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Thin Film SRF Cavity Developments at STFC Daresbury Laboratory

Daniel Seal
On behalf of the TF-SRF team

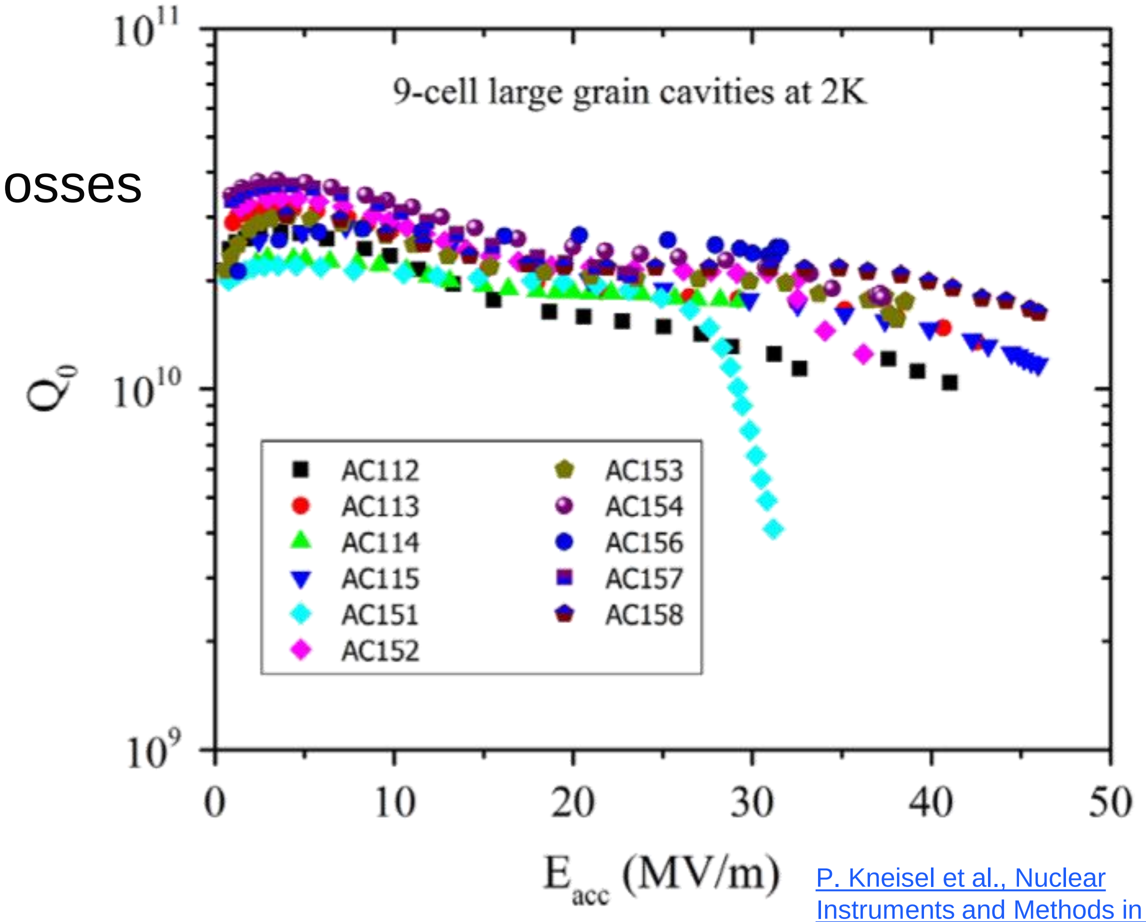
Particle Accelerators and Beams Conference 2026
30 June – 1 July 2026 | Lancaster

The Cockcroft Institute of Accelerator Science and Technology

Lancaster University

Bulk Niobium: The Benchmark

- ➢The material of choice for ~ 60 years
- ➢Highest T_c, B_{c1}, B_{sh} of any element
- ➢Excellent SRF performance with very low RF losses
- ➢Complex and costly fabrication and surface processing
- ➢Approaching fundamental limits
  - $Q_0 = 10^{10} – 10^{11}$ at 2 K
  - $E_{acc} < 50$ MV/m

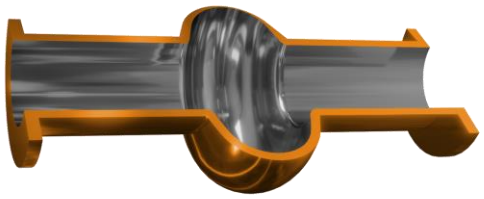


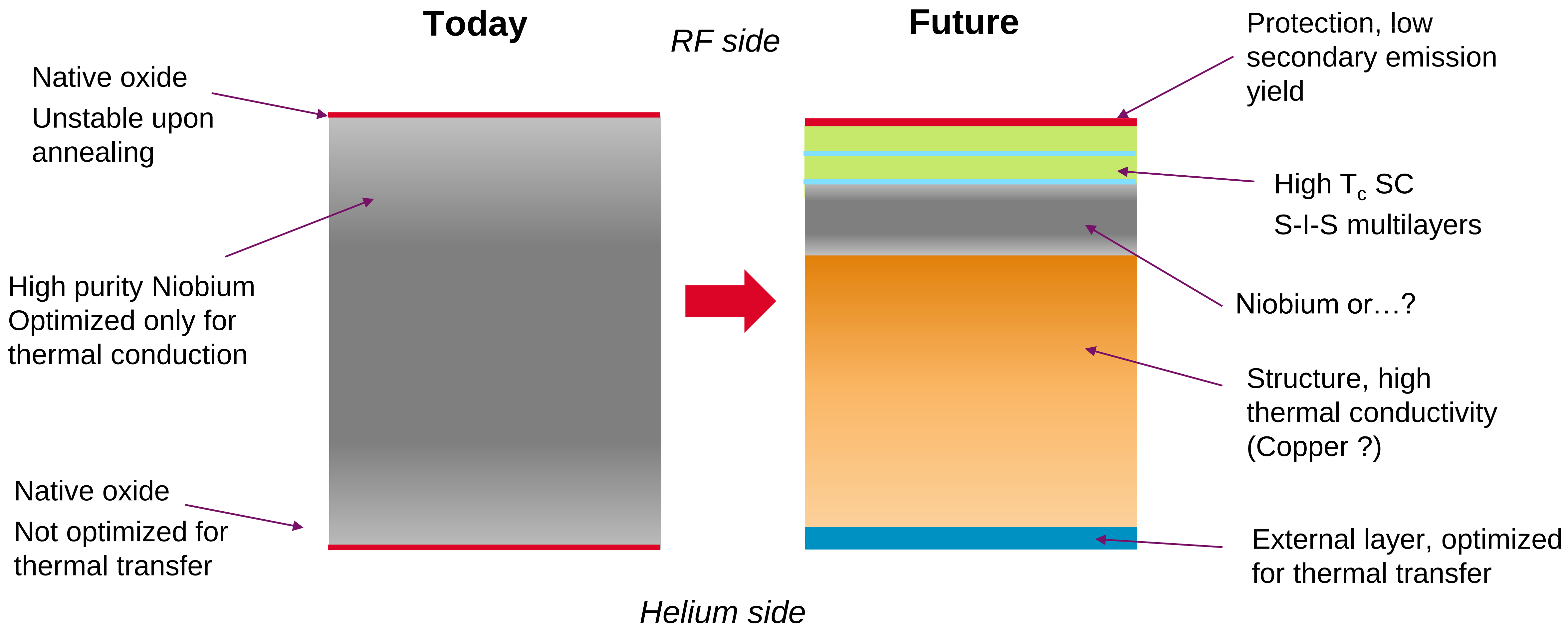
P. Kneisel et al., Nuclear Instruments and Methods in Physics Research A 774 (2015) 133–150

Q_0 = how efficiently a cavity stores energy

E_{acc} = average *E*-field *seen by the beam*

Future Directions: From Bulk Niobium to Thin Films

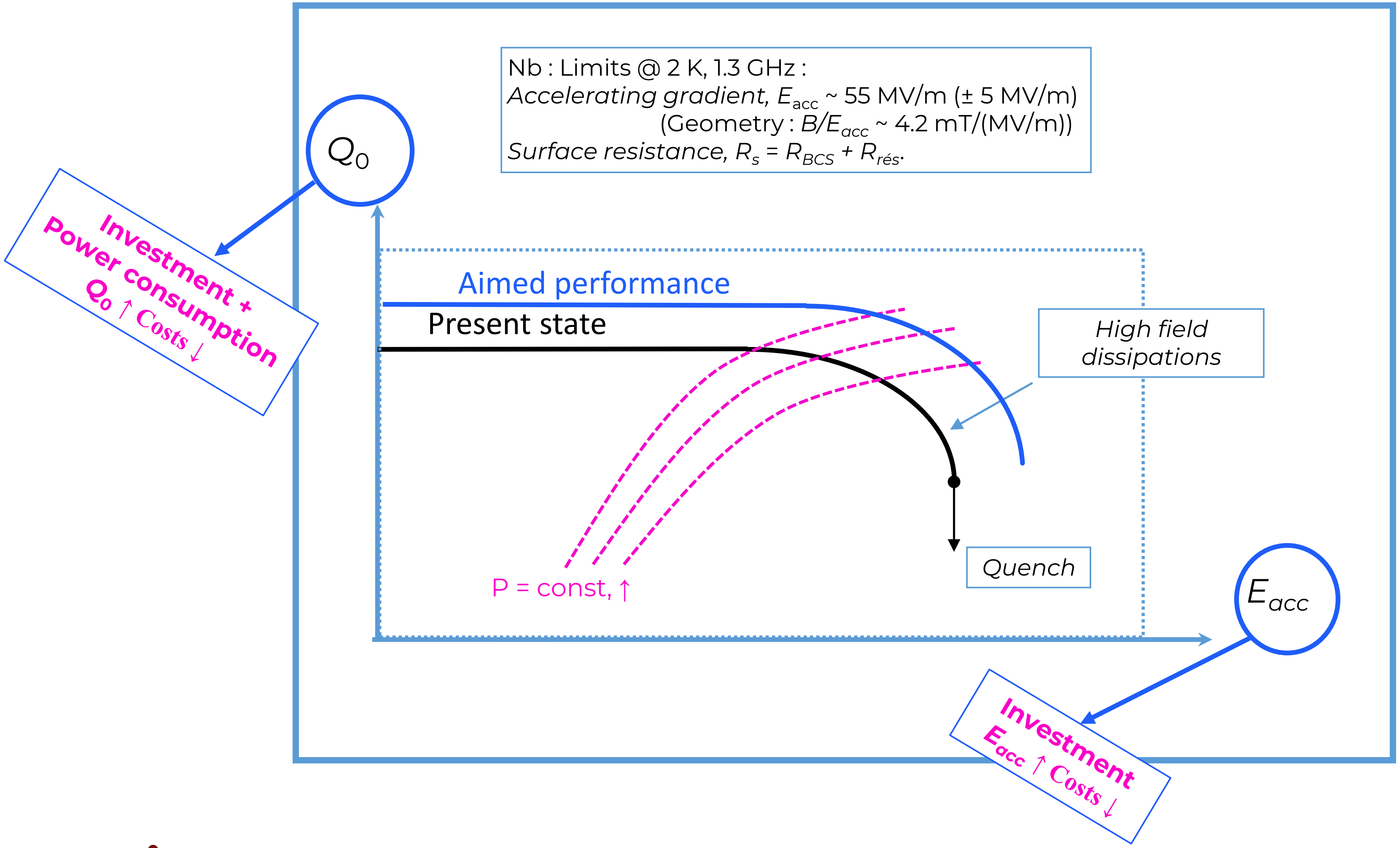




RF losses always happen in surface

[C. Antoine, IPAC 2023]

Why Thin Films?



Courtesy of C. Antoine (CEA)

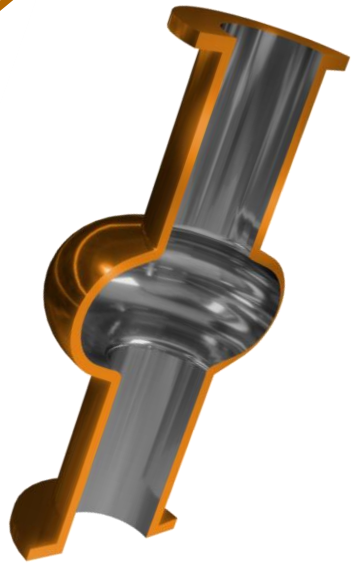
Superconductors Being Considered

Material	T_c (K)	B_{sh} (mT)@ 0 K
Pb	7.1	100
Nb	9.2	219
NbTiN	**17.3**	**439**
V_3Si	**17.0**	**490**
Nb_3Sn	**18.3**	**425**
NbN	17.3	214
Nb_3Al	18.5-19.1	
MgB_2	39.0	170

Courtesy of C. Antoine (CEA)

High B_{sh} → High E_{acc} → fewer cavities

↓ Infrastructure cost



Why thin film on copper?

- Cheaper than Nb
- Higher thermal conductivity
- Easily machinable

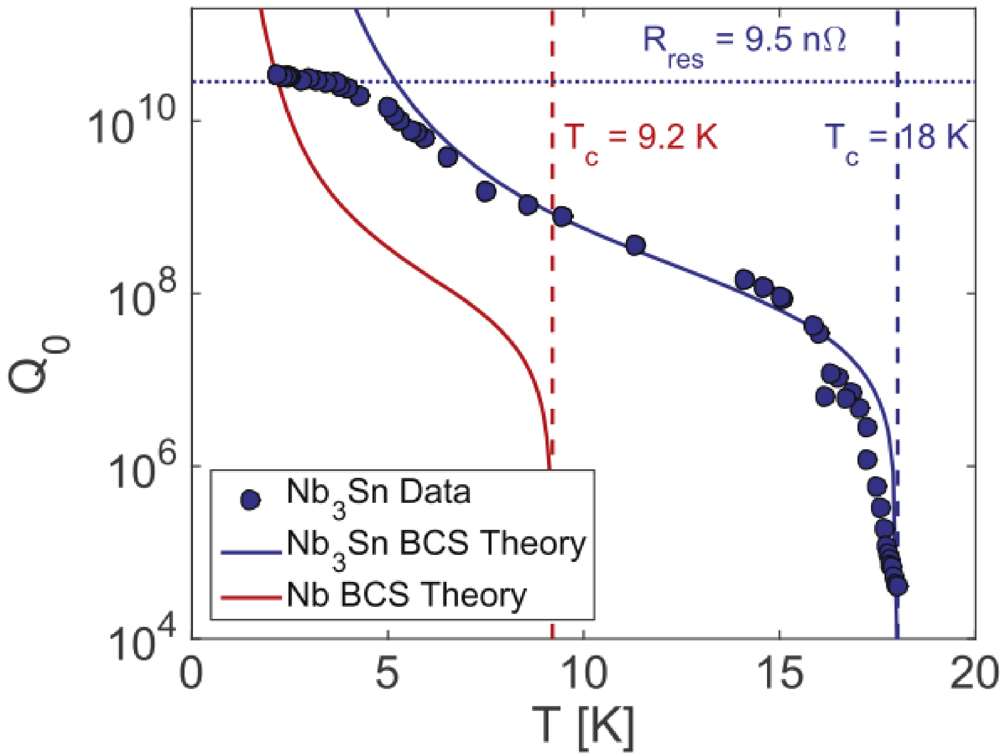
High T_c → High Q_0 → less cooling

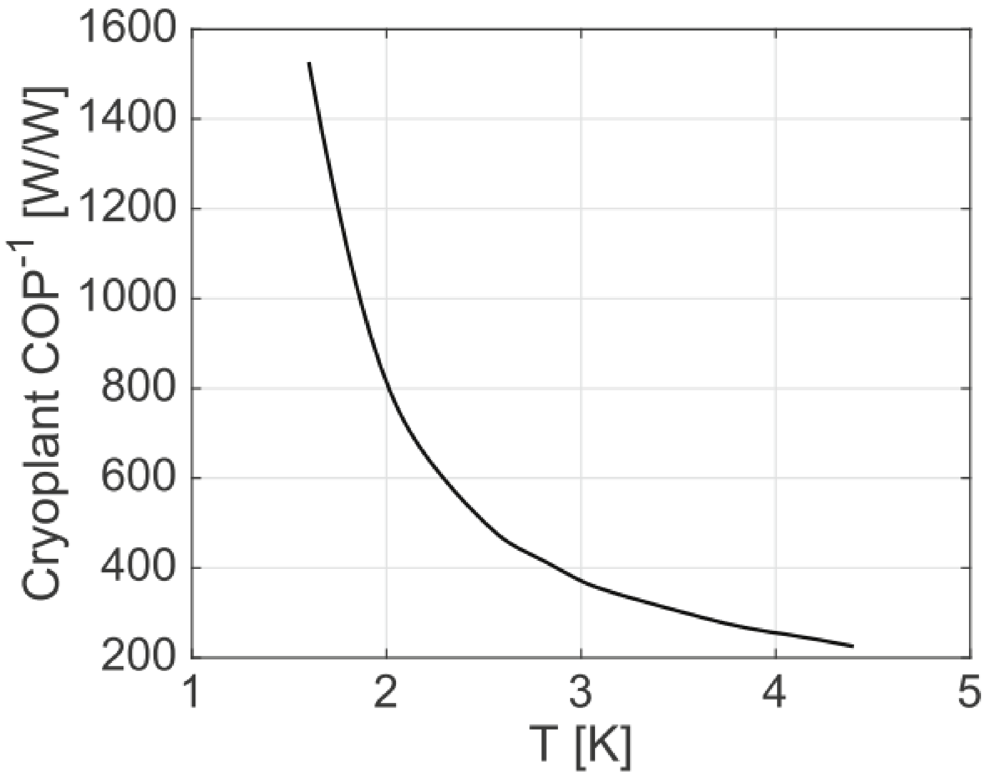
↓ Cryogenic cost

Best alternative: Nb_3Sn/Nb from Sn vapour diffusion – Q_0 ~ 10^{10}, E_{acc} ~ 20 MV/m at 4.2 K

Why Nb_3Sn?

Moving from 2 K to 4.5 K reduces cryogenic power by factor 3!

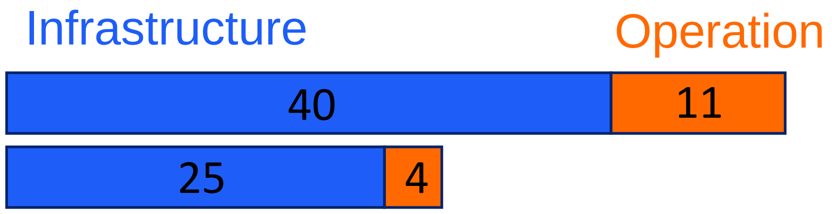




Estimated cryogenic costs of ESS (M€):

2 K (Bulk Nb)

4.5 K (Thin Film)



S. Posen, Supercond. Sci. Technol. 30 (2017) 033004

C. Antoine, IPAC 2023

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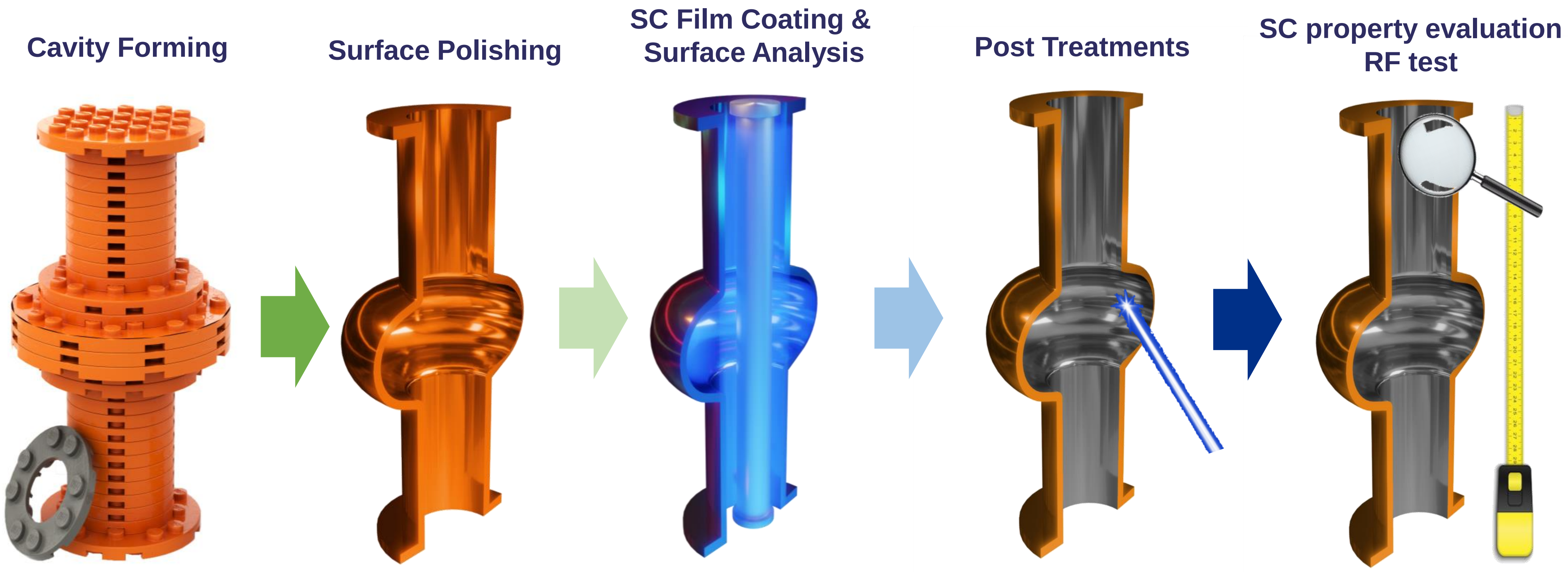
Thin Film SRF Development

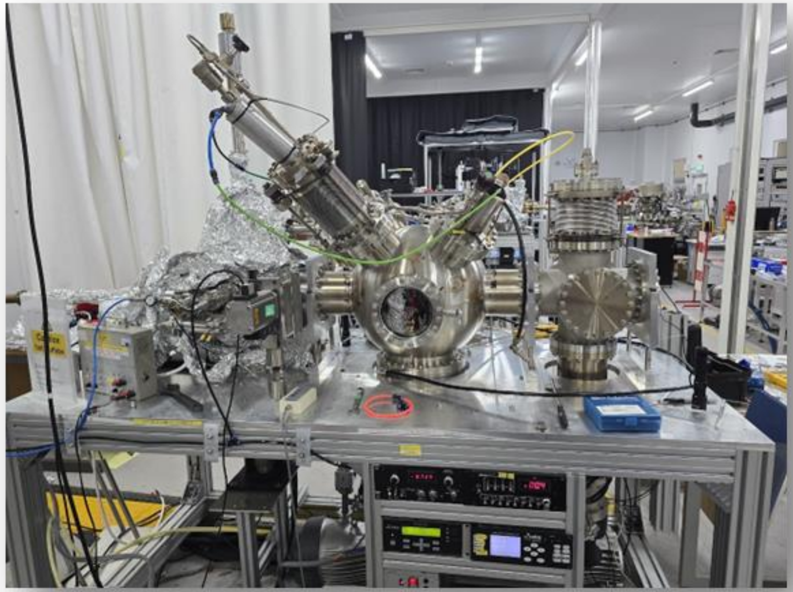
How a Thin Film SRF Cavity is Developed

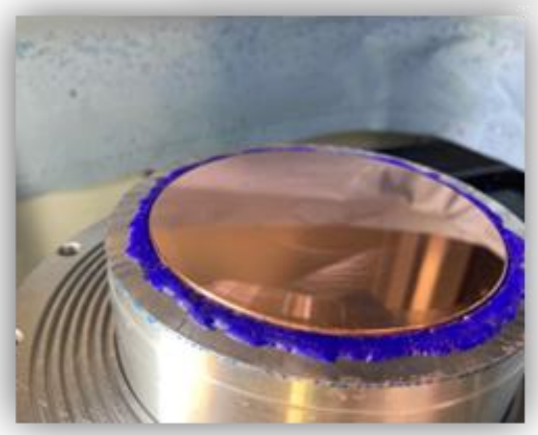


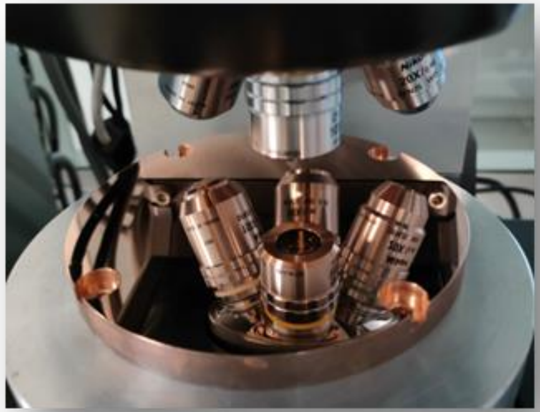
Most developments so far have been on planar samples

R&D on Planar Samples

- Rapid, low-cost deposition and testing in custom-built facilities
- Simple and consistent substrate preparation
- Systematic optimisation of deposition parameters
- Easy superconducting measurements & surface analysis
- Reduce risk of failure for full cavity coatings







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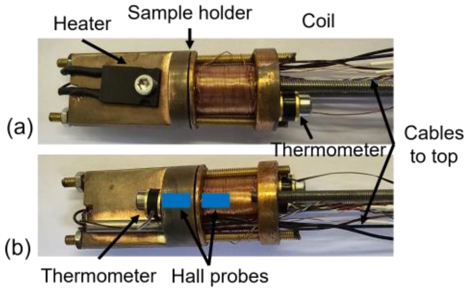
High Throughput Cryogenic Sample Testing

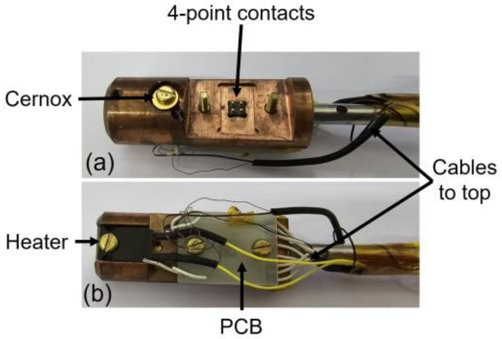
DC

- Used for initial thin film optimisation
- What is its T_c?
- What is its behaviour under ‘cavity-like’ parallel DC magnetic fields?

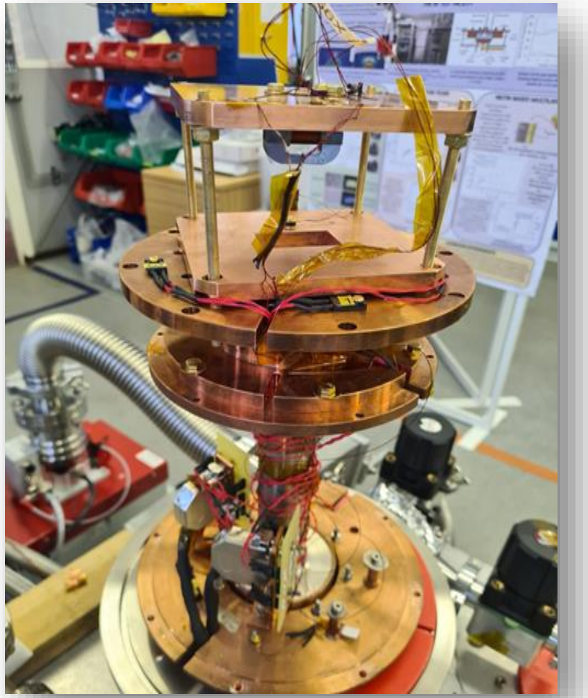
Magnetic T_c



Four-point probe



Magnetic field penetration



Courtesy of L. Smith (STFC), D. Turner (LU)

RF

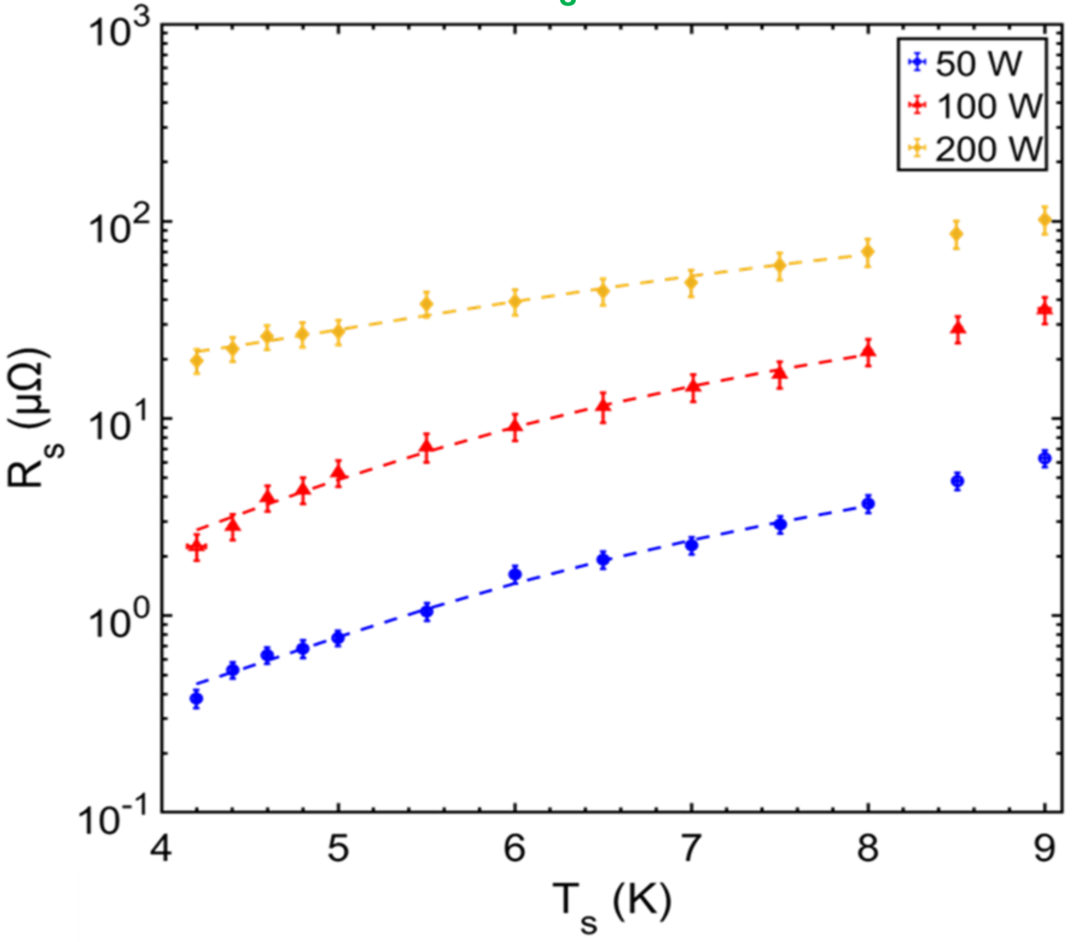
- A ‘good’ DC sample might be ‘bad’ for RF
- Crucial measurements of TF RF performance
- What is its R_s?

7.8 GHz Choke Cavity

Multiple sample tests per week

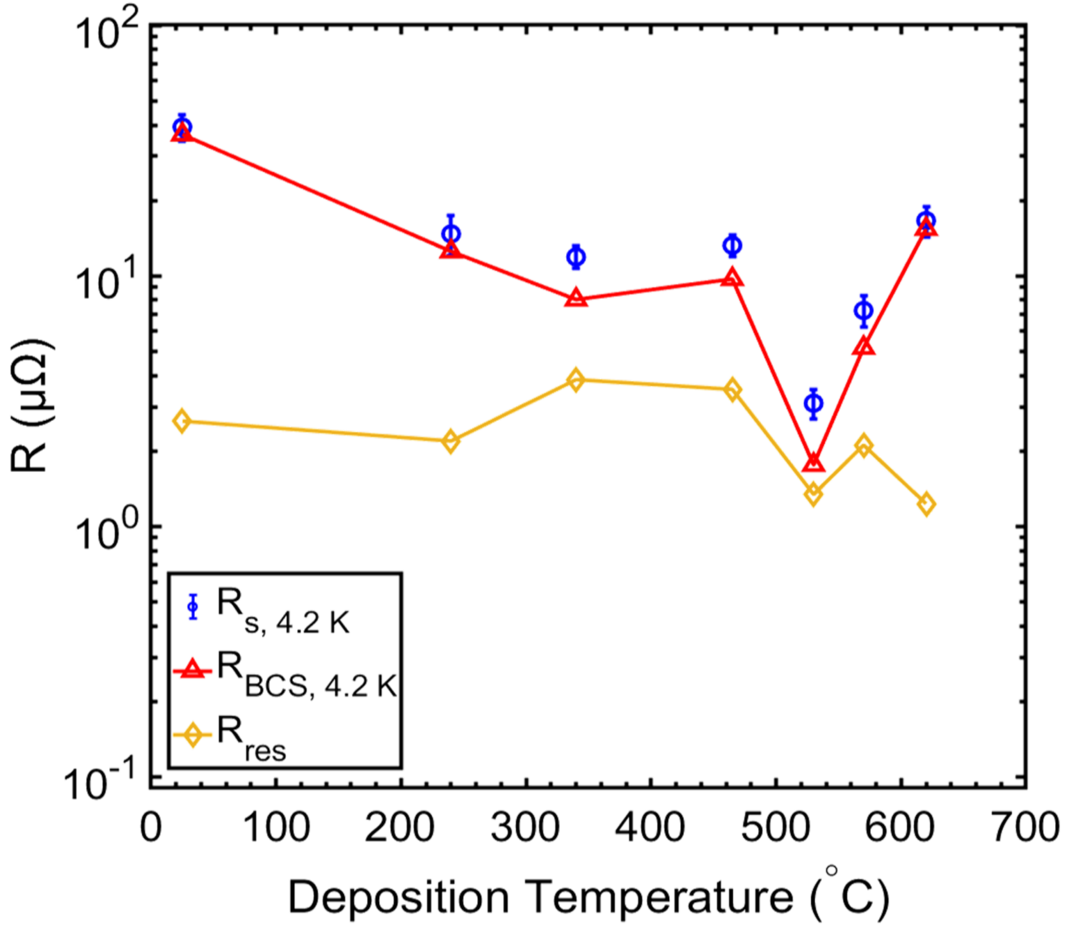
Optimising Thin Film Deposition Parameters

Nb_3Sn/Cu



RF surface resistance improves at lower power applied to the target cathode

Nb/Cu



Deposition temperature is a critical parameter for Nb/Cu performance – optimal ~ 530 °C

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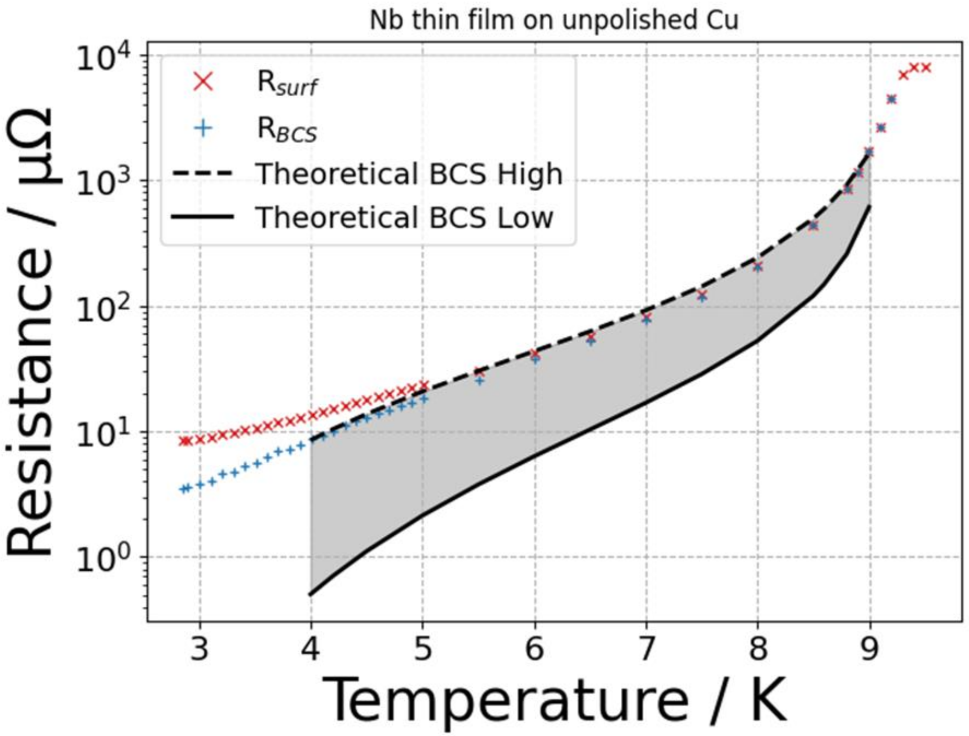
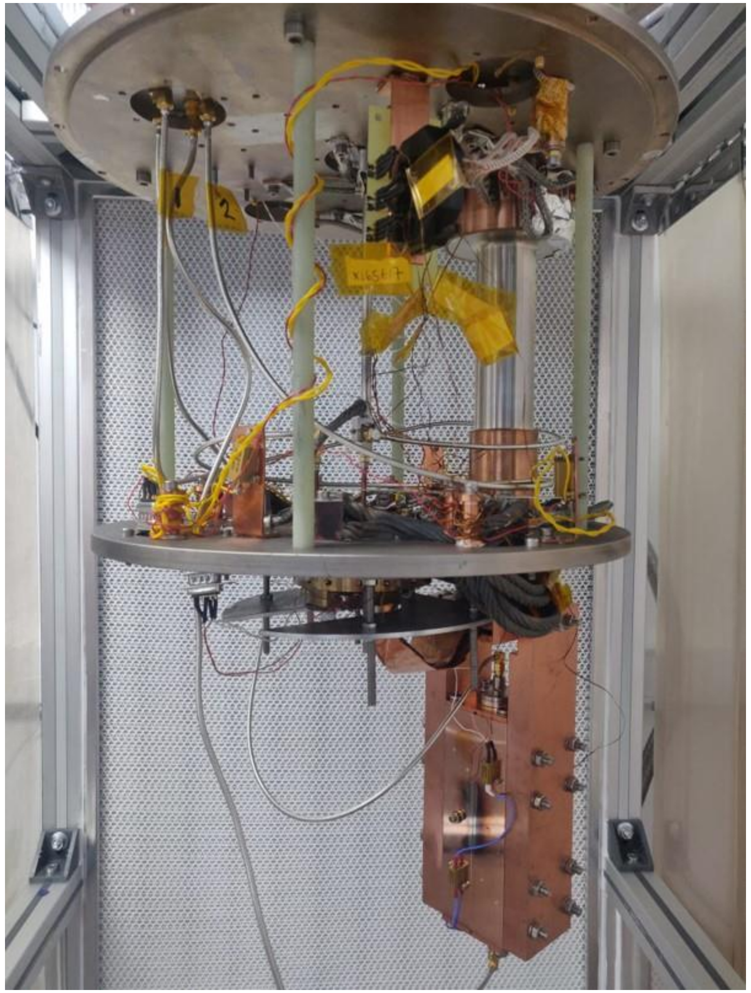
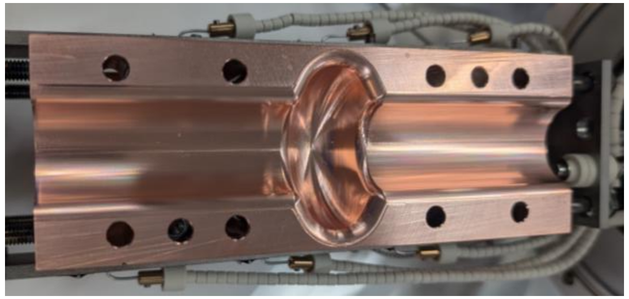
From Samples to Cavities

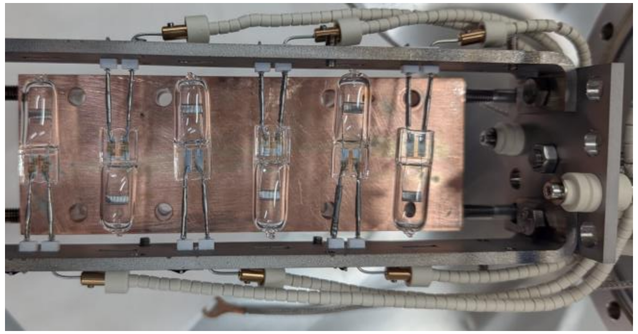
6 GHz Split Cavity Development

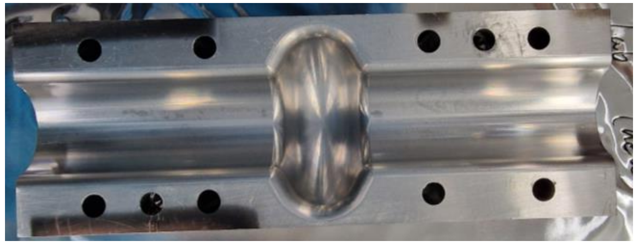
- How does a cavity behave on a curved surface
- Can be deposited in a closed or open geometry
- Visual inspections & some surface analysis
- Can be utilised for higher T_c materials







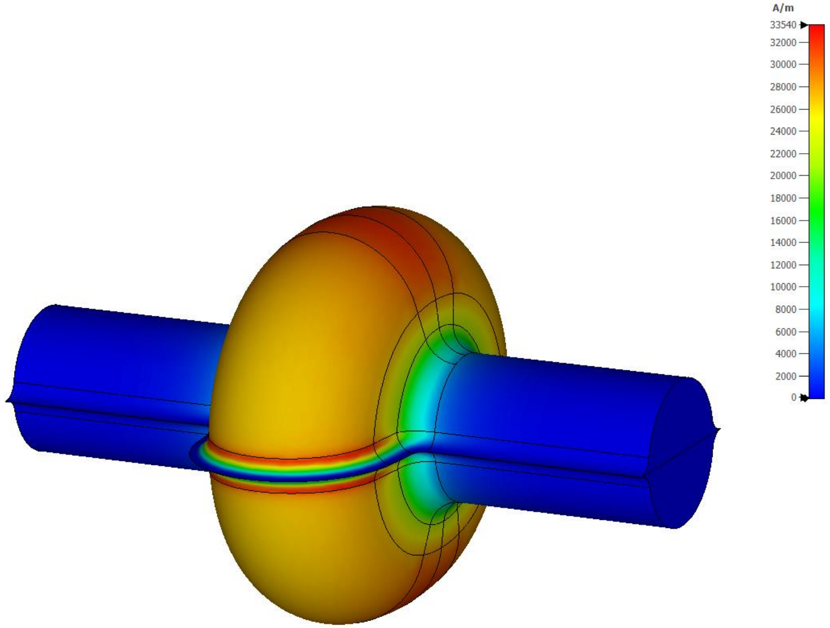




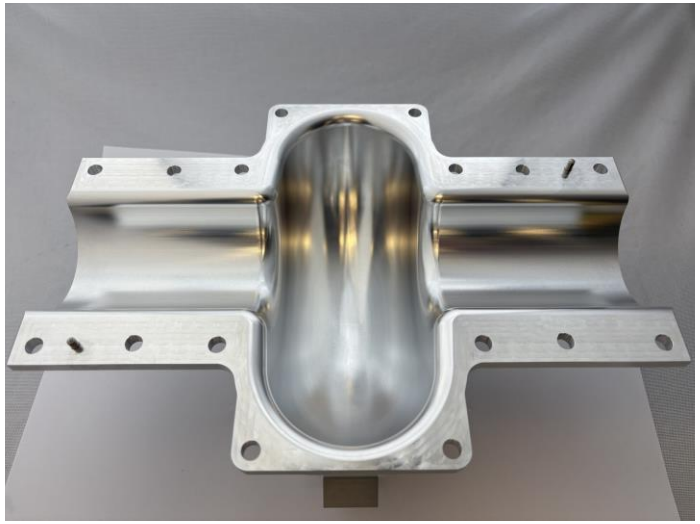
Courtesy of N. Leicester, D. Turner (LU)

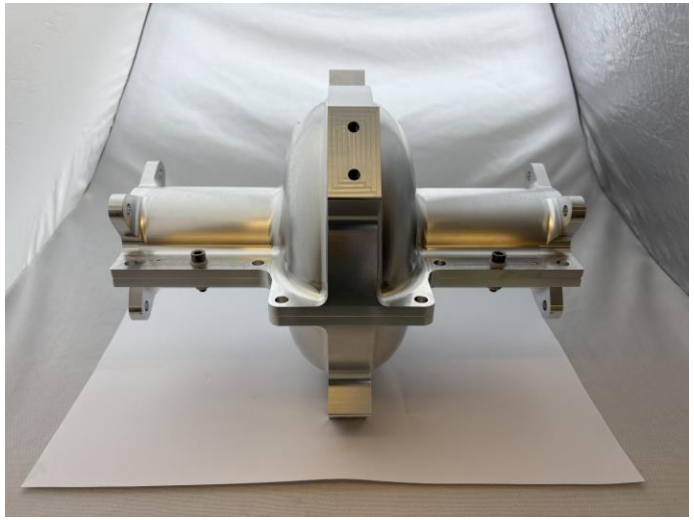
Development of a 1.3 GHz Split Cavity

- RF design based on single-cell 1.3 GHz TESLA cavity split longitudinally
- Cavity manufactured at STFC RAL Space
- Aluminium and copper versions manufactured
- Designed for testing in LHe-free cryostat



Courtesy of M. Dissanayake Mudiyanselage (LU)





Courtesy of L. Bushnell, M. Beardsley (STFC)

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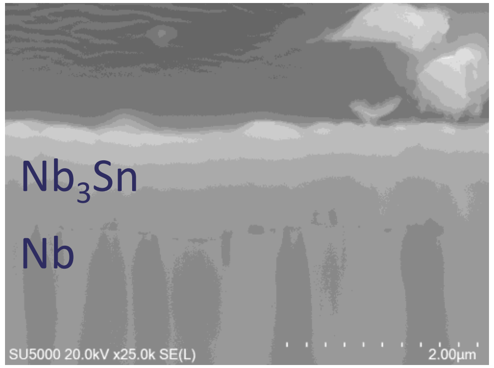
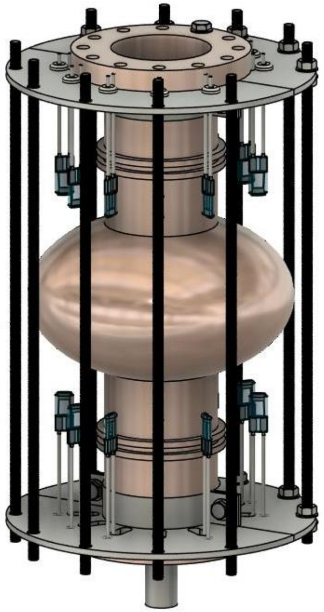
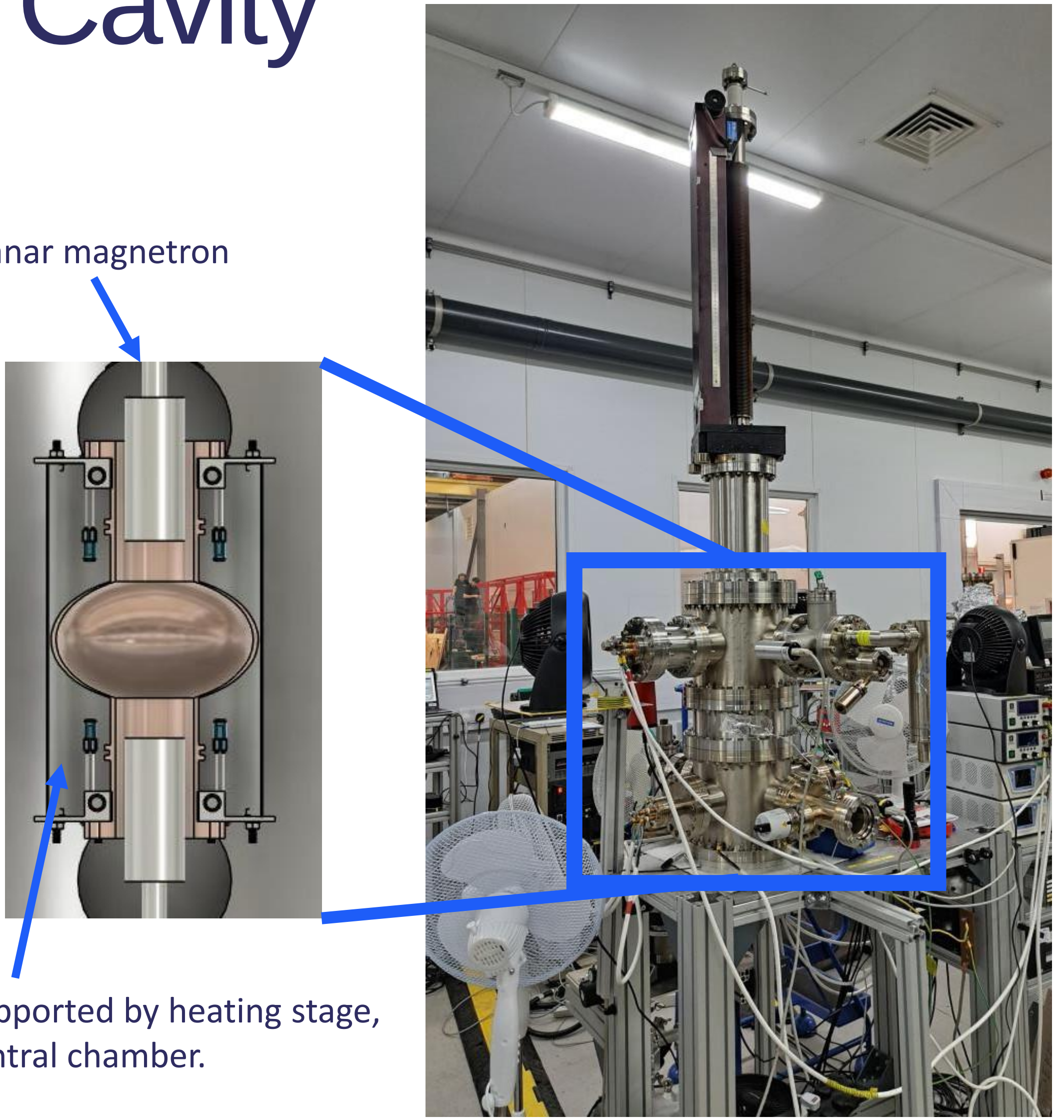
1.3 GHz Cavity Depositions

First Nb_3Sn-Coated 1.3 GHz Cavity

- No cylindrical Nb_3Sn target exists
- A trial facility developed using 2 x planar Nb_3Sn magnetrons
- Heating up to 650 °C
- First run using deposition parameters established on planar samples





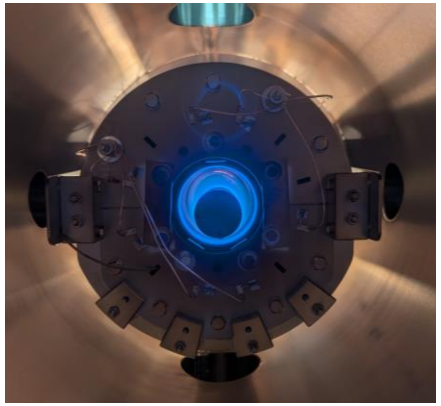


Courtesy of C. Benjamin, R. Valizadeh, J. Conlon (STFC)

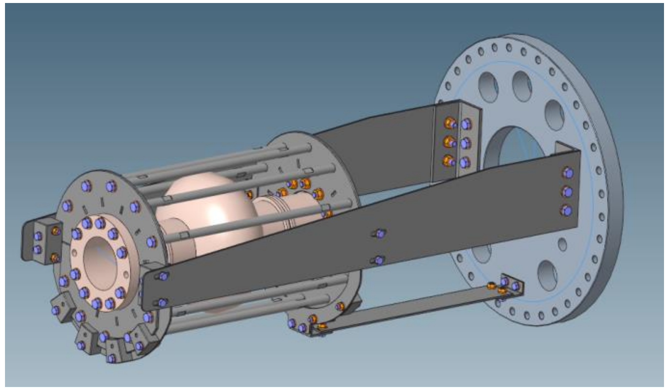
Successful trial run of first Nb_3Sn/Nb 1.3 GHz Cavity

A New Dedicated Cavity Deposition Facility

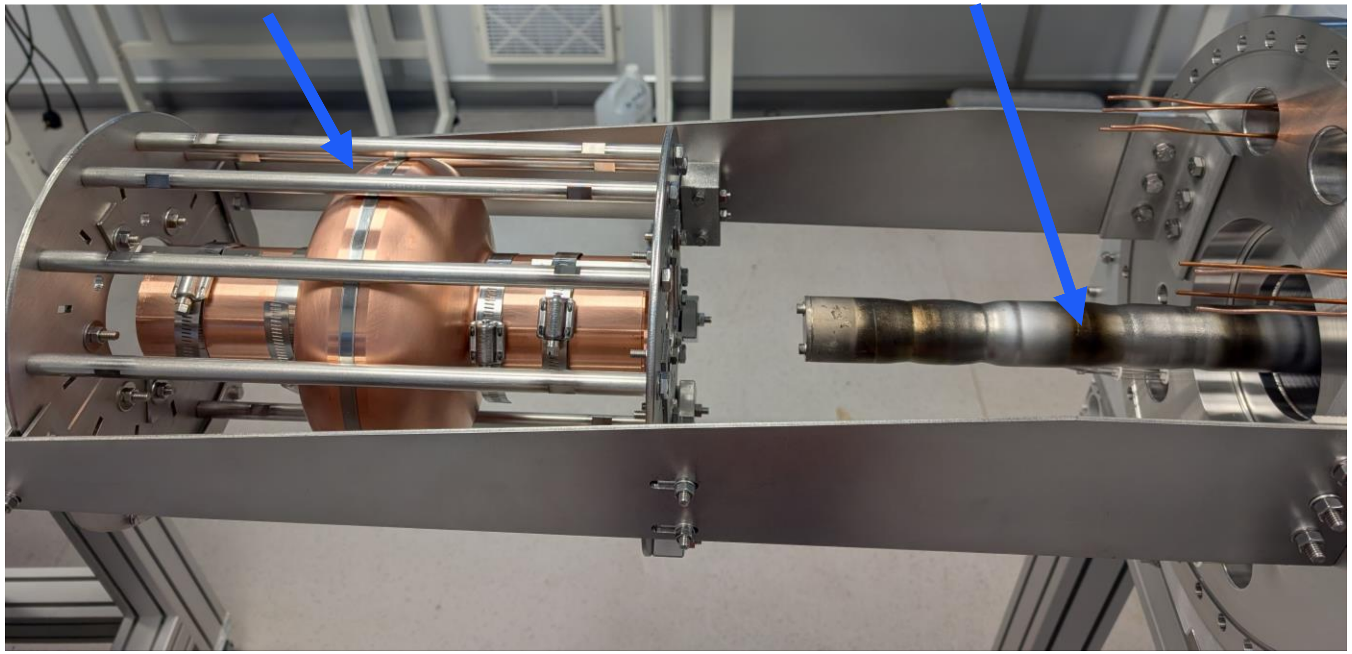
- The new facility is currently being developed in ISO 6 cleanroom.
- A dedicated facility for single and two-cell 1.3 GHz cavities with fully integrated heating stage.
- Initial tests with Nb cylindrical target and mock Cu cavities



Cu mock cavity segments



Nb Cylindrical Magnetron



Courtesy of C. Benjamin, R. Valizadeh, J. Conlon (STFC)

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1.3 GHz Cavity Testing

SRF Testing Facilities

CI RF Bunker

Low power testing with cryocoolers

SuRF Lab

High power testing with LHe – including cleanroom & HPR infrastructure

A High-Throughput Cryogenic RF Test Facility

Conduction cooling with 2.7 W/4.2 K cryocooler

Mounted 1.3 GHz cavity & heat link

Heat shield & MLI

OVC

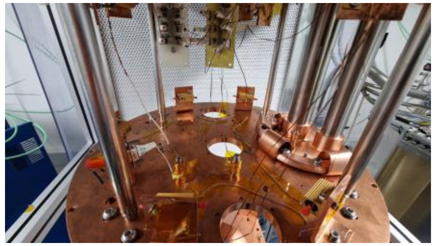
Magnetic shields

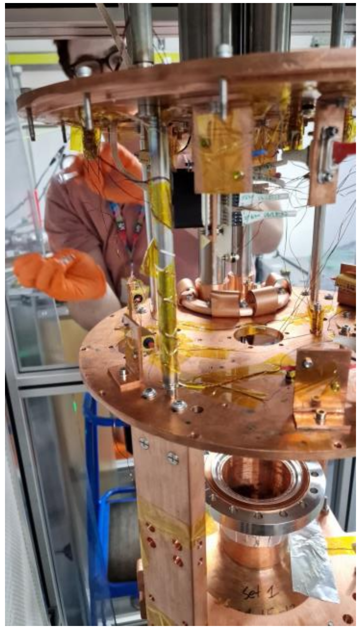
LLRF System

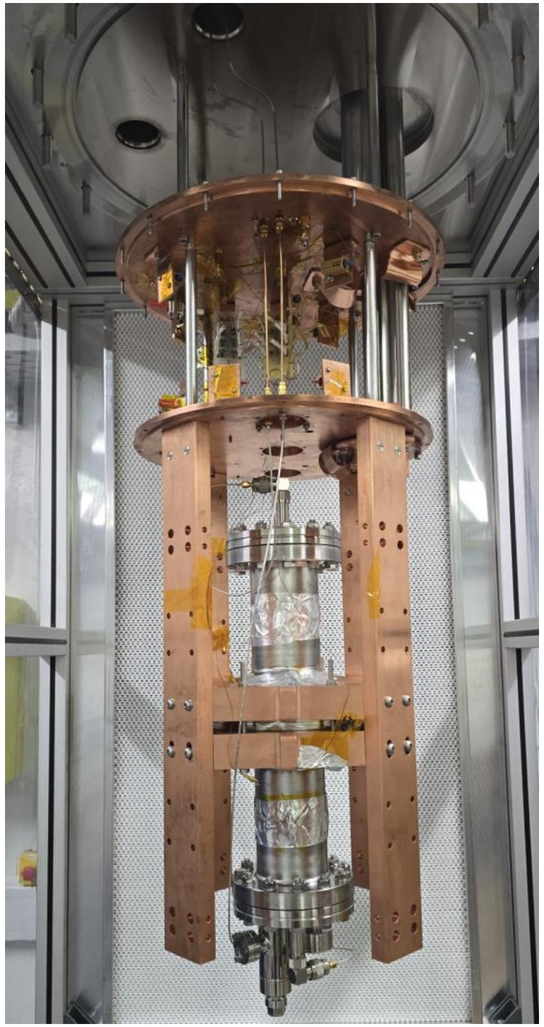
Facility Commissioning

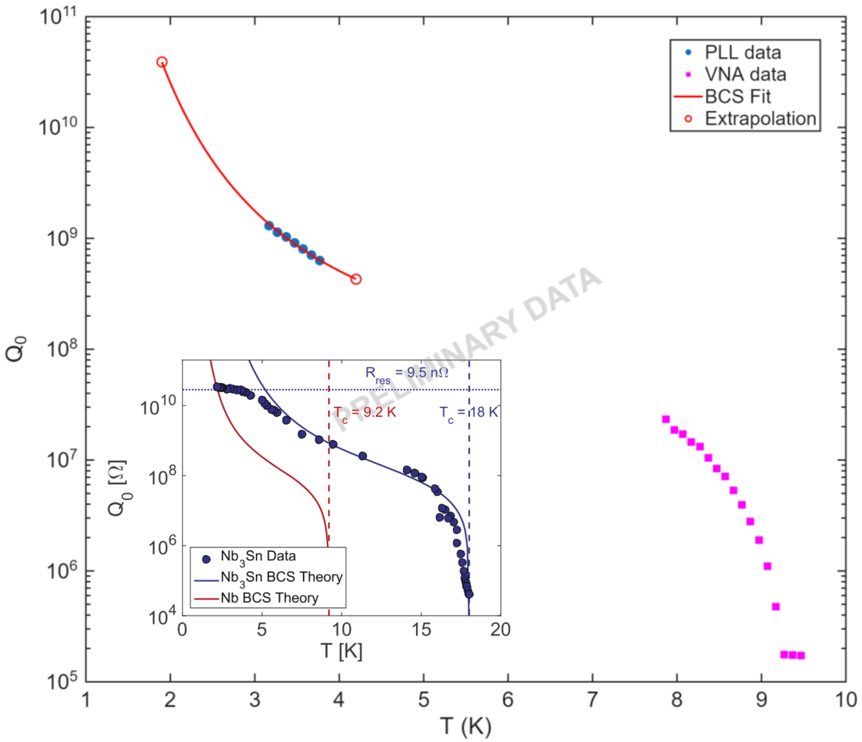
- Successful preliminary tests of a bulk Nb 1.3 GHz cavity
  - Base pressure ~ 10^{-7} mbar
  - Base temperature ~ 3.2 K
  - Cooldown time ~ 14 hours

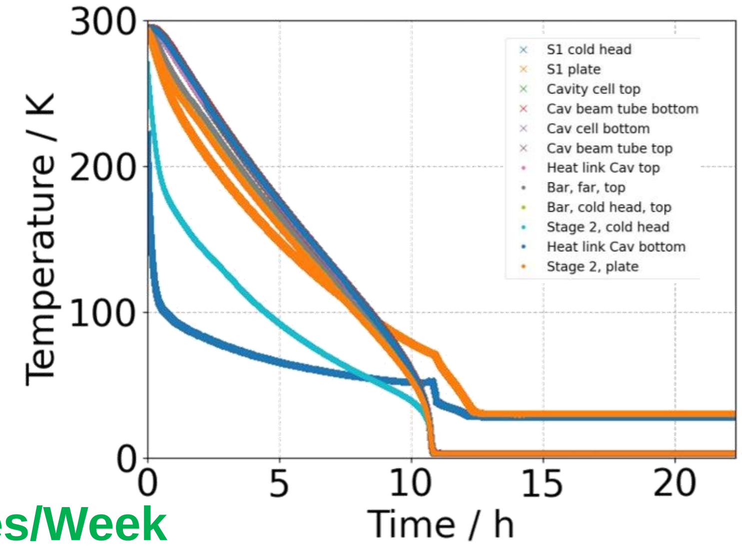
- Successful preliminary tests of a bulk Nb 1.3 GHz cavity:
  - $Q_0(T)$
  - $Q_0(E_{acc})$
  - $f(T)$
  - $\rightarrow R_s(T)$







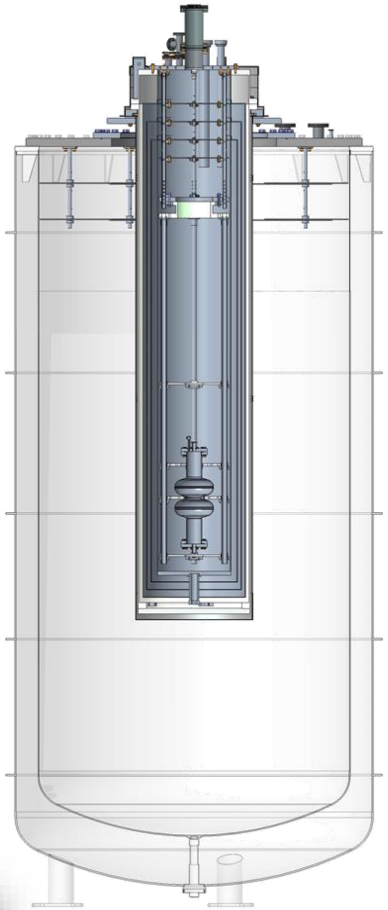




Cryocooler based facility ~ 1-2 Cavities/Week

High Power Cavity Testing

- 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:**
  - A single RF system for 650 and 700 MHz, and 1.3 GHz
  - $P \leq 200$ W, $T = 2$ & 4.2 K
  - Capability for 9-cell tests
- **Commissioning ongoing:**
  - Initial cryogenic tests successful
  - Plans for first bulk Nb cavity (treated at CEA) RF test in July



- LHe-free facility ~ 2 tests/year
  - Only good cavities will be tested after pre-screening in cryocooler based facility

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Outlook

Thin Film SRF Capability at STFC Daresbury Laboratory

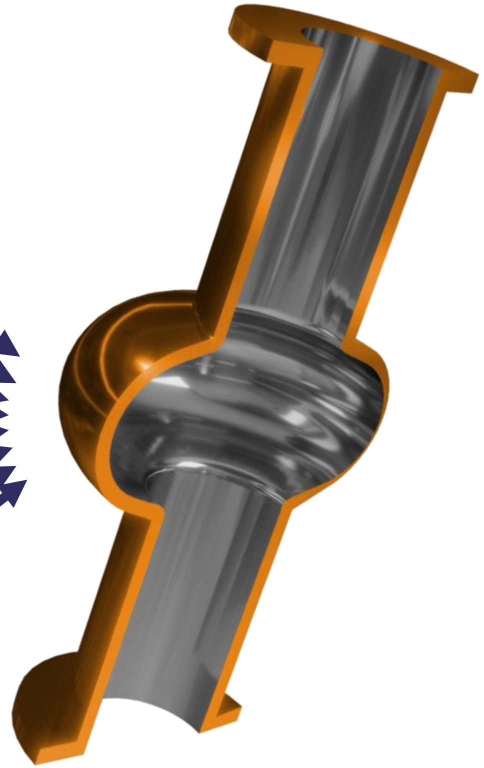
Last 12 years

- Planar sample deposition
- Materials characterisation
- Planar RF testing
- 6 GHz cavity development

Now

- 1.3 GHz cavity deposition
- Conduction-cooled RF testing
- High-power RF testing

Future accelerator applications



Ultimate Goal:
1.3 GHz Nb_3Sn/Cu coated cavities

- Entire workflow now established in-house
- Ready for an intensive programme of cavity optimisation and qualification

International Collaborations

ARIES
(2017-2021)
WP15

- **Small samples**, effect of substrate on superconducting thin film quality
- QPR tests
- **TRL-3**

IFAST
(2021-2025)
WP9

- **1st Nb_3Sn coated Nb cavity**
- **R&D** on Nb_3Sn thin films deposited with PVD and ALD
- Functional layers
- **TRL-4**

iSAS
(2024-2028)
WP3

- **Nb_3Sn coated Cu cavities**
- Magnetic field trapping
- Mechanical properties and tunability
- **TRL-5**

EPITA
(2026-2030)
WP4

- Nb_3Sn coated Cu cavities
- **Horizontal RF test**
- **Conduction cooling**
- **TRL-6**

Conclusions

- Thin film SRF research at STFC Daresbury Laboratory (ASTeC + CI) has progressed from **planar sample studies to cavity development.**

- Dedicated infrastructure established for both **thin film cavity deposition** and **cryogenic RF testing** of 1.3 and 6 GHz cavities.

- New capabilities enable a coordinated **a fully in-house** workflow from thin film deposition to RF performance evaluation.

- STFC Daresbury Laboratory is now well positioned for an **intensive programme of thin film SRF cavity R&D** to develop the next generation of accelerator technology.

- **Collaborations with international partners is the key to success**

Acknowledgements

STFC-ASTeC: O. B. Malyshev, R. Valizadeh, L. Smith, J. Conlon, C. Benjamin, S. Pattalwar, A. Blackett-May, A. Vick, A. Wheelhouse, S. Wilde, A. Palmer, A. Wootten, P. McGuinness, K. Sian, T. Sian, O. Poynton, J. Rigby, A. Ashraf, I. Skachko, Z. Bilques, P. Smith, A. Baig

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STFC-ISIS: G. Stenning

Lancaster University/CI: G. Burt, N. Leicester, H. Marks, A. Mogheyseh, M. Dissanayake Mudiyanselage, D. Turner

Liverpool University/CI: J. Bradley, S. Simon

EPITA WP4 and iSAS WP3 collaborators (> 15 international organisations, > 50 people)