U.S. Muon Accelerator Program
Activity Description

Muon Ionization Cooling Experiment (MICE)

I. Introduction

This document describes a research plan put forth in response to the recommendations of the P5 subpanel report and as directed by the DOE Office of High Energy Physics (OHEP). Recommendation 25 of the P5 report states that OHEP should:

- ... consult with international partners on the early termination of MICE.

The goal of the MICE experiment is to design, engineer, and build a section of cooling channel capable of giving the desired performance for a Neutrino Factory and place this apparatus in a muon beam and measure its performance in a variety of modes of operation and beam conditions. When first approved, MICE was envisioned to be deployed and operated in 6 steps:

I. Muon beam characterization with time-of-flight (TOF) and particle identification (PID) detectors.
II. Test of the first spectrometer and measurement of beam parameters
III. Test of both spectrometers in beam
IV. Addition of one focus-coil module and LH_2 absorber (AFC). Multiple Coulomb Scattering (MCS), energy loss (dE/dx) and straggling studies
V. Addition of a RFCC module (acceleration) and an addition AFC module to measure multi-step (sustainable) cooling
VI. Addition of a second RFCC module and the final AFC. Continued study of cooling with re-acceleration in additional lattice configurations.

The novel nature of the magnet designs led to a series of technical delays, and after the beam was fully characterized, the collaboration decided to eliminate Steps II, III and V, i.e., go directly from Step I to Step IV and subsequently to Step VI. After the formation of the US Muon Accelerator Program (MAP) in 2011, a US-MICE construction project was formed in order to efficiently complete the remaining US deliverables for Steps IV and VI. At present, the magnets required for Step IV operation have been successfully delivered.

In December 2013 the MICE plan was presented to the P5 committee detailing the remaining work to be done for Step IV and Step VI. In parallel, MICE and MAP management had already initiated an internal study to evaluate the costs and benefits (science output vs. cost and schedule) of aiming to complete MICE at Step V instead of Step VI. This was extensively discussed at the MICE collaboration meeting in February 2014. By the time of the MICE Project Board (MPB) and Resource Loaded Schedule (RLS) reviews in April of 2014, MICE management and the US and UK funding agencies were in agreement that completing MICE at Step V was the optimum choice and would provide the crucial scientific demonstration of measuring multi-step (sustainable) cooling such that MICE could be declared a success. This action reduces the US MICE construction costs by approximately $10M and takes 3 years off the schedule. [note: cost savings for the US experimental and management teams are not included in this savings]. By the time the P5 report was officially released on May 23, 2014, the MAP and MICE management had already approved the above recommendation. Furthermore, this approach was endorsed by the collaboration at its meeting in June.

II. US MICE construction project

All but one of the US deliverables for MICE Step IV have been completed and delivered to RAL. The only remaining item is the Partial Return Yoke (PRY) that provides the magnetic shielding needed to contain the stray fields and prevent them from affecting various components in the MICE hall. Purchase orders for the steel plates, support structure and machining are in place (at Keller Technology Corp. in NY for the support structure and machining and at JFE steel in Japan for the steel plate) and fabrication is ongoing.

For MICE Step V, the US deliverables are the RFCC module and the PRY for the Step V configuration. [Note: The Step IV PRY is reused in Step V, but additional parts are needed.] The RFCC module consists of a 2.5T solenoid called the coupling coil magnet (CCM) and two RF modules each of which contains two 201 MHz RF cavities.

II.1 Step V PRY

A preliminary design of the Step V PRY extension exists. Final engineering is planned for the first half of FY15. Procurement of the components is then expected to take 6 months and should begin in early FY16 in our expedited Step V construction plan. We intend to use the same steel and fabrication vendors as for the Step IV PRY since the Step IV PRY components are also used in Step V PRY system

II.2 Coupling Coil magnet (CCM)

The first coil has been tested in the new Fermilab Solenoid Test Facility (STF) reaching a maximum current of 194A. We note that this current is sufficient for the Step V cooling demonstration and appears to be limited by excess heat from the power leads. An engineering solution for intercepting the heat from the power leads was successfully applied to the MICE spectrometer solenoids and these techniques will be applied to the CCM during final assembly. The cryostat for the CCM is complete and at Fermilab and work is underway to prepare the assembly area (in the Industrial Center Building at Fermilab) and to finalize the assembly tooling. The cooling circuit and thermal shield fabrication has started at LBNL and delivery to Fermilab is expected by November 2014. The cold-mass support design is complete and we intend to have these components fabricated commercially. Their delivery is also expected by November 2014.

II.3 RF

As of late July 2014, a full system test of all RF components in the RFCC module of MICE Step V is underway in the MTA at Fermilab. This single cavity test system (SCTS) incorporates all the final production components that will be used in the RF subassemblies of the RFCC module. Thus the SCTS study will demonstrate all of the design elements required for these RF subassemblies. Presently, all the RF cavities (+ 4 spares) have been fabricated, all the tuner forks have been fabricated and all the RF windows have been fabricated. We still need to fabricate the RF tuner actuators (24) and RF power couplers (8). We have final designs for these components, but will wait until we have results from the SCTS test before going out for fabrication. This will be in early FY15, so waiting for these results to further validate the design does not impact delivery, since funding for their fabrication will not become available until FY15. The SCTS test mitigates a number of risks associated with the MICE RF:

1. Assembly procedures
2. Tuning range and reproducibility
3. High power testing of cavity up to 2X that needed in MICE
4. Tests in magnetic field (up to 1.5T on window next to MTA magnet) with high power
5. RF Power coupler specific tests
    a) Tests in magnetic field at the full level seen in MICE
    b) B field tests on RF window

II.4 Personnel

Table 1 lists the principal MAP supported technical personnel on the MICE construction project.

Table 1: MAP-funded technical personnel on the MICE construction project

Institute	MICE Personnel	Position
BNL	S. Plate R. Ceruti	Engineer Technical
FNAL	N. Andreev J. Coghill S. Feher A. Nobrega W. Robotham P. Rubinov Technician pool (2 FTE)	Engineer Technical Scientist Technical Engineer Engineer Technician
LBNL	D. Cheng A. DeMello H. Pan S. Virostek Technician pool (1 FTE)	Engineer Engineer Postdoc Engineer Technician

III. MICE cost and schedule

Schedule for the Remaining U.S. MICE Deliverables to the Rutherford Appleton Laboratory (RAL):
(based on current RLS 14-07-24-MICE.pdf)

Step IV Partial Return Yoke (staggered fabrication and partial shipments to optimize overall MICE Step IV installation at RAL, arrival dates at RAL):

South Frame	November 26, 2014
South Steel Wall	January 24, 2015
North Frame	March 2, 2015
North Steel Wall	March 24, 2015

^{6}LiH Absorber Disk: Fabrication complete. Preparing material for shipment to RAL.

Step V Partial Return Yoke: November 1, 2016 for delivery of complete set of parts (South Frame, South Steel Wall, North Frame, and North Steel Wall). If it would not interfere with the running of the Step IV MICE Experiment, staggered partial deliveries of Step V PRY components could be arranged (as for the Step IV PRY) in order to escalate the Step V installation.

RFCC (for Step V): January 24, 2017

Table 2: MICE Cost Estimate for FY15-17 (construction ending in FY17). Costs for management, construction, component testing and experimental support are all included in the following budget.

MICE Estimate - in $K	FY15	FY16	FY17	sum FY15-17
1.01 Program Management	1,257	900	152	2,309
1.02 MICE Construction	4,337	2,721	1,351	8,409
1.03 MICE Component Testing at MTA	1,001	200	0	1,201
1.04 Support of MICE Experiment	1,207	1,178	0	2,385
MICE total not including R&D RISK=	7,802	4,999	1,503	14,304
estimate to mitigate R&D RISK =	1,200	1,000	1,500	3,700
MICE Est. incl R&D RISK mitigation =	9,002	5,999	3,003	18,004
Budetary Goal =	9,000	6,000	3,000	18,000

IV. MICE Operations and running

Section 4…

During the run-up to Step IV, the MAP contributions to MICE operations support entail:

- Spectrometer Solenoid field mapping and analysis
- Supervising the integration at RAL of US-provided MICE equipment
- Heading the Controls and Monitoring (C&M) group
- Leading the development of MICE offline software

To this end, MAP is providing the (on-site) MICE Integration Scientist (who also leads the C&M group) and the Offline Software Head. Each of these positions requires full-time effort in order to be ready for MICE Step IV data-taking next year. MAP-supported personnel also participated in the Spectrometer Solenoid training and mapping (at the vendor in California) and field-mapping data analysis.

Step IV running is scheduled to start in 2015 following installation of the north-side PRY wall (the south side having been installed previously). In order to cover the full relevant range of momenta, optics, and absorber properties, multiple operating configurations are planned for study: empty, LH_2, and LiH (and possibly plastic) absorbers at three input-emittance values (3, 6, and 10 π mm·rad) at 140, 200, and 240 MeV/c for a range of focusing settings at the absorber. Each condition will require acquisition of ~10^6 events, or about 10^4 seconds at 100 events/sec. (Since the MICE target is inserted into the beam with only a 10^{-3} duty factor, the instantaneous event rate is 1000 times higher.) Prior to these physics runs, a period of commissioning runs will of course be required, as well as periodic calibration runs and (≈2-day) absorber changes interspersed with physics running. This run configuration "accounting" leads to an overall estimate of about a year of running, subdivided into the four "user runs" scheduled by ISIS in 2015–16.

The principal focus of DOE-funded MICE operations support is intended to ensure that Step IV operations can be carried out successfully. The focus is thus on key support roles in the experimental team. The budget explicitly does not support a large experimental team to exploit the experimental program although we do propose to augment the experimental manpower by having members of the construction team participate, along with personnel from our Ionization Cooling design team, who are charged with incorporating MICE Step IV results into their codes. Since MICE Step V operations are expected to begin in early FY18, and hence are beyond the scope of this proposal, we rest on assurances from the US DOE and NSF that proposals for the experimental exploitation of Step V will be accepted as Step V comes together.

The ongoing US experimental support responsibilities on MICE are anticipated to be calibration of the (US-built) Tracker scintillating-fiber (SciFi) detectors and their front-end, readout, and data-acquisition subsystems, calibration of the Ckov and TOF particle-ID detectors, and maintenance of these and the C&M systems. Table 3 shows MICE experimental collaboration members presently supported through MAP funding.

We note that a proposal has been submitted to the US NSF for expansion to fund a broader US experimental team for Steps IV and V. Although outside the scope of this DOE proposal, we strongly support broadening US support for exploitation of MICE Step IV in the near-term and MICE Step V on a longer timescale. Appendix A-1 briefly summarizes the situation with respect to MICE NSF support and currently NSF-supported manpower.

Table 3: MAP-funded scientific personnel on MICE experiment commissioning and operations.

Institute	MICE Personnel	Position
BNL	R. Palmer	Scientist
	H. Witte	Scientist
LBNL	D. Li	Scientist
	T. Luo	Postdoc
Fermilab	A. Bross, MICE Deputy Spokesperson	Scientist
	D. Adey	Postdoc
	S. Feher	Scientist
	M. Leonova	Scientist
	M. Popovic	Scientist
IIT	D. Kaplan (MAP L2 manager for MICE and NSF Consortium PI)	Faculty
	P. Hanlet, Expt. Integration Scientist	Research Faculty
	D. Rajaram, Offline SW Head	Research Faculty
	P. Snopok	Faculty
	Y. Torun	Faculty

Appendix 1: NSF support of MICE collaborators

MICE has benefited from significant NSF support: MRI grants to IIT and the Univ. of Mississippi and base grants to a consortium that has included groups from the Universities of Chicago, IIT, Iowa, Mississippi, New Hampshire, and California at Riverside. Current NSF-supported MICE personnel are shown in Table A-1. A consortium renewal proposal to NSF is currently under review.

Table A-1: NSF-supported personnel on MICE experiment operations

Institute	MICE Personnel	Position
IIT	D. Kaplan, NSF PI [1] M. Drews M. Winter	Faculty Undergraduate Undergraduate
U Mississippi	D. Summers, NSF PI L. Cremaldi, NSF Co-PI	Faculty Faculty
UC Riverside	G. Hanson, NSF PI C. Heidt	Faculty Graduate student

[1] Travel funds only