Nb_3Sn/Cu - Status and perspectives

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TE-VSC-SCC

TE-VSC Seminar – 18th March 2024

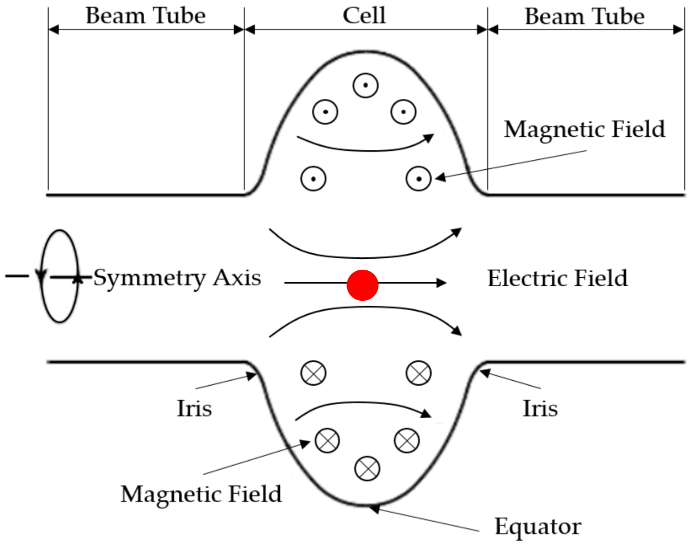
Outline

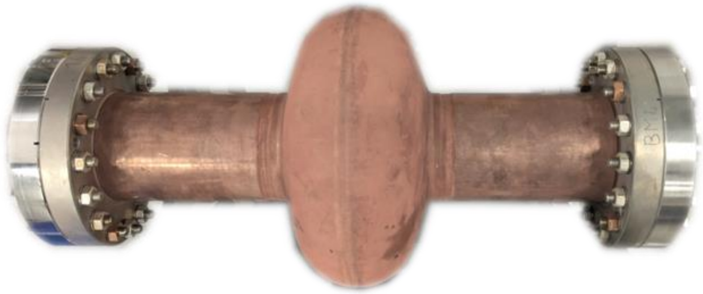
- Introduction: Why Nb_3Sn
- Nb_3Sn on small sample for development
- QPR for fine tuning
- Towards first cavity depositions
- Conclusion

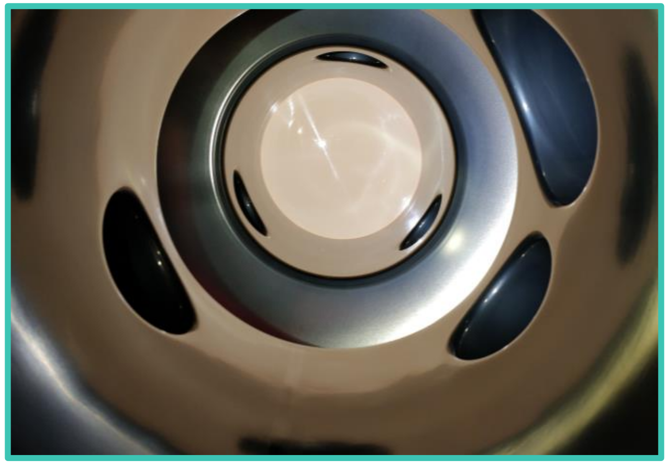
Introduction

Superconducting Radio Frequency (SRF) Cavities

- Accelerate charged particles
    - Electromagnetic standing wave
    - Force applied to charged particle
- Bulk Nb
- Nb/Cu (LHC, ISOLDE):
    - Cu = high thermal conductivity
    - Lower load on cooling system







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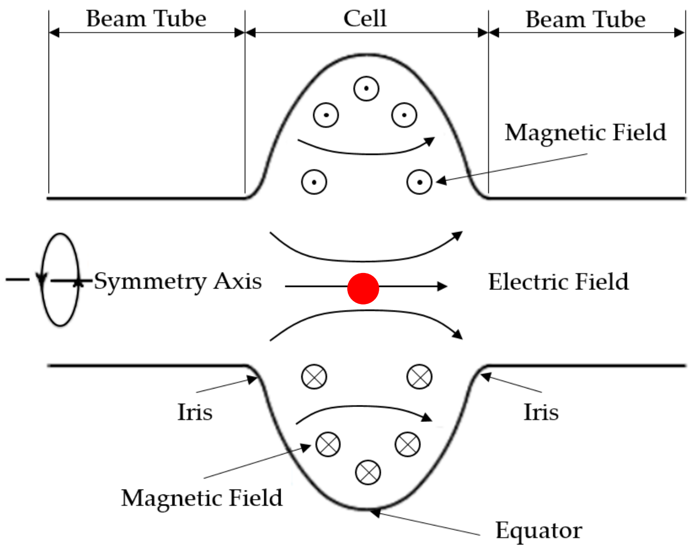
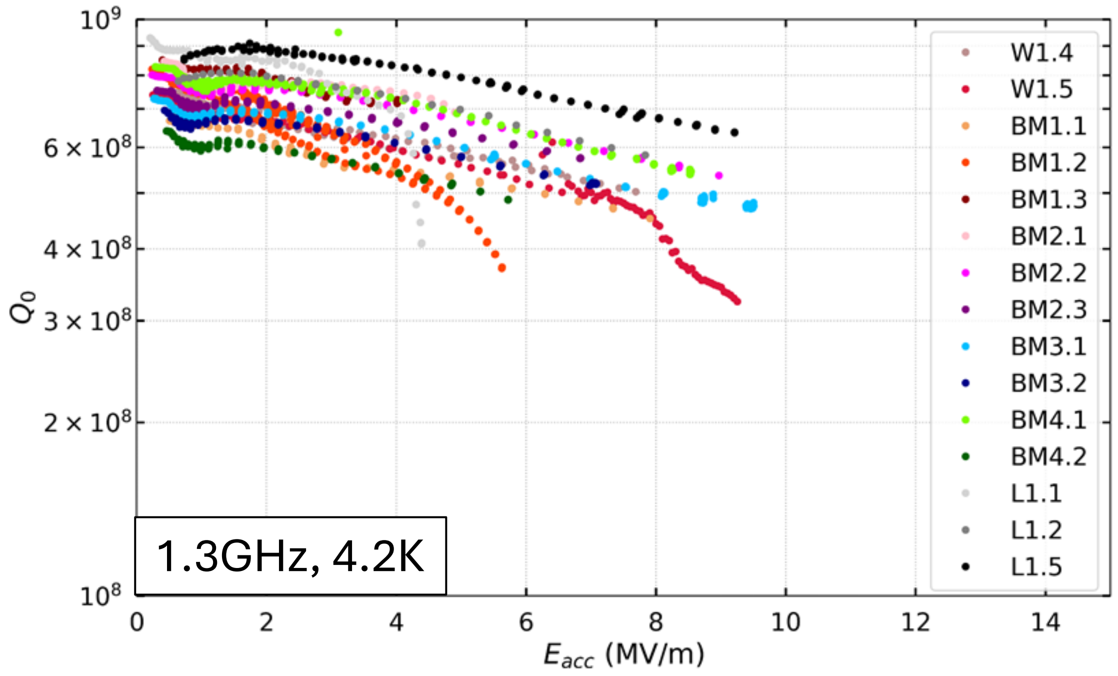
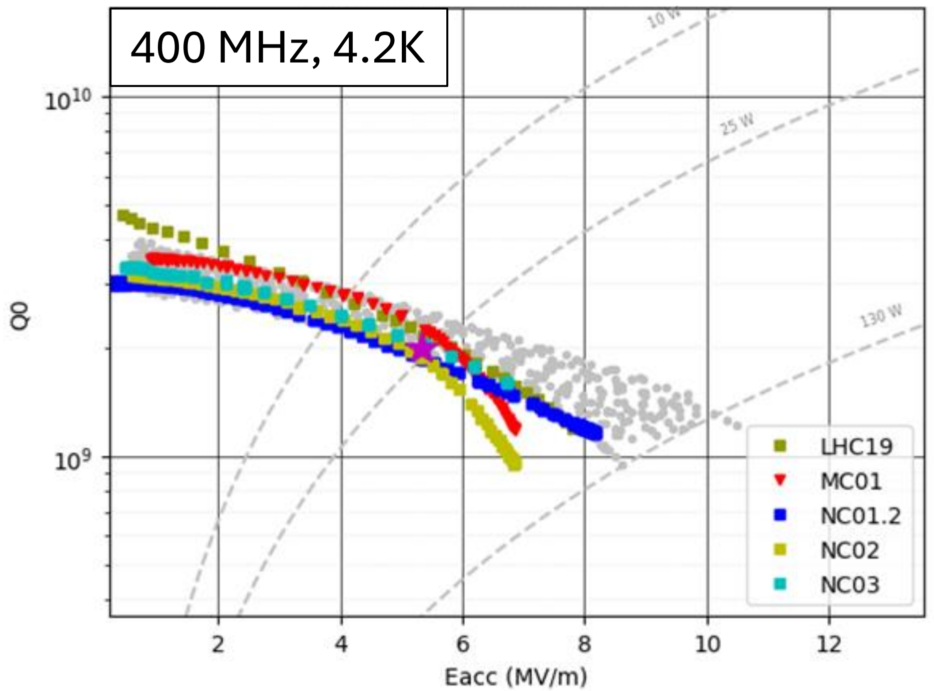


SRF Cavity Performance

- Quality factor $Q = \frac{\text{stored power}}{\text{dissipated power}}$
- Dissipated power proportional to R_s
- Rs ↘ with T_c ↗ → Good indicator !





Introduction

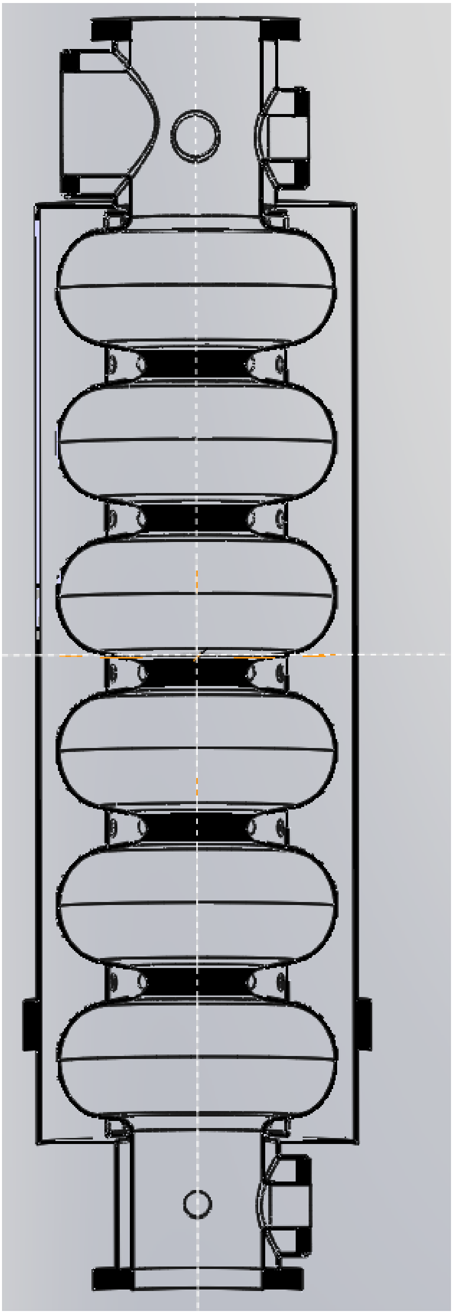
How Nb_3Sn compares to Nb ?

- Q_0 at 4.5 K ~ bulk Nb at 2 K
- Better overall performances

	Nb	Nb_3Sn
Tc (K)	9.2	**18.3**
R_{BCS} (nΩ)	45	**0.4**
H_{sh} (mT) @4.2K and 500MHz	220	**425**
Max th. Eacc (MV/m)	50	**100**

How this is interesting for accelerators ?

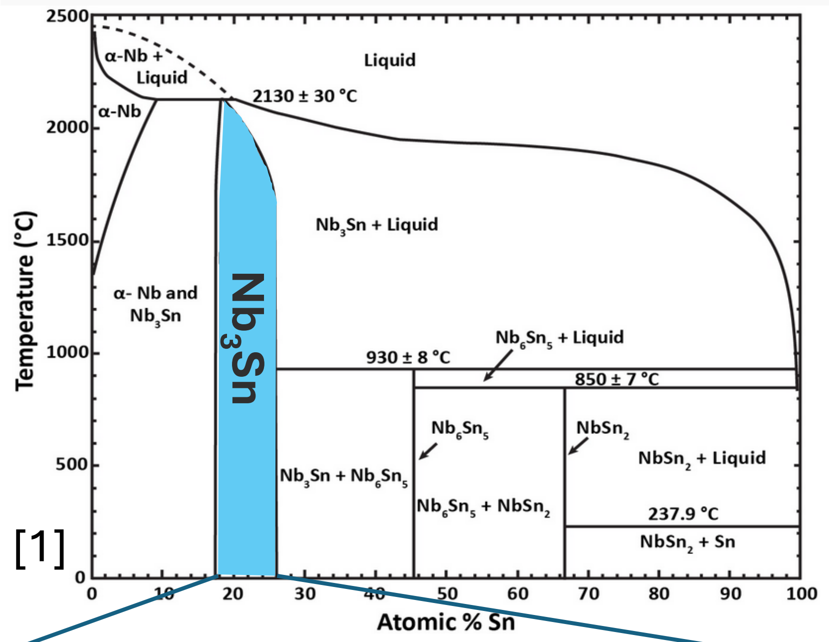
- For FCC: bulk Nb cavities for booster operations
- Could operate at 4.5K instead of 2K + Use of Cu substrate
- Energy and cost savings for future colliders

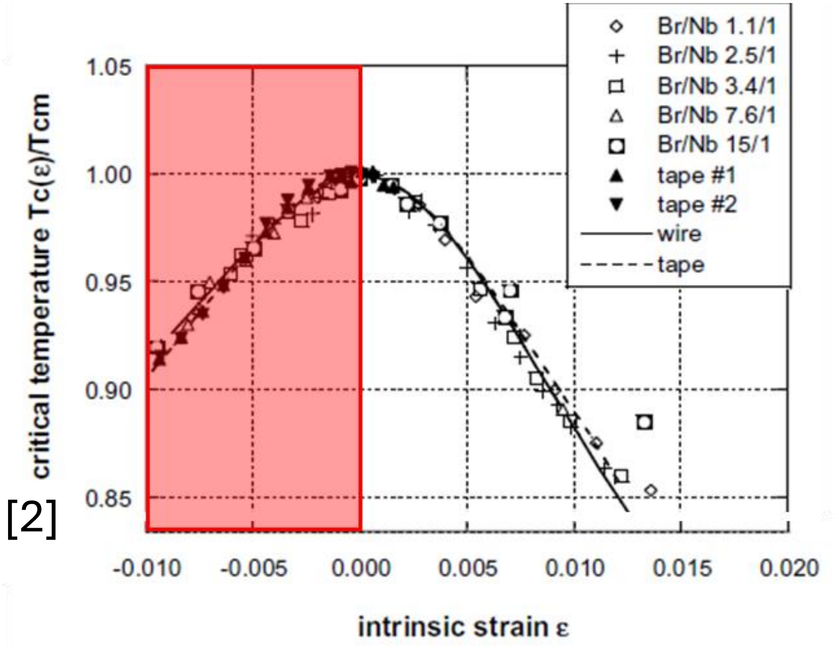


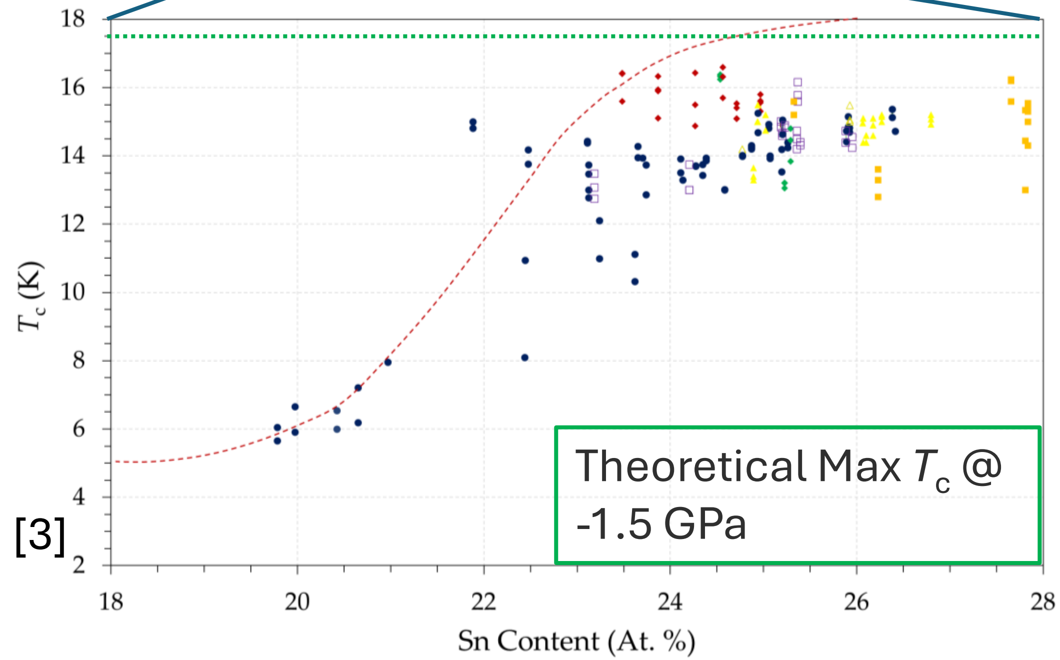
Introduction

Some challenges for Nb_3Sn dev:

- Very narrowed region in phase diagram
- Requires high temperature process
- Composition is crucial to ensure high perf.
  - Optimal Sn content 25 At.%
- Perf. are hindered by mechanical stress







[1] J. Charlesworth, I. MacPhail, and P. Madsen, J. Mater. Sci. **5**, 580 (1970)

[2] G. De Marzi et al. *J. Phys.: Condens. Matter* **25** (2013)

[3] A. Godeke. *Supercond. Sci. Technol.* **19** (2006)

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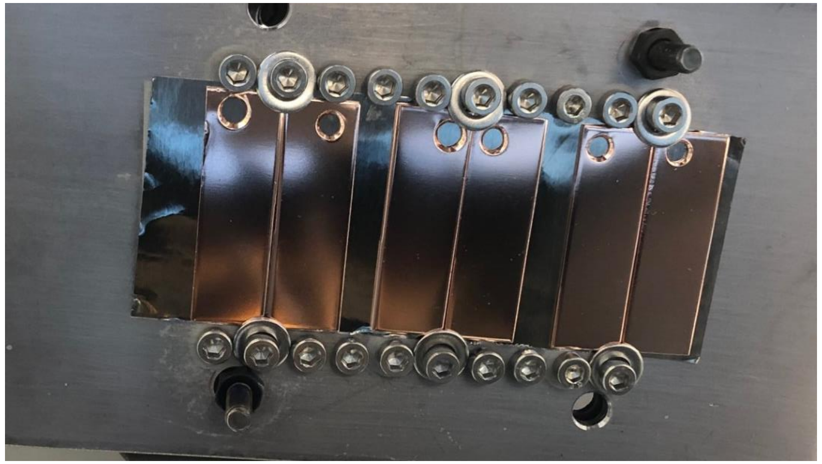
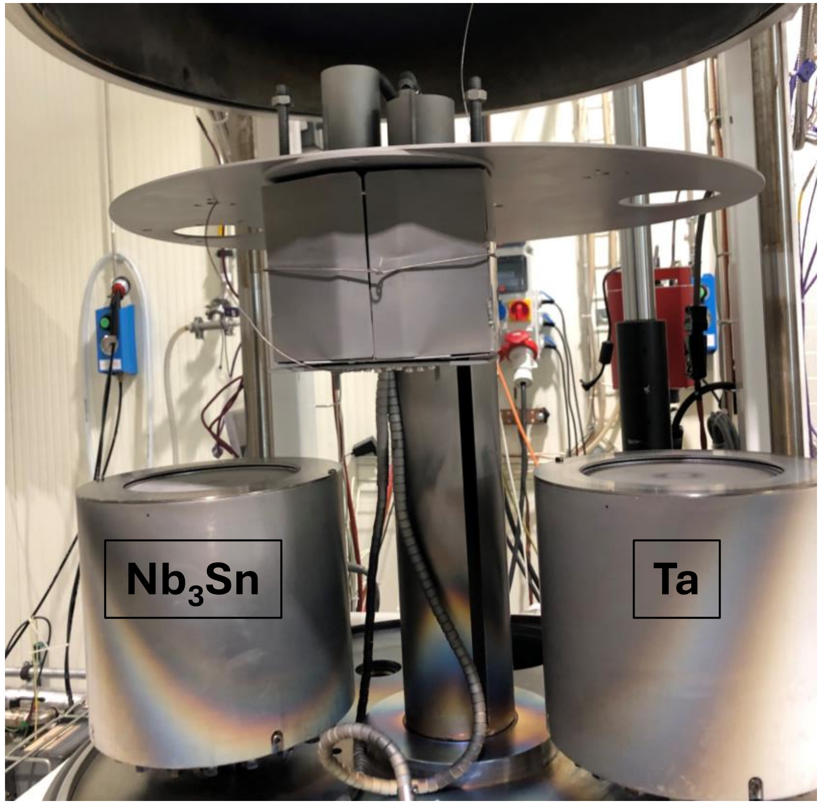
Development on small Cu samples



Surface preparation:

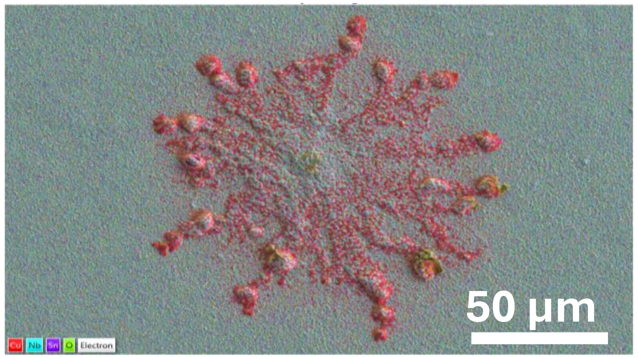
- SUBU (chemical polishing)
- EP (Electro polishing)
- PEP (Plasma electro polishing)



Coating process Bi-Polar HiPIMS:

- Samples mounted on T-regulated, rotative support
- Two steps coating
  - 1St dep: Ta barrier*
  - 2nd dep: Nb_3Sn layer

Prevents from copper diffusion [1] →

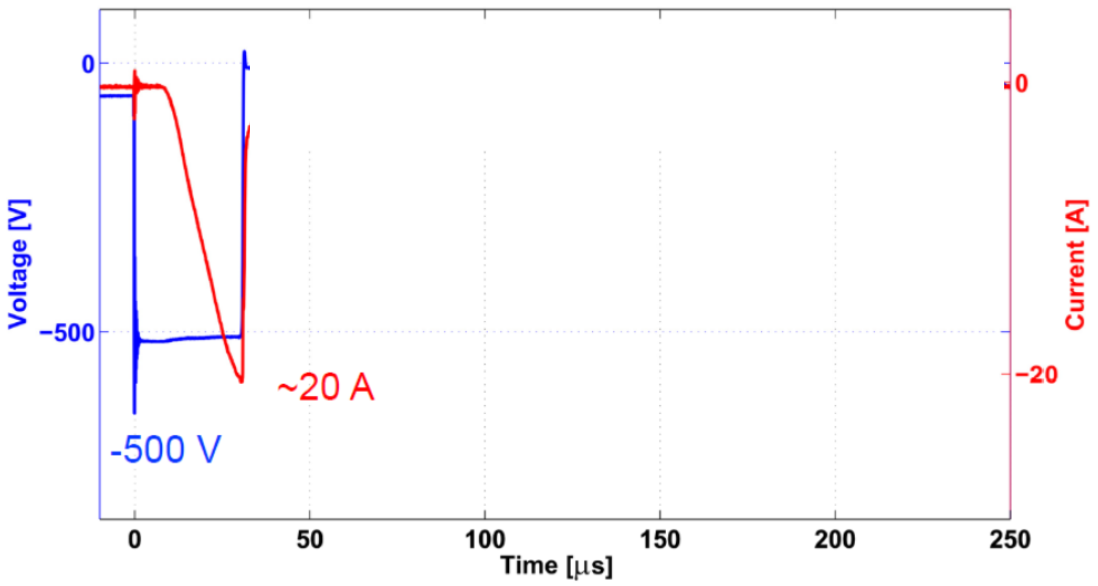


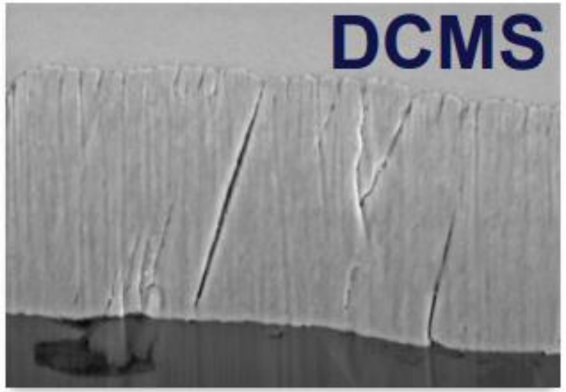
[1] E A Ilyina et al. *Supercond. Sci. Technol*. **32**. (2019)

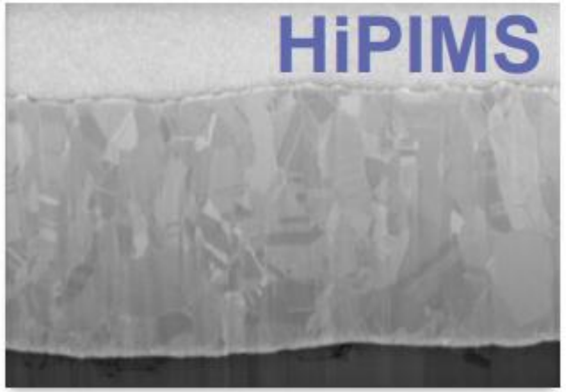
Development on small Cu samples

High Power Impulse Magnetron sputtering:

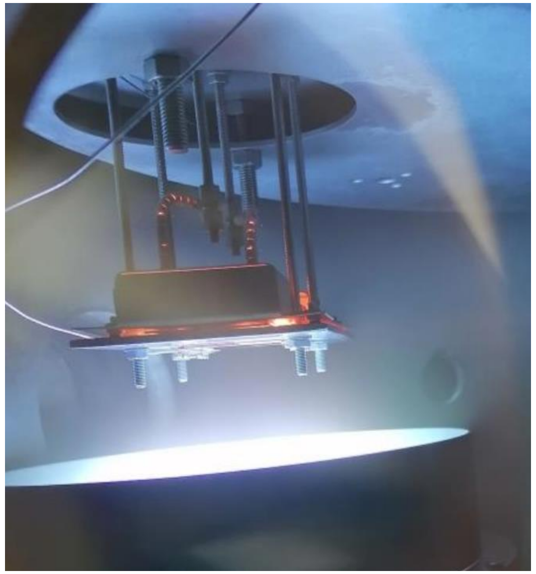
- High power density during short pulses
- Advantages for thin films:
  - Higher plasma ionisation
  - Higher film density
- Bi-Polar for Nb_3Sn devs:
  - Both negative and positive pulses
  - PP pushes charged species towards the sample
  - Even higher film density

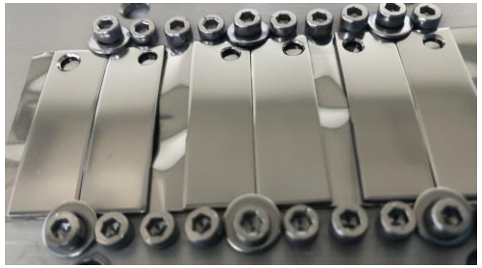






C.P.A Carlos et al. FCC week 2022





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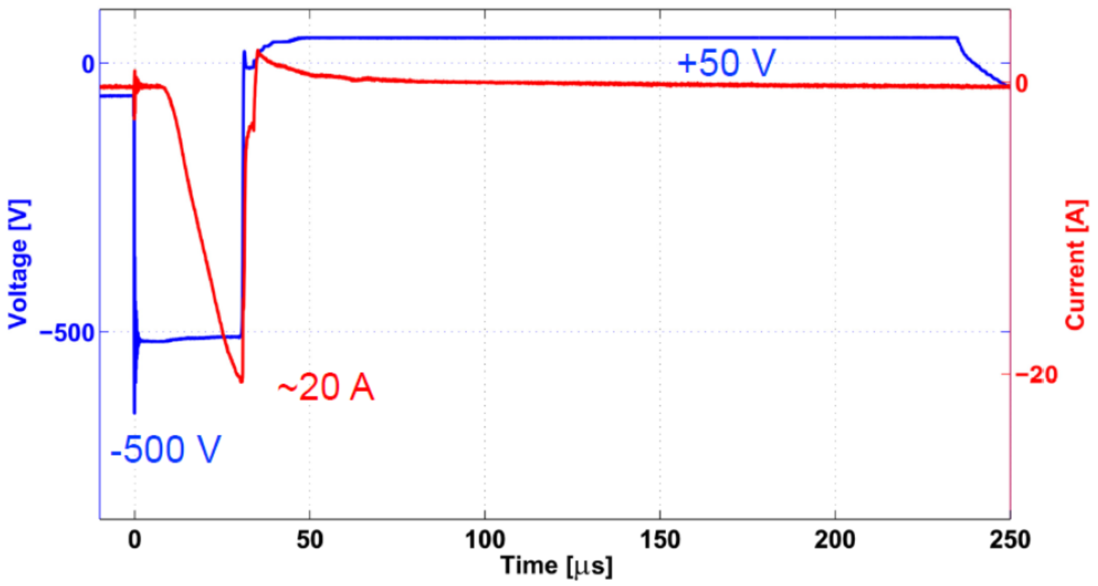
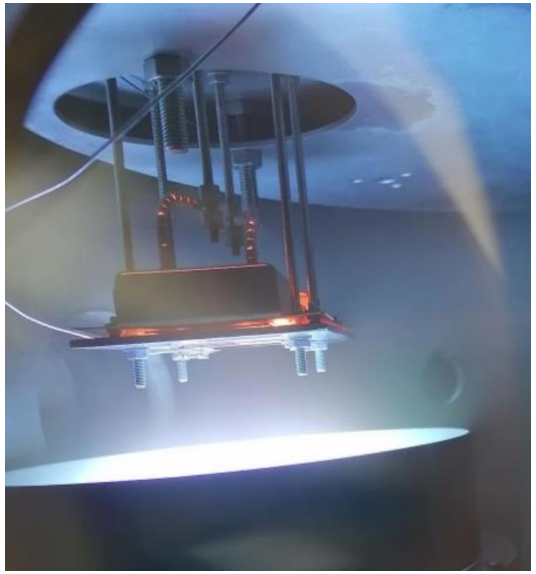
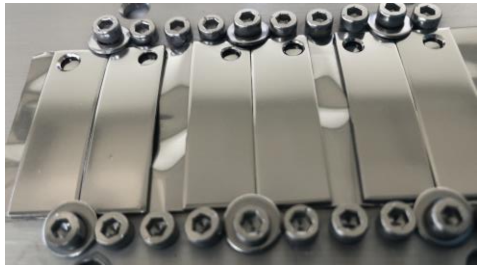


Extensive ongoing study (started by S. Leith):

Nb_3Sn	**Range explored**	**Best results**
Gaz	Kr	Kr
Temperature (◦C)	[500,750]	750
Pressure (mBar)	$[7.10^{-4}, 5.10^{-2}]$	$[8.10^{-3}, 2.10^{-2}]$
Positive Pulse (V)	[35,130]	50
Annealing (hrs)	[0,72]	24





Development on small Cu samples

Best results on small samples:

- Tc is capped at 16K
- First order impact of mechanical stress

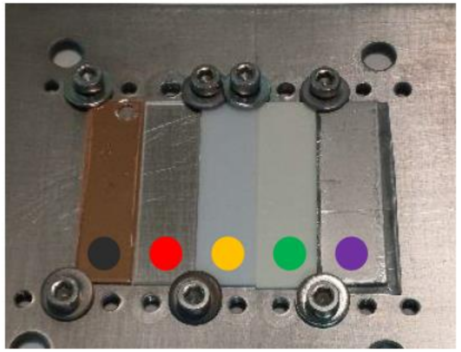
(Different CTE between Cu and Nb_3Sn)

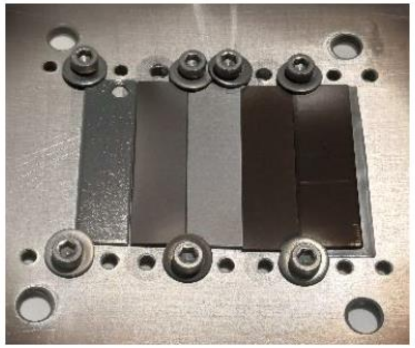
Demonstration:

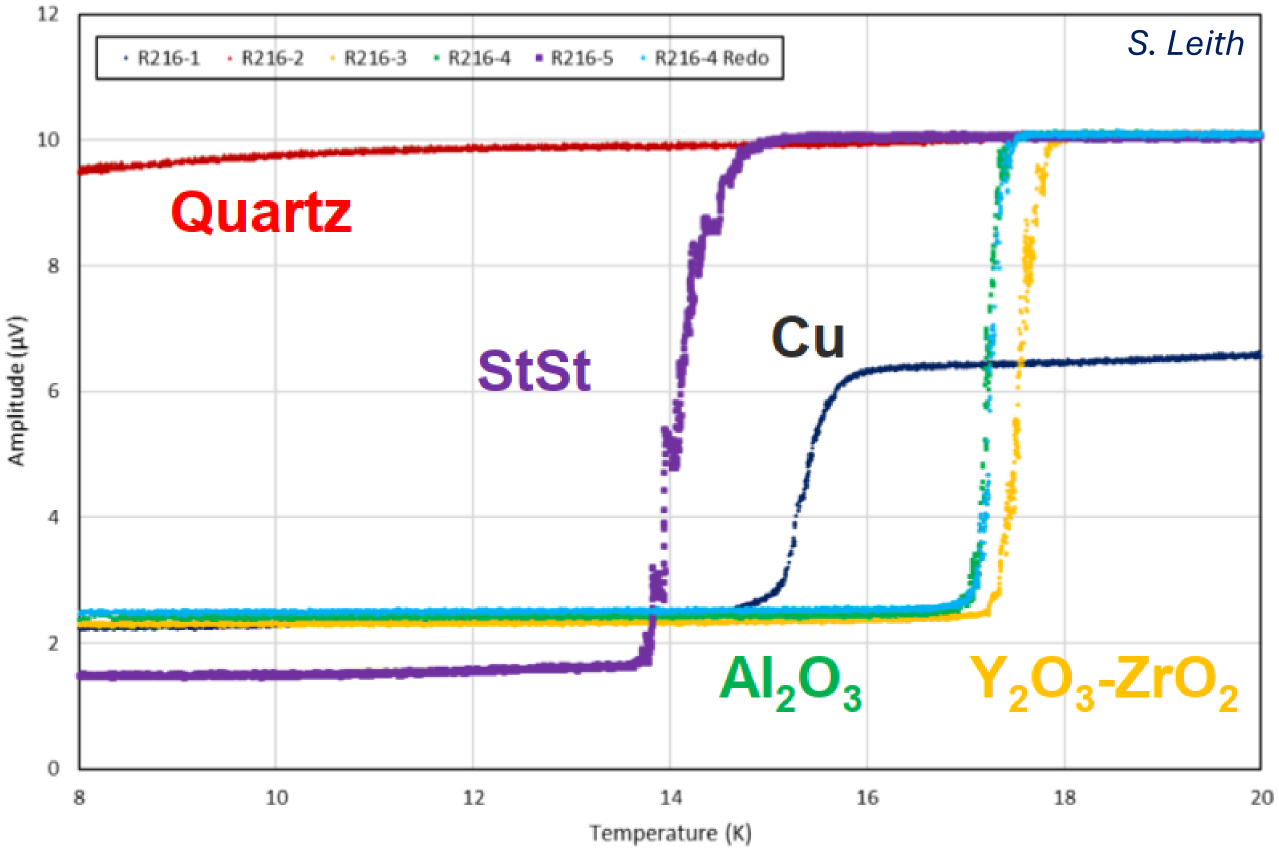
- Same coating recipe on different substrates
- Tc ↗ when CTE becomes closer to Nb_3Sn
- Total improvement = 2K

A promising solution:

- Changing Cu substrate for CuW
- First coating in characterization now







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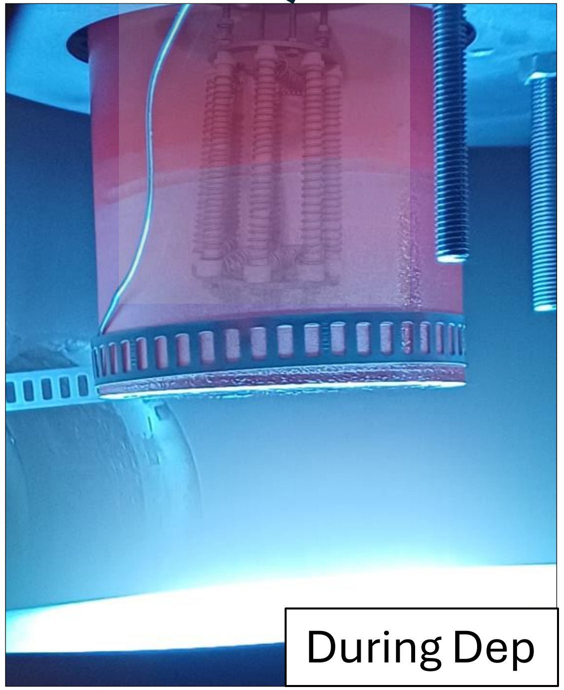
Recipe fine tuning with QPRs

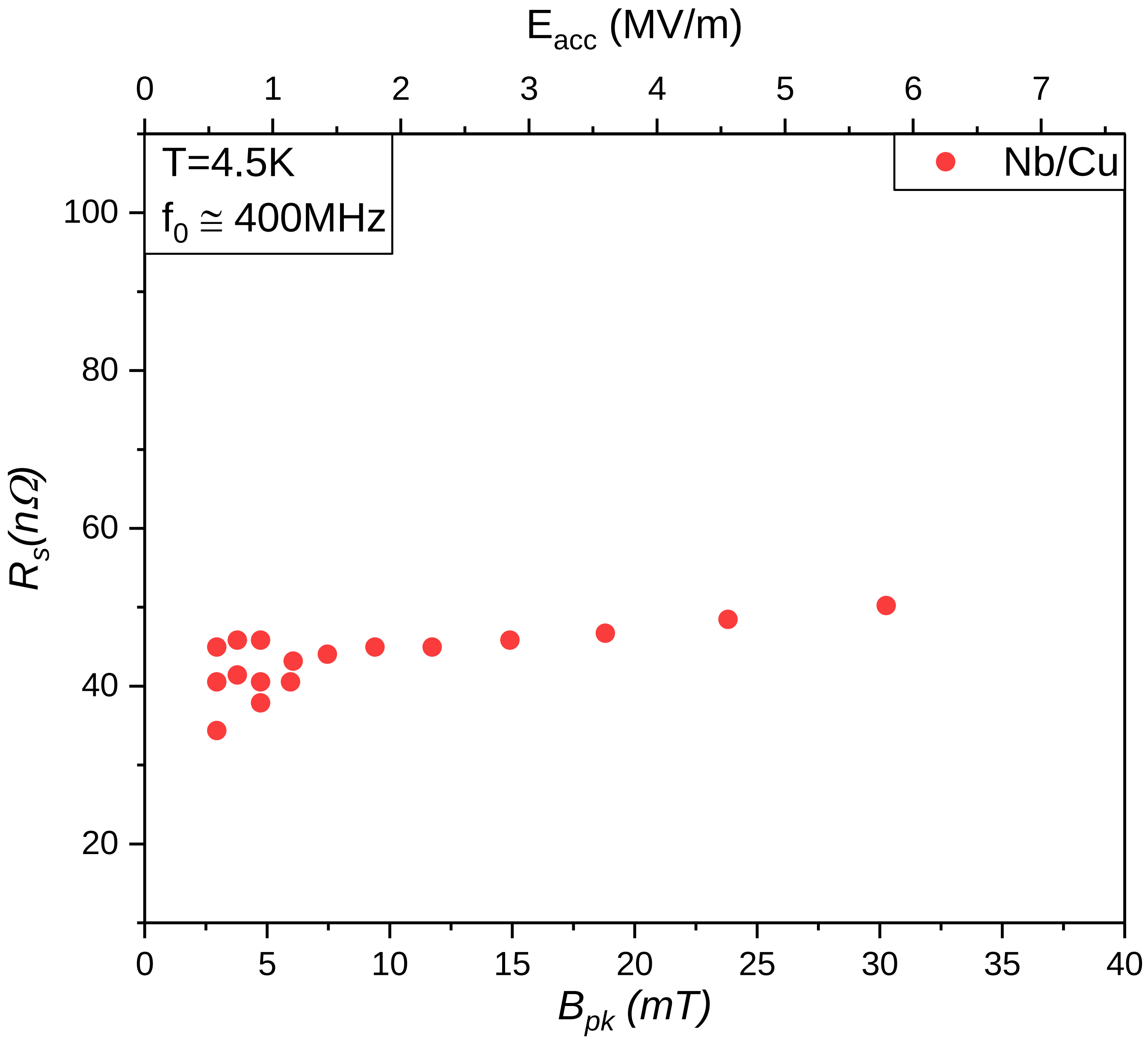
QPR = Quadrupole resonator:

- Flat object as close as possible to a cavity
- For thin films RF characterization
- Allows to quantify Rs



Recipe fine tuning with QPRs

Comparison with Nb/Cu layers:



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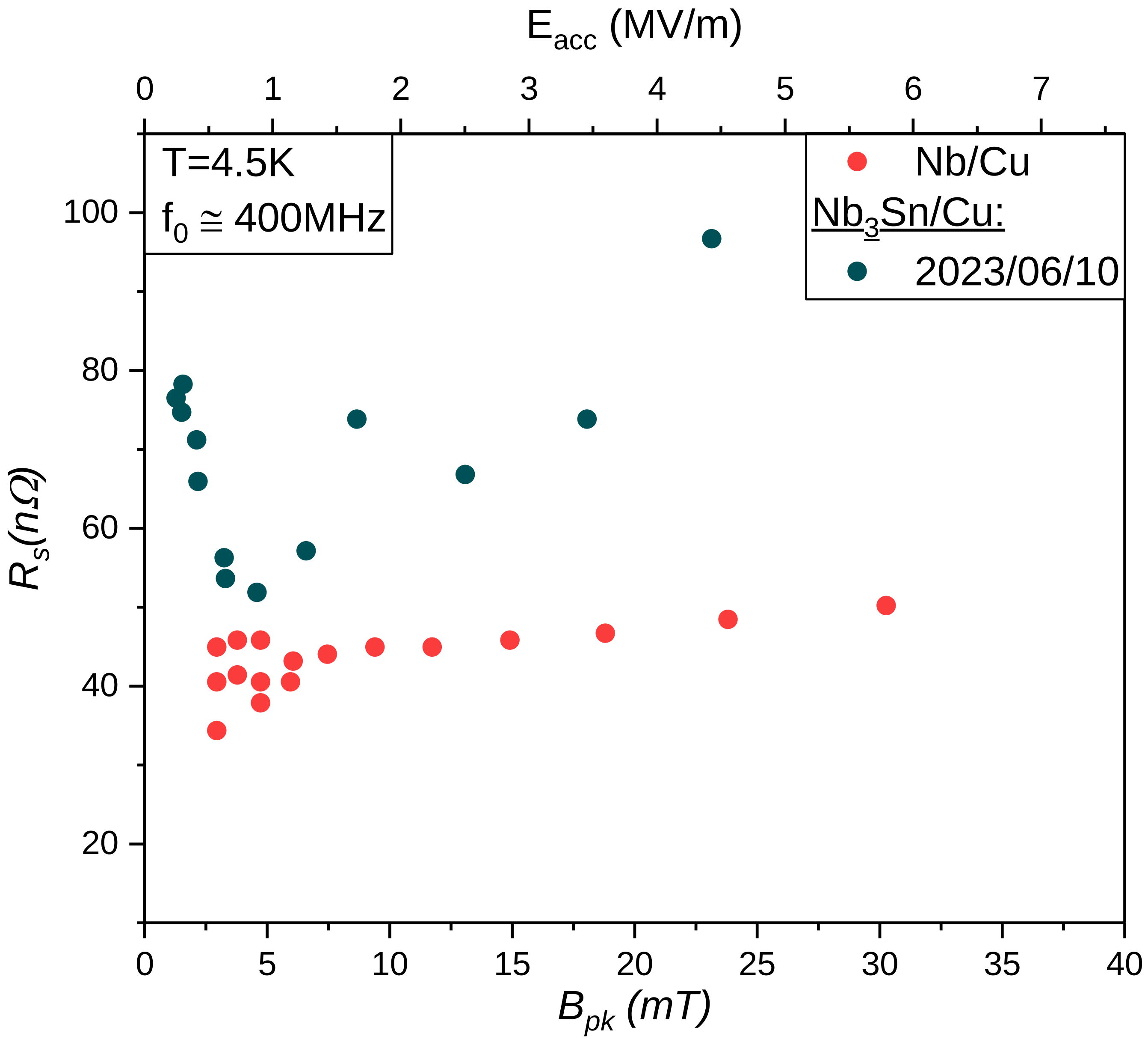

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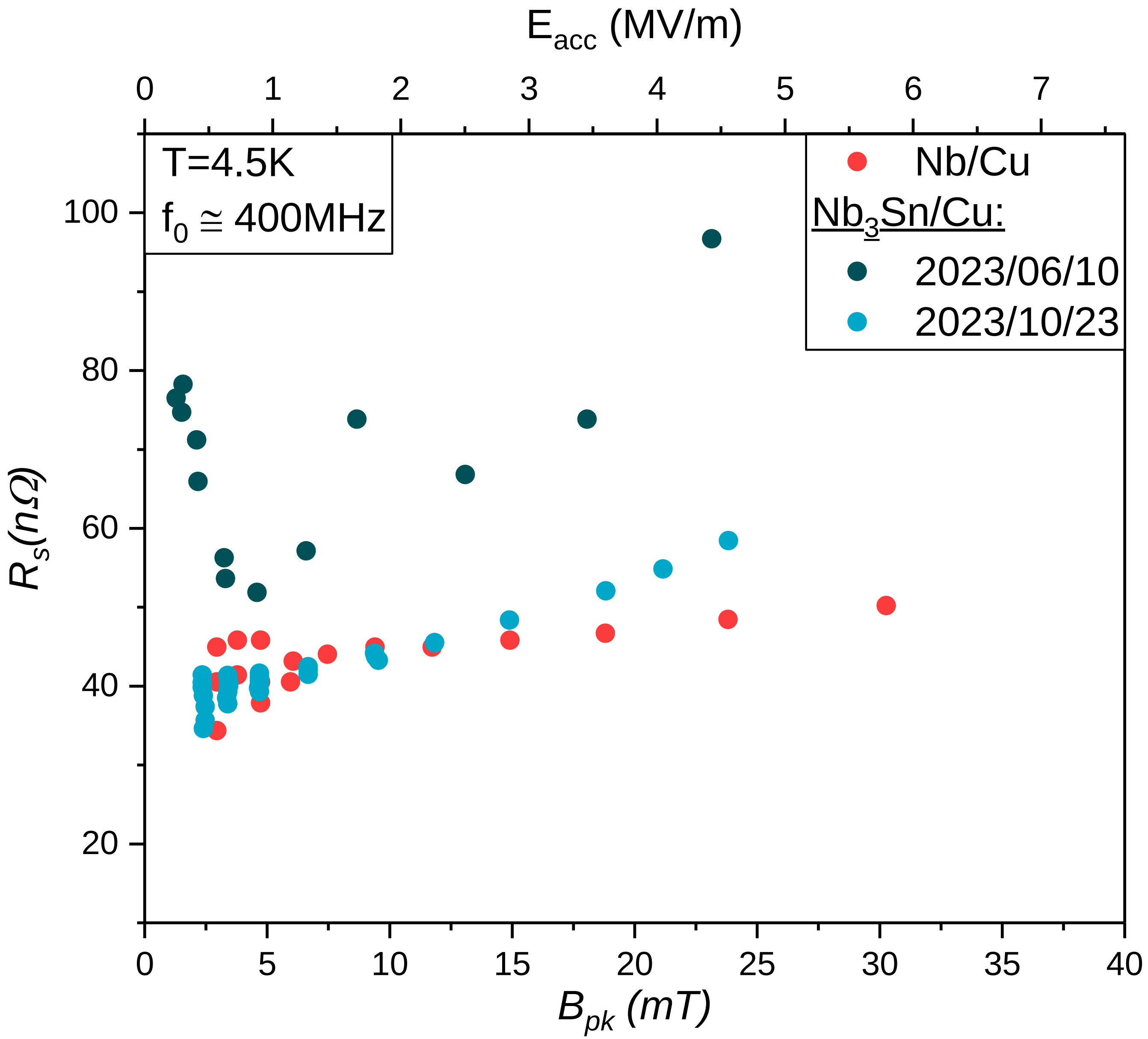
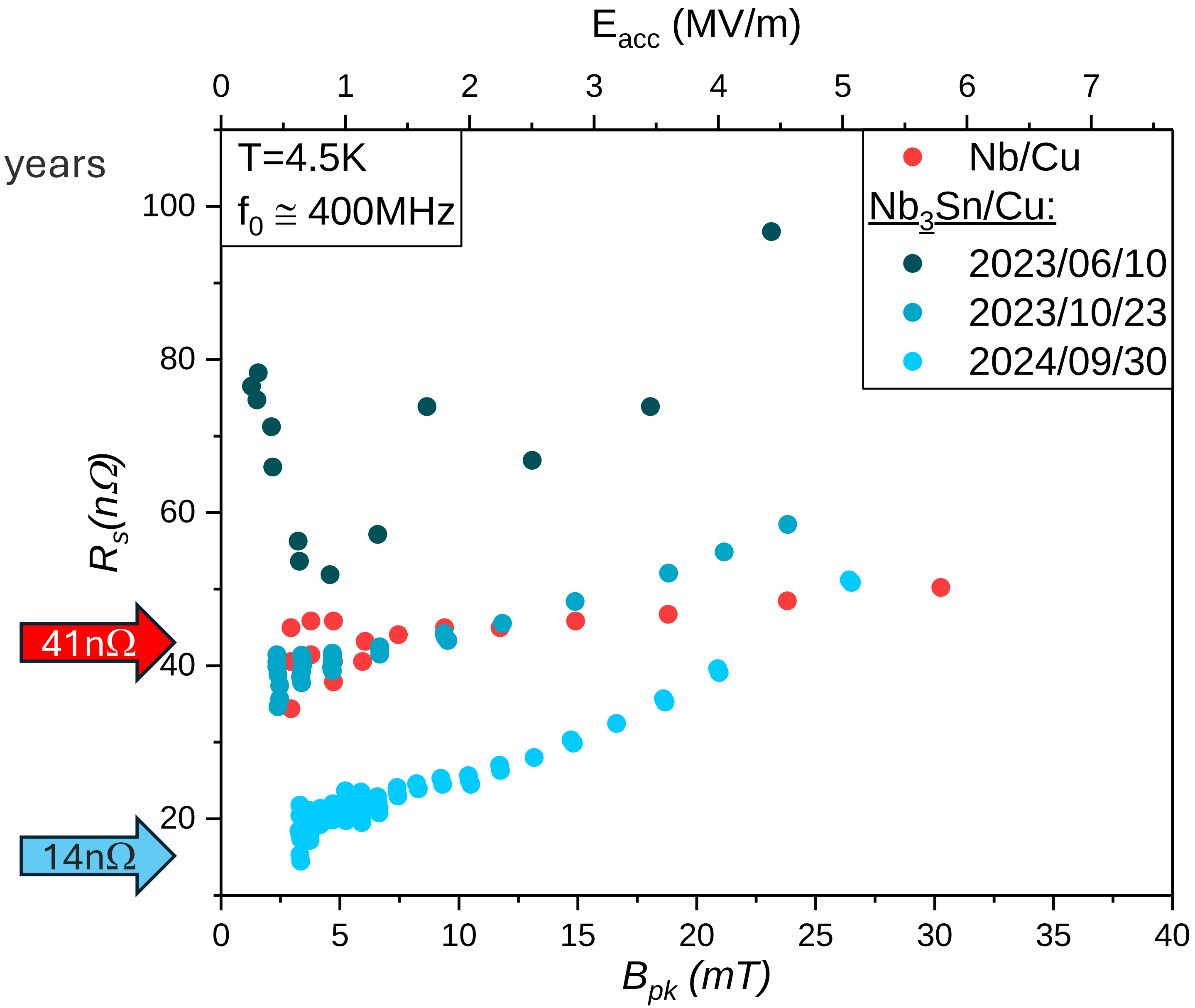


Recipe fine tuning with QPRs

Comparison with Nb/Cu layers:

- Significant improvements these past 2 years
- Rs 2-3 times lower for Nb_3Sn vs Nb !!!!



Recipe fine tuning with QPRs

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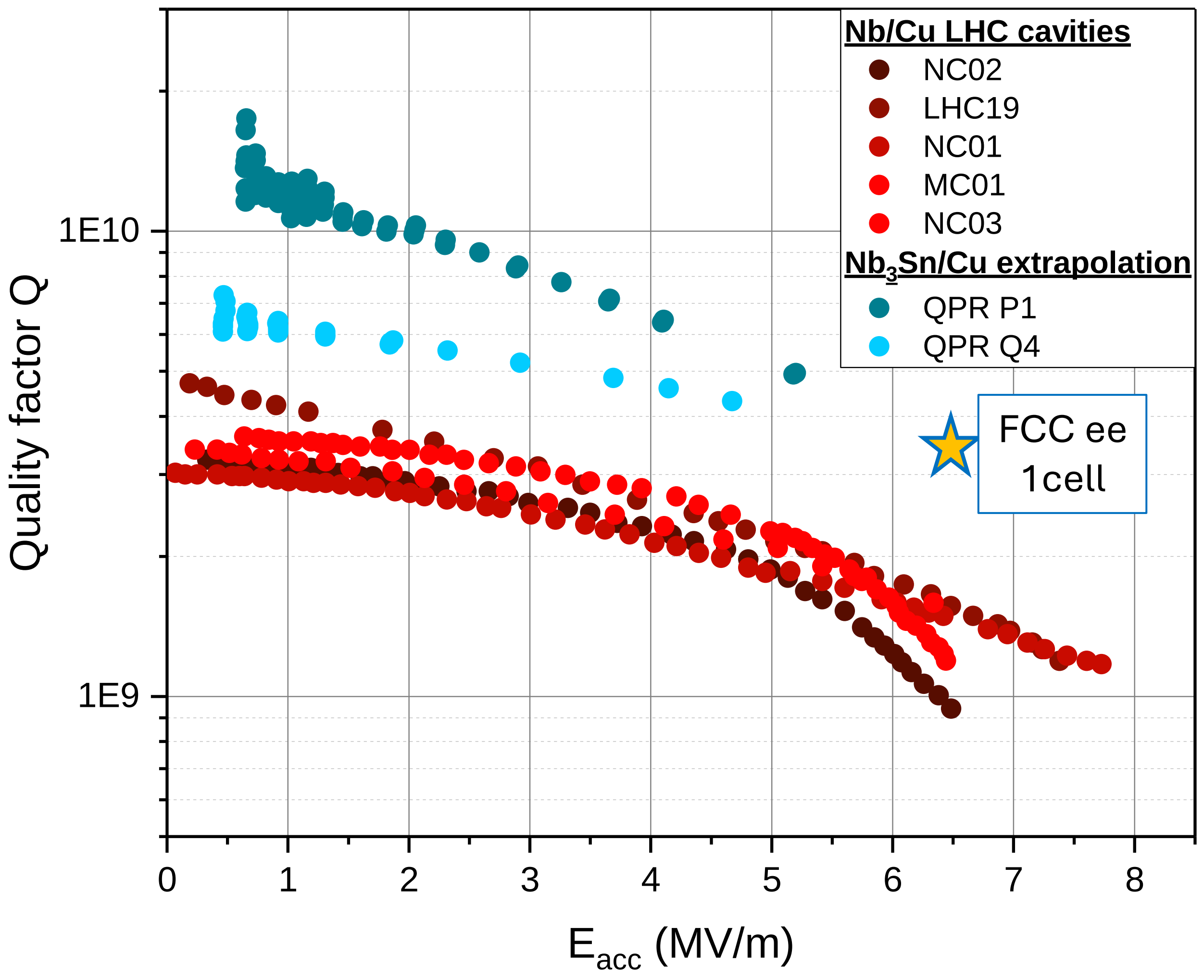
Extrapolation to cavity:

- Better performance than Nb/Cu cavities
- On the right way towards FCC requirements

Constant dev to even higher perfs:

- Substrate material and preparation
- Coating adjustments

First validation for cavity application



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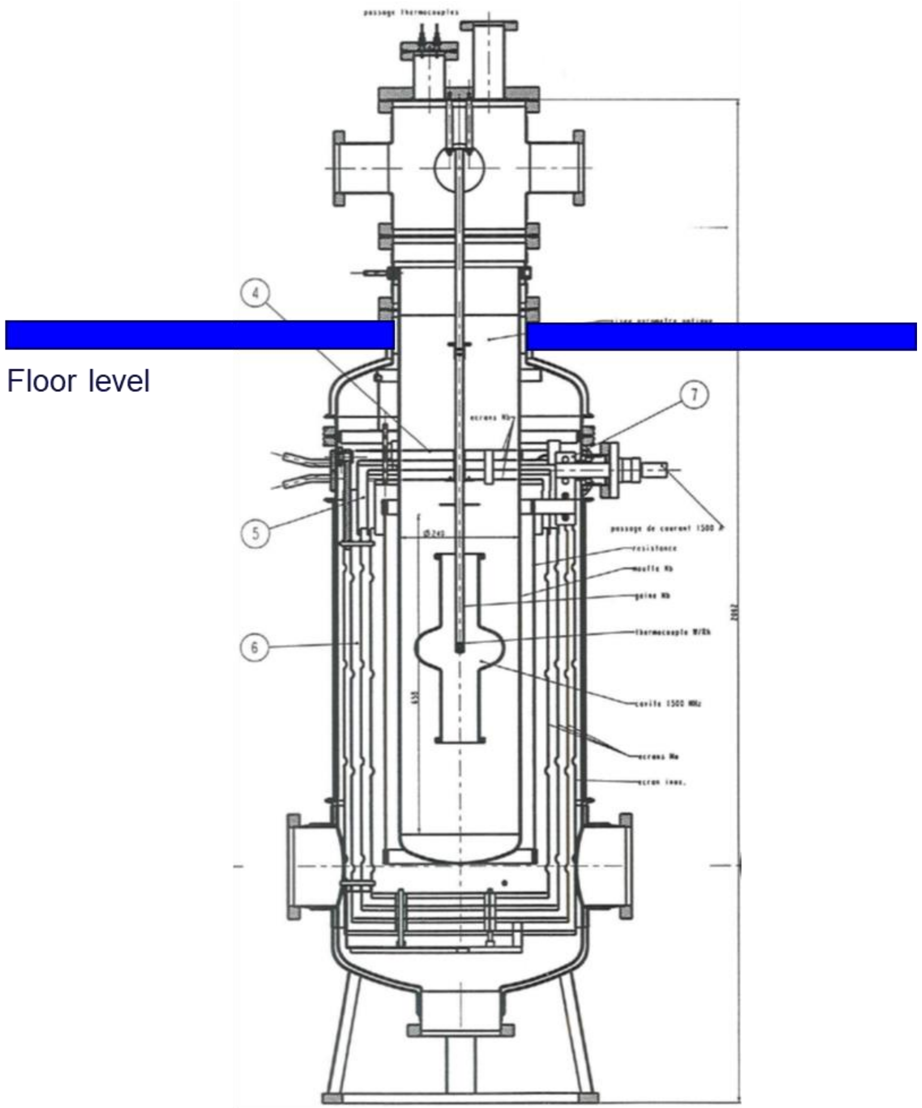
Towards cavity coating: Requirements

High temperature deposition (750C):

- Requires large furnace
- Cu cavities must be upgraded:
  - Increased cavity thickness
  - Rigid support structure inside the furnace ?
  - Alternative materials?



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Nb_3Sn target ideal geometry:

- Hollow and cylindrical (like Nb or Ta targets)
- Advantages:
    - Use our long-term experience
    - Allows for vertical coating
    - Avoid cavity rotation required by flat target

Towards cavity coating: Limitation

Nb3Sn target specifications:

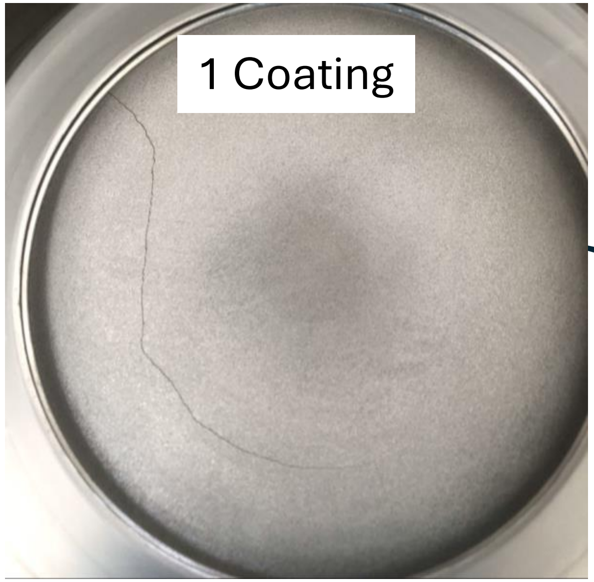
- Alloyed target
- Limitation to 2 targets:
  - One for diffusion barrier layer
  - One for Nb_3Sn

Nb3Sn target undesired properties:

- Fragile and prompt to cracking
- Dust creation
- Not compatible with cylindrical shapes

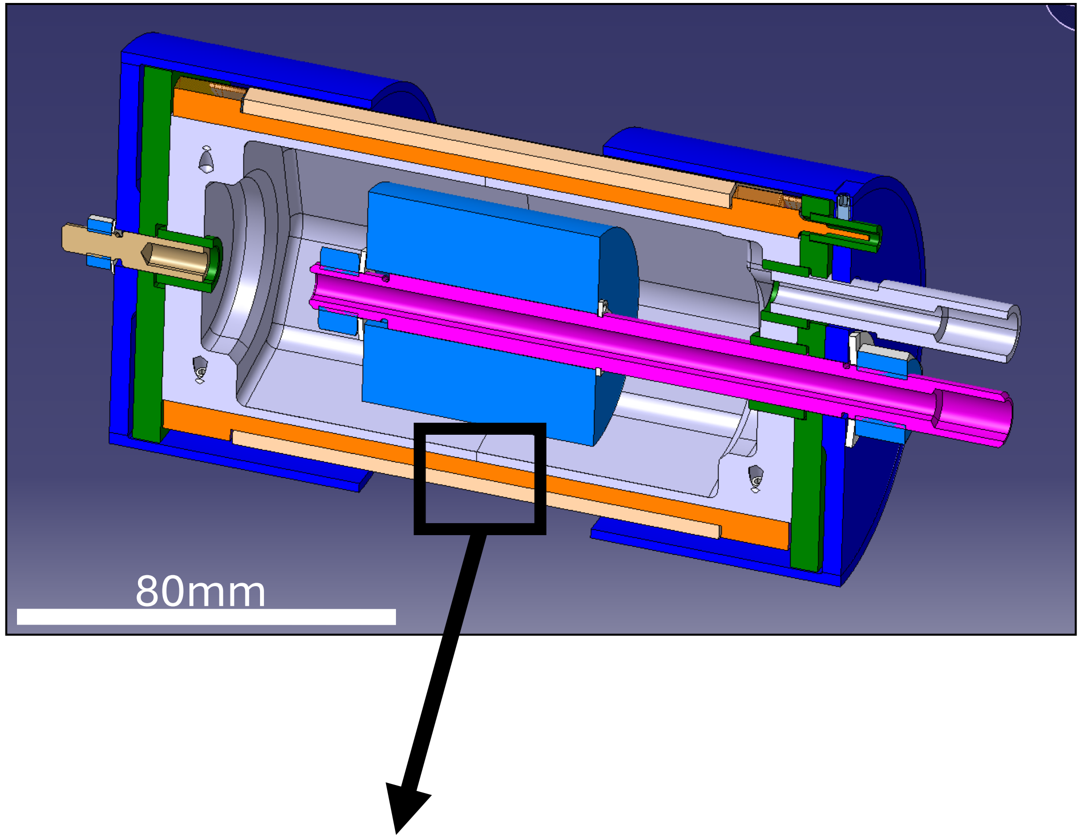
Root cause identification:

- Thermal cycles, power ramp rate, **max power**
- The cracking is unavoidable



Towards cavity coating: Solution

G. Girod (EN-MME)



Most promising solution:

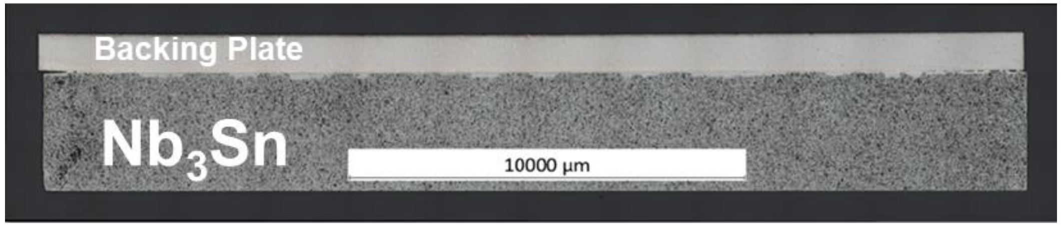
- Bonding on backing plate
- BP made of CuW (same CTE as Nb_3Sn)

First tests on small target:

- **Positive** on Ø 20mm target
- Ongoing for Ø 50mm target (then 150mm)

New magnetron design:

- Grounded magnet and dark space shields
- Cooling liquid bath for:
  - Magnet
  - Target through BP



V. Sibue and M. Crouvizier (EN-MME)

Conclusions

Big improvements have been made with the Nb_3Sn/Cu technology :

- Confirmation of Nb_3Sn coating repeatability
- RF performances higher than Nb/cu cavities
- Very promising for FCC

First cavity coating system designs:

- Nb_3Sn bonding on CuW is very promising to mitigate target breaking
- Allows for polyedric target → deposition system as close as possible to well known settings

Future developments:

- Complete target survival tests with larger targets
- Studies on QPR :
  - Coating improvements
  - Flux trap, thermal gradient effect
- Nb_3Sn coating on CuW

Thank you for your attention