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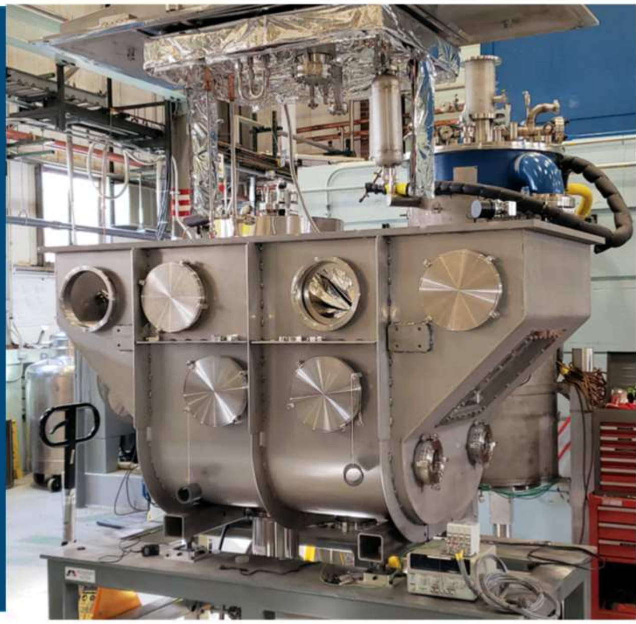
Bunch Lengthening System & Application to EIC

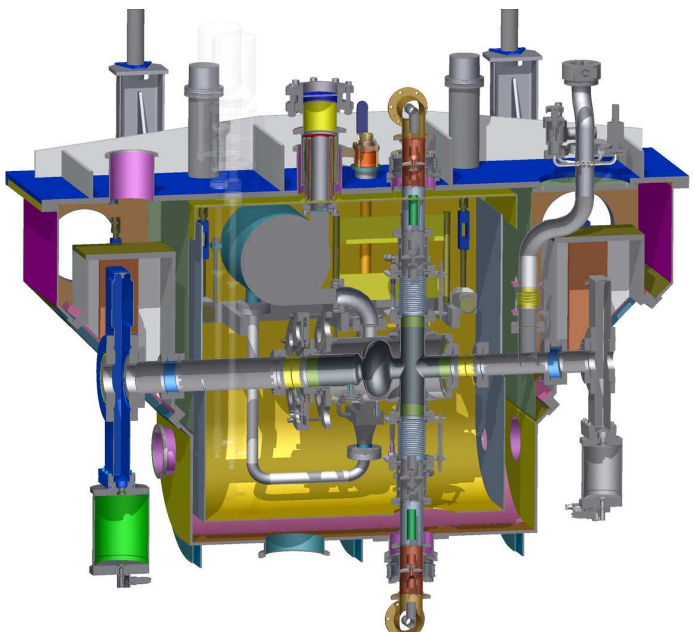


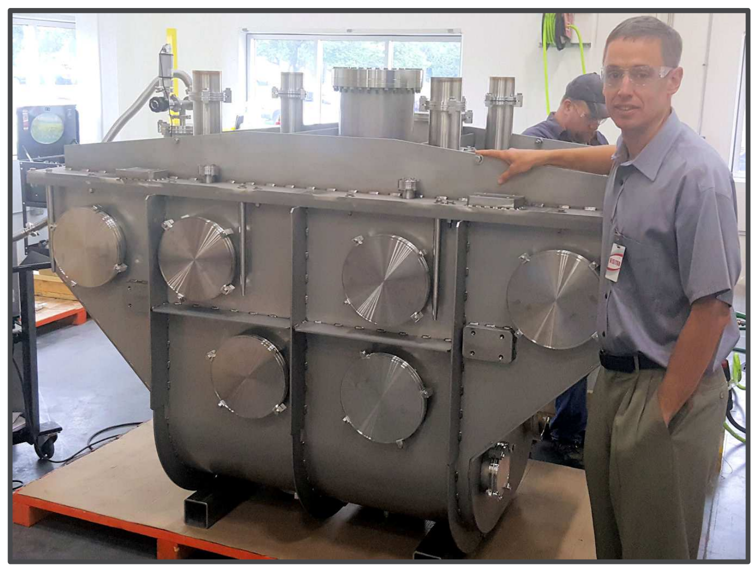
Michael Kelly
Accelerator Development Group Leader, Physics Division, Argonne National Laboratory

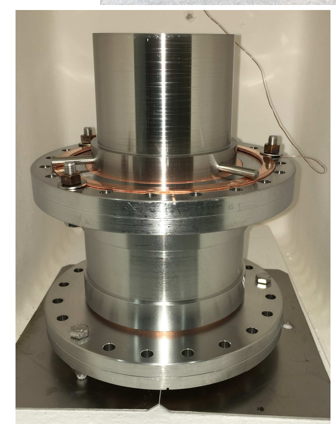
EIC Accelerator Collaboration Meeting

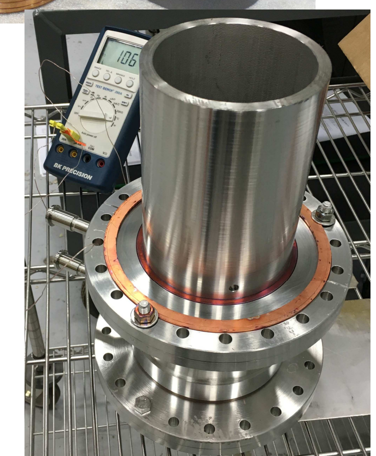
Thursday October 10, 2019

Bunch Lengthening Harmonic Cavity System For APS-U Electron Storage Ring



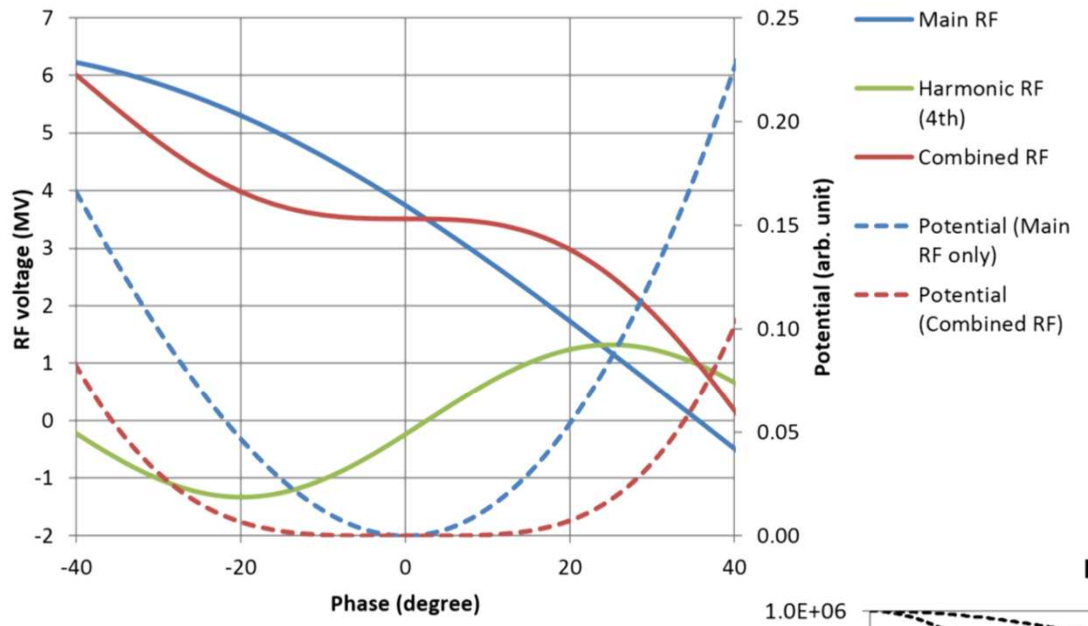




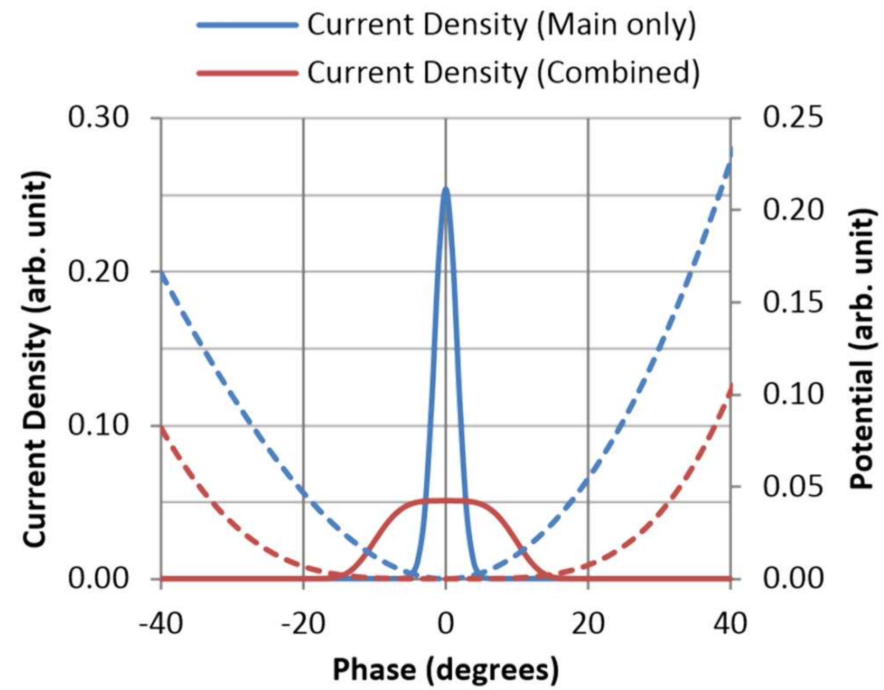


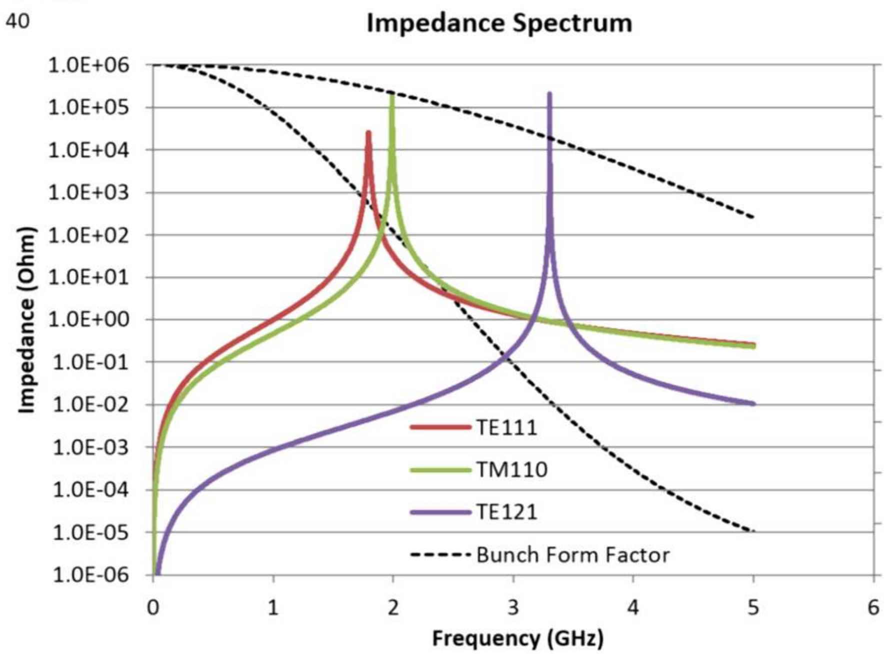
Bunch Lengthening: Simple Picture

Combined Main RF & Harmonic Voltage



Bunch Lengthening in Combined Potential





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Bunch Lengthening System Introduction

- Concept spring 2014: One superconducting harmonic cavity in the APS-U storage ring
  - ***Reduces Touschek effect, increases the beam lifetime***, providing a practical benefit to the majority of APS users
  - ***Reduces beam heating***
  - ***Other potential reasons for EIC: bunch linearization, mitigation of gap transient issues?***
- Compact: fits within less than ½ of an APS-U 5-meter straight section – Sector 38
- **Cryomodule**:
  - 1 SC cavity with mechanical tuner
  - 2 adjustable RF power couplers
  - 2 beamline higher-order mode dampers
  - Internal diagnostics (thermometry, level probes)
- **RF system (adjustable coupler)** for ***extracting*** up to 32 kW of beam power
- **LLRF** (mechanical slow tuner frequency control)
- **Liquid helium refrigerator and distribution**: Designed for 50 W into 2.1 K helium at the cryomodule (Linde model LR140)

Bunch Lengthening System Design Parameters

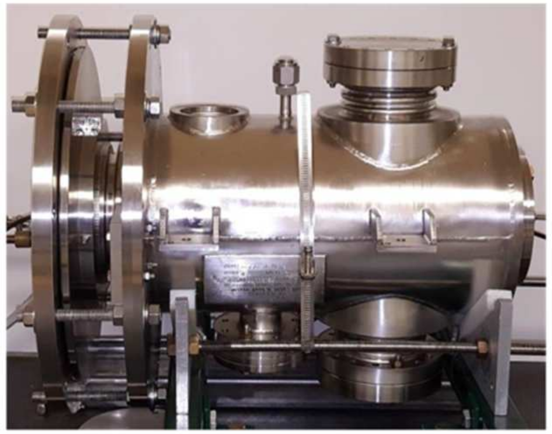
BLS high level system requirements

	Parameter	Symbol	Unit	Value
	Operating Temperature	T	K	2.1
	R/Q	r/Q	Ohm	104
	Cavity Quality Factor (2.1 K)	Q_0		$6x10^9$
	External Q_L range	Q_{ext}		$2x10^5$-$2x10^7$
	Detuning Frequency	Δf_r	kHz	10
High-level requirements	Q_L nominal	Q_L		$6x10^5$
High-level requirements	Cavity Resonant Frequency	f_r	MHz	1408
High-level requirements	Beam-Induced Voltage	V_b	MV	1.25
	Detuning angle	ψ_h	degrees	83.0
	Cavity Loaded Bandwidth	Δf_{BW}	kHz	2.35
	Total Beam Loss Power @ nominal Q_L=$6x10^5$	P_b	kW	25
	Cavity Wall Loss Power (2.1 K budget)	P_{wall}	W	2.5
	Peak Surface Electric Field	E_{peak}	MV/m	24
	Peak Surface Magnetic Field	B_{peak}	mT	49

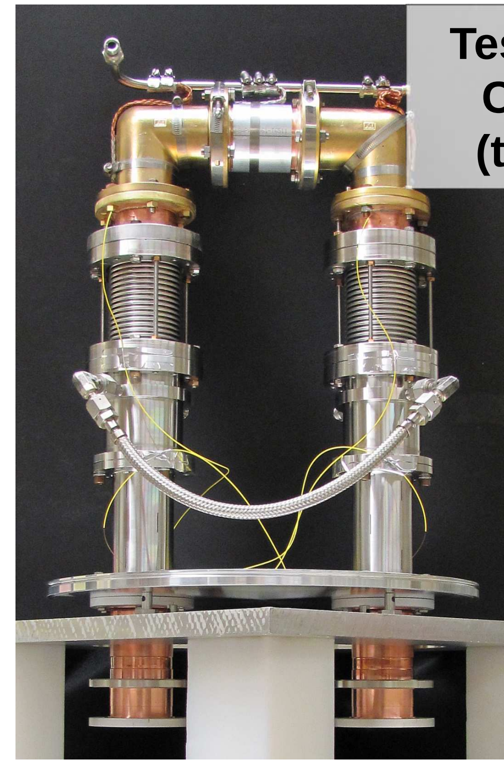
R&D To Mitigate BLS Technical Risks

Testing complete in May 2017; Designs are final; Prototypes will be used in production

1.4 GHz SRF Cavity

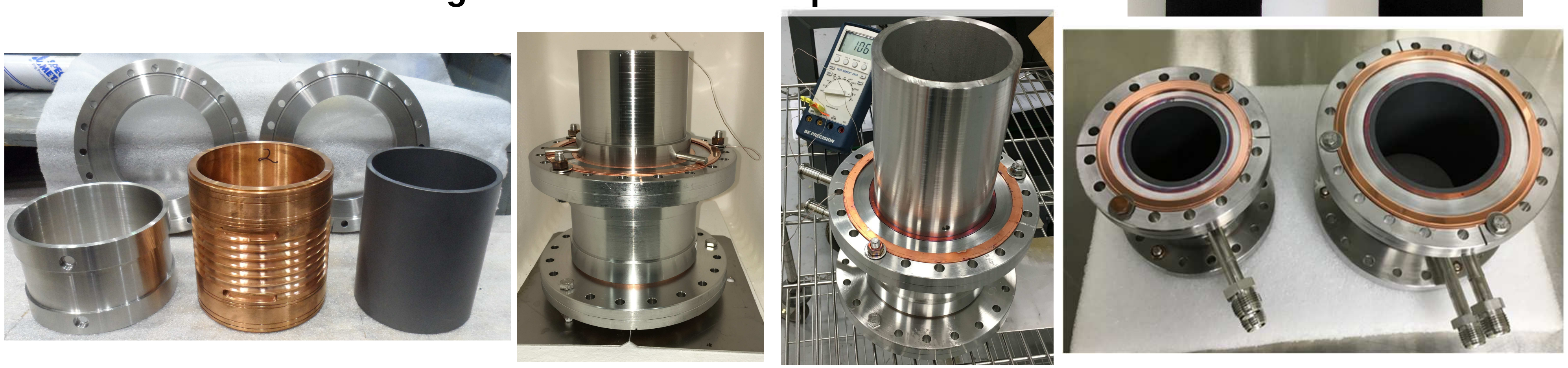


Cavity with pneumatic tuner



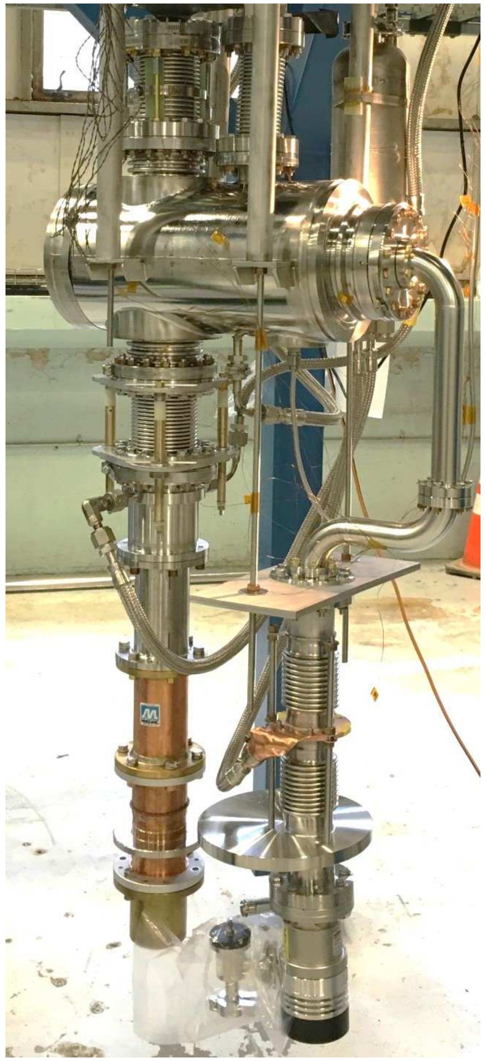
Testing high-power CW RF couplers (tested to 18 kW)

Higher-order mode damper assemblies

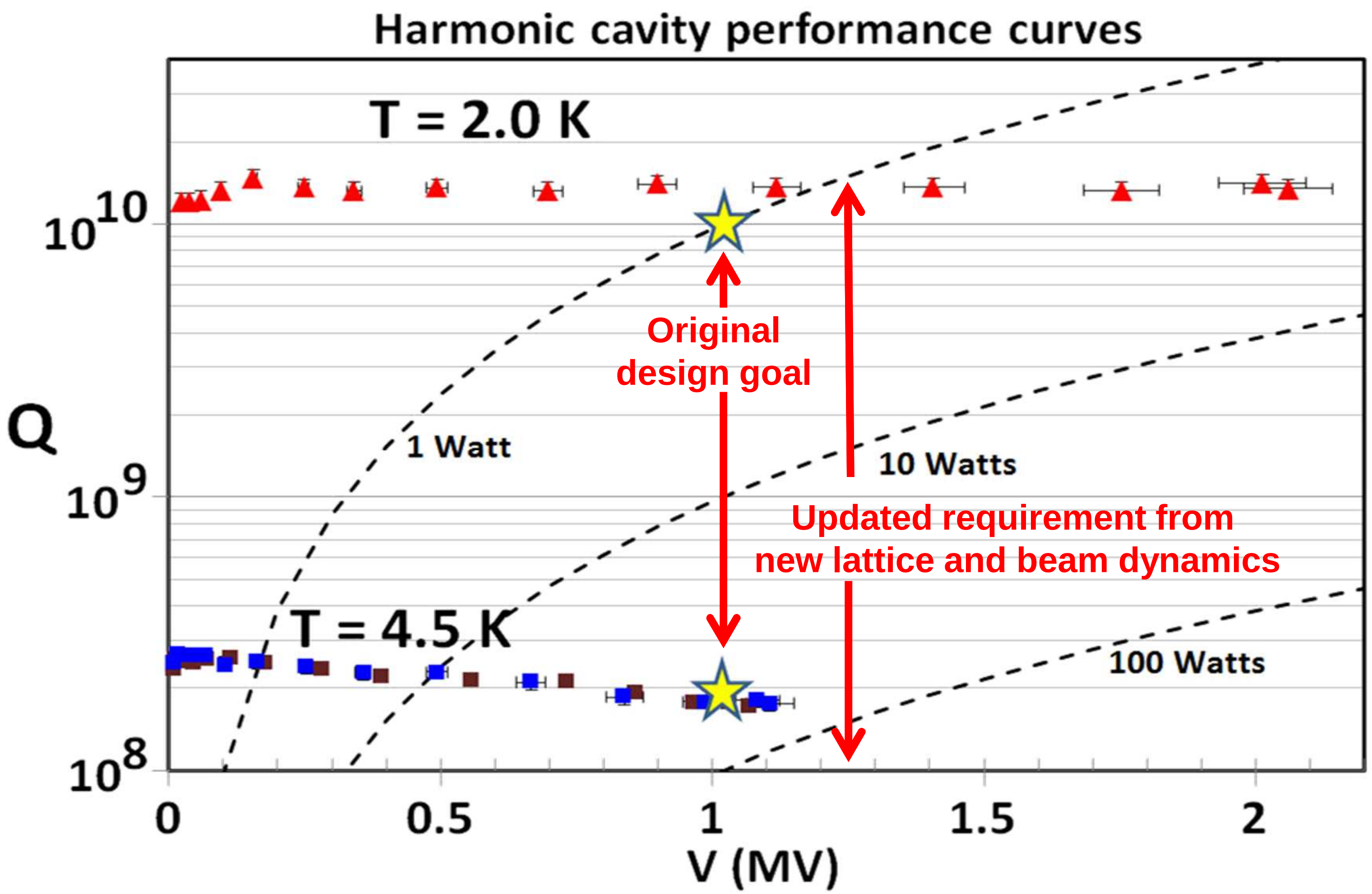


Highlight of the BLS R&D Program

SRF cavity tested and exceeds performance requirements

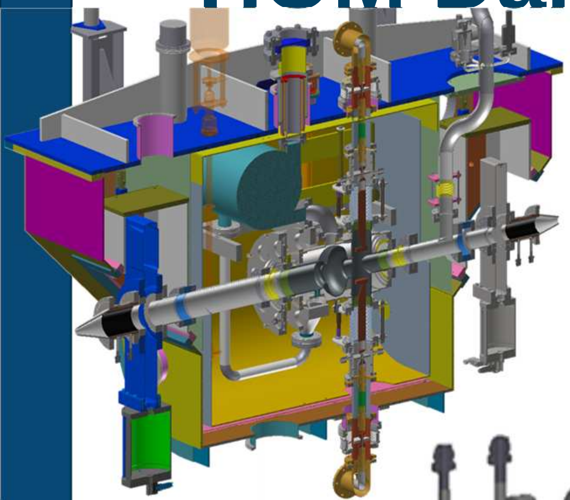


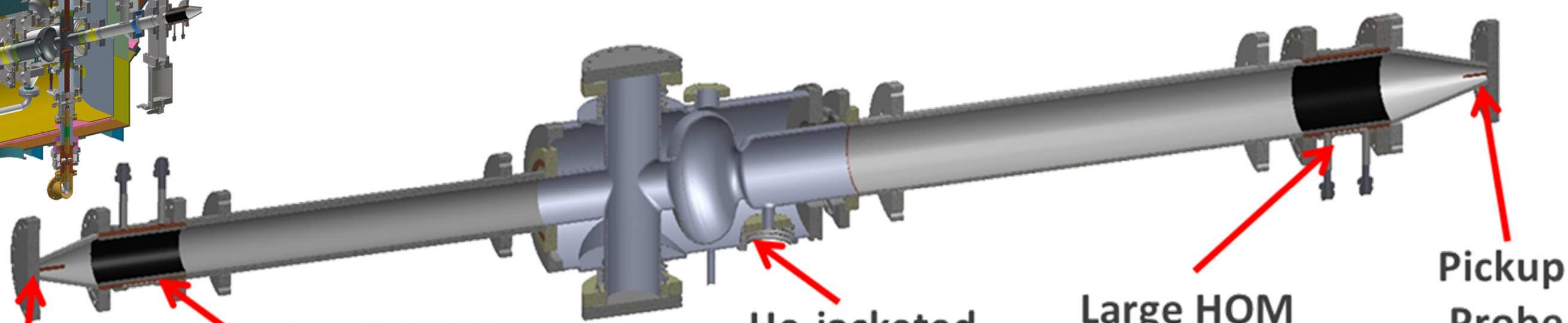
Testing in the Physics Division Accelerator Development Test Facility

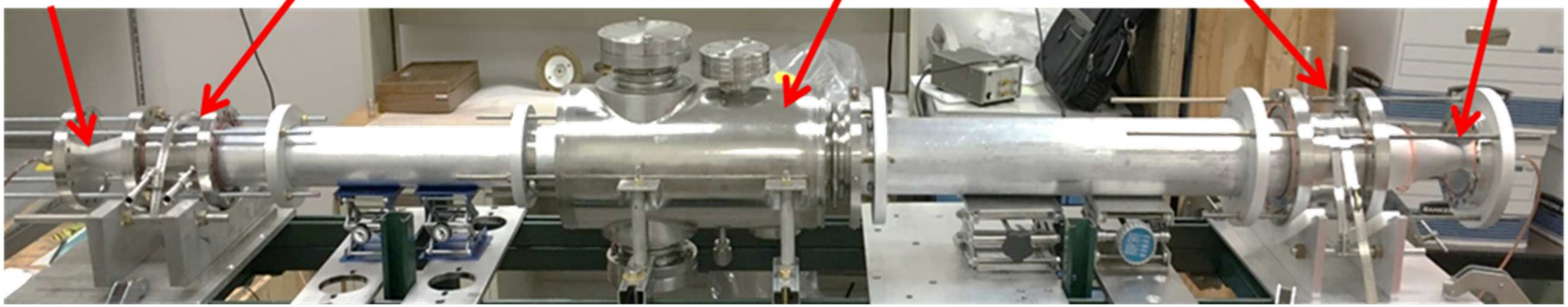


HOM Damping Using a Room Temp Beamline Absorber

1.4 GHz Harmonic Cavity System



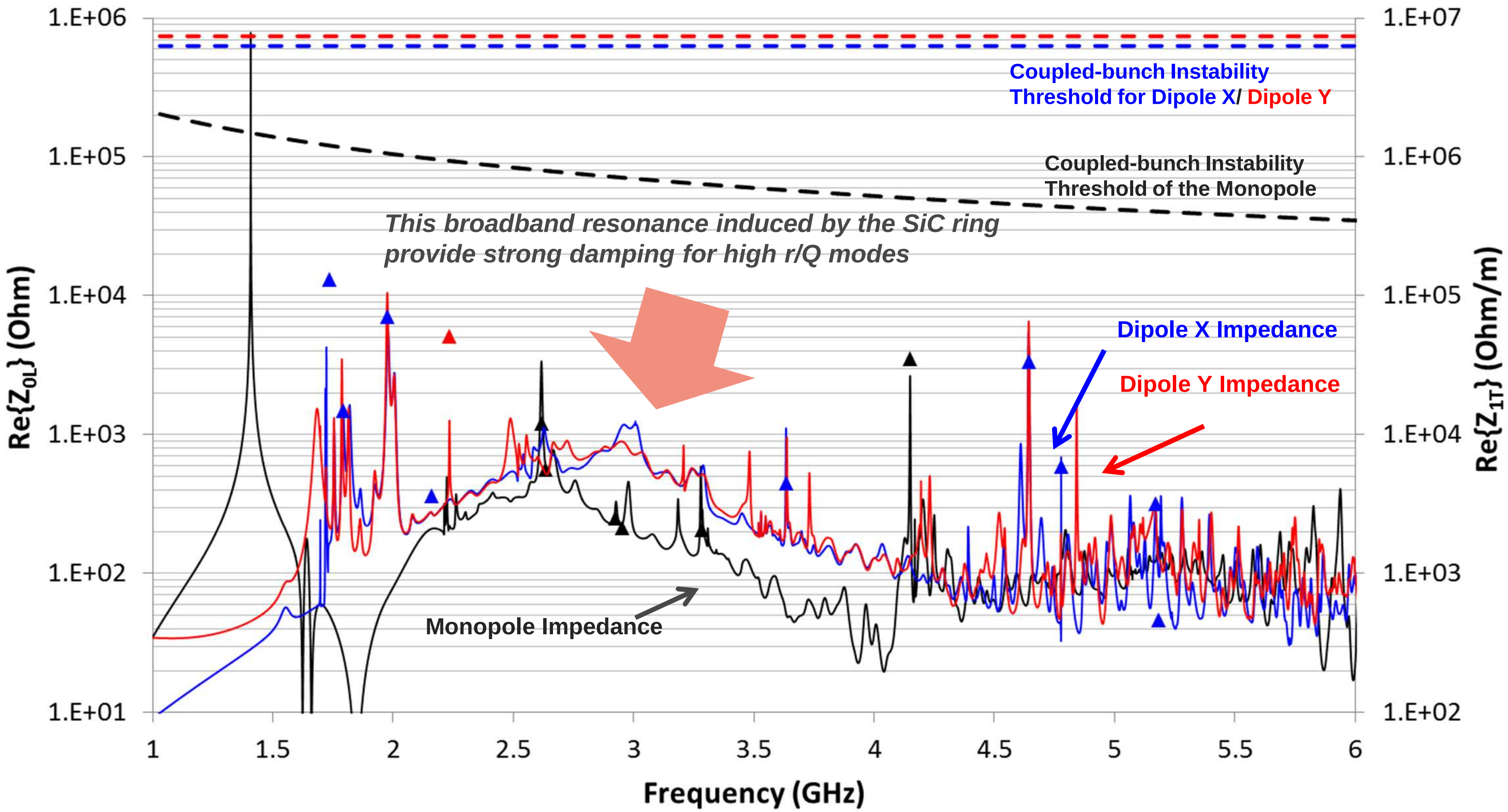




Simulated (CST MWS) Impedance Spectra

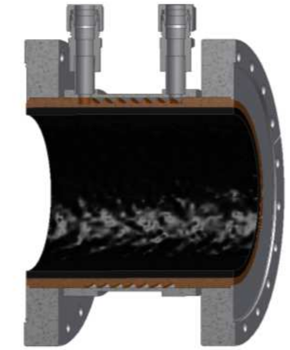
Solid lines – Time Domain   Trianges - Eigenmode

Monopole and Dipole Impedances Compared with Instability Thresholds

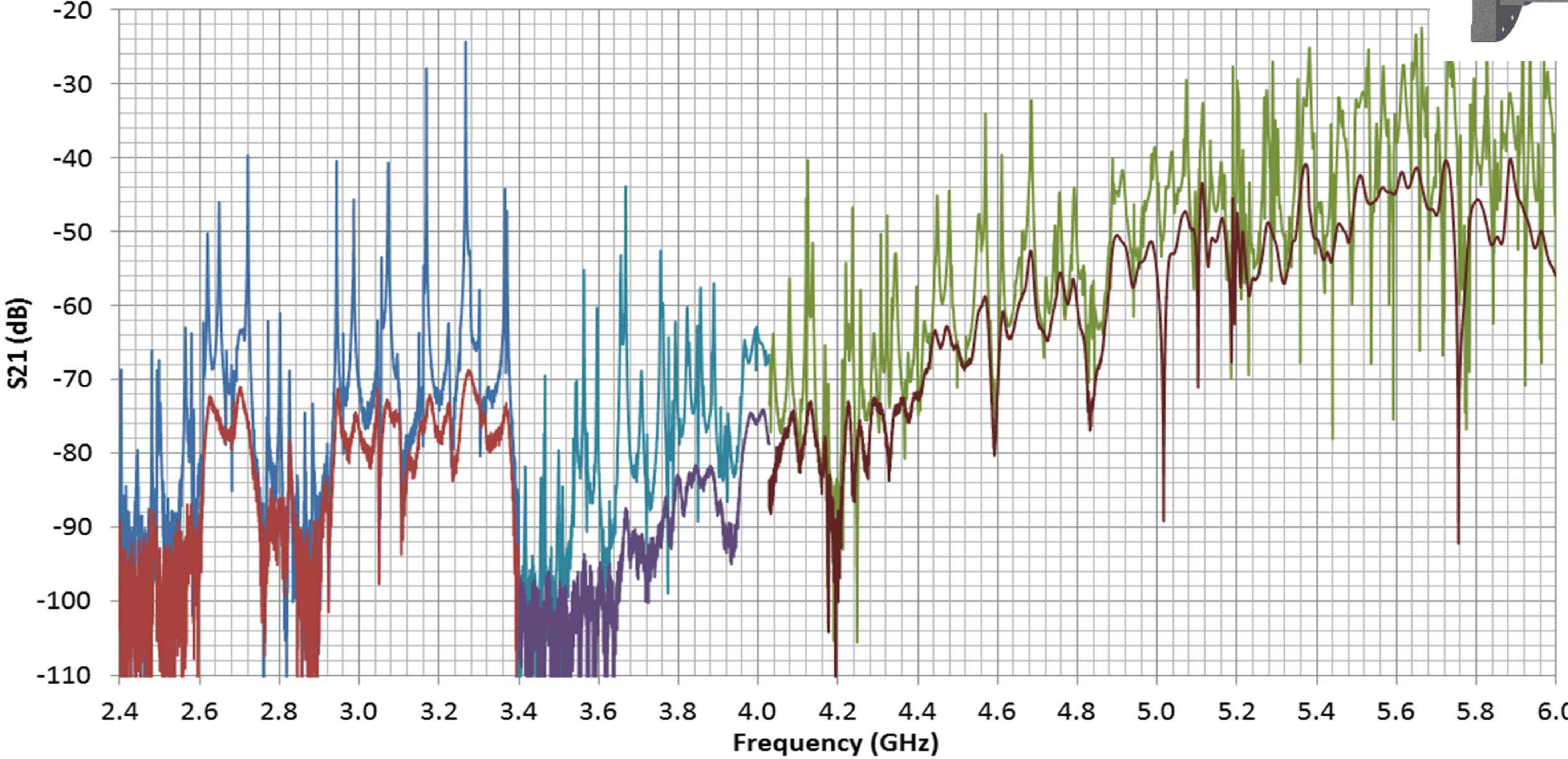


Experimentally Measured HOM Damping

Strong damping for all monopole modes; similar for dipole modes

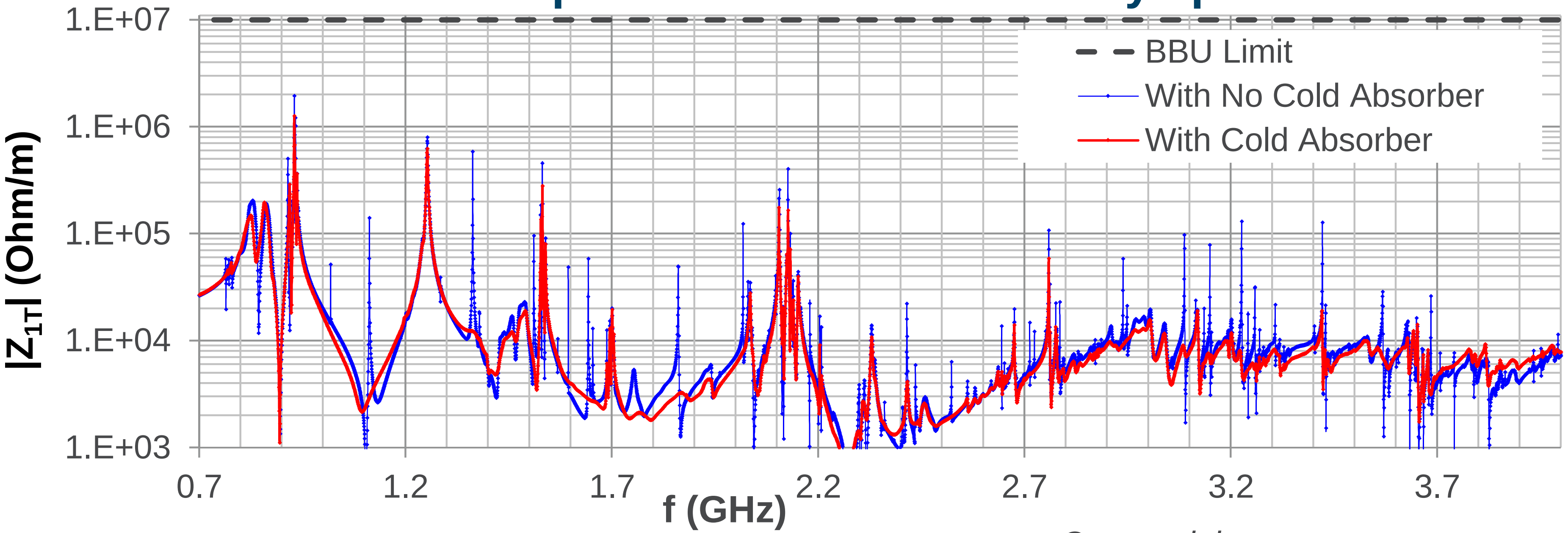


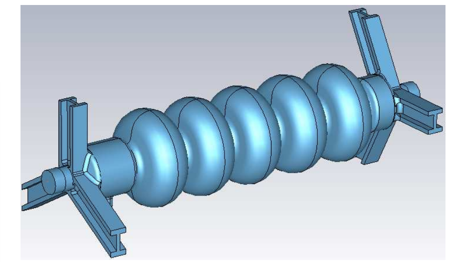
Upper curves – No damper **Lower curves – with damper**



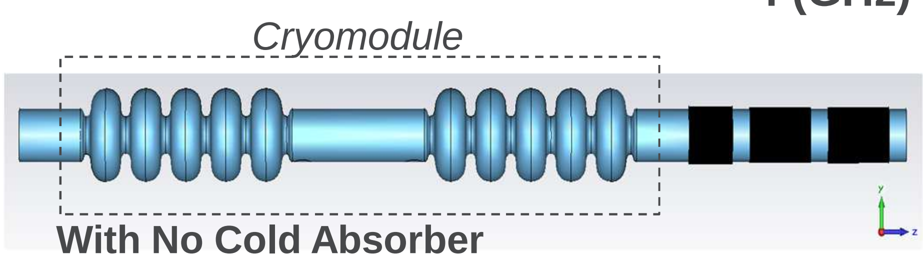
Beamline HOM Absorbers for EIC

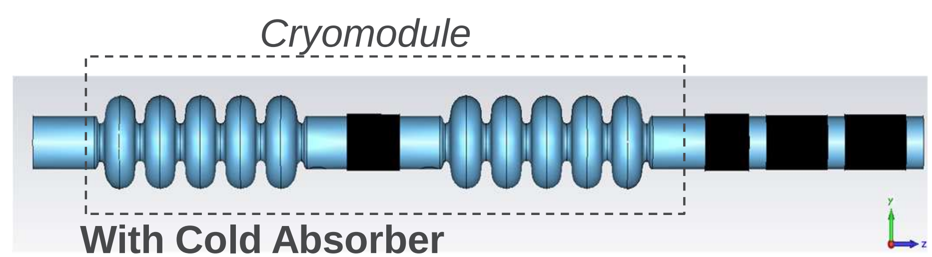
Possible to avoid the complexity involved with ridged waveguides
Does require modification of cavity aperture





'Standard' waveguide coupling





Conclusion: HOM damping with only beamline absorbers can provide strong damping; with multiple cavities per module a cold absorber may be necessary to avoid trapped modes

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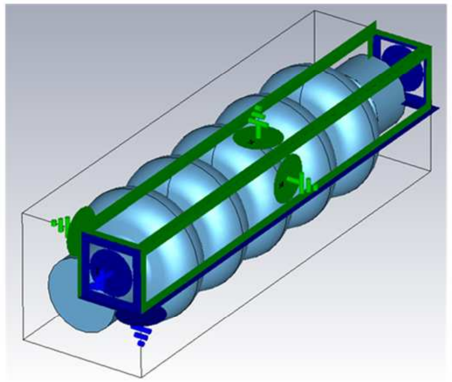
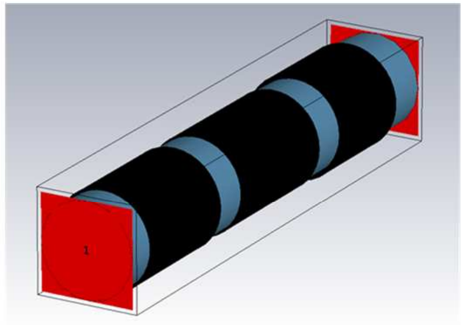
Properties of Beamline HOM Absorbers

Using 'dielectric resonator' effect
Absorbers can be tailored to most harmful HOMs

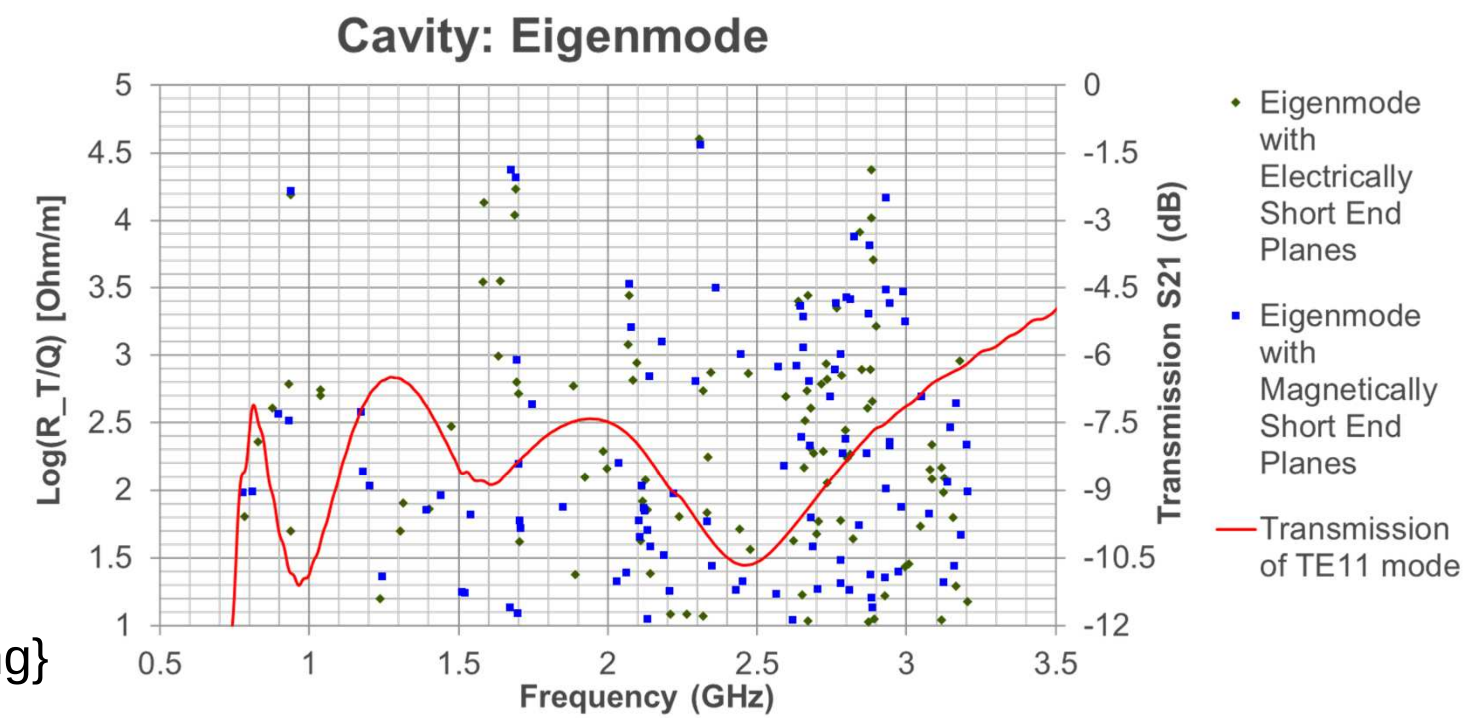
Cavity: Eigenmode



Beampipe with SiC Rings: Transmission Line



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

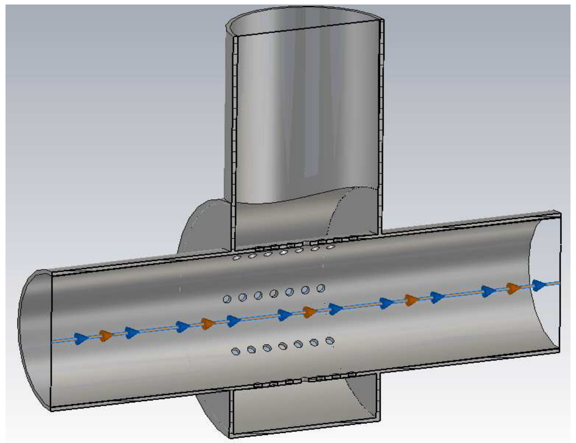


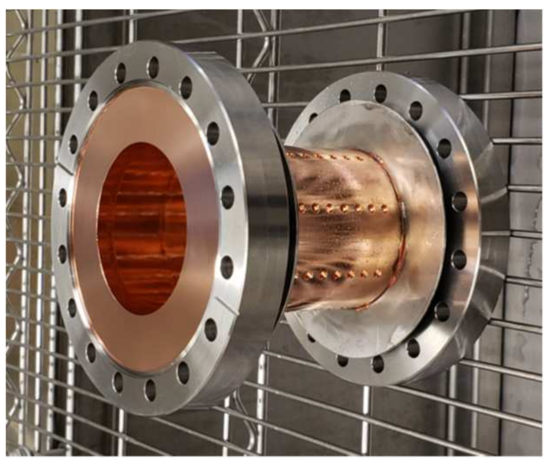
Conclusion: Possible to optimize dimensions of the silicon carbide rings for strong damping at highest R_T/Q; We take advantage of intrinsic property of the SiC ring as a broadband dielectric resonator

BLS Components for SRF Storage Rings

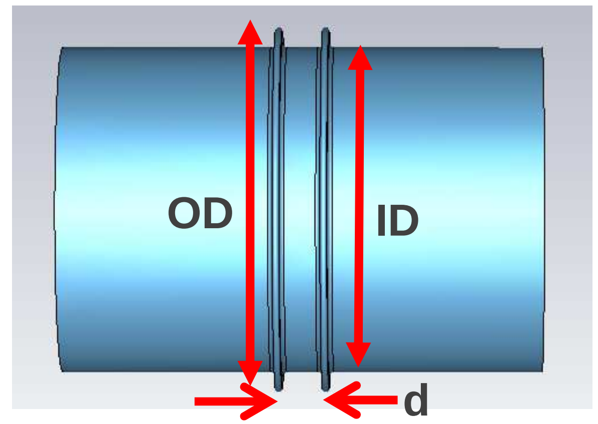
Engineered solutions for high current SRF accelerators

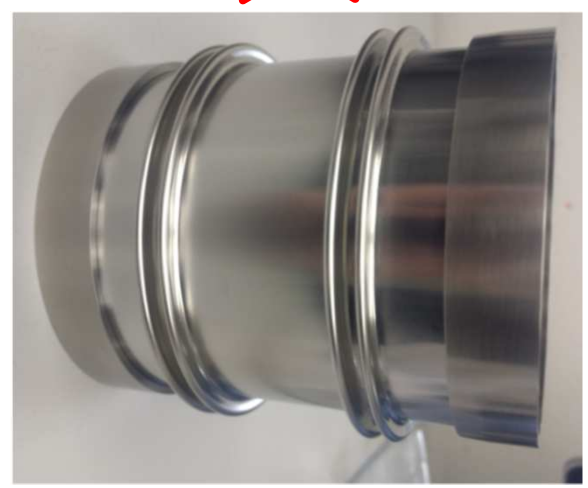
- **Low impedance**
- **Compatible with UHV requirements**
- **Compatible with SRF (clean room) requirements**





Cavity/beamline pump out port





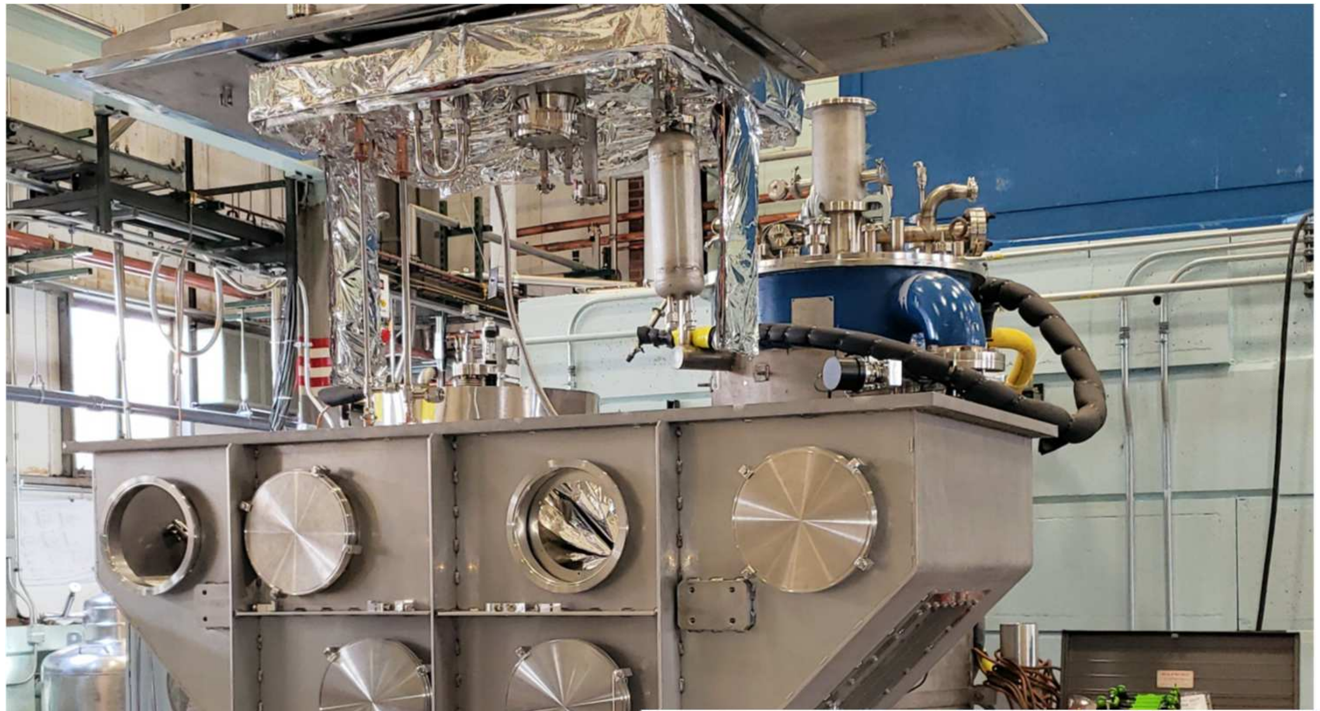
Cavity/beamline bellows for compliance and thermal isolation

BLS Cryomodule

Vessel delivered in 2018

Recent progress:

- Three cool downs of liquid nitrogen circuit
- Integrating cavity and helium circuit
- Cold test 2nd cavity this Oct./Nov.
- Complete full system test Q2 FY20
- Installation into APS-U 2022



Summary

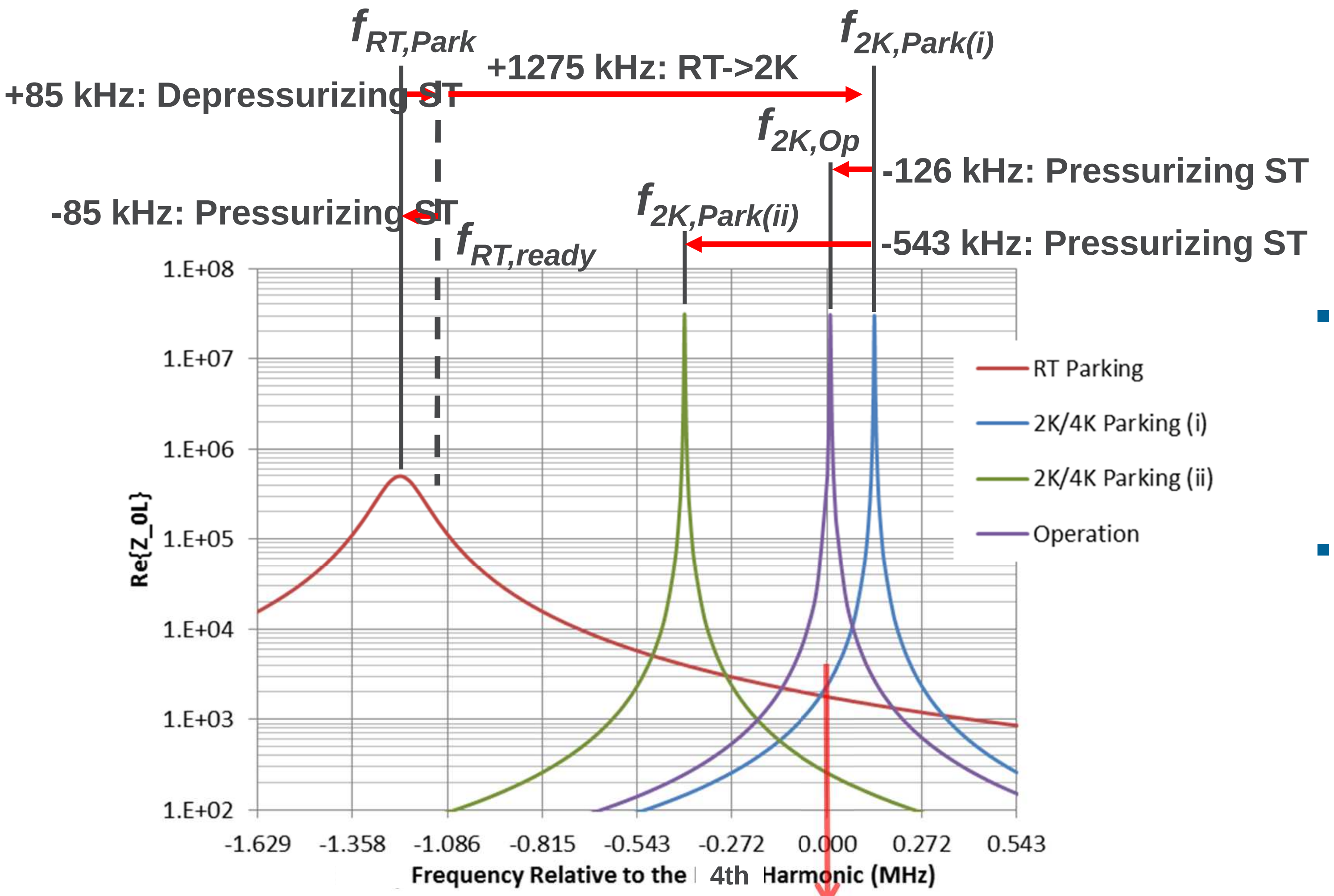
- Designed and built a higher harmonic cavity for APS Upgrade with MBA lattice
  - Controls the harmonic voltage and phase using the adjustable RF couplers as well as a pneumatic frequency tuner
  - Compact, high-gradient, ‘easy’ HOM damping
  - Reduces Touschek effect; also beam heating, improved bunch linearization, mitigation of gap transient instabilities?
- Appears likely to be included as a part of a future EIC
  - Well-developed technical solutions exist and will be demonstrated as part of APS-U bunch lengthening system

Gratefully Acknowledge: SH Kim (FRIB), G.P. Zinkann, M. Kedzie, Z.A. Conway (BNL), A. Abogoda, B. Mustapha, U. Wienands, T. Ng

Backup

Cavity Parking

$f_{2K,Park(i)} = f_b + 136\ kHz$: 1/2 revolution frequency higher than the 4th harmonic
$f_{2K,Park(ii)} = f_b - 407\ kHz$: 1-1/2 revolution frequency lower than the 4th harmonic
$f_{RT,Park} = f_b - 1.22\ MHz$: 4-1/2 revolution frequency lower than the 4th harmonic at RT



f_b=1408.128 MHz*

$f_{RT,ready}$ (for cooldown)
ST: Depressurized
Cavity space: under vacuum
He space: ~1.5 psig
Cryomodule insulation space: under vacuum

- Harmonic Voltage
  - **0.1 MV** @ 2K/4K Parking(i)
  - **36 kV** @ 2K/4K Parking(ii)
  - **12 kV** @ RT Parking
- Wall Dissipation Power
  - **10 mW/0.6 W** @ 2K/4K Parking(i)
  - **1 mW/0.06 W**@ 2K/4K Parking(ii)
  - **140 W** @ RT Parking

* This value is based on FReD. Since the cavity has not been final-tuned yet, this frequency can be changed as required in advance (as of July 2017).

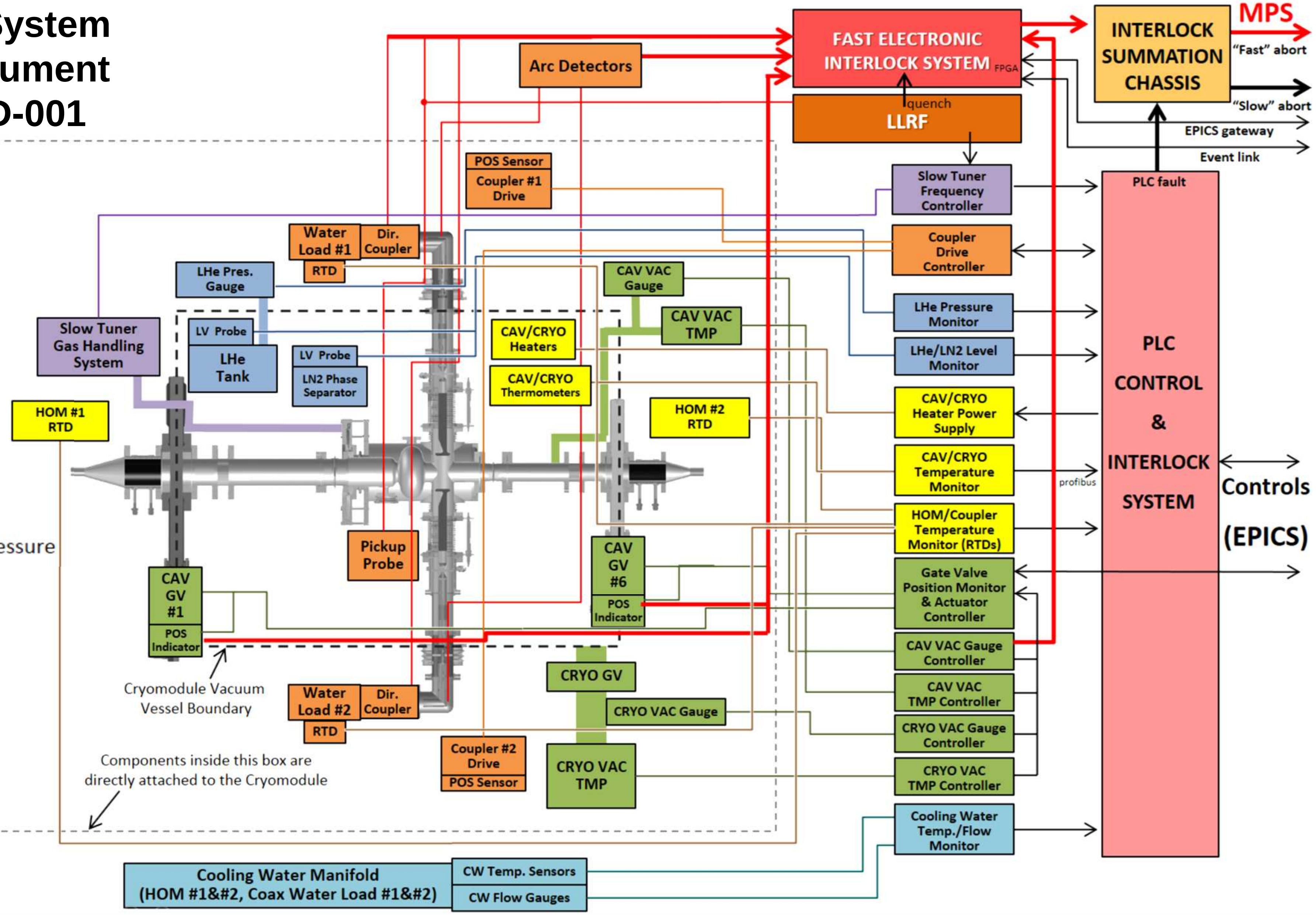
Bunch Lengthening System (External) Interfaces

Cryomodule/RF Systems/Controls/Machine Protection (MPS)

Bunch Lengthening System Interface Control Document APSU-2.03.03.05-ICD-001

Abbreviation

MPS: Machine Protection System
CRYO: Cryomodule, **CAV**: Cavity
VAC: Vacuum, **GV**: Gate Valve
POS: Position, **Dir.**: Directional
TMP: Turbo Molecular Pump
Temp.: Temperature, **LV**: Level, **Pres.**: Pressure



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2.1 K Heat Budget for BLS Cryomodule

Component	APS-U
Cavity dynamic RF	1.5 W
Power couplers (static + dynamic)	6 W
300 K to 2.1 K radiation (beamline)	6 W
Bayonets/valves	3 W
Instrumentation	2 W
Beamline conductive load	2 W
Slow tuner/vacuum lines/hangers	2 W
Burst disk assembly	1 W
80 K to 2.1 K radiation	0.1 W
Total	**24 W**

Assumptions:
No credit taken for MLI
Emissivity 2.1 K surfaces is assumed = 1

4.3 K Standby Heat Budget for BLS Cryomodule

Component	APS-U
Cavity dynamic RF	0 W
Power couplers (static + dynamic)	3 W
300 K to 2.1 K radiation (beamline)	6 W
Bayonets/valves	3 W
Instrumentation	2 W
Beamline conductive load	2 W
Slow tuner/vacuum lines/hangers	2 W
Burst disk assembly	1 W
80 K to 2.1 K radiation	0.1 W
Total	**16 W**

Assumptions:
Cavity detuned from resonance
No credit taken for MLI
Emissivity 2.1 K surfaces is assumed = 1