BBLRC

(Beam-Beam Long Range Compensator)

Preliminary Impedance Study

Leonardo Sito (impedance analysis)
and **Lorenzo Giacomel** (transverse stability analysis)
Replaced by B. Salvant

Special thanks to Alessandro Bertarelli, Federico Carra, Luca Gentini, Sebastien Joly, Nicolas Mounet, Guido Sterbini, Carlo Zannini.

Outline

1. **Introduction to the BBLRC**
2. Positioning and Mechanical Description
3. The need for an Impedance Study
4. Simulated model
5. Longitudinal Impedance Study:
   - Matching the wire termination
   - Dissipated Power
   - Impact of the dielectric support
6. Transverse Impedance Study
7. Conclusions

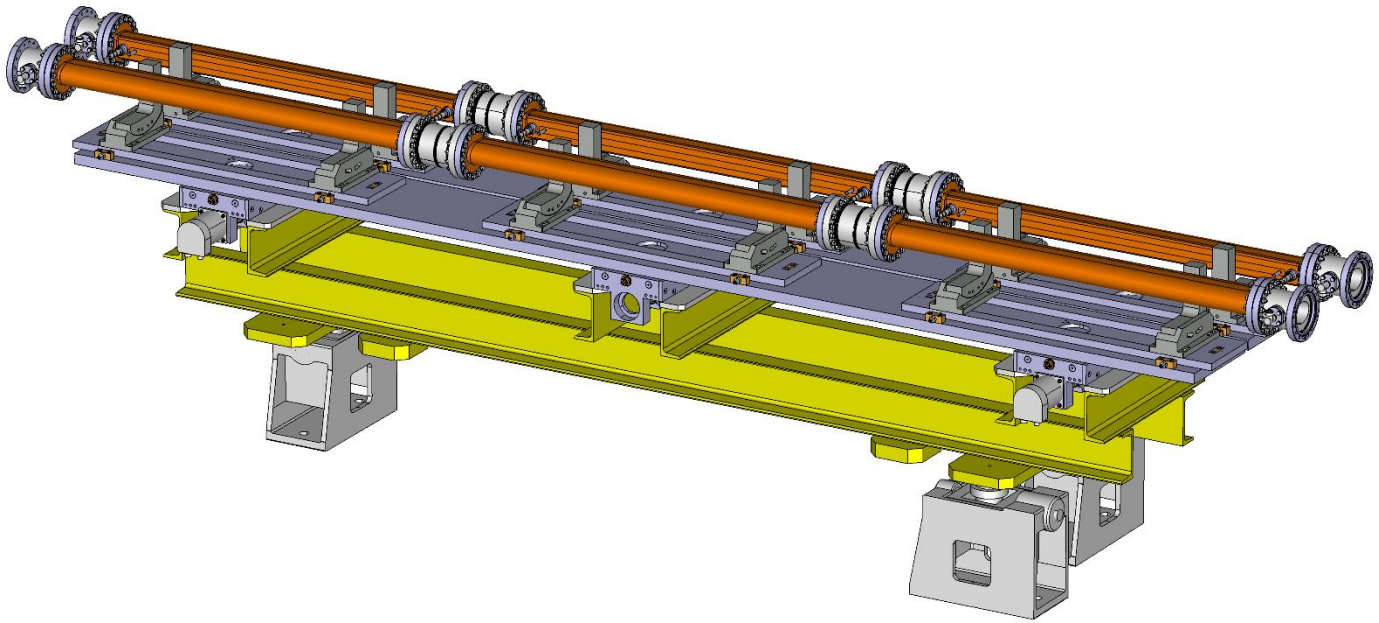
Introduction:

What is the electromagnetic impact of the BBLRC?

- **High Luminosity LHC** significant impact of the Beam-Beam Long Range (BBLR) interactions.
- To compensate for the BBLR effects: wire carrying a DC currents that can be moved with respect to the beam.

One proposed device is the DC wire Beam Beam Long Range Compensator (**BBLRC**).

BBLRC Unit



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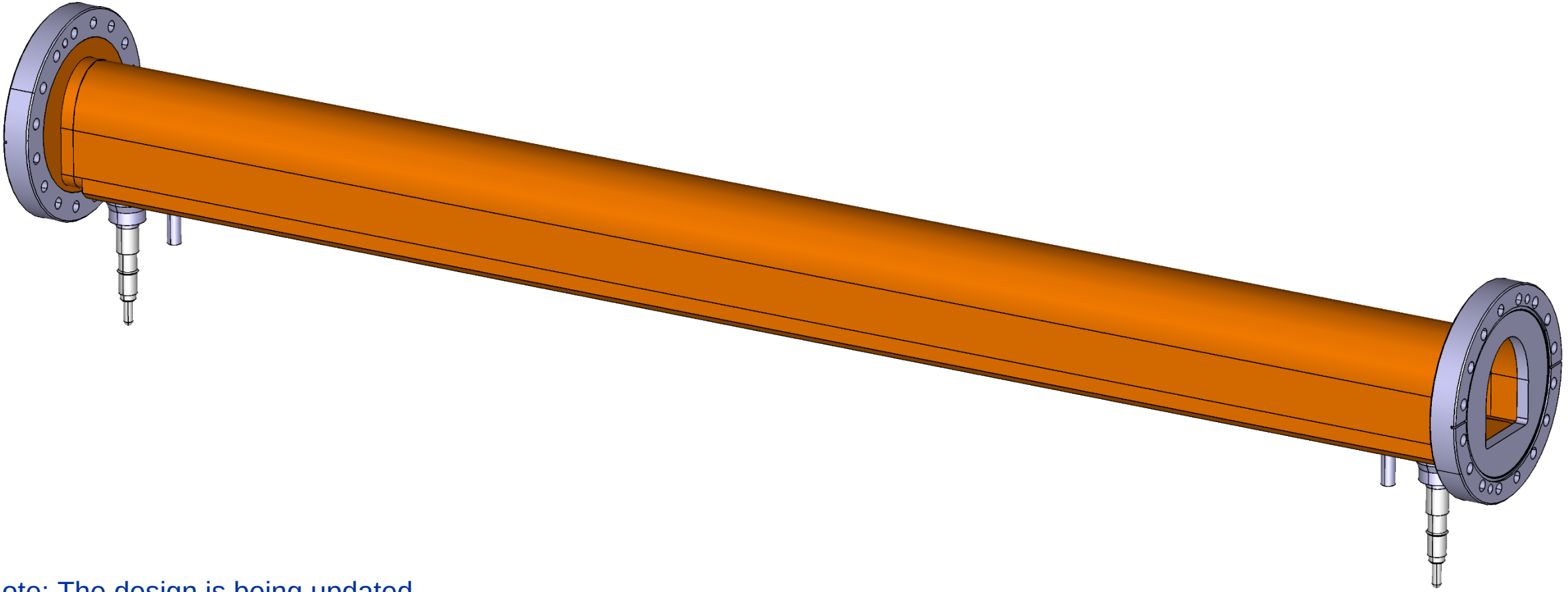
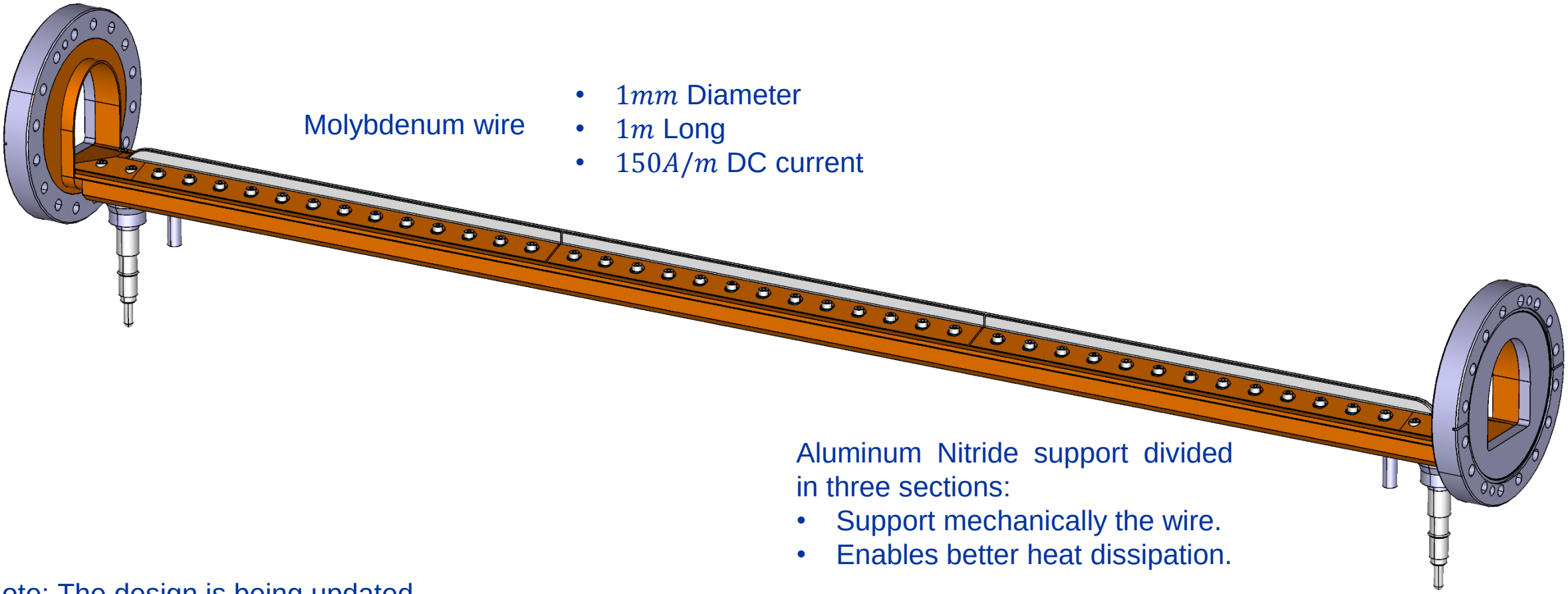
Mechanical Description and Positioning



Note: The design is being updated.
The taperings are going to be extended. The AlN support is going to be lower.

Positioning and Mechanical Description



Molybdenum wire

- $1mm$ Diameter
- $1m$ Long
- $150A/m$ DC current

Aluminum Nitride support divided in three sections:

- Support mechanically the wire.
- Enables better heat dissipation.

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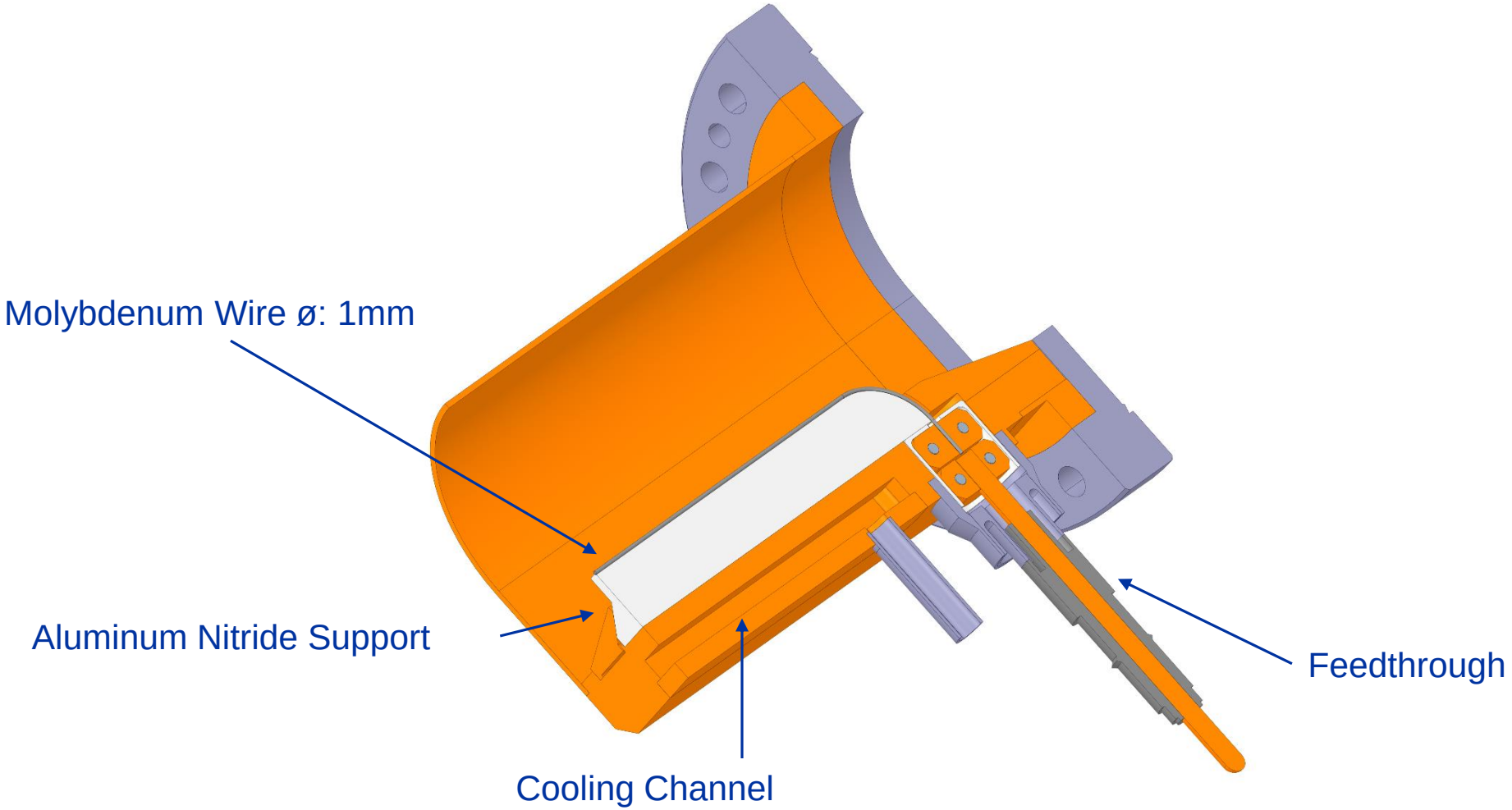
The taperings are going to be extended. The AlN support is going to be lower.

Positioning and Mechanical Description

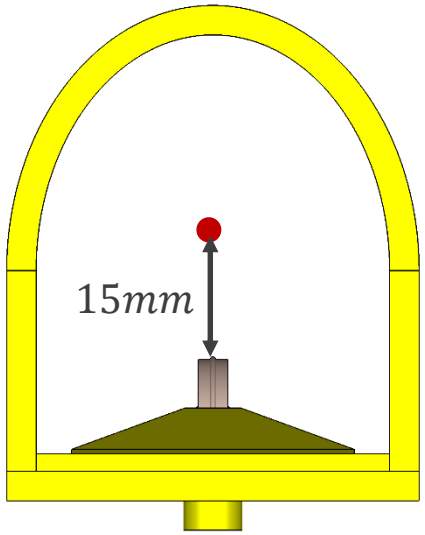


Positioning and Mechanical Description

Positioning:
- 4L1B1, 4L5B1
- 4R1B2, 4R5B2

Two optics: 30cm and 20cm.

Span of movement (of the beam's position in respect to the wire): roughly estimated to be: **[4.73 mm to 15.6 mm]**



Optics 30 cm

Courtesy of Guido Sterbini:

	betx	bety	alfx	alfy	x	y	px	py
ip1:1	0.300078	0.300021	-0.000795	0.001418	9.550482e-09	2.210019e-08	2.250425e-04	6.687663e-08
ip5:1	0.299738	0.300079	-0.001423	0.001209	-2.436731e-08	2.447524e-09	3.602199e-08	2.250566e-04

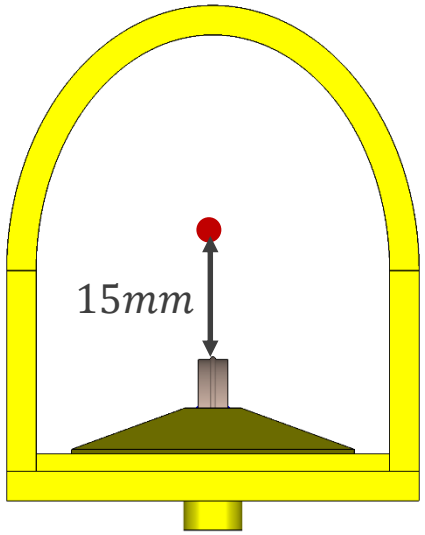
	name	keyword	s	betx	bety	sigma_x	sigma_y	mux	muy
wire_3.4l1.b1:1	wire_3.4l1.b1:1	marker	19804.662400	1177.712638	635.489786	0.000628	0.000461	46.102337	44.612182
wire_2.4l1.b1:1	wire_2.4l1.b1:1	marker	19805.912400	1211.495430	667.713482	0.000637	0.000473	46.102504	44.612487
wire_1.4l1.b1:1	wire_1.4l1.b1:1	marker	19807.162400	1245.758543	700.738877	0.000646	0.000485	46.102666	44.612778
wire_1.4r1.b1:1	wire_1.4r1.b1:1	marker	20181.162400	698.328670	1250.154304	0.000484	0.000647	46.617532	45.127639
wire_2.4r1.b1:1	wire_2.4r1.b1:1	marker	20182.412400	664.920813	1216.586506	0.000472	0.000638	46.617824	45.127800
wire_3.4r1.b1:1	wire_3.4r1.b1:1	marker	20183.662400	632.336359	1183.478058	0.000460	0.000630	46.618130	45.127966
wire_3.4l5.b1:1	wire_3.4l5.b1:1	marker	6475.068433	1179.115979	635.379981	0.000629	0.000461	14.722836	14.281069
wire_2.4l5.b1:1	wire_2.4l5.b1:1	marker	6476.318433	1212.937730	667.597518	0.000638	0.000473	14.723003	14.281374
wire_1.4l5.b1:1	wire_1.4l5.b1:1	marker	6477.568433	1247.240331	700.616589	0.000646	0.000485	14.723164	14.281665
wire_1.4r5.b1:1	wire_1.4r5.b1:1	marker	6851.568433	699.076579	1249.887159	0.000484	0.000647	15.238014	14.796529
wire_2.4r5.b1:1	wire_2.4r5.b1:1	marker	6852.818433	665.631116	1216.326070	0.000472	0.000638	15.238305	14.796690
wire_3.4r5.b1:1	wire_3.4r5.b1:1	marker	6854.068433	633.010020	1183.224246	0.000461	0.000630	15.238612	14.796856

Positioning and Mechanical Description

Positioning:
- 4L1B1, 4L5B1
- 4R1B2, 4R5B2

Two optics: 20cm and 30cm.

Span of movement (of the beam's position in respect to the wire): roughly estimated to be: **[4.73 mm to 15.6 mm]**



Optics 20 cm

Courtesy of Guido Sterbini:

	betx	bety	alfx	alfy	x	y	px	py
ip1:1	0.200130	0.200000	-0.001029	0.001908	6.158910e-09	2.265509e-08	2.250711e-04	8.762736e-08
ip5:1	0.199745	0.200064	-0.001703	0.001769	-2.546423e-08	3.388352e-09	4.357810e-08	2.250800e-04

	name	keyword	s	betx	bety	sigma_x	sigma_y	mux	muy
wire_3.4l1.b1:1	wire_3.4l1.b1:1	marker	19804.662400	1763.450514	952.011432	0.000769	0.000565	46.104849	44.614983
wire_2.4l1.b1:1	wire_2.4l1.b1:1	marker	19805.912400	1814.138887	1000.388231	0.000780	0.000579	46.104961	44.615186
wire_1.4l1.b1:1	wire_1.4l1.b1:1	marker	19807.162400	1865.547212	1049.967103	0.000791	0.000593	46.105069	44.615381
wire_1.4r1.b1:1	wire_1.4r1.b1:1	marker	20181.162400	1045.873941	1872.979649	0.000592	0.000792	46.614987	45.125291
wire_2.4r1.b1:1	wire_2.4r1.b1:1	marker	20182.412400	995.745233	1822.589169	0.000578	0.000782	46.615182	45.125399
wire_3.4r1.b1:1	wire_3.4r1.b1:1	marker	20183.662400	946.850602	1772.887506	0.000563	0.000771	46.615387	45.125510
wire_3.4l5.b1:1	wire_3.4l5.b1:1	marker	6475.068433	1766.922292	951.719212	0.000769	0.000565	14.725334	14.283857
wire_2.4l5.b1:1	wire_2.4l5.b1:1	marker	6476.318433	1817.709084	1000.080739	0.000780	0.000579	14.725445	14.284061
wire_1.4l5.b1:1	wire_1.4l5.b1:1	marker	6477.568433	1869.217198	1049.643952	0.000791	0.000593	14.725553	14.284255
wire_1.4r5.b1:1	wire_1.4r5.b1:1	marker	6851.568433	1047.842220	1872.370366	0.000593	0.000792	15.235452	14.794169
wire_2.4r5.b1:1	wire_2.4r5.b1:1	marker	6852.818433	997.617176	1821.995990	0.000578	0.000781	15.235647	14.794276
wire_3.4r5.b1:1	wire_3.4r5.b1:1	marker	6854.068433	948.628620	1772.310215	0.000564	0.000771	15.235851	14.794387

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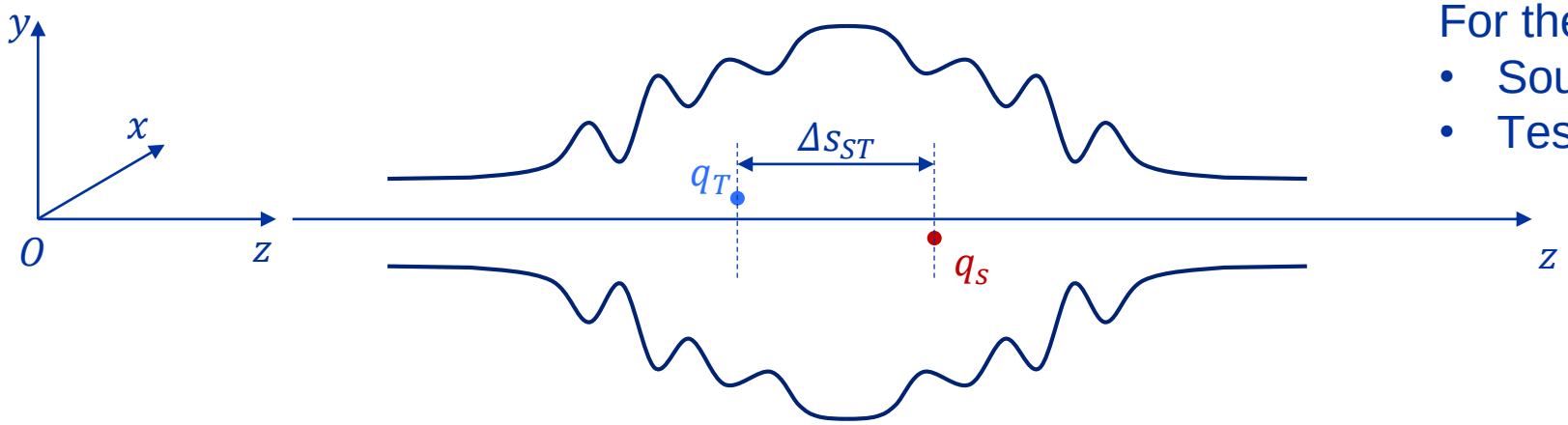
The need for an **Impedance Study**



For the analytical modeling of the Wakefield:

- Source Particle (position (x_S, y_S, z_S))
- Test Particle (position (x_T, y_T, z_T))

Energy loss/gained by a test charge behind a source charge:

$$\Delta U_{TS}\,(x_S, y_S, x_T, y_T, \Delta s_{ST}) = \int_{-\infty}^{+\infty} \boldsymbol{F}(x_S, y_S, x_T, y_T, \Delta s_{ST}, z_T) \cdot \boldsymbol{dz}$$

Longitudinal Wake Function:

$$w_z\,(x_S, y_S, x_T, y_T, \Delta s_{ST}) = \frac{\Delta U_{TS}\,(x_S, y_S, x_T, y_T, \Delta s_{ST})}{q_S q_T} = \frac{1}{q_S q_T}\int_{-\infty}^{+\infty} F_z(x_S, y_S, x_T, y_T, \Delta s_{ST}, z_T)dz$$

The need for an **Impedance Study**

The Longitudinal Wake Impedance is the Fourier Transform of the longitudinal Wake Function.

$$Z_z(\omega) = \int_{-\infty}^{+\infty} w_z(\Delta t_{ST}) e^{-j\omega\Delta t_{ST}} d(\Delta t_{ST})$$

$\Delta t_{ST} = \frac{\Delta s_{ST}}{v}$,
With v the speed of the particle

Advantages:

- Easier to consider resonant modes of the structure.
- Convenient analytical expression of the dissipated power.
- Modeling of instabilities due to impedance.

$$\Delta W = 2(f_0 e N_{beam})^2 \sum_{p=0}^{\infty} (|\Lambda(p\omega_0)|^2 Re[Z_z(p\omega_0)])$$

N_{beam}: number of particles in the beam
f_0: beam revolution frequency
$\Lambda(p\omega_0)$: normalized beam spectrum

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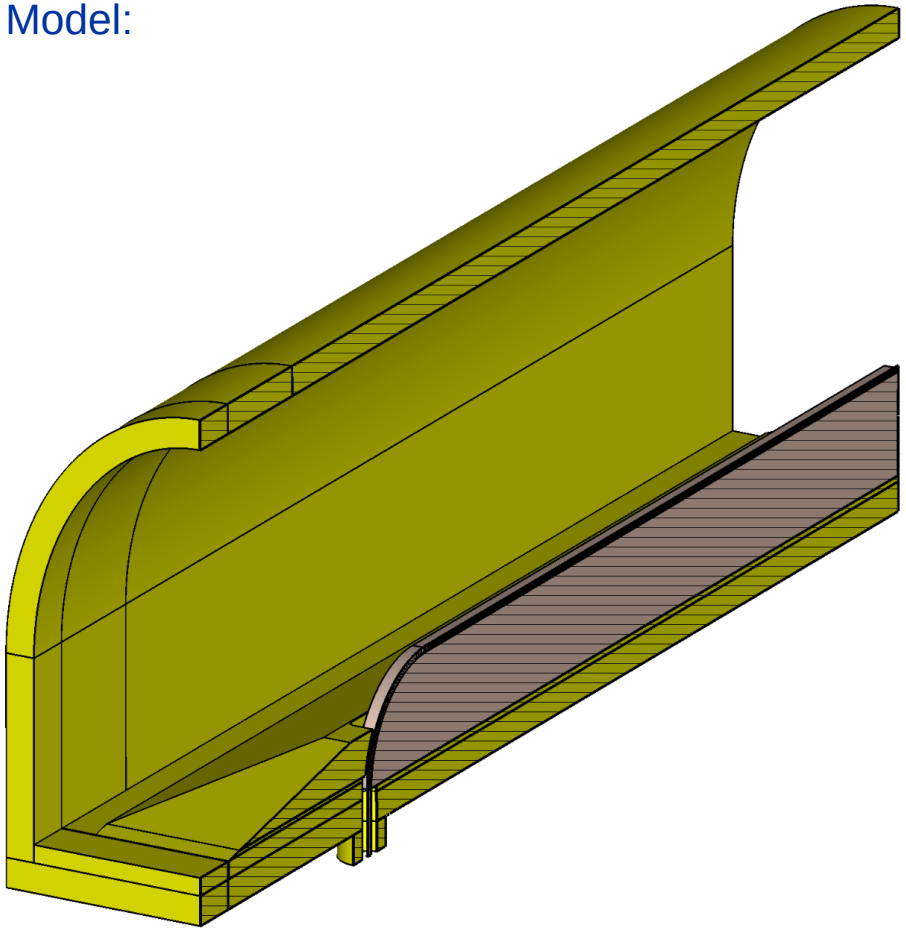
The BBLRC – single module: simplified

Simplified Model:



Model main features:

1. No small bendings.
2. No division of the AlN blocks.
3. No Stainless-Steel flanges.
4. No Stainless-Steel bolts..
5. No Cooling channel.
6. **Thicker Shell.**
7. **Coaxial Structure.**

The BBLRC – single module: simplified

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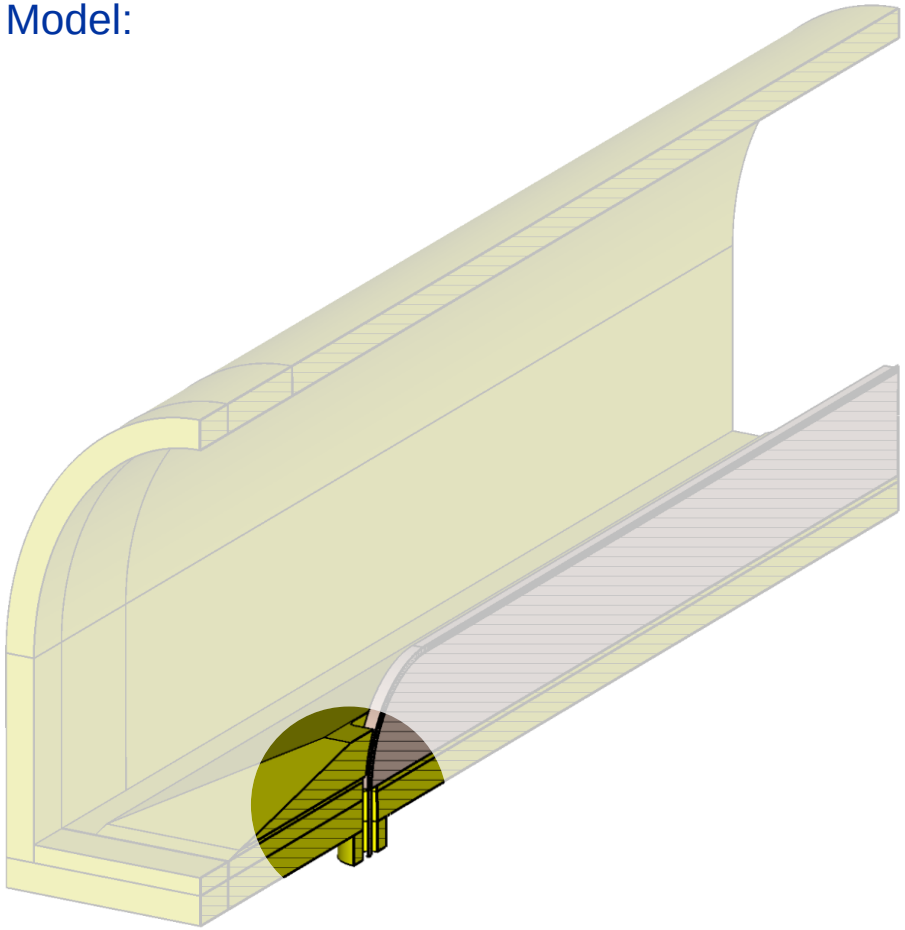

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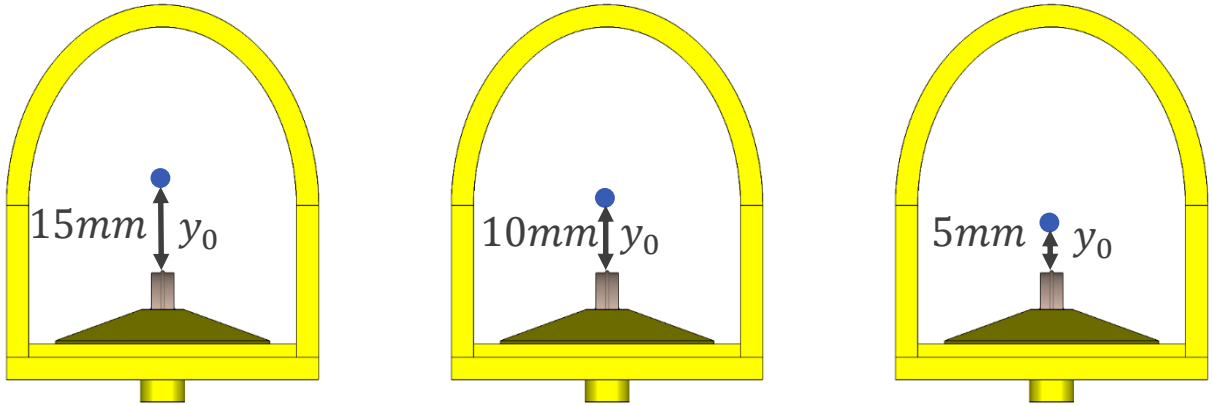
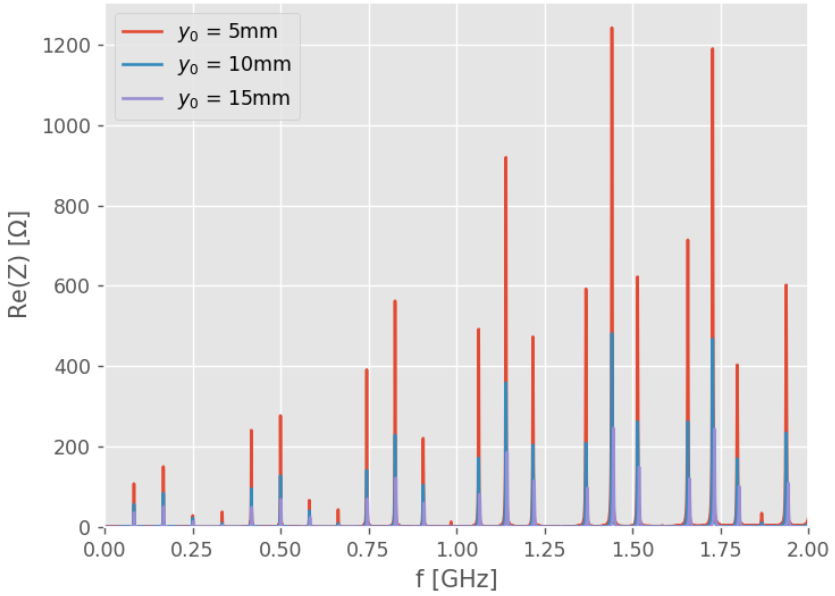
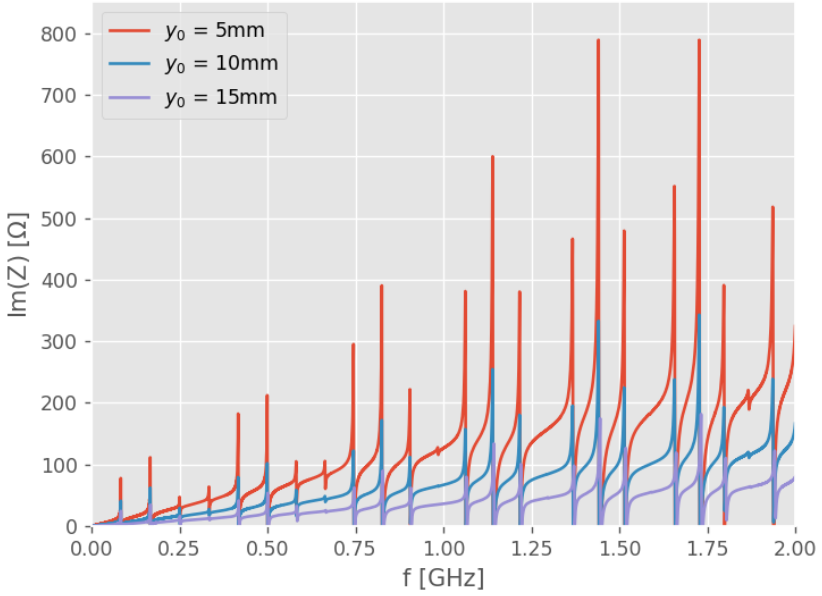
Longitudinal Beam Coupling Impedance

Three configurations of the beam in respect to the wire considered.



- Simulated Wake Length: $400m$.
- All the materials already present in CST material library.





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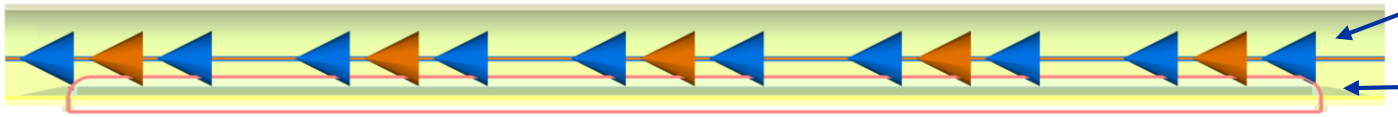
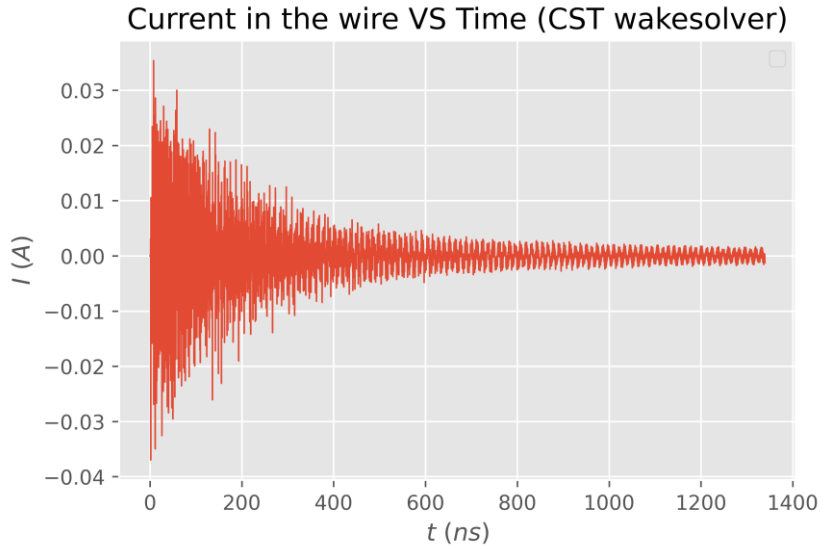
Longitudinal Beam Coupling Impedance

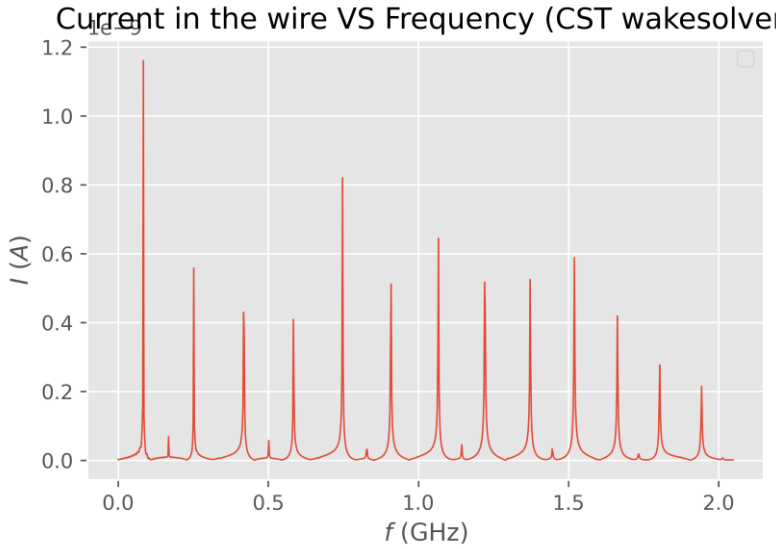
Termination of the wire is important for impedance

- Beam Position Monitors such as Striplines are designed with perfect matching to optimize signal extraction.
- No attention to the termination of the wire for RF.

To go more in depth: **Currents in the wire**.

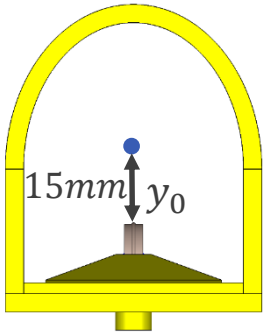


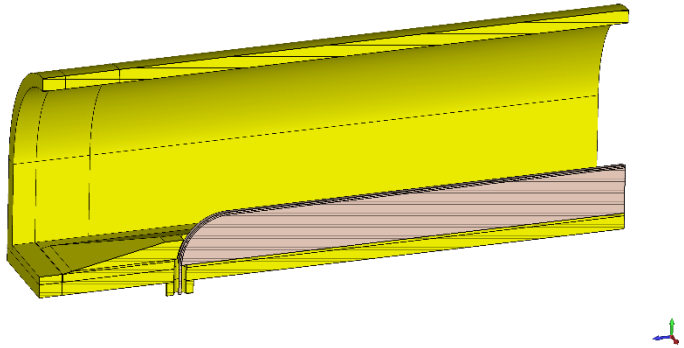


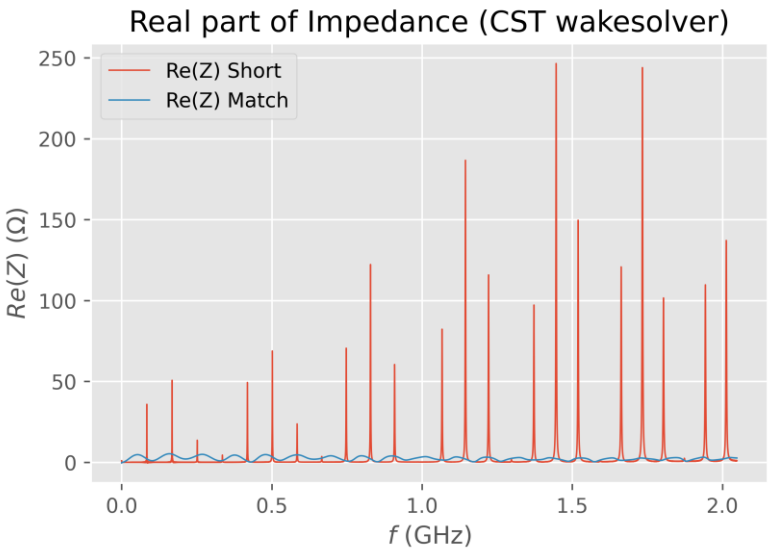


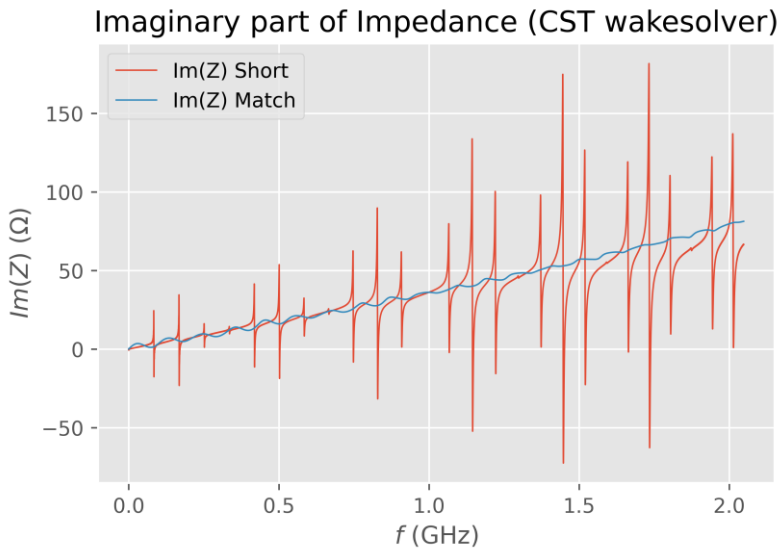
Longitudinal Beam Coupling Impedance

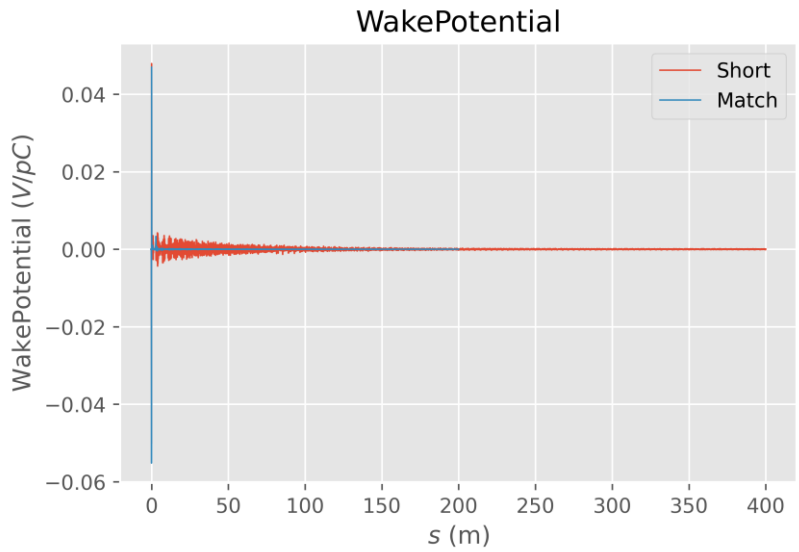
From an Impedance point of view the situation changes drastically if the Coaxial termination is closed on a load.







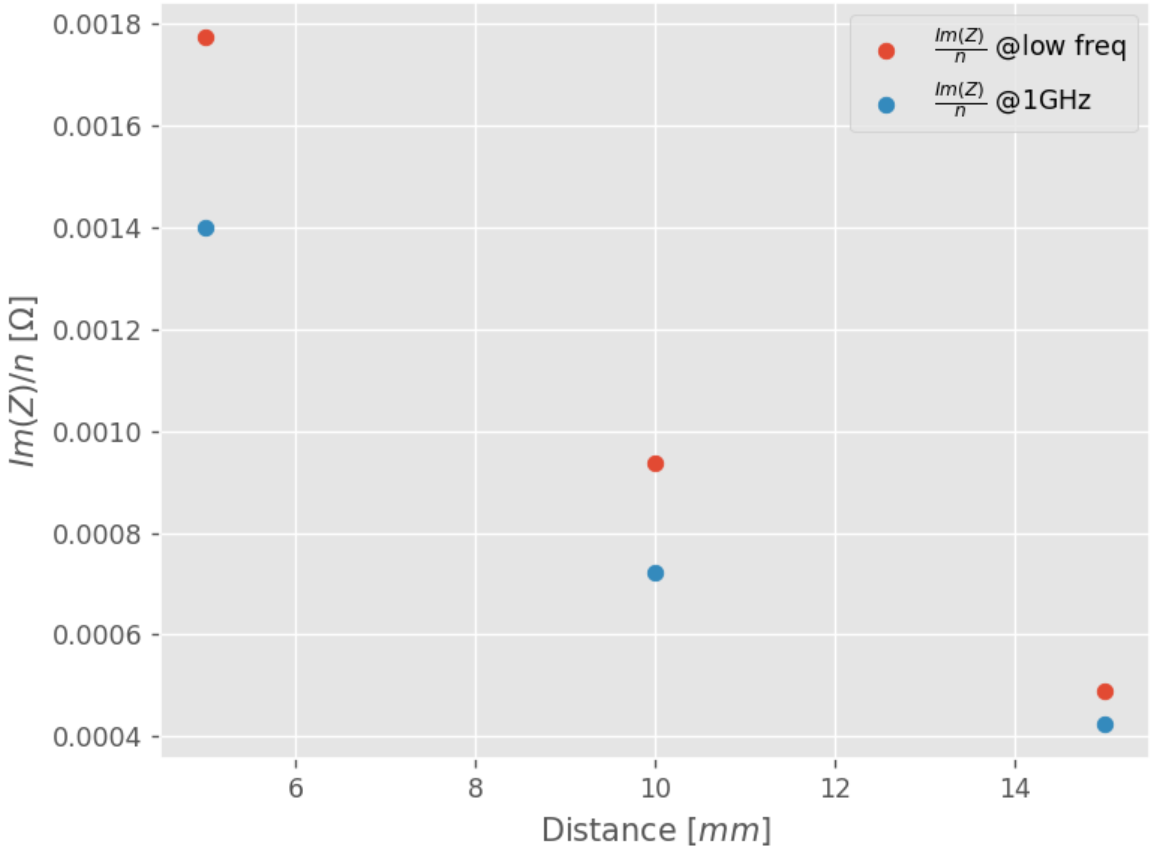




Effective Longitudinal Impedance

Impact of the beam position on the Longitudinal Effective Impedance: $\frac{Im\,(Z)}{n}$, $n = \frac{f}{f_{rev}}$

LHC Effective Impedance ~$90\ m\Omega$



Note: the Impedance value refers only to one module, each beam will interact with 12 modules.

→ Significant contribution of 5 to 17 $m\Omega$ for the total system

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Dissipated Power

Study on the dissipated power using Francesco Giordano's scripts (upgraded to Python 3 and new version of NXCals).
The model for the computation is:

$$\Delta W = 2(f_0 e N_{beam})^2 \sum_{p=0}^{\infty} (|\Lambda(p\omega_0)|^2 Re[Z(p\omega_0)])$$

Fill 6675:

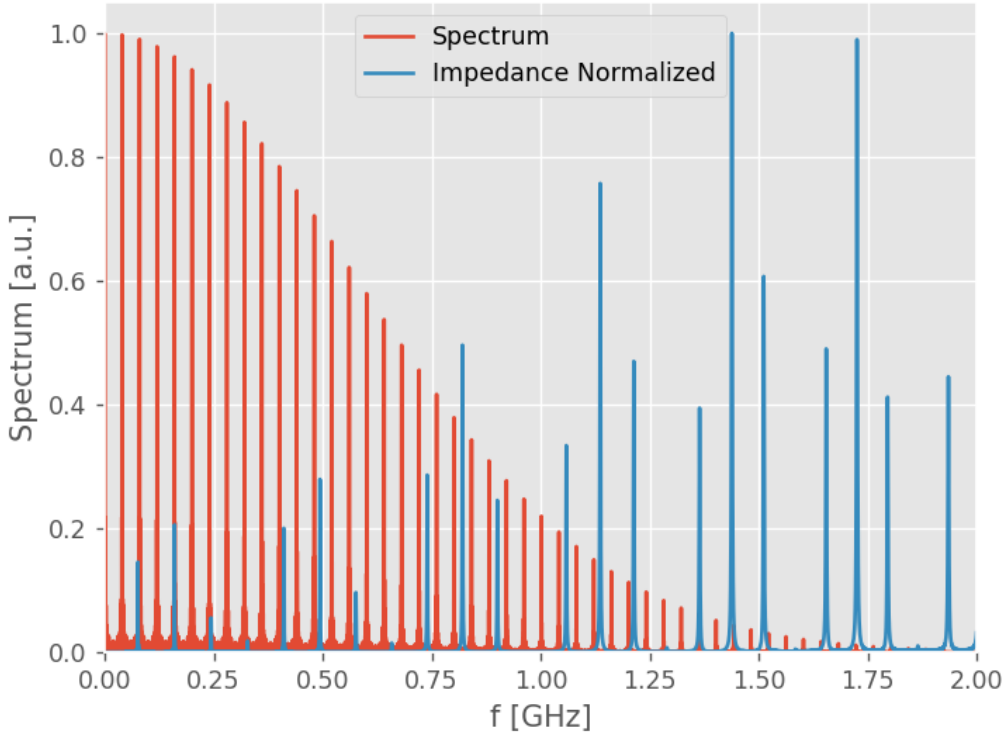
- M = 2556
- Nb = $1.15E11$
- Bunch Length = $1.1\ ns$

But as it is:

- Too much dependency on the Fill Spectrum.
- The peak frequency can be not precise.

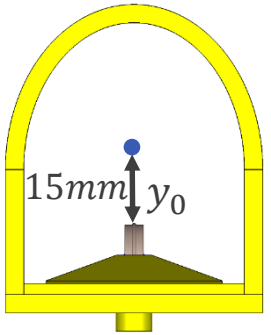
How to deal with this:

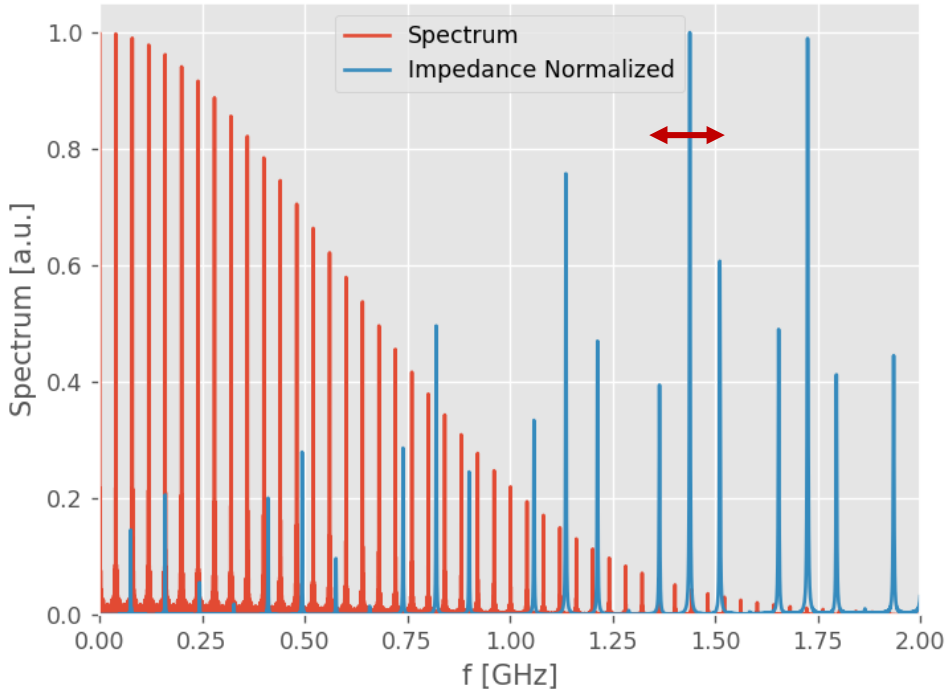
- Randomly Shift the peaks.



Dissipated Power

Shifting rigidly the Impedance peaks we have a worst-case scenario:





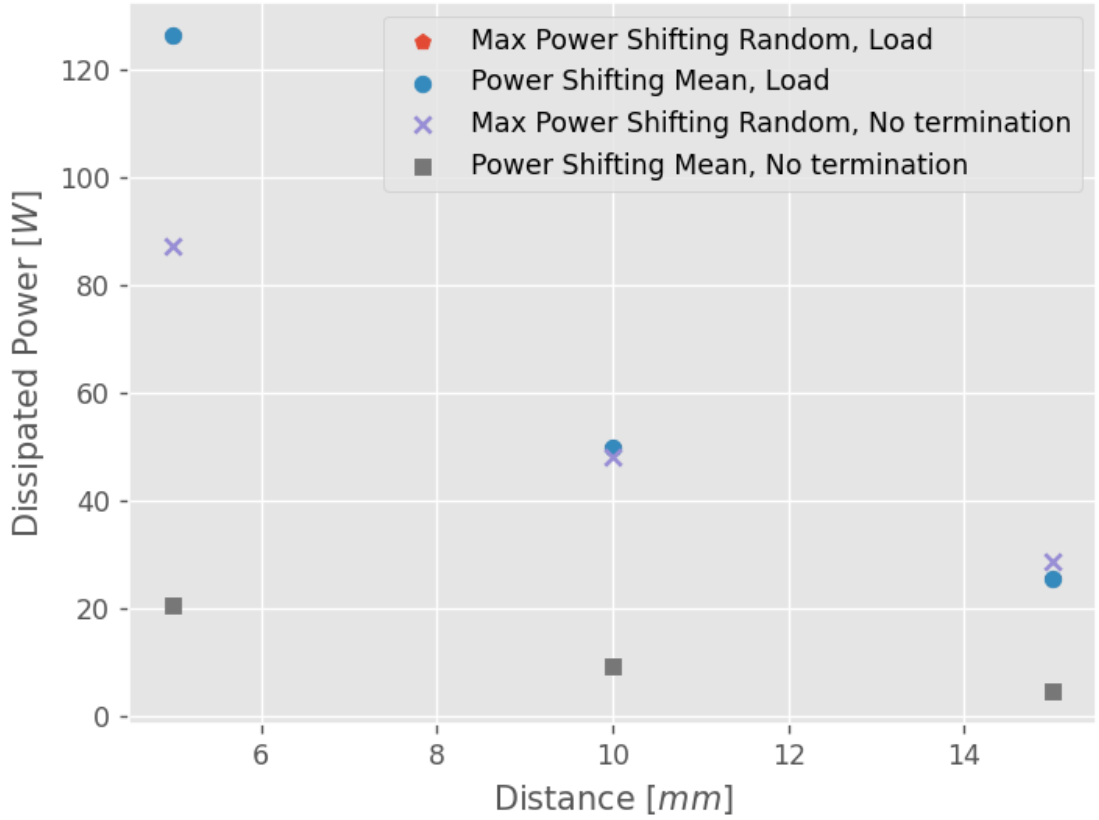
FILL 6675	Dissipated Power [W]
Matched termination	30.16 W
Not Matched, No statistical analysis	2.58 W
Not Matched, Random Shift, Max	31.40 W
Not Matched, Random Shift Mean	7.87 W

Changing the design to avoid reflections of the signal could be beneficial.

HL-LHC → need to multiply these numbers by a factor $(2.3/1.15)^2=4$ (at the beginning of the fill)

Dissipated Power

The dissipated power is growing when going closer to the wire.



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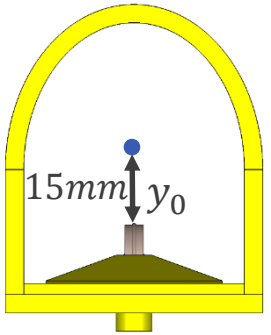
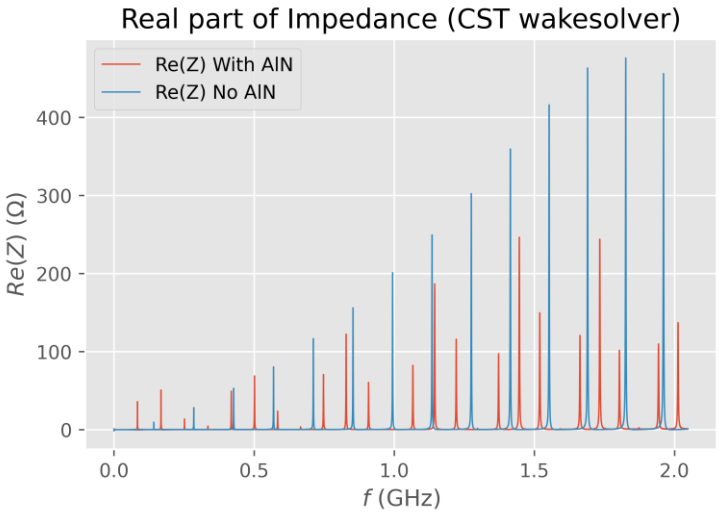
   - Matching the wire termination
   - Dissipated Power
   - **Impact of the dielectric support**
6. Transverse Impedance Study
7. Conclusions

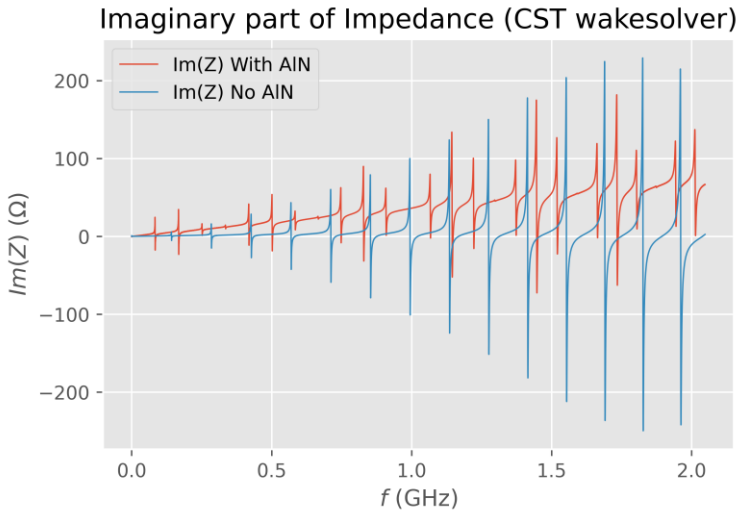
Impact of the AlN support

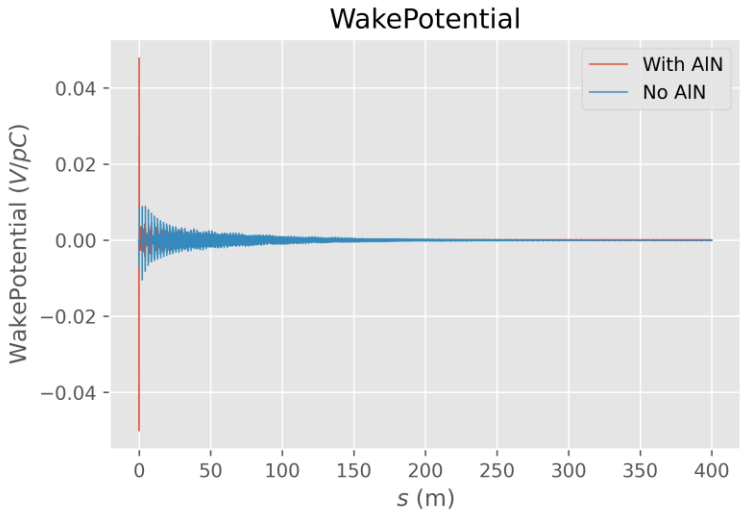
To study the impact of the AlN support on the device a simulation with and without AlN was performed.



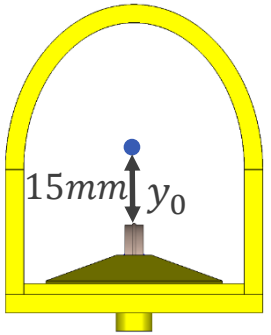
Impact of the dielectric:





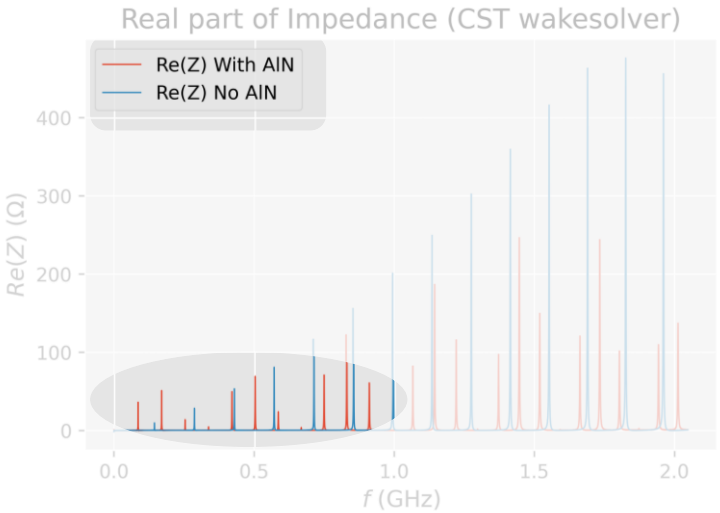


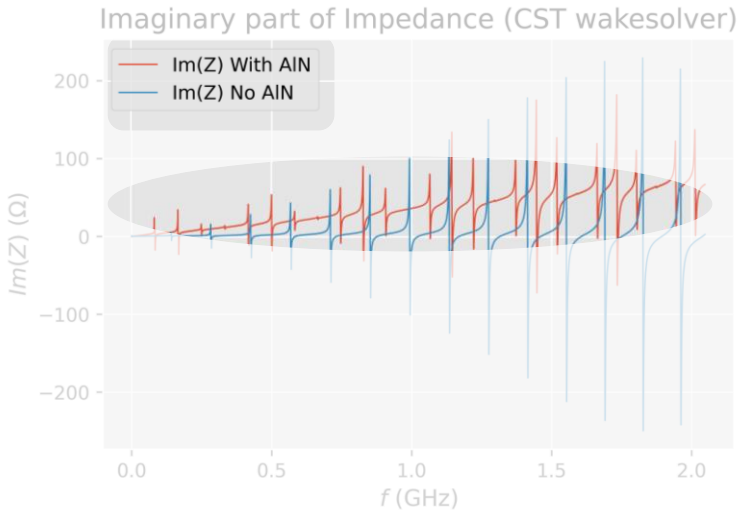
Impact of the AlN support

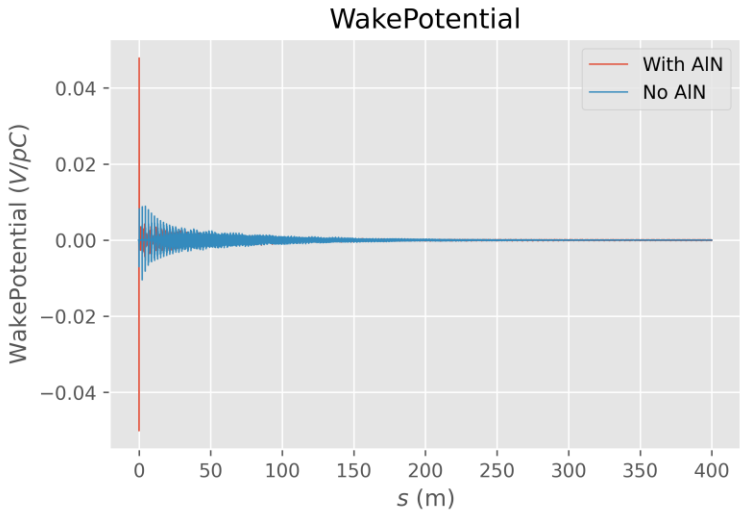


To study the impact of the AlN support on the device a simulation with and without AlN was performed.

Impact of the dielectric:







1. Peaks are shifting to lower frequencies.
2. Slope of the imaginary part is increasing.

Future work: what would happen coating a portion of the dielectric support?

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Transverse Dipolar Impedance

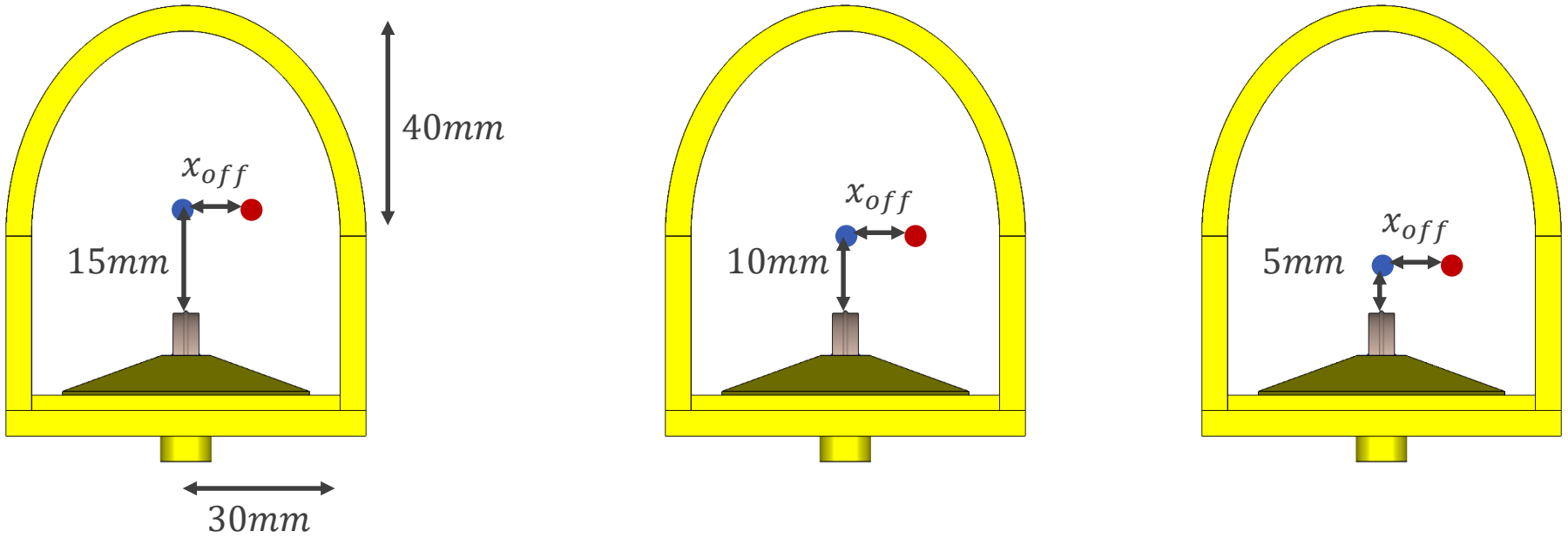
Transverse Dipolar Impedances from wake field solver:

Where x_{off} and y_{off} are the offset position of the beam in respect to the reference position.

$$Z_x^{dip} = \frac{-(Z_x(x_{off}) - Z_x(x_{off} = 0))}{x_{off}}$$

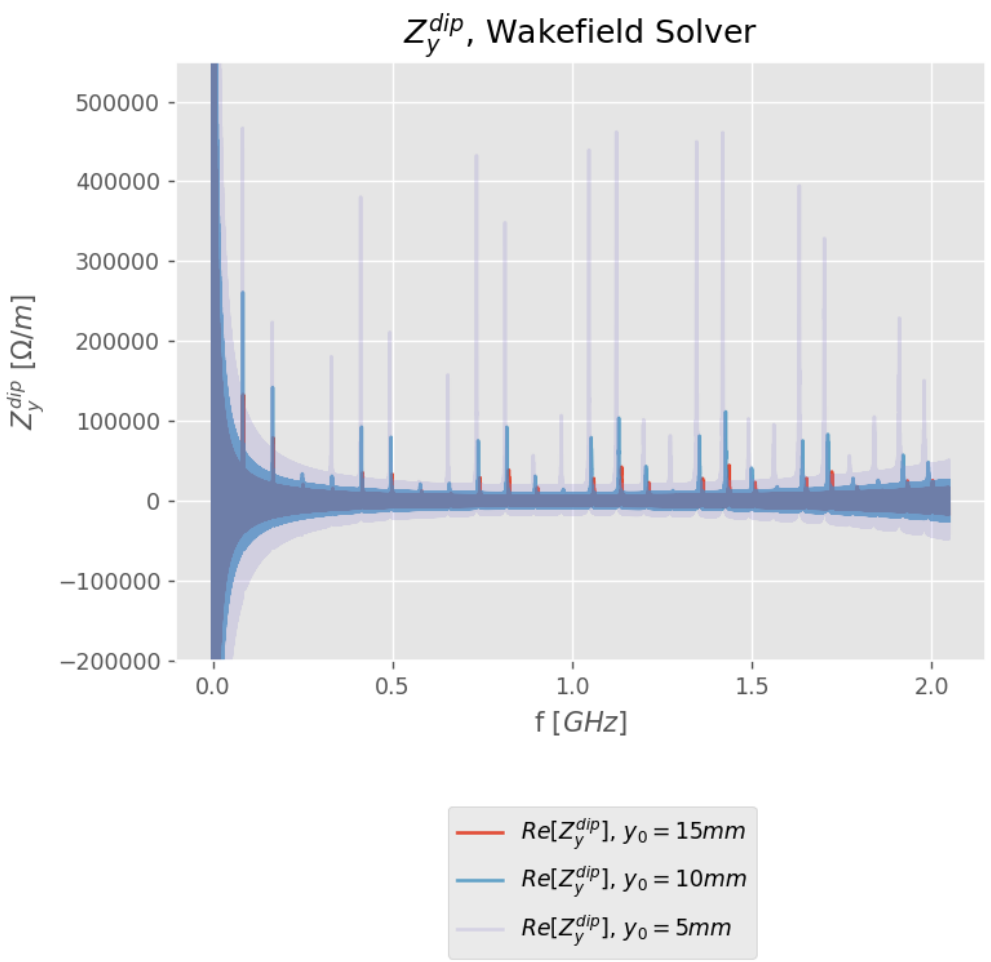
$$Z_y^{dip} = \frac{-(Z_y(y_{off}) - Z_y(y_{off} = 0))}{y_{off}}$$

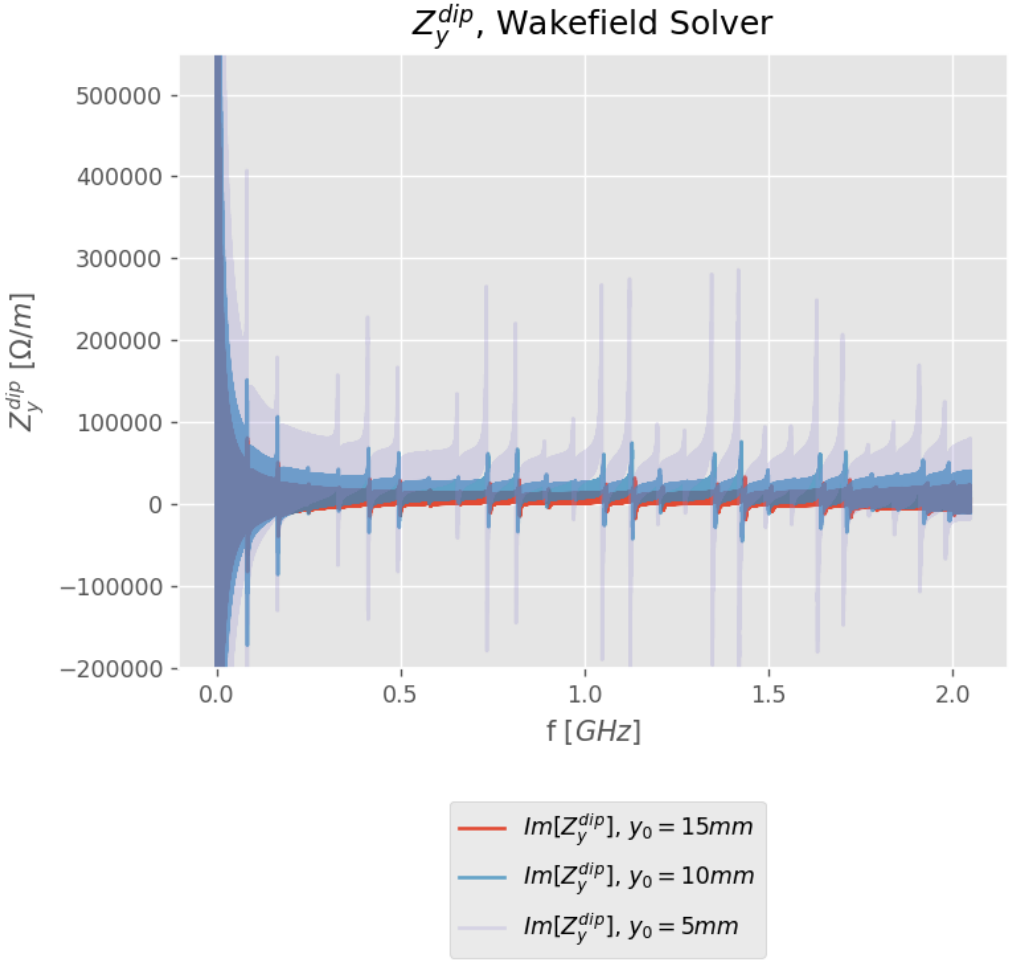
- Beam
- Integration path



Transverse Dipolar Impedance on y

ONGOING



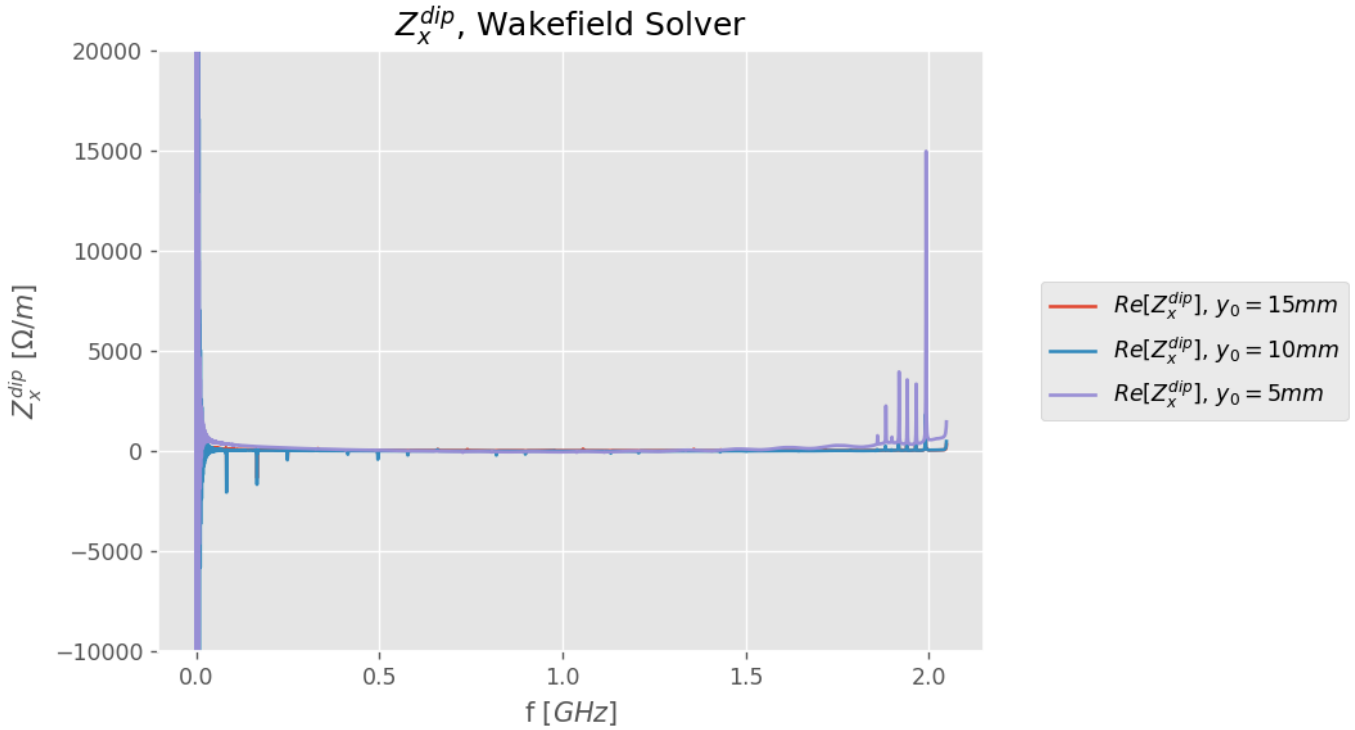


Transverse Dipolar Impedance on x

ONGOING

Issue with numerical dispersion:

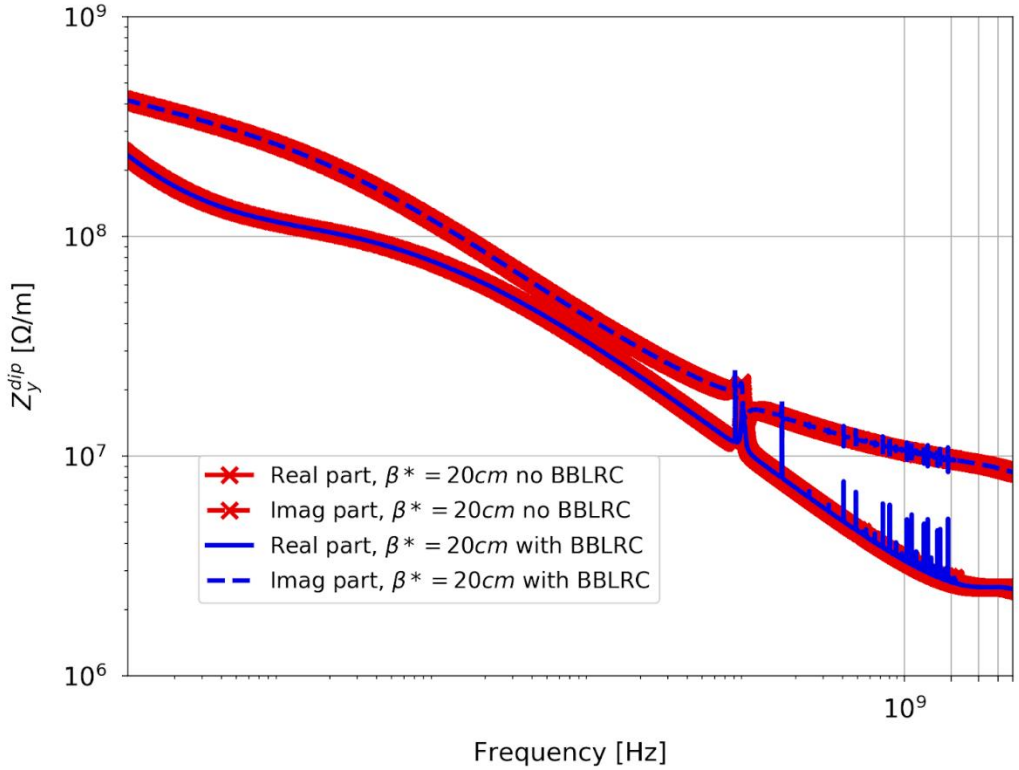
- Tried with cos-square filtering (0.2)
- Tried to numerically remove the dispersion.



The impedance of the BBLRC

ONGOING

Wire at 15mm distance from the beam, at the end of levelling .

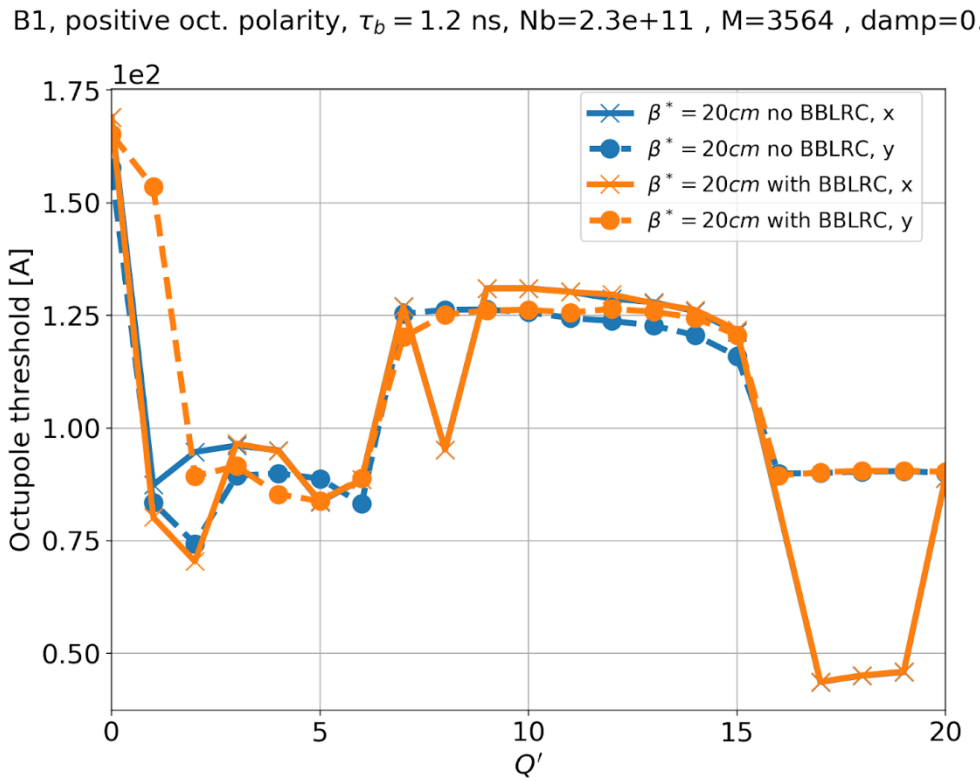


The BBLRC contributes mostly to the vertical dipolar impedance through a number of high-order modes

Impact of the BBLRC on transverse beam stability

ONGOING

We compute the octupole threshold with BBLRC to check the impact of the HOMs on beam stability



The increase of the stability threshold is well below 10A for Q'>10.
To be checked with 5 mm distance to the beam.

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7. **Conclusions**

Conclusion:

A preliminary study on the BBLRC is being made.
From the study some **aspects** have been underlined:

1. Longitudinal and Transverse **impedances** for three configurations.
2. The impact of terminating the wire with a **matched load.**
3. The impact of the **AlN support**.

→ Impedance contributions are significant but no showstopper was identified
→ A shielding (e.g. foil, grid) between the wire and the beam would strongly reduce impedance
→ The transitions need to be modelled and could also have a large contribution (bellows and tapers)

Further studies:

- Design to match the wire termination and avoid reflections.
- Possibility of coating a part of the AlN support.
- Measurements on the device and the prototype.
- Dissipated Power distribution.
- Study on the new design.
- Full longitudinal and transverse stability study

Thank you for your attention

BBLRC (Beam-Beam Long Range Compensator)
Preliminary Impedance Study