STATUS OF THE MUON IONIZATION COOLING EXPERIMENT (MICE)*

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Abstract

A muon collider and a muon-based neutrino factory are attractive options for particle physics. Their realization requires demonstration of muon ionization cooling, the only technique to rapidly reduce the emittance of the short lived tertiary muon beam. MICE, performed by a team from the U.S., Europe, and Asia at Rutherford Appleton Laboratory, will provide this demonstration. The experiment comprises one cell of a representative cooling channel, bracketed upstream and downstream by muon detection stations, each with a spectrometer solenoid (SS). Characterization of the RAL/ISIS muon beam line is complete. Fabrication of the two SS is nearly complete, with one having passed its acceptance tests, and the second nearly ready for testing. The first focus coil is presently being tested, with a second unit ready shortly. The cold mass for the coupling coil prototype is under test and its cryostat is in fabrication. Other required hardware, including RF cavities and liquid-H absorbers, is also being built. Their status and plans for carrying out the experiment are described.

CONCEPT AND STAGING

Ionization cooling of muons involves reducing the total momentum through energy loss while replenishing the component along the reference orbit with acceleration. MICE is a demonstration of muon cooling using a full cooling cell surrounded by tracking and particle identification detectors to measure each muon before and after it traverses the cell [1]. This way, a virtual beam can be constructed in software and its emittance measured with unprecedented precision. The goal is to measure a reduction of order 10% in normalized transverse emittance with a relative precision of 1% under different configurations of input beam and magnetic channel optics. Figure 1 shows the staging of the experiment. Step I, aimed at characterizing the beam using the particle identification detectors, is now complete. In addition, preliminary momentum reconstruction and emittance measurements were performed at this stage using the time-of-flight (TOF) detectors [2]. Reconstructed trace space distributions agree well with simulations for different combinations of momentum (140, 200 and 240 MeV/c) and normalized transverse emittance (3π, 6π and 10π mm). The first measurement of cooling with absorbers will take place in Step IV [3]. This will be followed by the final stage (Step VI) with the full cooling channel cell in place including RF acceleration [4].

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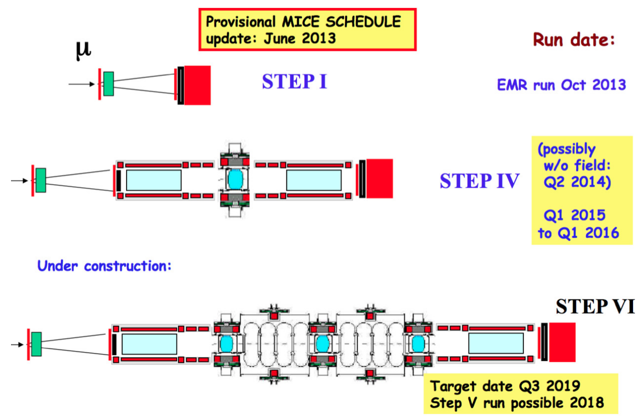

Figure 1: MICE staging and schedule.

BEAMLINE

A target system [5] utilizing a linear electromagnetic drive moves a Ti cylinder vertically toward the edge of the shrinking proton beam envelope just before extraction. In addition, a vertical closed orbit bump has been developed to steer the ISIS beam to meet the target at the correct phase and reduce losses in the machine induced by the MICE target [6]. Figure 2 shows the beamline elements and instrumentation. The pion beam from the target is captured by a quadrupole triplet (Q1-3) and momentum selected in a dipole (D1) before being directed into a decay solenoid (DS). A variable thickness proton absorber at the exit of the DS is used to remove protons from the beam. Momentum selection on the muons from pion decay is performed by

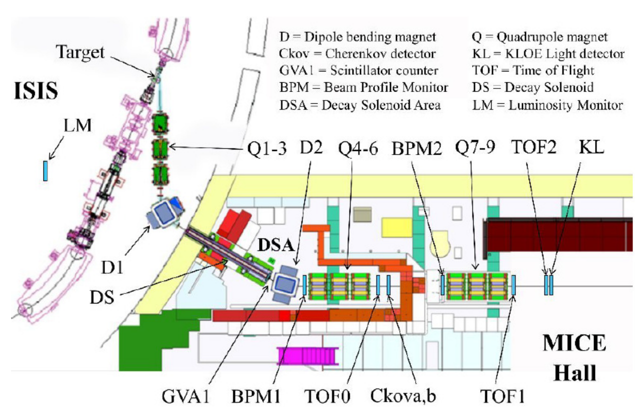

Figure 2: MICE beamline and instrumentation.

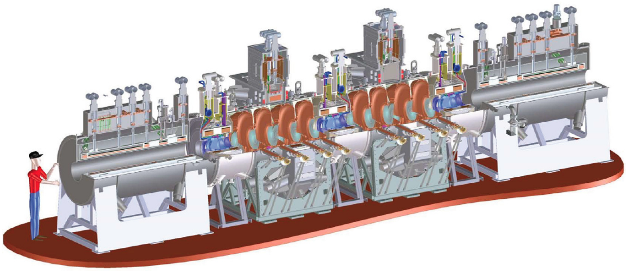

Figure 3: Partial cross section of the MICE channel showing, from the outside in: spectrometer solenoids; AFC modules with liquid hydrogen absorbers; RFCC modules with RF cavities, couplers and Be windows.

another dipole (D2). Two more quadrupole triplets (Q4-6, Q7-9) focus the muon beam. A variable thickness diffuser [7] is used to increase the emittance of the beam at the end of the beamline for some of the settings. The beamline settings have been successfully commissioned [8] and meet the experimental requirements [9].

COOLING CHANNEL HARDWARE

Figure 3 shows the layout of the final stage (step VI) of MICE. The cooling cell includes three AFC (Absorber-Focus Coil) and two RFCC (RF Cavity-Coupling Coil) modules.

AFC Modules

Liquid hydrogen absorber development is complete and the first absorber has been built and successfully tested [10]. Solid absorbers will also be tested in Step IV [11]. A cylindrical disc absorber has been built out of LiH and a wedge-shaped absorber has been designed [12]. Training and testing of the first AFC module magnet is complete and the second unit will be delivered to RAL shortly.

RFCC Modules

Ten RF cavity bodies have been built and most of the thin Be windows and ceramic vacuum windows are in hand [13]. One of the cavities was electropolished at LBNL [14] and is being assembled for operation in a vacuum vessel at the Fermilab MuCool Test Area (MTA) [15]. The tuning system for this cavity was built at Fermilab and LBNL and will be tested soon [16]. The first pair of RF power couplers is under fabrication at LBNL. A test stand at Daresbury Laboratory is being used to develop the RF amplifier chain that consists of four 2-MW systems. RF power and control system design is complete and installation is under way [17]. The first amplifier will be operated in the MICE hall soon. The cold mass for the first prototype coupling coil (CC) magnet is under test at a recently commissioned magnet test facility at Fermilab [18] and cryostat fabrication at LBNL is nearing completion. This CC magnet will be installed at the MTA in 2015. In the meantime, cavity tests will be carried out in the fringe field of a smaller magnet [19].

Spectrometer Solenoids

Assembly of both spectrometer solenoids is complete [20]. The first is on its way to RAL after successful final testing and magnetic field mapping [21]. Testing of the second is about to start.

DETECTORS

Two scintillating fiber trackers have been built [22] and successfully tested. The trackers will be installed inside the spectrometer solenoids and used to reconstruct muon position and momentum. The rest of the detectors are used for particle identification and most are labeled in Fig. 2. The two upstream TOF hodoscopes (TOF0, TOF1) [23], together with the Cherenkov counters (Ckova, b) [24] allow identification of incoming muons while the downstream calorimeter (KL) and electron-muon ranger (EMR) [25] next to it are used to reject muon decays and high energy pions [26]. The TOF counters also provide a measurement of the time coordinate for each muon. Assembly of the last detector, the EMR, was recently completed at the University of Geneva and a commissioning run will begin shortly to complete installation at RAL. The data acquisition system is complete and the software framework for Monte Carlo simulation, reconstruction and analysis of detector data is in place [27].

MAGNETIC SHIELDING

The MICE magnetic channel contains 18 large-bore superconducting coils over a length of about 15 m with no flux return. Steel walls have been installed at the edges of the MICE hall to shield the rest of the building (including the MICE and ISIS control rooms). However, detailed modeling has shown that the magnetic field within the hall would potentially interfere with operation of some components. This will be addressed by relocating some of the sensitive hardware and installing a partial return yoke (PRY) [28] around the magnetic channel to capture the flux. The conceptual design of the PRY is shown in Fig. 4 and detailed engineering is in progress.

OUTLOOK

The beamline has been operating successfully and all major cooling channel components are on track for delivery within the next few years. Commissioning of the last particle ID detector (EMR) is about to commence. Installation of the support infrastructure in the hall is well under way and a framework for controls and monitoring [29] is in place. Step IV of MICE will be ready early in 2015 for the first measurement of emittance reduction after a long ISIS shutdown. The latest version of the schedule can be obtained from the MICE website [30]. MICE is on track for demonstration of ionization cooling by the end of this decade which will pave the way for future muon based accelerator facilities [31].

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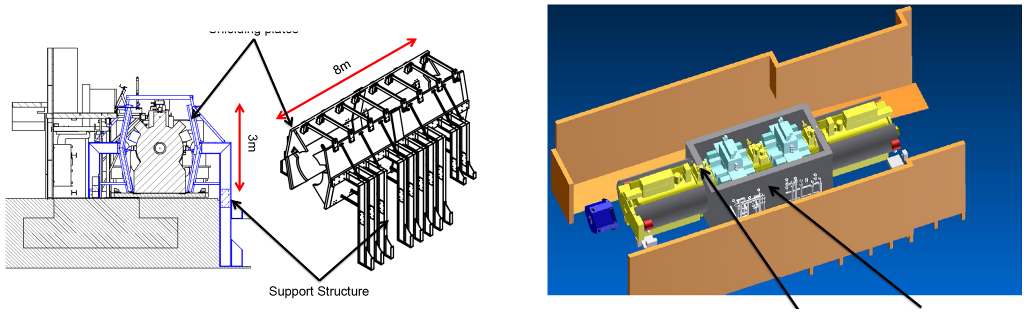

Figure 4: Partial return yoke concept for Step IV (left) and Step VI (right).

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