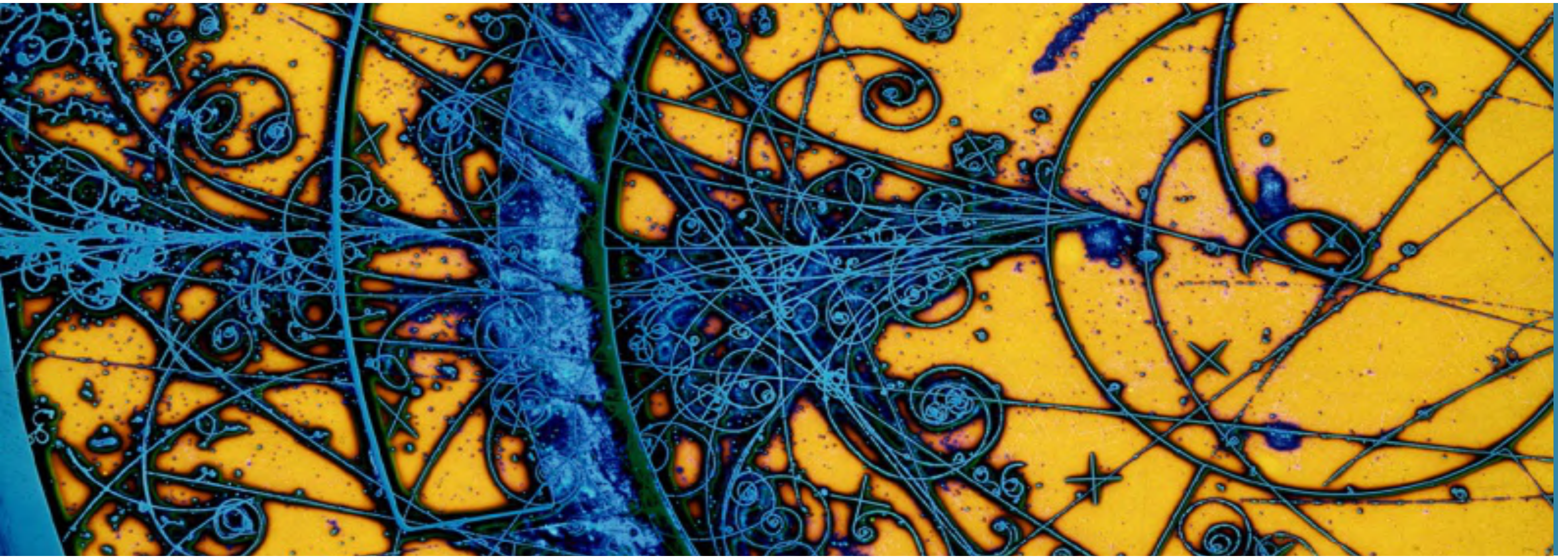
Broadband Frequency Electromagnetic Characterisation of Coating Materials

IPAC 2021



Istituto Nazionale di Fisica Nucleare

The Italian National Institute for Nuclear Physics

Andrea Passarelli, Can Koral*, Maria Rosaria Masullo, Vittorio Giorgio Vaccaro, Antonello Andreone*, Maria De Stefano*

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Coatings at high frequency

Layers of coating materials significantly increase the resistive wall impedance at **high frequency**

- Low conductivity, thin layer coatings (NEG, a-C)
- Rough surfaces (LESS)

Surface impedance of the beam pipe depends on electromagnetic properties of *coatings*

Electromagnetic characterization of “coating materials” is fundamental to evaluate accelerator performance limitations and build up a machine impedance model

Two different methods

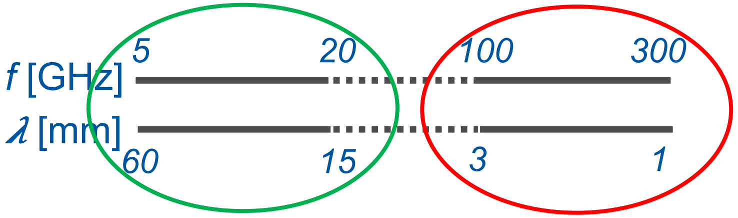
Electromagnetic characterization of Coating materials

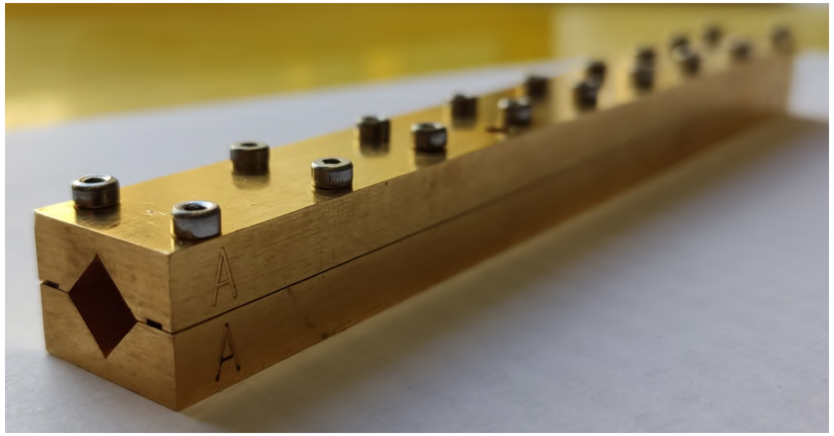
Dielectric resonator

- high sensitivity

Sub-THz waveguide

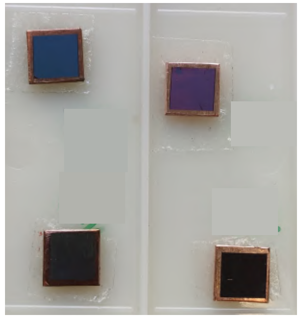
- small skin-depth





LESS (Laser engineered surface structures)

- conductivity compared with copper
- small samples



NEG (Non-Evaporable Getter)

- homogeneous coating

a-C (Amorphous carbon)

- coating thickness issues

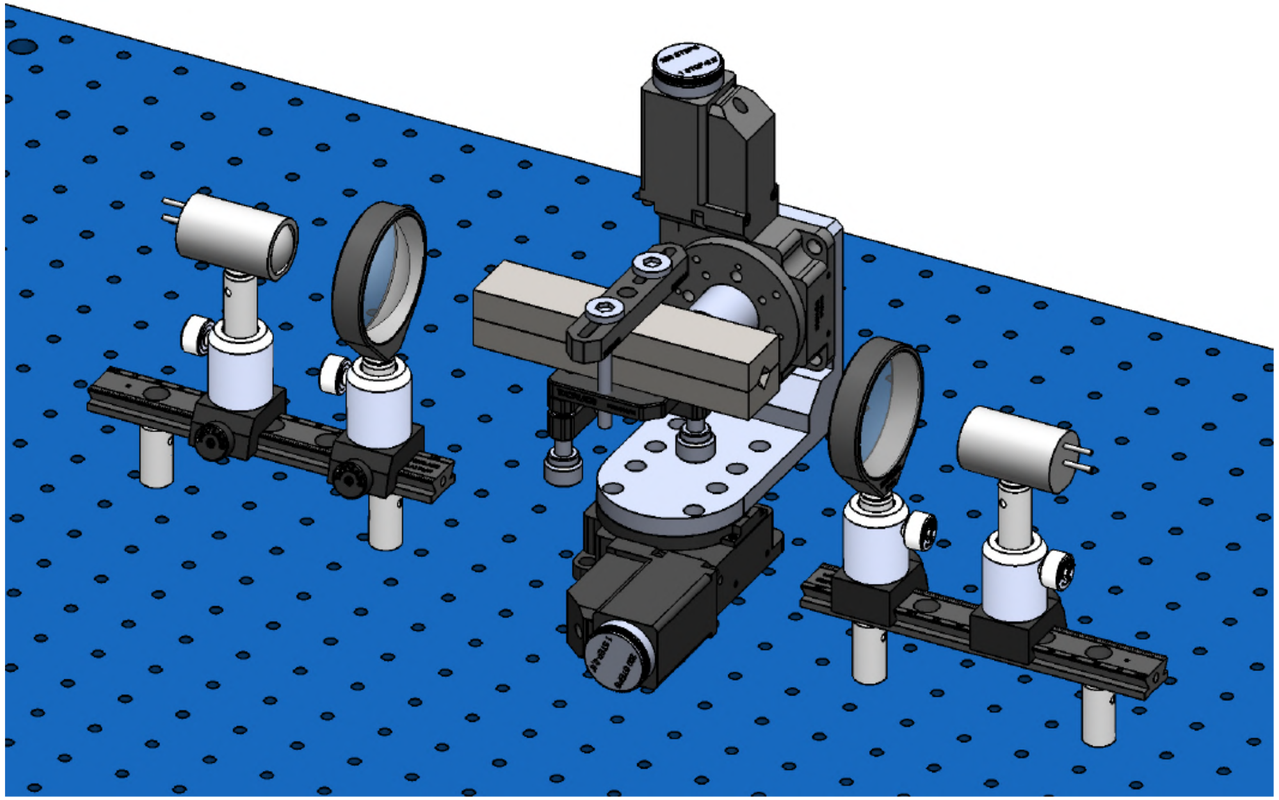
First method

Sub-THz waveguide attenuation

The proposed method

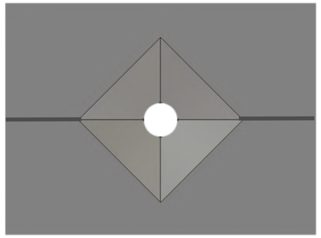
Evaluation of the **signal attenuation** inside a DUT with coating deposited.

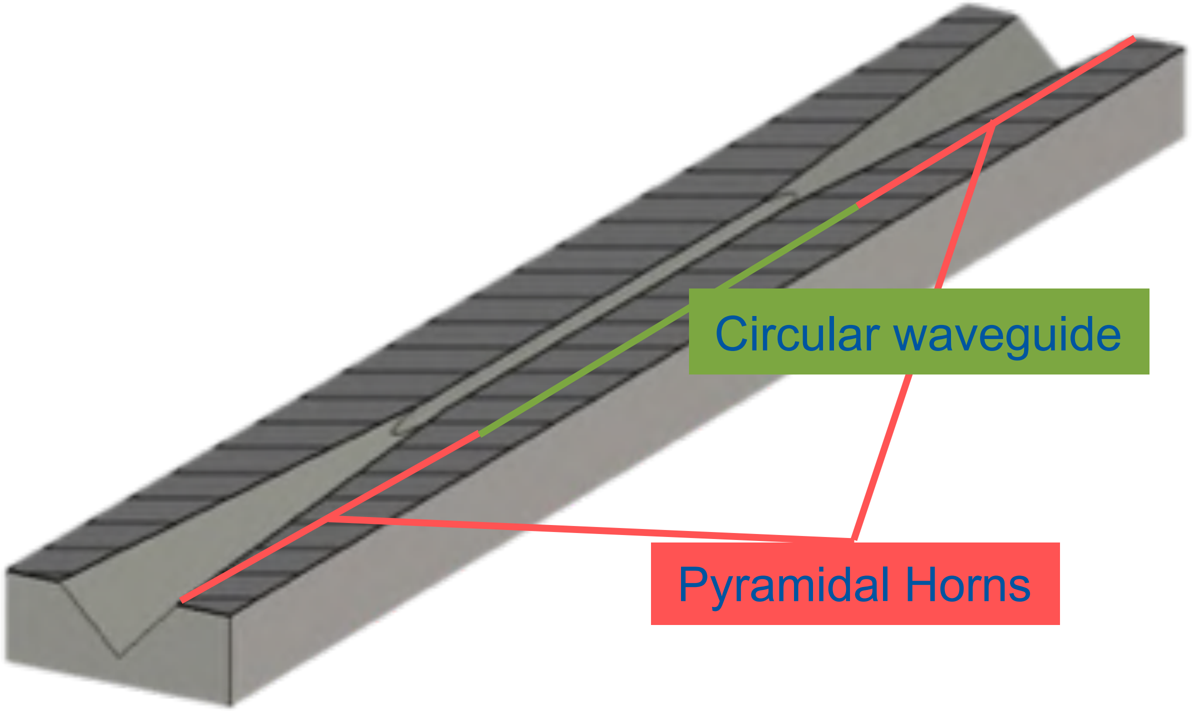
Electromagnetic characterization of coating material.



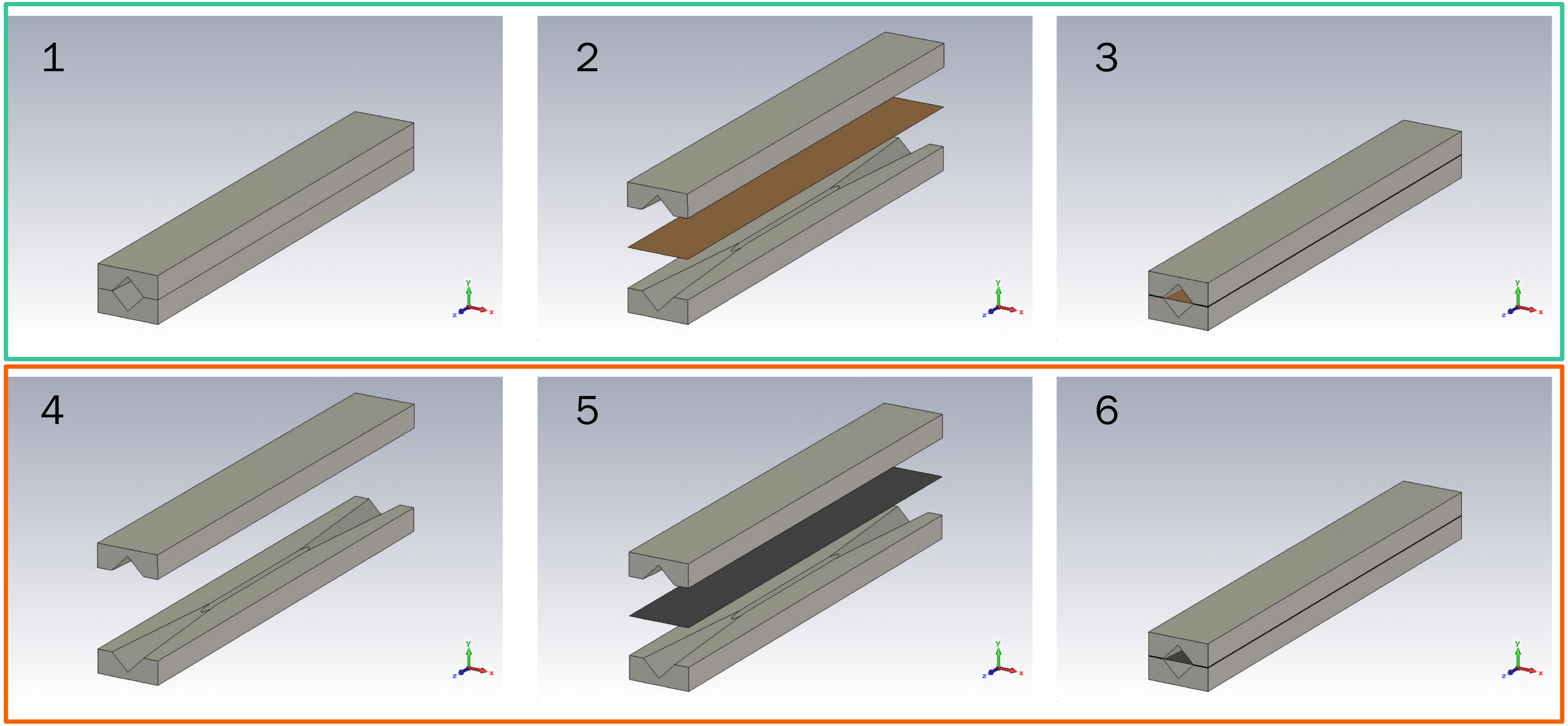
INFN

The Device Under Test

Dimension in mm	
Material	Iron
Waveguide	Circular
Length	42
Radius	0.9
Horns	Pyramidal
Length	39
External side	6
Total Length	120



The Device Under Test



Copper foil used as reference

Coated foil to measure

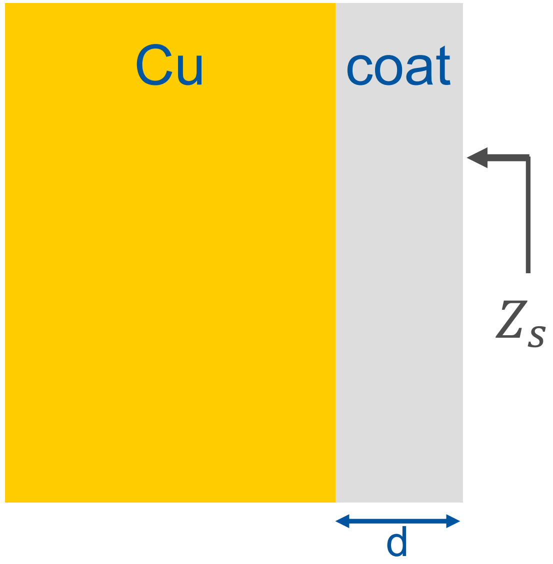
Methodology advantages: 1)Homogeneous deposition 2)System reusability 3)Large area coating

Analytical evaluations

Attenuation along the foil

Waveguide of length l_g ($TE_{1,1}$ mode) + pyramidal transitions of length l_t ($TE_{1,0}$ $TE_{0,1}$ modes)

$$A_{DUT} = \alpha l_g + 2\int_0^{l_t} \alpha(z)\, dz = \frac{1}{2} Re(Z_s) \frac{\int_l |\boldsymbol{n}\times\boldsymbol{H}_{1,1}|^2 dl}{Z_{1,1}|I_{1,1}|^2} l_g + \int_0^{l_t} Re(Z_s) \frac{\int_l |\boldsymbol{n}\times(\boldsymbol{H}_{1,0}+\boldsymbol{H}_{0,1})|^2 dl}{Z_{1,0}|I_{1,0}|^2 + Z_{0,1}|I_{0,1}|^2} dz$$

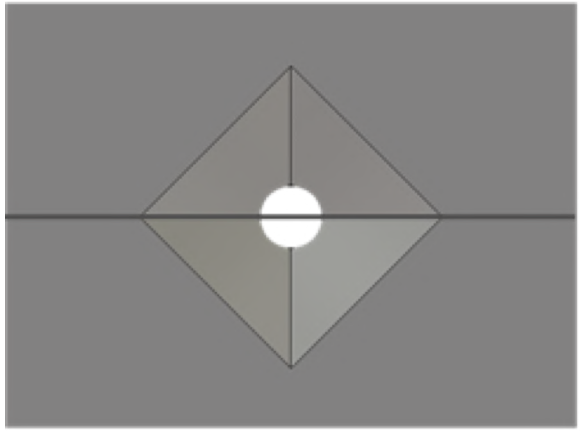


$$Z_s = Z_{coat} \frac{Z_{Cu} + jZ_{coat}\, tg(k_{coat} d)}{Z_{coat} + jZ_{Cu}\, tg(k_{coat} d)}$$

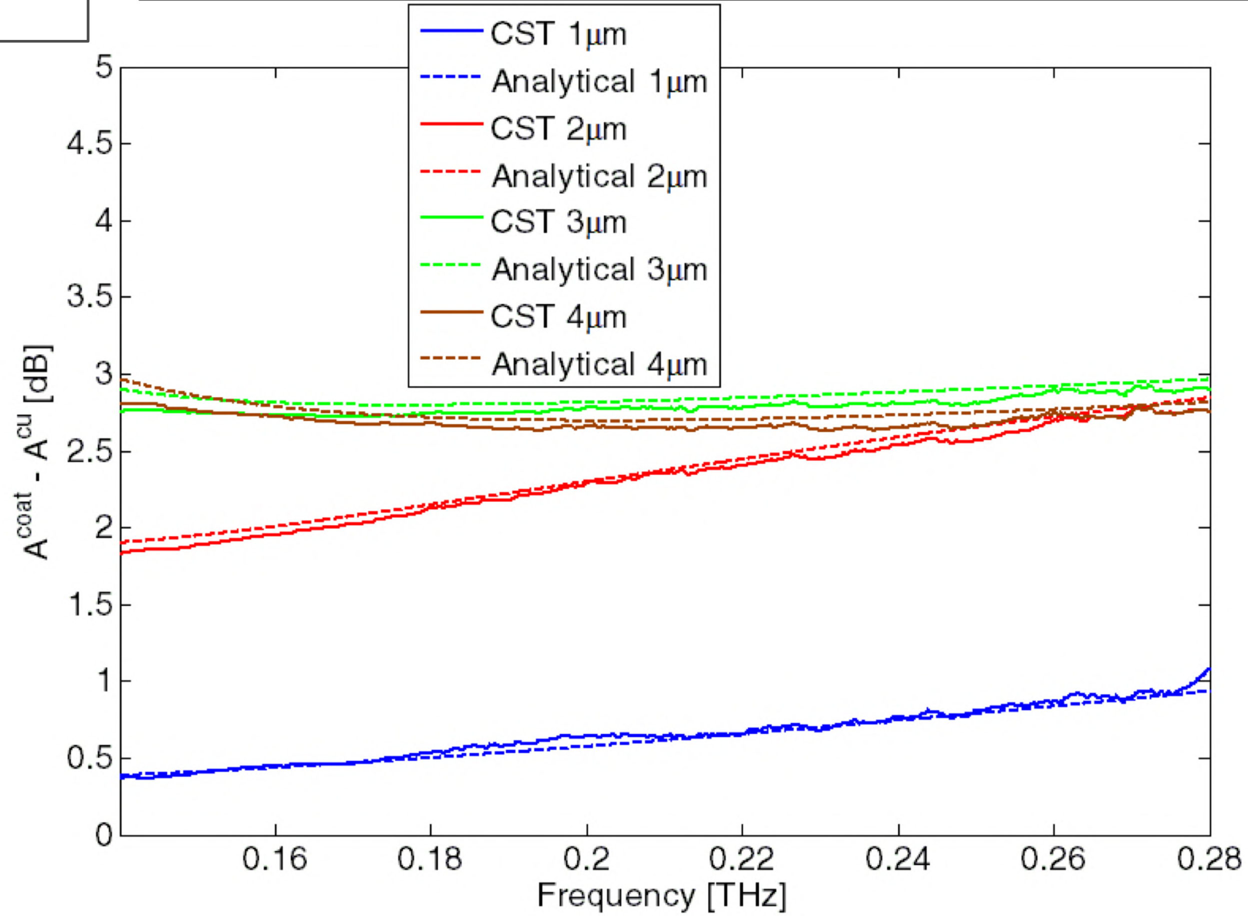
Transmission line method

Analytical evaluations – comparison with numerical solver

Copper conductivity: $\sigma_{cu} = 6 \cdot 10^7$ S/m
NEG conductivity: $\sigma_{NEG} = 3.5 \cdot 10^5$ S/m*



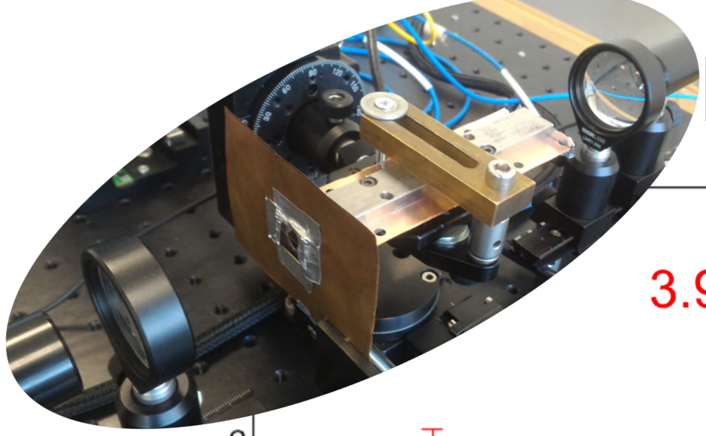
Cylindrical waveguide + Pyramidal transition

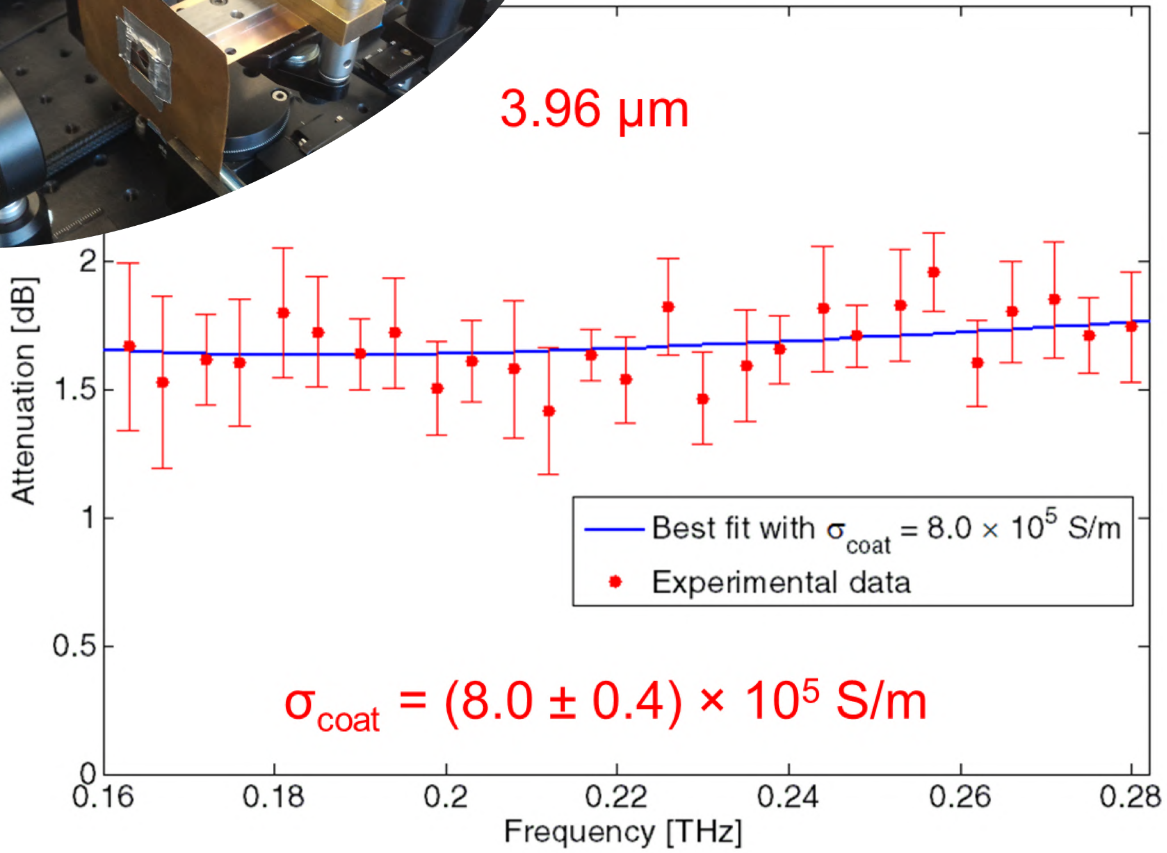


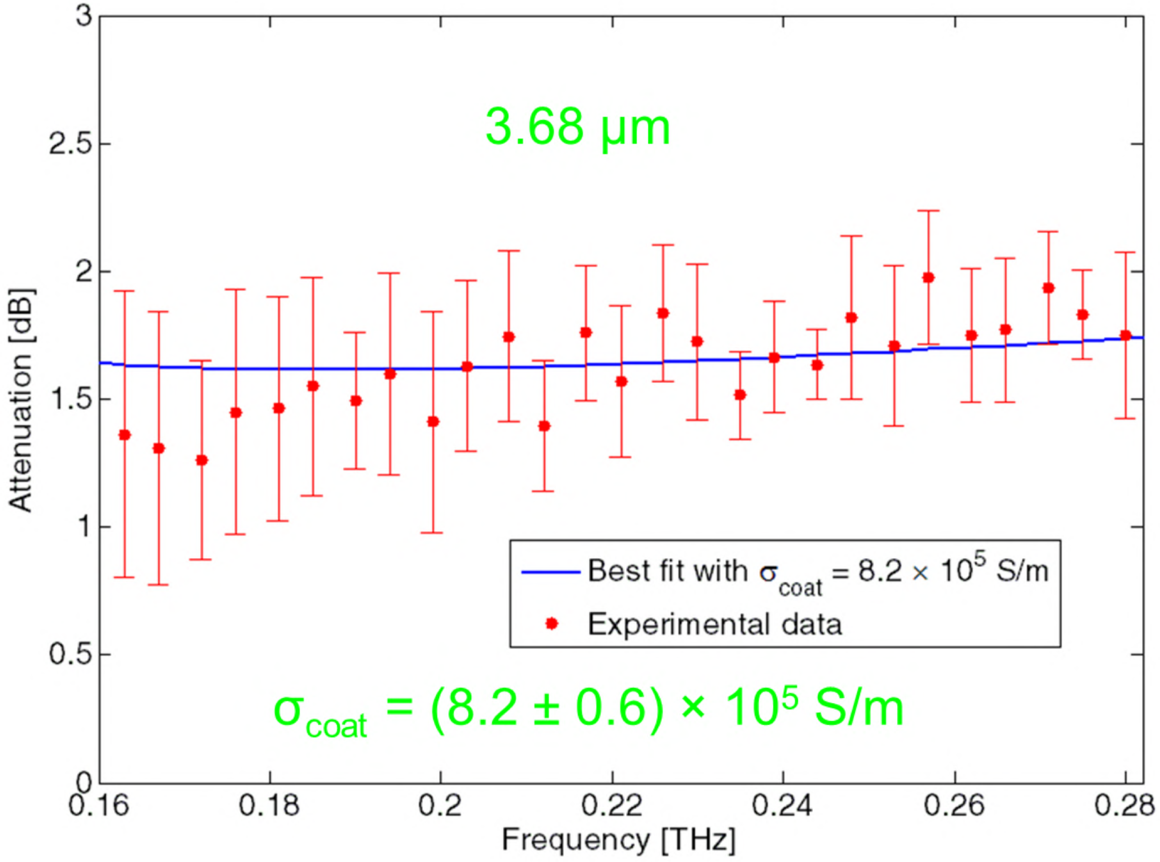
*E. Koukovini Platia et al.
Phys. Rev. Accel.Beams **20**, 011002 (2017)

Reliable analytical tool

First set of measurements on NEG coated foil







$\boxed{\sigma_{coat} \Longleftrightarrow Z_s}$

Novel measurement technique for the electromagnetic characterization of coating materials in the sub-THz frequency range.

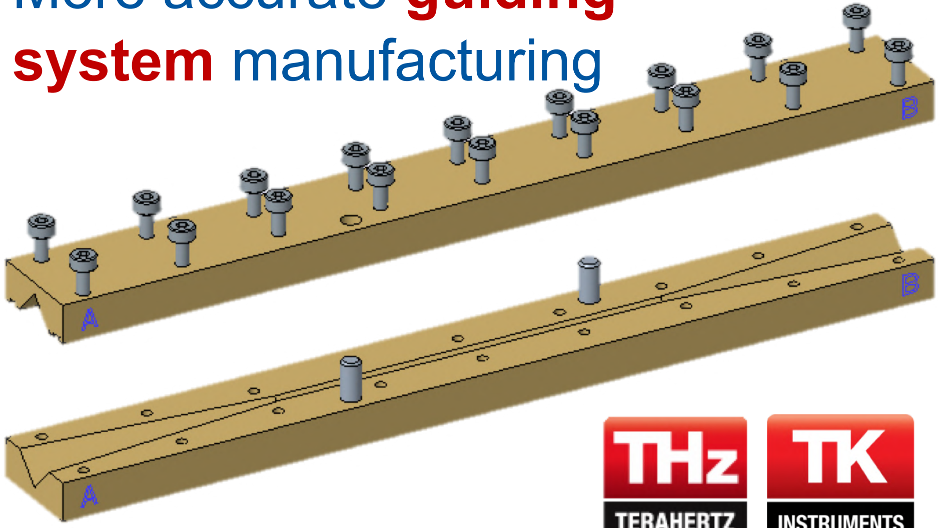
Andrea Passarelli, Hannes Bartosik, Giovanni Rumolo, Vittorio Giorgio Vaccaro, Maria Rosaria Masullo, Can Koral, Gian Paolo Papari, Antonello Andreone, and Oliver Boine-Frankenheim
Phys. Rev. Accel. Beams **21**, 103101 – Published 25 October 2018

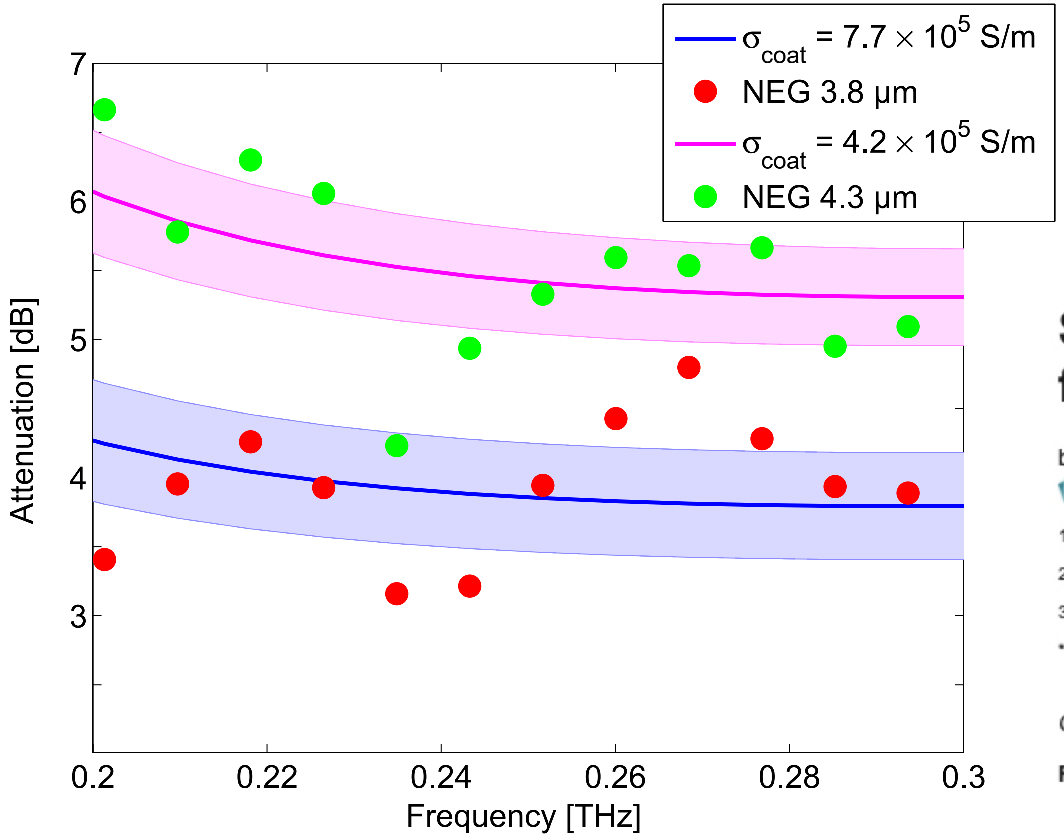
Measurement system upgrade

System specifications:
- Spectral Range: > 3 THz
- Dynamic Range > 70 dB
- Scanning Range ~ 300 ps
- Spectral Resolution < 3.5 GHz

Upgrade:
- > 5 THz
- > 90 dB
- ~ 850 ps
- < 1.5 GHz

More accurate **guiding system** manufacturing





Sub-THz Waveguide Spectroscopy of Coating Materials for Particle Accelerators

by Andrea Passarelli [1,2], Can Koral [2], Maria Rosaria Masullo [2], Wilhelmus Vollenberg [3], Lucia Lain Amador [3] and Antonello Andreone [1,2,*]

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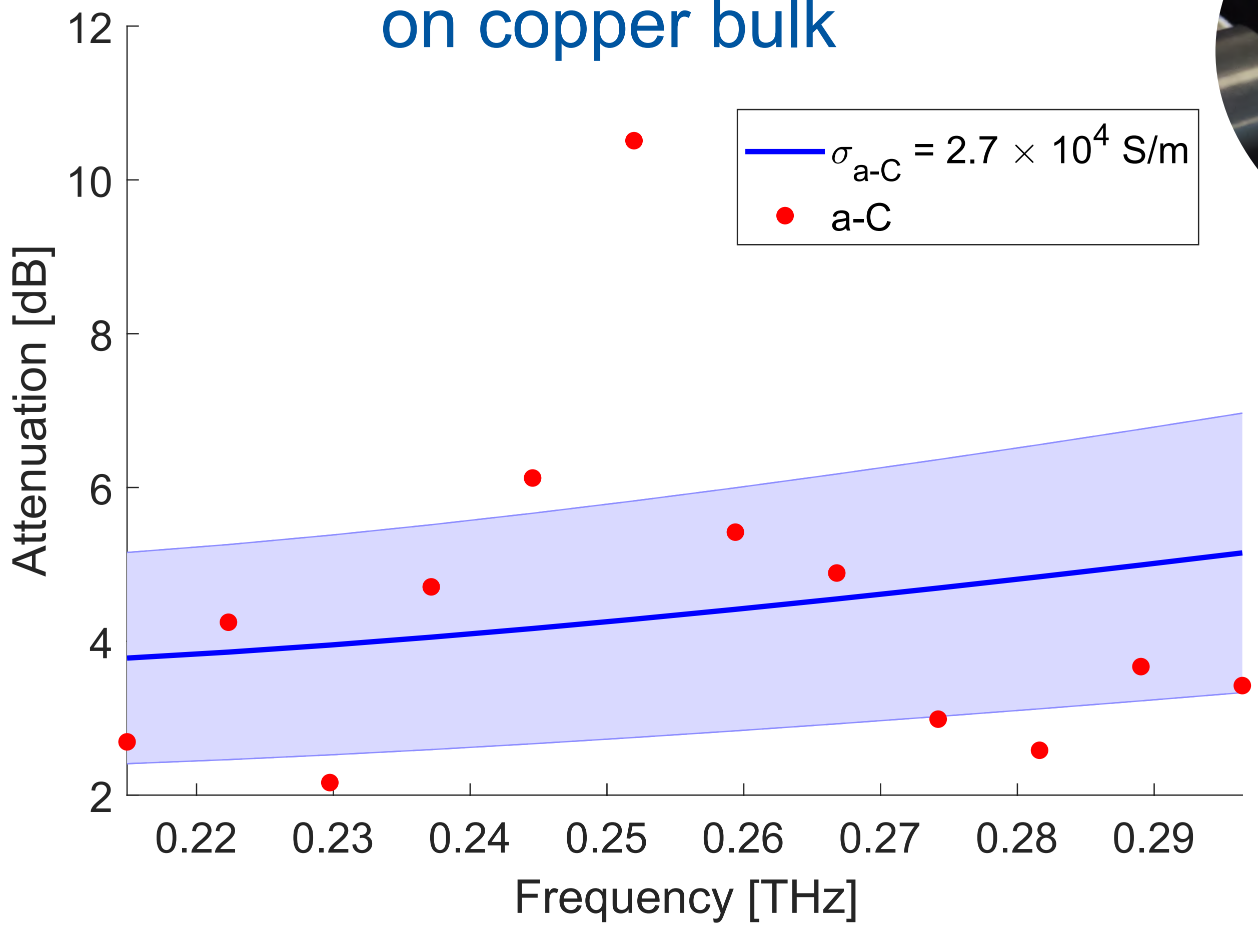
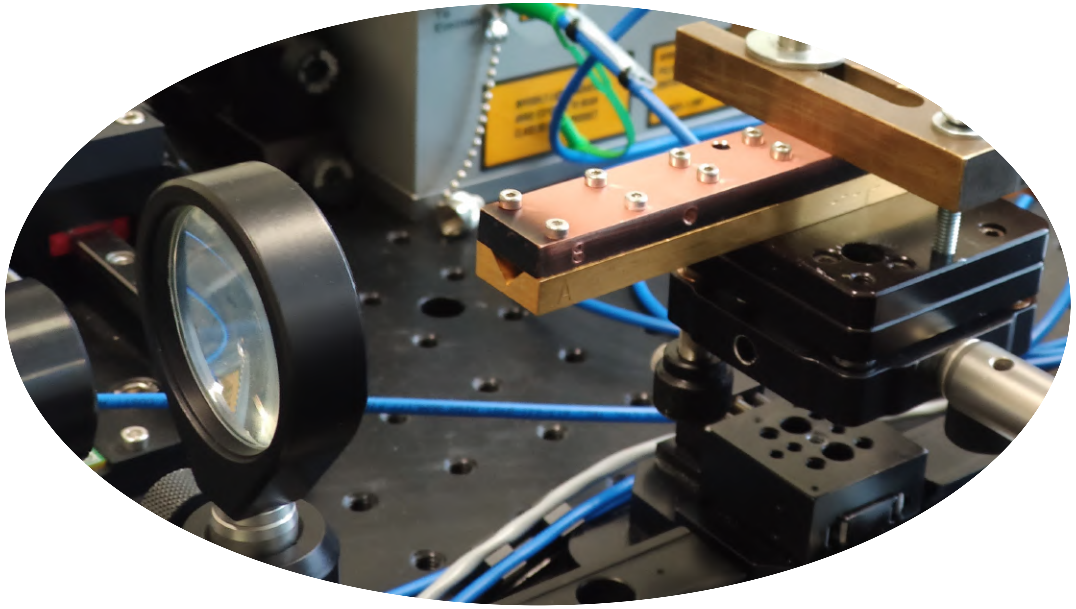
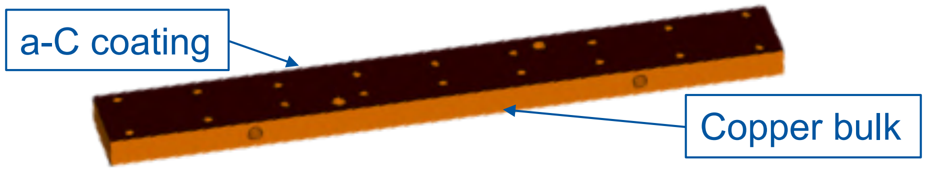
Measurement results on a-C

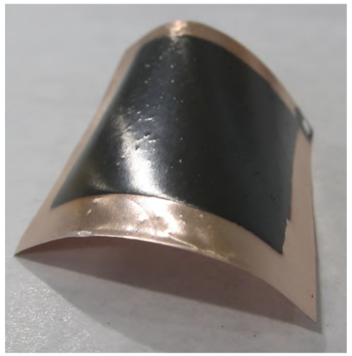
Two samples with 3 μm of **Amorphous carbon** on copper bulk







Mechanical stress a-C coating on Cu slab

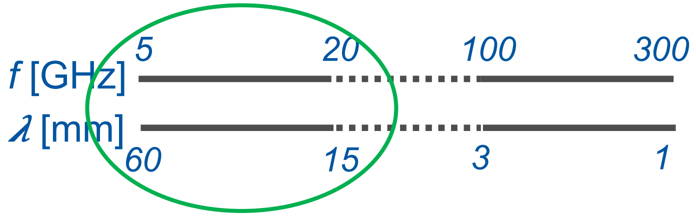


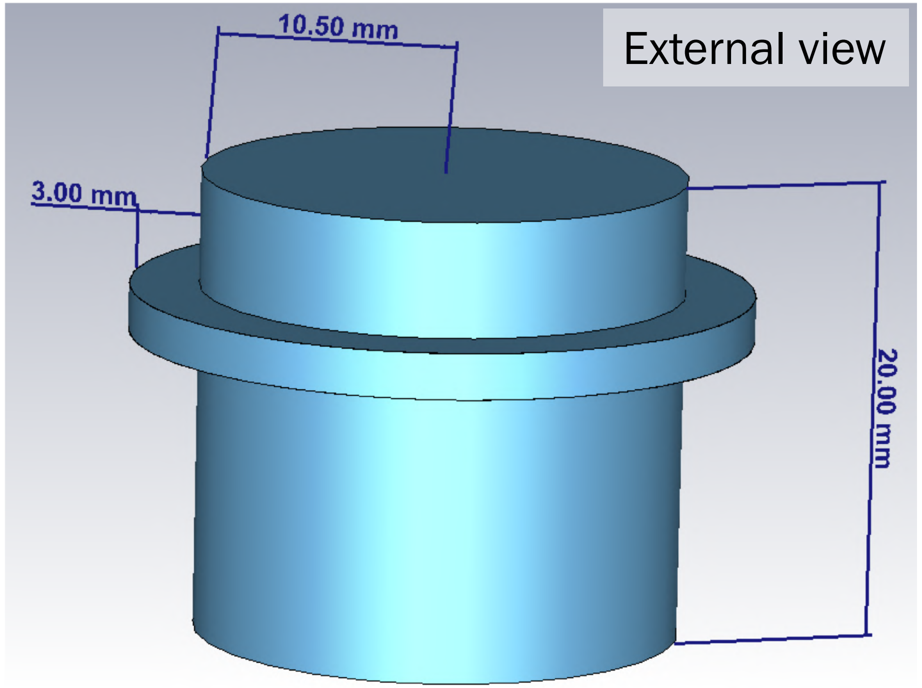
Second method

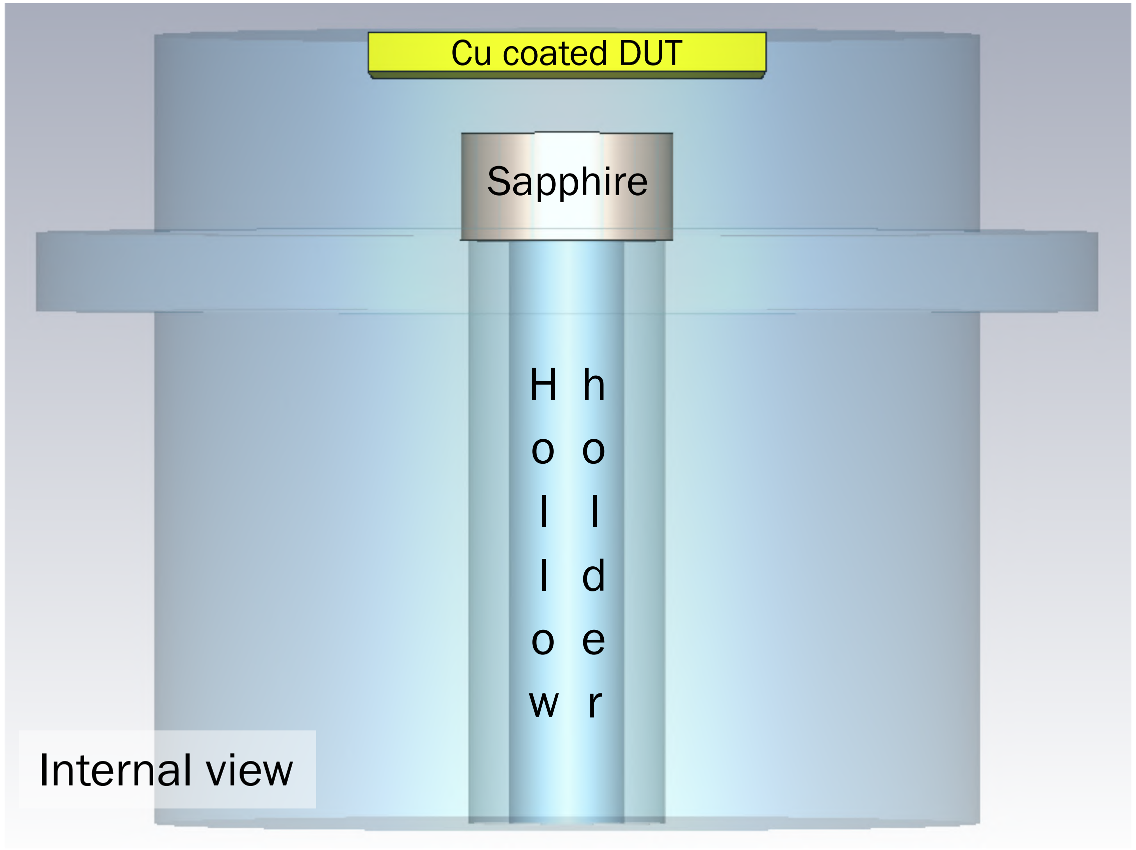
Resonant structure methodology

Resonant structure methodology

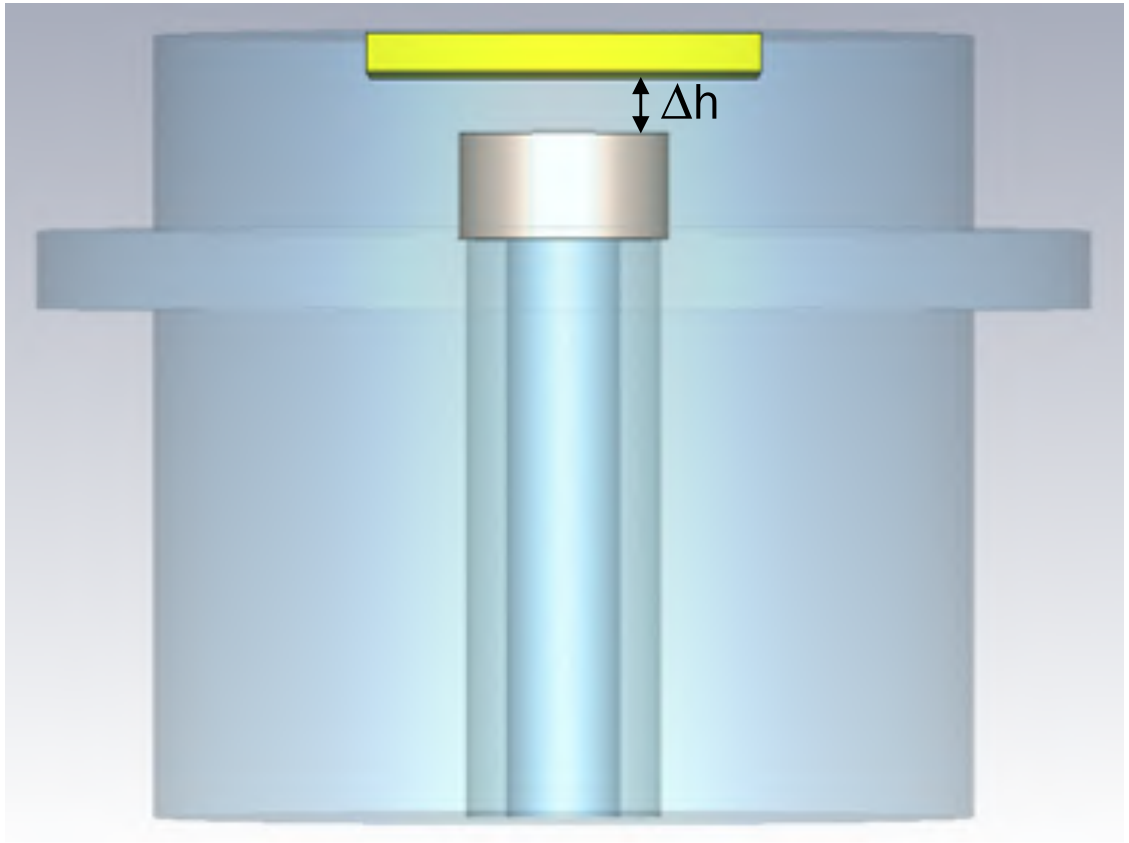
Dielectric resonator: Resonant structure methodology **improves the sensitivity** for the electromagnetic characterization of very thin laser surface treated structures and conductivity close to copper one

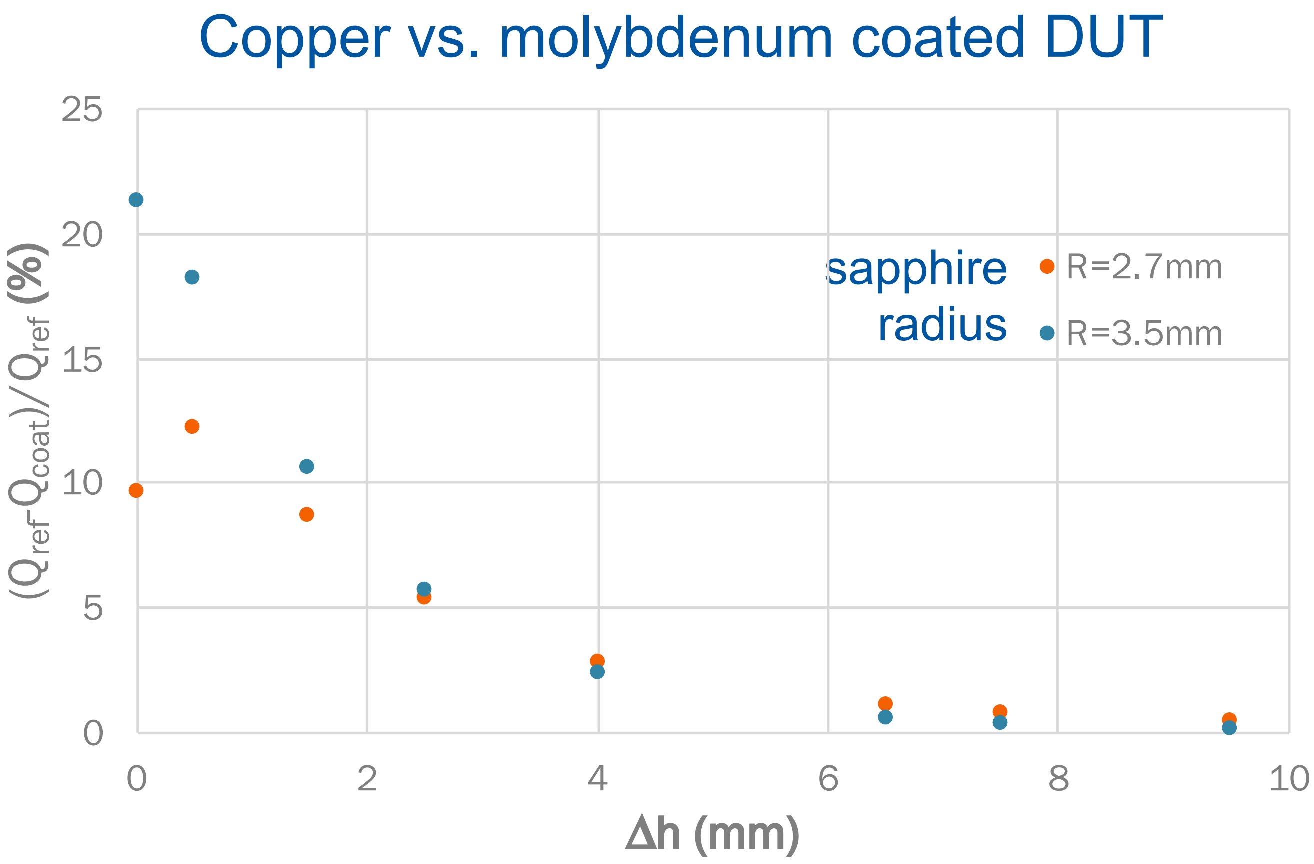






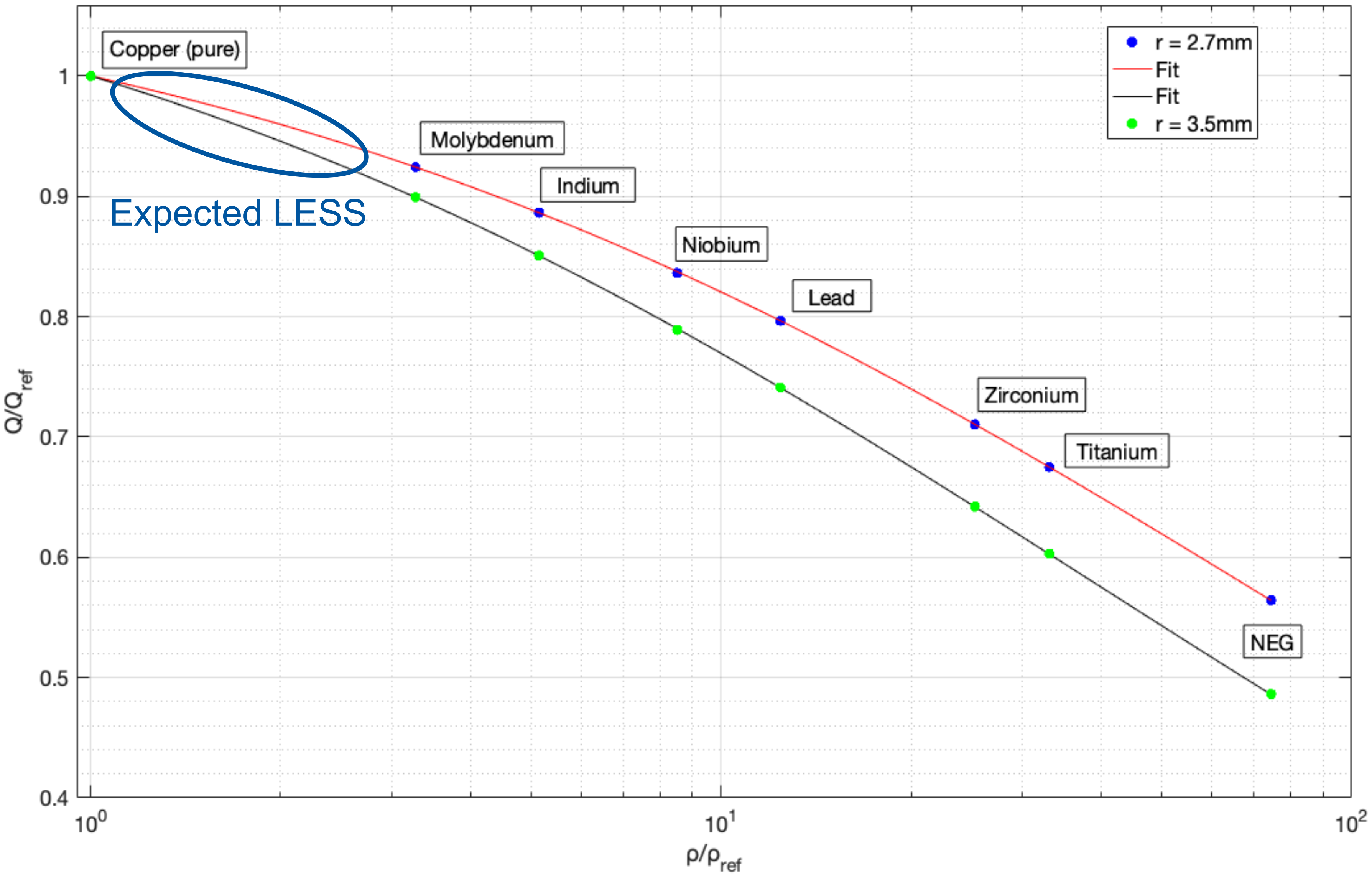
Resonant structure methodology





The maximum Q-factor percentage difference is obtained with a minimum distance between the DUT and the sapphire

Resonant structure methodology



The sapphire with larger radius (3.5 mm) will be used, because of its higher sensitivity in EM characterization of coating materials (LESS)

Conclusion & next steps

Electromagnetic characterization of coating materials

- Sub-THz waveguide attenuation
  - Reliable analytical model for the conductivity retrieval. Good agreement with CST solver.
  - Successful measurement campaign: reliable and handy method to evaluate the electromagnetic properties of samples under test.
  - Published results on NEG and novels on a-C coatings.
- Resonant structure methodology
  - Improves the sensitivity, useful for electromagnetic characterization of very thin laser surface treated structures (i.e. LESS)