Summary for TTC WG 4

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Fermilab

21April 2010

***Opinions, interpretations presented here are my own**

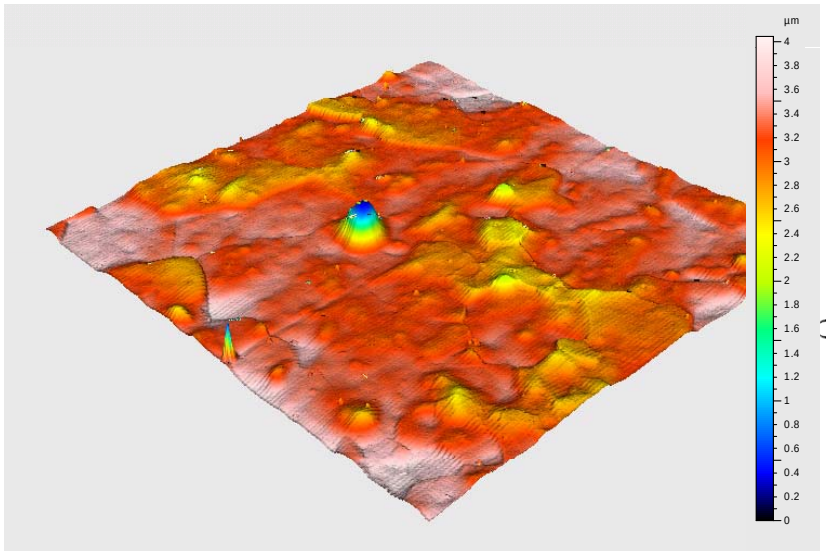
Workshop at a glance

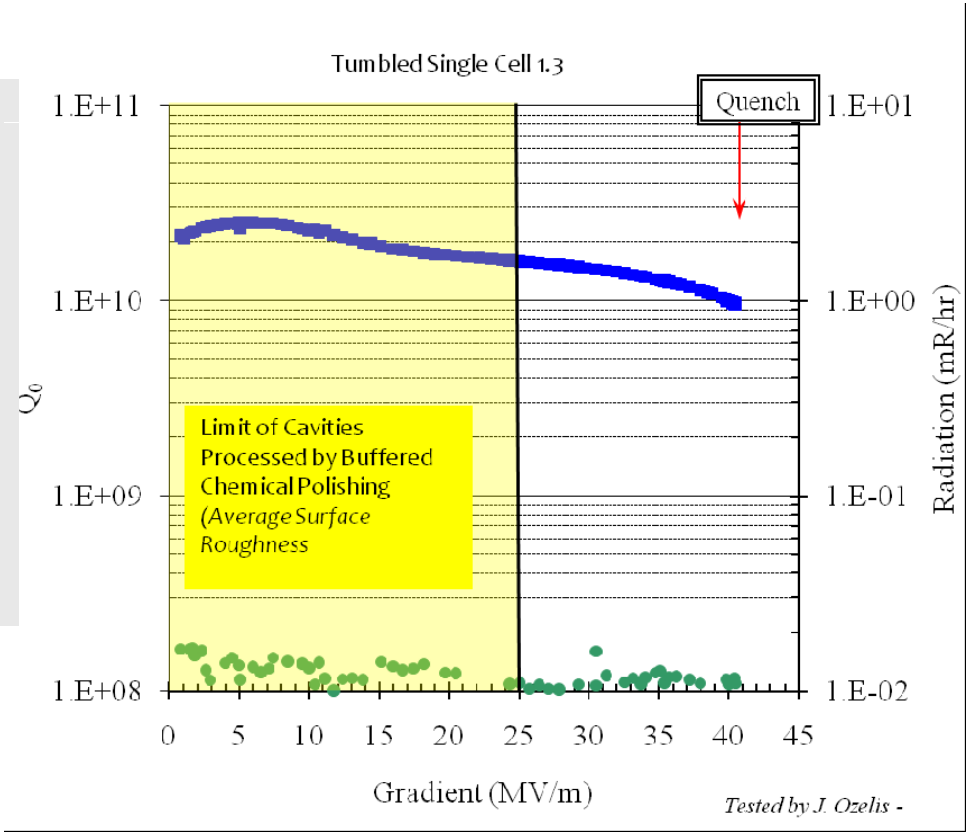
- **6th Workshop in a series started by P. Bauer, H. Edwards, G. Wu, C. Antoine**
- **56 Attendees**
- **8 Sessions**
  1. **Recent cavity results and drivers**
  2. **Recent coupon results and drivers**
  3. **Ideal limits to SRF**
  4. **Surface processing – bulk removal**
  5. **Surface processing – final processing, coating, and repair**
  6. **Q(E) and Rs measurements**
  7. **Forming and welding**
  8. **Alternate processes (films)**
- **http://indico.fnal.gov/conferenceDisplay.py?confId=3118**

DRIVERS FROM CAVITY TEST RESULTS

40 MV/m in tumbled cavity

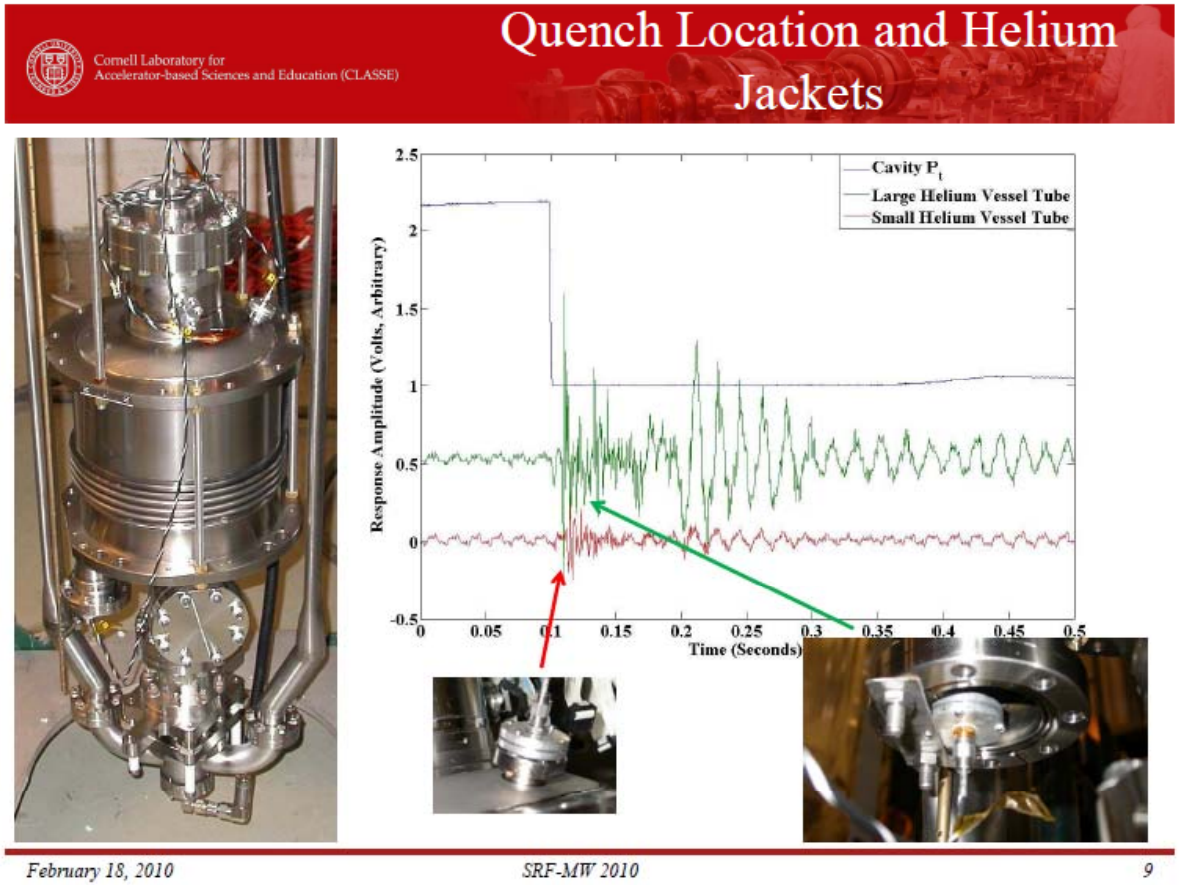
- **…Yet the surface looks very rough. Does this imply that sub-surface chemistry is more important than topography?**
  - **C Cooper, session 4**





Locating quenches inside He jackets

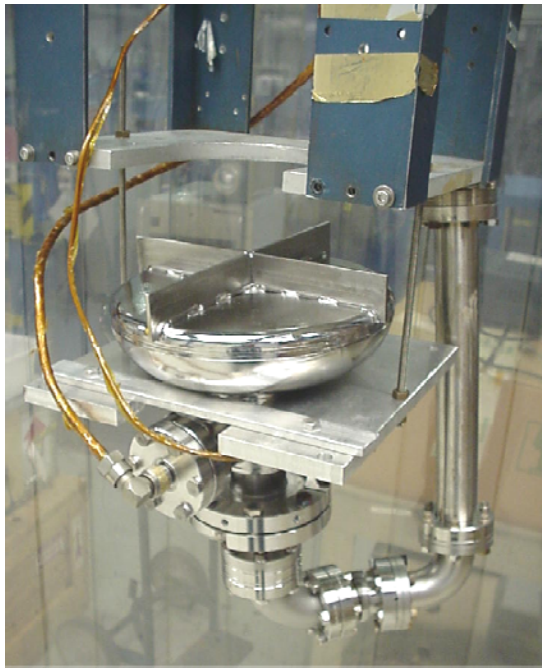
- **Second sound works even in He jacket** (Conway, §1)
- **Can second sound replace T-mapping for other needs too?**

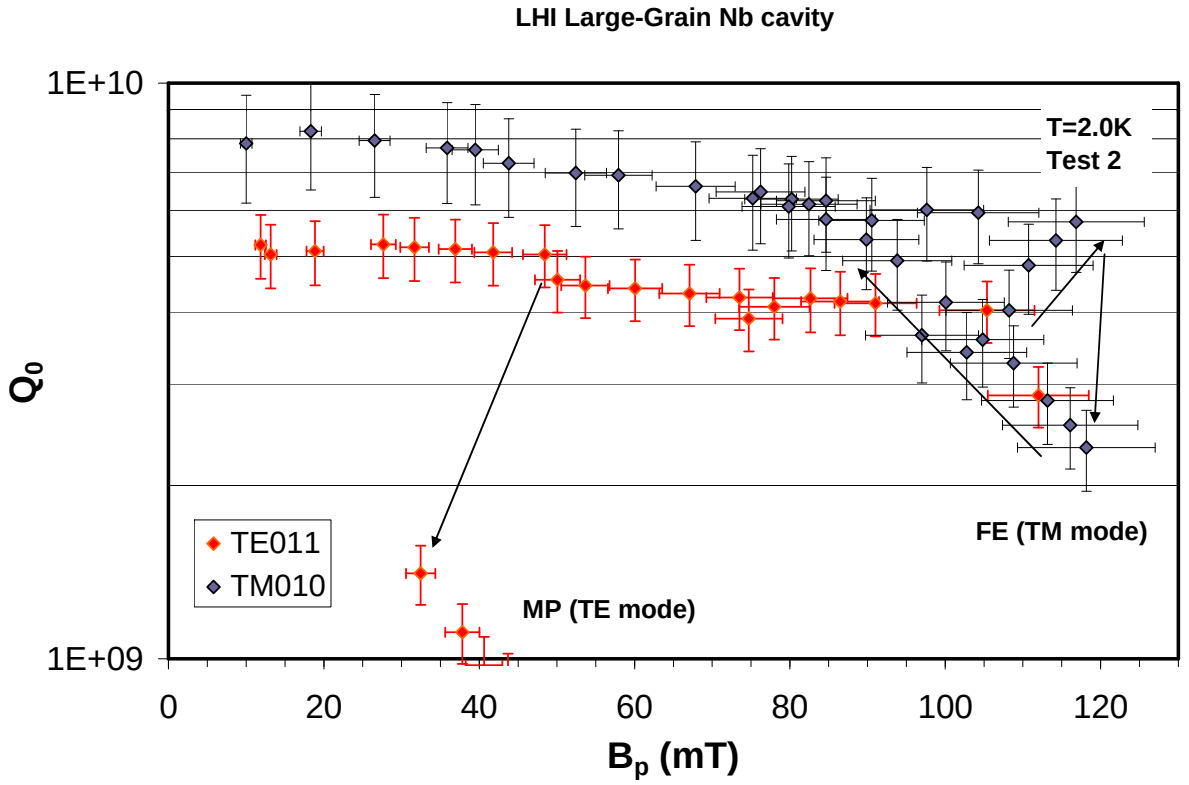


Laser-induced flux sweeping

Ciovati, session 1 – FE and MP prevent evaluation of laser-induced flux sweeping

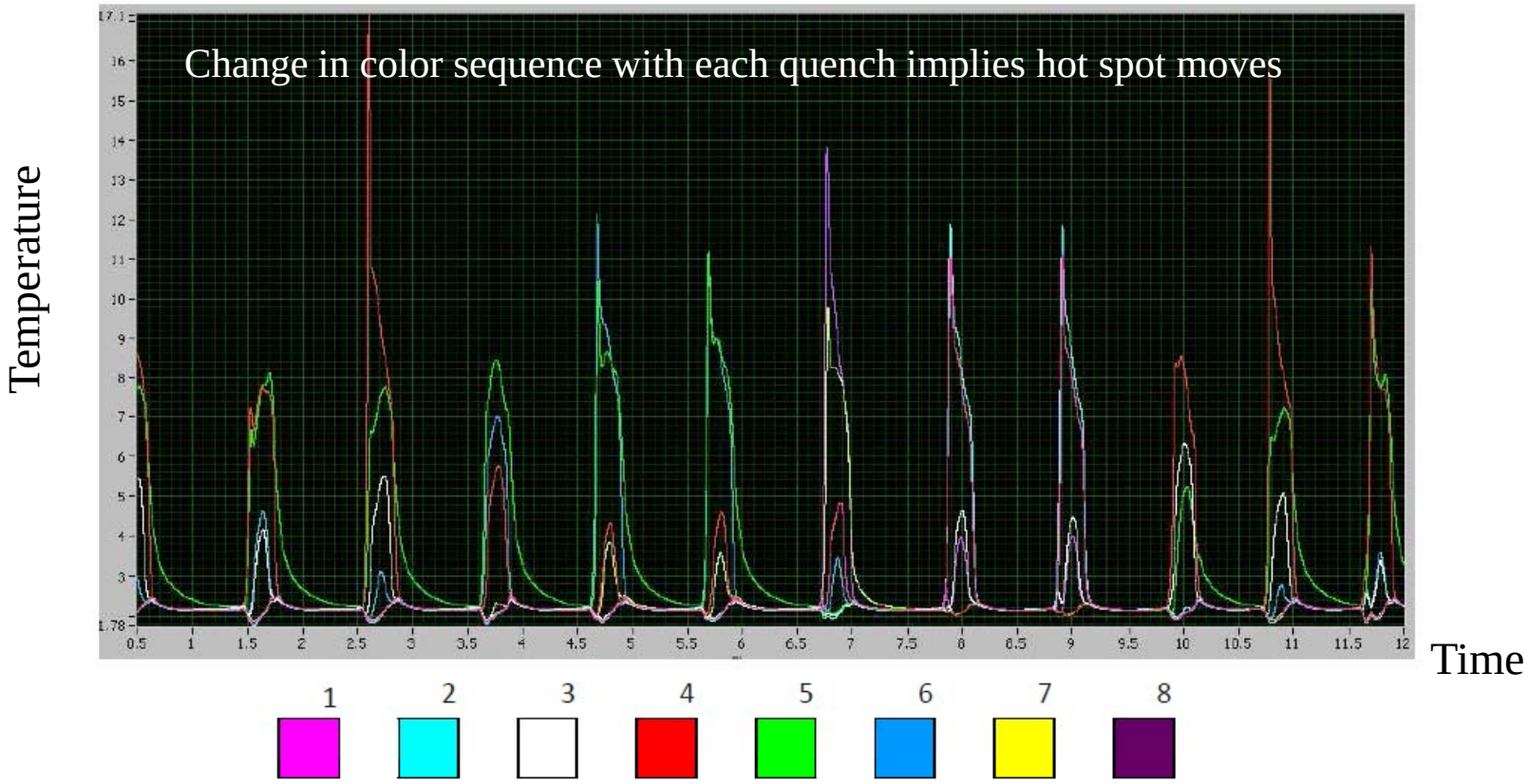
- **To try: He processing, Operate in a different mode (for example TM_{020} at 2.66 GHz), Analyze MP trajectories with a 3D code**





Quench locations that move

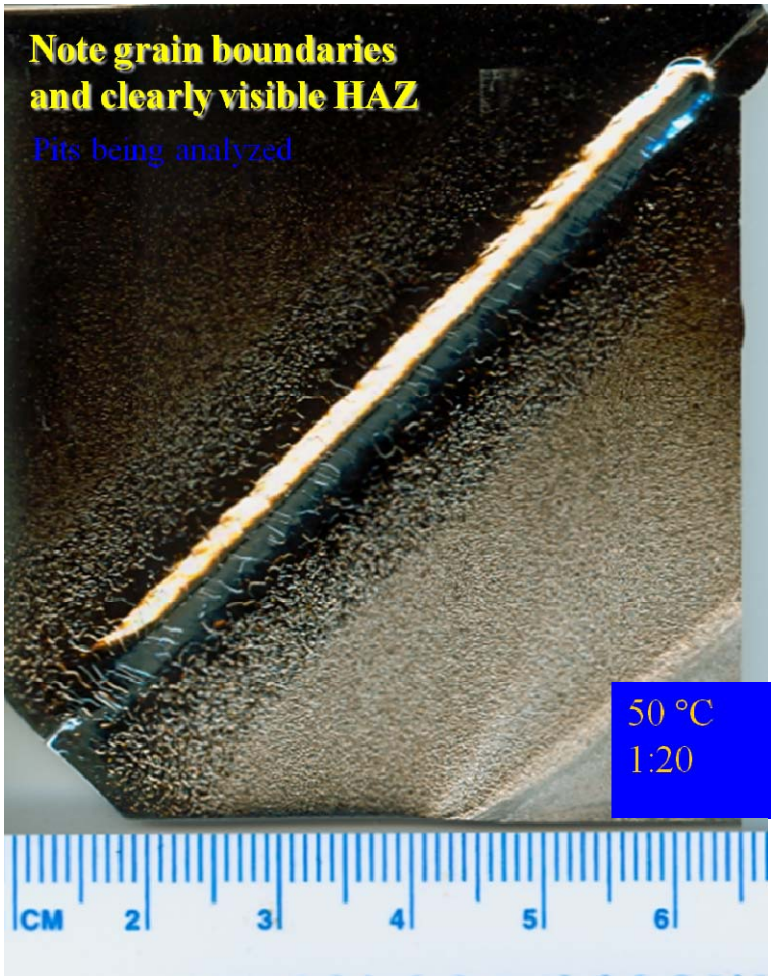
- **Above 2.2 K, quench location moves. Do thermal gradients sweep flux around equator?** **(Sergatskov, session 1)**



DRIVERS FROM COUPON RESULTS

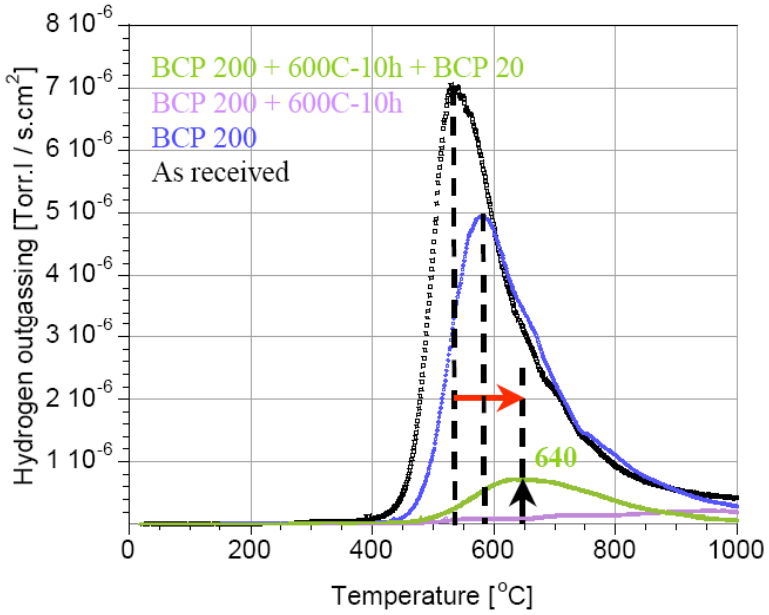
Electrochemistry - Drivers from coupon results

- **First coupon EP that looks like cavity EP** (Cooley, §2)
  - **Need 1:20 area ratio of cathode to anode**
  - **Need warmth (50 °C)**
  - **Need flow (1 L/min)**
  - **Unwanted reactions may then occur at cathode**
  - **Viscous layer might be removed**
  - **See Reece §3 talks – is electro-etching component present? If so, what is doing the etching?**

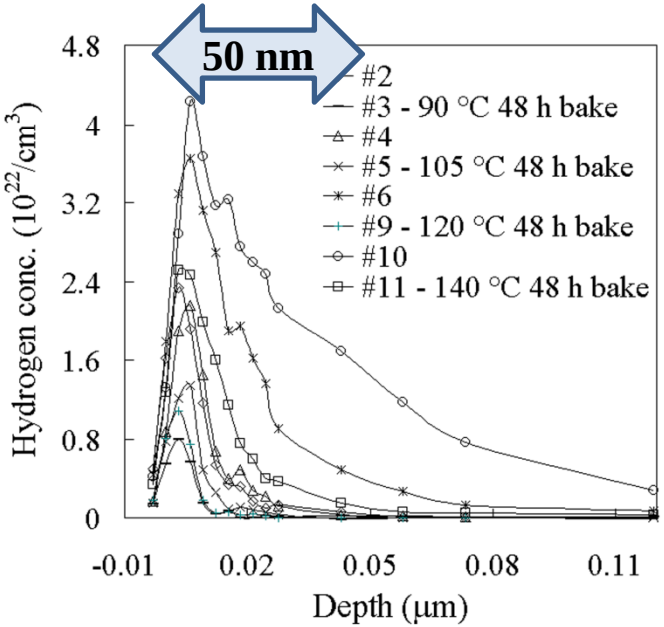


Few words about Hydrogen

- **Bulk hydrogen vs. surface hydrogen (Ciovati, session 1):**



P. Chiggiato, G. Chuste, I. Wervers, A.-M. Valente, JLab Technical Note, TN-09-056 (2009).

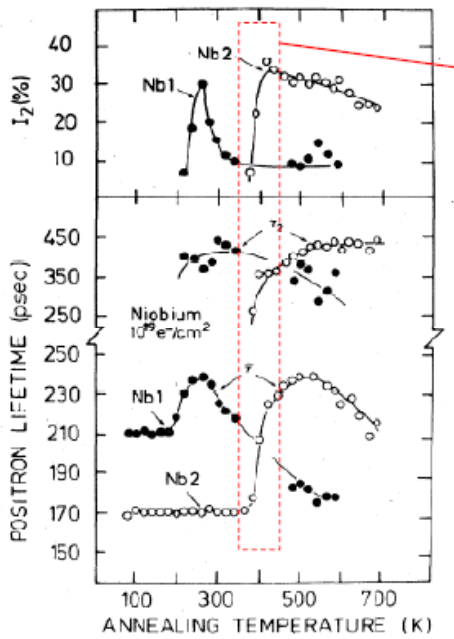


*G. Ciovati, J. Appl. Phys. **96**, 1591 (2004)*

- 600 °C Bake not sufficient to remove H from surface (SIMS data); need 800 °C
  - **H presence correlates with performance reduction.**
  - **Is this tied to dislocation motion?**
- **Propose 800°C, 3 hr plus 120 °C, 12 hr in UHV with no final chemistry**

Debate over 120°C baking
(and implications for high-field Q-drop or quench)

- **It's not oxygen (Romanenko, §2)**
  - Baking works 100% of time for EP, less so for BCP
  - HF + HPR + air exposure do not remove benefits
  - No oxygen-enriched layers, oxides go away and come back like before bake
- **It's hydrogen + dislocations (next slide)**
  - Surface hydrogen?
  - *Need new probes for H*
- **It's oxygen (Zasadzinski, §2)**
  - Point-contact tunneling shows clear difference for material from a "hot spot" vs a "cold spot" from T-map
  - Grain boundary full of something magnetic (oxygen spin?)
  - Nb^{4+} is evident from EPR
    - {121} defect
  - Does HF attack sub-oxides?
- **(2^{nd} slide following)**

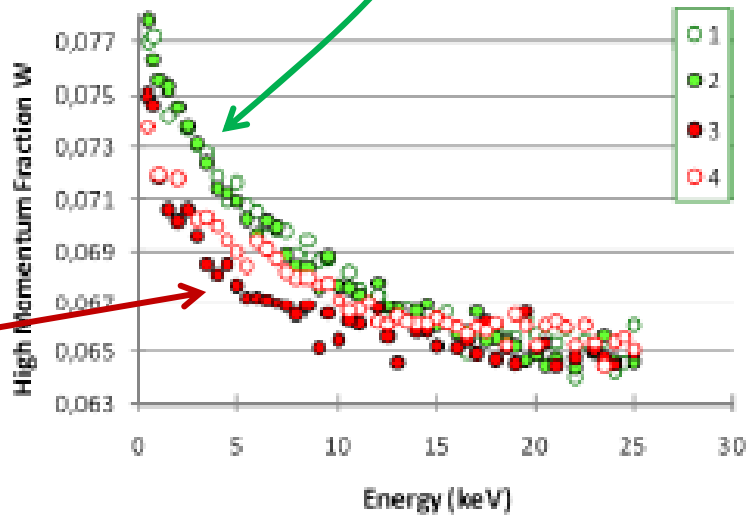


[P. Hautojarvi et al., Phys. Rev. B., Vol.35, Num.7, 1985]

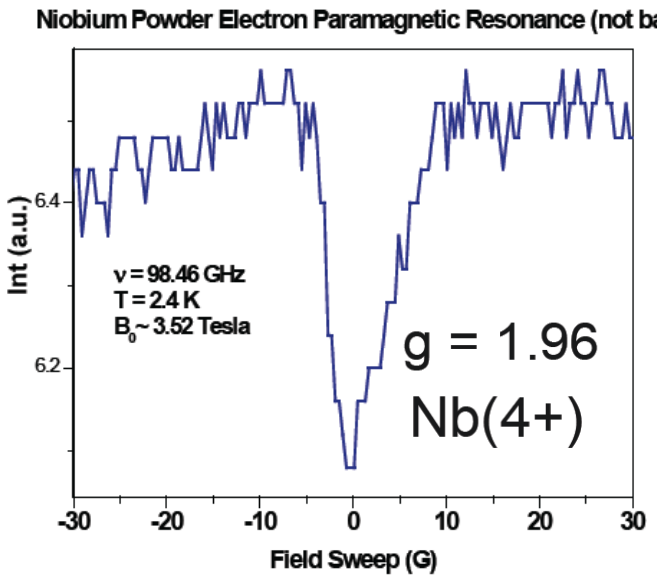
- Vac-H complexes in niobium containing some H (Nb2 in plots) dissociate at ~380K (107C) – compare to baking temperatures
- Mobile vacancies => dislocation climb becomes possible

Positron annihilation study: After bake there is a high fraction of mobile vacancies because H is unbound from them. Dislocations can then move.

Before bake vacancies are bound with H, so they cannot move and will not permit dislocations to move, either!



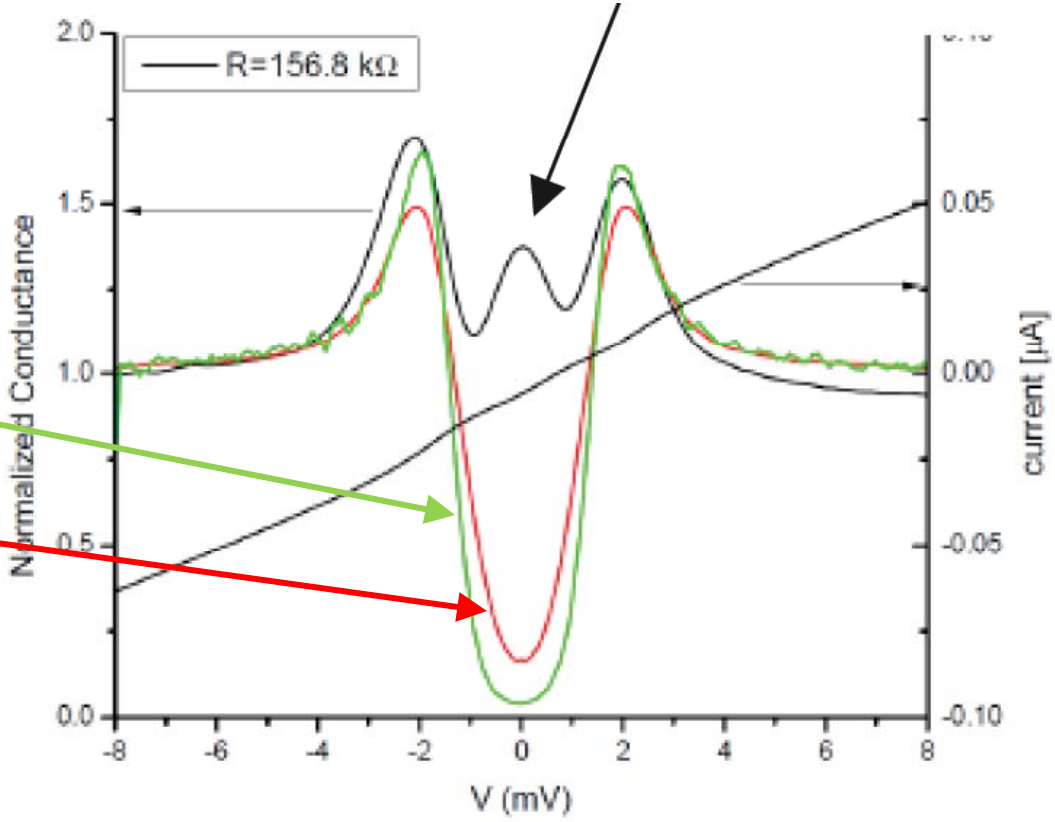
B. Visentin et al., Proceedings of SRF'09



Hot spot, near grain boundary
(Conduction at 0 mV is due to broken Cooper pairs)

Hot spot, far from grain boundary

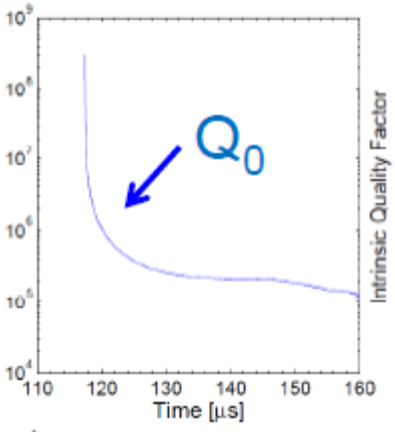
Cold spot, near grain boundary

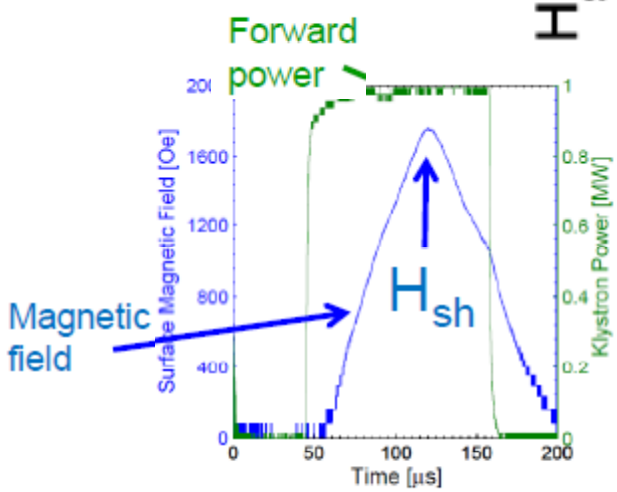


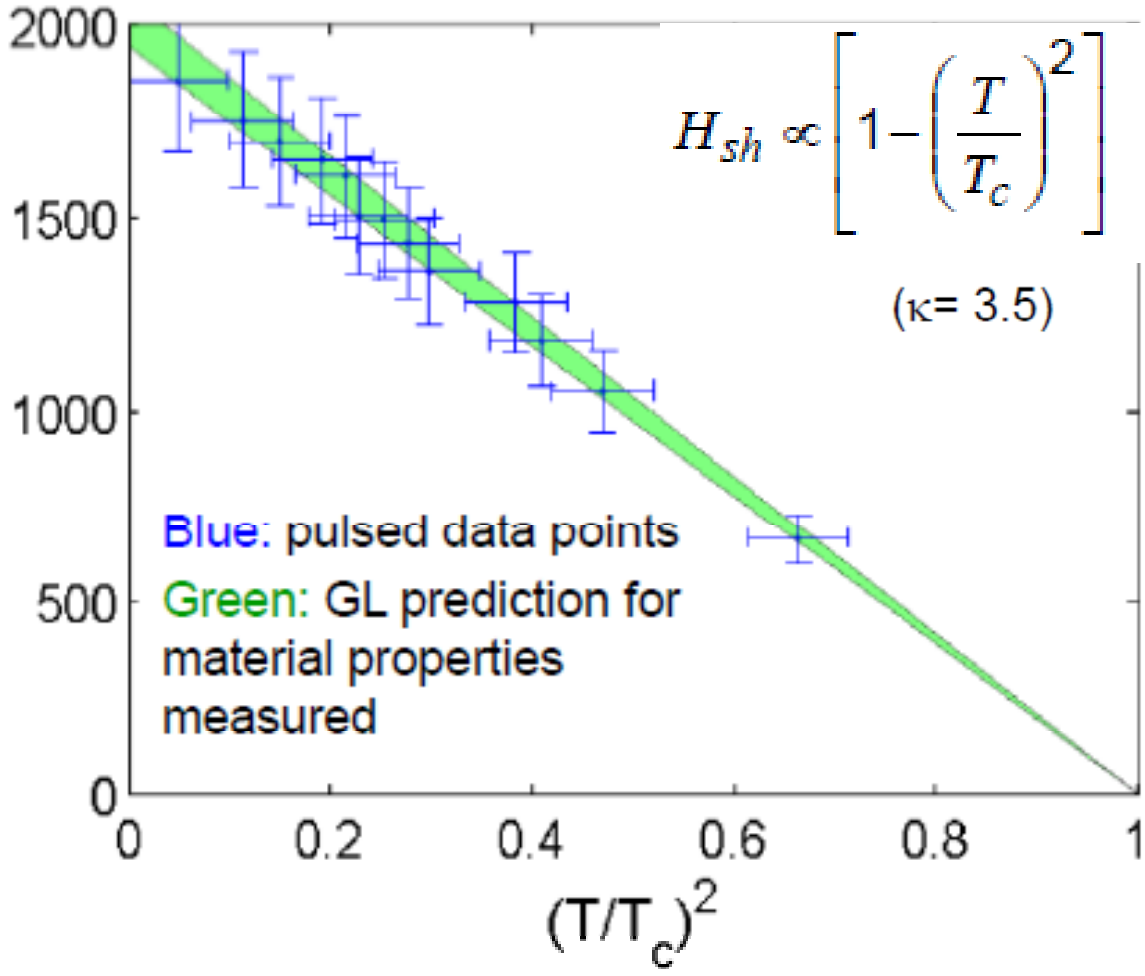
IDEAL LIMITS

Pulsed tests – H_{SH} limit was verified

Matthias Liepe, 6th SRF Materials workshop, Tallahassee

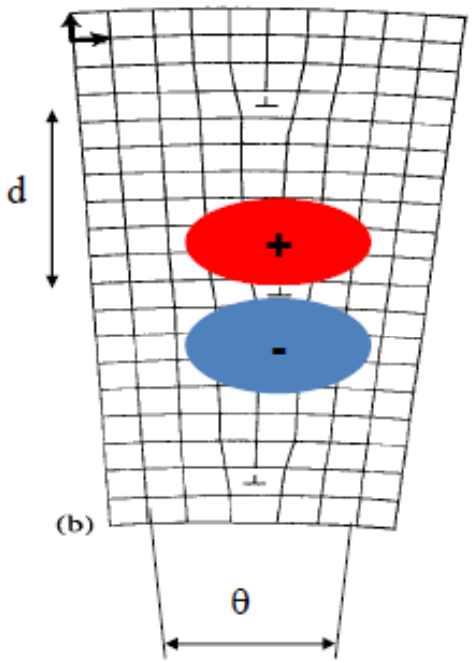






Cottrell Atmospheres

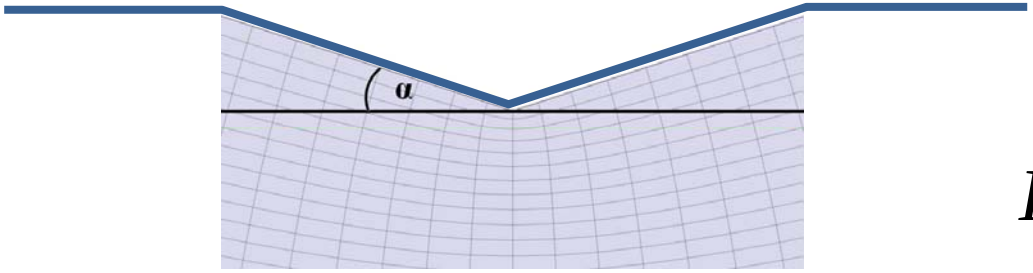
- **Impurity "clouds" around defects**
- **If hydrogen, then we must re-tool our surface science approach**
  - **NMR**
  - **μ - SR**
  - **Positron annihilation**
- **GB triple points can be collectors**
  - **Dislocations in Nb tend to pile up**
  - **Clouds follow**
- **Thus, some GBs can be benign, some can limit RF current!**



Segregation of big impurities in tensile (-) regions

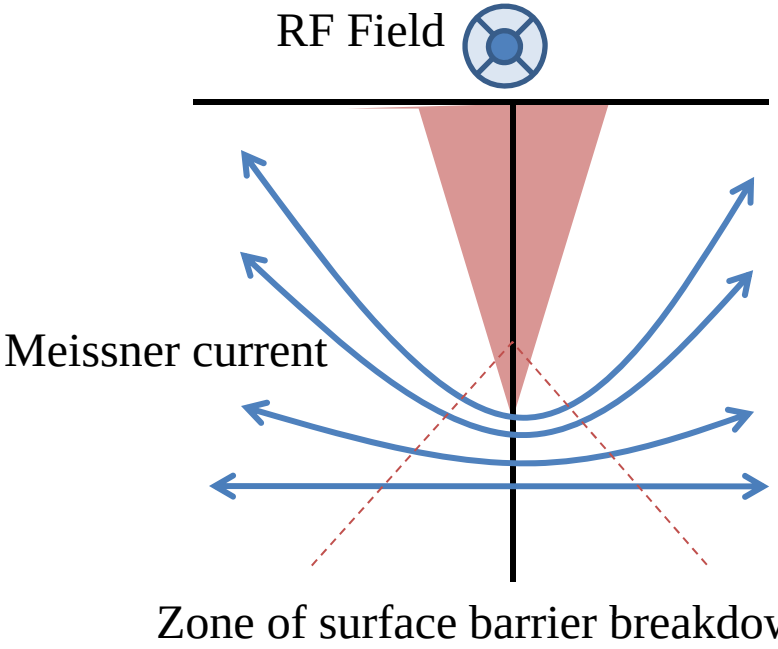
depletion in compressed (+) regions

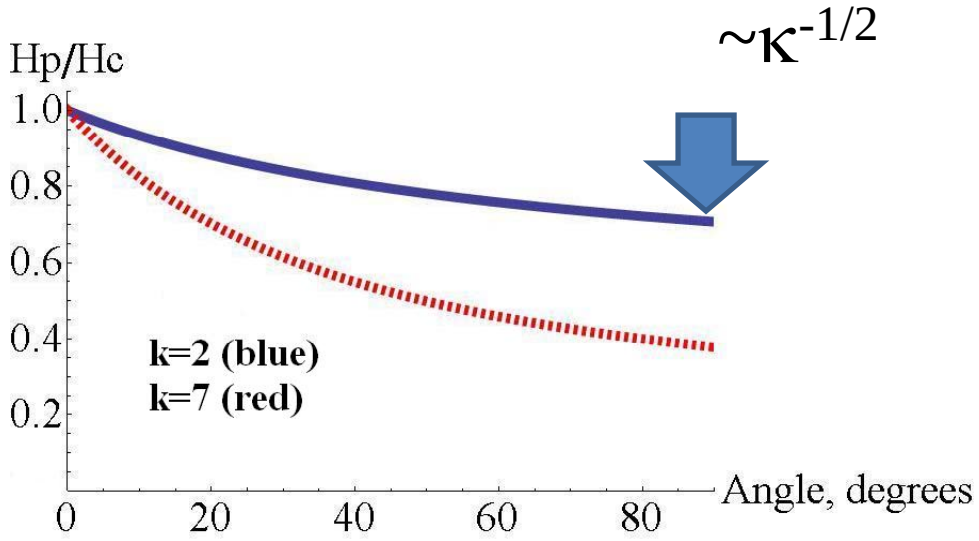
Onset of Q-drop due to flux penetration at grooves



A. Dzyuba, FNAL

$$H_{pen} = \left(\frac{\xi}{\lambda}\right)^{1-\frac{\pi}{\pi+2\alpha}} H_{crit}$$





Other fundamental topics

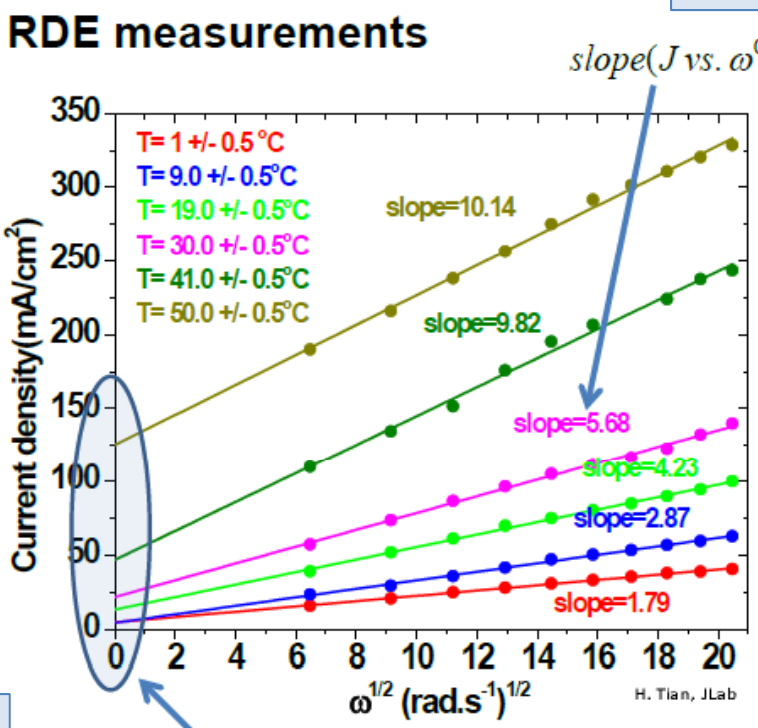
- **Pinning interactions cannot overcome Meissner current until 300-400 nm depth**
  - **Surface zones have oscillating flux**
  - **Sweeping effects require deeper thermal gradients**
- **Non-linear Meissner effect: current can suppress gap**
  - **Now has been measured at 20 GHz PRB 81, 020504R**
- **Optimization for low R_s is different than that for high E**

PROCESSING R&D AND REPAIR

Two electrochemical processes

- **Tian, Reece**

Diffusive



Excellent linear fit provides definitive evidence of a diffusion-limited process. Knowing ν and *c* yields *D*.

$c_F = 2.67\times10^{-3}$ mol/cm³

Convective?!

Strong evidence for temperature-dependent electrochemical etching in parallel with the diffusion-limited process. For analysis, we must separate these current contributions.

Control of EP temperature

Horizontal EP

- **Present: control *T* by controlling flow, but 1 Hz temperature swings remain**
  - **"Stable, but hot" – Reece**
  - **Electrolyte viscosity falls by 2x for 20°C rise!**
- **Difficult to control *T* by controlling voltage**
- **Water spray works well!**

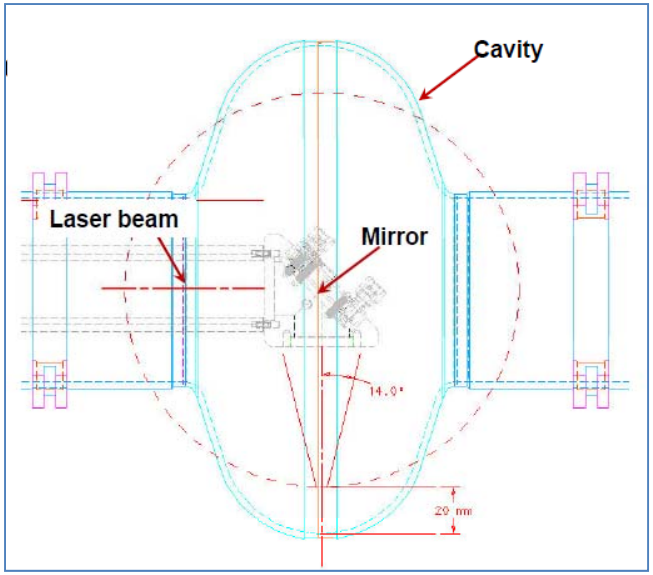
Action: Apply external cooling to horizontal EP

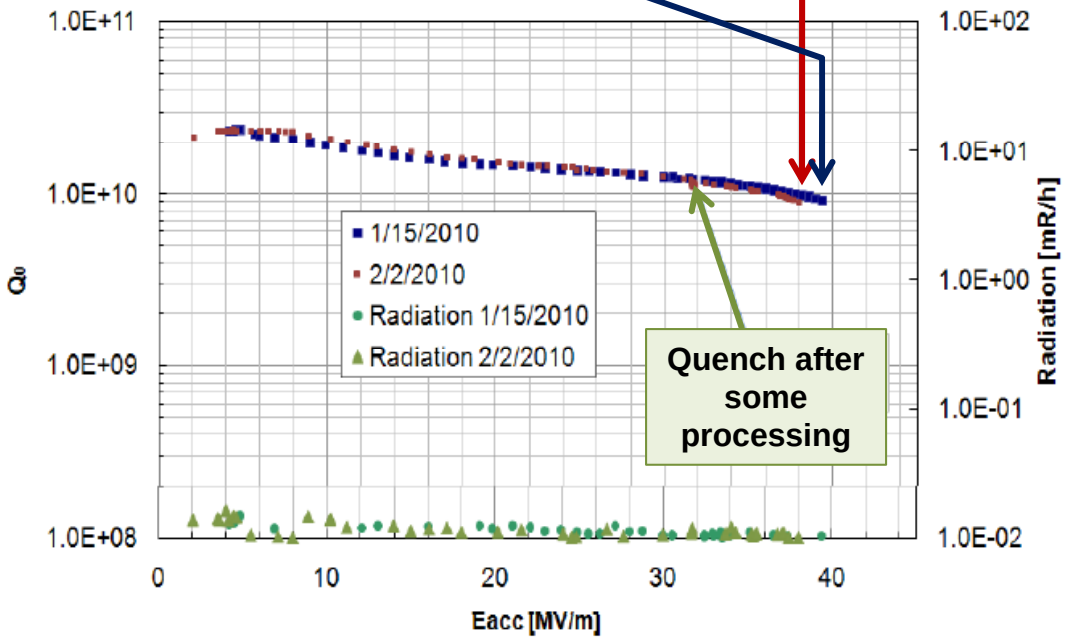
Vertical EP

- **Water spray works well!**
- **Present: top-bottom asymmetry**
- **Paddles, screws, other strategies to circulate electrolyte**
- **Also cavity flip**

Repair by laser re-melting

- **First attempts restored max gradient** (Ge, §5)
  - **Quench location remains at repaired spot**
  - **Argon purity can improve**





Alternate processing

- **Tumbling + light EP works well, 9-cell experiments soon**
- **Non-HF processing ideas ripe for support – tools designed, processes laid out**
  - **Faradayic electropolishing – large pulsed currents**
  - **Lactic acid, sulfonic acid, other electrolytes**
  - **Chemical-mechanical processing**
  - **Jet-slurry polishing**
- **New film deposition routes**
  - **Self-sustained metal plasmas**
  - **Other ALD**

NEW FACILITIES PROCESSING AND TESTING

New Facilities

Processing

- **JLab – integrated cavity processing facility**
  - **Vertical processing, cavity never moves from fixture, services are brought to cavity**
- **FNAL – integrated cavity processing apparatus**
  - **1-cell R&D**

Testing

- **Coupon Q(E)**
  - **SLAC is operating "mushroom" style cavity**
  - **Texas A&M and Jlab have sapphire resonators**
  - **Maryland has point-RF probes and laser-scanning RF experiment**
- **Proposed**
  - **Dual laser interferometry plus re-melting**
  - **Surface resistance measurement**

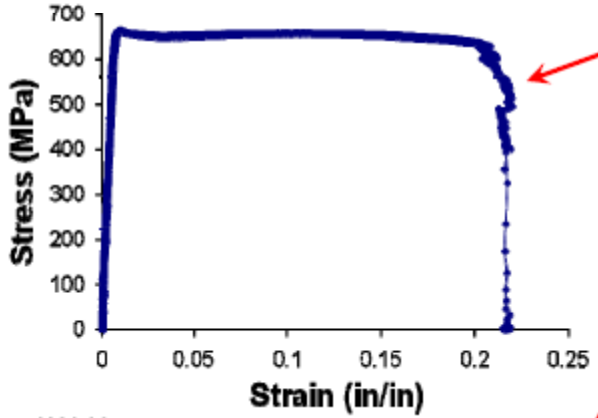
RAW MATERIALS

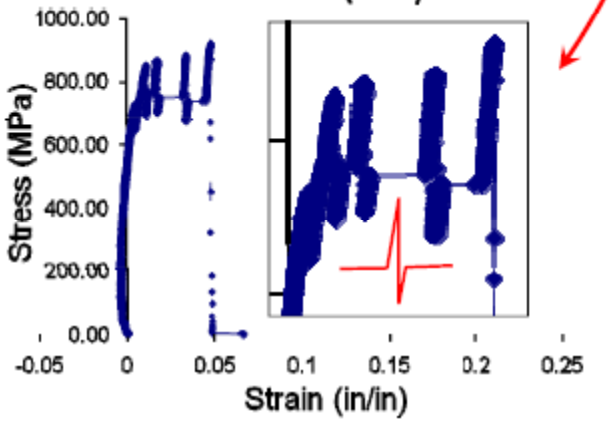
Niobium

- **Should we modify the specification?**
  - **2% flatness, RRR = 300, ASTM 6 interfere with each other**
  - **No batch is the same as any previous batch**
- **Stockpiles of pieces, end groups, formed items might be useful**
- **Tubes for hydroforming are now a product offered by vendors!**
  - **140 mm OD, 1.2 m long, 3-6 mm wall**
  - **ECAE of 6” tubes may be possible soon**
- **Special textures can be prepared, might be interesting**
- **Excessive cold work can be applied during forming**
  - **Does this lead to trouble later?**

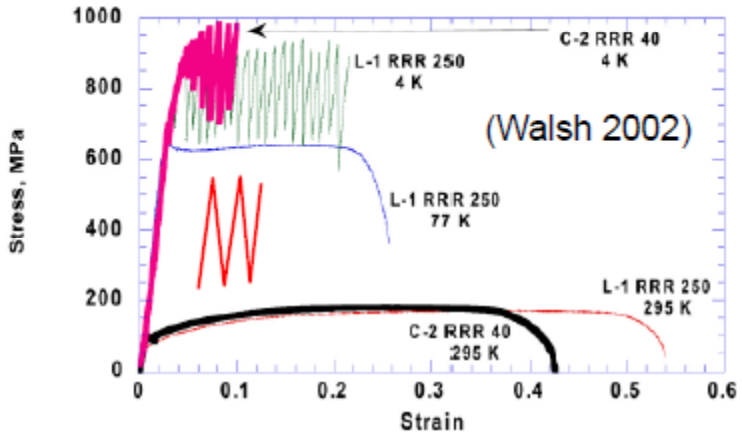
Nb testing at 4.2 K

Polycrystalline samples deformed at 77 and 4K agree with data from literature





- High RRR Nb has same yield and flow behavior at 77 K
- At 4K, Sample showed 5 instances of jerky flow before fracture, at lower strain than samples from literature



Conclusions - Recommendations

- **Pay as much attention to sub-surface contamination as topography, especially impurity clouds at dislocations and grain boundaries**
- **Understand hydrogen as much as we now understand oxygen (and understand oxygen better, too)**
  - **Re-tool surface science for hydrogen**
- **Water cool the outside of cavities during EP**
  - **Two electrochemical processes, maybe one is convective!**
  - **Decouple temperature control from acid flow**
- **Several repair routes are feasible**
- **Continue progress on alternate processing and alternate forming**
- **Relax the Nb spec?**