201-MHz NCRF Cavity Program

Derun Li
Center for Beam Physics
Lawrence Berkeley National Laboratory

Neutrino Factory & Muon Collider Collaboration Meeting
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Collaborators

Muon Collaboration

M. Dickson, R. MacGill, J. Staples, S. Virostek, M. Zisman

Lawrence Berkeley National Laboratory

A. Bross, A. Moretti, Z. Qian, …

Fermi National Accelerator Laboratory

J. Norem

Argonne National Laboratory

R. Rimmer, L. Phillips, G. Wu

Jefferson National Laboratory

Y. Torun

Illinois Institute of Technology

D. Summers

University of Mississippi

W. Lau, S. Yang

Oxford University, UK

Outline

- Introduction
- 201 MHz Cavity Progress
  - Cavity design and fabrication
    - Cleaning, vacuum and assembly
    - Shipping
  - Installation at MTA, FNAL
    - Installation: vacuum, RF couplers and probes, power transmission lines, baking system, …
    - Low power microwave measurements
  - Progress on curved Be windows
    - 21-cm curved Be windows for 201 MHz cavity
    - Asymmetric heating of the curved windows
  - Preliminary tests of the cavity
- Summary

Introduction

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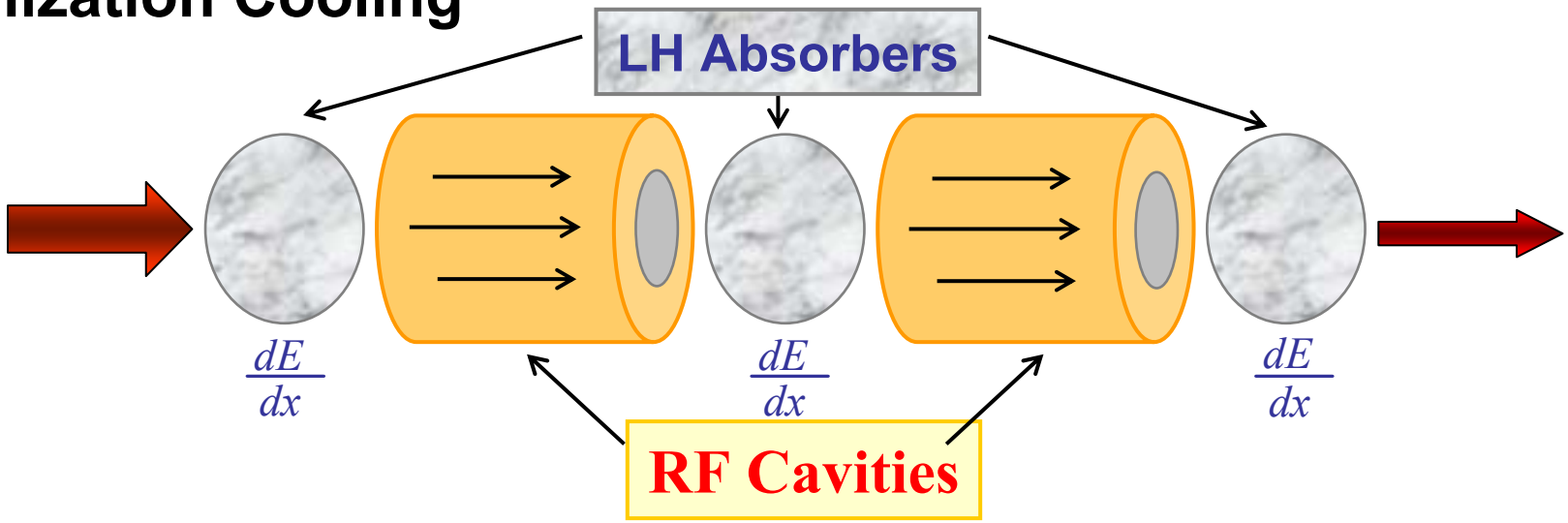
Ionization Cooling



- High gradient RF cavities to compensate for lost longitudinal energy
- Strong magnetic field to confine muon beams
- Lose energy in LH absorbers

Goal:

- Development of NC 201-MHz cavity at ~ 16 MV/m with solenoidal B fields

Introduction (Cont'd)

NCRF R&D Programs

Develop highest possible NCRF accelerating structure to meet the requirements for NF or MC

- **Prototype of 201 MHz cavity**
  - **Completed cavity design and fabrication**
  - **Cavity installation at MTA in Sept. 2005**
    - **Assembly and vacuum**
    - **RF power plumbing**
  - **RF conditioning started in Feb. 2006**
- **Experimental studies at 805 MHz with and without external magnetic fields up to 5-Tesla (Norem's presentation)**
  - **Completed 5-cell cavity with open iris test at Lab G**
  - **Designed, fabricated and tested pillbox-like cavity with demountable windows at Lab G and moved and resumed recently at MTA, FNAL**
  - **Tests with two curved Be windows**
    - **Reached 32 MV/m easily without external magnetic field**
    - **More tests are in progress with magnetic fields versus achievable gradient**
  - **Button test**

Cavity Status at Last MC Meeting

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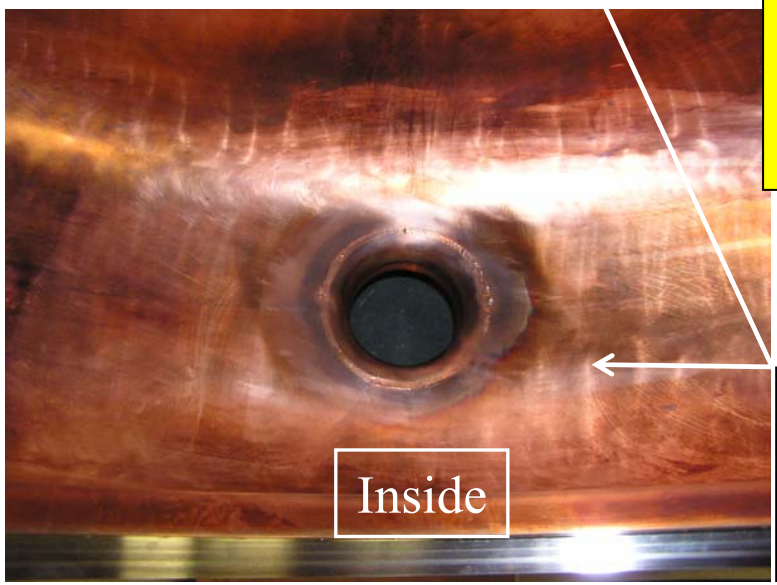
Where we were at last MC meeting in Berkeley (Feb-2005)

- ✓ Welding of cooling tube to cavity
- ✓ Extruding of four ports and vacuum leak tight
- ✓ Placed purchase order of curved Be windows

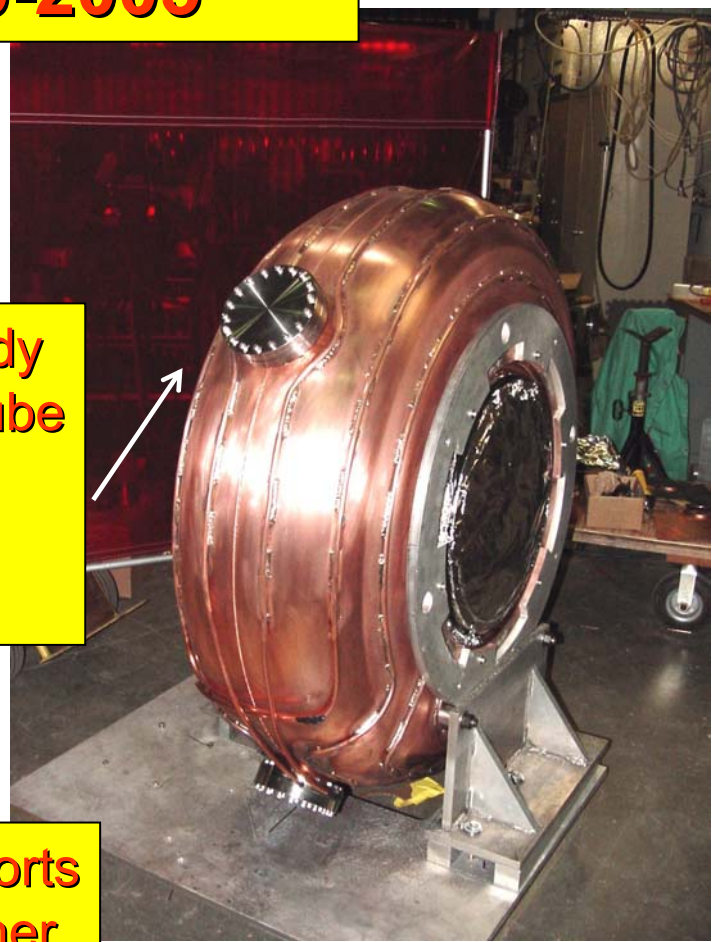
Work needs to be done:

- → Cavity interior buffing
- → Chemical cleaning and high pressure water rinse of the cavity interior
- → Surface cleaning + electro-polishing (EP)
- → High power RF conditioning of RF couplers with windows
- → Low power microwave measurements of the cavity with windows:
  - Frequency
  - Quality factor *Q*
  - Couplings
- → RF coupler measurement and tuning
- → Packing and shipping to MTA, FNAL

The Cavity at J-Lab in Feb-2005



- ✓ cavity body
- ✓ cooling tube
- ✓ ports and flanges
- ✓ leak tight



Extruded ports
Out and inner surface finish

fact
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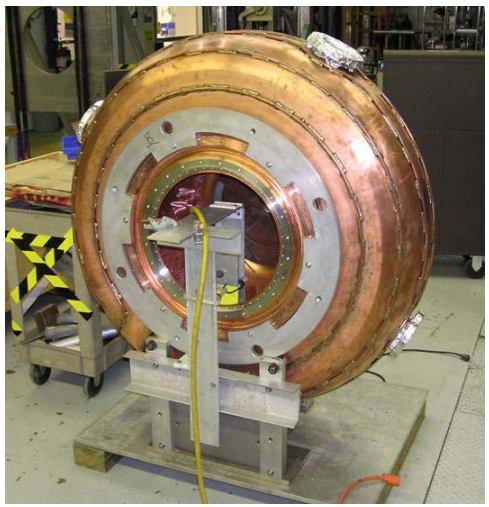
Berkeley Lab
75 Years of World-Class Science 1931-2006

Cavity Progress: Final Interior Buffing

- Final interior buffing of cavity is performed to ensure the surfaces are ready for electropolishing
- Less buffing needed near equator where fields are lower
- An automated process of buffing was developed using a rotary buffing wheel and a cavity rotation fixture
- Some local hand work required to clean up some areas
- A series of pads with graduated coarseness was used
- Goal was scratch depth shallow enough for EP removal



Cavity Progress: EP Setup

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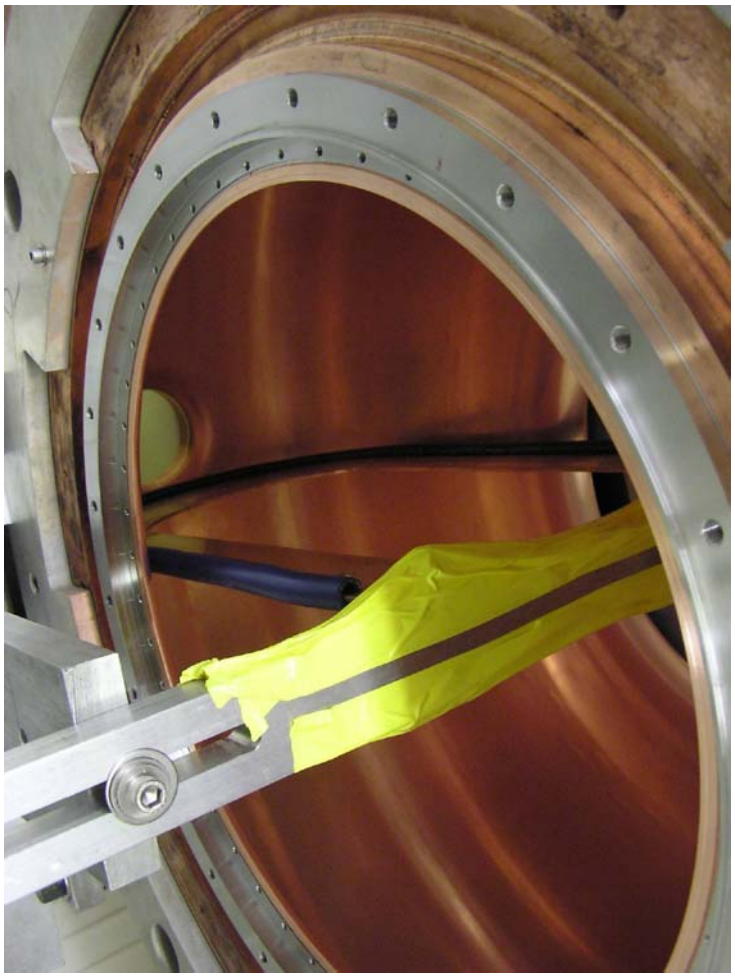
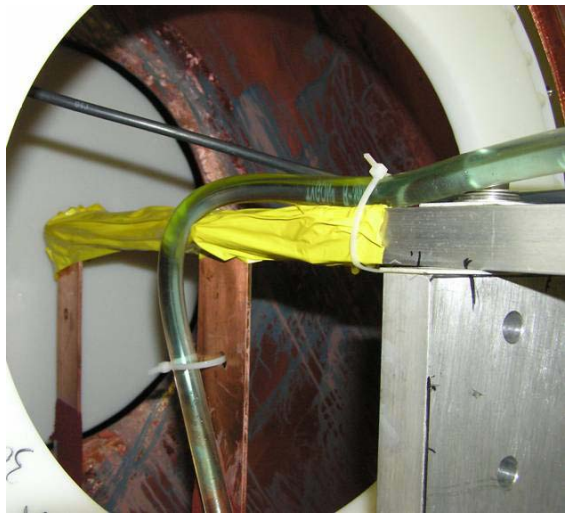
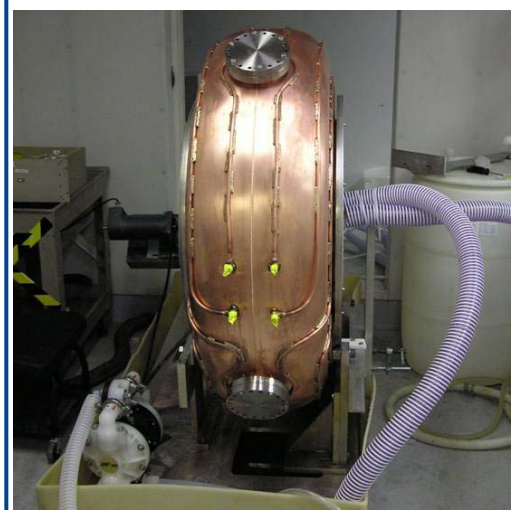


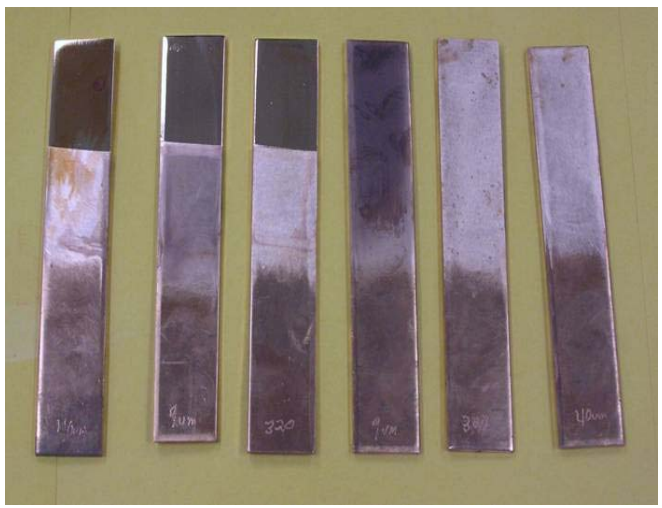
EP setup and the U-shape electrode for EP at J-Lab

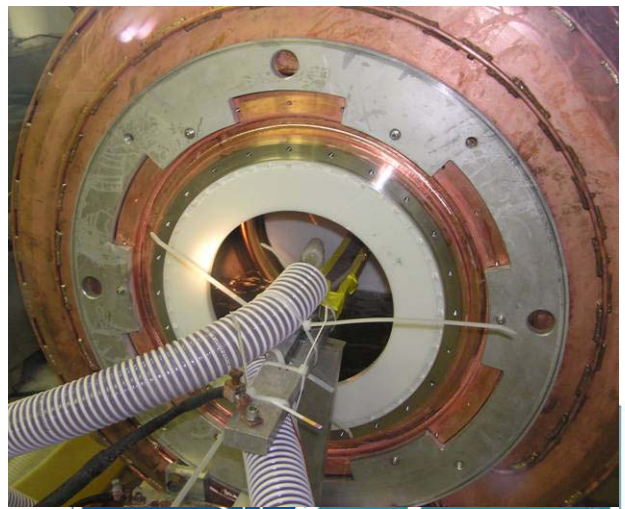
Interior Surface Electropolish

- After buffing, cavity underwent a chemical cleaning process
- Test bars with various degrees of buffing were run through an electropolish process
- Cavity was rotated with a U-shaped electrode fixed in place
- Initial polish failed due to depletion of the solution, and rebuffing was required
- 2nd EP successfully removed scratches in high field regions
- Final process is a high pressure water rinse of cavity surface



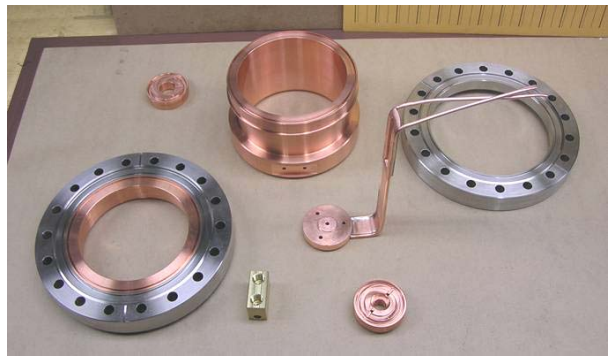


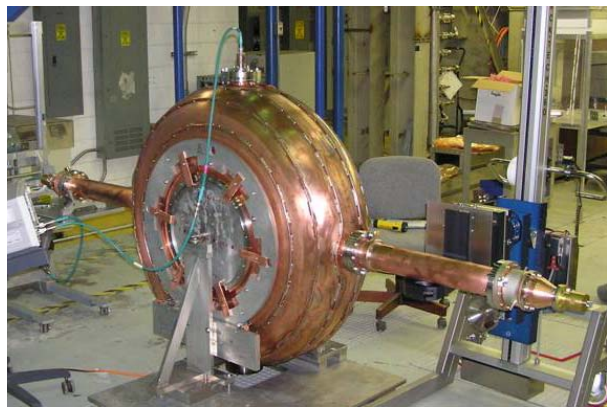


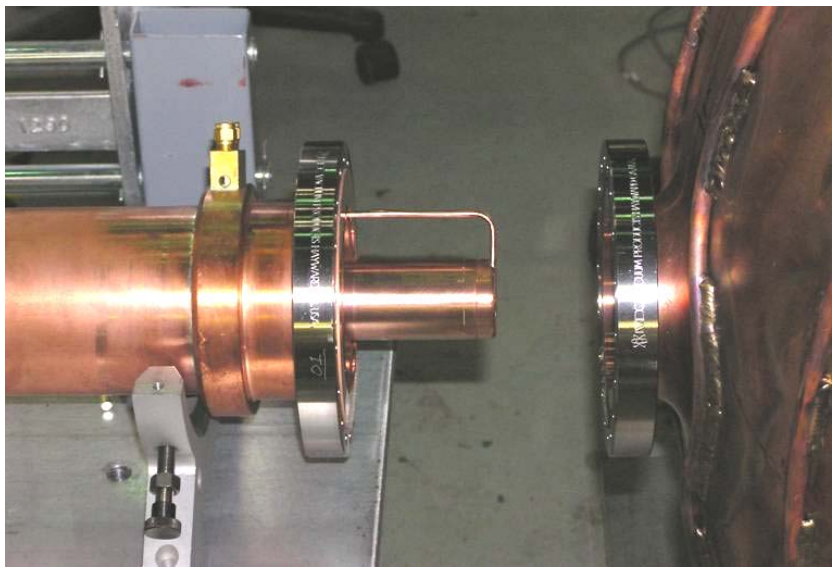


Cavity RF Couplers and Assembly

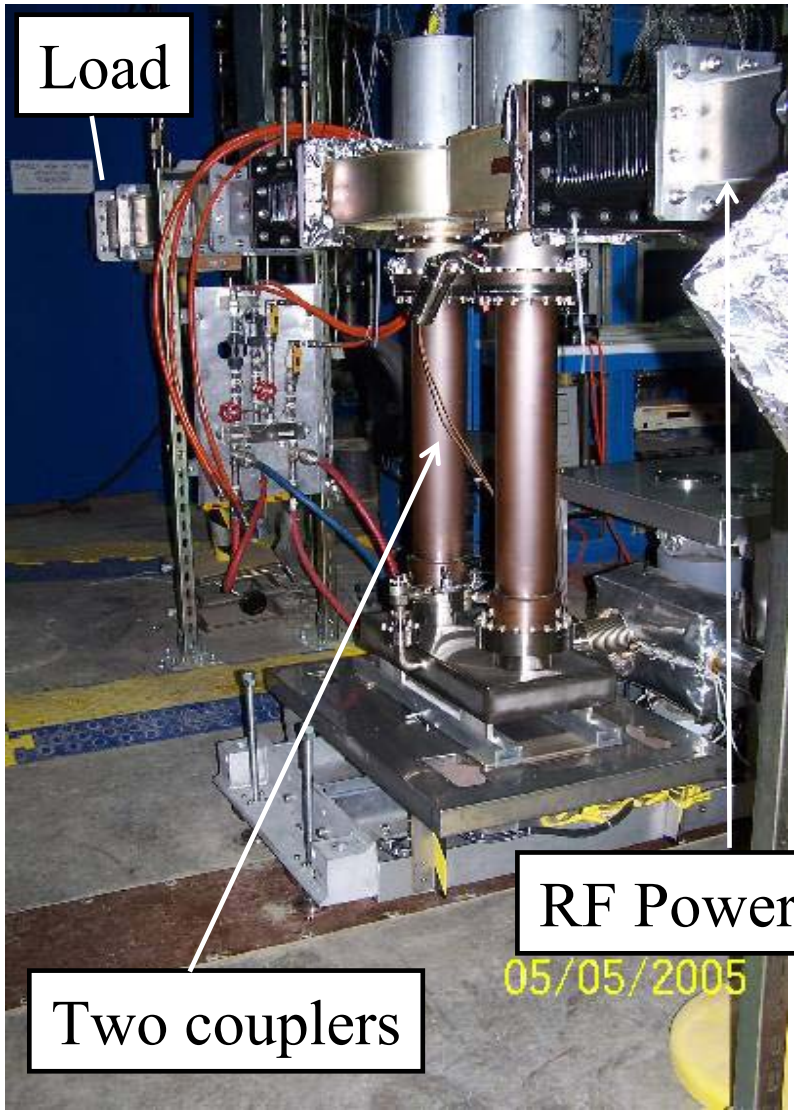
- Coupling loops were fabricated using standard copper co-ax
- Most coupler parts were joined by torch brazing – vacuum leaks were found in two of the outer conductor joints
- Coupling loop contains an integrated cooling tube
- The coupler was designed to mate with an SNS style RF window manufactured by Toshiba
- High power conditioning performed at SNS (ORNL)







Coupler Conditioning

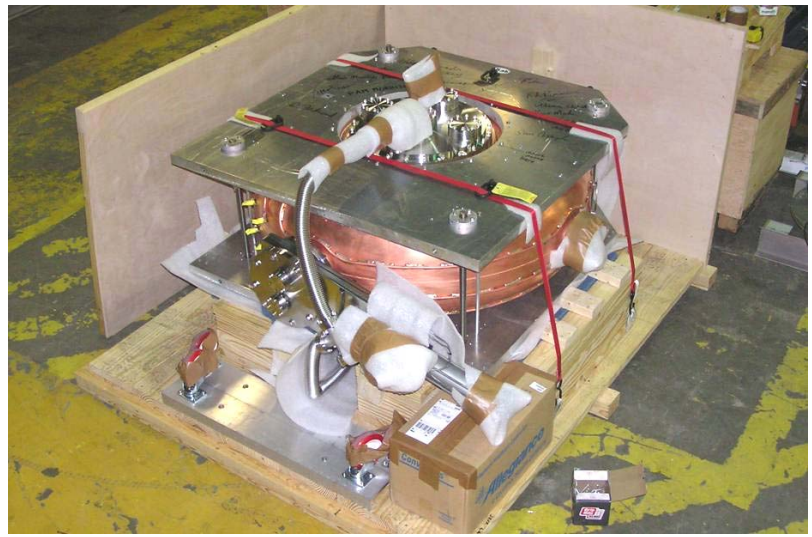


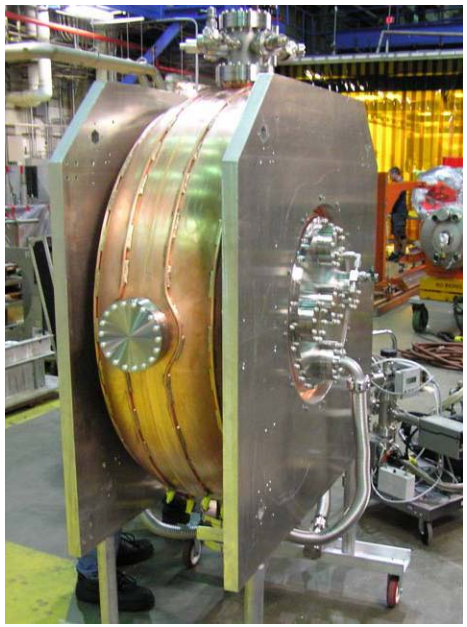
Two loop couplers

- Conditioning started during PAC-05 week at SNS, ORNL
- Good vacuum ~ low 10^{-8} T
- Achieved 600 kW in TW mode (matched load)
- Achieved 10 kW average power (~ 9 kW for nominal NF parameters)
- Achieved 2.4 MW peak power in SW mode (at variable short positions)
- Ceramic windows work perfectly within two weeks of the conditioning

Shipment to the MTA at FNAL

- System assembly included: tuner plates, port blank-offs, diagnostic spool, window cover plates, gate valve and window pump-out tubes
- Final leak check conducted prior to shipping
- Cavity was back-filled with nitrogen in its assembled state and packaged in a custom made crate for shipping to the MTA





Couplers

Final Assembly & Measurement at MTA

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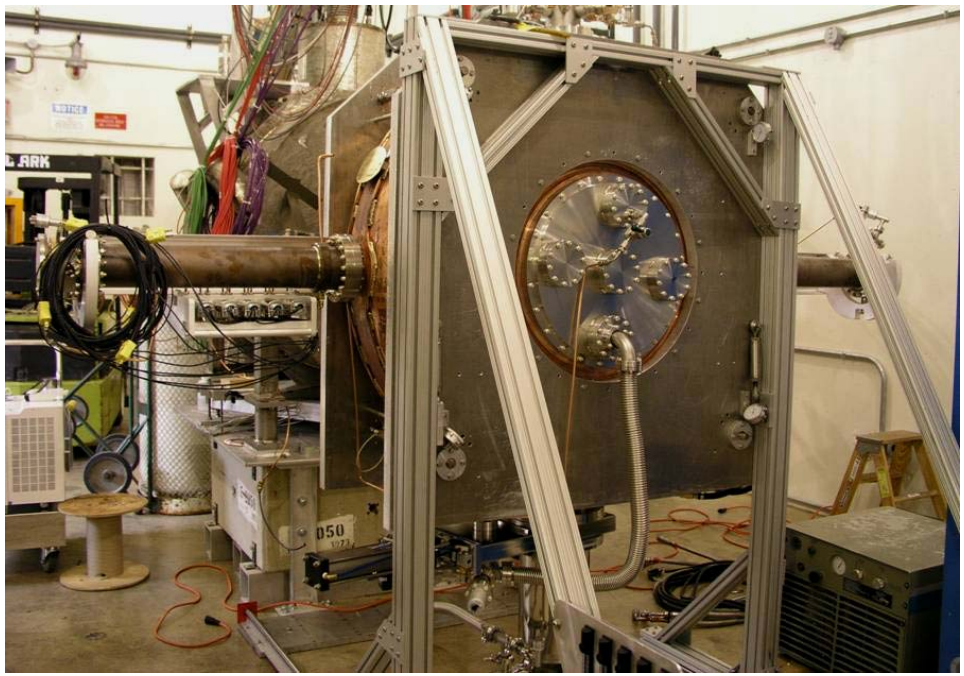
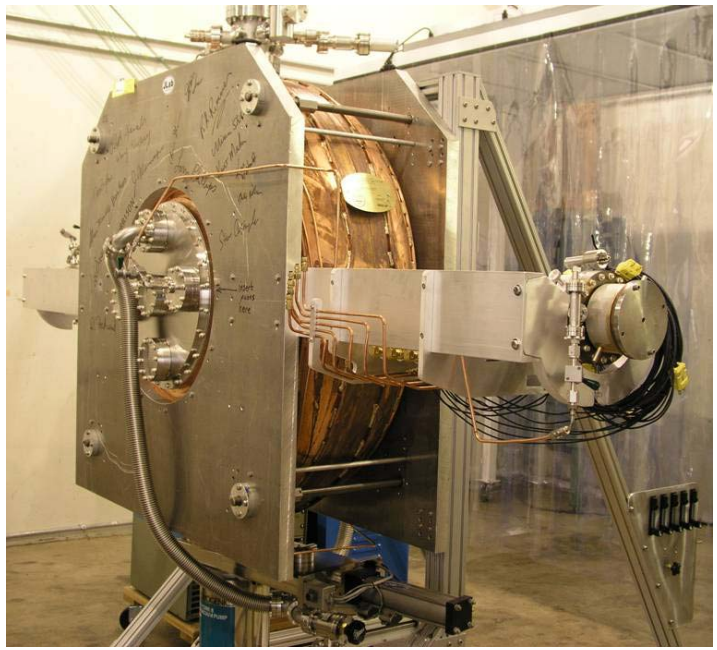
- Cavity assembly was mounted on the support and couplers were installed in a portable clean room
- Dummy copper windows (flat) are used initially
- Couplers were set and frequency was measured
- Bakeout system hardware was installed
- System is leak tight





Low Power Measurements

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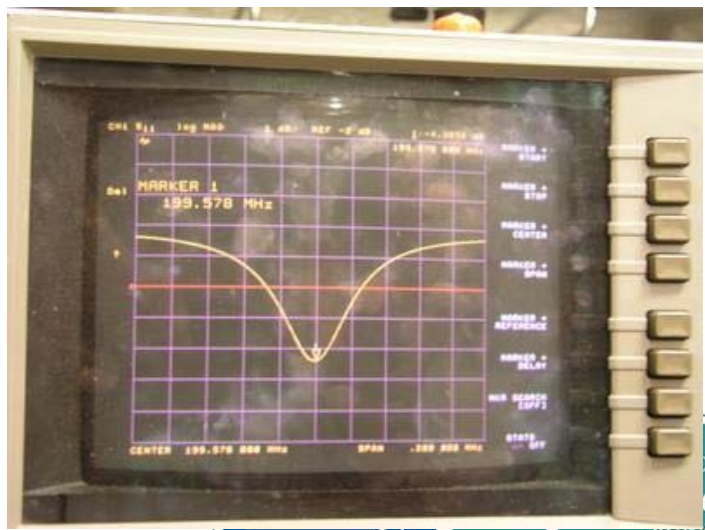
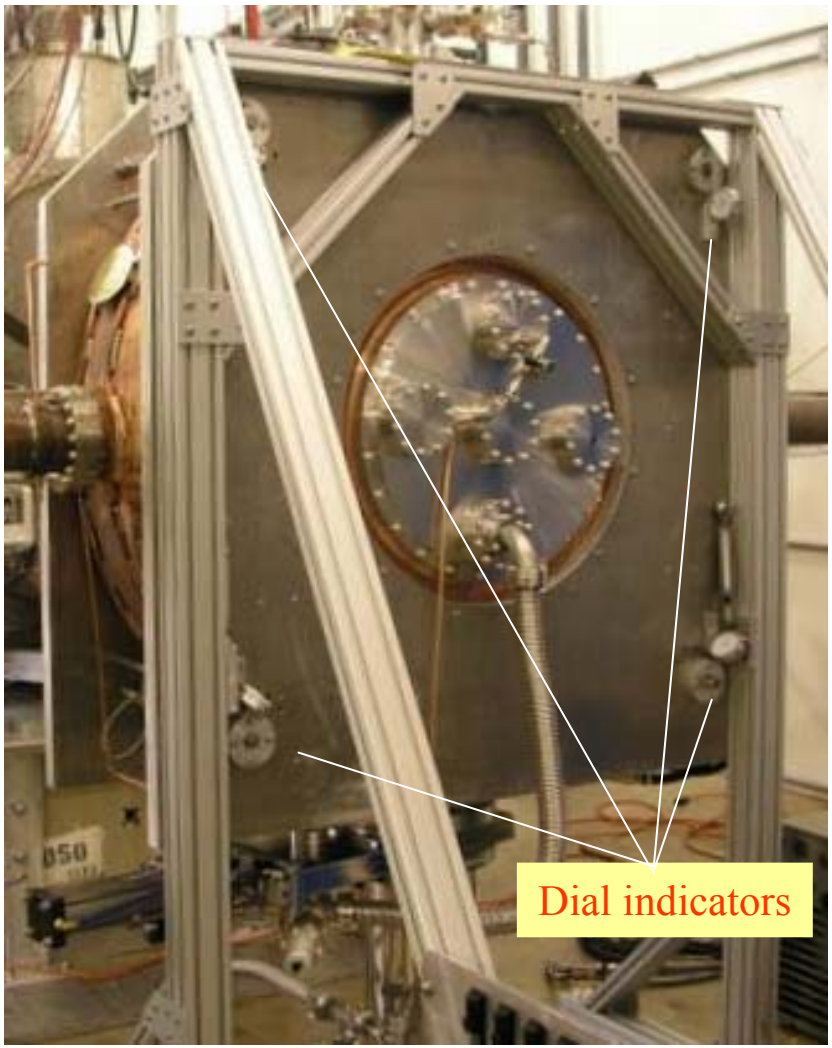
f = 199.578 MHz

Q_0 = 49,000 ~ 51,000 (better than 90% of the design value)

Two couplers
- balanced
- coupling adjustments



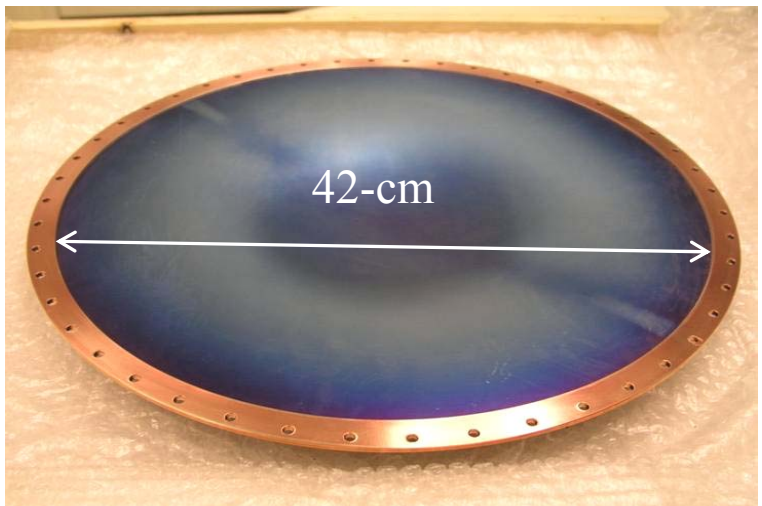
Tuner Measurements

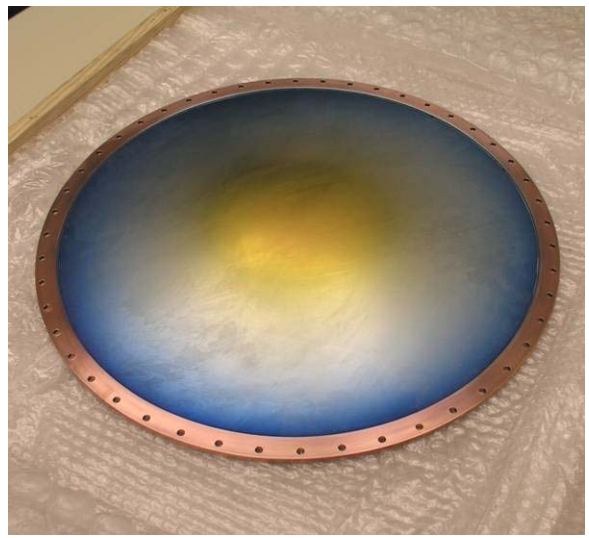


- Mechanical tuning plates at four locations
- Dial indicators to measure displacement between Al plates
- Tuning measurement in air
  - Equivalent to MICE cavity under vacuum
- Adjusted up to 2-mm with 8 steps of 0.25-mm each
- Measured tuner sensitivity
  - ~ 78 kHz/mm
- Calculated tuner sensitivity
  - 115 kHz/mm
  - Disagreements are due to deflection of the Al plates

Curved Be Windows

- **Two windows available (LBNL)**
  - 21-cm and 0.38-mm thick
  - "Good" braze (between annular frames and foil)
  - Achieved ~ 95 % of the designed profile
  - Thin Ti-N coatings
- **Ready for HP tests**





Asymmetric RF Heating (cont'd)

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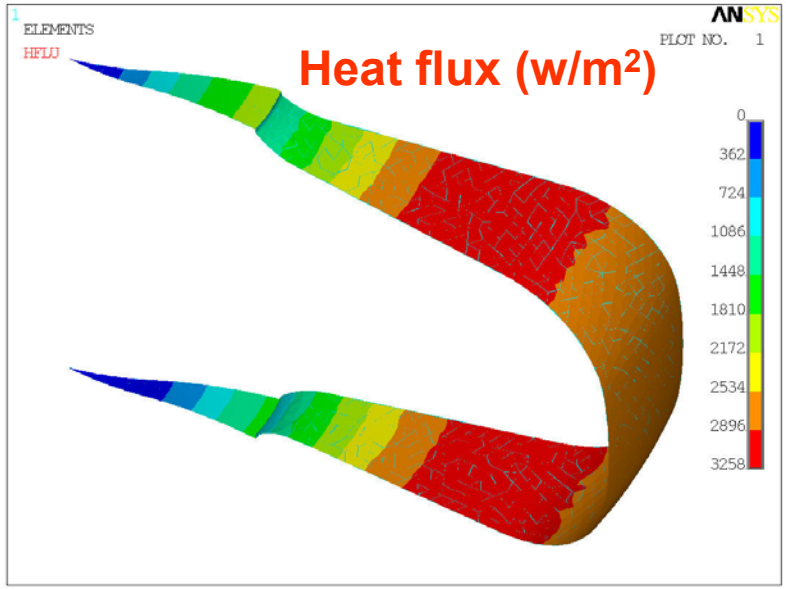
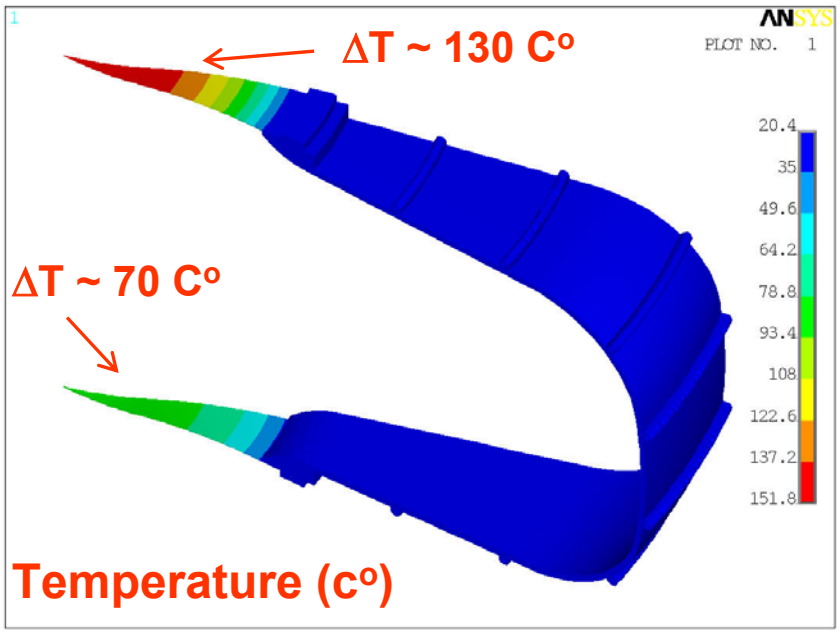
- **ANSYS simulations**
  - A 15° slice cavity model
  - Solve for RF fields
  - 8.4 kW average heating power
  - 20 C° water cooling
  - Heat flux and temperature distribution
  - Stress and displacement
  - Frequency shifts





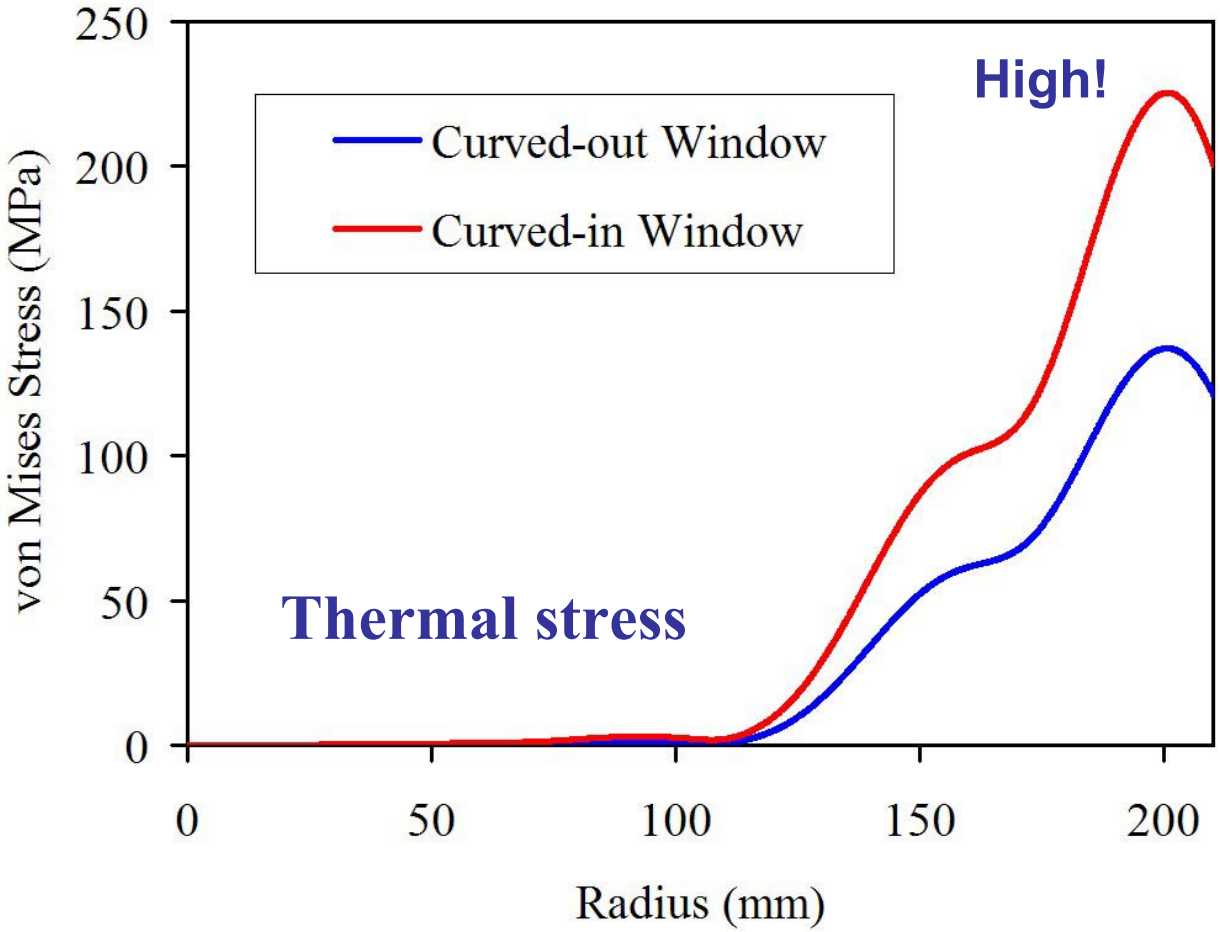
Frequency shift: 94 kHz (RT to FP)

- Cavity body expansion (small)
- Window displacement (major)

Tuner

- Tuning sensitivity 230 kHz/mm
- ± 500 kHz range

Asymmetric RF Heating (cont'd)



Elastic stress limit of beryllium is 310 MPa

Preliminary Test: Setup at MTA

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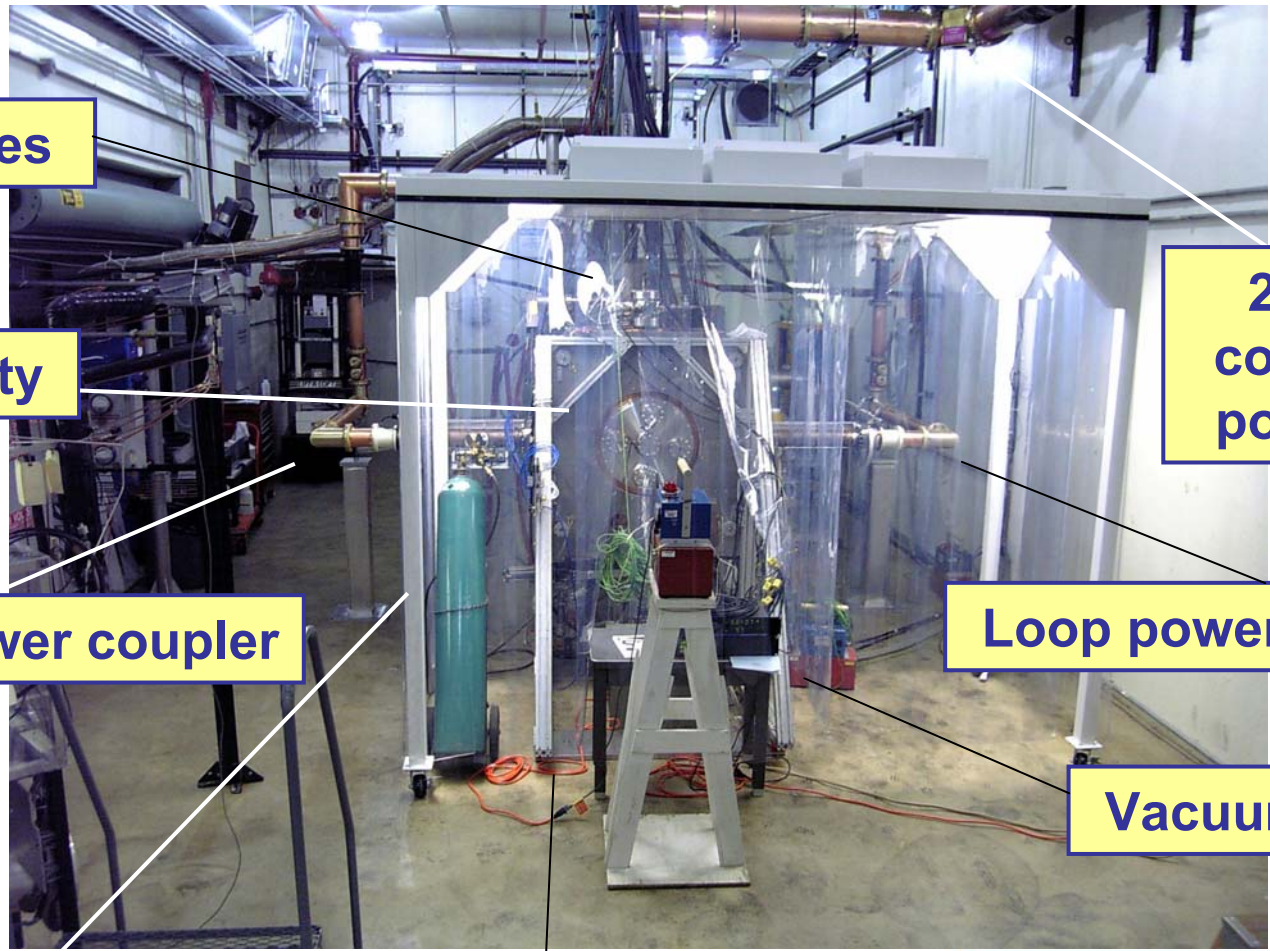

RF probes

The cavity

Loop power coupler

201 MHz coaxial RF power line

Loop power coupler

Vacuum pump

Portable clean room

Movable cavity support

Cavity Design Parameters

- **The cavity design parameters**
  - Frequency: 201.25 MHz
  - $\beta = 0.87$
  - Shunt impedance (VT^2/P): ~ 22 MΩ/m
  - Quality factor (Q_0): ~ 53,500
  - Be window radius and thickness: 21-cm and 0.38-mm
- **Nominal parameters for cooling channels in a muon collider or a neutrino factory**
  - ~ 16 MV/m peak accelerating field
  - Peak input RF power ~ **4.6 MW** per cavity (85% of Q_0, 3τ filling)
  - Average power dissipation per cavity ~ **8.4 kW**
  - Average power dissipation per Be window

    ~ 100 watts

Preliminary Test

- **Conditioning started late Feb. 2006 with**
  - Flat copper windows (plates) with Ti-N coatings
  - RF diagnostics
  - Good vacuum ~ high 10^{-9} Torr
- **Without external magnetic field, the cavity conditioned very quietly and quickly to reach**

  ~ 16 MV/m
- **Limited by RF power of 4.2 MW, could not go higher**

Summary

- The cavity reached design gradient of 16 MV/m very quickly, due to
  - Careful handling of the cavity
  - Good surface finish
  - EP and high pressure water rinsing
  - Little multipacting
- Test plan being developed
  - With external magnetic fields, achievable gradients versus the magnetic fields
  - Curved Be windows