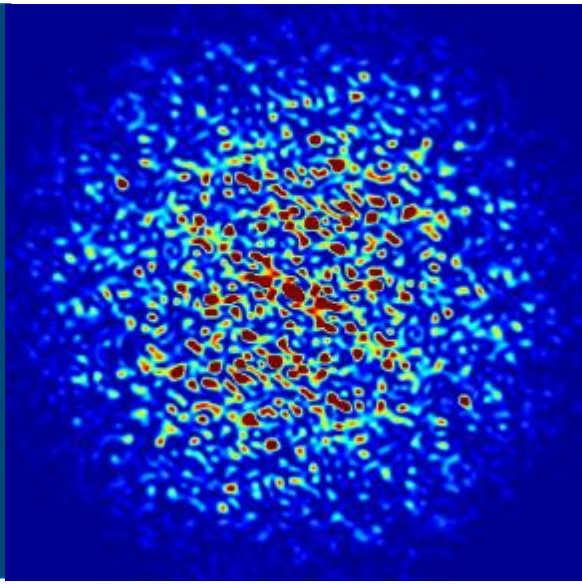
ANL Plan for EIC R&D: HOM damping



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Physics Division
Argonne National Laboratory

Nuclear Physics Accelerator R&D PI Meeting
November 13-14, 2018

Introduction

Main Goal: HOM dampers are a critical technology for the Nuclear Physics (NP) next generation electron ion collider (EIC) → Damping techniques for ERL and Storage Ring

- HOM techniques cross cut at least three high-priority R&D elements
- Ampere class electron beams in EIC linacs and storage ring must deal with HOMs

Row No.	Proponent	Concept / Proponent Identifier	Title of R&D Element	Panel Priority	Panel Sub-priority
11	PANEL	LR	SRF high power HOM damping	High	B
12	PANEL	RR	Complete design of an electron lattice with a good dynamic aperture and a synchronization scheme and complete a comprehensive instability threshold study for this design	High	B
3	PANEL	ALL	Strong hadron cooling	High	A

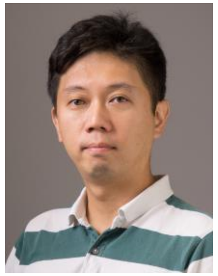
Project Goal

- FY16: Proposal to design HOM damping for ERL in the LR approach (Priority row #11 in the Jones report)
- FY17: Focus on HOM damping for ERL approach
- FY18: Extension to larger systems, higher frequencies, parallel computing
- Technical approach: (HOM damping in SRF structures)
  – Waveguides
  – Beamline absorbers
- Previous ANL contributions:
  – ANL has built and tested real hardware relevant to EIC; a high-power beamline HOM damper for electron storage ring (APS-U)
  – Simulation tools to address HOM damping in complex lattice of accelerating structures

Budget

Summary of Expenditures by Fiscal Year

	FY10+FY11	FY12+FY13	FY14+FY15	FY16+FY17	Totals
a) Funds allocated				$80K+$44K	$124K
b) Actual costs to date				$80K+$28K	$108K



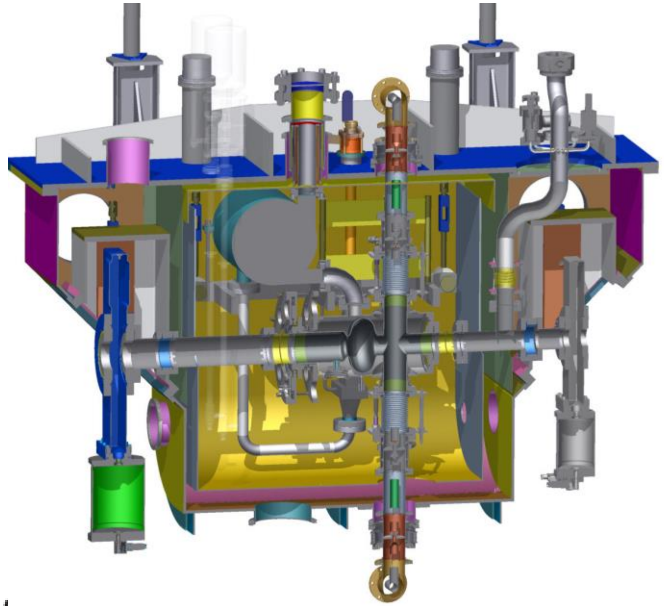
Sang-hoon Kim (presently FRIB)

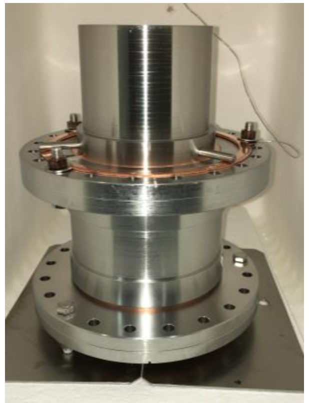
Aziz Abogoda (undergrad)

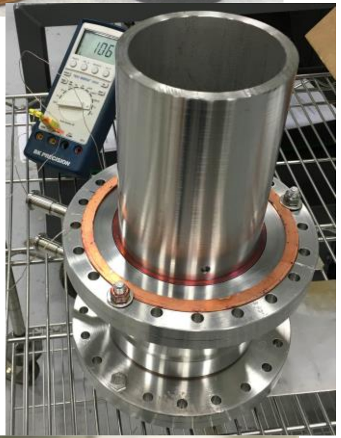
Brahim Mustapha

Mike Kelly

HOM Damping Solutions For APS-U High-current Electron Storage Ring Bunch Lengthening Harmonic Cavity System







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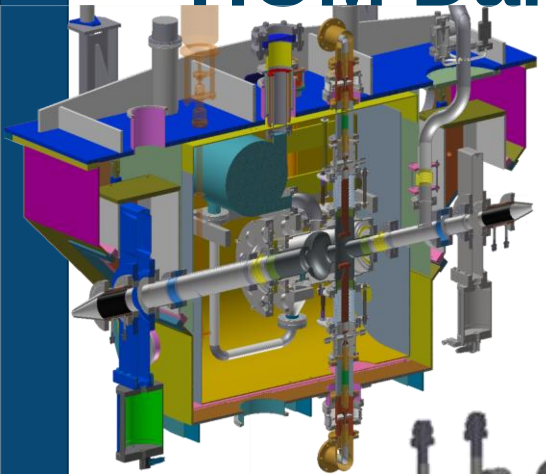
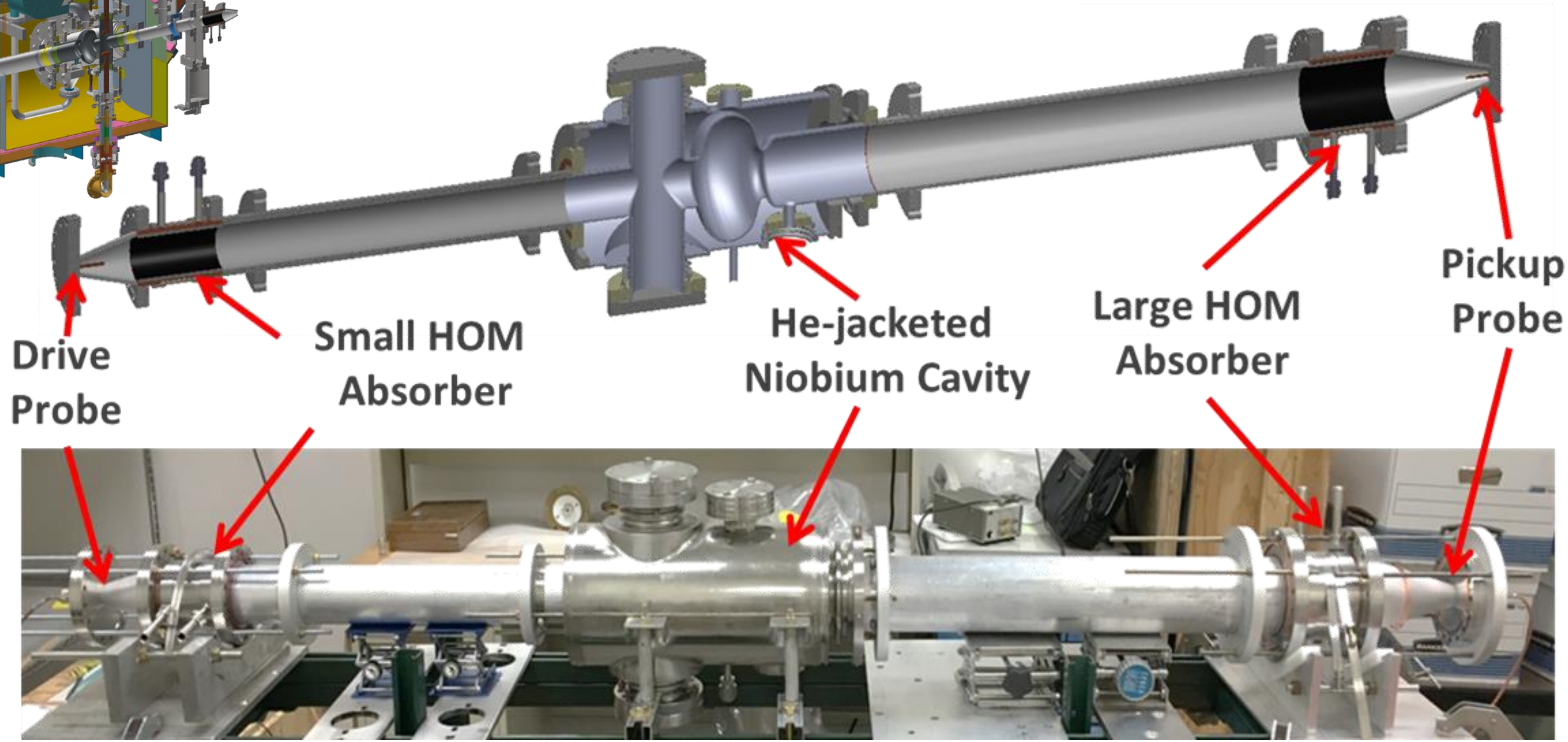
HOM Damping Using a Room Temp Beamline Absorber

1.4 GHz Harmonic Cavity System

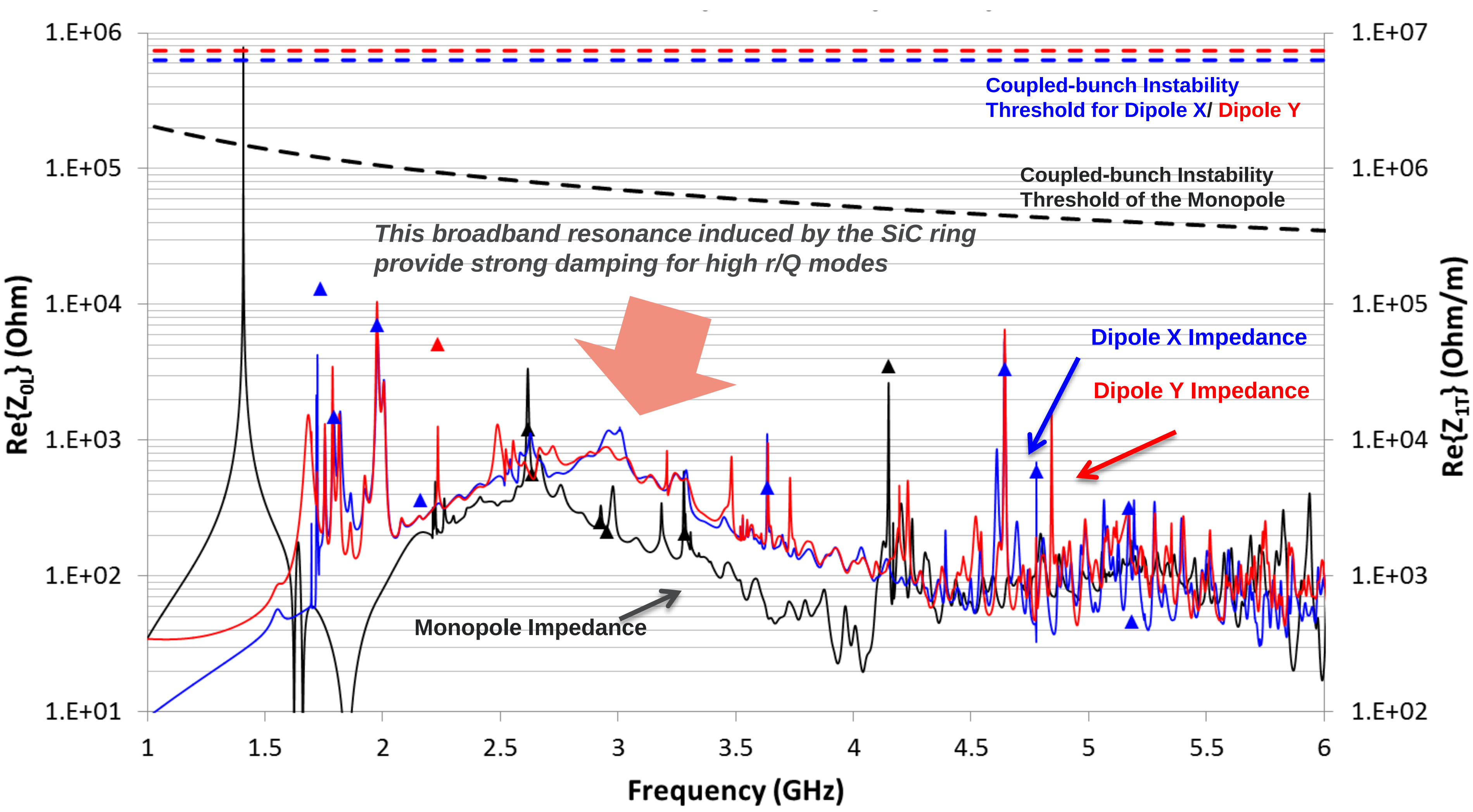




Simulated (CST MWS) Impedance Spectra

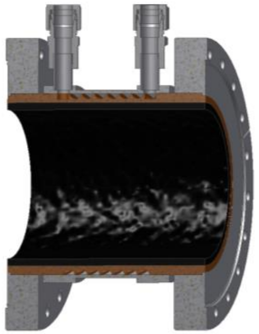
Solid lines – Time Domain   Trianges - Eigenmode

Monopole and Dipole Impedances Compared with Instability Threshold

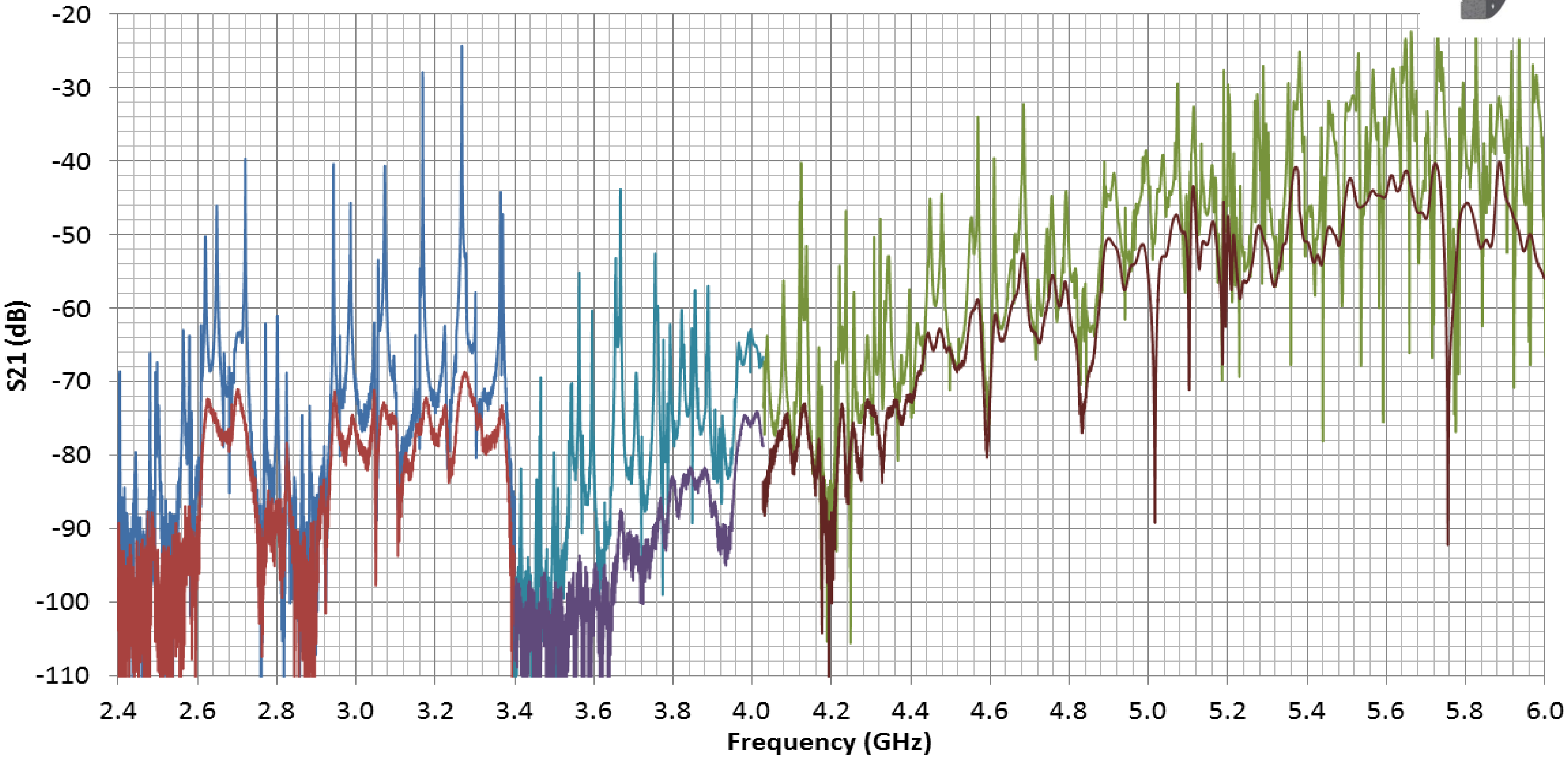


Experimentally Measured HOM Damping

Strong damping for all monopole modes; similar for dipole modes



Upper curves – No damper **Lower curves – with damper**



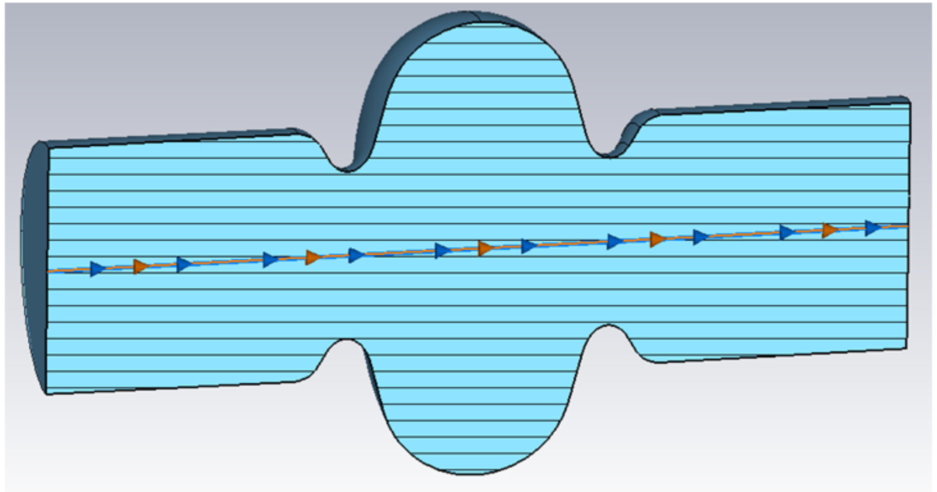
HOM Damping for EIC

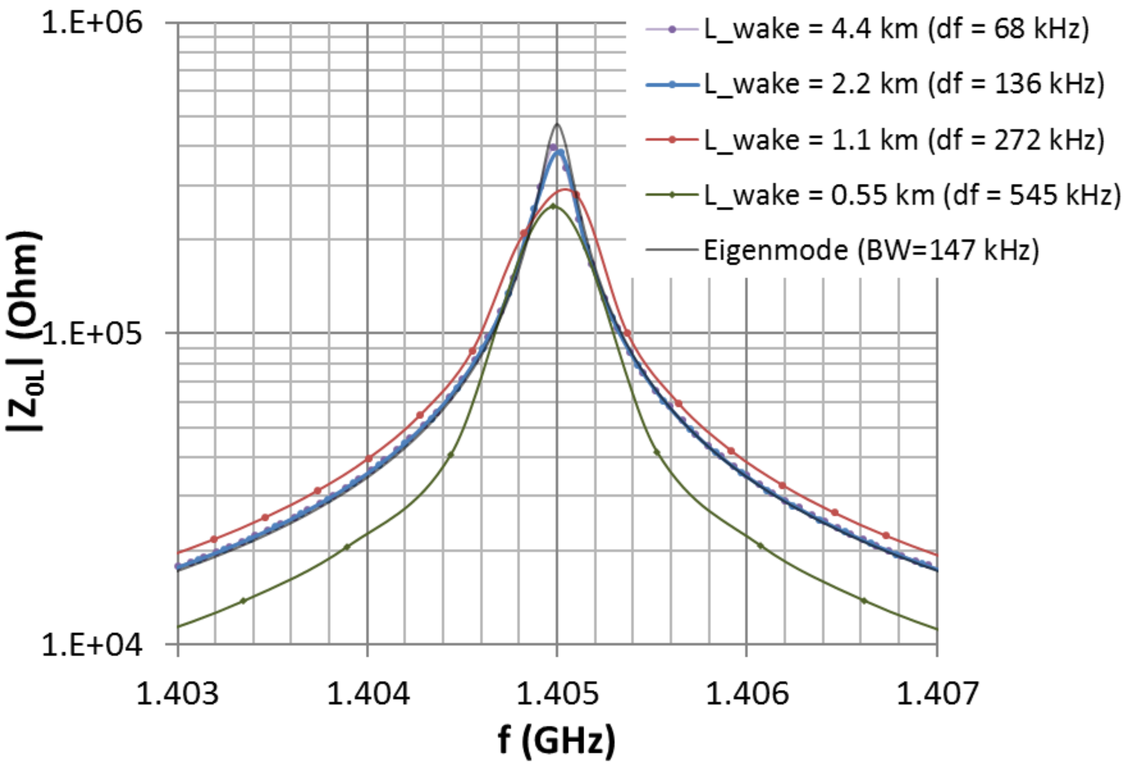
Limitations in HOM Impedance Simulations

Frequency resolution limited by wake integration time

A benchmark test with a sample cavity

Eigenmode results: f0 = 1.4058 GHz,
r/Q = 98.6 Ohm, Q0 = 9560 (Nb @ RT)



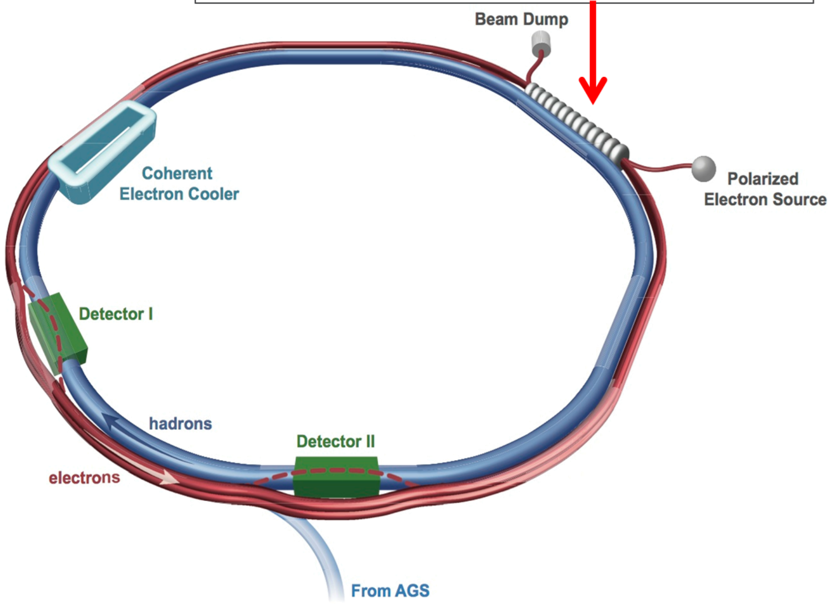


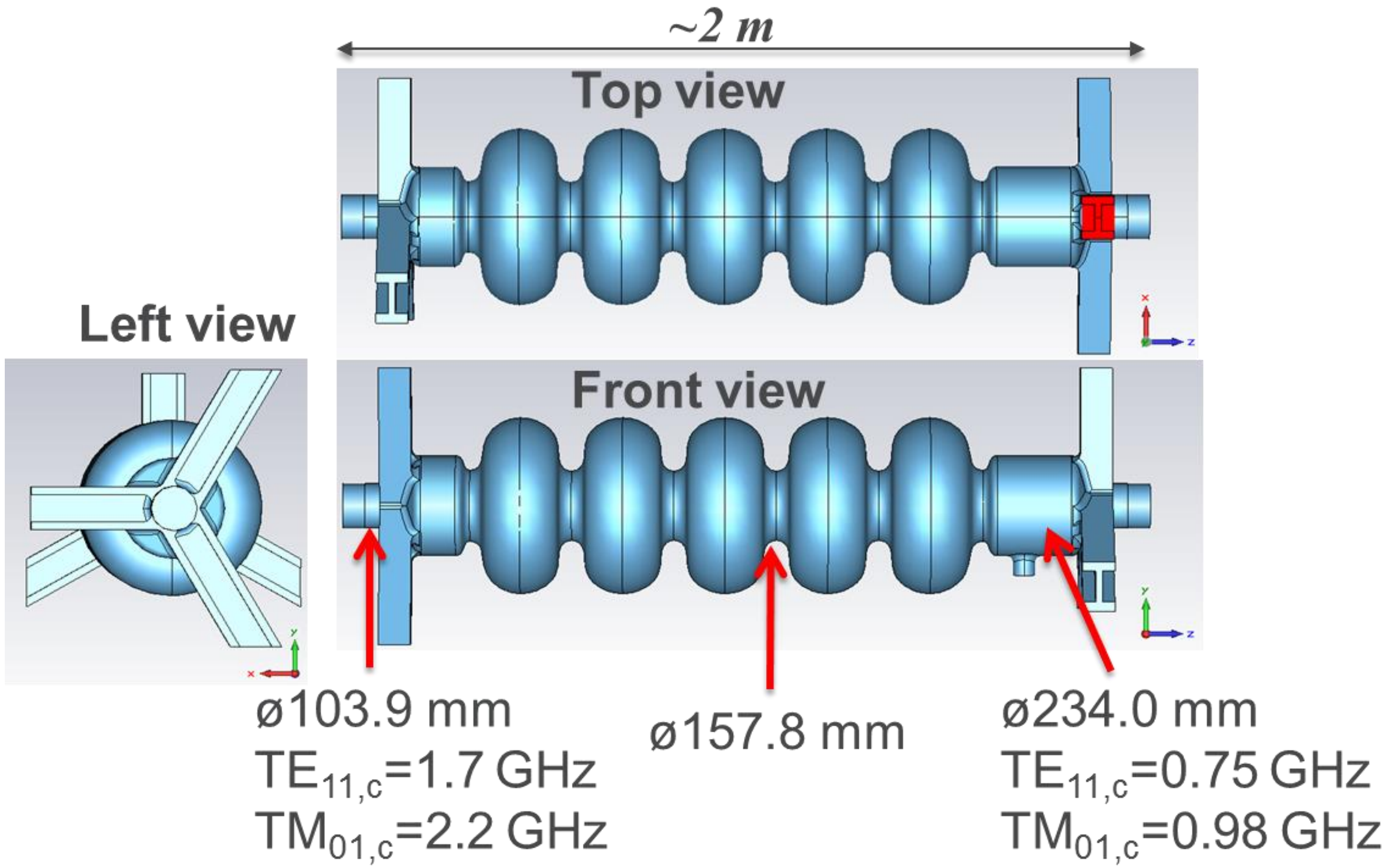
Conclusion: Peak impedance and apparent Quality factor (damping) are a strong function of the wake integration time and the mesh

ANL Starting Point 2016: 647 MHz 5-cell cavity with double-ridge waveguide HOM dampers

Concept of the eRHIC Linac–Ring option (Courtesy of W. Xu)

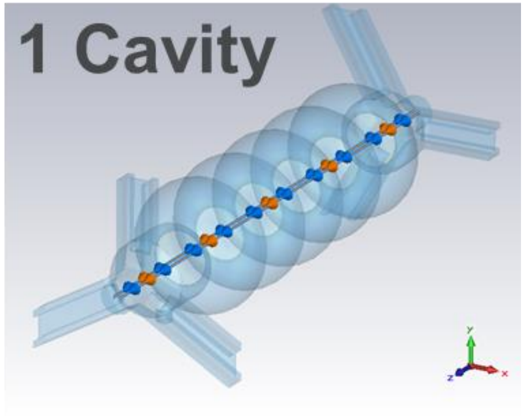
- 1.67 GeV/pass Energy Recovery Linac
- 80 x 647.4 MHz 5-cell–SRF Cavities
- Available tunnel space: 200 m

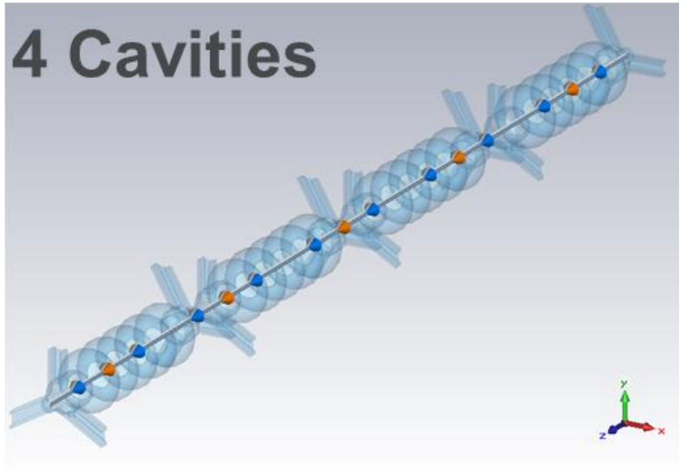




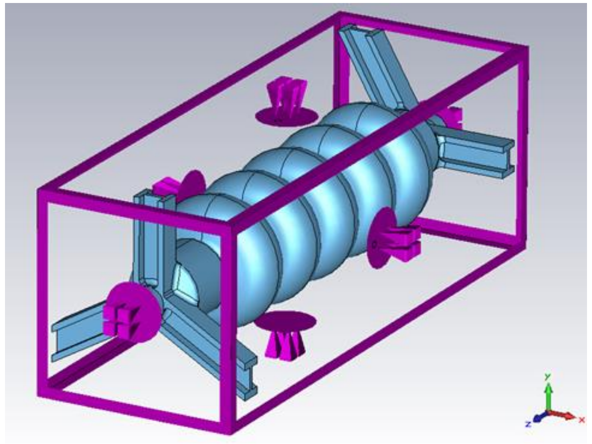
Monpole/Dipole HOMs With Double Ridged Waveguides

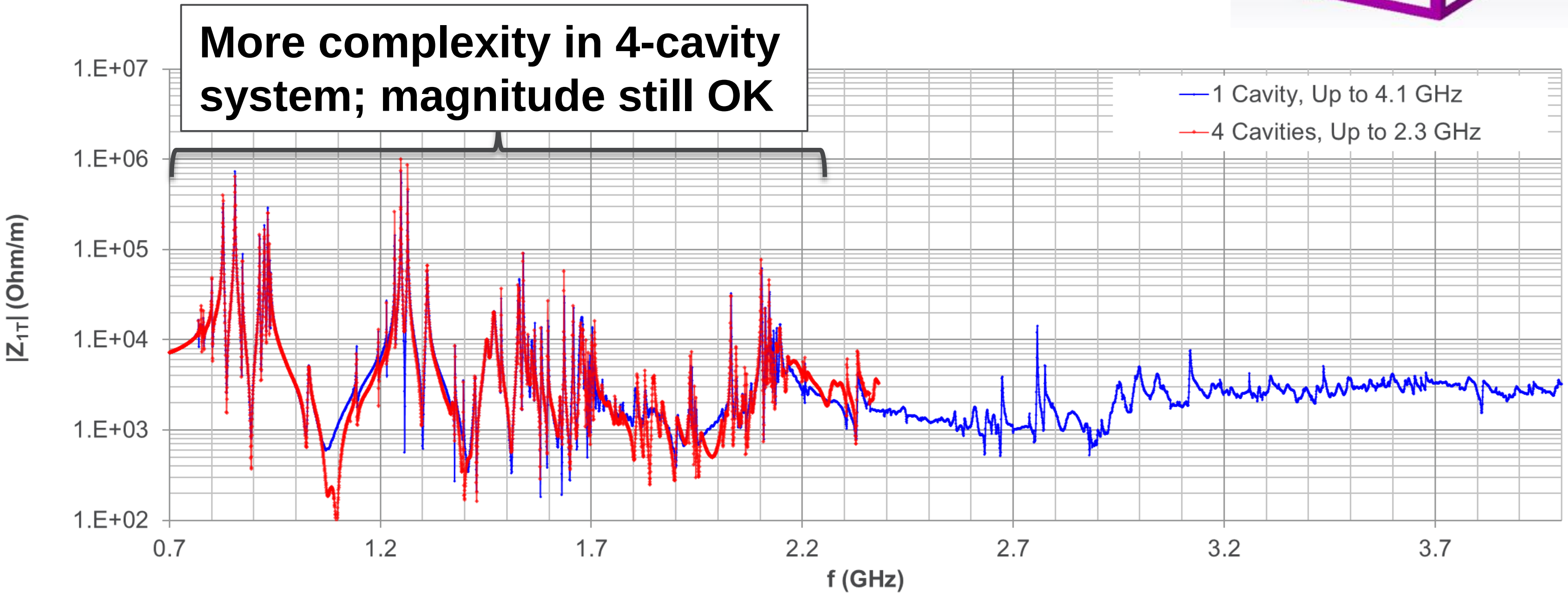
Waveguide Damping Looks Favorable for Initial Simulations





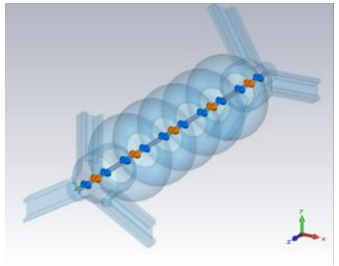
Perfectly Matched Layer (PML) at all boundaries

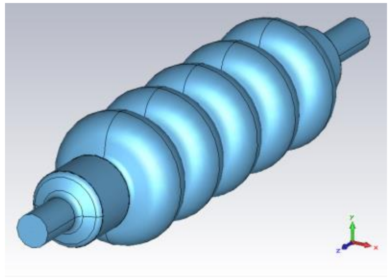


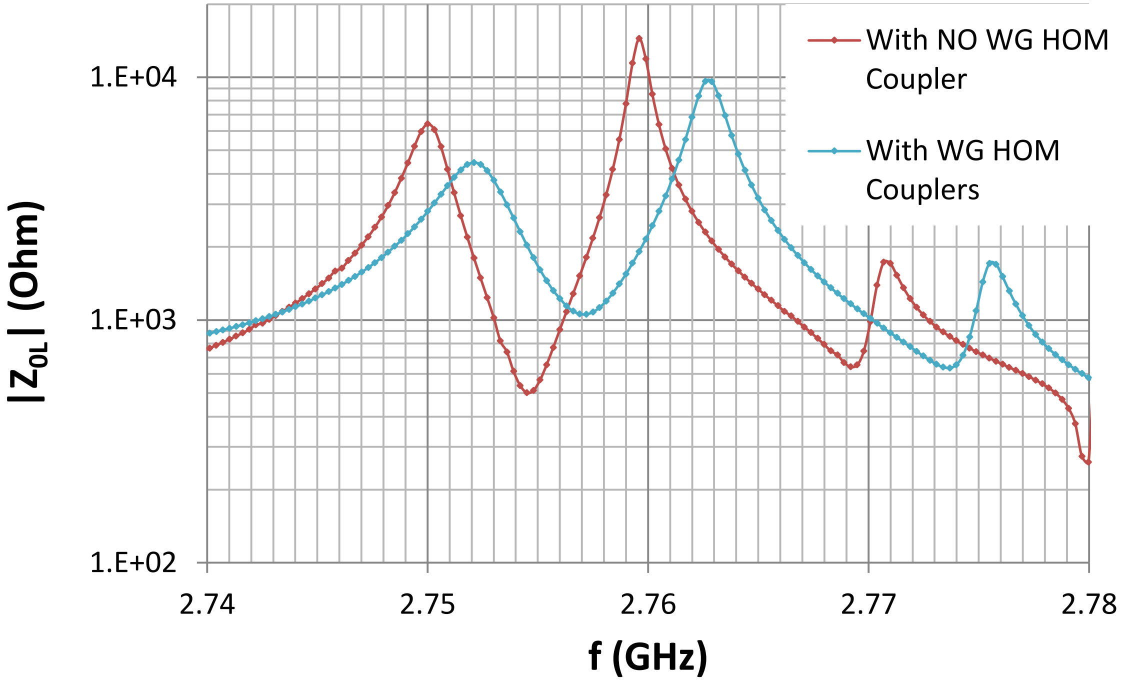


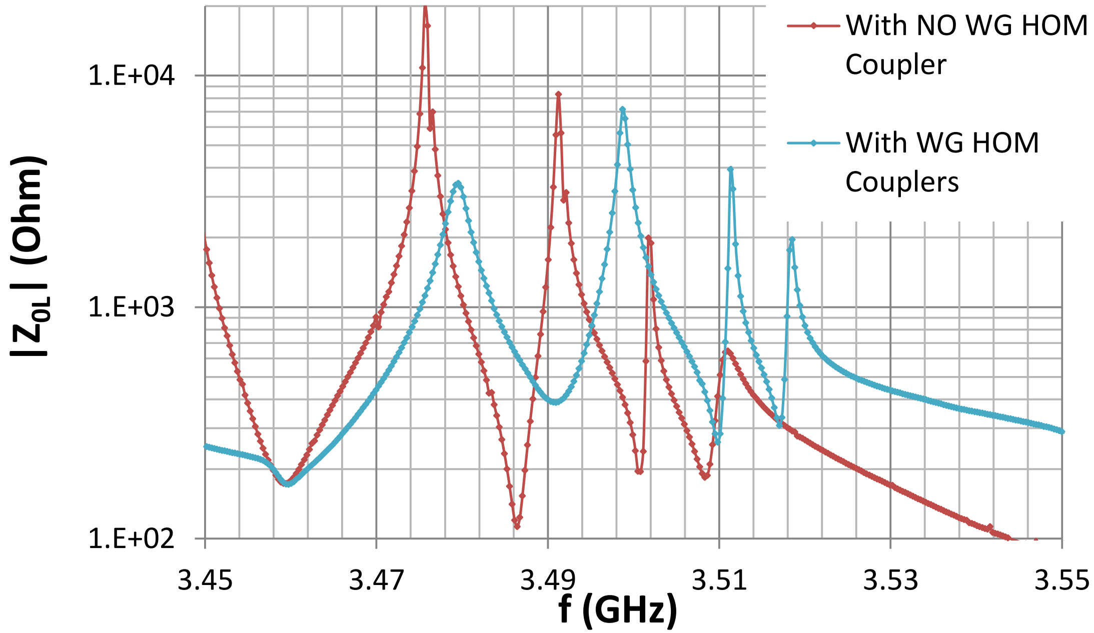
Monopole HOMs are Not Well Coupled to the Waveguides

Damping in some cases due to PML boundary condition assumption





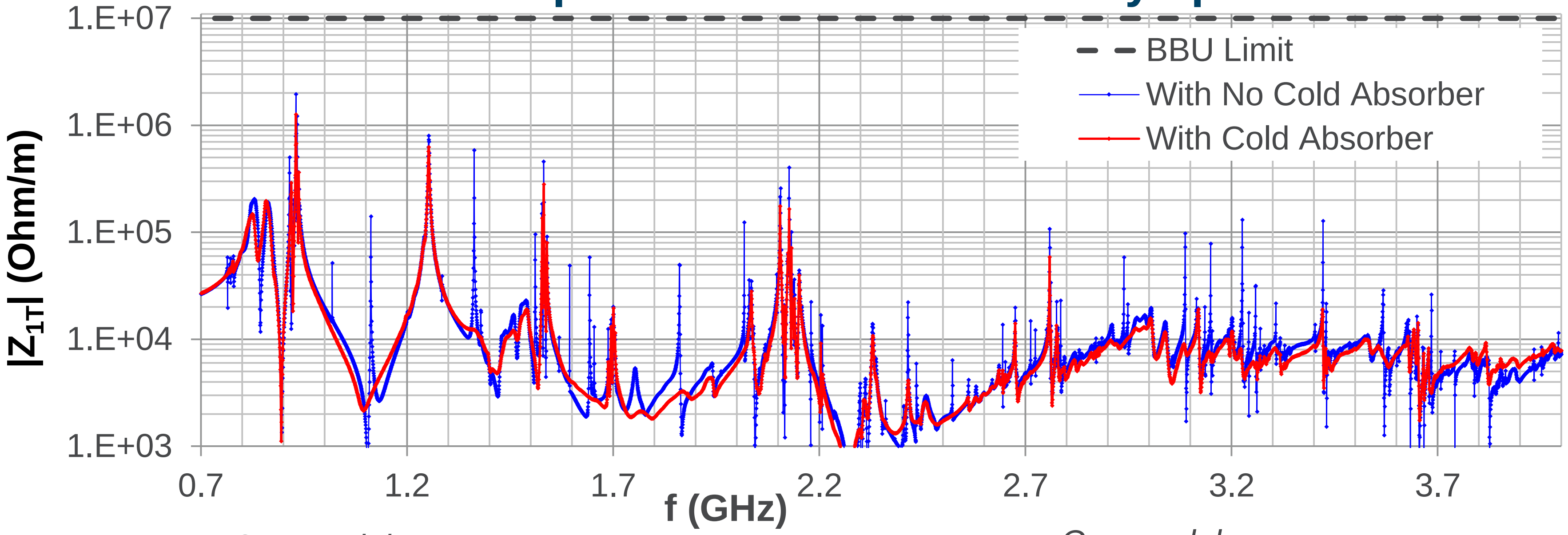


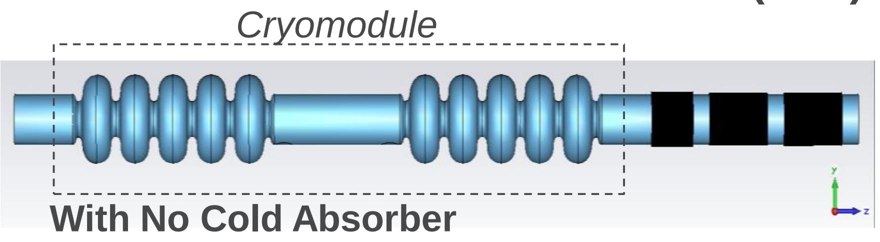


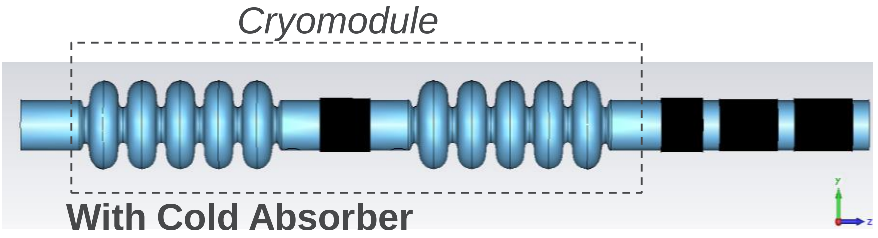
Conclusion: The ridged waveguide assembly alone is insufficient; some monopole modes only strongly coupled to the beam tube, i.e. the location of a beamline HOM damper

Alternative: Beamline HOM Absorbers

Possible to avoid the complexity involved with ridged waveguides
Does require modification of cavity aperture





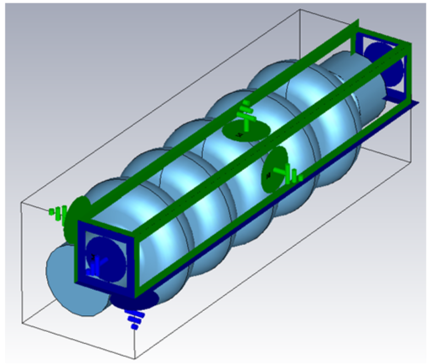


Conclusion: HOM damping with only beamline absorbers can provide strong damping; a cold absorber is necessary to avoid potential trapped modes

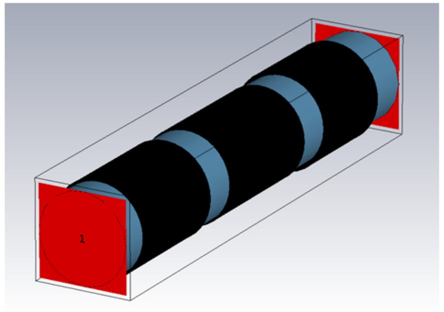
Properties of Beamline HOM Absorbers

Absorbers are being tailored to most harmful HOMs

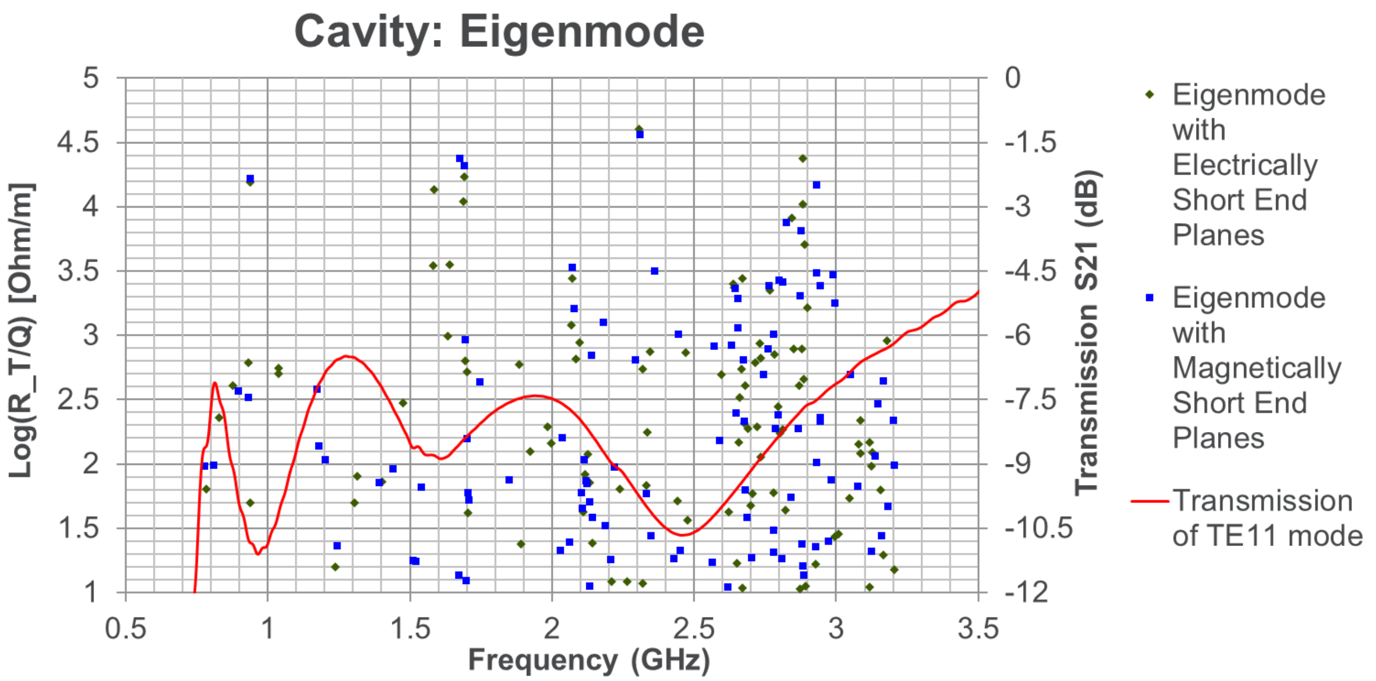
Cavity: Eigenmode



Beampipe with SiC Rings: Transmission Line



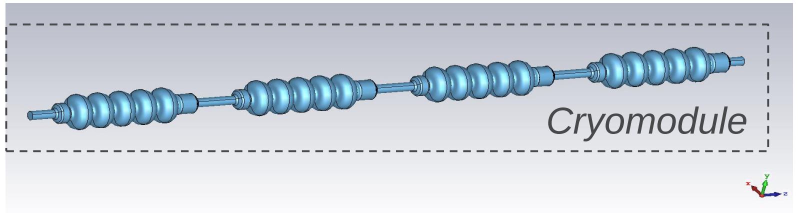
{4 mm thick x 35 cm long}
+ {6 mm x 30 cm}
+ {10 mm x 25 cm}



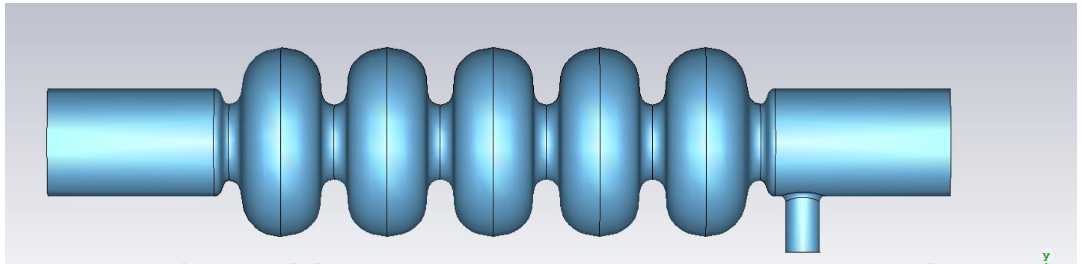
Conclusion: Possible to optimize dimensions of the silicon carbide rings for strong damping at highest R_T/Q; We take advantage of intrinsic property of the SiC ring as a broadband dielectric resonator

HOM Simulations for Arrays of Cavities/Cryomodules

Requires capability to performing large scale electromagnetic (EM) simulations



Goal: to reduce from present ~weeks to ~1 day time



Benchmarking case: 5-cell 650 MHz cavity

Mode	frequency (GHz)		
	CST	OMEGA3P	% Difference
1	0.6342	0.6342	0.0009%
2	0.6385	0.6385	0.0007%
3	0.6440	0.6440	0.0003%
4	0.6486	0.6486	0.0001%
5	0.6504	0.6504	0.0003%
6	0.7694	0.7694	0.0016%
7	0.7793	0.7792	0.0065%
8	0.7955	0.7954	0.0090%
9	0.8139	0.8139	0.0062%
10	0.8302	0.8302	0.0010%
		Mean % Difference:	0.0027%

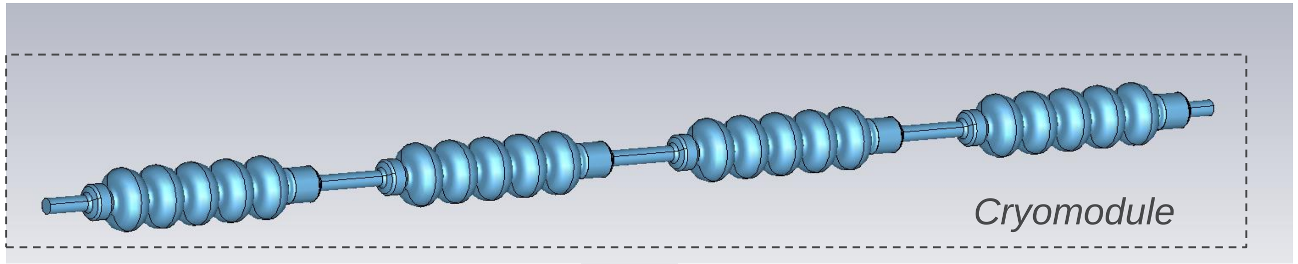
NERSC's clusters Edison and Cori →

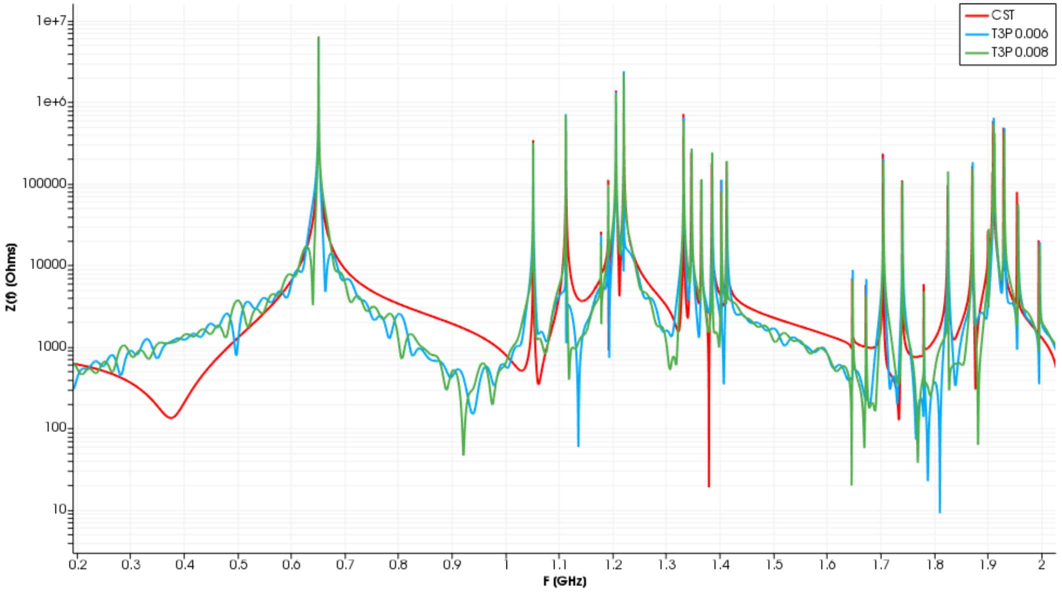
Code	# of Elements	Nodes	Memory/Node [GB]	Time [min]
OMEGA3P	320,679	10	1.8937	0.983
CST (2 passes & meshing)	738,476	1	44.623052	44.86

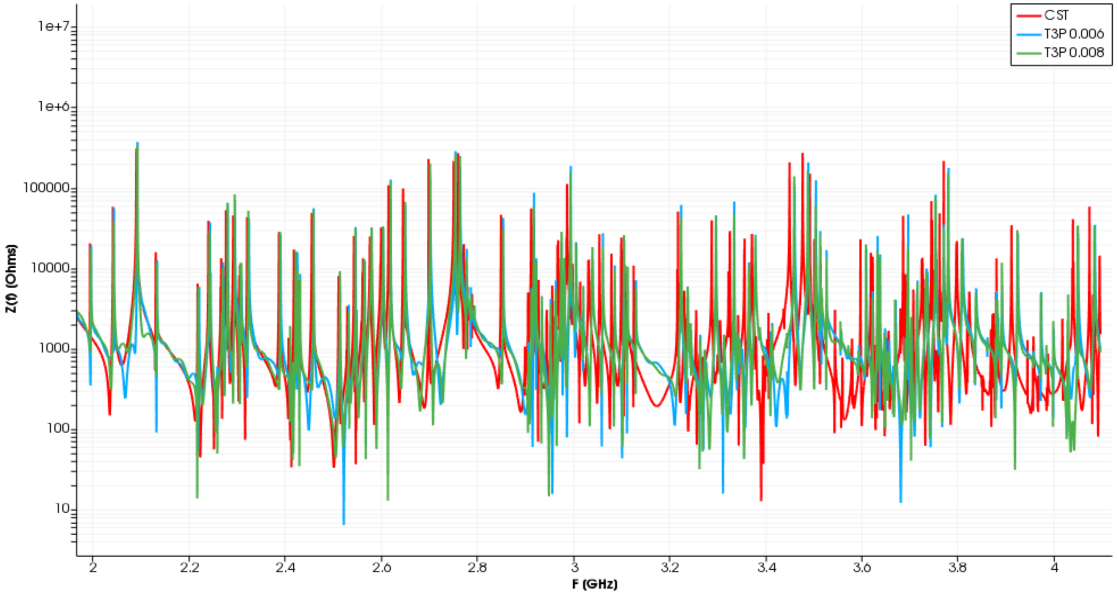
Conclusion: Eigenmode simulation shows good numerical agreement between two codes on two different machines with roughly 50 times improvement in calculation time

HOM Simulations for Arrays of Cavities/Cryomodules

Comparison of time domain spectra from CST and ACE3P





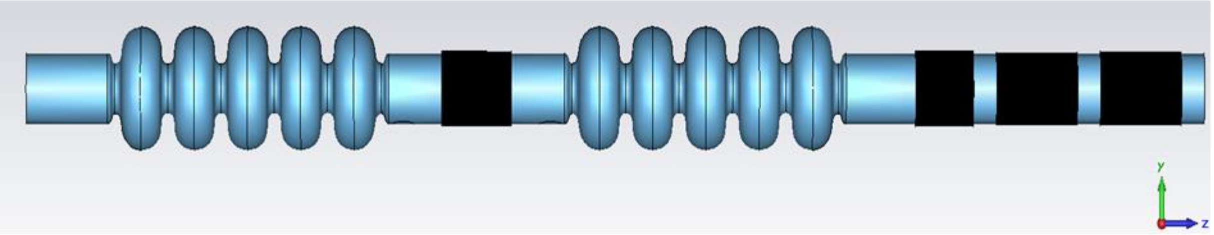


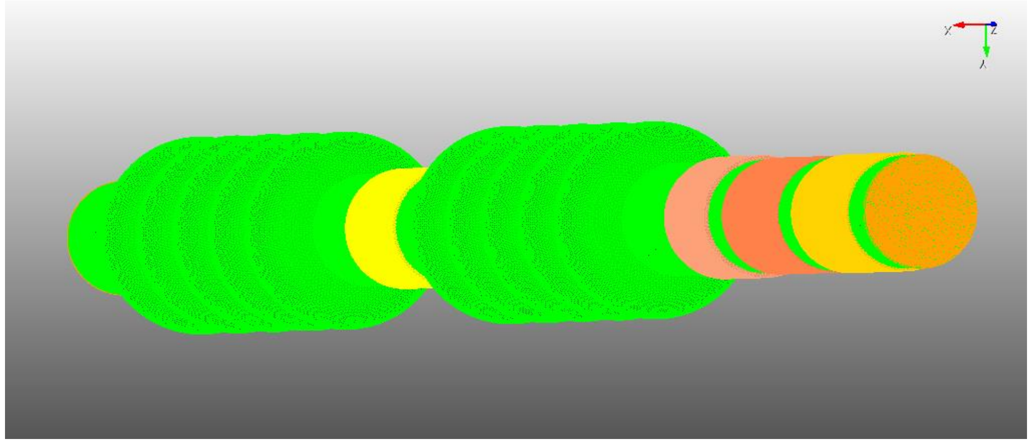
Conclusion: Time domain simulations show good agreement up to 2 GHz. The reason for small differences for frequencies around 4 GHz are under investigation.

HOM Simulations for Arrays of Cavities/Cryomodules

Comparison of time domain spectra from CST and ACE3P

Issue: CST and ACE3P use different frequency dispersion models for the permittivity. We do not yet have close agreement in time domain spectra calculations





The plan is to close out the present work by reconciling CST and ACE3P time domain simulations for structures with lossy dielectrics

Summary

- HOM damping solutions proposed by ANL can be reliably calculated and are relevant to 5-cell ERL SRF cavities

- An option using only beamline absorbers is possible. It will require cold absorbers placed between cavities inside the cryomodule

- We show that a combination of double-ridge waveguides and beamline absorbers is the most conservative solution to damp dangerous dipole and monopole modes

- ANL has performed HOM simulations on supercomputers at NERSC and ANL based on Ace3P
  - Greatly reduced simulation times; much better reliability at higher frequencies

- HOM damping will be critical for a reliable EIC; ANL is eager to integrate HOM work, into ***e.g.*** a harmonic cavity cryomodule for EIC bunch lengthening (see talks at 2018 EIC Workshop)

Backup

R&D Tasks

Schedule	Major Deliverables	Priority Task	**Panel Priority**	**Panel Sub-Priority**
FY17 Q3	Estimate HOM impedances and dissipation power for the full cavity, HOM damper system in the waveguide HOM.	11	**High**	**B**
FY17 Q4	Estimate HOM induced dissipation power separately in the waveguide HOM damper loads and in the SiC beamline HOM absorbers	11,12	**High**	**B**
FY18 Q1	Optimize beamline absorber geometry using ‘dielectric resonator effect’ Establishment of a large scale computing capability using ACE3P for HOMs on NERSC cluster	3,11,12	**High**	**A,B,B**
FY18 Q2	Establishment of similar capabilities on ANL clusters	3,11,12	**High**	**A,B,B**
FY18 Q3	HOM simulations for a 4-cavity system using ACE3P and comparisons to CST	3,11,12	**High**	**A,B,B**
FY18 Q4	HOM simulations of larger problems and higher frequencies	3,11,12	**High**	**A,B,B**