Development of a Superconducting RF Harmonic Cavity for eRHIC

Chase H. Boulware, Terry L. Grimm,
Sergey Arsenyev, Adam Rogacki
Niowave, Inc.
Lansing MI

NP SBIR/STTR Exchange Meeting, Gaithersburg MD
August 2015

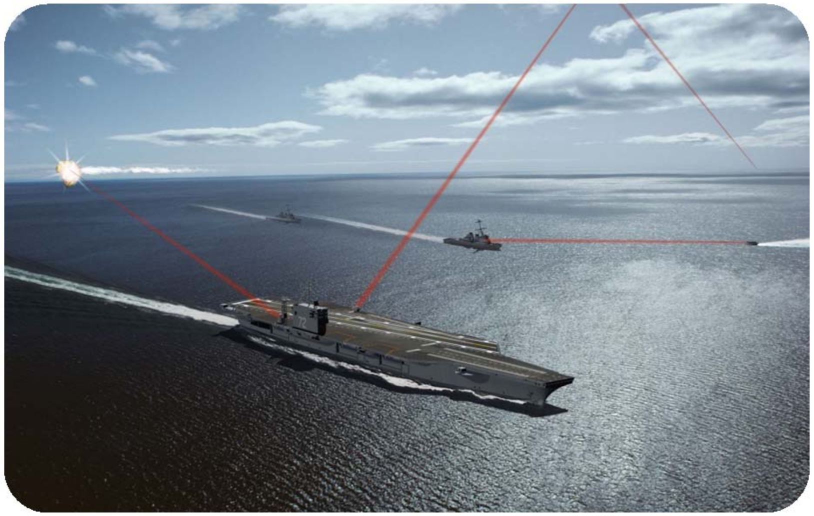
NIOWAVE
www.niowaveinc.com

Commercial Uses of Superconducting Electron Linacs

NIOWAVE
www.niowaveinc.com

High Power X-Ray Sources

Radioisotope Production

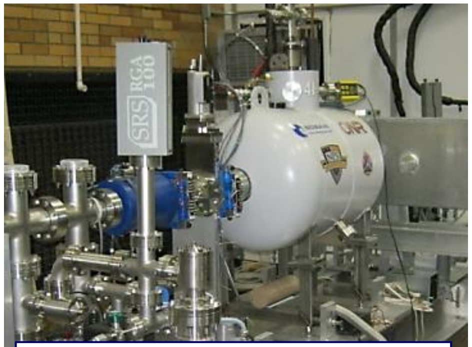


Free Electron Lasers

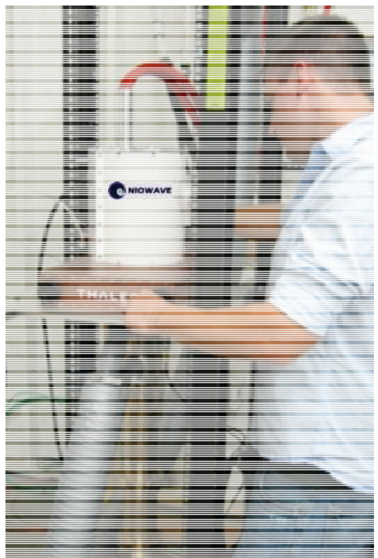
High Flux Neutron Sources

Turnkey Linac Subsystems

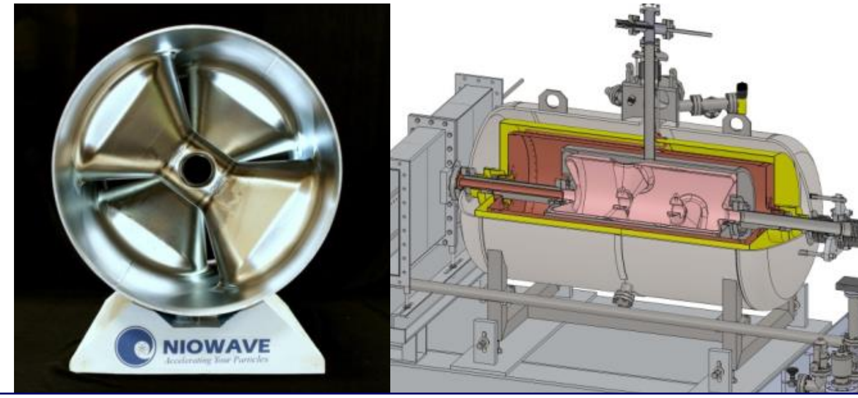
NIOWAVE
www.niowaveinc.com



RF electron guns



Solid-state and tetrode RF amplifiers
(up to 60 kW)



Superconducting cavities and cryomodules

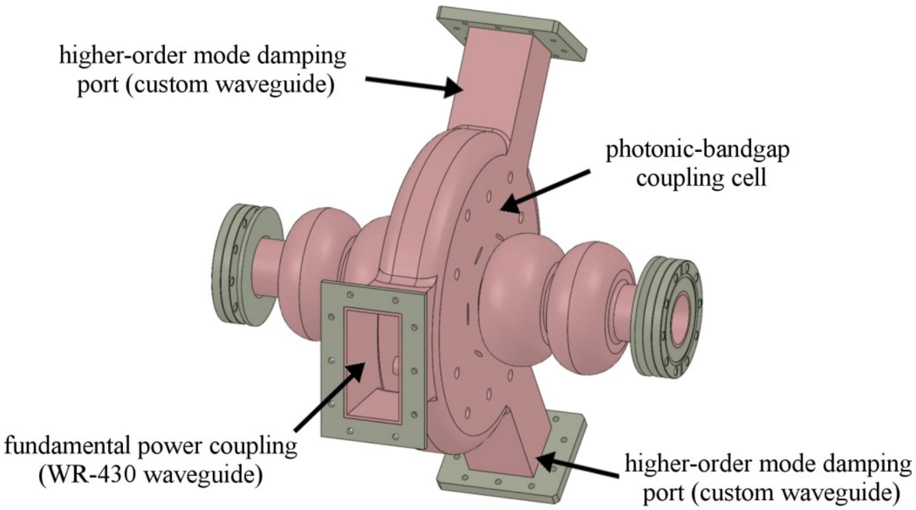
High-power couplers

Commercial 4 K refrigerators
(rugged piston-based systems,
100 W cryogenic capacity)

Project Overview

NIOWAVE
www.niowaveinc.com

- Harmonic linearizing cavity for eRHIC
  - benefits of long pulse operation
  - need for high-current linearizing section
- Superconducting photonic-bandgap (PBG) cavity design
  - PBG cell design
  - multi-cell cavity
- Cavity prototype fabrication
  - niobium forming
  - RF measurements and tuning
- Cavity prototype testing



Project Team

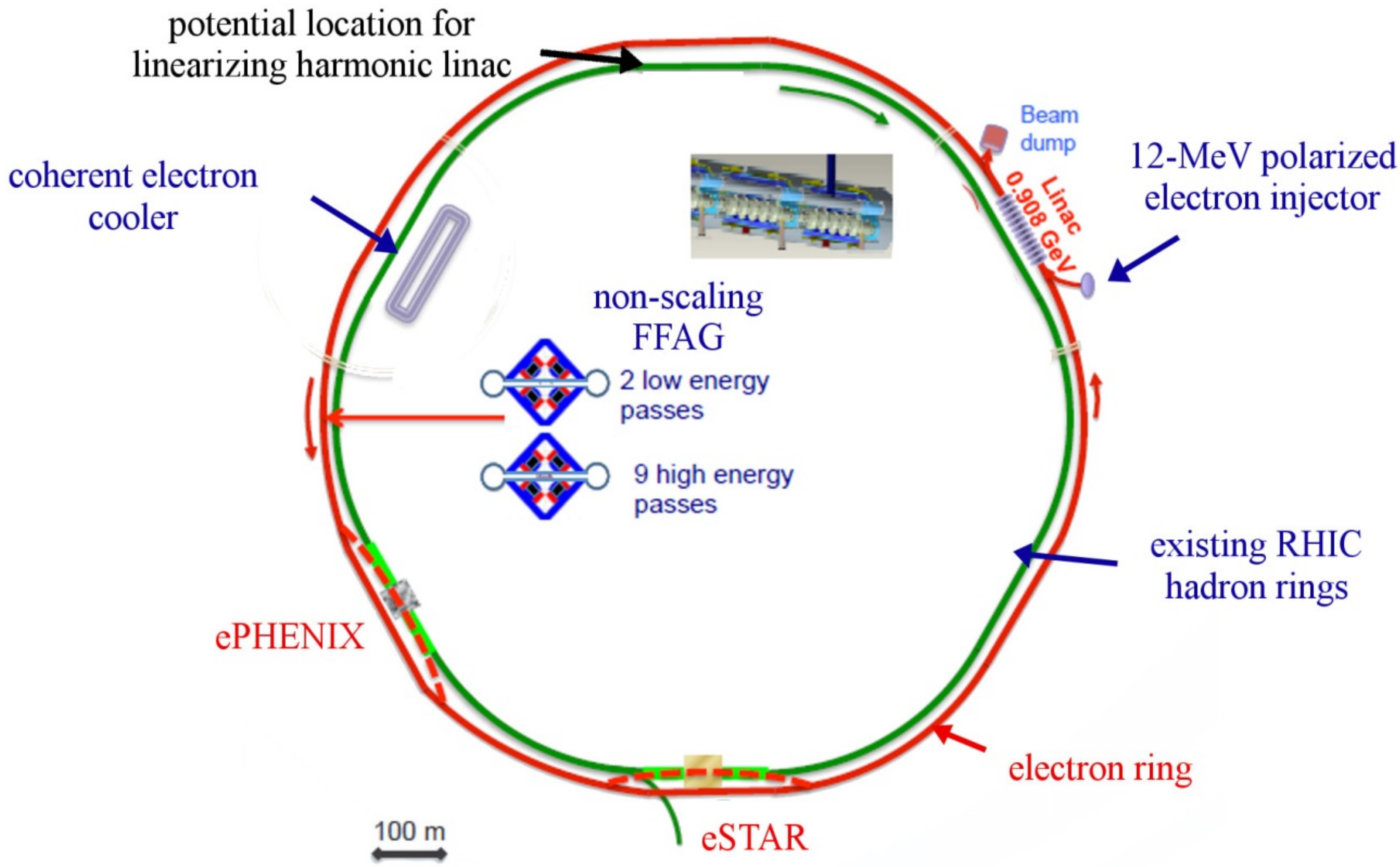
Chase Boulware, Terry Grimm, Adam Rogacki, other Design and Engineering Staff

Evgenya Simakov

Sergey Belomestnykh (consultation on eRHIC plans)

Sergey Arsenyev (currently at Niowave)

eRHIC



potential location for linearizing harmonic linac
coherent electron cooler
Beam dump
12-MeV polarized electron injector
Linac 0.908 GeV
non-scaling FFAG
2 low energy passes
9 high energy passes
existing RHIC hadron rings
ePHENIX
electron ring
100 m
eSTAR

eRHIC Beam Parameters

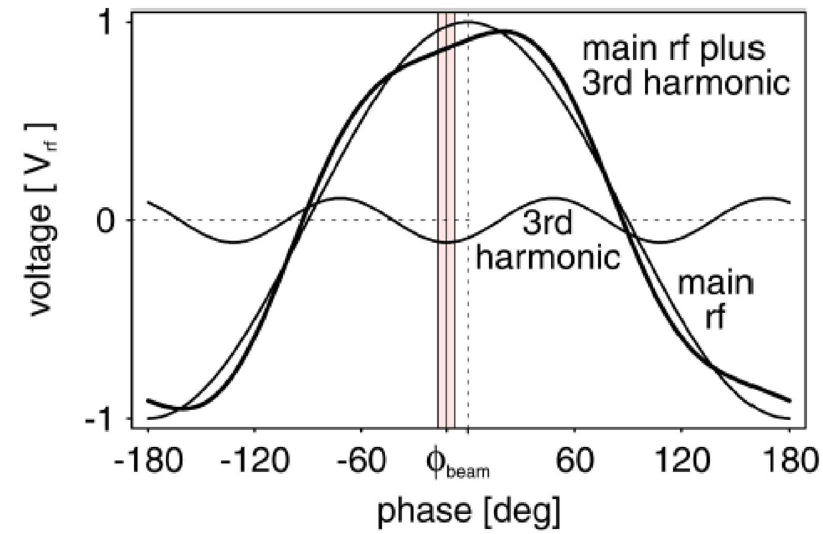
NIOWAVE
www.niowaveinc.com

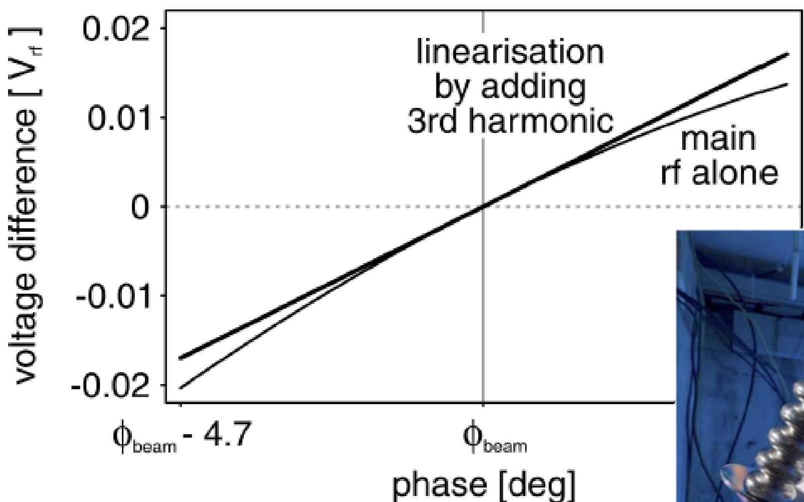
accelerating cavities RF frequency	413 MHz		
5th harmonic frequency	2064 MHz		
beam current	50 mA per pass		
bunch charge and repetition rate	5 nC @ 9.38 MHz		
electron beam energy (upgraded in stages)	5 GeV	20 GeV	30 GeV
bunch length (rms)	4 mm	2 mm	2 mm

- intense electron bunches lead to complex beam dynamics and drive unwanted higher-order modes
- longer bunches
  - reduced bunch intensity (good)
  - induced energy spread from main linac waveform depolarizes electron bunch (bad)

Harmonic SRF Linac

NIOWAVE
www.niowaveinc.com





- combination of acceleration from main linac and properly phased harmonic cavity
- example: DESY (XFEL) pursued this approach at the 3rd harmonic
  - frequency of 3.9 GHz (3 × 1.3 GHz)
  - SRF, but not operated CW

Photonic-bandgap Accelerators

NIOWAVE
www.niowaveinc.com

- geometric array of conductive rods has a bandgap
- removing a single rod creates a frequency specific resonator

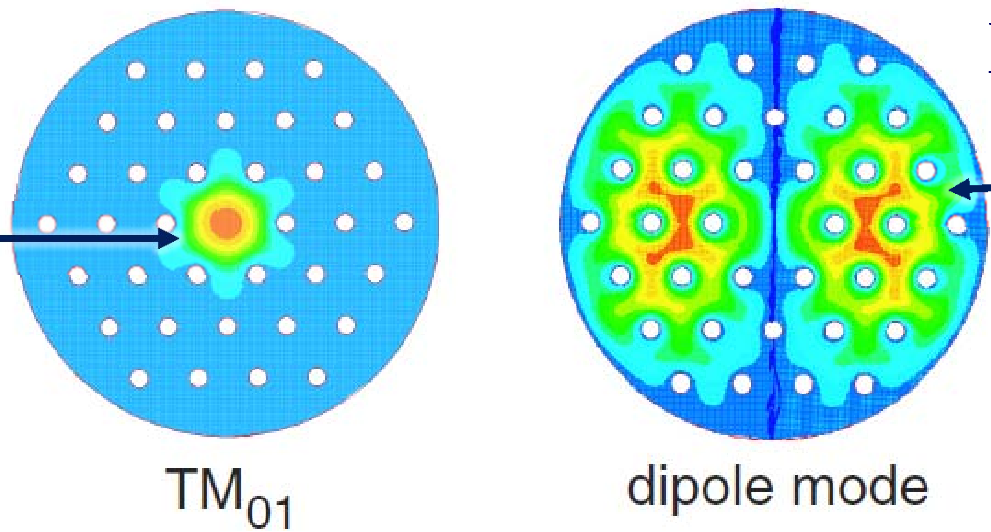
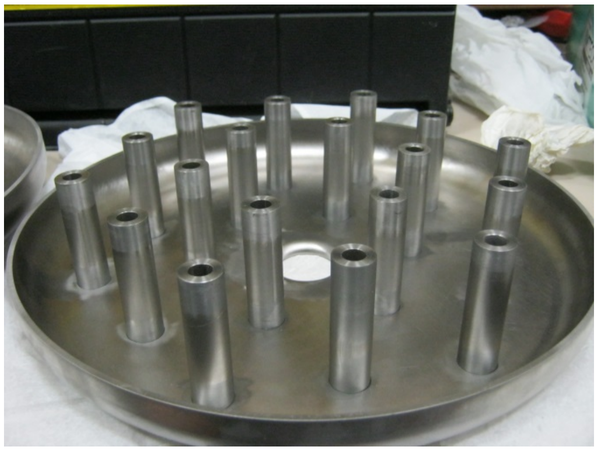
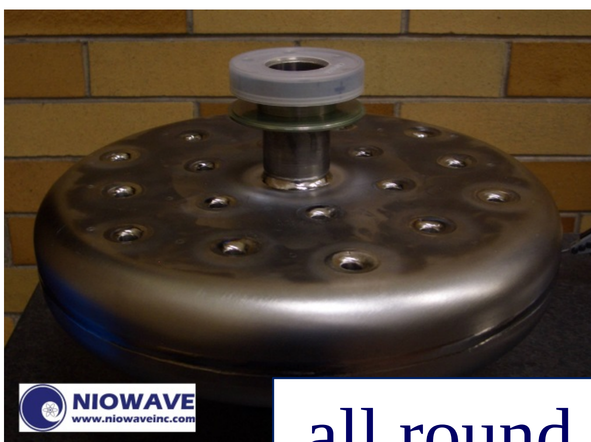


figure from Smirnova et al., PRL 95, 074801 (2005)

Single-cell PBGs

elliptical inner rods



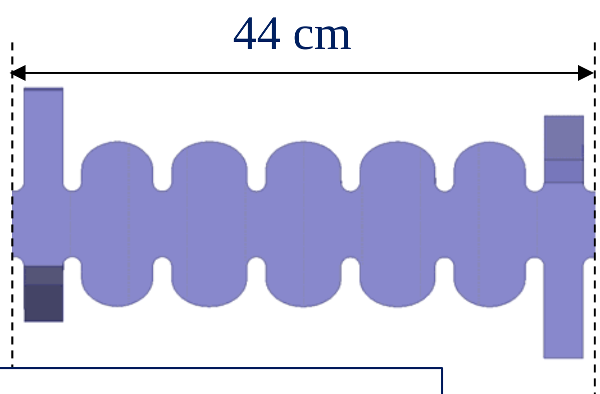


all round rods

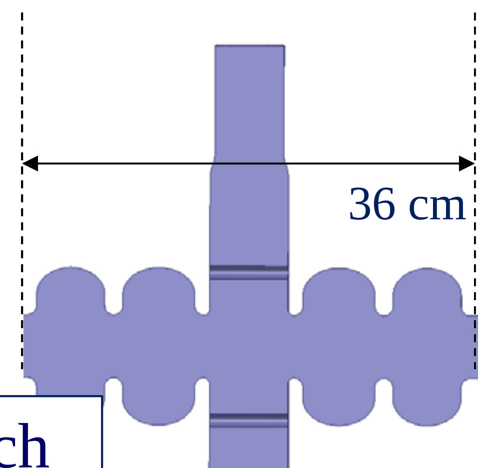
- Niowave and LANL collaborated on several single-cell PBG cavities
- demonstrated up to 18 MV/m in cryotests at LANL.

Multi-cell PBG cavity

- Higher gradients in multi-cell cavities
- 5-cell design uses one PBG center cell
  - PBG for both accelerating power coupling and HOM damping
  - replaces end assemblies



conventional design



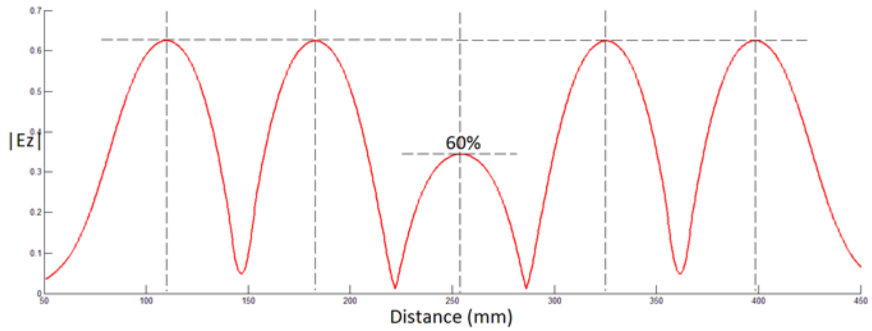
PBG approach

Tuning of Multi-cell cavity with PBG

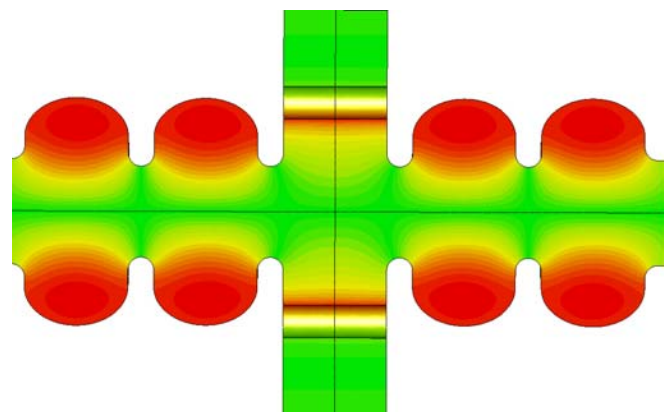
NIOWAVE
www.niowaveinc.com

PBG cell has higher peak fields than elliptical cell, so this cavity has special tuning.

- Design predates SBIR
- Implementation for Nb and RF measurements part of SBIR



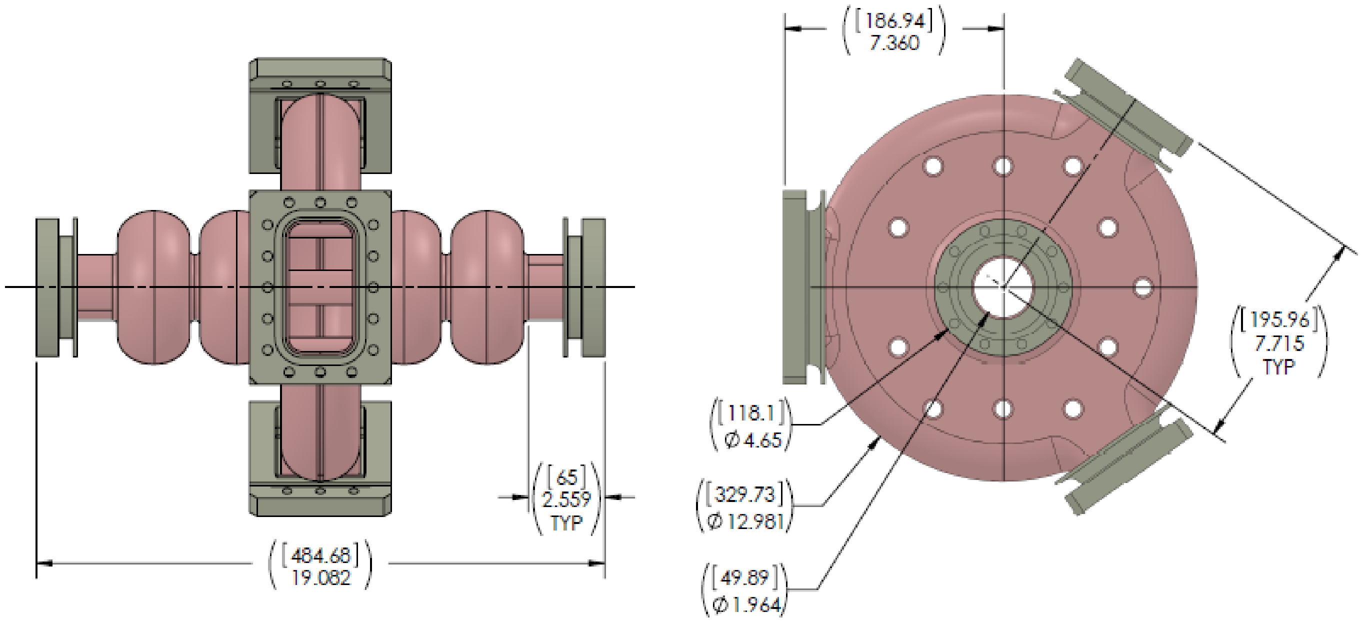
Electric field magnitude along central axis



Magnetic field magnitude on niobium surfaces (peaks equal in each cell)

Cavity Mechanical Design

NIOWAVE
www.niowaveinc.com



The SBIR kicked off with plans for manufacturing the 5-cell cavity design

- new forming steps for waveguide-cavity interface
- new rectangular vacuum seals designed based on aluminum diamond seals (TESLA design)

Cavity Fabrication [1]

Evgenya Simakov's Early Career project funded a copper prototype (project started a few months before Phase II SBIR). Many steps were prototyped.

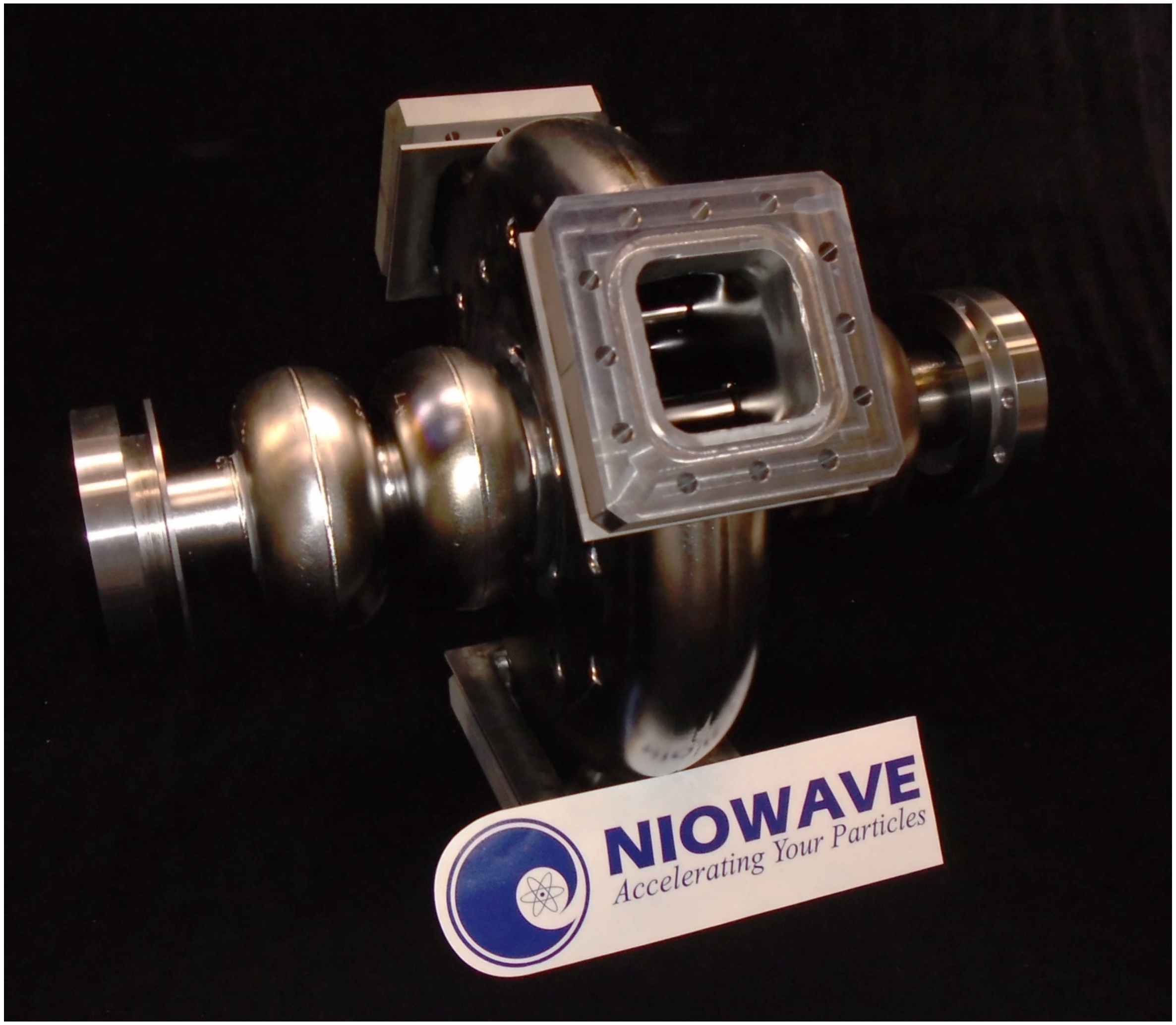
Cavity Fabrication [2]

NIOWAVE
www.niowaveinc.com

The SBIR project proceeded with niobium-specific issues

- electron-beam welding design and fixturing
- new rectangular vacuum seals and flanges designed based on aluminum diamond seals (TESLA design)

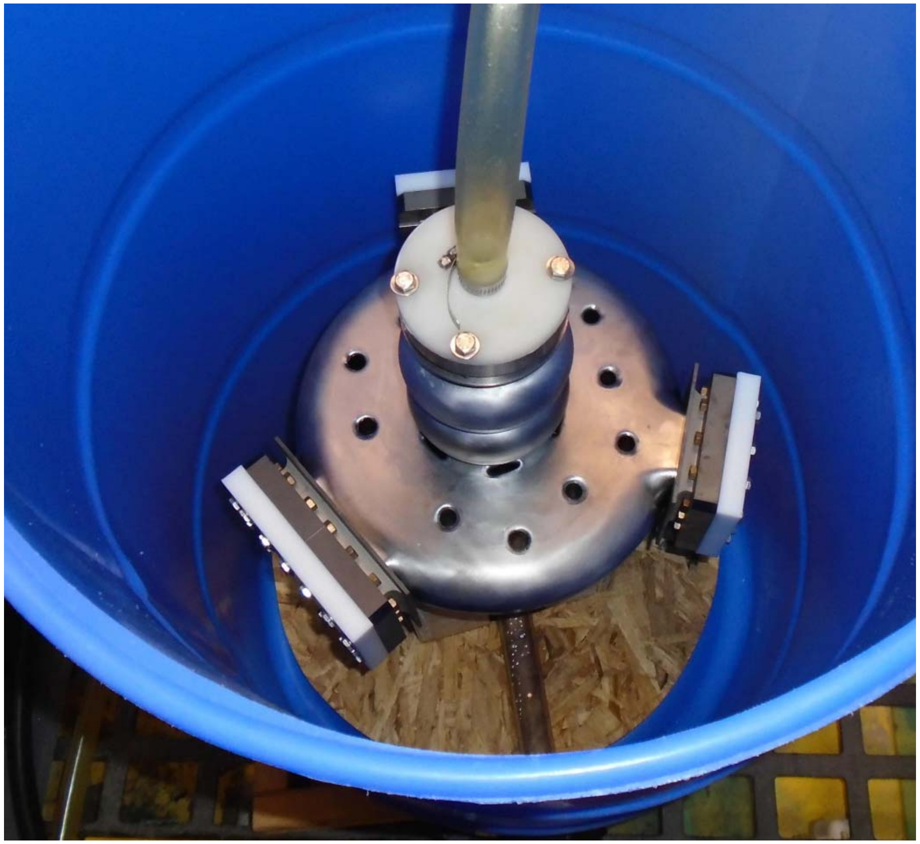
Cavity Fabrication [3]

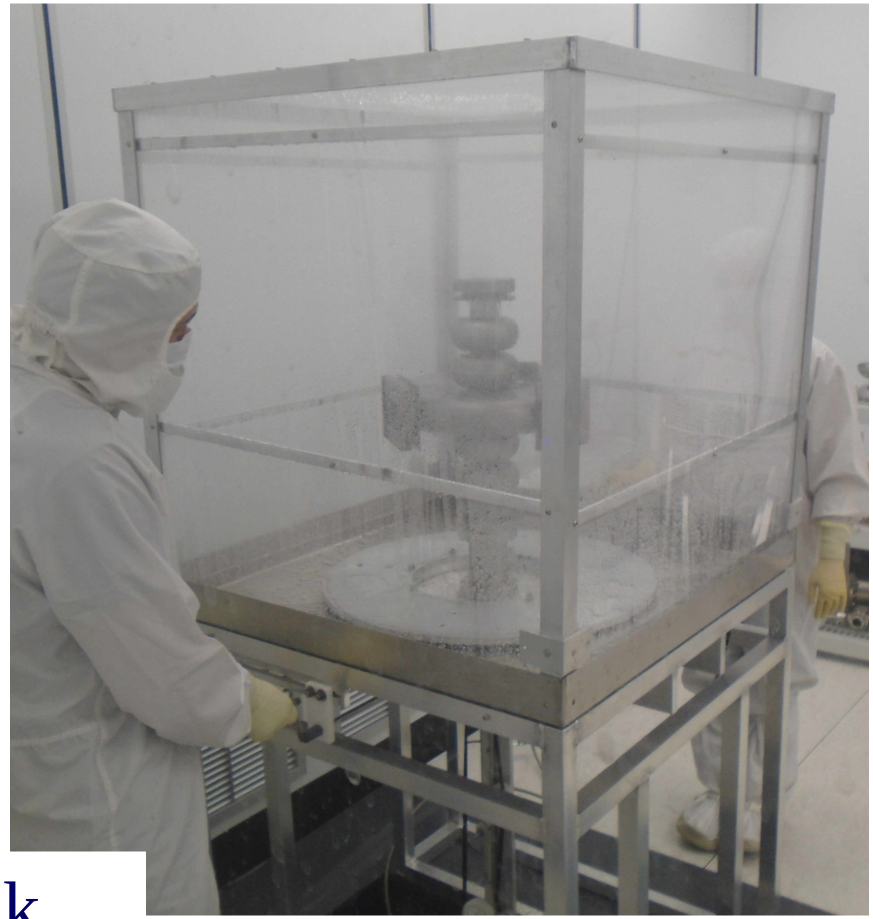


Niobium cavity after electron-beam welding. Pre-tuning met goals for frequency and flatness.

Cavity Processing

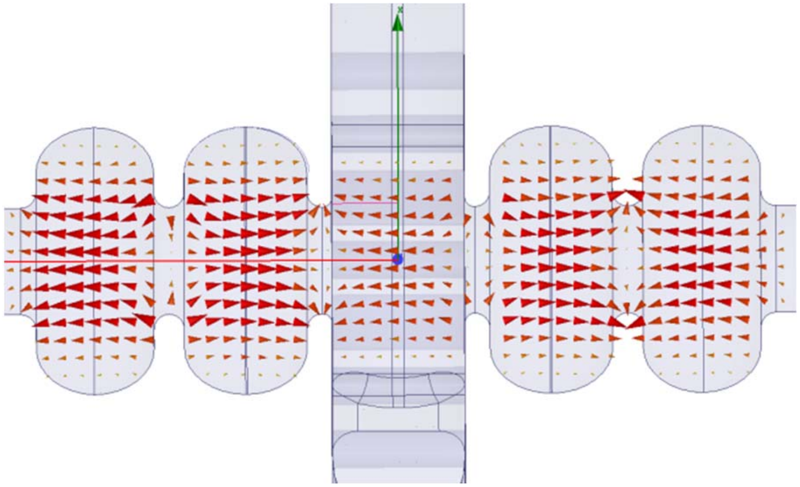
NIOWAVE
www.niowaveinc.com





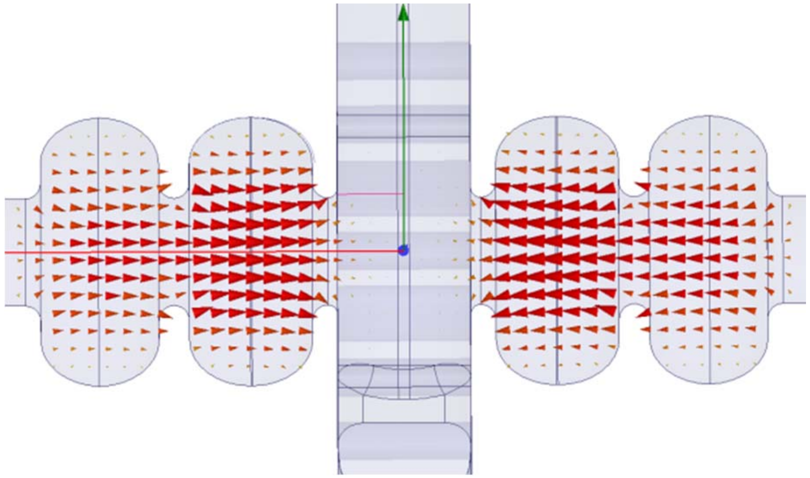
Complete cavity underwent bulk etching and high-pressure rinse at Niowave.

Cryotest at LANL



Accelerating mode showed anomalous low-field Q (10^6 instead of 10^8).

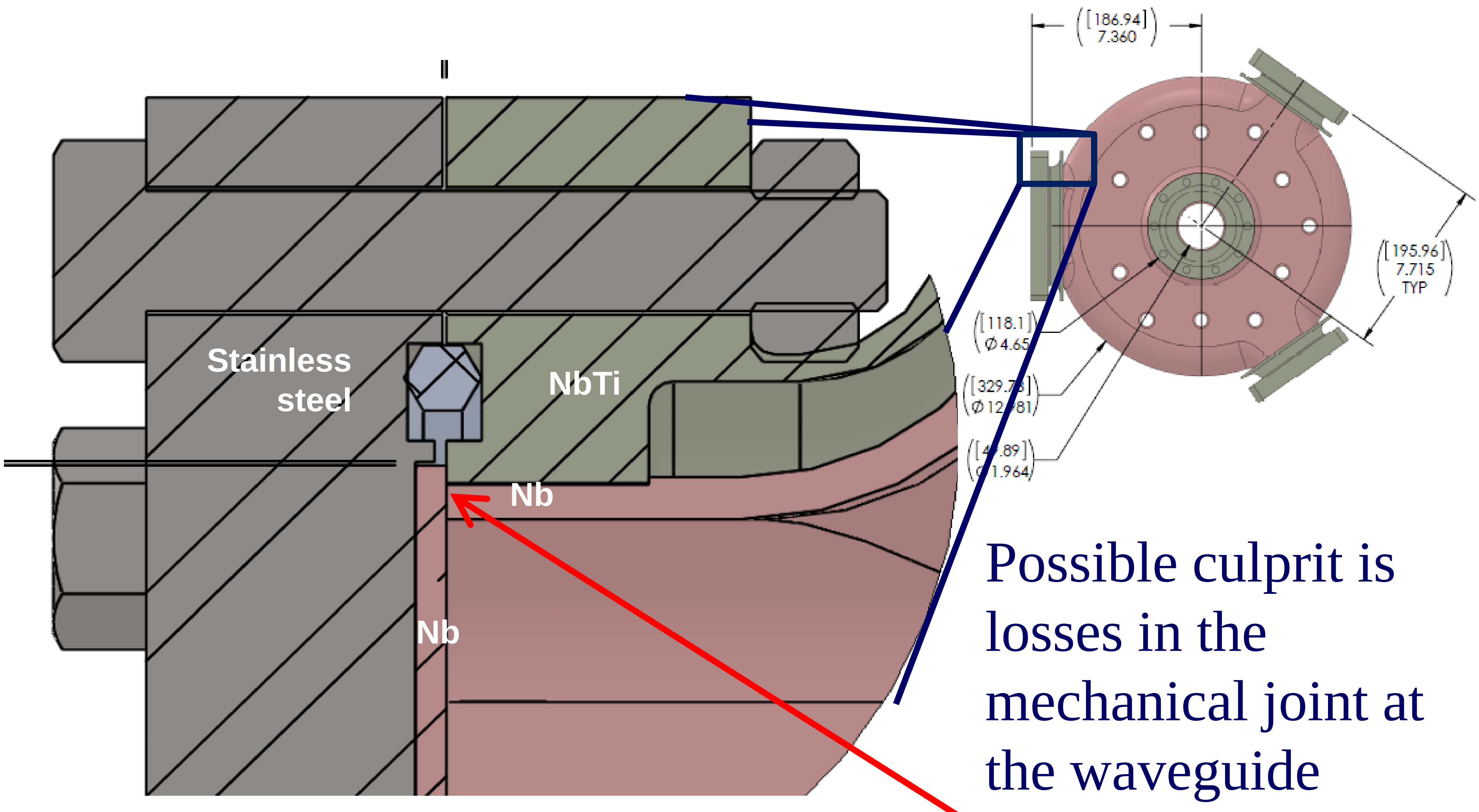
Other passband mode showed high Q and surface fields up to 18 MV/m were generated.



An initial cryotest of the structure has been performed, funded by Evgenya Simakov through her Early Career Project.

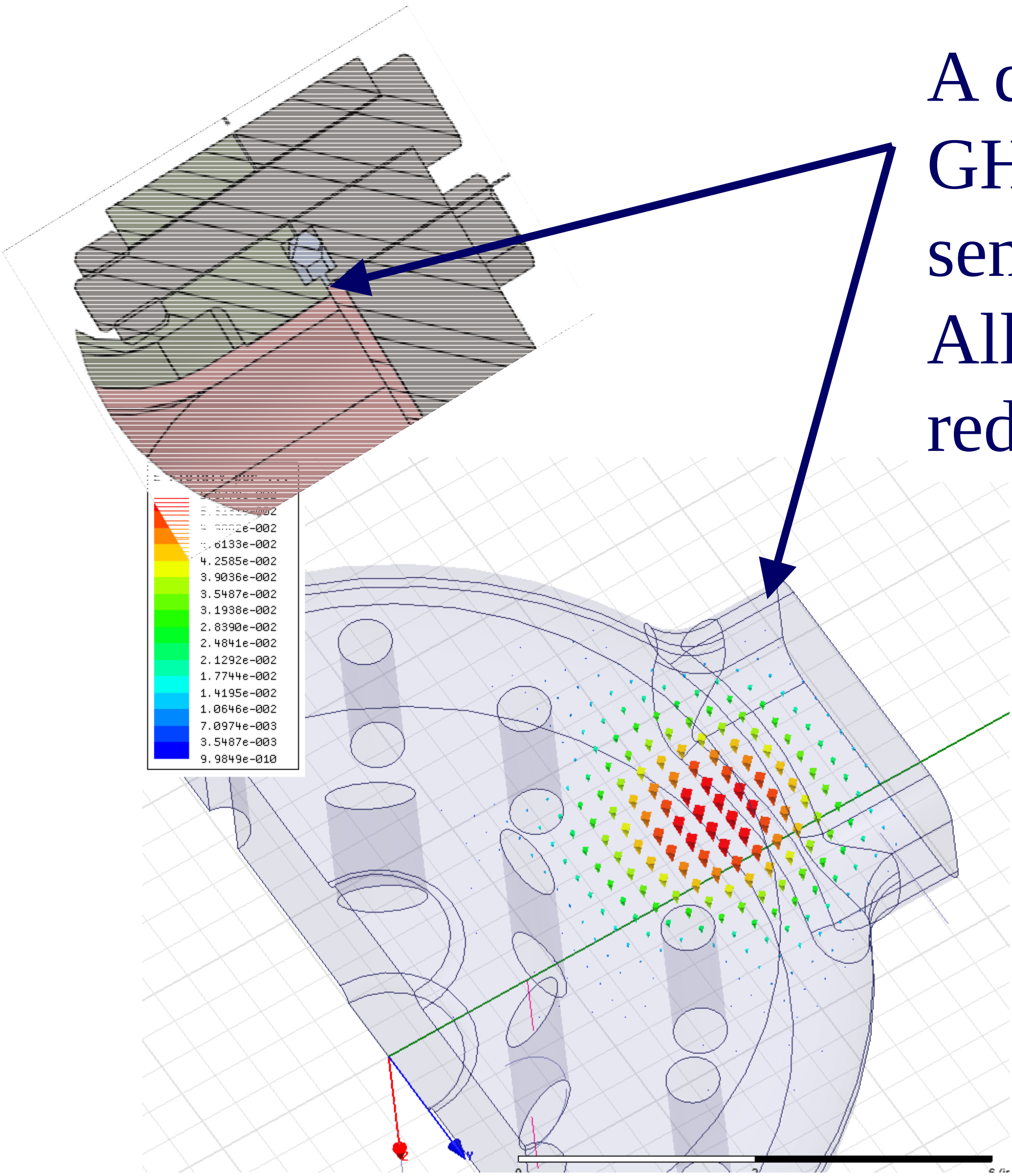
Mechanical Joint

NIOWAVE
www.niowaveinc.com



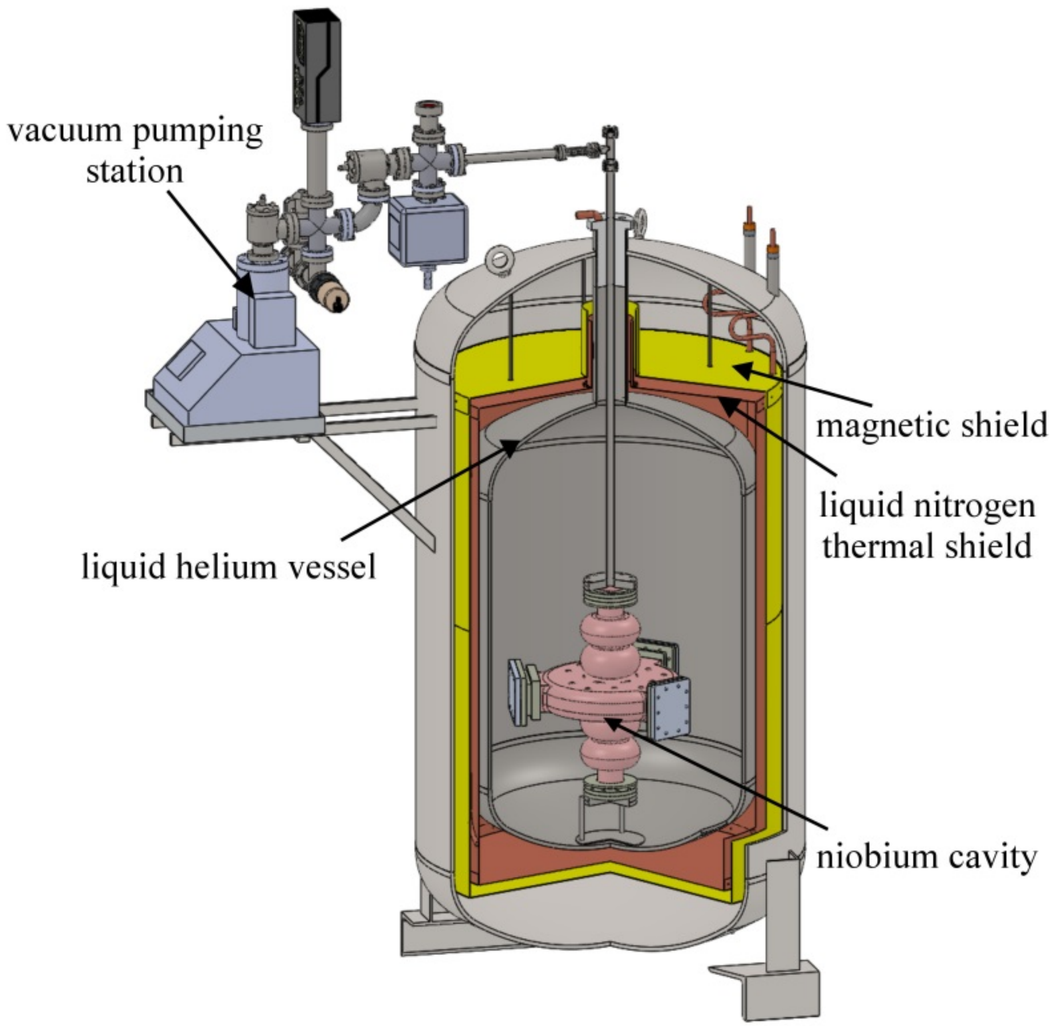
Possible culprit is losses in the mechanical joint at the waveguide flange.

Joint Losses Measurement with Trapped Mode



A different mode at 1.778 GHz is much more sensitive to joint losses. Allowed successful redesign of the joint.

Next Test at Niowave



Mechanical design for next test setup is now proceeding with design of a specialized titanium He vessel to replace the generic version in this cartoon.

Phase II SBIR Summary

NIOWAVE
www.niowaveinc.com

- Mechanical design of cavity – complete
- Cavity Manufacturing and Tuning – complete
- Cavity Processing – complete
- Vertical Test Design – *in progress*
- Vertical Test of Cavity – first test at LANL!

  next test being planned at Niowave
- Conceptual Cryomodule Design – *in progress*