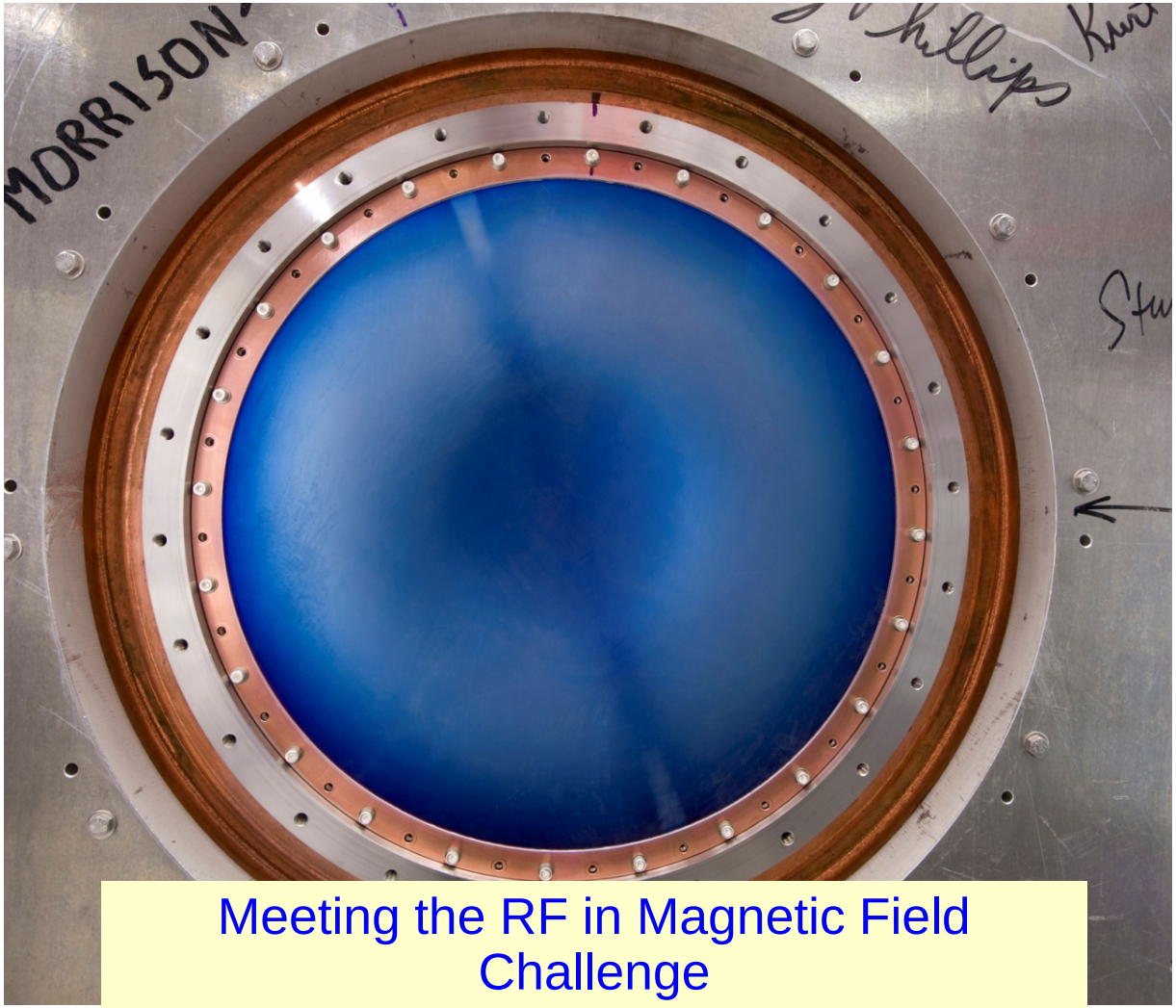
The Muon Accelerator Program Gradient Normal Conducting RF R&D (MuCool)



Meeting the RF in Magnetic Field Challenge

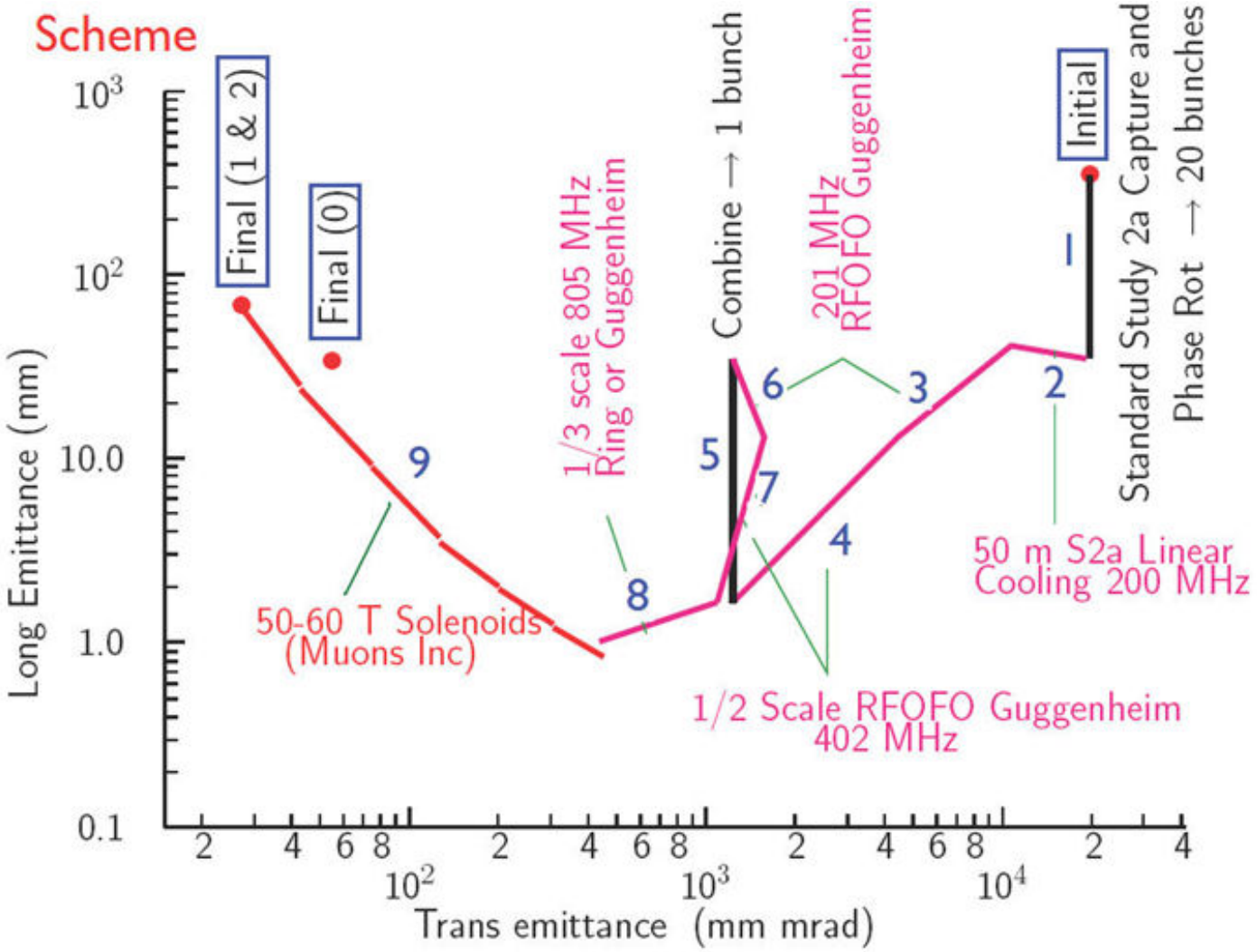
- Outline
  - The “RF Challenge”
  - Current Program (Where we are)
  - Current status of the MuCool Test Area (MTA)
  - Summary

Normal Conducting RF

R&D Issues for MAP and Present Status

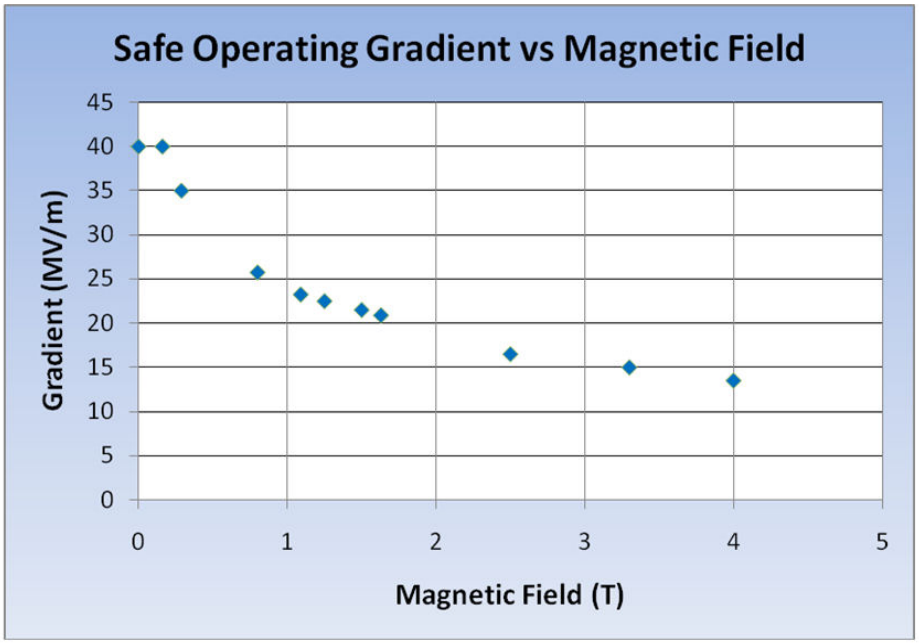
- Muon bunching, phase rotation and cooling requires Normal Conducting RF (NCRF) that can operate at "high" gradient within a magnetic field strength of up to approximately 6T
  - Required gradients (15-18MV/m) easily obtainable in absence of magnetic field
    - And since we are primarily considering pillbox structures, 15-18MV/m is also the max surface gradient

Muon Cooling Channel & RF

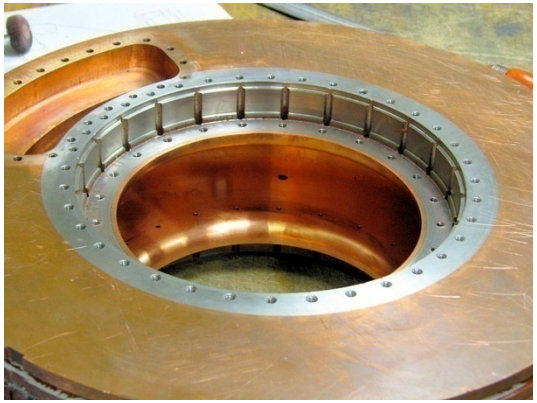


"Our" RF *Challenge*

- Significant degradation in maximum stable operating gradient with applied B field

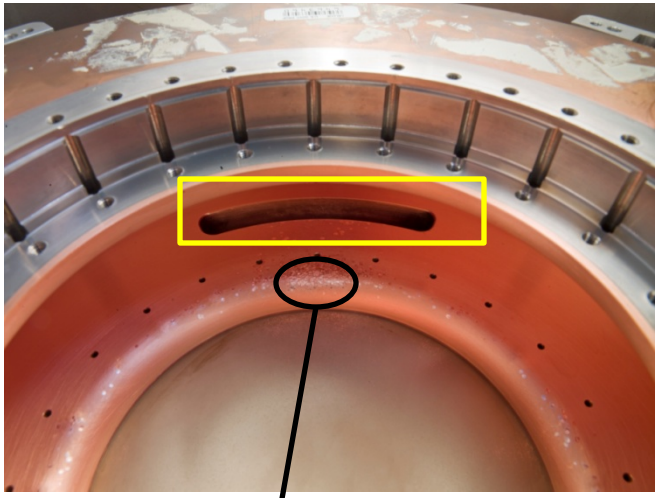


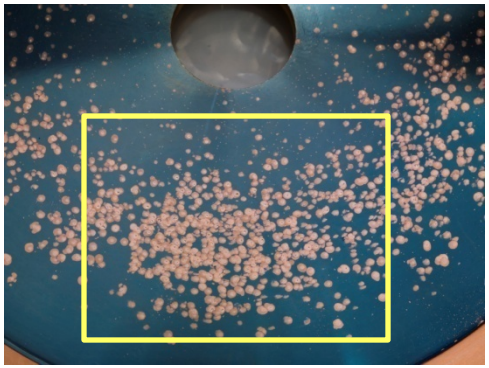
- 805 MHz RF Pillbox data
  - Curved Be windows
  - E parallel B
  - Electron current/arcs focused by B
- Degradation also observed with 201 MHz cavity
  - Qualitatively, quite different

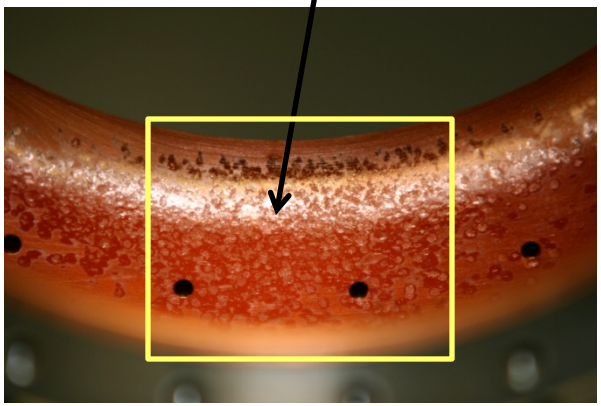


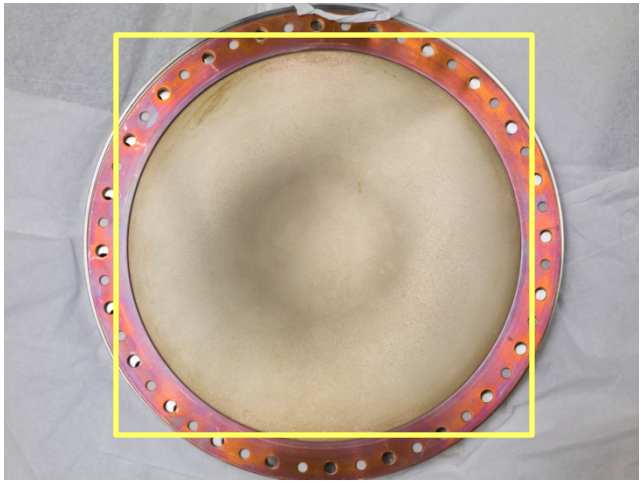
805 Pillbox

Post-Mortem







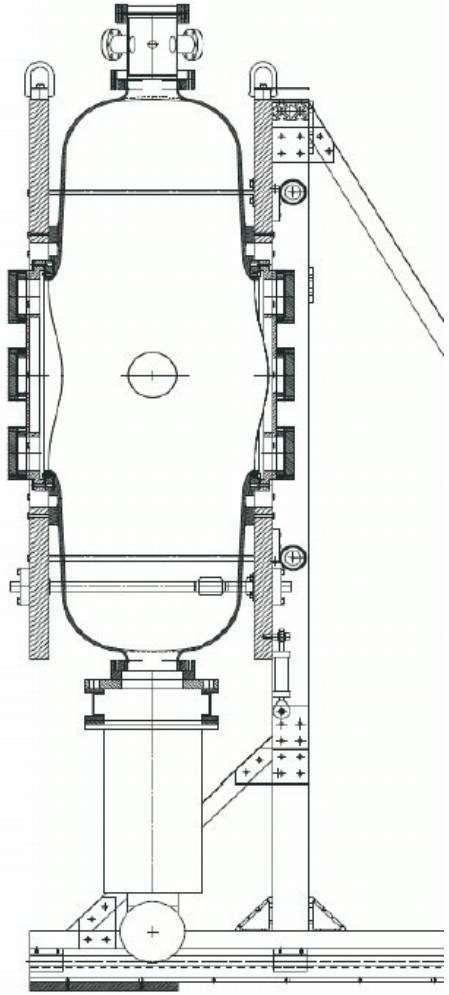


- Significant damage observed
  - Iris
  - RF coupler
  - Button holder
- However
  - No damage to Be window

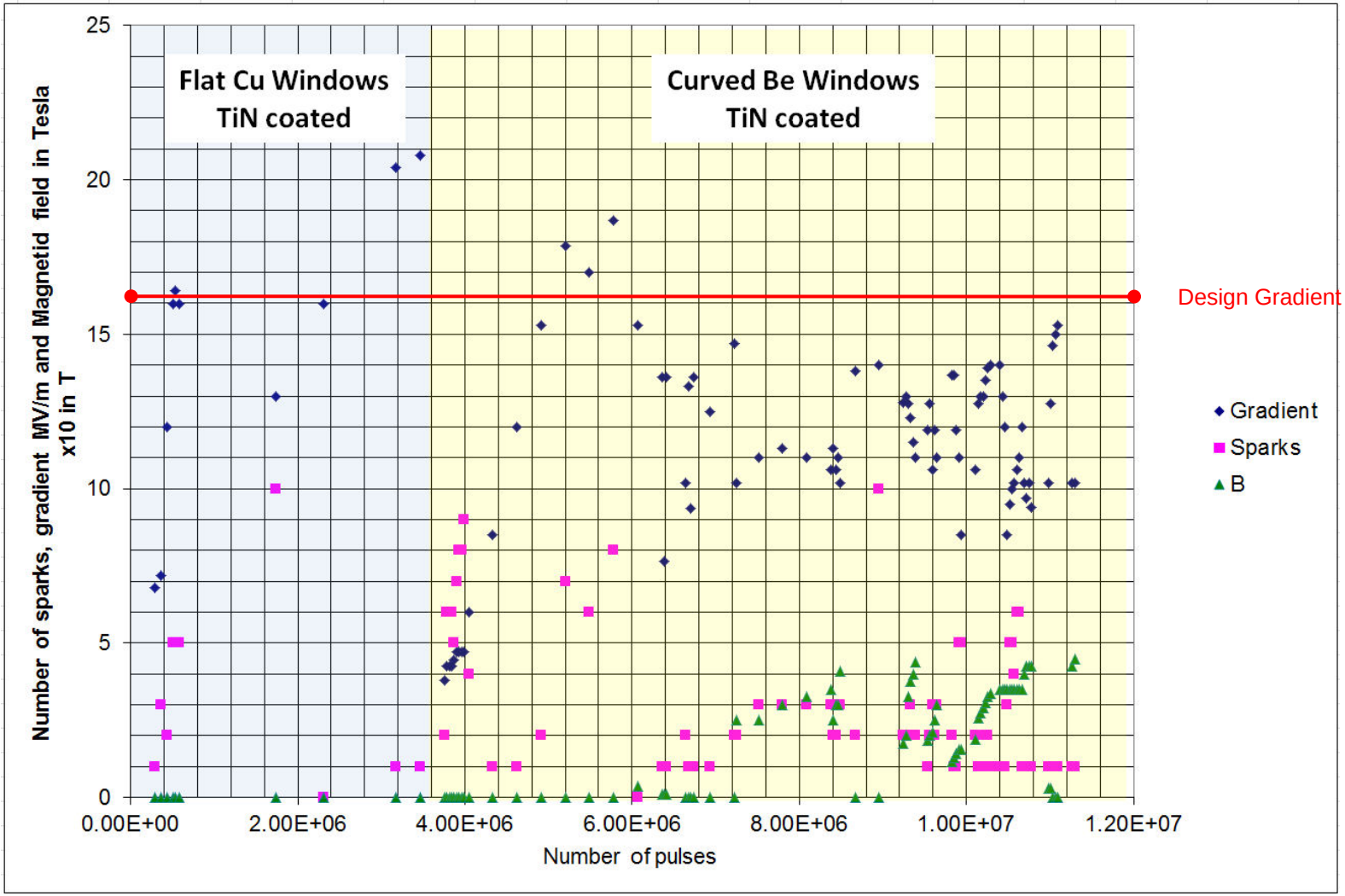
201 MHz Cavity Test

Treating NCRF cavities with SCRF processes

- The 201 MHz Cavity – *Achieved 21 MV/m*
  - Design gradient – 16MV/m
  - At 0.75T reached 10-12 MV/m



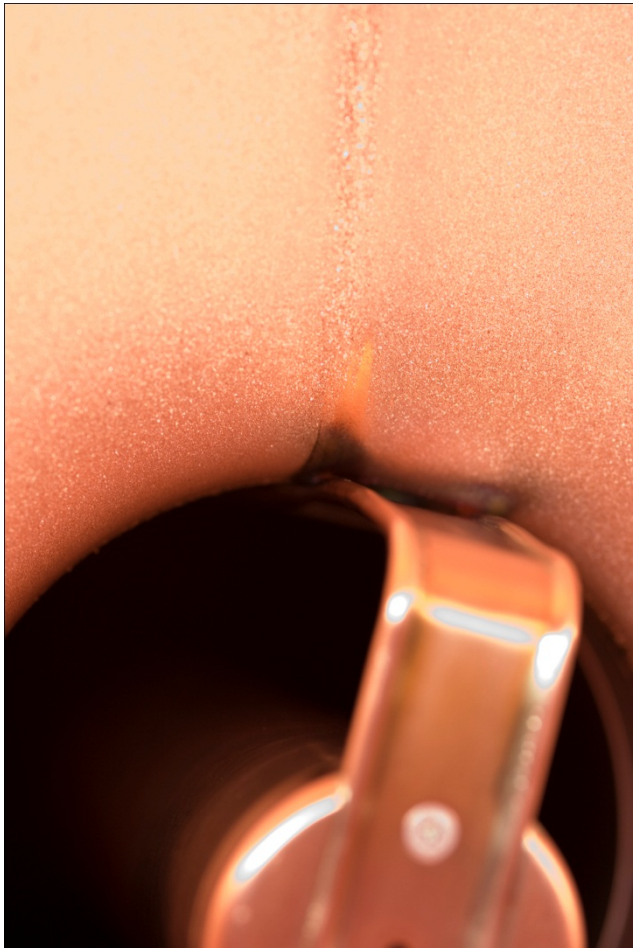
201 MHz Cavity Running



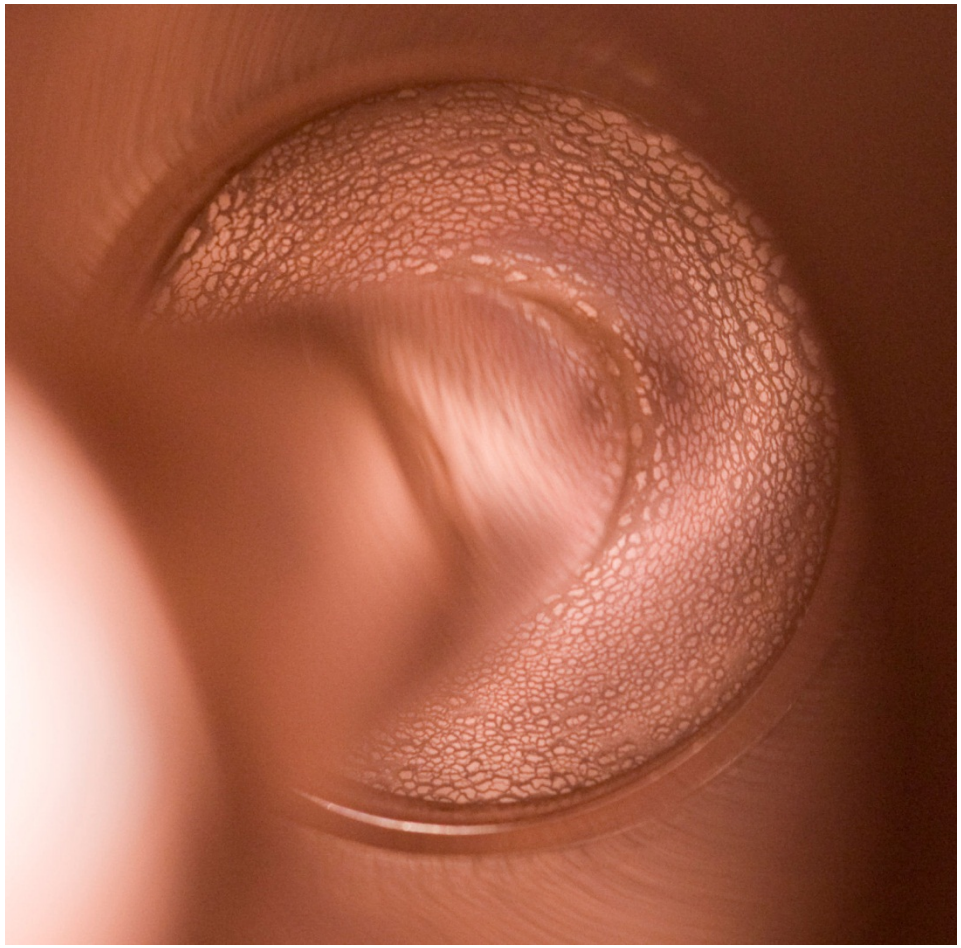
201 MHz Prototype

However, Observed no damage in cavity (- *except in coupler*)

201 MHz Cavity Coupler



Arcing at loop



Cu deposition on TiN coated ceramic RF window

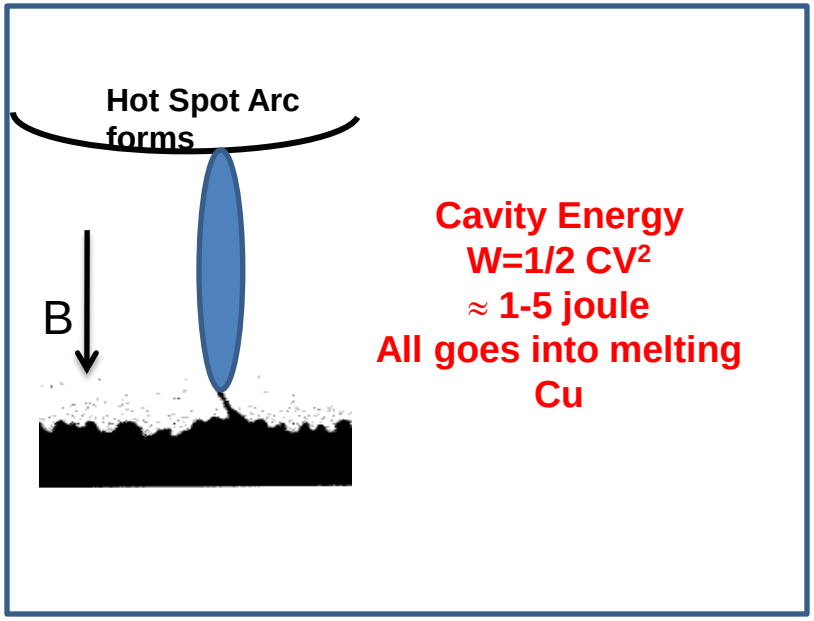
RF Breakdowns

- Are not all equal
  - NCRF conditioning (B=0), process allows for higher gradient operation *("conditioning")*
    - *Both our 805 MHz and 201 MHz followed the conventional wisdom here*
  - NCRF ($B \neq 0$), process can cause damage and require re-conditioning at lower gradient in order to reach the same gradient attainable before breakdown
    - 805 MHz cavity was severely damaged
    - 201 MHz was "altered"
      - At quite low B

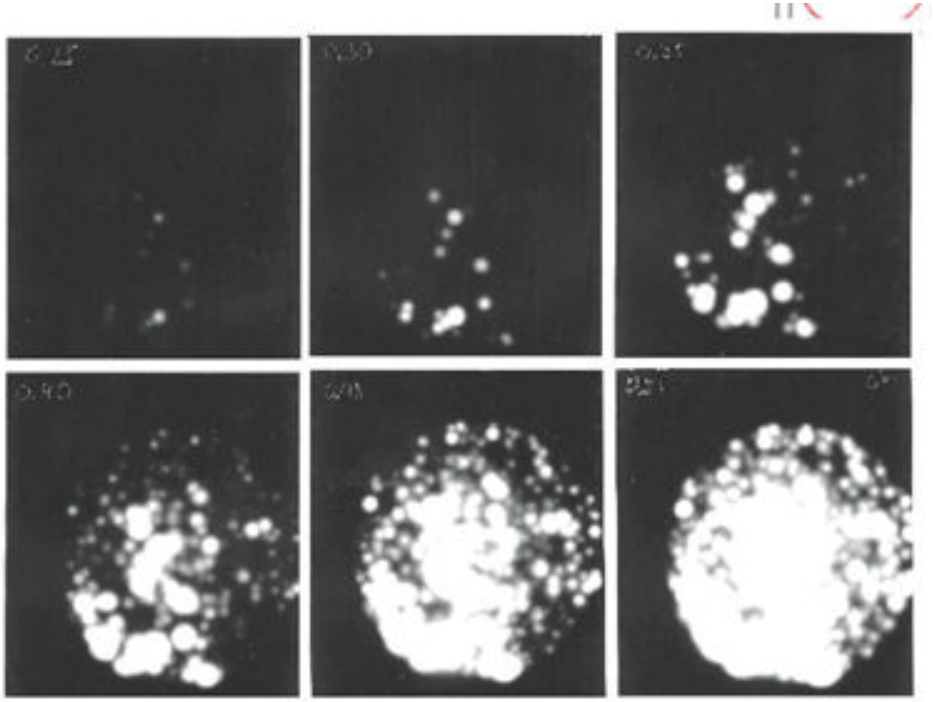
RF Operation in Vacuum 805 MHz Imaging

- Gives a picture of how the field emitters change with rf field.

8.8 - 17.6 MV/m



Cavity Energy
$W=1/2\ CV^2$
$\approx$ 1-5 joule
All goes into melting Cu

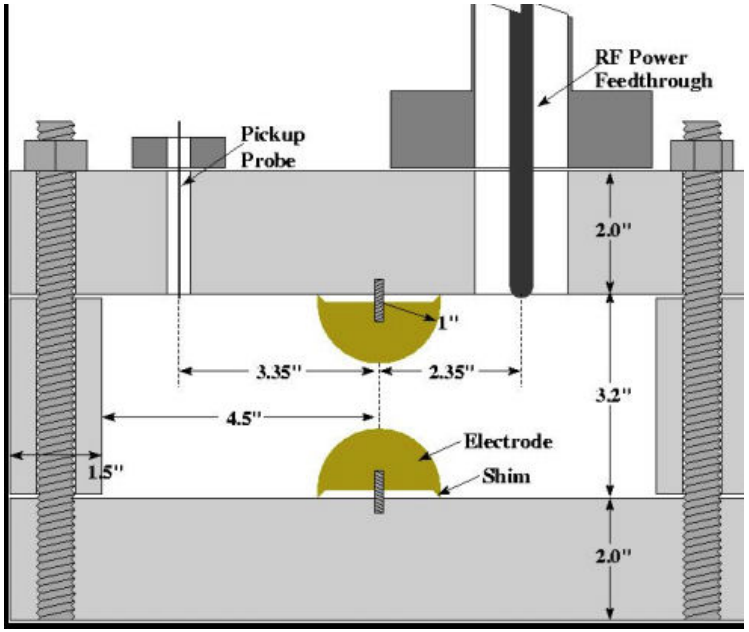


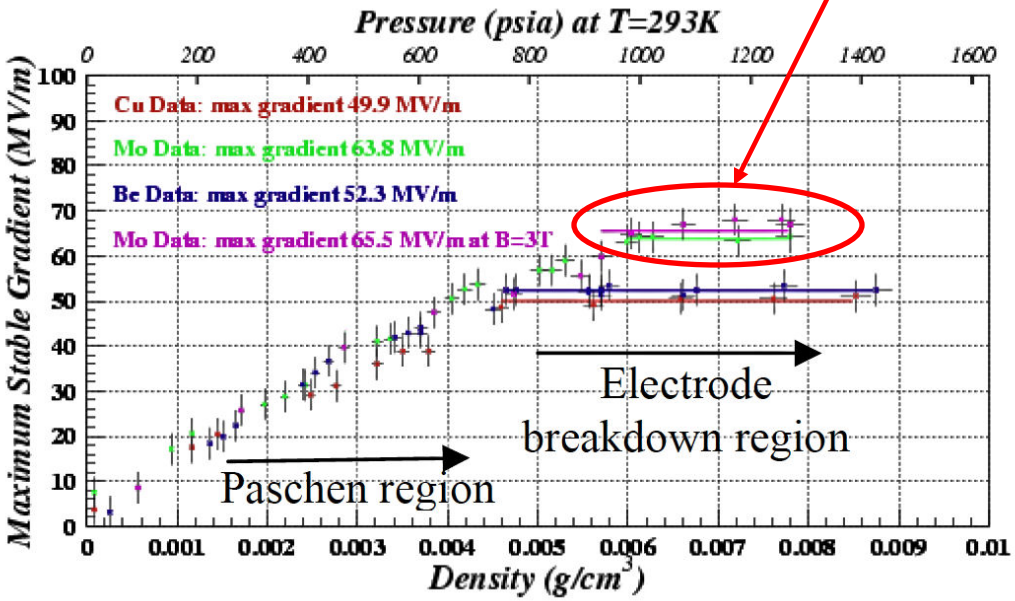
Surface Field Enhancement
Initiates the event & B focuses the e^- current which causes damage

High Pressure H_2 Filled Cavity Work *with Muons Inc.*

- High Pressure Test Cell
- Study breakdown properties of materials in H_2 gas
- Operation in B field
  - No degradation in M.S.O.G. up to ≈ 3.5T
- **Next Test – Repeat with beam**

No Difference B=0 & B=3T





Well beyond gradient requirement for HCC

The MAP NCRF Program
R&D Strategy

- *Technology Assessment (continuation of existing multi-pronged program & explore new ideas)*
  - Surface Processing
    - Reduce (eliminate?) surface field enhancements
      - SCRF processing techniques
        - » Electro-polishing (smooth by removing) + HP H_2O rinse
      - More advanced techniques (Atomic-Layer-Deposition (ALD))
        - » Smooth by adding to surface (conformal coating @ molecular level)

    Vacuum
  - Materials studies: Use base materials that are more robust to the focusing effects of the magnetic field
    - Cavity bodies made from Be or possibly Mo
  - Magnetic Insulation
    - Inhibit focusing due to applied B
  - High-Pressure Gas-filled (H_2) cavities

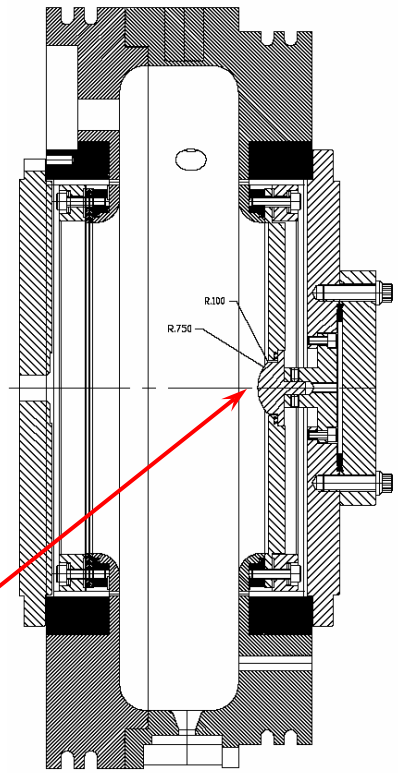
Testing Queue

- Primary goal is to collect a lot more data with as many test vehicles as possible (**And understand/fix coupler issues**) [Next 12-18 months]
  - 805 pillbox (modified & refurbished)
    - Fixed coupler port and will retest
      - With Cu and Be windows
      - New series of materials & processing (Cu) tests with Buttons (Imperial – A.Z-E)
  - Initial test of HP button cavity with proton beam
  - 201 MHz cavity coupler repair and re-test
  - 2nd HPRF beam test as needed
  - Rectangular box cavity with B ∥ E
  - 2nd rectangular box cavity with B ⊥ E
  - New pillbox is near ready (Muon's Inc.)
    - Can operate under pressure or vacuum
    - Has capability to replace end-walls (Be)
  - Be-Wall cavity
  - ALD cavity
    - Special-purpose cavity for processing in-situ with Atomic Layer Deposition
  - Test MICE production 201 MHz cavity in realistic B field [> 18 months out]

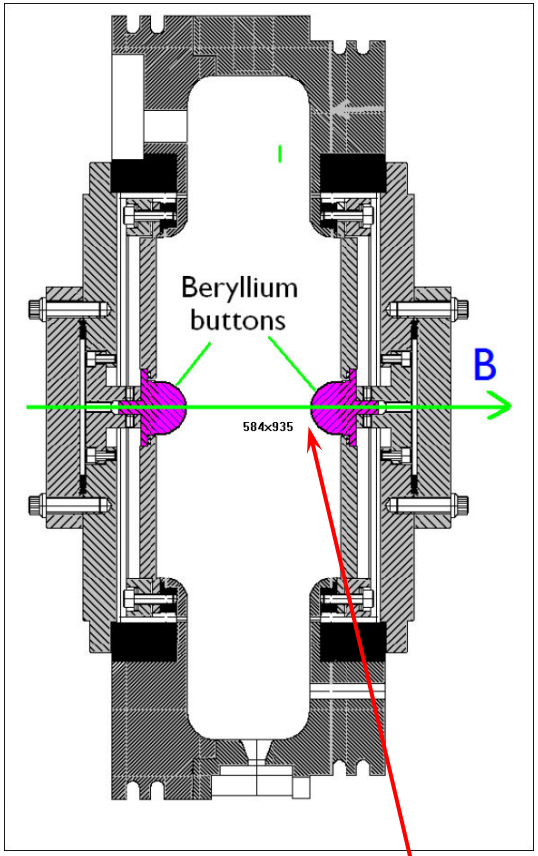
Recent R&D Highlights

Material Studies

- Pillbox cavity refurbished & "Button" system redesigned.
  - Note: Results to date did indicate that Mo can improve performance at a given B field by somewhat more than 50% & that TiN helped
    - 16.5MV/m → 26MV/m
    - But, lots of scatter in data



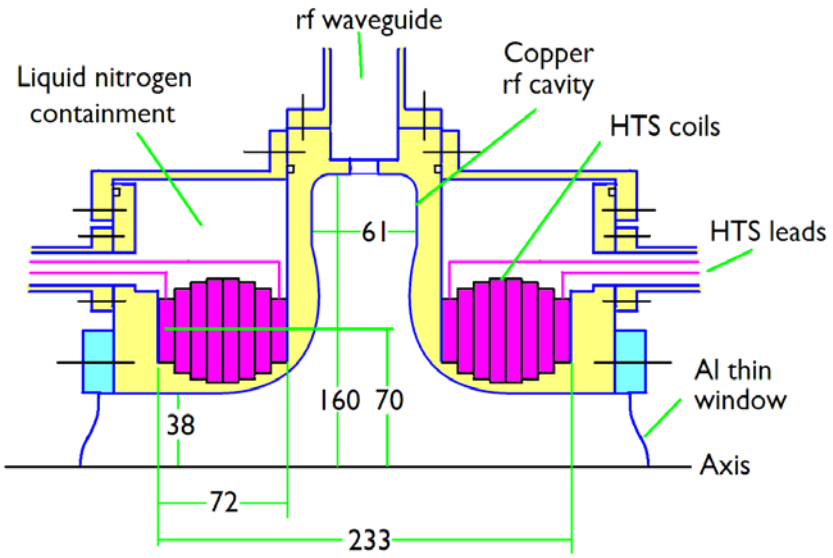
(*1.7x* field enhancement factor on button surface)

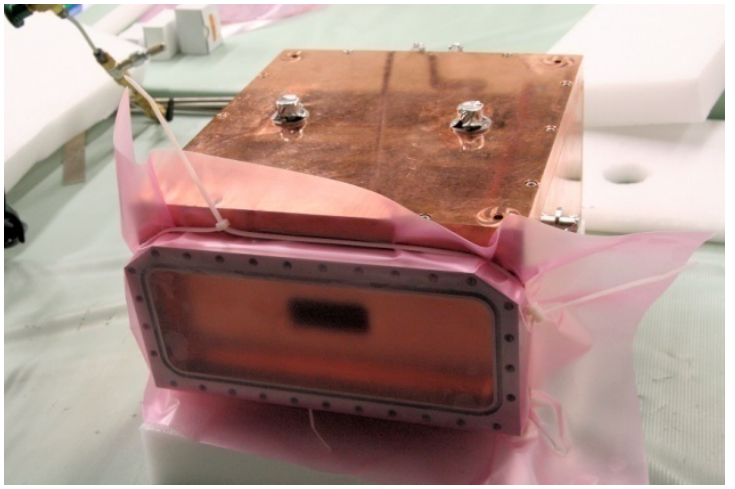


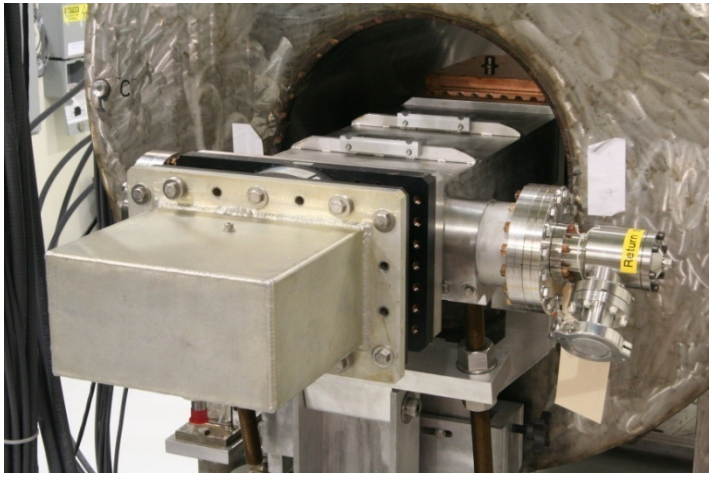
New - FE ≈ 3

Magnetic Insulation

Conceptual Design

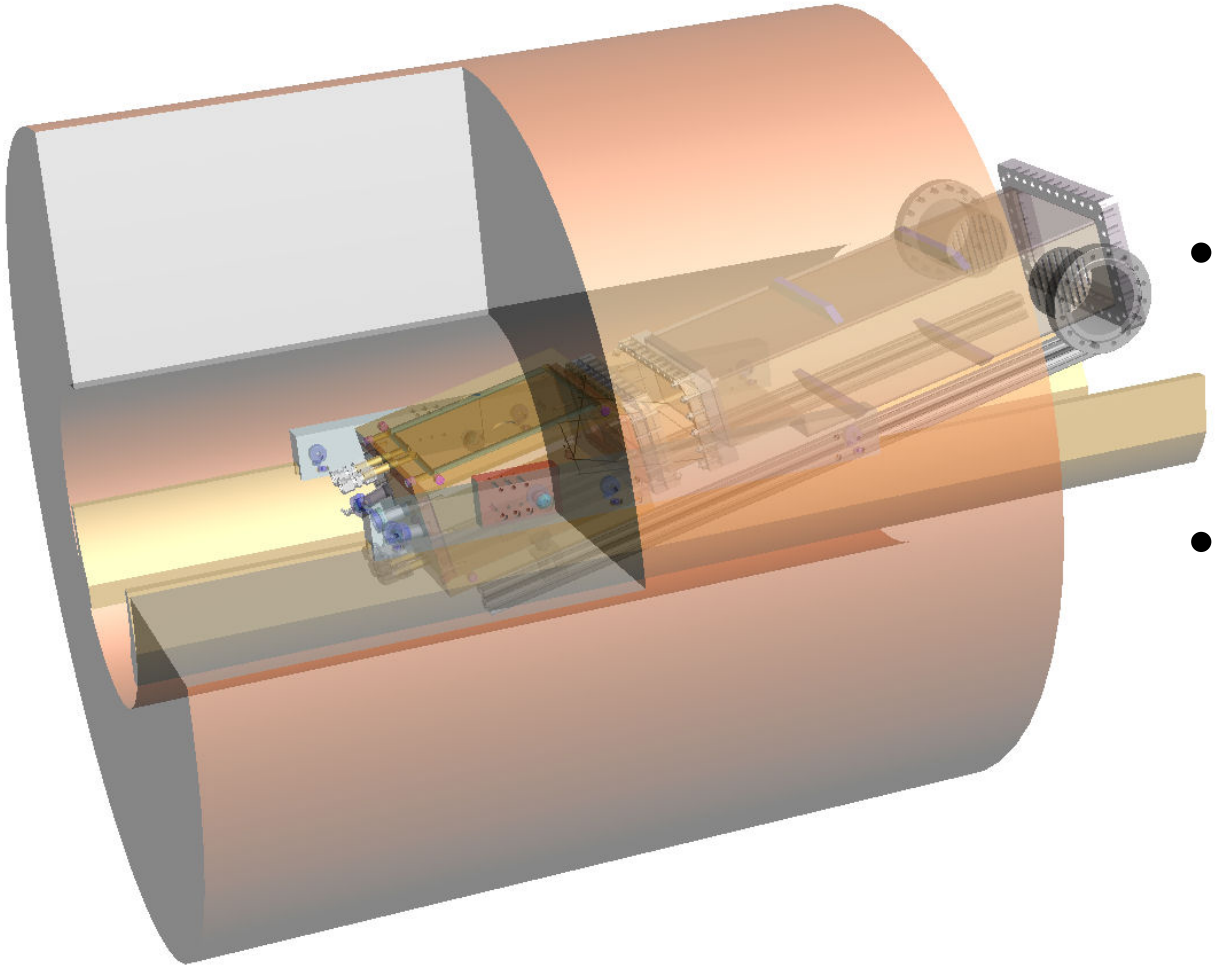






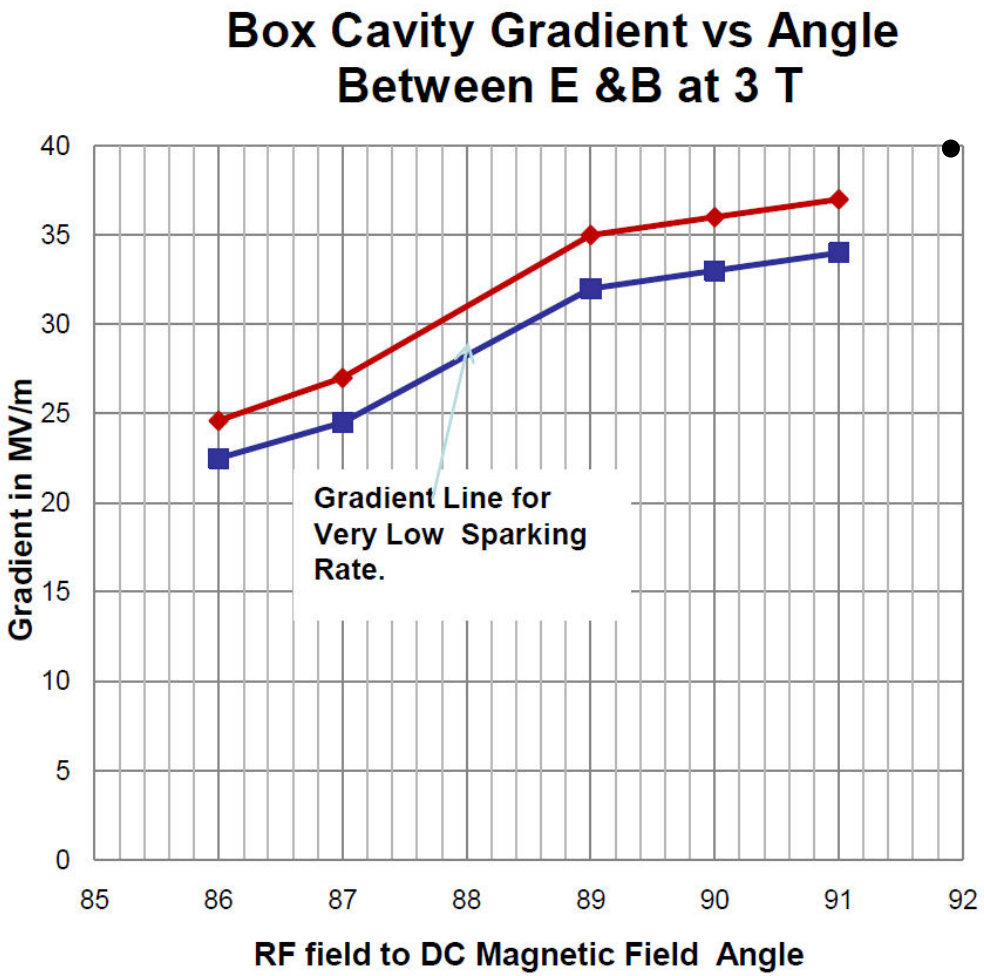
- Although lattices that employ magnetic insulation have drawbacks with respect to the required RF power, we are studying the concept using a newly completed 805 MHz box cavity

Box Cavity in Solenoid



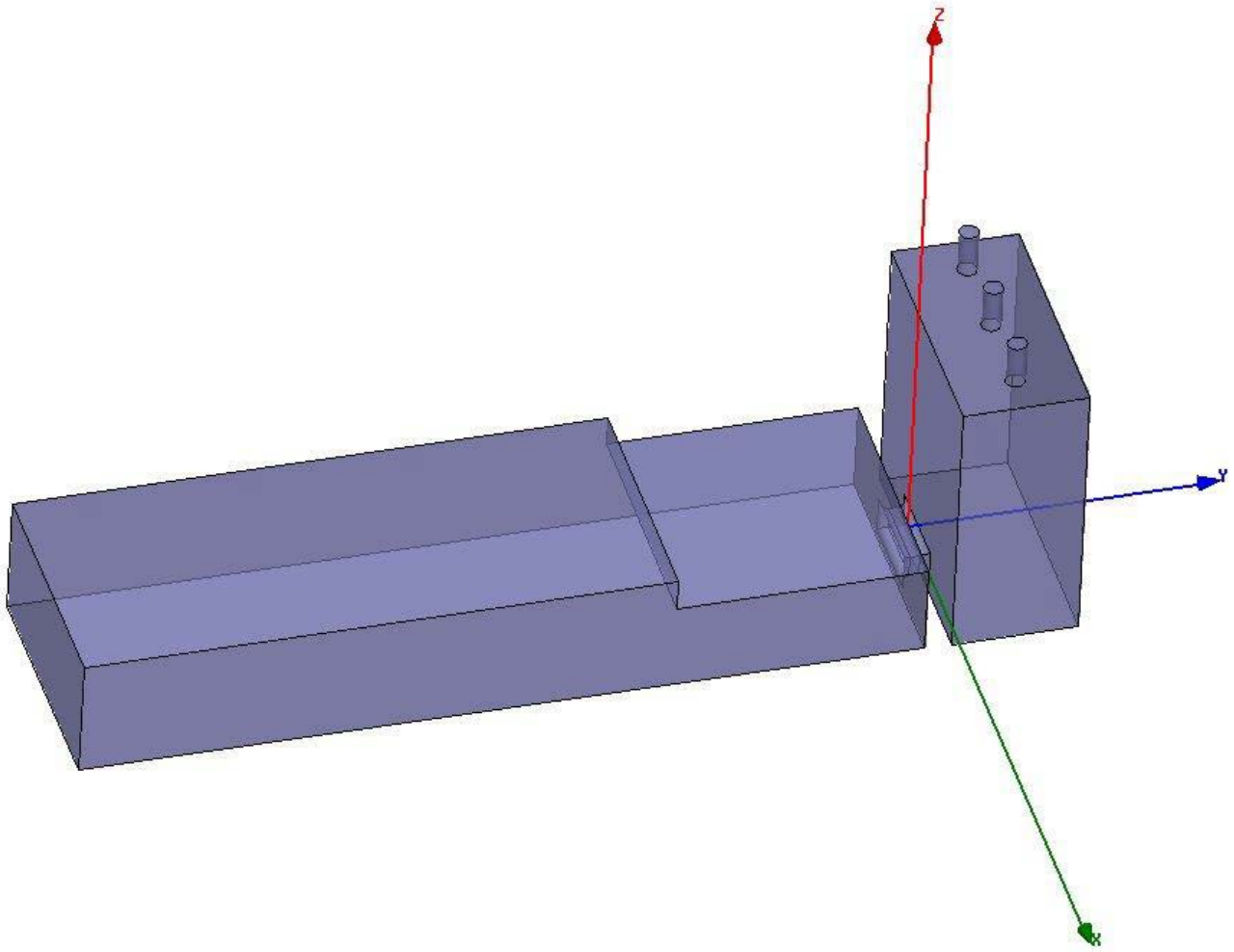
- Max angle w/r to horizontal ≈ 12^0
  - E at 78^o w/r to B
- Max Gradient (B=0)
  - 50MV/m

Box Cavity
Preliminary Data



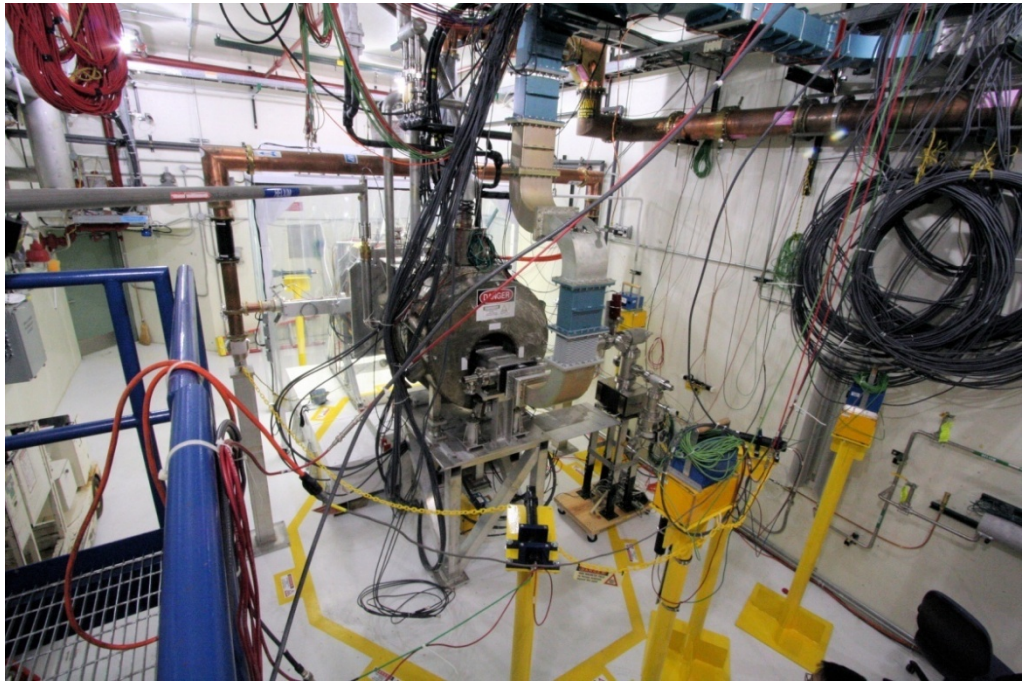
- Notes
  - B=0 running stable at ≈ 50 MV/m
  - Boroscopic inspection did not indicate much damage
    - May elect to cut open for detailed analysis
  - Follow-on
    - Test B ‖ E version of this cavity

Box Cavity – to be built
E ‖ B

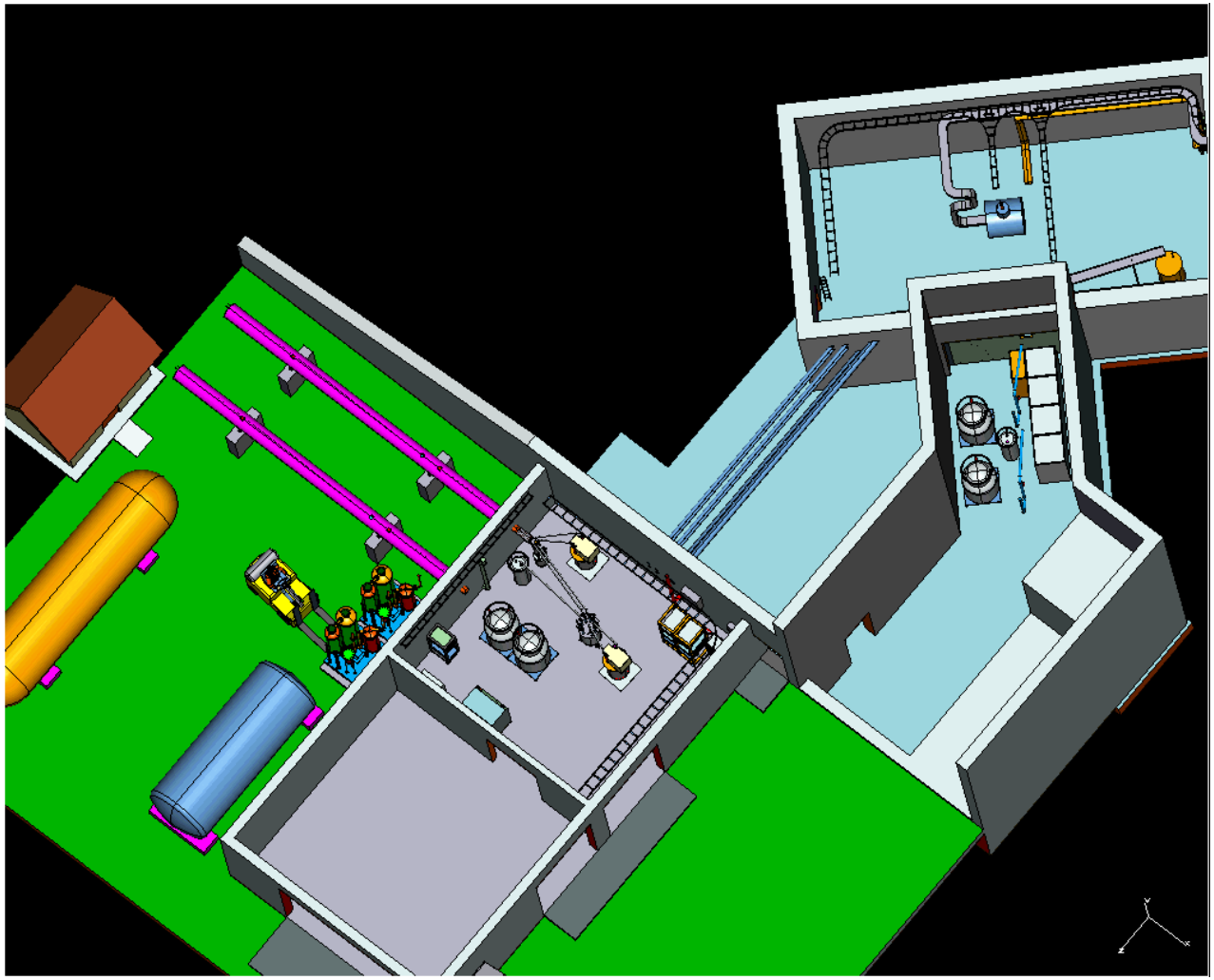


MAP RF Test Facility

- MuCool Test Area (MTA)
  - RF power
    - 201 MHz (5MW)
    - 805 MHz (12 MW)
  - Class 100 clean room
  - 4T SC solenoid
    - 250W LHe cryo-plant
  - Instrumentation
    - Ion counters, scintillation counters, optical signal, spectrophotometer
  - 400 MeV p beam line



MTA Layout

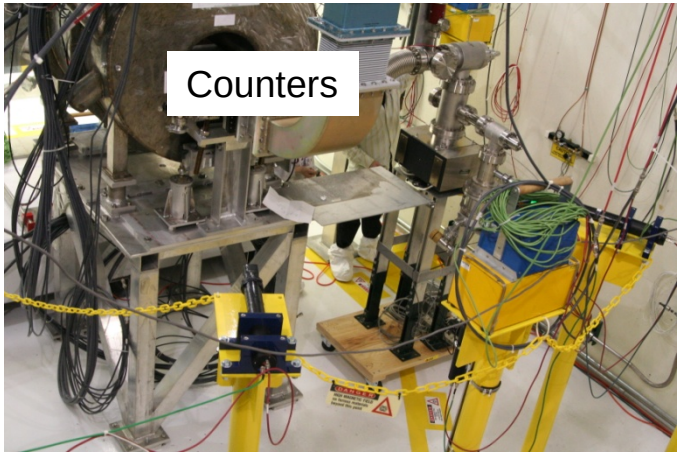


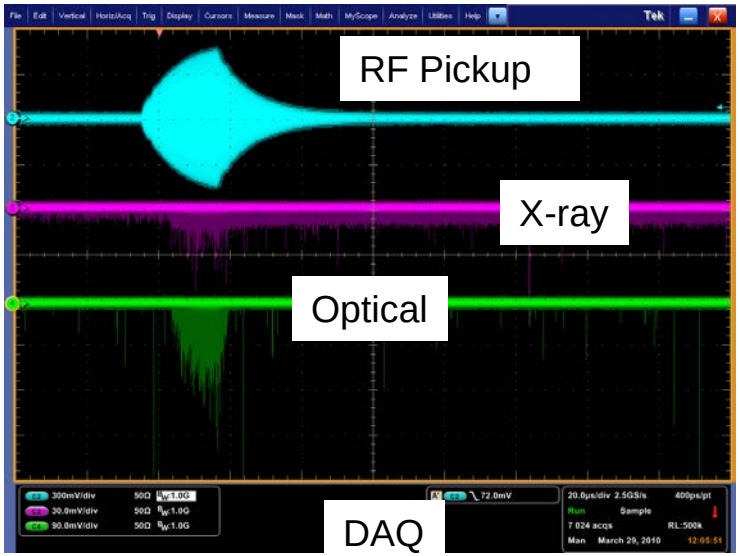
MTA Hall – Clean Room

MTA Hall – Clean Room II

- Goal for Clean room : Class 100
  - Achieved better than Class 10
    - Even with 3 people inside: Class 40
- Goal for Hall: Class 1000
  - Achieved Class 500

MTA Instrumentation



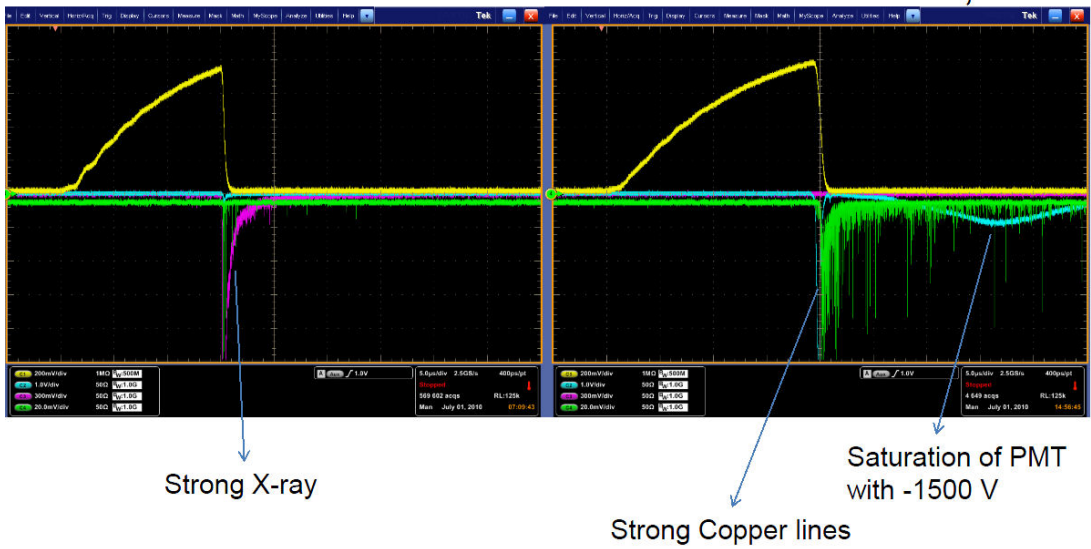


Optical Diagnostics

Yellow: Electric Pick Up
Cyan: Trigger PMT (-1500 V)
Magenta: X-ray (Channel 7)
Green: Spectrometer (515. 3 nm Copper line)

Data of 6/30: 0 T

Data of 7/01: 3 T, 0°

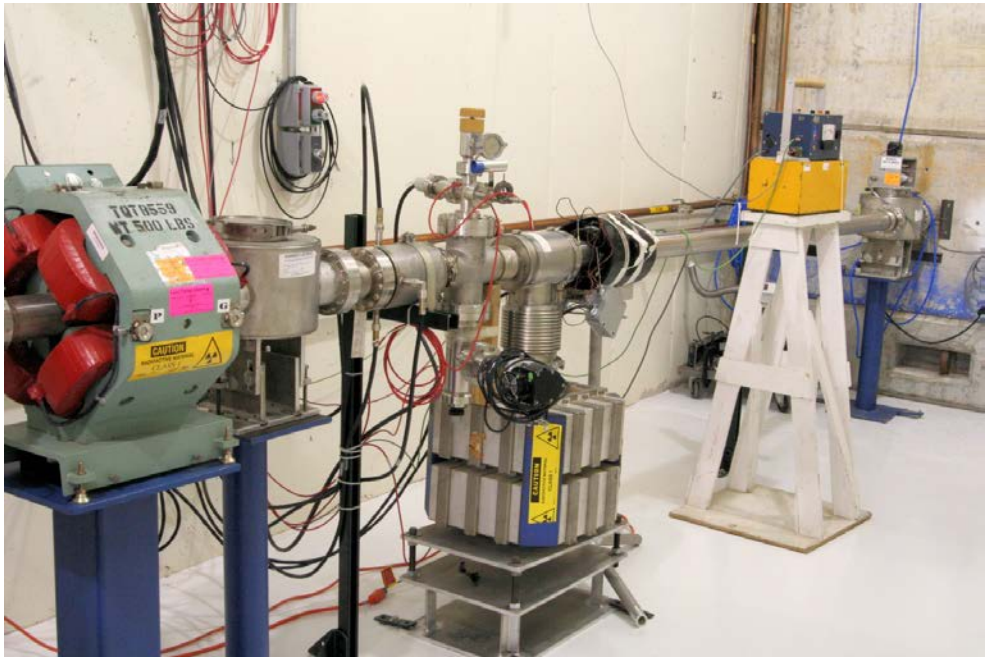


Acoustic diagnostics

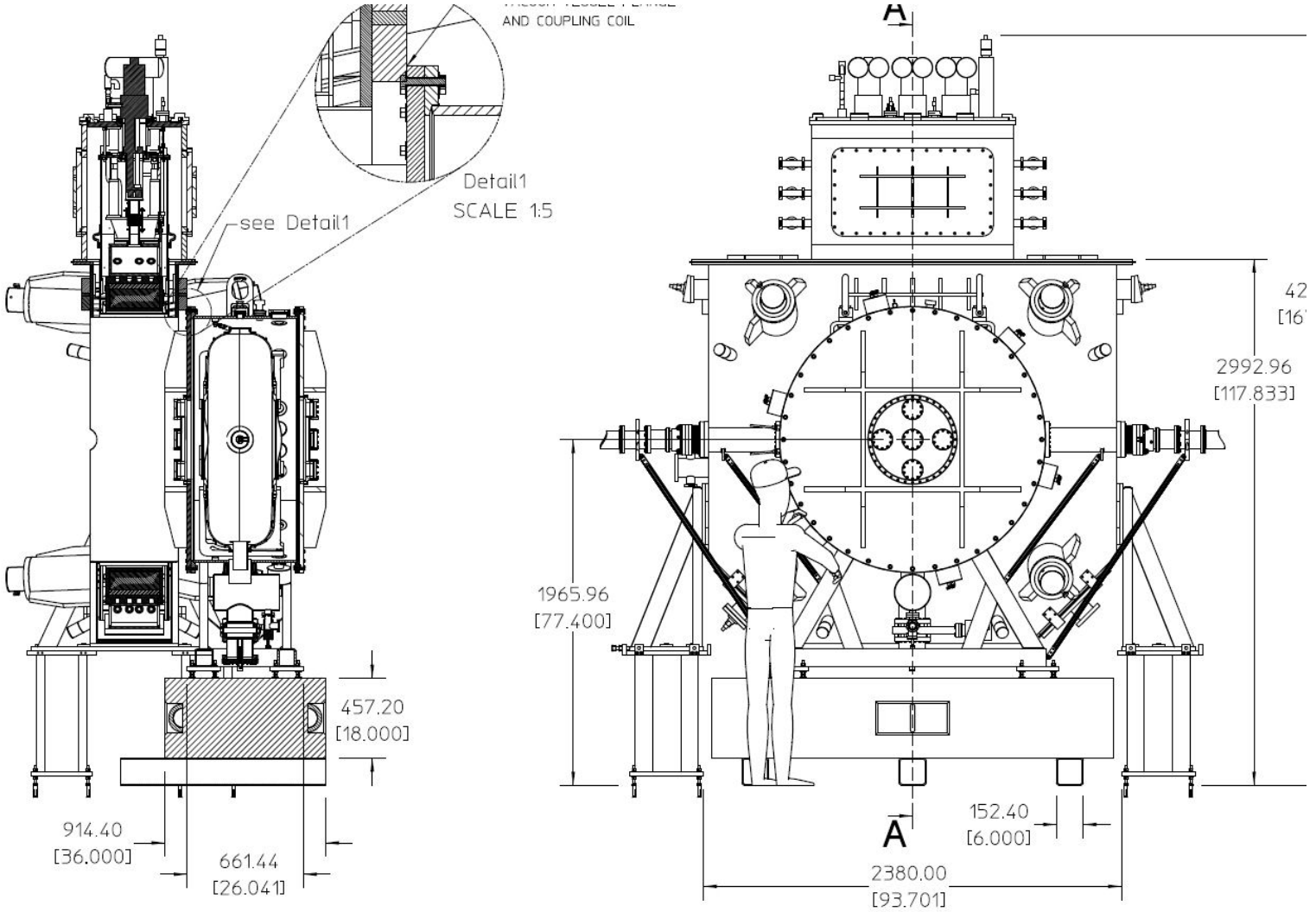
Planning to explore utilizing acoustic "imaging'
use instrumentation developed for COUPP

MTA Beam Line Status

- Beam Line Installation
  - Complete
- Beam Line commissioning to first beam stop.
  - Complete
- Radiation assessment submitted to DOE
- Radiation and Safety documents have now been approved by DOE and the Fermilab director
  - Running Approved!
- First beam experiments by March



Testing 201 MHz Cell in realistic B



Summary

- We have a comprehensive program aimed at developing a solution to the *"RF Challenge"*
- The experimental program is now coming on strongly and is backed by simulation efforts.
- The next 18 months will be very busy
- The arrival of the MuCool Coupling Coil will require 4-6 month down time for installation

END