The Superheating Field of Niobium

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Paper: arXiv:1002.3182v1

Goal and Approach

- Goal of this work: Measure the superheating field of Niobium
  - Temperature dependence (what is the value of the superheating field at ~2K)?
  - How does surface preparation impact the superheating field?
- Approach:
  - Theoretical: solve the Eilenberger equations (Mark Transtrum, Jim Sethna, Cornell)
  - Experimental: measure H_{sh} with pulsed high power in a single cell 1.3 GHz cavity (ML, Nick)

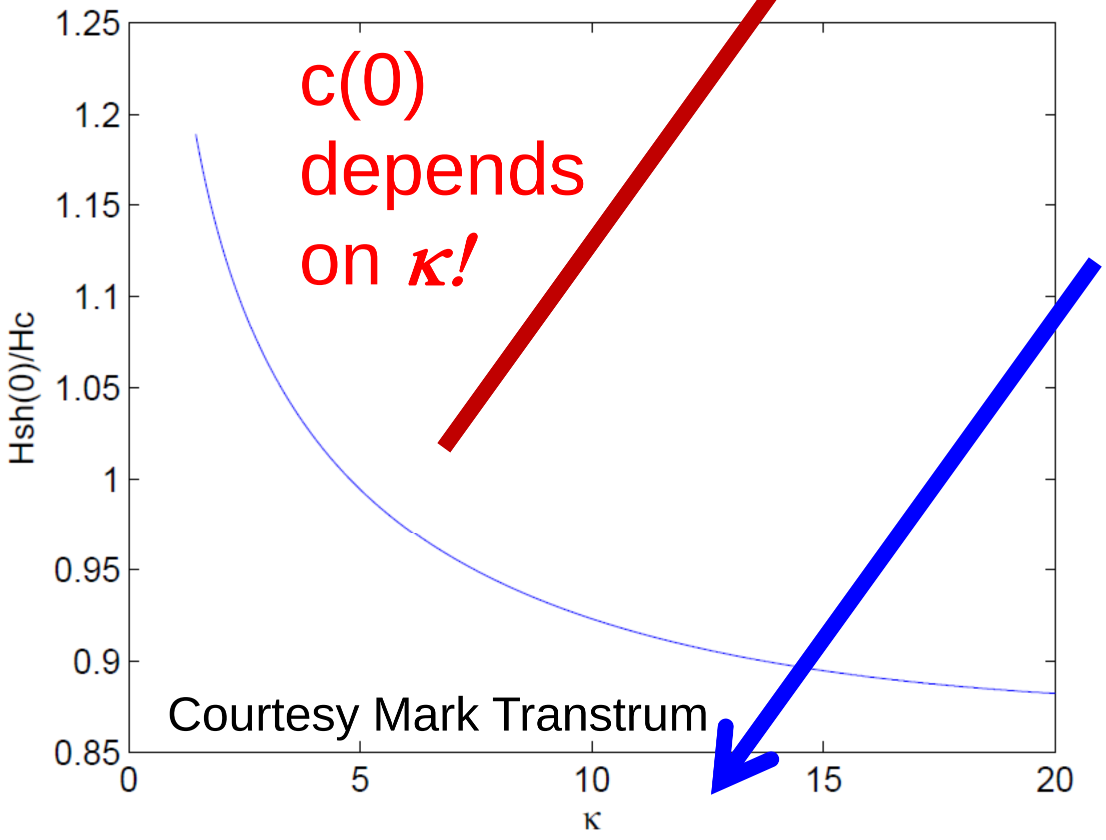
Outline

- Theory: What to expect (at least near T_c)
- Experimental setup: How to measure H_{sh}
- Results: What we got
- Discussion: What it all means
- Future: What we plan to do next

Theory near T_c (in the Ginsburg–Landau limit)

- Ginsburg-Landau theory:

$$H_{sh}(T) = c(0)H_c\left[1-\left(\frac{T}{T_c}\right)^2\right]$$



c(0) depends on *κ!*

Courtesy Mark Transtrum

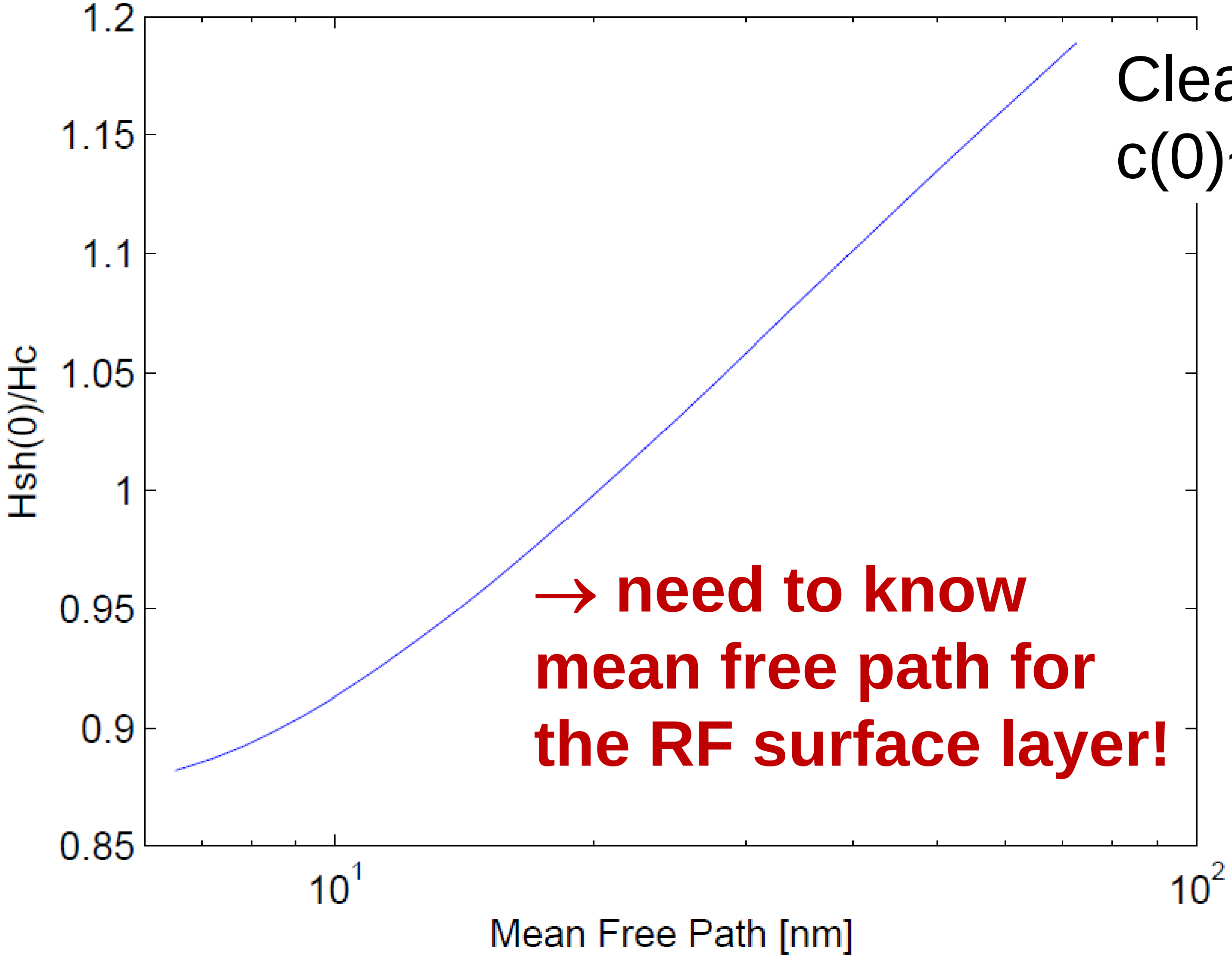
κ depends on the mean free path length (Pipard's equations)

$$\frac{1}{\xi} = \frac{1}{\xi_0} + \frac{1}{\ell},$$

$$\lambda = \lambda_L\sqrt{1+\frac{\xi_0}{\ell}}$$

$$\kappa(\ell) = \frac{\lambda_L}{\xi_0}\left(\frac{\xi_0+\ell}{\ell}\right)^{3/2}$$

c(0) for Niobium vs. mean free path



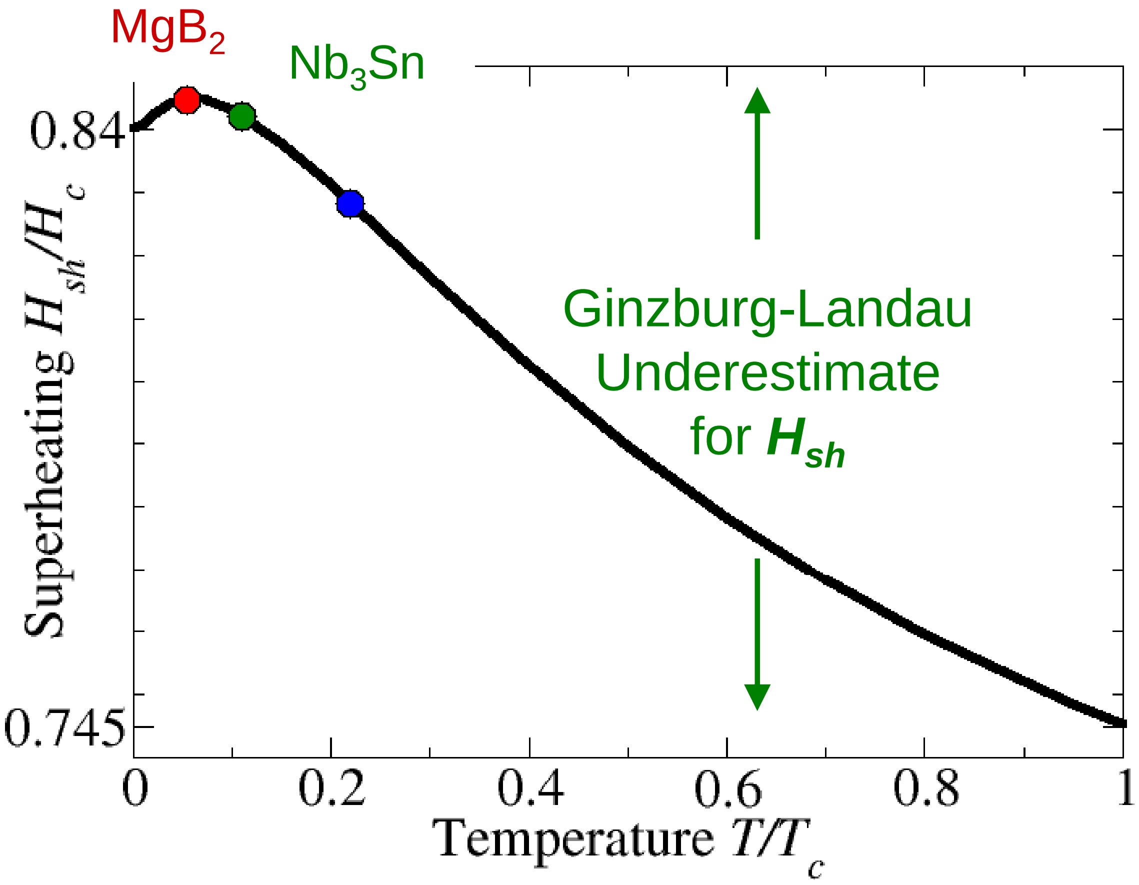
Clean limit:
c(0)~1.2

→ need to know mean free path for the RF surface layer!

Superheating field $H_{sh}(T)$ from the Eilenberger Equations for large κ (courtesy Jim Sethna et al.)

13% larger H_{sh} at low T than Ginzburg-Landau estimate

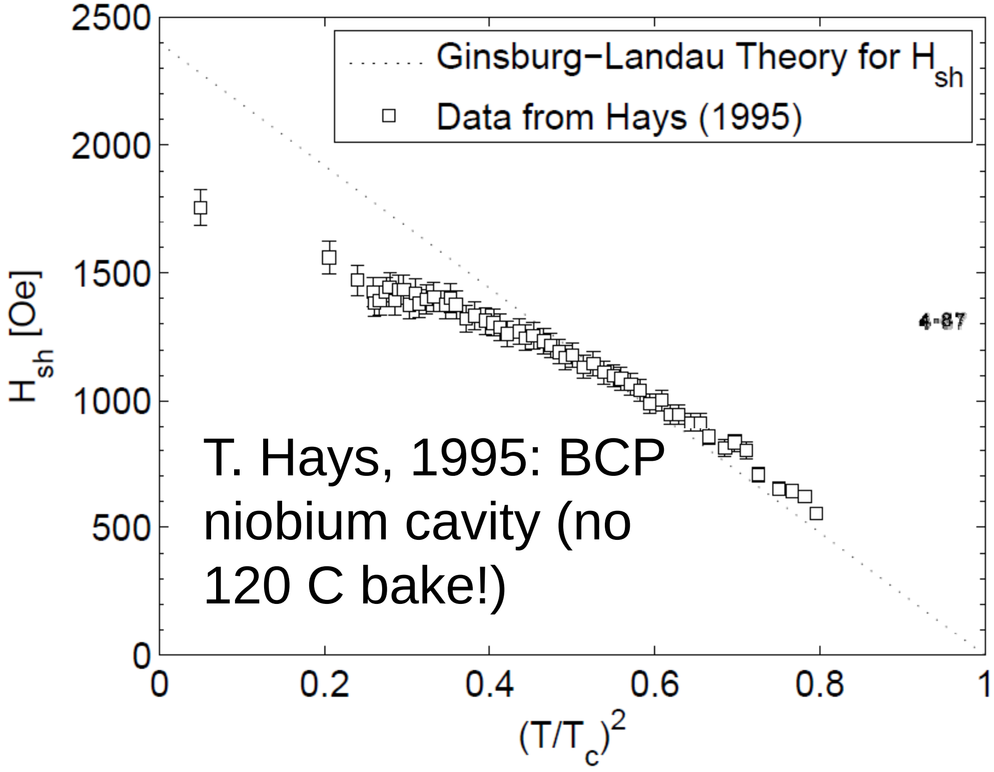
- T=0, Eilenberger:
  $H_{sh}/H_c = 0.84$
  (V.P.Galaiko, JETP 1966)
- $T=T_c$ Ginzburg-Landau:
  $H_{sh}/H_c = 0.745$
- T-dependence: Catelani 2007



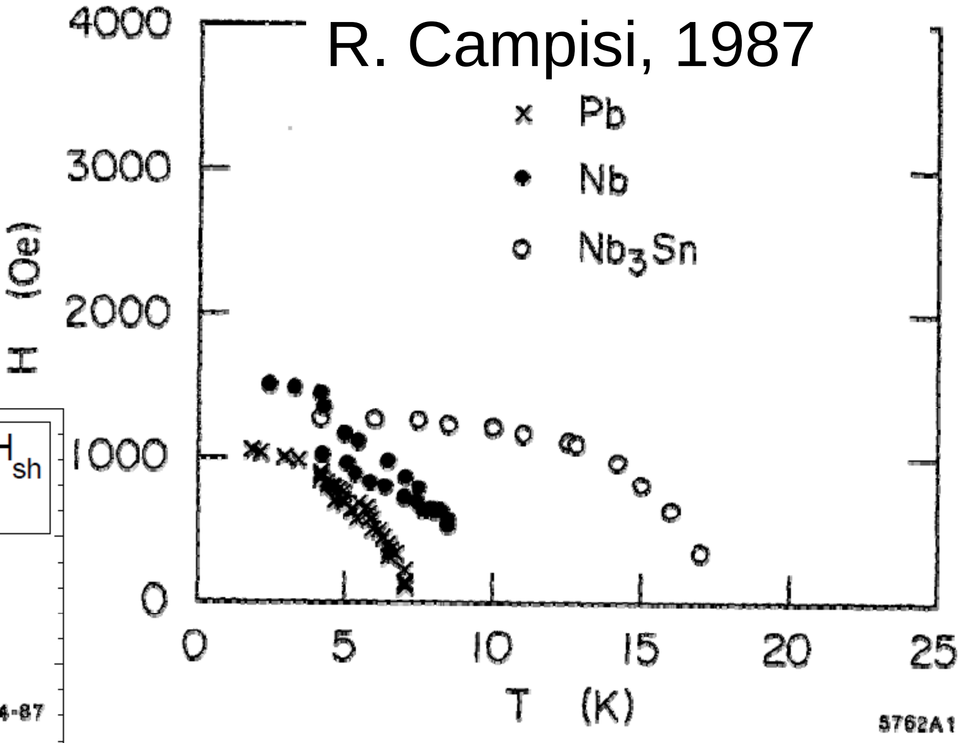
Similar few % effect for Niobium with κ~1?

Previous results:

- Measured field fall well below GL prediction at low temperatures!



T. Hays, 1995: BCP niobium cavity (no 120 C bake!)



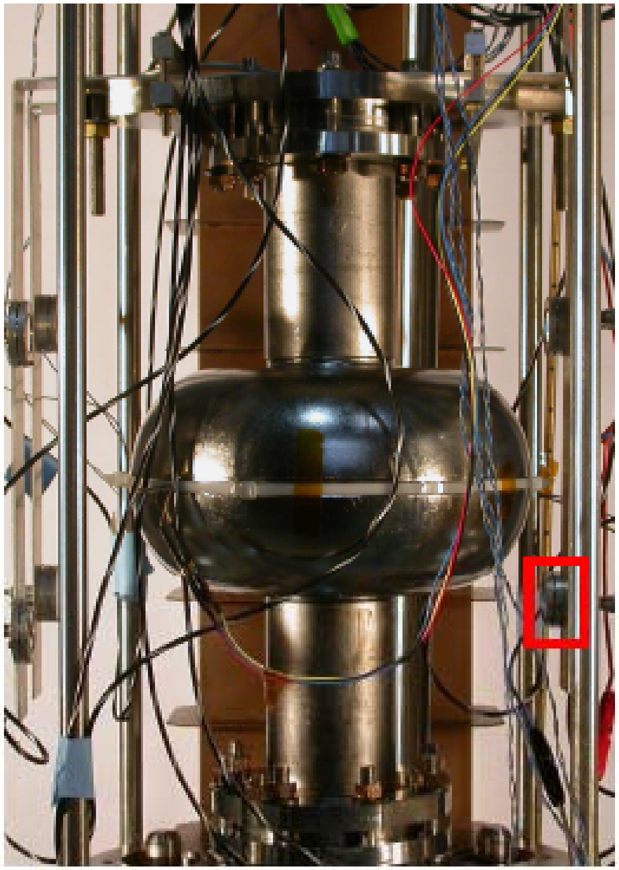
R. Campisi, 1987

- Real effect?
  -> line nucleation model (Yogi, Saito)?
- Or: field limited by other effects and not the superheating field?

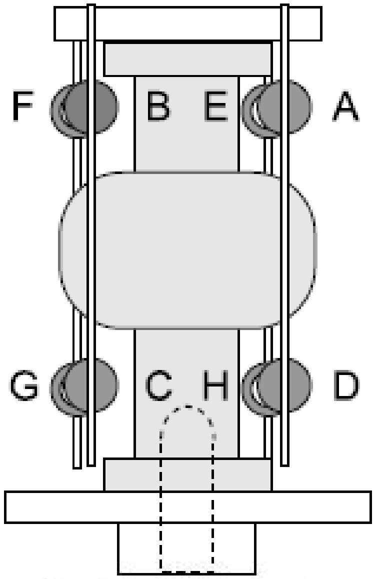
Or Measurements: Method and Setup

- Use short (~100 µs) high power pulses to drive 1.3 GHz Niobium cavity (800C, 10 µm EP, 110C bake for 48h)

(a)



(b)



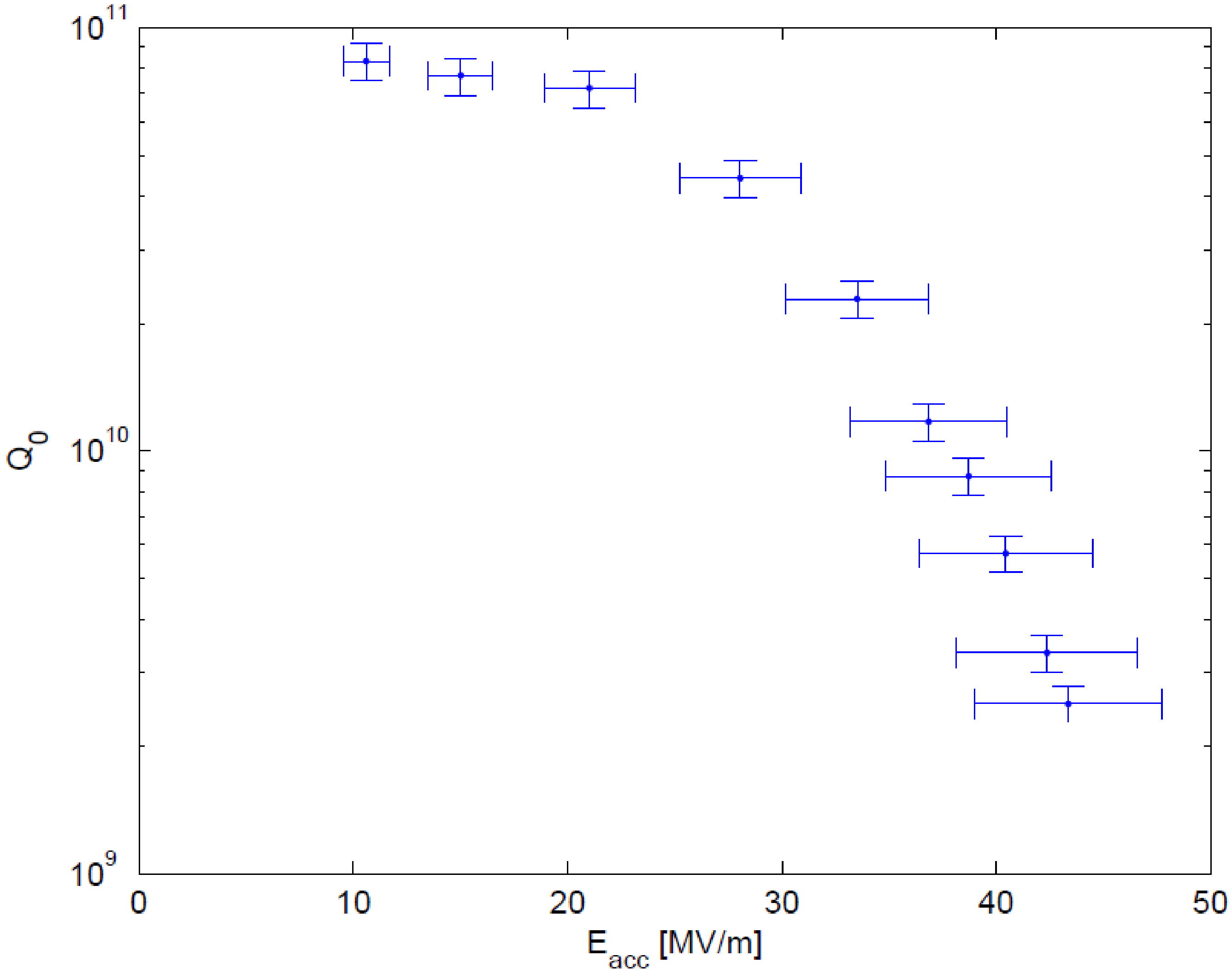
(c)

Diagnostics:

- Temperature sensors in bath and on cavity
- OST’s to locate origin of quench

  -> can distinguish between quench by local defect and global phase transition at H_{sh}

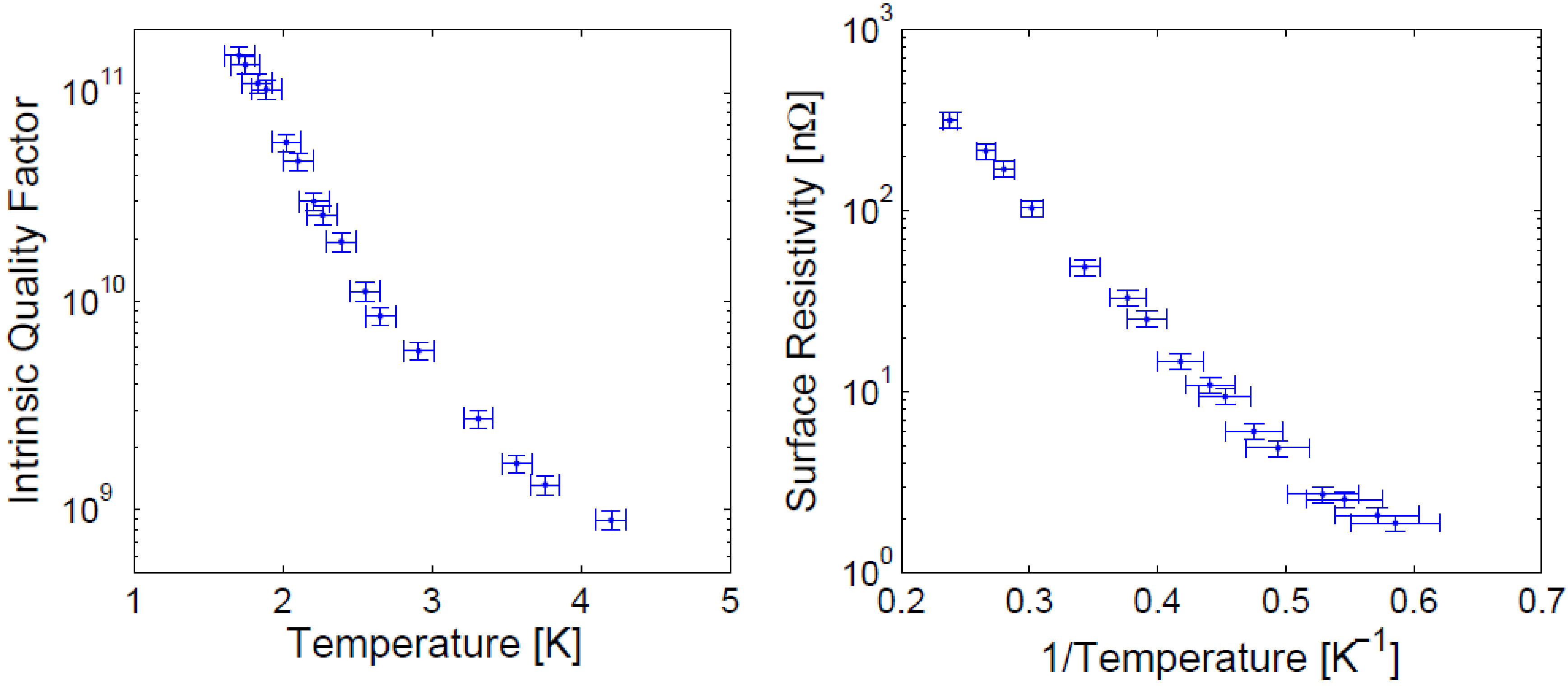
CW Results at 1.7 – 1.8K



- High Q_0!
- 44 MV/m max
- High field Q-slope (even after EP and 110C bake)

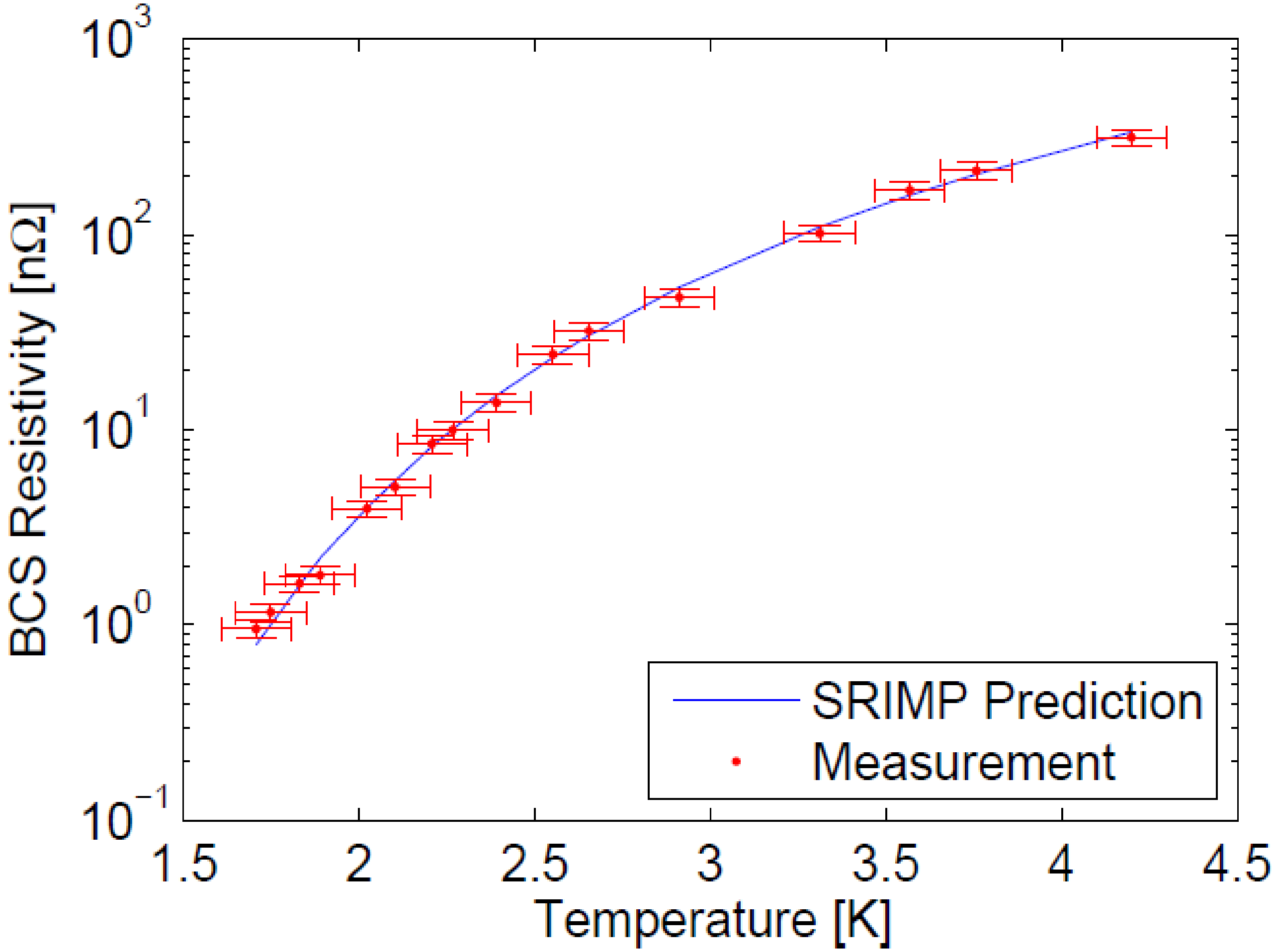
Matthias Liepe, 6th SRF Materials workshop, Tallahassee

CW Results: Q(T) at low fields (5MV/m)



- Very low residual resistance of (0.92±0.23) nΩ!

Fit of R_{BCS} with SRIMP



Fit gives for the mean free path of the RF layer:

ℓ = 26.91±1.19 nm

$\rightarrow$ $\kappa =$ **3.49** ± 0.16

$\rightarrow$ c(0)=Hsh(0)/Hc

= **1.044** ± 0.001

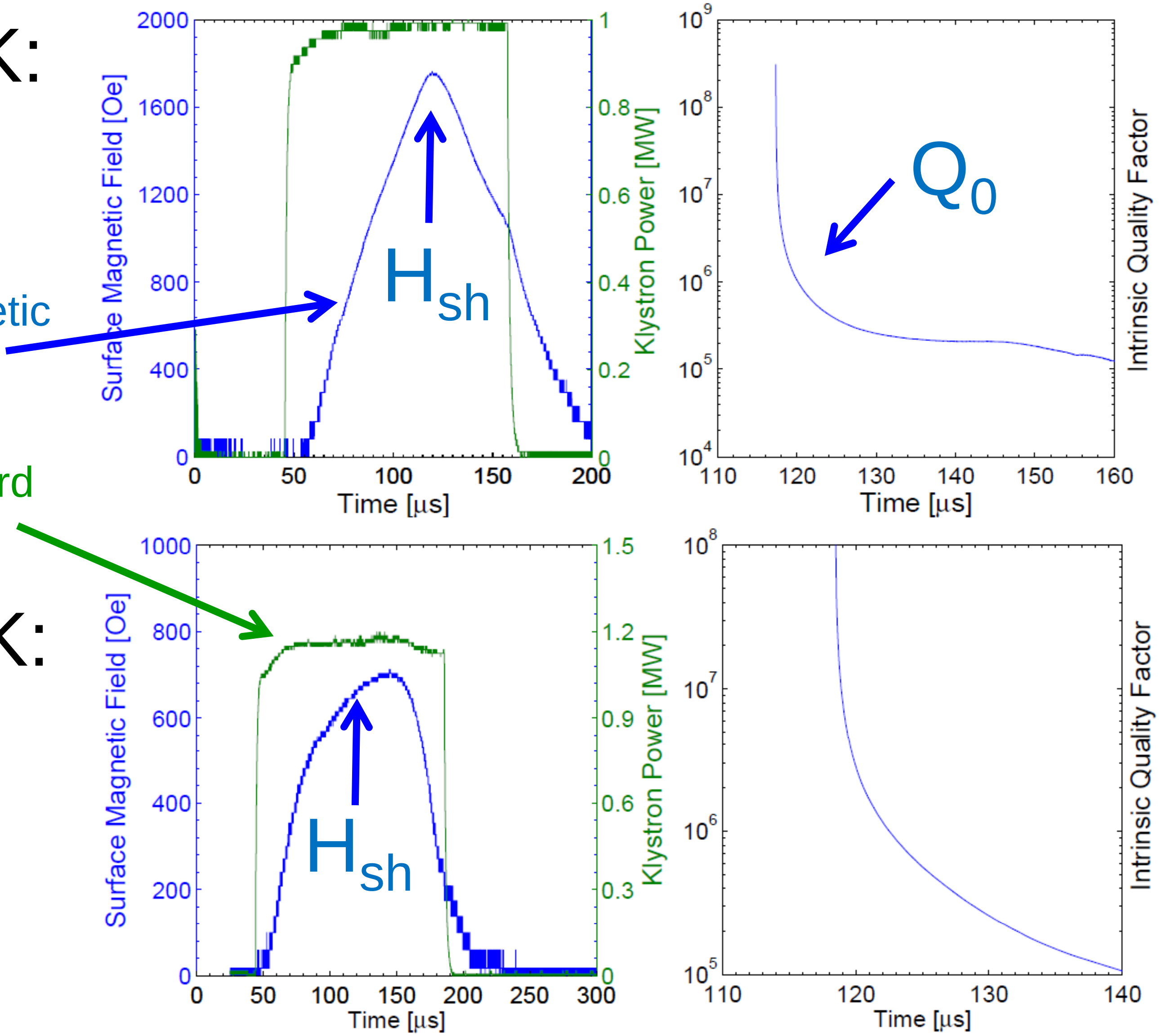
Pulsed Measurements

at 3K:

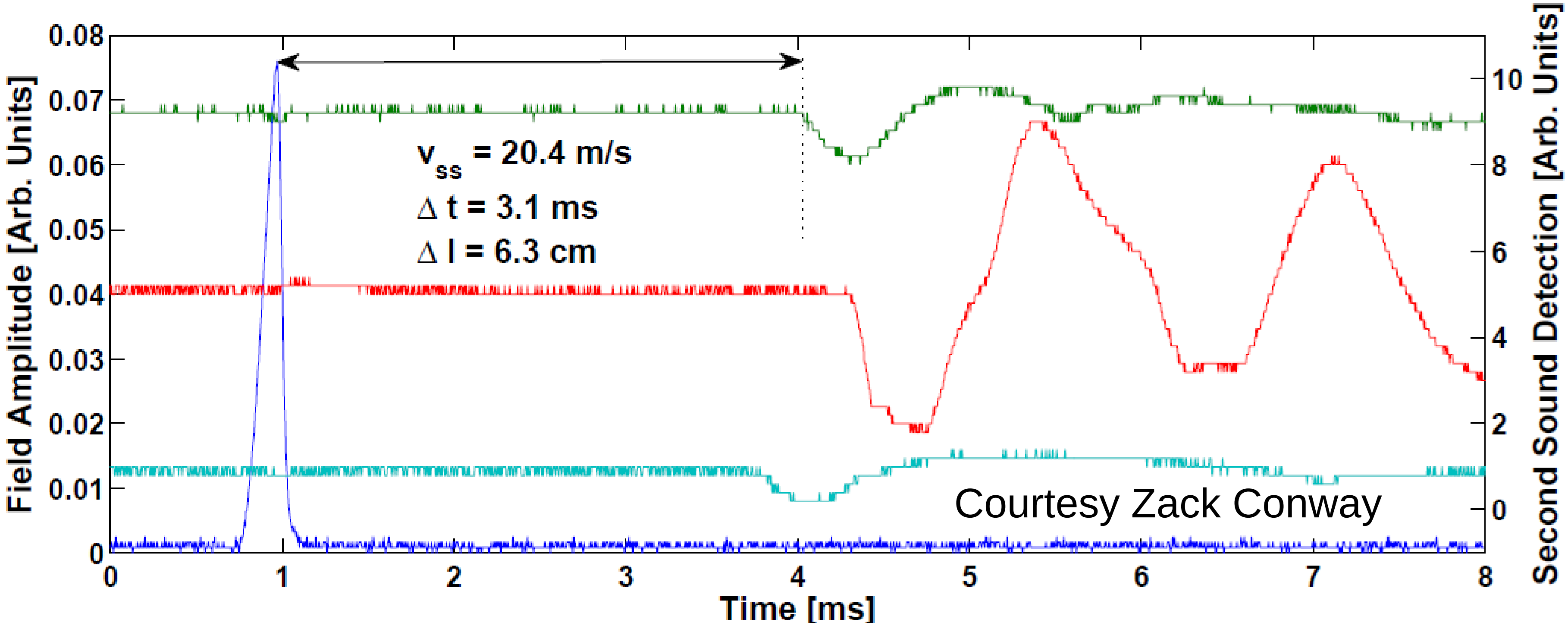
Magnetic field

Forward power

7.2 K:

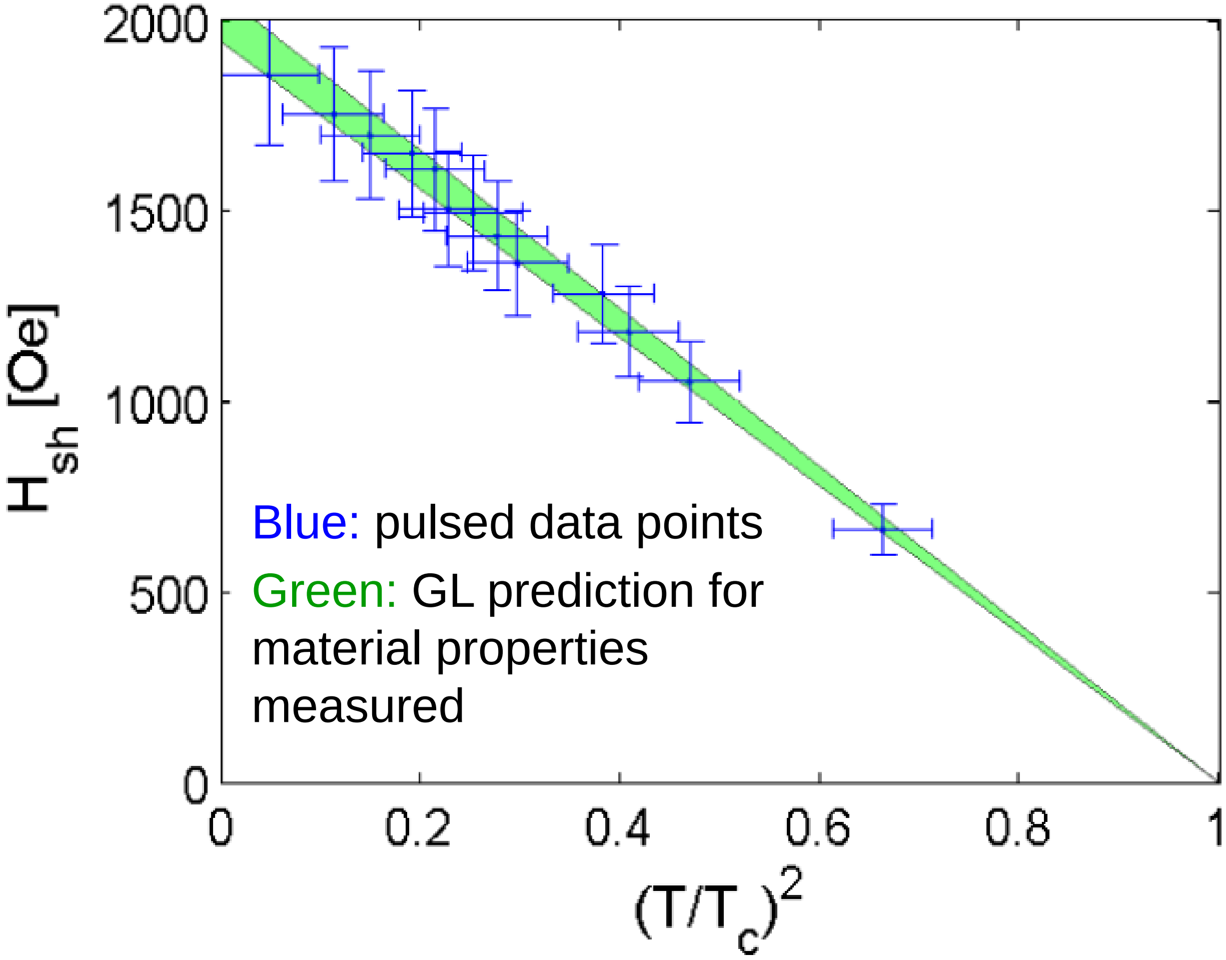


OST Data: Global phase transition



- All 8 OSTs show that second sound waves arrives first from the nearest high magnetic surface field area on the cavity, and not from a single defect location → global phase transition!

End result: $H_{sh}(T)$ of Niobium with $\kappa = 3.5$



Blue: pulsed data points

Green: GL prediction for material properties measured

- Within ± 10% error bars:

$$H_{sh} \propto \left[1 - \left(\frac{T}{T_c}\right)^2\right]$$

down to 1.6 K

- Slop is in very good agreement with prediction from GL theory for material properties measured (κ= 3.5)

Discussion

- For 110-120C baked cavity at low T:
  - Maximum surface field ≈ 2000 Oe ± 10%
  - This corresponds to ~43 MV/m ± 10% in an ILC shape cavity
- Superheating field should be 20 to 25% higher in an cavity without low temperature heat treatment
  - Need to find alternative method for removing the high field Q-slope without reducing the mean fee path in the surface layer!

Future Plans

- Plan to continue high pulsed power measurement:
  - Study $H_{sh}(T)$ for different surface preparations
    - Baked vs. unbaked
    - BSP vs EP
    - ...
  - Measure $H_{sh}(T)$ for Nb_3Sn cavity
- If you have a cavity with gradients of ~40 MV/m, send it to use for pulsed measurement