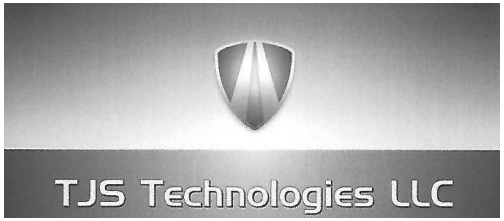

HOM Absorber Design for eRHIC ERL Cavity (Now EIC)

SBIR Grant Award No. DE-SC0018466

T. Schultheiss
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2022 SBIR STTR Exchange Meeting
Aug 23-25, 2022

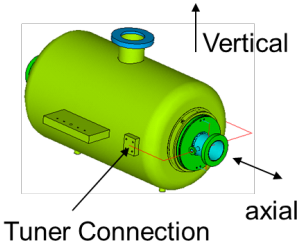
Outline

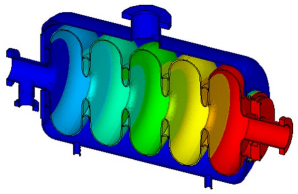
- TJS Technologies LLC (2016)
  - Engineering Services
    - MSU Michigan State University
      - FRIB ASME evaluation of 644 MHz Cavity and Tuner
    - FHI Fritz Harbor Institute - ongoing
      - Free Electron Laser Deflector Cavity
        - » RF Thermal Analysis – Design, Coupling
        - » Beam dump and beam dump window
    - JLAB - ongoing
      - SRF Cavity Cooled by Cryocoolers – Thermal Analysis
      - FPC Coupling to Locate the FPC nearer the cavity (450kW per FPC)
      - Coaxial FPC Evaluation – RF/Thermal Analysis
  - Higher Order Mode Absorber SBIR Phase I & II
    - Fabricated Prototypes
      - Waveguide planned low power RF testing
      - Beamline planned high power RF testing
  - Phase IIA
    - Tasks
    - Evaluate HOM absorber for Crab Cavity

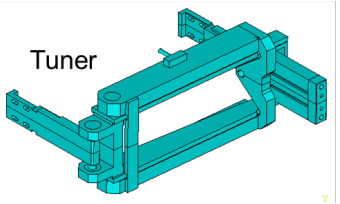
Engineering Service MSU

ASME Structural evaluation of FRIB 644 MHz Cavity and Tuner

- **General Requirements of ASME code Section VIII Division 2 – Design by Analysis**
- **Material Properties**
- **Boundary Conditions**
- **Loads to be Considered**
- **Design By Analysis 2015 Section VIII, Division 2 Part 5 of ASME Code**
  - Protection Against Plastic collapse Part 5.2
    - »Limit Load Analysis Part 5.2.3
    - »Elastic-Plastic Analysis Part 5.2.4
  - Protection Against Local failure Part 5.3
    - »Elastic Analysis 5.3.2
  - Protection against collapse From Buckling Part 5.4
    - –Bifurcation – Eigenvalue Buckling Part 5.4.1.2
  - Protection Against Failure From Cyclic Loading Part 5.5
    - –Experience with comparable equipment operating under similar conditions Part 5.5.2
    - –Ratcheting Assessment – Elastic-Plastic Stress Analysis Part 5.5.7
- **Vibration**
- **Frequency Sensitivity to Pressure**
- **Tuner Evaluation**

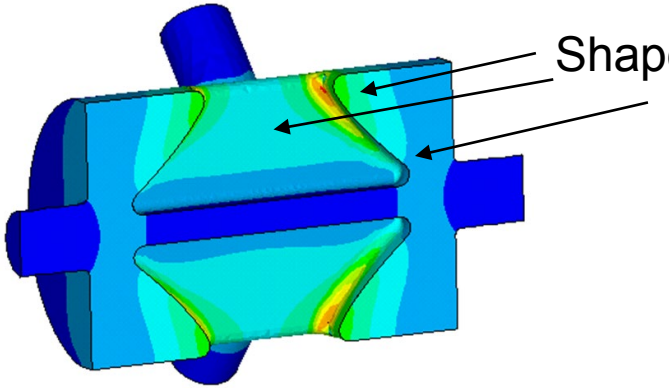




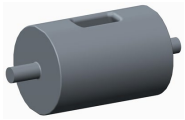


Engineering Service FHI

Develop a Beam Deflector to Provide 2 500 MHz Beams from a single 1 GHz beam for 2 Color FEL



Shape modified for 500 MHz

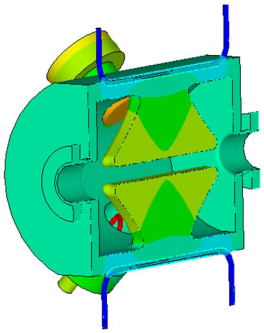


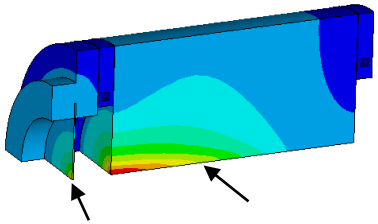
Frequency shift for manufacturing and tuning

RF Analysis

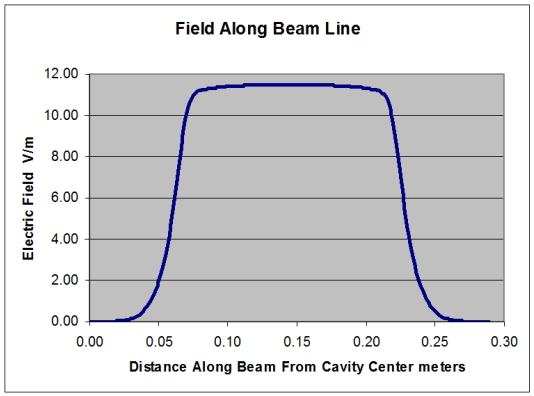
Deflector Cavity

Beam Dump and Window

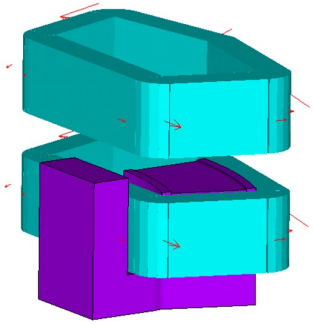




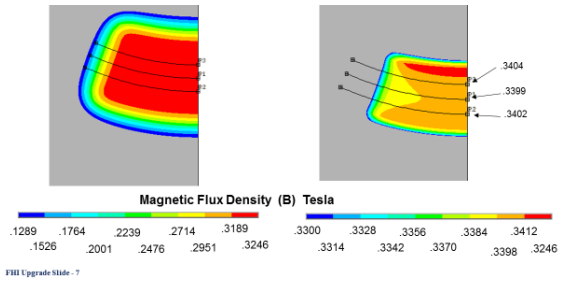
Thermal Analysis



Electric Field Along Beamline

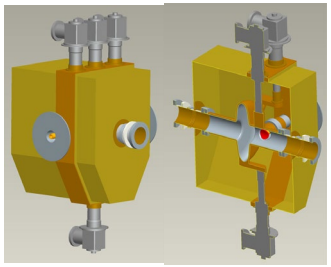


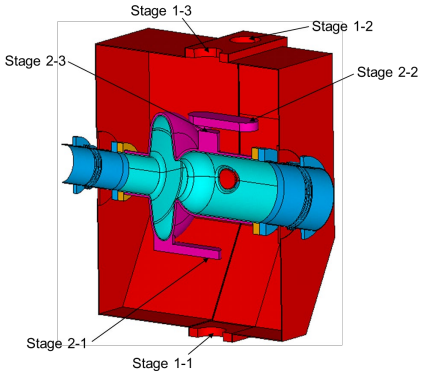
3-D Magnet calcs
Coil geometry
Specification
Field Quality

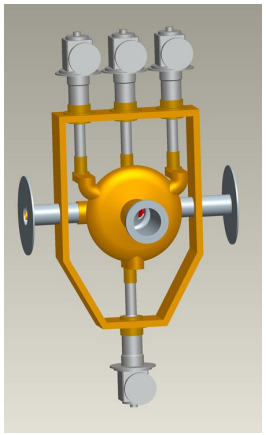


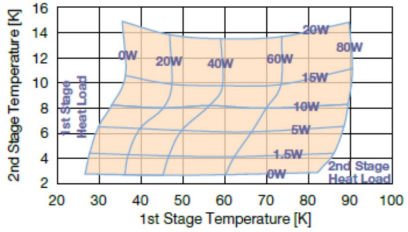
Magnet Analysis

Engineering Service JLAB



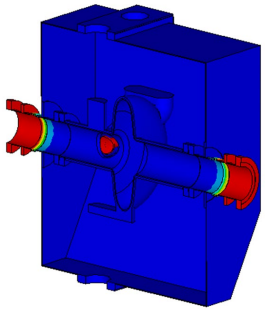


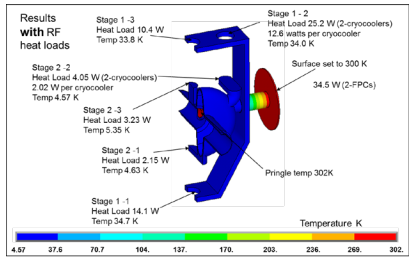


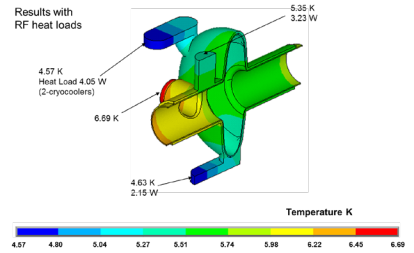


Cryocooler Capacity Map

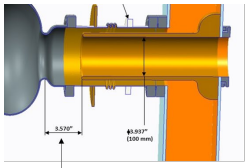
RF and Thermal Analysis and Side Coupling for power couplers





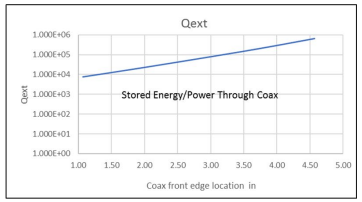


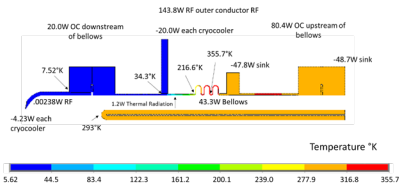
RF and Thermal Analysis Beam Pipe Coaxial Power Coupling



Distance from Cell 1 Iris	Qext
4.57	6.376E+05
3.59	1.658E+05
3.57	1.615E+05
3.47	1.427E+05
2.07	2.482E+04
1.07	7.632E+03

Stored Energy/Power Through Coax
Target Qext = 1.65e5





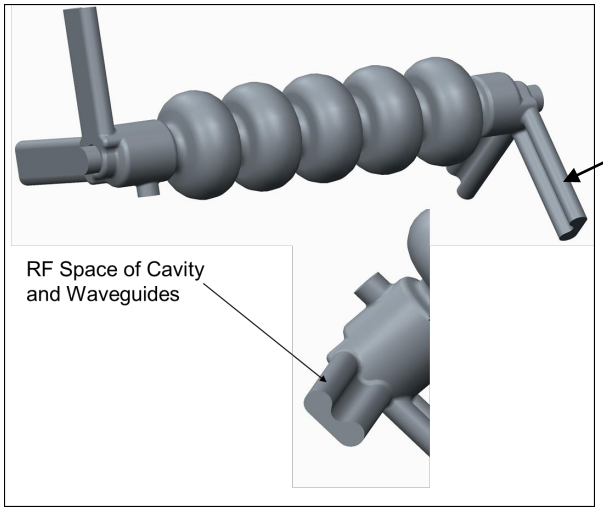
Higher Order Mode Absorber SBIR

- Motivation
  - In 2017 and 2018 BNL evaluated designs for the electron accelerator in eRHIC, now EIC, the proposed electron-ion collider
    - It included electron cooling using a multi-cell cavity with high average current and high bunch charge in CW energy recovery mode. This cavity would require a higher order mode absorber with considerable power absorption capability
    - There is also interest in Crab Cavity HOM absorbers

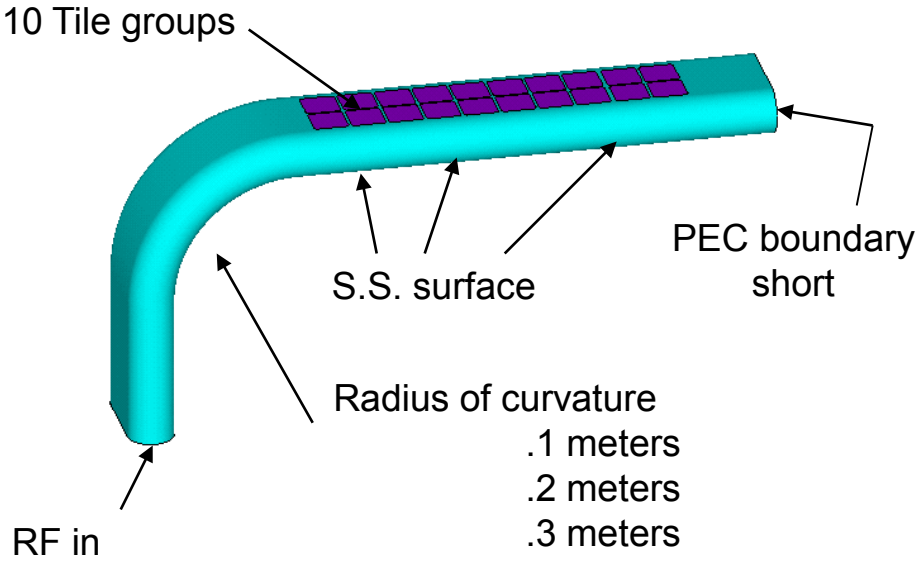
Higher Order Mode Absorber SBIR Tasks

- Phase I
  - Define/update HOM specifications with BNL
  - Develop the concept design of the absorber module
  - Perform RF/Thermal and Structural Analysis of the HOM module
  - Develop manufacturing plan and design for the HOM absorber module to a cost level.
- Phase II
  - Manufacture Prototypes
    - Waveguide HOM
    - Beamline HOM
- Phase II A
  - Develop low weight waveguide HOM absorber – Crab Cavity?
  - RF sweep tests of waveguide prototype to determine S11 of HOMs
  - High Power absorption tests of tile/backer cores

BNL Designed Cavity and B-shaped waveguide Phase I



BNL developed a B-Shaped waveguide to suppress multi-pacting and improve impedance, decreasing the number of waveguides per cavity
BNL paper SRF2017 TUPB002



Input Excitation Port

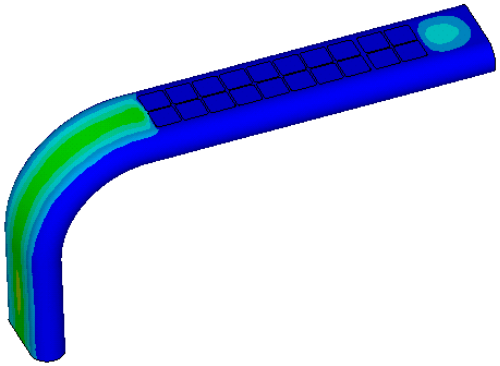
Frequency Dependent permittivity and Loss tangent

Surface Losses assuming Stainless Steel

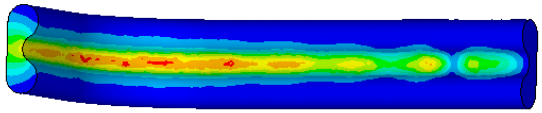
Output
S11, Power for each tile group
For each Frequency
Sum Power for each tile group over HOM frequencies

Tile groups with varying thickness
Made from SC-35, graphite loaded Silicon Carbide

Fields at 1.2197 GHz
Curved Waveguide Radius .1 meters



Power 241.6 Watts (966.5/4)
S11 .0363
ReflP .319 W



Tabulate Results for all evaluated HOMs
4 HOMs per cavity

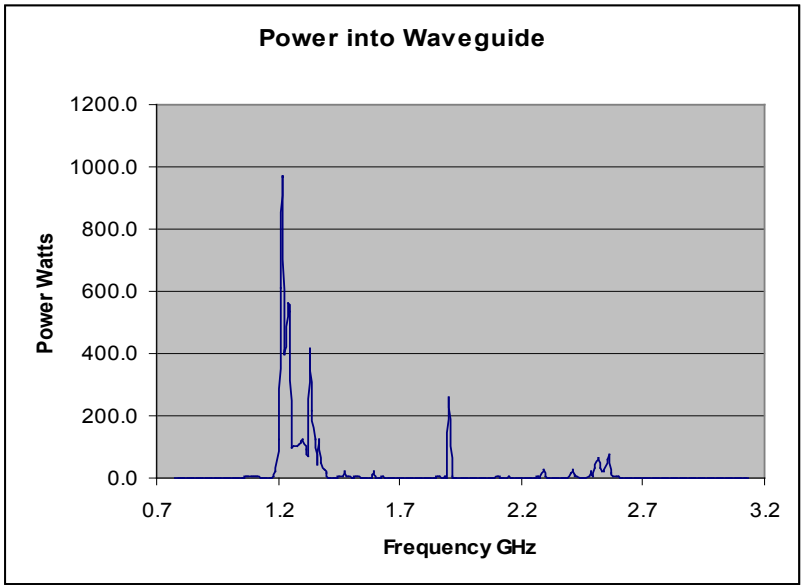
Freq	Power	S11	ReflP	Surf Loads	Id1	Id2	LD3
1.21974E+09	2.41637E+02	3.63340E-02	3.18999E-01	1.34287E+00	2.05640E+01	2.10396E+01	2.38696E+01
1.21036E+09	1.52642E+02	2.50770E-02	9.59898E-02	8.57093E-01	1.29309E+01	1.27258E+01	1.45691E+01
1.23850E+09	1.40402E+02	6.30190E-02	5.57593E-01	7.64159E-01	1.22239E+01	1.29842E+01	1.51182E+01
1.24789E+09	1.33295E+02	7.37400E-02	7.24802E-01	7.18159E-01	1.18679E+01	1.25528E+01	1.50519E+01
1.33233E+09	1.03705E+02	8.02920E-02	6.68568E-01	5.16512E-01	1.37696E+01	1.05113E+01	1.55004E+01
1.22912E+09	1.02832E+02	5.03010E-02	2.60185E-01	5.65519E-01	8.82375E+00	9.26745E+00	1.05817E+01
1.90467E+09	6.51005E+01	1.17180E-01	8.93905E-01	2.25240E-01	1.63844E+01	1.32115E+01	8.47076E+00
1.34171E+09	5.33818E+01	7.12660E-02	2.71118E-01	2.63818E-01	7.34672E+00	5.55251E+00	8.01851E+00
1.30418E+09	3.16275E+01	9.60880E-02	2.92014E-01	1.61430E-01	3.66959E+00	3.07313E+00	4.51124E+00
1.20097E+09	3.15965E+01	2.84580E-02	2.55887E-02	1.79180E-01	2.66583E+00	2.49959E+00	2.93756E+00
1.35110E+09	3.13223E+01	6.06370E-02	1.15167E-01	1.53636E-01	4.44486E+00	3.36306E+00	4.70684E+00
1.36986E+09	3.09785E+01	3.57750E-02	3.96479E-02	1.49785E-01	4.60074E+00	3.59557E+00	4.60617E+00
1.29480E+09	2.82145E+01	9.73070E-02	2.67153E-01	1.45229E-01	3.11195E+00	2.72818E+00	3.91699E+00
1.28542E+09	2.63835E+01	9.65040E-02	2.45710E-01	1.36982E-01	2.76559E+00	2.54465E+00	3.54499E+00
1.27603E+09	2.62213E+01	9.37260E-02	2.30342E-01	1.37344E-01	2.61716E+00	2.52373E+00	3.39182E+00
1.26665E+09	2.55163E+01	8.90190E-02	2.02201E-01	1.34870E-01	2.43513E+00	2.44740E+00	3.16344E+00
1.25727E+09	2.49354E+01	8.23760E-02	1.69206E-01	1.33040E-01	2.28961E+00	2.37570E+00	2.95315E+00
1.31357E+09	2.27740E+01	9.28180E-02	1.96202E-01	1.15280E-01	2.77424E+00	2.23229E+00	3.31811E+00
2.56145E+09	1.94891E+01	8.87690E-02	1.53573E-01	7.36090E-02	3.76744E+00	3.24892E+00	2.35598E+00

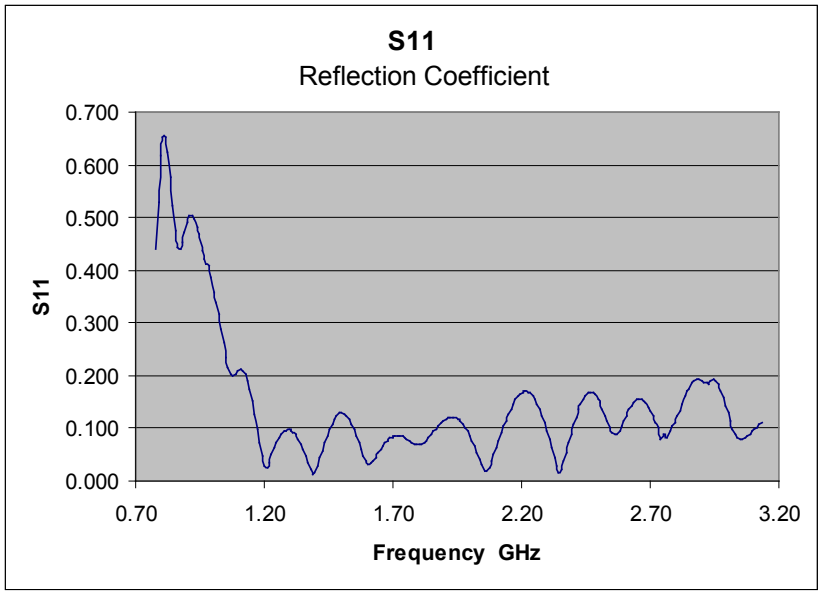
Surface Loss 1.34 W
SS surface elec cond

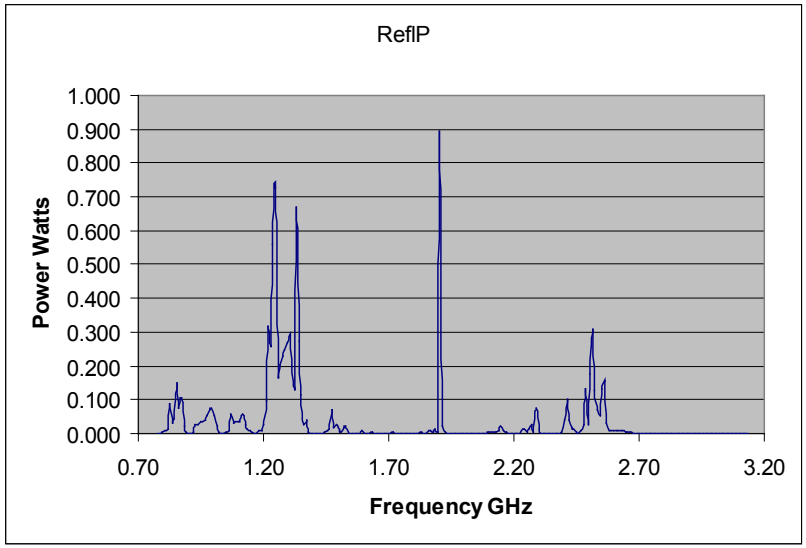
Electric Field V/m

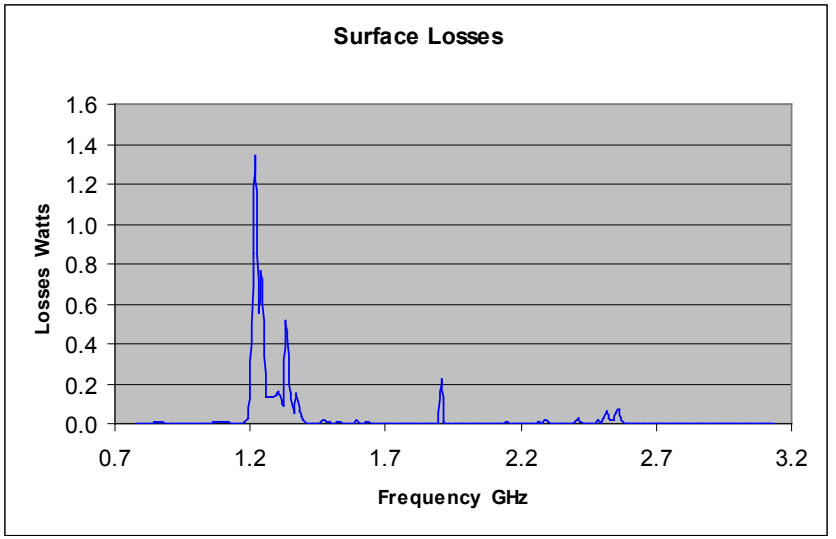
0.0 1780. 3561. 5341. 7121. 8902. 10682. 12462. 14243. 16023.

Power In, S11, Reflected Power, Surface Loss

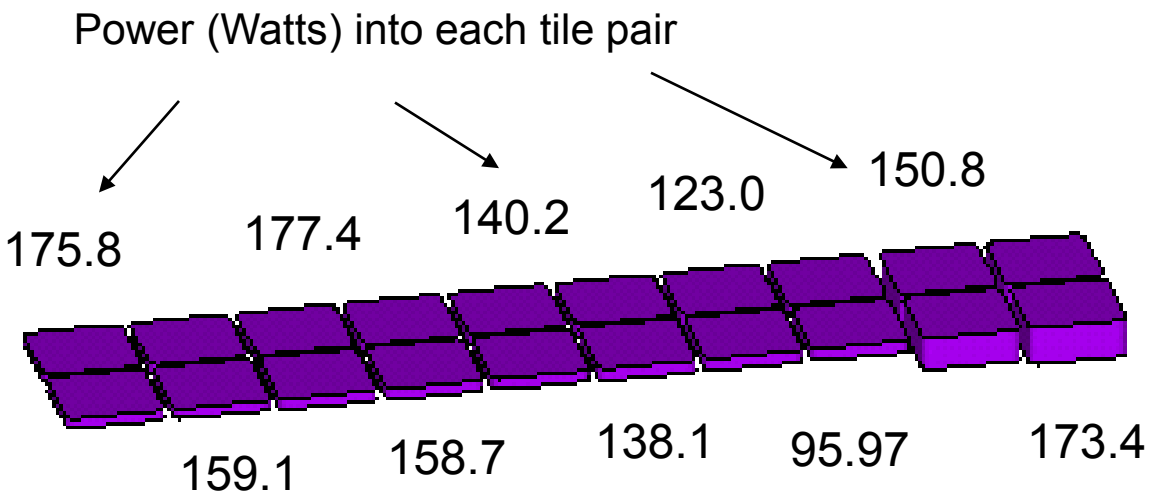








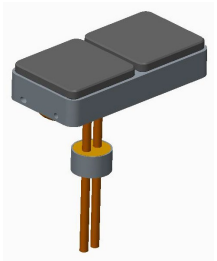
Sum of Power into Waveguide Absorber



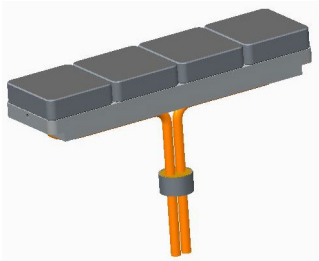
- Initial HOM absorber module geometry (4 HOM Absorbers per cavity)
  - 1492.4 W of 1501.5 W is absorbed 99.7%
  - 10 tile pairs
  - Thickness range .200” to .7

Higher Order Mode Absorber SBIR Phase II

- Manufacture HOM Cores
  - Can be used for Waveguide or Beamline Absorber

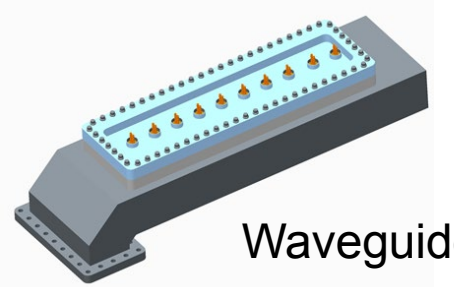


Waveguide core

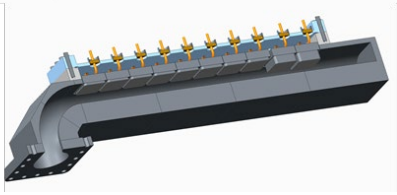


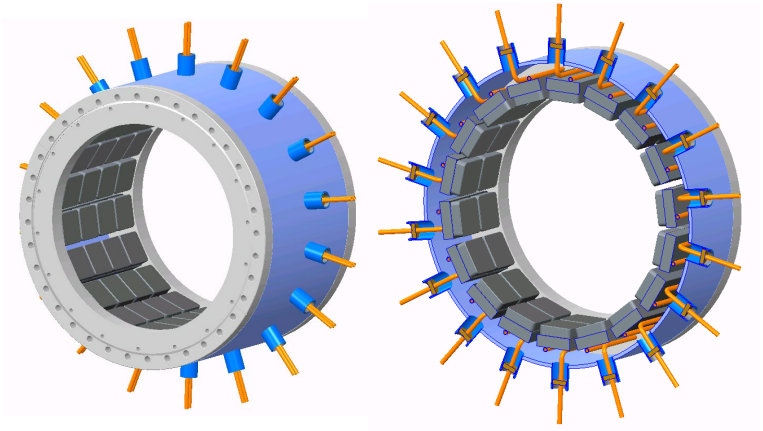
Beamline core

- Manufacture Housing and Assemble Core and Housing



Waveguide HOM





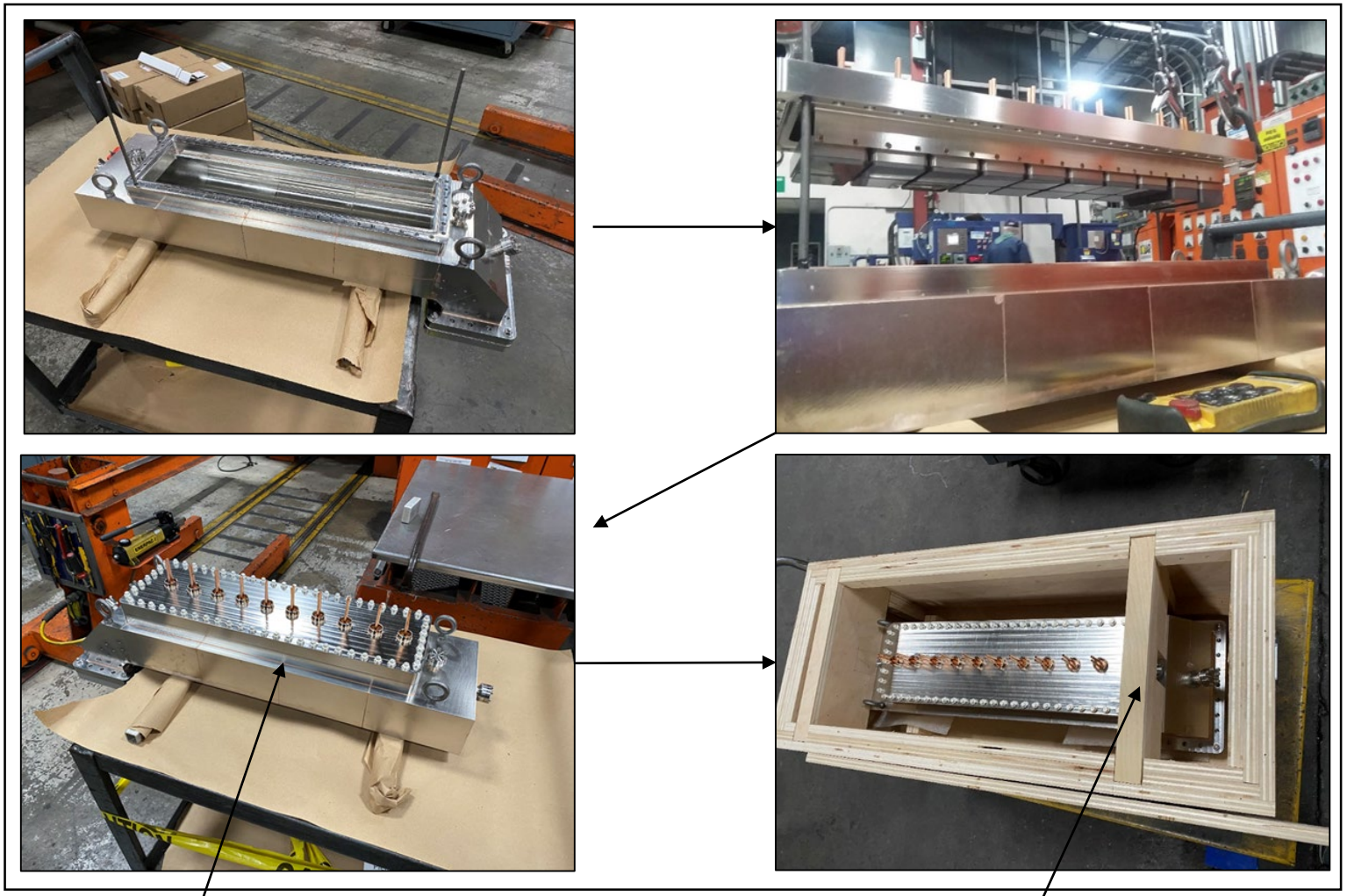
Beamline HOM

Initial Braze Step in Fabrication of Cores

Backer/Cooling Tube Assemblies (without SiC tiles)

Backer-Tile Assemblies shown after joining

First Waveguide HOM Prototype



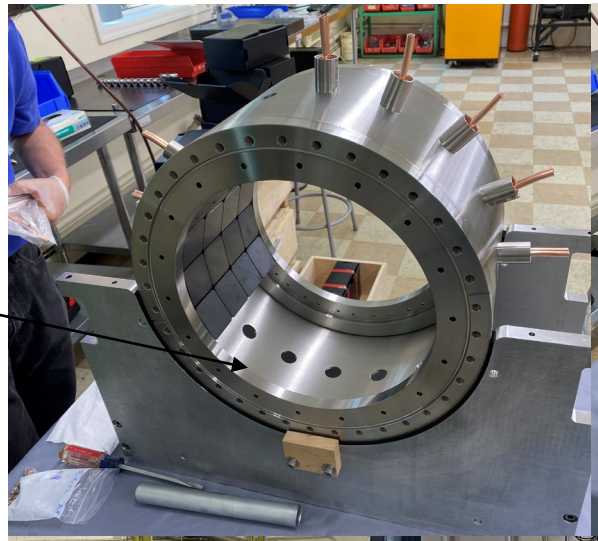
Lowering tile/backer flange assembly into housing

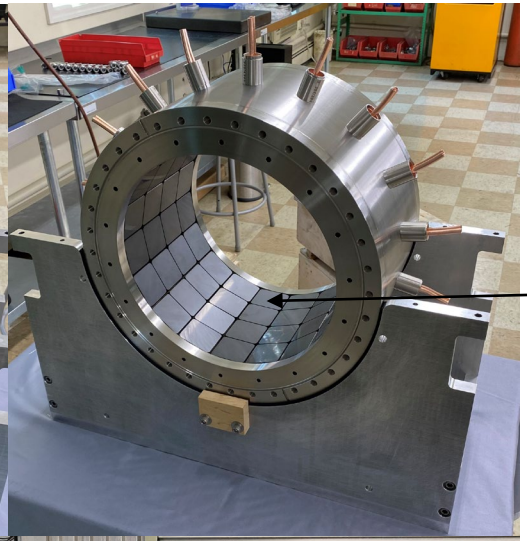
Bolt Flange assembly to housing

Inserting and restraining in crate

First Beamline HOM Prototype

Partially Assembled





Fully Assembled

Lowering into crate

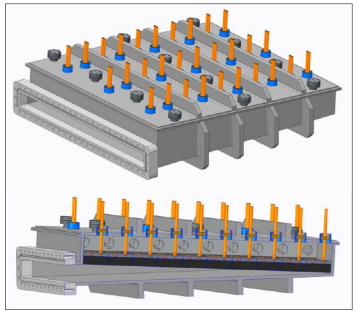
Used BNL design for thickness and depth of SiC and HOM diameter, direct replacement in their test set-up

Higher Order Mode Absorber Phase IIA

- Low Power RF Tests
  - Waveguide Assembly - S11 vs Frequency
  - Compare to Analysis
  - Evaluate RF Properties

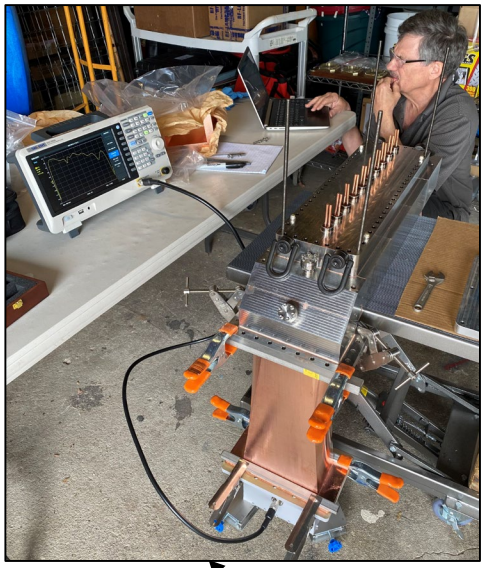
- Power Absorption Tests at BNL
  - Tile/Backer Assembly
  - RF Power in
  - Measure Temperature

- Develop Low Weight Design
  - Decrease weight of Tile/Backer Assembly
    - Decrease Backer Thickness
  - Decrease weight of Housing
    - For Crab Cavity HOM Absorber
      - Minimize wall thickness meeting pressure vessel code

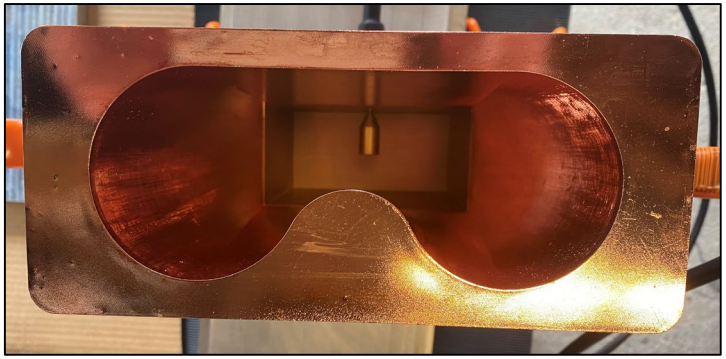


Phase IIA Waveguide HOM RF Sweep Test

Test With Flush Dummy Insert

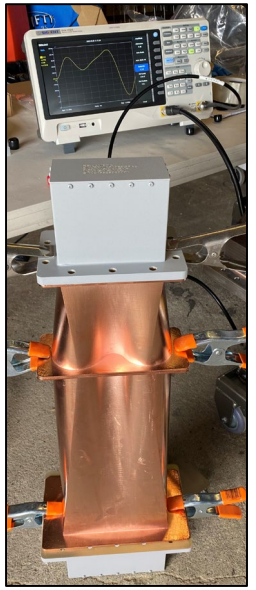


Test With HOM Load Assembly

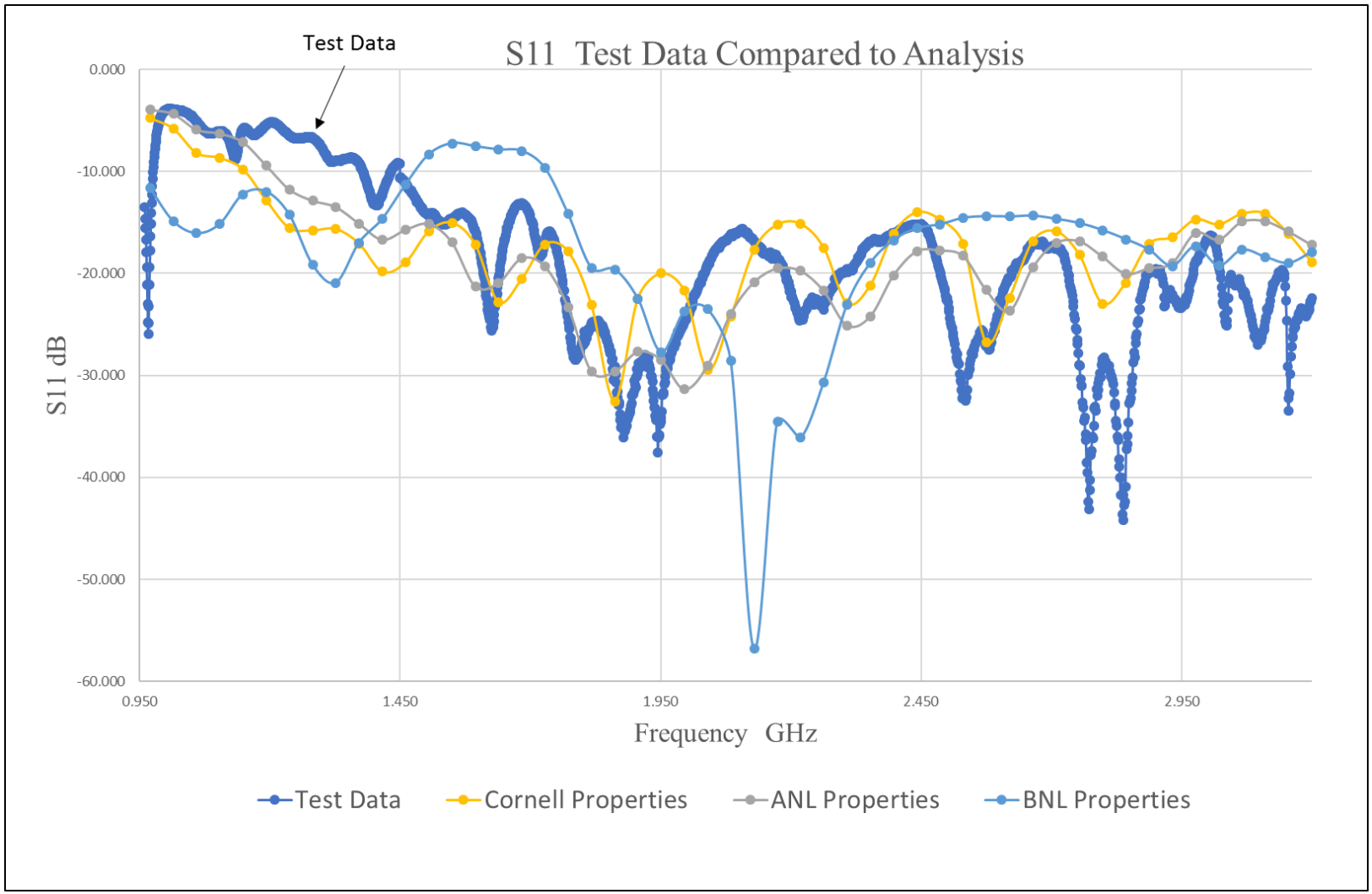


← Adapter-to-Transition Assembly

Through Measurement of
Two Adapter/Transitions →
(WR770 – WR510)



Phase IIA Core RF Absorption Test Set-up

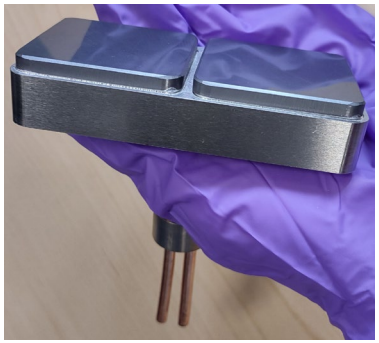


We are evaluating RF Properties at Freq < 1 GHz

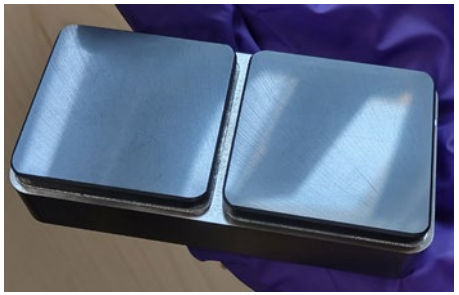
Phase IIA Power Absorption Tests at BNL

A Optris Xi 400 thermal camera replacement was installed. The entire stand was raised to make installation of test pieces easier.

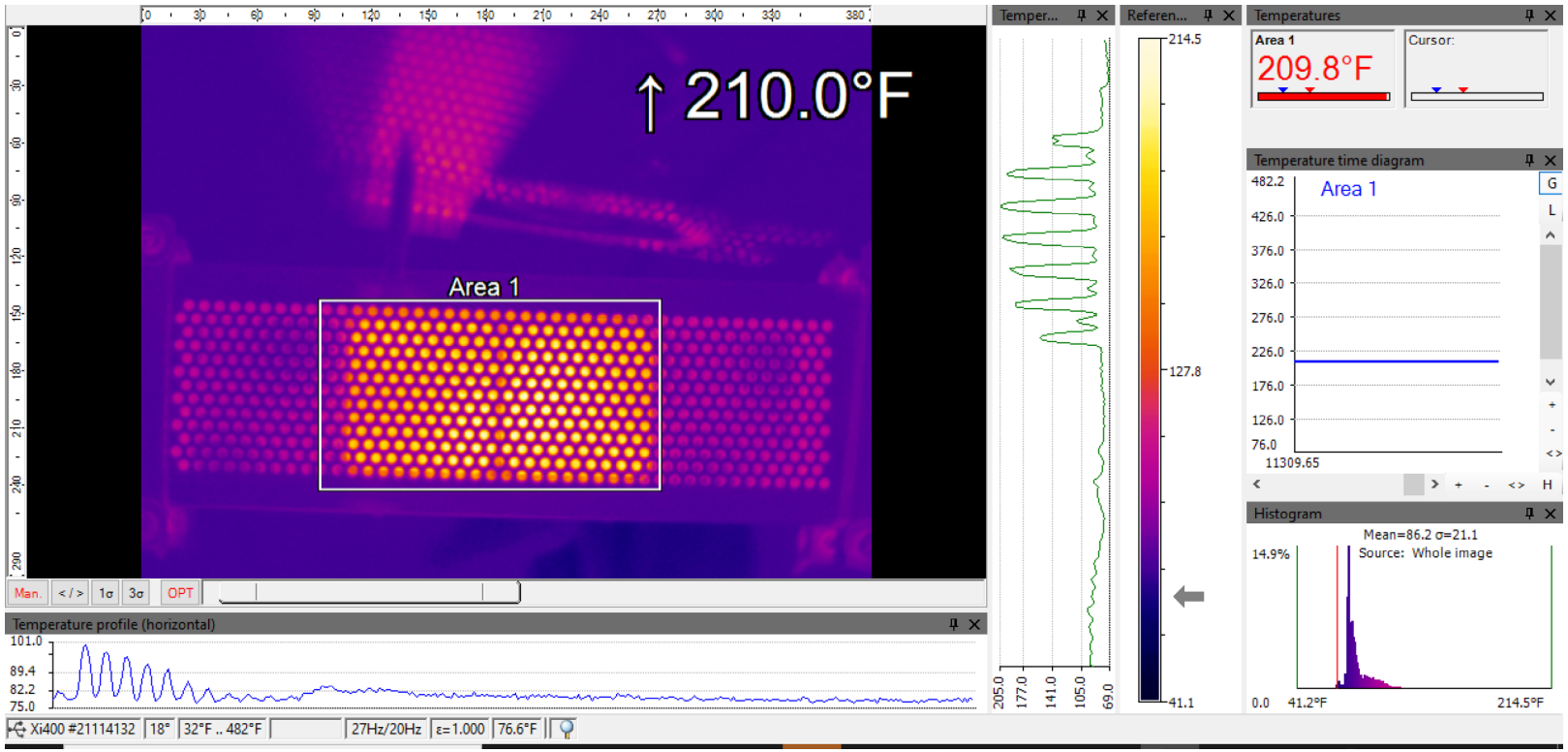
Thermal Image 2-Tile



.200” thick tiles at 1010 Watts

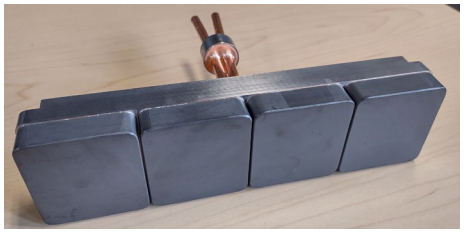


RF Power

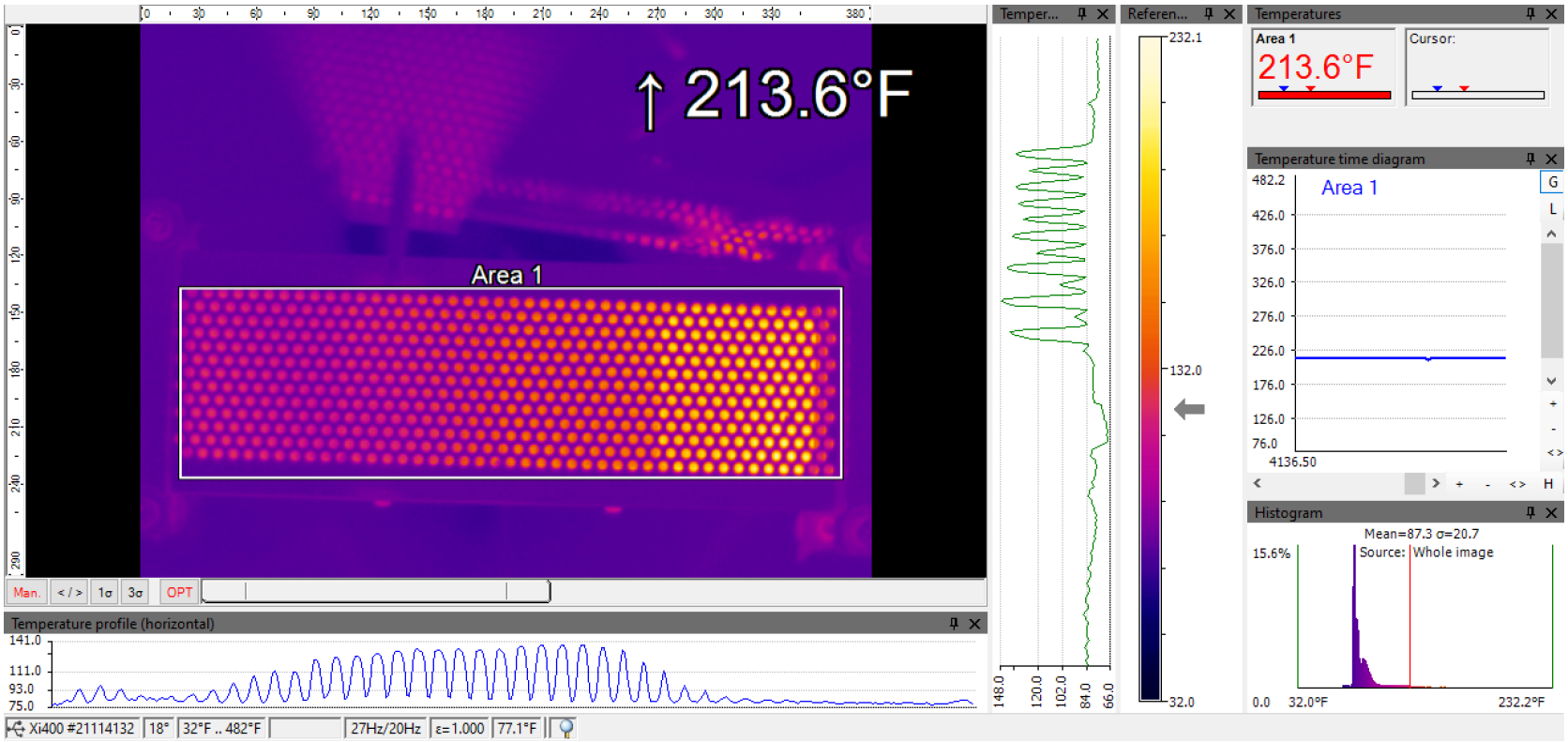


Thermal Image 4-Tile

.550” thick tiles at 962 Watts
4-Tile assembly



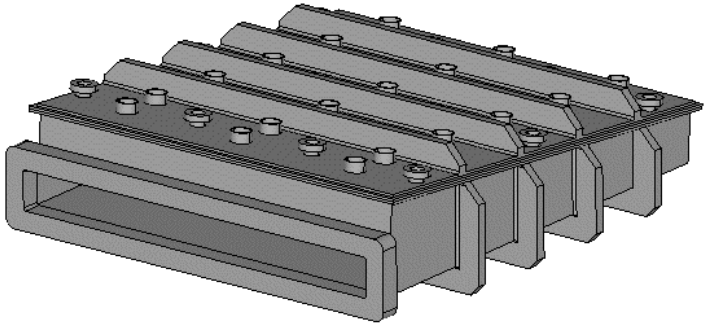
RF Power

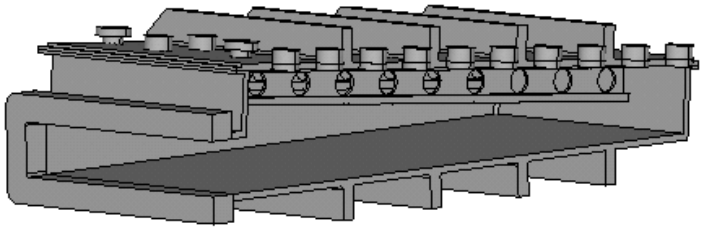


Develop Low Weight Design

- Tile/Backer Assembly
  - Copper cooling tubes and Backer material
    - Mismatch of CTE
    - Must have flat surface for joining tiles
    - Joining tests to determine minimum thickness

- Minimize Housing Wall Thickness
  - Perform Pressure Vessel Code analysis
    - Crab Cavity HOM expected to be part of Hermetic string





SBIR Summary

- Fabricated waveguide and Beamline HOM Absorbers
- Evaluating HOM absorber for Crab Cavity
  - HOM freq to absorb > 300 MHz
  - Evaluating RF properties of Absorber material at Freq < 1 GHz
- Developing Lightweight waveguide housing and Backer designs
- Beampipe absorber diameter can be accommodated by varying number of cores circumferentially
- Using HOM core can develop many geometries to accomplish HOM absorption
- 2-Tile and 4-Tile cores absorb a minimum of 1 kW of energy each
- Present Crab Cavity Design will absorb minimum of 30 kW

- Thank You
  - Michelle, BNL, JLAB, DOE