Non-Evaporable-Getter (NEG) properties characterization at ultra-high frequencies

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LOWεRING 2015, ESRF, Grenoble

Acknowledgements: S. Calatroni, A. Fontenla, P. Garritty, P.C. Pinto, G. Rumolo, C. Zannini, W. Vollenberg, M. Taborelli (CERN), J. Hesler, A. Arsenovic (VDI)

NEG coating

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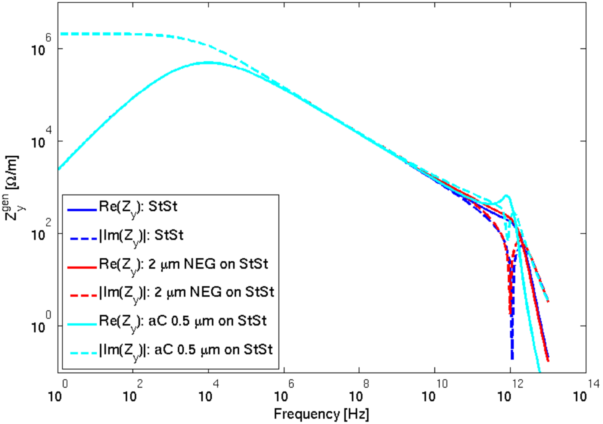
- Light sources with NEG coating: ELETTRA, SOLEIL, ESRF, MAXIV (fully coated), and foreseen for CLIC Damping Rings, the upgrade of APS, Diamond, SLS, ESRF etc
- Use of coating is suggested to mitigate some undesirable collective effects (in the electron damping ring, good vacuum will be necessary against fast beam ion instabilities) but it can contribute to the machine impedance

Motivation for high frequency measurements

- The short rms bunch length of 1.8 mm translates into hundreds of GHz in the frequency domain
- The electromagnetic (EM) characterization of the material properties up to high frequencies is required for the impedance modeling of the DR components

Wigglers’ impedance for different coatings



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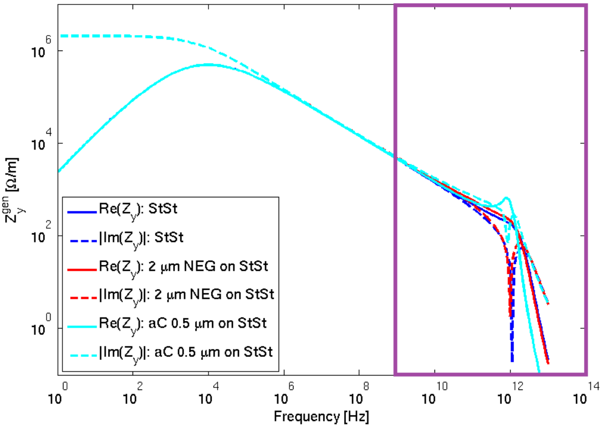

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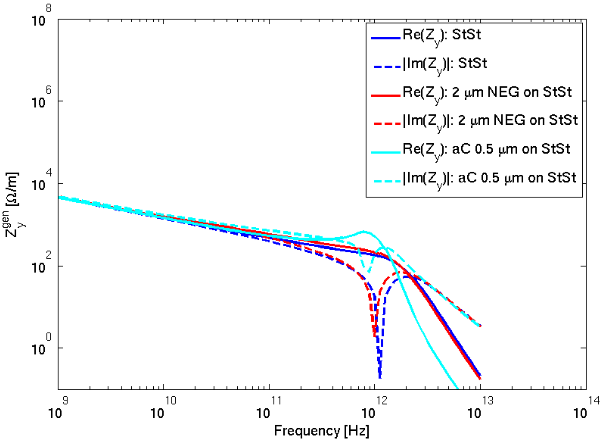
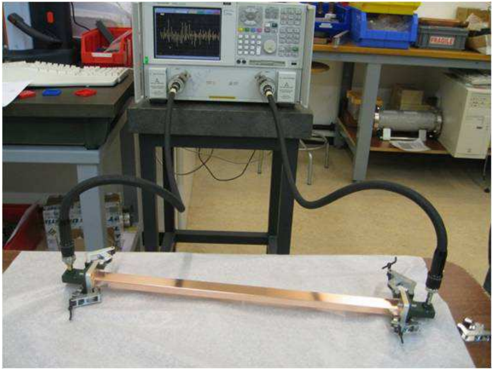


- Coating is transparent up to 10 GHz
- NEG properties at high frequencies were still unexplored

Proposed method

- Use of rectangular waveguides and measurement of the S_{21} transmission coefficient



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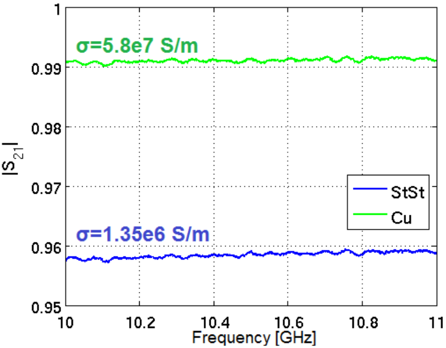

Proposed method

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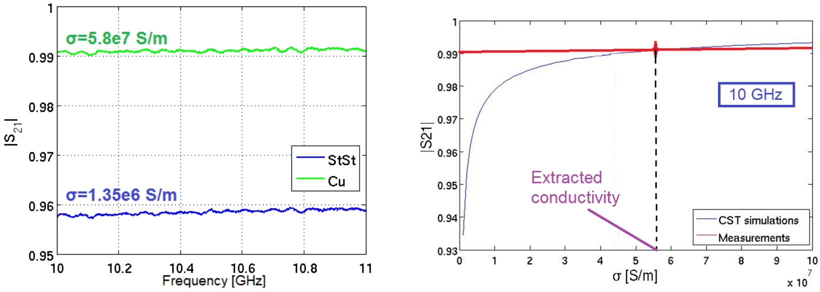
- The S-parameters can also be obtained numerically from 3D simulations using CST

The principle of the method



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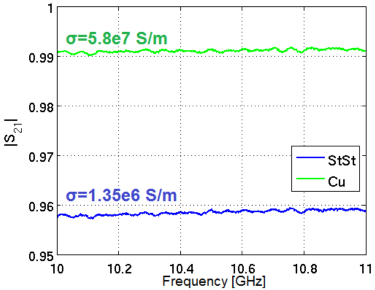

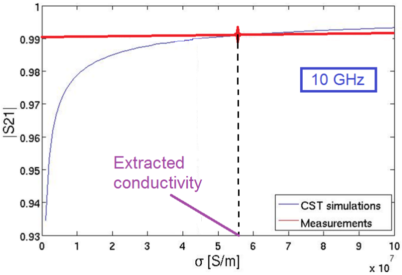

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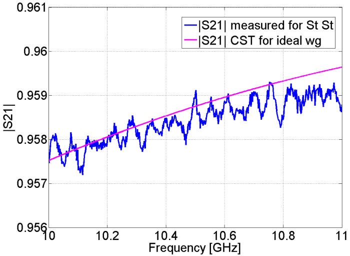
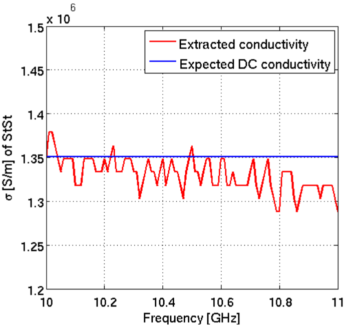
- By repeating the intersection over all frequencies, the σ can be extracted as a function of frequency

Benchmark of the method





- Extracted conductivity for stainless steel in good agreement within 5% with the expected one

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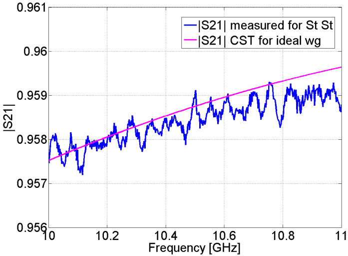
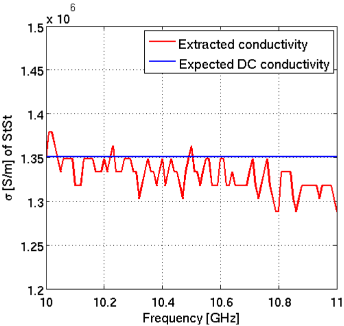
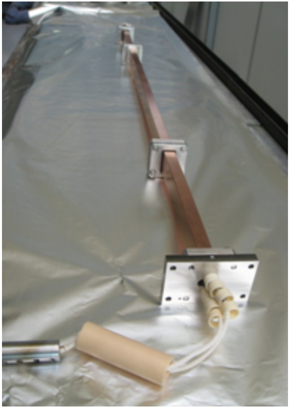
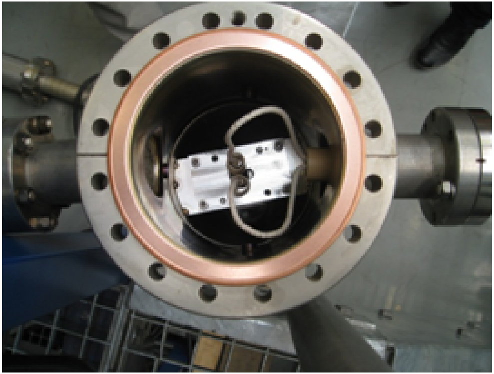




- Extracted conductivity for stainless steel in good agreement within 5% with the expected one
- Successful benchmark for a well known material

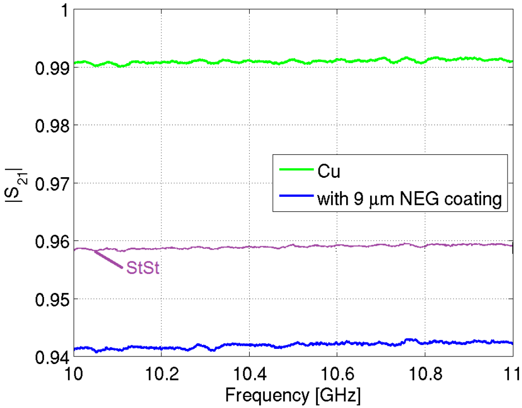
NEG coating





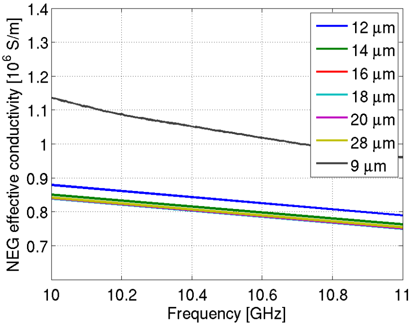
- Coating by TE/VSC group at CERN

Measurements with NEG coating



- EM interaction with NEG induces more losses
- Thick film to maximize the interaction of the field with NEG

NEG effective conductivity between 10-11 GHz



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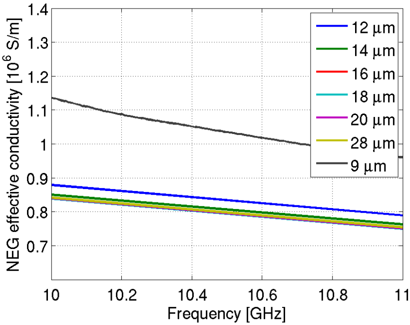

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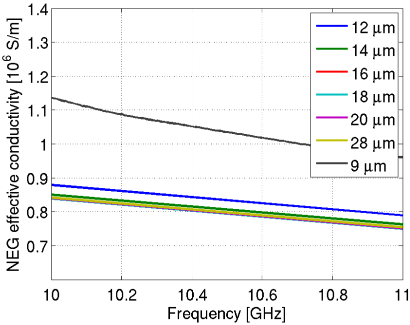
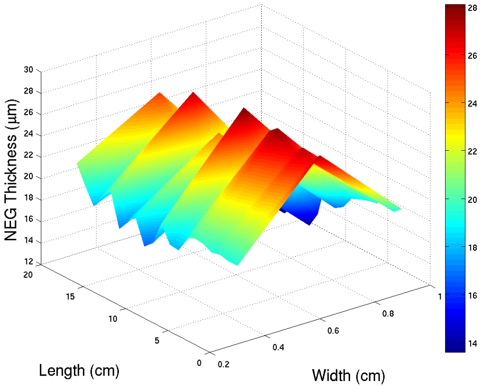


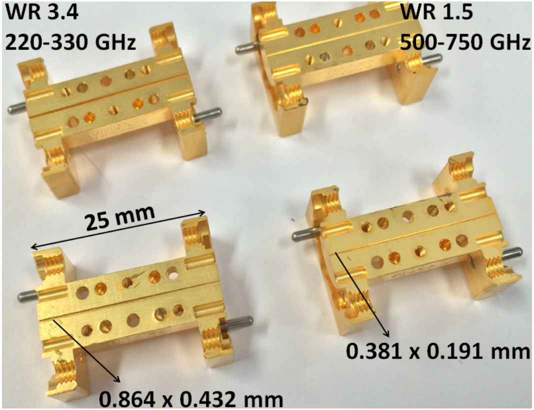
- Extracted conductivity is $(1 \pm 0.2) \times 10^6$ S/m
- Measurements of the DC conductivity estimate values between 0.66 and 1×10^6 S/m. The extracted σ is in good agreement with the DC value
- Frequency dependent behavior. But still too low frequencies to expect any relaxation

X-ray fluorescence profile analysis



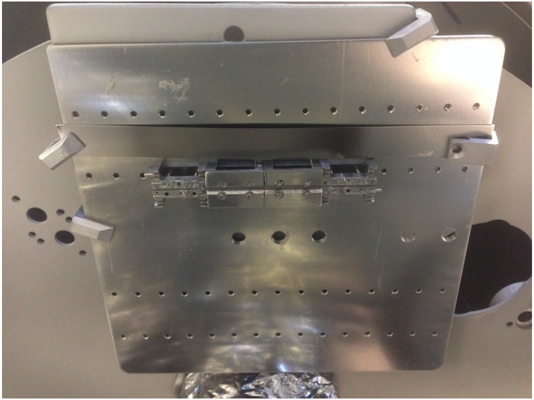
- Variation of the film thickness between 12 and 28 μm. The target value was 20 μm
- The non-uniformity was not included in CST so far

Measurements at 220-330 GHz and 500-750 GHz



- Aluminum gold-plated waveguides from Virginia Diodes Inc. (VDI)
- WR3.4: 0.864 x 0.432 mm
- WR1.5: 0.381 x 0.191 mm

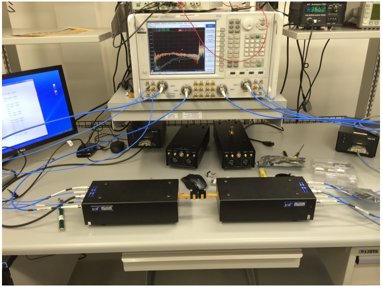
NEG coating

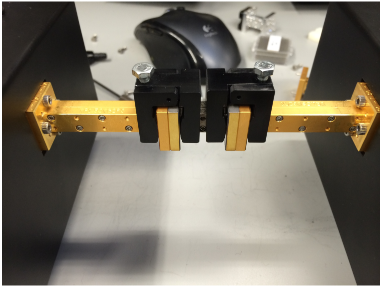


- Challenging coating due to the very small aperture and the rectangular shape (3 μm targeted thickness)

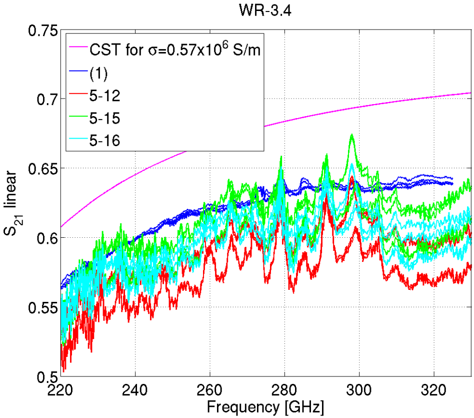
Measurements at VDI

Full two-port S-parameter measurements were performed to measure the NEG-plated Aluminum waveguides. Each waveguide is measured in both forward and backwards orientation.



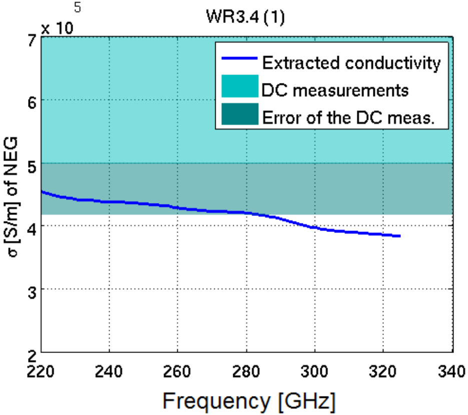


S_{21} measurements with NEG coating



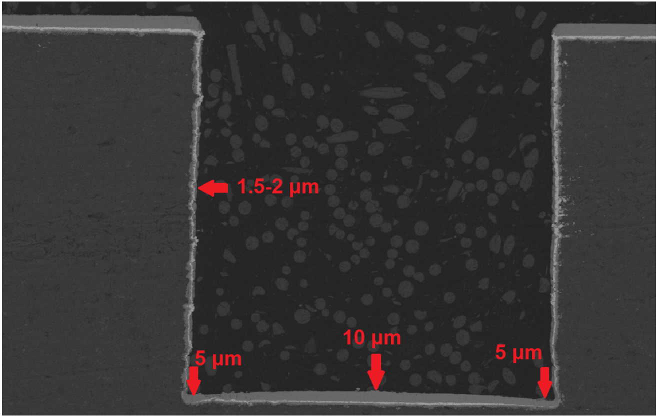
- Measurements of DC conductivity gave values between 0.5×10^6 S/m and 0.7×10^6 S/m. Average value used in CST simulations
- 15% sample-to-sample variance

Effective conductivity of NEG at 220-330 GHz



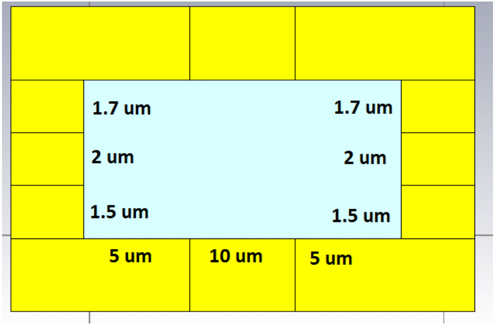
- Frequency dependent behavior is observed

Coating profile

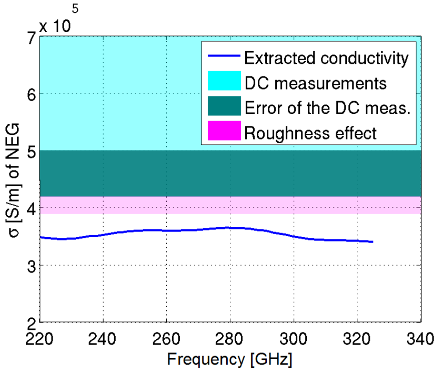


Non-uniform coating, between 5 and 10 μm on the bottom and 1.5 and 2 μm on the side walls

Implementation of the coating thickness in CST

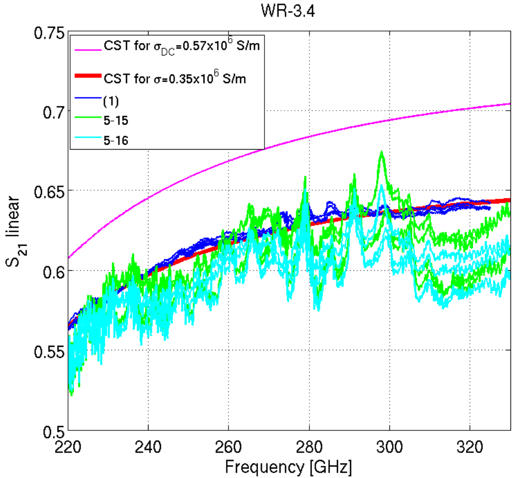


Effect of the non-uniform coating

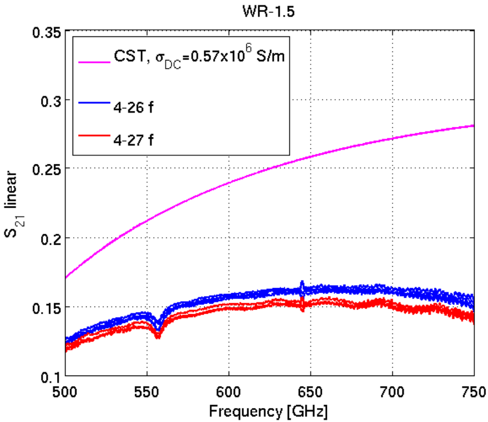


- Milder dependency with frequency. Implementation of the real profile is crucial
- Extracted effective conductivity is $(0.35 \pm 0.05) \times 10^6$ S/m, that accounts for roughness and the non-uniform film coating

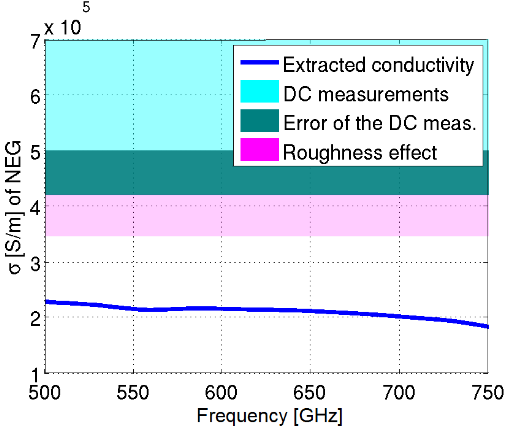
Effect of the non-uniform coating (2)



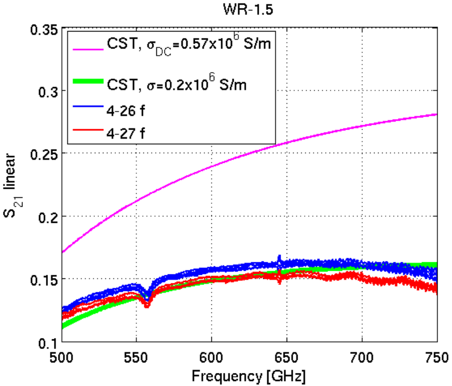
Measurements at 500-750 GHz



Implementation of a non-uniform coating in CST

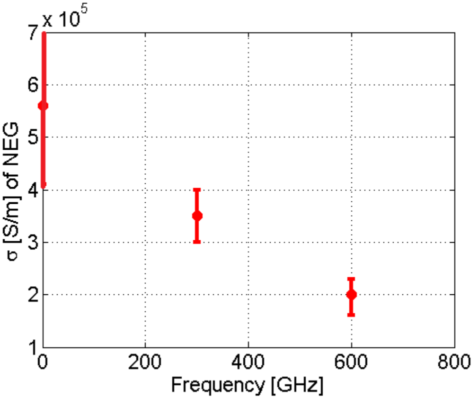


Effect of the non-uniform coating



Extracted effective σ_{NEG} is 0.2×10^6 S/m between 500 and 750 GHz

Measurements along all the frequency ranges



- Effective conductivity is a factor of 2-3 smaller than the DC

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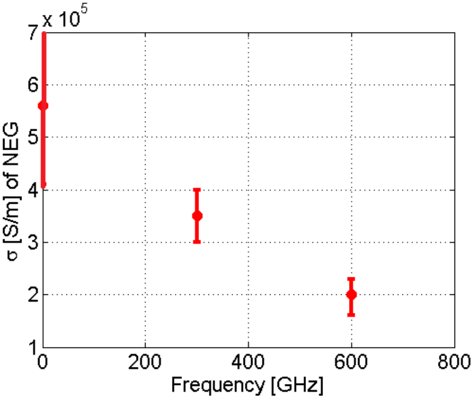


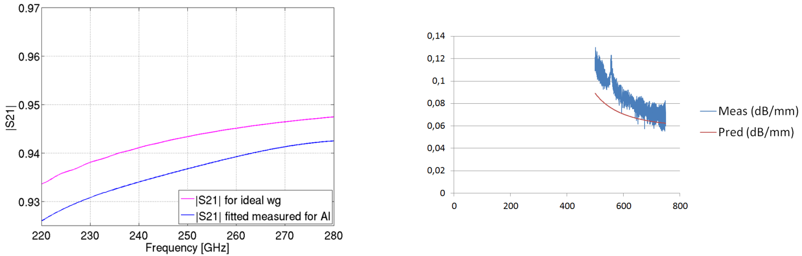
- Effective conductivity is a factor of 2-3 smaller than the DC
- At such high frequencies, it is important to account the lower effective σ due to roughness and non-uniformity of the profile

Conclusions

- The experimental method was successfully benchmarked in X-band with stainless steel waveguides
- It was applied to characterize NEG conductivity in several frequency ranges: 10-11 GHz, 220-330 GHz, 500-750 GHz
- The extracted conductivity agrees well with the DC value for 10-11 GHz
- DC conductivity measurements depend on the different cathode used in each set up
  - First setup: 0.66 and 1×10^6 S/m
  - Second setup: 0.5 and 0.7×10^6 S/m
- At higher frequencies, the extracted σ is about 20% lower from DC
- Effective conductivity at high frequencies can be significantly lower than the DC, even if relaxation effects are still not important in the frequency range

Thank you for your attention!

Measurements with Al gold plated WR3.4 waveguide and WR1.5 waveguide



- Comparison of measured S_{21} for a WR3.4 Al gold plated waveguide and simulated with CST Al waveguide
- Agreement within 2% for WR3.4 and around 10 – 15% for the WR1.5

Extracted conductivity of NEG in X-band with the non-uniform profile