Universität Rostock

Traditio et Innovatio

ALTERNATIVE DESIGN OF A 5-CELL CAVITY FOR THE $t\bar{t}$ OPERATING POINT

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Content

- SRF overview – $t\bar{t}$ operating point
- Machine parameters
- Review of the baseline design (FCCUROS5)
- Aim
- Cavity Design
- Comparison with FCCUROS5
- Summary and Outlook

SRF Overview

- The previous RF baseline presented in the CDR [1] considers:
  - Hybrid system **4-cell 400 MHz** and 5-cell 800 MHz cavities - $t\bar{t}$ working point [2]

- The current RF baseline considers:
  - Hybrid system **2-cell 400 MHz** and 5-cell 800 MHz cavities - $t\bar{t}$ working point [2]

- The **FCCUROS5** is a cavity geometry design proposed for the $t\bar{t}$ working point [2, p. 68]

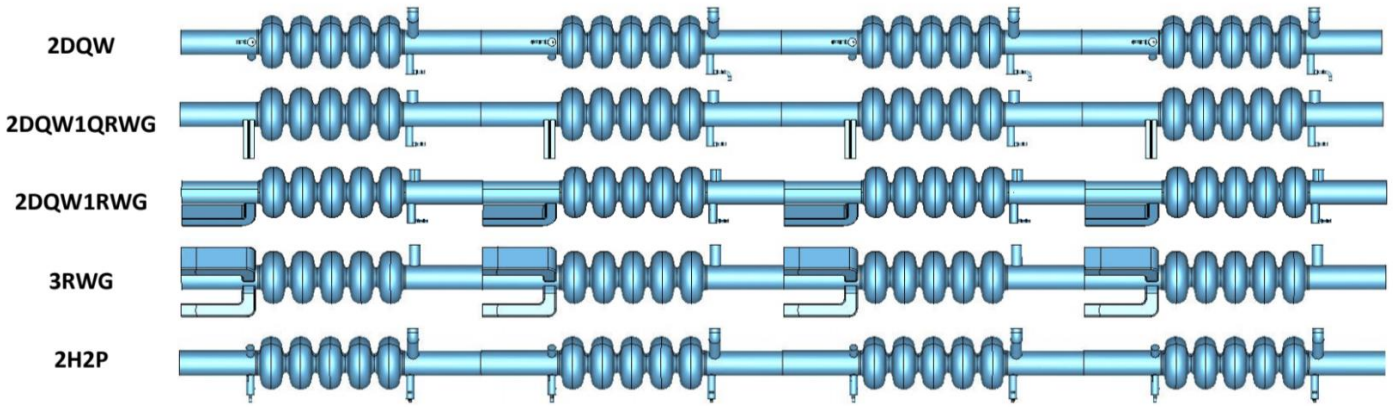
[1] M. Boscolo et al., "FCC-ee machine design overview", in FCC week, Amsterdam, 2018.
[2] S. Gorgi Zadeh, "Accelerating cavity and higher-order mode coupler design for the Future Circular Collider", Ph.D. thesis, Theoretische Elektrotechnik, Universität Rostock, 2020;http://purl.uni-rostock.de/rosdok/id00003023

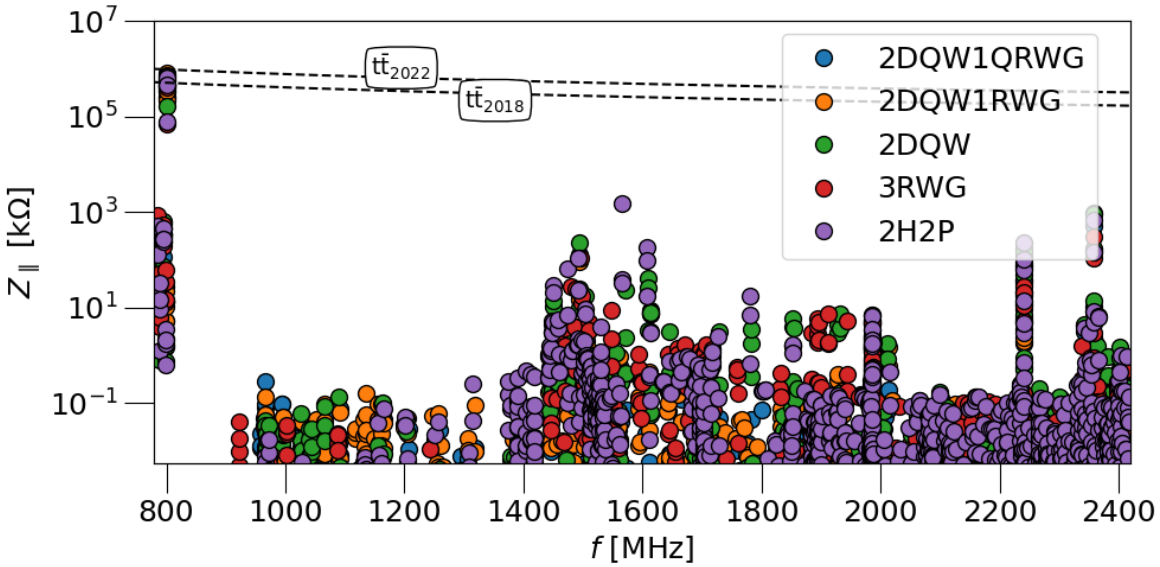
Machine Parameters

Machine parameter	$t\bar{t}$ Operating Point
Beam energy [GeV]	**182.5**
Beam current [mA]	**10**
Beam RF voltage [GV]	**9.2**
Bunch intensity [10^{11}]	2.26
Bunch SR length [mm]	**1.67**
Bunch BS length [mm]	2.54

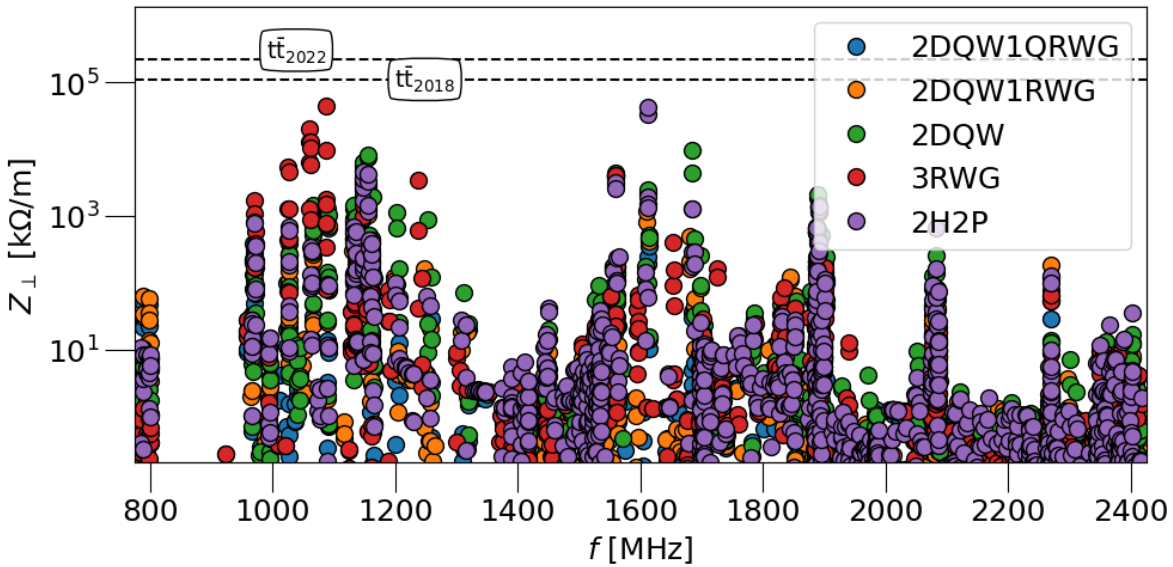
Review of FCCUROS5 (2019)

- The plots show that the FCCUROS5 is still suitable for operation at the $t\bar{t}$ operating point.





Longitudinal impedance plot



Transverse impedance plot

Aim

- Investigate the possibility of improving the performance of the FCCUROS5 for the $t\bar{t}$ operating point, especially concerning higher-order modes (HOMs) effects.

- Also, considering the high beam current of 140 mA for the Z booster, by improving the HOM characteristics of the 5-cell cavities, the same type of 5-cell 800 MHz cavities can be used for the boosters of all four operating points

Design Procedure

$$\min_{\mathbf{x}_i, \mathbf{x}_e \in \mathbf{X}} \left(\frac{E_{\mathrm{pk}}}{E_{\mathrm{acc}}}, \frac{B_{\mathrm{pk}}}{E_{\mathrm{acc}}}, -R/Q, |Z_{\parallel,p}|, |Z_{\perp,q}| \right)$$

$$\text{s.t.} \quad R_{\mathrm{eq}}/\mathrm{mm} = \arg\min_{R_{\mathrm{eq}}} \; f(R_{\mathrm{eq}}) - f_{\mathrm{FM}},$$

$$L_{\mathrm{e}}/\mathrm{mm} = \arg\min_{L_{\mathrm{e}}} \; f(L_{\mathrm{e}}) - f_{\mathrm{FM}},$$

$$A_{\mathrm{i,e}}, B_{\mathrm{i,e}}/\mathrm{mm} \in [20, 80],$$

$$a_{\mathrm{i,e}}, b_{\mathrm{i,e}}/\mathrm{mm} \in [10, 60],$$

$$R_{\mathrm{i,i,e}}/\mathrm{mm} \in [60, 85],$$

$$L_{\mathrm{i}}/\mathrm{mm} = 93.5,$$

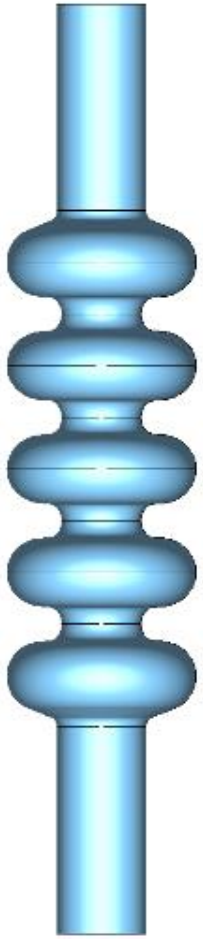
$$\alpha_{\mathrm{i}} \geq 90^\circ,$$

$$\frac{E_{\mathrm{pk}}}{E_{\mathrm{acc}}} \leq 3,$$

$$\frac{B_{\mathrm{pk}}}{E_{\mathrm{acc}}} / \frac{\mathrm{mT}}{\mathrm{MV/m}} \leq 5,$$

Algorithm 1 Pareto-based Genetic Algorithm

Initialisation: $\mathbf{X} = (\mathbf{x}_1, \ldots, \mathbf{x}_Q)$, $n = 0$, v_t;
  ▹ First generation, v_t : hypervolume threshold value.
while $n < N$ **do** ▹ Generation loop
  for $\mathbf{x} = \mathbf{x}_1 \ldots, \mathbf{x}_Q$ **do** ▹ Half-cell geometry loop
    run SLANS, ABCI
      ▹ for $\frac{E_{\mathrm{pk}}}{E_{\mathrm{acc}}}, \frac{B_{\mathrm{pk}}}{E_{\mathrm{acc}}}, R/Q, |Z_{\parallel,p}|, |Z_{\perp,q}|$
  $\mathbf{P}_n \leftarrow$ Evaluate and interpolate Pareto hypersurface
  if $n > 0$ **then**
    Evaluate hypervolume v between $\mathbf{P}_n$ and $\mathbf{P}_{n-1}$
    if $v < v_t$ **then**
      break
  do Ranking and Selection, Crossover, Mutation
  do Introduce random half-cell geometries
  $\mathbf{X} \leftarrow$ newly created geometries
return $\mathbf{P}_n$



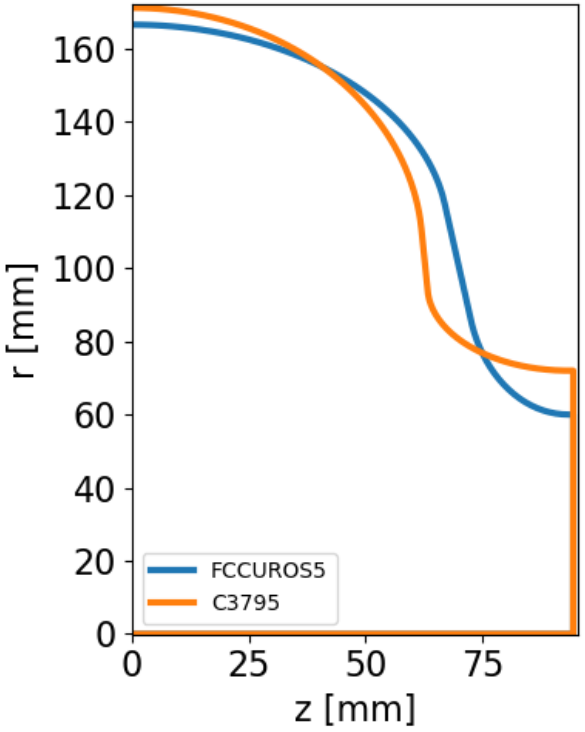
Objective function

Multi-objective optimisation algorithm

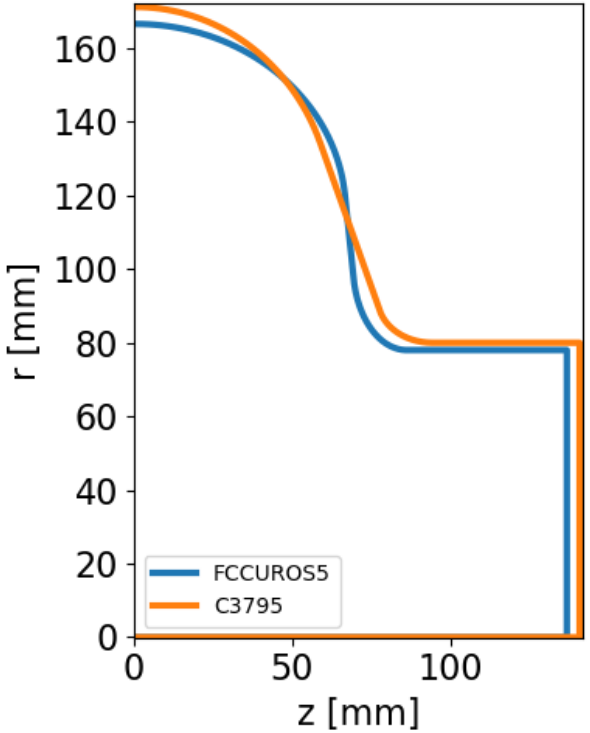
C3795

Geometric Parameters

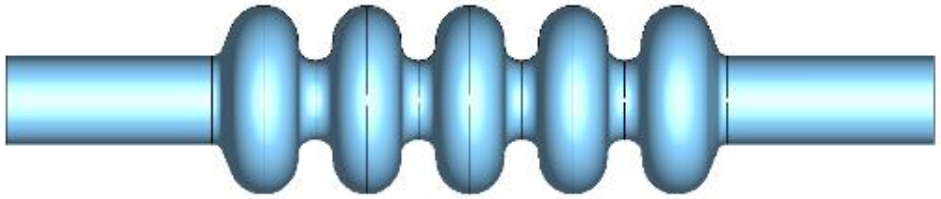
Variable	C3795	FCC_{UROS5}
R_i, R_{ie} [mm]	**72**/80	**60**/78



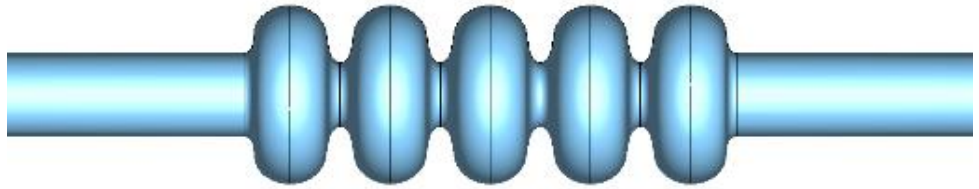
Mid half-cell contour



End half-cell contour



C3795



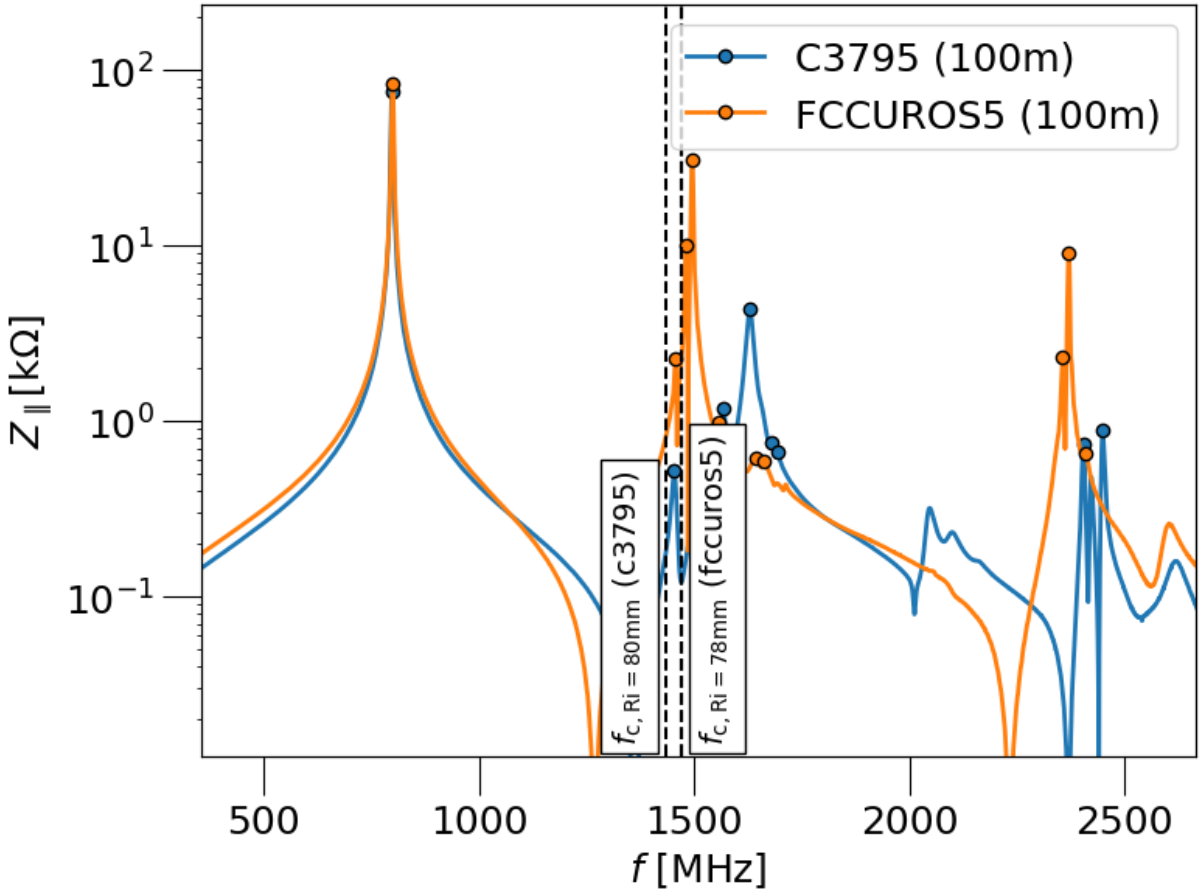
FCCUROS5

Design Comparison

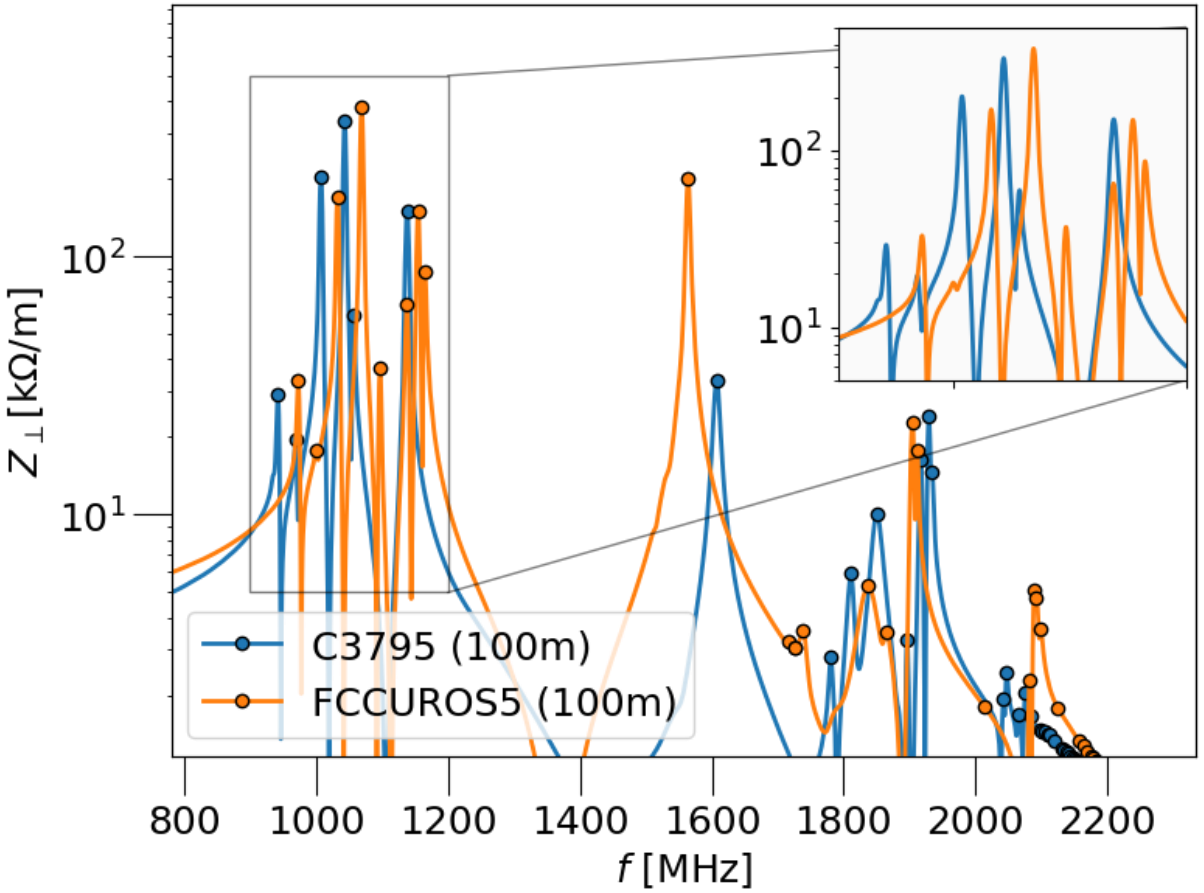
Fundamental Mode Figures of Merit Comparison

Variable	FCCUROS5 (2019)	C3795 (2023)
R/Q [Ω]	521.06	448.1244
G [Ω]	272.93	261.63
$G.R/Q$ [Ω^2]	1.422e5	1.172e5
k_{cc} [%]	2.04	2.64
E_{pk}/E_{acc} [-]	2.05	2.43
B_{pk}/E_{acc} [mT/MV/m]	4.33	4.88

Impedance Plot Comparison



Longitudinal impedance plot



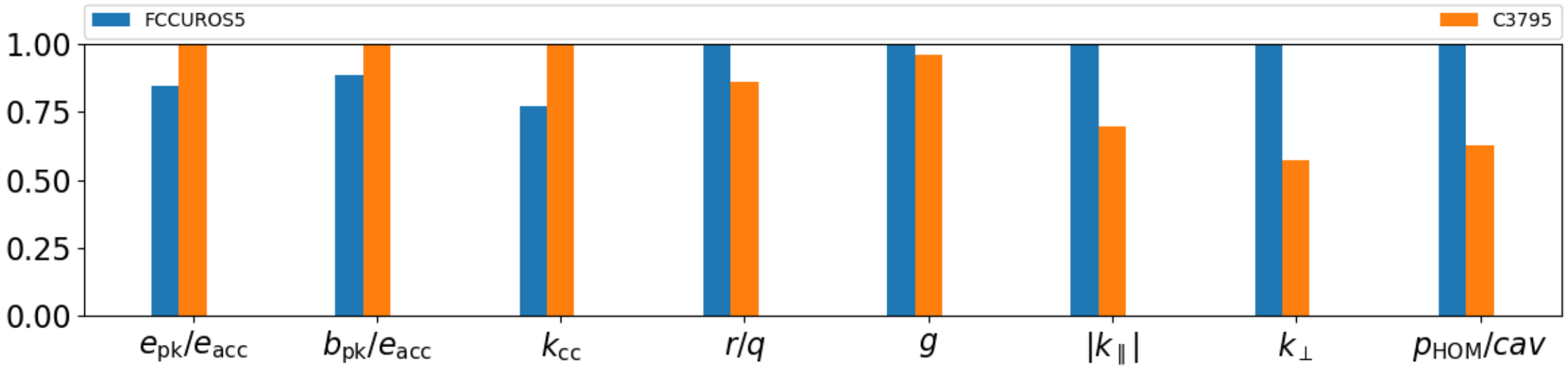
Transverse impedance plot

HOM Figures of Merit Comparison

Variable	FCCUROS5 (2019)	C3795 (2023)
$k_{\parallel}$[V/pC] (SR, σ_z=1.67 mm)	3.784	2.632
$k_{\perp}$[V/pC/m] (SR, σ_z=1.67 mm)	3.539	2.017
P_{HOM} [W] (SR, σ_z=1.67 mm	1115	698

Beam Current [mA] = 10mA, Bunch Intensity N_b [10^{11}] = 2.26

FM and HOM Figs. of Merit Comparison Summary



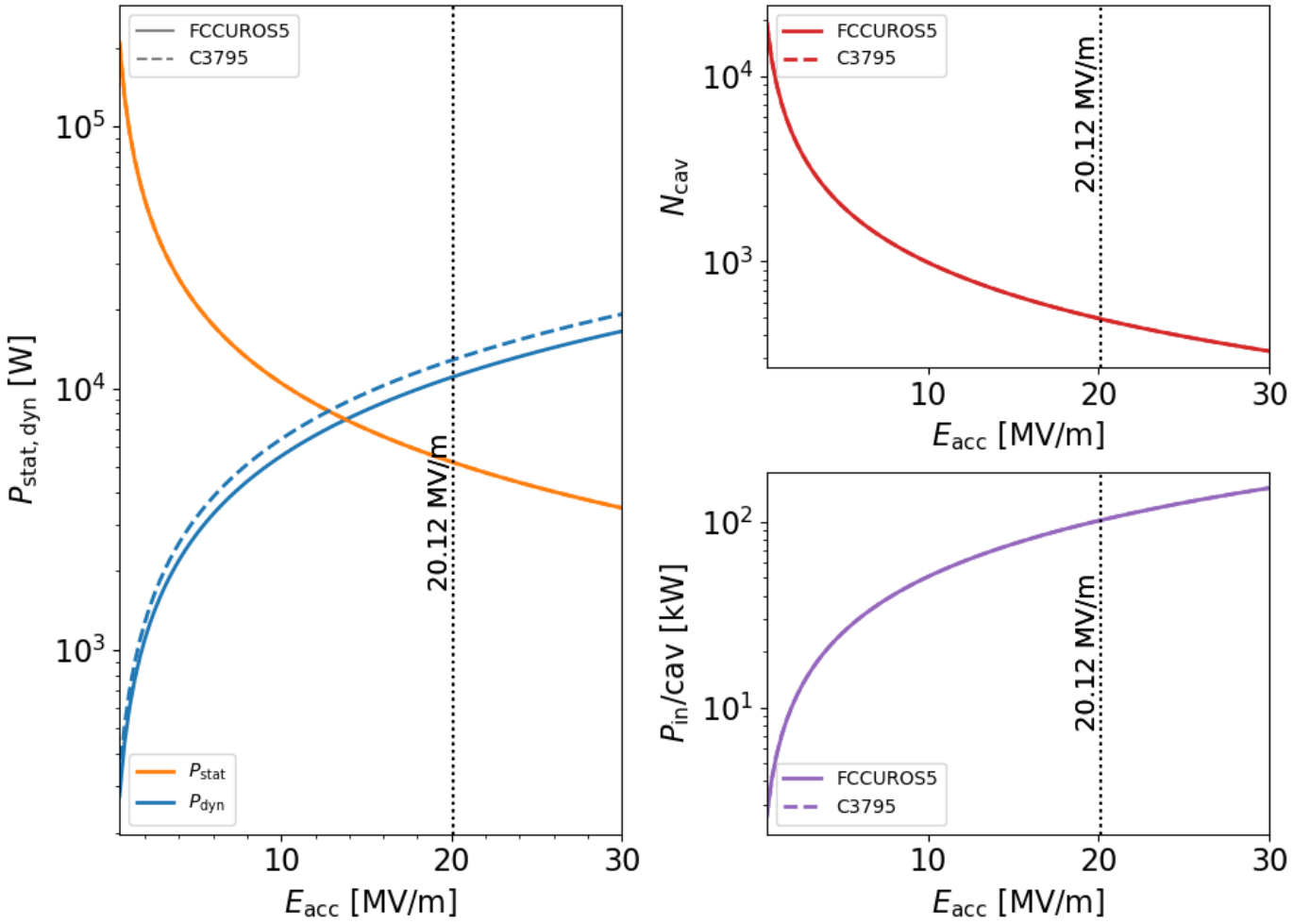
19% ↑ 13% ↑ 29% ↑ 14% ↓ 4% ↓ 30% ↓ 43% ↓ 34% ↓

FM Figures of Merit

HOM Figures of Merit

Bar plot summary of FM and HOM figures of merit.

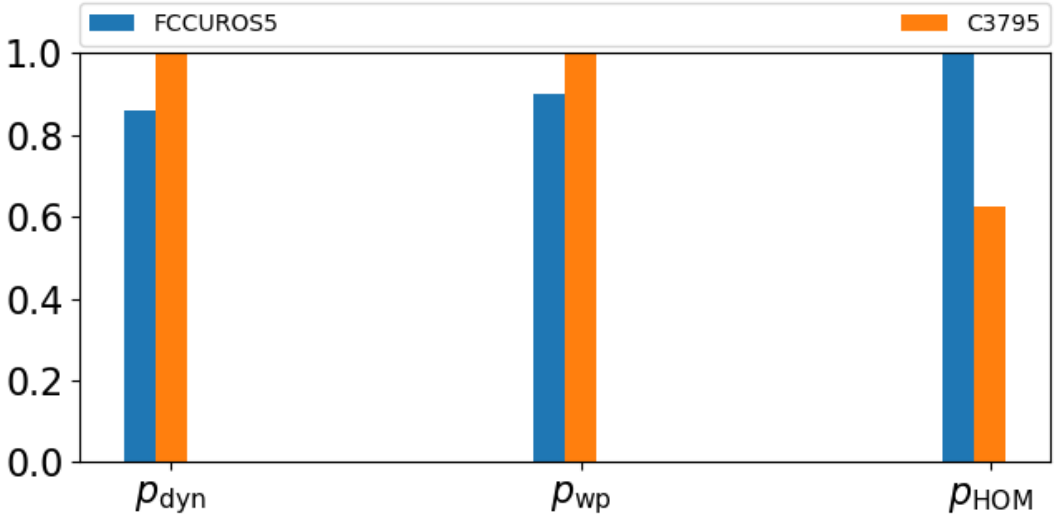
Power Comparison



Plot of static and dynamic power loss, no of cav and input power (P_{in}) vs E_{acc}

Assumed $Q_0 = 3.0E10$

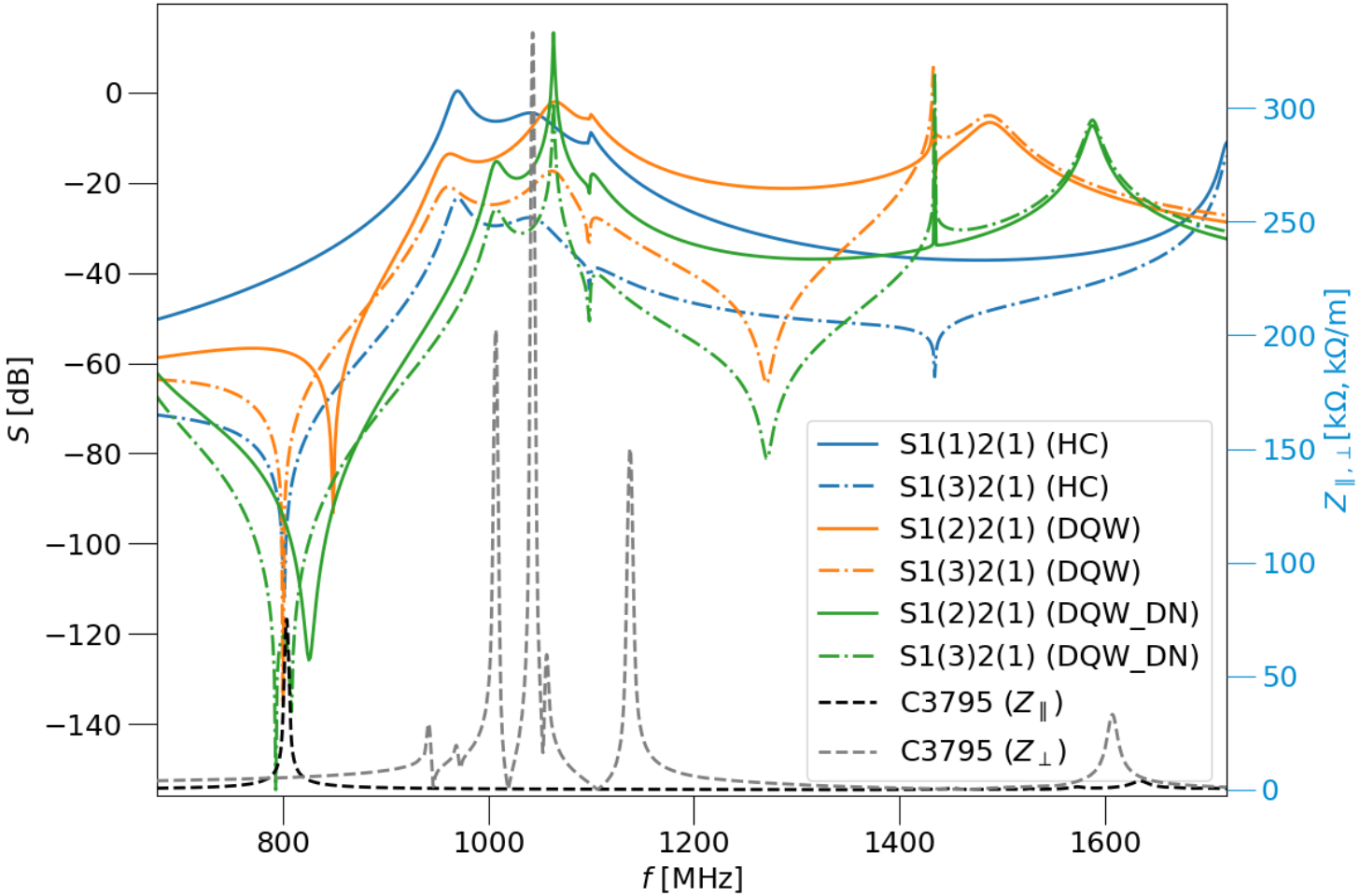
Variable	C3795	FCUROS5
n_{cav}	488	488
P_{stat} (kW)	5.19	5.19
P_{dyn} (kW)	12.89	11.10
P_{wp} (MW)	12.1	13.47
$P_{HOM,tot}$ (kW)	340.44	543.94



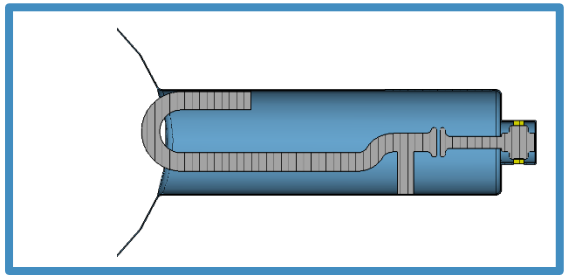
Bar plot summary dynamic, wall and HOM power comparison.

C3795 + HOM Couplers Study

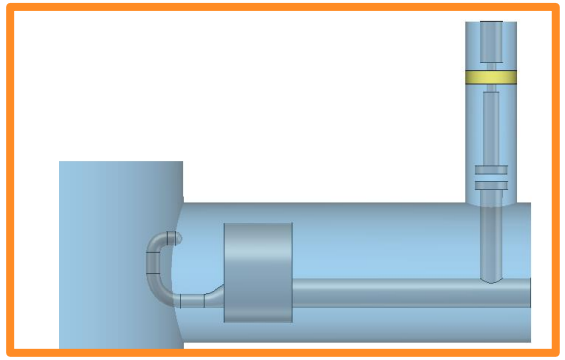
HOM Coupler Designs and Optimisation



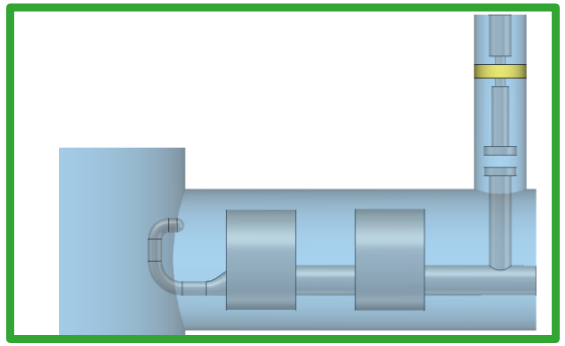
Transmission properties of LHC-type hook coupler (HC), double quarter wave (DQW), and DQW double notch (DQW_DN) coupler.



Hook – type Coupler

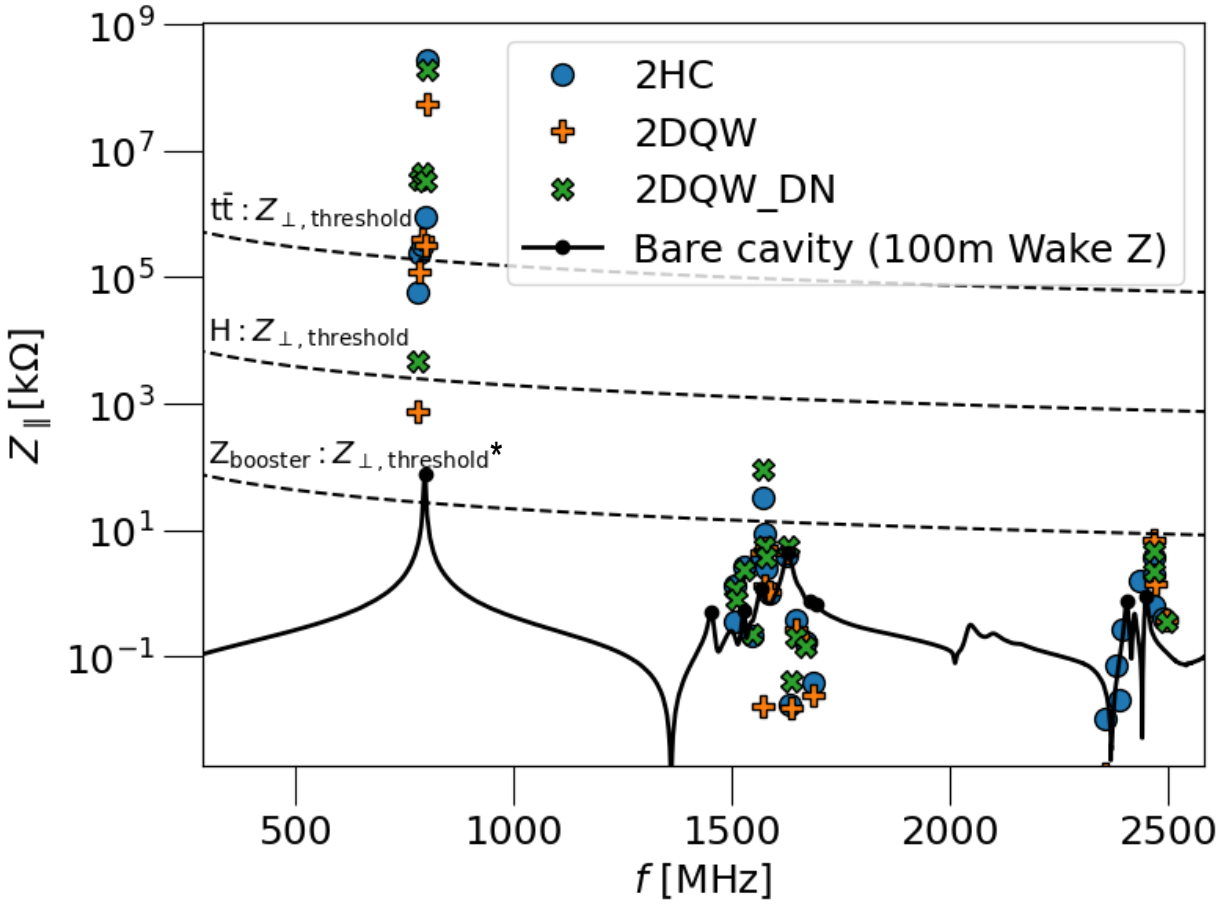


DQW Coupler

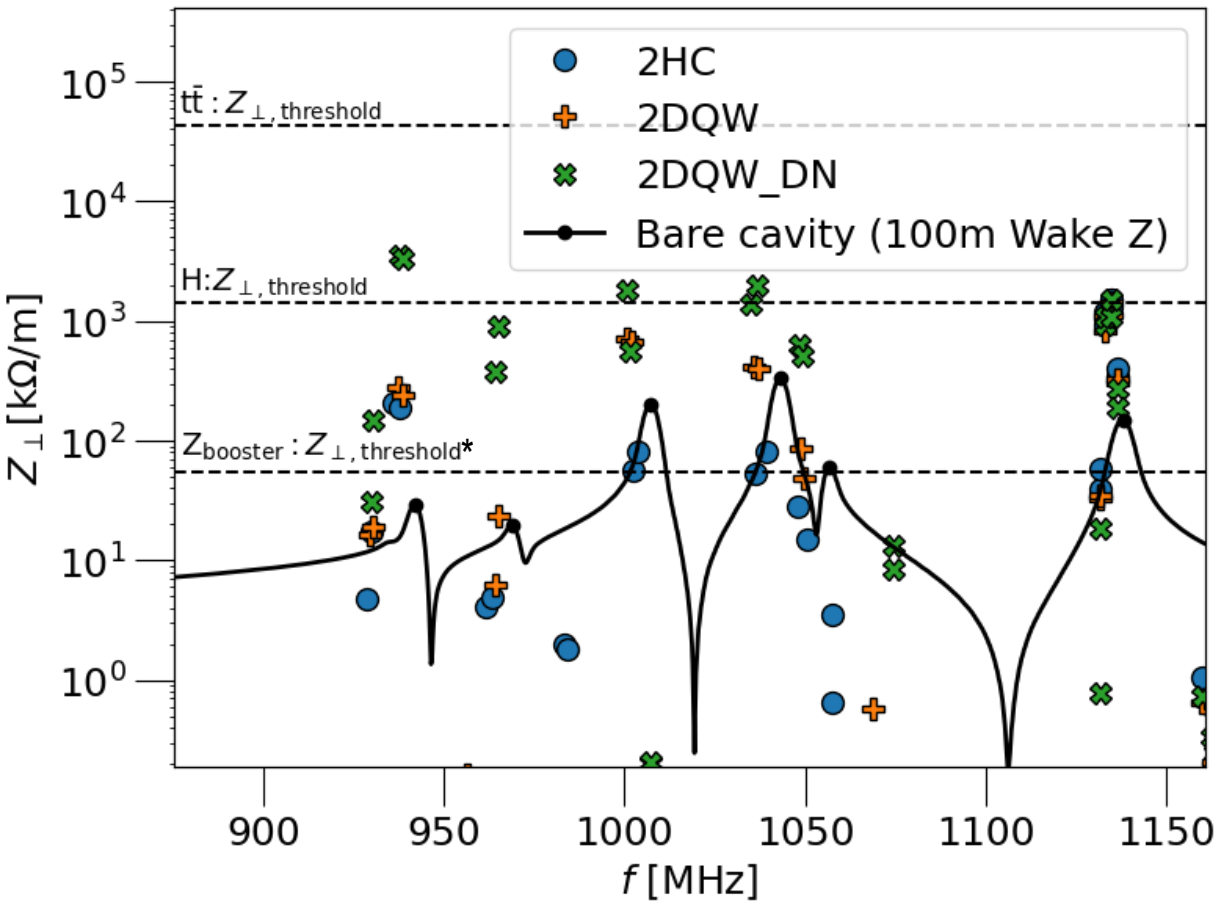


DQW Coupler (Double notch)

Lossy Eigenmode Impedance Plot for Cavity + HOM Couplers



Cavity + HOM coupler assembly longitudinal impedance plot



Cavity + HOM coupler assembly transverse impedance plot showing first dipole passband modes

*Assumed current for Z-booster operating point is 128mA

Summary and Outlook

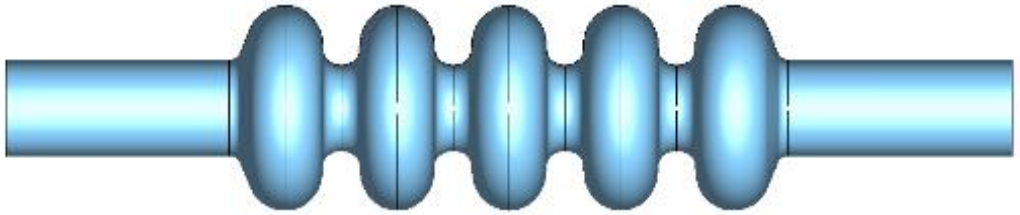
- A 5-cell elliptical cavity geometry (C3795) was optimised for operation at the $t\bar{t}$ operating point
- C3795 untraps the first longitudinal HOM and is better in the longitudinal plane at the cost of FM degradation
- FCCUROS5 cavity remains a good option for the $t\bar{t}$ operating point
- The HOM power is 34% less for the C3795. The cost of this reduction is an increase of 19% and 13% in peak electric and magnetic fields, respectively
- The C3795 cavity geometry is better suited for the booster cavities of the Z-working point than the FCCUROS5 cavity geometry
- Study on HOM coupler is ongoing

Appendix

Designed Cavity

Geometric Variables							
A, A_e [mm]	B, B_e [mm]	a, a_e [mm]	b, b_e [mm]	R_i, R_{ie} [mm]	L, L_e [mm]	R_{eq} [mm]	α [◦]
62.22/62.58	66.13/57.54	30.22/17.21	23.11/12.00	72/80	93.5/93.795	171.20	94.50, 112.09

Fundamental Mode Figures of Merit					Higher-Order Mode Figures of Merit		
R/Q [Ω]	G [Ω]	$G.R/Q$ [Ω^2]	E_{pk}/E_{acc} [-]	B_{pk}/E_{acc} [mT/MV/m]	$k_{\parallel}$[V/pC] (SR, σ_z=1.67 mm)	$k_{\perp}$[V/pC/m] (SR, σ_z=1.67 mm)	P_{HOM} [W] (SR, σ_z=1.67 mm)
448.1244	261.63	1.172e5	2.43	4.88	2.639	2.014	375.48



Designed cavity - C3795