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

Eirini Koukovini-Platia

Diamond Light Source

TWIICE 2 - Topical Workshop on Instabilities, Impedance and Collective Effects

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 (1/2)

- Vacuum chambers coated with a thin film of a suitable getter material can work as a pump by activating the getter during in situ bake-out

NEG coating (1/2)

- Vacuum chambers coated with a thin film of a suitable getter material can work as a pump by activating the getter during in situ bake-out
- Reduction of pressure rise under particle bombardment

NEG coating (1/2)

- Vacuum chambers coated with a thin film of a suitable getter material can work as a pump by activating the getter during in situ bake-out
- Reduction of pressure rise under particle bombardment
- Need for distributed pumping due to long chambers and progressive reduction of apertures made the use of thin getter coatings popular among the accelerators

NEG coating (1/2)

- Vacuum chambers coated with a thin film of a suitable getter material can work as a pump by activating the getter during in situ bake-out
- Reduction of pressure rise under particle bombardment
- Need for distributed pumping due to long chambers and progressive reduction of apertures made the use of thin getter coatings popular among the accelerators
- CERN is the pioneer in NEG pumps and coatings

NEG coating (1/2)

- Vacuum chambers coated with a thin film of a suitable getter material can work as a pump by activating the getter during in situ bake-out
- Reduction of pressure rise under particle bombardment
- Need for distributed pumping due to long chambers and progressive reduction of apertures made the use of thin getter coatings popular among the accelerators
- CERN is the pioneer in NEG pumps and coatings
- The NEG alloy TiZrV has a remarkably low activation temperature of 180-200°C

NEG coating (1/2)

- Vacuum chambers coated with a thin film of a suitable getter material can work as a pump by activating the getter during in situ bake-out
- Reduction of pressure rise under particle bombardment
- Need for distributed pumping due to long chambers and progressive reduction of apertures made the use of thin getter coatings popular among the accelerators
- CERN is the pioneer in NEG pumps and coatings
- The NEG alloy TiZrV has a remarkably low activation temperature of 180-200°C
- 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

NEG coating (2/2)

- NEG coatings reduce static and radiation induced degassing, helping maintain the desired good vacuum

NEG coating (2/2)

- NEG coatings reduce static and radiation induced degassing, helping maintain the desired good vacuum
- In the DRs ultra-high vacuum of 0.1 nT is required

NEG coating (2/2)

- NEG coatings reduce static and radiation induced degassing, helping maintain the desired good vacuum
- In the DRs ultra-high vacuum of 0.1 nT is required
- Do not require additional space or equipment and are ideal for regions where other pumps types cannot be used

NEG coating (2/2)

- NEG coatings reduce static and radiation induced degassing, helping maintain the desired good vacuum
- In the DRs ultra-high vacuum of 0.1 nT is required
- Do not require additional space or equipment and are ideal for regions where other pumps types cannot be used
- Use of getter coating helps mitigate some undesirable collective effects (i.e. fast beam ion instabilities) but it can contribute to the machine impedance due to the poor resistivity of Ti, Zr, V

NEG coating (2/2)

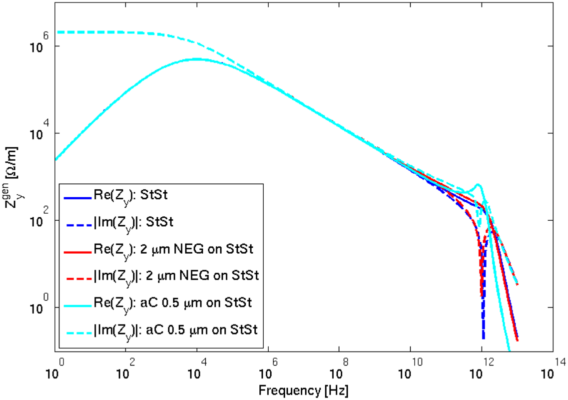
- NEG coatings reduce static and radiation induced degassing, helping maintain the desired good vacuum
- In the DRs ultra-high vacuum of 0.1 nT is required
- Do not require additional space or equipment and are ideal for regions where other pumps types cannot be used
- Use of getter coating helps mitigate some undesirable collective effects (i.e. fast beam ion instabilities) but it can contribute to the machine impedance due to the poor resistivity of Ti, Zr, V
- Light sources with years of NEG usage (ELETTRA, ESRF, SOLEIL etc) have a lot of experience on resistive-wall impedance budget and the effect on the single-bunch threshold

Motivation for high frequency measurements

- The popular use of getter thin film coating and the decreasing bunch length of electron storage rings motivated the study of the material properties in a high frequency regime
- The short bunches (1.8 mm for the DRs) translate into a high frequency spectrum of several hundreds of GHz
- The electromagnetic (EM) characterization of the getter properties up to high frequencies is required for the impedance modeling of the accelerator components
- Effect of surface roughness and the non-uniformity of the coating

Wigglers' impedance for different coatings

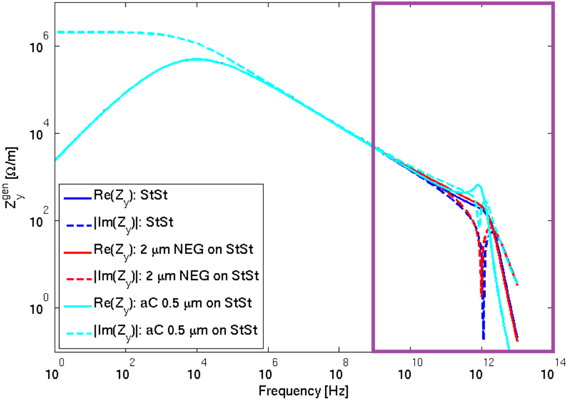
ImpedanceWake2D, N. Mounet CERN-THESIS-2012-055



- Coating is transparent up to 10 GHz

Wigglers’ impedance for different coatings

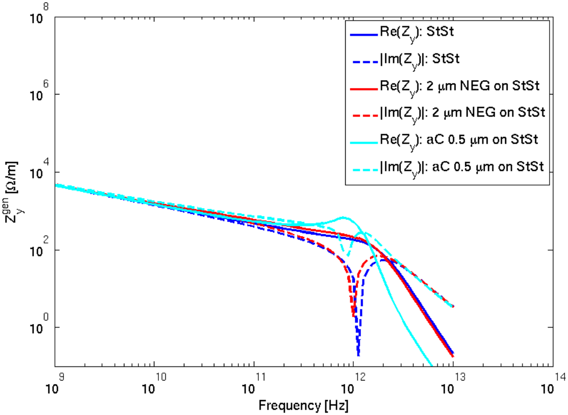
ImpedanceWake2D, N. Mounet CERN-THESIS-2012-055



- Coating is transparent up to 10 GHz

Wigglers' impedance for different coatings

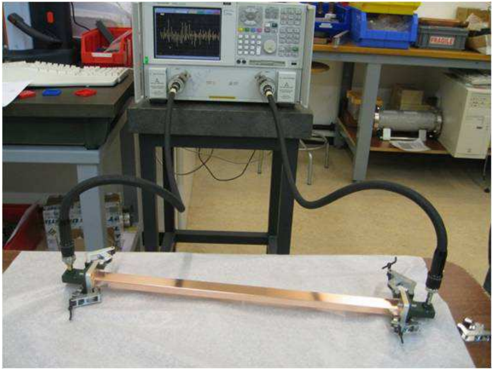
ImpedanceWake2D, N. Mounet CERN-THESIS-2012-055



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

Proposed method

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

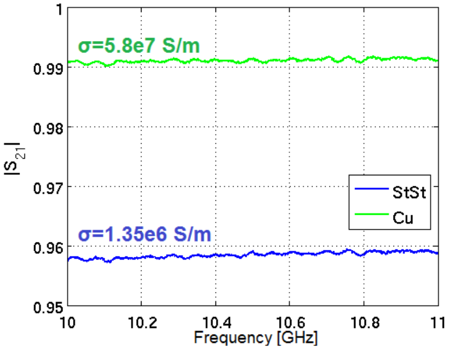


Proposed method

- S_{21} transmission is related to the conductor loss and therefore the unknown material conductivity

Proposed method

- S_{21} transmission is related to the conductor loss and therefore the unknown material conductivity



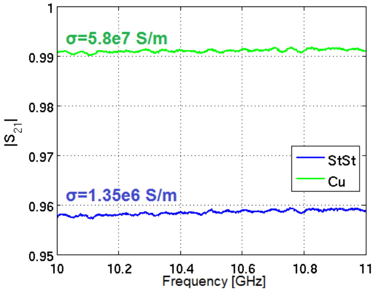
Proposed method

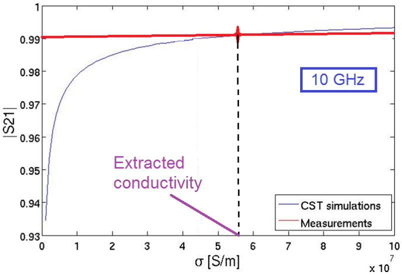
- NEG coating can be applied on the inner surface of the waveguide

Proposed method

- NEG coating can be applied on the inner surface of the waveguide
- The S-parameters can also be obtained numerically from 3D simulations using CST Particle Studio

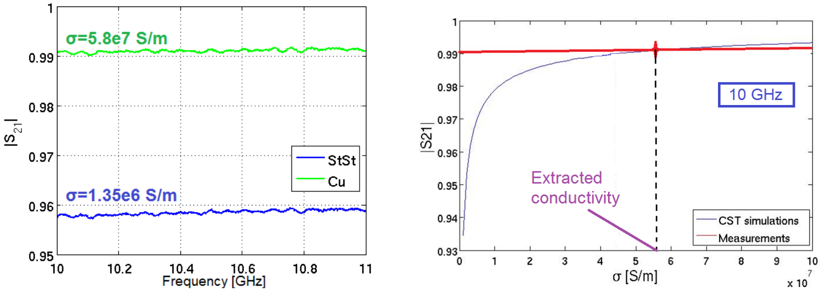
The principle of the method





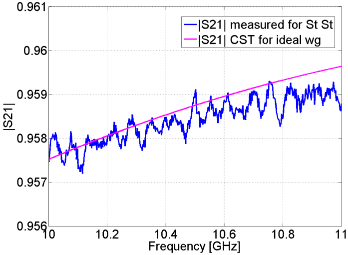
- The conductivity can be extracted by intersecting the simulation with the measured data. Example at 10 GHz

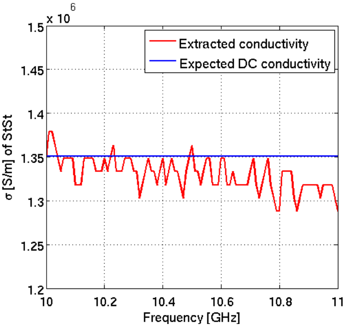
The principle of the method



- The conductivity can be extracted by intersecting the simulation with the measured data. Example at 10 GHz
- By repeating the intersection over all frequencies, conductivity can be plotted as a function of frequency

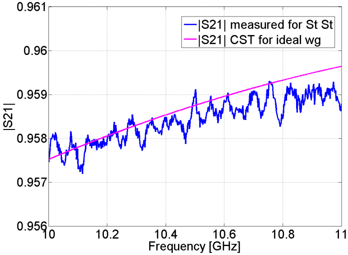
Benchmark of the method with stainess steel (316LN)

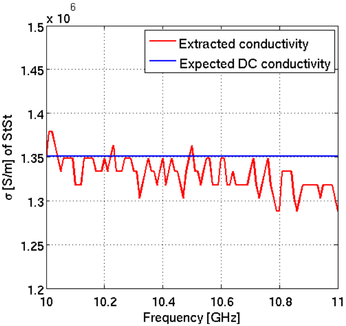




- Extracted conductivity is in good agreement within 5% with the DC known value of 1.35×10^6 S/m

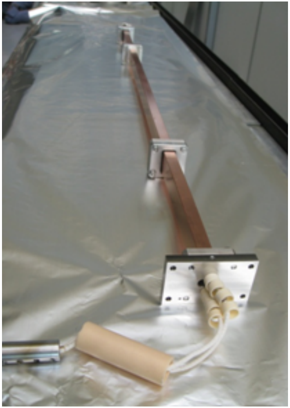
Benchmark of the method with stainess steel (316LN)

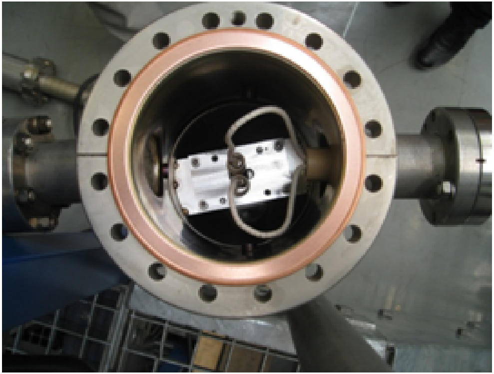




- Extracted conductivity is in good agreement within 5% with the DC known value of 1.35×10^6 S/m
- Successful benchmark for a known material

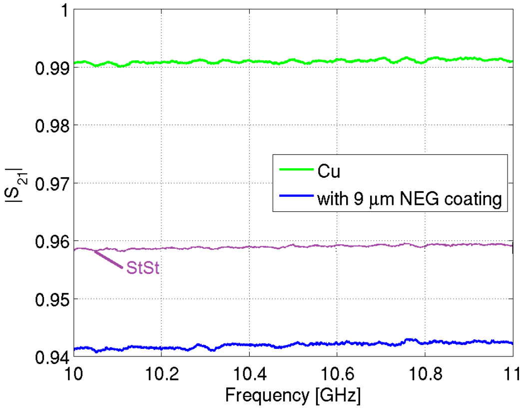
NEG coating





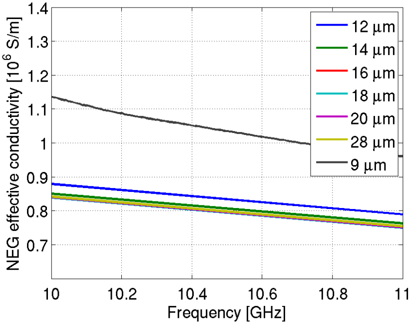
- Coating of the waveguide's inner surface by DC magnetron sputtering (TE/VSC group at CERN)

Measurements with NEG coating



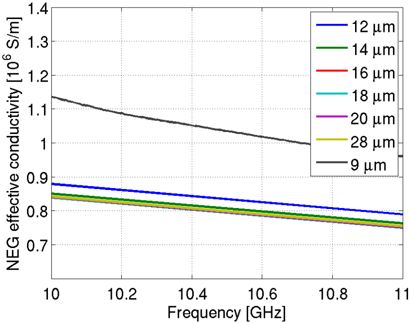
- EM interaction with NEG induces more losses
- Thick film to maximize the interaction of the field with NEG

NEG effective conductivity between 10-11 GHz



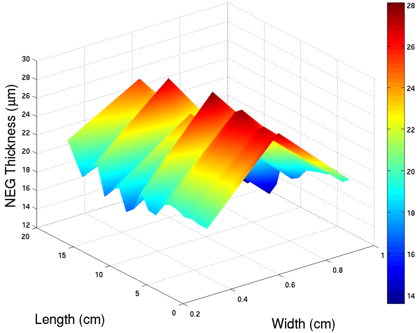
- Measurements at CERN of the DC conductivity: 0.66×10^6 S/m - 1×10^6 S/m. The extracted σ agrees with the DC value

NEG effective conductivity between 10-11 GHz



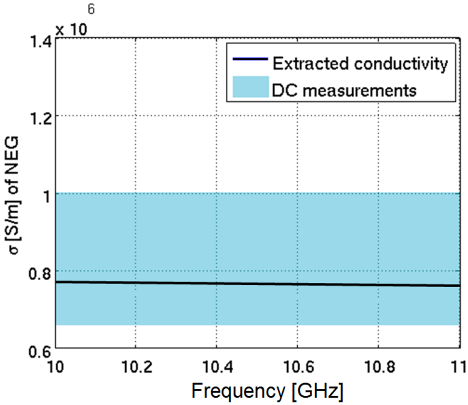
- Measurements at CERN of the DC conductivity: 0.66×10^6 S/m - 1×10^6 S/m. The extracted σ agrees with the DC value
- Seemed to exhibit a frequency dependent behavior

X-ray fluorescence profile analysis



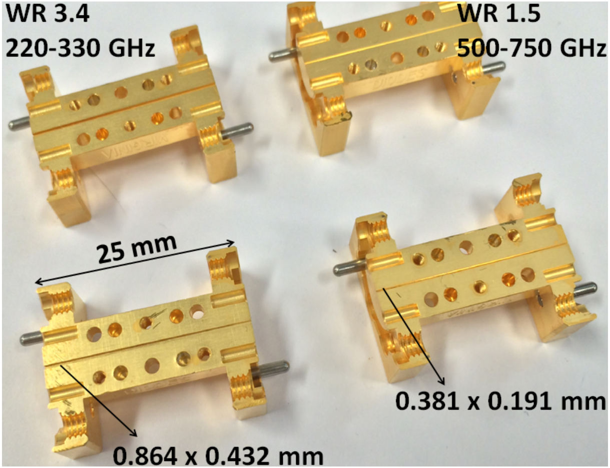
- Variation of thickness found: 12-28 μm. Target value: 20 μm. Difficult morphology of the rectangular waveguide to achieve uniform coating
- The non-uniformity was not previously considered in CST simulations

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



Extracted conductivity is $(0.79 \pm 0.1) \times 10^6$ S/m

Measurements at 220-330 GHz and 500-750 GHz

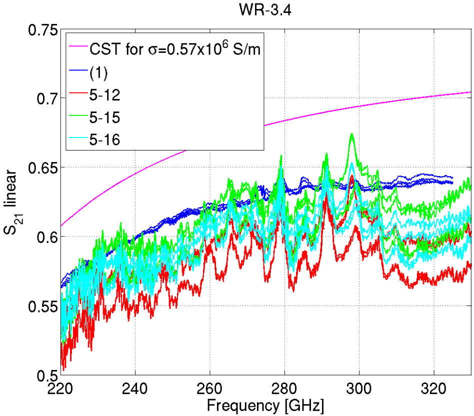


- Aluminum gold-plated waveguides from Virginia Diodes Inc. (VDI)

NEG coating

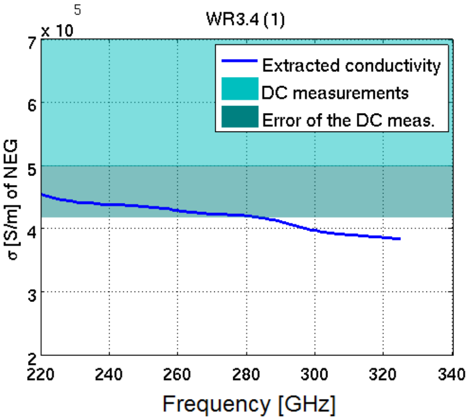
- Challenging coating due to the very small aperture and the rectangular shape (3 μm targeted thickness)

S_{21} measurements with NEG coating



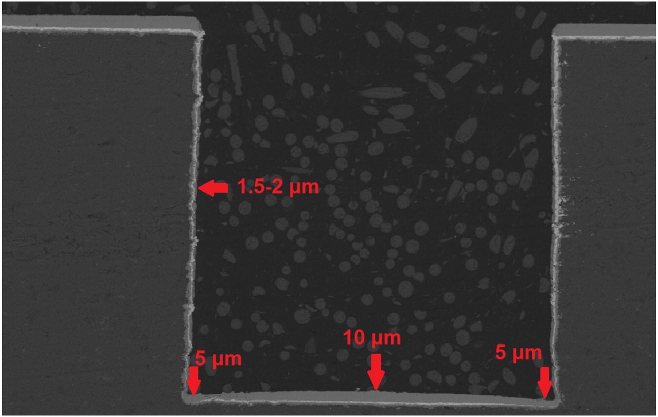
- 15% sample-to-sample variance (4 waveguides measured)

Effective conductivity of NEG at 220-330 GHz



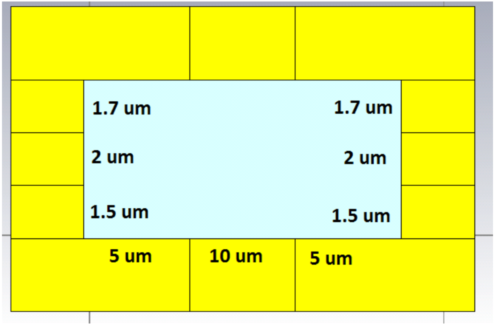
- Measurements of DC conductivity with this coating system: 0.5×10^6 S/m - 0.7×10^6 S/m
- Frequency dependent behavior observed

Coating profile

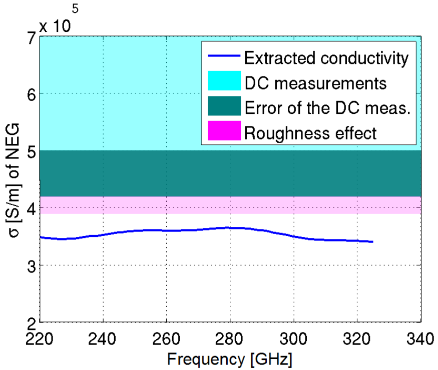


Non-uniform coating, between 5 and 10 μm on the bottom and 1.5 and 2 μm on the side walls

Implementation of the coating thickness in CST

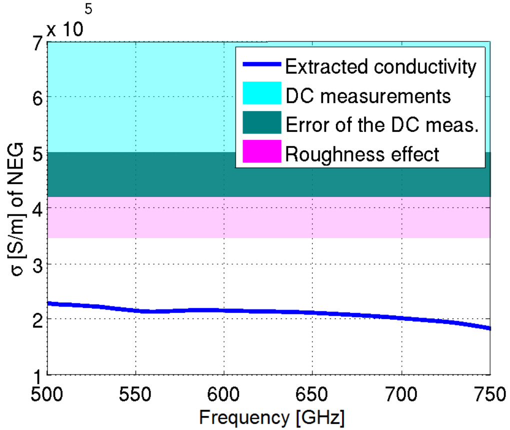


Effect of the non-uniform coating



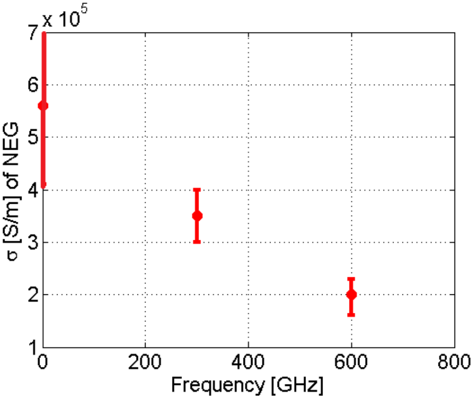
- Milder dependency with frequency. Implementation of the real profile is crucial
- Extracted effective conductivity is $(0.35 \pm 0.05) \times 10^6$ S/m, that accounts for roughness and the non-uniform film coating

Effective conductivity of NEG at 500-750 GHz



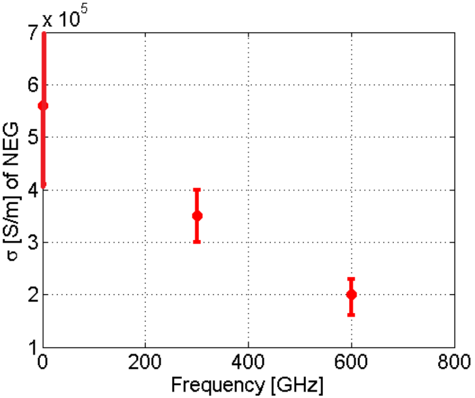
Extracted effective σ_{NEG} is 0.2×10^6 S/m between 500 and 750 GHz

Measurements along all the frequency ranges



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

Measurements along all the frequency ranges



- Effective conductivity is a factor of 2-3 smaller than the DC
- At such frequencies, it is important to account for the effective conductivity which is smaller due to roughness and non-uniformity of the thickness

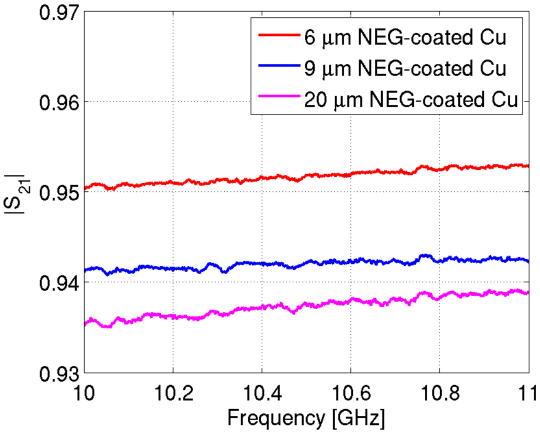
Conclusions

- The experimental method was successfully benchmarked in X-band with stainless steel waveguides
- It was then used to characterize NEG conductivity in several frequency ranges: 10-11 GHz, 220-330 GHz, 500-750 GHz
- The extracted conductivity for 10-11 GHz agrees well with the DC value
- DC conductivity measurements depend on the different cathode used in each coating system
  - First system: 0.66 - 1 $\times 10^6$ S/m
  - Second system: 0.5 - 0.7 $\times 10^6$ S/m
- At higher frequencies, the effective conductivity is about 20% lower from DC

- E. Koukovini-Platia, G. De Michele, G. Rumolo, C. Zannini. *High Frequency Electromagnetic Characterization of NEG Properties for the CLIC Damping Rings*. IPAC 2014, Dresden
- E. Koukovini-Platia, G. Rumolo, C. Zannini. *Electromagnetic characterization of NEG properties above 200 GHz for the CLIC damping rings*. IPAC 2015, Richmond, VA, USA.
- E. Koukovini-Platia. CERN-THESIS-2015-152

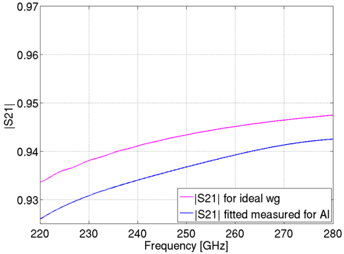
Thank you for your attention!

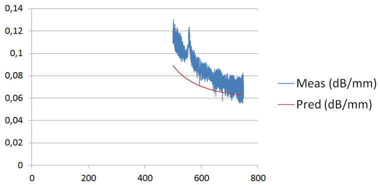
S21 with various thickness



Source of TiZrV for WR3.4, WR1.5 coatings

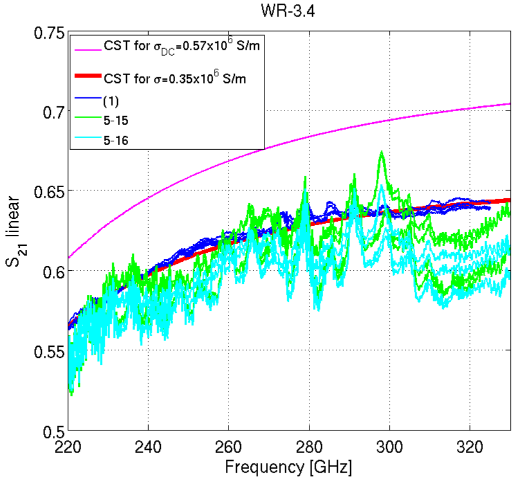
Measurements with Al gold plated WR3.4 waveguide and WR1.5 waveguide



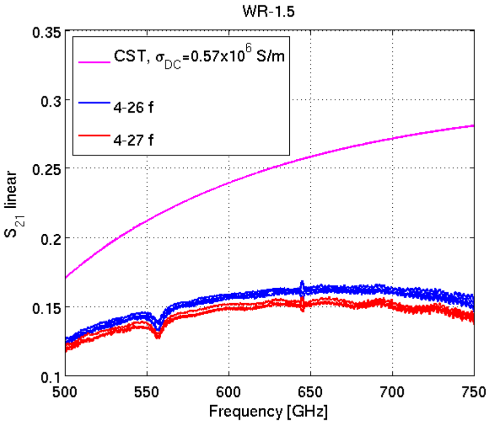


- Comparison of measured S_{21} for a WR3.4 Al gold plated waveguide and simulated with CST Al waveguide
- Agreement within 2% for WR3.4 and around 10 – 15% for the WR1.5

Effect of the non-uniform coating (2)



Measurements at 500-750 GHz



Effect of the non-uniform coating