MICE bimonthly project update ♯7

1 Introduction

This, the seventh bimonthly progress report, presents the status of the project at the end of December 2016. The updated project dashboard may be found at `http://micewww.pp.rl.ac.uk/dashboard/`.

Executing the Step IV programme

The collection of data for the execution of the scientific programme of Step IV is proceeding according to the schedule agreed through international and national peer review. Data-taking for both the field-off and the field-on lithium-hydride (LiH) scattering programme is complete. Data has been taken over a range of emittance for a variety of beam momenta for the study of the ionization-cooling effect of LiH with the magnetic channel in solenoid mode. Initial analysis of this data indicates that reduction of normalised transverse emittance can be observed with MICE.

The next ISIS User Cycle will start with the collection of data in flip mode to continue the study of ionization cooling with LiH.

ISIS has cancelled User Cycle 2017/02 which was to have taken place from mid July to mid August 2017. The loss of this user Cycle clearly impacts the collaboration's ability to deliver the full scientific programme of Step IV unless the experiment is permitted to take data in Cycle 2017/03 which is scheduled to start on the 19th September 2017 and run to the 27th October 2017. The collaboration plans to make a case for data taking in Cycle 2017/03 at the March 2017 meeting of the MICE Project Board.

Publications

The EMR-hardware paper [1] and the tracker-software paper [2] have been published. Three papers are currently in preparation: "Direct measurement of emittance using the MICE scintillating fibre tracker" [3]; "Multiple Coulomb Scattering in lithium-hydride" [4]; and the "Design and expected performance of the MICE demonstration of ionization cooling" [5]. Preliminary results on all three papers were presented at the summer conferences (for representative summaries see [6–8]). A final revision of the cooling demonstration paper is being made following comments from the collaboration. The paper will be submitted to the journal early in the New Year.

Liquid-hydrogen absorber

The attempt to cool the liquid-hydrogen (LH_2) absorber in R9 in November 2016 was not successful. Remedial work on the LH_2 turret and the absorber windows is now complete. Pump-down of the system began on the 21st December 2016 and the cool-down was initiated on the 23rd December 2016.

Since it has not yet been possible to demonstrate that hydrogen will successfully be liquefied, the project still carries the risk that the LH_2 scattering and emittance-evolution programme can not be carried out. Since, in addition, the project still carries the risk of further degradation of the performance, or failure, of the downstream solenoid (SSD), the MICE-UK oversight committee permitted the consideration of means by which the scientific output of the experiment could be maximised should either risk (failure to liquefy hydrogen, further failure of SSD) occur. The collaboration has therefore completed the design of the reconfigured tracker to be used in a modified cooling-demonstration configuration [9]. The components to allow the reconfigured tracker to be assembled will be manufactured at NIKHEF in the New Year. In addition, the two single-cavity modules which have been under construction at LBNL will be completed and shipped to RAL in February or March of

2017. The collaboration has therefore made it possible to deliver a first-rate scientific programme in the event of one or both of the risks mentioned above being realised.

Personnel changes

Over the reporting period, K. Long has been elected Spokesman for a second term and A. Bross has been re-appointed as Deputy Spokesman. C. Rogers (STFC, ASTEC), D. Rajaram (IIT) and J. Pasternak (Imperial) will continue as Physics Coordinator, Software and Computing Coordinator and Accelerator Integration Scientist respectively. P. Hanlet (IIT), who is presently the Experiment Integration Scientist and Controls and Monitoring Coordinator will leave the experiment in February 2017. A. Kurup (Imperial) will take over the Controls and Monitoring Coordinator role and P. Hodgson (Sheffield) will take on the Experiment Integration Scientist role. P. Hanlet is also the on-site expert for the spectrometer solenoids. Negotiations are underway to define the necessary continuation of on-site expert cover for the spectrometer solenoids.

Upgrade proposal

The high-quality data that has been collected through the smooth operation of the experiment at Step IV has allowed the collaboration to devise an upgrade to the Step IV configuration by which a demonstration of ionization cooling could be delivered. The upgraded experiment is based on the configuration described in [9]. It is the collaboration's intention to bring forward a fully costed proposal for the minimum upgrade necessary to deliver a cooling demonstration in time for it to be considered by the MICE Project Board at its next meeting.

International context

The CERN Director General has initiated the "Physics Beyond Colliders" workshop to study scientific opportunities for CERN that fall outside the LHC programme. The possibility that a muon storage ring (nuSTORM) could be implemented at CERN to allow precise and detailed measurements of neutrino-nucleus cross sections to be made will be studied as part of this workshop.

2 Data taking and analysis

2.1 Operations

Over the reporting period ISIS have completed User Cycles 2016/03 and 2016/04. In 2016/03 MICE operated a 16-hour per day shift cycle. 160 shifts were offered to the collaboration with 150 taken up. The spectrometer solenoids and focus coil were all operating during the Cycle; Cycle 2016/03 was the first in which data was taken with the entire magnetic channel energised. The second user cycle, 2016/04, was, if anything, even more successful. A full 24-hour/7-day data-taking programme was executed. All 155 allocated shifts were taken up. All channel magnets were operational over the full Cycle.

The data-taking program included multiple-scattering and energy-loss measurements with a lithium-hydride absorber and a series of investigations into emittance evolution using beams of different momentum and emittance. The latter series of the measurements required the spectrometer solenoids and the focus coil to be ramped to five different settings. The channel magnets operated flawlessly, ramping to each requested setting without problems and operating stably during changes of current. The stable operation of the full channel and 24-hour data-taking allowed as much data to be taken during 2016/04 as was taken since January 2016. Figure 1 shows the integrated number of particle triggers collected this year; 88.9×10^6 triggers were collected.

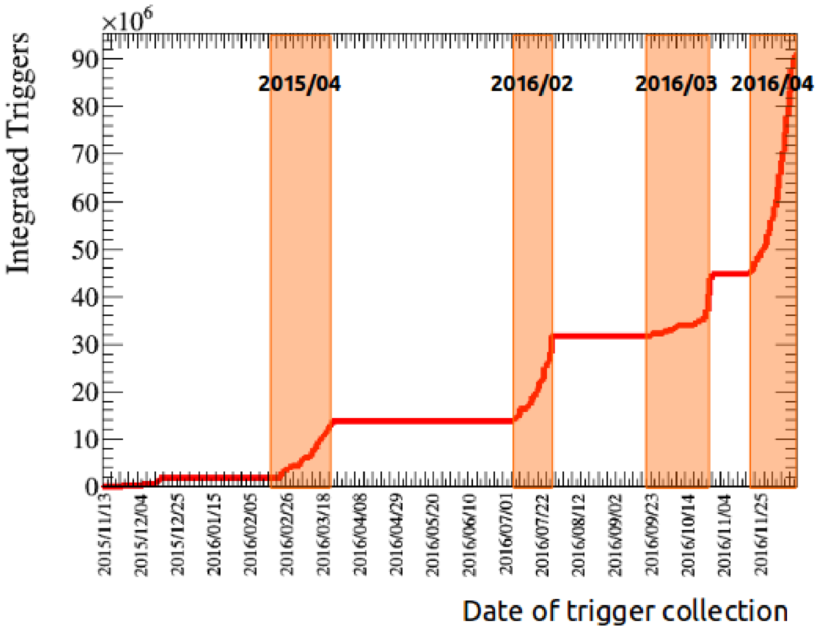

Figure 1: The integrated number of particle triggers collected by the MICE experiment in 2016. The shaded bands highlight the ISIS user cycles during which MICE was operational. MICE has collected just under 90×10^6 particle triggers this year.

The next User Cycle, 2016/05, begins on the 14^{th} February 2017 and lasts for 6 weeks. The data-taking plans for this Cycle are still under discussion. The LiH emittance programme will be completed by taking data in flip mode. Details of the run plan will be agreed in January 2017. During the 2016/05 Cycle the decision on whether to power the M2 coil in SSD will be made and the measurement program adjusted according to the outcome of this decision.

2.2 Analysis

Over the review period the paper documenting the construction and performance of the EMR [1] and the paper describing the tracker software [2] have been published. Three papers are currently in preparation: "Direct measurement of emittance using the MICE scintillating fibre tracker" [3]; "Multiple Coulomb scattering in lithium-hydride" [4]; and the "Design and expected performance of the MICE demonstration of ionization cooling" [5]. Preliminary results on all three papers were presented at the summer conferences (for representative summaries see [6–8]). The key results were summarised in our last report [10].

In the emittance-measurement paper, the collaboration will demonstrate the reconstruction of the emittance of the beam entering the upstream solenoid. The publication is based on a short run with a field of 4 T in the upstream solenoid that was taken in the autumn of 2015. At present analysis is focused on the determination of the systematic uncertainties. In particular, particles incident on the upstream solenoid may pass through the mechanism that actuates the diffuser. The mechanism, together with the diffuser plates in the "out of beam" position, presents a significant amount of material to the beam causing the particles that pass through it to loose a substantial amount of energy. Tracks reconstructed in the tracker have been extrapolated to the position of the diffuser, those that pass too close to the edge of the diffuser mechanism are rejected. The effect of uncertainties on the detector response on the measured emittance and z-momentum have been assessed by comparison of data with Monte Carlo simulation. The resulting uncertainties are considerably lower than the statistical errors of the small data sample.

The scattering paper will report the measurements of multiple Coulomb scattering of muons on lithium hydride using the field-off data taken in the winter and spring of 2016. Over the reporting period work has focused on the estimation of systematic uncertainties. The dominant uncertainty is that related to the estimation of muon momentum from the time-of-flight detectors, which is due to the non-co-axial trajectory of muons used in the analysis. A new study has been added to compare the scattering width with semi-analytical models of scattering in many different momentum bins. A first meeting of the lead authors of the scatting paper and the "MICE internal" referees recommended several refinements to the paper. A new analysis was requested to assess more carefully the bias introduced by acceptance and detector inefficiency. This work is now underway.

The demonstration-of-ionization-cooling paper has been approved by the internal referees and distributed for comment to the collaboration. The revised paper will be distributed once more early in the New Year before it is submitted to the arXiv and the Physical Review Accelerators and Beams (PRAB).

2.2.1 Analysis of data collected during ISIS User Cycle 2016/03

During ISIS User Cycle 2016/03 field-on data was collected to complete the LiH multiple-Coulomb-scattering programme and to study energy loss.

The measured momentum-loss distribution is compared to simulation in figure 2. The simulated momentum-loss distribution is strongly influenced by experimental (detector and reconstruction) effects. After experimental effects have been taken into account, the simulated momentum-loss distribution is in reasonable agreement with the data. Work is ongoing to remove instrumental effects from the momentum-loss distribution through deconvolution.

The field-on measurement of multiple Coulomb scattering in the absorber is also progressing. The advantage of this analysis is that muons that undergo large angle scatters are transported along the beam line. This enables an analysis of the tails of the multiple-Coulomb-scattering distribution to be made. The tracks have been extrapolated to the absorber and the change in angle of the tracks due to scattering in the absorber has been studied. At present the analysis is focused on validating the track-extrapolation routines and understanding issues related to magnet alignment.

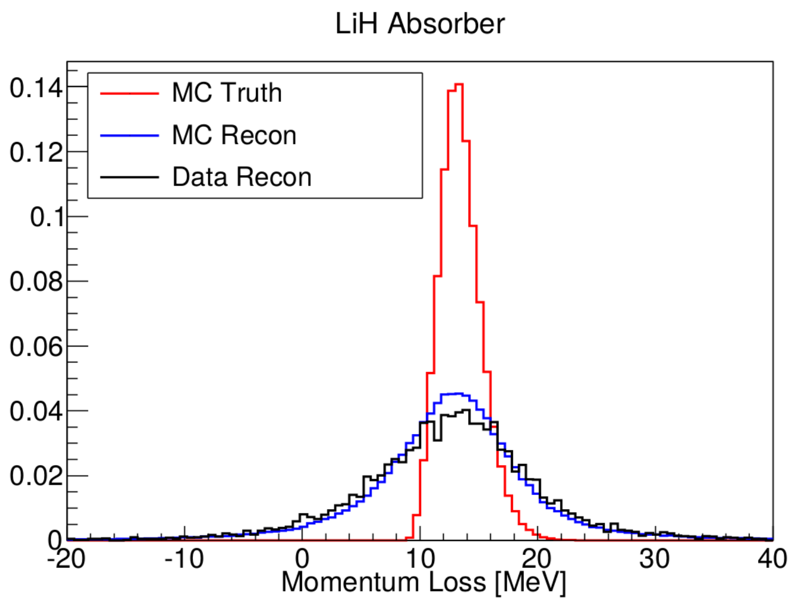

Figure 2: Measured change in momentum for a set of muons passing through the lithium-hydride absorber is shown as the black histogram. The simulated momentum-loss distribution is shown in red ("MC Truth"). The simulated momentum-loss distribution after detector and reconstruction effects have been taken into account is shown in blue ("MC Recon").

2.2.2 Data collection during ISIS User Cycle 2016/04

During ISIS User Cycle 2016/04 data was collected to study the evolution of normalised transverse emittance in the magnetic channel. Data was taken with a number of different momentum and focusing conditions to study the dependence of the emittance change on these parameters. Preliminary analysis indicates that the behaviour of the lattice is in agreement with that expected from Monte Carlo simulations. Analysis of tracks extrapolated from the upstream tracker to the downstream tracker indicates that mean trajectory offsets are at the level of a few millimetres, which is consistent with the known precision of the magnetic-field alignment. A deficit of tracks in the downstream tracker has also been observed. Initial studies indicate that the hardware performance is compatible with cosmic and test-beam exposures and with data collected earlier this year in the MICE Hall. Potential issues related to the efficiency of the pattern recognition in the downstream tracker are being explored.

Figure 3 shows the distribution of transverse amplitude for samples of the data taken at 140 MeV/c with nominal input emittance of 6 mm and 10 mm. Good muons are defined to be those that pass through the whole apparatus, i.e. these muons are measured in both the upstream and in the downstream trackers. Transverse amplitude is calculated at the tracker reference surface (the measurement surface of the station closest to the absorber). The transverse-amplitude distribution of muons observed in the upstream tracker that are not observed downstream indicates that transmission losses are dominated by muons with a large transverse amplitude upstream of the absorber. If the combination of energy loss in the LiH and the optics of the channel are such as to produce ionization cooling, then the population at low transverse amplitude measured in the downstream tracker should be larger than that measured in the upstream tracker. Figure 3 shows an indication of such an effect in the 6 mm data. In the 10 mm data, an excess of events at low transverse amplitude is observed in the downstream distribution for transverse amplitudes below $\sim$ 20 mm. This is the first indication that the international Muon Ionization Cooling Experiment will be able to demonstrate, and study, ionization cooling in the MICE Muon Beam.

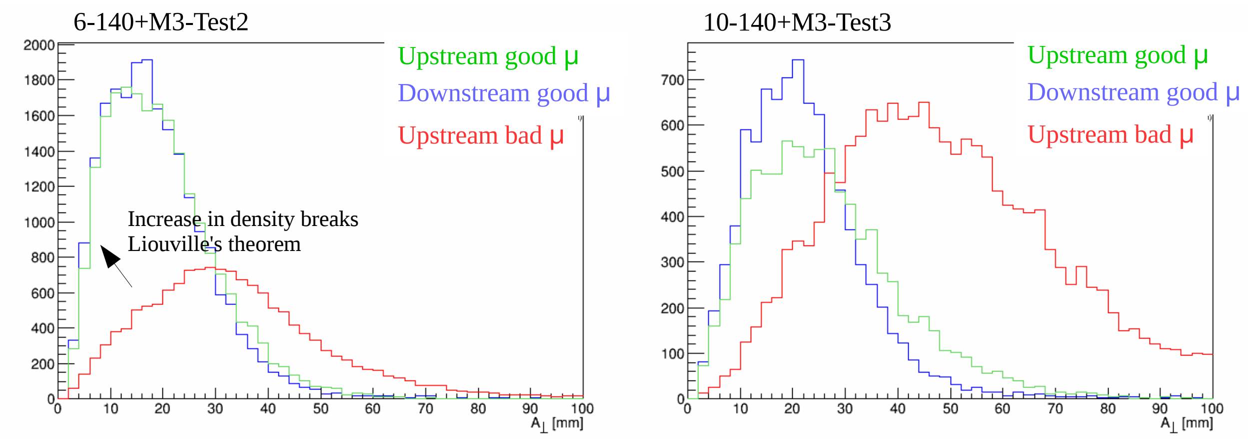

Figure 3: Distributions of transverse amplitude measured at the upstream and downstream tracker reference surfaces for 140 MeV/c beams with nominal input emittance of 6 mm (left panel) and 10 mm (right panel). Muons observed in the detectors upstream and downstream of the lithium-hydride absorber are labelled good muons ("good μ"). The distribution of transverse amplitude at the reference surface of the upstream (downstream) tracker is shown in green (blue). Muons observed in the upstream tracker that do not appear in the downstream tracker are labelled bad muons ("bad μ"). The distribution of transverse amplitude for bad muons at the reference surface of the upstream tracker is shown in red.

3 Magnet commissioning

3.1 Spectrometer solenoids

Final upgrades to the spectrometer-solenoid quench-protection systems (hardware and software) are now complete. The principal upgrades implemented include:

- The implementation of new QPS software that is able to validate the duration of the "External Trip Fault" signal to prevent the opening of the contactors due to large, sharp spikes in the noise generated by the power-supply-interlock systems; and
- The disabling of the HTS and LTS signals from the quench-detectors for the "F" and "G" leads of SSD. These leads are the "return" from the "end" coils and are subject to large noise signals due to a short between voltage taps. The end coils in SSD will not be used and these leads may therefore safely be disconnected.

In addition, work to increase the stability of the power-supply control systems has continued; almost all issues have now been addressed. Some communication issues remain with the AMI 420 controllers that interface to the TDK-Lambda Genesys power supplies. Work on communication with the AMI 420s will continue in the Christmas 2016 ISIS shutdown.

During the testing of SSD with current it was observed that the voltage signals recorded on the LTS and HTS leads are relatively high. These voltages are proportional to the rate of change of the magnet current (dI/dt). Further investigation revealed that there is a short between two voltage-tap wires: VTL-04 (F lead bottom end of HTS) and VTL02 (G lead bottom end of HTS). Since these voltage taps are responsible for the voltage measurements on both the LTS and the HTS segments of the F and G leads, all four voltage segments showed voltages proportional to the voltage drop across the centre coil. Based on these results, the voltage taps for the F and G leads of SSD were disconnected. In the upstream spectrometer solenoid (SSU), the trim coils can be used, since the magnet has no voltage-tap or ground-fault issues.

The control issues with the Lakeshore 625 power supplies, which provide the "trim current" for the end coils, have been resolved. To simplify the system, the end coils are not presently in use. As noted above, the end coils on SSD will not be used because of the short between voltage taps. To simplify the system, the trim coils are not presently in use on SSU. The absense of operation of the end coils does not affect the efficiency of the pattern recognition. The additional, small, non-linearity in the magnetic field will be taken into account in the final track fit.

The parameters in the spectrometer solenoid QPS have been optimised. The systems have now been in stable operation for many weeks. The "External Fault Trip" validation time was set to 650 msec, which has suppressed "sympathetic" contactor opening during tests.

A simulation of forces on the SS cold masses has been completed and no operational issues have been identified with any of the magnet settings that have currently been proposed. The estimated forces are also below those experienced during testing at the manufacturer.

3.2 Focus-coil module

Over the reporting period the cooling-water supply was stabilised. The $18°$C supply-water temperature improved the cryogenic performance; the system is able to control the pressure using the heater both at rest and at field (up to ~ 100 A, to date). There is no indication that there would be a degradation at higher currents. The pressure within compressor/cold-head circuit has been monitored and adjusted slightly to 340 psi. This allowed a good cryogenic performance to be established such that the module can fill itself with helium slowly from a supply of room-temperature gas.

The axial magnetic-displacement force has been added to the mimic, allowing very simple and immediate information on the magnetic interaction with the spectrometer solenoids to be recorded. This has been used to validate the finite-element calculations of the inter-module forces mentioned above. The maximum external magnetic force measured on the focus-coil cold mass to date has been 13 Tons.

4 Schedule

Over the reporting period a significant number number of mechanical works have been completed, including:

- The repair of two air conditioning units in MICE Hall;
- The installation of a fifth air-conditioning unit to provide additional cooling capacity and redundant coverage for any future issues that might arise with the environmental controls;
- Commissioning of an additional external chiller in the MICE Hall "loading bay" to provide fail-over cooling capacity for the superconducting magnets should the "roof system" fail;
- The re-configuration and re-commissioning of the roof-based cooling system. This work was carried out with assistance from ISIS;
- The separation of the cooling systems for the superconducting and warm magnet systems. This allows the use of "town water" for the cryocooler compressors while retaining low conductivity in the warm-magnet and warm-magnet power-supply circuits;
- The commissioning of the new warm-magnet water-system, including the controls and monitoring and integration into the experiment's EPICS system;
- The service of the decay solenoid fridge system including a new "air-end" for the Kaeser compressor; and
- The checking of the PRY and superconducting-magnet-support-bolt torques.

A number of important modifications to the controls and monitoring systems have also been completed, including:

- Increased protection to operator error in both the spectrometer-solenoid and focus-coil control systems—an essential addition when moving to routine operations;
- Written operating procedures for the FC and SS magnets;
- Improved quench-protection for the spectrometer solenoids including compensation for voltages induced by the ramping of the FC magnet. The upgraded system has the benefit that it records the relative timings of all current excursions in the EPICS control-and-monitoring system, an important addition when quench propagation needs to be determined after a trip event;
- The addition of a "spike catcher" to the quench logging to allow the capture and study of events below the quench-detector trip threshold—this to aid diagnosis of signals seen on the SS voltage tap connections during running;
- Improved quench logging for the FC magnet system; and
- Implementation of communication delays to serial communications for the Lakeshore, Cryo-mech and AMI systems. In conjunction with "rogue-value detection" software (comparison of received values with the preceding 5 values and rejection of the value if a large discrepancy is found) has completely eliminated errors from the Lakeshore systems. The Cryo-mech and AMI systems are also much improved. This work was not completed prior to the start of the ISIS User Cycle 2016/03 and will be been picked in the Christmas 2016 shutdown.

Commissioning of the magnet string to a nominal field of 3 T in the spectrometer solenoids was completed on Friday 16^{th} September 2016. During commissioning of the magnet string additional noise was measured on one of the voltage taps from the trim/centre coil connections in SSD, which temporarily prevented use of the active ground fault detection system. The problem has now been mitigated by the supply of heated air flow to keep the connectors dry. The problem was compounded by the impedance to ground presented by the magnet trim power supplies which are not fully floating. A study of the effect on the analysis of a failure to use the end coils was performed and demonstrated that the absence of the end coils did not degrade the pattern recognition performance. Since the small field non-uniformity can be accommodated in the final track fit, it was decided to simplify the spectrometer-solenoid power-supply system by removing the trim supplies from the circuit. This removed a number of sources of noise from the QPS system without impairing magnet protection and has allowed trouble-free operation of the superconducting magnet systems during ISIS 2016/04.

The focus coil was extracted from the beam line and the LiH absorber was inserted during the short ISIS shutdown between ISIS 2016/03 and ISIS 2016/04. During this operation an autonomous ramp of one of the match coils of SSU was observed. The magnet expert on duty at the time noted the event and paused the ramp while the current was still low. The Duty Coordinator reported the event to the Group Leader in Matters of Safety as required. The Safety Health and Environment Group registered the incident as "serious or potentially serious" (SoPS) because, even though the magnetic field levels reached were not dangerous, the PRY was partially dismantled and free ferrous material was present near the area where high magnetic fields could have been generated. A review of MICE safety management has been scheduled to begin in the New Year under the chairmanship of T. Durkin (RAL, PPD).

Technical investigation of the autonomous-ramp event concluded that the potentially serious consequences of the autonomous ramp occurred as a result of insufficiently clear documentation and procedures provided for the Duty Coordinators together with imprecise application of the MICE operating protocols. The documentation has been amended and a number of procedural improvements have been made. Together these actions eliminate the possibility of powering any magnet while the PRY is incomplete. The technical investigation, however, did not provide definitive evidence of the cause of the autonomous-ramp event. A second autonomous-ramp event has since been observed during a ramp between magnet settings. A number of detailed changes to the controls-and-monitoring software significantly reduce the possibility of any future autonomous ramp and we have successfully operated the superconducting magnet channel for all of ISIS User Cycle 2016/04 without incident. This leads us to believe that the magnet channel can be operated safely with the current controls-and-monitoring software, but, the aforementioned incidents must be fully investigated to attempt to determine their cause. A rolling review of the controls-and-monitoring system has been established to investigate the controls-and-monitoring system. The objective is to find the cause of the autonomous-ramp behaviour or to determine that the probability of a recurrence is sufficiently low for the present mode of operation to continue. The review is chaired by K. Long (Imperial/ASTeC) and the review team includes B. Martlew, the Daresbury Laboratory Controls Group Leader. Technical experts from MICE make up the remainder of the review panel.

During the absorber change it was discovered that in the absence of the FC and a locked-out set of bellows, SSU and SSD were able to relax slightly on their mounts, releasing the strain accumulated during the preceding months of operation. It was necessary to return SSU and SSD to their former positions to allow the re-insertion of the FC. SSU and SSD were then re-surveyed for position.

The hydrogen system was cooled in R9 to below 40 K for the first time. Further cooling to the target 20 K was not possible due to the higher-than-expected heat load on the second stage of the cold-head. A number of improvements have been made, including:

- The removal of two pipes within the hydrogen turret that form part of the "pre-cool" circuit. The pre-cool circuit will not be used and the pipes in question caused a heat-leak within the hydrogen turret;
- The removal of a further two "pre-cool circuit" pipes outside of the hydrogen turret but within vacuum space that surrounds the hydrogen absorber vessel. These pipes caused an additional radiative load within the insulating vacuum;
- The removal of one hydrogen-supply pre-cool capillary pipe;
- The disconnection of two poorly-positioned thermal shorts in the hydrogen turret;
- The re-location of one stainless pressure-transducer link pipe;
- Additional heat sinking of four support struts within the hydrogen turrets. The shorts will move the heat load from the over-loaded second stage to the under-loaded first stage of the cryo-cooler;
- The installation of additional of MLI on absorber windows; and
- Increased clearance between the hydrogen-supply pipe and the magnet warm bore.

The measures detailed above are sufficient to warrant a further cooling attempt. The module is now re-assembled in R9. Pump-down began on the 21st December 2016 and the cool-down was initiated on the 23rd December 2016.

ISIS User Cycle 2016/05 has been planned in 2 stages. The first three weeks of the data-taking period, which starts on the 14th February 2017, will be dedicated to further study of emittance evolution using LiH in the "flip-mode" configuration. In preparation, commissioning of the focus coil in flip mode within the PRY will be carried out early in January 2017. The actions to be taken in the second three week period will be determined in January 2017 when the result of the second cool-down of the LH_2 system is known. If the LH_2 absorber achieves the required temperature in January 2017 it may be desirable to sacrifice a small amount of data taking time at the end of ISIS 2016/05 in order to gain more data-taking time with LH_2 during ISIS User Cycle 2017/01.

5 Risk

There have been no changes to the Risk Register over the reporting period. It was planned that the project would be in a position to retire the risk associated with the cooling of the liquid-hydrogen absorber in November 2016. This has not been possible but the progress made to date indicates that there is a reasonable probability that this risk can be retired in January 2017. The uncertainty in data-taking introduced by the retention of this risk has been mitigated by the use of a flexible plan for ISIS User Cycle 2016/05 as noted above. The anticipated evolution of risk is shown in figure 6.

Key risks from the project risk register are presented in table 1. MICE 23, the risk associated with the failure of equipment continues to be relevant as the equipment ages. Some of the costs related to maintenance and replacement of equipment have been anticipated and it will therefore be possible to manage the costs so incurred within this years budget. MICE 8, resourcing issues from the STFC and national labs, may rise in importance in the New Year as attempts to recruit new technical staff externally in collaboration with ISIS have not been successful. Additional technical resource will therefore need to be sought from within the RAL site staff and/or, possibly, from the University groups.

References

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[2] A. Dobbs, C. Hunt, K. Long, E. Santos, M. A. Uchida, P. Kyberd, C. Heidt, S. Blot, and E. Overton, "The reconstruction software for the MICE scintillating fibre trackers," *JINST* **11** (2016), no. 12, T12001, `1610.05161`.

[3] The MICE collaboration, "Direct measurement of emittance using the MICE scintillating fibre tracker." `http://micewww.pp.rl.ac.uk/projects/analysis/wiki/Direct_measurement_of_emittance_using_the_MICE_scintillating_fibre_tracker`.

[4] The MICE collaboration, "Multiple Coulomb Scattering in Lithium Hydride Absorbers." `http://micewww.pp.rl.ac.uk/projects/analysis/wiki/Multiple_Coulomb_Scattering_in_Lithium_Hydride_Absorbers`.

[5] The MICE collaboration, "Design and expected performance of the MICE Demonstration of Ionization Cooling." `http://micewww.pp.rl.ac.uk/projects/analysis/wiki/Design_and_expected_performance_of_the_MICE_Demonstration_of_Ionization_Cooling`.

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[7] R. Bayes, "Measurements of the Multiple Coulomb Scattering of Muons by MICE," in *18th International Workshop on Neutrino Factories and Future Neutrino Facilities Search (NuFact16) Quy Nhon, Vietnam, August 21-27, 2016*. 2016.

[8] J.-B. Lagrange, C. Hunt, V. Palladino, and J. Pasternak, "The MICE Demonstration of Muon Ionization Cooling," in *Proceedings, 7th International Particle Accelerator Conference (IPAC 2016): Busan, Korea, May 8-13, 2016*, p. TUPMY004. 2016.

[9] K. Long and C. Whyte, "Progress in redefining the scope of the cooling demonstratiaon." `http://micewww.pp.rl.ac.uk/documents/177`, 2016.

[10] The MICE Executive Board, "MICE bimonthly project update ♯6." `http://micewww.pp.rl.ac.uk/documents/180`, 2016.

31st July 2017	Combined magnet operational tests to 2T complete	Combined magnet operational tests to 3T complete	LiH operational	Liquid Hydrogen system operational	1st operation of M2D	End of Step IV Operations	End of Analysis
May-16	31/07/16	15/08/16	15/11/16	14/02/17	15/04/17	31/07/17	31/07/18
Jul-16	26/07/16	15/08/16	15/11/16	14/02/17	15/04/17	31/07/17	31/07/18
Aug-16		16/09/16	15/11/16	14/02/17	15/04/17	31/07/17	31/07/18
Sep-16			15/11/16	14/02/17	15/04/17	31/07/17	31/07/18
Oct-16			15/11/16	14/02/17	15/04/17	31/07/17	31/07/18
Nov-16			15/11/16	14/02/17	15/04/17	31/07/17	31/07/18
Dec-16			15/01/17	02/05/17	15/05/17	31/07/17	31/07/18
Jan-17							
Feb-17							
Mar-17							
Apr-17							
May-17							
Jun-17							
Jul-17							
	on time	<1 month	1-2 months	2-4 months	4+ months	Complete	

Figure 4: MICE project dashboard. Following the national and international reviews of the project that took place in the spring and early summer of 2016, only those milestones pertaining to the Step IV programme have been retained. In future, changes in the projected milestone-completion dates are indicated using the colour code defined in the legend. Completed milestones are shaded grey.

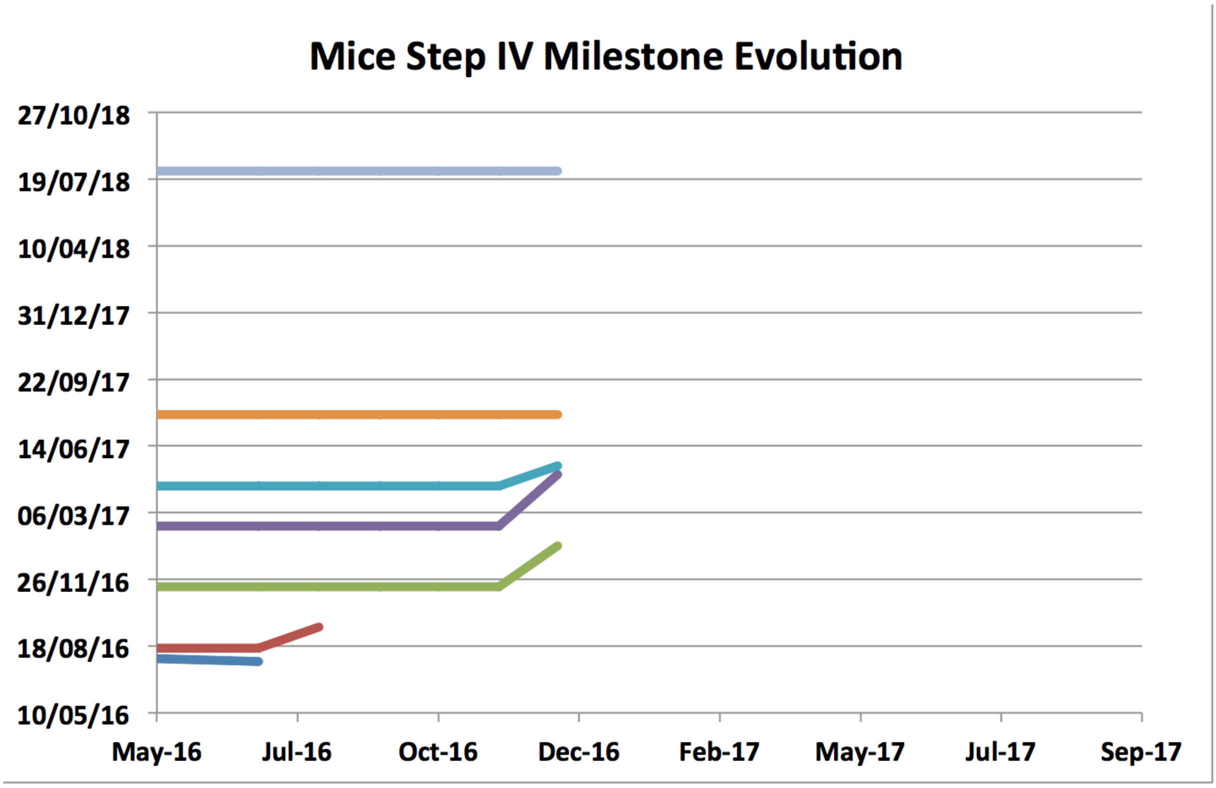

Figure 5: MICE milestone-slip chart. Following the national and international reviews of the project that took place in the spring and early summer of 2016, only those milestones pertaining to the Step IV programme have been retained.

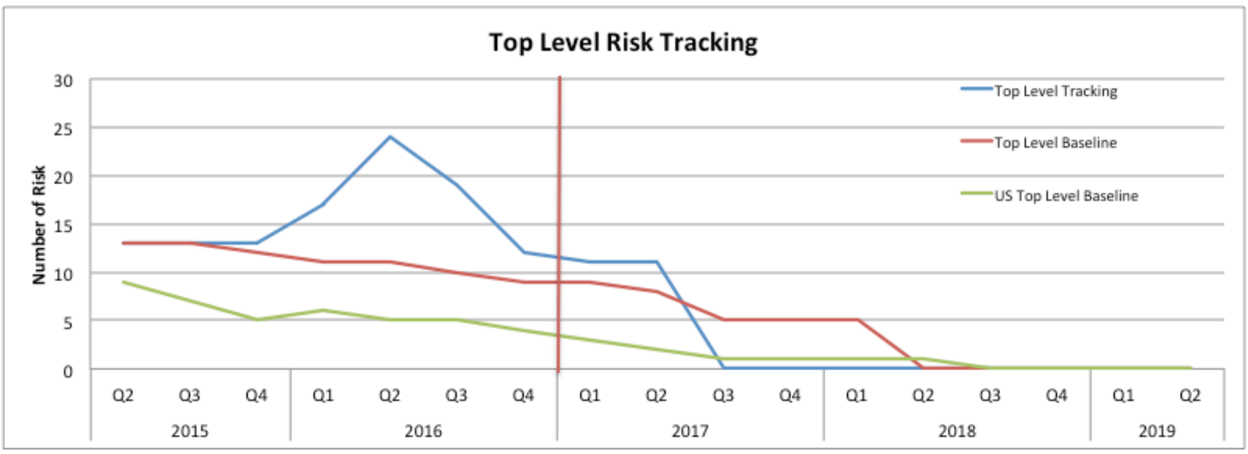

Figure 6: Expected evolution of top level risks.

Table 1: Key risks extracted from the project risk register.

Active Risk	**12**
Retired Risk	**13**

ID	Risk Description	Potential impact on project	Risk score			Ownership	Proposed Action	Post-action risk score			Comment / Conclusion
			L	I	LxI			L	I	LxI	
MICE 3	Magnetic field effecting operation of electrical equipment relating to the continued operation of the cooling channel magnet systems and detectors.	Inability to operate the cooling channel	5	5	25	MICE - UK / MAP	Installation of a partial return yoke has mitigated the major risk. Movement of the control and power supply equipment to a dedicated room outside of the magnetic field.	1	4	4	Much work has been completed and provision of additional rack room has enabled the majority of the sensitive equipment to be moved away from the hall. The PRY has not yet been installed and so has not been tested, the residual risk still applies. Significant investment from UK and US to mitigate risk has been expended. Non staff risk persists in the event of additional material being required.
MICE 4	Extended period of re-training for the lattice of magnets for Step IV - SS1/AFC/SS2.	Timescales for the training period, cost of the amount of LHe required to carry out the training the availability of the Lhe. Expert personnel required to be available for magnet operations over a protracted period of time.	4	5	20	MICE-UK / MAP	Discussions with BOC (or supplier) to agree delivery timescales and availability during heavy use periods. Magnet integration task force to define commissioning method to keep schedule and cost to a minimum.	4	4	16	Each re-cool and fill of the Spectrometer Solenoid can take upto 500l LHe, AFC remebers it's training. Each full lattice quench could cost in the region of £7K. Initial investigations with BOC show that the predicted amount of LHe will be available during the commissioning period.
MICE 8	Resourcing issues from the STFC and national labs	inability to complete significant sections of work on agreed time or cost scales.	4	5	20	MICE - UK / MAP	Realised. Escalation of the issue to the STFC and DOE.	2	4	8	Project scope has changed leading to a different labour profile required to complete the project.
MICE 16	Failure of a Focus Coil Magnet	Internal cold mass or associated equipment deep within the assembly. LTS leads.	3	5	15	MICE UK	Follow all specific operational aspects as defined by the experts for the superconducting magnet	1	5	5	Transportation, dis-assembly, investigation, fix and reassembly would be extreamly costly and extensive with regard to schedule. A spare magnet would be out of the reach of the project. A repair intervention would be 12 months including testing and commissioning and manufacture of new magnet system, test and commission around 2 years.
MICE 17.1	Failure of Upstream Spectrometer Solenoid Magnet	Internal cold mass or associated equipment deep within the assembly. LTS leads.	4	5	20	MAP	New quench protection system	1	5	5	Has the same design issues as SSD, confidence improving with operation and testing with forces.
MICE 19	Failure of M2 in SSD.	Reduction in scientific output and resulting cooling effect.	3	4	12	MICE-UK / MAP	Maximise data collection before running M2.	2	4	8	Consider completing data set for one absorber.
MICE 20	Failure of Helium space feedthrough in SSD.	Reduction in scientific output and resulting cooling effect.	3	4	12	MICE-UK / MAP	Limit number of quenches	2	4	8	
MICE 23	Risk of equipment failure/breakage	Cost of repair/replacement. Time lost during recovery	3	3	9	MICE UK	Spares inventory / proper planned maintenance	3	1	3	to some degree inevitable due to age of equipment
MICE 24	Problems during magnet string commissioning	Further compromise of SSD / Delays to program	3	5	15	MICE UK	Conservative magnet settings.	3	3	9	Always recognised as a challenge - complicated and exacerbated by SSD situation
MICE 28	Inability to cool absorber to required temp	No H2 absorber / reduced science	3	5	15	H2 Group	Heat load modelling/design revision	2	5	10	improvements to heat load design.
MICE 29	Further compromise of SSD performance	Slower data-taking, more remedial action required	3	5	15	MICE-UK / MAP	Power supply improvements, feedthrough heating improvements.	3	5	15	Anomalous earth leakage and noise seen - now absent, but as yet unexplained.
MICE 30	Insufficient international manpower available.	Delay in remediation of non-UK assets and associated reduction in effort on other tasks.	4	3	12	MICE-UK / MAP	Discussion with international management to maximise staff availability.	3	3	9	Long standing issue.