The Collaborative Effects of Intrinsic and Extrinsic Impurities in Low RRR SRF Cavities

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Motivation

- Many SRF studies follow a "clean bulk dirty surface" technique to optimize the BCS resistance by adding extrinsic impurities
- What role do intrinsic impurities serve?
  - Lower the mean free path
  - Might perform similar functions as extrinsic impurities
- Understanding of intrinsic impurities will enable future high Q_0/high gradient surface treatments

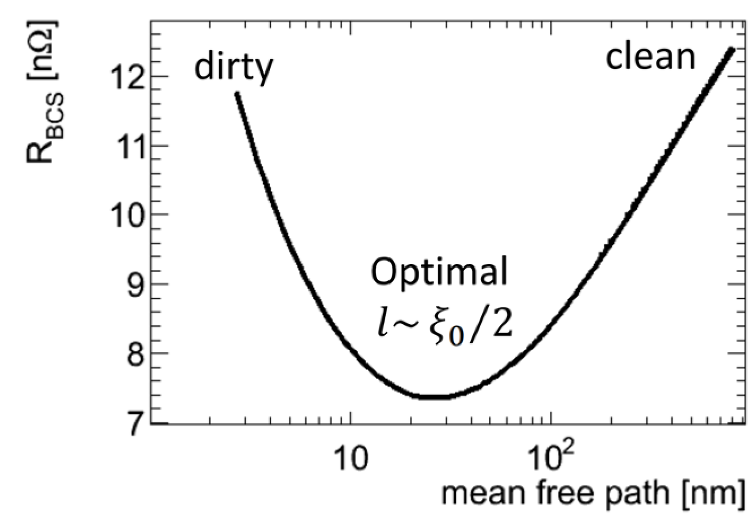
RRR = Residual Resistance Ratio

- Ratio between DC resistivity of material at room temperature to its residual value at low temperature
- RRR ∝ mean free path
- High RRR for SRF is ~300
- RRR is lowered by impurities in the Nb

$$Q_0 = \frac{G}{R_s} \sim$$ Number of oscillations to dissipate stored energy

$$R_s(T) = R_{res}(< 1.5\ K) + R_{BCS}(T)$$

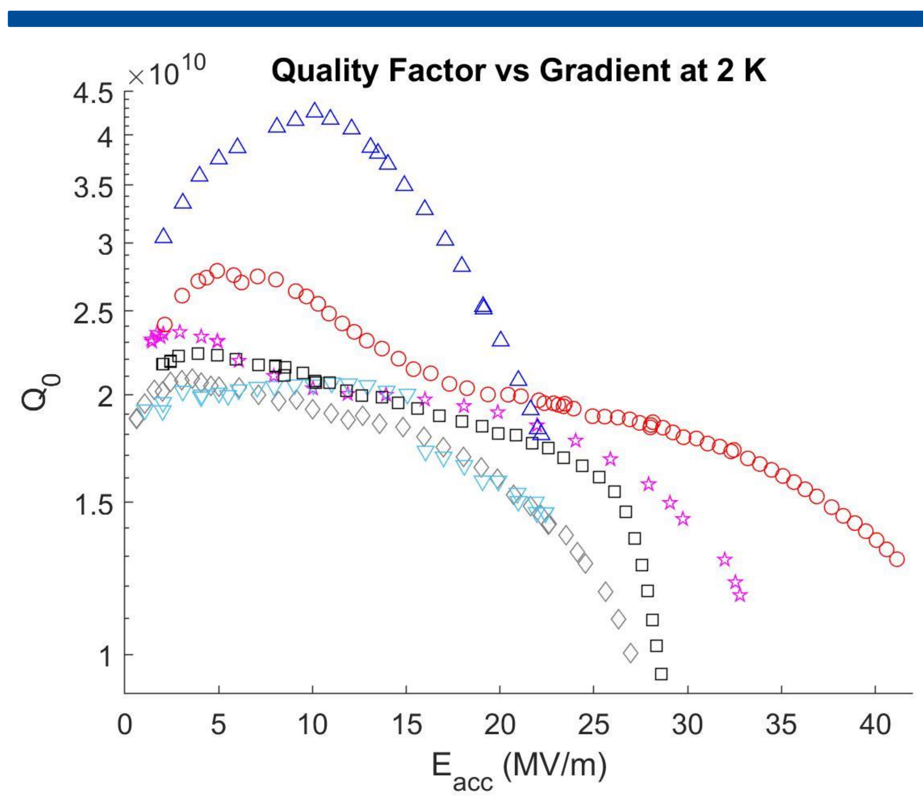
Temperature Independent (R_{res}) — Temperature Dependent (R_{BCS})



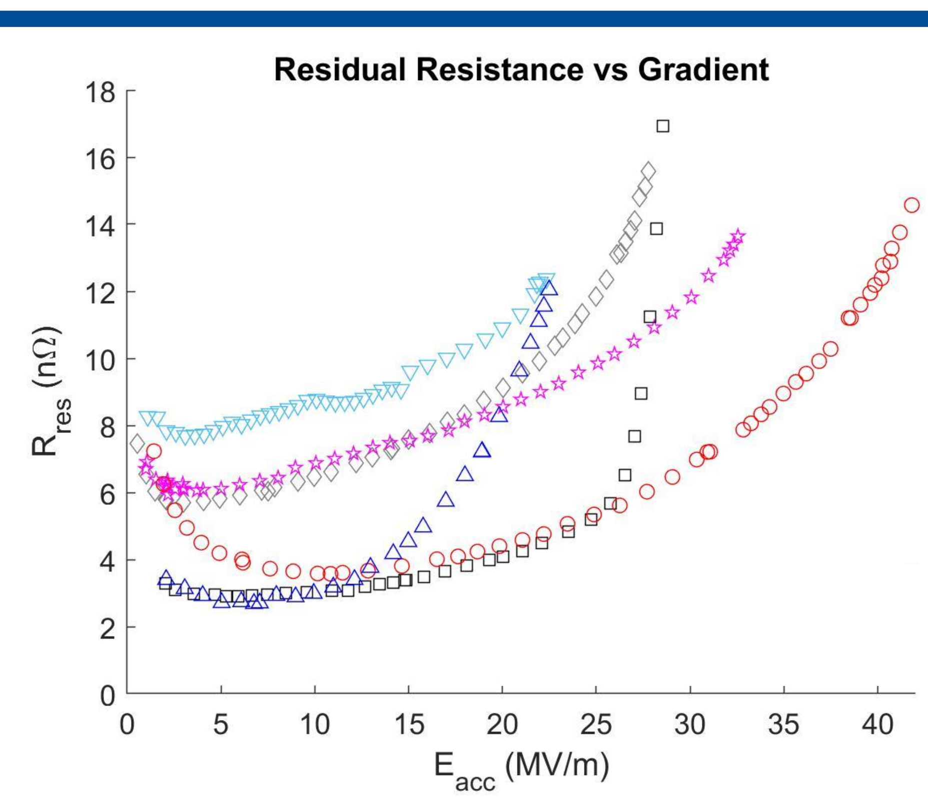
Optimization of BCS resistance versus mean free path https://indico.frib.msu.edu/event/38/attachments/159/1139/SRF2021_lecture_miyazaki_ver4.pdf

Experiment

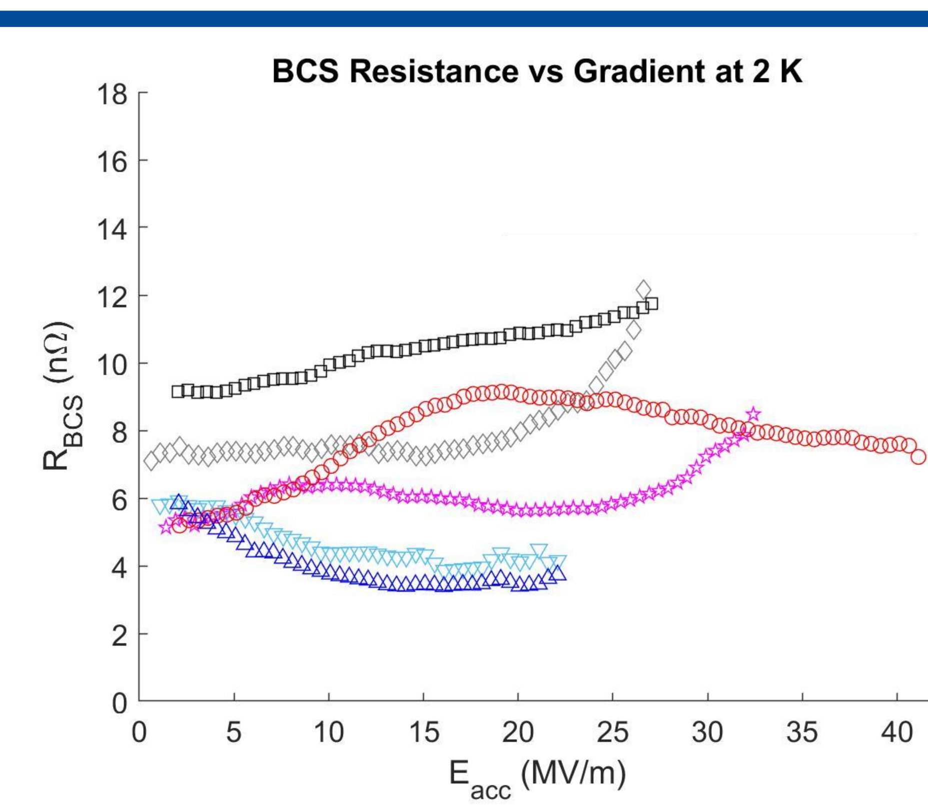
- RF testing on 1.3 GHz single-cell TESLA-shaped low RRR (= 61) cavity in electropolished (EP) condition
  - Quality factor vs gradient
- Repeat testing after:
  - Low temperature bake (LTB) 120 °C x 48 hours
  - N-doping 2/6+5 μm recipe
- Sample study on low RRR coupons
  - Secondary ion mass spectrometry (SIMS)



- Low RRR < high RRR
- Low RRR shows less dramatic response to surface treatments
  - Weakened Q_0 slope suggests intrinsic impurities may capture free H



- Low RRR > high RRR
  - Oxide structure may be different
  - Intrinsic impurities may drive additional loss
- Low RRR: N-doped > EP ≈ LTB
- LTB enables smallest increase with gradient



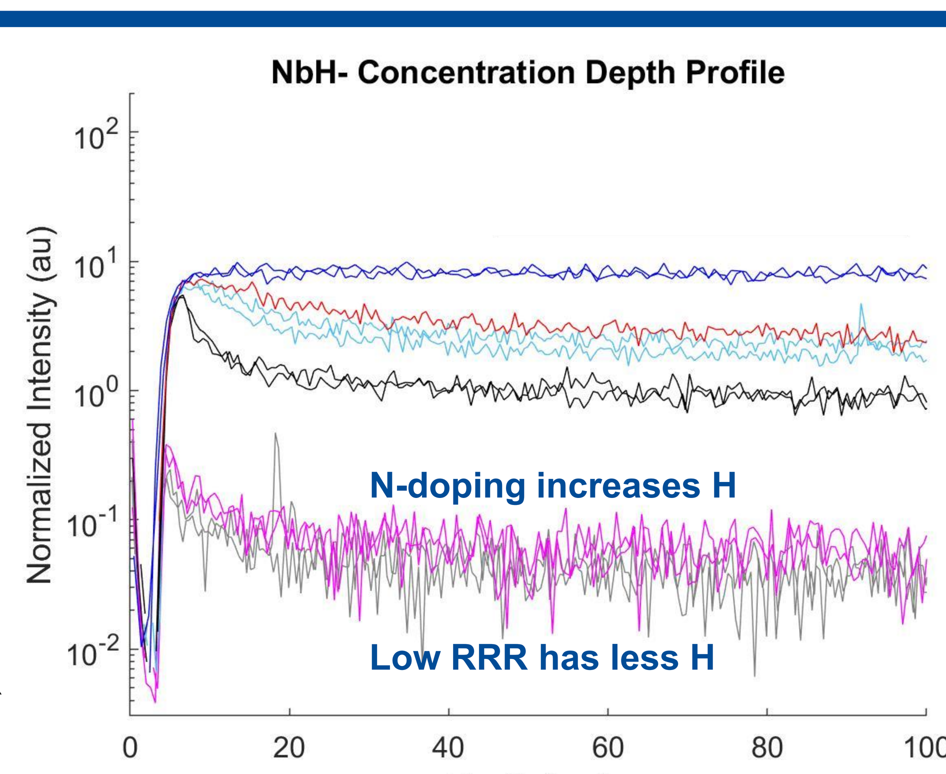
- Low RRR EP < high RRR EP
- Low RRR LTB < high RRR LTB
- Low RRR N-doped ≈ high RRR N doped
- N-doped has lower BCS than EP and LTB

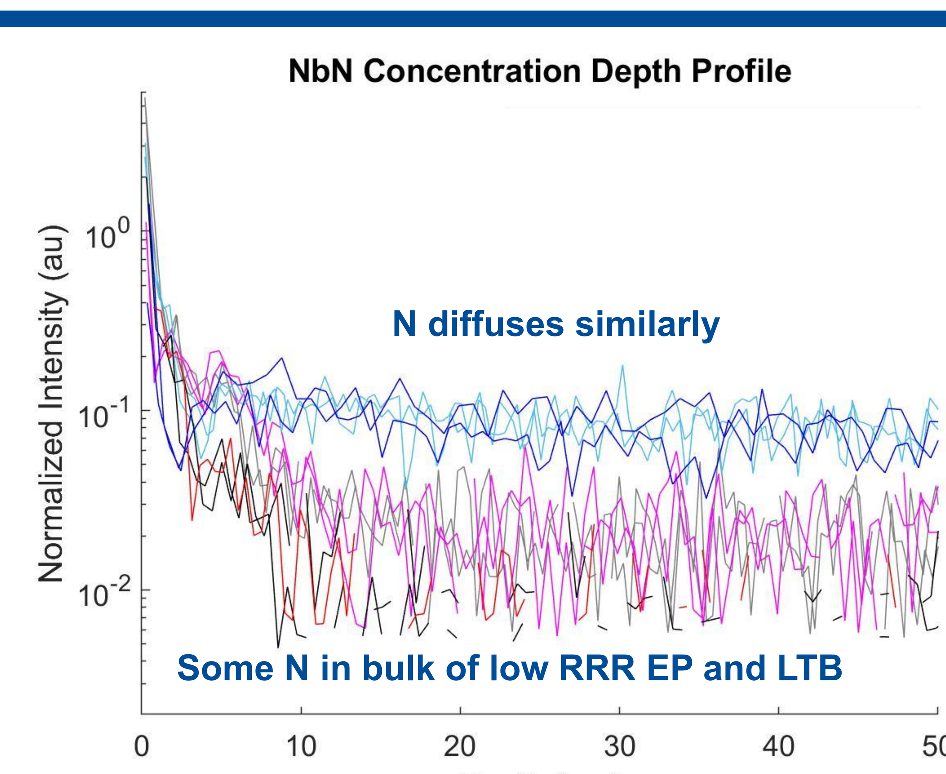
Legend	Low RRR	High RRR
EP	◇	□
LTB	☆	○
N-doped	▽	△

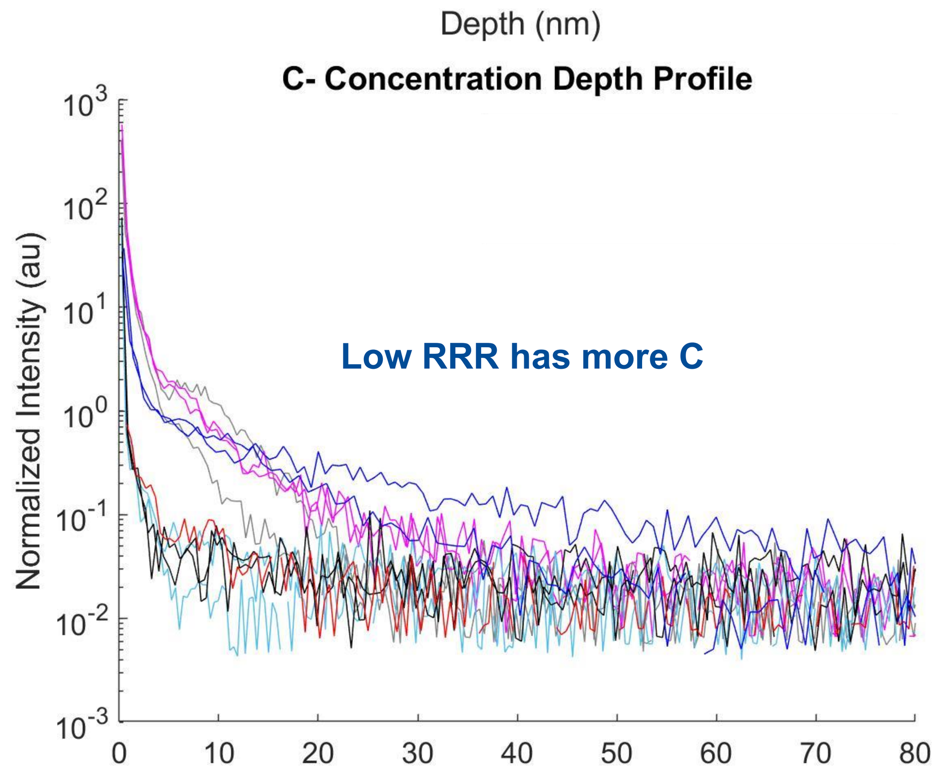
Impurity Profiles

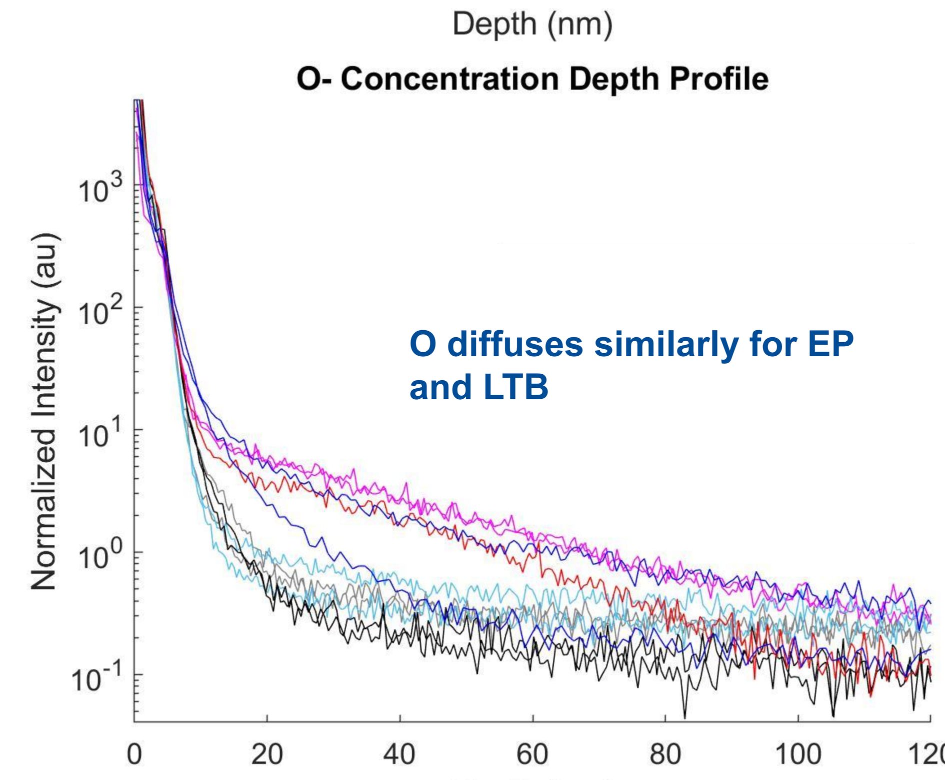
- Normalized y axis by Nb signal
- Normalized x axis by Nb_2O_5 signal
- Low RRR has less free H
- O profiles do not explain difference in LTB tests
- No obvious impurities which explain the much lower RRR
  - Something else may govern RRR

Legend	Low RRR	High RRR
EP	—	—
LTB	—	—
N-doped	—	—









Conclusions

- Low RRR shows:
  - High residual resistance
  - Low BCS resistance
  - Similar diffusion of O and N
- Low RRR in EP and LTB conditions behave differently than high RRR
  - O signals nearly identical, so there must be intrinsic impurities that decrease BCS
  - Combination of O and intrinsic impurities enables higher Q_0 and gradients
- N-doping is a robust treatment in different purity SRF cavities
  - Similar BCS resistance
  - Similar diffusion
  - Further studies needed to understand heightened NbH- signal
  - Low RRR appears sensitive to trapped flux

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