MICE STATUS*

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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 Collider. The Muon Ionization Cooling Experiment (MICE)* is under construction at the Rutherford Appleton Laboratory (UK). It comprises a dedicated beam line to generate a range of input emittances and momenta, with time-of-flight and Cherenkov detectors to allow the selection of a pure muon beam. A first measurement of emittance is performed in the upstream magnetic spectrometer with a scintillating fibre tracker. A cooling cell follows, 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 May 2010 it is expected that the beam and most detectors will be commissioned. The first measurement of input beam emittance will follow thereafter. The paper ends by describing the MICE programme of emittance and cooling measurements.

INTRODUCTION

The Neutrino Factory and the Muon Collider offer unique opportunities both to discover and to study new physics. The Neutrino Factory will produce the most intense, collimated, high-energy neutrino beam ever achieved. Because of the high intensity and high purity of the neutrino beam produced by the decay of stored muons precise measurements can be made of the parameters that describe neutrino oscillations and leptonic CP-violation. The Muon Collider will allow for a precise study of any new physics emerges from the LHC. For example the masses, widths and couplings of any neutral Higgs boson could be precisely measured via s-channel production [1].

Muons for both accelerators are produced with a large initial emittance and a large energy spread. In order to inject the beam into the muon acceleration systems, the emittance needs to be reduced and due to the short muon lifetime (2.2 μs) the only viable cooling technique is ionization cooling.

MICE will be the first experiment to demonstrate the ionization cooling technique that is essential to a Neutrino Factory and a Muon Collider. The aim of the MICE collaboration is to design and fabricate a section of cooling channel capable of giving the required performance for a Neutrino Factory. The cooling apparatus will be placed in a muon beam and its performance will be measured in a variety of operating modes and beam conditions, with the aim of measuring cooling and validating the cooling simulations.

EXPERIMENTAL LAYOUT

The MICE experiment is under construction at RAL on a dedicated muon beam line [2]. A titanium target [3] is dipped into the ISIS 800 MeV proton beam with a frequency of 0.3—Hz. The pions, which are produced from the proton-titanium collision, are focused by a quadrupole triplet and momentum selected (P=400 MeV/c) by a dipole magnet D1 (see fig.1). The majority of pions decay to muons in a 5 m long, 5 T superconducting solenoid (DS). Further downstream, a dipole selects muons at a momentum of 200 MeV/c, ensuring muon purity better than 99.9%. The pure muon beam then passes through a second triplet of quadrupoles and finally through two Cherenkov detectors which identify muons [4].

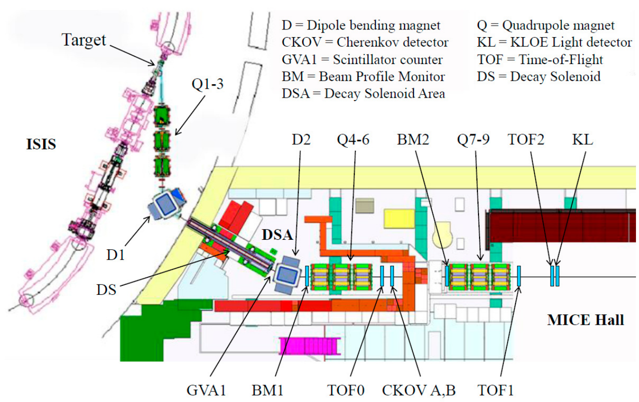

Figure 1: The MICE beam line at ISIS [3].

Cooling is provided by a 5.5 m cooling channel (see fig.2) [5]. The incoming muon beam passes through a TOF (Time-of-flight) counter which makes precise time measurements and then through a lead diffuser where a tuneable input emittance (1-12π mm.rad) is generated. A spectrometer then measures the positions and momenta of each particle. The cooling section follows this initial momentum measurement, consisting of three absorbers (liquid Hydrogen, LH2, or solid Lithium Hydride, LiH) alternating with two RF coupling coil modules (RFCC). The absorbers are inside an absorber-focus-coil (AFC) module with superconducting coils that provide strong focusing at the absorbers. The RFCC modules each contain four, normally conducting, 201—MHz RF cavities which sit inside a focusing magnetic field.

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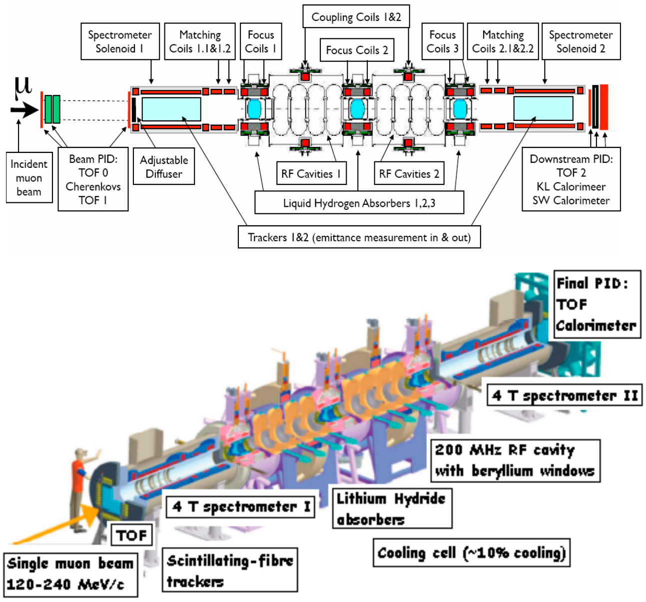

Figure 2: The MICE Cooling Channel (top) in 2D and (bottom) in 3D.

After the cooling section, the track positions and momenta are measured by a second spectrometer identical to the first. Finally, a TOF counter together with a calorimeter, provide further time and PID measurements while also rejecting background electrons from muon decay.

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The MICE experimental program will be achieved in Steps (see fig.3). Step I is underway while the preparation of the following steps is going well.

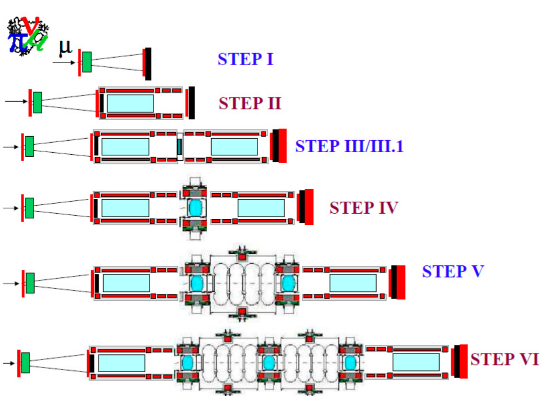

Figure 3: The MICE Stages.

Data taking and results

MICE resumed taking data in September 2009 with the decay solenoid operational, after a long break due to target problems. The beam line is now complete and data taking, on-line and offline reconstruction and analysis are running routinely. Muon beams of positive and negative polarity have been observed (see fig.4) and the first measurements of emittance using the TOF detectors have been performed.

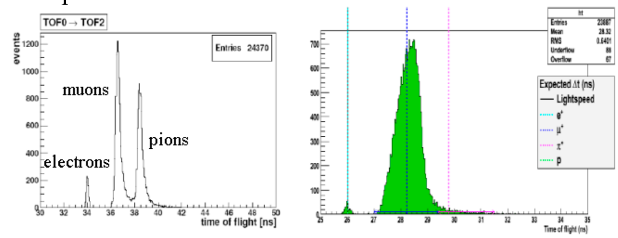

Figure 4: Time-of-flight distributions for particles in a pion beam (left) and in a muon beam (right) (data taken in December 2009). The plot on the right is the time-of-flight distribution of a pure muon beam with a large energy spread.

Target

The target, which is installed in ISIS, has been operated for 165k pulses without any sign of failure [6]. However, a second target, constructed in the same way as the first and operated in an assembly area, failed, creating excessive wear on its bearings. An active program of development has been pursued. Plastic bearings have been shown to deliver in excess of 2.15M pulses without any wear evident on the bearing surfaces (see fig. 5). Development work continues with a view to producing two new targets before the end of 2010 [7].

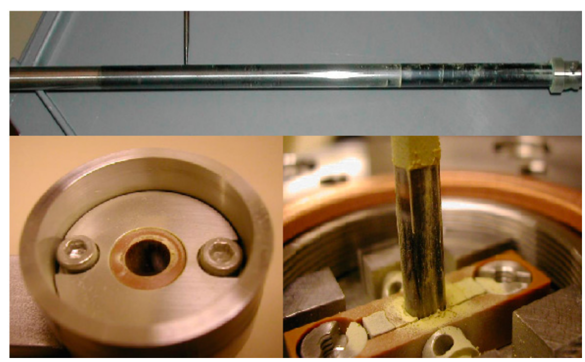

Figure 5: Top: Dust on shaft. Bottom left: Top face of lower bearing after removal. Bottom right: Close-up view of the off-line target shaft once opened after 2.16 million pulses-the dust is easy to see [7].

Detectors

The construction of two trackers is completed and both have been commissioned with cosmic rays. The TOF2 (Milano) was delivered to RAL in November 2009 and is fully functional with a time resolution of 50 ps. The KL (KLOE-Light lead-scintillating fibre calorimeter) detector (Roma III) has been set-up in the MICE beam since June 2008 and is fully operational. The EMR (Electron-Muon-Ranger) construction was halted for a few months in the winter of 2010 when it was realized that the magnetic field level in the downstream area of MICE was much higher than originally foreseen. The test of a final EMR design module is underway in Geneva, and delivery is expected later this year.

Cooling Components

The LiH absorber, originally intended for Step III.1, has been re-sized so that it can also be used in the AFC module at Step IV. The LiH disk is now being manufactured. The magnetic shielding plates have been produced and delivered to Fermilab. One Hydrogen absorber module has been fabricated and is now under test at KEK.

To date, 11 absorber windows have been produced, two of which have been burst tested at room temperature. The results of the burst test are consistent with the design specification. The design for the hydrogen delivery system is progressing. The cryostat and dummy absorber vessel required to test the system have been successfully commissioned with liquid helium.

The construction of the diffuser has made substantial progress and is now almost complete.

The fabrication of the first five cavities was completed in December 2009. The beryllium windows are currently being fabricated (Brush Wellman Inc.), three of which are finished and have been delivered to LBNL. Measurements of the electromagnetic properties of the cavities are already underway [8].

Spectrometer Solenoids

The fabrication of the spectrometer solenoids [9] is underway at Wang NMR under the supervision of LBNL. Although the construction of both magnets had been completed, the magnets failed during tests in 2008 and 2009. Since the other magnets in MICE have many features in common with the spectrometer solenoids, it is crucial to fully understand the problems with the spectrometer solenoids. After detailed investigation, it was concluded that the HTS (High Temperature Superconducting) leads were insufficiently cooled and that the problem could be resolved by adding a single stage cryocooler in the vicinity of the leads and making improvements to the heat paths in this area.

The test results of the first spectrometer solenoid will be used to determine the final modifications of the second magnet. The first magnet was fitted with an additional single-stage cryocooler and equipped with a number of voltage taps. The magnet was kept cold until Easter 2010 in a state close to thermal equilibrium, allowing various measurements to be performed (see [9] for more details).

The Focus Coil magnet is being manufactured by TESLA (UK). Time was devoted to establishing the final construction drawings, effecting procurement of materials, and completing the design of the quench system. The module will be delivered in October 2010.

MICE SCHEDULE

Due to the difficulties that have been encountered in the commissioning of the spectrometer solenoids, the schedule for Steps II and III has slipped by a year. It is planed that the first magnet will arrive at RAL during 2010 allowing Step II to start around Easter 2011.

A fault in the refrigerator system of the decay solenoid occurred during a routine service in January 2010. The solenoid is now cooling down and data taking is expected to restart intensively towards the end of May 2010. Step I data taking will then continue to August 2010 when a long shut down begins. ISIS operation will resume in February 2011.

The full EMR detector, with 24 modules and magnetic shielding, will be ready for installation in MICE by February 2011. It is expected that a completed absorber will be assembled, tested and shipped to RAL by October 2010. Although there has been a considerable progress on the construction of the RF cavities (LBNL), the R&D on RF in magnetic field will start when the first coupling coil is commissioned. For this year the aim is to test a full high-power RF amplifier and to significantly advance design of the RF-power-distribution system in the MICE Hall [10].

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