Design of HOM Damping for High Current SRF Cavities for Electron Ion Collider (eRHIC) at BNL (ANL / BNL / LBNL Collaboration)

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Outline

- ❑ Project Description, Goal & Budget
- ❑ Highlights - HOM Damping in the APS-U High Harmonic Cavity
- ❑ HOM Damping in eRHIC ERL Cavities
- ❑ Current Status of the Project
- ❑ Proposed Future Work
- ❑ Summary

Project Goal - Description

- This project started in FY-16, the goal is to design, fabricate and demonstrate a high power, full spectrum HOM damping scheme for the eRHIC ERL SRF cavities. (Priority row #11 in the Jones report)

- A combination of dual-ridge waveguides with room-temperature RF loads for low frequency HOMs and room-temperature beamline HOM absorbers for high frequency HOMs is being investigated

- ANL's Physics Division has significant experience with the development of beamline HOM absorbers for the Higher Harmonic Cavity (HHC) for the Advanced Photon Source Upgrade (APS-U).

- ANL's focus / contribution is on the room-temperature beamline absorbers and RF windows for the waveguides.

Budget Summary & Expenditures For FY16-17

	FY16+FY17	Total
Funds allocated	80k+44k	$124k
Actual costs to date	75.6k+0k	$75.6k

✓ FY-17 Milestones, using FY-16 funds

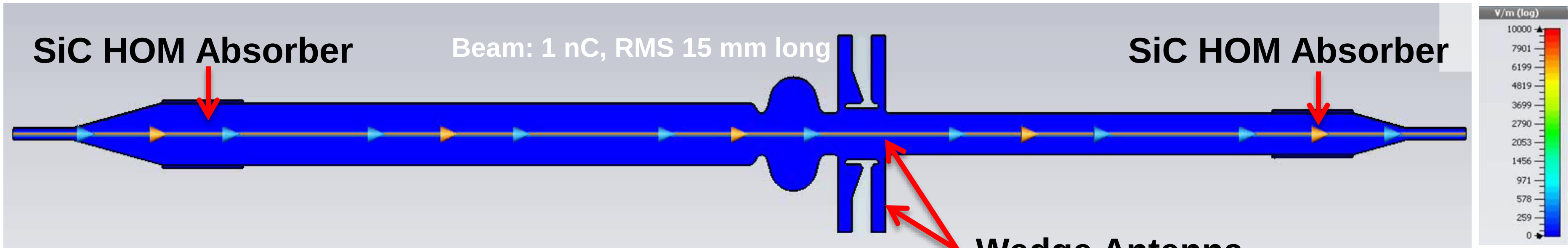
Quarter	Milestones
Q1FY17	Optimize the silicon carbide (SiC) HOM absorber dimensions for the BNL cavity taking into account direct interaction of the beam with the SiC and the "dielectric resonator" effect of the SiC
Q2FY17	Optimize the geometries of the cavity HOM coupler assemblies with respect to trapped modes in the waveguide couplers.
Q3FY17	Estimate HOM impedances and dissipation power for the full cavity, HOM damper system in the waveguide HOM.
Q4FY17	Lower resolution simulations for all higher frequency HOMs which propagate through the beam tube.

HOM Damping in APS-U HHC

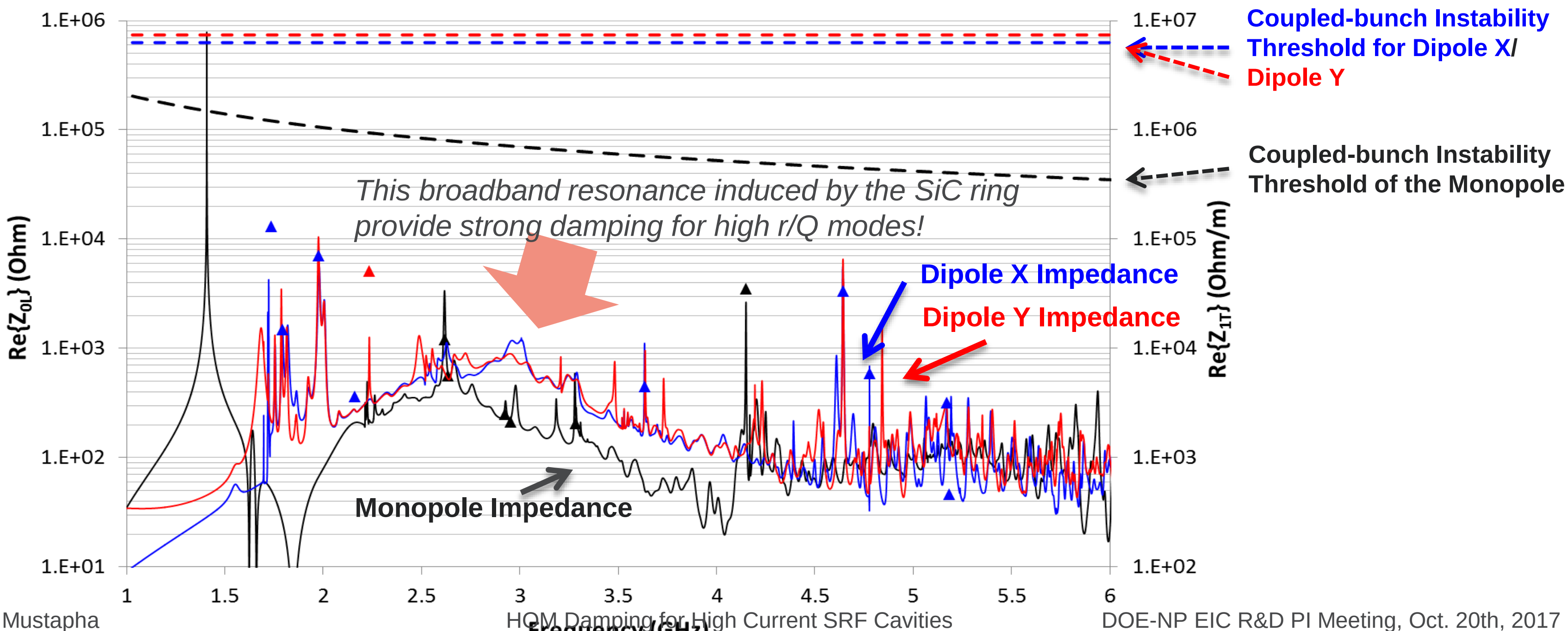
HOM Damping in APS-U HHC

✓ Silicon Carbide (SiC) beamline HOM absorbers and wedged coupler antenna

Animation: Wake Induced by Single Bunch

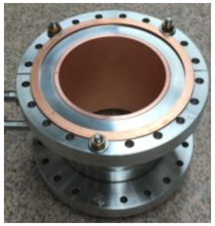


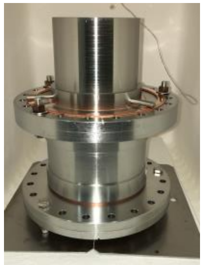
Monopole and Dipole Impedances Compared with Instability Threshold

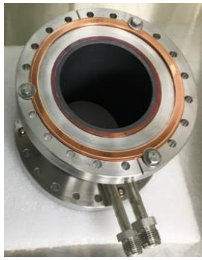


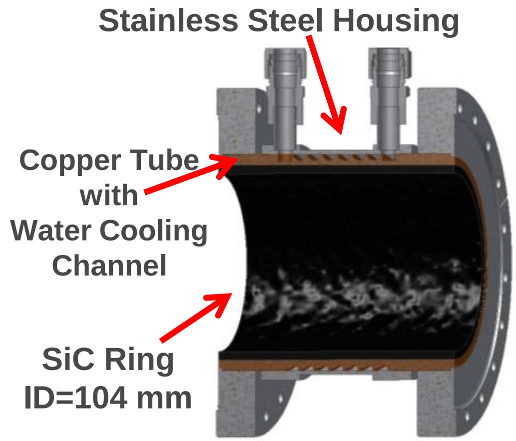
HOM Absorber - SiC

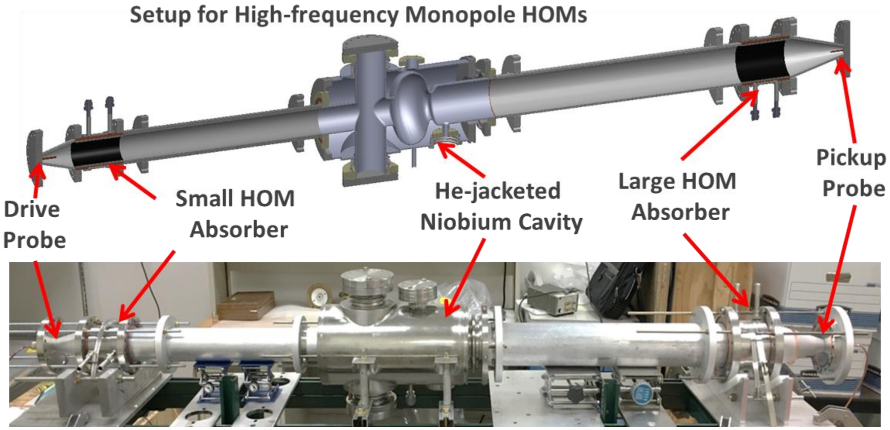
- Estimated dissipation power = ~1 kW per each side; it is located at room temperature and water-cooled
- Material: Graphite-direct-sintered SiC, Coorstek SC-35, the same one used by Cornell (Courtesy of R. Eichhorn)
- Shrink fit with 0.1 mm interference, chosen based on mechanical analysis
- HOM damping tests at room temperature
  - Damped Qs are 700 or less and they are dominated by the SiC so same damping is expected in the real cryomodule
- Thermal tests with a radiative heat source
  - Temperature rise on the SiC inner surface = 2°C at 1 kW

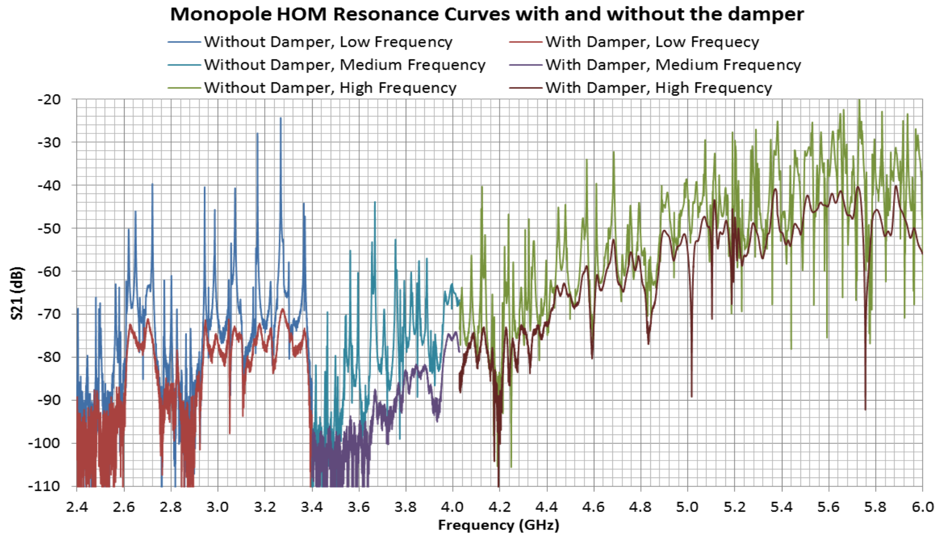






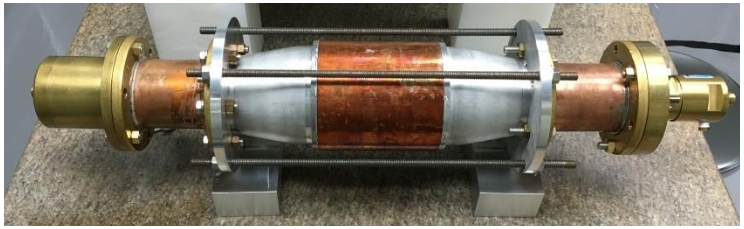


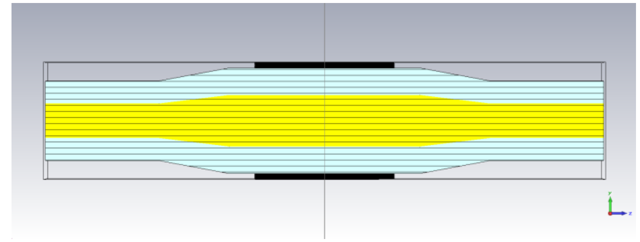


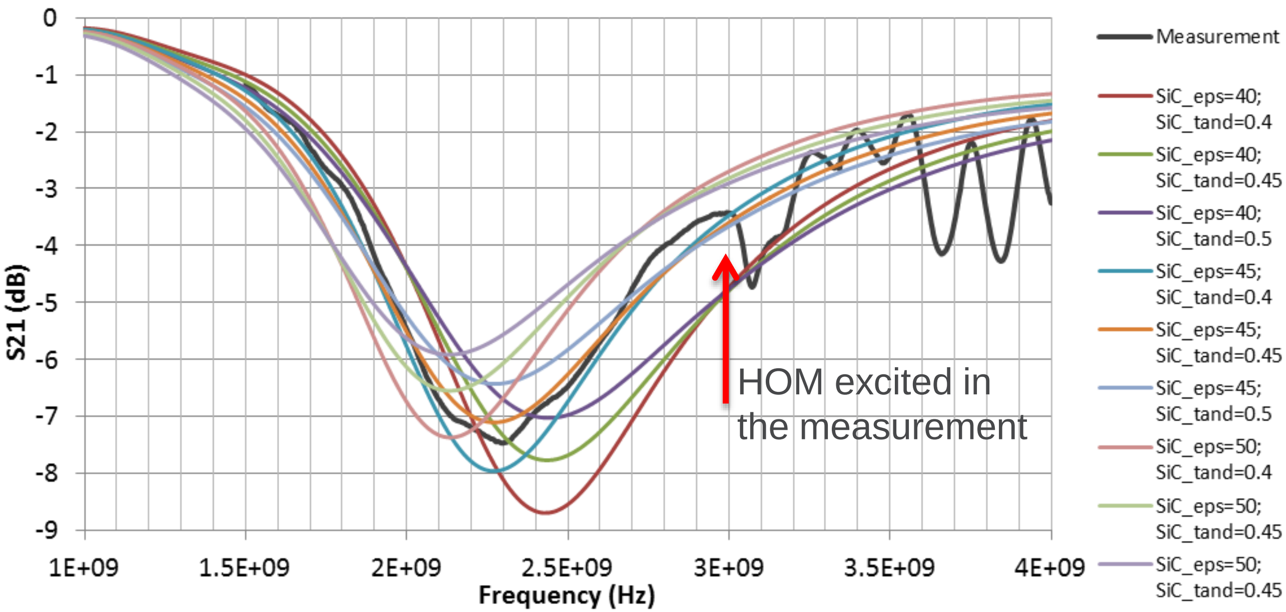


Measured Properties of the Absorber Material - SiC

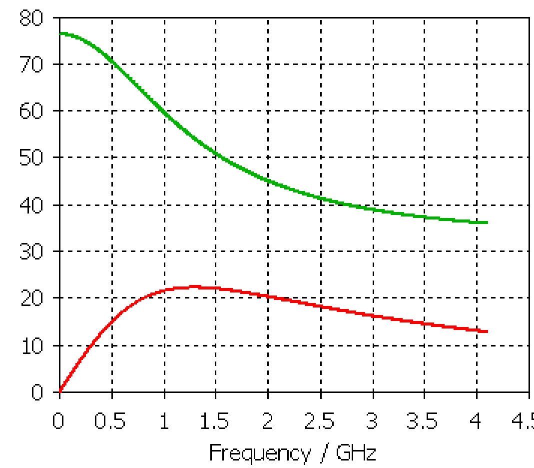
✓ Characterized empirically based on Transmission Spectrum along a Coax







Real (green) and imaginary (red) permittivity values used in CST*



* CST input:
epsilon=45, tan del.=0.45 @ 2 GHz
N=1 constant tan del. fit

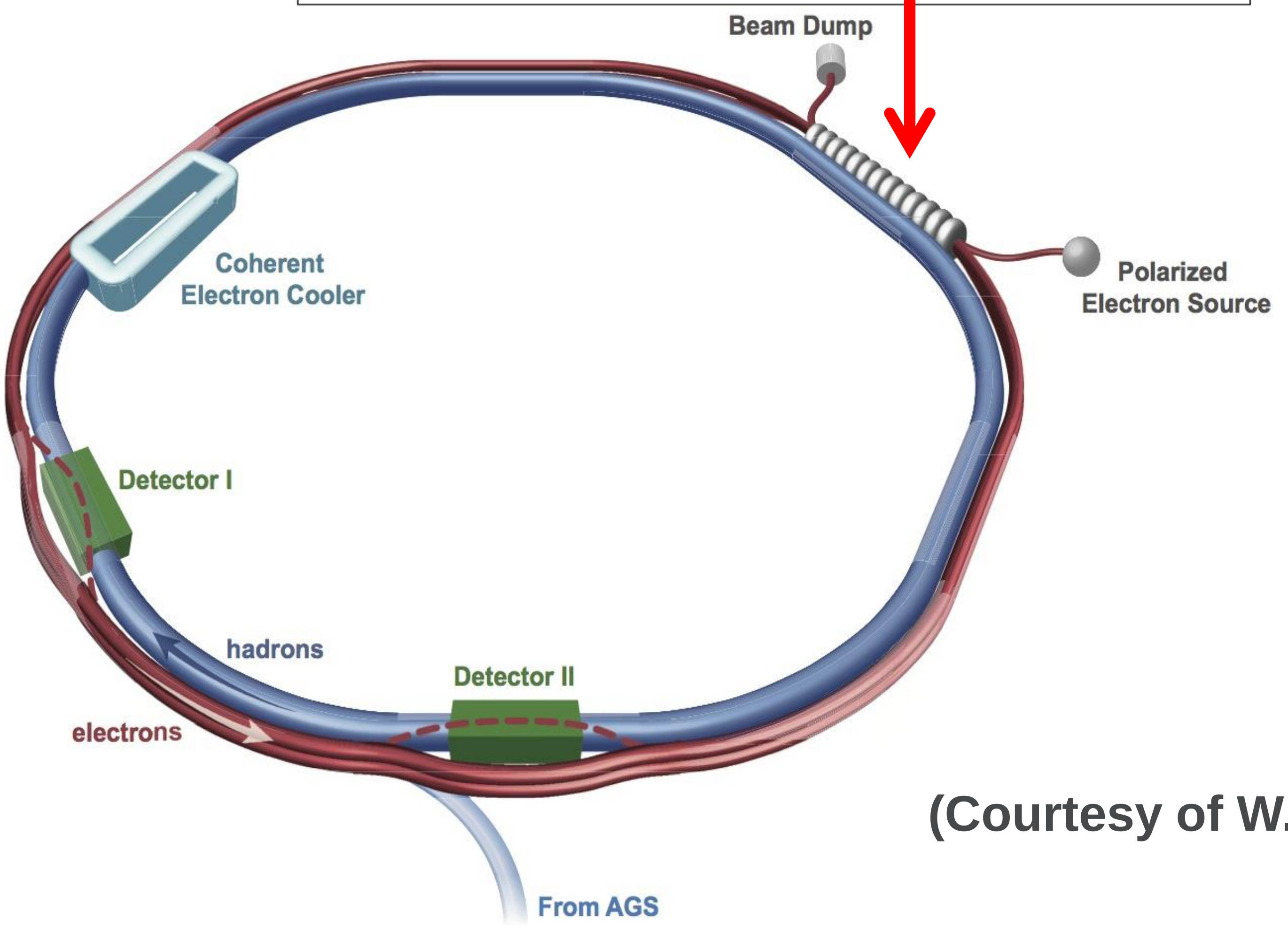
***Reflection is negligible so most of the insertion loss is due to dissipation in the SiC**

- Coorstek SC-35 Cylinder: ID=103 mm, thickness=5 mm, Length=135 mm (APS-U - HHC)
- Closest to the measurement: epsilon=45, tan delta=0.45

HOM Damping in eRHIC ERL

Concept for eRHIC ERL - Linac-Ring Option

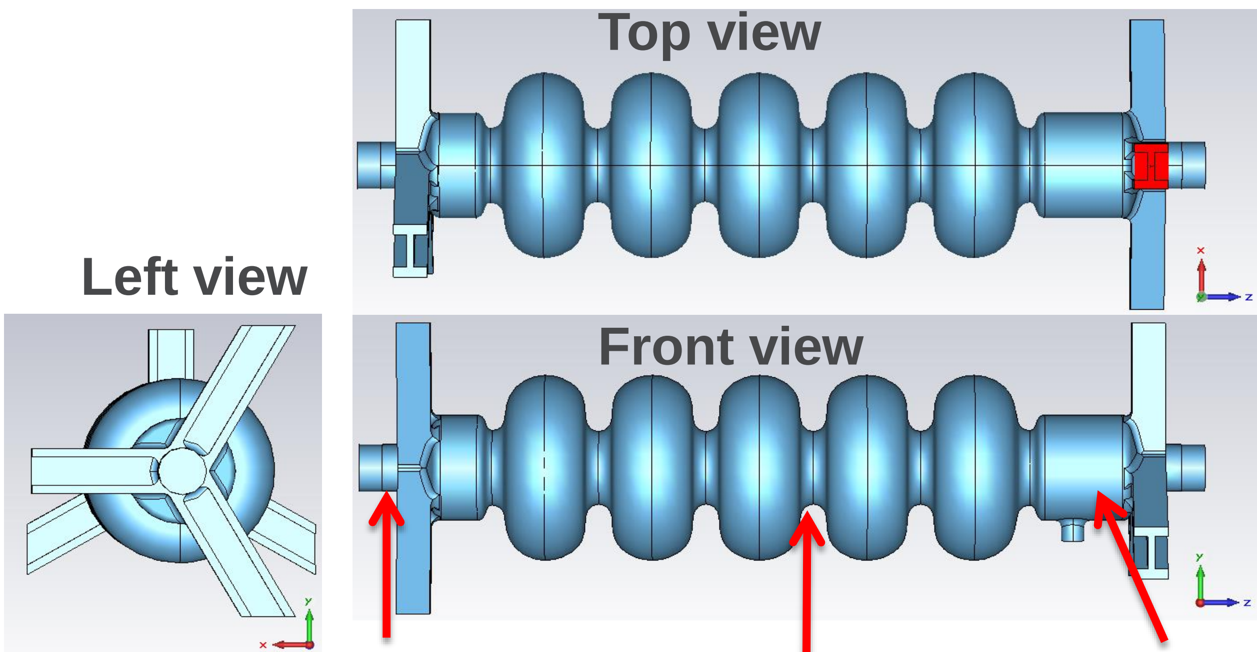
- 1.67 GeV/pass Energy Recovery Linac
- 80 x 647.4 MHz 5-cell–SRF Cavities
- Available tunnel space: 200 m



(Courtesy of W. Xu)

Original Damping Concept: Double-Ridge Waveguides

647 MHz 5-cell cavity with double-ridge waveguide HOM dampers

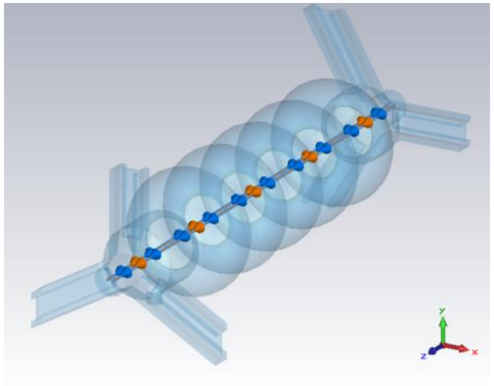


ø103.9 mm
$TE_{11,c}$=1.7 GHz
$TM_{01,c}$=2.2 GHz

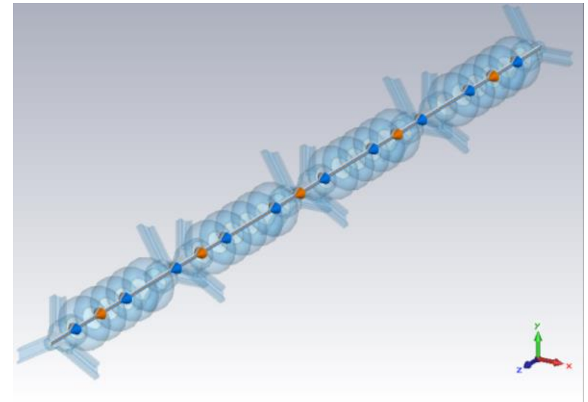
ø157.8 mm

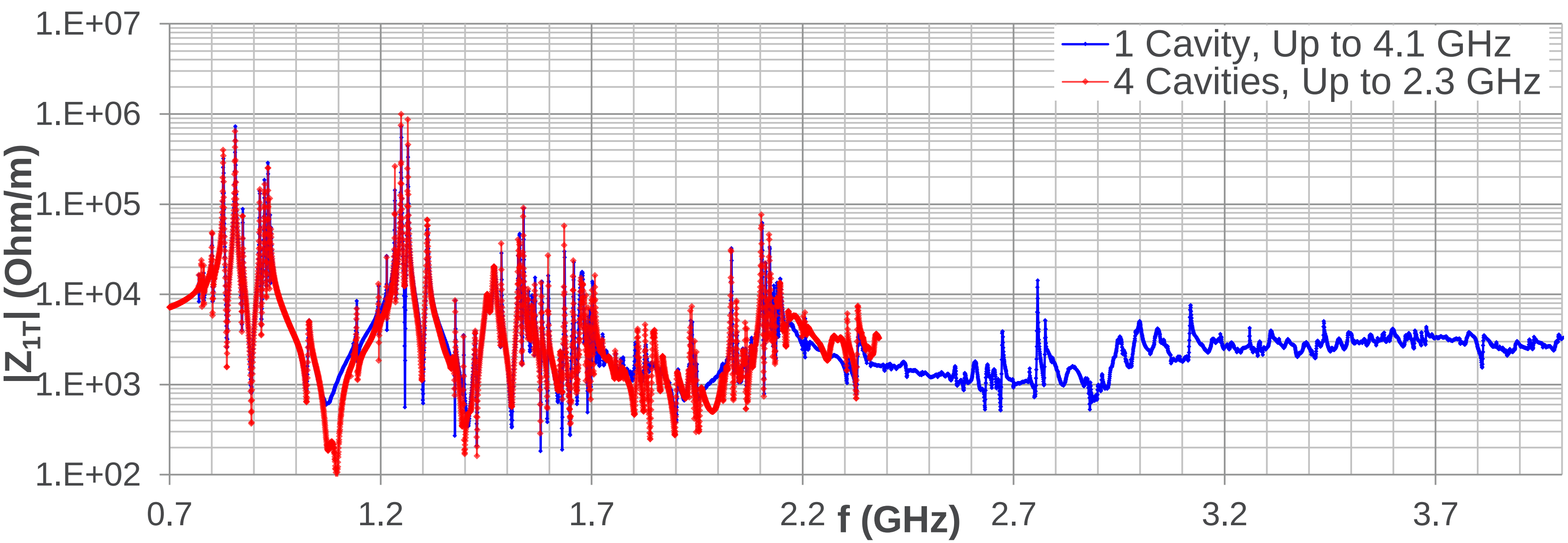
ø234.0 mm
$TE_{11,c}$=0.75 GHz
$TM_{01,c}$=0.98 GHz

Dipole Modes: 1 Cavity vs. A string of 4 Cavities



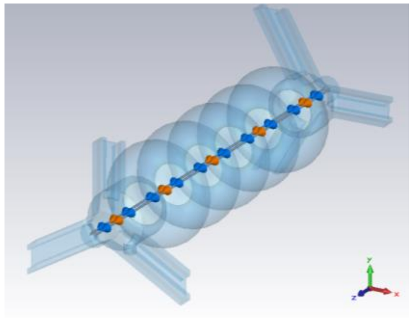
Each beam pipe end is equivalent to an 'ideal' beam line HOM absorber, but not between cavities

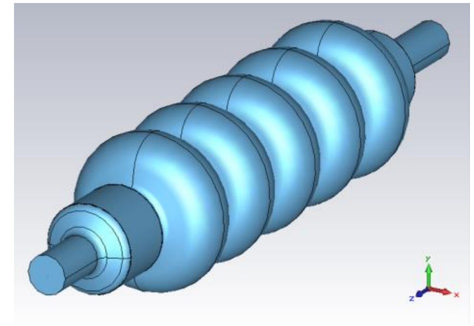


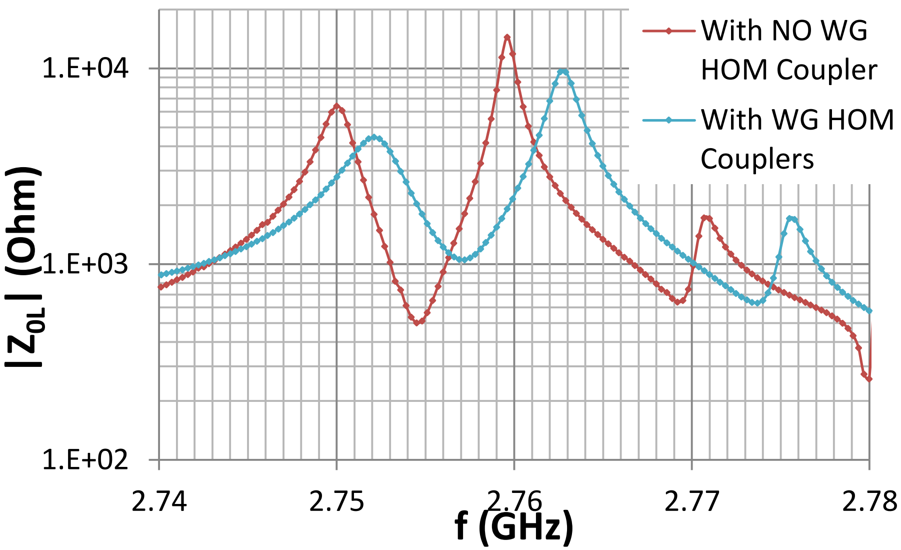


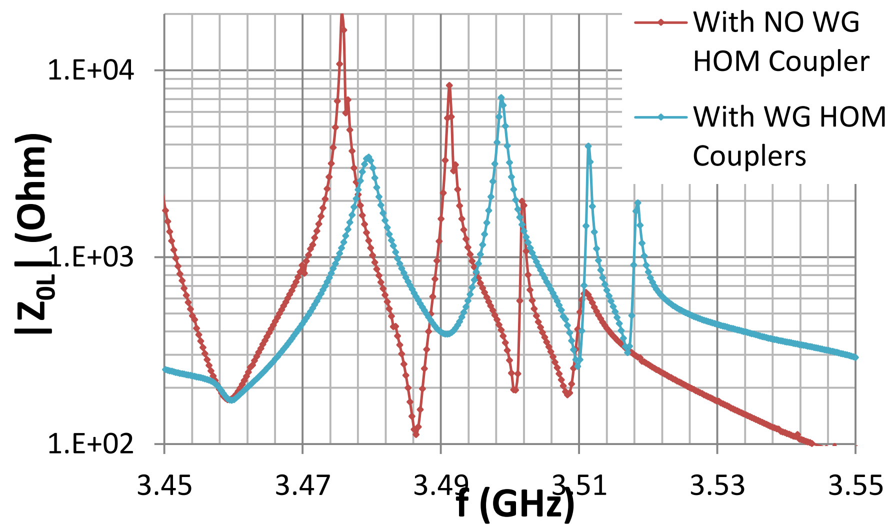
✓ Above 1.7 GHz, more impedance structure appear in the 4-cavity string due to inter-cavity HOM coupling, but the peaks still 2 orders of magnitude below limit

Monopole Modes: With & Without WG Dampers





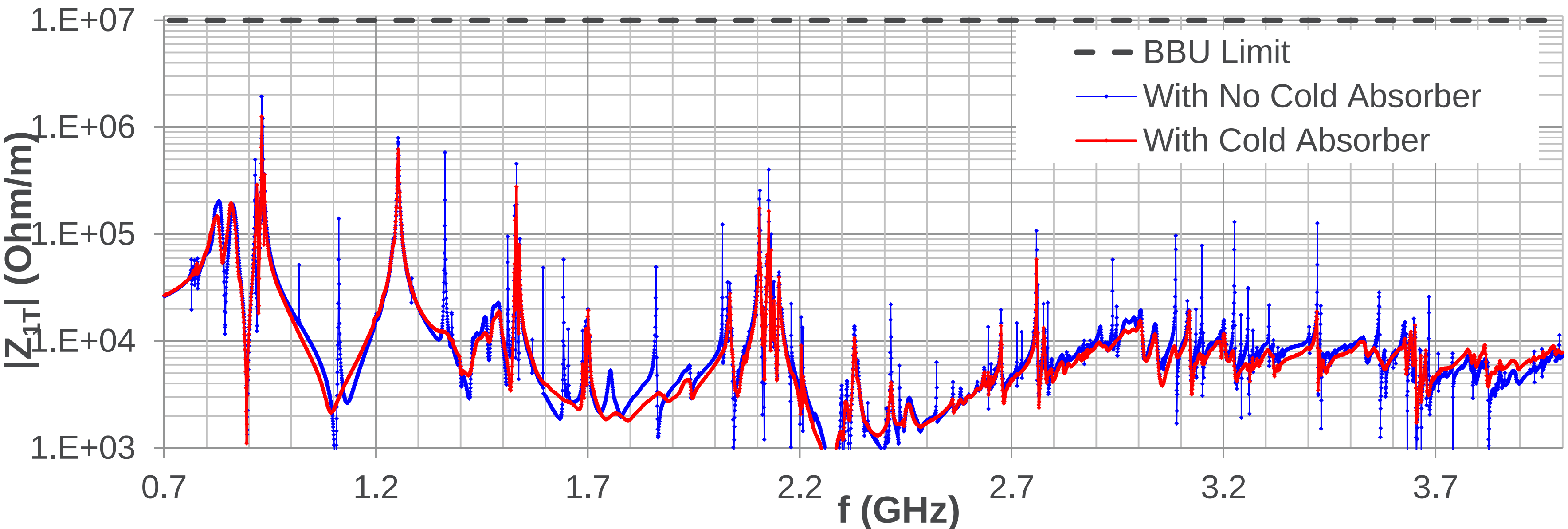


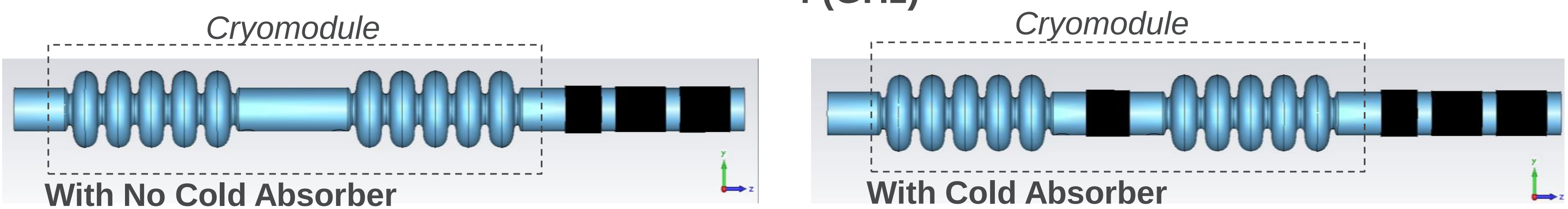


✓ Several HOMs are weakly coupled to the WG HOM coupler; the beamline HOM absorbers should help reduce the wall loss on the HOM coupler waveguide as well as the dissipation power in the matched loads

Beamline HOM Absorbers as An Alternative

Dipole Impedance: Using Only Beamline HOM Absorbers





- ✓ HOM damping with only beamline HOM absorbers can provide sufficient damping as required by the BBU threshold; cold absorber is necessary to avoid potential trapped modes
- ✓ The lengths of the HOM absorbers in this solution are ‘ideal’; they were chosen such that the S21 is so low that the inter-cryomodule HOM coupling can be ignored. Since there is still one order of magnitude in peak impedances, these absorbers could be shortened

Project Status - Summary

- Double-ridge Waveguide HOM Couplers: no problematic inter-cavity HOM couplings are observed in the simulated frequency range, and it is not expected that will happen at higher frequencies.

- Beamline HOM absorbers are necessary because some monopole modes above the beam pipe cutoff are not strongly coupled to the waveguide HOM couplers.

- Beamline HOM Absorber Only option is possible with an absorber at the cold beam pipe. An initial solution have rather long section of the HOM absorbers.

- These lengths could be reduced with further modeling and simulations.

- Future work focus will shift to apply to ERL for hadron cooling (priority row #2) and the electron storage ring for the Ring-Ring option (row #12)

Proposed Future Work

Future Work

- These simulations were performed using the CST software on a local computer cluster (64 CPUs – 256 GB RAM).
- Some of these simulations took a week to 10 days to complete.
- The limitation is both in speed and scope. Simulations were limited to ~ 5 GHz frequency range and to one or two cavities problems.
- We propose to use the Ace3P software developed at SLAC on one of the large computers at ANL in order to be able to solve problems with multiple cavities and cryomodules up to at least 10 GHz in frequency.
- As a first step, we will use the Ace3P software on the NERSC cluster to re-produce and benchmark using CST results, then start simulations for a whole cryomodule of 4 cavities and more and develop HOM solutions …

Future Work – Expected Speed-Up

	Software	Computer	Parallel CPUs	Memory	Typical Longitudinal dimension	Speed factor	EIC Run Time
PHY cluster	CST	CST cluster	32	256 GB	2 meters	30	30 days
Proposed	ACE3P	Cetus@ANL	65,536	65 TB	100 meters	60,000	30 min

- HOM interactions between complex accelerating and damping structures separated by distances of 10's of meters – such as in an ERL or electron storage ring - can only be studied using supercomputers.

- ANL will use this capability to optimize HOM damping parameters to make use of the ANL dielectric resonator HOM damper effect as demonstrated for the APS-U HHC.

Summary

- HOM Damping studies were performed for the eRHIC ERL SRF Cavities - Linac-Ring Option
- It was shown that a combination of double-ridge waveguides and beamline absorbers is the best solution to damp most dangerous dipole and monopole modes
- A beamline absorber only option is possible but will require cold absorbers placed between cavities inside the cryomodule
- Future work will focus on HOM damping in ERLs for hadron cooling and electron storage rings – applicable to both eRHIC and JLEIC
- To extend the scope and speed-up the simulations, the Ace3P software will be used on supercomputers at NERSC and ANL.