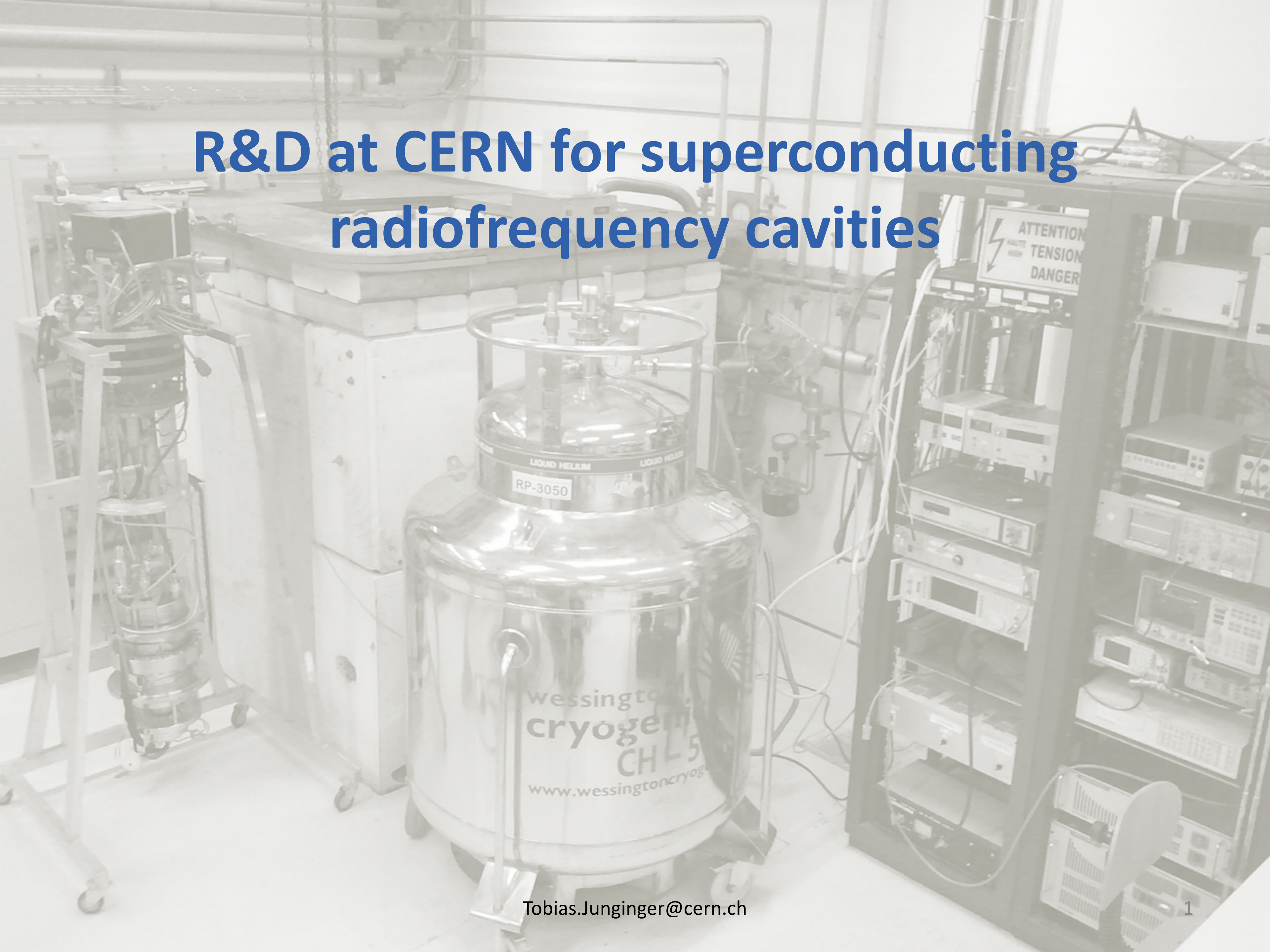
R&D at CERN for superconducting radiofrequency cavities



Tobias.Junginger@cern.ch

Motivation

- Power consumption in a superconducting cavity is proportional to its surface resistance R_S
- R_S shows a complex behavior on external parameters, such as temperature, frequency, magnetic and electric field

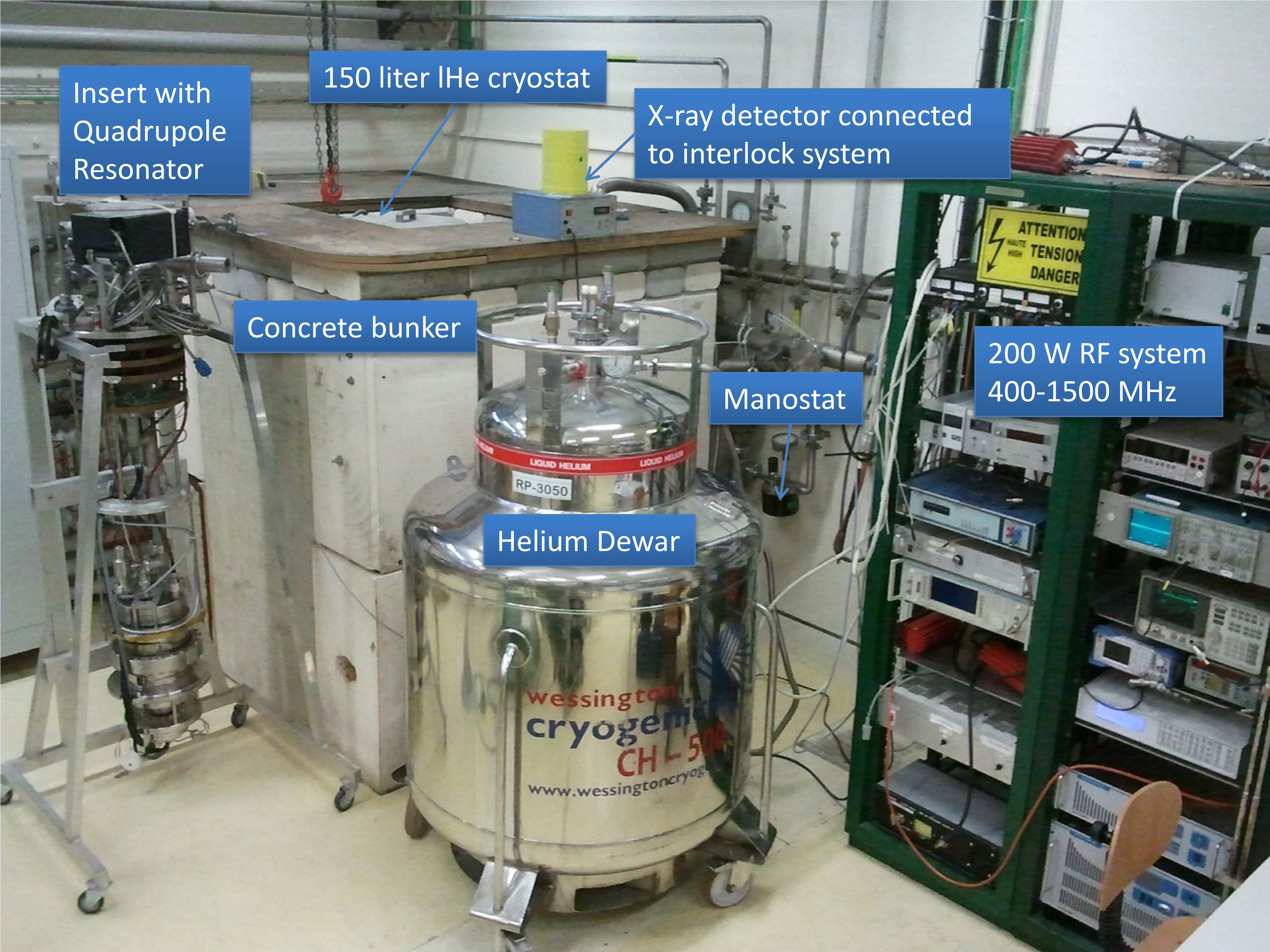
$$P_c \propto R_S(f, T, B, E)$$

- Some open questions:
  - Origin of the residual resistance
  - Origin of the field-dependent resistance
  - Stronger field-dependent resistance of niobium films compared to bulk niobium
  - Influence of magnetic and electric field
  - Relation to the surface properties
  - Possibilities and limitations of materials other than niobium

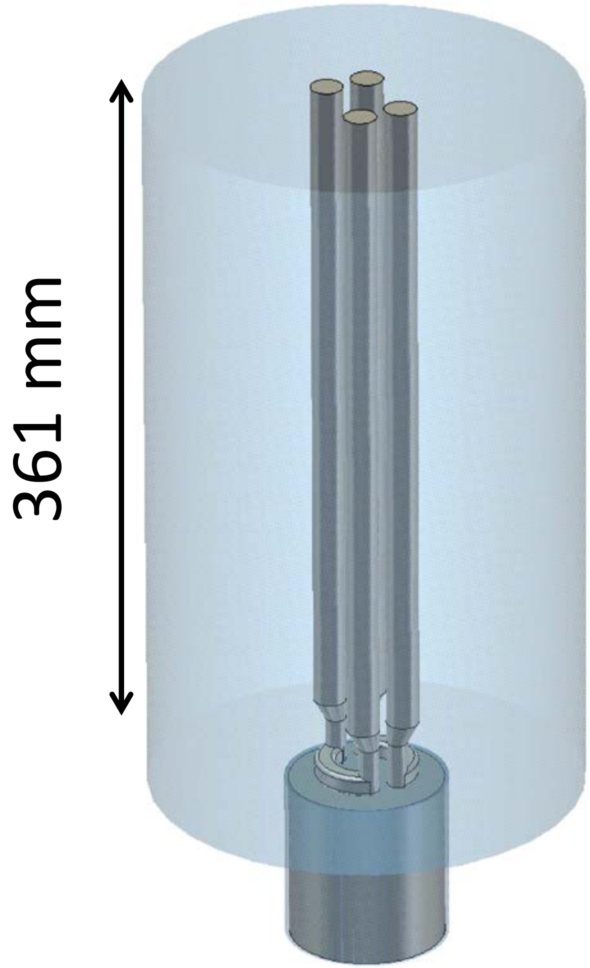
Motivation

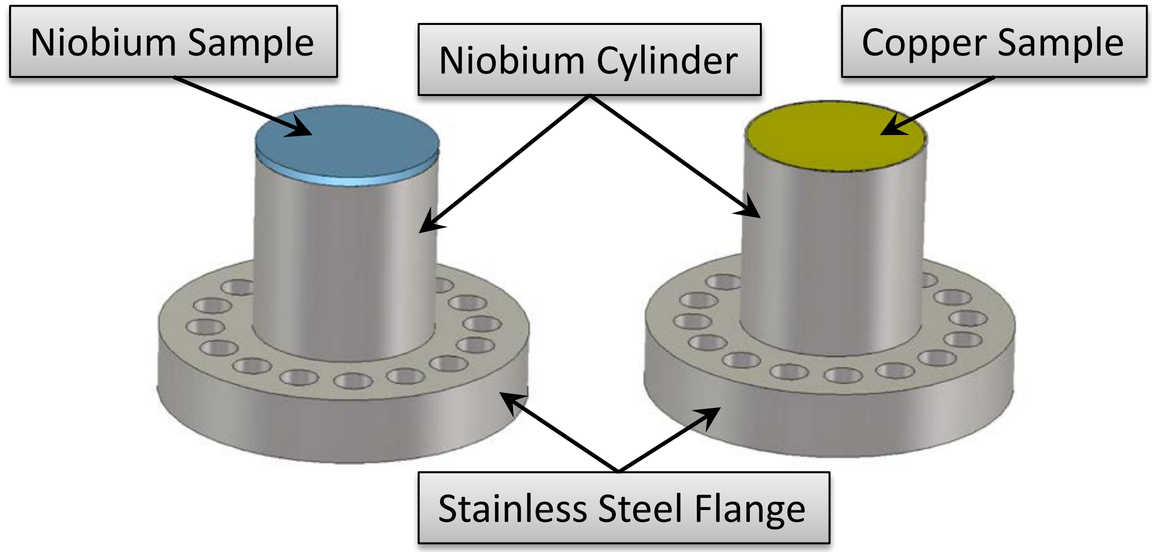
PhD Project 1 - Sarah Aull (Univ. Siegen):
RF characterization of samples over a wide parameter range using a Quadrupole Resonator to test surface resistance models on different materials

PhD Project 2 - Giovanni Terenziani (Univ. Sheffield):
Develop High Power Impulse Magnetron Sputtering (HIPIMS) coatings to overcome limitations of standard Direct Current Magnetron Sputtering (DCMS) coatings


Insert with Quadrupole Resonator
150 liter lHe cryostat
X-ray detector connected to interlock system
Concrete bunker
200 W RF system 400-1500 MHz
Manostat
Helium Dewar
ATTENTION HAUTE TENSION DANGER
LIQUID HELIUM
RP-3050
wessington
cryogenics
www.wessingtoncryog

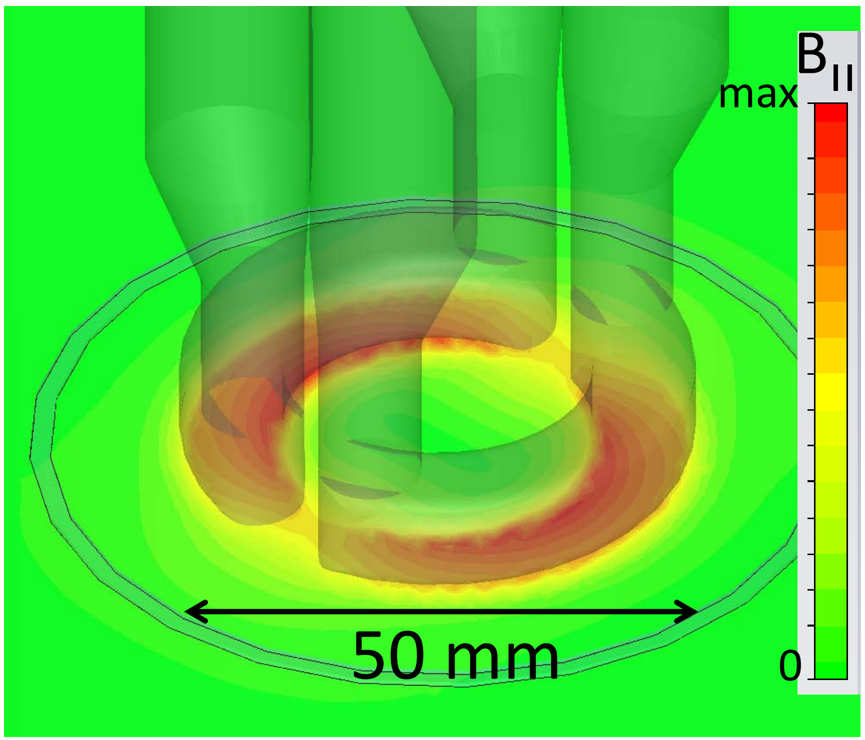
Design of the Quadrupole Resonator





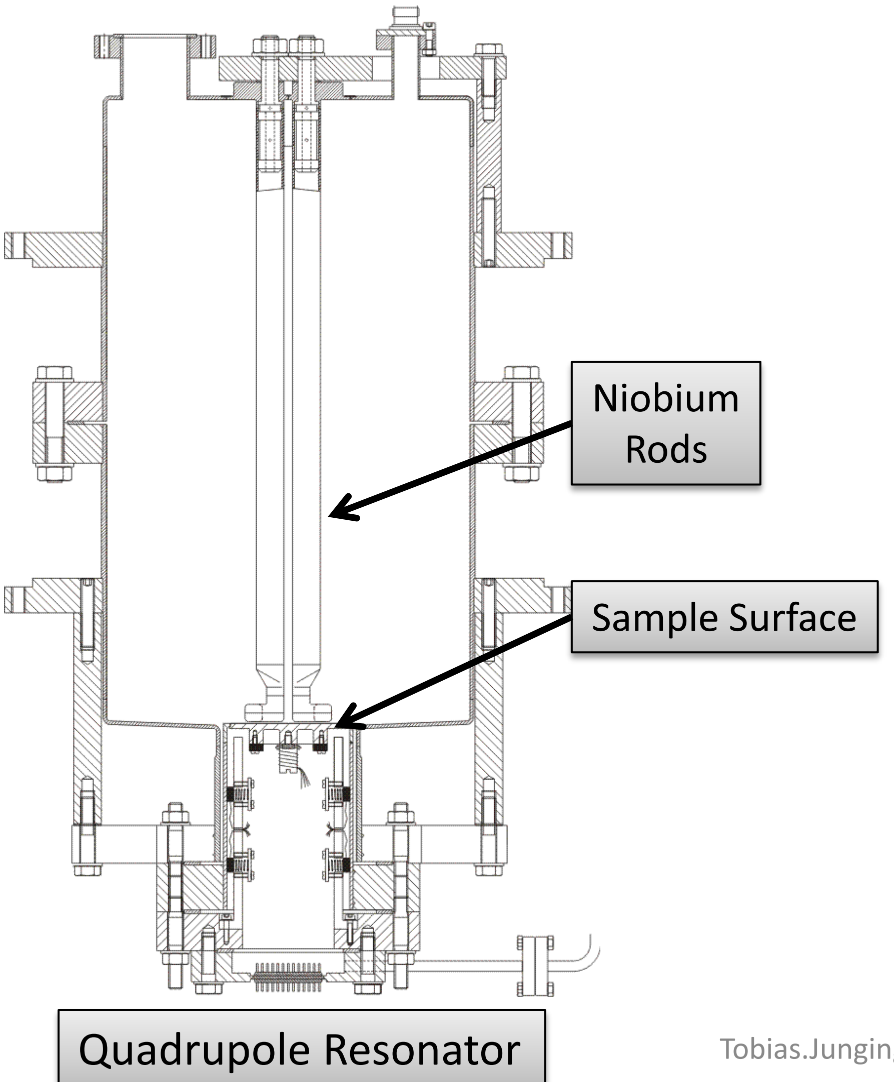
- Sample diameter: 75 mm
- The sample needs to be EB-welded to the sample cylinder
- Bulk niobium and copper samples are available

Field Configuration & Features



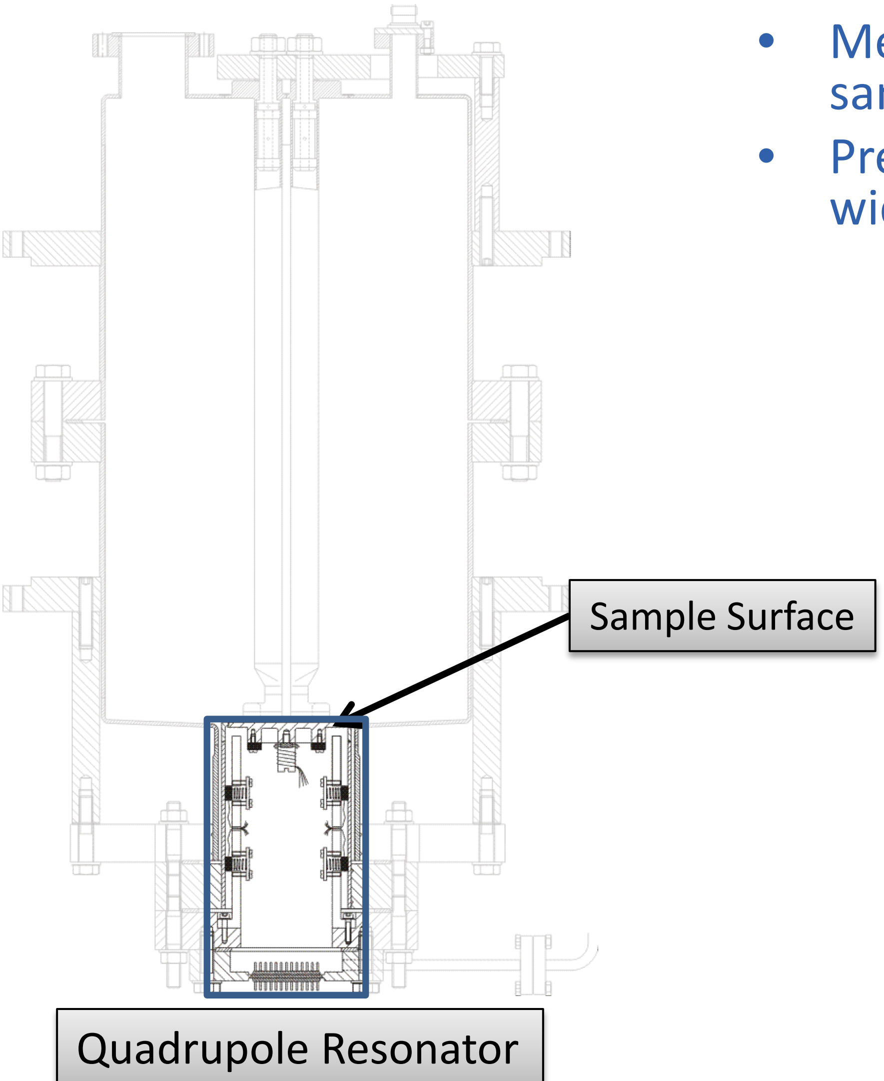
- Resonant frequencies:
  400, 800, 1200 MHz
- Almost identical magnetic field configuration
- Ratio between peak magnetic and electric field proportional to frequency

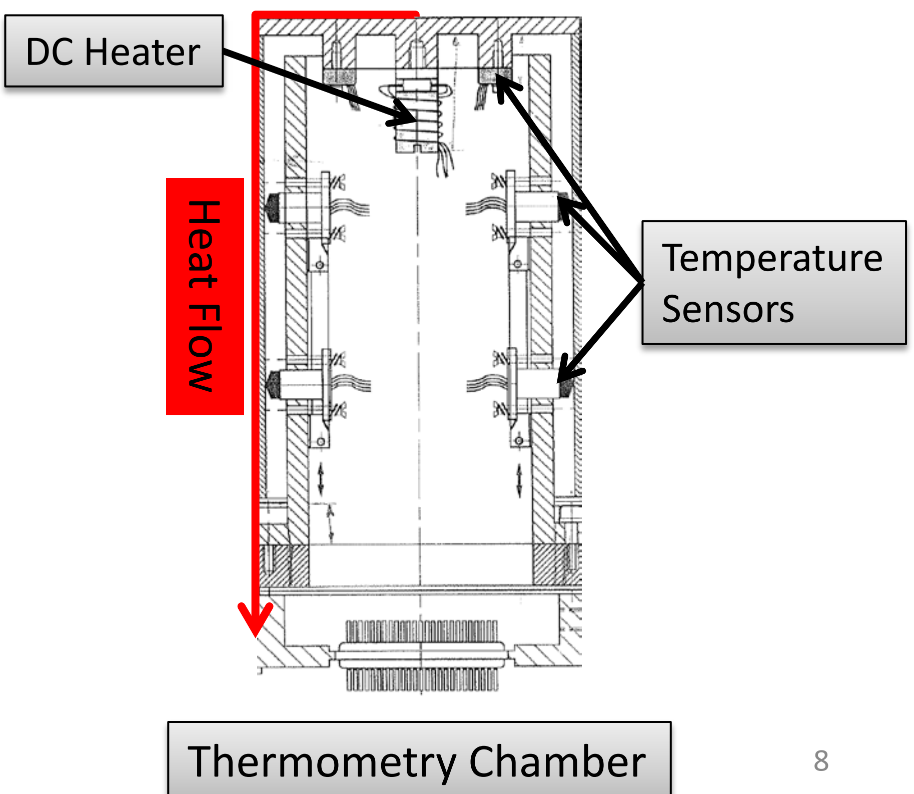
The Calorimetric Technique



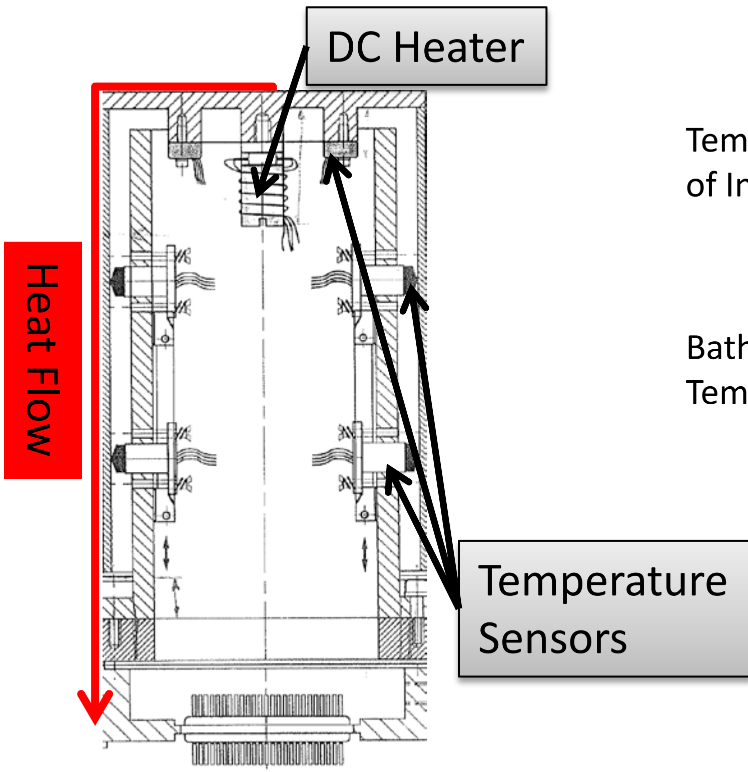
The Calorimetric Technique

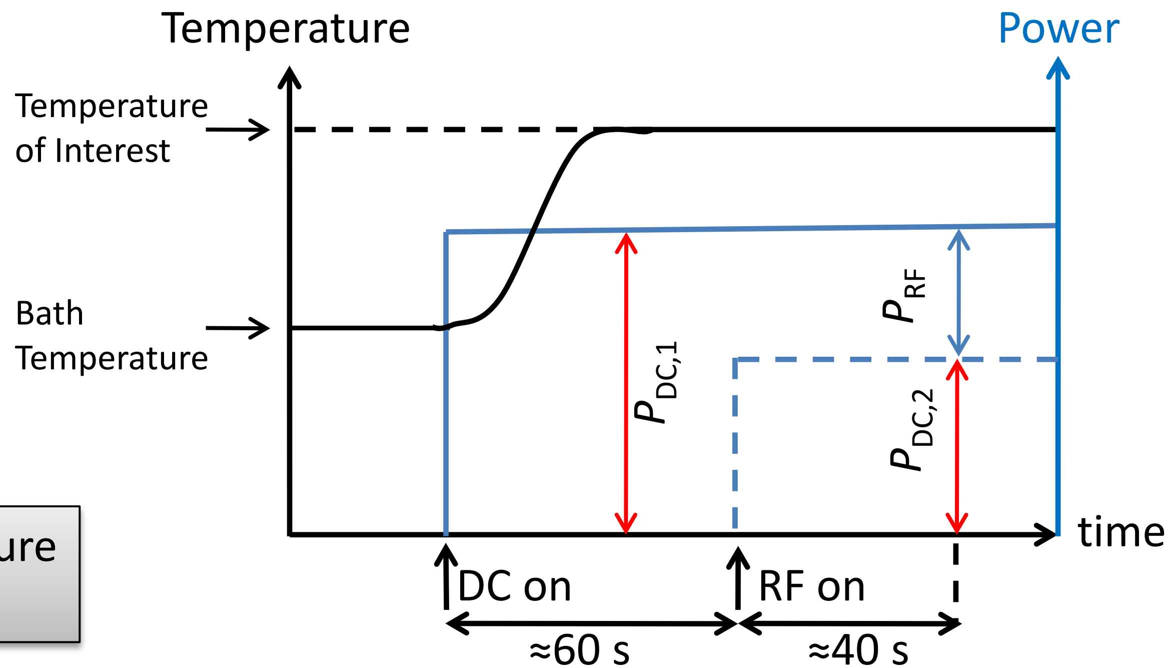
- Measuring the temperature on the sample surface
- Precise Calorimetric measurements over wide temperature range





The Calorimetric Technique

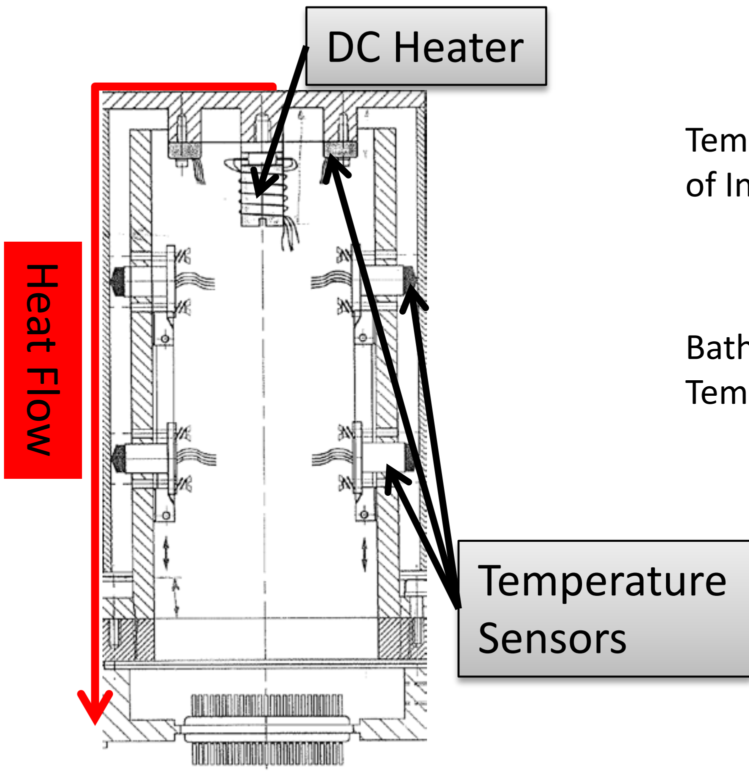


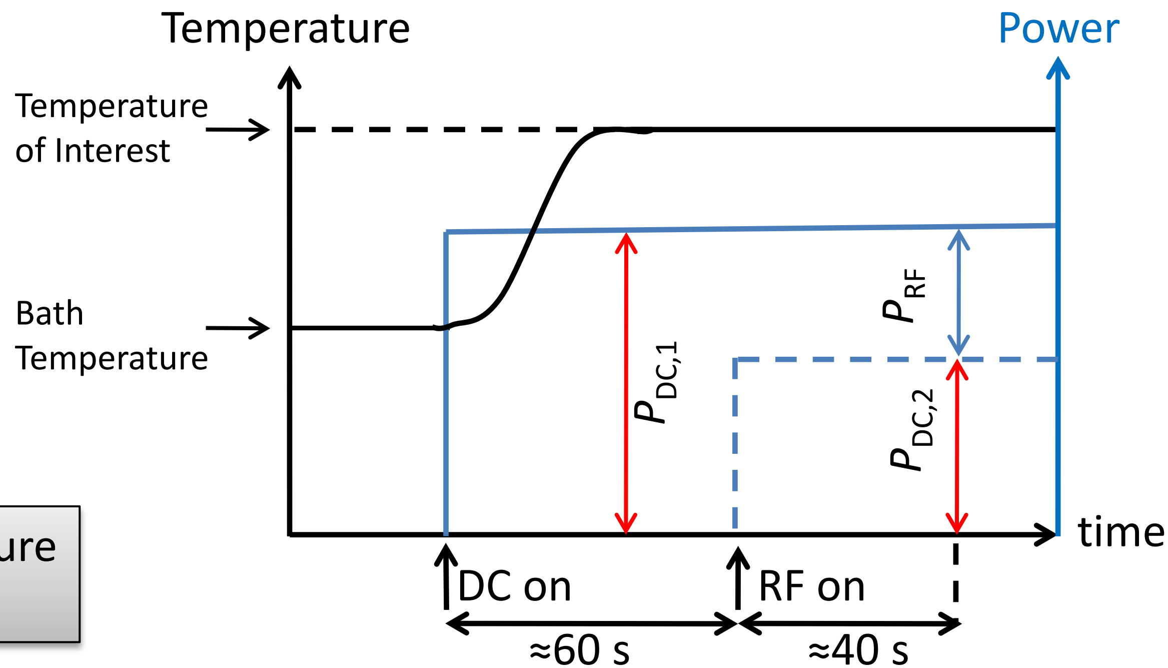


$$P_{RF} = P_{DC,1} - P_{DC,2} \approx 1/2\, R_{Surface} \int_{Sample} H^2 dS$$

$$R_{Surface} = \frac{2(P_{DC,1} - P_{DC,2})}{\int_{Sample} H^2 dS}$$

The Calorimetric Technique





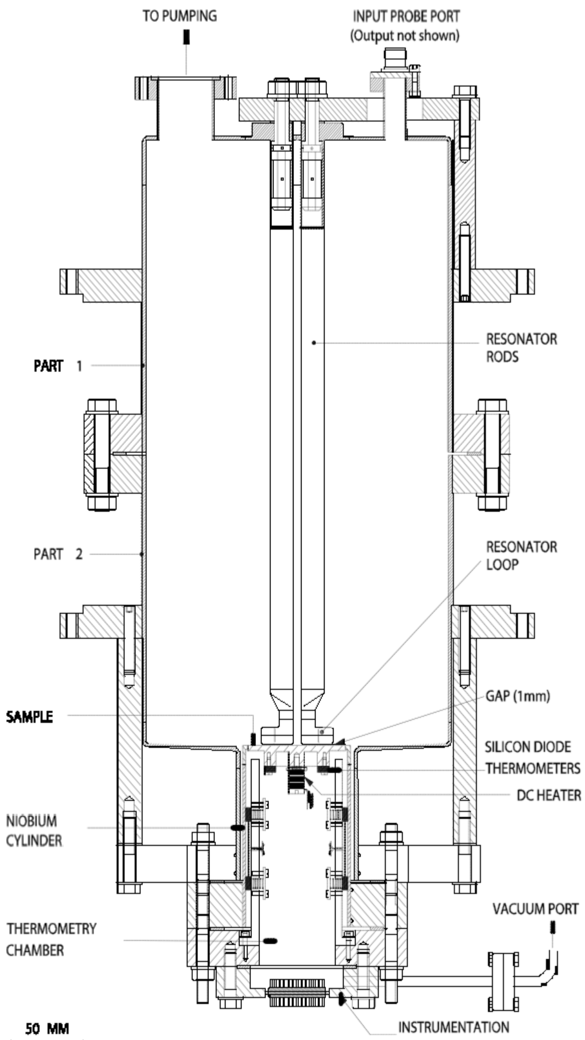
$$P_{RF} = P_{DC,1} - P_{DC,2} \approx 1/2\, R_{Surface} \int_{Sample} H^2 dS$$

$$R_{Surface} = \frac{2(P_{DC,1} - P_{DC,2})}{\int_{Sample} H^2 dS}$$

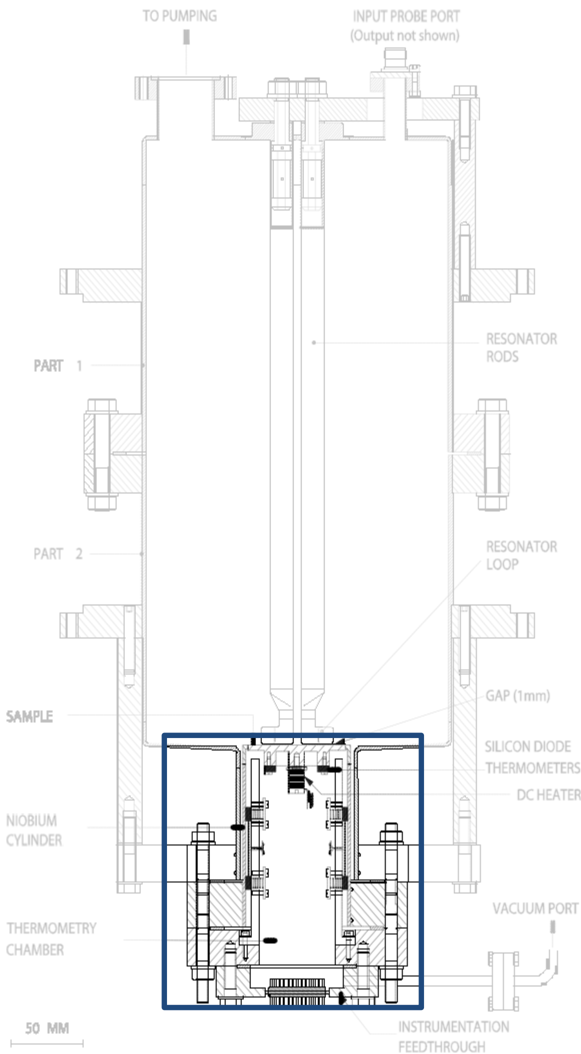
Measured directly

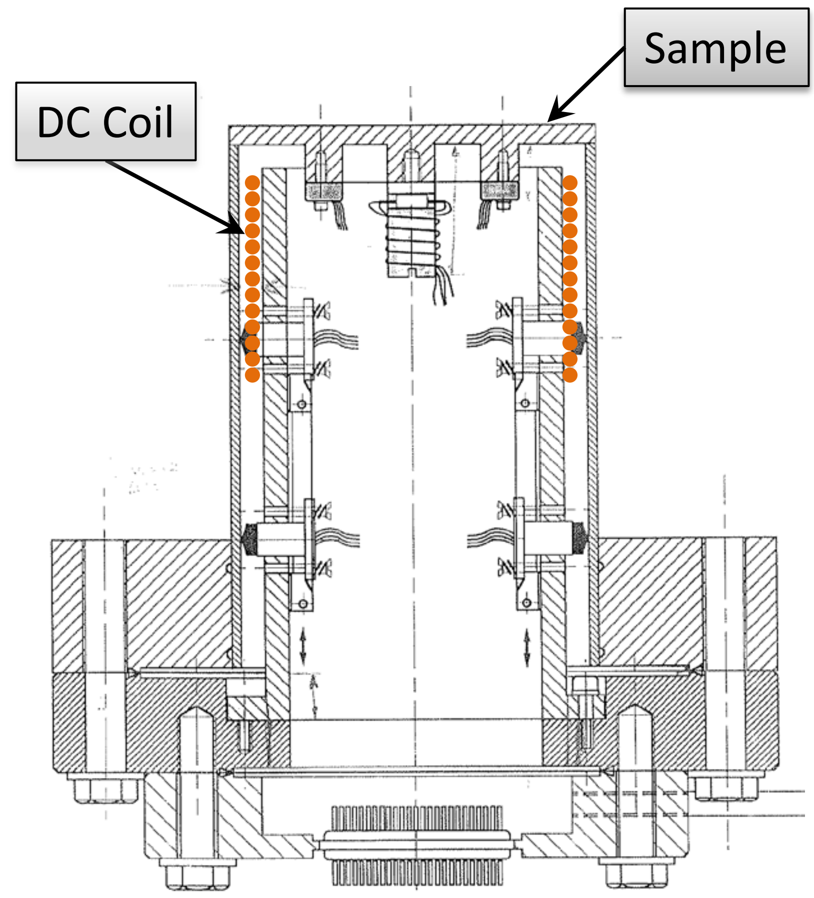
- Measurement of transmitted power P_t
- $P_t = c\int H^2 ds$, c from computer code

Flux Trapping

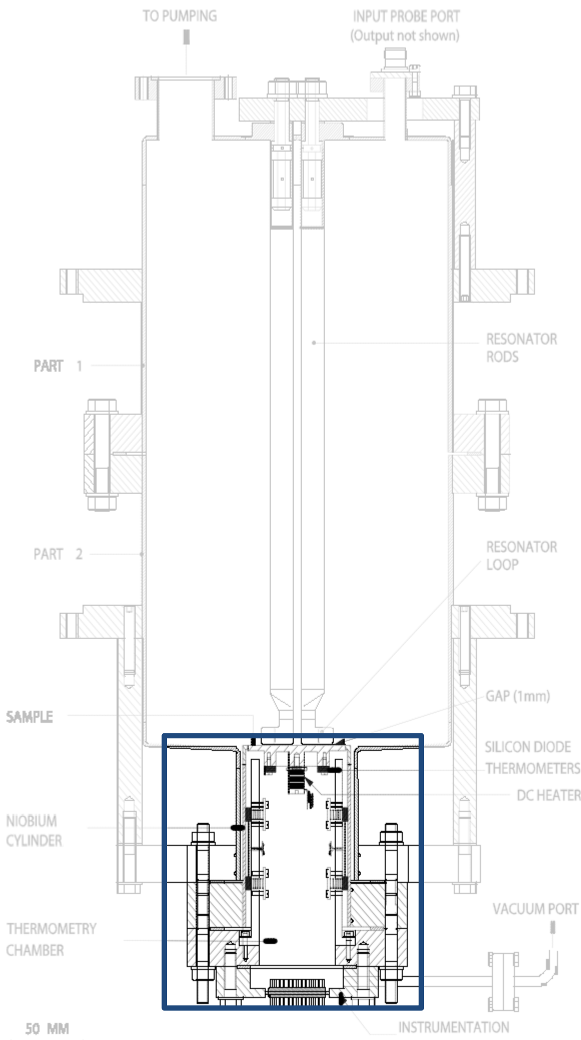


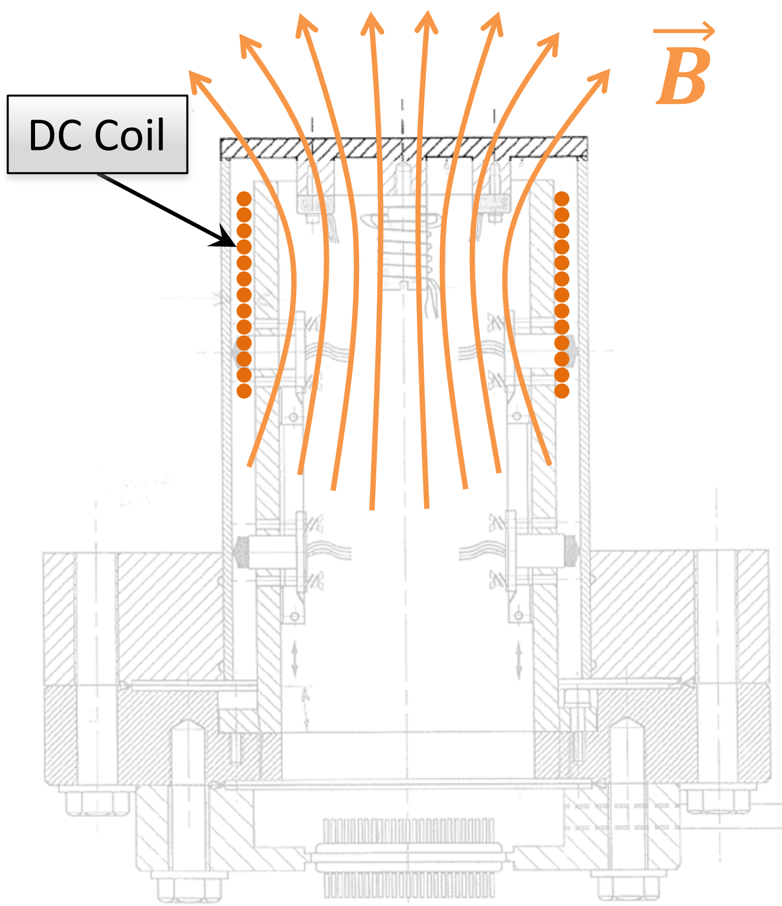
Flux Trapping



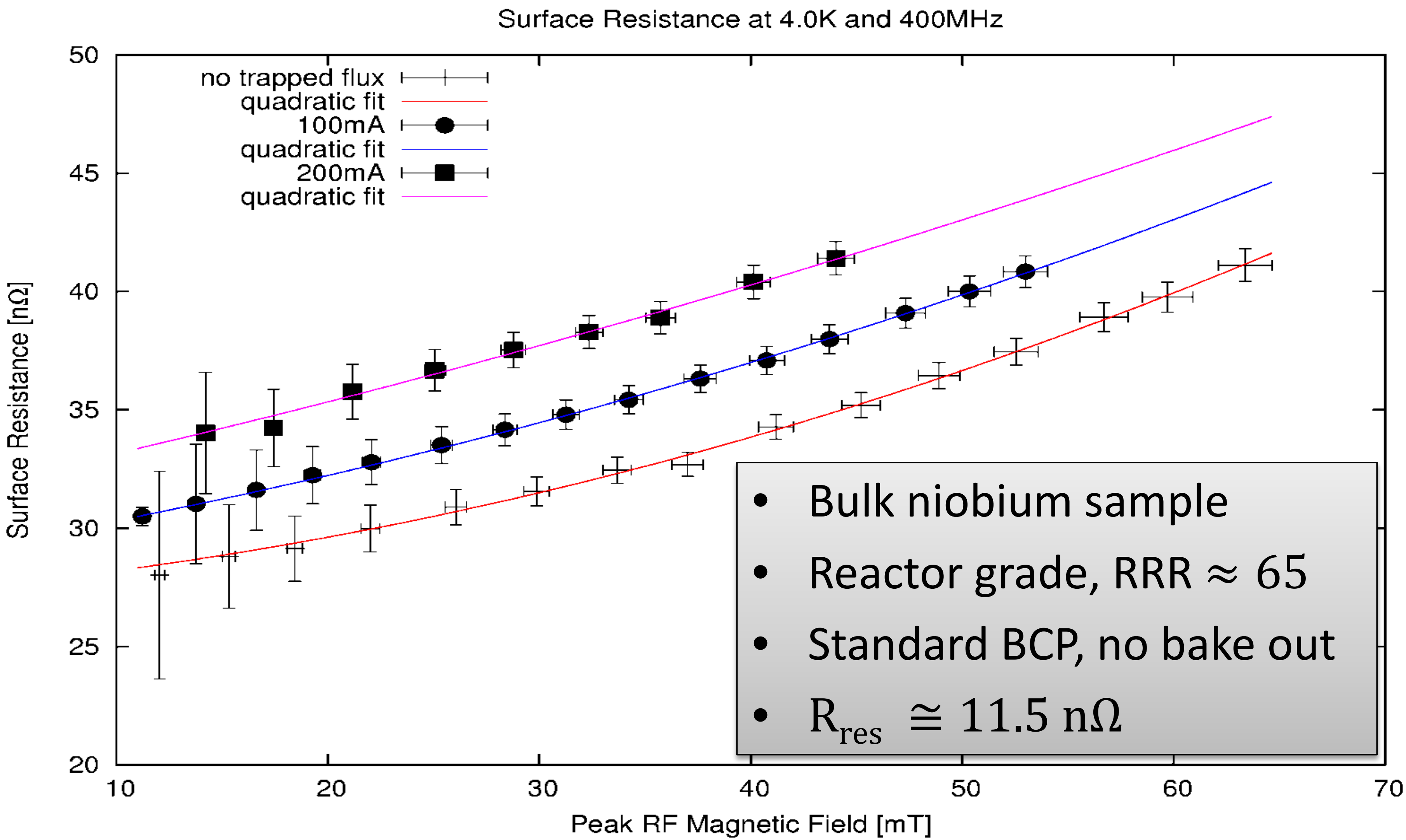


Flux Trapping





Trapped Flux at 400MHz and 4K

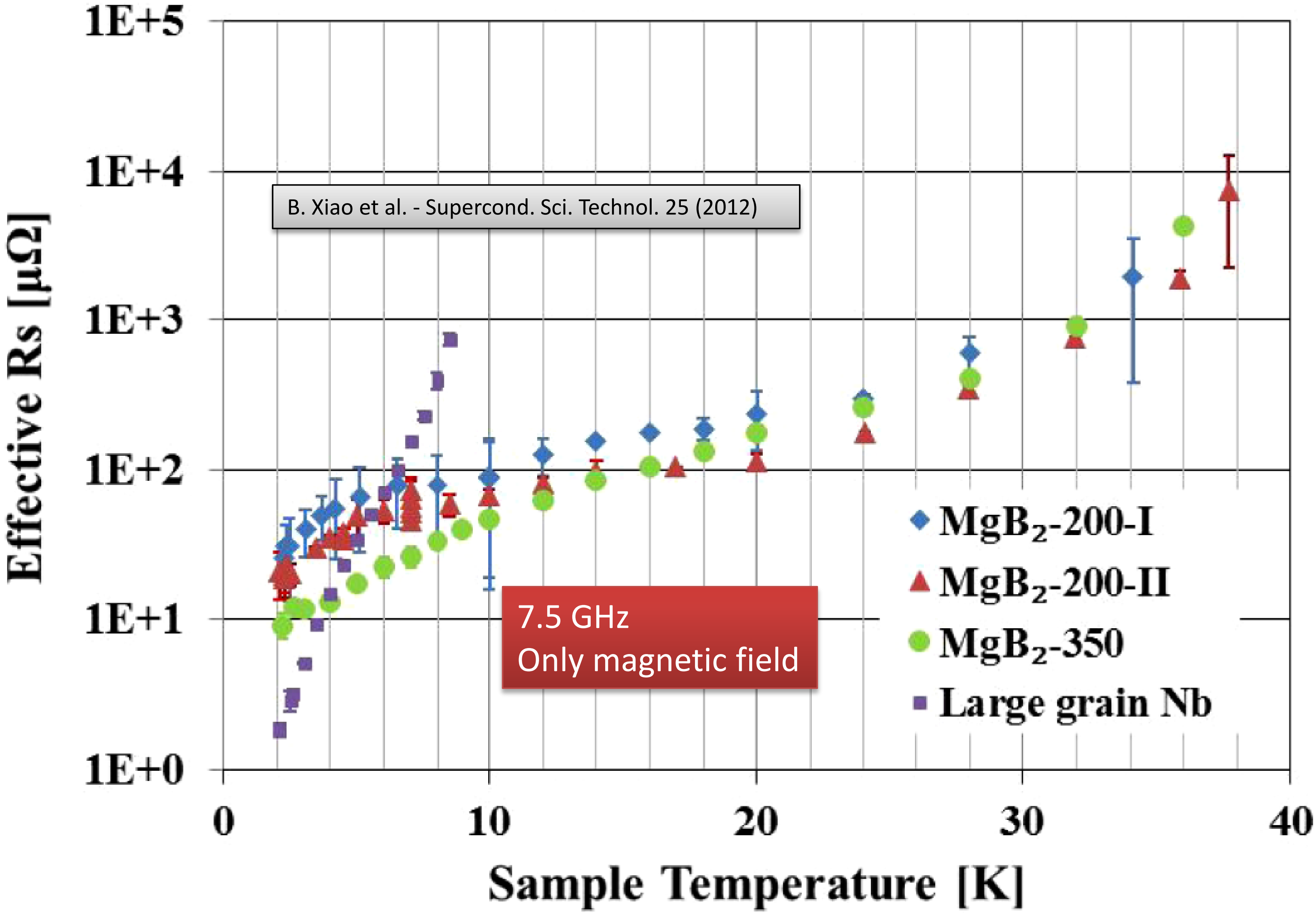


- Bulk niobium sample
- Reactor grade, RRR ≈ 65
- Standard BCP, no bake out
- $R_{res} \cong 11.5$ nΩ

Magnesiumdiboride MgB_2

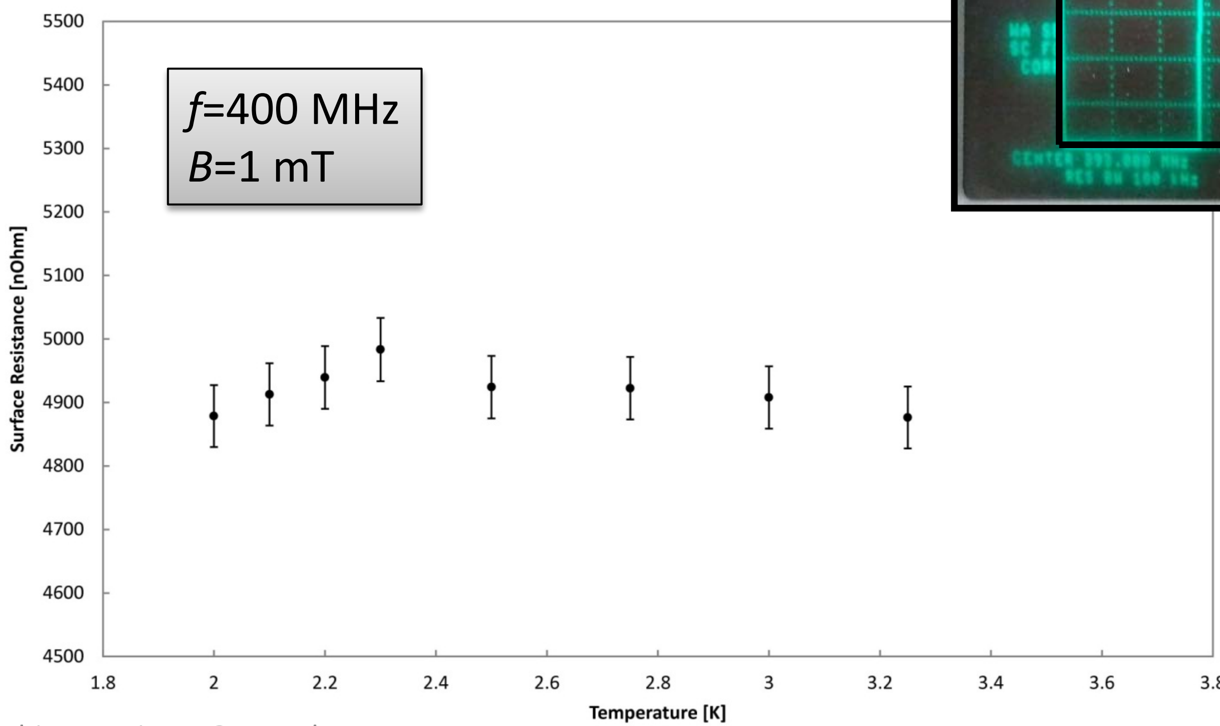
Material	Bulk Niobium	MgB_2
R_{res}	A few nΩ	?
dR/dT (theoretically well understood)	Lowest for all elements	Better
dR/dB	Lowest increase, best studied material	So far worse, very few measurements
B_{c1}	Close to Bc ≈ 200 mT	Worse
B_{sh}	Above Bc	Better

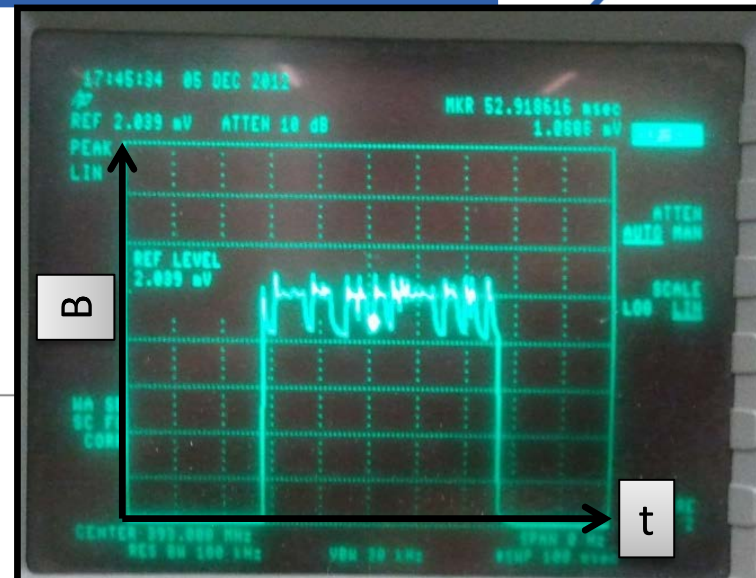
Magnesiumdiboride MgB_2



Magnesiumdiboride MgB_2

- Barrier in transmitted power above 1.3 mT
- Multipacting?





Tobias.Junginger@cern.ch

Quadrupole Resonator - Summary and Outlook

- Sample tests over a parameter range inaccessible to elliptical cavities:
  - Three different RF frequencies, with almost identical magnetic field configuration
  - Frequency dependent electric field configuration
  - Wide temperature range
  - Accuracy of about 0.05 nΩ
  - Study the influence of trapped magnetic flux

  → **Unique possibilities to test surface resistance models and study new materials**
- Next sample to be tested: Niobium on Copper deposited by HIPIMS technology

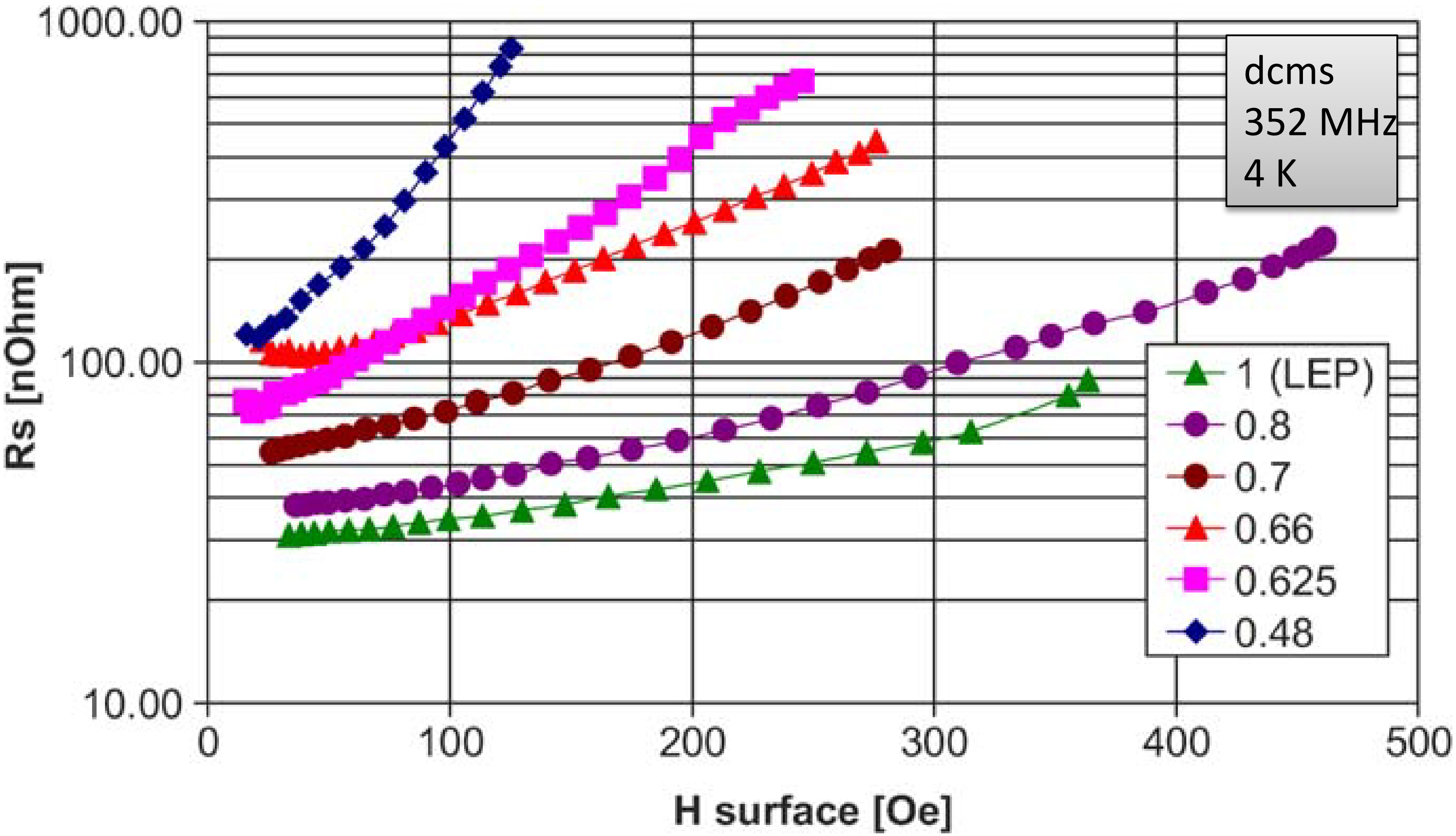
Lessons learned with sputtered films

- 288 Nb/Cu cavities installed in LEP
- 16 Nb/Cu cavities installed in LHC
- About 300 coatings on 1.5 GHz for R&D
- Low-beta studies, several 10's of coatings

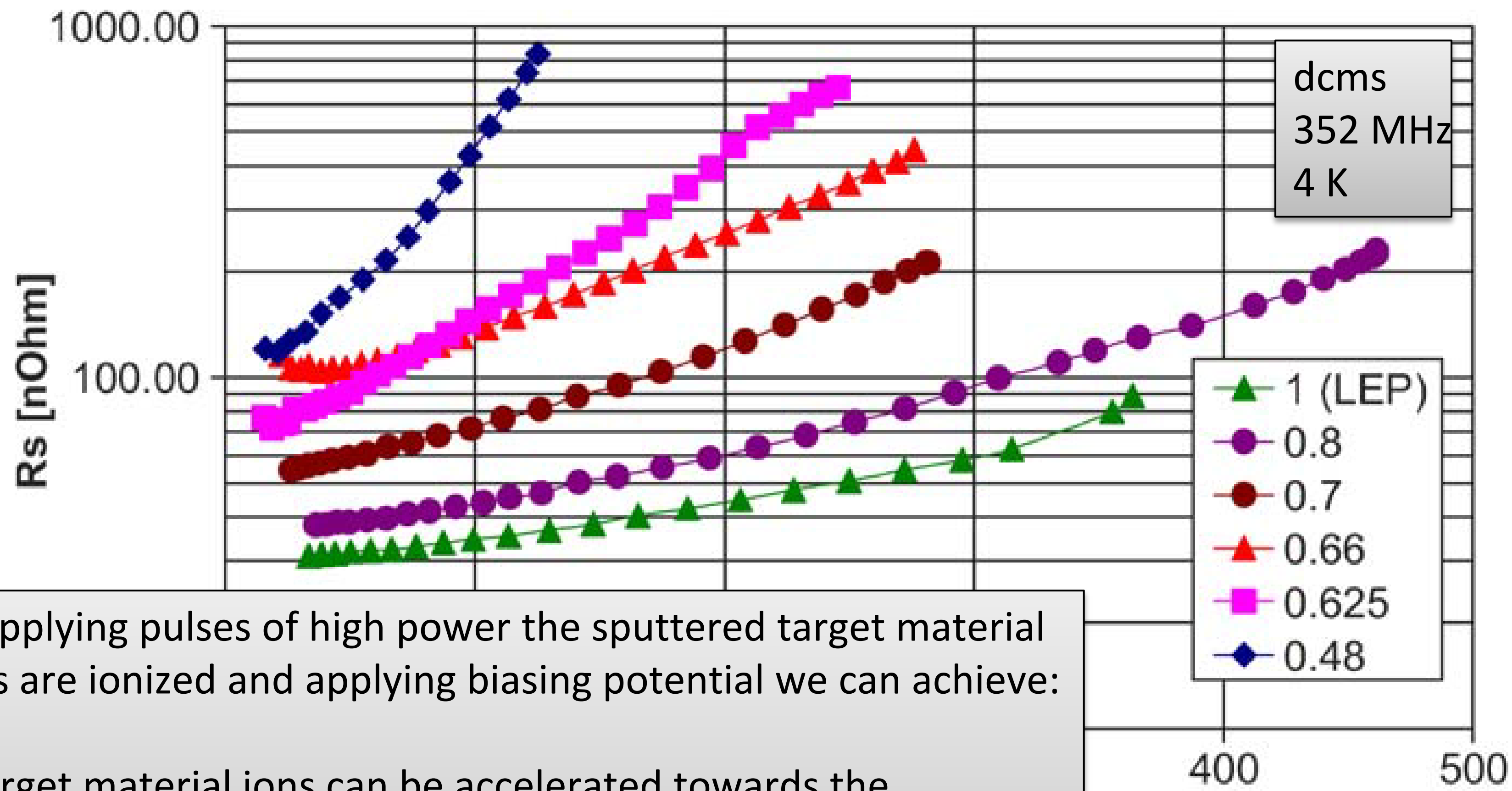
- Advantages of films
  - Lower losses at 4.2 K and moderate accelerating gradient compared to bulk niobium
  - Reduced sensitivity to earth magnetic field, x100 less than bulk Nb: no need for magnetic shielding
  - Cheaper material

- Major disadvantage of films
  - Steep R_S increase with RF field

From dcms to HIPIMS



From dcms to HIPIMS

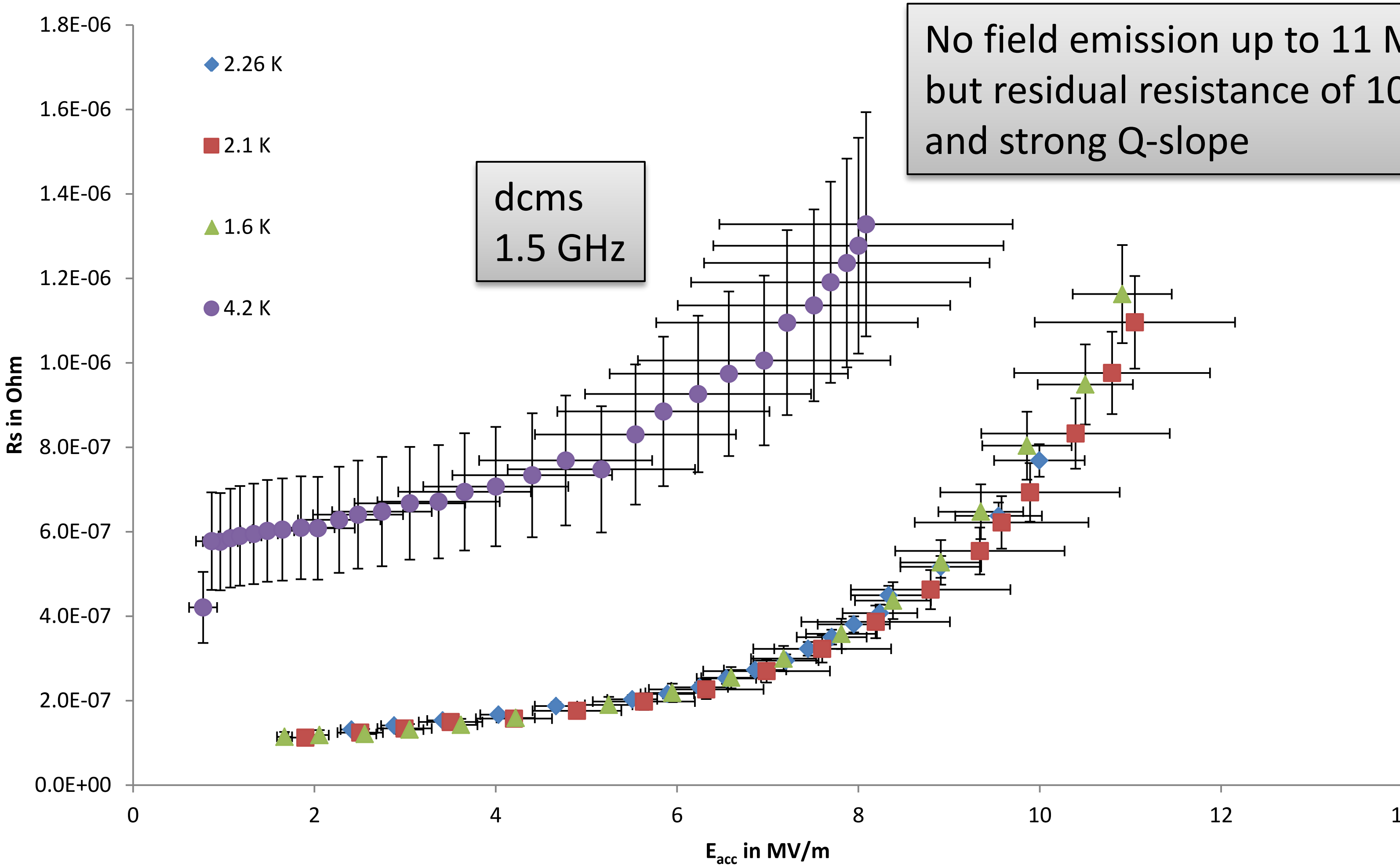


- By applying pulses of high power the sputtered target material atoms are ionized and applying biasing potential we can achieve:

➢ target material ions can be accelerated towards the substrate, higher kinetic energy upon arrival

➢ ions are directed to the surface, thus non-flat surfaces can be sputtered with good uniformity of the film

Reproducing old dcms results



No field emission up to 11 MV/m, but residual resistance of 100 nΩ and strong Q-slope

Reproducing old dcms results

Is the residual resistance caused by uncoated areas?

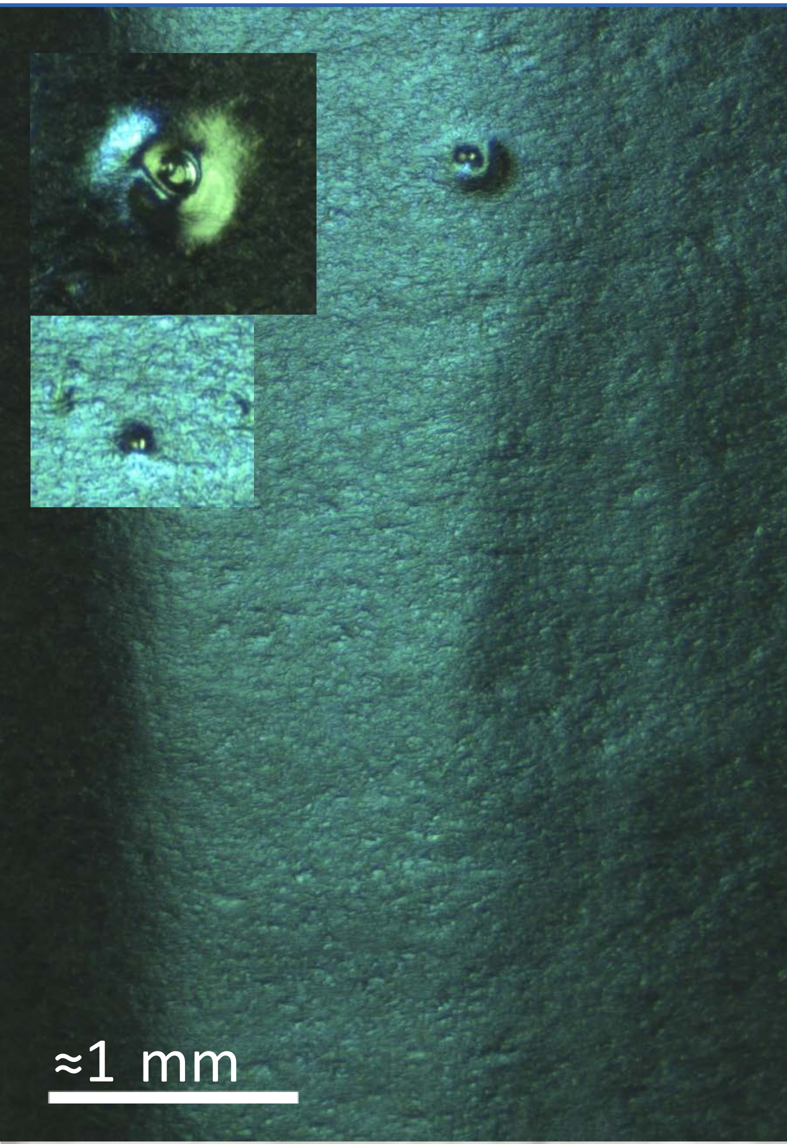
R_S of copper at 1.5 GHz is about 1 mΩ
R_{res}=100 nΩ

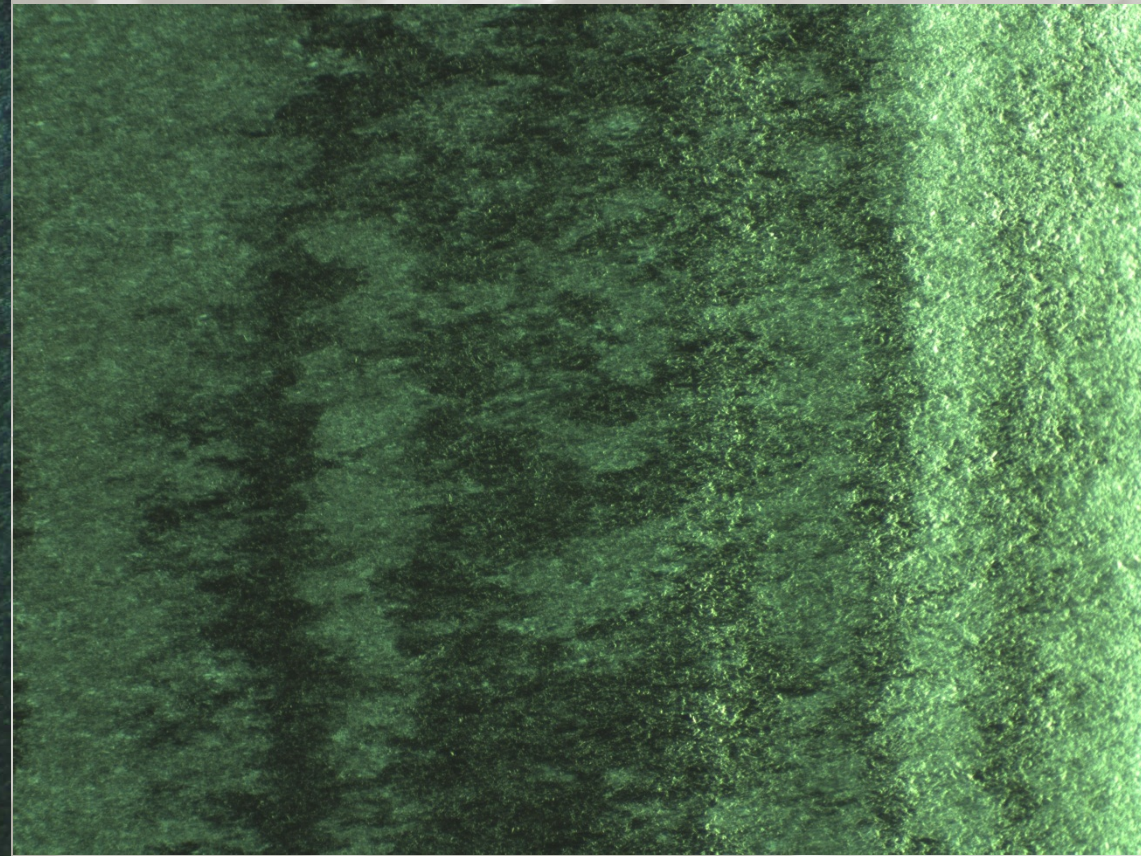
$$R_{\mathrm{Res}} = R_{\mathrm{N}} \frac{\text{Uncoated Surface Area}}{\text{Total Surface Area}} \,?$$

Total Surface Area=670 cm2
→ Uncoated surface area=6.7 mm2
Should be detectable with optical inspection system

Optical Inspection

Optical Inspection





Acknowledgement

- Quadrupole Resonator: S. Aull, S. Doebert, J. Knobloch
- Coating of cavities: G. Terenziani, S. Calatroni, A. P. Ehiasarian
- Optical Inspection: Janic Chambrillon

After 50 years of experience with superconducting cavities, we are approaching the fundamental limitations of niobium by recipes for which the underlying physics is not completely understood. For some accelerator applications SRF technology is the only choice. For reliable production, building compacter machines and cheaper electricity bills basic R&D and material studies are necessary!