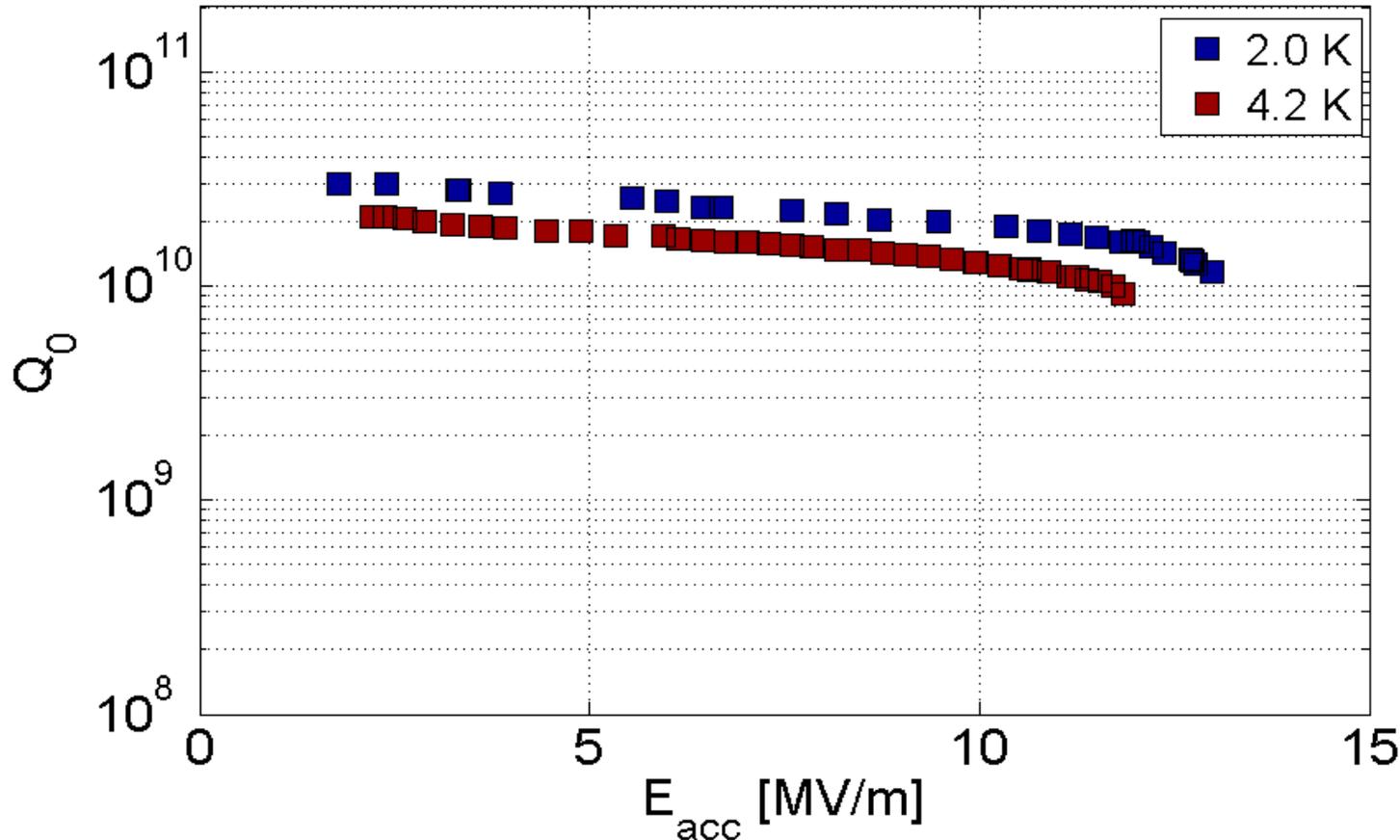


# $\text{Nb}_3\text{Sn}$ for SRF Applications

Sam Posen and Matthias Liepe  
Cornell University





2K

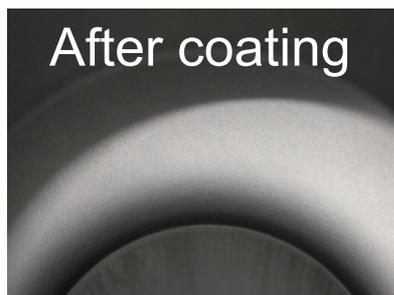
- **First accelerator cavity made with an alternative superconductor that outperforms Nb at usable gradients!**
- **Proves that  $B_{c1}$  is not a fundamental limit for SRF!!**



# Why Nb<sub>3</sub>Sn?

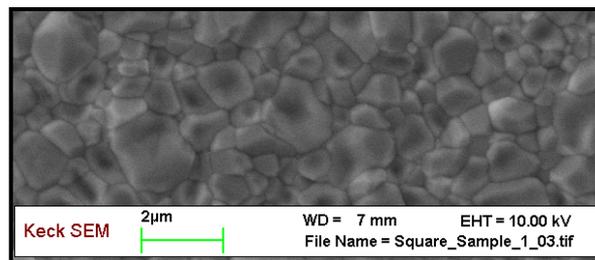
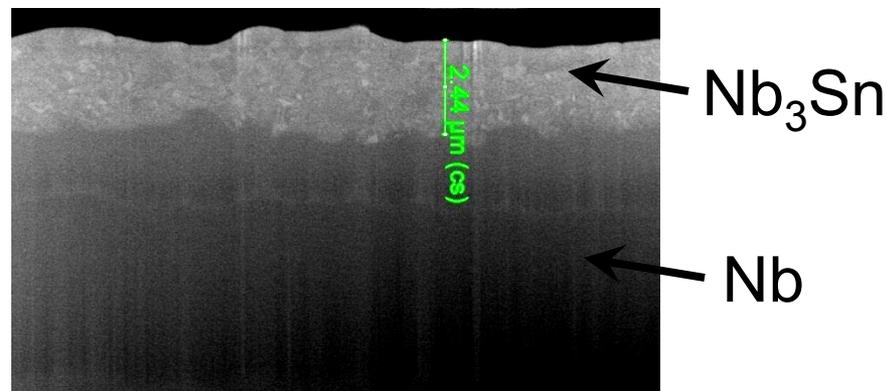
## Potential

- Small  $R_s$  – high  $T_c \sim 18$  K (twice Nb)
- Large  $B_{sh} \sim 400$  mT (twice Nb)
- Decent  $\xi \sim 3-4$  nm
- Can alloy existing Nb cavities
- Non-reactive



## Challenges

- Material is brittle
  - Low thermal conductivity
- Films avoid these

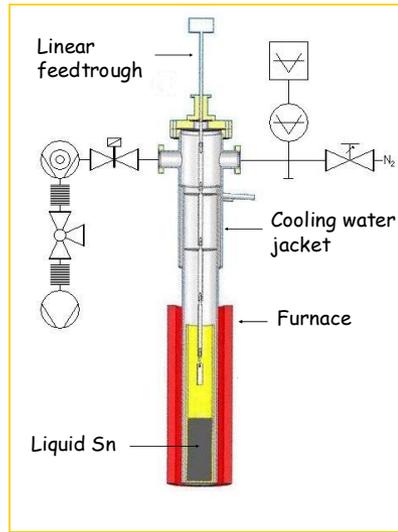


Images  
from  
Cornell

## Liquid Tin Dipping – INFN

Problems with tin droplets on surface and spurious tin-rich phases

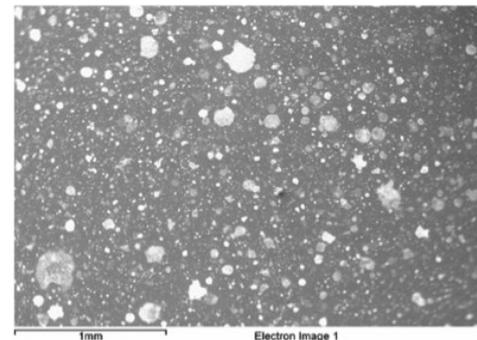
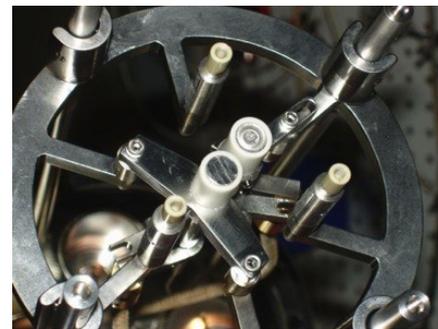
*S. Deambrosis et al. (2009)*



## Cathodic Arc Deposition – Alameda Applied Sciences



- More energetic ions than sputtering
- Low T<sub>c</sub> measured

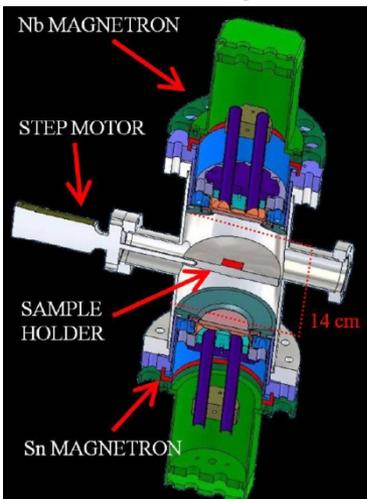


*M. Krishnan et al. (2012)*

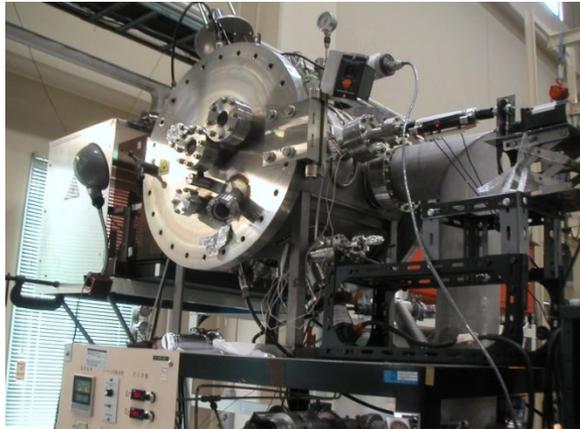
## Multilayer Sputtering – INFN

- Alternate coatings of Nb and Sn, then anneal
- No encouraging RF results so far

*A. Rossi et al. (2009)*



## Pulsed Laser Deposition - KEK

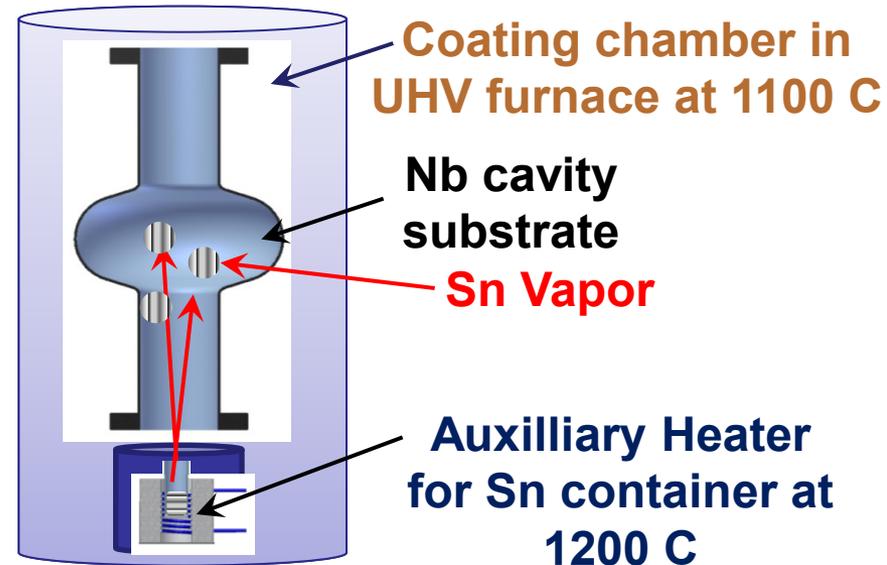


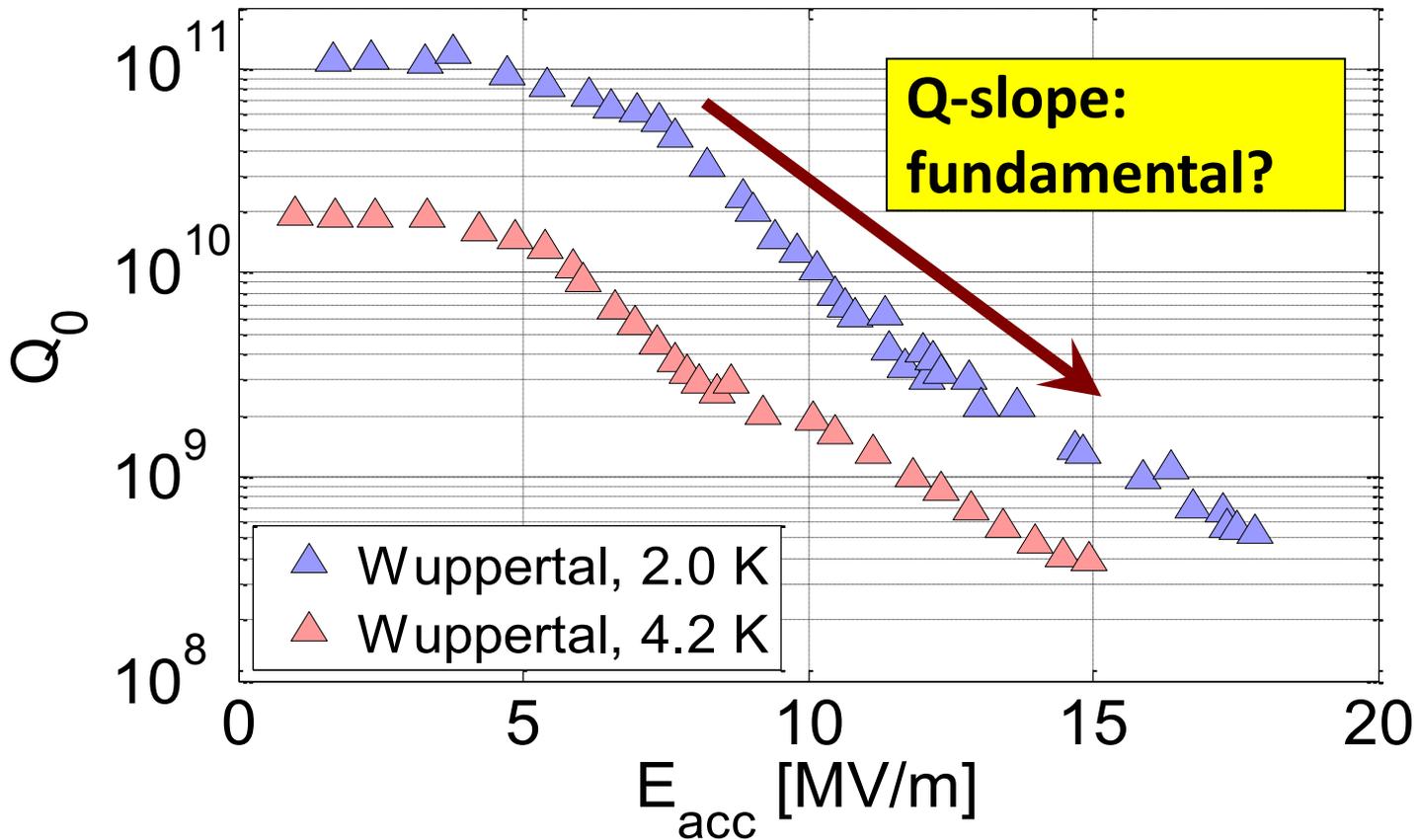
- Studies have started
- Also use PLD for MgB<sub>2</sub>

*S. Mitsunobu et al.*

## Vapor Diffusion –Siemens AG, U. Wuppertal, Cornell, and Jefferson Lab

- In UHV furnace, tin vapor alloys with Nb cavity
- Very promising RF results





- Excellent  $R_s$  at low fields, but **large Q-slope** above  $\sim 5$  MV/m
- Various suggested causes: intergrain losses, bad stoichiometry, and **vortex penetration at lower critical field  $B_{c1}$**

Ideal superconductor is metastable from  $B_{c1}$  up to  $B_{sh}$   
but surface defects of size  $\sim \xi$  might lower energy  
barrier.

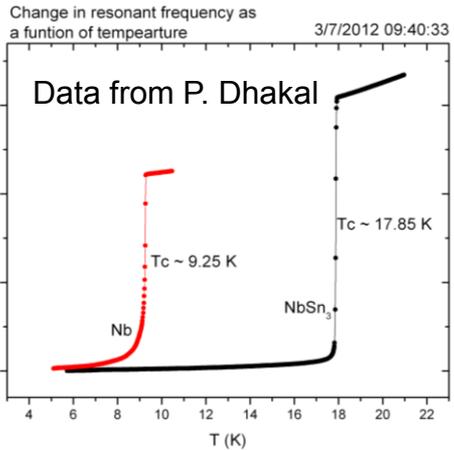
Is  $\xi$  of  $Nb_3Sn$  so small that  $B_{c1}$  is the limit?

If vortices penetrate at  $B_{c1}$ , **all** alternative SRF  
materials would be severely limited.

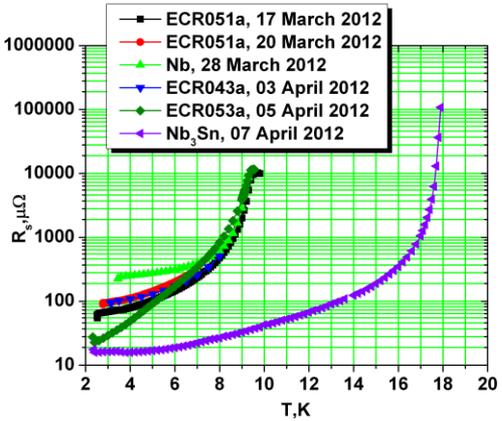


# JLab Nb<sub>3</sub>Sn Work

(see poster TUP071 for details)



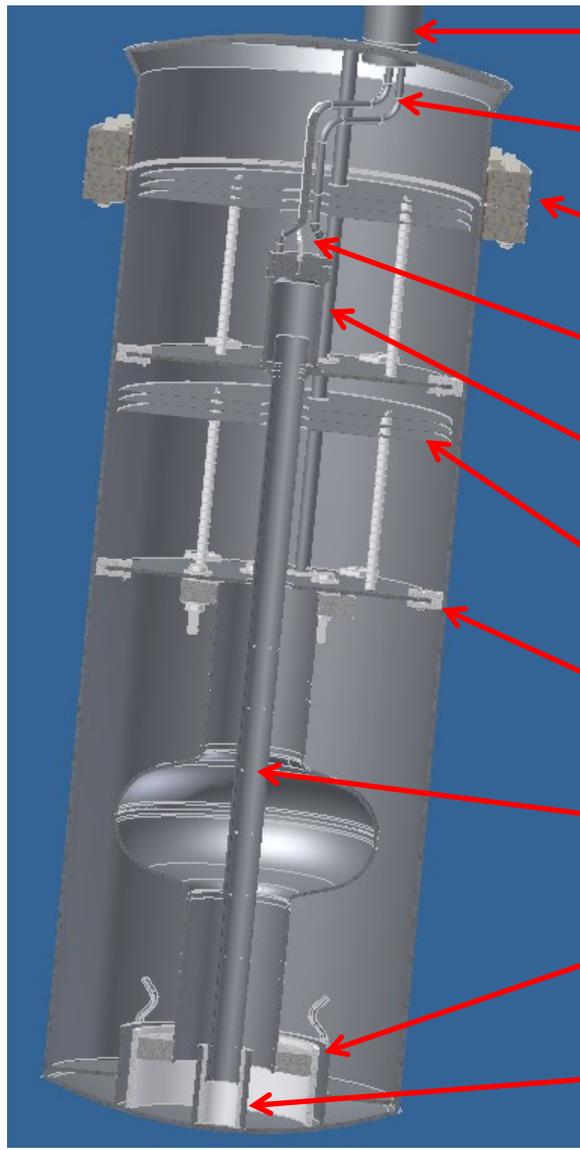
Transition temperature is ~ 17.85 K. The best of three samples shows very smooth surface with no residual tin contamination



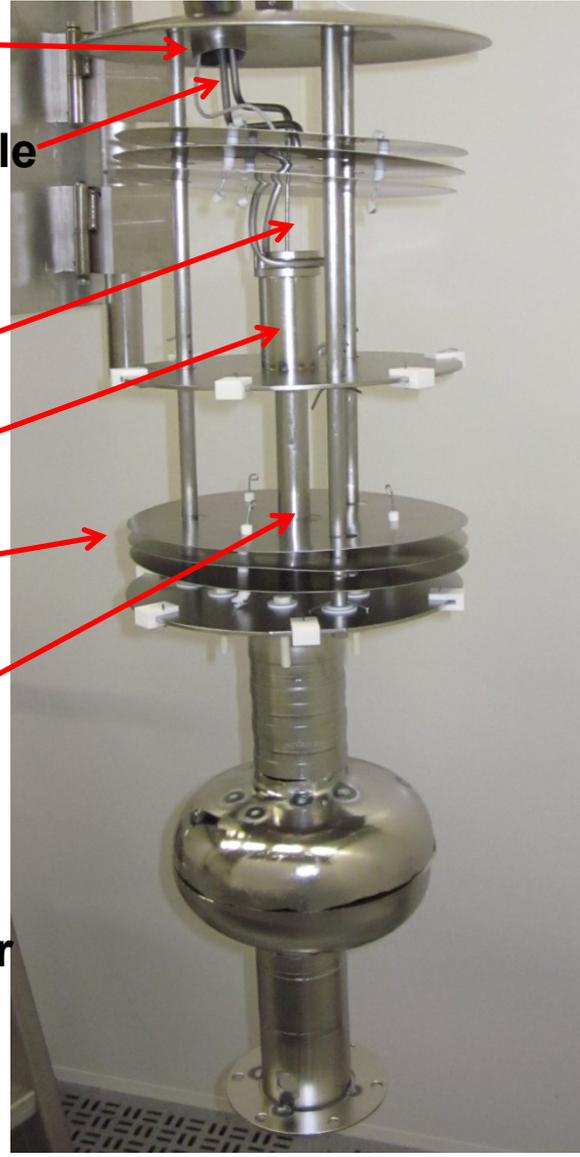
Recent measurements of surface resistance of several ECR films, bulk Nb sample, and Nb<sub>3</sub>Sn sample as a function of temperature at 7.4 GHz.

- Preliminary studies with **samples** have been done. RF measurements on a sample indicated the **transition temperature of 17.9 K** and RF surface resistance of about 30 μΩ at 9 K and 7.4 GHz.
- The **horizontal insert** has been built and inserted in the furnace. The first furnace run has been done at 1200 °C for 2 hours.
- **R&D furnace for Nb<sub>3</sub>Sn** development was ordered in October 2012, delivered in August 2013, and is being commissioned.





- Pump-out line
- He gas cooling line for crucible
- 14" conflat mating flanges
- Crucible thermocouple
- Sn and SnCl<sub>2</sub> crucible
- Nb heat shields
- Nb cavity support plate
- Sn vaporguide
- Cavity flange support cylinder
- Vapor guide support cylinder





# Cornell Nb<sub>3</sub>Sn Work

(see poster TUP087 for details)

1. Degas
2. Nucleation
3. Coating
4. Annealing

Flange to UHV furnace

Heat Shields

UHV Furnace

Cavity Temp Thermo -

Heater Temp Thermo -



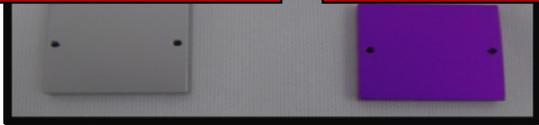
Tin Heater

Tin Container

## Anodization

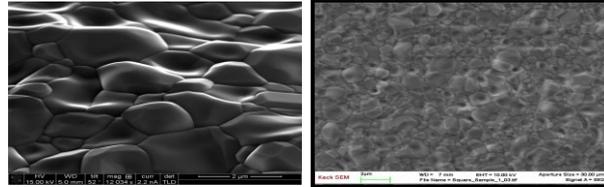
Not anodized

Anodized



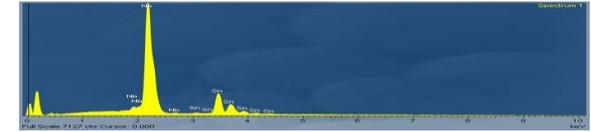
Pink -> Nb<sub>3</sub>Sn

## SEM



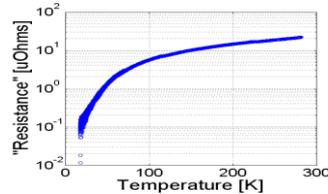
Grains ~1  $\mu$ m.  
Appearance similar to  
Nb<sub>3</sub>Sn from other  
studies

## EDX / XPS



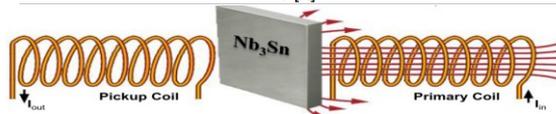
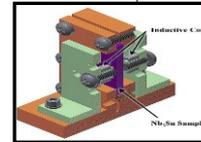
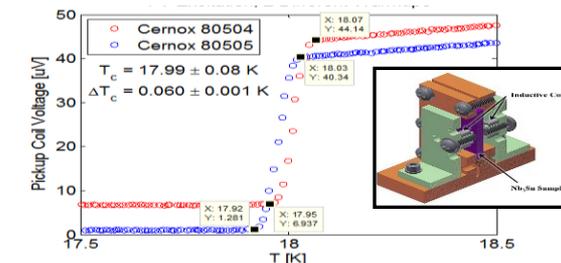
24.2  $\pm$  0.5 atomic %  
Sn, uniform over  
surface; 2  $\mu$ m deep

## RRR Measurement



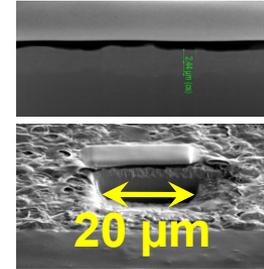
Minimal degradation of  
thermal conductivity from  
coating process

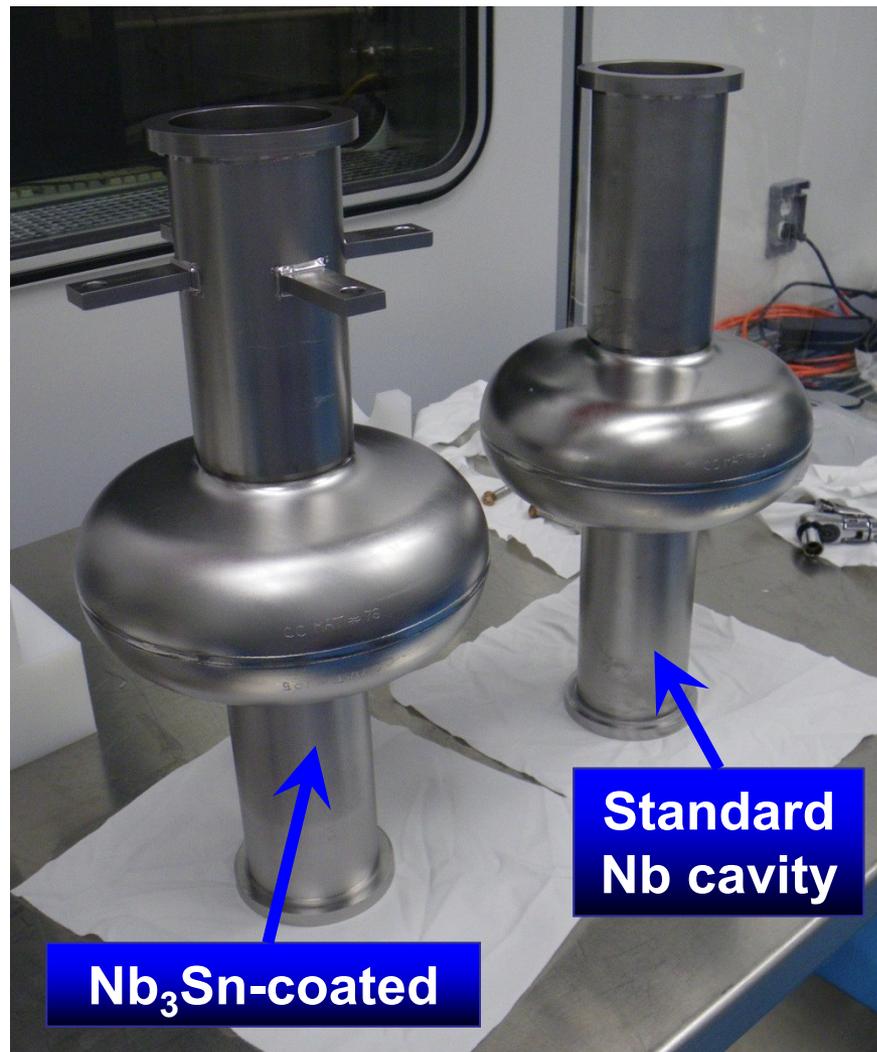
## T<sub>c</sub> Measurement



## FIB

Sample prep for TEM,  
view of coating cross  
section





**Top Half  
Cell**

**Before  
Coating**

**Cornell  
Nb<sub>3</sub>Sn Cavity**

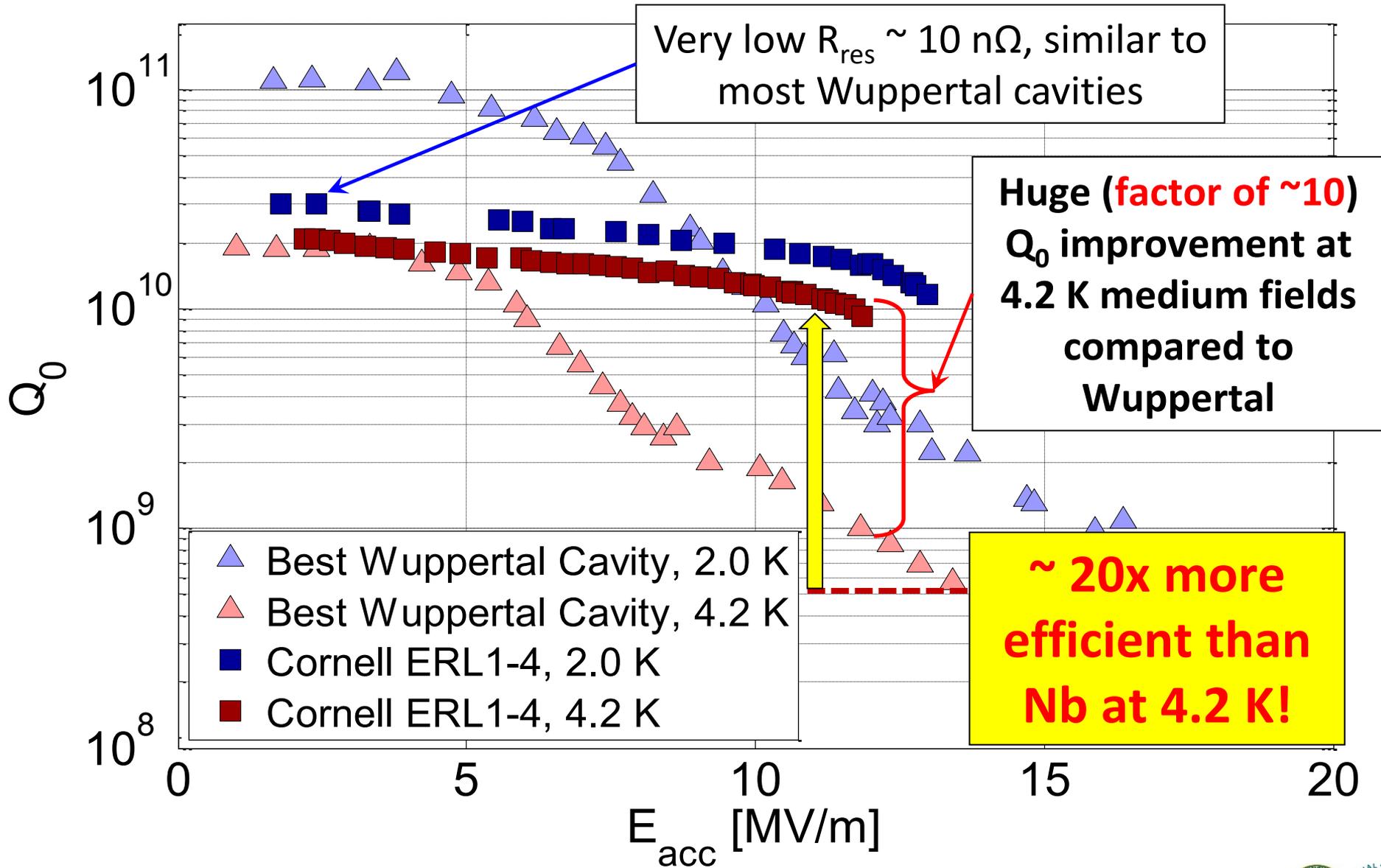
**After  
Coating**

**Bottom  
Half Cell**

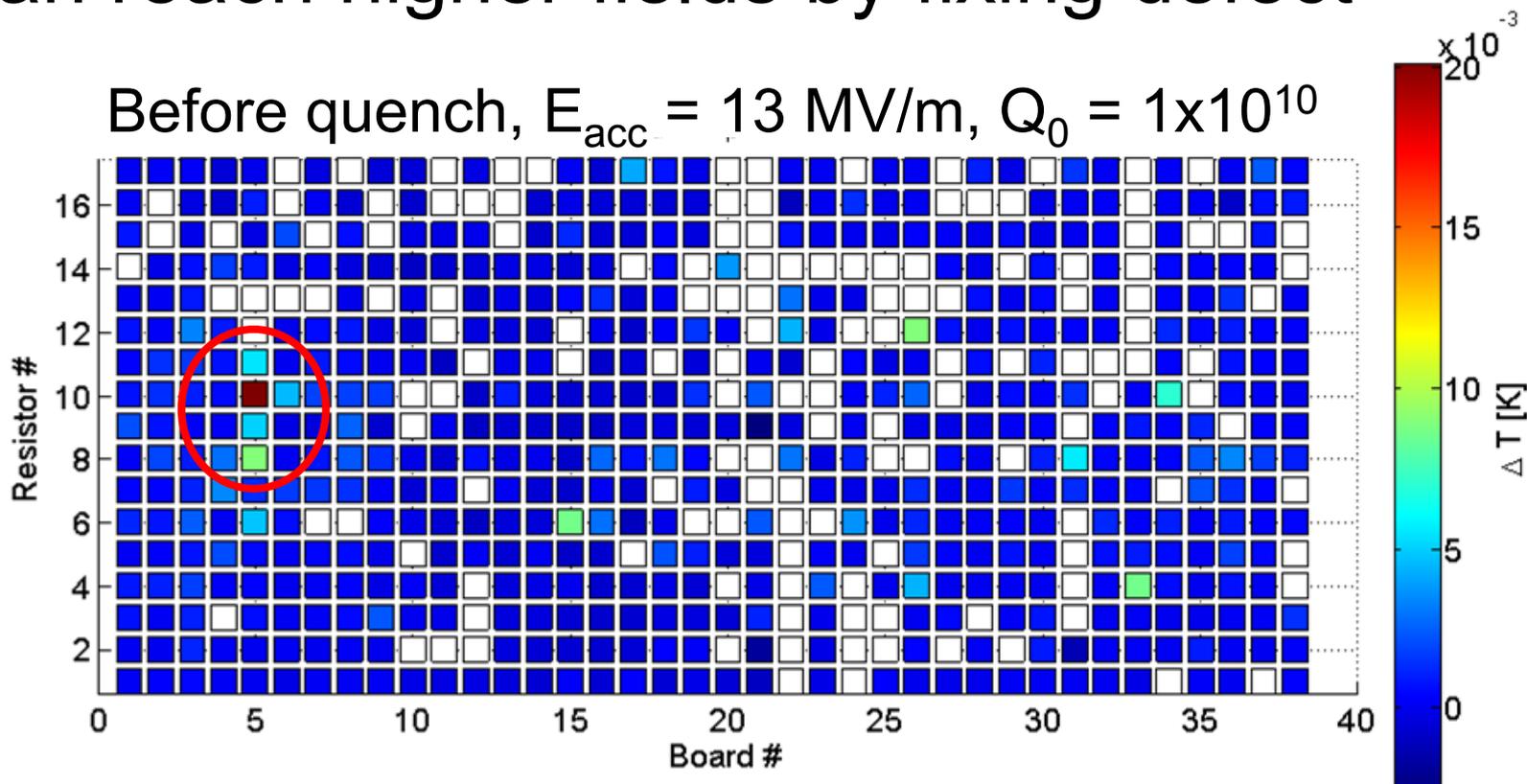
- New Nb<sub>3</sub>Sn cavity: ERL shape (similar to TESLA), single cell, 1.3 GHz
- Tested after very slow cool (>~6 min/K)
- Excellent performance, especially at 4.2 K
- **The first accelerator cavity made with an alternative superconductor that outperforms Nb at usable gradients!**



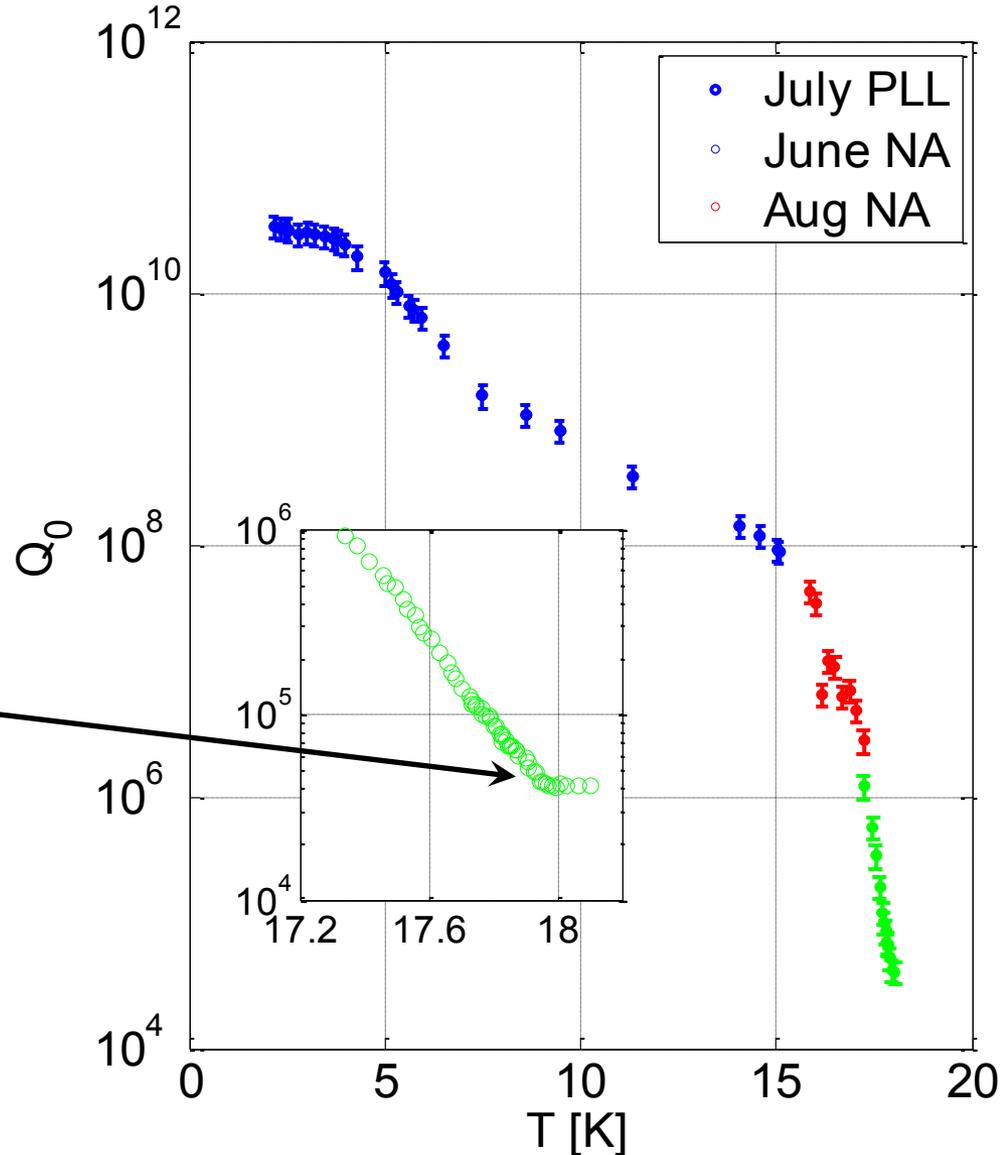
# Breakthrough Nb<sub>3</sub>Sn Cavity



- Localized pre-heating just below first quench
- Defect – not a fundamental limit
- Can reach higher fields by fixing defect

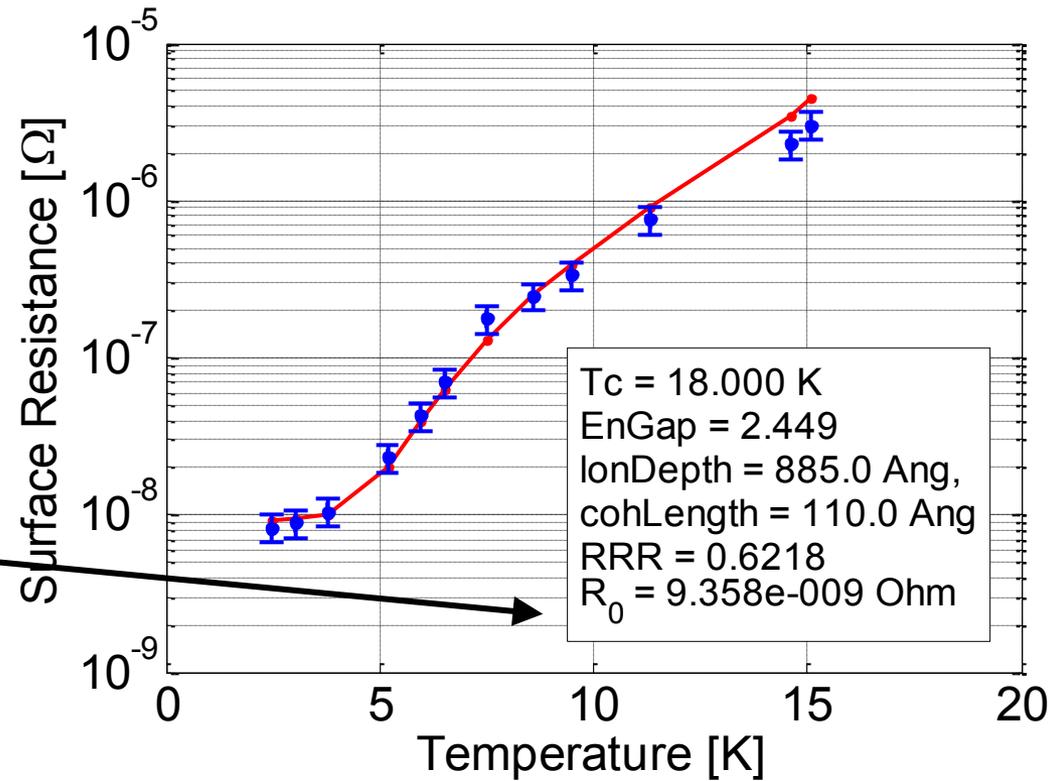


- No sign of  $Q_0$  change near  $T_c$  of niobium: excellent  $Nb_3Sn$  coverage!
- High  $T_c$  of 18.0 K close to maximum literature value
- Extract material parameters from this data



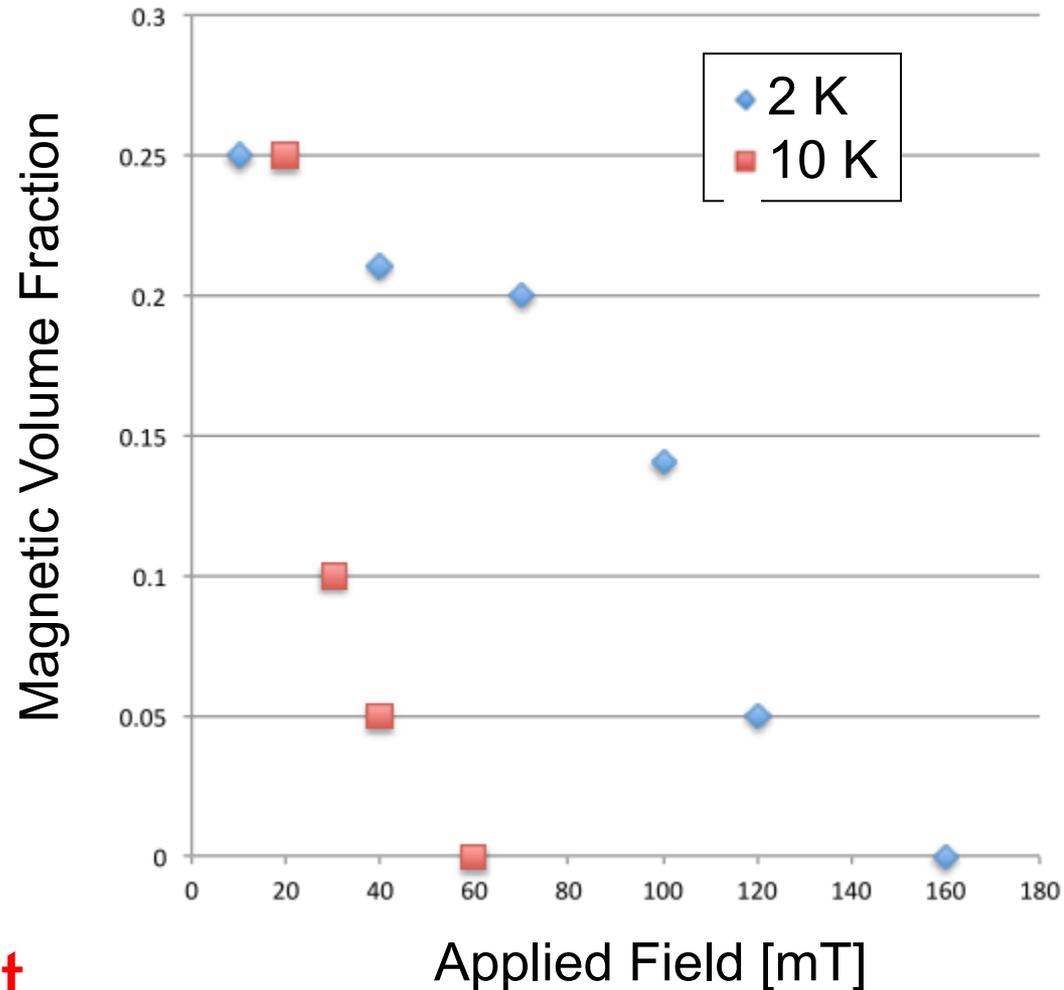
Parameter	Value
$\lambda_L(0)$ [nm]	$89 \pm 9$
$\xi_0(0)$ [nm]	$7.0 \pm 0.7$
$T_c$ [K]	$18.0 \pm 0.1$
$\Delta/k_B T_c$	$2.4 \pm 0.1$
$l$ [nm]	$3.7 \pm 0.5$
$R_{res}$ [n $\Omega$ ]	$9 \pm 2$
$\lambda_{eff}(0)$ [nm]	$(1.5 \pm 0.2) \times 10^2$
$\xi_{GL}(0)$ [nm]	$3.2 \pm 0.2$
$\kappa$	$47 \pm 6$
$B_c(0)$ [T]	$0.47 \pm 0.06$
$B_{c1}(0)$ [T]	$0.027 \pm 0.005$
$B_{sh}(0)$ [T]	$0.33 \pm 0.05$

} from fit

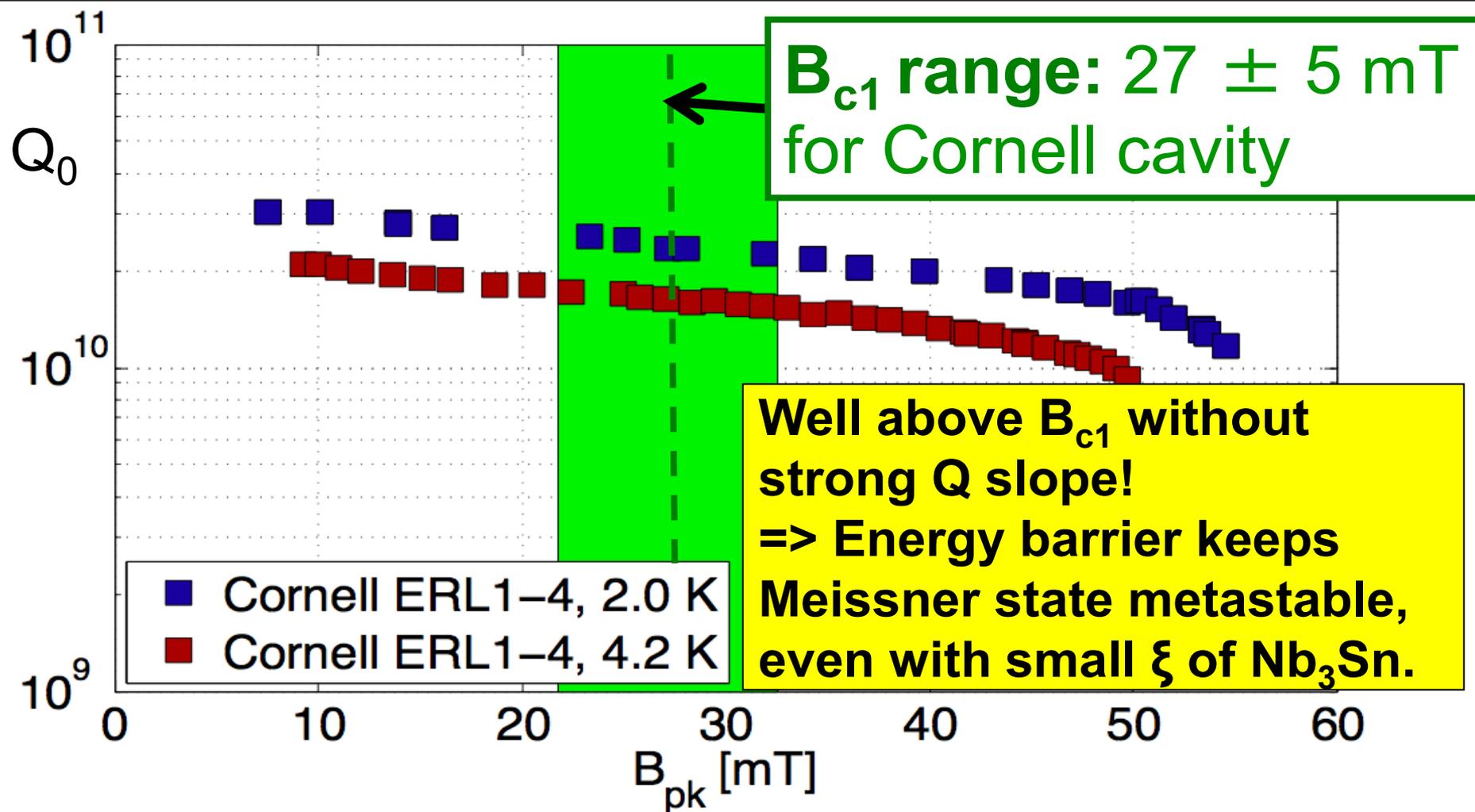


- Good agreement with literature values for ideal  $Nb_3Sn$
- See Sam's paper for derivations

- $B_{c1}$  of  $Nb_3Sn$  witness sample measured directly via muon-SR by Anna Grassellino et al.
- $B_{c1} \sim 20\text{-}30\text{ mT}$   
-> agrees well with cavity measurement



A. Grassellino et al., TUP029 (Presented at the SRF Conference, Paris, France, 2013).



**B<sub>c1</sub> is NOT a fundamental limitation!**

The end of this talk...  
...just the beginning of Nb<sub>3</sub>Sn  
for SRF

Thank you for your attention!