Progress in the construction of the MICE cooling channel

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Abstract. The international Muon Ionization Cooling Experiment (MICE), sited at Rutherford Appleton Laboratory in the UK, aims to build and test one cell of a realistic ionization cooling channel lattice. This comprises three Absorber–Focus-Coil (AFC) modules and two RF–Coupling-Coil (RFCC) modules; both are technically challenging. The Focus Coils are dual-coil superconducting solenoids, in close proximity, wound on a common mandrel. Each pair of coils is run in series, but can be configured with the coil polarities the same ("solenoid mode") or opposite ("gradient mode"). At the center of each FC there is a 20-L liquid-hydrogen absorber, operating at about 14 K, to serve as the energy loss medium for the ionization cooling process. The longitudinal beam momentum is restored in the RFCC modules, each of which houses four 201.25-MHz RF cavities whose irises are closed with 42-cm diameter thin beryllium windows. To contain the muon beam, each RFCC module also has a 1.4-m diameter superconducting coupling solenoid surrounding the cavities. Both types of magnet are cooled with multiple two-stage cryo-coolers, each delivering 1.5 W of cooling at 4 K. Designs for all components are complete and fabrication is under way. Descriptions of the various components, design requirements, and construction status will be described.

1. Introduction

The international Muon Ionization Cooling Experiment (MICE) at the Rutherford Appleton Laboratory (RAL) [1], shown in figure 1, aims to build and test one cell of a realistic ionization cooling lattice and was designed to measure a 10% emittance reduction by ionization cooling to within 1%, an absolute emittance measurement of 0.1%. MICE is being assembled in Steps, illustrated in figure 2, as detector components become available, with data taken at each step. The MICE beam line, Step I detectors, and results from Step I data taking are presented in [2]. (Steps II and III consisted of one spectrometer solenoid and tracker and both spectrometer solenoids and trackers but without the liquid hydrogen absorber, respectively, and will be combined in Step VI.)

Measurements of the initial and final emittances using the spectrometer solenoids, trackers, focus coil, and various absorbers will take place in Step IV. In Step V the re-accelerating RF, coupling coil, and second absorber-focus-coil (AFC) module will be added. The second RF-coupling-coil

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(RFCC) module and third AFC module will be installed in Step VI to complete the full cell of the cooling channel, and studies of the cooling channel will be carried out.

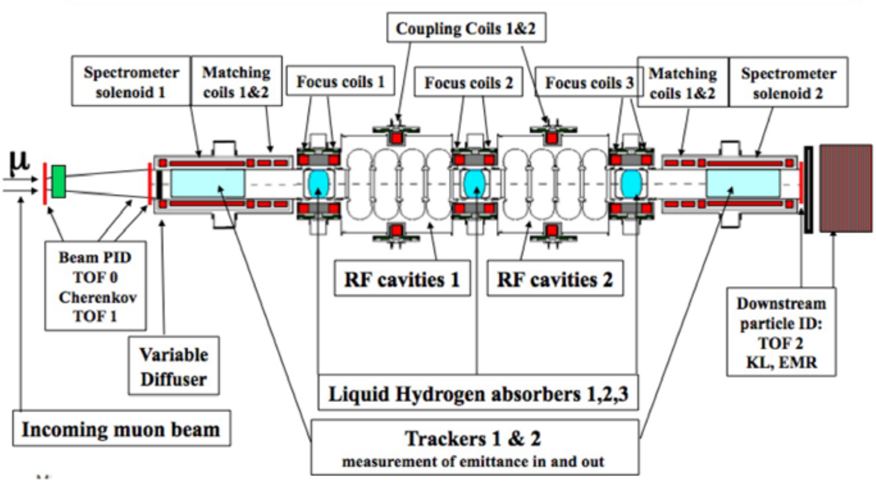

Figure 1. MICE layout.

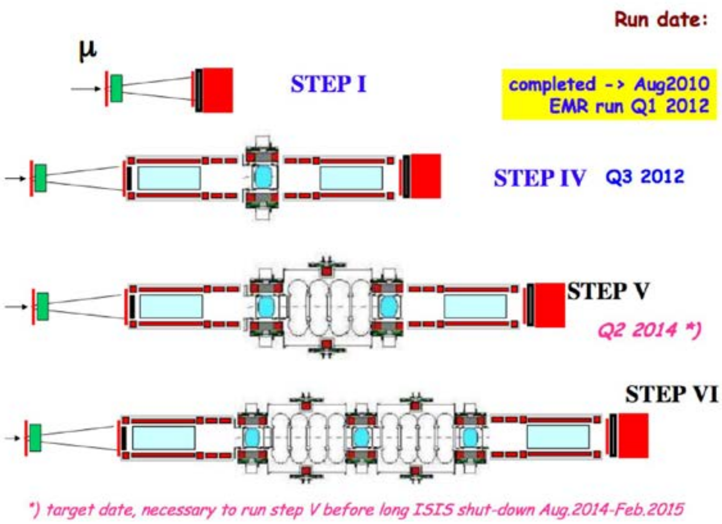

Figure 2. MICE schedule.

2. MICE Step IV

The goal of Step IV is the measurement of the ratio of emittances before and after the absorber. The spectrometer solenoids, trackers, and absorbers will be installed by the third quarter of 2012, with data taking during the fourth quarter of 2012 and first quarter of 2013.

The two scintillating fiber trackers with VLPC readout [3] were constructed with contributions from the Japan, the UK and the US institutions and have been operational since 2009. The trackers are used to measure the emittance using a single-particle technique. They are currently being re-commissioned with cosmic data and upgraded software.

The two spectrometer solenoid magnets are superconducting magnets, each consisting of five coils wound on a common aluminum mandrel. Cooling of the radiation shield and cold mass is provided by a series of fivetwo-stage cryocoolers and one single-stage crycooler. Liquid helium is maintained in the cold mass by means of a recondensation circuit. The magnets, one of which is shown in figure 3, are being built by Wang NMR in Livermore, California, with management now directly under the Lawrence Berkeley National Laboratory (LBNL) Accelerator and Fusion Research Division (AFRD), which has led to a substantial increase in resources. Good MICE magnet coordination has been established. Reconsiderations of the issues of cooling a large magnet with cryocoolers plus electromagnetic coupling between the coils has led to better solutions for thermal balance and quench protection of the magnet and leads. A plan and milestones for Step IV running have been established.

The AFC module consists of a focus coil magnet assembly with two superconducting coils that can be operated with the same ("solenoid mode") or opposite ("flip mode") polarity, a liquid hydrogen absorber body, and absorber windows and safety windows. A liquid hydrogen storage and delivery system is also required. The magnet assembly, shown in figure 4, is being constructed by Tesla in the UK. The first liquid hydrogen absorber was built and cooling-tested at KEK and has now been delivered to RAL. The absorber windows, one of which is shown in figure 5, are being provided by the University of Mississippi (United States).. There is also a system to install solid absorbers.

Data will be taken with vacuum (with only helium and windows for the tracker), liquid hydrogen absorber empty, liquid hydrogen absorber full, and various solid absorbers (lithium hydride disks and a wedge-shaped absorber to study emittance exchange).

There is good progress on the focus coil, the absorbers, and the liquid hydrogen system.

Figure 3. Spectrometer solenoid at Wang NMR.

Figure 4. Focus coil (Tesla Eng., Ltd.).

Figure 5. Absorber window (University of Mississippi).

3. MICE Step V

The goal of Step V is to gain experience with the RFCC module operation. The RFCC module, a second AFC module, and RF power, controls and connections will be installed. Tests of "sustainable cooling," with the momentum lost in the absorbers restored by the RF cavities, begin with Step V. The aim is to take Step V data before the long ISIS shutdown August 2014 to February 2015.

The coupling coils located around the RF cavity assemblies provide additional longitudinal magnetic field to confine the beam between the absorbers. The coupling coil design and construction are being carried out by a collaboration between LBNL and the Harbin Institute of Technology (HIT) Institute of Cryogenics and Superconductivity Technology in China, with management now directly under the LBNL AFRD, which has led to a substantial increase in resources. The first coil has been wound at Qi Huan Corp, China, and shipped to HIT in June 2011. Welding of the cold mass cover plate will take place at HIT. The coil will then be shipped to the US. The plan is to test the coil in a cryostat, probably at Fermilab. The test of the first coil is critical. More conductor will be ordered for the two remaining coils (an additional coil for MICE and one for the Fermilab MuCool Test Area). The design of the quench protection and leads is underway.

RF cavity production is advancing well. Ten (8 + 2) cavity bodies have been delivered to LBNL. Nine titanium-nitride coated beryllium windows have also been delivered and accepted. A single-cavity test module has been designed and will be tested at Fermilab MuCool Test Area (MTA). The problem of RF cavity breakdown in high magnetic fields is under investigation at the MTA , and the first coupling coil will be used for this crucial test.

The RF power distribution system, shown in figure 6, and infrastructure have been designed. RF power units from LBNL and CERN are being refurbished. The LBNL unit has been tested at 1 MW output power with no evidence of significant X-ray production and will now be pushed towards 2 MW. The CERN unit will be reassembled and tested next. The total RF power needed will be 4 MW for Step V and 8 MW for Step VI.

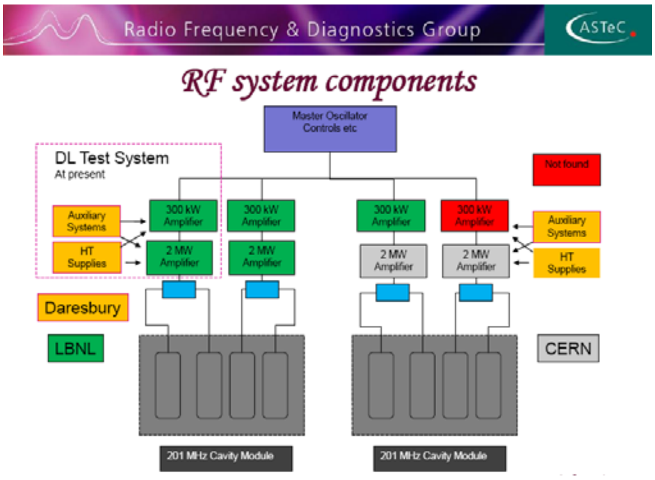

Figure 6. RF power distribution system.

4. MICE Step VI

The addition of another RFCC module and a third AFC module will bring MICE to Step VI, the full cell of the cooling channel, which has the optics and characteristics needed for 10% or more emittance reduction. Data will be taken to study the performance of the cooling channel, the goal of MICE. If the Step V RFCC module is not ready before the long ISIS shutdown, proceeding directly to Step VI will be considered, although there are some risks involved.

5. Conclusions

We have made good progress on the re-baselined MICE schedule. We have a plan and milestones established for the spectrometer solenoids for Step IV running in October 2012. MICE aims to take data in Step V mode before the ISIS long shutdown in August 2014. Completing the coupling coils is critical to this plan, and the schedule depends on the cryostat test of the first coil. MICE is on the way towards demonstrating ionization cooling!

References

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