Development of a Tunable 28 MHz Superconducting RF Cavity for RHIC

DOE-NP Phase II SBIR

Terry Grimm

October 2011

Niowave, Inc.

NIOWAVE
www.niowaveinc.com

- Privately Owned
- 45,000 square feet
  - Engineering & design
  - Machine shop
  - Fabrication & welding
  - Chemistry facility
  - Class 100 Cleanroom
  - Cryogenic test lab
  - Accelerator test facility

Lansing, Michigan Headquarters

Niowave Leadership

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Dr. Terry Grimm
President & Senior Scientist

- PhD from Massachusetts Institute of Technology
- 20 Years experience in Department of Energy
  - Superconducting Super-Collider
  - National Superconducting Cyclotron Laboratory at MSU
  - Numerous contracts with DOE at Niowave

Jerry Hollister
Chief Operating Officer

- Bachelors in Engineering from University of Michigan
- Active duty Naval Officer for 6 years
- Warranted Contracting Officer for US Navy
- Current Trustee at Lansing Community College

Mark Sinila
Chief Financial Officer

- Bachelors in Business Administration from Albion College Honors Program
- 20 years experience in business administration
- Prior CFO for multi-state manufacturer

Primary Customers and Uses of Superconducting Particle Accelerators

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- Large accelerators
  - Current DOE projects: Brookhaven, Fermi, Jefferson Lab, Large Hadron Collider
  - Future: FRIB, eRHIC, Project-X, ILC & many more
- X-ray sources
  - Defense, Medical and Industrial
- Free electron lasers
  - Defense, Medical and Industrial
- Radioisotope production
  - Medical and Industrial

Niowave Products for Superconducting Particle Accelerators

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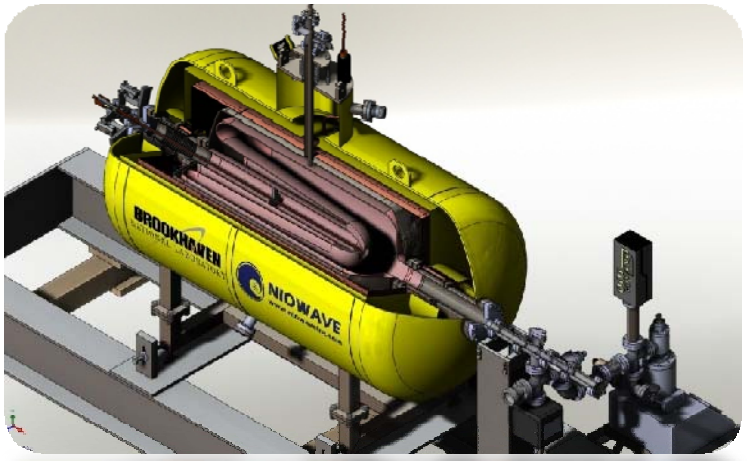

- Electron Guns & Injectors

- Cryomodules & Turn-key Accelerators

- Niobium (In Stock)

- Niobium Superconducting Cavities

Superconducting Cavities

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Niowave produces superconducting cavities at a broad range of frequencies and geometries, and will customize to meet specific applications.

- Elliptical cavities
- Quarter-wave cavities
- Deflecting structures
- Single and Multi-spoke cavities

Single spoke cavity

80.5 MHz Quarter-Wave resonator

Cavity frequencies
28 MHz to 9.5 GHz

1.3 GHz 9-cell cavities for ILC

Superconducting Metals

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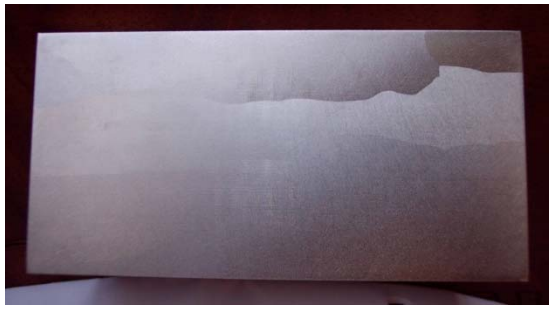
- Niobium Supplier
  - Large and fine grain niobium in a variety of RRR values.
    - Sheets from 1mm to 35mm
    - Ingots and rods
    - Niobium-Titanium also in stock



- Residual Resistivity Ratio (RRR) measurements
  - Only company in the world that offers service
  - Qualified materials for: Cabot, HC Starck, ATI Wah Chang, Heraeus, Plansee and CBMM (Brazil)

Superconducting Electron Linacs

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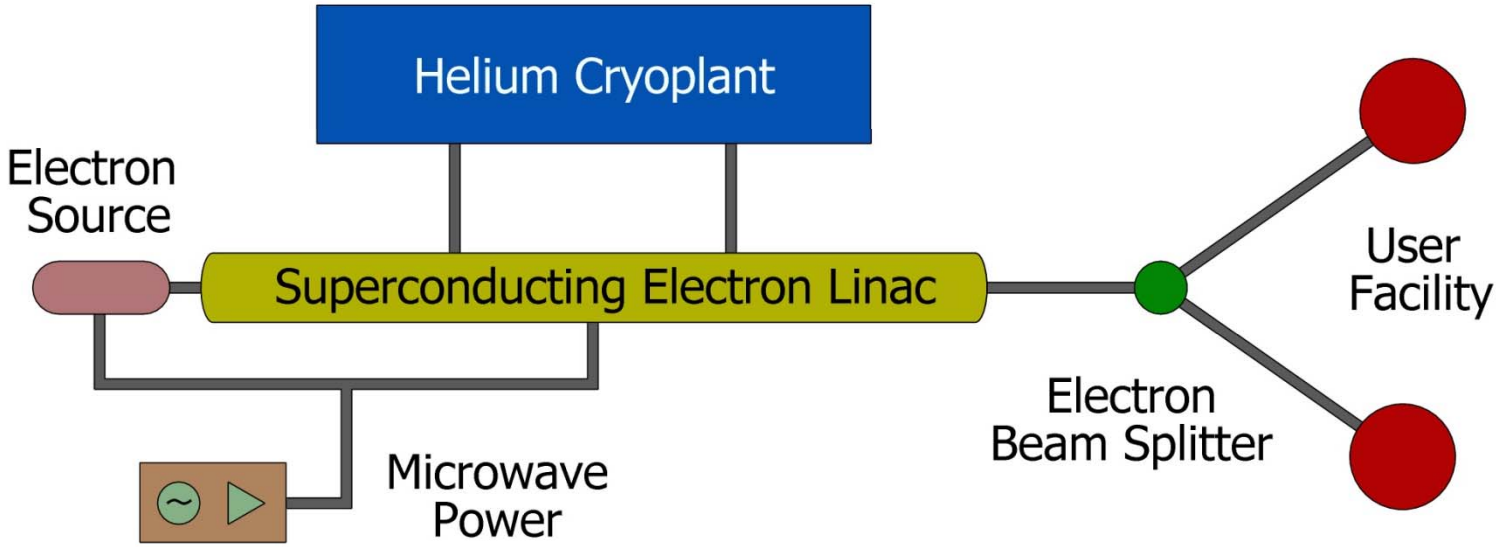

Turn-key Systems

- Superconducting Linac
- Helium Cryoplant
- Microwave Power
- Target / User Facility
- Licensing

Electron Beam Energy	**0.5 – 50 MeV**
Electron Beam Power	**1 W – 1 MW**
Electron Bunch Length	**~50 ps**

Superconducting Linacs

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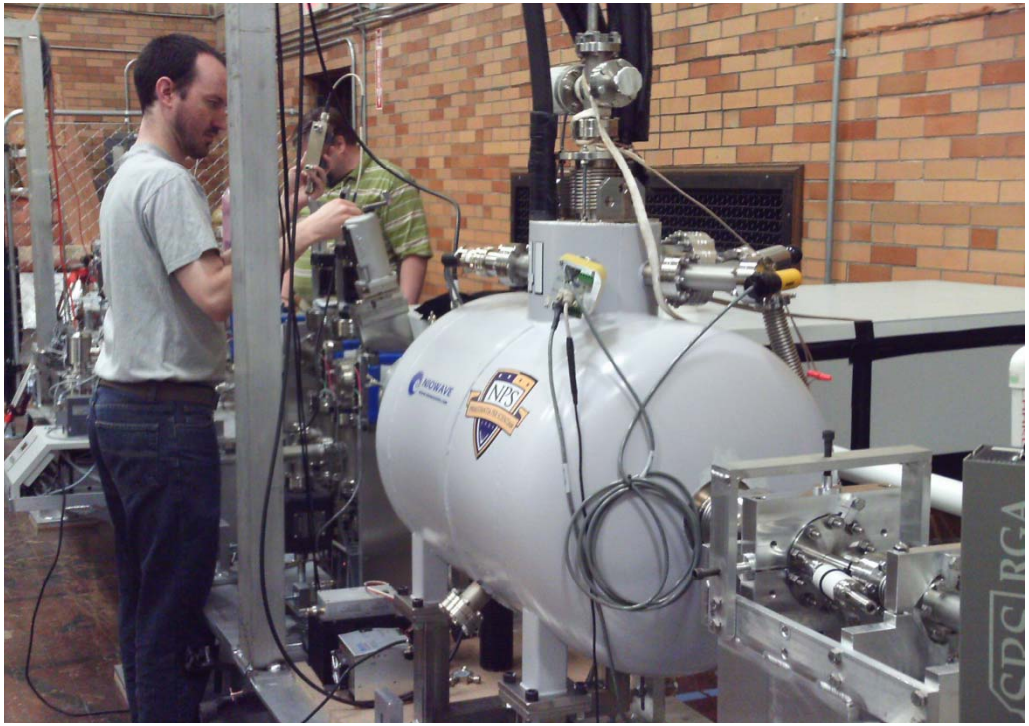
- NPS-Niowave 500 MHz SRF Injector
  - First superconducting linac designed, fabricated and tested entirely within industry
  - First delivery of an SRF beam source to a US Navy facility
  - First cool-down and characterization of an SRF beam source at a US Navy facility



Published Results:
Harris, et al,
"Design and operation of a superconducting quarter-wave electron gun,"
Phys Rev STAB 14 (2011)

Helium Cryogenics

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Niowave offers several options, depending on the required cooling load and planned operating schedule.

- Batch filling
  - Use liquid helium Dewars
  - Standard sizes: 100, 250 and 500L
- 5W Cryocooler at 4.4K
  - Smaller systems or low duty cycle
  - Integrated into linac
- 100W Refrigerator/Cryoplant at 4.4K
  - Larger systems or high duty cycle / CW operations
  - 24 hrs / 7 day operations

Batch filling with a 250L helium Dewar

100 W Cryoplant

Microwave RF Sources

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Niowave offers a broad range of options, depending on the frequency, power and electrical efficiency requirements.

- Solid State Amplifiers
  - Low power : ~ 1 kW
  - High reliability
- Tetrodes
  - Intermediate power: ~10 kW
- Inductive Output Tubes (IOTs)
  - Medium power: ~100 kW
- Klystrons
  - High power: ~1000 kW (1 MW)

10 kW Tetrode

90 kW IOT

Tunable 28 MHz SRF Cavity

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This project is done in collaboration with

Dr. Ilan Ben-Zvi

Dr. Sergey Belomestnykh

(Brookhaven National Laboratory)

The funding is provided by the DOE SBIR program

Contract # DE-SC0001215.

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NATIONAL LABORATORY

U.S. DEPARTMENT OF
ENERGY

The Relativistic Heavy Ion Collider [1]

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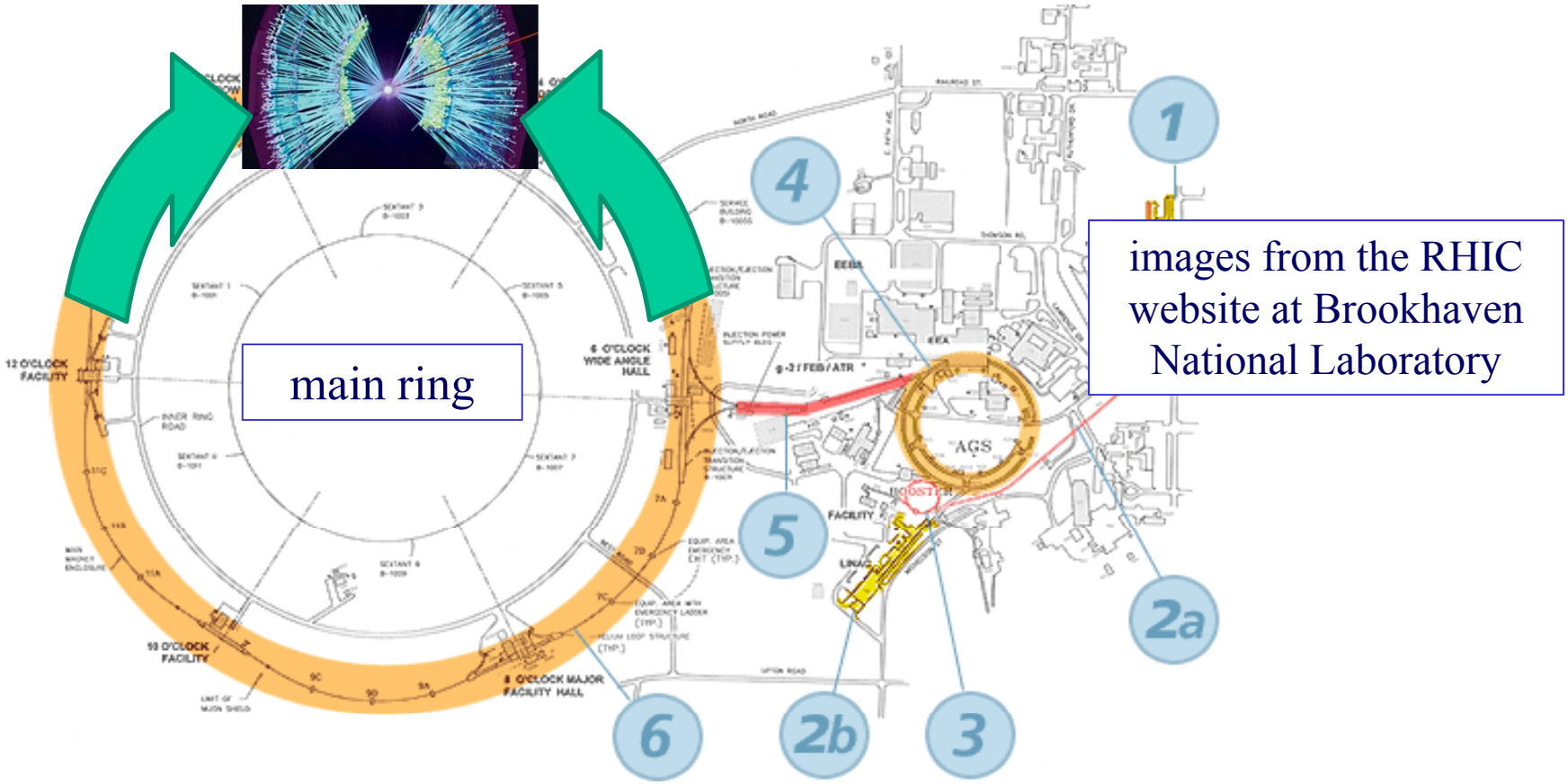

The Relativistic Heavy Ion Collider (RHIC) studies matter at extreme temperature and pressure by colliding all sorts of nuclei including high-atomic-number species like gold.

The Relativistic Heavy Ion Collider [2]

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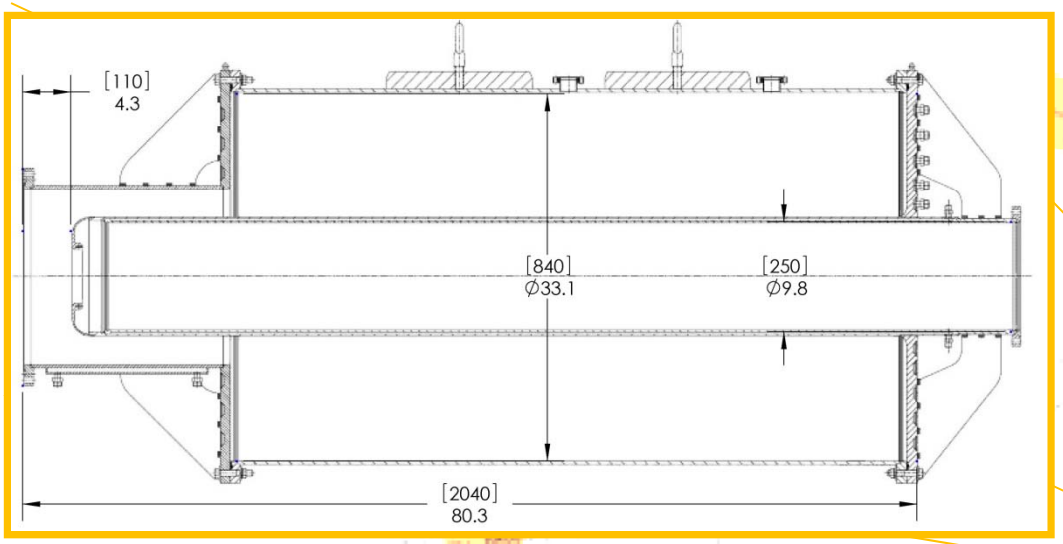
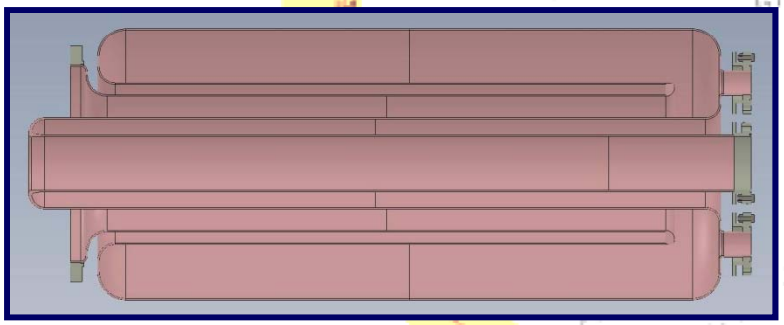


normal conducting copper structure currently in use at RHIC



superconducting cavity designed under this project

This project involves the design and construction of a superconducting cavity to replace the accelerating RF cavities in the RHIC ring.

Innovative nature of this proposal

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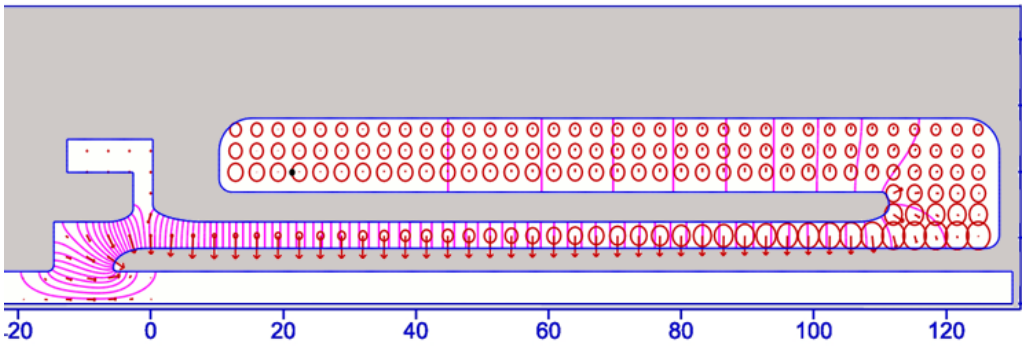
The superconducting structure designed in this SBIR is unique research and represents a significant contribution to RHIC.

- "folded" quarter-wave resonator geometry has not been previously built



- tuning range (~1 % of the operating frequency) is unprecedented for a superconducting cavity
- at 28.1 MHz, this will be the lowest frequency superconducting cavity in operation

Folded quarter wave

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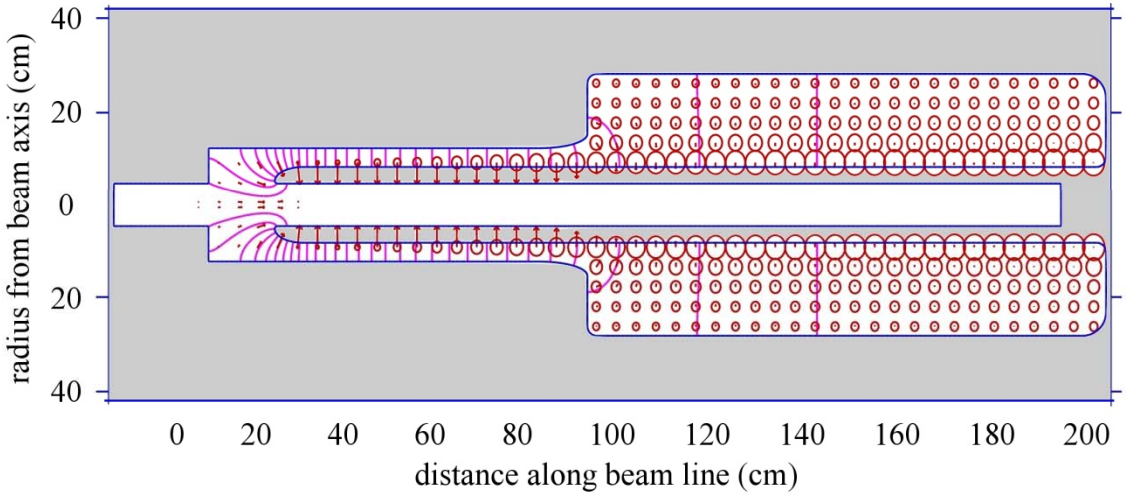
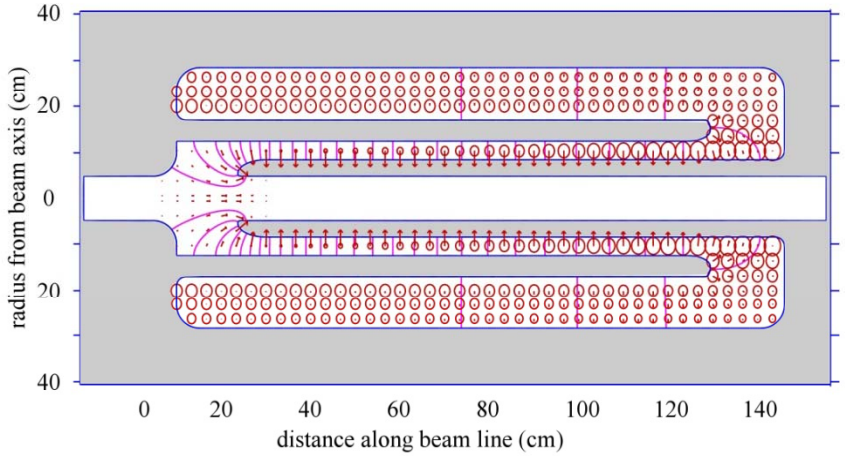


conventional quarter-wave structure with large capacitance to operate at 28 MHz



folded quarter-wave at 28 MHz

The folded quarter-wave geometry allows very low frequency operation at reduced cavity length.

Tuning scheme

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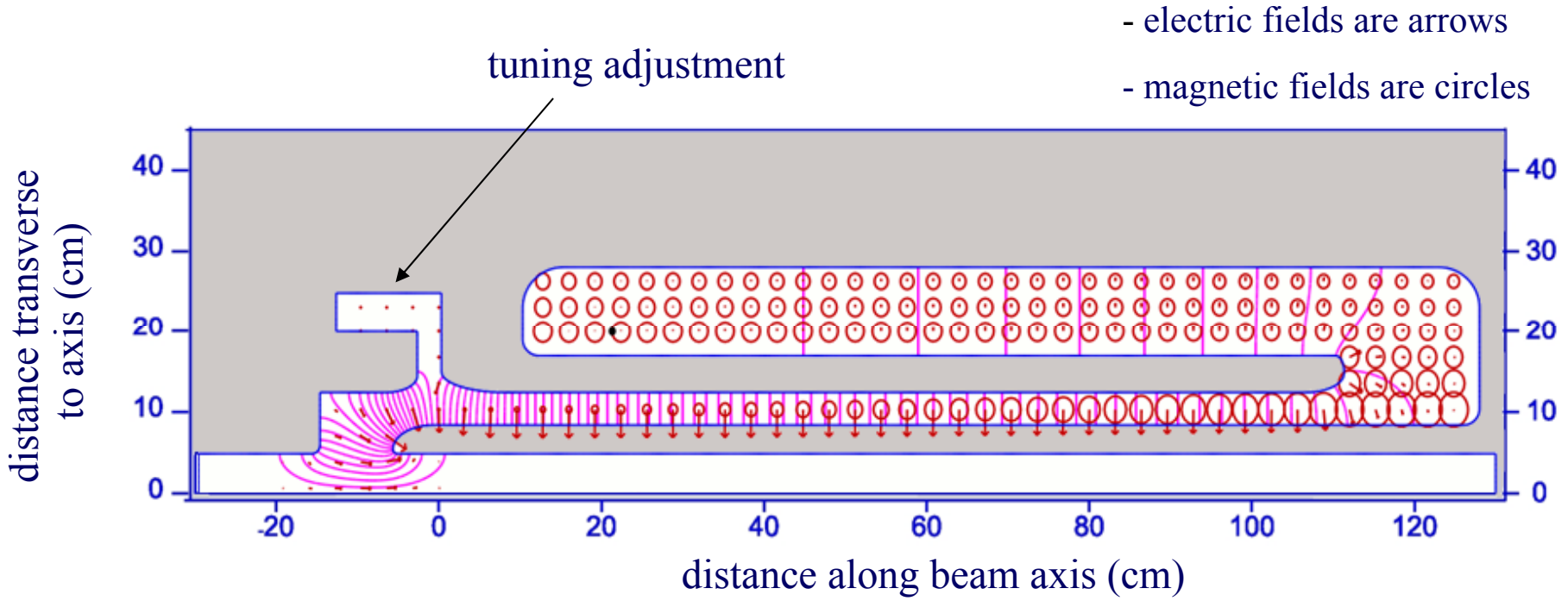

Addition of a second capacitor – only a small section must be moved to tune the cavity the required 200 kHz.

This moving part can be part of a separate section attached by a flange to the rest of the cavity.

Design Parameters

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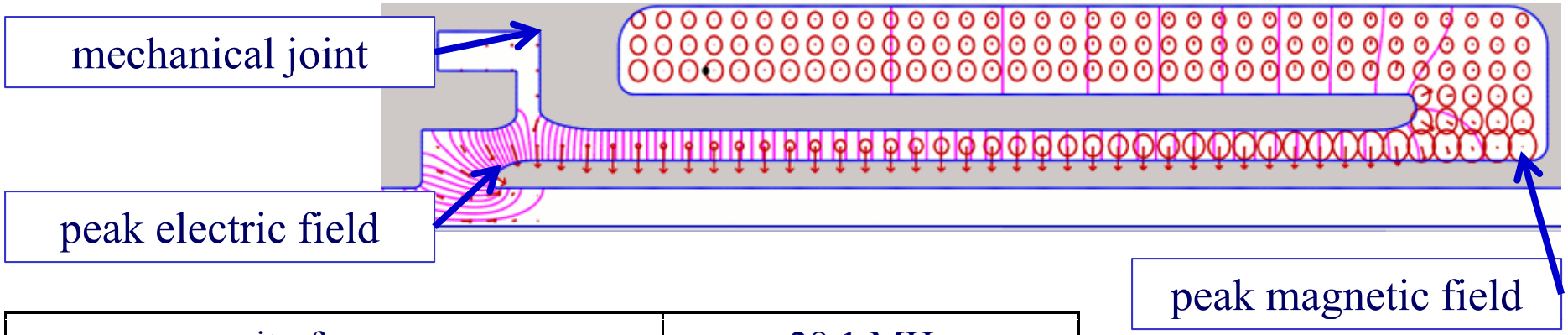

cavity frequency	28.1 MHz
tuning range	200 kHz
tuning slew rate	22 kHz/s
design voltage	650 kV
peak surface electric field	26 MV/m
peak surface magnetic field	44 mT
magnetic field at mechanical joint	2 mT
cavity Q	1.6×10^9
effective shunt impedance (R/Q)	66 Ω
dissipated power	4.1 W

Mechanical design [1]

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large niobium-titanium flange joins the main cavity to tuning section – challenging R&D!

mechanical tuner motion with a Nb bellows which confines the fields (prevents power dissipation in the vacuum vessel)

ports on the end of the cavity serve a dual role:
- fill, drain and rinse ports for the acid etching
- access for microwave antennas
  - power coupler
  - damper for higher-order modes

Mechanical design [2]

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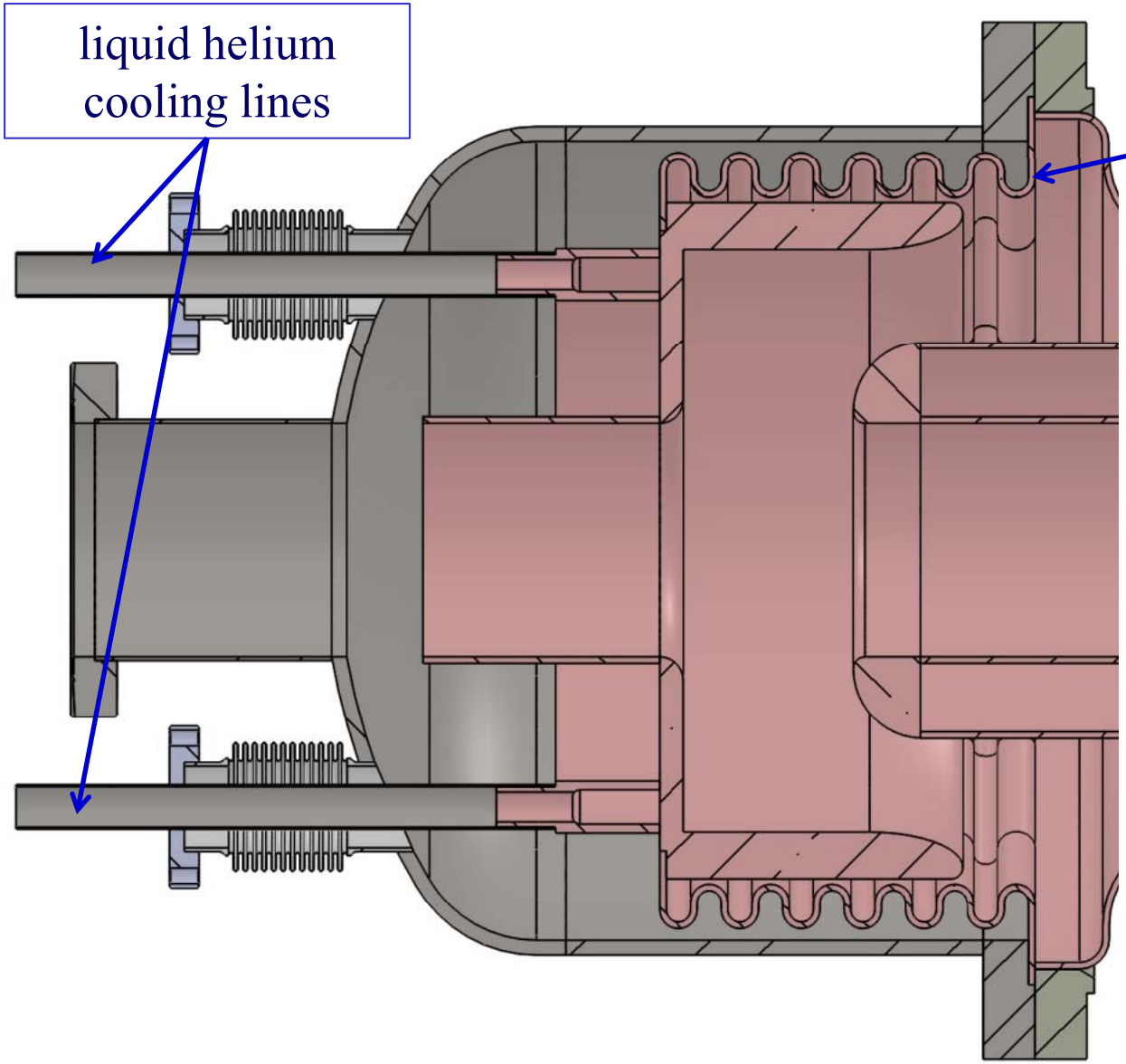

Niobium bellows provides 3 cm of motion to achieve the tuning range of 200 kHz.

Mechanical design [3]

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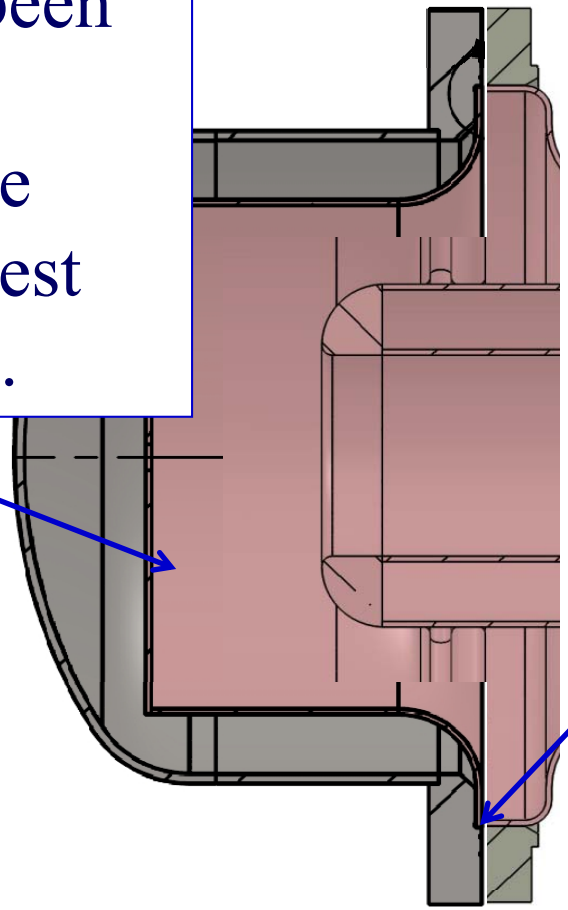
A niobium cap has been made to replace the tuning section for the initial cooldown to test the mechanical joint.



Niobium-niobium mechanical joint should support the required current while superconducting.

Fabrication [1]

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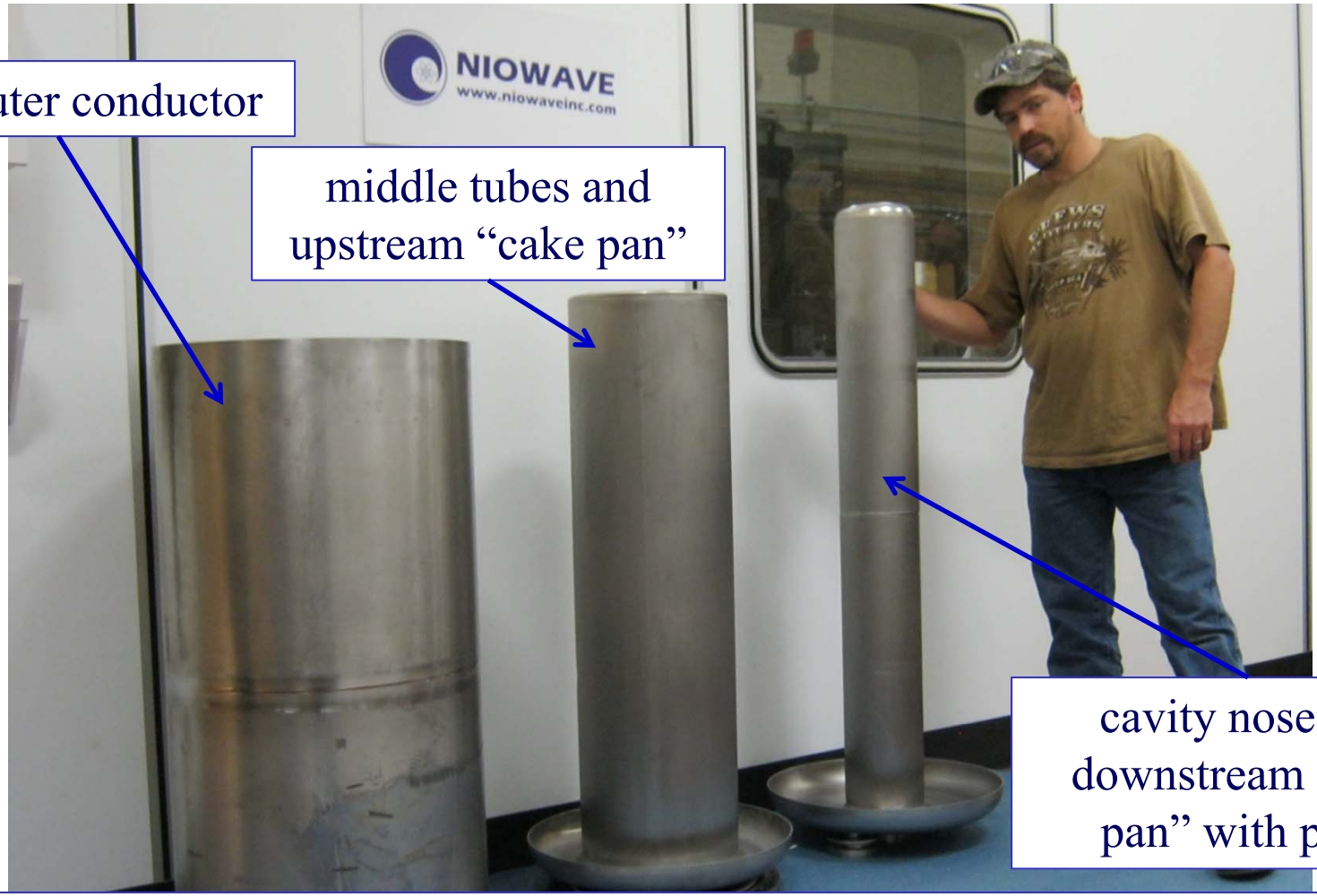

The large subassemblies are now ready to be joined (by electron beam welding) to create the main cavity.

Fabrication [2]

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preparation of niobium assemblies in the Niowave clean room

test fitting of all subassemblies prior to electron beam welding

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Phase II Completion

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- Electron beam welding should be complete by end of 2011
  - RF measurements (f, Q at room temperature)
  - Leak checked
- Phase II complete
  - Ship to BNL for processing and cryogenic testing

Phase III - Tunable 28 MHz Cavity

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- Continue collaboration with BNL
  - Power coupler and pickup designed and installed
  - Process (acid etch, high pressure rinse) and cryogenic test
  - Build prototype tuner and test with cavity
  - Design cryomodule with integrated power coupler, tuner, HOM couplers, and helium vessel