# MICE Beamline Description

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The Muon Ionization Cooling Experiment (MICE) Muon Beam line is a dedicated transfer line to transport pions, and following decay, muons, from the ISIS synchrotron. The muons were delivered to MICE where they were used to demonstrate ionisation cooling, a novel beam physics technique that can be used to provide high-quality beams for muon-based accelerator facilities such as a neutrino factory or muon collider.

## 1 Apparatus

The MICE Muon Beam line consists of a titanium target that dips into the ISIS beam in the synchrotron at a rate of 0.8 Hz. In order to get a high pion yield with relatively low losses induced in the ISIS beam it is desirable to insert the target only during the high energy part of the synchrotron cycle. Because the physical size of the beam reduces during the acceleration cycle, extremely high accelerations (80 g) are required to project the titanium target into the ISIS beam. These accelerations are achieved using a linear motor actuating a shaft coated in diamond-like graphite and mounted on precisely aligned Vespel polymer bearings. Bump magnets are also used to bring the beam on to the MICE target as the target is inserted into the MICE beamline, enabling higher rates with fewer induced losses in the synchrotron.

The resultant pions are transported through a quadrupole triplet, into a dipole where a first momentum selection is performed. The pions are transported through a 5 T superconducting solenoid, where a significant proportion decay. A second dipole performs a momentum selection of the resultant muons. By selecting muons arising from forwards or backwards decay in the pion's rest frame, a beam with different rate and muon purity can be chosen.

A pair of quadrupole triplets transports the final beam to MICE. Two time-of-flight hodoscopes and a pair of threshold Cherenkov detectors are used to reject pions on a particle-by-particle basis. A diffuser in the upstream region of MICE introduced scattering into the beam to increase the beam emittance.

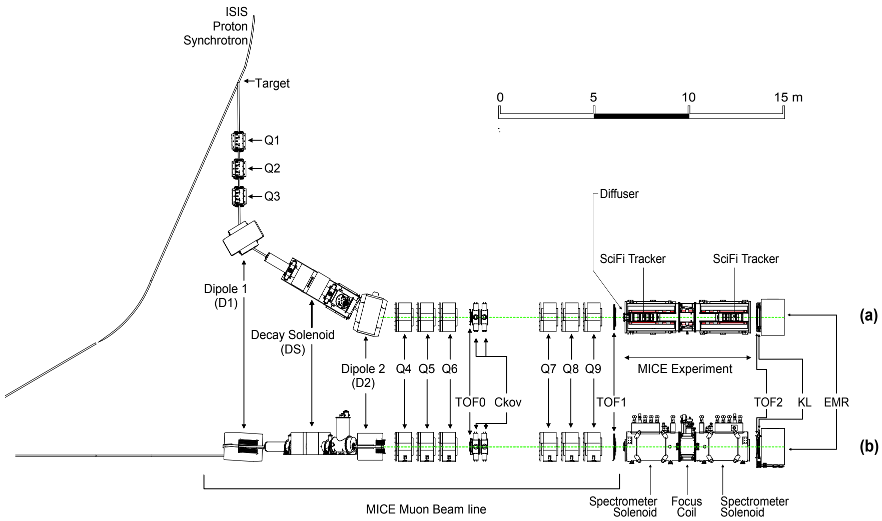


Figure 1: Schematic of the MICE Muon Beam line as installed in 2015, in (a) plan and (b) elevation.

# 2 Pure Muon Beams

Pure muon beams were produced with momenta in the range 140 to 240 MeV/c and momentum spread of around 20-25 MeV/c. Higher momenta are challenging to achieve due to the higher D1 currrent required to accommodate backwards decaying muons in such a mode. A full table of the parameters of measured, pure muon beams is shown in [2] and the measured impurity is discussed in [3]. The rate was limited by maximum allowed activation of the ISIS synchrotron and saturation of the MICE data acquisition equipment. Rates of 30 muons per target dip have been achieved with very low muon beam impurity. A full discussion of available rate is found in [4]. Owing to the smaller momentum spread and higher rate, the MICE Collaboration used a mixed muon-pion beam for production data taking since 2015, relying on the excellent MICE diagnostics to reject impurities.

# 3 Muon-Pion Beams

Mixed muon and pion beams were produced with momenta in the range 140 to 400 MeV/c. At lower momenta pions are readily rejected using the time-of-flight method.

Rates measured in the MICE ToF counters ToF0 and ToF1 for several beam settings with different beam momenta are listed in table 1. The rate listed is for muon, pion and electrons combined.

Table 1: Rate and momentum of mixed muon-pion beams. The rate listed is for muons, pions and electrons combined. Momenta are calculated using a naive velocity calculation, ignoring the effects of intervening materials and other sources of systematic error.

| Run | Rate at ToF0 [Hz] | Rate at ToF1 [Hz] | Induced Loss [V] | $t_{02}$ [ns] | $p_{02}$ [MeV/c] |
|---|---|---|---|---|---|
| 10243 | 341.4 | 72.54 | 3.40 | 65.4 | 148 |
| 10268 | 448.3 | 101.2 | 4.04 | 62.2 | 174 |
| 10262 | 437.9 | 102.7 | 2.83 | 59.5 | 211 |
| 10312 | 459.8 | 138.6 | 2.26 | 58.6 | 229 |
| 10261 | 622.5 | 156.3 | 2.74 | 57.6 | 255 |
| 10304 | 535.2 | 188.8 | 2.97 | 56.0 | 321 |
| 10303 | 280.2 | 116 | 5.28 | 54.6 | 456 |

The induced loss in the synchrotron is also listed in the table, measured by ionisation counters near to the ring. While MICE sought to operate at the maximum permitted rate, variability in ISIS operations and the MICE DAQ led to run-to-run fluctuations in the actual induced loss. The momentum of the muons as measured between ToF0 and ToF2, over a distance of 15.85 m, is also listed. The momentum listed is calculated from a naive estimation of the muon velocity; material in the muon path led to variability in the actual momentum which is not properly accounted in the calculated momenta.

Detailed analysis is in progress to yield momenta and beam composition for selected beam settings, but is beyond the scope of this note. A few sample histograms of the time of flight between ToF0 and ToF2 are shown in fig. 2, plotted using the MICE control room (online) reconstruction, indicating the compositions of different settings. Here, momentum is selected in D2; electrons are visible with a time-of-flight around 53 ns, corresponding to the speed of light, while muons and pions are visible with relatively lower velocities. In each distribution, muons make up the majority of particles but significant pion and electron impurities are visible and may be easily separable.

# References


[1] M. Bogomilov et al, The MICE Muon Beam on ISIS and the beam-line instrumentation of the Muon Ionization Cooling Experiment, Journal of Instrumentation, Volume 7, Number 5, 2012.

[2] M. Rayner et al, Characterisation of the muon beams for the Muon Ionization Cooling Experiment, European Journal of Physics C, Volume 73, Number 10, 2013.

[3] D. Adams et al, Pion contamination in the MICE muon beam, Journal of Instrumentation, Volume 11, 2016.

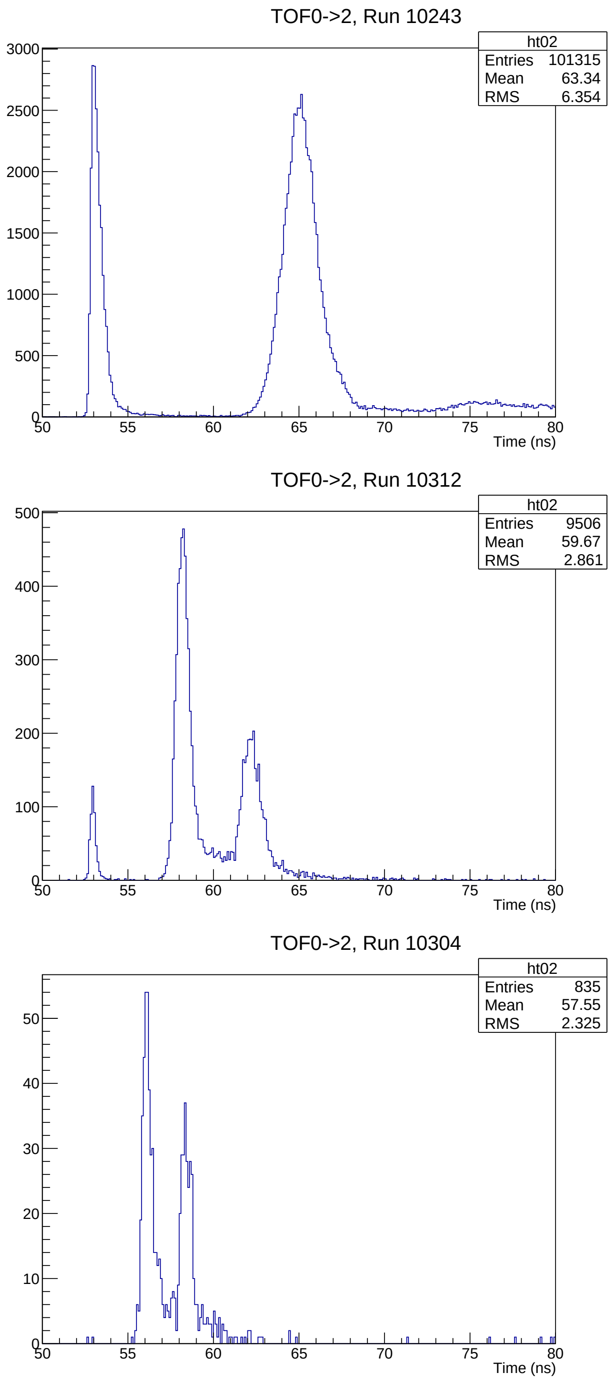


Figure 2: Time-of-flight for run 10243 (top), run 10312 (middle) and run 10304 (bottom). Following momentum selection in D2, three peaks are visible corresponding to electrons, muons and pions.

[4] A. Dobbs, Particle Rate and Host Accelerator Beam Loss on the MICE Experiment, Thesis, Imperial College London, November 2011. Available from `http://mice.iit.edu/phd/adobbs_thesis_corrected_2011-10-30.pdf`