



**Cristian Pira** (INFN LNL) on behalf of ISAS WP3 Collaboration

# WP3: $\text{Nb}_3\text{Sn}$ on Cu films for 4.2K cavity operation



**Second Annual Meeting @HZB, April 23, 2026**

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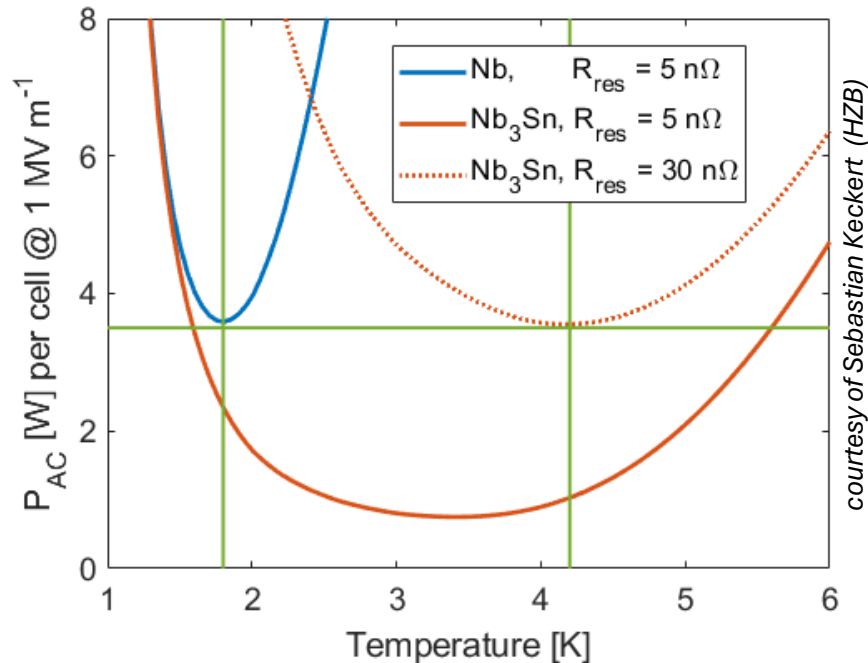


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**Energy saving** is mandatory for **next generation accelerators**...

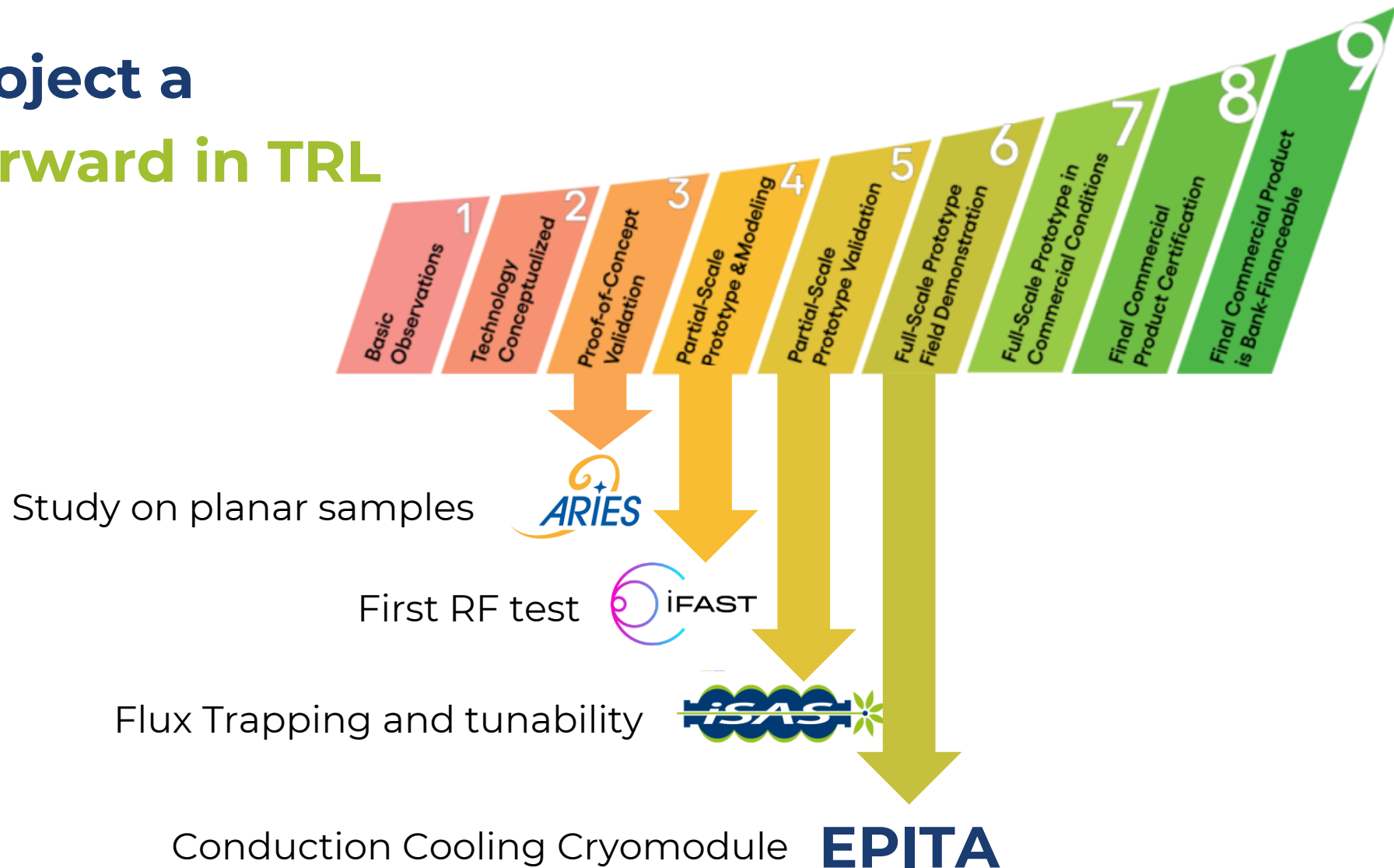
...**cryogenics** is one of the **larger energy cost** in modern SRF accelerators

➔ **Move from bulk Nb @2K to Nb<sub>3</sub>Sn @4.5 K**  
**reduces cryogenic power by a factor of 3**



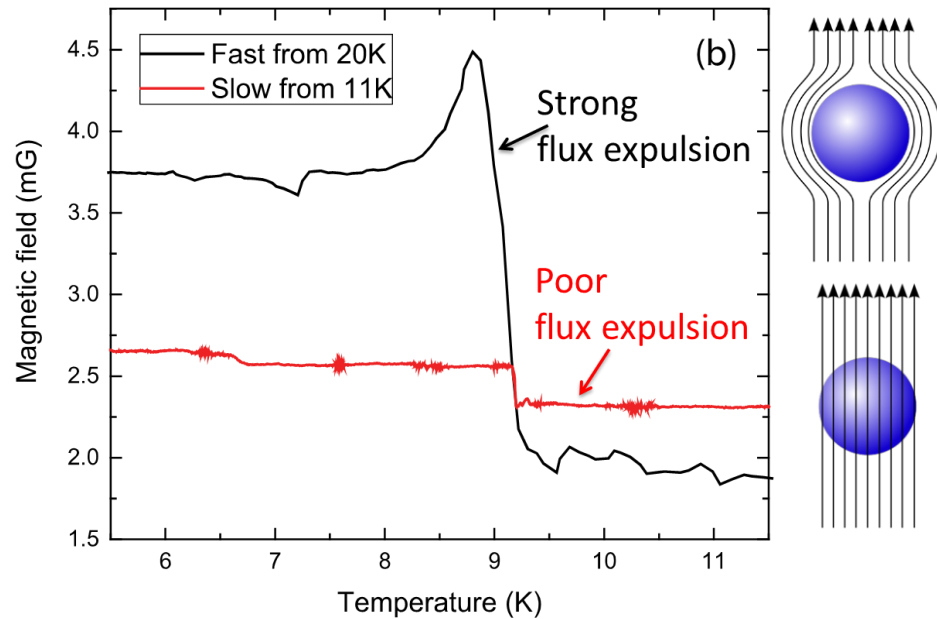
**Goal of iSAS WP3 is optimization of Nb<sub>3</sub>Sn on Cu technology**  
 focusing on **minimizing trapped flux** and increasing coating mechanical strength to allow **cavity tunability**

## Any Project a step forward in TRL

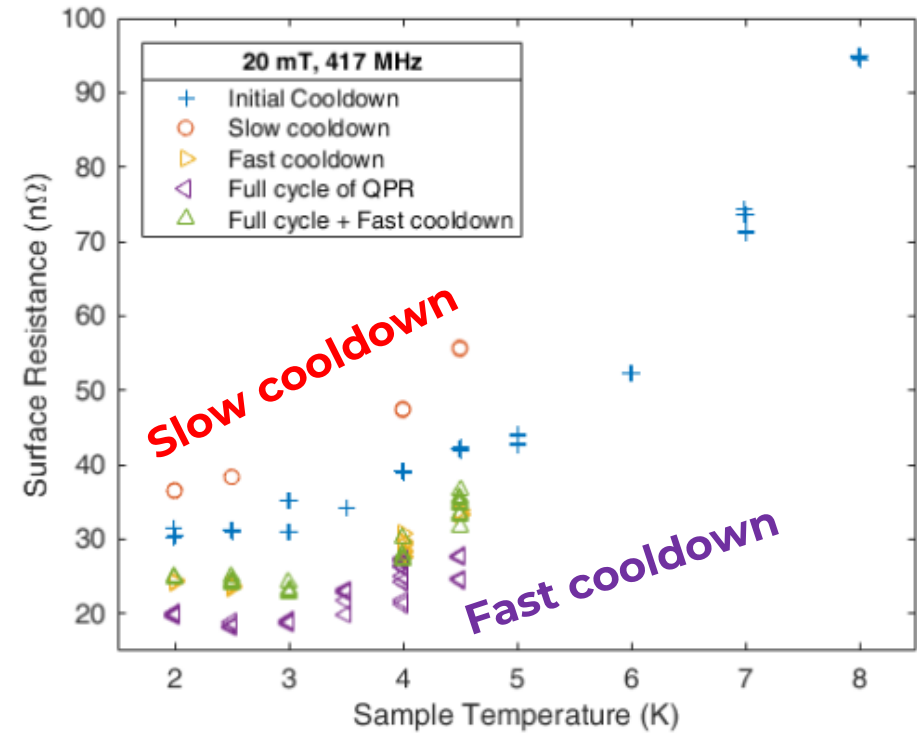


# Trapped Flux

$$Q_0 \propto \frac{1}{R_{BCS} + R_{res} + \eta S B}$$

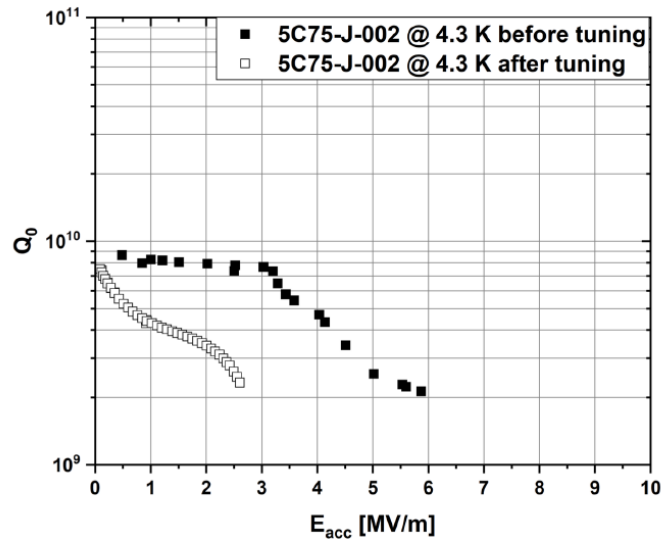


A. Romanenko, A. Grassellino, O. Melnychuk, D. A. Sergatskov, *J. Appl. Phys.* 115, 184903 (2014)

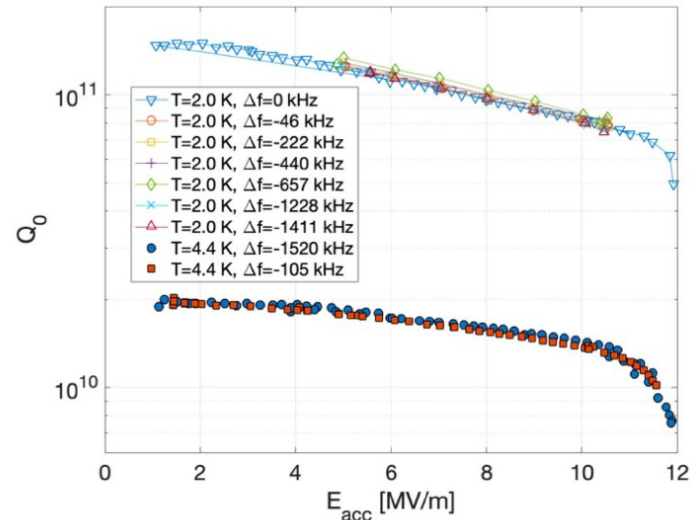


- ▶ Nb<sub>3</sub>Sn coating suffer flux trapping
- ▶ **Cooldown procedure influence R<sub>s</sub>**

# Cavity Tunability



**Strong performance degradation** after **room temperature** tuning for 200 kHz



**Little change** in the coated cavity performance after tuning up to 1400 kHz at **cryogenic temperatures**

**Nb<sub>3</sub>Sn is extremely brittle**

*neev, G. (2023). Tunability/robustness of Nb3Sn (No. MILAB-SLIDES-23-402-TD). Fermi National Accelerator oratory (FNAL), Batavia, IL (United States).*

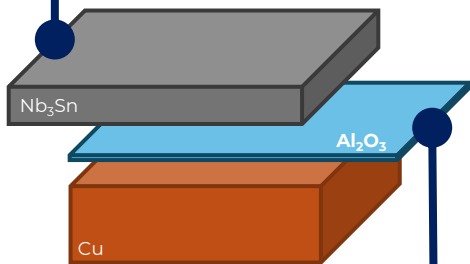
- ▶ **Vapor Tin Diffusion Nb<sub>3</sub>Sn on Nb cavities can be tuned only at cryogenic T**
- ▶ **An interlayer in Nb<sub>3</sub>Sn on Cu coatings can be added to enhance film mechanical stability and tunability**

# WP3: Nb<sub>3</sub>Sn on Cu films for 4.2K cavity operation

Institutes participating: INFN, CEA, HZB, UKRI

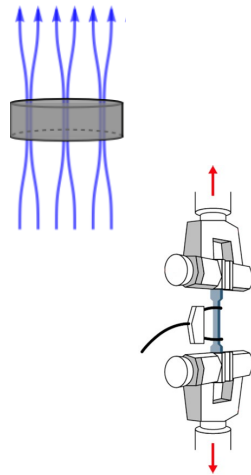
Convener: Cristian Pira (INFN LNL)

**INFN**  
**UKRI** Improve Nb<sub>3</sub>Sn coating performances  
(Task 3.5)



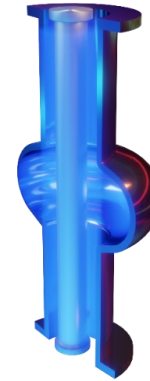
**cea** Develop an Adaptive Layer to insert between Nb<sub>3</sub>Sn coating and Cu substrate  
(Task 3.4)

**UKRI**  
**HZB** Helmholtz Zentrum Berlin flux trapping test on planar samples  
(Task 3.2)



**cea** mechanical strength test on planar samples and cavities  
(Task 3.3)

**INFN**  
**UKRI** Coat a 1.3 GHz cavity with optimized recipe  
(Task 3.5)



**HZB** Helmholtz Zentrum Berlin 4.2 K SRF vertical test of Nb<sub>3</sub>Sn on Cu optimized cavity  
(ISAS WP3 final goal)  
(Task 3.5)





## **WP3: Nb<sub>3</sub>Sn on Cu films for 4.2K cavity operation**

Institutes participating: INFN, CEA, HZB, UKRI

Convener: Cristian Pira (INFN LNL)

### **Task 3.1: Coordination of R&D on SC cavities – M1-M48 (INFN, CEA, HZB, UKRI) – Cristian Pira**

*This task aims to coordinate the different task activities and organize the periodic WP meetings.*

### **Task 3.2: Flux Trapping – M1-M32 (INFN, CEA, HZB, UKRI) – Oleg Malyshev**

*This task aims to minimize flux trapping in Nb<sub>3</sub>Sn thin films studying and optimizing coating parameters and cooling procedure*

### **Task 3.3: RF Tunability – M1-M32 (INFN, CEA, HZB, UKRI) – Oliver Kugeler**

*This task aims to study and improve mechanical properties of SC thin films to assess the impact of future cavity tuning during normal 4.2 K operation*

### **Task 3.4: Adaptive Layers – M1-M40 (INFN, CEA, HZB, UKRI) – Thomas Proslie**

*This task aims at developing suitable adaptive layers synthesized by Atomic Layer Deposition (ALD) to reduce the detrimental effect of mechanical deformation on the superconducting properties of Nb<sub>3</sub>Sn*

### **Task 3.5: Working Cavity – M1-M48 (INFN, CEA, HZB, UKRI) – Reza Valizadeh**

*This task encompasses the main outcome of WP3: to optimize the SC cavity coating procedure at 1.3 GHz using the experience and knowledge gained in Tasks 3.2-3.4. and demonstrate suitability for operation at 4.2 K.*

### Coordination (INFN, CEA, HZB, UKRI) – Cristian Pira

- Periodic meeting (in person and online) every 2-3 months (possibly in collaboration with I.FAST → EPITA)
- Zanon is joining WP3 meetings as industrial reviewer

**WP3 Meeting 01** - Task leaders Pre-Kick-Off remote meeting on 21/02/2024 <https://agenda.infn.it/event/40107/>

**WP3 Meeting 02** - Kick-Off meeting in Paris (hybrid) on 16/04/2024 (in collaboration with I.FAST WP9) <https://indico.cern.ch/event/1357302/sessions/528505/#20240416>

**WP3 Meeting 03** - Task Leaders remote meeting on 17/07/2024 (in collaboration with I.FAST WP9) <https://indico.cern.ch/event/1437516/>

**WP3 Meeting 04** - Hybrid meeting in Berlin on 02-03/12/2024 (in collaboration with I.FAST WP9) <https://events.hifis.net/event/1875/>

**WP3 Meeting 05** - Annual meeting in LNL (hybrid) on 12/03/2025 <https://indico.ijclab.in2p3.fr/event/11291/timetable/#20250312>

**WP3 Meeting 06** - I.FAST Annual meeting in Cracow (hybrid) on 08/04/2025 <http://indico.cern.ch/event/1464979/timetable/#20250408.detailed>

**Informal update** during SRF2025 Conference in Tokyo (21-26/09/2025)

**WP3 Meeting 07** - Online meeting on 24/11/2025 <https://indico.ijclab.in2p3.fr/event/12433/>

**WP3 Meeting 08** - Online meeting on 20/03/2026 <https://indico.ijclab.in2p3.fr/event/13566/>

**WP3 Meeting 09** - Annual meeting in HZB (hybrid) on 22/04/2026 <https://indico.ijclab.in2p3.fr/event/11960/timetable/#20260422>

## Coordination (INFN, CEA, HZB, UKRI) – Cristian Pira

✓ Milestone 39 Impact Risk Analysis WP3 – INFN – Presentation/report M24 **Completed**

Critical risks & risk management strategy					
Risk No	Description	Probability (scale 1<4)	Severity (scale 1<4)	Criticality (PxS)	Mitigation measures
1	Beneficiary leaves the project	1	3	3	Pro-actively: documentation, collaboration, strong coordination; Post-facto: redistribute tasks
2	Lack of candidates for temporary positions	1	4	4	Maximize job advertisements as early as possible and as wide as possible (professional networks), leverage on the iSAS consortium
3	<b>Appearance of small defects on the superconducting layers dramatically affecting the RF performance</b>	3	4	12	<b>Test the coatings on smaller prototypes before depositing on the 1.3 GHz prototype; thermometry measurements will identify defects and help improving deposition (Task 3.5)</b>
4	Scaling the SC coatings from planar samples to 3D geometry more difficult than expected	2	3	6	Additional R&D on small 3D structures to find and solve technical issues in advance (Task 3.2, Task 3.4)
5	<b>Fragility of A15 film may results in reduced tunability of the coated cavity</b>	3	4	12	<b>Initial test on small sample in Task 3.3 to optimize thin-film coating procedure, followed by coating on a 1.3 GHz cavity in Task 3.2</b>
6	Delamination of ALD layers on Cu at high Temperature	1	1	1	Test of multilayers and different alloys to mitigate this risk
7	Further increase of costs for Helium and/or power	1	3	3	Proportional reduction of number of tests or test duration

# Flux Trapping (INFN, CEA, HZB, UKRI) – Oleg Malyshev

## Objectives

- ▶ Explore new coating parameters for planar samples and small resonators to minimize flux trapping in SC A15 films.
- ▶ Upgrade the STFC choke cavity and the HZB QPR to support detailed flux trapping analyses of coated superconducting films.
- ▶ Characterize trapped flux, flux viscosity and the interaction with the RF field with SC A15 films in small resonators and samples with the upgraded systems.

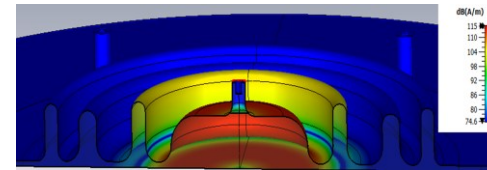
 **Deliverable 3.2** Flux trapping Report on flux dynamics study in Nb<sub>3</sub>Sn on Cu samples - *HZB - Report M30* **On track**

 **Milestone 3.1** Modification of choke cavity for flux trapping study - *Engineering report M12* **Completed**

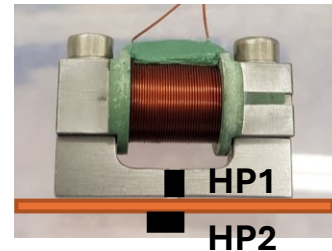
# 4 Characterization Facilities Updated during ISAS



**Choke Cavity Field Penetration Facility**  
( $R_S$  measurements with 7.8 GHz cavity)



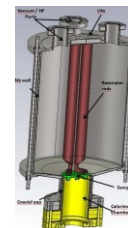
**Magnetic Field Penetration Facility**



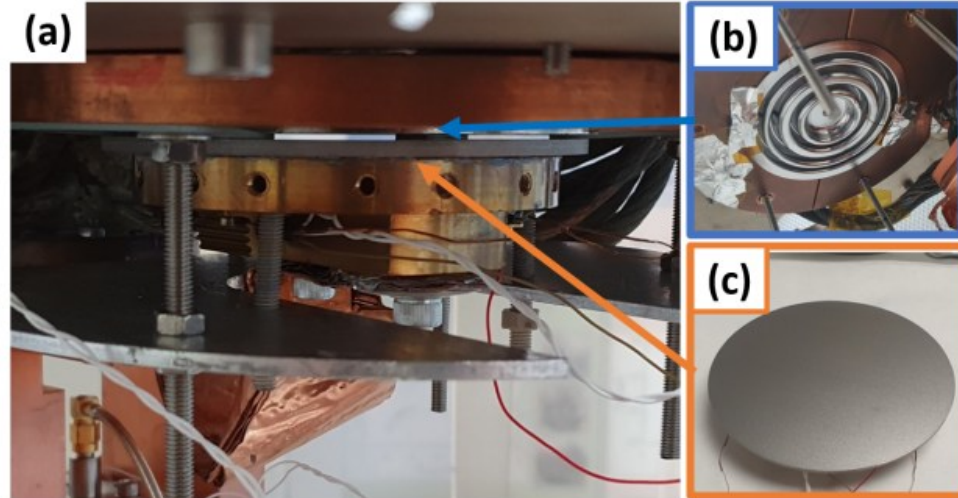
**CRAFT Facility** (Measurement of flux trapping and flux dynamics)



**Quadrupole Resonator (QPR) Facility**



## Choke Cavity Facility



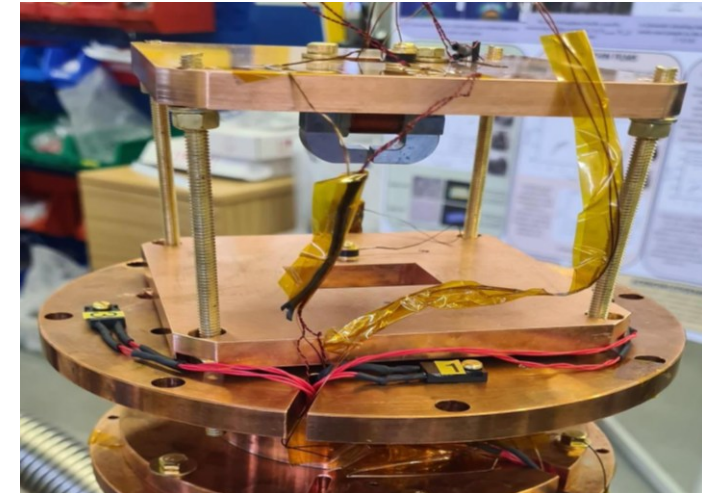
Measuring  $R_s$  and  $T_{c-RF}$  of these samples with the choke cavity facility of samples

### SAMPLES

**Substrates:** 100 mm diameter disks with thickness of 2-3 mm made of Cu or Nb

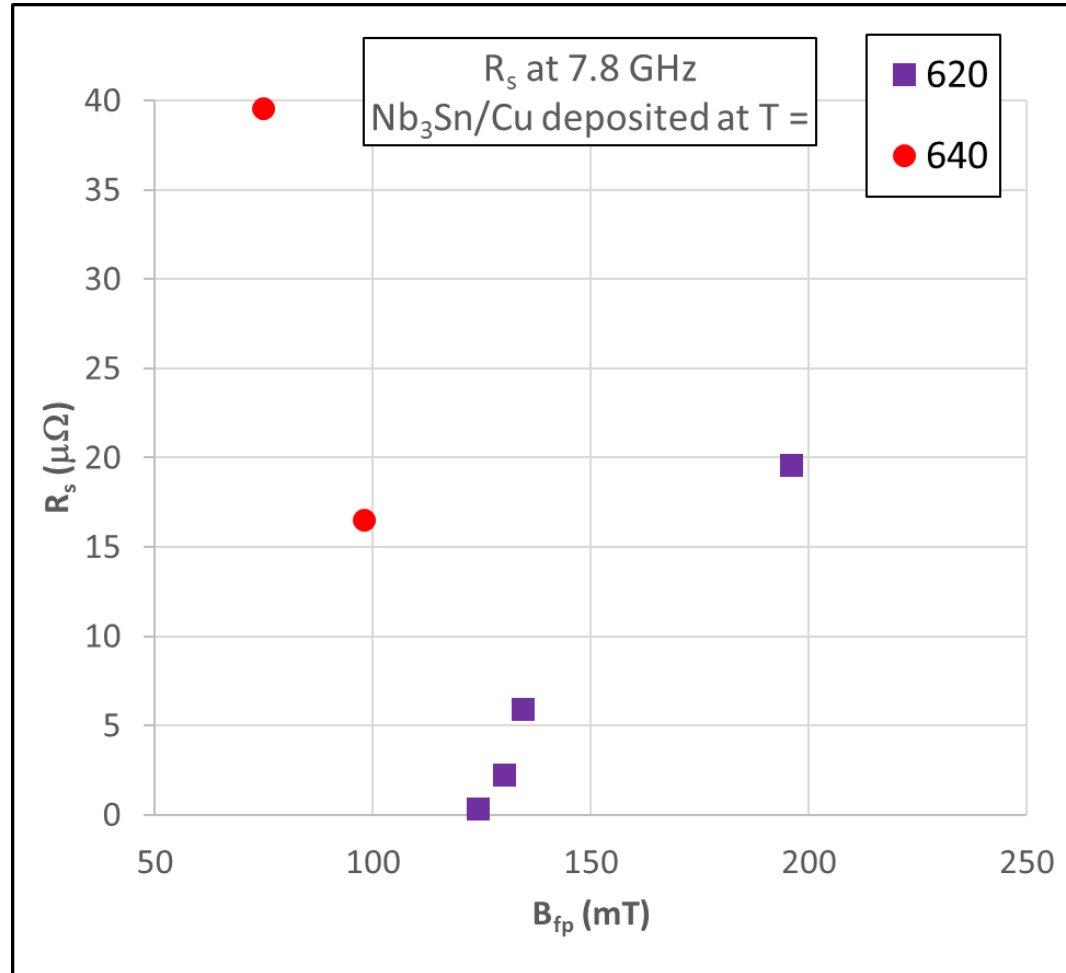
**Coating: Nb and Nb<sub>3</sub>Sn** (different deposition parameters explored: temperature, time, power, DC, HIPIMS, etc.)

## Full magnetic field penetration facility

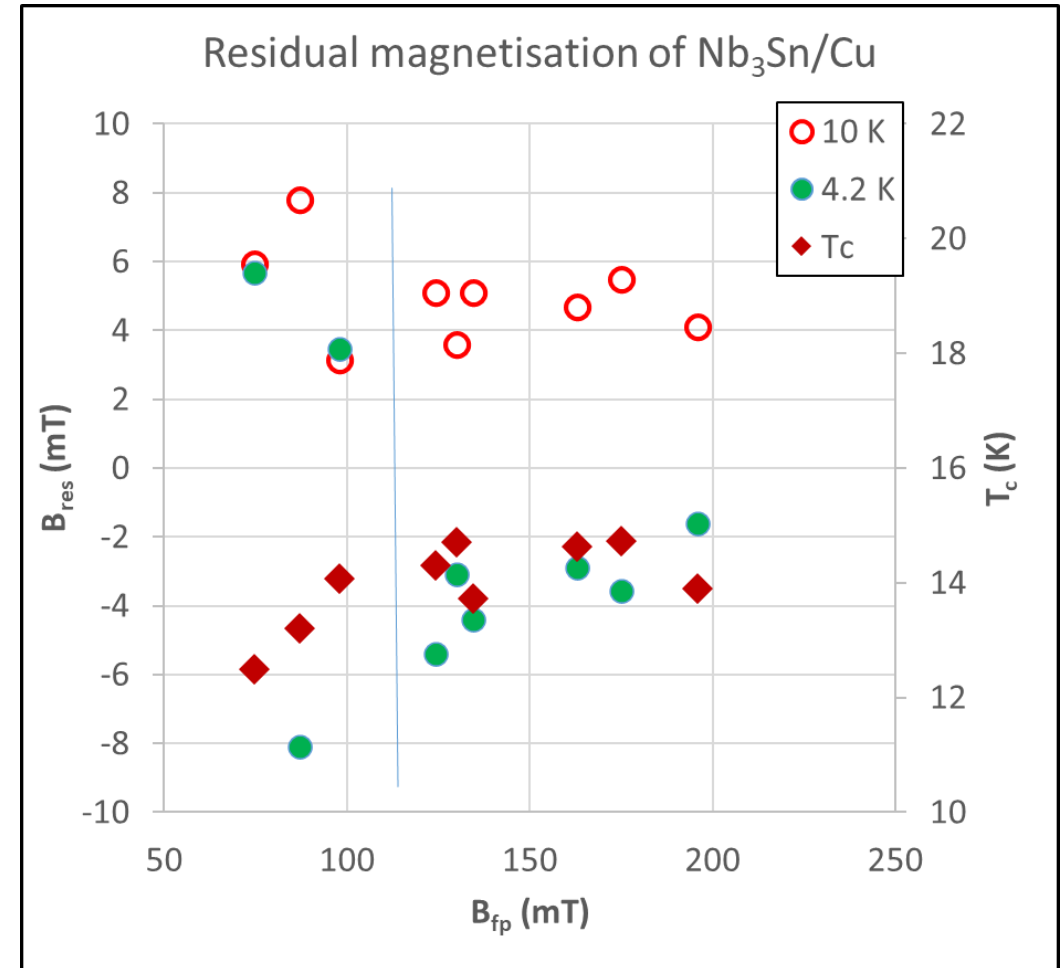


Testing the same samples with magnetic field penetration facility for full penetration magnetic field  $B_{fp}(T)$ , residual magnetisation  $B_{res}(T)$  and  $T_{c-dc}$

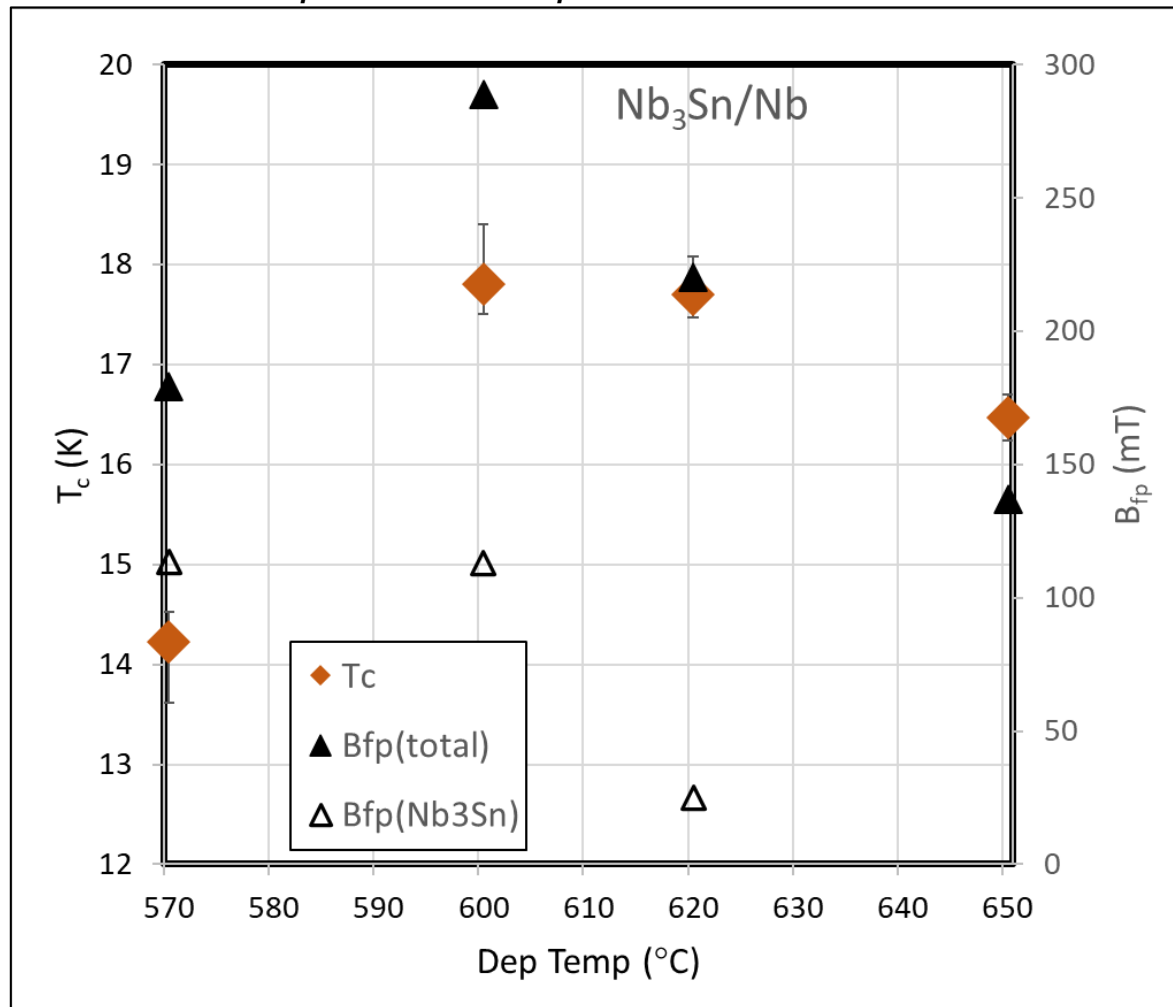
Relation between  $R_s(7.8 \text{ GHz})$  and  $B_{fp}$  measured at 4.2 K



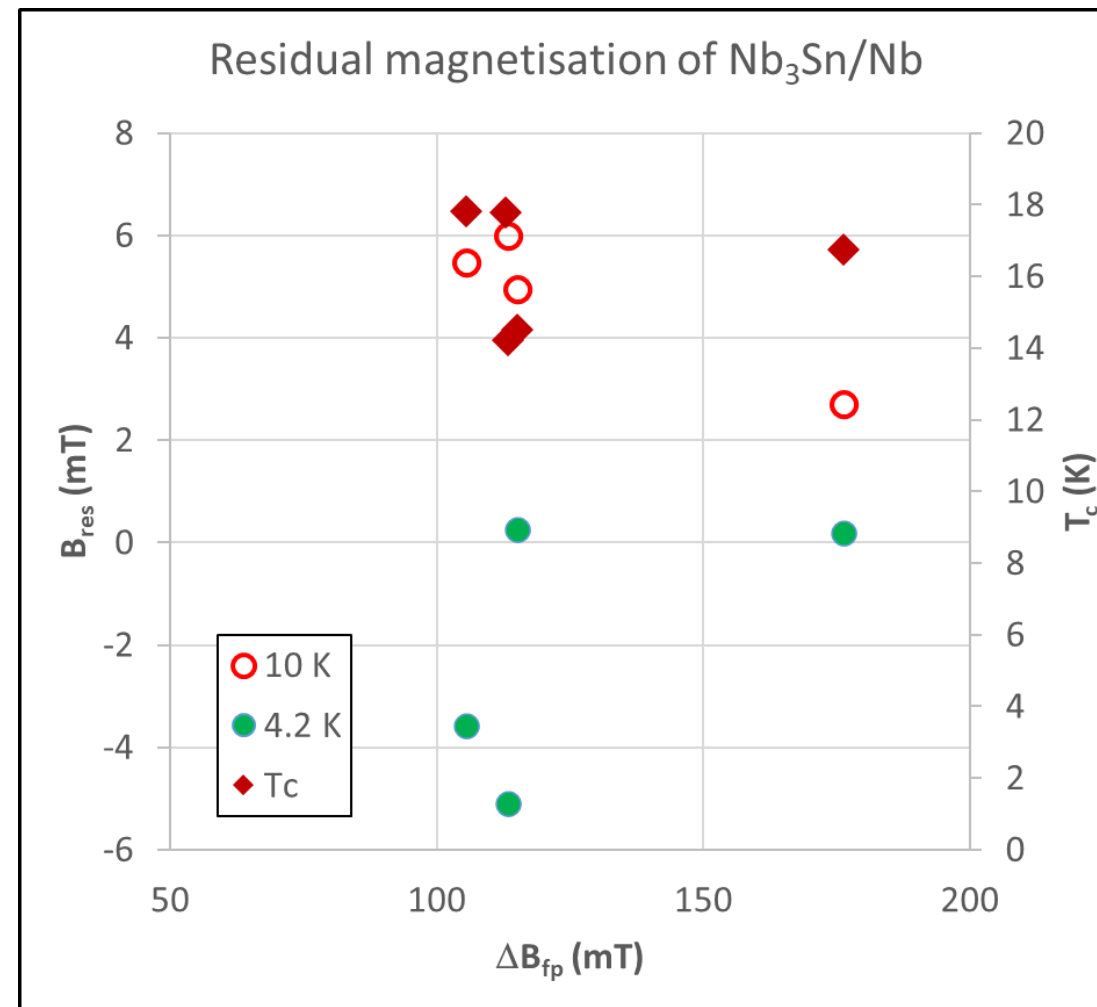
Corelation between  $T_c$ ,  $B_{fp}$  measured at 4.2 K and  $B_{res}$  measured at 4.2 and 10 K



Relation between  $T_c$  and  $B_{fp}$  measured at 4.2 K as a function of deposition temperature

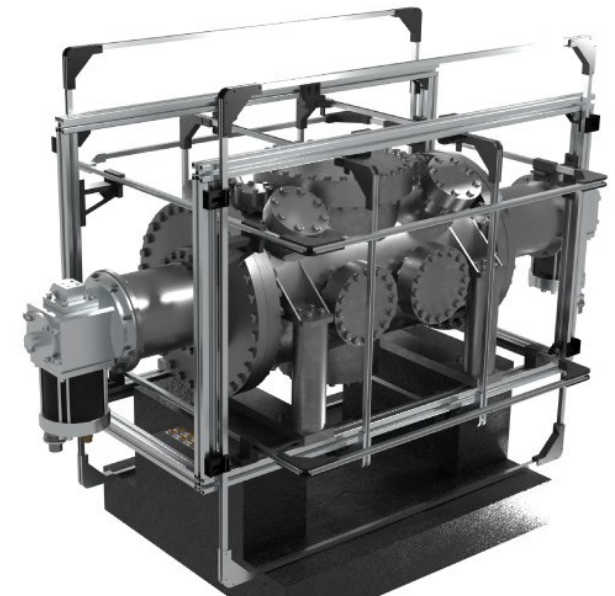
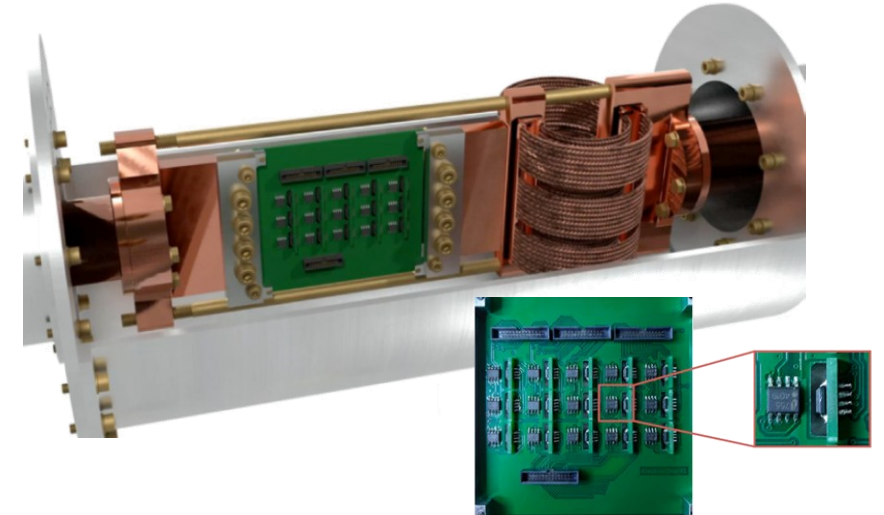


Corelation between  $T_c$ ,  $\Delta B_{fp}$  measured at 4.2 K and  $B_{res}$  measured at 4.2 and 10 K



## CRAFT Facility

- 2 cryocoolers to cool down sample
- Sample (100x60x3)mm<sup>3</sup>, clamped in copper blocks at either end
- Two heaters at the end of the blocks allow for precise control of temperature gradient and cool down rate
- Multiple AMR sensors for magnetic field measurements
- grouping of 3 sensors to measure field vector in 3d
- 15 AMR sensor groups measure magnetic field just above the sample
- 2 Cernox sensors measure temperature gradient across sample
- Active field compensation with three Helmholtz-coils
- Minimum flux density at location of reference sensors < 30nT
- Maximum flux density 220μT

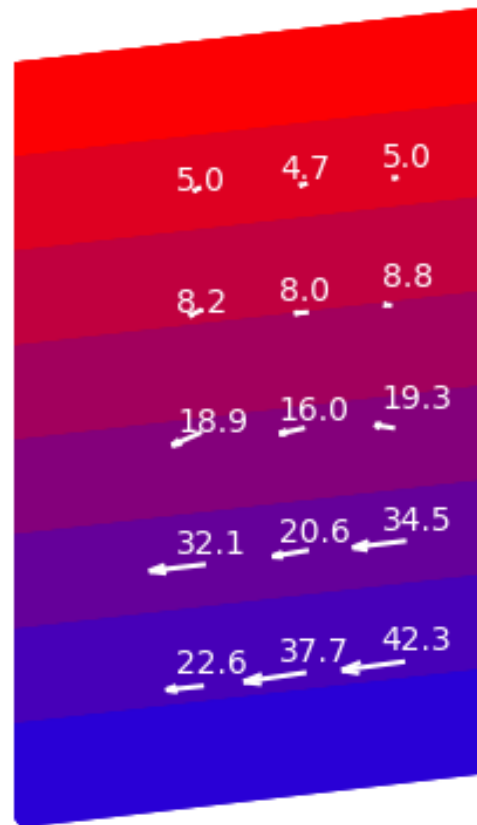


## CRAFT Facility

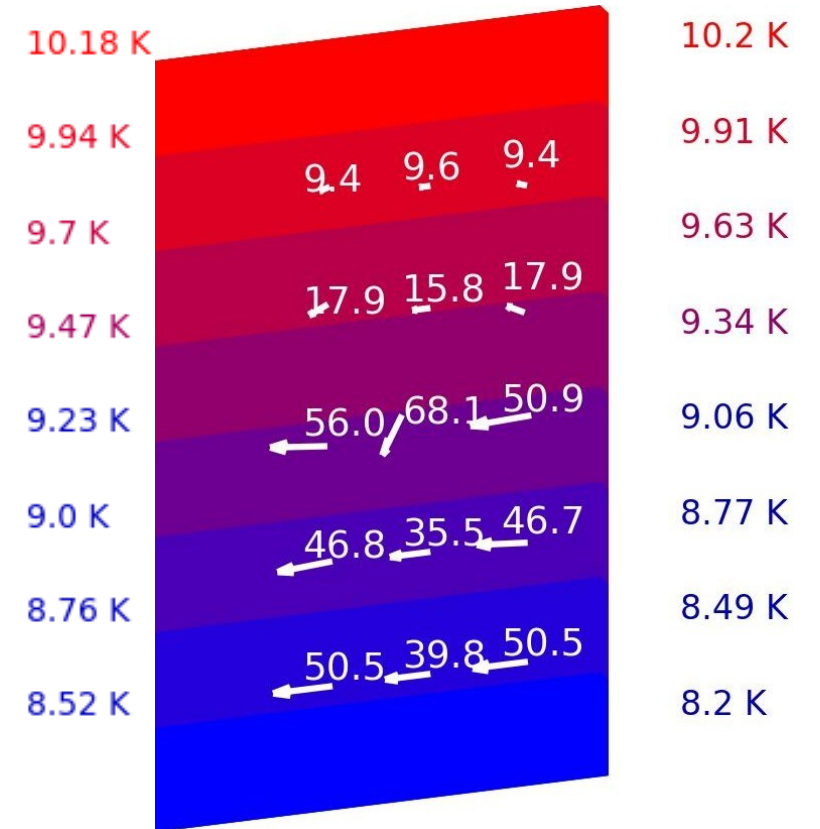
### Good agreement between simulation and experimental results

- Simulate flux density generated by the current density
- Extract flux density at sensor positions
- Compare to measurement
- Nb/Cu (10 μm) Sample
- Partially superconducting
- Good qualitatively agreement
- Magnitude can change drastically by changing conductivity of the copper

Measurement



Simulation

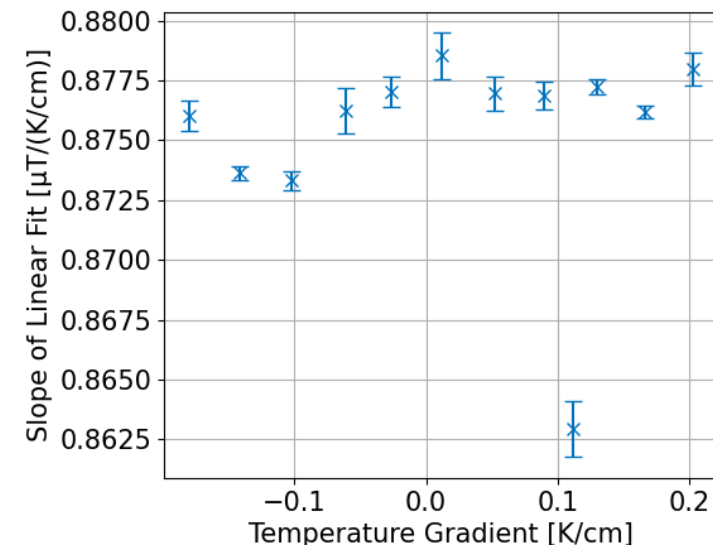
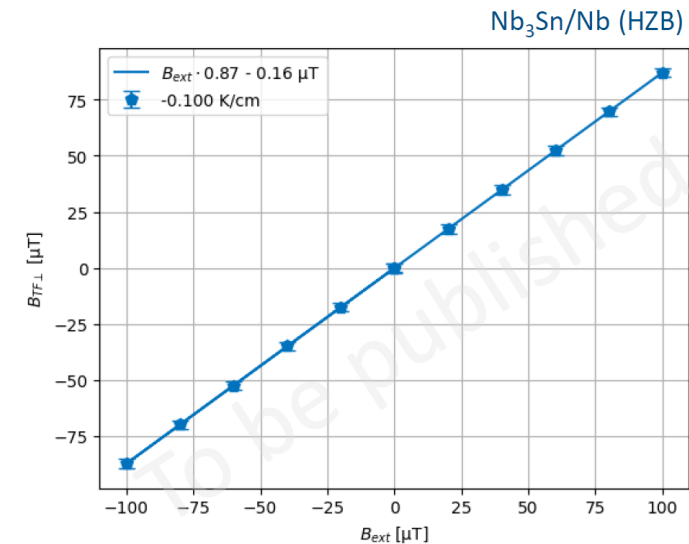


## CRAFT Facility

### TRAPPING EFFICIENCY

- Cool down samples different external fields with constant temperature gradient
- Plot trapped flux versus external field
- Slope of linear fit is trapping efficiency
- **No dependency on temperature gradient**

This is in contrast with bulk samples where the trapping efficiency decreases with increasing temperature gradient

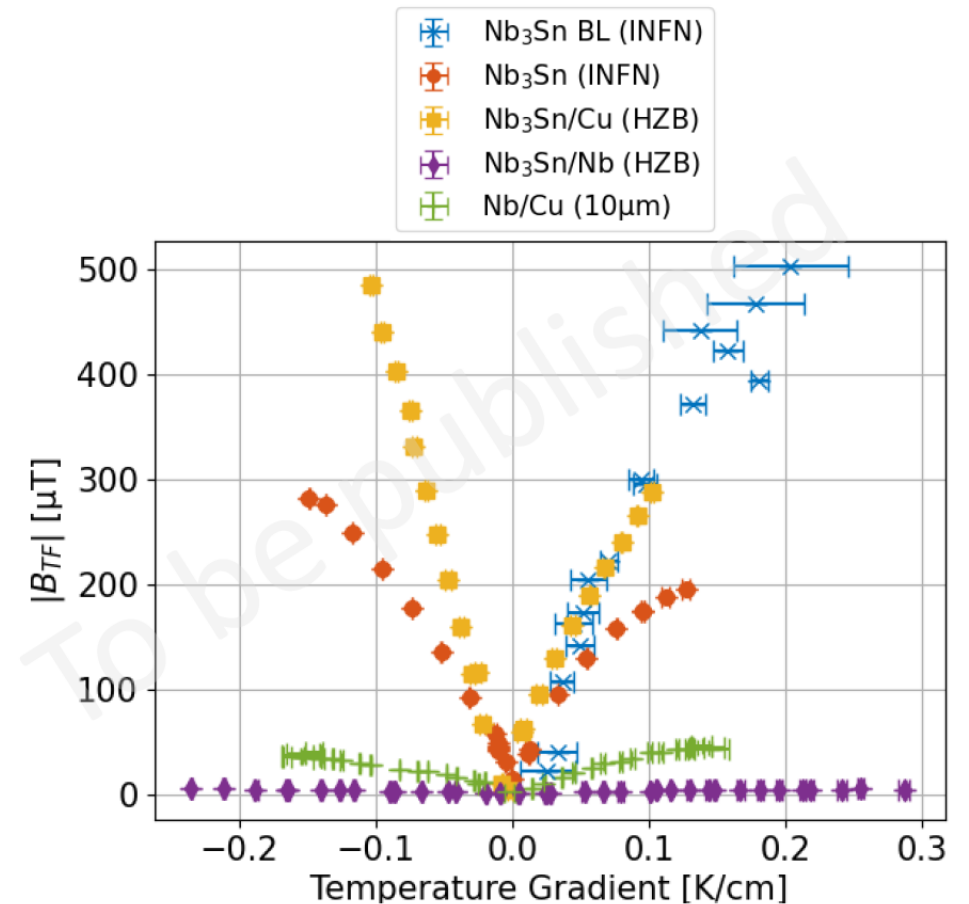


## CRAFT Facility

### Measurement overview

- All Nb<sub>3</sub>Sn samples on copper substrate created large fields during cooldown
- Sample on niobium substrate did not show this behavior
- **Low T<sub>c</sub> Nb<sub>3</sub>Sn samples present Trapped Flux inhomogeneity → non uniform SC phases**

Name	TF Orientation	Uniform T <sub>c</sub>	T <sub>c</sub> [K]
Nb <sub>3</sub> Sn BL (INFN)	inhomogeneous	no	14.7 ± 0.2
Nb <sub>3</sub> Sn (INFN)	inhomogeneous	no	13.2 ± 0.8
Nb <sub>3</sub> Sn/Cu (HZB)	inhomogeneous	no	14.5 ± 0.6
Nb <sub>3</sub> Sn/Nb (HZB)	homogeneous	yes	17.7 ± 0.3
Nb/Cu (10μm)	homogeneous	yes	9.2 ± 0.1
Nb/Cu (4μm)	homogeneous	yes	9.2 ± 0.1



### Next steps

✓ **Milestone 3.1** Modification of choke cavity for flux trapping study - *Engineering report M12* **Completed**

🕒 **Deliverable 3.2** Flux trapping Report on flux dynamics study in Nb<sub>3</sub>Sn on Cu samples - *HZB - Report M30* **On track**

- New samples from INFN and STFC in preparation
- Search for correlation between deposition parameters and the initial penetration field is currently in progress

# RF Tunability (INFN, CEA, HZB, UKRI) – *Oliver Kugeler*

## Objectives

- ▶ Explore new coating parameters on planar samples and small resonators to enhance the mechanical strength in SC A15 films.
- ▶ Mechanical film-stability tests with planar samples.
- ▶ Build cavity tuning system and perform vertical cryo-tests of coated cavities to explore RF performance limits and acceptable tuning without incurring film damage.
- ▶ Devise cavity tuning schemes for Nb<sub>3</sub>Sn cavities fulfilling the required tuning parameters while taking into account the constraints of Nb<sub>3</sub>Sn. The implementation of FE-FRT to assist will be considered.

✓ **Deliverable 3.1** Cavity tuning Report on implementation of cavity Q vs F tuning tool - *HZB - Report M24*

Completed

🕒 **Milestone 3.3** Report on mechanical strength test of SC coatings - *Test report M30*

On track

✓ Deliverable 3.1 Cavity tuning Report on implementation of cavity Q vs F tuning tool

Completed

### Background

- Nb<sub>3</sub>Sn-coated copper cavities must be mechanically tuned to adjust resonant frequency
- Tuning causes deformation that can damage the coating (e.g., cracks, delamination, ageing)
- TESLA-type 1.3 GHz cavities require ~1 MHz tuning range, corresponding to ~2 mm length change ( $\sim 8 \times 10^{-4}$  relative frequency change)
- Coarse tuning is slow (minutes) using a motor-driven lever system with high mechanical advantage
- Cavities also experience fast, small oscillations (0–300 Hz) from piezos for microphonics and compensation
- Deformation is **non-uniform**: local bending, stress concentrations (geometry, welds, tuner contact)
- **A prototype setup with a blade tuner and copper cavity is used to study coating stability under realistic conditions**

## What happen during cavity tuning?

### From Macroscopic to Atomic Scale

Strain translates to:

**picometer-scale lattice changes**

Affects both:

**Substrate (Cu/Nb) & Nb<sub>3</sub>Sn coating**

### Superconducting Consequences

Strain modifies:

**Lattice spacing → electronic structure**

Possible effects:

**Shift in T<sub>c</sub>, Change in critical current, Altered flux pinning**

RF impact:

**Increased surface resistance, Local hot spots at high fields**

### Impact on Nb<sub>3</sub>Sn Coating

Nb<sub>3</sub>Sn is **brittle vs. ductile** substrate

Strain induces:

**Tensile + shear stress, Stress at interface**

Real coatings:

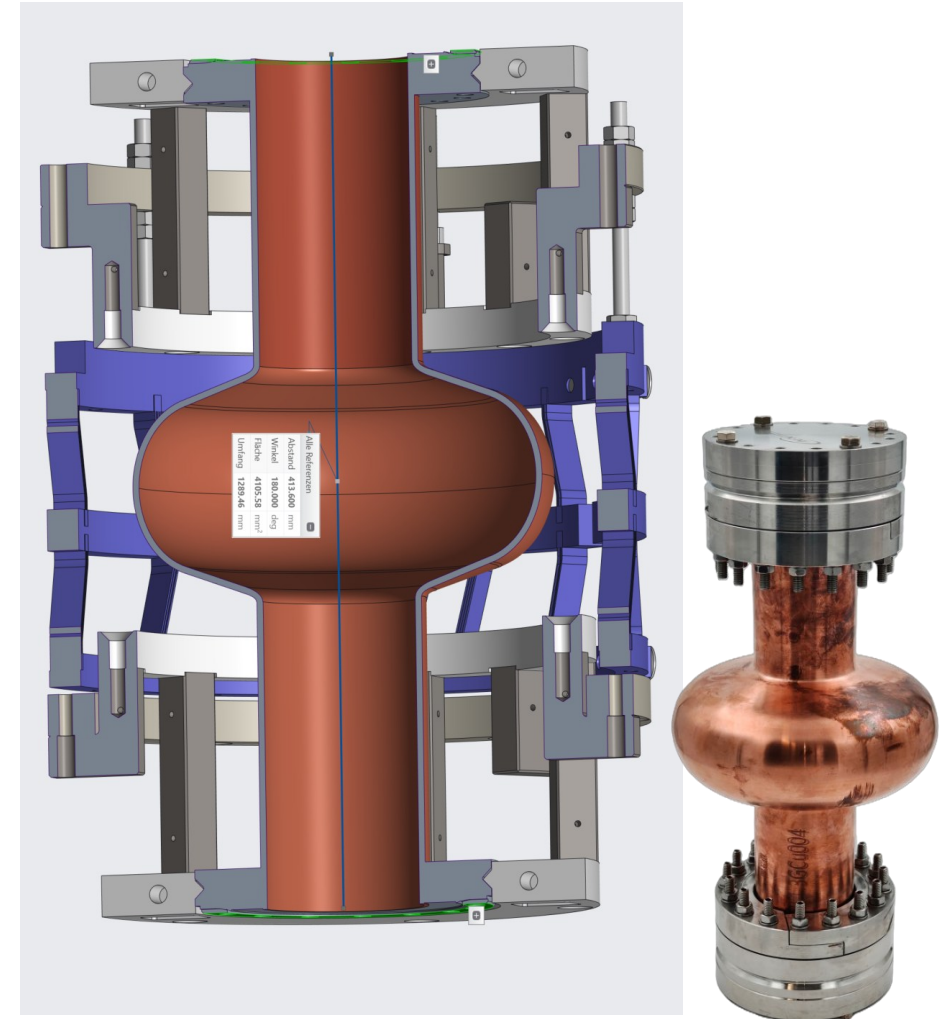
**Grain boundaries, defects → stress concentrators**

Can lead to:

**Microcracks, Delamination, Damage accumulation over cycles**

## Blade Tuner Facility

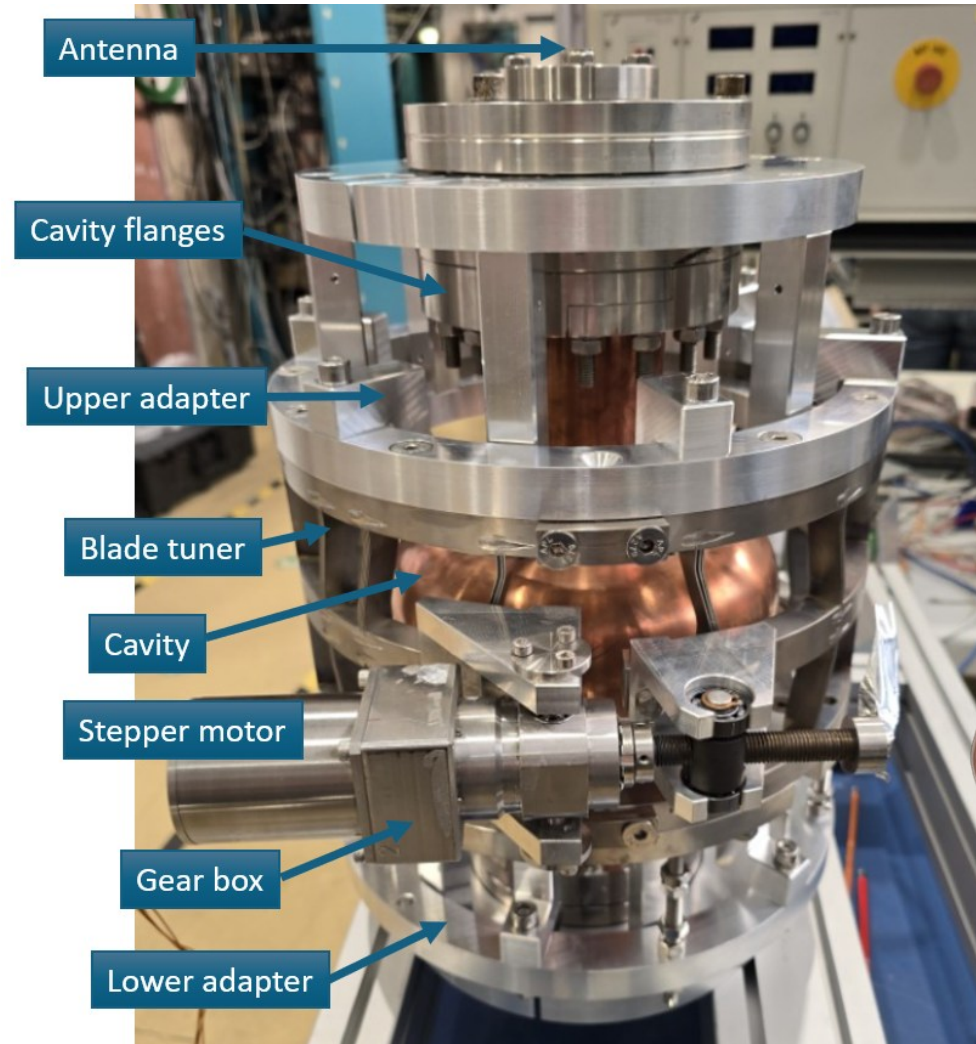
- Copper prototype cavities provided by **INFN** with **TESLA-shaped geometry**, formed by spinning
- Ends equipped with **horn-shaped „flanges“**  
→ vacuum-tight via CF-100 adapters
- Permanent vacuum connections (not removed after assembly)
- **Blade tuner design:**
- Three concentric rings along cavity axis  
→ connected via **titanium blades (spring elements)**
- Middle ring split  
→ converted into **axial cavity deformation**
- Lateral motion  
→ converted into **axial cavity deformation**
- Challenge: Standard tuners attach to **LHe tank**, not bare cavity, to be used in bath cryostat
- Solution: Custom **groove + adapters (HZB)** to connect tuner directly to cavity



## Blade Tuner Facility

### Actuation & RF Measurement

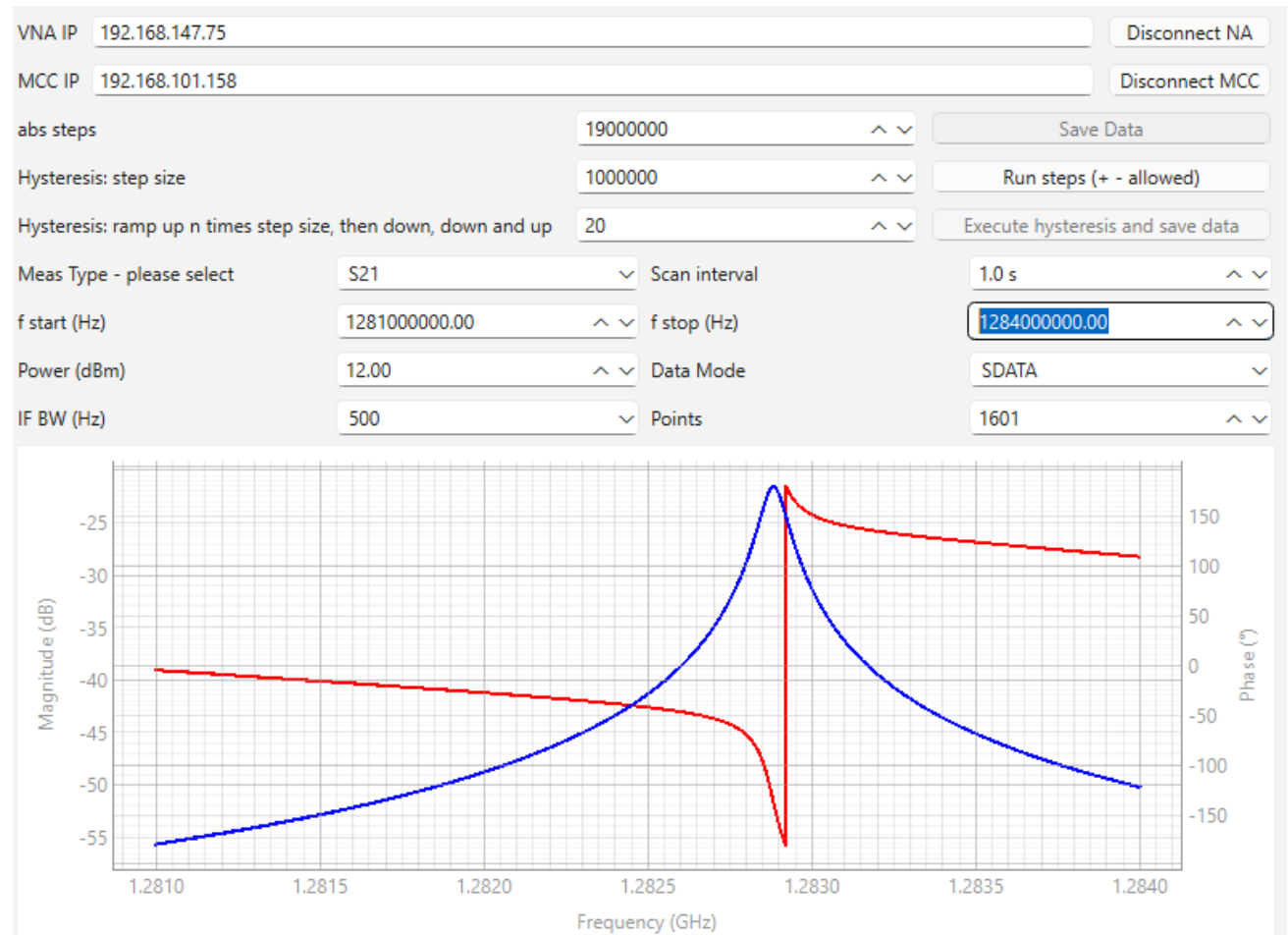
- **Stepper motor (Phyton) + harmonic drive**  
→ precise, reproducible cavity length control
- Two antennas:
  - One **strongly coupled**
  - One **weakly coupled**
- **Vector Network Analyzer (VNA):**
- Measures S-parameters  
→ resonance frequency & bandwidth
- Automated via **Python GUI (ChatGPT-assisted)**



## Blade Tuner Facility

### Prompt engineered DAQ tool

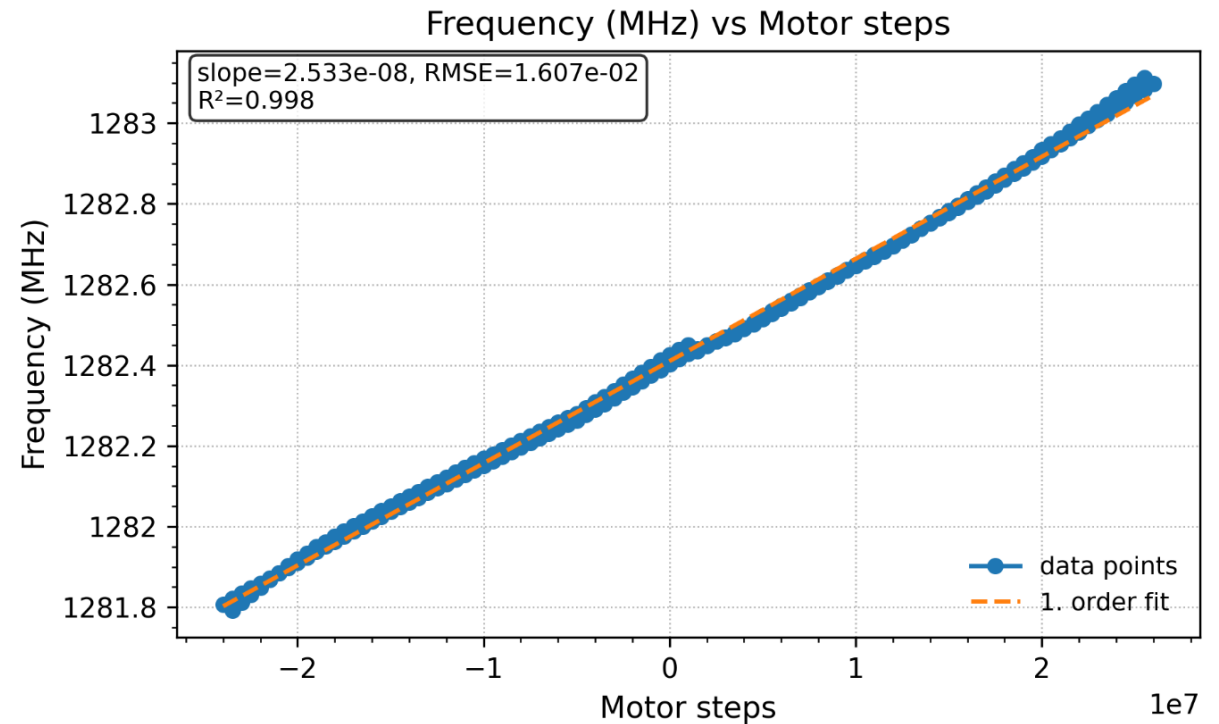
1000 lines of python code entirely generated by AI



## Blade Tuner Facility

### Results:

- Range ok
- Linearity ok
- Small hysteresis
- Small plastic deformation at >1MHz elongation (can be healed)



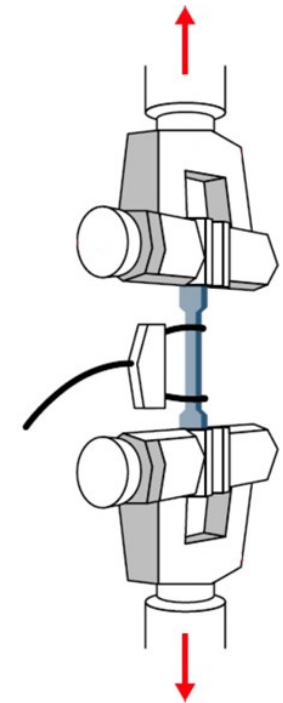
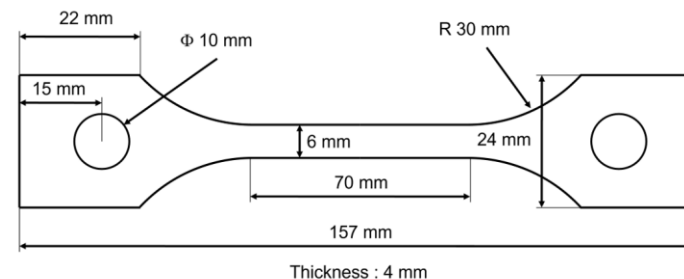
🕒 Milestone 3.3 Report on mechanical strength test of SC coatings - *Test report M30*

On track

## Mechanical Strength Test on Planar Samples

### 4 Probe T<sub>c</sub> measurement during sample elongation

- Design of traction test Cu C2 (OFHC) samples were elaborated at **CEA** and sent for production
- The Cu traction samples will be electropolished, half will be coated by ALD and sent to **INFN** and **UKRI** for Nb<sub>3</sub>Sn/Nb deposition



### Next steps

✓ **Deliverable 3.1** Cavity tuning Report on implementation of cavity Q vs F tuning tool - *HZB - Report M24*

Completed

- Confirm vacuum tightness upon tuning
- Use better antenna
- Operate with Nb<sub>3</sub>Sn coated cavity in bath cryostat (above lambda point)
- Optional: equip HRD (movable antenna tool)

🕒 **Milestone 3.3** Report on mechanical strength test of SC coatings - *Test report M30*

On track

- The Cu traction samples will be electropolished, half will be coated by ALD and sent to **INFN** and **UKRI** for Nb<sub>3</sub>Sn/Nb deposition

## Adaptive Layers (INFN, CEA, HZB, UKRI) – *Thomas Proslie*

### Objectives

- ▶ Develop adaptative layers by atomic layer deposition on Cu that are stable up to 650 °C.  
*Insulating oxides layer: Al<sub>2</sub>O<sub>3</sub>, ZrO<sub>2</sub>, ZrAlO<sub>x</sub> as diffusion barriers*
- ▶ Compare performance Nb<sub>3</sub>Sn on Cu with and without adaptive layers on planar samples and QPR.

✓ **Deliverable 3.3** Adaptive Layer Report on QPR study of Nb<sub>3</sub>Sn on Cu & adaptive layers - *CEA - Report M38*

On track

🕒 **Milestone 3.2** Developed ALD adaptive layers on Cu - *Test report M24*

Completed

✓ Milestone 3.2 Developed ALD adaptive layers on Cu - M24 **Completed**

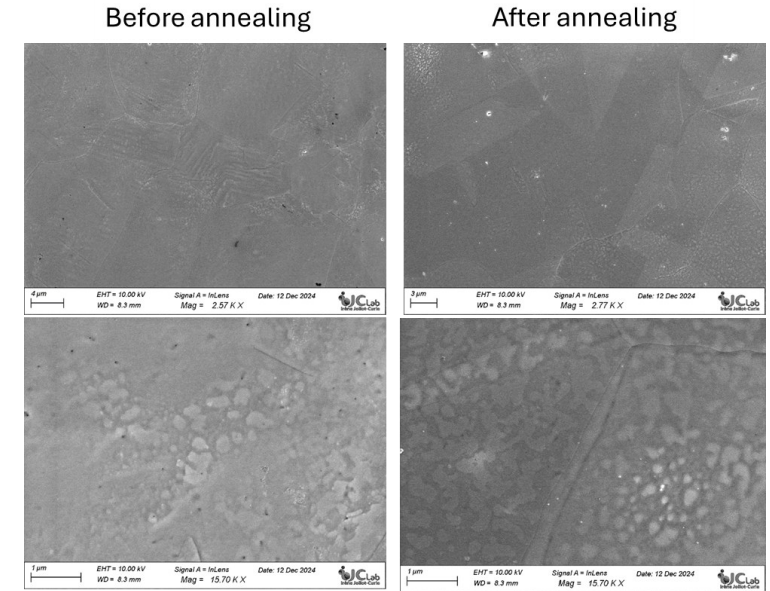
## MAIN RESULTS ACHIEVED

Developed several insulating ALD layers:  
Al<sub>2</sub>O<sub>3</sub>; ZrO<sub>2</sub>, AlZrO<sub>x</sub>, bilayers Al<sub>2</sub>O<sub>3</sub> - ZrO<sub>2</sub>

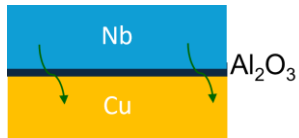
- stable up to 700°C for 2 hrs in high vacuum  
(Nb/Nb<sub>3</sub>Sn deposition conditions)
- High Pressure Rinsing (HPR) test passed

Studied the influence of the film structure and chemical composition on the superconducting film growth

- The presence of an **ALD Al<sub>2</sub>O<sub>3</sub> layer does not affect the structural and superconducting properties** of Nb films deposited on top (XRD, Tunneling spectroscopy, TEM).

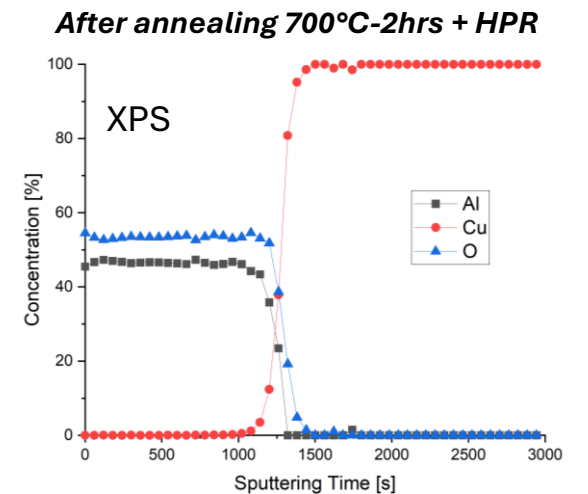


## FIRST IMPLEMENTATIONS



Coated a 1.3 GHz Cu cavity (deposition system built in IFAST) from **CERN** with 20 nm thick Al<sub>2</sub>O<sub>3</sub> layer – sent back to CERN for **Nb deposition by HiPIMS**  
→ *problem of Nb delamination after HPR*

Coated EP Cu samples from **INFN-LNL** with several oxide ALD layers alloys sent back to INFN for Nb and **Nb<sub>3</sub>Sn deposition**

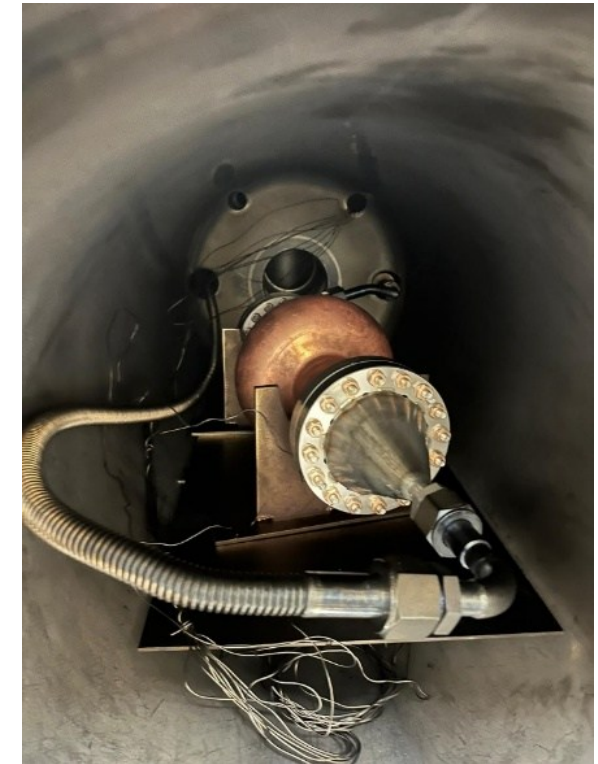


🕒 **Deliverable 3.3** Adaptive Layer Report on QPR study of Nb<sub>3</sub>Sn on Cu & adaptive layers - *M38*

**On track**

## Current developments (1)

- **Coated a second 1.3 GHz Cu cavity from CERN** with modified deposition parameters with 20 nm thick ALD layers -> sent back to CERN for Nb deposition by HiPIMS
- **No delamination after HPR**
- **RF test showed a ten time reduction in thermo-currents intensities !**
- Exploring the thickness dependence of the ALD interface layer on the thermo-current suppression capabilities and RF tests performances.

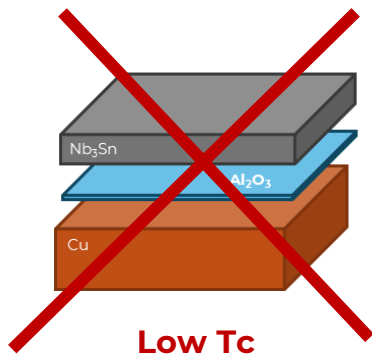
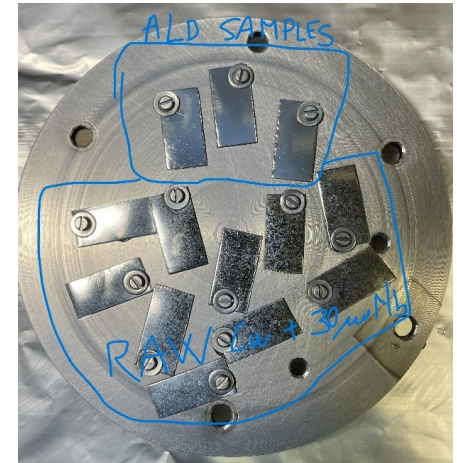


**Deliverable 3.3** Adaptive Layer Report on QPR study of Nb<sub>3</sub>Sn on Cu & adaptive layers - *M38*

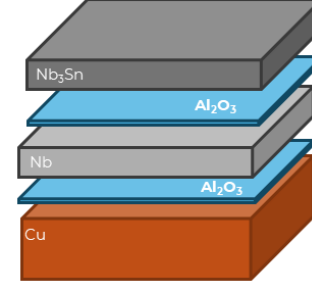
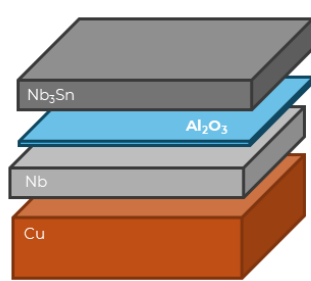
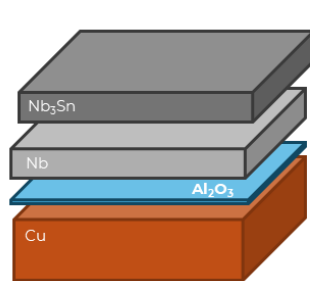
**On track**

## Current developments (2)

- Deposition of Nb and Nb<sub>3</sub>Sn at INFN-LNL on ALD coated Cu coupons
- Transport measurements done at INFN-LNL showed that the **T<sub>c</sub> (~ 16 K) is not affected by the presence of a ~ 20-25 nm thick ALD layer**. Further characterization is underway.
- Other EP Cu and EP Cu with Nb coatings sent to CEA for ALD coating. *In progress*
- R&D on planar coupons evaluating different configurations:



Low T<sub>c</sub>



T<sub>c</sub> ~ 17 K

Buffer Layer	T <sub>c</sub>	ΔT <sub>c</sub>
No buffer layer	13.8 K	0.3 K
16 μm Nb	16.5 K	0.6 K
30 μm Nb	16.7 K	0.5 K
<b>30 μm Nb + 18 nm Al<sub>2</sub>O<sub>3</sub></b>	<b>16.3 K</b>	<b>0.5 K</b>
<b>30 μm Nb + 25 nm AlZrO<sub>x</sub></b>	<b>16.9 K</b>	<b>0.2 K</b>
<b>30 μm Nb + 5 nm Al<sub>2</sub>O<sub>3</sub> + 22 nm ZrO<sub>2</sub></b>	<b>16.8 K</b>	<b>0.2 K</b>

## Next steps

✓ **Milestone 3.2** Developed ALD adaptive layers on Cu - *M24* **Completed**

🕒 **Deliverable 3.3** Adaptive Layer Report on QPR study of Nb<sub>3</sub>Sn on Cu & adaptive layers - *M38* **On track**

- Continue R&D on planar coupons trying different configurations
- Coat and test QPR with optimized configuration

## Working Cavity (INFN, CEA, HZB, **UKRI**) – *Reza Valizadeh*

### Objectives

- ▶ Improve I.FAST 1.3-GHz superconducting coating recipe based on Tasks 3.2-3.4 results.
- ▶ Prepare 1.3-GHz thin film cavities with an optimized coating recipe.
- ▶ Perform full cavity characterization @4.2 K (Q vs E, Q vs F, and flux trapping in the VTS@SupraLab vertical test stand).

🕒 **Deliverable 3.4** 4.5-K Cavity Report on 4.5-K Cavity performance & tunability tests - INFN - *Report M46* **On track**

🕒 **Milestone 3.4** Characterization of Nb<sub>3</sub>Sn reference cavity - *Test report M34* **On track**

## Optimized coating recipe

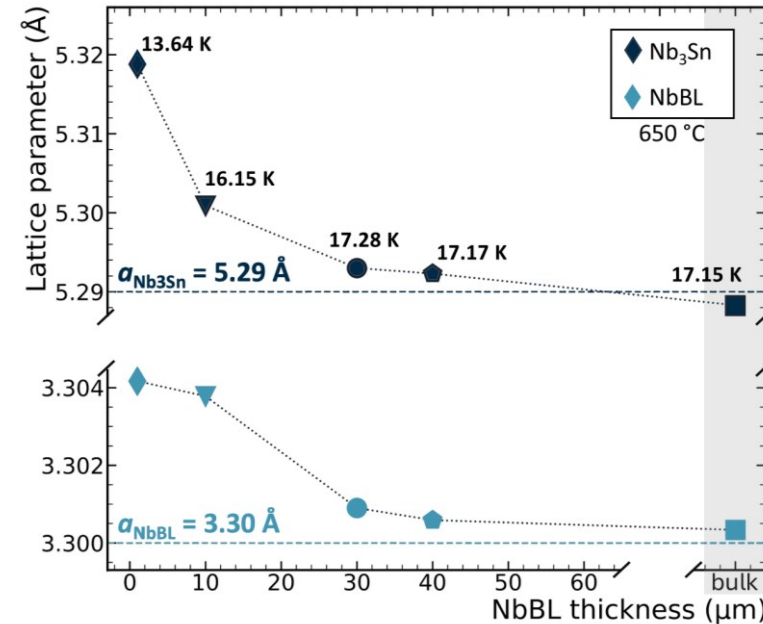
1. Low cathode Power  
≤ 250 mW/cm<sup>2</sup>
- +
2. High deposition Pressure:  
2 x 10<sup>-2</sup> mbar
- +
3. Deposition Temperature:  
600 °C – 650 °C
- +
4. No post Annealing
- +
5. Nb buffer layer ≥ 30 μm

**T<sub>c</sub> > 17 K**

**scientific reports**

OPEN [Recipe optimization and SRF test of Cu-compatible Nb<sub>3</sub>Sn films by DC magnetron sputtering from a stoichiometric target](#)

D. Fomesu<sup>1,2</sup>, D. Ford<sup>1</sup>, E. Chyhyrynets<sup>1</sup>, S. Keckert<sup>2</sup>, J. Knobloch<sup>2,3</sup>, O. Kugeler<sup>2</sup>, M. Lazzari<sup>1</sup>, G. Marconato<sup>1</sup>, A. Salmasso<sup>1</sup>, A. Zubtsovskii<sup>1</sup> & C. Pira<sup>1</sup>



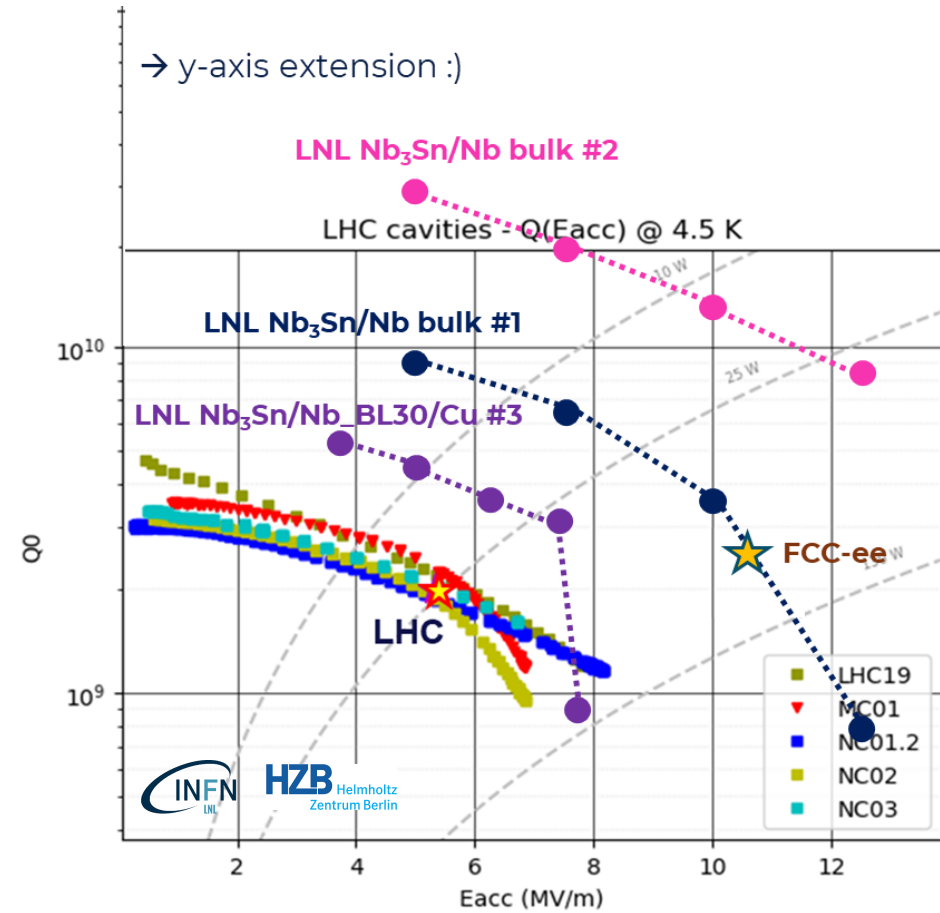
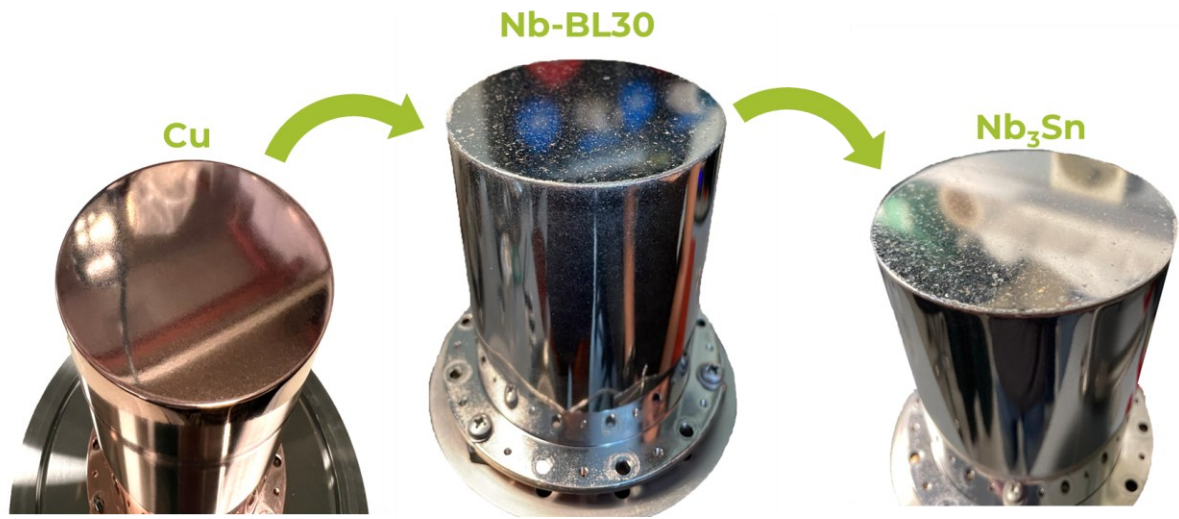
**Barrier Layer against Sn and Cu diffusion**

**Accommodation layer (release thermal stress)**

## RF Test on QPR (*recipe validation*)

### Sample #2 on Nb<sub>3</sub>Sn on Nb bulk (State of the art)

- $T_c = 17.45$  K
- Quench > 85 mT extrapolated @ 0 K
- $R_s < 9$  n $\Omega$  @ 4 K, 20 mT
- Better than VTD sample up to 50 mT

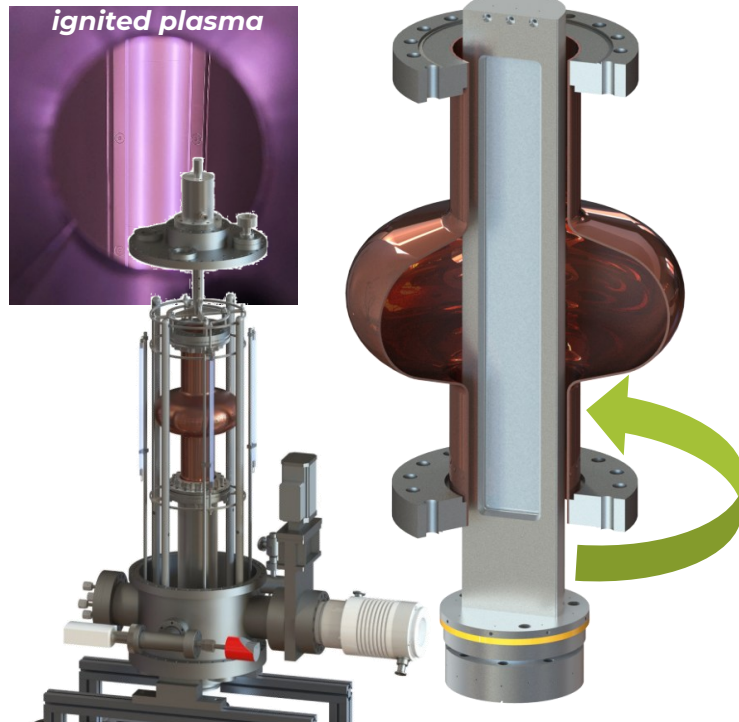


**Q value 10 times > LHC!**

## 2 Different 1.3 GHz coating system ready (testing phase)



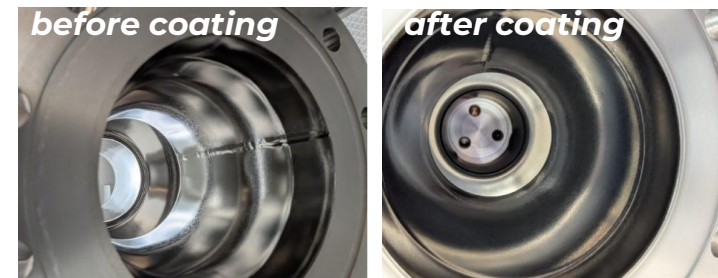
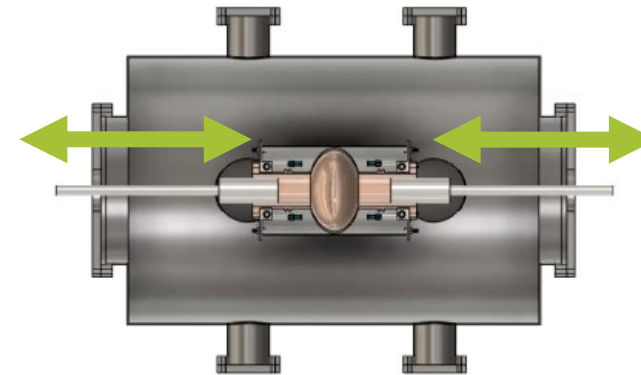
Rectangular magnetron  
Rotating Cavity



[M. Lazzari et al., "Development of a new system for Nb<sub>3</sub>Sn thin film deposition on 1.3 GHz cavities", in Proc. SRF2025, Tokyo, doi:10.18429/JACoW-SRF2025-TUP31](#)



Double movable magnetrons  
Fixed cavity



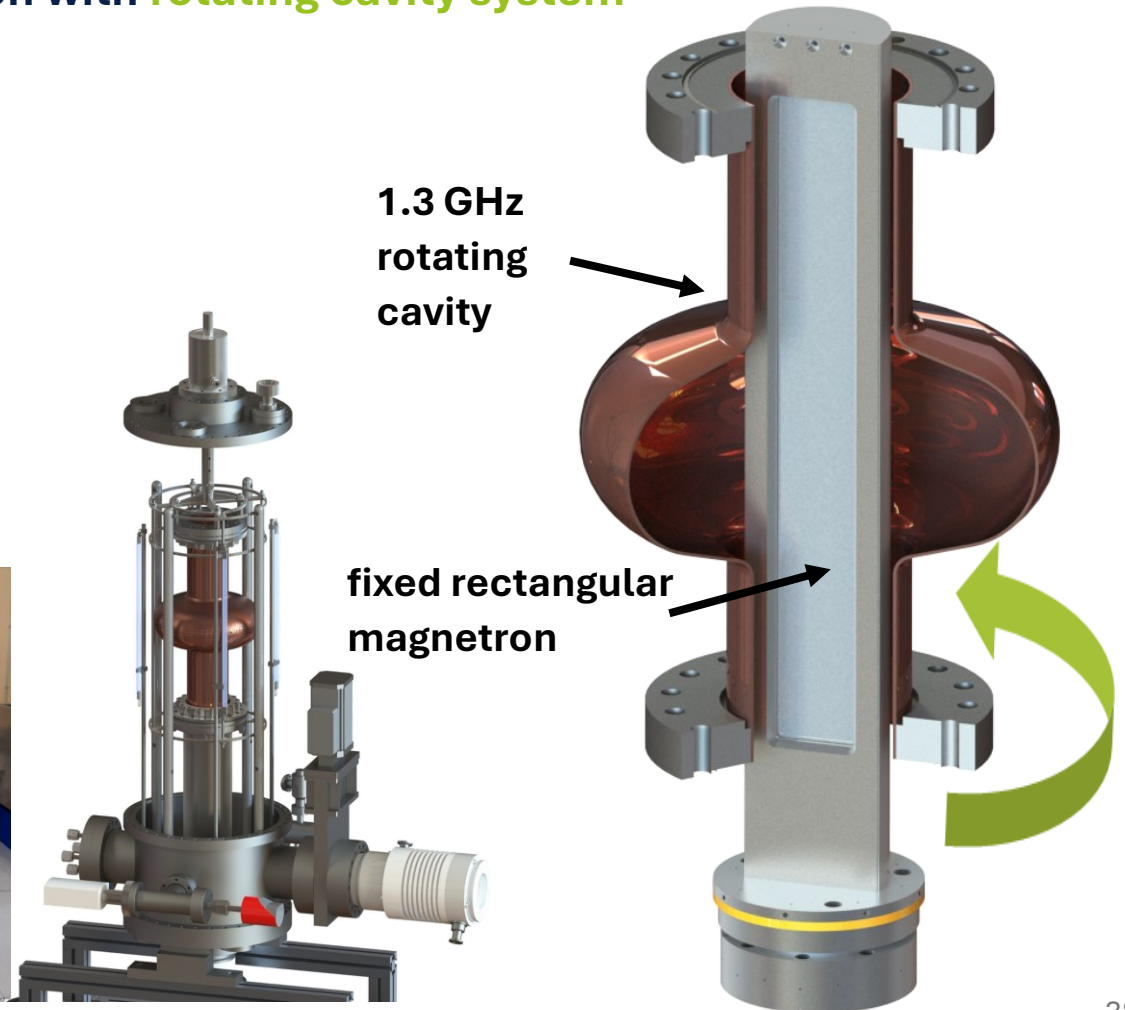
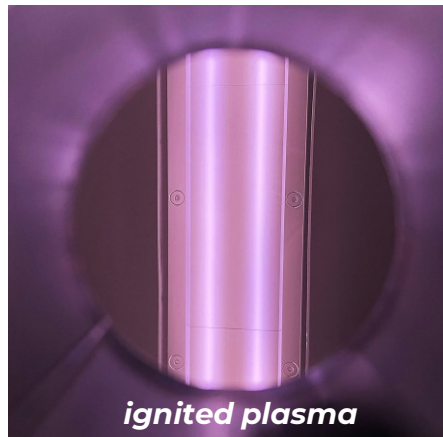
[N. Leicester et al., "Development of a 1.3 GHz longitudinally split RF research cavity for use in testing of superconducting thin films", in Proc. SRF2025, Tokyo, doi:10.18429/JACoW-SRF2025-TUP19](#)

# 1.3 GHz coating system @ LNL

Custom fixed rectangular planar magnetron with **rotating cavity system**

## Current Status:

- **vacuum system** assembled and tested
- **heating system** completed and tested
- **magnetron test** ongoing
- **first Nb cavity coating** planned for late 2026
- **Coating on Cu cavity** planned for 2027



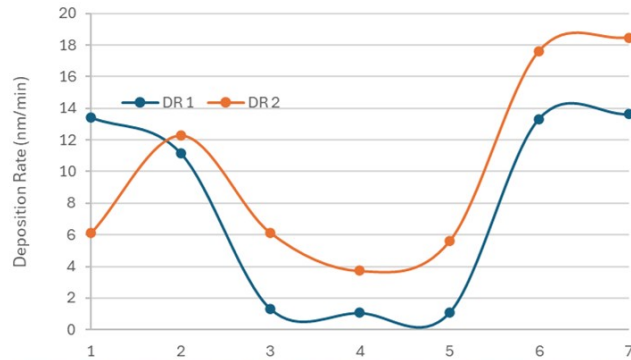
# 1.3 GHz coating system

Custom fixed rectangular planar magnetron with **rotating cavity system**

## Rectangular Magnetron

- Test with Nb target
- 3 sets of magnets to be tested (0.68 T, 0.92 T, 1.02 T)
- Tested 0,92T and 1.02 T configuration up to 1 A

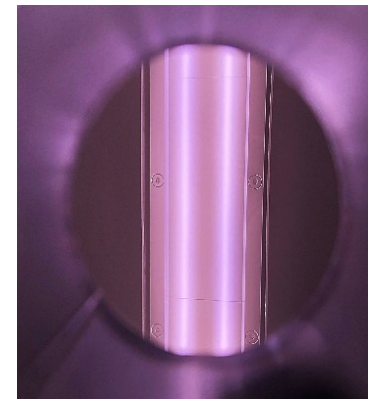
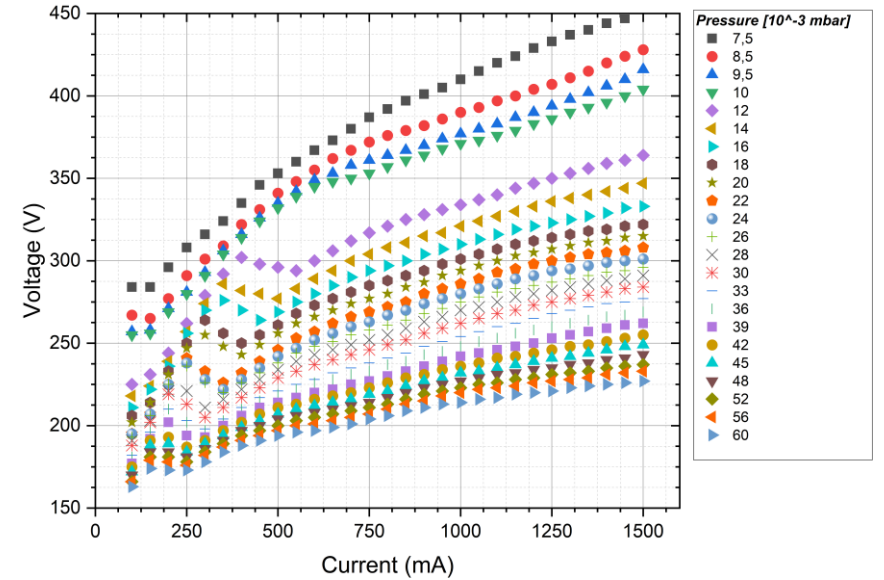
→ classical power law obtained



$$DR2_{equator} \sim 4 \times DR1_{equator}$$

$$DR1_{equator} / = DR1_{cut-off} \sim 13$$

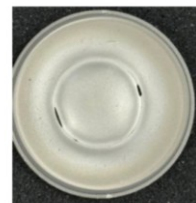
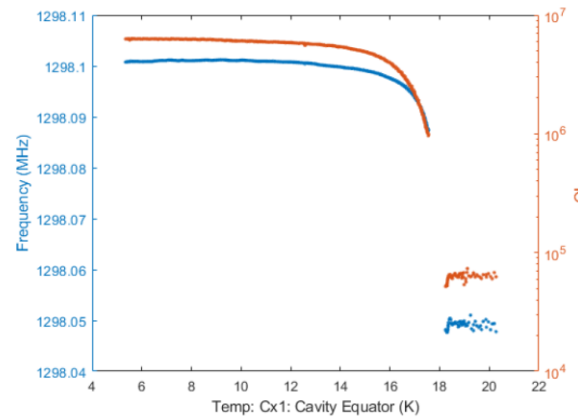
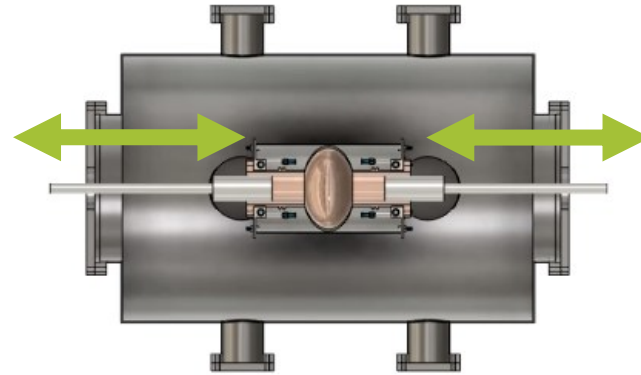
$$DR2_{equator} / = DR2_{cut-off} \sim 5$$



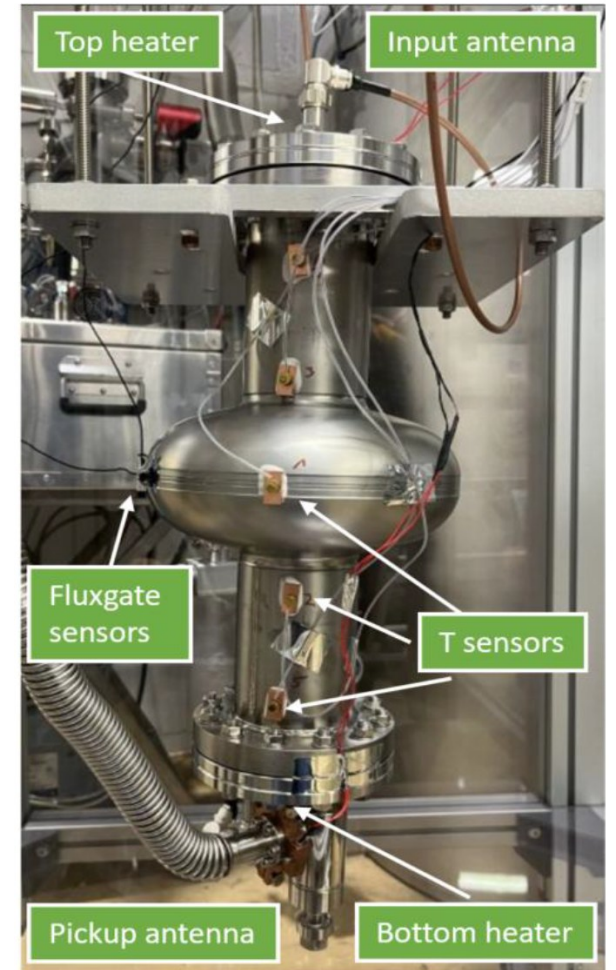
## First Cavity Coated @UKRI

### Nb<sub>3</sub>Sn on Nb bulk (reference cavity)

- Tested at HZB
- No HPR after Deposition
- Fixed RF couplers (designed for Q<sub>o</sub> of 10<sup>9</sup>)
- Manually slow cool Down
- No thermo-currents were recorded with the azimuthally placed sensors.
- **T<sub>c</sub> = 18.1 K**
- No T<sub>c</sub> of Nb was detected: Possibly cavity fully coated
- RF surface resistance of 8 x 10<sup>6</sup>
- **Poor Q factor:**
  - Cu contamination at surface layer due to diminishing target
  - Present of other normal conducting material due to poor cavity handling.
  - Or other reasons to be determined.



After target removed

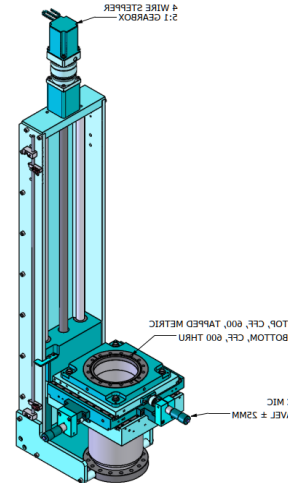
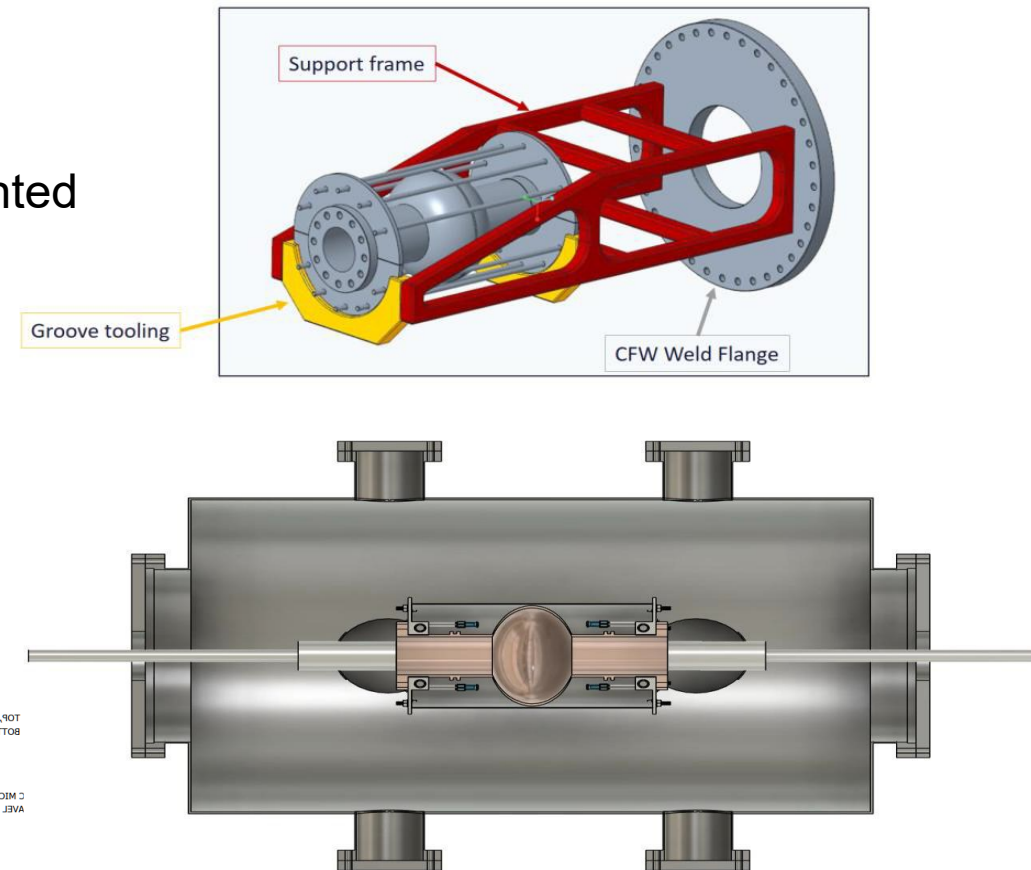
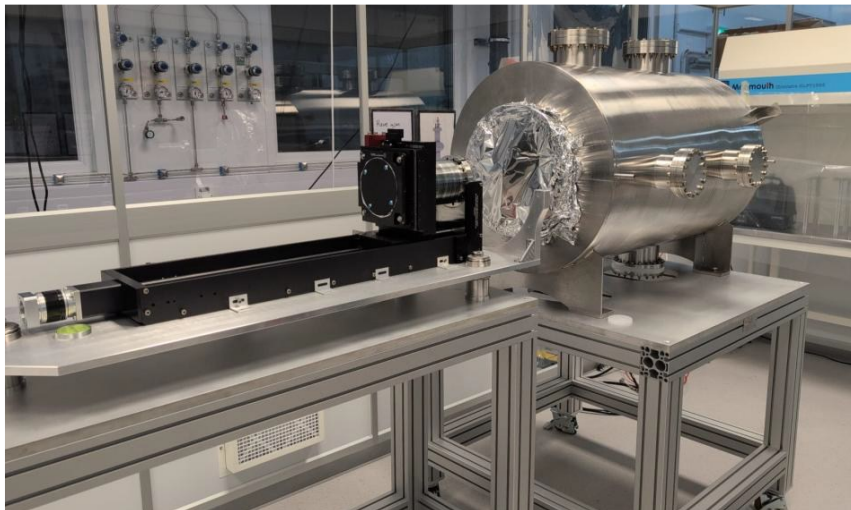


# 1.3 GHz coating system @ STFC

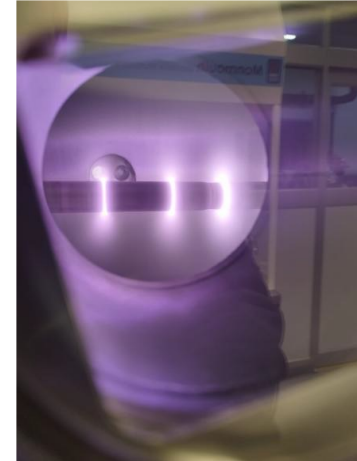
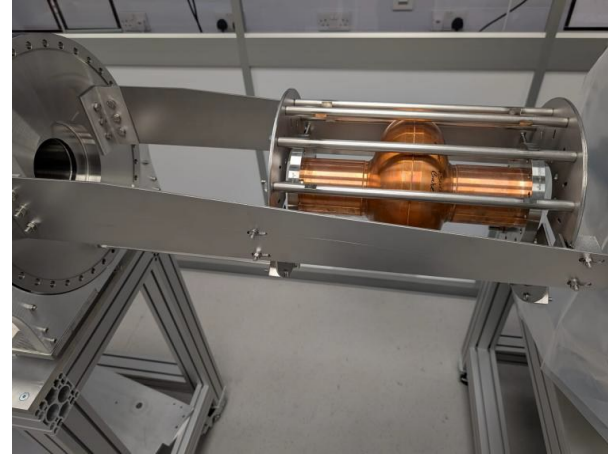
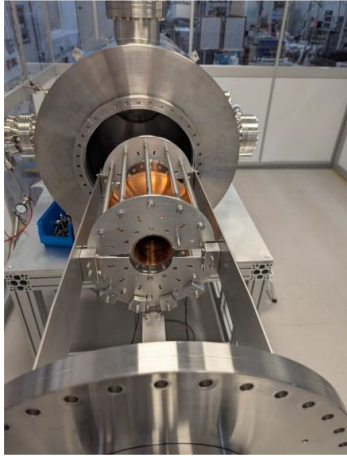
Double movable magnetrons with **fixed cavity**

## Current Status:

- Chamber already mounted
- Manipulators for each magnetron are delivered and mounted
- Few modification is on the way before full assembling



# Deposition of Nb on Cu cavity



## PROGRAM

1. Optimisation and design of deposition facilities
2. Nb deposition on copper cavity soon
3. 1.3 GHz Nb<sub>3</sub>Sn cavity prototyped by PVD using Nb cavity as substrate

A few problems keep persisting at STFC and delaying the progress:

- In-house surface polishing & HPR
- Cylindrical target for Nb<sub>3</sub>Sn (may be)

## Next Steps

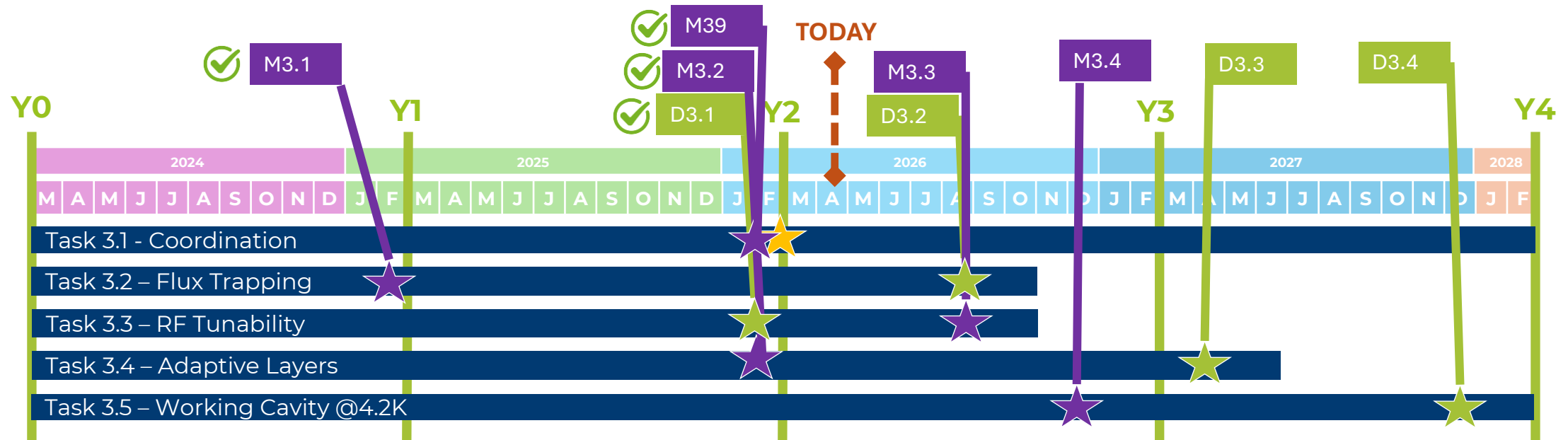
1. Characterize the Reference Cavity with Blade Tuner and flux trapping probe @HZB to complete milestone 3.4 (M34)
2. Continue test on coupons to optimize SC film quality along the cavity and and ensure performance reproducibility
3. Coating Nb<sub>3</sub>Sn on Bulk Nb cavity first + RF test
4. Coating Nb<sub>3</sub>Sn on Cu cavity + RF test (deliverable 3.4, M46)

# WP3 Nb<sub>3</sub>Sn on Cu: plans to achieve milestones & deliverables

Milestones & deliverables  
**on track**

- ✓ M3.1 Modification of choke cavity for flux trapping study - *Engineering report M12*
- ✓ M3.2 Developed ALD adaptive layers on Cu - *Engineering report M24*
- ✓ M39 Impact risk analysis WP3 – *Presentation/report M24*
- ⌚ M3.3 Report on mechanical strength test of SC coatings - *Test report M30*
- ⌚ M3.4 Characterization of Nb<sub>3</sub>Sn reference cavity - *Test report M34*

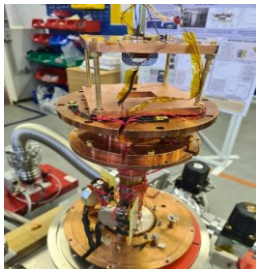
- ✓ D3.1 Cavity tuning Report on implementation of cavity Q vs F tuning tool - *Report M24 - HZB*
- ⌚ D3.2 Flux trapping Report on flux dynamics study in Nb<sub>3</sub>Sn on Cu samples - *Report M30 - HZB*
- ⌚ D3.3 Adapt. Layer Report on QPR study of Nb<sub>3</sub>Sn on Cu & adaptive layers - *Report M38 - CEA*
- ⌚ D3.4 4.5-K Cavity Report on 4.5-K Cavity performance & tunability tests - *Report M46 - INFN*



## Advanced characterization facilities

(task 3.2 and 3.3)

### Flux trapping



Choke cavity and field penetration facility upgrade done

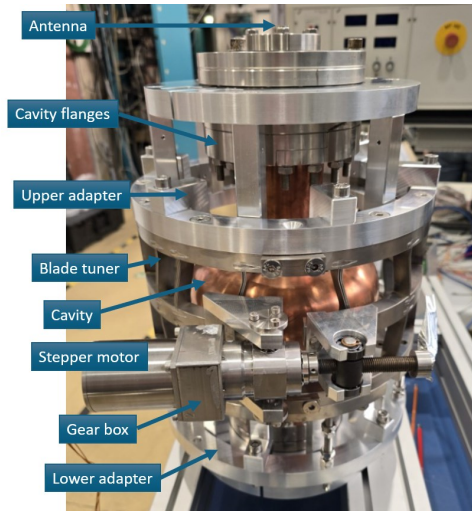


CRAFT Facility built and tested



Milestone 3.1 completed

### Tunability



Blade Tuner built and tested



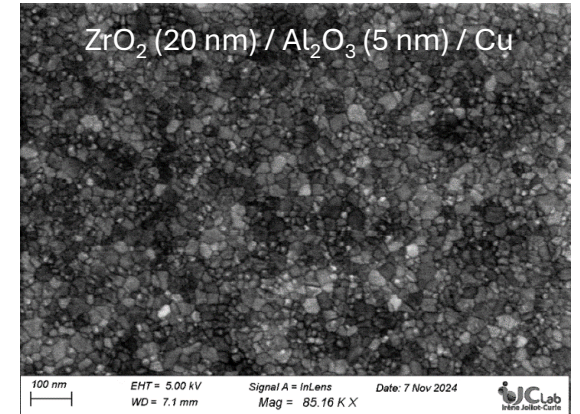
Deliverable 3.1 completed

## Adaptive layers

(task 3.4)

Al<sub>2</sub>O<sub>3</sub>, ZrO<sub>2</sub> and AlZrO<sub>x</sub> oxides successfully coated by ALD and stable up to 750 °C

Mitigation of thermo-electric currents proved on Nb

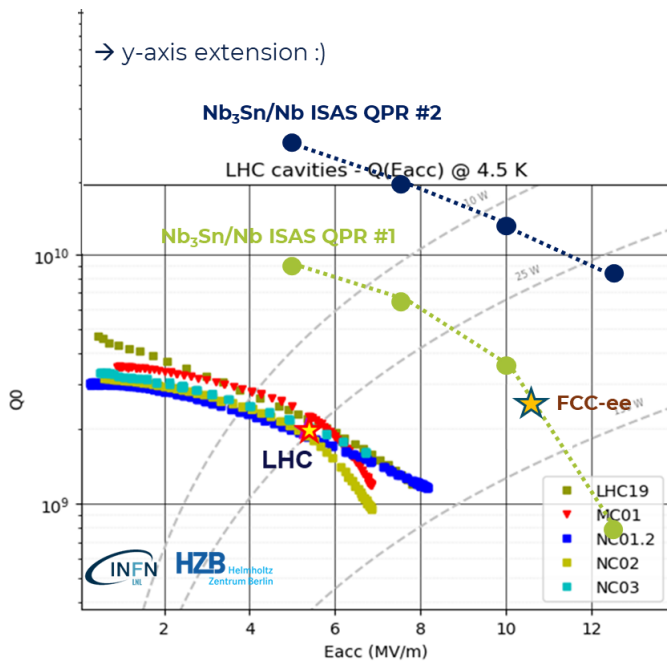


Milestone 3.2 completed

(task 3.5)

**Coating recipe optimized and validated on small planar resonator (QPR)**

**Q value 10 times > LHC!**



D. Fonnesu et al., "Recipe optimization and SRF test of Cu-compatible Nb<sub>3</sub>Sn films by DC magnetron sputtering from a stoichiometric target. Sci Rep 16, 3539 (2026)

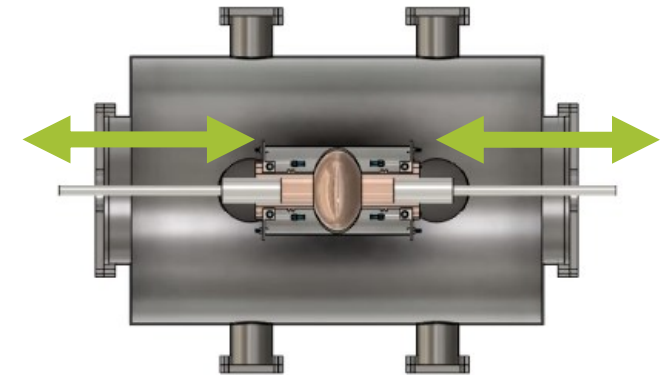
**2 Different 1.3 GHz coating system ready (testing phase)** (task 3.5)



Rectangular magnetron  
Rotating Cavity



Double movable magnetrons  
Fixed cavity



M. Lazzari et al., "Development of a new system for Nb<sub>3</sub>Sn thin film deposition on 1.3 GHz cavities", in Proc. SRF2025, Tokyo, doi:10.18429/JACoW-SRF2025-TUP31

N. Leicester et al., "Development of a 1.3 GHz longitudinally split RF research cavity for use in testing of superconducting thin films", in Proc. SRF2025, Tokyo, doi:10.18429/JACoW-SRF2025-TUP19

### Conclusion

- Milestone and deliverables on track
- During Period 1, the individual components of the puzzle were produced (*coating facilities, characterization facilities, optimized coating recipes, ...*)
- During Period 2, these pieces will be combined to produce the 1.3 GHz cavity





**Thank You!**