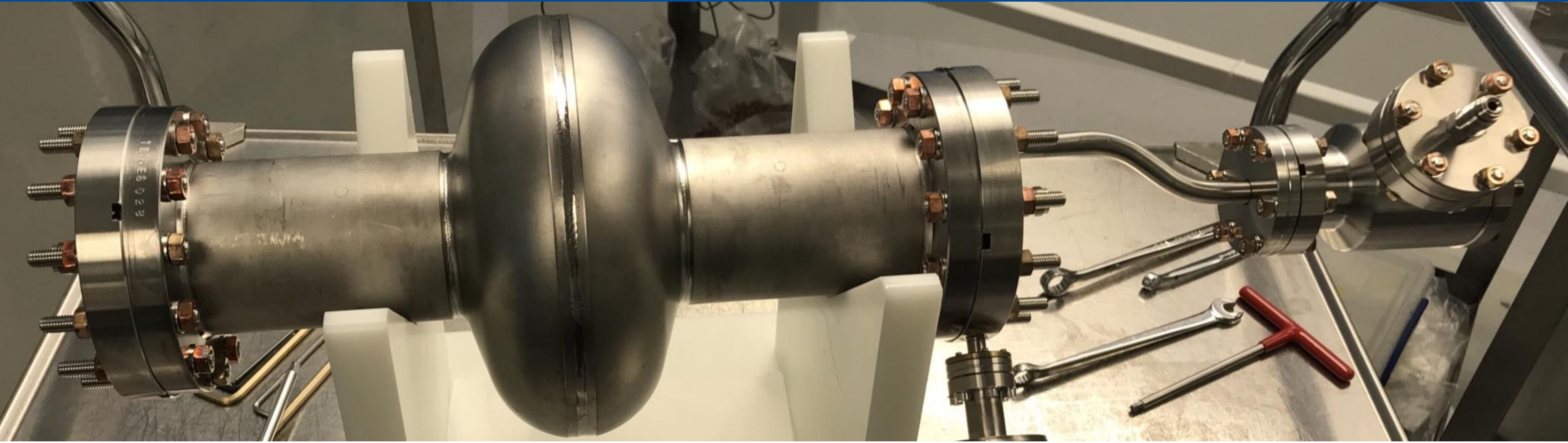

Update on Analysis of Low RRR SRF Cavities

Katrina Howard, Daniel Bafia, Young-Kee Kim

TTC2023 at Fermilab
5 December 2023

In partnership with:

THE UNIVERSITY OF CHICAGO

Continuation of Low RRR Studies

- Many SRF studies follow a “clean bulk dirty surface” technique to optimize the BCS resistance by adding extrinsic impurities
  - Low temperature bake and N-doping are current focus
- What role do intrinsic impurities serve?
  - Might perform similar functions as extrinsic impurities which have been shown to improve performance
- Goal: use understanding of intrinsic impurities to design future surface treatments for high gradient and quality factor
  - Taking new avenue by studying low RRR cavities
  - Low purity Nb → increased concentration of **intrinsic** impurities
  - Taking a deep dive in characterizing performance with TMAP

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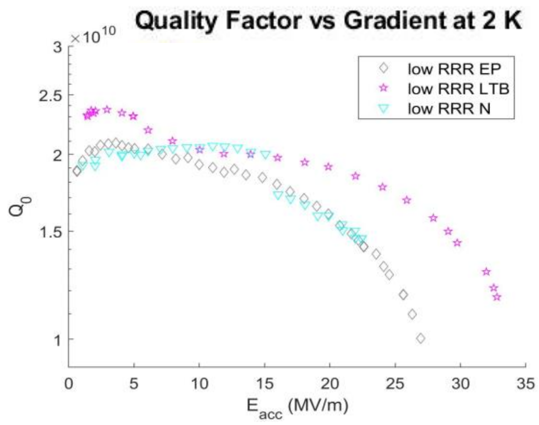

Surface treatments appear to vary cavity performance, but slightly differently when compared to high RRR cavities

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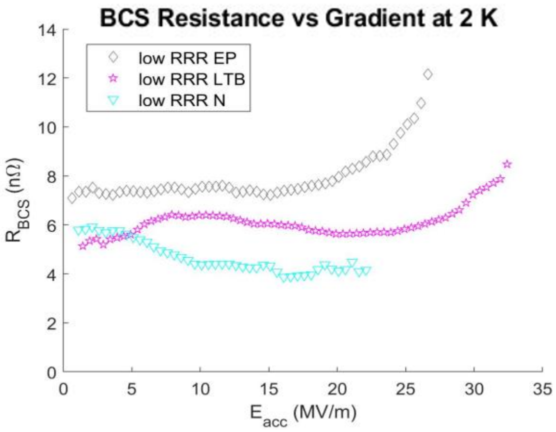
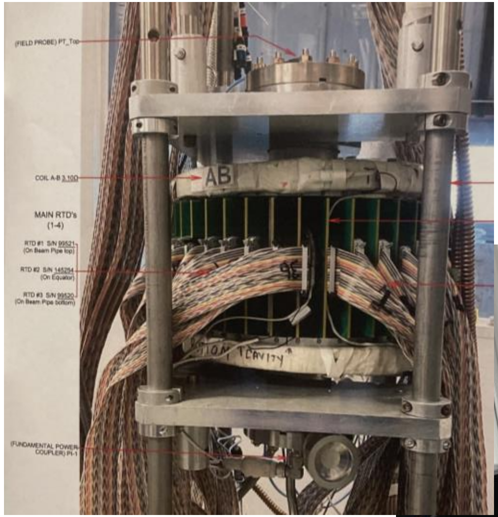
Observe many of the phenomena characteristic of each treatment, but again to slightly different extents



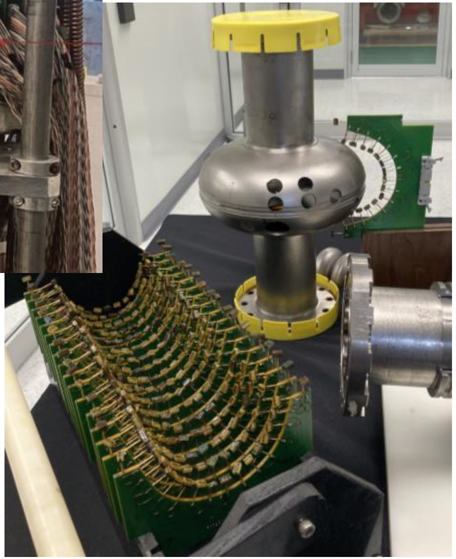
Using TMAP to Further Characterize Performance of Low RRR Cavities

Sequential TMAP Study on Single Low RRR Nb SRF Cavity

- 1.3 GHz TESLA-shaped single-cell low RRR (= 61) cavity
- RF testing after surface treatments
  - Electropolished (40 µm EP for baseline)
  - Low temperature bake (120 ℃ x 48 hours)
  - N-doping (2/6 recipe with 5 µm EP)
  - Underdoped (additional 2 µm EP from N-doped surface)



16 RTD's per board



36 boards

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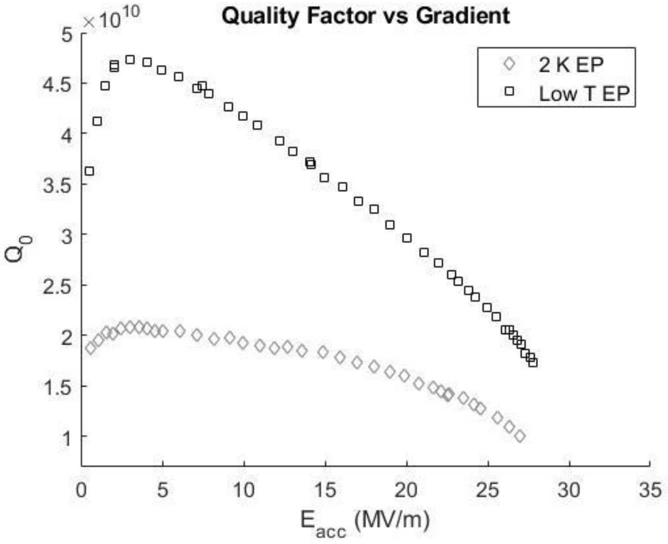
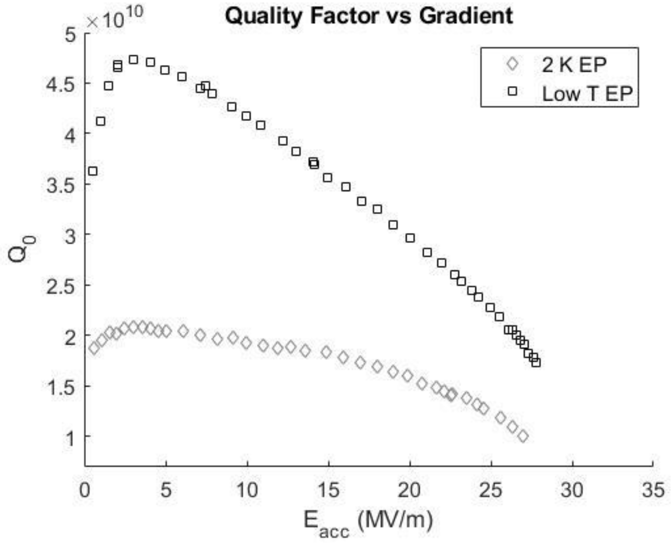
Sequential TMAP Study 1/4: EP

- Cavity received 40 µm EP to reset surface
- Low RRR has slightly lower Q_0 than high RRR
- Q_0 slope begins sooner but less sharp than high RRR

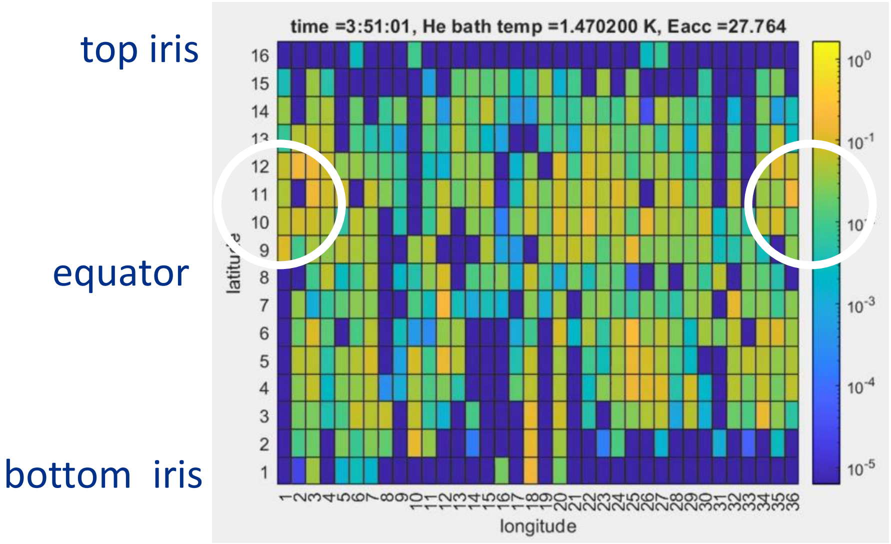


Sequential TMAP Study 1/4: EP

- Cavity received 40 µm EP to reset surface
- More localized heating but not only at quench location

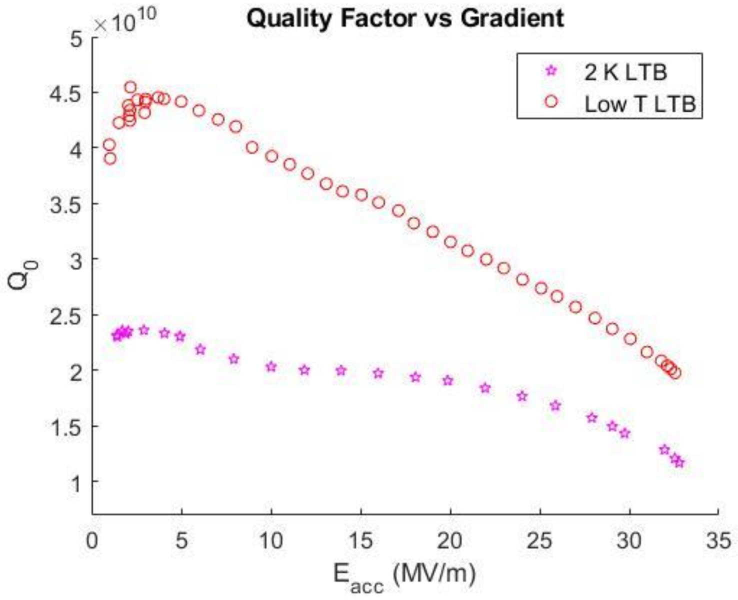


TMAP Profile Just Before Quench



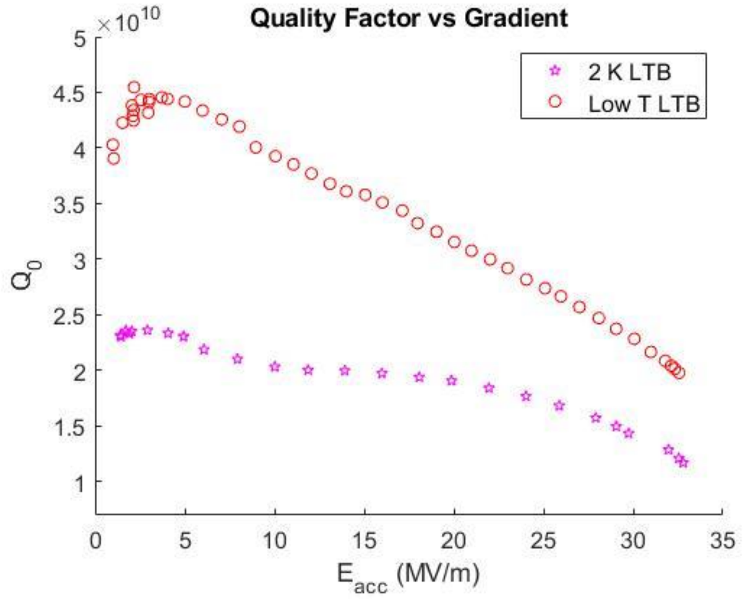
Sequential TMAP Study 2/4: LTB

- Low temperature bake (120 ℃ x 48 hours)
- Low RRR experiences reduced response to LTB treatment



Sequential TMAP Study 2/4: LTB

- Low temperature bake (120 ℃ x 48 hours)
- More widespread heating, including at quench location

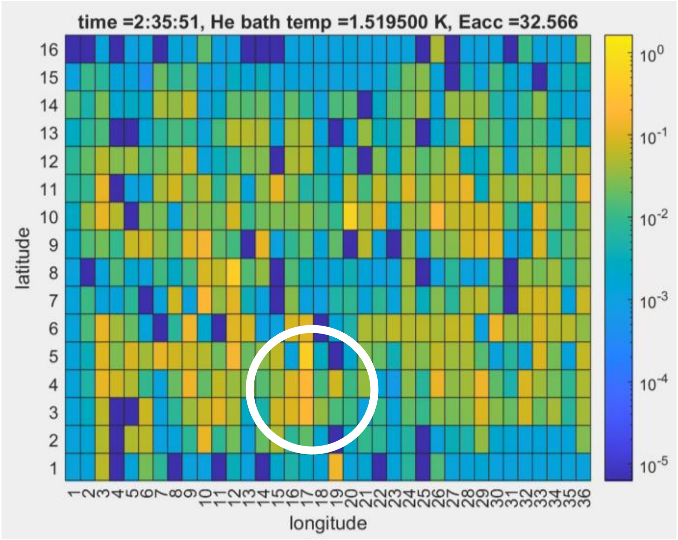


TMAP Profile Just Before Quench

top iris

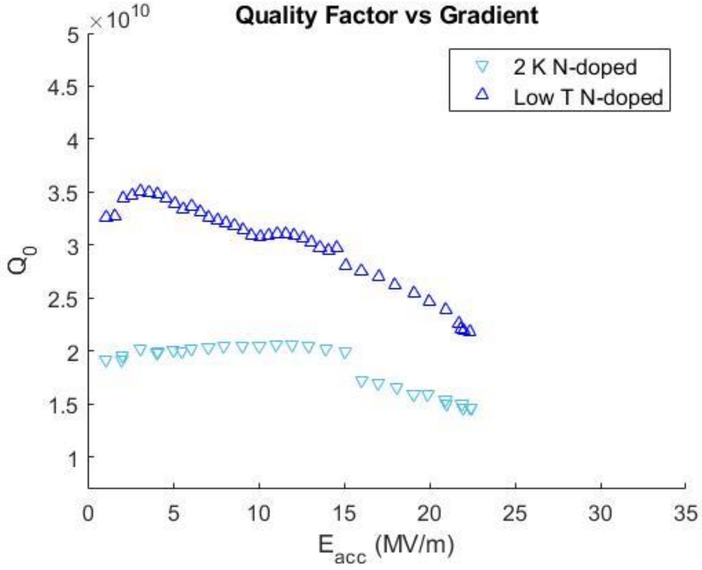
equator

bottom iris



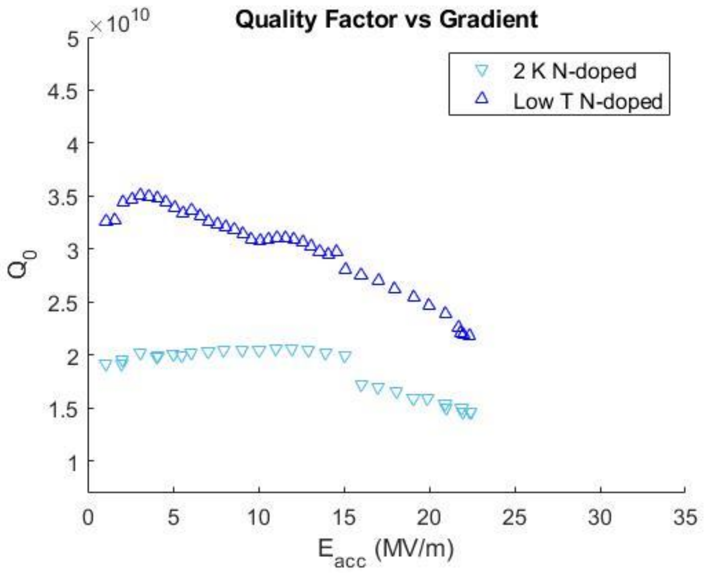
Sequential TMAP Study 3/4: N-doped

- N-doping 2/6 recipe with 5 µm EP
- Much lower Q_0 than high RRR but similar gradients reached

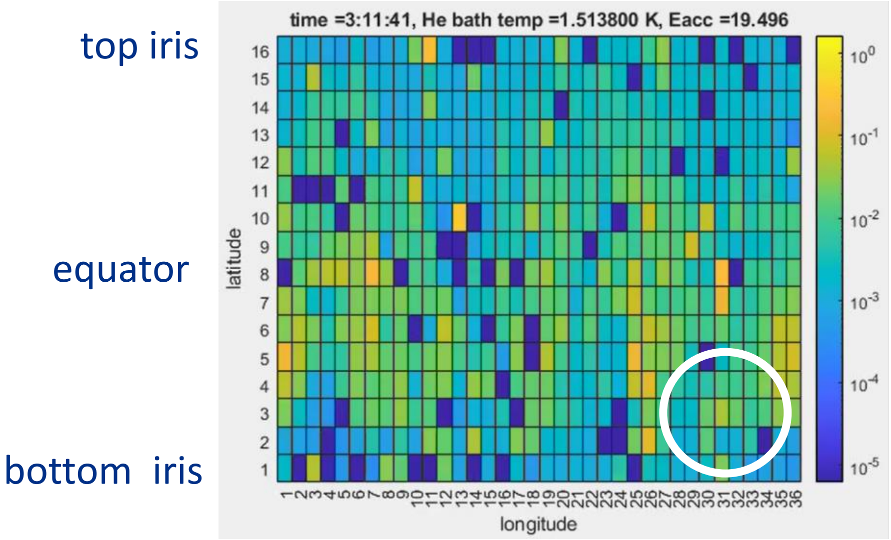


Sequential TMAP Study 3/4: N-doped

- N-doping 2/6 recipe with 5 μm EP
- More widespread heating, not specifically at quench location

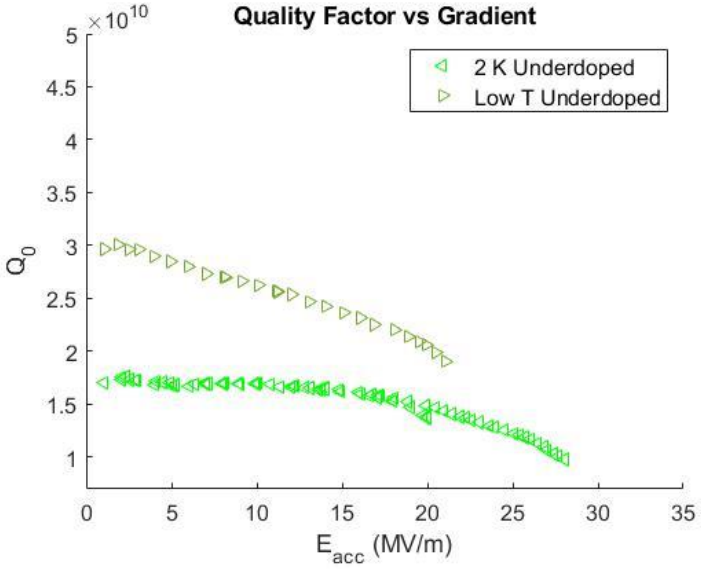


TMAP Profile Just Before Quench



Sequential TMAP Study 4/4: Underdoped

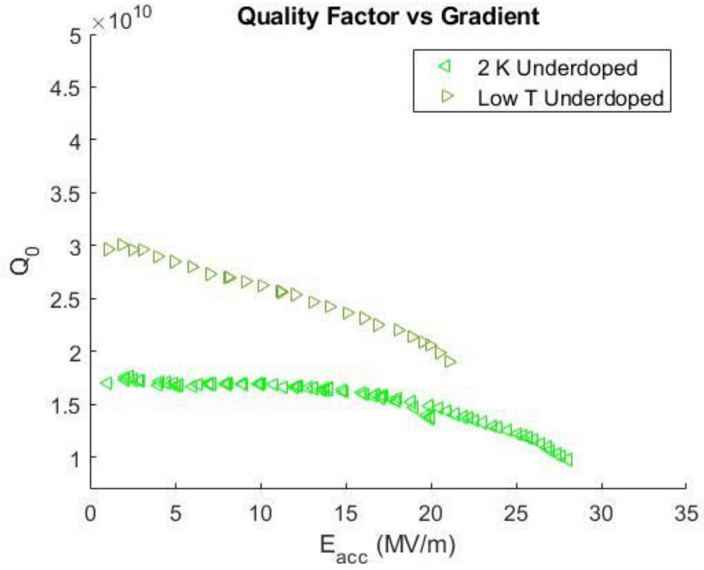
- Underdoped (additional 2 µm EP from N-doped surface) to see how decreasing N concentration changes performance
- Significantly lower Q_0 but reaches higher gradient than N-doped



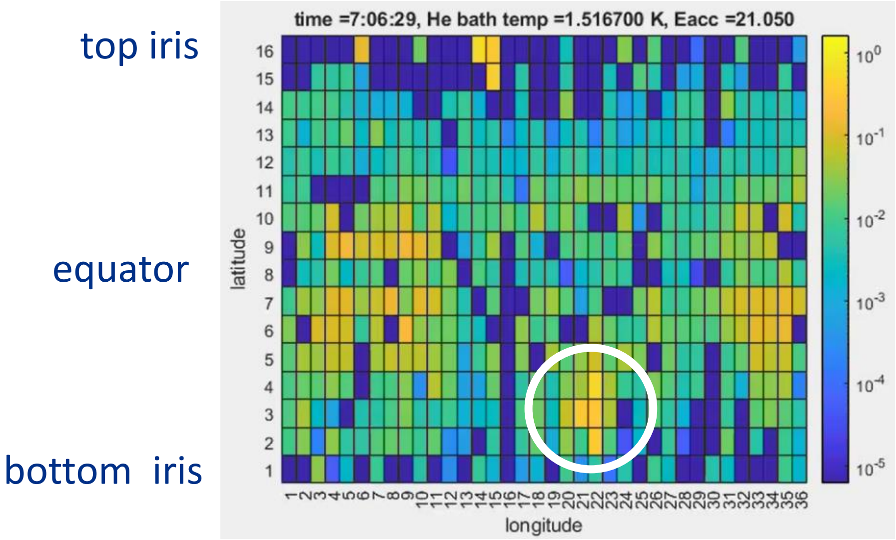
Sequential TMAP Study 4/4: Underdoped

– Underdoped (additional 2 μm EP from N-doped surface) to see how decreasing N concentration changes performance

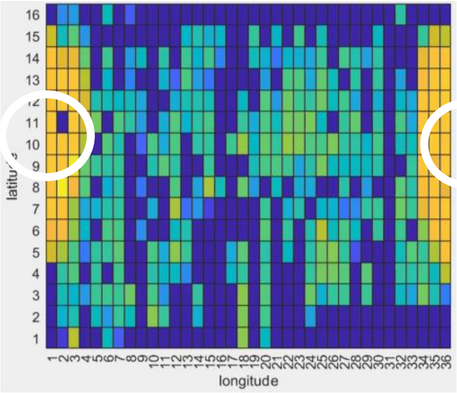
– More localized heating, including at quench location



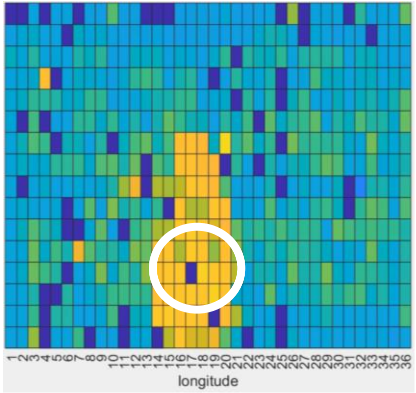
TMAP Profile Just Before Quench



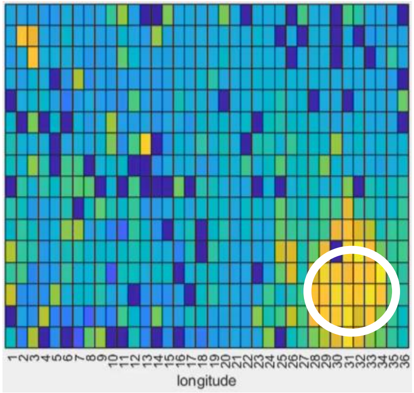
Comparing TMAPs for All Studied Treatments



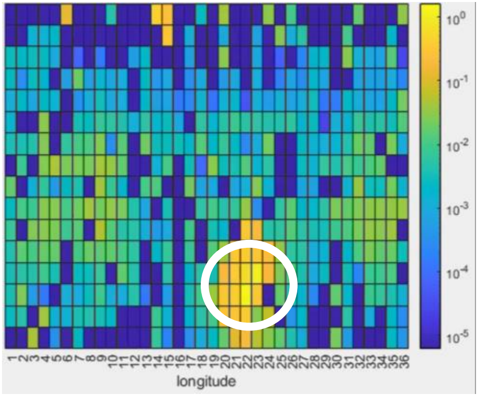
EP



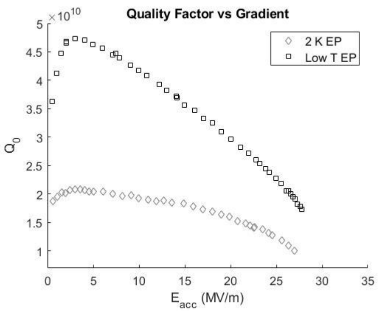
LTB

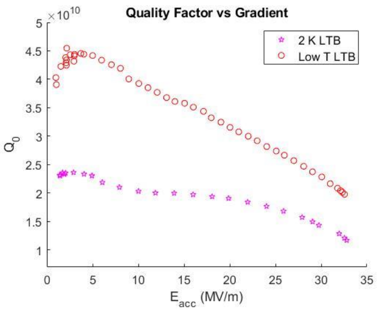


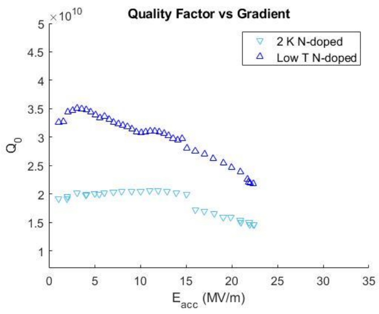
N-doped

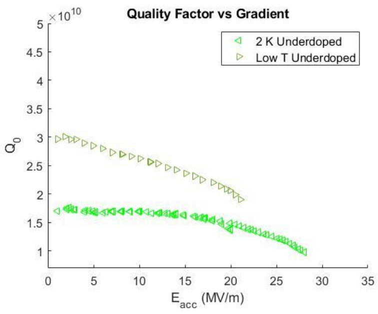


Underdoped









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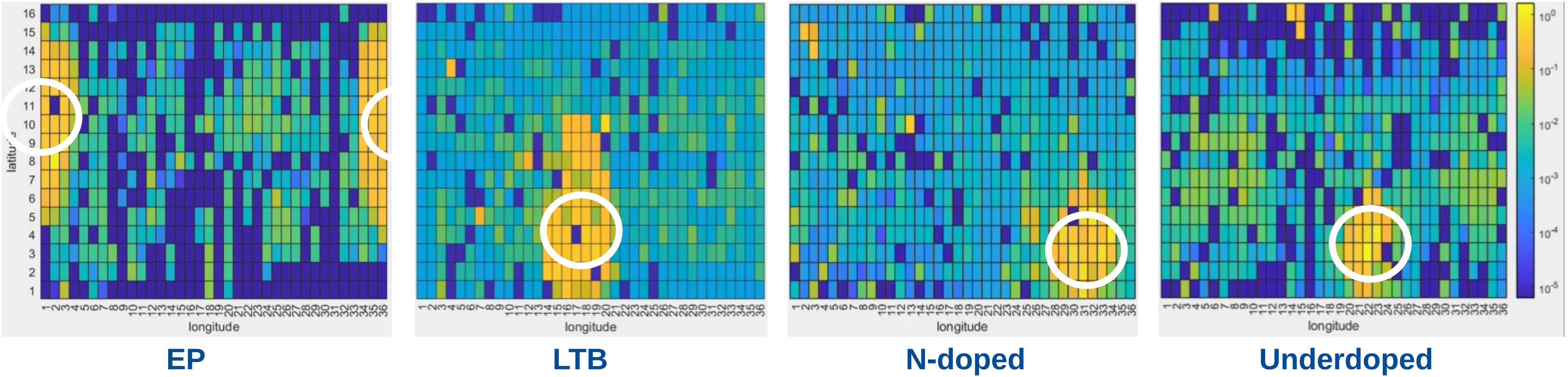
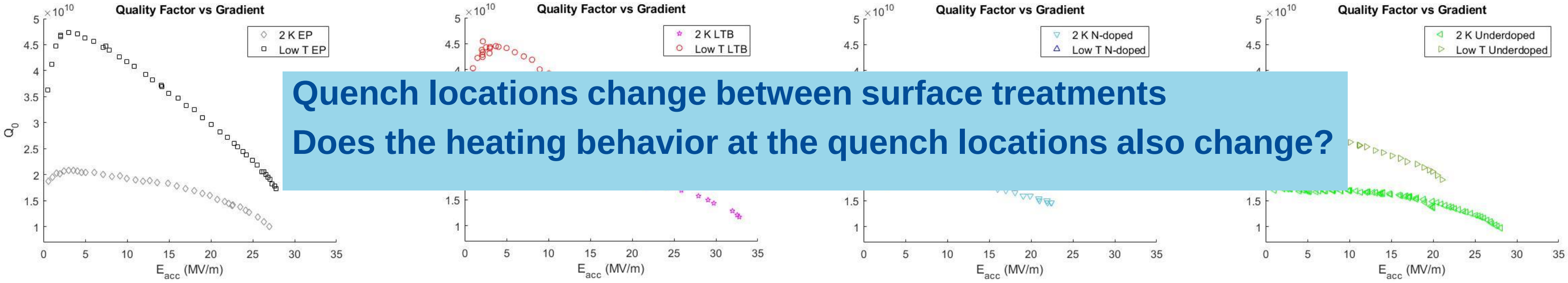


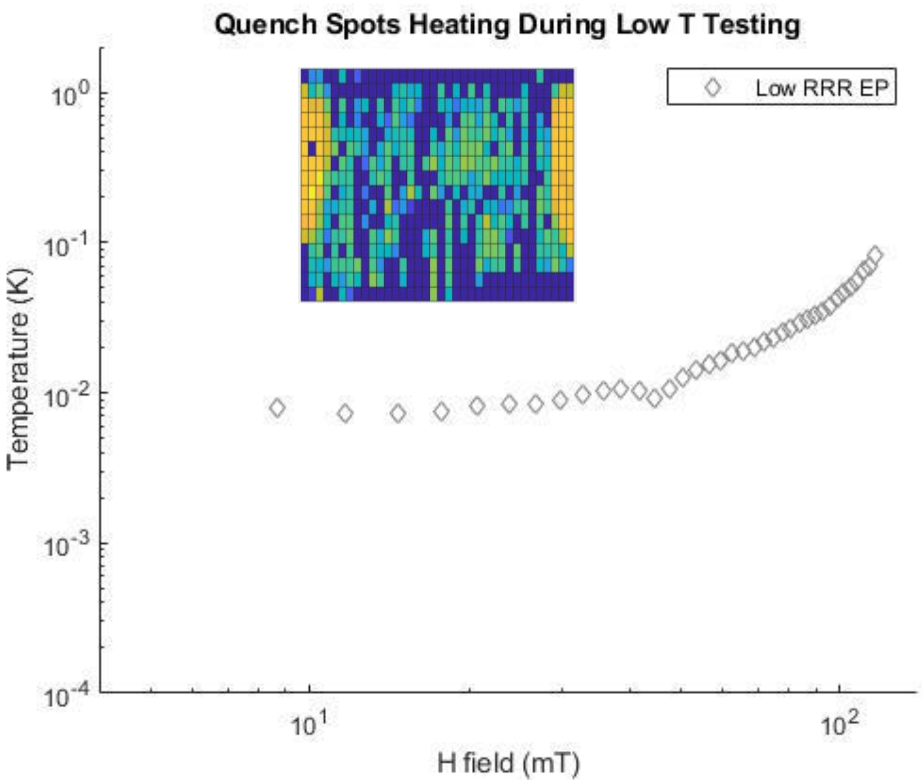


Quench locations change between surface treatments

Does the heating behavior at the quench locations also change?

Comparing Quench Spot Heating Profiles

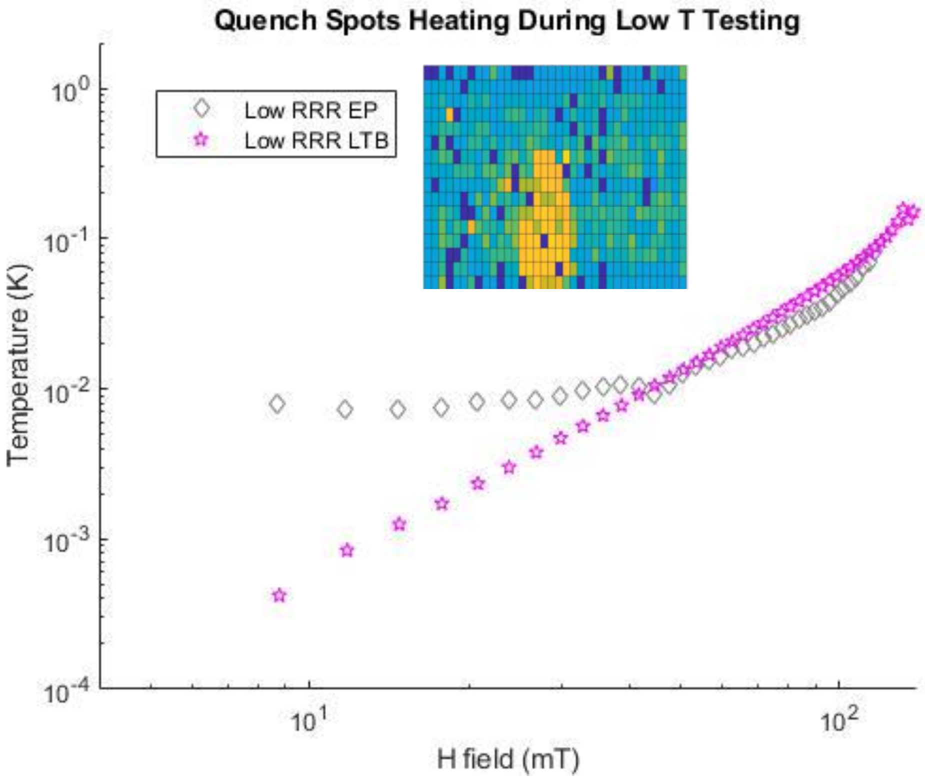
EP: Change in slope corresponds to onset of HFQS



Comparing Quench Spot Heating Profiles

EP: Change in slope corresponds to onset of HFQS

LTB: Delay in Q-slope means we do not see onset of additional losses



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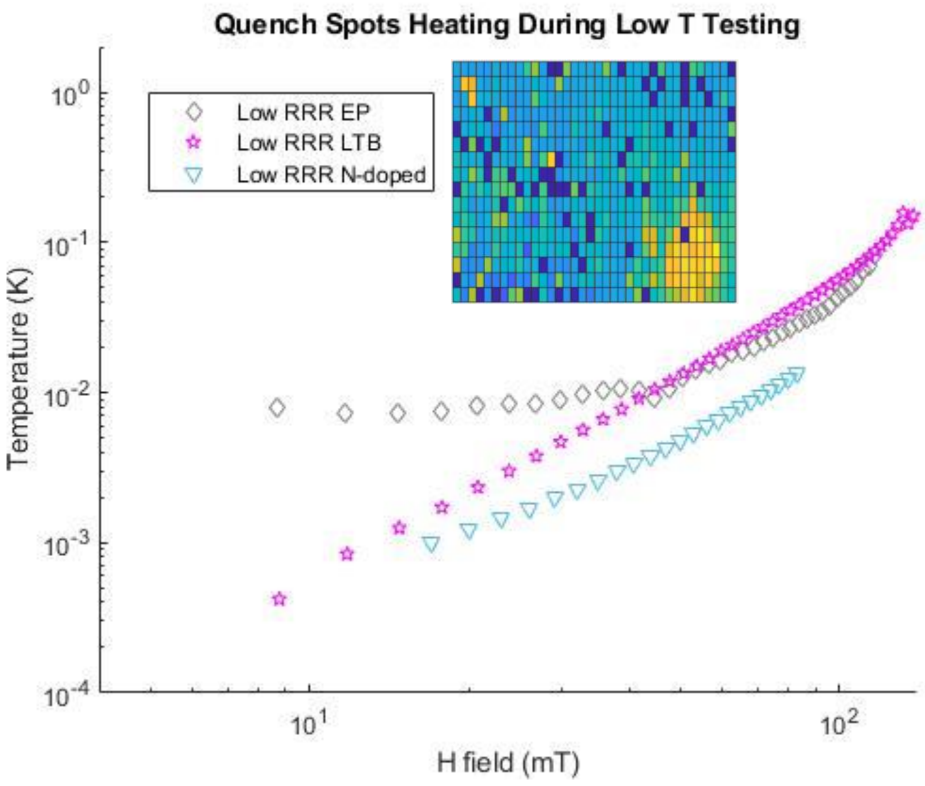
N-Doped: quench of magnetic origin so we do not see change in heating slope



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EP: Change in slope corresponds to onset of HFQS

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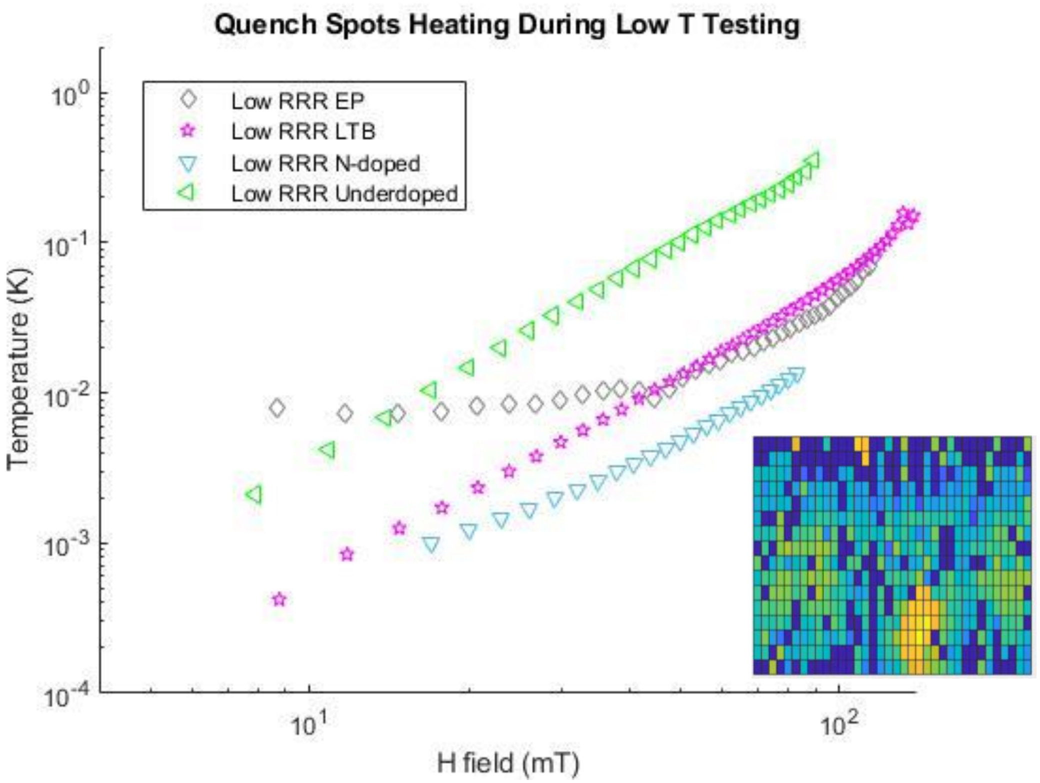
Underdoped: Large heating corresponds to large losses



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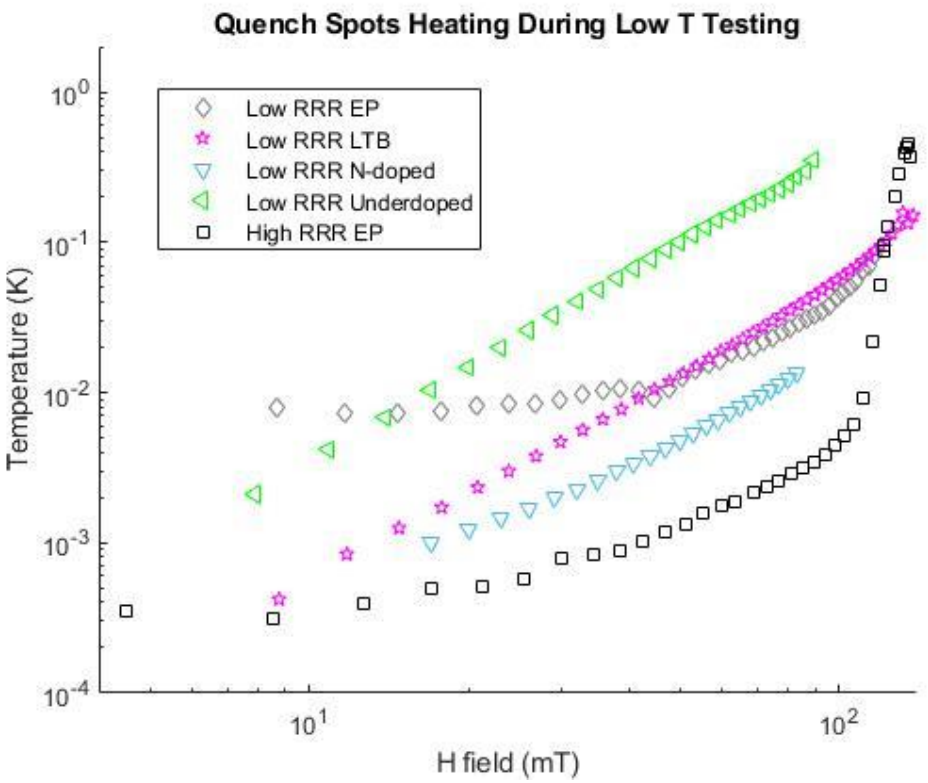
Underdoped: Large heating corresponds to large losses

Compare against high RRR EP:

- **Lower initial heating due to low impurity concentration**
- **Sharper change in slope than low RRR EP because of stronger HFQS onset (thermal quench)**



Cavity Performance Summary

- Lower quality factors but reach similar gradients
  - ~1.5e10 at ~20 MV/m for 2K
- Larger heating at quench locations but less sudden changes in slope
  - More magnetic quench behavior (less thermal)
- Combined effects of intrinsic and extrinsic impurities

Next Steps

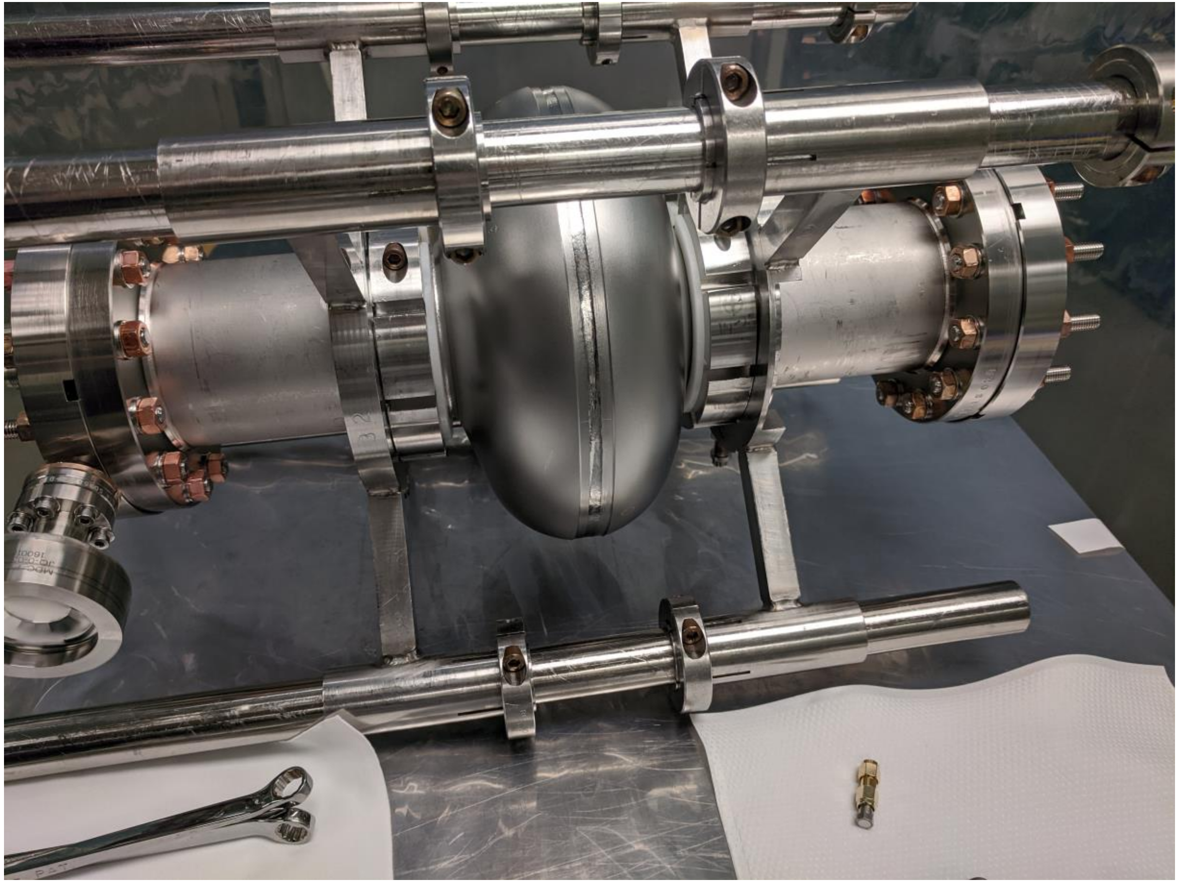
- Sample Study: identifying key impurity
- Calculation of mean free path from frequency vs temperature data
- N-infusion cavity testing and sample study

Discussion Topics

- How was RRR determined and how can we remeasure?
  - Cell material from Tokyo Denkai (Ta Wt % .0193, RRR = 61)
- How might oxygen and nitrogen behave differently in a Nb lattice with more impurities?
- How can intrinsic impurities affect the sensitivity to trapped flux?
  - Especially in N-doped and underdoped

This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics. This work was supported by the University of Chicago.

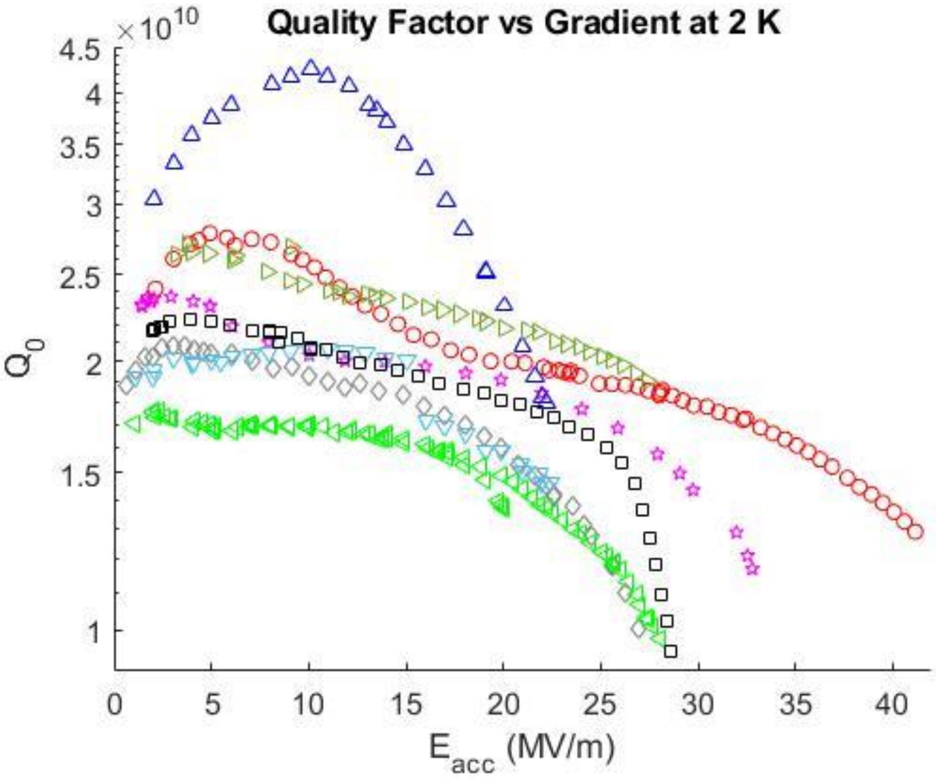
Extra Slides



Quality Factor vs Accelerating Gradient at 2 K

- **Performance of EP, LTB, and N-doped are similar at medium gradients**
- **LTB delays Q_0 slope and reaches highest Q_0 and gradient**
- **N-doping reaches lowest gradient**
- **Underdoped has lowest Q_0**

	Low RRR	High RRR
EP	◇	□
LTB	☆	○
N-doped	▽	△
Underdoped	◁	▷

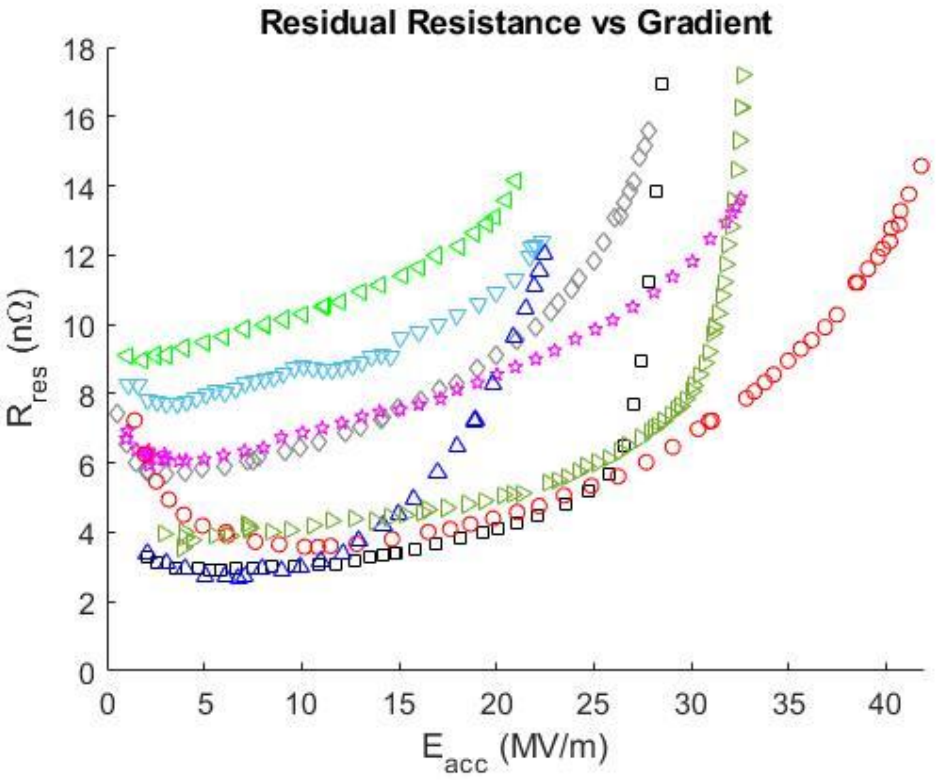


Residual Resistance vs Accelerating Gradient

$$R_{res} = \frac{G = 270\ \Omega}{Q_0(low\ T)}$$

- **Low RRR EP and LTB R_r equal at low and mid fields**
- **LTB treatment enables smallest increase with gradient**
- **N-doped R_r always slightly larger than EP and LTB**
- **Underdoped shows increase from N-doped**

	Low RRR	High RRR
EP	◇	□
LTB	☆	○
N-doped	▽	△
Underdoped	◁	▷



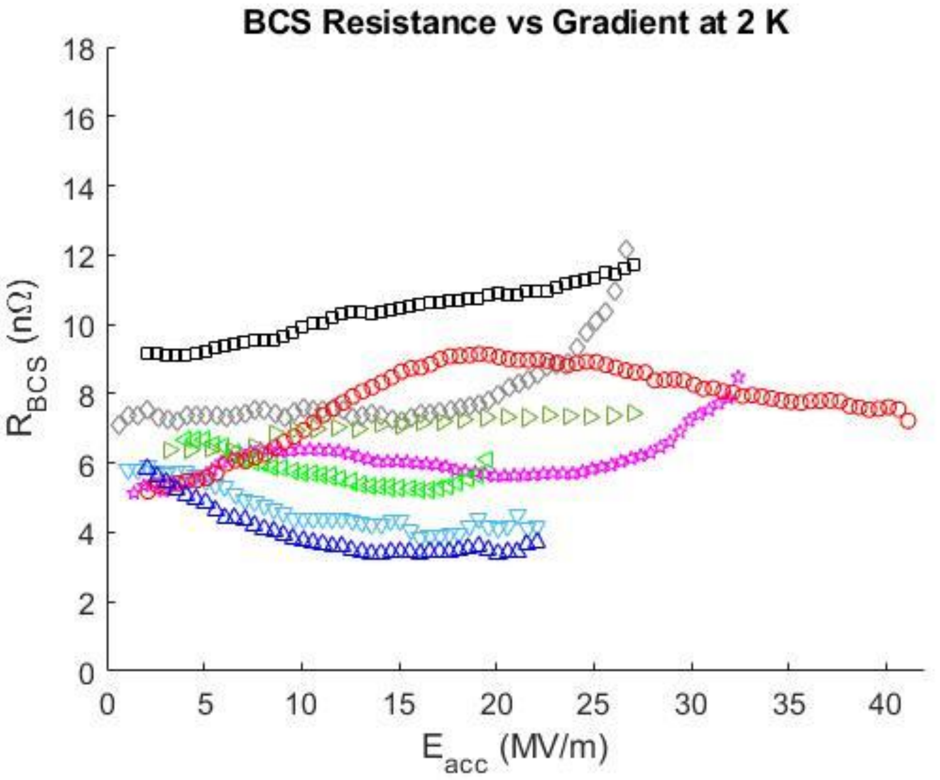
BCS Resistance vs Accelerating Gradient

$$R_{BCS}(2\ K) = R_s(2\ K) - R_{res}$$

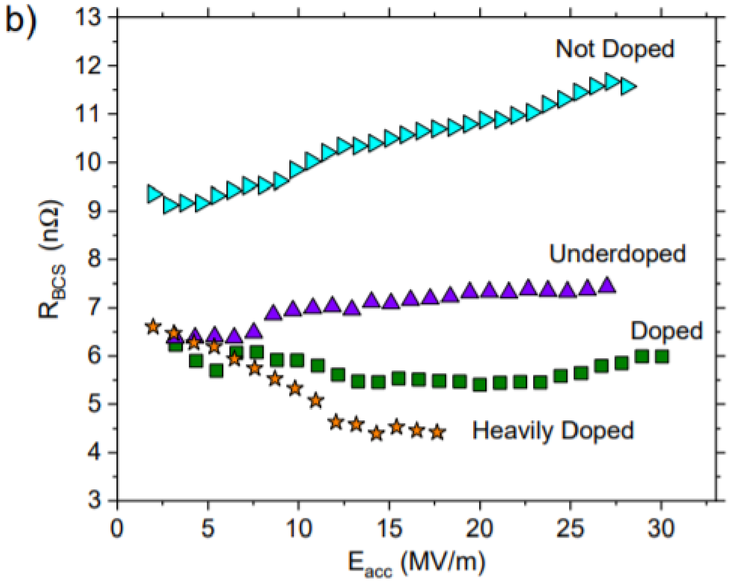
Low RRR exhibits low BCS behavior

- **Low RRR R_{BCS} is lowest at mid field**
- **Any benefit of dirty surface is lost at high field in EP and LTB**
- **N-doped has lower R_{BCS} than EP and LTB**

	Low RRR	High RRR
EP	◇	□
LTB	☆	○
N-doped	▽	△
Underdoped	◁	▷

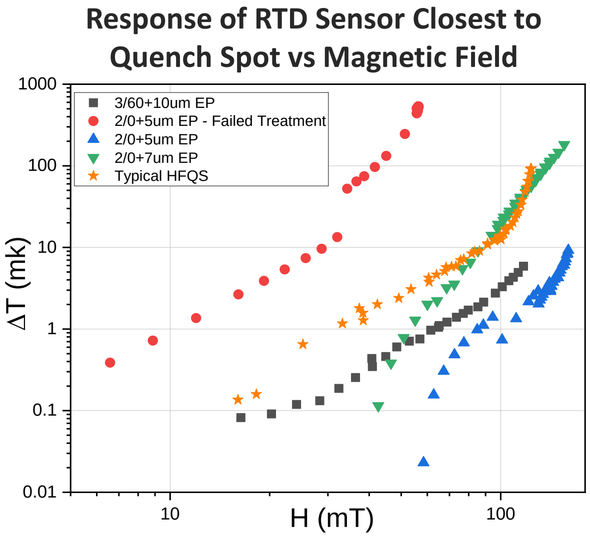


Effect of Doping Severity



N-doping severity effect on BCS resistance

Daniel Bafia's Thesis Fig 6.7b



N-doping severity effect on heating at quench spots

Daniel Bafia TTC'20