Development of a Multicell Superconducting Cavity with a Photonic-Bandgap Coupling Cell

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

NP SBIR/STTR Exchange Meeting, Gaithersburg MD
August 2016

*MIT graduate student in residence (now PhD)

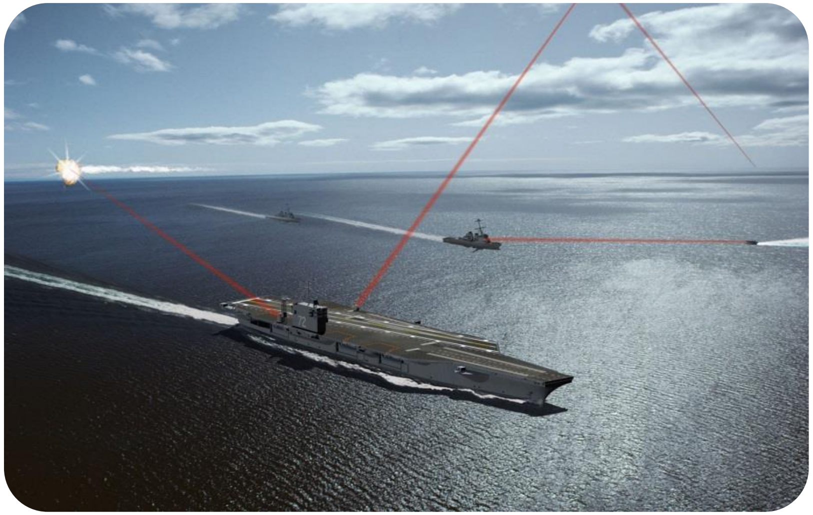
NIOWAVE
www.niowaveinc.com

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 [1]

NIOWAVE
www.niowaveinc.com

Superconducting cavities in specialized geometries

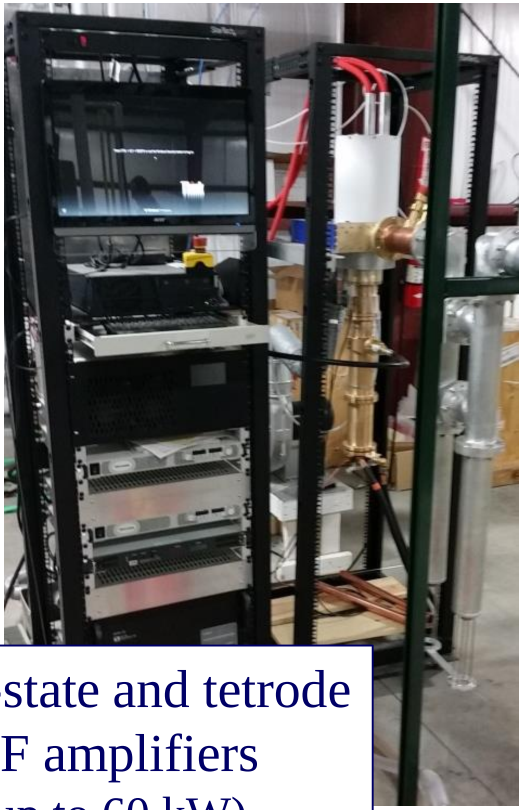
Cryomodules

Turnkey Linac Subsystems [2]

NIOWAVE
www.niowaveinc.com

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

Industrial Accelerator Controls
(Programmable Logic Controllers with
PC interface)

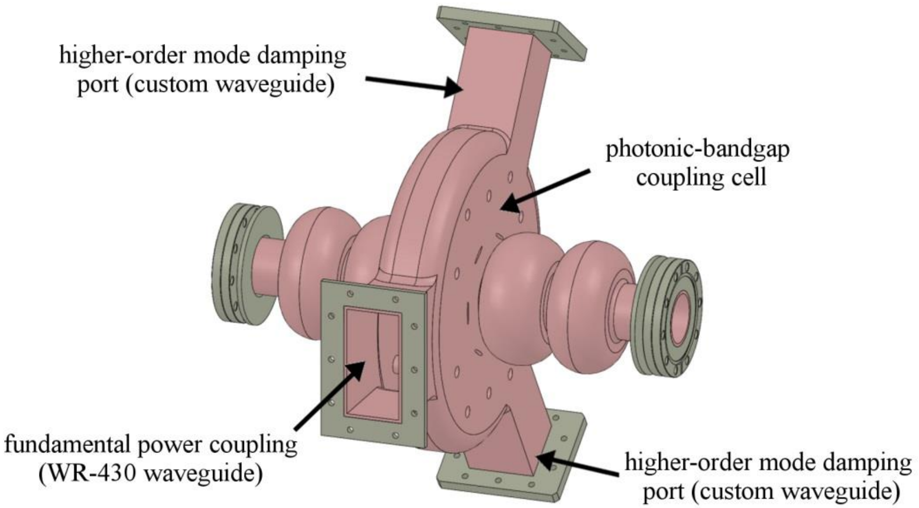


Solid-state and tetrode
RF amplifiers
(up to 60 kW)

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
- Beam-capable cryomodule concept



Project Team

NIOWAVE
www.niowaveinc.com

NIOWAVE Accelerating Your Particles

Chase Boulware, Terry Grimm, Eike Schnabel, other Design and Engineering Staff

Los Alamos NATIONAL LABORATORY EST. 1943

Evgenya Simakov

BROOKHAVEN NATIONAL LABORATORY

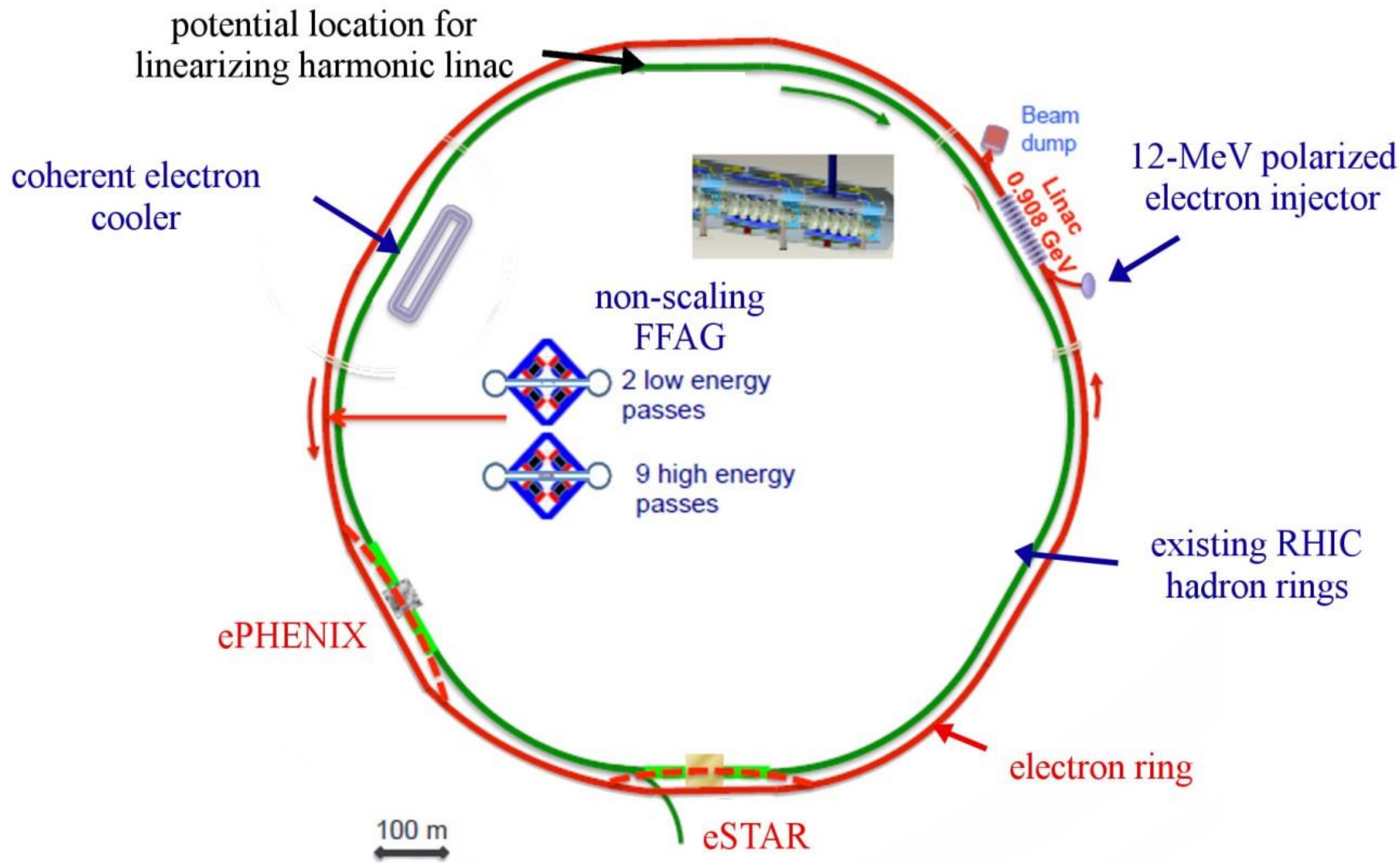
Ilan Ben-Zvi, Sergey Belomestnykh* (consultation on eRHIC plans)

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Sergey Arsenyev**

*now at Fermilab **now at CERN

eRHIC



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

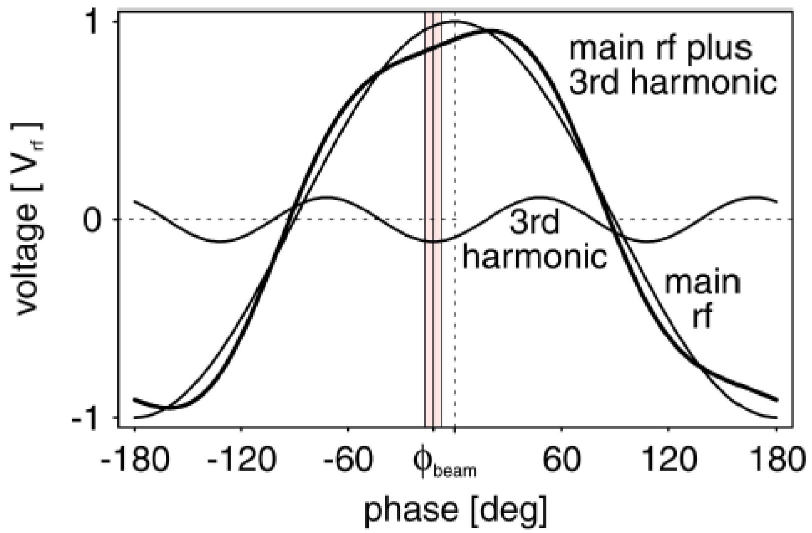
eRHIC Beam Parameters

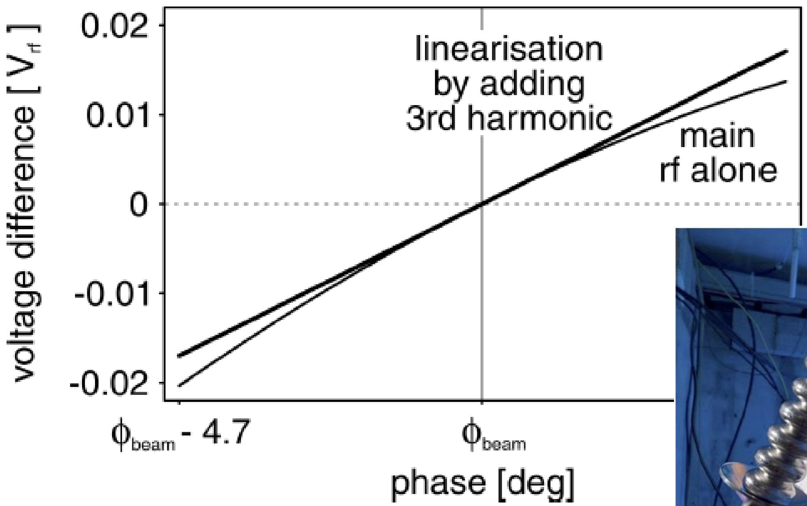
accelerating cavities RF frequency	413 MHz		
5^{th} harmonic frequency	2064 MHz		
beam current	50 mA per pass		
bunch charge and repetition rate	5 nC @ 9.38 MHz		
electron beam energy (upgraded in stages)	5 GeV	20 GeV	30 GeV
bunch length (rms)	4 mm	2 mm	2 mm

- 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



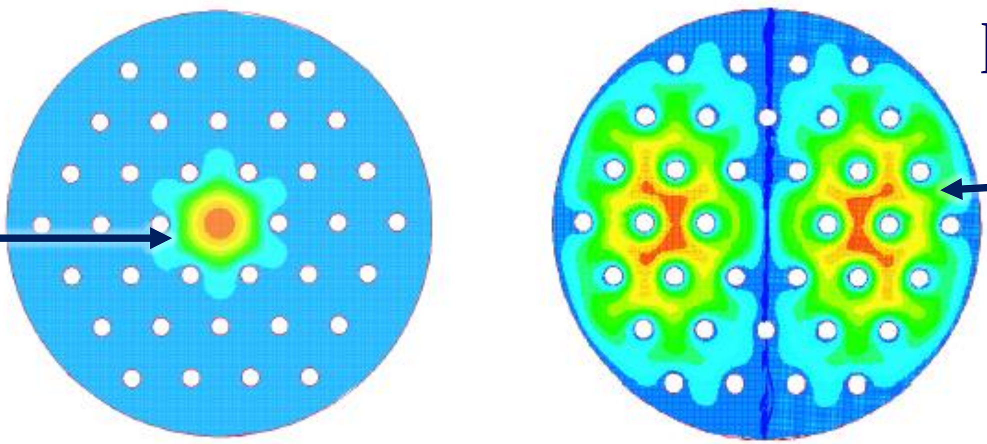


- combination of acceleration from main linac and properly phased harmonic cavity
- example: DESY (XFEL) pursued this approach at the 3rd harmonic
  - frequency of 3.9 GHz (3 × 1.3 GHz)
  - SRF, but not operated CW

Photonic-bandgap Accelerators

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

well-confined fundamental



HOM propagates to boundary

TM$_{01}$ dipole mode

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

Single-cell PBGs

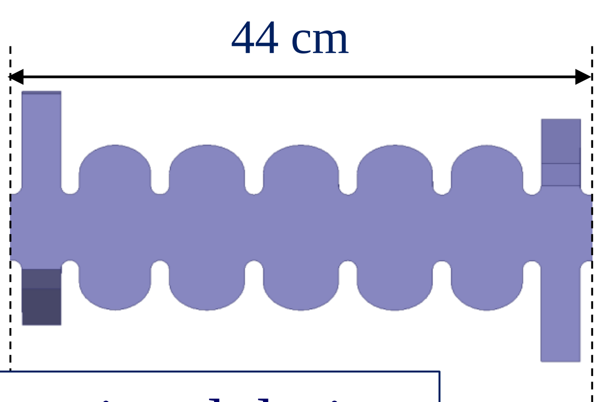
elliptical inner rods

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

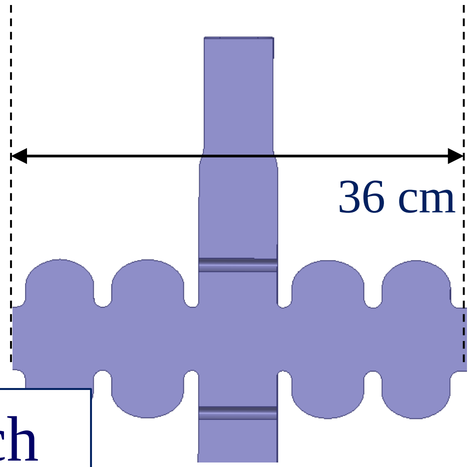
all round rods

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



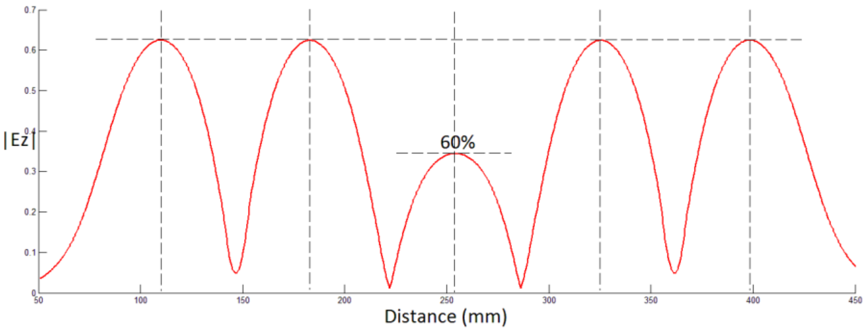
PBG approach

Tuning of Multi-cell cavity with PBG

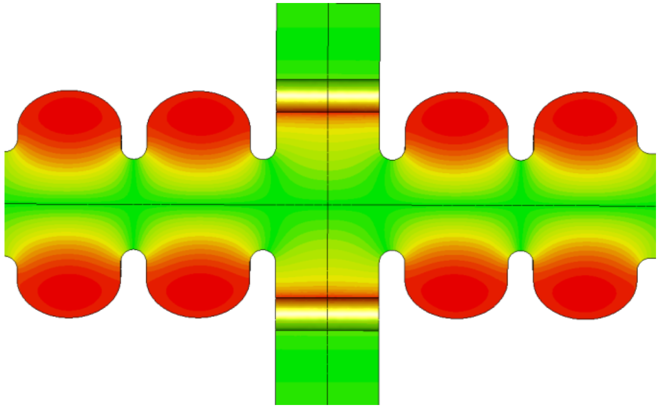
NIOWAVE
www.niowaveinc.com

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



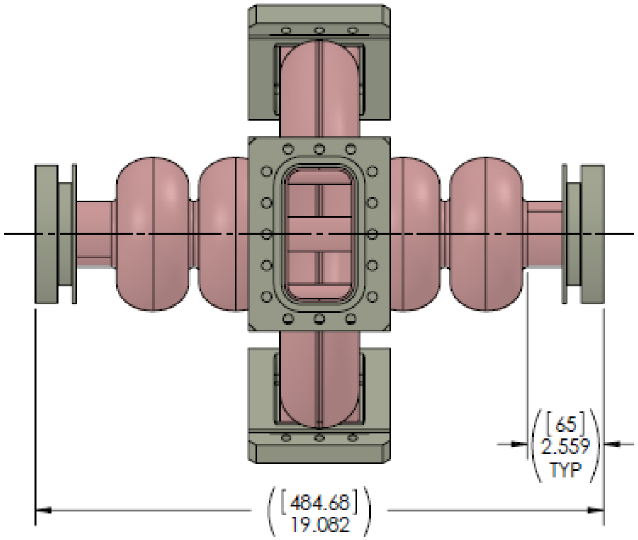
Electric field magnitude along central axis

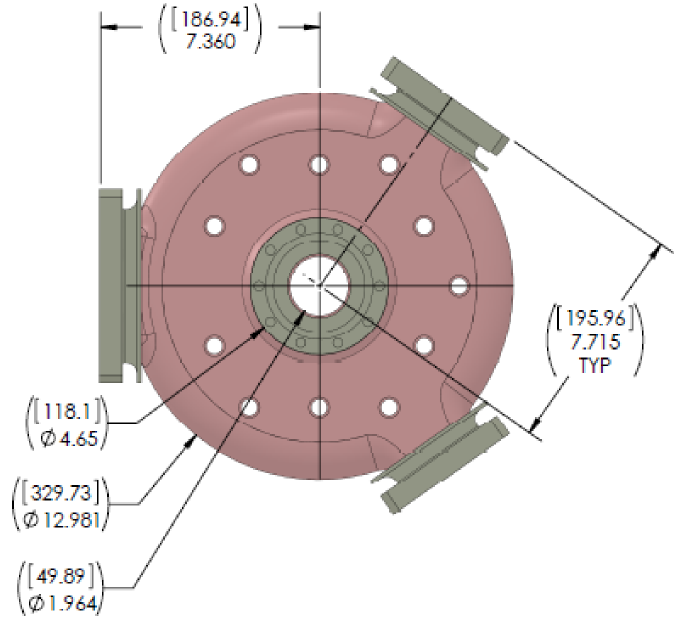


Magnetic field magnitude on niobium surfaces (peaks equal in each cell)

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]

NIOWAVE
www.niowaveinc.com

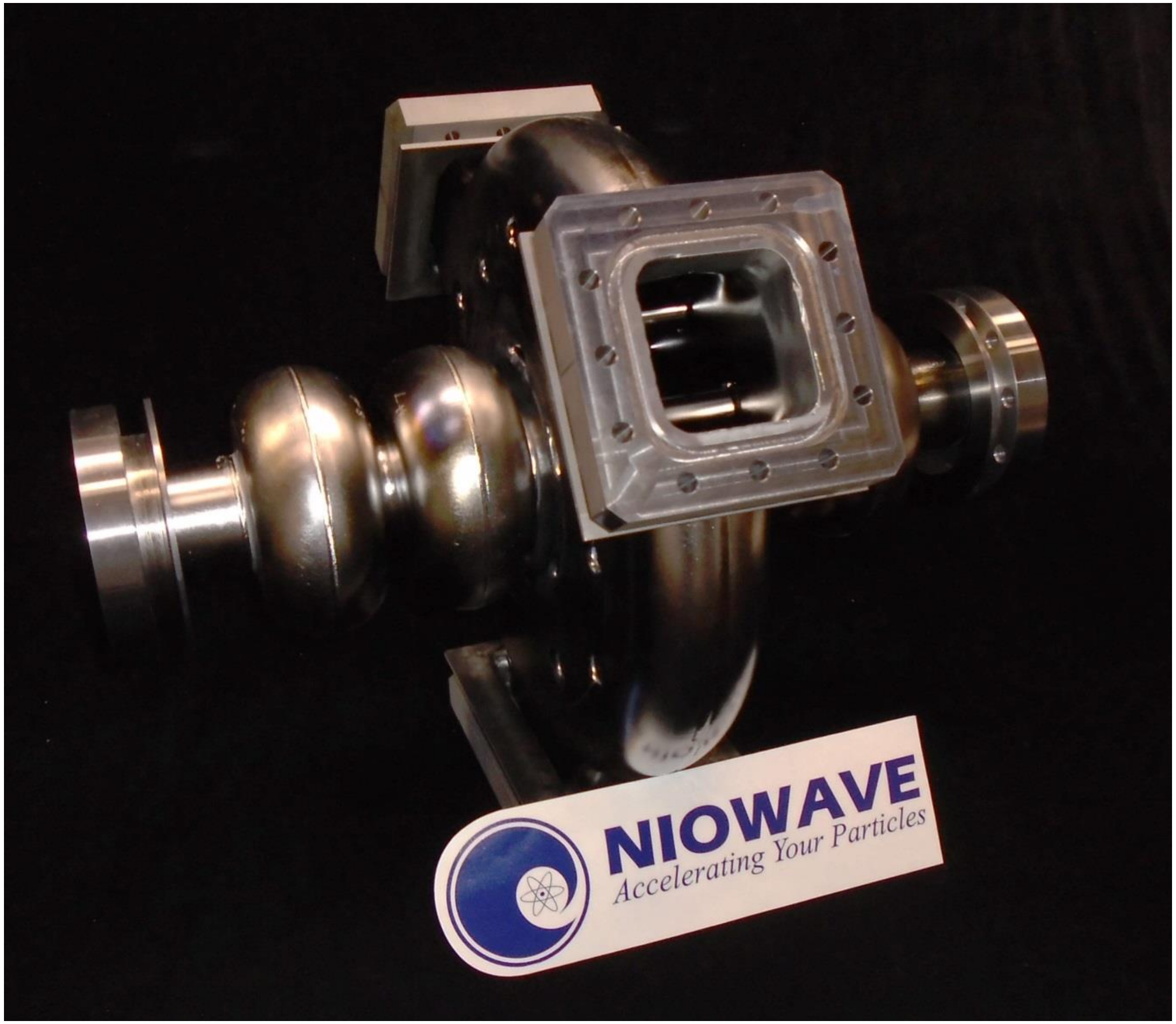
Evgenya Simakov's Early Career project funded a copper prototype (project started a few months before Phase II SBIR). Many steps were prototyped.

Cavity Fabrication [2]

The SBIR project proceeded with niobium-specific issues

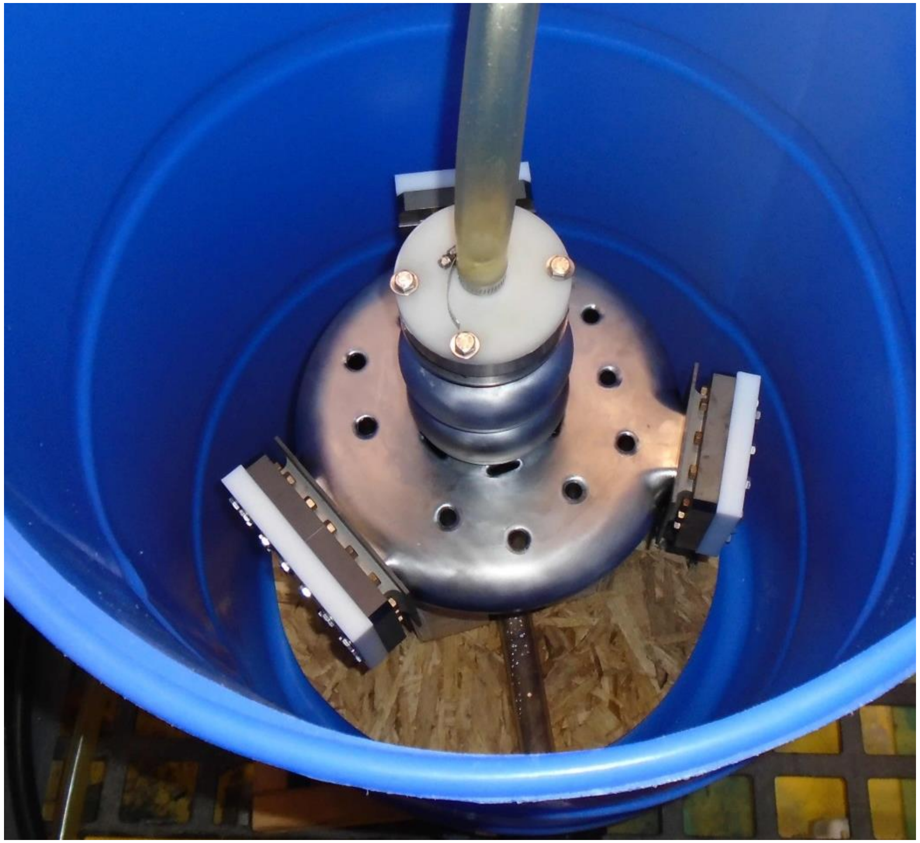
- electron-beam welding design and fixturing
- new rectangular vacuum seals and flanges designed based on aluminum diamond seals (TESLA design)

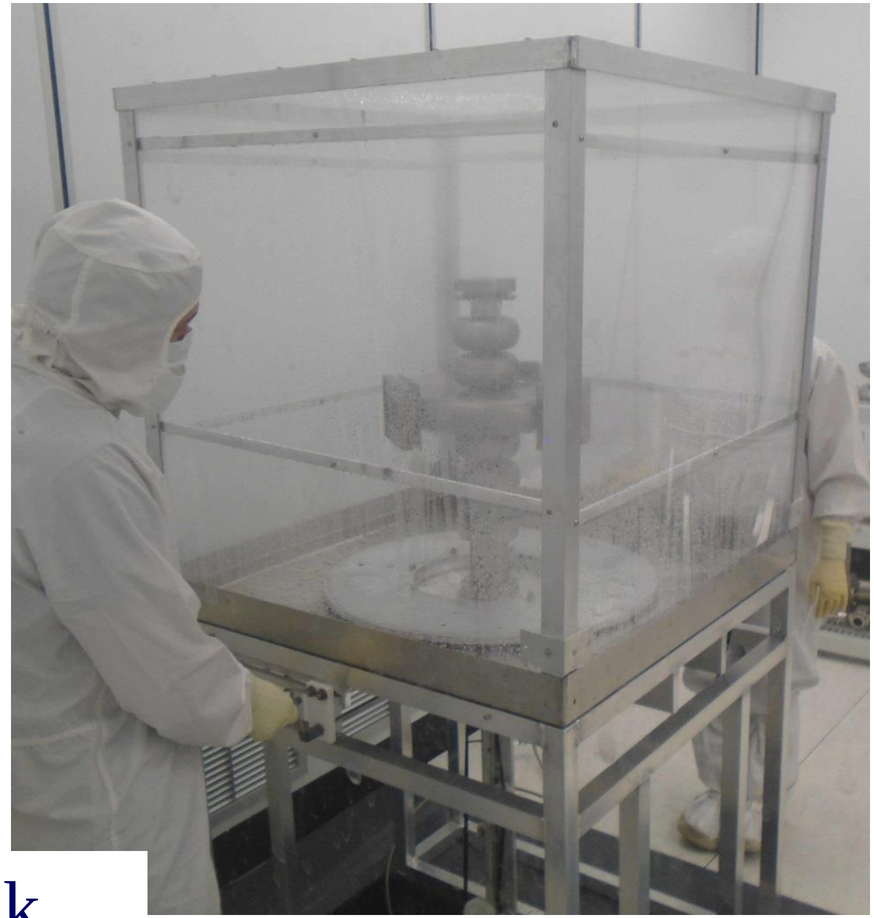
Cavity Fabrication [3]



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

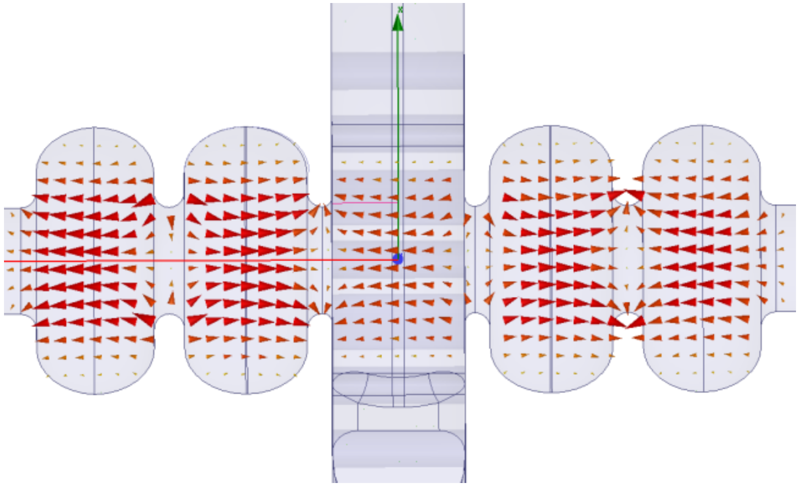
Cavity Processing





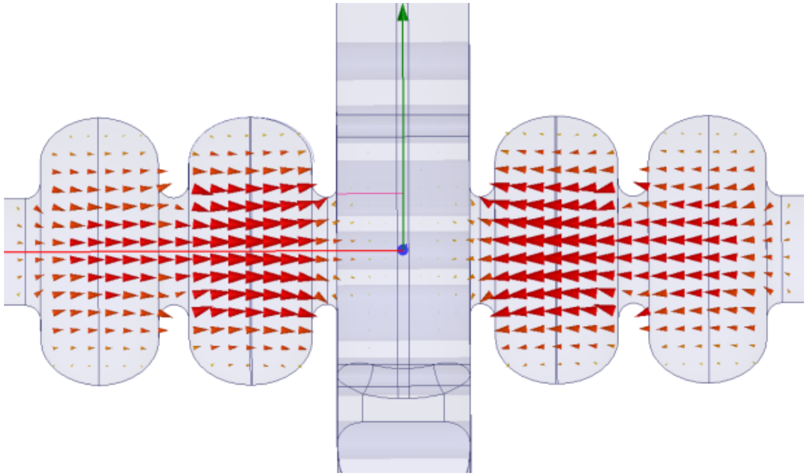
Complete cavity underwent bulk etching and high-pressure rinse at Niowave.

Cryotest at LANL



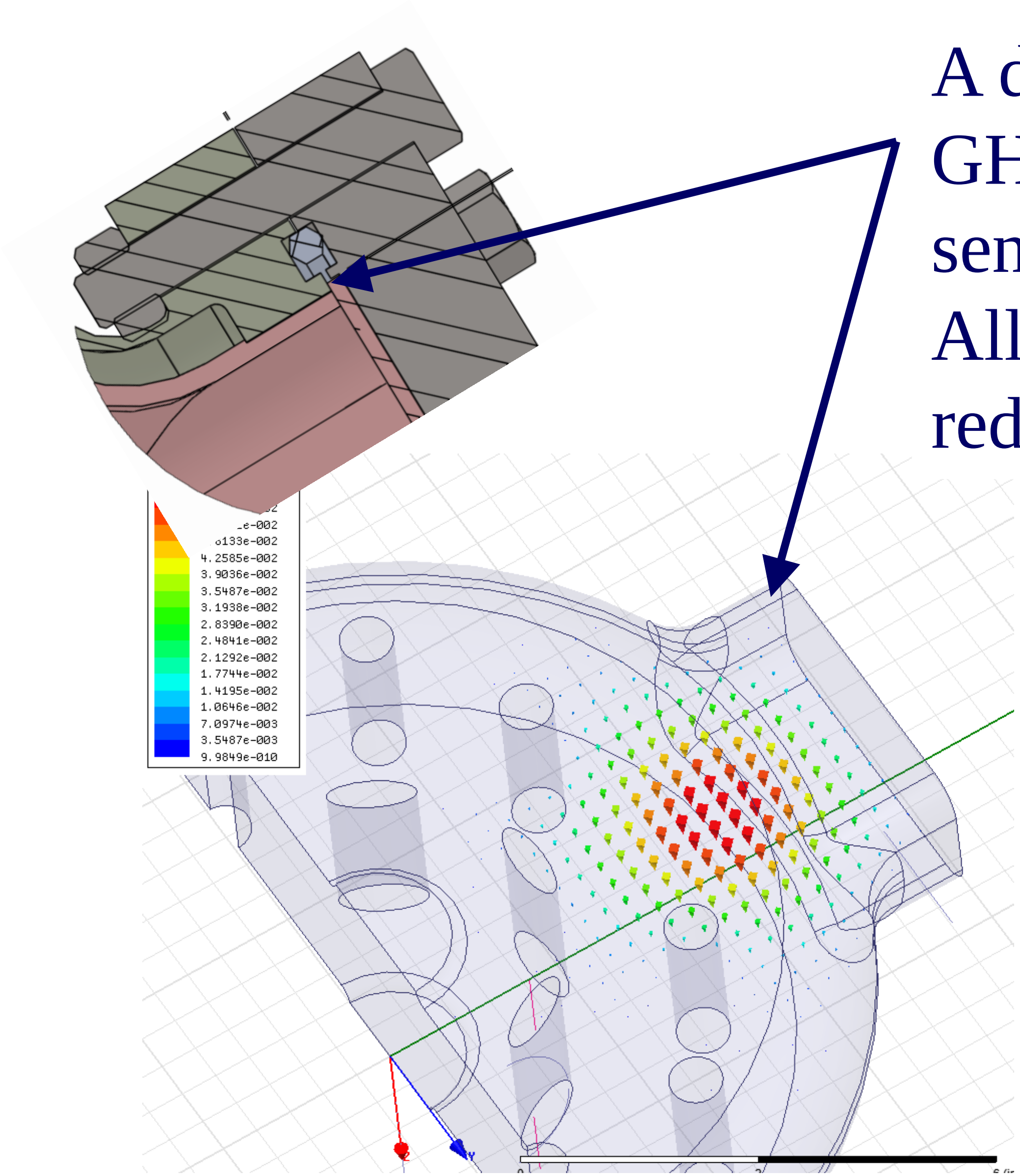
Other passband mode showed high Q and surface fields up to 18 MV/m were generated.

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



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

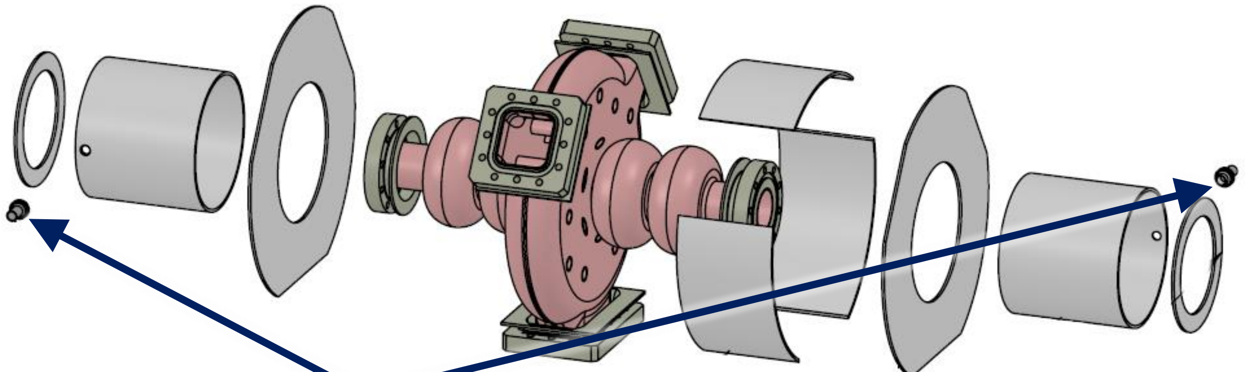
Joint Losses Measurement with Trapped Mode



A different mode at 1.8 GHz is much more sensitive to joint losses. Allowed successful redesign of the joint.

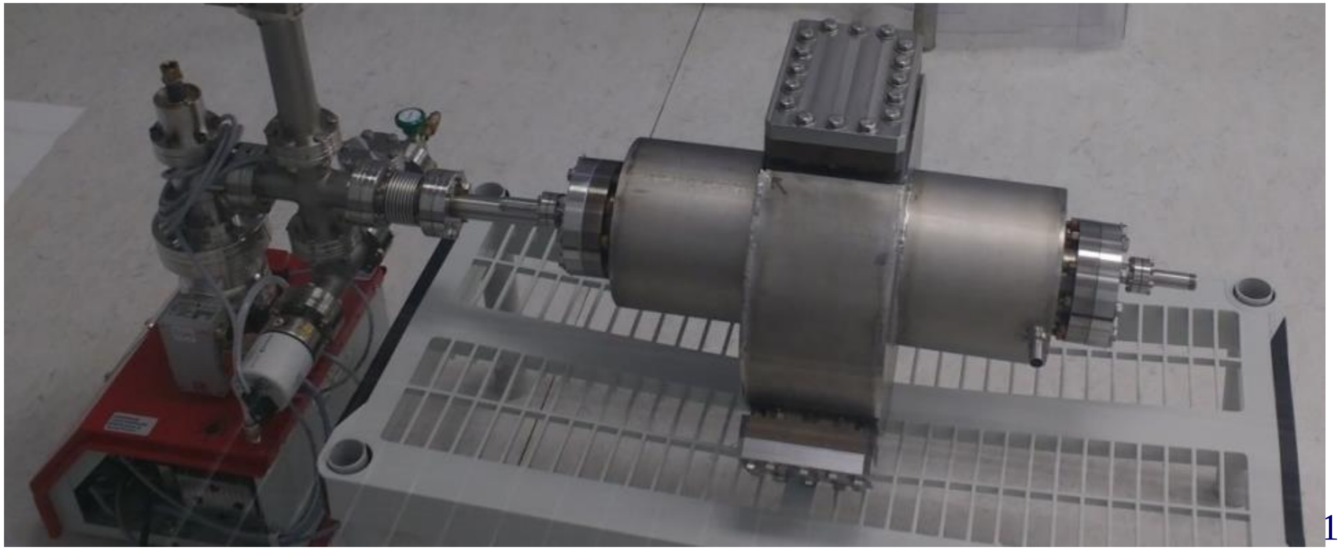
Install into Helium Vessel

NIOWAVE
www.niowaveinc.com



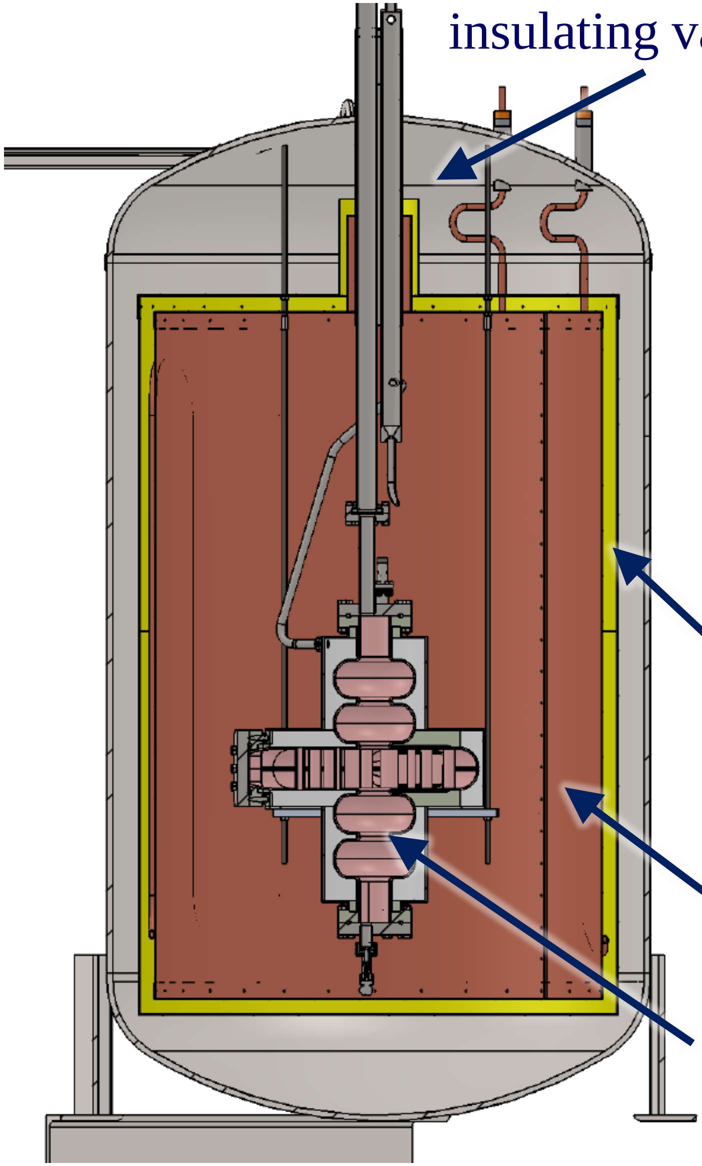
liquid helium
in/out

The helium vessel is constructed from titanium to be compatible with the vacuum flanges.

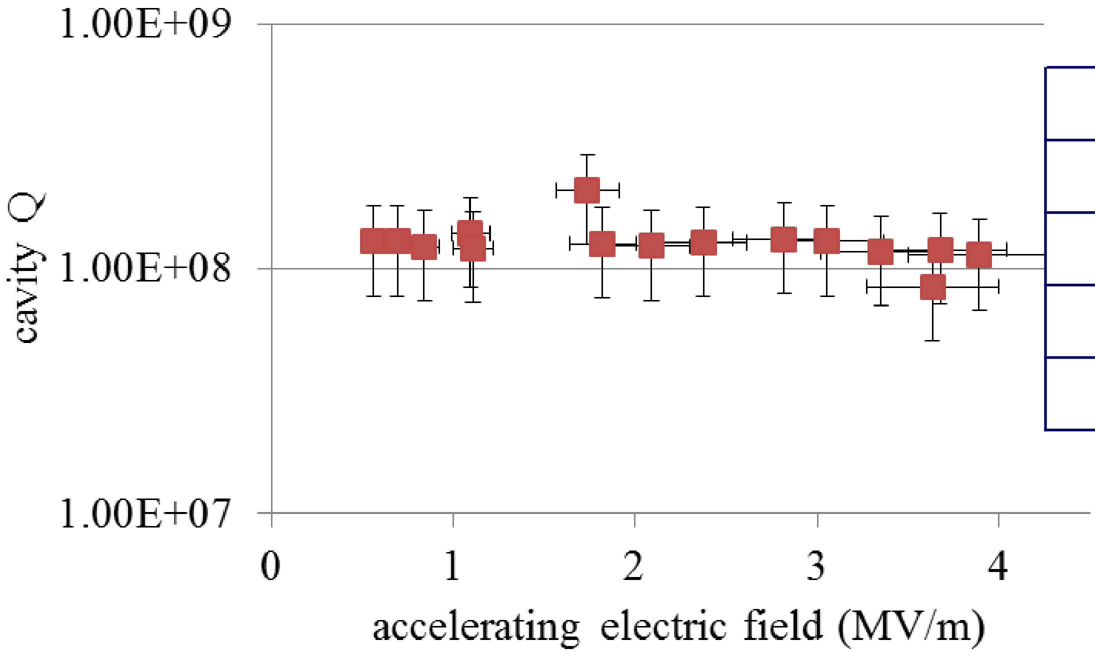


Cryotest of PBG Multicell Cavity

NIOWAVE
www.niowaveinc.com



Cryotest Results

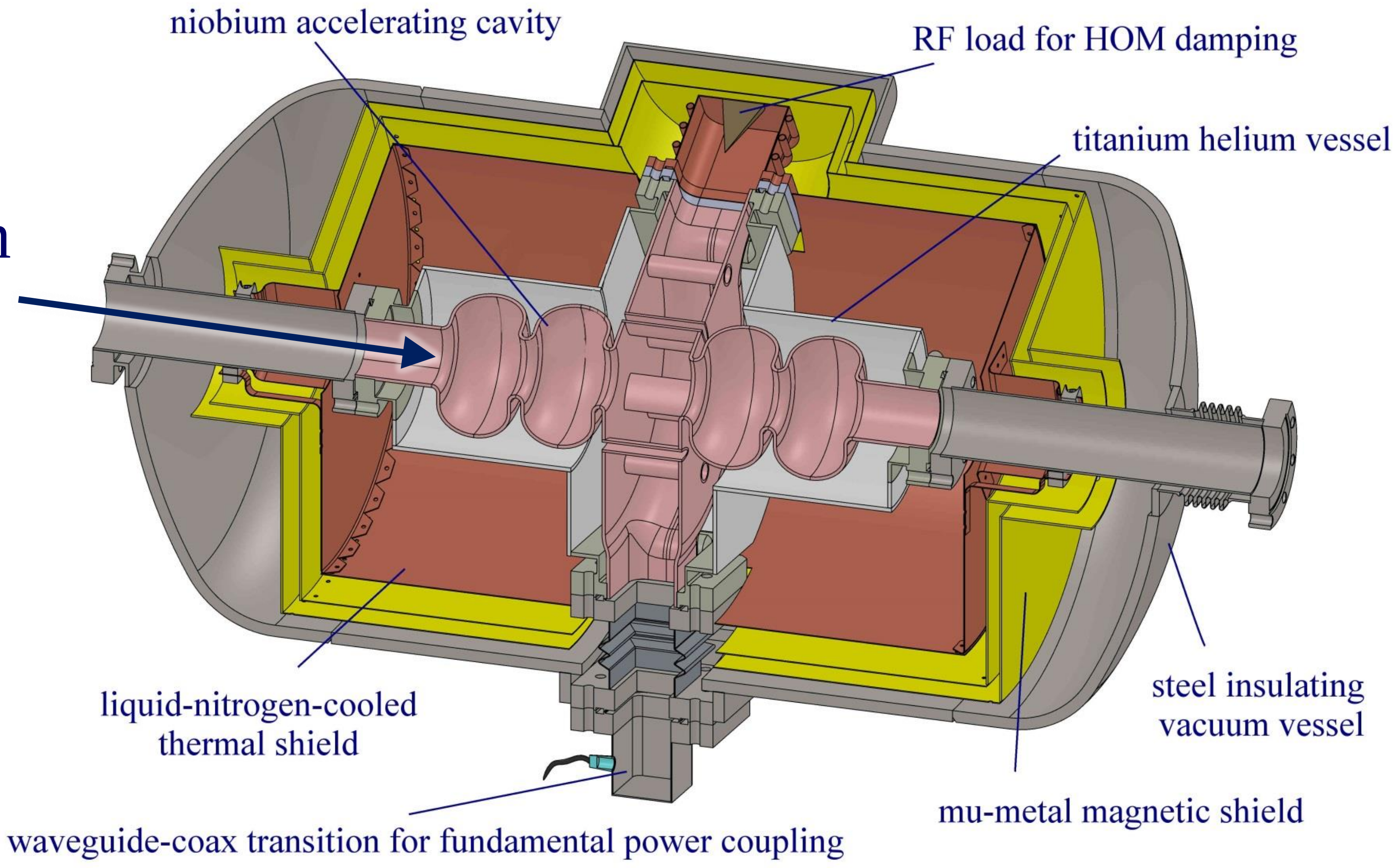


mode	calculated loaded Q	measured loaded Q
$\pi/5$	1.3×10^8	1.2×10^8
$2\pi/5$	3.7×10^7	5.5×10^7
$3\pi/5$	2.5×10^7	4.6×10^7
$4\pi/5$	2.1×10^7	1.9×10^7
π	2.9×10^7	2.5×10^7

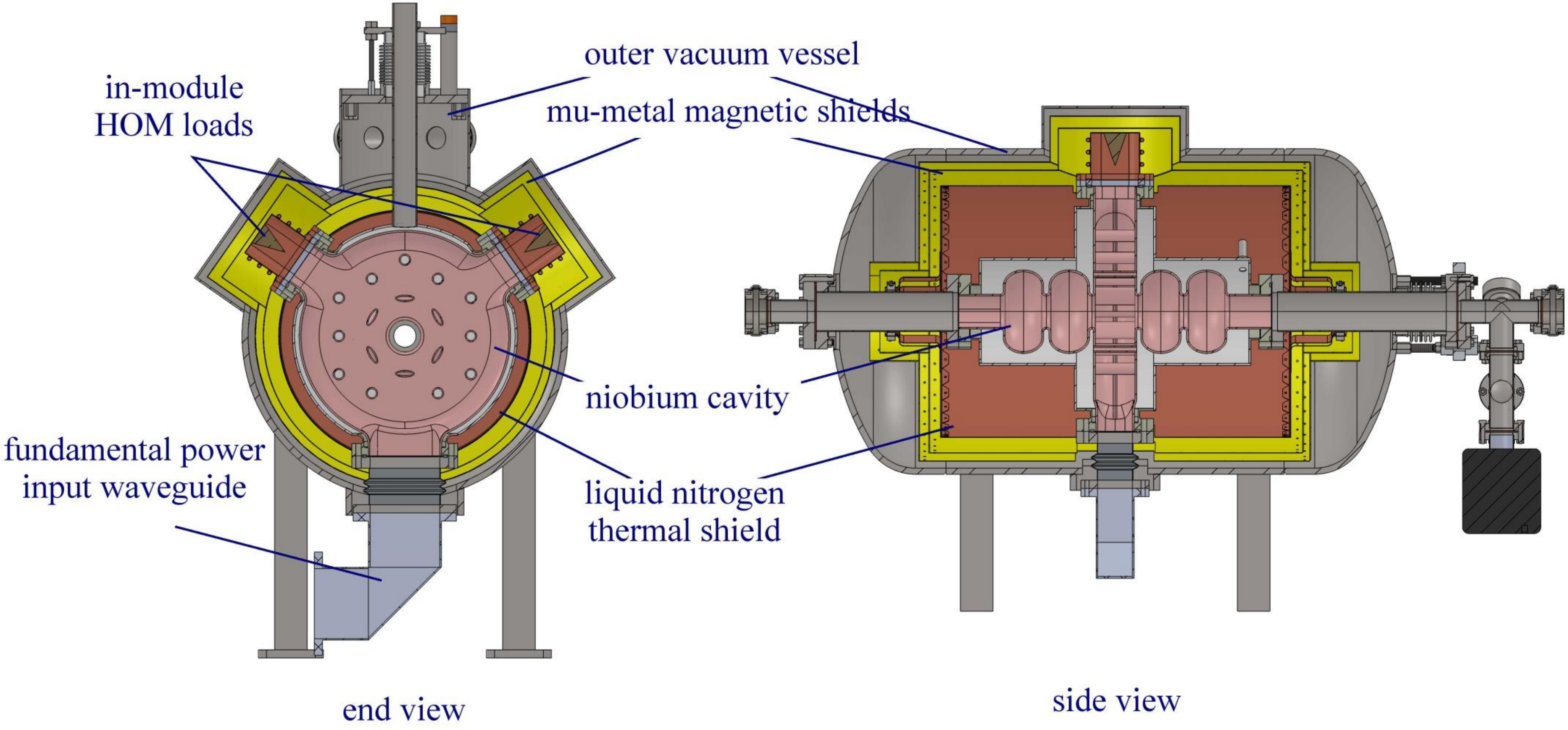
Measured cavity quality factor shows that the joint is working and the cavity is performing up to 4 MV/m accelerating gradient (limited by available RF power).

Beam-Capable Cryomodule Concept [1]

electron beam



Beam-Capable Cryomodule Concept [2]



Sharing Results with the Accelerator Community

- Conferences, most recently an invited talk by Sergey Arsenyev at the 2015 Superconducting RF conference
- Peer-reviewed Journal Publications
    - Applied Physics Letters (vol 108, 22603, 2016)
    - Physical Review Accelerators and Beams (vol 19, 081301, 2016)
- Sergey's PhD thesis
    - Photonic Band Gap Structures for Superconducting Radio-frequency Particle Accelerators (Advisors Rick Temkin, MIT, and Evgenya Simakov, LANL, accepted September 2016)

Phase II SBIR Summary

NIOWAVE
www.niowaveinc.com

- First multi-cell superconducting accelerating cavity with a photonic-bandgap coupling cell has been built
    - niobium cavity with titanium helium vessel
    - novel tuning strategy implemented
    - new RF and vacuum seal developed
- Successful testing at cryogenic temperature verifies cavity performance
- Cavity now ready for tests with beam!