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Cryogenic RF performances of Nb_3Sn films on copper

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On behalf of FCC RF & WP 3

8th international workshop on thin films and new ideas for SRF
October 9th 2018

Beyond

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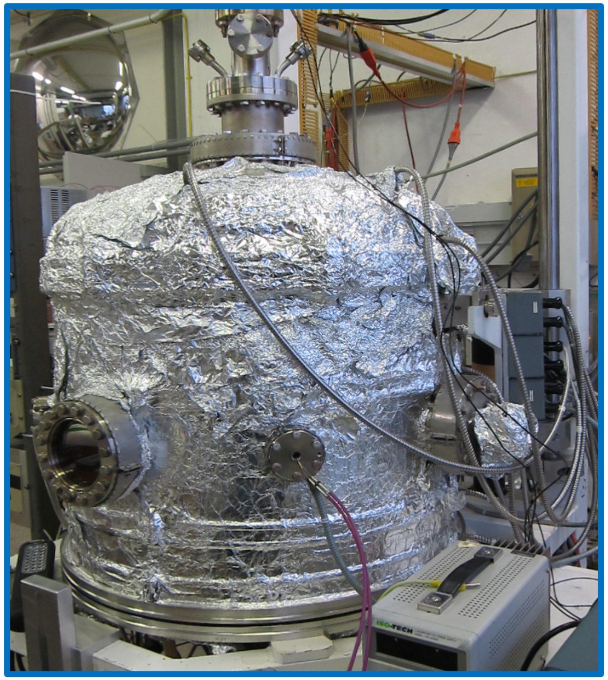
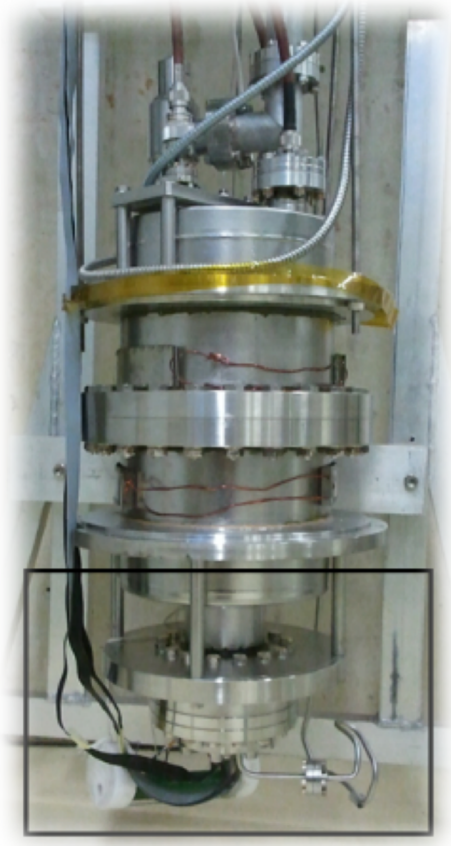
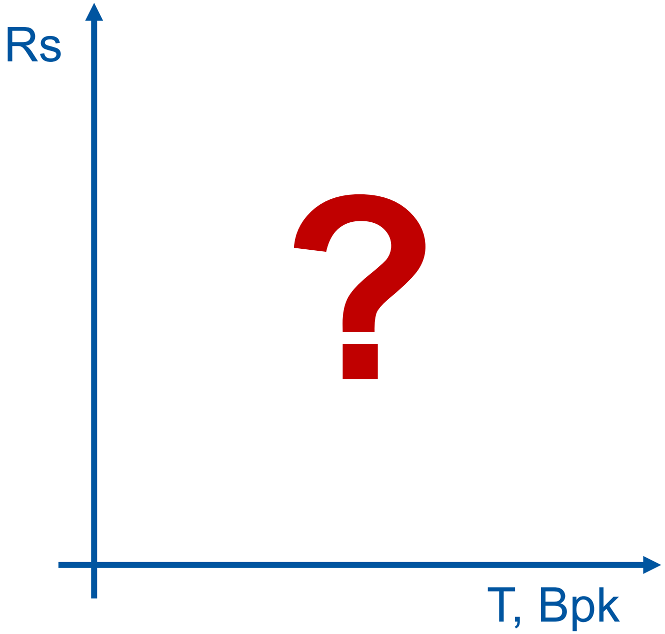
Outlines



Coatings



Measurements

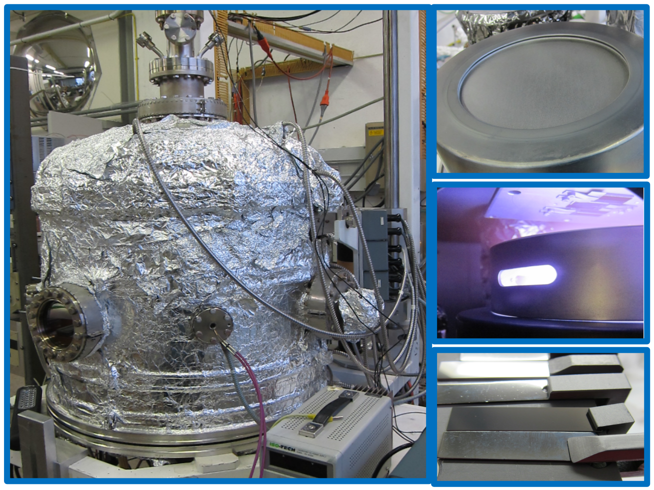


Results

Coating procedure and characterization

Coating via magnetron sputtering

Reacted
After Coating



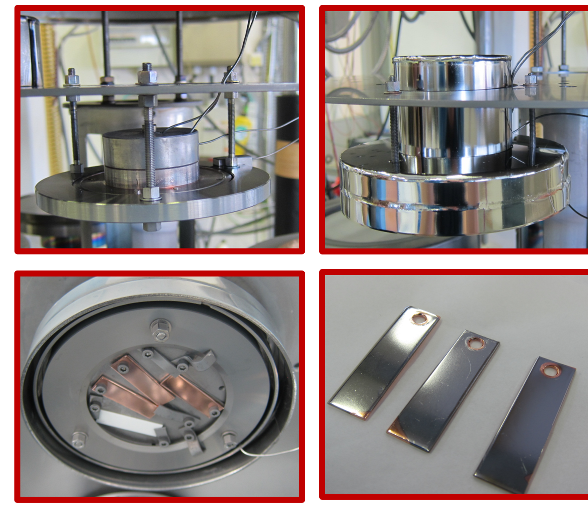
Coating parameters:

Coating gas: *Ar* or *Kr*

Coating pressures:
$7 \cdot 10^{-4}$ *mbar* … $5 \cdot 10^{-2}$ *mbar*

Composition:
Sn 20 At% to 27 At%

Reacted
During Coating



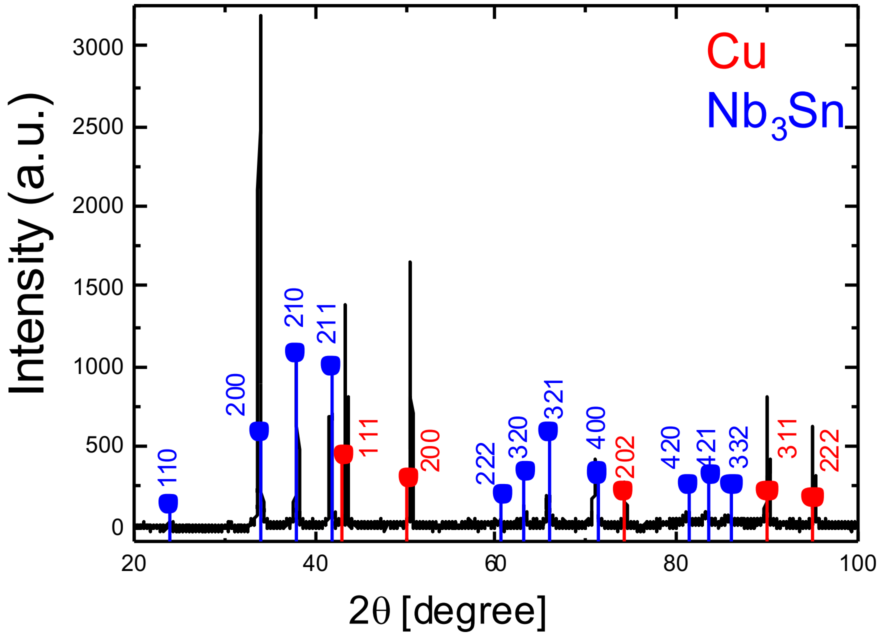
Compulsory Annealing

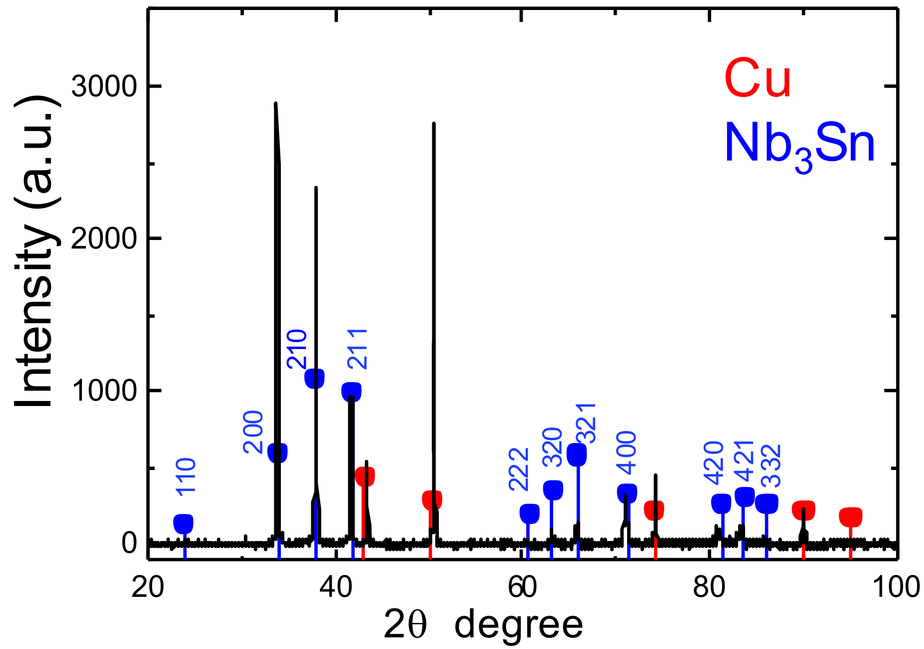
Annealing temperatures	600 - 800°C
Annealing time	24 h… 72 h

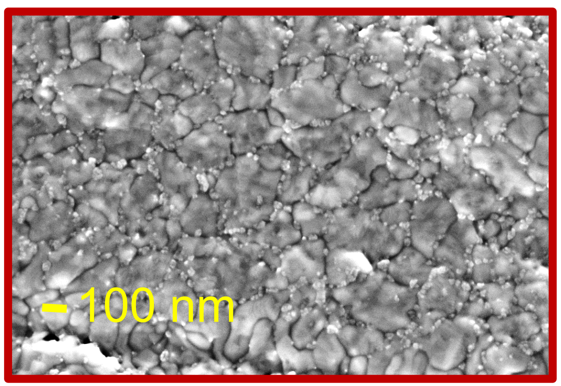
Alternative Annealing

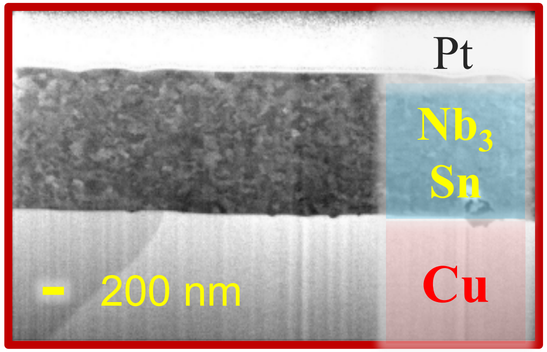
Coating temperatures	600 - 735°C
Alternative Additional Annealing	24 h… 72 h

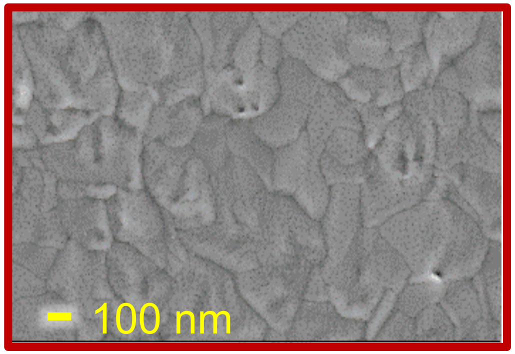
Structure and morphology





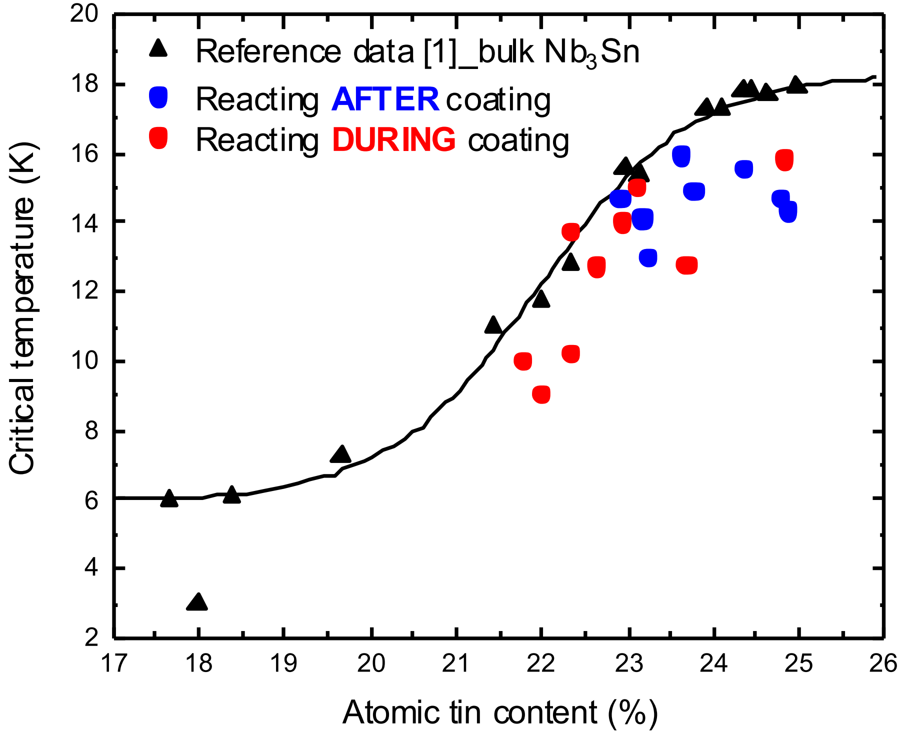


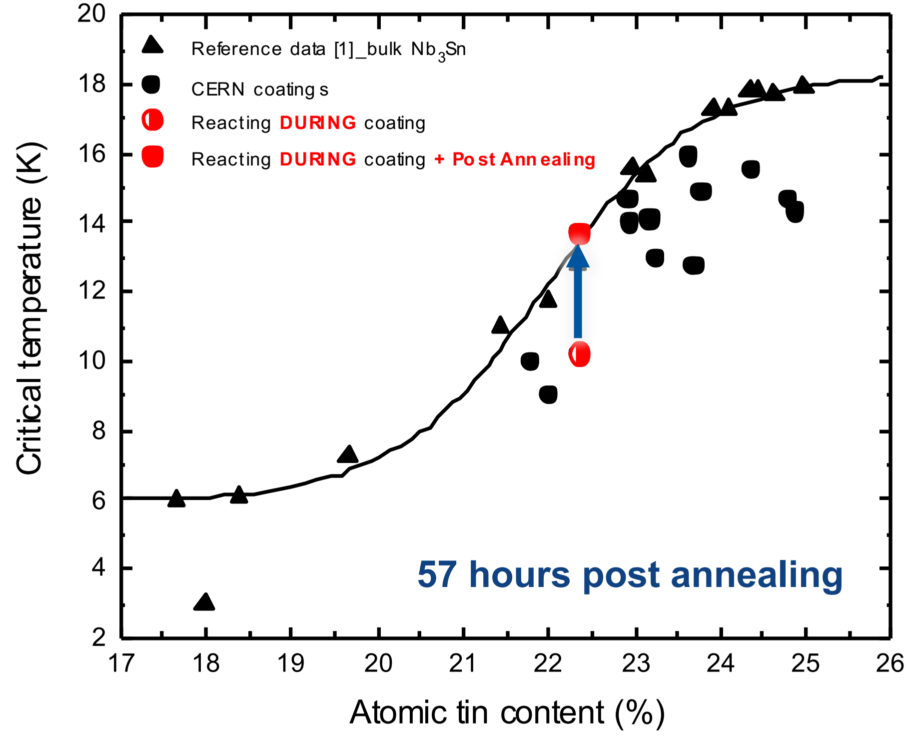




Thanks to A. Lunt (FIB-SEM) and J. Busom-Descarrega (XRD)

T_c films vs bulk





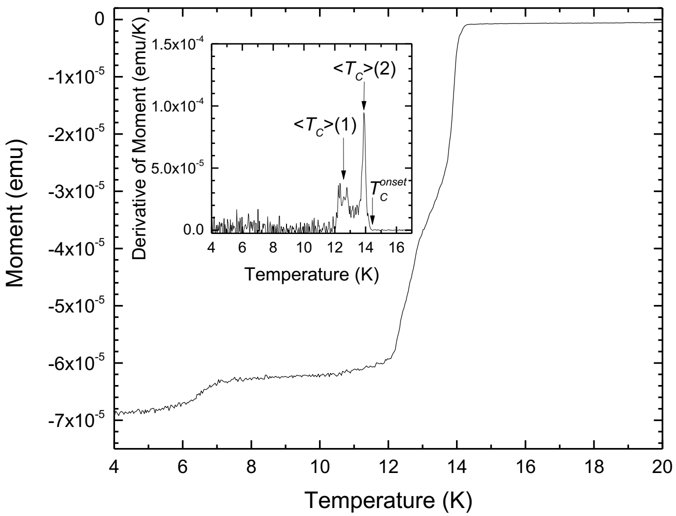
Thanks to M. Bonura and C. Senatore, University of Geneva

[1] *A. Godeke. Supercond. Sci. Technol., 19 (2006) R68-R80*

Sample 1 vs Sample 2

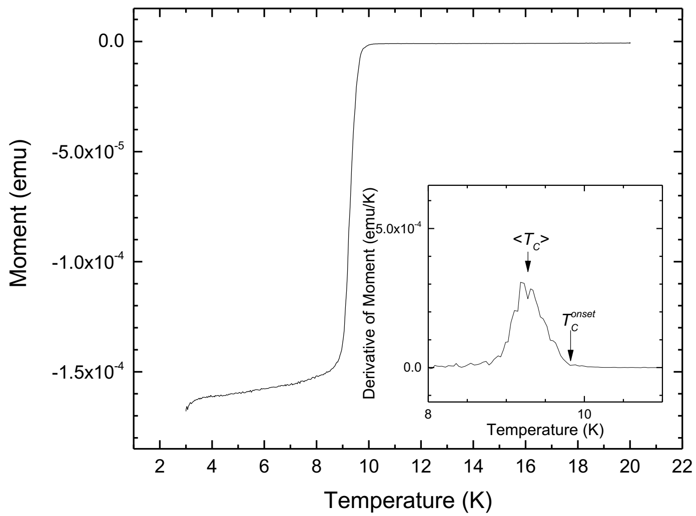
Sample 1 :

Cu / ***Nb*** / *Nb_3Sn* (~ **1.5 – 1.7** µm)
$P_{coating}$ = 7 · 10^{-3} mbar (**Kr**)
$T_{coating}$ = 680°C (real lower)
$T_{annealing}$ = 72 hours @ 670°C (real lower)



Sample 2 :

Cu / ***Ta*** / *Nb_3Sn* (~ **1.7 – 1.8** µm)
$P_{coating}$ = 5 · 10^{-3} mbar (Ar)
$T_{coating}$ = 750 °C
$T_{annealing}$ = 24 hours @ 750 °C

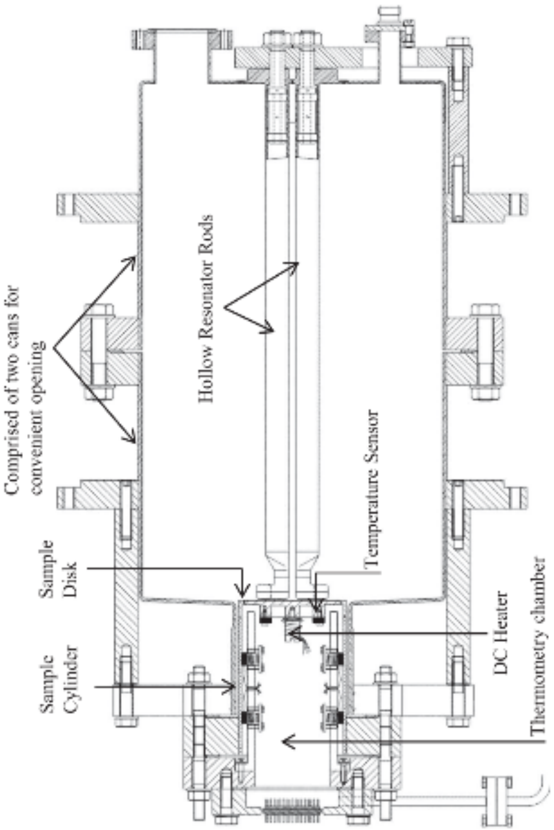


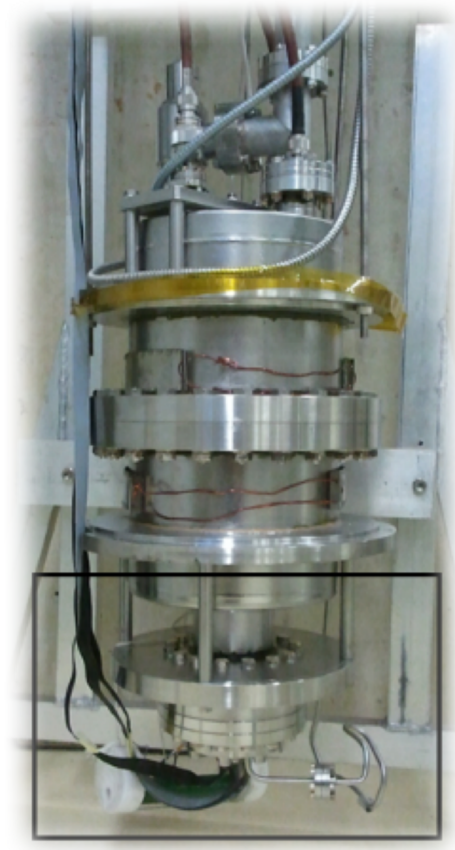
Thanks to M. Bonura and C. Senatore, University of Geneva

IR lamps heating

RF measurement setup and technique

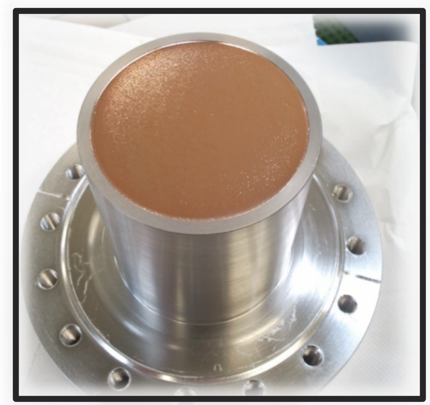
RF performances characterized via a quadrupole resonator





Calorimetric technique

$$R_s = \frac{2\mu_0^2 (P_{DC1} - P_{DC2})}{\int_{sample} |\vec{B}|^2 dS}$$



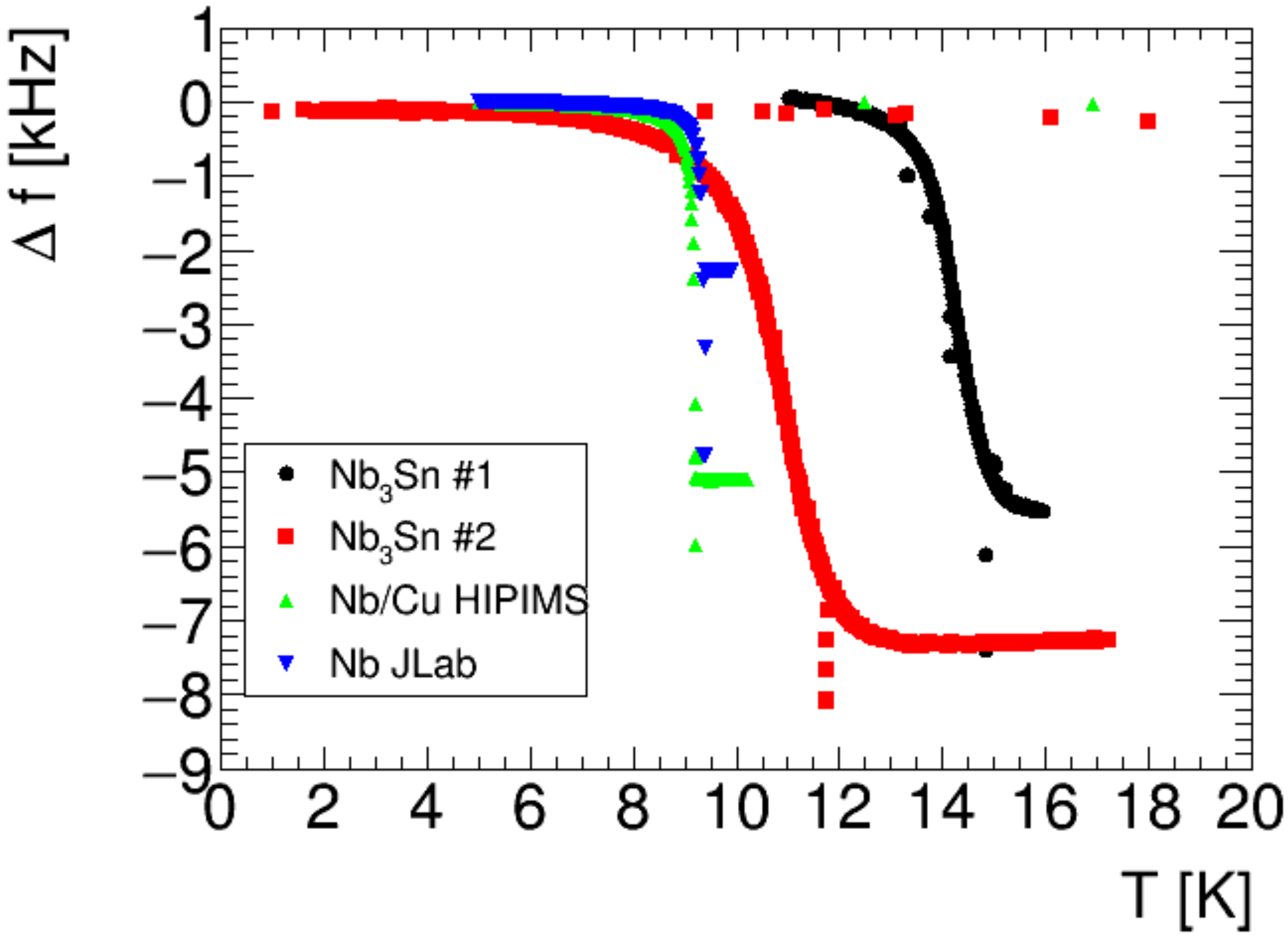
QPR pros&cons

- Multi-frequency operation: ideal for basic studies
- Small samples are easily coated and can be analyzed after the RF characterization
- Samples are more cost effective than cavities

- Limited max RF field depending on the frequency mode
- Limitations on the minimum Rs measurable
- Mechanical vibration of the rods

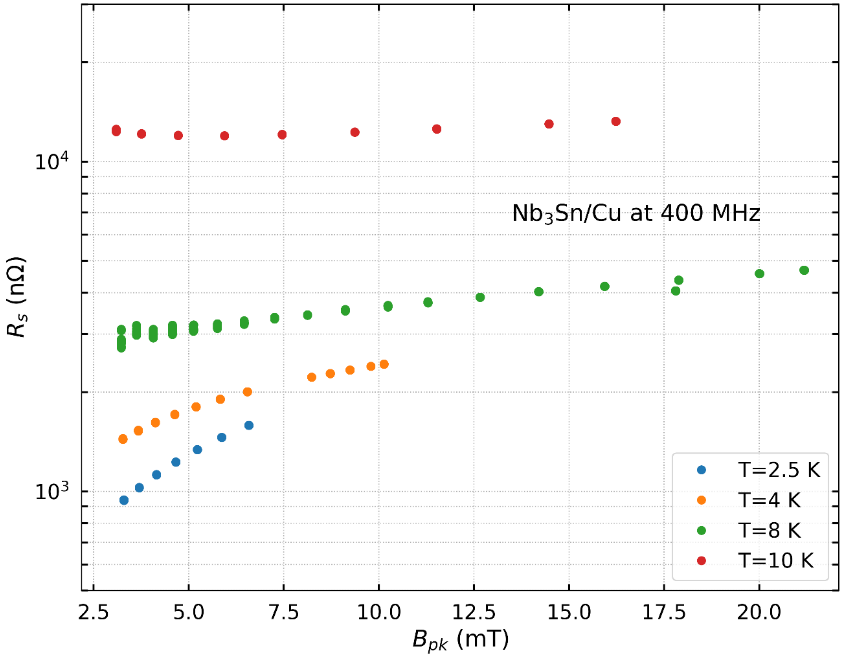
Results

Sample 1 vs Sample 2

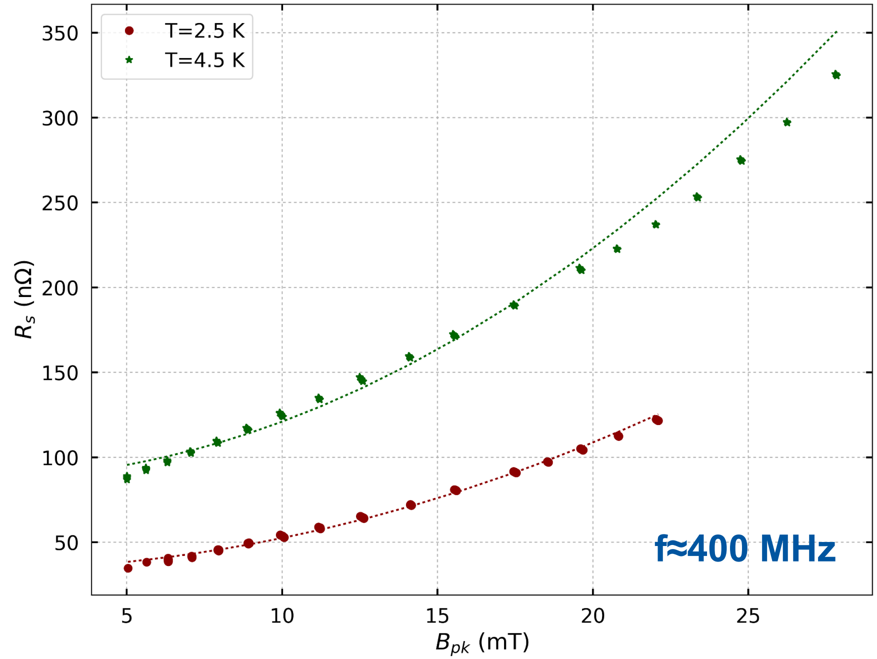


Sample 2 performs much better

Sample 1

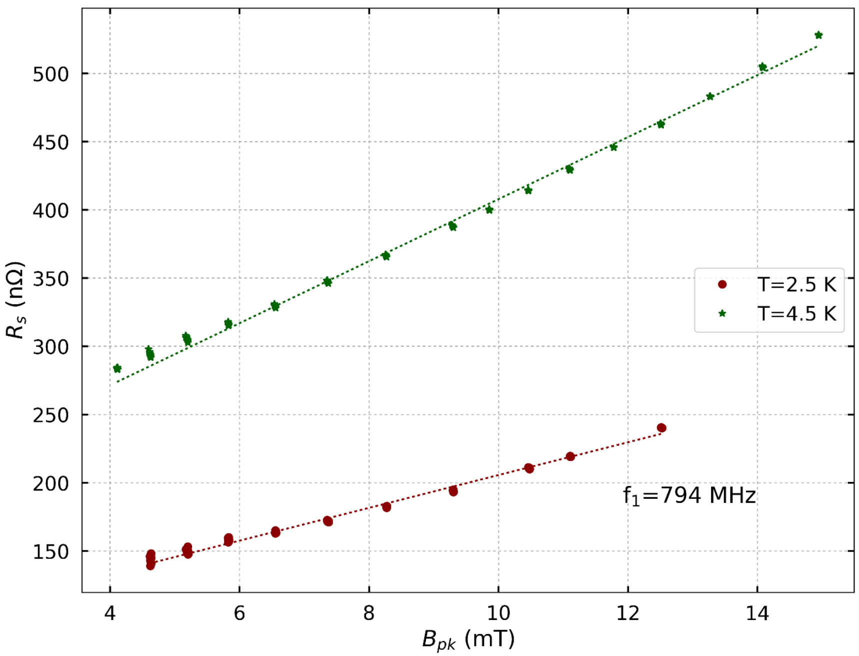


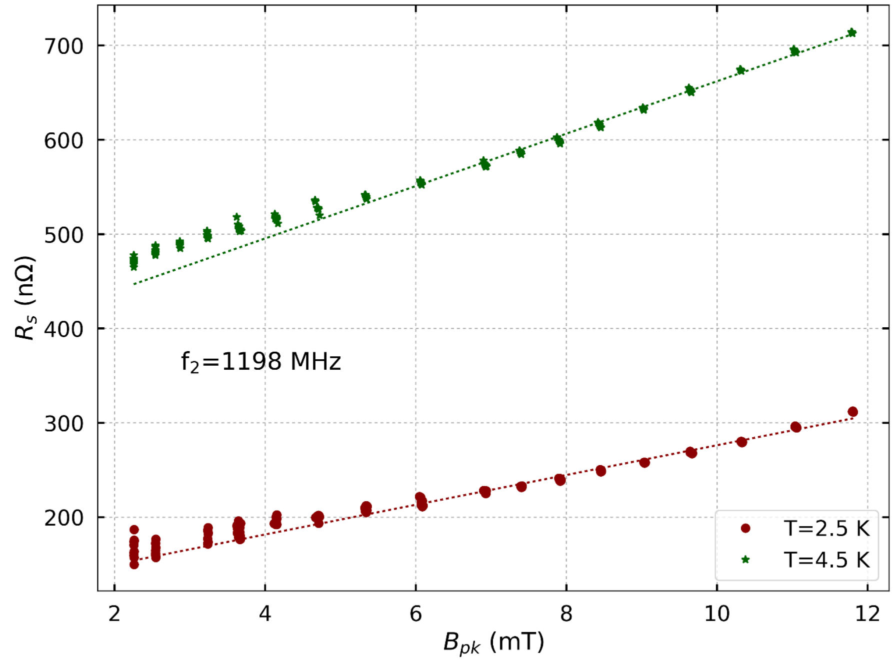
Sample 2



R_s lower by more than a order of magnitude

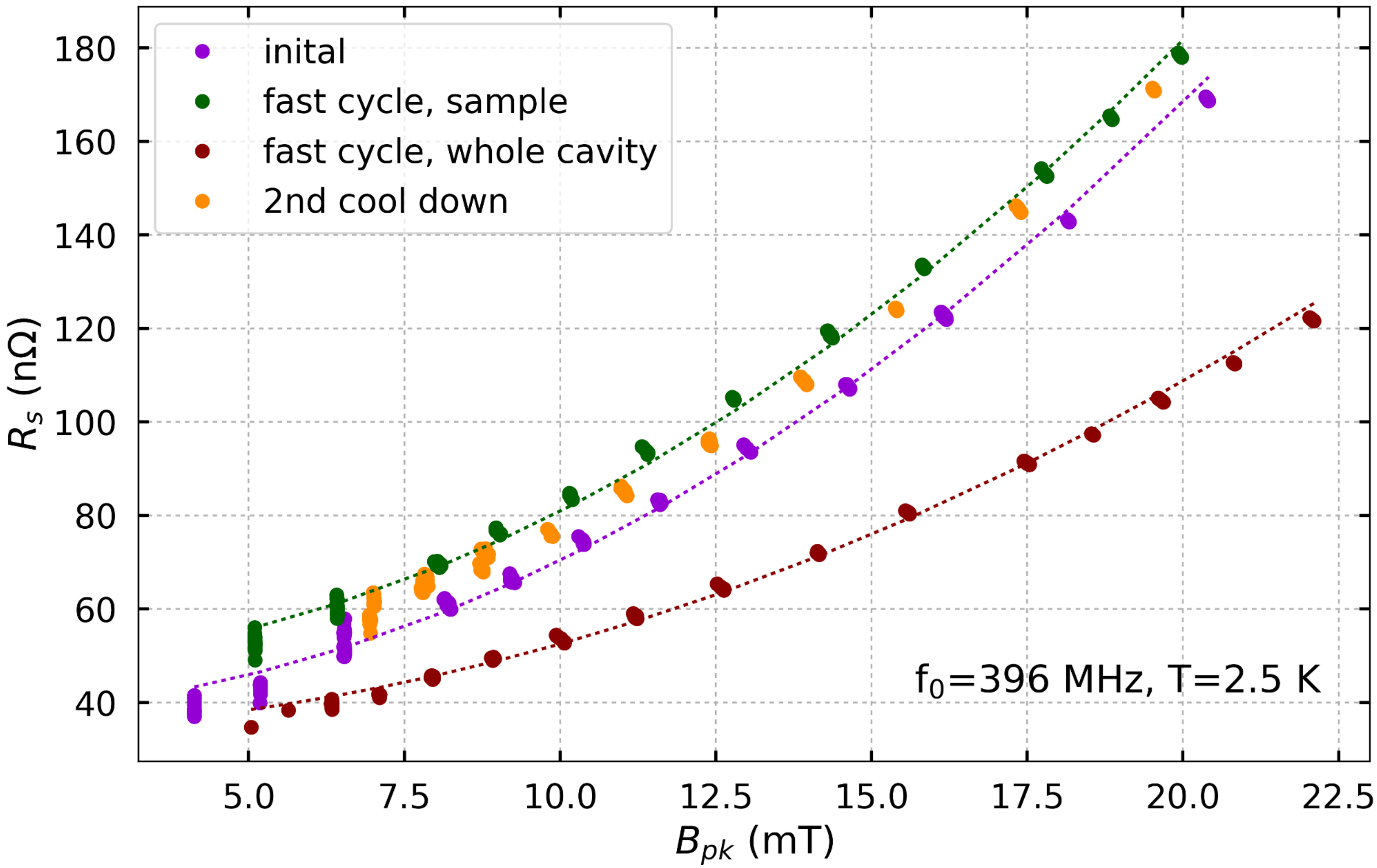
Pronounced Q-slope



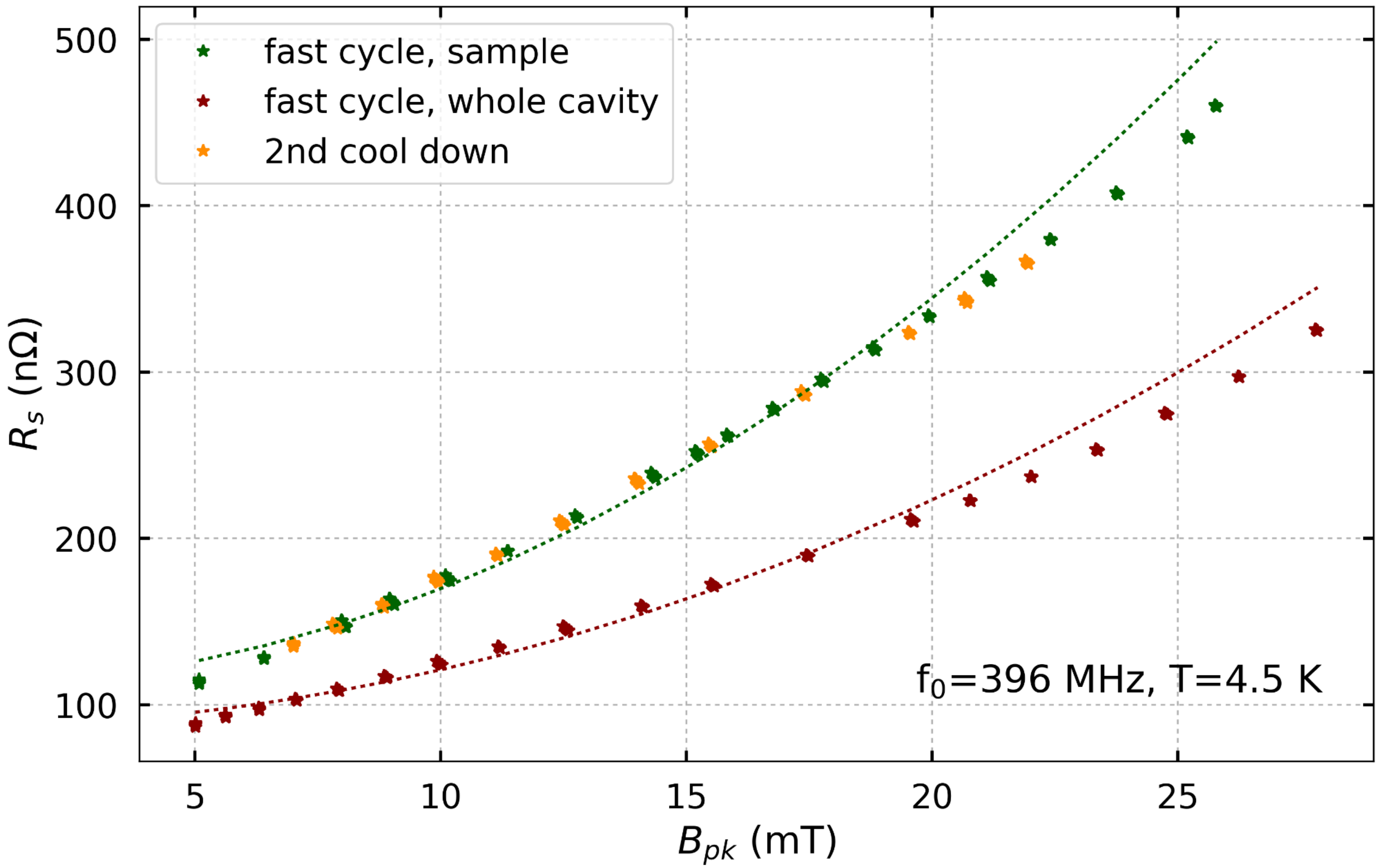


The slope increases with both temperature and frequency
It requires further investigation

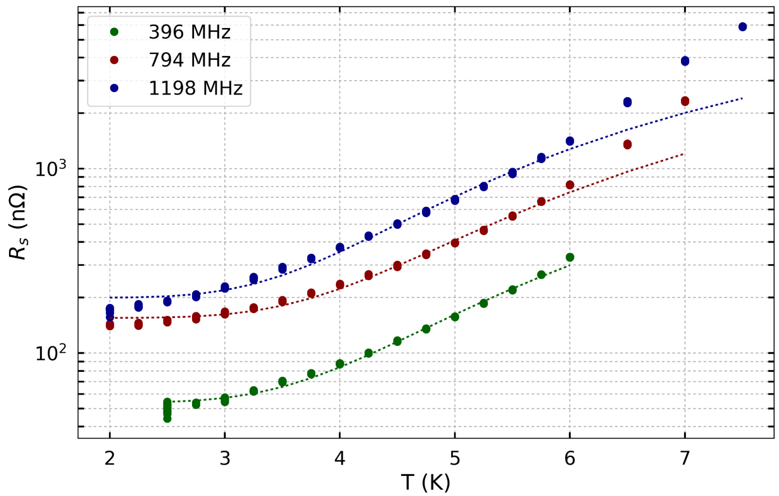
Large sensitivity to thermal cycling

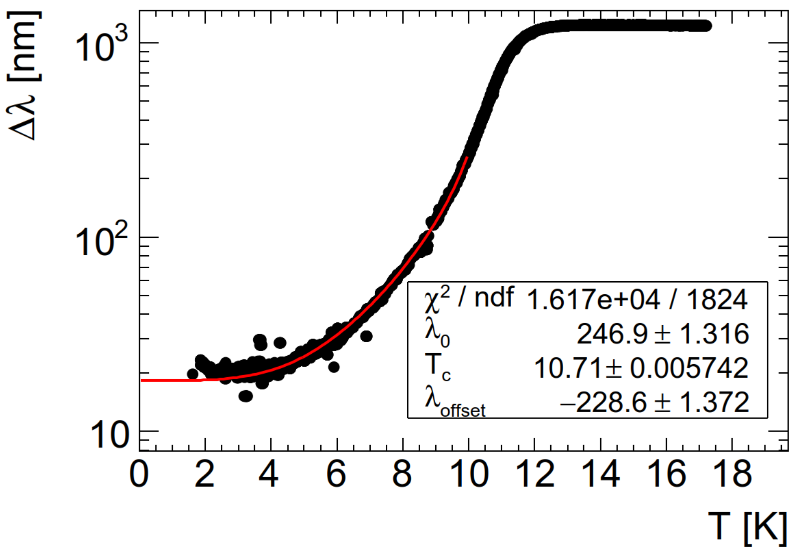


Large sensitivity to thermal cycling



BCS superconducting parameters from temperature dependence





$$R_s(T) = \frac{A}{T}\exp\left(-\frac{\Delta_0}{T}\right) + R_{res}$$

	Padamsee	This sample
ξ_0 [nm]	3.8	-
λ_L [nm]	60	-
Δ_0/T_c	2.25	2.81
T_C [K]	18.00	**10.71**
Δ_0 [K]	40.5	30.1

- Assuming (ξ_0, λ_L) gives **$l = 0.37$ nm** from λ_0 formula
- $l \ll \xi_0$ very dirty

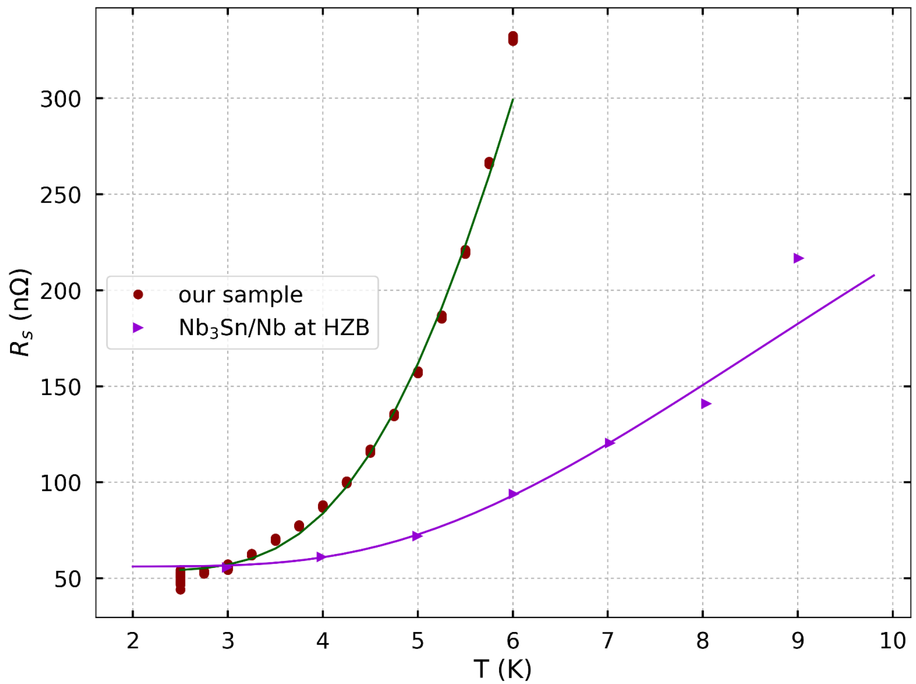
→ Reduction in T_c?

Cf. S. Posen PhD thesis $l = 1.7 - 4.8$ nm

$$\Delta\lambda(T) = \frac{\lambda_0}{\sqrt{1-(T/T_c)^4}} + \lambda_{\text{offset}}$$

$$\lambda_0(l) = \lambda_L\sqrt{1+\frac{\pi\xi_0}{2l}}$$

Aiming at larger mean free path



S. Keckert et al., SRF2017

	our sample	HZB
$A(\xi_0, \lambda_L, l)$ [nΩK]	2.23x10^5	2.99x10^4
Δ_0 [K]	30.1	29.9
R_{res} [nΩ]	53.8	56.1

BCS parameter *A* is the major difference

Very short mean free path could explain this

↓

Full BCS parameter determination necessary

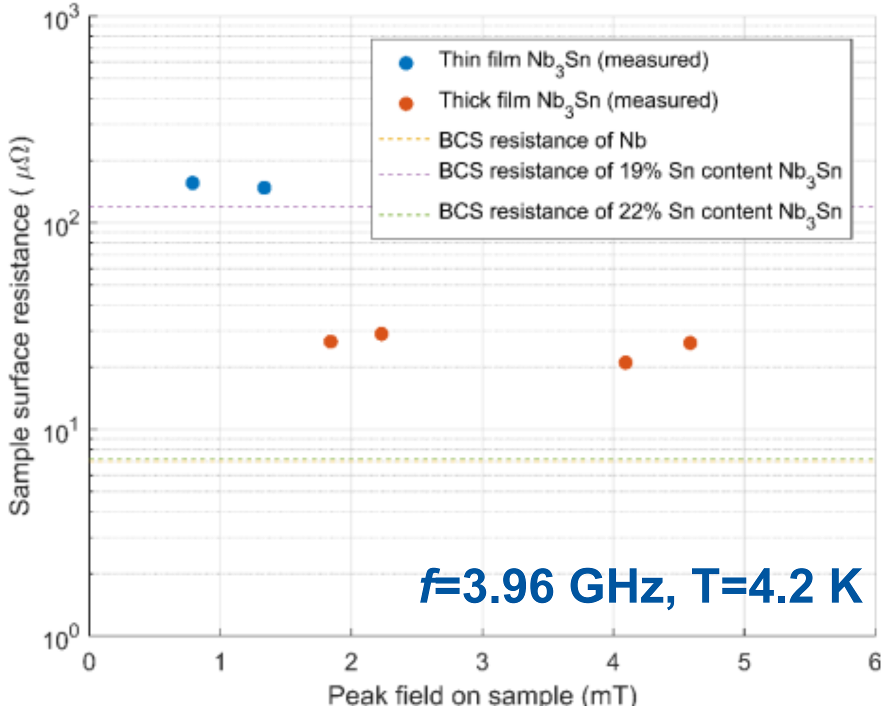
Our films compare to state of the art Nb_3Sn on copper

Table 1: Material Parameters (from literature) [2] [1] [6] [7]

	Clean Nb	19% Sn Nb_3Sn	22% Sn Nb_3Sn	T_c = 11 K NbN
T_c (K)	9.2	6	12	11
$\frac{\Delta}{k_b T_c}$	1.89	1.5	1.5	2
λ (nm)	39	89	89	450
ξ (nm)	38	7	7	4
l (nm)	1000	2	2	6

$$R_{BCS} \propto f^2$$

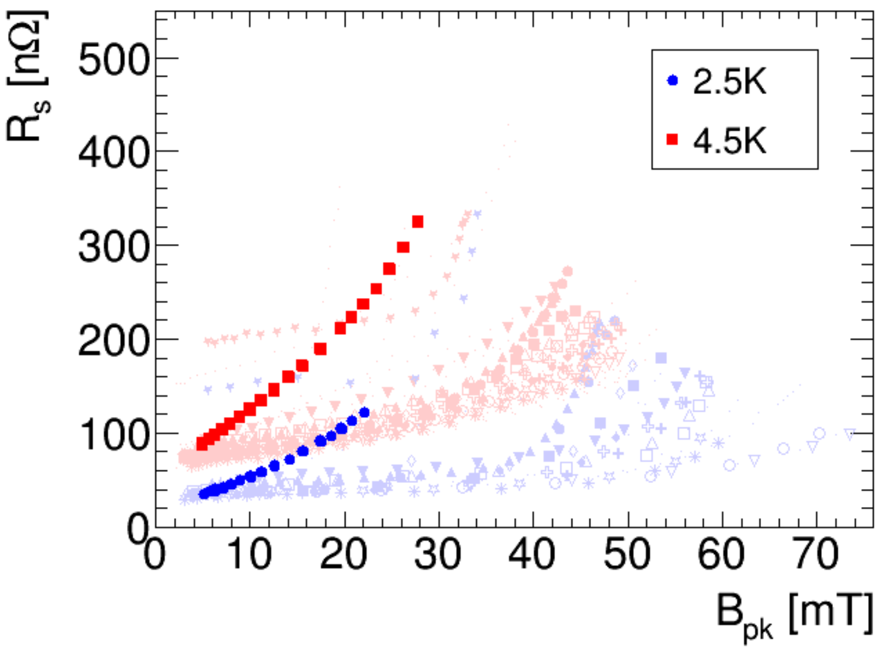
$$R_{BCS} \approx 200\ n\Omega$$



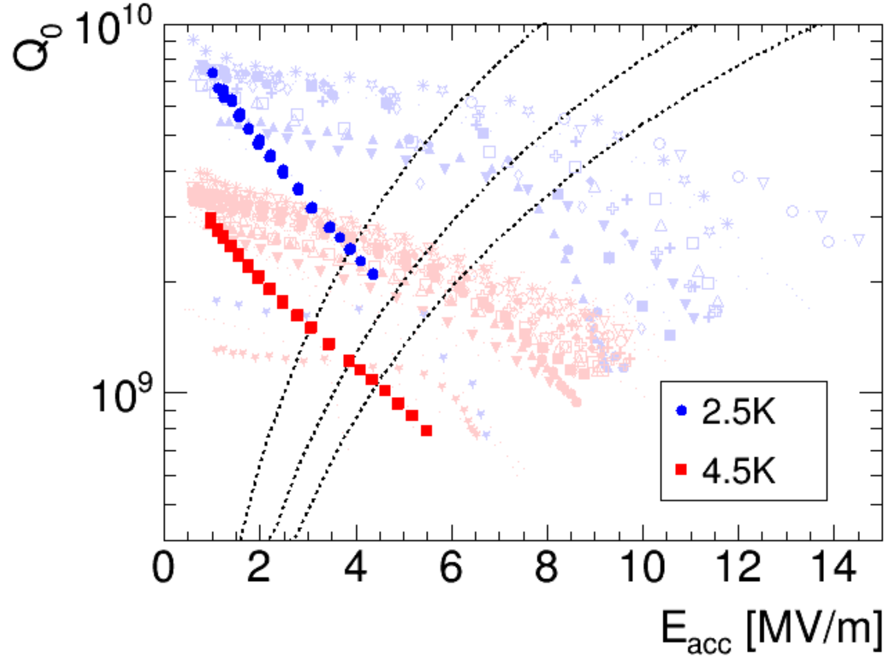
T. Oseroff et al., IPAC2018

Comparing to Nb/Cu LHC cavities

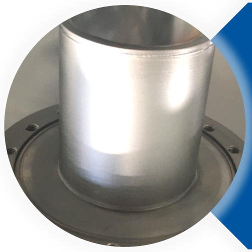
Best cool down



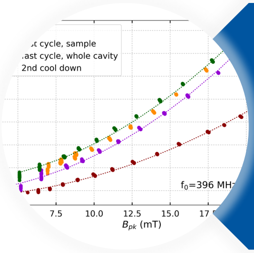
Predicted Q vs E assuming uniform coating



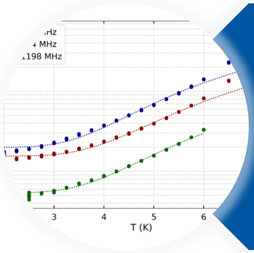
Conclusions



Good quality of the Nb_3Sn coatings

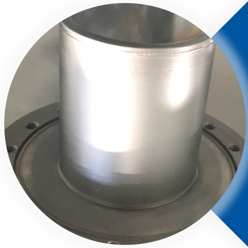


Low residual resistance

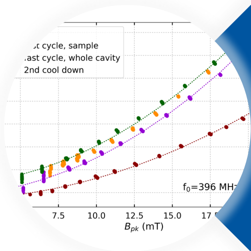


Pronounced Q-slope and very short mean free path

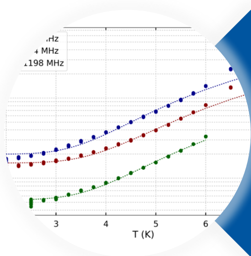
Conclusions



Good quality of the Nb_3Sn coatings



Low residual resistance



Pronounced Q-slope and very short mean free path

There are reasons to be very optimistic

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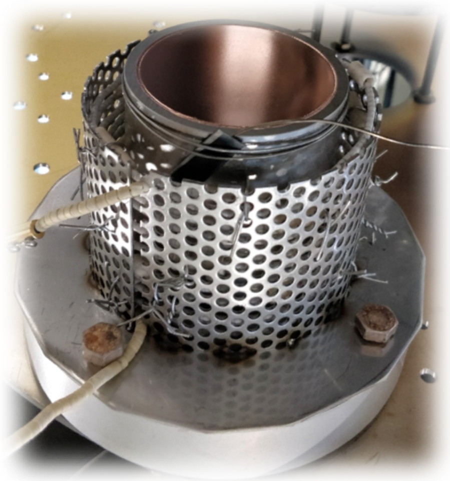
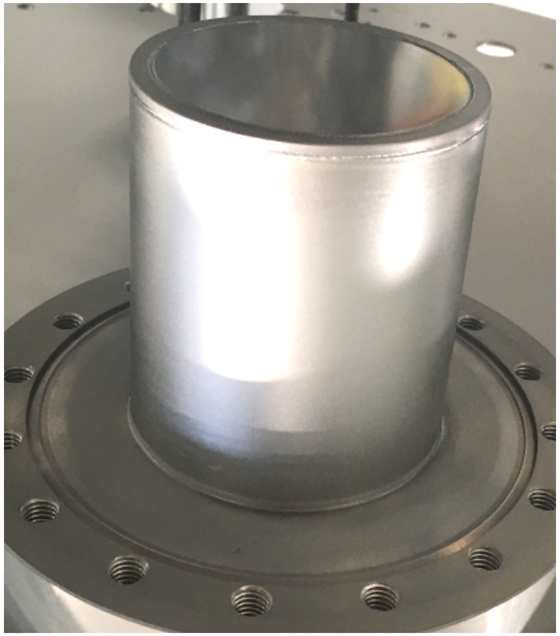
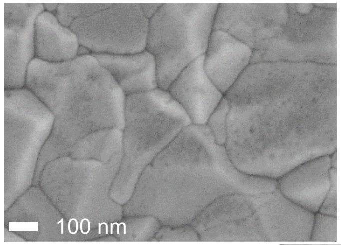
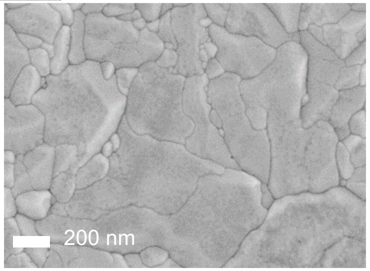
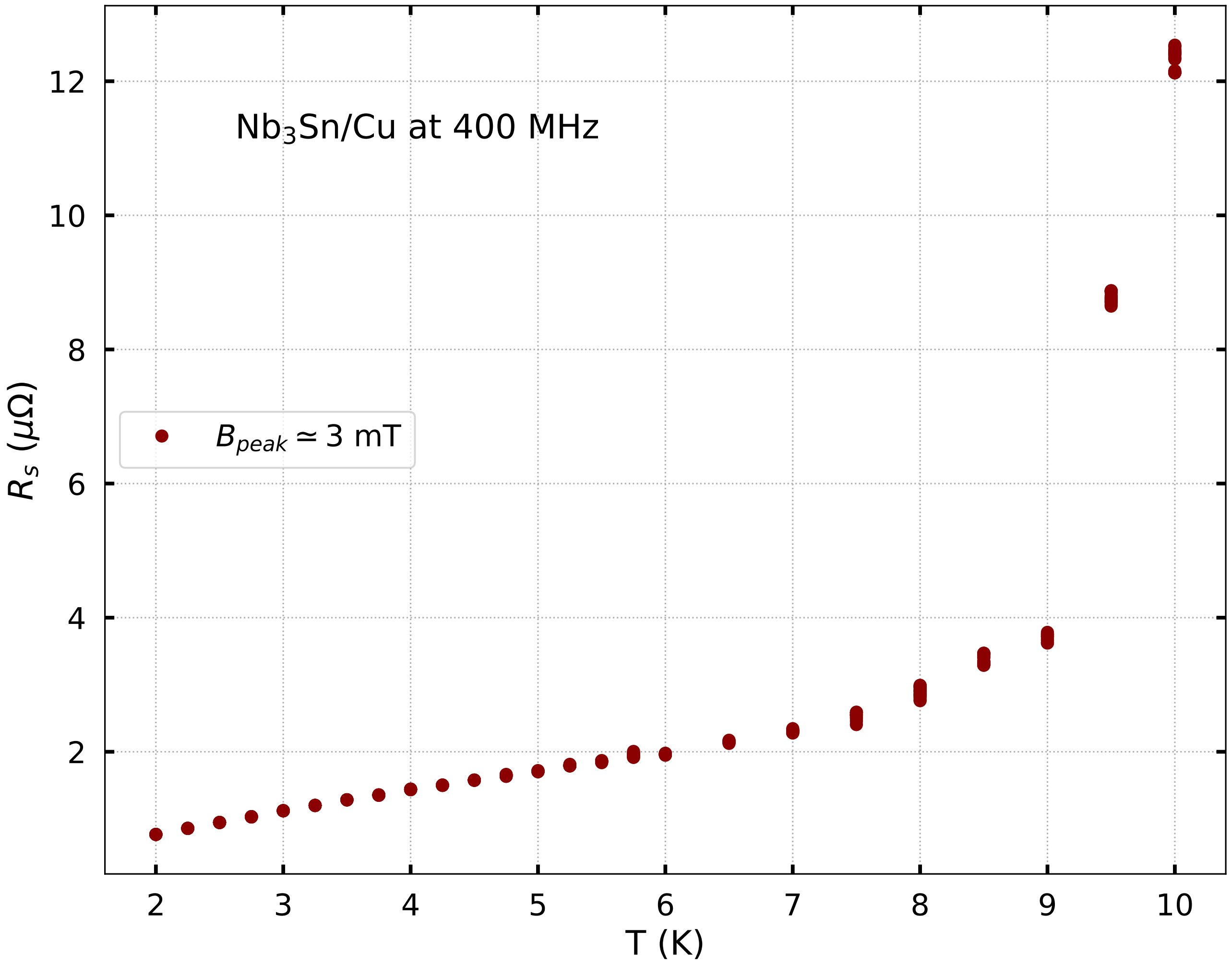


Desired coating conditions could not be reached









Nb3Sn/Cu at 400 MHz
$B_{peak} \simeq 3$ mT
R_s ($\mu\Omega$)
T (K)
2
4
6
8
10
12
2
3
4
5
6
7
8
9
10

Cf. T_c reduction by short l

J. T. Rairden and C.A. Neugebauer "Critical Temperature of Niobium and Tantalum Films", Proc. IEEE 52, 10, p1234-1238 (1964)

Higher substrate temperature during deposition
→ lower impurity (oxygen contect)→ higher T_c

In case of Nb

$$T_c = 9.46 - \frac{2.48}{RRR} = 9.46 - \frac{6.7}{l\,[\mathrm{nm}]}\ [\mathrm{K}]$$

If $l \ll \xi_0$, T_c could be reduced drastically

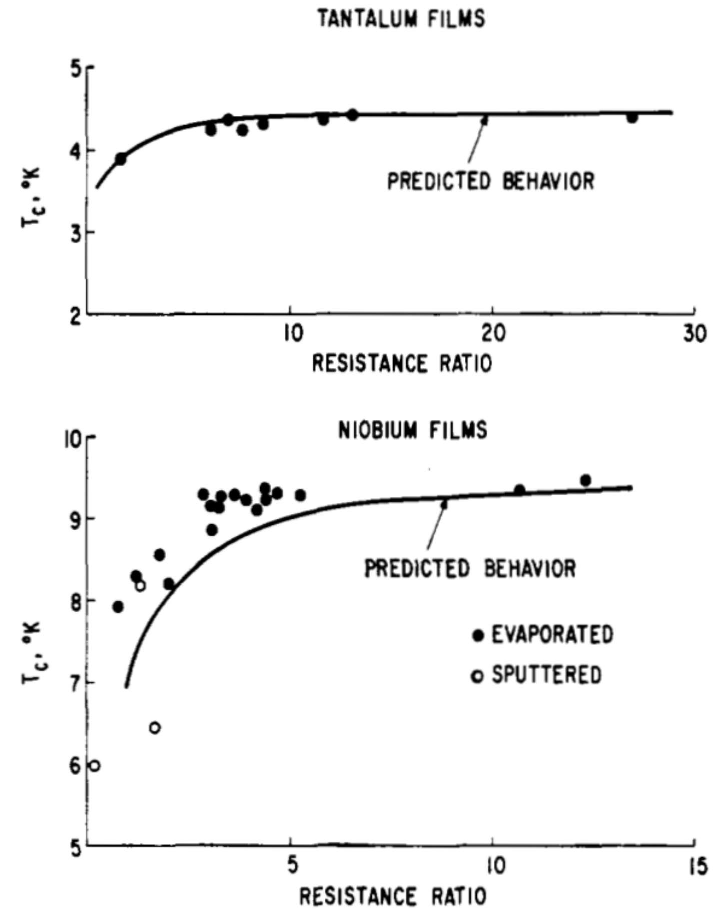
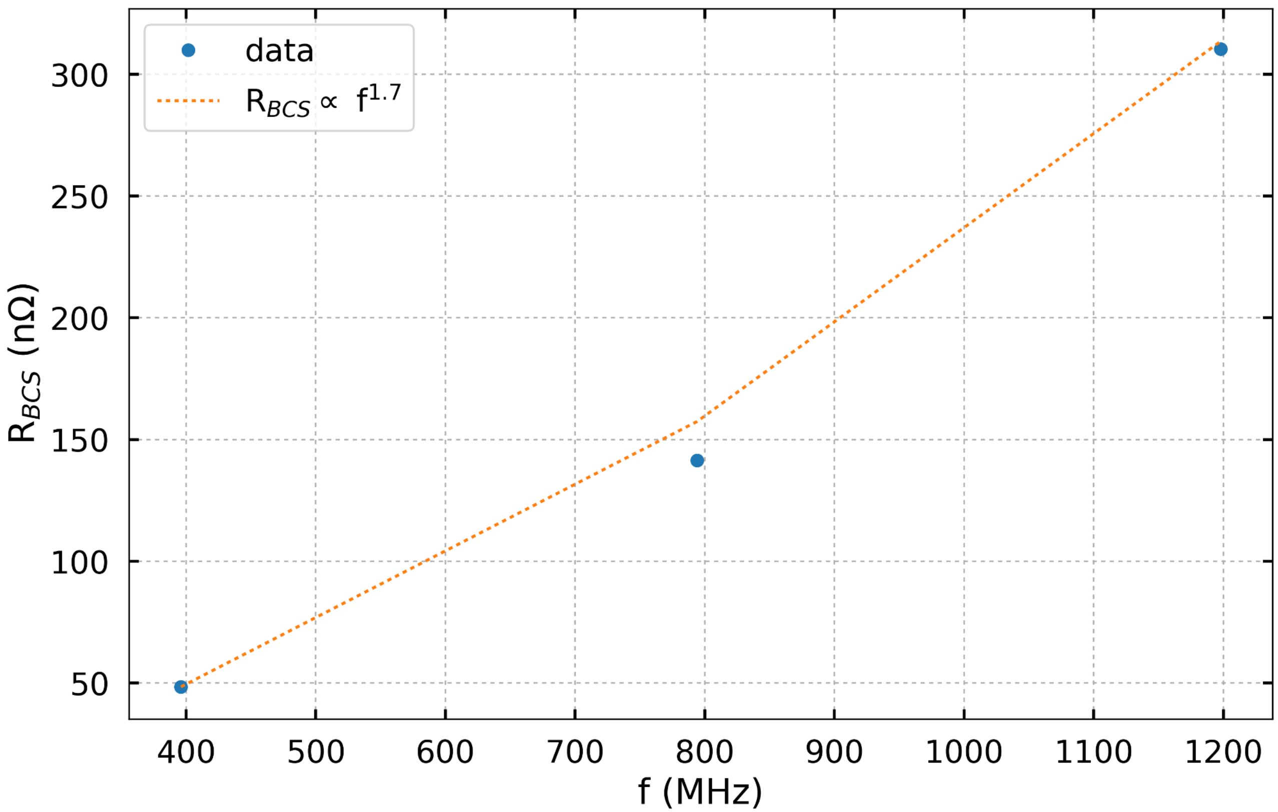


Fig. 3—Critical temperatures of Niobium and Tantalum films as a function of their resistance ratio.


data
$R_{BCS} \propto f^{1.7}$
300
250
200
150
100
50
R_{BCS} (nΩ)
400
500
600
700
800
900
1000
1100
1200
f (MHz)