Nb_3Sn R&D at Fermilab

Sam Posen

Linear Collider Workshop 2018
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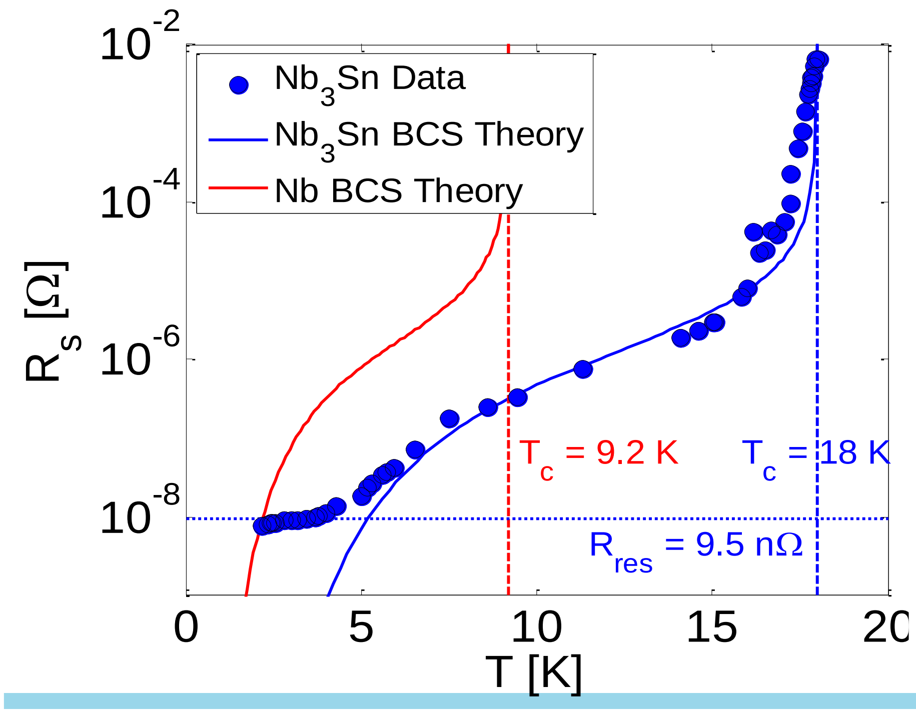
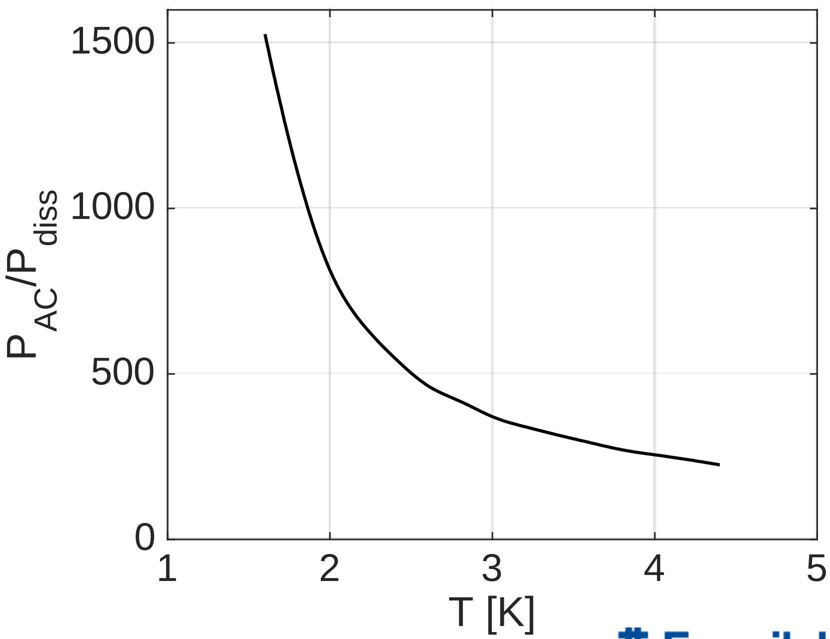
Higher $Q_0(T)$ with Nb_3Sn

- Large T_c ~ 18 K
  - Very small $R_{BCS}(T)$ – $R_{BCS}(T) \sim e^{-1.76 T_c/T}$
  - High Q_0 even at relatively high T
- Higher temperature operation
  - Simpler cryogenic plant
  - Higher efficiency

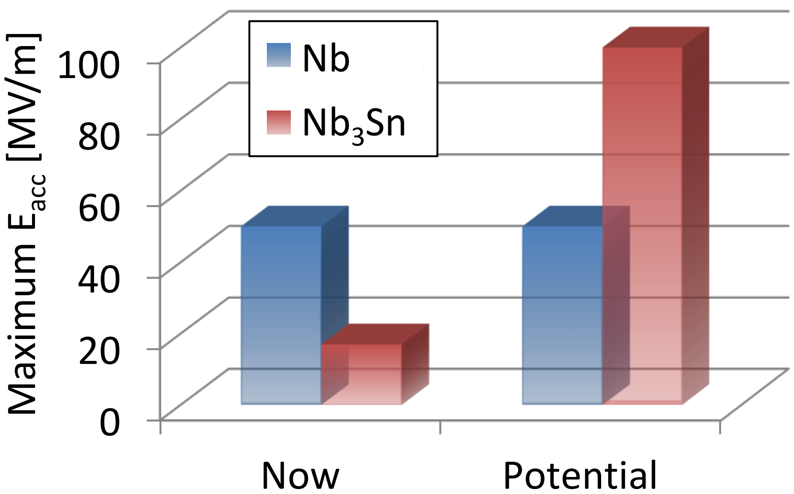
CERN cryogenic plant

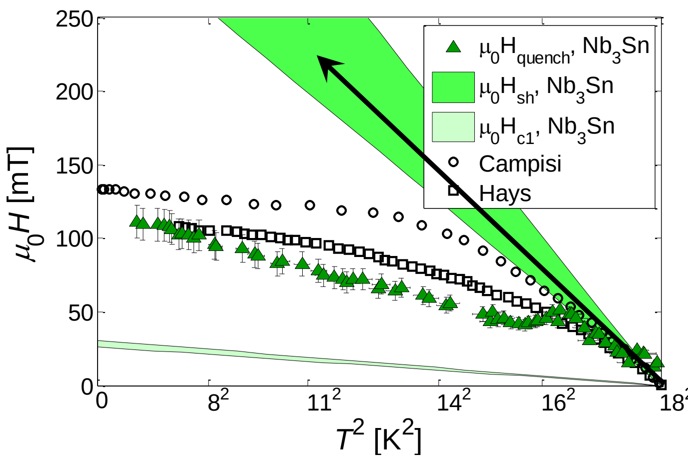




Maximum Accelerating Field

- For high gradient applications, the superheating field of Nb_3Sn is predicted to be twice that of niobium
- This is significantly beyond current performance levels
- **Potential for high gradient applications (e.g. future >250 GeV ILC upgrade) motivates R&D focused on improving maximum field**





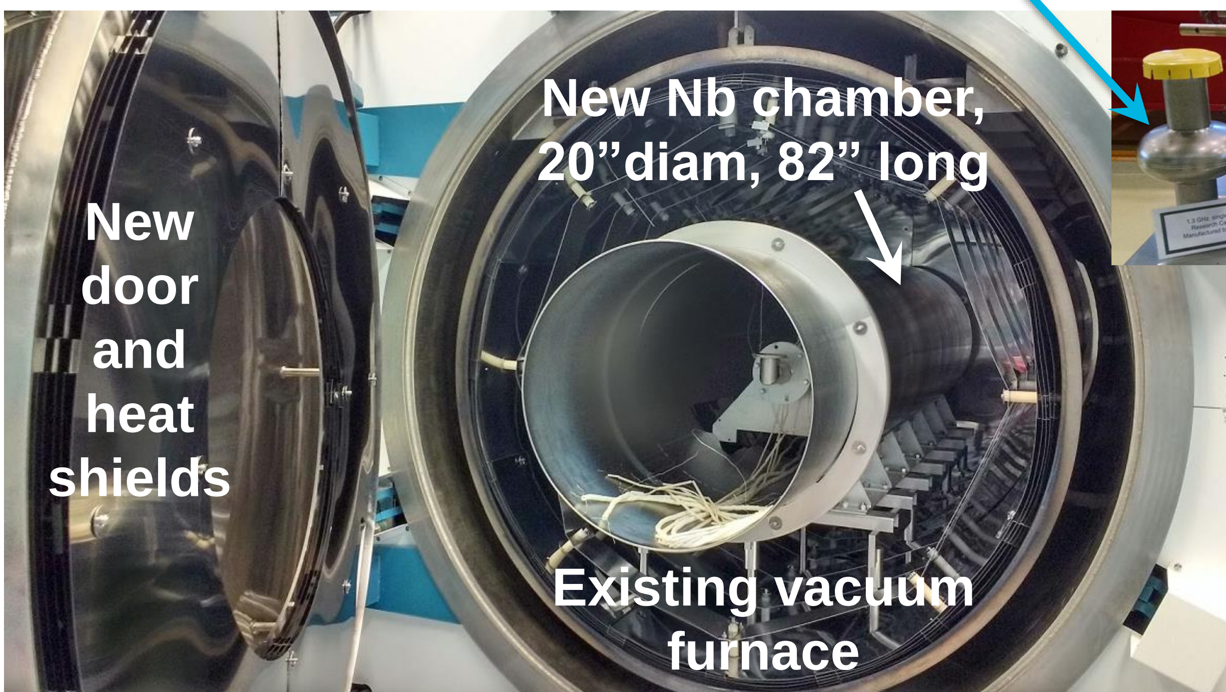
S. Posen, N. Valles, and M. Liepe, *Phys. Rev. Lett.*, 115, 047001 (2015).

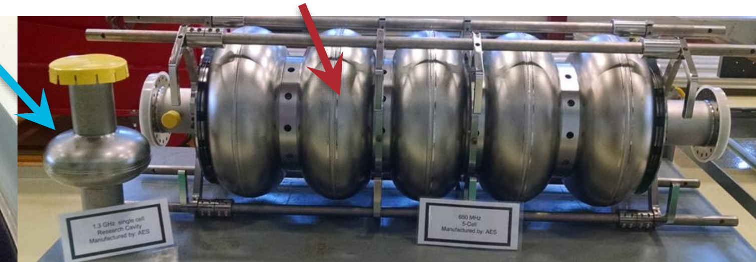
Nb_3Sn SRF Experimental Program at Fermilab

- Initiated in 2015, first coatings by early 2017
- Nb_3Sn SRF program goals:
  1. Push Nb_3Sn cavity performance (both Q_0 and E_{acc})
  2. Scale up to production-style cavities and study in cryomodule-like environment

1.3 GHz 1-cell (current state of Nb_3Sn R&D)

650 MHz 5-cell (future)





Coating Parameter Optimization

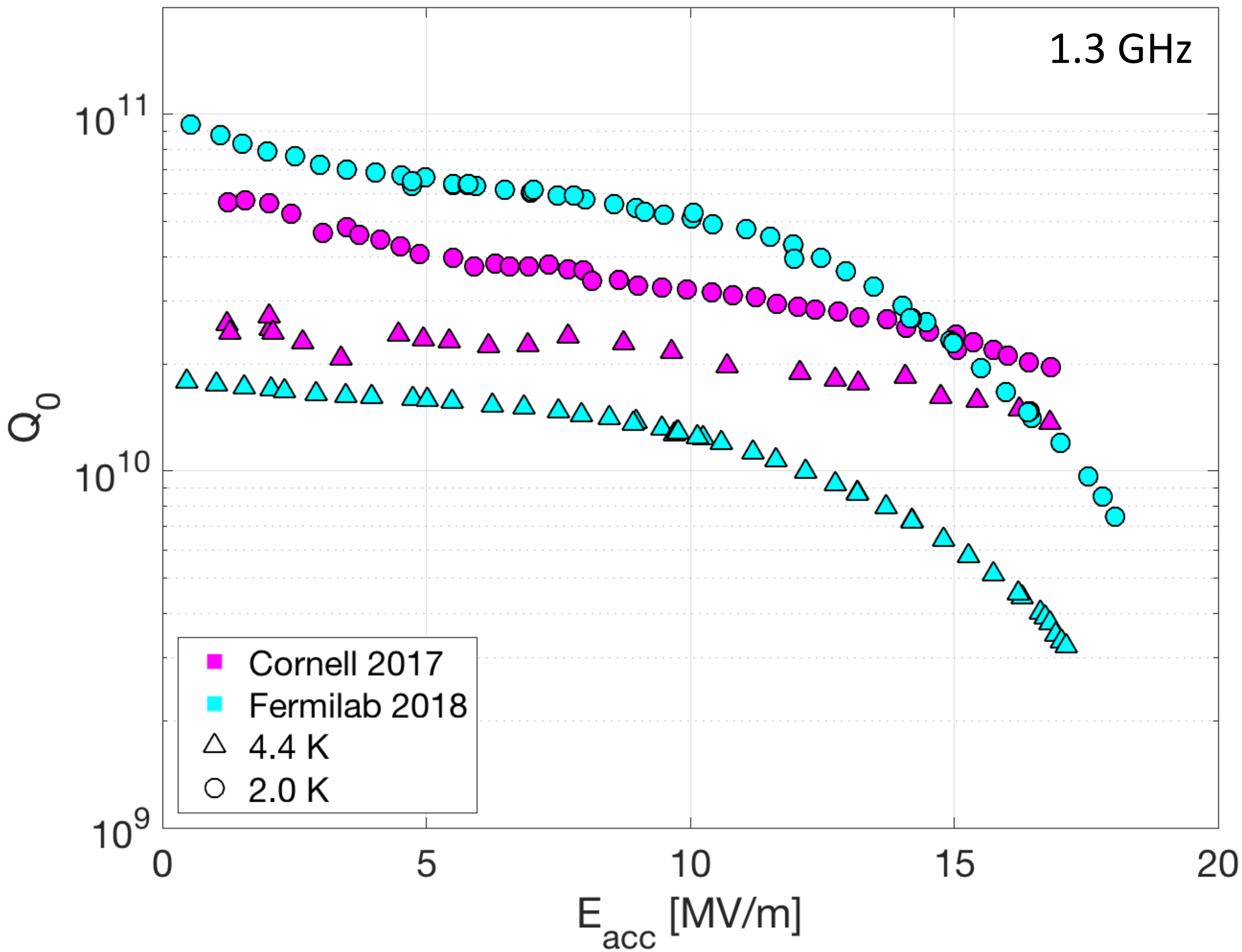
- To date, best appearance and performance at Fermilab achieved with:
  - Smallest diameter crucible tested
  - Heater at maximum power (crucible ~1200 C)
  - Cavity anodized to 30 V prior to coating

S. Posen, TTC Meeting 2018, Tokyo, Japan

Q vs E

- Very high Q_0 at 2.0 K ~5e10 at useful fields ~10 MV/m
- Excellent low and mid-field Q_0 at 4.4 K >1e10
- Still some Q-slope but nice quench field
- Sharp 18 K transitions

S. Posen, TTC Meeting 2018, Tokyo, Japan

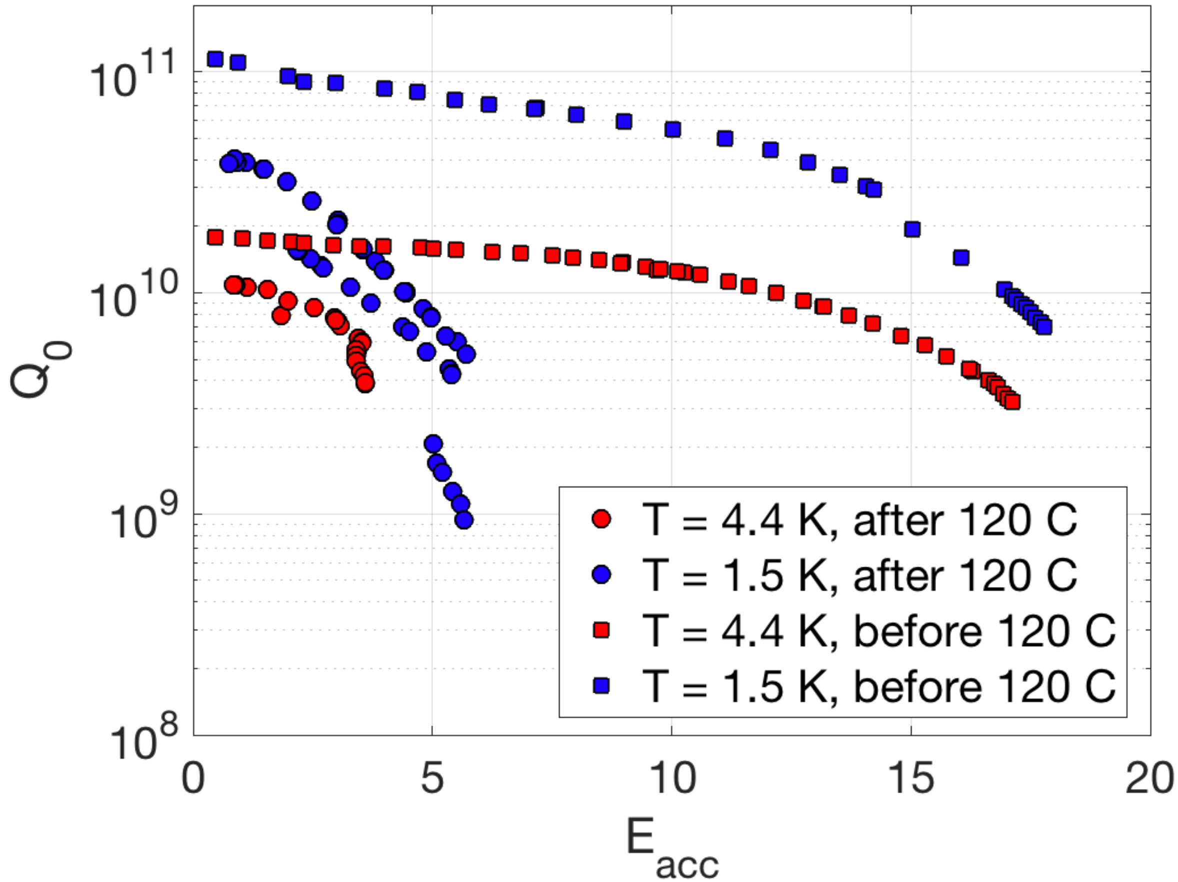


Nb at 2.0 K, 10 MV/m: ~1×10^{10} - 3×10^{10}

Nb at 4.4 K, 10 MV/m: ~3×10^{8} - 5×10^{8}

120 C Bake Experiment

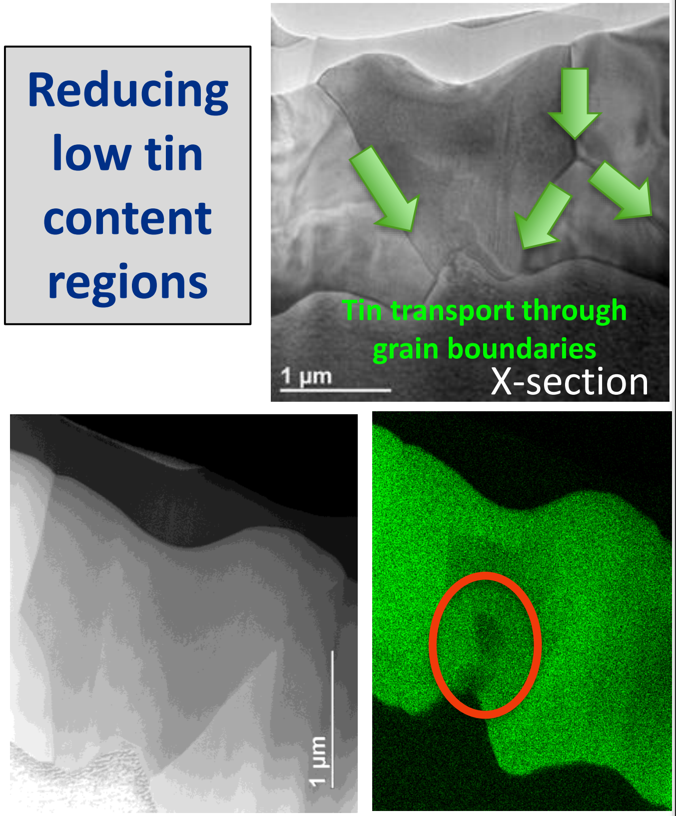
- 120 C 48 h bake increases maximum gradient of Nb cavities
- Simple study: what is effect of 120 C on Nb_3Sn?



Increasing E_{acc} in Nb_3Sn Cavities

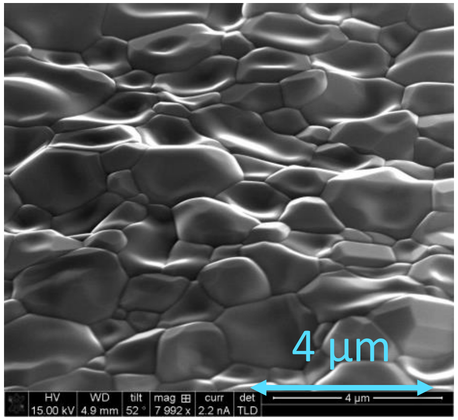
- Several promising paths forward for continued progress including:

Reducing low tin content regions

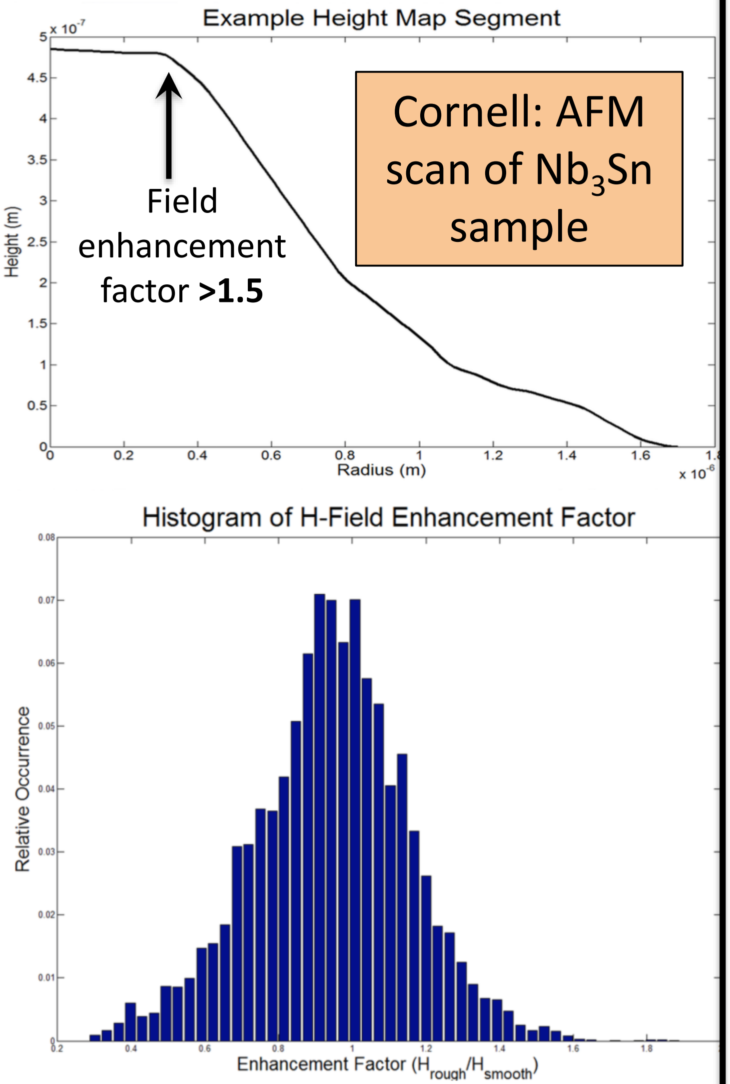


Y. Trenikhina, S. Posen, D. Hall, and M. Liepe, Proc. SRF Conference 2015, TUPB056, 2015

Smoothing sharp-edged surfaces



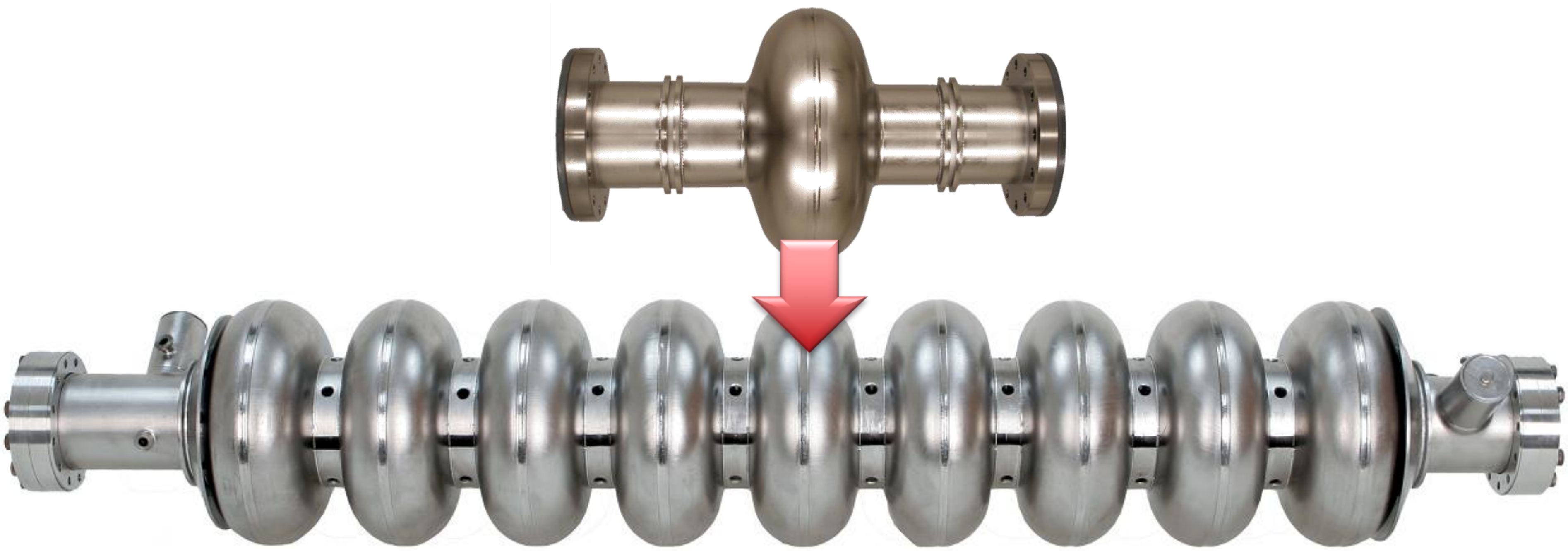
S. Posen, Ph.D. Thesis, Cornell University (2015).

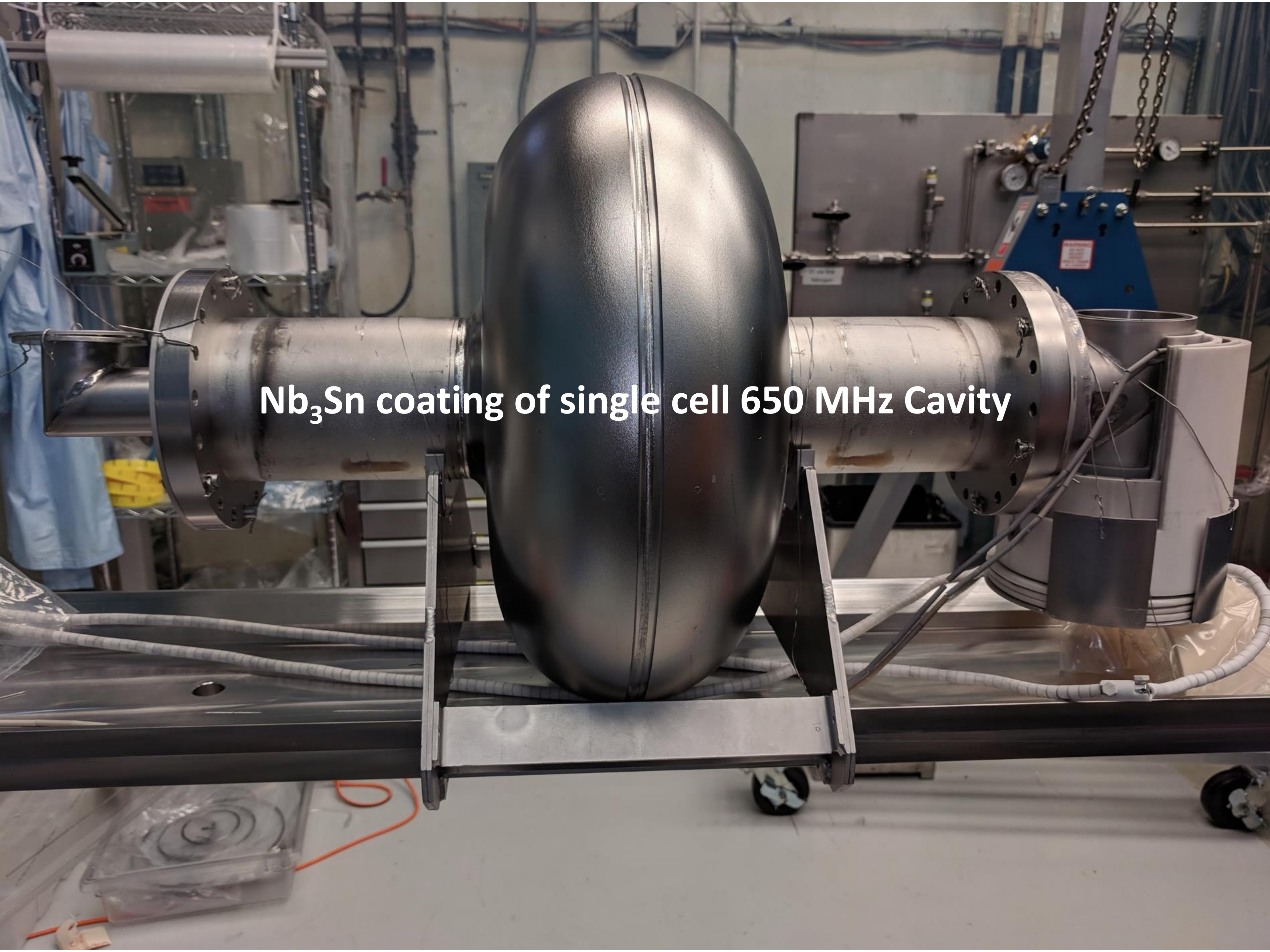


R. Porter, D. L. Hall, M. Liepe, J. T. Maniscalco, Proc. Linac Conference 2016, MOPRC027 (2016).

Scaling Up to Large Cavities

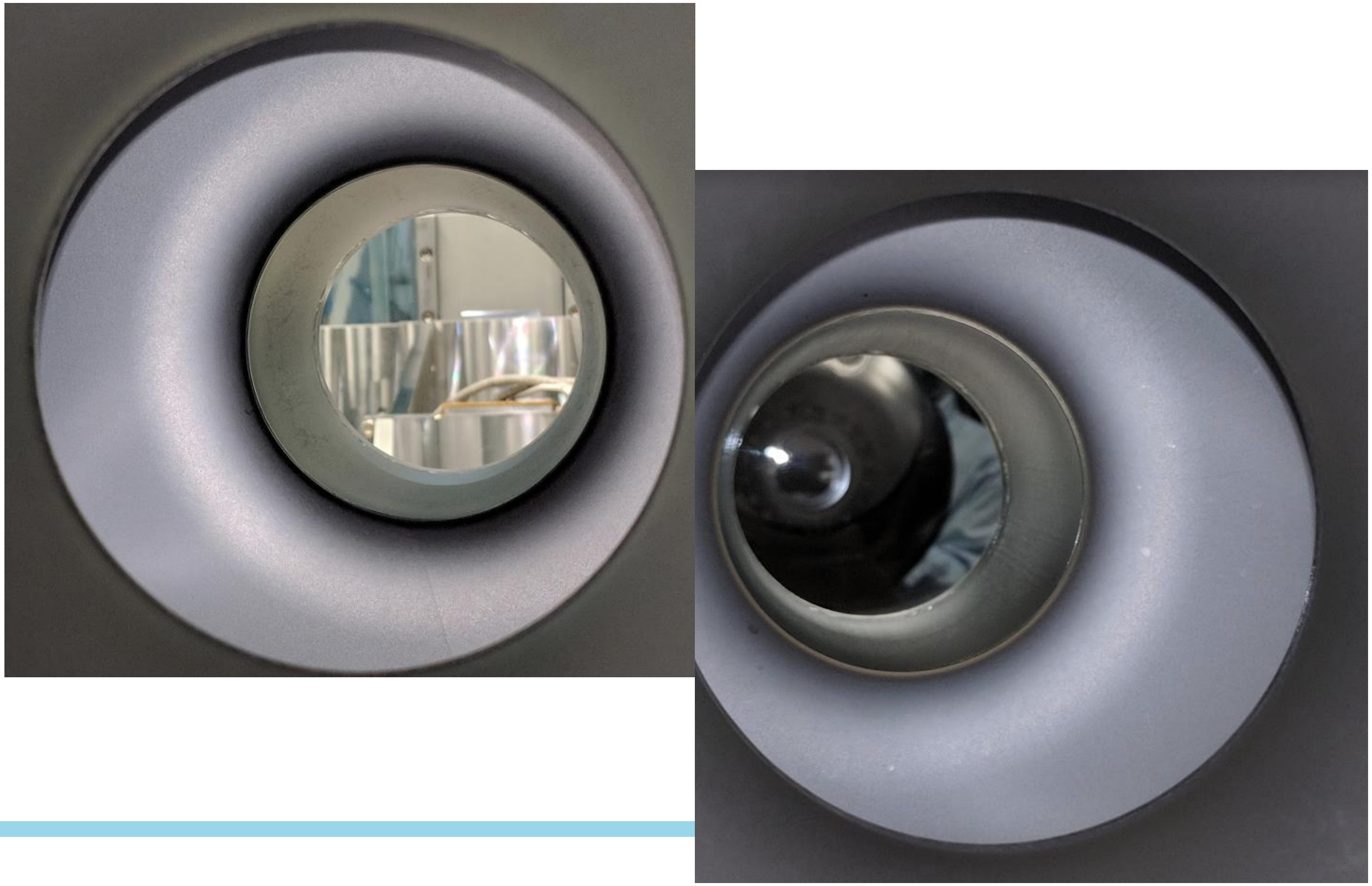
- Coating a 9-cell TeSLA cavity is quite different from the single cell 1.3 GHz cavities with strong Nb_3Sn performance recently
- Intermediate steps possible?




Nb3Sn coating of single cell 650 MHz Cavity

650 MHz Cavity Coating

- First coating attempt using these parameters: 2.6 g of tin, 0.8 g $SnCl_2$, cavity anodized to 30 V, 7 hours with furnace at 1100 C, including 4 hours at maximum heater temperature

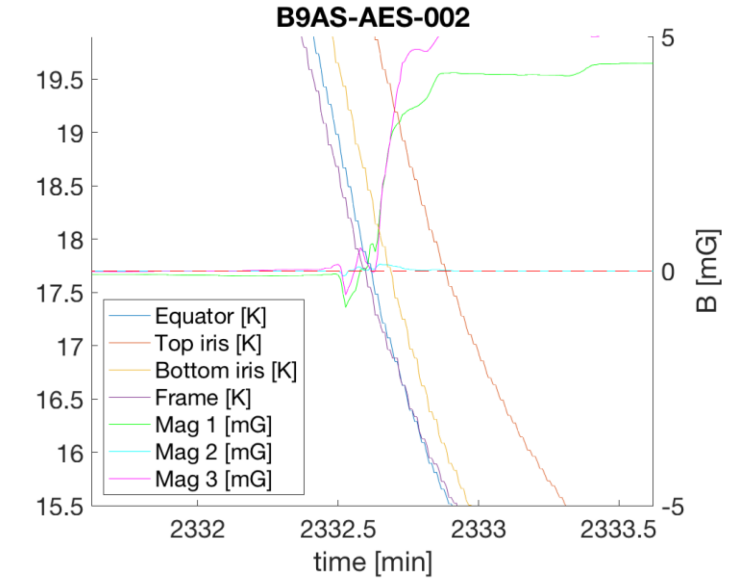


Testing Schedule

- Day 1:
  - Cooldown 0: non-uniform – transfer liquid out and cool again
  - Cooldown 1: uniform – Q vs E at 4.4 K (multipacting limited)
- Day 2:
  - Cooldown 2 – Q vs E in helium gas between 4.5 K – 6.5 K
- Day 3:
  - Still cold – Q vs T down to 2 K, Q vs E at 2 K
- Day 4:
  - Cooldown 3: magnetic field applied – Q vs E at 4.4 K

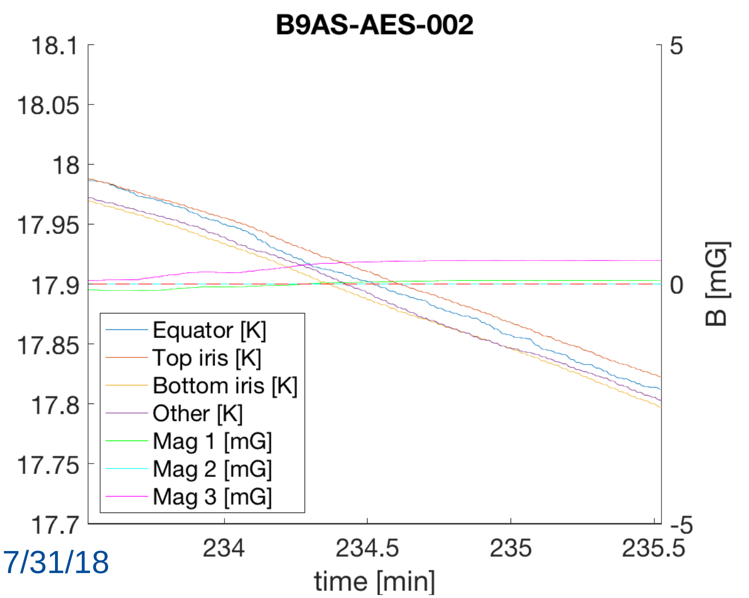
Day 1

VTS



Cooldown 0:

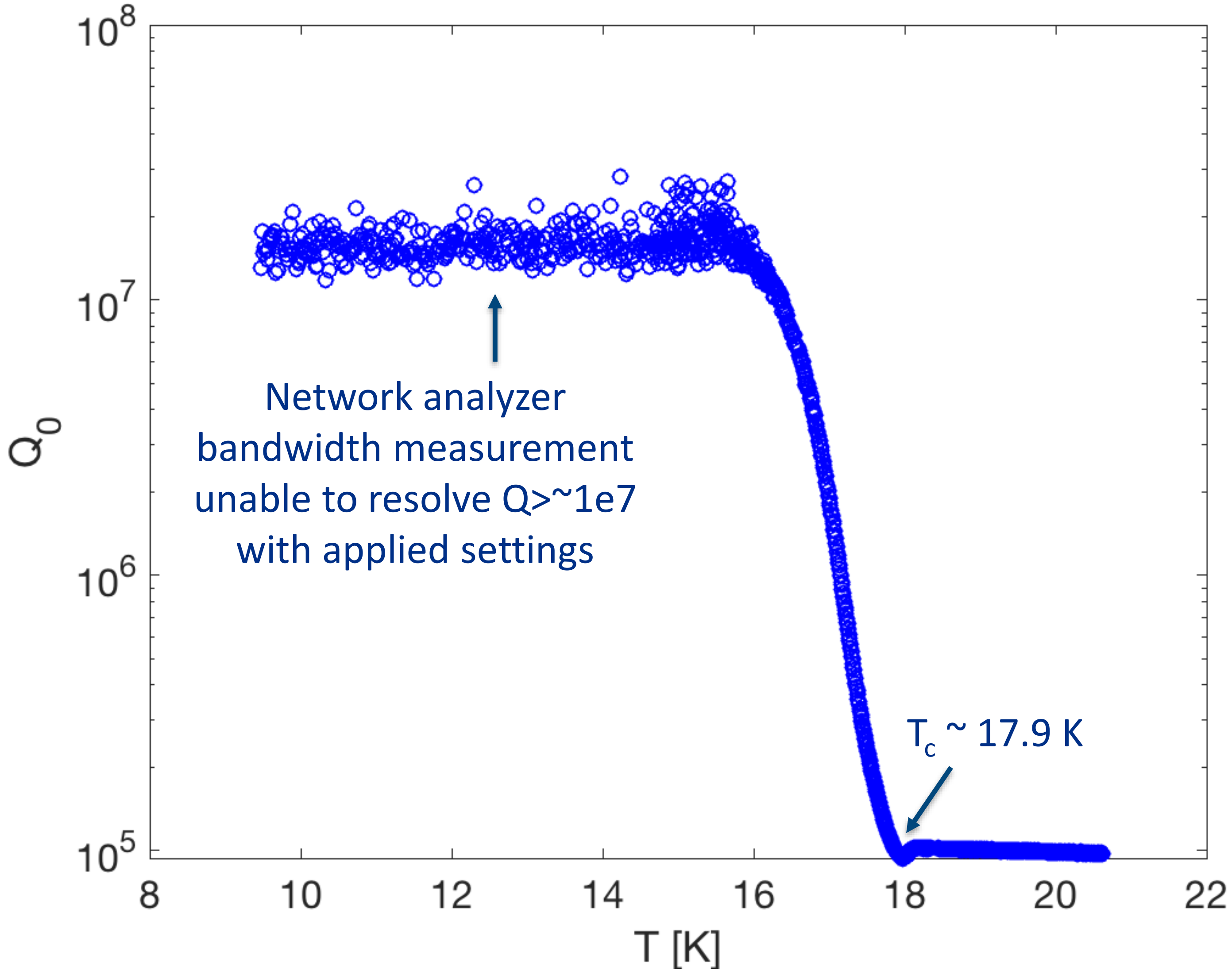
- Non-uniform cooldown
- ΔT ~ 3 K
- Compensated ambient field
- High residual resistance – transferred liquid out, warmed above T_c and cooled down again



Cooldown 1

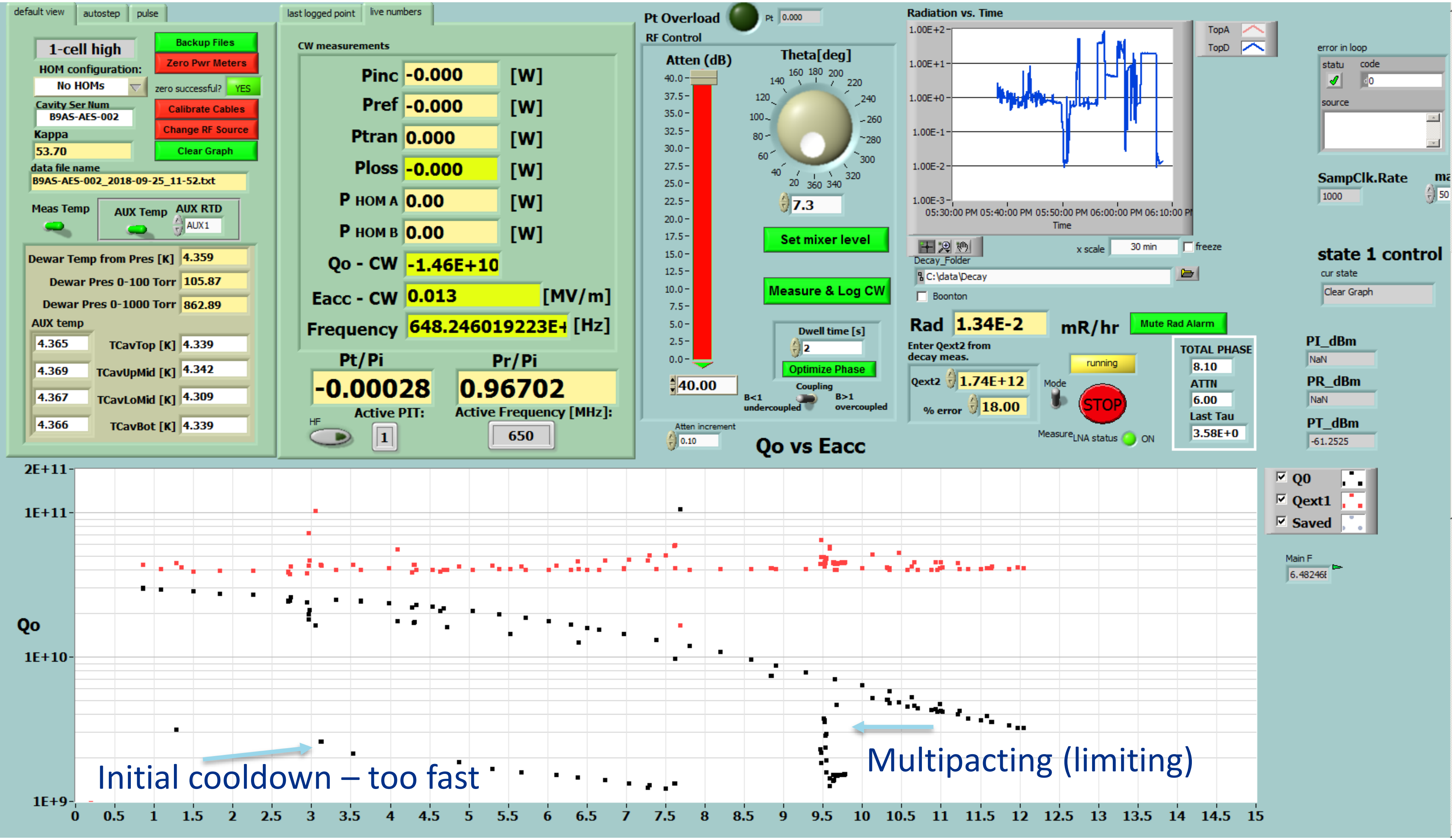
- Carefully controlled cooldown
- ΔT ~ 20 mK
- Compensated ambient field

Q vs T from network analyzer



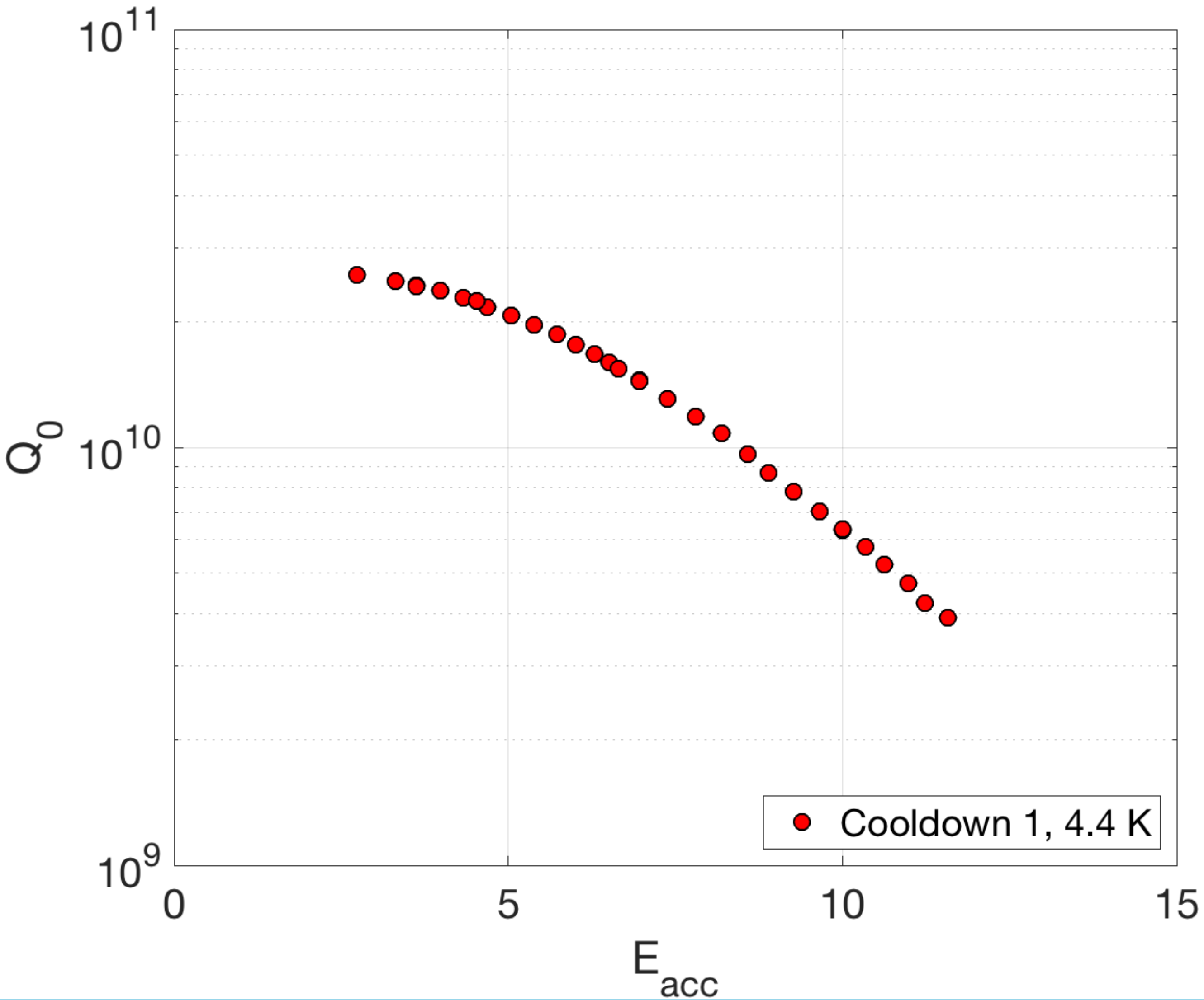
Fermilab

Q vs E at 4.4 K in liquid

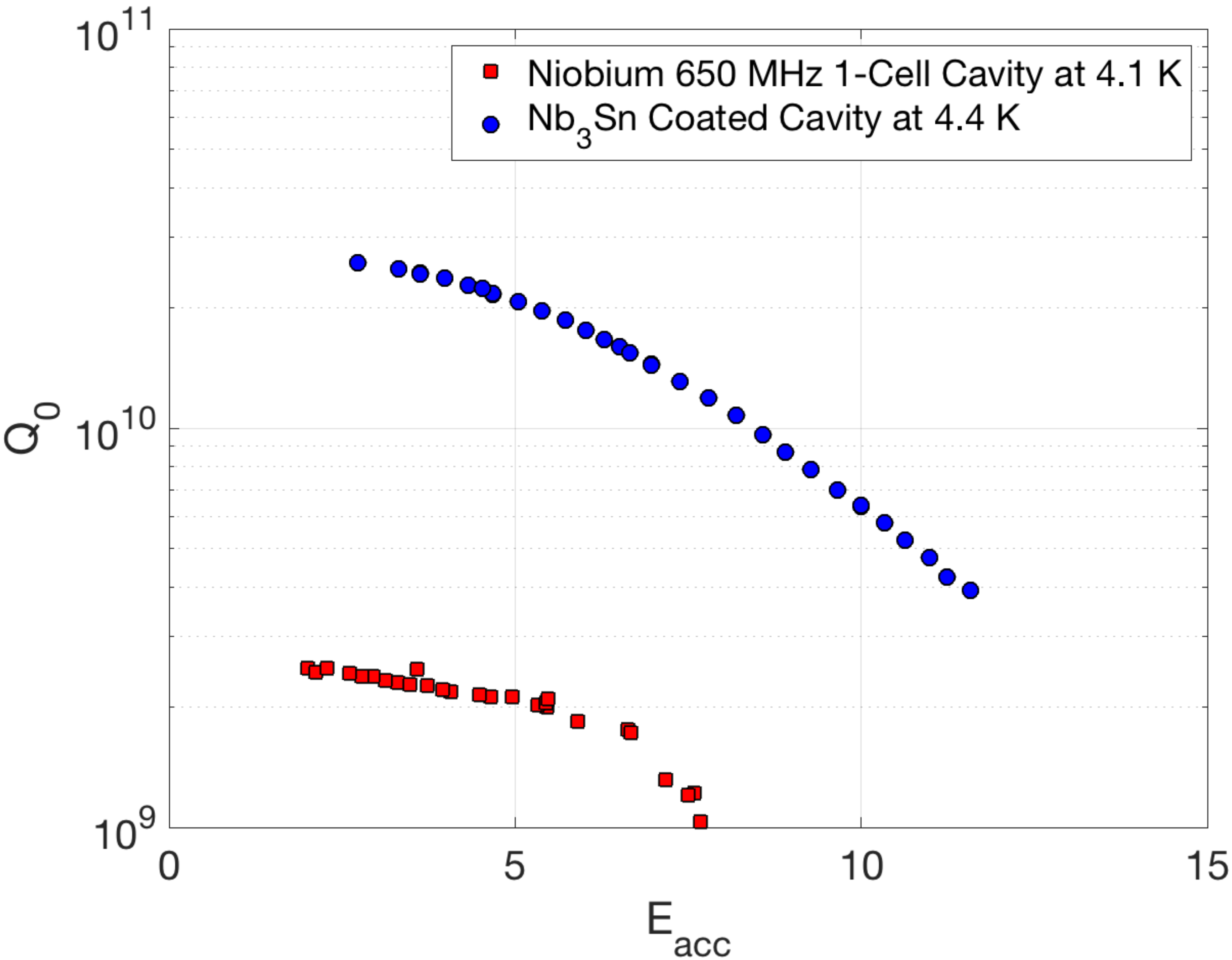


Fermilab

Cooldown 1 – 4.4 K Q vs E

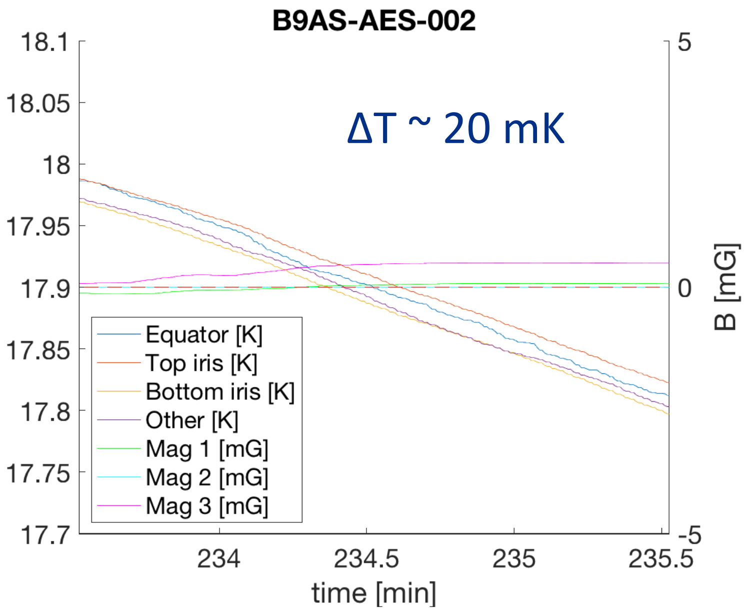


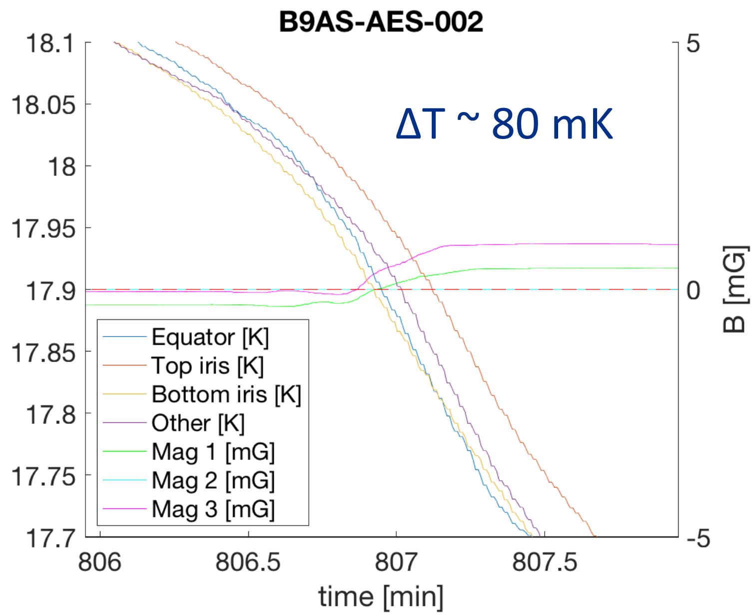
Q vs E Comparison to Before Coating



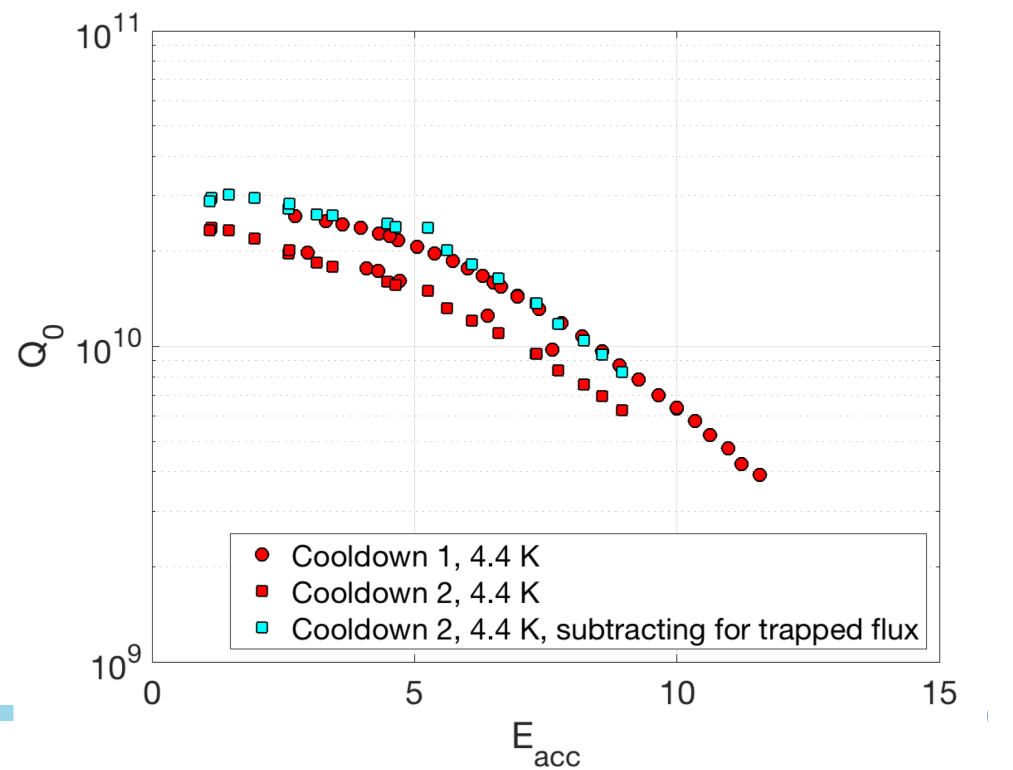
Day 2

Note on Cooldown

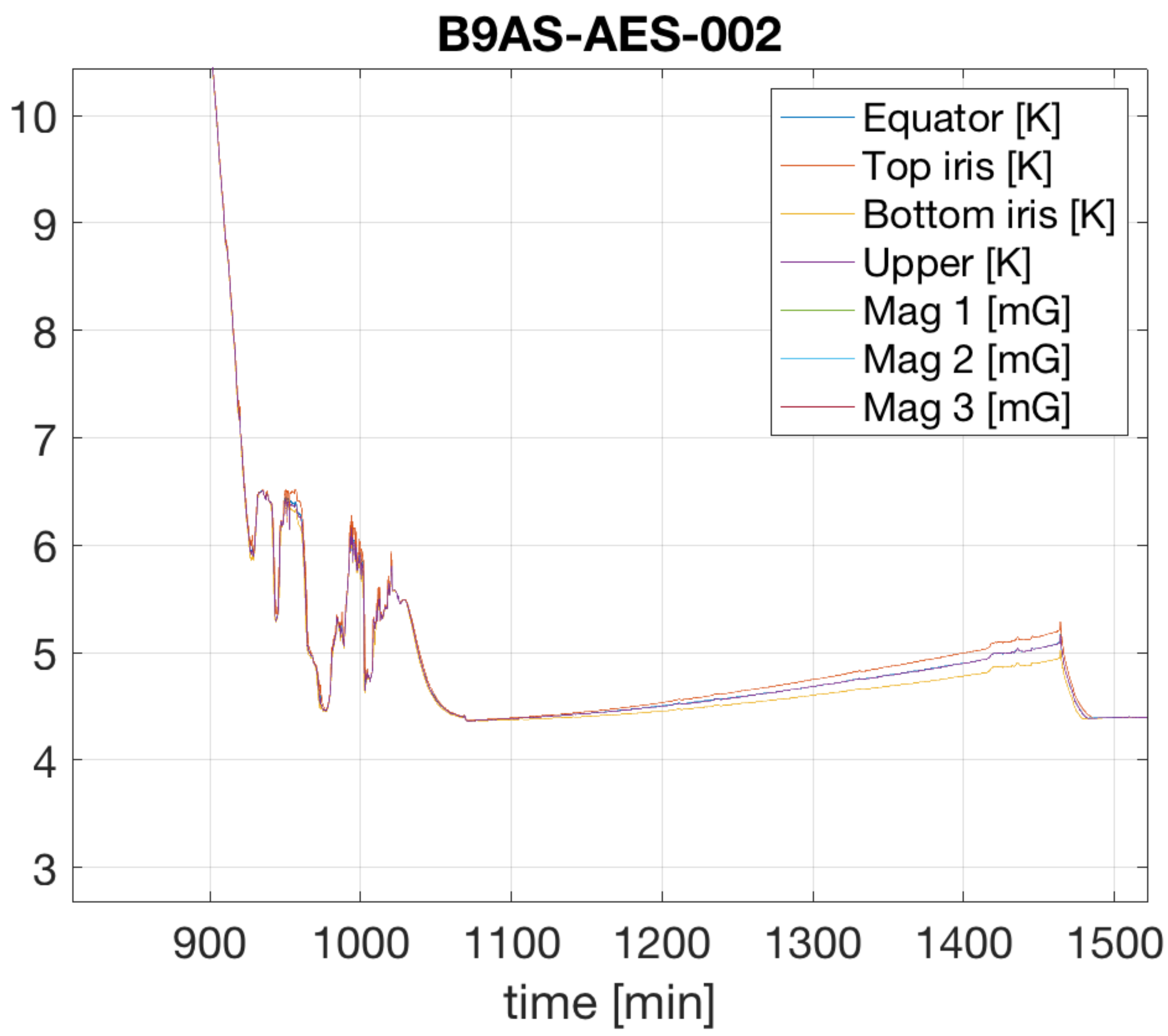




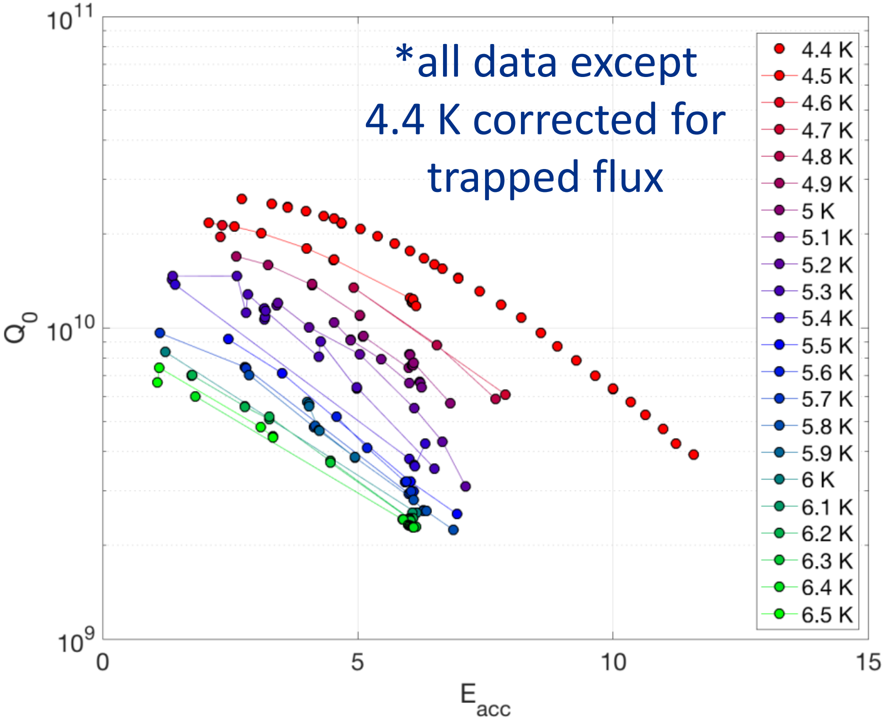
- Uniformity of cooldown is extremely important
- Full recalibration applied to double check data
- Correction applied to data from 2nd cooldown (incl. data in gas) to subtract effect of trapped flux

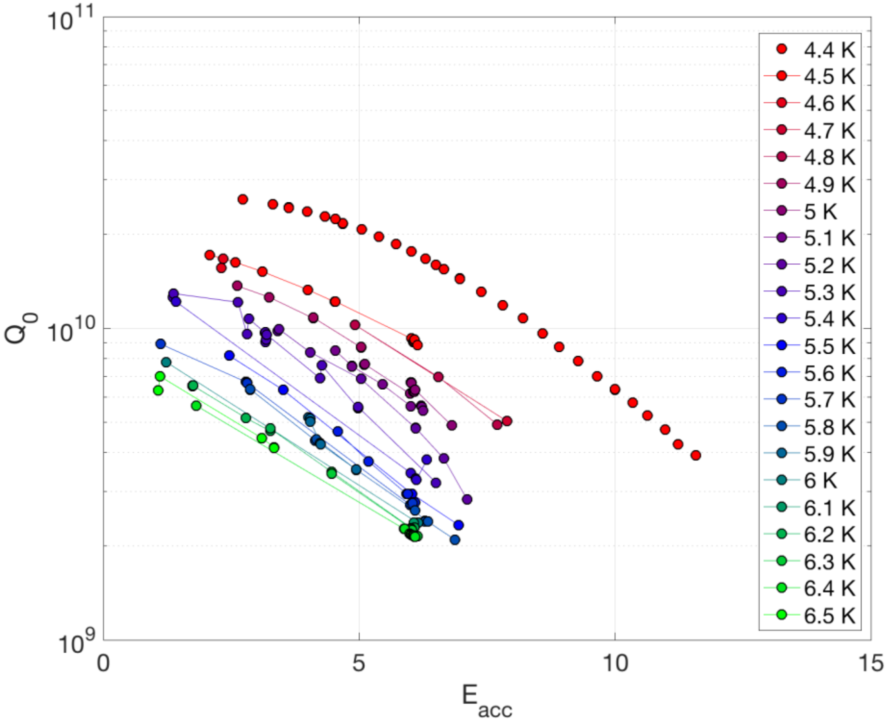


Measurements in Gas

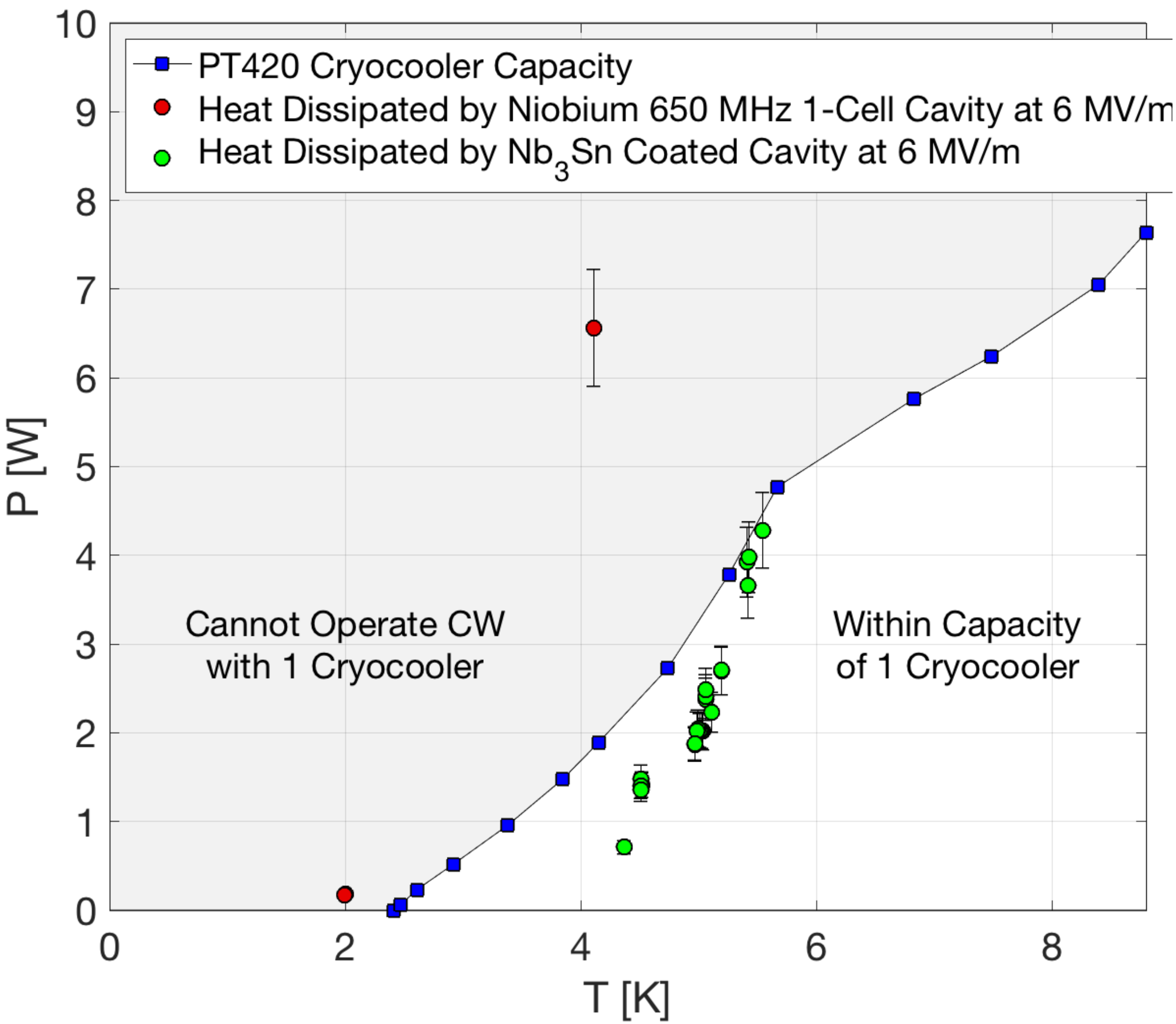


Q vs E – including measurements in gas*





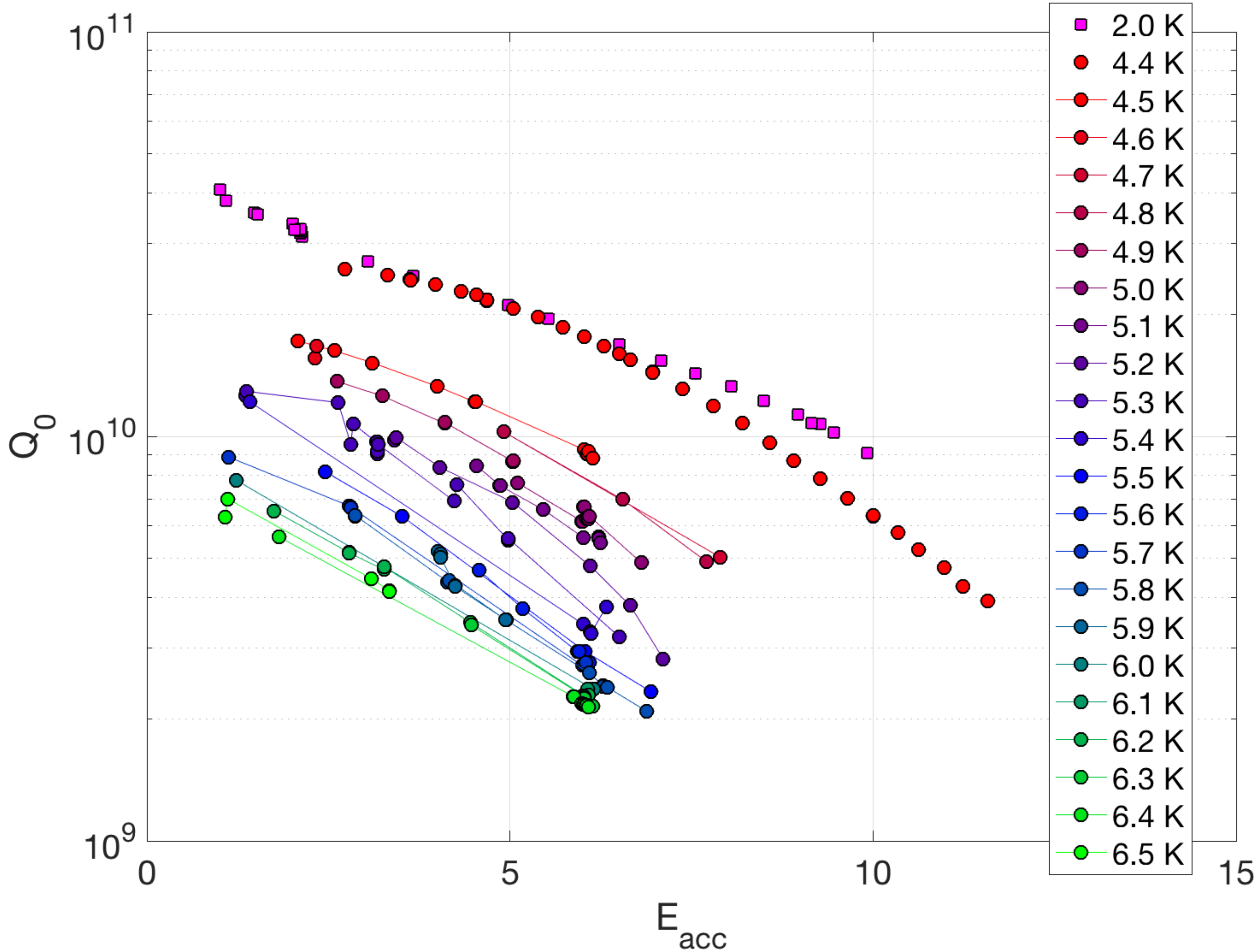
Dissipated Power Compared to Before Coating



Fermilab

Day 3

Measurement at 2.0 K – as measured



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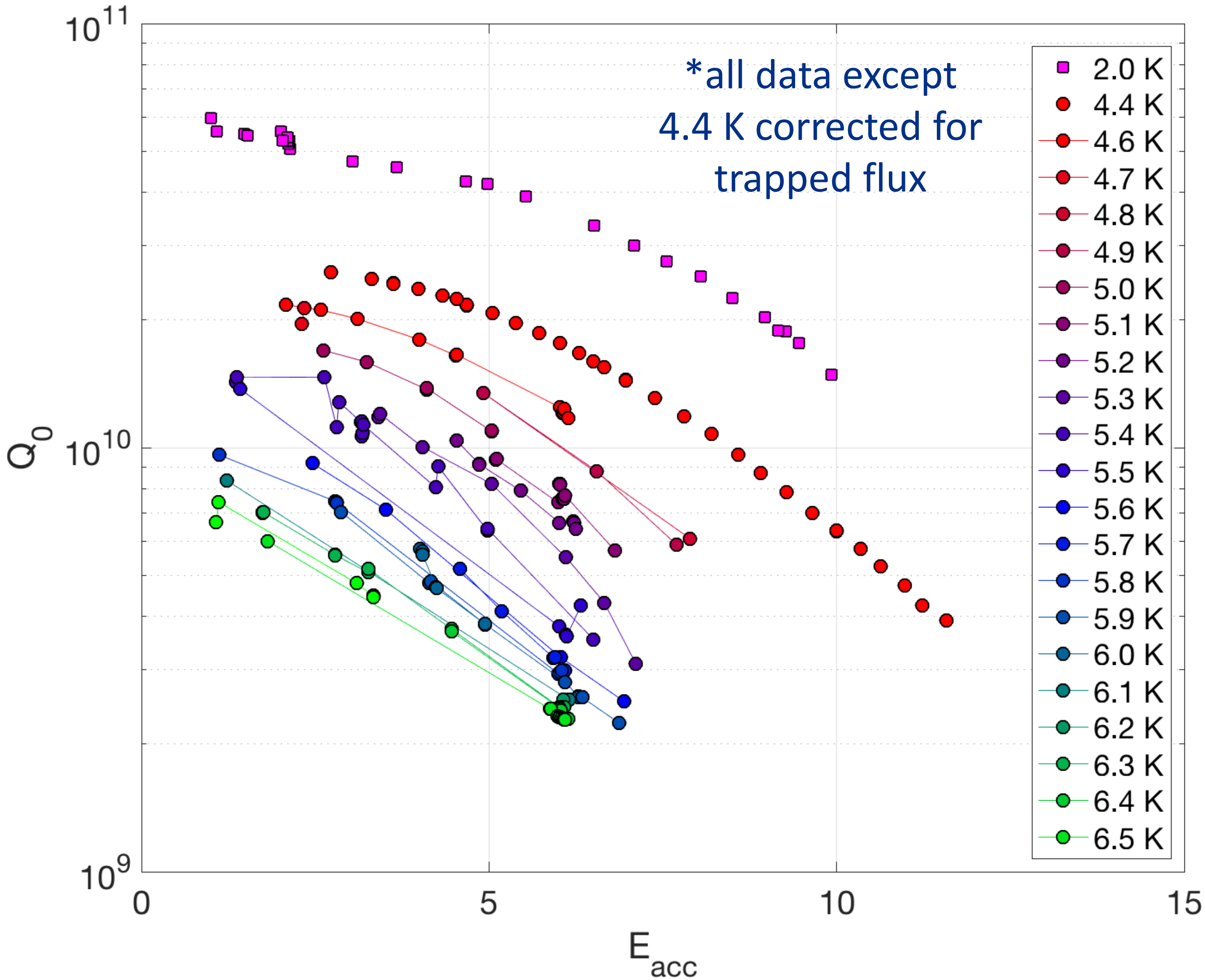
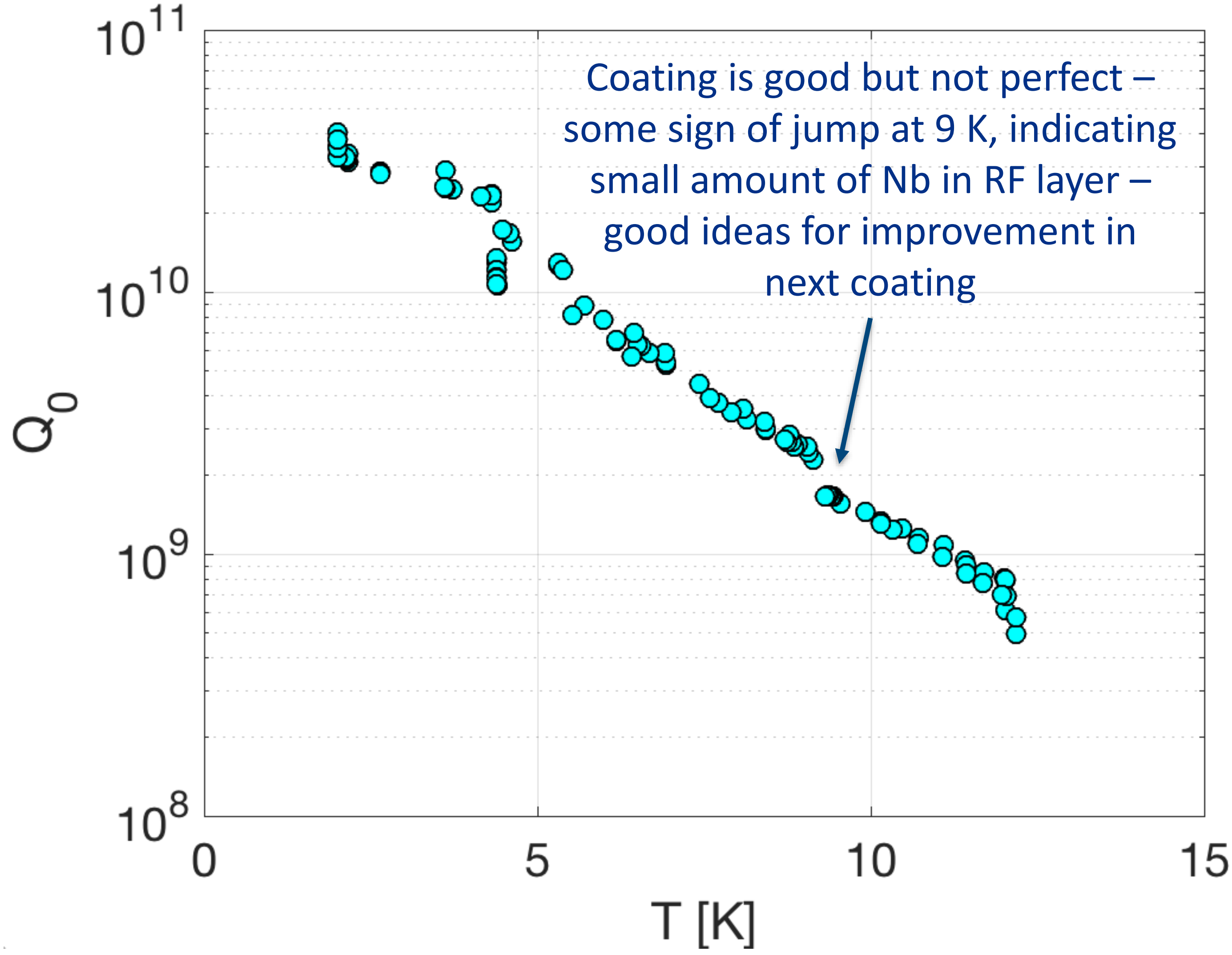
Measurement at 2.0 K – corrected for trapped flux



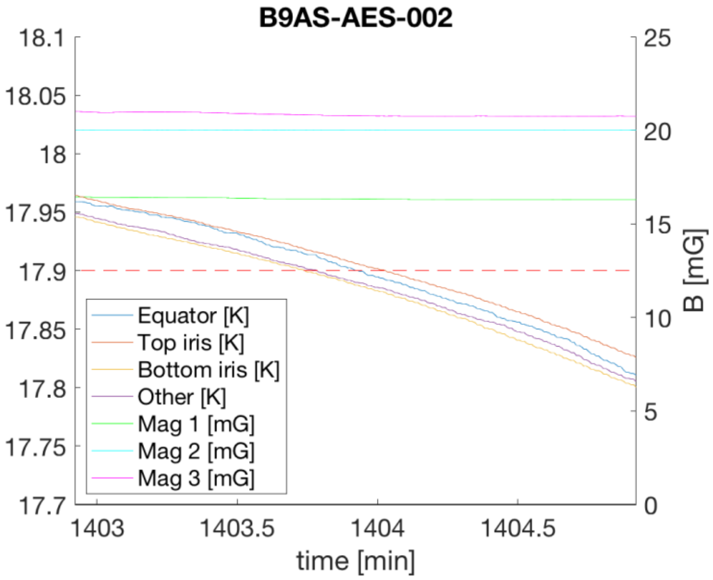
Low Field Q vs T

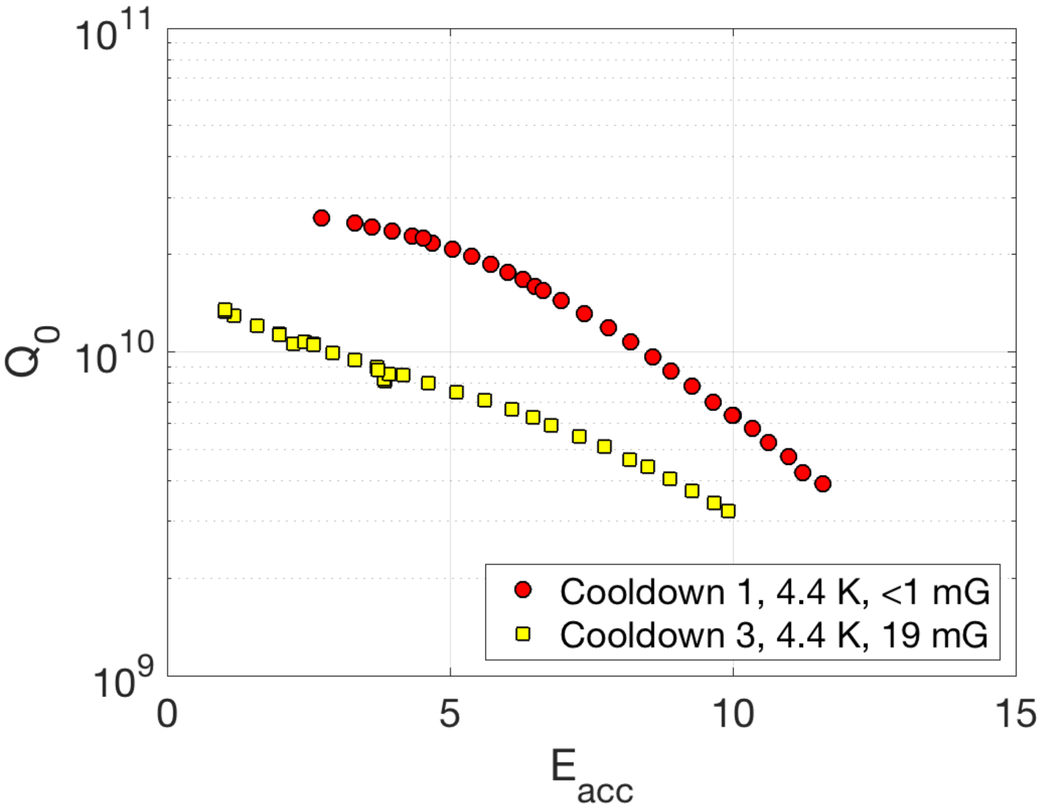


Day 4

Measurement after Trapping ~19 mG Field

- Added R_s at 5 MV/m: 21 nΩ – assuming linear, sensitivity ~1.1 nΩ/mG trapped
- Added R_s at 10 MV/m: 39 nΩ – assuming linear, sensitivity ~2.1 nΩ/mG trapped





Summary and Outlook

- **Nb_3Sn** offers a path to **operation at higher temperatures**, where cooling is substantially more efficient, potentially opening new applications
- **For high gradient applications**, experimentation and improving understanding of film growth processes brings us closer to realizing the full potential of this promising material
- Nb_3Sn **focus for near future**:
  - Reproducibility on single cells
  - Push to remove Q-slope and increase maximum gradient
  - Move into other frequencies and into multicells