INFN LNL

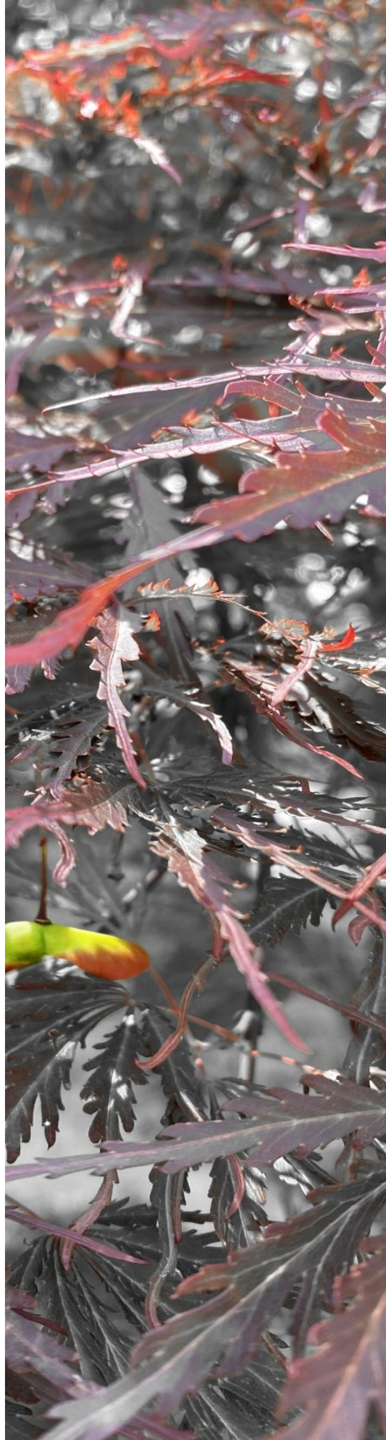
Cristian **Pira**

on behalf of LNL SRF group

SAMARA
SRF R&D @LNL

Meeting CSN5 LNL

13/03/2024



SAMARA

Superconducting **A**lternative **M**aterials for **A**ccelerating cavities and haloscope **R**esonators for **A**xions

Material	Tc	H_{c2}
Nb	9.2 K	0.4 T
Nb_3Sn	**18.3 K**	**30 T**

WORKS IN VERY HIGH MAGNETIC FIELD
Axion Haloscopes

REDUCES CRYOGENIC POWER BY A FACTOR 3
Accelerating Cavities

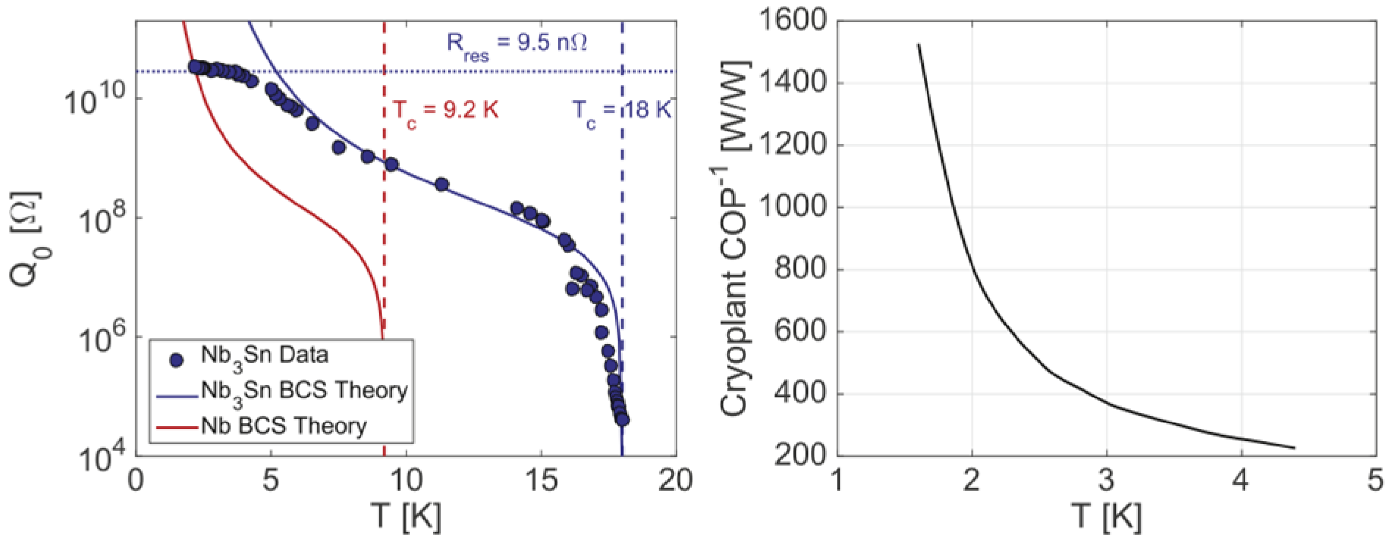
Accelerating Cavities

***Energy saving** is mandatory for the **next generation accelerators**…*

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

Move from bulk Nb @2K to Nb_3Sn @4.5 K

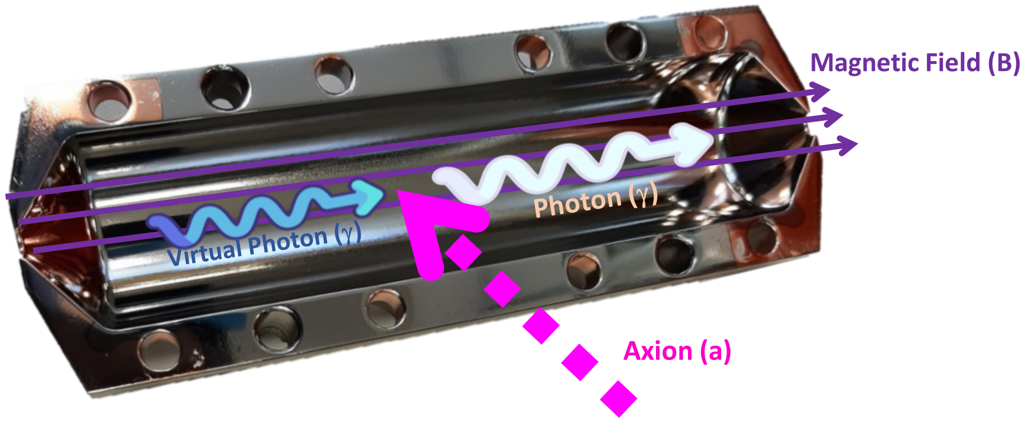
reduces cryogenic power by a factor of 3



Quantum Sensing

SRF Axion Haloscopes

- The axion haloscope was designed to scope microwave photon signals from the axions in our galactic halo
- The signal power can be enhanced by the resonance effect that occurs when the axion mass matches the natural frequency of the detection system



$$P_{a\gamma\to\gamma} = g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a} B^2 \omega_0 V C \frac{Q_a Q_c}{Q_a + Q_c}$$

Conversion Power; Coupling Constant; Dark Matter Axion Density; Volume; **Cavity Quality Factor**; Axion Mass; Magnetic Field; Resonant Frequency; Axion Quality Factor (10^6)

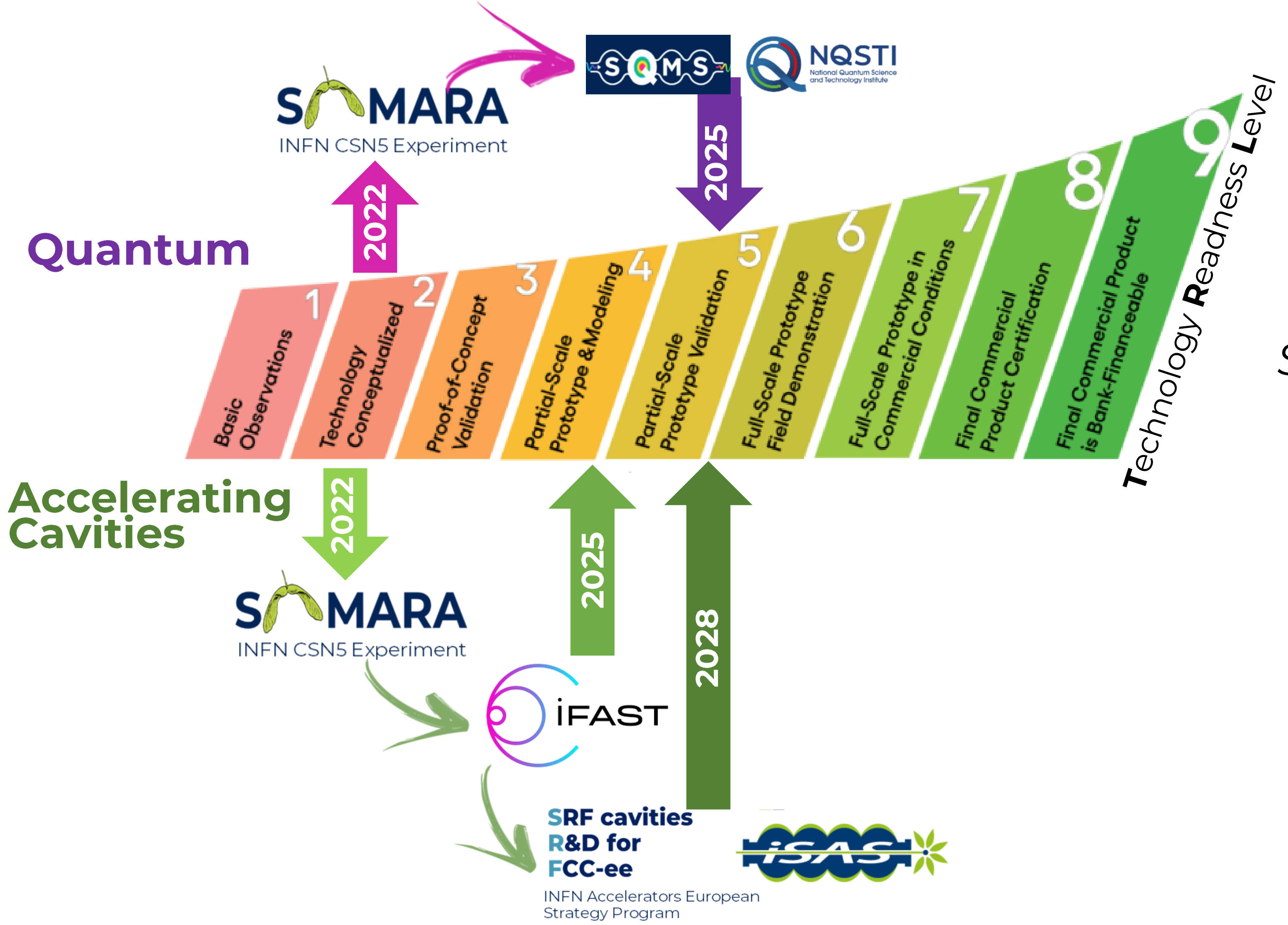
D. Kim *et al.* JCAP03(2020)066

Q factor of Cu haloscope limited by anomalous skin effect

to improve Q

SRF in High Magnetic Field *(Mixed State)*

Other SRF Projects and Collaborations



SAMARA Partners:

INFN Torino, INFN Roma Tre, INFN LNF, INFN Milano

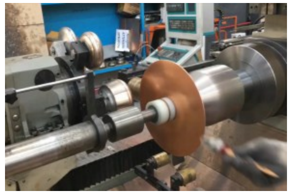
SRF Partners:

CERN, CEA, IJCLab Irène Joliot-Curie, UKRI Science and Technology Facilities Council, ELÚ, HZB Helmholtz Zentrum Berlin, HZDR Helmholtz Zentrum Dresden Rossendorf, Rīgas Tehniskā Universitāte, Universität Siegen, Jefferson Lab, Fermilab, DESY, INFN Padova, Università di Padova, Piccoli srl Torneria in Lastra Metallica

R&D in all the production chain

iFAST

Cavity Forming



Seamless Spinning

Additive Manufacturing

iFAST
SAMARA INFN CSN5 Experiment
SRF cavities R&D for FCC-ee INFN Accelerators European Strategy Program

Surface Polishing

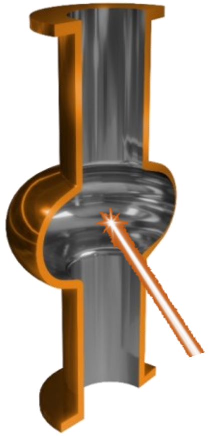
Plasma Electrolytic Polishing

iSAS
iFAST
SAMARA INFN CSN5 Experiment
SRF cavities R&D for FCC-ee INFN Accelerators European Strategy Program

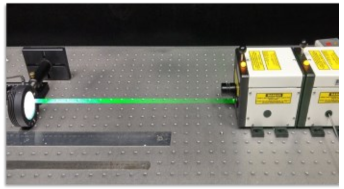
SC film coating

Nb_3Sn by DC Magnetron Sputtering

iFAST



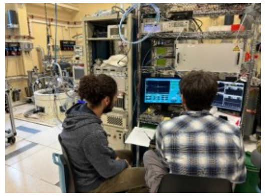
Post Treatments



Laser and Flash Lamp Annealing

iSAS
iFAST
SAMARA INFN CSN5 Experiment
SRF cavities R&D for FCC-ee INFN Accelerators European Strategy Program

SC property evaluation
RF test



6 GHz RF Test
Tc measurement,
XRD, SEM, EDS

LNL Personnel involved in SRF R&D activities

SAMARA — Permanent Staff

Name	Profile	%
Cristian Pira	Tecnologo	45
Giorgio Keppel	Primo Tecnologo	15
Fabrizio Stivanello	Coll. Tecnico E.R.	55

SAMARA — Non Permanent Staff

Name	Profile	%
Roberta Caforio	Borsista	20
Giovanni Marconato	Borsista	100
Alessandro Salmaso	Borsista	80

iFAST — Non Permanent Staff

Name	Profile	%
Davide Ford	Coll. Tecnico E.R.	100
Dorothea Fonnesu	Assegnista	100

NQSTI National Quantum Science and Technology Institute — Non Permanent Staff

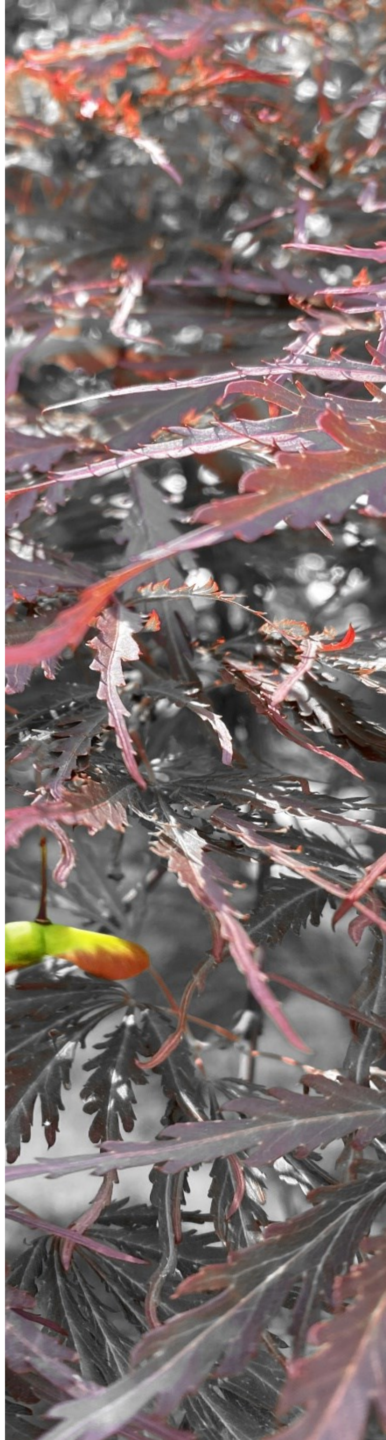
Name	Profile	%
Eduard Chyhyrynets	Tecnologo	100
Thomas Bortolami	Coll. Tecnico	100

2 Laureandi: Anita Fetaj e Matteo Lazzari


Thank you!
Servizio Tecnologia delle Superfici e Superconduttività

INFN LNL

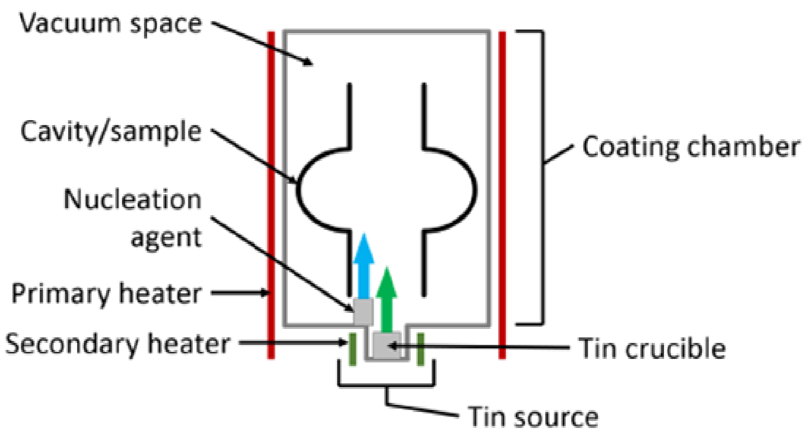
SAMARA
BACKUP SLIDES

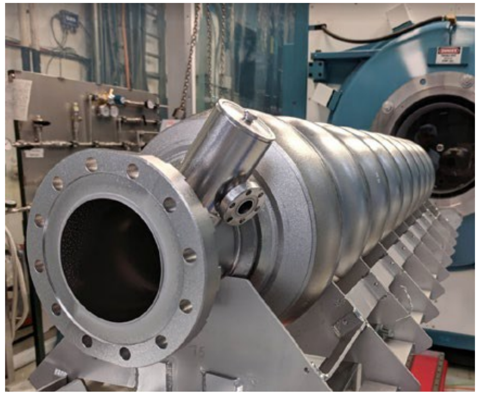


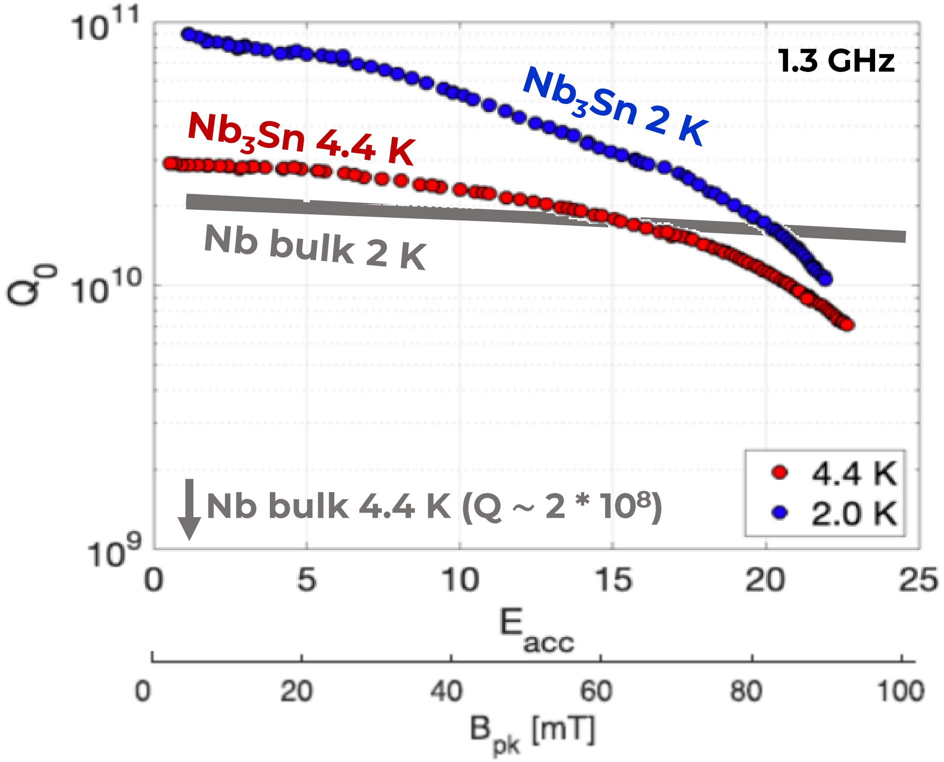
Nb_3Sn state of the art

Vapor Tin Diffusion

Cornell, Fermilab, JLab, KEK







S. Posen, SRF 2019 proceedings (elaborated)

Technology limitation:

- **Reproducibility**
- **Substrate cost**

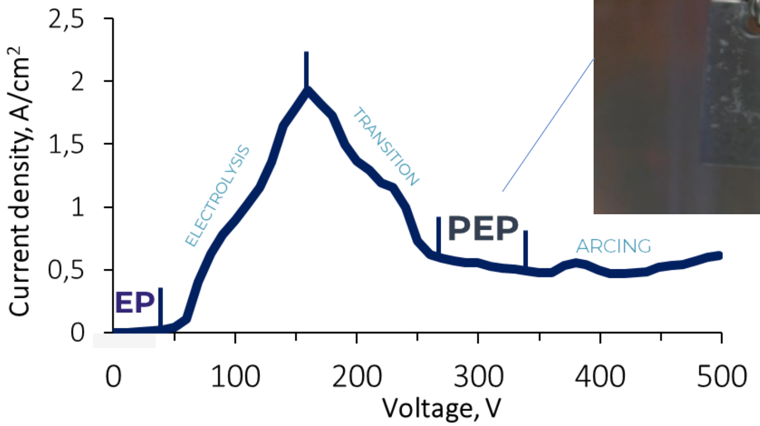
A different approach:
Nb_3Sn on Cu

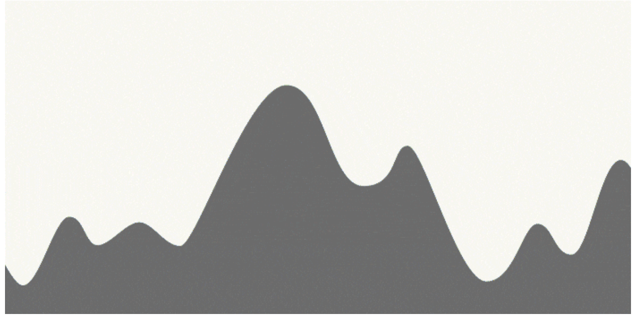
Cu substrate as several advantages:

- **Cheaper** than Nb
- Higher **thermal conductivity**
- Higher **mechanical stability**
- **PVD technology** (Nb on Cu) already used for
  LEP, LHC, HIE-ISOLDE @ CERN
  ALPI @ INFN LNL
- **Interlayer** can be added to engineering the surface

Plasma Electrolytic Polishing PEP

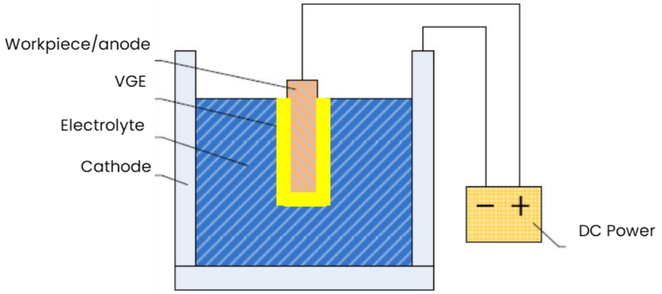
Mechanism





Same EP set-up

Different regime



J. Wang et al., AMR, 2012

Advantages

Green

Diluted water solutions, enviromentally friendly

Fast

The fastest non-destructive polishing

Efficiency

Equal thickness removal yield lowest roughness among competitors

Versatility

Less sensitive to the cathode shape! AM compatible

Surface Polishing

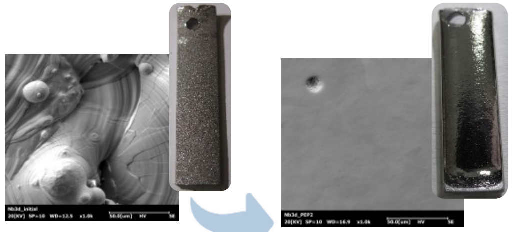
Plasma Electrolytic Polishing PEP

Results

1x Nb 3x Cu

Solution Patentees by INFN

Additive Manufacturing



Initial
Ra= 13 μm

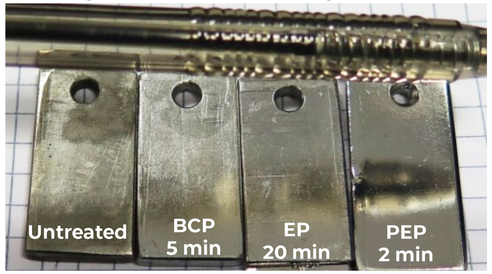
PEP 30 min
Ra= 1.5 μm

QPR Samples HZB Helmholtz Zentrum Berlin

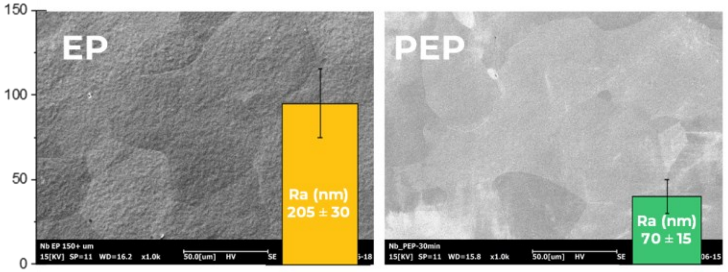
Nb QPR polishing optimizaztion on-going

Full Cu QPR ready for coating

Nb planar samples



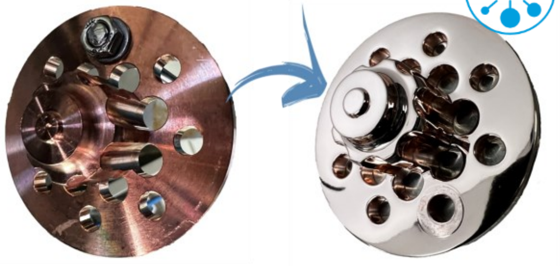
6.5 μm removed



150 μm removed in ~ 5 h

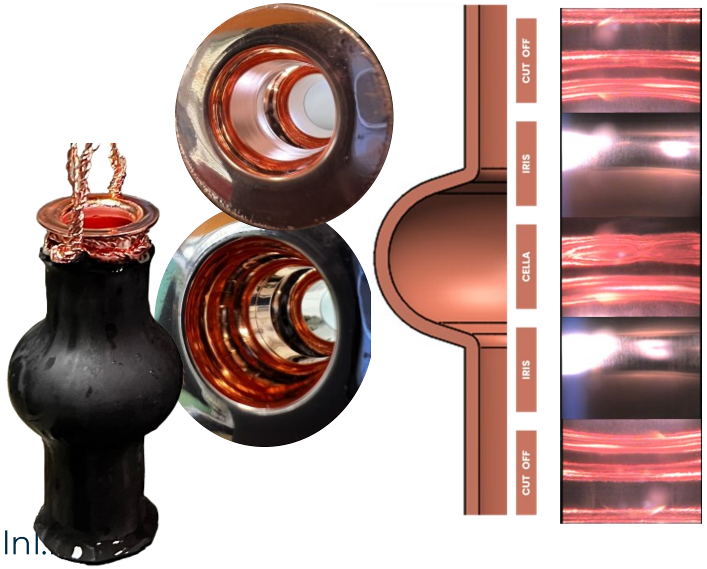
150 μm removed in ~ 40 min

Cu Photocatodes DESY.



Ra ~ 8 nm!!!

6 GHz Cu cavity

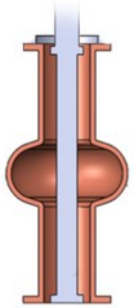


No internal cathode!

70 μm removed in 10 minutes

30 A (100 cm2 → 1.3 GHz ~ 300 A)

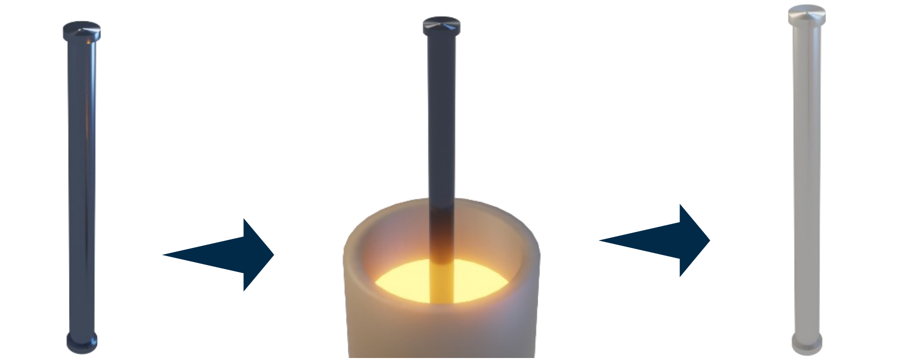
Nb_3Sn coatings: target production



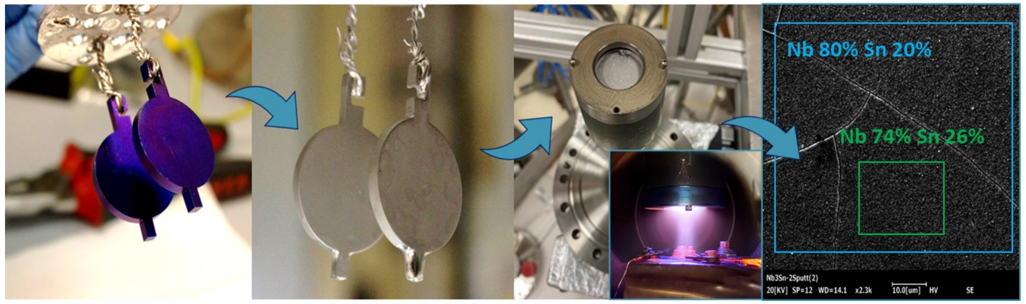
Single target configuration easiest to scale onto elliptical geometry

Nb_3Sn cylindrical target are not commercially available

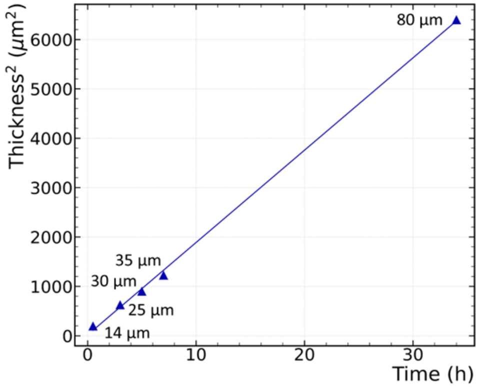
LNL Strategy for Nb_3Sn cylindrical target production for 6 GHz cavities



Raw Nb target → ***Dipping in liquid Sn*** → *Nb_3Sn cylindrical target*



Proof of concept



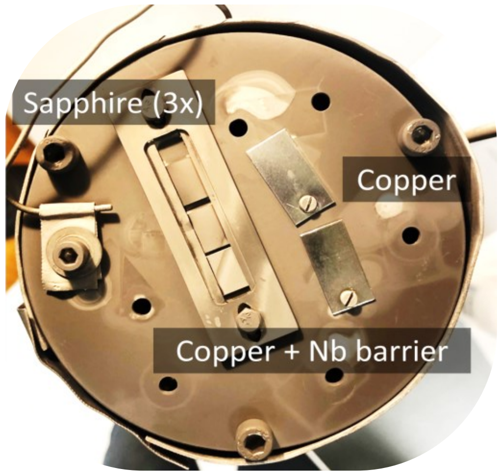
Nb_3Sn **thickness** related to **dipping time**

Possible **tin content modulation**

Nb_3Sn coatings

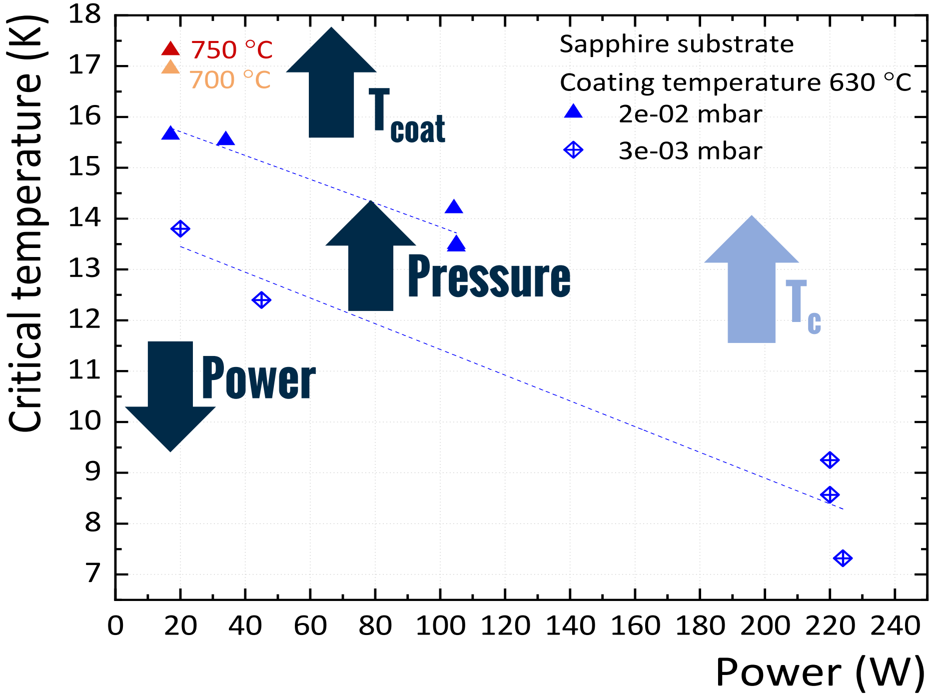
Sputtering parameter optimization

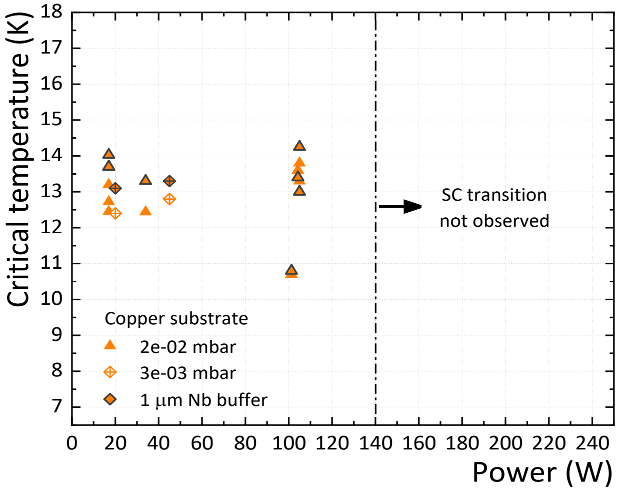
Nb_3Sn deposited via DCMS from 4’’ planar **stoichiometric target** in Ar atmosphere → **Single target configuration easiest to scale onto elliptical geometry**



In the same run different substrates are coated in the same conditions

Tc clear trends visible on Sapphire



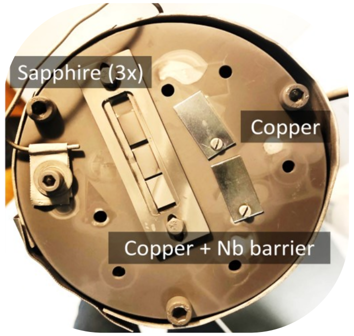


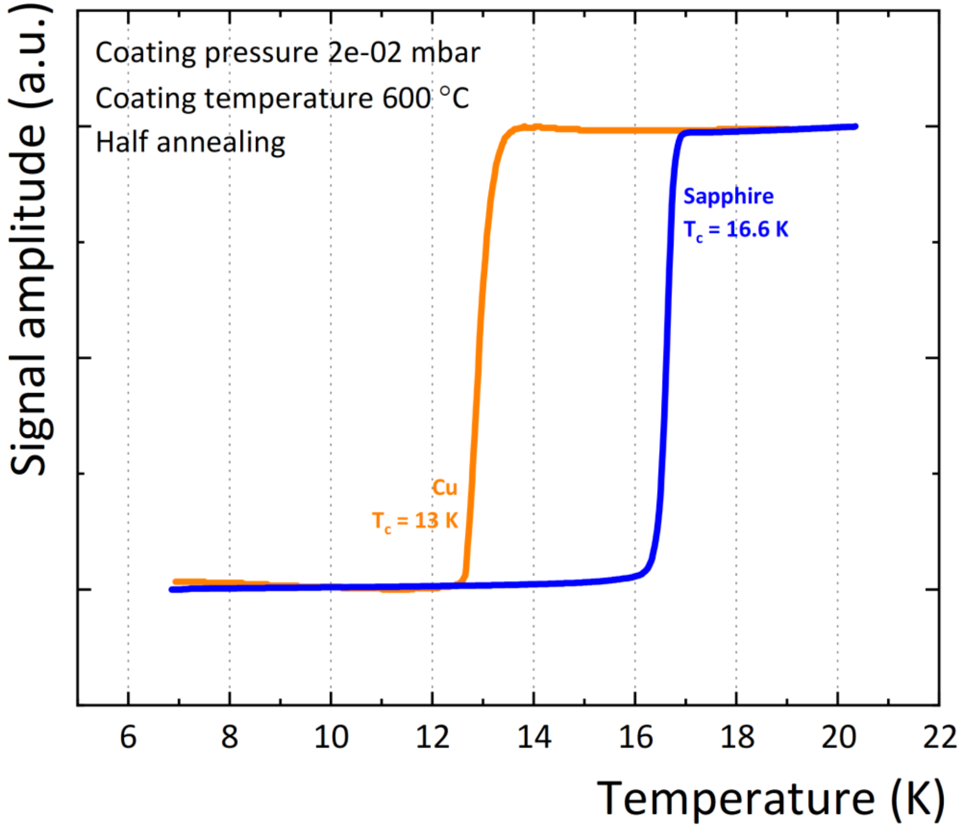
Nb_3Sn Tc stucks at 14 K on Cu

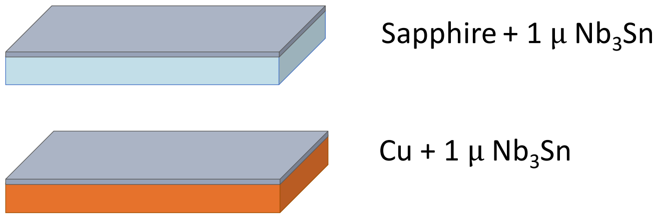
Interface effect

Nb_3Sn coatings

Sputtering parameter optimization

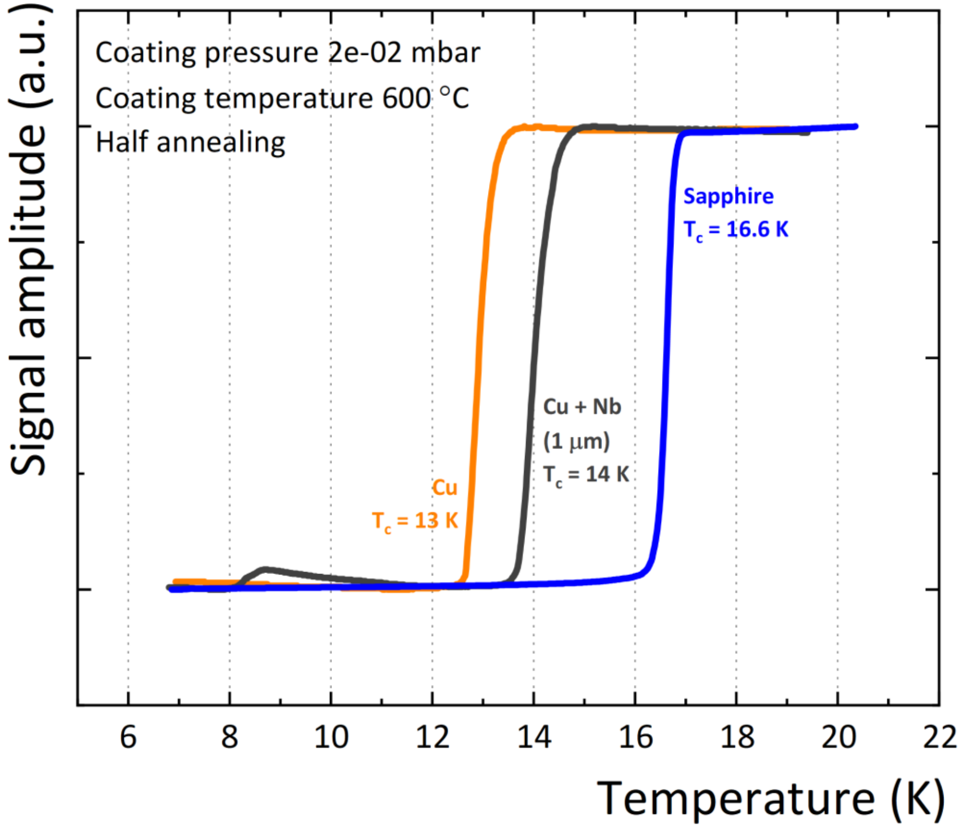


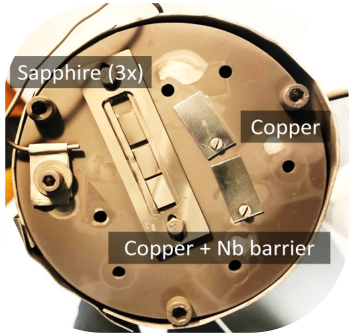


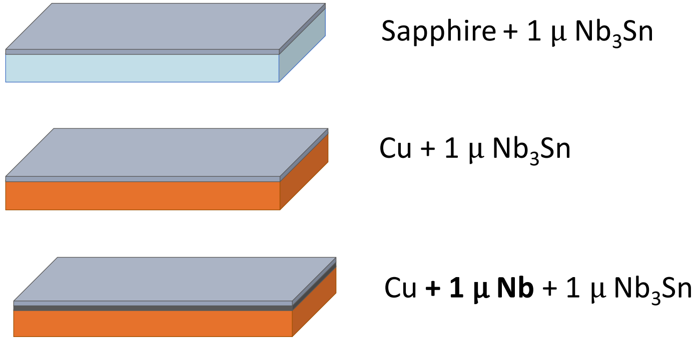


Nb_3Sn coatings

Sputtering parameter optimization

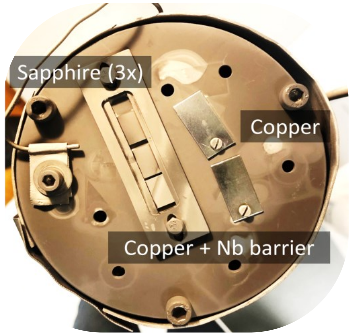


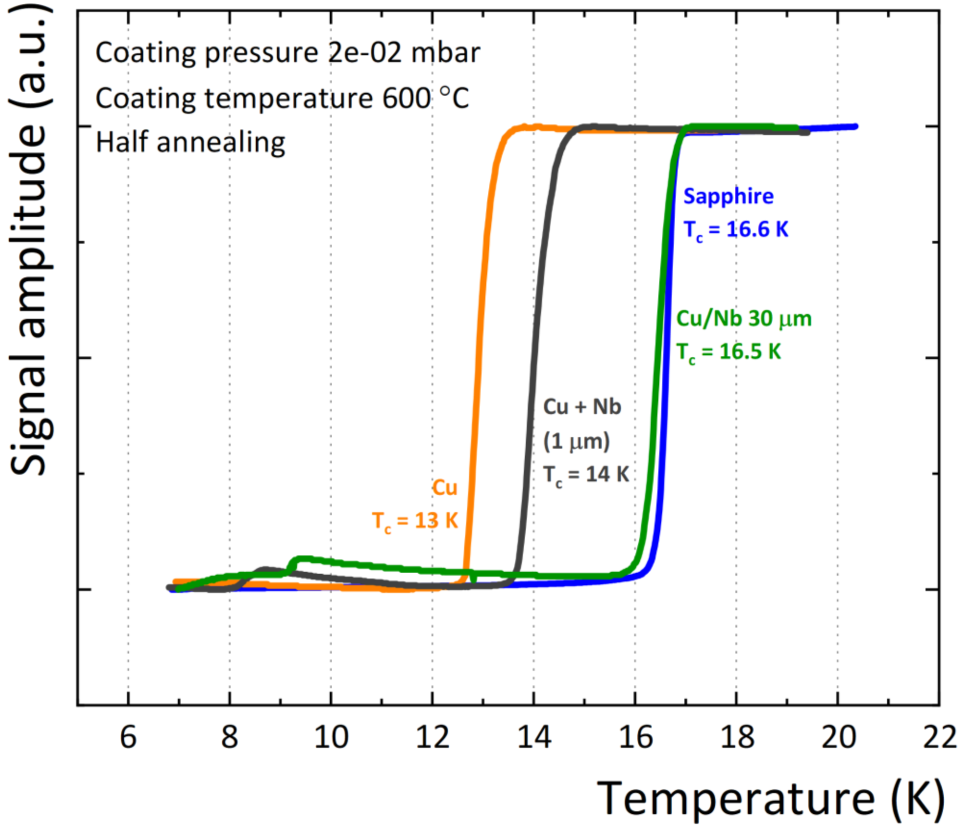


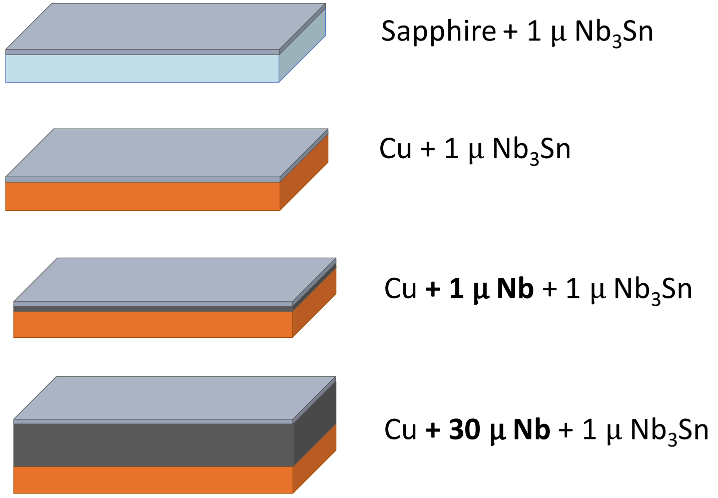


Nb_3Sn coatings

Sputtering parameter optimization





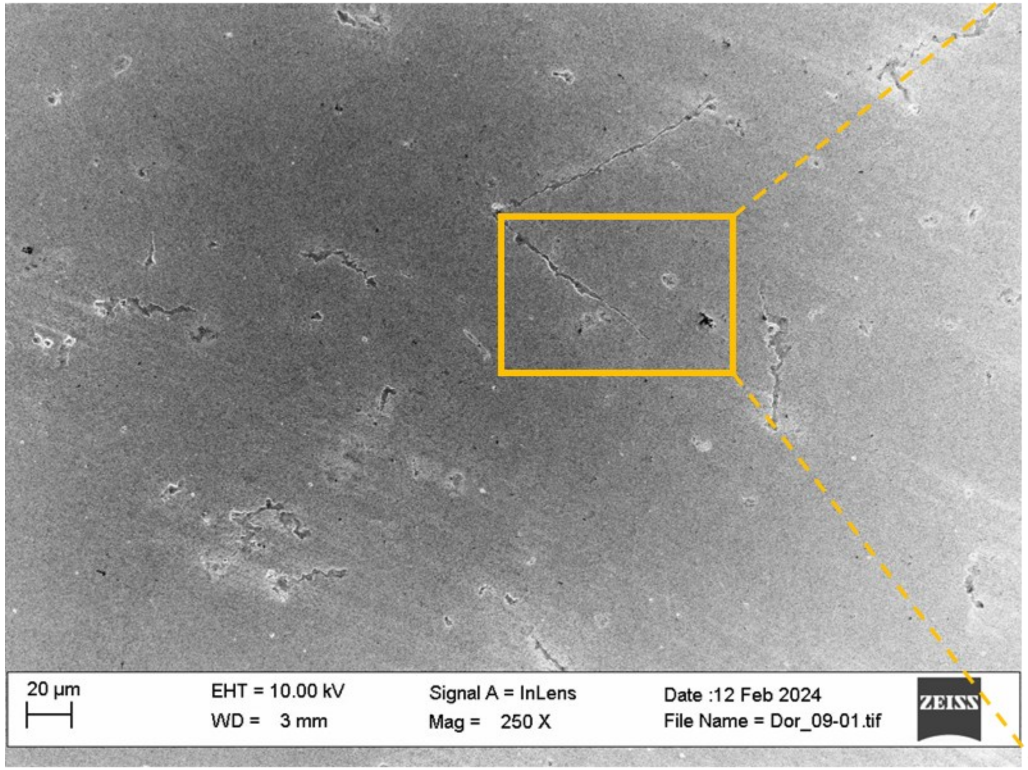


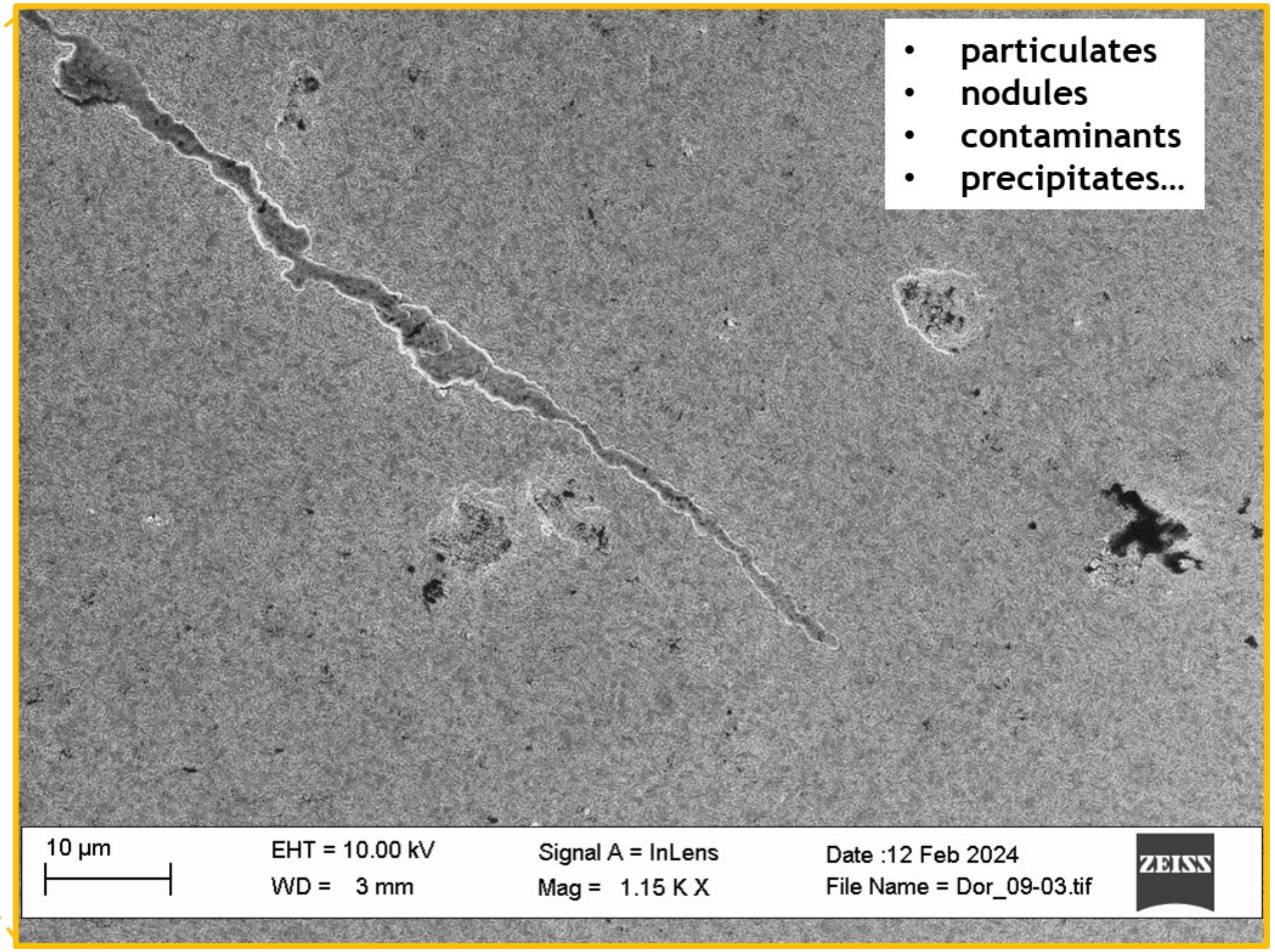
A very thick Nb layer enhance Tc close to Nb_3Sn nominal values

T_c = 17.3 ± 0.25 K
on Cu+50 um BL @T_{dep}=600 °C

Barrier or accommodation effect?

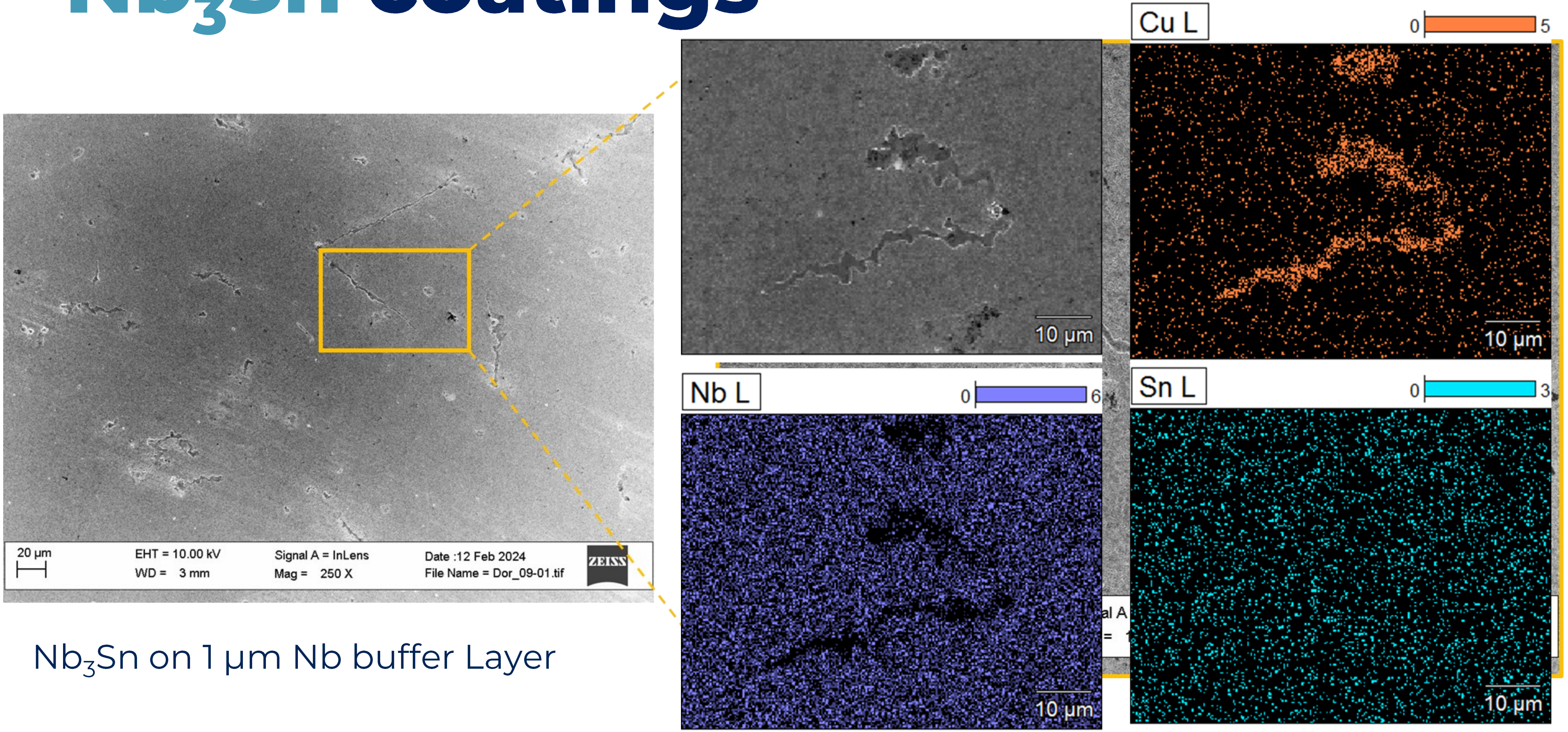
Nb_3Sn coatings





Nb_3Sn on 1 µm Nb buffer Layer

Nb_3Sn coatings

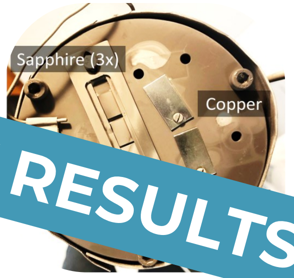


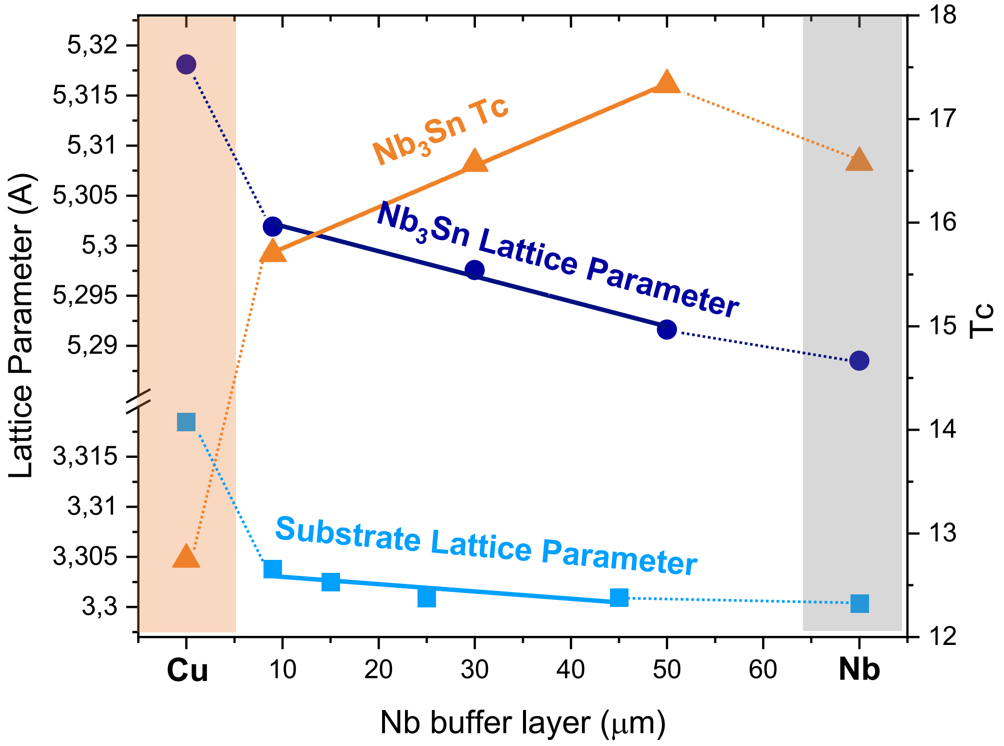
Nb_3Sn on 1 µm Nb buffer Layer

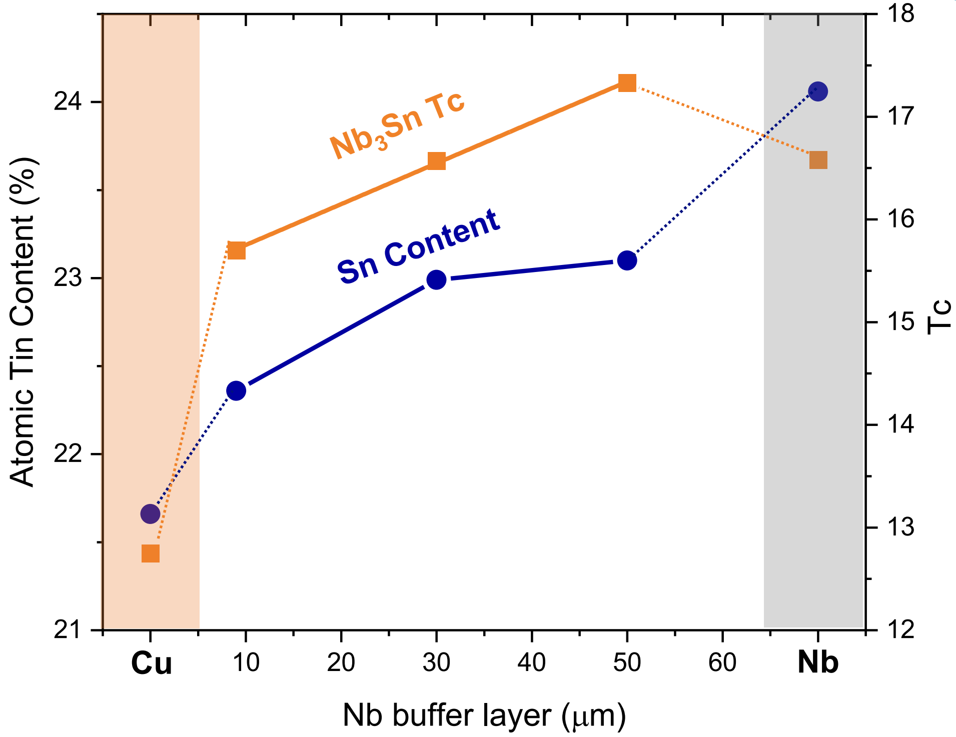
Nb_3Sn coatings

Sputtering parameter optimization

PRELIMINARY RESULTS







The role of the thick Nb layer is to accommodate the Nb_3Sn lattice parameter

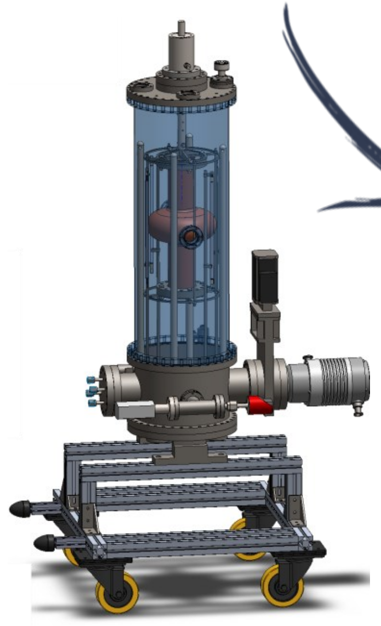
Nb_3Sn coatings

Path to final prototype

Nb_3Sn on bulk Nb to validate coating performances

Develop Nb thick coating *on 1.3 GHz Elliptical Cavities*

Nb_3Sn on Cu with thick Nb coating *on 1.3 GHz Elliptical Cavities*

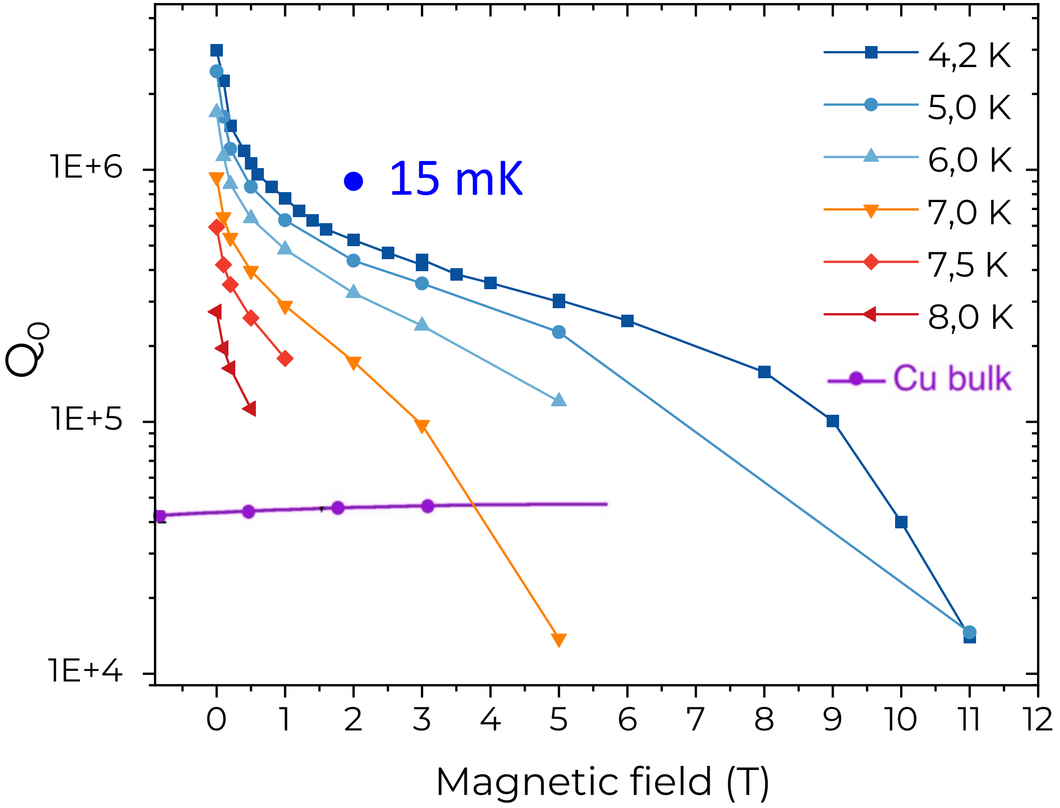


1.3 GHz coating system

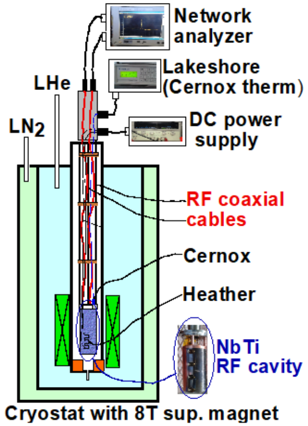
RF test on QPR ongoing @ HZB

Quantum Sensing

NbTi Hybrid Haloscope



- **$Q_0 \approx Q_0$ simulation** → limited by Cu cones
- **$Q_{0\ NbTi}$ > 20 * $Q_{0\ Cu}$** @ 15 mK, 2T
- **$Q_{0\ NbTi}$ > 10 * $Q_{0\ Cu}$** @ 4K, 5T
- **$Q_{0\ NbTi}$ > $Q_{0\ Cu}$** up to 9 T @ 4K



Next Step: Nb_3Sn