MTA Plans and Results

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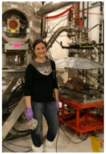
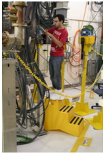
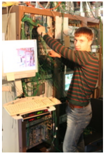
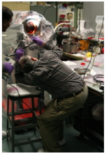
MICE cm32
Feb 10, 2012 – RAL



Of MICE & MuCool

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
- 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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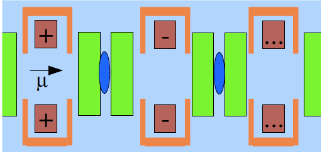
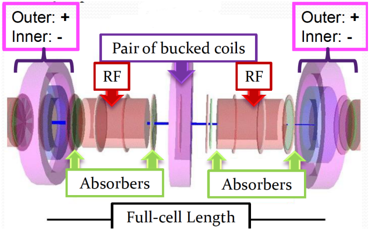
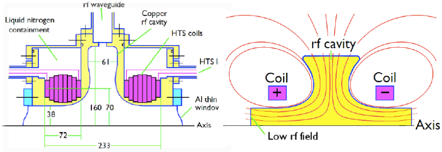
3. Shielding: iron, bucking coils (Rogers, Alekou)





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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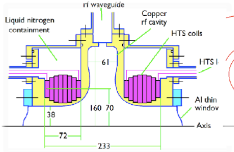
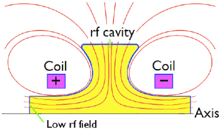
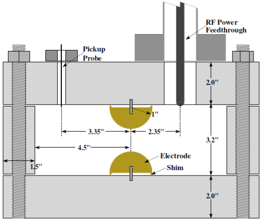
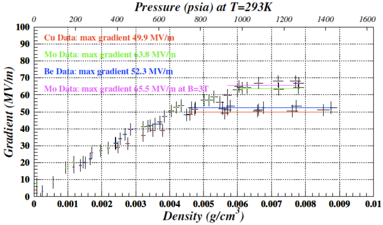




Loss of x 2 gradient advantage in pillbox geometry

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 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, pickup 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
- BPM, MW and scintillator for beam profile

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 future system tests
- multipronged approach to cover maximum ground with available resources

<table>
<tr><th colspan="2">Cavity</th><th>Outstanding issues</th><th>Proposed resolution</th><th>Experimental tests</th></tr>
<tr><td rowspan="4">Vacuum</td><td rowspan="3">pillbox</td><td rowspan="4">Breakdown and damage</td><td>Better materials</td><td>Mo, W, Be buttons
Be-walled 805-MHz cavity</td></tr>
<tr><td>Surface processing</td><td>Electropolished buttons
201-MHz pillbox in B-field</td></tr>
<tr><td>Coatings</td><td>ALD-coated buttons
ALD-coated cavity</td></tr>
<tr><td>rectangular
open-iris</td><td>Magnetic insulation</td><td>E⊥B box cavity
E‖B box cavity
Modified cavity-coil geometry</td></tr>
<tr><td colspan="2" rowspan="3">Pressurized</td><td>B-field/pressure effects</td><td>Materials tests</td><td>805-MHz 4-season cavity</td></tr>
<tr><td>Beam-induced ionization</td><td>Measure ionization lifetime</td><td>805-MHz cavity in beam</td></tr>
<tr><td>Frequency dependence</td><td>Test at different frequency</td><td>Pressurized 201-MHz cavity</td></tr>
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805 pillbox

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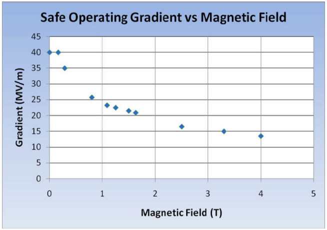

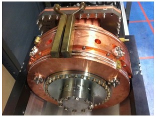

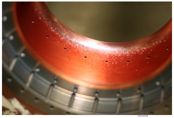

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- 805 MHz pillbox cavity used to
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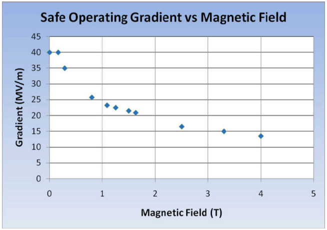

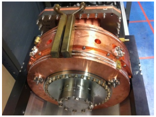

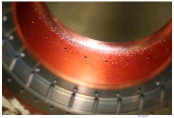

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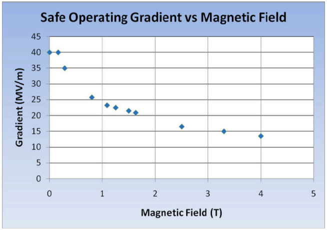

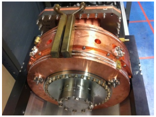

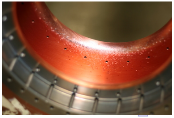

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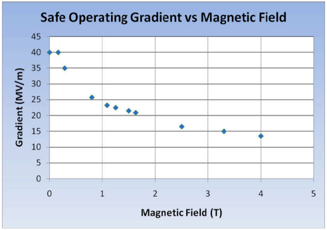

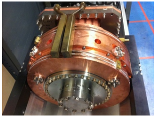

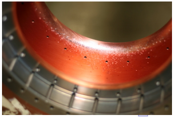

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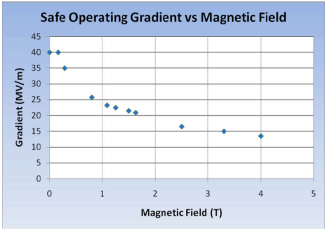

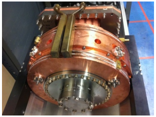

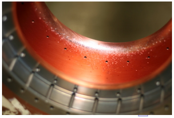

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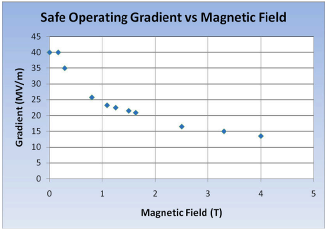

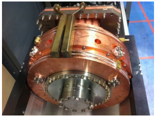

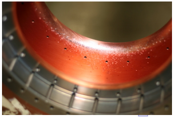

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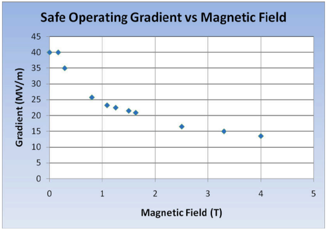

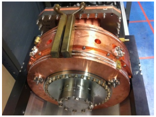
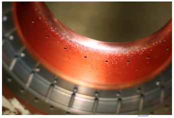


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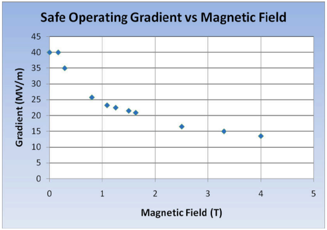

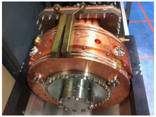

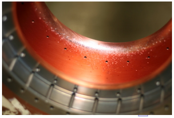

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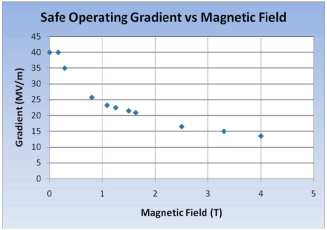

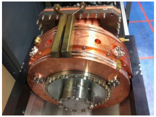

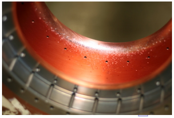

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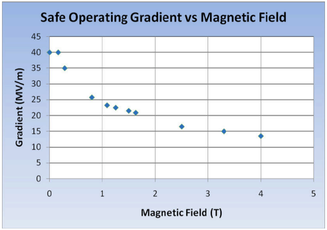
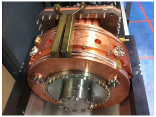
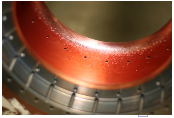
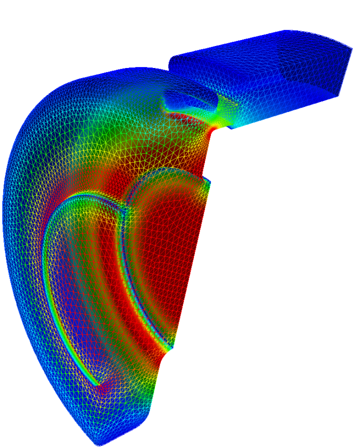
- Improved version under design (SLAC)



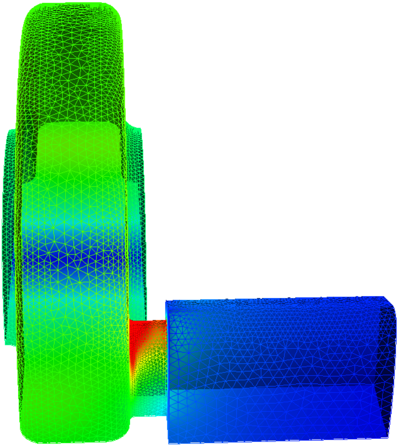




Track3P – 3T external field – gradient scan to 10 MV/m



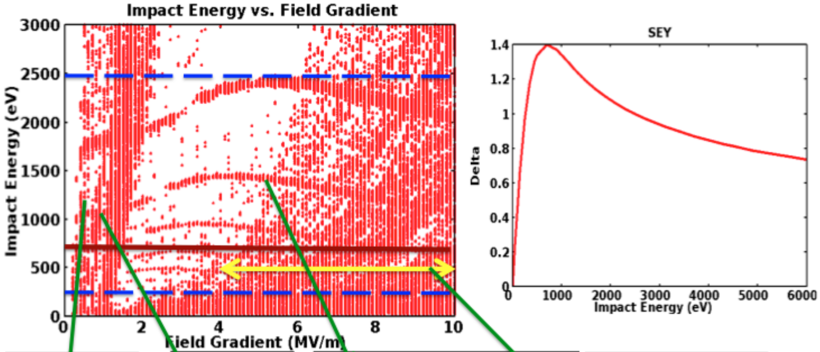
E magnitude

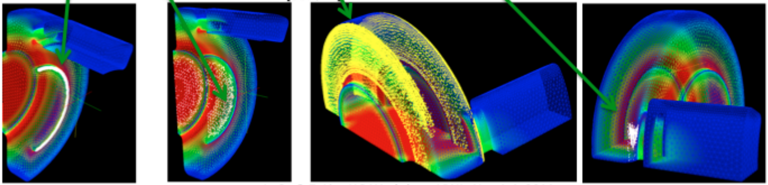


H magnitude

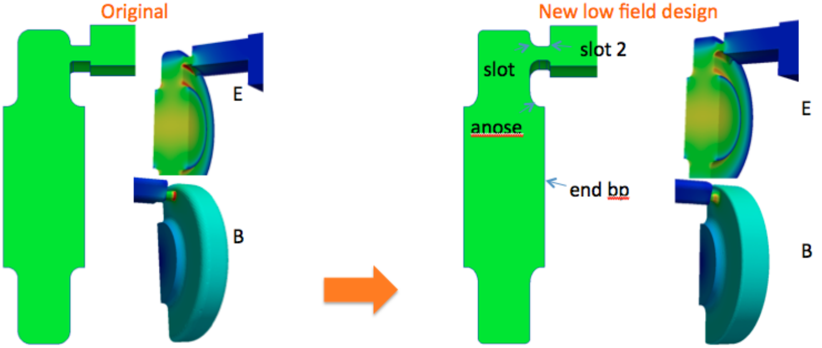
805 pillbox – Multipacting simulation – L. Ge, Z. Li

Multipacting resonance vs gradient





New design with low surface field

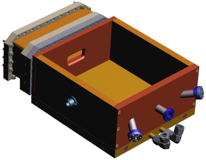


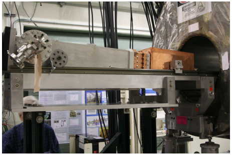
Rounding and elliptical profile ⇒ factor 0.55/0.63 in surface E/H field

	slot height	slot rounding	slot rounding 2	anose	Emax	Emax slot2	Emax anose	Emax end bp	Emax other surface	Hmax	slot angle	Qext
Original	15.2/6.4	3.175	0	11.4	69.81		44.95	32.88	46.22	0.304	53	12899
New	14.5/6.4	9.5	3.5	15	39.03	33.31	38.71	32.95	34.67	0.195	48	14422

Box Cavity

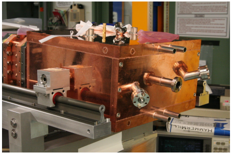
- Rectangular geometry chosen for test cavity to allow fast fabrication and simplify analysis
- Support system designed to rotate cavity pivoting around magnet center by up to 12^o
- Rectangular coupling aperture with rounded edges and a coupling cell built to match the power coupler to waveguide
- Three 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

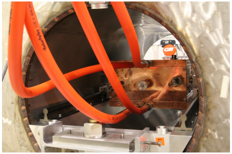




Box Cavity

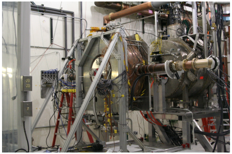
- Operated in the MTA magnet Mar-Sep 2010
- Commissioned to 50 MV/m at B=0
- Took data at 0, ± 1, 3, 4^o wrt B axis (3T)
- Large effect seen at 3-4^o (stable gradient down to about 25 MV/m)
- Some degradation even at $\leq 1^o$ (33 MV/m)
- Visual inspection of interior, no obvious damage
- RF, optical 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



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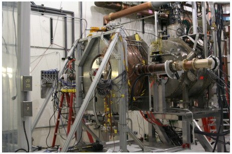

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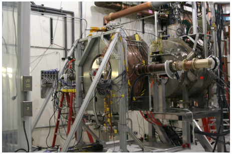

201 pillbox

201 MHz MICE prototype cavity

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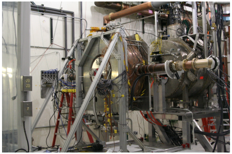
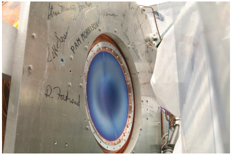
- conditioned to design gradient very quickly
- ran successfully with thin curved Be windows

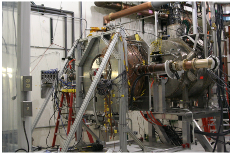


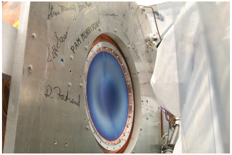


201 pillbox

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





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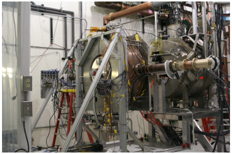
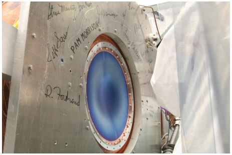
  reduced performance





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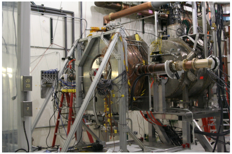

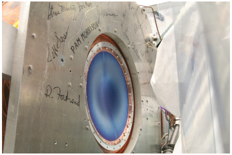

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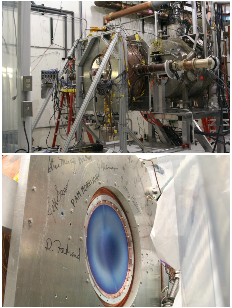
- large diameter coil needed for field configuration closer to MICE



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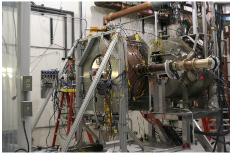
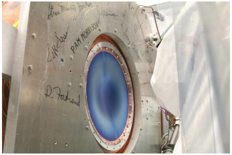
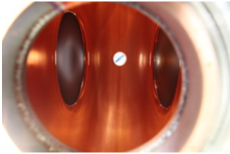
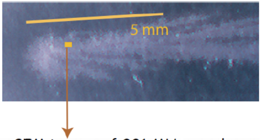
- large diameter coil needed for field configuration closer to MICE
- No surface damage seen on cavity interior



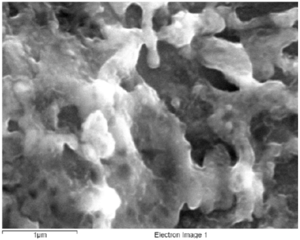




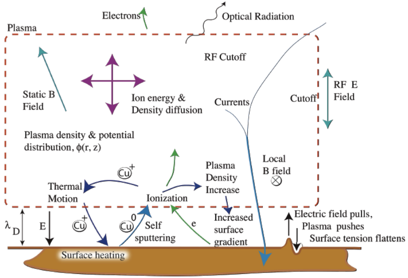
Evidence for some sparking in the coupler



SEM images of 201 MHz coupler.



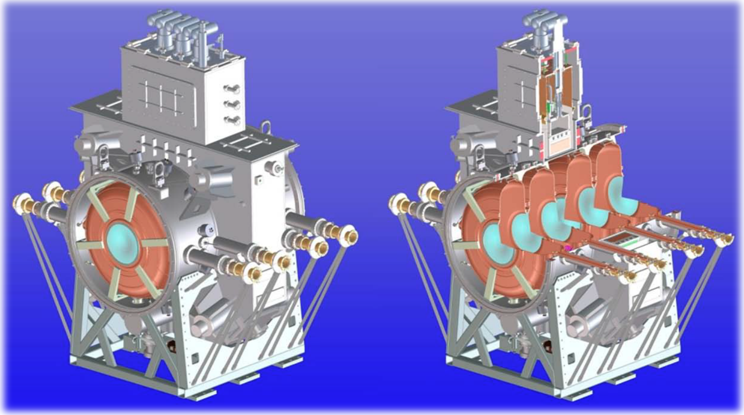
Unipolar arc?



201 pillbox – MICE

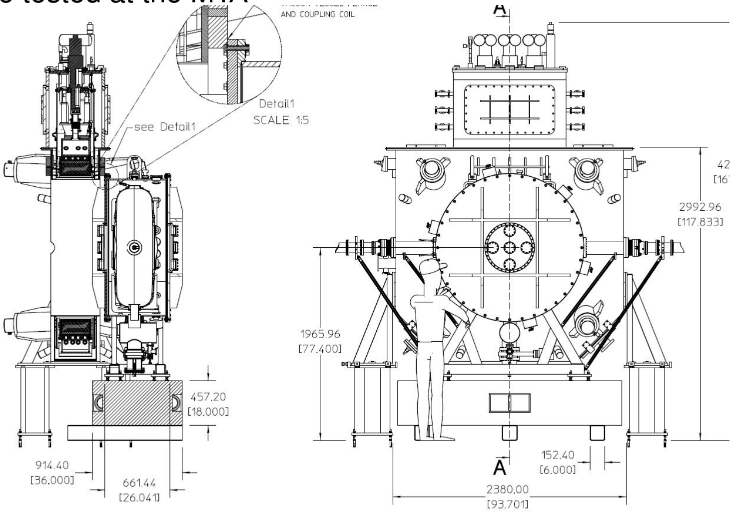
Each RFCC module has

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



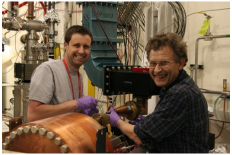
201 Single-cavity module (D. Li talk)

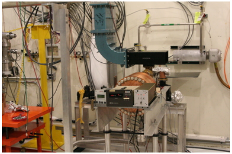
To be tested at the MTA



4-Season cavity (Muons Inc., LANL)

- modular pillbox with replacable end walls





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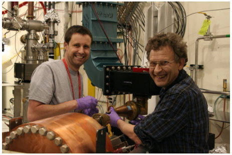

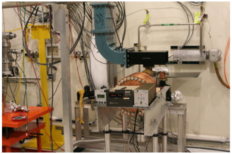

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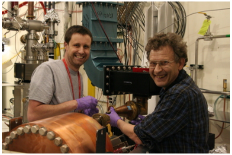
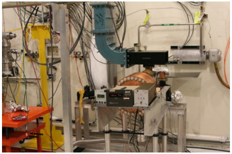

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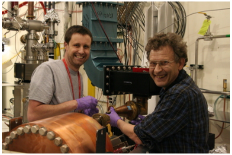

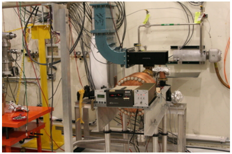

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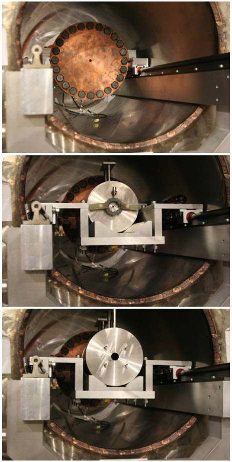
- G. Kazakevich *et al.*. PAC11

HPRF cavity beam test (Yonehara)

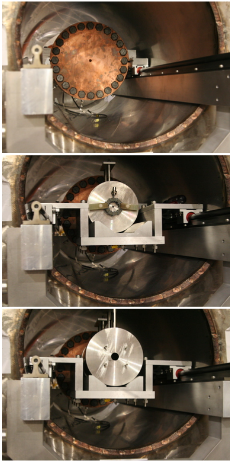
- First beam experiment at MTA



HPRF Program

HPRF cavity beam test (Yonehara)

- First beam experiment at MTA
- Ran Jul-Aug 2011



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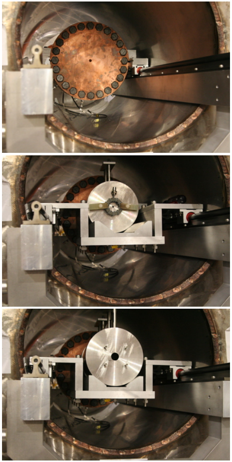

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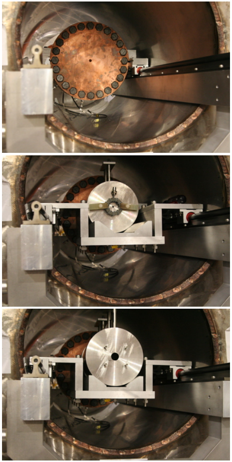

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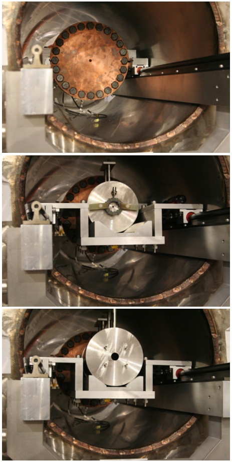

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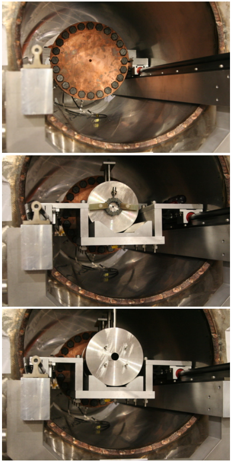

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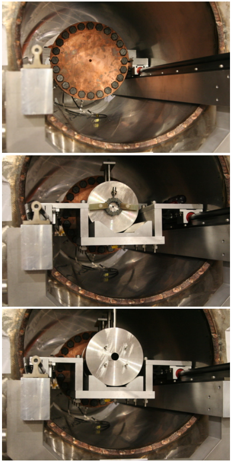
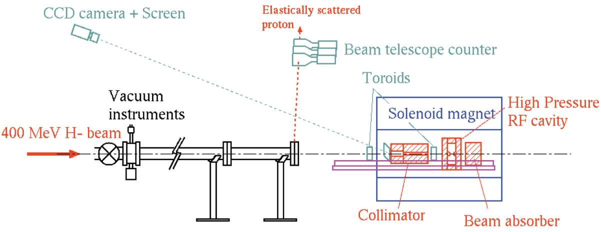
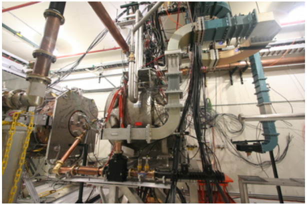
  - Intense muon bunch creates lots of electron-ion pairs
  - potentially shorting the RF cavity
  - may be mitigated by electronegative dopant gas
    (K. Yonehara *et al.*, PAC09, IPAC10)

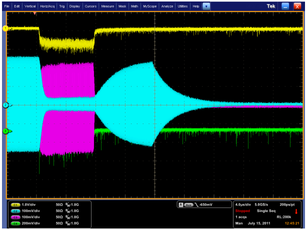


HPRF Beam Test





- 500 psi N2
- 500, 800 and 950 psi H2
- 8μs beam, 2 intensities
- dopant test (N2, SF6)
- analysis in progress
- next test (with magnetic field, dopants) in a few weeks



Beam

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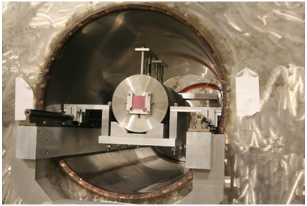
- $O(10^{11})$ protons through collimators



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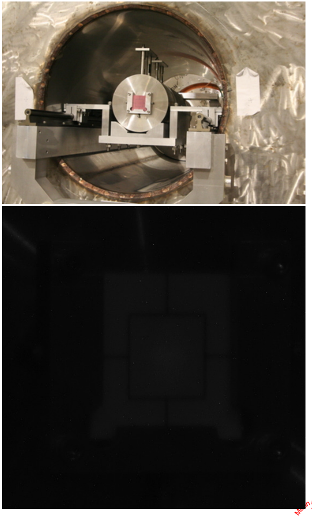

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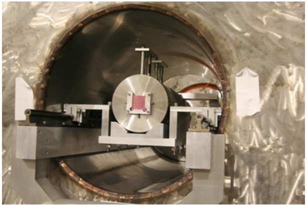

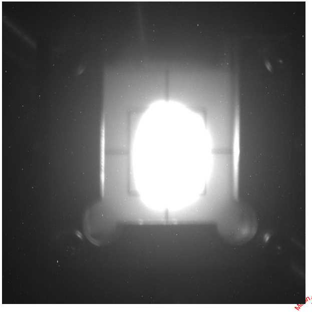

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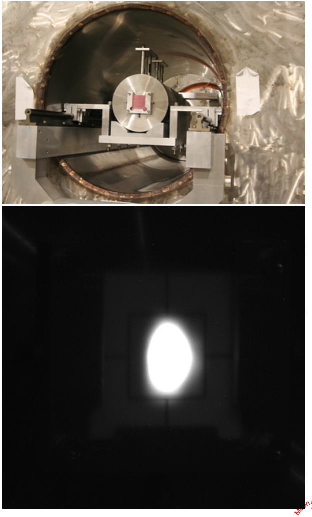

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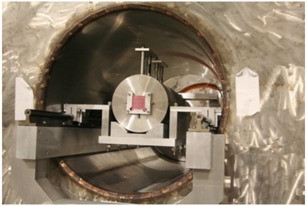

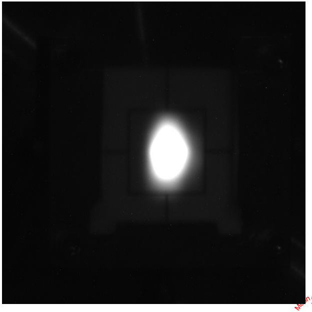

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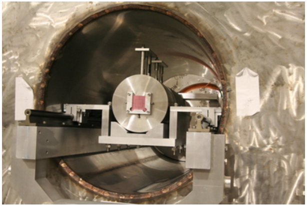

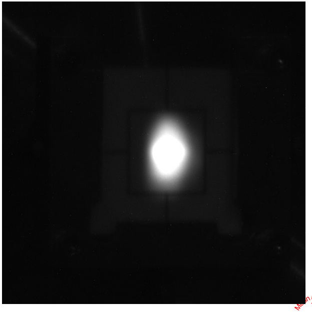

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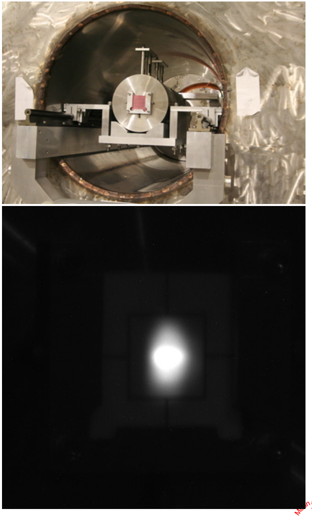

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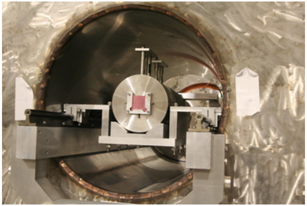

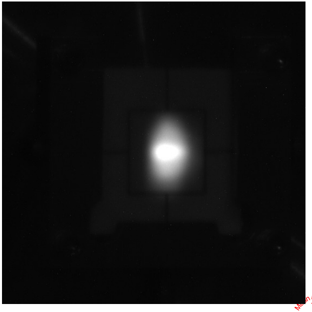

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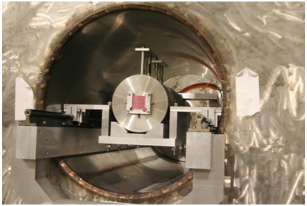

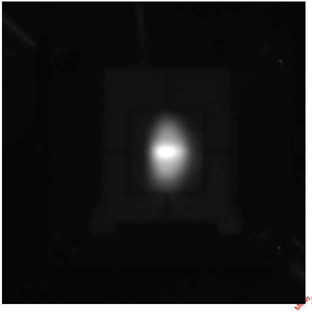

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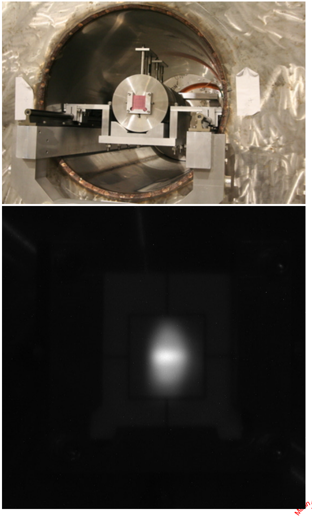

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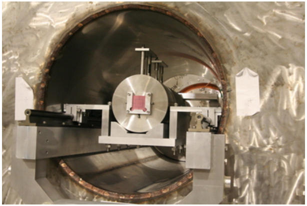

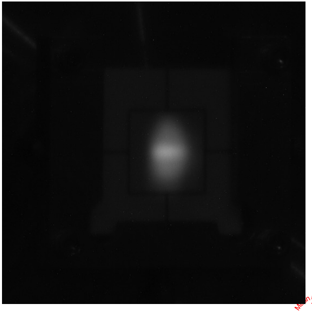

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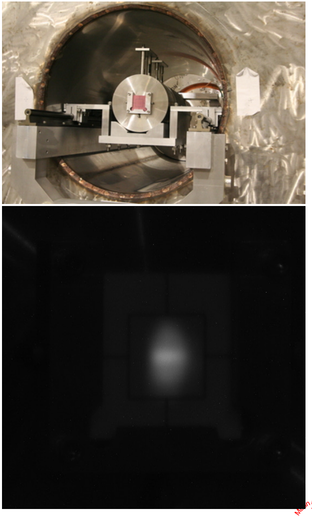
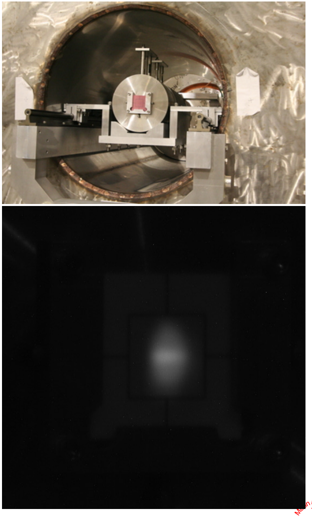


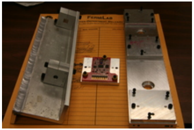
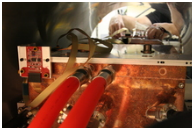
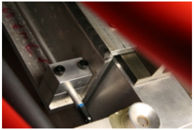
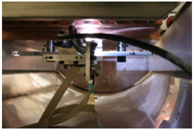
Beam

- 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

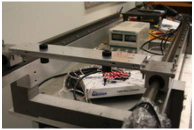


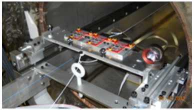
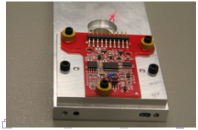
Magnetic Field Mapping

- 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

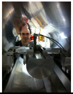
- Fiducial holes drilled during cavity fabrication
- Machined blocks to mount NIKHEF sensors
- Used cavity as mounting fixture – data taken at corners
- Gaussmeter fixed in bore for normalization
- Bore mapped in detail with cart on rails



Students at the MTA (past 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
  - HPRF cavity in beam – 2nd test imminent
  - 805 MHz pillbox cavity with Be/Cu buttons – complete
  - 201 MHz single cavity module (summer?)
  - further HPRF beam tests
  - 4-season cavity in B, with Be
  - ALD cavity – under design
  - New 805 MHz pillbox
  - Be-wall pillbox
  - Dielectric-loaded cavity
- Infrastructure
  - beam commissioning, cryo plant upgrade, magnet field mapping complete
  - RF circulator/switch to be installed in Linac
  - coupling coil and single-cavity module in Hall
- Expect to demonstrate a working solution to RF cavity operation in high magnetic field within the next few years