I.FAST Period 2 Review, 15/07/2024

Oleg B. Malyshev (UKRI) / Claire Antoine (CEA)

WP9 coordinators

WP9 objectives

- Define a strategy for innovative superconducting RF (SRF) cavities coated with a superconducting film.
  - Deposition techniques: PVD and ALD
  - Superconducting films: Nb, NbN, Nb_3Sn, V_3Si (and others) and SIS
  - Optimization of flat SRF thin films production procedure
- Optimise and industrialise the production
  - of seamless copper cavities and
  - of the deposition techniques.
- Produce and test prototypes of SRF (single-cell elliptical) cavities:
  - Initially with pre-prototypes with f = 6 and 3 GHz
  - Scaling up for f = 1.3 GHz.
- Test a new laser treatment of Nb coated cavity.

➢ **Main goal**:

- Improving the performance and reducing the cost of acceleration systems
  - both production and operation

WP9 structure

Task 9.1

Coordination and Strategy

for innovative superconducting accelerating cavities

Prototype

Task 9.2

Innovative SC accelerating cavity **prototype**

1.3 GHz cavity coating and testing

Developing

Task 9.3

Optimisation of process parameters and target development for SRF cavity coating with **A15 material**

6 GHz cavities

Task 9.4

Surface engineering by atomic layer deposition

ALD

Task 9.5

Improvement of mechanical and superconducting properties of RF resonator by

laser radiation

Task 9.6

Optimization of flat SRF thin films production procedure

QPR and HWR

Task 9.1: Coordination and strategy for innovative superconducting accelerating cavities

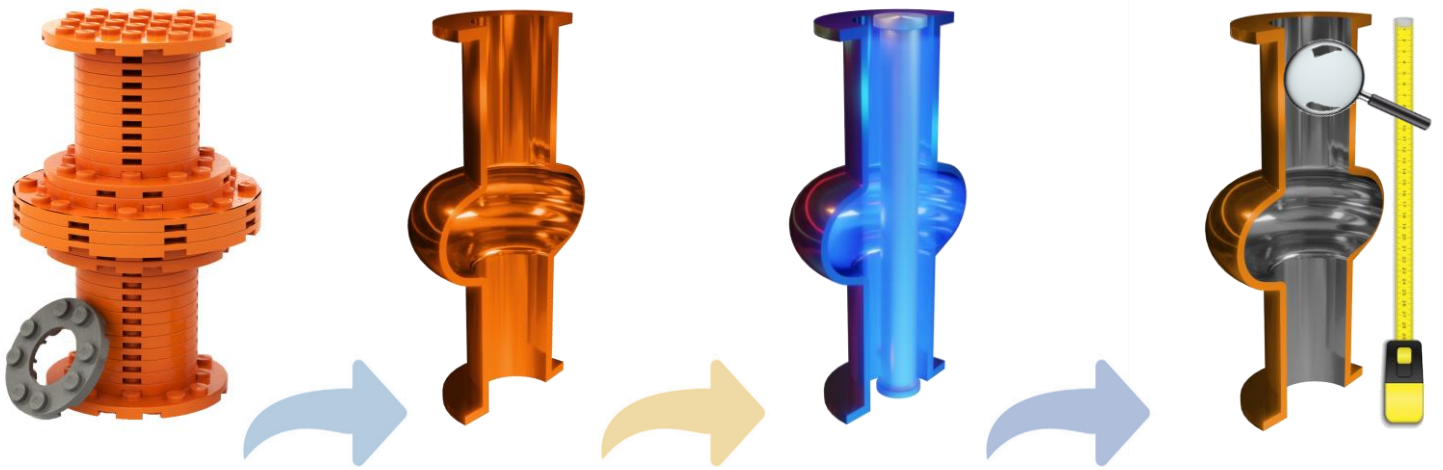
Task Leaders: C. Antoine (CEA), O. Malyshev (UKRI)

- Coordination:
  - Regular WP9 meeting take place every 3-4 months
- Strategy
  - The representatives of **all HEI in Europe**, where TF SRF programme exist, are invited and present at the WP9 meetings
    - CERN and DESY/Hamburg Uni are not official partners in WP9
  - Implementation of Accelerator Research and Development Roadmap of the European Strategy for Particle Physics (ESPP). Annex 1, https://cds.cern.ch/record/2800190?ln=it)
    - Claire and Oleg are also co-chairs for both: IFAST WP9 and EPSS theme on TF SRF
    - All WP9 members are involved in discussion and in providing necessary information for report to the Large Particle Physics Laboratory Directors Group (LDG) mandated by the CERN Council
  - WP9 member were well involved in organising and participating in SRF-23 in USA
  - Organising the **11th International Workshop on Thin Films and New Ideas for Pushing the Limits of RF Superconductivity** on 16-20 Sep. 2024
    - Milestone MS37 on organising this workshop: DELAYED from M28 to M42
    - Deliverable D9.1 Thin film SRF roadmap report, DELAYED from M35 to M45.
      - Both D9.1 and MS37 delays are related to organising and discussing at the workshop, which dates have been moved from June 2023

Task 9.2: Innovative SC accelerating **cavity prototype**

(INFN-LNL, INFN-LASA, PICCOLI, UKRI, USI, CEA, IEE, HZB) *Task Leader: C. Pira (INFN)*

4 main steps to develop to get the first 1.3 GHz Nb_3Sn on Cu prototype produced and tested



Cavity Forming → In progress

Surface Polishing → Standard process Ready

Surface Polishing → Innovative Process in progress

SC film coating → In progress

SC property evaluation RF test → Facilities Ready

Task 9.2: Cavity Forming

- **Production Protocol has been optimised**
  - CNC machine
  - Reduced Annealing Temperature (400 °C, previous 500 °C)
  - New intermediate Deep Drawing Step
- **Several cavity substrates 1.3 GHz (and 6 GHz for task 9.3) sent to STFC and UniSiegen for coating tests**
- **New optimized die produced and tested by Piccoli**
- **OFE Copper procurement**

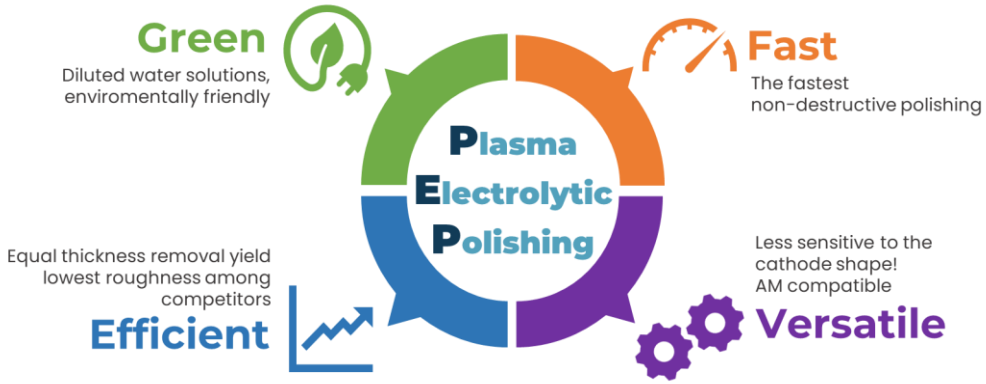
New 1.3 GHz Die for Spinning produced by Piccoli

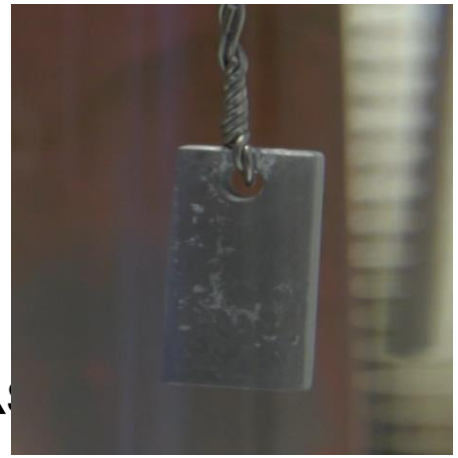
- **Ready for final prototype substrates production**

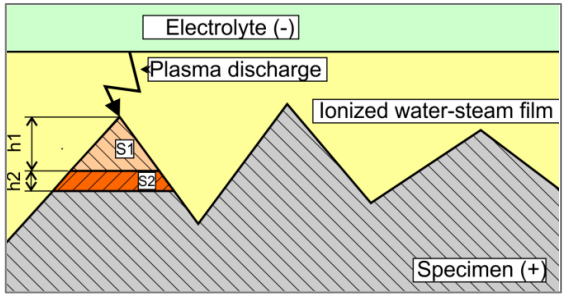
Task 9.2: Cavity Polishing

- Polishing via SUBU5 chemical process as baseline established @LNL
- Ongoing R&D on innovative Plasma Electrolytic Polishing (PEP)

PEP Advantages







6 GHz Cu cavity

No internal cathode

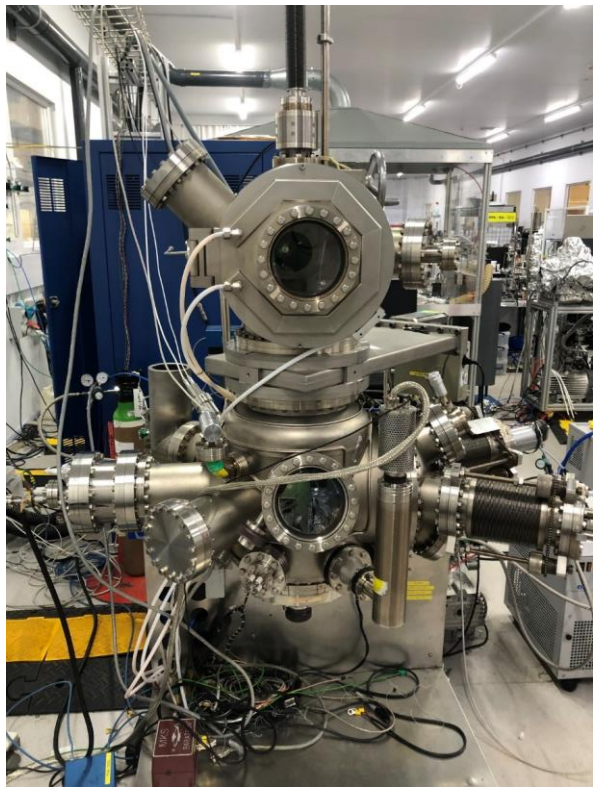
70 µm removed in 10 minutes

30 A (100 cm2 → 1.3 GHz ~ 300 A)

Task 9.2: 1.3 GHz cavity Coating at INFN/LNL and UKRI/DL

- ❑ 1.3 GHz Coating systems is ready
- ❑ First tests on cavity mockup in 2024
- ❑ R&D on samples successfully ongoing
  → T_c close to Nb_3Sn nominal one (best results on Cu so far in literature)

PVD (left) and Dipping (right) coating systems @LNL



PVD coating system @UKRI/DL outside (left) and inside with a cavity (right)

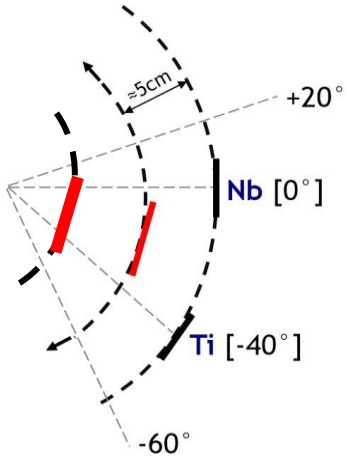
Task 9.3: Optimisation of process parameters and target development for SRF cavity coating with A15 material

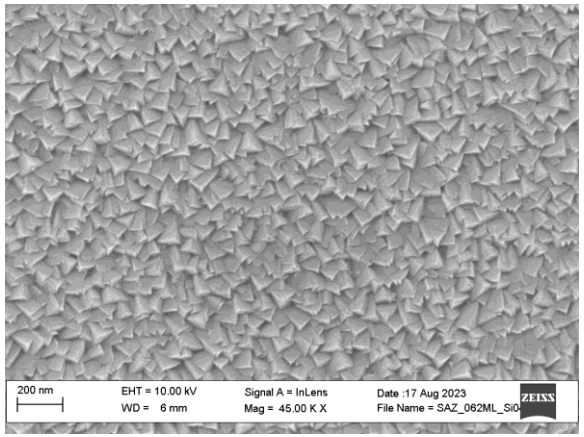
(UKRI, INFN, IEE, USI, HZB, HZDR) *Task Leader: R. Valizadeh (UKRI)*

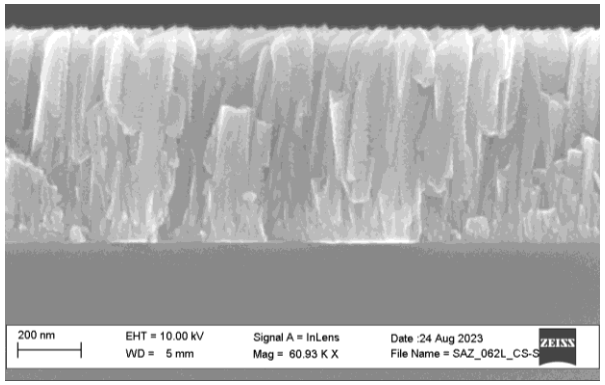
Development of thin films **on planar copper substrates:**

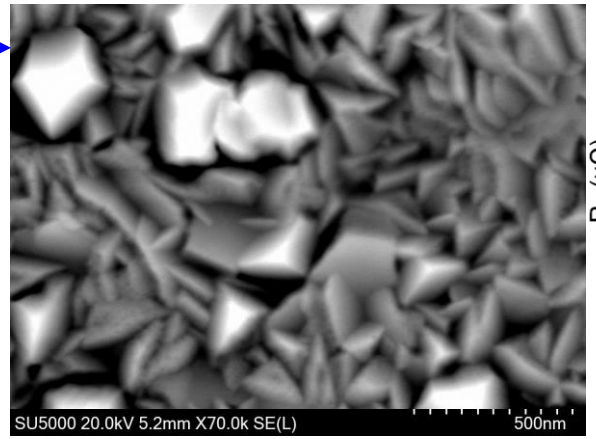
- Nb_3Sn at INN/LNL
- Nb_3Sn, NbTi and V_3Si at UKRI
- NbN at US

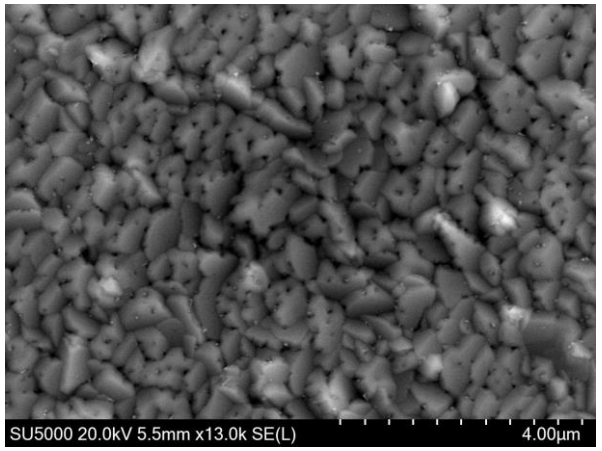
Increase sub.-target distance $\mathcal{L}$



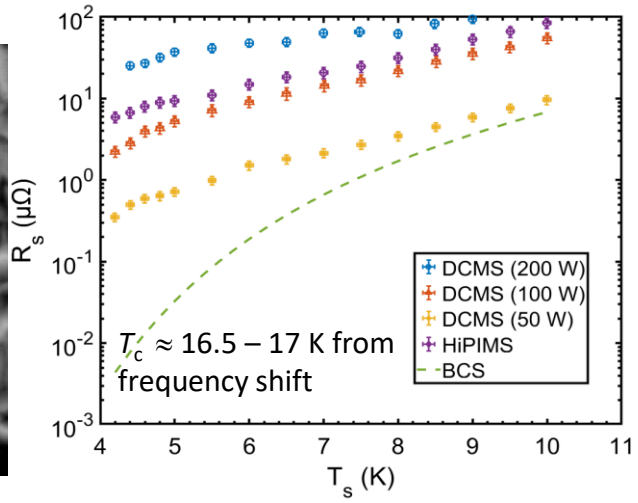


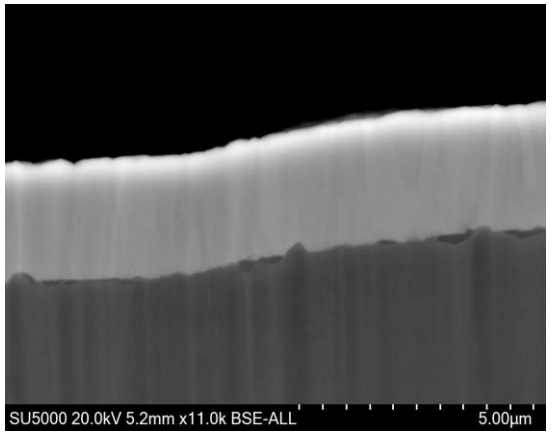






RF surface resistance at 7.8 GHz

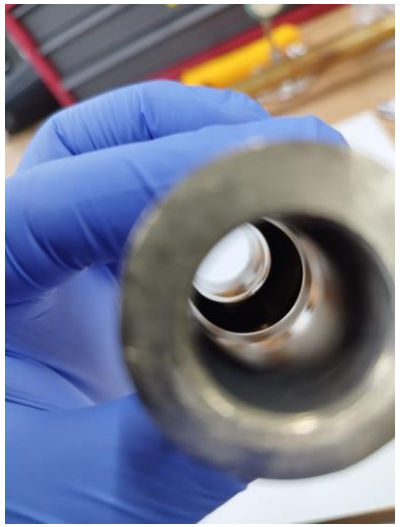


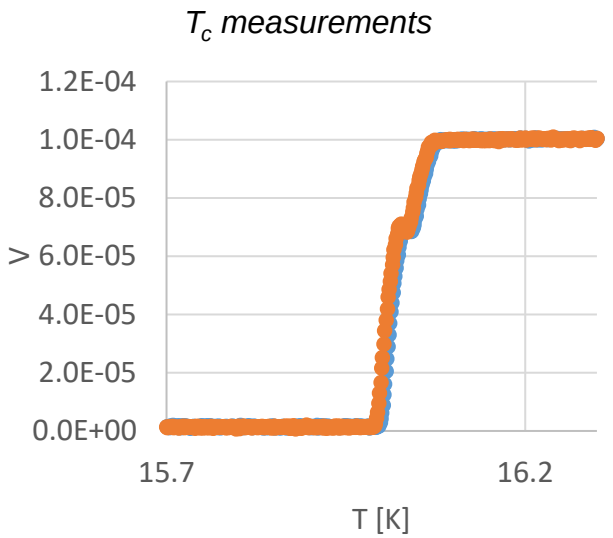


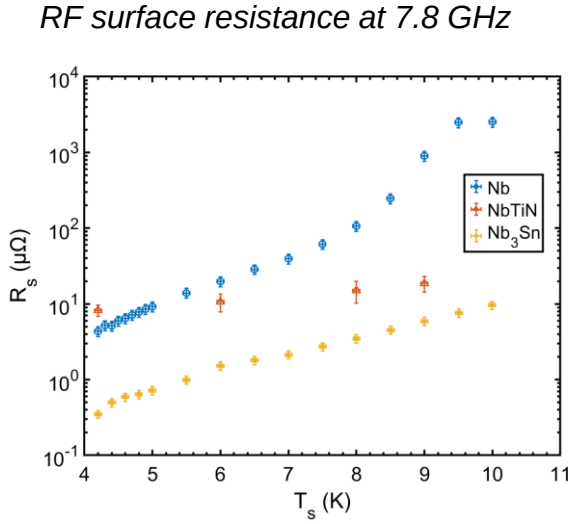
Task 9.3: Optimisation of process parameters and target development for SRF cavity coating with A15 material

(UKRI, INFN, IEE, USI, HZB, HZDR) *Task Leader: R. Valizadeh (UKRI)*

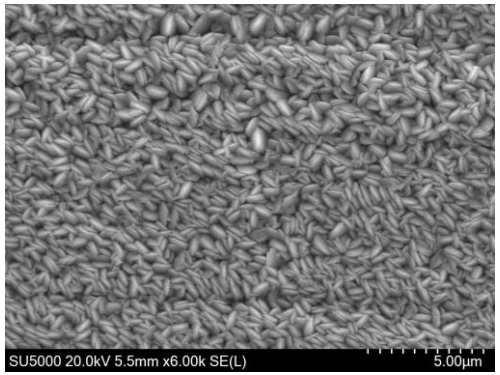
Depositing NbTiN thin films from Nb rod and Ti wire **on a 6 GHz RF cavity** at UKRI

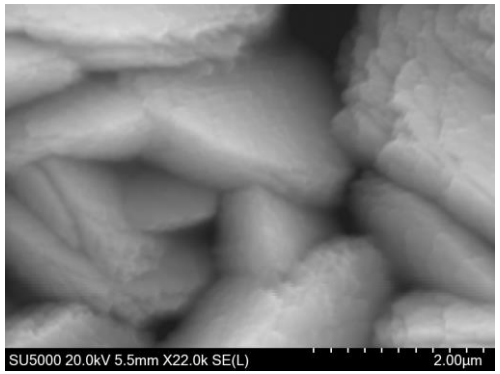






After several iteration of changing Ti wire loops composition of $Ti_{0.5}Nb_{0.5}$ reached





- **Deliverable D9.3**: First 6 GHz cavity coated and characterised - DELAYED from M36 to M42.

The Deliverable was delayed in order to achieve more successful results. The cavity deposited with NbTiN was produced, T_c was correct, however the Q-value was 2 decades lower than what it was expected due to film delamination. A new cavity is already prepared but not tested yet.

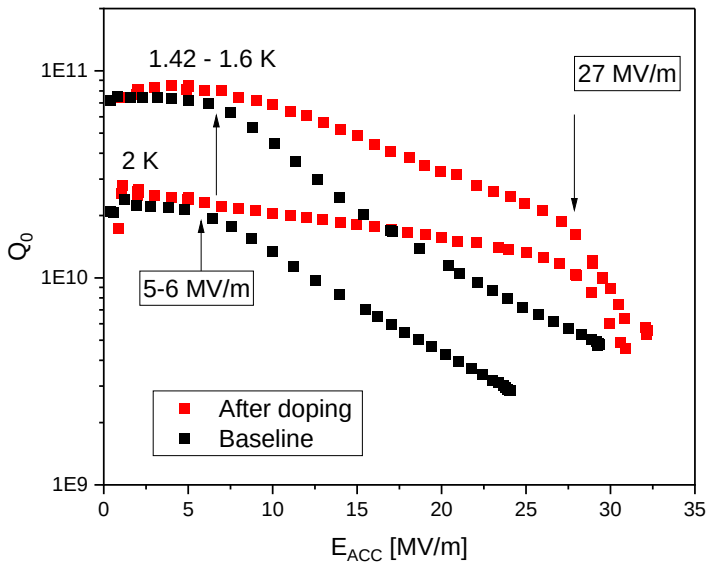
Task 9.4: Surface engineering by atomic layer deposition (ALD)

(CEA, CNRS) Task Leader: T. Proslier (CEA)

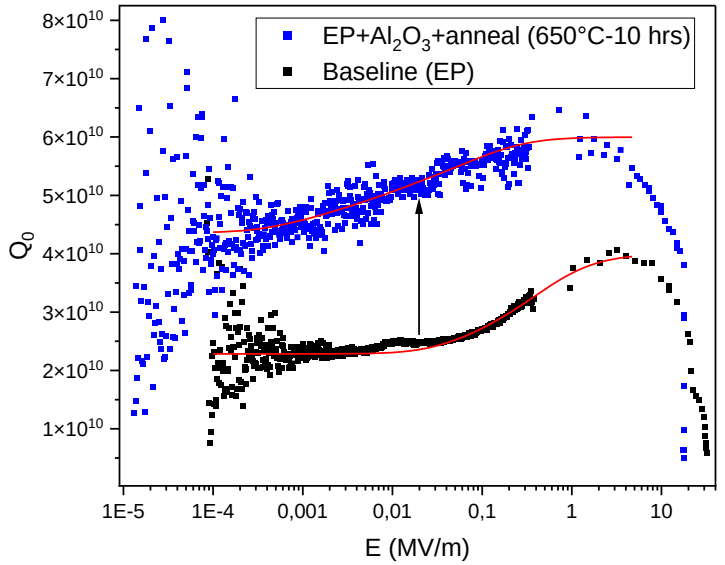
- ✓ **Increased Q at low field** **for 3D superconducting resonators 1,3 GHz.** Publication + patent
- ✓ **Increased penetration field** **on samples** by 24%. First depositions of multilayers in 1.3 GHz cavities
- ✓ **N doped cavity by ALD** **of NbN**. Optimization underway.

  First depositions of multilayers in 1.3 GHz cavities

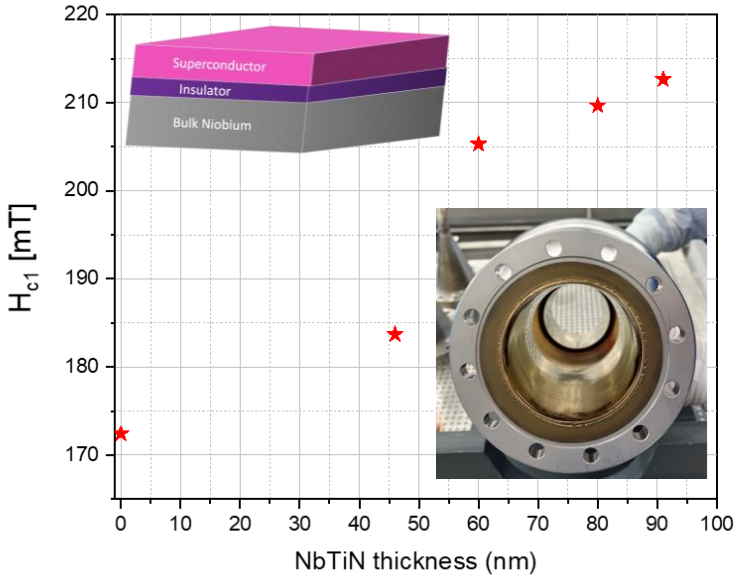
Doping by ALD: NbN (5nm) + thermal annealing



High Q studies for Qubits and accelerators



High Gradient for accelerators increased penetration field.

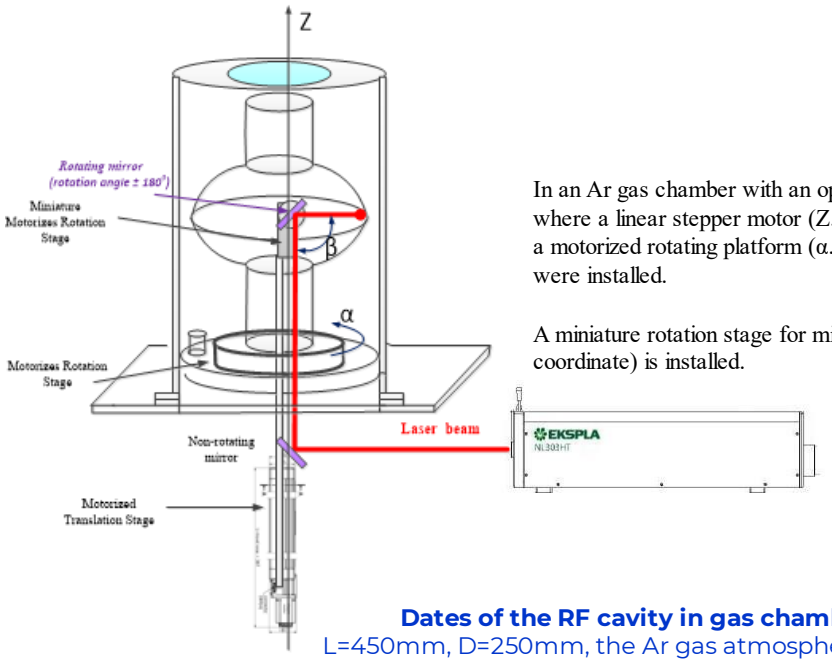


➢ **Milestone MS40**: Construction and operation of a high temperature ALD system dedicated to SRF cavities - **ACHIEVED.**

Task 9.5: Improvement of mechanical and superconducting properties of RF resonator by laser radiation

(RTU, UKRI, INFN, IEE, HZB) *Task Leader: A. Medvids (RTU)*

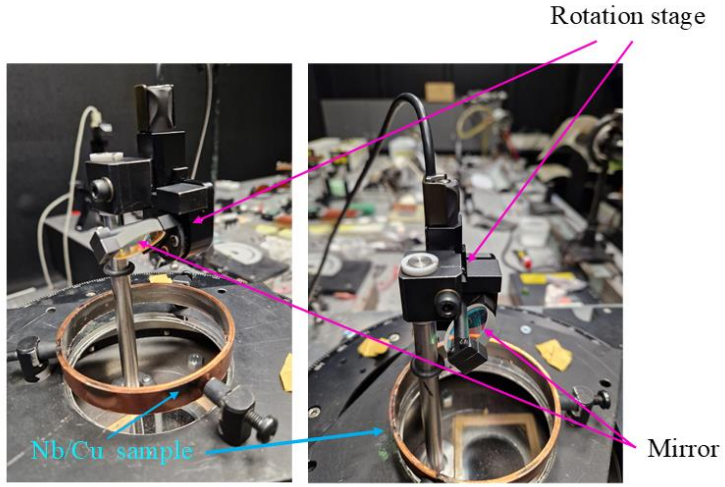
Improvement of mechanical properties of Nb/Cu structure after irradiation by nanosecond laser



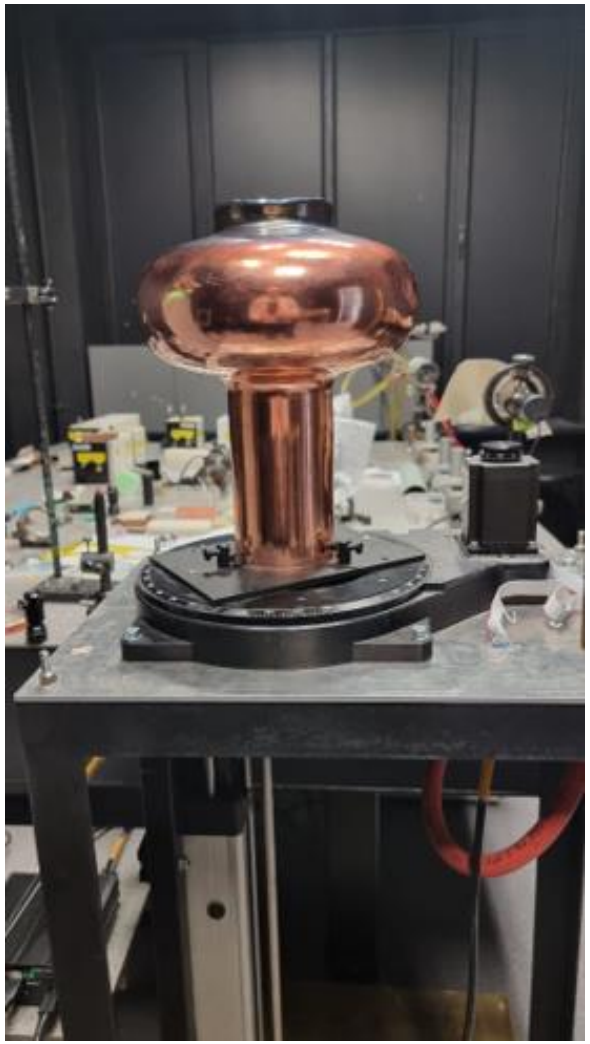
In an Ar gas chamber with an optical window, where a linear stepper motor (Z. coordinate) and a motorized rotating platform (α. coordinate) were installed.

A miniature rotation stage for mirror rotation (β. coordinate) is installed.

Dates of the RF cavity in gas chamber:
L=450mm, D=250mm, the Ar gas atmosphere 1.5 atm pressure.



A miniature rotation stage for mirror rotation (β coordinate) is installed.

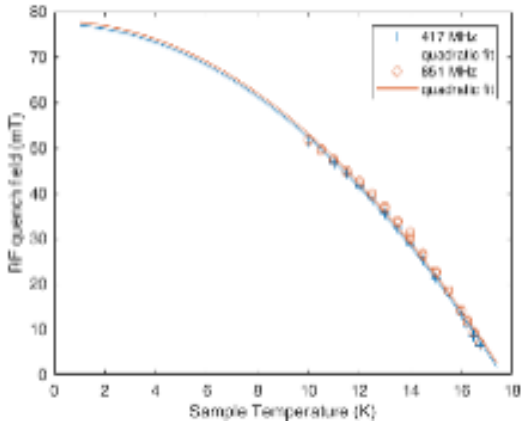


- **Milestone MS41**: A facility for laser operation for complex 3D treatment is tested on 1.3 GHz cavity (Month 36)
  A 2-month DELAY because of technical problems.

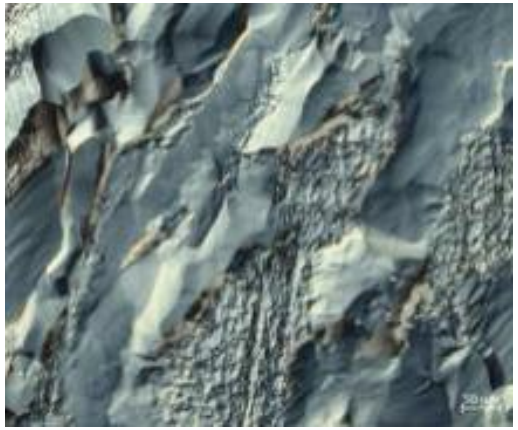
Task 9.6: Optimization of flat SRF thin films production procedure

(HZB, INFN, UKRI, USI, CEA) *Task Leader: O. Kugeler (HZB)*

- HZB has experienced a cyber attack in summer 2023
  - which led to the encryption of most programming code including virtualised backups for the QPR operation
  - The attack also affected cryogenics, radiation protection, RF operation and utilities.
  - No QPR measurements have been performed for 7 months.



- QPR samples from UKRI-DL (multilayer), CEA (ALD coating) and INFN-LNL (Nb3Sn) were deposited and waiting for RF testing:
  - The INFN-LNL (Nb_3Sn) sample has been tested for quench field
  - Others will be measured in 2024.



Summary

✓ **On track** with Deliverables and Milestones
(minor delays due to technical challenges)

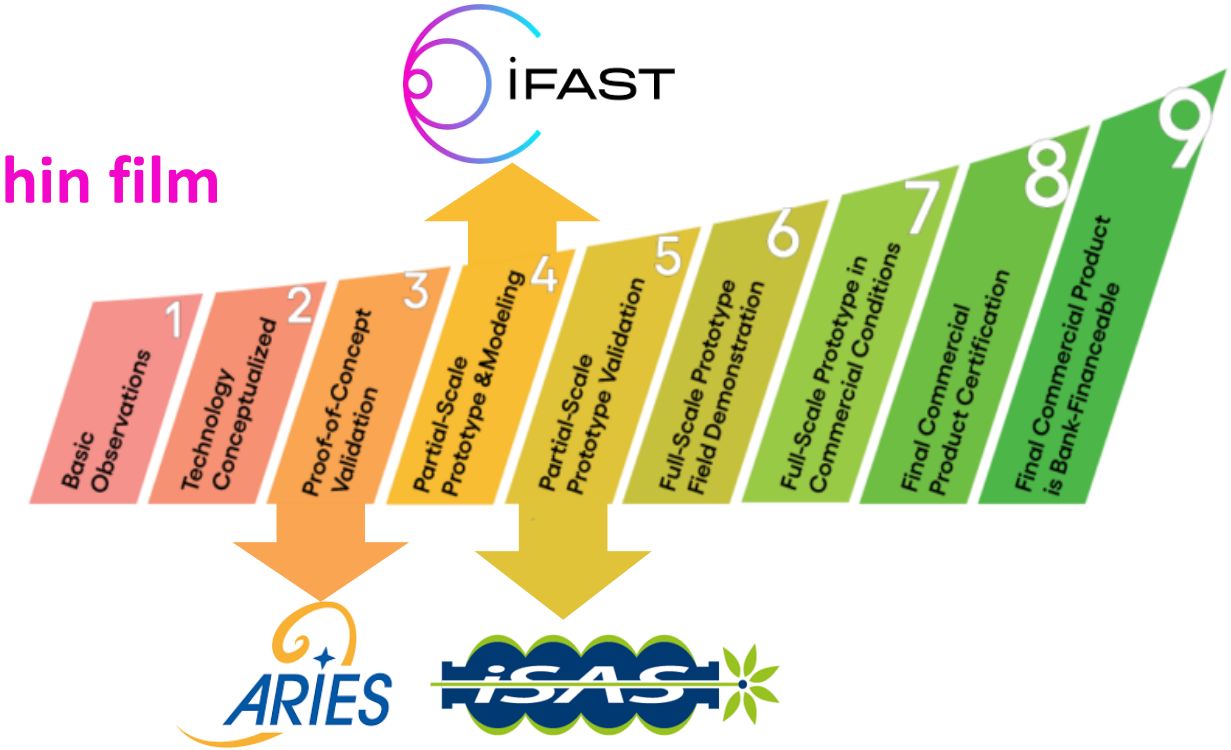
What is a difference between ARIES, IFAST and iSAS?

ARIES
- Substrate preparation
- Nb thin film
- Planar samples only

iFAST
- Nb_3Sn, NbN, NbTiN, V_3Si thin film
- Interface diffusion
- Target Production
- Coating Parameters
- Depositing on and testing 1.3 GHz cavity

iSAS
- Trapped Flux
- Tuning

iFAST



I.FAST Period 2 Review, 15/07/2024

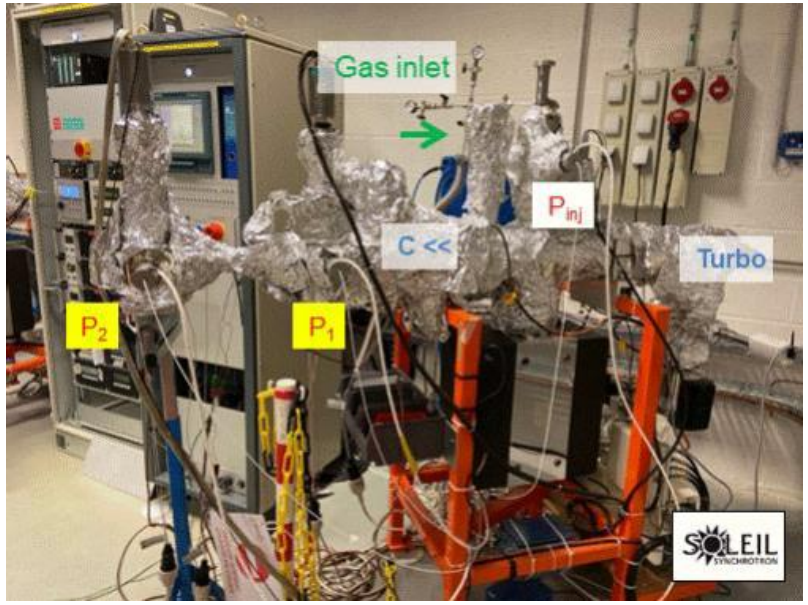
Partners: UKRI, DESY, DLS, Soleil.

O. Malyshev (UKRI) - Task Leader

(1) NEG coating pumping properties evaluation

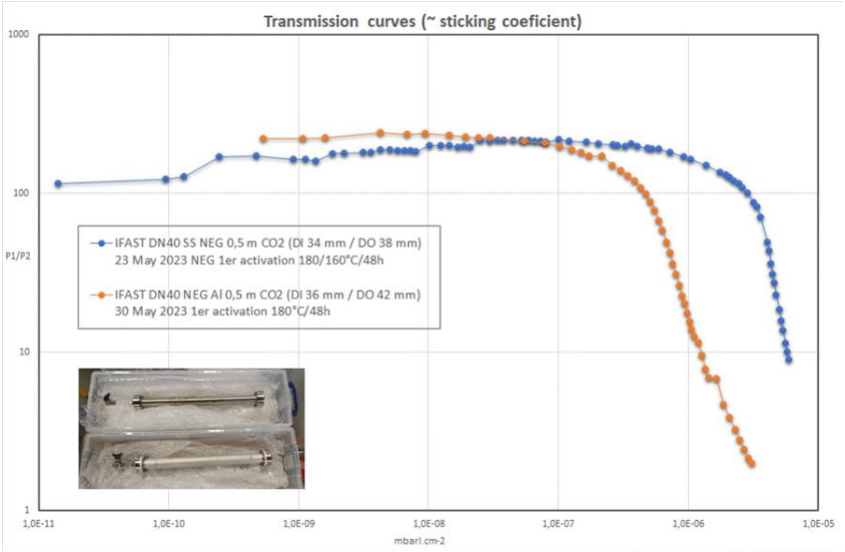
➢Testing facilities:

- Four facilities have been designed on similar principles and can be used with similar samples.
- Thus, measurements can be cross-verified in 4 laboratories.



➢Samples:

- ID = 34-36 mm and L = 500 mm and equipped with two CF40 flanges
- made of 316 LN and aluminium
- NEG coated at UKRI,
- then tested at DLS, DESY, Soleil and UKRI.



➢Samples:

- ID = 20 mm and L = 500 mm and equipped with two CF40 flanges
- made of copper
- Prepared at DESY
- NEG coated at UKRI,
- then tested at DLS, DESY, Soleil and UKRI.

(2) PSD from NEG coated accelerator vacuum chambers

➢This activity is the main objective for Task 10.5

Sample preparation:

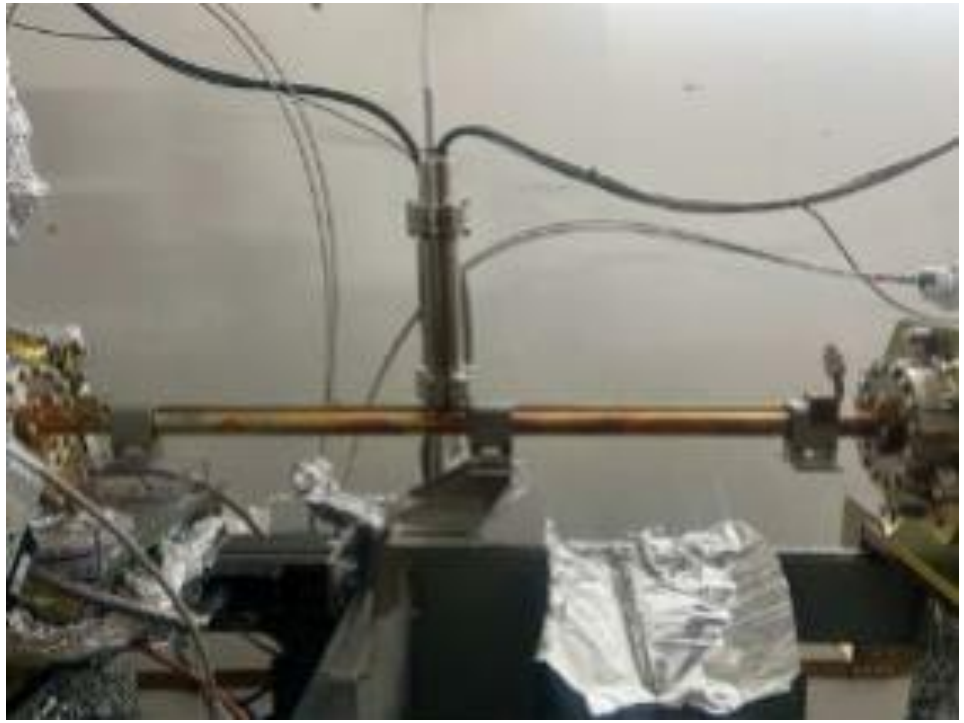
➢Problems in P2:

1) Low quality of deposition targets (at UKRI) results in coating with low performance
   - Solution: changing a supplier
2) Non-uniform deposition (at UKRI and DESY) on tubes with ID = 20 mm and L = 1 m
   - 10 cm from the edges were not fully coated
     - Solution: longer coil or short moving coil
     - Working with instrumentation:
       - Deposition power supply,
       - Discharge gas pressure,
       - Target alignments

✓Sorted out

(2) PSD from NEG coated accelerator vacuum chambers (c-ed)

- Main progress:
  - Two PSD samples deposited at UKRI with a TiZrV columnar film in Nov-Dec 2023
    - Samples have been tested at UKRI for pumping properties after activation to 180 °C for 24 h
    - Then shipped to DLS and Soleil for PSD measurements
  - PSD facilities:
    - Access limited by technical shutdowns
    - ✓ Samples have been installed at DLS in March 2024 and Soleil in April 2024.
    - ✓ PSD experiments are ongoing



The TiZrV NEG coated copper sample with ID = 20 mm and L = 1.0 m installed in the SR beamline at DLS

- Deliverable Report "First PSD data from NEG coating":
  - Due Date – Month 36 from installation date
    - Too sort from the date of installing on SR beamlines
  - Extension for 8 months is required to collect data and analyse the results
  - New deadline – **Month 44**