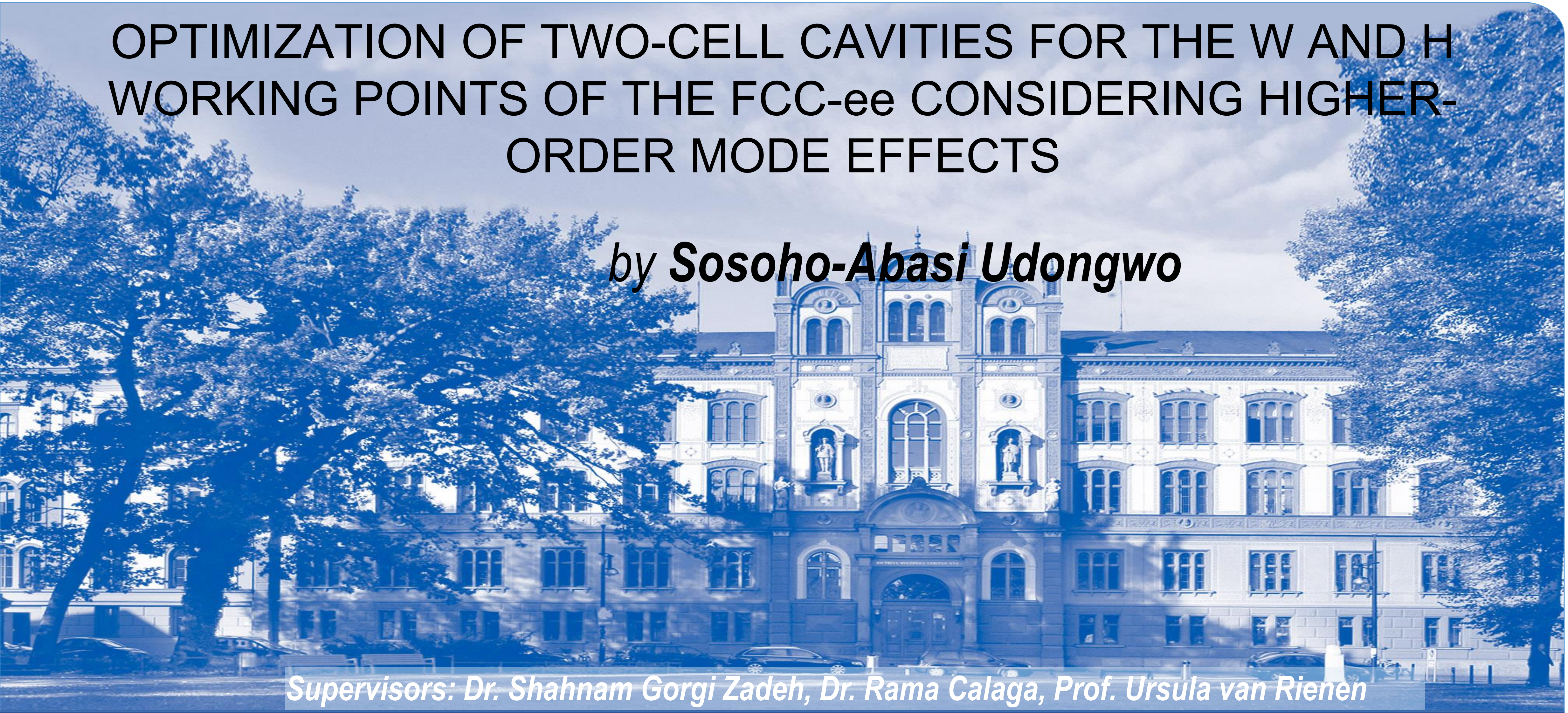
Universität Rostock

Traditio et Innovatio

OPTIMIZATION OF TWO-CELL CAVITIES FOR THE W AND H WORKING POINTS OF THE FCC-ee CONSIDERING HIGHER-ORDER MODE EFFECTS

by ***Sosoho-Abasi Udongwo***



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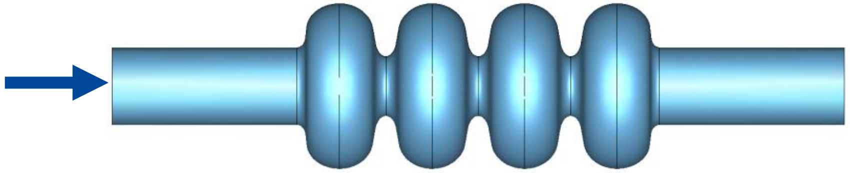
Content

Introduction

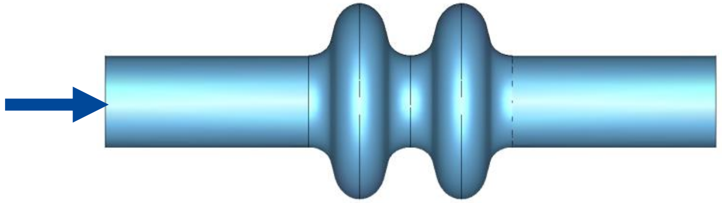
- The lepton collider of the Future Circular Collider (FCC-ee) aims at conducting precision measurements on the Z, W, and H bosons and the top quark

- The present RF baseline considers four-cell 400 MHz cavities for the W and H working points



- A detailed study of the W working point has shown strong higher-order mode (HOM) effects in the four-cell cavities [1]

- In this study, a two-cell cavity is designed as an alternative scenario for the current W- and H-RF setups with special attention paid to HOM aspects



[1] *S. Gorgi Zadeh, Accelerating cavity and higher order mode coupler design for the Future Circular Collider, PhD thesis, Universität Rostock, 2020. http://purl.uni-rostock.de/rosdok/id00003023 - open access*

Quantities of Interest

- The primary quantities of interest are the impedances of higher-order modes (HOM)
  - HOM Longitudinal Impedance $|Z_L|$ and
  - HOM Transverse Impedance $|Z_T|$

$$Z_L = \frac{1}{c}\int_{-\infty}^{\infty} w_{\parallel}(r,s)e^{-\frac{j\omega s}{c}}ds$$

$$Z_T = \frac{-j}{c}\int_{-\infty}^{\infty} w_{\perp}(r,s)e^{-\frac{j\omega s}{c}}ds$$

- Secondary quantities of interest are these quantities of the fundamental mode (FM):
  - $E_{\mathrm{pk}}/E_{\mathrm{acc}}$
  - $B_{\mathrm{pk}}/E_{\mathrm{acc}}$

  where $E_{\mathrm{pk}}, B_{\mathrm{pk}}$ and E_{acc} represent the peak electric field on the surface of cavity, peak magnetic field on the surface of the cavity, and accelerating field, respectively

Optimization Method

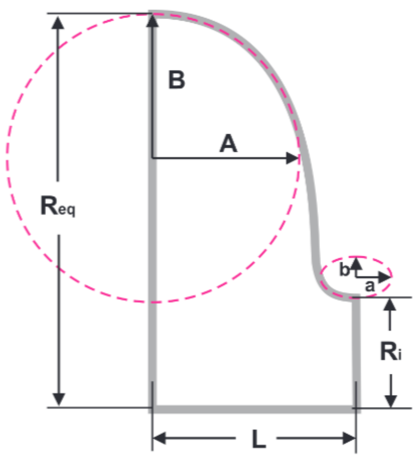
- In order to reduce the search space for this study, the equator and iris ellipses were assumed to have a circular shape, i.e. $A = B$ and $a = b$

- A parameter sweep in 4D was carried out considering $A \in [50,110], a \in [20,70], L \in [160,190]$, and $R_\mathrm{i} \in [150, 160]$, where all dimensions are in mm

- The HOM and FM quantities of interest are combined to form objective functions using the weighted exponential sum method

$$F_{obj} = \left(\sum_{i}^{m} (w_i f_{i,n})^p \right)^{\frac{1}{p}} \text{ [2]}$$

where w_i represents weights, p represents the norm order and n is used to indicate that the objective functions are normalised. w and p are both set to 1 in this study



[2] *R.T. Marler and J.S. Arora, Survey of multi-objective optimization methods for engineering, Structural Multidisciplinary Optimization 26,369–395 (2004), DOI 10.1007/s00158-003-0368-6*

Objective Functions

$$\min_{L,R_i,A=B,a=b} (F_{\mathrm{FM}}, F_{\mathrm{HOM}})$$

$$F_{\mathrm{HOM}} = \frac{\mathrm{Max}\left(Real\{Z_{L(f>450\ \mathrm{MHz})}\}\right)}{0.3\ \mathrm{k\Omega}} + \frac{\mathrm{Max}\left(|Z_{T(f>650\ \mathrm{MHz})}|\right)}{3\ \mathrm{k\Omega/m}}$$

$$F_{\mathrm{FM}} = \frac{\frac{E_{\mathrm{pk}}}{E_{\mathrm{acc}}}}{2.2} + \frac{\frac{B_{\mathrm{pk}}}{E_{\mathrm{acc}}}}{5\ \frac{\mathrm{mT}}{\mathrm{MV/m}}}$$

$$\mathrm{s.t.} \quad f_{\mathrm{FM}}(R_{\mathrm{eq}}) = 400.79\ \mathrm{MHz}$$

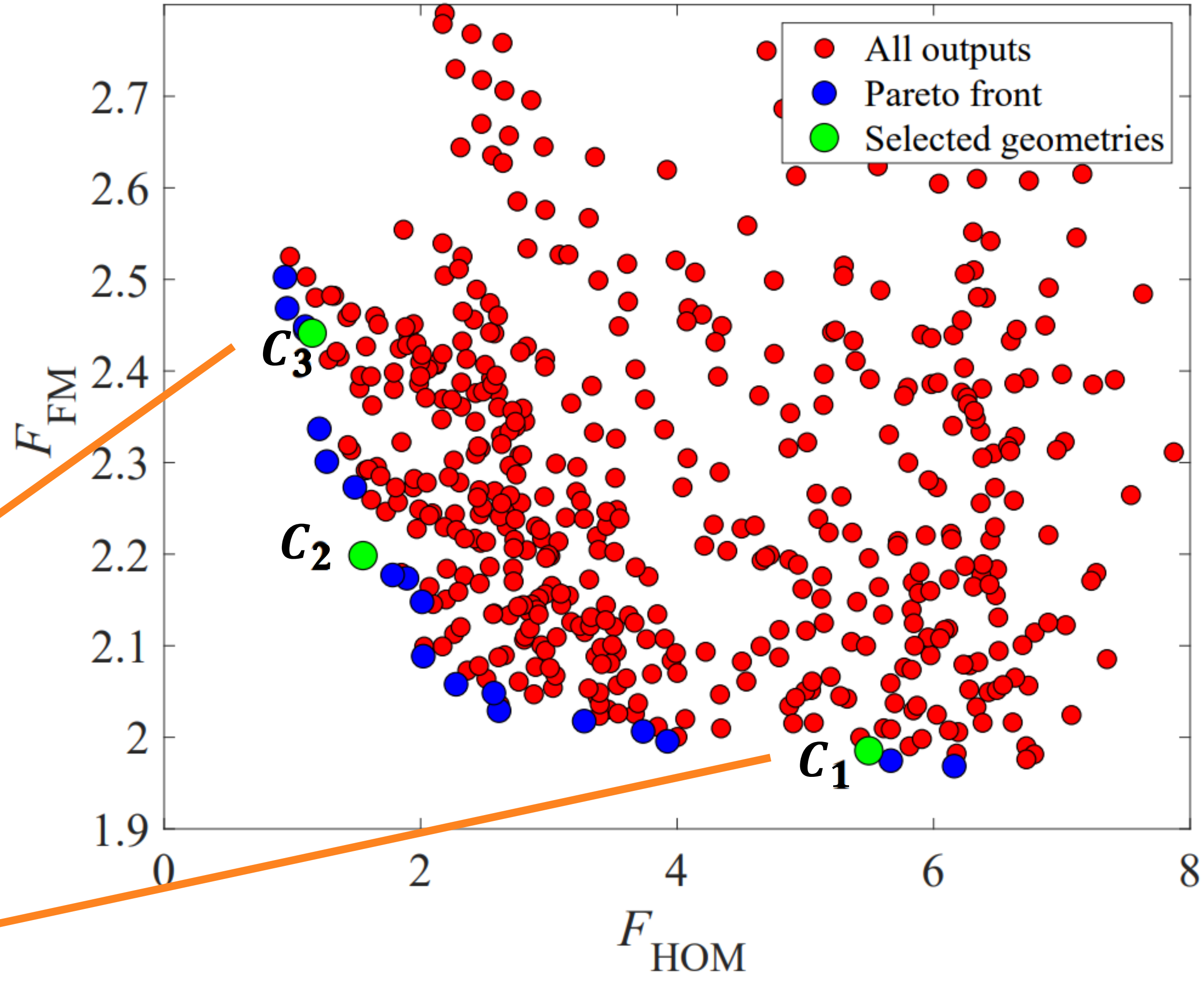
FM frequency tuning

- $E_{\mathrm{pk}}/E_{\mathrm{acc}}$ is normalized by 2.2 and $B_{\mathrm{pk}}/E_{\mathrm{acc}}$ by $5\ \frac{\mathrm{mT}}{\mathrm{MV/m}}$
- The maximum longitudinal impedance peak above the FM is normalized to 0.3 kΩ, and the maximum transversal impedance peak above the frequency of the first two dipole passbands is normalized to 3 kΩ/m, considering a wake length of 50 m

A Pareto distribution of the two objective functions

- The Pareto front of this optimization with the two objective functions F_{HOM} and F_{FM} is highlighted by the blue markers

- Three geometries are selected from the Pareto front. Geometry 1 (C_1) favors F_{FM}, Geometry 3 (C_3) favors F_{HOM}, and Geometry 2 (C_2) is a sample in the middle range

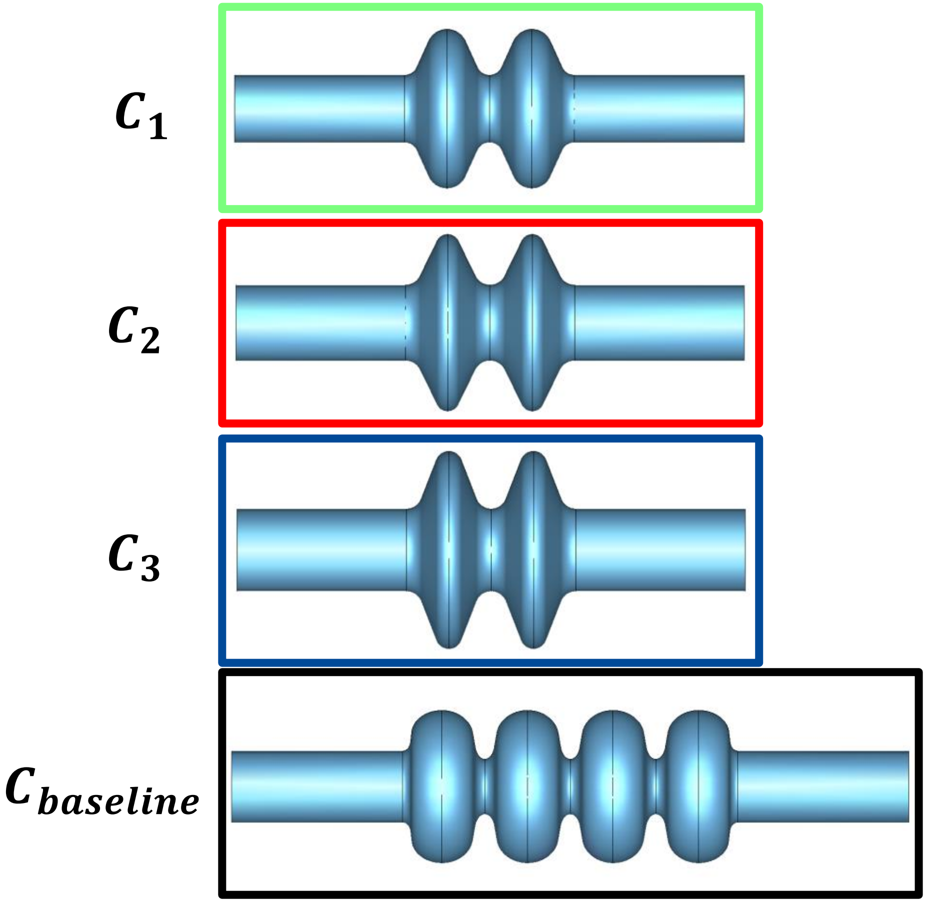


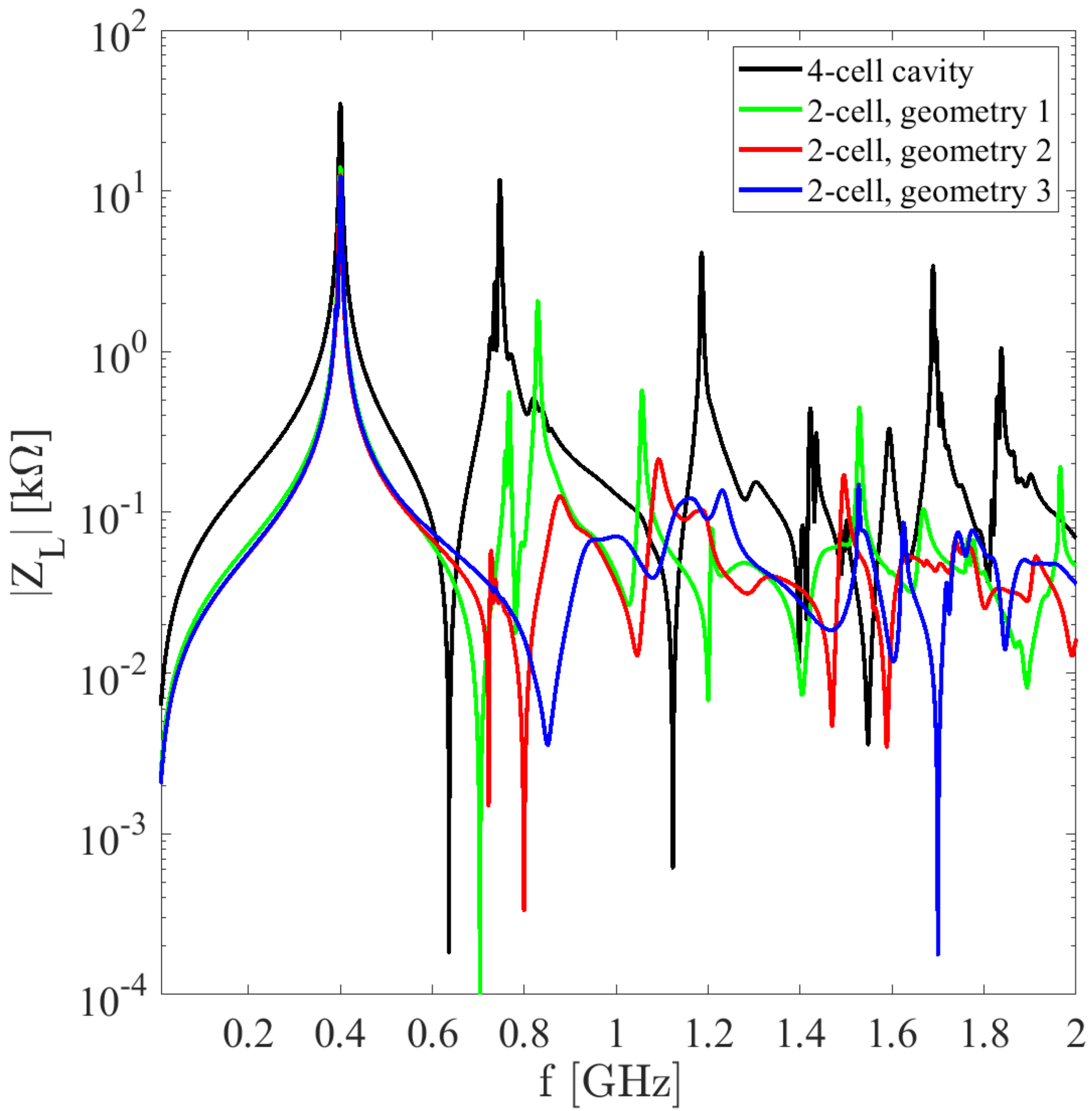
More in favor of F_{HOM}

More in favor of F_{FM}

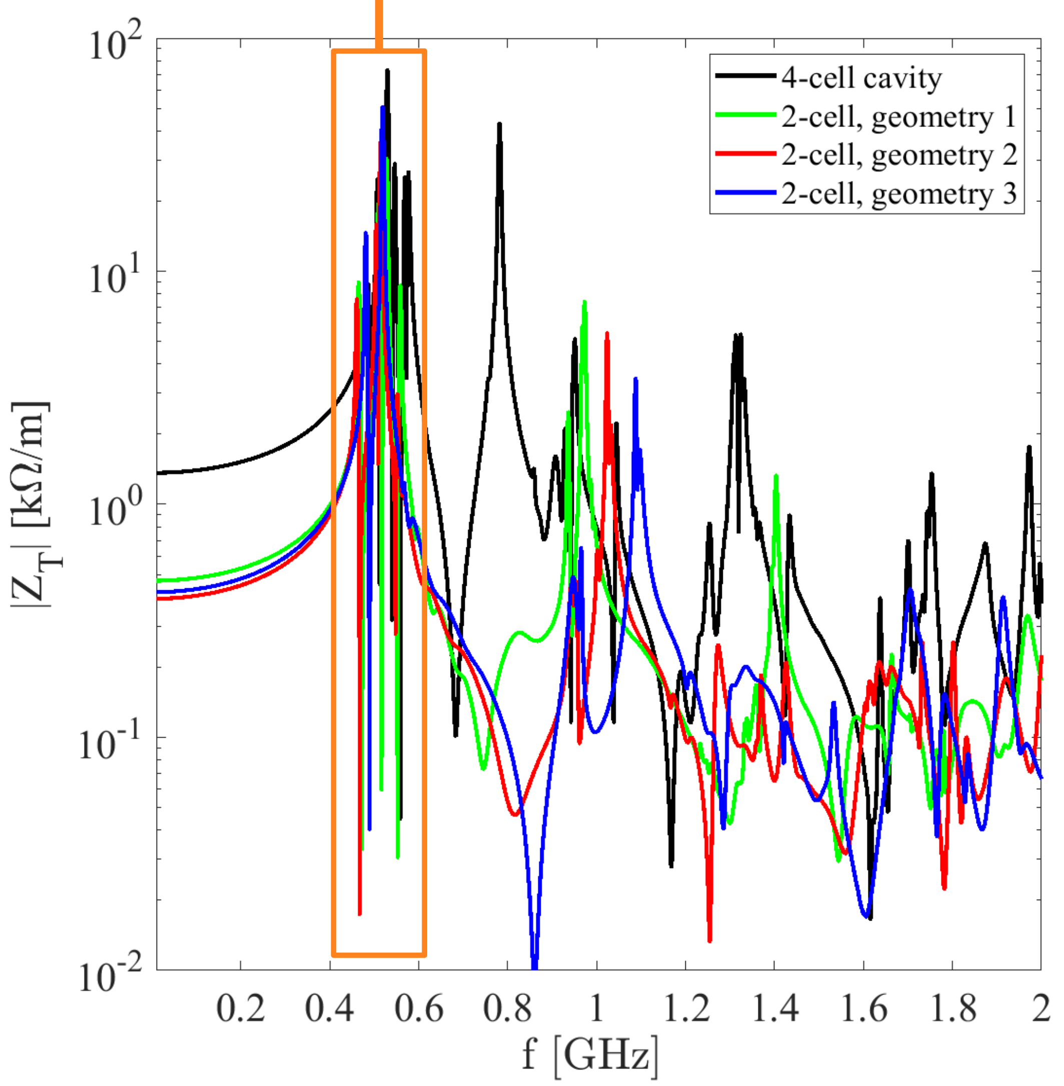
Longitudinal Wakefield Impedance Plots for Selected Cavities

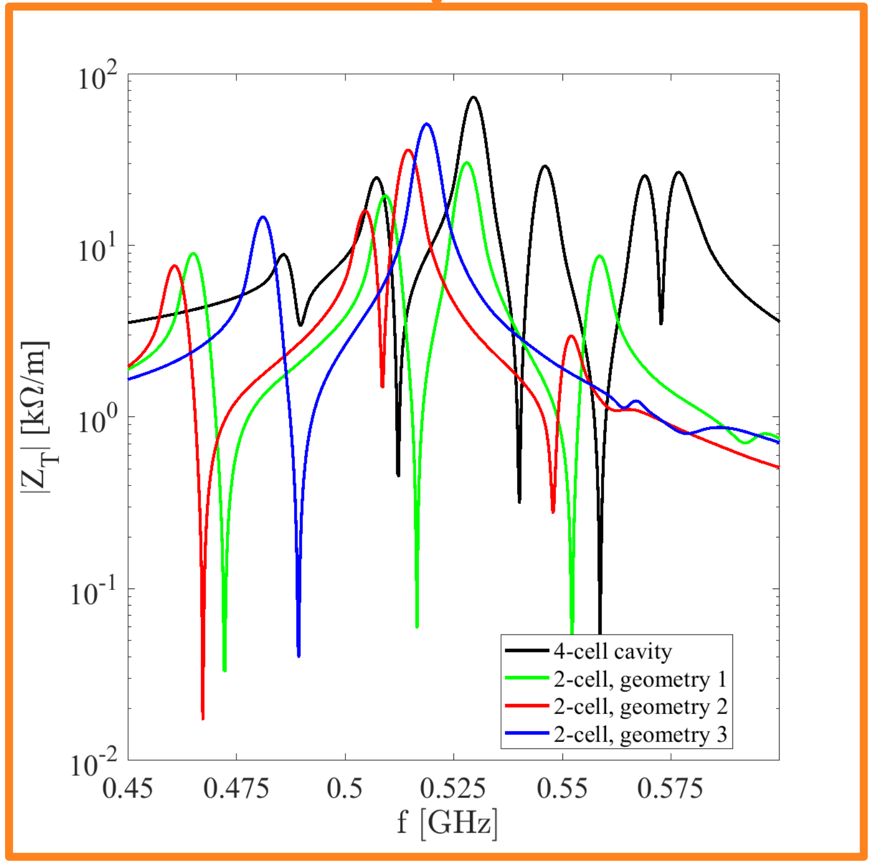
- The longitudinal wakefield impedance plot shows a strong reduction in the HOM impedance for the selected two-cell cavities, especially for C_3





Transversal Wakefield Impedance Plots for Selected Cavities





From the zoomed area, it can be seen that geometry 3 has less number of peaks which simplifies the design of HOM couplers

Result Summary

Parameter	$k_{\parallel}$* [V/pC]	$k_{\perp}$ [V/pC/m]	$f_{TE111} - f_{TM010}$ [MHz]	R_{sh}/Q_{FM} [Ω]	E_{pk}/E_{acc}**	B_{pk}/E_{acc} [mT/(MV/m)]
C_1	0.02678	0.5401	66.01	165.8	2.03	5.3
C_2	0.017582	0.4242	60.21	147.2	2.12	6.2
C_3	0.01504	0.4564	80.51	144.7	2.46	6.6
$C_{baseline}$	0.048025	0.82	85.21	411.3	2.0	4.2

*A bunch length of 50 mm was used for the calculation of the HOM loss factors, **E_{acc} is calculated from V_{acc} with a length of $n_{cell} \times 374$ mm.

The dimensions are given in mm

Var	C_1	C_2	C_3	$C_{baseline}$
A/A_e	90	50	50	135.44/133
B/B_e	90	50	50	114.9/102
a/a_e	60	70	60	43.5/34
b/b_e	60	70	60	71.19/46
$R_i/R_{i,e}$	150	160	155	120/156
L/L_e	190	180	160	187/171.5
R_{eq}	355.042	374.924	372.642	333.182
α/α_e	114.5°	116.1°	111.3°	100°/96.9°