Recent Progress in Nb3Sn for SRF cavities at UKRI

Reza Valizadeh, Oleg Malyshev, Christopher Benjamin, Dan Seal, James Conlon,
Andrew Vick, Alan Wheelhouse (STFC),
Graeme Burt (Lancaster University)

Outline

- Objectives & Strategy
- Thin Film Testing & Validation
- Cavity Deposition
- Summary

Science and Technology Facilities Council

Science and Technology Facilities Council

ASTeC

SRF Thin Film Objectives

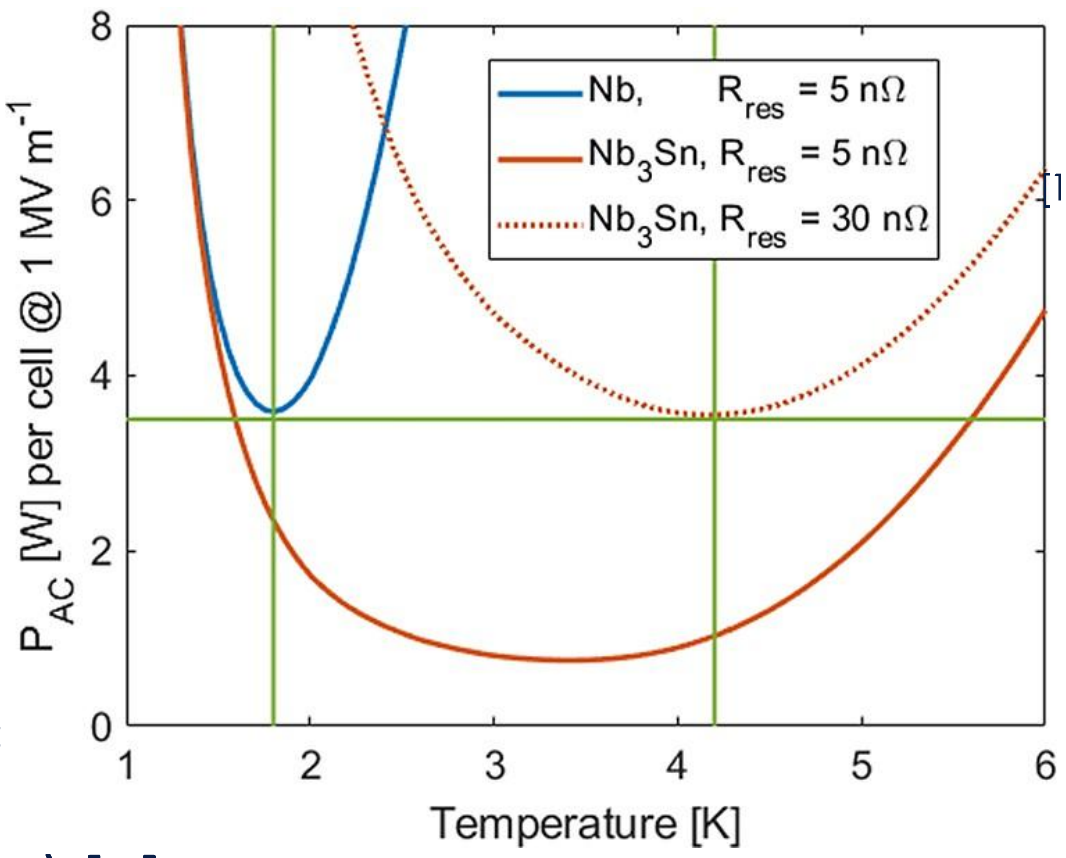
Aims & Objectives

- To develop and validate a novel class of SRF cavities based on Nb_3Sn and NbTiN thin films:
  - improve accelerator performance and efficiency through higher accelerating fields,
  - better stability,
  - reduced material costs,
  - lower operational costs compared to traditional bulk niobium cavities
- Development of in-house skills and capabilities to deposit, measure and test thin film cavities
- Thin film cavity of high T_c tested in cryomodule with beam

Science and Technology Facilities Council

Nb_3Sn for SRF – Potential

- T_c (Nb) = 9.2 K T_c (Nb_3Sn) = 18.3 K
- **results in lower R_{BCS}** at a given temperature
    - operation at 4.5 K
    - reduce grid power to run cryo plant **by factor of 3**



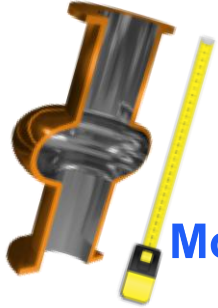
[1]

- potential demonstrated by **VTD cavities (state of the art**

Q_0 ~ 2 x 10^{10} at 20 MV/m (4.4 K, 1.3 GHz) [2]

Science and Technology Facilities Council

Thin Film Testing & Validation



RF Test With Choke Cavity

3 tests per week!

Most importantly, how does the thin film perform under RF conditions?

7.8 GHz Choke Cavity

Low field measurements:

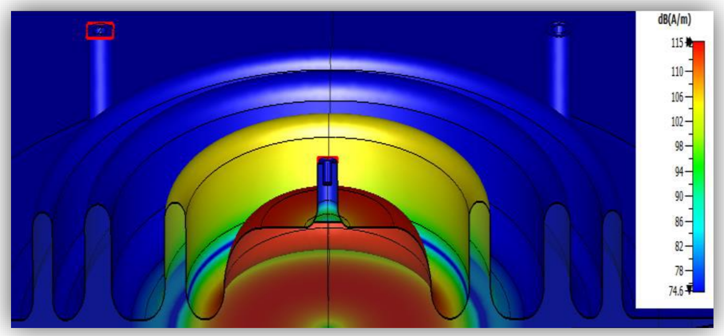
- R_s vs $B_{s,\,pk}$
- R_s vs T_s
- *Penetration depth* vs T_s

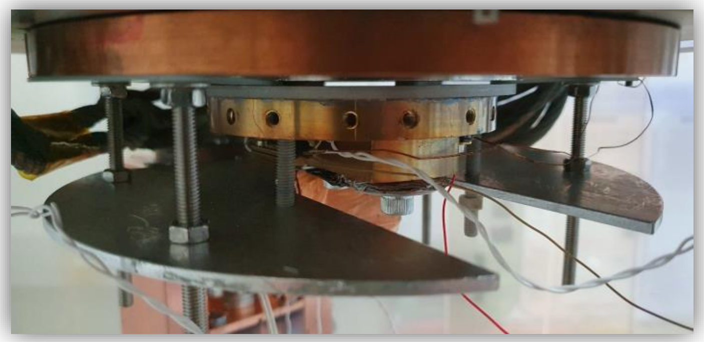
Mass parameter optimisation prior to:

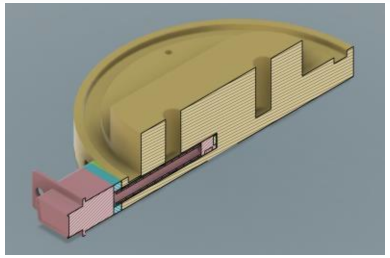
- High field/low frequency tests with QPR
- Cavity tests

Upgrades to increase $B_{s,\,pk}$:

- Hall sensors for residual magnetisation studies
- Magnetic shields
- TF coated Cu cavities
- CI bunker

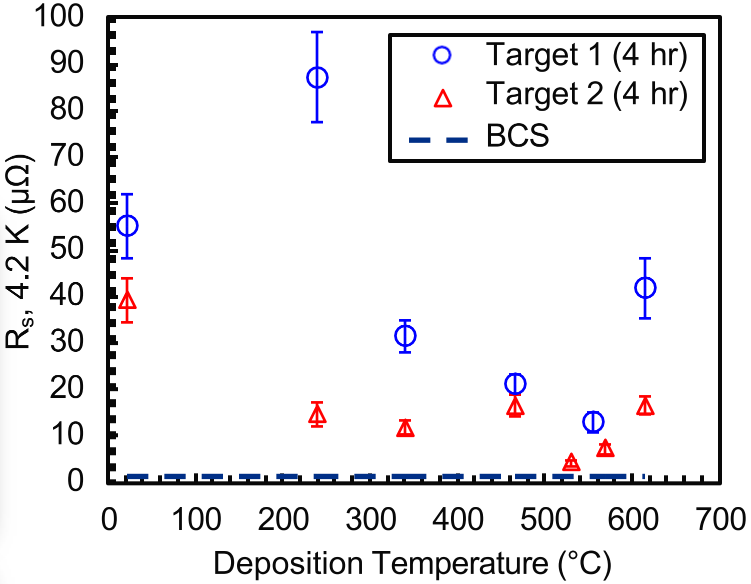




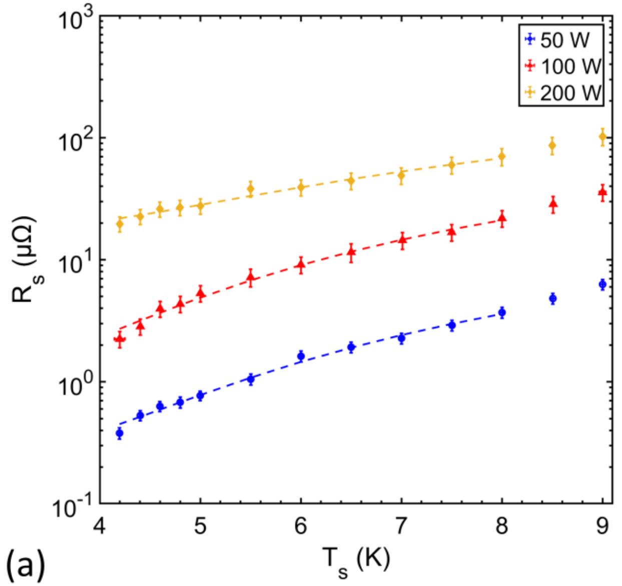


Courtesy of P. McGuinness (ASTeC)

Effect of deposition temperature on Nb/Cu



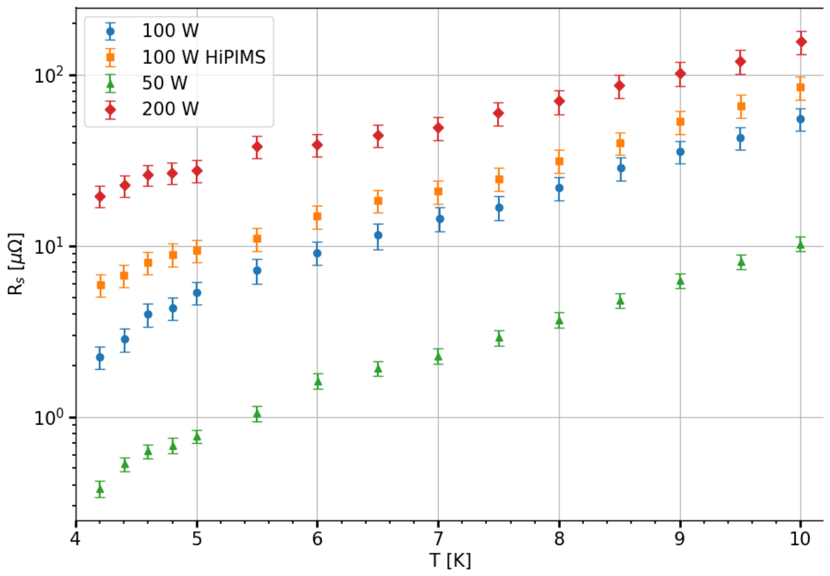
Effect of magnetron power on Nb_3Sn/Cu



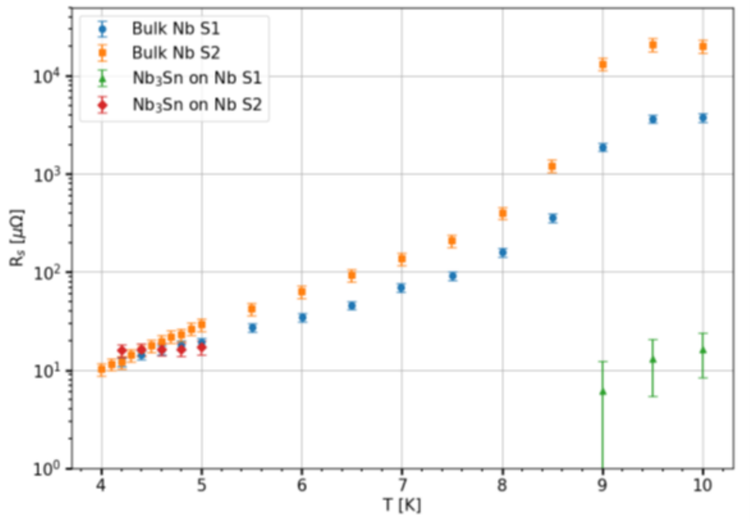
D. Seal (ASTeC)

Science and Technology Facilities Council

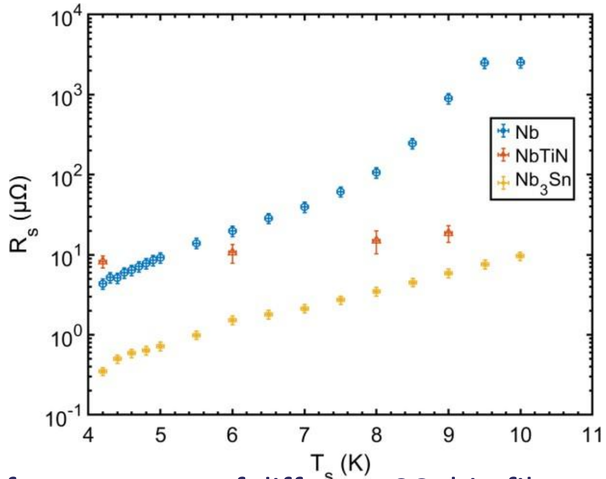
Optimisation of deposition parameters using choke cavity



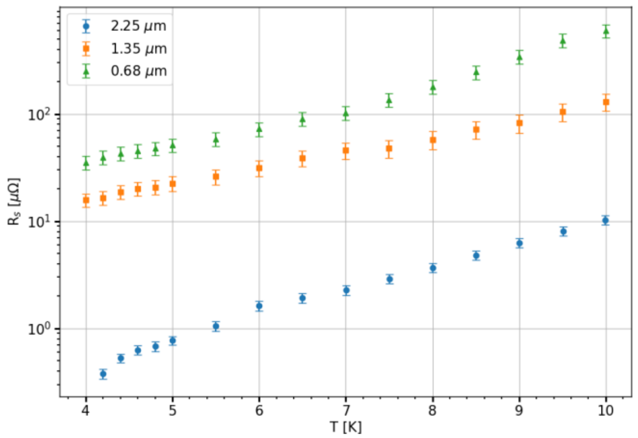
Optimisation of deposition power for Nb_3Sn on Cu



Surface resistance on Nb with different surface roughness surface preparation



Surface resistance of different SC thin film on Cu



Surface resistance of different thickness on Cu

- Optimum deposition power for Nb_3Sn is stablished at 50 W DC power
- Film Thickness dependence of Nb_3Sn on Cu
- Best surface resistance so far is achieved on Nb substrate
- For high T_c, Nb_3Sn seems to be more suitable candidate for 4 K operation having lower R_s than NbTiN.

UKRI Science and Technology Facilities Council

Low Power Cavity Test Facility

First tests in 2025!

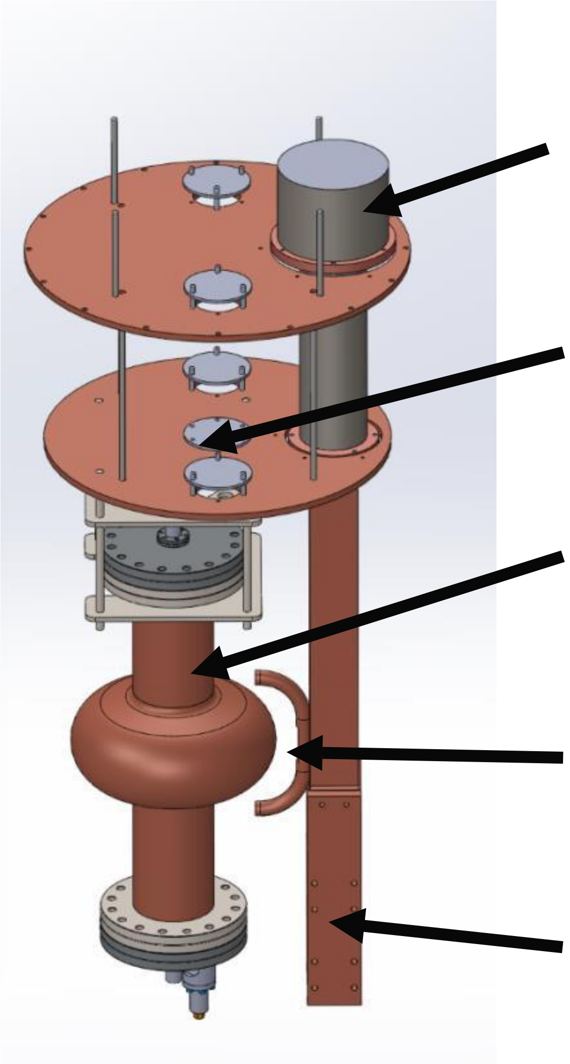
Cryocooler based facility

- $P < 2.5$ W, $T > 4$ K (est.)
- Quick first cavity test
- Good cavities will have high power test in LHe

4 types of cavity

- 1.3 GHz closed
- 1.3 GHz split
- 6 GHz closed
- 6 GHz split

Cavity facility alongside Choke Cavity facility



Cold head

Feedthroughs for RF, wiring etc

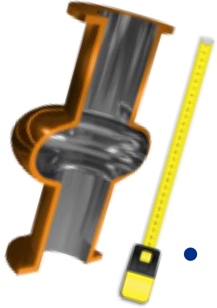
1.3 GHz cavity

Adapter for heat links

6 GHz split cavity

Courtesy of O. Poynton & J. Rigby

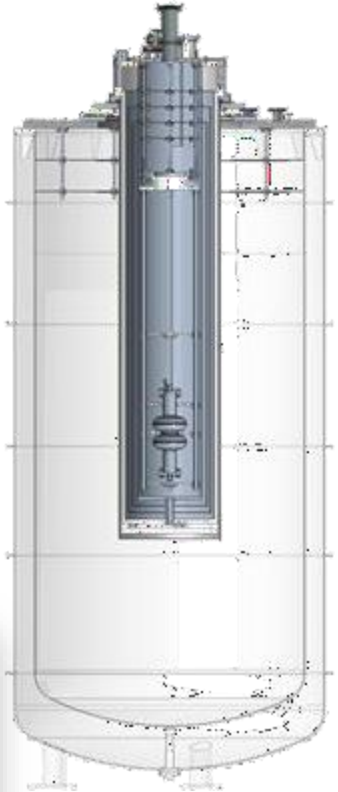
Science and Technology Facilities Council



High Power Cavity Testing

Commissioning in 2025!

- Full Q_0 vs E_{acc} test with LHe
- Testing with existing STFC/DL LHe infrastructure mainly used for ESS & PIP-II cavity tests
- **Upgrades now allow for:**
  - For thin film SRF programme
  - A RF single system for 650 and 700 MHz, and 1.3 GHz
  - $P \leq 200$ W, $T = 2$ & 4.2 K
  - Capability for 9-cell tests



Courtesy of T. Sian & C. Hill

Existing SRF Test Facilities in SuRF Lab at Daresbury Laboratory

Science and Technology Facilities Council

However, very limited number and durations for free timeslots, i.e. only good cavities should be characterised

Coordinated by T. Sian (ASTeC)

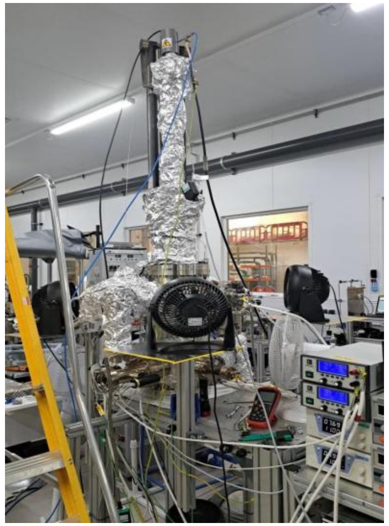
Science and Technology Facilities Council

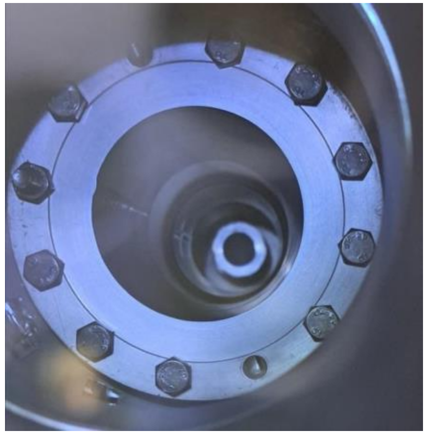
ASTeC

1.3 GHz Cavity Deposition

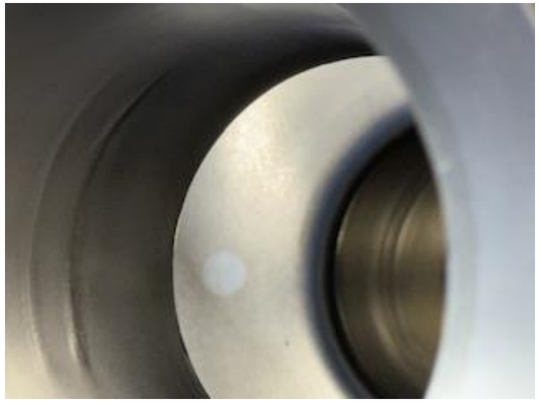
First Nb_3Sn calibration on 1.3 GHz Nb Cavity

- First trial run of Nb_3Sn deposition of 1.3 GHz Nb cavity with deposition parameters established on planar samples.
- The trial run proved to be successful.

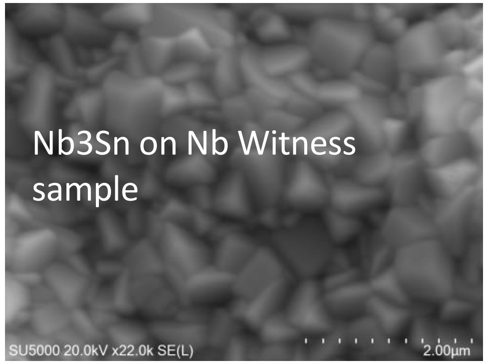


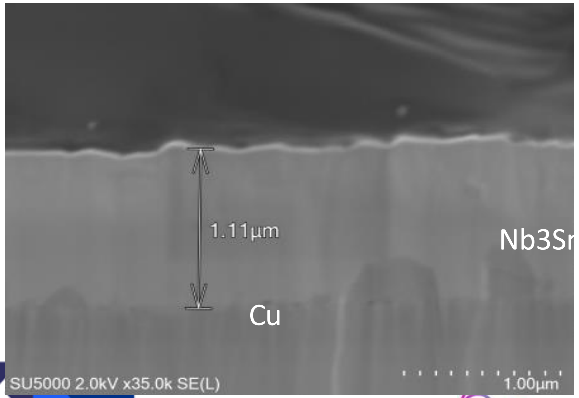


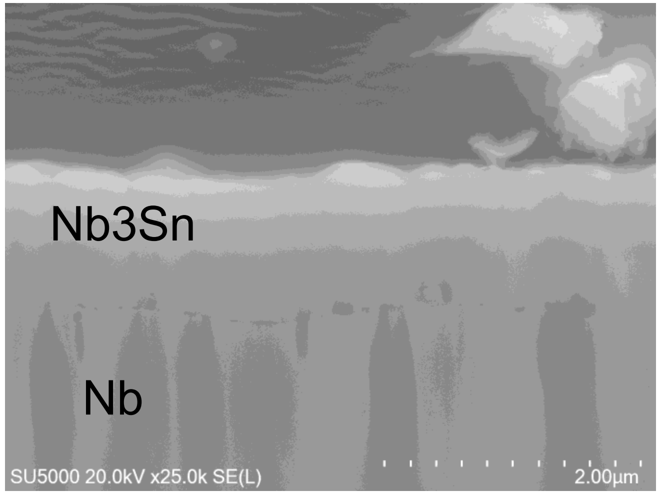
View from bottom flange

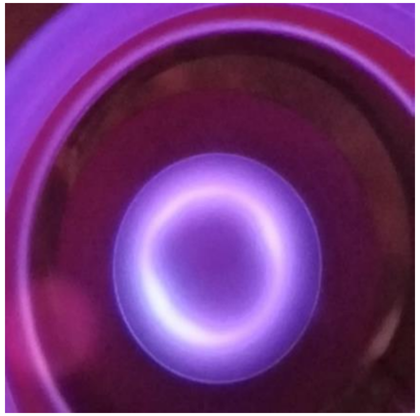


View after deposition of Nb_3Sn ar
uncoated area under witness sample









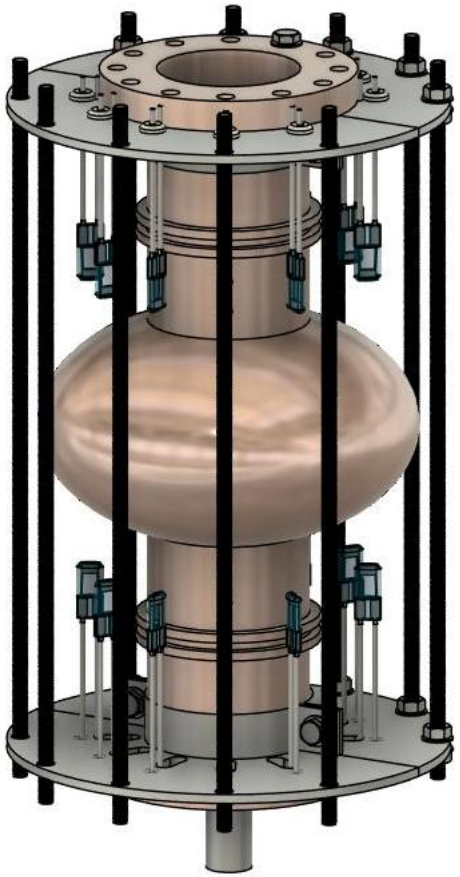
View during deposition at 650° C

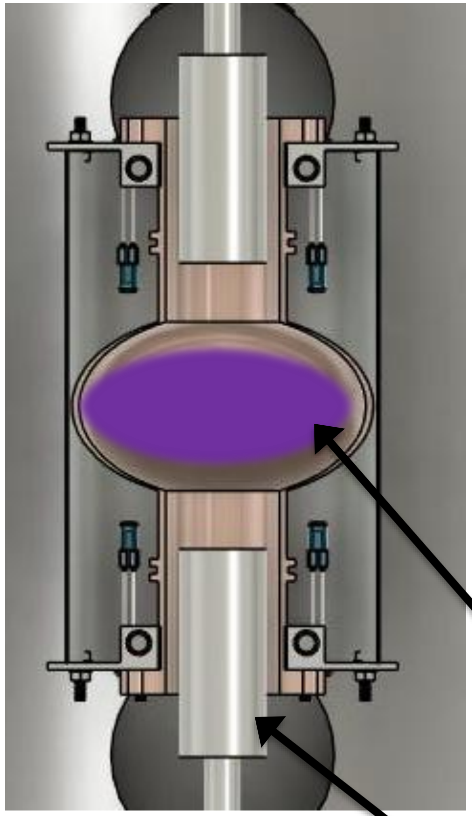
Technology Facilities Council

iFAST

First 1.3 GHz Nb cavity deposited with Nb3Sn

Cavity heating stage





- Cavity is deposited using magnetron sputtering (PVD).
- Deposition inside a UHV system.
- Deposition at 600 °C
- Custom in-house magnetron designed and tested can be positioned inside the cavity.
- Two magnetron opposite each other was moved in and out during deposition total 30 hours.

Sputtered material (Plasma)

Magnetron

Science and Technology Facilities Council

First Nb_3Sn on Nb cavity at STFC.

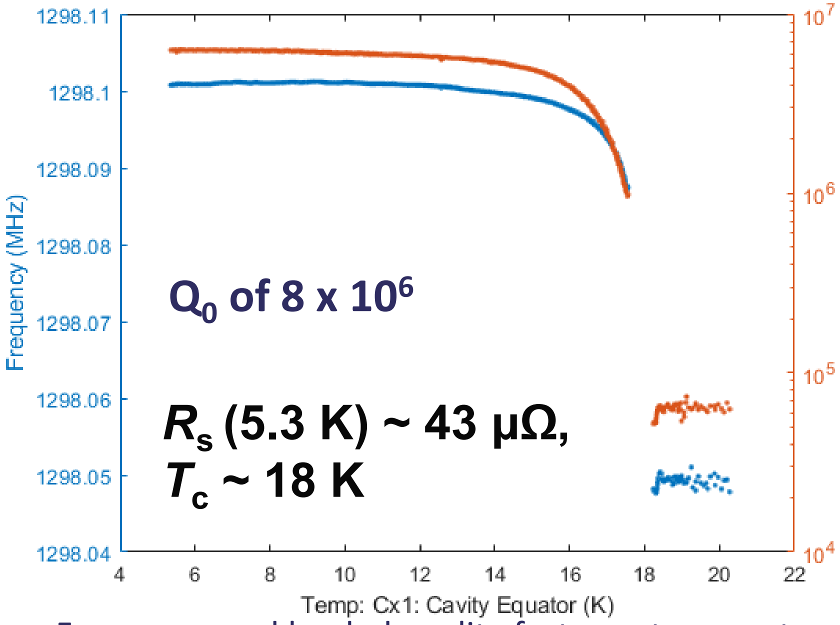
- After some test depositions the first 1.3 GHz Nb has been coated with Nb_3Sn.
- After visual inspection, the cavity was prepared for testing in an ISO 4 cleanroom environment.
- The cavity transported to HZB for testing.

Inside the cavity after deposition

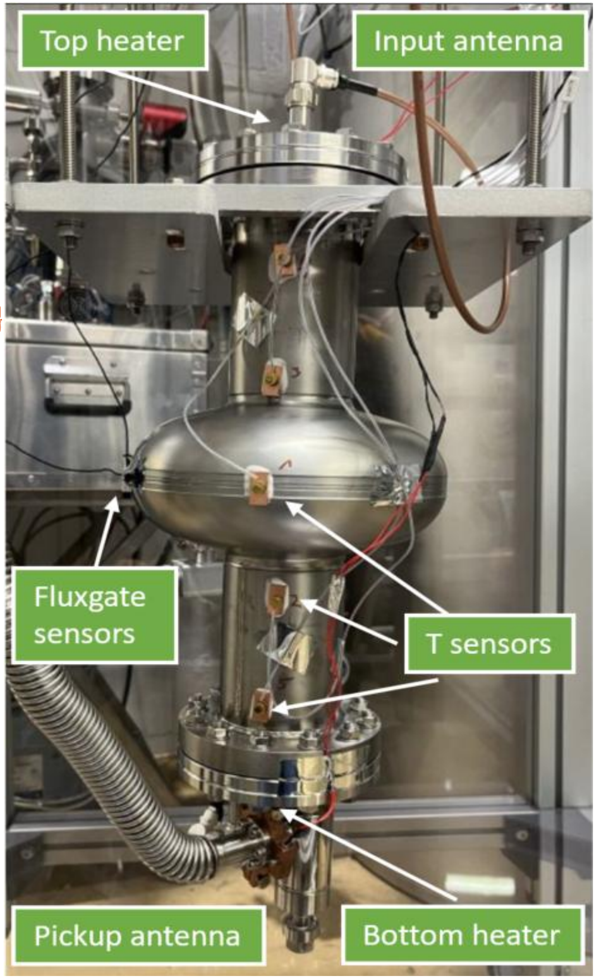
Science and Technology Facilities Council

RF Test At HZB

- No thermo-currents were recorded with the azimuthally placed sensors.
- While the Tc was at 18.1 K it only achieved a Q_0 of 8 x 10^6
- No Tc of Nb was detected: Possibly cavity fully coated.
- 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.
  - No HPR after Deposition



Frequency and loaded quality factor vs temperature

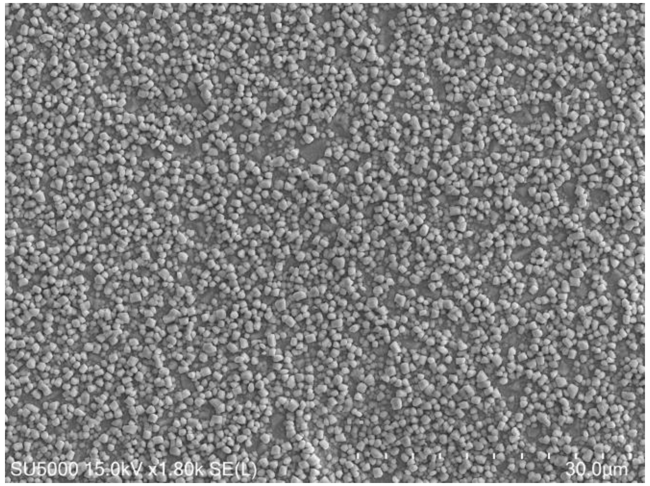


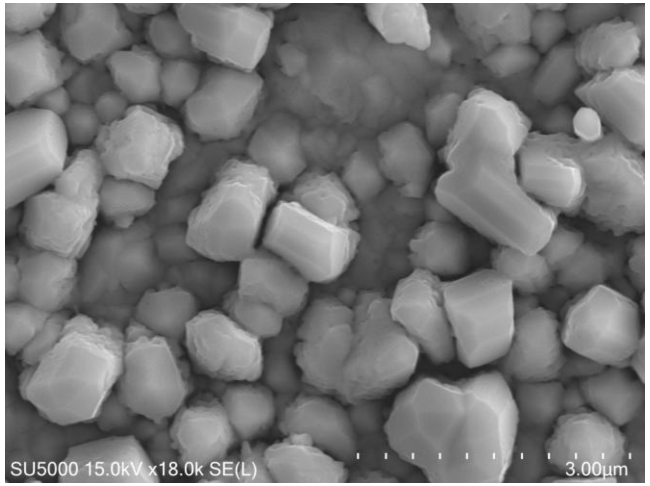

Just after venting chamber


After target removed

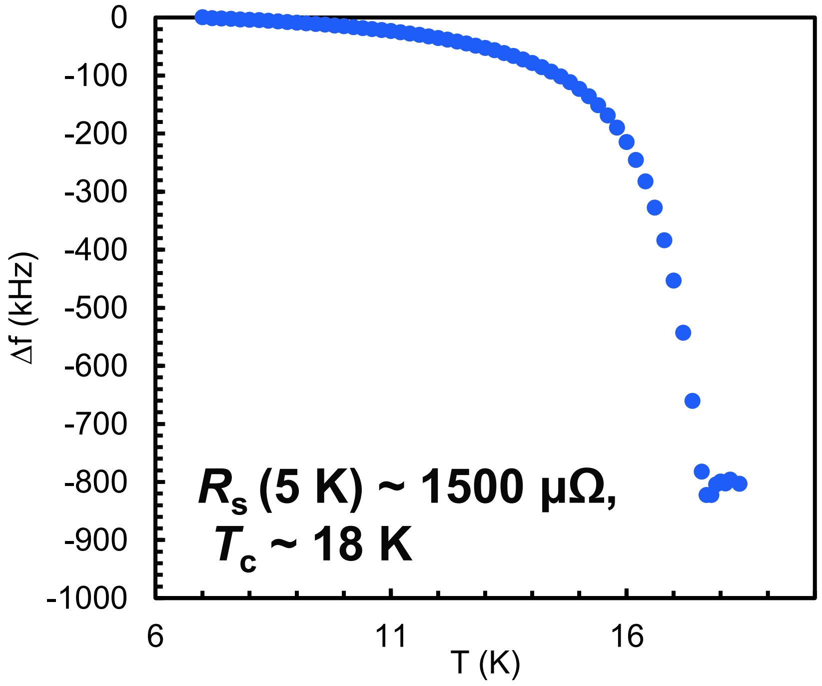
Science and Technology Facilities Council

Nb Disk deposition inside segmented Nb Cavity C



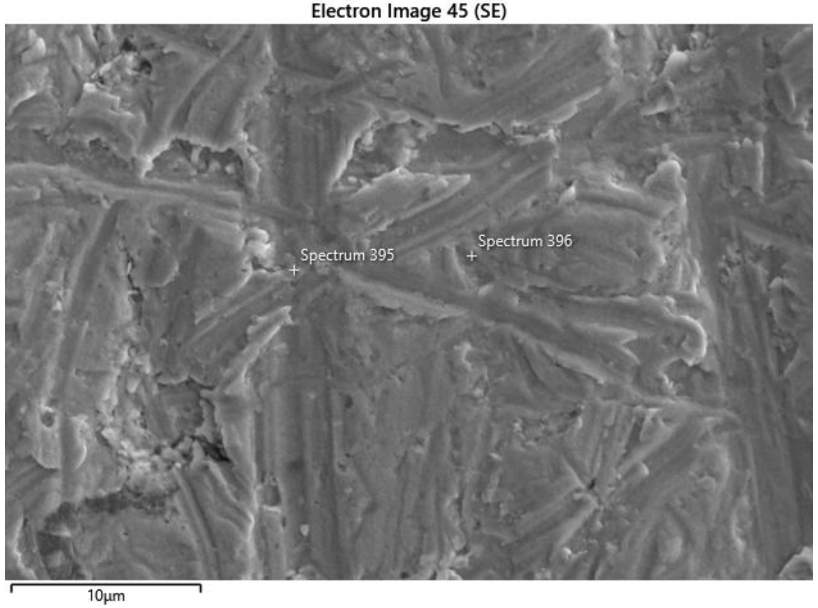


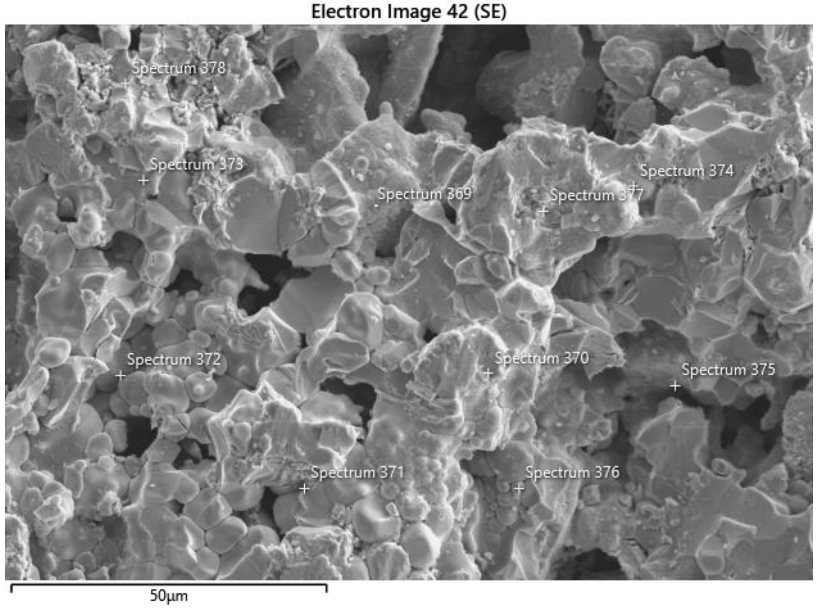
- Unfortunately, this resulted in mixed composition and non superconducting phase (high Sn content) gave
- May be caused:
- By low temperature deposition below 600 C
- Or target non homogeneity

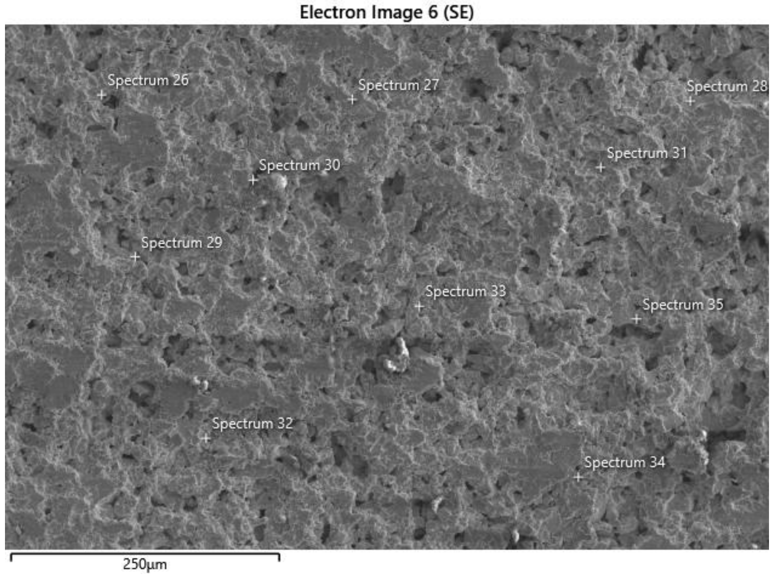


Science and Technology Facilities Council

Pre and post Annealed targets





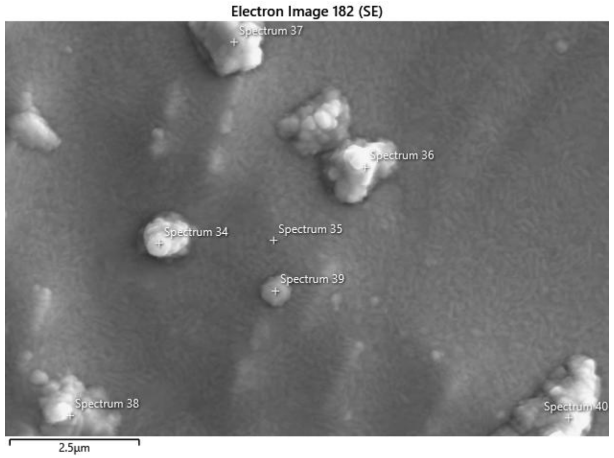


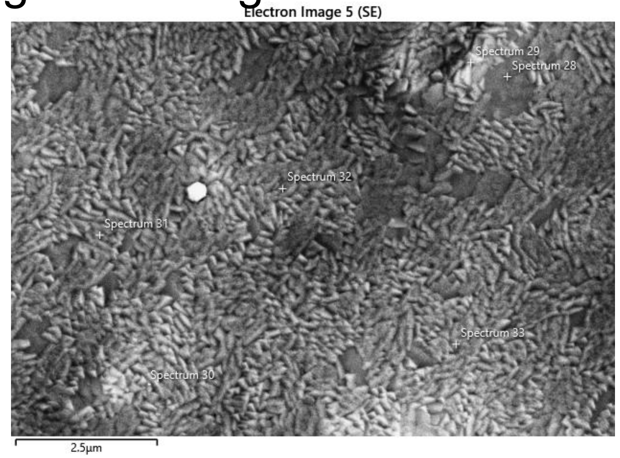
Pre annealed (Name)	Average Nb At%	Average Sn At %	No. of spectra
Site 4	70.13	29.87	10
Site 9	70.38	29.62	9
Post Annealed			
Site 1	68.98	30.02	10
Site 2	66.82	33.18	9
Site 3	63.61	36.39	7
Nb 100 mm Holder			
Center (Light spot)	95.88	4.12	2
Edge (Dark)	99.85	0.15	2

Science and Technology Facilities Council

Comparison of Nb3Sn deposition from two different targets two different magnetron outside cavity

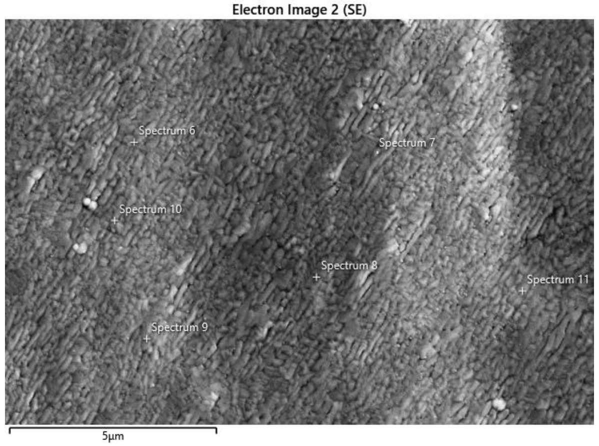
New target/HM magnetron

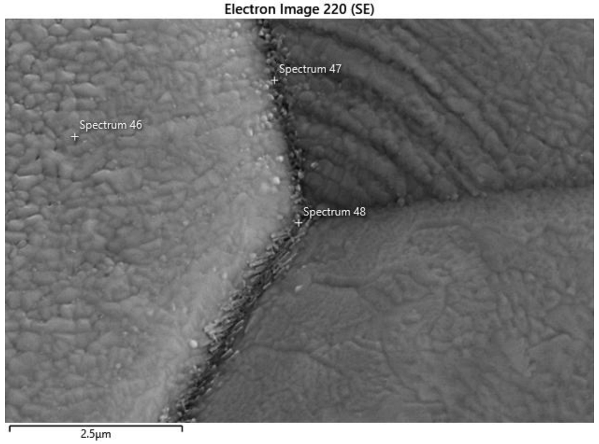




Statistic	Nb	Sn
Max	76.43	26.83
Min	73.17	23.57
Average	75.38	24.62
Standard Deviation	0.76	0.76

Old target/Com magnetron



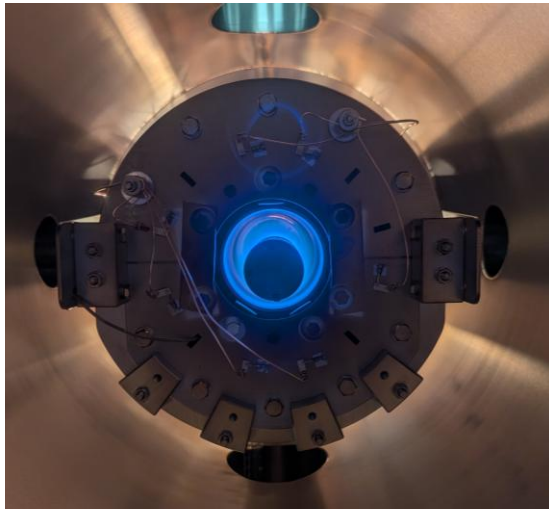


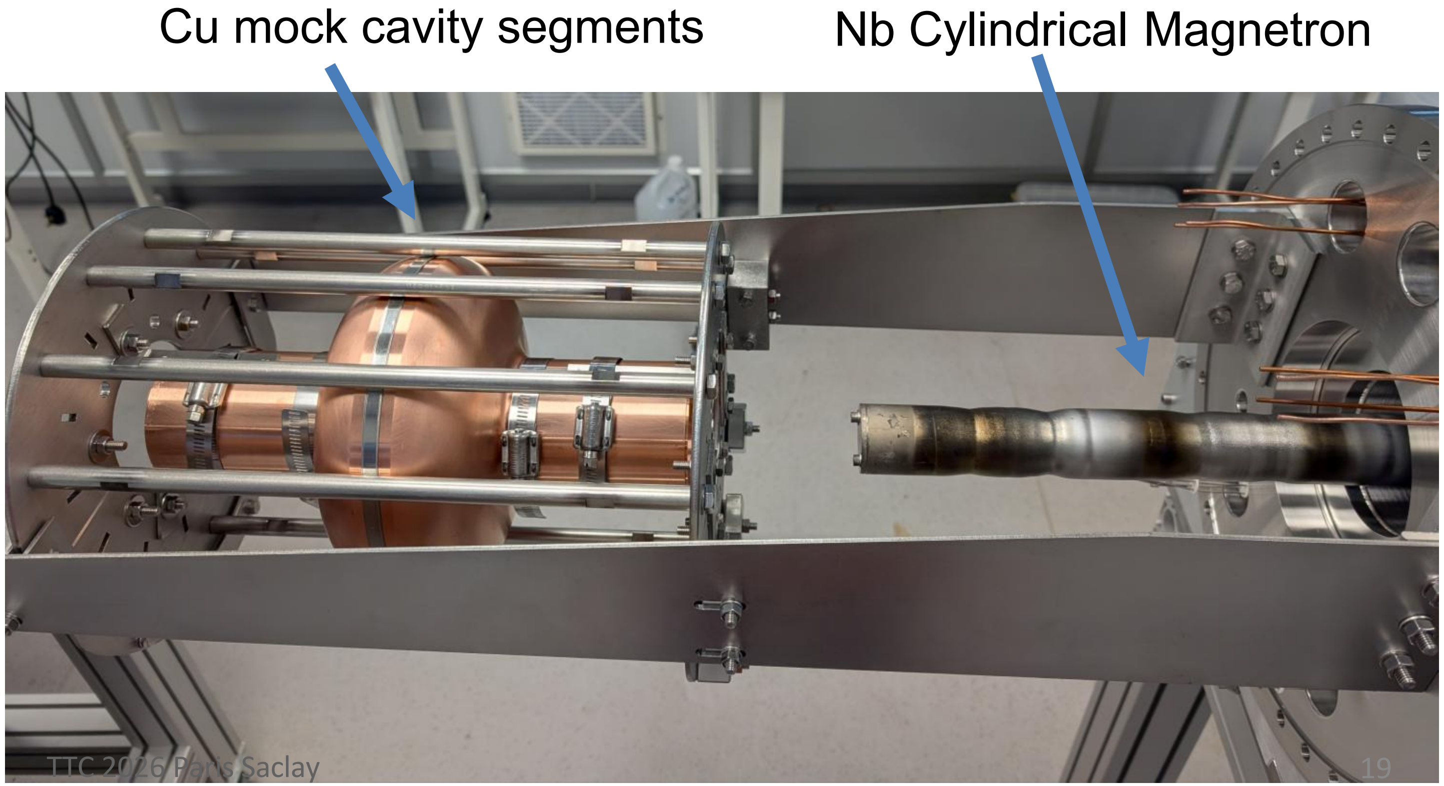
Statistic	Nb	Sn
Max	78.05	24.11
Min	75.89	21.95
Average	76.93	23.07
Standard Deviation	0.72	0.72

Science and Technology Facilities Council

Copper Cavity deposition facility

The new deposition facility currently being commissioned at Daresbury Laboratory. It will be a dedicated facility for the deposition of 1.3 GHz cavities (Both single and two-cell).
The facility will be situated in an ISO 6 cleanroom environment.
Initial deposition tests are being conducted using a Nb cylindrical target and mock Cu cavity components. Integrating the heating stage.





Summary

- First 1.3 GHz Nb cavity was produced by magnetron sputtering, the major deliverable for IFAST and progression of ISAS.
- Although full coverage and high T_c was achieved, it resulted in low Q_0 of $8x10^6$ and R_s (5.3 K) ~ 43 μΩ, T_c ~ 18 K
- After optimising deposition parameters on flat samples further optimization is needed for cavity deposition
- Additional processing may be needed to remove non-superconducting phase growth to achieve low surface resistance:
    - Post thermal annealing
    - Mechanical or chemical polishing
    - Laser or plasma processing
- The ultimate goal is to deposit Nb_3Sn on copper cavity:
    - Do we need suitable buffer layer
    - Do we need further optimisation from Nb to Cu cavity?
    - Lack of cylindrical target further complicates the process.

Science and Technology Facilities Council