SUPERCONDTUCTING THIN FILMS ON HIGHER ORDER MODE ANTENNAS TO INCREASE THE CW PERFORMANCE OF SRF CAVITIES AT MESA

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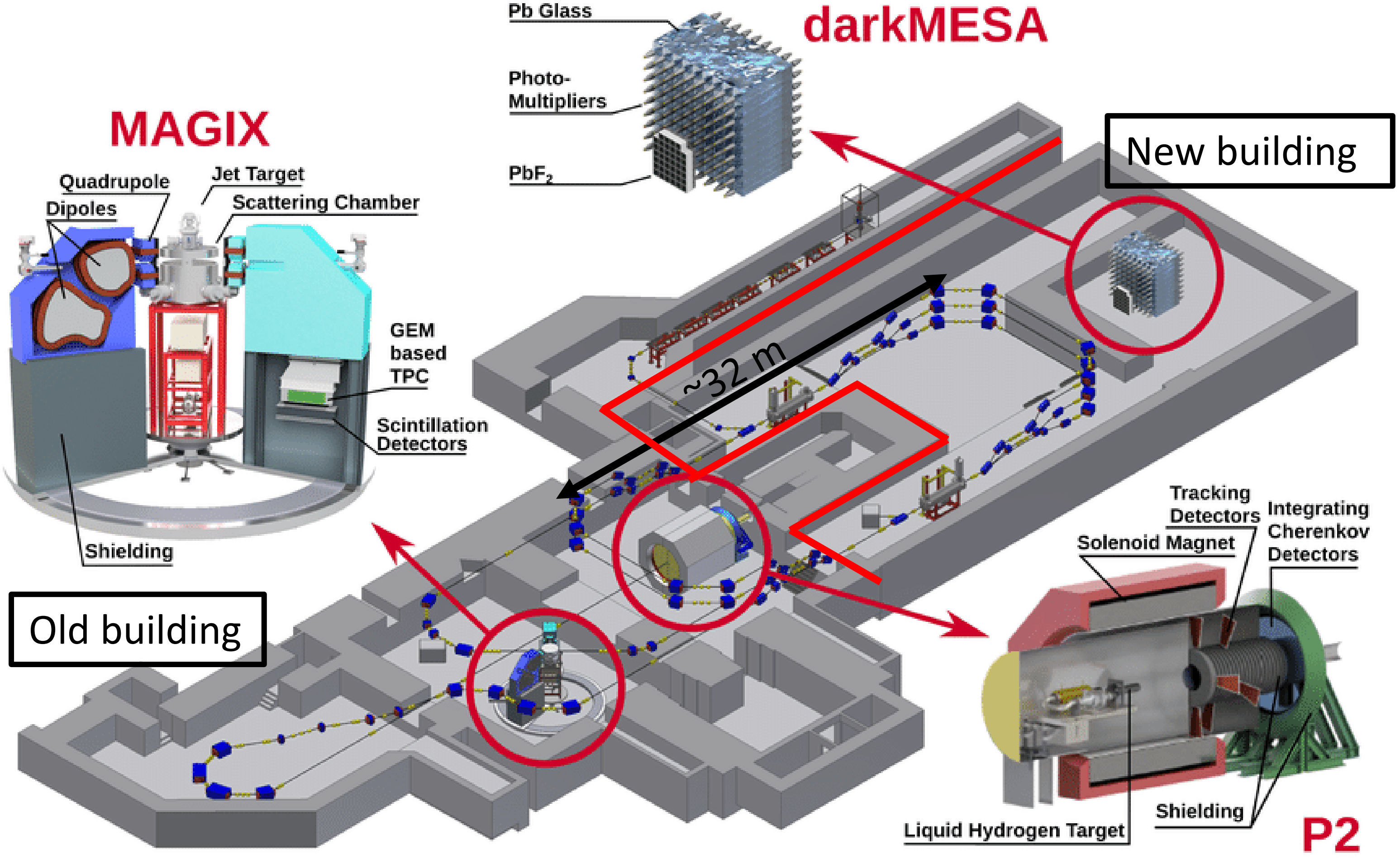
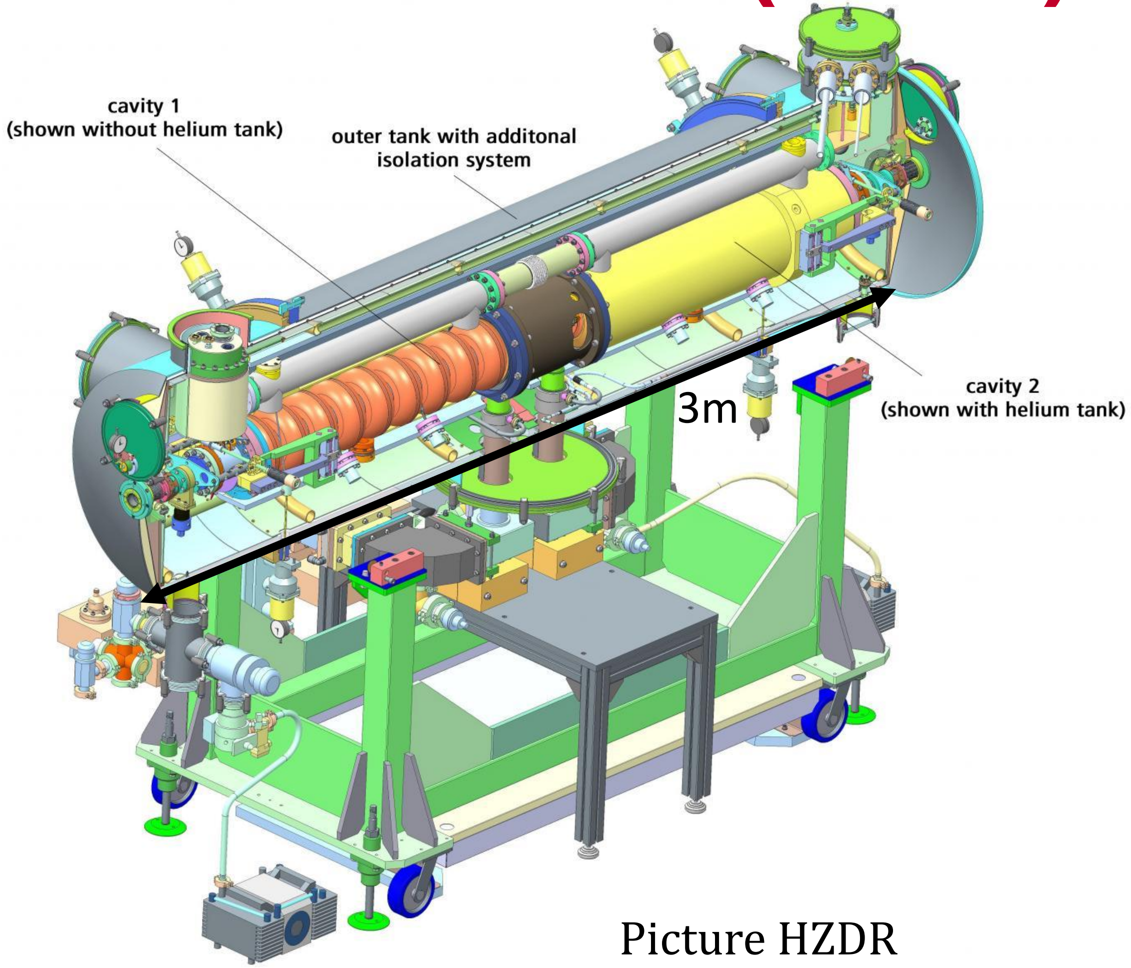
MAINZ ENERGY-RECOVERING SUPERCONDUCTING ACCELERATOR

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	$1.25 * 10^{10}$
f	1.3 GHz



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:

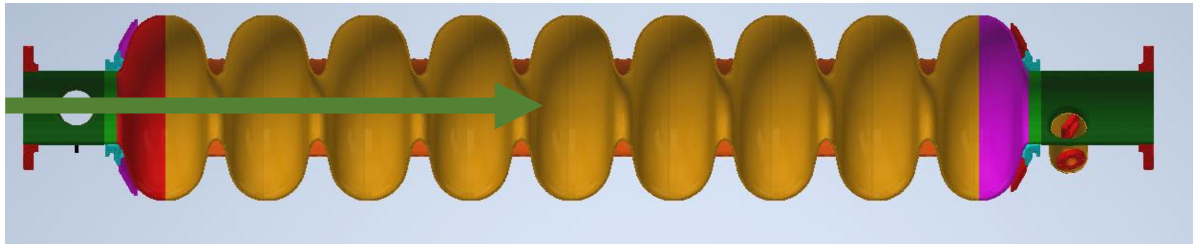
- Piezo tuner (XFEL/Saclay)
- Sapphire ceramic for HOM-antenna
- Cold mass of HOM RF-cable
- Modified LHe-port for the Joule-Thomson valve

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

*We acknowledge the transfer of one cryomodule to Mainz by the STFC Daresbury.

HIGHER ORDER MODES - BEAM INDUCED HOMS

In ER-mode:
4 e- beams simultanious
(2 time accelerating; 2 times decelerating)



Power stored in HOMs:

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

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.

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

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

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

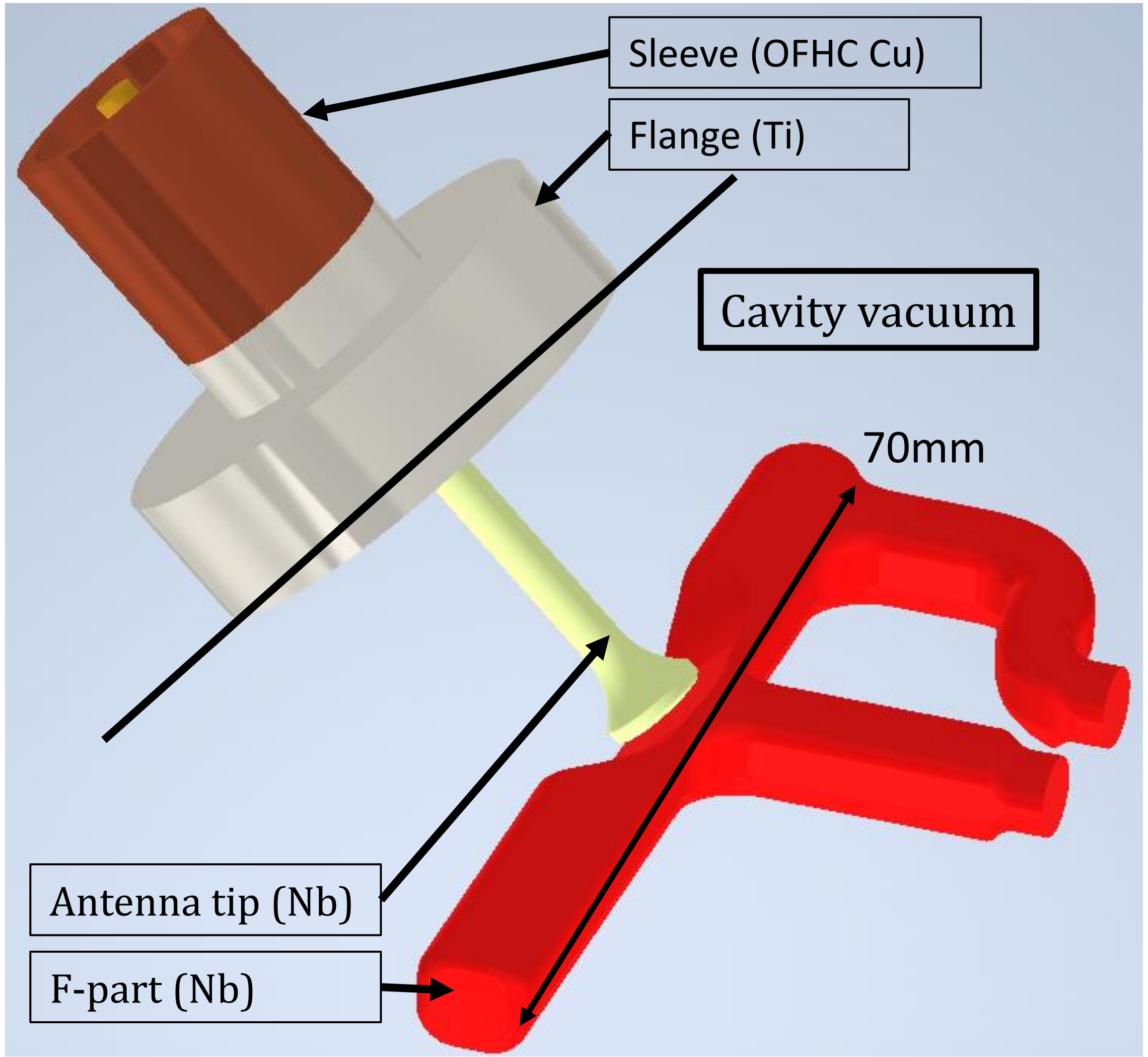
HIGHER ORDER MODES – GEOMETRICAL BOUNDARIES

How to handle 1000 mW?

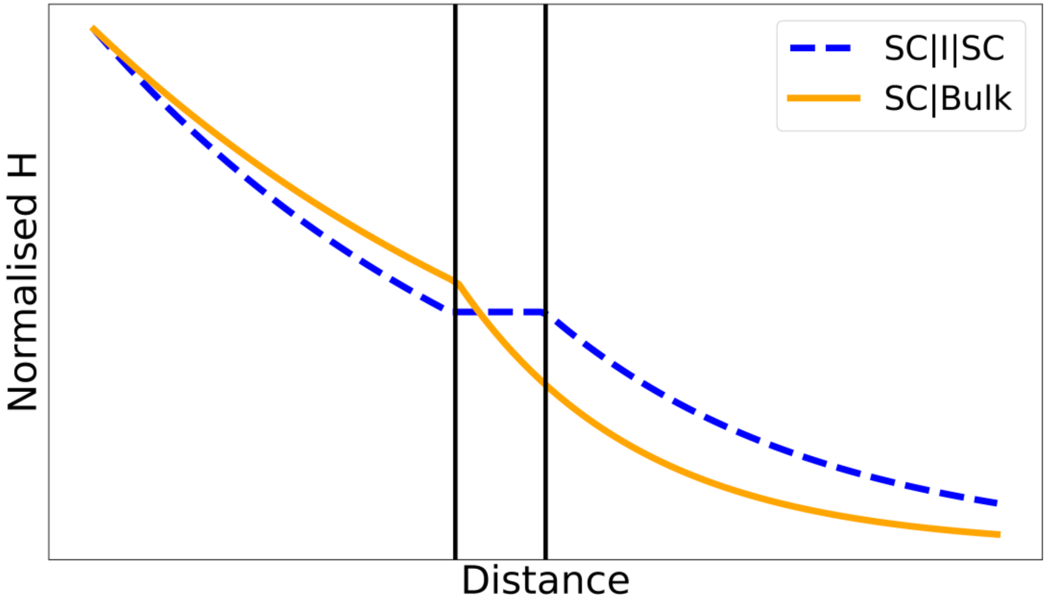
- Geometrical design of HOM antenna and F-part cannot be changed

→ Minimal invasive change:

- Change the surface material to a higher T_C superconductor



SC THIN FILMS



SC	T_C / K	λ_L / nm
Nb	9.2	39
NbTiN	17.3	150-200
Nb_3Sn	18.3	80-100

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

Thin Film Nb_3Sn ($d > \lambda_L$)	Bulk Oxygen Free High Thermal Conductive (OFHC) Cu (region mm)

Thin Film NbTiN ($d < \lambda_L$)	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)

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

M. Hein „High-Temperature-Superconductor Thin Films at Microwave Frequencies“, Springer Verlag 1999

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

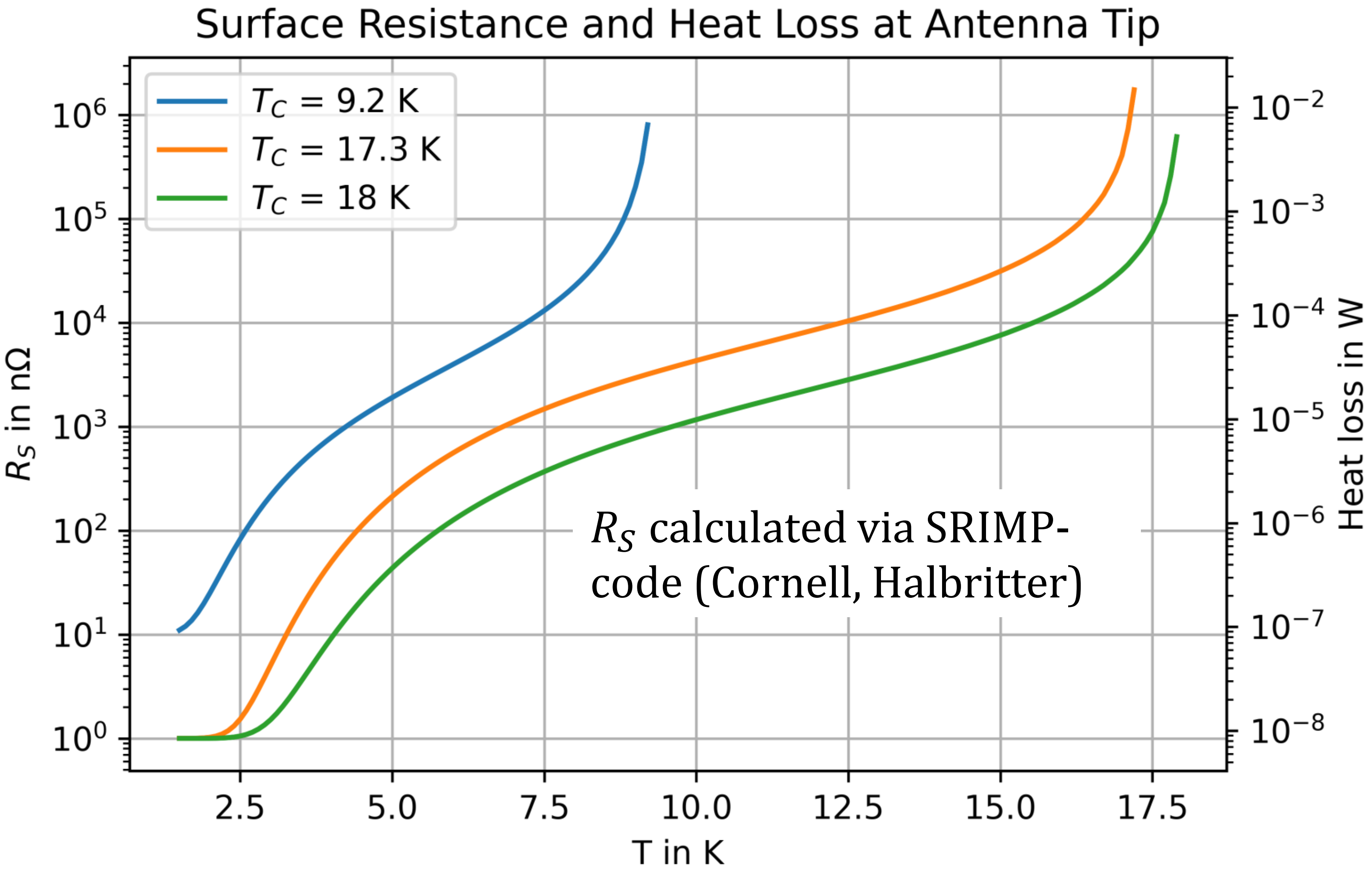
[2] all values are multiplied by $\frac{1.60218 * 10^{-22}}{k_B * T_{C,i'}}$

Heat loss at the antenna can be calculated via R_S:

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

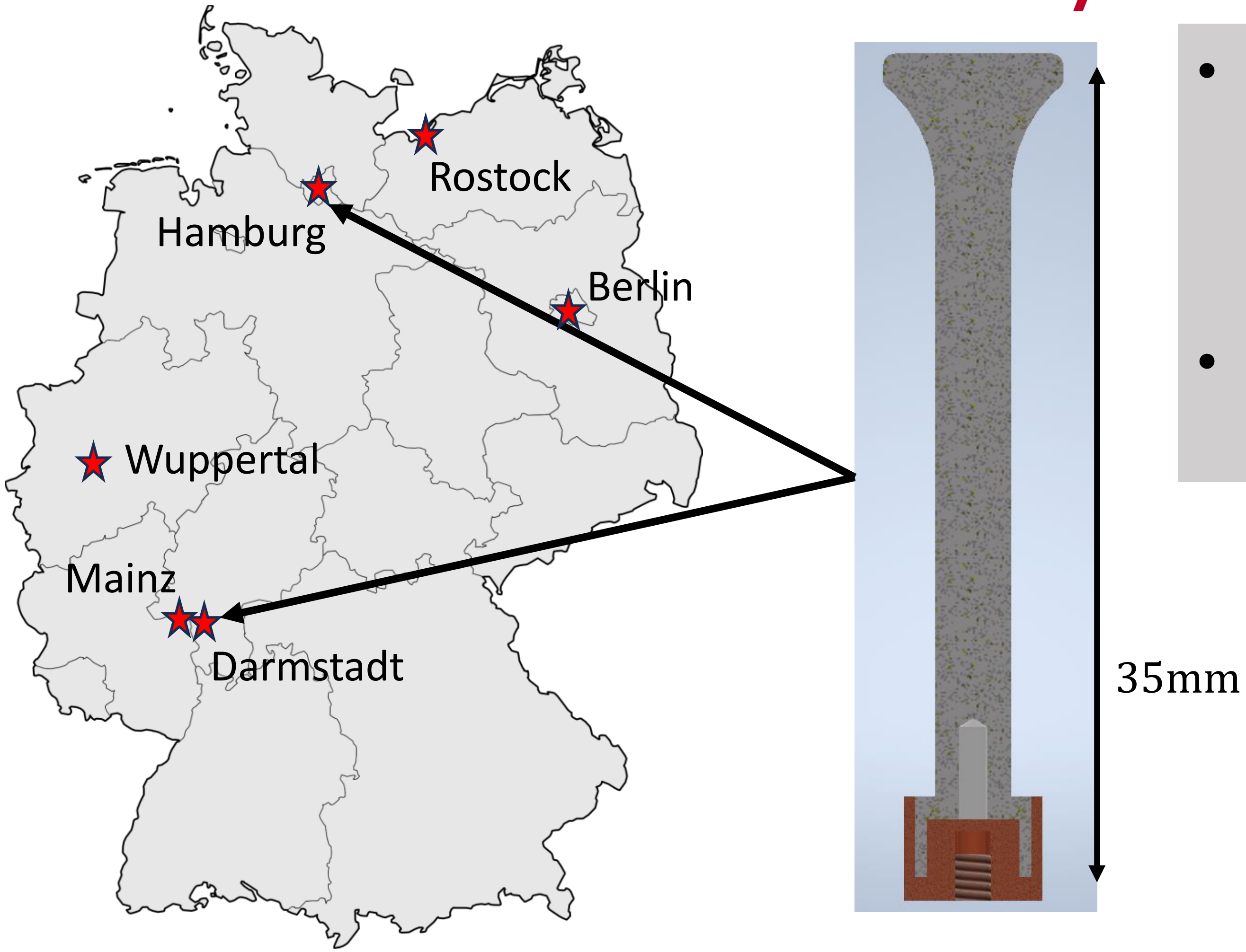
${}^{H_\perp}/_{H_{Peak}}$ between 1% and 10%

Beam-cavity interaction neglected!



R_S calculated via SRIMP-code (Cornell, Halbritter)

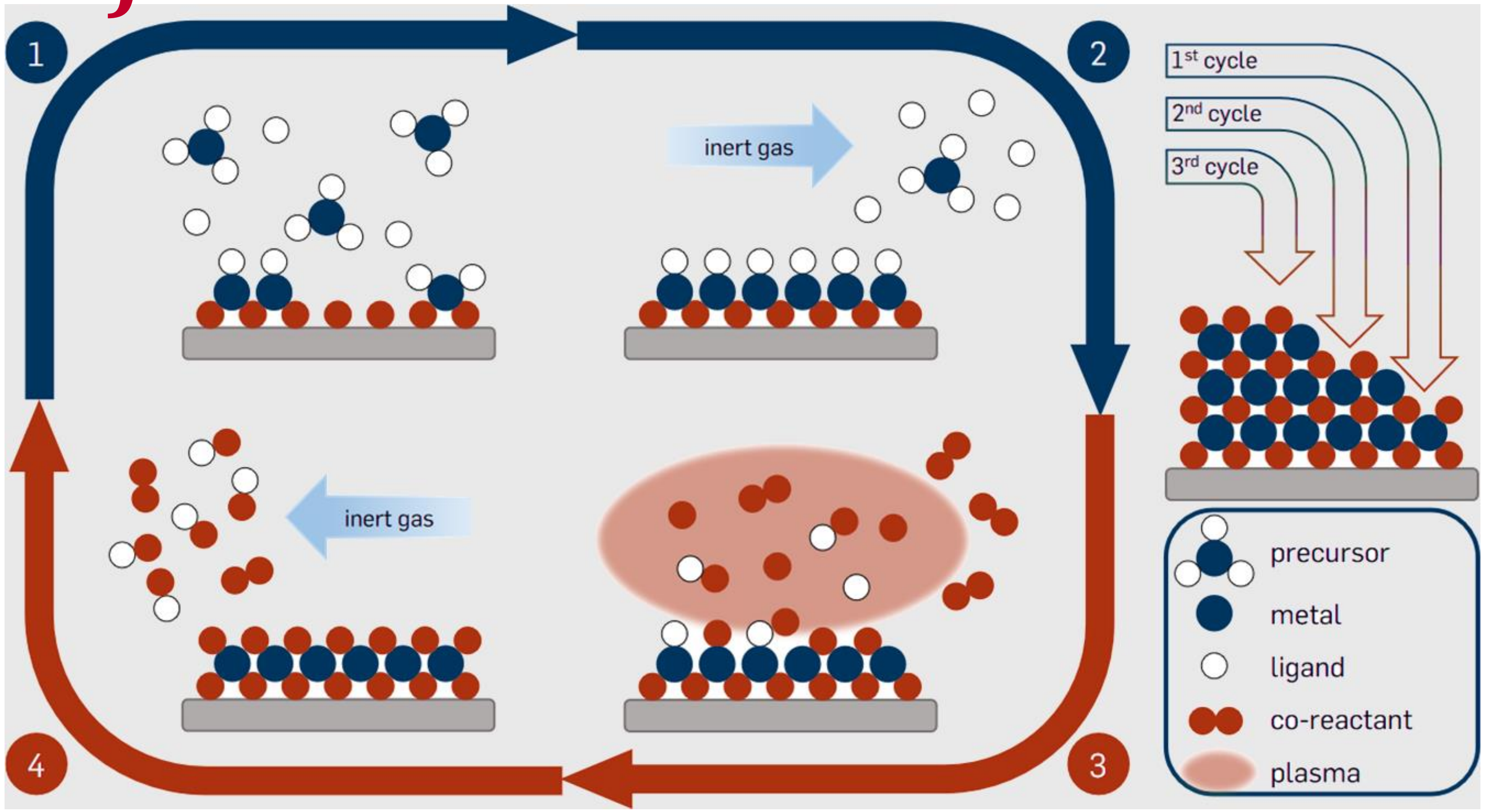
SC THIN FILMS – TOSCA/SUPER SURFER



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 Sputtering

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

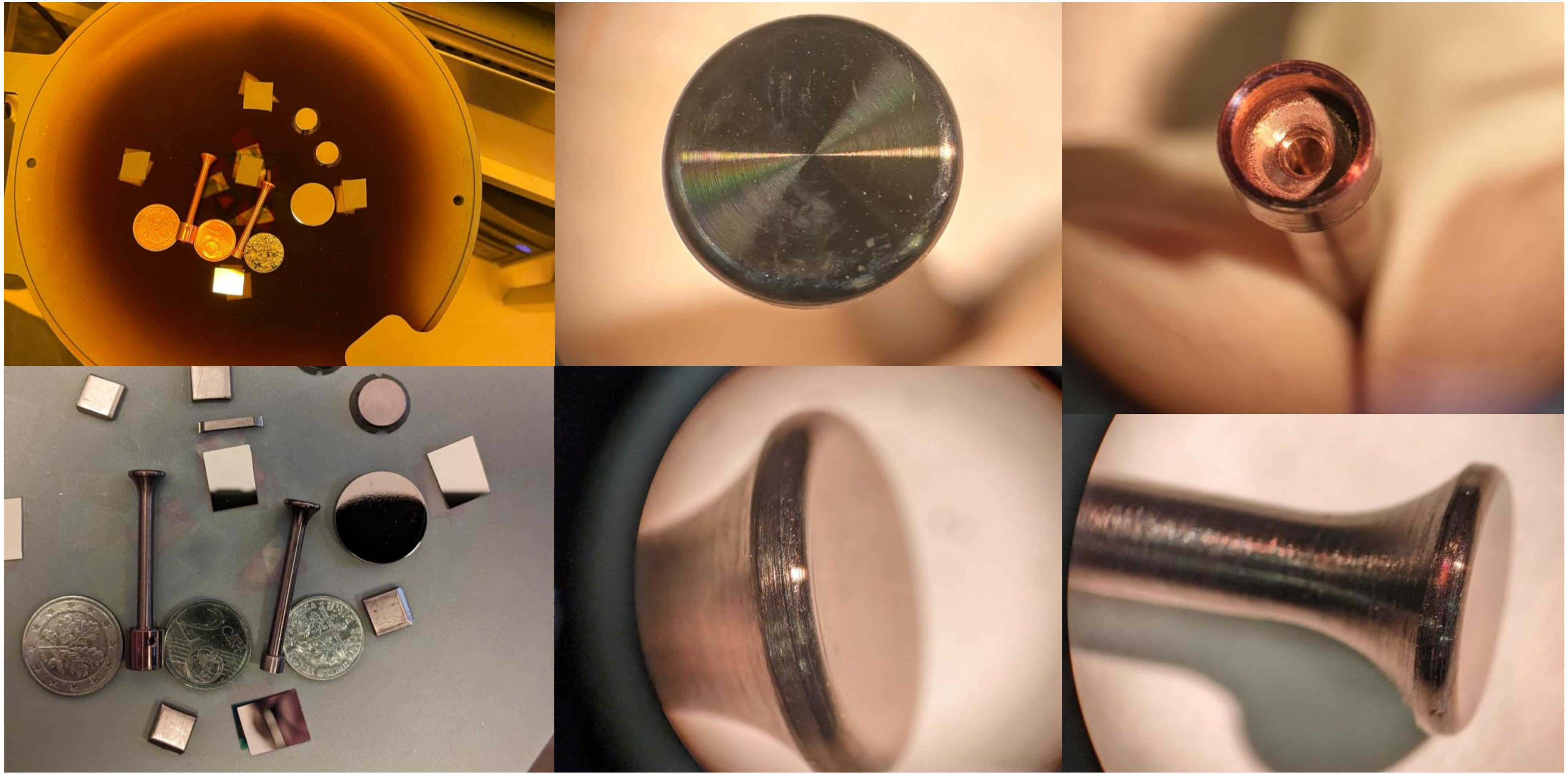


L. Mai, (2020), DOI:10.13154/294-7658.

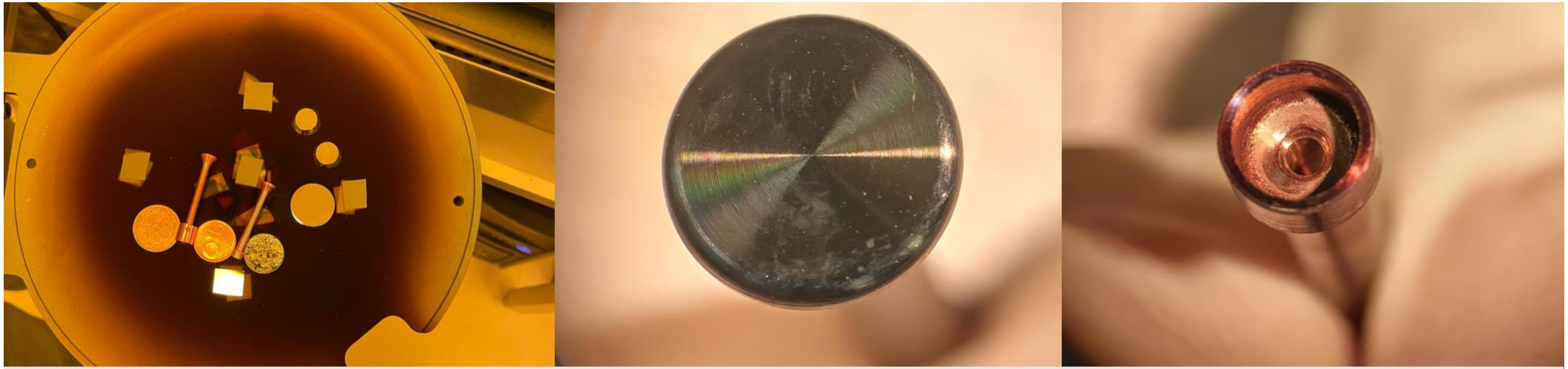
- lower deposition temperature (<300 °C)
- higher film quality

→ Slow Thermal Annealing (STA) at 900°C

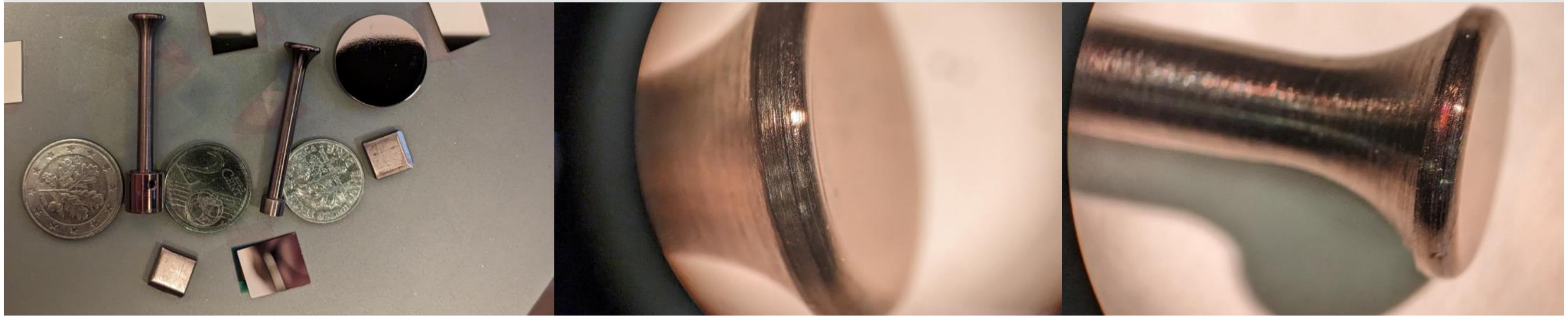
SC THIN FILMS – NBTIN ON HOM ANTENNA



SC THIN FILMS – NBTIN ON HOM ANTENNA



Nb antennas are now on the way to Hamburg for coating!



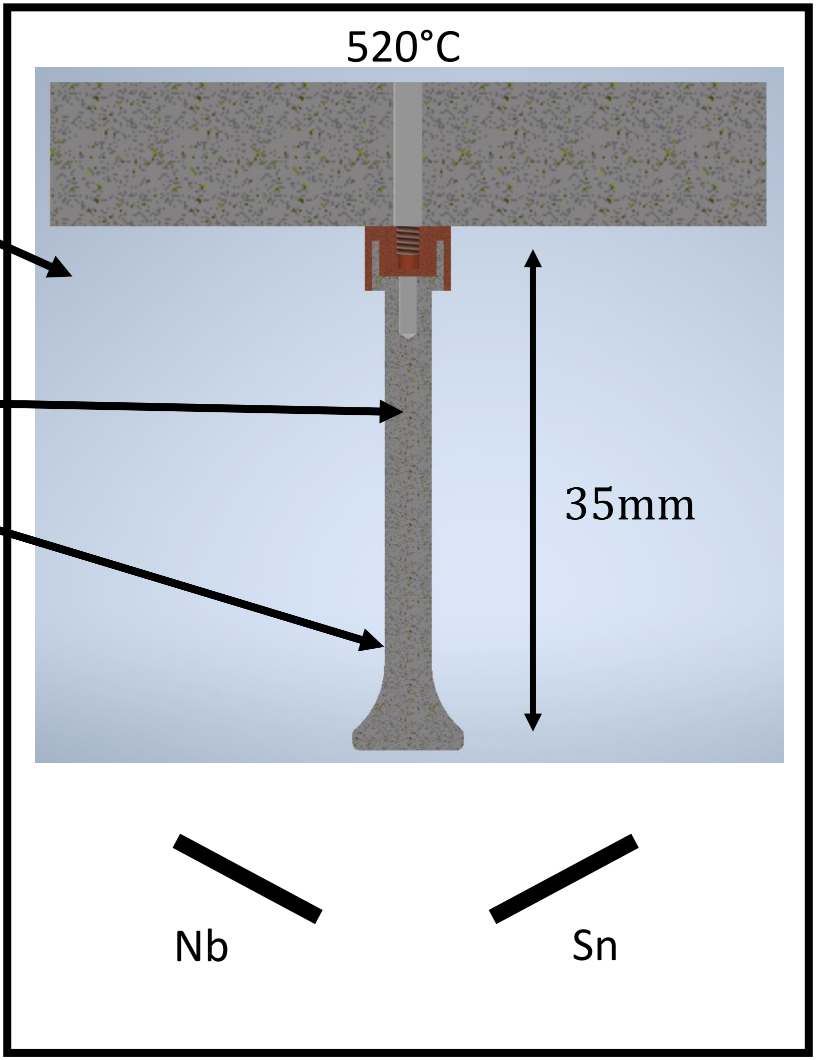
SC THIN FILMS - NB_3SN CO-SPUTTERING

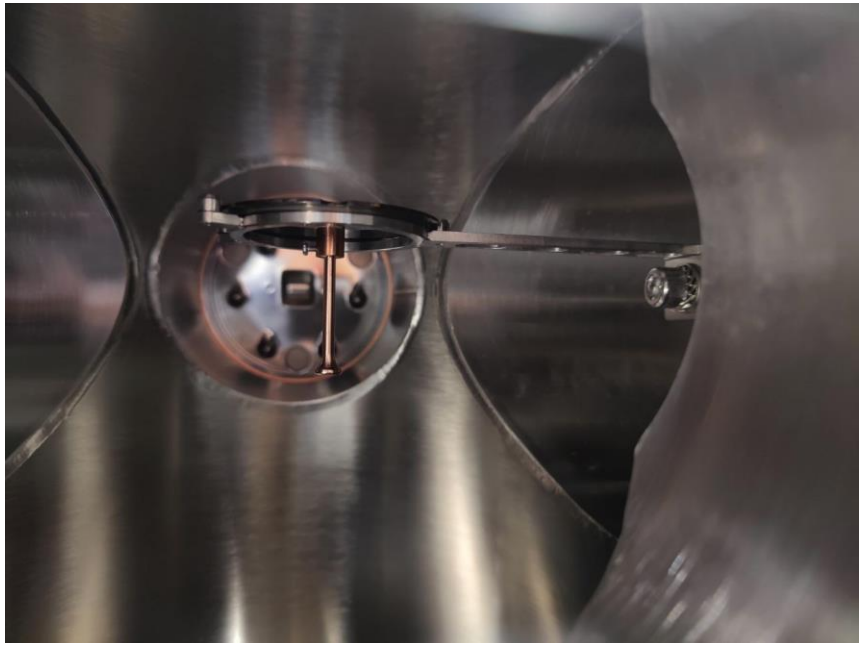
Low pressure Ar environment

Cu-antenna
Nb_3Sn-film

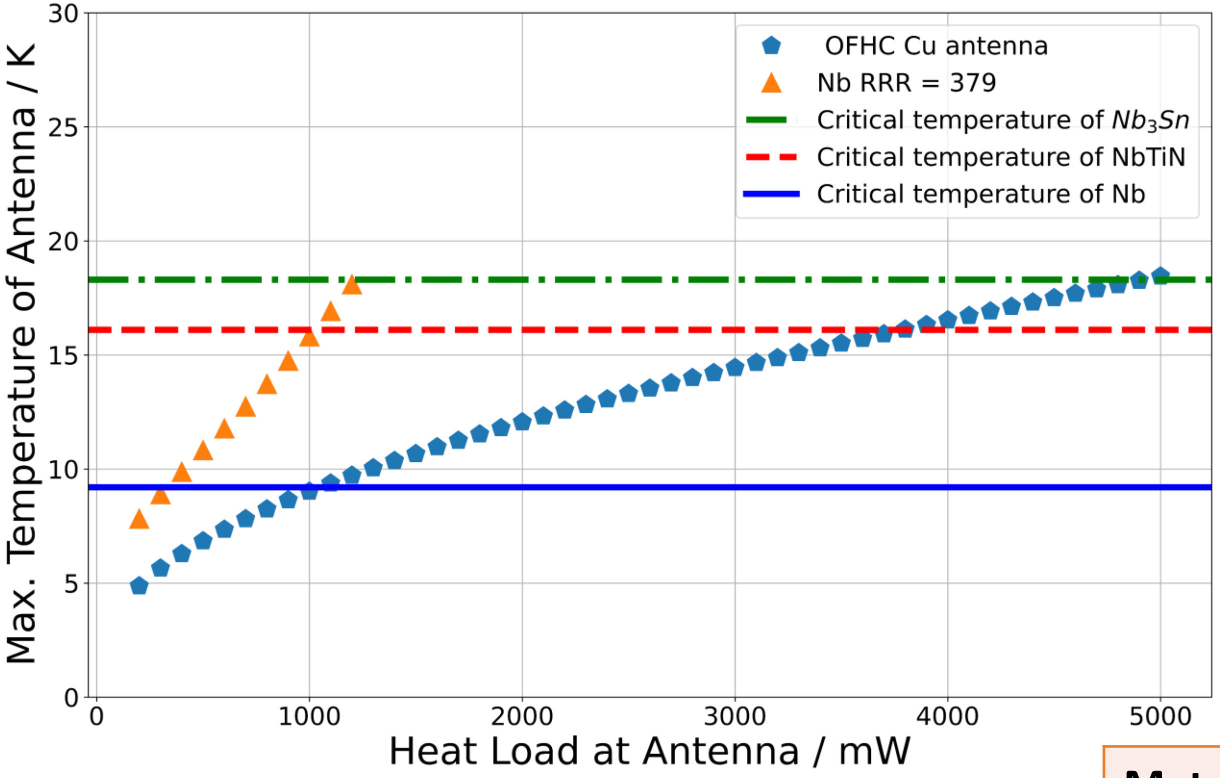
Fixed positions of Nb and Sn source
→ no uniform thickness of the film

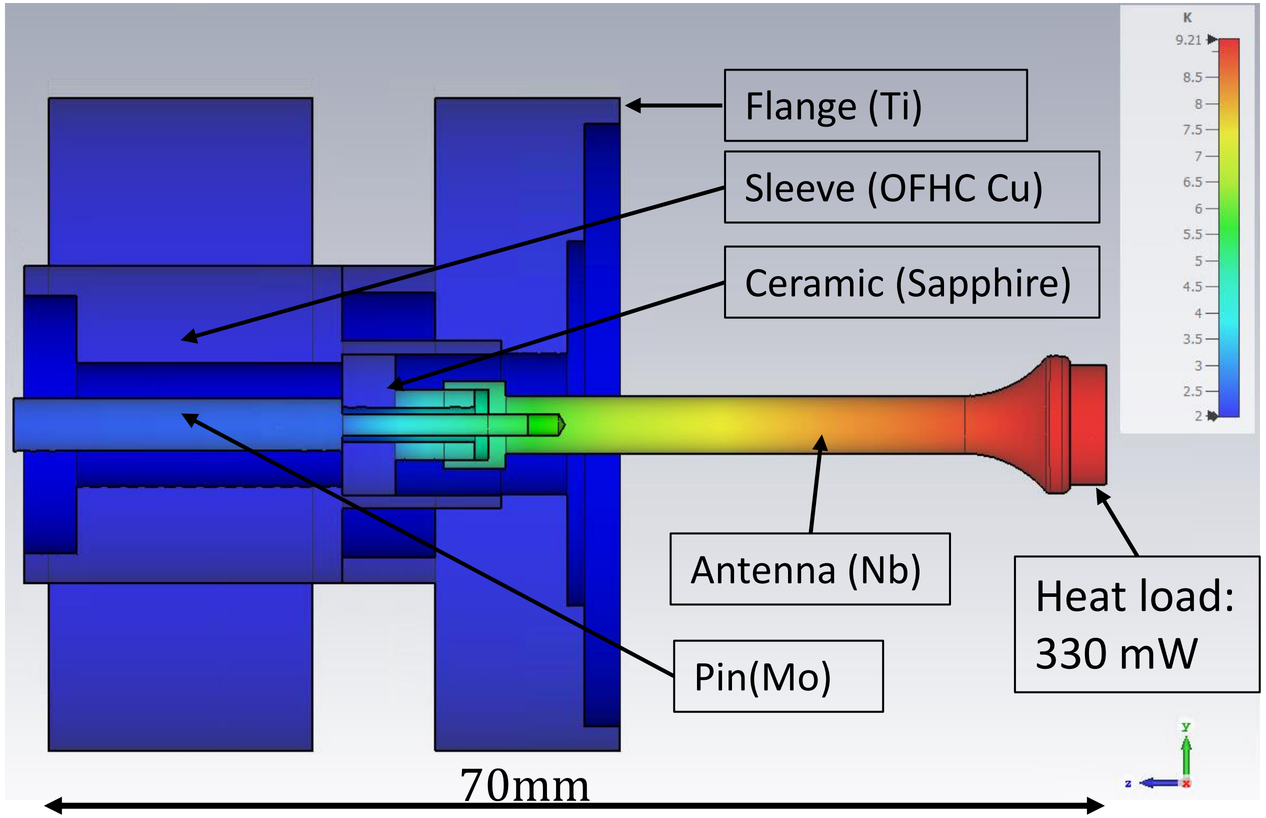
Modifications on sample holder are ongoing





CST RESULTS





Material	P_A in mW ($T_A = T_{C,Nb}$)	P_A in mW ($T_A = T_{C,NbTiN}$)	P_A in mW ($T_A = T_{C,Nb_3Sn}$)
Nb	~330	~1050	~1250
Cu	~1000	~3750	~4700

Thermal properties are dominated by the bulk material (Nb, Cu) for d > λ_L

d: thickness of coating; λ_L: London penetration depth

TEST PLANS FOR TESLA CAVITIES AND HOM ANTENNAS

Antenna tip

- Measuring the heat transport properties of coated/uncoated antennas
- Static heat load at tip
- Temperature sensors on antenna

Test-dummy

- Measure heating and power transmission in "Beam-pipe with F-Part"

In Cavity-Performance

- Baseline test: Vertical cold test (VCT) with "old HOM antennas"
- VCT with coated antennas

→ Tests with e-beam

SUMMARY & OUTLOOK

Summary:

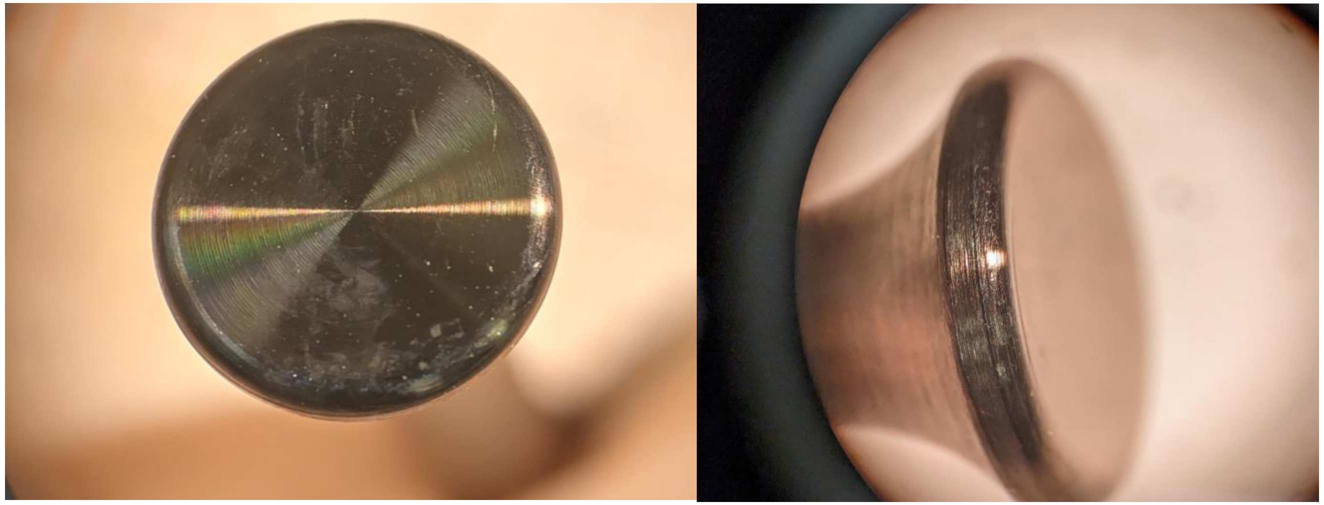
- Beam induced HOM power will exceed the power limit of the HOM antennas with the 10 mA upgrade at MESA

$$P_{HOM,B} = 1000\,mW > P_{MESA,lim} = 330\,mW$$

- 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 to study beam cavity interaction(ongoing)



Thank you for your attention!

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