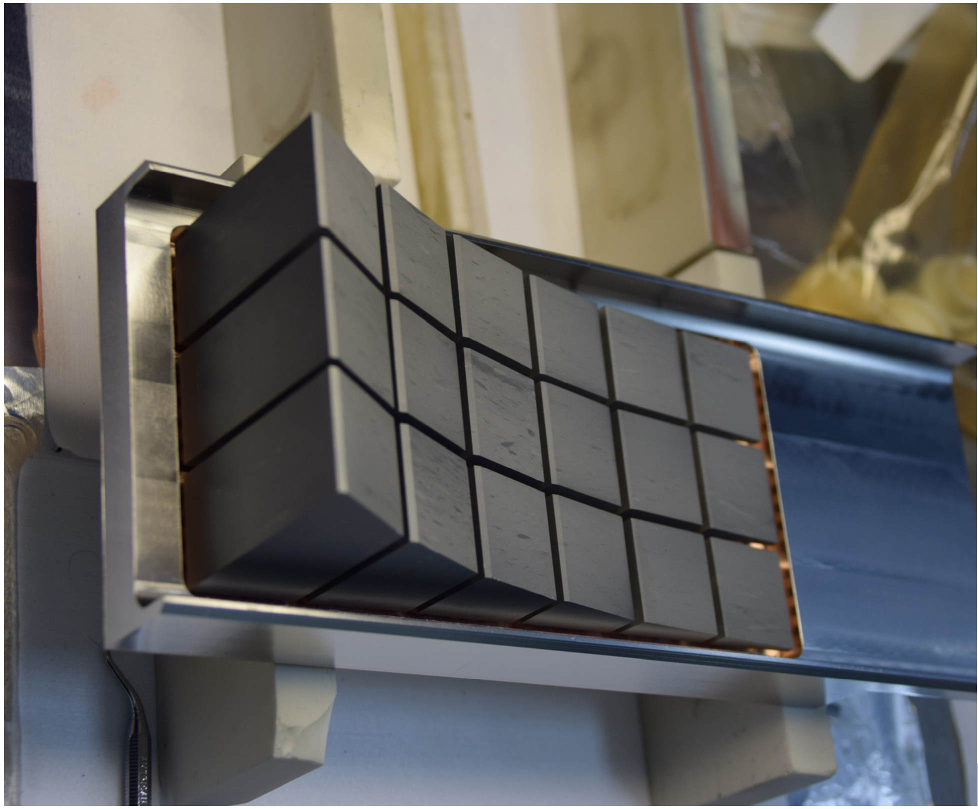
Waveguide HOM Loads for High Current Elliptical Cavities

ERL 2019, Berlin



Jiquan Guo, JLab

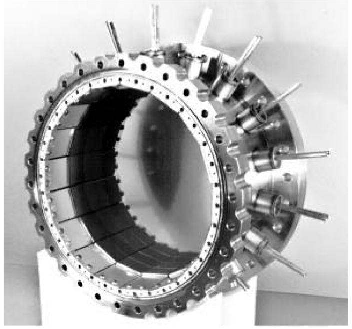
Outline

- Introduction
  - Waveguide HOM dampers
  - Absorber material
  - brazing technique
- bERLinpro HOM load development
  - RF-thermal design and fabrication
  - Testing results
  - HOM waveguide 1-D thermal optimization
- BESSY VSR 1.5 GHz HOM load development
  - RF-thermal design and fabrication
  - Testing results
  - HOM waveguide 1-D thermal optimization
- Summary

HOM Dampers for High Current RF Cavities

- HOM damping is essential for RF cavities in accelerators with beam current ranging from <1 mA to Ampere level
- Dampers can come with designs using antenna, waveguide, or beampipe design.

CEBAF C25/C50 cavities with waveguide HOM damper

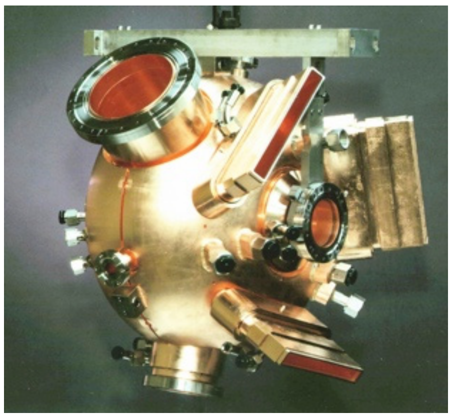


CESR beampipe HOM absorber

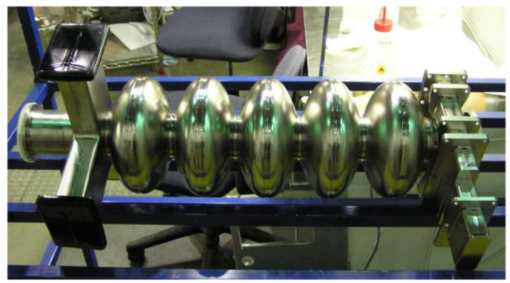
CEBAF C100 cavity with antenna HOM damper

HOM Dampers for High Current RF Cavities

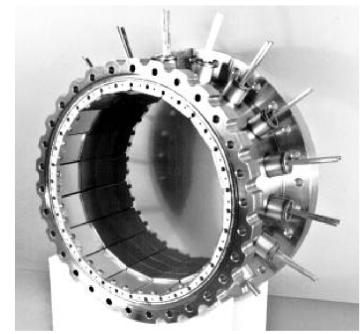
- HOM damping is essential for RF cavities in accelerators with beam current ranging from <1 mA to Ampere level
- Dampers can come with designs using antenna, waveguide, or beampipe design.



PEP-II 476MHz NCRF cavity with on-cell WG HOM damper



CEBAF C25/C50 cavities with waveguide HOM damper



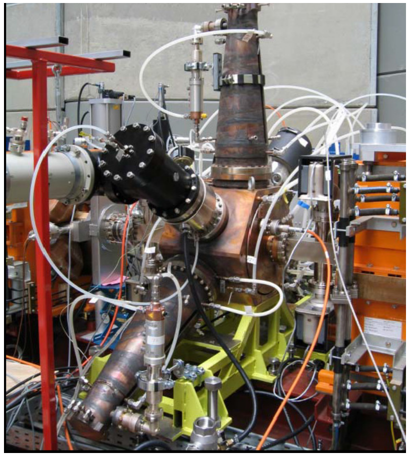
CESR beampipe HOM absorber

CEBAF C100 cavity with antenna HOM damper

Waveguide HOM Dampers

- Waveguide is a natural high-pass filter
  - Ideal to transmit the HOM to the absorber while keep the fundamental mode within the cavity
- High power handling capacity
- The absorber can be placed at higher temperature and water cooled.
- Can be extracted either from the beampipe or on-cell. Extra beampipe length required is small.
- Higher static loss than antenna dampers but tolerable for SRF designs

Jlab 750MHz high current cavity



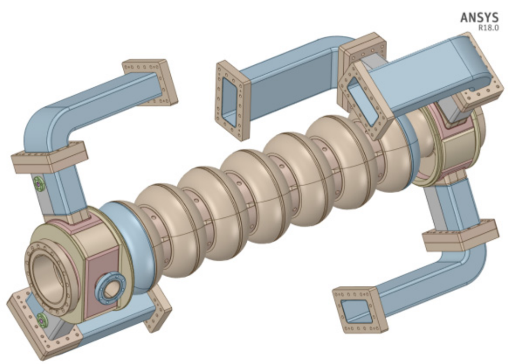
BESSY II 500MHz cavity with circular double ridged waveguide HOM damper

HZB SRF Projects with Waveguide HOM Dampers

JLab is collaborating with HZB on the development of HOM loads for three variants of SRF cavities in two accelerator projects at HZB

bERLinpro,

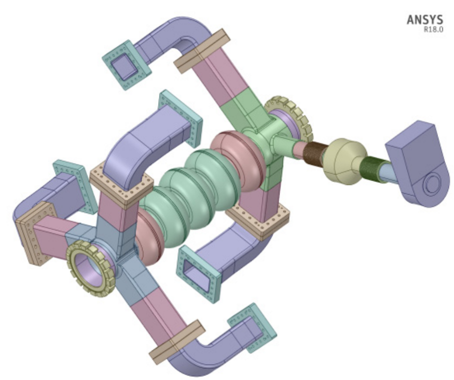
- 100 mA 50 MeV single pass ERL
- 1.3 GHz 7-cell TESLA shape cavities,
- 5 waveguide HOM damper per cavity,
- estimated HOM power ~27 W per load maximum



bERLinpro cavity model

BESSY VSR (Variable pulse length Storage Ring) upgrade,

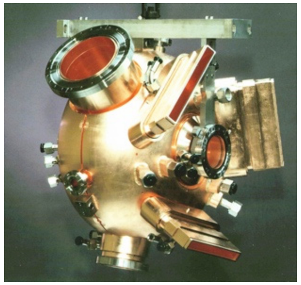
- 300 mA storage ring light source with complicated bunch pattern
- 1.5 GHz (3rd harmonic) and 1.75 GHz (3.5th harmonic) cavities
- 5 waveguide HOM damper per cavity,
- estimated HOM power ~460 W per load maximum in the 1.5 GHz cavities



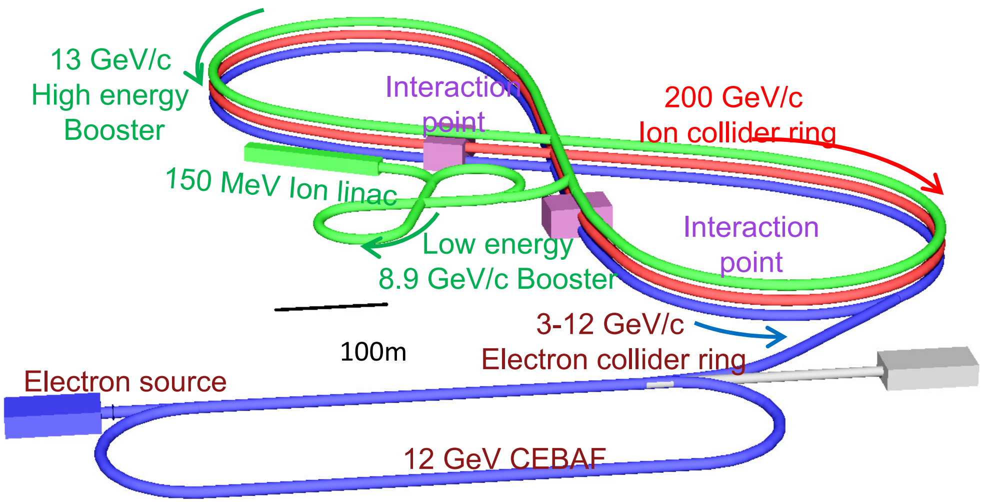
VSR 1.5 GHz cavity model

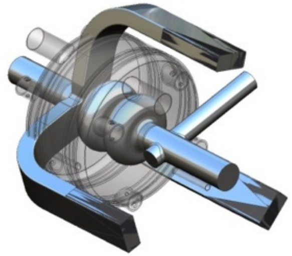
JLEIC High Current Elliptical Cavities

- An Electron Ion Collider (EIC) has been selected as USDOE's primary new facility construction priority.
- JLab Electron Ion Collider (JLEIC) is one of the two competing EIC proposals.
- JLEIC has an ion ring (and a full size booster) of up to 0.75 A, electron ring up to 3.6 A, and a circulating cooler ring (CCR) of up to 1.5 A with a 140 mA ERL.

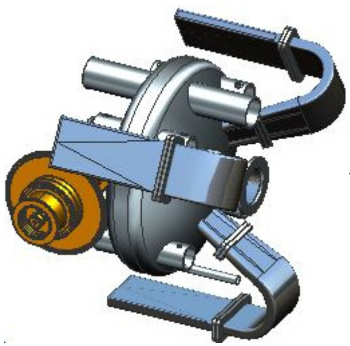


Reuse PEP-II NCRF cavity for e-ring

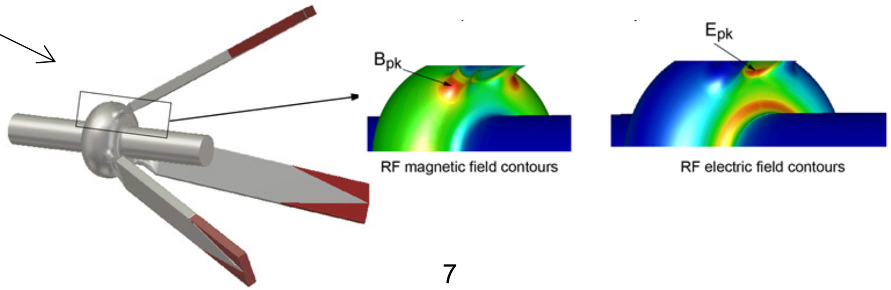


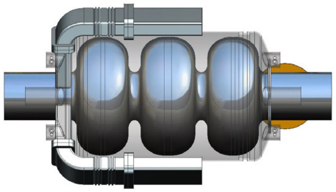


Hadron ring – 952.6 MHz bunching cavity with WG damper on beampipe



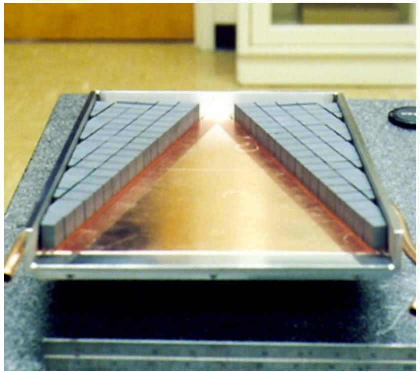
New e-ring SRF cavity with on-cell HOM damper



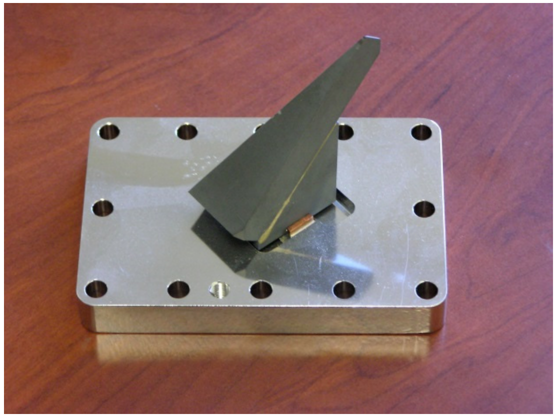


Hadron Cooling – 476.3 MHz ERL cavity

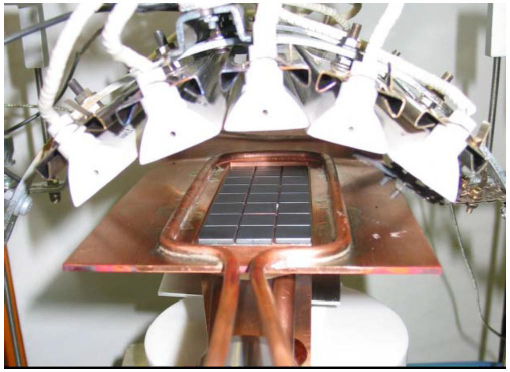
Previous Waveguide HOM Absorber Designs



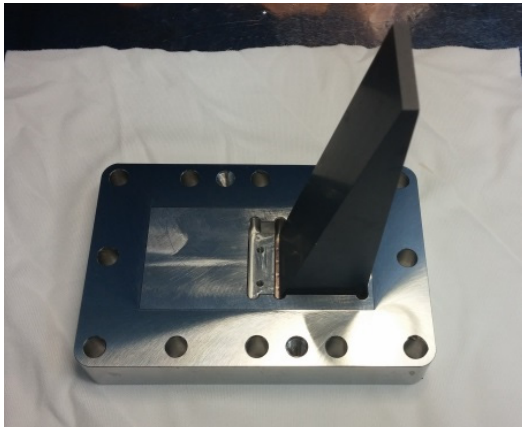
PEP-II high power waveguide warm load
R. Pendleton et. al., EPAC94



Original CEBAF “sundial” 2K load



BESSY 500 MHz cavity ferrite HOM absorber under IR radiating testing



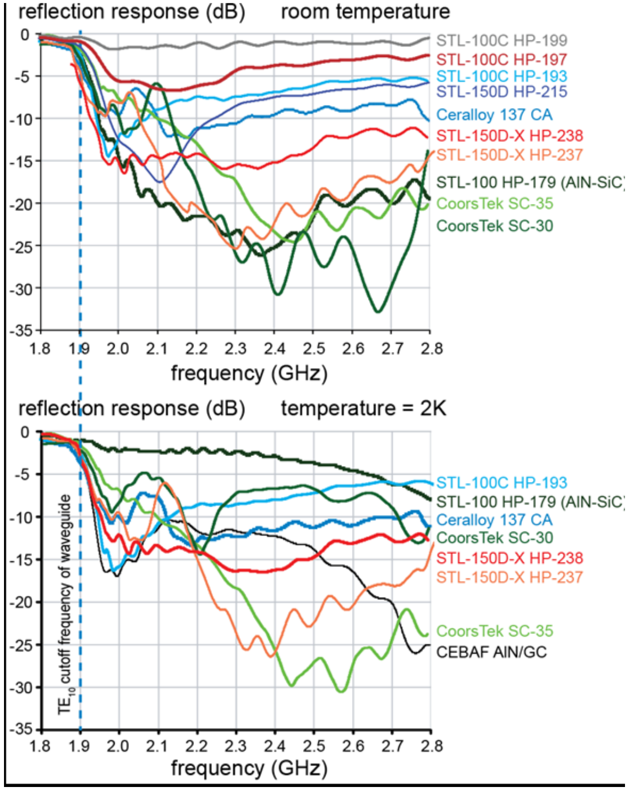
New CEBAF waveguide HOM absorber design

HOM Absorber Material R&D

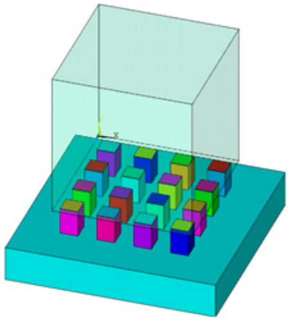
- Previous absorber materials discontinued by vendors
  - Ceradyne Ceralloy 13740 (AIN based) for PEP-II
  - Ceradyne glassy-carbon for CEBAF
- Possible candidates selected in 2011:
  - CoorsTek: SC35 (2K), SC30 (warm), graphite loaded SiC, better RF absorption
  - Sienna Tech: STL-150D-X (2K), STL-100 (warm), AIN based composite, better mechanical strength
- Updated candidates:
  - Sienna Tech: STL-150D11/STL-150D075 (2K), STL-100HTC (warm)
- New material candidates:
  - Surmet (Doped AION), Muons Inc., Coorstek SC-90, etc

Absorber material R&D with test load

F. Marhauser et. al., TUPS106 IPAC11



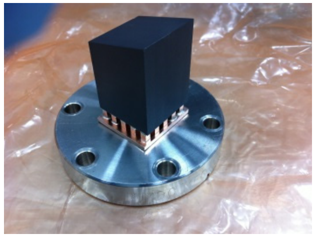
Brazing Technique and CoorsTek Experience

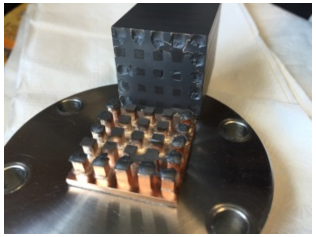


Pegboard braze concept

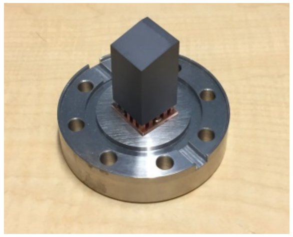
Cu pegboard sandwiched between ceramics and SS, good thermal conductivity, easy to yield, reducing thermal stress

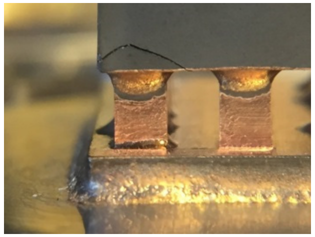
0.1” square pegs with 0.1” spacing



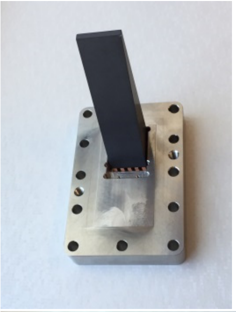


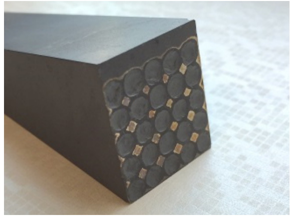
1st try, failed after thermal cycles



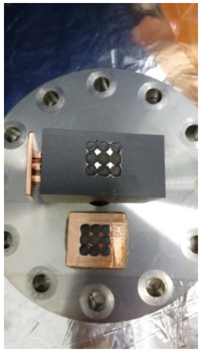


2nd try, cracked after sitting for months



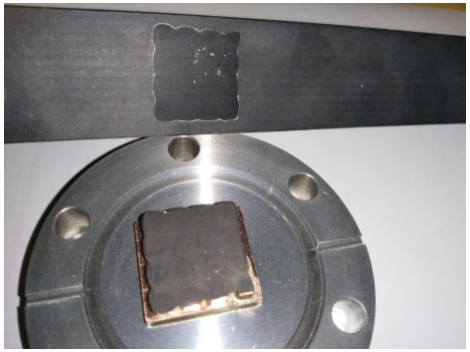


3rd , C75 design, failed after tested in cavity



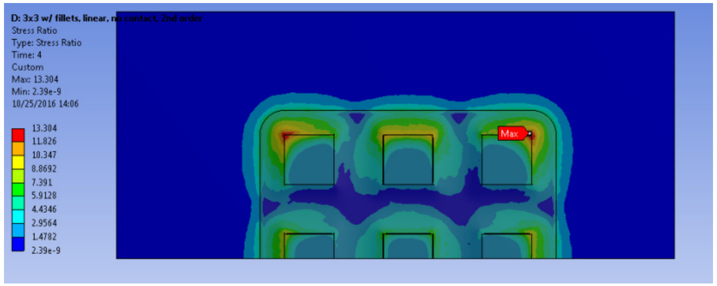
4th trial with 3x3 peg to reduce stress

All CoorsTek SC-35 braze in 2016 failed



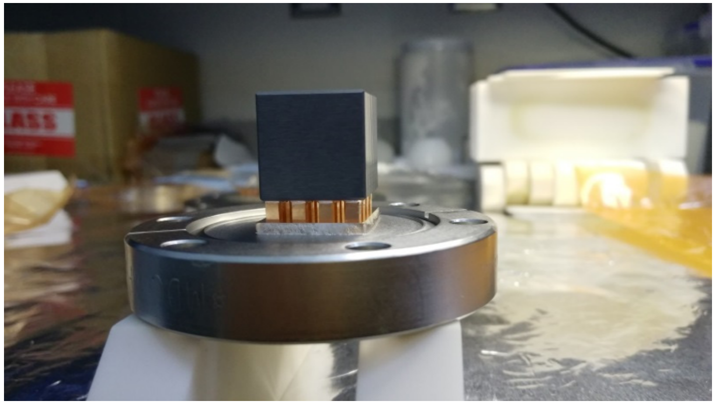
CoorsTek SC-30 braze also failed, although it’s listed with higher flexural strength

Ceramic peels off from the braze joint

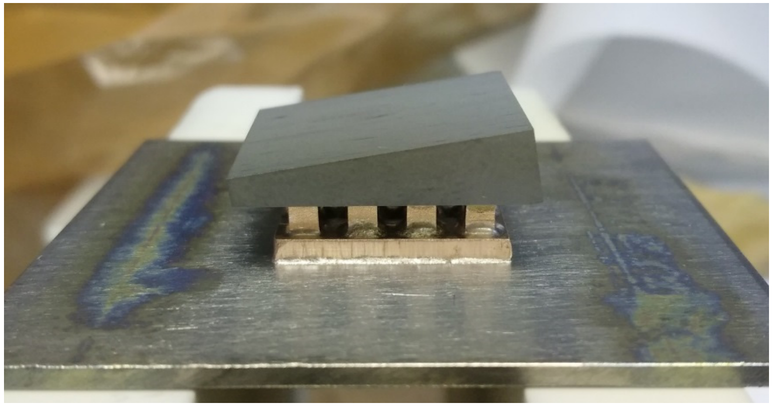


Thermal stress at the peg corners. Stress increase with pegboard size

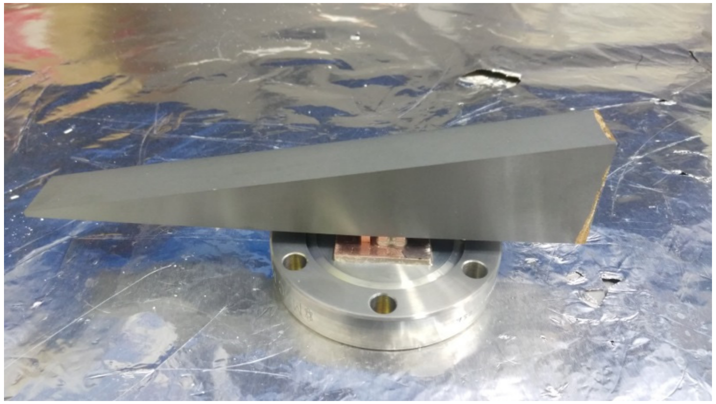
Brazing test for AlN Based Material



Test braze of Ceradyne Ceralloy 13740 (leftover) in 2016, passes thermal cycles



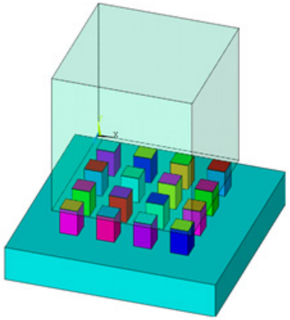
Test braze of thin Sienna STL-100HTC tile, front thickness 0.1”, passes thermal cycles



Test braze of old Sienna STL-150D-X material, passes thermal cycles

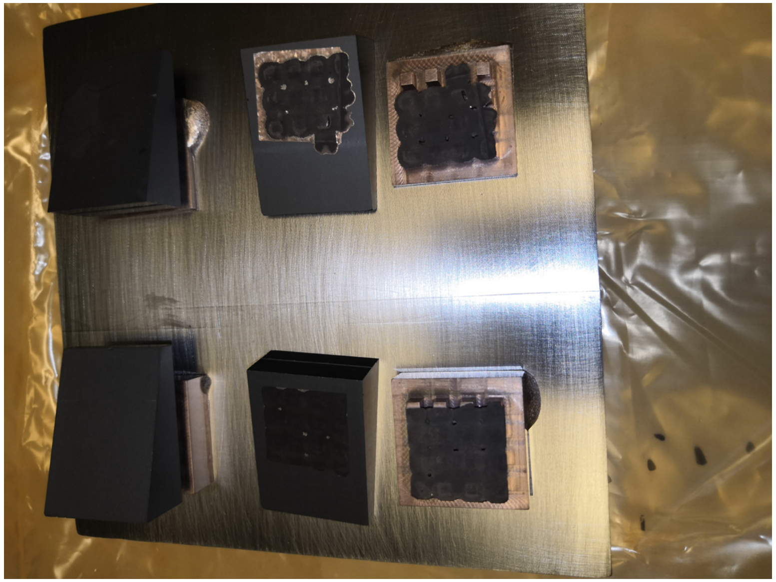
We switched to AlN based materials and succeeded in test braze for both leftover Ceradyne material and old/new Sienna Tech material

Braze with Tungsten-Copper Alloy



Use W55/C45 alloy as the pegboard material, possible to reduce the thermal stress

W55/C45 alloy has thermal expansion coefficient closer to ceramics, but harder to yield.

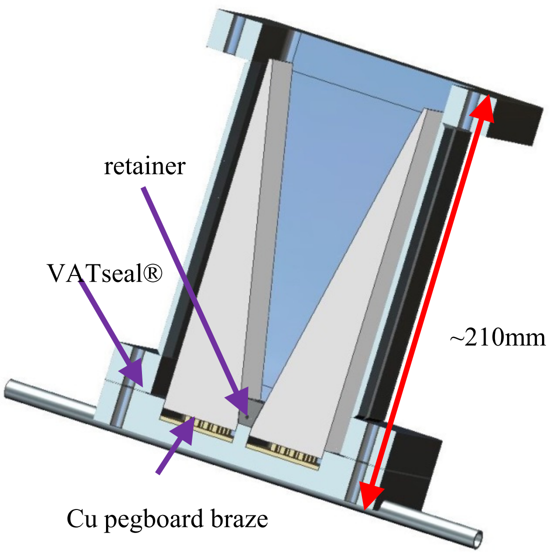


Recent (Sept 2019) Coorstek SC30 (two on the right) and SC35 (two on the left) braze test with W55/C45 alloy pegboard

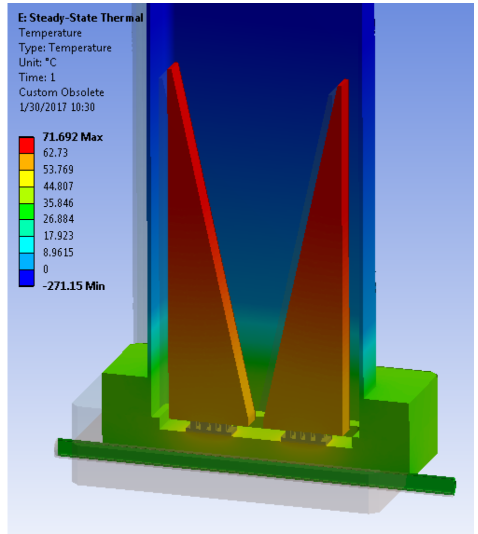
SC30 failed by peeling off, similar to the copper pegboard braze

SC35 stays after a few LN2 thermal cycles, further mechanical tests needed

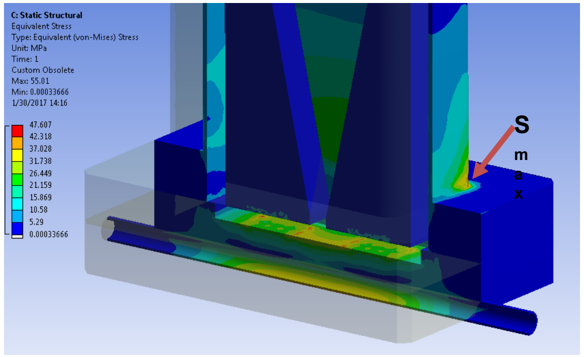
bERLinpro HOM Load Design



Mechanical design



RF-thermal simulation
Temperature distribution



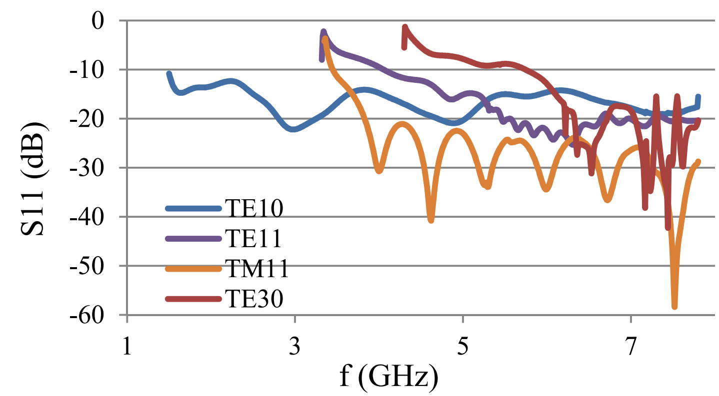
Simulated thermal stress
No notable stress in the braze joints

Use Sienna Technology STL-100HTC (high thermal conductivity AlN-SiC composite), V shape wedges

Wedges are 7", longer than the initial SC-30 design

Thermal simulation uses a combination of 4 waveguide modes with a total power of 27 W and 30°C 0.28L/min cooling water in laminar flow

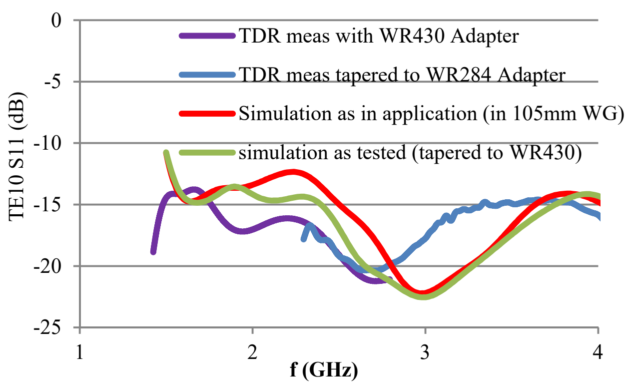
HOM waveguide 105mm×50mm, with 1.43GHz TE10 mode cutoff frequency. First HOM at ~1.7GHz, major HOM power at 2.6 GHz TE10.



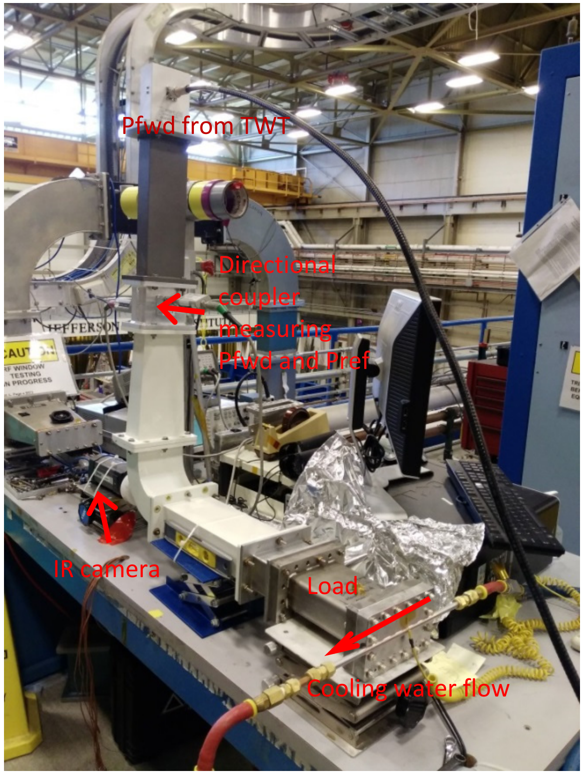
Simulated S11 for different waveguide modes

bERLinpro HOM Load Testing

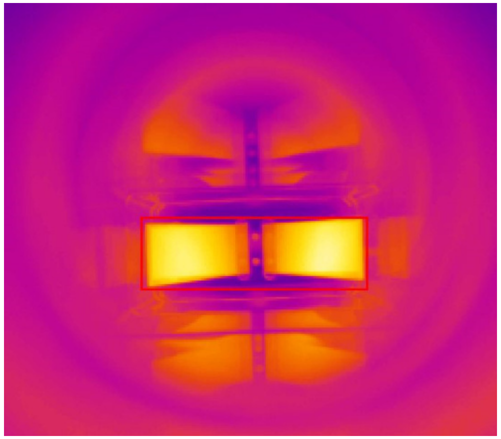
Brazed load



NWA measurement results vs simulation



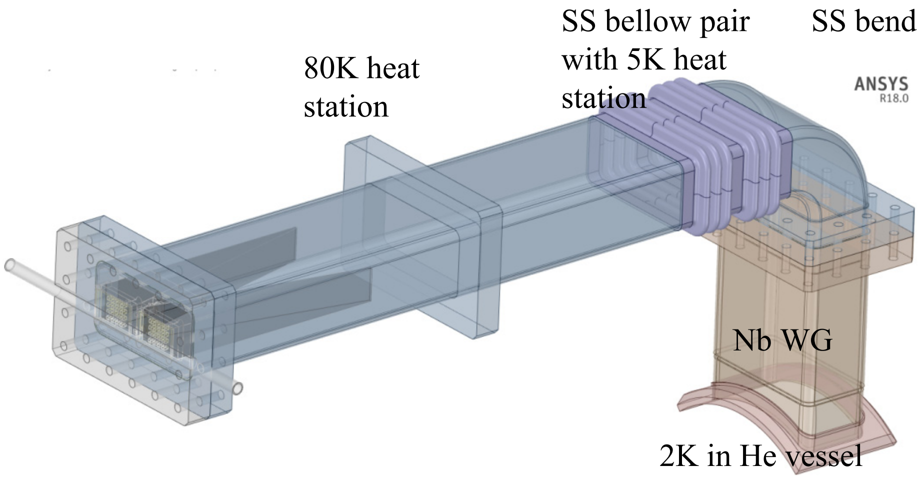
High power test setup
Powered by a TWT
Tested with single TE10 mode at 2.6 GHz, up to 50 W

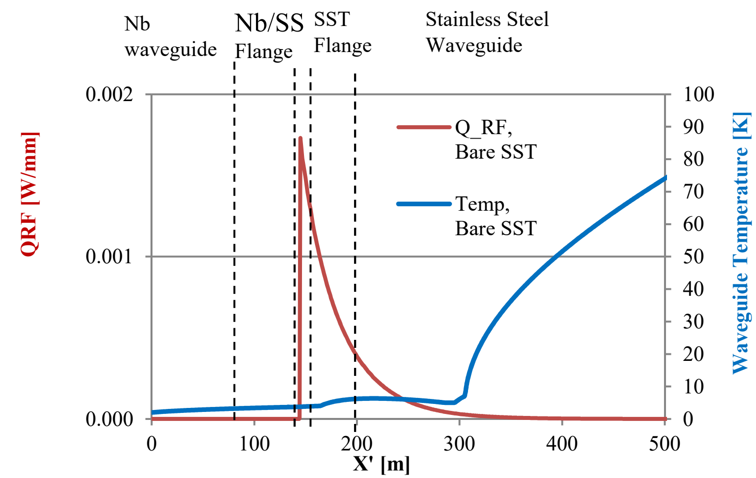


IR image at equilibrium, with 50W incident power.
T_{max} 64.9°C (not calibrated)
T_{flange} 43°C
cooling water 0.07Gal/min, 31°C

Temperature lower than simulation, mainly due to different boundary and convection

bERLinpro HOM waveguide 1-D thermal optimization

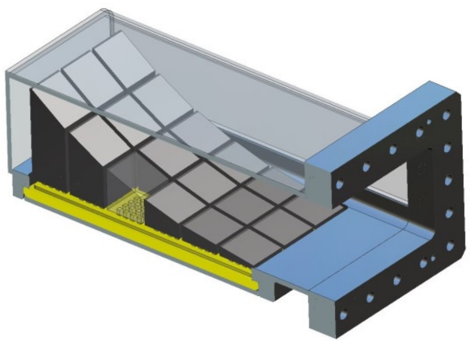




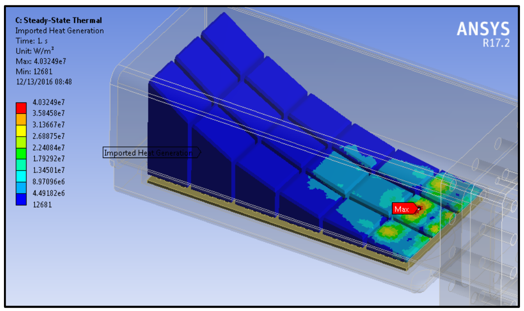
2K heat: 0.05W
5K heat: ~1W
80K heat: ~7W

With bellows, heat load dependence on 80K heat station position is weak.

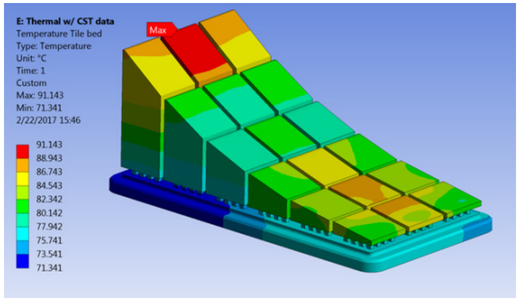
VSR 1.5 GHz Cavity HOM Load Design



VSR 1.5 GHz load model



Combined RF heat in the VSR 1.5 GHz load



Simulated temperature in the VSR 1.5 GHz load, 460 W combined RF power

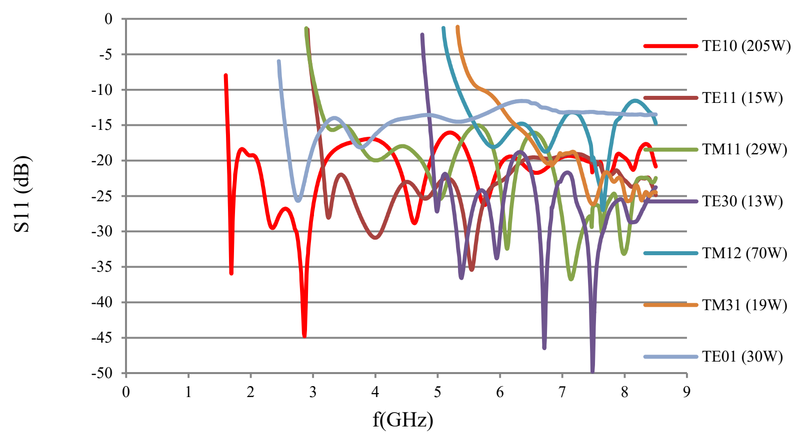
Also use Sienna Technology STL-100HTC absorber

HOM waveguide size 88mm × 60mm at beampipe, tapered to 96mm × 62mm at load (TE10 cutoff 1.56 GHz)

First HOM at ~1.65GHz TE10 mode, first major power spectrum at 1.75GHz, maximum RF power per load 460 W.

Taper in height direction to reduce the reflection of TE10 alike modes close to cutoff frequency; curved tapering to reduce the total length of the load

Consider to use the same load with different tapering for the 1.75 GHz cavities



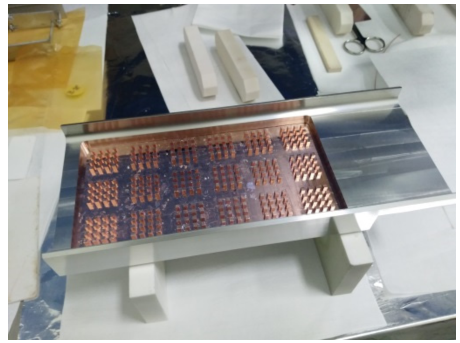
Simulated S11 of different waveguide modes

Jefferson Lab

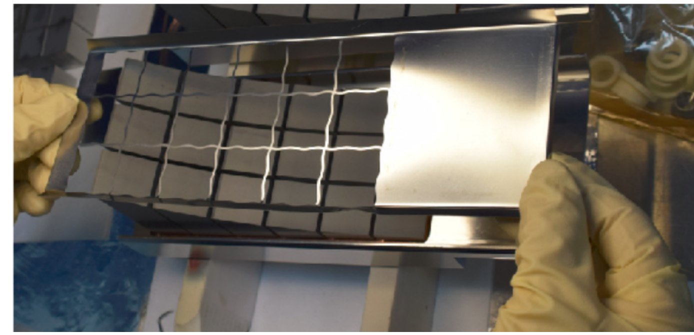
VSR 1.5 GHz Cavity HOM Load Prototype

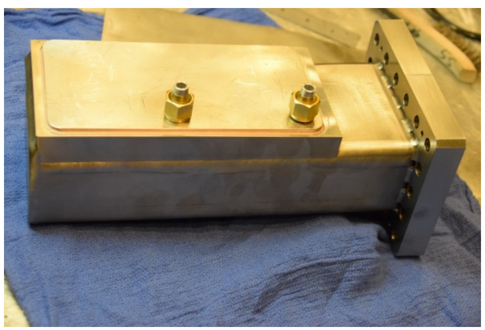
1st braze the cooling channel

2nd braze the bottom assembly

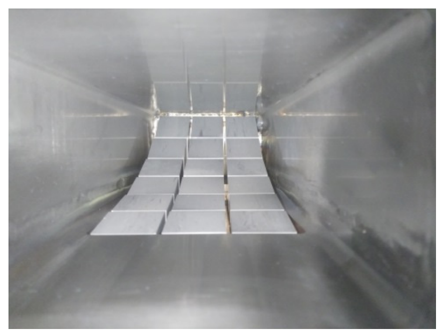


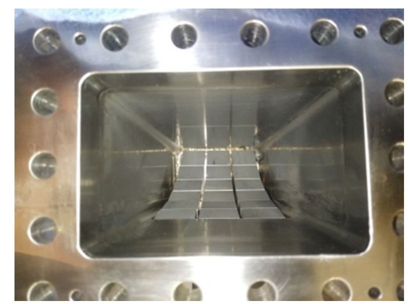
3rd braze the ceramics to the pegboard
Positioned with egg crate shape retainer





Weld into the load

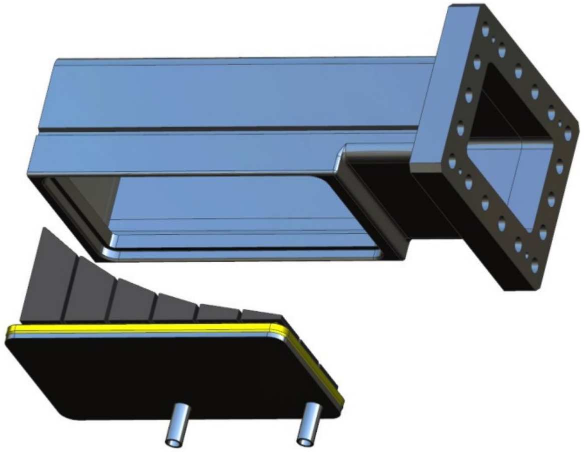




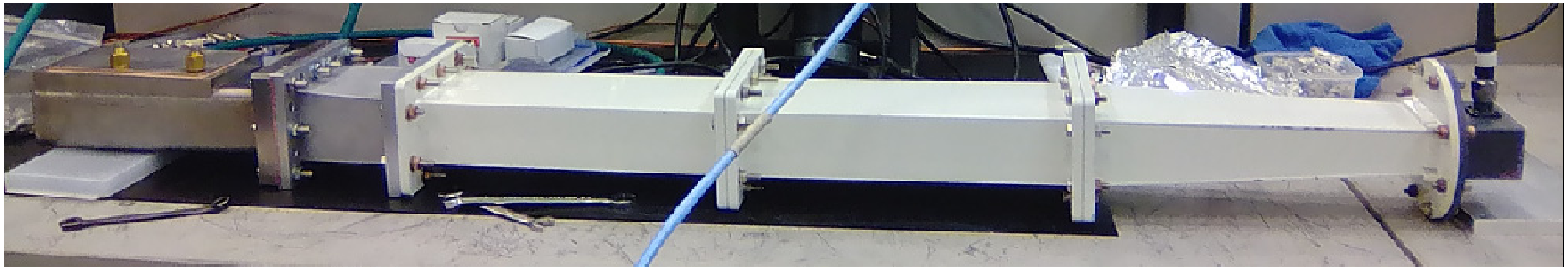
Although the prototype is considered successful, the currently adopted assembly (braze/weld) sequence is difficult to: 1. clean after weld; 2. keep the flange surface finishing to VAT seal specification; 3. keep the weld precision

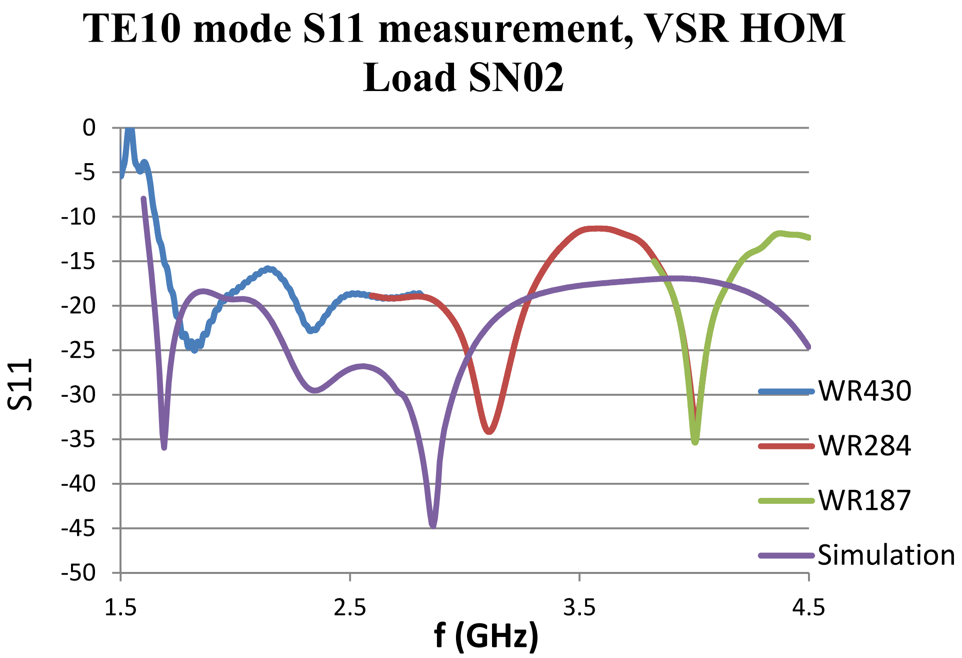
VSR HOM Load Assembly Procedure Optimization

- The production version will change the assembly sequence:
  - 1. braze the cooling channel;
  - 2. braze ceramics to the pegboard;
  - 3. weld the load housing; machine the flange to the final surface finishing and clean the housing
  - 4. braze the housing assembly with the ceramic assembly



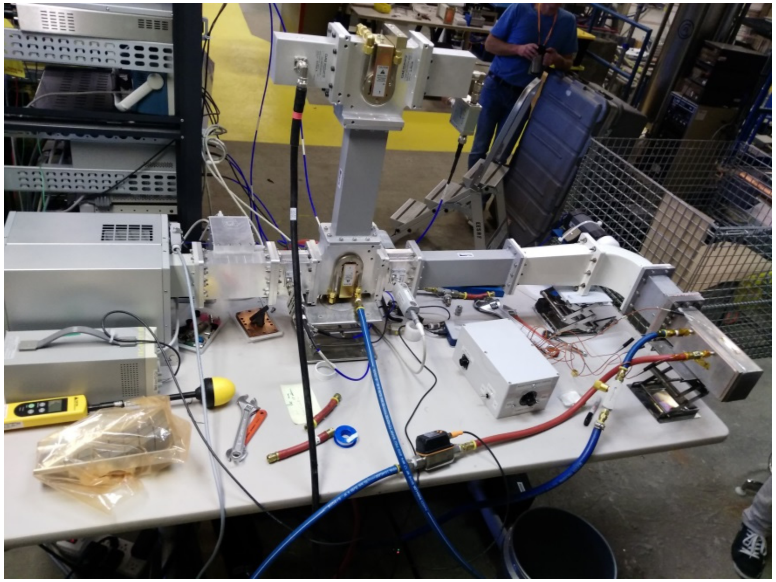
VSR 1.5 GHz HOM Load Low Power Testing

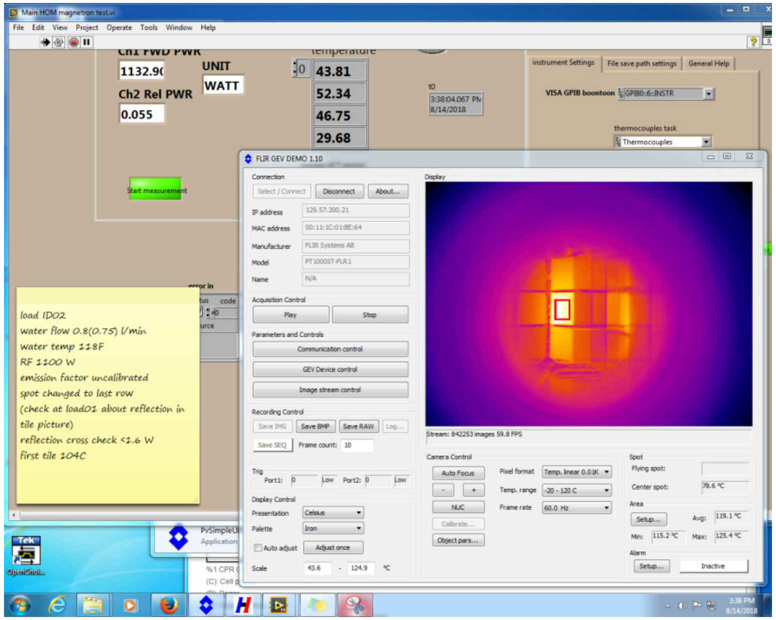




- Broadband S11 measured with E5071C NWA using TDR gating to remove adapter reflection.
- Measured up to 4.5GHz due to limitation of NWA with TDR function
- Use different adapters for different frequency range
- Satisfying the 10dB specification,
- SN02 results are quite similar to SN01

VSR 1.5 GHz HOM Load High Power Testing



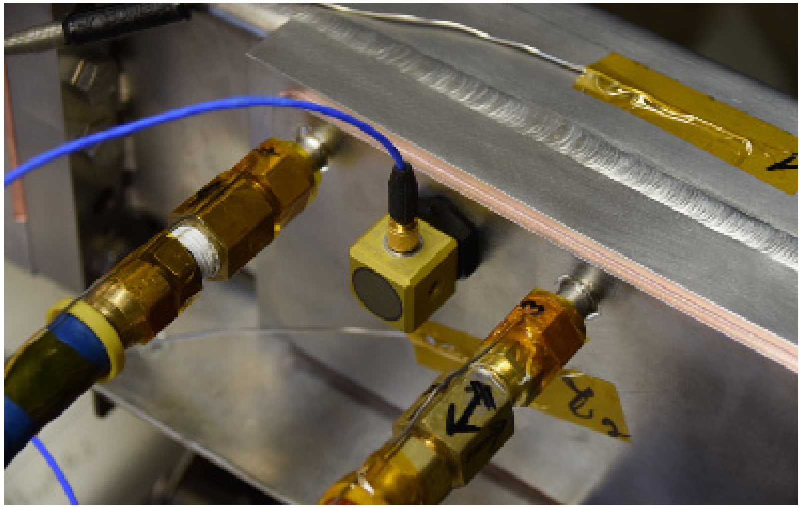


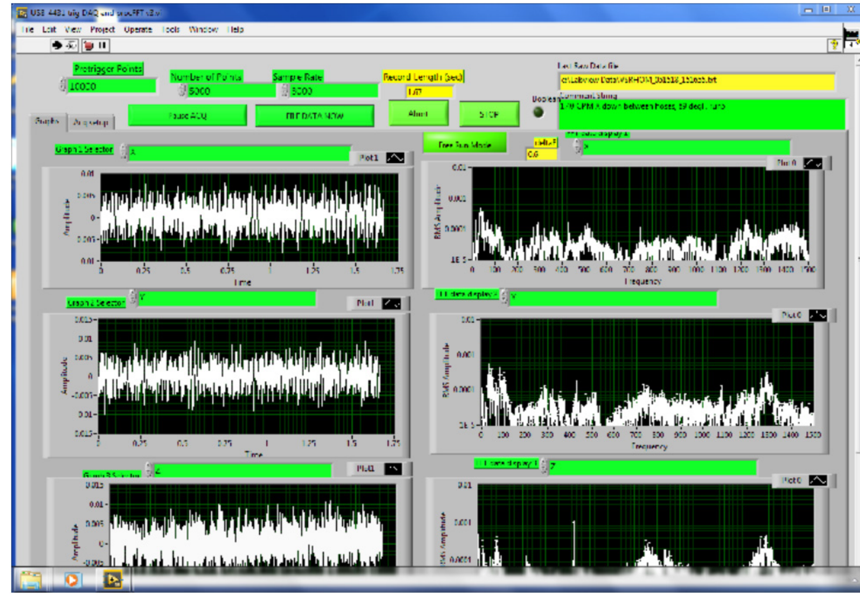
Test setup
RF power provided by a 2.45 GHz 1.1 kW magnetron (H. Wang, THPAL145, IPAC2018)

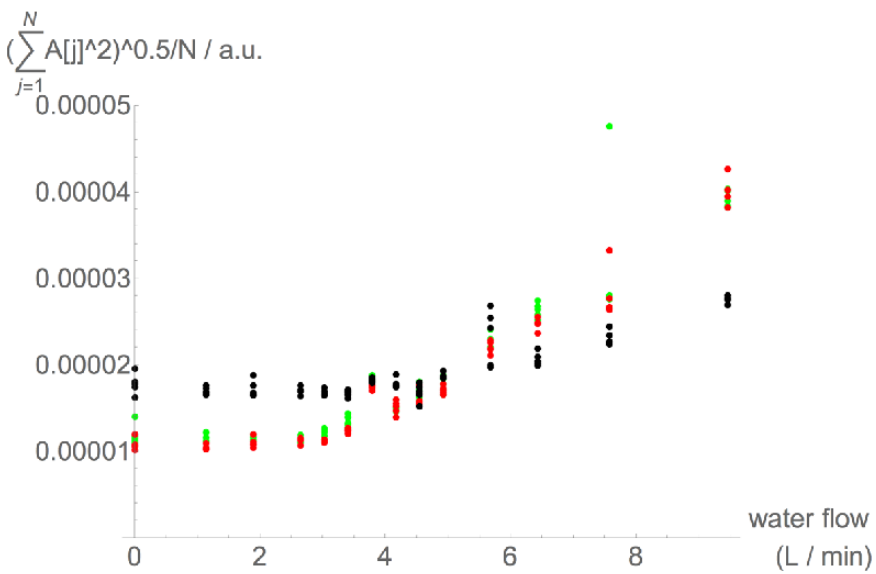
IR measurements with 1.1 kW RF incident power and 0.8L/min cooling water
Hottest spots are in the last row and the front row, agrees with simulation.
The peak tile temperature is lower than simulation, but can be mostly explained by different boundary conditions (convection, waveguide, etc).

Jefferson Lab

VSR 1.5 GHz HOM Load Vibration with Cooling Water

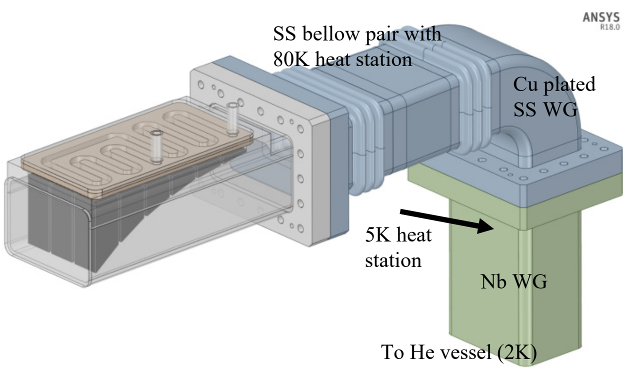


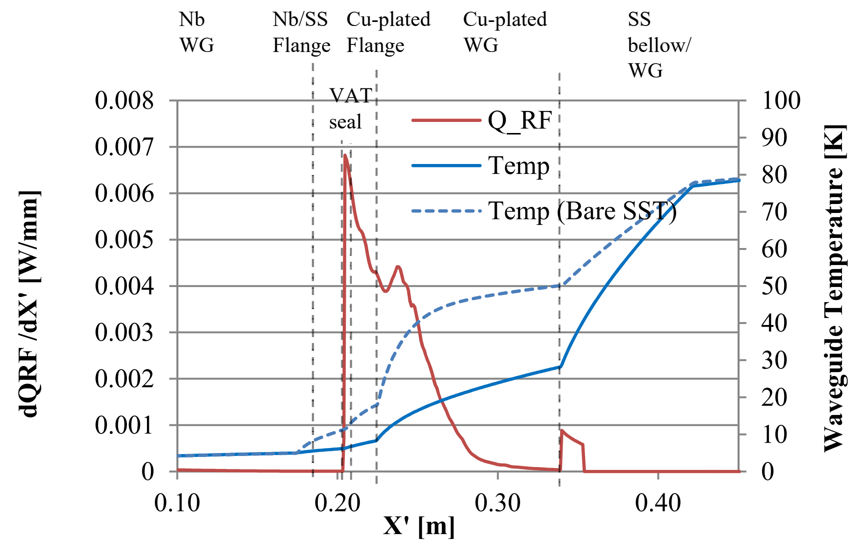




- Approximately linear sound increase above threshold of ~ 3 L/min
- Laminar threshold Renault number ~13000, basically in the upper limit
- Initial mechanic design assumes the threshold Renault number at lower bound at the lower limit ~1500

VSR 1.5 GHz HOM waveguide 1-D thermal optimization





Copper plating required in the waveguide section between the bellow and the flange to avoid quench in the Nb waveguide. However the bellows can be bare stainless steel, avoiding the difficulty to plate rectangular bellows.
Heatload ~0.1W in 2K, ~0.6W in 5K, and 3.4W in 80K per waveguide

Summary

- We identified the new HOM absorber materials to replace the discontinued Ceradyne ceramics, and demonstrated the pegboard brazing for the Sienna materials.
- We successfully prototyped the high power HOM loads for bERLinpro and BESSY VSR 1.5 GHz SRF cavities. The RF and thermal testing results are satisfying. Minor assembly procedure modification is needed to improve cleaning before we start to fabricate the loads in series.
- We also finished the HOM waveguide 1-D thermal optimization for both the bERLinpro and BESSY VSR 1.5 GHz cavities, pending final mechanic design.
- Experience in bERLinpro and BESSY VSR HOM load development will be applied to future projects such as EIC.

Acknowledgements

- Collaboration between HZB and JLab
- HZB team:
  - H. Ehmler, H-W Glock, F. Glockner, A. Neumann, A. Tsakanian, A. Velez,
- JLab team:
  - G. Cheng, F. Fors, J. Guo, J. Henry, K. Macha, F. Marhauser, M. Marchlik, L. Page, T. Powers, R. Rimmer, M. Stutzman, L. Turlington, H. Wang, S. Wang, S. Williams, L. Zhao
- And more…

HELMHOLTZ | ASSOCIATION

HZB Helmholtz Zentrum Berlin