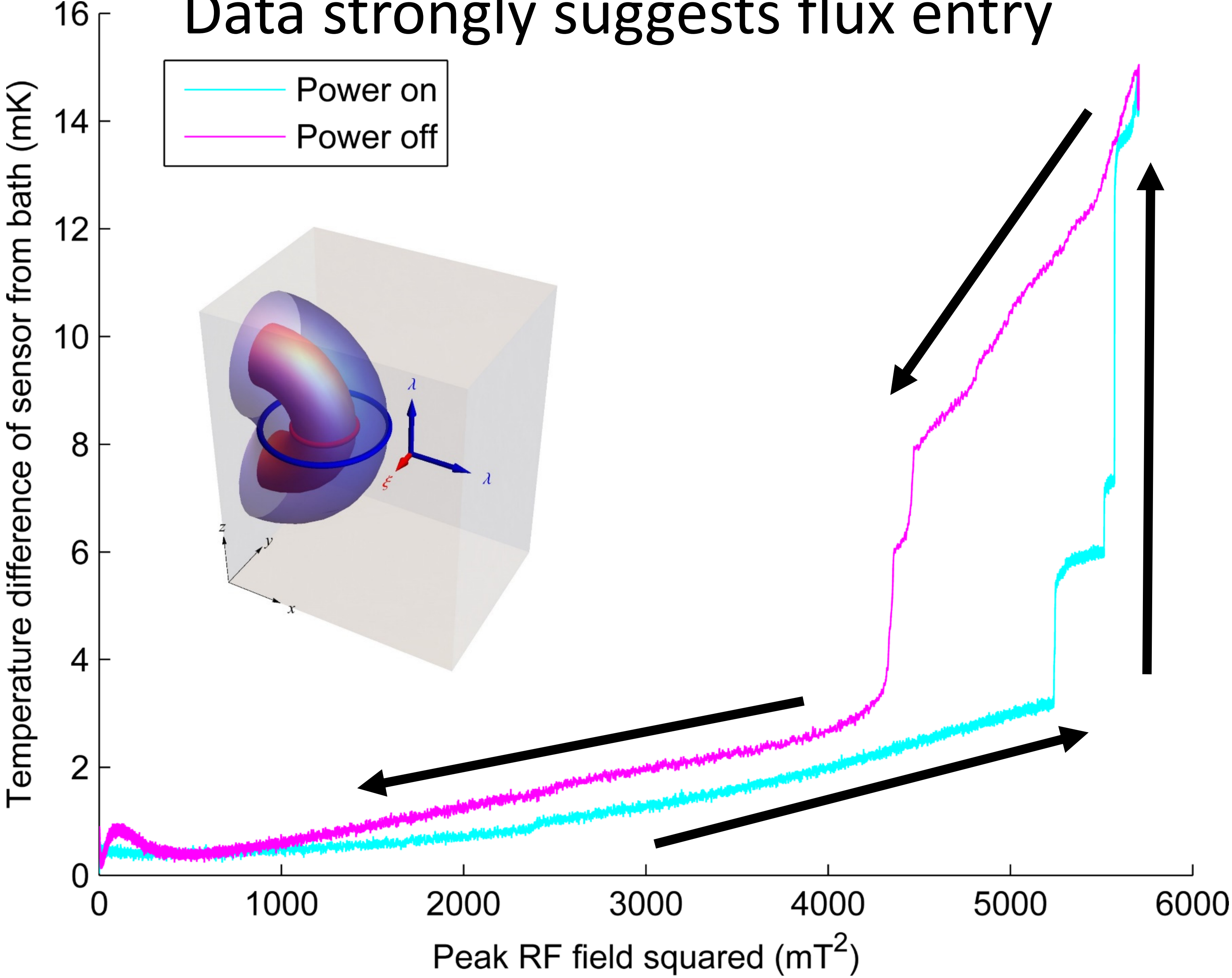
## $Nb_3Sn$ cavities are limited by a quench at a defect




## But what kind of defect, and why?

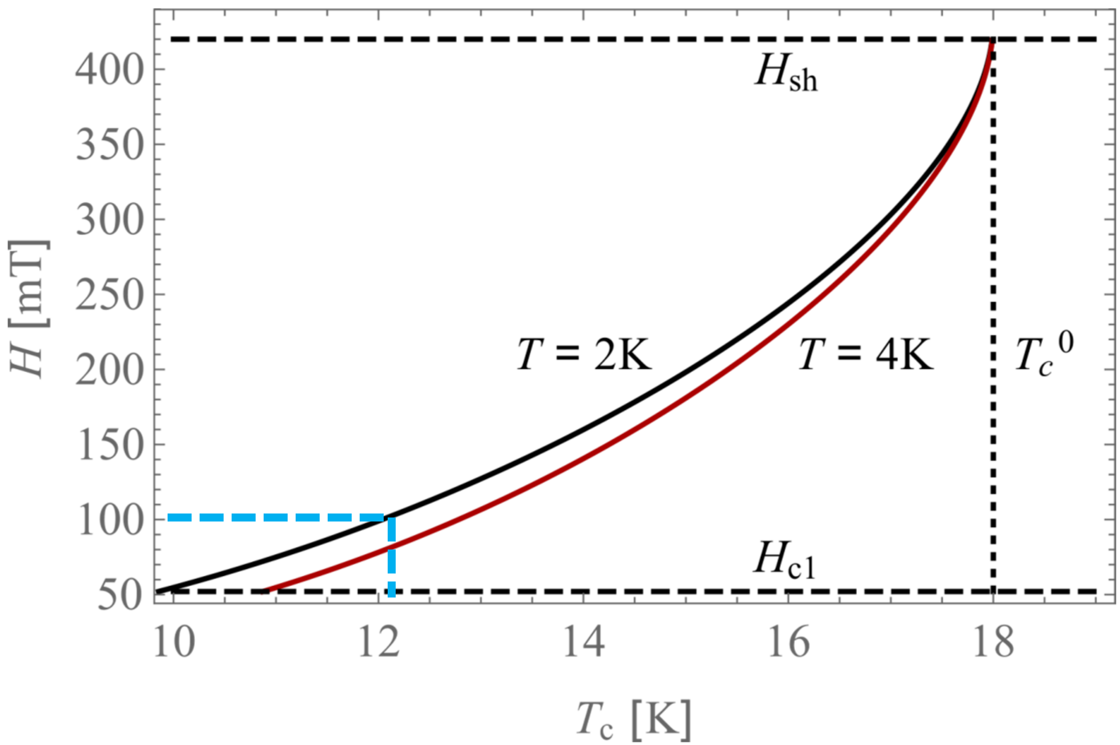
# Temperature at quench origin

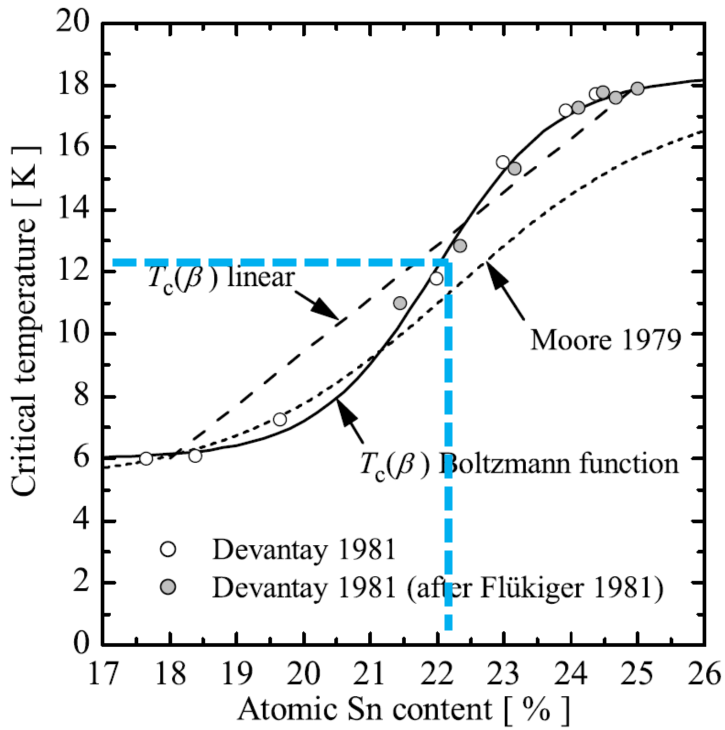
## Data strongly suggests flux entry



# $T_c$ suppresion

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

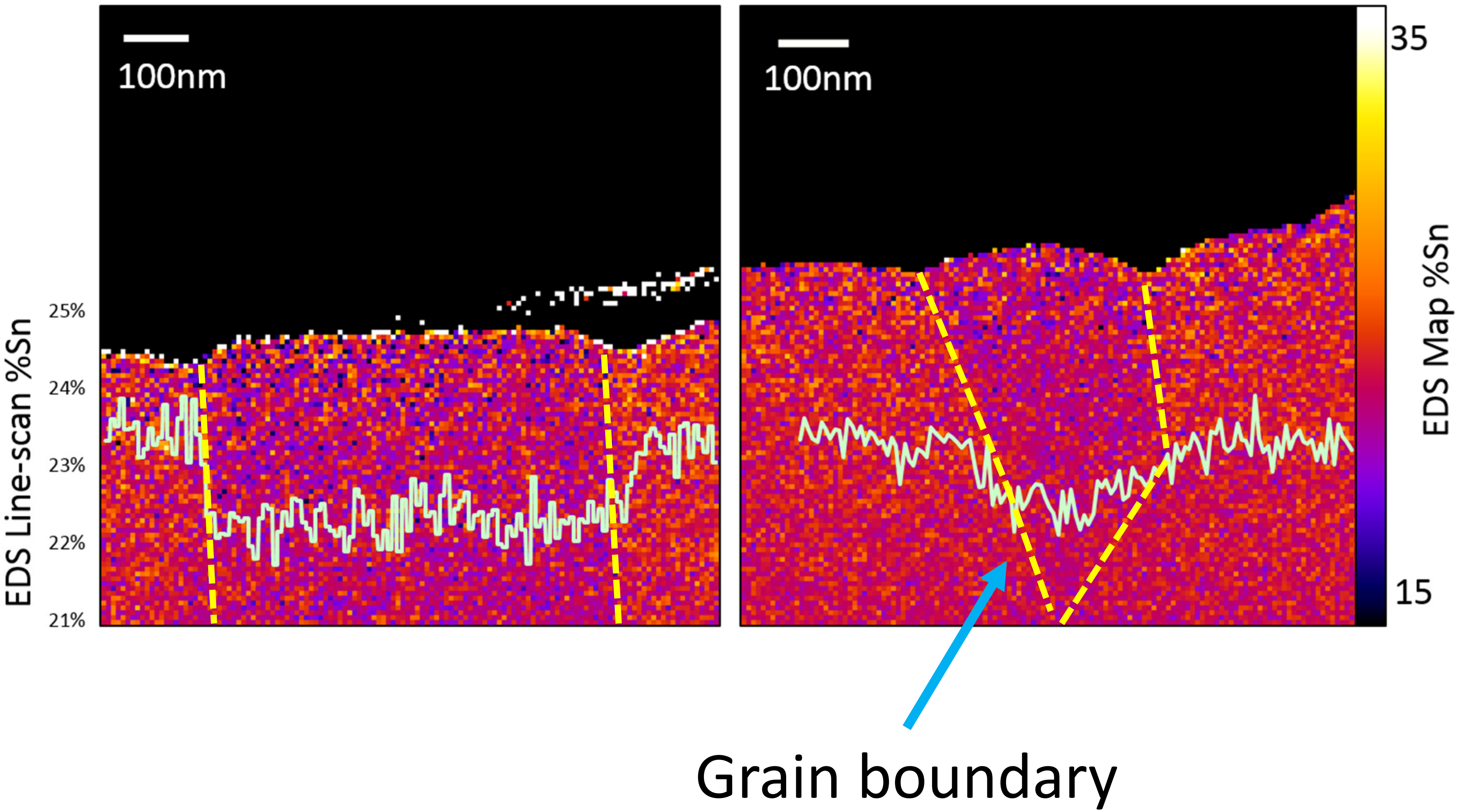



Flux entry could occur at tin-depleted surface defects

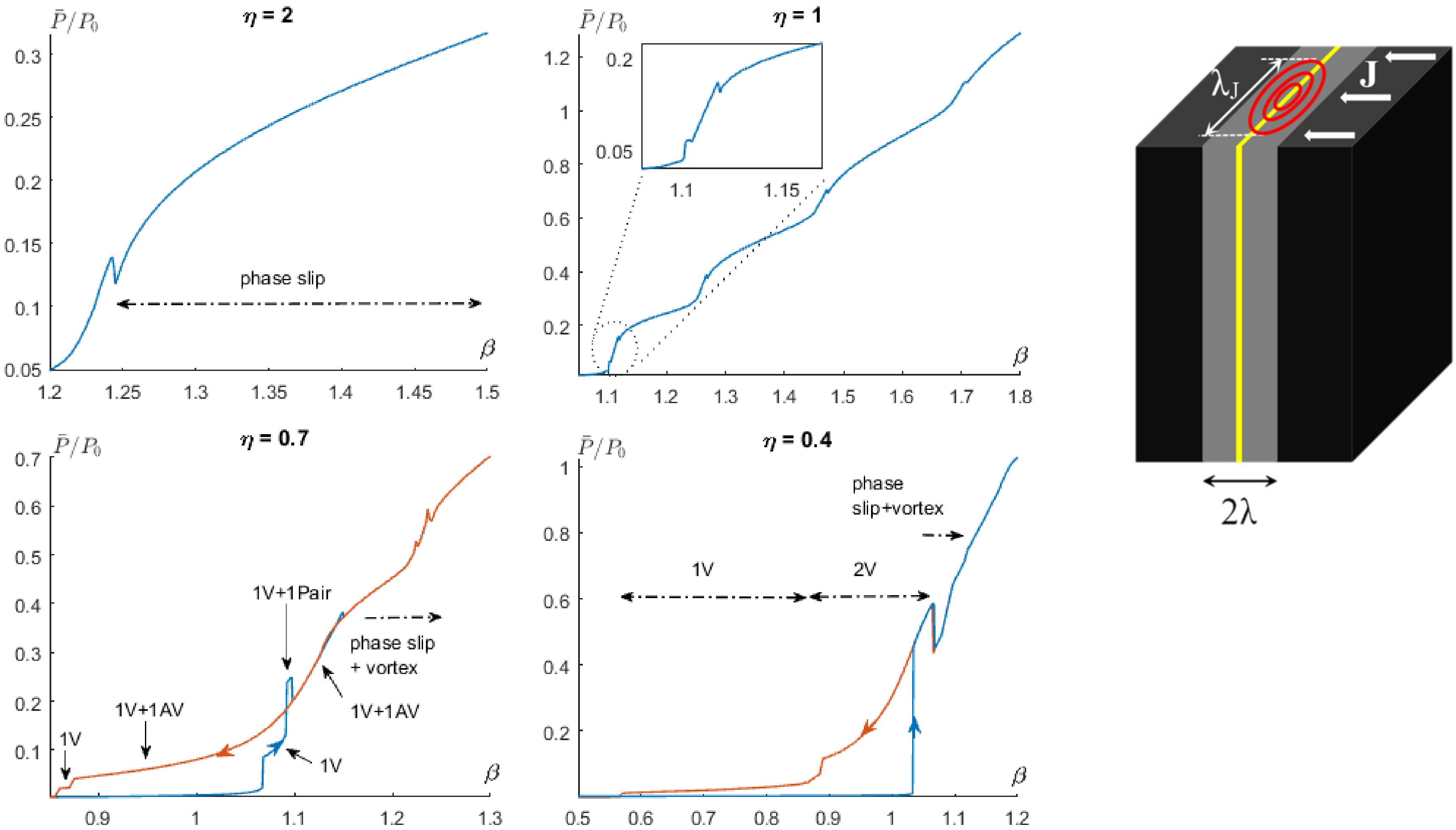
# Tin-depletion in grains

## Cross-section of the $Nb_3Sn$ RF surface



# Other sources of flux entry

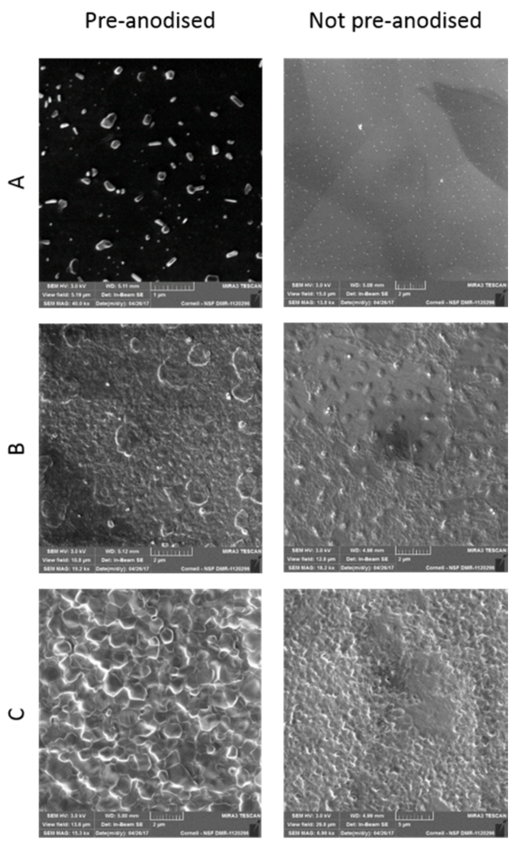
## Grain boundaries acting as vortex entry points



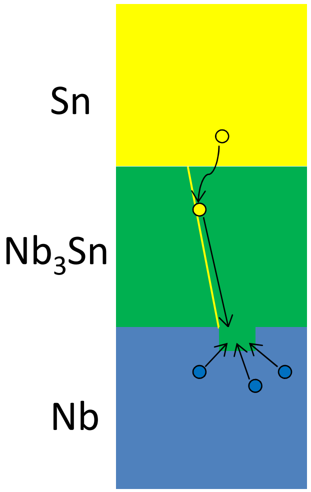

A. Sheikhzada, A. Gurevich, arXiv:1703.02843

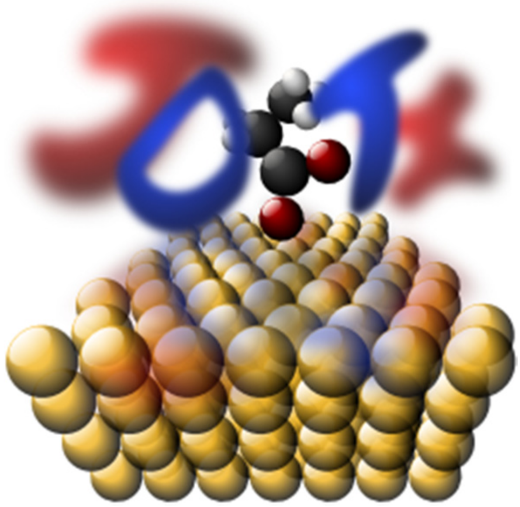
# Understanding layer growth

## Surface analysis of sample coupons




## Simulations use Joint Density Function Theory



We compare growth simulations to features seen in coupons and correlate these with RF performance

# Outlook and conclusion

$Nb_3Sn$ cavities have achieved the performance specifications demanded by modern machines

- **Cavity efficiency**
  - We routinely get quality factors of $>10^{10}$ at 4.2 K and gradients of >14 MV/m
- **Accelerating gradient**
  - Cavities are limited by localised defects
  - Surface features are being correlated to growth simulations to understand layer growth and guide the coating recipe

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