International
MUON Collider
Collaboration

Normal conducting RF cavity R&D for Muon Ionization Cooling

BERKELEY LAB

by Tianhuan Luo, ATAP, LBNL

With contributions from many others in MICE and MAP

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Introduction

- R&D for the MICE 201 MHz cavity.
- Brief review of other cavities R&D.
- Some proposed topics for future R&D.

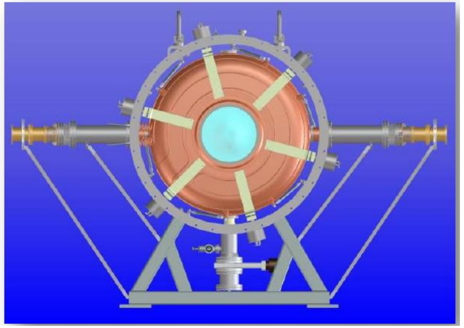
201 MHz Normal Conducting RF Cavity for MICE

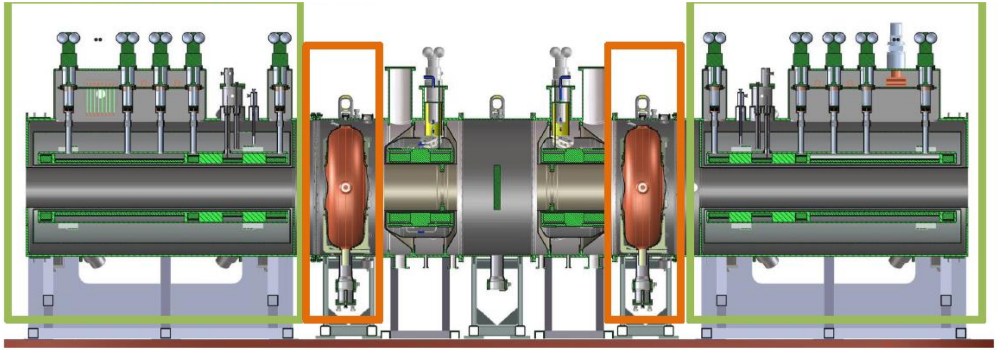
- MICE RF cavity design is based on the prototype cavity for the US MuCool program.

Cavity length	430	mm
Cavity inner radius	610	mm
Cavity body thickness	6	mm
Be window diameter	420	mm
Be window thickness	0.38	mm
Cavity shunt impedance	22	MΩ/m
Cavity quality factor Q_0	53,000	

- A normal conducting pillbox cavity.
- Two curved Be windows covering the beam irises.
- Cavity profile is optimized for high shunt impedance, low peak surface, production convenience, and multipacting consideration.

f0 (MHz)	E_peak	P_peak	Pulse length	Duty factor	B (on axis)
201.25	10.3 MV/m	2 MW	1.0 ms	0.1%	~ 1 T

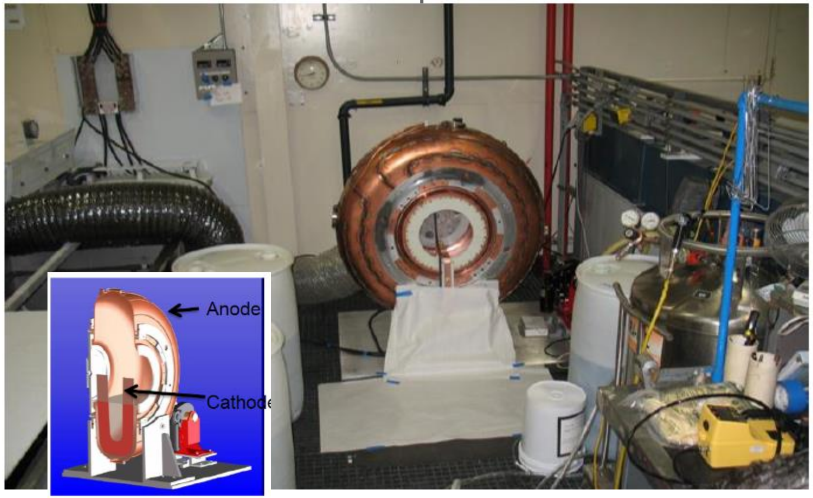




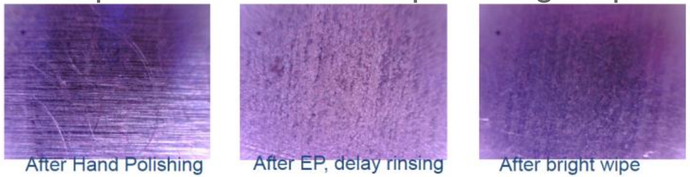
Smooth surface to suppress field emission

- Previous studies indicate a significant reduction of cavity stable operation level in the presence of the strong B field, which is a major challenge for the RF cavity for the muon ionization cooling.
- For MICE cavity, we carried out an SRF-type polishing procedure to smooth the cavity surface thus to suppress the field emission: mechanical polishing -> pre-cleaning -> electropolishing -> bright wipe.
- Mirror-like smoothness is achieved after the polishing procedure.

EP setup at LBL



Coupon test at different polishing steps

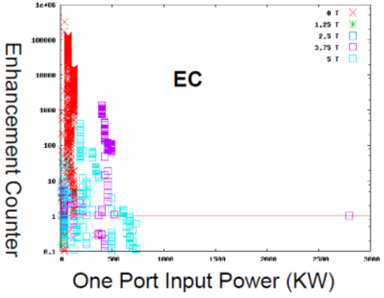


Mirror-like cavity surface after polishing

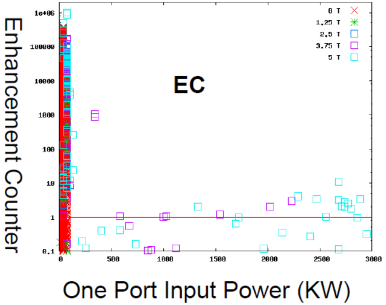
Geometry design and TiN coating to suppress multipacting

- Even though MICE is operated with pulsed mode, its 1ms pulse length is long and considerable MP can build up. Also its Q is quite high -> relatively slow rise/fall time.
- The cavity body design avoids parallel planes which can lead to hazardous MP.
- The MP simulation shows MP patterns in the coaxial waveguide and the loop coupler especially at the lower power range.
  - Remove the strip at the loop coupler.
  - TiN coating the waveguide outer tube and the loop coupler.

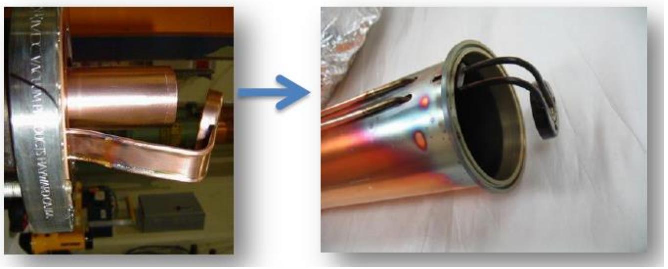
MP near the coupler



MP in the coax waveguide



Modification of the loop coupler

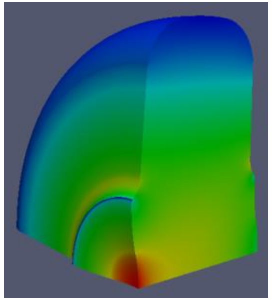


TiN coating with PVD at LBNL

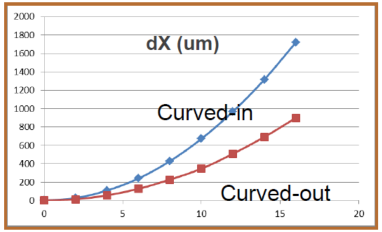
Be windows to enhance cavity acceleration efficiency

- Be windows to cover the cavity irises to significantly increase the cavity shunt impedance.
- Be windows have to be thin (0.38mm for MICE cavity), to minimize the interaction with Muon beam.
  - •Thin window -> small thermal conduction & small mechanical rigidity.
- Be window is curved to control the thermal expansion direction of the window.
  - Unsymmetric Ez field along the central axis, field enhancement on the convex window.
  - Uneven heating on the two windows -> uneven distortion -> frequency drift.
- Lorentz force detuning: not a concern for MICE operation but could become significant for thinner Be windows or higher operation E field.

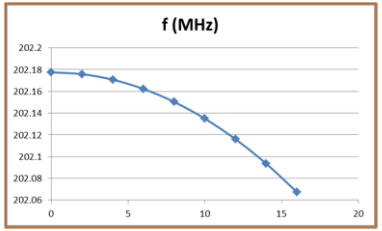
E field



Displacement at the center of Be windows and the frequency drift due to thermal expansion

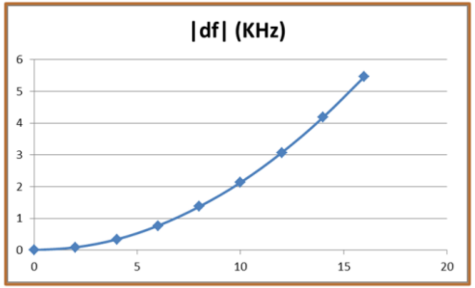


E_eff (MV/m)



E_eff (MV/m)

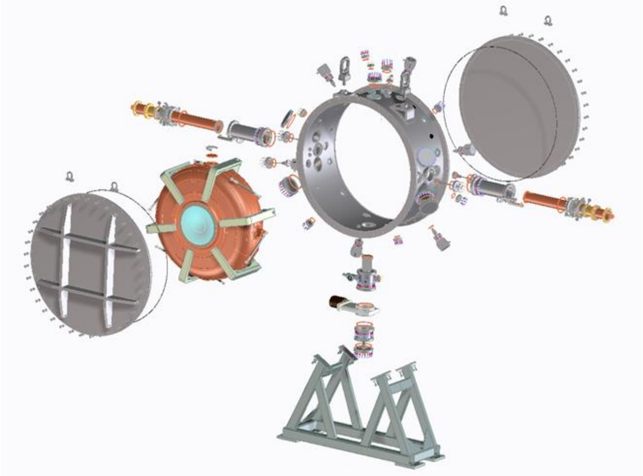
LFD



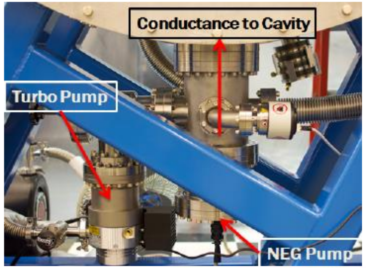
E_eff (MV/m)

Vacuum and frequency tuning

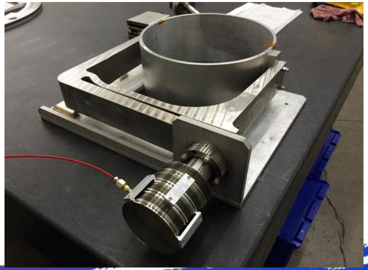
- The cavity is enclosed in a vacuum environment. Target vacuum is 10e-8 Torr for the cavity and 10e-6 Torr for the vessel.
  - Two separated vacuum volumes with limited conductance between them.
  - A differential pressure box was designed and constructed to protect the beryllium window during pump-down, vent, and possible system failure.
- The frequency is tuned by six tuner arms around the cavity body, each squeezed by a pressurized actuator to deform the cavity shape.
  - Tuning system can achieve a frequency tuning range of +/- 200 kHz at least.
  - The actuator has passed the functional test and the lifetime test.



Vacuum test

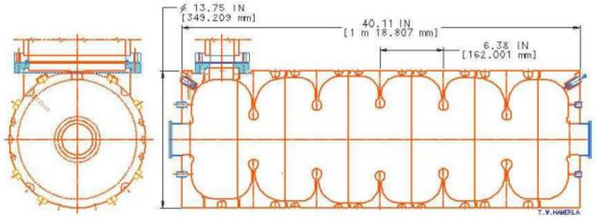


Actuator test

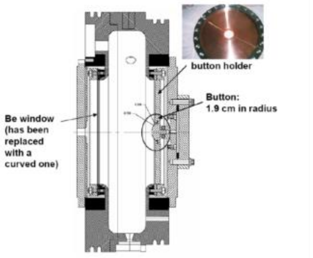


R&D on understanding the RF breakdown in multi-Tesla environment and its mitigation to achieve stable operation at required accelerating fields

805 MHz iris loaded cavity with a beam envelope matched aperture.

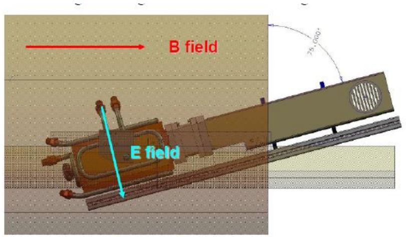


805 MHz Cavity Button test



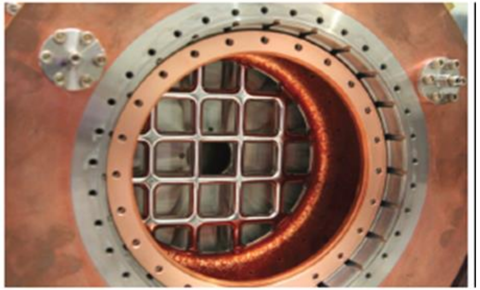
To find materials and coatings that can withstand high surface electric field in strong magnetic field.

805 MHz Box cavity



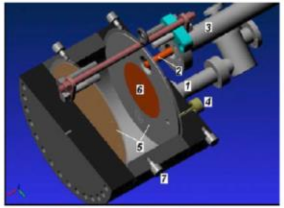
To study the breakdown mechanism with adjustable angle between E, B field directions

805 MHz Cavity with grid windows



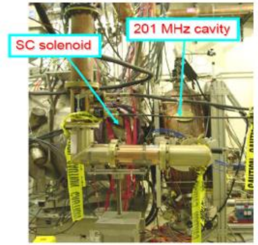
Alternative to the fully covered Be windows

805 MHz all-season cavity



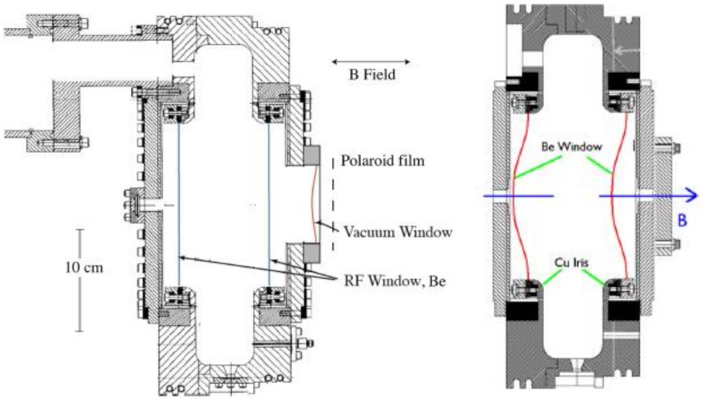
A versatile cavity for both vacuum and high-pressure test.

201 MHz prototype cavity

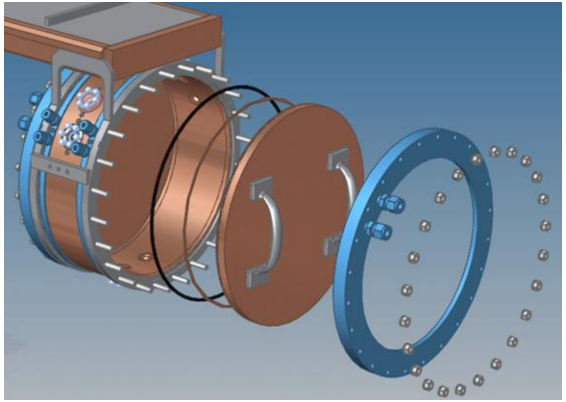


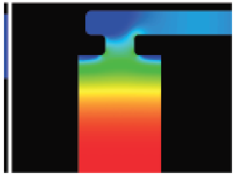
R&D on understanding the RF breakdown in multi-Tesla environment and its mitigation to achieve stable operation at required accelerating fields

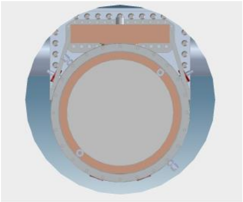
805 MHz LBL cavity with demountable windows



805 MHz modular cavity







The latest R&D cavity is the 805 MHz modular cavity.

- altering cavity geometry to minimize the effects of dark current and pulsed heating.
- cleaning and polishing interior cavity surfaces to reduce the density of field emission sites.
- investigating the role of material type, production, surface conditioning, etc. in the breakdown process.

Achieve the steady operation at ~ 50 MV/m in B=3T environment.

Possible future R&D topics for NC vacuum cavity for Muon Ionization Cooling

- Applying multi-objective optimization algorithms to the cavity design
    - Further improve the shunt impedance and reduce the peak cooper surface fields.
    - The deformation shape of Be windows.
    - Design the compact multiple-cavity module with efficient RF power feeding systems. Explore possible novel power coupling topologies.
- So far the design and testing work has been mainly on 201 MHz and 805 MHz. More work is needed for cavities of 325 MHz, 650 MHz and other frequencies.
- In the later stage of the ionization cooling, the Be windows need to be considerably thinner than MICE windows. The properties and the manufacturing of ultra-thin curved Be windows should be examined.
- Cavity R&D is closely related to the ionization cooling lattice design and the SC focusing solenoid development.

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Thank you for attention