MuCool Test Area Program

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MAP 2013 Collaboration Meeting
Fermilab – June 20, 2013

MuCool

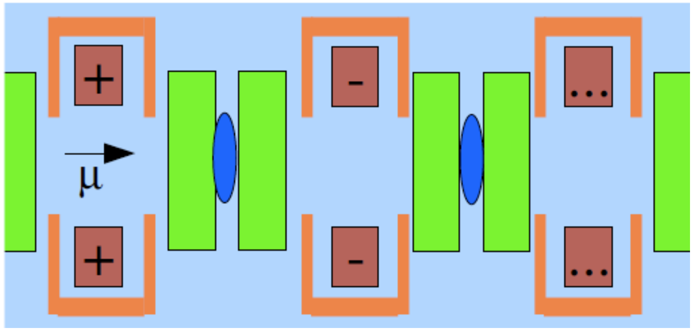
R&D program at Fermilab to develop ionization cooling components

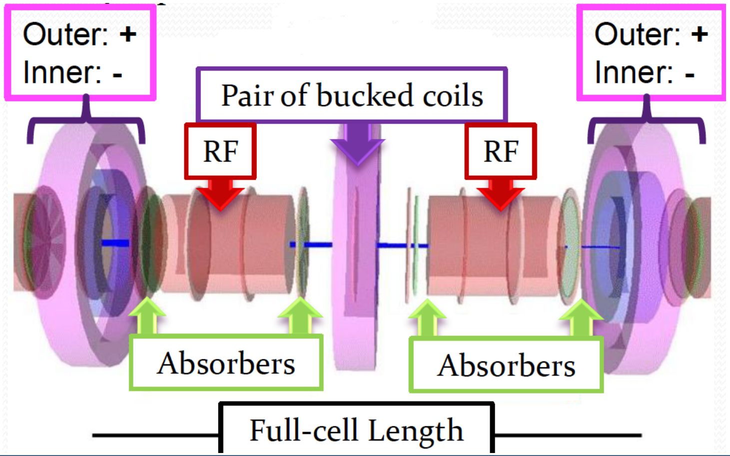
Mission

- Design, prototype and test components for ionization cooling
  - Absorbers (LH2, solid LiH)
  - RF cavities
  - Magnets
  - Diagnostics
- Inform associated Design & Simulation studies
- Support System Tests (MICE, 6D Cooling Demo)
- Current focus: RF cavity performance in strong external magnetic fields

Potential solutions

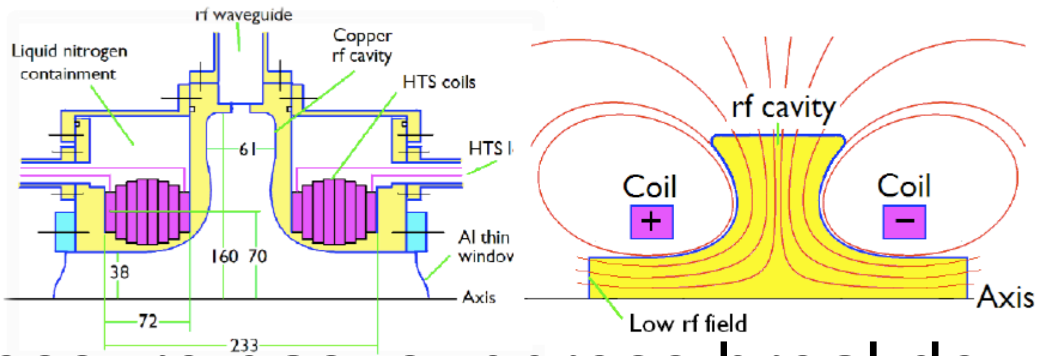
- Better materials: more robust against breakdown/damage (melting point, energy loss, skin depth, thermal diffusion length, etc.)
- Surface treatment: suppress field emission (SRF techniques, coatings, atomic layer deposition)
- Shielding: iron, bucking coils (IDS-NF option)



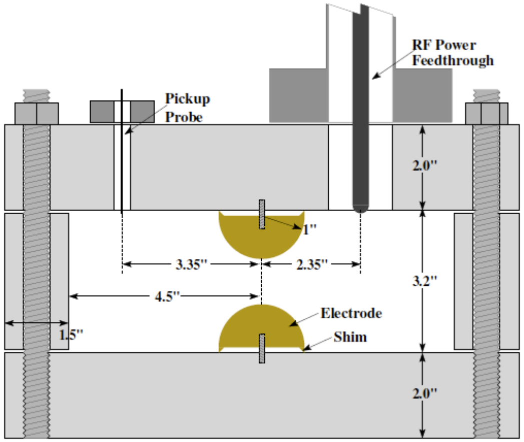


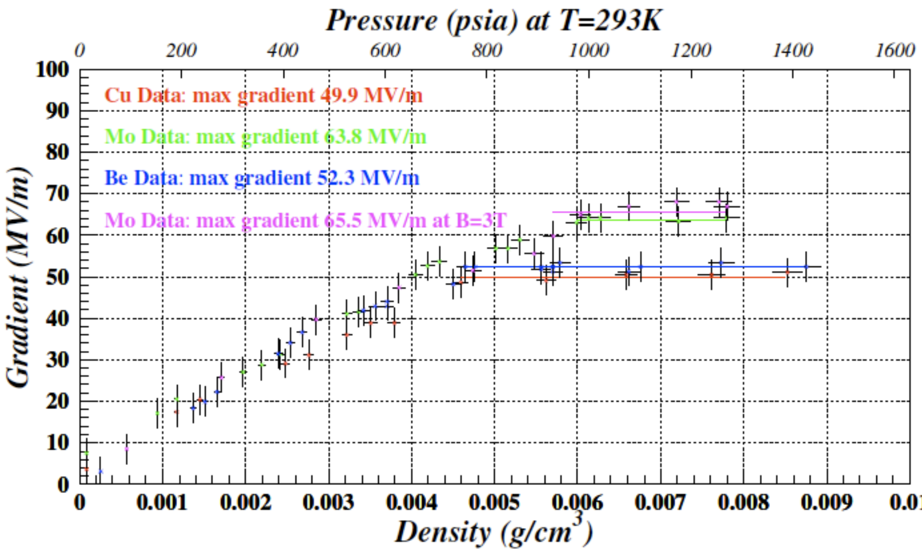
Potential solutions

- Magnetic insulation: modified cavity/lattice designs to keep B perpendicular to E on cavity surfaces



- High-pressure gas: suppress breakdown by moderating electrons

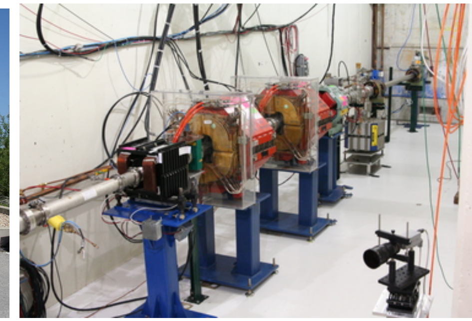




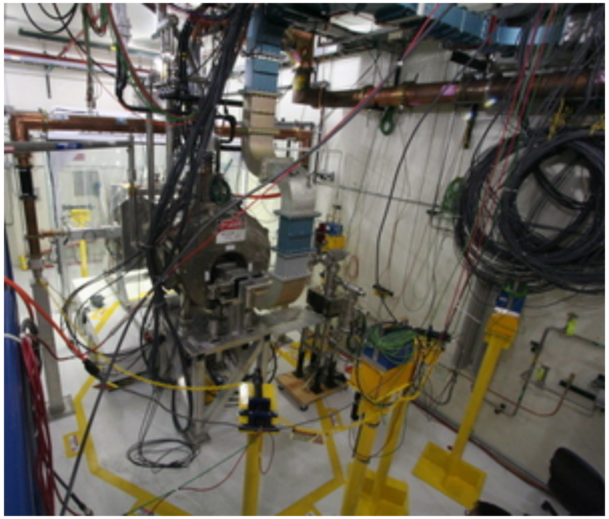
MuCool Test Area
http://mice.iit.edu/mta/

Dedicated facility built at the end of the Linac to address MuCool needs



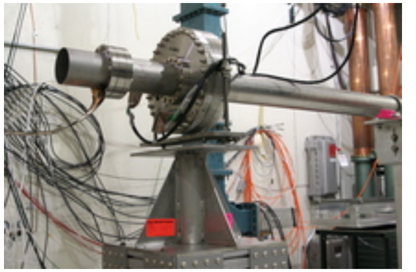



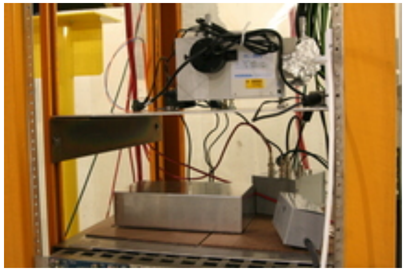
- RF power (12MW @ 805MHz, 4.5MW @ 201MHz)
- Large-bore 5T superconducting solenoid
- Cryogenic plant
- 400-MeV H- beamline
- Class-100 portable clean room
- Hydrogen safety infrastructure
- 805- and 201-MHz cavities
- Radiation detectors

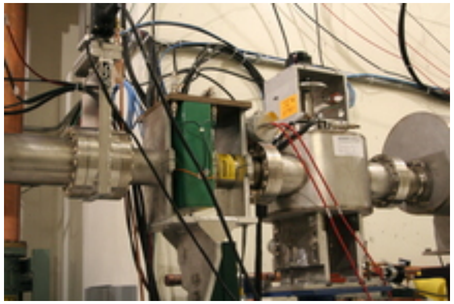



MTA Diagnostics

- RF directional coupler and pickup signals
- Vacuum pressure
- Scintillator+PMT counters for X-ray rates, spectra
- Ionization chambers for radiation dose rates
- Spectrometer for cavity light analysis
- Thermocouples for cavity temperature
- Acoustic sensors for spark detection (under development)
- Toroids for beam intensity
- BPM, MW and scintillator for beam profile/position
- Environmental monitoring







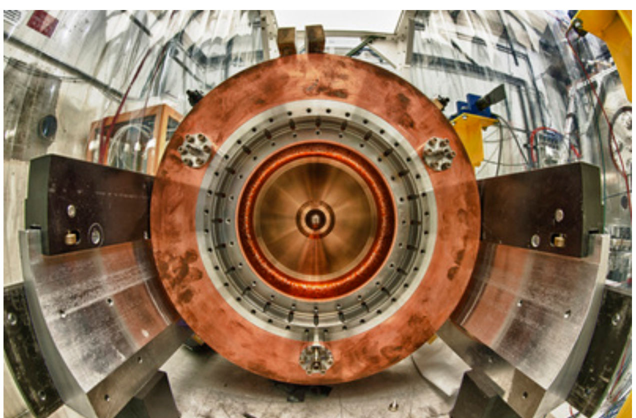
MTA Program Overview

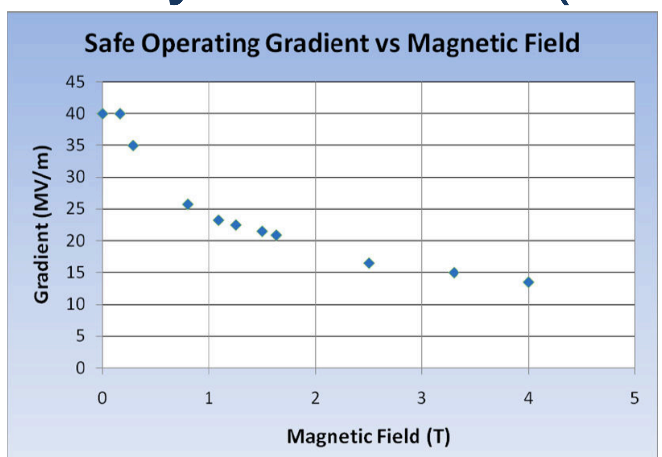
- Goal: Demonstrate a working solution to RF cavity operation in high external magnetic field for muon cooling
- Major MAP deliverable
  - and near-term technical risk for MICE
- Major impact on cooling channel design and future system tests
- A multipronged approach has been followed

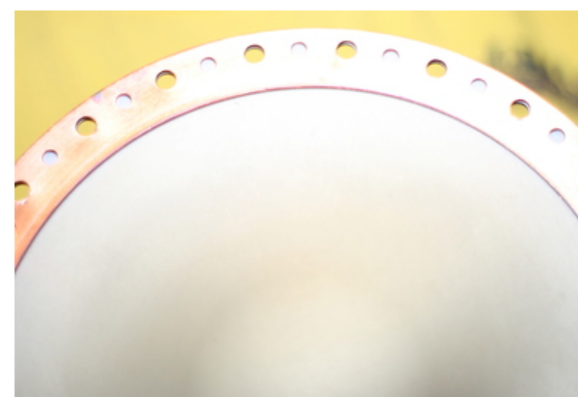
⇨ Identify most promising paths for detailed study

805-MHz Pillbox Button Cavity Program (Magnetic Field, Materials, Windows)

- Pillbox geometry with thin curved Be windows
- Button holder for removable electrode inserts
- Used to
  - Quantify magnetic field dependence of gradient
  - Establish feasibility of thin windows (Cu, Be)
  - Test potential cavity materials (Cu, Be, Mo, W)



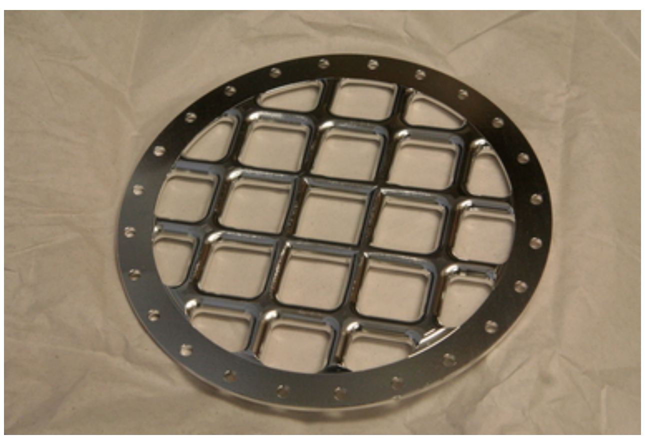


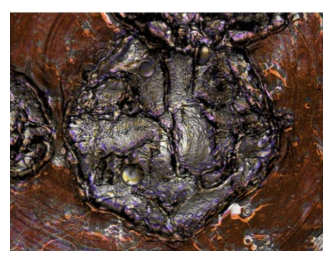


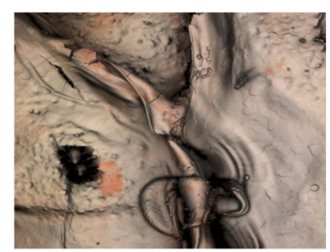
Fermilab 805-MHz Pillbox Button Cavity Program

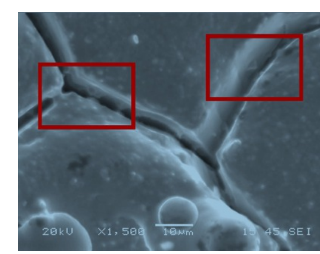
- Most recent test: Be vs Cu buttons & flat Cu endplates
  - Higher gradient with Be buttons
  - Minimal surface damage on Be
  - Surface microscopy in progress
- Will also be used to test grid-tube windows

Run	Configuration	B [T]	Gradient [MV/m]
1	flat Cu plates	0	19
2		3	9.5
3	Be buttons	0	27
4		3	29
5		0	40
6		3	31
7		1.5	33
8		3	33
9	Cu buttons	0	30
10		3	28
11		0	35
12		3	28
13		1.5	30



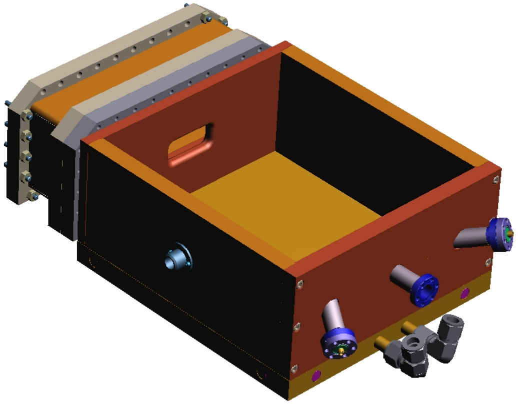


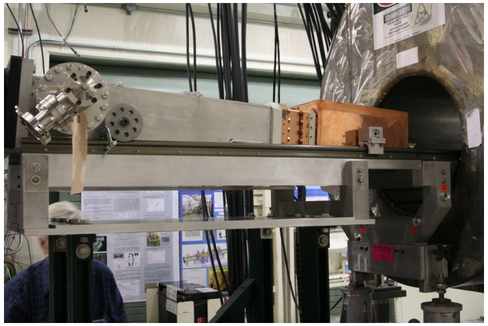




805-MHz Rectangular Box Cavity (Magnetic insulation, surface treatment)

- Rectangular geometry for fast fabrication and simple analysis
- Utilizes electro-polished Cu plates
- Tested in magnet
  - 50 MV/m at B=0
  - 33 MV/m at 0-1^{o} from 90
  - 25 MV/m at 3-4^{o}
- Magnetic insulation works
  - But within small range of angles
  - Gain in gradient not enough to offset x2 less shunt impedance
  - Challenging cavity/magnetic lattice integration
- Dropped from consideration

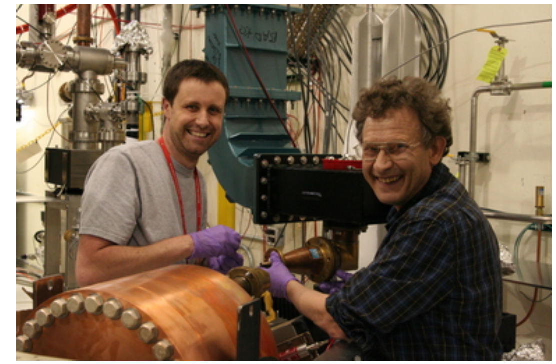


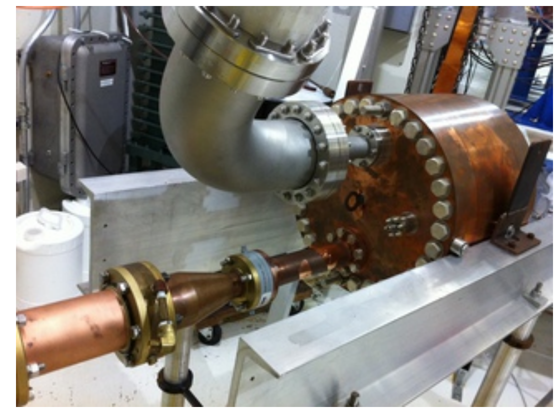


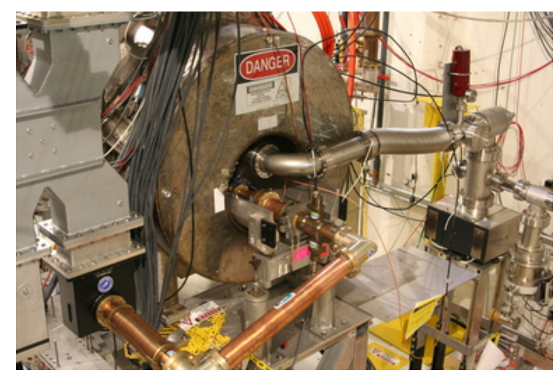
Fermilab

Magnetic Field Dependence
"All-season" Cavity (Muons Inc, LANL)

- Modular pillbox with replaceable endplates
- Designed for both vacuum and high pressure
- Made of 316SS with 25μ Cu plating
- 3.9/6.6/2.7cm-thick center ring/inner/outer plates
- RF volume ϕ29.1 x 12.9 cm
- 1-5/8" coax coupler
- f=810.375 MHz under vacuum, Q=28k
- Power: 1.2MW @ 25 MV/m
- No cooling included in design
- Operated in magnet
  - 25 MV/m at B=0 and 3 T
- Re-run with RF pickup (>3M pulses)
  - Confirmed at B=0 (29 MV/m)
  - 20 MV/m at B≠0
  - Data analysis in progress

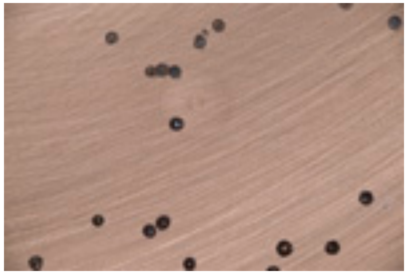


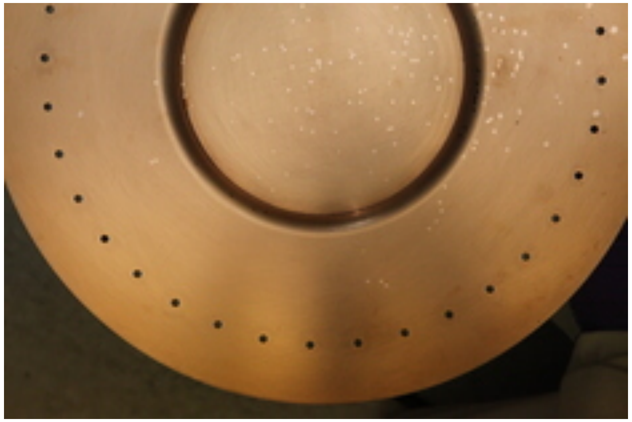


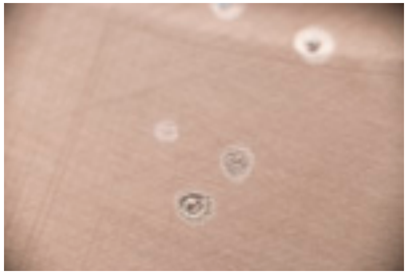


Magnetic Field Dependence
"All-season" Cavity (Muons Inc, LANL)

- Inspection
  - Damage spots on endplates (about same # as sparks)
  - Spot size (mm) similar to those in other Cu cavities
  - Evidence of arcing at coupler center conductor

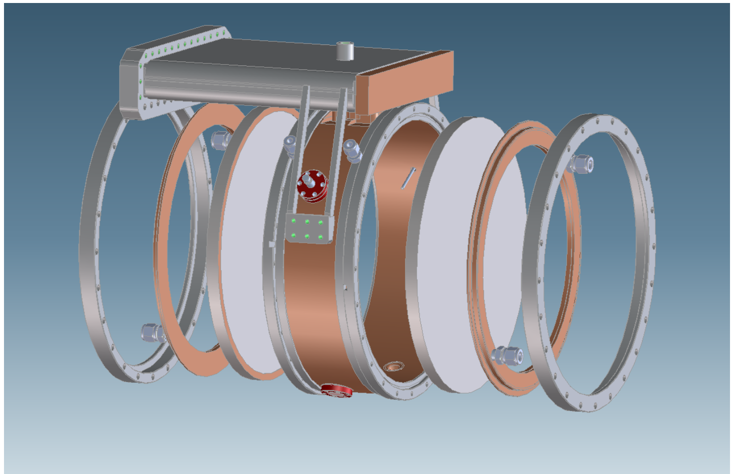


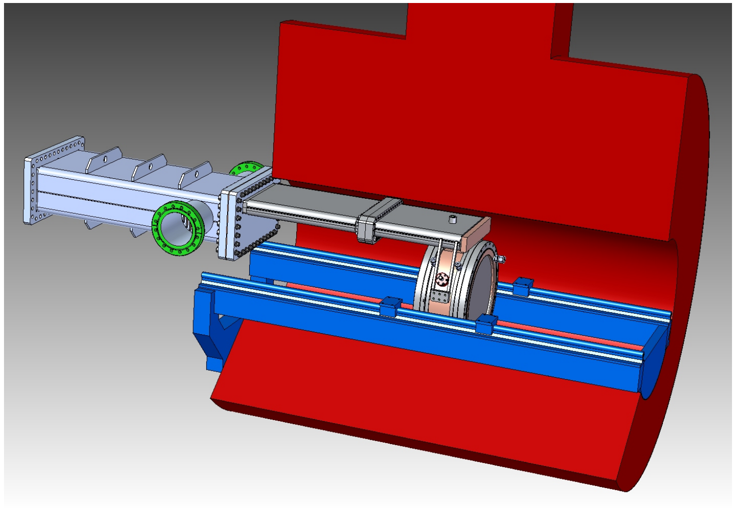




Future Vacuum Pillbox Cavity R&D
805-MHz Modular Cavity (SLAC/LBNL)

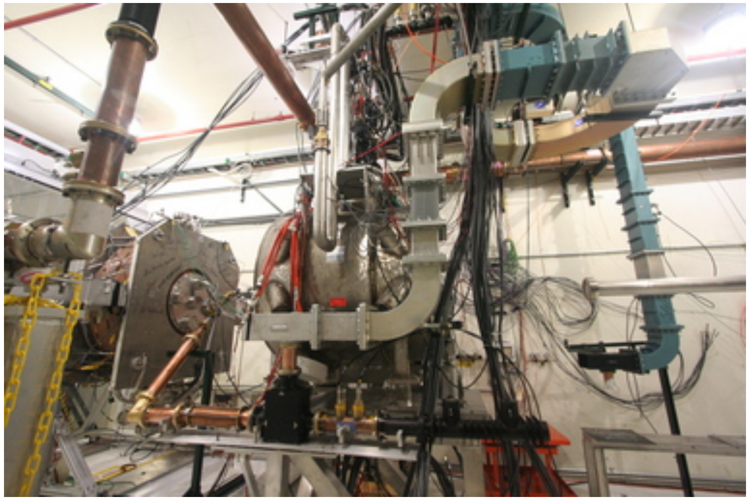
- New R&D vehicle for detailed systematic studies
  - Modular design for easy assembly, parts replacement
  - Removable endplates (Cu, Be, other materials, treated surfaces)
  - Coupling iris moved to center ring and field reduced (*more realistic design*)
  - RF design validated by detailed simulation
  - Ports for instrumentation
  - Fabrication started
  - Expected delivery to MTA: Fall `13

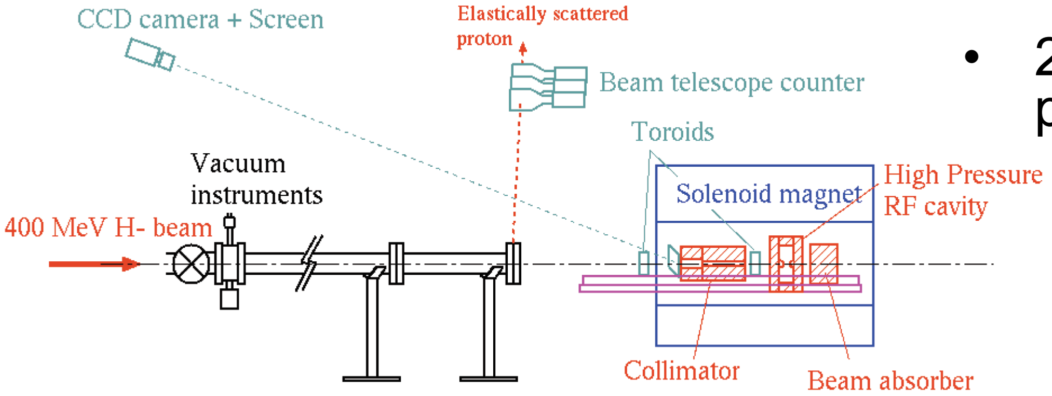




Pressurized RF
805-MHz HPRF Cavity (Muons Inc)

- HPRF concept previously tested at the MTA (Hanlet et al., EPAC06)
  - Dense H_2 gas buffers dark current while serving as cooling medium
  - Allows gradients up to the surface breakdown limit with no B-field effect
  - H_2 supports 1 MV/m per atm
- Response to high-intensity beam
  - Electron-ion pairs produced by beam
  - Beam-induced plasma loads the cavity
  - Mitigate with electronegative dopant gas

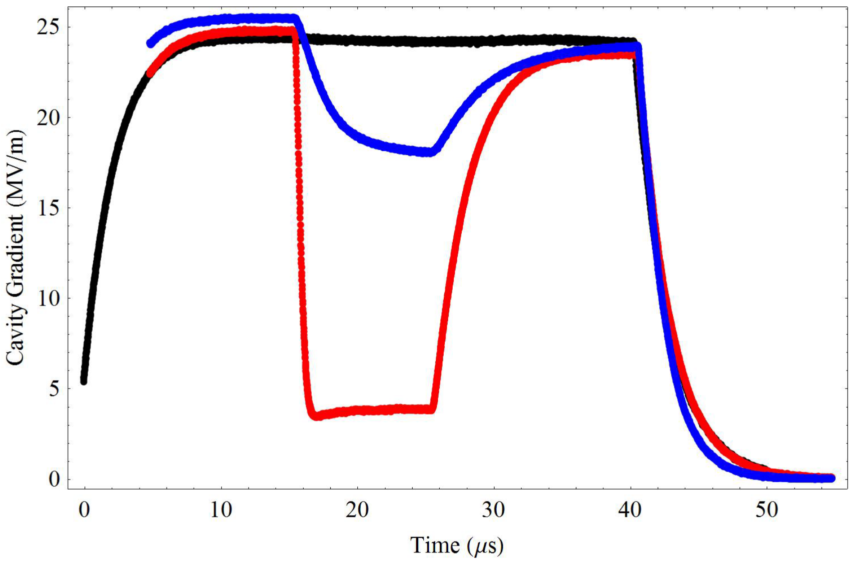




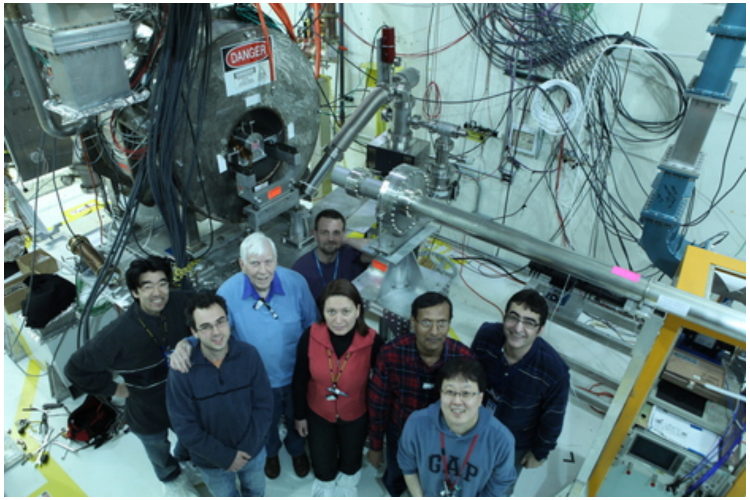
- 2 beam tests performed to evaluate plasma dynamics in the cavity
  - Fermilab Linac beam (400-MeV p)
  - dE/dx per p similar to 100-MeV/c μ
  - ~10^9 protons per bunch

Fermilab 805-MHz HPRF Cavity Beam Test

- Wide range of parameters
  - 10^{10}-3×10^{11} ppp, 5-50 MV/m
  - 300-1520 psi H2, B=0 and 3T
  - Electronegative Dopant Studies: SF6 & dry air effect vs. concentration
  - Ion Mobility Studies: He+air, N2+air, D2
- Publication draft under review
  - Quantitative theory validated by measurement of energy in H2/ D2+dopant (B. Freemire thesis)
  - Electronegative 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

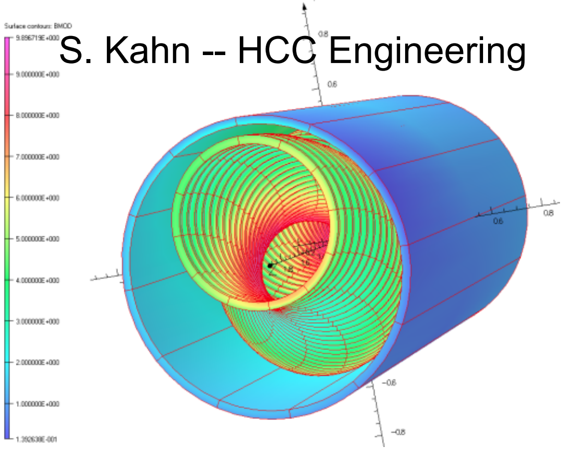


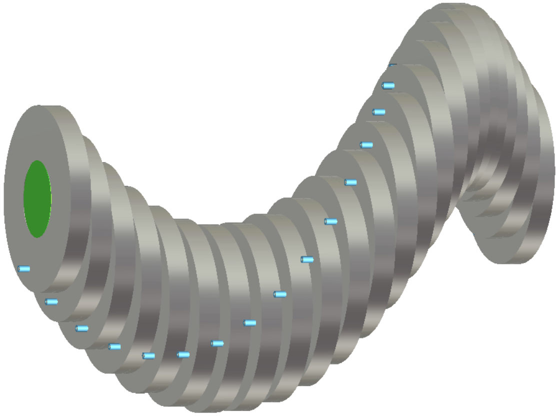
1470psi H2 beam 1% dry air

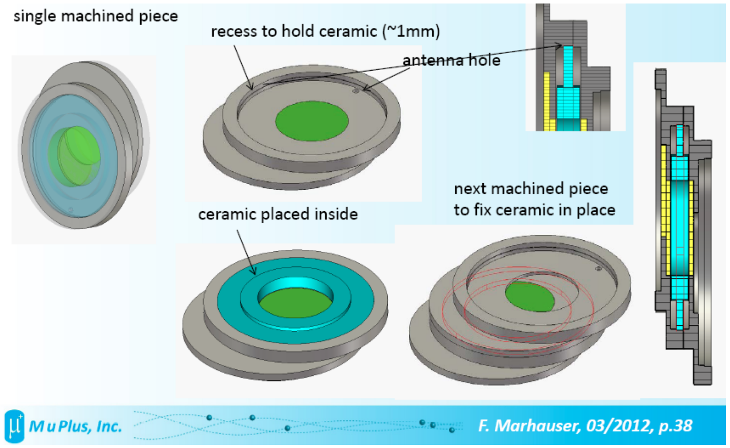


805-MHz Dielectric-loaded HPRF

S. Kahn -- HCC Engineering

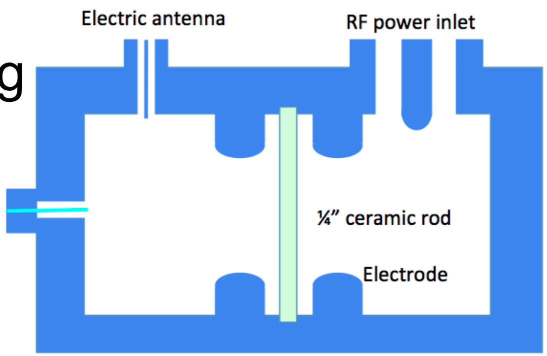


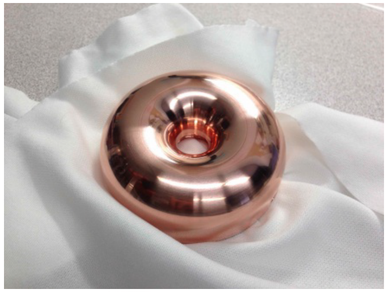




- Magnet apertures in HCC with RF inside helical solenoids lead to large fields on conductors
- Dielectric loading to shrink RF cavities
- High-pressure gas to suppress dielectric surface breakdown

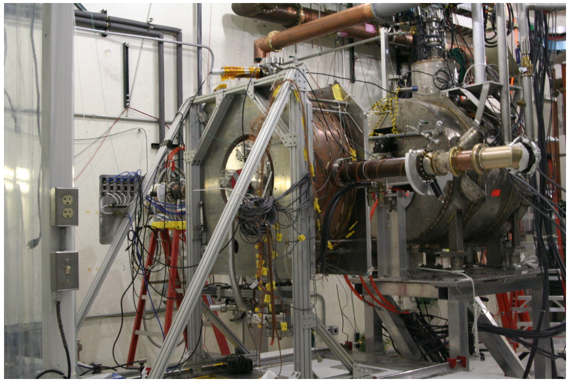
- Muons Inc. grant for HCC engineering design (G. Flanagan, K. Yonehara)
- Hardware in hand
- Initial test with Al2O3 carried out

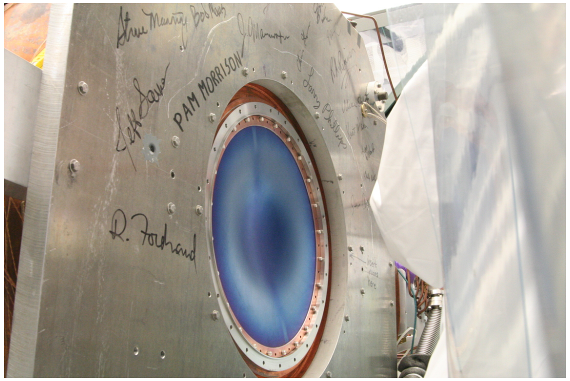


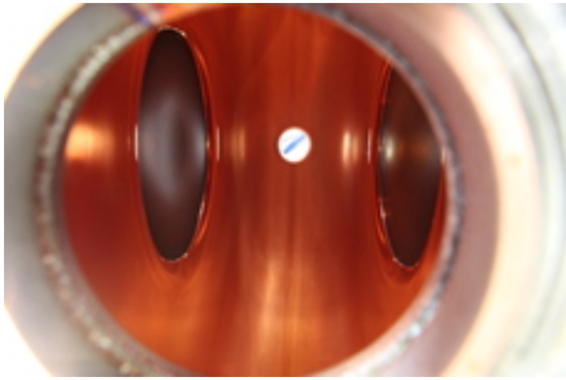


201-MHz Program (Surface treatment, NF channel, MICE)

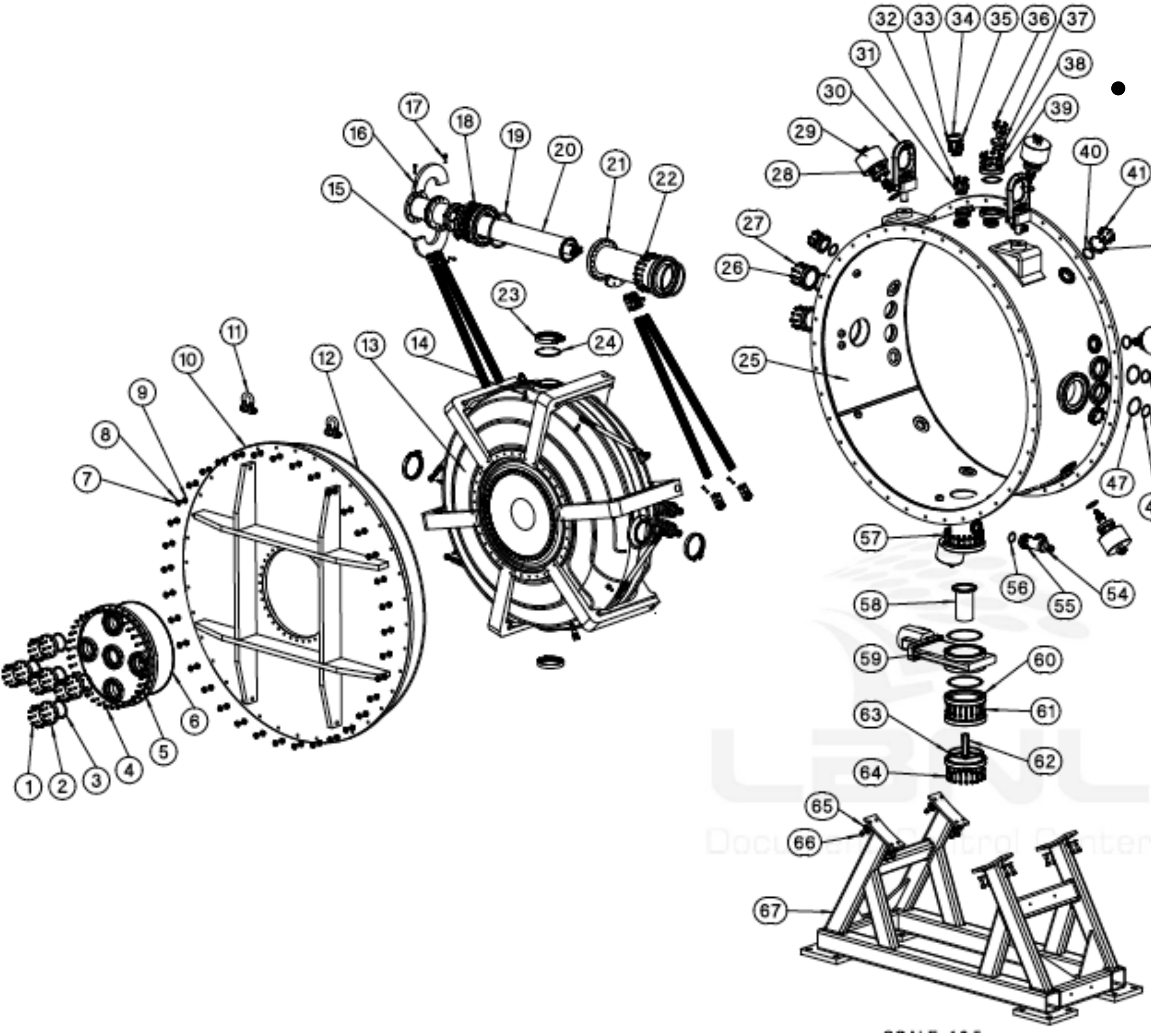
- 201-MHz MICE prototype cavity with SRF-like surface treatment (EP, HP rinse)
  - Conditioned to design gradient quickly
  - Demonstrated operation with large curved Be windows
  - Somewhat reduced performance in fringe field of solenoid
  - No surface damage seen on cavity interior
  - Some evidence for sparking in the coupler
    - Multi-pacting studied (T. Luo)
    - Design now modified
    - Also looking into 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



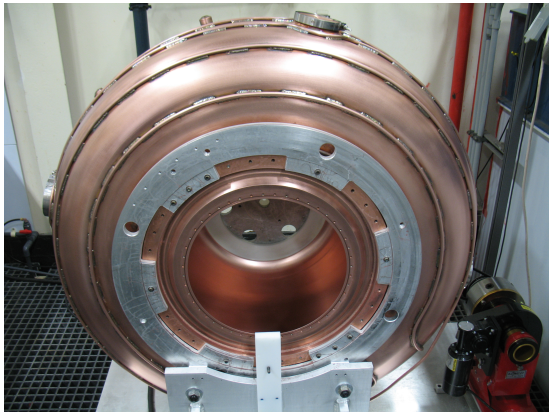




201-MHz Single-Cavity Module

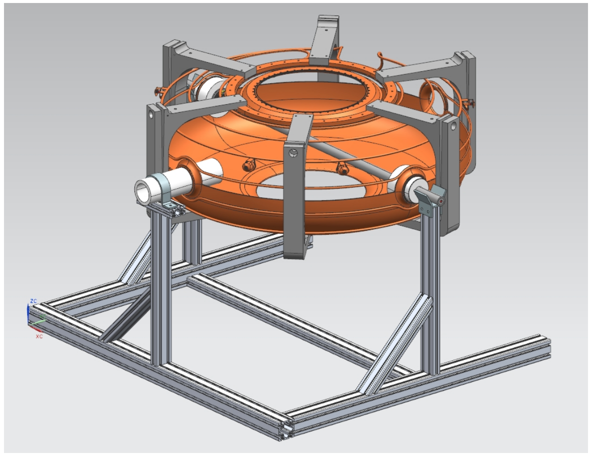


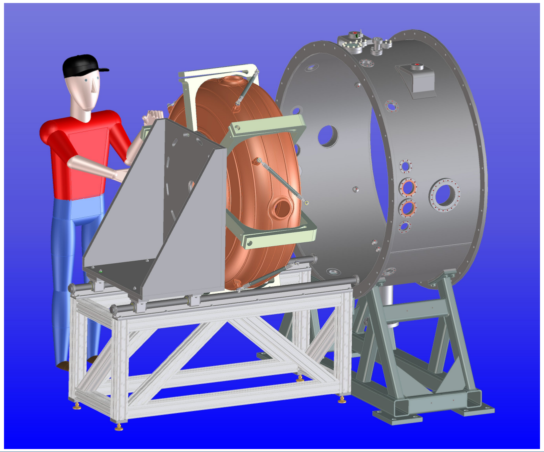
- MICE cavity in vacuum vessel for MTA test
- Components
  - 1st MICE cavity EP'ed at LBNL
  - Vacuum vessel built at Keller Technology
  - Be windows in hand
  - Actuators built at LBNL
  - Tuner forks built at FNAL
  - Ready for fabrication of new couplers at LBNL

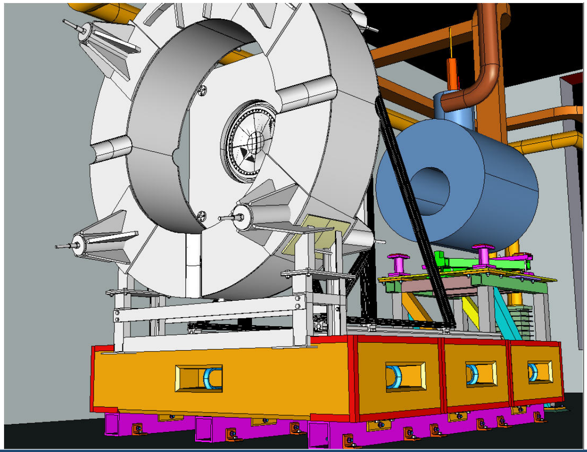


201-MHz Single-Cavity Module

- Assembly/integration
  - Cavity and vessel at Lab-6
  - Clean room prepared
  - Assembly fixtures built
  - Tuner control bench tested
  - Plan in place for handling and transport
- Expect operation Fall 2013
  - Option for beam test
- Ultimately will be tested with the first Coupling Coil Magnet
  - Requires 6-month MTA shutdown

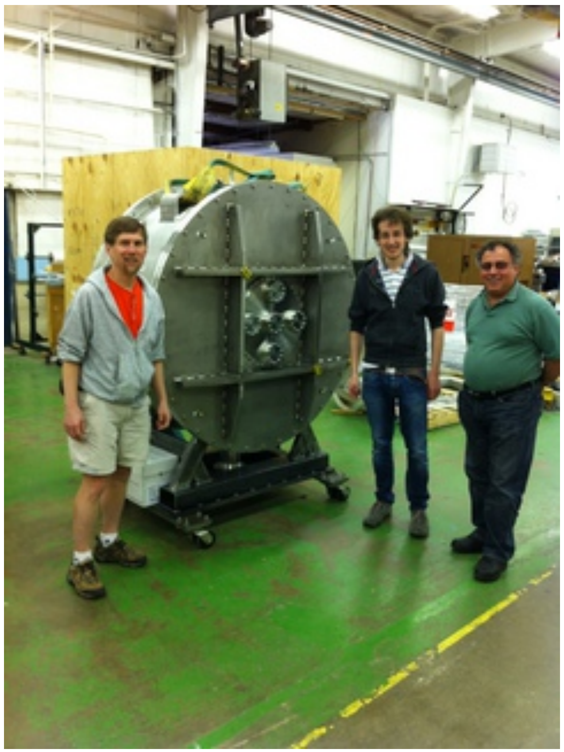






Components in Lab-6

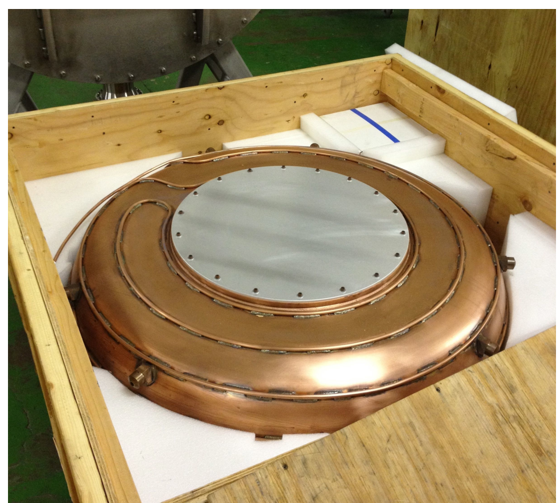
Vacuum vessel on transport stand



Tuner installation fixture (horizontal stand)

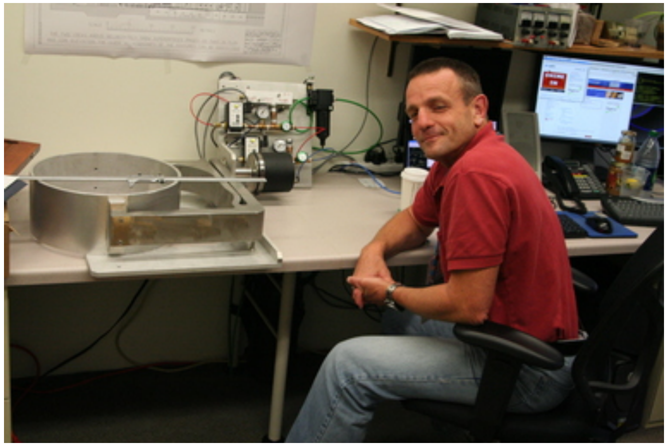
Tuner forks

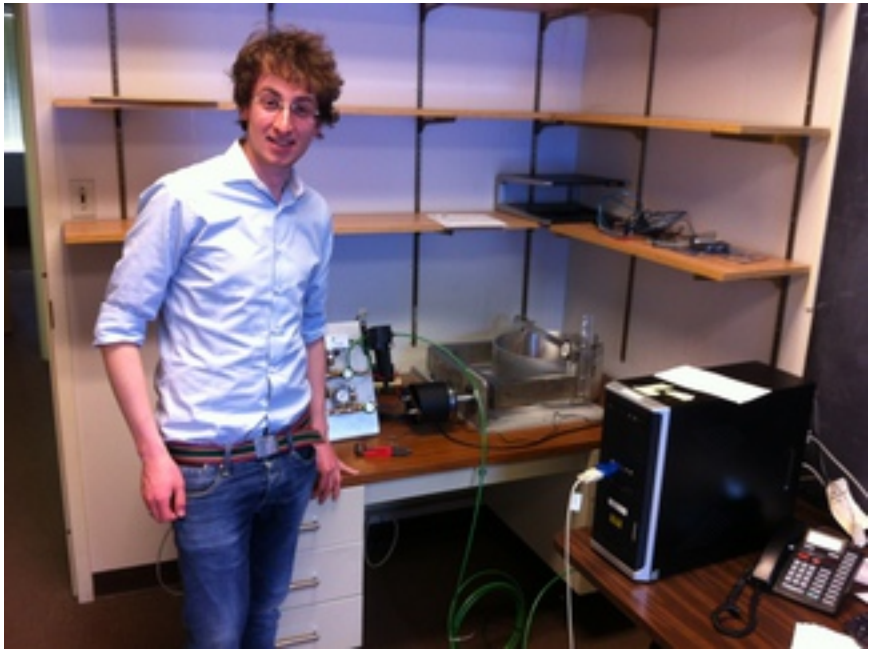
Cavity

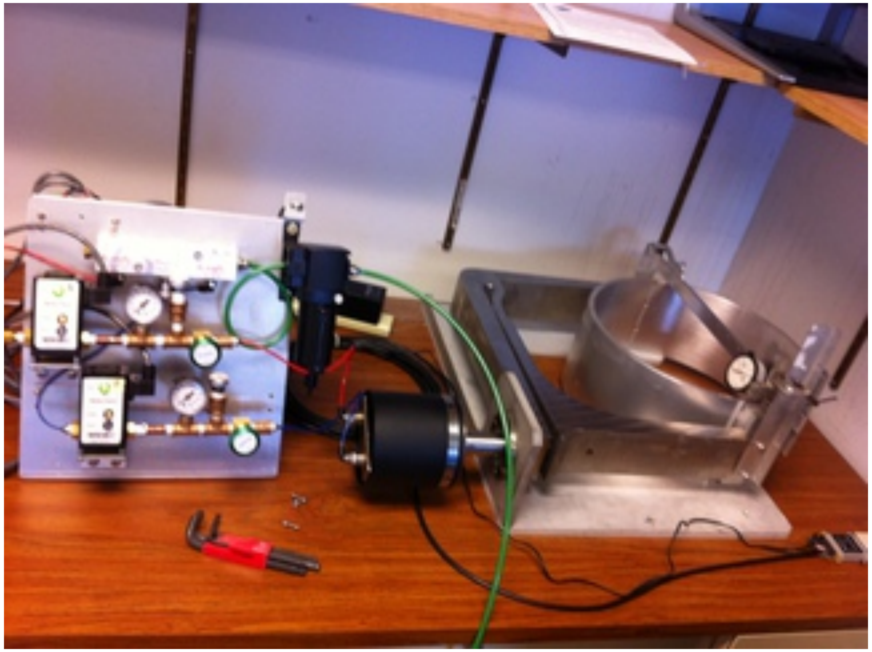


Tuner bench tests

- First set up on P. Hanlet's desk (EPICS)
- Transferred to L. Somaschini's desk (LabVIEW)
  - Master's thesis project
- Forks to be trimmed/tested in Lab-6
- All actuators in hand
- 2 new proportional valves purchased

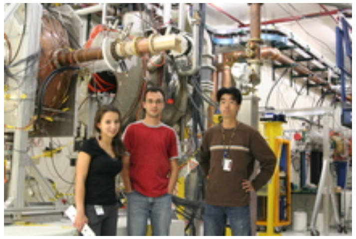


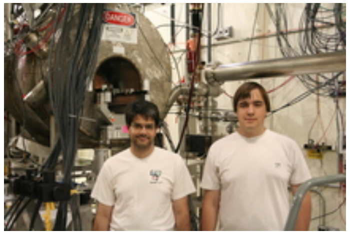


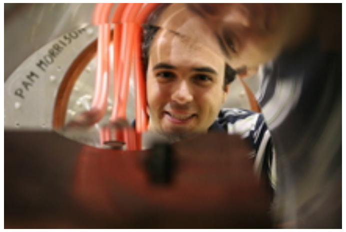


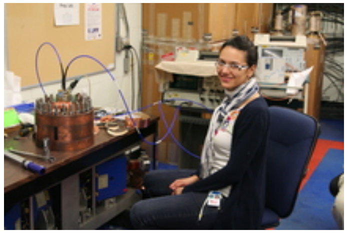
Recent student projects http://mice.iit.edu/mta/students/

- Luca Somaschini (Pisa) – 201-MHz tuner system
- Jared Gaynier (Kettering) – circulator & CC installation
- Lisa Nash (U. Chicago) – dielectric loaded HPRF
- Adam Sibley (Trinity) – HPRF breakdown study
- Oleg Lysenko (U. Chicago) – HPRF beam test
- Jessica Cenni (Pisa) – dielectric loaded cavity
- Tom Mclaughlin (Valparaiso) – magnet mapping, circulator installation
- Ivan Orlov (Moscow State) – HPRF beam test simulation
- Raul Campos (NC State) – beamline magnet support
- Peter Lane (IIT) – acoustic sensors for RF breakdown
- Timofey Zolkin (U. Chicago) – dark current instrumentation
- Giulia Collura (Torino) – HPRF beam test
- Ben Freemire (IIT) – HPRF beam test (Ph. D.), other tests
- Last Feremenga (U. Chicago) – magnetic field mapping
- Anastasia Belozertseva (U. Chicago) – magnet mapping





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- Sheath parameters for non-Debye plasmas: Simulations and arc damage, I. V. Morozov *et al.*, Phys. Rev. ST Accel. Beams 15, 053501 (2012)
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- Study of Electron Swarm in High Pressure Hydrogen Gas Filled RF Cavities, K. Yonehara *et al.*, IPAC10 proceedings, p3503

Outlook

- Experimental program
  - HPRF beam tests successfully concluded
    - Looks promising for Neutrino Factory and Muon Collider application
    - Dielectric loading tests started
  - Vacuum cavity R&D bearing fruit
    - 20+ MV/m @ 3T demonstrated in Cu pillbox (all-season cavity), follow-on testing underway
    - Alternative window geometry to be explored
    - New modular cavity in fabrication for detailed systematic studies (Cu/Be walls, gradient vs B)
    - Beam tests will be included in experimental program
    - 201-MHz single-cavity module (MICE) tests
      - Tests with Coupling Coil Magnet will follow when magnet prototype ready
- Infrastructure upgrades (beamline, RF, magnets)
- ***R&D program now pointing the way to RF solutions for ionization cooling channels!***