STATUS OF THE INTERNATIONAL MUON IONIZATION COOLING EXPERIMENT*

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Abstract
Muon ionization cooling provides the only practical solution to prepare high brilliance beams necessary for a neutrino factory or muon colliders. The **m**uon **i**onization **c**ooling **e**xperiment (MICE) is currently under development at the Rutherford Appleton Laboratory in UK. The experiment comprises a dedicated beam line to generate a range of input emittance and momentum of a muon beam, with time-of-flight and Cherenkov detectors to ensure a pure muon beam. A first measurement of emittance is performed in the upstream magnetic spectrometer with a scintillating fiber tracker. A cooling section will then follow, alternating energy loss in liquid hydrogen and RF acceleration. A second spectrometer identical to the first one and a particle identification system provide a measurement of the outgoing emittance. In September 2009, it is expected that the beam and some detectors will be in the final commissioning phase and the time of the first measurement of input beam emittance only months away. The plan of steps of measurements of emittance and cooling that will follow in the rest of 2009 and later.

INTRODUCTION

Neutrino **f**actory (NF) and **m**uon **c**ollider (MC) offer high potential physics opportunities, but both NF and MC are difficult to build. Muon beams are produced with very large six-dimensional emittance and have short lifetime (~ 2.2 micro-second at rest). One of the main challenges is how to effectively manipulate intense muon beams, in particular to reduce the transverse emittance of the muon beams, namely cooling. Ionization cooling is considered to be the only practical cooling scheme for muons. No one has ever demonstrated the muon ionization cooling yet. MICE is such a demonstration experiment where a section of real ionization cooling channel hardware (based on the US Feasibility Study-II design) will be built and tested. The experiment is currently under construction at the Rutherford Appleton Laboratory (RAL) in UK [1]. The experiment comprises a dedicated beam line to generate a range of input emittance and momentum of a muon beam, with time-of-flight and Cherenkov detectors to ensure a pure muon beam. The emittance of the incoming muon beam will be measured in the upstream magnetic spectrometer with a scintillating fiber tracker. A cooling section will then follow. The cooling section consists of three liquid hydrogen absorbers and eight 201-MHz normal conducting RF cavities surrounded by two superconducting solenoid magnets. Muon beams lose energies in the liquid hydrogen absorber and gain longitudinal energies only from RF cavities, therefore a net reduction in transverse emittance. A second spectrometer that is identical to the first one and a particle identification system provide a measurement of the outgoing emittance. Figure 1A & 1B show an engineering model of the MICE experiment setup and the ionization cooling channel.

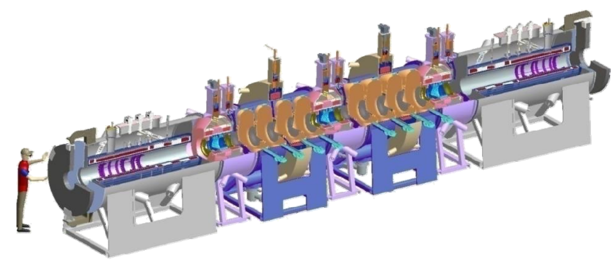

Figure 1A: MICE experiment layout: two spectrometer solenoids with particle ID and timing for emittance measurement and a section of cooling channel in between.

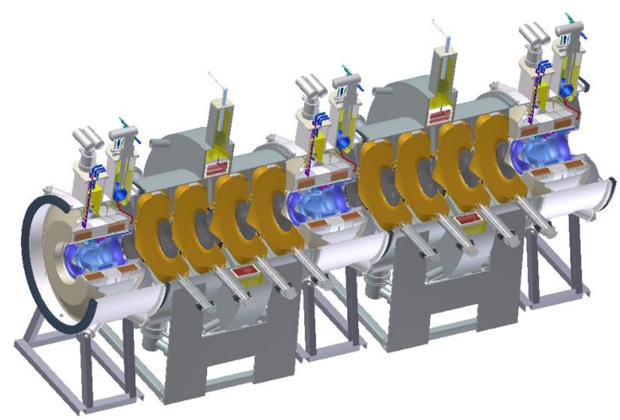

Figure 1B: MICE cooling channel consists of three liquid hydrogen absorbers (blue) and eight 201-MHz normal conducting RF cavities (yellow) surrounded by five superconducting solenoid magnets.

The aim of MICE is to measure ~ 10% cooling of 140 - 240 MeV/c muons with a measurement precision of $\Delta\varepsilon/\varepsilon$ of 10^{-3}. In addition, it is also necessary to explore and demonstrate that we can design, engineer and fabricate the hardware needed for MICE and place them in a muon beam and measure their performance. Moreover, MICE will help to validate design tools (simulation codes) we have developed and check agreements with the experiment.

MICE collaboration has over 150 collaborators from Belgium, Bulgaria, China, Holland, Italy, Japan,

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Switzerland, UK and USA, respectively. Responsibilities of each participating country are illustrated in Figure 2.

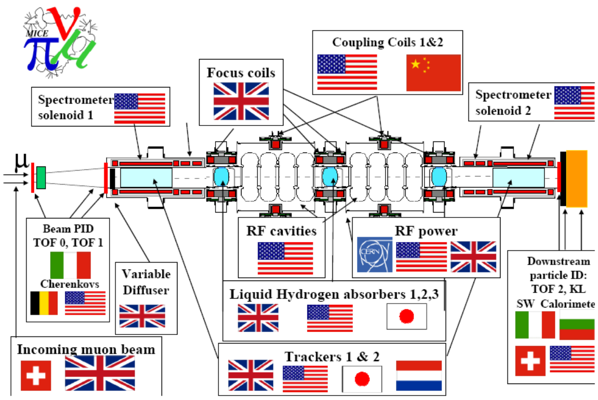

Figure 2: As an international collaboration experiment, MICE hardware is contributed by participating countries and the responsibility of each participating country is illustrated above with its national flag.

EXPERIMENTAL HALL

A dedicated MICE experimental hall has been assigned at RAL and is currently under construction, its location is shown in Figure 3. Necessary infra-structures for hosting the experiment are being implemented by MICE collaborators at RAL.

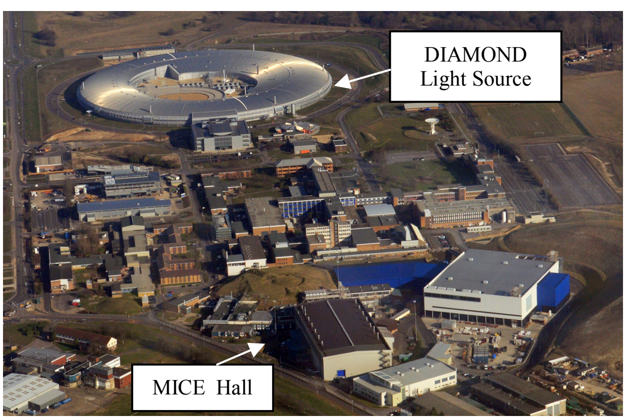

Figure 3: MICE experimental hall at RAL, UK

MICE BEAMLINE

The MICE muon beamline will be extracted from ISIS synchrotron at RAL. All magnets for MICE beamline have been installed, as shown in Figure 4 and the beamline location relative to ISIS is illustrated in Figure 5.

Figure 4: Magnets in MICE beamline (fish-eye lens view)

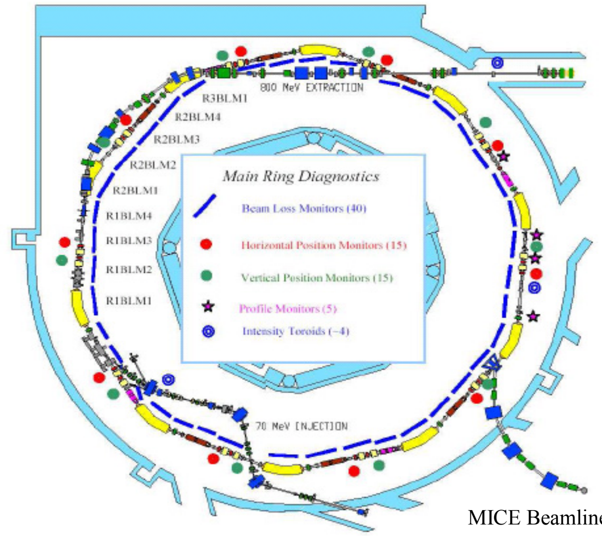

Figure 5: MICE beamline at ISIS of RAL

MICE TARGET

The MICE target is a thin slab of titanium with dimensions 35mm × 10mm × 1mm attached to the end of a cross shaped shaft 565mm long. The target is dipped into the beam at a rate of 1.0 Hz where it is assumed to interact with 1.4×10^{12} incident protons per pulse. The beam is assumed to be incident on the target 15mm from the base on the narrow face, a schematic of the MICE target insertion mechanismis illustrated in Figure 6. The first target was installed at ISIS in August 2009. It has been tested and successfully used for the MICE beamline commissioning.

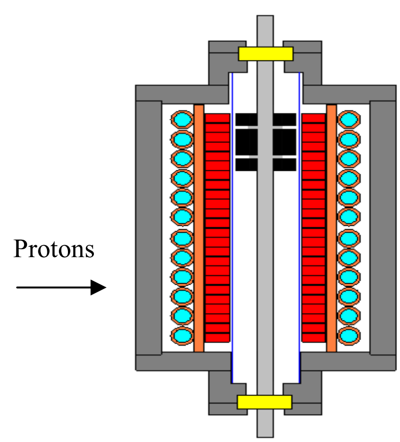

Figure 6: Schematic of MICE target insertion mechanism

MICE ABSORBER

There are three AFC (Absorber and Focusing Coil) modules in the MICE cooling channel. Each module has one liquid hydrogen absorber surrounded by a superconducting solenoid magnet, as shown in Figure 7. The AFC module design is complete; and a production readiness review was held recently. Fabrication contract of the AFC modules has been awarded. The first AFC module could be delivered to RAL as early as July 2010.

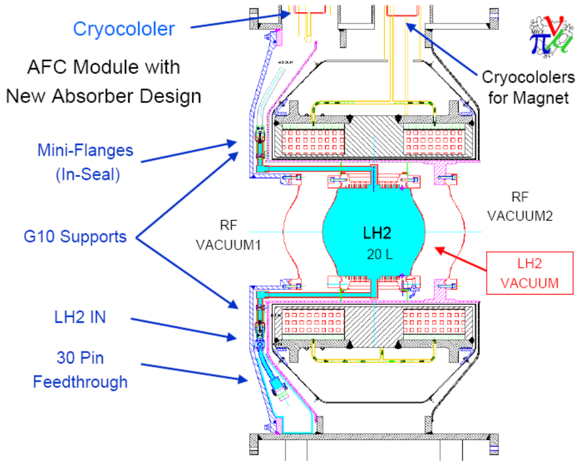

Figure 7: Schematics of the MICE AFC module

RFCC MODULE

There are two RFCC (**RF** cavity and **C**oupling **C**oil) modules. Each RFCC module consists of four 201-MHz normal conducting RF cavities surrounded by one superconducting solenoid (coil) magnet, as shown in Figure 8.

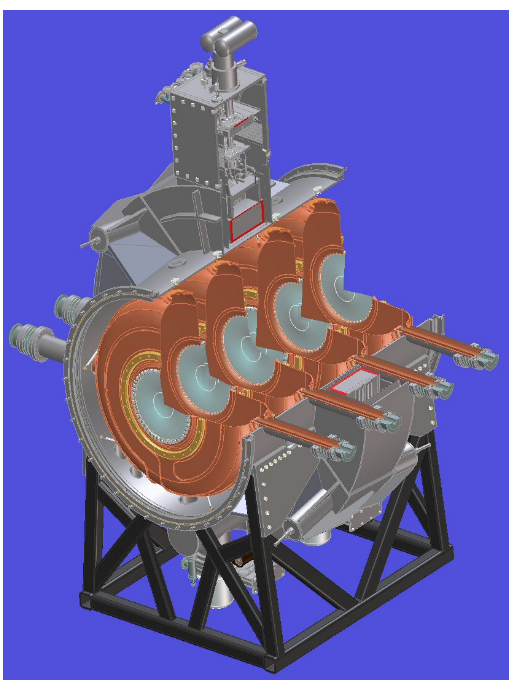

Figure 8: RFCC module: four 201-MHz normal conducting cavities and one superconducting solenoid (coil) magnet.

201-MHz Normal Conducting RF Cavity

MICE cavity design and fabrication techniques are based on a 201-MHz prototype cavity developed for the US MuCool program. Cavity body is formed by e-beam welding at the equator of two pre-spun half shells from ~ 6-mm copper sheets. The first 5-cavity fabrication contract was awarded to Applied Fusion, a company in California in early 2009. The fabrication has been progressing well; the first five cavities are nearly complete and could be delivered to LBNL in December 2009. Figure 9 is a photo taken in the summer of 2009 showing the fabrication progress. Each cavity has two coaxial loop couplers with integrated SNS type ceramic RF windows, and two curved thin beryllium (0.38-mm thickness) to cover the 42-cm open beam irises. Four cavities will be installed in a vacuum vessel, as shown in Figure 8. Therefore both the cavities and beryllium windows do not have differential pressures. Due to limited available RF power sources for MICE, each cavity will provide an accelerating gradient of 8 MV/m, corresponding to 1 MW peak RF power per cavity with 1-ms pulse length and 1 Hz repetition rate.

Figure 9: First five MICE cavities in fabrication.

Superconducting Coupling Coil Magnet

There are two superconducting coupling coil magnets in MICE cooling channel. The magnet design and fabrication are conducted through collaboration between Lawrence Berkeley National Laboratory (LBNL) and Harbin Institute of Technology (HIT) in China. A series of design reviews have been held. The engineering design is complete, contract bidding is in process. Each magnet is being cooled by cry-coolers. Three test coils have been winded. Figure10 and 11 show the engineering design model and a photo of hardware fabrication.

Fabrication of the MICE coupling magnets expects to start soon; the first magnet could be delivered in middle of 2011.

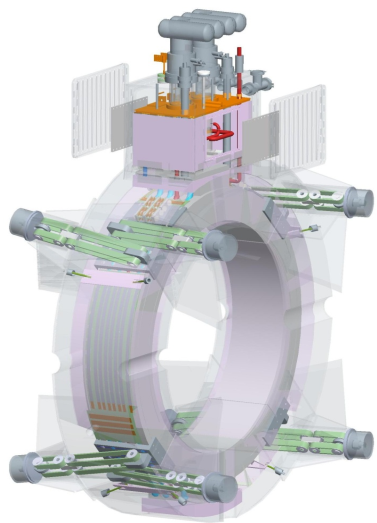

Figure 10: The MICE superconducting coupling coil magnet design (engineering model)

Figure 11: Coil mandrel under welding.

BEAMLINE COMMISSIONING

Beamline commissioning started in March 2008. We have successfully observed rates in beam counters versus the ISIS beam loss. Muon particles were observed using TOF/CKOV counters, as shown in Figure 14.

DETECTOR SYSTEM

The MICE detector system consists of two spectrometer solenoid magnets; one upstream and one downstream of the cooling channel. The system is designed to measure the full set of the muon emittance parameters. Each of the spectrometers provides a high-resolution measurement of the five parameters of the muon helix in a tracker embedded in a 4 T solenoid and a precise time measurement. Moreover, muon/pion/electron identifiers (a t_0 timing station and a small Cherenkov) are situated in front of the upstream detector and muon-electron identifiers (a larger Cherenkov and an electromagnetic EM-Calorimeter) are situated beyond the downstream spectrometer. The spectrometer magnet design and fabrication progress are shown in Figure 12 and 13, respectively.

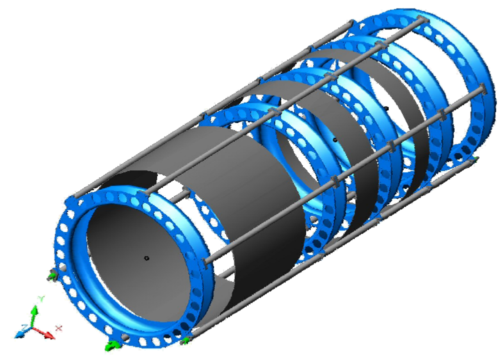

Figure 12: MICE spectrometer: Two trackers in 4-Tesla solenoid, with 5 SciFi tracking stations in each tracker.

Figure 13: One of the spectrometer solenoid magnets is being tested at the fabrication company.

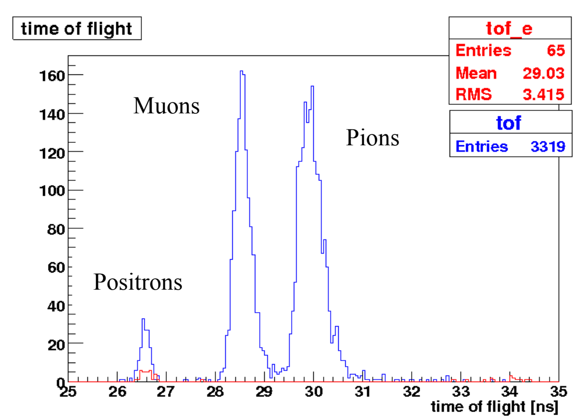

Figure 14: Particles were observed using TOF/CKOV counters at MICE beamline.

MICE SCHEDULES

MICE schedule has been delayed due some technical difficulties in hardware delivery and available funding. Figure 15 is the latest schedule for MICE with stepped approaches. The first emittance measurement with muon ionization cooling will occur in 2011 (STEP V).

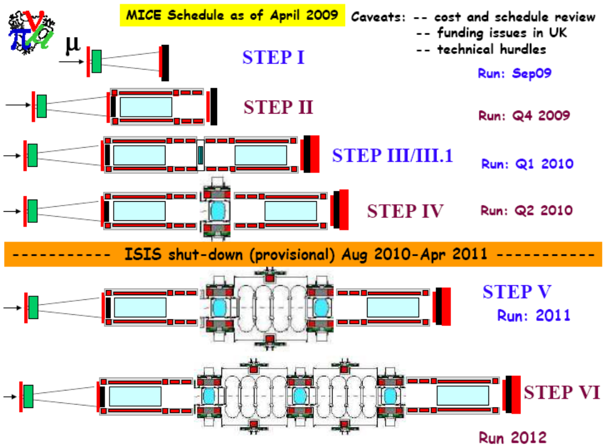

Figure 15: The latest schedule for MICE

SUMMARY

MICE target and detectors are all working now. MICE beamline has been commissioned successfully. The Experiment Hall for MICE and associated infrastructures, RF distribution design are nearly complete. Fabrication of hardware components for the MICE cooling channel are in progress. The first emittance measurement with muon ionization cooling will occur in 2011 (STEP V).

REFERENCES

[1] Technical notes and publications on MICE can be found at: http://www.mice.iit.edu