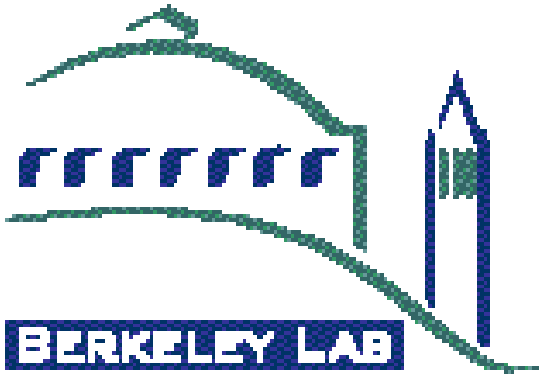




# MUCOOL RF R&D Activities

John Corlett

Accelerator and Fusion Research Division

LBNL

# Cooling RF R&D - Staff

*Berkeley*

John Corlett

Mike Green

Neal Hartman

Subal Kar

Mike Leung

Derun Li

Bob MacGill

*Fermilab*

Norbert Holtkamp

Tom Jurgens

Al Moretti

Zubao Qian

Vincent Wu

*IIT*

Ed Black

*Mississippi*

Don Summer

Mike Booke

# Cooling RF R&D - Issues

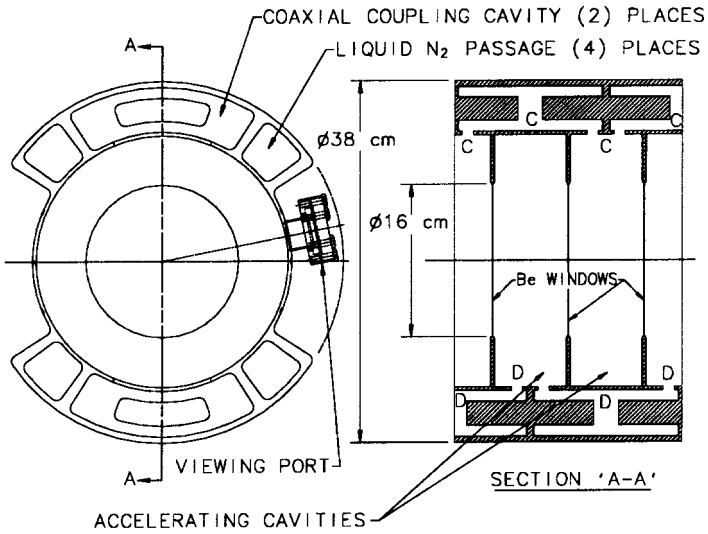
- High accelerating field (≈ 15 - 30 $MVm^{-1}$)
- Large beam pipe apertures (≈ 38 - 16 cm diameter)
- Strong magnetic field (≈ 5 T)
  - Maximize shunt impedance - minimize power requirements
    - Novel accelerating structures
      - Closed-cells
        - » Windows or grids of tubes
- *breakdown, multipacting, heating, dark current, ...*

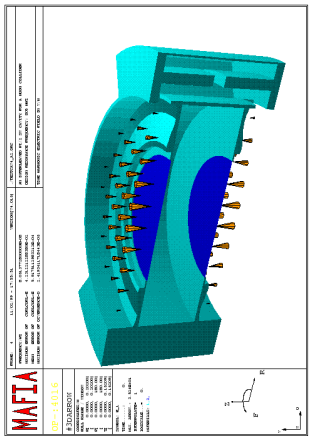
# Cooling RF R&D

- 805 MHz
  - Collider parameters
  - "End" of cooling section
- Hardware
  - $\pi/2$ interleaved cavity
    - Be windows
    - Low-power test cavity
      - $LN_2$ temperature
    - High-power test cavity
  - $\pi$-mode open cell cavity
    - Cold-test cavity
    - High-power test cavity
  - Superconducting solenoid
  - Lab G development

- 201.25 MHz RF cavity
  - Neutrino factory parameters
  - "Beginning" of cooling section
- Paper studies
  - $\pi/2$ interleaved cavity
    - Be windows
    - Thin-walled tubes
  - Integration into cooling channel

# 805 MHz π/2 pillbox with Be windows

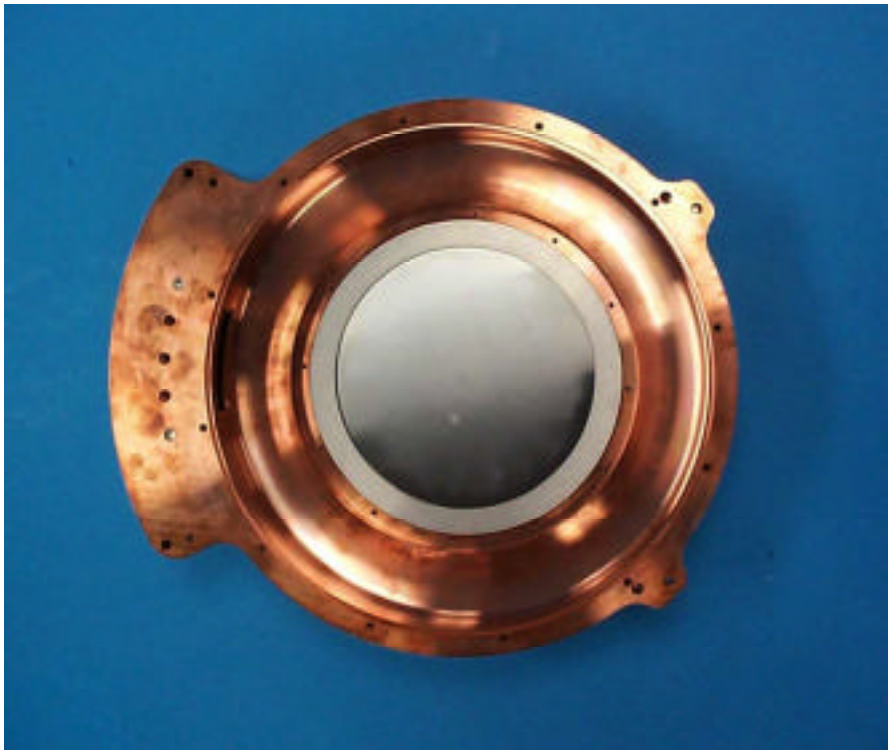


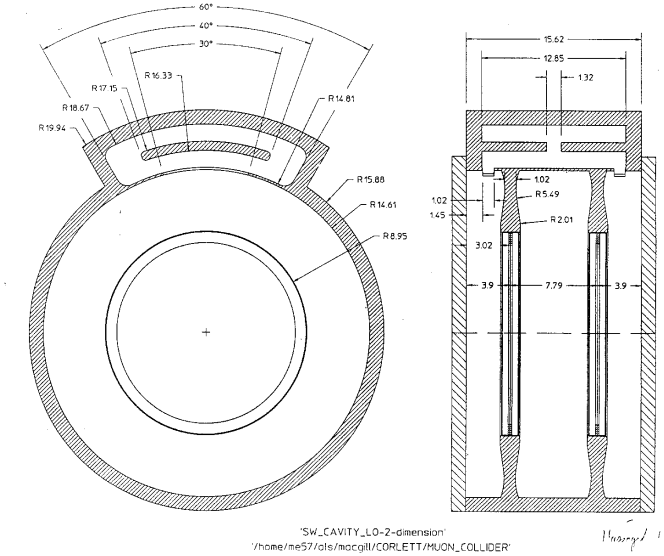




- Per-cell dissipated power 250 W
- Be window dissipated power 43 W
  - $E_o$ = 30 $MVm^{-1}$
  - 3τ filling
  - 15 Hz
  - Q = 21,000
    - » ≈ *kHz cell-to-cell stability*
  - $Z_o$ = 54 $M\Omega m^{-1}$
  - $ZT^2$ = 44 $M\Omega m^{-1}$

# Low-power test cavity

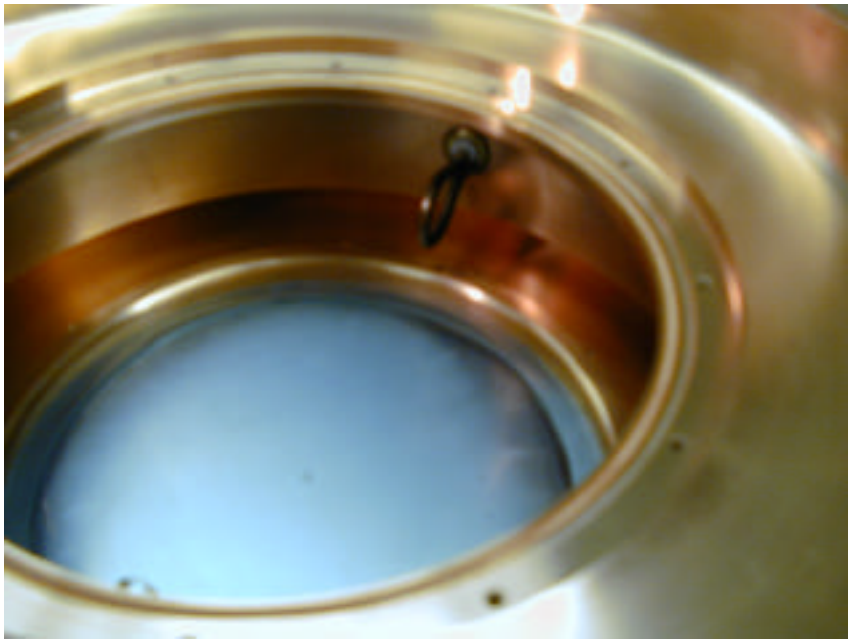
- Test Be windows
  - Mechanical stability
    - » ≈ *μm stability*
    - RF heating
    - Halogen lamp heating
    - Low temperature
      - » Gain factor 2 in $ZT^2$

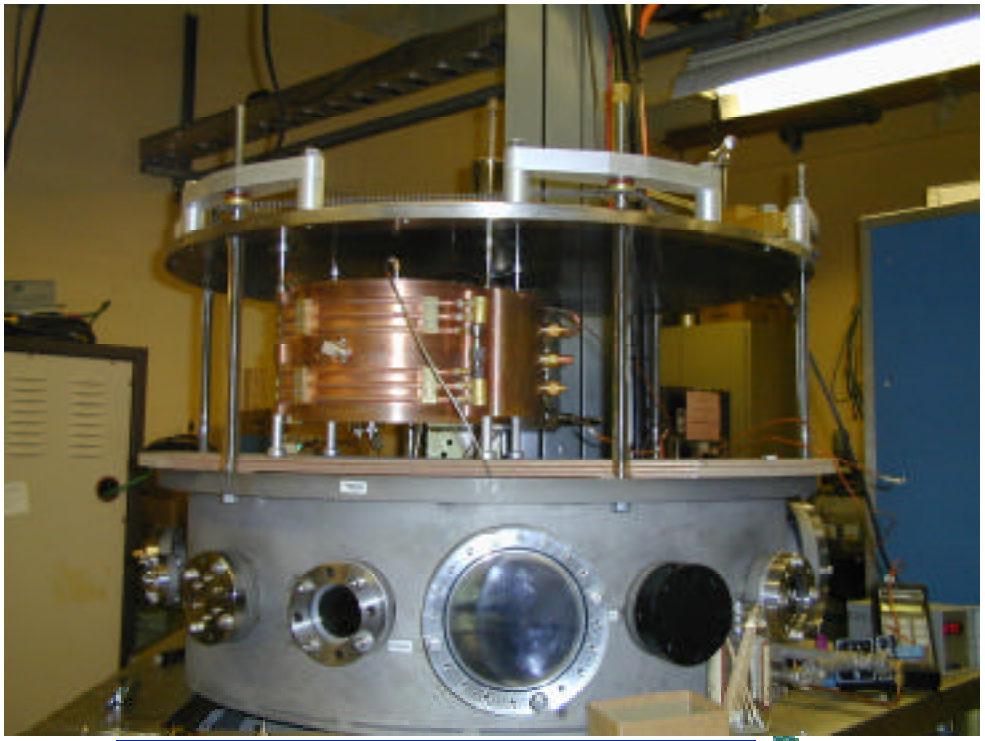




# Low-power Test Cavity Measurements

- Low-temperature tests in vacuum
  - ≈ 500 W RF input
  - Halogen lamp heating
  - $LN_2$ cooling





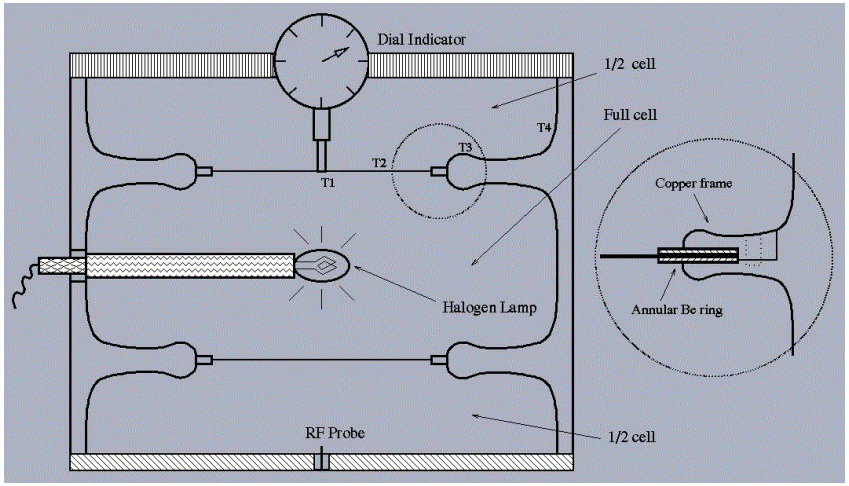
# RF windows for 805 MHz cavities

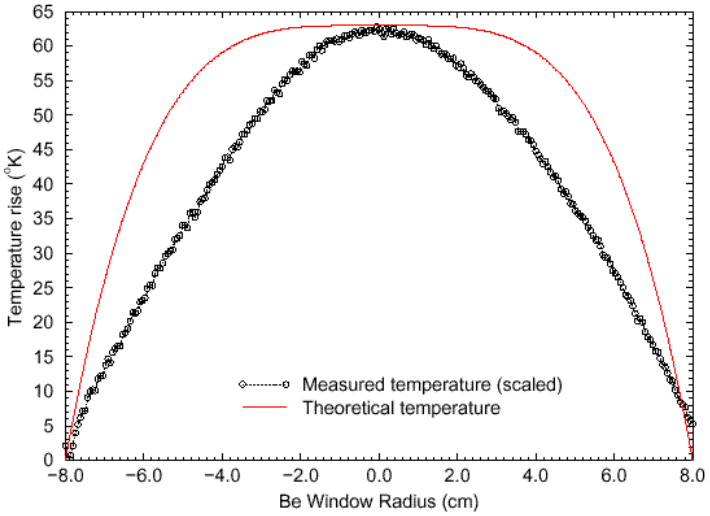
- Be foils 0.005” thick
- 99.8% Be
- Foil diffusion bonded to Be frame
  - 0.063” thick rings
  - 6.3” internal diameter
  - 7.58” outside diameter
- Foil flatness 0.001”
- Pre-stressed
  - Different CTE alloys foil/frame

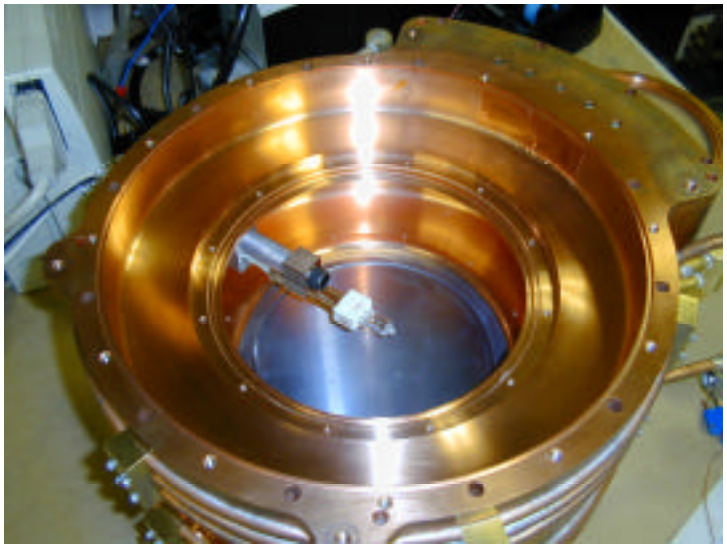
- Windows purchased for tests
  - *Not “designed” in detail*

# Window Measurements
# Halogen Lamp Heating

- Al and Be foils
  - Al not stressed
  - Heat with halogen lamp
    - Temperature profile broadly similar to RF heating

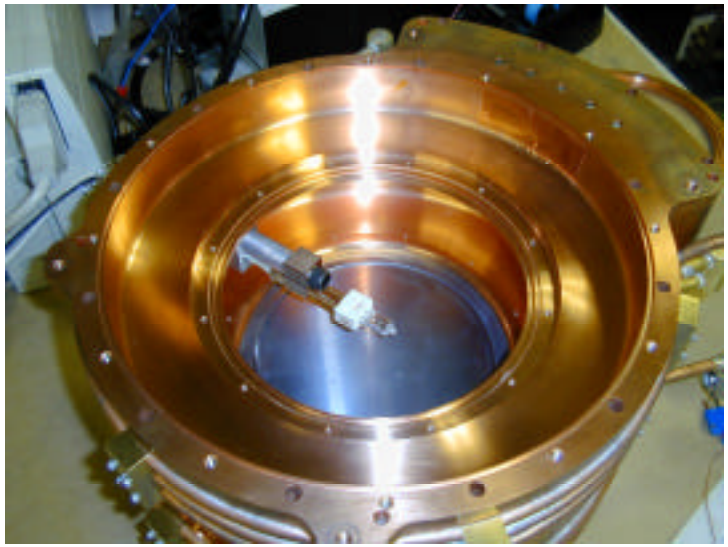


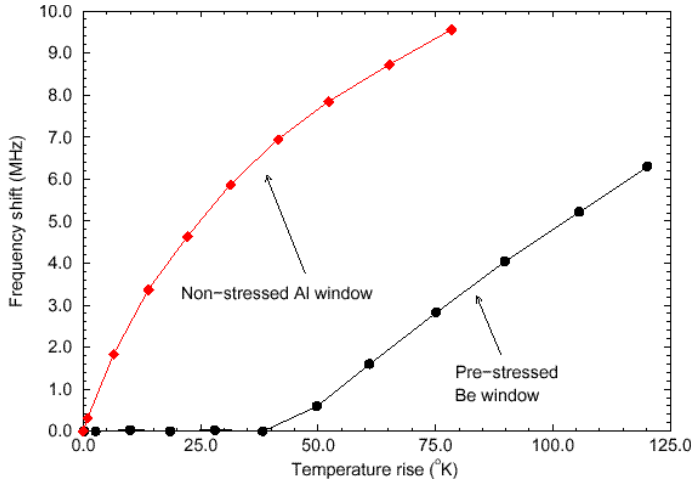



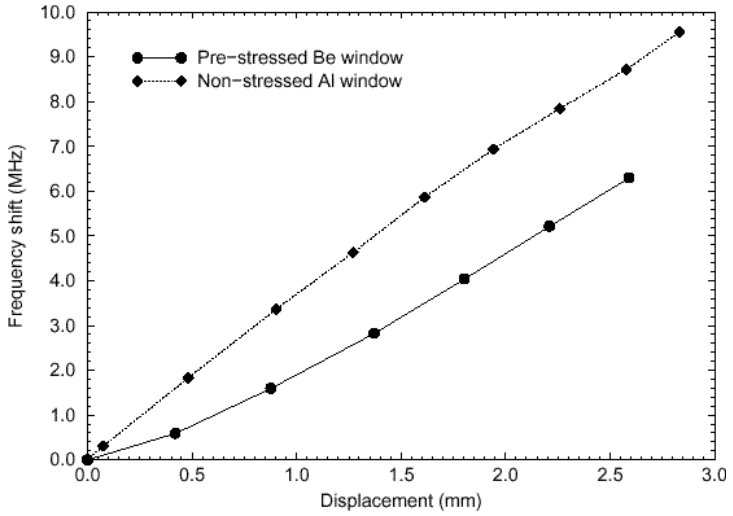



# Halogen Lamp Heating Room Temperature

- Al and Be foils
- Halogen lamp heating

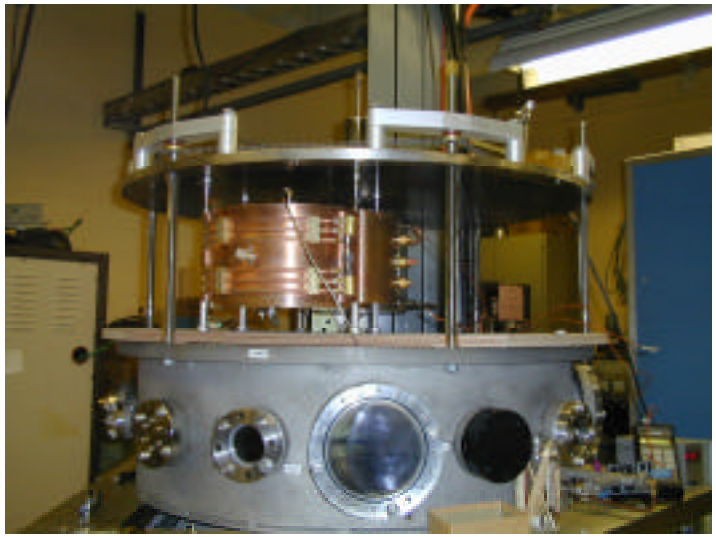


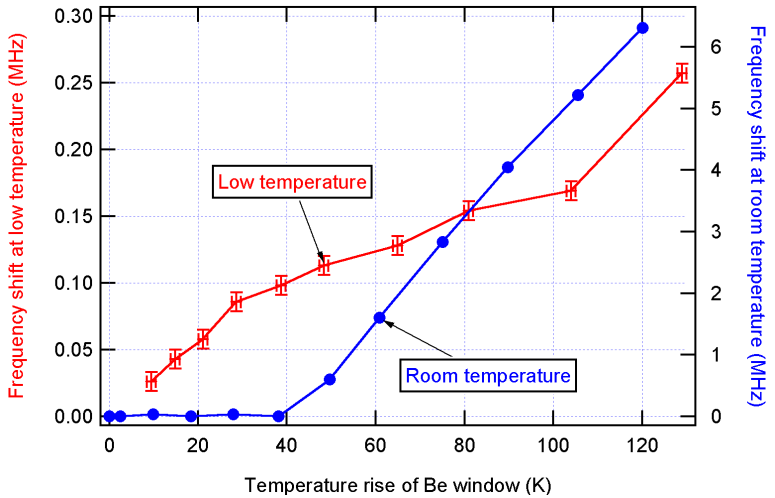


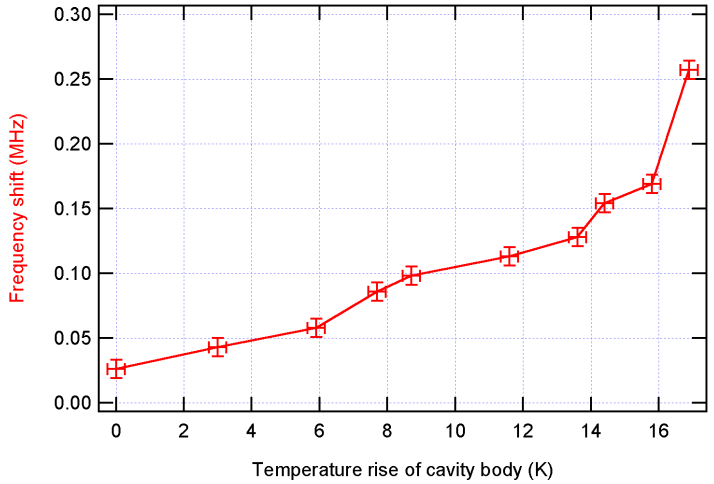



# Halogen Lamp Heating Low Temperature

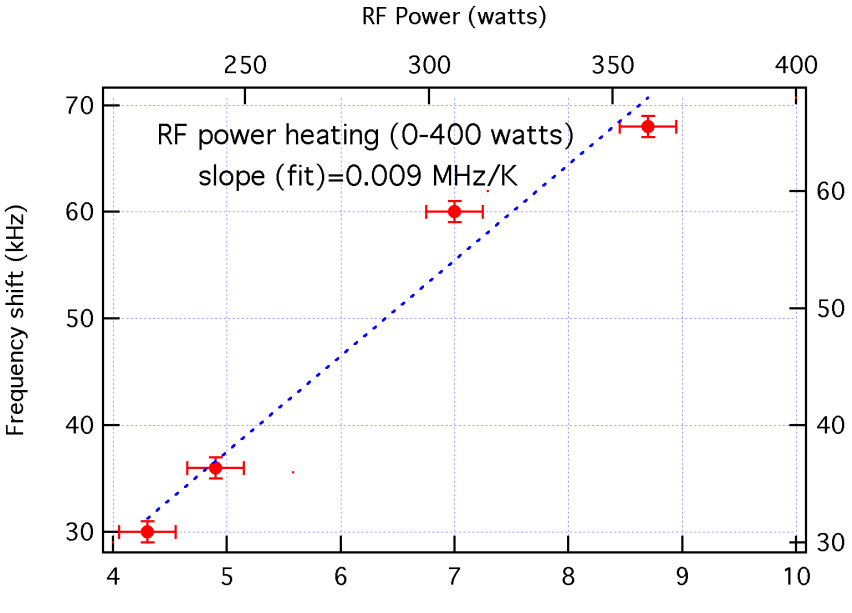
- Cool cavity with $LN_2$
- Heating with halogen lamp
  - Window does not move
    - $\Delta f$ due to cavity body $\Delta T$

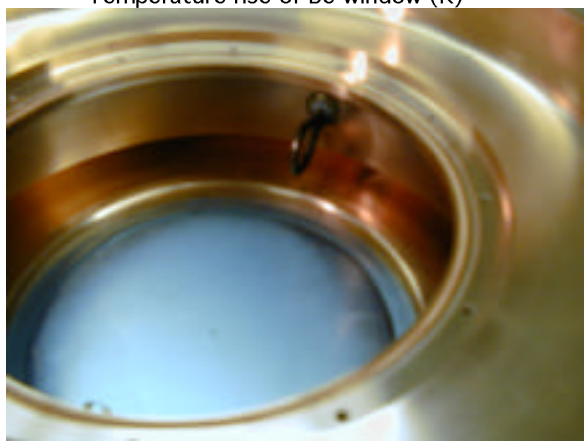


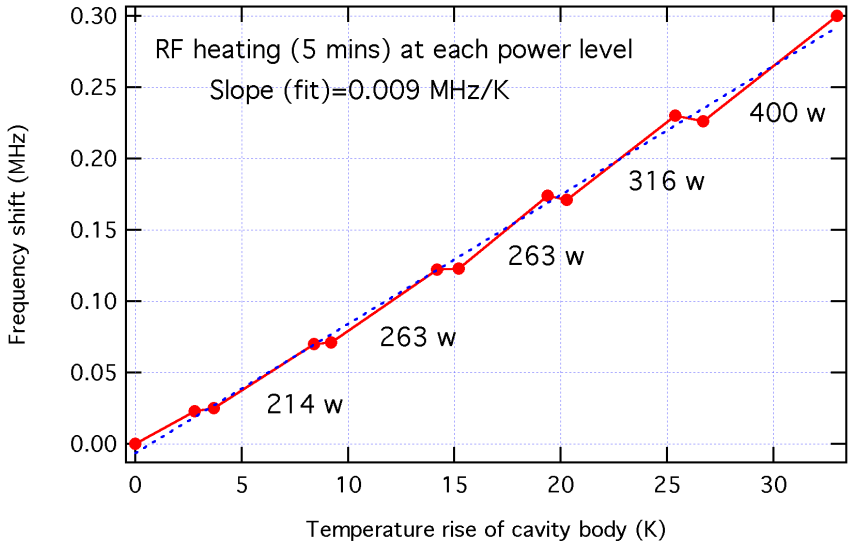


# RF Heating
# Low Temperature



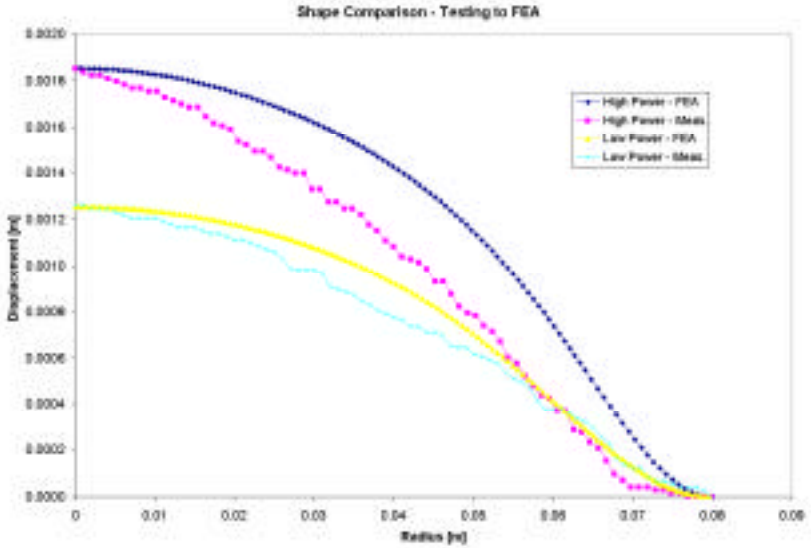



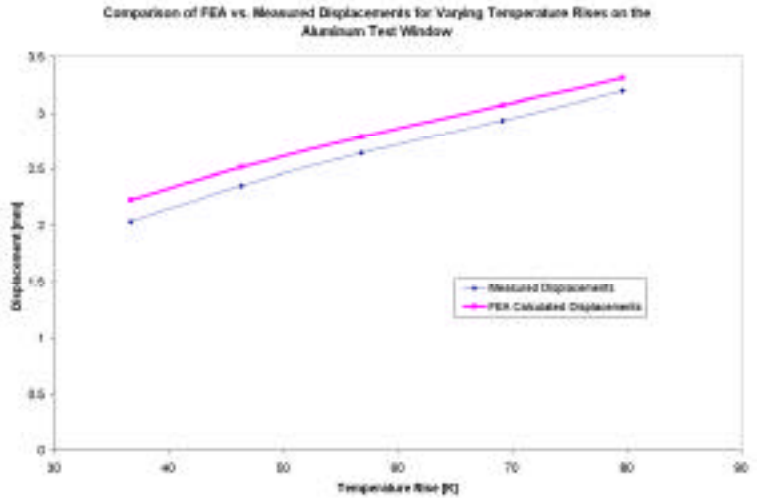



- Heating with RF
  - $Q_l \approx 4000$
    - Bolt-together cavity
  - RF on for ≈ 5 min cycles
  - Window does not move
    - Δf due to cavity body ΔT
      - » "Null" measurement

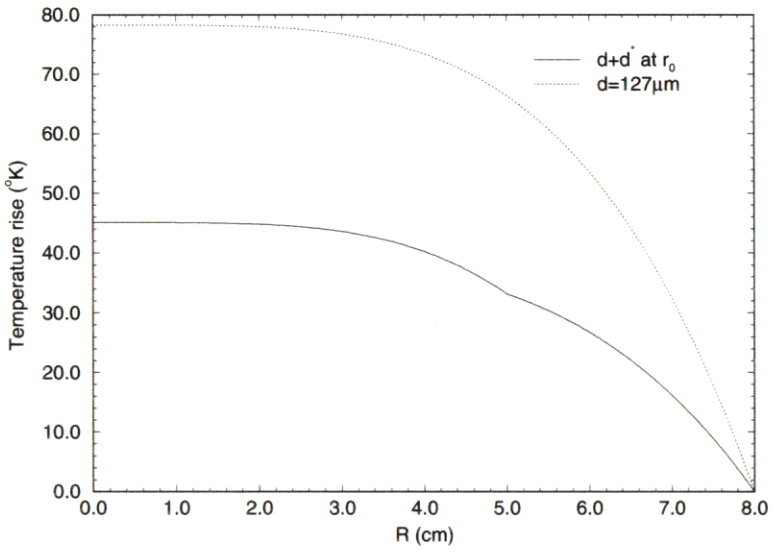
# Be Window FEA

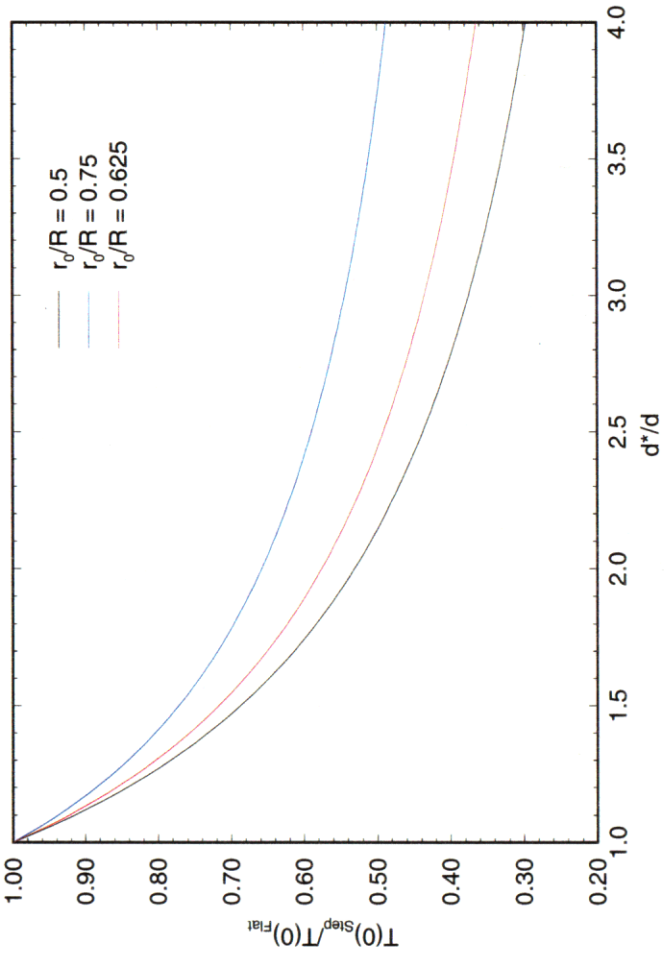
- ANSYS model of Be and Al foil windows
- Include pre-stress of Be foil
  - Difficult to model accurately
- Room temperature foil distortion arises from temperature gradient in foil
  - Need increased conductivity
    - thicker foils
    - low temperature
  - Increase pre-stress?



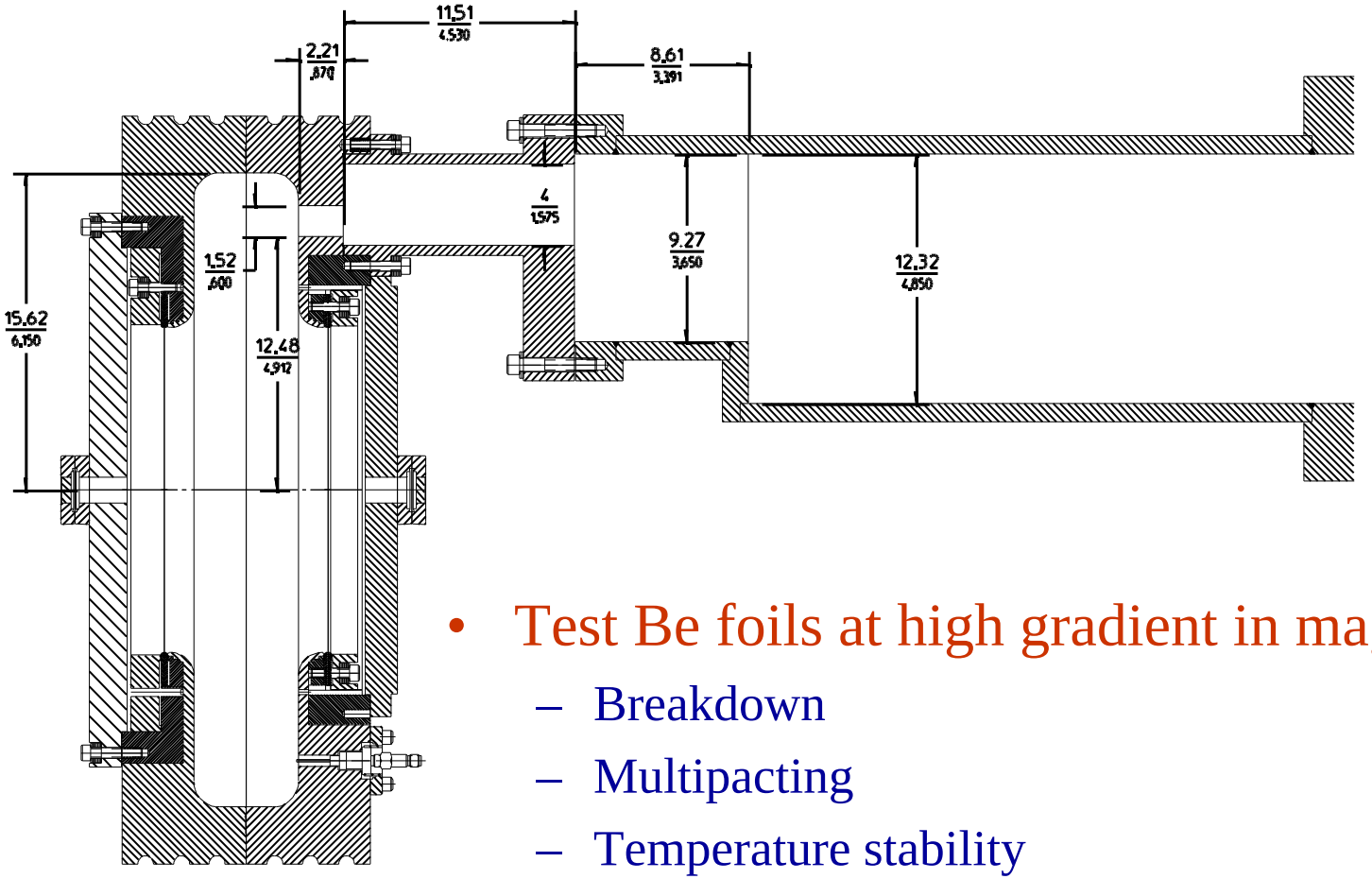



# Increased Be Window Thickness



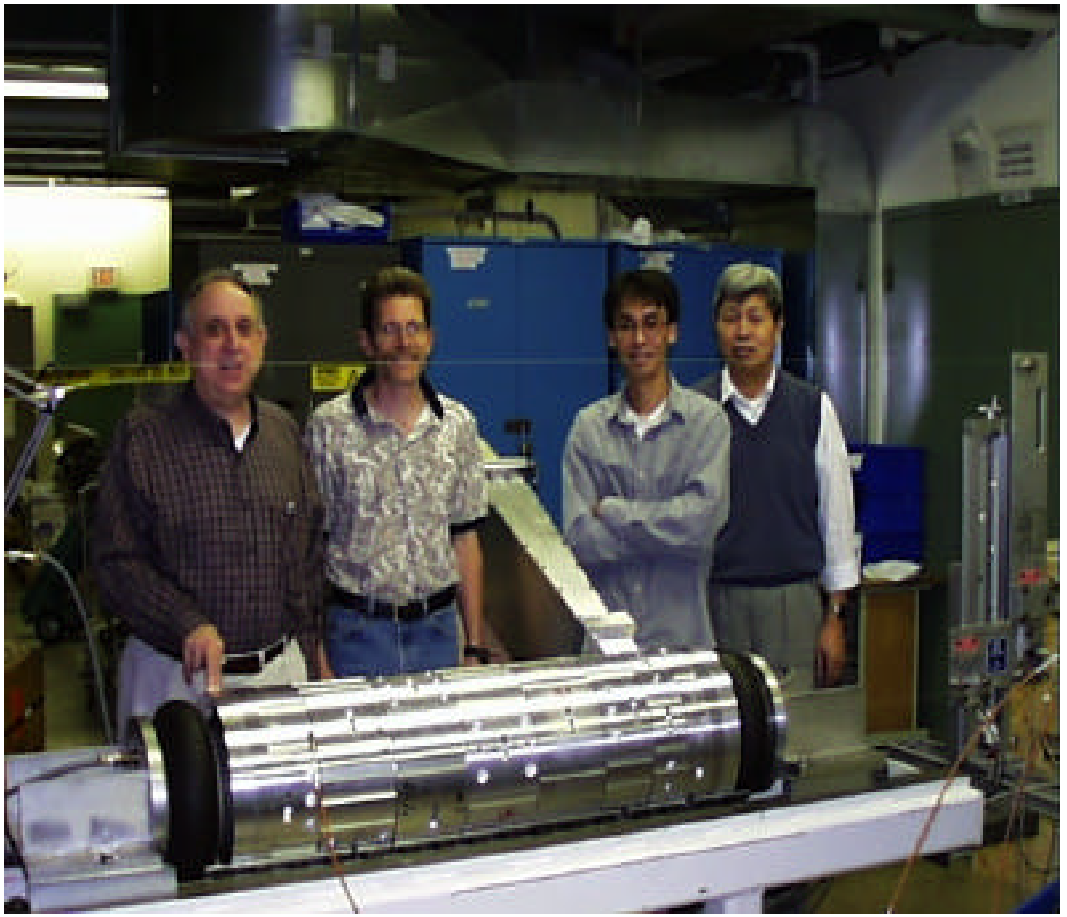
# High-power Pillbox Cavity




- Test Be foils at high gradient in magnetic field
  - Breakdown
  - Multipacting
  - Temperature stability
    - Test in Lab G facility

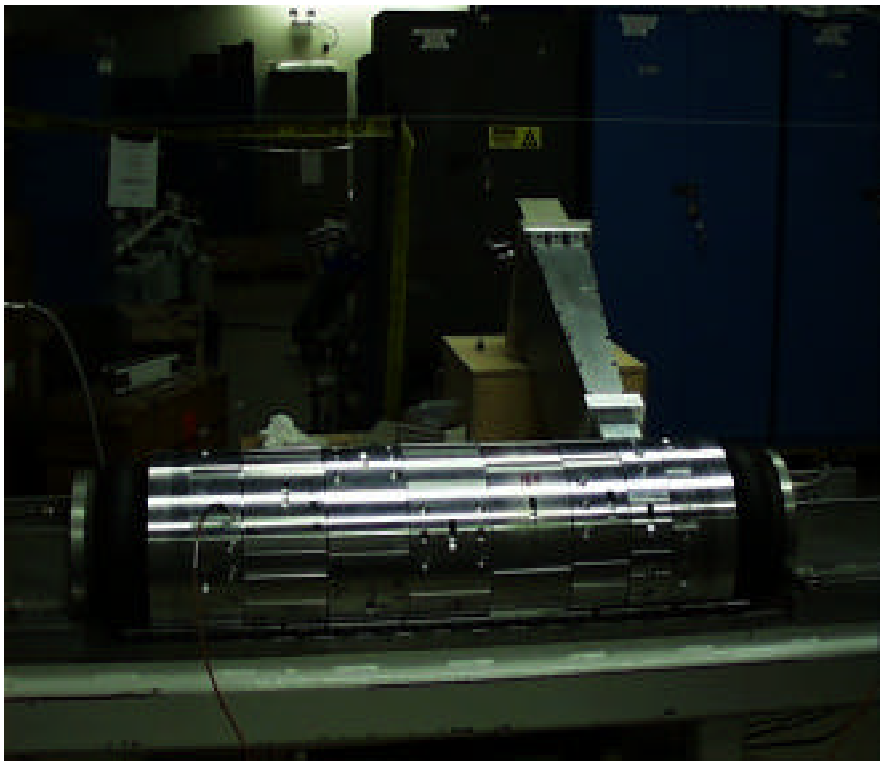
Muon Collaboration

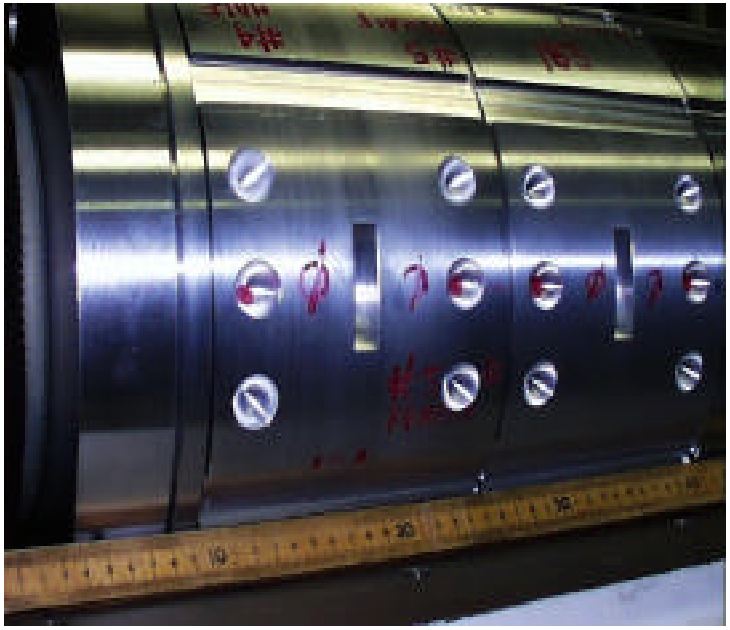
# 805 MHz 6-cell π-mode Cavity



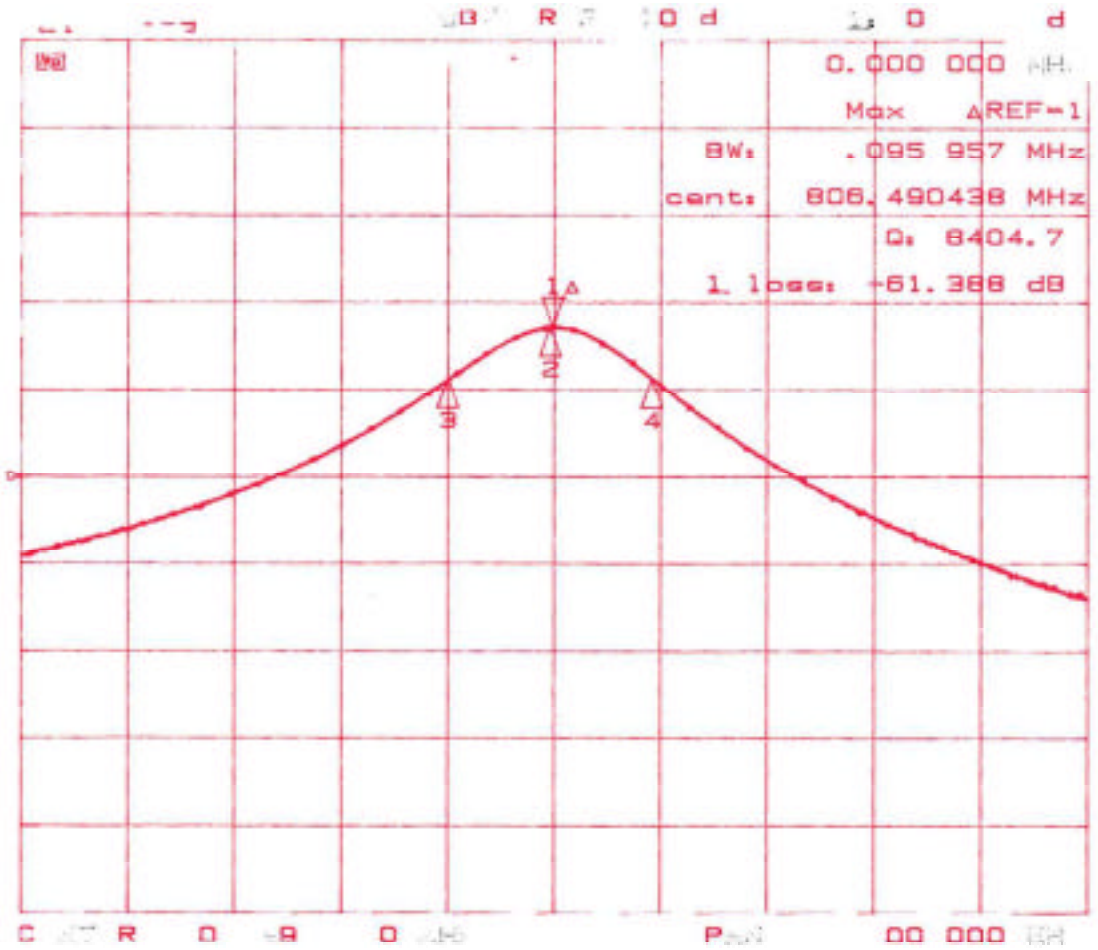
# 805 MHz 6-cell π-mode Cavity

- Al prototype tests
  - Determine final dimensions for Cu cavity
- Cu cavity machining has begun
  - 12 tuning points per cell

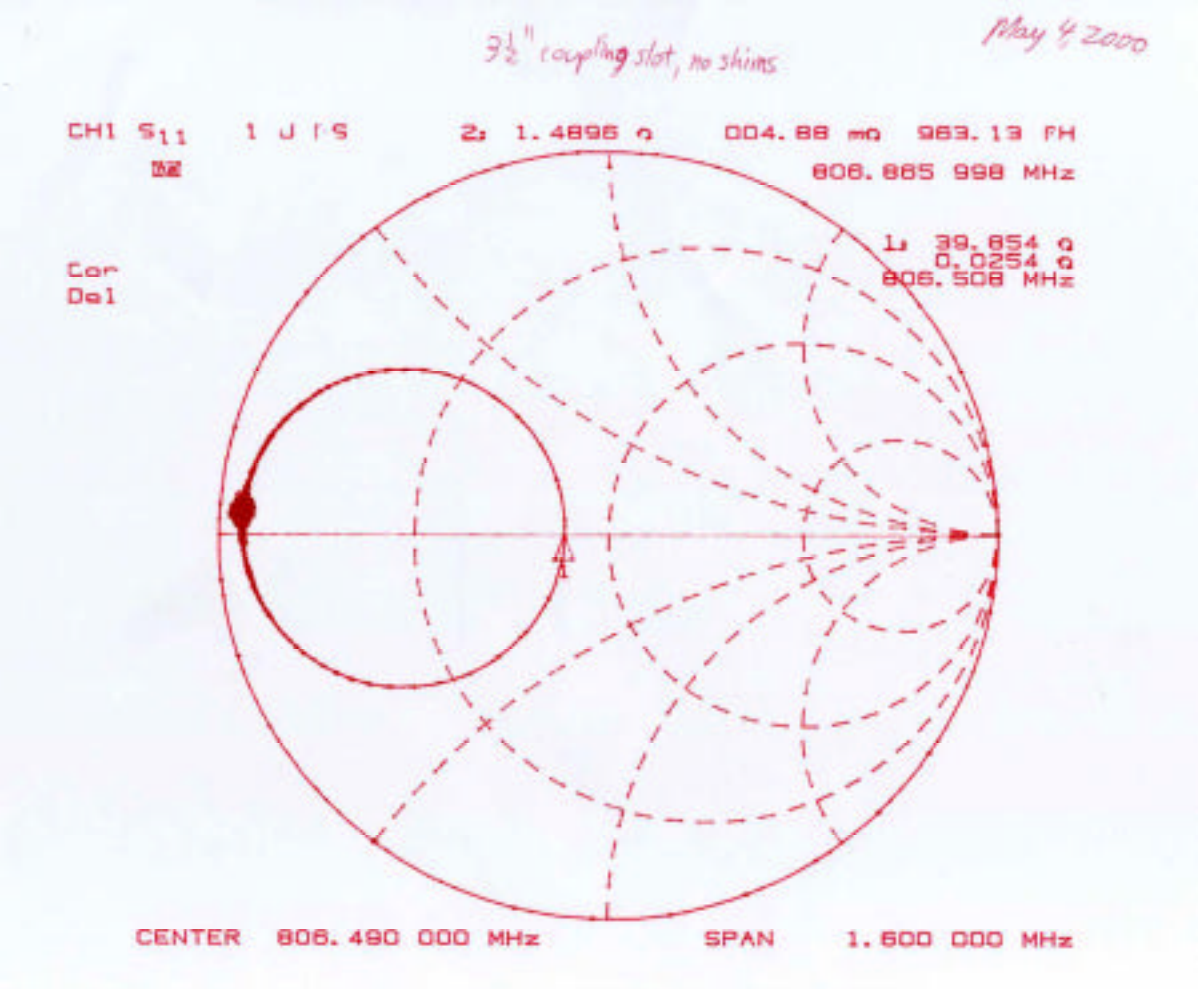




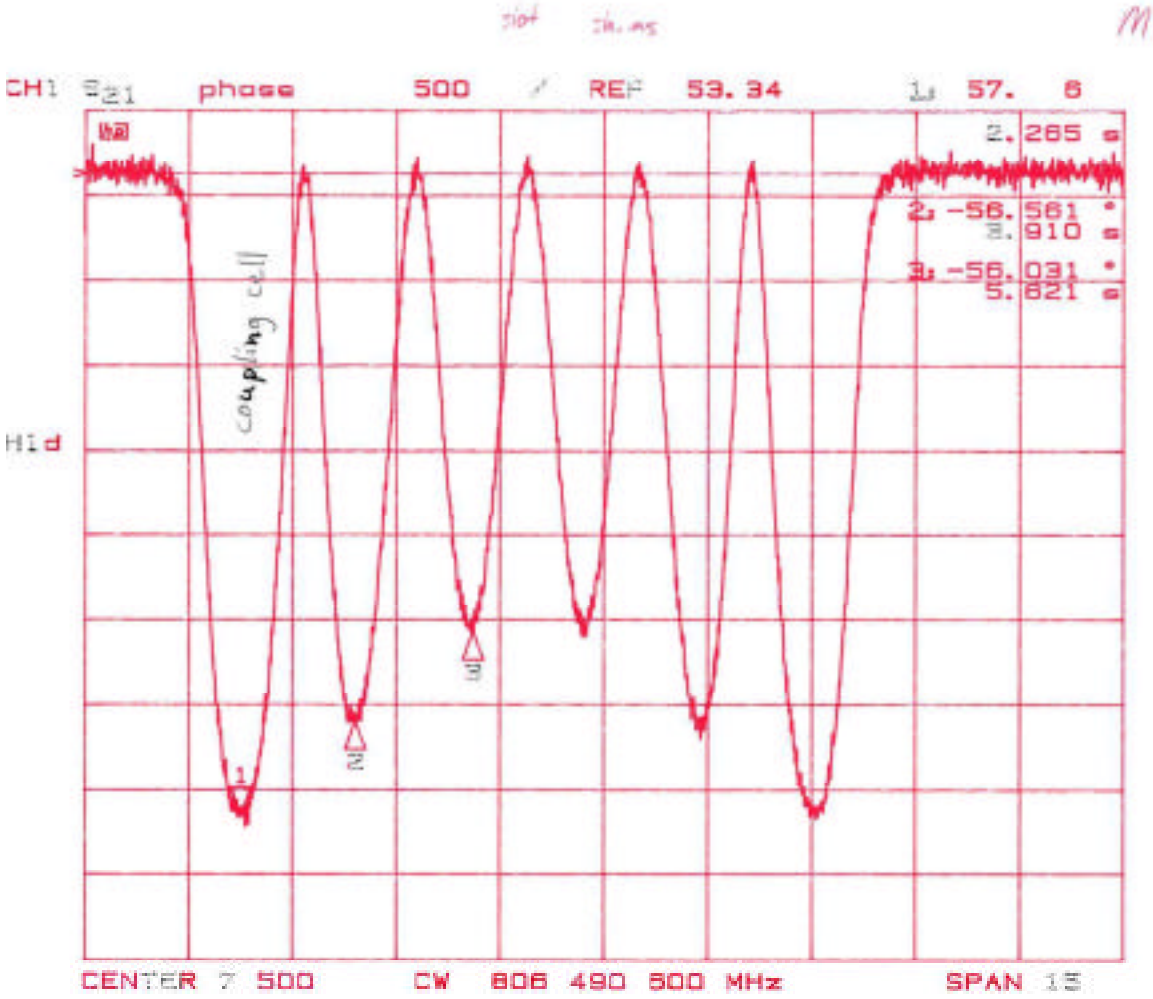
# Π-Mode Frequency and Q Measurement



# Π-Mode
# Input Impedance Measurement

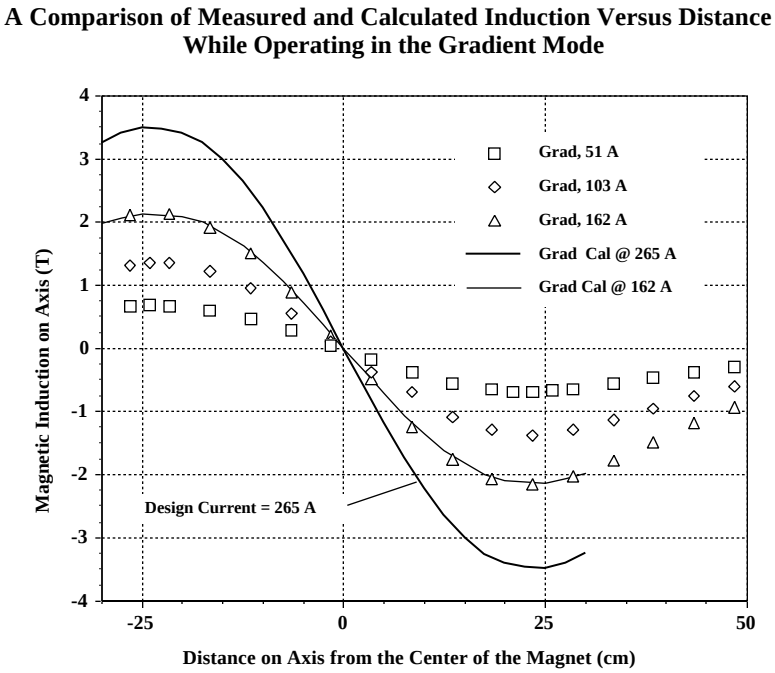


# Π-Mode Field Measurement



# Superconducting Magnet

- Magnet produces up to 5T field on axis
  - Solenoid or bucking mode
  - models fields in solenoid channel



# Superconducting magnet

# Status of Lab G

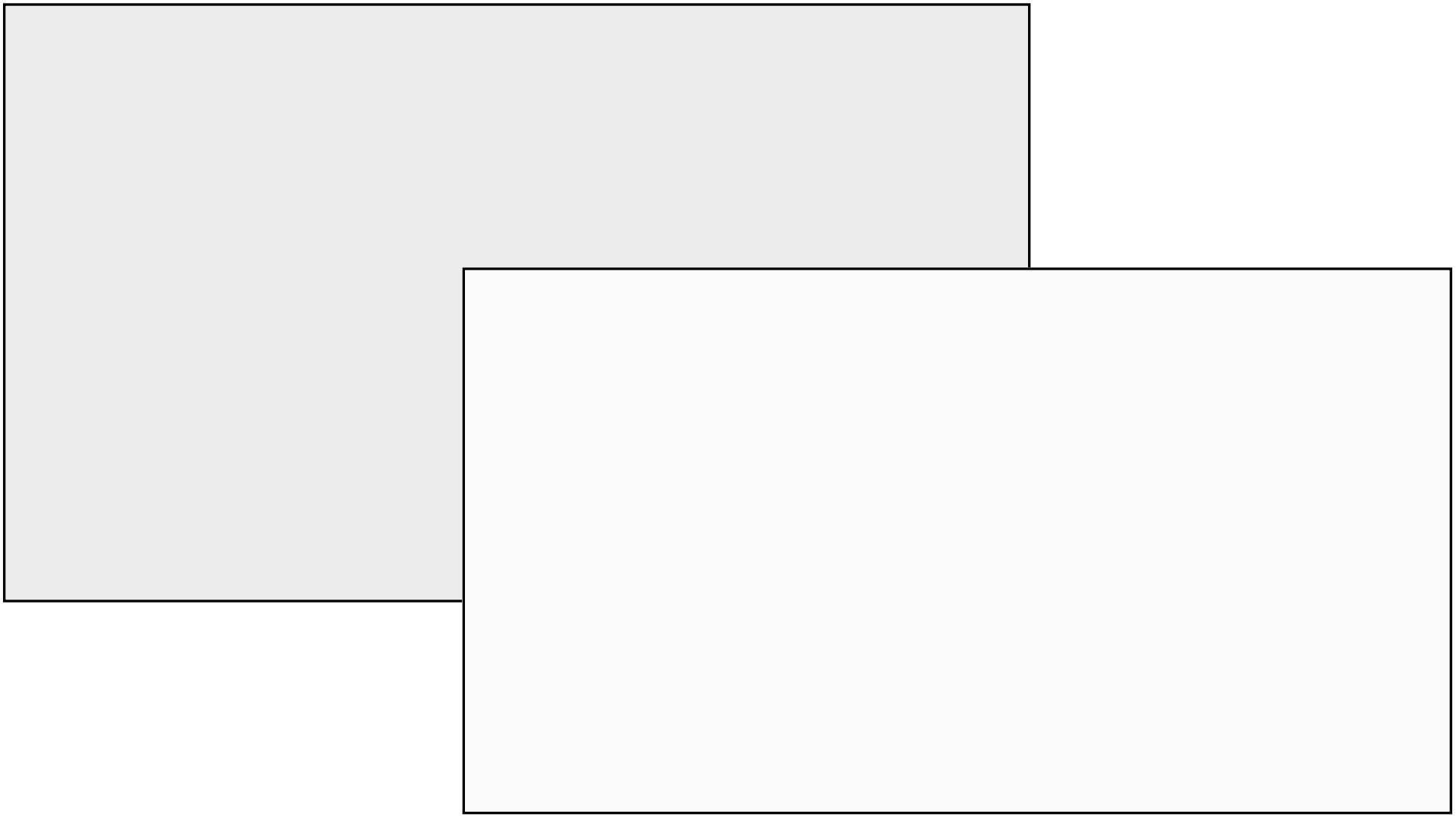
- Modulator and klystron in place
- Water system installed up to cave
- Interlocks being assembled

- Superconducting magnet to be installed
- Shielding roof to be completed
- RF power waveguide to be installed

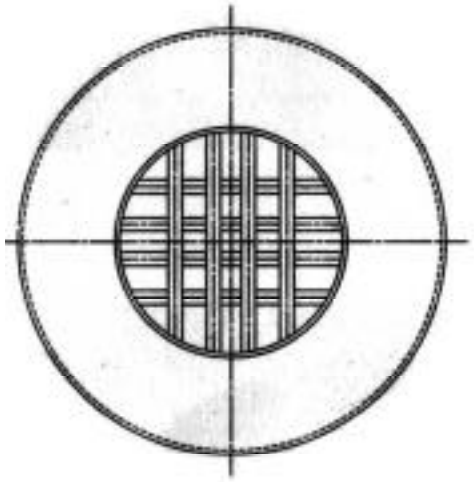
# Crossed Tube and Pillbox Cavities

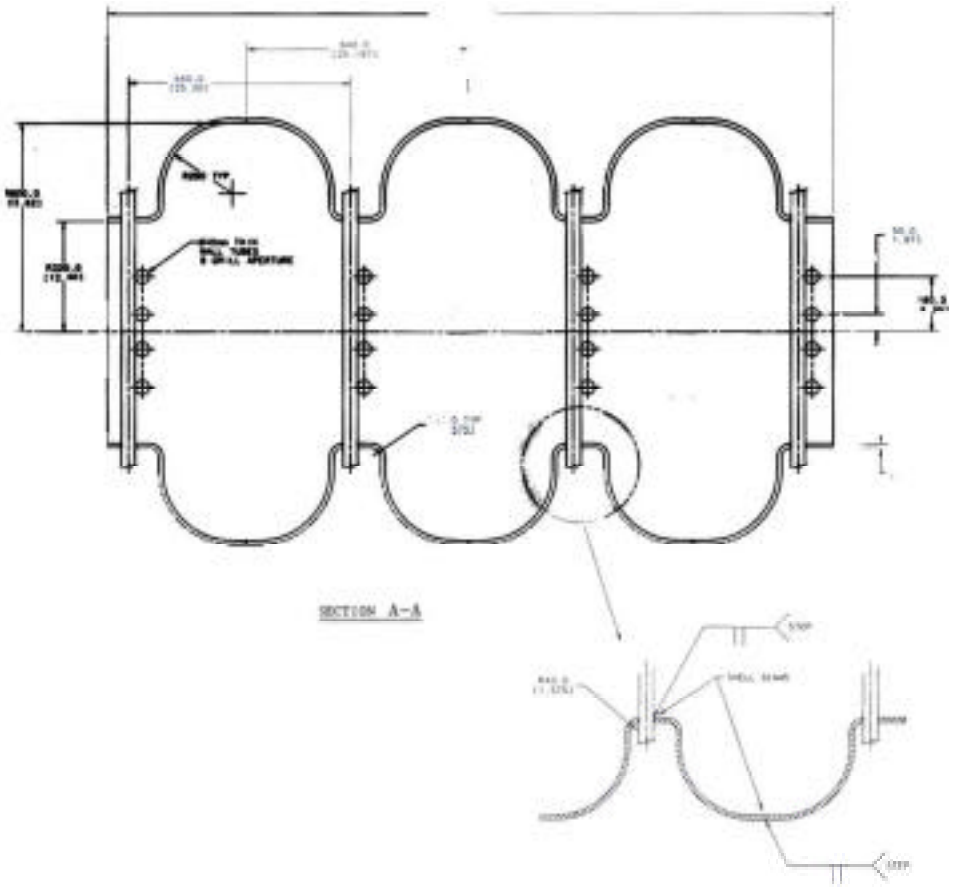
| Parameter | Crossed Tube | Pill Box |
|---|---|---|
| Frequency | 201.25 MHz | 201.25 MHz |
| Accelerating Phase Angle | Sin(25 degrees) | |
| Peak Accelerating Field | 15.0 MV/m | 15 MV/m |
| Peak Surface Field | 22.5 MV/m | 15 MV/m |
| Kilpatrick Limit | 14.8 MV/m | 14.8 MV/m |
| Cavity Type | Open Cell with crossed tubes over aperture | Beryllium foil windows over 15 cm radius apertures |
| Cavity Dimensions | internal r is 0.600 m internal cell length, $\lambda\beta/3$, is 0.432 m. | internal radius is 0.600 m, internal cell length, $\lambda\beta/3$, is 0.432 m. length of accelerating section is 0.864 m. |
| Impedance | 28.4 MΩ/m | 34.1 MΩ/m |
| Shunt Impedance | 20.3 MΩ/m | 23.3 |
| Transit Time Factor T | 0.845 | 0.827 |
| Peak Voltage per Cell | 6.5 MV | 5.7 MV |
| Q | 47,500 | 52,600 |
| Fill Time | 38 μs, critically coupled | 42 μs |
| rf Pulse | 114 μs | 125 μs |
| Peak Power per Cell | 3.45 MW | 2.8 MW |
| Average Power per Cell | 8.0 kW | 5.3 kW |
| Window Type | 4 cm diameter Al crossed tubes | 15 cm radius, 127 μm thick Be foil |
| Average Power on Tubes | 30 W (worst tube) | 53 W (heated from both sides) |

# 201.25 MHz RF Layouts



# 201 MHz Gridded (Crossed-tube) Cavity





- Large apertures accommodated
- Air cooling inside tubes
- Coupling between cavities ~ 0.1%
- Cavities independently excited
- Tube walls can be thin  < 0.1 mm
- Spun construction - 1.27cm (0.5 in) wall thickness
- Tunable by wall displacement

Muon Collaboration

# R&D Plans

BERKELEY LAB

| Item | Description | Completion date | M&S | Labor (m-m) |
|---|---|---|---|---|
| Be window finite element analysis | Develop FEA model of Be foil window, determine engineering feasibility for 805 MHz and 201 MHz size windows. | Jun-00 | $10,000 | 1 |
| Thin-walled tube analysis | Develop engineering model for thin-walled tube structures | Jun-00 | | 1 |
| Low-power open-cell test cavity | Complete measurements of low-power open-cell test cavity | Jun-00 | $1,000 | 1 |
| Install superconducting magnet in Lab G | | Jun-00 | $25,000 | 3 |
| Lab G 805 MHz RF | Complete installation and commissioning of 805 MHz RF system | Jul-00 | $5,000 | 2 |
| Be window model | Design and build test windows based on FEA results | Sep-00 | $30,000 | 2 |
| Thin-walled tube test model | Design and build test tube assemblies | Sep-00 | $30,000 | 2 |
| 805 Mhz open-cell high-power cavity | Design and build a prototype high-power open-cell cavity at 805 MHz to test behaviour in high RF fields. | Sep-00 | $100,000 | 3 |
| 805 MHz high-power pillbox with Be end plates | Design and build a high-power pillbox cavity at 805 MHz to test Be surfaces to determine behaviour in high RF and magnetic fields. | Oct-00 | $70,000 | 3 |
| Testing 805 MHz high-power open cell cavity | Testing high-power open cell cavity at 805 MHz | START 10/1/2000 | $35,000 | 4 |
| Test Be window(s) | Test window(s) | Nov-00 | $1,000 | 1 |
| Test thin-walled tube assemblies | Testtube assemblies | Nov-00 | $1,000 | 1 |
| Testing 805 MHz pillbox high-power cavity with Be end plates | Testing high-power pillbox cavity at 805 MHz to test Be surfaces | START 1/1/2001 | $35,000 | 4 |
| Modifications and further high-power cavity testing at 805 MHz | Unforseen challenges, changing geometries, surface coatings, etc... | CONTINUES through Sep-01 | $100,000 | 8 |
| | | Total (805 MHz): | $443,000 | 36 |

| Item | Description | Completion date | M&S | Labor (m-m) |
|---|---|---|---|---|
| Preparation for 201 MHz equipment in Lab G. | Purchase and install 201 MHz tetrode and power supplies into Lab G. Coaxial lines, interlocks, etc. Prepare for superconducting solenoid. | Feb-01 | $400,000 | 12 |
| Prototype high-power 201 MHz cavity | Design and build a prototype high-power cavity at 201 MHz to test behaviour in high RF fields and magnetic fields. Use Lab G facilities with 200 MHz tetrode installed. | May-01 | $360,000 | 12 |
| 201 MHz cavity testing | Testing high-power cavity at 200 MHz. Conditioning, operating at high-power varying pulse length, varying magnetic field... | Oct-01 | (costs included in lab G. preparation) | 4 |
| Modifications to cavity | Based on experimental experience, modify cavity - e.g. anti-multipactor coatings? Change geometry of power feedthrough? Improve cooling in some areas? | Feb-02 | $120,000 | 4 |
| 201 MHz cavity testing | Additional testing of high-power test cavity | May-02 | $30,000 | 3 |
| Second high-power RF cavity | Develop second iteration of cavity design based on experience with first prototype and it's modifications. Manufacture second cavity. | Jan-03 | $300,000 | 7 |
| 201 MHz cavity testing | Testing second high-power test cavity | Mar-03 | $30,000 | 3 |
| | | Total (201MHz): | $1,240,000 | 45 |

# Summary

- 805 MHz
  - Be windows studies continuing
    - Low power test cavity measurements ($\pi/2$ interleaved pillbox)
    - ANYSYS FEA model
    - Designing high-power test cavity
  - Π-mode 6-cell open-cell cavity
    - Al model testing complete
    - High-power Cu cavity being built
  - Lab G preparations complete this summer
    - » High power tests in Lab G this year
- 201 MHz
  - Designing high-power test cavity
    - » Build high-power test cavity next year
    - » Develop 201 MHz RF test stand in Lab G