MTA Status and Progress

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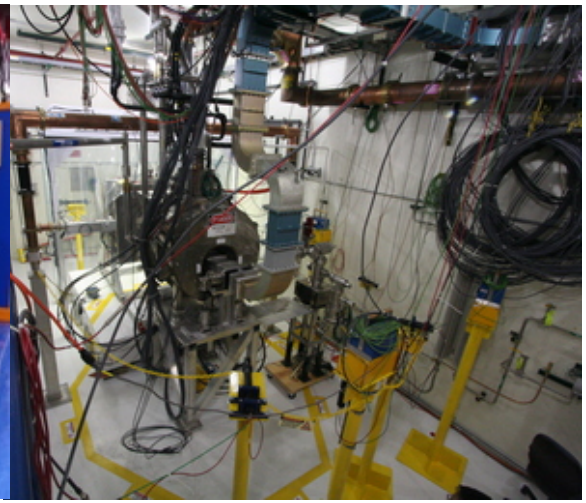
Outline

- Introduction of MTA
  - Facility capabilities
- MTA R&D programs
  - Vacuum RF
  - HPRF
- MICE prototype cavity testing
- Modular cavity
- Summary

Introduction of MTA

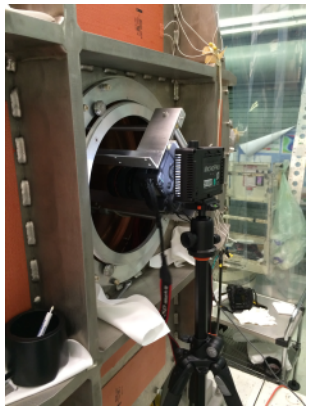
MTA – Muon Test Area

- A dedicated facility at the end of the linac built for MuCool R&D at Fermilab
- The facility has
  - A control area in Linac Gallery
  - An underground experimental hall
  - Surface building (cryo plant)
- Important infrastructure upgrades for last 3 years
- Unique testing capabilities in the world
  - Superconducting magnets
  - High power RF
  - Proton beam line
  - Etc.
- Very well-matched to the proposed MuCool R&D programs



Capabilities of the MTA Facility

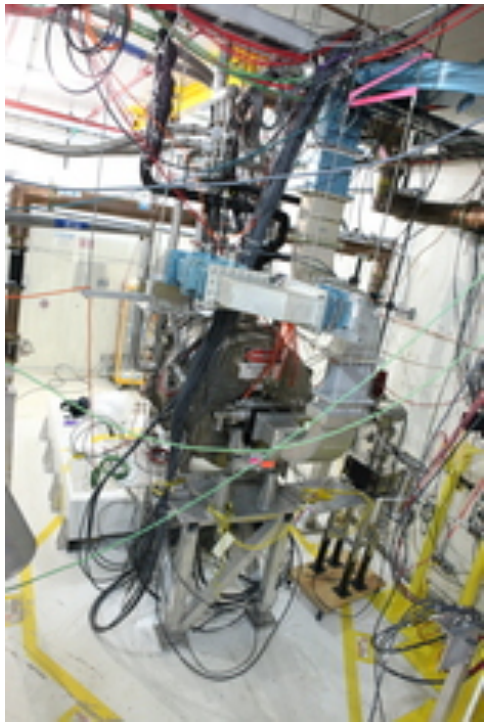
- **High power RF**
  - 12 MW at 805 MHz
    - Hot station as a spare for the Linac
      - Excellent availability for MTA 805 MHz RF testing programs
  - 4.5 MW at 201 MHz
    - Station used to condition spare 7835 tubes for Linac operations
      - Access for MTA programs for MuCool and MICE 201 MHz prototype cavity
    - RF switch and load upstream
      - Allows amplifier operation independent of MTA hall configuration



- **Automated monitoring & control software**
  - Flexibility to customize for different applications
    - 805-MHz system - enables unattended operation for high statistics
    - Commissioned and used for 201-MHz system
- **Superconducting solenoid magnet (Lab-G magnet)**
  - Large (44-cm) warm bore and fits 805-MHz cavities (modular, HPRF)

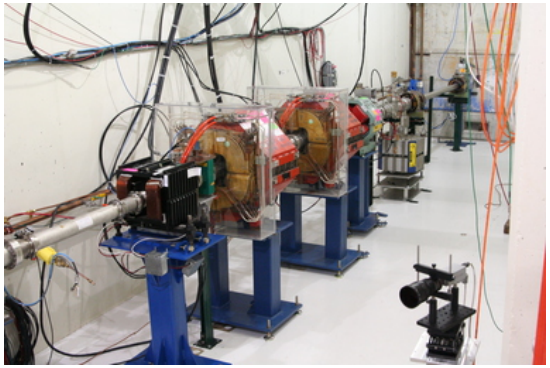
Capabilities of the MTA Facility (cont'd)

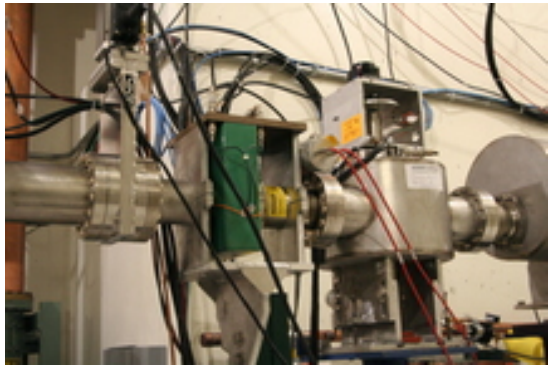
- **Superconducting solenoid magnet (cont'd)**
  - Fringe field can be used for MICE cavity testing
- **Cryogenic plant**
  - Provides LHe for superconducting solenoid operation
- **Class-100 portable clean room**
  - Mainly for cavity assembly and inspection in the hall
- **H_2 safety infrastructure**
  - HPRF cavity tests with H_2 gas
  - A LH_2 absorber test was carried out in the past
- **Overhead crane (5-ton hoist, 10-ton beam)**
  - Used for handling MICE single cavity test vessel
- **Infrastructures**
  - Chilled water system
    - Adequate cooling capacity (16 kW) for modular (805 MHz) + MICE cavities (201 MHz)
  - Vacuum systems
    - Supporting modular and MICE cavities
  - High-pressure gas



Capabilities of the MTA Facility (cont'd)

- **400-MeV H^- beamline (full Linac bunch intensity) and instrumentation**
  - Commissioned to multiple locations within hall
  - Multiwire chambers, toroids, scintillating screen
- **Extensive diagnostics for RF cavity testing**
  - RF field probes in cavities, forward/reflected power in waveguides
  - Vacuum pressure
  - X-ray rates and spectrum
    - Ionization chambers
    - Plastic scintillator + PMT counters
    - NaI crystal + PMT counter
  - Light intensity, spectrum
    - Fibers looking into RF surface
    - Spectrometer
  - Interior inspection station
    - Scanner, microscope

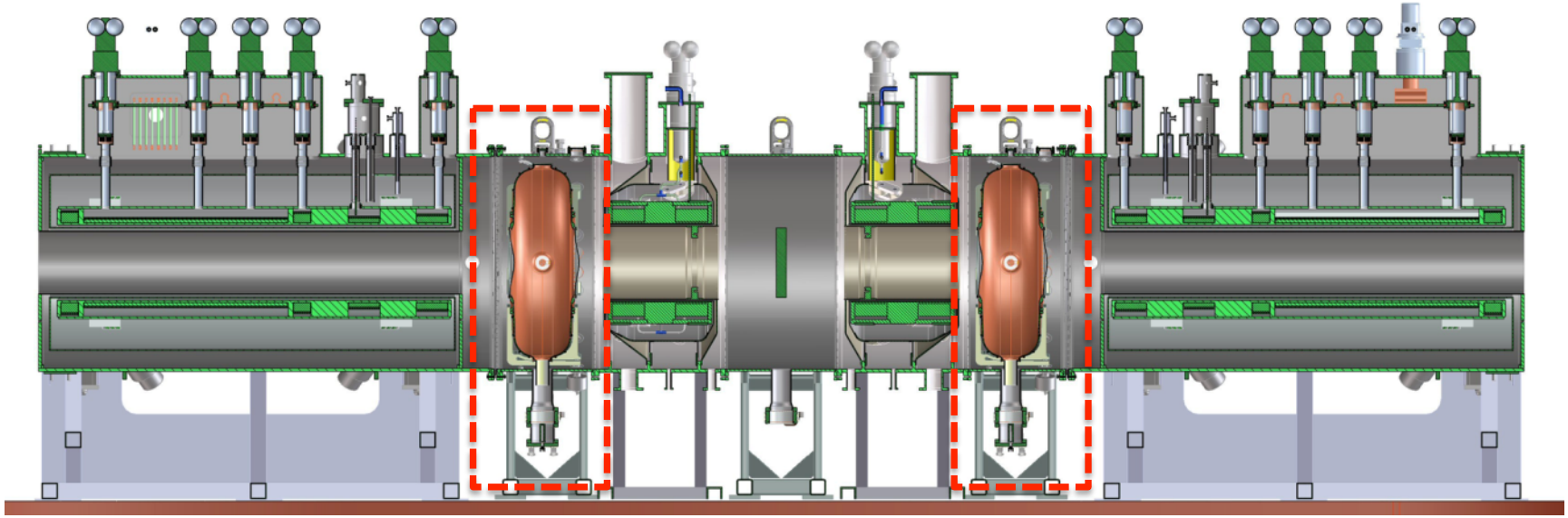




MTA RF Programs

- **Mission:**
  - Design, construction and testing of high gradient NCRF cavities and demonstrate their RF operation in strong magnetic field.
  - Goals:
    - ~ 25 MV/m at 805 MHz @ 3T
    - ~ 16 MV/m at 201 MHz @ 3T
- **Thrusts:**
  - **Vacuum RF cavity (at 805 MHz)**
  - High Pressure gas RF cavity (at 805 MHz)
    - Suppress the effects of dark current with HP H_2 gas
    - Using HP H_2 gas to cool muons
  - **Support of MICE RF (201 MHz)**

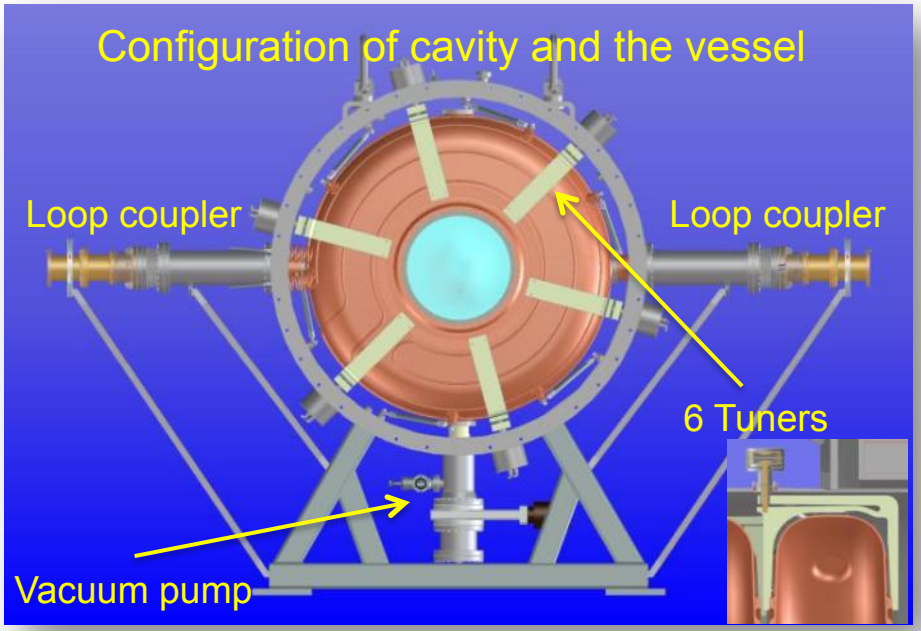
Re-baseline MICE Cooling Channel

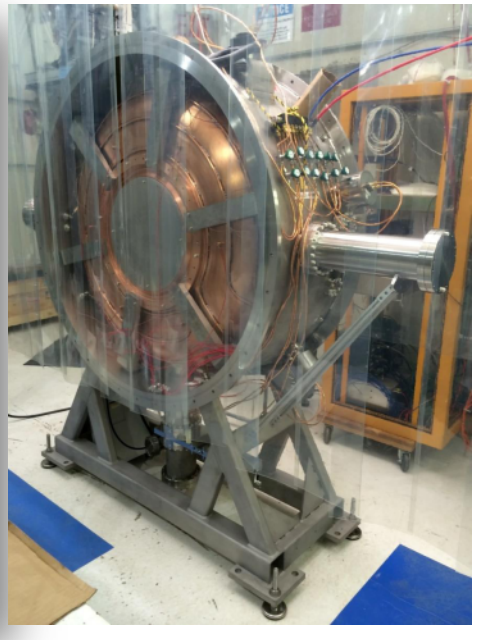


- **New MICE cooling channel needs two RF modules**
- **Each MICE RF module has**
  - One 201 MHz RF cavity (at 10.3 MV/m)
  - Two Beryllium windows
  - Two RF power couplers
  - One vacuum vessel hosting the 201 MHz RF cavity
  - Six tuner arms and six actuators
  - Cavity support struts
  - Vacuum pump system and water cooling
  - Diagnostics and bypass lines

MICE Prototype Cavity

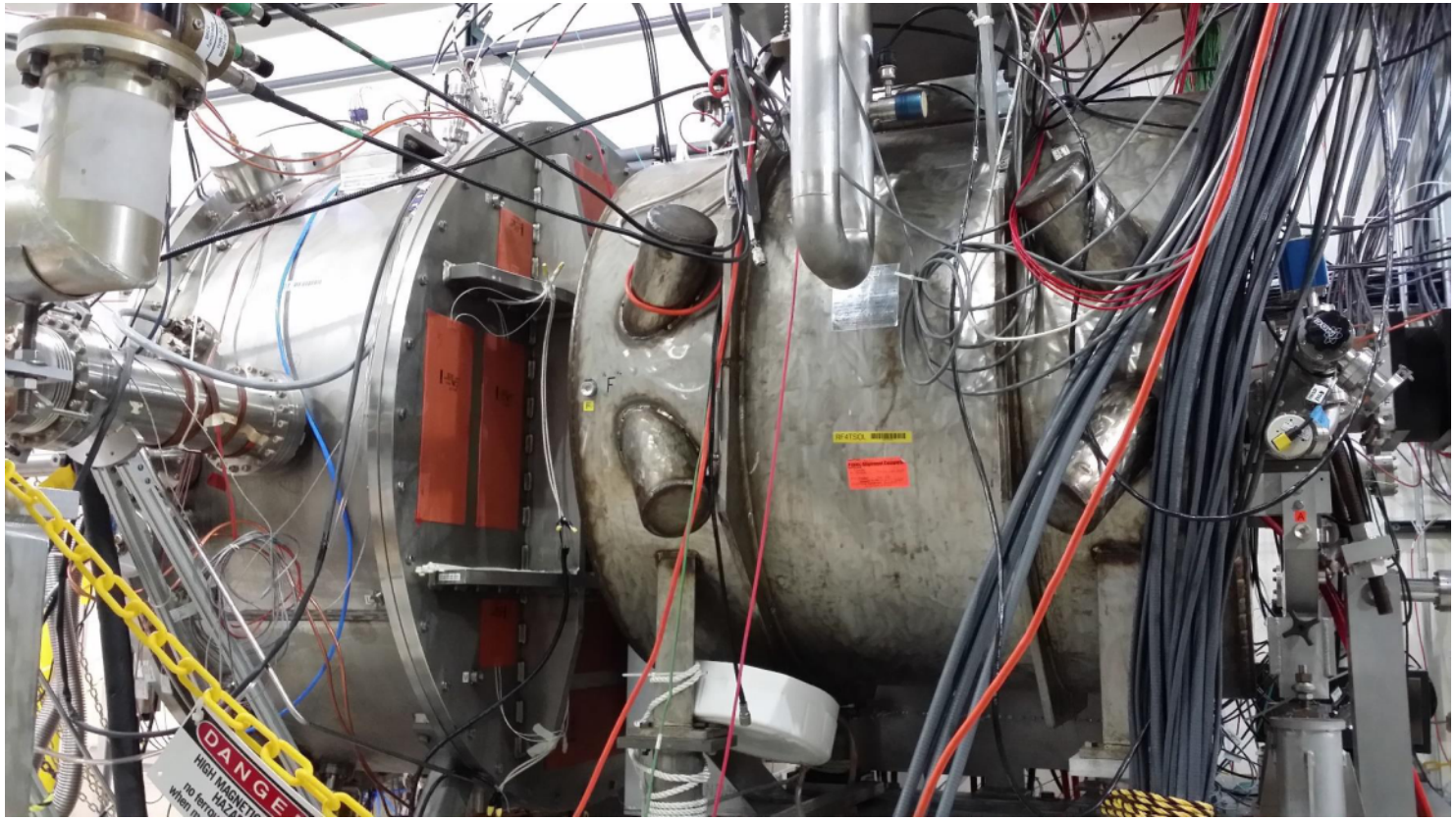
- **Single Cavity Test Vessel**
  - Same dimensions and features that a MICE RFM vacuum vessel would have
  - Installation fixtures and cavity handling procedures + hands-on experience
  - SCRF-style post-processing, handling and assembly
  - RF commissioning and testing with external magnetic field
  - Cavity can be installed close to the 5-T superconducting solenoid magnet at MTA, very similar to MICE configuration





MICE Prototype Testing

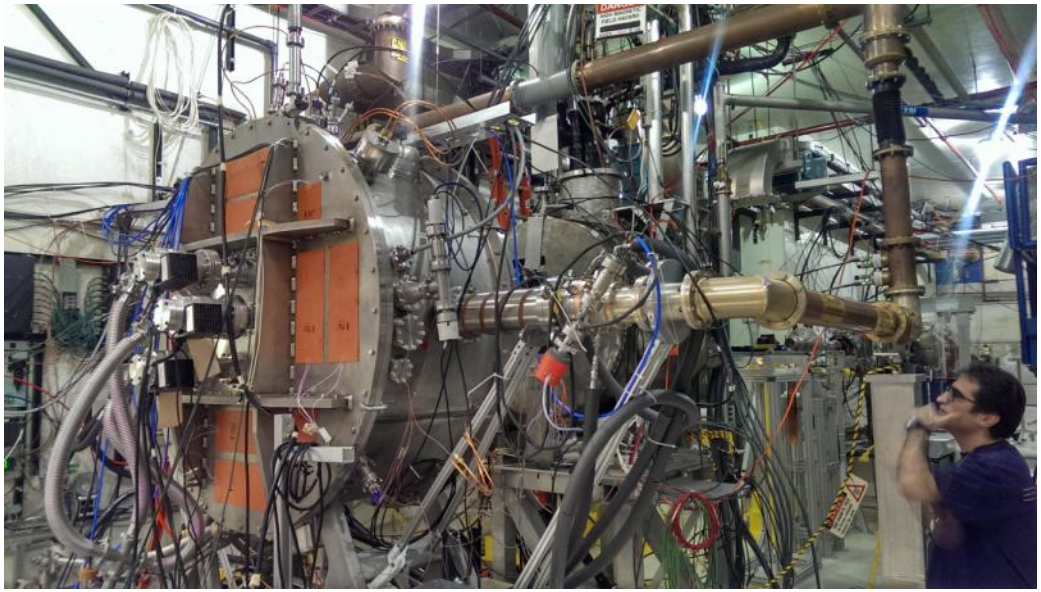
- **Single cavity module next to 5-T superconducting solenoid magnet**



- **Magnetic fields in the cavity:**
  - **0.1 Tesla at downstream wall; 0.17 Tesla in the center and 0.33 Tesla at the upstream wall**

Recent MICE Cavity Testing Results

- **The cavity reached to 8 MV/m (MICE) without conditioning in 3 days (early August 2014) !**
- **B = 0 with Cu windows** (Sept. 15 – Nov. 26 2014)
  - Achieved RF gradients of 13.5 MV/m with breakdown probability of → 10^{-6}, only recorded total of 32 breakdown events
- **B = 0 run with curved Be windows** (March 18 – April 6, 2015)
  - 0.5 millions + pulses at > 11 MV/m (≈ 1.6 MW input power)
  - Dose rate comfortably below tracker damage threshold
  - No breakdown events
  - Up to 14 MV/m for short periods
  - No issues with the cavity or services (vacuum, water)
  - All instrumentation and DAQ worked well



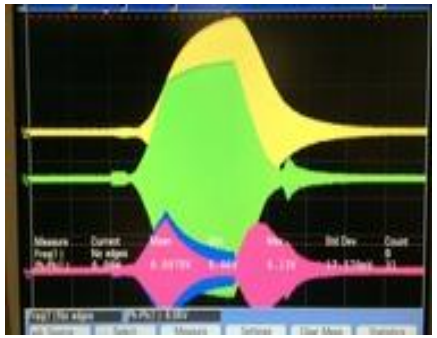
Recent MICE Cavity Testing Results

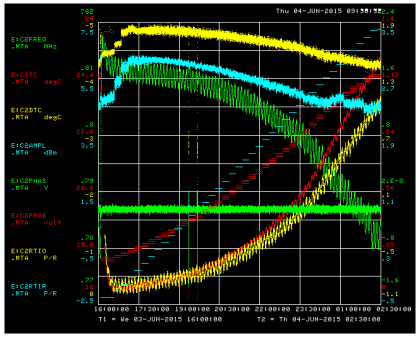
- **B = 5 T run with Be windows** (April 24 – May 15, 2015)
  - Detectors and other components moved, rebuilt as needed.
  - 1 M+ pulses at > 8 MV/m (≈ 1 MW input power)
  - 3 M+ pulses at >11 MV/m (~1.6 MW input power)
  - Dose rate comfortably below tracker damage threshold
  - No issues with the cavity or magnet operation
  - No breakdown events
  - Up to 14 MV/m; held at 13.5 MV/m for 3 M+ pulses
- **B field scan and Tuner System Test with Be windows** (May 25 – June 5, 2015)
  - Tuner System Test at MICE operation frequencies
  - Collected 0.25 M + pulses at 1MW power at B=0 and 10 Hz rep rate;
  - 0.5 M+ pulses at 2 MW at B=5 Tesla and 5 Hz rep rate (MICE: 1 Hz rep rate);
  - Detector calibration to observe dependencies of various signals on:
    - Magnetic field
    - RF gradient
    - Calibration with known radiation sources.

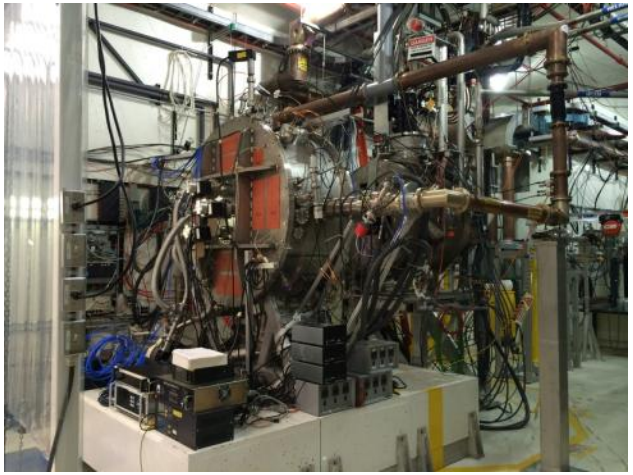
Summary of MICE Cavity Testing

- **Conclusion**
  - Gained valuable experience for MICE cavity assembly and integration to the vacuum vessel; developed fixtures and procedures needed for MICE RF modules
  - Cavity and its subsystems perform well at and above MICE gradient (10.3 MV/m), power and B-field specifications;
  - At and above MICE specifications, no breakdown behavior difference was observed for B=0 and B=5 T.
  - Tuners work as intended.
- **Ongoing work**
  - Characterization of radiation load for detectors
  - Dark current studies
  - High power testing of MICE RF couplers

Congratulations to RF Team

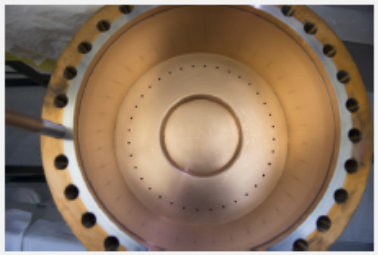


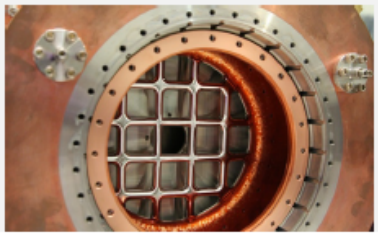


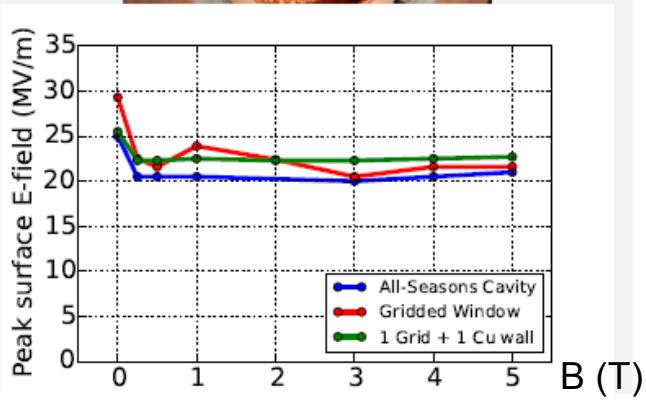


R&D on RF in Strong Magnetic Field

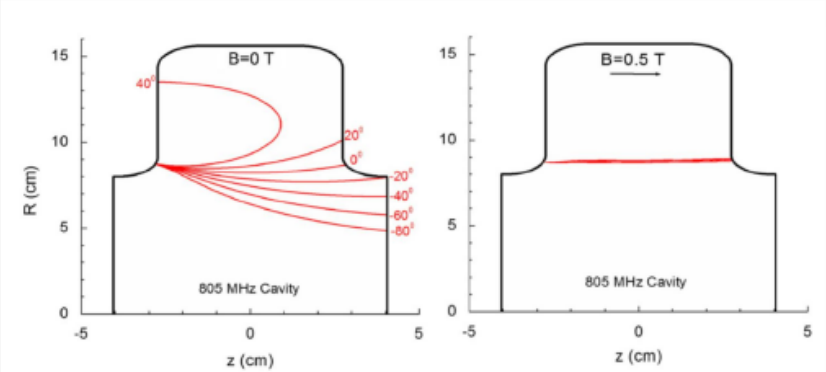
Effect of *B*-fields on 805 MHz gradients







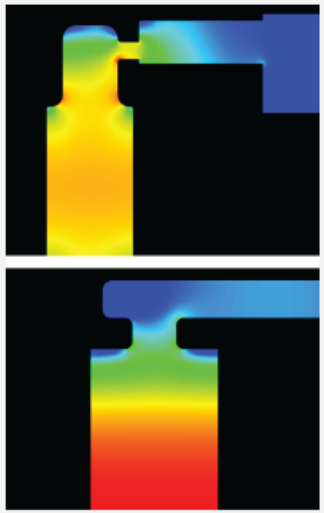
D. Stratakis, *et al.*, *NIMA* **620**, 2010, pp147-154.



- Dark current focused by solenoid into "beamlet".
- Beamlet persists over many RF cycles, leading to fatigue, failure, breakdown.

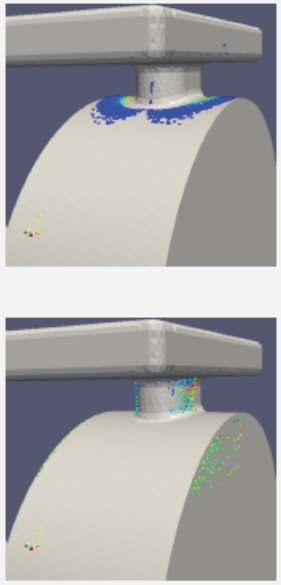
805 MHz Modular Cavity

Design focuses breakdown on walls, not coupler.



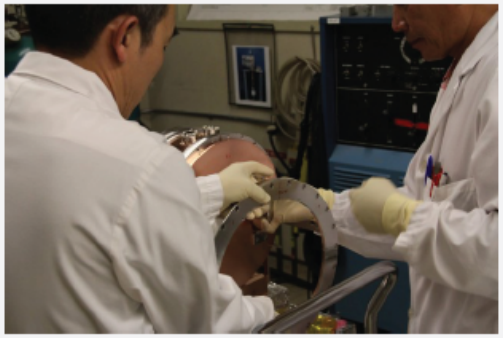
(Top) Old 805 MHz cavity E-field. (Bottom) Modular cavity.

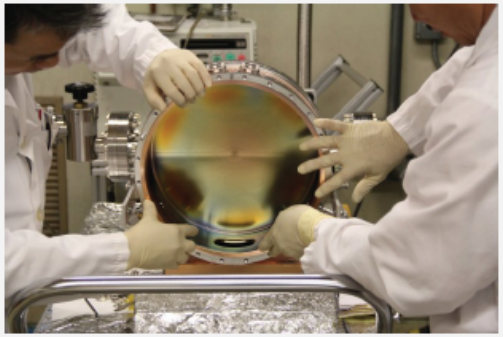
Multipacting optimized for $0 < B < 5$ T.



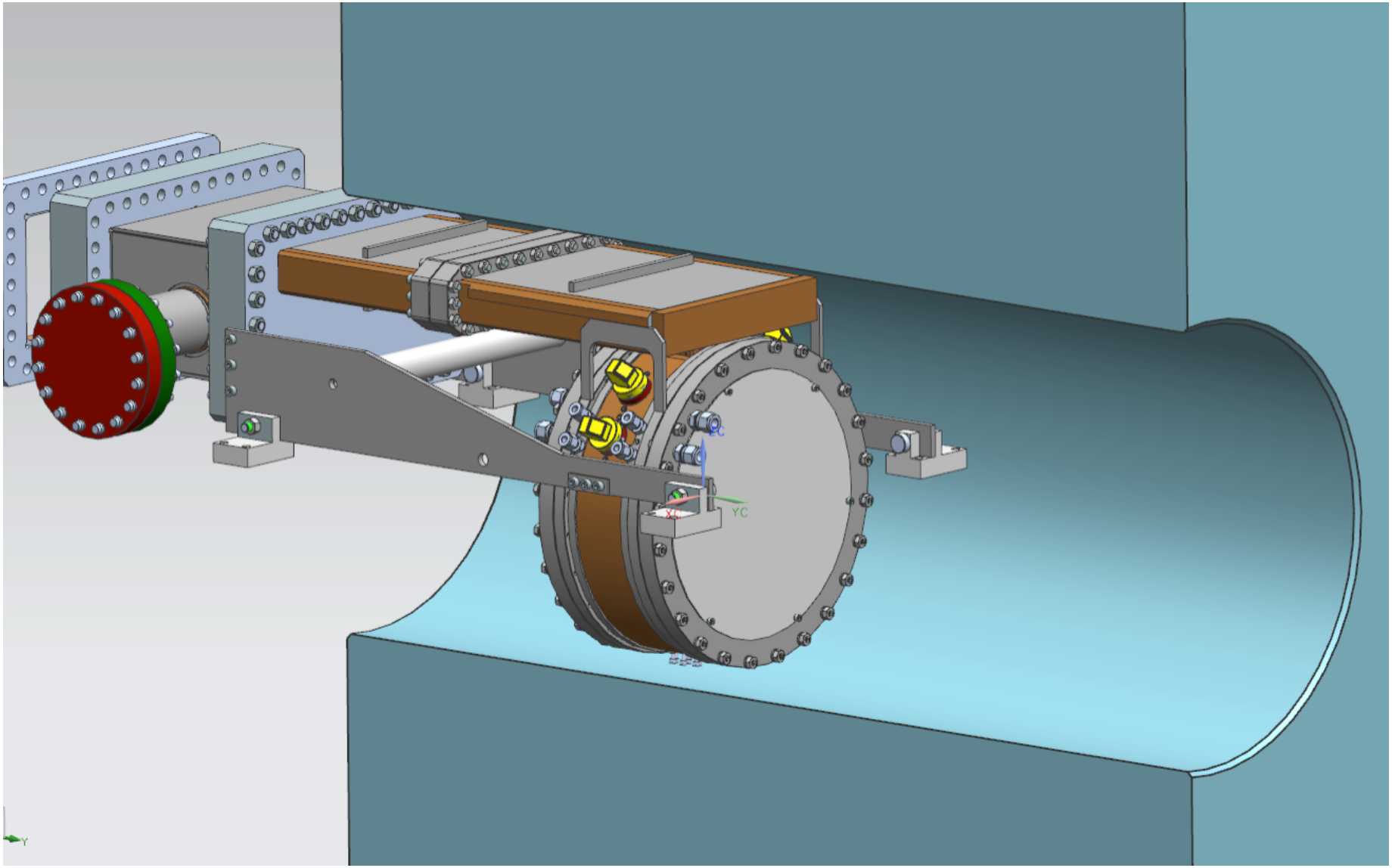
ACE3P-simulate MP trajectories for $B = 0$ (top) and $B = 3$ T (bottom).

Removable end walls for inspection, materials studies.



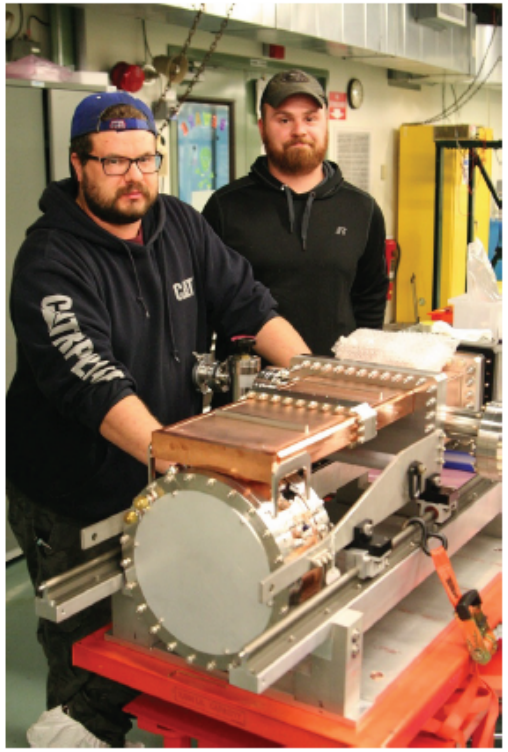


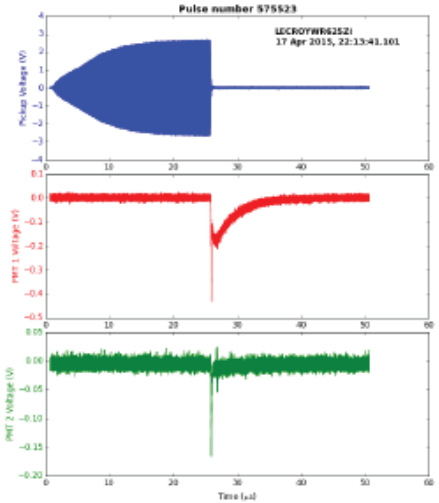
Assembly Configuration/Overview



Current Status of the Modular Cavity

Commissioned to 30 MV/m in May 2015;
Repair of modulator and klystron complete;
Resume soon once the chiller is ready.





Sample spark capture during recent high-power run.

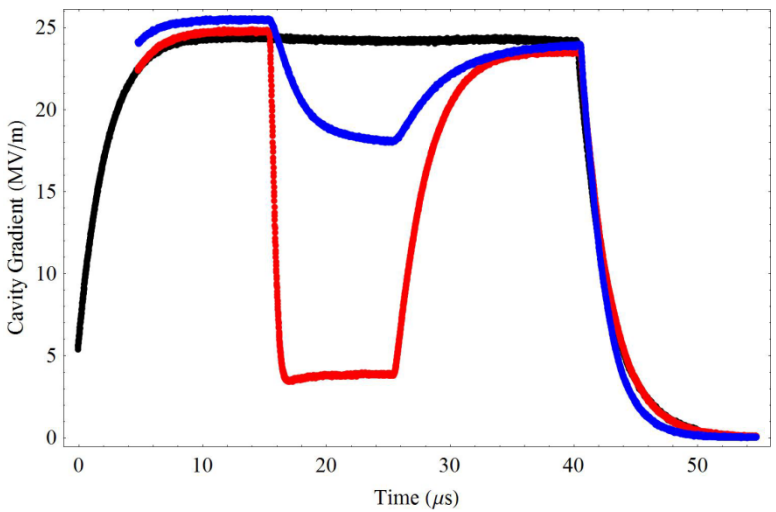
Experimental Program Overview

- Establish max. safe operating gradient for $B = 0$, $B = 5$ T.
- Conduct "surface lifetime" studies of gradient vs. time.
- Replace Cu walls with Be.
- Precise breakdown light, x-ray, dark current measurements.

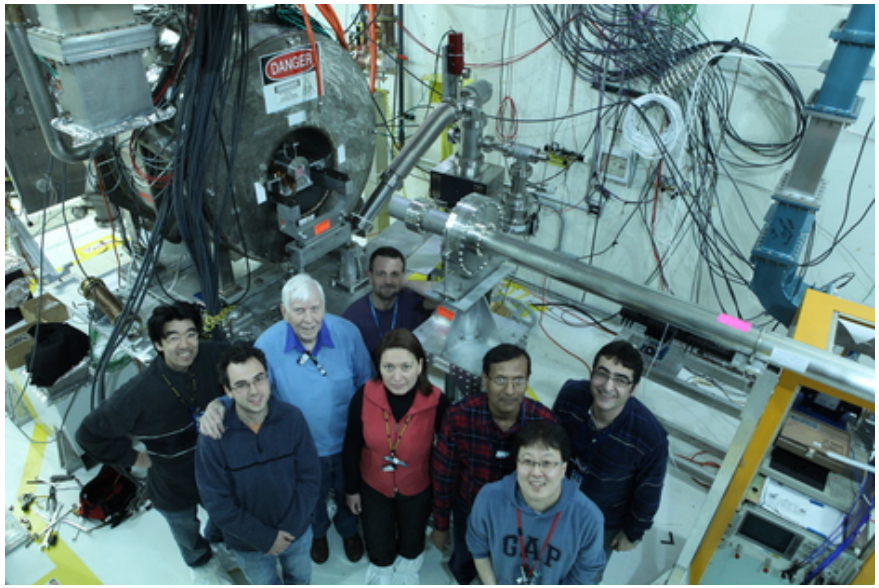
High Pressure H_2 Filled RF Cavity

- **HPRF demonstrated a solution for RF in a strong magnetic field**
- Fundamental Question: *"What happens when intense beam passes through cavity?"*.
  - Beam testing at MTA and testing results published
    - M. Chung et al., ***PRL 111, 184802, 2013***
  - Quantitative theory validated by measurement of energy in H2/D2+dopant
  - Electronegative dopants turn mobile ionization electrons into heavy ions, reducing RF losses by large factor

Phys. Rev. Lett. 111, 184802 (2013) [5 pages]
Pressurized H_2 rf Cavities in Ionizing Beams and Magnetic Fields

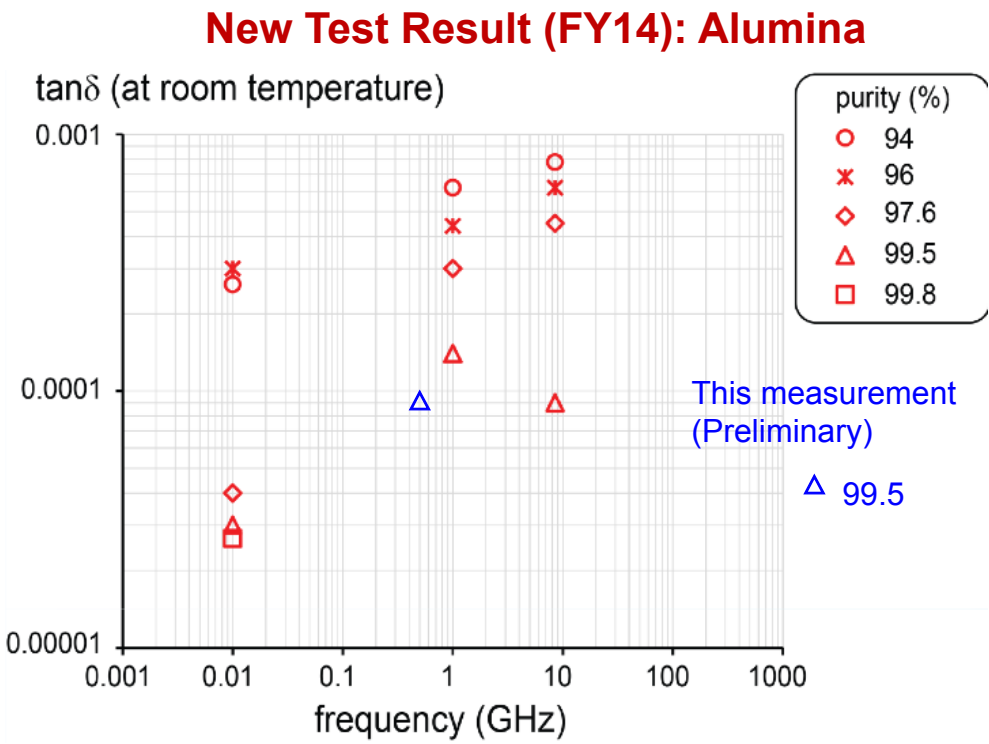


1470psi H_2 ⇨ w/beam ⇨ add 1% dry air

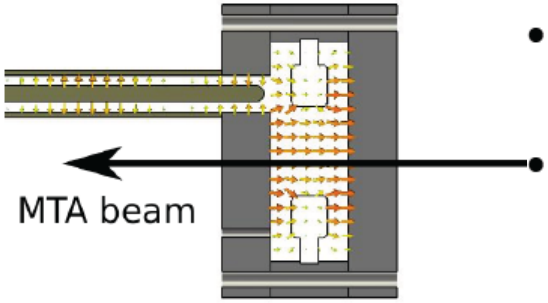


High Pressure H_2 Filled RF Cavity

- **We have demonstrated an ionization cooling solution using HPRF cavities**
- The results extrapolate well to Neutrino Factory operation and a range of MC beam parameters
  - Plasma loading due to beam loading
  - Bunch intensity limits evaluated
- Dielectric-loaded HPRF cavity R&D
  - Dielectric material tested up to equivalent of ~ 25 MV/m on axis acceleration gradient with 99.8 % Al2O3 (Alumina)



High Pressure RF Cavity



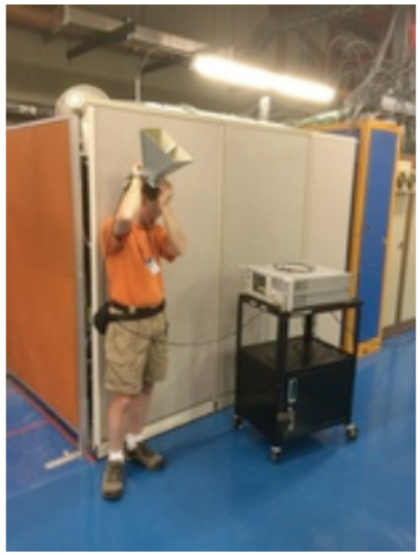
- Load cavity with dielectric to reduce transverse size (smaller magnets in cooling channel).

- H2-safe readout added (D. Peterson)
  - cavity gas pressure
  - will add cavity temperature, waveguide pressure
- Mechanical setup ready
  - will run at 805-MHz station 2
- Run plan in place (B. Freemire)
  - 4 alumina donuts (varying purity), several gas pressures for each
  - 2-3 weeks
- Pressure test (T. Anderson, B. Freemire, K. Yonehara)
  - safety paperwork complete, valves installed
  - 1st attempt yesterday
- New coupler fabrication (for beam test) close to completion (A. Moretti)
- Publication under review for the rest of the beam test data (B. Freemire)

Slide from Y. Torun at MTA meeting on July 24, 2015

Schedule for Near Future

- Infrastructure
  - need to retrain solenoid
  - chiller repair in progress
  - clean room service next week
  - RF leak in Linac Gallery
- HPRF
  - pressure test (Jul/Aug), run (Aug/Sep)
- Modular Cavity
  - finish initial B=0T run, inspect interior (Aug)
- MICE
  - vacuum system service before next run
  - explore dark current with new detector configuration
- Contingent on availability of RF sources, tech labor
- Fermilab accelerator complex shutdown (Jul-Oct)
  - limited access to resources
  - power outages and other interruptions
- Analysis/documentation effort continuing
  - detector calibration
  - HPRF PRST-AB



Slide from Y. Torun at MTA meeting on July 24, 2015

Summary

- **MTA, an unique test facility in the world for muon cooling hardware R&D, with combined capabilities of**
  - **Beam**
  - **SC solenoid magnet**
  - **RF power**
  - **Diagnostics**
  - **Cryogenics and chillers**
- **Successful testing of MICE prototype RF cavity, met/exceed MICE specs ➔ SCRF-style cavity processing**
  - **New MICE RF power couplers will be tested at MTA**
- **Demonstrated a cooling solution with HPRF cavities**
  - **The results extrapolate well to NF and MC beam parameters**
  - **Continue R&D on HPRF cavities loaded with dielectric**
- **Experimental RF R&D programs will continue at MTA, near term plans developed for**
  - **Modular cavity**
  - **HPRF cavity**