RadiaBeam

Compact, low-cost higher order mode absorbers formed by cold spray of metal matrix composites

DOE-NP SBIR/STTR Exchange Meeting

August 15, 20223

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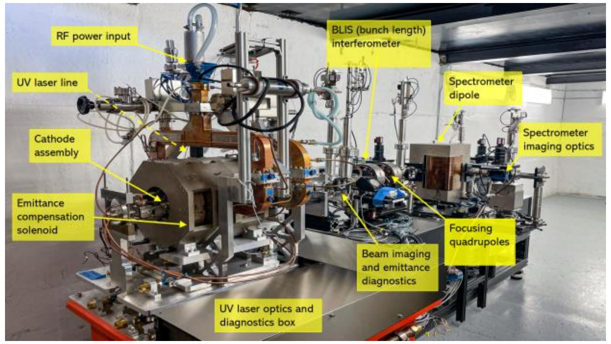
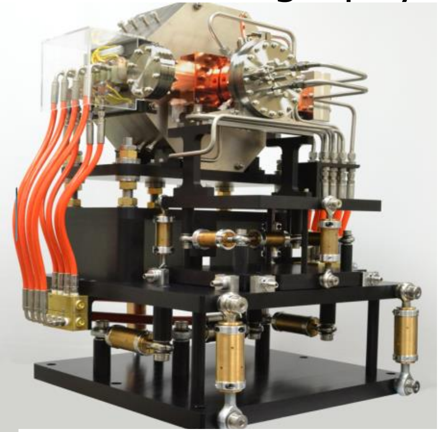
RadiaBeam: Brightness, *Applied*

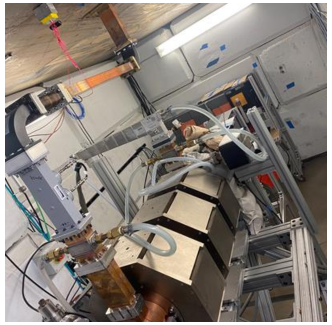
- Spin-out of UCLA Physics Department: 2004
  - Located in Santa Monica, California
- Charge particle optics, custom magnets & >MeV X-ray systems
  - Sim, design, fab and testing of high power RF structures
  - Custom instrumentation with vac-compatible manufacturing
  - Cryogenic engineering
  - 9MeV Radiography/CT services

DARPA - Inverse Compton scattering source



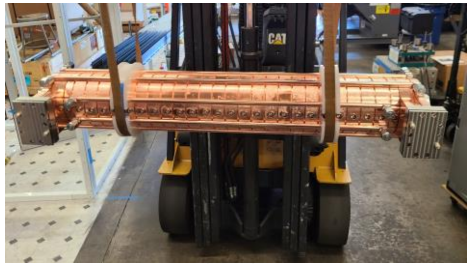


Turn-key accelerator



9MeV FLEX Linac Services

Brazed linac

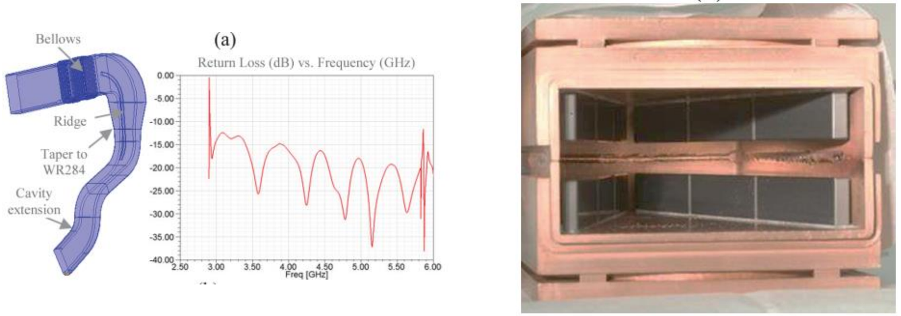


Custom Magnets

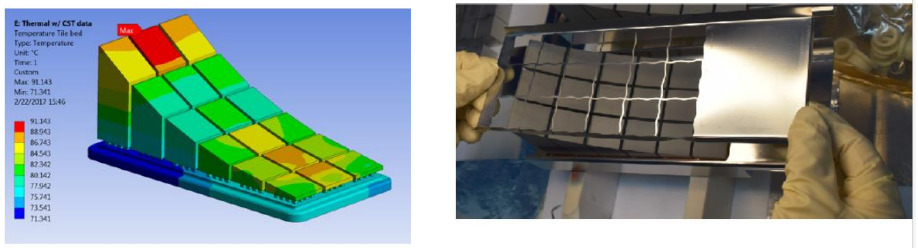
White room manufacturing of copper

Introduction- SRF beam line absorbers

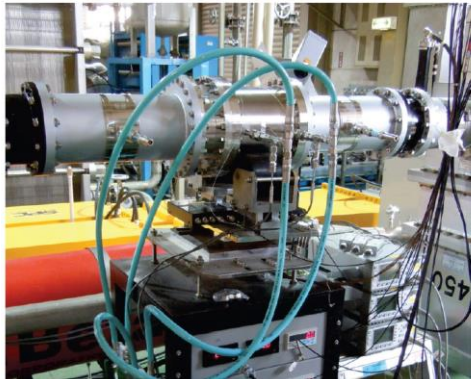
- **Motivation**: Long range wakefields at high currents can strongly affect the accelerator beam dynamics via higher order modes(HOM). As machines move to higher currents, higher bunch charges and shorter bunches, problem becomes more pronounced.
- **Solution:** HOM dampeners which preserve fundamental
  - Waveguide, loop/antenna-couplers, **beam line absorber (BLA)**



Argonne - APS WR284 Waveguide loads for SPX CM
Technology: Soldering + EBW (St Gobain Hexoloy)

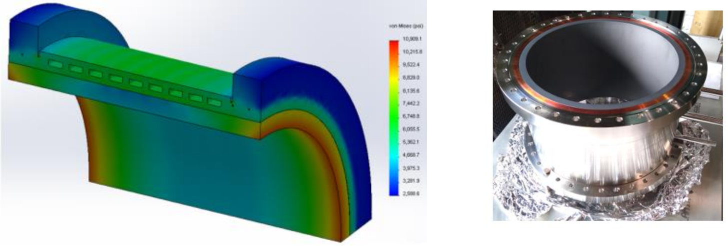


JLab prototype waveguide-load developed for Helmholtz-Zentrum Berlin Technology: Brazed (Sienna STL-100HTZ)



18kW high power tests of SiC at KEK in collaboration with Toshiba Energy Systems
Technology: SiC

BLA developed by DESY/Kubrina Lumina (Poland)
Kubrina Lumina supplied x35 BLA assemblies to LCLS-II
Technology: Brazed 80K AlN (Sienna STL-150D)



BNL LDRD three high power 308mm ID BLAs
Technology: Shrink fit SiC (Coorstek SC-35)

Introduction: Non-SRF examples

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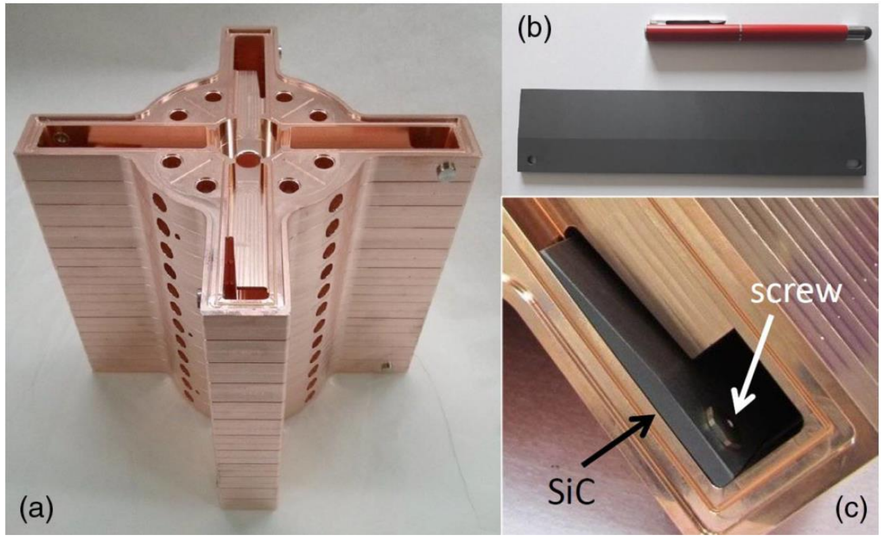
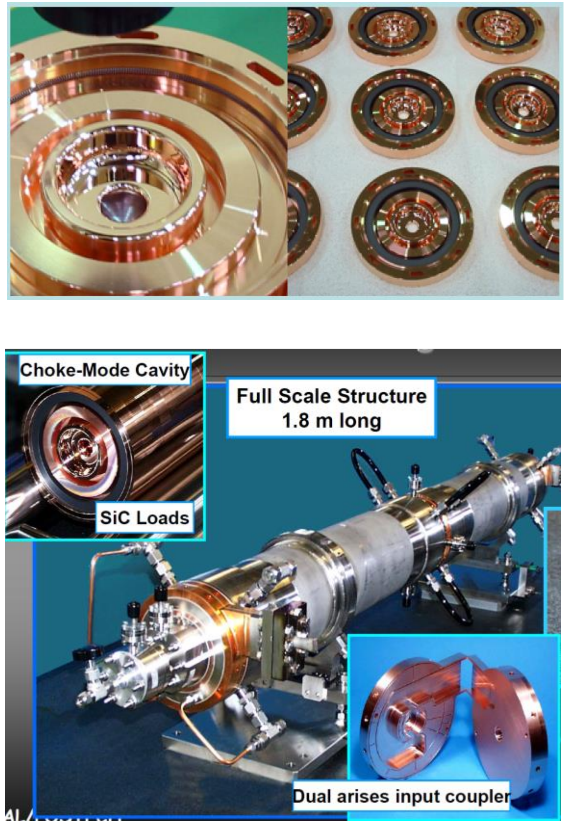
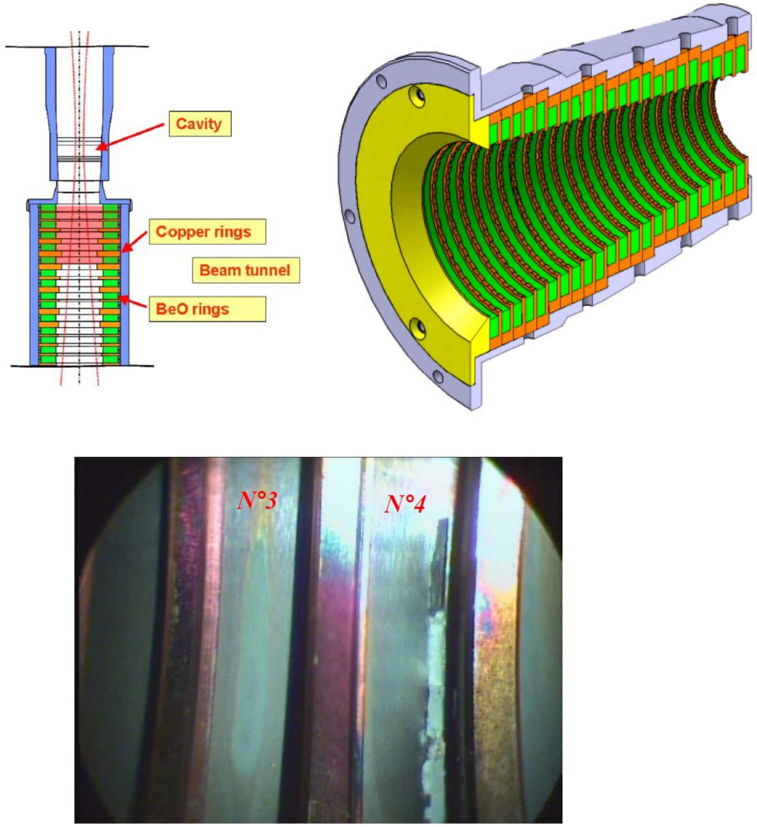


On-Cell waveguide loads for C-band NCRF structure
INFN & Andalo Gianni
Technology: Fastened SiC (Ekasic-P)



Choke-mode C-band NCRF structure for Spring-8
10,000+ cells
KEK & Mistubishi Heavy Industries
Technology: SiC (CERASIC) + Spring clips



Gyrotron beam tunnel to suppress parasitic
Oscillations- Thales
Technology: BeO/SiC(6040) + brazing

Requirements

Beam line absorber assembly requirements:

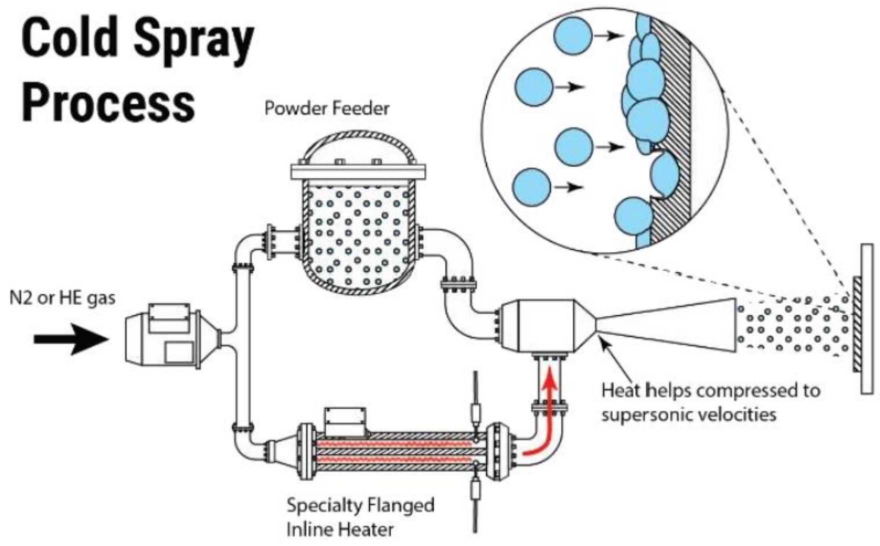
1. Amenable to bonding to a water-cooling circuit 2. Good thermal conductivity 3. Toughness/no cracking: integrity during fabrication and under load 4. Broadband RF absorption characteristics	Conventional-specification
5. Minimize beam-induced electrostatic charging/finite DC surface conductivity 6. UHV compatible/low outgassing 7. No dust/particulate generation 8. Stable against high energy radiation	Accelerator-specifications

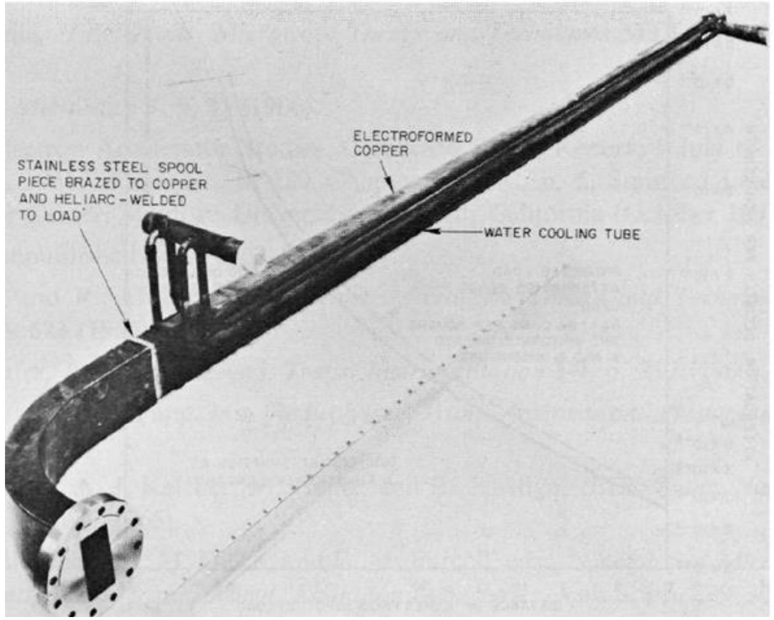
Additional considerations

- Niche application with limited demand: supply and quality issues
- Ceramic variability: small RF coupons can be different than large, full-scale parts
- Establishing specifications and qualification methods requires lab support
- High power testing to failure is valuable for risk mitigation but expensive

Approach

- Cold Spray: corrosion or wear resistance for repair and mitigation, dimensional restoration of mating surfaces like flanges
- Development challenges:
  - Nozzle clogging
  - High ceramic loading: feedstock ≠ coating composition
  - Low porosity w/o expensive He usage

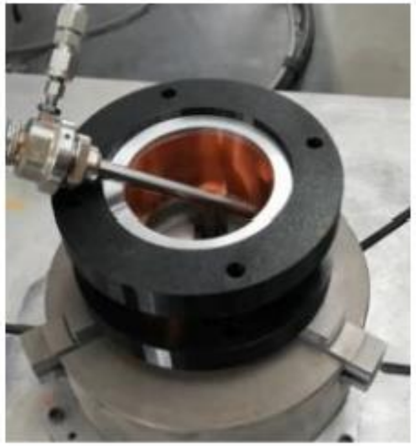




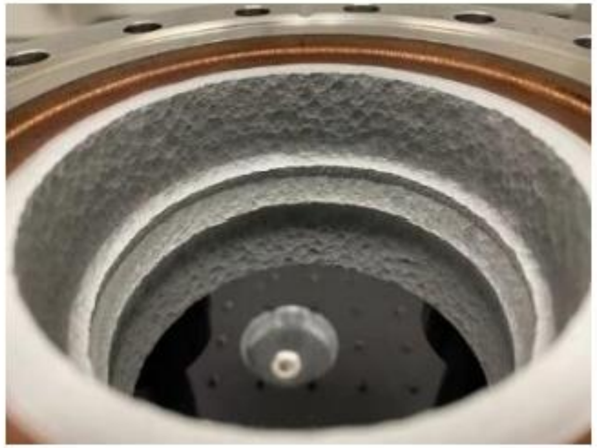
2MW S-band dry load at SLAC flame spray with Kanthal
Metallic/resistive loss = large surface area

Principle of process

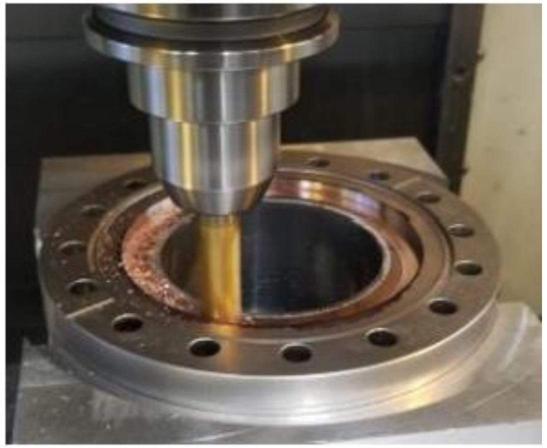
Brazed assembly



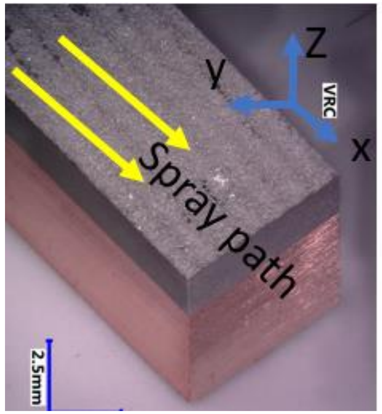
Cold spray ID with Al/SiC composite – Centerline medium pressure system



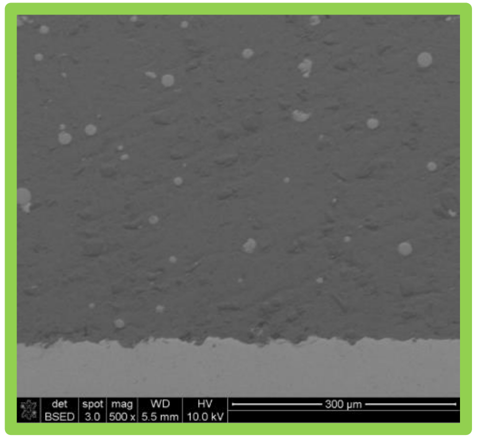
ID coating on copper



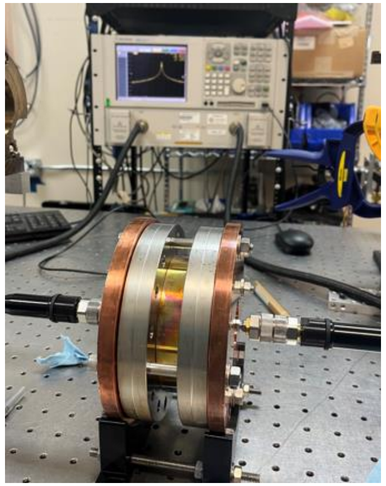
Post-spray machining



Metallurgical Analysis



SEM Analysis



Pillbox measurement
3.0Ghz, Rs = 16m

Outgassing test: rate of rise
Q= 6E-7 mbar L/s

Deliverables

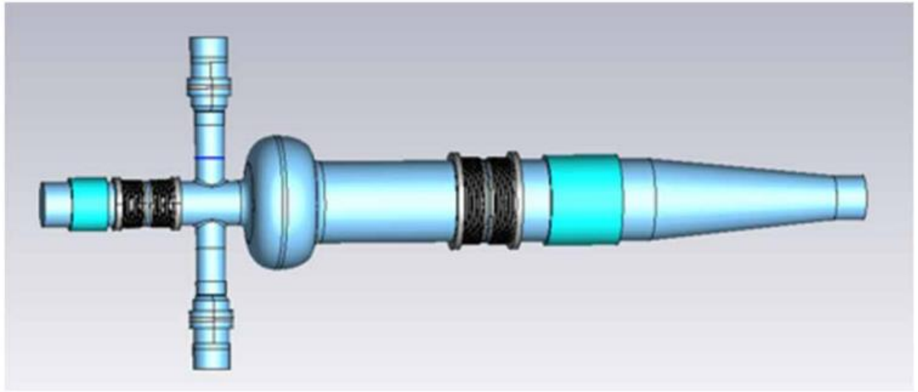
- **General**: Domestic supplier of beamline-ready RF load assemblies with strict quality and schedule control
  - Medical device manufacturer: modern engineering drawing, material handling and process documentation
  - In-house design, manufacturing, inspection and testing capabilities

- **Specific**: Lossy internal diameter coating method which eliminates precision/cost of shrink fit ceramics
  - Year 1 observations: flat coupons do not capture process of ID spraying
  - Damage to brazed knife edges during spraying

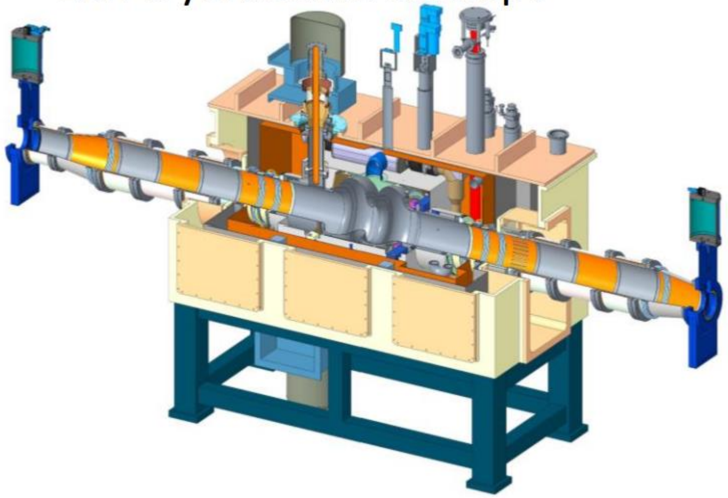
Phase II Objectives	
Design and fabrication of water-cooled BLA housing	Brazed assembly with RF metal vac seals
Coupon level cold spray studies	Based on EIA 3 1/8" standard
Cold spray BLA housing	Based on EIA 3 1/8" standard
RF testing	Low and high power
Vacuum testing	Outgassing rate of assembly, RGA spectrum

Potential Application

- Asymmetric 591MHz EIC eSR cryomodule: 40kW/cavity HOM power
  - BNL designed, fabricated and tested prototype R-154mm BLA based on shrink-fit SC-35
    - Mature lab product developed, limited commercial opportunity
  - Self-heating of R75mm BLA above water-cooling heat transfer threshold
    - Self heating of SC-35 depends on variable RF property data
    - Potential for novel, system level solution including lossy dielectric with lower self-heating and/or broadband resistive BLA via cold spray



ESR cryomodule concept



Rimmer, R. A., et al. "Cavity and Cryomodule Developments for EIC." eeFACT2022

Comparison vs shrink-fit SiC

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- Coorstek UltraSiC GI(SC-35): Direct sintered SiC loaded with graphite
  - Oil & Gas: Dry-running bearing for extreme environments
  - Similar products: Saint Gobain-Hexoloy SG; 3M EkaSiC-P;etc
- Reducing cost requires understanding established costs drivers
- Metrology: CMM and 3D surface topography
  - Important for Cu wall contact area and heat transfer

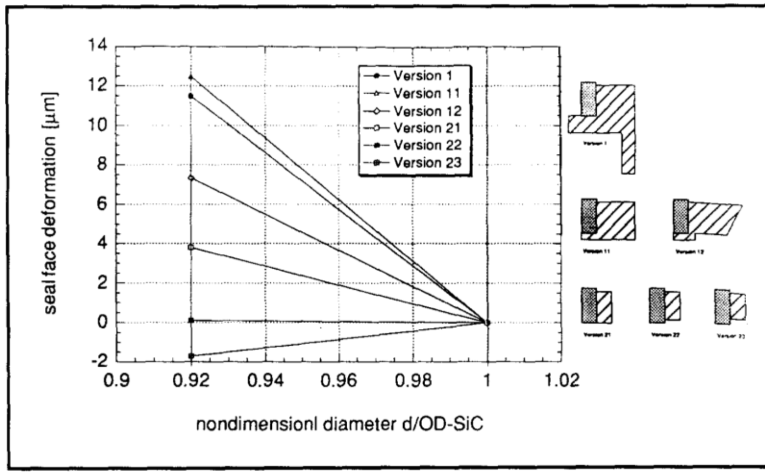
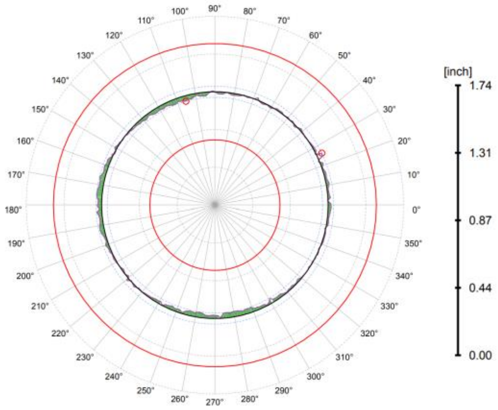


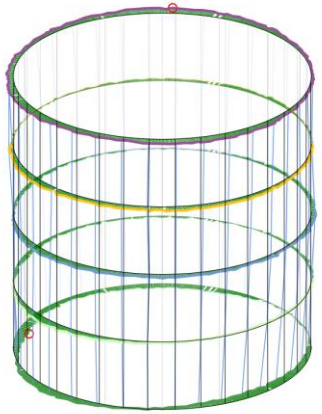
Figure 13. Seal face deformation after shrink fitting

X18 SC-35 cylinders: [3,5,10]mm WT

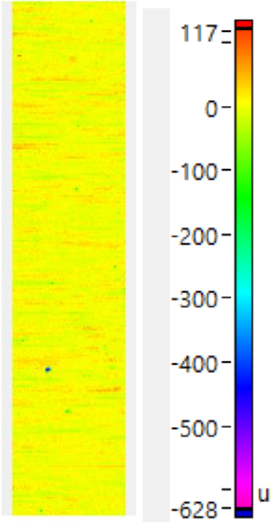
Property	Specification	Measured: min/max	Status
OD-LSQ	3.031” ± 0.001	[3.0311..3.0315]	Pass
OD– Min Circ	3.031” ± 0.001	[3.0312...3.0318]	Pass
Cylindricity	0.001”	[0.0002...0.0004]	Pass
Roughness	32u”	[8...14]	Pass



Circularity



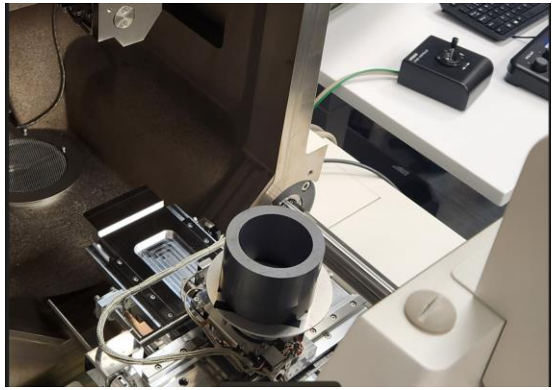
Cylindricity



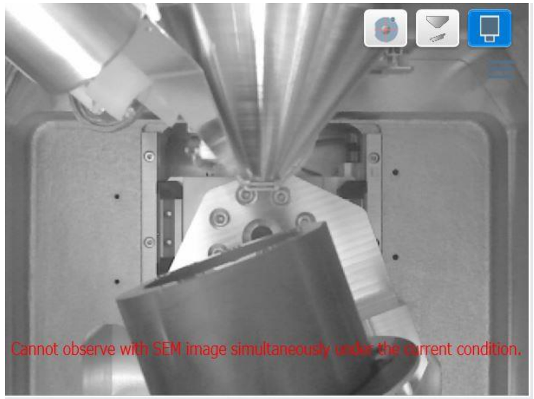
Surface Texture

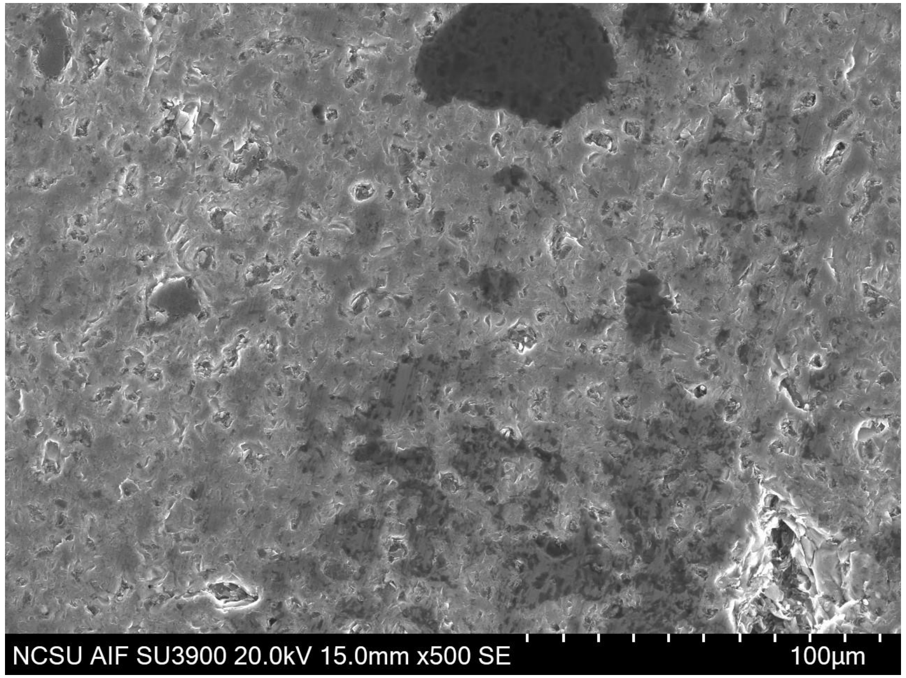
Microstructure Analysis

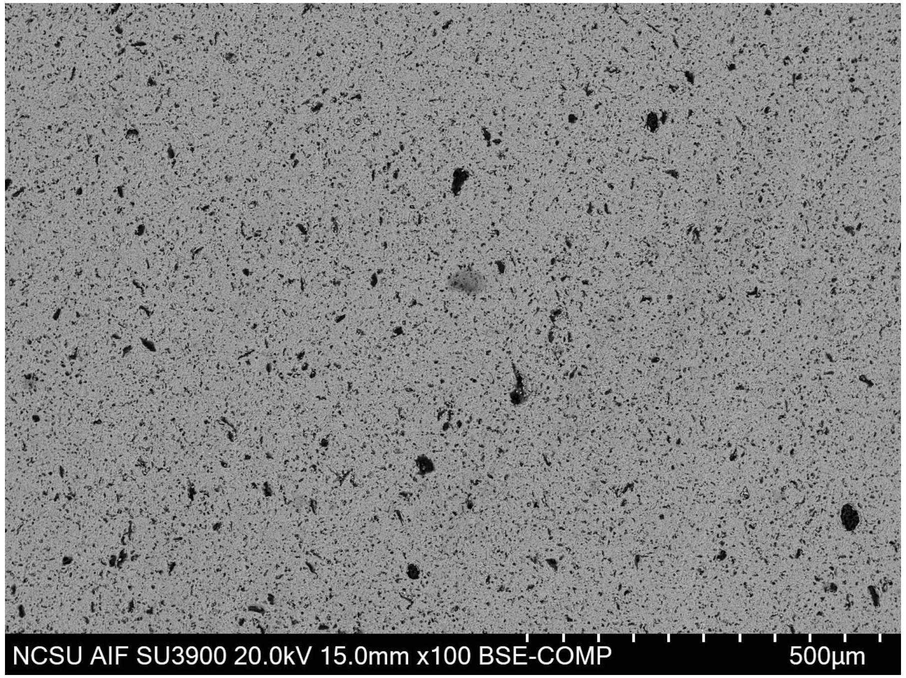
- NCSU – AIF: Large chamber SEM with variable pressure imaging (charging)
  - Secondary electron imaging: Topographic features & pore distribution
  - Backscatter electron imaging: graphite distribution



3” Øx 2”L







Cleaning & particulate shedding

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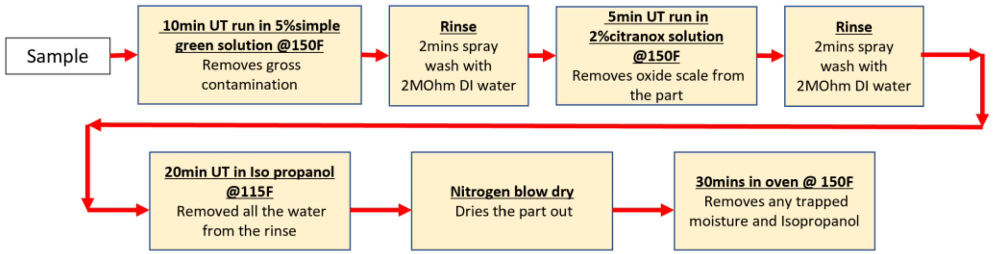
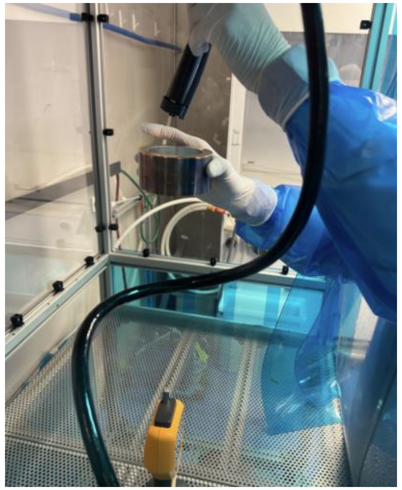
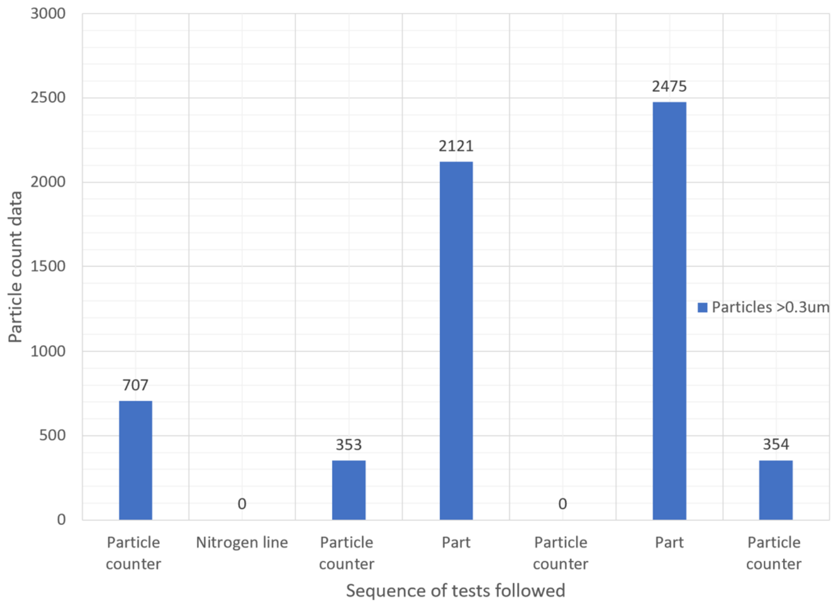
- Contaminate and particulate free BLAs critical to UHV beamline operation near SRF cavities
- Particulate count testing performed in ISO5 hood according standards:
  - ASTM E2042/2042M *Standard Practice for Cleaning and Maintaining Controlled Areas and Clean Rooms*
  - ISO-14644-2 *Monitoring to provide evidence of cleanroom performance related to air cleanliness by particle concentration*
- 0.3um and 5um particle channels monitored sampled at 2.8L/min for 1 min w/ Top gun ionizer blow off gun
- Particle count high: improvements to cleaning and blow-off procedure needs



RadiaBeam BLA cleaning procedure

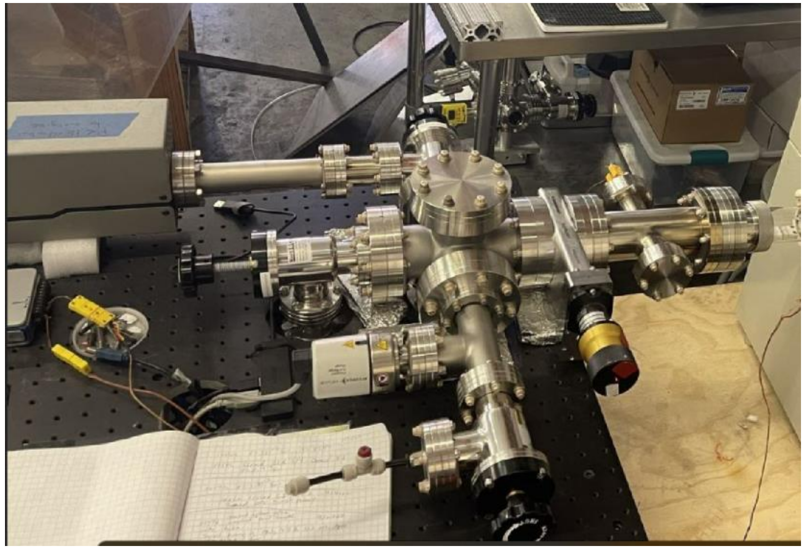


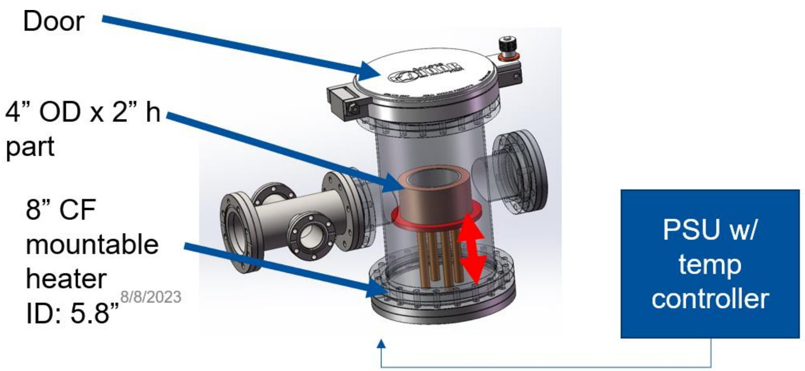
Particle counting in soft-wall clean hood

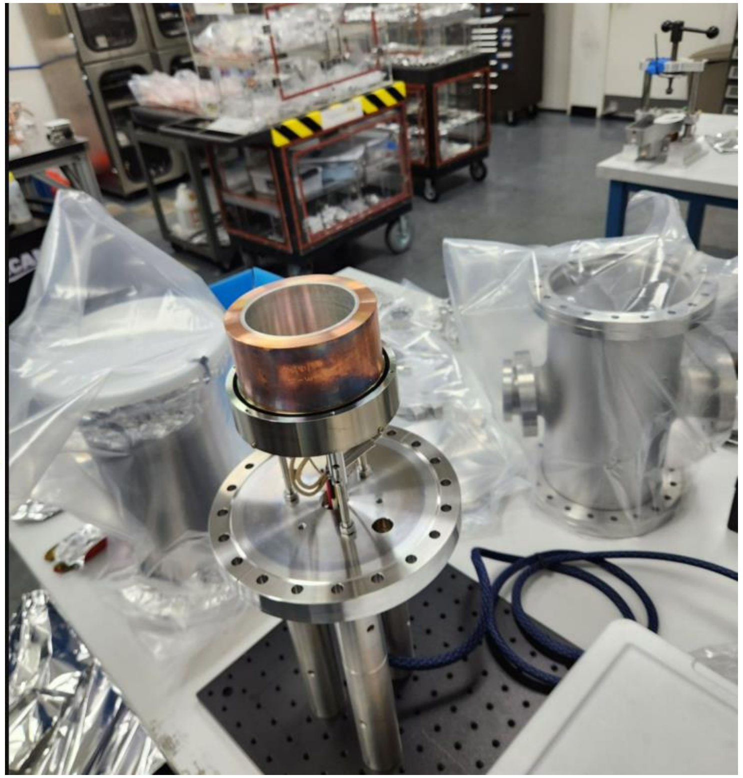


Vac outgassing tests

- Load cylinders into vacuum chamber and conductively heat with 4” wafer heater
  - All equipment in hand: pump cart with RGA, heater assembly, EPICS data logging system etc)
  - Assembly and commissioning scheduled for Sept 2023

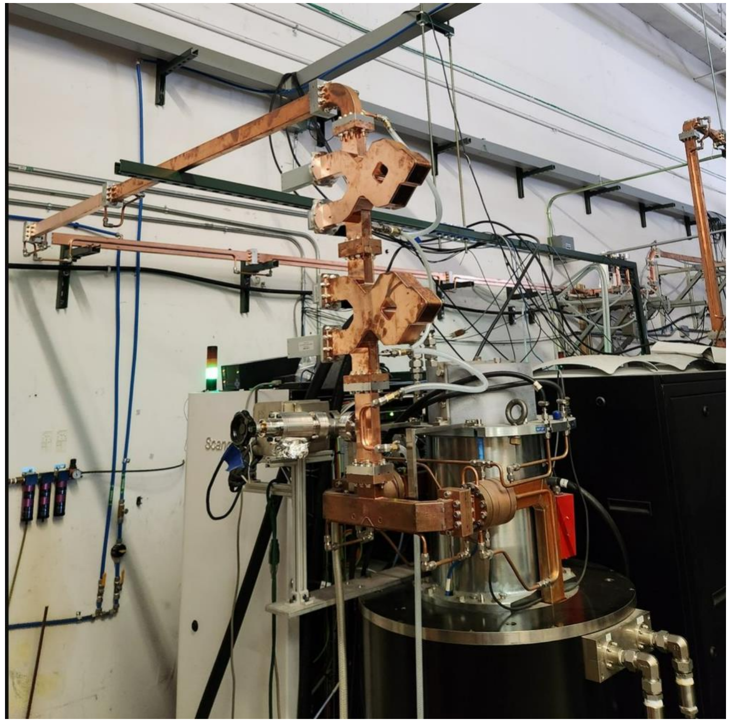


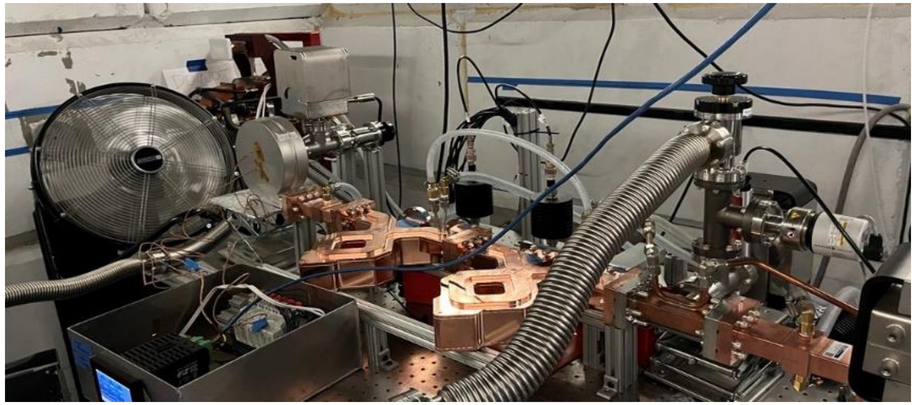




In-house high power testing

- High power testing of stainless 3D printed spiral vacuum load w/ 50MW C-band pulsed power station
  - Convection cooling (pulsed operation)
  - ~9 hours of conditioning, .047 MW to 8.1 MW peak power [20Hz]
  - Monitored temperature and vacuum
- Max VSWR at full power: 1.2:1 w/ no circulator

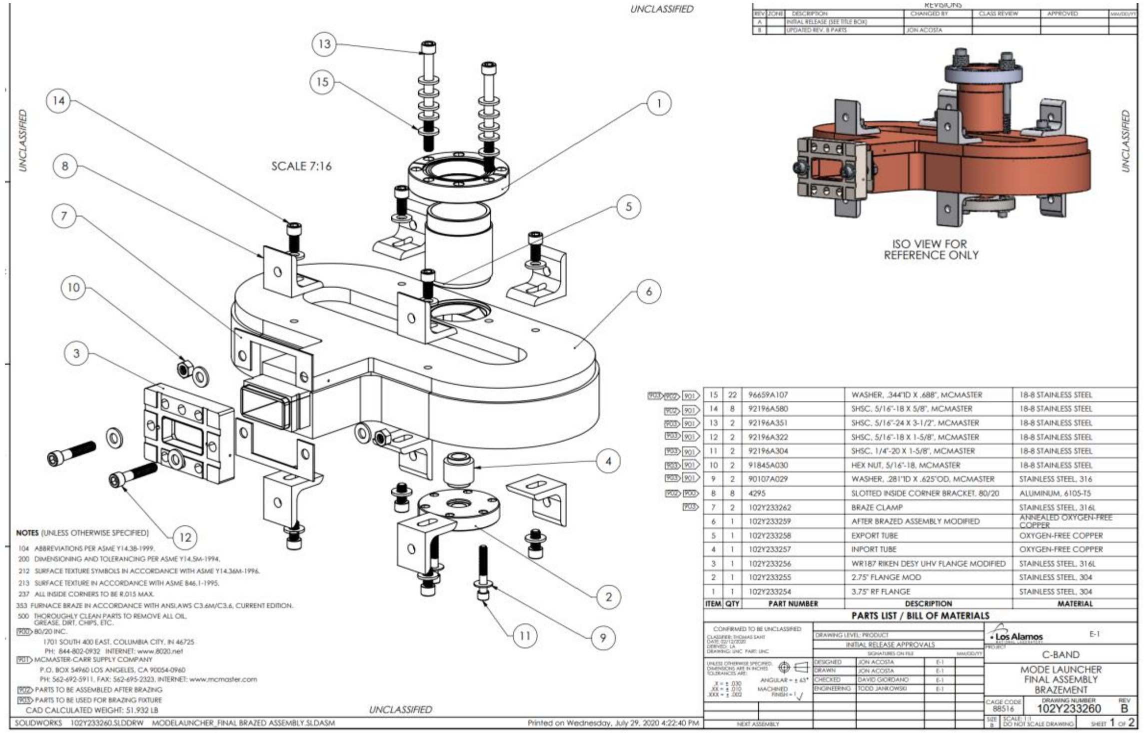




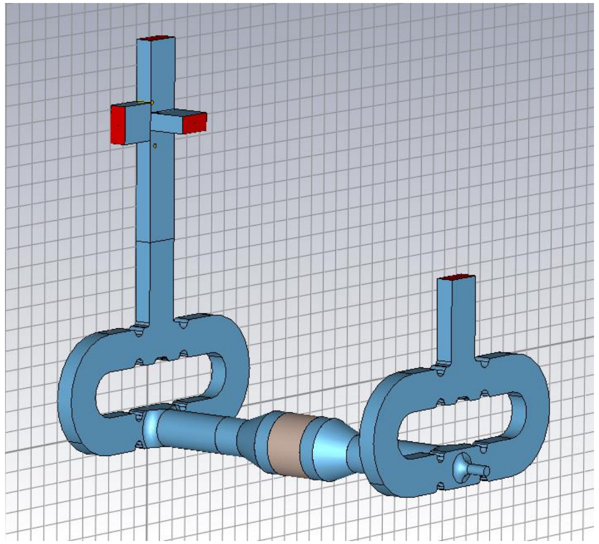
RadiaBeam C-Band Power Station	Power Station #2
Modulator	M1833-2 K300
Klystron	Canon: E37202
RF Peak Power	50 MW
RF Average Power	5 kW
Pulse Length (max)	1 μs
PRF	100 Hz
Frequency	5712 ± 5 MHz

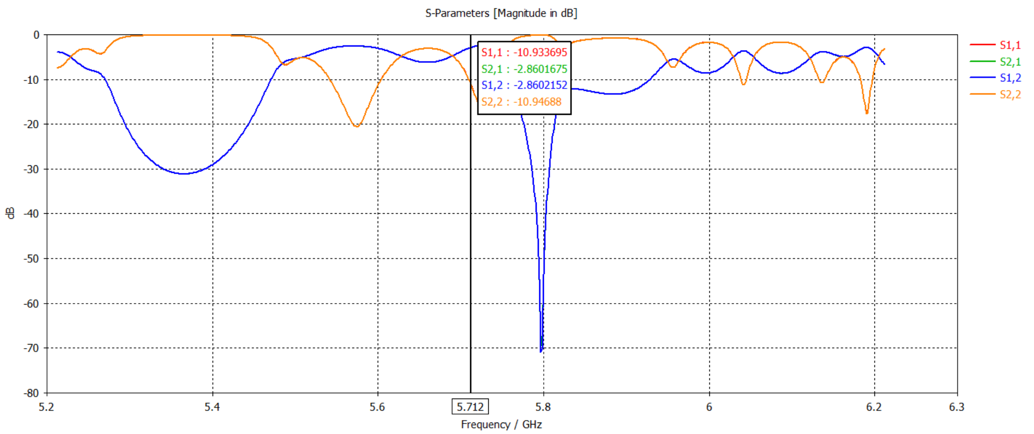
RF testing

Rectangular to circular mode converter needed for BLAs



C-band WR187 TE01 to TM01 mode launcher (1.872” OD)





High power testing at Radiabeam

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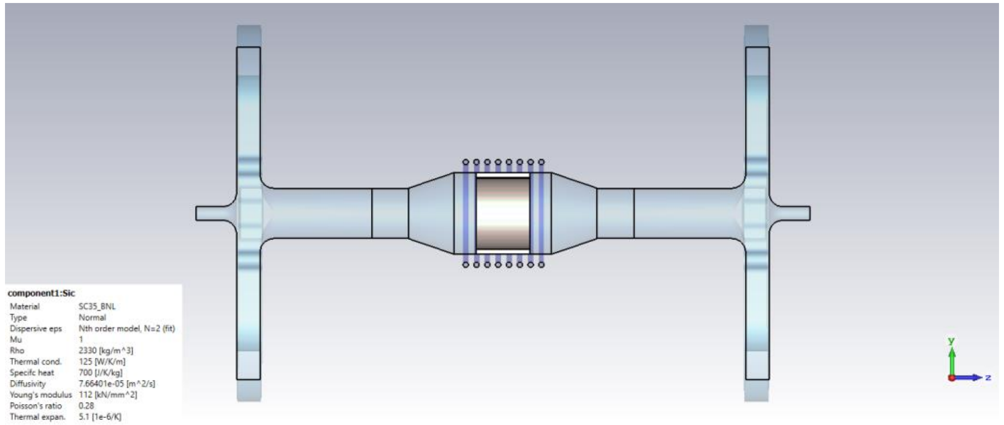
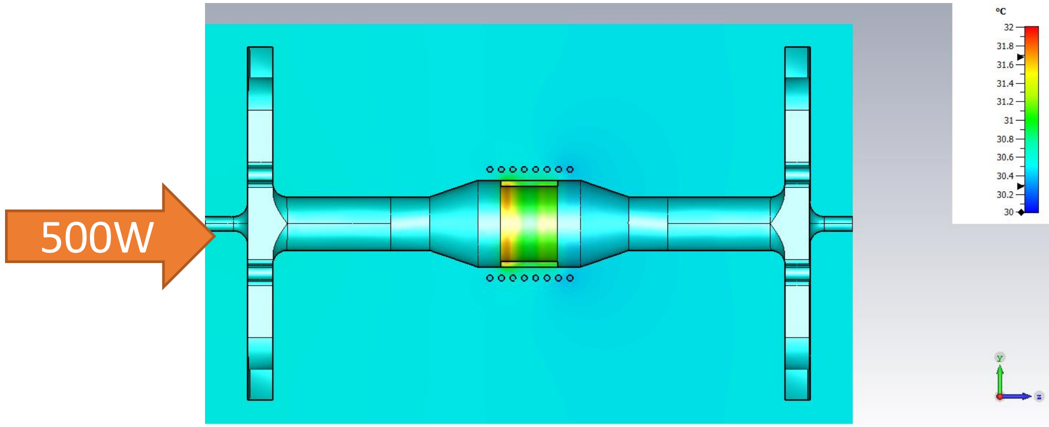
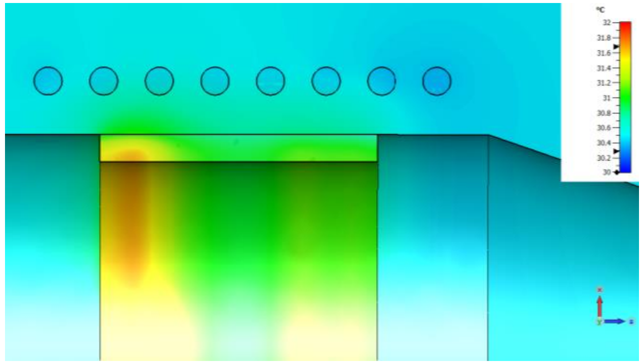
- BNL large diameter SC-35 BLA: 5.7dBm/mm^3
- CST transmission model development
  - 3mm WT SiC with water cooling
  - 5MW peak, 1uS pulse length, 0.01% duty (500W ave)
  - Absorbed: 193W, (3.4 dBm/mm^3)
  - Reflected: 52W
  - Transmitted: 255W
- Thermal model development with: 10kW/m^2 K wall cooling







Nuclear Physics community - Discussion

- Testing standard: clear, unambiguous test results for dry UHV RF loads?
  - How to address variability of broadband RF data?
- Market demand signal from Lab??
  - Internal Lab development versus commercial BLAs
    - LCLS-II BLA: purchased from Europe with Sienna Tech(US) ceramic and DESY development
    - APS-U BLA: fabricated internally
    - EIC BLA: BNL LDRD for fabrication, design and testing

Summary

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- Compact BLAs: volumetric heat dissipation, lossy dielectrics with high thermal conductivity
  – Heavy ceramic loading of cold spray coatings to make into dielectric is extremely difficult
  – Outgassing from coating porosity is a challenge
  – Shrink-fit SiC BLA solution is mechanically and thermally robust
- Comprehensive testing plan for reduced diameter BLA developed
  – Cost and performance comparison between conventional ceramics and cold spray parts
  – High power tests under vacuum critical to establishing commercial product for NP community

Acknoledgements

- DOE Office of Science Nuclear Physics – Michelle Shinn
- RadiaBeam: Kenichi Kanata, Nanda Matavalam, Camille Clement
- ANL: Michael Kelly
- Jlab: Jiquan Gao & Haipeng Wang

References

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Test image 1 at RadiaBeam