Electromagnetic characterization of materials for the CLIC Damping Rings and high frequency issues

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Acknowlegdements
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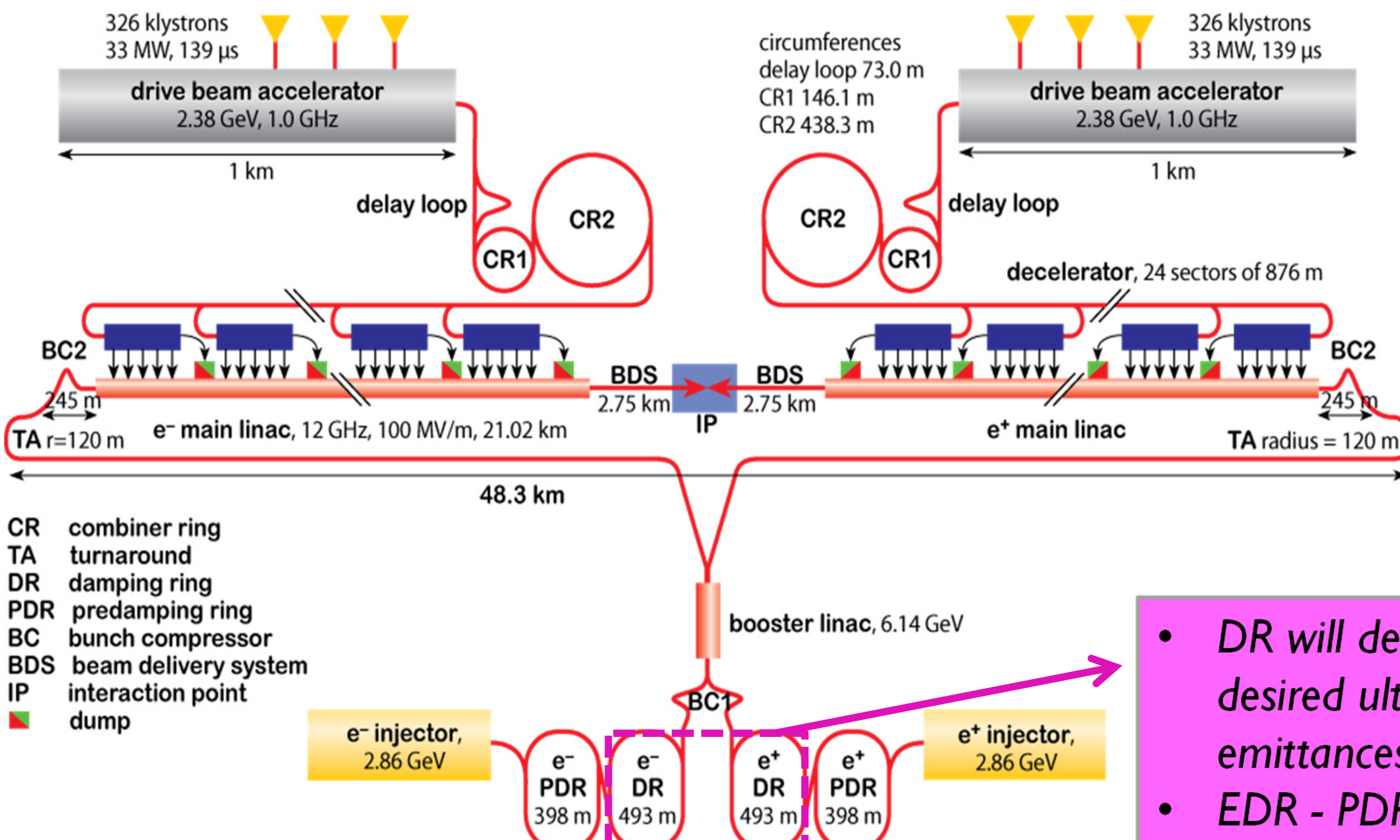
Outline

- Introduction
- Motivation
- Experimental method- simulations
- First results- testing simulations
- Conclusions- future planning- challenges

Introduction (I)
CLIC: a future multi-TeV e^+e^- collider

- Compact Linear Collider (CLIC)
- Allows the exploration of a new energy regime, in the multi-TeV range beyond the capabilities of today's particle accelerators



- *DR will deliver the desired ultra low emittances*
- *EDR - PDR*

Introduction (II)
Damping Rings

CLIC DR parameters

Parameters	CLIC@3TeV
Energy [GeV]	2.86
Circumference [m]	427.5
Energy loss/turn [MeV]	4.0
RF voltage [MV]	5.1
Stationary phase [°]	51
Momentum compaction factor	1.3e-4
Damping time x/s [ms]	2/1
Number of dipoles/wigglers	100/52
Dipole/wiggler field [T]	1.0/2.5
Bend gradient [1/m^2]	-1.1
Bunch population [10^9]	4.1
Horizontal normalized emittance [nm.rad]	456
Vertical normalized emittance [nm.rad]	4.8
Bunch length [mm]	1.8
Longitudinal normalized emittance [keVm]	6.0

- Small emittance, short bunch length and high current
- Rise to collective effects which can degrade the beam quality

Introduction (III)
Collective effects

- Represent phenomena describing the evolution of a particle beam under the effect of self-induced forces
- Could lead to instabilities, tune shift, beam loss and emittance growth
- Determine the performance of an accelerator (by limiting the beam intensity or degrading beam quality)
- Study to ensure safe operation under nominal conditions
- Focus on impedance

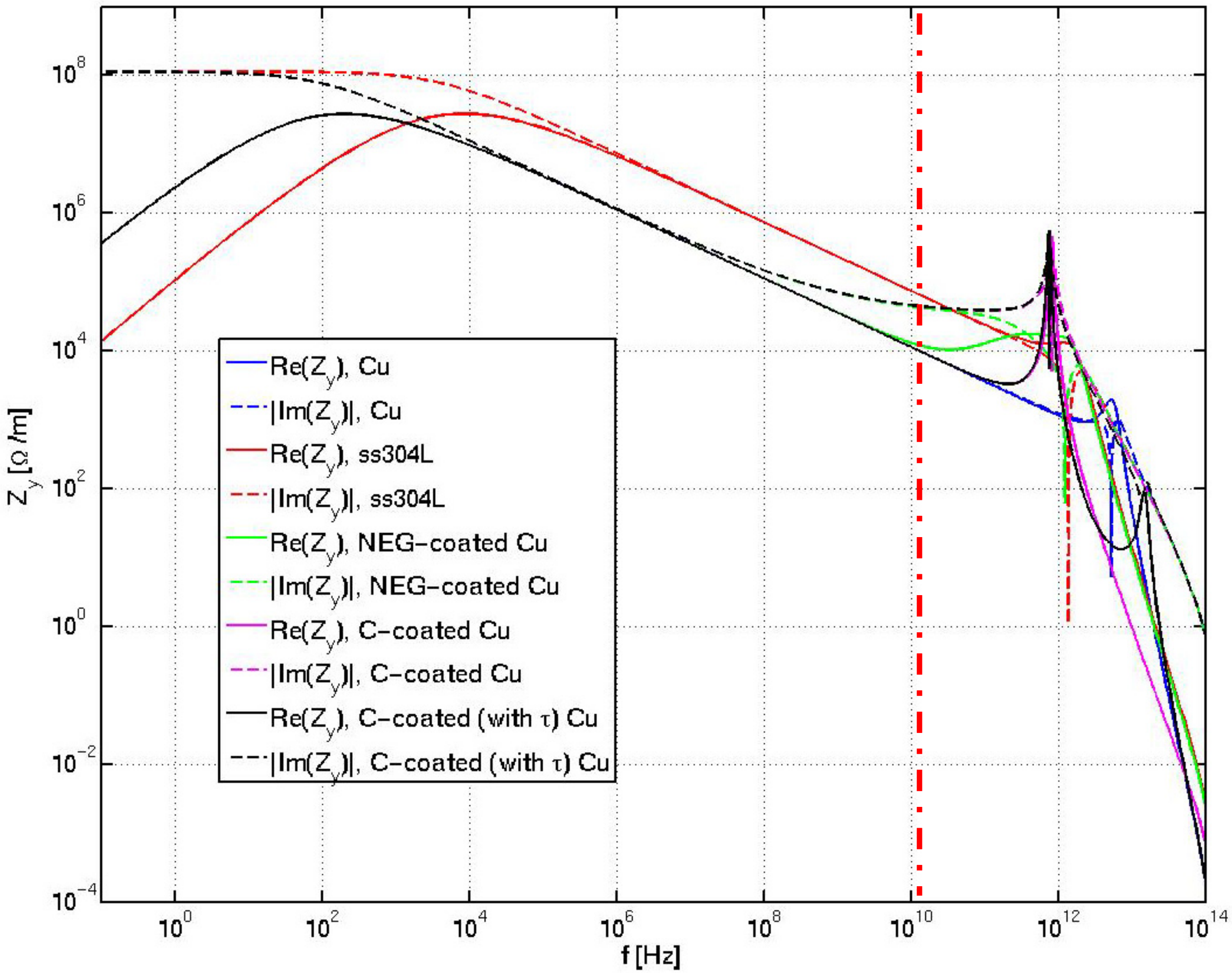
<u>To suppress some of those effects, coating will be used</u>

- Positron Damping Ring (PDR): electron-cloud effects → <u>amorphous carbon (aC)</u>
- Electron Damping Ring (EDR): fast ion instabilities → need for ultra-low vacuum pressure → <u>Non-Evaporable Getter (NEG)</u>

Introduction (IV)
Tools

- HEADTAIL code
  - Simulates single bunch collective phenomena associated with impedances (or electron cloud)
  - Computes the evolution of the bunch centroid as a function of time over an adjustable number of turns
- ImpedanceWake2D
  - Computes the longitudinal and transverse wake functions of multilayer structures, cylindrical or flat
- CST Microwave Studio

Resistive Wall Vertical Impedance: Various options for the wigglers pipe



⇒a-C necessary for e⁻ cloud mitigation

⇒NEG for good vacuum

⇒Coating is "transparent" up to ~*10* GHz

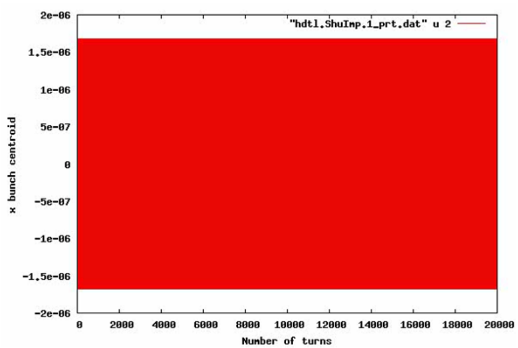
⇒ But at higher frequencies some narrow peaks appear

⇒ Important to define the contribution of the resistive wall

N. Mounet

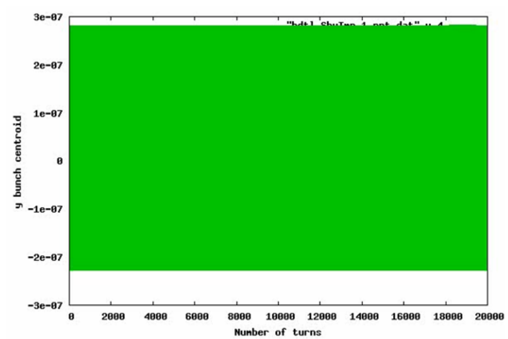
Single bunch simulations to define the instability thresholds

x bunch centroid position



Number of turns

y bunch centroid

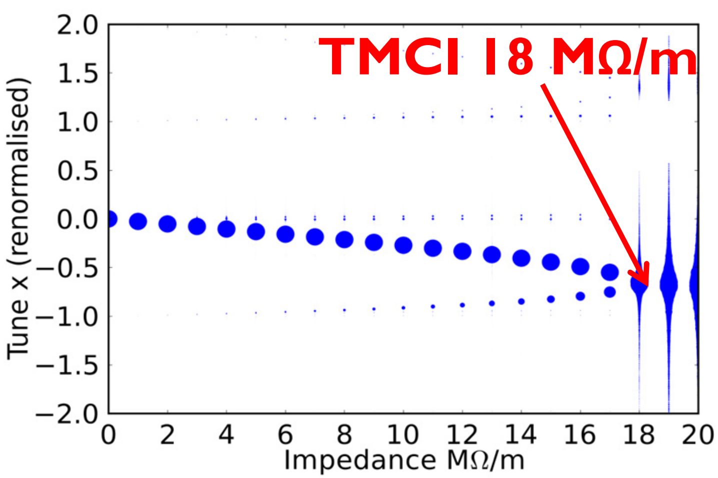


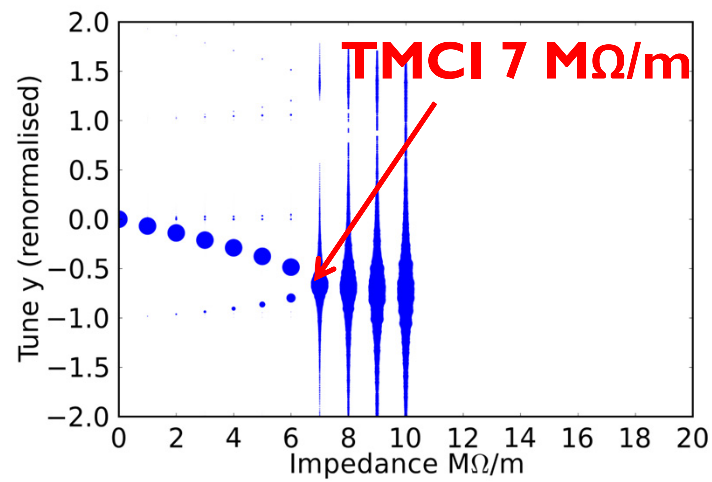
Number of turns

HEADTAIL output:
Position of the centroid over the number of turns

FFT/ Sussix

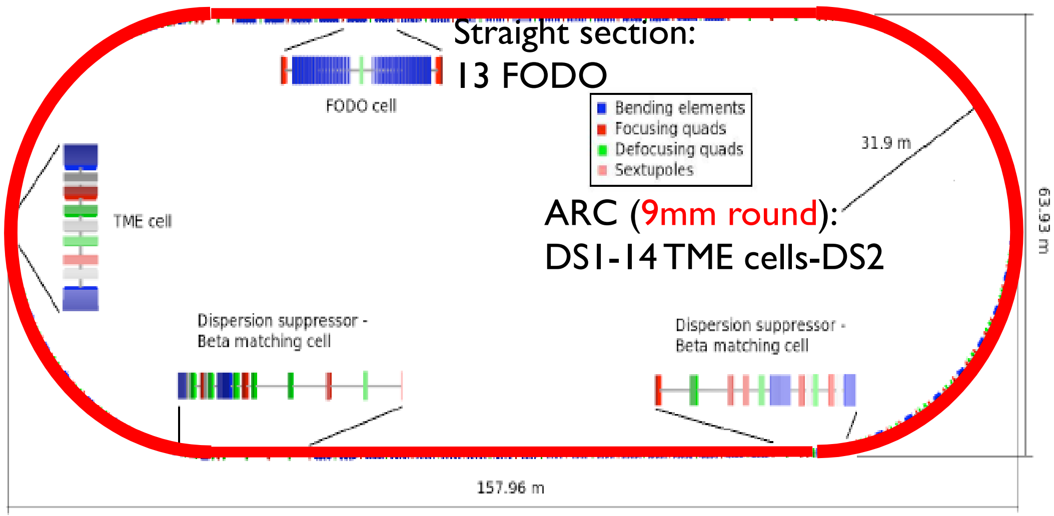
<u>Mode spectrum of the horizontal and vertical coherent motion as a function of impedance</u>





For zero chromaticity, the impedance budget is estimated at 7 MΩ/m

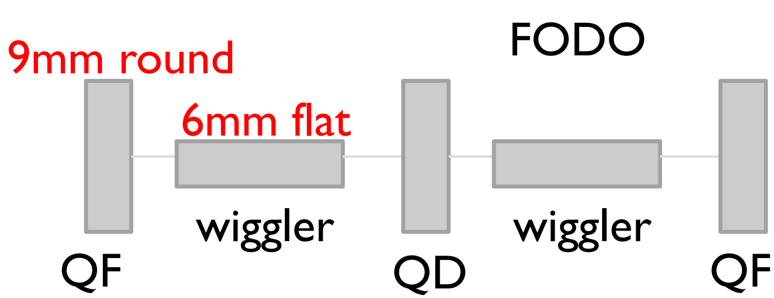
Estimating the machine impedance budget with a 4-kick approximation



- A uniform coating of NEG, 2μm thickness, ($\sigma = 10^6$ S/m) was assumed around the ring made from stainless steel
- The contributions from the resistive wall of the beam chamber were singled out for both the arc dipoles and the wigglers

1 kick → broadband resonator (S_{kick}=1m)

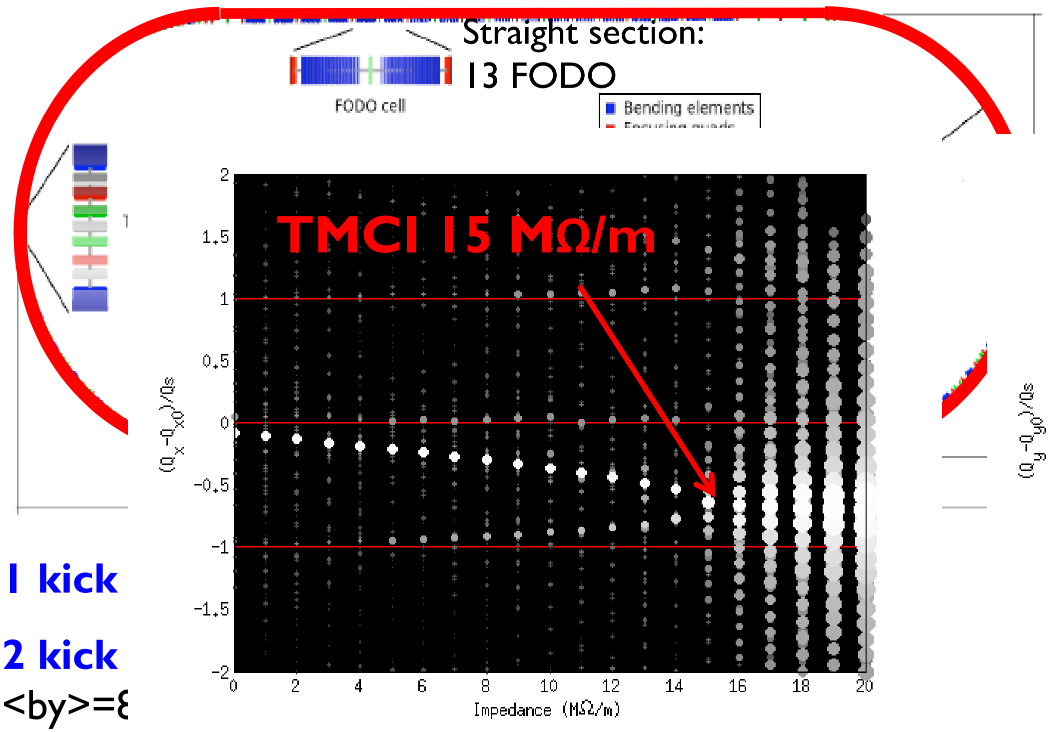
2 kick → arc (L=270.2m, 9mm, round, <bx>=2.976m, <by>=8.829m, S_{kick}=150m)



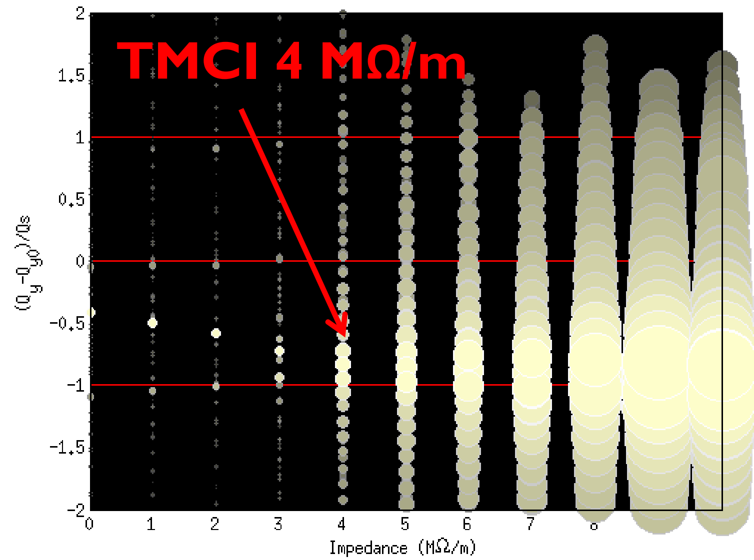
3 kick → wigglers (L=104m, 6mm, flat, <bx>=4.200m, <by>=9.839m, S_{kick}=41.3m)

4 kick → rest of the FODO (L=53.3m, 9mm, round, <bx>=5.665m, <by>=8.582m, S_{kick}=39.2m)

Estimating the machine impedance budget with a 4-kick approximation



- A uniform coating of NEG, 2μm thickness, ($\sigma=10^6$ S/m) was assumed

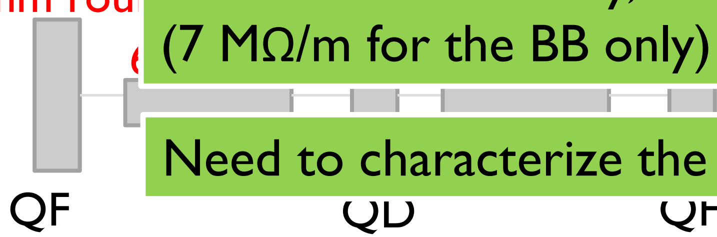


1 kick

2 kick

<by>=8

9mm rou



For zero chromaticity, the impedance budget is estimated at 4 MΩ/m (7 MΩ/m for the BB only)

Need to characterize the properties of NEG

m, round, <bx>=5.665m, <by>=8.582m, s_{kick}=59.2m)

Motivation

EM properties of NEG and aC → Code calculating wake fields/ impedances → Instabilities studies for the CLIC DR

- Need to characterize the properties of the coating materials at high frequencies (CLIC), i.e. 500 GHz

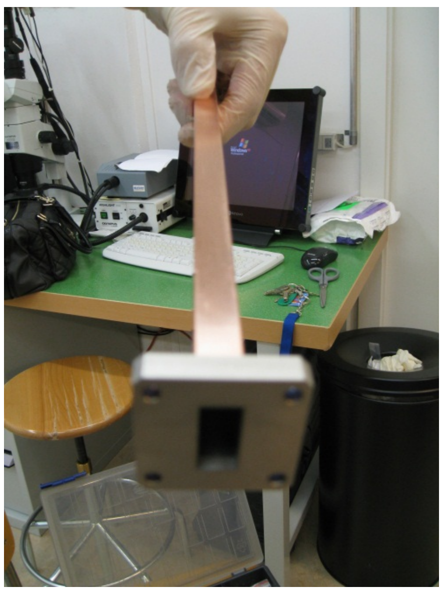
- Characterize the electrical conductivity of *NEG*

- Combination of experimental method and EM simulations

TiZrV coating

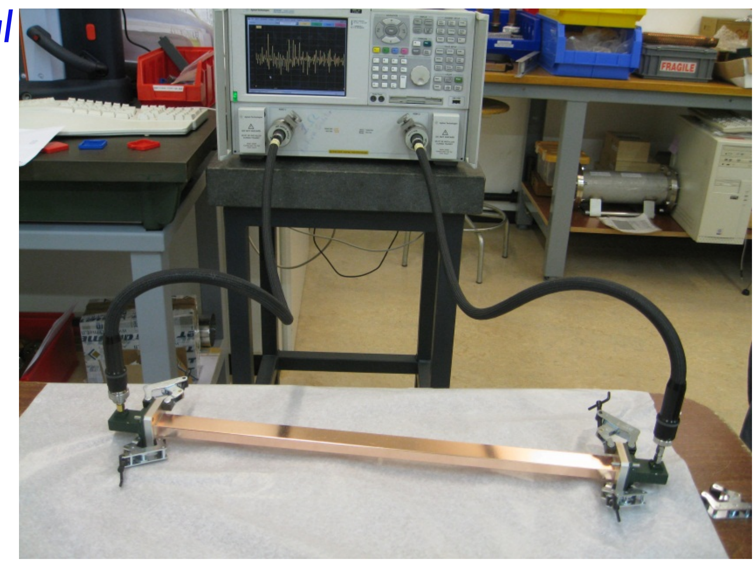
Experimental Method (I)

- Waveguide Method
  - First tested at low frequencies, from 9-12 GHz
  - Use of a standard X-band waveguide, 50 cm length
  - Network analyzer
  - Measurement of the transmission coefficient S_{21}



X band Cu waveguide of 50 cm length

Experimental setup

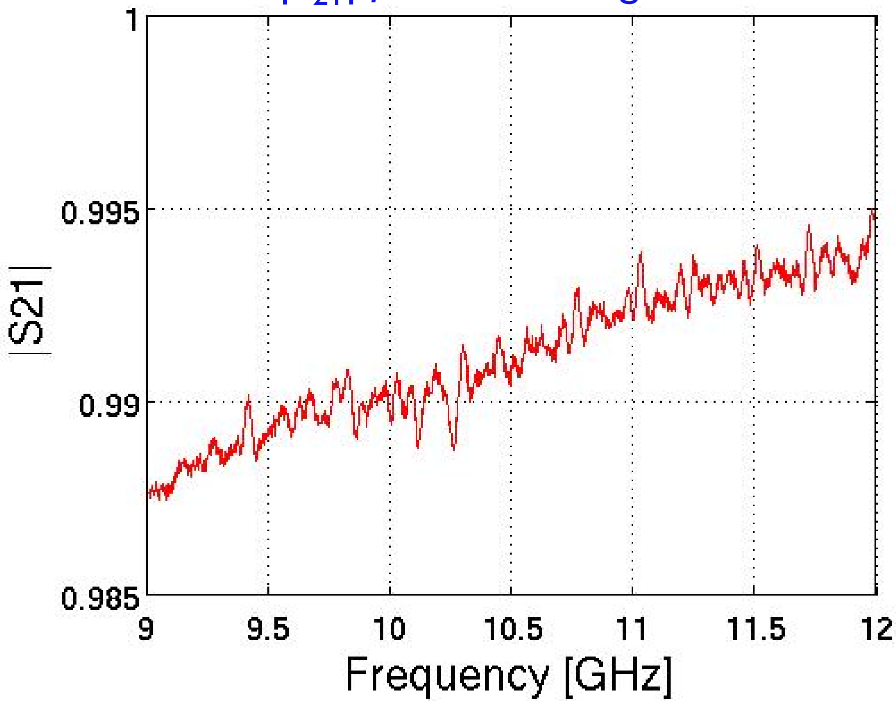


Experimental Method (II)

Copper waveguide

- First test: a pure copper (Cu) X band waveguide
- Measure the S_{21} from 9-12 GHz

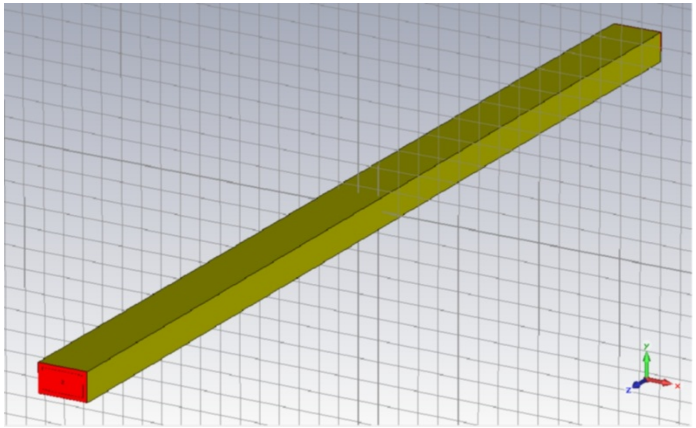
$|S_{21}|$ *for a Cu waveguide*



- Signals traveling in the waveguide experience loss due to the conductor resistance
- S_{21} is related to the loss suffered in the transmission from one port to the other
- Cu is a very good conductor and the losses are small
- S_{21} is related to the material conductivity

3D EM Simulations (I)
CST Microwave Studio

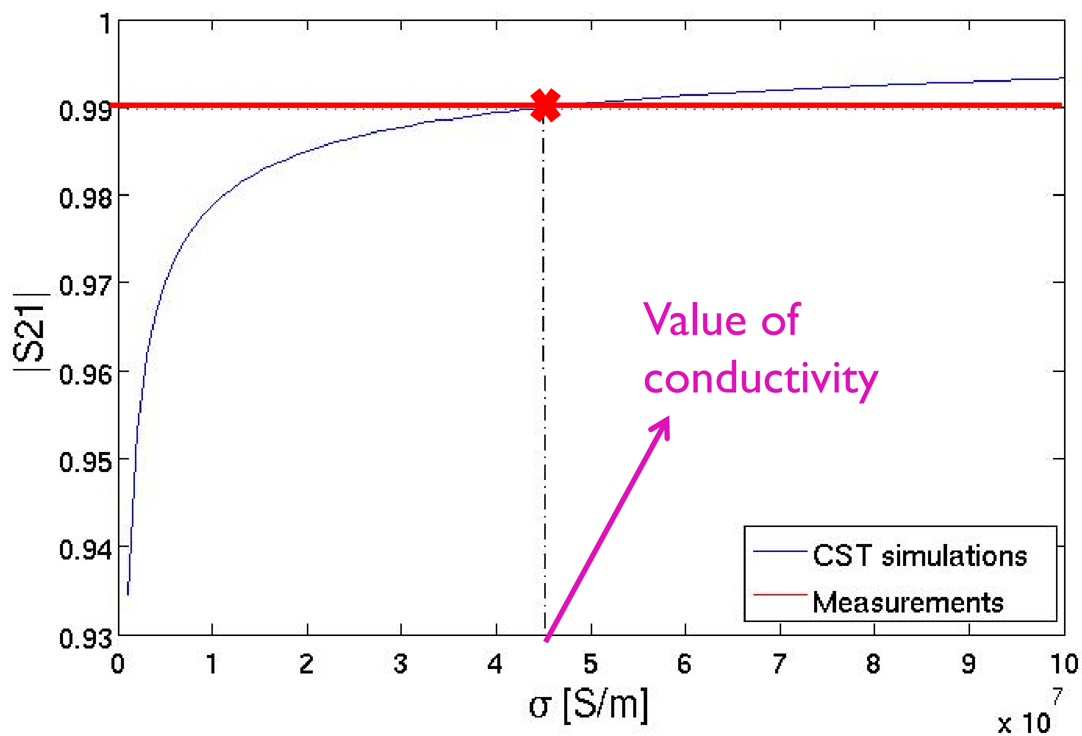
- Software package for electromagnetic field simulations
- The tool Transient Solver also delivers as results the S-parameters
- CST is used to simulate the Cu waveguide (same dimensions as the ones used in the experiment → simulating the experimental setup)



X band Cu waveguide simulated with CST MWS

3D EM Simulations and measurements (I)

- X band Cu waveguide, $\varepsilon_r = \mu_r = 1$, σ is the (unknown) scanned parameter
- For each frequency from 9-12 GHz, the output result is the S_{21} coefficient as a function of conductivity
- Combine with the measurement results → σ as a function of frequency

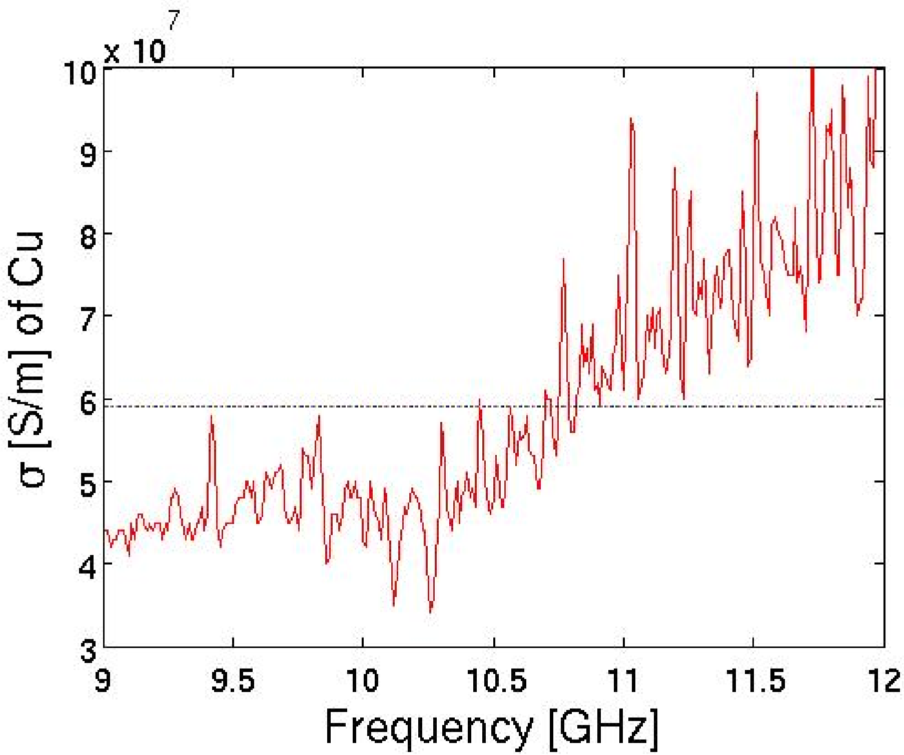


<u>Example at 10 GHz</u>

Intersection of the simulation results with the measurement → point of intersection defines the conductivity

3D EM Simulations and measurements (II) Conductivity of Cu

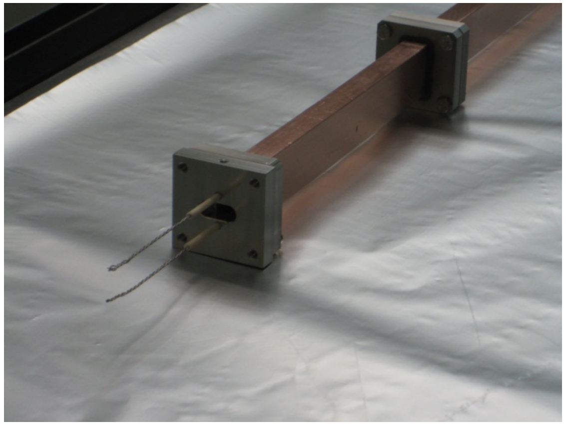
- Result from the intersection of measurements with CST MWS simulations

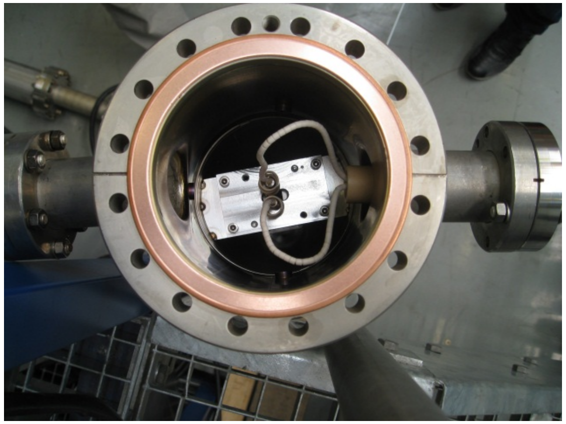


- Cu conductivity was estimated within the same order of magnitude with the known value
- Average is 5.91×10^7 S/m
- Good agreement with the known value of 5.8×10^7 S/m
- The attenuation is very sensitive to the errors because of the small losses (high conductivity of Cu)
- Despite this, the results were encouraging to continue with a coated waveguide

Experimental Method (III)

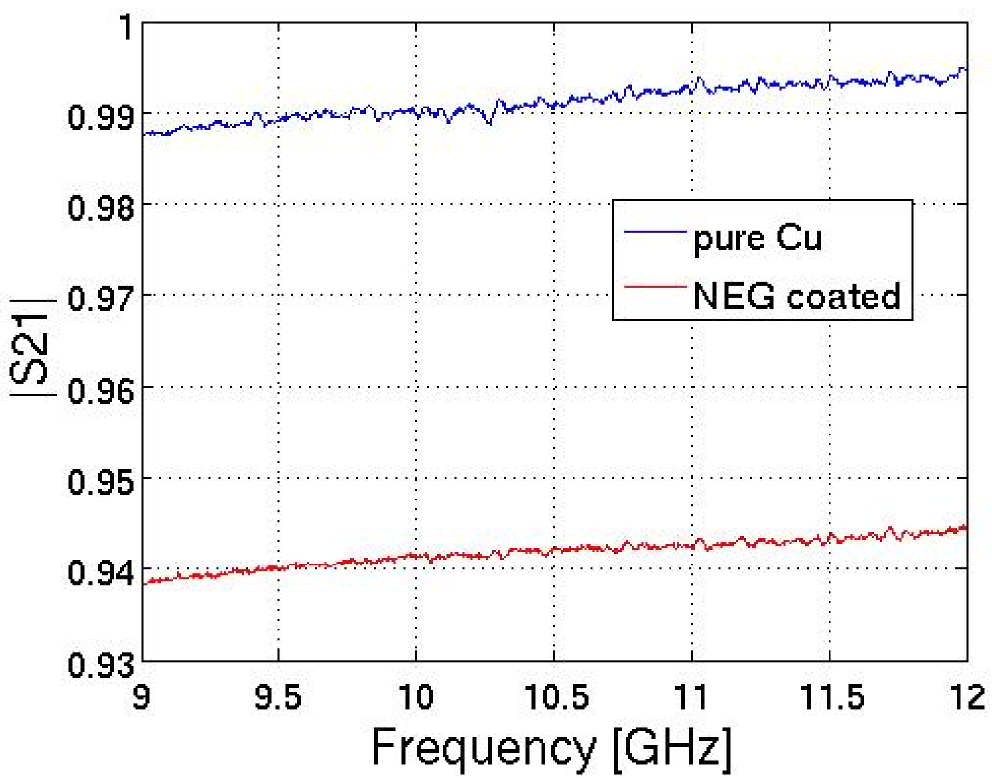
- NEG coated Cu waveguide
  - Same Cu waveguide used before is now coated with NEG
- <u>Coating procedure</u>
  - Elemental wires intertwisted together produce a thin Ti-Zr-V film by magnetron sputtering
  - Coating was targeted to be as thick as possible (9 μm from first x-rays results)





Experimental Method (IV)

- NEG coated Cu waveguide
  - Measure the S_{21} from 9-12 GHz

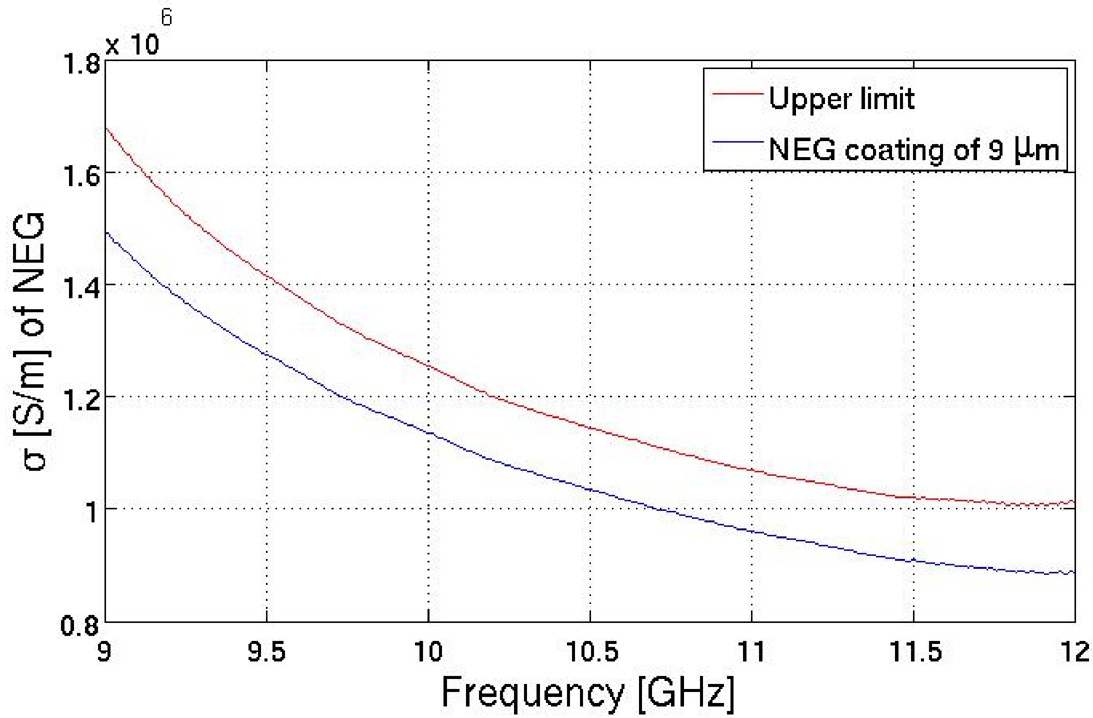


- S_{21} results indicate that the skin depth is small enough compared to the coating thickness
- Allows the EM interaction with the NEG

3D EM Simulations and measurements (III) Conductivity of NEG

- Real thickness profile → unknown
- First indication from x-rays
- 2 scenarios
  - skin depth << thickness → losses only from NEG → σ_{NEG}
    - simulation: infinite thickness of NEG → upper limit
  - skin depth ~ thickness → losses from NEG and Cu → σ_{NEG}
    - simulation: NEG-coated (9μm) Cu waveguide

3D EM Simulations and measurements (IV) Conductivity of NEG



- Upper limit for the conductivity of NEG in this frequency range
- Preliminary results

- Errors
  - Experimental method (stainless steel waveguide)
  - Benchmark CST MWS coating simulations

First tests of the CST MWS simulations (I)

- Check the results reliability of coating simulations
- First tests

Compare simulations

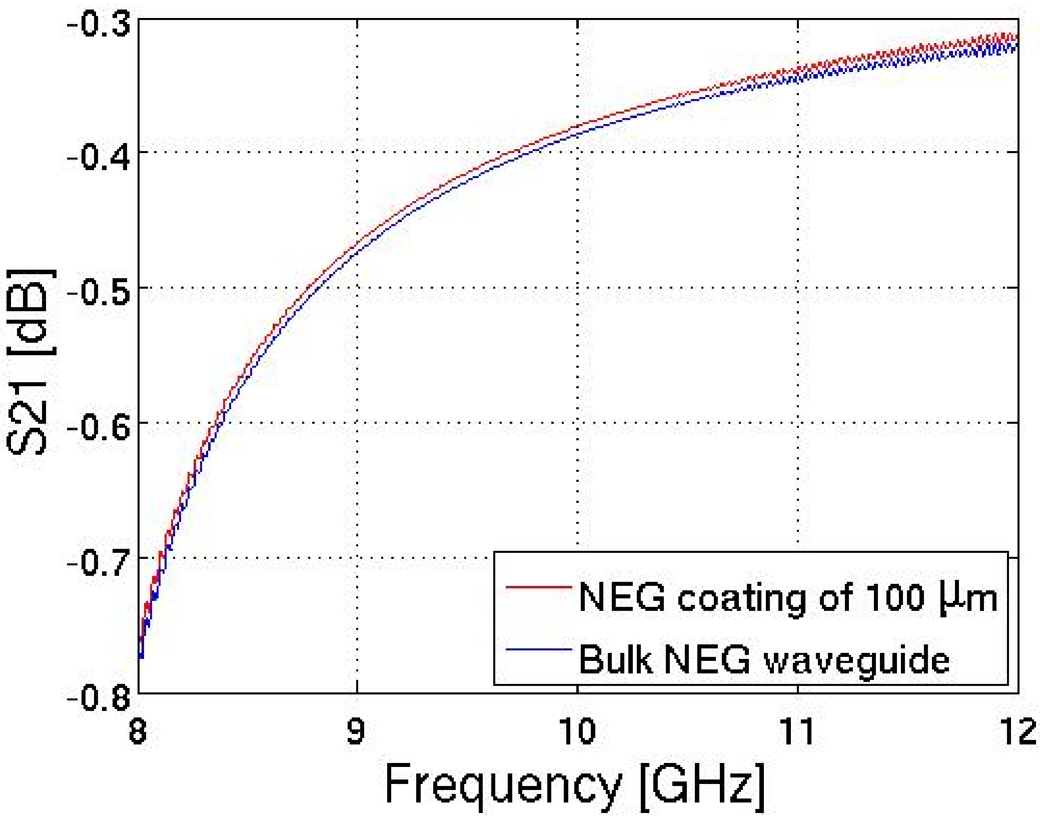
1. A Cu waveguide NEG coated of 100 μm (2 materials)
   - Assuming σ_{NEG} = 2x10^6 S/m, the skin depth is varying from 3.9-3.2 μm for 8-12 GHz

$$\delta = \sqrt{\frac{2}{\mu\omega\sigma}} \approx 503\sqrt{\frac{1}{\mu_r f\sigma}}$$

   - skin depth << 100 μm thickness → EM interaction only with NEG
2. A waveguide from NEG (1 material)

First tests of the CST MWS simulations (II)

- Compare the results from simulations for the 2 cases



The results are in a very good agreement, 1% error

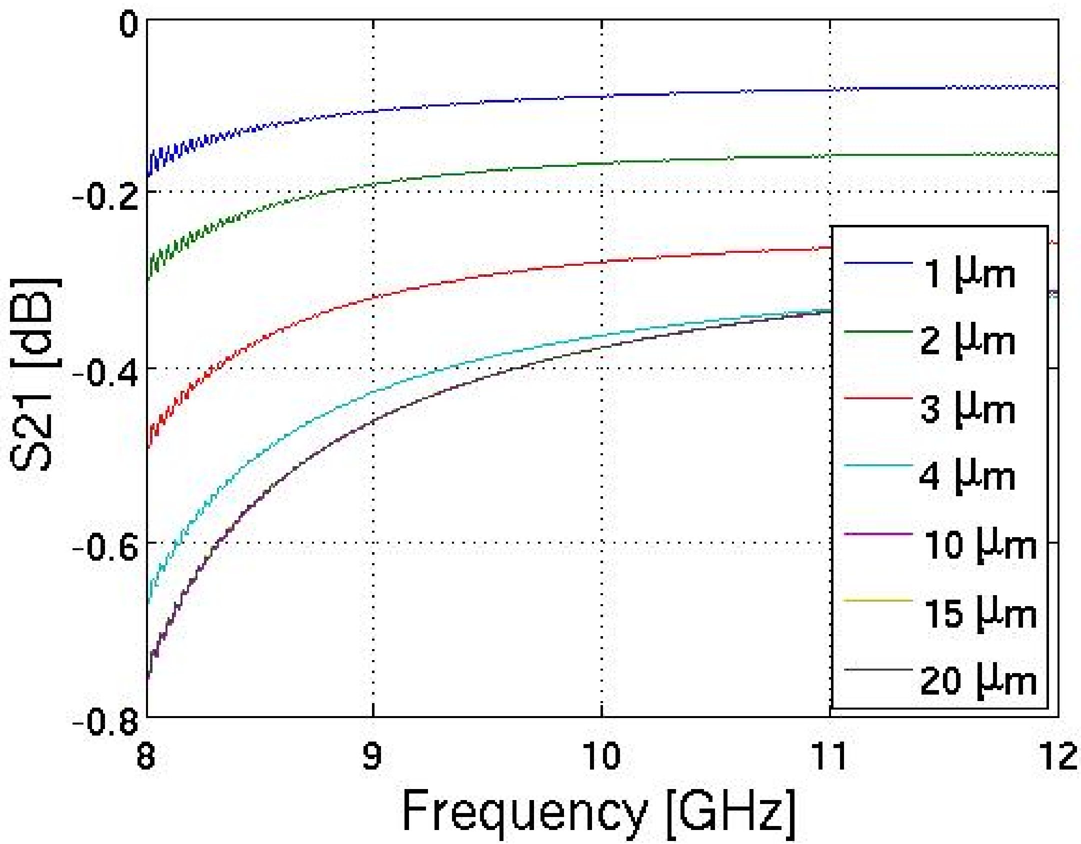
First tests of the CST MWS simulations (III)

- Simulate different values of NEG thickness and check the output of simulations

  - From 8-12 GHz, skin depth varies from 3.9-3.2 μm ($\sigma_{NEG} = 2x10^6$ S/m)
  - Simulate thickness from 1-20 μm

First tests of the CST MWS simulations (IV)

- Compare results for different NEG thickness from 1-20 μm



- For small values, 1-4 μm, the skin depth is larger or comparable to the thickness → small losses due to Cu
- For 10-20 μm, the skin depth << thickness → higher losses due to NEG

The results are in agreement with the expected ones

Summary

⇒NEG (Non Evaporable Getter)/ aC (amorphous Carbon) coating is necessary for good vacuum and to fight e$^-$ cloud in the EDR and PDR of CLIC

⇒Unknown material properties at high frequencies

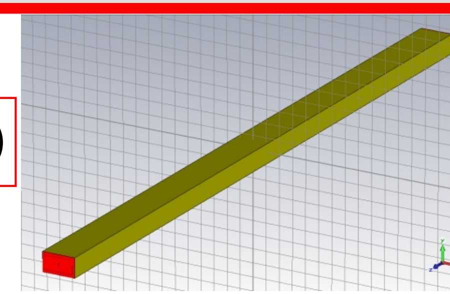
⇒Combine experimental results with CST simulations

⇒Powerful tool for this kind of measurements

Experimental method

50 cm Cu wg
9-12 GHz

CST MWS simulation



$S21(\sigma)$ — Intersection — $(f, S21)$

Material properties σ, ε, μ → Calculation of the wake fields → Study of instabilities with HEADTAIL

Conclusions- Future work

⇒The waveguide method combined with CST EM simulations was tested at frequencies from 9-12 GHz for a Cu NEG coated waveguide

⇒The results were encouraging

⇒Upper limit for the NEG conductivity at this frequency range

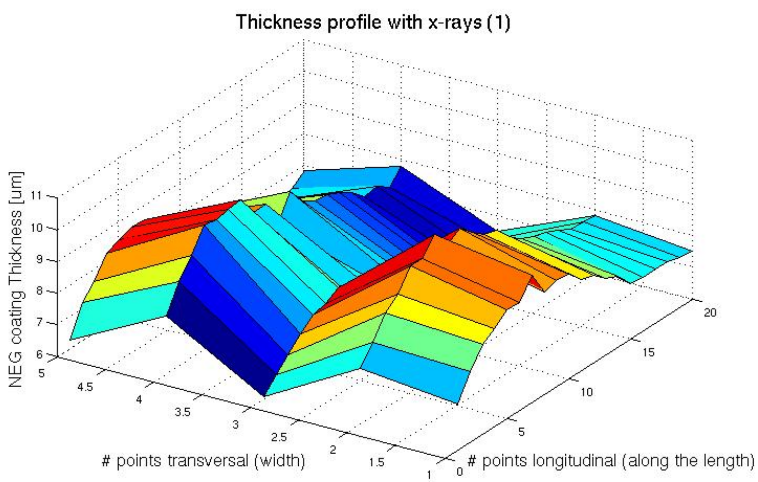
⇒Measurements for a stainless steel waveguide will take place (error of the method)

⇒CST MWS simulations will be benchmarked (error of simulations)

⇒Measurements on a different coating? aC?

Challenges…

- Measure properties at high frequencies…
  - Up to 500 GHz/ 500 GHz Network analyzer (EPFL)
  - Very short waveguides, Y-band (0.5 x 0.25 mm)
- Challenges
  - Manufacture of the small waveguide
  - Coating technique
  - Profile measurements
- Simulation
  - Non-uniform coating



Acknowledgements

- A.T. Perez Fontenla
- G. Arnau Izquierdo
- S. Lebet
- M. Malabaila
- P. Costa Pinto
- M. Taborelli

Thank you for your attention!