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MuCool Test Area (MTA) Facility Operations

Beyond MAP…

Outline

- Facility Introduction and History
- MTA Overview
  - Capabilities
  - Accomplishments
  - Current & Future Research Thrusts
- MTA Transition Plan
- Facility Support & Budget
- Summary

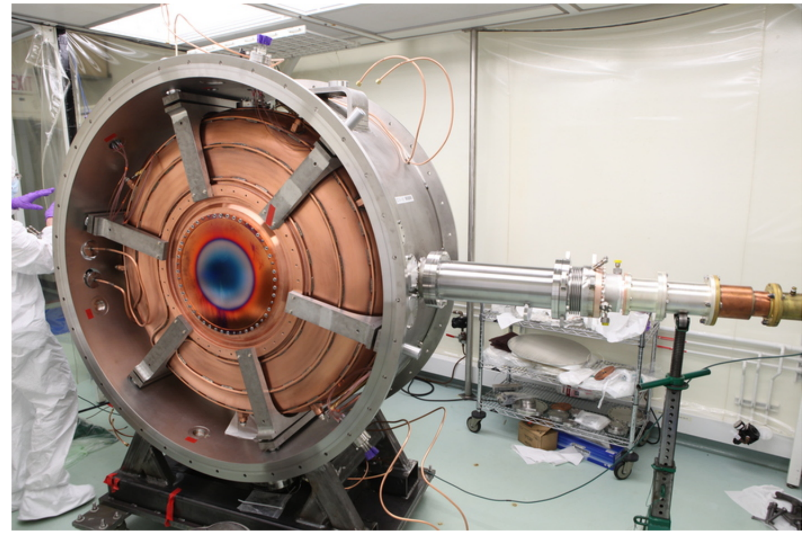
MuCool Test Area (MTA) Introduction and History

- Test facility to provide RF test capability in high magnetic fields and to deliver Linac beam for RF and detector testing.
  - Presently operated by the Muon Accelerator Program (MAP)
  - Supports separate as well as combined beam and magnetic field testing

- Detailed Facility Planning began in 2002
- Facility was initiated utilizing NFMCC (Neutrino Factory Muon Collider Collaboration) funding
- In 2011, “ownership” passed to the newly formed MAP

MTA Introduction and History II

- Major research thrusts under MAP
  - Technology Development for muon ionization cooling
  - Performance specifications for the MAP muon accelerator design effort
  - Support for the International Muon Ionization Cooling Experiment (MICE) ⇨ testing program for the ***MICE 201 MHz RF Module***



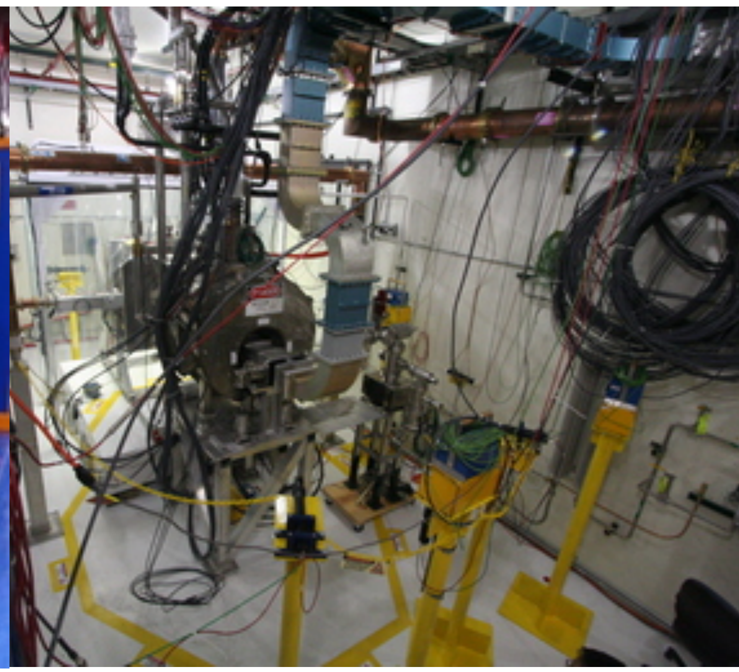
- The facility also provides unique capabilities for detector development
  - High beam intensities
  - Ability to operate detectors in strong magnetic field (up to 5T)

MTA Overview - Capabilities

- Facility Includes:
  - Control area in Linac Gallery
  - Underground experimental hall
  - Surface building (cryogenics plant)



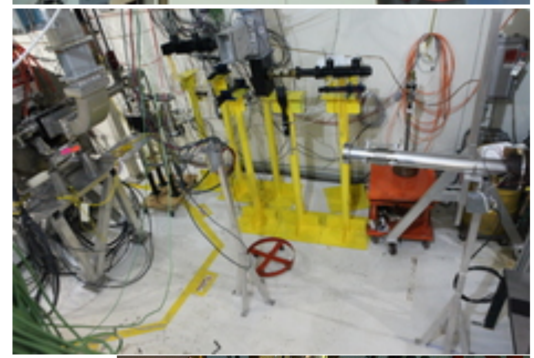




MTA Overview - Capabilities

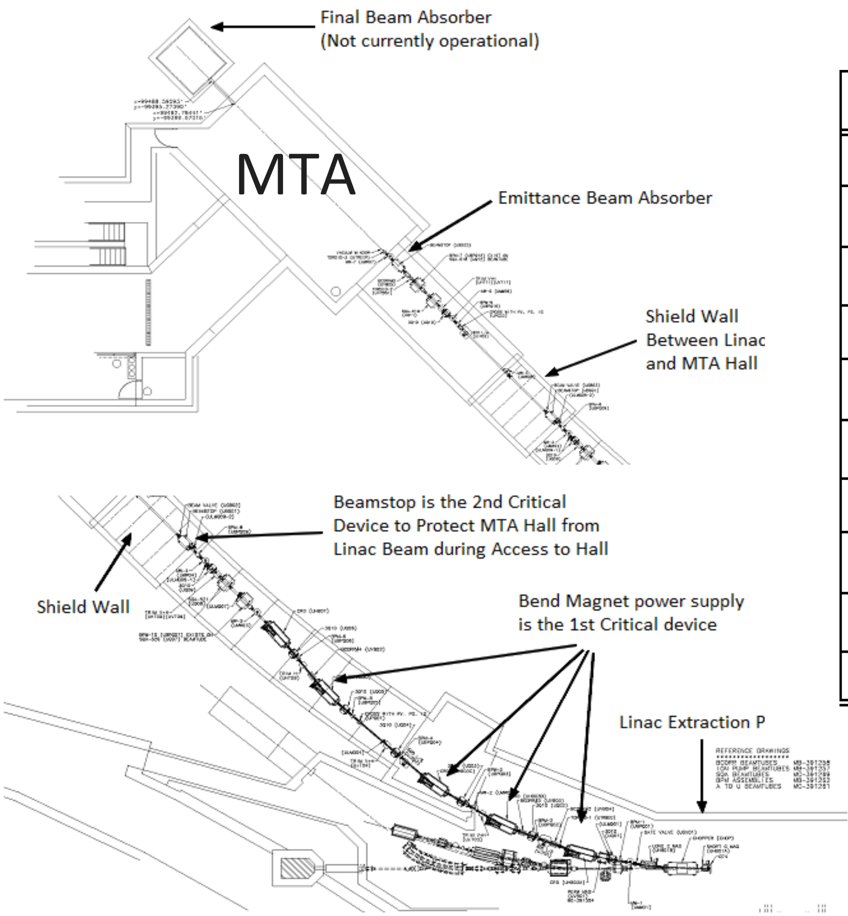
- RF Capability linked to Fermilab Linac
  - 805 MHz
    - 12 MW RF power available
      - RF Station is hot spare for Linac
    - RF switch, circulator and loads installed upstream
      - Allows klystron operation/service independent of MTA hall configuration
      - Provides clean RF signals for experimental data
    - RF switch and 2 waveguide branches in hall provide support for 2 independent test stations
  - 201 MHz
    - 4.5 MW RF power available
      - RF Station is conditioning station for spare 7835 Linac tubes
      - Shared access with MTA program
    - RF switch and load installed upstream
      - Allows amplifier operation independent of the MTA hall configuration

– Extensive diagnostics available for RF cavity characterization



MTA Overview - Capabilities

- 400-MeV H- beamline and instrumentation
  - Commissioned to multiple locations within hall



Parameter	Value	Unit
Kinetic Energy	400	MeV
Energy Spread Full Width	1.25	MeV
Beam Current	25	mA
RF Structure	201.24	MHz
Bunch Length (95%)	<0.8	ns
Pulse Length	Up to 50	μs
Max Particles/Bunch	7.5×10^{8}	
Max Particles/Pulse	7.5×10^{12}	
Max Beam Power	7.5	kW
Beam Emittance (95%, normalized)	8	pi mm-mrad

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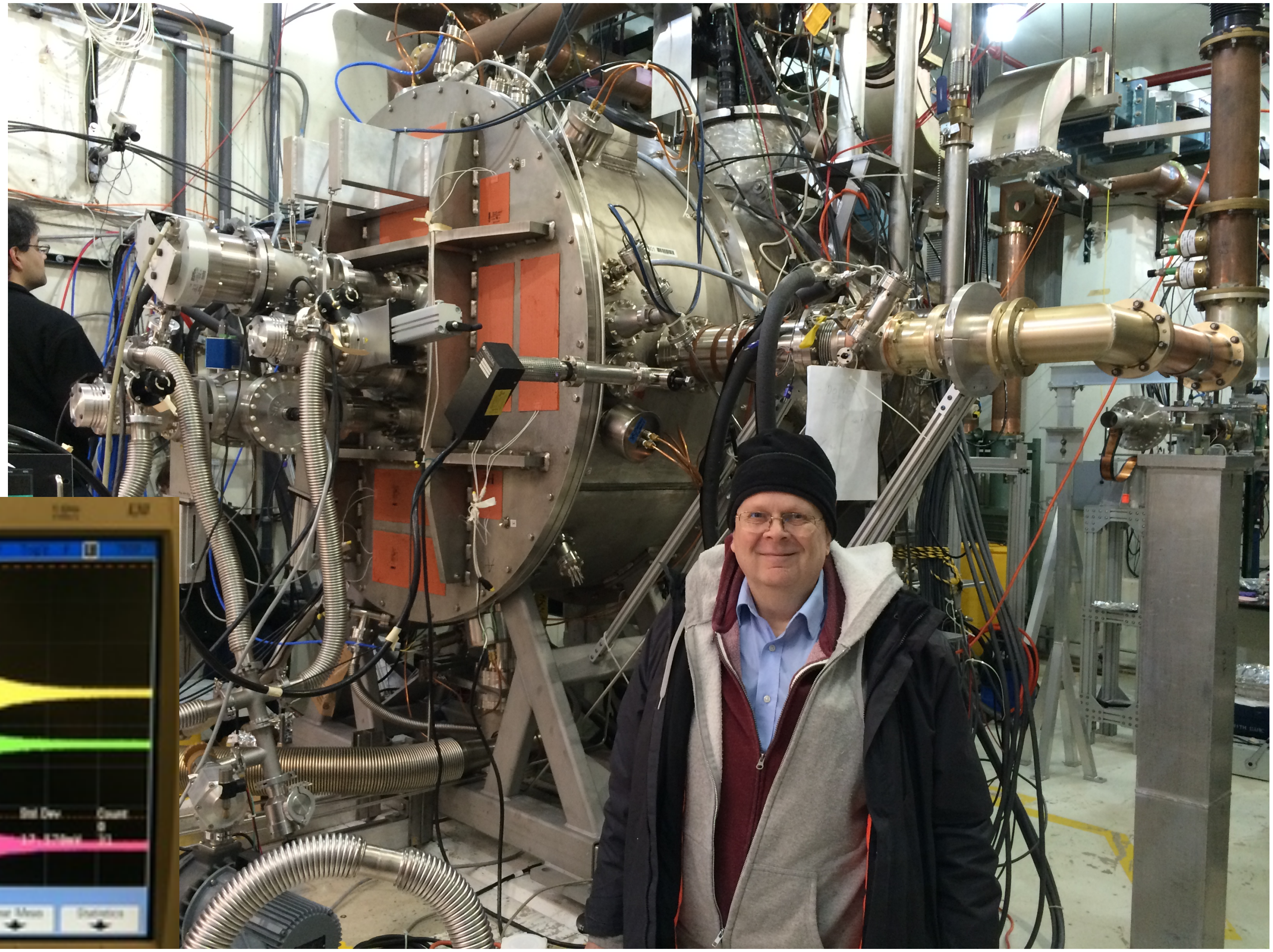
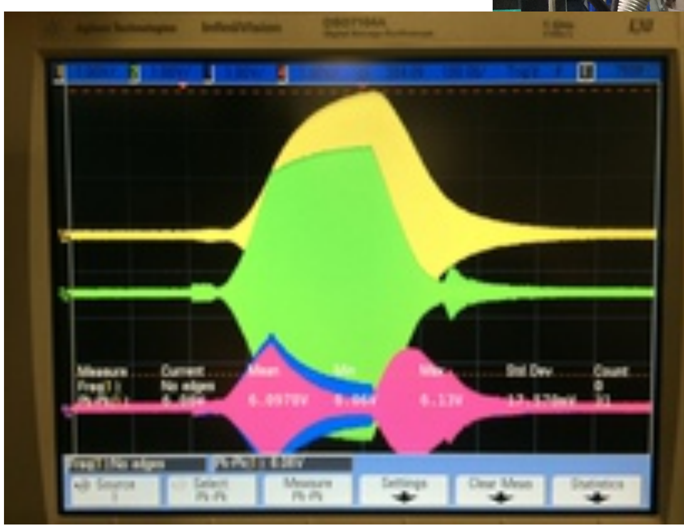
MTA Overview – Accomplishments

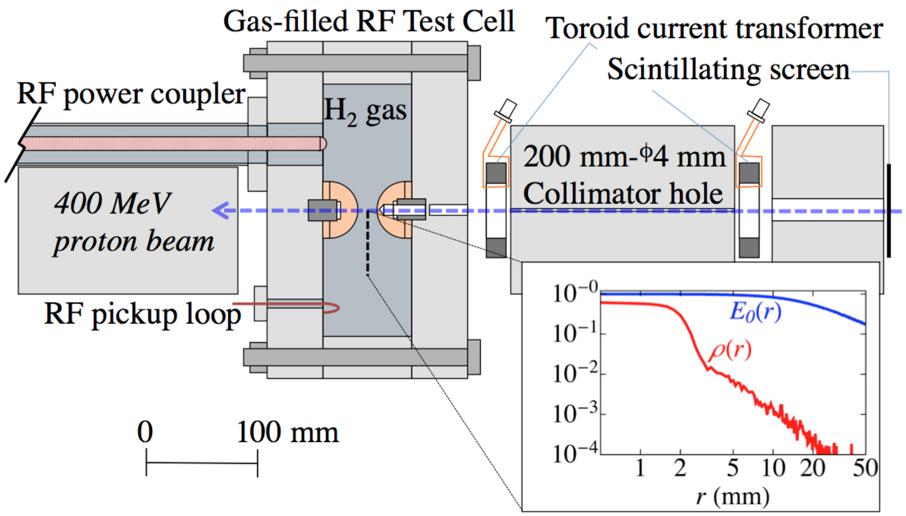
Characterization of MICE 201 MHz RF Module



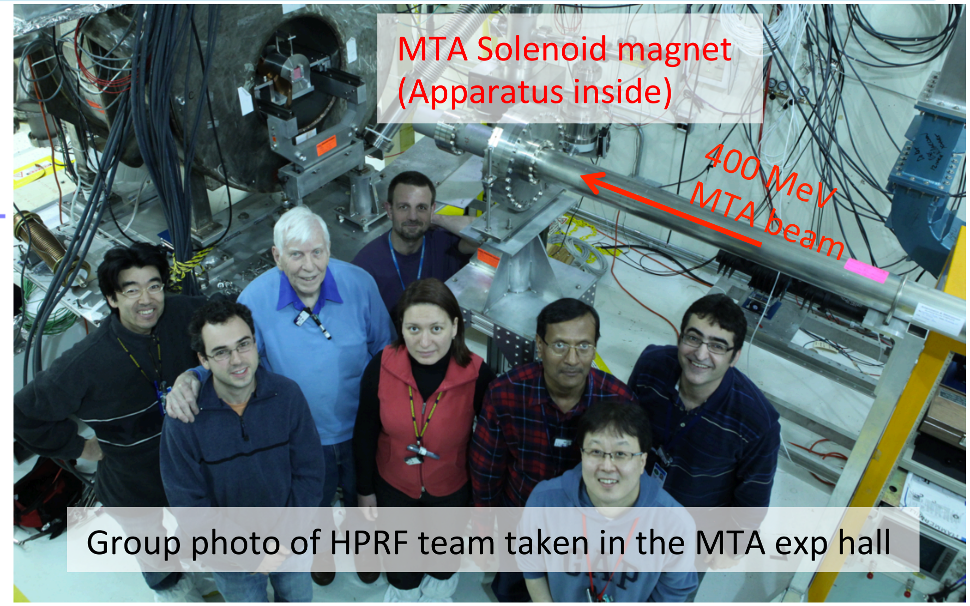


MTA Overview - Accomplishments

How does gas interact with intense beam in RF fields?

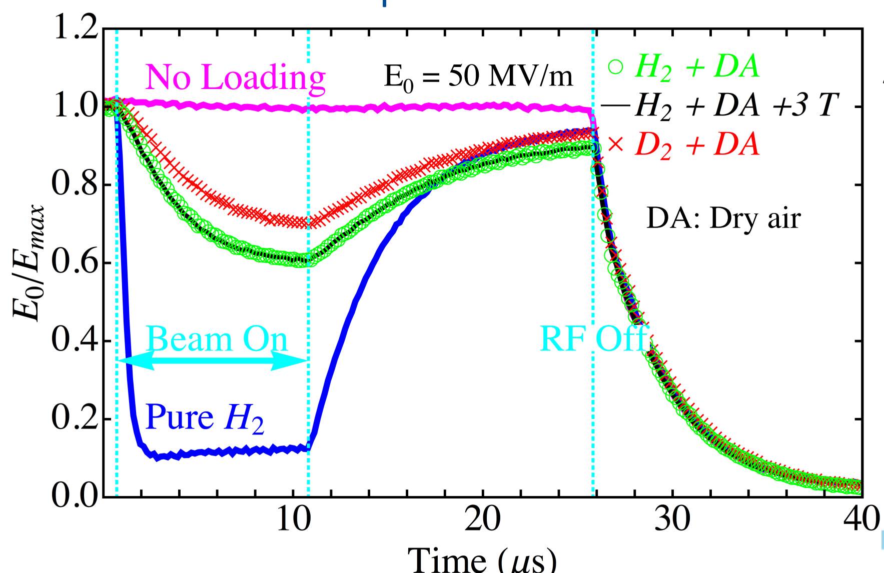


Apparatus of MTA beam test



Group photo of HPRF team taken in the MTA exp hall

Observed RF amplitude in the HPRF test cell



Accomplishments

- Experimentally verify RF power loading model due to beam-induced plasma (call plasma loading)
- Improve plasma loading by doping a tiny amount of electro-negative gas (DA = dry air, and SF_6)
- Published the result to *PRL 111, 184802, 2013*

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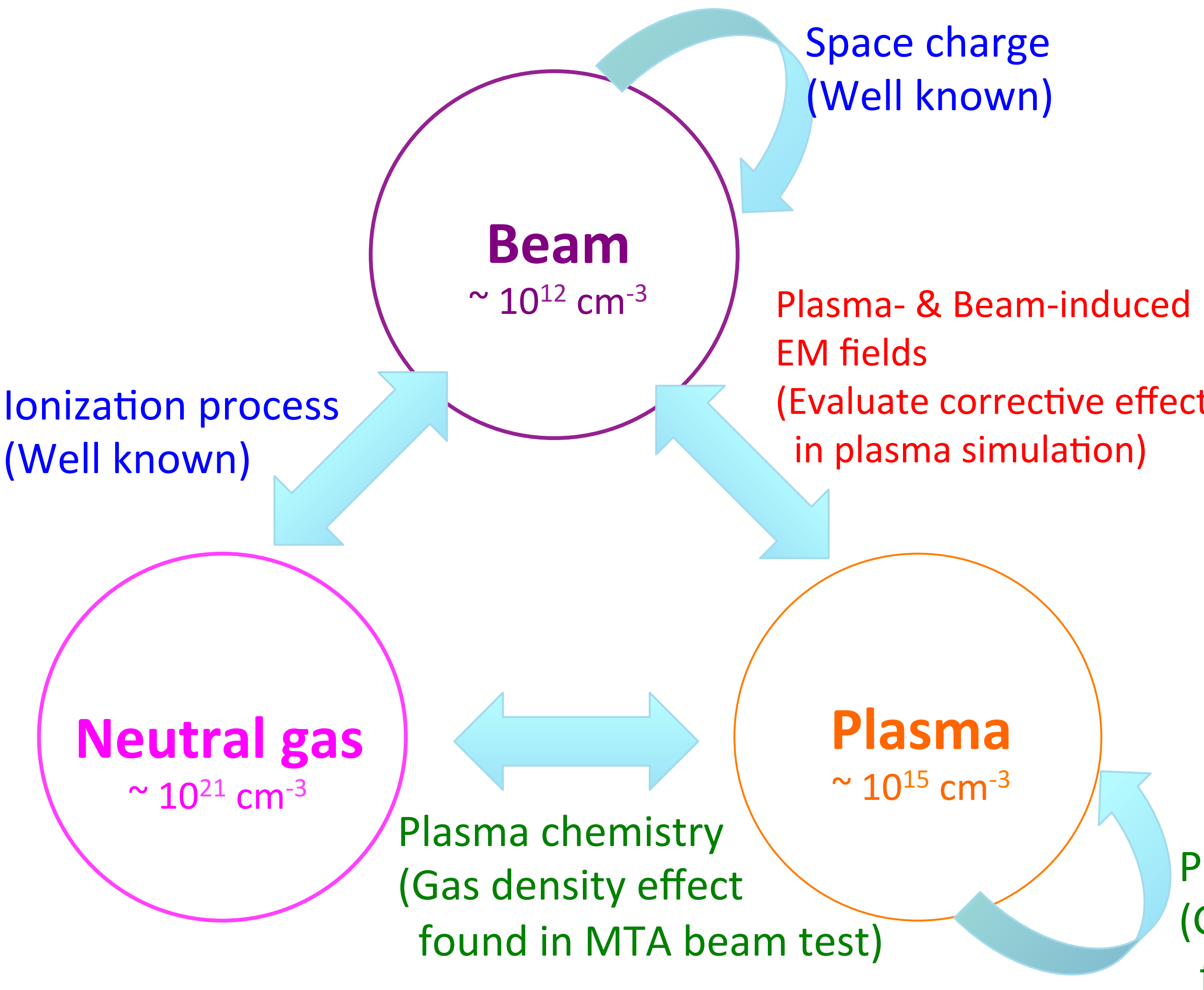
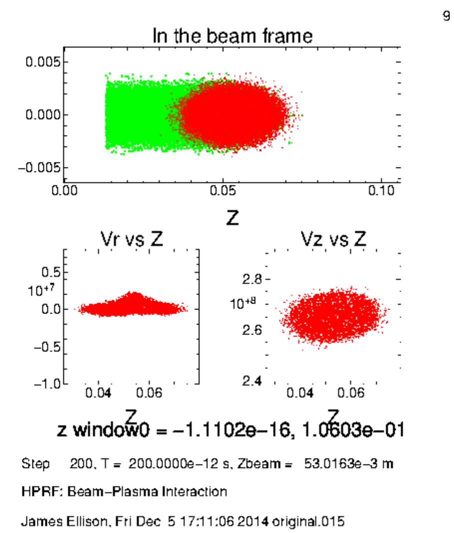
MTA Overview – Accomplishments

Physics of Gas-Filled RF cavity ➩ Interactions among three elements

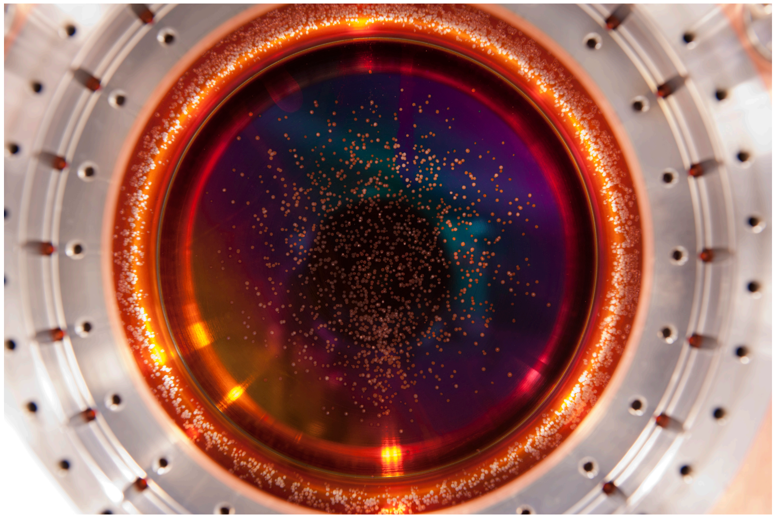




Beam (red) & Plasma (green);
Use initial HCC beam emittance;
No RF (no longitudinal focus);
Observe beam oscillation

MTA Overview - Accomplishments

RF Breakdown in Normal Conducting Cavities



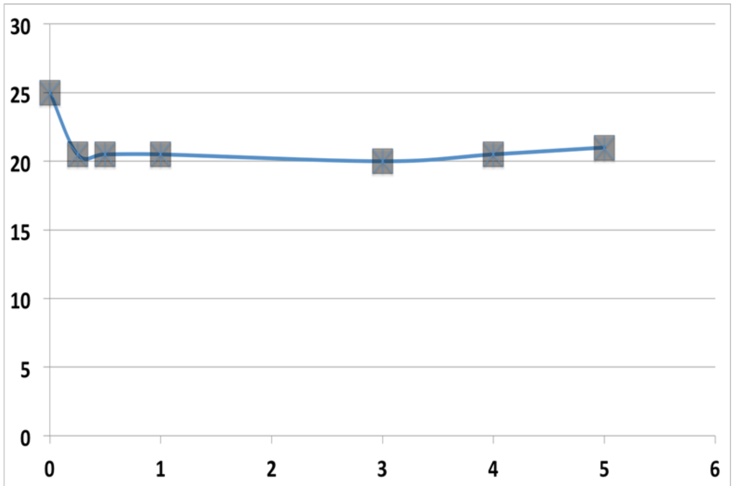
Spark damage in an 805 MHz copper cavity

Digital microscope image of mm-scale spark "crater"

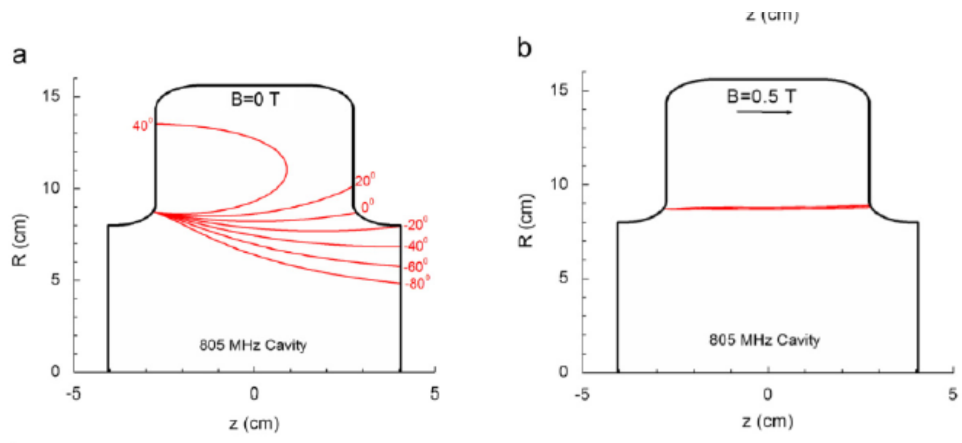
- This problem affects most RF structures, including cavities
  - Klystrons
  - Power couplers
  - Photoinjectors
- Strong DC magnetic fields compound the problem

MTA Overview - Accomplishments

Strong DC magnetic fields limit the maximum achievable surface electric field.



Magnetic field (T)

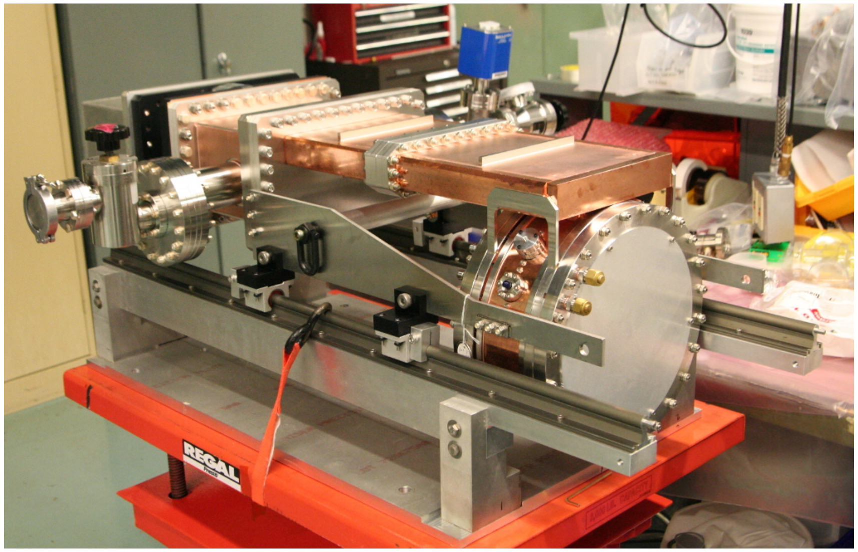


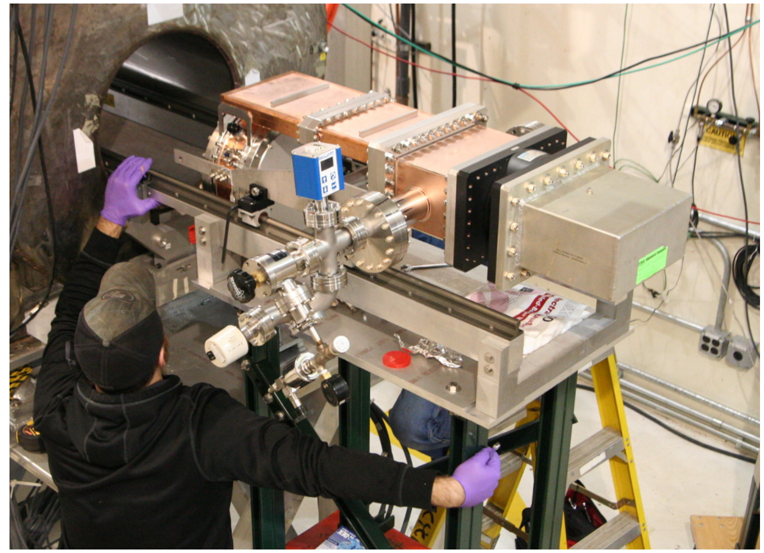
D. Stratakis *et al.* NIMA 620 (2010) 147-154.

- Our model of this phenomenon is supported by measurements of several 805 MHz RF cavities.
  1. Field emitter (FE) sites active over multiple RF periods
  2. Solenoid focuses FE current into "beamlets"
  3. Beamlets induce cyclic fatigue on Cu walls, breakdown follows.
  4. No appreciable increase in focusing past B ≈ 0.5 T.

MTA Overview – Current & Future Research Thrusts

Reconfigurable RF Pillbox for High Gradient Cavity R&D



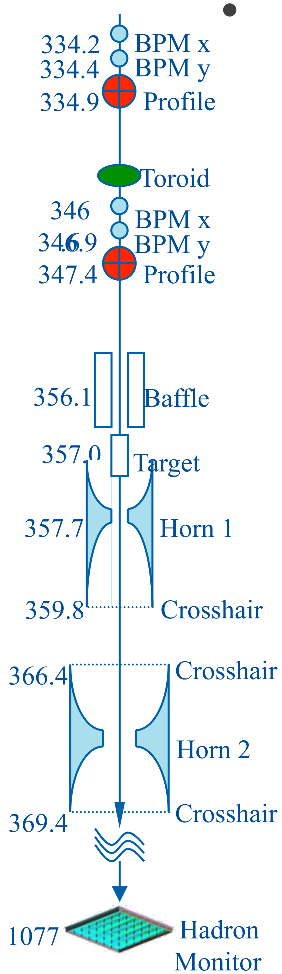


Cavity is heavily instrumented with interchangeable components

Program goals:

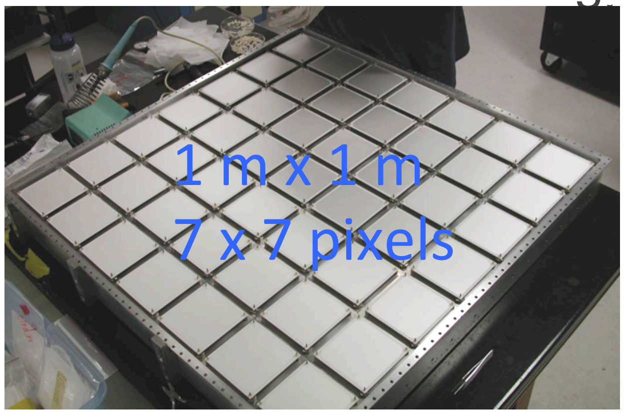
- Characterize breakdown in strong B-fields with improved control of systematic error sources.
- Establish “RF lifetime” of active cavity surfaces with & without B-fields
- Surface physics : confirm damage model using beryllium cavity walls

MTA Overview – Current & Future Research Thrusts

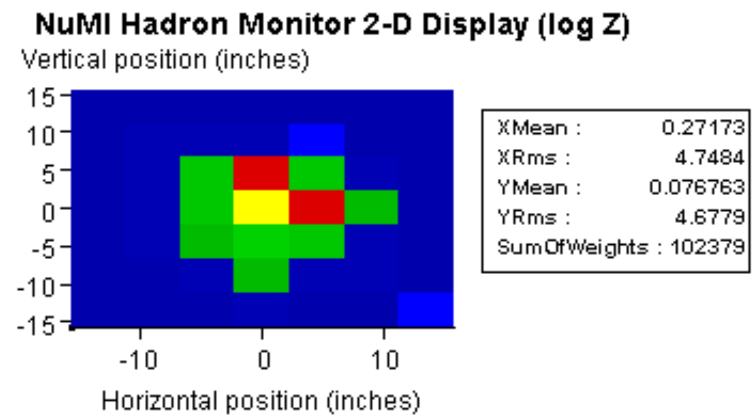


NuMI beam line

- Hadron Monitor Technology



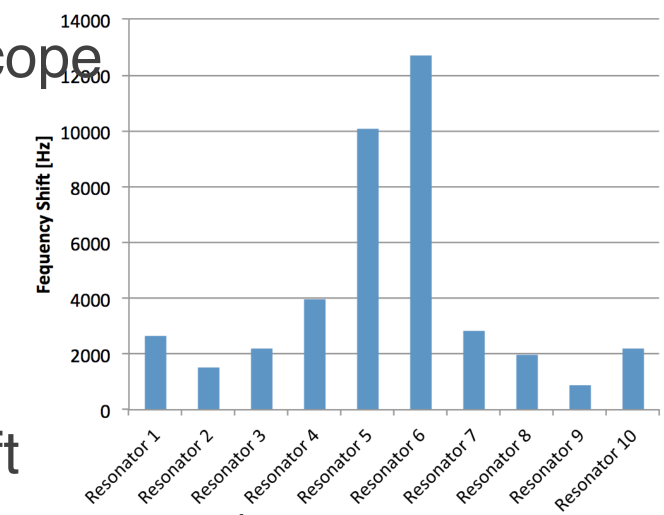
Ionization Chamber



  – LBNF requires monitor with improved radiation resistance
  – A gas-filled RF resonator hodoscope offers a robust alternative

$$\frac{\varepsilon}{\varepsilon_0} = 1 + \frac{n_e e^2}{\varepsilon_0 m\left(\omega_{rf}^2 + \nu^2\right)}\left(1 + i\frac{\nu}{\omega_{rf}}\right)$$

  – Real part of relative permittivity provides resonant frequency shift
  – Gas-filled RF resonator strips (δx = 10 cm)



MTA Overview – Current & Future Research Thrusts

- Compact RF energy storage cell (SC)
  - Provides beam loading compensation for intense beams
  - Dielectric-loaded cells offer high energy storage density
  - High pressure gas stabilizes against breakdown

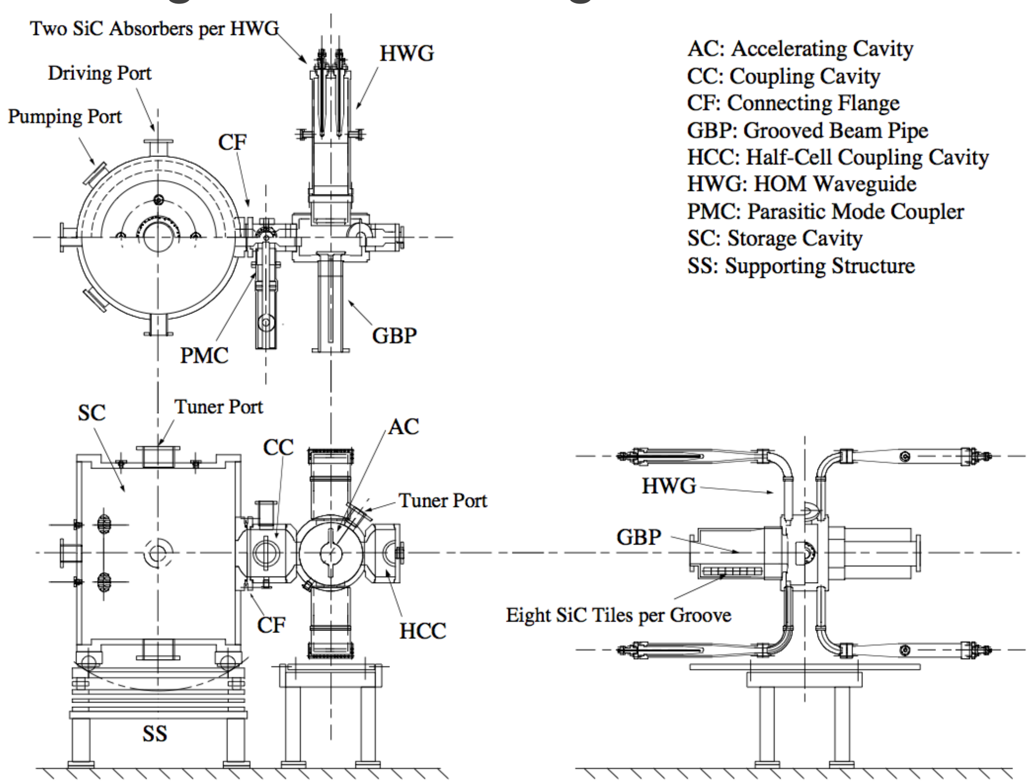


Fig. 5. A schematic drawing of the ARES cavity system.

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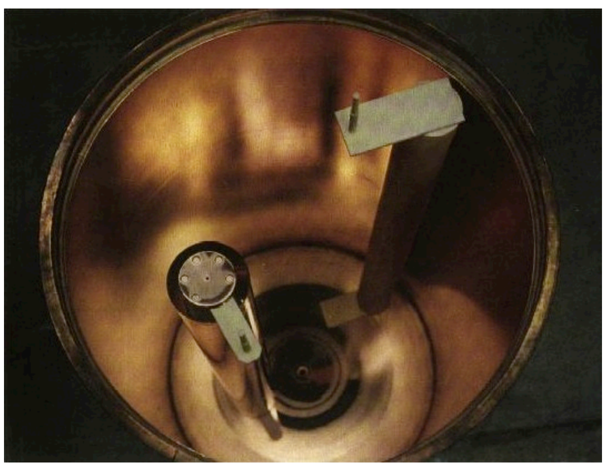
MTA Overview – Current & Future Research Thrusts

- Opportunities for ADMX
  - Axion-to-photon conversion detection
  - Cold, normal-conducting RF cavities operating in strong magnetic fields
  - Ongoing dialogue with ADMX members about collaboration opportunities.



- Detector/Diagnostic R&D
  - How does detector hardware behave in strong magnetic fields? Intense beam?
  - These studies can be done concurrently with RF R&D in many cases.
  - Also Beam Loss Monitor R&D

MTA Transition Plan

FY15

- The Muon Accelerator Program (MAP) fully supports facility operations
  - Primary Focus:
    MICE RF Module (201 MHz) Characterization
    High Gradient RF R&D (with both vacuum and gas-filled RF cavities)
- AD provides support for delivery of linac beam to facility

FY16

- Thru Mar 31,2016 – MAP fully supports facility operations
  - Focus on MICE RF Module Characterization
- Apr 1, 2016 onwards ⇨
  AD Test Facility for detector development (in B-field, with beam) & high gradient RF R&D

FY17 and beyond…

- Ongoing operation for detector development & high gradient RF R&D

MTA – Facility Support & Budget

- Manpower and M&S Requirements
  - Core facility support requirement is ~3.4 FTEs
    - Facility Coordination and Beam Operations Support
    - Mechanical & Vacuum Engineering Support
    - RF Engineering & Systems Support
    - Cryogenics and H2 Operations Support
    - Technician Support
    - Utilities
  - Major M&S Categories
    - Cryogens
    - Beamline hardware
    - Mechanical support for experimental apparatus

MTA Operations	Direct M&S ($k)	Loaded M&S (23.53% OH)	Direct SWF (FTE)	Loaded SWF (~$200k/FTE)	FY14 Total ($k)	FY15 Total ($k)	FY16 Total ($k)	FY17 Total ($k)
FY14 Actuals	$401	$484		$645	$1,129			
MTA supported by MAP thru mid-FY16								
FY16	$175	$216	2.2	$440			$656	
FY17	$355	$439	3.4	$680				$1,119

Summary

- The MTA offers a unique combination of test facility capabilities for detector development and RF R&D
  - High intensity beams for development of radiation robust detector technologies
  - RF infrastructure to support high gradient RF R&D as well as more novel RF devices
  - Provides a large bore 5T solenoid for detector and RF studies in high magnetic field
    - Beam line provides capability for beam tests in magnetic field
- A range of capabilities that is not readily reproduced

Thank you for your attention!

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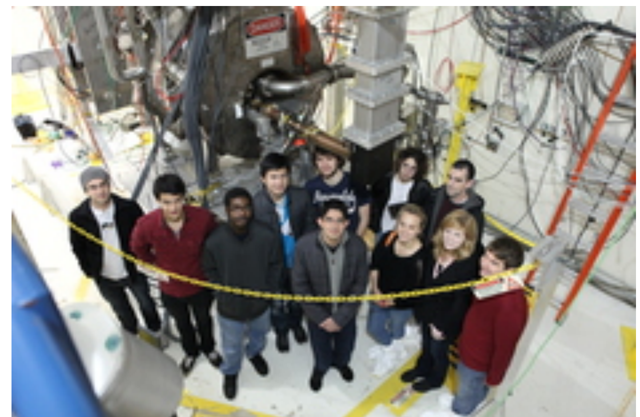
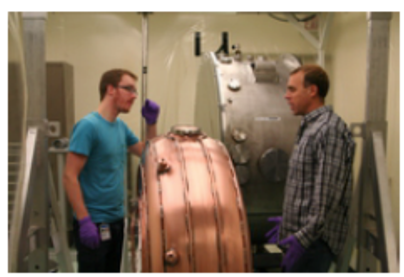
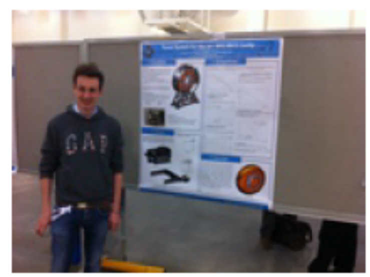
BACKUPS FOLLLOW

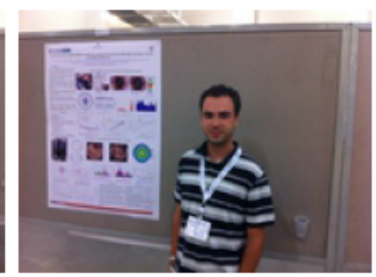
MTA - Training the next generation

- MTA program has supported a steady stream of student projects
  - Ben Freemire, IIT
    - Ph. D., May 2013, HPRF beam test
  - Peter Lane, IIT
    - Working toward Ph. D. (breakdown localization with acoustic sensors on MICE cavity)
  - Alexey Kochemirovskiy, U. Chicago
    - Working toward Ph. D. (modular cavity program)
  - Luca Somaschini, INFN Pisa
    - M. Sc., Feb 2014 (MICE cavity tuner system)
  - Jared Gaynier, Kettering U.
    - Undergrad, major contributions to MICE cavity assy
  - Huy Phan (McDaniel C.), Gabriela Arriaga (NIU)
    - Undergrad, dielectric loaded HPRF, window design
  - http://mice.iit.edu/mta/students/ (full list, >20 students over past 3 years)
- Students first author on several IPAC14, IPAC13, NAPAC13 abstracts









RF R&D Outlook

- Tremendous progress made over the past 3 years
- We are at an exciting threshold in the MTA program
  - MICE cavity operational
    - assembly complete, commissioning in progress
  - Operating point for 805-MHz vacuum RF in 0-5T established with long pillbox cavity
    - next step (modular cavity) – test program starting
  - HPRF program advanced (no magnetic field issue)
    - plasma loading/mitigation in beam evaluated
    - successful proof-of-principle dielectric loading test, follow-up program in progress
- Facility has the capabilities in place to support a transformational accelerator R&D program
- Poised to make significant additional progress in the next 2 years if supported within GARD