Ernest Orlando Lawrence
Berkeley National Laboratory

Neutrino Factory
Muon Collider

MUCOOL RF Program

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MUTAC Review at BNL
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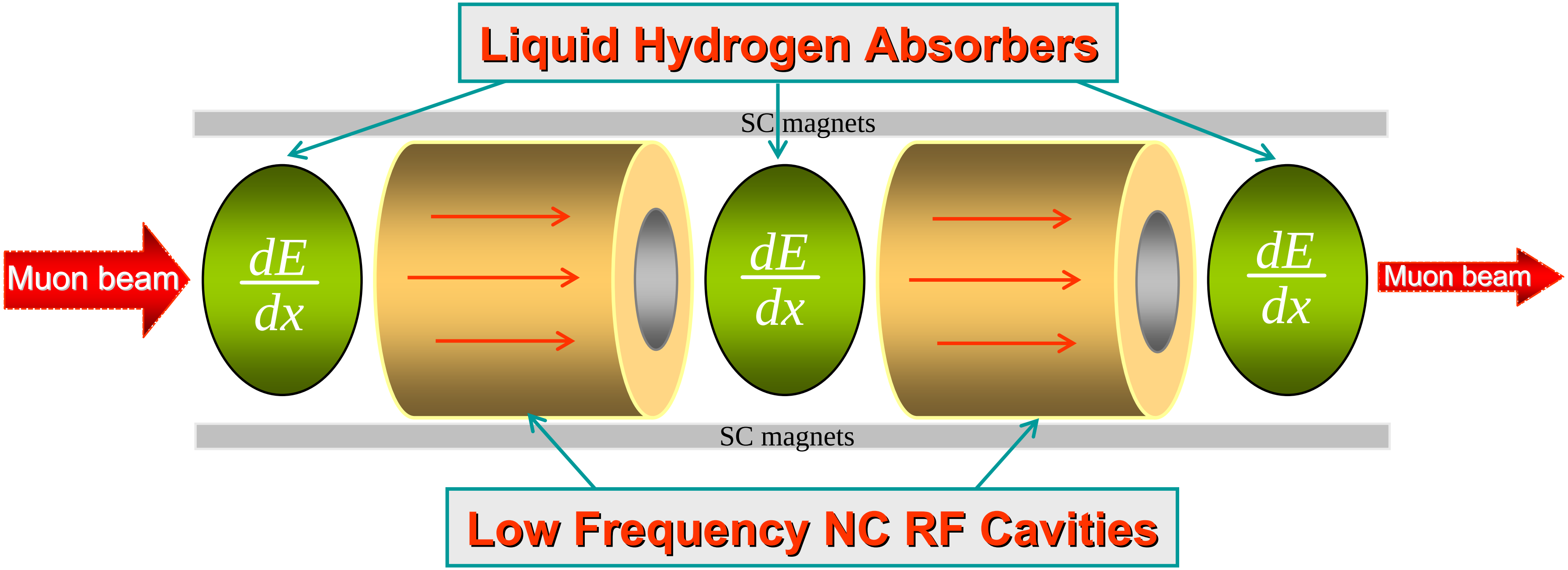
Ionization Cooling



- Strong magnetic field to confine muon beams
- Muons lose energy in liquid hydrogen absorbers
- Low frequency and high gradient RF cavities to compensate for the energy lost in longitudinal direction

A Real Cooling Channel

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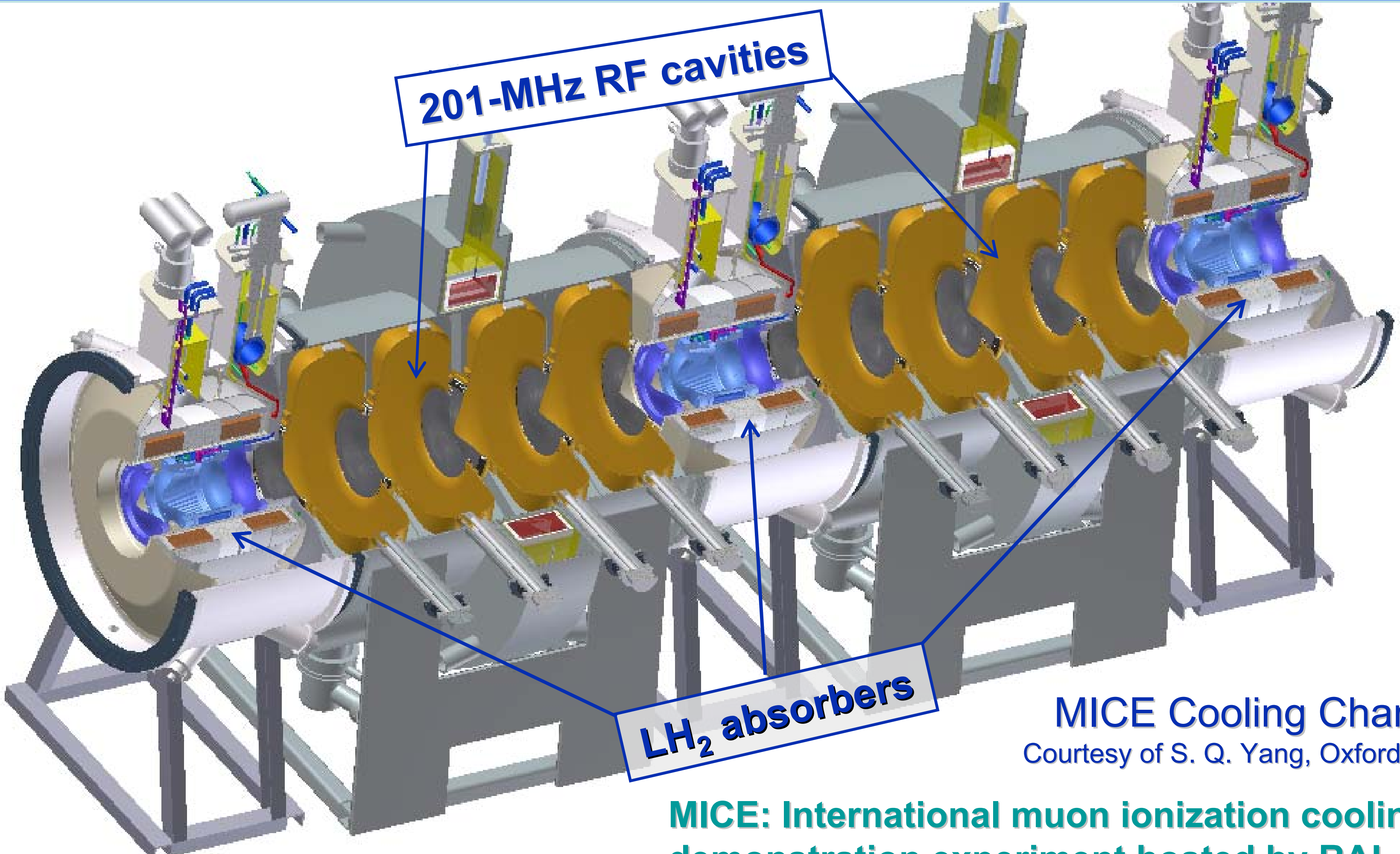
Single particle measurements: 10% cooling of ~ 200 MeV/c muons requires ~ 20 MV of RF Measurement precision can be as good as $\Delta(\varepsilon_{out}/\varepsilon_{in}) = 10^{-3}$



MICE Cooling Channel

Courtesy of S. Q. Yang, Oxford Univ.

MICE: International muon ionization cooling demonstration experiment hosted by RAL, UK

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Primary Goals

Neutrino Factory / Muon Collider

- Development of normal conducting 201-MHz cavity that can operate at a gradient of ~ 16 MV/m in a few Tesla magnetic fields environment
  - Exploring engineering solutions (challenges)
    - ✓ Cavity design (physics)
    - ✓ Engineering design
      - ✓ Cavity body
      - ✓ Ports
      - ✓ Couplers and RF windows
      - ✓ Be windows
    - ✓ Fabrication
  - ✓ RF conditioning and operation without and with *B* fields
- Preliminary studies
  - Experimental studies at 805-MHz with the Lab-G magnet
  - The 201-MHz cavity reached 16 MV/m without and with "magnetic fields"
  - Operating a cavity at 16 MV/m with strong *B* could be very challenging, but to be confirmed experimentally

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Neutrino Factory Muon Collider

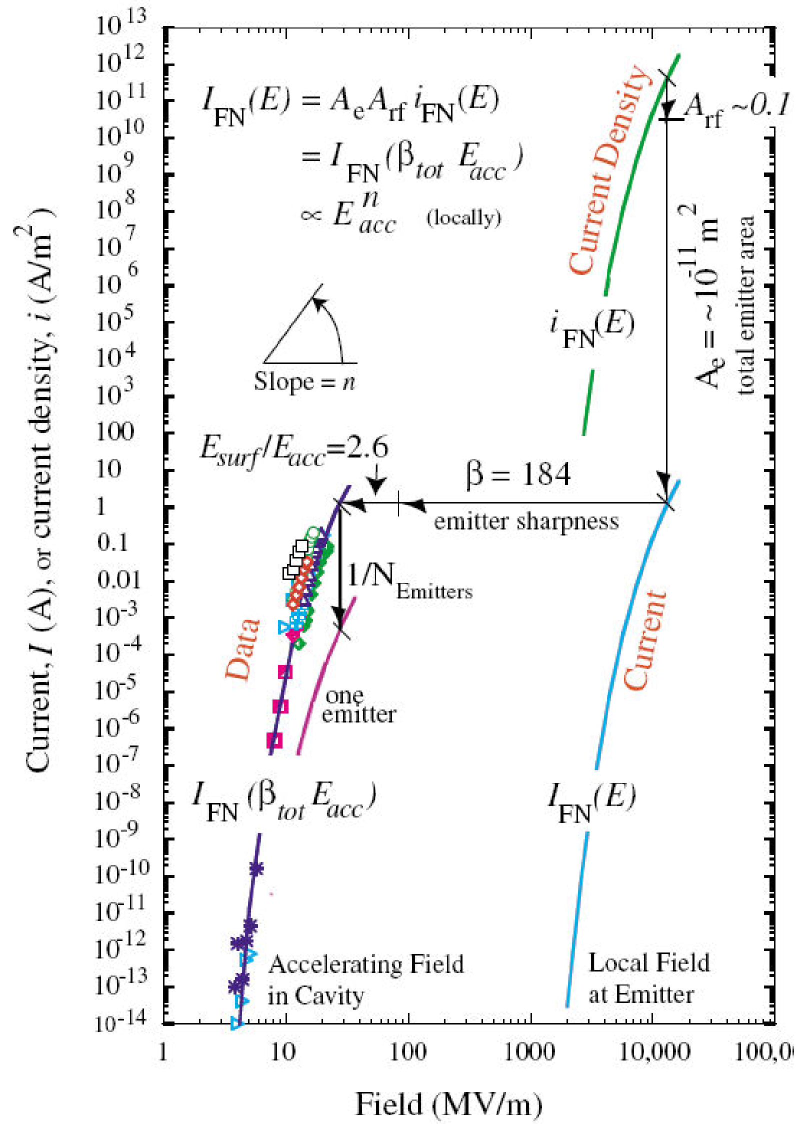
Fundamental Focus

Study the limits on accelerating gradient in NCRF cavities in magnetic field

- **We believe that the behavior of RF breakdown in general can be described (predicted) by**
- **Tensile strength of the material(s) used in the cavity fabrication (T)**
- **Local surface field enhancements (β_{eq})**

$$E_{surf} = \leq \sqrt{(2T/\varepsilon_o)}/\beta_{eq}$$

- **This should apply to all accelerating structures**
- **In SC structures local heating becomes problem first**
- **Follows universal curve**



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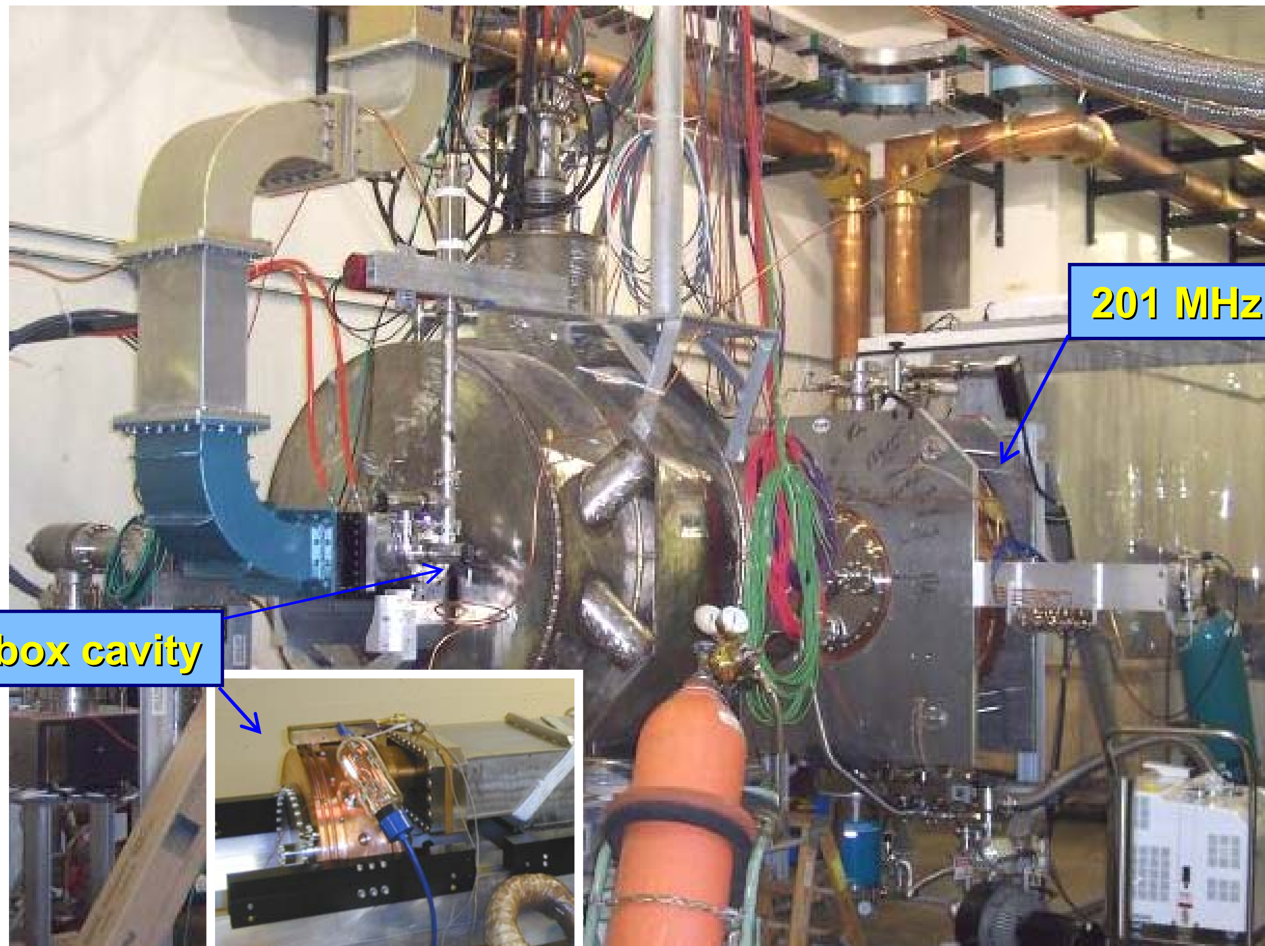
Neutrino Factory Muon Collider

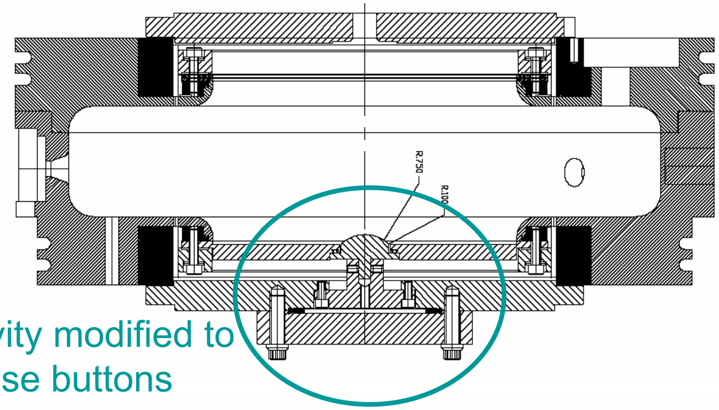
Cavity Test Setup at MTA

The 805-MHz and 201-MHz cavities installed at MTA, FNAL to study RF breakdown with external magnetic fields.

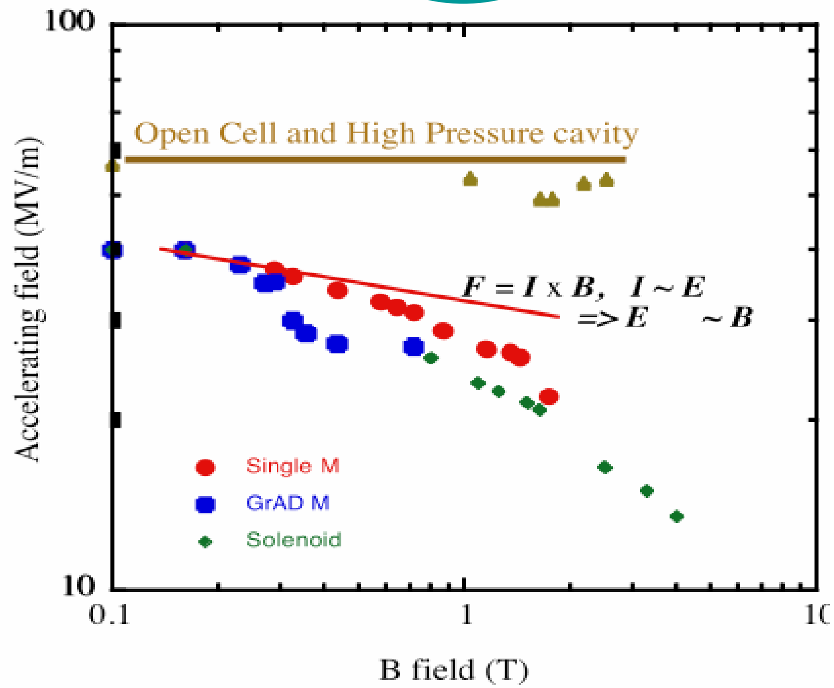


RF Breakdown R&D Using the 805-MHz Pillbox Cavity

- **What have we found so far**
  - **Achievable RF gradient is limited by external magnetic field,**
  - **Recent data confirms that conditioning with B fields is difficult.**
- **How does magnetic field affect RF cavities?**
  - **Physics of RF breakdown with magnetic fields**
  - **What materials and material properties are desirable?**
  - **What surface modification is possible?**
- **Button tests**
  - **Cavity re-configuration with buttons**
  - **Different button materials and coatings**



Cavity modified to house buttons

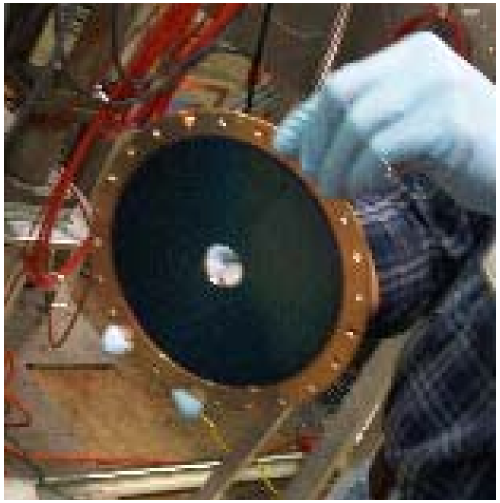


RF R&D with Button Tests

Looking for materials and coatings that can withstand high peak surface fields in strong magnetic fields

– Button tests at MTA, FNAL
  - ✓ Button holder for quick replacement of buttons
  - ✓ Special window and flange
  - ✓ Button is being installed for high power tests
    - Cu, Ti-N Cu, electro-polished Cu, Be, SS, Cr and W/Mo

– Ready for high power tests




Molybdenum buttons

201-MHz MICE Prototype

- **The cavity design parameters**
  - Frequency: 201.25 MHz
  - β = 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 time)
  - Average power dissipation per cavity ~ 8.4 kW
  - Average power dissipation per Be window ~ 100 watts

The 201-MHz cavity at MTA

High Power Tests

First RF conditioning started in late Feb. 2006 with

- Flat copper windows (plates) with Ti-N coatings
- RF diagnostics: field, power & radiation measurements
- Good vacuum ~ high 10^{-9} Torr

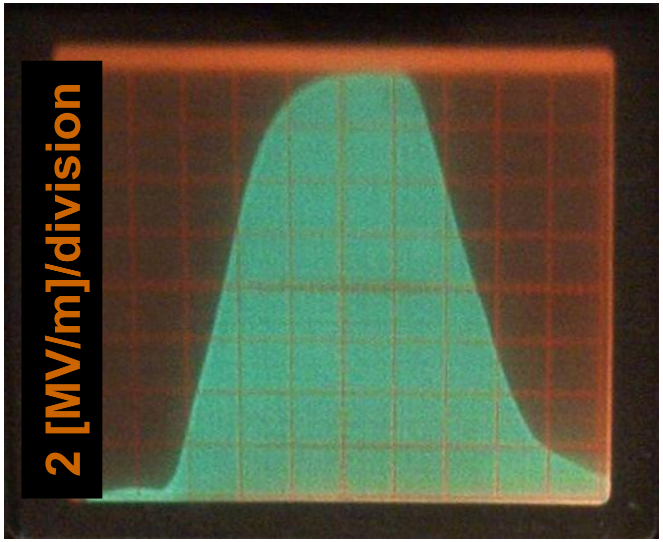
One year ago: without external magnetic field, the cavity was conditioned very quietly and quickly & reached ~ 16 MV/m

RF conditioning and tests continue.

We can reach 18 MV/m with and without magnetic fields.

We seem to see unexpected effects that will affect MICE performance.

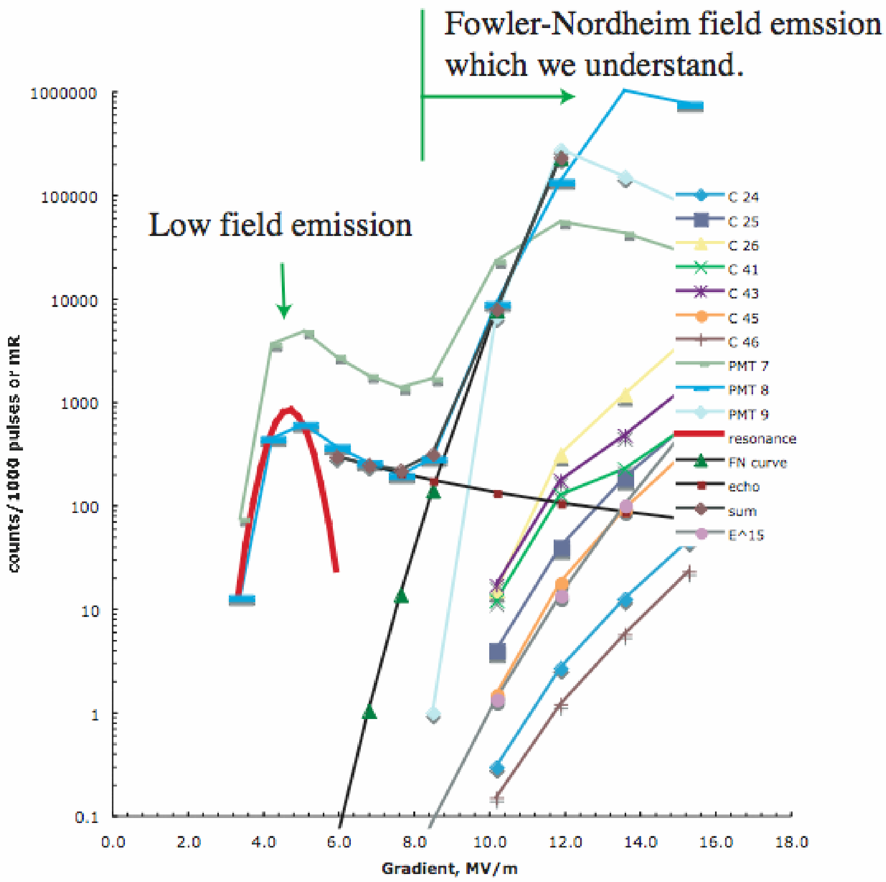
RF Pulse for conditioning



0.1 ms/division

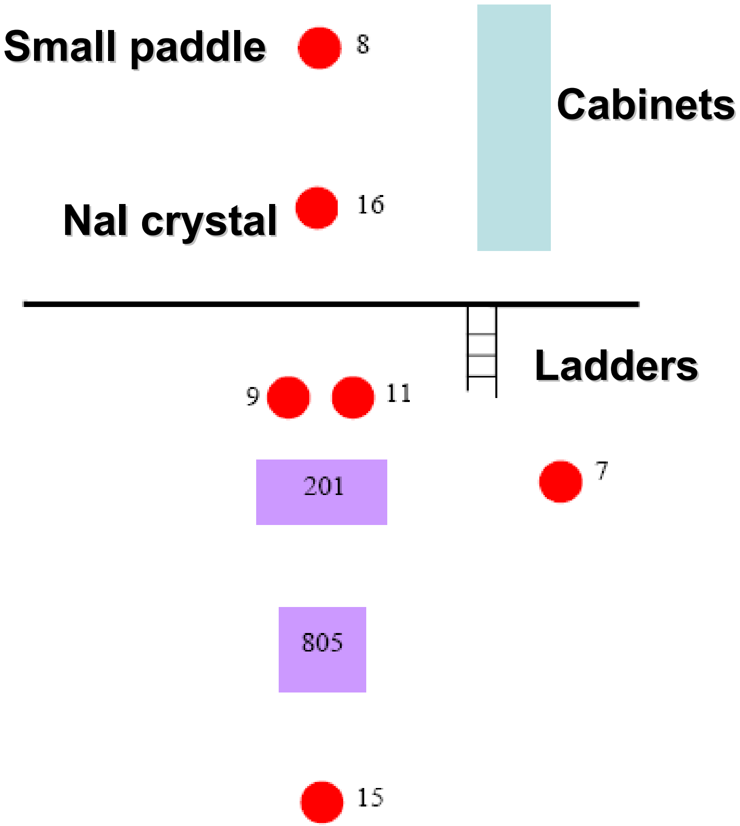
(400 ~ 800 μs at 10-Hz rep. rate)

New Observations



Distribution of PMT detectors

6 PMT detectors; 7 chipmunks around the cavities at MTA



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Comments & Be Windows

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- The cavity reached design gradient of 16 MV/m with almost no hard breakdown events, possible factors for the success:
  - Careful handling of the cavity
  - Good and clean surface finish
    - EP and high pressure water rinsing
  - Ti-N coatings of the windows
- High power tests with strong magnetic field are needed.
  - A coupling coil magnet
- Two curved Be windows are installed recently
  - Positive pressure with N_2 gas during the installation
  - Portable clean room, the environment is class 100
  - Inspection of the cavity surface
    - Clean and shining surface without any sign of damage
  - Be windows were baked in vacuum oven before installation
  - Two curved Be windows oriented pointing to the same direction
  - No differential pressure on Be windows

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Be Window Installation

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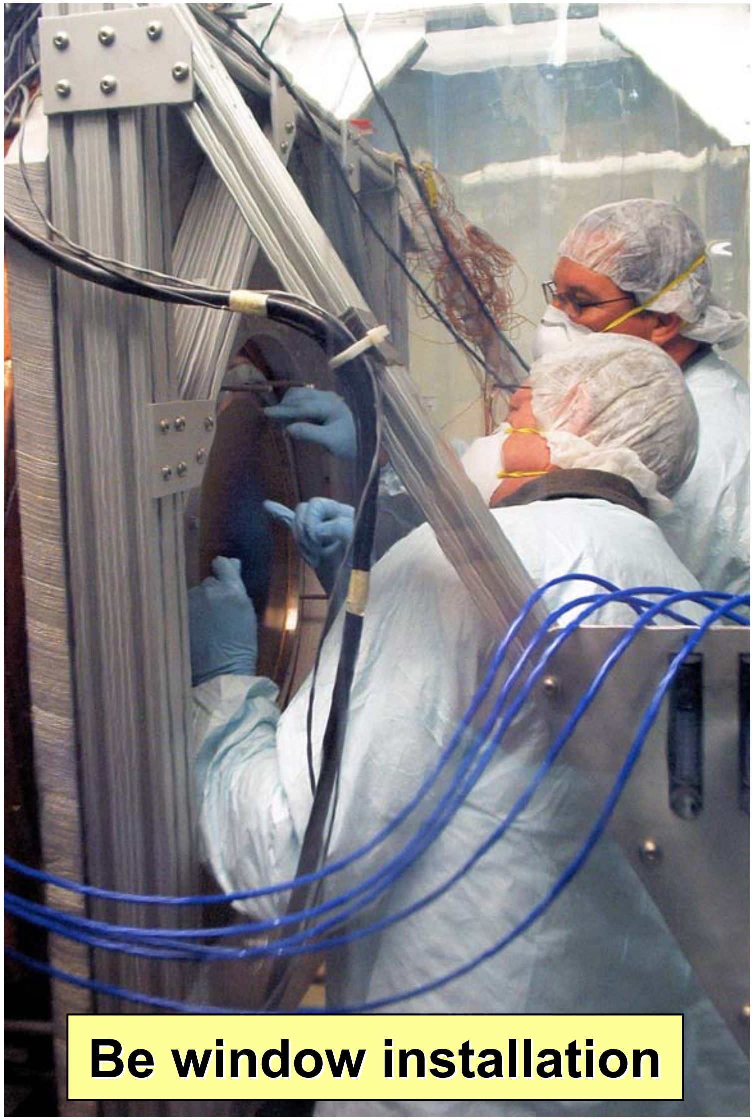
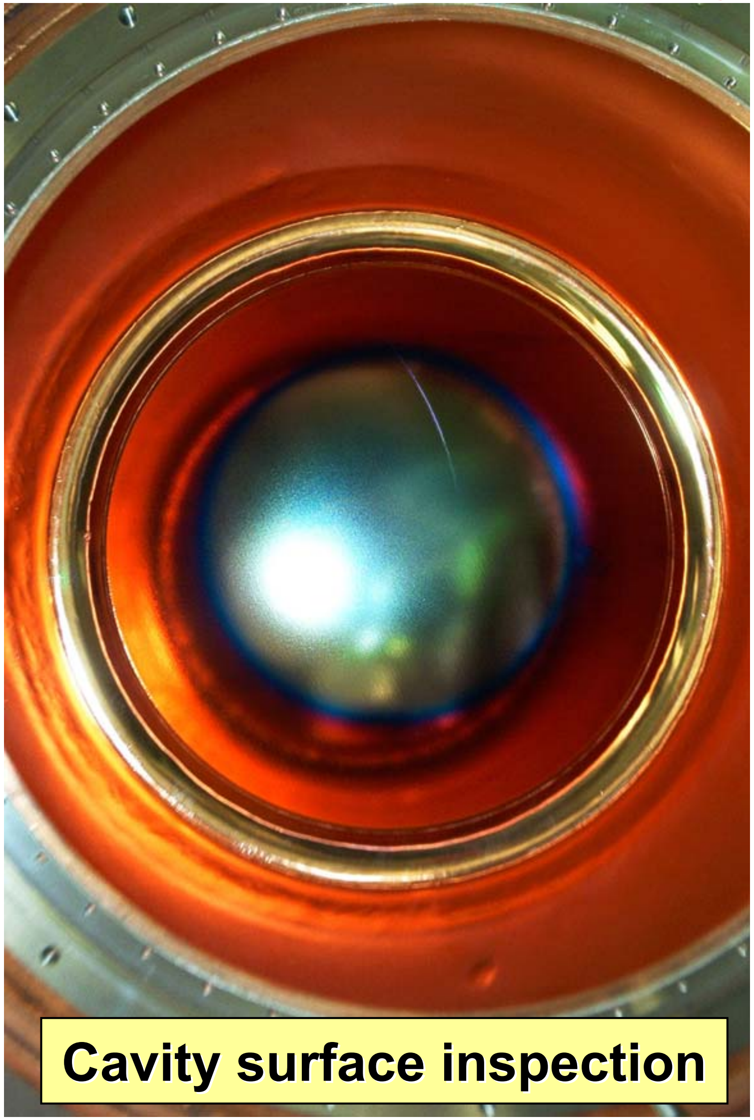




Numerical Studies

- **Modeling the experiment setup for both 805-MHz and 201-MHz cavity to understand**
  - RF conditioning with magnetic field
  - Multipactoring
  - RF breakdown

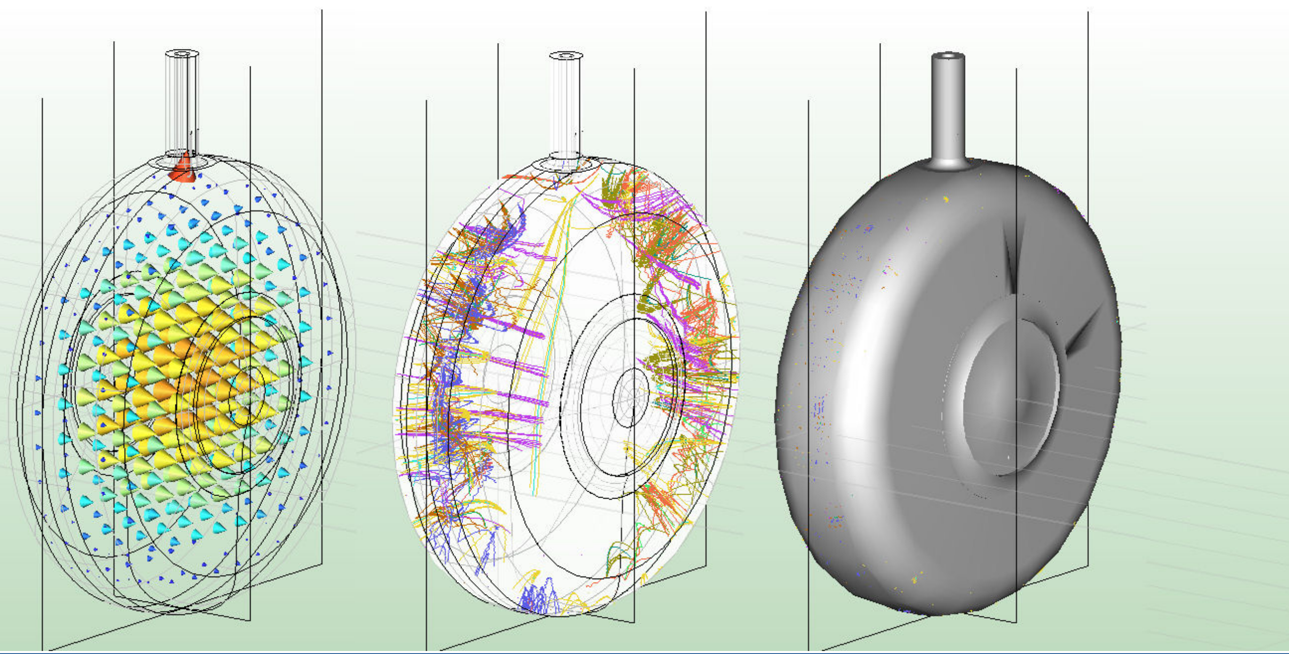
201-MHz cavity modeling:

-Time domain

(LORENTZ-HF code) simulations

- Preliminary results
- More results are coming soon

- In collaboration with a UK group



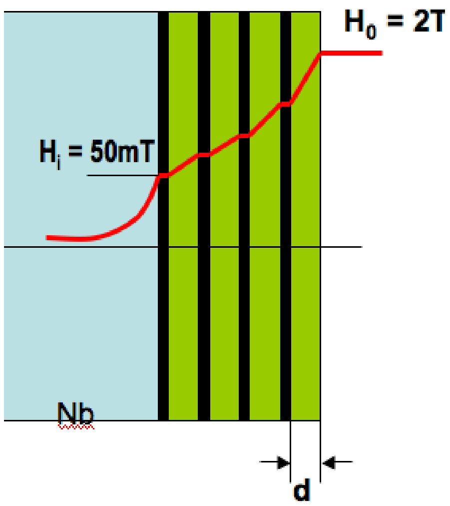
Progress in rf modeling

- We now have a model of rf breakdown which explains copper systems.
  – 70 pages in Phys. Rev. & NIM

- The model is being extended to high pressures and magnetic fields.

SCRF Development

- SCRF development started with Cornell studies of a SC 201 MHz cavity and are continuing.
- Studies of SCRF materials are starting at ANL.
- ANL/MSD is developing nanofabricated SCRF composites (A. Gurevich), that:
  - Eliminate known SCRF limits,
  - Based on Atomic Layer Deposition,
  - Reduce fabrication costs,
  - Increase thermal efficiency.



Future Plans

- Microwave measurements to find or confirm
  - Cavity frequency stability with large Be windows
  - RF coupling
  - RF probe calibration
- High power tests
  - Gradient tests with Be window and B=0
  - Repeat *B* field measurements
  - Move cavity closer to magnet - need more field
- Button tests with 805-MHz cavity
  - Study materials, coatings and geometry
  - Repeat gradient tests with and without *B* fields