Mitigation of parasitic losses in the QPR enabling direct measurements of low R_{res}

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M. Wenskat, R. Kleindienst, J. Knobloch, O. Kugeler, D. Tikhonov

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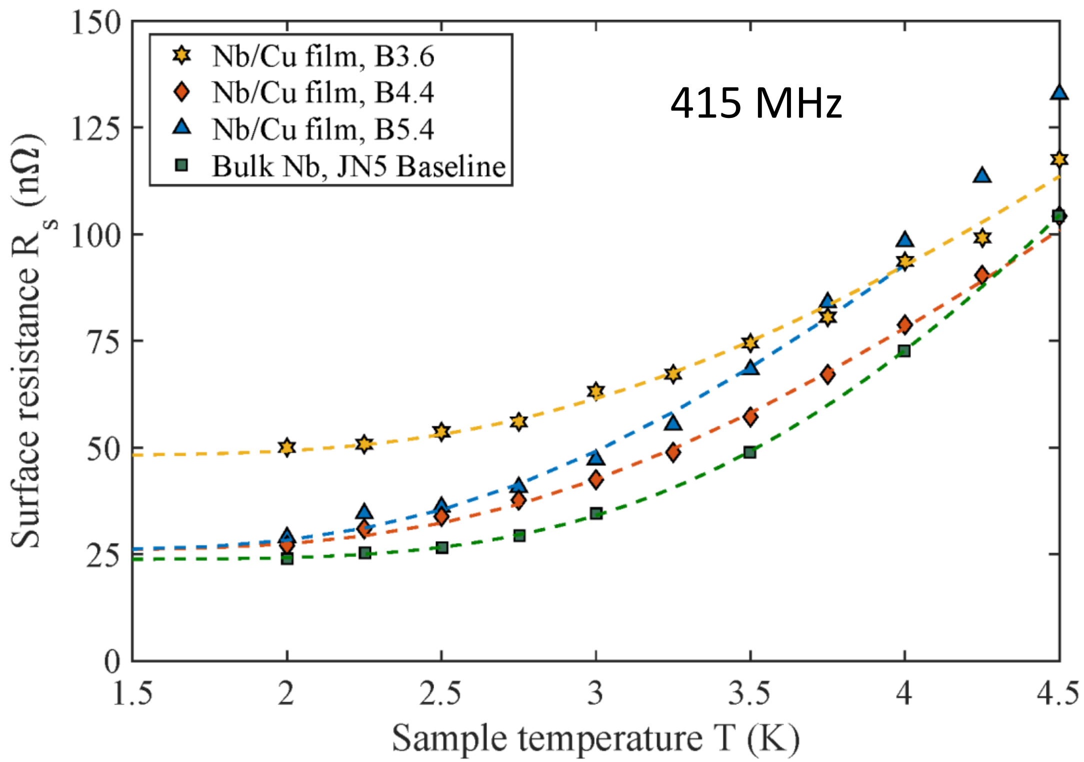
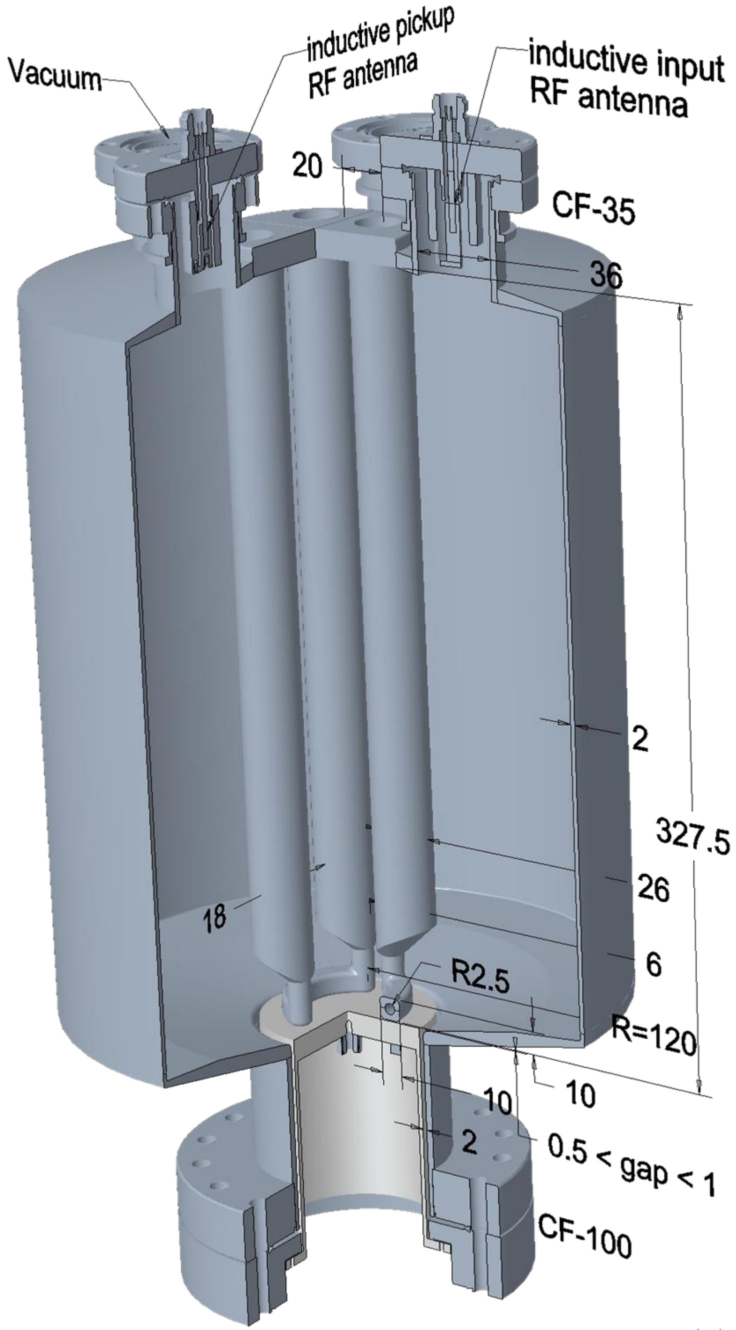
TESLA Technology collaboration meeting

STARTING SITUATION



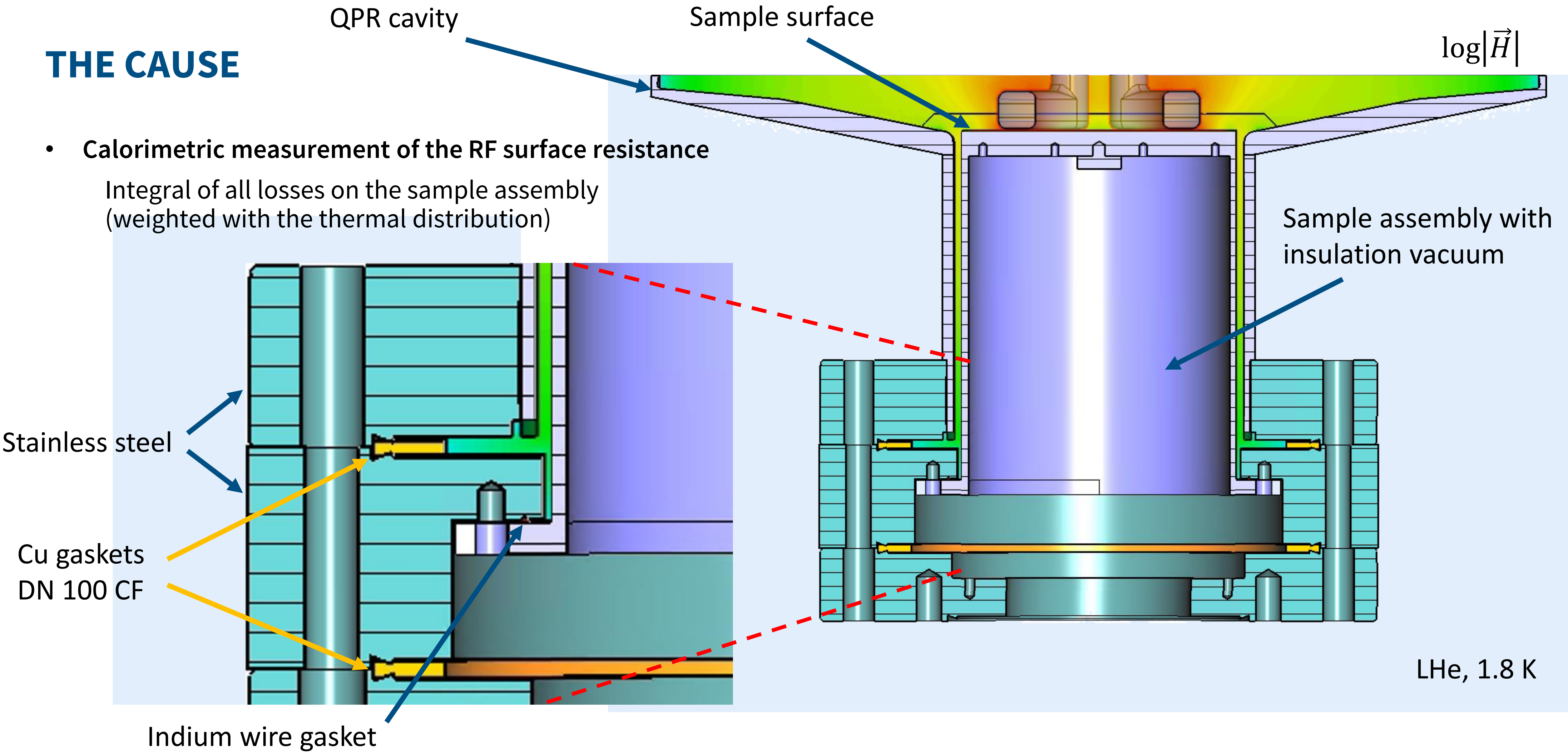


→ **Surprisingly high and similar residual resistance observed on various QPR samples**

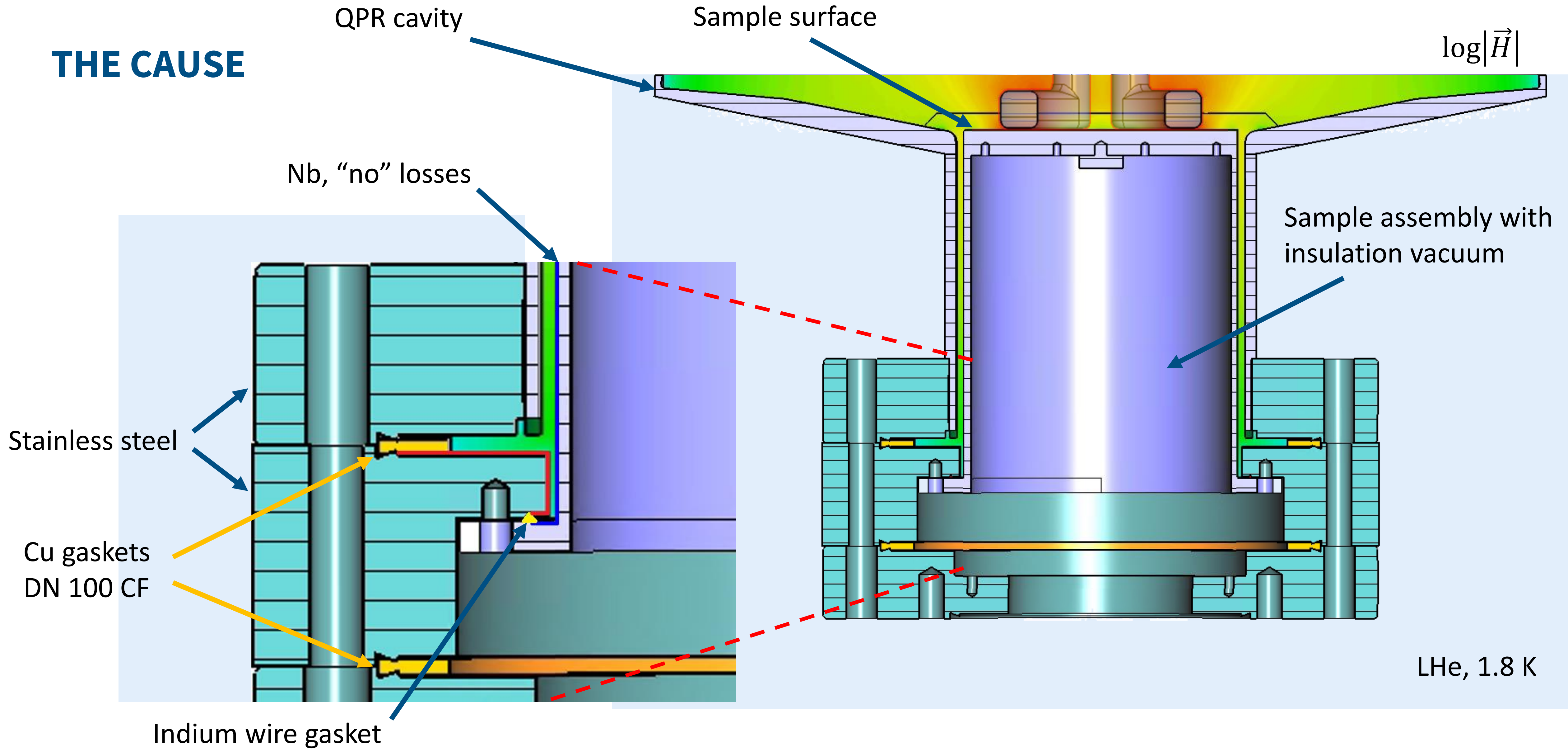
THE CAUSE

- **Calorimetric measurement of the RF surface resistance**

  Integral of all losses on the sample assembly (weighted with the thermal distribution)



THE CAUSE

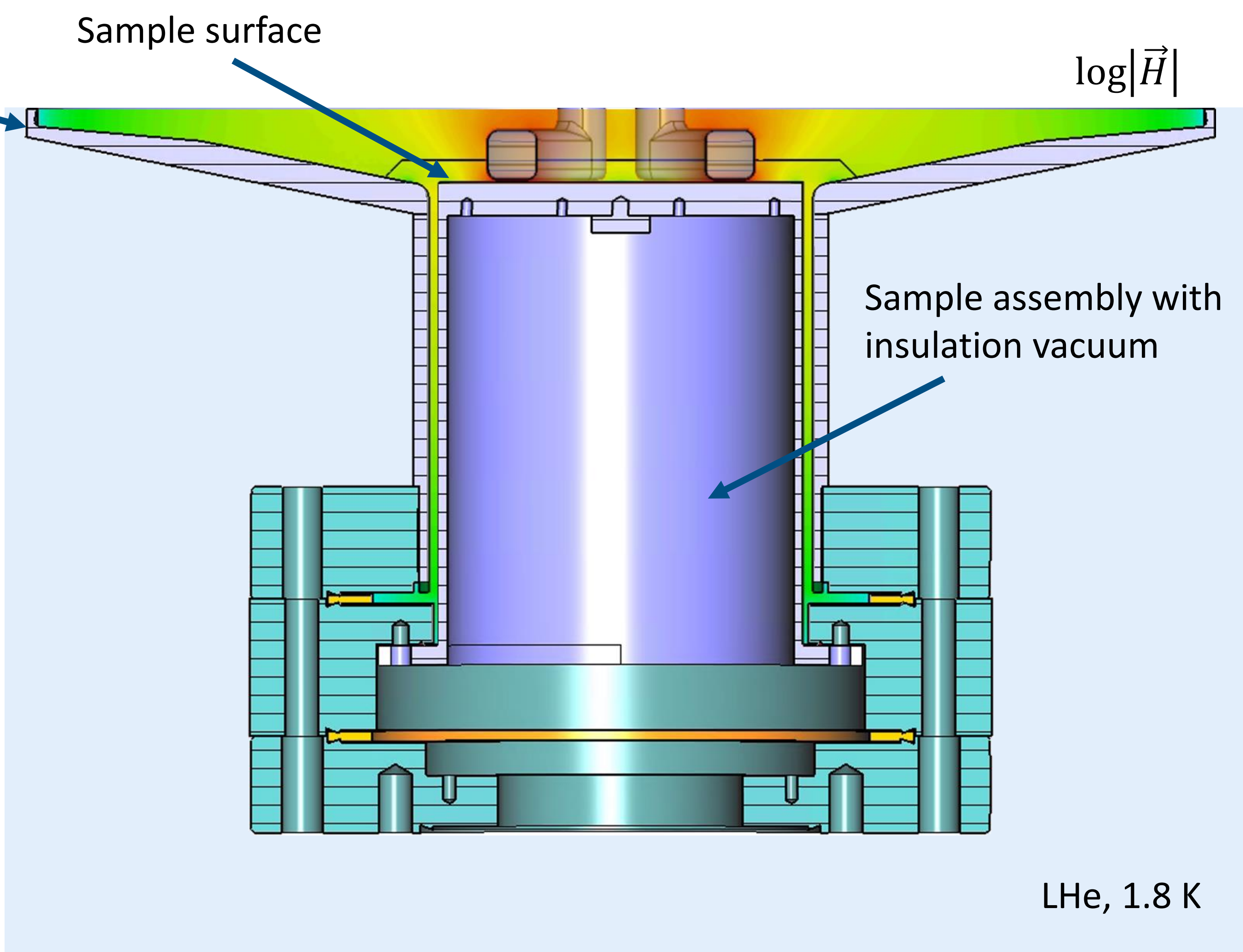

QPR cavity
Sample surface
$\log|\vec{H}|$
Nb, “no” losses
Sample assembly with insulation vacuum
Stainless steel
Cu gaskets DN 100 CF
LHe, 1.8 K
Indium wire gasket

THE CAUSE

- **Calorimetric measurement of the RF surface resistance**
  Integral of all losses on the sample assembly (weighted with the thermal distribution)

- **non-zero RF magnetic field in the coaxial gap → parasitic losses on nc parts of the sample assembly**

- **Very low thermal conductivity of stainless steel at cryogenic temperatures**



SIMULATION PROCESS

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Eigenmode Solver

- RF field
- Normalize solution to B_{RF}

→ Power loss density on stainless flange P_{RF}

Thermal Solver 1

- Temperature distribution due to P_{RF}
- Interpolation: T_{sample} vs. P_{RF}

Thermal Solver 2

- Temperature distribution due to sample heater (P_{DC})
- Interpolation: T_{sample} vs. P_{DC}

Inverse Interpolation

- P_{RF} vs. P_{DC}
- Equivalent sample heater power → Get impact on calorimetric measurement

R_S

- Calculate R_S at given B_{RF} due to P_{RF}

→ Get systematic error for R_S measurements

$$R_S = c \cdot \frac{\Delta P_{DC}}{(B_{RF})^2}$$

	Q_1		
B (mT)	T (K)	P (mW)	R_S (nΩ)
5	2.008	0.067	12.6
10	2.030	0.266	12.6
20	2.117	1.062	12.6
50	2.621	6.527	12.4
100	3.803	28.17	13.4

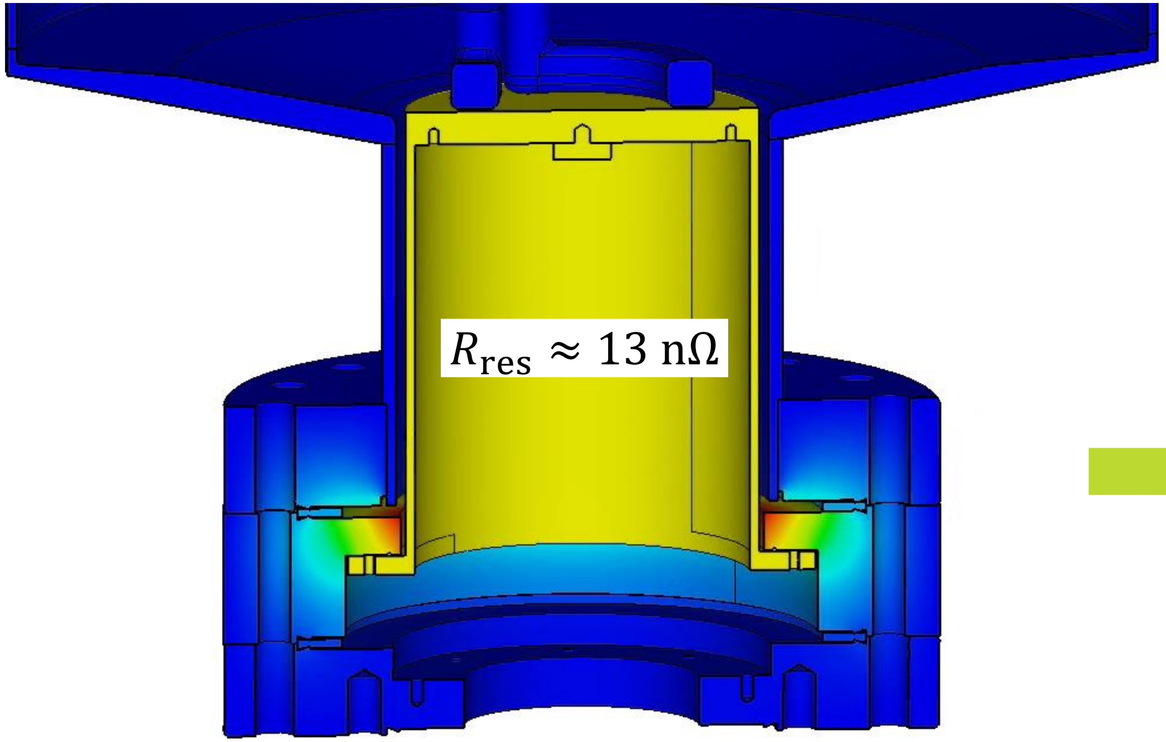
RF → T 1 → T 2 → R_S

Note: This only gives ΔR_S (B_{RF}). The entire simulation chain could be repeated as a function of sample temperature.

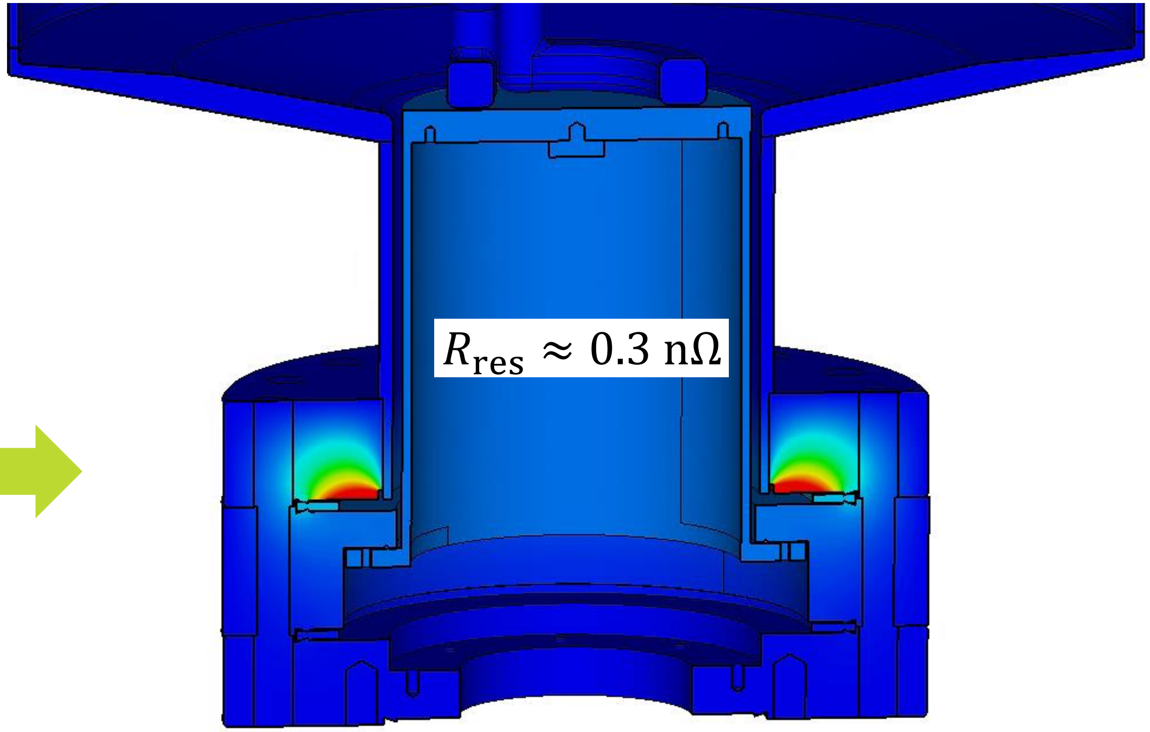
THE SOLUTION

➔ We have to „switch off“ losses on the sample adapter flange

T_{max} = 4.4 K



T_{max} = 2.5 K

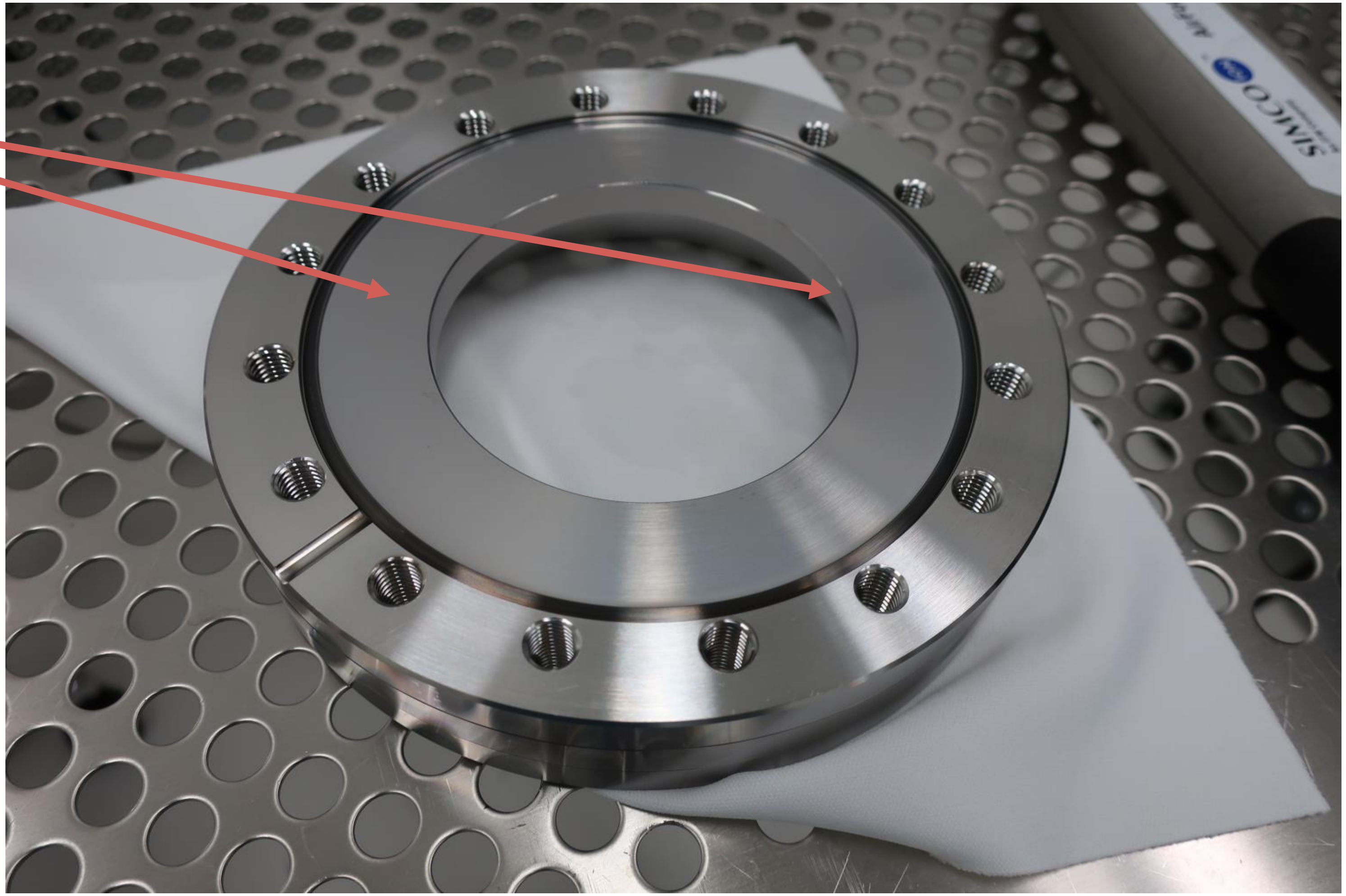


Same RF field, different color scale!
(Eigenmode solver, 1 J stored energy)

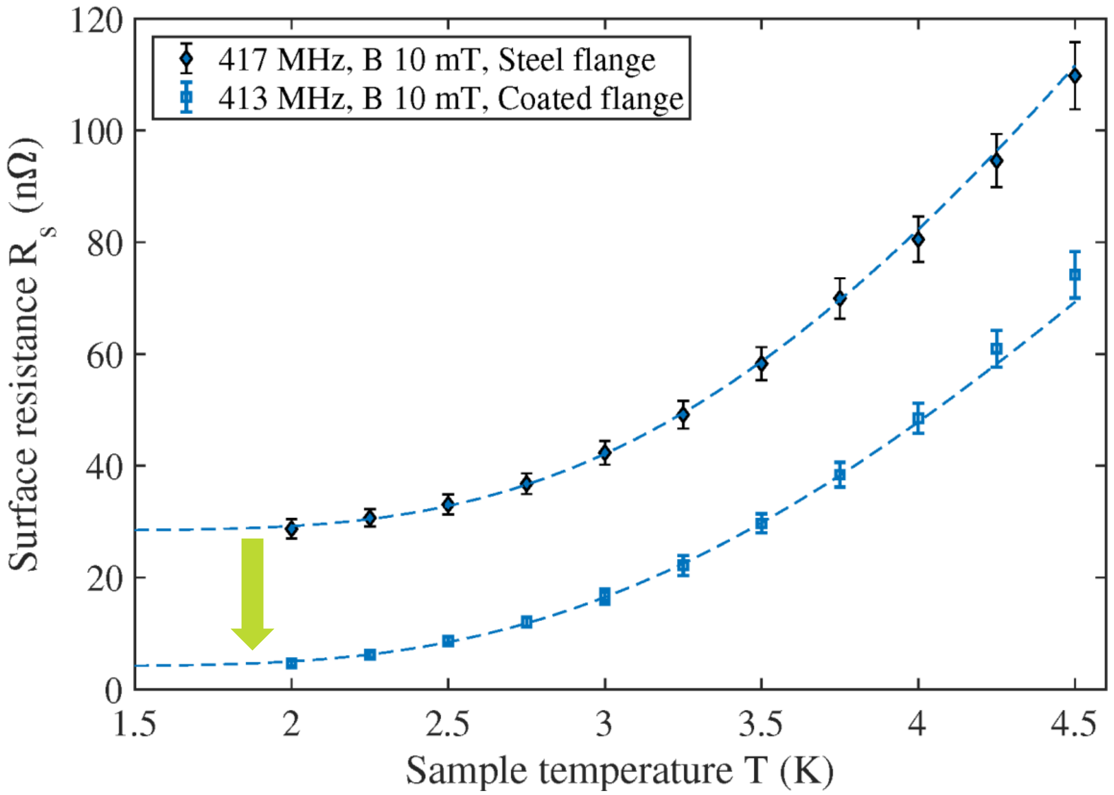
THE SOLUTION

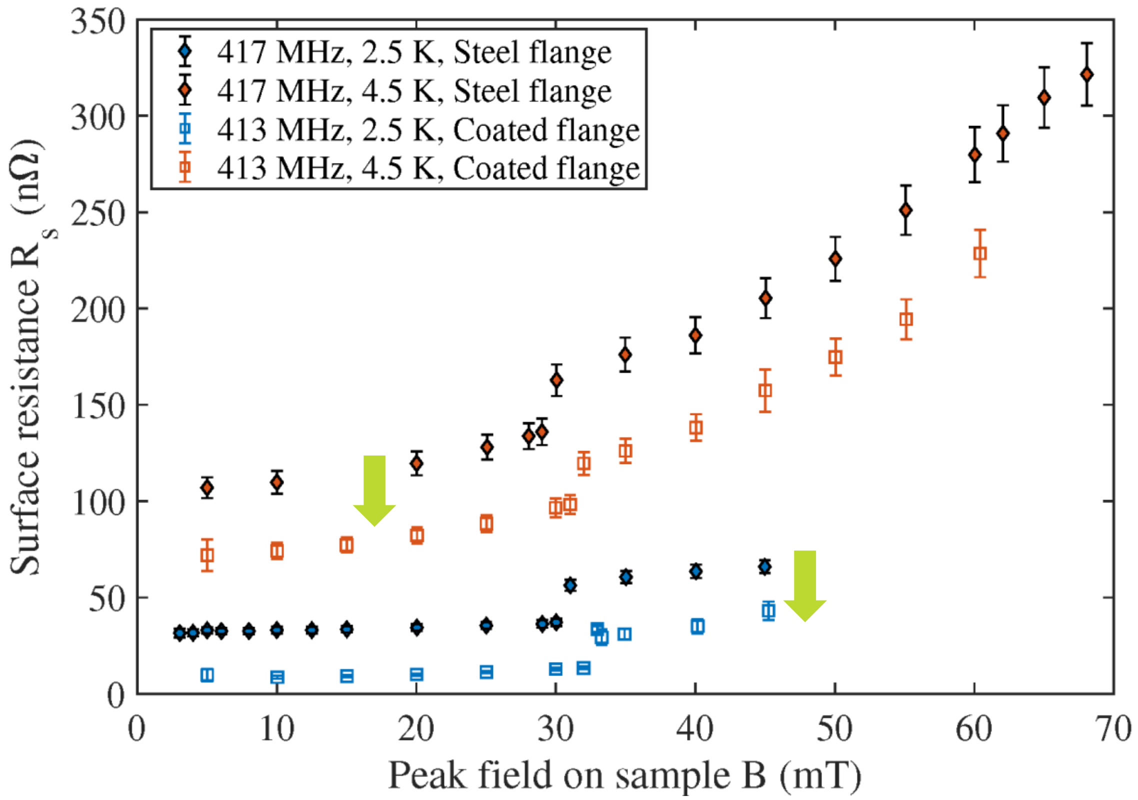
Thin film coating: Nb on stainless steel

- DCMS coating of surfaces
  that are exposed to RF fields
- few µm → full screening
- CF knife edge covered during coating



THE IMPACT





Measured ΔR = 24 nΩ

ΔR is independent of RF field → bias of R_{res} only

THE IMPACT

First „usable“ R_{res} at the third QPR mode (1.29 GHz)

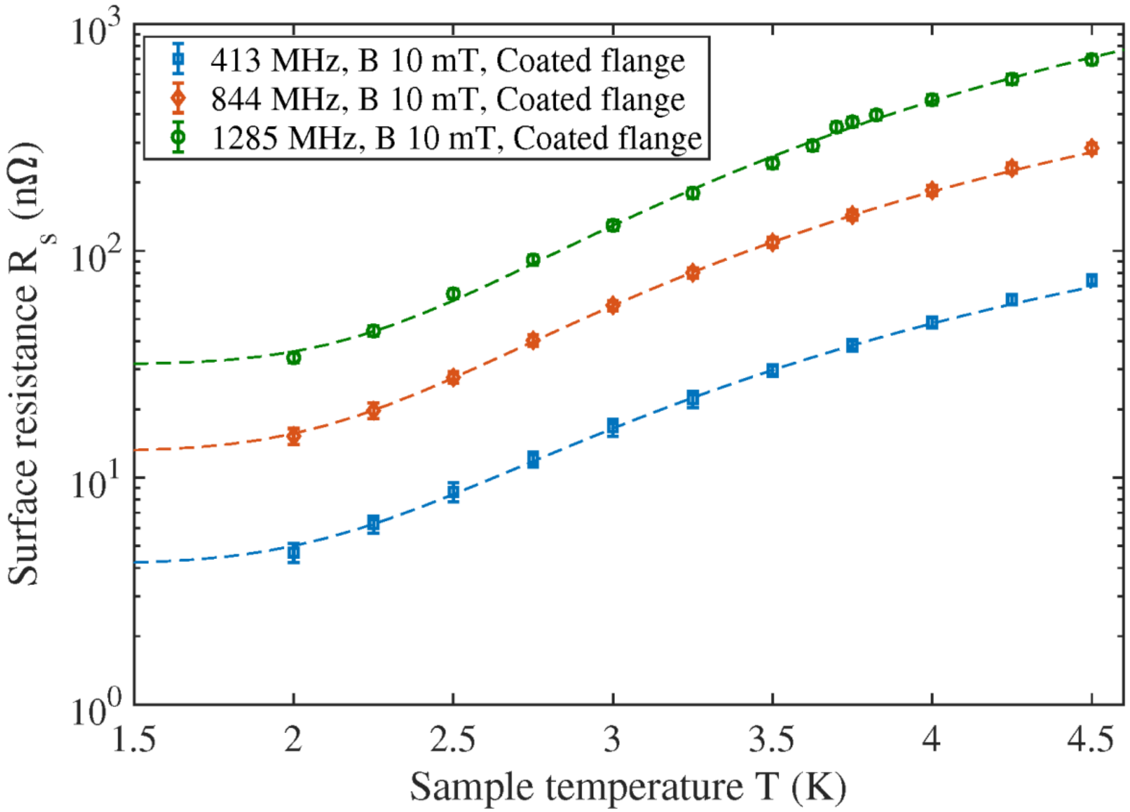
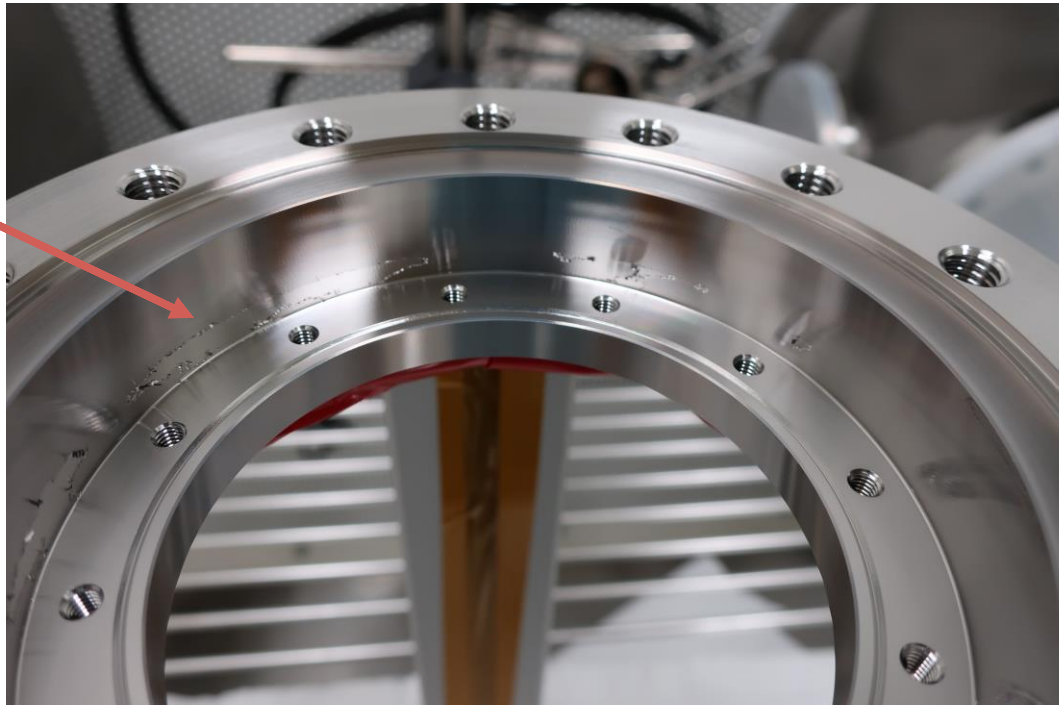


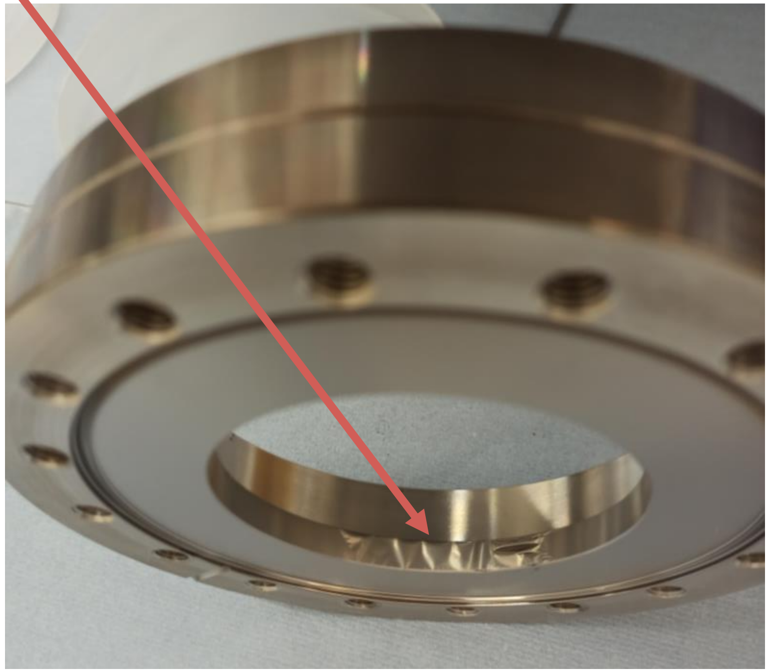
TABLE III. Residual resistance obtained from fitting and selected R_S measurement data at 2.0 and 4.5 K. For all data given, here a constant RF field level of 10 mT was applied.

Setup	Frequency (MHz)	R_S at 2.0 K (nΩ)	R_S at 4.5 K (nΩ)	R_{res} (nΩ)
Baseline	413	28.7	110	28.5
Niobium	417	4.7	74.2	4.2
Coated	844	15.2	284	13.1
Flange	1285	33.8	696	31.6

OUTLOOK #1: OPTIMIZE COATING

- Optimization covering masks ongoing
- 1st coating: Nb ‘remnants’ at bottom part of the flange
- 2nd coating: bottom part covered with 2nd mask
  → low adhesion at inner cylindrical surface due to resputtering





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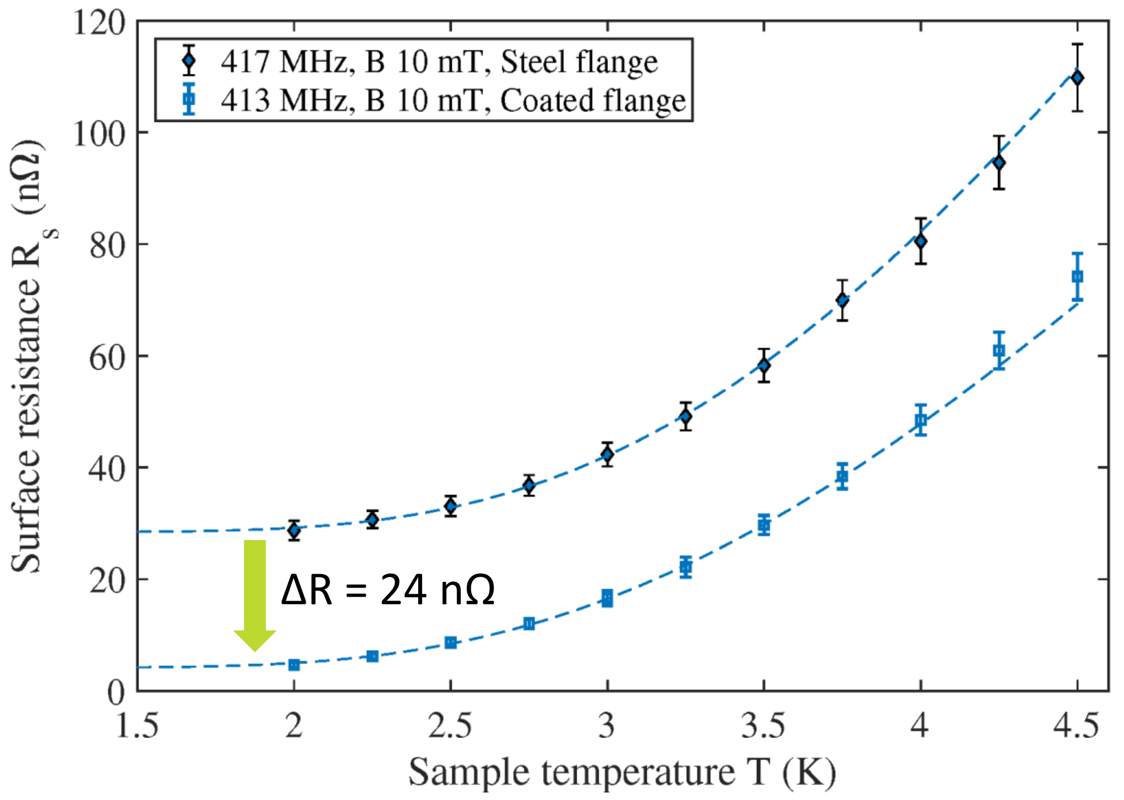
OUTLOOK #2: NEXT STUDIES

- Measured ΔR_S larger than expected from simulations
- Study the impact of geometry errors
  (broken symmetry, manufacturing tolerances)
- Example: tilt one pair of rods by 0.175°
  → displacement 1 mm

TABLE I. Sample temperature, effective power, and parasitic surface resistance for the first three quadrupole modes of the QPR resulting from the finite conductivity of the applied materials.

	Q_1			Q_2			Q_3		
B (mT)	T (K)	P (mW)	R_S (nΩ)	T (K)	P (mW)	R_S (nΩ)	T (K)	P (mW)	R_S (nΩ)
5	2.008	0.067	12.6	2.015	0.129	26.0	2.032	0.282	63.1
10	2.030	0.266	12.6	2.058	0.515	26.0	2.124	1.127	63.0
20	2.117	1.062	12.6	2.219	2.050	25.9	2.446	4.449	62.1
50	2.621	6.527	12.4	3.059	12.84	25.9	3.879	30.08	67.3
100	3.803	28.17	13.4	4.801	58.56	29.5	6.513	131.6	73.6



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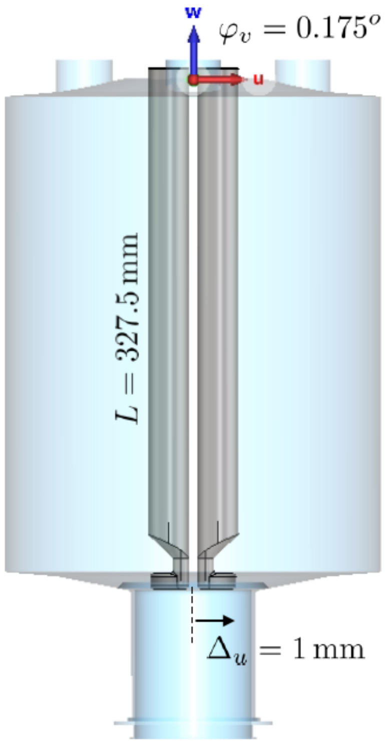
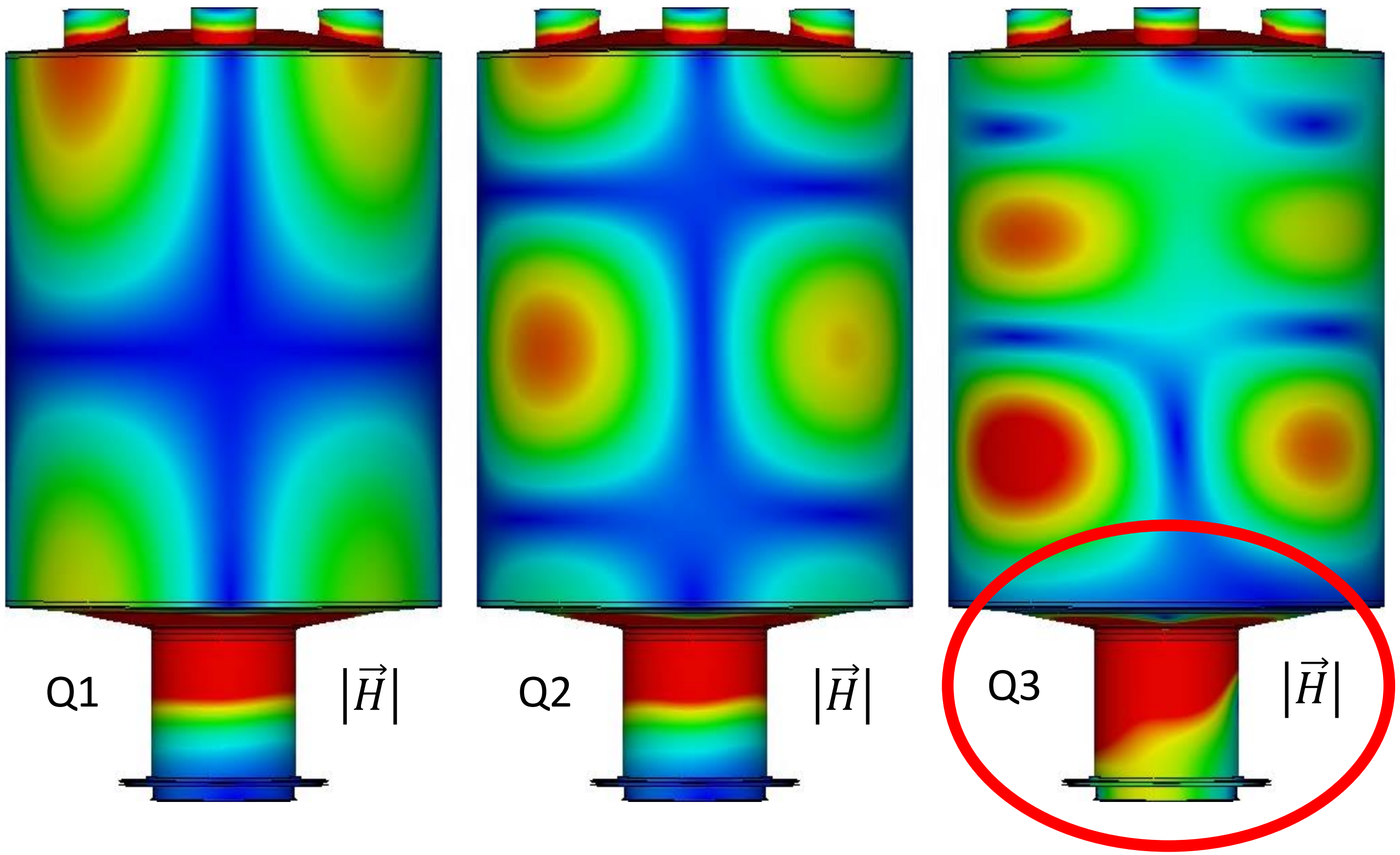
- Study the impact of geometry errors (broken symmetry, manufacturing tolerances)
- Example: tilt one pair of rods by 0.175°
  → displacement 1 mm





- CST eigenmode solver (color plot with linear scaling!)
- Asymmetric quadrupole mode
  → increased fields in the coaxial structure
- Drastic impact for Q3

[Courtesy: W. Ackermann, TEMF, TU Darmstadt]

WAVEGUIDE MODE MAGNITUDES: BASELINE

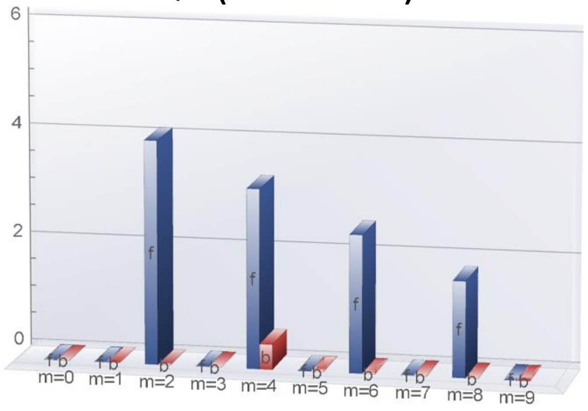
Decomposition of RF field into waveguide modes

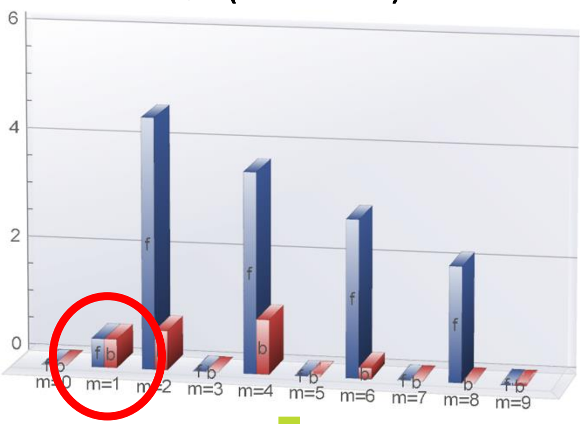
- m=0 monopole
- m=1 dipole
- m=2 quadrupole
- …

Q1 (433 MHz)

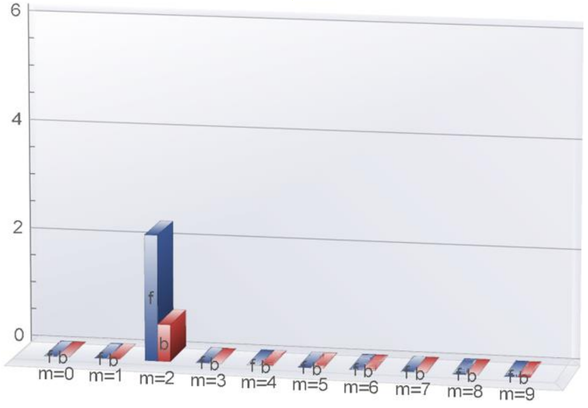
Q3 (1.3 GHz)

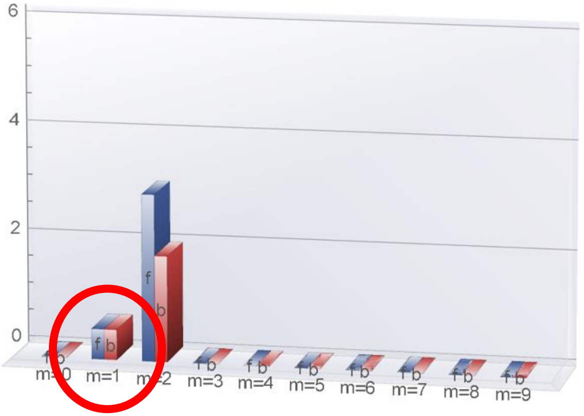
Top

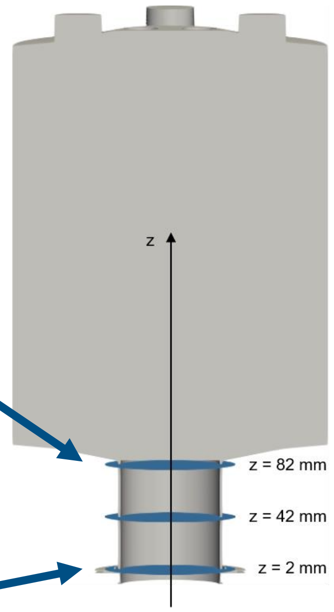




Bottom







Blue: forward travelling

Red: backwards travelling

Logarithmic scaling

Dipole cutoff at 1.24 GHz
→ travelling wave!

[Courtesy: W. Ackermann, TEMF, TU Darmstadt]

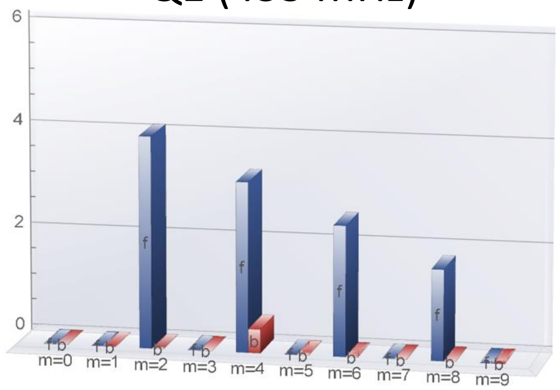
BASELINE

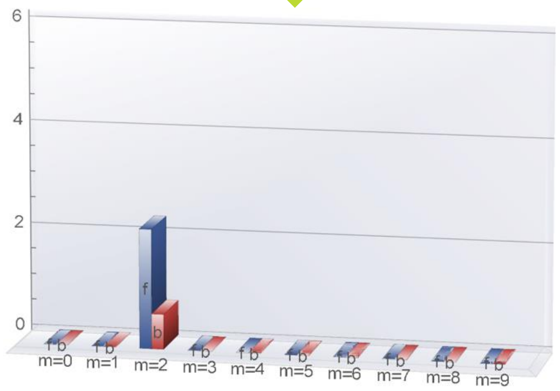
TILTED RODS (0.175°)

Top

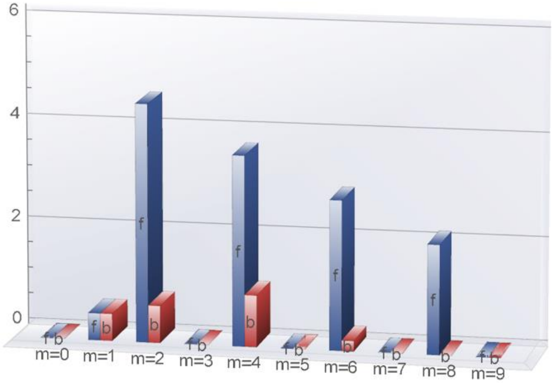
Bottom

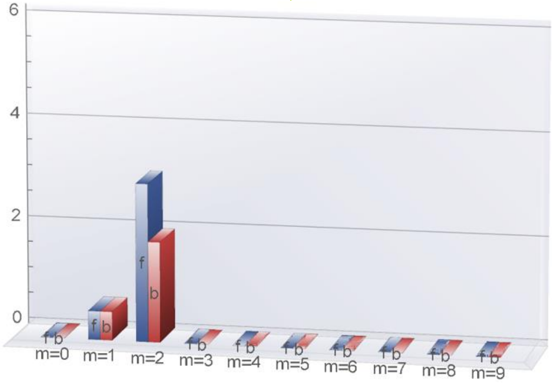
Q1 (433 MHz)





Q3 (1.3 GHz)





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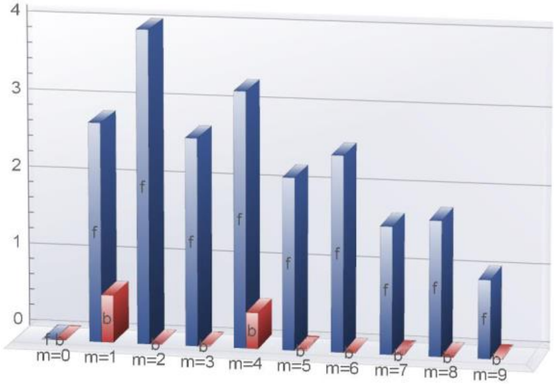

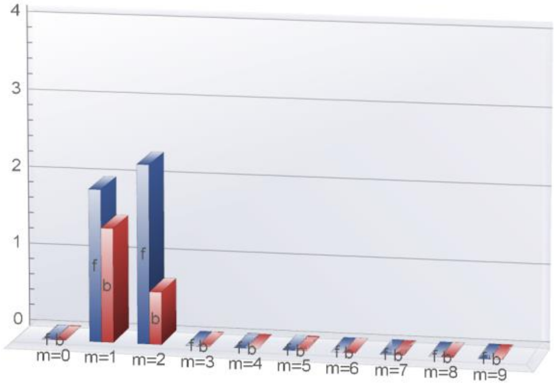

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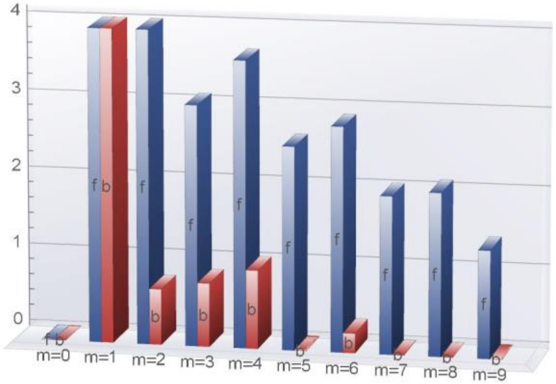

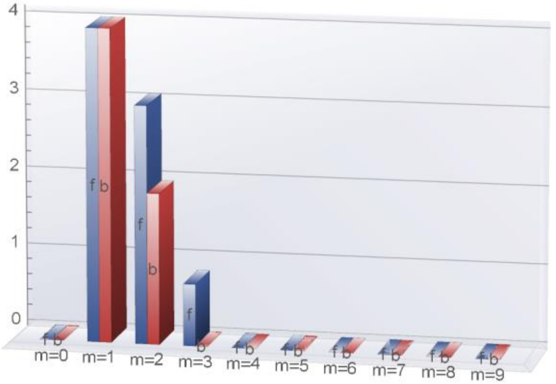

Blue: forward travelling

Red: backwards travelling

Logarithmic scaling

→ Nb coating also reduces the impact of geometrical imperfections

[Courtesy: W. Ackermann, TEMF, TU Darmstadt]

SUMMARY

- Initially: measured R_{res} unexpectedly high
- Cause: parasitic heating on nc adapter flange
  → understood by extensive numerical simulations
- Solution: few µm of Nb coating on the stainless steel flange
- Verified experimentally with QPR data

➔ Coated flange is new standard for QPR measurements

Thank you for your attention !

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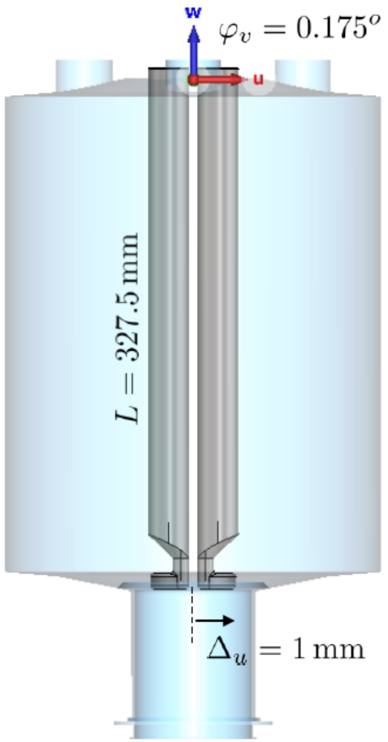
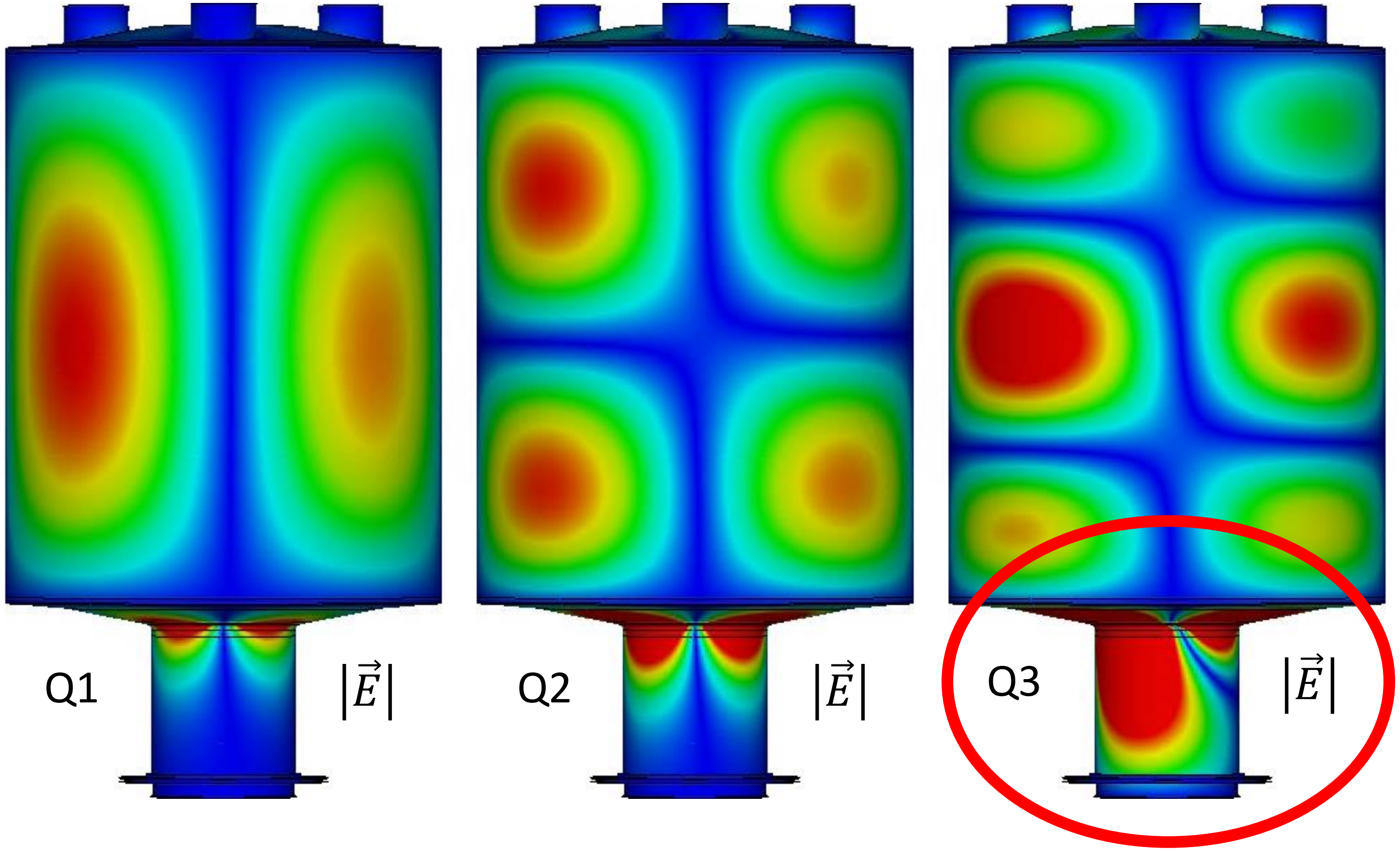
- Example: tilt one pair of rods by 0.175° → displacement 1 mm





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