

## A 201-MHz NORMAL CONDUCTING RF CAVITY FOR THE INTERNATIONAL MICE EXPERIMENT\*

D. Li<sup>#</sup>, A. DeMello, S. Virostek, M. Zisman, LBNL, Berkeley, CA 94720, U.S.A.  
R. Rimmer, Jefferson Lab, Newport News, VA 23606, U.S.A

### Abstract

MICE (Muon Ionization Cooling Experiment) [1] is an international demonstration experiment for the ionization cooling of muon beams. Eight RF cavities are proposed to be used in the MICE cooling channel. These cavities will be operated in a strong magnetic field; therefore, they must be normal conducting. The cavity design and construction are based on the successful experience and techniques developed for a 201-MHz prototype cavity for the US MuCool program. Taking advantage of a muon beam's penetration property, the cavity employs a pair of curved thin beryllium windows to terminate conventional beam irises and achieve higher cavity impedance. The cavity resembles a round, closed pillbox cavity. Two half-shells spun from copper sheets are joined by e-beam welding to form the cavity body. There are four ports on the cavity equator for RF couplers, vacuum pumping and field probes. The ports are formed by means of an extruding technique.

### INTRODUCTION

MICE will provide the first demonstration of ionization cooling of muon beams. The experiment is being built and carried out at Rutherford Appleton Laboratory (RAL) in UK using muon beams generated from ISIS. It will measure emittance reduction of  $\sim 10\%$  for  $\sim 200\text{-MeV}/c$  muons. Figure 1 shows a layout of MICE with detectors and the ionization cooling channel.

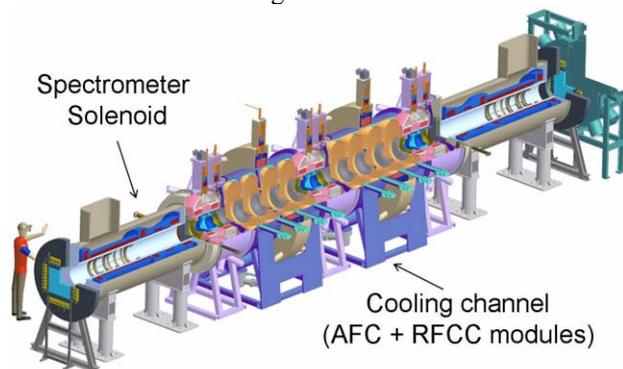


Figure 1: Layout of MICE experiment.

The MICE cooling channel consists of three Absorber and Focusing Coil (AFC) modules and two RF cavity and Coupling Coil (RFCC) modules [2]. As the cavities have to be operated in a strong magnetic field, they must be

normal conducting. Each RFCC module contains four 201-MHz normal conducting RF cavities and one superconducting (SC) coupling coil (or SC solenoid), as shown in Figure 2. In this paper, we present the 201-MHz normal conducting RF cavity design and fabrication plans for MICE. The cavity design is based on a successful prototype cavity for the US MuCool program with minor difference in interfaces.

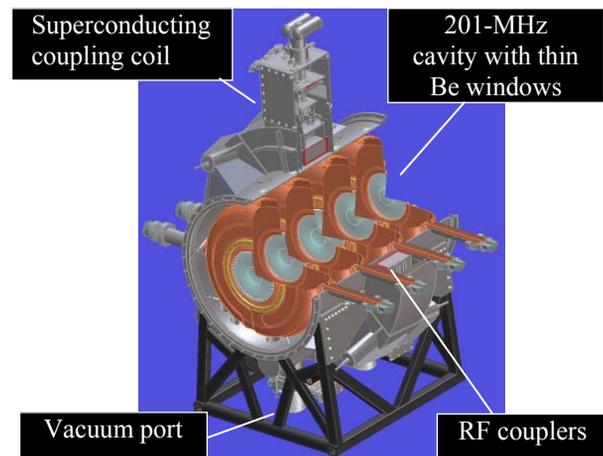


Figure 2: Cut-view of the MICE RFCC module: four 201-MHz normal conducting RF cavities and one SC coupling coil in the module.

### 201-MHz CAVITY FOR MICE

#### The Cavity Design

The MICE cavity design is based on the successful 201-MHz prototype cavity for the US MuCool Program [2, 3, 4]. The cavity design adopts a round pillbox profile with low peak electric surface field; and the conventional open irises are terminated by curved thin beryllium windows (0.38-mm thick and 42-cm diameter). The main cavity parameters are listed in Table 1.

Table 1: Main design parameters of the 201-MHz cavity

Parameters	Values	Units
Frequency	201.25	MHz
Shunt Impedance	22	MΩ/m
Cavity diameter	121.7	cm
Beam iris (diameter)	42.0	cm
Cavity gap (length)	42.0	cm
Quality factor Q	53, 500	

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<sup>#</sup>DLi@lbl.gov

A 3-dimensional parameterized CST MWS model was built to simulate RF field, as shown in Figure 3. Four port and curved beryllium windows are included in the model. Finite Element Analysis code, ANSYS has also been used to simulate RF fields, and for thermal and mechanical designs [3].

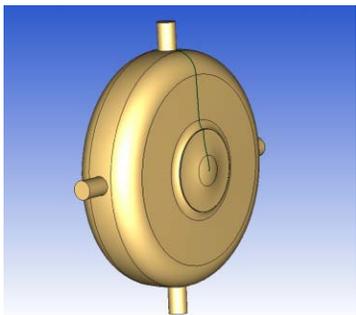


Figure 3: CST MWS model for MICE 201-MHz cavity.

Limited by available RF power, MICE 201-MHz cavities will be operated at a gradient of 8-MV/m; ~1 MW peak RF and ~1kW average power per cavity at 1-ms pulse and 1-s repetition rate.

### The Cavity Body Fabrication Concept

Similar to the MuCool prototype cavity, the cavity body will be spun against a pre-design and machined mold with 6-mm flat copper sheets. Two half shells will then be e-beam welded together at equator to form the cavity. There are four ports at the cavity equator for RF power couplers, vacuum and RF probes; the ports will be formed by pulling a die through a hole cut across the equator weld (extruding), a technique developed and successfully used for the MuCool prototype cavity. Water cooling tubes will be externally TIG brazed to the cavity body. Two curved and thin beryllium windows will be bolted on to the cavity aperture. Figure 4 is an exploded view of the cavity showing the details of the cavity concept.

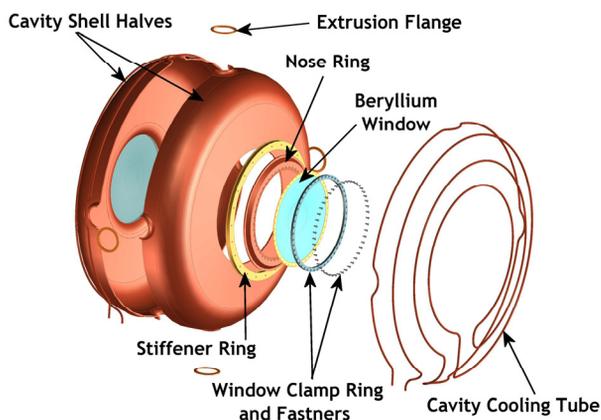


Figure 4: 201-MHz MICE cavity concept.

After fabrication, the cavity surface will be cleaned both mechanically (if necessary) and chemically before electro-polish (EP). Unlike the MuCool prototype cavity, MICE cavities will be installed inside a vacuum vessel;

therefore there is no differential pressure on cavity body and the thin beryllium windows.

### Curved and Thin Beryllium Windows

Each cavity has a pair of curved and thin beryllium windows with TiN coating. The window has a double-curved shape and is 0.38-mm thick and 42-cm diameter. The window profile and thickness are designed and determined in consideration of mechanical and thermal stress caused by RF heating. The window (foil) shape is formed at a high temperature against a die with the designed profile. Copper frames are brazed to windows after the forming. The windows are mounted in the cavity in such a way that one curves out and the other one curves out to minimize cavity frequency shifts. Figure 5 shows a photo of a beryllium window made for the MuCool prototype.

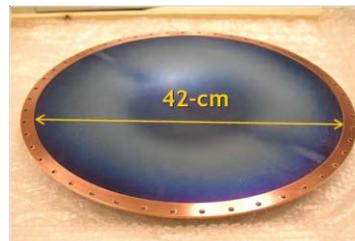


Figure 5: The thin and curved beryllium window for the 201-MHz cavity for MuCool.

### RF Power Coupler

There are two loop couplers at critical coupling for each cavity. Fabrication of the couple uses standard off-the-shelf copper coaxial components. The coupling loop has integrated water cooling lines. Each coupler uses one SNS style ceramic RF windows manufactured by Toshiba Company. Figure 6 shows a photo of the RF loop coupler (right) and ceramic RF window for the MuCool prototype cavity.



Figure 6: SNS Ceramic RF window (left) and loop RF coupler for MuCool prototype cavity.

The coupler for the MuCool prototype cavity was conditioned at Oakridge National Laboratory first and successfully tested at MTA (MuCool Test Area) at FNAL (Fermi National Accelerator Laboratory) for up to 2.5-MW peak power.

### Cavity Tuners

The cavity will be tuned in two steps, coarse tuning and fine tuning. The coarse tuning is realized by deforming

the cavity body using the stiffener ring (if necessary after fabrication to bring the cavity frequency within the dynamic tuning range). Fine tuning uses six dynamic tuners on each cavity, as shown in Figure 7, to provide a tuning range of 0 to 460-kHz with sensitivity of +230-kHz/mm per side. The six tuners are spaced evenly every 60° around the cavity. The tuners touch cavity and apply loads only on the stiffener ring of the cavity (see Figure 4). The tuners will work in push-in mode (i.e. squeezing to lower cavity frequency) only; therefore the fabricated cavity frequency is targeted and pre-tuned at slightly higher than the designed frequency, 201.25-MHz. This tuning concept has been tested at MTA, FNAL using the MuCool prototype cavity in air.

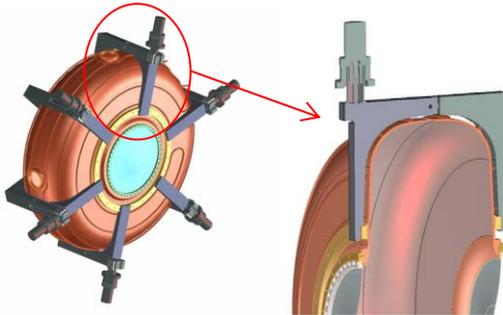


Figure 7: Six tuners on each cavity (left) and enlarged view of each tuner (right) showing the actuator, pivot point and stiffener ring.

## RF TESTS OF THE MUCCOL PROTOTYPE CAVITY

In addition to exploring engineering challenges for designing and fabrication of a 201-MHz cavity with beryllium windows, it is critical to ensure that the cavity can be operated at a high accelerating gradient in a strong magnetic field, necessity of muon ionization cooling channels.

The design and fabrication of the MuCool prototype cavity was through a collaborative among LBNL, J-Lab, Mississippi University and Oxford University in UK. The cavity was installed, conditioned and operated at MTA, FNAL since 2005. The cavity was tested with flat copper windows first and reached to 16-MV/m in a few days. The cavity was then being tested with a pair of curved beryllium windows, and again reached to ~ 19-MV/m quickly. The test setup at MTA is shown in figure 8.

Due to RF heating on the curved thin beryllium windows, we observed cavity frequency shifts slowly when we increased input RF power from low to high. There is a ~ 125-kHz frequency change in ~ 10-minute period when the RF cavity gradient was measured ramping up from 0 to 19-MV/m (for 150-micro-second pulse with 10-Hz repetition rate). Nevertheless the cavity frequency was stable, i.e. no mechanical vibration from the thin windows was observed during the commissioning and operation.

We have observed in the MuCool 805-MHz cavity tests that the achievable accelerating gradients are limited by

external magnetic fields [5, 6]. It requires a large SC solenoid magnet to study the magnetic field effect on the 201-MHz cavity. Taking advantage of MTA setup, we instead moved the cavity next to Lab-G magnet to use its stray magnetic field. Latest test results indicate that the cavity gradient can be maintained at 14-MV/m with the maximum stray magnetic field of 0.75-Tesla at the nearest beryllium window. This is a very encouraging result; more thorough data analysis is being conducted. New collaborations are being formed to study and simulate the magnetic effects on RF cavities.



Figure 8: The 201-MHz prototype cavity was installed and tested at MTA, FNAL since 2005.

## SUMMARY

The 201-MHz cavity design for MICE is essentially complete and ready to be fabricated soon. Purchase of long lead cavity materials and components are being placed. Eight 201-MHz RF cavities are needed for MICE; and will be delivered together with RFCC module to RAL, UK by 2010. The cavity design and fabrication process are based on successful MuCool cavity.

## REFERENCES

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