MICE & MuCool

Yağmur Torun

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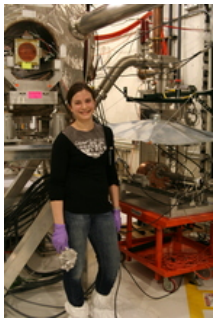
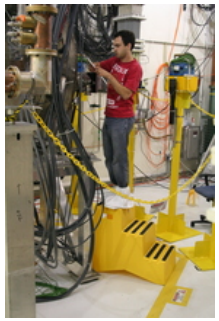
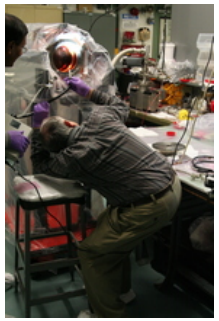
NuFact11
Aug 4, 2011 – Geneva

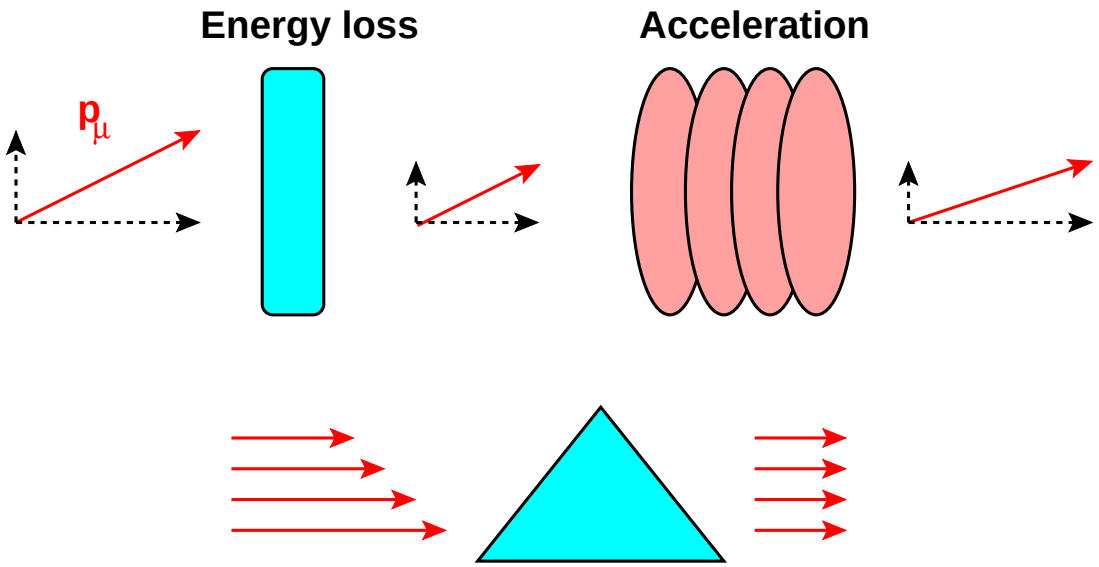





Ionization Cooling

- The only muon cooling scheme that appears practical within the muon lifetime (2.2μs)



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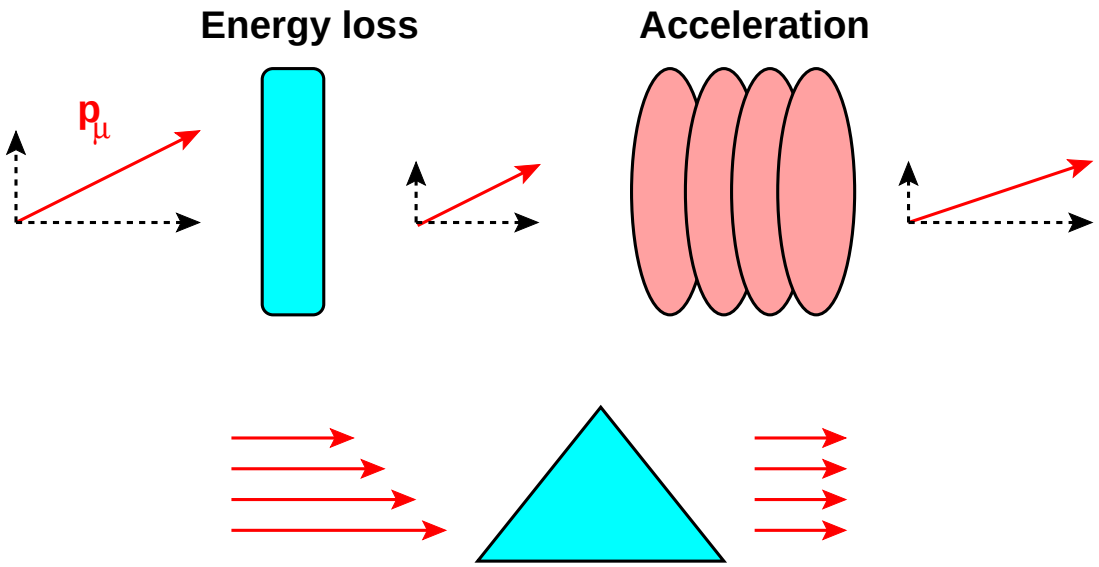

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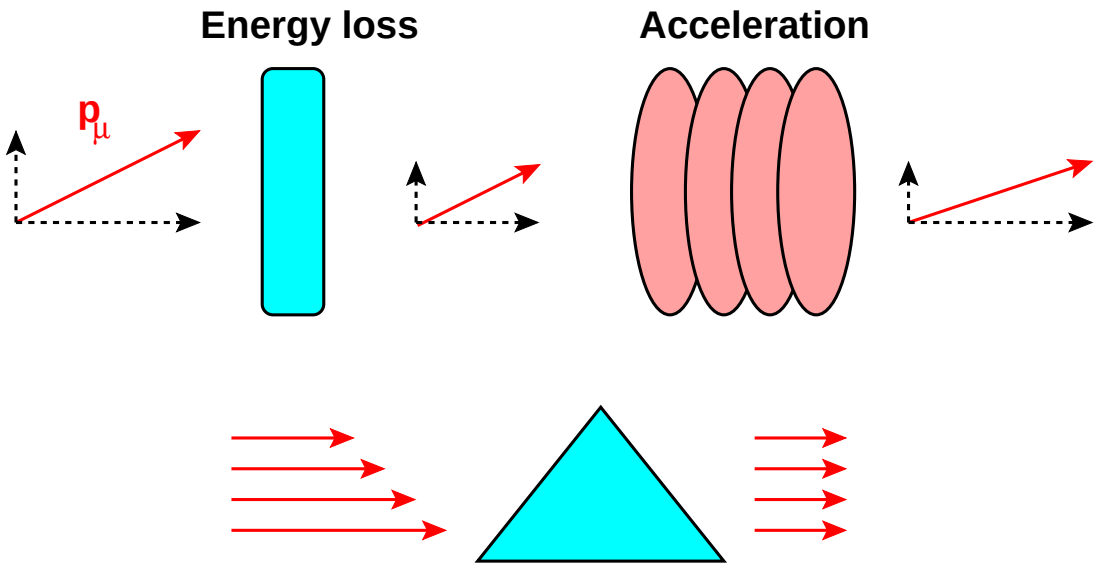

- Cooling mainly transverse in a linear channel
- Longitudinal cooling requires momentum-dependent path-length through the energy absorbers

Ionization Cooling

Normalized transverse emittance ε of muon beam in solenoidal channel

$$\frac{d\varepsilon}{ds} \simeq \frac{\left\langle \frac{dE}{ds} \right\rangle}{\beta^2 E} (\varepsilon - \varepsilon_0), \quad \varepsilon_0 \simeq \frac{0.875\text{MeV}}{\left\langle \frac{dE}{ds} \right\rangle X_0} \frac{\beta_\perp}{\beta}$$

ε_0: equilibrium emittance (multiple scattering $\sim$ cooling)

- Energy absorbers with large ΔE per radiation length (LH2: 29MeV/m x 8.9m; LiH: 151MeV)
- Strong focusing (large B-field), $\beta_\perp \sim p/B$
- High-gradient rf cavities to replace longitudinal momentum and for phase focusing

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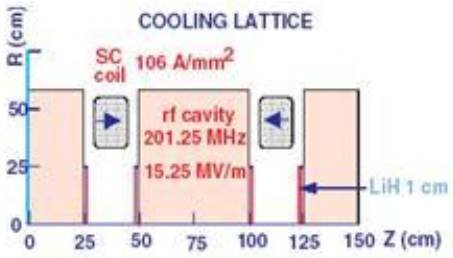

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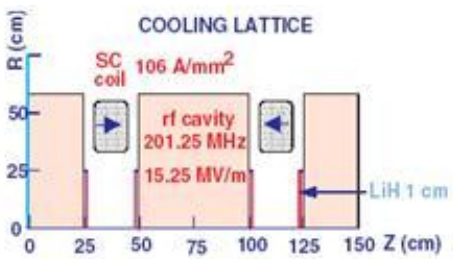

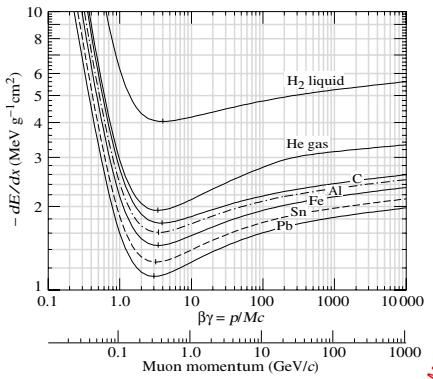

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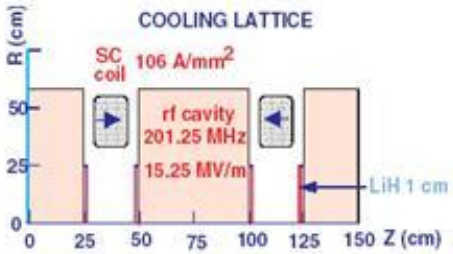

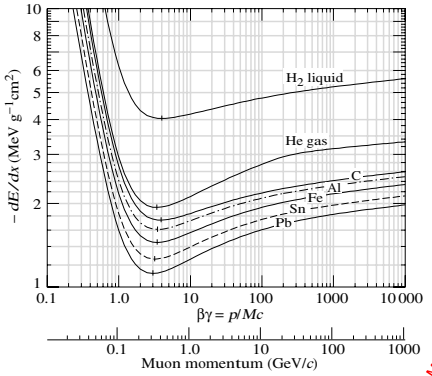

Of MICE & MuCool

MICE

Experiment at RAL to demonstrate and measure cooling

MuCool

R&D program at Fermilab to develop ionization cooling components

Of MICE & MuCool

MICE

Experiment at RAL to demonstrate and measure cooling

aims of the International Muon Ionization Cooling Experiment are:

- to show that it is possible to design, engineer and build a section of cooling channel capable of giving the desired performance for a Neutrino Factory
- to place it in a muon beam and measure its performance in various modes of operation and beam conditions, thereby investigating the limits and practicality of cooling

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mission:

- design, prototype and test components for ionization cooling
  - energy absorbers (LH2, solid LiH)
  - RF cavities
  - magnets
  - diagnostics
- carry out associated simulation and theoretical studies
- support system tests (MICE, future cooling experiments)

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.)
2. Surface processing: suppress field emission (superconducting RF techniques, coatings, atomic layer deposition)
3. Shielding: iron (Rogers), bucking coils (Alekou, WG3)

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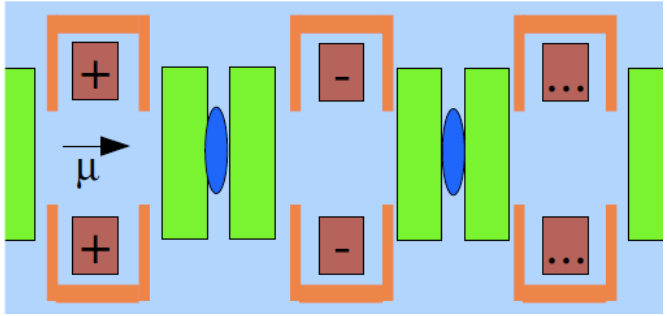

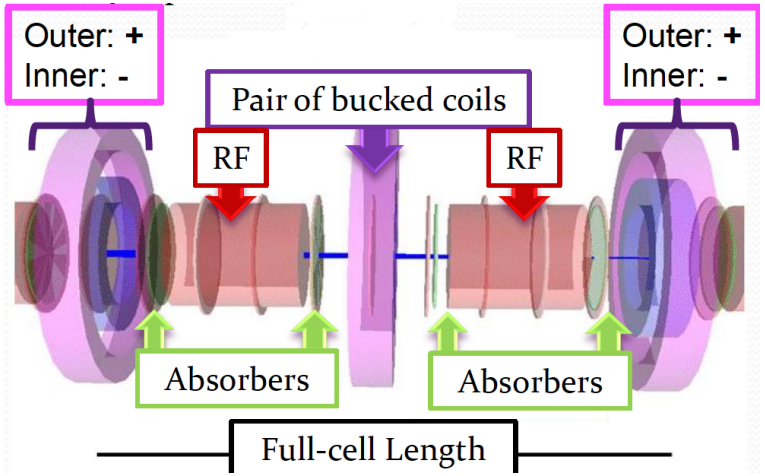

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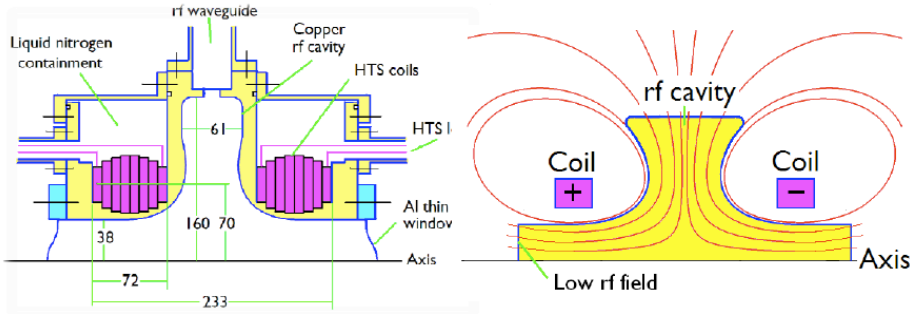

Loss of x 2 gradient advantage in pillbox geometry

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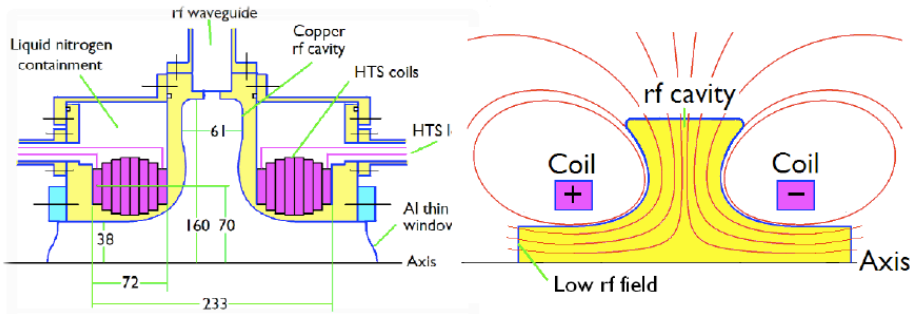

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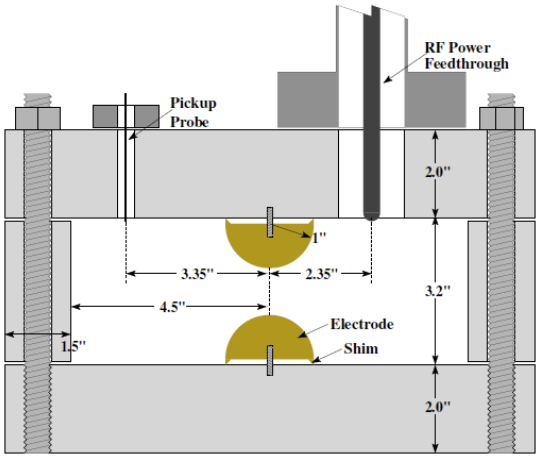
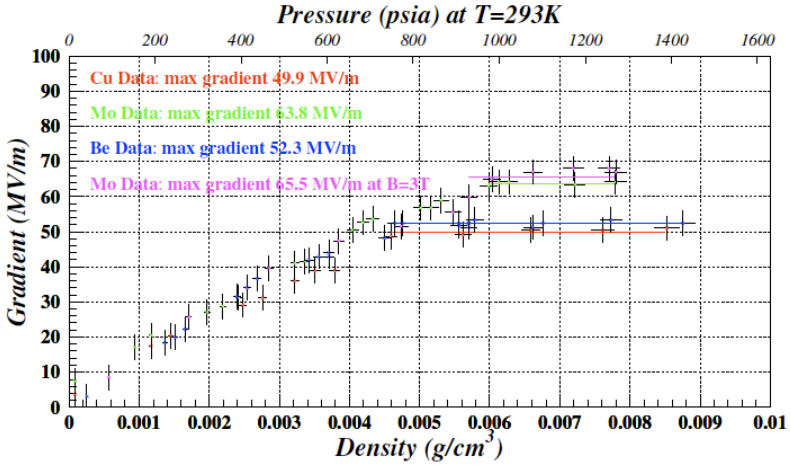




MuCool Test Area (MTA) – http://mice.iit.edu/mta/

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

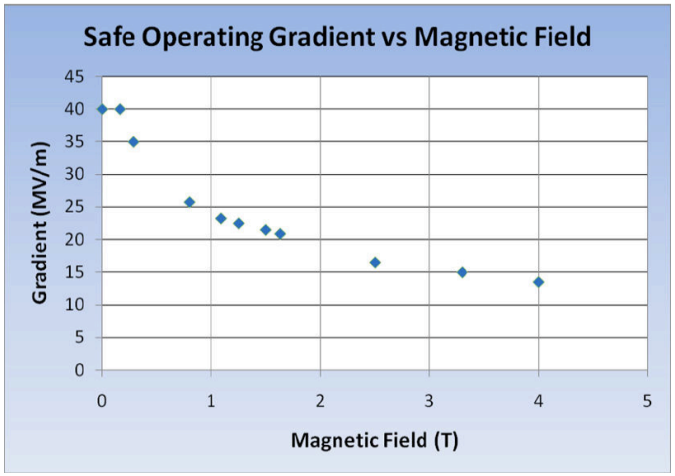
Summary of MuCool experimental program

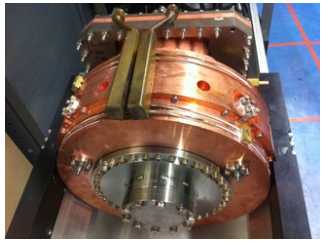
- trying to demonstrate a working solution to RF cavity operation in high external magnetic field for muon cooling
- major MAP milestone
- big impact on cooling channel design and future system tests
- multipronged approach to cover maximum ground with available resources

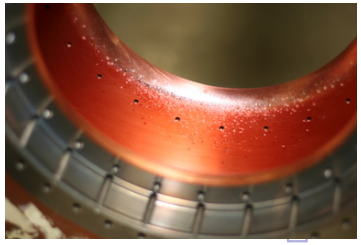
Cavity		Outstanding issues	Proposed resolution	Experimental tests
Vacuum	pillbox	Breakdown and damage	Better materials	Mo, W, Be buttons Be-walled 805-MHz cavity
			Surface processing	Electropolished buttons 201-MHz pillbox in B-field
			Coatings	ALD-coated buttons ALD-coated cavity
	rectangular open-iris		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

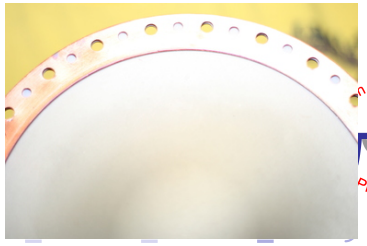
805 pillbox

- 805 MHz pillbox cavity used to
  - quantify magnetic field dependence of gradient
  - establish feasibility of thin windows
  - test buttons with different materials/coatings
- Back after rebuild at JLab, tested again
- Poor performance (10 MV/m at 3T)
- To be tested with Be buttons soon
- Reprocessing afterwards (Bowring)









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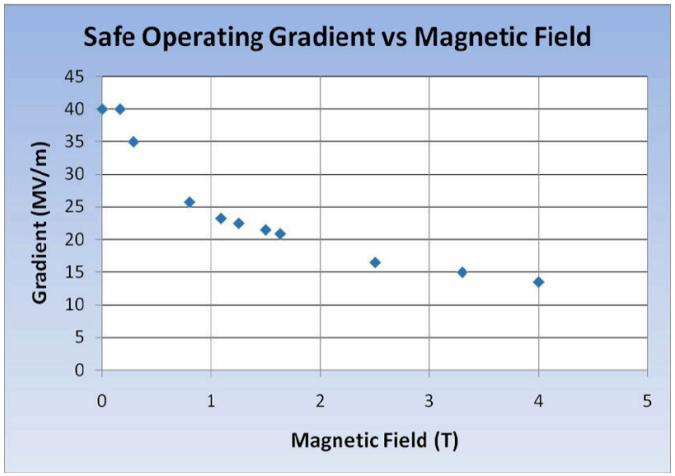

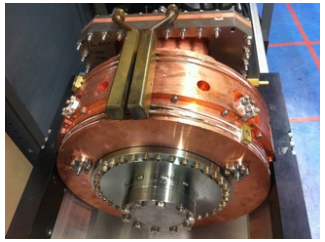

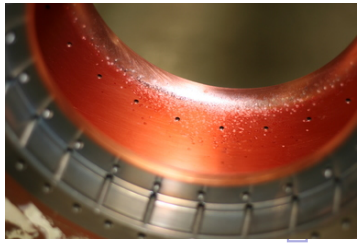

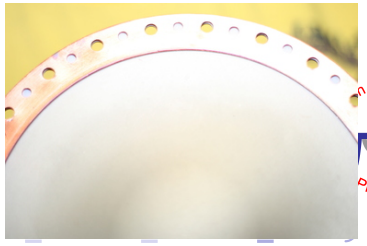

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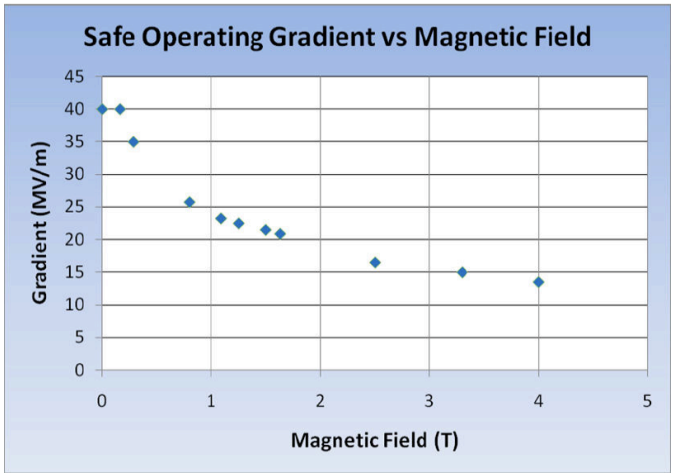

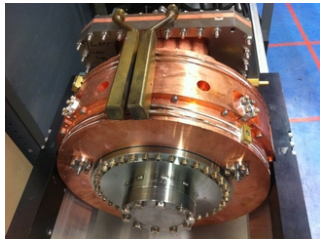

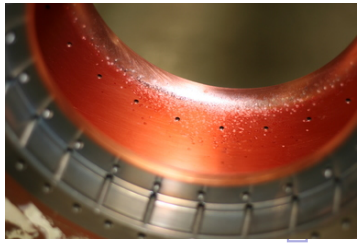

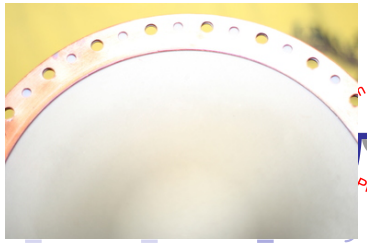

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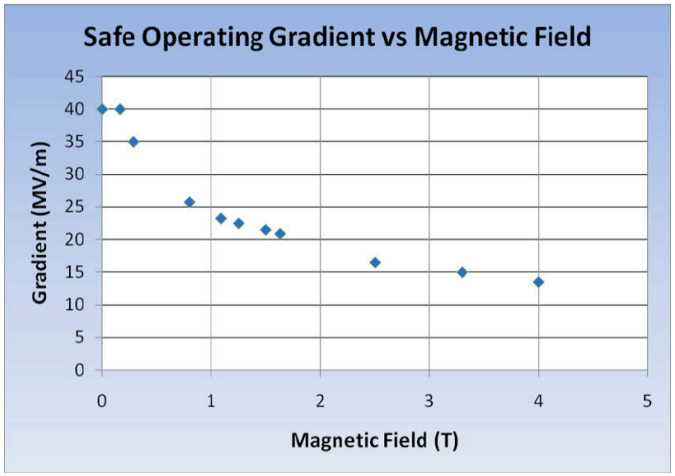

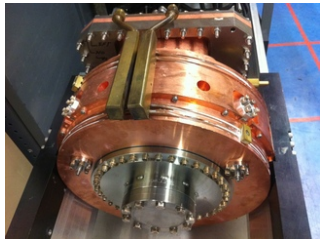

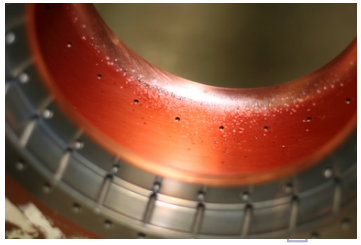

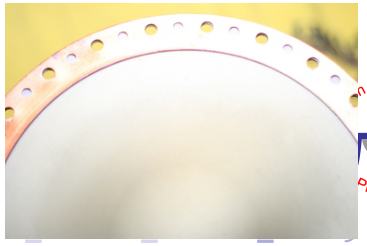

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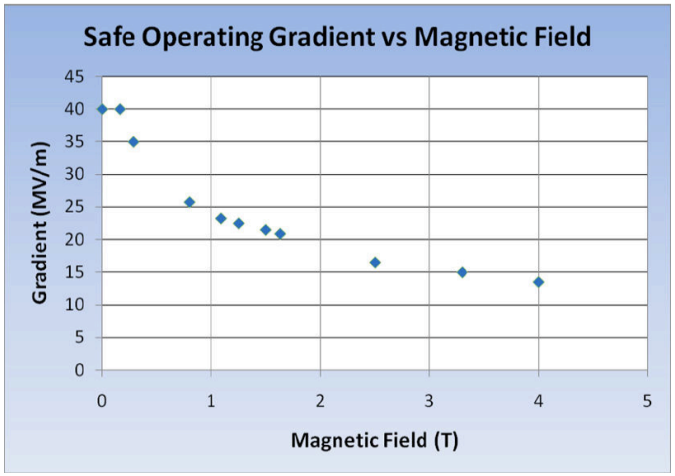

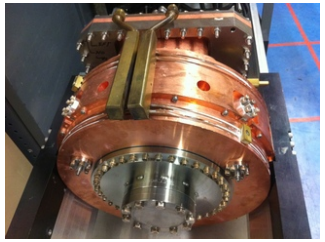

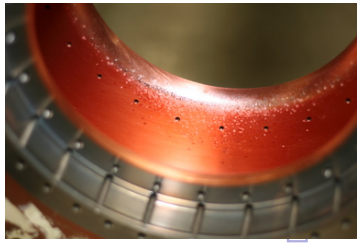

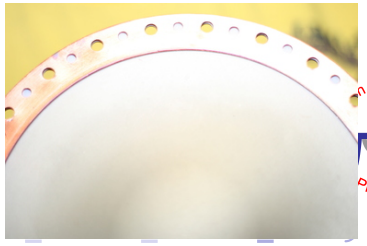

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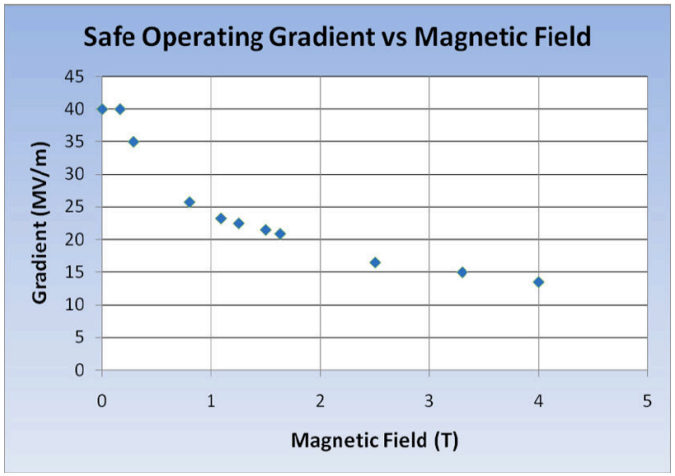

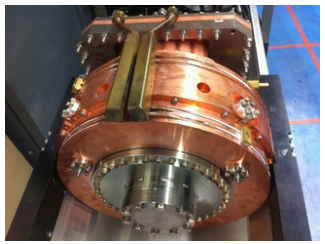

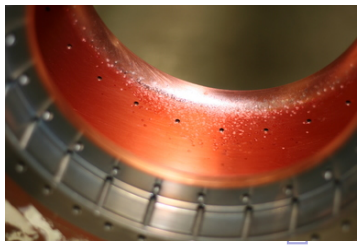

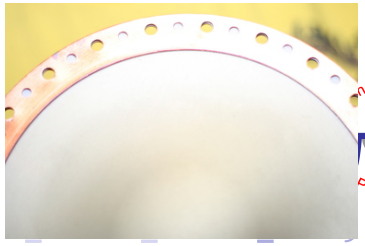

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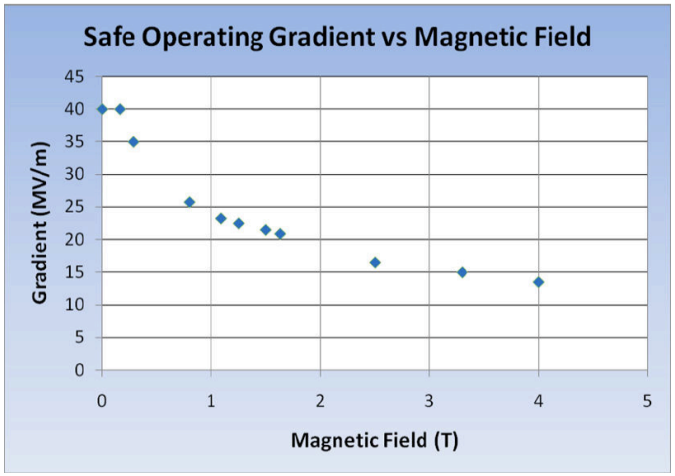

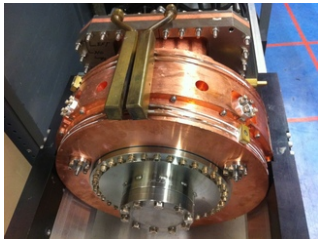

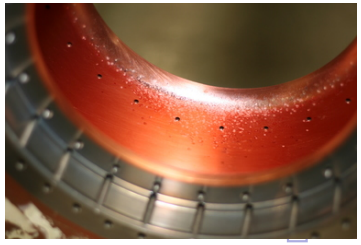

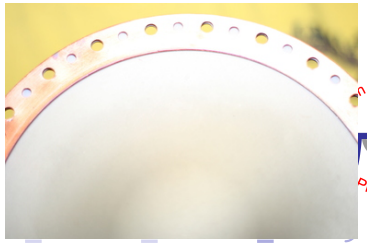

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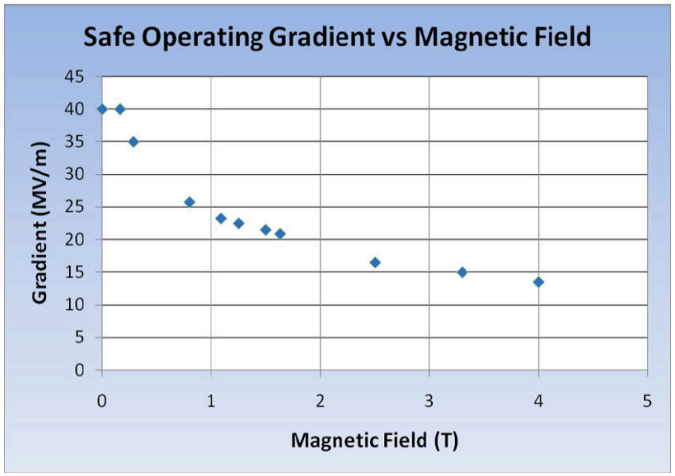

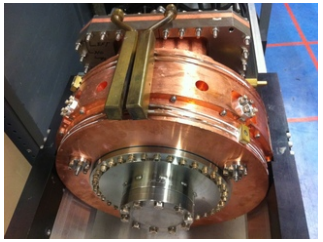

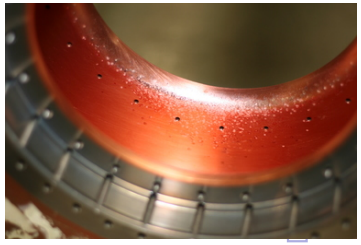

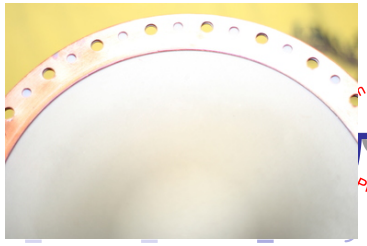

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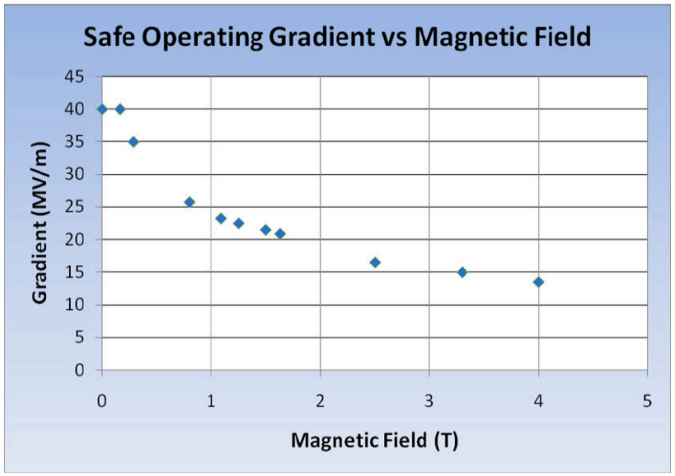

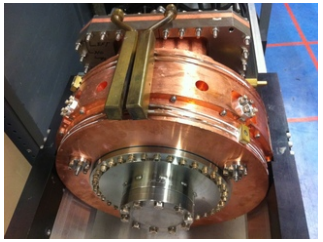

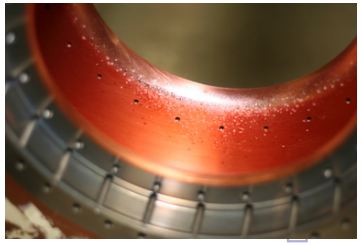

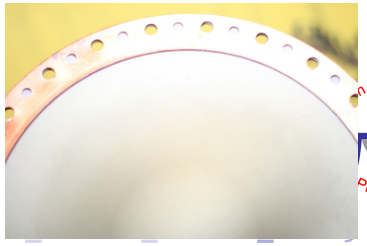

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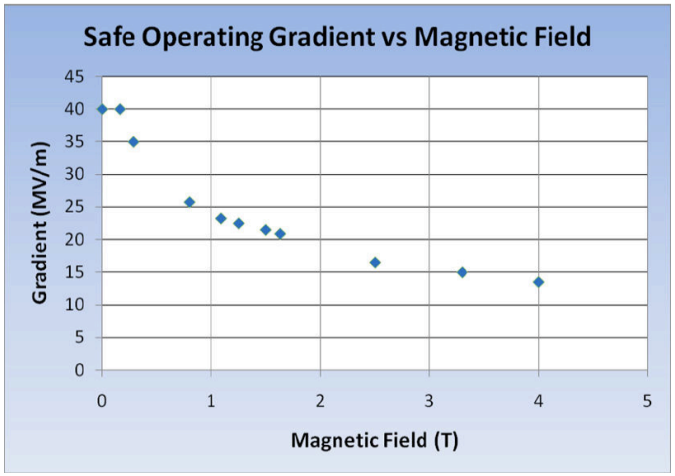
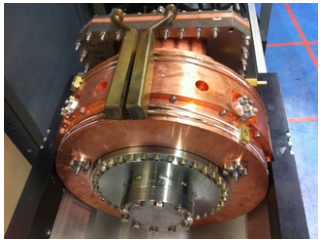
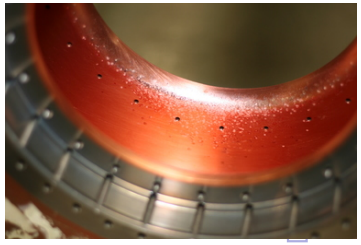
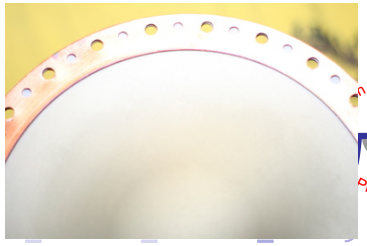


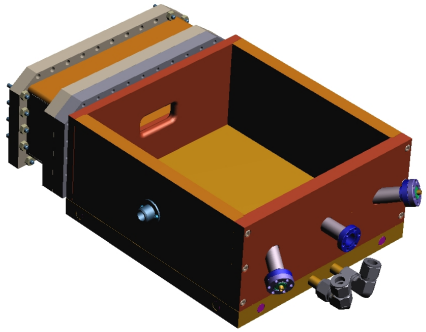


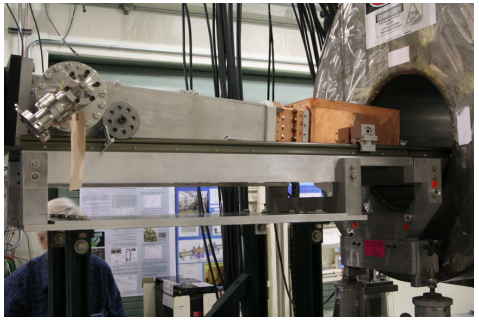




Box Cavity

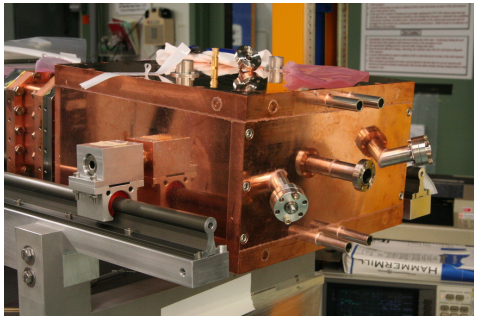
- Rectangular geometry chosen for test cavity to allow fast fabrication and simplify analysis
- Support system designed to rotate cavity pivoting around magnet center by up to 12°
- Rectangular coupling aperture with rounded edges and a coupling cell built to match the power coupler to waveguide
- Three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

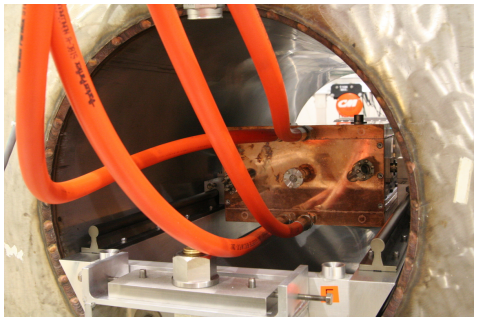


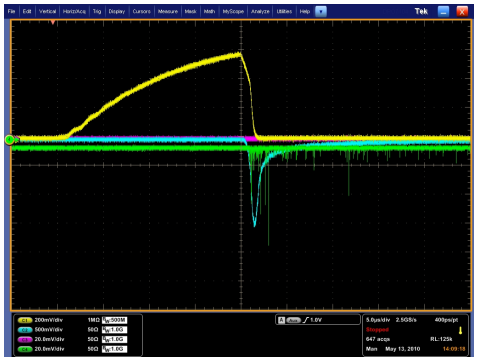


Box Cavity

- 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

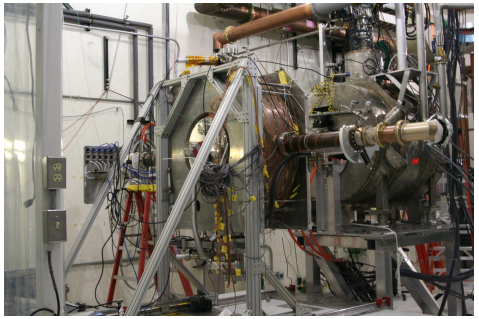






201 pillbox

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

- radiation output measured (MICE detector backgrounds)
- large diameter coil needed for field configuration closer to MICE
- No surface damage seen on cavity interior

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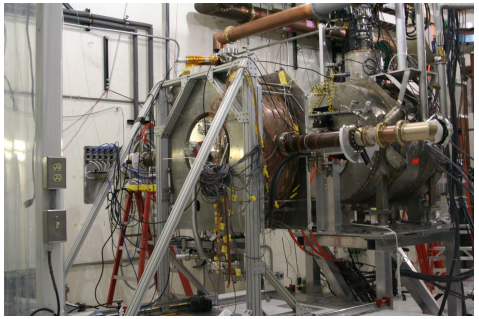

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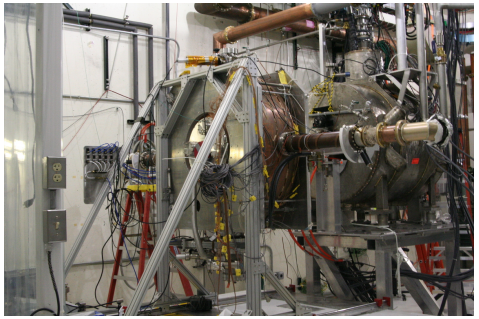

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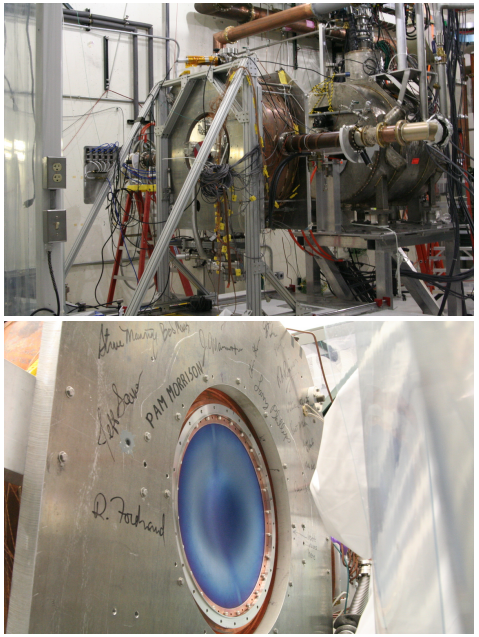

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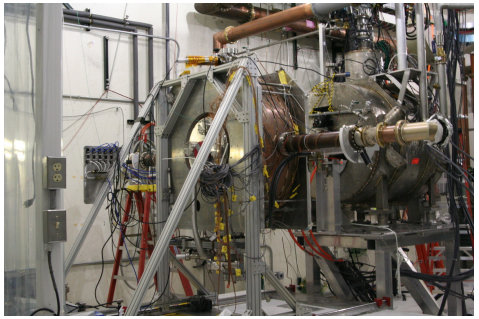

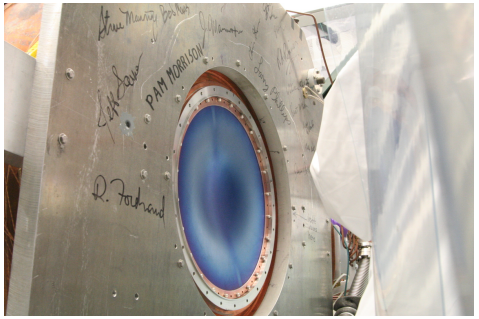

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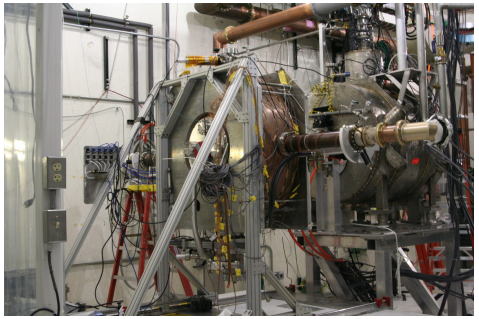

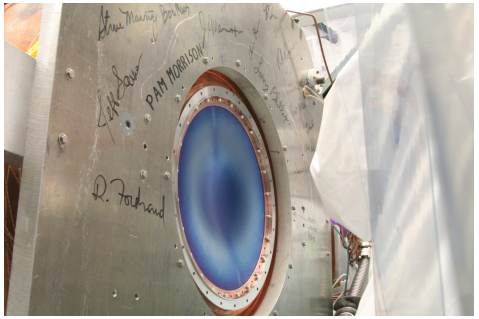

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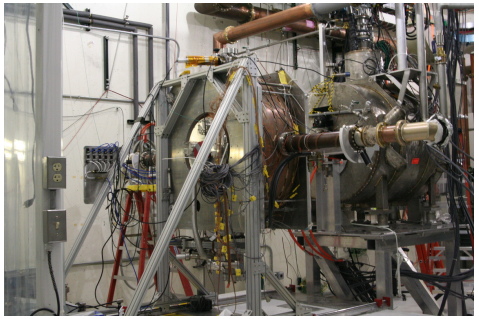

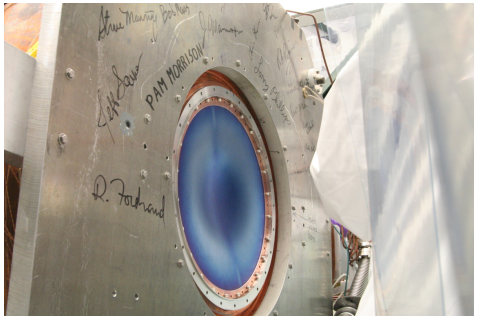

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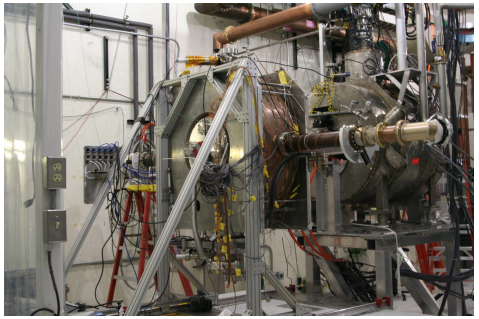

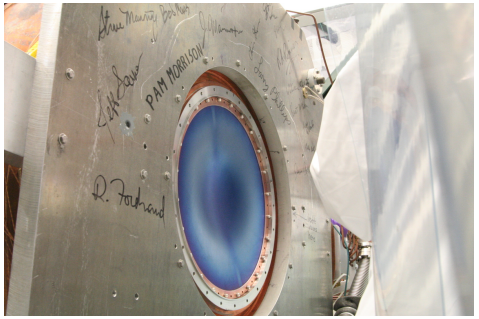

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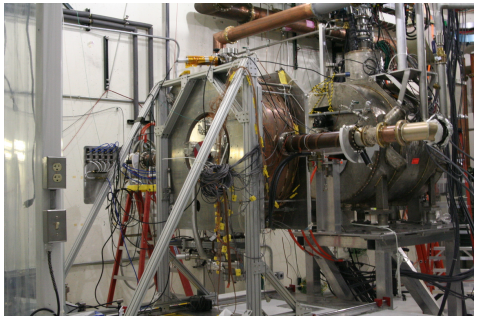

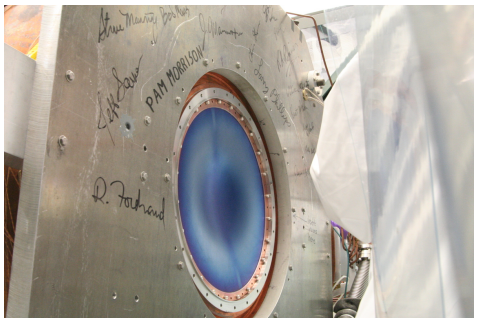

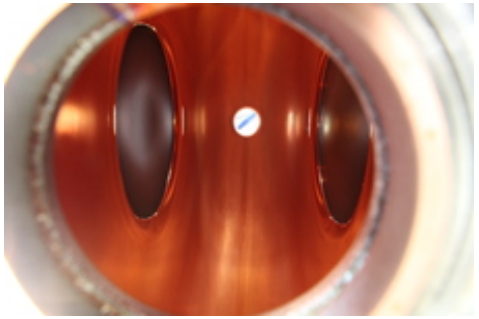

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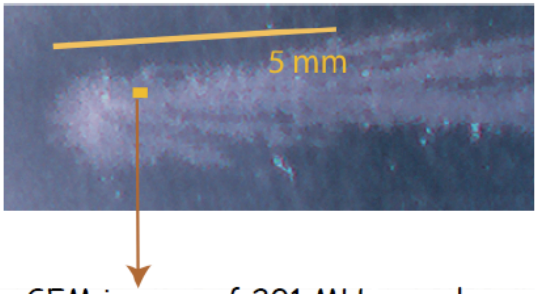
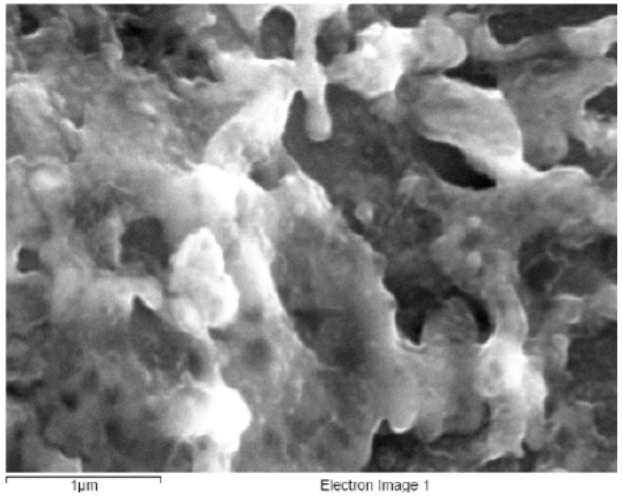
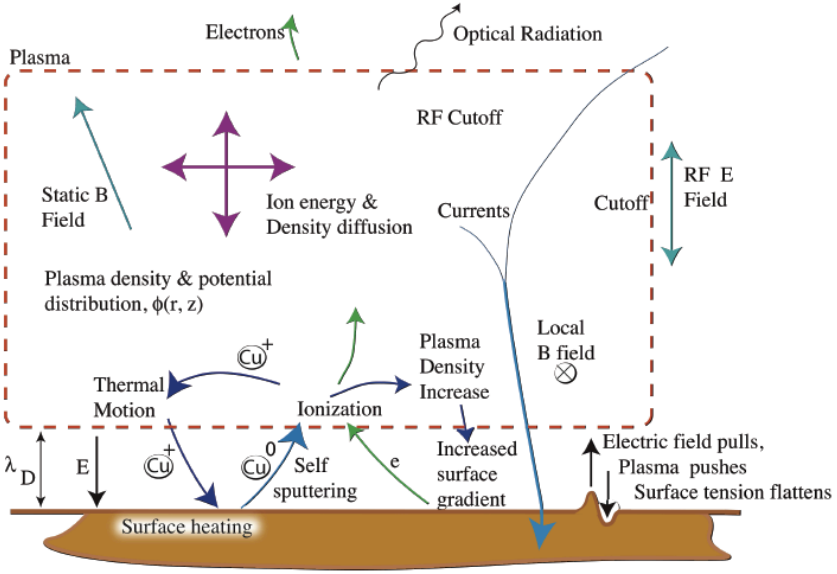
Evidence for some sparking in the coupler



SEM images of 201 MHz coupler.



Unipolar arc?



4-Season cavity (Muons Inc., LANL)

- modular pillbox with replacable end walls
- designed for both vacuum and high-pressure
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HPRF cavity beam test (Yonehara, WG3)

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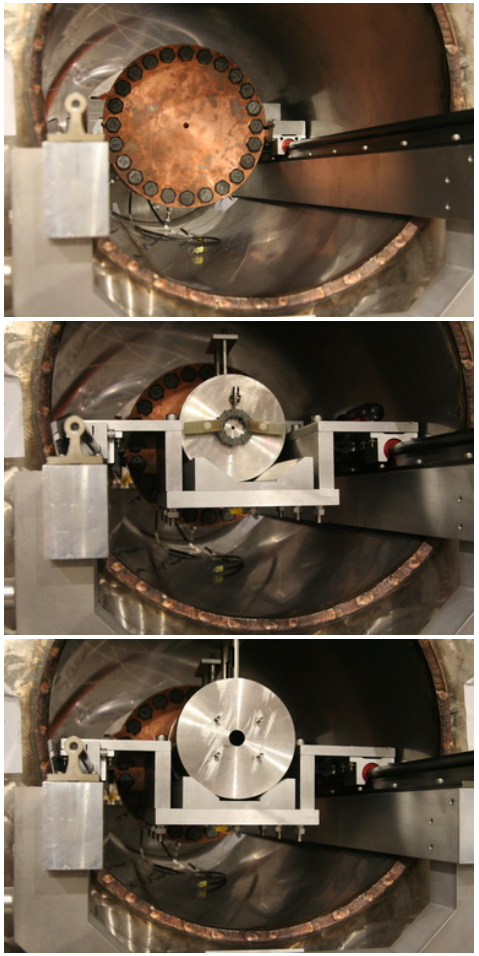

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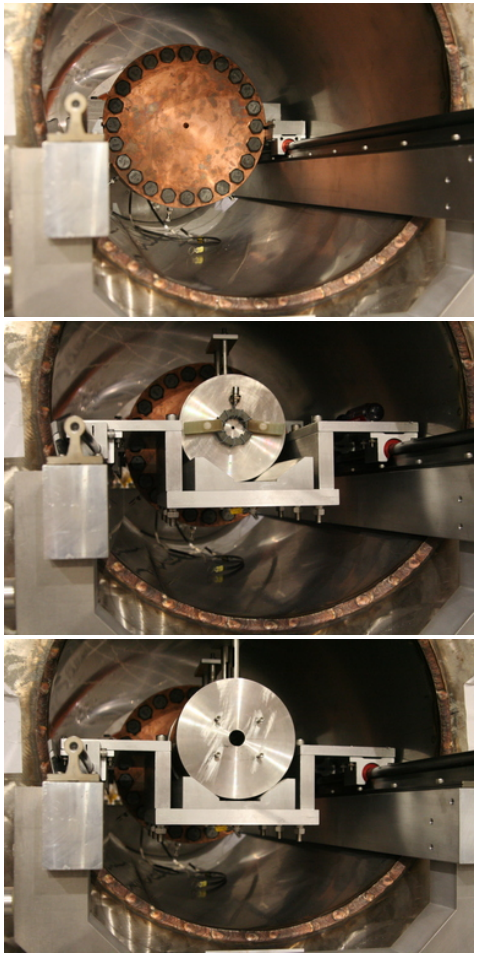

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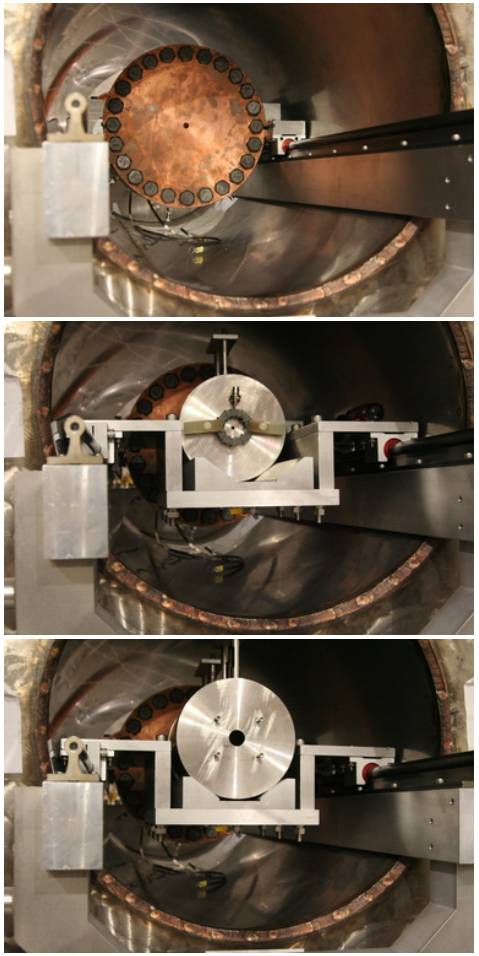

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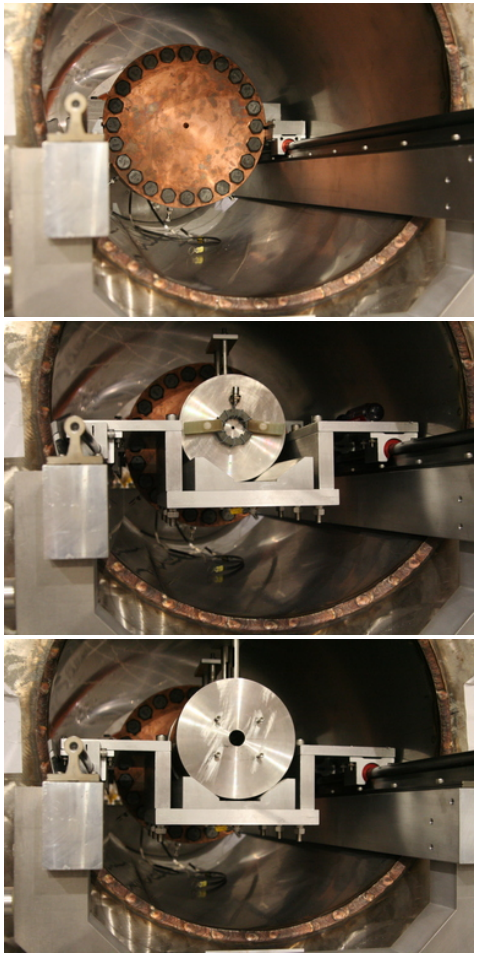

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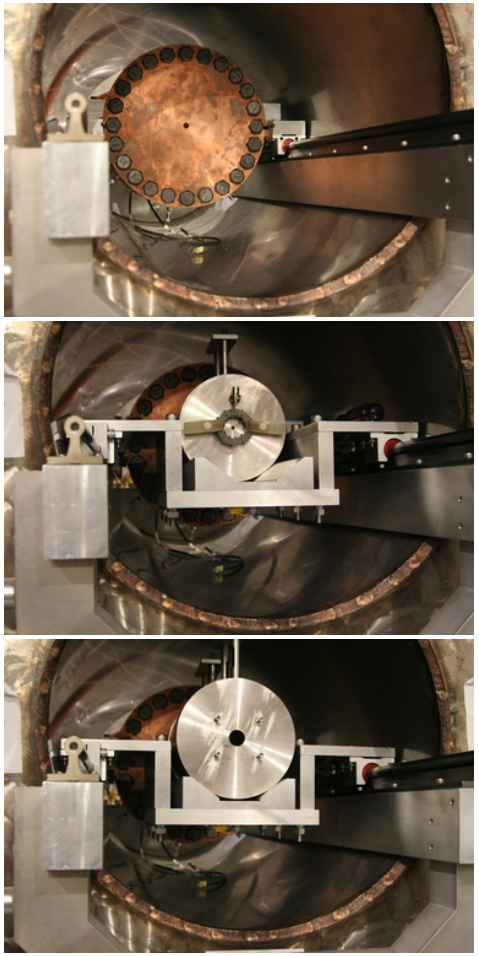

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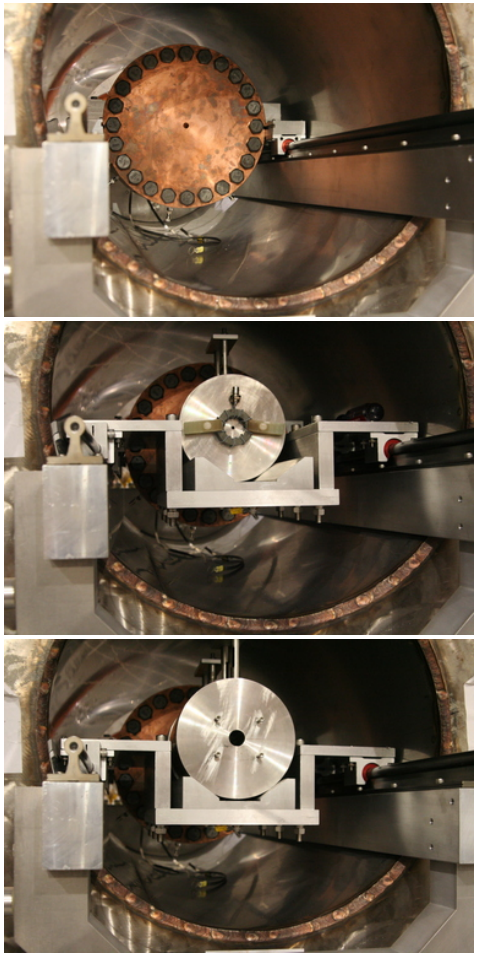

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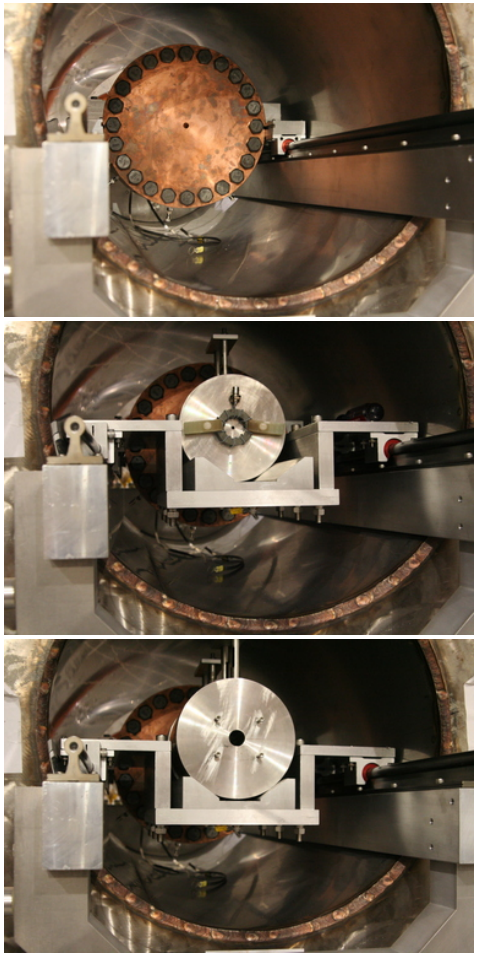
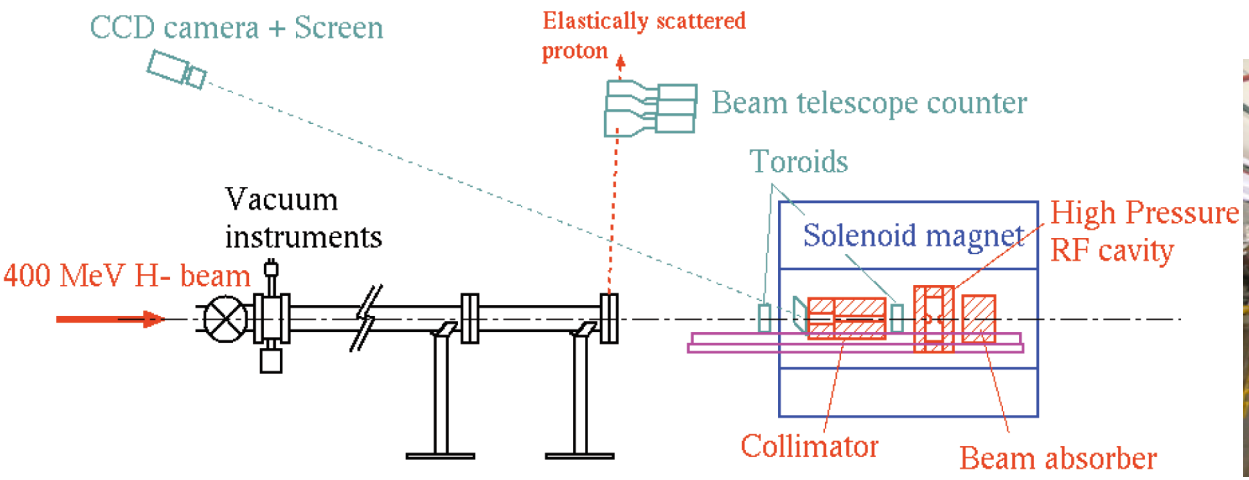
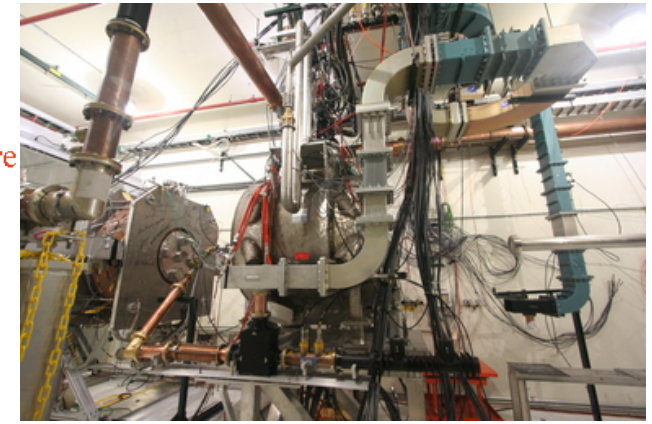
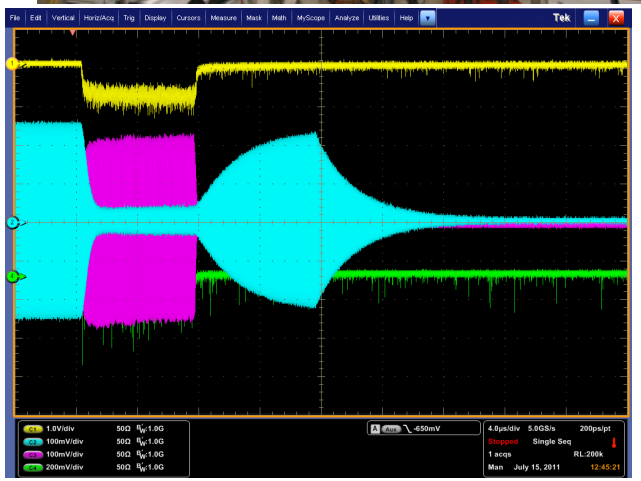


HPRF Beam Test







- 500 psi N2
- 500, 800 and 950 psi H2
- 8μs beam, 2 intensities
- dopant test (N2, SF6) next week
- analysis in progress

Beam

- First beam pulse to "emittance absorber" (beam stop 2) Feb 28
- Intensity about 1.8×10^{12} protons/pulse at 1 pulse/min
- Phosphor screen upstream of collimator to measure beam spot
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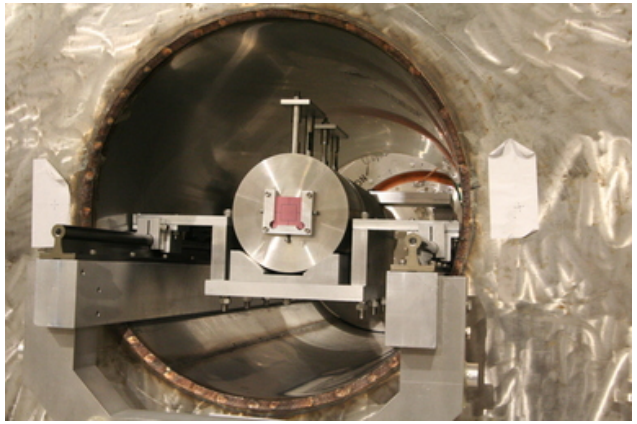

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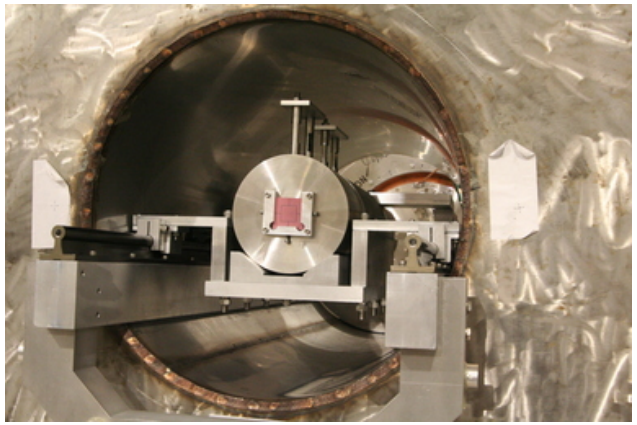

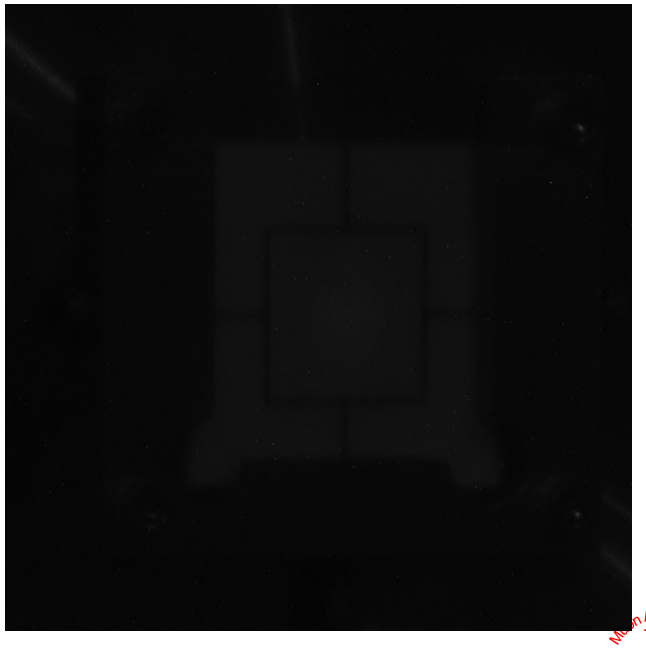

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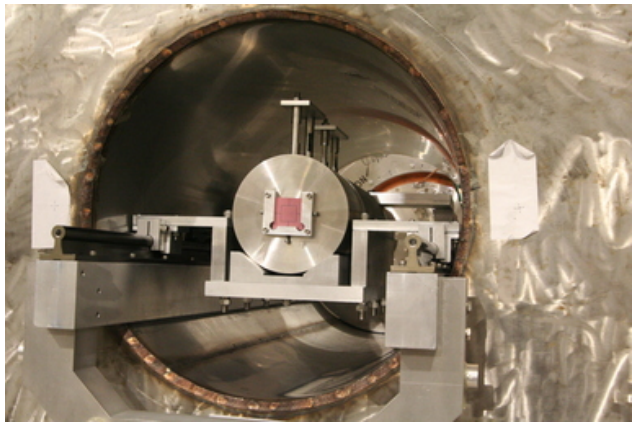

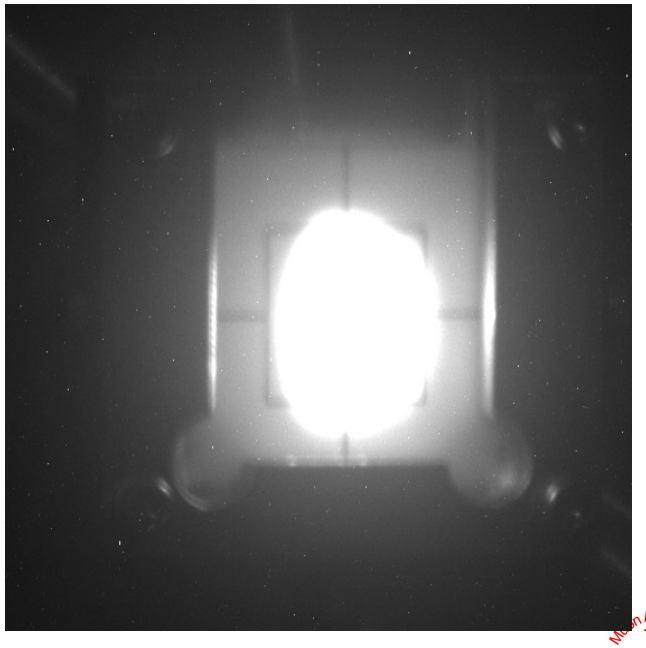

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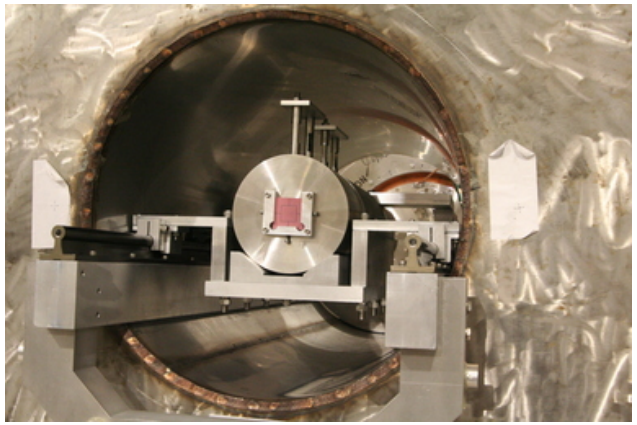

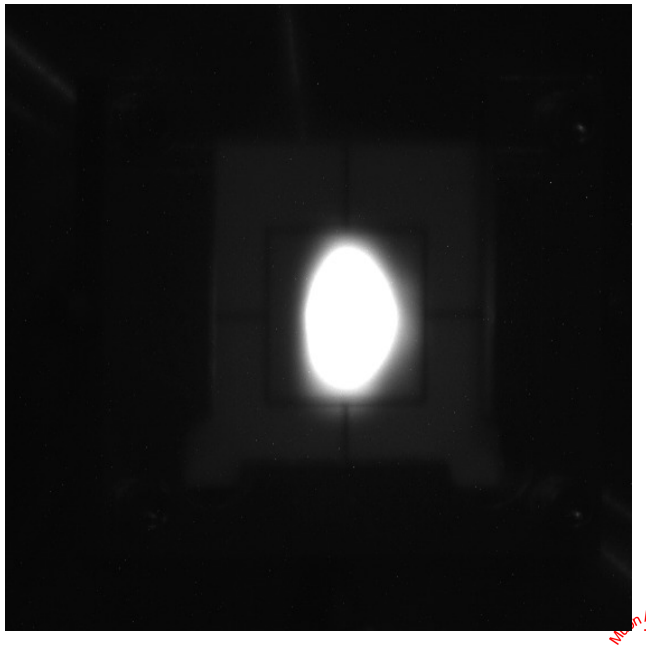

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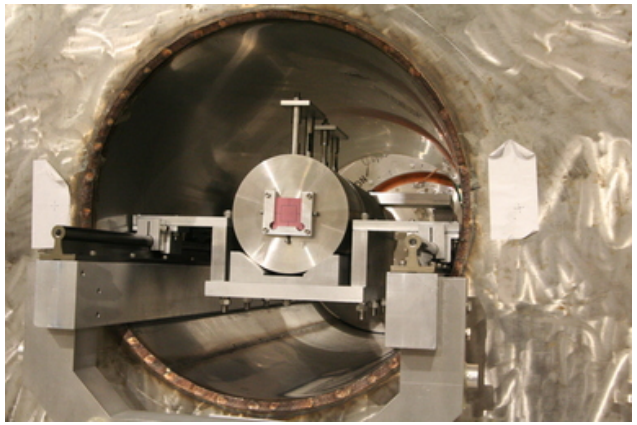

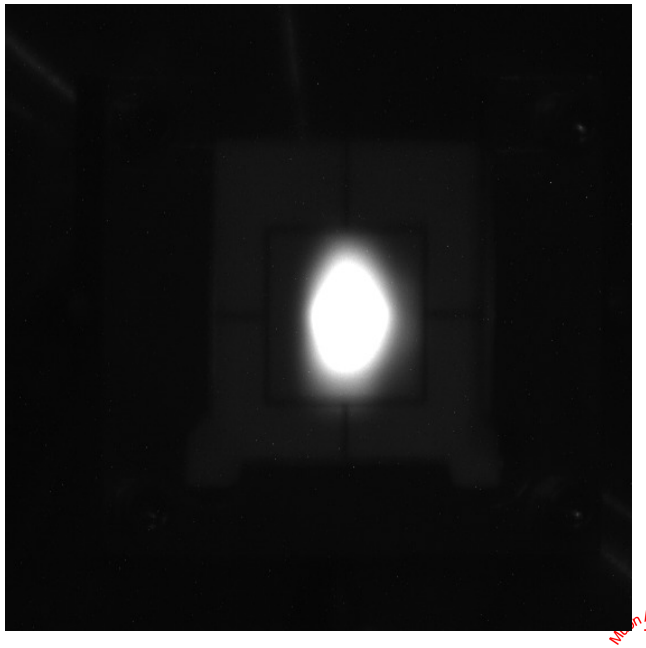

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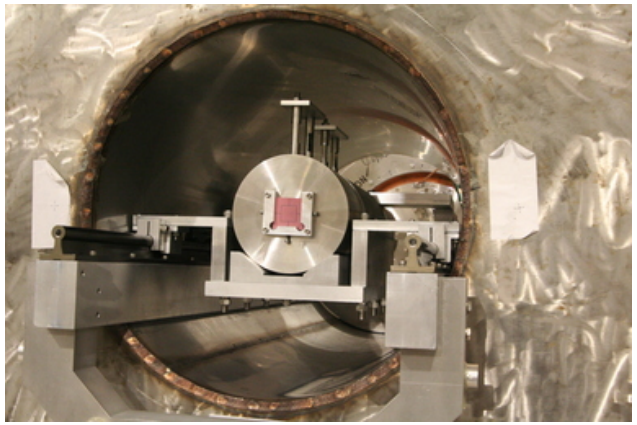

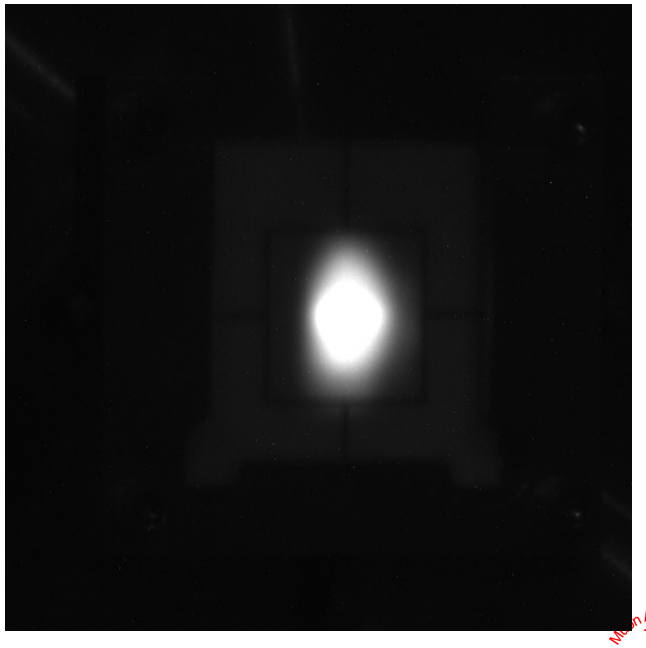

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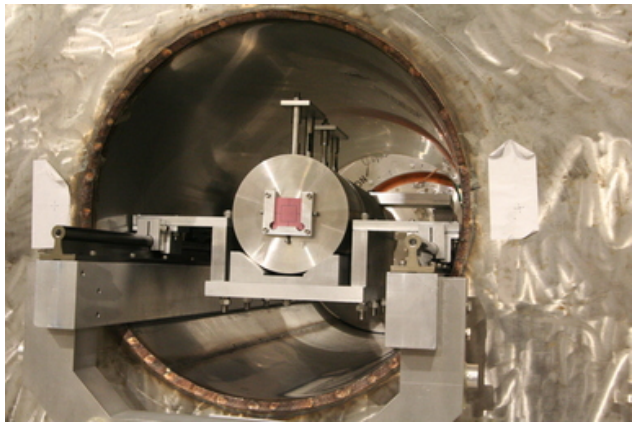

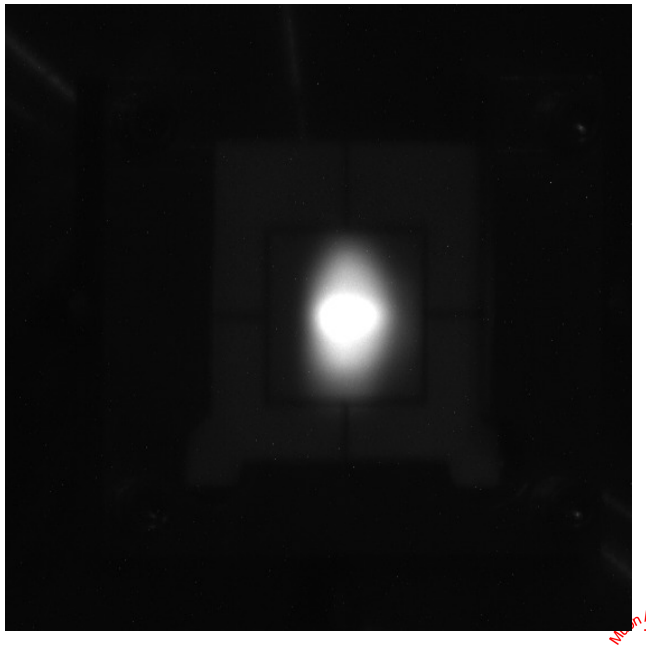

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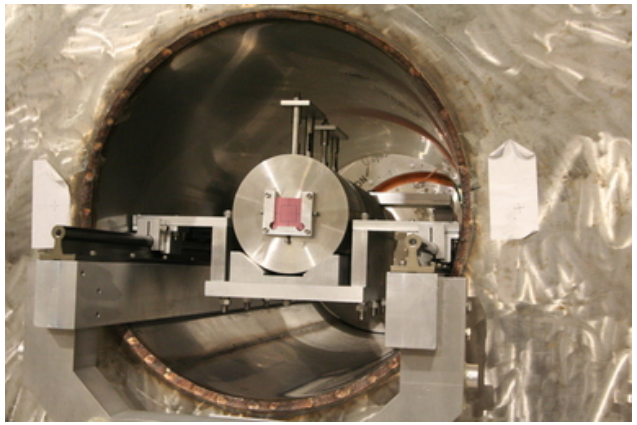

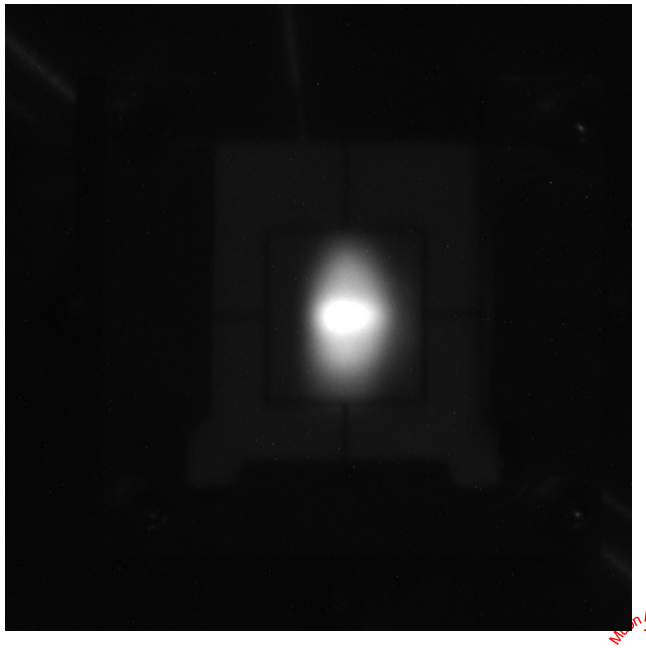

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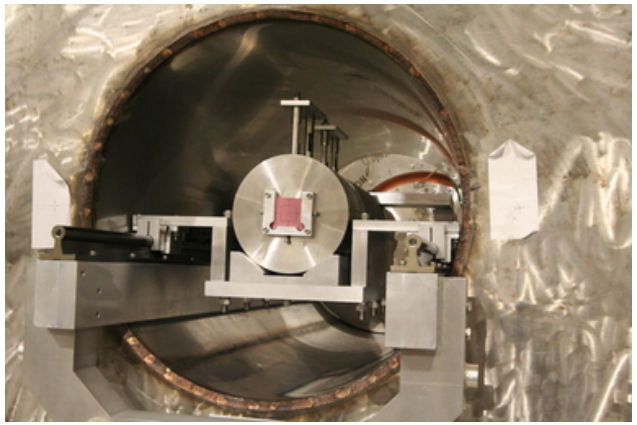

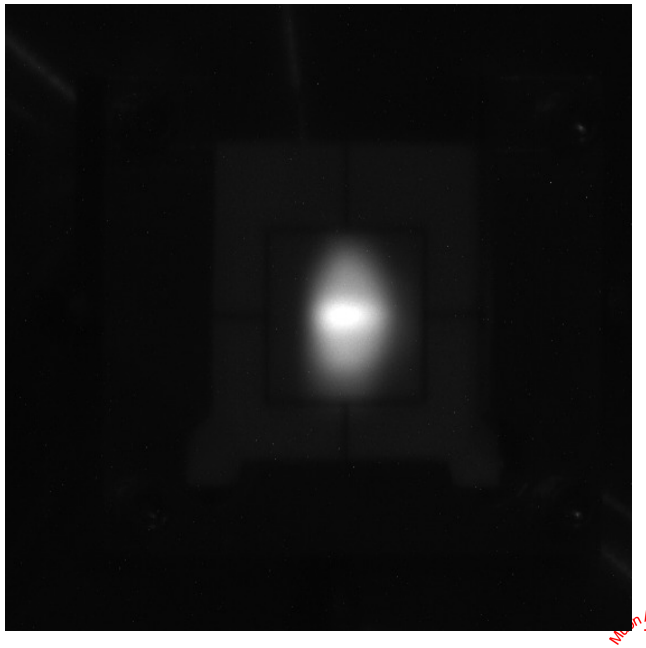

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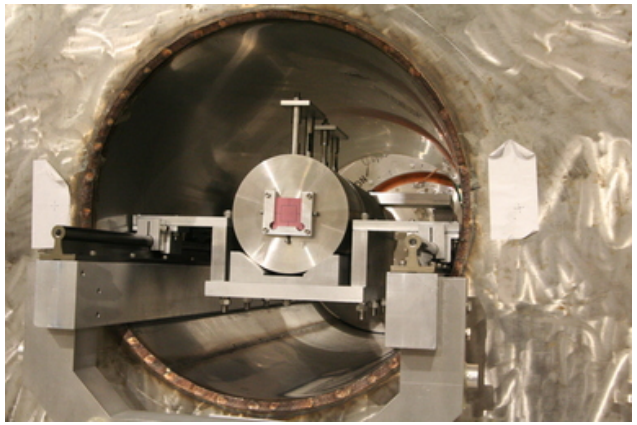

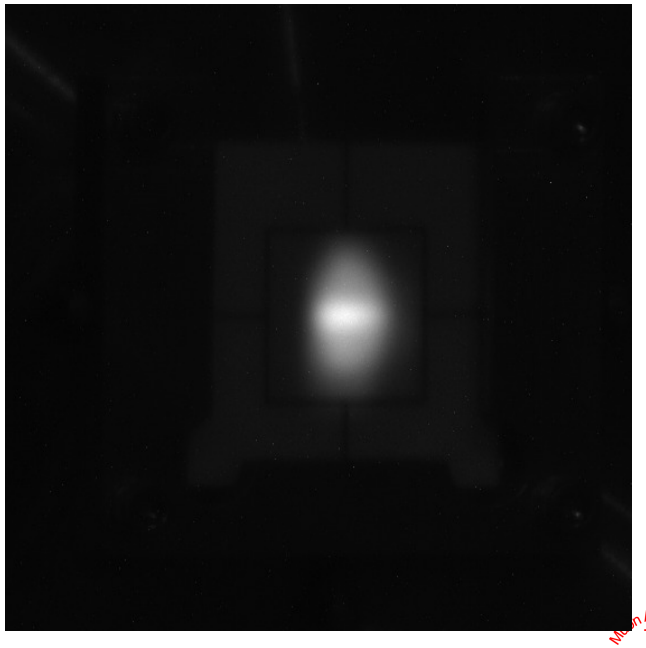

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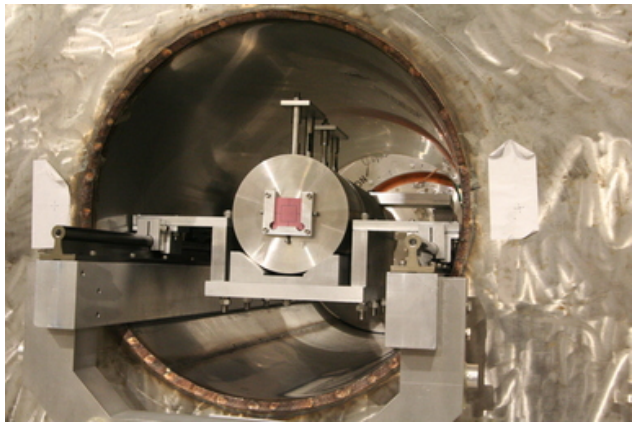

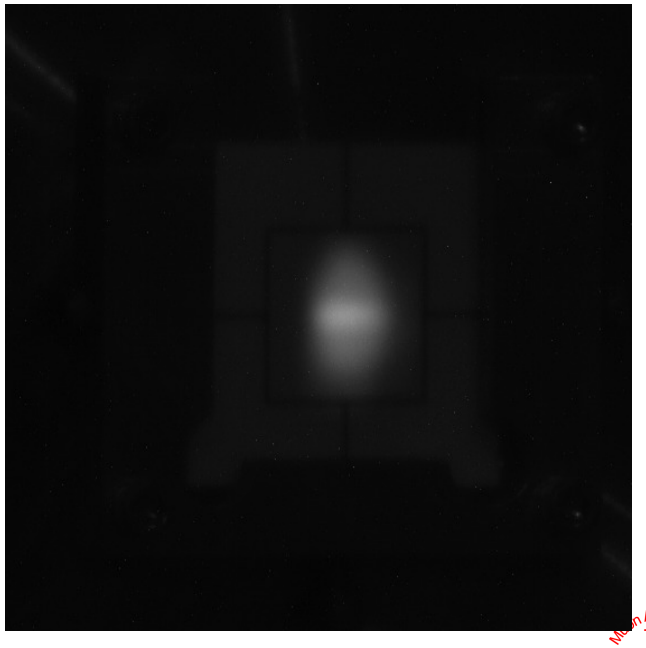

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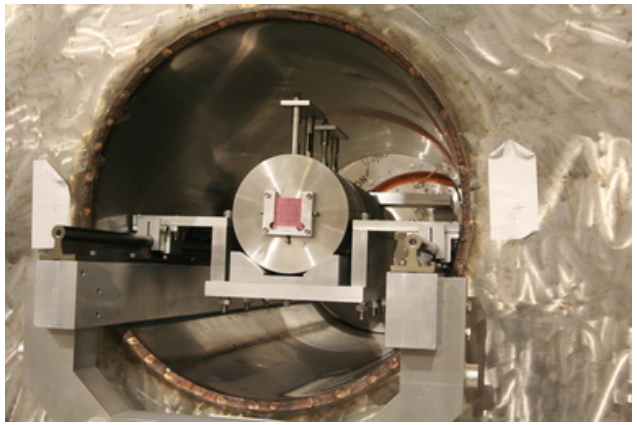

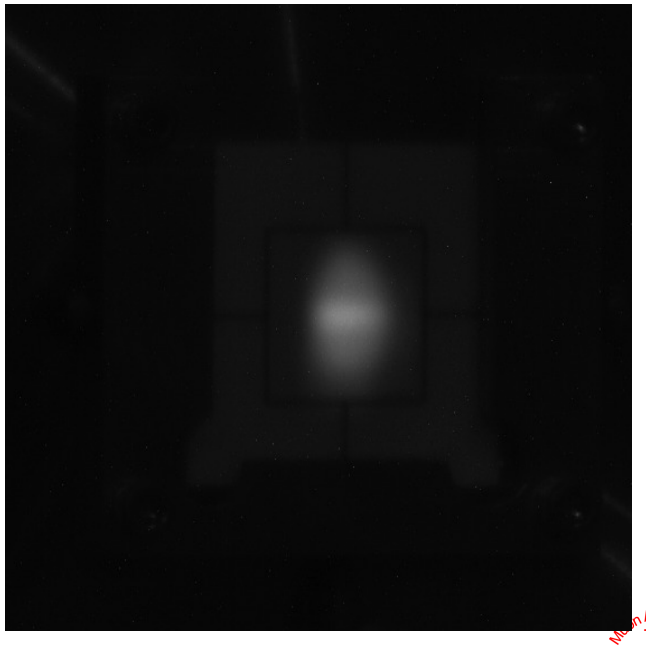

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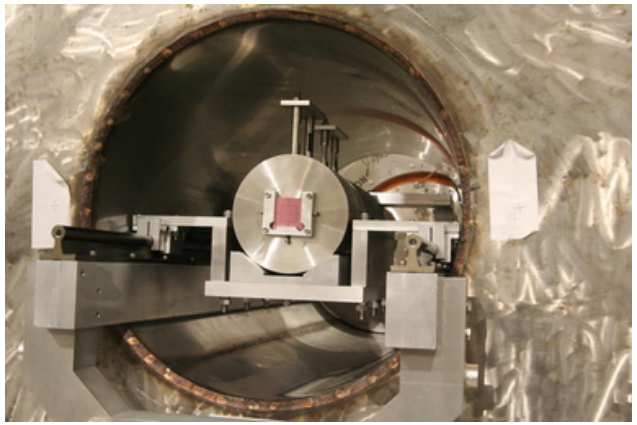
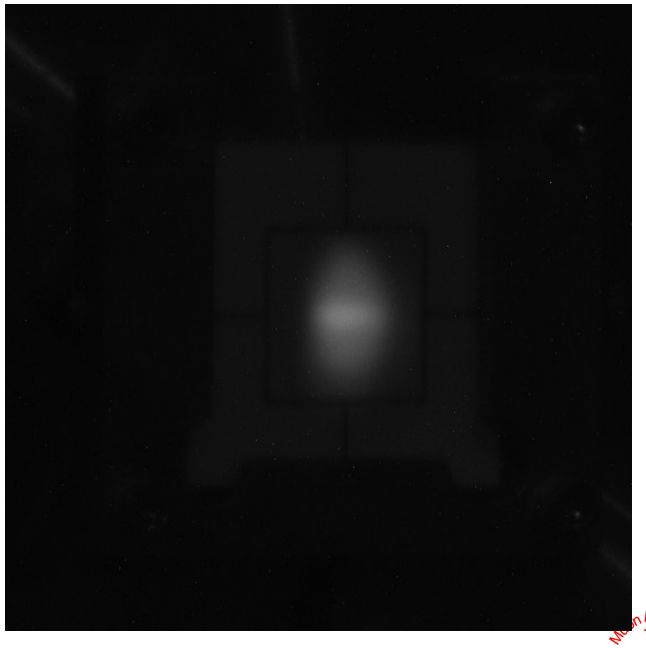
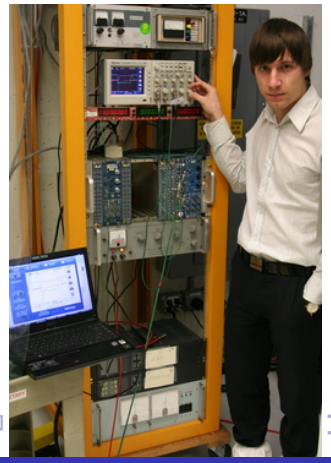




Students at the MTA (past year)

- 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) – magnetic field mapping



MTA Schedule and Outlook

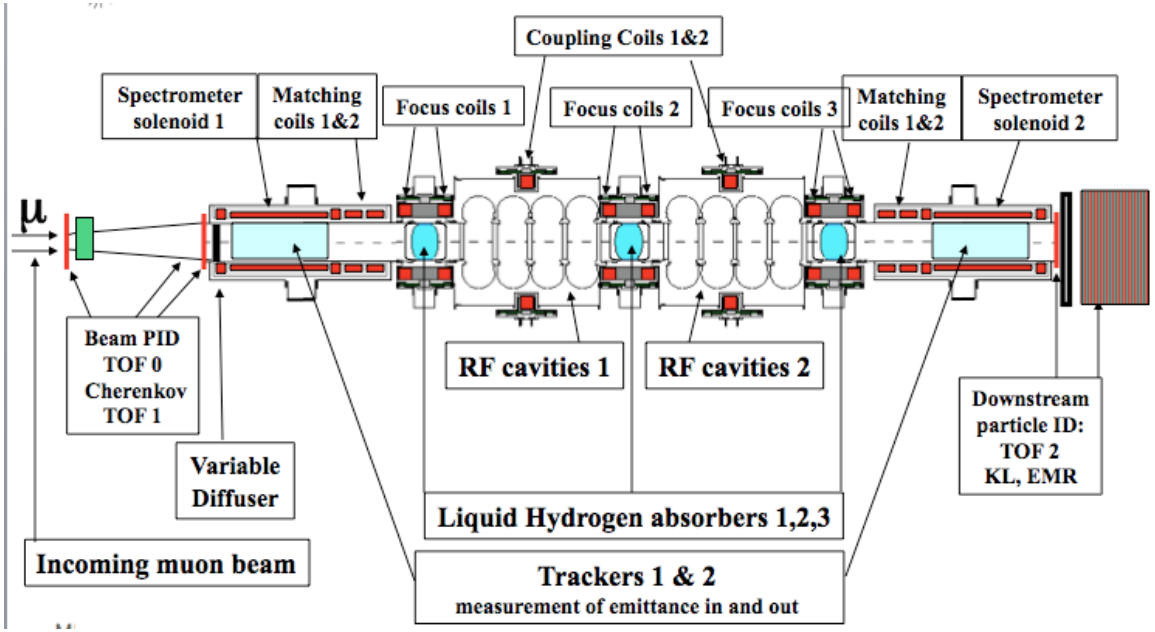
- Experimental program
  - HPRF cavity in beam – first test to be finished next week
  - 805 MHz pillbox cavity with Be buttons – Aug 2011
  - 201 MHz cavity coupler repair and operation in large B
  - further HPRF beam tests as needed – by Mar 2012
  - rectangular box cavity with B $\parallel$ E
  - more B $\perp$ E rectangular box cavity tests?
  - 4-season cavity – Aug 2011
  - ALD cavity – under discussion
- Infrastructure
  - beam commissioning complete
  - cryo upgrade in progress
  - magnet field mapping soon
  - 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 2 years

MICE

- Ionization cooling has many challenges in practice
- Need demonstration with real hardware to establish
  - components can be engineered
  - performance can be accurately predicted

MICE concept

- Beamline to deliver 140-240 MeV/c muons
- Track one μ at a time through one cell of cooling lattice (FSII)
- Momentum measurement before and after the cooling hardware
- Particle ID to remove decays and beam contamination
- Form muon "bunch" in software

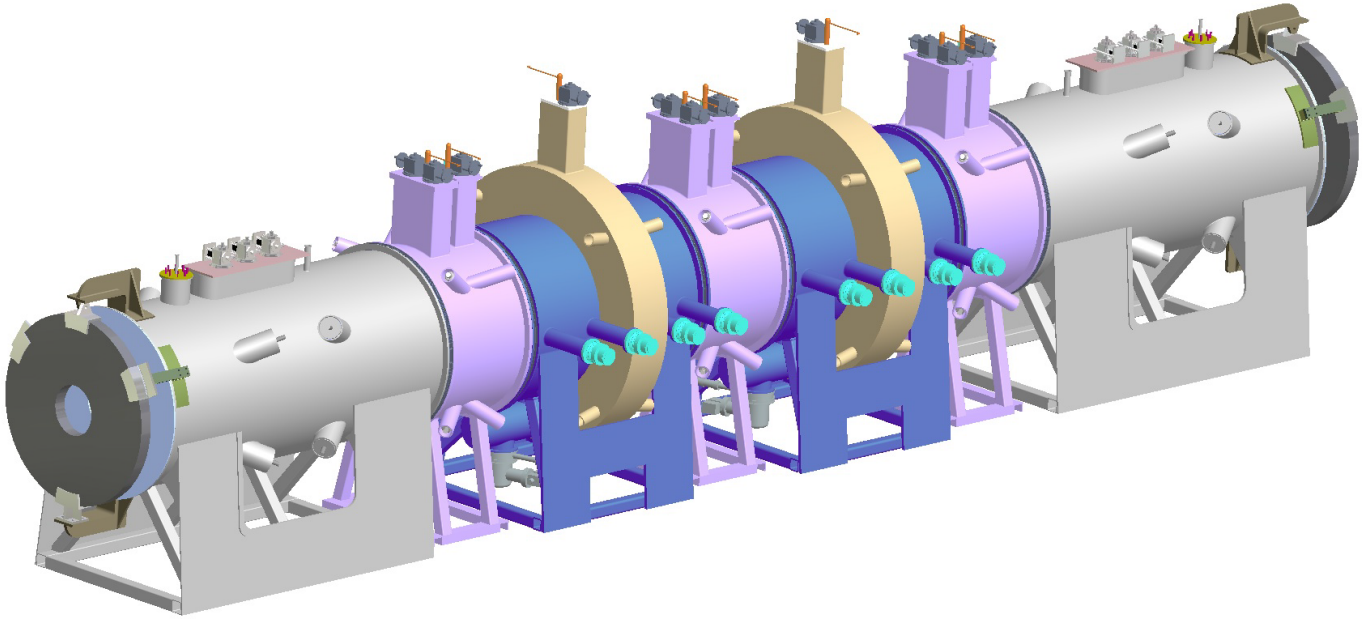


Requires

- High purity muon beam, low-mass trackers + PID detectors

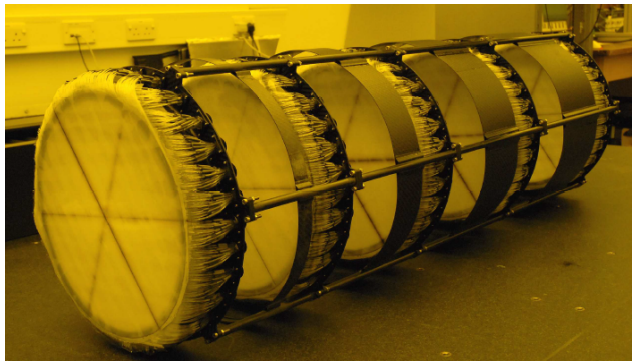
MICE accelerator hardware

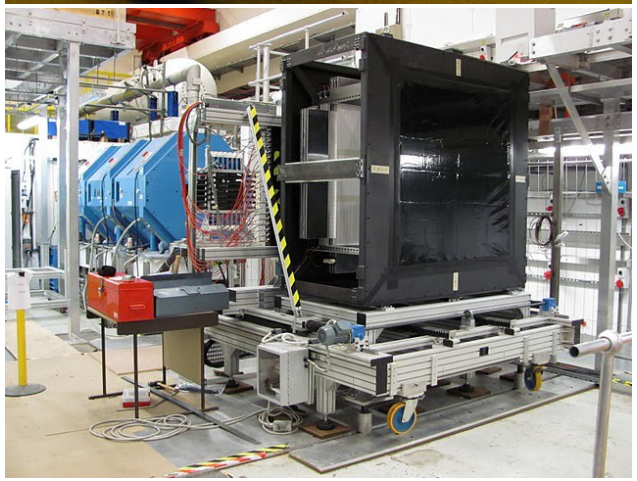
- 3 absorber + focus coil (AFC) modules
  expected delivery this year
- 2 rf cavity + coupling coil (RFCC) modules
  cavities to be completed this year, CC under construction (Zisman, WG3)
- 2 spectrometer modules for trackers and matching (under repair)
- G. Hanson (WG3)



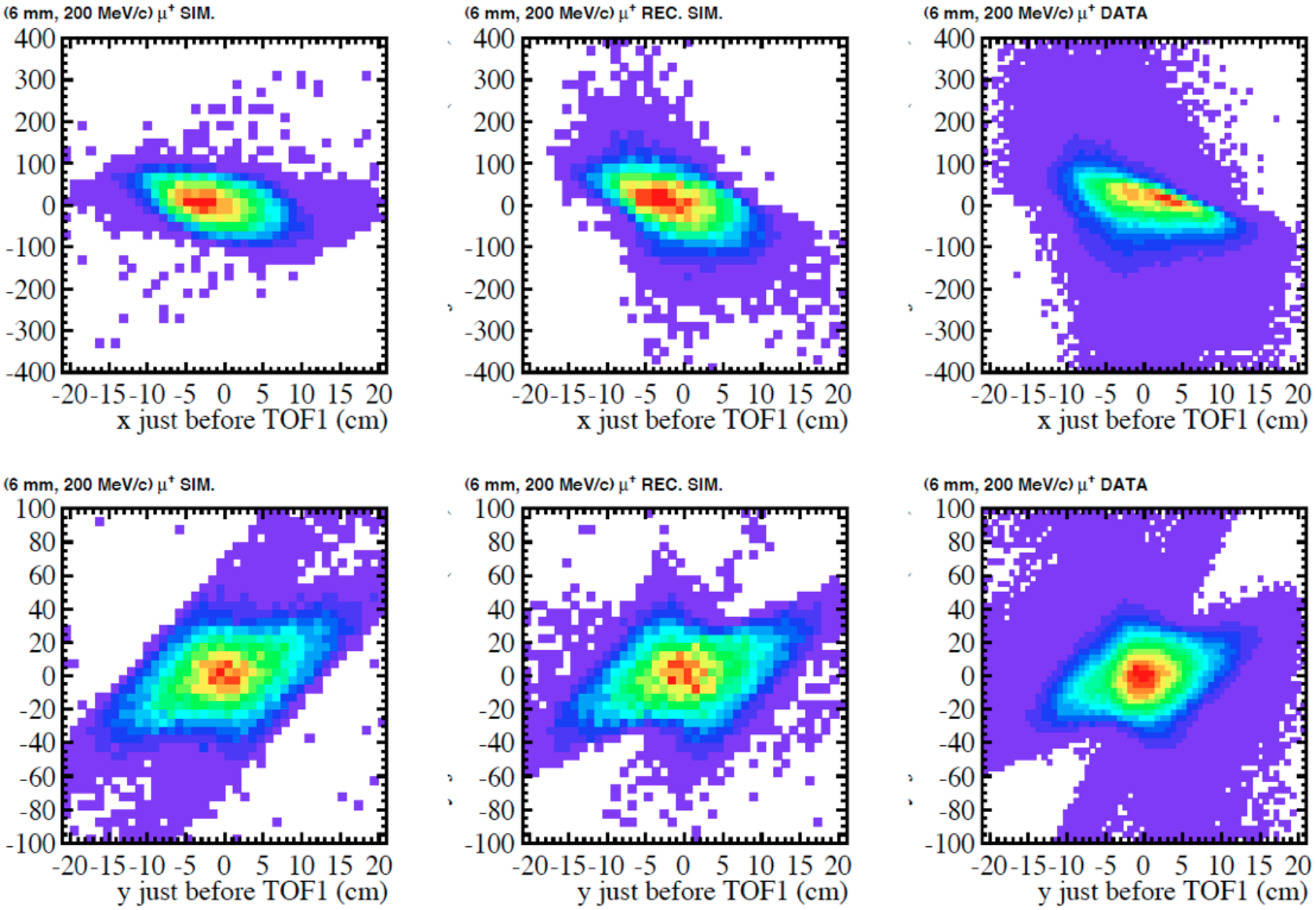
MICE detectors

- 2 SciFi trackers ready
- 3 TOF walls commissioned in Step I, upgraded afterward
- 2 aerogel CKOVs commissioned
- KL commissioned, EMR partially installed





Phase space from TOF (Rayner)



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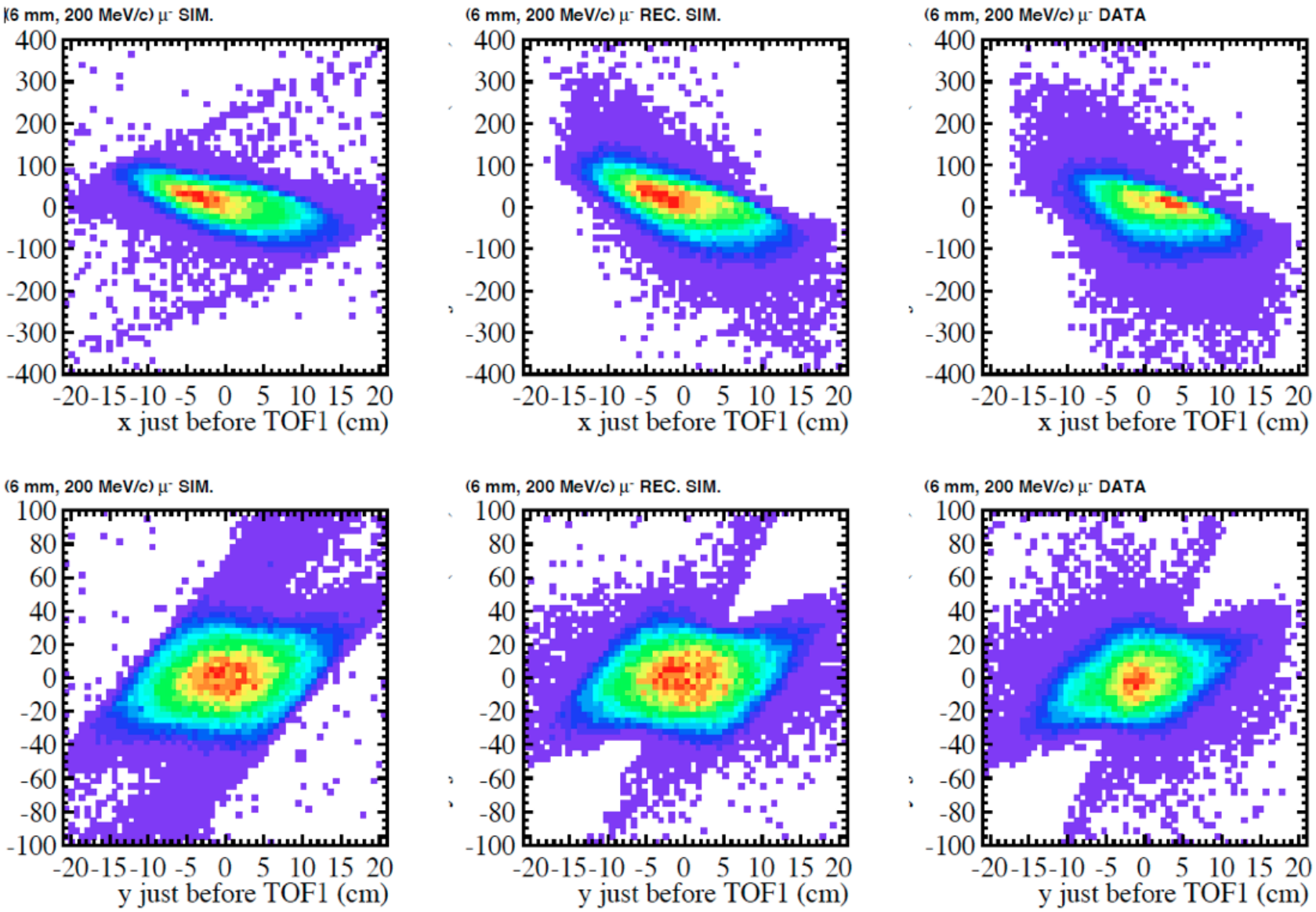
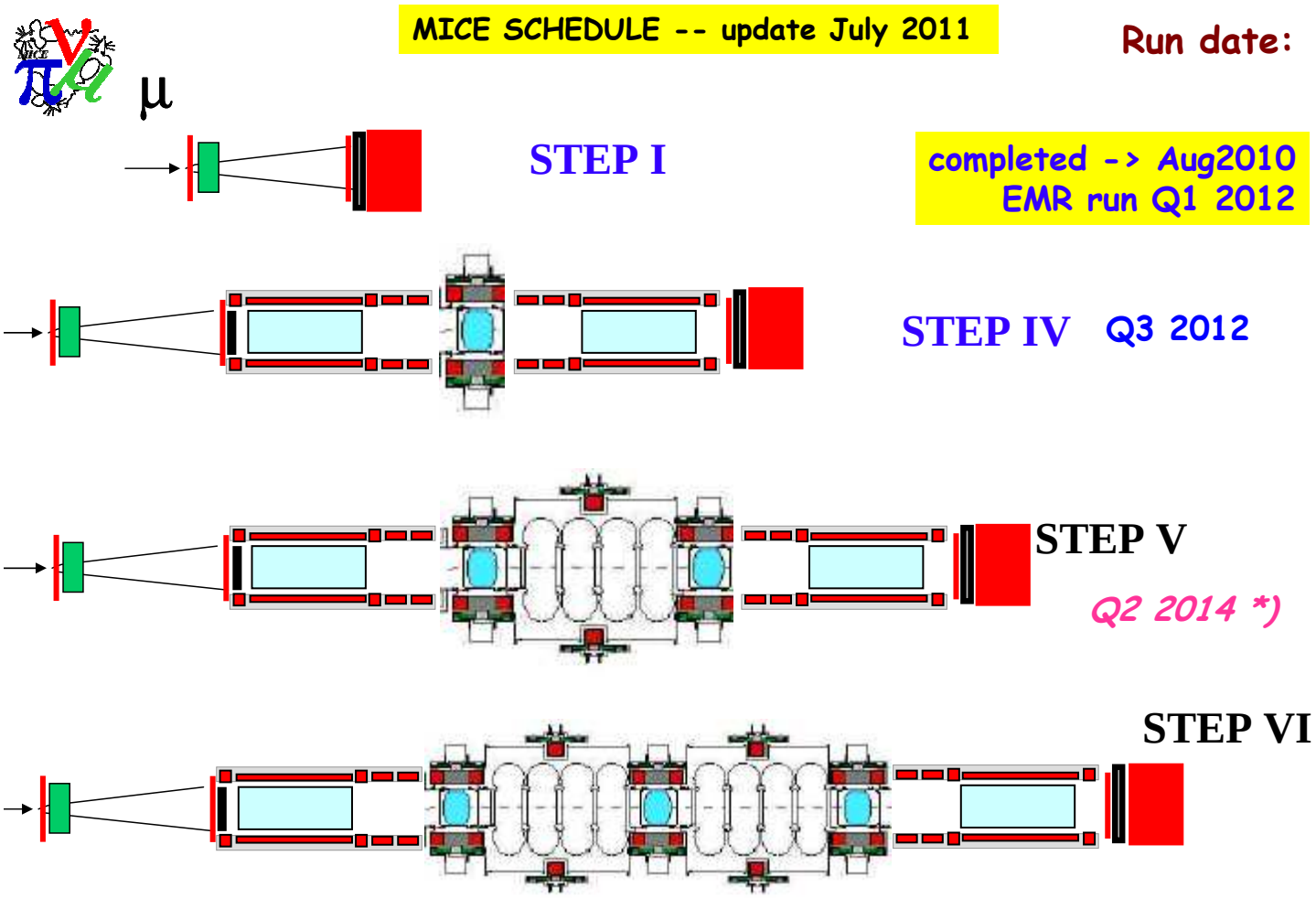


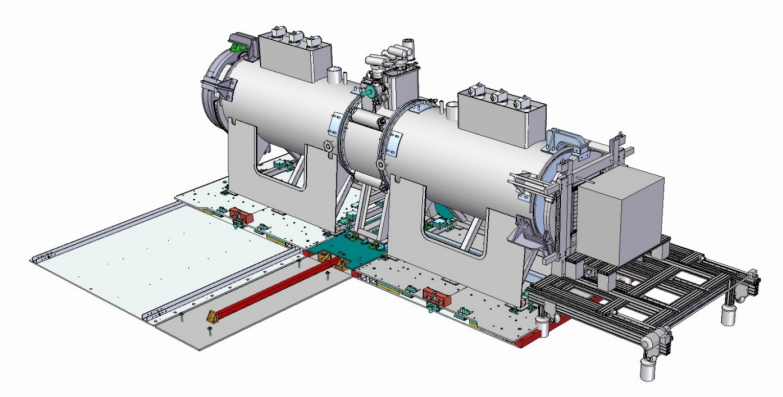
MICE schedule



*) target date, necessary to run step V before long ISIS shut-down Aug.2014-Feb.2015

Next steps

- Step IV: emittance measurement with trackers
- Step V: cooling measurement with RF
- Step VI: full period of cooling lattice



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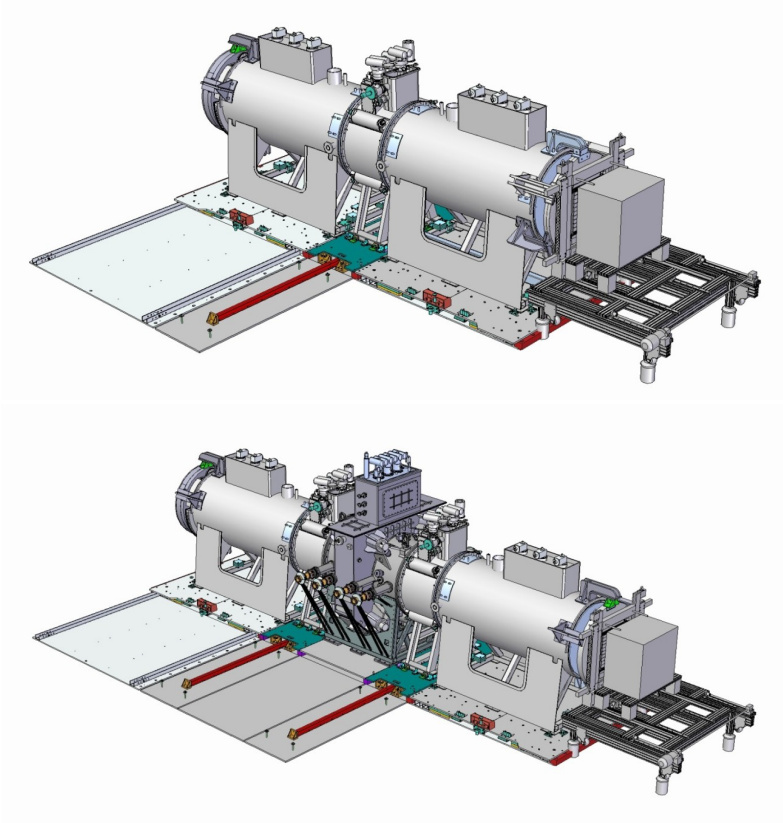

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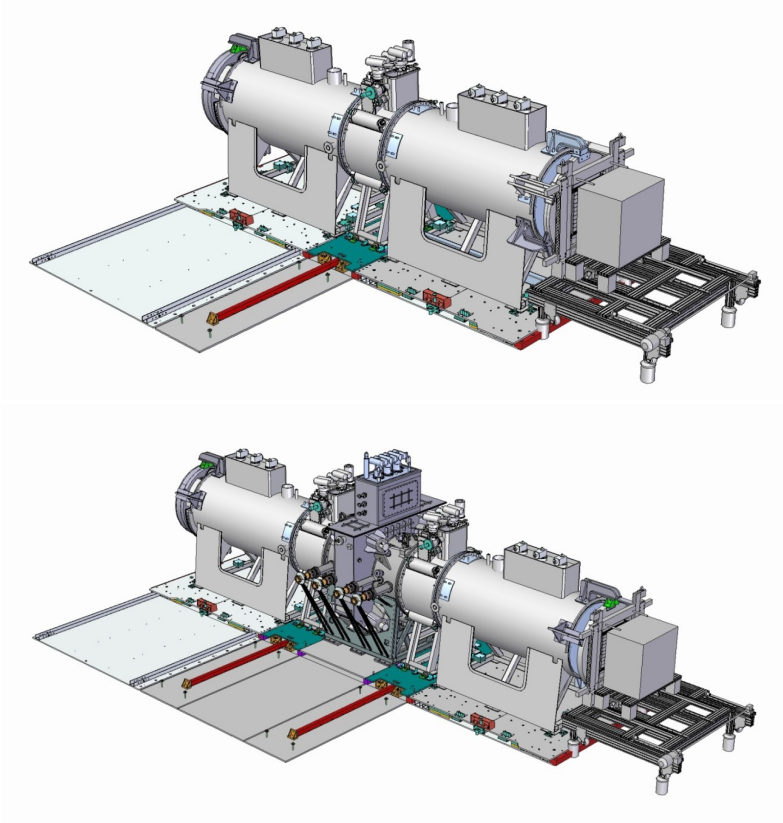

MICE outlook

- Step I complete
- Beamline magnets, target and instrumentation operational
- Magnets and absorbers under construction
- Tracking detectors ready
- PID detectors mostly commissioned (EMR in progress)
- Online and offline software developed
- Schedule under control
- 5 Ph. D.'s so far, 6 more expected this year
- Demonstrate ionization cooling within 3 years

Summary

- MICE and MuCool making steady progress
- On track for establishing practical ionization cooling technology in the next few years