RF Technologies for Ionization Cooling Channels

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COOL'15
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Ionization Cooling – Background

- *Overview of Muon Cooling* – Dan Kaplan, Monday
- *Status, Recent Results and Prospect of the International Muon Ionization Cooling Experiment (MICE)* – Chris Rogers, Tuesday
- *Affordable, Scalable, and Convincing 6-D Muon Cooling* – Rol Johnson, Tuesday
- *Study of Helical Cooling Channel for Intense Muon Source* – Katsuya Yonehara, Tuesday
- *Progress of Front End and HFOFO Snake* – Dave Neuffer, Thursday
- *End-to-End Design of 6D Muon Ionization Cooling* – Diktys Stratakis, Thursday

- Ionization cooling currently best method for cooling muon beam
- How does this work in practice?

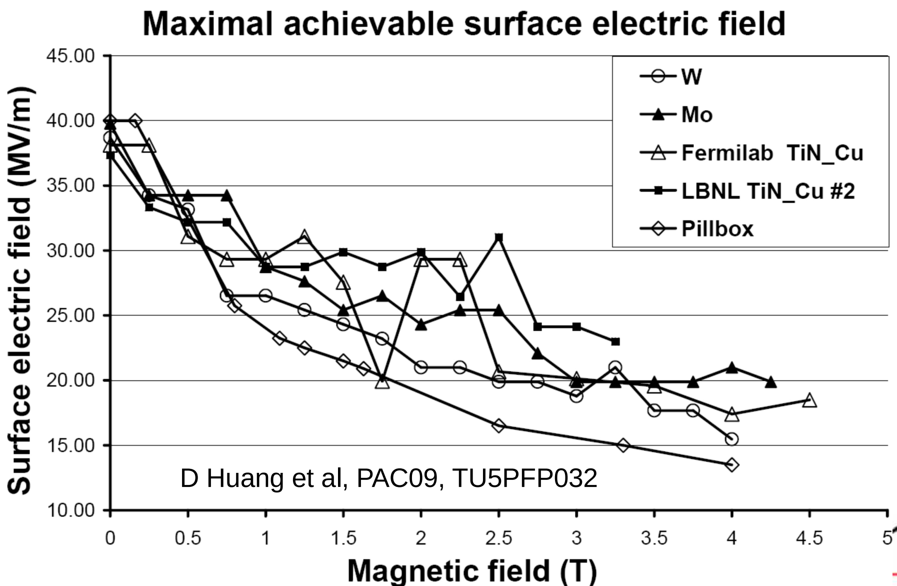
Part I –
Technology Development

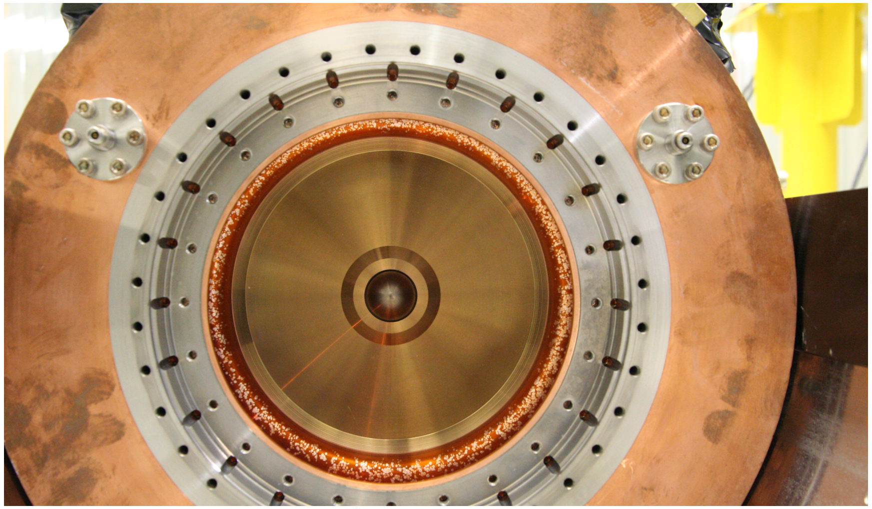
Ionization Cooling Requirements

- Cornerstones of ionization cooling:
  - Small beta function in cooling material → strong focusing
  - Replace lost beam momentum through use of RF cavities
- Result:
  - RF cavities in ~20 T at end of channel (less at beginning)
    - Note: Final cooling not considered

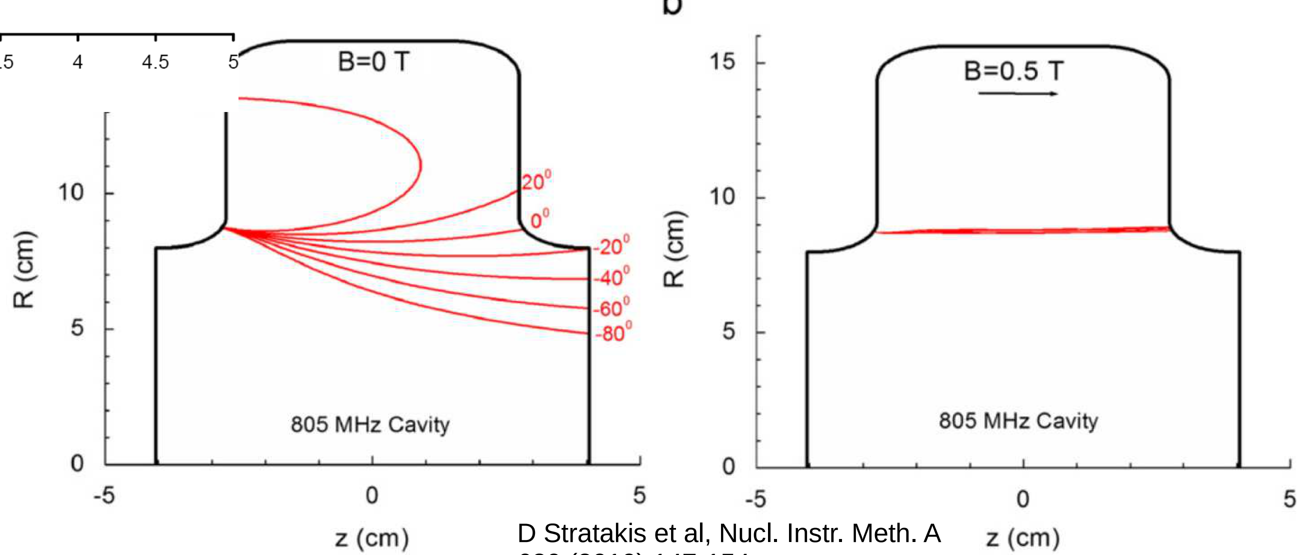
RF Cavities in Magnetic Fields

- Past data suggested external magnetic fields significantly reduce cavity maximum electric field





- Field emission beamlets focused by B-field
- Multiple cycles produce heating & damage
- How can this be circumvented?

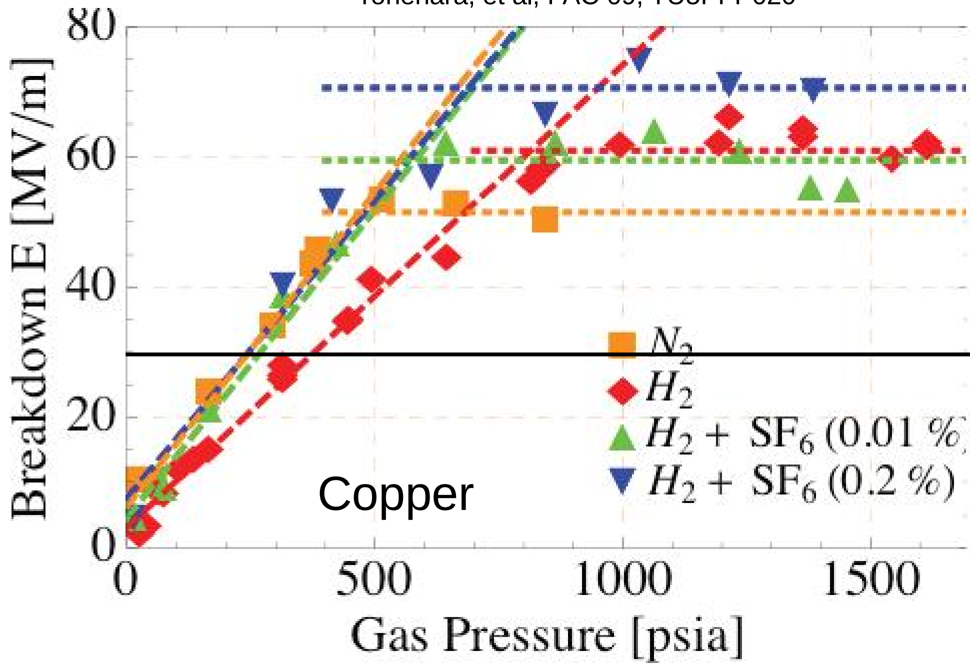


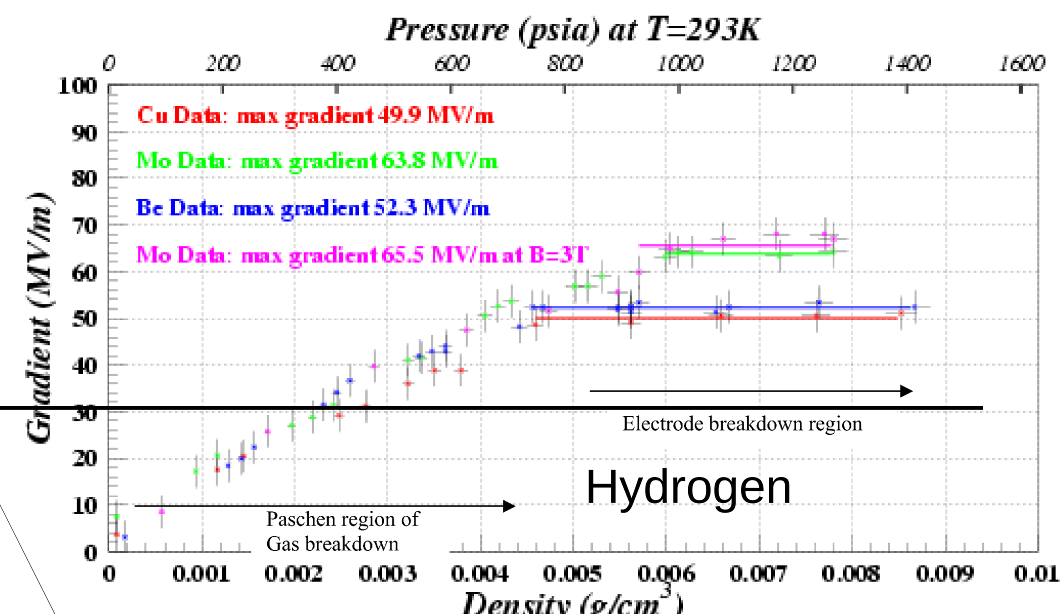
D Stratakis et al, Nucl. Instr. Meth. A 620 (2010) 147-154

A Solution

- Filling cavities with gas prevents breakdown
  - Electrons lose energy through collisions with gas molecules
    - Insufficient energy to traverse cavity and form arc
- Gas species and surface materials have been studied

Yonehara, et al, PAC 09, TU5PFP020



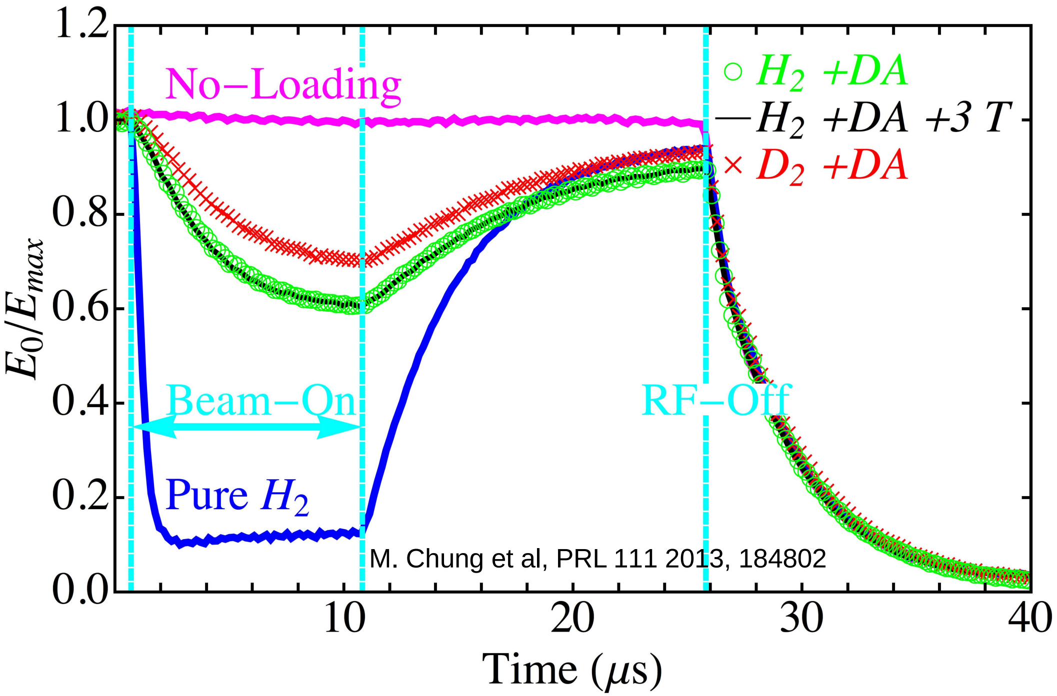


Hanlet, et al, EPAC 2006, TUPCH147

Maximum cooling channel design

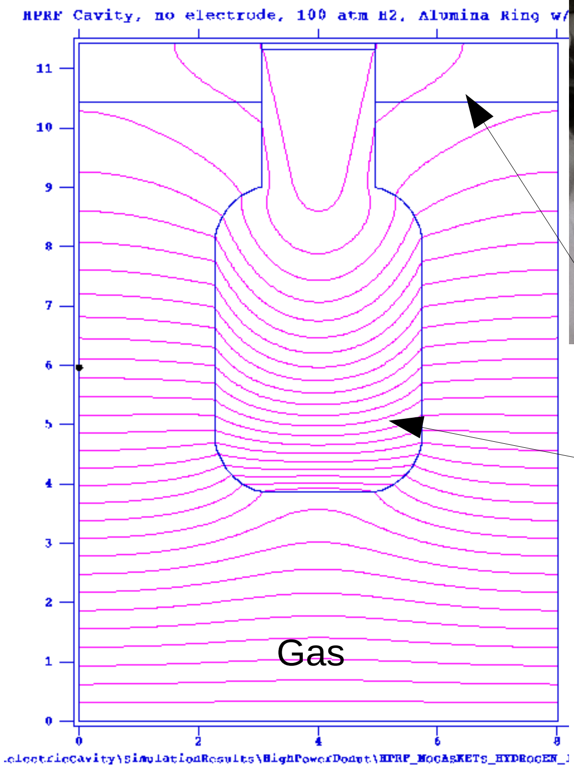
What About the Beam?

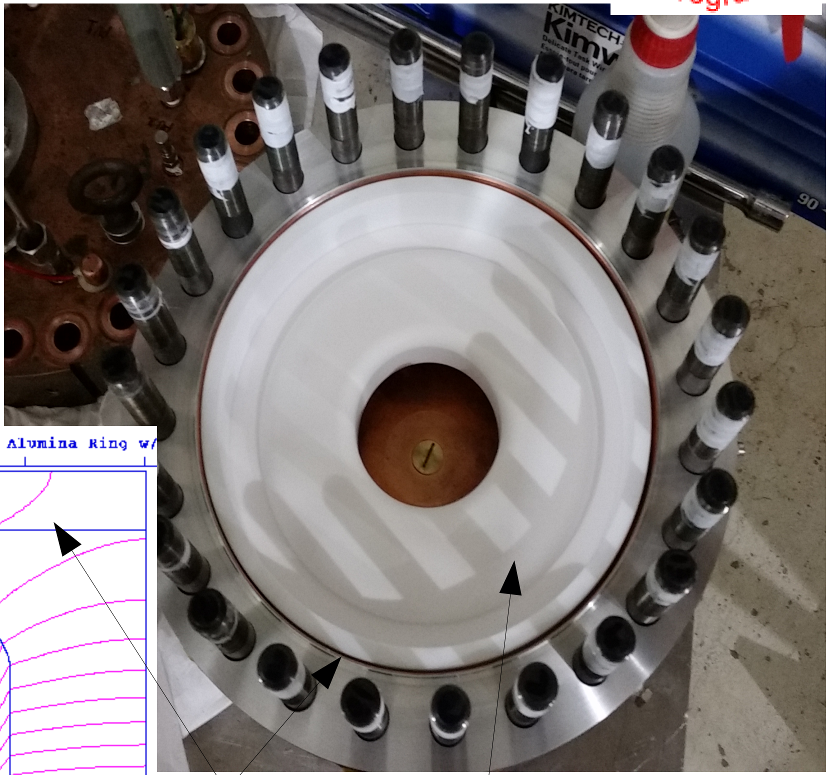
- Won't the beam-induced plasma immediately short the cavity?
  - No!
- Plasma dissipates RF power → "plasma loading"
- Experiment performed to quantify extent of plasma loading
- Plasma processes & dependencies measured
  - Per particle energy dissipation
  - Electron-ion recombination
  - Electron-electronegative molecule attachment
  - Ion-ion "recombination"
- Indicates high pressure gas filled RF cavities feasible for ionization cooling channels



Moving Toward a Prototype

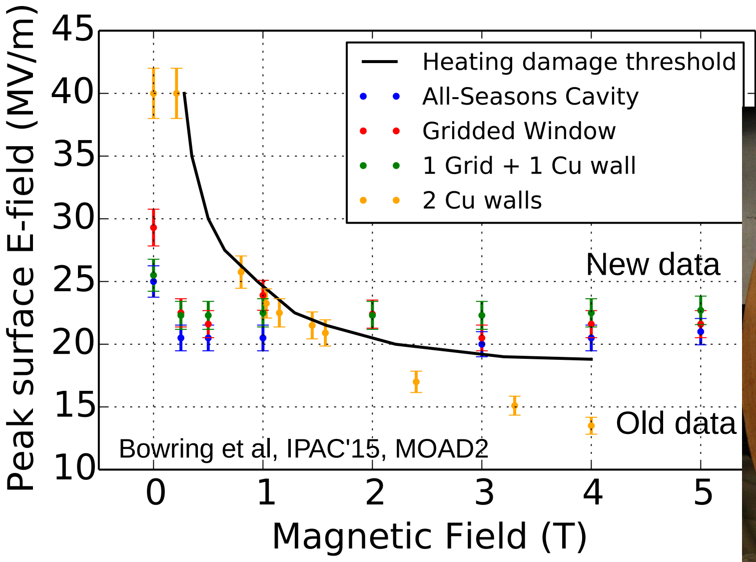
- RF cavities operate within high field solenoid magnet bores in one cooling channel design
  - Superconducting magnets have small bores
- Two options to shrink cavities:
  1) Make reentrant
  2) Increase dielectric constant
- Option 2 can be investigated with existing high pressure test cell
  - Loss of material dictates power requirements
  - Dielectric strength dictates max. E field
- First high power data collected
- Beam test planned end 2015

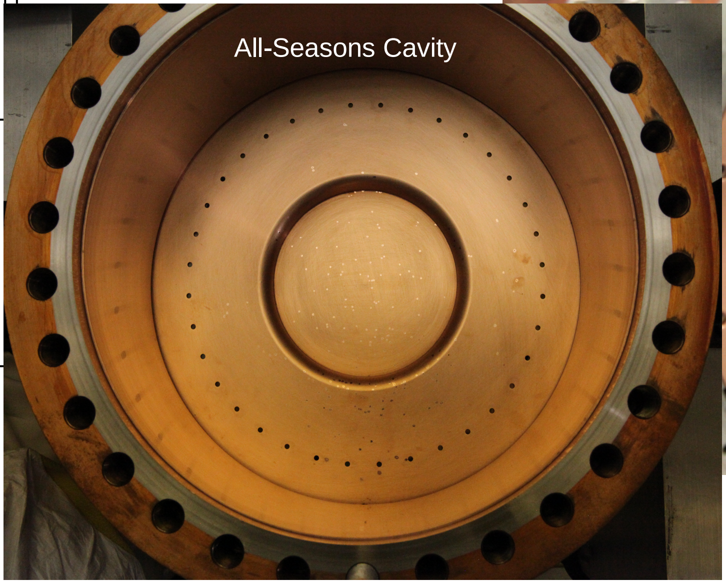


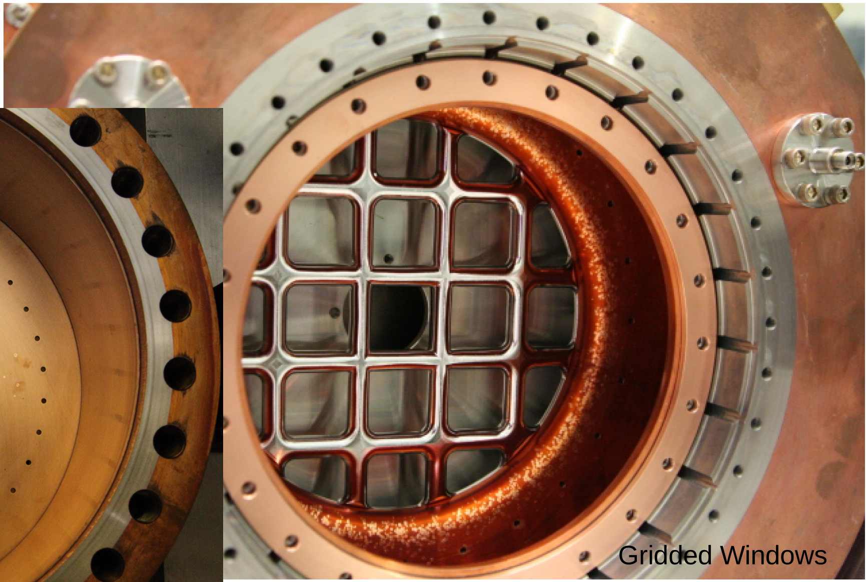


How Can We Make Vacuum Cavities Work?

- More recent results indicate designs/techniques exist to mitigate breakdown in vacuum cavities in external magnetic fields
- Cavity length → minimize electron impact energy (All-Seasons Cavity)
- Gridded window → allow electron beamlet to exit cavity volume (Pillbox Cavity)
- Electropolishing → minimize field emission (MICE Cavity)

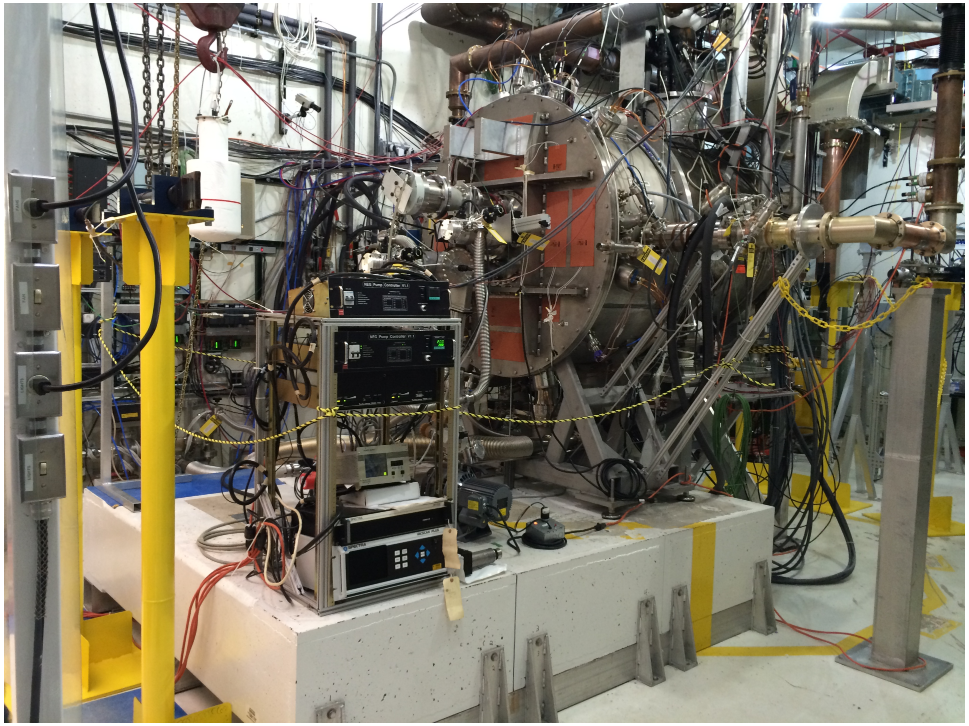


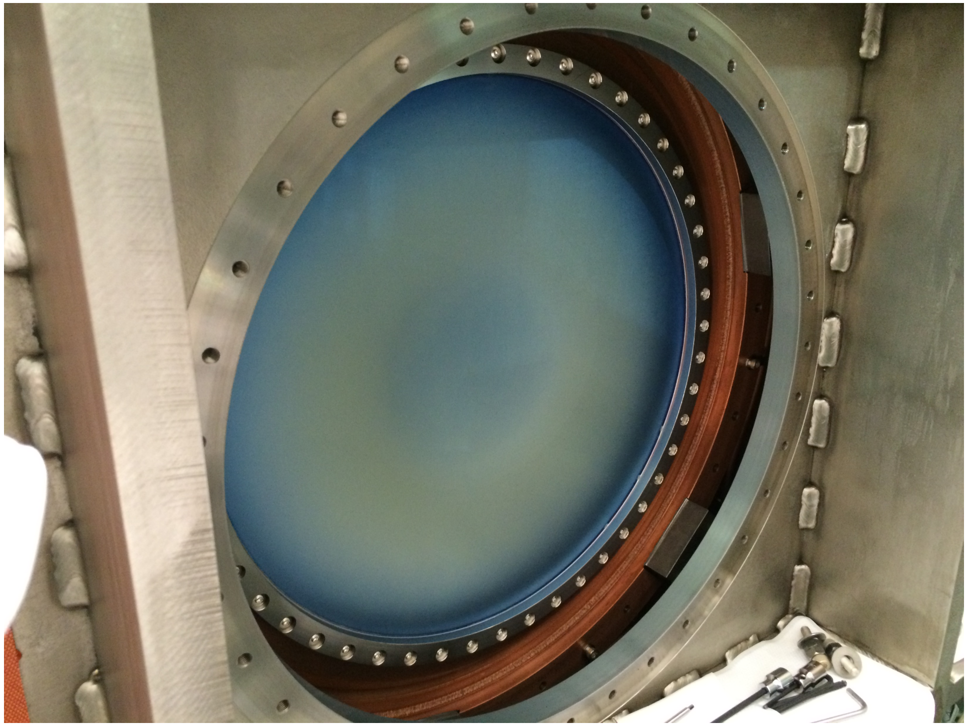




201 MHz MICE Cavity

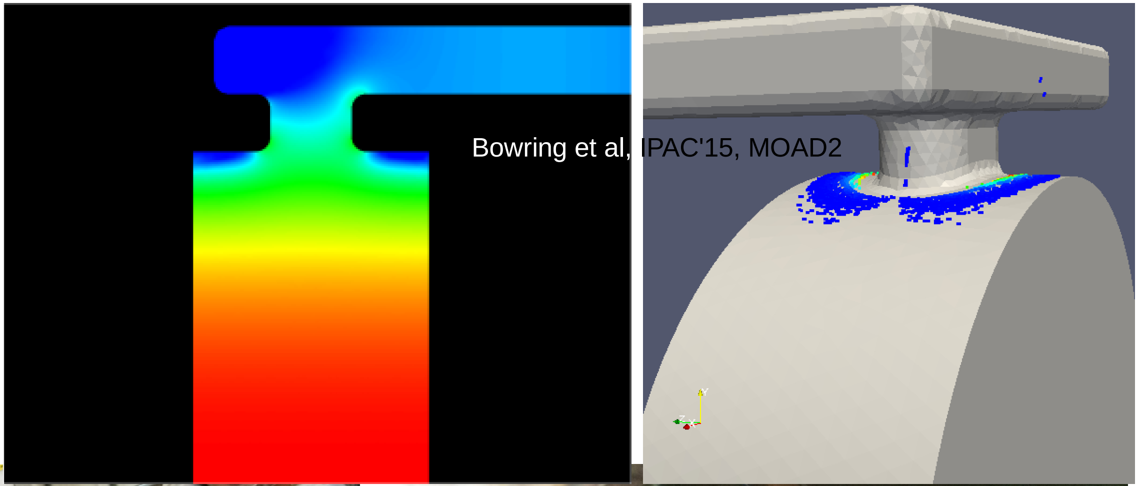
- SRF techniques employed
  - Electropolished
  - Assembled in clean room environment
- Commissioned Be windows to MICE specification (10.3 MV/m) with no sparks in both B=0 & B≠0
- Cavity ran with Be windows up to 14.5 MV/m with B≠0, limited by RF source power

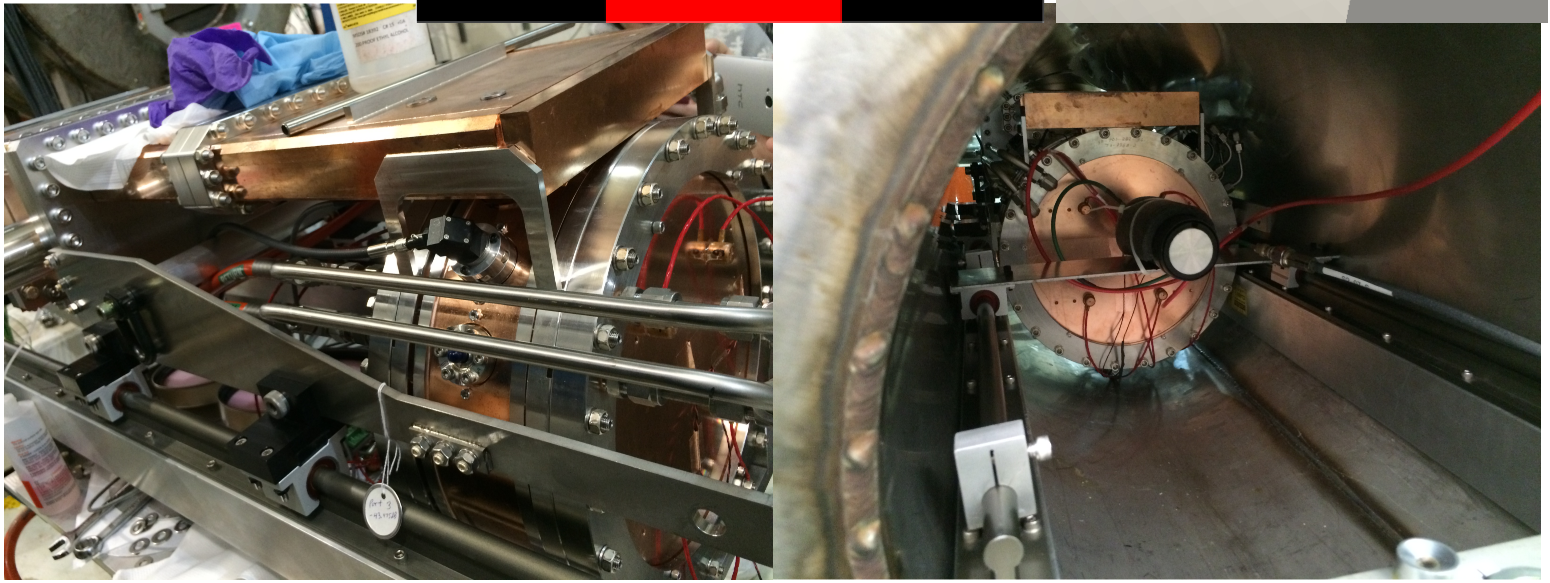




A New Vacuum Test Cell

- Flexible, systematic study of designs/techniques desirable
  - Build upon lessons learned from past vacuum cavities
- Modular Cavity built to address:
  - Materials
  - Surface treatments
  - Cavity geometry
- Commissioned using Cu end plates in B=0
- B-field run imminent
- Should demonstrate feasibility of vacuum cavities in ionization cooling channels





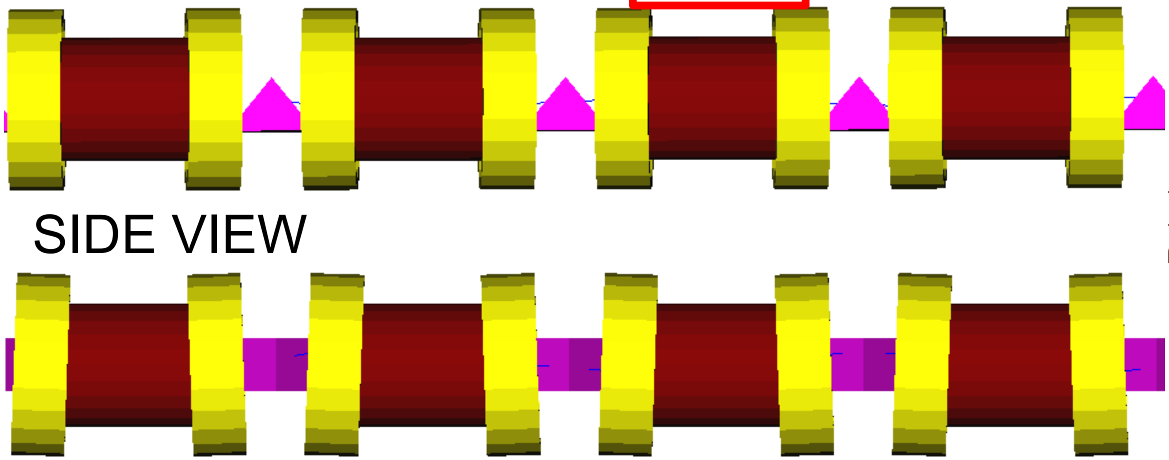
Part II –
Technology Application

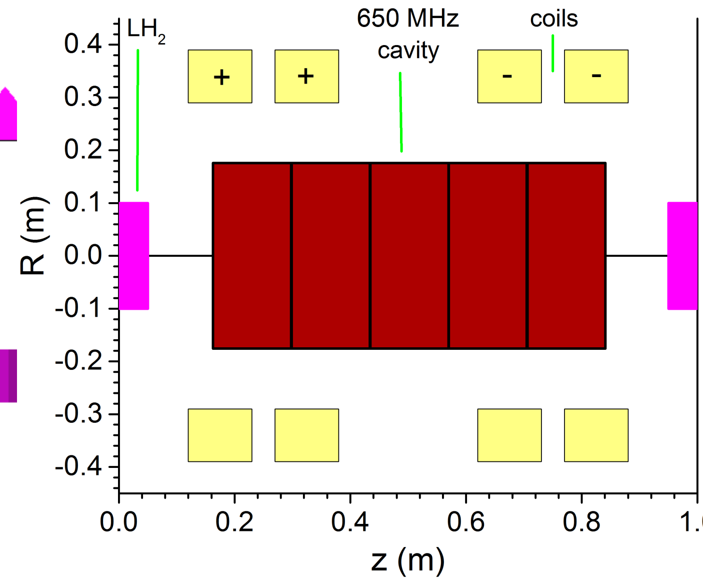
Two Ionization Cooling Channels

Hybrid

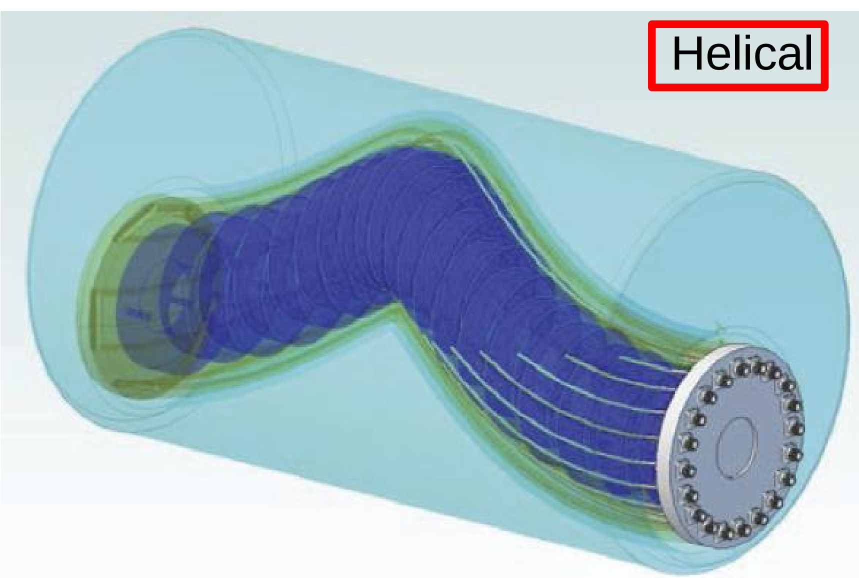
TOP VIEW

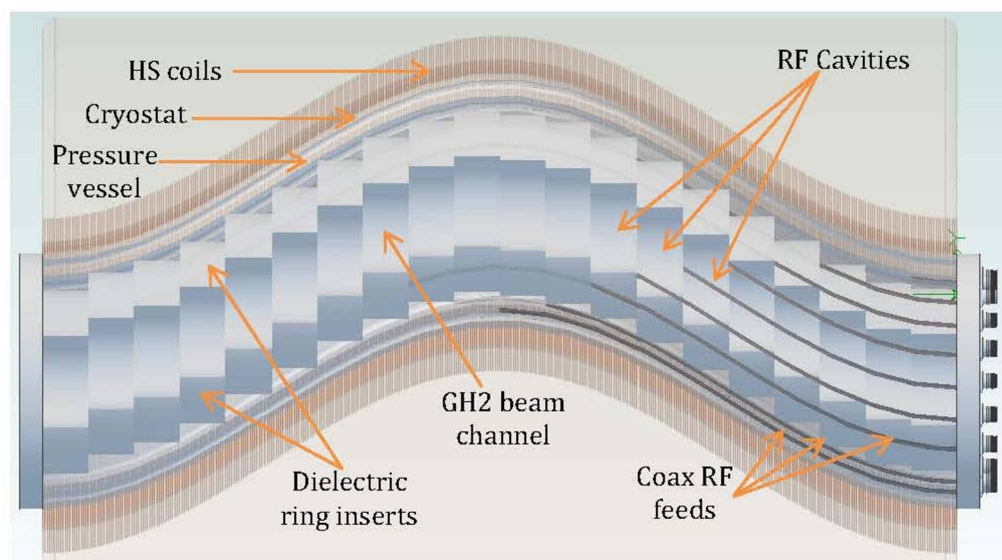
SIDE VIEW





Helical





Helical & Hybrid Concepts

- Both channels utilize gas filled cavities at 325 & 650 MHz doped with O_2

- Helical:
  - Helix
  - 160 atm H_2
  - Continuous H_2
  - Helical solenoids

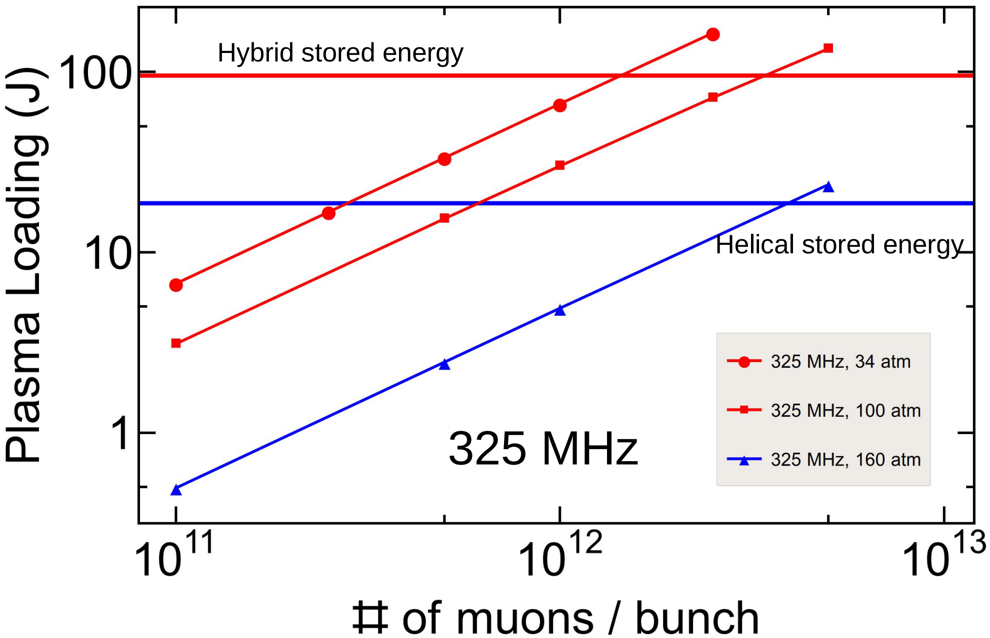
- Hybrid:
  - Rectilinear
  - 34 (or 100) atm H_2
  - Wedge LH_2 absorbers
  - Tilted solenoids

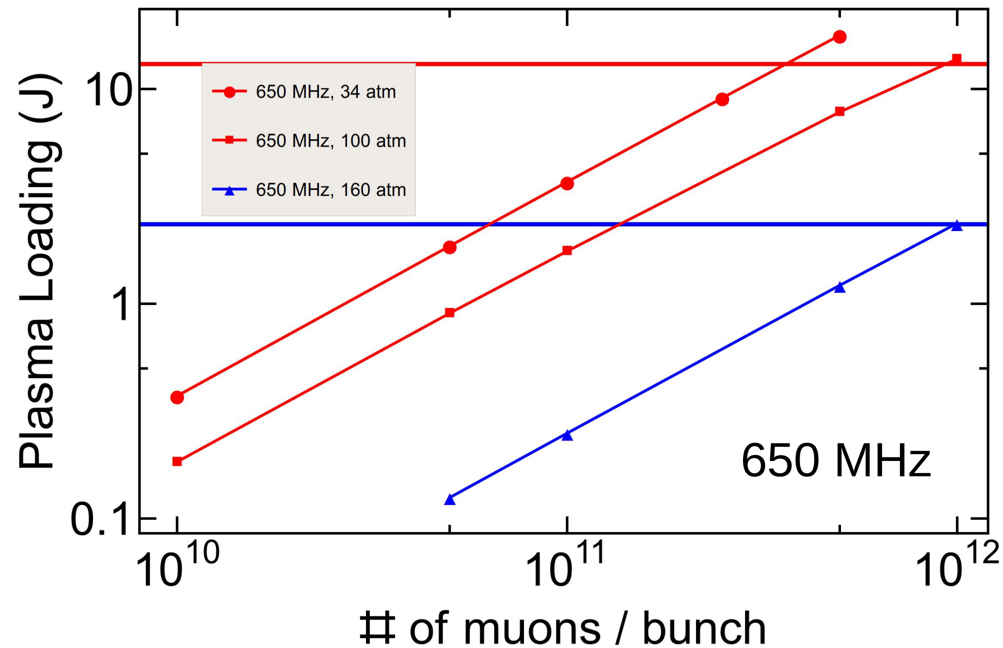
Summary

- Ionization cooling channels require RF cavities to operate in multi-tesla magnetic fields
- Achievable gradient in cavities shown to be limited due to magnetic field in past studies
- A solution exists!
  - Fill the cavities with gas
- It is looking increasingly likely that vacuum cavities also work
  - provided suitable design and surface treatment
- Multiple designs for cooling channels based on these technologies exist
  - Achieve emittance requirements for Higgs Factory
  - See Yonehara's and Stratakis's talks

Plasma Loading Estimate

- How much field degradation can we expect from plasma loading?
  - i.e. What *bunch* intensity is acceptable?





See Freemire et al NAPAC'13 TUODA1 & Stratakis et al IPAC'15 TUPWI059 for details

- Stored energy completely dissipated:

	325 MHz			650 MHz		
P (atm)	34	100	160	34	100	160
10^{11} / bunch	14	34	39	3.6	9.3	9.9

- **10^{12} μ / bunch for 325 MHz and 10^{11} μ / bunch for 650 MHz seem reasonable**