The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404

Meeting 3: Harmonic RF System Review
CERN, 3 November 2014

Alternative Options for 800 MHz Harmonic Cavity

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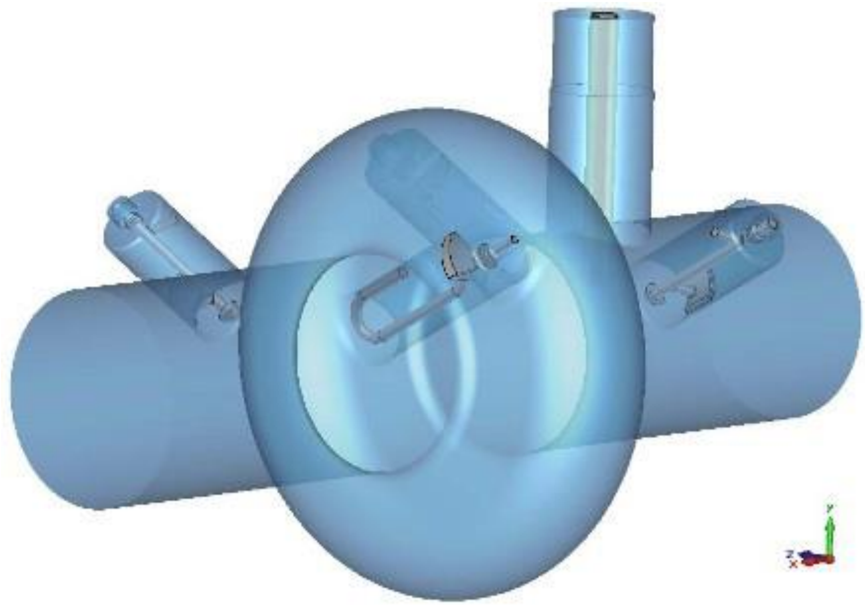
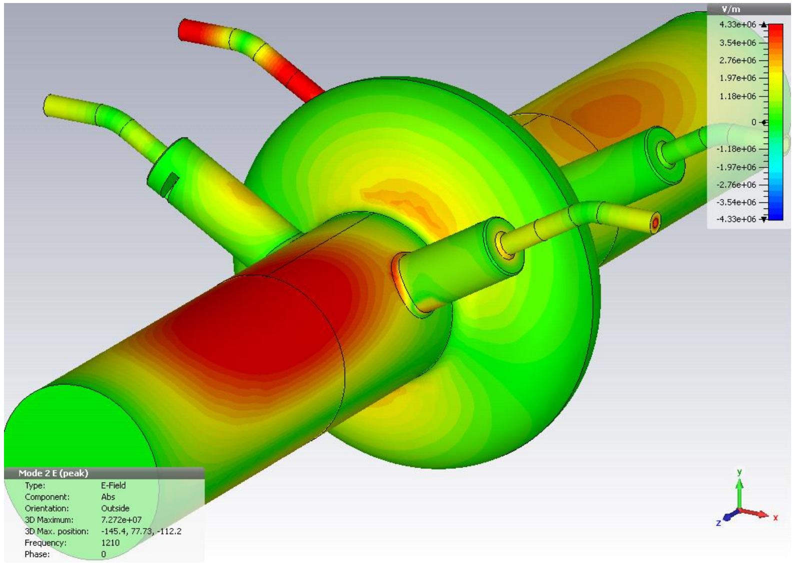
OUTLINE

- Baseline Design: questions, doubts
- Single Cavity
- 2 Separated Cavities in a Single Cryostat
- 4 and more Separated Cavities

Baseline Design

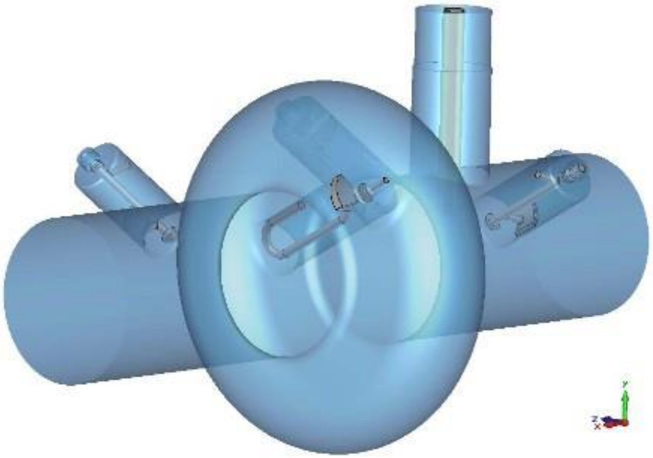


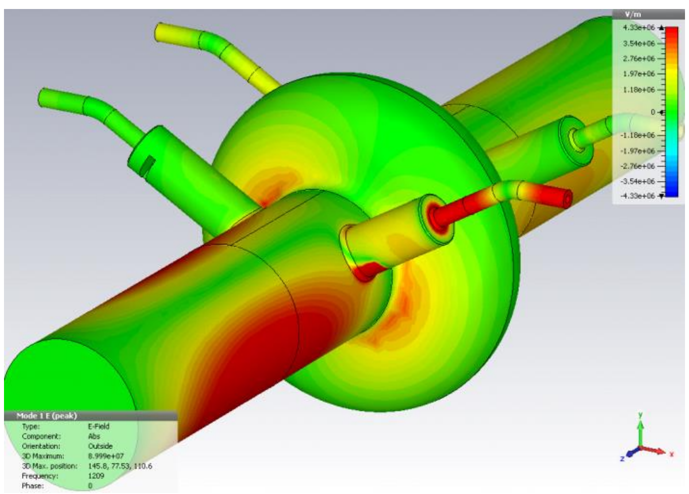


Some References

1. L.Ficcadenti, J.Tückmantel, R.Calaga, “*LHC Landau Cavity Design*”, BR Section Meeting, 29 March 2012.
2. L.Ficcadenti, J.Tückmantel, R.Calaga, “*LHC Landau Cavity Design*”, HiLumi LHC-LARP Annual Meeting – Frascati, November 2012
3. T.Roggen, “*The 800 MHz Higher Harmonic System for HL-LHC*”
4. S.Papadopoulos, “*Higher Order Mode Couplers Optimization for the 800 MHz Harmonic System for HL-LHC*”.

Problems, Questions?





L.Ficcadenti el al.

- Is there enough space to place HOM dampers and a robust main coupler (300 kW) on the beam pipe?

- Eventual HOM trapped between HOM couplers, main couplers and HOM couplers

- Multipacting in HOM couplers (with RF power, high current beam)

- Couplers break the cylindrical symmetry

just an example...

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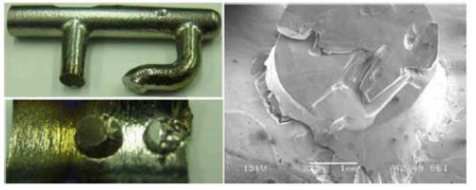
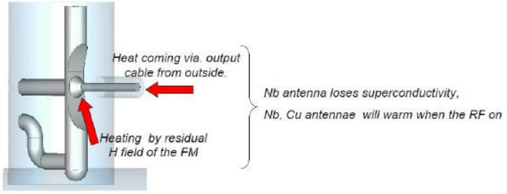
"Bumps in the road"

- Fermilab: multipacting damage to HOM couplers on 3.9 GHz cavities (MP → overheating → fracture) → redesigned to shift MP levels above operating gradients



- CW operation (12 GeV CEBAF upgrade): heating of the output antenna by the residual magnetic field of the fundamental mode → redesigned to improve heat removal and reduce residual field pick up



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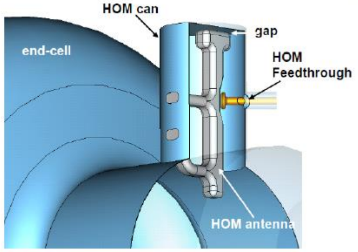
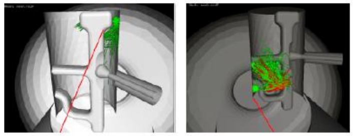
SNS experience

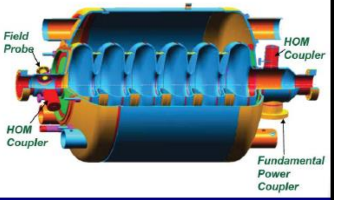
- Two cryomodules are removed form the linac
- One showed large coupling of the fundamental RF power to HOM port. Removed feedthroughs, blank-off, and detuned HOM notch frequency. This cryomodule has been back in service with good performance.
- Second cryomodule: found 3 places having leaks at HOM feedthroughs. Removed feedthroughs, blank-off, and detuned. Will be back in service soon.

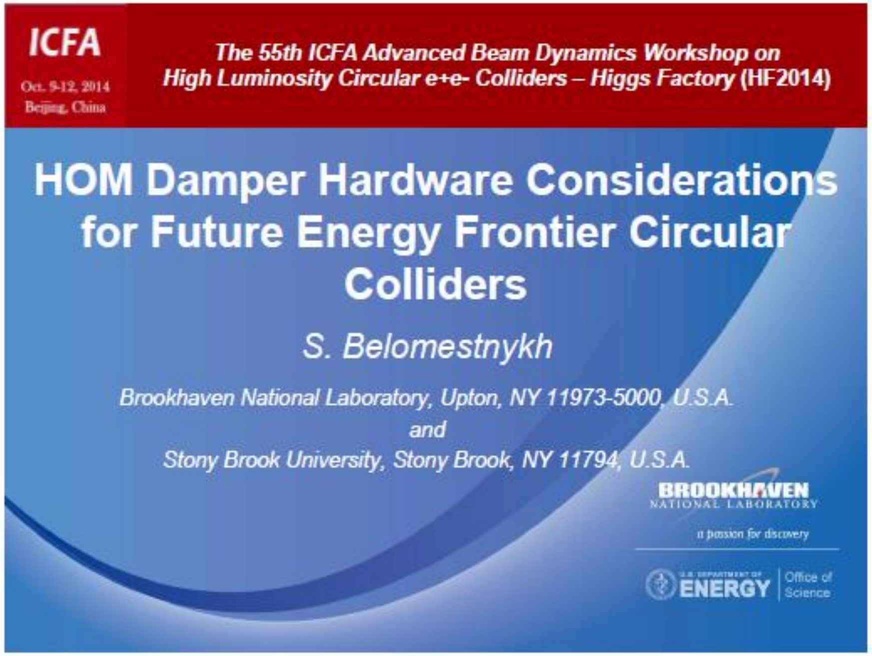
- HOM couplers added as extra safety against longitudinal instabilities
- Some HOM feed-throughs have been damaged or show abnormal transmission curves
- Exact cause of anomalies not completely known, but conservatively turned off of run at limited gradients



Multipacting in HOM2





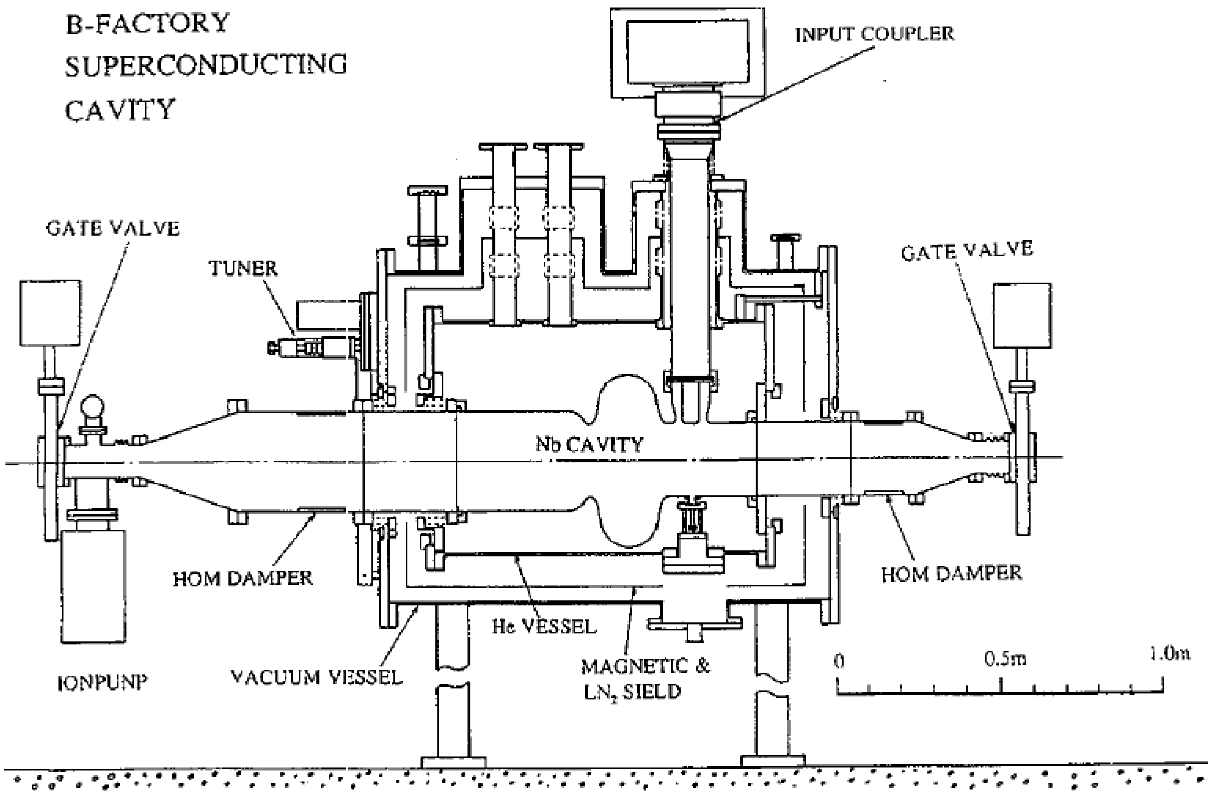


Summary

- There are many proven designs of HOM dampers.
- However, only beam pipe absorbers demonstrated so far power levels of interest to future circular colliders.
- LHC type couplers were designed for ~1 kW HOM power levels, but operates at lower HOM power levels.
- There are also several new designs under development, which might be suited for future circular colliders.

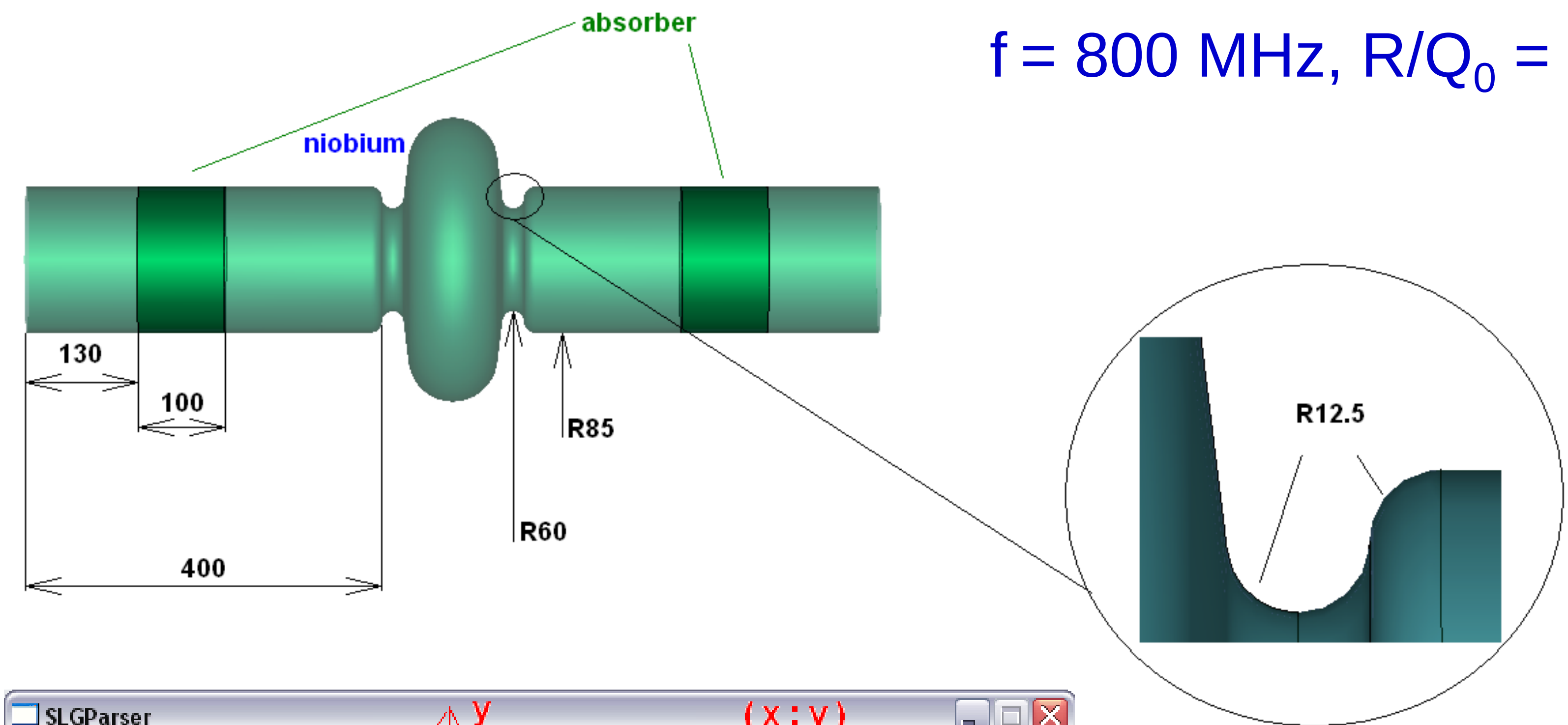
Since high R/Q is not required it is worthwhile to exploit the “single mode” cavity design:

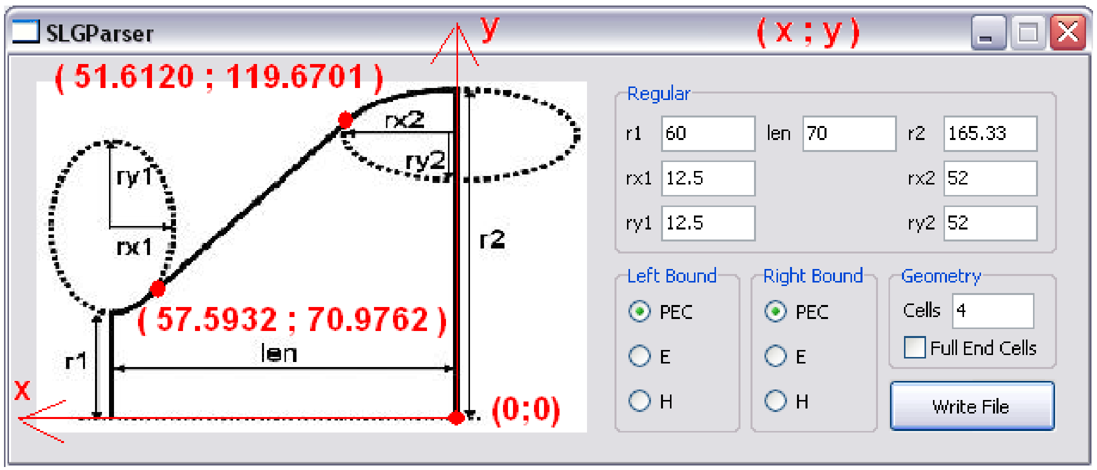
1. Relatively Simple
2. No HOMs

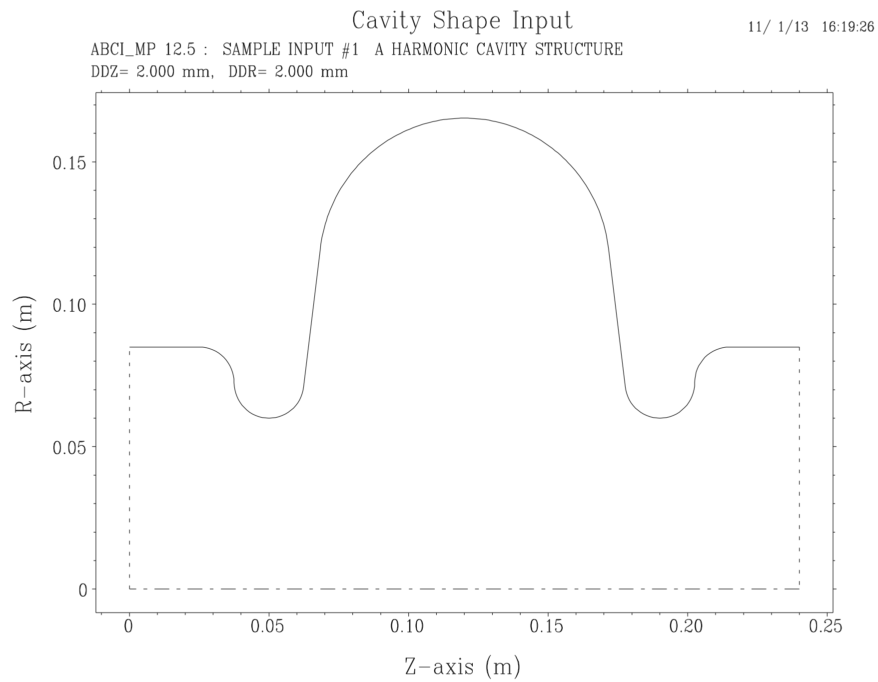


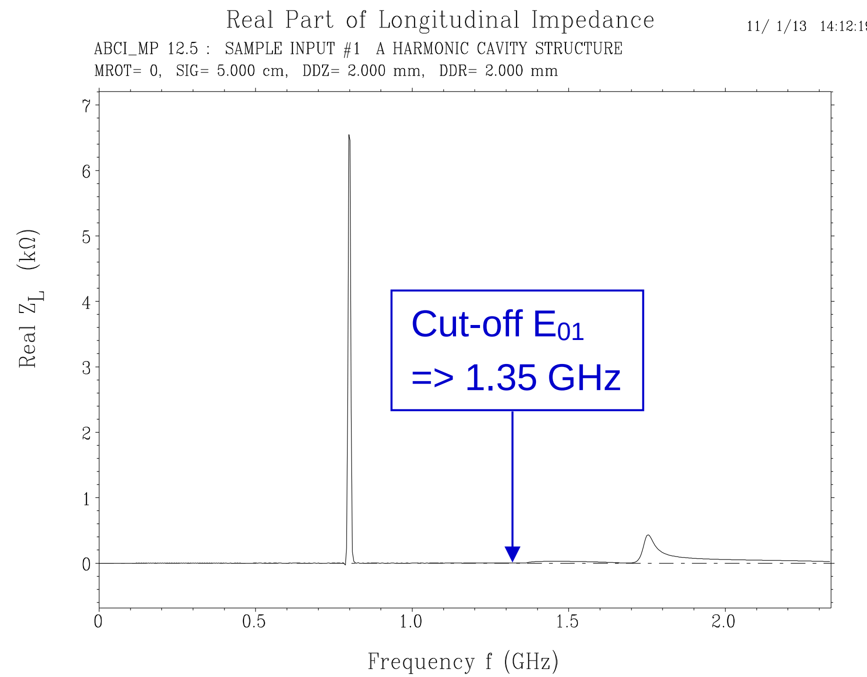
From KEKB Design Report

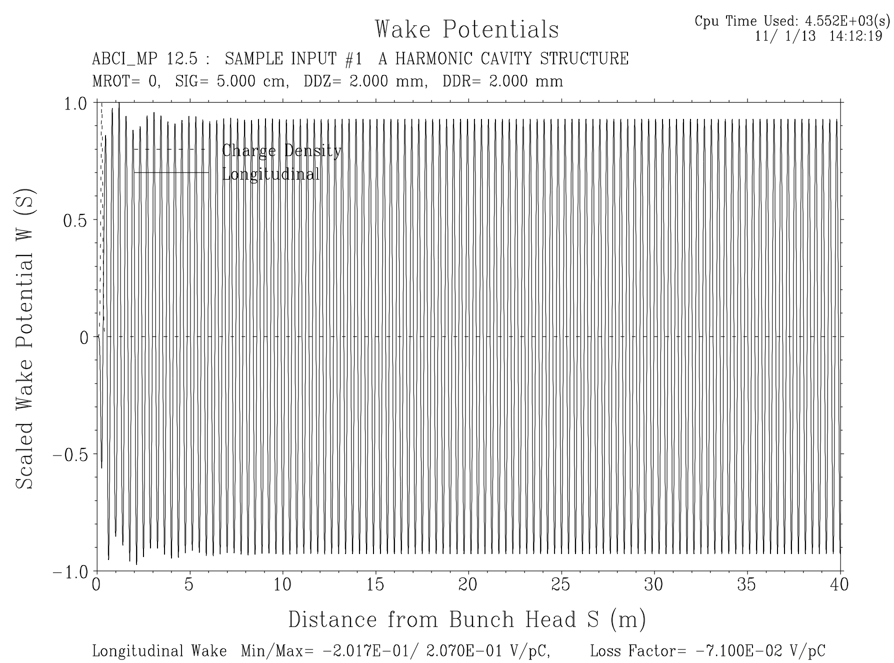
f = 800 MHz, R/Q_0 = 53.33

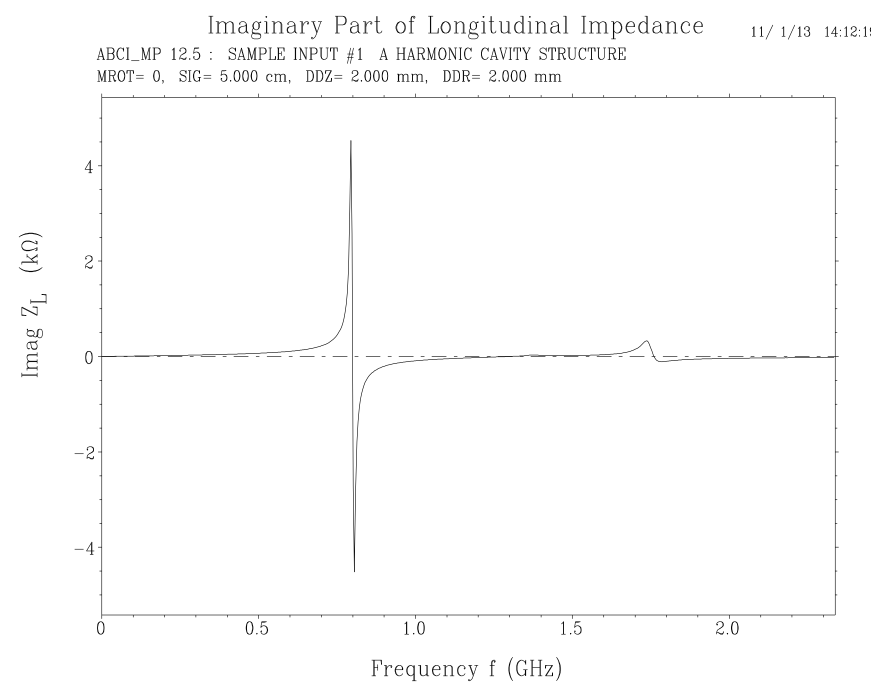


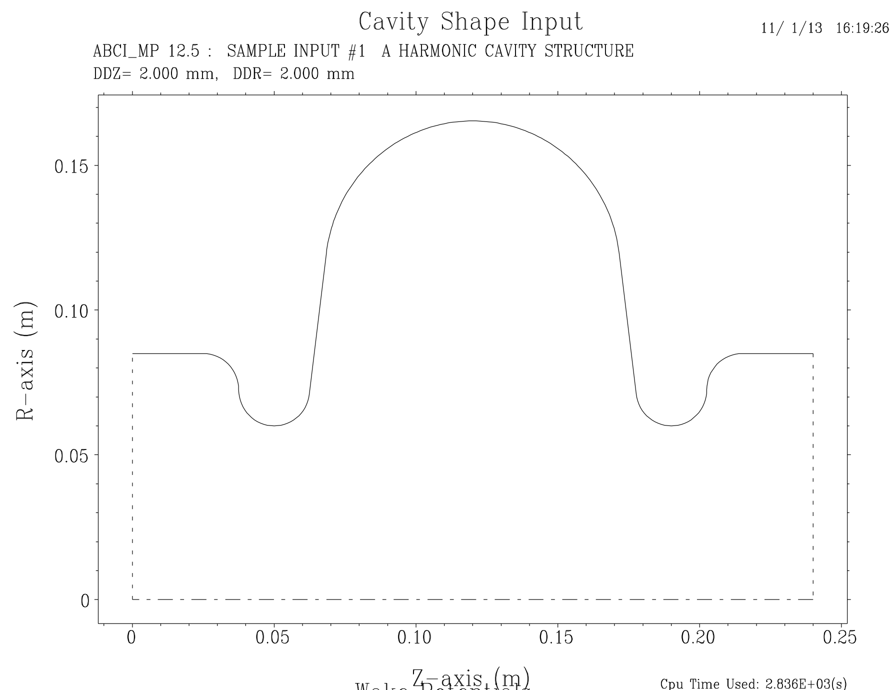


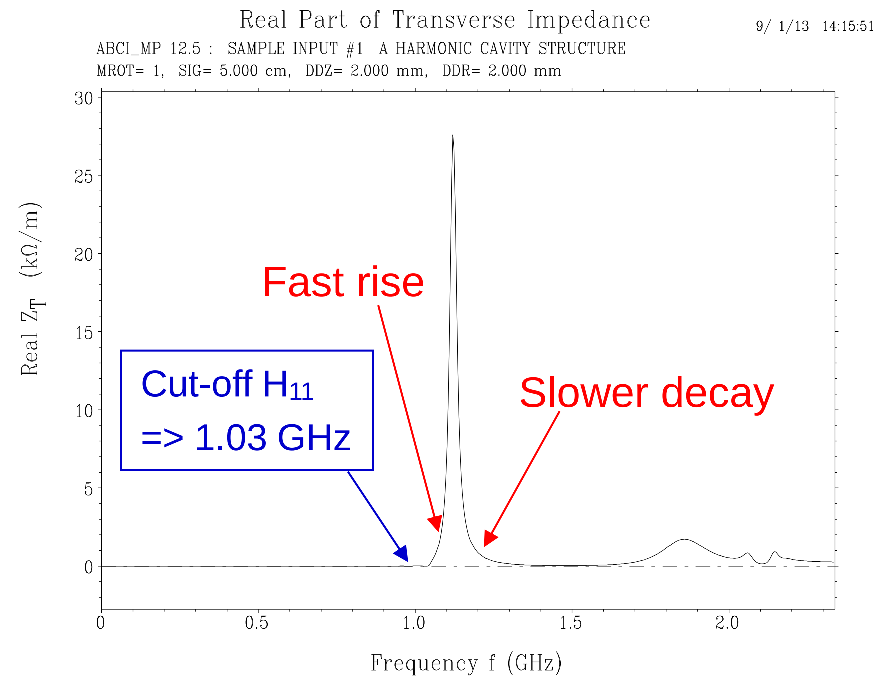

Cavity Shape Input
11/ 1/13 16:19:26
ABCI_MP 12.5 : SAMPLE INPUT #1 A HARMONIC CAVITY STRUCTURE
DDZ= 2.000 mm, DDR= 2.000 mm
R-axis (m)
0
0.05
0.10
0.15
0
0.05
0.10
0.15
0.20
0.25
Z-axis (m)

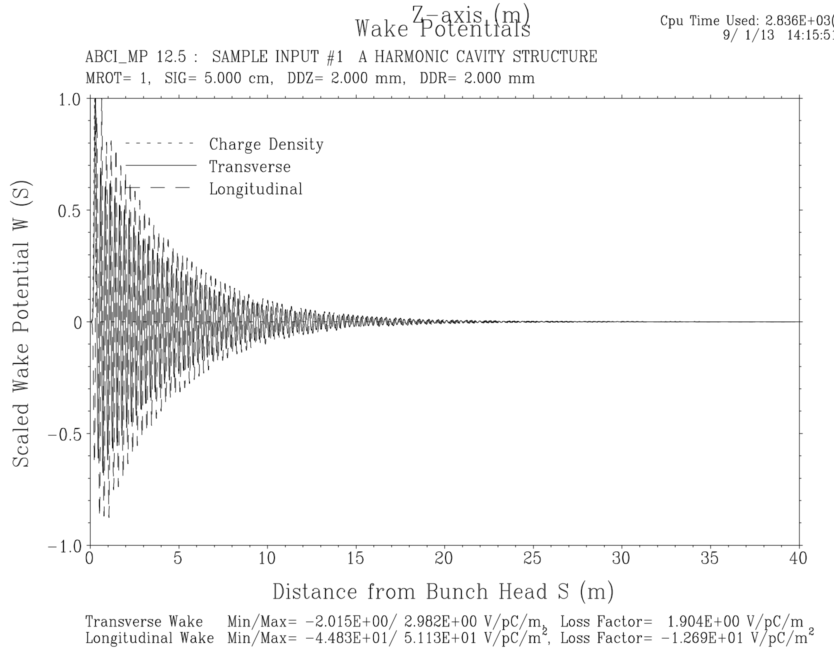

Real Part of Longitudinal Impedance
11/ 1/13 14:12:19
ABCI_MP 12.5 : SAMPLE INPUT #1 A HARMONIC CAVITY STRUCTURE
MROT= 0, SIG= 5.000 cm, DDZ= 2.000 mm, DDR= 2.000 mm
Real Z_L (kΩ)
Cut-off E_{01}
=> 1.35 GHz
0
1
2
3
4
5
6
7
0
0.5
1.0
1.5
2.0
Frequency f (GHz)

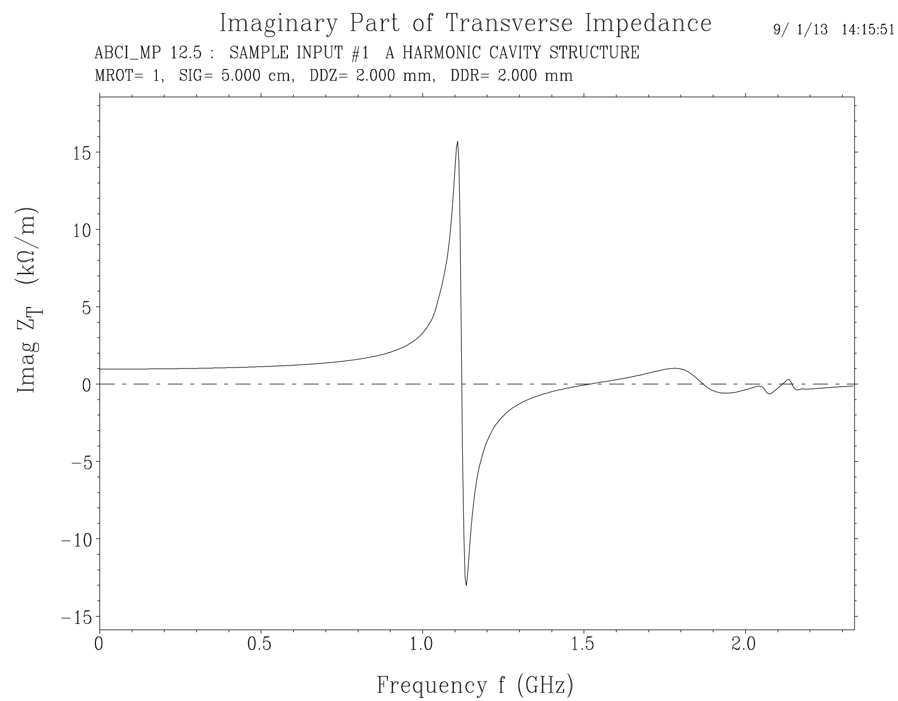

Wake Potentials
Cpu Time Used: 4.552E+03(s)
11/ 1/13 14:12:19
ABCI_MP 12.5 : SAMPLE INPUT #1 A HARMONIC CAVITY STRUCTURE
MROT= 0, SIG= 5.000 cm, DDZ= 2.000 mm, DDR= 2.000 mm
Charge Density
Longitudinal
Scaled Wake Potential W (S)
1.0
0.5
0
−0.5
−1.0
0
5
10
15
20
25
30
35
40
Distance from Bunch Head S (m)
Longitudinal Wake Min/Max= −2.017E−01/ 2.070E−01 V/pC, Loss Factor= −7.100E−02 V/pC


Imaginary Part of Longitudinal Impedance
11/ 1/13 14:12:19
ABCI_MP 12.5 : SAMPLE INPUT #1 A HARMONIC CAVITY STRUCTURE
MROT= 0, SIG= 5.000 cm, DDZ= 2.000 mm, DDR= 2.000 mm
Imag Z_L (kΩ)
4
2
0
−2
−4
0
0.5
1.0
1.5
2.0
Frequency f (GHz)


Cavity Shape Input
11/ 1/13 16:19:26
ABCI_MP 12.5 : SAMPLE INPUT #1 A HARMONIC CAVITY STRUCTURE
DDZ= 2.000 mm, DDR= 2.000 mm
R−axis (m)
0.15
0.10
0.05
0
0
0.05
0.10
0.15
0.20
0.25
Z−axis (m)


Real Part of Transverse Impedance
9/ 1/13 14:15:51
ABCI_MP 12.5 : SAMPLE INPUT #1 A HARMONIC CAVITY STRUCTURE
MROT= 1, SIG= 5.000 cm, DDZ= 2.000 mm, DDR= 2.000 mm
Real Z_T (kΩ/m)
30
25
20
15
10
5
0
Fast rise
Cut-off H_{11}
=> 1.03 GHz
Slower decay
0
0.5
1.0
1.5
2.0
Frequency f (GHz)


Wake Potentials
Cpu Time Used: 2.836E+03(s)
9/ 1/13 14:15:51
ABCI_MP 12.5 : SAMPLE INPUT #1 A HARMONIC CAVITY STRUCTURE
MROT= 1, SIG= 5.000 cm, DDZ= 2.000 mm, DDR= 2.000 mm
Scaled Wake Potential W (S)
1.0
0.5
0
−0.5
−1.0
Charge Density
Transverse
Longitudinal
0
5
10
15
20
25
30
35
40
Distance from Bunch Head S (m)
Transverse Wake Min/Max= −2.015E+00/ 2.982E+00 V/pC/m, Loss Factor= 1.904E+00 V/pC/m
Longitudinal Wake Min/Max= −4.483E+01/ 5.113E+01 V/pC/m², Loss Factor= −1.269E+01 V/pC/m²


Imaginary Part of Transverse Impedance
9/ 1/13 14:15:51
ABCI_MP 12.5 : SAMPLE INPUT #1 A HARMONIC CAVITY STRUCTURE
MROT= 1, SIG= 5.000 cm, DDZ= 2.000 mm, DDR= 2.000 mm
Imag Z_T (kΩ/m)
15
10
5
0
−5
−10
−15
0
0.5
1.0
1.5
2.0
Frequency f (GHz)

Comparison of the Predicted and Measured Loss Factor of the Superconducting Cavity Assembly for the CESR Upgrade*

S. Belomestnykh†, W. Hartung, J. Kirchgessner, D. Moffat, H. Muller, H. Padamsee, and V.Veshcherevich†
Laboratory of Nuclear Studies, Cornell University, Ithaca, NY 14853 USA

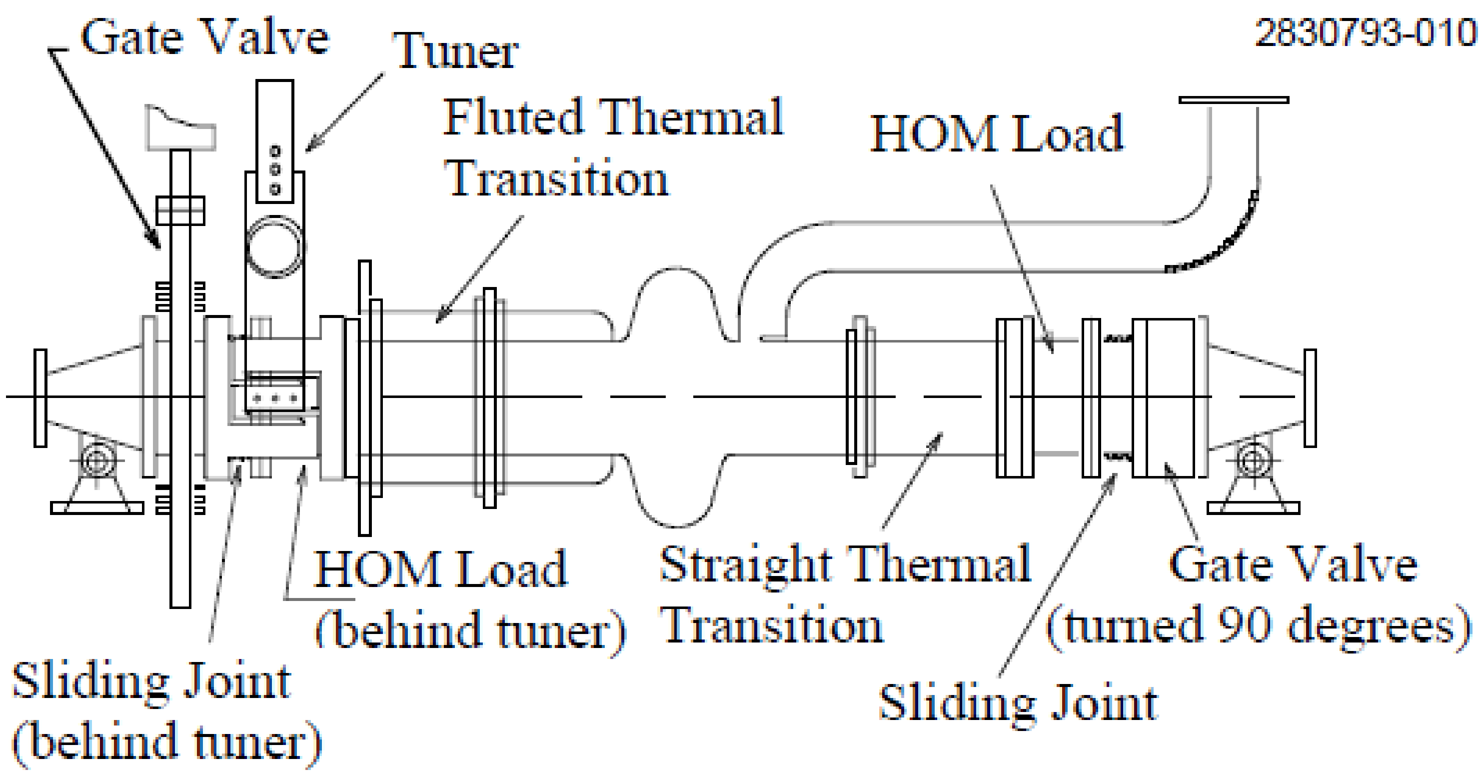
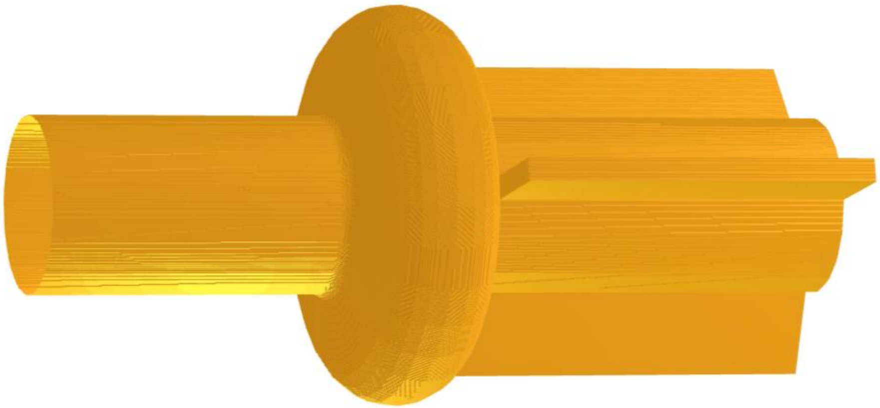
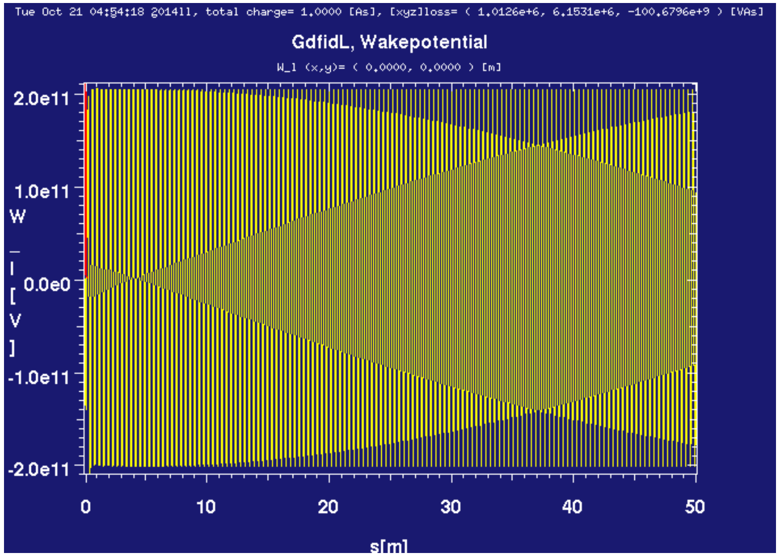
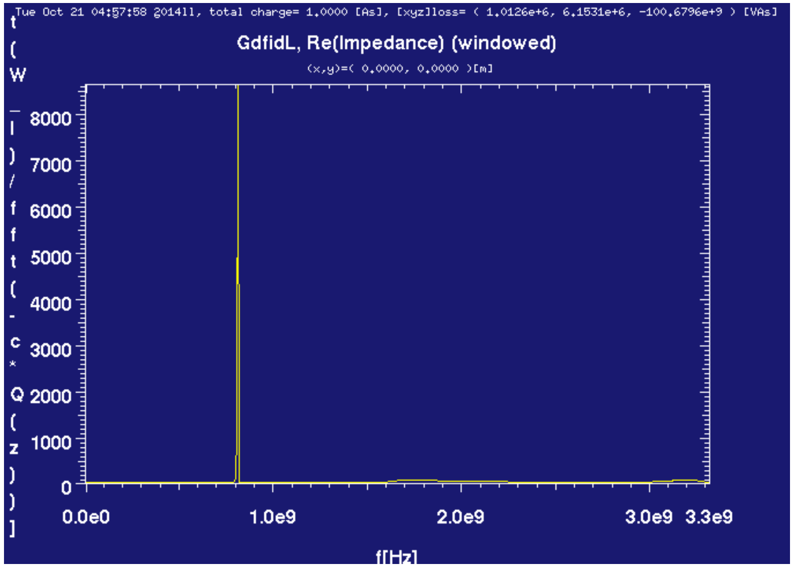


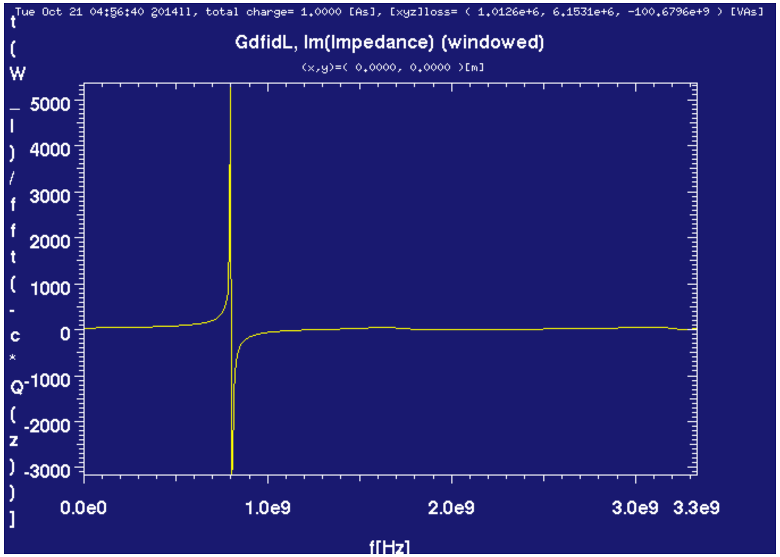
Figure 1. Schematic of the SRF cavity module.

Longitudinal Impedance

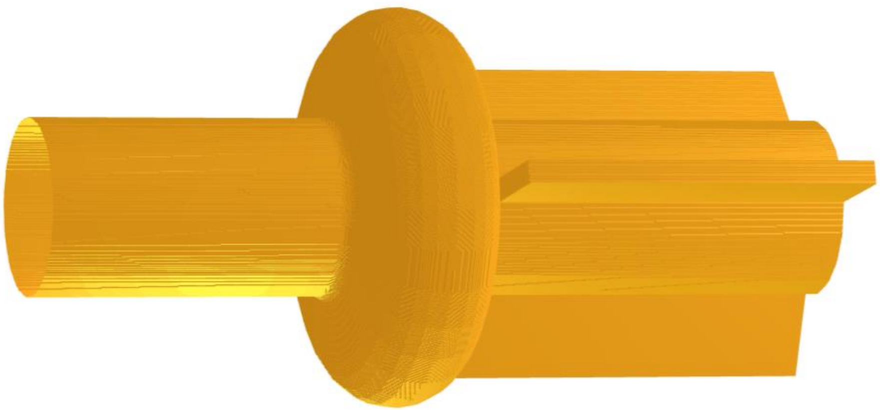


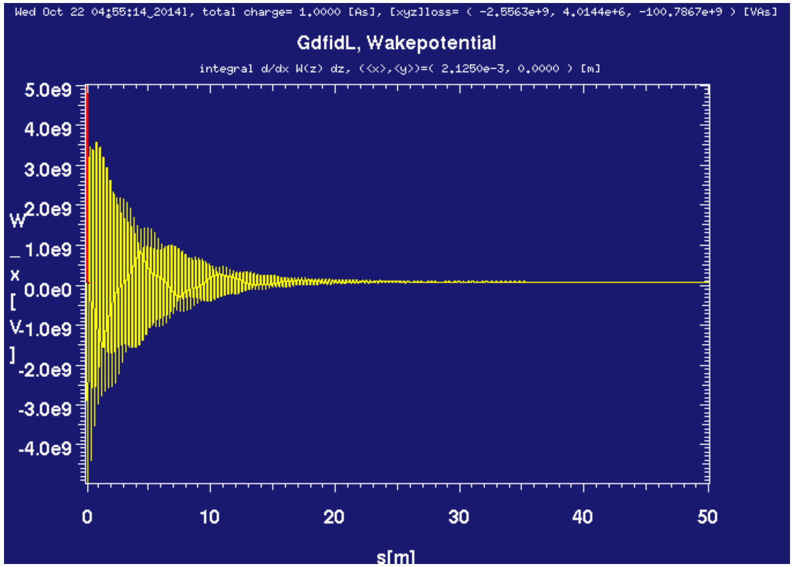




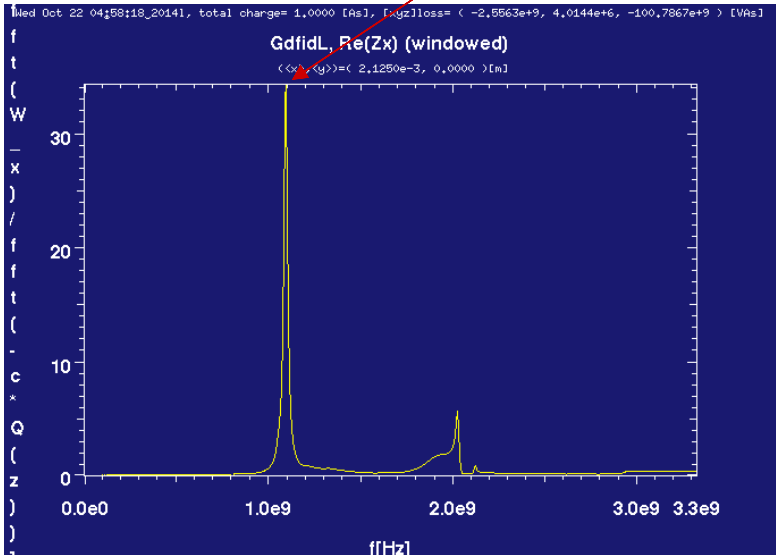


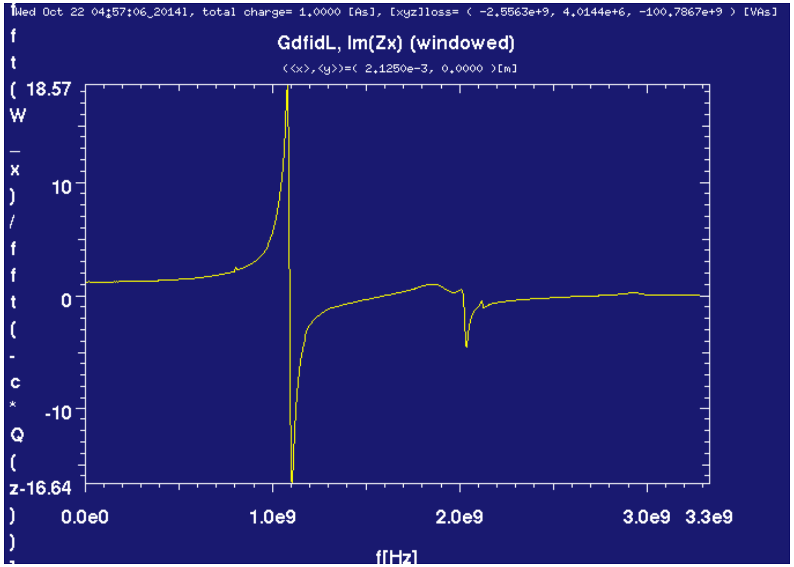
Transverse Impedance



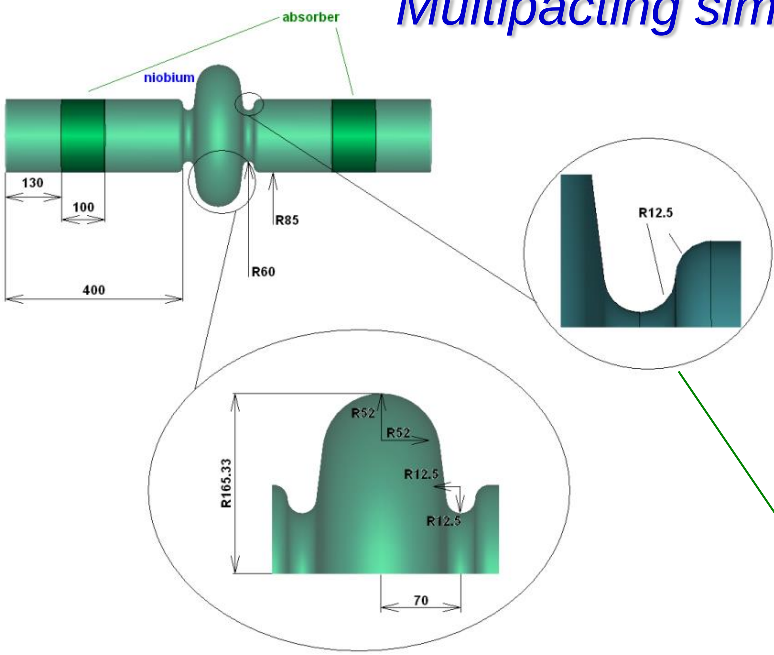


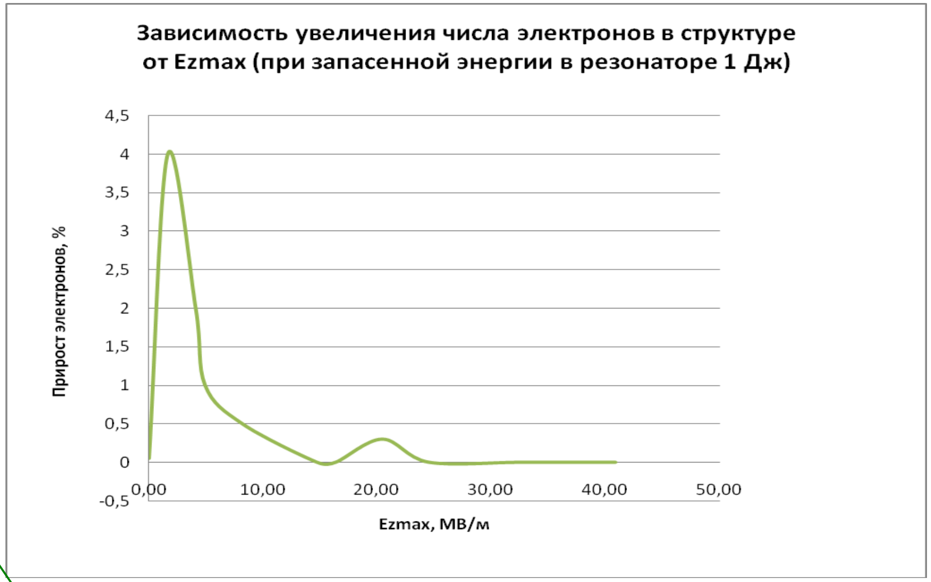
14 kΩ/m

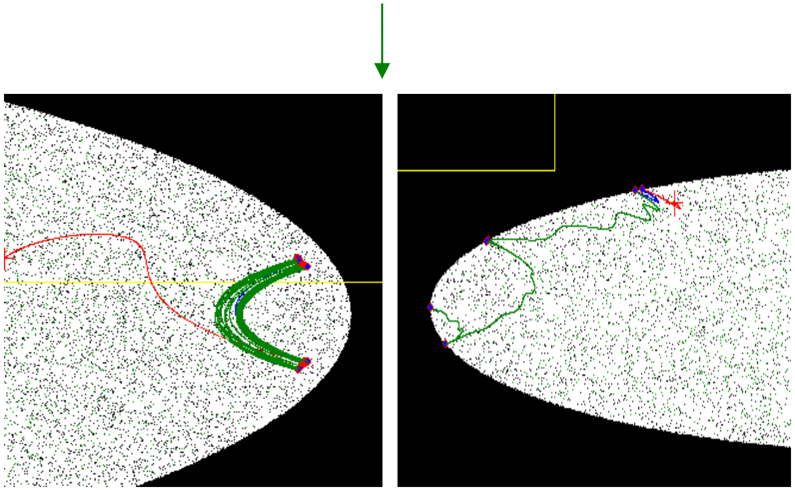




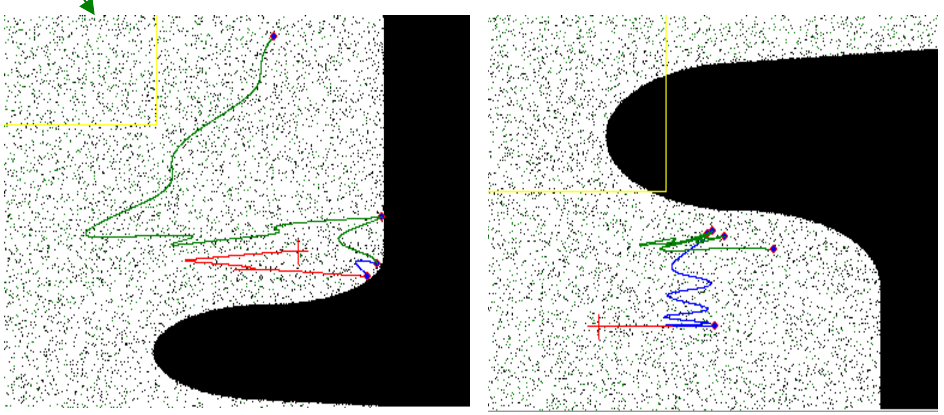
Multipacting simulations for the SC cavities – MultP-M code





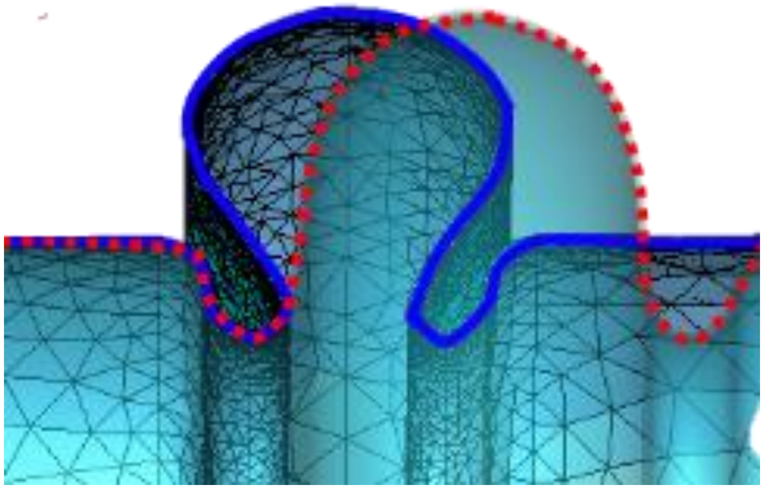


Possible multipacting for E_z in the range from 1.7-7 MV/m



No stable trajectories are found

Lorentz Force Detuning



Structure deformation with one end fixed

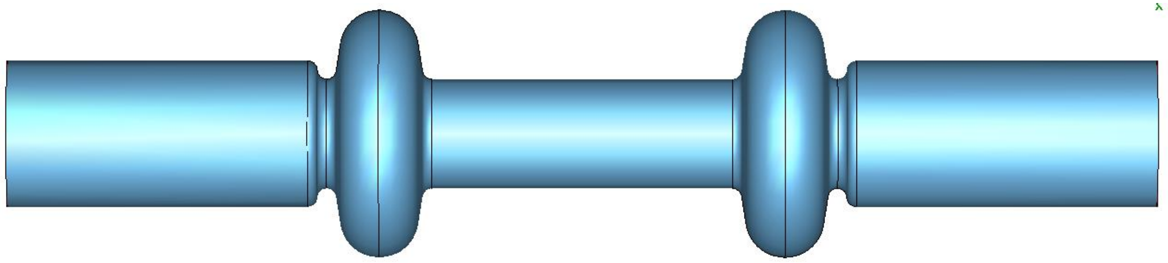
The problem is solved by inserting the ring stiffeners in the grooves

From Rama Calaga's talk "HL-LHC RF Road-Map" given at the LHC Performance Workshop, Chamonix, 24 September 2014:

Proposal: Build 2-cavity 800MHz (Nb-Cu) prototype $\rightarrow$ ~5-6yrs

Benefit (even in BS-mode) outweighs the cost (beam stability)

Our Proposal



Geometry is perfectly azimuthally symmetric

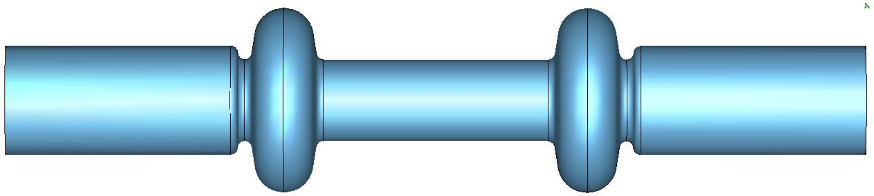
There are no dangerous HOM

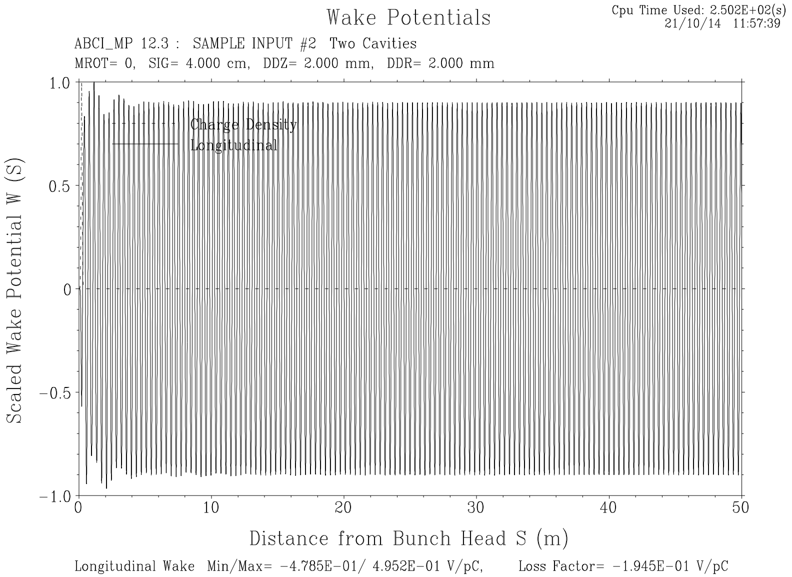
The is no need need to use additional HOM couplers (8 couplers are reqired in the baseline version)

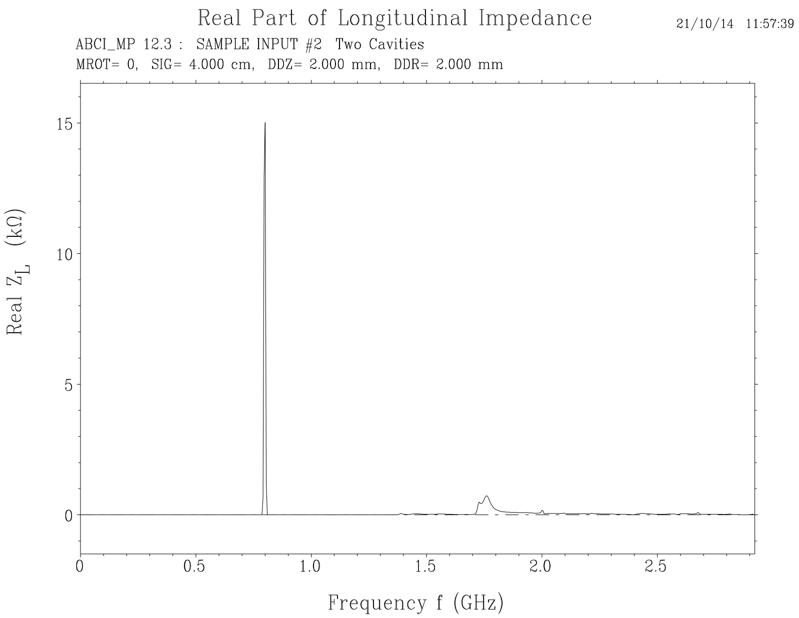
Cavities do not communicate with each other due to the small radius of the connecting pipe.

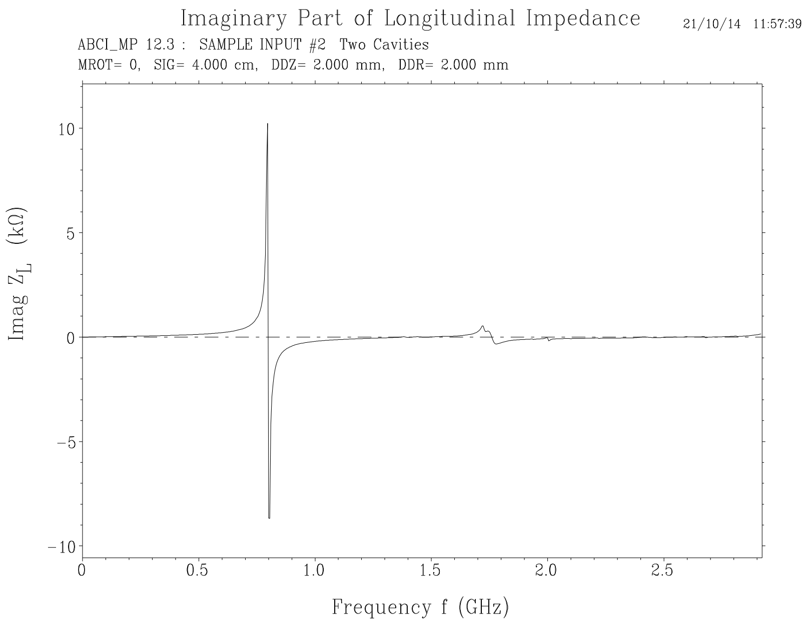
Main coupler can be placed on the beam pipe with a smaller radius

Longitudinal Impedance

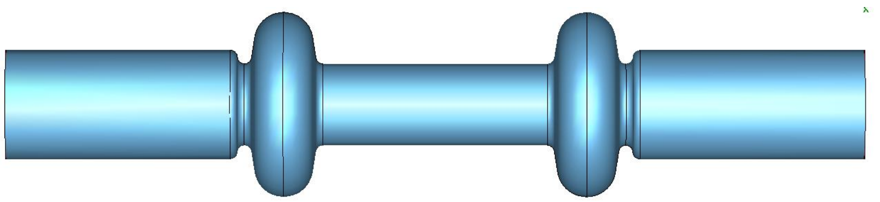


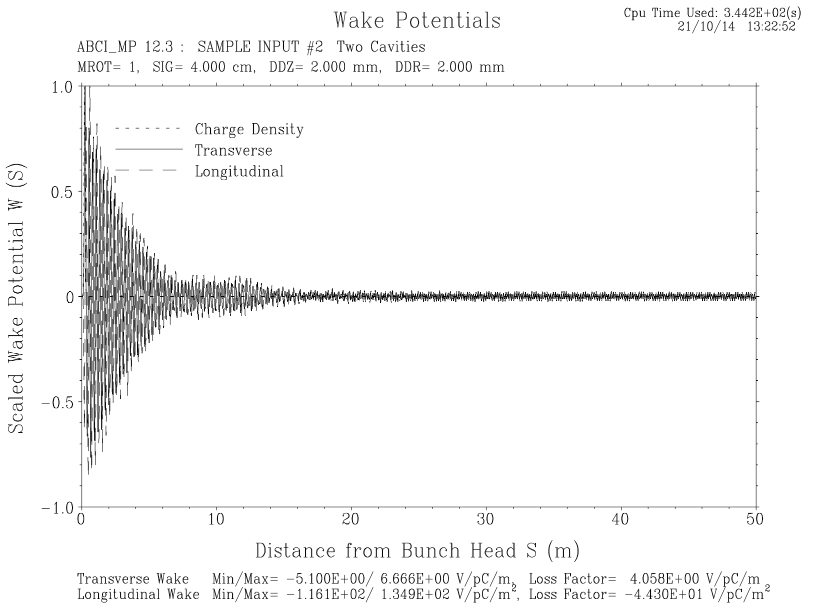


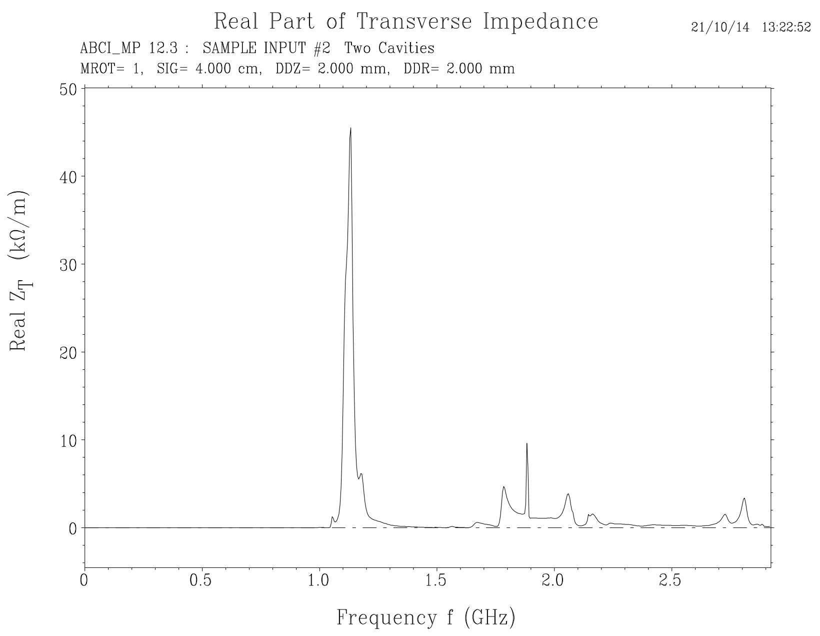


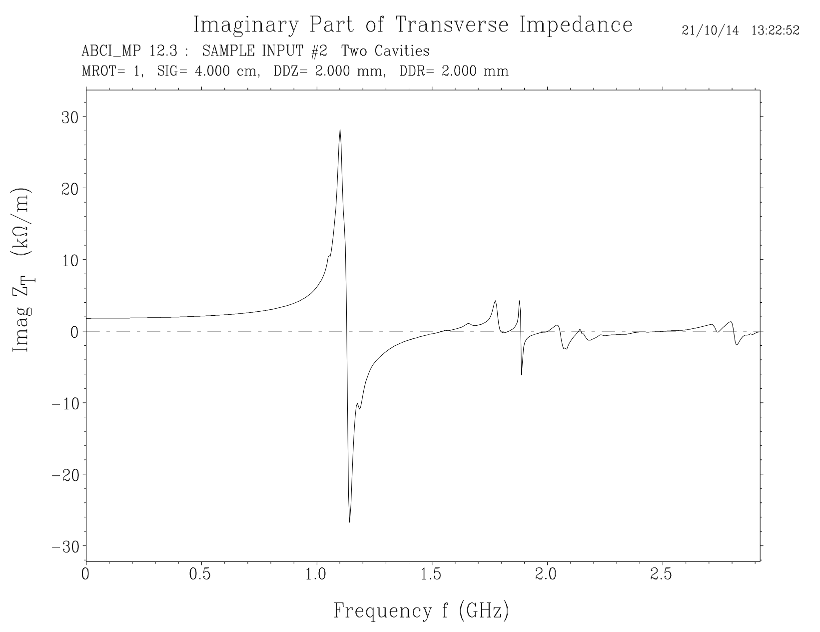


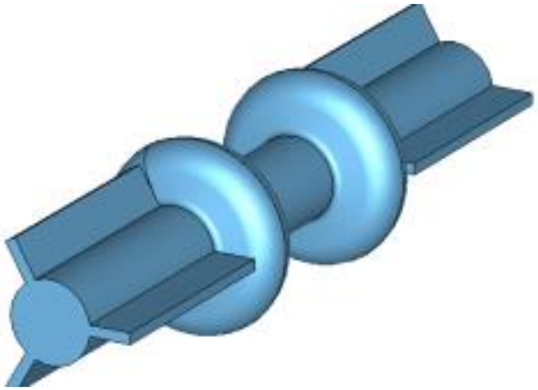
Transverse Impedance

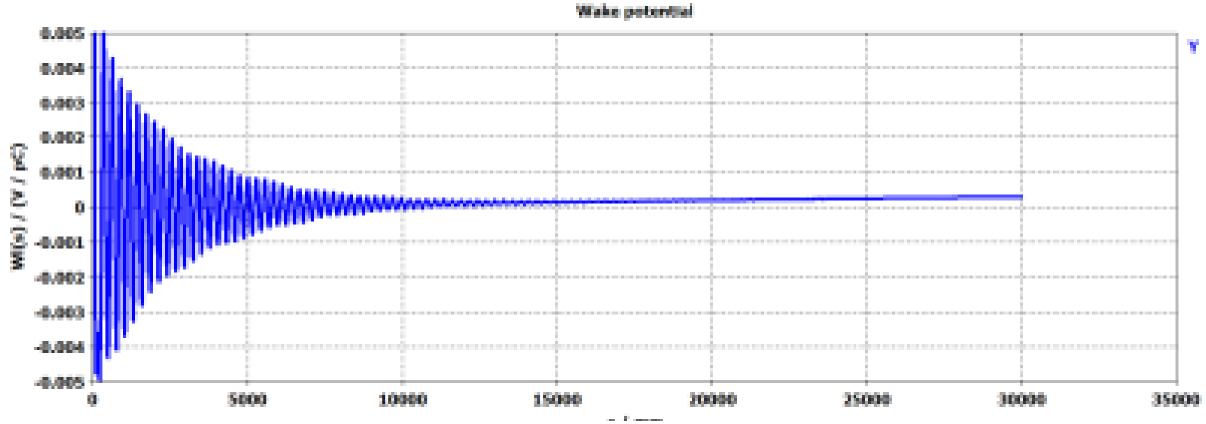


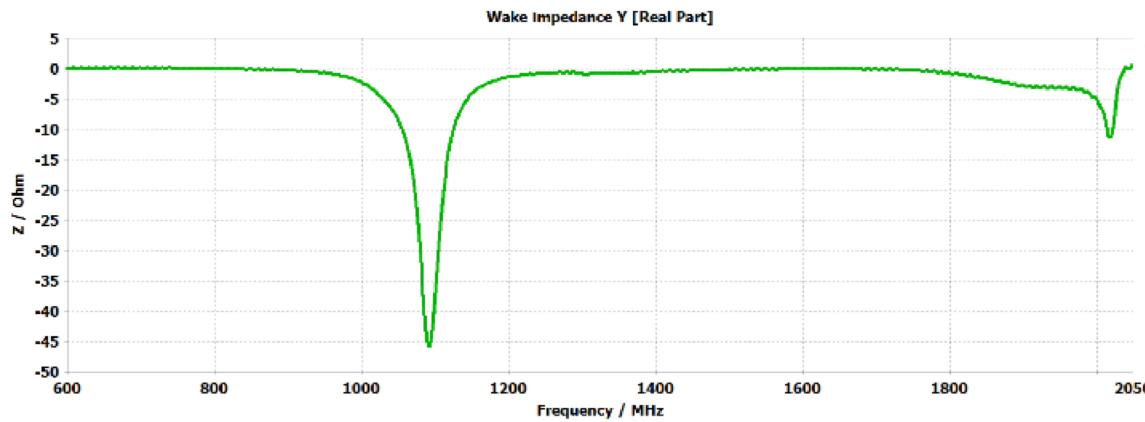


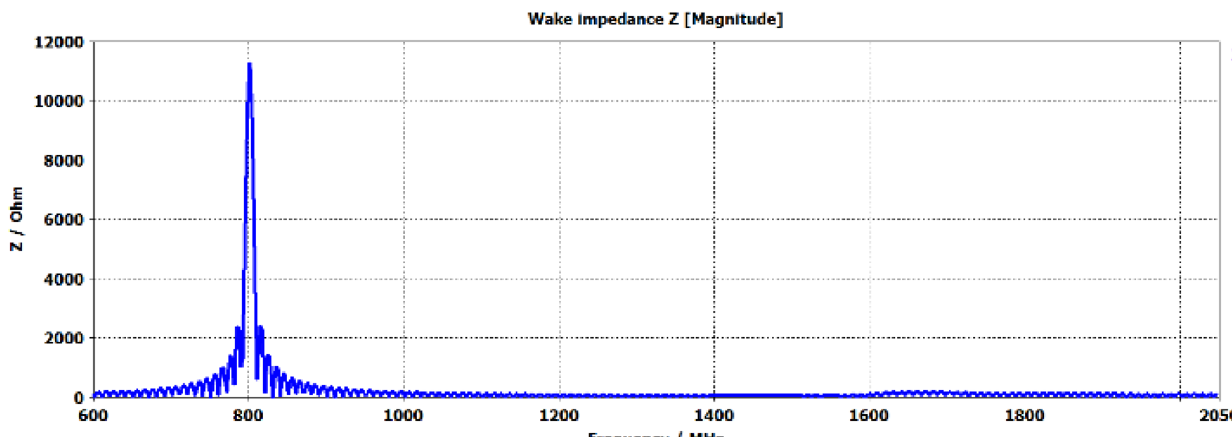




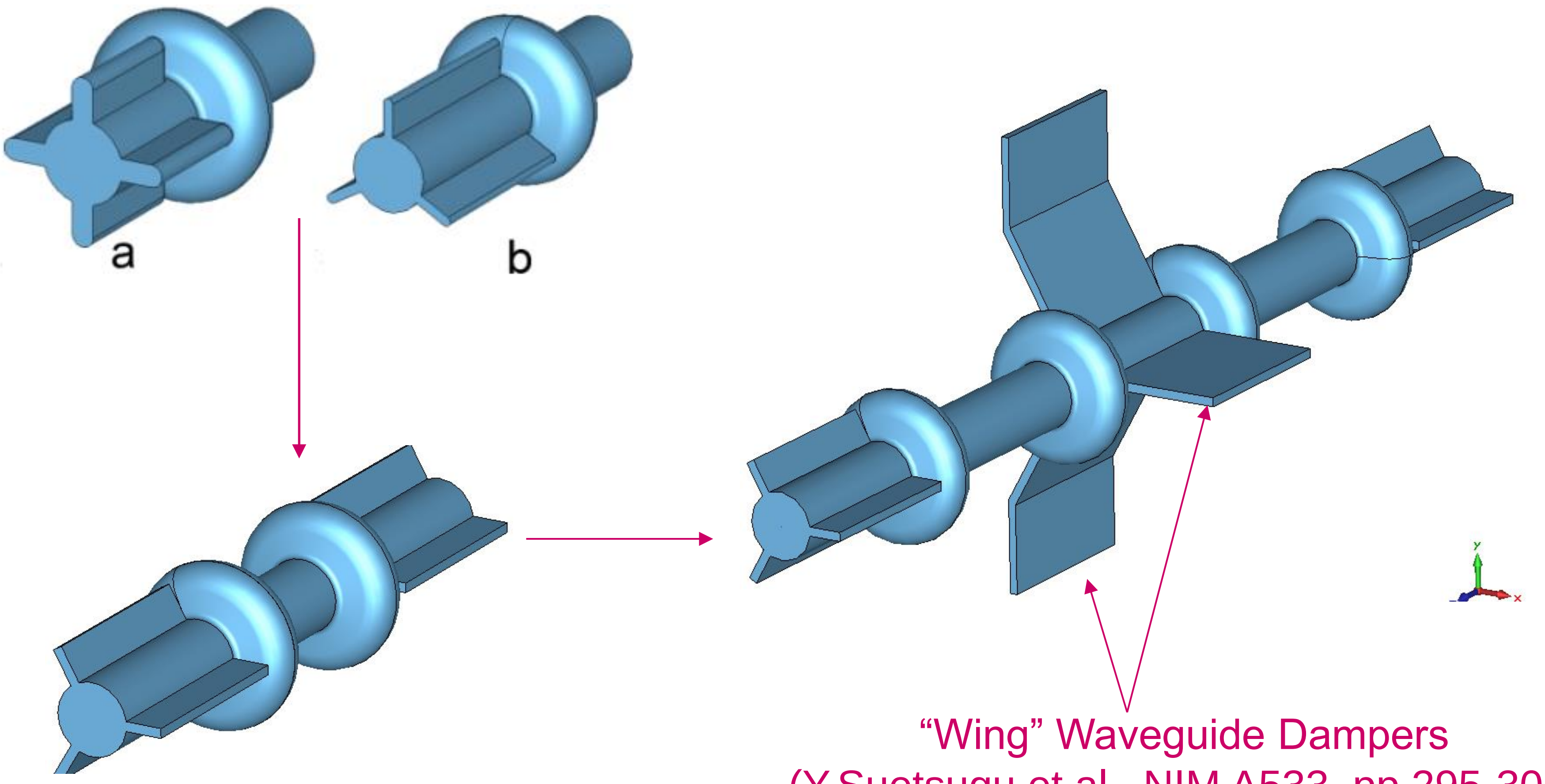



Wake potential
W(s) / [V / pC]
Y
0.005
0.004
0.003
0.002
0.001
0
-0.001
-0.002
-0.003
-0.004
-0.005
0
5000
10000
15000
20000
25000
30000
35000


Wake Impedance Y [Real Part]
Z / Ohm
Frequency / MHz
Y
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
600
800
1000
1200
1400
1600
1800
2050

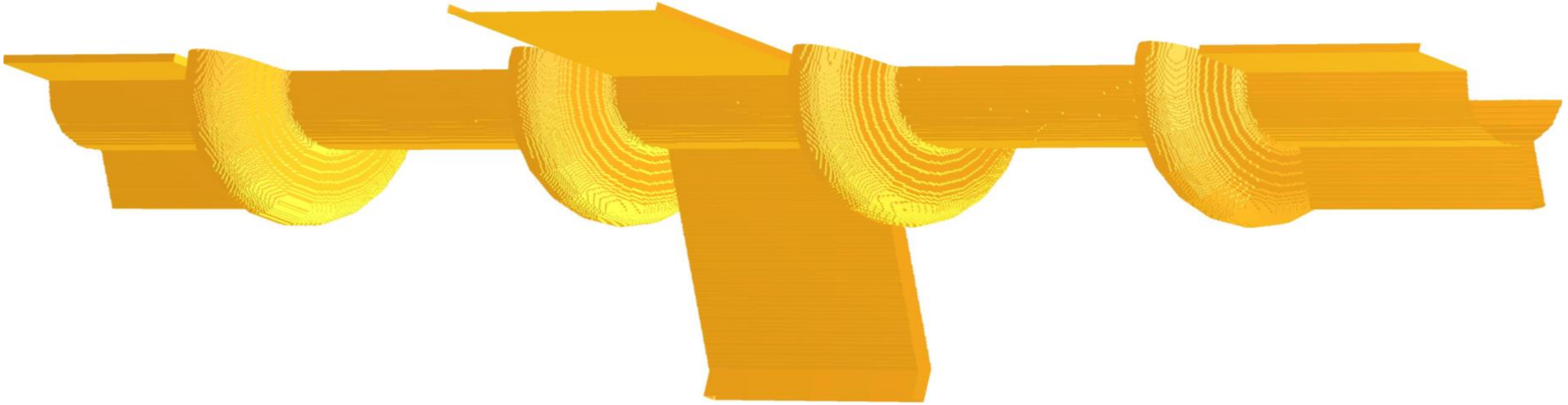

Wake Impedance Z [Magnitude]
Z / Ohm
Frequency / MHz
Z
12000
10000
8000
6000
4000
2000
0
600
800
1000
1200
1400
1600
1800
2050

Proposal of 4 separated cavities in a single cryostat

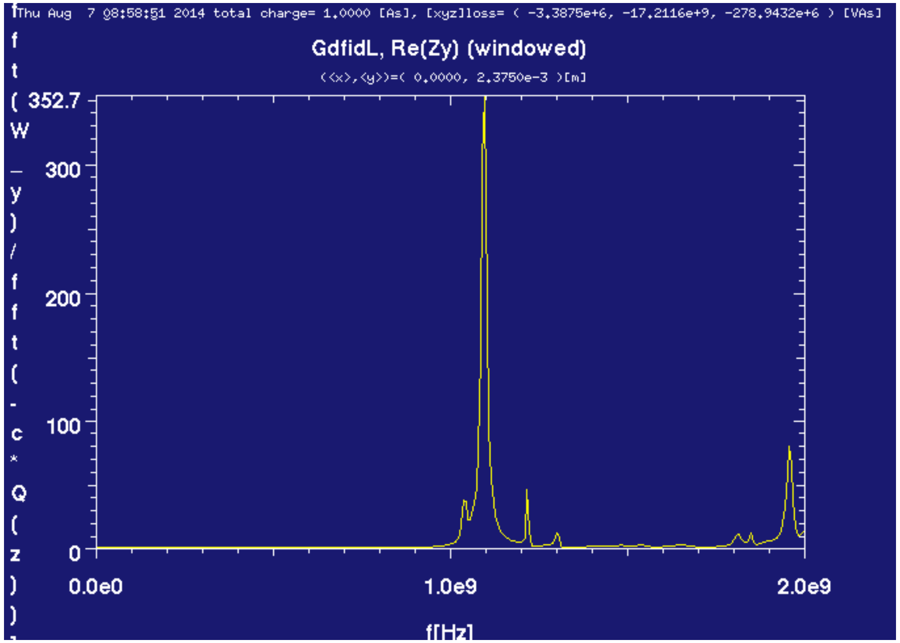


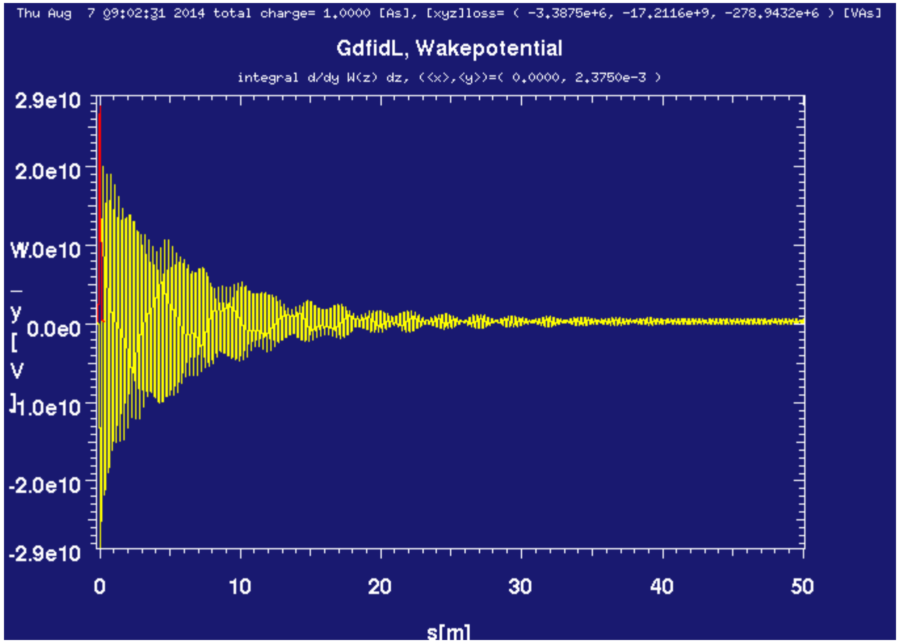
“Wing” Waveguide Dampers
(Y.Suetsugu et al., NIM A533, pp.295-305)

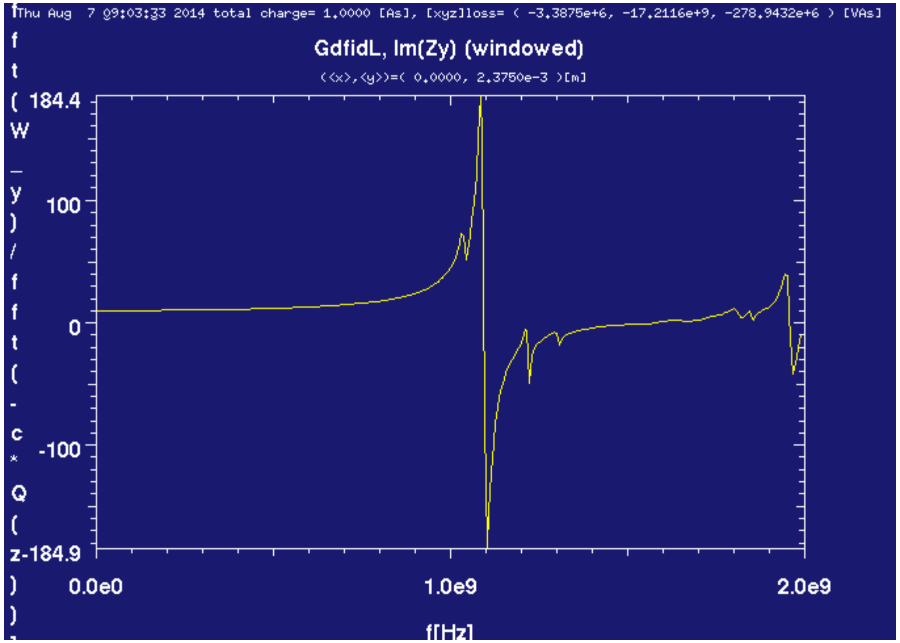
GdfidL Model

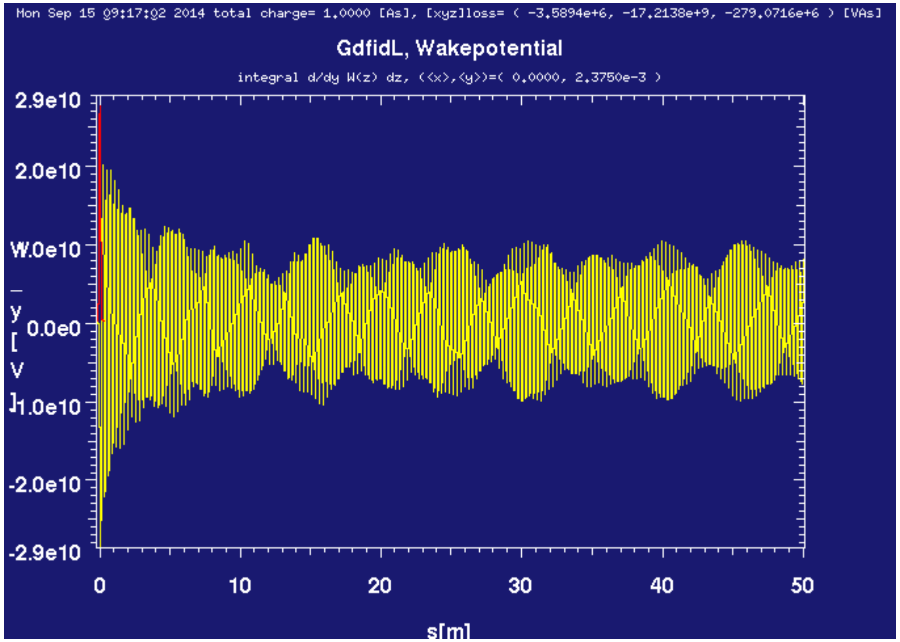


Dipole Wake Field and Impedance

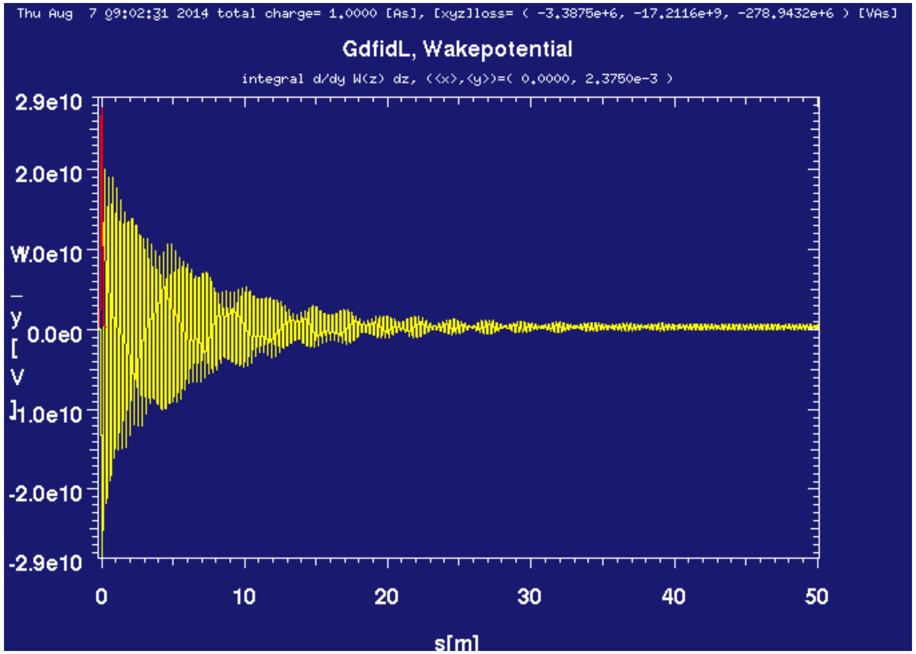






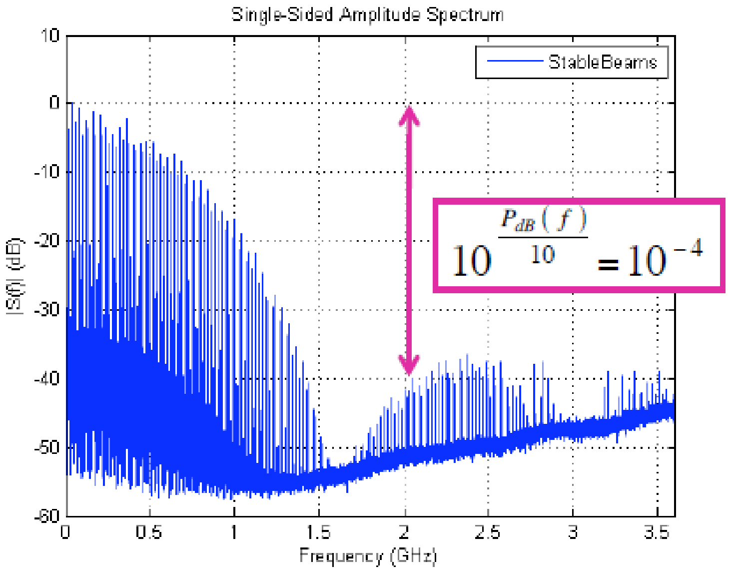


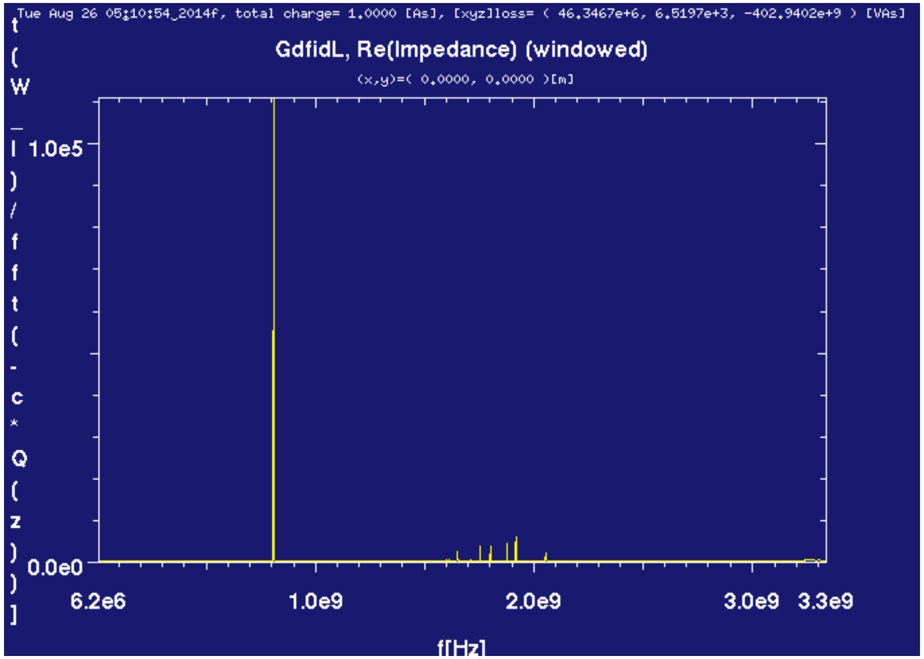
← Shorted waveguides

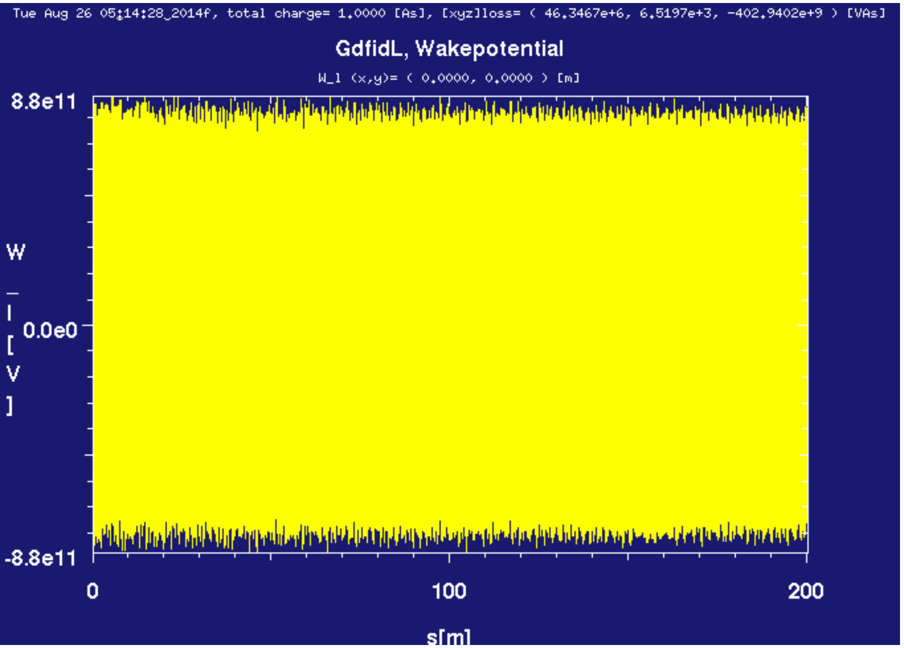


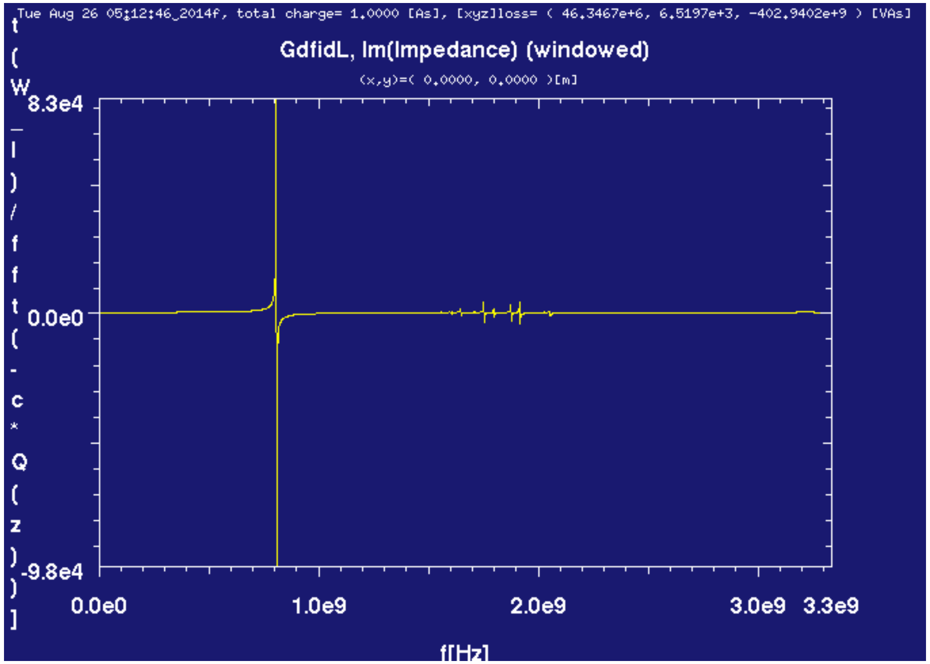
← Matched waveguides

Longitudinal Wake Field and Impedance

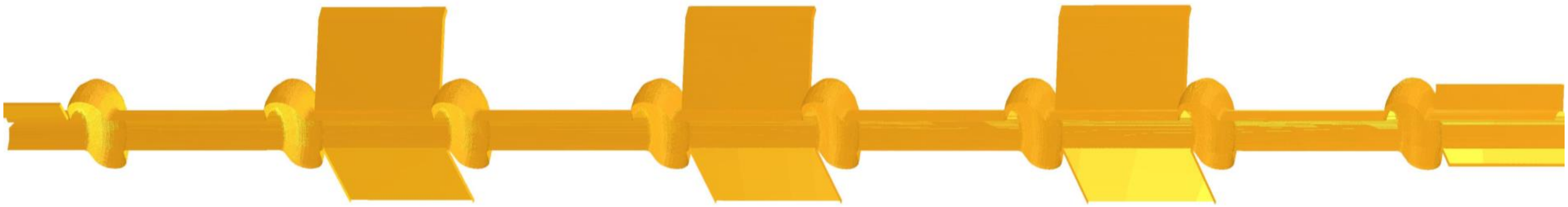


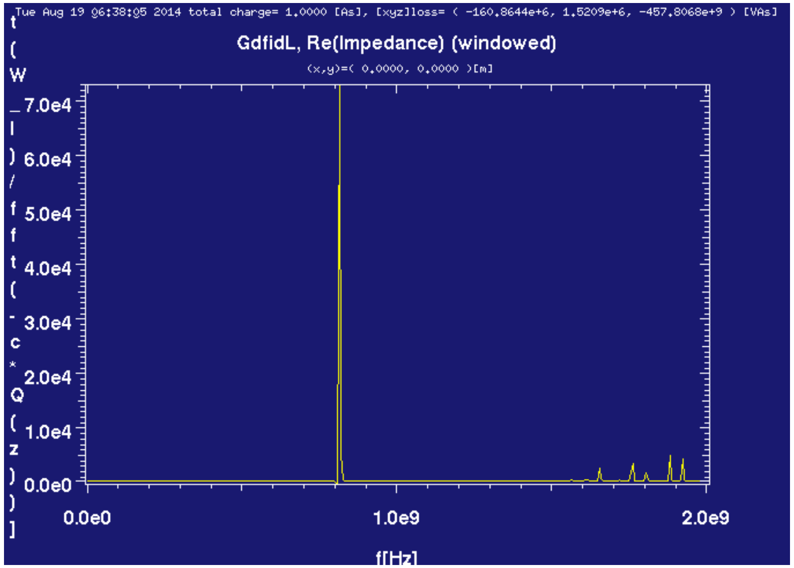


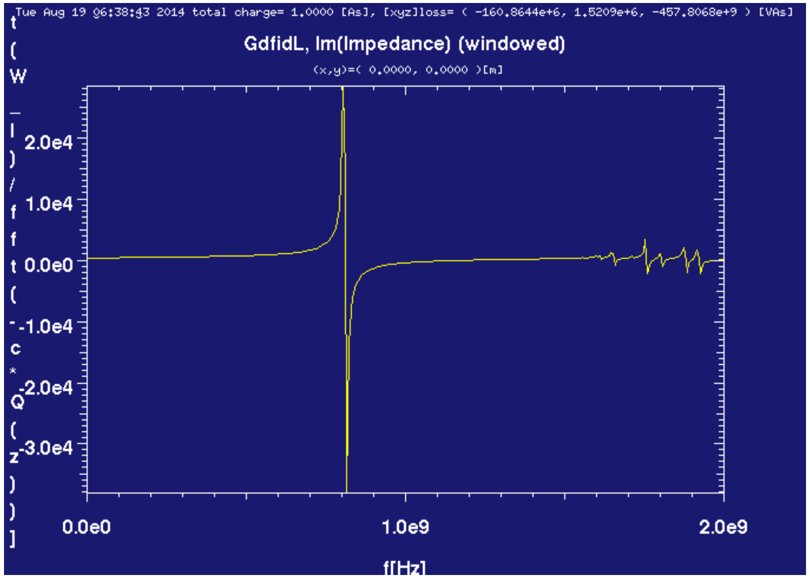




Eight Cavities

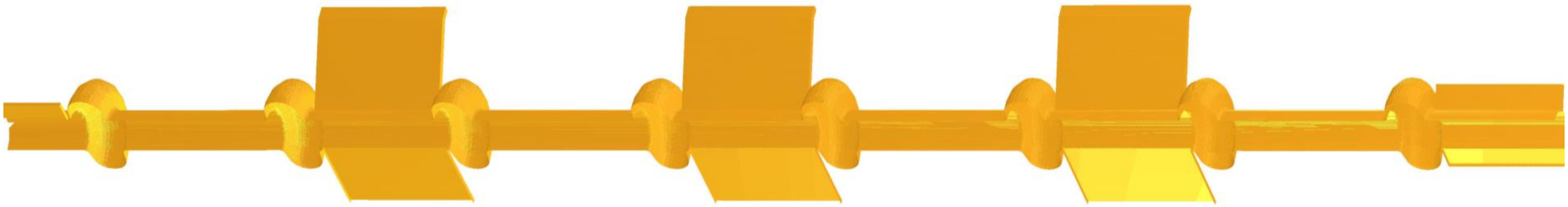


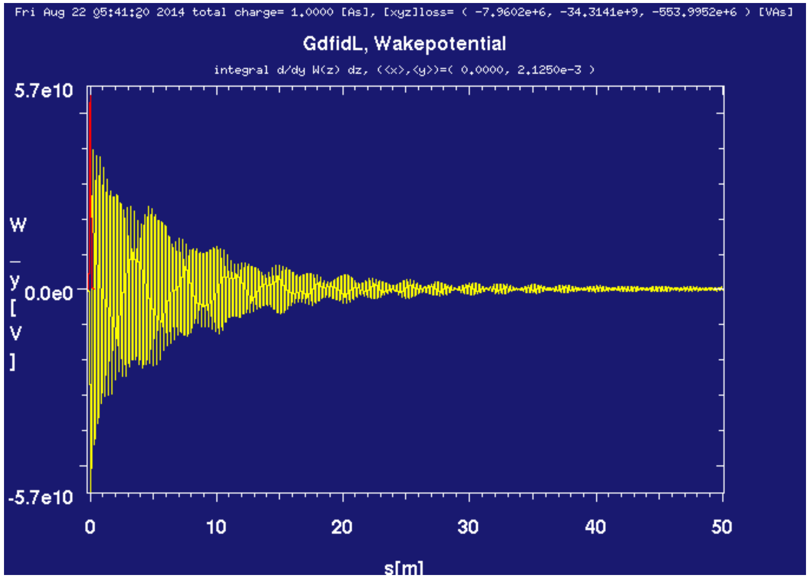


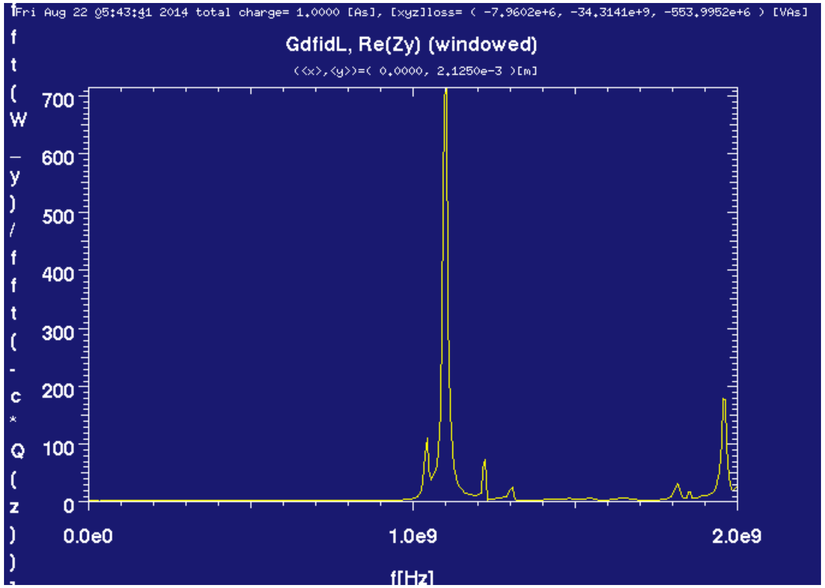


Longitudinal Impedance

Eight Cavities





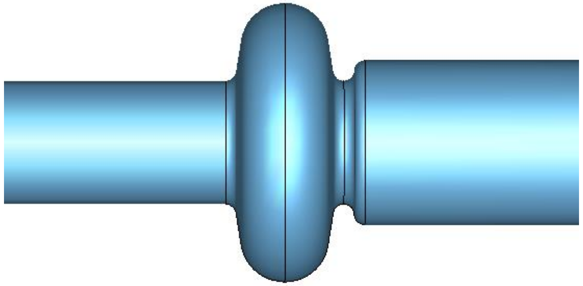


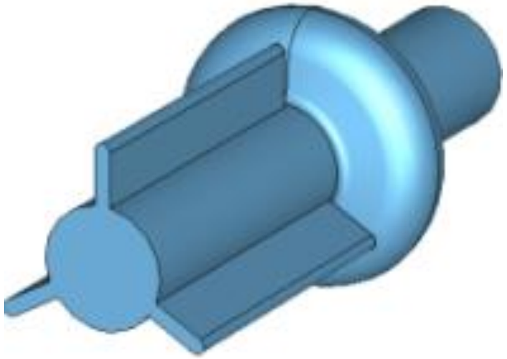
Transverse wake potential

Real part of transverse impedance

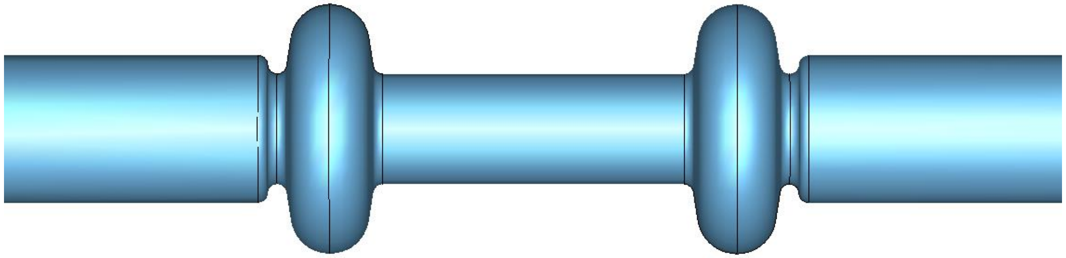
Alternative Solutions for:

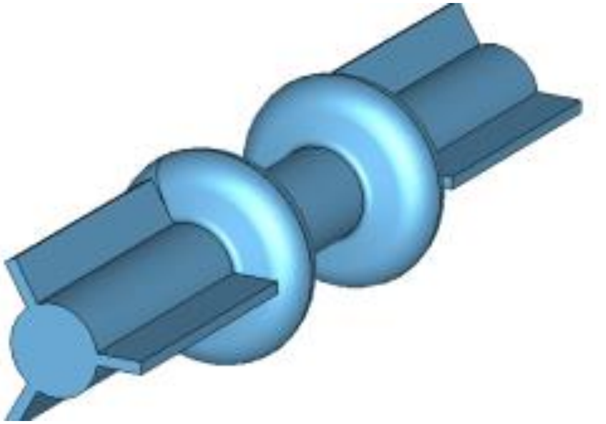
Single cavity



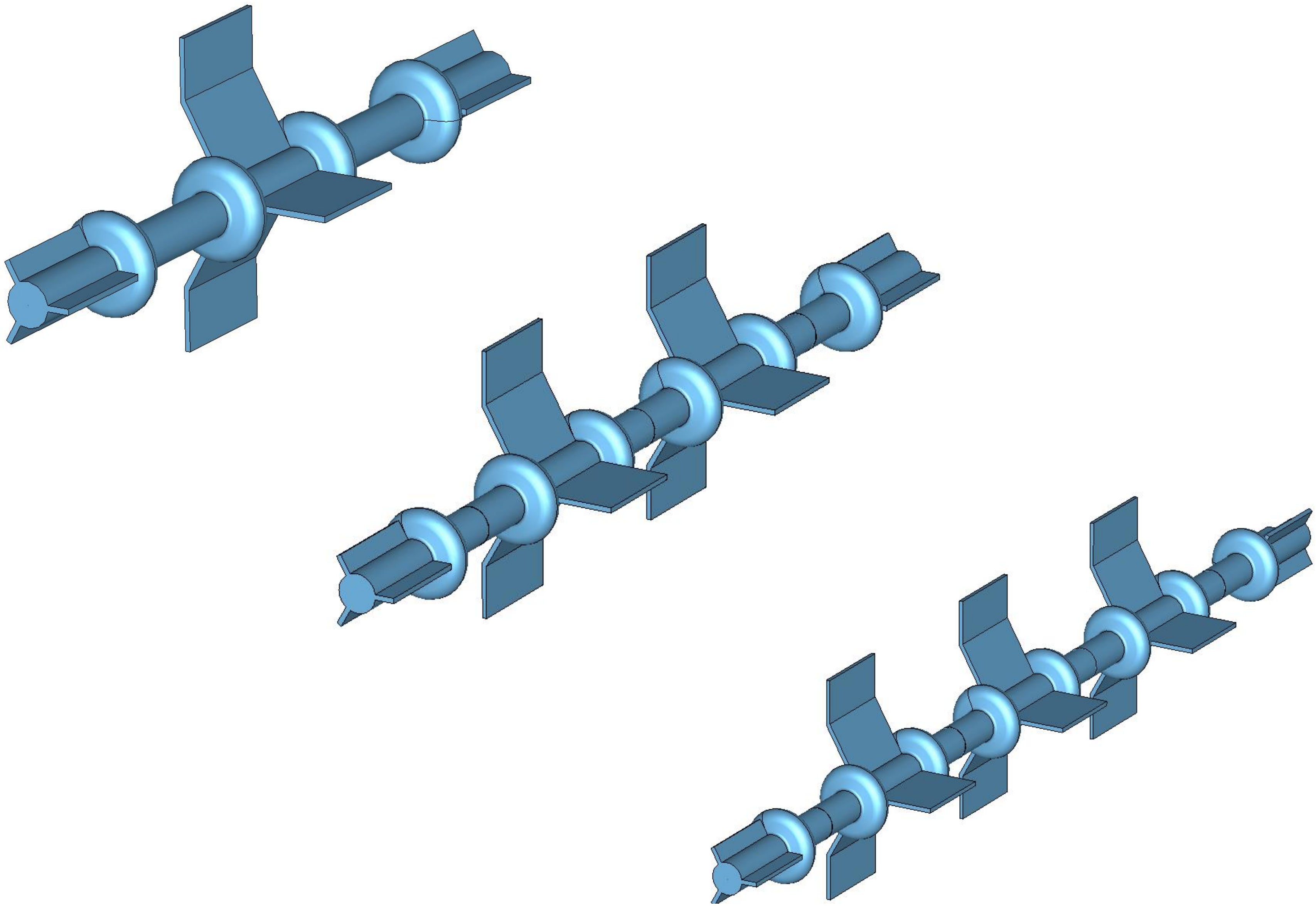


Two Cavities





Multiple Cavities with Fluted Beam Pipes and “Wing” Waveguide Dampers



Short Summary

1. The proposed options with 1 and 2 cavities do not seem to have serious problems (impedance, multipackting, stiffeness). No dedicated HOM dampers are needed.

2. The options with 4 and more cavities require high frequency HOM power extraction from the intermediate connecting beam pipes. The “wing” type dampers look attarctive for this purpose. At present other damping techniques are also under consideration.

3. Much work is still to be done. First of all, the design of the main coupler should be elaborated (CERN?).