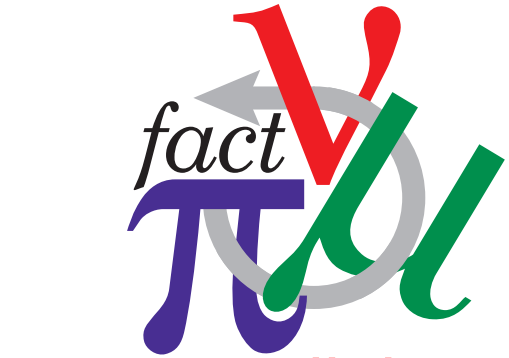
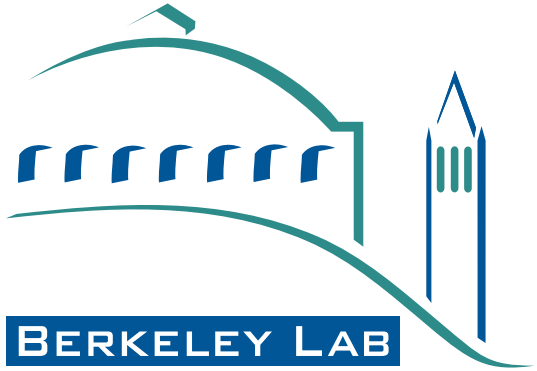




MUCOOL RF R&D Activities

John Corlett

Accelerator and Fusion Research Division

LBNL

MUCOOL RF R&D - Staff

Muon Collaboration

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

MUCOOL RF R&D

Muon Collaboration

- 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
- *frequency stability, breakdown, multipacting, heating, dark current, ...*

MUCOOL RF R&D

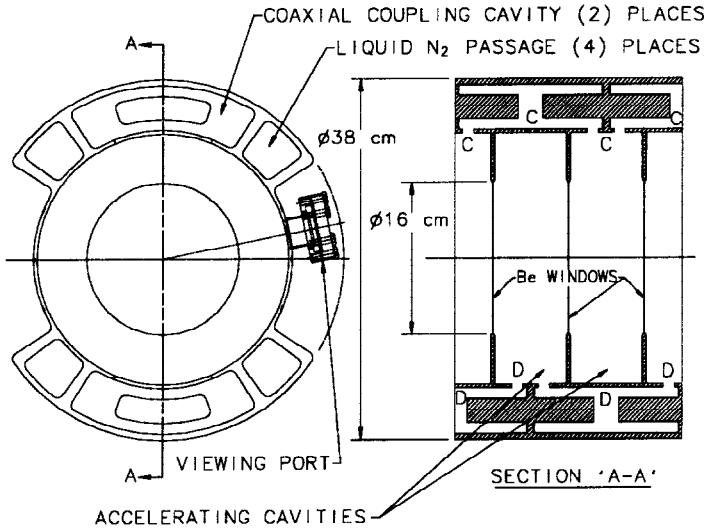
Muon Collaboration

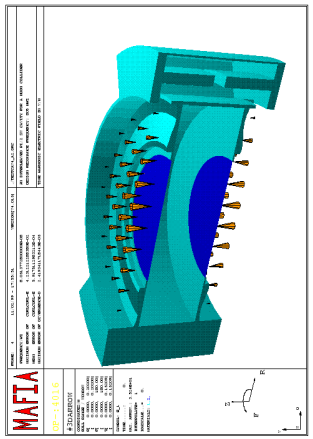
- 805 MHz
  - Collider parameters
  - "End" of cooling section
- Hardware
  - $\pi/2$ interleaved cavity
    - Be windows
    - Low-power test cavity
      - LN_2 temperature
    - High-power test cavity
  - π-mode open cell cavity
    - Cold-test cavity
    - High-power test cavity
  - Superconducting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

Muon Collaboration





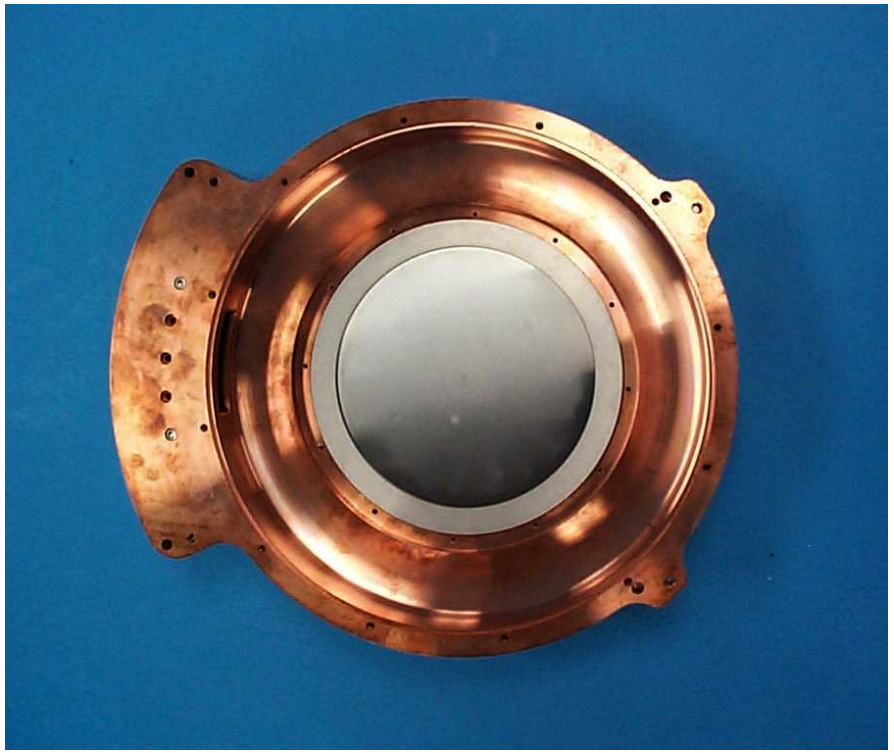
- E_o = 30 MVm^{-1}
- 3τ filling
- 15 Hz
- Q = 21,000
  - » *≈ kHz cell-to-cell stability*
- Z_o = 54 $M\Omega m^{-1}$
- ZT^2 = 44 $M\Omega m^{-1}$

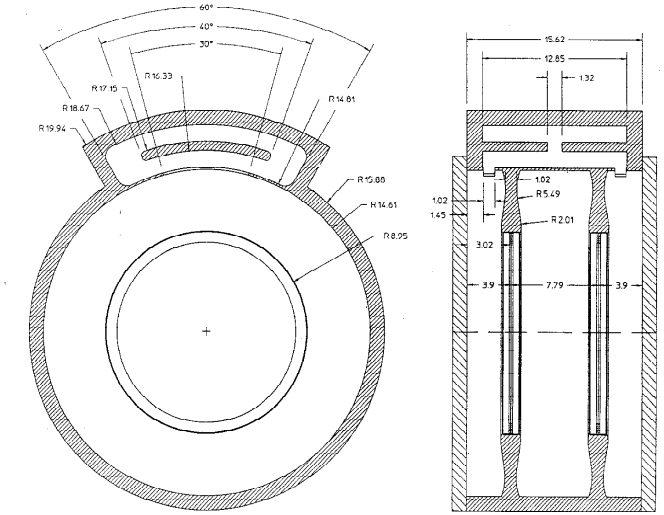
- Per-cell dissipated power 250 W
- Be window dissipated power 43 W

Low-power test cavity

Muon Collaboration

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

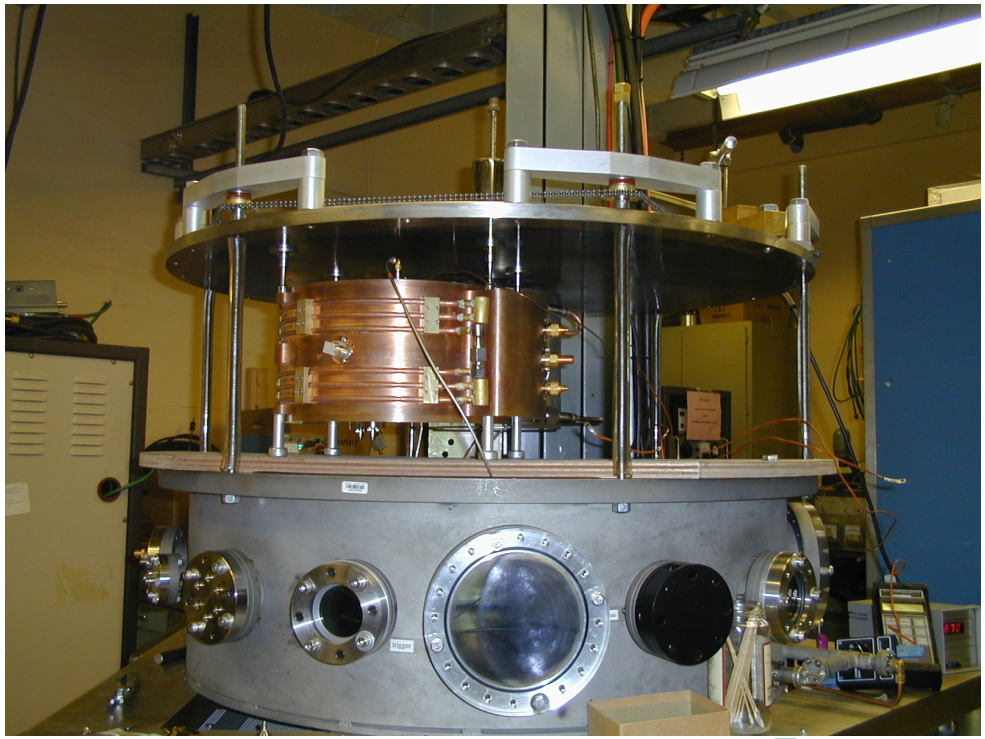


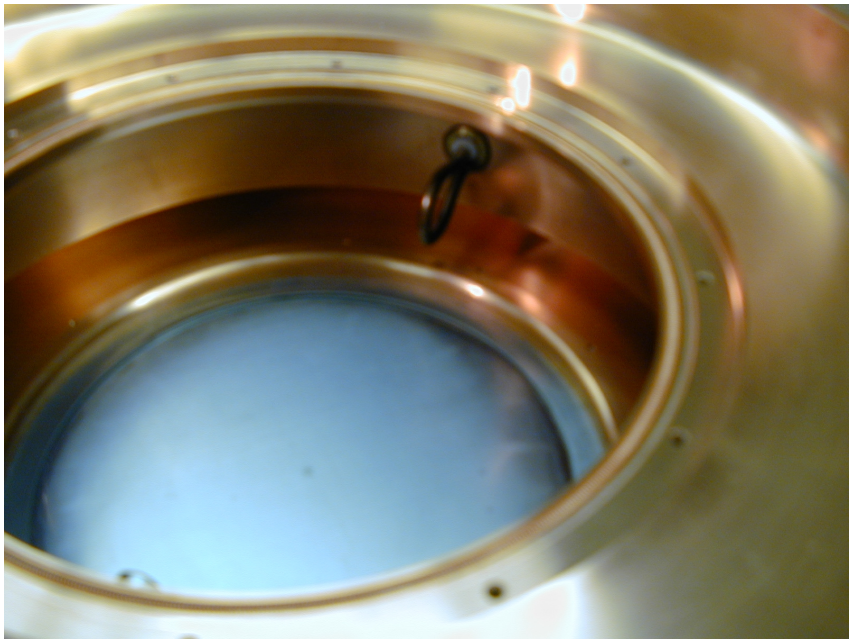


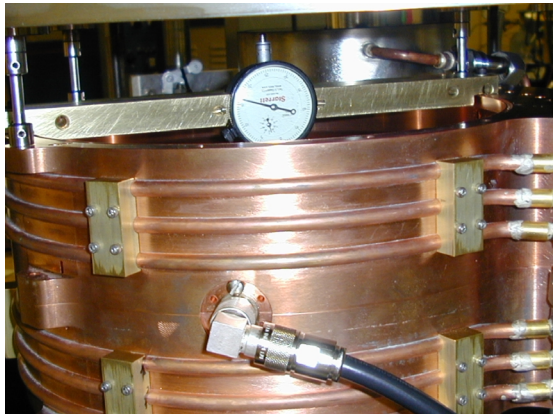
Low-power Test Cavity Measurements

Muon Collaboration

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





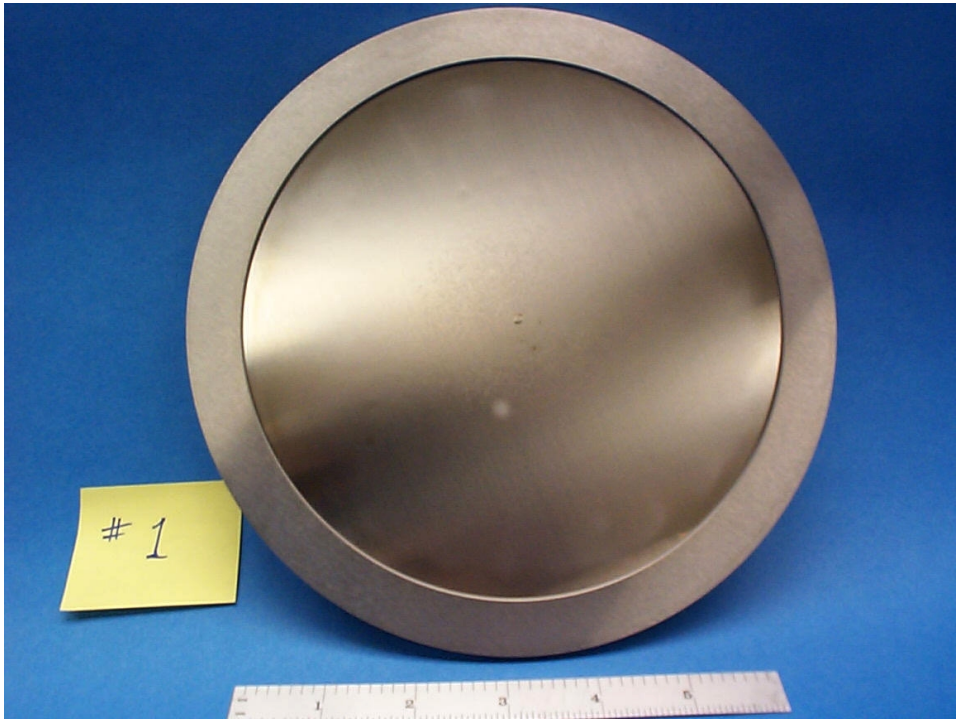


RF windows for 805 MHz cavities

Muon Collaboration

- Be foils 0.005” thick
- 99.8% Be
- Foil brazed 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

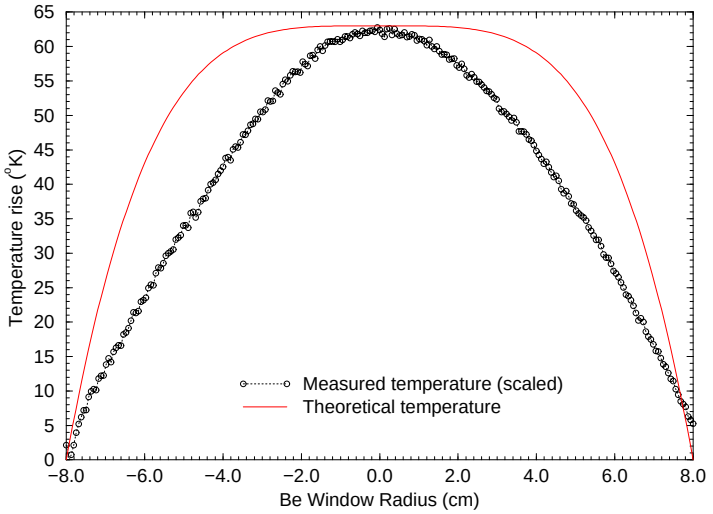
- Windows purchased for tests
  - *Not “designed” in detail*

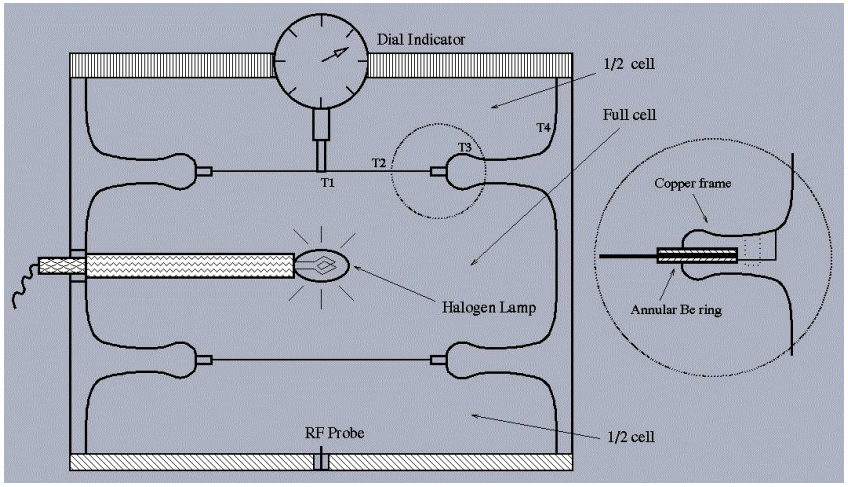


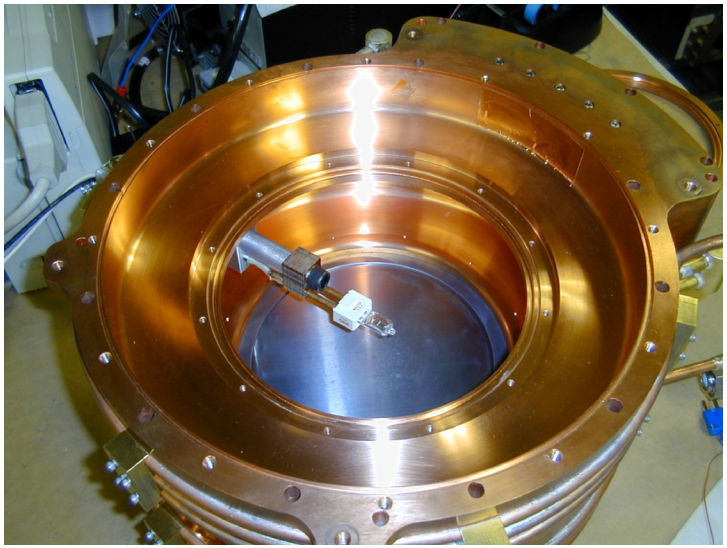
Halogen Lamp Heating Window Measurements

Muon Collaboration

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



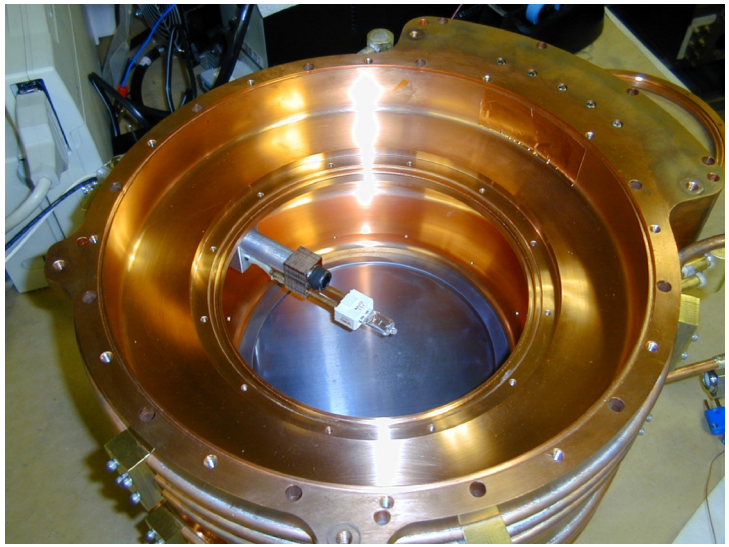


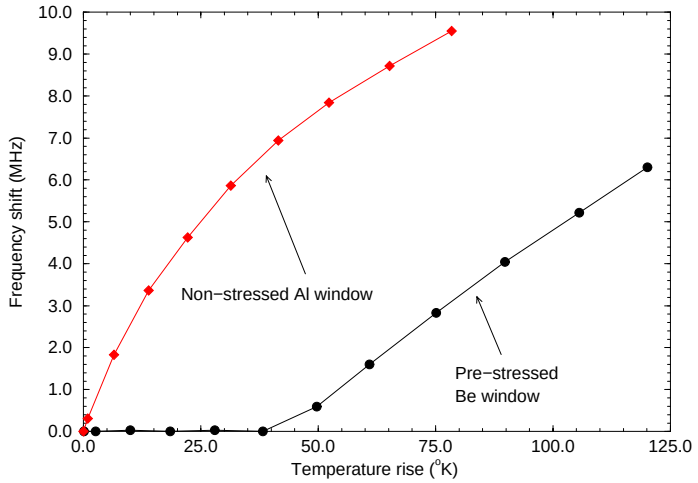


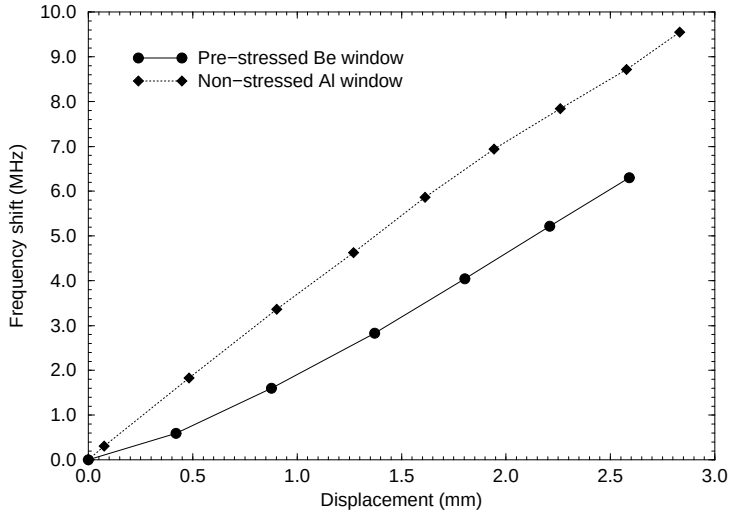
Room Temperature Measurements

Muon Collaboration

- Al and Be foils
- Halogen lamp heating



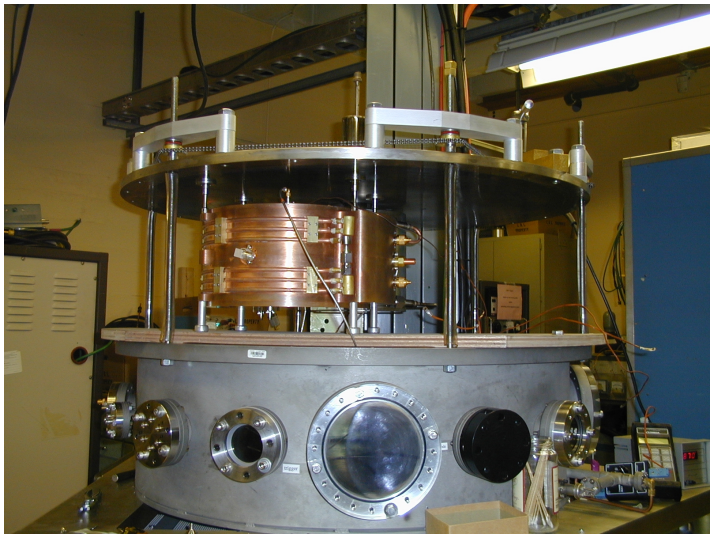


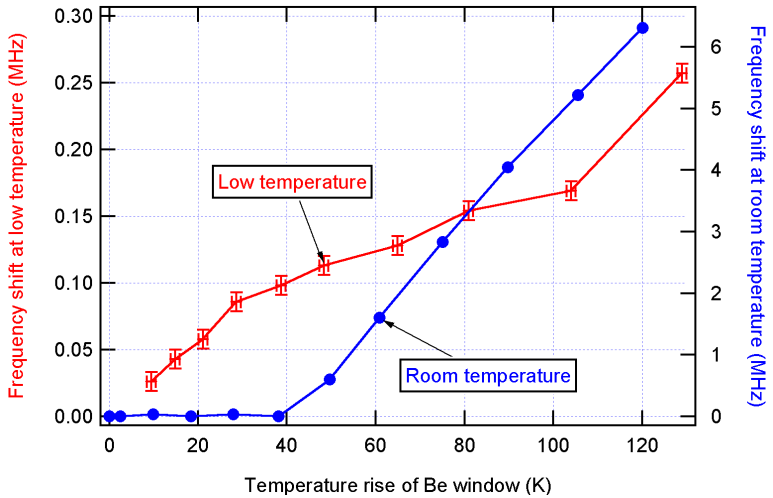


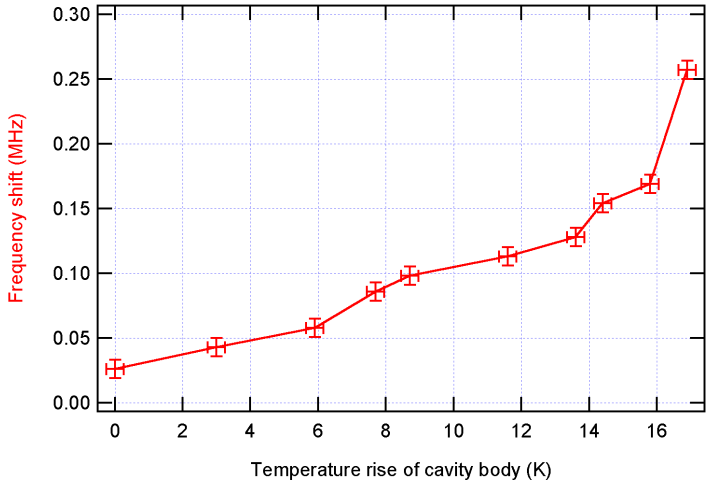
Low Temperature Measurements

Muon Collaboration

- Cool cavity with LN_2
- Heating with halogen lamp
  - Window does not move
    - Δf due to cavity body ΔT

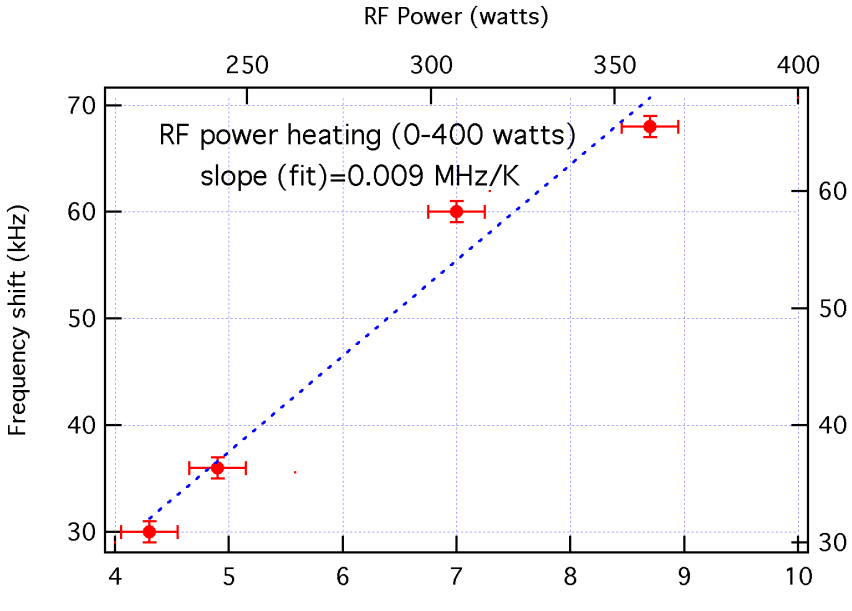


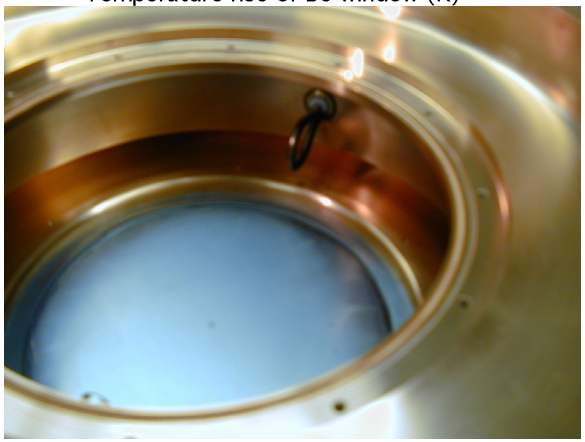


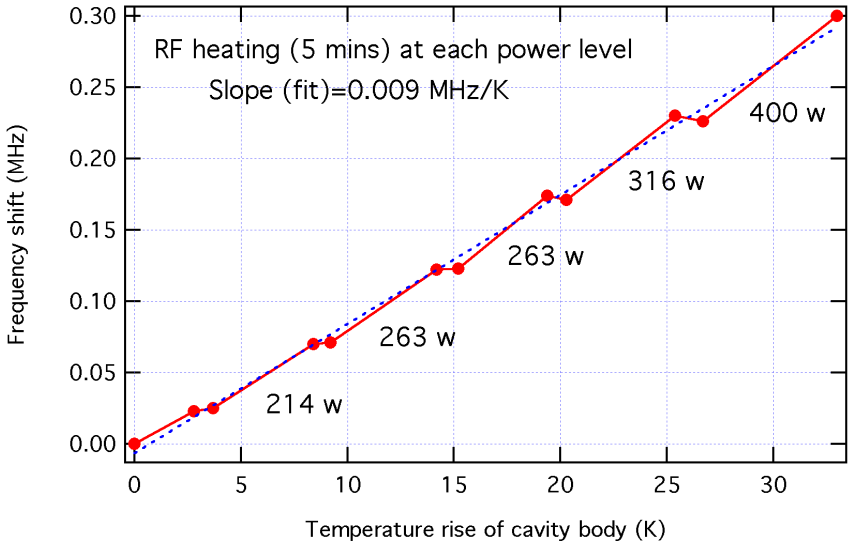


Low Temperature Measurements

Muon Collaboration





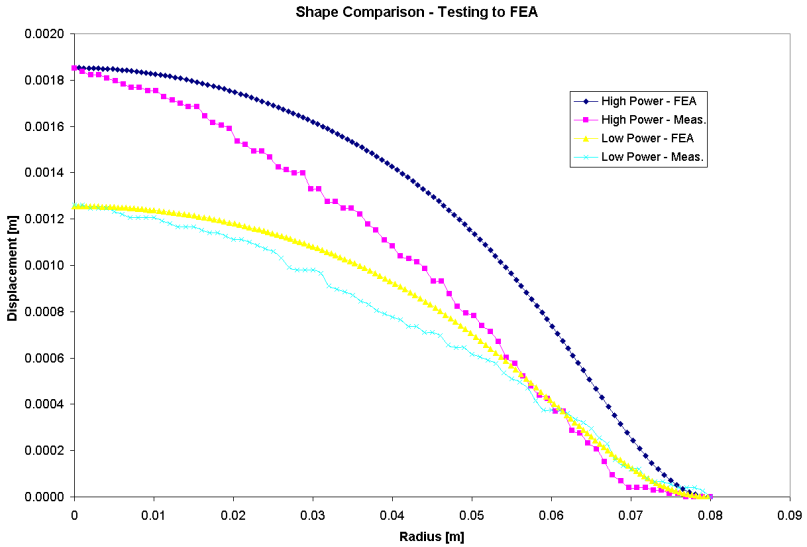


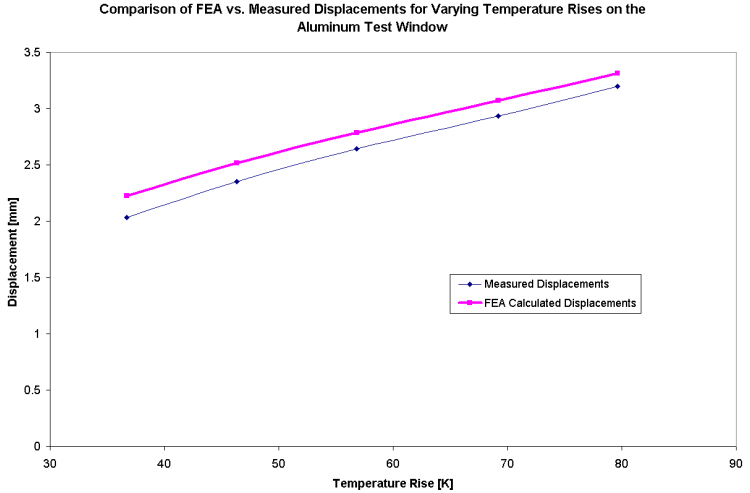
- Heating with RF
  - $Q_l \approx 4000$
    - Bolt-together cavity
  - RF on for ≈ 5 min cycles
  - Window does not move
    - Δf due to cavity body ΔT

Be Window FEA

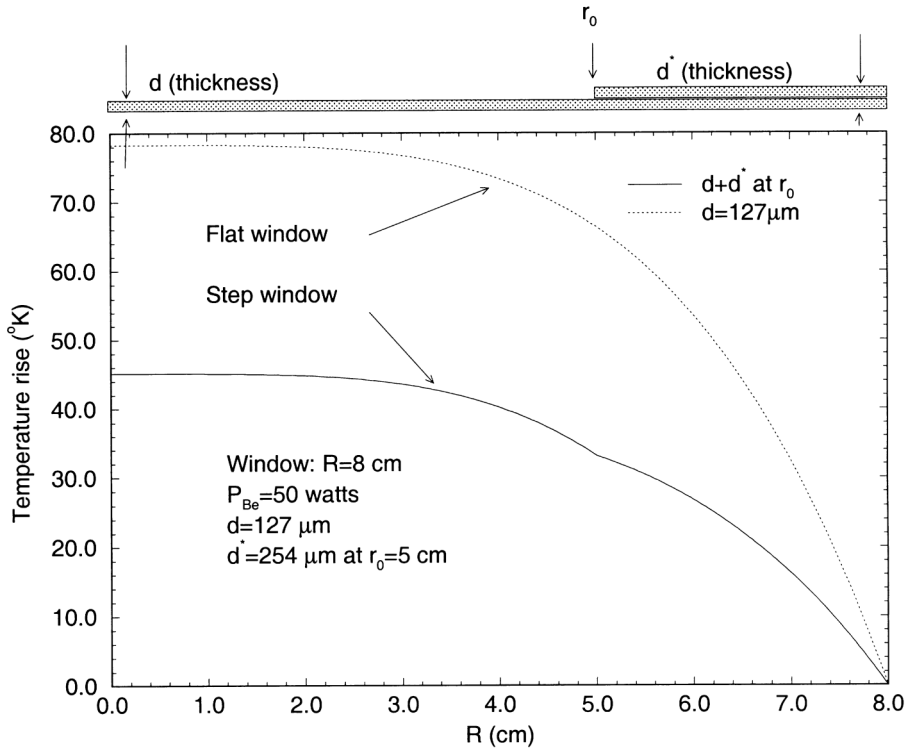
Muon Collaboration

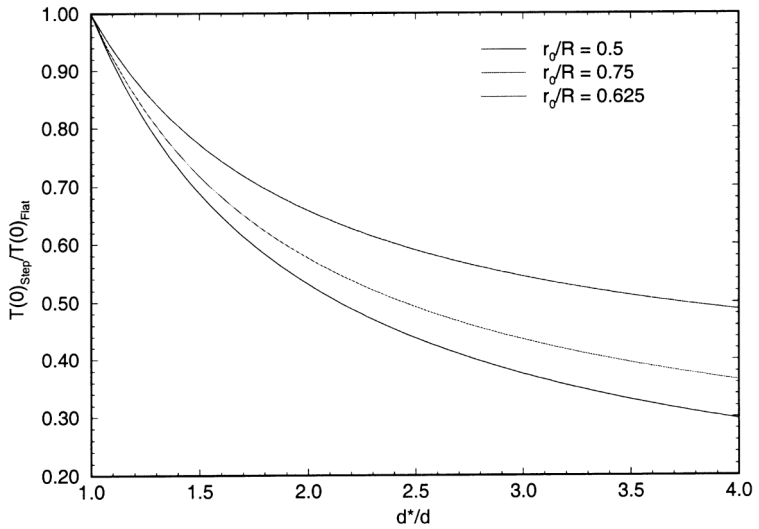
- ANSYS model of Be and Al foil windows
- Include pre-stress of Be foil
  - Difficult to model accurately
- Room temperature foil distortion arises from temperature gradient in foil
  - Increase thermal conductivity
    - thicker foils
      - » grade foil thickness
    - low temperature
  - Increase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





Increased Be Window Thickness

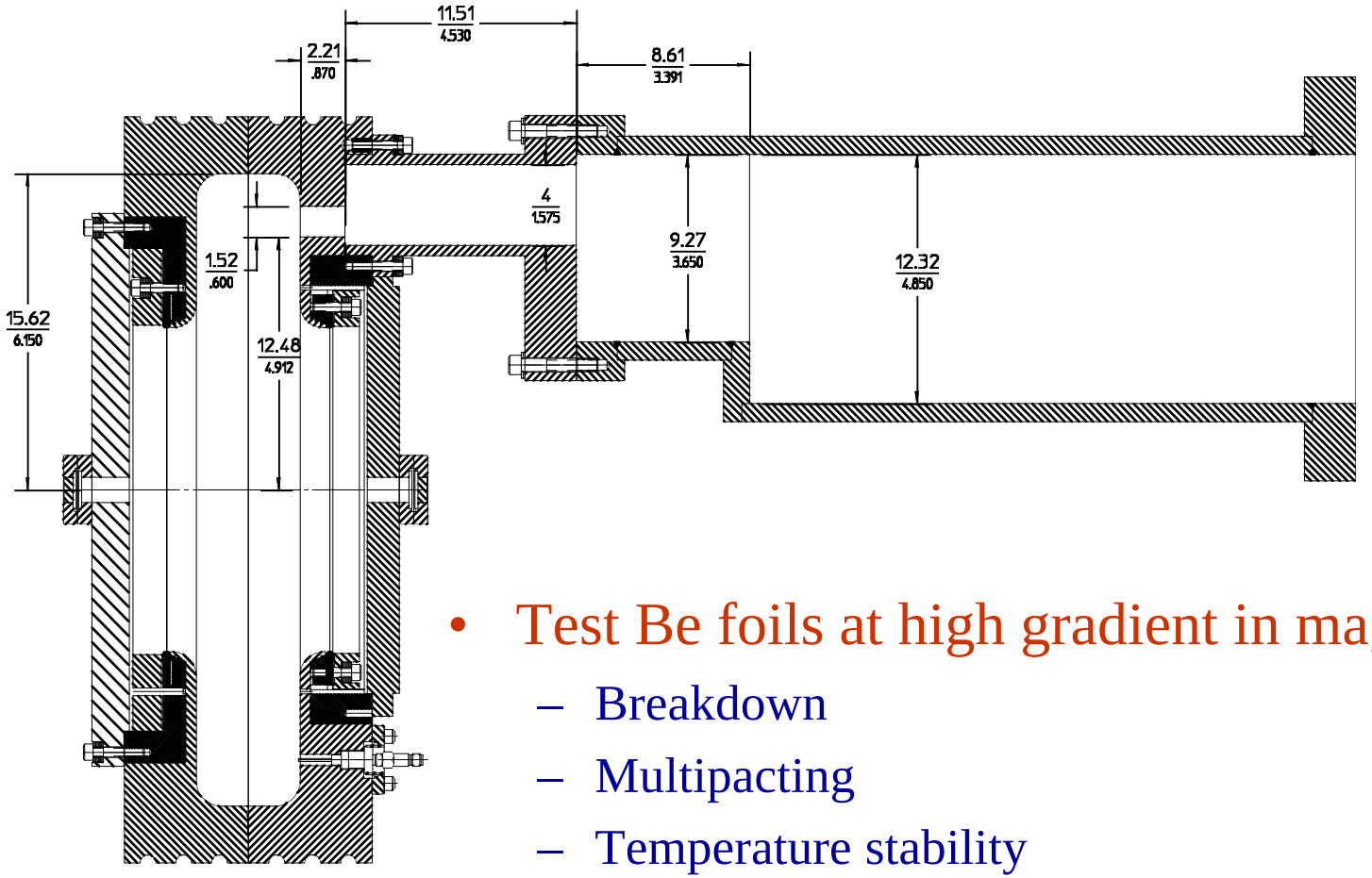




- Thicker window at large radius
  - Increase thermal conduction
    - Cooler window
      - Reduce window expansion

High-power Pillbox Cavity

Muon Collaboration

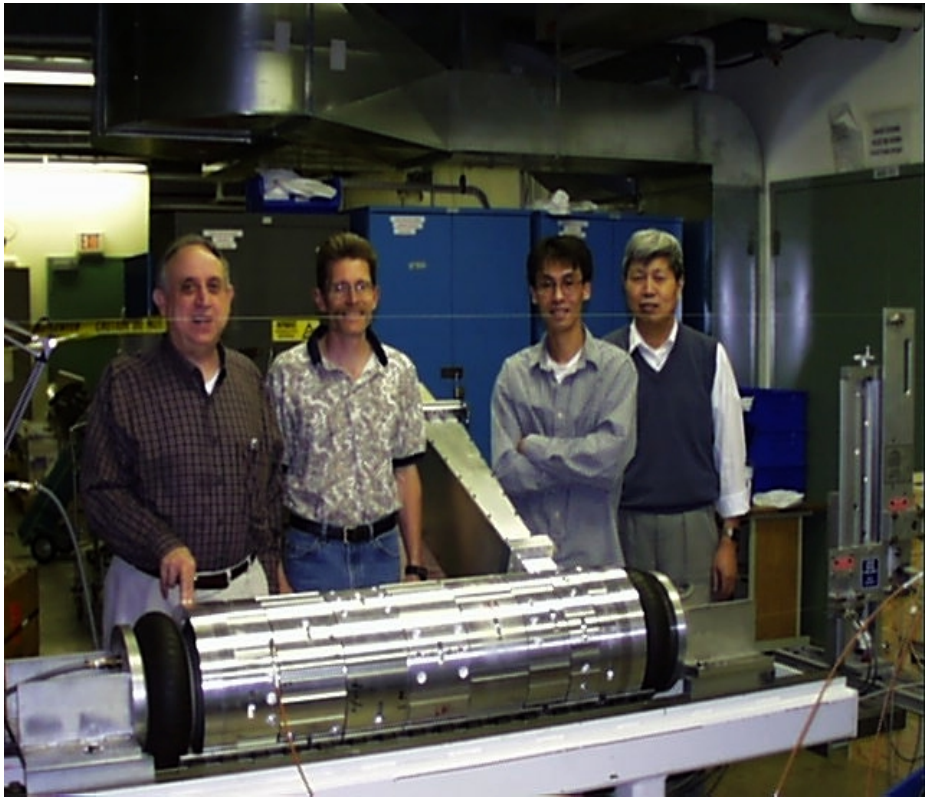


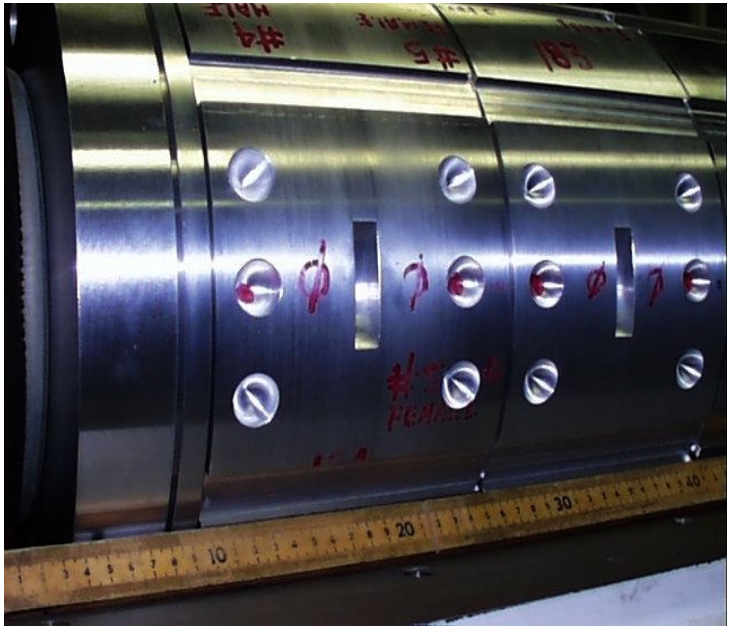
- Test Be foils at high gradient in magnetic field
  - Breakdown
  - Multipacting
  - Temperature stability
    - Test in Lab G facility

805 MHz 6-cell π-mode Cavity

Muon Collaboration

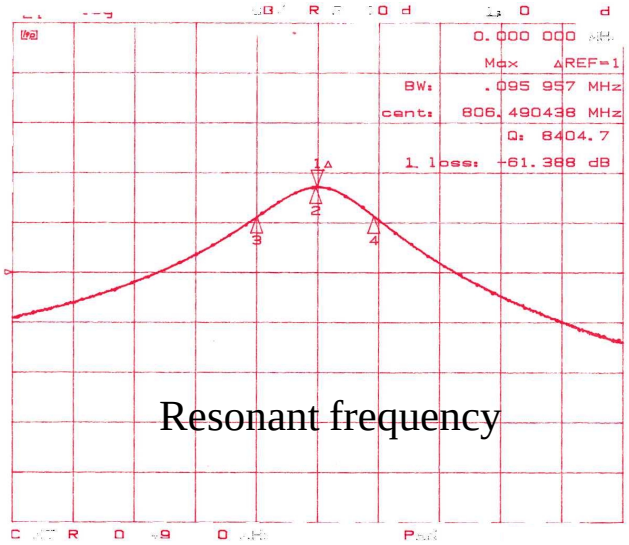
- Al prototype tests
  - Determine final dimensions for Cu cavity
- Cu cavity machining has begun
  - 12 tuning points per cell



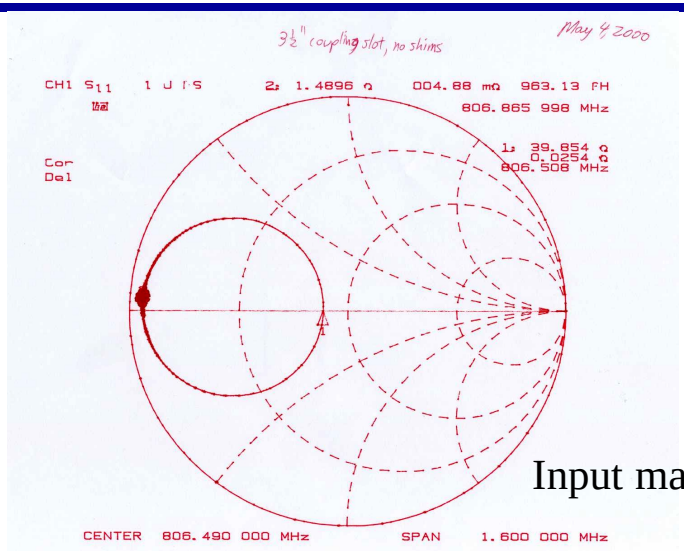


805 MHz 6-cell π-mode Cavity Measurements

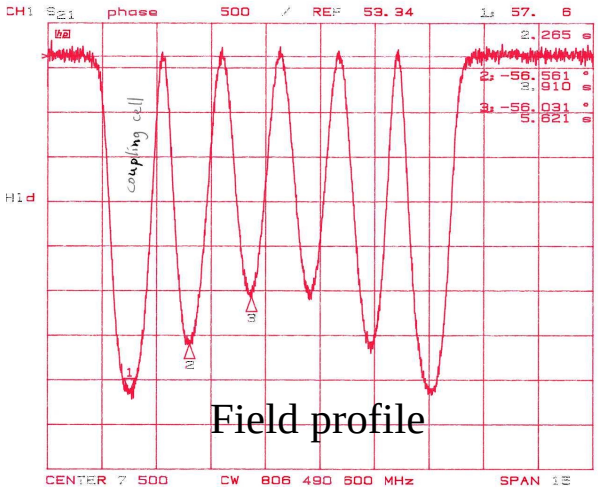
Muon Collaboration



Resonant frequency



Input match

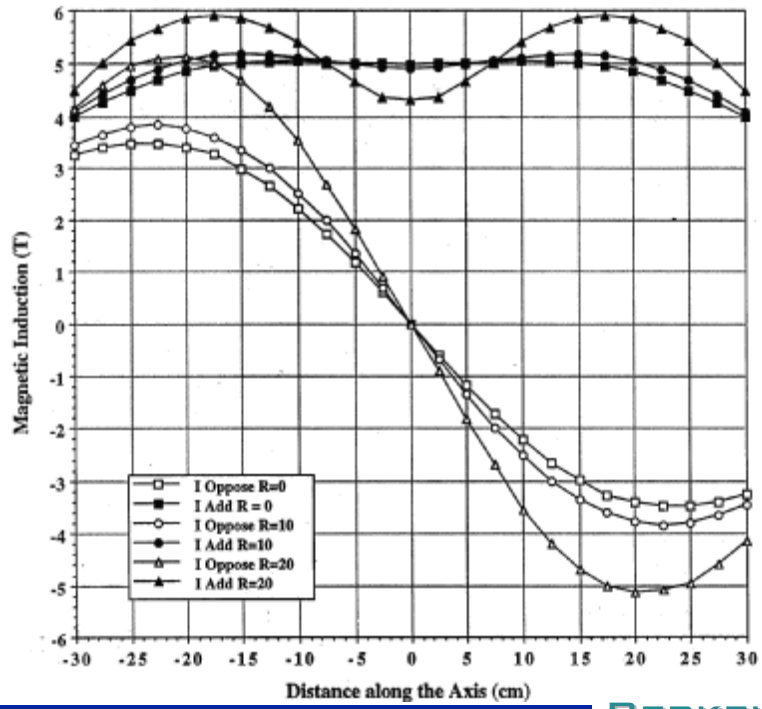


Field profile

Superconducting Magnet

Muon Collaboration

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



Status of Lab G

Muon Collaboration

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

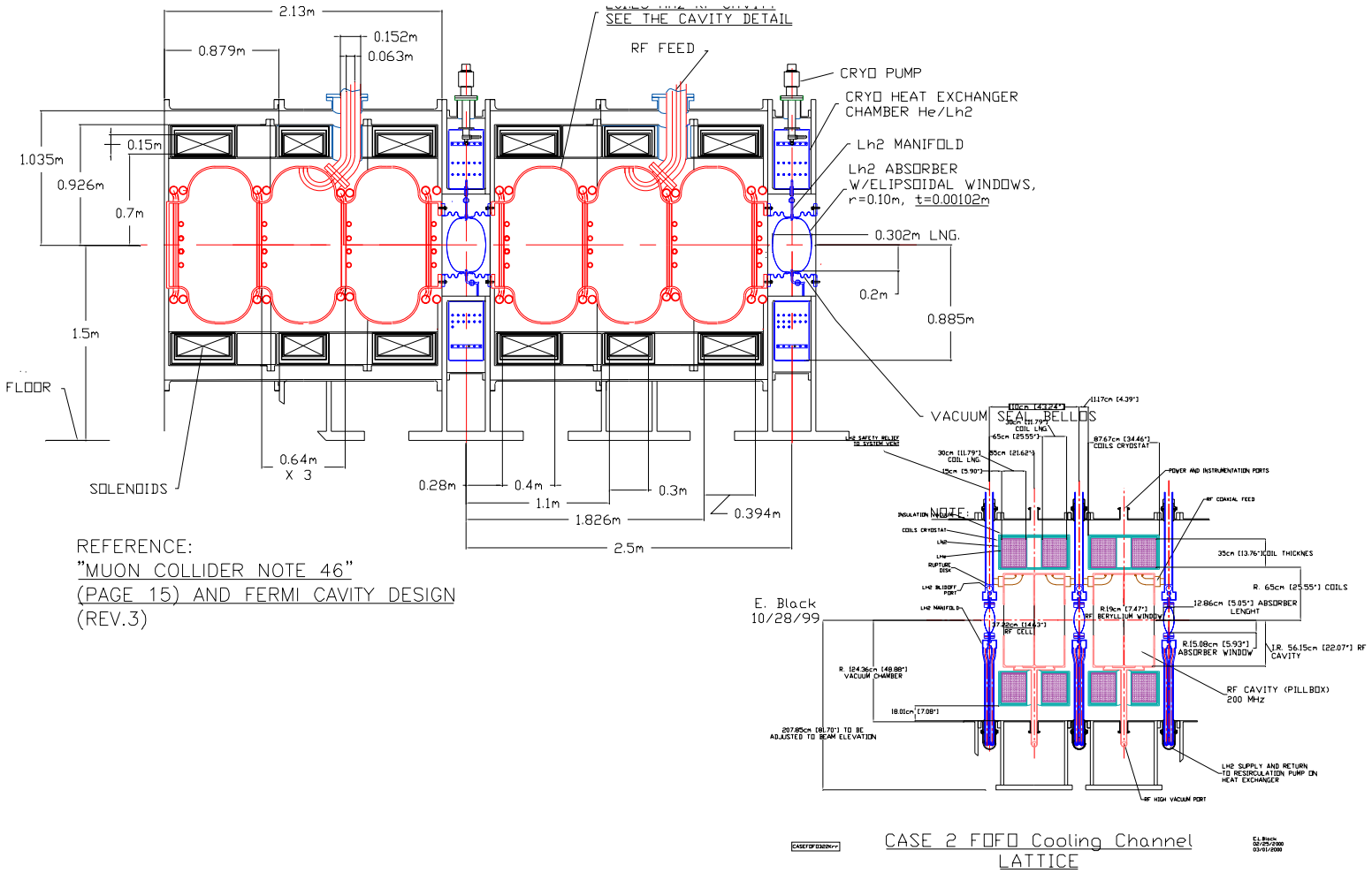
- Superconducting magnet to be installed
- Shielding roof to be completed
- RF power waveguide to be installed

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 accelera-ting section is 0.864 m.
Impedance	28.4 M‰/m	34.1 M‰/m
Shunt Impedance	20.3 M‰/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 s
rf Pulse	114 μs	125 s
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 m thick Be foil
Average Power on Tubes	30 W (worst tube)	53 W (heated from both sides)

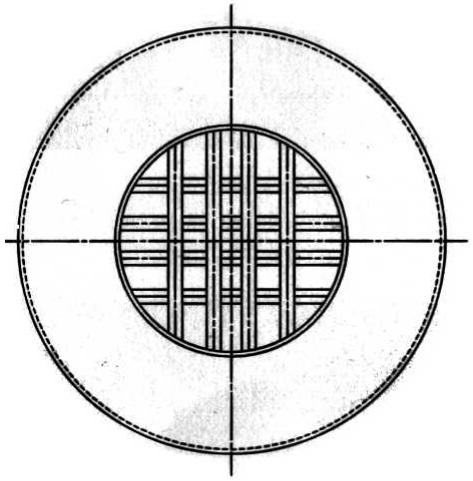
201.25 MHz RF Layouts

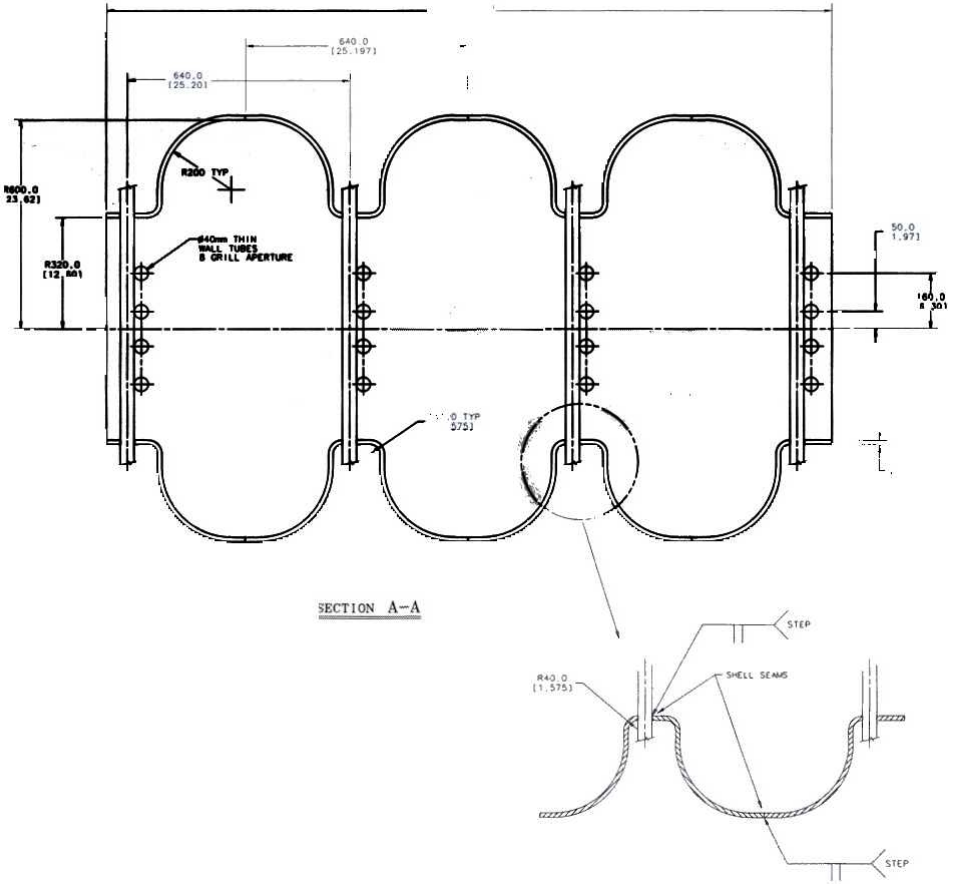
Muon Collaboration



201 MHz Gridded (Crossed-tube) Cavity

Muon Collaboration





- 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

R&D Plans

Muon Collaboration

Item	Description	
Be window finite element analysis	Develop FEA model of Be foil window, determine engineering feasibility for 805 MHz and 201 MHz size windows.	FY '00
Low-power open-cell test cavity	Complete measurements of low-power open cell test cavity	
Install superconducting magnet in Lab G		
Lab G 805 MHz RF	Complete installation and commissioning of 805 MHz RF system	
Be window model	Design and build test windows based on FEA results	
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.	
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.	
Testing 805 MHz high-power open cell cavity	Testing high-power open cell cavity at 805 MHz	FY '01
Test Be window(s)	Test window(s)	
Testing 805 MHz pillbox high-power cavity with Be end plates	Testing high-power pillbox cavity at 805 MHz to test Be surfaces	
Modifications and further high-power cavity testing at 805 MHz	Unforseen challenges, changing geometries, surface coatings, etc...	

Item	Description	
Thin-walled tube analysis	Develop engineering model for thin-walled tube structures	FY '00
Thin-walled tube test model	Design and build test tube assemblies	
Test thin-walled tube assemblies	Testtube assemblies	
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.	FY '01
Design prototype high-power 201 MHz cavity	Design a prototype high-power cavity at 201 MHz to test behaviour in high RF fields and magnetic fields. Incorporate Be windows or grids.	
Build 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 201 MHz tetrode installed.	FY '02
201 MHz cavity testing	Testing high-power cavity at 201 MHz. Conditioning, operating at high-power varying pulse length, varying magnetic field...	FY '03
Modifications to cavity	Based on experimental experience, modify cavity - e.g. anti-multipactor coatings? Change geometry of power feedthrough? Improve cooling in some areas?	
201 MHz cavity testing	Additional testing of high-power test cavity	

Summary

Muon Collaboration

- 805 MHz
  - Superconducting magnet delivered
  - Lab-G development almost complete
  - Be windows studies continuing
    - Low power test cavity measurements ($\pi/2$ interleaved pillbox)
    - ANY SYS FEA model
    - Build high-power test cavity
  - Π-mode 6-cell open-cell cavity
    - Al model testing complete
    - High-power Cu cavity being built

      » High power tests in Lab G FY'01

- 201 MHz
  - Continue cell termination design work
    - Window
    - Tubes
      - Decide on feasible design
  - Develop 201 MHz RF test stand in Lab G
  - Develop high-power cavity
    - » Design FY'01
    - » Build FY'02
    - » Test FY'03