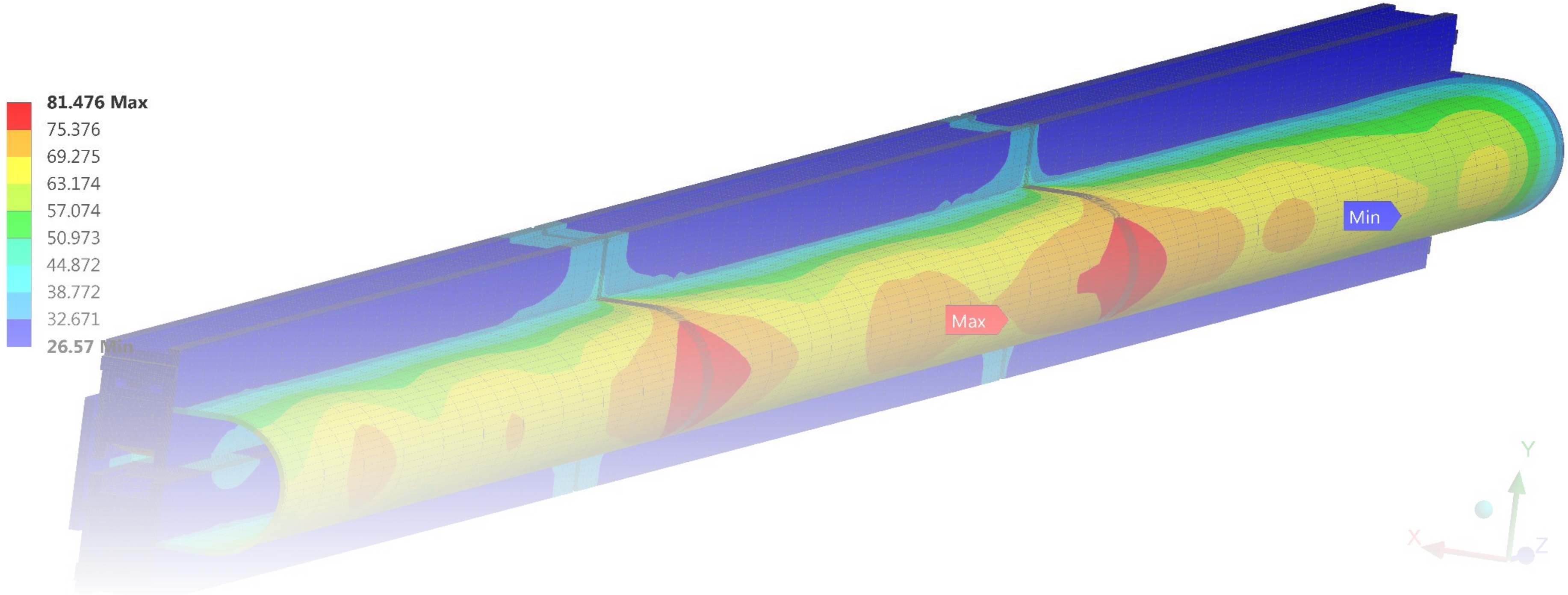

Updated impedance studies for the TDIS

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06/07/2018 WP14 Coordination Meeting: TDIS

CERN | EN ENGINEERING DEPARTMENT

STVDIVM VRBIS

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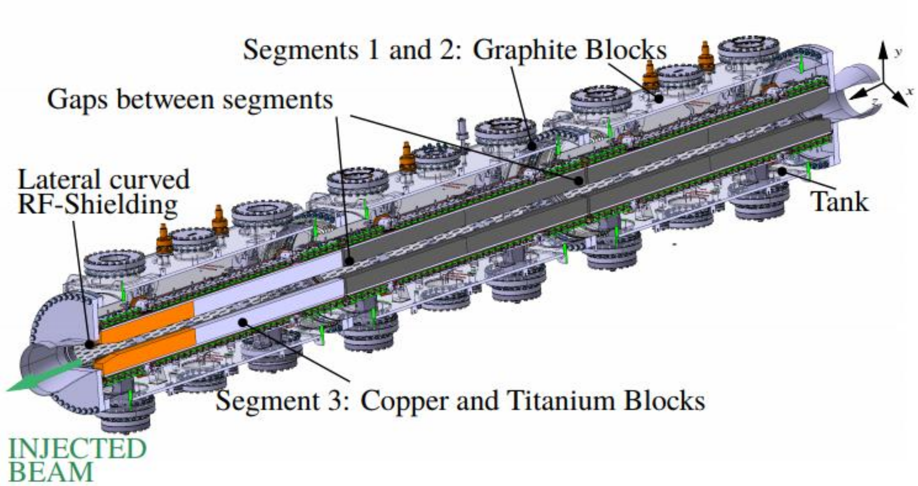
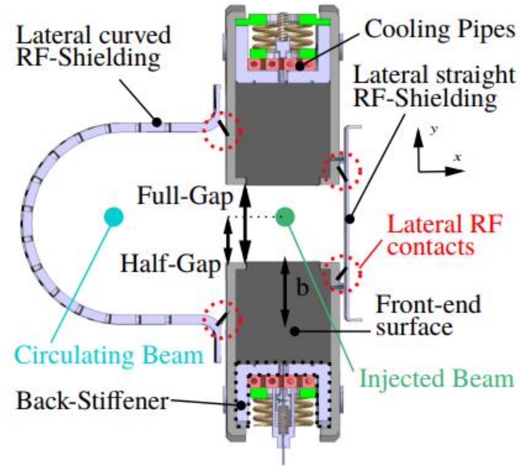
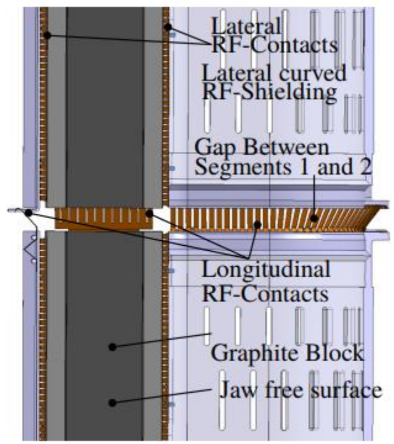
Scope Of the Presentation

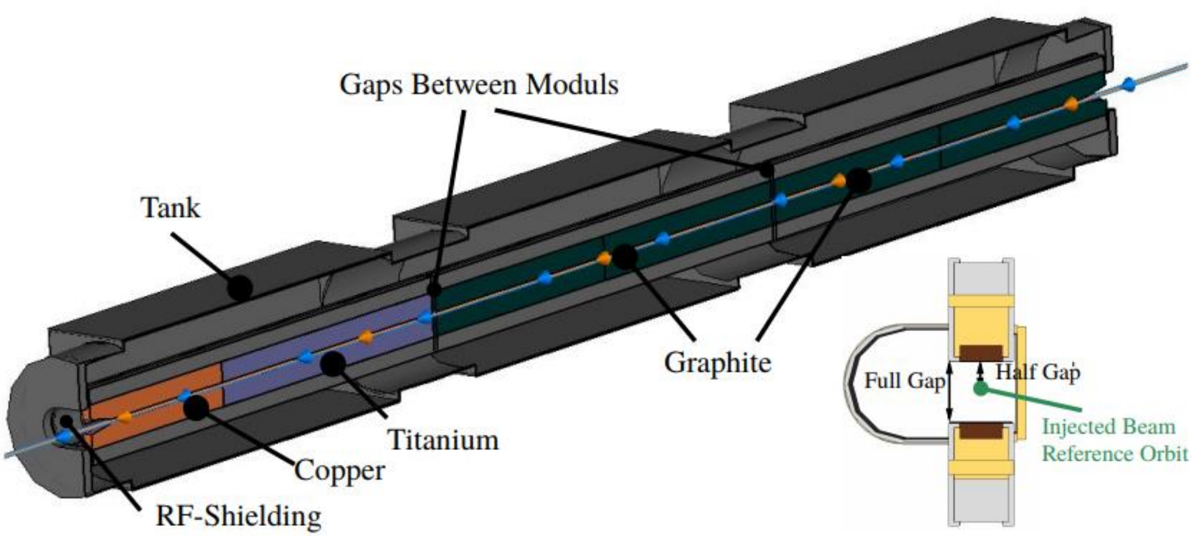
- Introduce the model geometry and the CST simplifications
- Simulation Results
  - Electromagnetic
    - Nominal Scenarios vs RF-Finger Failure Scenarios
    - Impact of the Carbon Sheet Plate
  - Thermomechanical
    - RF-Heating 3D Map
    - Temperature and Stresses
- Next Step: The Two Counter-Rotating Beams Problem

Model Geometry and CST Simplifications







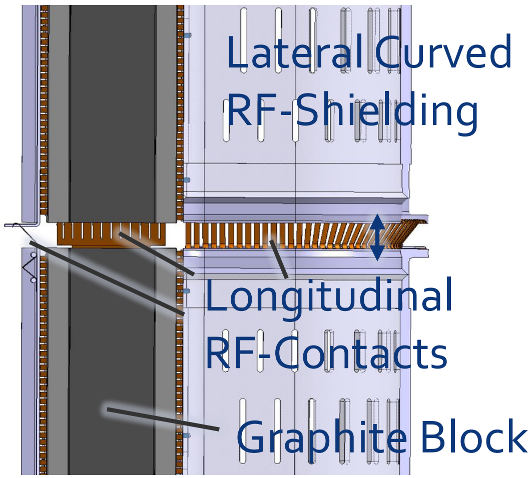


Top: The TDIS model for production, general overview and detail: front view cut with main parts labeled, RF-finger system.
Bottom Left: The CST simplified model, only the features important for the electromagnetic simulations have been preserved.

Impedance Simulations: Two Possible Scenarios

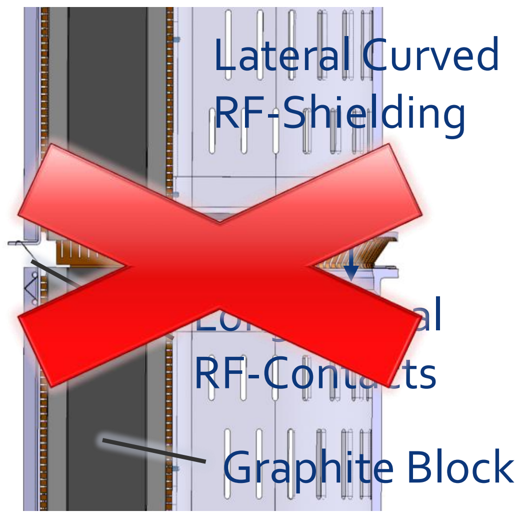
- Nominal Scenarios

  In this scenario the longitudinal RF-contact are considered, i.e. the electrical contacts between the segments is guaranteed and the image currents can smoothly flow in the device.



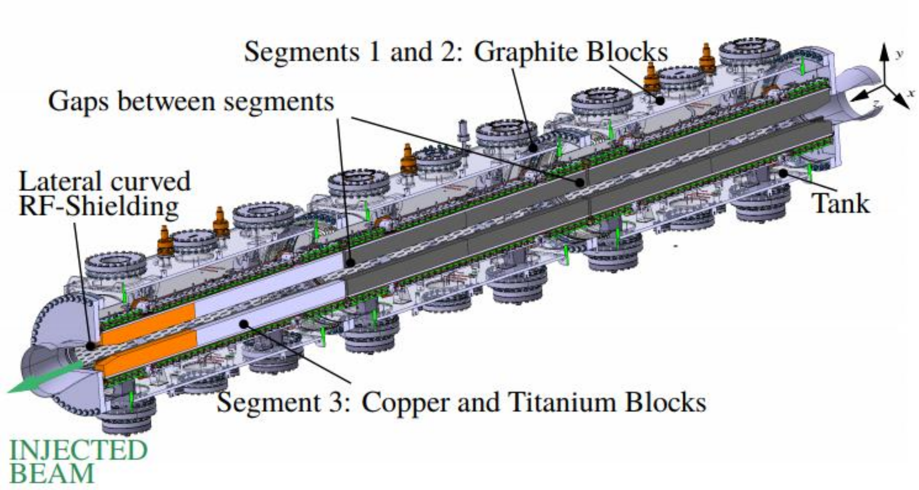
- RF-Finger Failure Scenarios (Pessimistic Scenario)

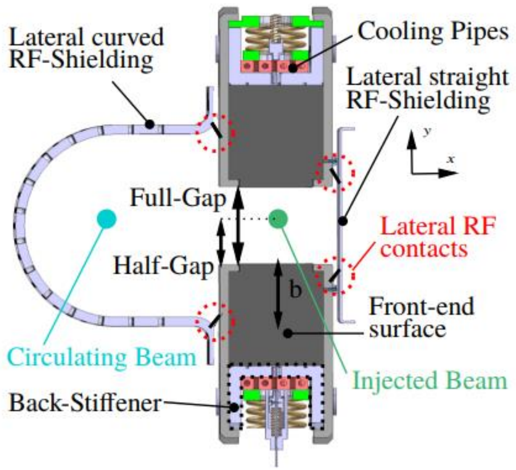
  In this scenario the longitudinal RF-contact are NOT considered (they are present in the design and in the simulations but they do not physically touch the parts on one tip). There is not electrical contacts between the segments and the image currents cannot smoothly flow in the device. An higher Impedance is expected.



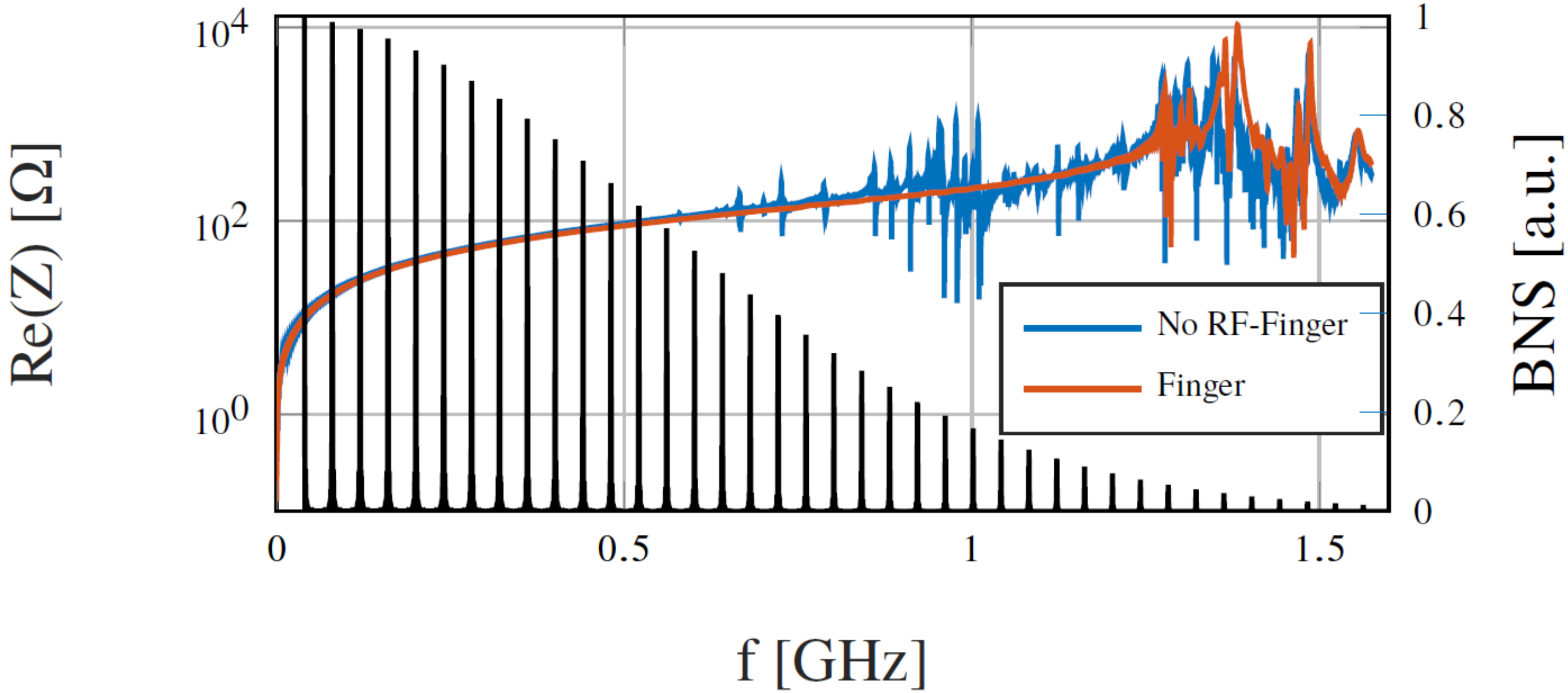
Extra Comments

- The presented simulations have been done with a half-gap aperture of the jaws of 5 mm instead of the current fixed value of 3.8 mm. This is because at the time the simulations were run the half-gap data was not available yet and a tentative value was used. However, due to the small difference between the tentative value and the correct one small changes are expected in the electromagnetic behavior of the device.



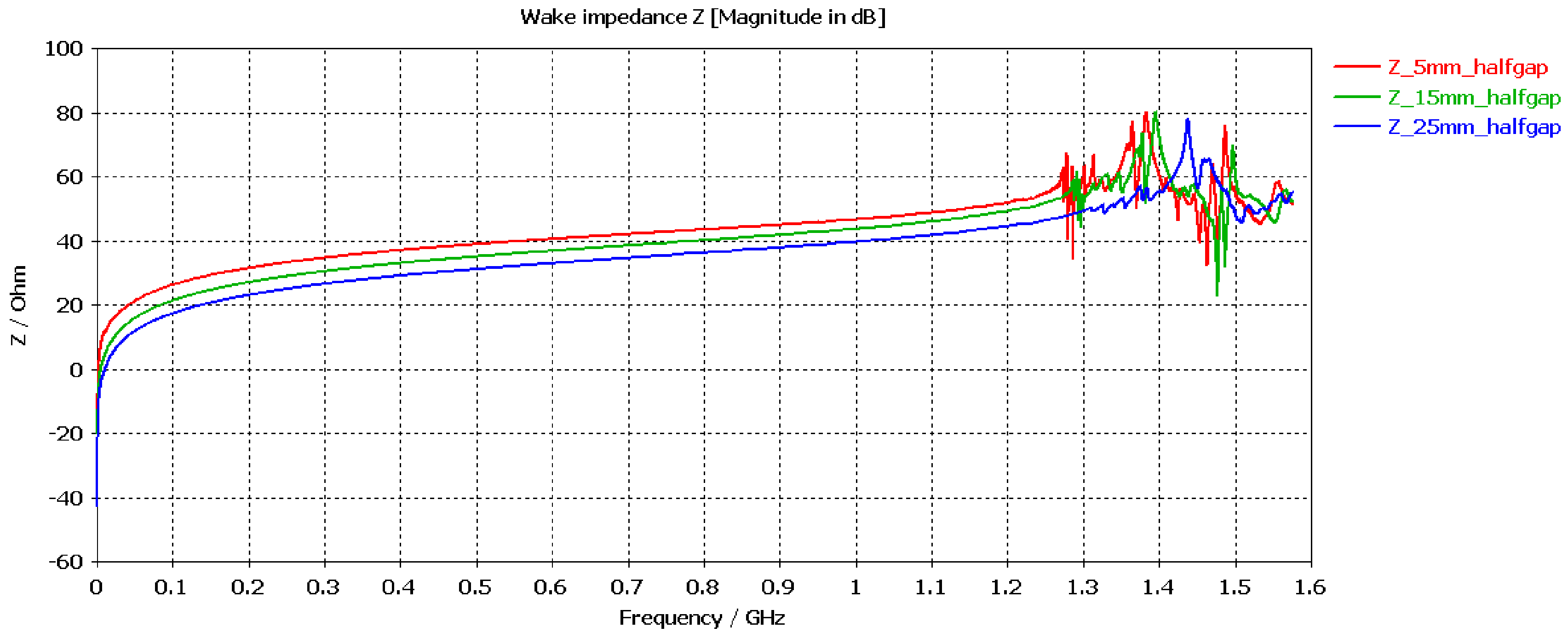


Impedance Simulations: Two Possible Scenarios, General Overview



Beam normalized spectrum (BNS) in black and longitudinal impedance real part in log scale, 5 mm half-gap (at injection). For the scenario with fingers, there are no trapped resonant modes inside the structure below 1.25 GHz. Indeed, electric contacts prevent trapped modes below the cut-off frequency of the LHC pipe. In the scenario without RF fingers, several trapped modes are presents below 1.25 GHz. This is a dangerous situation because at this frequency they could strongly couple with the beam.

Nominal Scenario: Different Gap Apertures

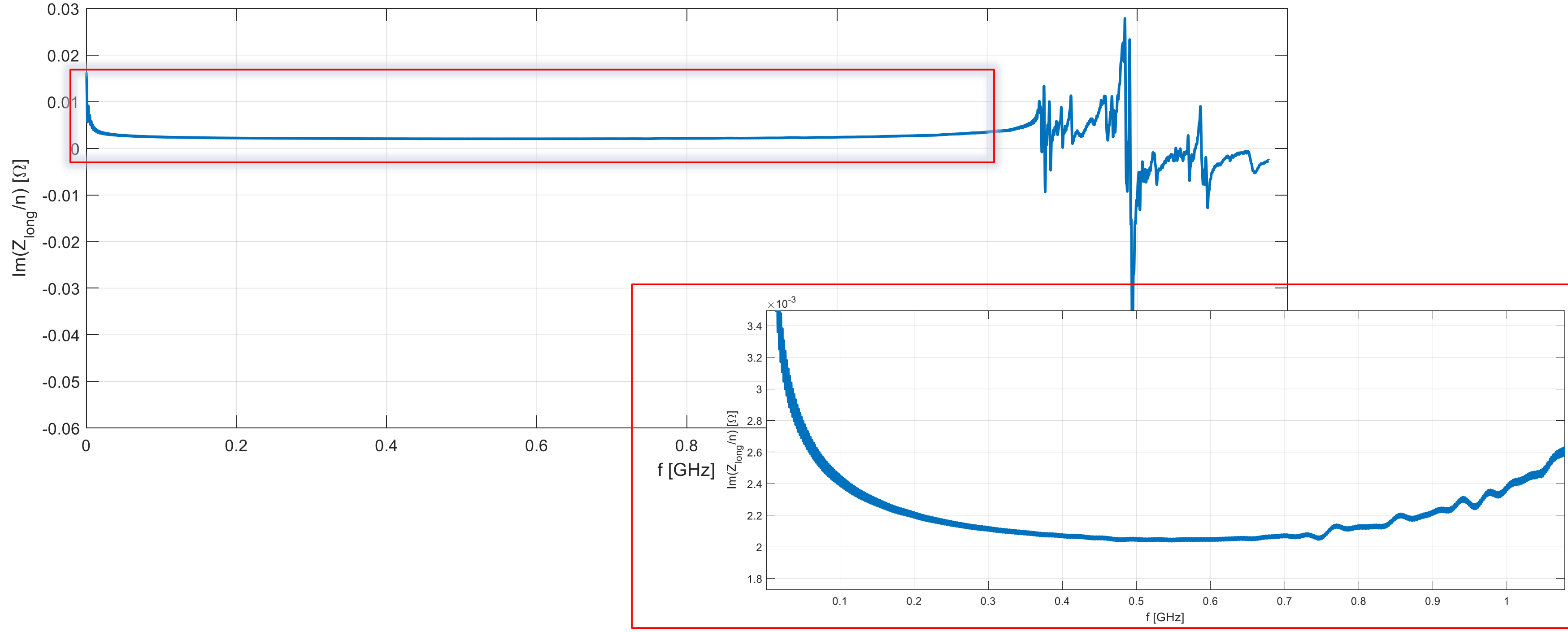


Impedance worst case half gap: 5 mm

No HOMs below 1.25 GHz whatever the jaws aperture

Good impedance behavior of the device!

Nominal Scenario: Imaginary Impedance

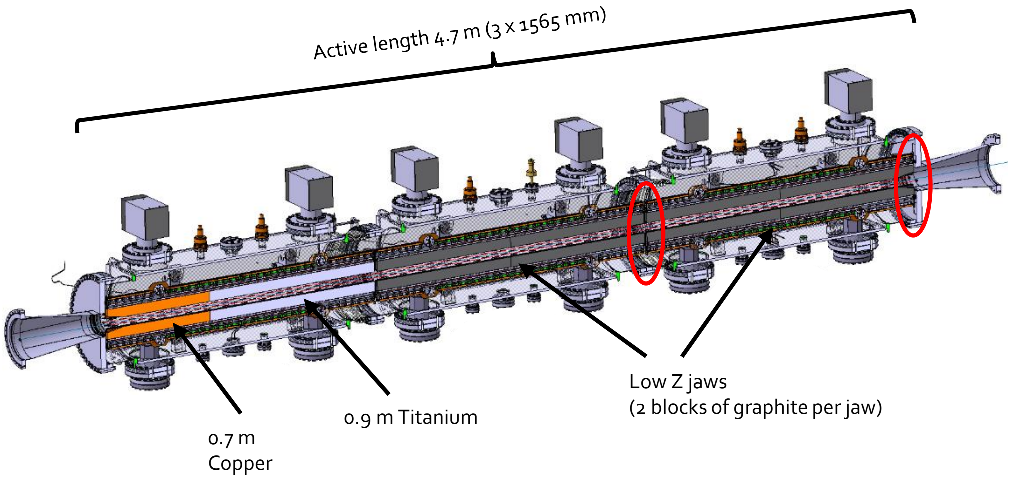


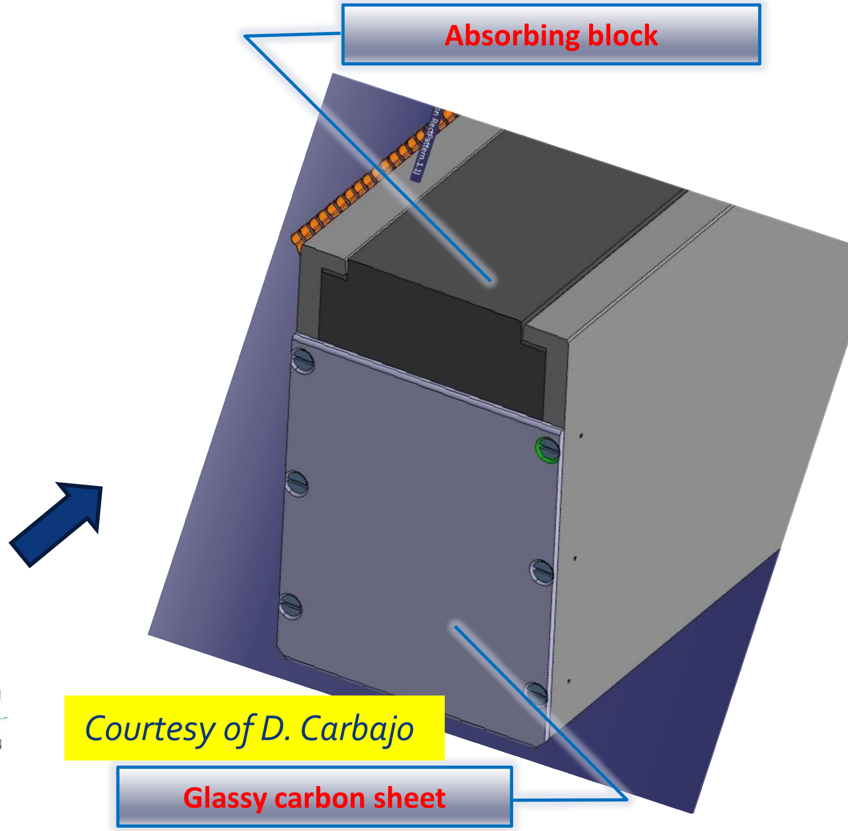
Imaginary Impedance for 5 mm half-gap.

2 milliohm at the flat part.

Impact of the anti-scratching glassy-carbon sheet on Impedance

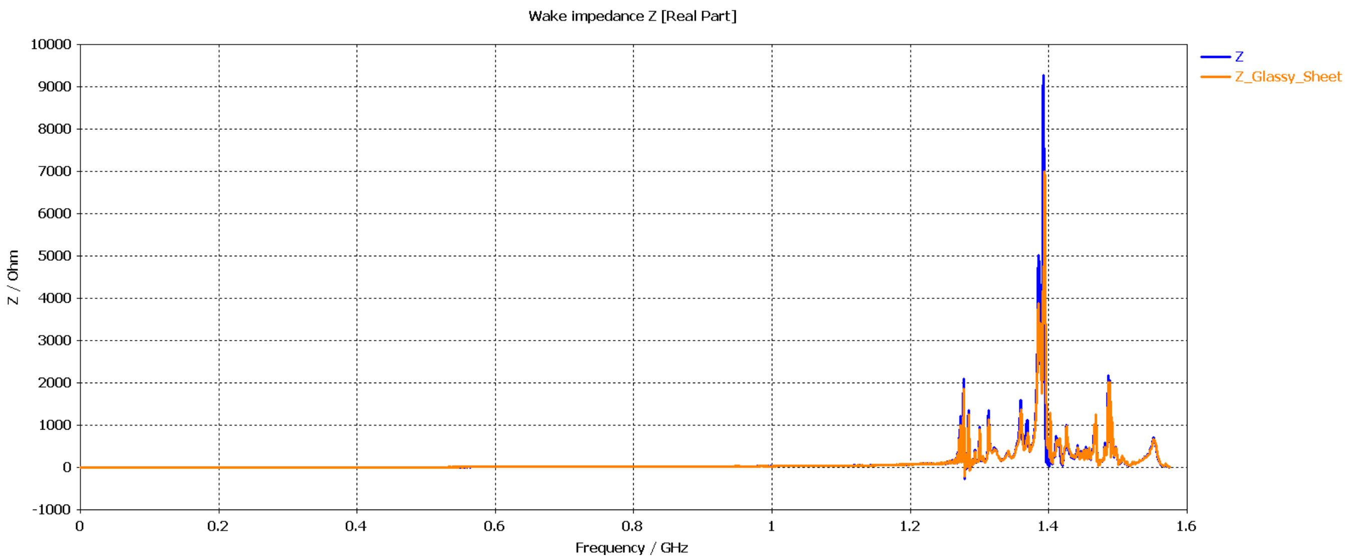
- A glass-like carbon sheet would prevent the fingers from scratching the graphite block, UFO should be avoided
- 2mm thickness, 45uOhm*m

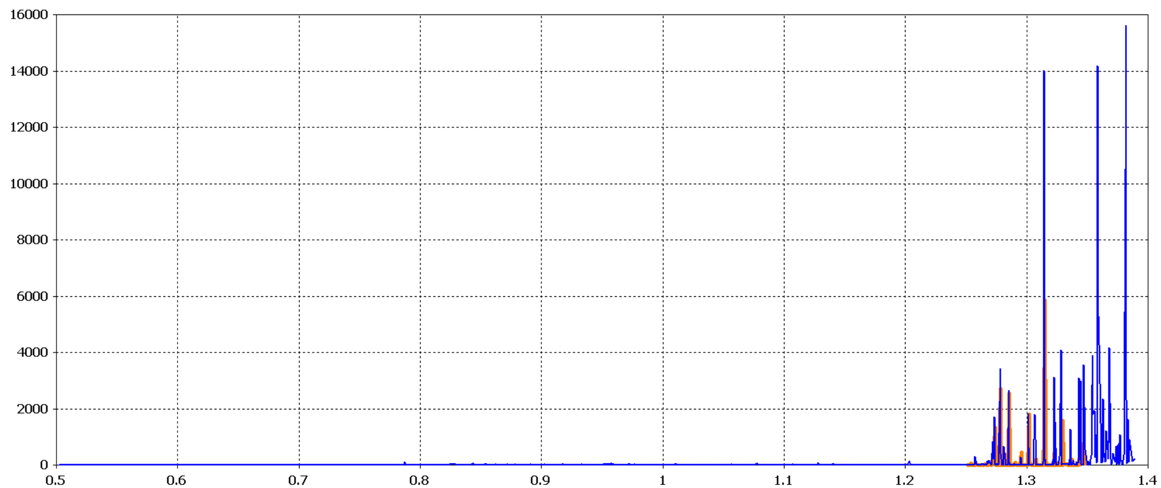




Courtesy of D. Carbajo

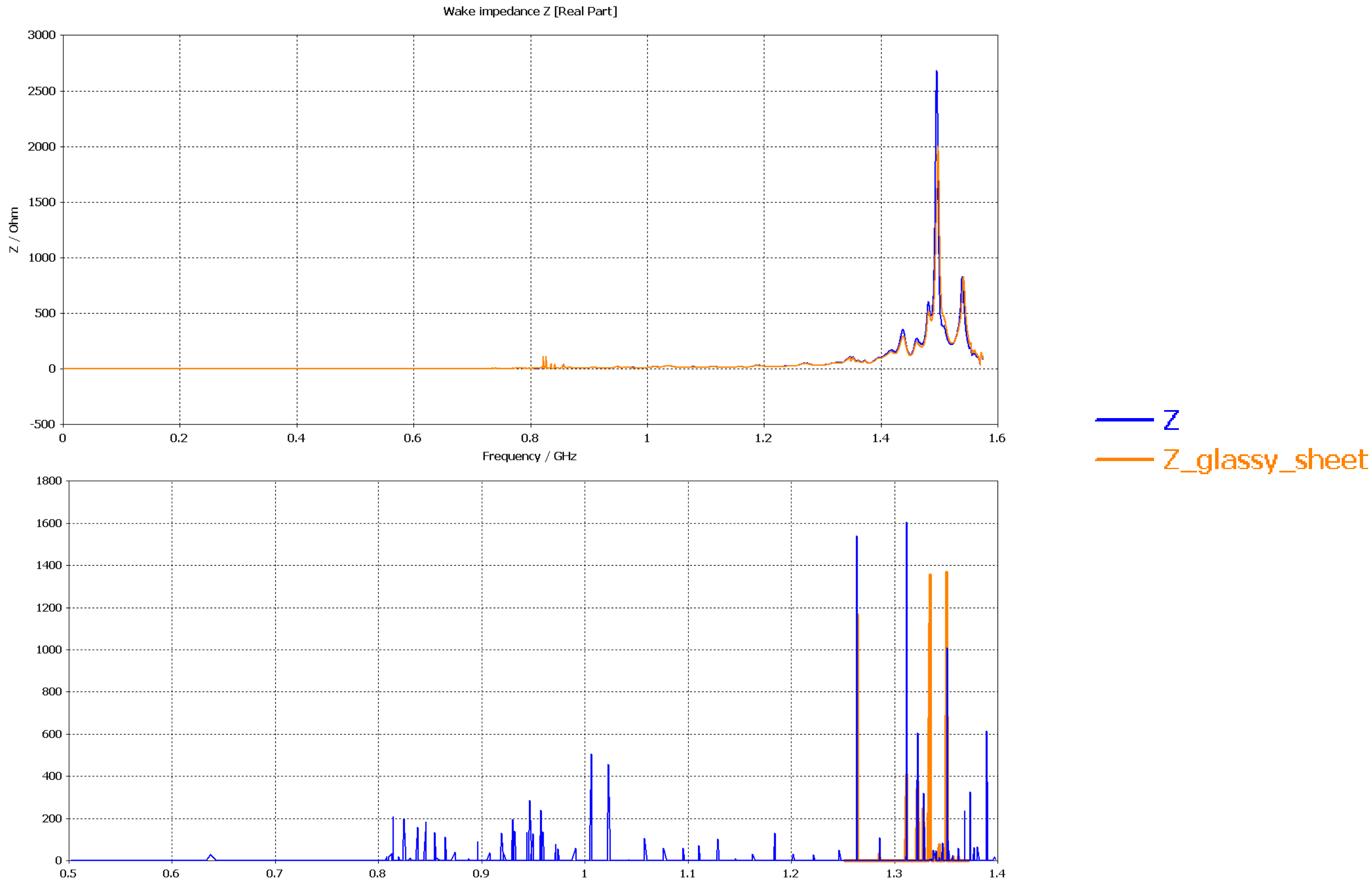
Longitudinal Impedance 5mm Half-gap



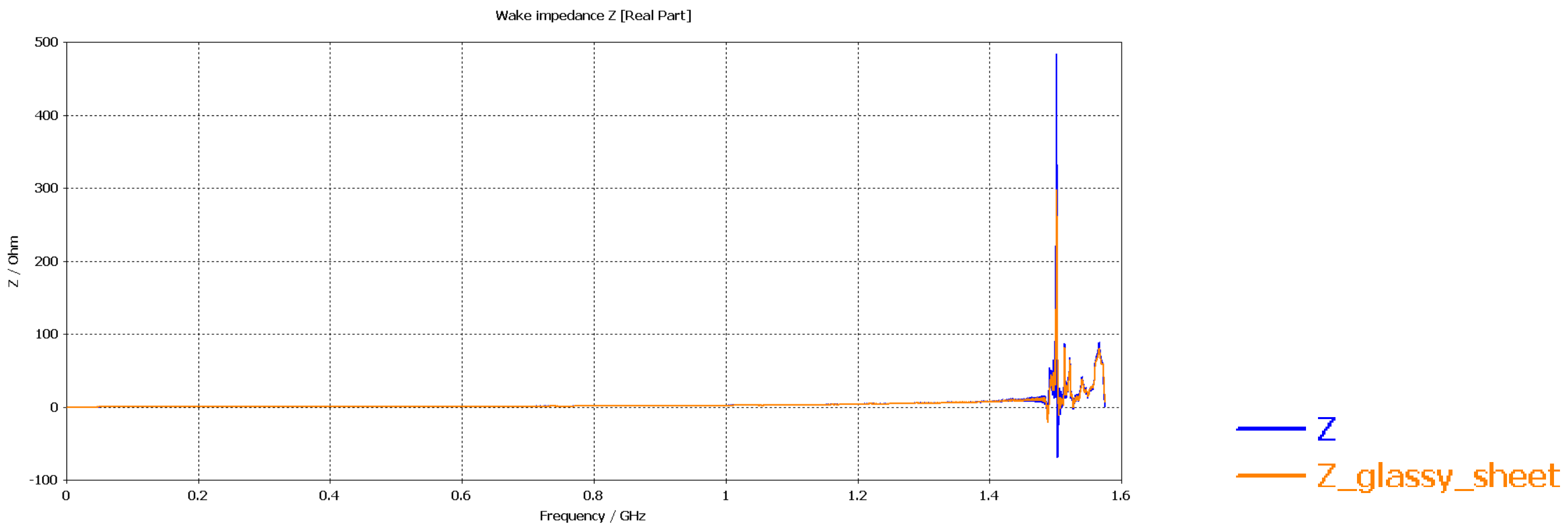


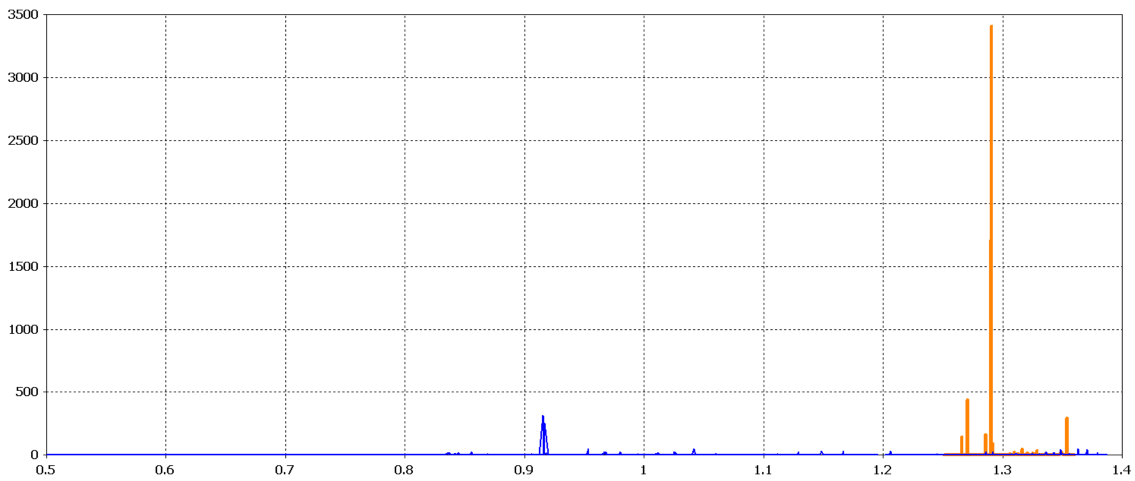
Z
Z_glassy_sheet

Longitudinal Impedance 15mm Half-gap



Longitudinal Impedance 55mm Half-gap



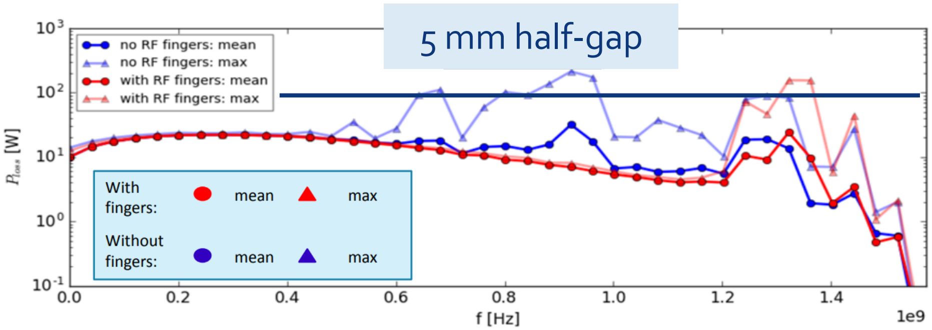


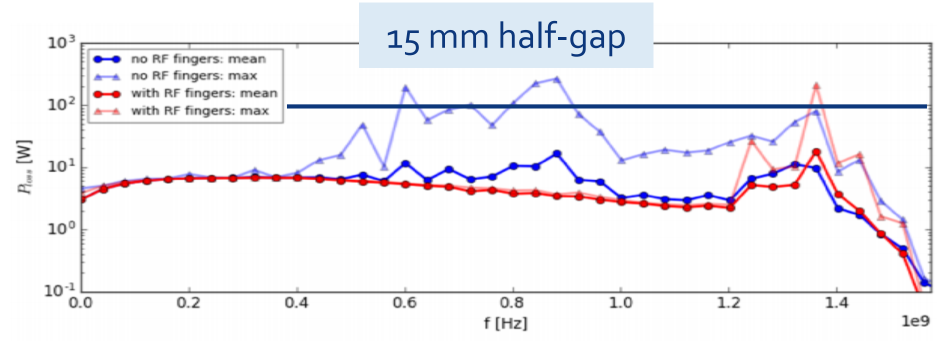
→ Consistent discrepancy to be further analyzed in eigenmode solutions

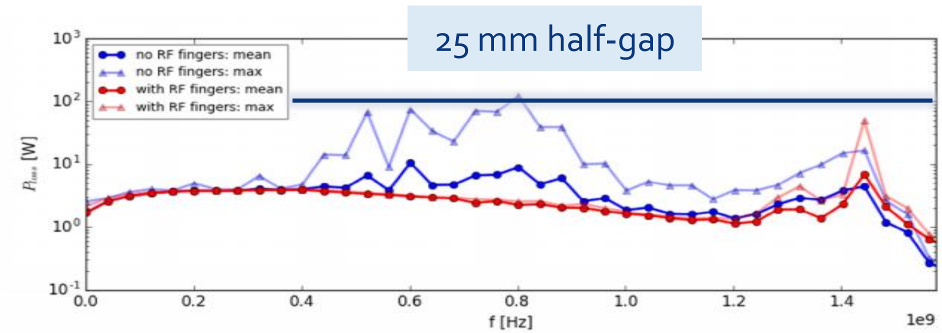
Thermomechanical Simulations

The Electromagnetic Interactions between the beam and the TDIS cause an energy deposition on the device itself (RF-Heating). This can results in an uneven temperature increase with consequent mechanical stresses induced by the thermal gradient. Since the TDIS predecessor, the TDI, has had severe issues probably due to the RF-heating an accurate analysis of the impedance related thermal load has been performed.

RF-Heating On the TDIS in The Two Different Scenarios



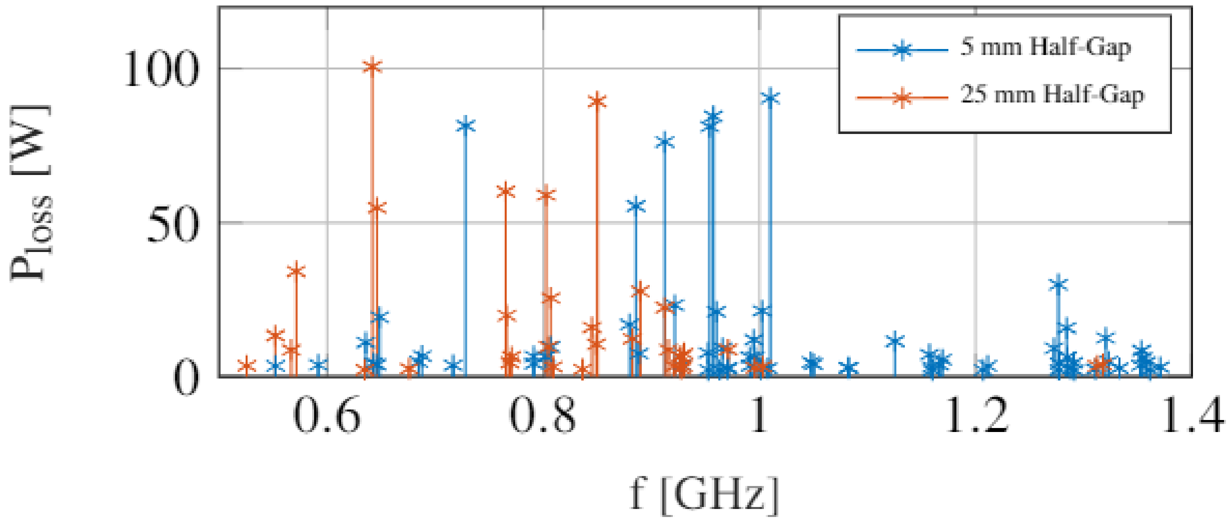




Courtesy of N. Biancacci

- The worst case scenario: Failure of the fingers, half gap 5 mm, 1003 W dissipated Power in HOM and 800 W in Resistive wall Impedance (In case of NO finger failure 465 W dissipated because of HOMs and 800 W dissipated Because of resistive wall impedance)
- Max and mean are related to the computation method, max is the worst case.

RF-Heating On the TDIS for the Finger Failure Scenario HOM, Different Half Gaps



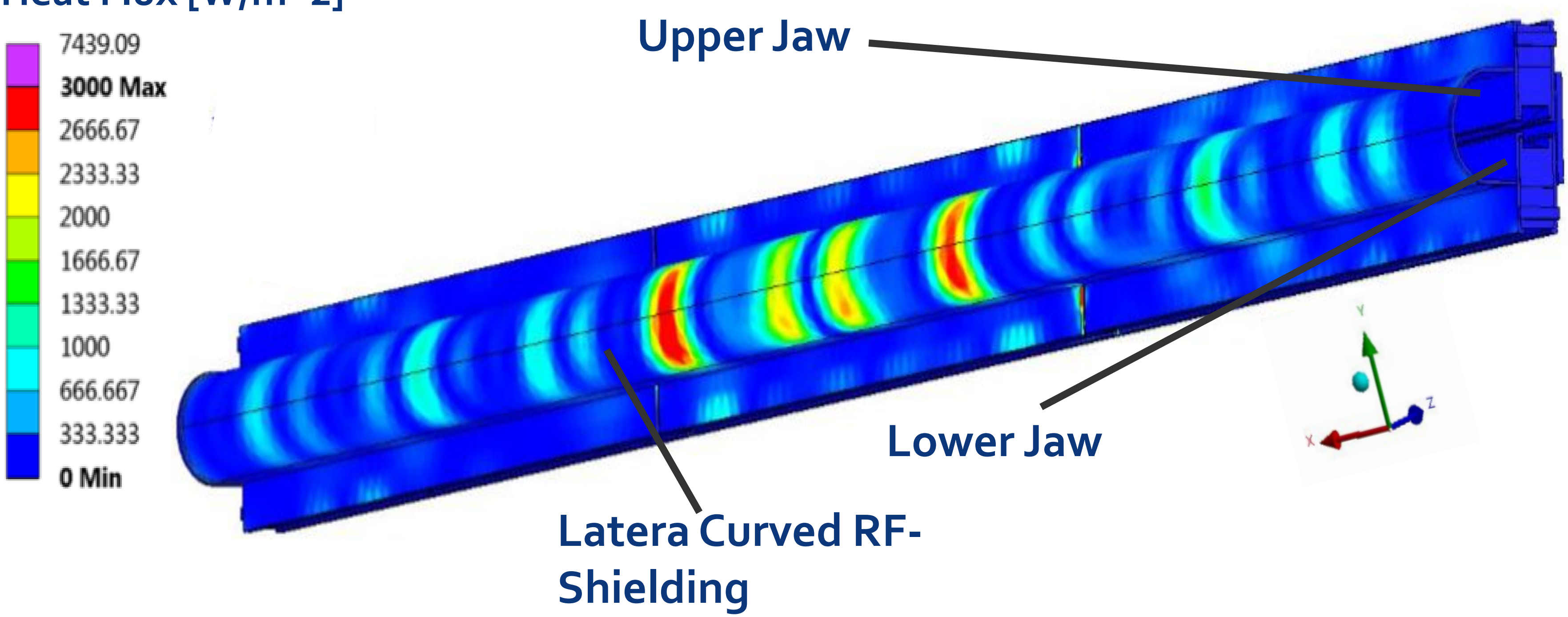
Each HOM is responsible for a different heating flux. In the figure above is reported the heating contribution of the HOMs in the TDIS for two different half-gap aperture of the jaws. In order to obtain the total heating flux in the device all the single HOM contribution have to be summed.

- Half-gap 25 mm, total heating flux 798.3 W
- Half-gap 5 mm, total heating flux 1003 W

Always considering a worst case scenario approach, the 5 mm case was considered for the thermomechanical simulations. Furthermore, in this configuration also the resistive wall impedance heating contribution is the highest.

The 3D RF-heating Map

Impedance RF-Heating
Heat Flux [W/m^2]



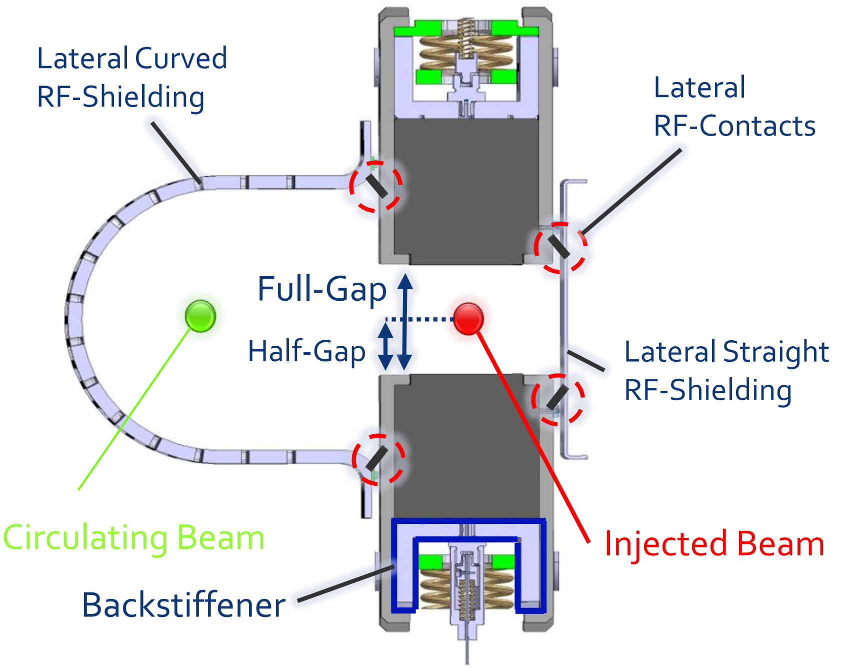
A new method for mapping the HOM heating flux was developed and was applied to the TDIS. Above the Heating flux on the device is reported. The maximum Energy deposition is, as expected, on the gap between the segments. However, there is a non negligible heating flux on the RF-shielding.

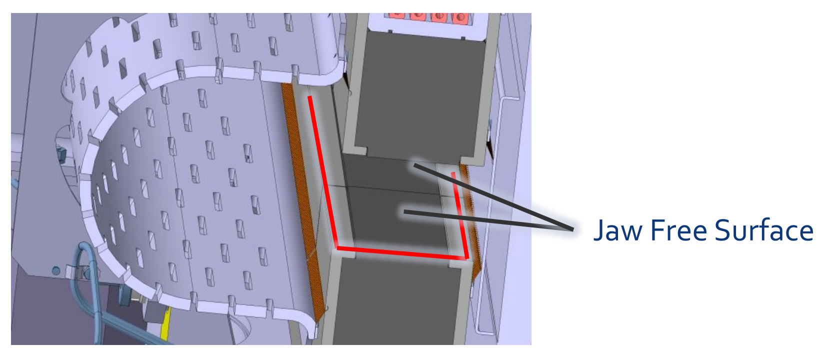
The Thermo-Mechanical Simulations Scenarios

Injection Case with RF-Finger Failure:

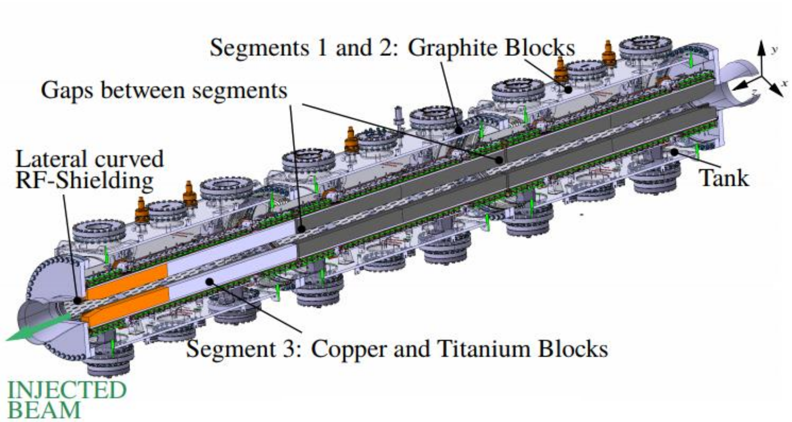
- Jaws Half-gap 5 mm
- Only The Injected beam has been considered
- Maximum injection time 45 minutes

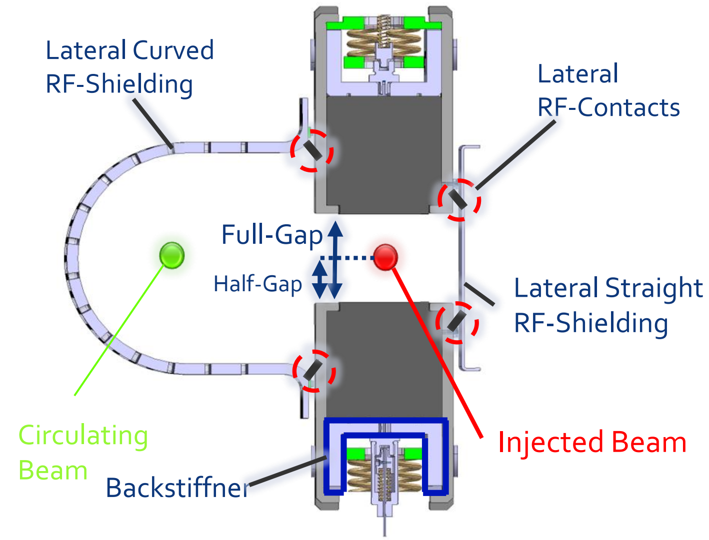
Source	Heat Load [W]	Affected Element
Secondary Halos	580	Jaws free surfaces
Resistive Wall	798.3	Jaws free surfaces
HOM	1003.6	Entire TDIS

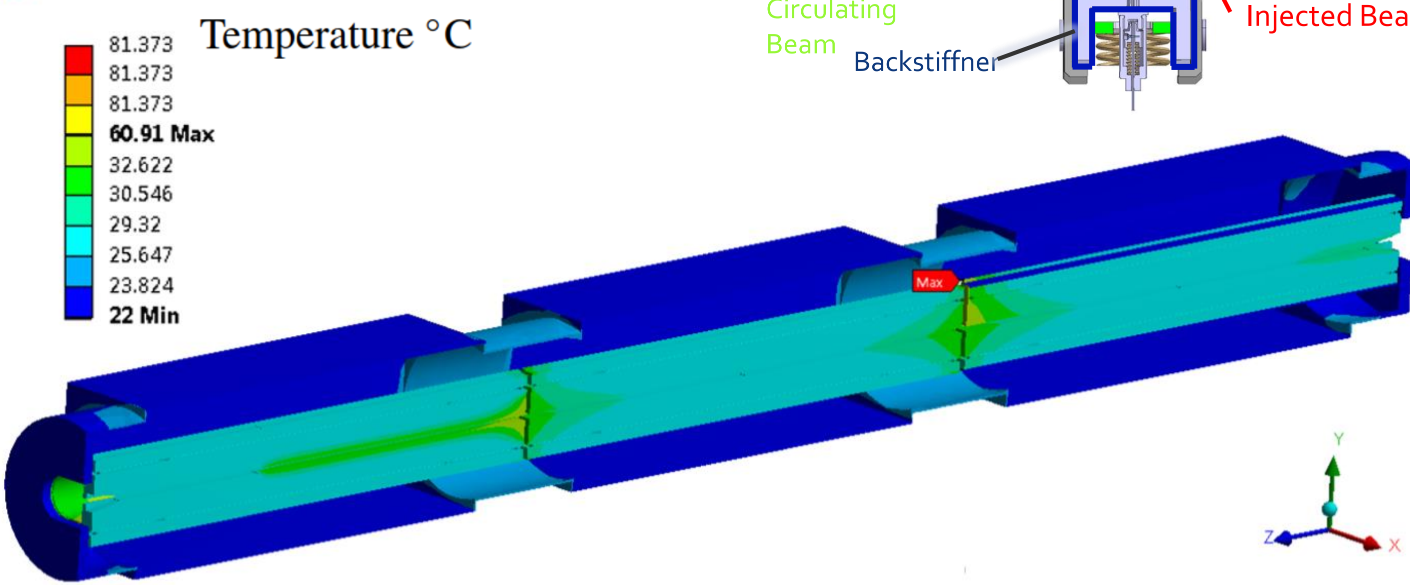




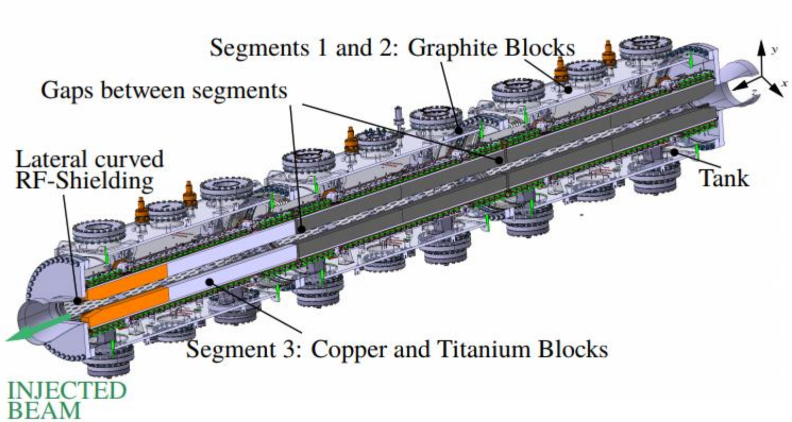
The thermos mechanical Simulations Results

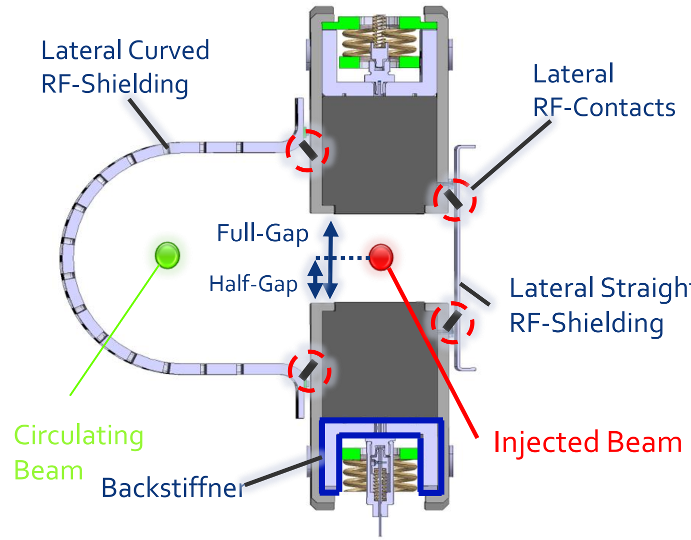


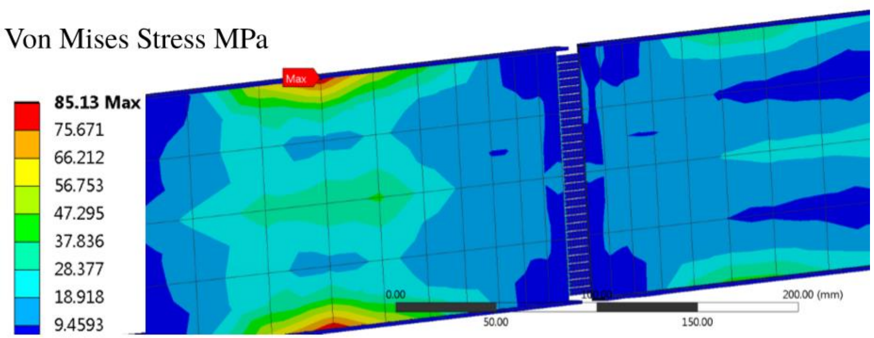


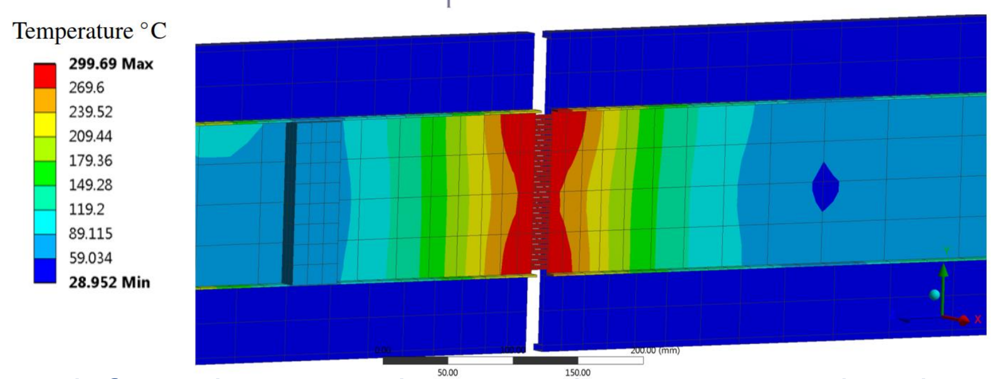


The Thermo mechanical Simulations Results





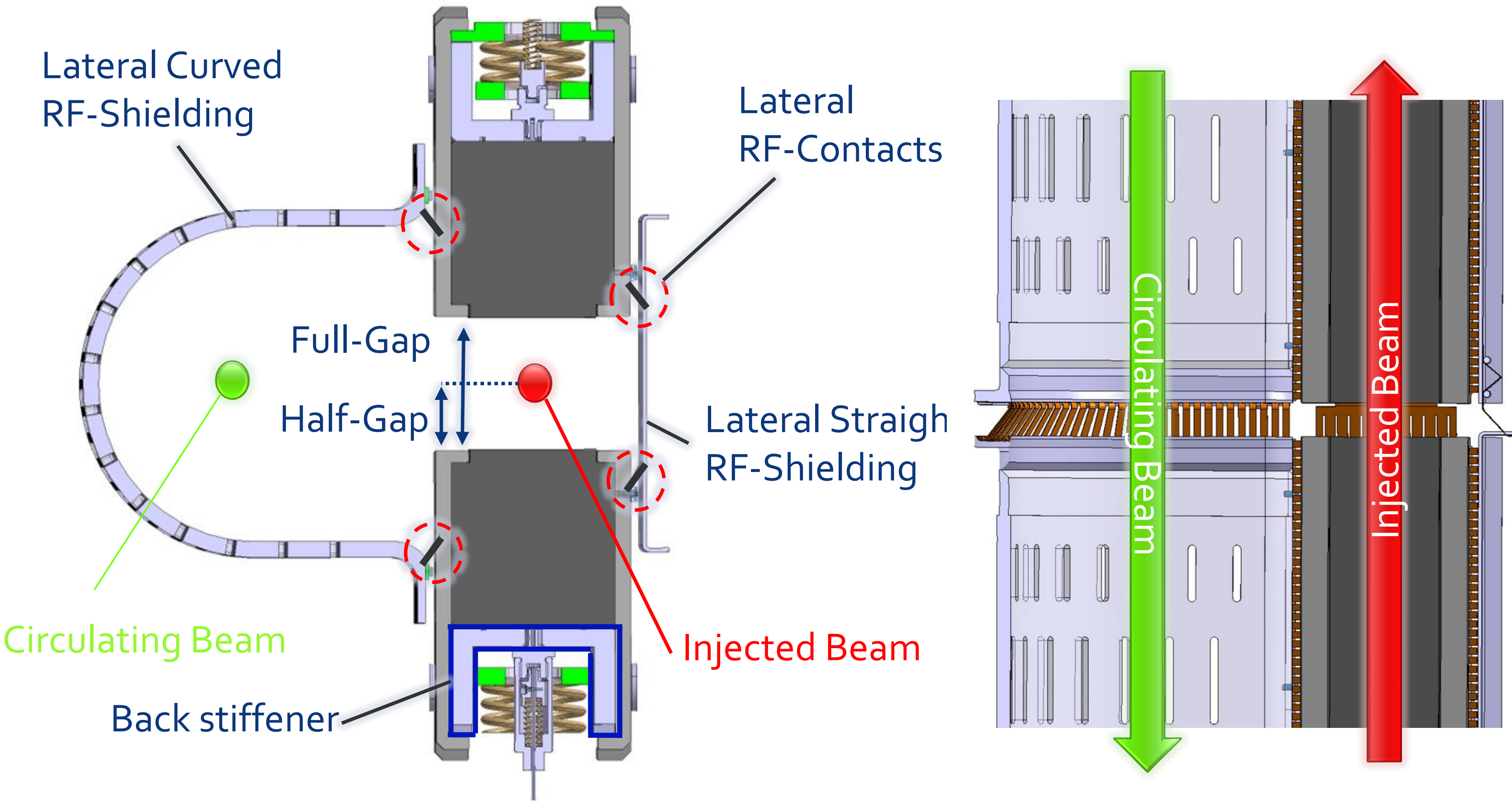




The maximum temperature is in the RF-fingers may deform the pieces, however this is not considered as a issues since the design allows for its free expansion.

The maximum developed stresses in the lateral RF-shielding are not dangerous for the material.

Next Step: The Two Counter-Rotating Beams Problem

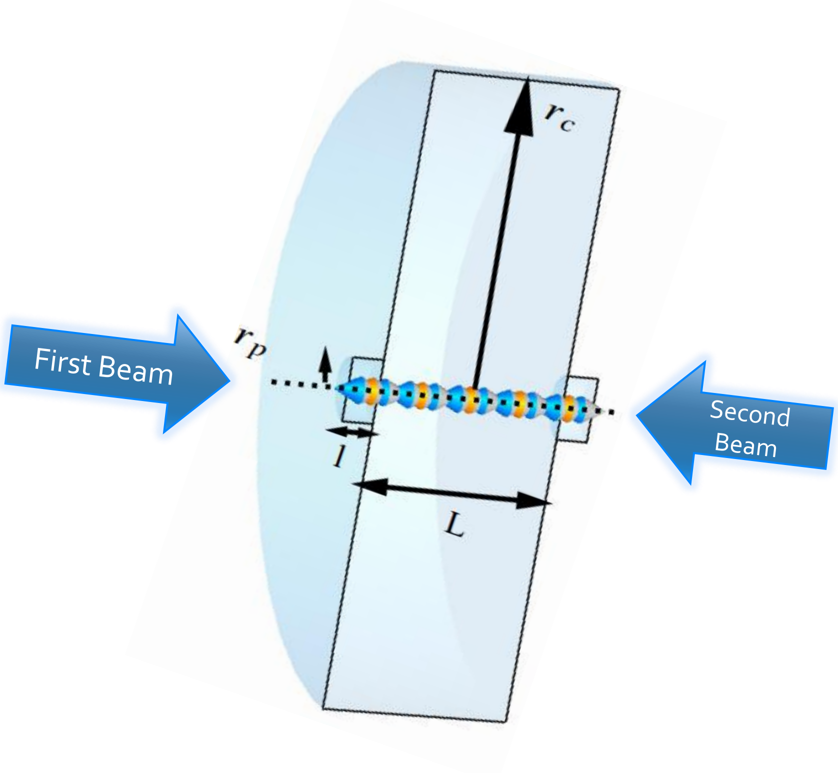


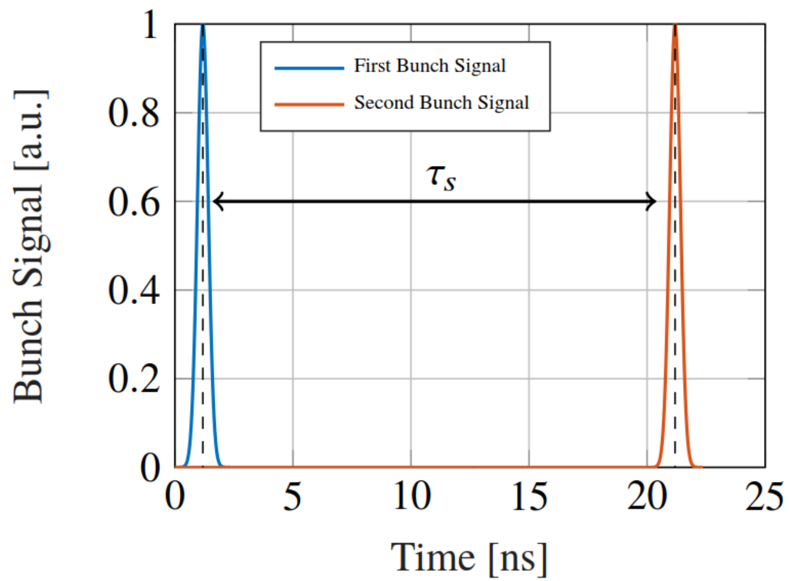
How the deposited energy in the device is affected?

Next Step: The Two Counter-Rotating Beams Problem

- Phenomenon not fully understood. The pioneering study of C. Zannini, G. Rumolo and G. Iadarola (“Power loss calculation in separated and common beam chambers of the LHC”), who found a solution for a specific pipe geometry, seems to indicate an interference-like behavior of the RF deposited energy dependent on the time delay between the entrance of the first and the second beam in the device.
- Thus, according to this result, the RF-heating load of two counter-rotating beams in a worst case scenario could be up to 4 times the heat load induced in the same device by a single beam.
- In order to benchmark this finding for more complex geometries a series of simulations have been carried out. The passage of two counter rotating beams in a cavity, both positioned exactly at the centre of the structure was modelled.

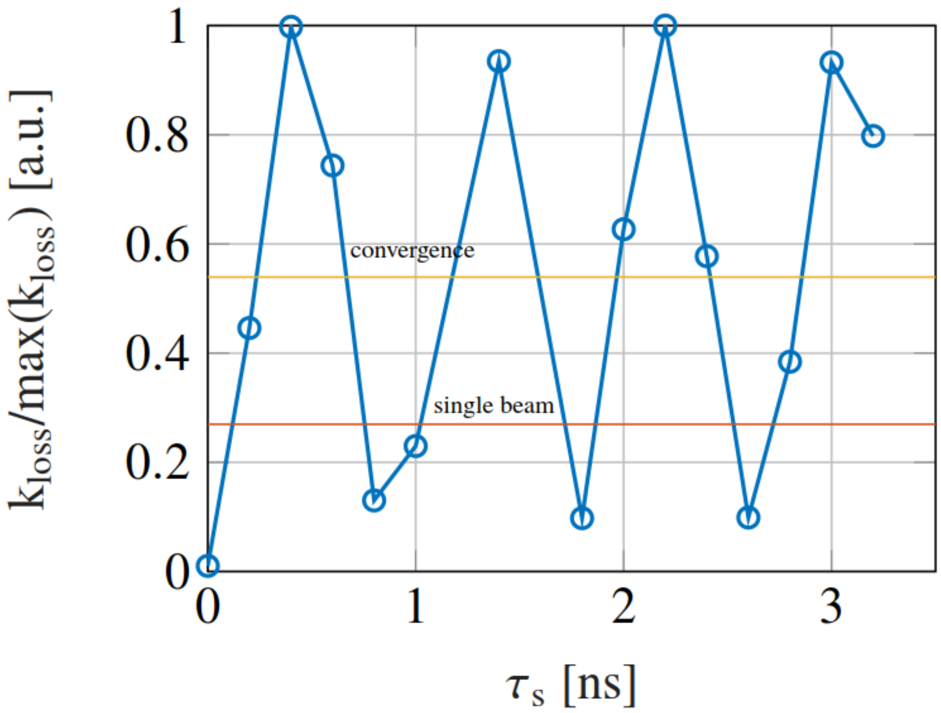
Preliminary Results from a Simple Model





Two beam (composed by only one gaussian bunch) were sent in the pill-box cavity with different delay times (τ_s) between the entrance of the first one and the second one. The energy deposited in the device was studied.

Preliminary Results from a Simple Model



In the graph, with the blue line, is reported the normalized energy deposited in the pill-box in function of the time delay between the bunches. It is possible to see the oscillating interference-like behavior predicted by the Zannini, Rumolo and Iadarola work. Furthermore, in orange is reported the normalized energy deposited by a single beam passing in the device. It is clear that for specific value of τ_s the energy deposited by two beams is up to 4 times the energy deposited by a single beam.

Conclusions

- The TDIS geometry and its simplifications for the electromagnetic and thermomechanical analysis have been presented
- Electromagnetic Simulations:
  - Nominal configuration scenario (No failure in the device).
    - Simulations showed a good electromagnetic behavior of the device that does not present any high order resonant electromagnetic modes below 1.25 GHz. The analysis were repeated for different half-gap apertures and the results were positive in any case.
    - The effect of the RF-heating was investigated, 800 W are dissipated because of Resistive wall impedance and 500 W because of HOMs.
  - Failure Scenario (Lost of contact by the longitudinal RF-Fingers)
    - Simulations showed a bad electromagnetic behavior of the device. High order resonant electromagnetic modes are present below 1.25 GHz. The analysis were repeated for different half-gap apertures with similar results.
    - The effect of the RF-heating was investigated, 800 W are dissipated because of Resistive wall impedance and 1003 W because of HOMs.

Conclusions

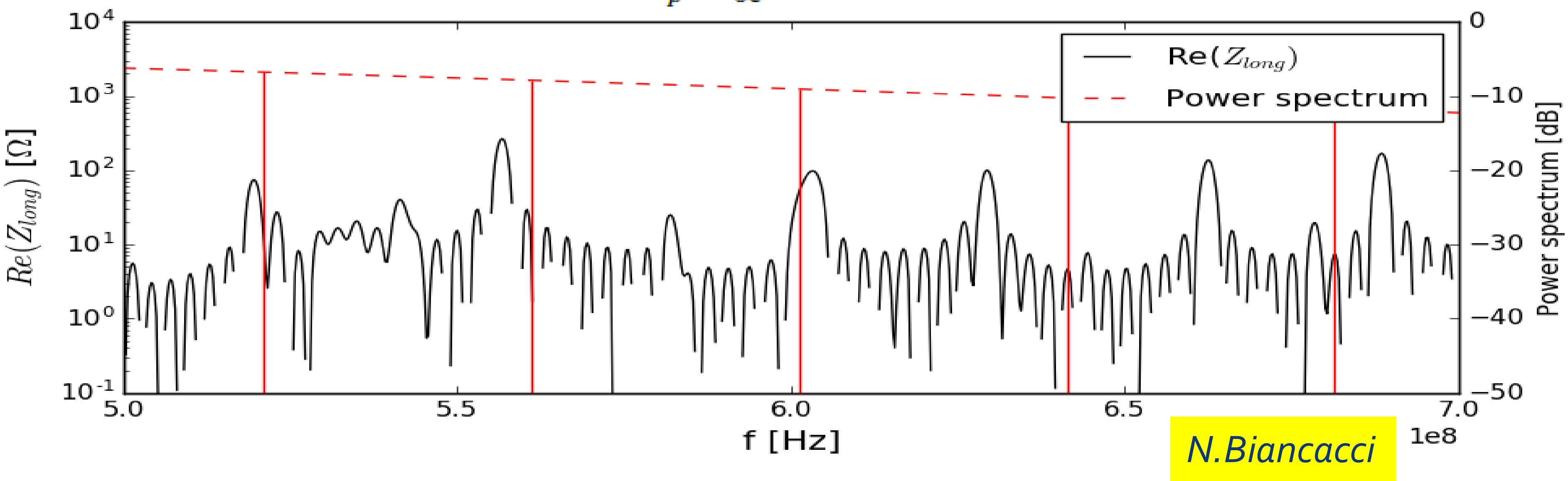
- The impact of the anti-scratching glassy-carbon sheet on impedance was investigated. It improves the impedance performance of the device decreasing the shunt impedance of the HOMs

- Thermo-mechanical Simulations. The worst case scenario for the energy deposited in the TDIS was considered: the pessimistic RF-Finger Failure scenario with a jaws half-gap aperture of 5 mm. The heating source were Resistive wall impedance 800 W, HOMs 1003 W, Secondary Halos 580 W, total 2400 W. Despite the fact that our findings have highlighted some possible critical areas, neither the developed temperatures or the related mechanical stresses seems to be high enough to cause problems.
- The Two Counter-Rotating Beams Problem. This is a possible issue in the TDIS. The phenomenon is not fully understood and further studies are ongoing to develop a physical model.

Thank You For Your Attention

Power Losses Computation

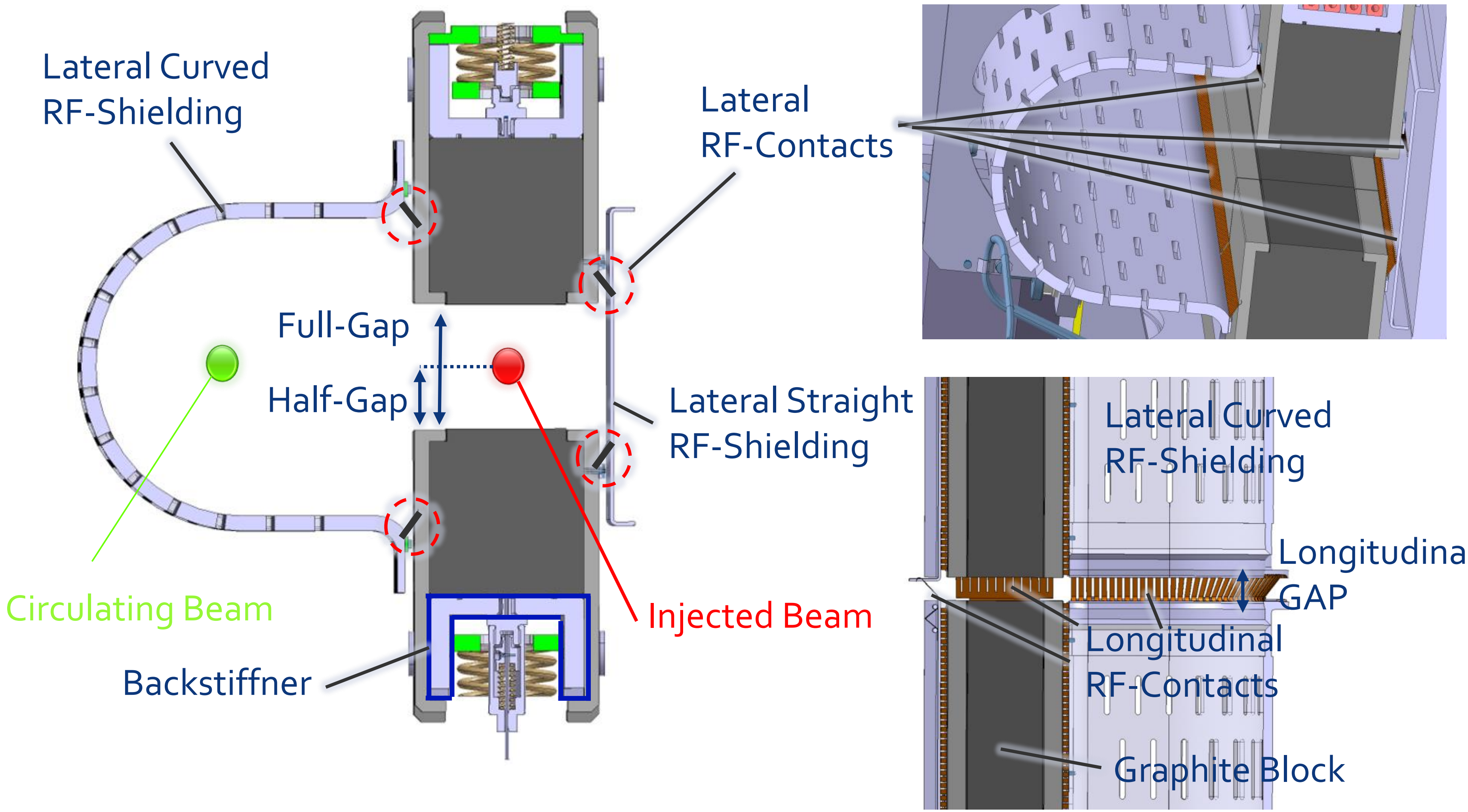
$$\Delta W = (f_0 e N_{\text{beam}})^2 \sum_{p=-\infty}^{p=\infty} \left(\left| \bar{\Lambda}(p\omega_0) \right|^2 \text{Re}\left[Z_{||}(p\omega_0) \right] \right)$$



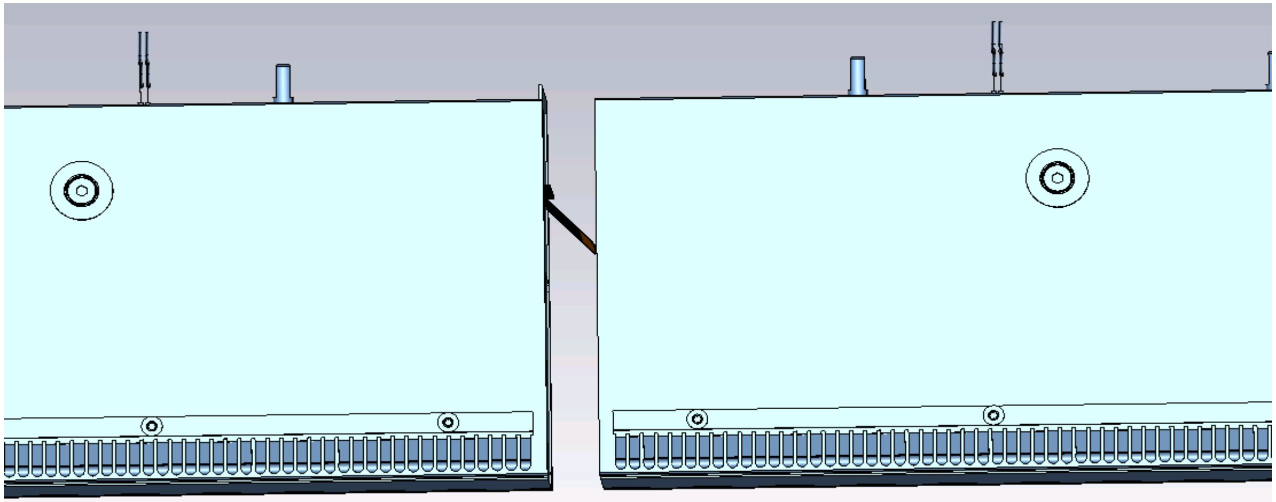
→ A uniform noise of $\pm 10\ MHz$ has been added to each f_r for all the considered modes (same effect as shifting the beam spectrum)

→ The maximum of the power loss for each mode has been selected as the worst case scenario

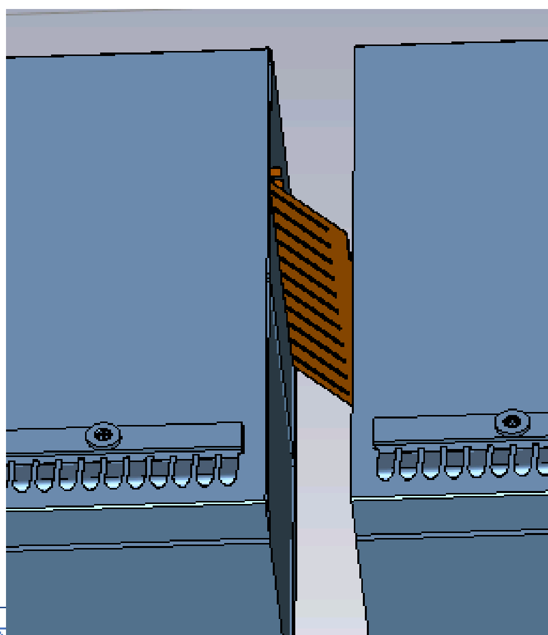
The TDIS: Geometry, the RF-System



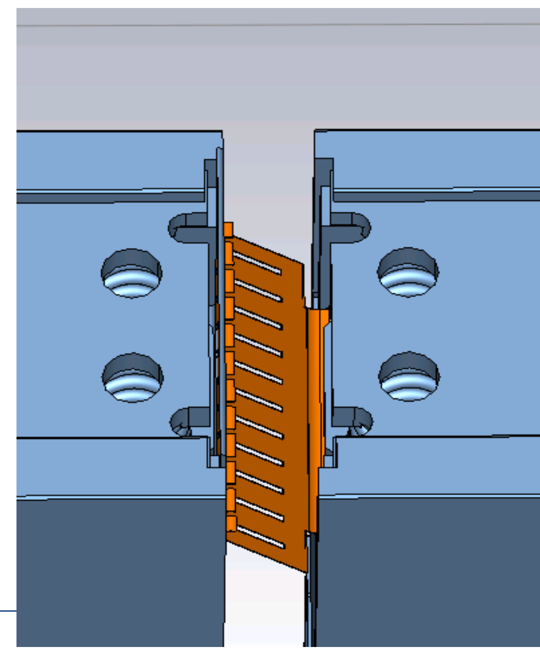
Longitudinal Fingers



Lateral View



Bottom View



Top View

Extra Comments

- The presented simulations have been done with an half-gap aperture of the jaws of 5 mm, considering only the injected beam passing between the jaws. Other half-gap apertures have been investigated (25 mm and 55 mm). However, the simulation results showed that the highest shunt impedances for the high order electromagnetic resonant modes are for the 5 mm half-gap value previously reported.