The role of cool down dynamics on the performance on Nb/Cu cavities

– HIE-ISOLDE resonator as an example–

A. Miyazaki[1,2], W. V. Delsolaro[1], Y. Kadi[1], K. Schirm[1], A. Sublet[1], S. Teixeira Lopez[1], M. Therasse[1]

[1] *Organisation européenne pour la recherche nucléaire* (CERN), Switzerland

[2] *School of Physics and Astronomy, the University of Manchester, UK*

Email: Akira.Miyazaki@cern.ch

SRF2017 @ 蘭州

Contents

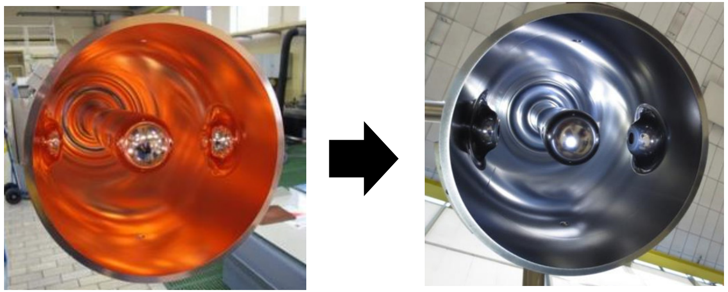
- HIE-ISOLDE Nb/Cu cavity
- Cool down dynamics and thermal gradient
- Study on thermoelectric current
- Cool down dynamics of the seamless cavity
- Summary

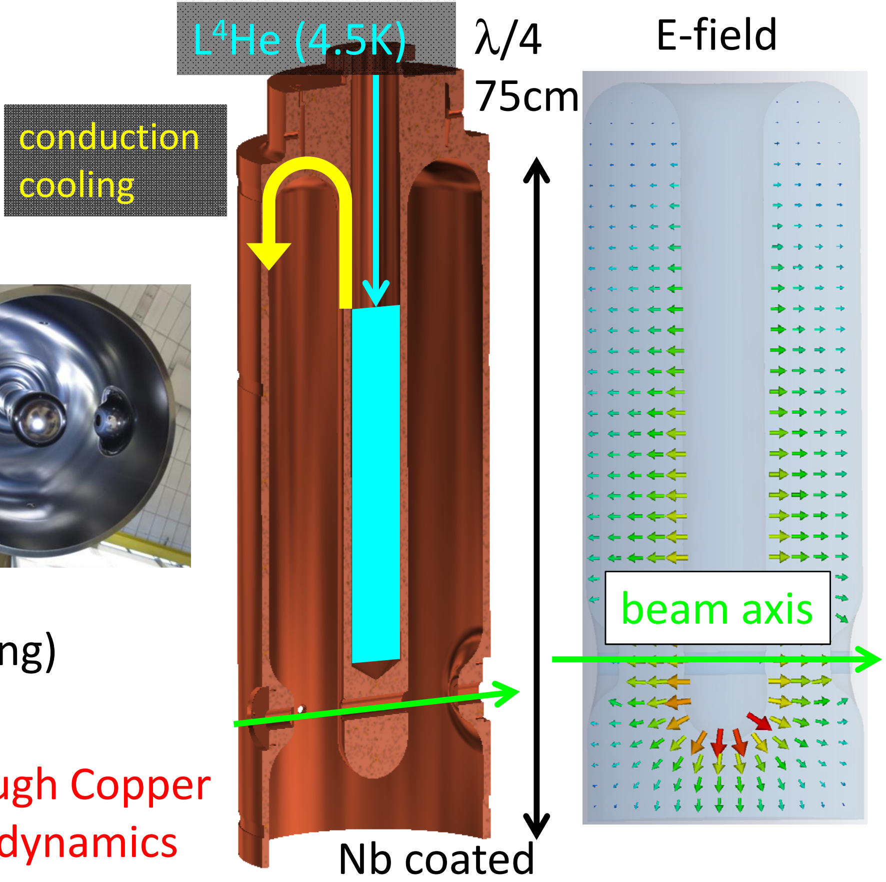
Contents

- HIE-ISOLDE Nb/Cu cavity
- Cool down dynamics and thermal gradient
- Study on thermoelectric current
- Cool down dynamics of the seamless cavity
- Summary

HIE-ISOLDE Nb/Cu Quarter-wave Resonator

f_0 MHz	101.28
E_{acc} MV/m	6
B_{peak} mT	58
Q_0	4.7×10^8



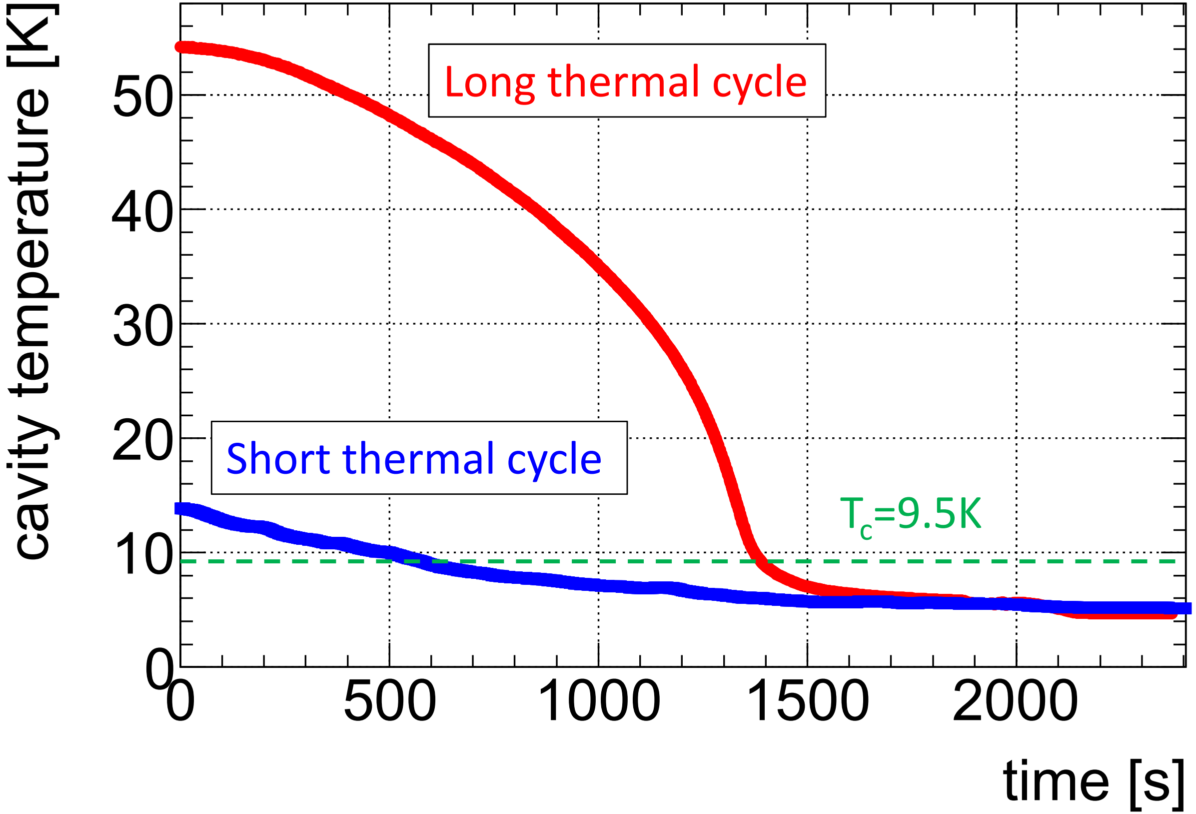


- Nb film (DC-bias sputtering)
- Common vacuum
- Conduction cooling through Copper
  → Interesting cool down dynamics

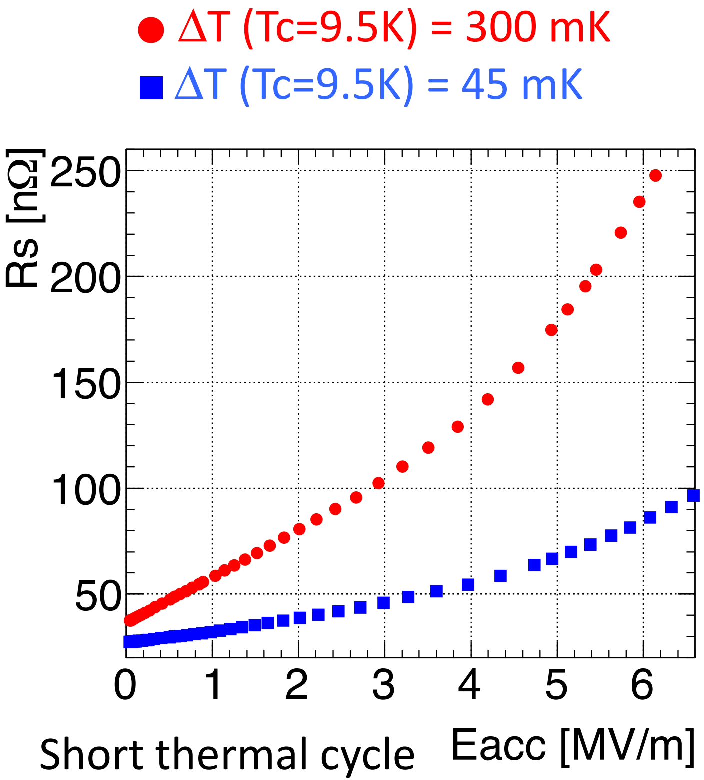
Contents

- HIE-ISOLDE Nb/Cu cavity
- Cool down dynamics and thermal gradient
- Study on thermoelectric current
- Cool down dynamics of the seamless cavity
- Summary

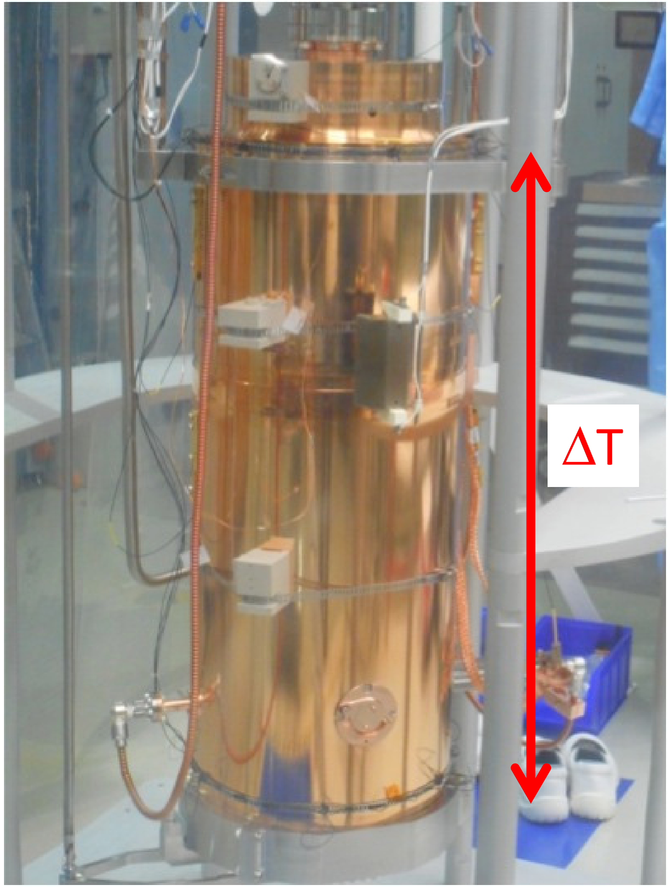
Typical cool down processes



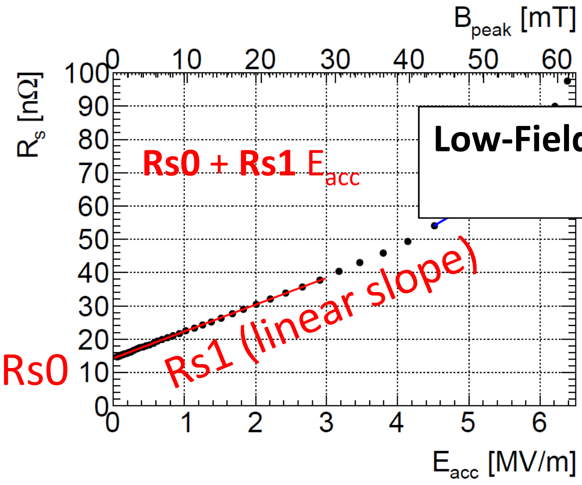
Rs *strongly* depends on the thermal gradient ΔT



Short thermal cycle
→ Uniform cool down
→ Better performance



Both Q_0 and Q-slope depend on ΔT



Come to my poster THPB047

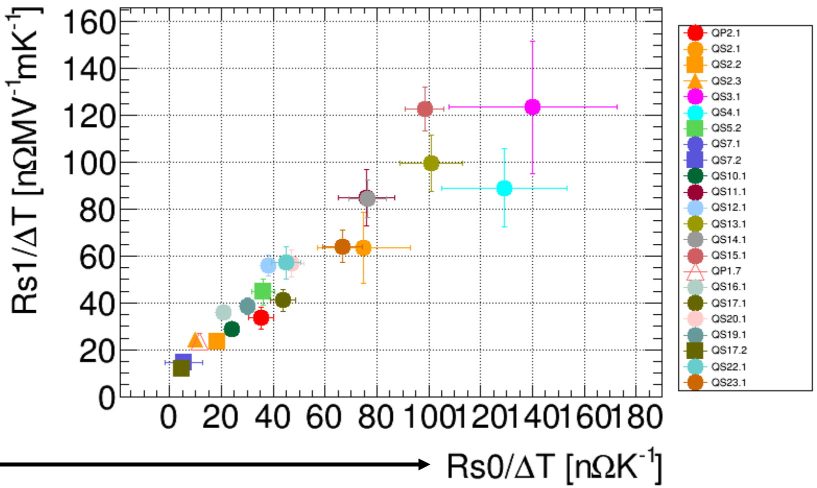
Low-Field slope component
$Rs1 \propto \Delta T$

The linear fit is valid up to B_{peak}/B_c=0.15

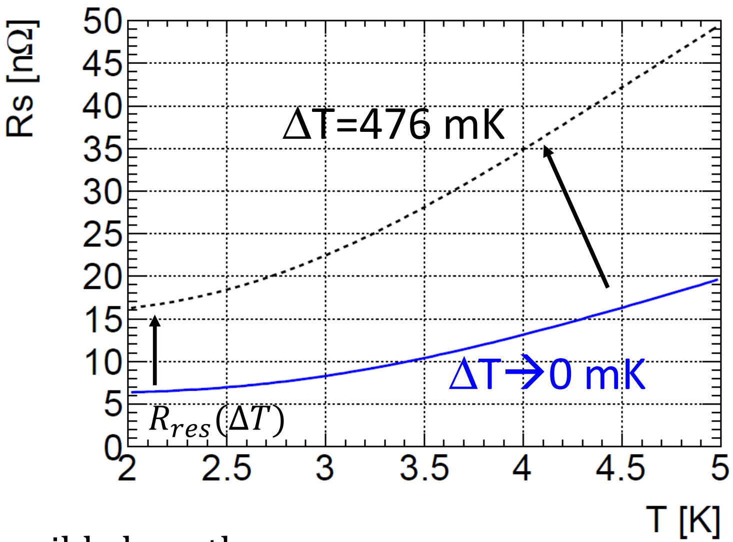
$(B_c = 200\ mT)$

Low-Field surface resistance
$Rs0 \propto \Delta T$

Correlation factor 95%



ΔT effect at low RF field



- The residual component is bigger
- The T-slope is steeper

Possible hypotheses

i) An additional term is added

Come to my poster THPB046

$$R_s(T;\Delta T) = R_{BCS}(T) + \boldsymbol{R_{new}(T;\Delta T)} + R_{res}(\Delta T)$$

→ Not easy to reproduce $\exp(-\Delta/T)$ (quasi-particles' thermal excitation)

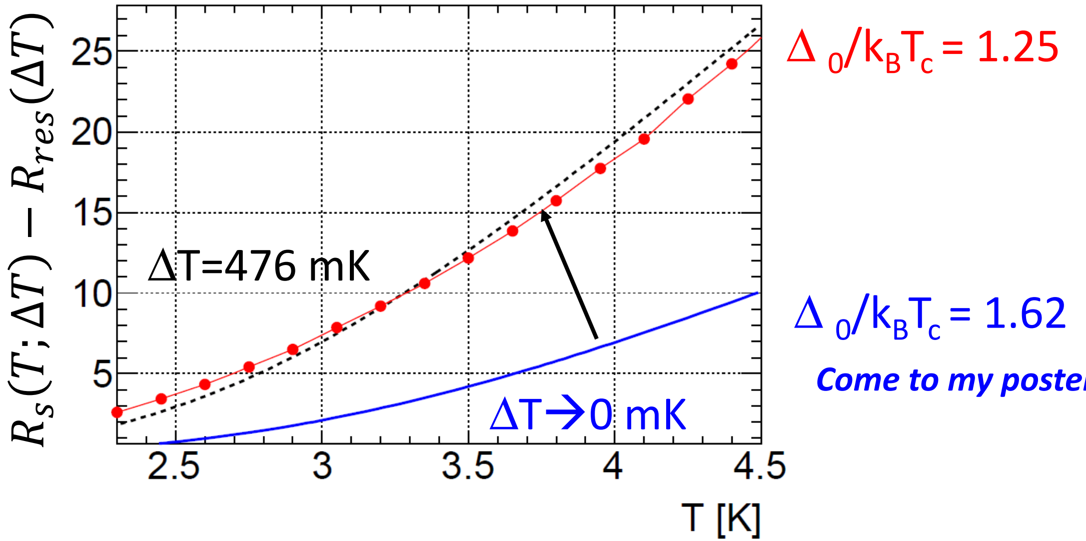
ii) Modified BCS term [in Tayler expansion $R'_{BCS}(T;\Delta T) \propto \Delta T \times R_{BCS}(T)$]

$$R_s(T;\Delta T) = \boldsymbol{R'_{BCS}(T;\Delta T)} + R_{res}(\Delta T)$$

iii) Some of the BCS material parameters are affected by ΔT

$$R_s(T;\Delta T) = R_{BCS}[T;\boldsymbol{x(\Delta T)}] + R_{res}(\Delta T)$$

Decrease coupling Δ_0/k_BT_c



Come to my poster THPB046

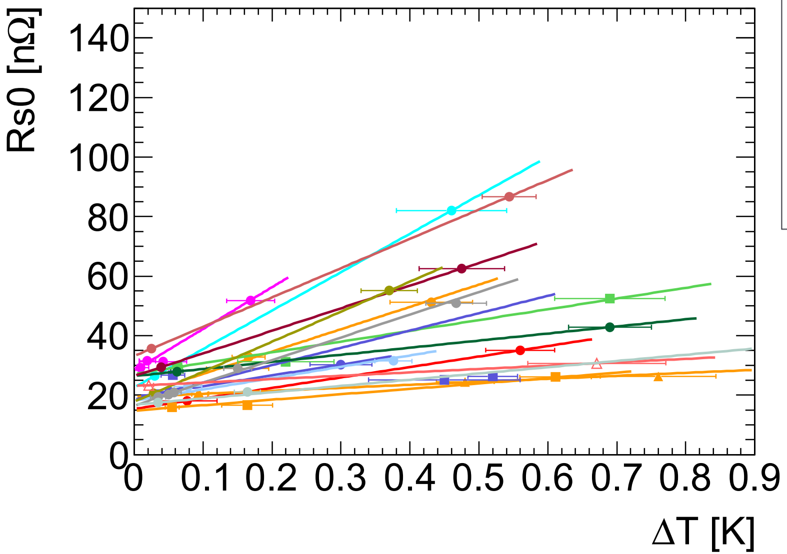
$0.77\times\Delta_0/k_BT_c$ ($\Delta T=0$) can reproduce the degraded Rs (T) by thermal gradient

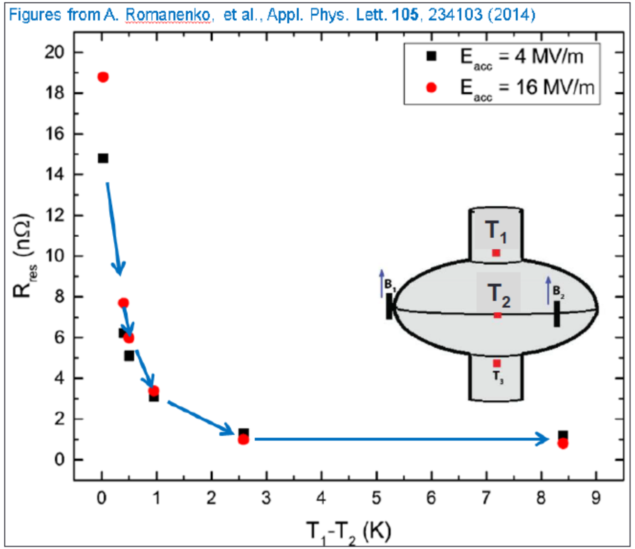
→ **Gap reduction by a supercurrent produced by ΔT?**

→ A current comparable to J_c is required ☹

Comparison with bulk Nb cavities

Experiments by A. Romanenko explained by T. Kubo (TTC2015)
→ More efficient flux expulsion by bigger ΔT





Bulk Nb: $R_s \propto 1/\Delta T$

Our Nb/Cu: $R_s \propto \Delta T$

OPPOSITE! ☺

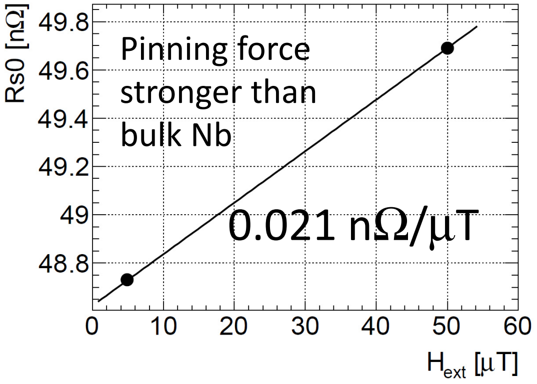
A possible interpretation is **trapped flux produced by thermoelectric effect**

Contents

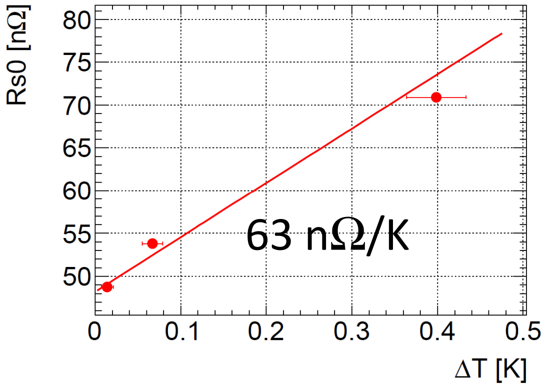
- HIE-ISOLDE Nb/Cu cavity
- Cool down dynamics and thermal gradient
- Study on thermoelectric current
- Cool down dynamics of the seamless cavity
- Summary

Estimated B-field produced by ΔT

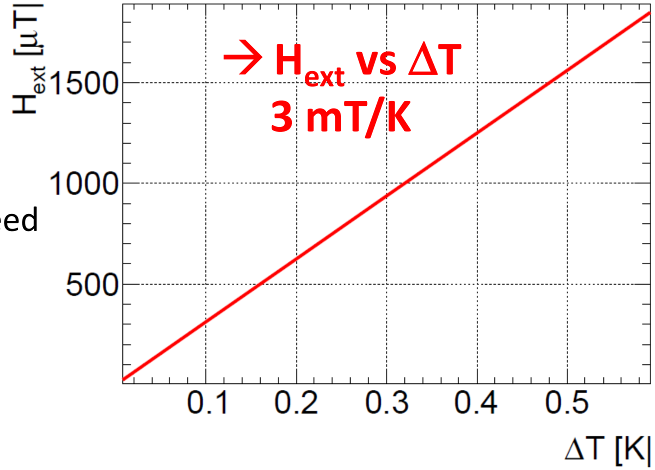
Rs0 vs H_{ext} (constant ΔT)



Rs0 vs ΔT (constant H_{ext})

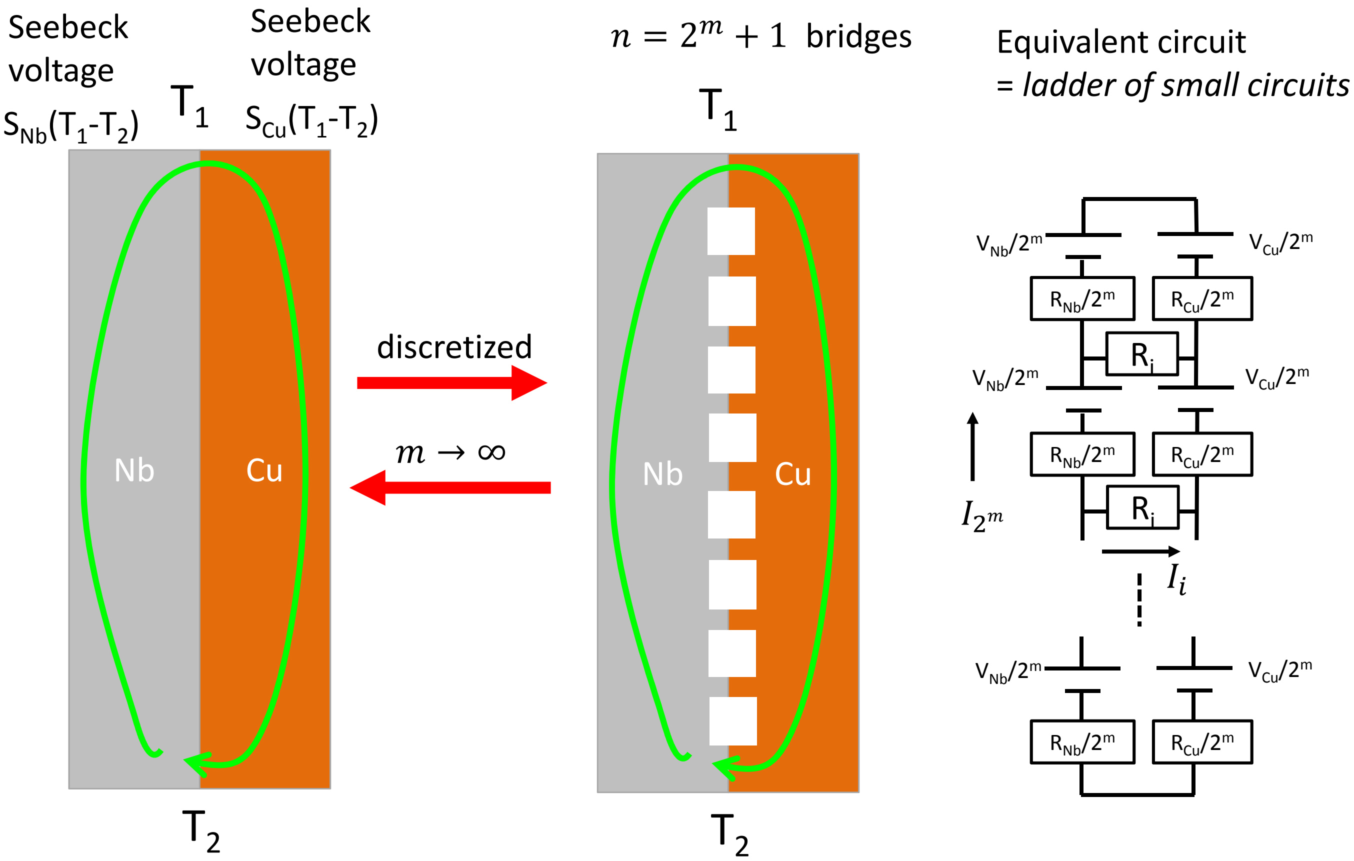


Linearity at H_{ext} >> 100 μT is not guaranteed



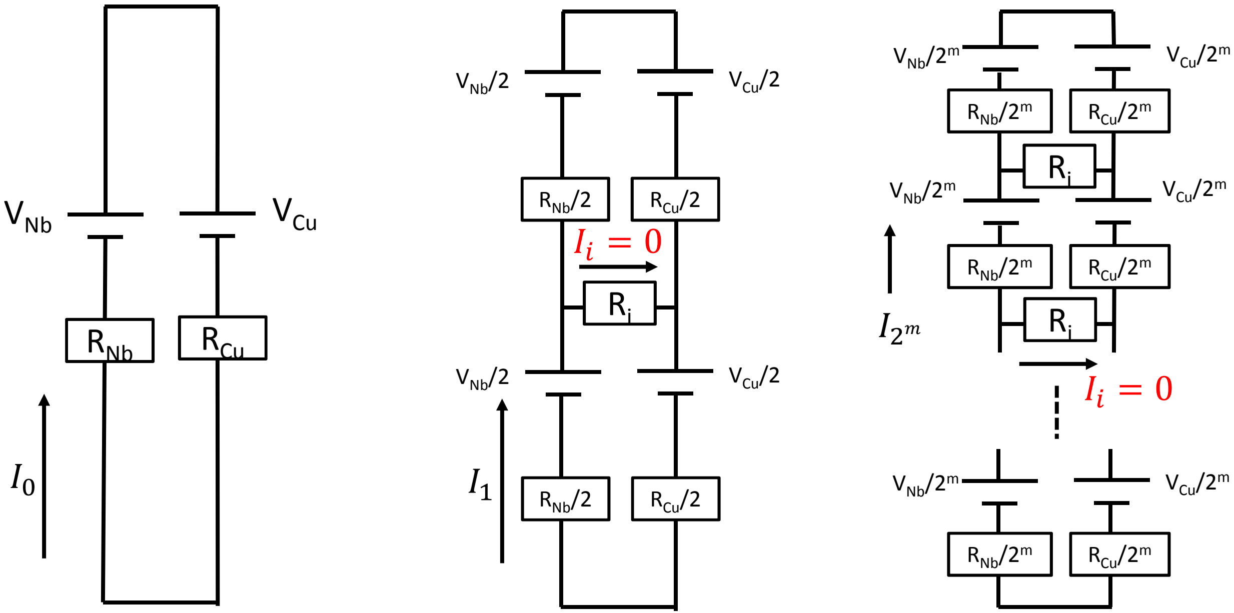
Can we produce such a huge field by thermoelectric effect?

Thermoelectric current in bi-metal structure 1/2



Thermoelectric current in bi-metal structure 2/2

No bridge | $n = 1$ bridge | $n = 2^m + 1$ bridges



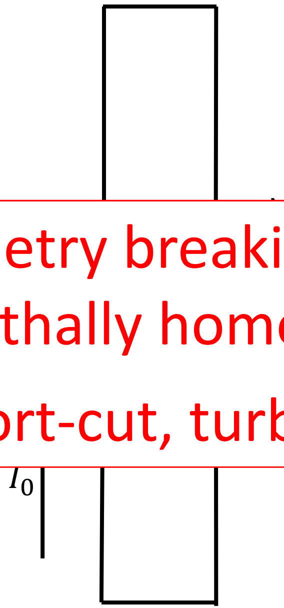
$$I_0 = \frac{V_{Nb} - V_{Cu}}{R_{Nb} + R_{Cu}}$$

$$I_1 = \frac{\frac{V_{Nb}}{2} - \frac{V_{Cu}}{2}}{\frac{R_{Nb}}{2} + \frac{R_{Cu}}{2}} = \boldsymbol{I_0}$$

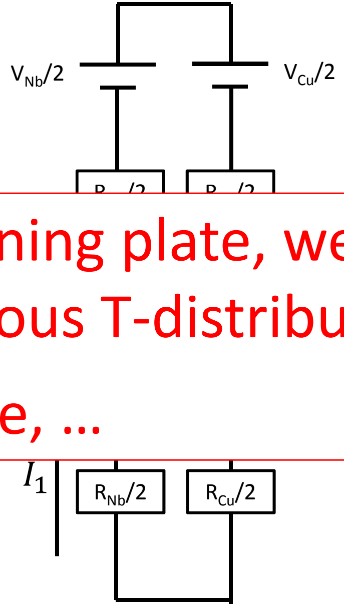
$$I_n = \frac{\frac{V_{Nb}}{2^m} - \frac{V_{Cu}}{2^m}}{\frac{R_{Nb}}{2^m} + \frac{R_{Cu}}{2^m}} = \boldsymbol{I_0}$$

Thermoelectric current in bi-metal structure 2/2

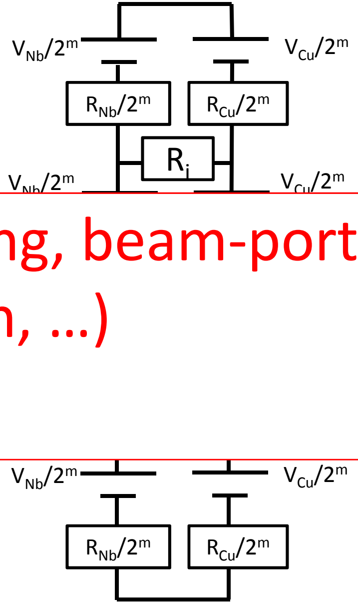
No bridge



$n = 1$ bridge



$n = 2^m + 1$ bridges



Symmetry breaking (tuning plate, welding, beam-port, azimuthally homogeneous T-distribution, …)

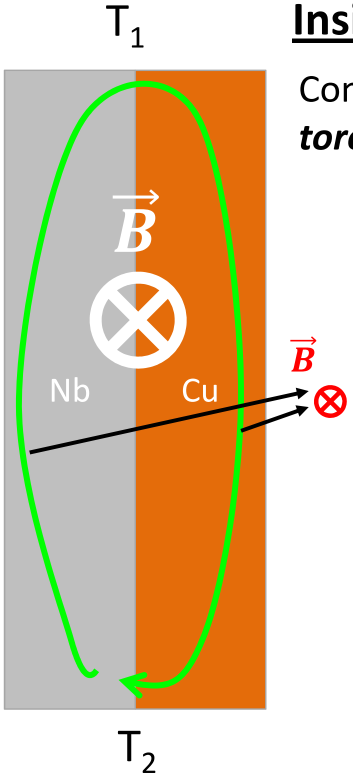
→ short-cut, turbulence, …

$$I_0 = \frac{V_{Nb} - V_{Cu}}{R_{Nb} + R_{Cu}}$$

$$I_1 = \frac{\frac{V_{Nb}}{2} - \frac{V_{Cu}}{2}}{\frac{R_{Nb}}{2} + \frac{R_{Cu}}{2}} = \boldsymbol{I_0}$$

$$I_n = \frac{\frac{V_{Nb}}{2^m} - \frac{V_{Cu}}{2^m}}{\frac{R_{Nb}}{2^m} + \frac{R_{Cu}}{2^m}} = \boldsymbol{I_0}$$

Magnetic field produced & measured



Inside

Confined
toroidal field

Outside

Biot-Savart law

$$\vec{B}_{Nb} = \frac{\mu_0}{4\pi} \oint \frac{I d\vec{l}_{Nb} \times \vec{r'}}{|\vec{r'}|^3}$$

$$\vec{B}_{Cu} = \frac{\mu_0}{4\pi} \oint \frac{I d\vec{l}_{Cu} \times \vec{r'}}{|\vec{r'}|^3}$$

$$\vec{I}_{Nb} \sim -\vec{I}_{Cu}$$

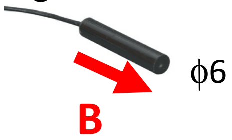
Most of the magnetic field is cancelled outside the cavity

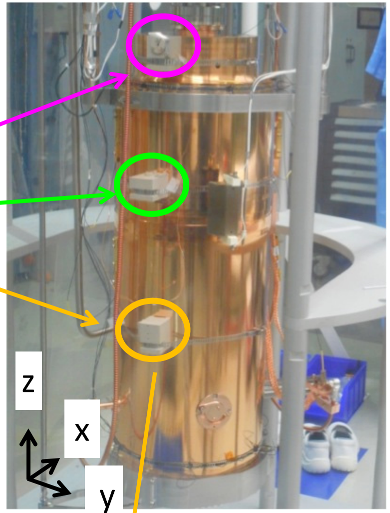
Still no direct evidence ☹

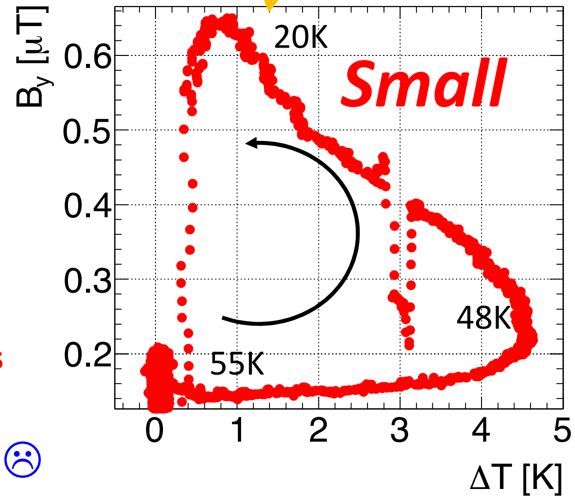
Measurement by fluxgate sensors was done

- Bx (radial)
- Bz (axial)
- By (azimuthal)

Bartington
Fluxgate sensor







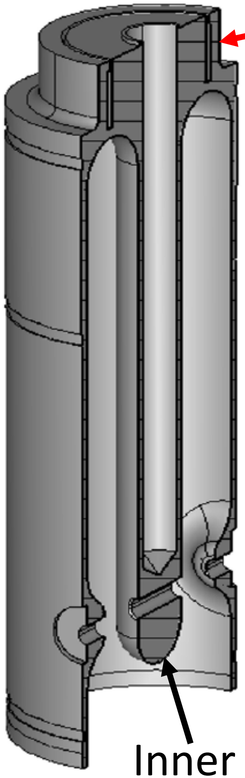
Contents

Seamless cavity (**see Silvia's talk WEYA03**)

Welded cavity

welding

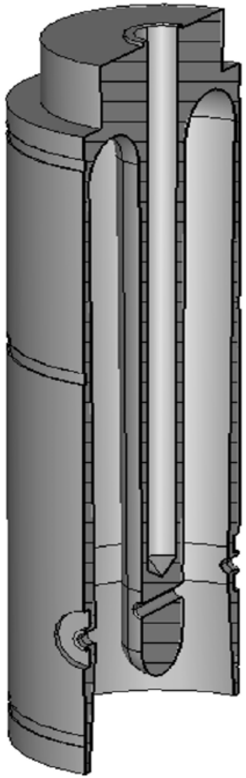
outer part



Inner part

modification →

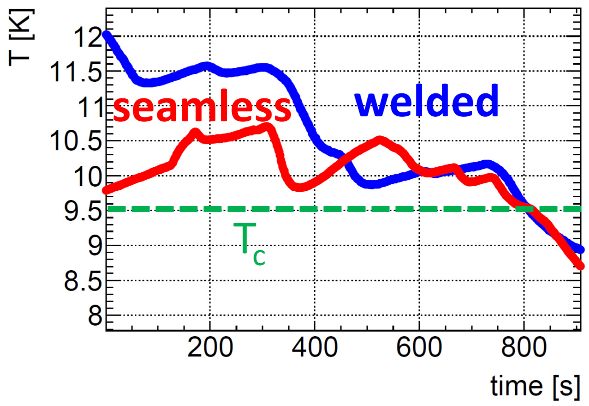
Seamless cavity



Machined from a bulk Cu billet

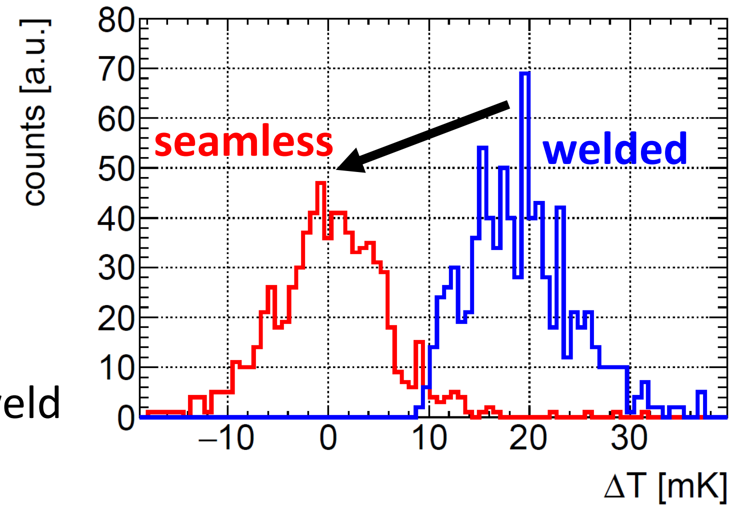
Different cool down dynamics was expected!!

Cool down & thermal gradient

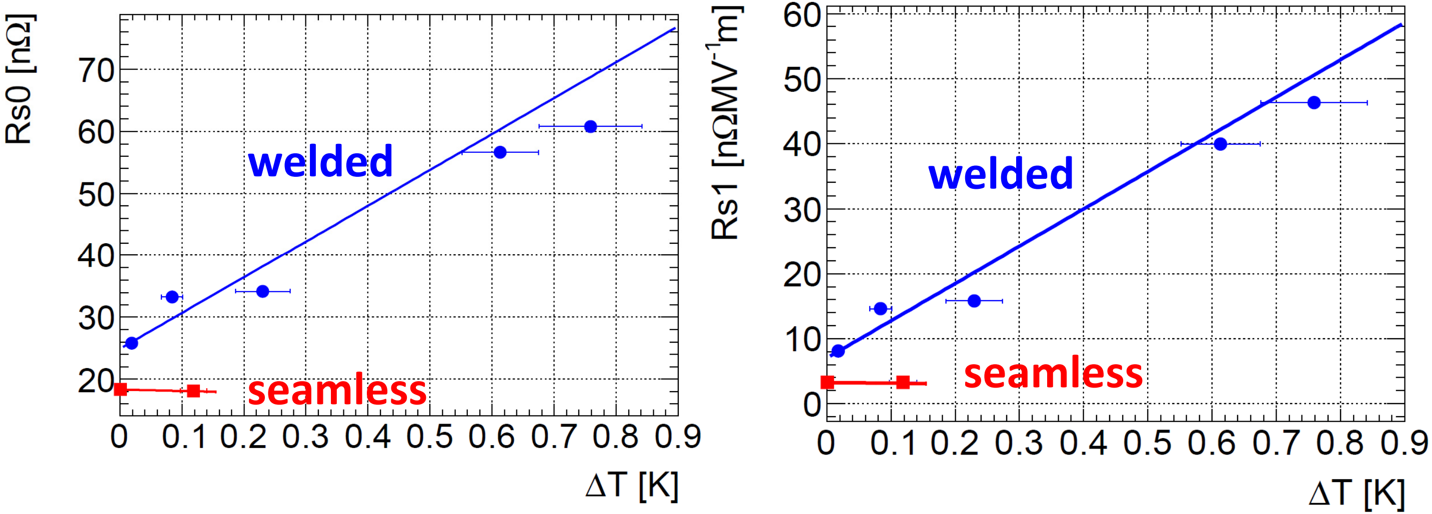


- Cool down process was optimized
- Slow cool down above T_c in order to make the cavity temperature uniform
- Similar method to both welded and seamless cavities

- **The thermal gradient achieved was 1 order of magnitude better than welded cavity!**
- Thanks to better thermal conductance without the weld

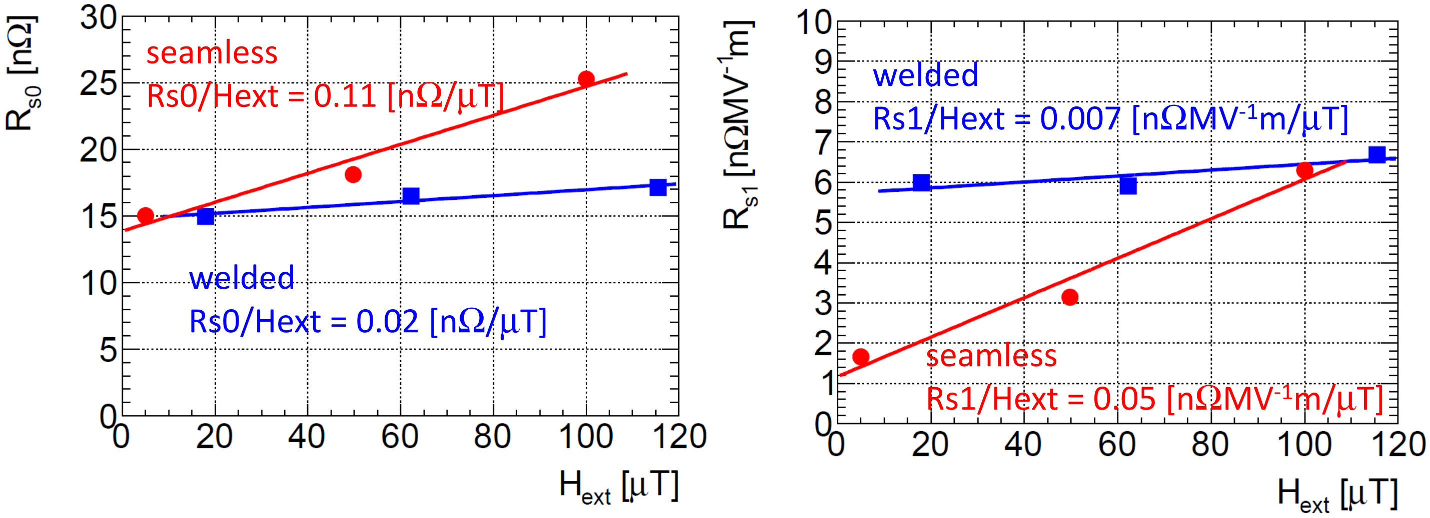


Sensitivity to ΔT



No ΔT dependence was observed in the seamless cavity!

Sensitivity to H_{ext}



Seamless cavity is 1 order of magnitude more sensitive to the external magnetic field

- In any case much more insensitive than bulk Nb O(1) [nΩ/μT]

Contents

- HIE-ISOLDE Nb/Cu cavity
- Cool down dynamics and thermal gradient
- Study on thermoelectric current
- Cool down dynamics of the seamless cavity
- Summary

Summary

- The original design of the HIE-ISOLDE Nb/Cu cavity is very sensitive to the cool down process, which affects Q_0, Q-slope, and T-slope (*Come to my poster **THPB046***)
- Contrary to bulk Nb, uniform cool down is more preferable (*Come to my poster **THPB047***)
- Thermal gradient corresponds to a very strong external magnetic field
- Magnetic field probably produced by a thermoelectric current in bi-metal structure was observed but quantitative study has not yet done
- The seamless cavity has very good thermal conductivity, and is also not affected by the thermal gradient at all (*See Silvia's talk **WEYA03***)
- These experimental facts may help us to theoretically understand the effect of cool down dynamics in Nb/Cu