# 5-Year RF R&D Plan

**MUTAC Review**

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Fermi National Accelerator Laboratory


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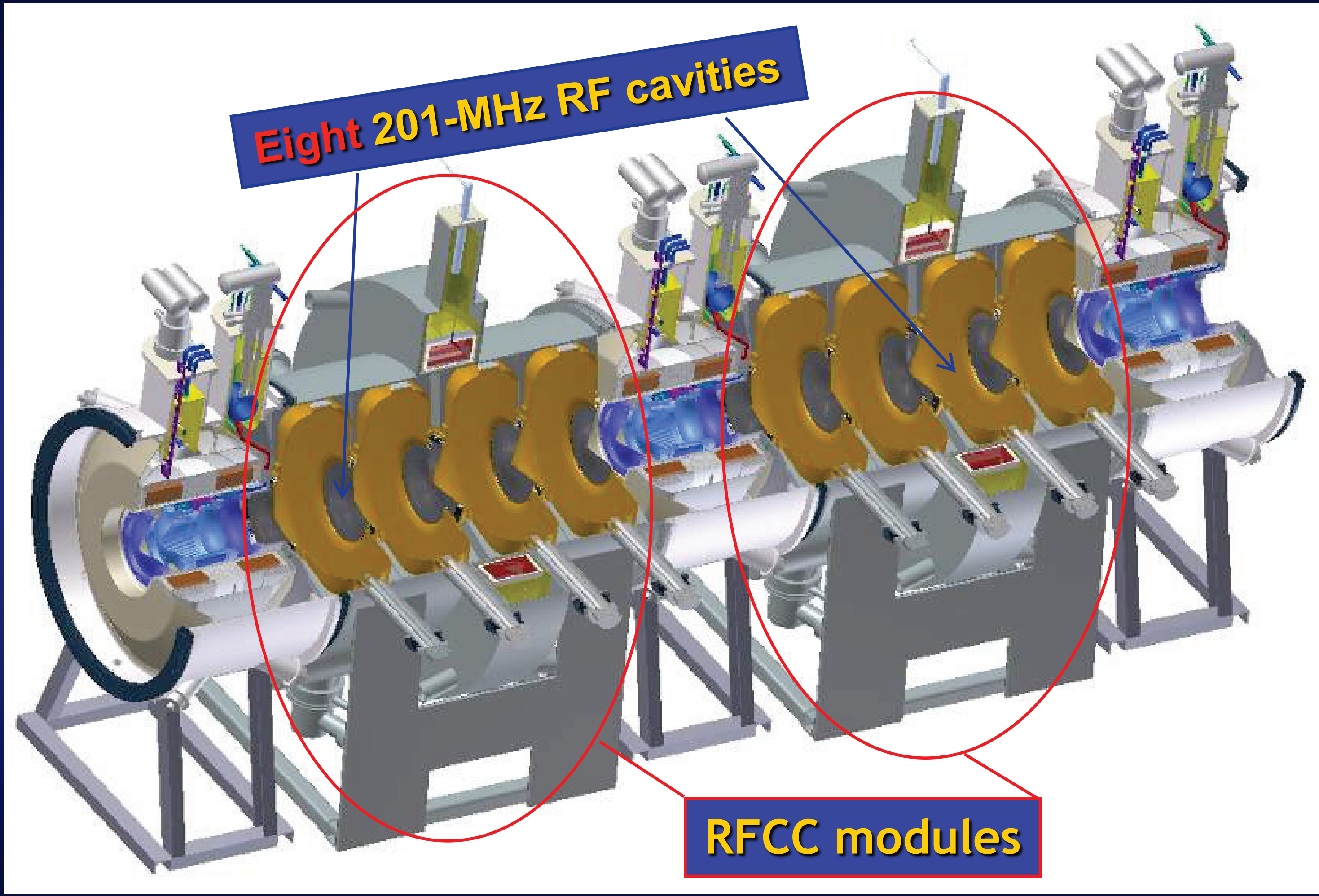
# Outline

- Introduction
- RF R&D Plans
  - RF cavities for MICE
    - Status (cavity body, RF coupler, Be windows, Tuners, …)
  - MuCool 201-MHz cavity
    - Baseline design for MICE
  - Experimental Studies at 805-MHz
    - RF gradients (pillbox cavity with and without RF buttons) in multi-Tesla magnetic fields (Huang)
    - Cavity with magnetic insulation to study ExB effect
    - High pressured RF cavity (Muons, Inc. + FNAL) (Yonehara)
    - Beam test plan at MTA, FNAL (Torun)
  - Other Programs
    - Atomic layer deposition (ALD) cavity (ANL)
    - Dielectric RF cavity (Muons Inc. + FNAL)
    - RF breakdown studies (Palmer)
- Summary

# Introduction

- Recommendations from last MUTAC Review on RF programs
  - Pursue a more aggressive program at MTA, taking advantages of its unique facilities to do experiments that compliment the MICE program
- Development of normal conducting 201-MHz cavity that can operate at a gradient of ~ 16 MV/m in a few Tesla magnetic fields environment (MICE gradient is limited to 8 MV/m by available RF power)
  - Hardware development: exploring engineering solutions and challenges (MuCool and MICE)
  - RF breakdown studies in magnetic fields and possible solutions

# Muon Ionization Cooling Channel (MICE)




MICE Cooling Channel
Courtesy of S. Q. Yang, Oxford Univ.

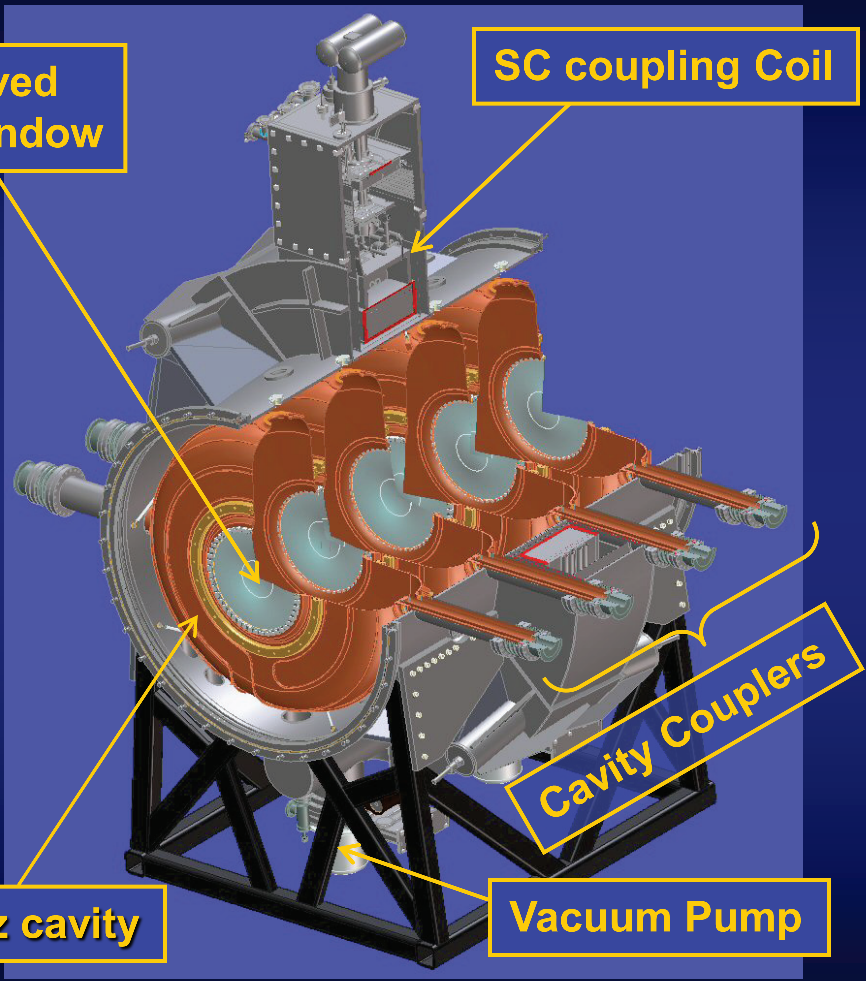
# Status of MTA Vacuum RF Programs

- **Current status**
  - Designed, built and tested 805-MHz and 201-MHz cavities at MTA, FNAL
  - The 201-MHz cavity reached 19 MV/m without external magnetic field
  - The cavity kept at 14 MV/m with ~ 0.75 Tesla stray magnetic fields from Lab-G magnet
- **What we have learned so far**
  - Achievable accelerating gradients degrade due to external magnetic fields (nearly a factor of 2 at 3-Tesla magnetic field)
  - External magnetic fields cause damage on cavity surface associated with RF fields

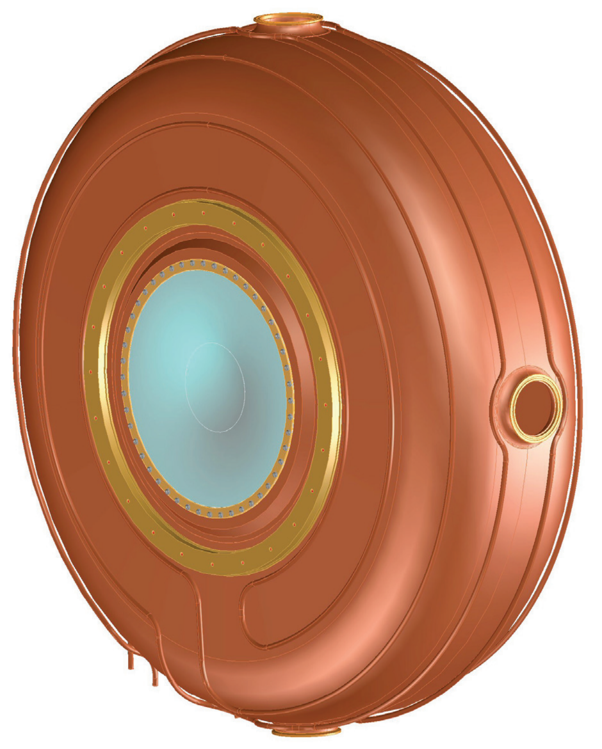
# Summary of R&D Plans

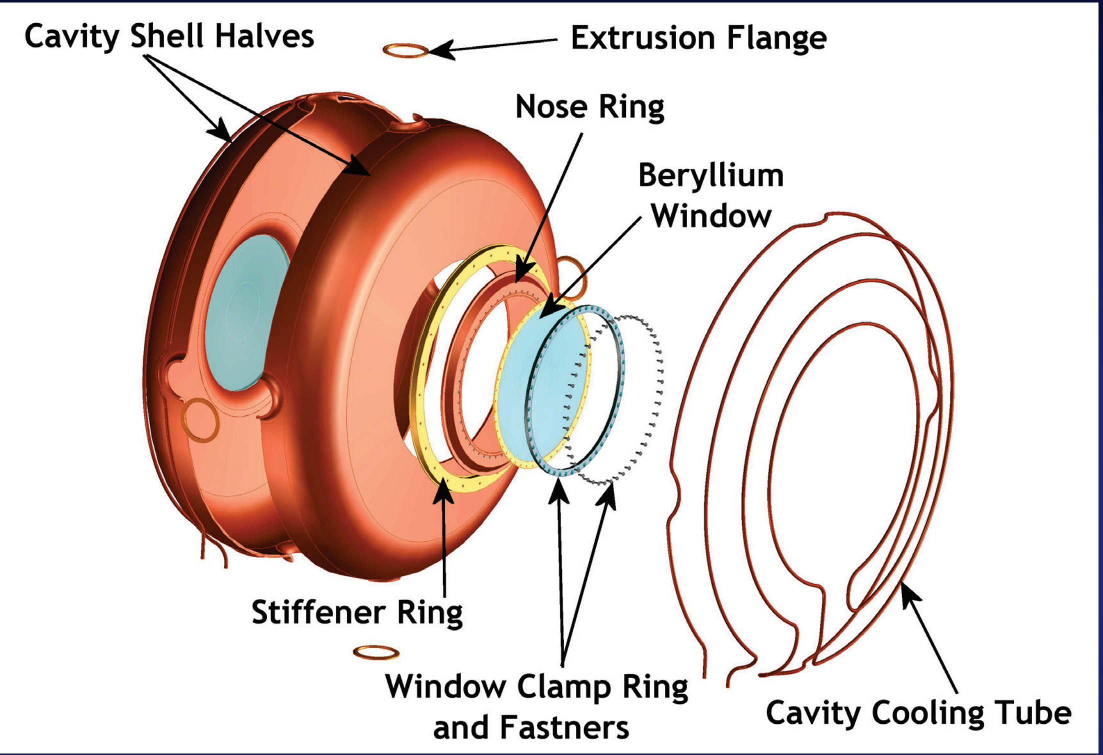
- Continue experimental studies at 805-MHz
  - The 805-MHz pillbox cavity has been refurbished and ready for more button tests for RF breakdown studies
  - High pressured cavity test at MTA (Muons, Inc. + FNAL)
- 201-MHz cavity program
  - RF cavities for MICE
  - Superconducting coupling coil for MuCool RF breakdown studies at MTA
    - Collaboration with ICST of HIT, Harbin for design and fabrication: fabrication contract to be awarded this week
- RF breakdown studies
  - Magnetic insulation
    - Box cavities at FNAL to study ExB effects
  - High pressured cavity at different frequencies (Muons, Inc.)
  - Atomic layer deposition (ALD) cavity
  - Physics model to understand RF breakdown in magnetic fields

# Responsibility for MICE (RFCC Module)



# The 201 MHz Cavity (MuCool/MICE)






Spinning of half shells using thin copper sheets and e-beam welding to join the shells; extruding of four ports; each cavity has two pre-curved Beryllium windows, but also accommodates different windows

# 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 diameter and thickness: 42-cm and 0.38-mm
- Nominal parameters for MICE and cooling channels in a neutrino factory
  - 8 MV/m (~16 MV/m) peak accelerating field
  - Peak input RF power: 1 MW (~4.6 MW) per cavity
  - Average power dissipation per cavity: 1 kW (~8.4 kW)
  - Average power dissipation per Be window: 12 watts (~100 watts)

# Other Module Components

Cavity Suspension

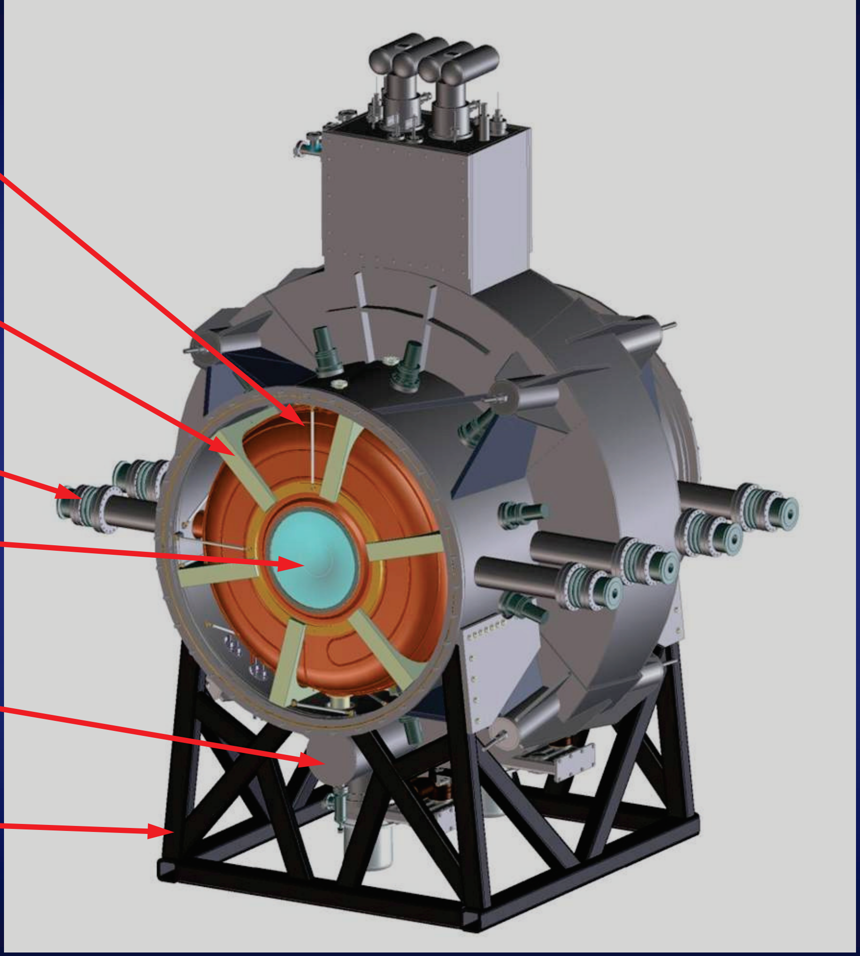
Dynamic Tuners

RF Coupler

Beryllium Window

Vacuum System

Module Support

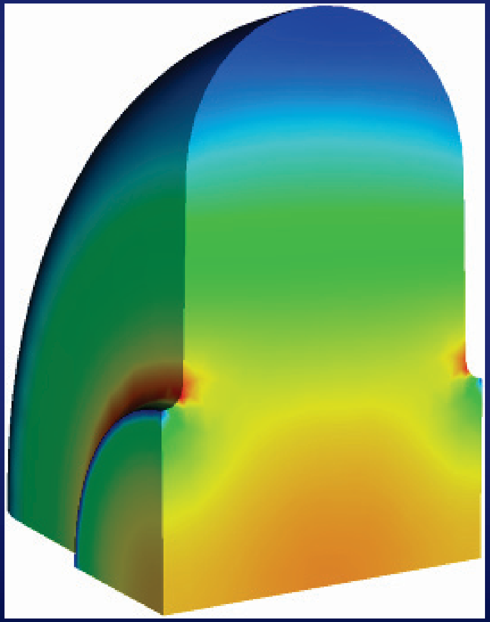


# MICE RF Cavity Status

- MICE RF cavity design is based on the successful prototype cavity for the US MuCool program
- Fabrication of the prototype cavity was successful
- The fabrication techniques used to produce the prototype will be used for the MICE RF cavities
    - A slight reduction in cavity diameter to raise the frequency
- Cavity fabrication contracts have been awarded
- Copper sheets have been shipped to the spinning company
- First five cavities will be delivered to LBNL middle next year
- Fab. & design of other accessory components progressing well
    - Be windows, RF power coupler, tuners, cavity support, vacuum and integration with RFCC module

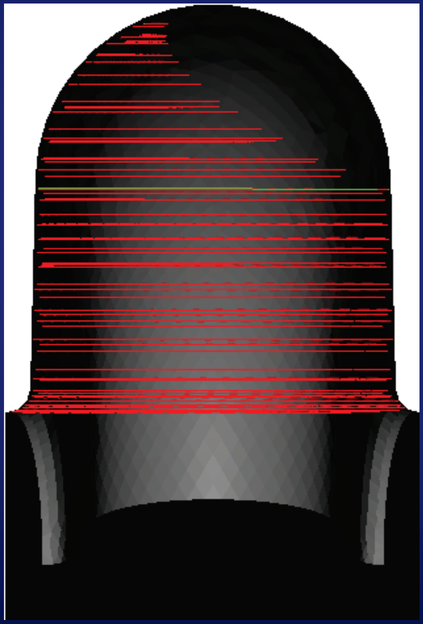
# Study of Magnetic Insulation

- **Numerical studies at BNL and SLAC (in collaboration) using Omega-3P and Track-3P codes,**
  - Cavity with flat windows: 5 MV/m on axis; 2-T uniform external magnetic field; scan of a few points from one cavity side



E field contour

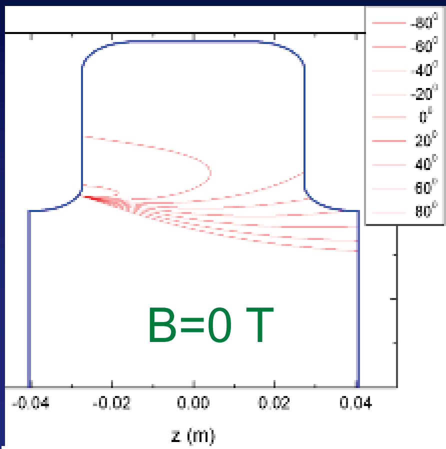
Trajectories without external B field

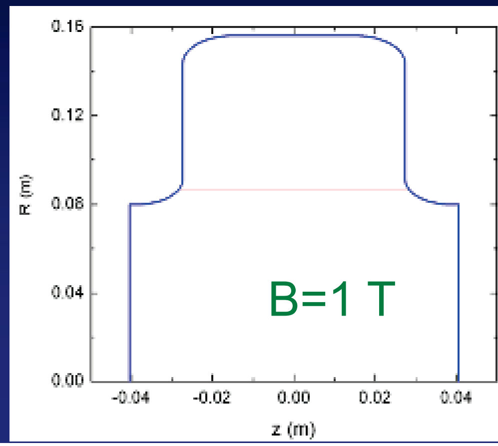


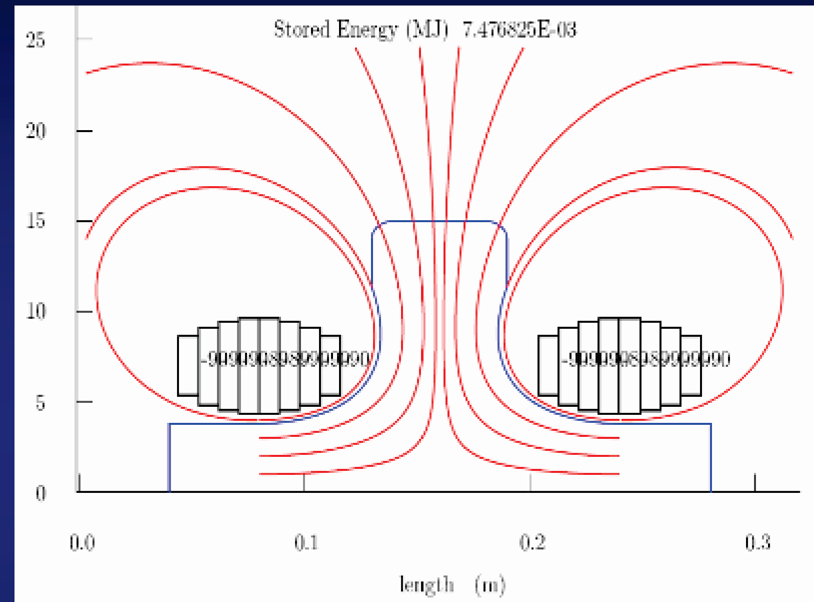
Trajectories with external B = 2-T field

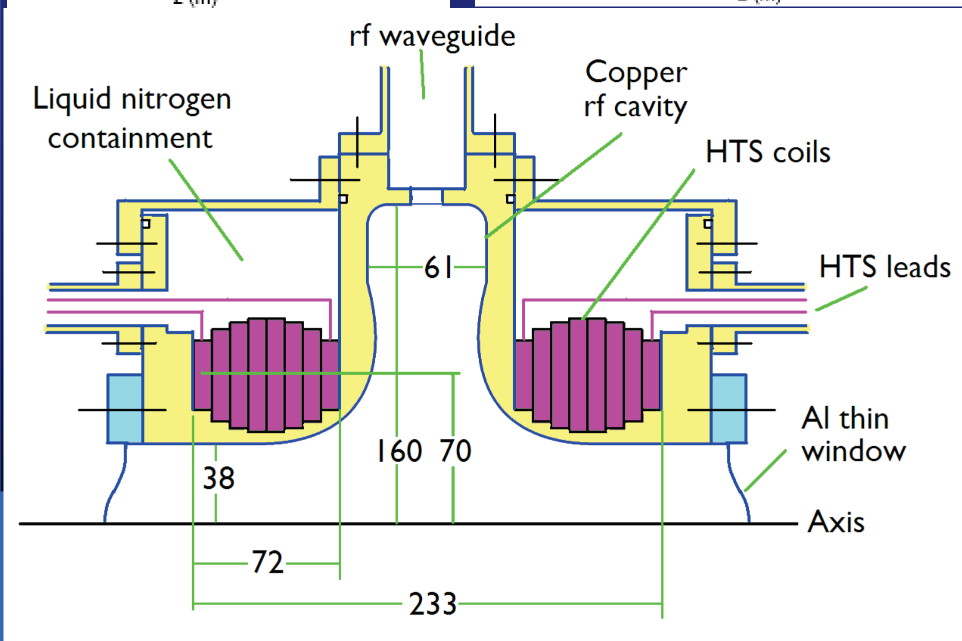
# Magnetic Insulated RF Cavity

- **Similar simulation results and magnetic field shielded RF cavity (BNL)**



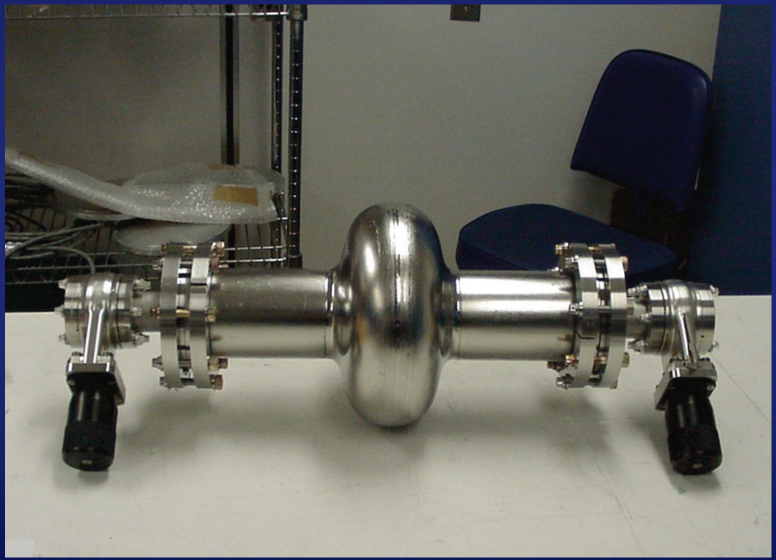



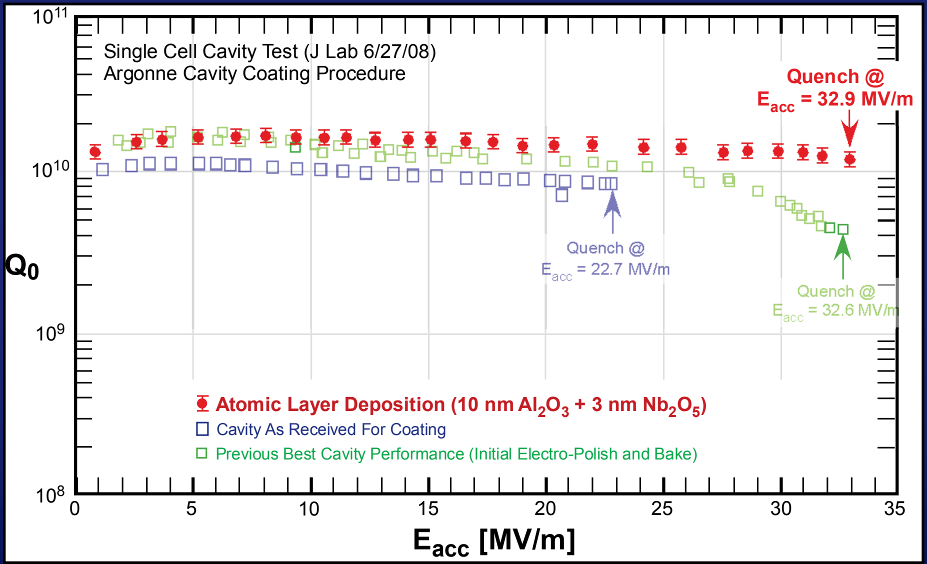




**Test of magnetic field shielded concept will be conducted using a box cavity (FNAL) at MTA**

# Can an ALD Cavity Eliminate Field Emission?

- **Single-cell cavity ALD coated at ANL**
  - Alumina barrier layer plus niobium oxide coating
- **Cavity prepared and tested at JLab**
  - Result equaled best previous performance with no FE



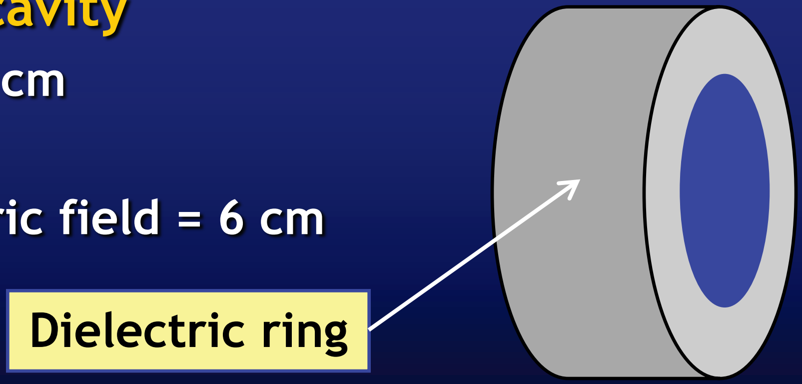



- **Encouraging results and the coating process is conformal, can coat compounds (e.g. NbN, and multilayers (Gurevich structure)**

# Dielectric Loaded RF Cavity

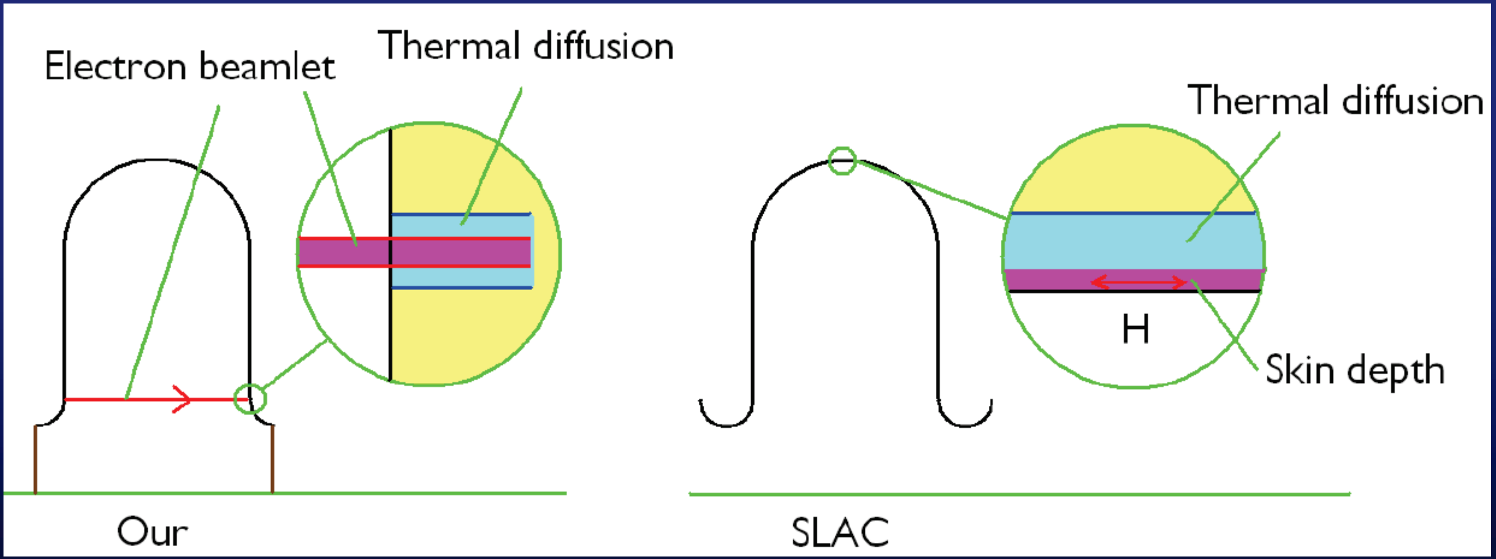
## Motivation:

- To fit pressurized cavities in HCC, size of cavity has to be reduced
- Examples:
  - 800 MHz dielectric loaded cavity
    - Maximum RF cavity radius = 8 cm, (pillbox cavity: 14.3 cm)
    - Radius of effective electric field (95 % from peak) = 3 cm
  - 400 MHz dielectric loaded cavity
    - Maximum RF radius = 16 cm (pillbox cavity: 28.6 cm)
    - Radius of effective electric field = 6 cm



# RF Breakdown Studies

- Two related RF breakdown problems by heating (magnetic & RF)
  - Magnetic field
  - Ohmic heating
- Possible solutions
  - Choice of materials
  - Lower initial temperatures



# Possible solution for Vacuum RF Breakdown?

- Based on the physics model, Beryllium is the ideal material for the cavity surface
- Aluminum is significantly better than Copper
- Operation at low temperature
- Magnetic Insulation
- Material and surface studies
  - ALD process

# Summary

- Muon Ionization Cooling Channel requires normal conducting RF cavity operating in a few Tesla magnetic field
  - Remains a challenge
- 201-MHz RF cavity for MICE progressing well
  - Contracts have been awarded and the first five cavities expect to be delivered to LBNL middle next year
  - Superconducting coupling coil contract to be awarded this week
- Plans for RF breakdown studies
  - Vacuum cavity
    - 805-MHz button cavity tests
    - 201-MHz cavity test to be resumed soon
    - ALD processed cavity to eliminate field emission
    - Dielectric loaded cavity
    - New cavity?
  - High pressured RF cavity tests
  - Test of magnetic field shielding cavity
- Superconducting RF for acceleration