Development of Superconducting RF Multi-Spoke Cavities for Electron Linacs

DOE-NP Phase II SBIR

Terry Grimm

October 2011

NIOWAVE
www.niowaveinc.com

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

NIOWAVE
www.niowaveinc.com

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

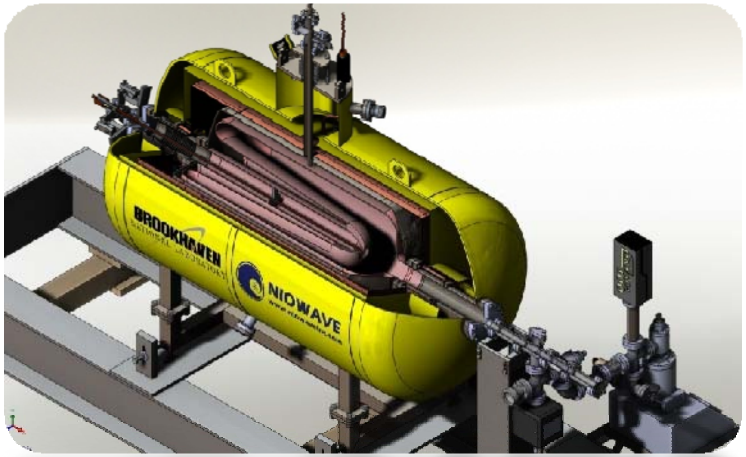
Primary Customers and Uses of Superconducting Particle Accelerators

NIOWAVE
www.niowaveinc.com

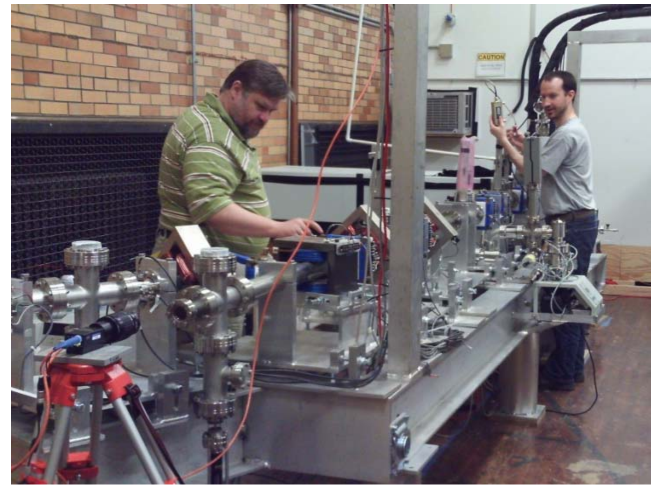
- Large accelerators
  - Current DOE projects: Brookhaven, Fermi, Jefferson Lab, Large Hadron Collider
  - Future: FRIB, eRHIC, Project-X, ILC & many more
- X-ray sources
  - Defense, Medical and Industrial
- Free electron lasers
  - Defense, Medical and Industrial
- Radioisotope production
  - Medical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

Niowave Products for Superconducting Particle Accelerators

NIOWAVE
www.niowaveinc.com

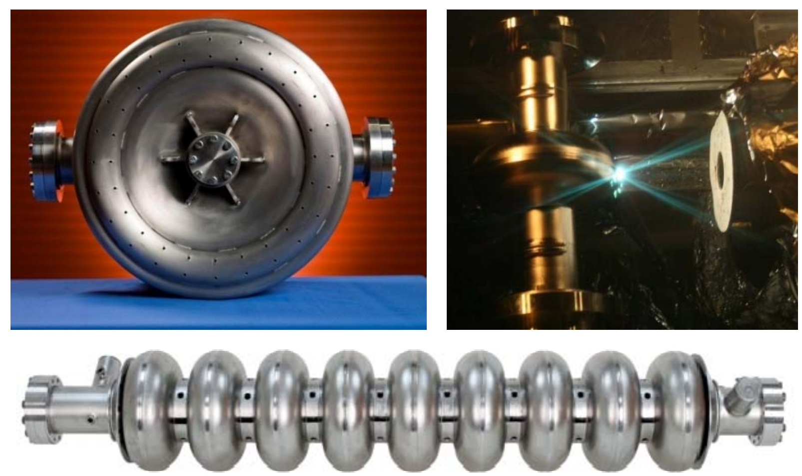


- Electron Guns & Injectors



- Cryomodules & Turn-key Accelerators

- Niobium (In Stock)



- Niobium Superconducting Cavities

Superconducting Cavities

NIOWAVE
www.niowaveinc.com

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

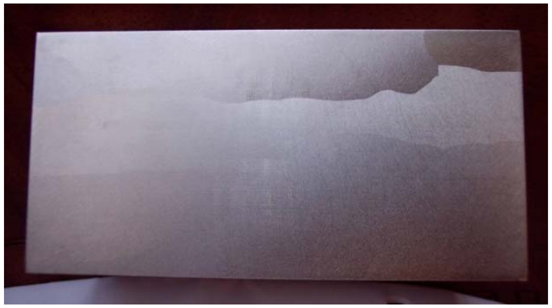
Cavity frequencies
28 MHz to 9.5 GHz

1.3 GHz 9-cell cavities for ILC

Superconducting Metals

NIOWAVE
www.niowaveinc.com

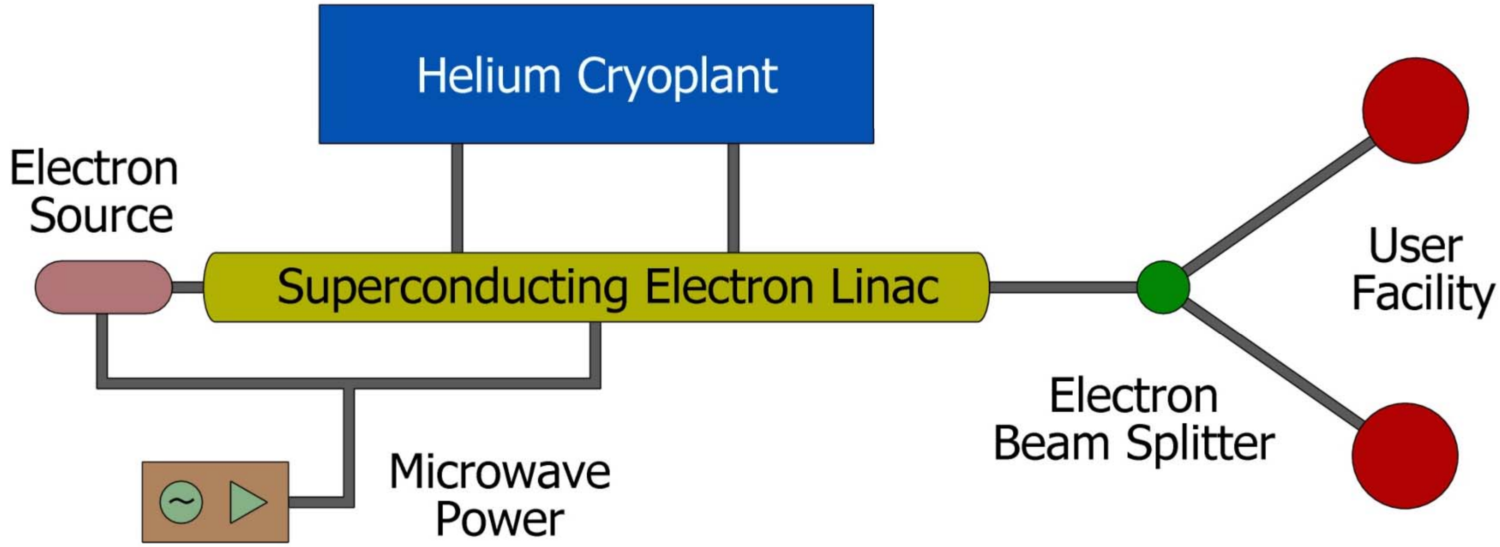
- Niobium Supplier
  - Large and fine grain niobium in a variety of RRR values.
    - Sheets from 1mm to 35mm
    - Ingots and rods
    - Niobium-Titanium also in stock



- 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

NIOWAVE
www.niowaveinc.com



Turn-key Systems

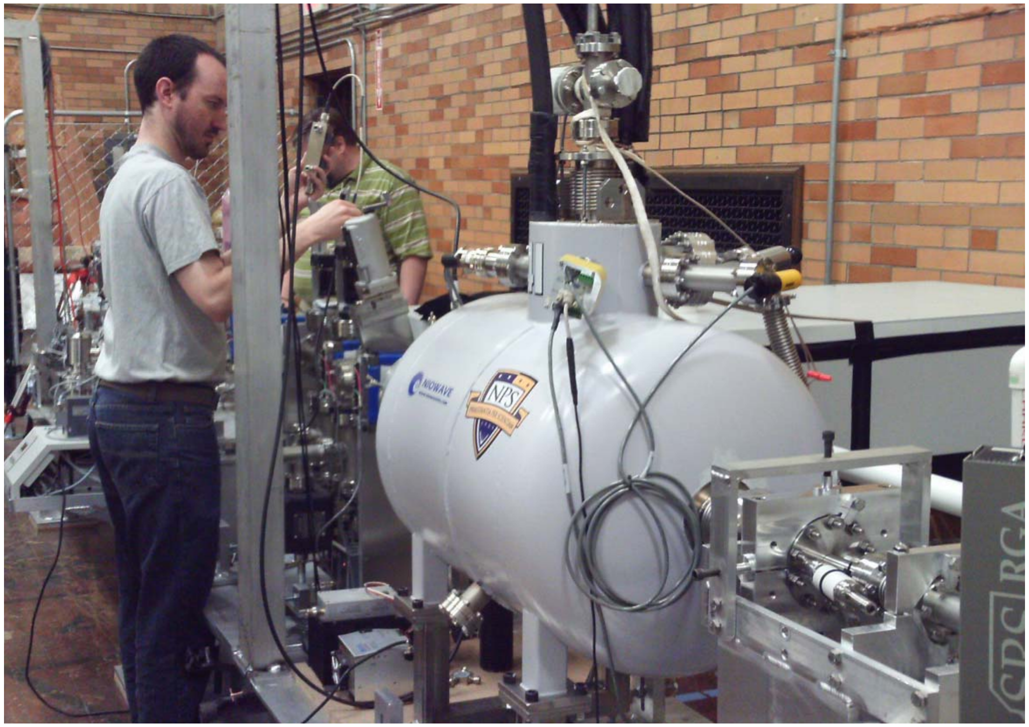
- Superconducting Linac
- Helium Cryoplant
- Microwave Power
- Target / User Facility
- Licensing

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

Superconducting Linacs

NIOWAVE
www.niowaveinc.com

- 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

NIOWAVE
www.niowaveinc.com

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

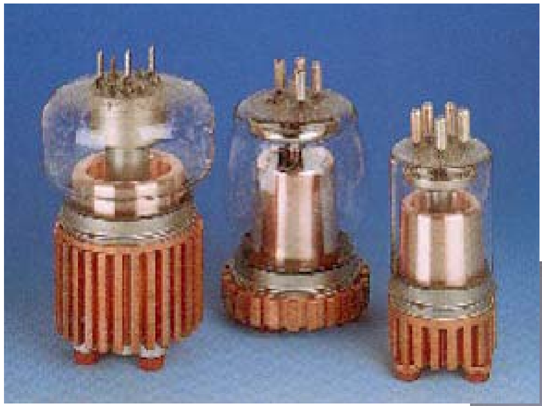
100 W Cryoplant

Microwave RF Sources

NIOWAVE
www.niowaveinc.com

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

500 MHz Electron Spoke

NIOWAVE
www.niowaveinc.com

This project is done in collaboration with:

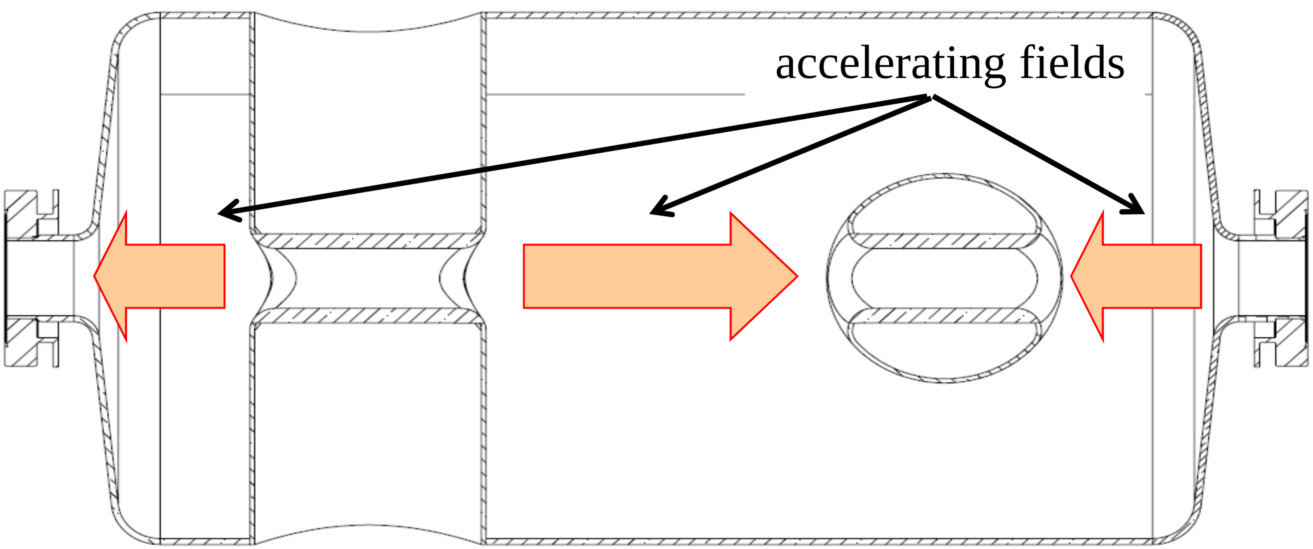
Prof. Jean Delayen - Old Dominion University (ODU) and Thomas Jefferson National Laboratory (JLAB)

The funding is provided by the DOE SBIR program
Contract # DE-FG02-08ER85172.

Concept of the Multi-Spoke Cavity

NIOWAVE
www.niowaveinc.com

- The electric field between the spokes and between the spoke and the end-plate is used for acceleration of the beam.
- Particles are synchronized with the alternating RF wave so that they see acceleration in each of the three gaps.
- Single- and multi-spoke cavities have been successfully used with heavy ions, but this project will be the first multi-spoke cavity to accelerate electron beams.



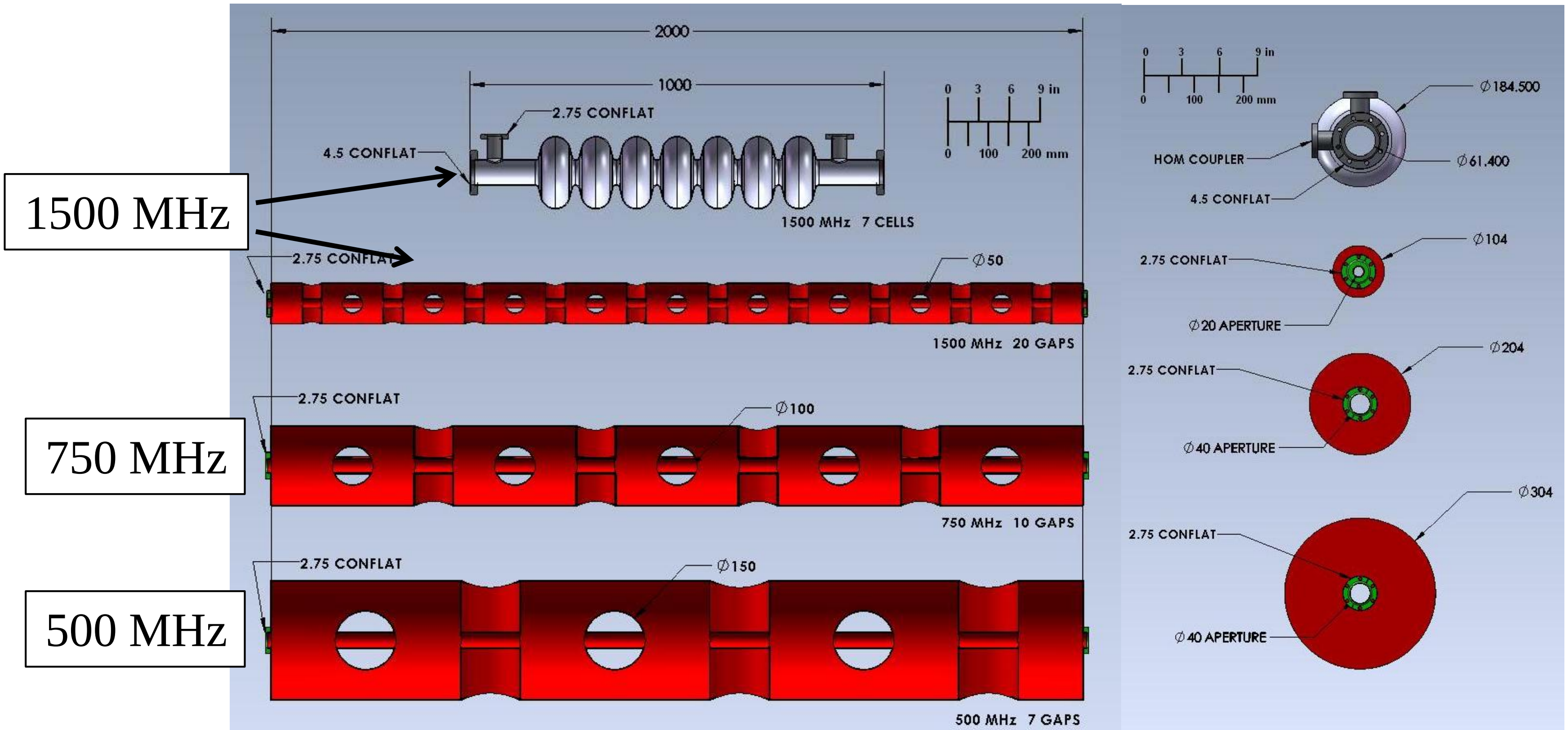
Scientific Justification

NIOWAVE
www.niowaveinc.com

- Why 500 MHz
  - Reduced cryogenic losses at lower frequency
    - Commercial 4.2 K cryoplant
  - Compact structure that is more resistant to vibrations (microphonics) compared to the traditional elliptical ILC-type cavities
  - Commercial, CW microwave sources available
    - 90 kW IOTs
    - 1 MW klystrons

Multi-Spoke vs Elliptical

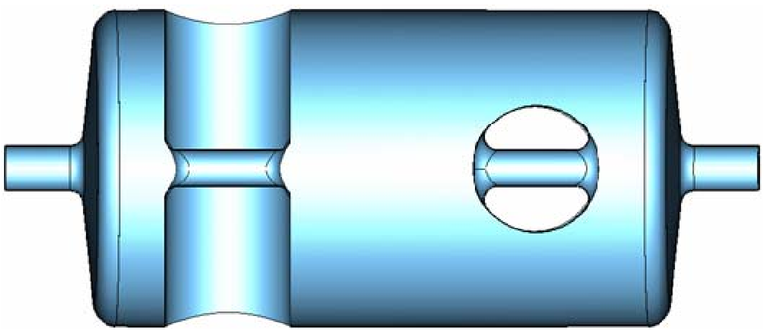
NIOWAVE
www.niowaveinc.com

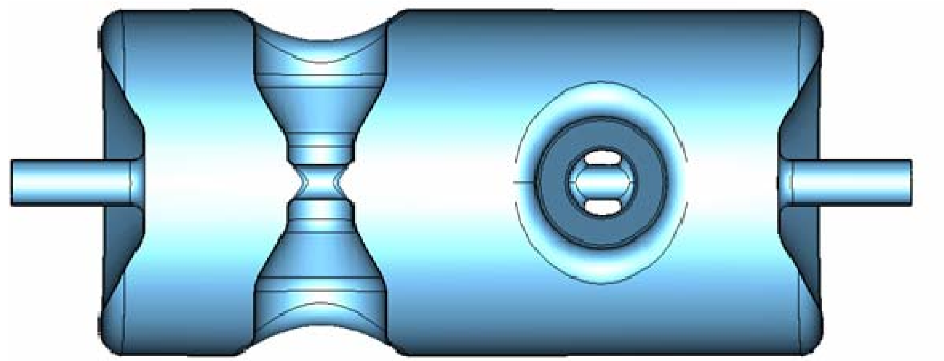


- The multi-spoke cavity is significantly more compact than an elliptical cavity at the same frequency.
- The operating frequency can then be reduced without sacrificing “real estate gradient” and benefit from the 4.2 K operating temp.

Alternative EM Designs

NIOWAVE
www.niowaveinc.com





“Basic” EM Design

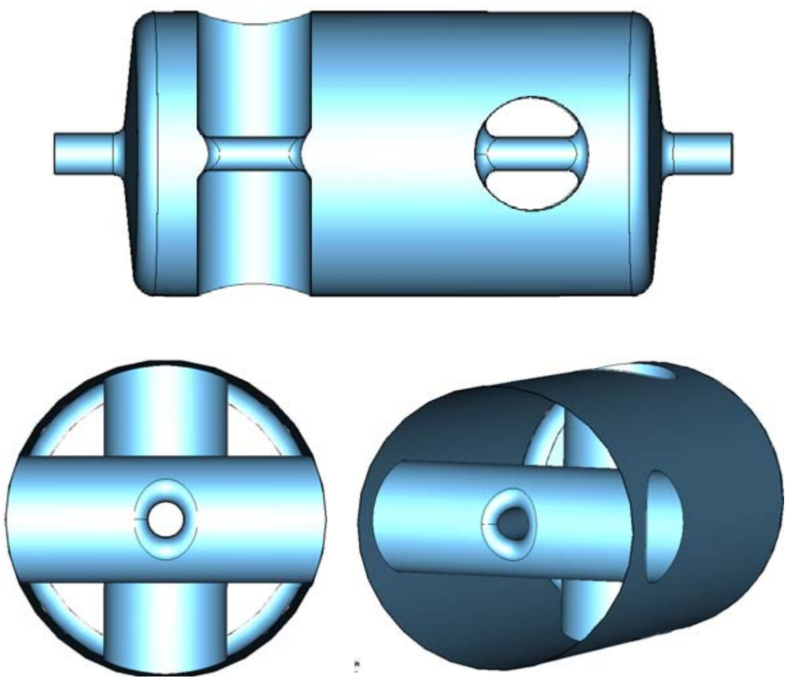
- Simpler for fabrication, better suited for prototype
- Lacks the performance of the “advanced” option

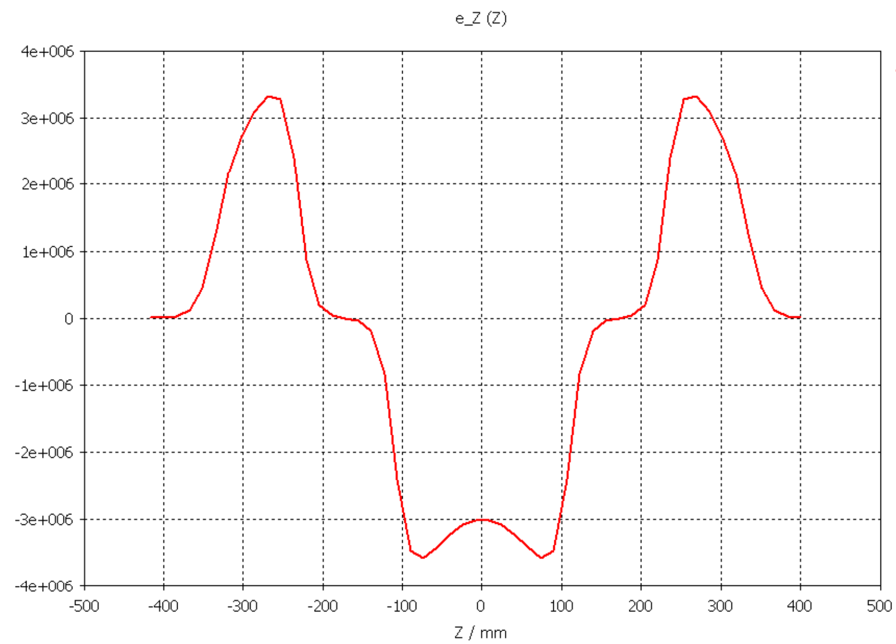
“Advanced” EM Design

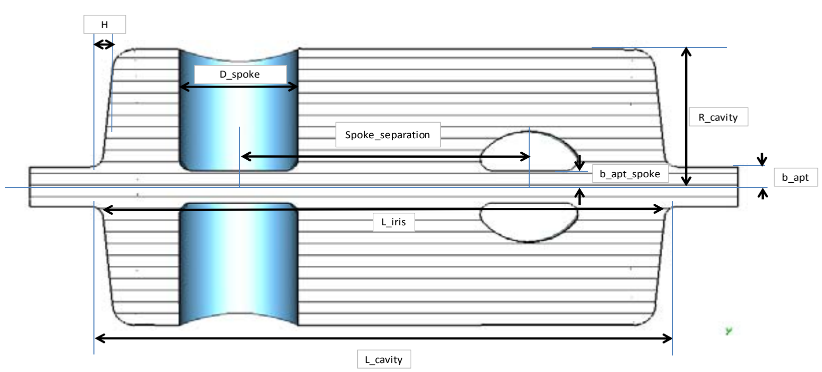
- More complicated for fabrication
- Higher accelerating fields lead to savings for the mid-to-large scale project where R&D costs are spread out over many cavities

Prototype "Basic" EM Design

NIOWAVE
www.niowaveinc.com

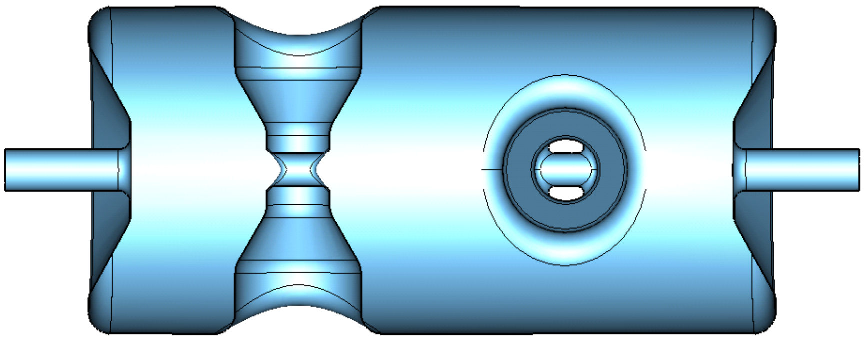


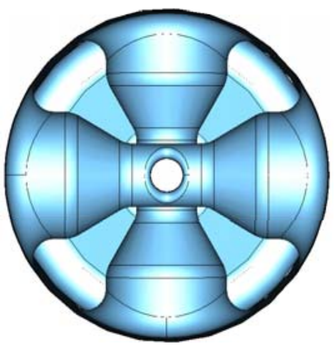


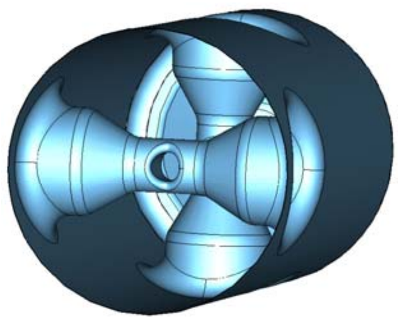


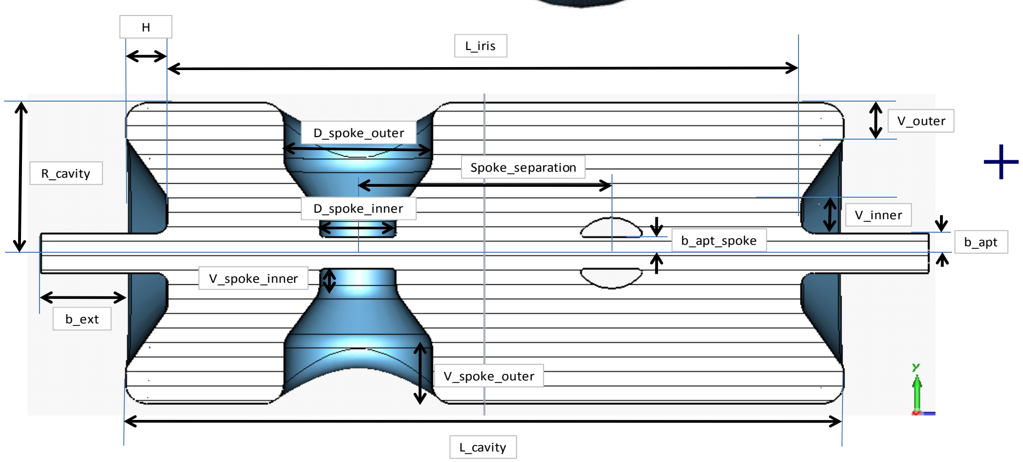
+ Simpler for fabrication
+ Better suited for prototype
– Lacks the performance of the "advanced" option

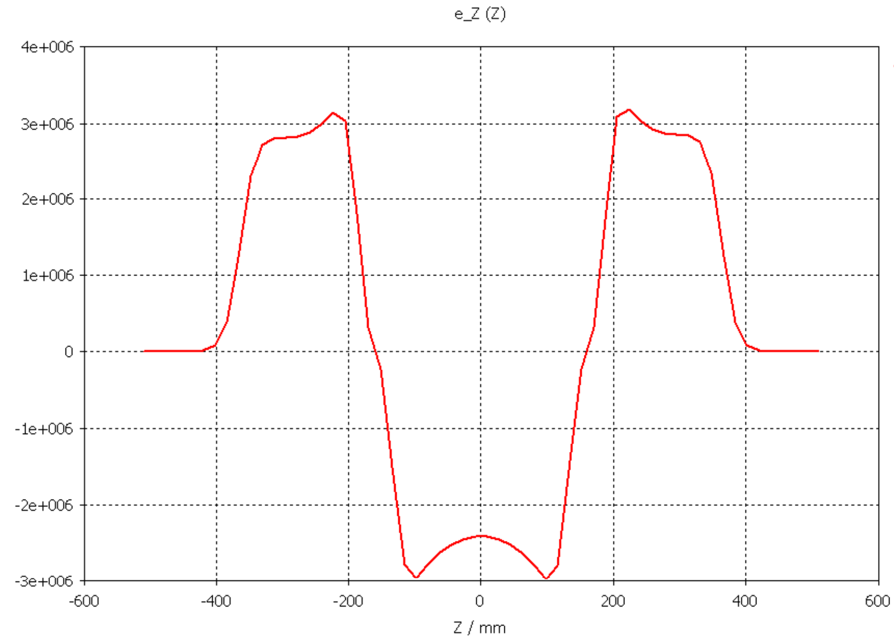
“Advanced” EM Design











– More complicated for fabrication

+ Better suited for mass production of units for the mid-to-big scale project

EM parameters – basic and advanced designs

NIOWAVE
www.niowaveinc.com

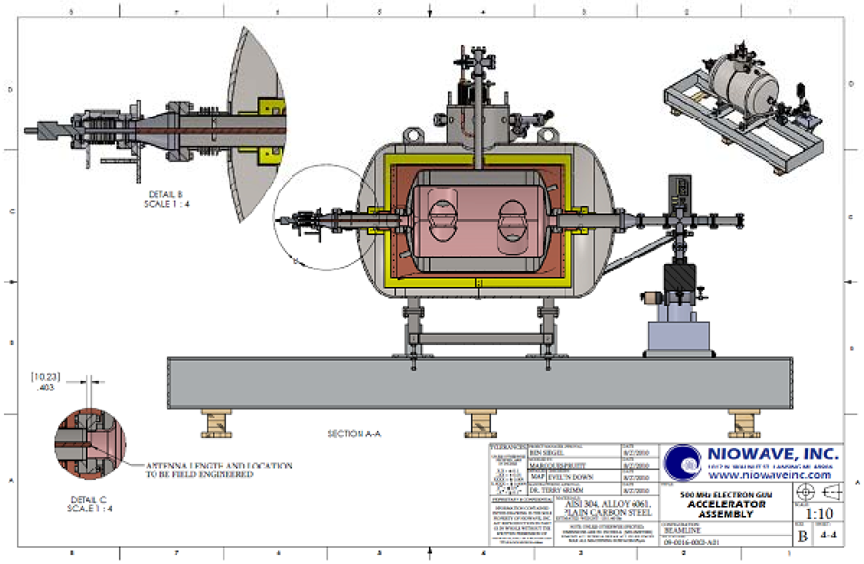
- disadvantages of advanced design
  - cavity size larger (by ~20-25% in both radius and length)
  - more complicated spokes and cavity end-plates geometry
  - higher total amount of losses for the same B_{peak}
- advantages of advanced design
  - Accelerating voltage increased by more then 55%
  - R/Q is increased by ~31%
  - Geometric factor is increased by ~38%

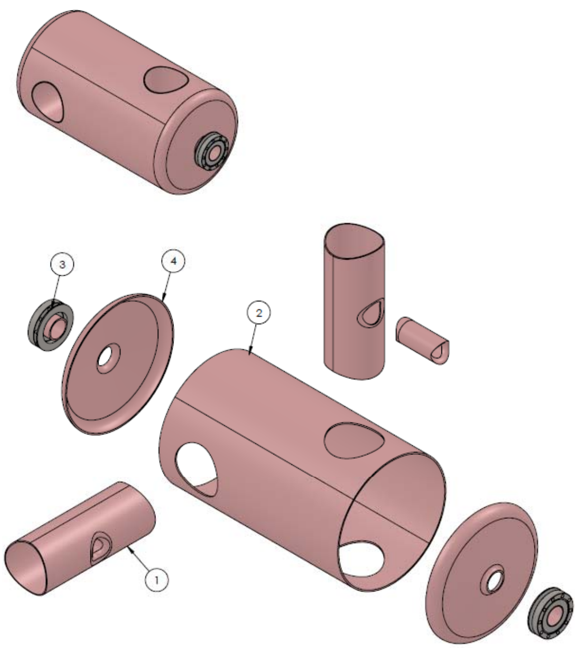
	Basic	Advanced
Frequency (MHz)	500	500
Vo (MV)	4.07	6.32
Ea (MV/m)	7.36	11.6
Eo (MV/m)	16.89	18.73
Epeak (MV/m)	21.69	29.47
Bpeak (mT)	80.0	80.0
Bp/Ep (mT/(MV/m))	3.69	2.71
Rres (nOhm)	5.0	5.0
R_{BCS} (nOhm)	79.0	79.0
Pd (W)	29.64	39.13
T (K)	4.2	4.2
Q	1.27E+09	1.77E+09
G (Ohm)	106.9	147.8
R/Q (Ohm)	438.9	576.6
TTF	0.83	0.76

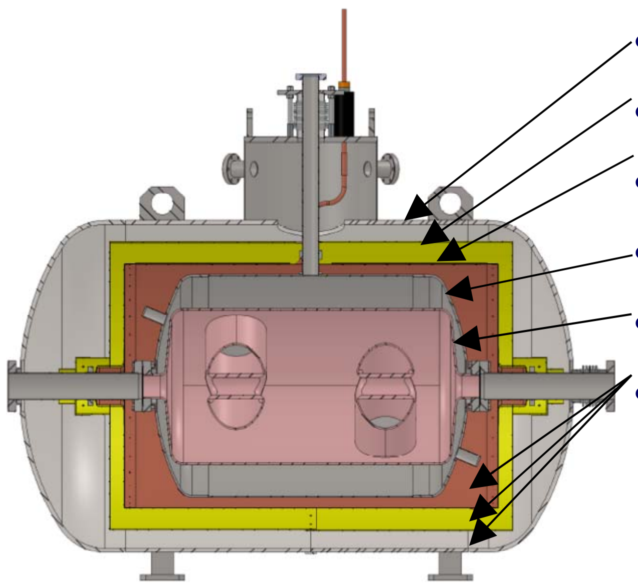
Mechanical Cavity and Cryomodule Design

NIOWAVE
www.niowaveinc.com

- The production drawings detailing the manufactured parts and assembly process are produced



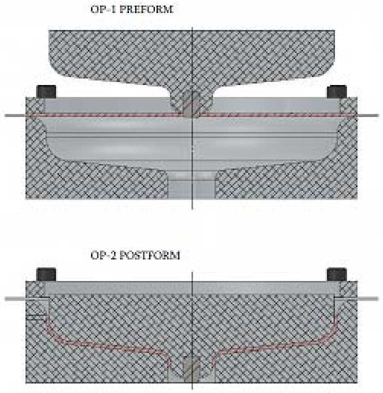


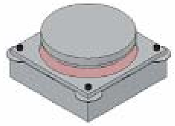


- Vacuum vessel
- Mu-shield
- LN2 copper shield
- LHe cryovessel
- Nb cavity
- Mylar superinsulation in the cryomodule vacuum

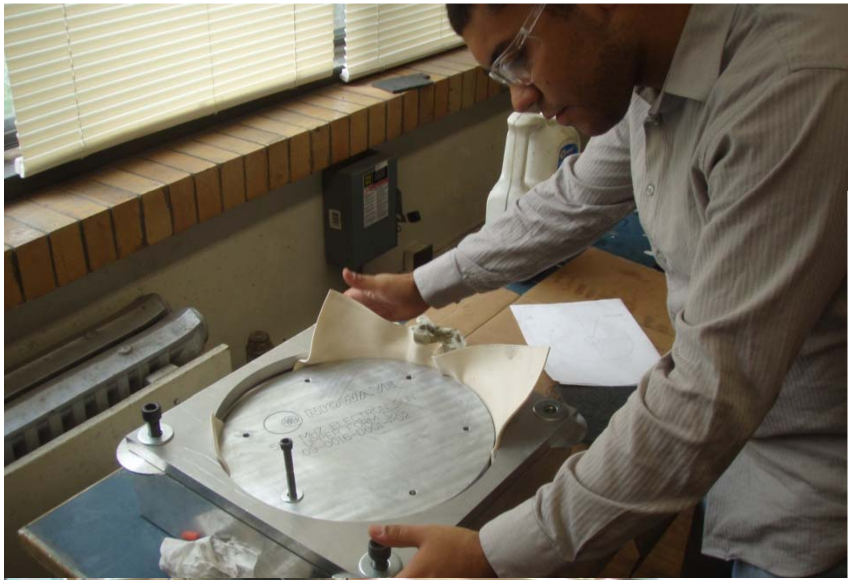
Fabrication

NIOWAVE
www.niowaveinc.com





Deep drawing of copper prototype of the niobium 4 mm thick end-plate for confirmation of the fixture feasibility



Fabrication [2]

mu-metal magnetic shield and the liquid He cryovessel

copper thermal shield

machined niobium parts

vacuum vessel ready for assembly

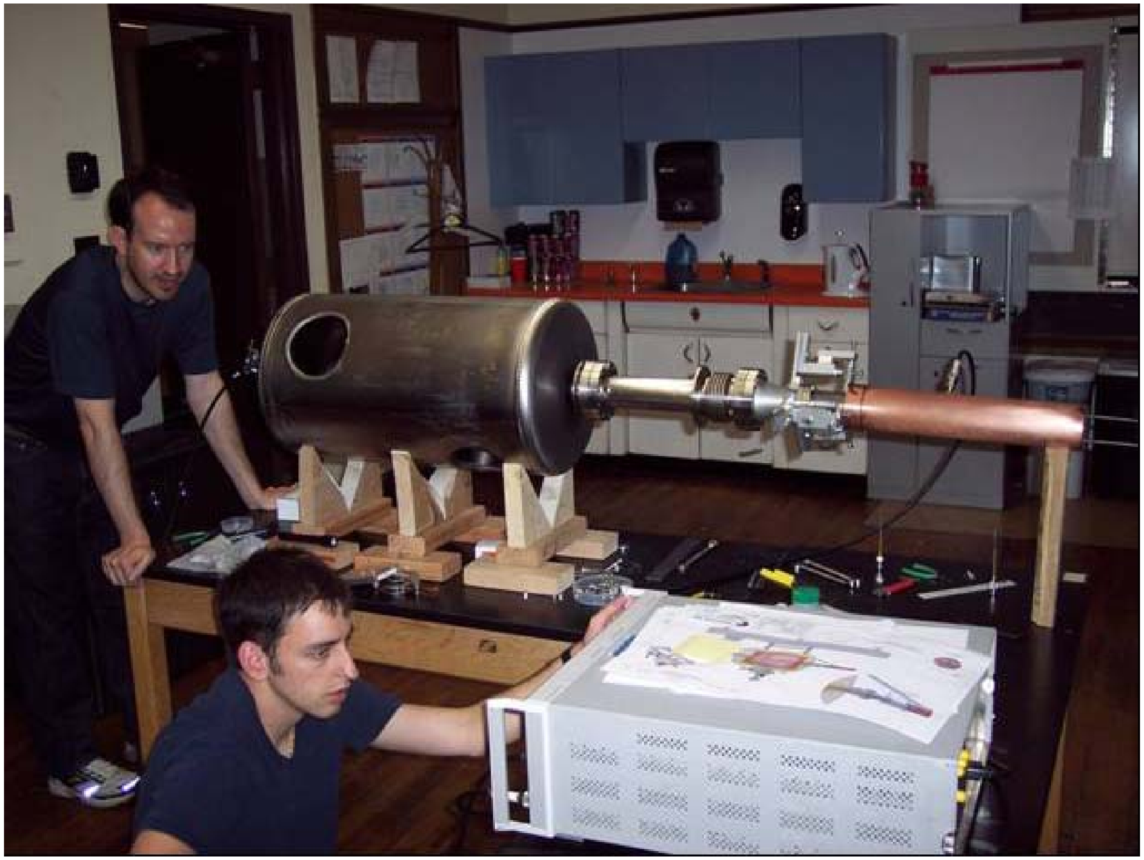
Cavity Assembly and Welding

NIOWAVE
www.niowaveinc.com

- The niobium cavity parts were assembled together in the clean room, class 100, and electron-beam welded

Preliminary Cavity Measurements

NIOWAVE
www.niowaveinc.com



- Preliminary RF measurements of the welded niobium cavity were performed before assembly of the whole cryomodule

Cryomodule Assembly

NIOWAVE
www.niowaveinc.com





- The cavity and RF power coupler installation was done in the clean room

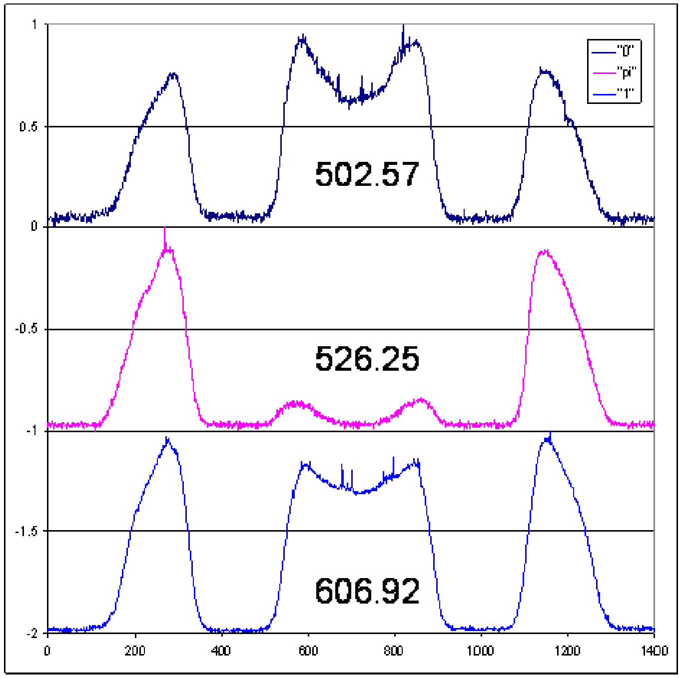
- The cryomodule assembly was done in stages

Cavity RF Measurements

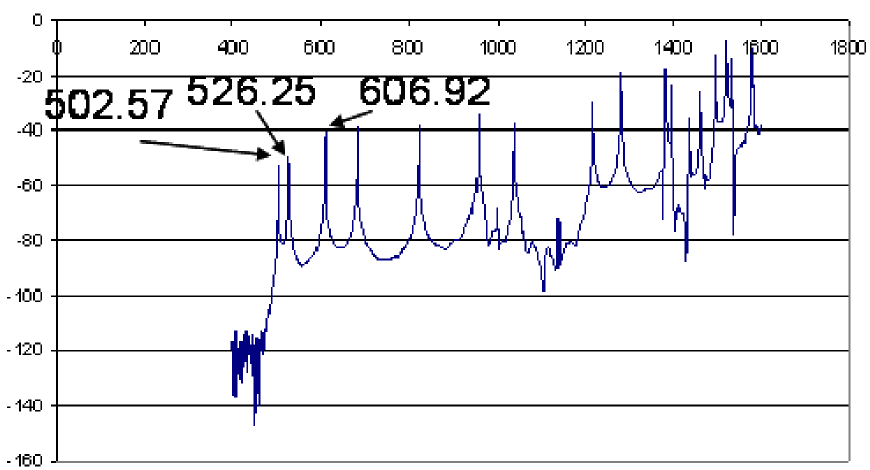
- Cavity RF measurements were done after full cryomodule assembly at Room Temperature
- Due to weak coupling being designed for cryogenic temperatures, the modes were measured with the coupler modes on the background

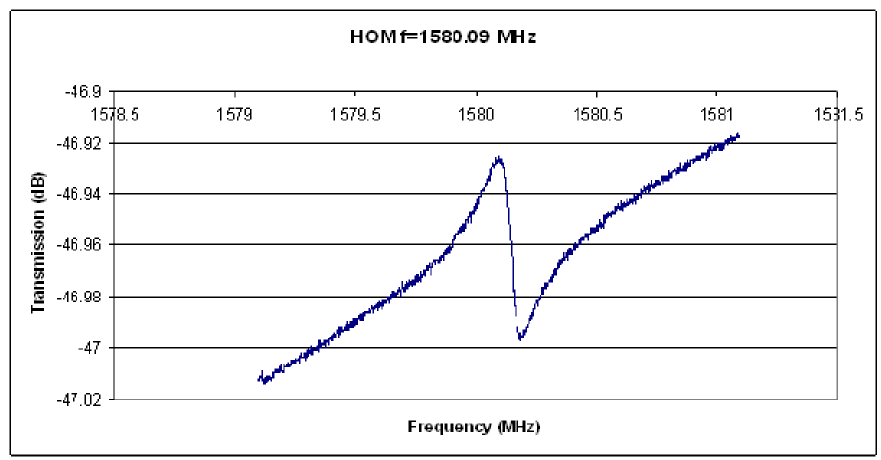
Measurement of RF Properties of the Multi-Spoke Cavity

NIOWAVE
www.niowaveinc.com



- The bench-top measurements of the cavity spectrum and the bead-pull measurements of the on-axis electric field were done
- The HOMs measurement in the whole cryomodule assembly were done in final preparations for the cryogenic tests





Test Plans

NIOWAVE
www.niowaveinc.com

- The DOE SBIR Phase-II project has been finished and the final report delivered
- The niobium cavity and the full cryomodule were fabricated and assembled
- RF measurements at room temperature confirmed the design parameters
- First beam test is possible at Niowave in 2011
  - subject to additional funding (Phase III)

Phase III – Electron Spoke

NIOWAVE
www.niowaveinc.com

- MIT's CUBIX Compton X-ray project uses the proposed concept for their accelerator
- Office of Naval Research (ONR)
  - fund the cryogenic test of the 500 MHz electron spoke (Naval Postgraduate School, ODU)
  - Advanced designs for high power lasers (ONR, NPS, ODU, LANL, Boeing)