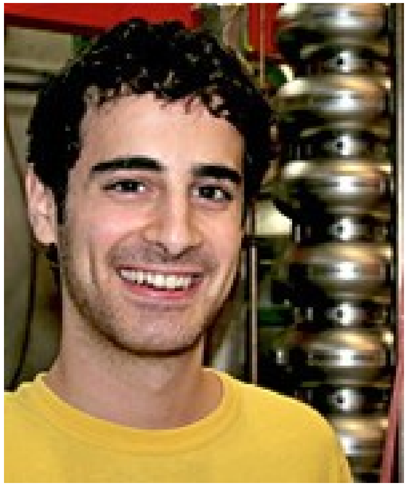
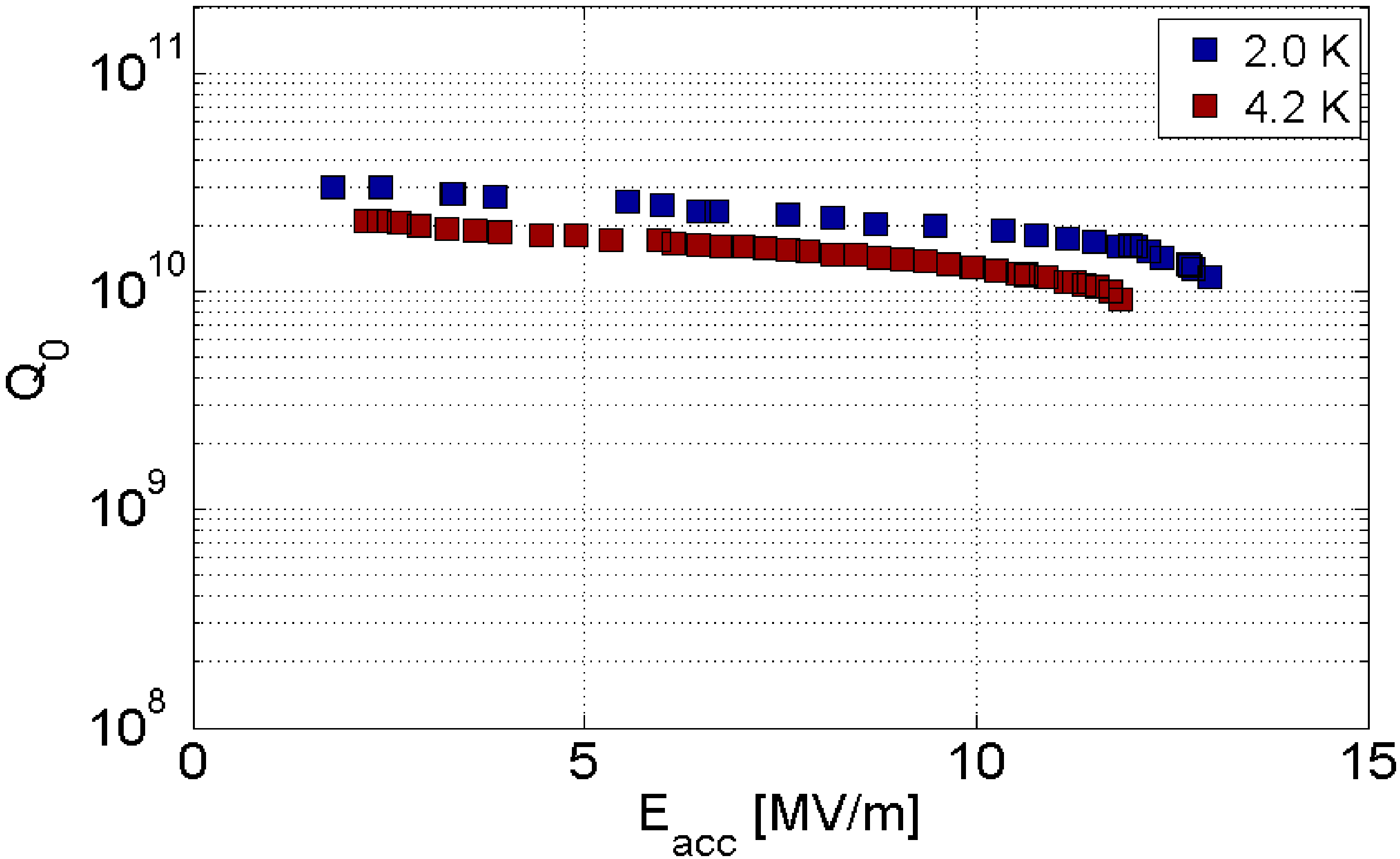
Nb_3Sn for SRF Applications

Sam Posen and Matthias Liepe
Cornell University



Cornell 1.3 GHz Nb_3Sn Cavity



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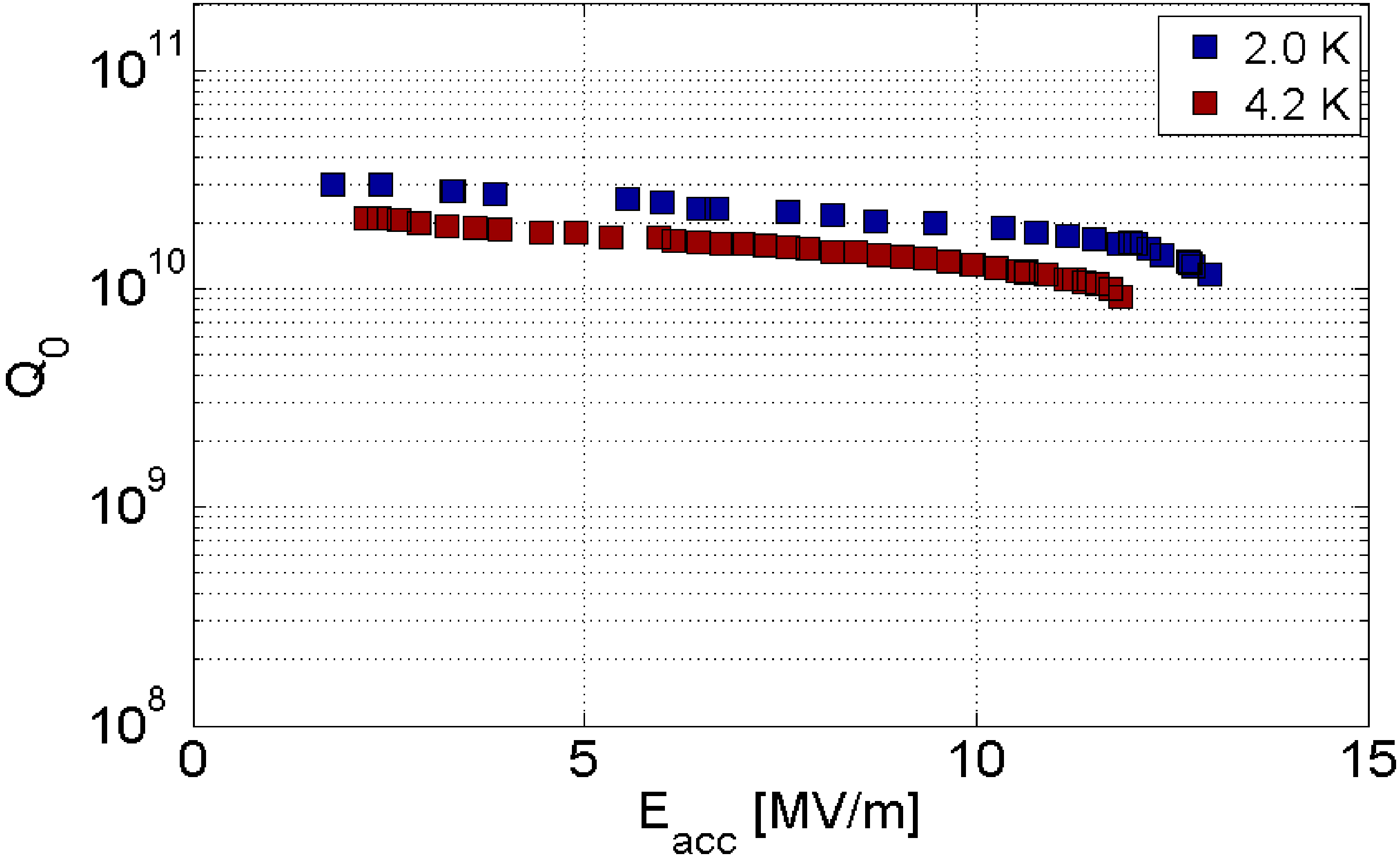
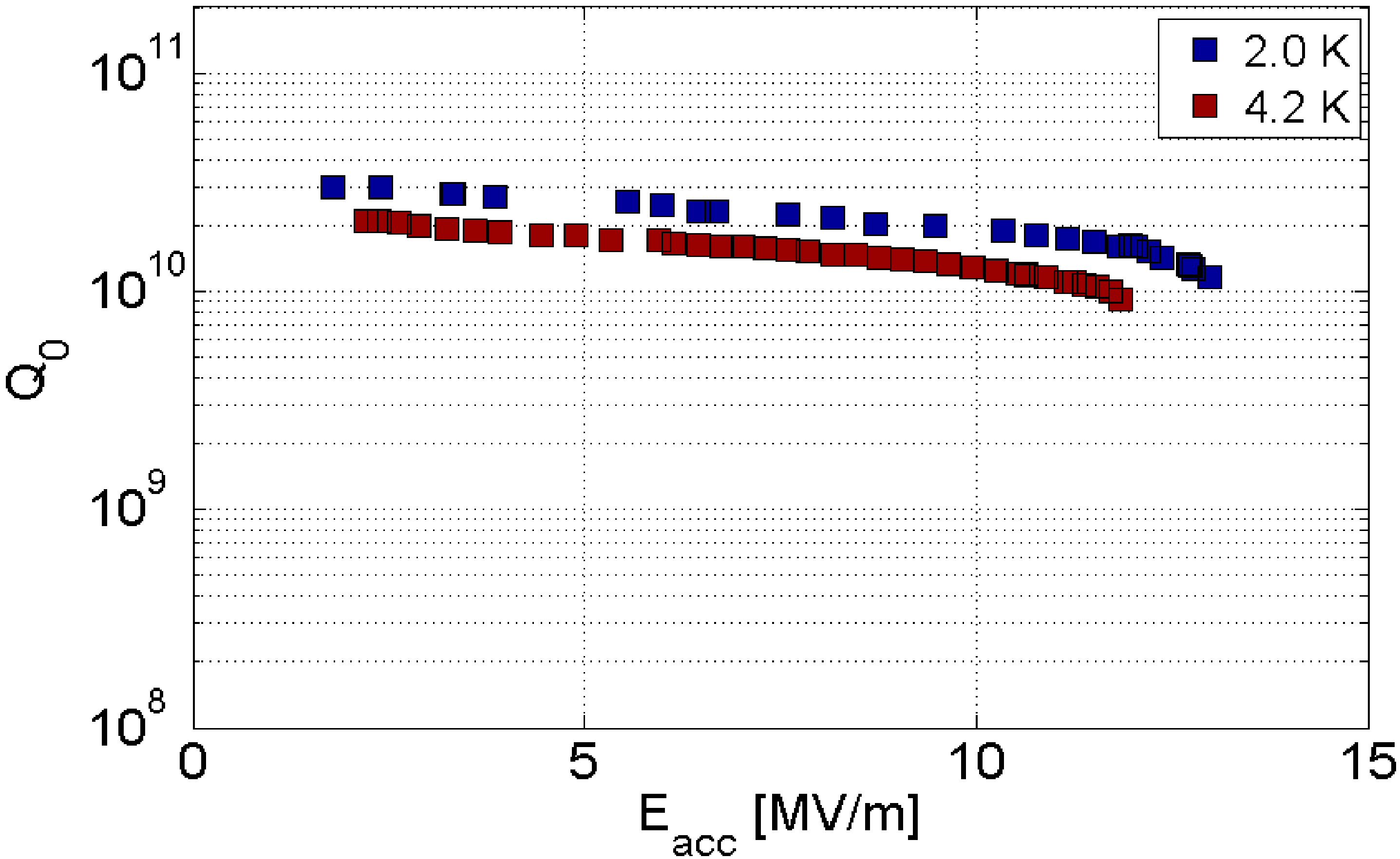


2K

- **First accelerator cavity made with an alternative superconductor that outperforms Nb at usable gradients!**

Cornell 1.3 GHz Nb_3Sn Cavity



2K

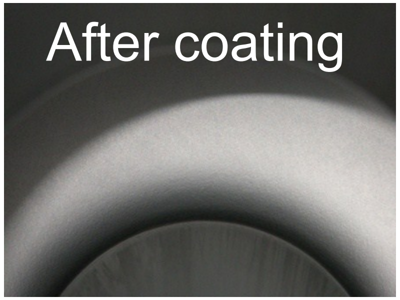
- **First accelerator cavity made with an alternative superconductor that outperforms Nb at usable gradients!**
- **Proves that B_{c1} is <u>not</u> a fundamental limit for SRF!!**

Why Nb_3Sn?

Why Nb_3Sn?

Potential

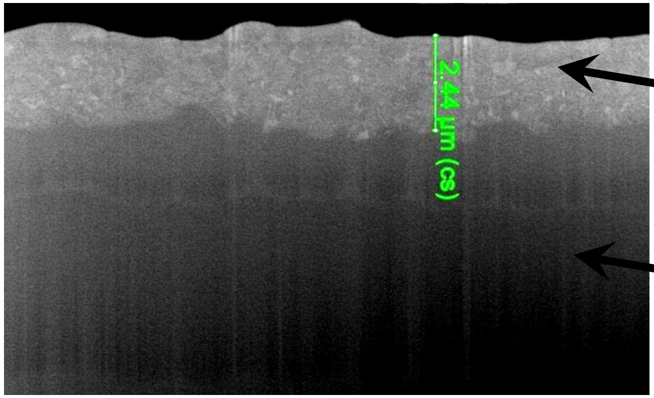
- Small R_s – high T_c ~ 18 K (twice Nb)
- Large B_{sh} ~ 400 mT (twice Nb)
- Decent ξ ~ 3-4 nm
- Can alloy existing Nb cavities
- Non-reactive



Challenges

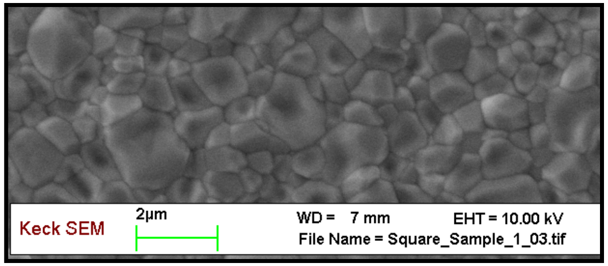
- Material is brittle
- Low thermal conductivity

→ Films avoid these



Nb_3Sn

Nb

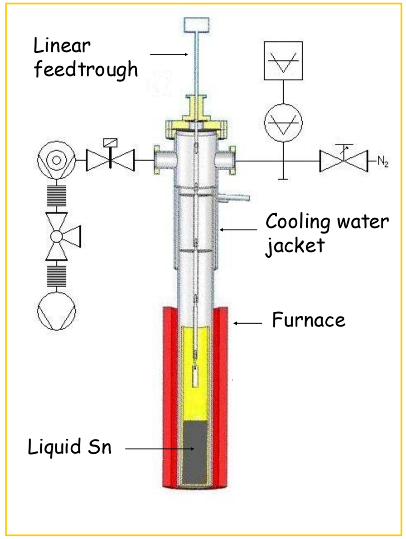


Images from Cornell

Nb_3Sn Preparation Methods

Liquid Tin Dipping – INFN

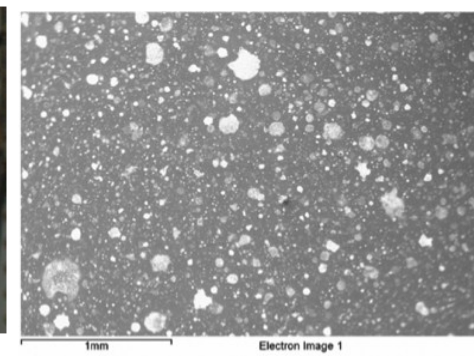
Problems with tin droplets on surface and spurious tin-rich phases



S. Deambrosis et al. (2009)

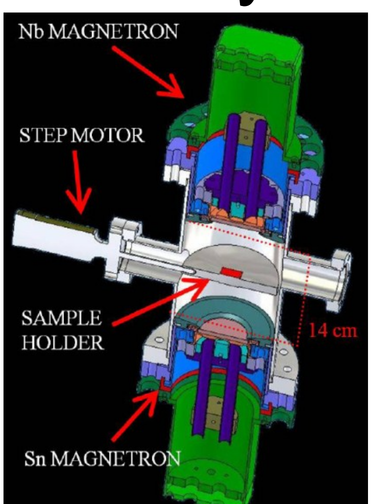
Cathodic Arc Deposition – Alameda Applied Sciences

- More energetic ions than sputtering
- Low T_c measured



M. Krishnan et al. (2012)

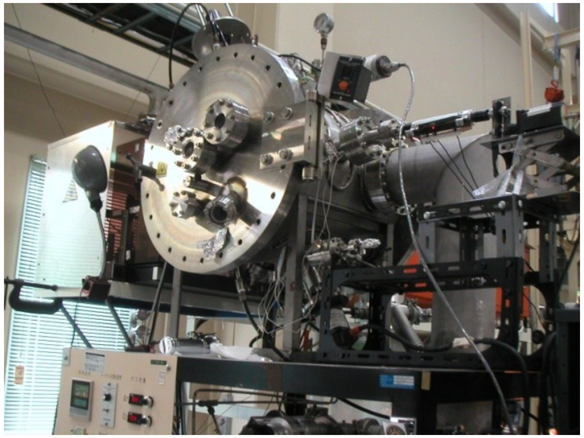
Multilayer Sputtering – INFN



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

A. Rossi et al. (2009)

Pulsed Laser Deposition - KEK

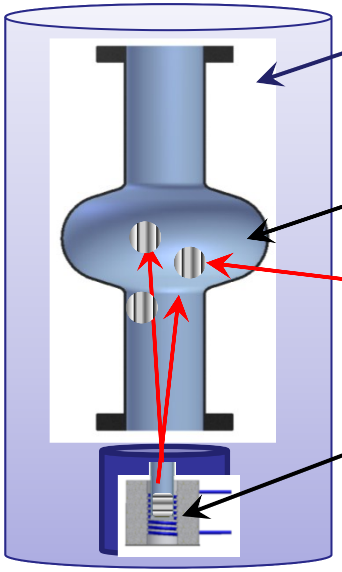


- Studies have started
- Also use PLD for MgB_2

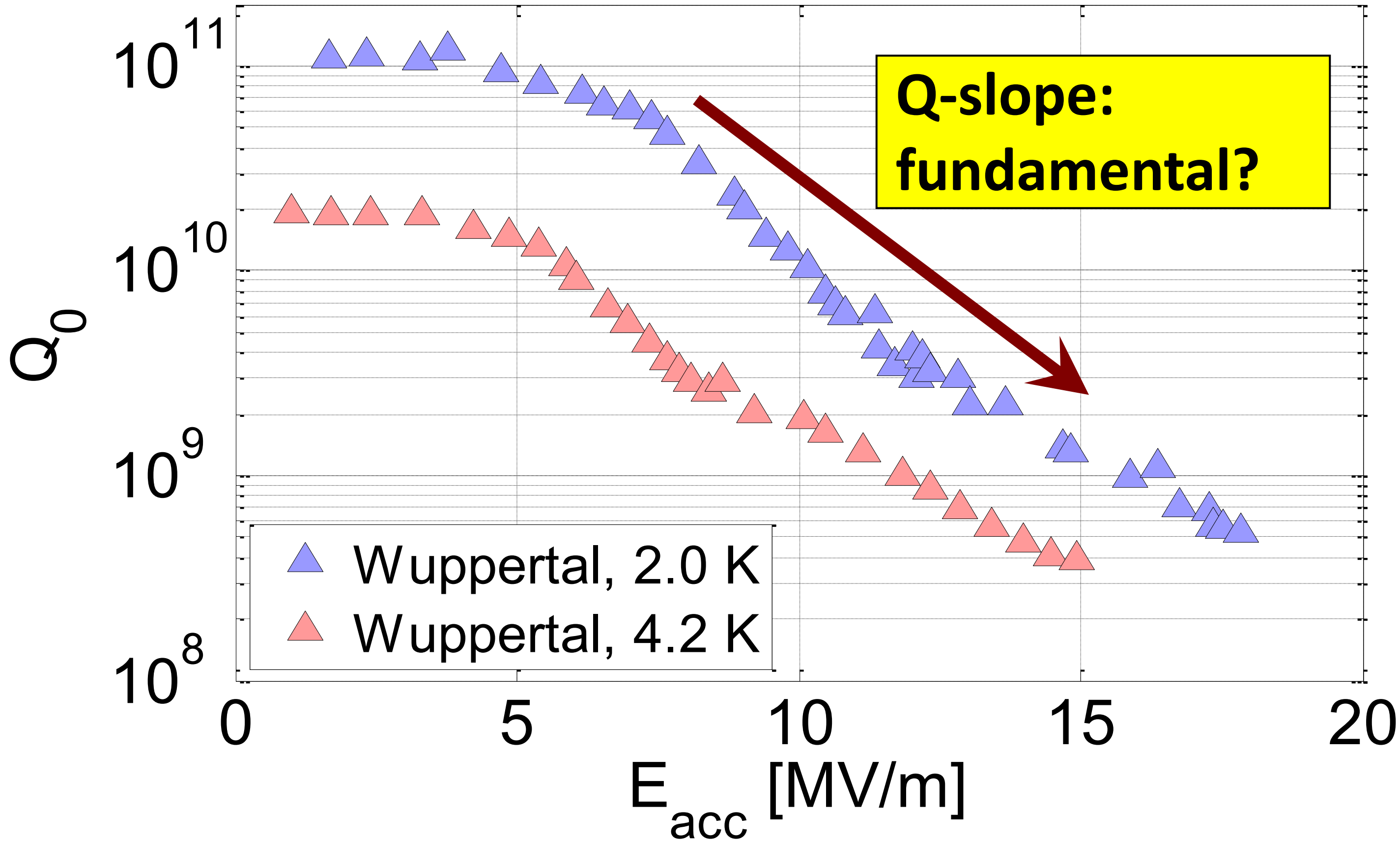
S. Mitsunobu et al.

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

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



Nb_3Sn cavities from U. Wuppertal



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

THE Question

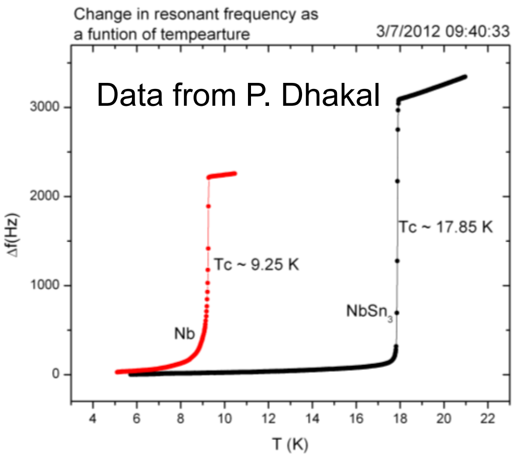
Ideal superconductor is metastable from B_{c1} up to B_{sh} but surface defects of size ~ξ might lower energy barrier.

Is ξ of Nb_3Sn so small that B_{c1} is the limit?

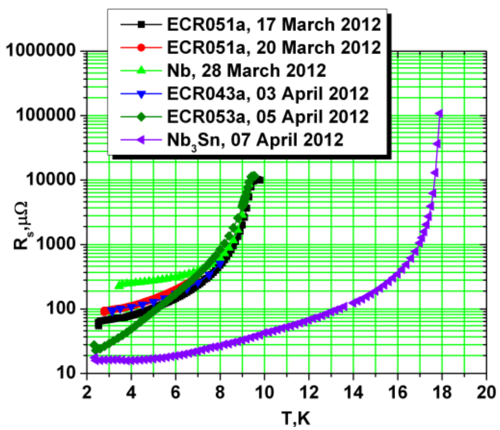
If vortices penetrate at B_{c1}, **all** alternative SRF materials would be severely limited.

JLab Nb_3Sn Work
(see poster TUP071 for details)

JLab Nb_3Sn Work (Grigory Eremeev)



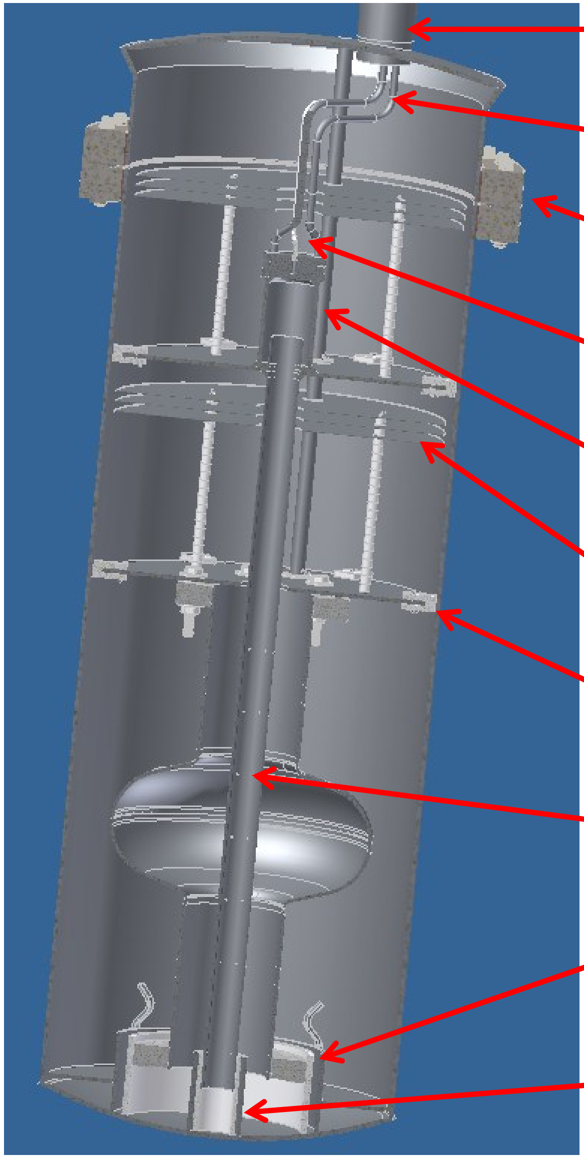
Transition temperature is ~ 17.85 K. The best of three samples shows very smooth surface with no residual tin contamination



Recent measurements of surface resistance of several ECR films, bulk Nb sample, and Nb_3Sn 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 $\mu\Omega$ 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_3Sn development was ordered in October 2012, delivered in August 2013, and is being commissioned.

JLab Nb_3Sn Work (Grigory Eremeev)



Pump-out line

He gas cooling line for crucible

14” conflat mating flanges

Crucible thermocouple

Sn and $SnCl_2$ crucible

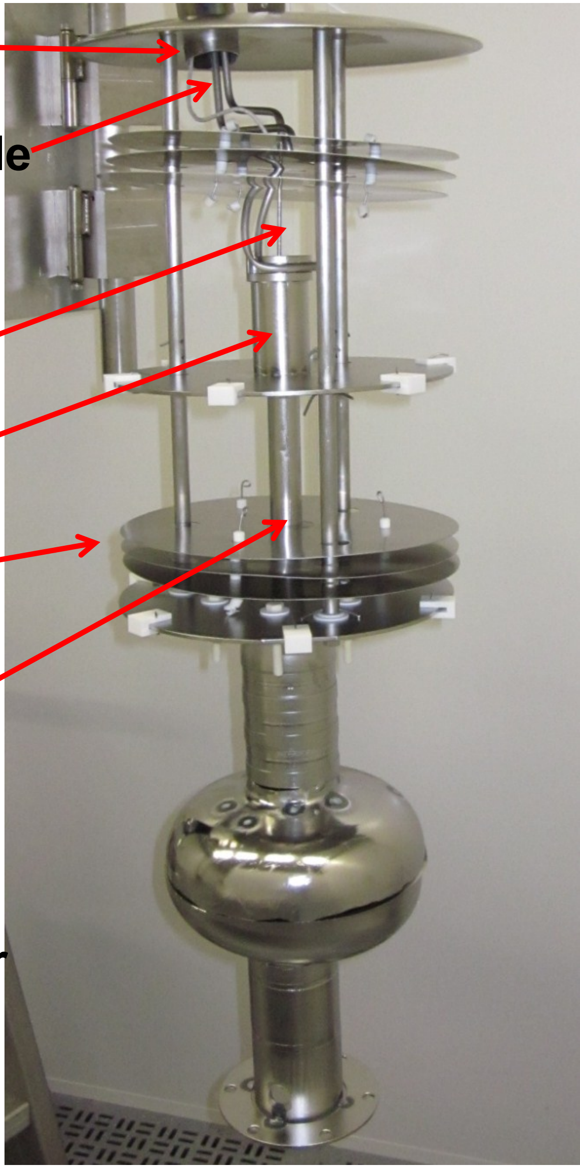
Nb heat shields

Nb cavity support plate

Sn vaporguide

Cavity flange support cylinder

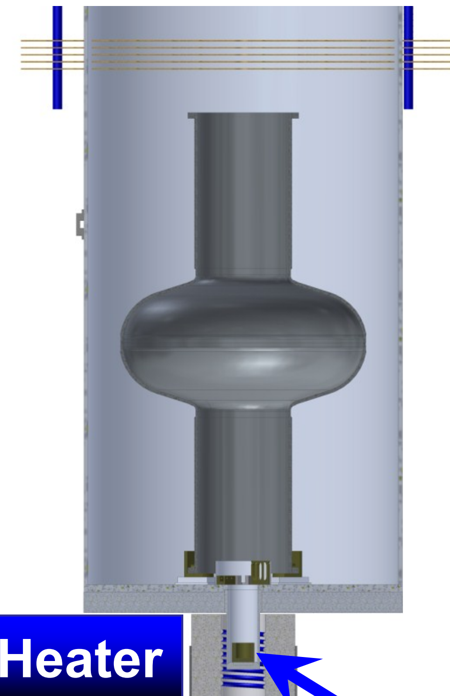
Vapor guide support cylinder



Cornell Nb_3Sn Work
(see poster TUP087 for details)

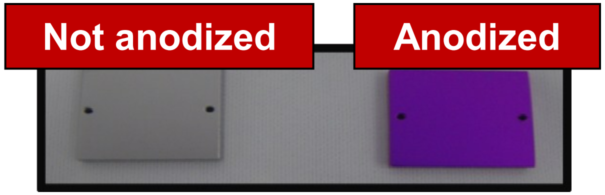
Cornell Cavity Coating Chamber

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



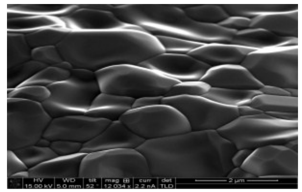
Nb_3Sn Sample Studies

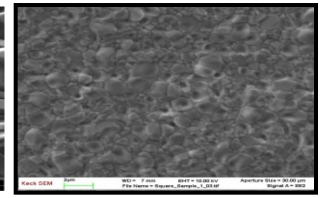
Anodization



Pink -> Nb3Sn

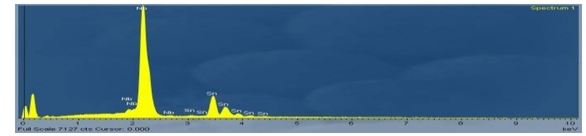
SEM





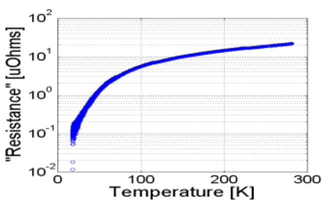
Grains ~1 μm. Appearance similar to Nb_3Sn from other studies

EDX / XPS



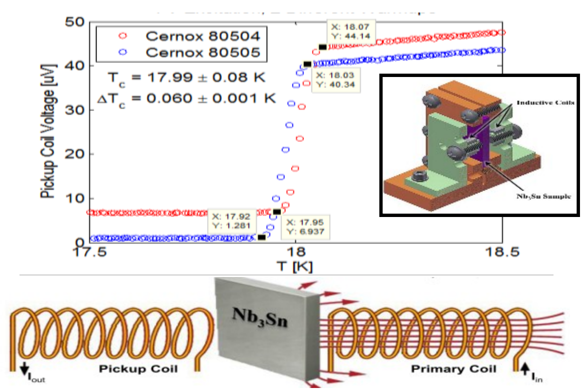
24.2 ± 0.5 atomic % Sn, uniform over surface; 2 μm deep

RRR Measurement



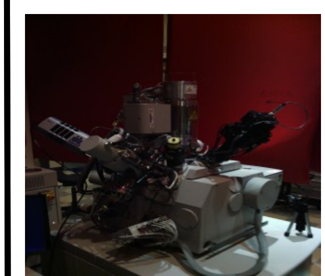
Minimal degradation of thermal conductivity from coating process

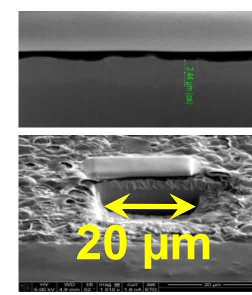
T_c Measurement



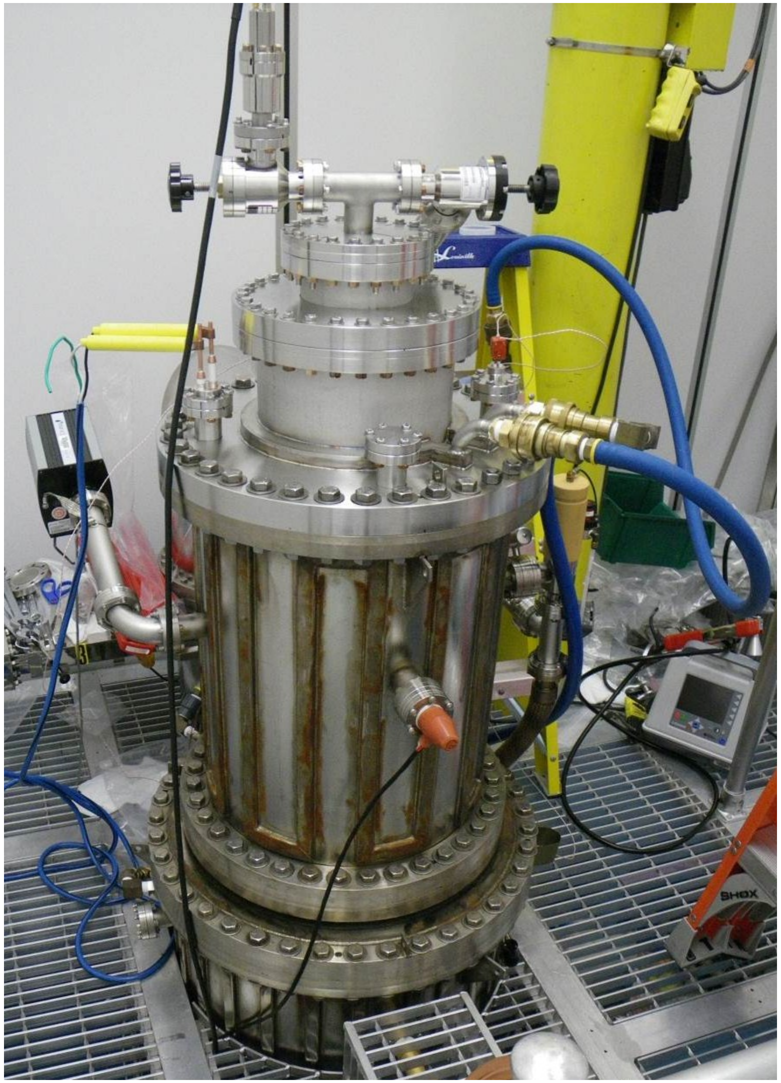
FIB

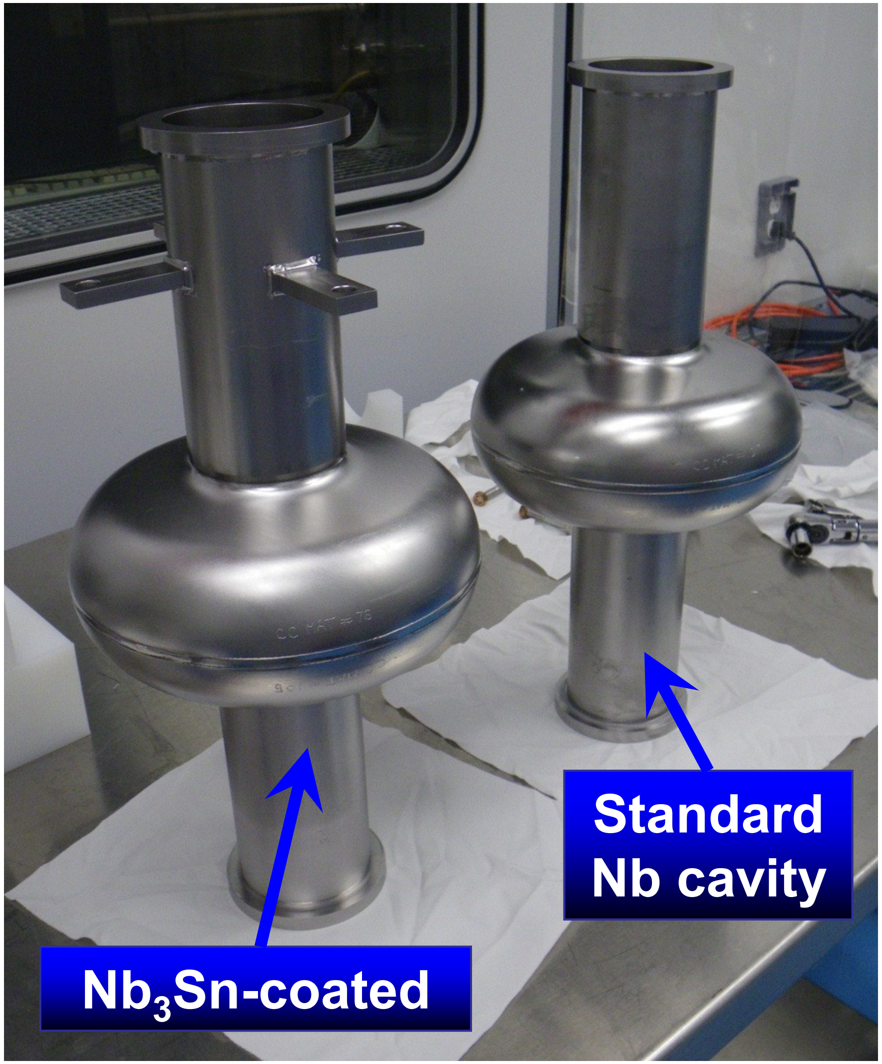
Sample prep for TEM, view of coating cross section

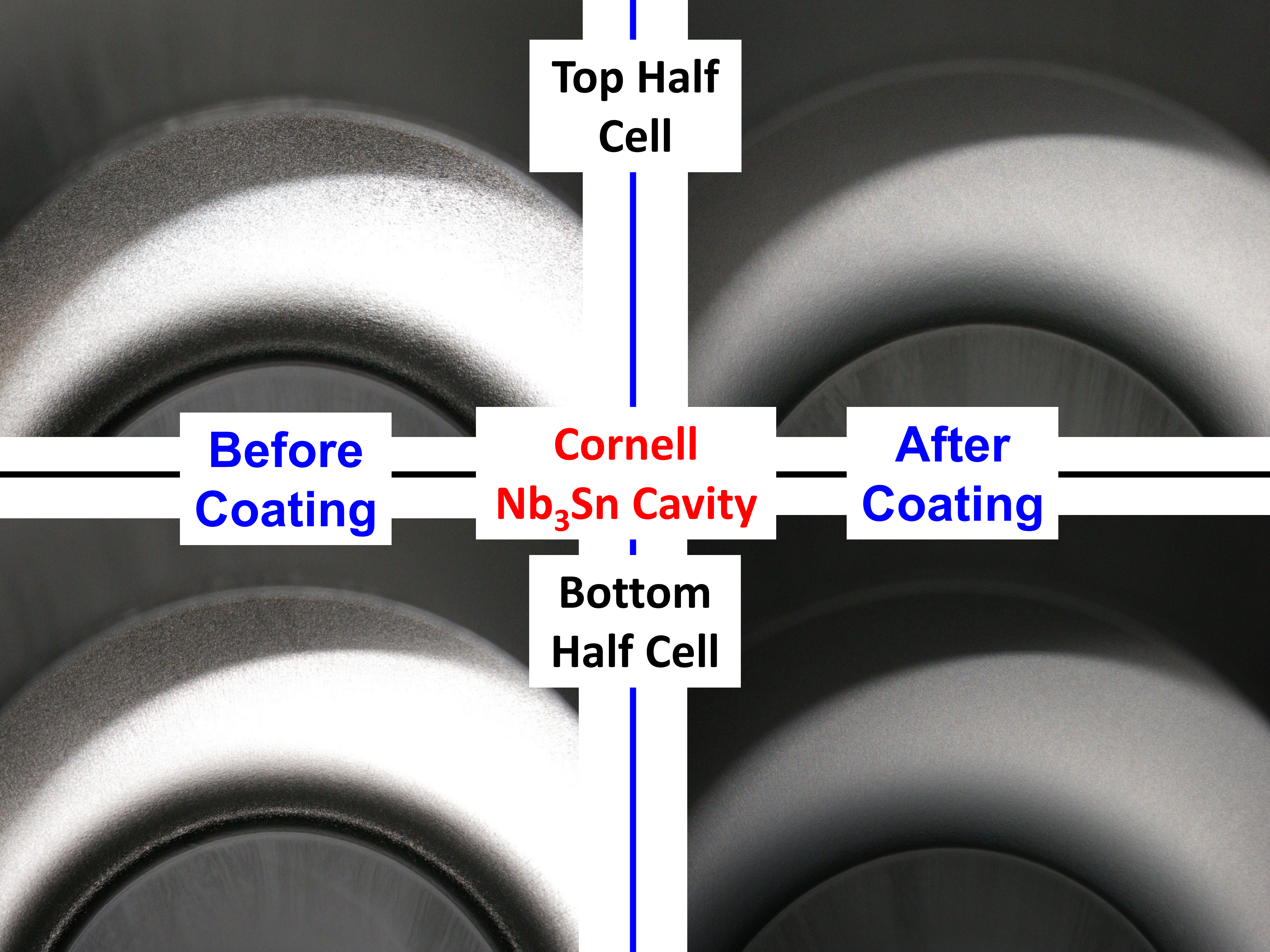




Cornell Nb_3Sn Coated Cavity



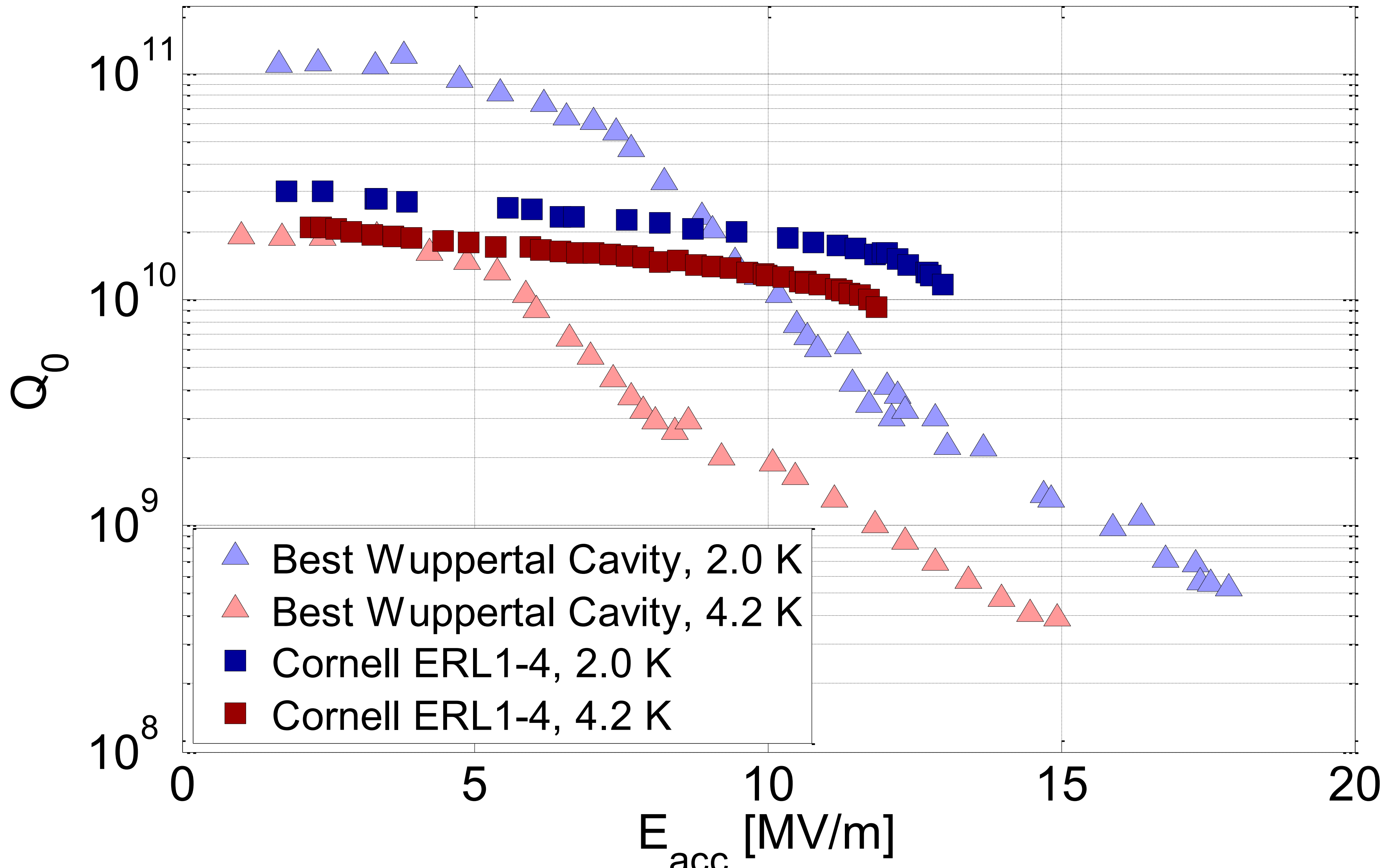



Top Half Cell
Before Coating
Cornell
Nb_3Sn Cavity
After Coating
Bottom Half Cell

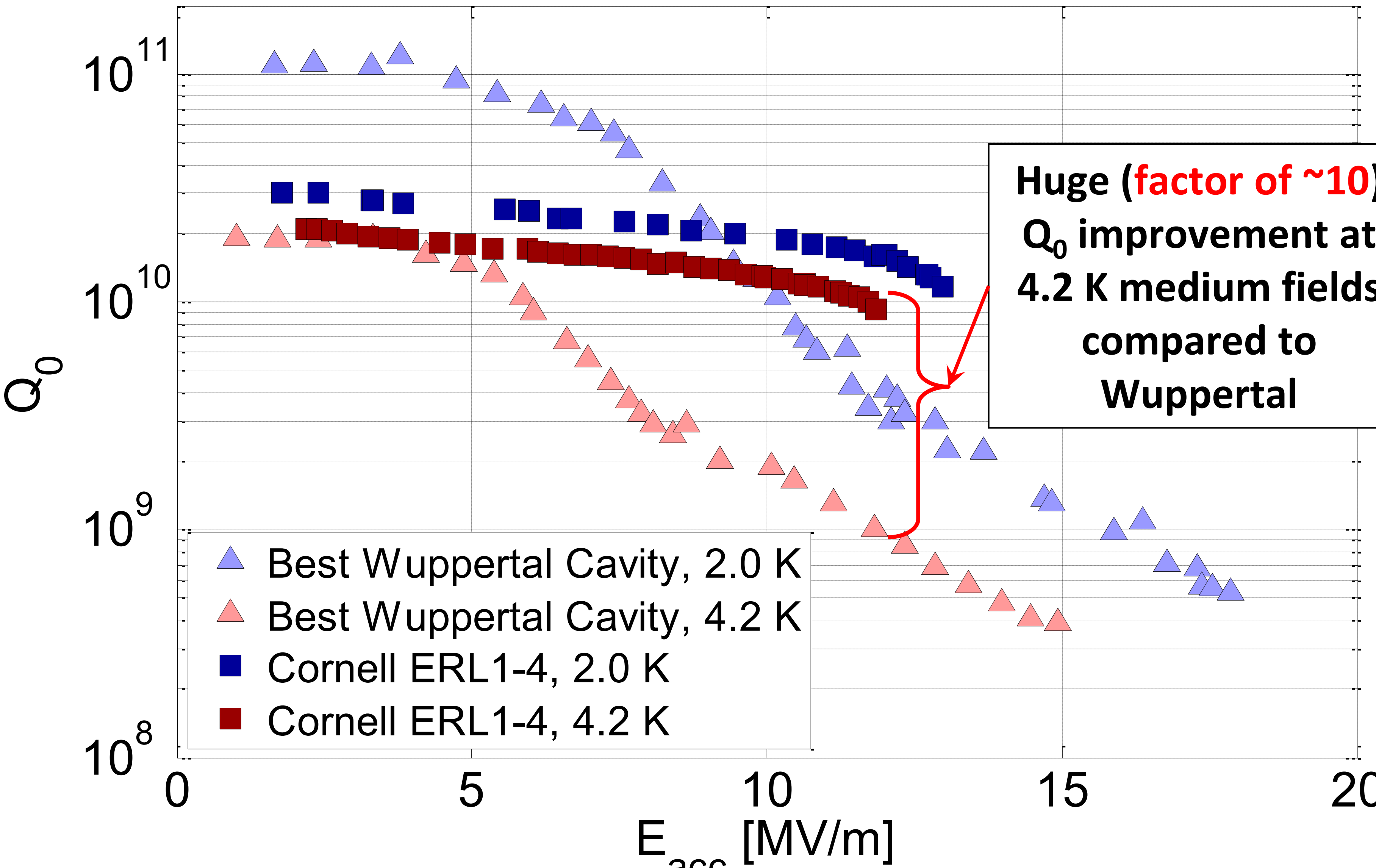
Cornell Nb_3Sn Cavity

- New Nb_3Sn 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_3Sn Cavity

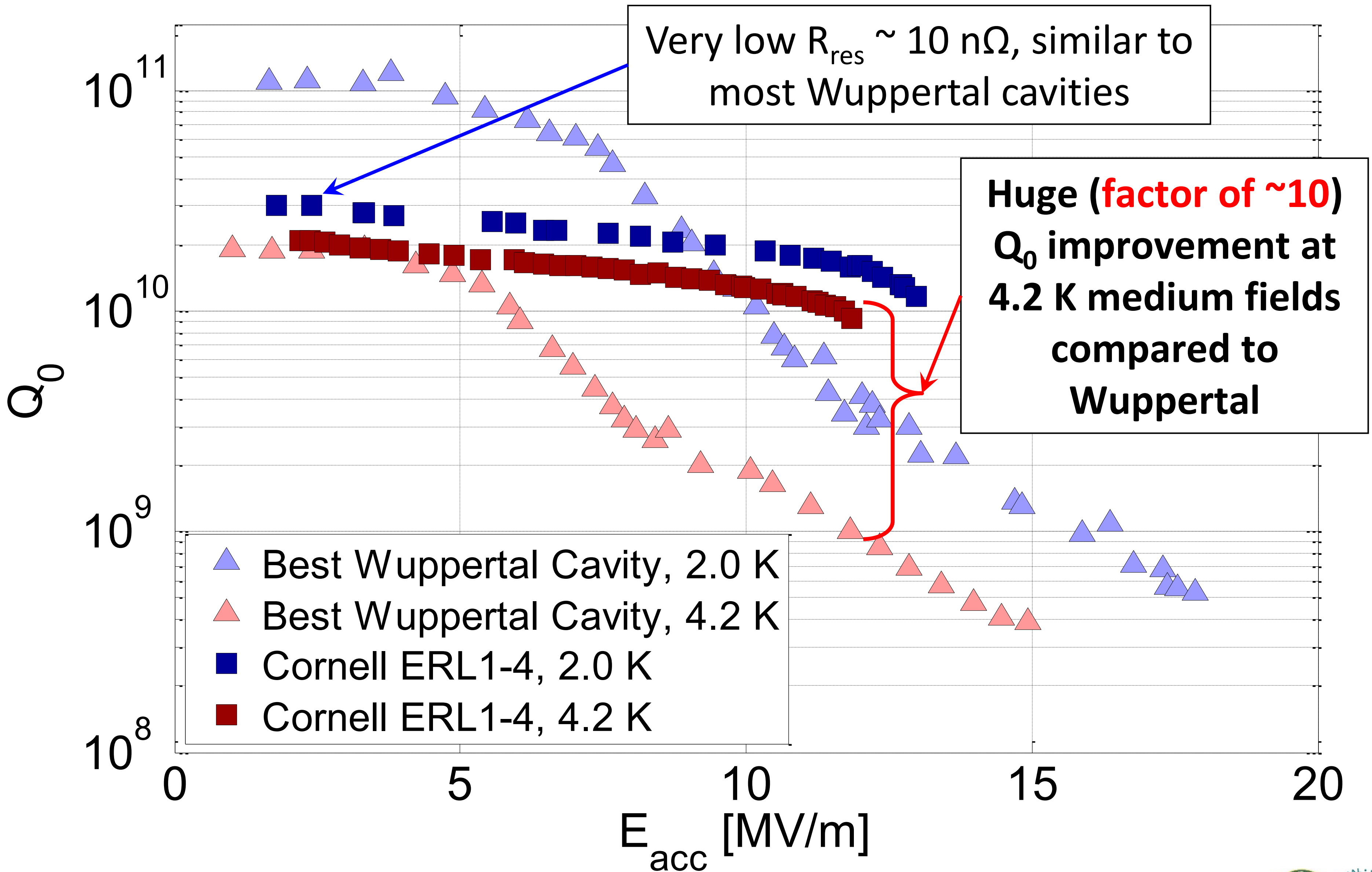


Breakthrough Nb_3Sn Cavity



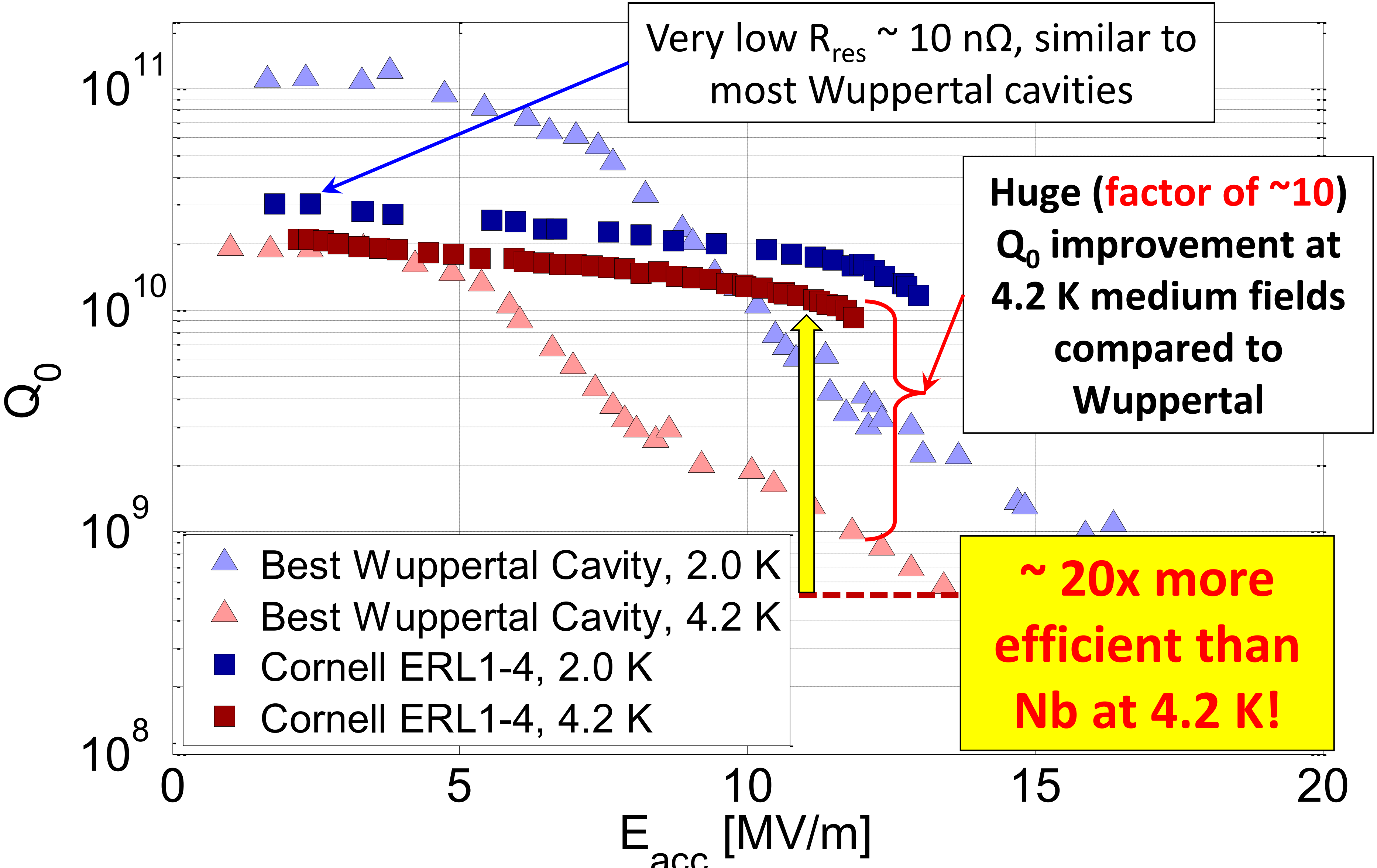
Huge (factor of ~10) Q_0 improvement at 4.2 K medium fields compared to Wuppertal

Breakthrough Nb_3Sn Cavity



Breakthrough Nb_3Sn Cavity

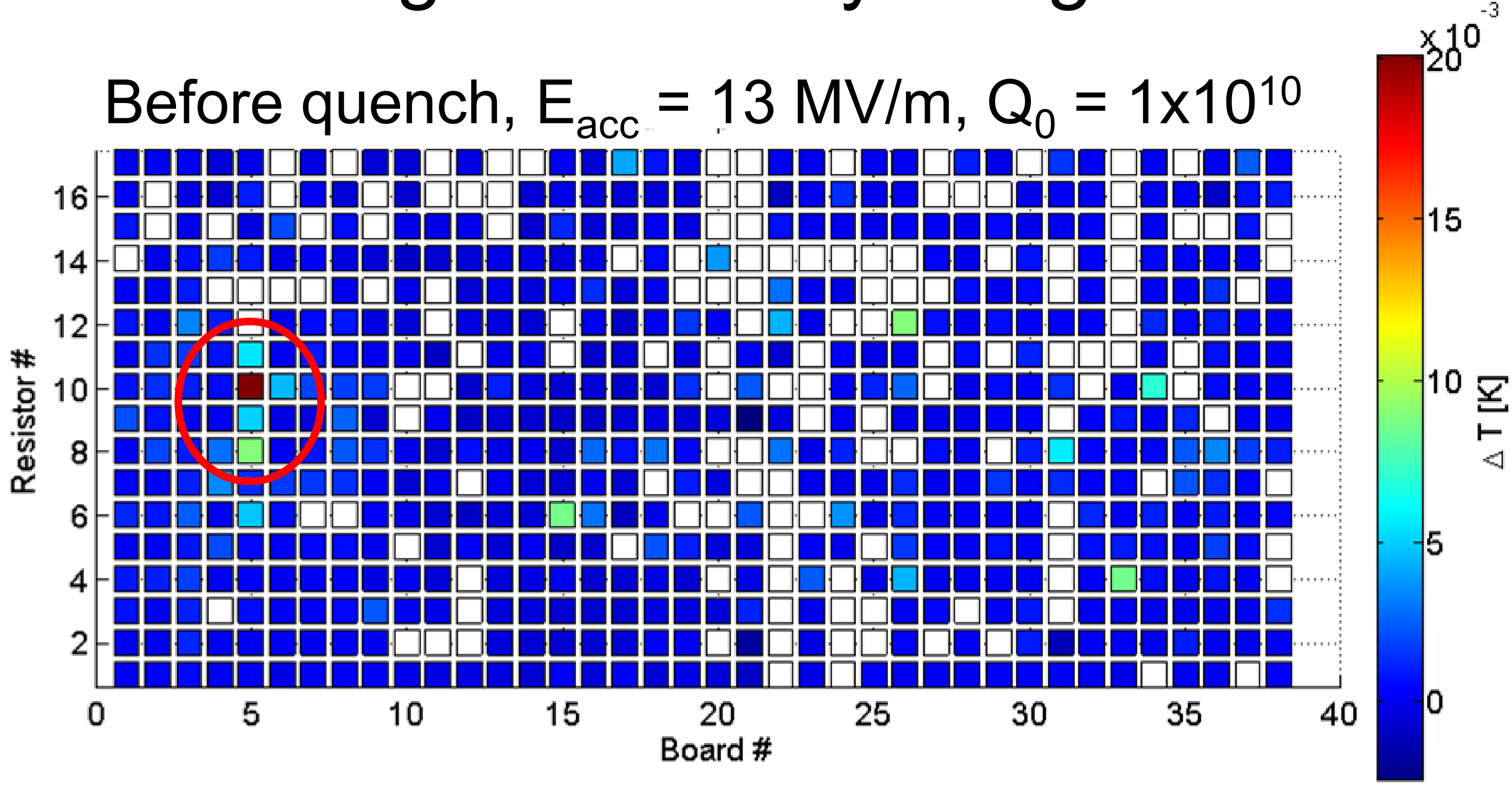
SRF2013 PARIS
16th International conference on RF Superconductivity



Limiting Defect at 2K

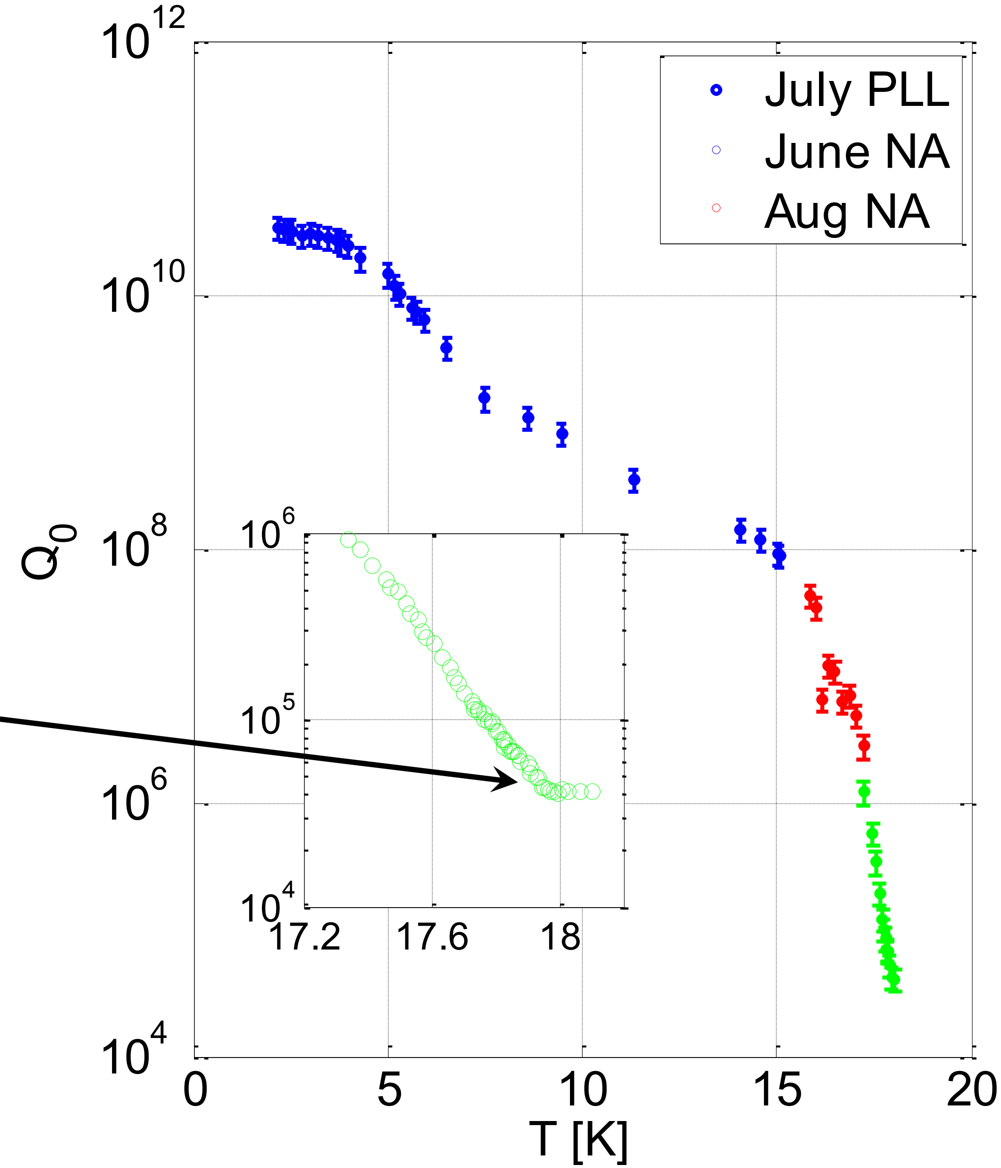
- Localized pre-heating just below first quench
- Defect – not a fundamental limit
- Can reach higher fields by fixing defect

Before quench, E_{acc} = 13 MV/m, $Q_0 = 1\times10^{10}$



Q vs T

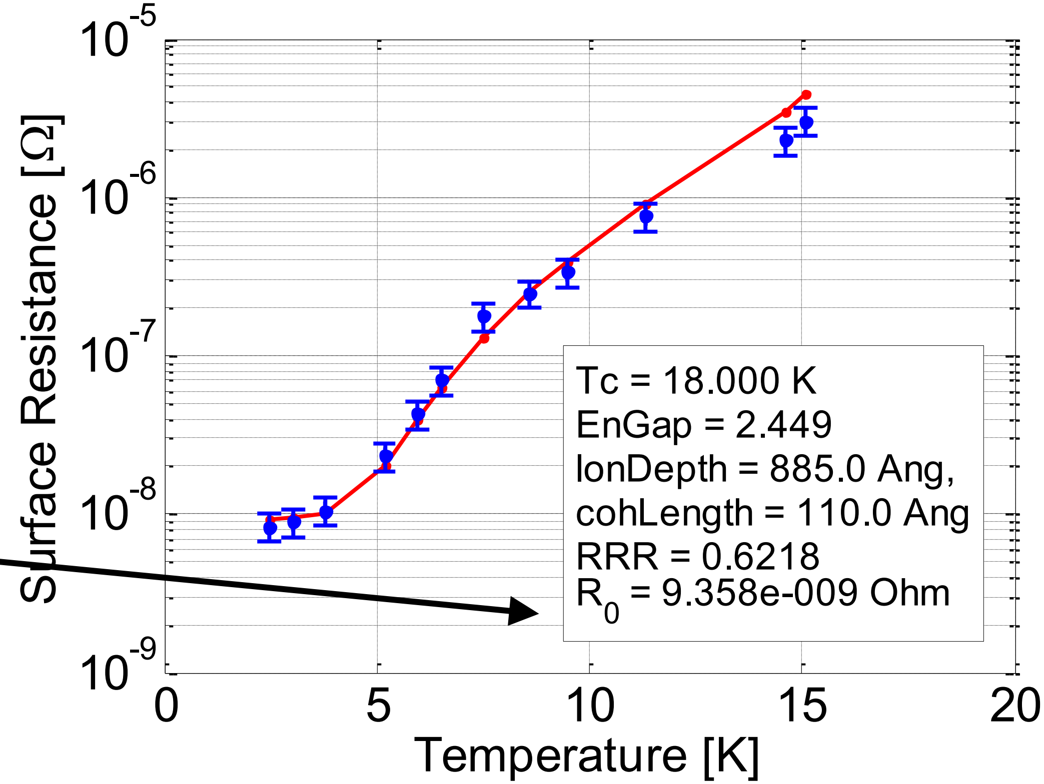
- No sign of Q_0 change near T_c of niobium: excellent Nb_3Sn coverage!
- High T_c of 18.0 K close to maximum literature value
- Extract material parameters from this data



Fits to Material Parameters

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

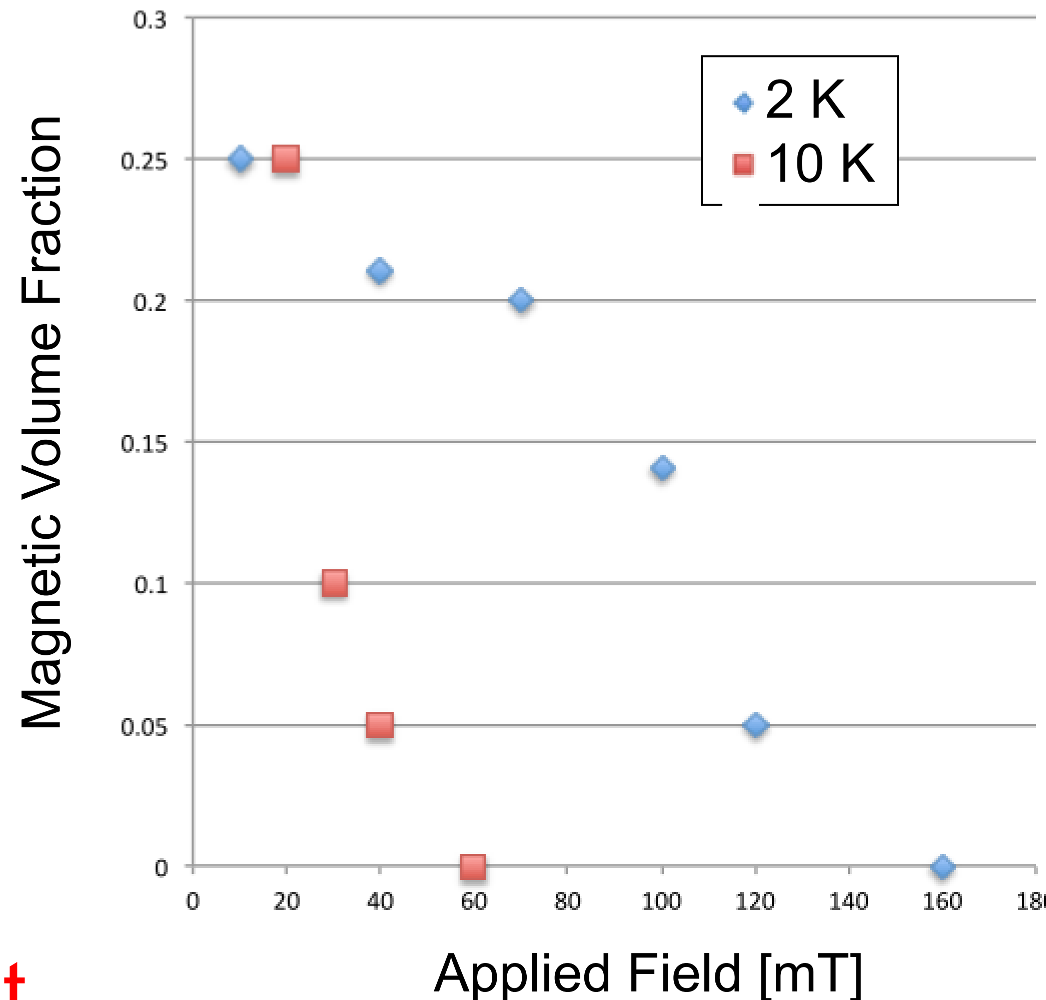
from fit



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

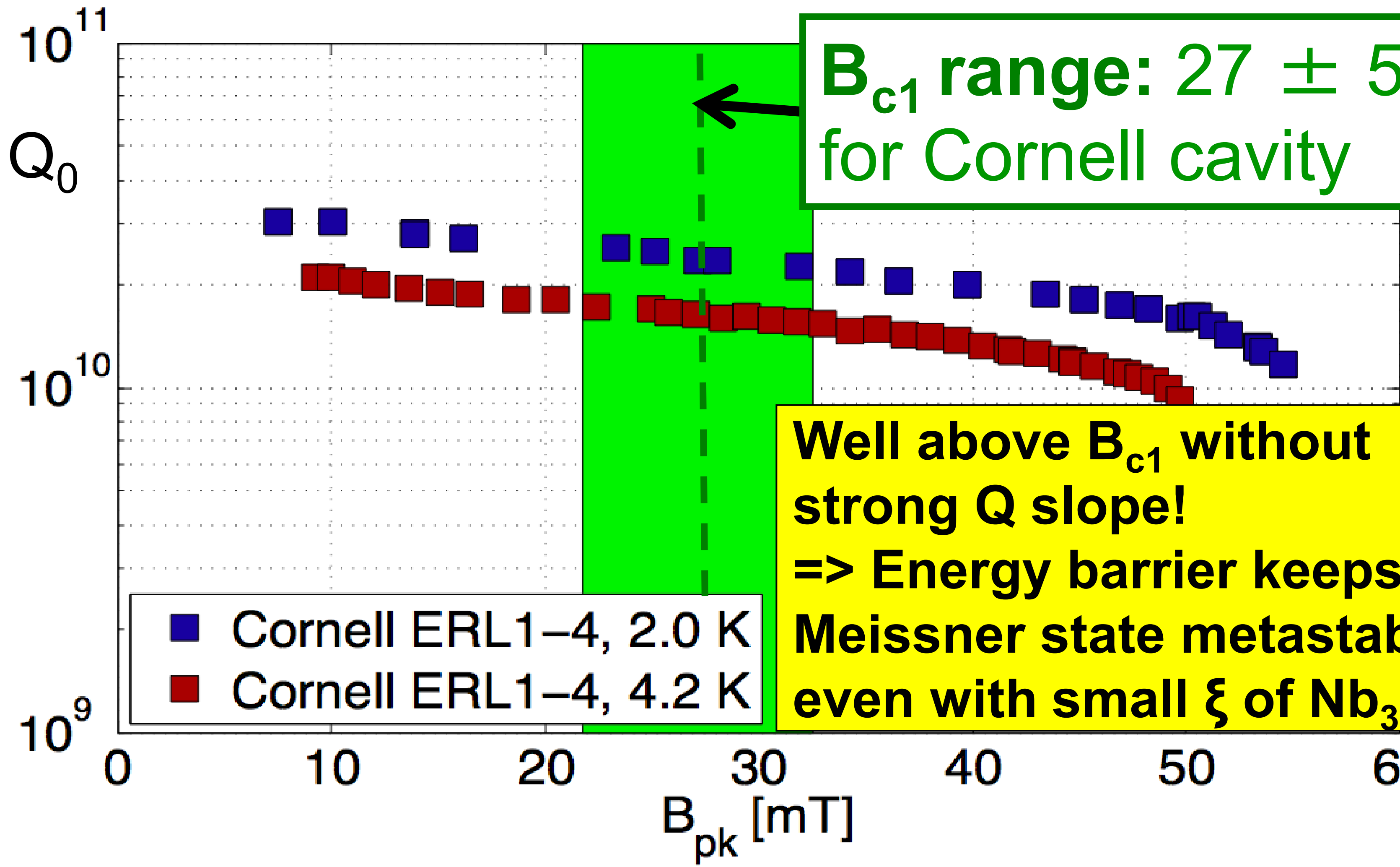
Sample B_{c1} Measurement

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



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

Cornell Nb_3Sn Cavity and B_{c1}



B_{c1} range: 27 ± 5 mT for Cornell cavity

Well above B_{c1} without strong Q slope!
=> Energy barrier keeps Meissner state metastable, even with small ξ of Nb_3Sn.

B_{c1} is NOT a fundamental limitation!

The end of this talk…

…just the beginning of Nb_3Sn for SRF

Thank you for your attention!