HIPSTER

High **I**ntensity **P**erformance and **S**ustainable **T**echnology for **E**nergy **R**ecovery Linacs

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Envisaged for SuperSurfer:

Subproject 1: SRF for ERLs

- Further tests of alternative antenna materials, maybe with electron beam already (WP1)
- Coupling the cavities to a smaller bandwidth for saving RF power (WP2)

Subproject 2: Beam Dynamics for ERLs

- Optimizing recirculating machines for highest beam quality and stability

→ Subproject 2 not funded

Funding

Personnel:

2 positions funded, third person in Subproject 2 cut:

one PhD student (Paul Plattner) and one PostDoc (Ricardo Monroy)
both have been hired for TOSCA already

Invest:

Cut in invest by 40,000 EUR (95,000 instead of 135,000)

Travel etc.:

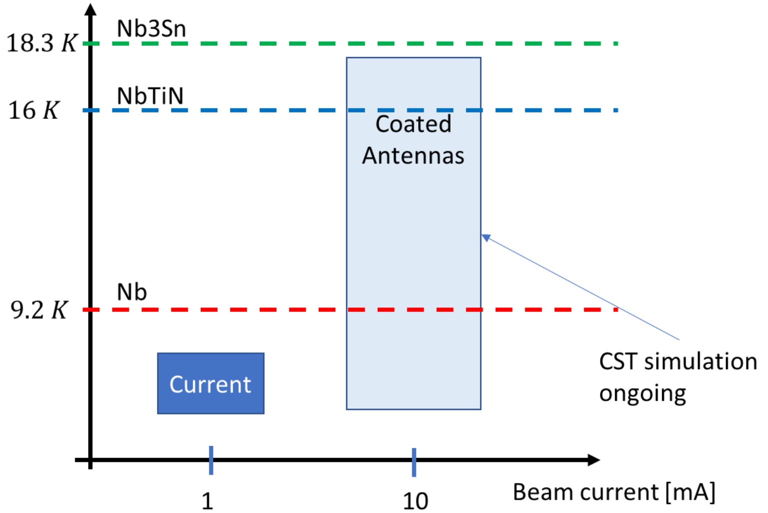
26,000 approved (we asked for approx. double amount)

Subproject 1: SRF for ERLs

Concern: Heating of HOM-antennas

Solution (within TOSCA 1):

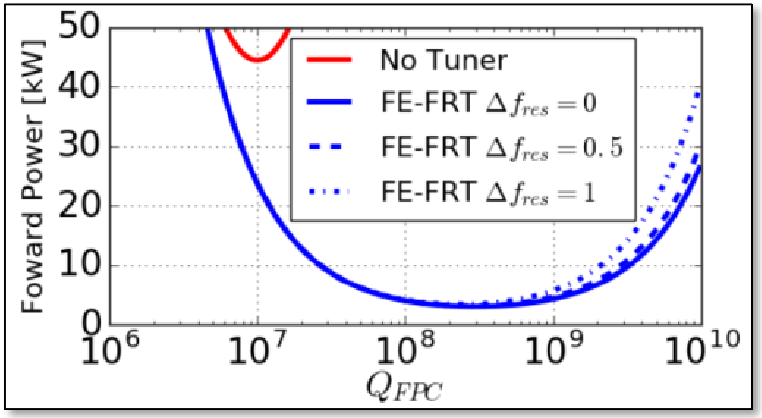
Coating of antennas with high T_C superconductors (ongoing work)



P. Plattner, JGU, DPG 2023

For low beam loading machines (like ERLs having virtually no beamloading) the **required RF power** is dominated by microphonics

→ Residual microphonics require over-coupled FPC and are cost extensive



Case study: RF power for PERLE vs Q_e with and without FRT (N. Shipman, CERN, ERL 22)

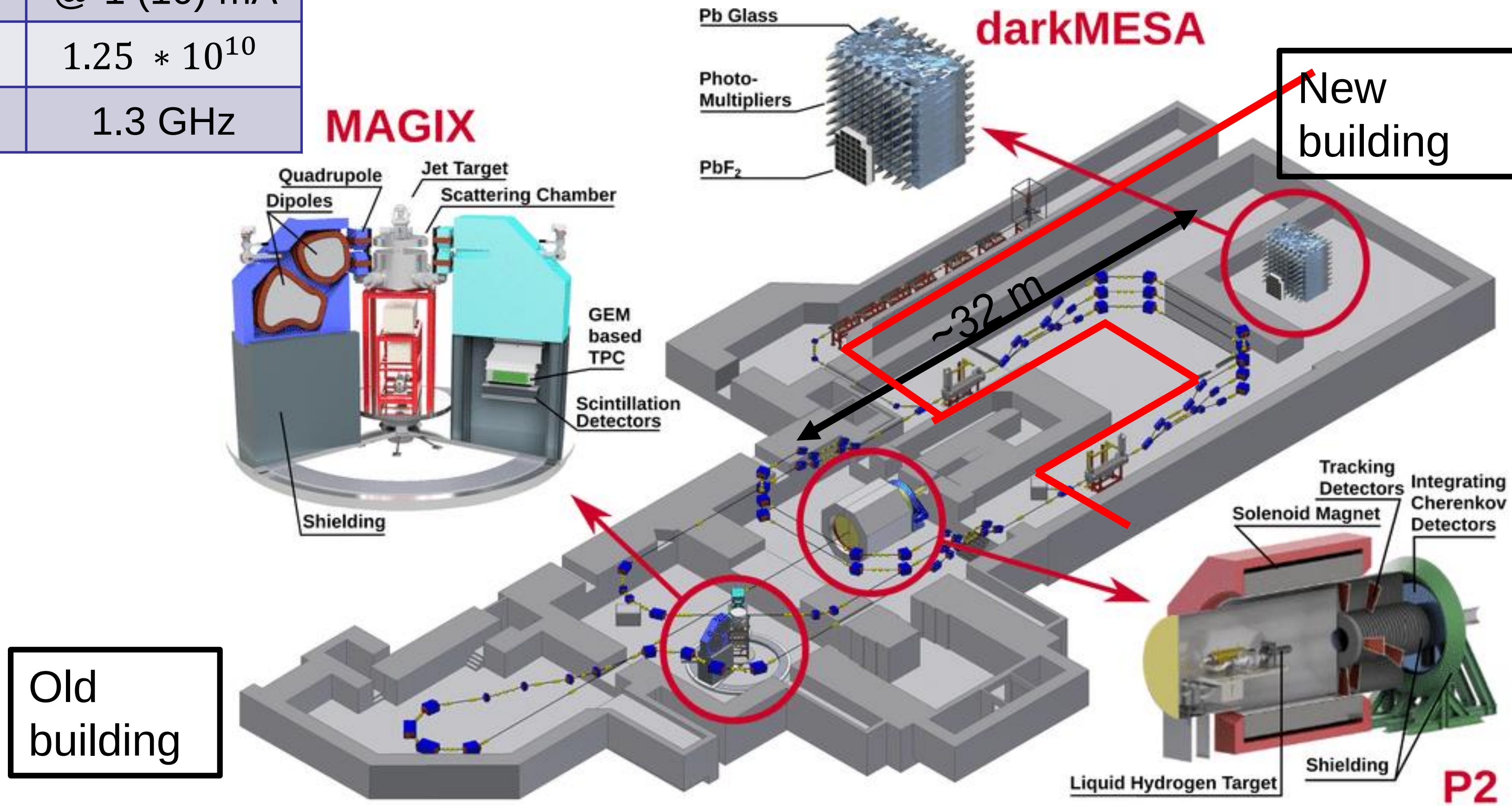
Our goals for TOSCA 2:

Add a **fast reactive tuner** to our test-cryomodule and reduce Q_e significantly by integrating a variable low power FPC. Finally test everything **with beam** at HZB sealab

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

MESA Project

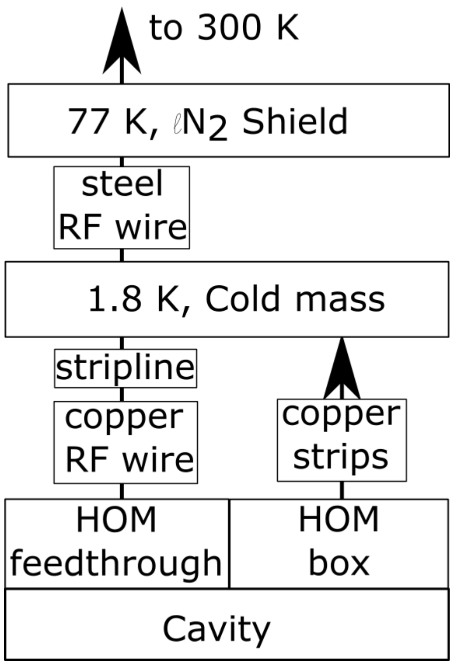
(fully funded, commissioning starts in 2025)

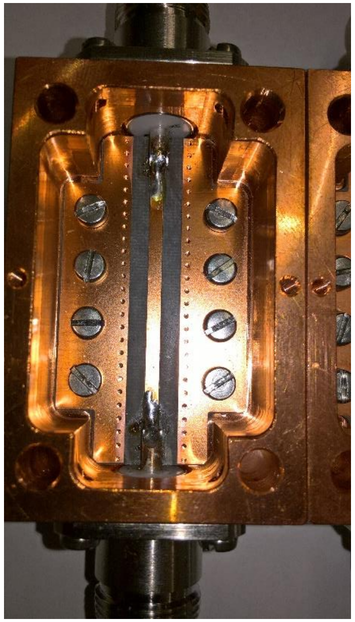


MESA Enhanced ELBE-type Cryomodules

1. Concern: Heating of the HOM-Antenna
2. Changes:

- Sapphire windows at HOM feedthrough
- Strip line in HOM cable for cooling





Cryomodule (2 XFEL Cavities @ 12.5 MV/m)

Overview goals WP1 (antennas/module improvements)

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Tasks as defined in the application:

Task 1: Cold test (vertical) of cavities equipped with high TC superconductors (WP1.1)

Task 2: Integration of the tested cavities into the cryomodule (WP1.2)

Task 3: Design and integration of a variable input coupler for low forward power (WP1.3)

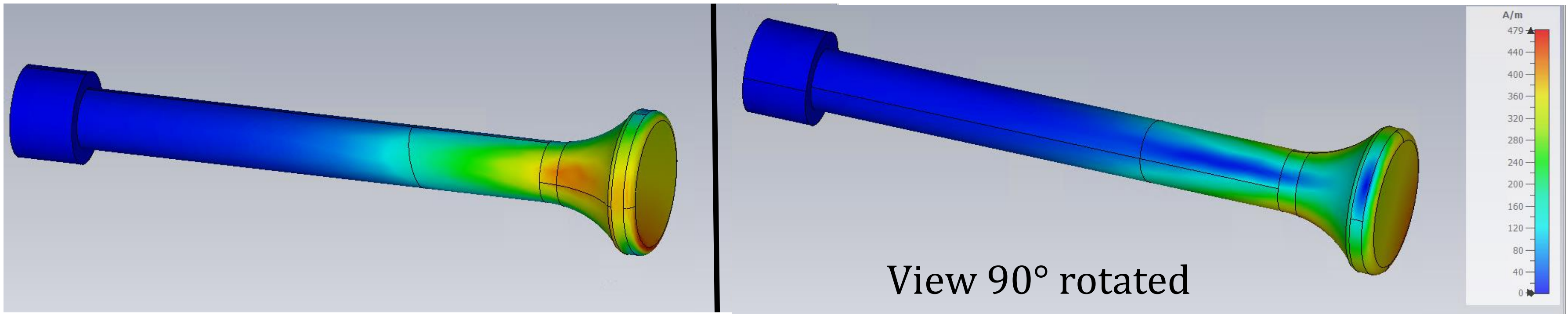
Task 4: Cold tests and optimization of the completed module (WP1.4)

→ WP1 continues and extends ongoing work from TOSCA

→ Task 3 needs to be canceled (or postponed) due to cuts in funding of investment

Magnetic field at antenna

(P. Plattner)



Maximum of magnetic field at antenna $\mathrm{H}_{\mathrm{max,T}} = 0.53\ \mathrm{mT}$

Field distribution: maximum at the tip of the antenna

Field maxima of HOMs not at tip and $\mathrm{H}_{\mathrm{max,HOM}} < \mathrm{H}_{\mathrm{max,T}}$

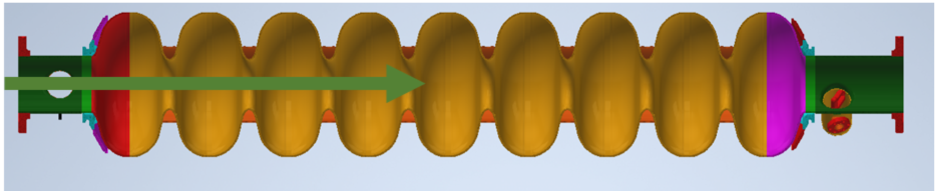
$^{\mathrm{H}_{\mathrm{max,HOM}}}/_{H_{max,T}} \approx 0.001$ for strongest dipole mode

$$\mathrm{H}_{\mathrm{max,T}} = 1\%\ \mathrm{H}_{\mathrm{peak}}$$

$$\mathrm{E}_{acc} = 12.5\ \frac{MeV}{m}$$

HOM antenna heating
(P. Plattner)

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



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.

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

Magnetic field at antenna

(P. Plattner)

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 $\frac{\pi}{2}$

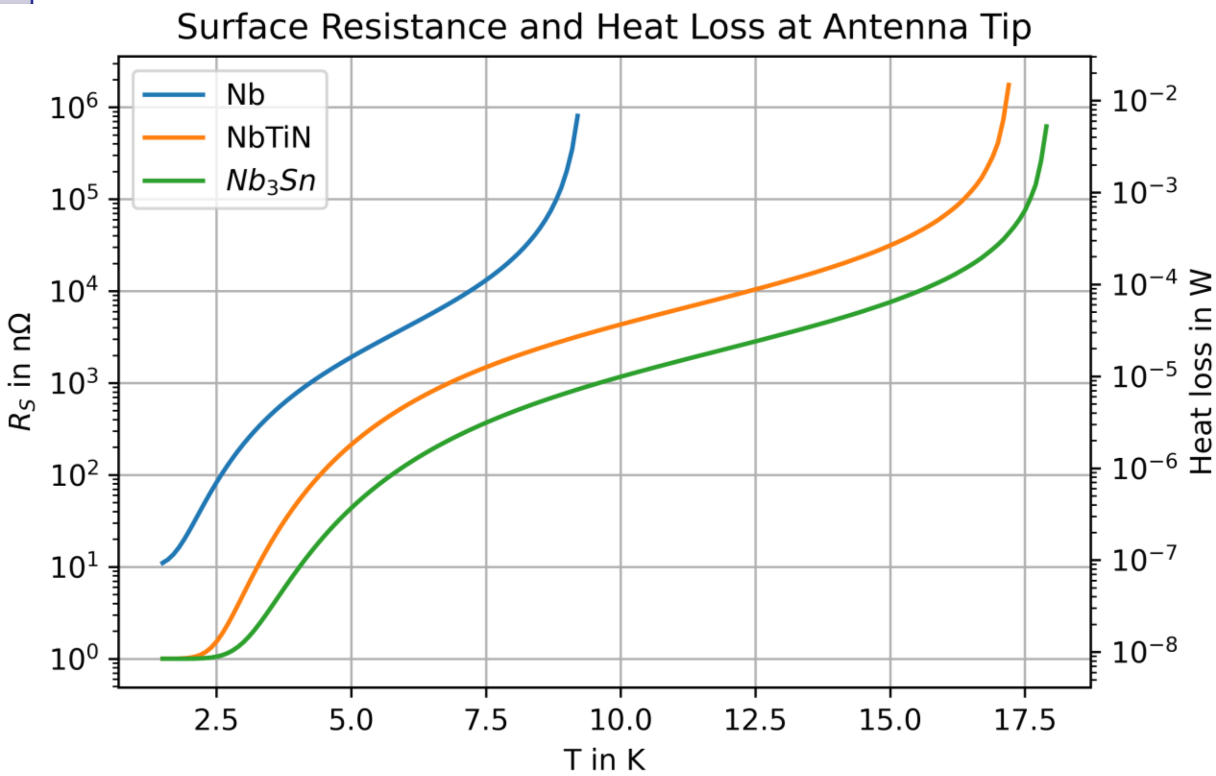
[2] all values are multiplied by $\frac{1.60218 * 10^{-22}}{k_B * T_{C,i}}$

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

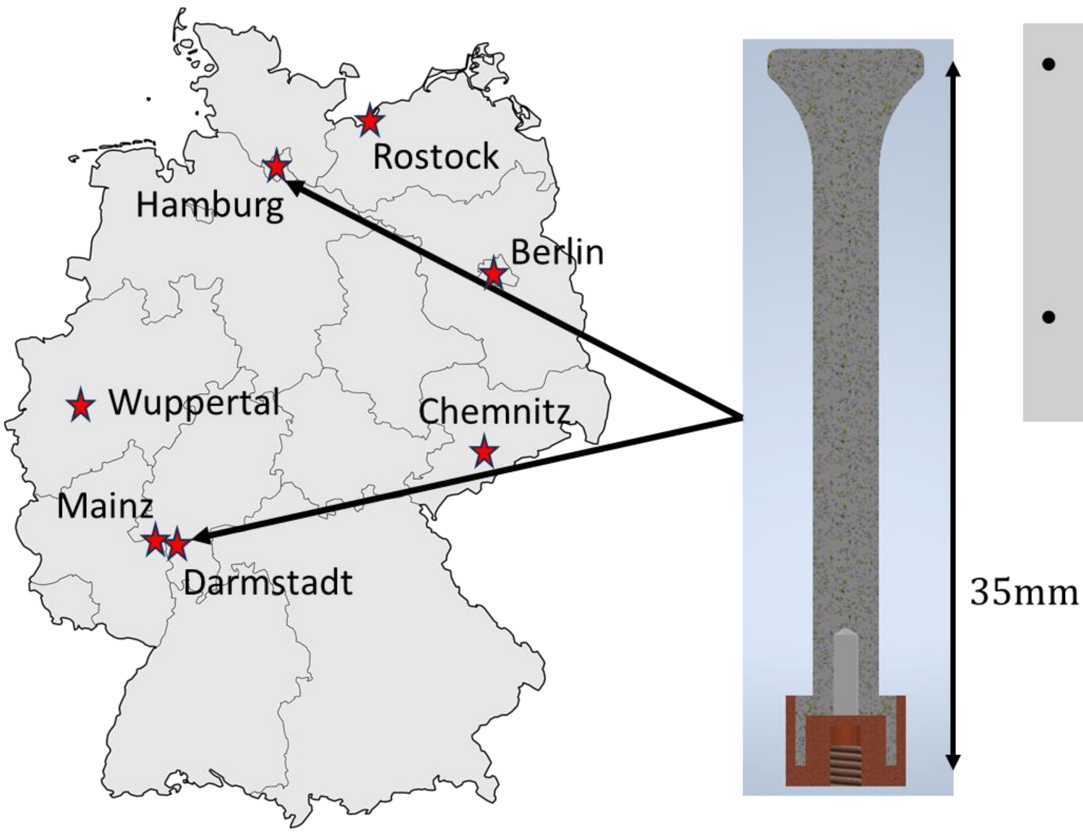
Beam-cavity interaction neglected!



R_S via SRIMP (Halbritter, Cornell)

H = 0.53 mT

Producing SC Thin films in TOSCA/SuperSurfer
(P. Plattner)

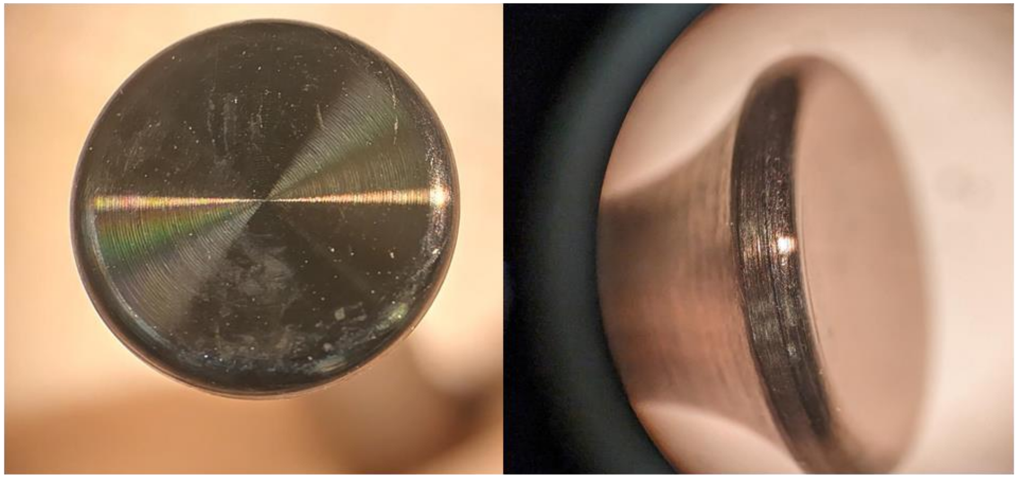


https://upload.wikimedia.org/wikipedia/commons/thumb/e/e3/Karte_Deutschland.svg/1513px-Karte_Deutschland.svg.png

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

Producing SC Thin films in TOSCA/SuperSurfer
(P. Plattner)

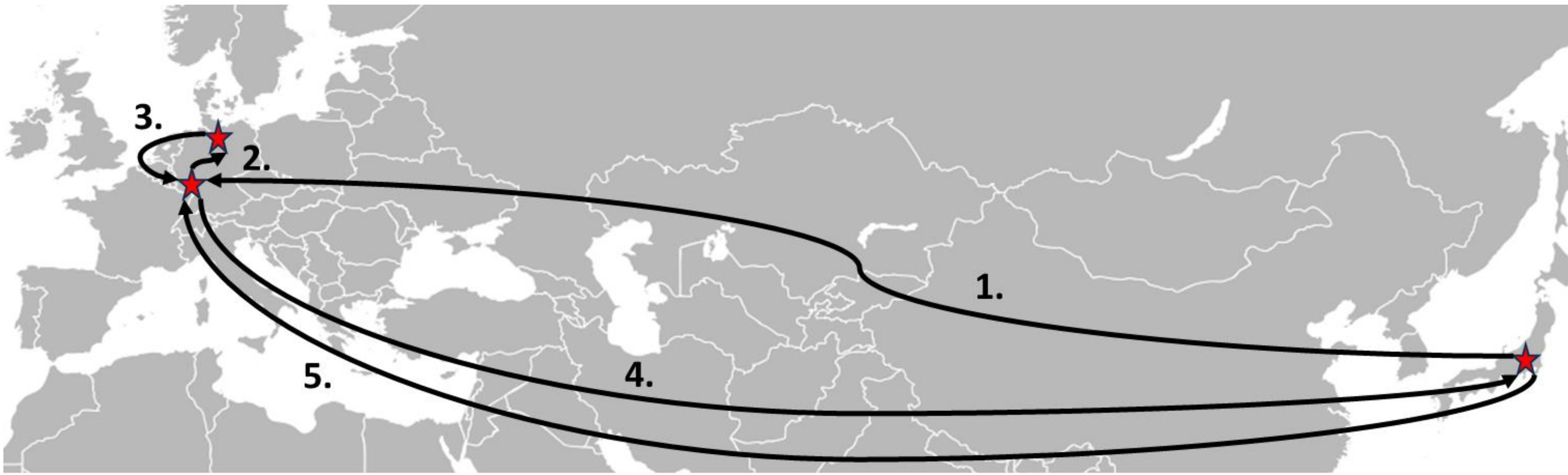
NbTiN(PEALD) @Hamburg
Substrate: Niobium
Time: 4 days
Thickness: ~100nm ($\geq \lambda_L$)
T_C = 16 K (on flat samples)
Deposition Temperatur < 300°C → backe out at 900°C



Nb_3Sn (Co-Sputtering) @TU Darmstadt
Substrate: Copper
Time: 1 hour
Thickness: ~400nm
T_C = ~14 K (on cylindrical substitue)
Deposition Temperatur 520°C

Picture from Amir Fahood

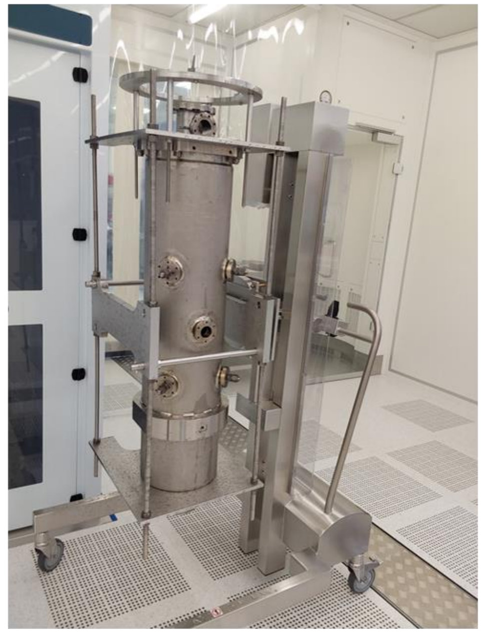
Producing SC Thin films in TOSCA/SuperSurfer
(P. Plattner)



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

Ongoing work
(P. Plattner)

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)

Overview goals WP2 (antennas/module improvements)

Tasks as defined in the application:

Task 1: Warm material RF tests at new designed test bench, Material characterization (WP2.1)

Task 2: Designing a prototype for cold rf tests (beam pipe coupling, proof of concept) (WP2.2)

Task 3: Integration of the prototype into existing rf ports at TESLA/XFEL cavities (enable testing of dressed cavities in cryomodules) and cold tests. (WP2.3)

→ New project within SuperSurfer

Power saving with FRT
(T. Stengler)

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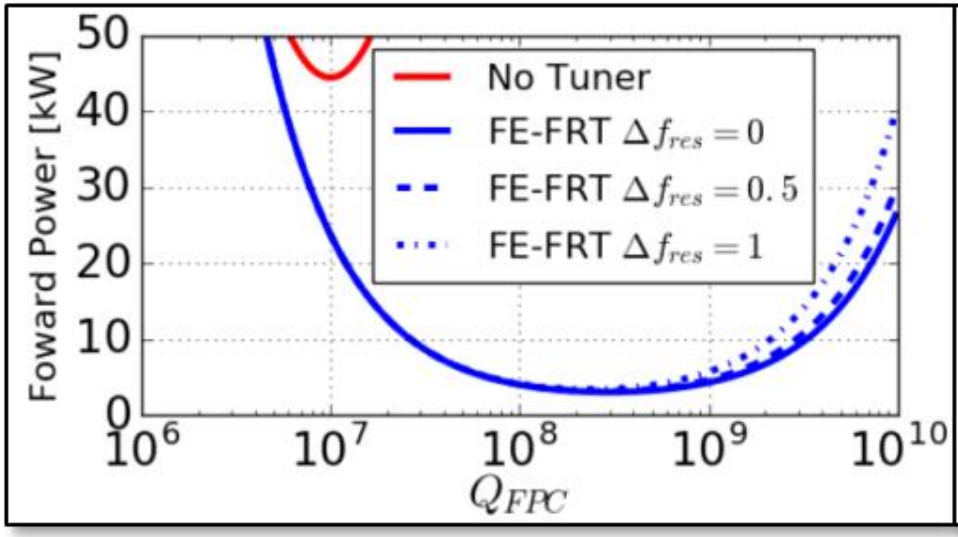
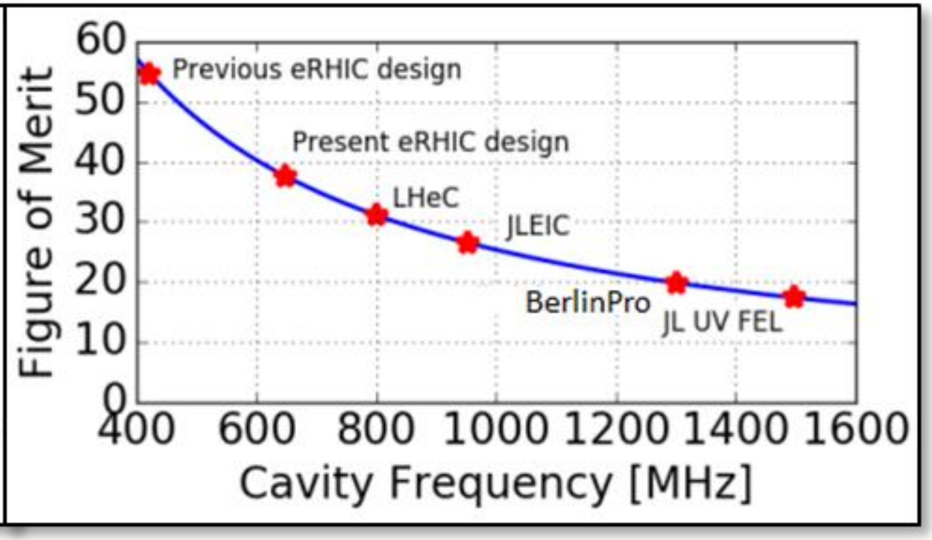
Microphonics in SRF cavities yield in high coupling bandwidth and thus power consumption

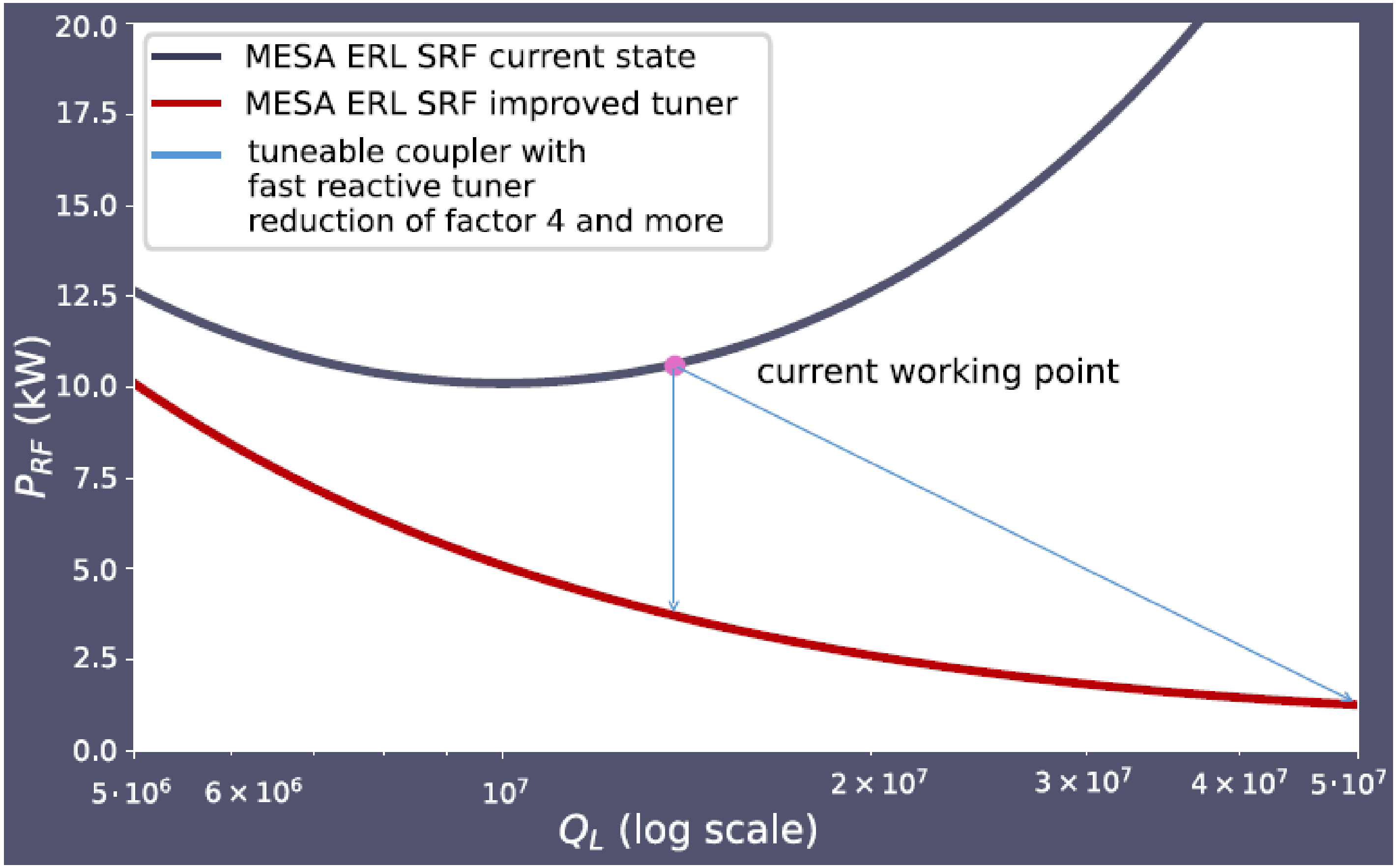




Pictures: N. Shipman (HZB)

→ For MESA: 5 kW microphonics reserve + 2.5 kW reflected power (+ beam)

Power saving with FRT, the MESA case
(T. Stengler)



→ Best performance using fast tuner + smaller coupling bandwidth

→ Significant power saving even without new couplers

Ongoing work
(R. Monroy)

- Design of a test bench for warm testing
- Survey and aquisition of FRT materials

Goals:

- Preparation of a RF design
- Inclusion into MESA control system
- Cold tests