MuCool Program Overview

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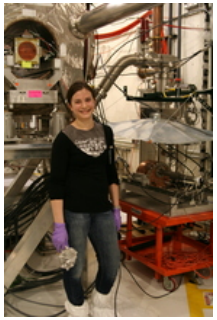
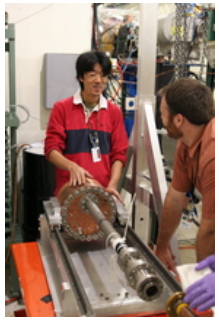
Illinois Institute of Technology/Fermilab

MAP Collaboration Mtg
Mar 4, 2012 – SLAC





MuCool

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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
- carry out associated simulation and theoretical studies
- support system tests (MICE, future cooling experiments)

MICE

System test to demonstrate and measure cooling

Useful reading

Serious degradation of RF cavity performance in strong external magnetic fields.
Currently main focus of MuCool.

- Magnetic field effect first seen at Fermilab's Lab-G with a 6-cell 805-MHz cavity
  J. Norem *et al.*, Phys. Rev. ST Accel. Beams 6 (2003) 072001
- Studied in more detail at MTA with 805-MHz pillbox cavity
  A. Moretti *et al.*, Phys. Rev. ST Accel. Beams 8 (2005) 072001
- Various models proposed
  A. Hassanein *et al.*, Phys. Rev. ST Accel. Beams 9 (2006) 062001
  R. B. Palmer *et al.*, Phys. Rev. ST Accel. Beams 12 (2009) 031002

Potential Solutions

1. Better materials: more robust against breakdown (melting point, energy loss, skin depth, thermal diffusion length, etc.)

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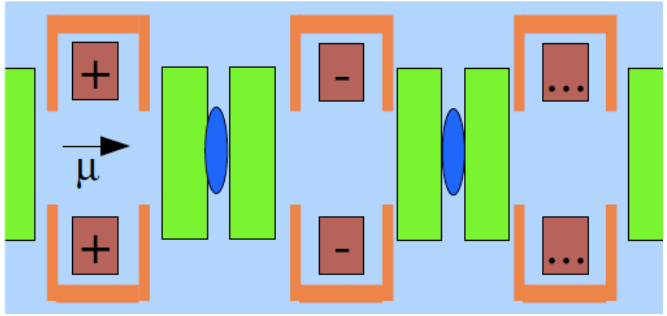
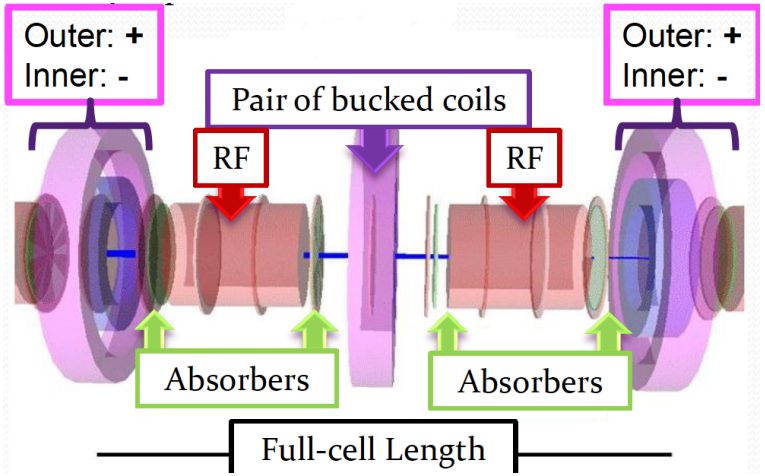
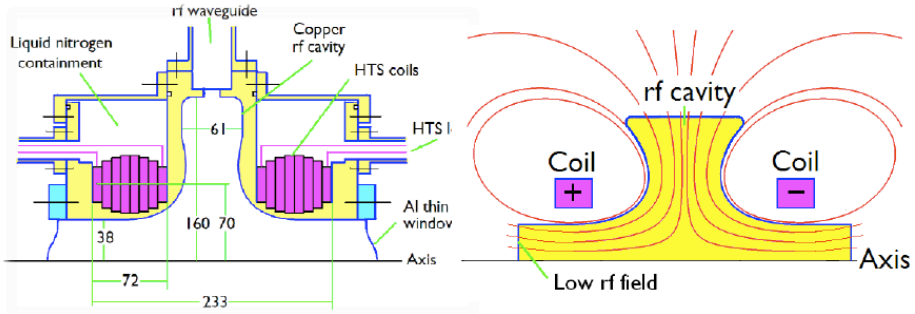
2. Surface processing: suppress field emission (superconducting RF techniques, coatings, atomic layer deposition)
3. Shielding: iron, bucking coils (Rogers, Alekou)





Potential Solutions

4. Magnetic insulation: modified cavity/coil designs to keep B⊥E on cavity surfaces (Palmer, Stratakis)



Loss of x 2 gradient advantage in pillbox geometry

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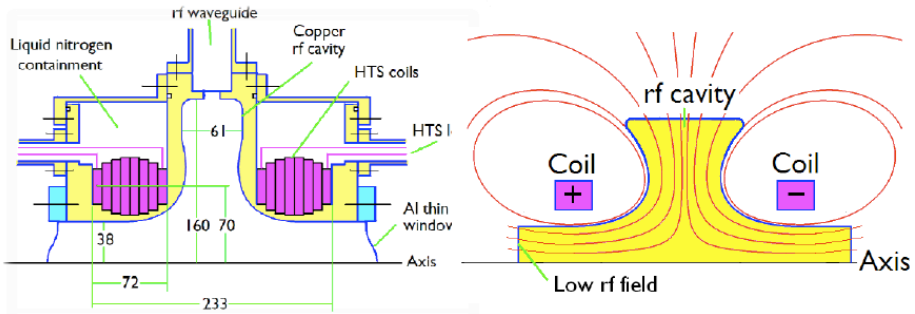
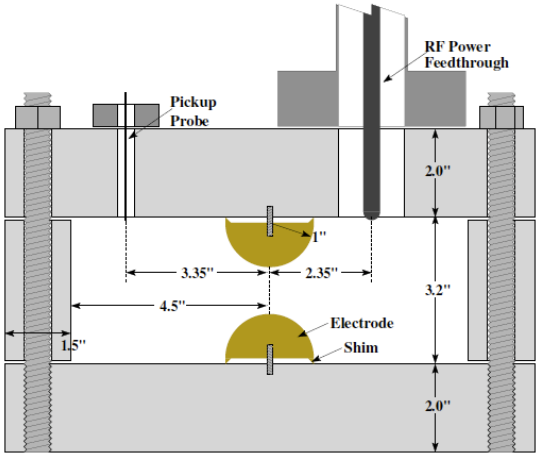
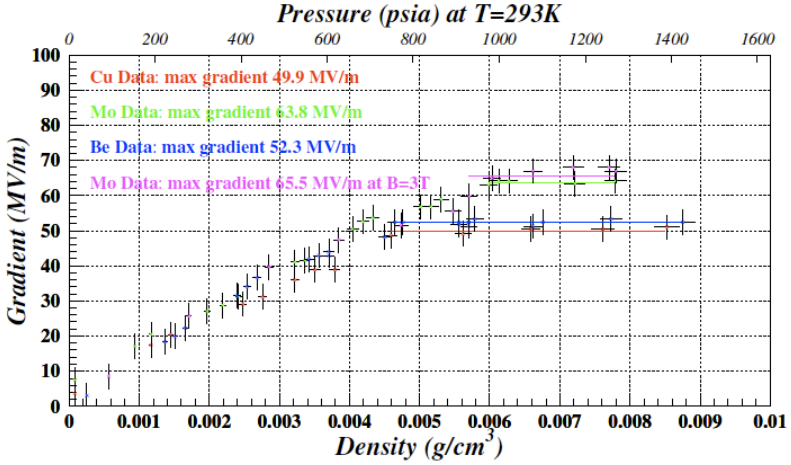


Loss of x 2 gradient advantage in pillbox geometry

5. High-pressure gas: suppress breakdown by moderating electrons (Muons Inc., Yonehara *et al.*)





MuCool Test Area (MTA) – http://mice.iit.edu/mta/

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



- RF power (13 MW at 805 MHz, 4.5 MW at 201 MHz)
- Superconducting magnet (5 T solenoid)
- Large coupling coil under construction
- 805 and 201 MHz cavities
- Radiation detectors
- Cryogenic plant
- 400 MeV p beamline

MTA Diagnostics

- RF forward/reflected power, pickup antenna signals
- Vacuum pressure
- Scintillator+PMT counters for X-ray rates, spectra
- Ionization chambers for radiation dose rates
- Spectrometer for cavity light analysis
- Acoustic sensors for spark detection (under development)
- Toroids for beam intensity
- Beam position monitors
- Multiwire chambers and scintillator screen+camera for beam profile (M. Jana poster)

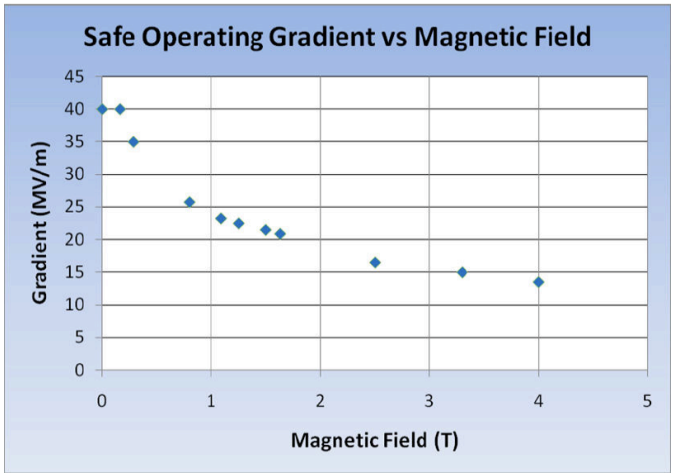
Summary of MuCool experimental program

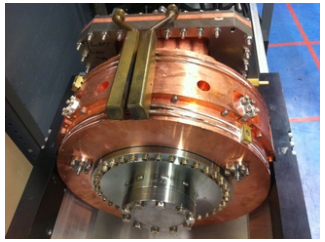
- trying to demonstrate a working solution to RF cavity operation in high external magnetic field for muon cooling
- major MAP milestone (and technical risk for MICE)
- big impact on cooling channel design and system tests
- multipronged approach to cover maximum ground with available resources

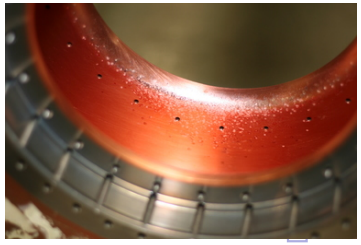
Cavity		Outstanding issues	Proposed resolution	Experimental tests
Vacuum	pillbox rectangular open-iris	Breakdown and damage	Better materials	Mo, W, Be buttons Be-walled 805-MHz cavity
			Surface processing	Electropolished buttons 201-MHz pillbox in B-field
			Coatings	ALD-coated buttons ALD-coated cavity
			Magnetic insulation	$E \perp B$ box cavity $E \parallel B$ box cavity Modified cavity-coil geometry
Pressurized		B-field/pressure effects	Materials tests	805-MHz 4-season cavity
		Beam-induced ionization	Measure ionization lifetime	805-MHz cavity in beam
		Frequency dependence	Test at different frequency	Pressurized 201-MHz cavity

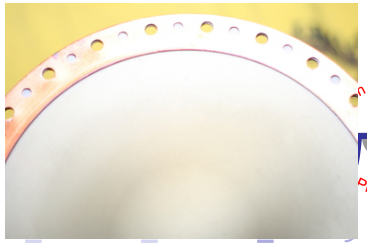
805 pillbox

- 805 MHz pillbox cavity used to
  - quantify magnetic field dependence of gradient
  - establish feasibility of thin windows
    flat Cu windows unstable at high power, curved Cu and Be windows work well
  - test buttons with different materials/coatings
    problems with Cu – Be, Mo and W looked more promising
- Rebuilt at JLab, tested again (10 MV/m at 3T)
- Ran with larger curvature Be & Cu buttons
- Modified versions with reduced coupler field (SLAC, Z. Li talk) and Be-walls (LBNL, D. Li talk) under design



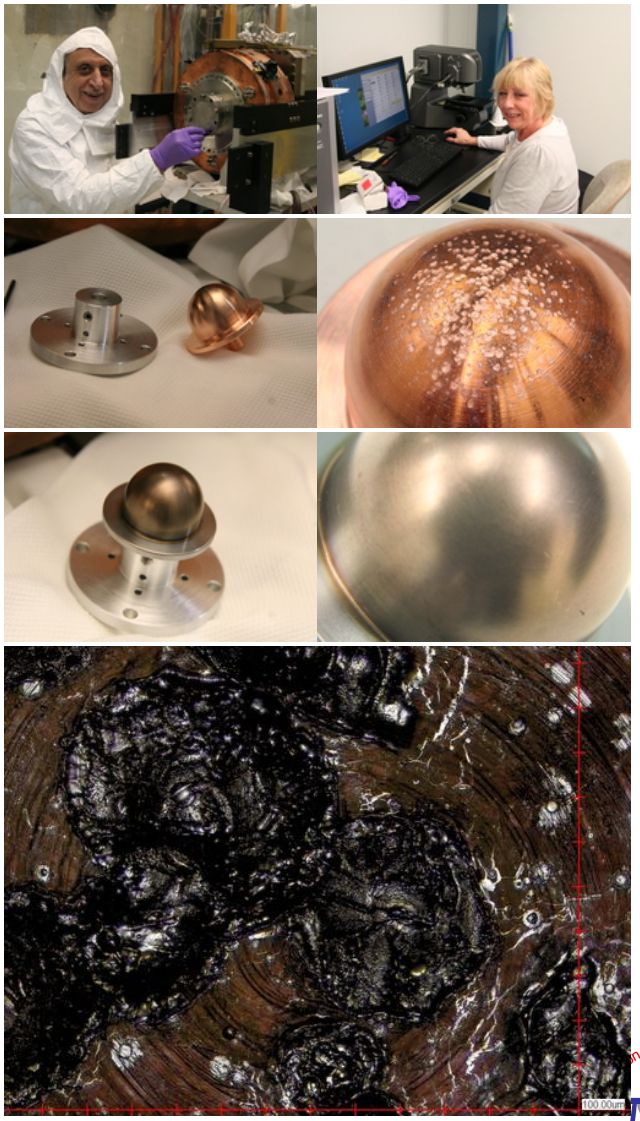


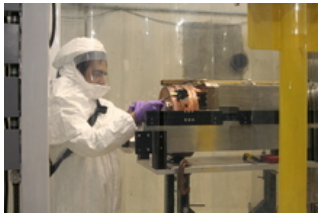




Button inspection (M. Jana, D. Hicks, T. Shen)

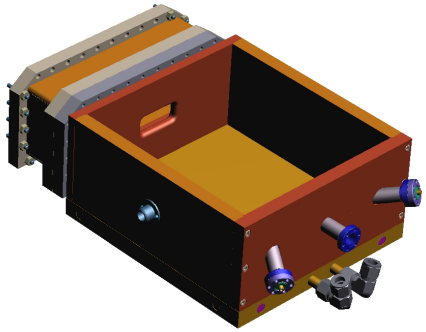
- Photographed after exposure to RF
- Visual inspection: very few visible marks on Be; Cu from craters deposited on endplates
- Taken to microscopy lab in Fermilab Tech. Div.
- Map of surfaces under microscope complicated by large curvature
- Profilometry and SEM over interesting areas
- Note: allowed Be dust in MTA Hall (14k cu.ft.): 0.6mg

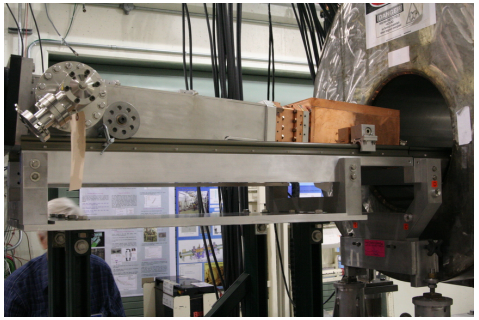




Box Cavity

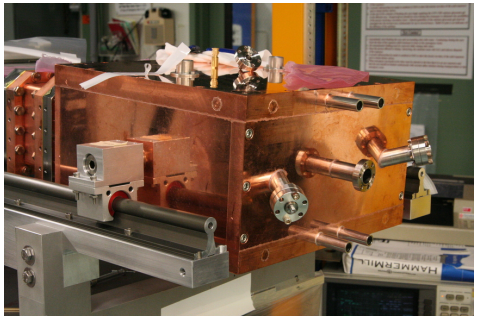
- Rectangular geometry chosen for test cavity to allow fast fabrication and simplify analysis
- Support system designed to rotate cavity pivoting around magnet center by up to 12°
- Rectangular coupling aperture with rounded edges and a coupling cell built to match the power coupler to waveguide
- Three CF flange tubes for rf pickups and optical diagnostics
- $f_0 = 805.3$ MHz, $Q_0 = 27.9 \times 10^3$, coupling factor 0.97
- YT *et al.*, IPAC10

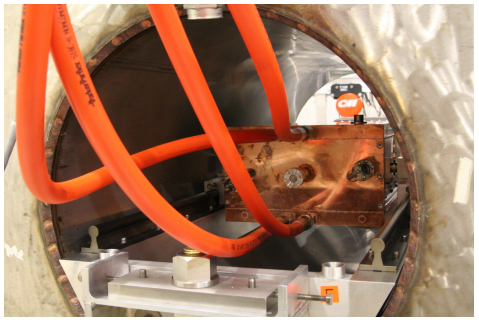


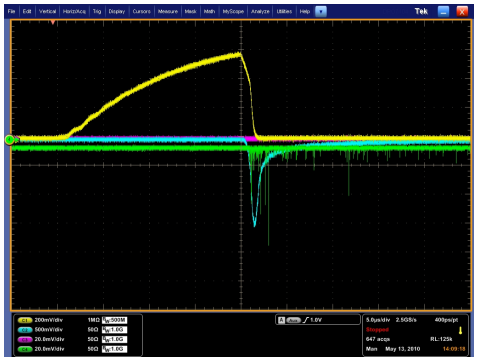


Box Cavity

- Operated in the MTA magnet Mar-Sep 2010
- Commissioned to 50 MV/m at B=0
- Took data at 0, ± 1, 3, 4° wrt B axis (3T)
- Large effect seen at 3-4° (stable gradient down to about 25 MV/m)
- Some degradation even at $\leq 1^o$ (33 MV/m)
- Visual inspection of interior, no obvious damage
- RF, optical and X-ray signals during sparks saved for analysis
- Magnetic insulation seems to work but not well enough to make up for lost shunt impedance



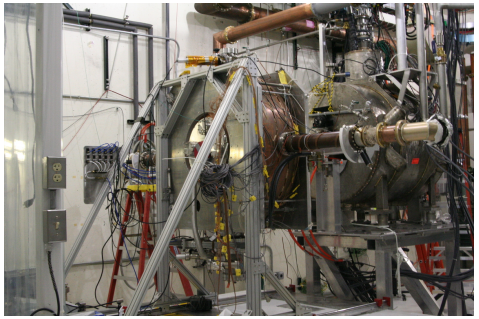


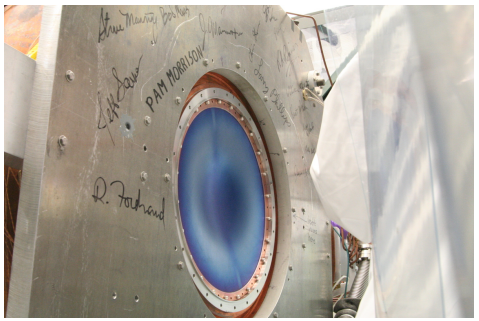


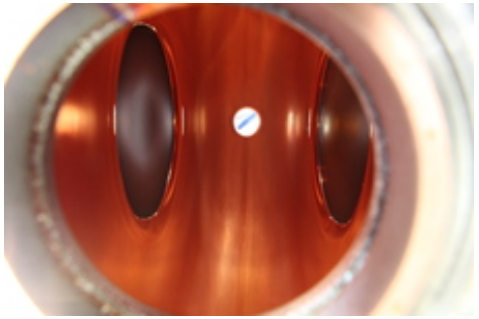
201 pillbox

201 MHz MICE prototype cavity

- SRF-like processing (electropolished, etc.)
- conditioned to design gradient very quickly
- ran successfully with thin curved Be windows
- operated in stray magnetic field
  reduced performance
- radiation output measured (MICE detector backgrounds)
- large diameter coil needed for field configuration closer to MICE
- No surface damage seen on cavity interior

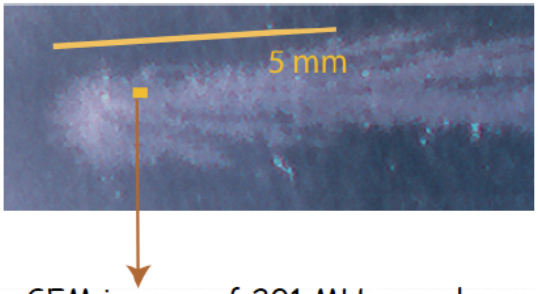




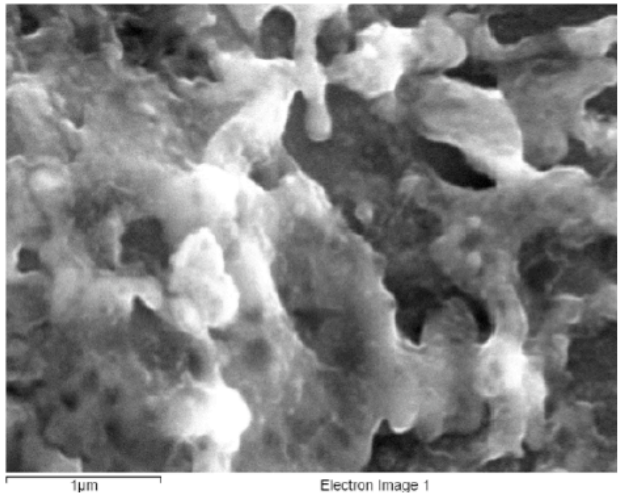


201 pillbox

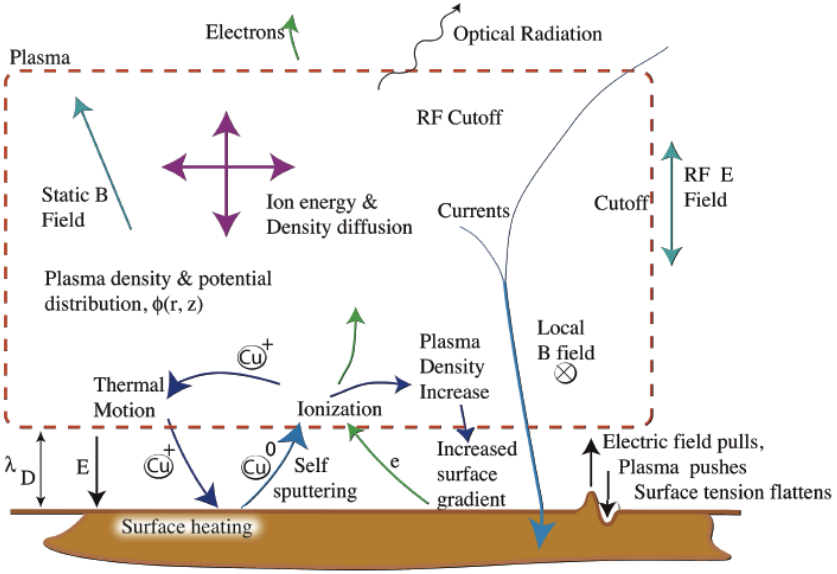
Sparking in the coupler (design now modified)



SEM images of 201 MHz coupler.



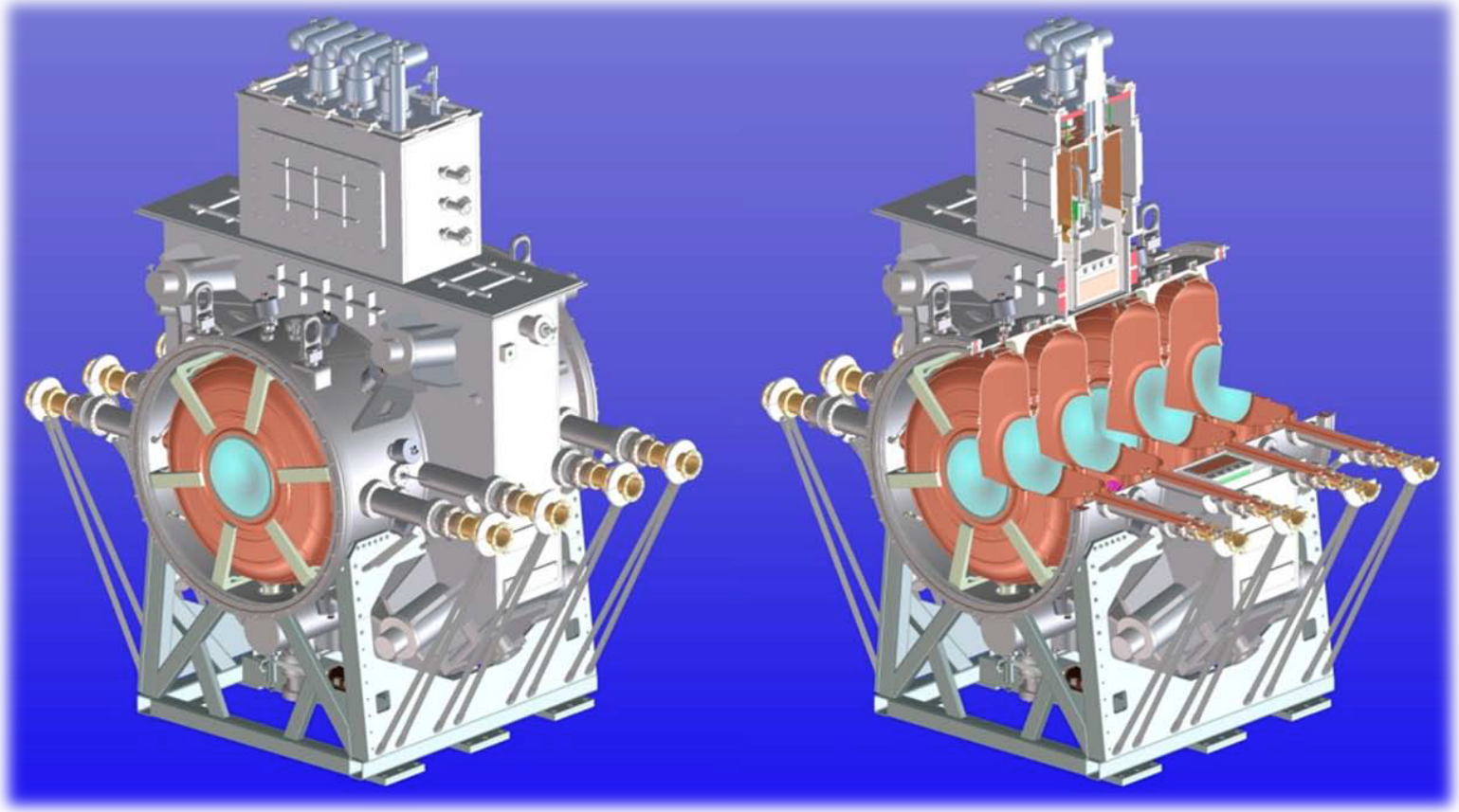
Unipolar arc? (Norem)



201 pillbox – MICE

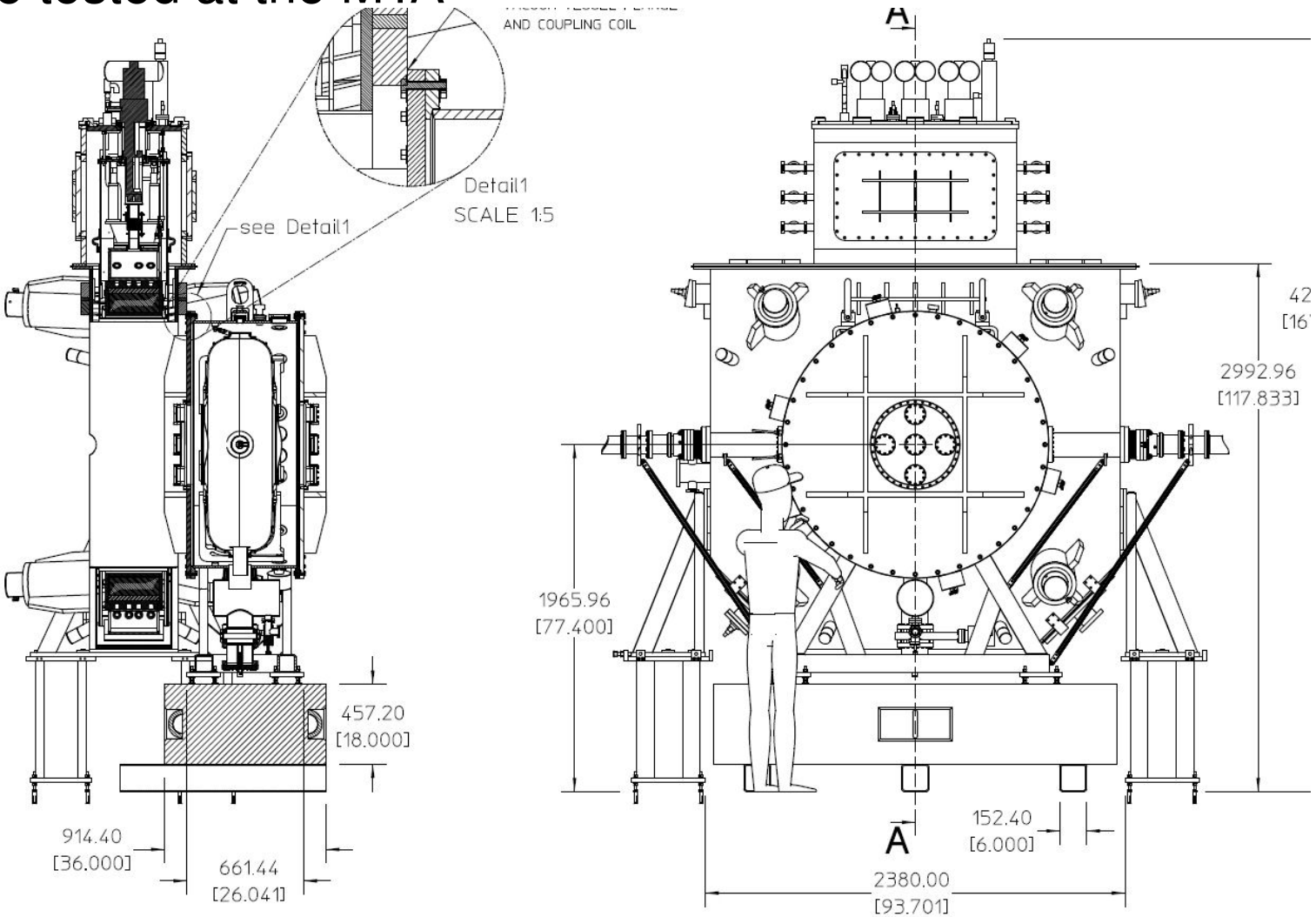
Each RFCC module has

- 4 201-MHz cavities with Be windows
- large bore magnet (coupling coil)
- 10 cavities built, to be processed (EP, etc.) at LBNL



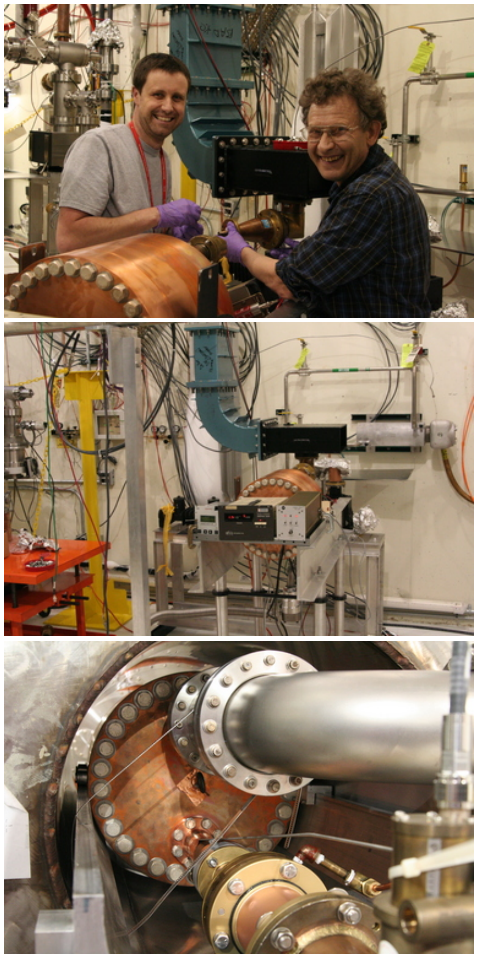
201 Single-cavity module

To be tested at the MTA



4-Season cavity (Muons Inc., LANL)

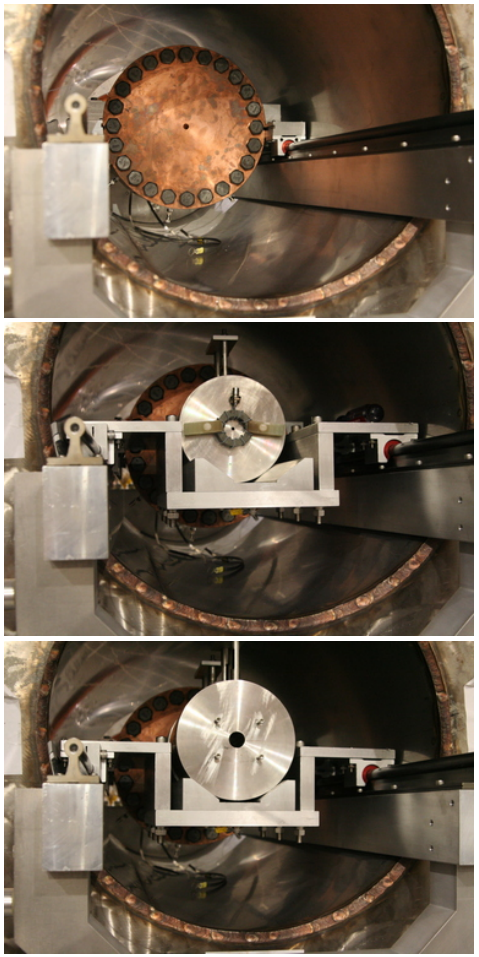
- modular pillbox with replacable end walls
- designed for both vacuum and high-pressure "a cavity for all seasons"
- G. Kazakevich *et al.*. PAC11
- operated at RF station 2 and again in magnet
- gradient limited by (lack of) cooling (28 MV/m at 2Hz)
- same stable gradient at B=0 and 3T (25 MV/m)
- looking into Be walls



HPRF Program

HPRF cavity beam test (K. Yonehara talk, B. Freemire poster)

- First beam experiment at MTA



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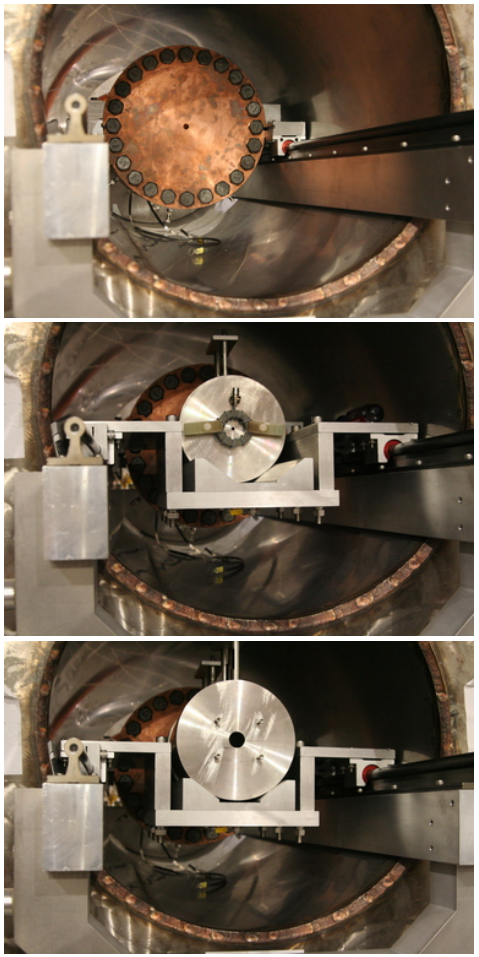

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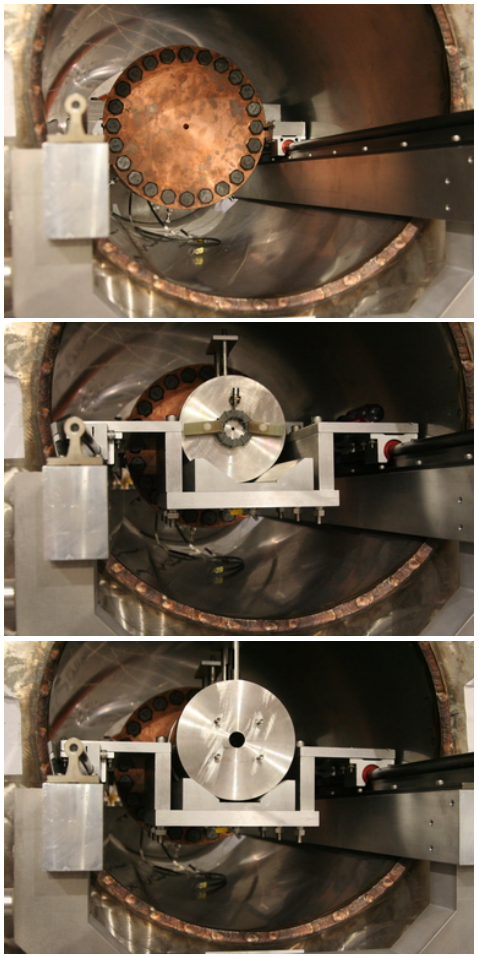

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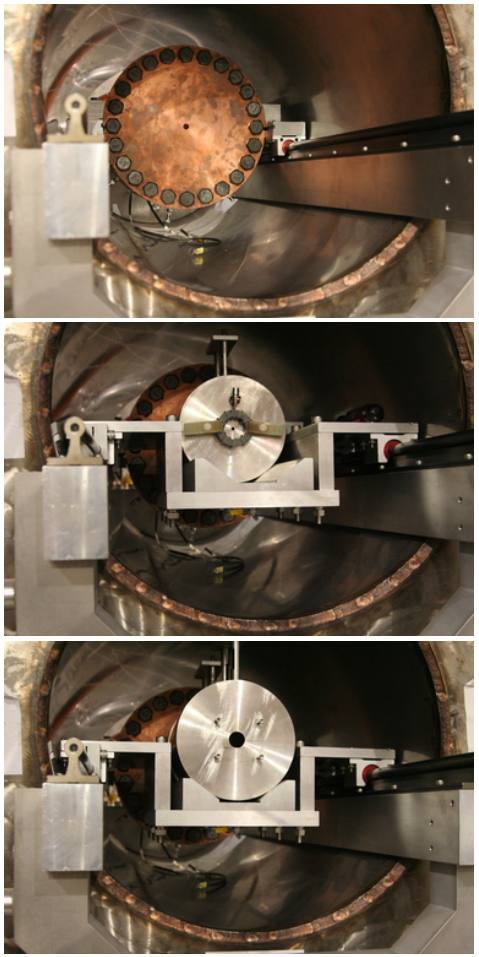

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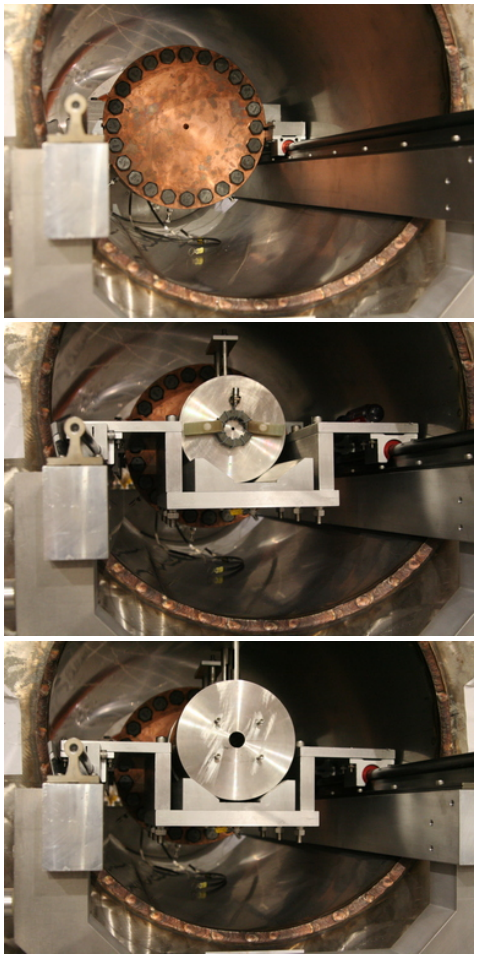

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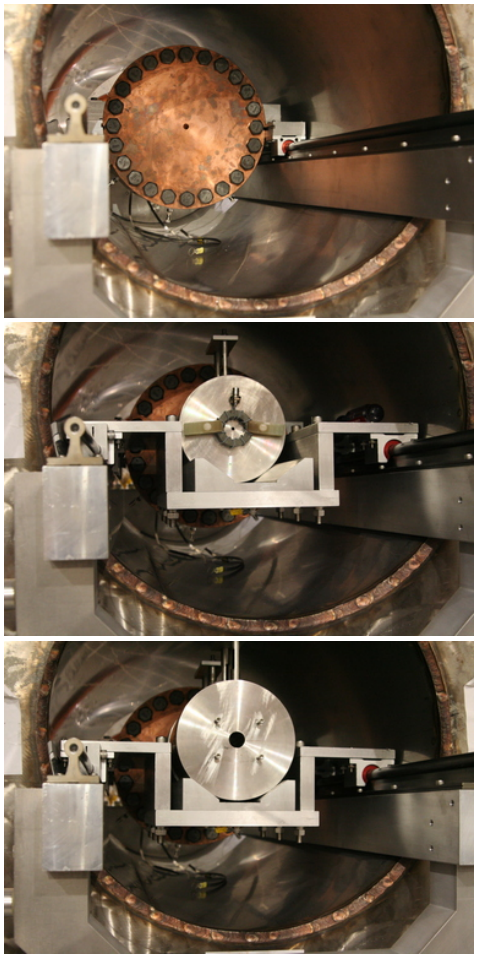

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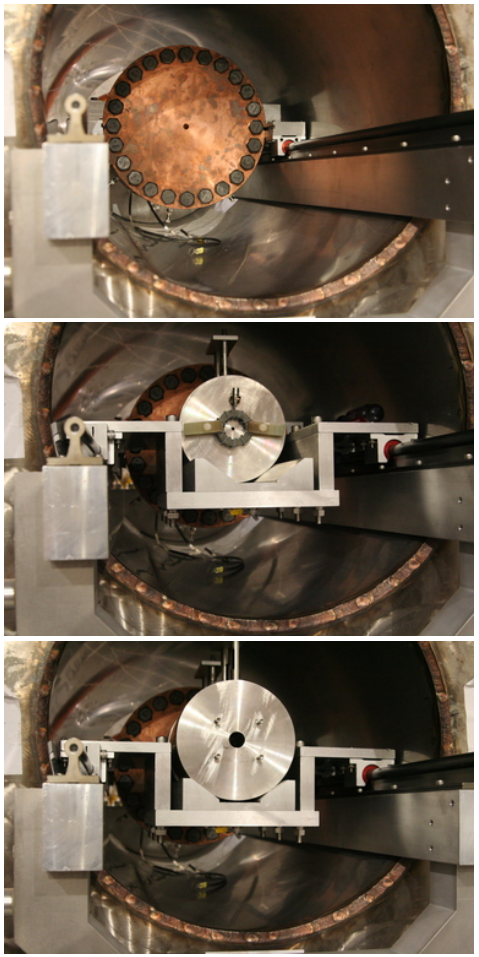
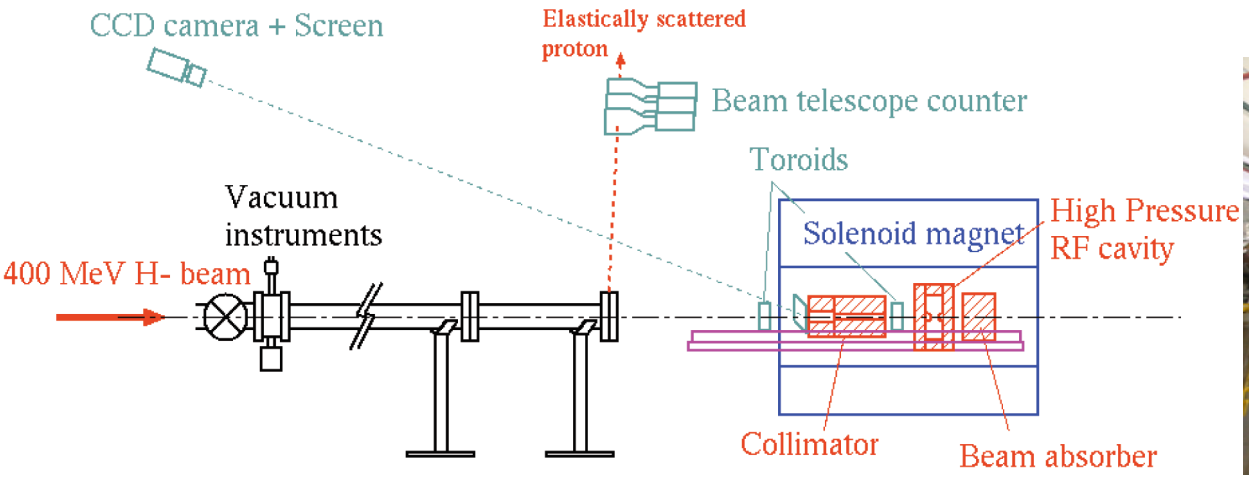
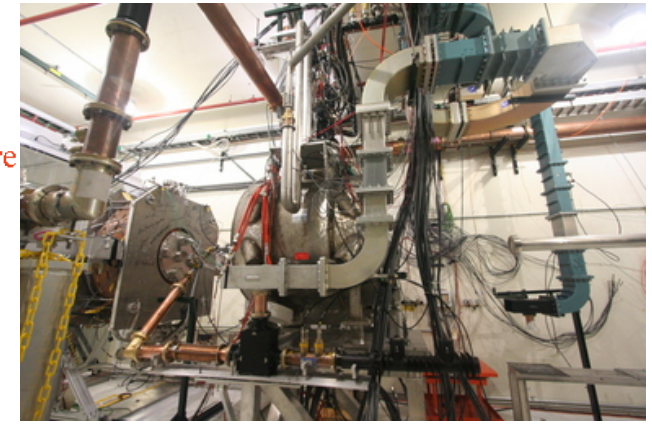
  - Intense muon bunch creates lots of electron-ion pairs
  - potentially shorting the RF cavity
  - may be mitigated by electronegative dopant gas
    (K. Yonehara *et al.*, PAC09, IPAC10)

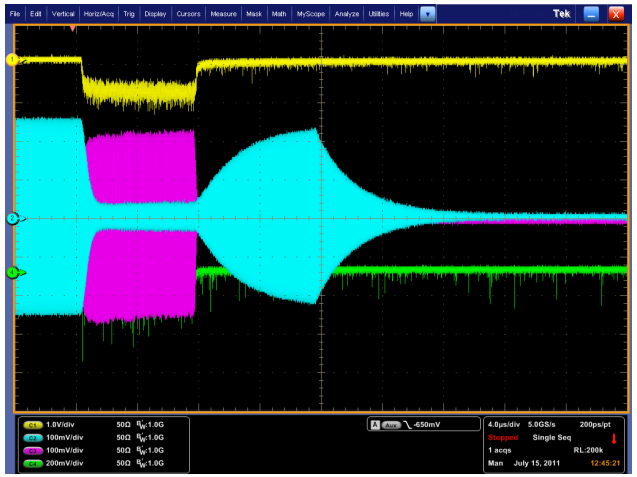


HPRF Beam Test





- 500 psi N2; 500, 800, 950 psi H2
- 8μs beam, 2 intensities, 2 dopants (N2, SF6)
- next test about to start
  expand range in pressure, beam intensity, more dopants
- B-field (safety doc, M. Leonova)
- gas analysis (L. Jenner, T. Schwarz)

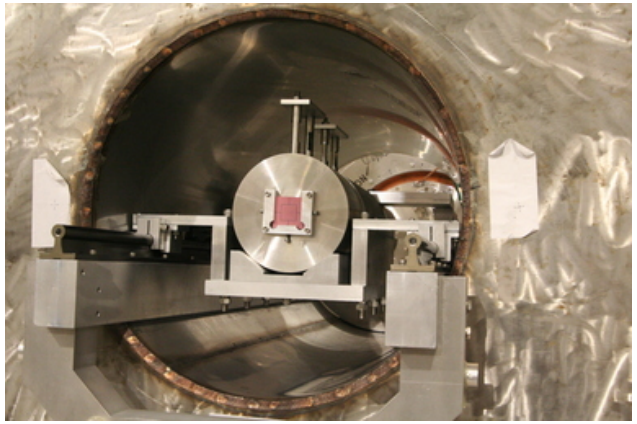


RF scorecard

Branch	Hardware	E_{surf} [MV/m]		E" $_{acc}$"
		B=0	B=3T	(B=0)
Baseline	805-pillbox	40	16	40
		20	10	20
	HPRF-Cu-button	50	-	35
	805-4season	25	25	25
Materials	805-W,Mo-buttons	38-39	18-20	22-23
	805-TiN/Cu-button	38	24	22
	805-TiN/Cu-button	35	28	12
	805-Be-button	40	31	13
Surface proc.	201-pillbox	21	14(0.4T)	21
MagIns/surf.	805-box	50	22-33	0
HPRF/Mat.	805-Mo-button	64	65	45
	805-Be-button	52	-	36

Beam

- First beam pulse to "emittance absorber" (beam stop 2) Feb 28
- Intensity about 1.8×10^{12} protons/pulse at 1 pulse/min
- Scintillator screen upstream of collimator to measure beam spot
- Beamline and instrumentation upgraded
- $O(10^{11})$ protons through collimators



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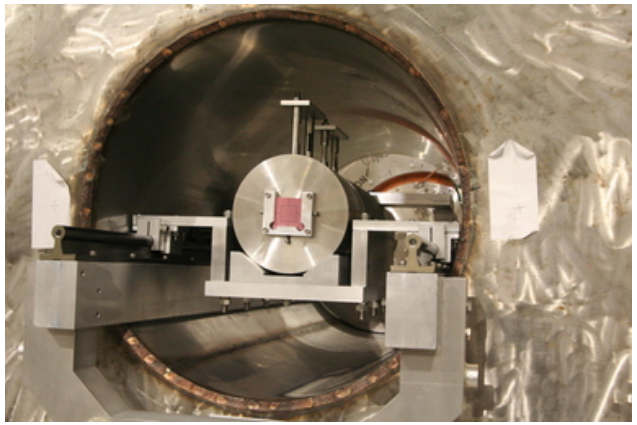

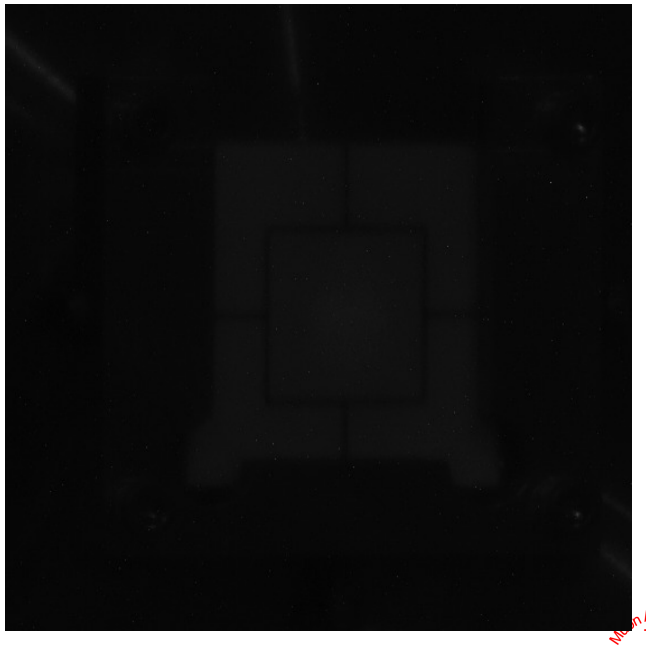

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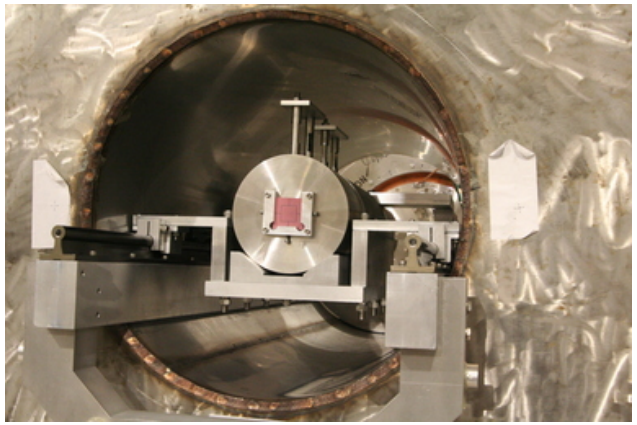

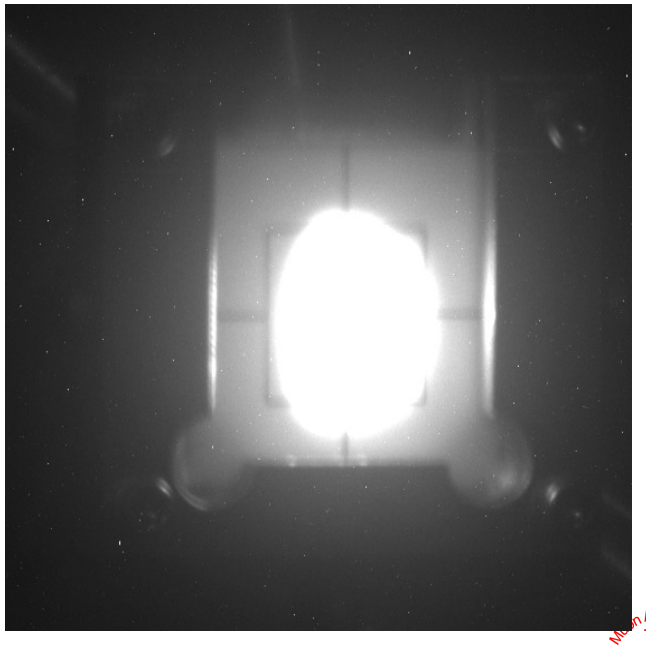

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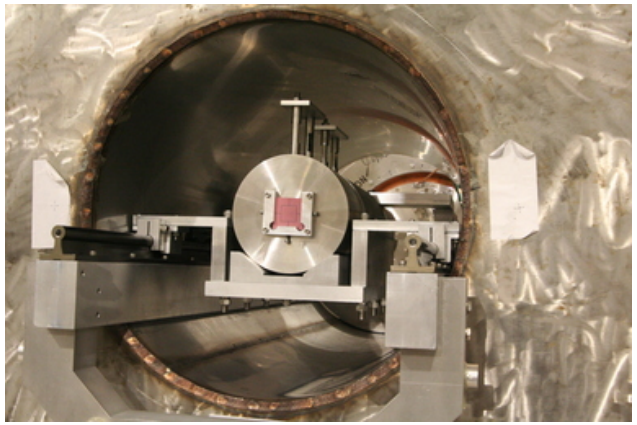

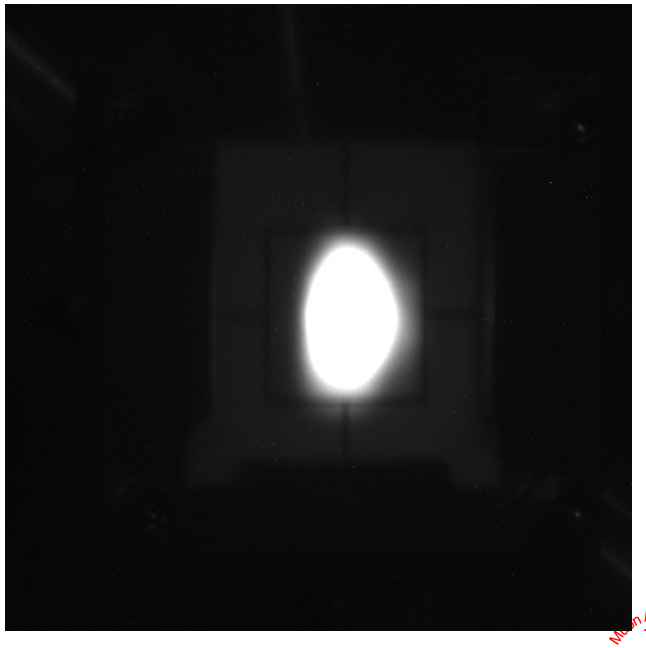

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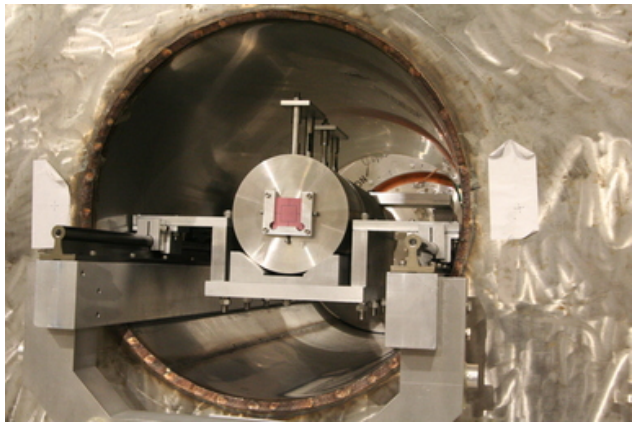

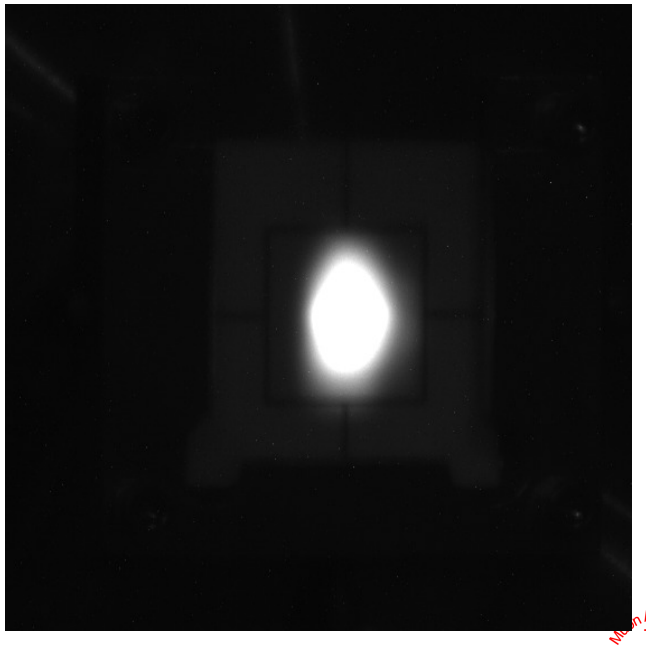

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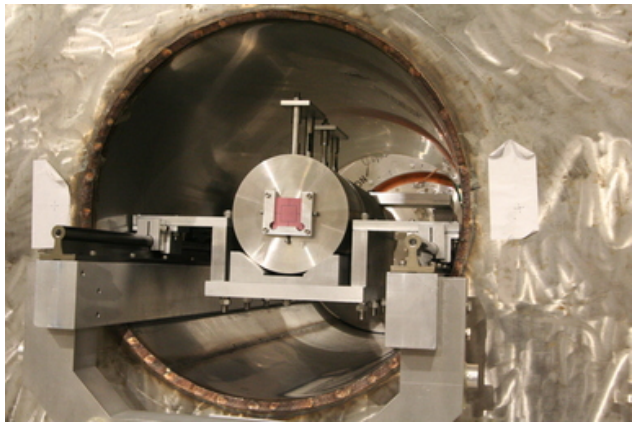

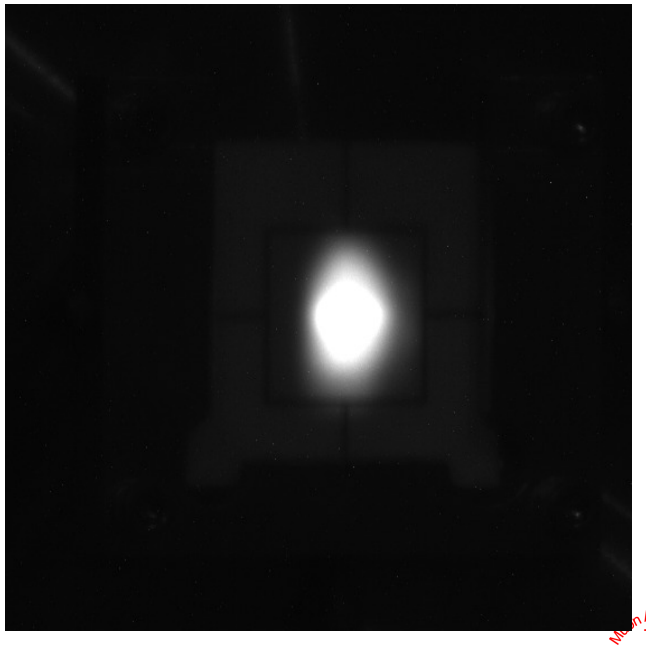

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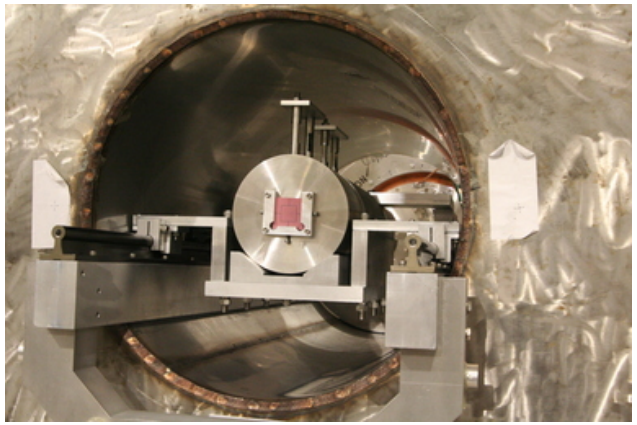

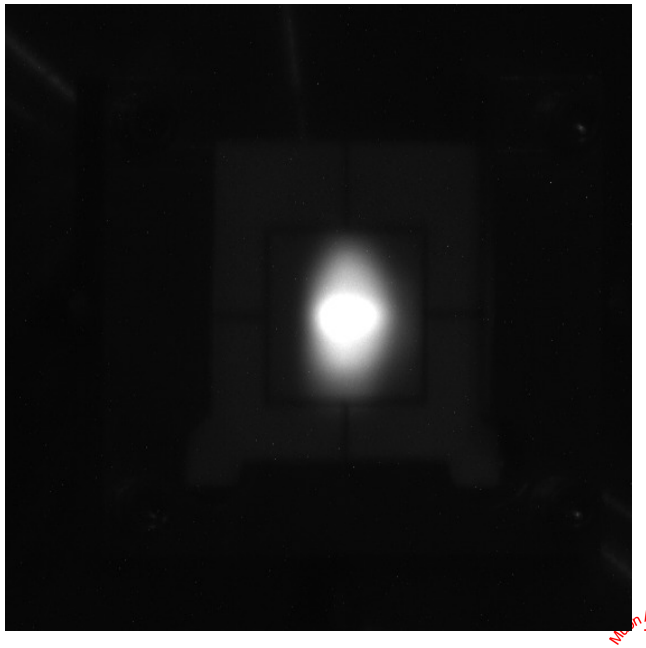

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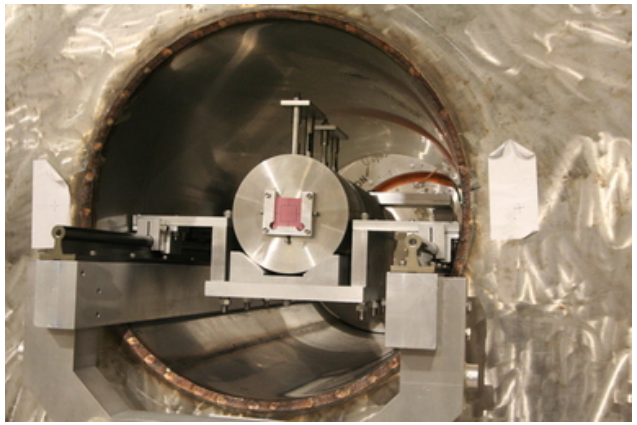

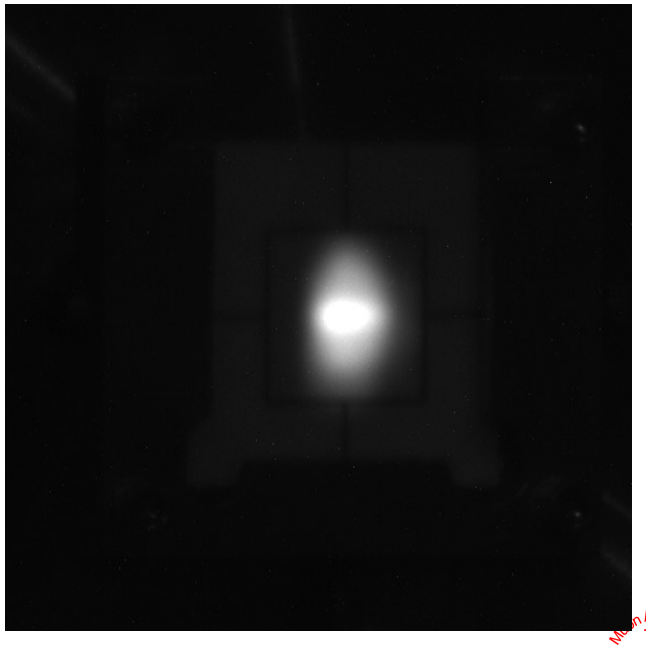

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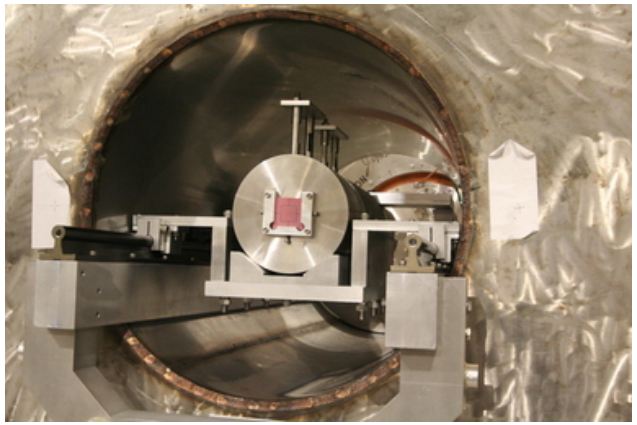

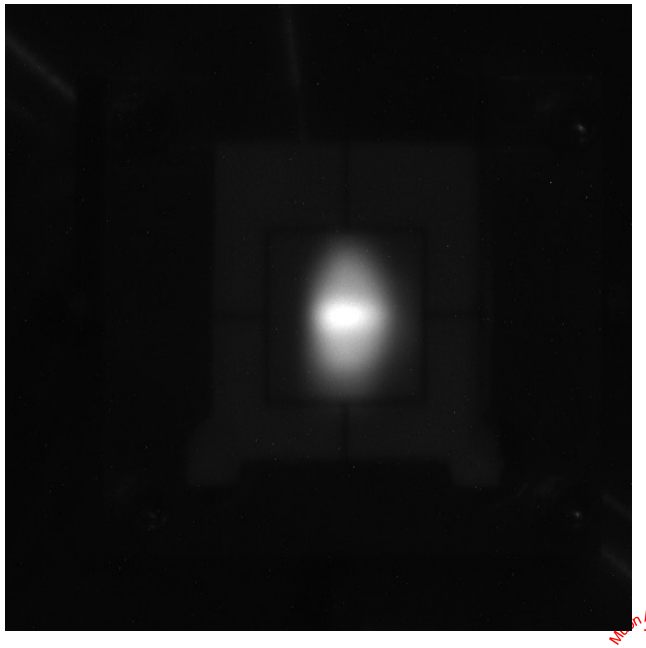

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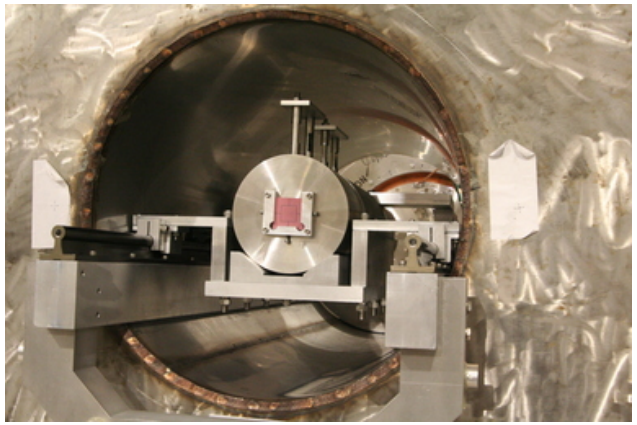

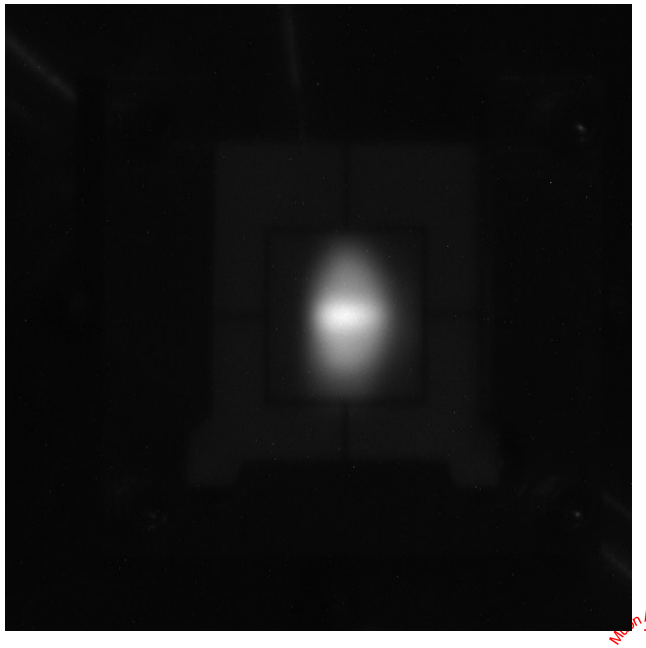

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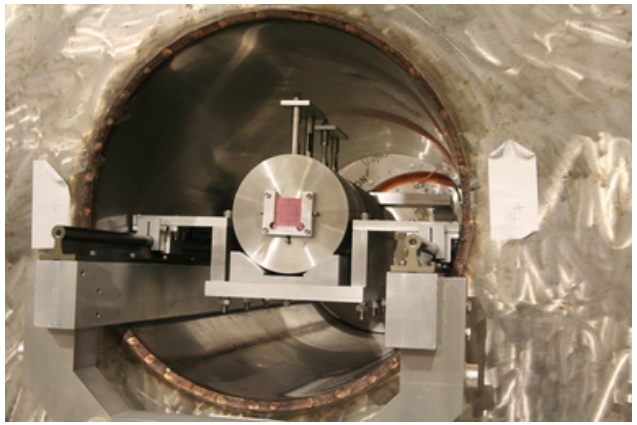

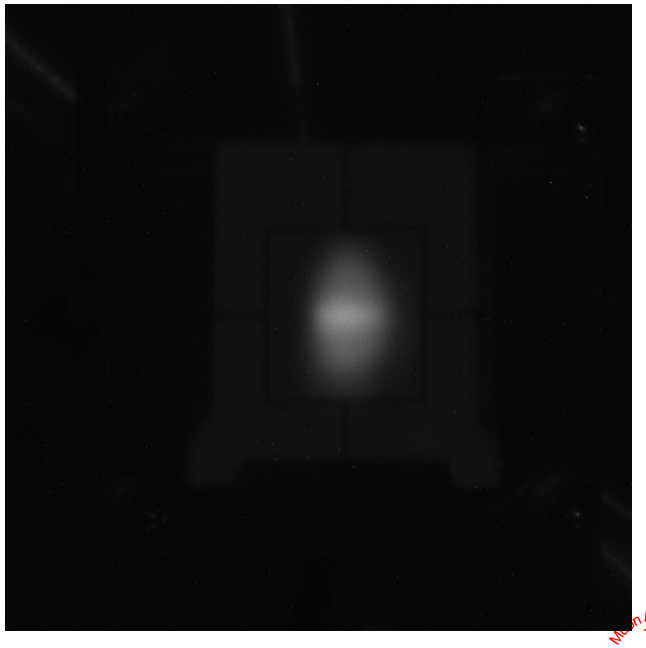

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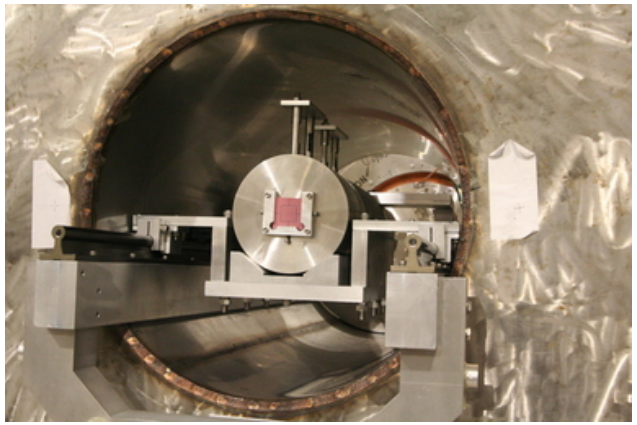

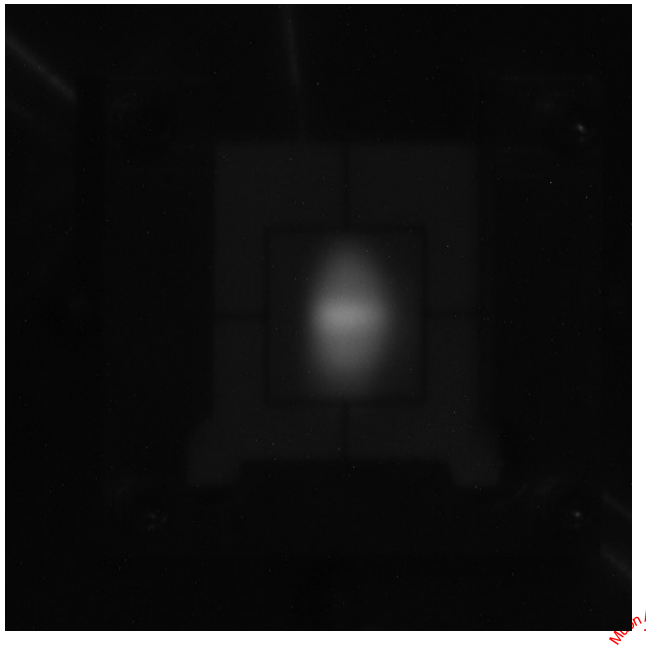

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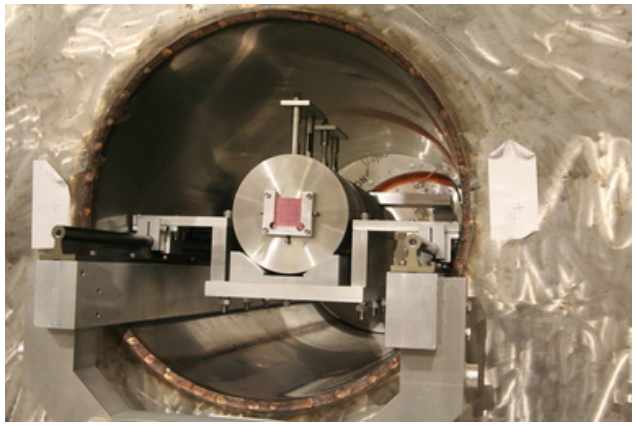
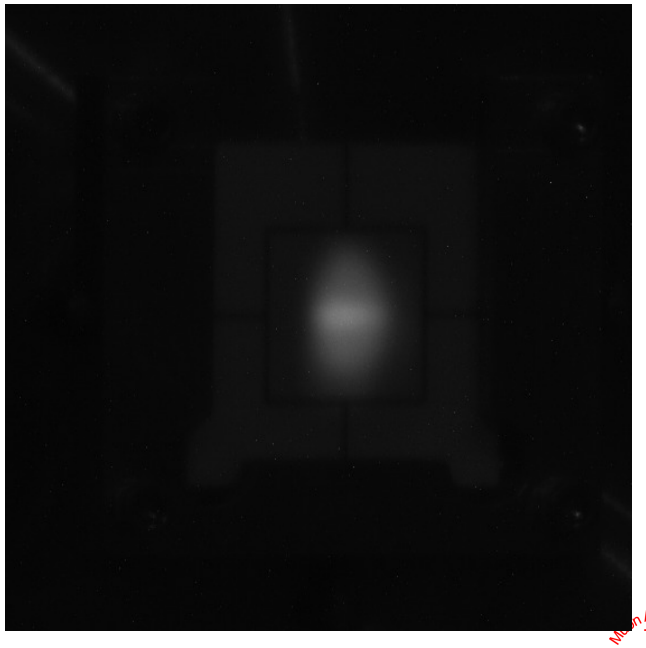
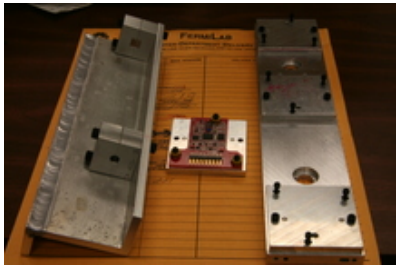
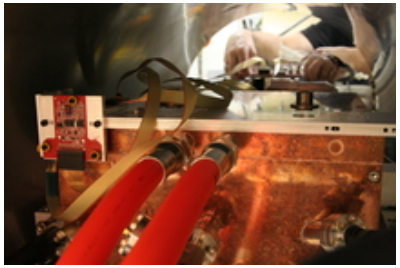
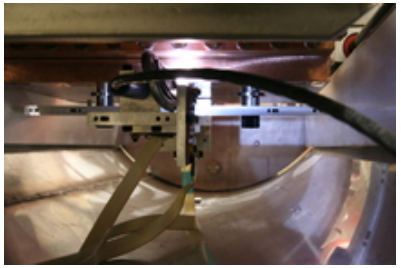




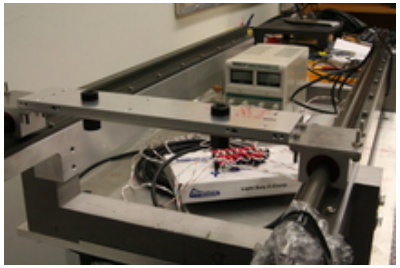
Magnetic Field Mapping

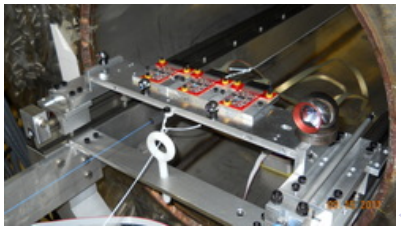
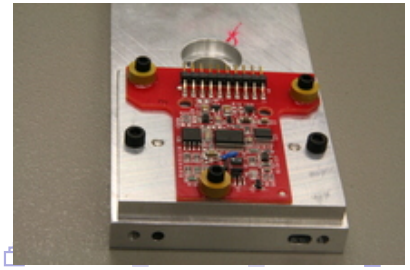
- Magnetic insulation depends strongly on angle
- MTA solenoid field never mapped in detail before
- Expect good alignment of magnetic axis with bore based on manufacturing tolerances but wanted to confirm



- Fiducial holes drilled during cavity fabrication
- Machined blocks to mount NIKHEF sensors
- Used cavity as mounting fixture – data taken at corners
- Gaussmeter fixed in bore for normalization
- Bore mapped in detail with cart on rails



Students at the MTA (past 1.5 year)

- Anastasia Belozertseva (U. Chicago) – magnetic field mapping
- Last Feremenga (U. Chicago) – magnetic field mapping
- Ben Freemire (IIT) – HPRF beam test (thesis), everything else
- Giulia Collura (Torino) – HPRF beam test
- Timofey Zolkin (U. Chicago) – dark current instrumentation
- Peter Lane (IIT) – acoustic sensors for detecting cavity sparks
- Raul Campos (NC State) – beamline magnet support
- Ivan Orlov (Moscow State) – HPRF beam test simulation
- Tom Mclaughlin (Valparaiso) – magnet mapping, circulator installation
- Jessica Cenni (Pisa) – dielectric loaded cavity
- Jared Gaynier (Kettering) – circulator installation




MTA Schedule and Outlook

- Experimental program
  - 805 MHz pillbox cavity with Be/Cu buttons – complete surface analysis in progress
  - 805-MHz 4-season cavity in B – complete
  - HPRF cavity – 2nd beam test imminent
    other beam & non-beam tests as needed
  - 201-MHz single cavity module (summer?)
  - ALD cavity – under design
  - New 805-MHz Cu pillbox
  - New 805-MHz Be-wall pillbox
  - Dielectric-loaded cavity
- Infrastructure
  - beam commissioning, cryo plant upgrade, magnet field mapping complete
  - RF circulator/switch installation in progress
  - single-cavity module assembly, installation in Hall
- Expect to demonstrate a working solution to RF cavity operation in high magnetic field "soon"