Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

Possible Field Dependence of Superconducting Properties in N-Doped Cavities

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Outline

- Deconvolution of R_{res} and R_{BCS}
- Fitting of field dependent data:
  - Exponential fitting
  - BCS fitting with SRIMP
  - Fitting with Xiao code
- Magnetic Field Studies
- Conclusions

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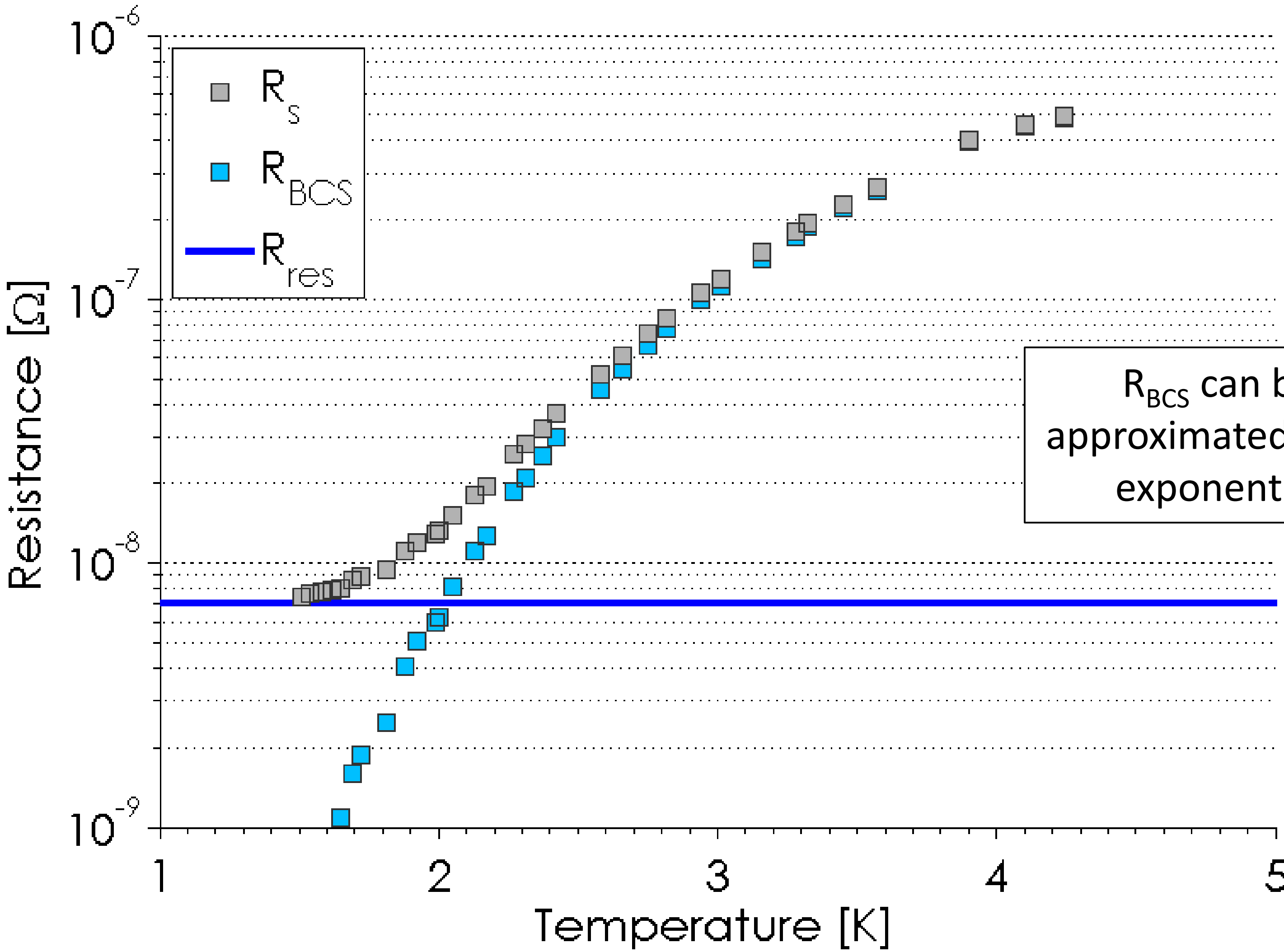
Surface Resistance



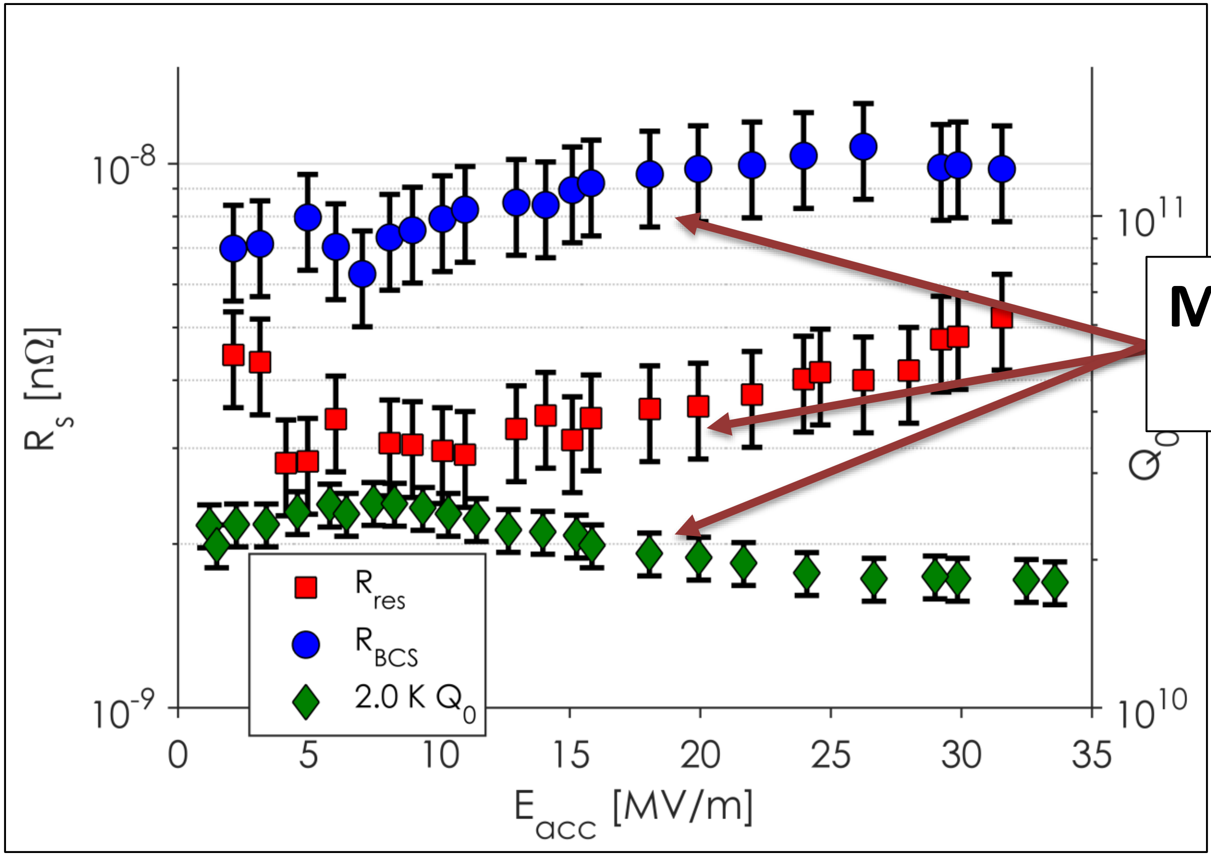
R_{BCS} can be approximated as an exponential

Deconvolution of R_{res} and R_{BCS}

Both R_{res} and R_{BCS} have been shown to be field dependent:

$$R_s = R_{res}(E_{acc}) + R_{BCS}(E_{acc}, T)$$

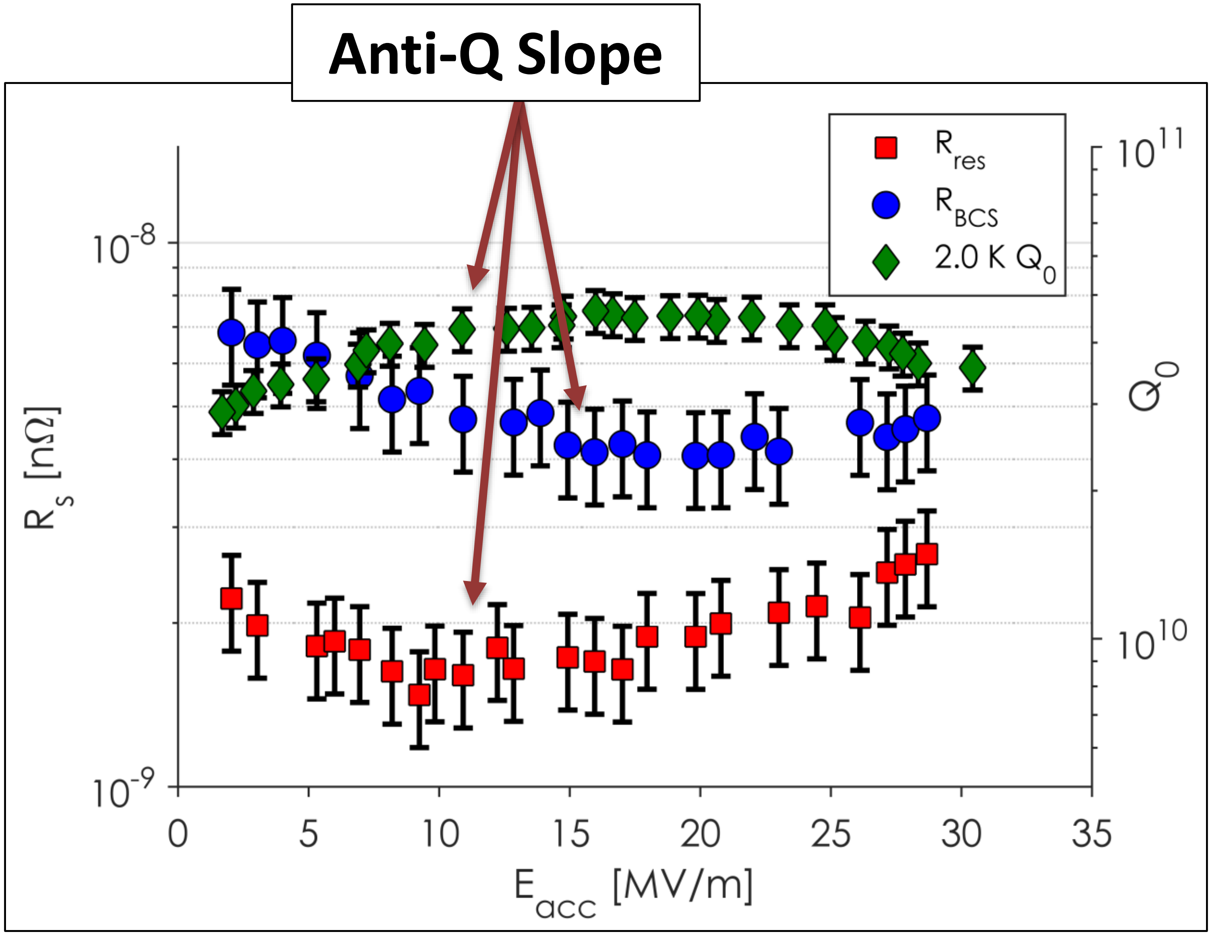
Deconvolution in 120ºC Cavities



Medium Field Q Slope

Medium field Q slope caused by a combination of increasing residual and BCS resistances in 120ºC baked cavities

Deconvolution in N-Doped Cavities



Anti-Q slope caused by a decreasing BCS resistance in N-Doped Cavities

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Exponential Fitting

The usual BCS equation for fitting:

$$R_{BCS} = \frac{A}{T} e^{-\epsilon / k_B T}$$

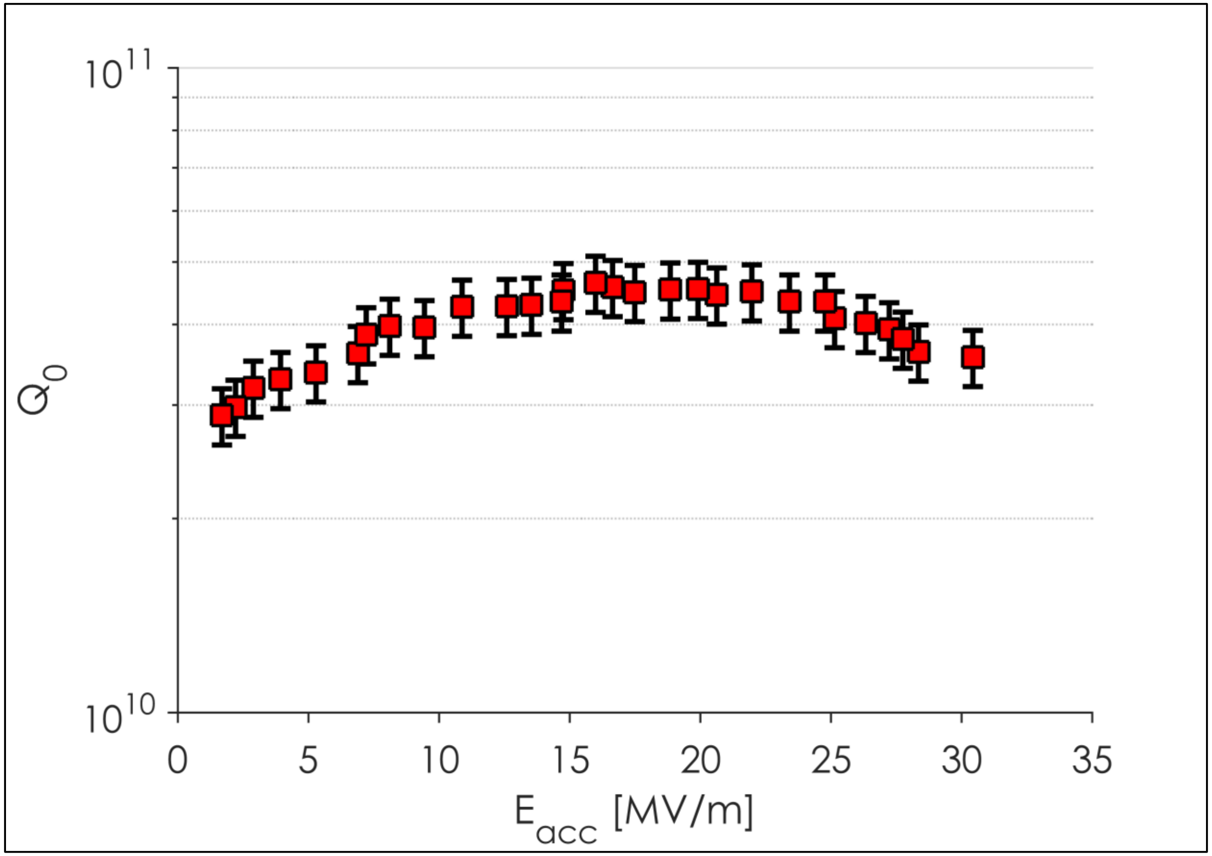
Both A and ε can vary with E_{acc} however fitting both together leads to sloppy fitting.

$$R_{BCS} = \frac{A(E_{acc})}{T} e^{-\epsilon / k_B T}$$

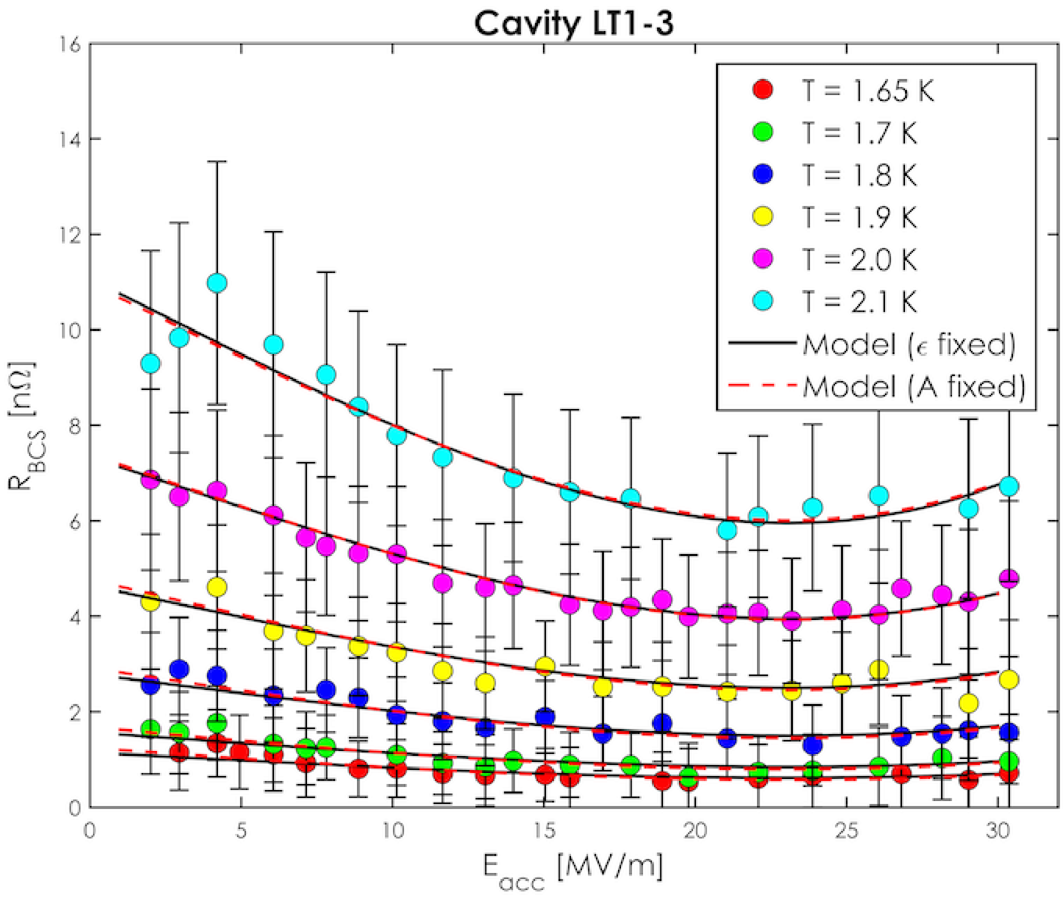
$$R_{BCS} = \frac{A}{T} e^{-\epsilon(E_{acc}) / k_B T}$$

Cavity LT1-3

1.3 GHz Single Cell ILC shaped cavity: bulk VEP, 800°C bake in vacuum for 3 hours, 20 min in 60 mTorr of N_2 for 20 minutes, 30 minute anneal, 12 µm VEP

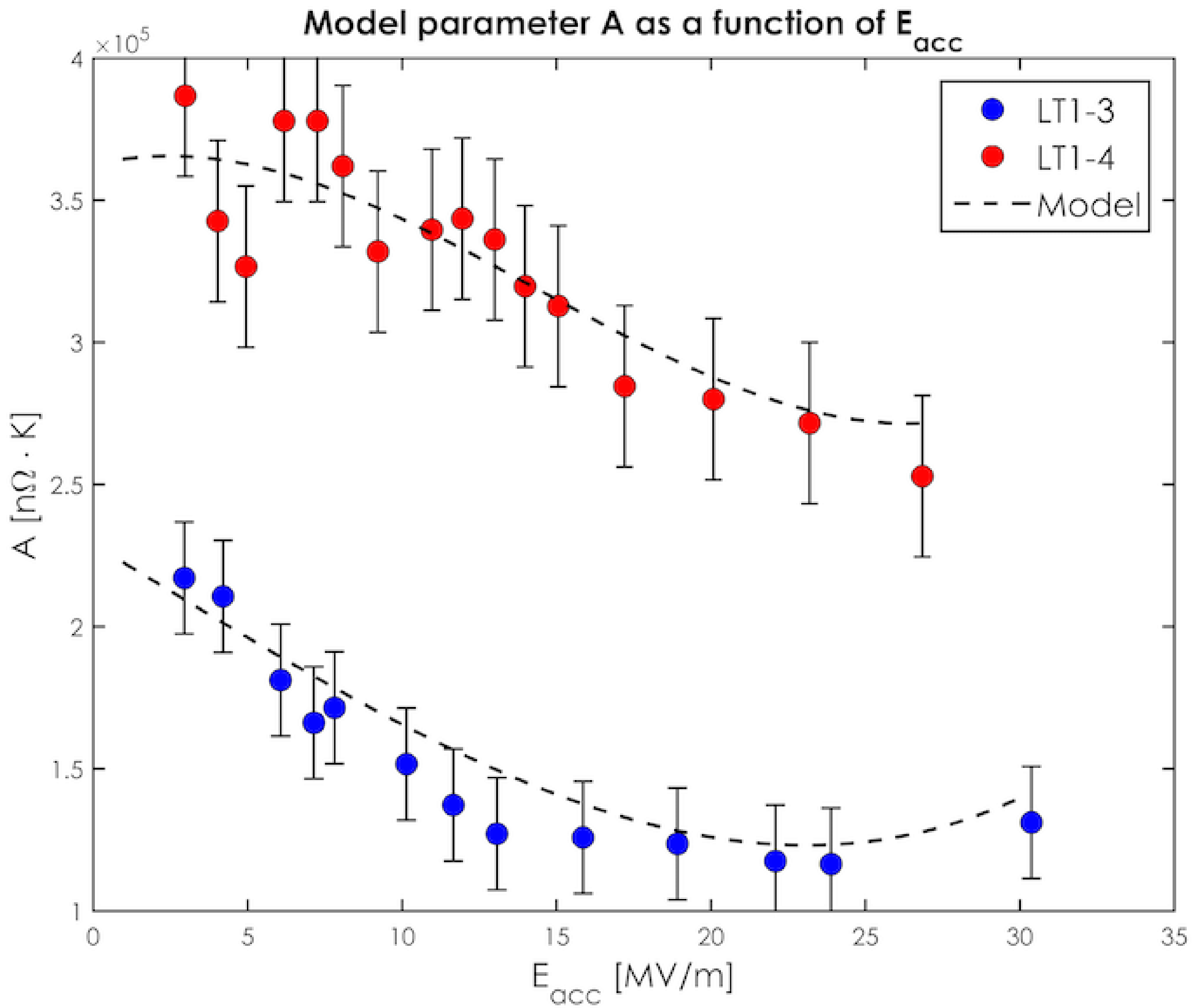


Exponential Fitting

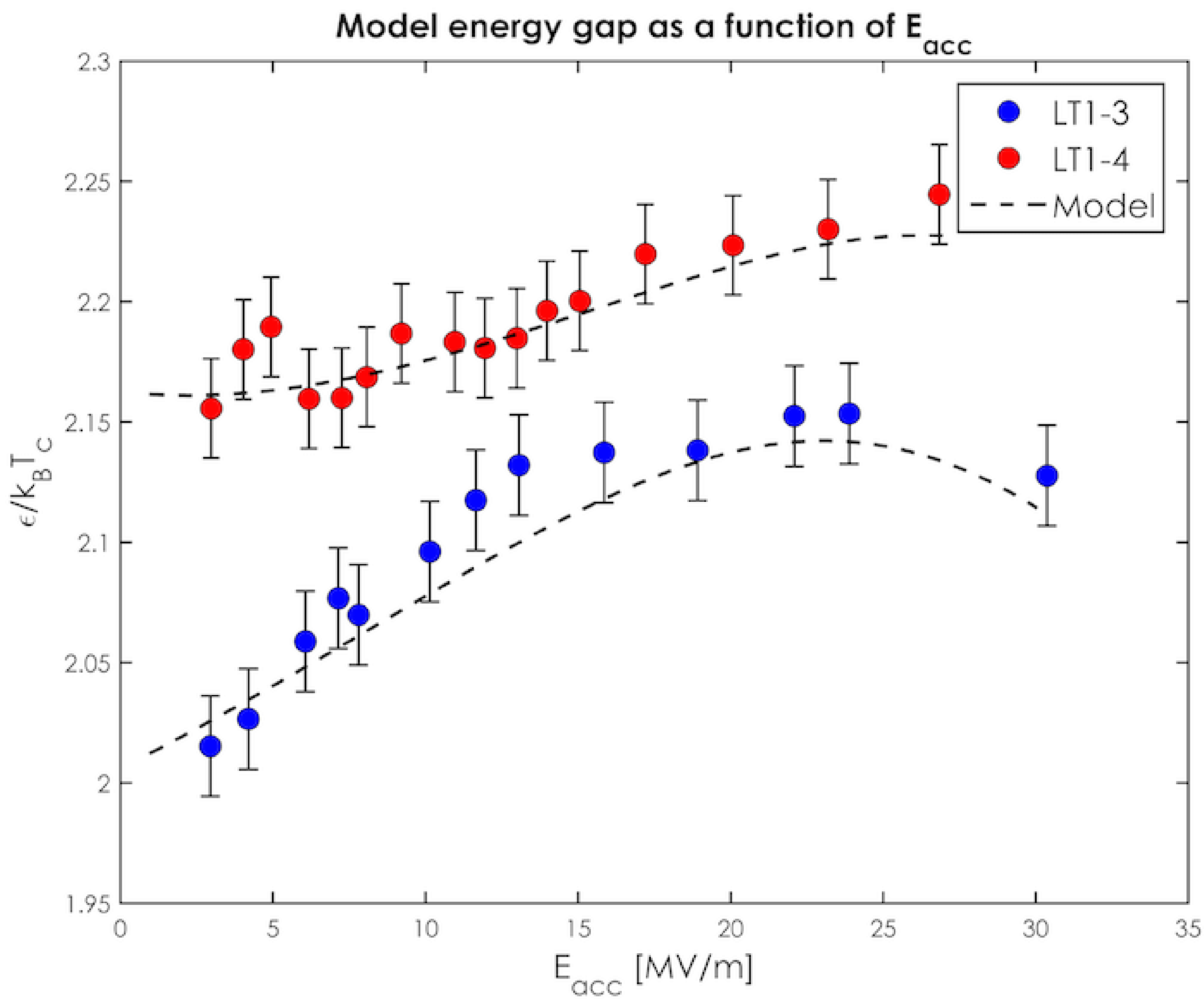


Both models can fit the R_{BCS} data well in the anti-Q slope region

Exponential Fitting



Exponential Fitting



Exponential Fitting

- Fits with both A and ε field dependent are sloppy
- Individual fits however can fit R_{BCS} vs E_{acc} data very well
- A decreasing A with field or an increasing ε can explain the anti-Q slope observed in N-doped cavities

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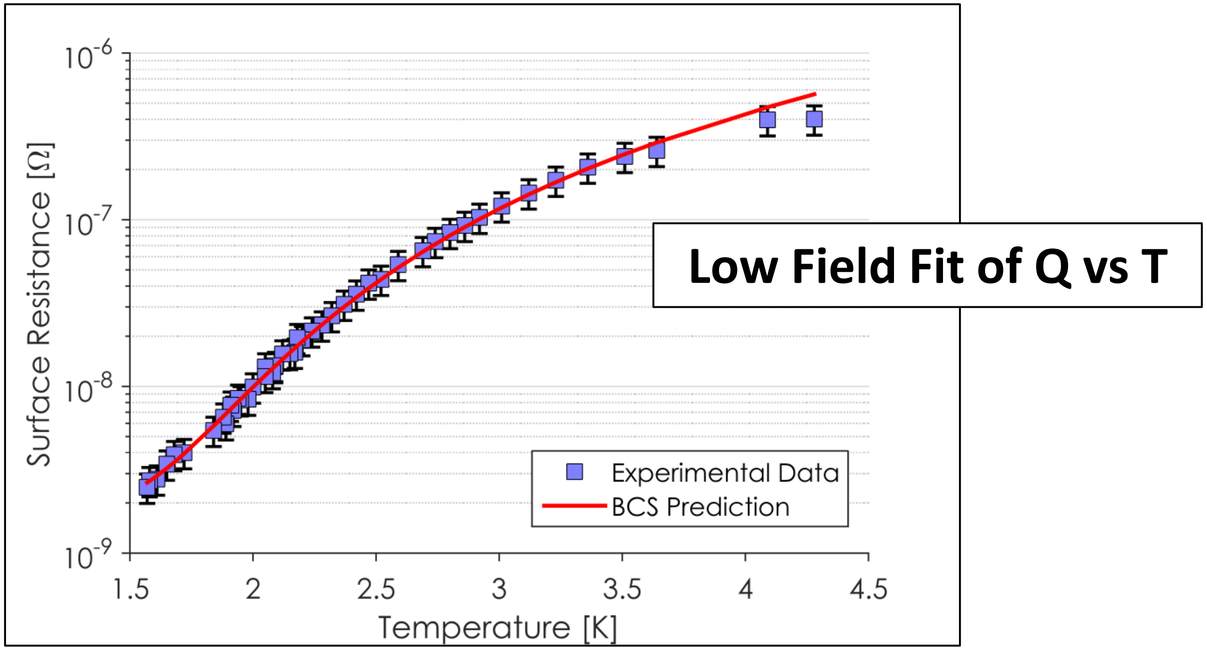
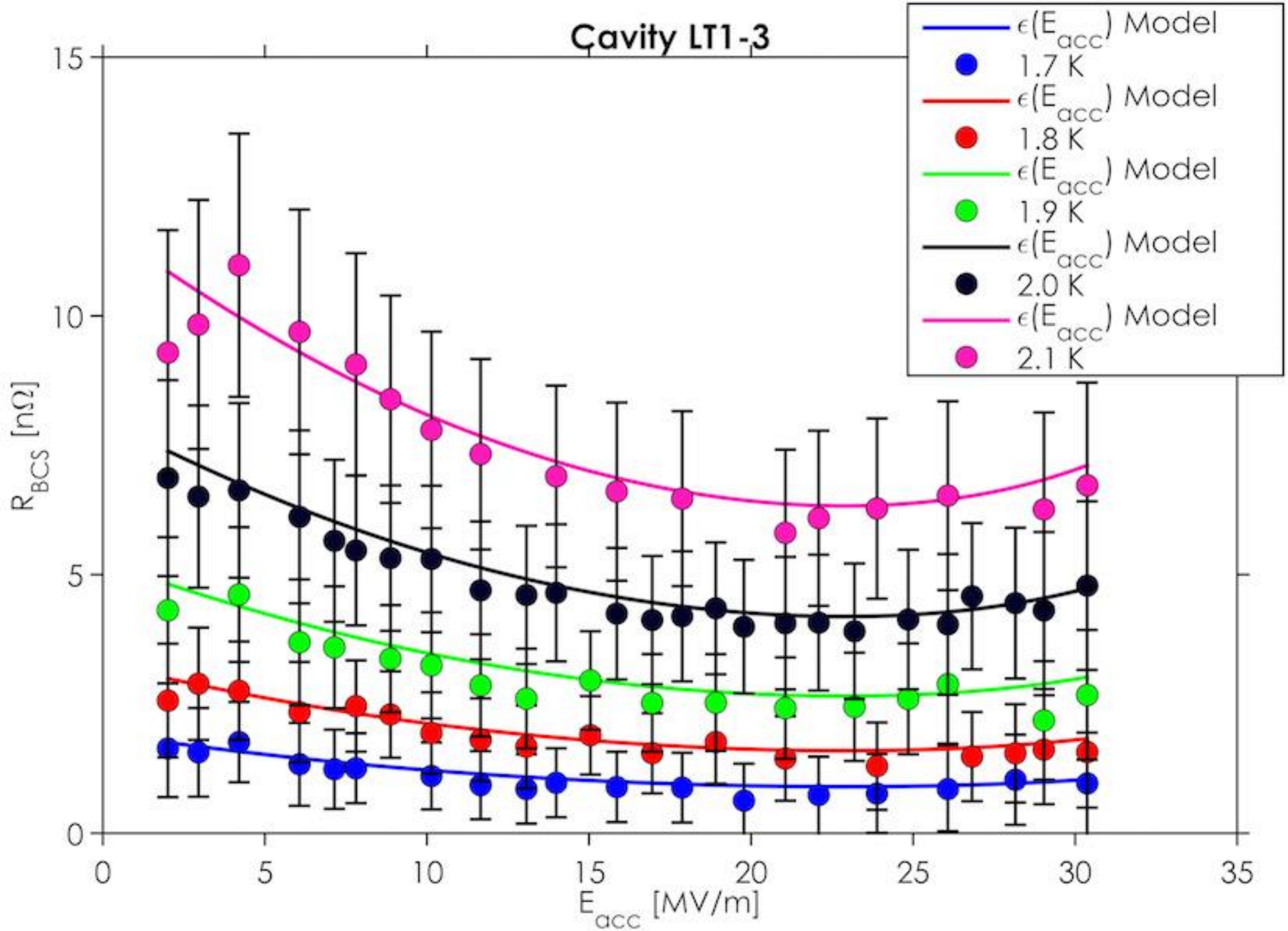
BCS Fitting with SRIMP

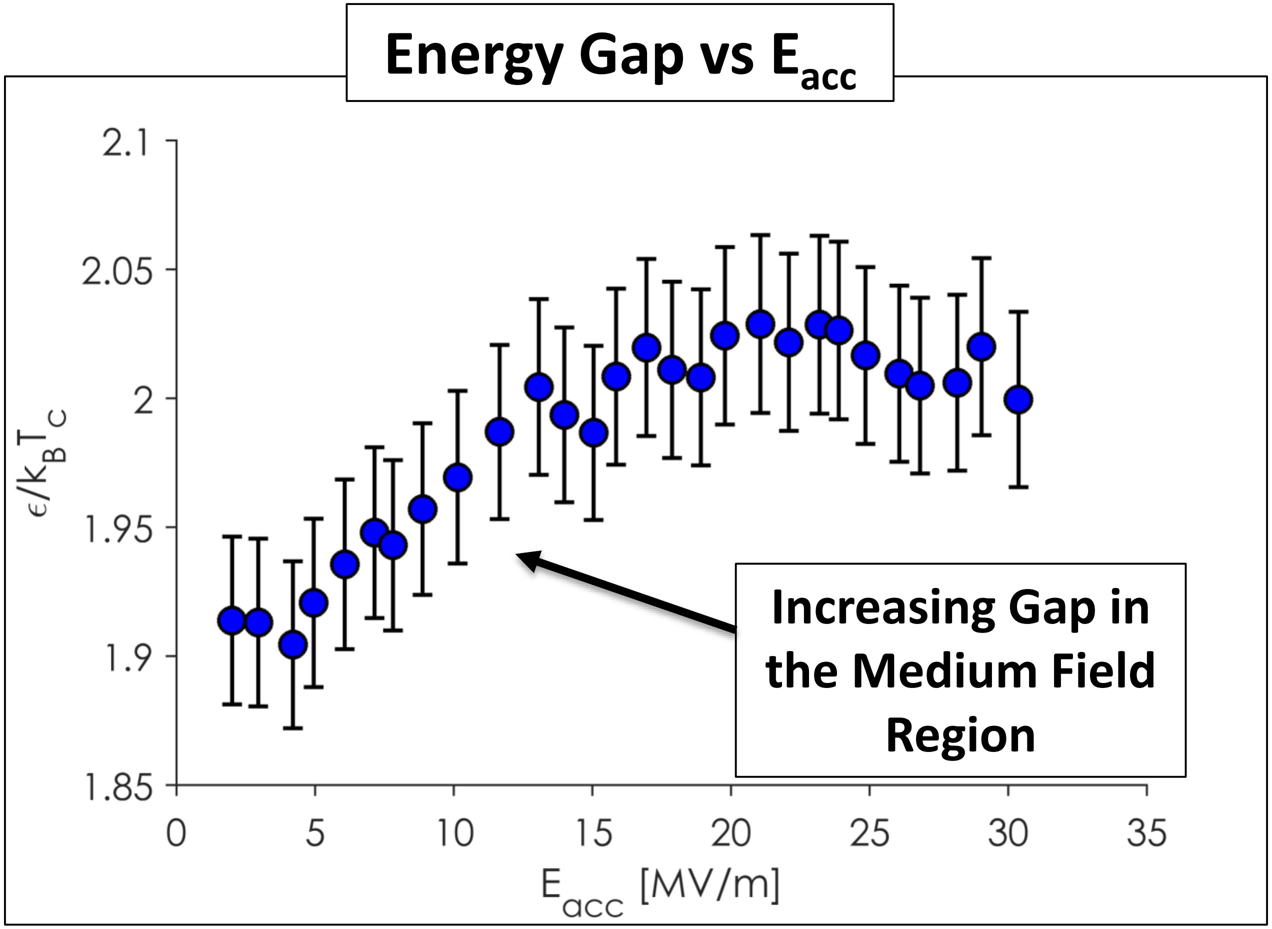
- SRIMP, a code written by Halbritter, can be used to calculate R_{BCS} based on material parameters
  - T_c, Mean Free Path, $\varepsilon/k_B T_c$, coherence length, and penetration depth



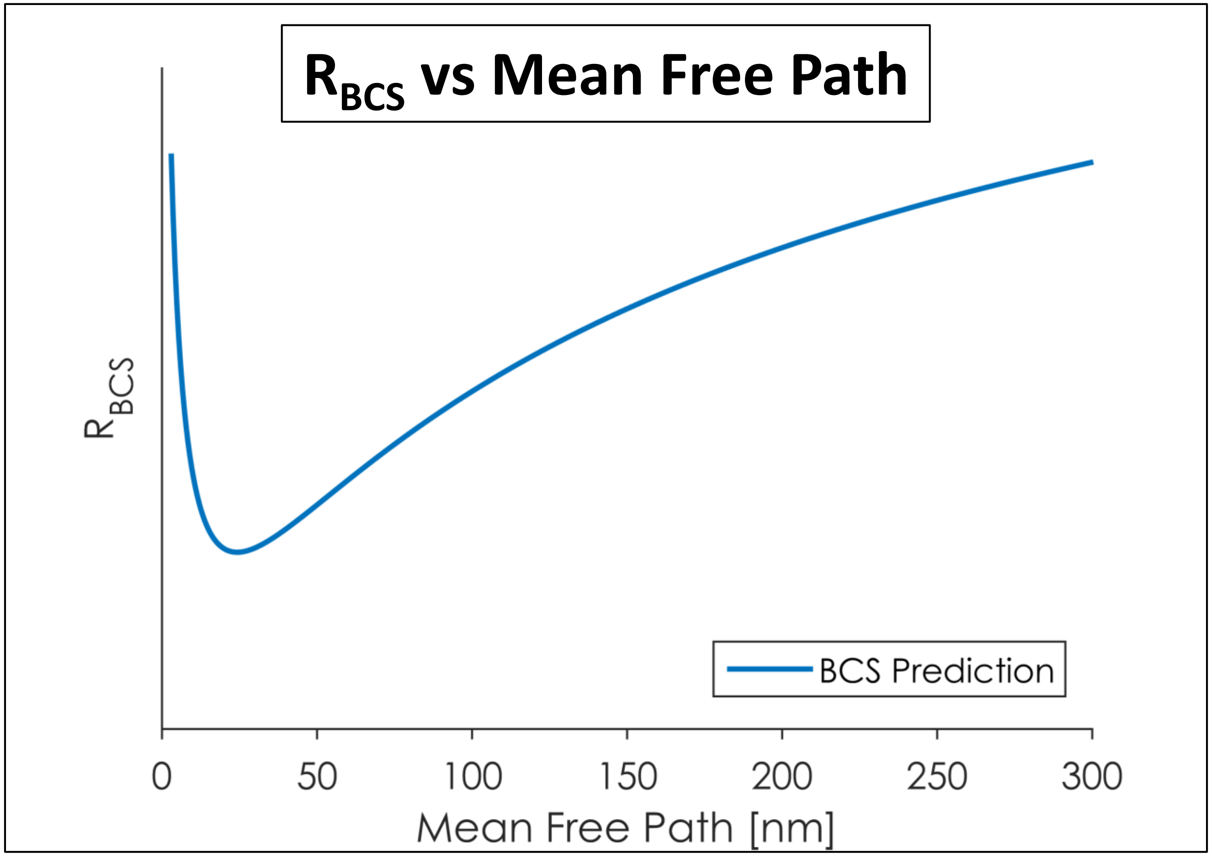
BCS Fitting with SRIMP



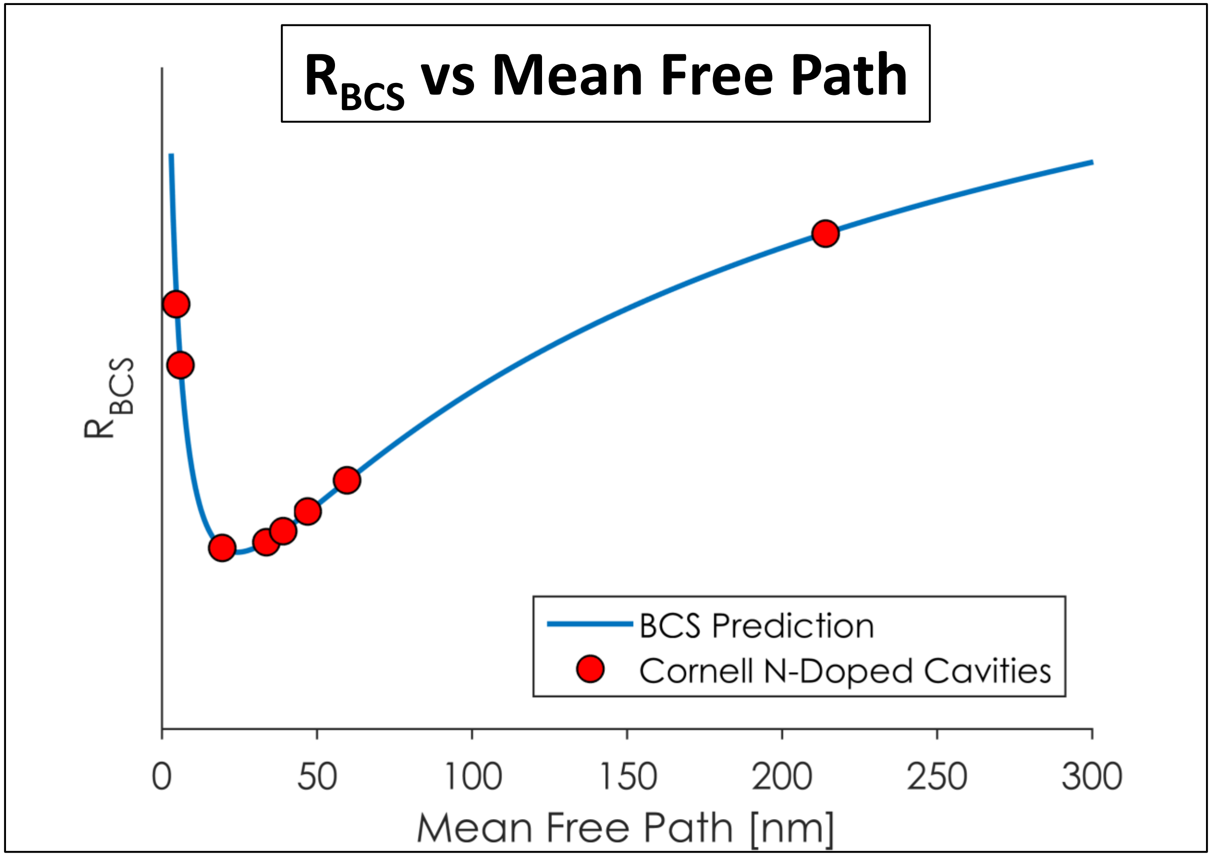
BCS Fitting with SRIMP



BCS Fitting with SRIMP



BCS Fitting with SRIMP



- N-Doped cavities are on both sides of the R_{BCS} vs Mean free path minimum
- Increasing or decreasing mean free path with field alone cannot explain the anti-Q slope

BCS Fitting with SRIMP

- Field dependence of BCS resistance in N-Doped cavities is related to the energy gap
- Nitrogen-doped cavities have mean free paths that are on both sides of the R_{BCS} vs mean free path minimum
  - An increasing or decreasing mean free path with accelerating field cannot explain a decreasing BCS resistance in all cavities

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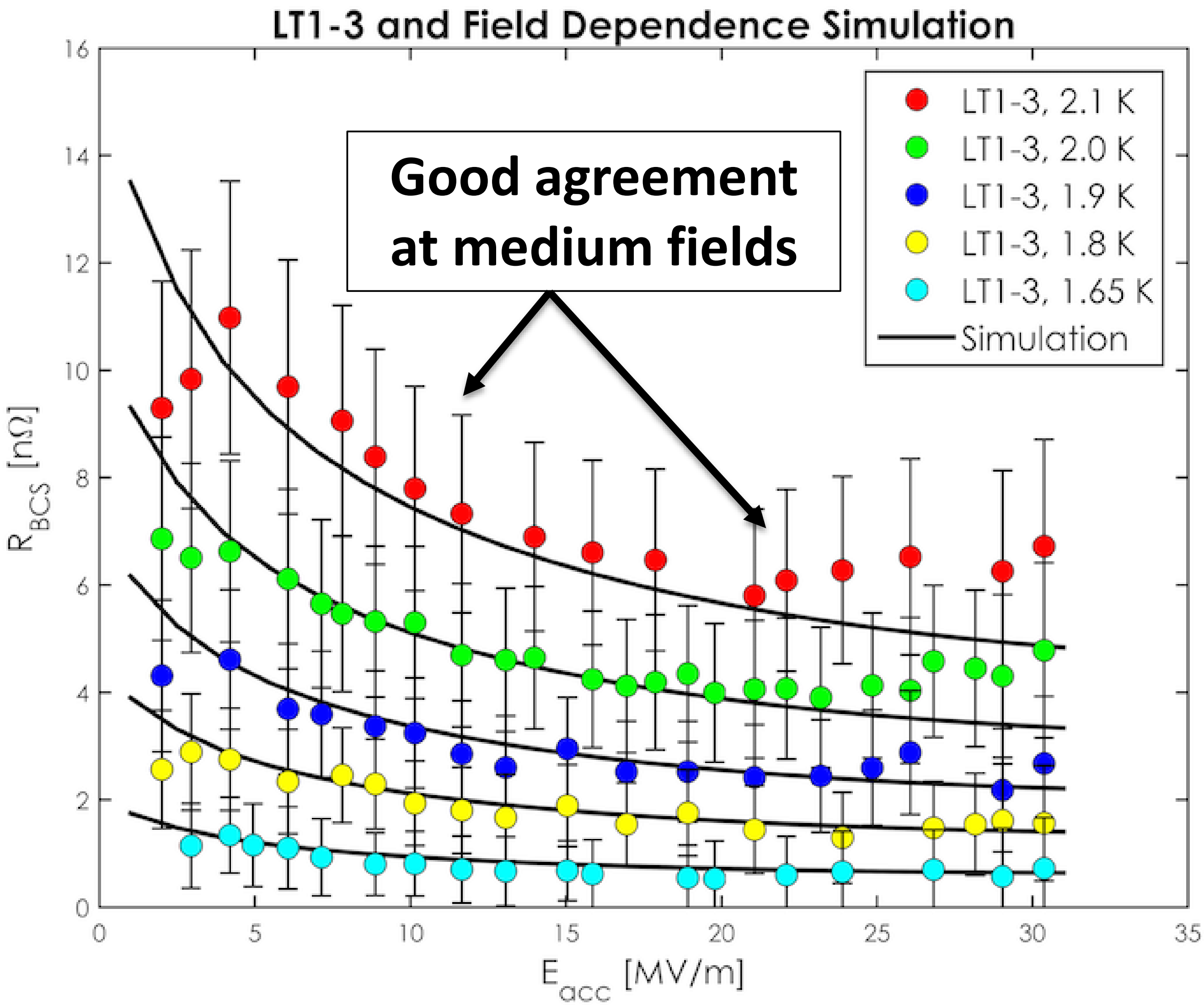
Fitting with Xiao Code

- Xiao et. al. developed a code to include field dependence in BCS theory using an extension of Mattis-Bardeen theory
- Using low field material parameters obtained from SRIMP fitting, the full field dependence of the BCS resistance can be computed at different temperatures

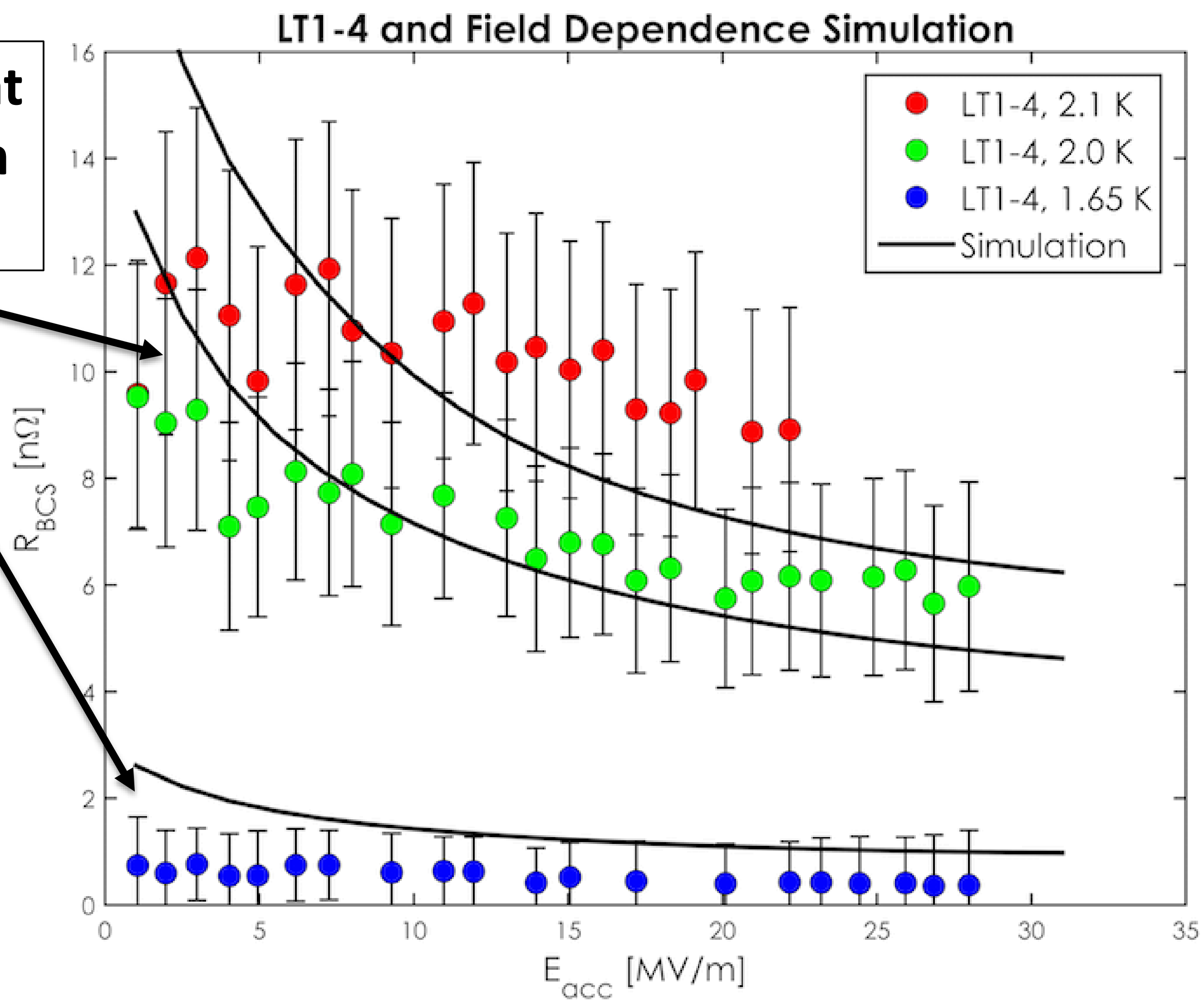
B. P. Xiao et. al. Superconducting surface resistance under radiofrequency field. Physica C, 490(0):26–31, 2013.

Fitting with Xiao Code



Fitting with Xiao Code

Poor agreement at medium and high fields



Fitting with Xiao Code

- Xiao code can accurately predict behavior of BCS resistance at medium fields in Nitrogen-doped cavities
- Theory deviates from observed behavior at low fields:
  - The theory predicts a much more drastic increase in BCS resistance than we observe

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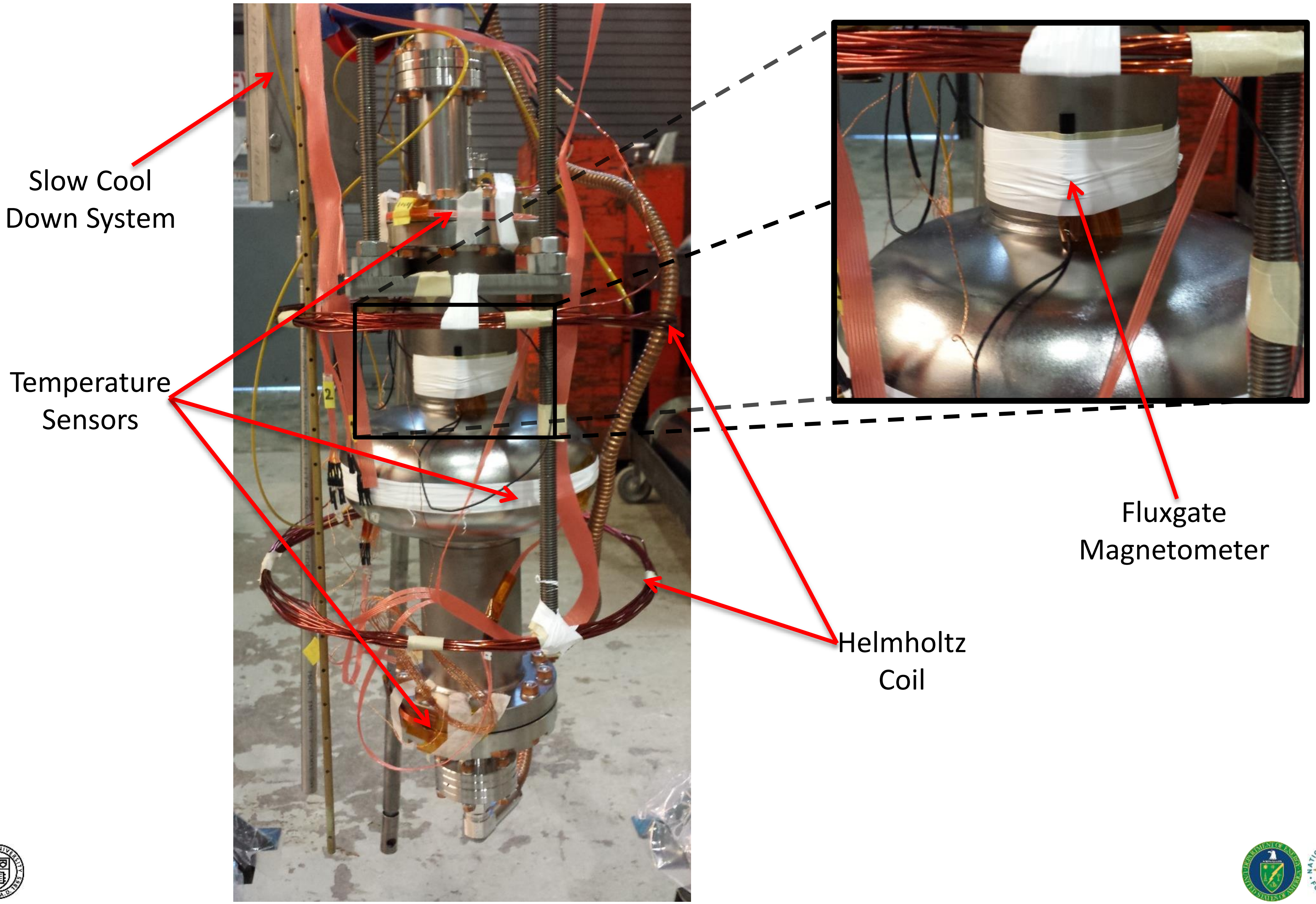
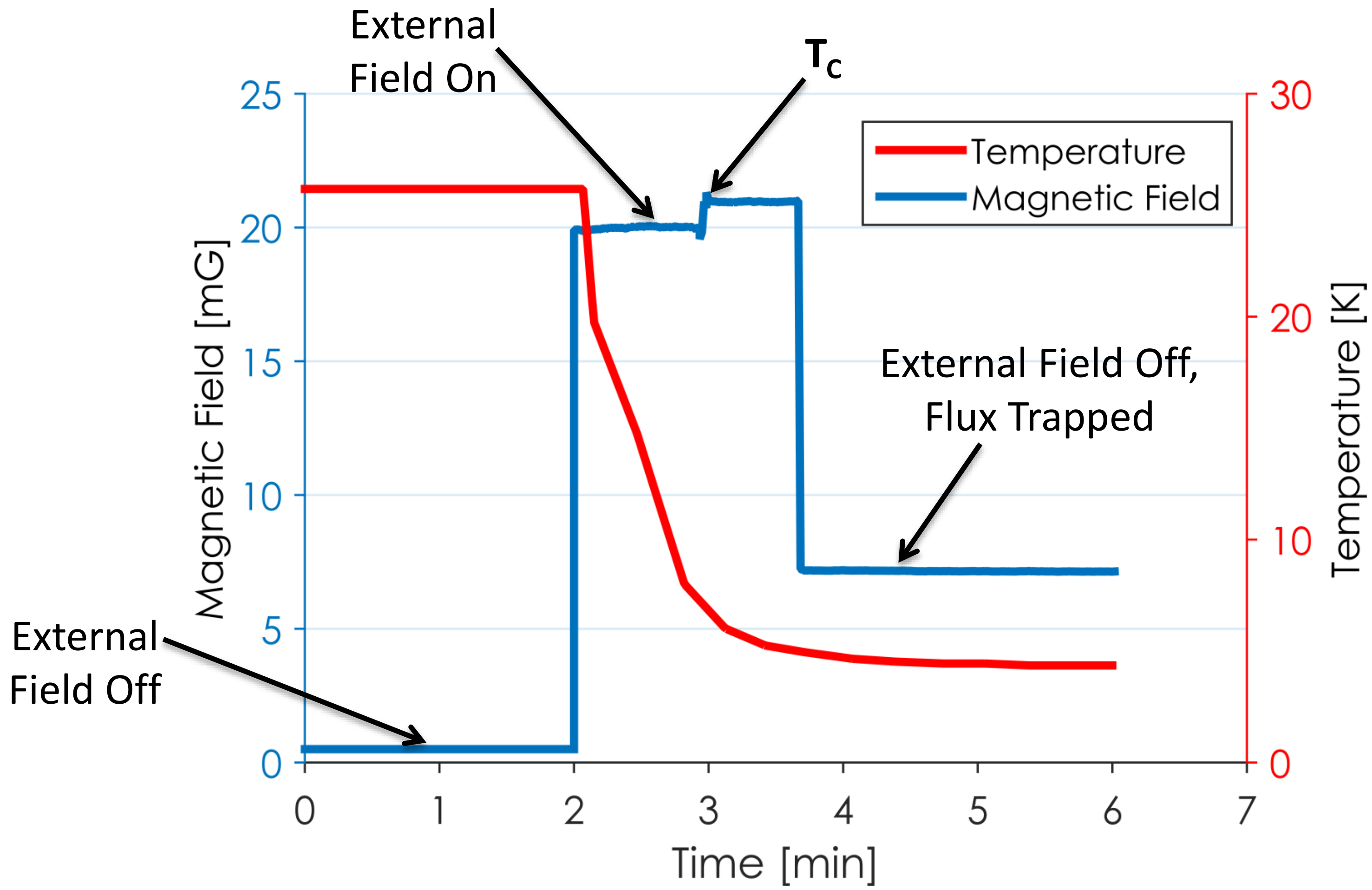
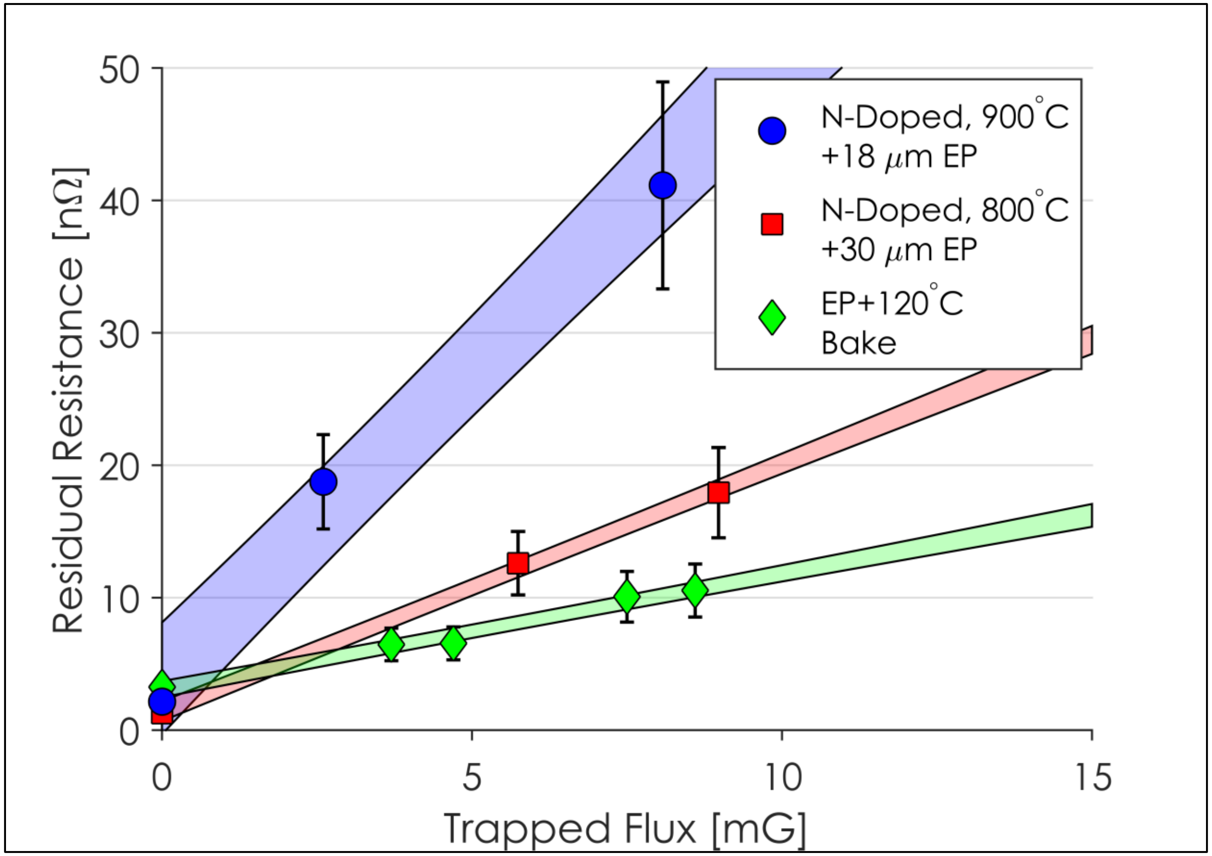
Flux Trapping Studies



Fluxgate Measurements

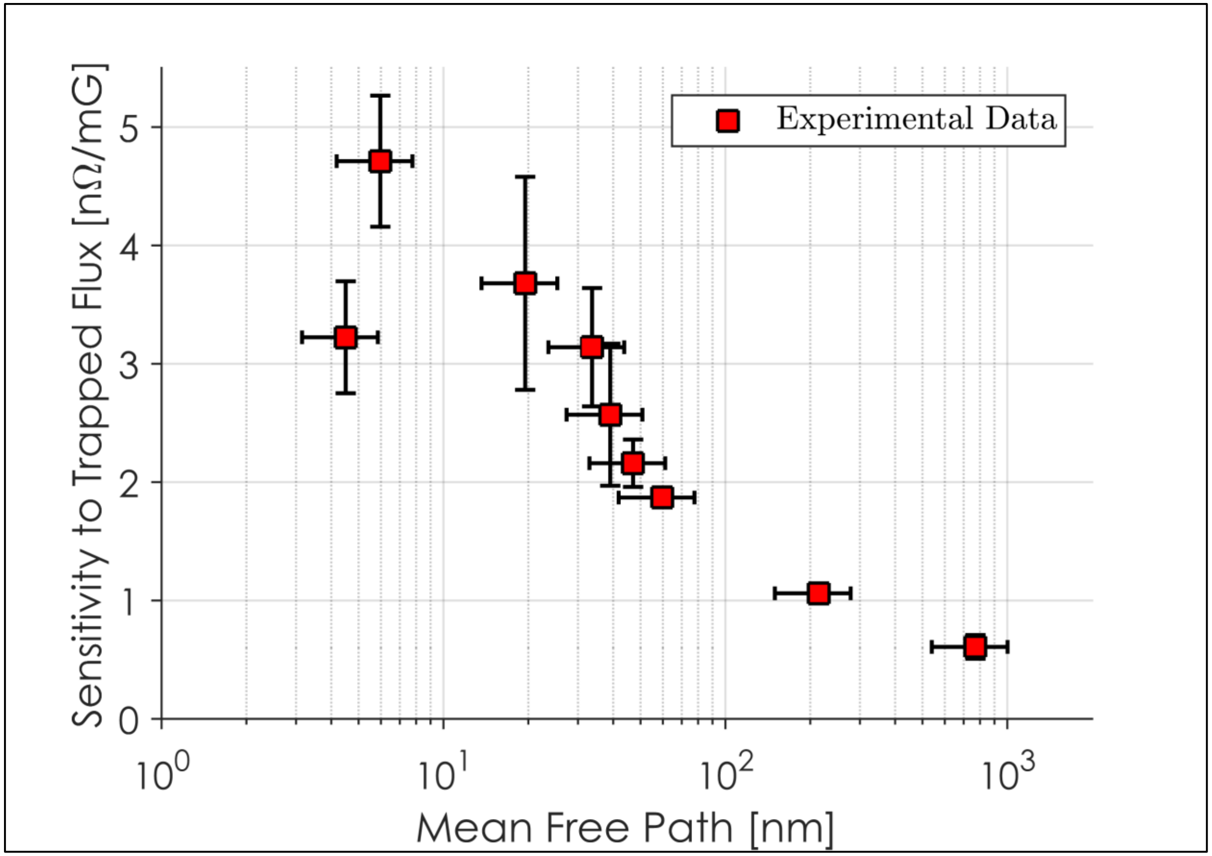


Sensitivity to Trapped Magnetic Flux



A total of 10 cavity preparations were tested, each with different mean free paths – N-doping gives us the tools needed to finely tune the mean free path

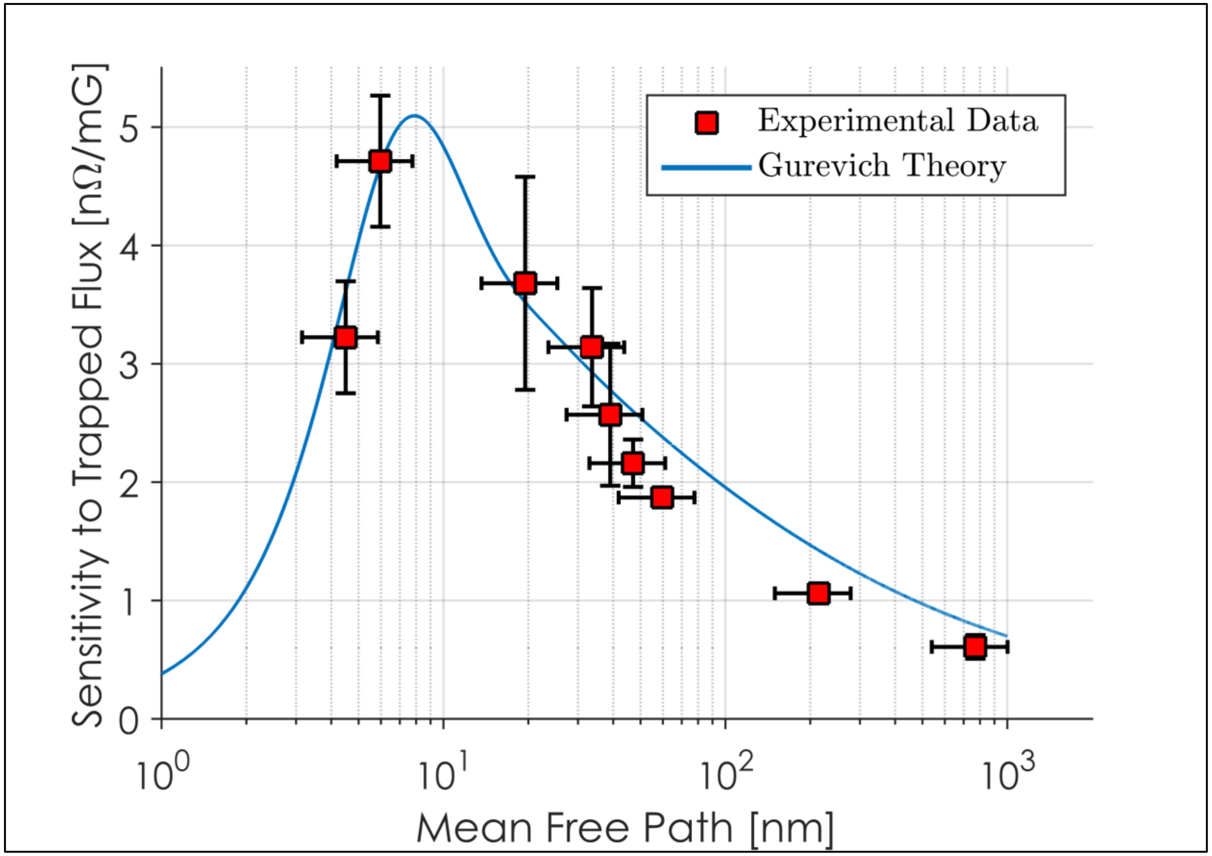
Sensitivity to Trapped Magnetic Flux

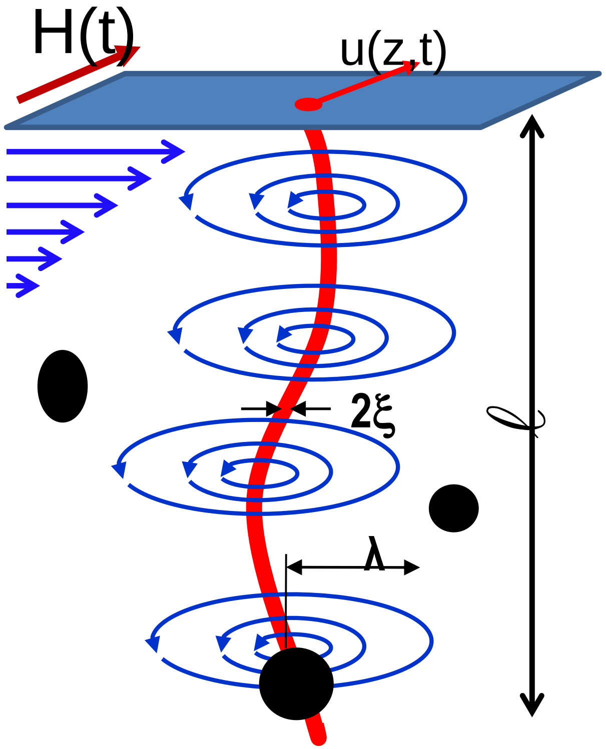


- In the clean limit, longer mean free path leads to lower sensitivity of R_{res} to trapped magnetic flux
- In the dirty limit, shorter mean free path leads to lower sensitivity

See our paper on ArXiV for full details:
Gonnella et. al. arXiv:1509.04127

Sensitivity to Trapped Magnetic Flux





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- This is well described by theoretical predictions proposed by Alex Gurevich (*Physical Review B*, 87(5):054502, 2013.)
- This model is heavily dependent upon mean spacing between pinning sites: we assume a linear relationship between this mean free path

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Conclusions

- Medium field Q slope in 120^{o}C cavities is caused by a combination of increasing BCS and residual resistances
- Anti-Q slope in Nitrogen-doped cavities is caused purely by decreasing BCS resistance
- This anti-Q slope can be explained in a variety of ways: decreasing A or increasing ε in exponential fitting and increasing ε/k_BT_c in full BCS fitting
  - Changing mean free path cannot solely explain the anti-Q slope since low field mean free paths are on either side of the minimum in N-Doped cavities

Conclusions

- Xiao code, a field-dependent derivation of Mattis-Bardeen theory can accurately predict BCS resistance at medium fields from low field material parameters but fails at low fields
- Losses due to ambient magnetic fields are heavily dependent on mean free path and are very well explained by Gurevich's theory of vortex oscillations