STATUS OF SUPERCONDUCTING THIN FILMS ON HIGHER ORDER MODE ANTENNAS FOR MESA

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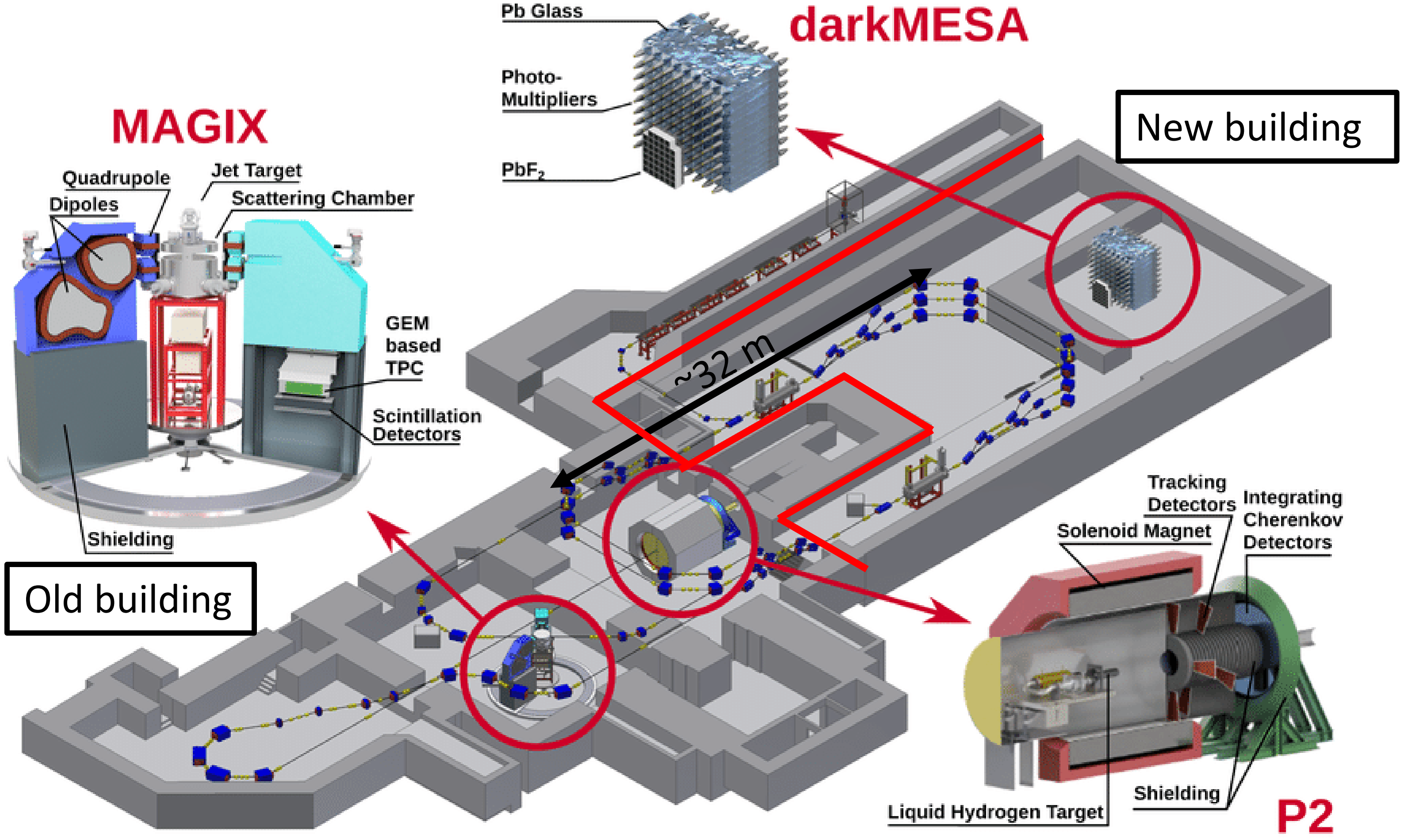
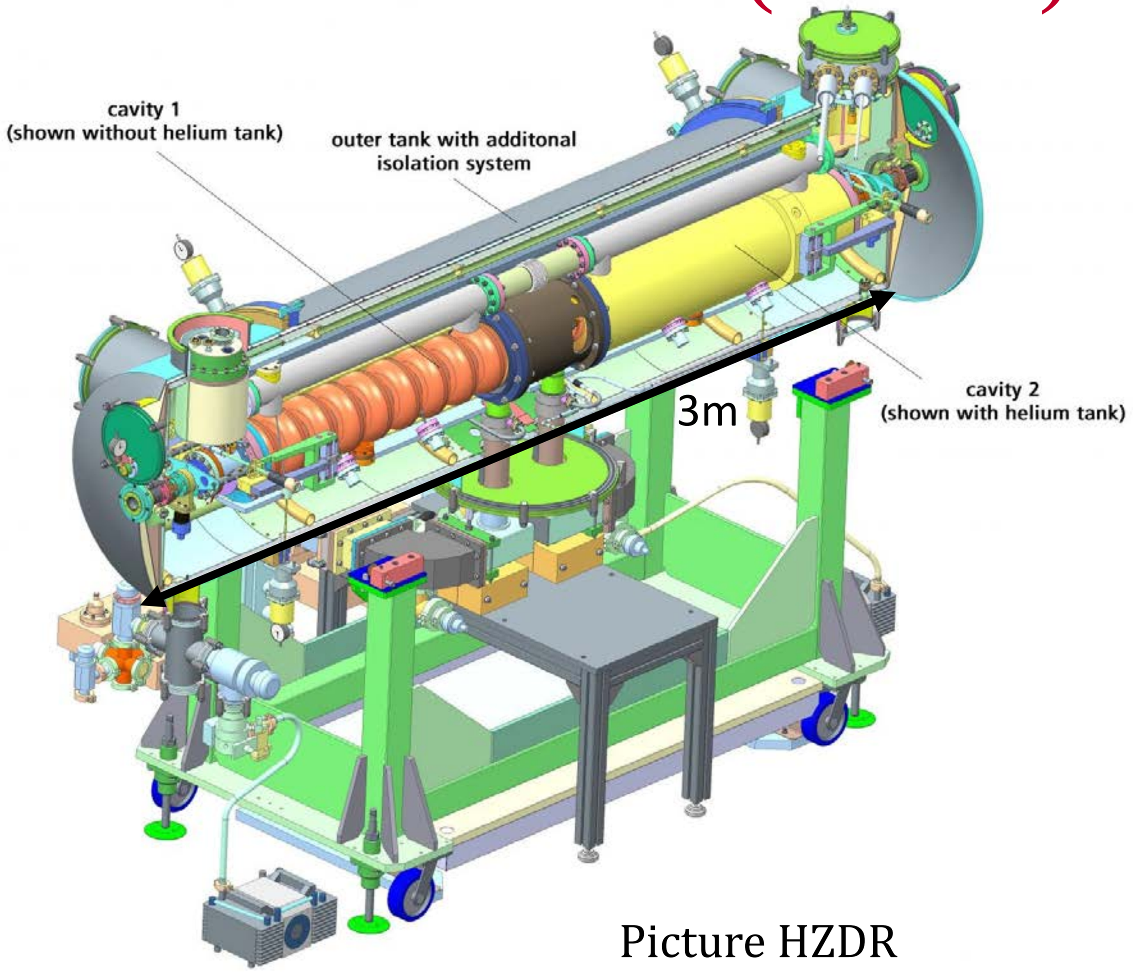
MAINZ ENERGY-RECOVERING SUPERCONDUCTING ACCELERATOR

Injector NC	5 MeV
Cryomodules SC	25 MeV
EB-mode P2	155 MeV @150 µA (pol.)
ER-mode MAGIX	105 MeV @ 1 (10) mA
Q_0	$1.25 \ast 10^{10}$
f	1.3 GHz

Talk from T. Stengler (TUO05)



MESA ENHANCED ELBE-TYPE CRYOMODULES (MEEC)



Picture HZDR

2 Cryomodule of the „Rossendorf"-type (2x 9-Cell TESLA/XFEL cavities) fabricated by Research Instruments (RI)

Specific modification for MESA:

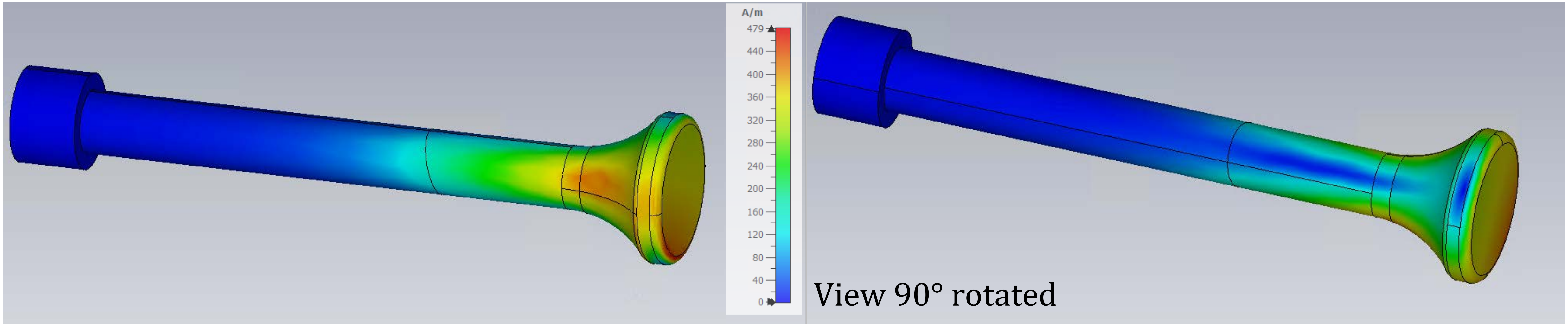
- Piezo tuner (XFEL/Saclay)
- Sapphire ceramic for HOM-antenna
- Optimized cooling of HOM RF-cable
- Modified LHe-port for the Joule-Thomson valve

→ Two MESA Cryomodules are onsite and tested
→ ALICE Module (spare/testing)*
→ Further optimisation for beam current at 10 mA

*We would like to thank STFC Daresbury for their generous gift.

MAGNETIC FIELD AT ANTENNA

$H_{max,T} = 1\%\ H_{peak}$
$E_{acc} = 12.5\ \frac{MeV}{m}$



Maximum of magnetic field at antenna $H_{max,T} = 0.53\ mT$
Field distribution: maximum at the tip of the antenna
Field maxima of HOMs not at tip and $H_{max,HOM} < H_{max,T}$

$$H_{max,HOM}/H_{max,T} \approx 0.001 \text{ for strongest dipole mode}$$

POWER LOSS AT ANTENNA TIP

Material	Nb
T_C / K	9.27
F / GHz	1.3
λ_L / nm	39
ξ / nm [1]	380
$\Delta_{reduced}$ [2]	1.5

[1] all values are multiplied by $\frac{\pi}{2}$

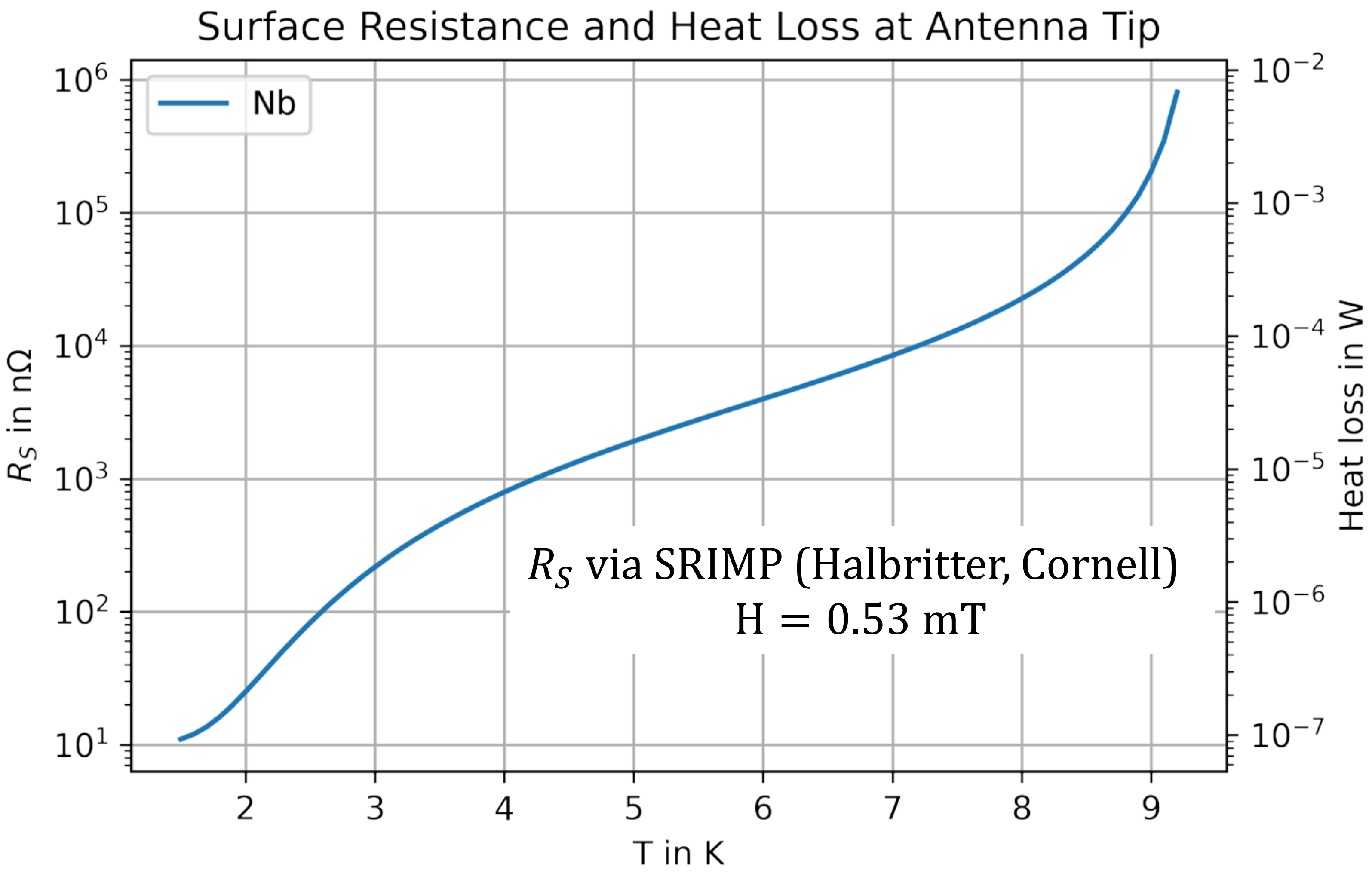
[2] all values are multiplied by $\frac{1.60218 * 10^{-22}}{k_B * T_{C,i}}$

Heat loss at the antenna can be calculated via R_S:

$$P_{loss} = \frac{1}{2} R_S \int |H|^2 ds$$

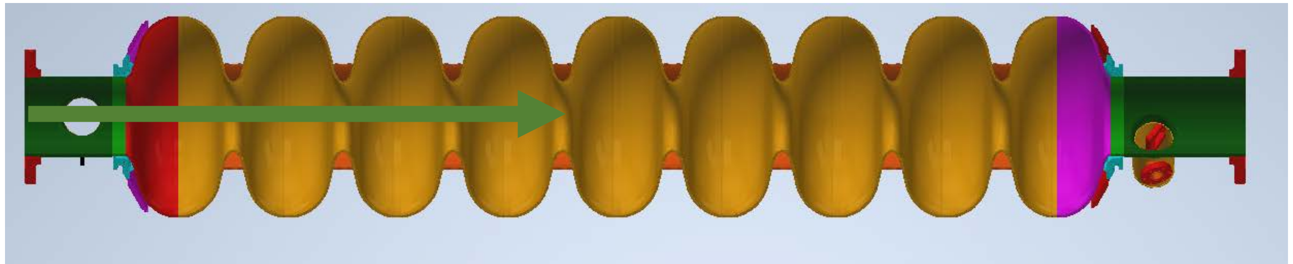
Dominated by 1.3 GHz

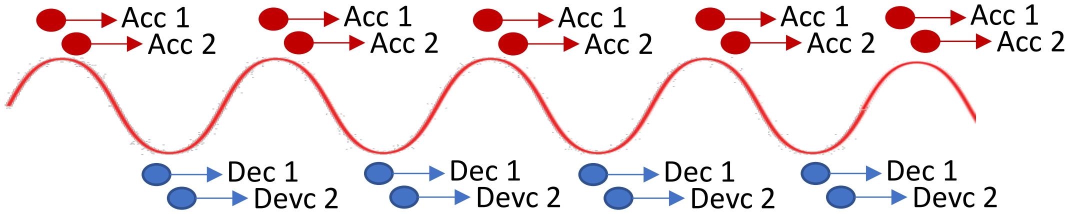
Beam-cavity interaction neglected!



HIGHER ORDER MODES - BEAM INDUCED HOMS

In ERL-mode: 4 e- beams simultanious
(2x accelerating; 2x decelerating)





Simulated Beam Blow Up limit: **12 mA** (C. Stoll, Phd. Thesis, 2020 Mainz)

Calculated thermal power limit: **95 mW (~3.2 mA)** (T. Stengler, Phd Thesis, 2020 Mainz)

Power stored in HOMs (longitudinal):

$$P_{HOM} = N * q * k * I$$

N: #beams; q: bunch charge; k: loss factor; I: average beam current

→ 30% of P_{HOM} at HOM antenna tip

L. Merminga, D.R. Douglas, and G.A. Krafft. High-current energyrecovering electron Linacs. Annual Review of Nuclear and Particle Science, 53(1):387–429, 2003.

I [mA]	q [pC]	P_{HOM} [mW]	P_{Tip} [mW]
1	0.7	30.8	10
10	7.7	3080	1000

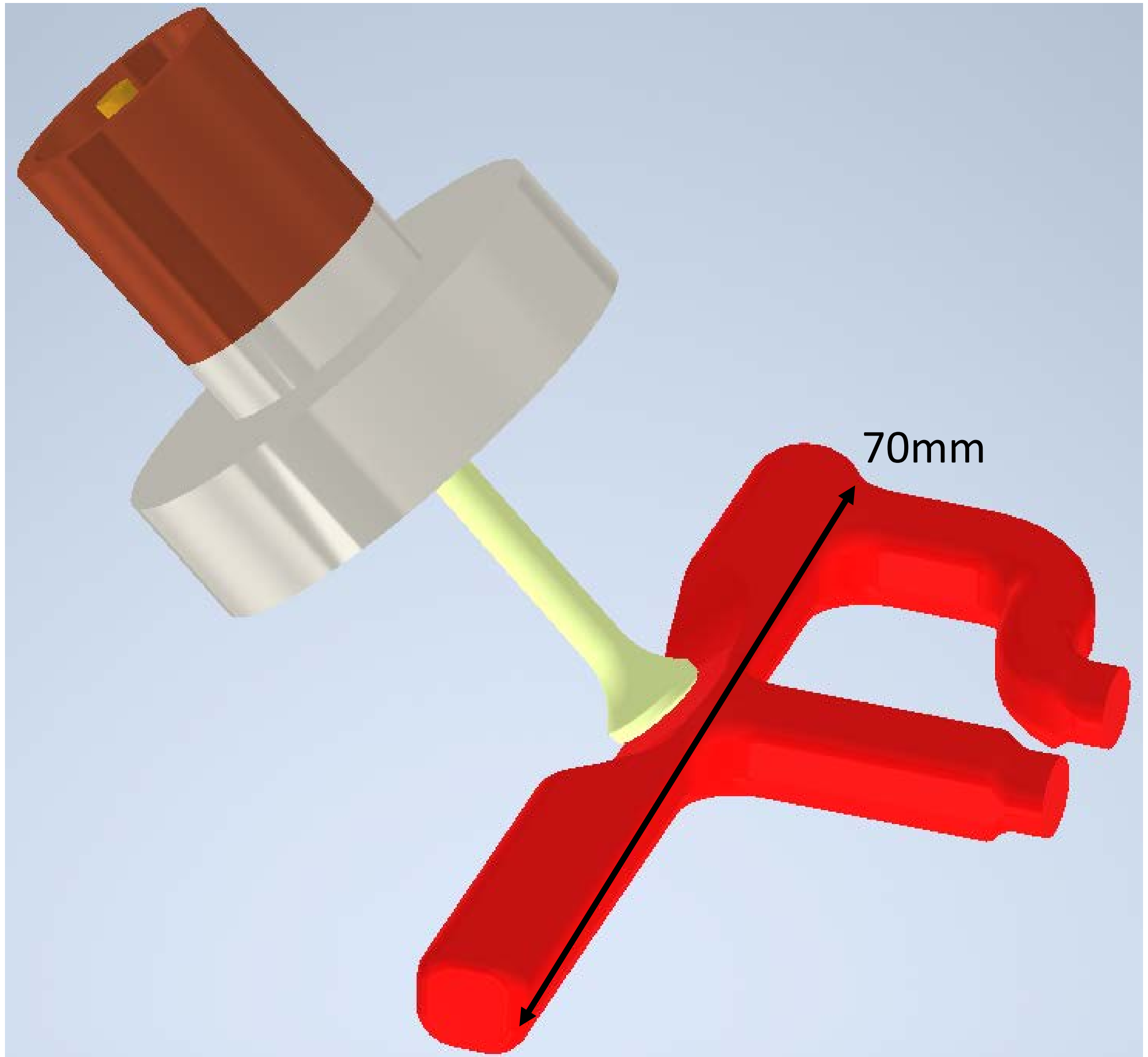
HIGHER ORDER MODES – GEOMETRICAL BOUNDARIES

How to handle 1000 mW?

- Geometrical design of HOM antenna and F-part cannot be changed

→ Minimal invasive change:

- Change the surface material to a higher T_C superconductor



SC THIN FILMS

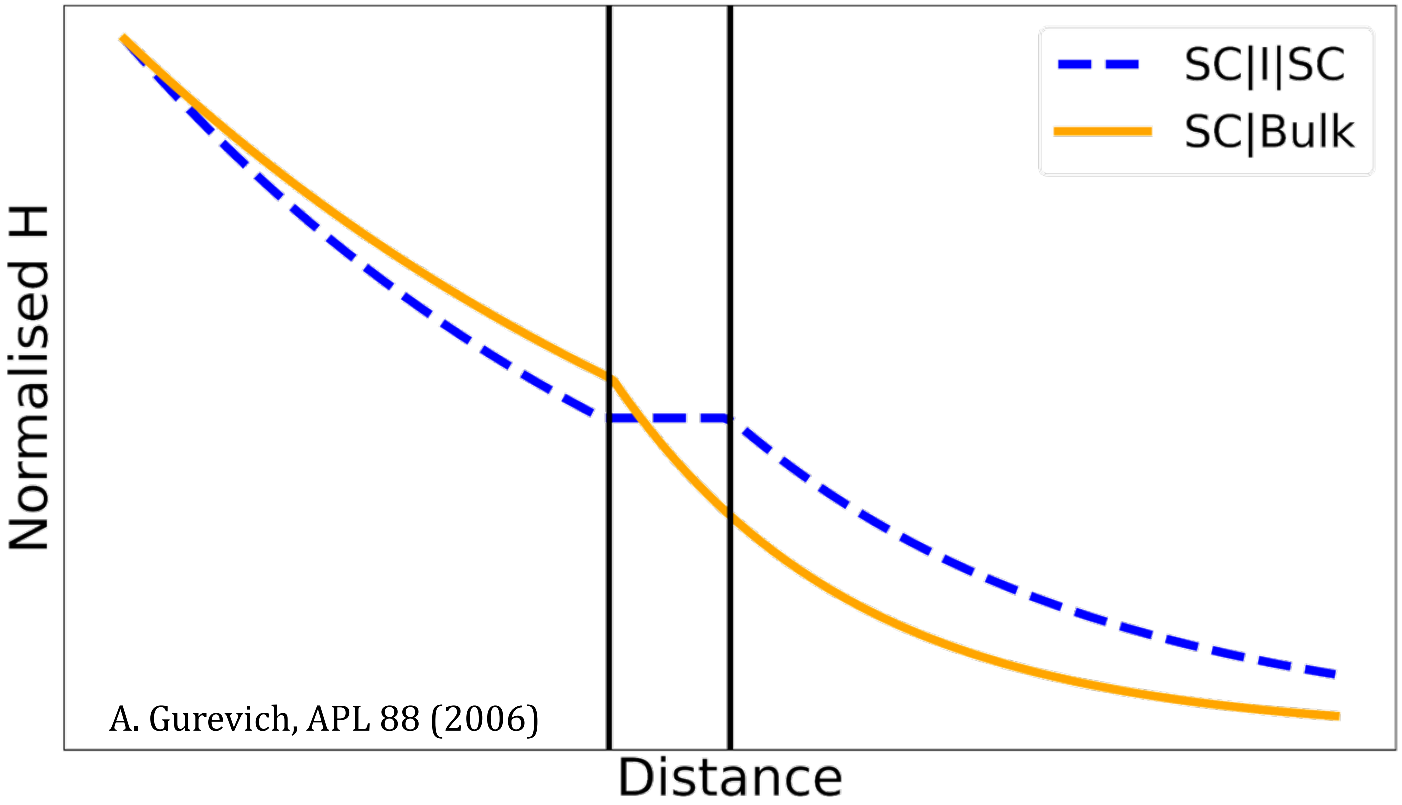
Thin Film Nb$_3$Sn (d > λ_L)

Bulk OFHC-Cu (region mm)

Thin Film NbTiN (d < λ_L)

Insulator AlN (15 nm)

Bulk Nb (region mm)



Decision for HOM antenna:

- Coating on Nb and OFHC Cu substrates
- Complex multilayer structure not necessary (no high field region)

SC	T_C / K	λ_L / nm
Nb	9.2	39
NbTiN	17.3	150-200
Nb$_3$Sn	18.3	80-100

A–M Valente–Feliciano 2016 *Supercond. Sci. Technol.* **29** 113002 **DOI** 10.1088/0953–2048/29/11/113002

POWER LOSS AT ANTENNA TIP

Material	Nb	NbTiN	Nb_3Sn
T_C / K	9.27	17.3	18
F / GHz	1.3	1.3	1.3
λ_L / nm	39	240	90
ξ / nm [1]	380	50	70
$\Delta_{reduced}$ [2]	1.5	2.8	3.1

[1] all values are multiplied by $\frac{\pi}{2}$
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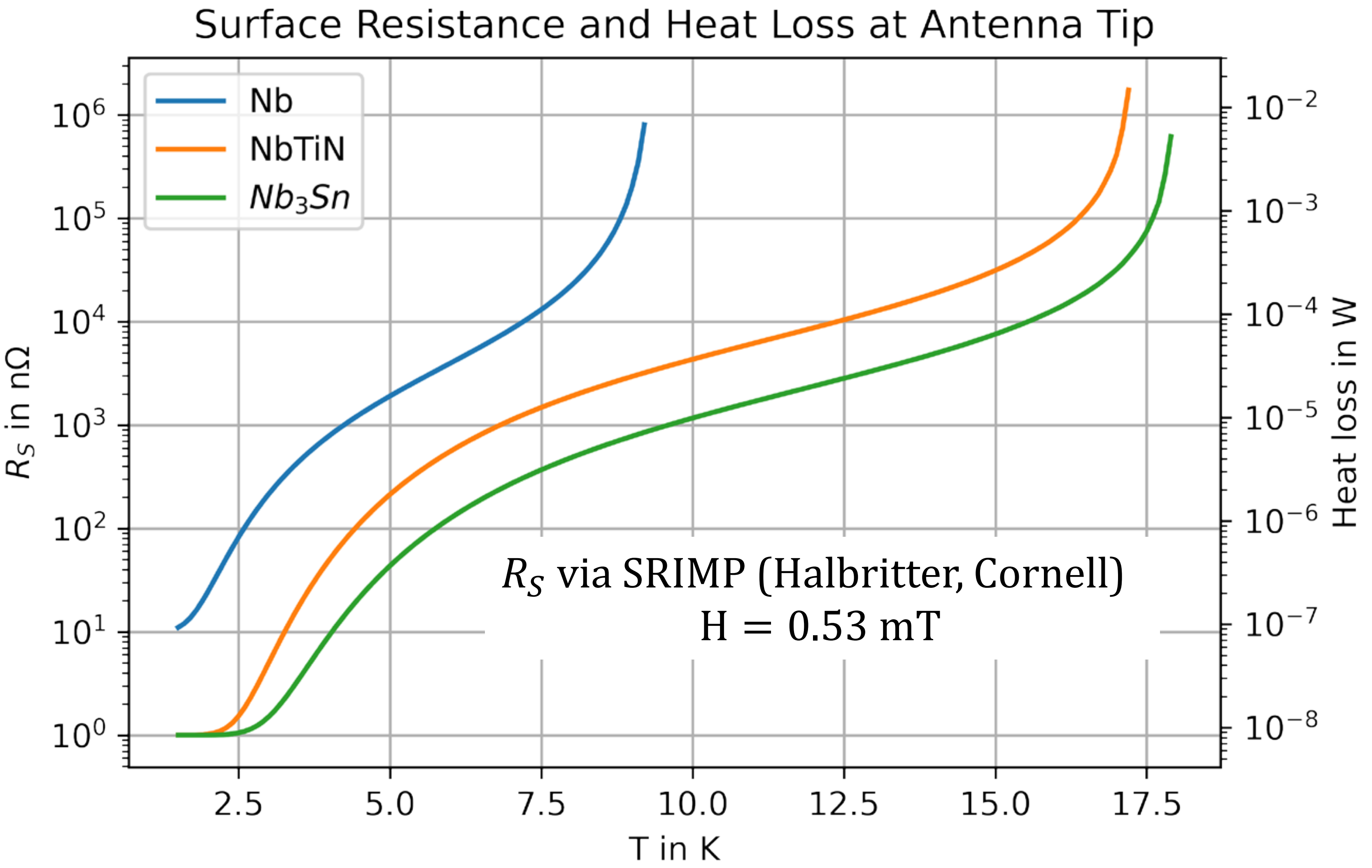
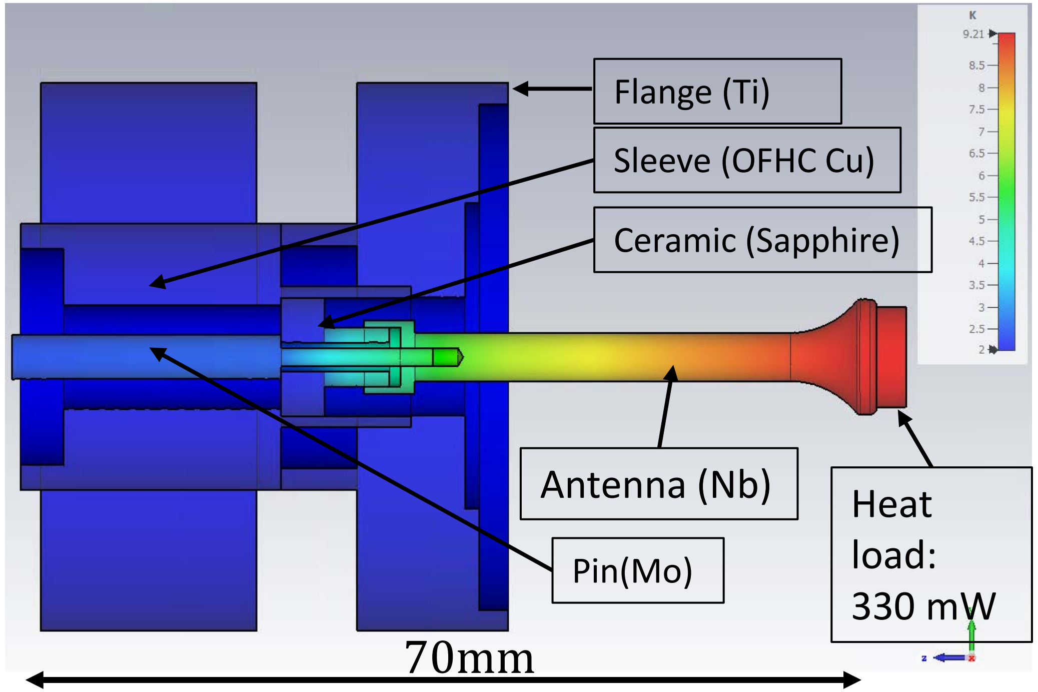
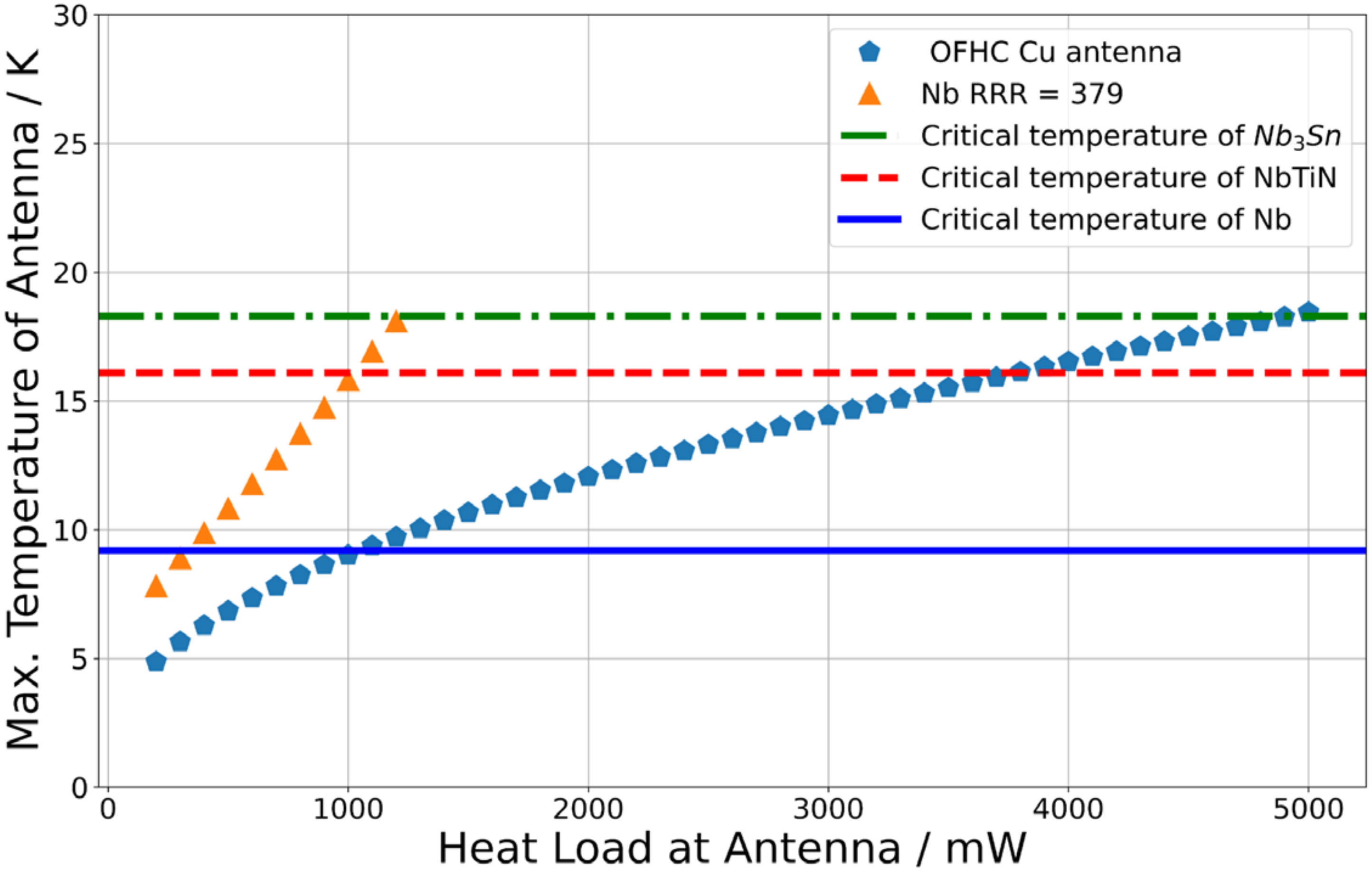
Dominated by 1.3 GHz
Beam-cavity interaction neglected!



CST RESULTS





Thermal properties are dominated by the bulk material (Nb, Cu)

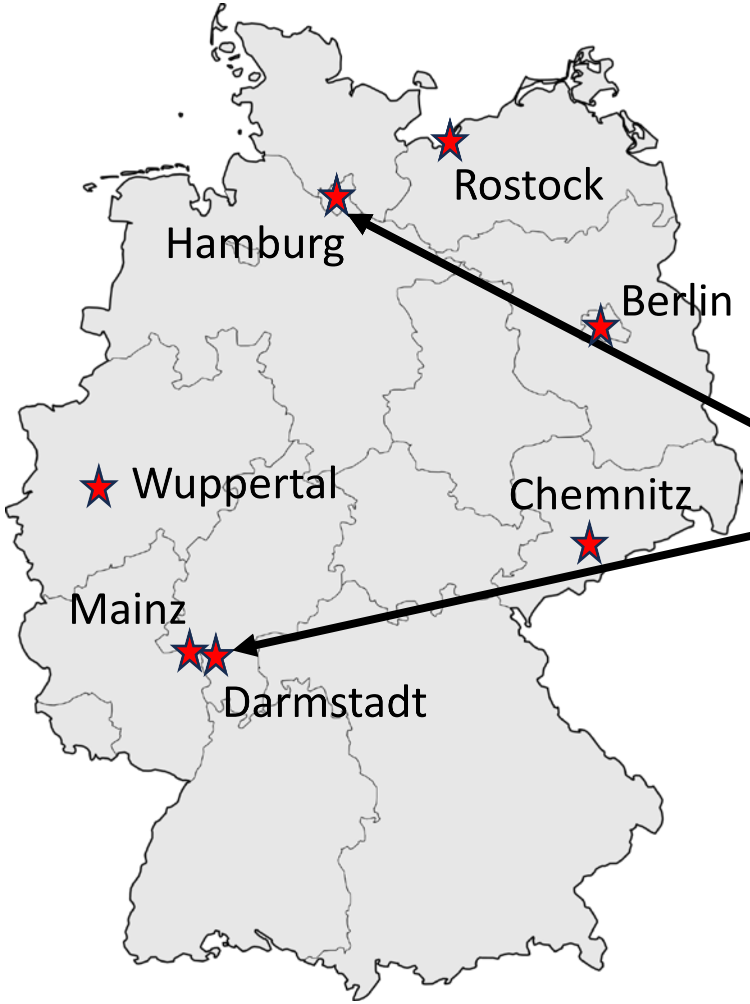
Nb antenna:

- $T_{antenna}(\sim 1000mW(\approx 10.4\ mA)) = T_{C,NbTiN}$

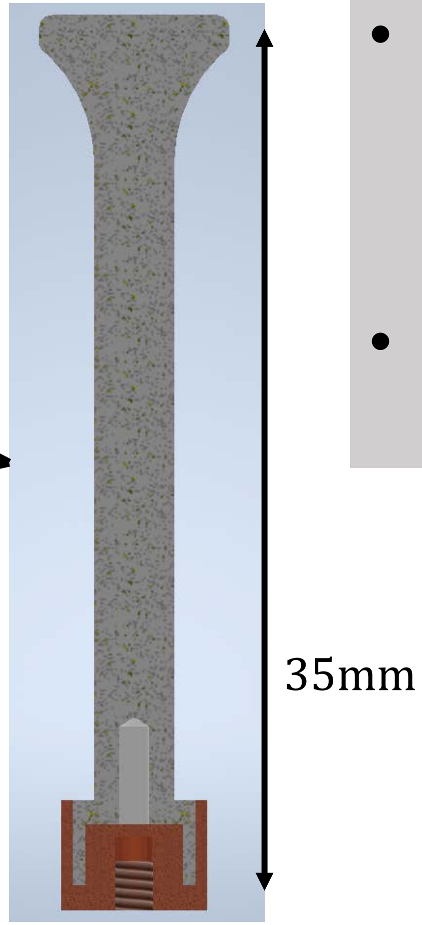
Cu antenna:

- $T_{antenna}(\sim 4700mW(\approx 22.5\ mA)) = T_{Nb_3Sn}$

SC THIN FILMS – TOSCA/SUPER SURFER



https://upload.wikimedia.org/wikipedia/commons/thumb/e/e3/Karte_Deutschland.svg/1513px-Karte_Deutschland.svg.png

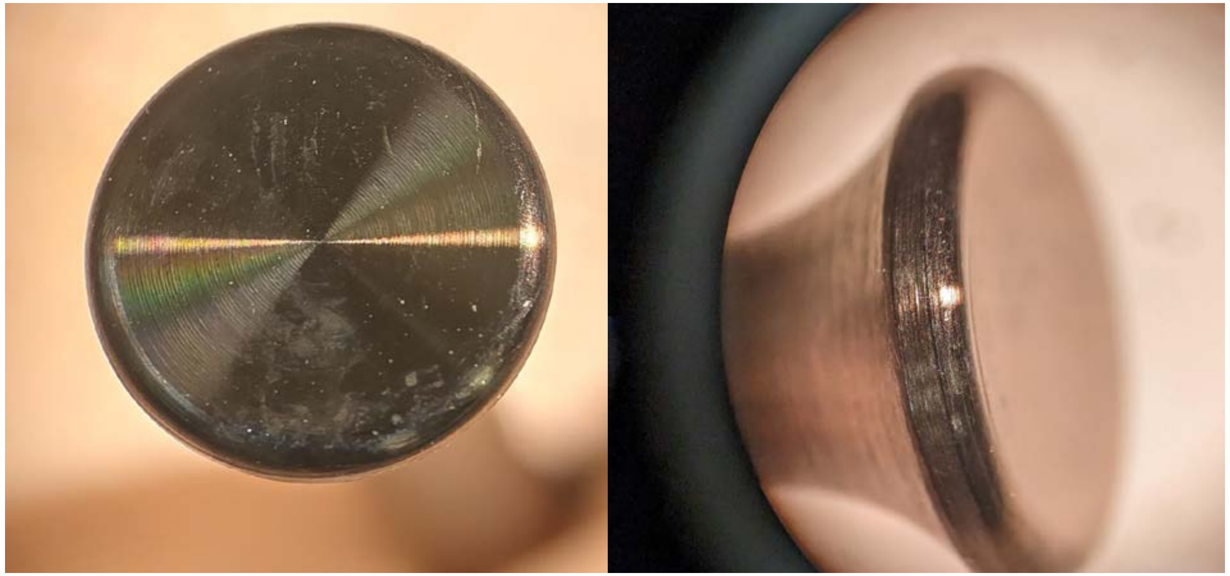


- UHH: NbTiN on Nb (SIS possible) Plasma Enhanced Atomic Layer Deposition (PEALD)
- TUDA: Nb_3Sn on OFHC Cu Co-Sputtering

SC THIN FILMS – NBTIN ON HOM ANTENNA

NbTiN(PEALD) @Hamburg
Substrate: Niobium
Time: 4 days
Thickness: ~50nm (<λ_L)
T_C = 16 K (on flat samples)
Deposition Temperatur < 300°C
→ Slow Thermal Annealing at 900°C

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

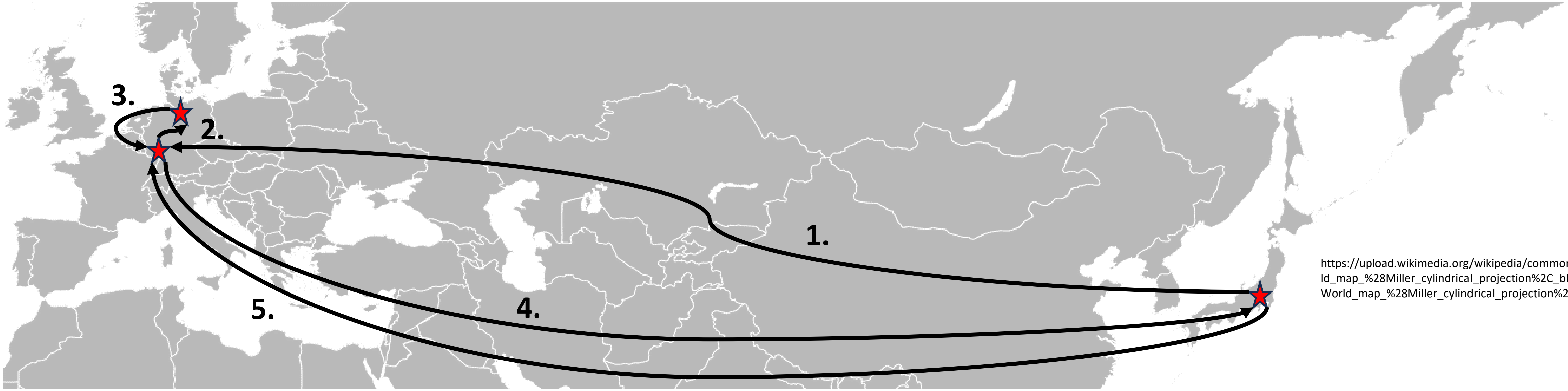


Nb$_3$Sn (Co-Sputtering) @TU Darmstadt
Substrate: Copper
Time: 1 hour
Thickness: ~400nm (≥λ_L)
T_C = ~14 K (on cylindrical substitue)
Deposition Temperatur 520°C

Picture: Amir Fahood

TECHNISCHE UNIVERSITÄT DARMSTADT

THE JORNEY OF A NBTIN COATED ANTENNA



https://upload.wikimedia.org/wikipedia/commons/thumb/5/5d/World_map_%28Miller_cylindrical_projection%2C_blank%29.svg/2560px-World_map_%28Miller_cylindrical_projection%2C_blank%29.svg.png

1. KYOCERA in Japan → Mainz: production of Nb antenna
2. Mainz → UHH: NbTiN coating (currently here!)
3. UHH → Mainz
4. Mainz → KYOCERA for brasing
5. KYOCERA → Mainz for testing in cavities

REFURBISHMENT OF AN ELBE-TYPE CRYOMODYLE

Personal entrance (ISO 6)

Material entrance (ISO 7)

Clean room 1 (ISO 6)

Ultrasonic bath (USB) system

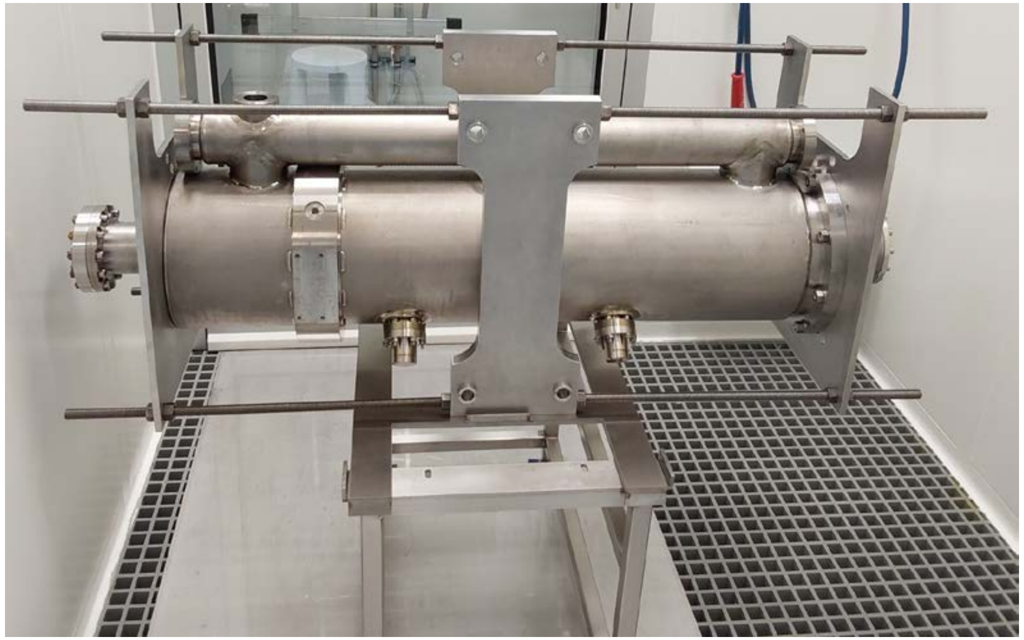
High pressure rinse (HPR)

Personal airlock

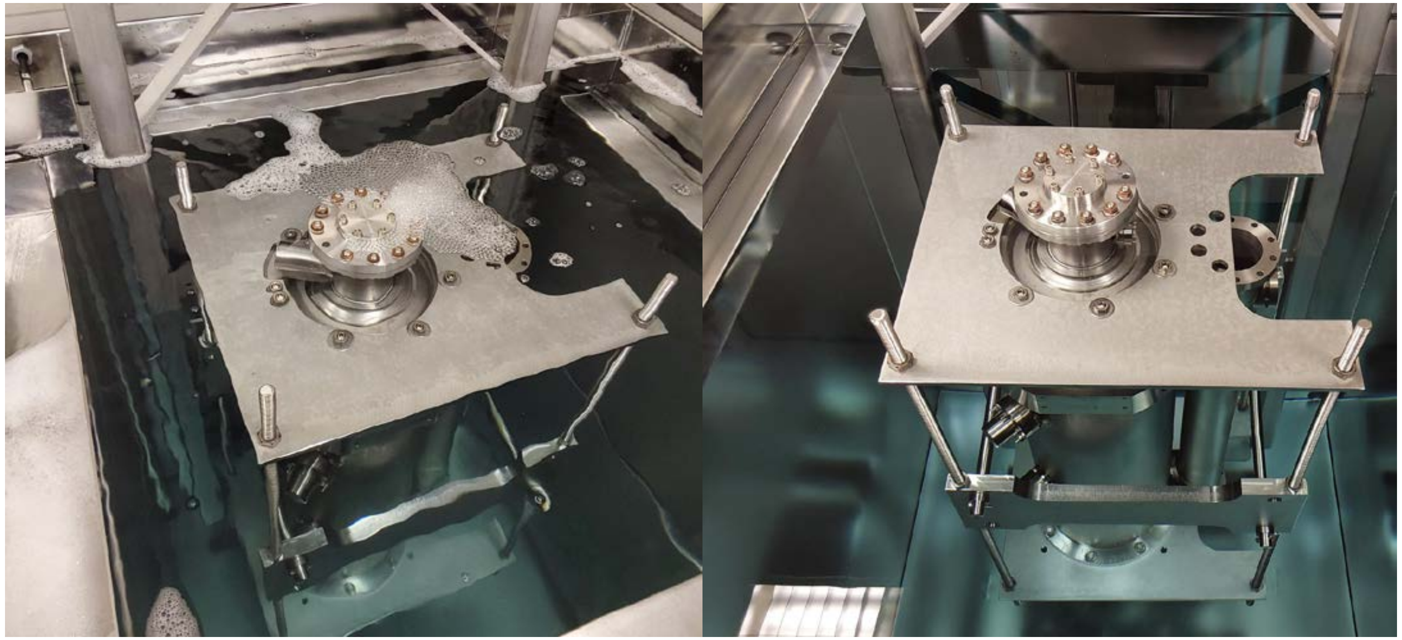
Material gate

Clean room 2 (ISO 4)

REFURBISHMENT OF AN ELBE-TYPE CRYOMODYLE



Material entrance



Ultrasonic bath (USB) system:

- 30 min USB with Tickopur R33
- Rinsing with ultrapure water < 0.18 µS

REFURBISHMENT OF AN ELBE-TYPE CRYOMODYLE

HPR: (TESLA recipe)
each cell rinsed for 5 min (18x)

Drying for ~24 hour after HPR

Next steps:

- Installing accessories
- Vacuum with RGA
- Cold test at ATMF (basline)

- 2nd cold test with coated HOM antennas 2025
- Assembling of the CM
- Test CM with e- beam (2026)

SUMMARY & OUTLOOK

<u>Summary:</u>

- Beam induced HOM power will exceed the power limit of the HOM antennas with the 10 mA upgrade at MESA

$$P_{HOM,B} = 1000\,mW > P_{MESA,lim} = 95\,mW$$

- SC Thin Films of NbTiN and Nb_3Sn will **increase the limit**

SUMMARY & OUTLOOK

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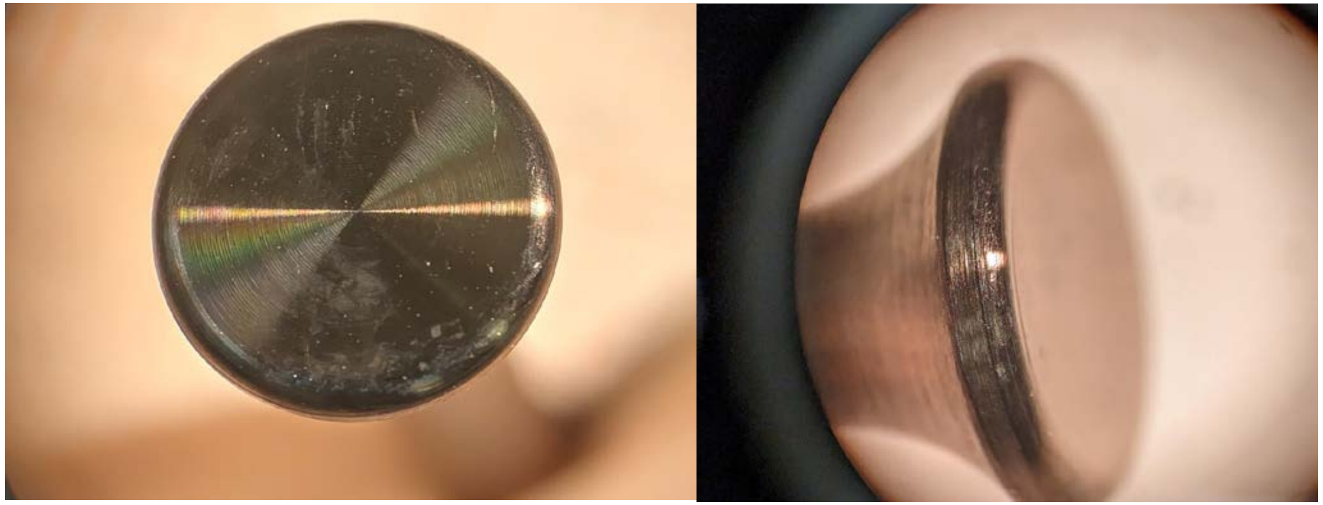
- SC Thin Films of NbTiN and Nb_3Sn will **increase the limit**

Outlook:

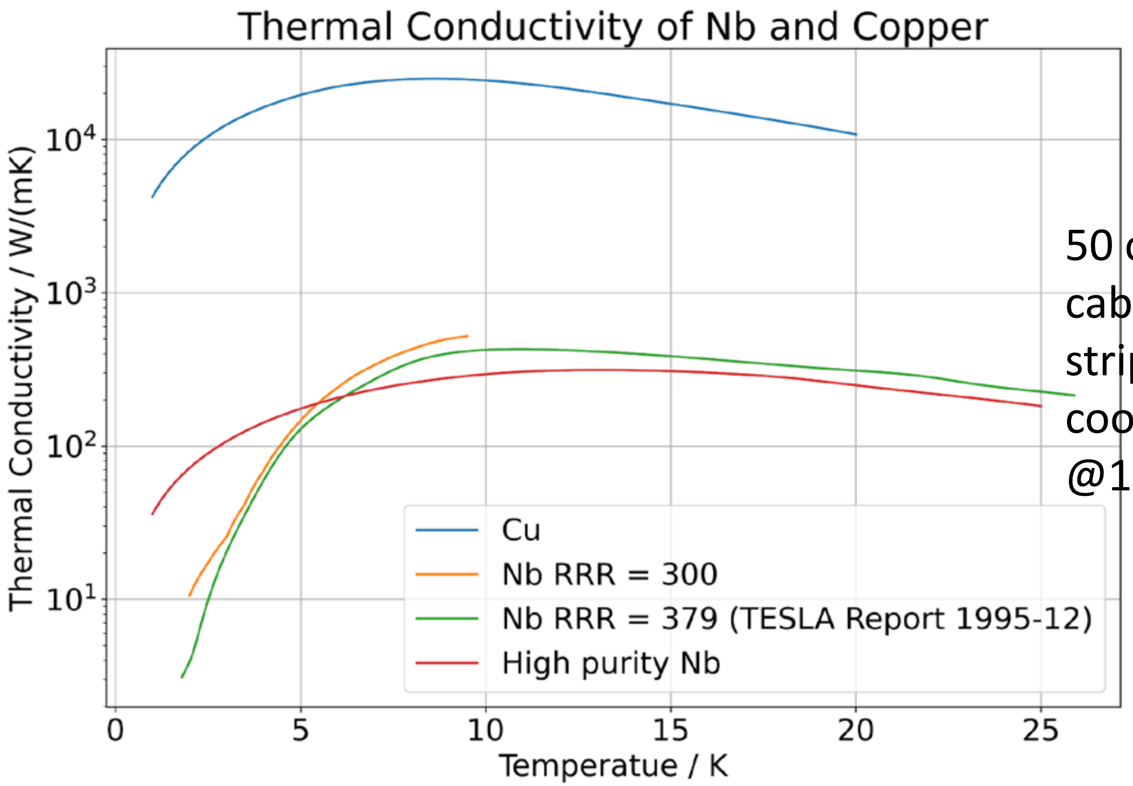
- Refurbishment of 2 9-cell TESLA cavities is ongoing (MESA-ERL-test CM)
- Coating of antennas ongoing
- Cavity performance test via VCT
- CST simulation for HOM heating/ wake field ()



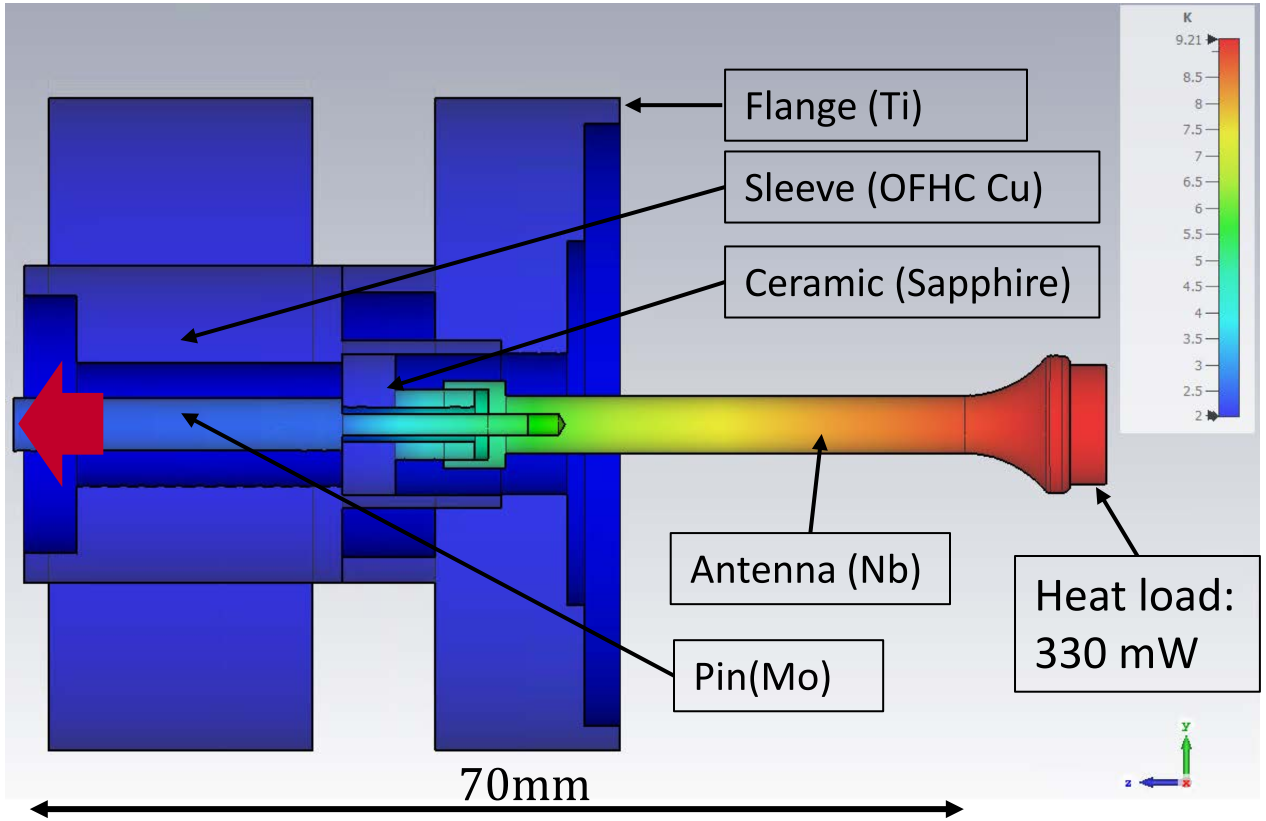
Thank you for your attention!

Work supported by BMBF through 05H21UMRB1.

SC THIN FILMS



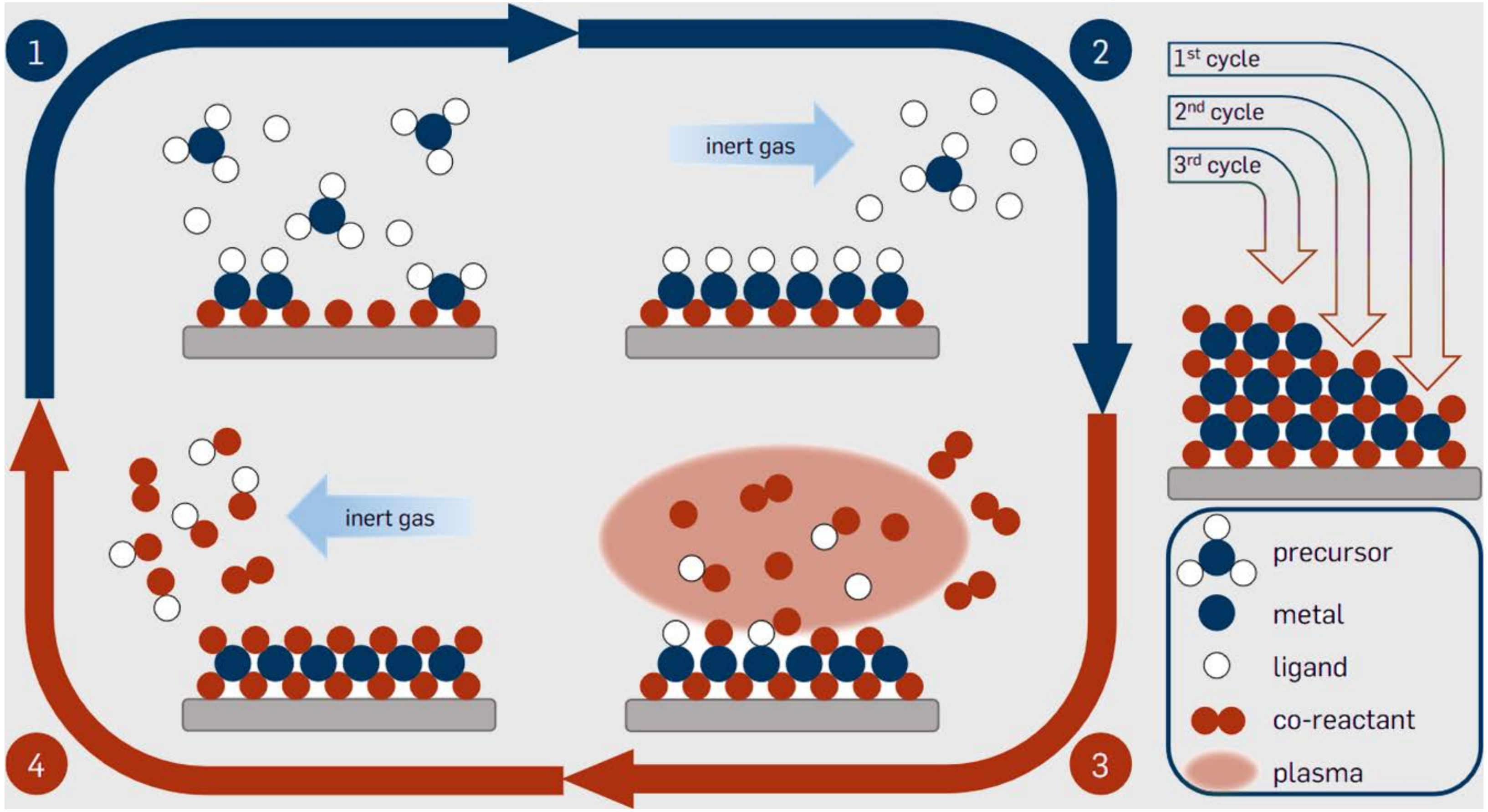
50 cm Cu cable to stripline cooler @1.8K



Material	κ@2K [W/mK]
Nb	70
Cu	8400

Thermal Conductivity of the Elements
C. Y. Ho, R. W. Powell and P. E. Liley
Journal of Physical and Chemical Reference Data 1, 279 (1972);
https://doi.org/10.1063/1.3253100

SC THIN FILMS – PLASMA-ENHANCED ALD (PEALD) NBTIN

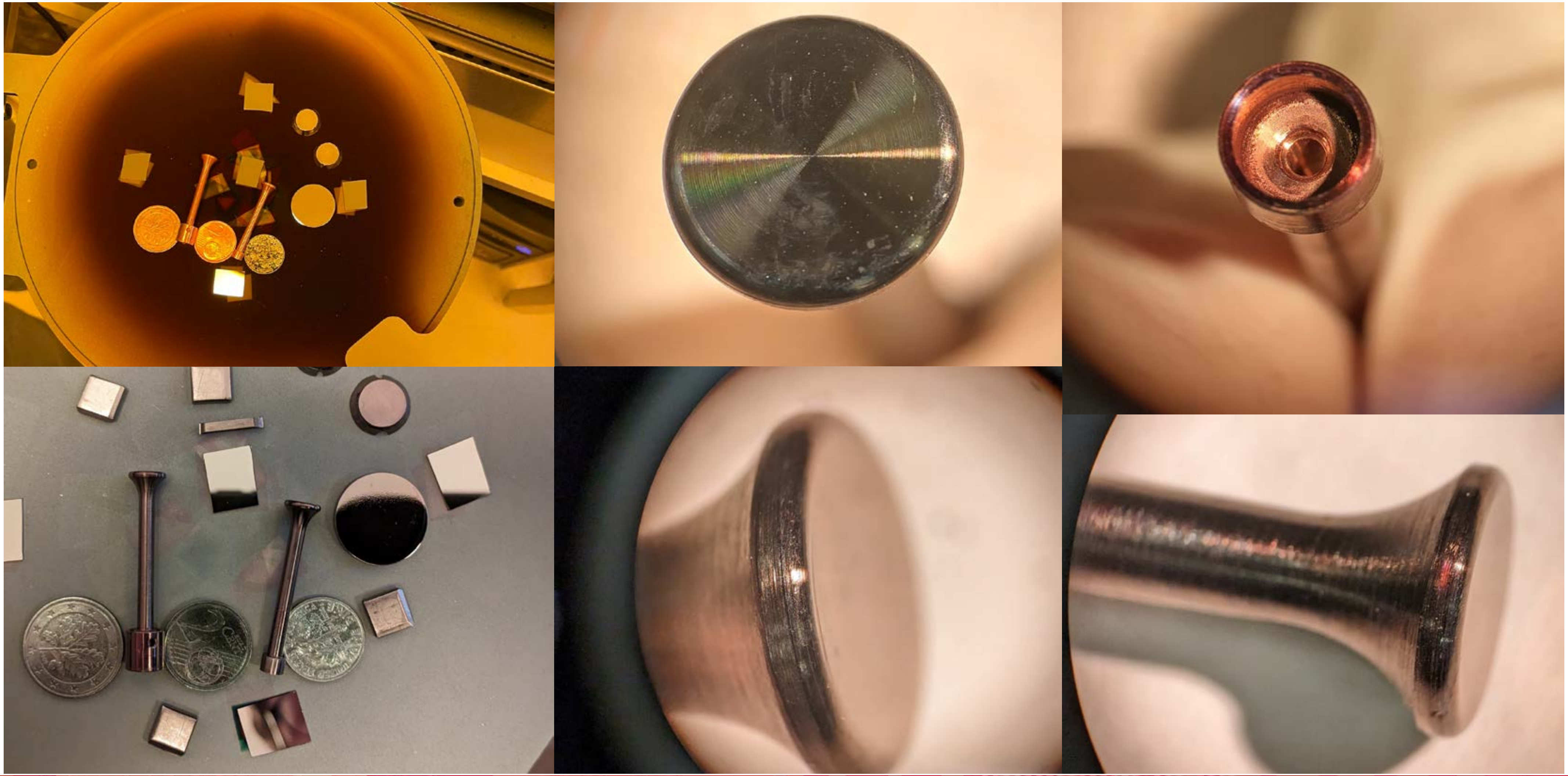


L. Mai, (2020), DOI:10.13154/294-7658.

- lower deposition temperature (<300 °C)
- higher film quality

→ Slow Thermal Annealing (STA) at 900°C

SC THIN FILMS – NBTIN ON HOM ANTENNA



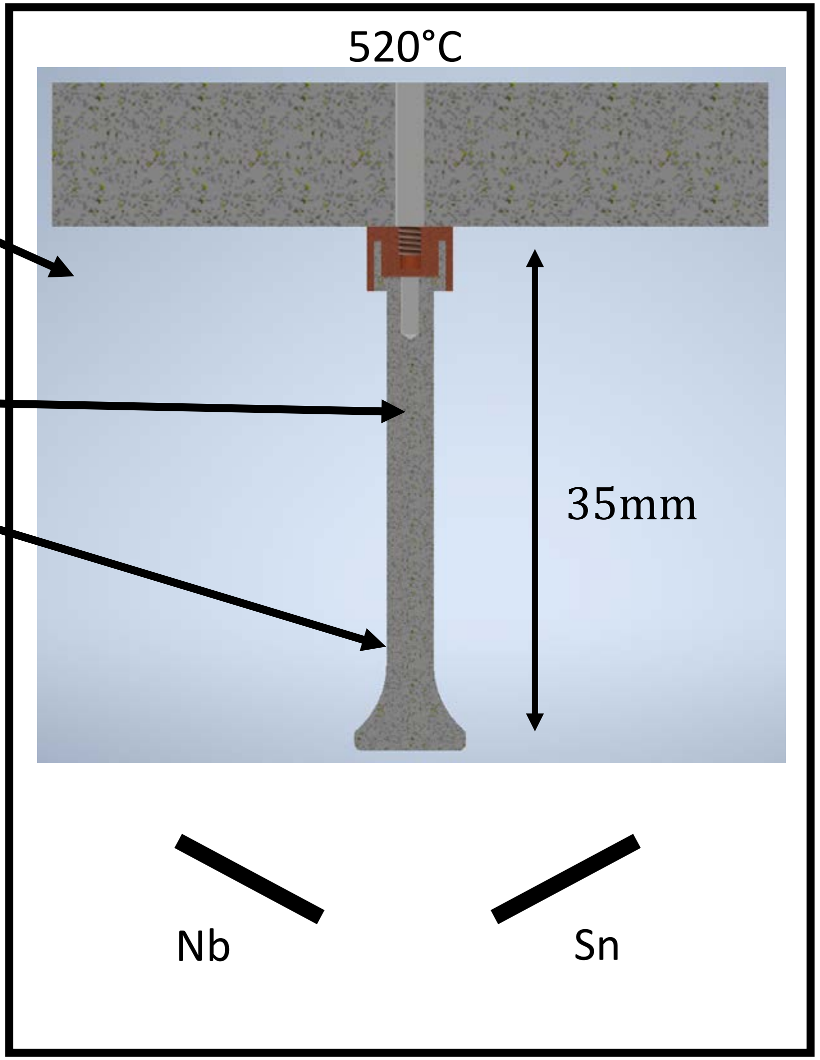
SC THIN FILMS - NB_3SN CO-SPUTTERING

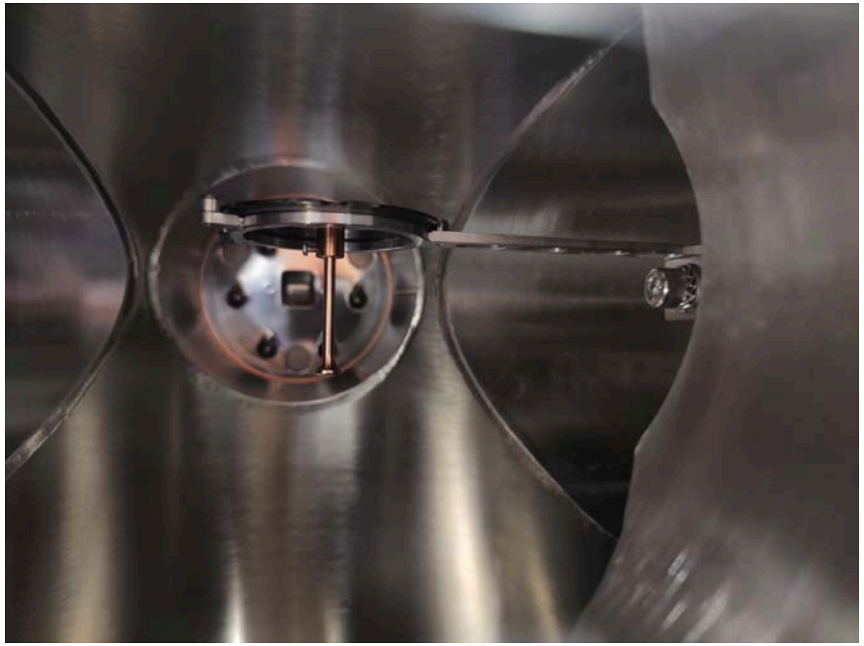
Low pressure Ar environment

Cu-antenna
Nb_3Sn-film

Fixed positions of Nb and Sn source
→ no uniform thickness of the film

Modifications on sample holder are ongoing





DESY Design (right)

- 29.56 mm tip length

Design from RI (left)

•Cyocera feedthrough with flange and antenna tip

•25 mm tip length

Bakeout at max 300C