MuCool Test Area Program & Plans

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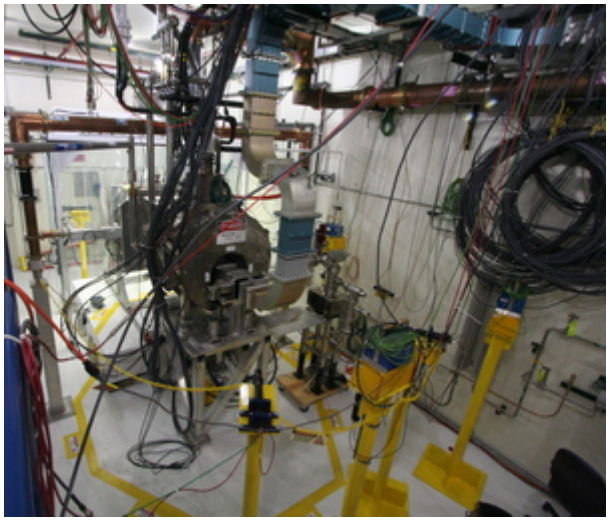
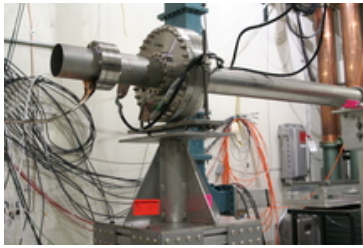
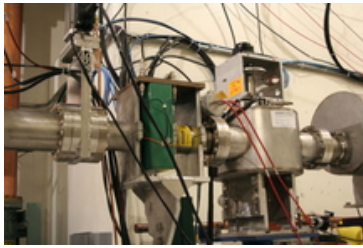
May 30, 2014

MuCool Test Area
http://mice.iit.edu/mta/

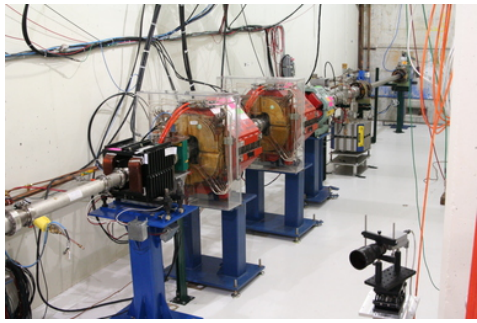
Dedicated facility at the end of the Linac for muon cooling R&D

- RF power at 2 frequencies
  - 12/4.5 MW @ 805/201 MHz
- Large-bore 5T sc solenoid
- LHe cryogenic plant
- 400-MeV H- beamline and instrumentation
- Class-100 portable clean room
- H2 safety infrastructure
- Extensive diagnostics for RF cavity tests
- ***Unique in the world***







Mission and Current Program

- Advance ionization cooling ***Technology R&D***
  - help design, prototype, test components
    - grid windows, modular pillbox, dielectric-loaded HPRF
- Inform muon ***Accelerator Design***
  - provide performance envelope
    - vacuum RF in external magnetic field
    - HPRF in beam
- Support ***MICE***
  - Single-Cavity system assembly, instrumentation, testing

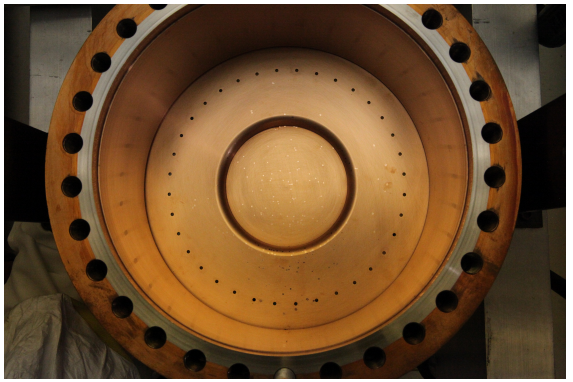
805-MHz Vacuum RF

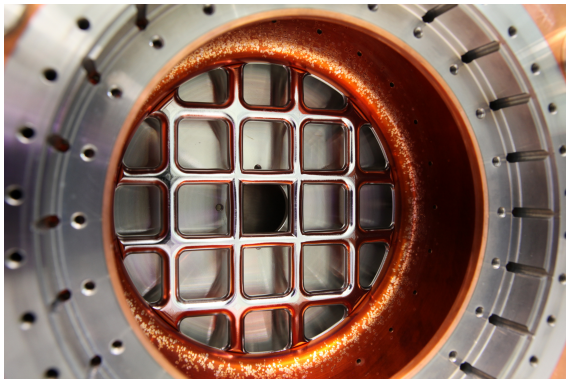
- Completed last year: buttons on old (LBNL) pillbox
  - Higher gradient, minimal surface damage with Be buttons
  - Heavy damage around coupler region during past operation

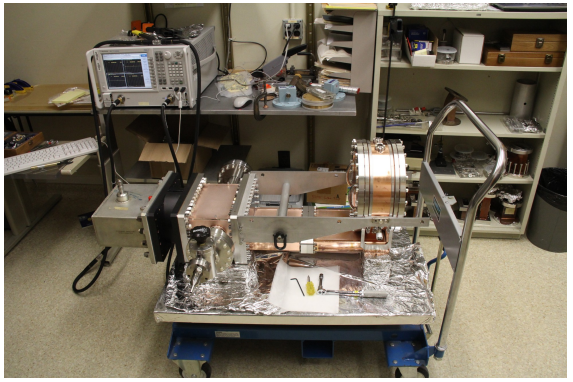
- Completed last year: All-Season Cavity (Muons, Inc)
  - True pillbox with long gap
  - 25 MV/m at B=0
  - 20-22 MV/m for B=0.25-5 T

- Just finished: Gridded windows on old pillbox
  - Last test before retiring cavity
  - 25+ MV/m (surface) at B=0
  - 22-23 MV/m for up to B=5 T
  - Tested with pair of grids and flat/gridded plate mix

- Future: Modular Cavity
  - Aimed at well-controlled systematics
  - Incorporates all lessons learned
    - Removable endplates for easy assembly
    - Redesigned coupler configuration
    - RF design validated by extensive simulation
    - Instrumentation ports
  - Fabrication complete at SLAC, RF parameters verified
    - Need modification to mechanical design for reliable sealing

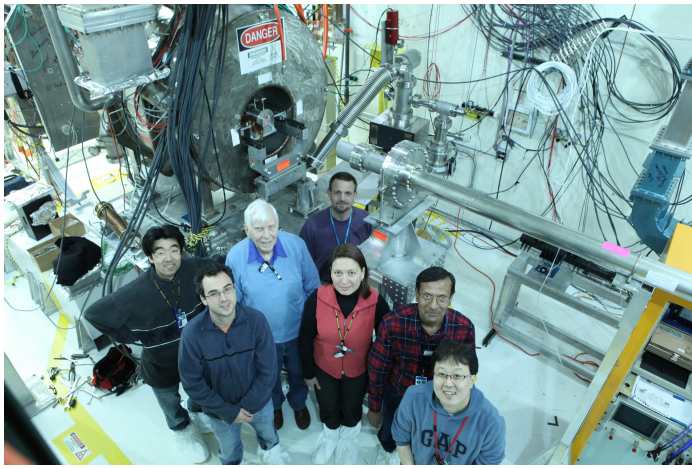






805-MHz HPRF

- 2012 Beam test
- Analysis of full data set complete
- Beam-induced plasma loading measured for pure/doped H2/D2, B=0/3 T
- Good agreement with theory
- Plasma loading < beam loading
- Looks promising for Muon Collider intensity



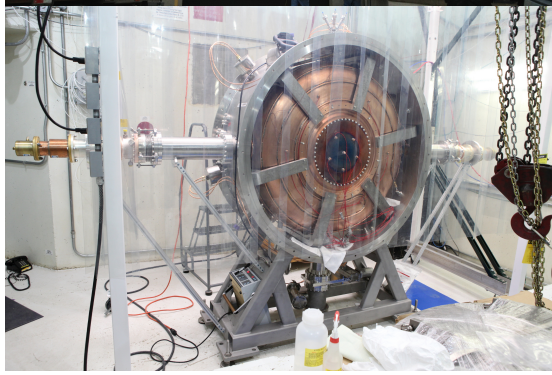
- Last year: Dielectric loading concept
- Needed to shrink cavity/magnet sizes in HCC
- Alumina sample tested to surface breakdown limit (14 MV/m)

- Current: Dielectric sample tests
- Old cavity modified, samples procured
- Low power tests to identify best choice(s)

- Future: Dielectric-loaded cavity beam test
- High-power RF test of sample(s) in test cell
- Beam test

201-MHz MICE Cavity

- First MICE cavity electropolished at LBNL
- Initial assembly completed at Lab-6
- Minor design modifications based on experience
- Fixtures built, tested during assembly
- Full tuning system assembled, tested for the first time; response measured
- First pair of MICE prototype couplers installed, adjusted
- Transported to MTA Hall early May
- Installation in progress

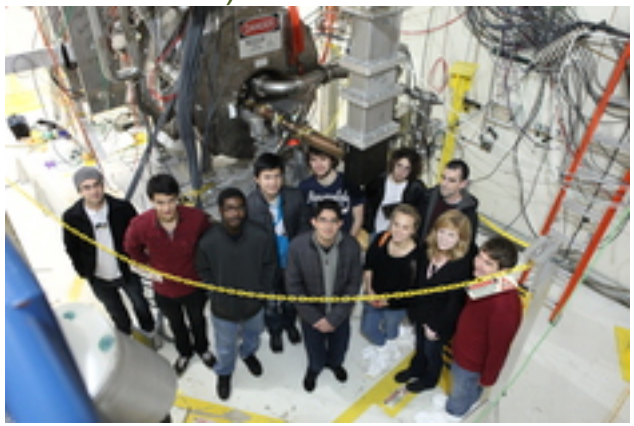


Facility/Infrastructure

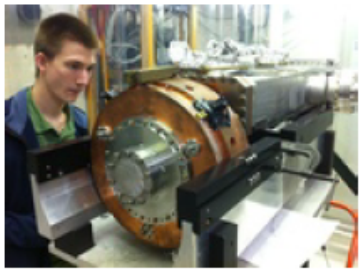
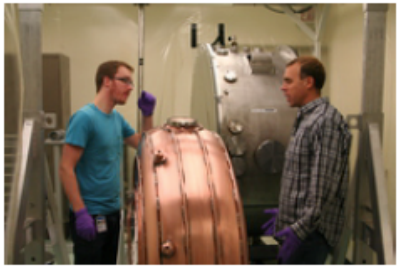
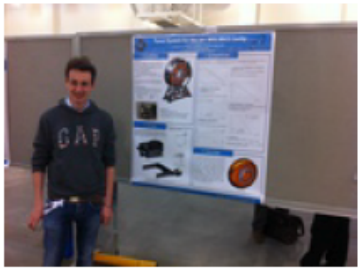
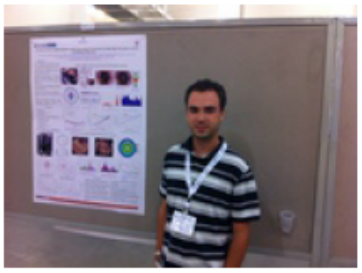
- Upgrades and maintenance continued in parallel with experimental program
  - Beamline upgrade commissioned: permanent magnet installation, survey/alignment, electrical hookup and controls, documentation
  - 805-MHz circulator & switch commissioned: much more flexibility in operations
  - Software for RF conditioning/control rewritten: improved reliability enabling unattended operation 24-7
  - Modifications to 201-MHz LLRF system (for MICE cavity) designed, implemented, tested
  - Solenoid power supply instrumented, He vent line equipped with valves for recovery, magnet retrained to full rating
  - Additional desk space in Linac Gallery (“control room”), storage space near MTA hall
  - Clean room prepared in Lab-6, used for MICE cavity assembly
  - Overhead crane installed in hall
  - Framework for supporting external user experiments (detector and readout prototype irradiation)

Next generation

- MTA program continued to support steady stream of students in FY13
  - Ben Freemire, IIT
    - Ph. D., May 2013 (HPRF beam test)
  - Peter Lane, IIT
    - Working toward Ph. D. (breakdown localization with acoustic sensors)
  - Luca Somaschini, INFN Pisa
    - M. Sc., Feb 2014 (MICE cavity tuner system)
  - Jared Gaynier, Kettering U. (Fermilab coop)
    - Undergrad, major contribution to MICE SCM assy
  - Logan Rowe, John Sobolewski (coop)
    - Components for button pillbox and ASC
  - Lisa Nash (U. Chicago), Yiqing Ding (Purdue U.)
    - Grad, dielectric loaded HPRF design/testing



- Students first author on several IPAC13, NAPAC13, IPAC14 abstracts

Recent publications

- Pressurized H2 rf Cavities in Ionizing Beams and Magnetic Fields, M. Chung *et al.*, Phys. Rev. Lett. 111, 184802 (2013)
- High Pressure Gas-Filled RF Cavities for Use in a Muon Cooling Channel,B. Freemire *et al.*, NA-PAC13 proceedings
- Investigation of Breakdown Induced Surface Damage on 805 MHz Pill Box Cavity Interior Surfaces, M. Jana *et al.*, NA-PAC13 proceedings
- Multipacting Study for the RF Test of the MICE 201 MHz RF Cavity at Fermilab MTA, T. Luo *et al.*, NA-PAC13 proceedings
- Modeling Vacuum Arcs in Linac Structures, J. Norem *et al.*, NA-PAC13 proceedings
- Fermilab MuCool Test Area Cavity Conditioning Control Using LabVIEW, D. Peterson and Y. Torun, NA-PAC13 proceedings
- Algorithms and Self-consistent Simulations of Beam-induced Plasma in Muon Cooling Devices, R. Samulyak *et al.*, NA-PAC13 proceedings
- Tuner System Assembly and Tests for the 201-MHz MICE Cavity, L. Somaschini *et al.*, NA-PAC13 proceedings
- Assembly and Testing of the First 201-MHz MICE Cavity at Fermilab, Y. Torun *et al.*, NA-PAC13 proceedings
- Measurement of transmission efficiency for 400 MeV proton beam through collimator at Fermilab MuCool Test Area using Chromox-6 scintillation screen, M. R. Jana *et al.*, Rev. Sci. Instrum. 84, 063301 (2013)
- Analysis of Breakdown Damage in an 805 MHz Pillbox Cavity for Muon Ionization Cooling R&D, D. Bowring *et al.*, IPAC13 proceedings
- A Modular Cavity for Muon Ionization Cooling R&D, D. Bowring *et al.*, IPAC13 proceedings
- Transient Beam Loading Effects in Gas-filled RF Cavities for a Muon Collider, M. Chung *et al.*, IPAC13 proceedings
- Beam Induced Plasma Dynamics in a High Pressure Gas-Filled RF Test Cell for use in a Muon Cooling Channel, B. Freemire *et al.*, IPAC13 proceedings
- Multipacting Simulation of the MICE 201 MHz RF Cavity, T. Luo *et al.*, IPAC13 proceedings
- High Power Tests of Alumina in High Pressure RF Cavities for Muon Ionization Cooling Channel, L. Nash *et al.*, IPAC13 proceedings
- The RF System for the MICE Experiment, K. Ronald *et al.*, IPAC13 proceedings
- RF Cavity Spark Localization Using Acoustic Measurement, P. Snopok *et al.*, IPAC13 proceedings
- Simulation of Beam-induced Gas Plasma in High Gradient RF Field for Muon Colliders, K. Yonehara *et al.*, IPAC13 proceedings
- Summary of Dense Hydrogen Gas Filled RF Cavity Tests for Muon Acceleration, K. Yonehara *et al.*, IPAC13 proceedings

IPAC14 abstracts

- Tuner System simulation and tests for the 201-MHz MICE Cavity, L. Somaschini *et al.*
- RF design and operation of a modular cavity for muon ionization cooling R&D, D. Bowring *et al.*
- Tests of Dielectric Loaded High Pressure Gas Filled RF Cavities, B. Freemire *et al.*
- Plasma Chemistry in a High Pressure Gas Filled RF Test Cell for use in a Muon Cooling Channel, B. Freemire *et al.*
- Installation and Commissioning of the MICE Single-Cavity Module, R. Pasquinelli *et al.*
- Instrumentation for characterizing 201-MHz MICE Cavity at Fermilab, M. Chung *et al.*
- Acoustic localization of breakdown in the MICE Single-Cavity Module, P. Lane *et al.*
- Extended RF Testing of the 805-MHz Pillbox "All-Season" Cavity for Muon Cooling, Y. Torun *et al.*
- Tube-Grid Windows for Pillbox Cavities, A. Moretti *et al.*
- The Fermilab MuCool Test Area and Experimental Program, Y. Torun

Outlook

- Operating point for 805-MHz vacuum RF in 0-5T established, ASC program concluded
  - preparations complete for next step: modular cavity
    - test program to start this summer
  - publication in preparation
- MICE cavity assembly complete
  - installation in progress
    - commissioning/tests starting next month
  - MICE RF Workshop next week
- Plasma loading for HPRF in beam evaluated
  - looks promising, 2nd publication draft
- Proof-of-principle dielectric loading test complete
  - follow-up program in place
    - material tests starting next month

BACKUP

Many will point to the right way after the wheel is broken

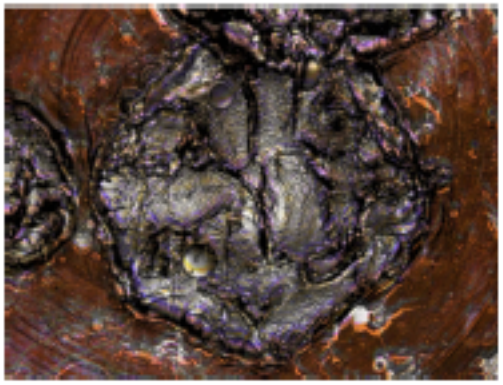
Turkish proverb

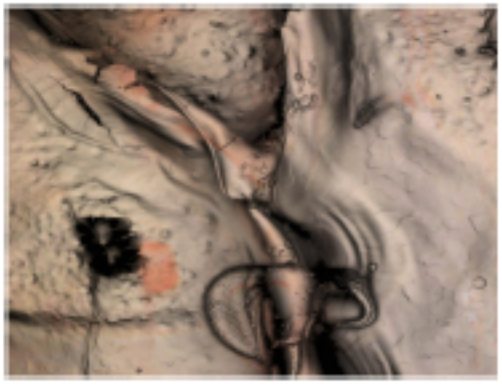
805-MHz Vacuum Cavity Program

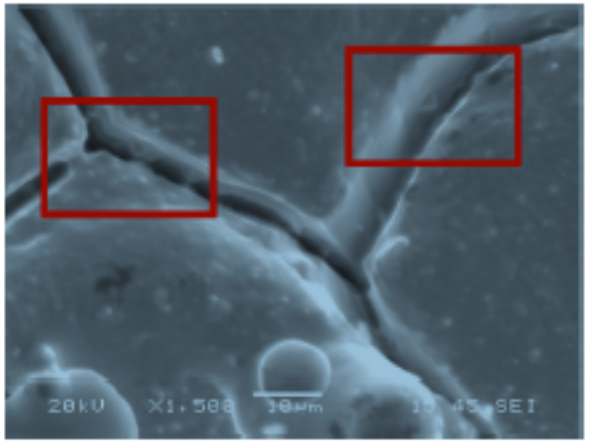
[Magnetic Field] [Surface Processing]
[Cavity Materials] [Window Options]

- Original LBNL pillbox
- Removable electrode inserts
- Used to study
  - B-field dependence of gradient
  - Feasibility of thin windows (Cu, Be)
  - Potential cavity materials (Cu, Be, Mo, W)

- Be vs Cu buttons & flat Cu endplates
  - Higher gradient with Be buttons
  - Minimal surface damage on Be
  - Surface microscopy
    - Bowring et al., IPAC13







805-MHz Vacuum RF Program: Button Pillbox Cavity

- Jana et al., NAPAC13

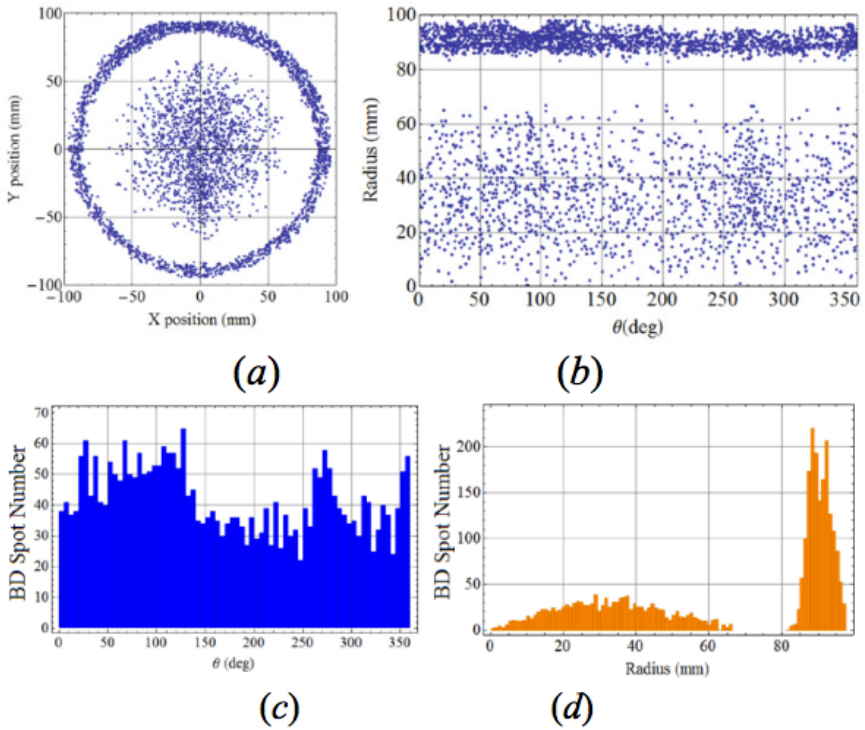
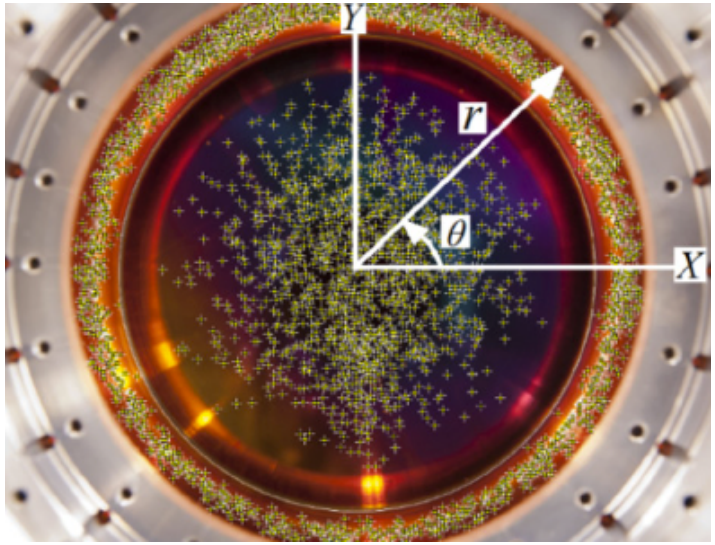


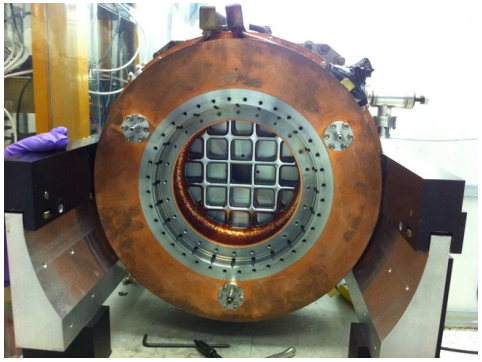
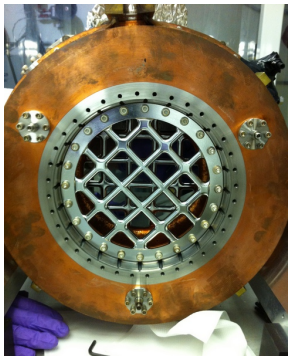
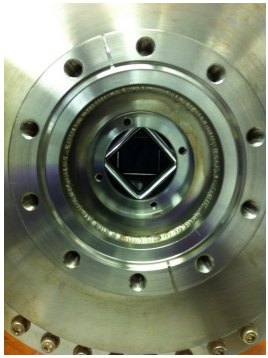
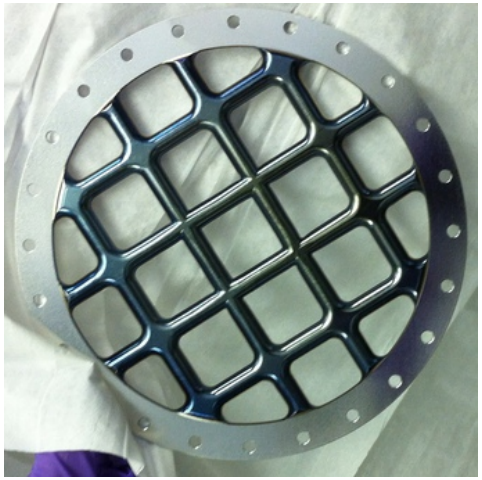
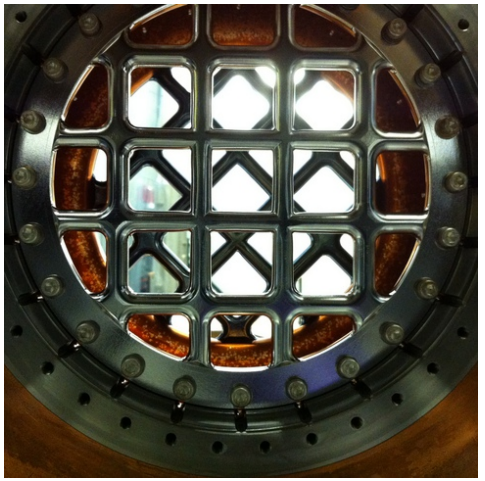
Figure 4: BD spot distribution in X-Y plane (*a*) and r-θ plane (*b*), BD spot no. vs θ plot (*c*) with bin size: 5° and BD spot no. vs *r* plot (*d*) with bin size 0.9 mm.

- Breakdown spot distribution consistent with E-field



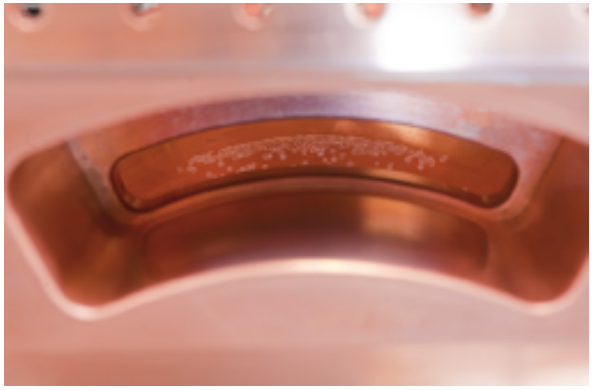
805-MHz Vacuum RF Program: Button Pillbox Cavity

- Windows: low radiation length, good electrical and thermal conductivity
  - Flat thick Cu ✔
  - Thin pre-stressed flat Be ✖
  - Thin curved TiN/Be ✔
  - Exploring alternative: gridded tube windows
    - Solid Al
    - Electro-polished
    - TiN coated (one face)
    - Cavity assembled with grids (and spacer), installed in solenoid -- expect to start running next week
  - M. Alsharo'a Ph. D. thesis, IIT, 2004

805-MHz Vacuum Button Pillbox Cavity Looking back

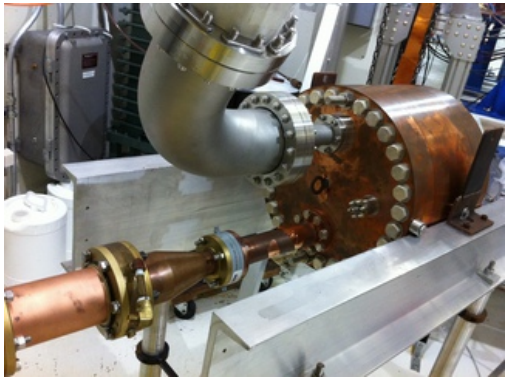
- Gradient limited by high field in coupler region
  - originally to protect Be windows
- Demountable windows and electrodes reached through external cover plates
  - flexible assembly
  - *transformed* for many uses
  - last test about to start
- Some vacuum seal problems
- Practical instrumentation
  - RF pickup probes
  - viewports for breakdown light
  - thin external windows for dark current, x-ray measurement

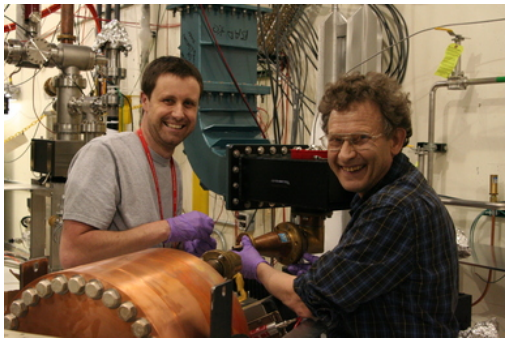


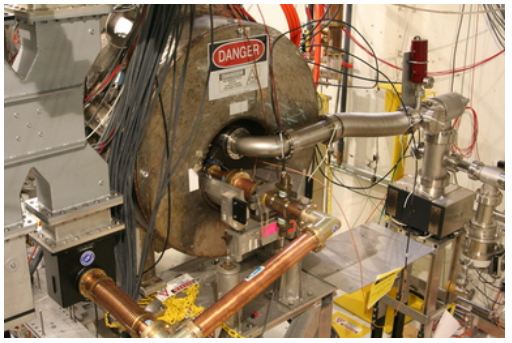
805-MHz Vacuum Cavity Program

[Long pillbox]

- "All-season" cavity (Muons Inc, LANL)
  - Modular pillbox with replaceable endplates
    - Designed for both vacuum and high pressure
    - 316SS with 25um Cu coating
    - 3.9/6.6/2.7cm-thick center ring/outer/inner plates
  - Φ29.1 x 12.9cm inner RF volume
  - 1-5/8" coax coupler
  - Q ~ 28k, frequency 810.+ MHz
  - 1.2MW @ 25 MV/m
  - No active cooling in design
    - Tried external water blanket, did not work
    - Limited rep rate: 5/2/1/0.5 Hz @ 10/15/20/25 MV/m
    - Ran ~24/7 since late March (RF control software upgrade)
  - No RF pickup
    - Used gas port

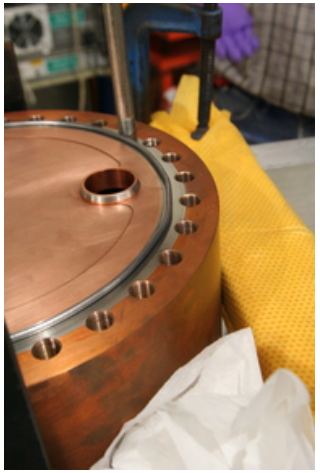


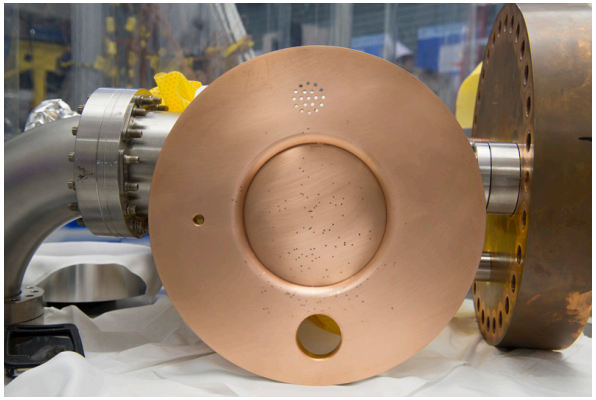


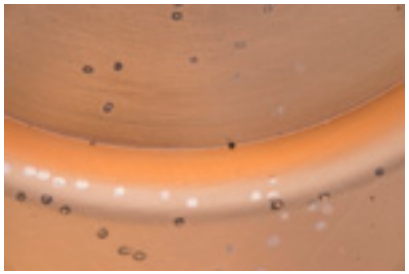


805-MHz Vacuum RF Program: All-Season Cavity

- Operated in magnet: 25 MV/m at B=0, 3 T
- Re-run with RF pickup
  - Confirmed B=0 data
  - 20-22 MV/m at 3T
- Inspection
  - coupler damage (repaired)
  - mm-size spots on endplates
- Reassy: poor Q
  - shape distortion at high power
  - used Cu wire for RF contact
  - Pb wire for vacuum seal
  - Replaced pickup (failed shortly after)

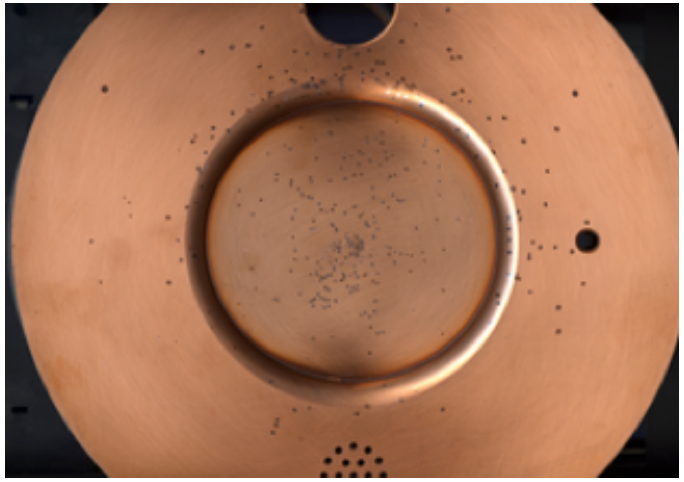


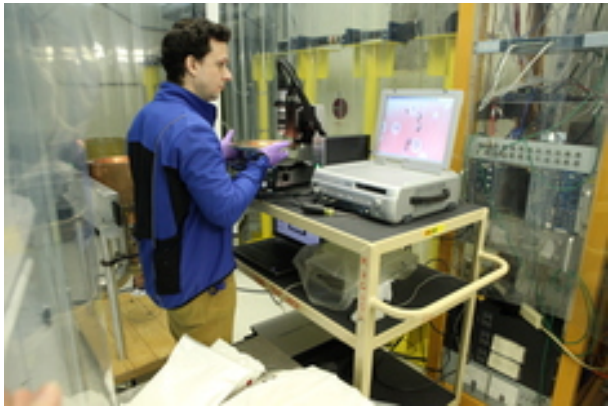


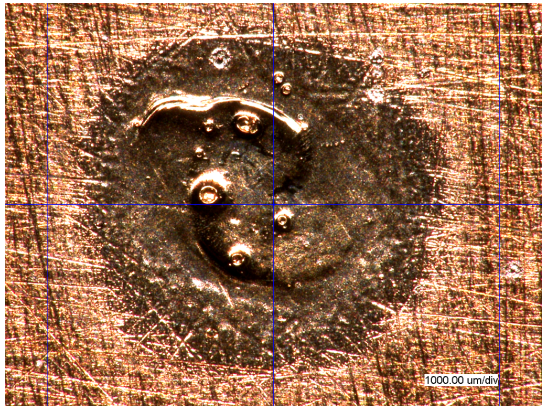


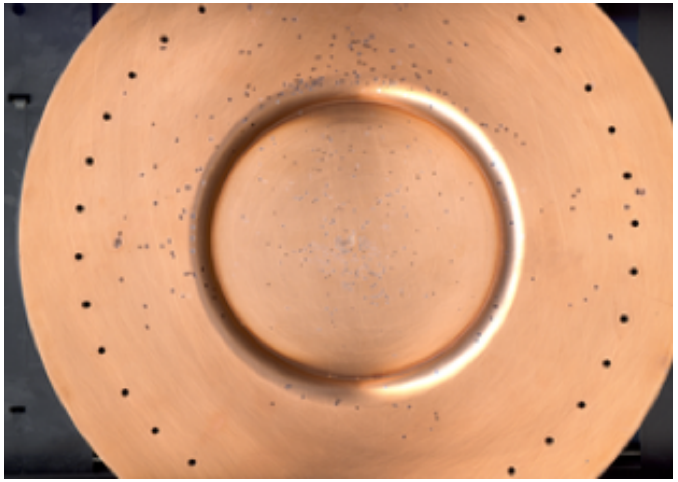
805-MHz Vacuum RF Program: All-SeasonCavity

- Last run
  - 25 MV/m at B=0
  - 20-22 MV/m @ B=0.25-5T [preliminary] (sparking rate ≤ 1 in 10^5)
- Inspection
  - similar spots on endplates
  - more around coupler
  - scanner & microscope tested
- Data analysis in progress
  - publication draft soon
  - cavity removed from MTA



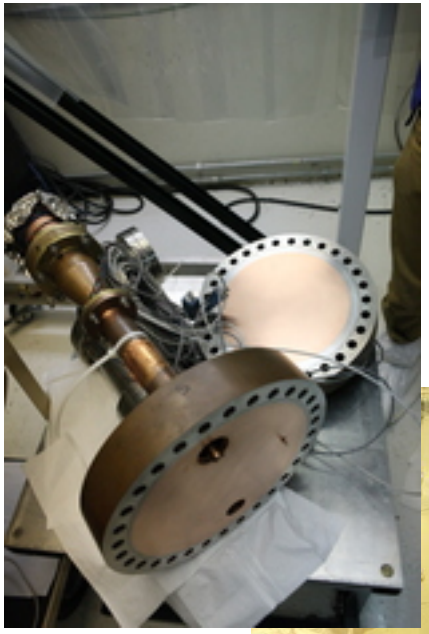






805-MHz All-Season Cavity
Looking back

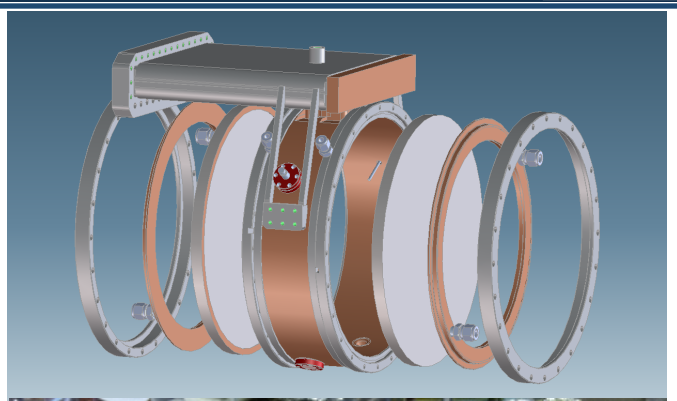
- Did operate it in all seasons!
- Limited by lack of cooling
- No heat treatment after machining
  - distorted during high-power operation
  - loss of contact/Q, vacuum seal problems
- Heavy-duty construction for high pressure
  - assembly/handling challenge
  - Limited clearance/provision for instrumentation
- Drop-in test plates clamped by external cover plates
  - simple bolt-together design (many bolts!)
- Many input configurations
  - hybrid, circulator
  - coupling issues at high power
- Practical experience
  - clean room assembly
  - optical inspection
  - control software, data analysis

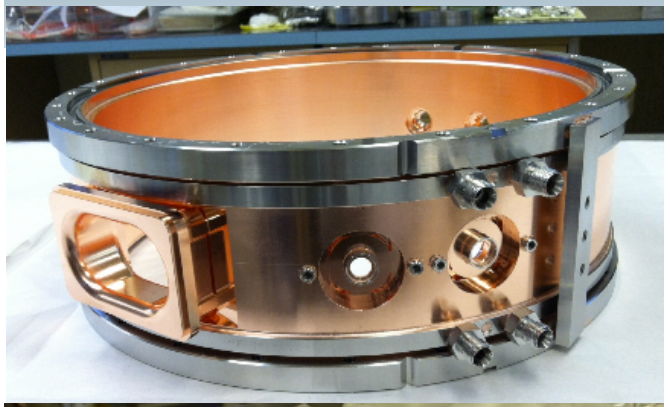


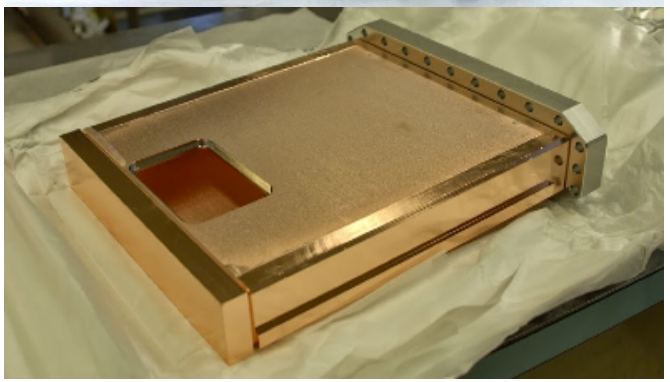
805-MHz Vacuum Cavity Program

Moving forward

- New modular cavity for detailed systematic studies (SLAC, LBNL)
  - Modular design for easy assembly, inspection, parts replacement
  - Removable endplates (initially Cu; Be, other materials, treated surfaces)
  - Coupling iris moved to center ring and field reduced (*more realistic design for cooling channel*)
  - RF design validated by detailed simulation
  - Ports for instrumentation
  - Inspection setup under preparation
  - Fabrication close to completion
  - Expected delivery to MTA: FY14 Q2
- Incorporates all lessons learned

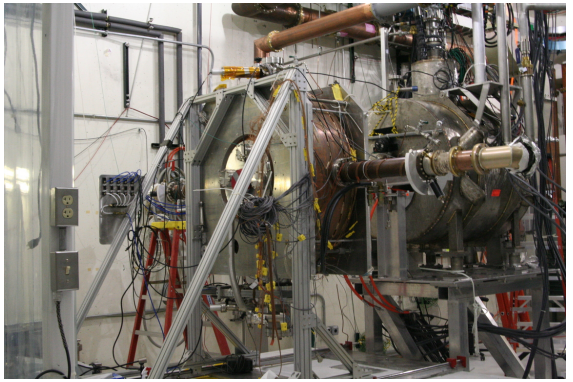


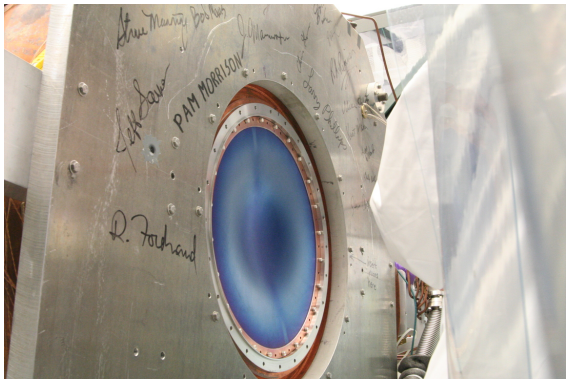


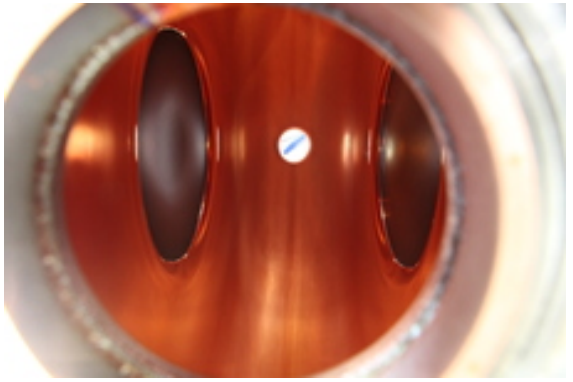


201-MHz Vacuum RF Program [Surface treatment, NF channel, MICE]

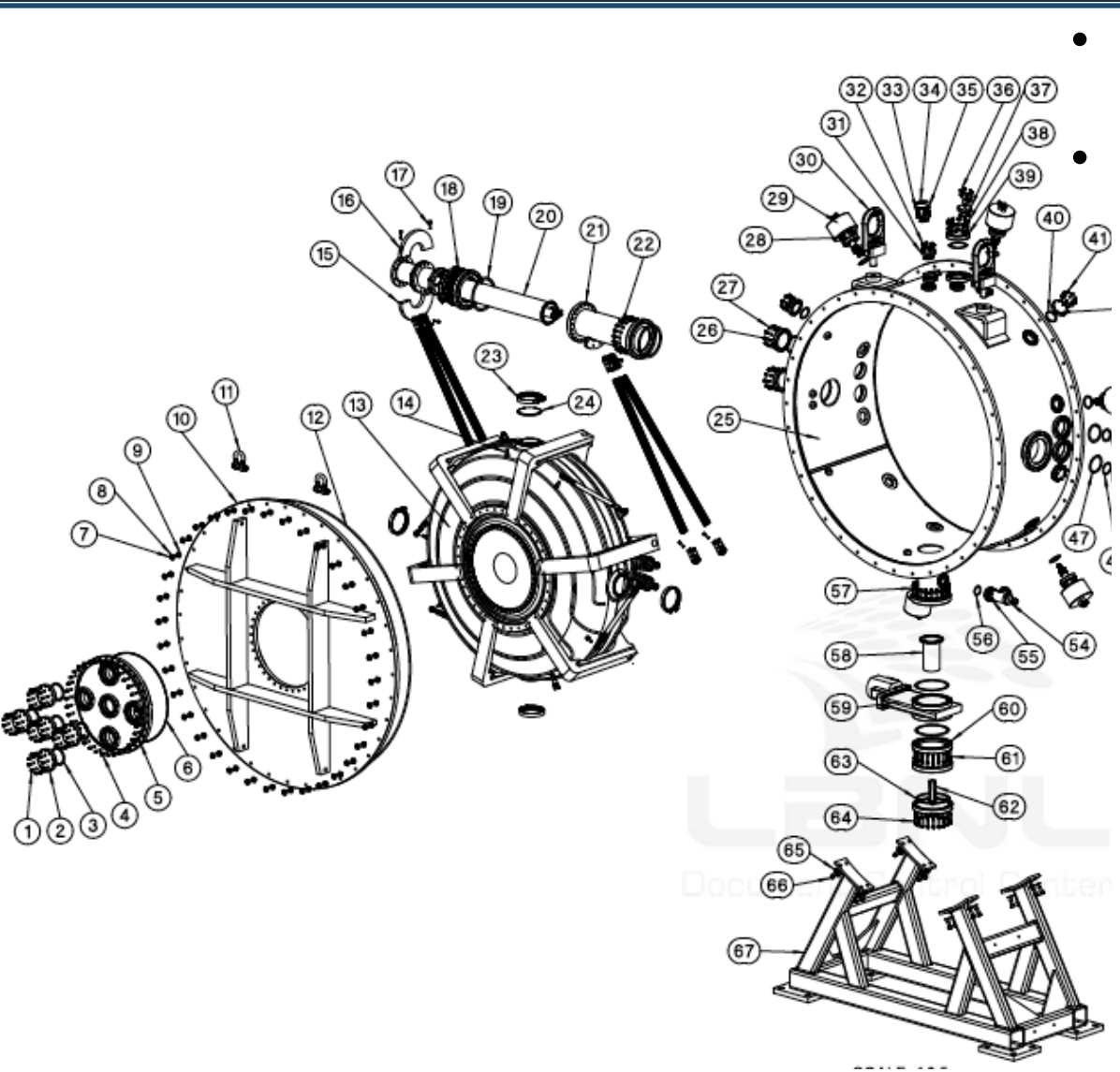
- 201-MHz MICE prototype cavity with SRF-like surface treatment (EP, HP rinse)
  - Conditioned to design gradient quickly
  - Demonstrated operation with large curved Be windows
  - Somewhat reduced performance in fringe field of solenoid
  - No surface damage seen on cavity interior
  - Some evidence for sparking in the coupler
    - Multi-pacting studied (T. Luo)
    - Design now modified
    - Also incorporated TiN coating
  - Radiation output measured (MICE detector backgrounds)
- Future
  - Install/operate single-cavity vessel
  - Large diameter magnet (coupling coil) needed for field configuration closer to MICE/cooling channel



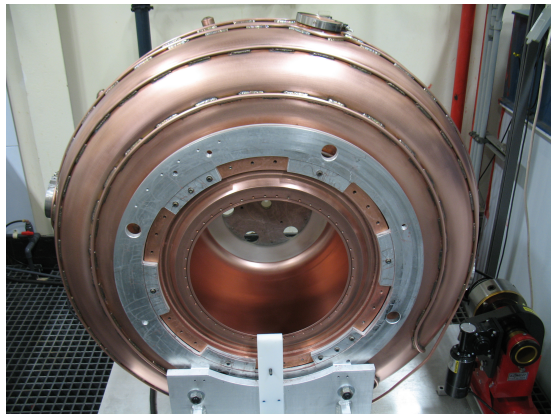




201-MHz Single-Cavity Module

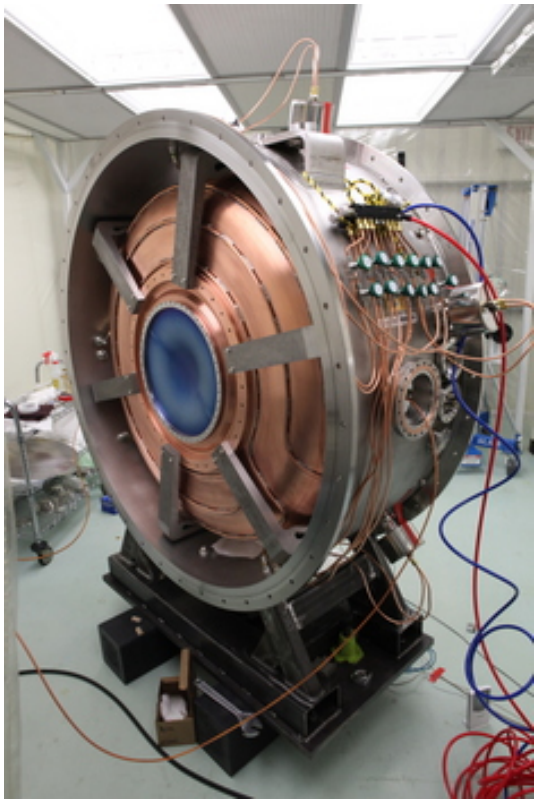


- MICE cavity in vacuum vessel for MTA test
- Components
  - 1st MICE cavity EP'ed at LBNL
  - Vacuum vessel built at Keller
  - Be windows to be reused
  - Actuators, couplers built at LBNL
  - Tuner forks built at FNAL

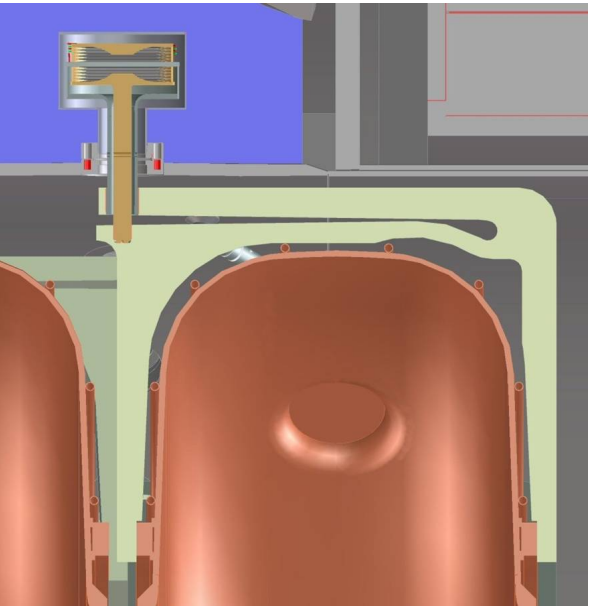


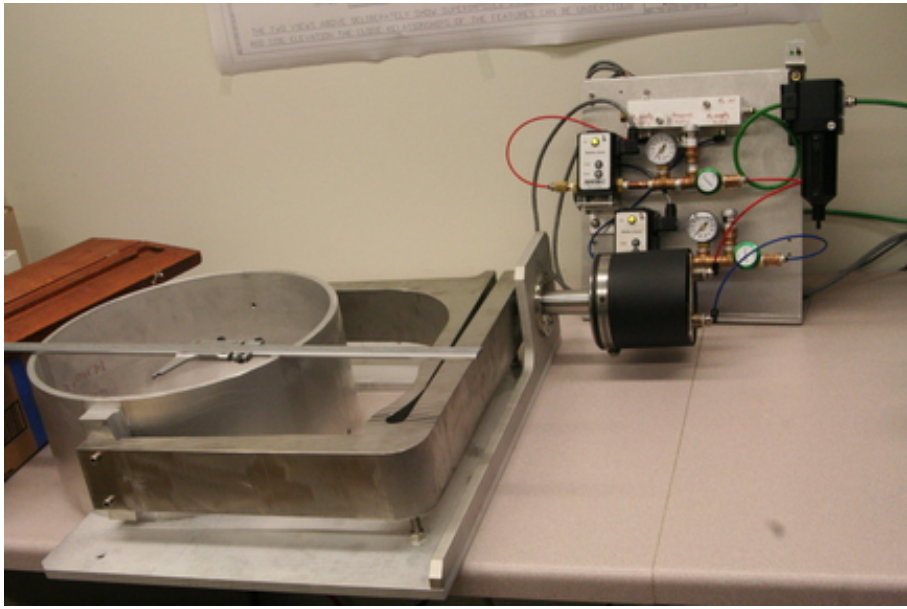
201-MHz Single-Cavity Module

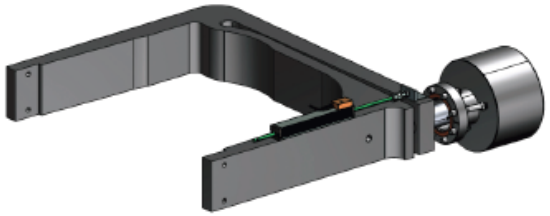
- Assembly/integration
  - Clean room prepared in Lab-6
  - Main assembly completed there
  - Transported to MTA
  - Tuner system tested
  - Hall infrastructure
    - Services mostly in place
    - Overhead crane installed
  - Expect operation Summer 2014
    - depends on RF source availability
  - beam test also under consideration
- Ultimately to be tested with the first Coupling Coil Magnet
  - Requires 6-month MTA shutdown

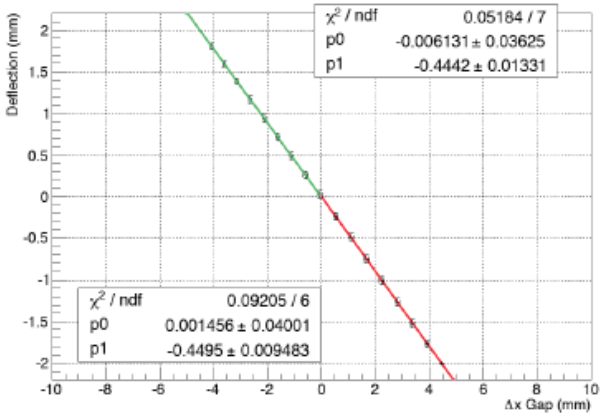


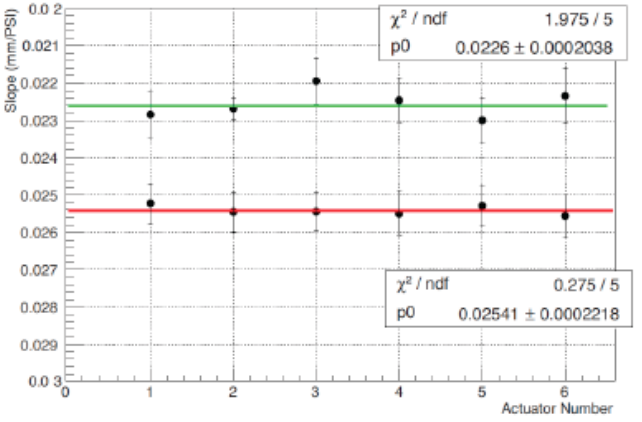
201-MHz Tuner System



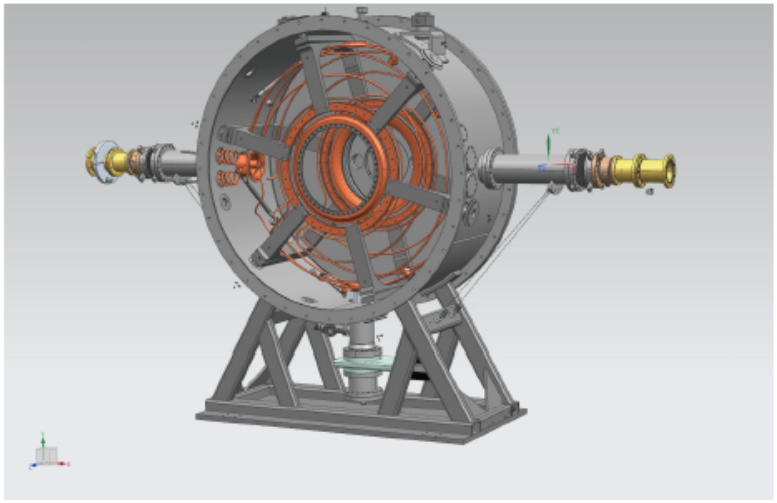


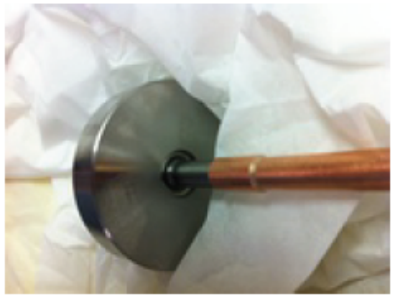


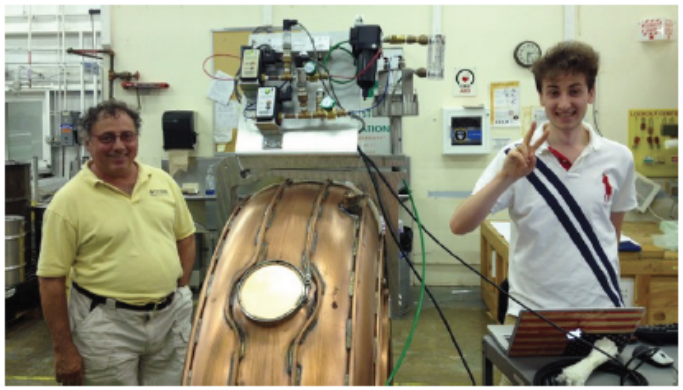


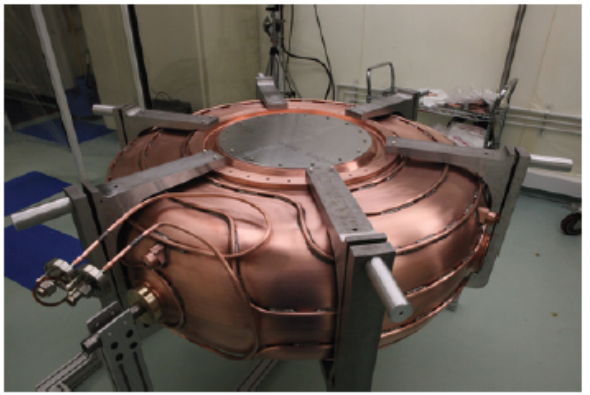


Assembly in Lab-6

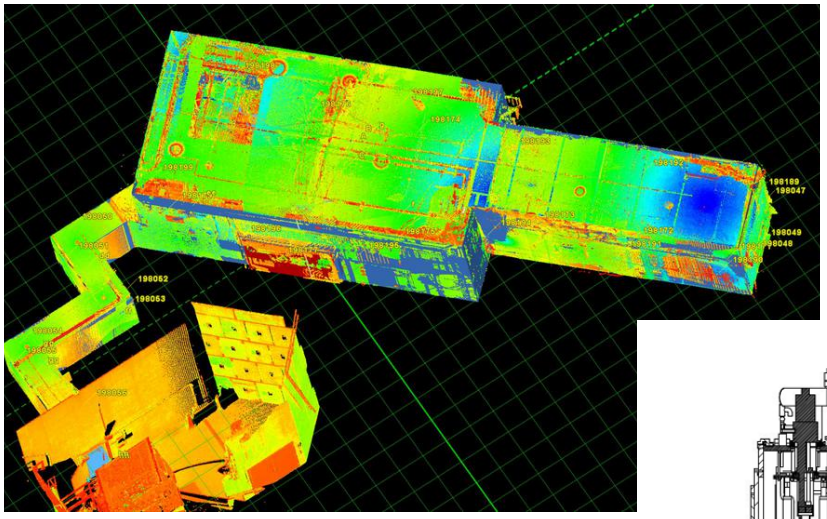


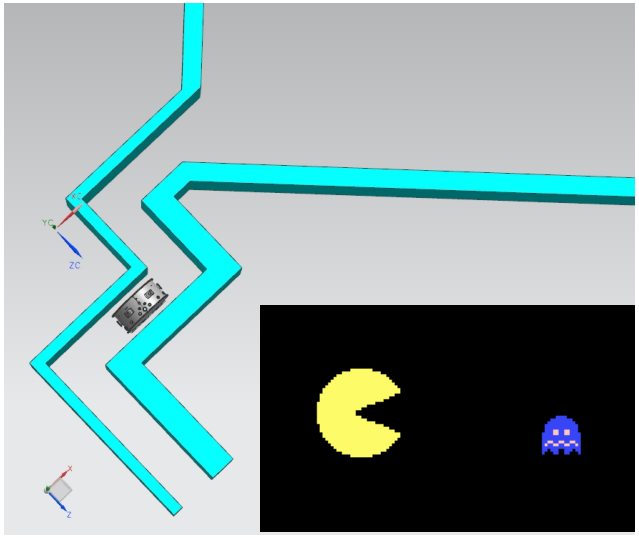


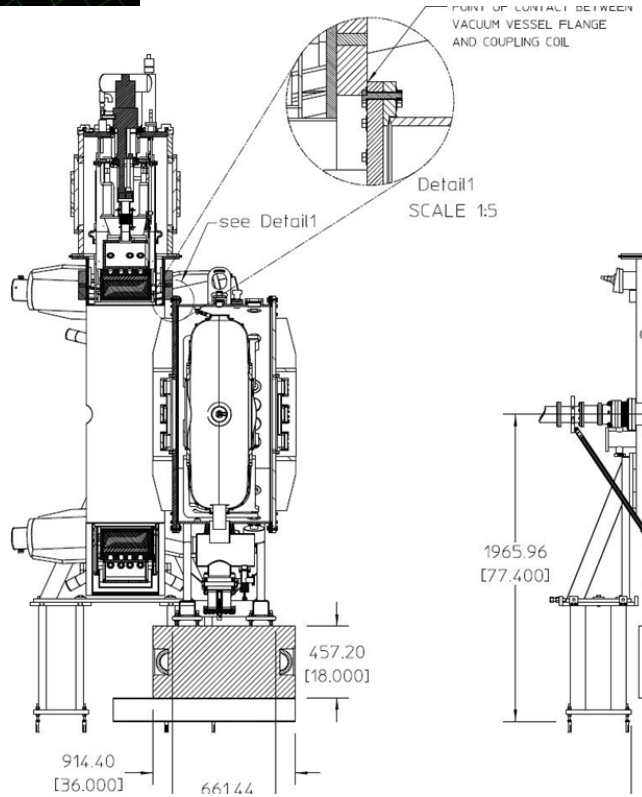




Transport to MTA

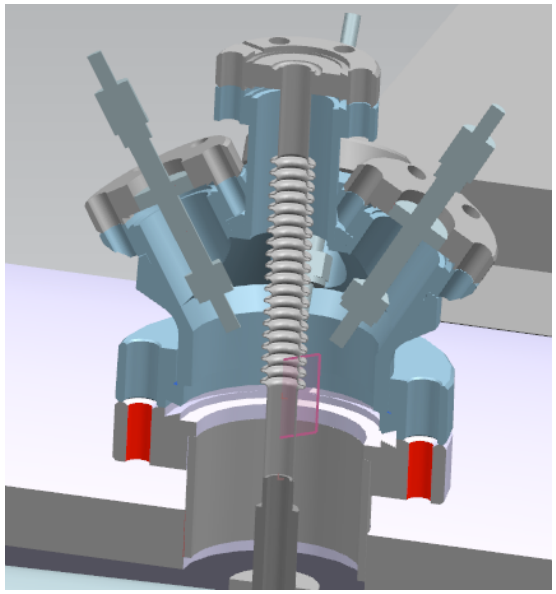


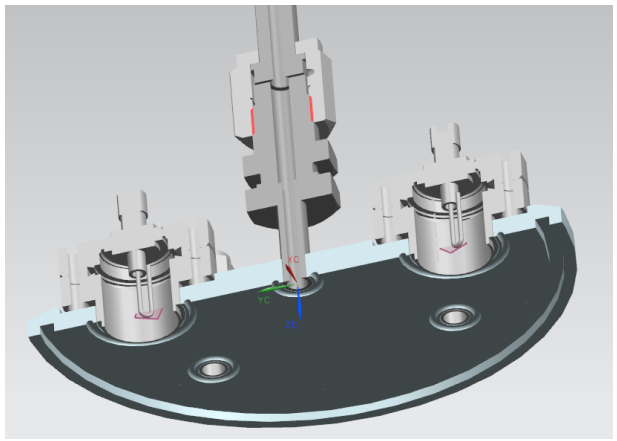


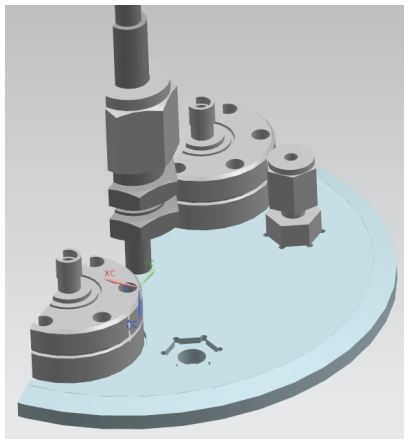


Diagnostics

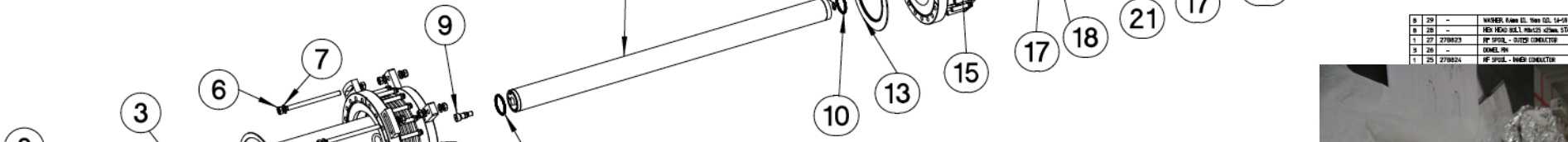
- Vessel
  - top plate for
    - RF pickups
    - cavity vacuum pickup
    - optical fibers
  - acoustic sensors tested on 805-MHz cavities
  - vacuum
  - Thermocouples
  - infrared sensor for window temperature
  - Faraday cup
- Couplers
  - directional couplers for forward/reverse power
  - vacuum
  - viewport/fibers
  - electron pickups
- External
  - air pressure (tuner control)
  - water temperature/pressure



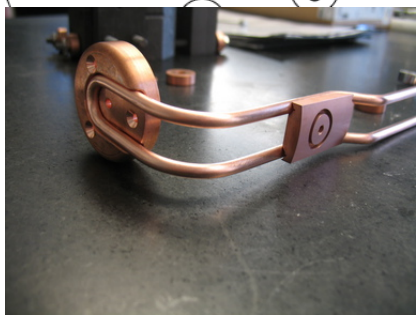


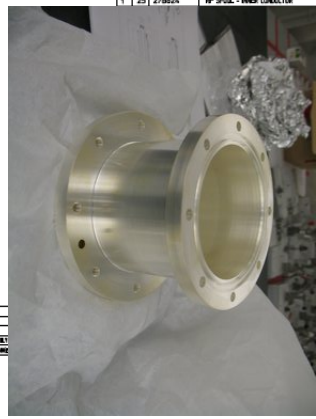


Coupler Fabrication at LBNL



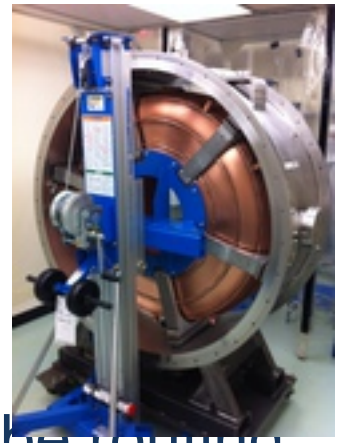
RF COUPLER – EXPLODED VIEW
SCALE 1:2

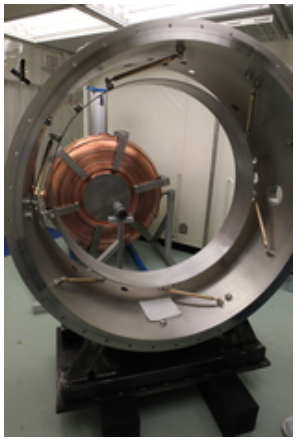




201-MHz MICE Single-Cavity Module Lessons learned

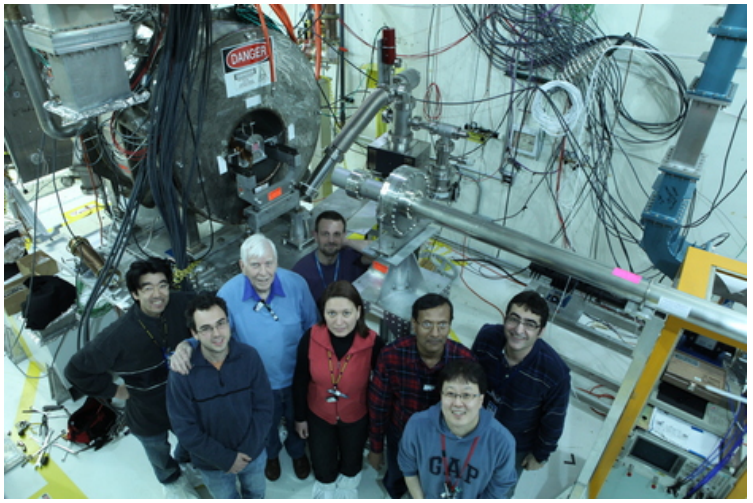
- Complete assembly sequence worked out
  - Modifications as needed
- Experience directly relevant to MICE RFCC module
  - Clean room practice
  - Assembly fixtures
  - Alignment tools
  - Tuner fork machining
  - Tuner transfer functions
  - Water feed-throughs, cooling tube routing
  - Support struts
  - Vacuum system
  - RF probes and other instrumentation
  - Possibly LLRF





805-MHz HPRF Cavity Program

- HPRF previously tested at the MTA
  - Dense H_2 gas buffers dark current while serving as ionization cooling medium
  - No B-field effect, 1 MV/m per atm H2
- 2 beam tests to evaluate response to high-intensity beam
  - Beam-induced plasma loads cavity
  - Mitigate with electronegative dopant
  - Wide range of parameters explored
  - Demonstrated operation with beam in 3T field
- Initial results published
  - Quantitative theory validated by measurement of energy loss in H2/D2+dopant
  - Dopants turn mobile ionization electrons into heavy ions, reducing RF losses by large factor
- Results extrapolate well to Neutrino Factory operation and a range of Muon Collider beam parameters
  - Plasma loading < beam loading
  - Bunch intensity limits being evaluated
- Also preparing for dielectric-loaded HPRF cavity test to enable smaller coils in HCC



PRL 111, 184802 (2013) PHYSICAL REVIEW LETTERS week ending 1 NOVEMBER 2013

Pressurized H_2 rf Cavities in Ionizing Beams and Magnetic Fields

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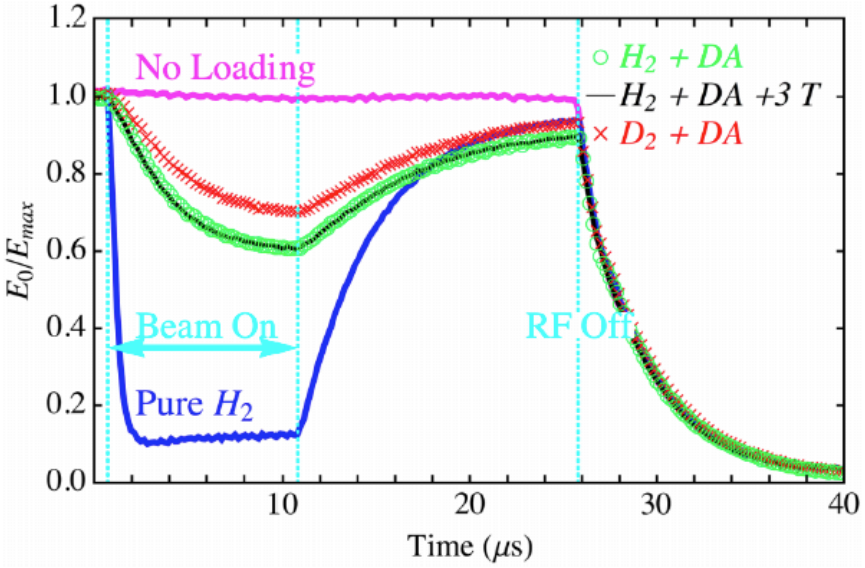
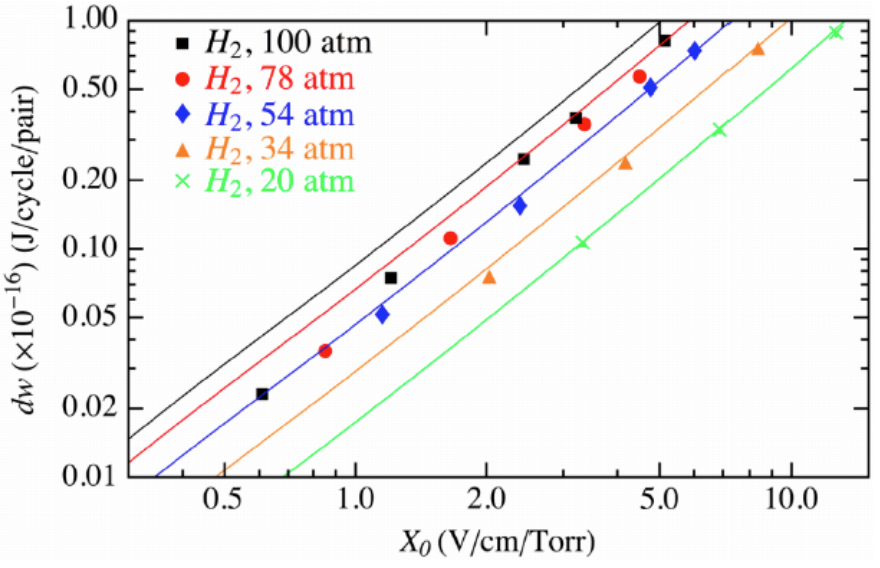
(Received 12 July 2013; published 29 October 2013)

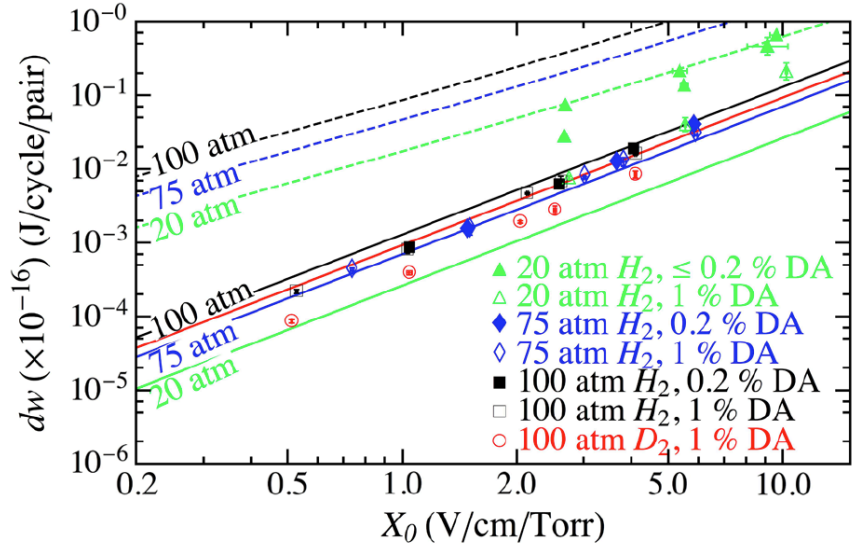
Measured (for H2/D2+dry air)
- Energy loss/e-ion pair/RF cycle
- e attachment time to oxygen
- Ion-ion recombination rates

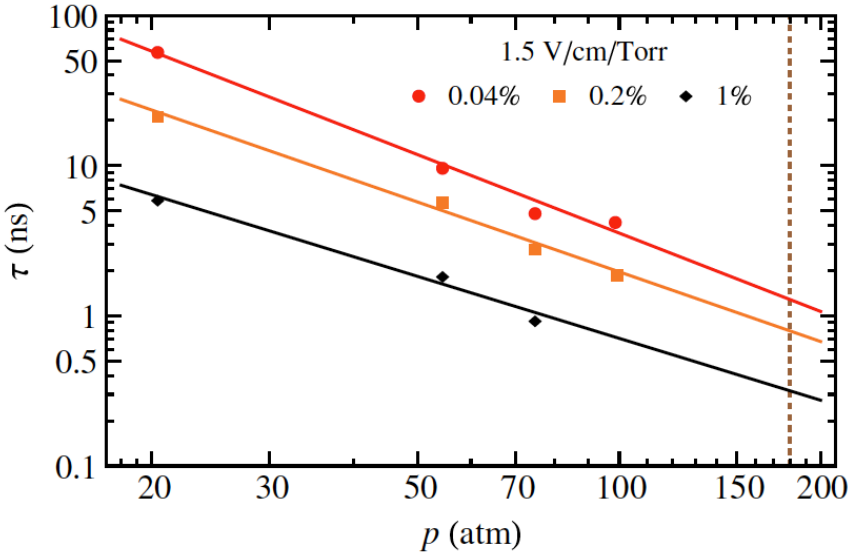
Analysis of rest of the data close to completion

Plasma Loading in HPRF Beam Test



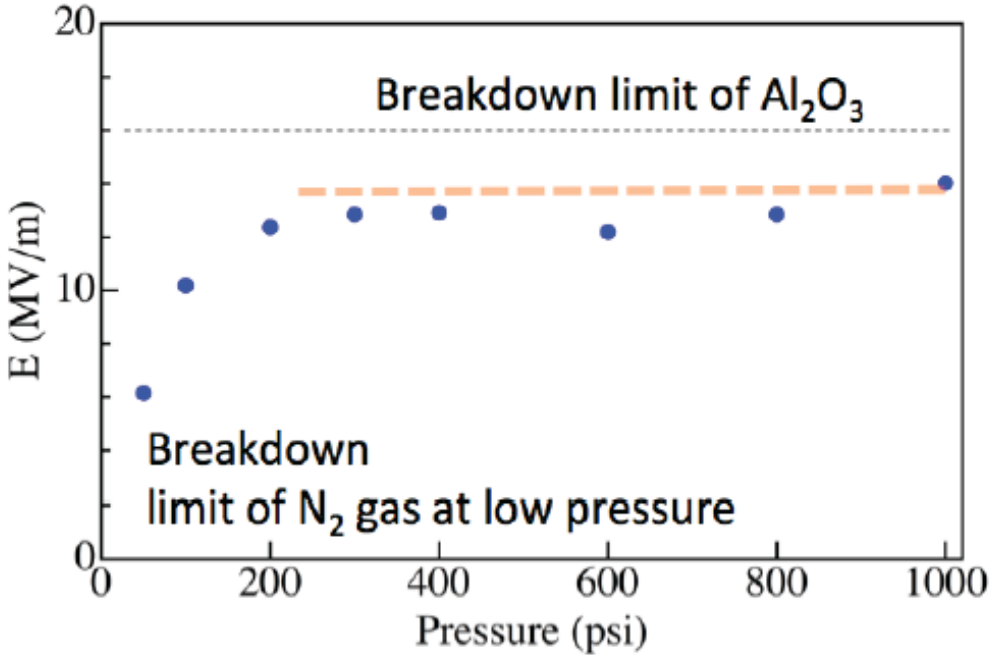




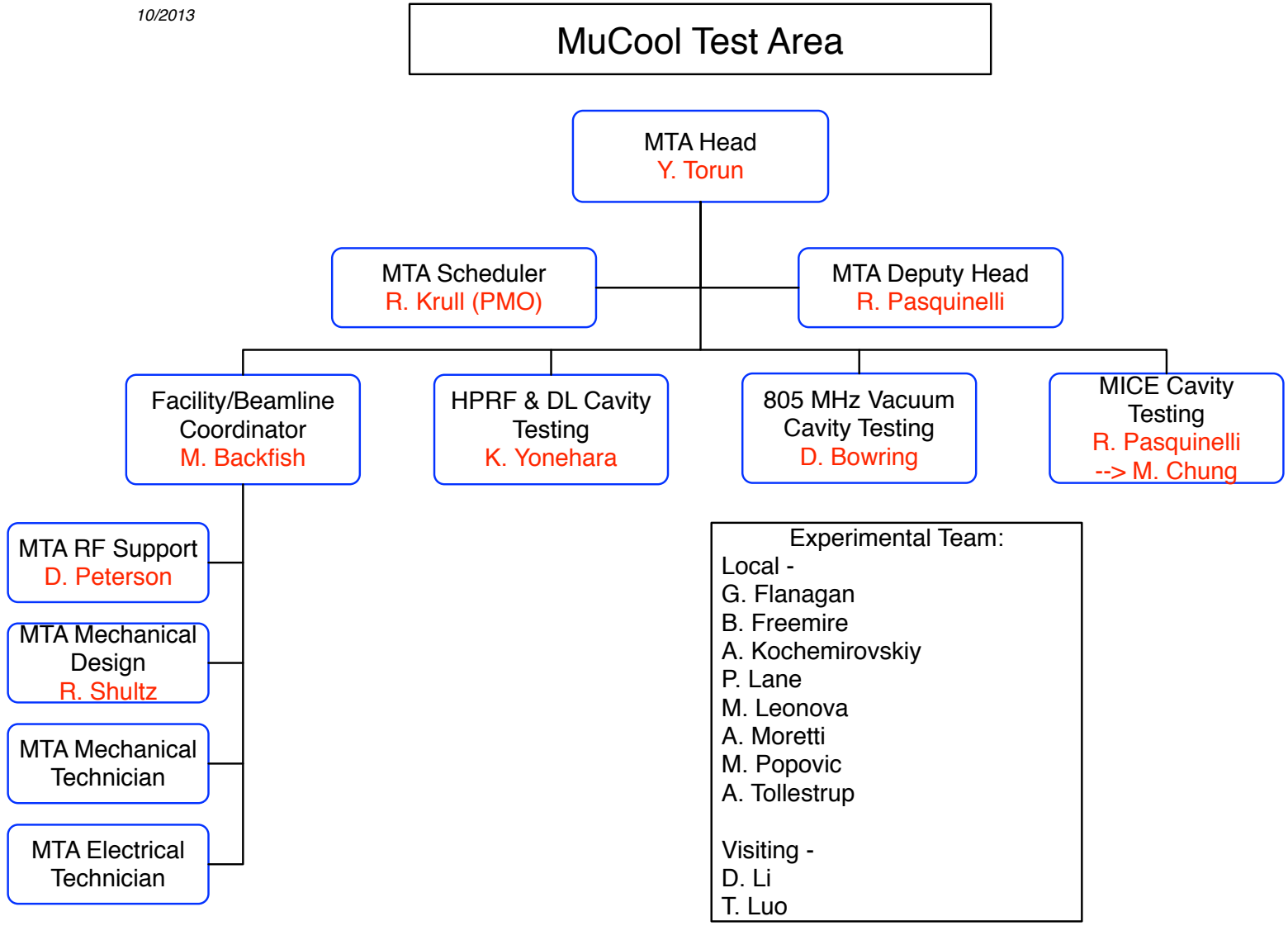


Dielectric-loaded HPRF

- Need to shrink transverse cavity size to reduce magnet apertures in HCC
- Proof-of-principle test: HPRF test cell + alumina
  - suppression of breakdown up to surface breakdown limit of material
- Other samples to be measured at low power
- High power test in MTA for promising candidates (suitable dielectric constant, low loss tangent)
- Beam test if successful
- Also looking at reentrant cavity design (Muons Inc)



Personnel


10/2013
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MTA Scheduler
R. Krull (PMO)
MTA Deputy Head
R. Pasquinelli
Facility/Beamline Coordinator
M. Backfish
HPRF & DL Cavity Testing
K. Yonehara
805 MHz Vacuum Cavity Testing
D. Bowring
MICE Cavity Testing
R. Pasquinelli
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