MUON IONIZATION COOLING EXPERIMENT Step VI

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Abstract

The Muon Ionization Cooling Experiment (MICE) [1] is a demonstration experiment to prove the viability of cooling a beam of muons for use in Neutrino Factories and Muon Colliders. MICE Step VI which represents a section of the cooling channel proposed in the Neutrino Factory Study–II [2] will demonstrate a 10% reduction in transverse beam emittance measured at the level of 1%. This requires measuring emittance to 0.1%. The measurement will be made using all the beam line elements present in the MICE Step IV configuration with the addition of two low-Z absorber modules and two RF-Coupling Coil (RFCC) modules. The RFCC modules each contain four normal-conducting low frequency RF cavities with a guiding magnetic field provided by a large diameter coupling coil magnet. The experiment can explore a variety of momentum, beta function and magnetic field configurations that will prove valuable in the design of future cooling channels. The current status and progress towards Step VI are discussed.

INTRODUCTION

The aim of the International Muon Ionization Cooling Experiment (MICE) [3, 4, 5] at the Rutherford Appleton Laboratory (RAL) is to design, build, and test one full cell of a ionization cooling channel lattice. The experiment is designed to measure a 10% reduction in emittance to within 1%. MICE is staged in “Steps”, as shown in Fig. 1, as detector components become available so that data can be taken and important measurements made at each step. Step I, which was completed in 2010, was dedicated to beamline commissioning [5], particle identification, and measurement of the emittance of the incident beam. Step IV [6] will measure the emittances before and after various absorbers using superconducting spectrometer solenoid trackers [7]. Step VI – the subject of this paper – is the final stage in MICE where the RF system will be integrated to form a realistic cell of a cooling channel.

MICE STEP VI

The goal of Step VI is to test “sustainable” cooling with one full cell of the cooling channel. In Step IV particles lose momentum in all directions and the transverse emittance is reduced as they pass through the absorbers. The longitudinal momentum lost in the absorbers will be restored in Step VI using re-accelerating RF cavities. Fig. 3 shows a simulation of the change in p_z as particles go through MICE. As shown in Fig. 2 Step VI in its final configuration will include three absorber focus coil (AFC) modules and two RFCC modules. The AFC module is described in [6]. The design, construction, and status of the RFCC modules are discussed below.

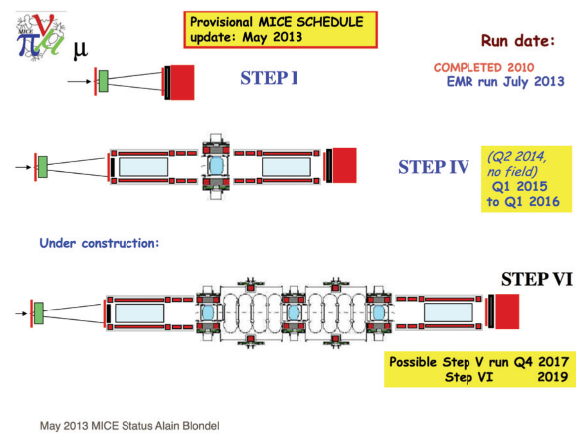

Figure 1: Schedule of the MICE experiment.

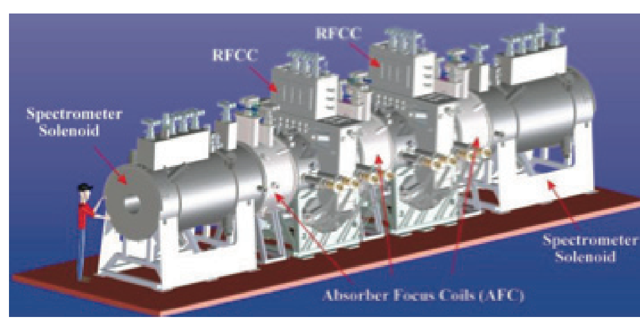

Figure 2: CAD drawing of the fully assembled MICE experiment.

RFCC MODULES

Each RFCC module [8] consists of four 201 MHz RF cavities installed in a vacuum vessel and surrounded by a solenoidal magnetic field generated by a 2.5 T superconducting coupling coil (CC) magnet cooled by three cryocoolers. A three-dimensional cutaway view of an RFCC module is shown in Fig. 4.

RF Cavities

The MICE RF cavities are normal-conducting high-gradient copper cavities with thin TiN-coated beryllium

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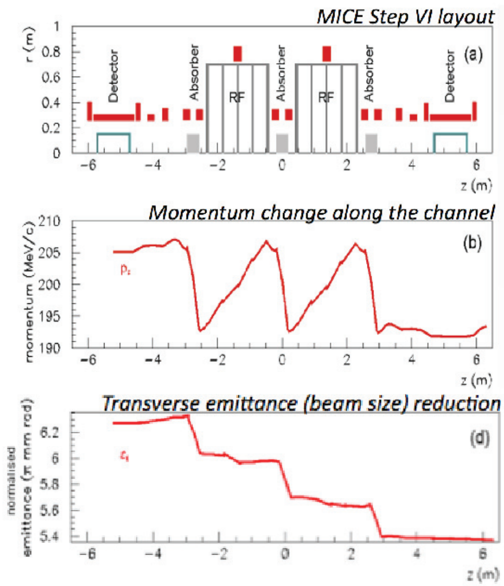

Figure 3: Simulation of 205 MeV/c particles traversing the MICE experiment.

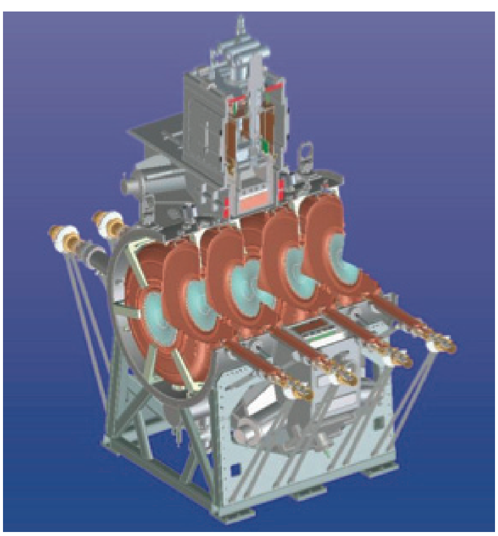

Figure 4: Cutaway of a CAD drawing of an RFCC module. There will be two such modules in Step VI.

windows to terminate beam irises. The cavities will be electropolished to suppress field emission and breakdown. The large diameter beryllium windows are nearly transparent to muons and accept large transverse emittances.

All cavities (including two spares) and 11 beryllium windows have been manufactured. One of the cavities has been electropolished and electropolishing of the remaining cavities is in progress [9]. Fig. 5 and Fig. 6 show an electropolished cavity and the beryllium windows respectively. The polished cavity will be tested at Fermilab's MuCool Test Area described later. Low power RF measurements have been made at LBNL to measure each cavity's frequency and quality factor and the measurements were found to agree with design specifications.

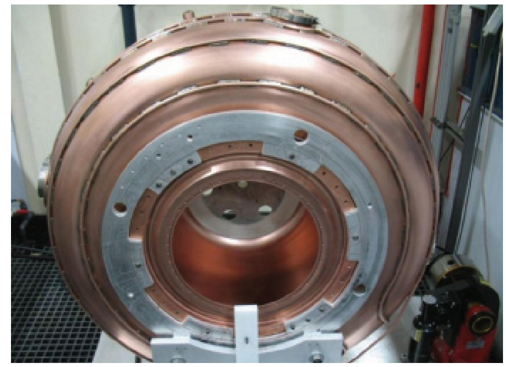

Figure 5: RF cavity after electropolishing.

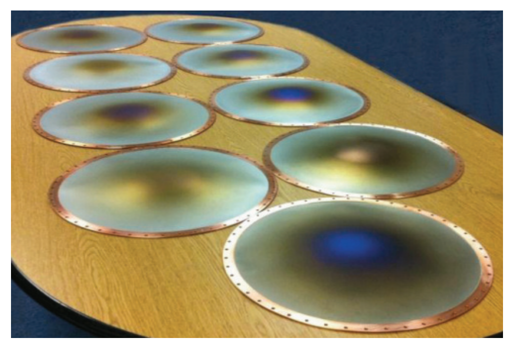

Figure 6: TiN-coated beryllium windows for the RF cavities. The nine windows delivered first are shown.

RF Power

The total RF power needed in Step VI will be 8 MW (1 MW per cavity). The RF power distribution system and infrastructure have been designed. The amplifier system comprises 4 kW solid-state amplifiers, 250 kW pulsed, tetrode amplifiers and 2 MW pulsed triode amplifiers. High-voltage power supplies for these amplifiers have been designed to allow operation at 1 Hz and 1 ms RF pulse length. The amplifier system will be able to produce a power of at least 2 MW which will be split between two cavities. RF power units from LBNL and CERN are being refurbished and assembled at Daresbury Lab. The first set of amplifiers shown in Fig. 7 from LBNL have been tested at 1 MW output power with no evidence of any significant ionizing radiation. The design of the low-level RF and the power distribution system is progressing.

Coupling Coils

The 2.5 T superconducting CC magnets located around the RF cavity assemblies are the largest magnets in the

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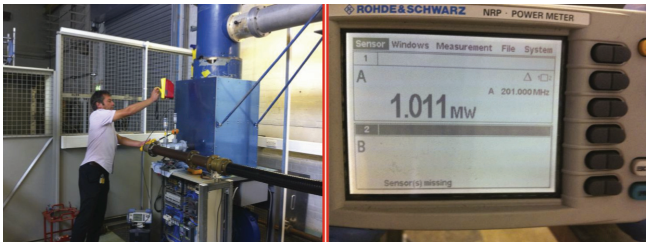

Figure 7: RF amplifier under test at Daresbury.

MICE cooling channel and provide an additional longitudinal magnetic field to confine the beam between the absorbers. The coupling coil magnets and cryostats are designed by a collaboration between LBNL and the Harbin Institute of Technology (HIT), China. The first coil was wound at Qi-Huan Corp., China, and shipped to HIT. After preparation at LBNL it has been shipped to Fermilab where it is being tested and will be trained in the Solenoid Test Facility. Fig. 8 shows the cold mass at Fermilab.

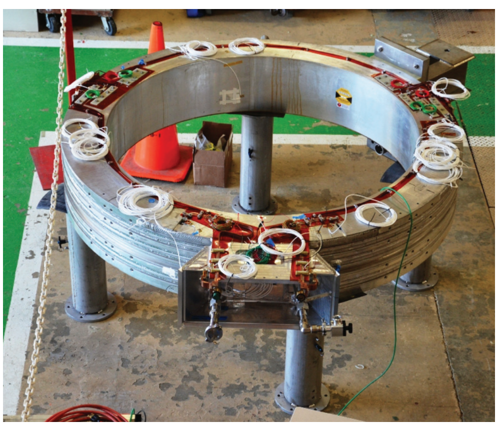

Figure 8: Coupling coil cold mass at Fermilab where it will be tested and trained.

Tests

Preparations are underway for single-cavity tests at Fermilab at the MuCool Test Area with an electropolished MICE cavity. A vacuum vessel, shown in Fig. 9, has been built with all of the same ports as the actual RFCC vessel. New 201 MHz couplers have been fabricated and tuners, shown in Fig. 10 have been built and tested. The cavities will be tested with an actual MICE coupling coil magnet. The tests will be used to develop assembly experience, study the performance of cavities, tuners, and controls.

CONCLUSION

The construction of MICE Step VI is progressing well. All RF cavities and windows for one RFCC module have been fabricated. An electropolished cavity is being outfitted for tests. The first coupling coil has been wound, prepared and shipped and it is being readied for training. Power amplifiers are being assembled at Daresbury Lab

Figure 9: Single-cavity test vacuum vessel at Fermilab.

Figure 10: RF tuner arms.

and the first amplifier has been tested to 1 MW power. MICE Step VI is expected to be assembled and ready for data-taking in 2019.

MICE Step VI will provide a full cooling cell allowing tests of all optics configurations and precise measurement of emittance and the first full demonstration of muon ionization cooling.

ACKNOWLEDGMENT

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