Medium Field Q-Slope in Low β Resonators

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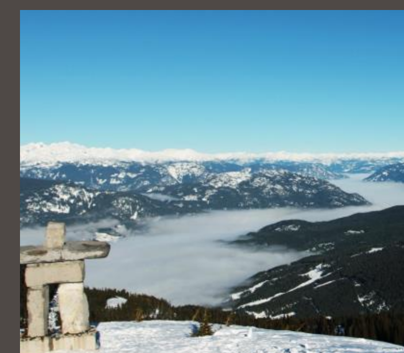
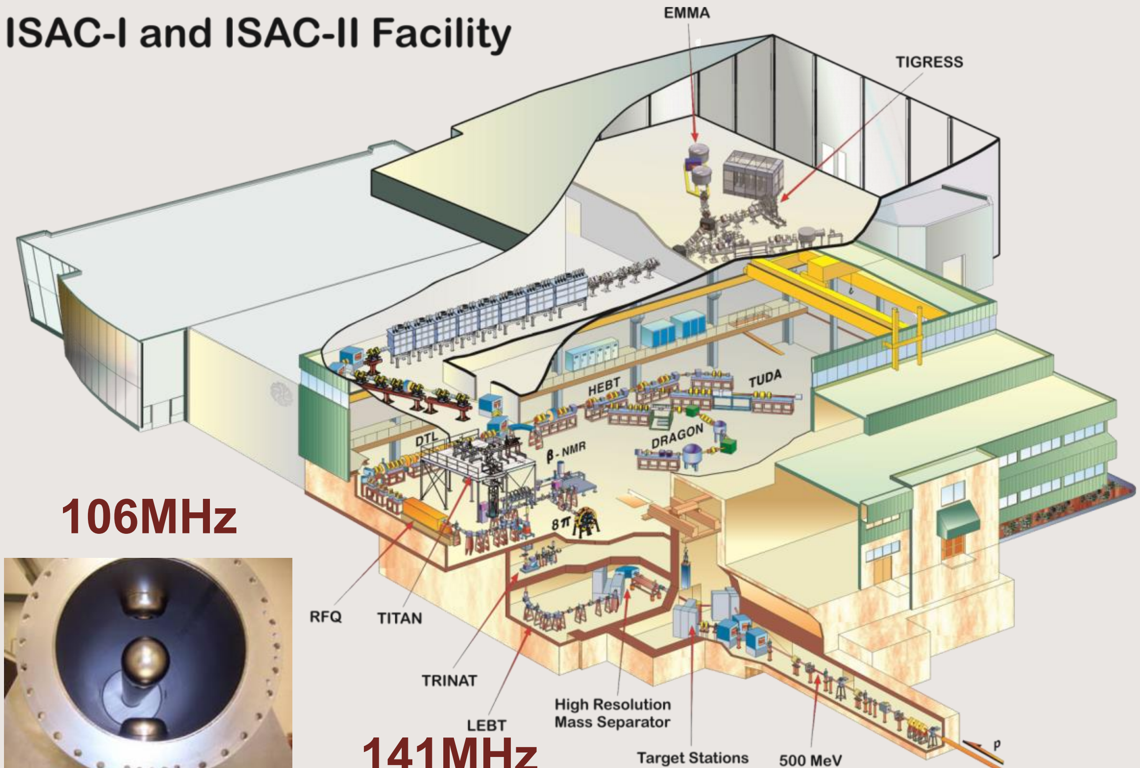
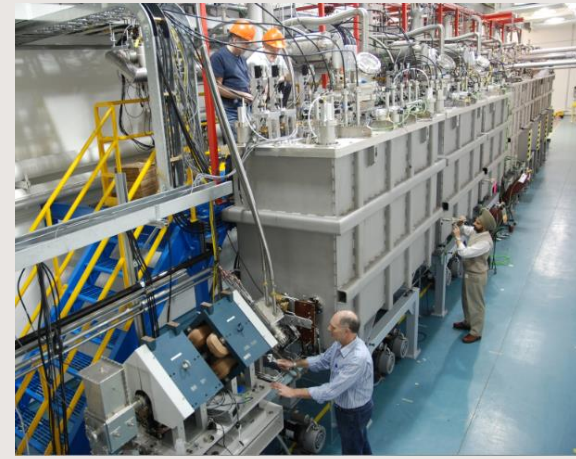
on behalf of SRF group, TRIUMF

SRF2015, Whistler, BC



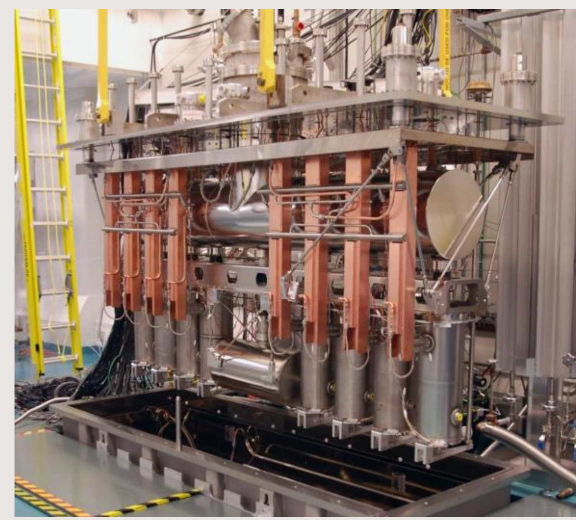
ISAC Facility



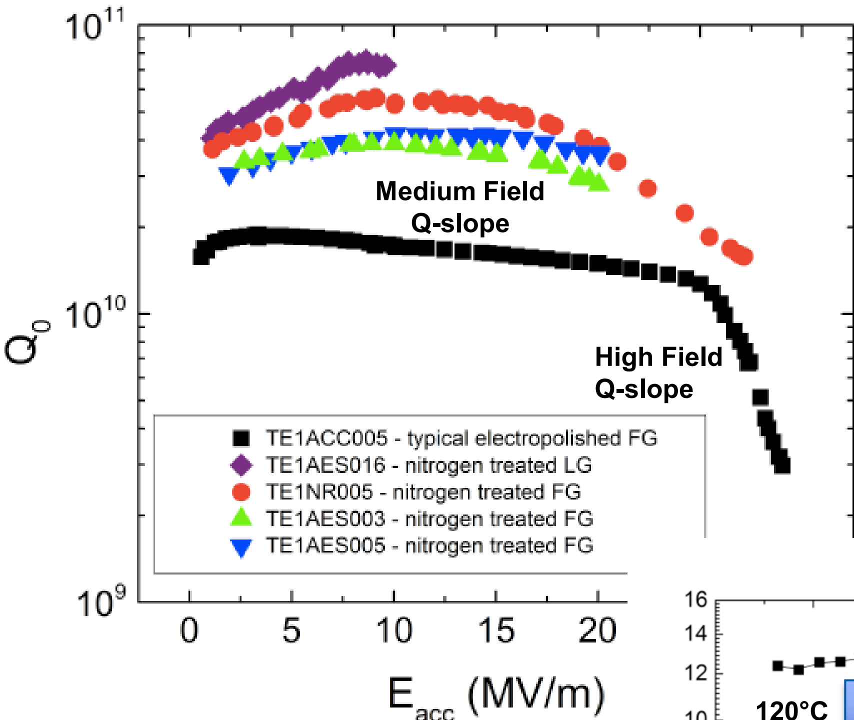


106MHz

141MHz

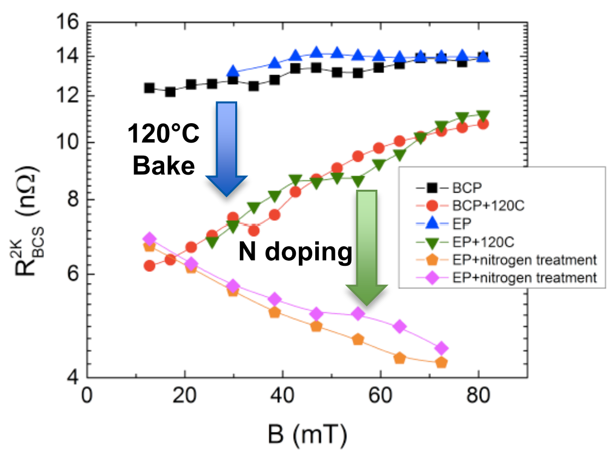


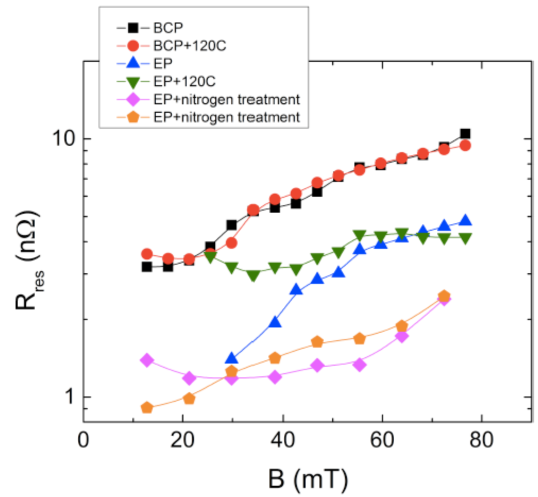
1.3GHz Development



- **Optimizing and understanding RF performance have been focused on 1.3GHz cavities.**
- **High Q studies for LCLS-II.**
  - **N doping enhanced low field Q-slop, and increased Q in medium field.**
  - **Recipe is being optimized for higher quench field**
- **Separating R_{res} and R_{BCS} on various field helps to have an insight of mechanism.**

A. Grassellino, et al., 'Nitrogen and Argon Doping of Niobium for Superconducting Radioactive Cavities: a Pathway to Highly Efficient Accelerating Structures', arXiv:1306.0288, July 2013.

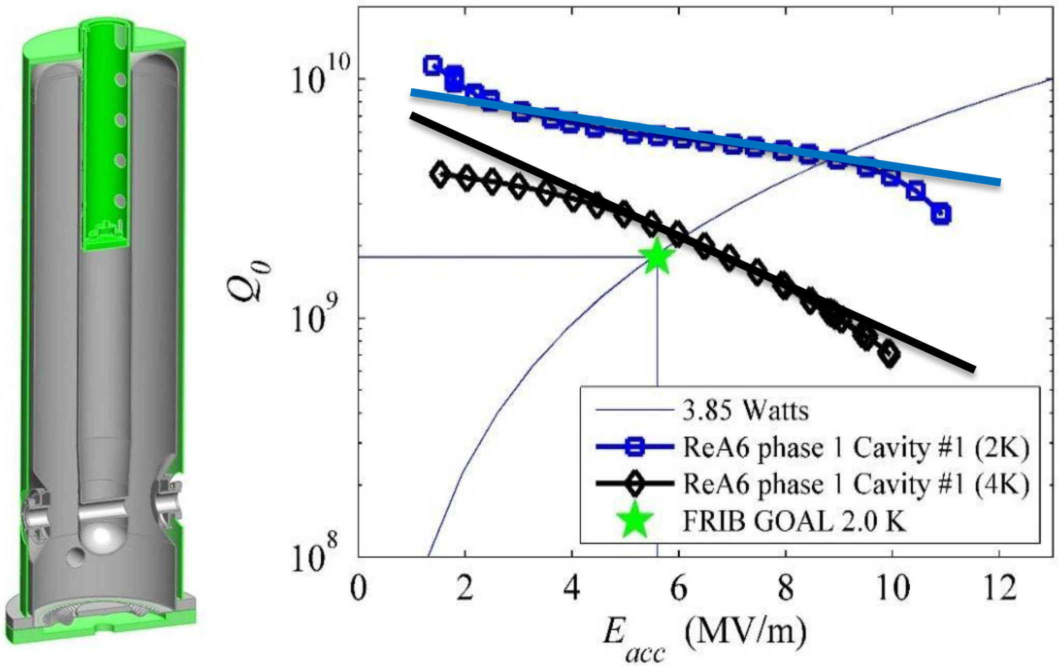




Low β Resonators

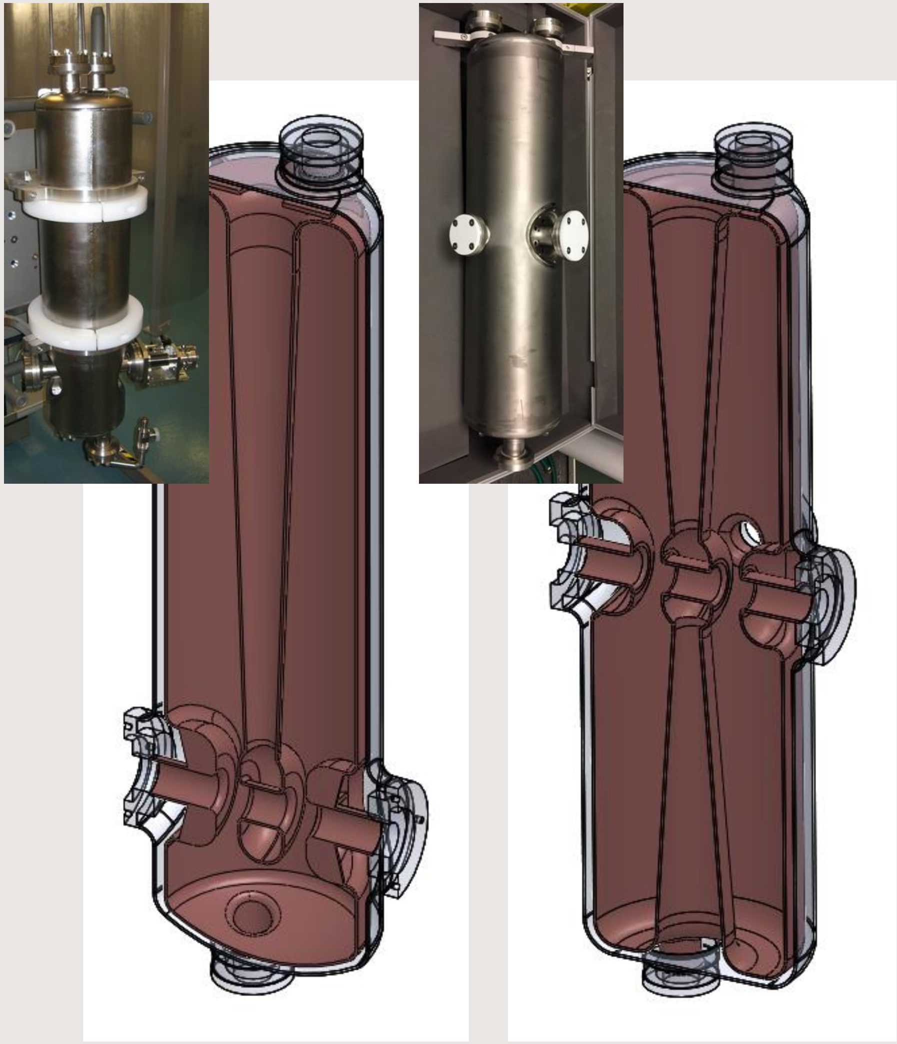
- 4K reduce cryogenics system cost for low frequency applications.
- Strong Medium Field Q-Slop (MFQS) exists in low frequency and low β resonators.
- Presently facilities are choosing to operate at 2K even at low frequency to avoid MFQS, such as FRIB and RISP.
- 120˚C bake improves 4K Q in medium field. (SPIRAL-II and FRIB)
- MFQS and improving 4K performance need to be further understood.

FRIB 80.5MHz β=0.085 QWR



K. Saito, 'FRIB Project: Moving to Production Phase', This conference.

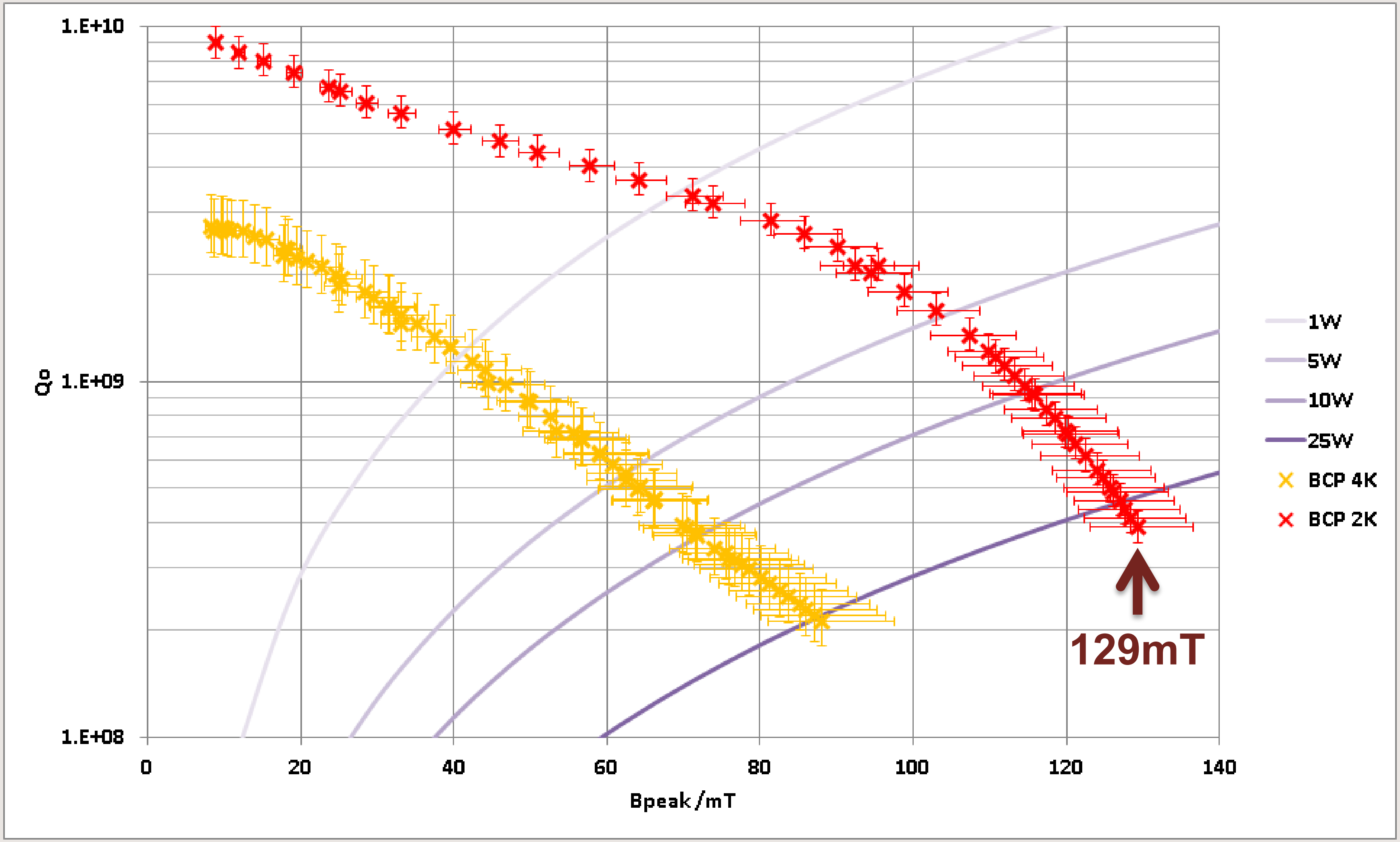
RISP Coaxial Resonators



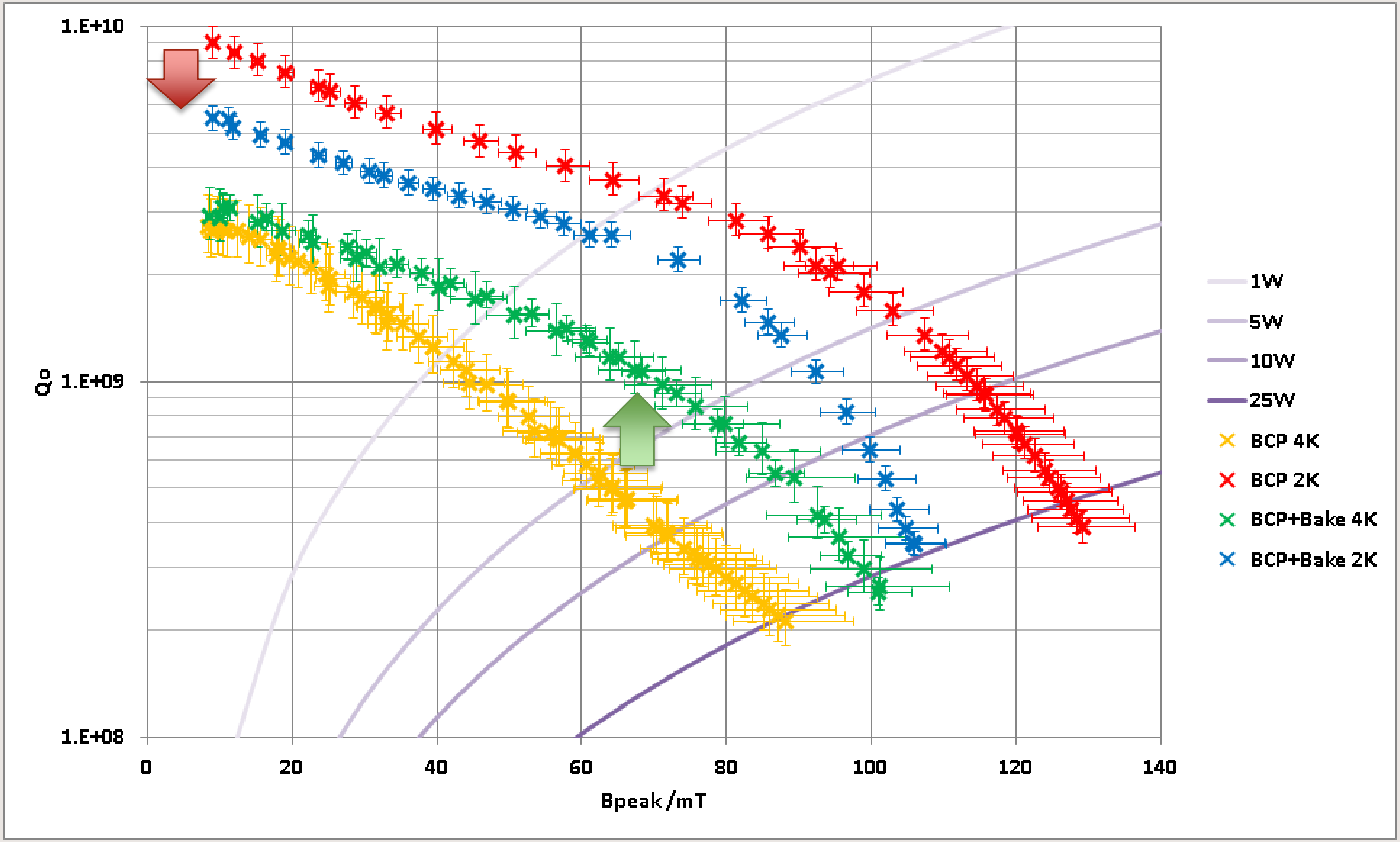
- **81.25MHz QWR and 162.5MHz HWR designed by RISP.**
- **Cavity treatments**
  - **120μm BCP (+15μm for HWR)**
  - **HPR**
  - **48hr 120°C bake**
- **Cavities were tested before and after bake.**

	QWR	HWR	Unit
Frequency	81.25	162.5	MHz
β	0.047	0.12	1
$L_{eff}=\beta\lambda$	0.173	0.221	m
E_{peak}/E_{acc}	5.3	5.6	1
B_{peak}/E_{acc}	9.5	8.2	mT/MV/m
G	21	40	Ω
U/E_{acc}^2	0.126	0.159	$J/(MV/m)^2$

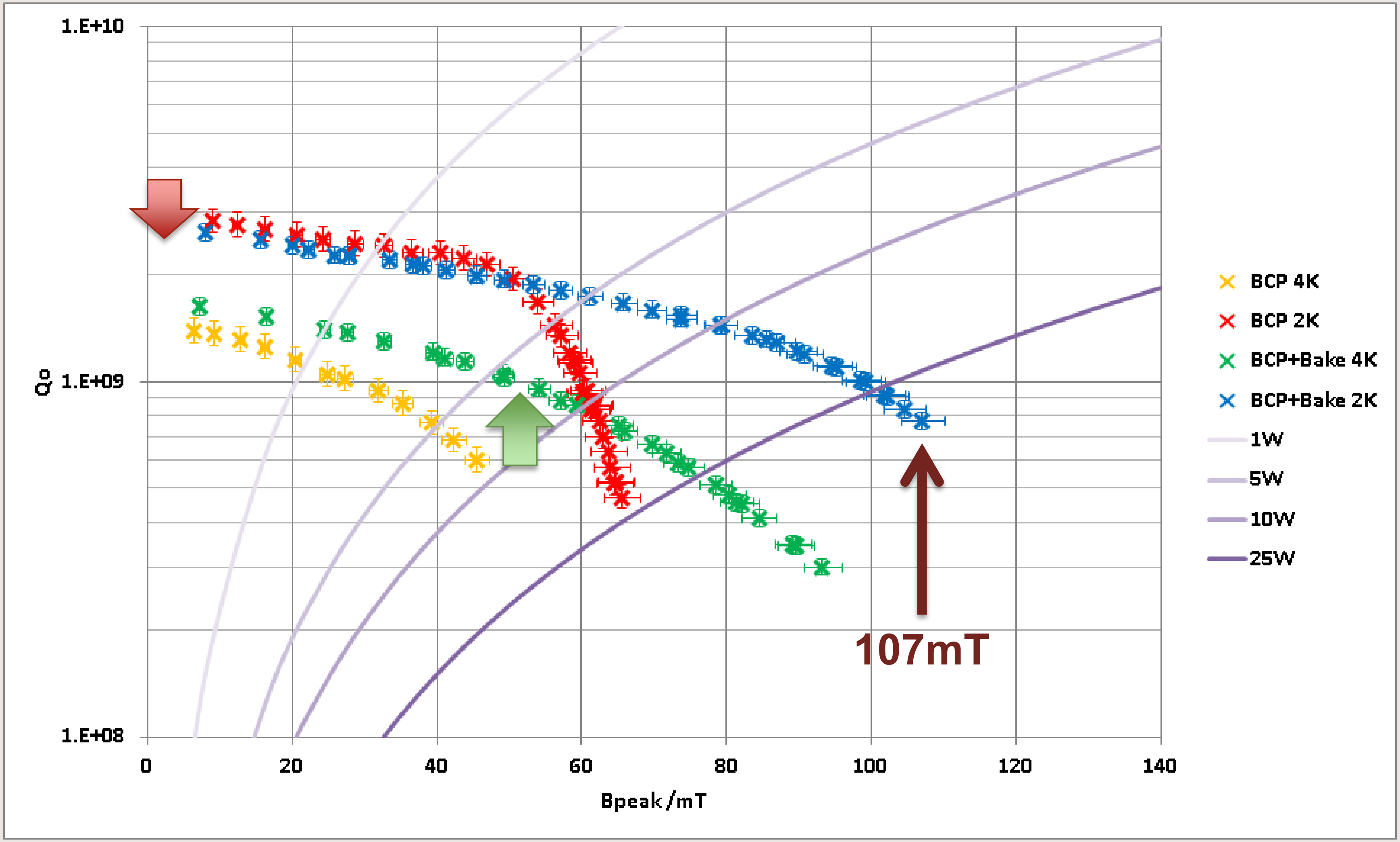
QWR BCP Result



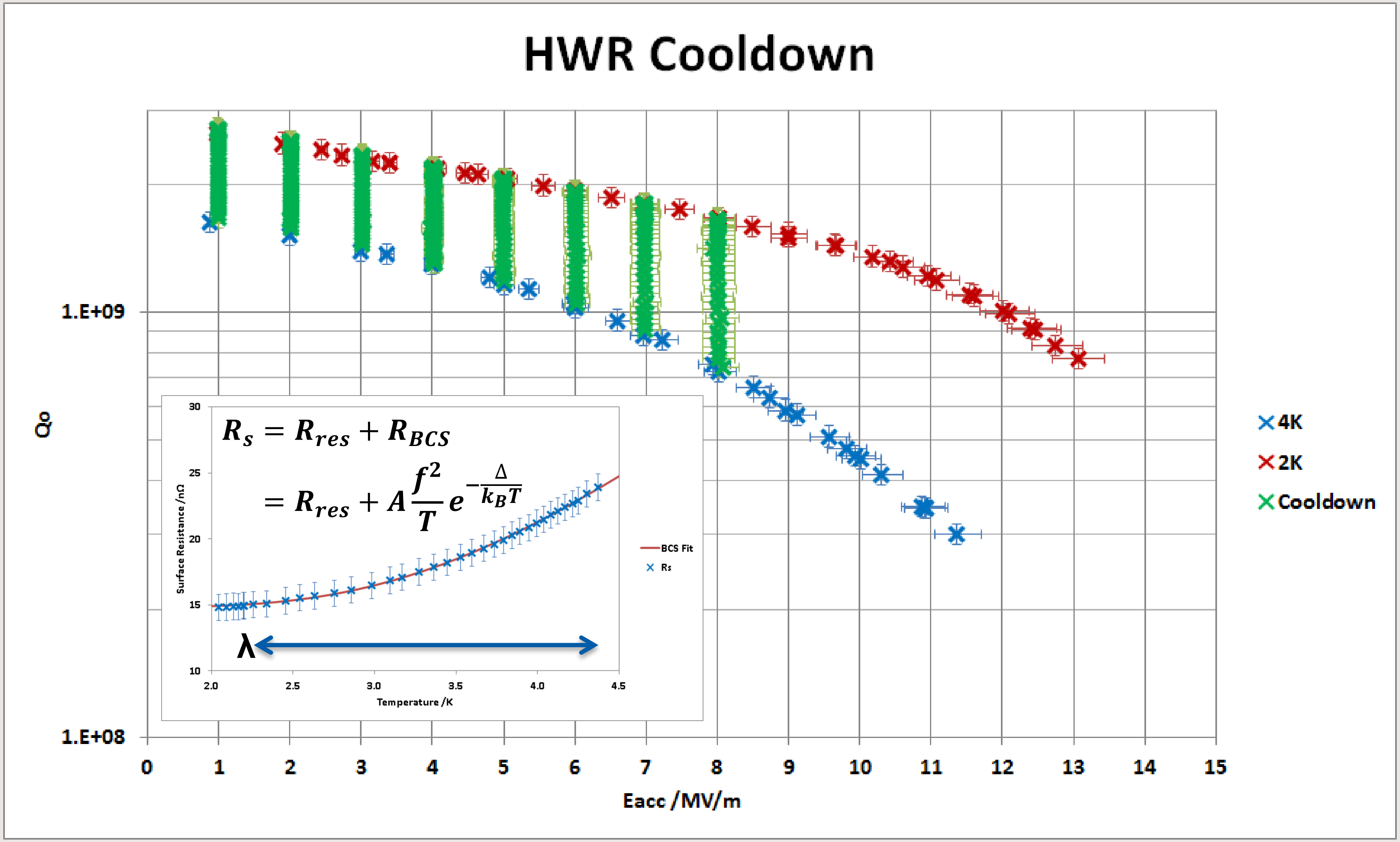
QWR Comparison



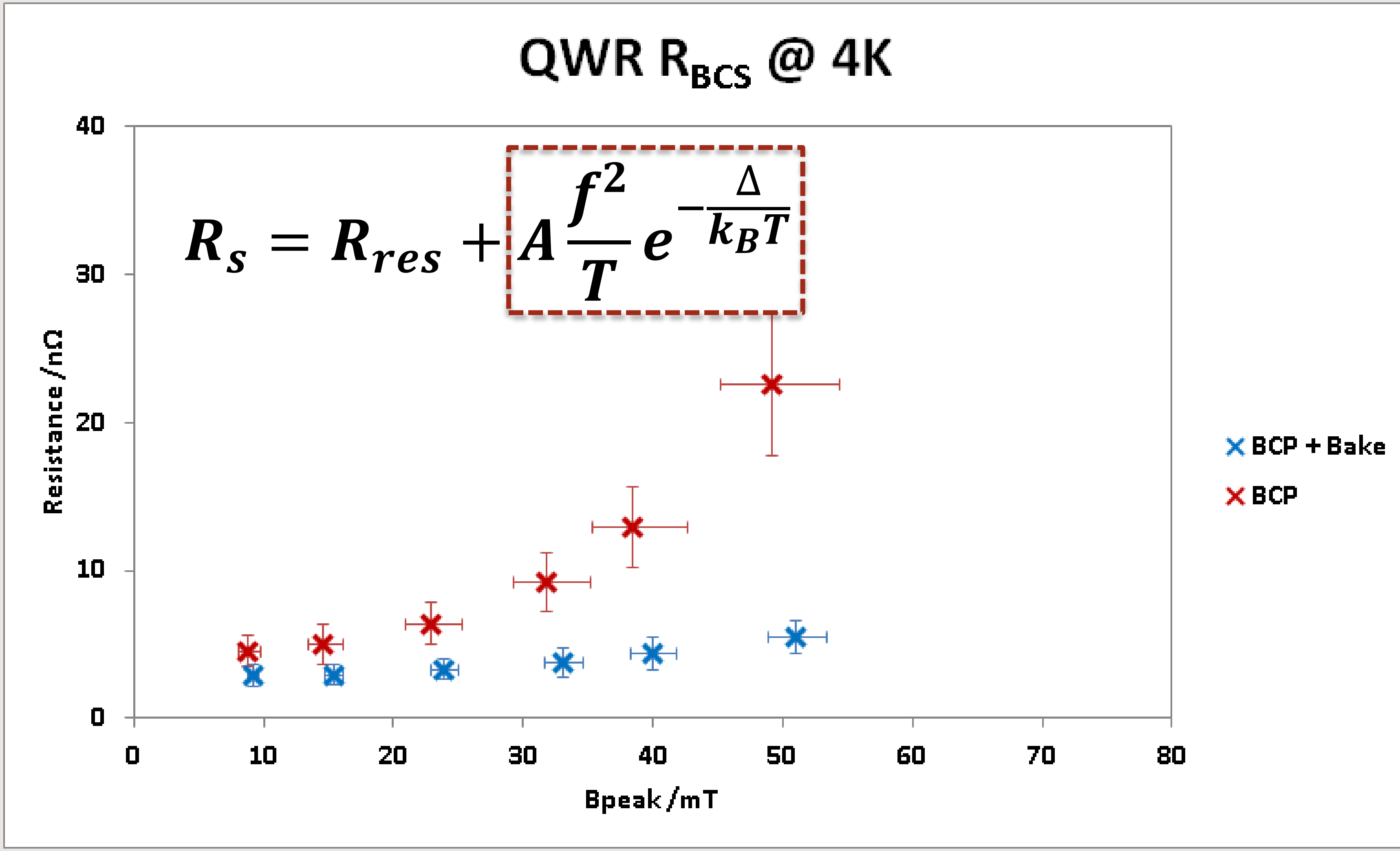
HWR Comparison



4K to 2K

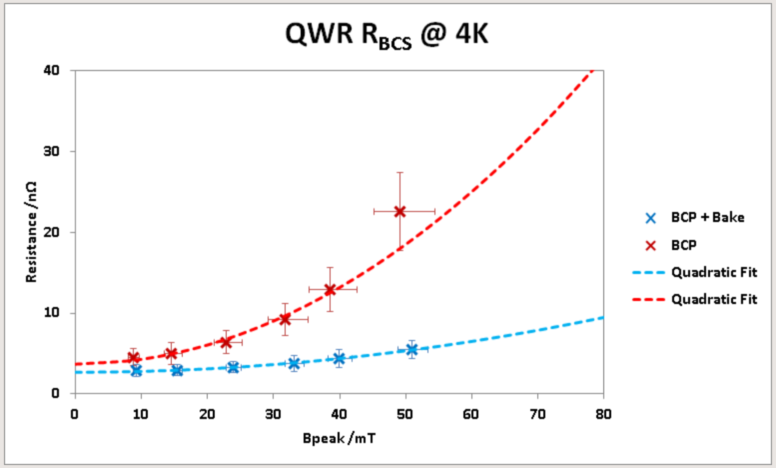

HWR Cooldown
1.E+09
1.E+08
Q0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Eacc /MV/m
4K
2K
Cooldown
$R_s = R_{res} + R_{BCS}$
$= R_{res} + A\frac{f^2}{T}e^{-\frac{\Delta}{k_B T}}$
λ
Surface Resistance /nΩ
30
25
20
15
10
2.0
2.5
3.0
3.5
4.0
4.5
Temperature /K
BCS Fit
Rs

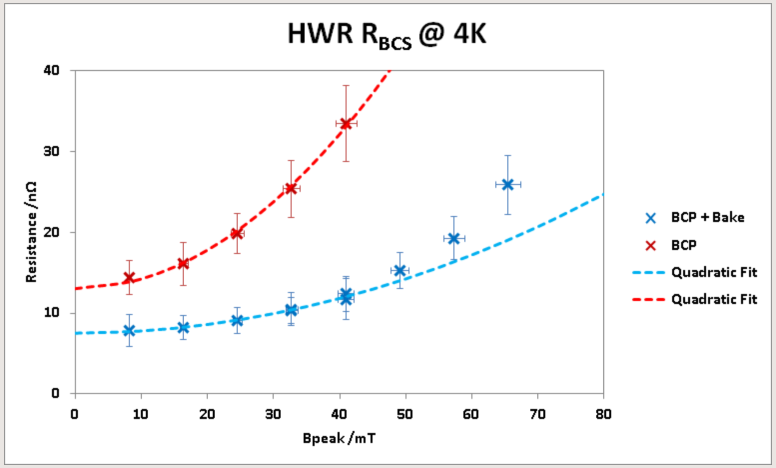
BCS Resistance



$$R_s = R_{res} + A\frac{f^2}{T}e^{-\frac{\Delta}{k_B T}}$$

Quadratic Dependent R_{BCS}



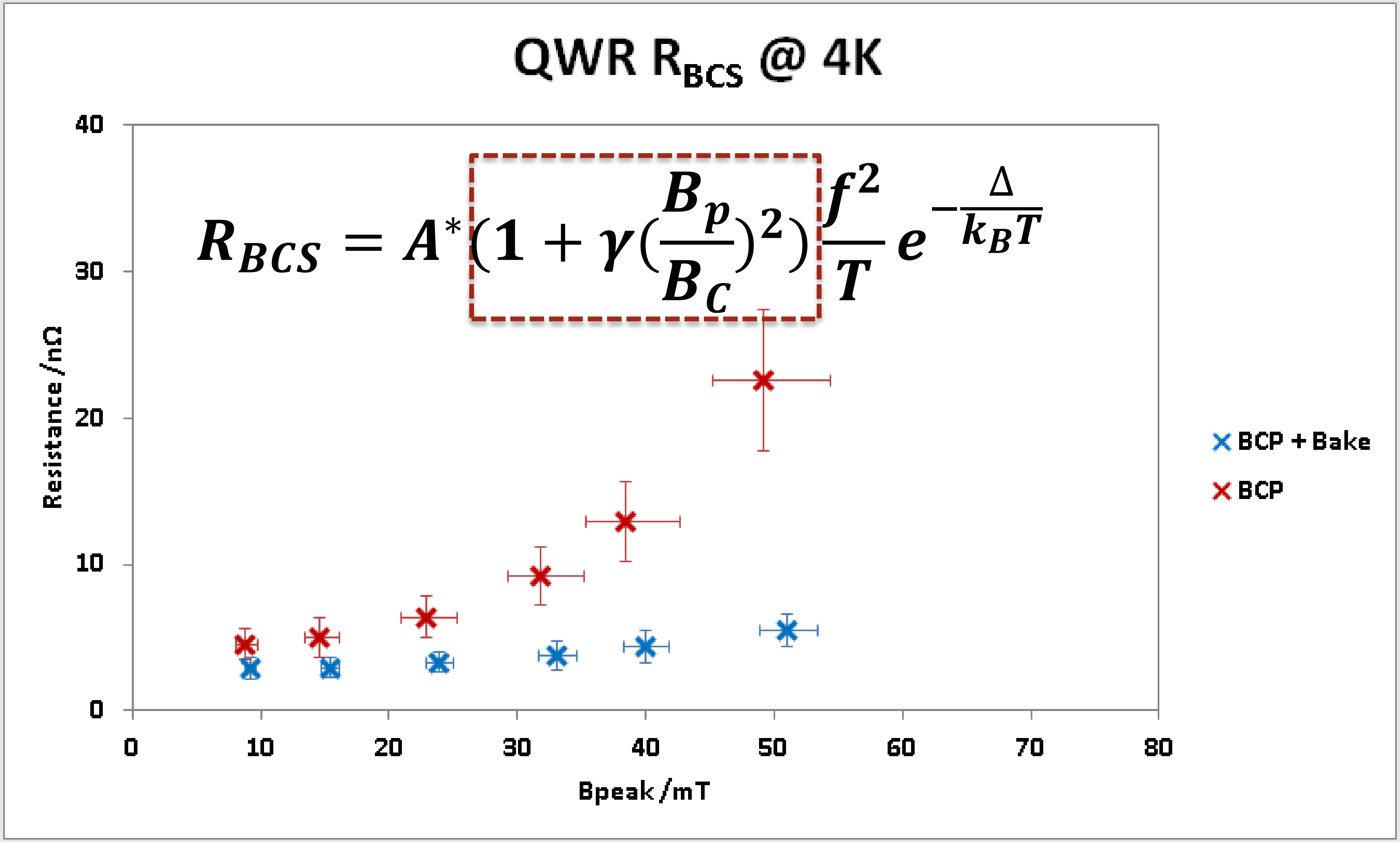


$$R_{BCS} = R_{BCS0}\left(1 + \gamma\left(\frac{B_p}{B_C}\right)^2\right)$$

	R_{BCS0} @ 4K	γ
	nΩ	1
QWR BCP	3.70	64.2
QWR Bake	2.69	15.8
HWR BCP	13.03	36.7
HWR Bake	7.53	14.3

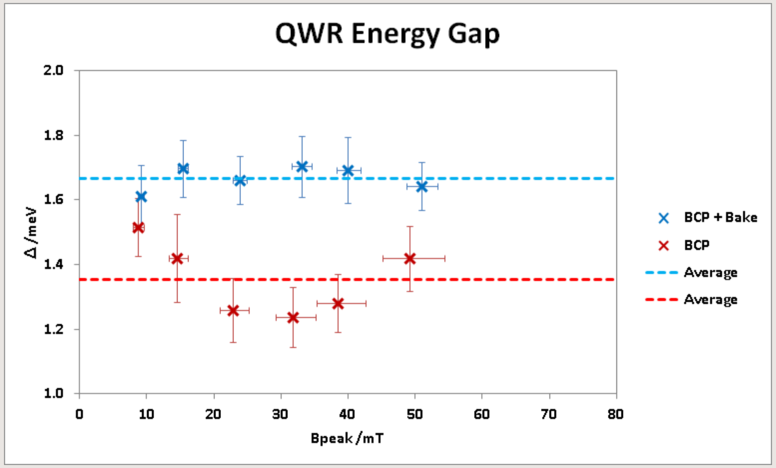
- Bake reduced R_{BCS0} and field dependent coefficient.
- Field dependence is quadratic for B_{peak}<40mT.
- Slope is stronger than quadratic at the field of >60mT.

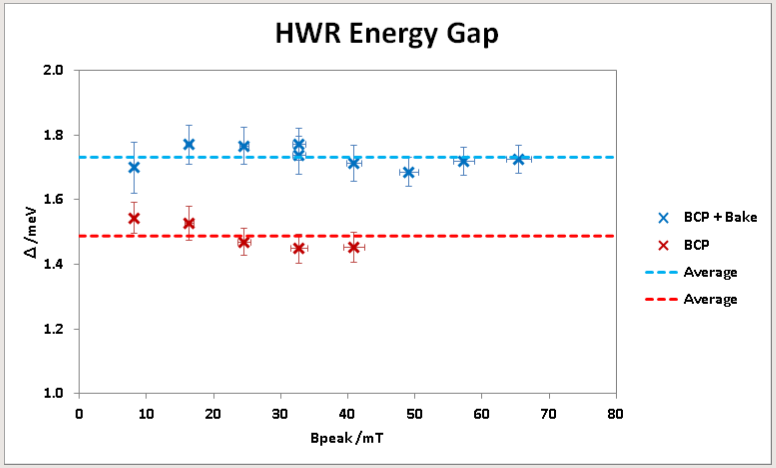
BCS Resistance



$$R_{BCS} = A^{*}\left(1 + \gamma\left(\frac{B_p}{B_C}\right)^2\right)\frac{f^2}{T}e^{-\frac{\Delta}{k_B T}}$$

Energy Gap



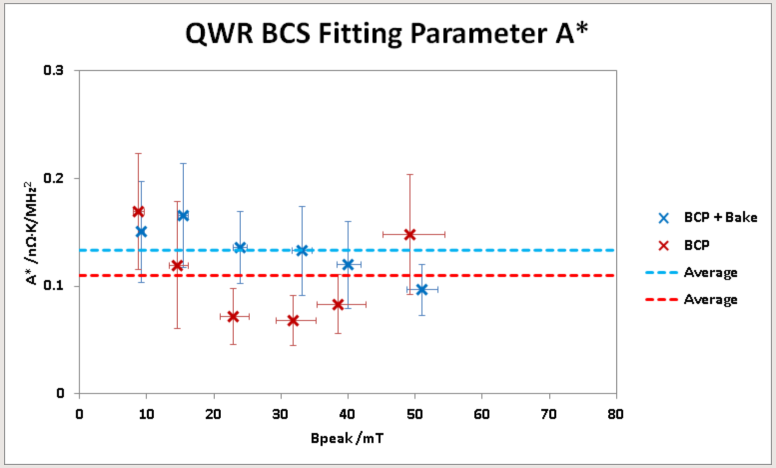


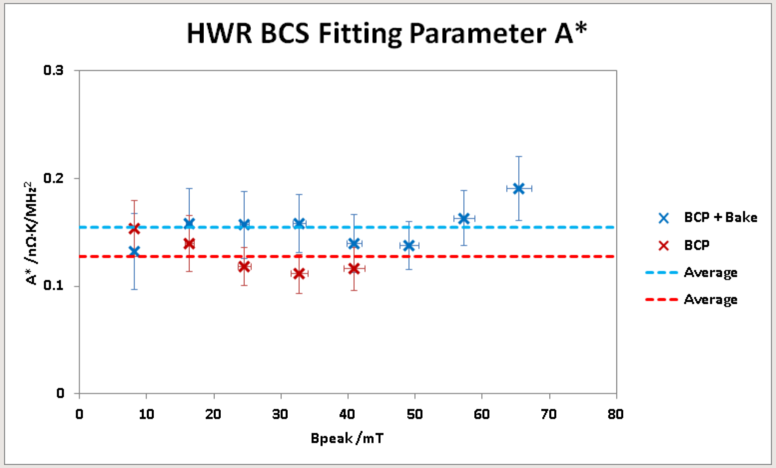
$$R_{BCS0} = A^* \frac{f^2}{T} e^{-\frac{\Delta}{k_B T}}$$

Δ meV	QWR	HWR
BCP	1.35	1.49
Bake	1.67	1.73

- Field dependence of energy gap is not obvious in low and medium field.
- Bake increased average value of energy gap by about 20%.

Fitting Parameter A*



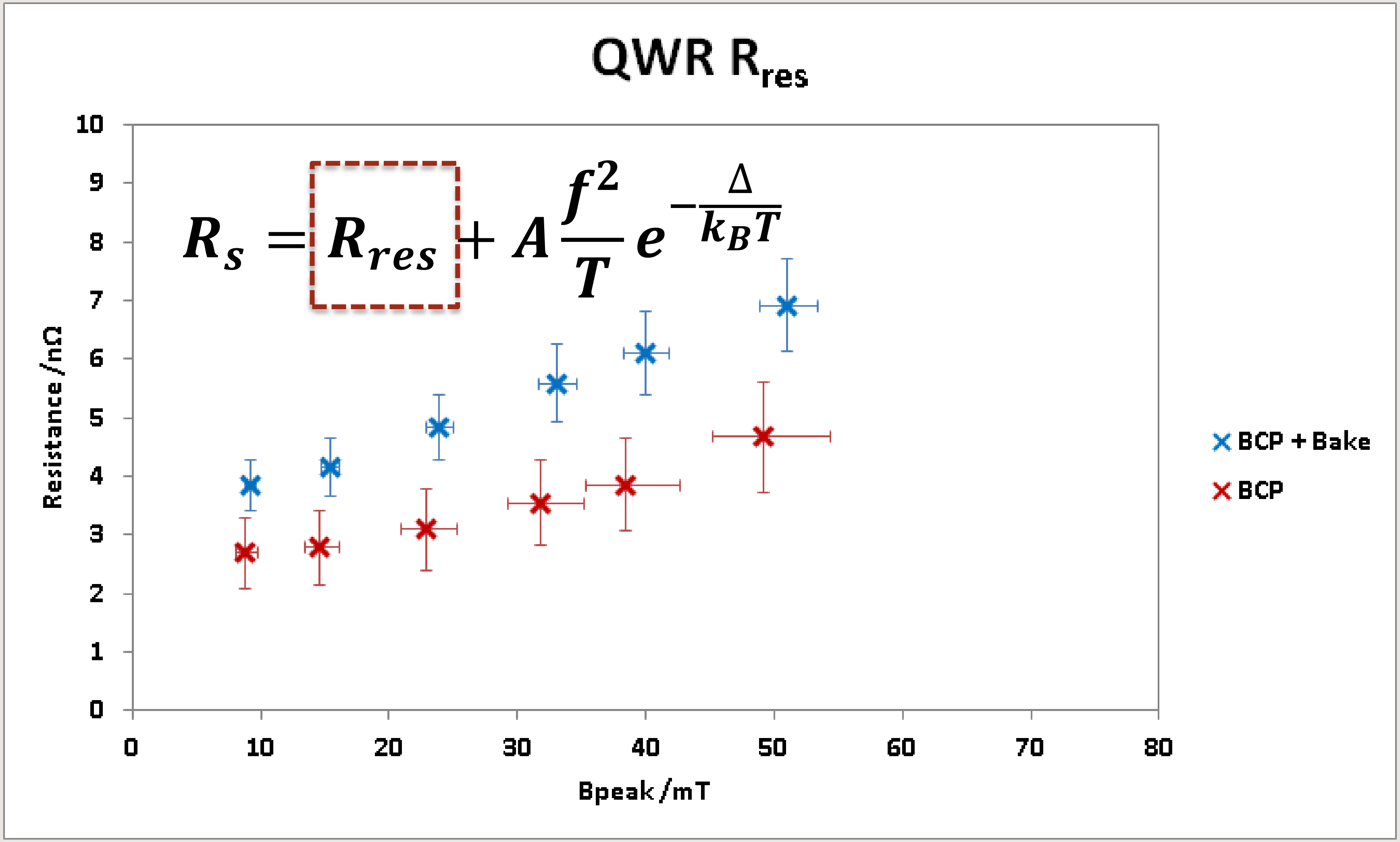


$$R_{BCS0} = A^* \frac{f^2}{T} e^{-\frac{\Delta}{k_B T}}$$

A* nΩ·K/MHz^2	QWR	HWR
BCP	0.110	0.128
Bake	0.133	0.155

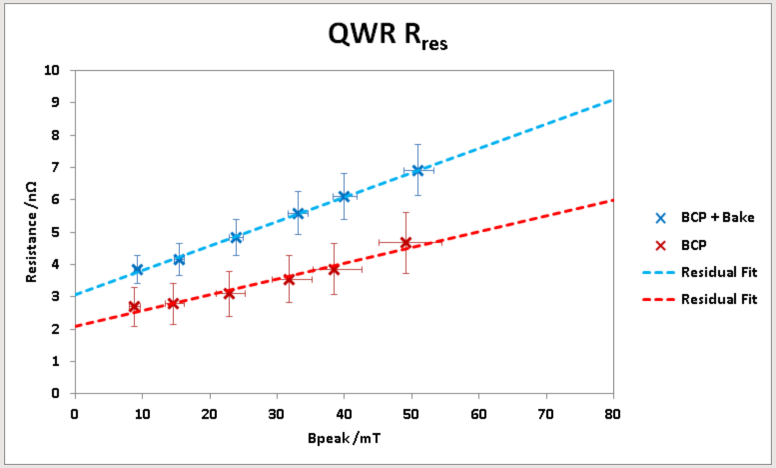
- Bake effect for A* is not obvious with these two data set. The differences are within error bars.

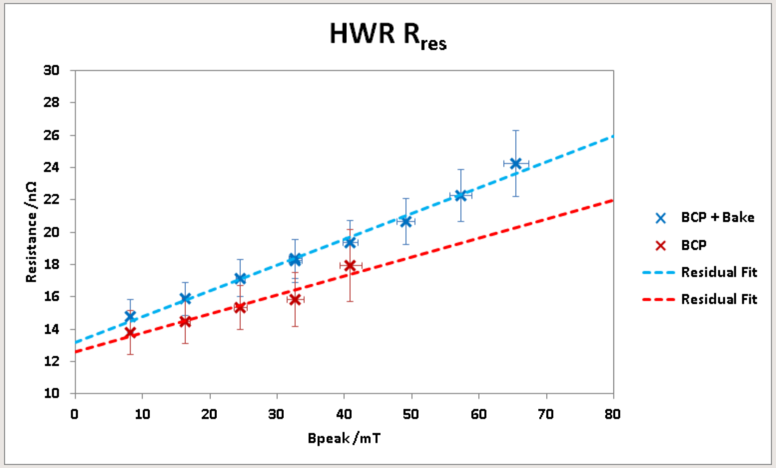
Residual Resistance



$$R_s = R_{res} + A\frac{f^2}{T}e^{-\frac{\Delta}{k_B T}}$$

Linear Dependent R_{res}



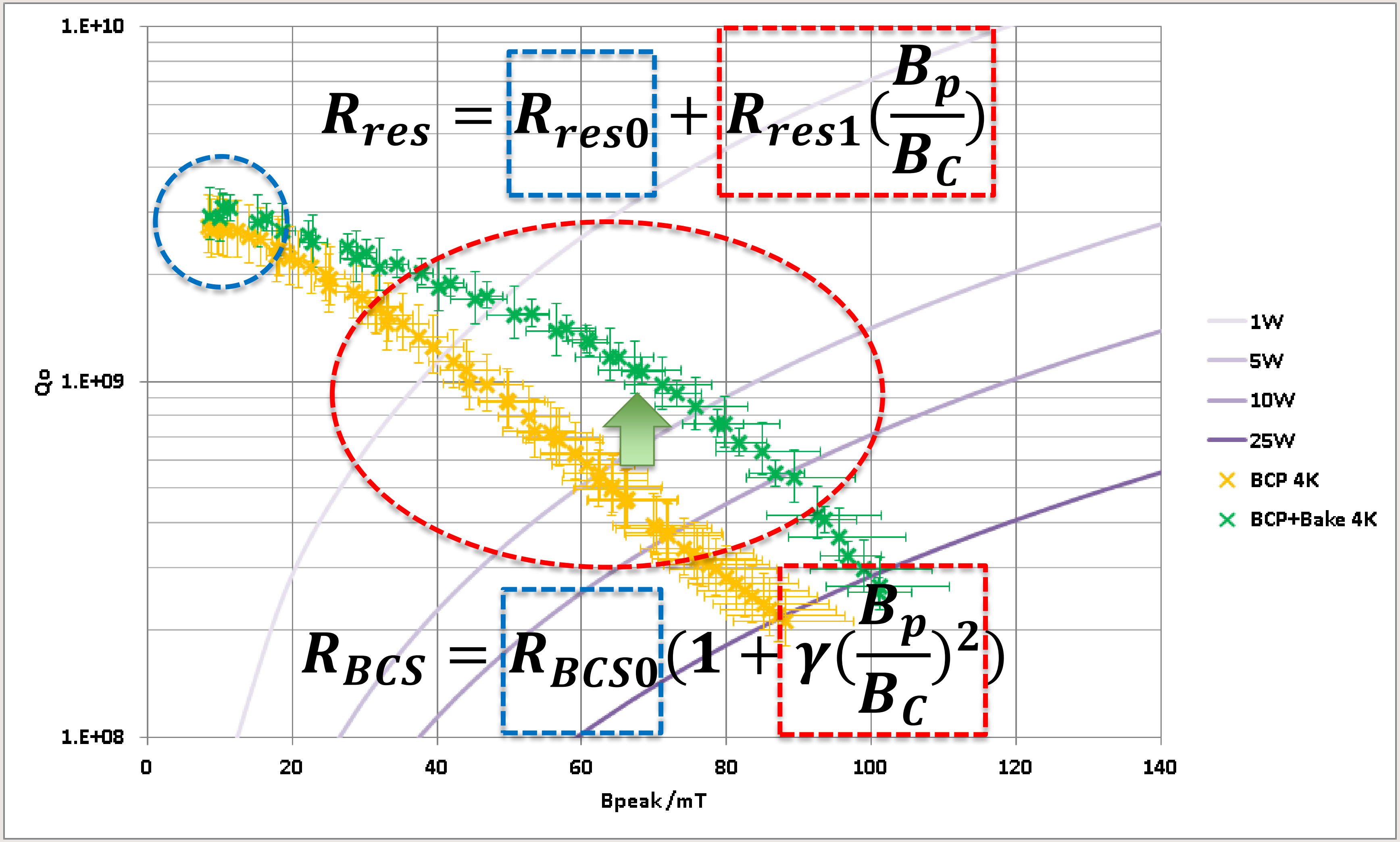


$$R_{res} = R_{res0} + R_{res1}\left(\frac{B_p}{B_C}\right)$$

	R_{res0} nΩ	R_{res1} nΩ
QWR BCP	2.09	9.76
QWR Bake	3.07	15.1
HWR BCP	12.6	23.5
HWR Bake	13.2	31.9

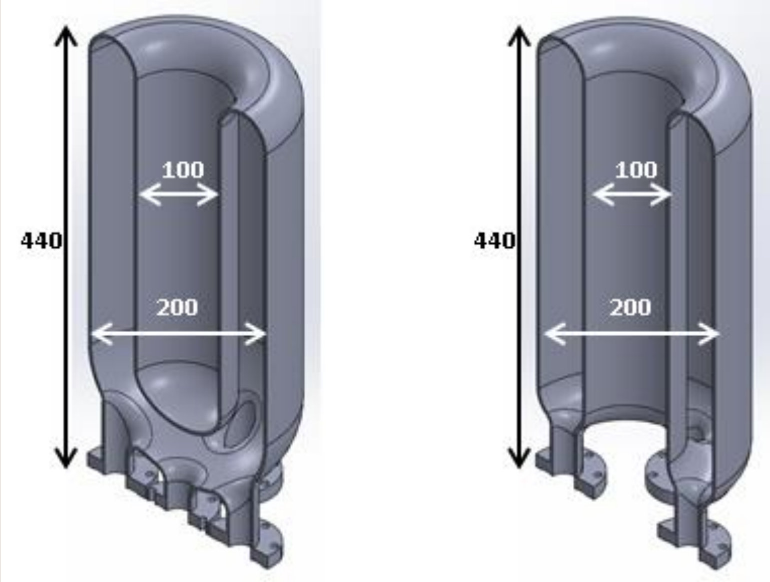
- Bake increased R_{res0} and field dependent slope.
- High R_{res} of HWR is suspected due to cool down procedure and trapped flux.
- R_{res1} is proportional to frequency within error bar.

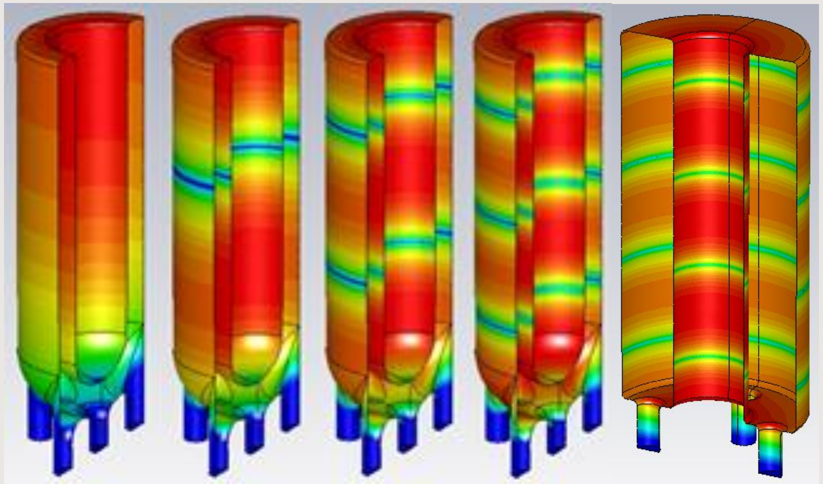
QWR 4K Q-Slope



Multi-modes Test Resonators

- **Motivation**
  - Systemic study tools for field and frequency dependent surface resistance.
  - Coaxial geometry that is common for low β resonator.
  - ‘Single cell’ for low β resonators.
- **Resonator Design**
  - Resonance frequency
    - Integer harmonics of 200MHz
  - Field optimization
    - Uniform field distribution for different modes
  - Good access for processing and cleaning
  - Fit RF induction oven for heat treatment and doping study





Summary

- Preliminary MFQS study on low β resonator with measuring cool down Q data at various field level.
- 120˚C bake improved 4K performance in medium field for both RISP QWR and HWR by reducing R_{BCS0} and field dependent coefficient. On the opposite side, bake increased R_{res}.
- With our data, field dependent component of BCS resistant is shown to be quadratic, and residual part is linear field dependent.
- More tests and data are required to have an insight of MFQS for low β resonators.
- More treatments will be studied, such as HF rinse after bake, heat treatments, and doping.
- This is just a beginning.

Acknowledgment

- This study grew out of our collaboration with RISP during the qualifying tests of their prototype cavities at TRIUMF.
- We thank them for the opportunity to extend the study to explore medium field Q-slope.

- Thanks to David Longuevergne for useful discussion.

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Backup

Linear Dependent R_{res}

	R_{res0} nΩ	R_{res1} nΩ	$errR_{res1}$
QWR BCP	2.09	9.76	1.83
QWR Bake	3.07	15.1	0.73
HWR BCP	12.6	23.5	7.50
HWR Bake	13.2	31.9	2.54

	f_{HWR}/f_{QWR}	$R_{res1\_HWR}/R_{res1\_QWR}$
BCP	2	2.12 ± 0.20
Bake	2	2.40 ± 0.89

Geometry Factor

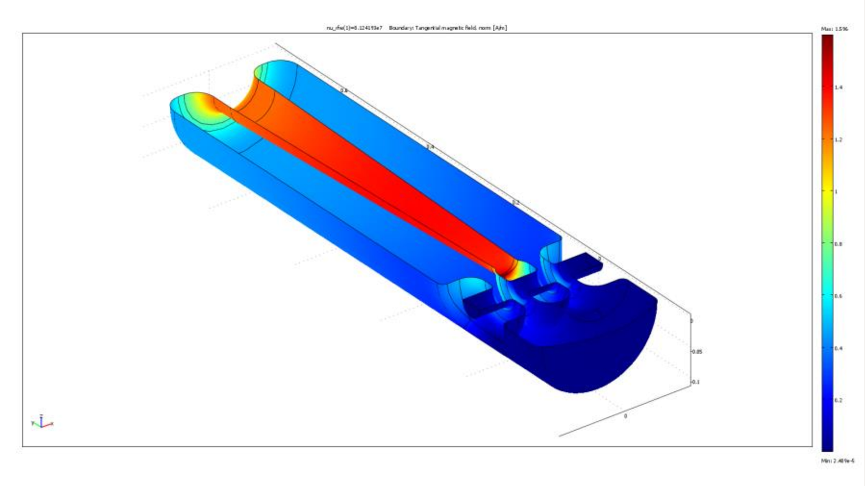
$$\frac{G}{Q_0} = R_s \quad \Rightarrow \quad \frac{G}{Q_0} = \frac{\int R_s(B)|B|^2 ds}{\int |B|^2 ds}$$

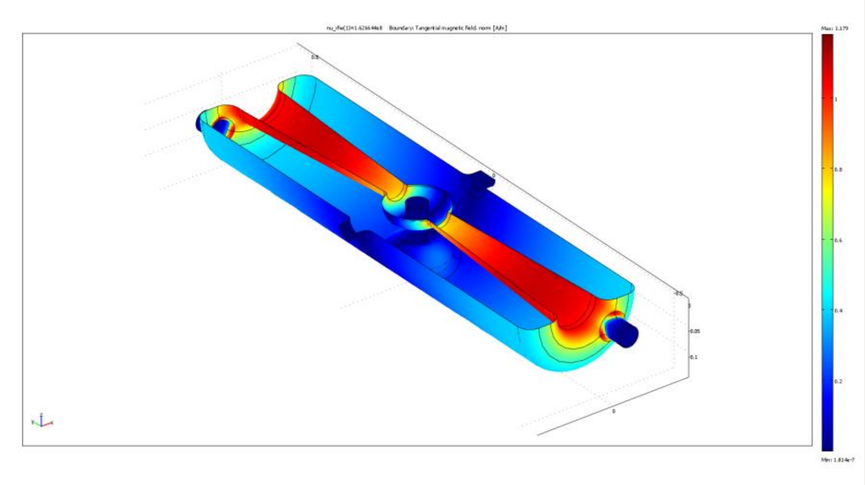
$$R_s(B) = R_{s0} + \alpha_1|B| + \alpha_2|B|^2$$

$$\frac{G}{Q_0} = R_{s0} + \alpha_1\beta_1 B_p + \alpha_2\beta_2 {B_p}^2$$

$$\beta_n = \frac{\int (|B|/B_p)^{n+2} ds}{\int (|B|/B_p)^2 ds}$$

	QWR	HWR
β_1	0.68	0.71
β_2	0.53	0.58





From $R_s(B_p)$ to $R_s(B)$

$$R_{res} = R_{res0} + R_{res1}\left(\frac{B_p}{B_C}\right)$$

$$R_{BCS} = R_{BCS0}\left(1 + \gamma\left(\frac{B_p}{B_C}\right)^2\right)$$

$$R_{res} = R_{res0} + R_{res1}^{*}\left(\frac{B}{B_C}\right)$$

$$R_{BCS} = R_{BCS0}\left(1 + \gamma^{*}\left(\frac{B}{B_C}\right)^2\right)$$

	R_{res1}	R_{res1}^{*}	γ	γ*
	nΩ	nΩ	1	1
QWR BCP	9.76	14.4	64.2	121.6
QWR Bake	15.1	22.2	15.8	29.9
HWR BCP	23.5	32.9	36.7	63.6
HWR Bake	31.9	44.7	14.3	24.8