MICE BEAMLINE

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Abstract

The Muon Ionization Cooling Experiment (MICE) is under development at the Rutherford Appleton Laboratory (UK). The goal of the experiment is to build a section of a muon cooling channel that can demonstrate the principle of Ionization cooling over a range of emittances and momenta. The MICE beam line must generate several matched muon beams with different momenta and optical parameters at the entrance of the cooling channel. This is done using a titanium target which is dipped into the ISIS proton beam, a 5T superconducting pion decay solenoid, two dipole magnets and a mechanism for inflation of the initial emittance called diffuser. First measurements of muon rates and beam emittance performed using two TOF hodoscopes detectors will be presented.

MICE, THE INTERNATIONAL MUON IONIZATION COOLING EXPERIMENT

Muon ionization cooling provides the only practical solution to prepare high brilliance beams necessary for a neutrino factory or muon collider, because it is fast enough to cool the beam within the muon lifetime. The Muon Ionization Cooling Experiment (MICE) [1, 2] is under development at the Rutherford Appleton Laboratory (UK). The goal of the experiment is to build a section of a cooling channel that can demonstrate the principle of cooling and to prove this by measuring its performance in a muon beam.

MICE BEAMLINE WORKING PRINCIPLE

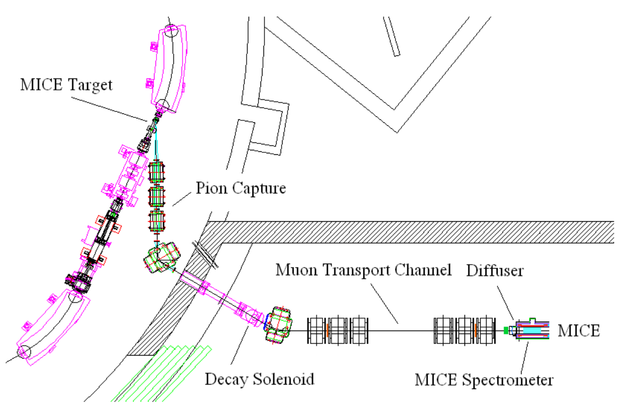

Figure 1: A schematic layout of the MICE beamline channel.

Production of particles in the MICE beamline (Fig. 1) begins with a titanium target dipping into the ISIS 800 MeV proton synhrotron beam. This has been used to run MICE as a stand-alone experiment and also parasitically during standard ISIS user runs. The particles (mostly pions), resulting from interaction of the proton beam and the target, are captured and momentum-selected by the first dipole magnet (D1). After this 5T superconducting decay solenoid is used to contain and transport the pions and their decay muons. Another dipole (D2) then selects the final particles for propagation through the rest of the MICE beamline. This second dipole is used to choose different populations of particles and to create beams designed for MICE emittance measurement or for calibration of the de-

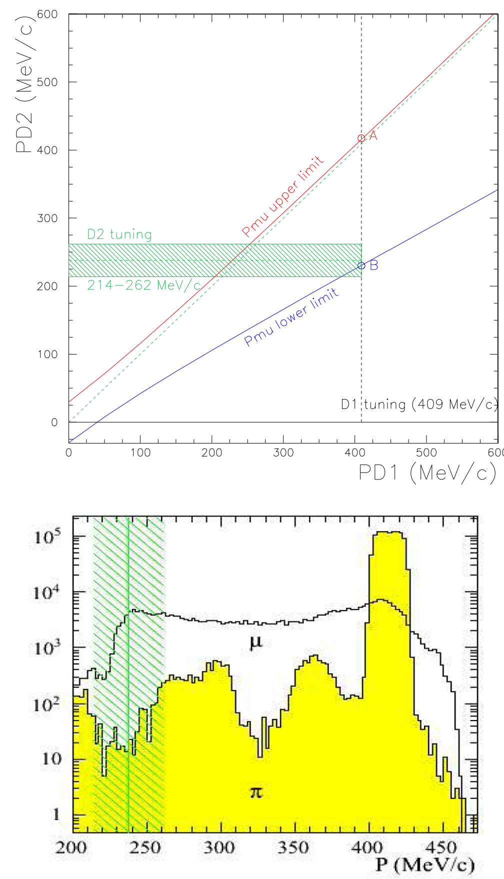

Figure 2: Top: kinematic limits for muons provided by pion decays. The red and the blue lines are the upper and the lower limits of the muon spectrum as a function of the momentum selected by the first dipole. Bottom: simulation of the muon and pion spectra at the exit of the decay solenoid. Only high momentum pions survive. The green band shows the acceptance of D2, when tuned for backward-going muons.

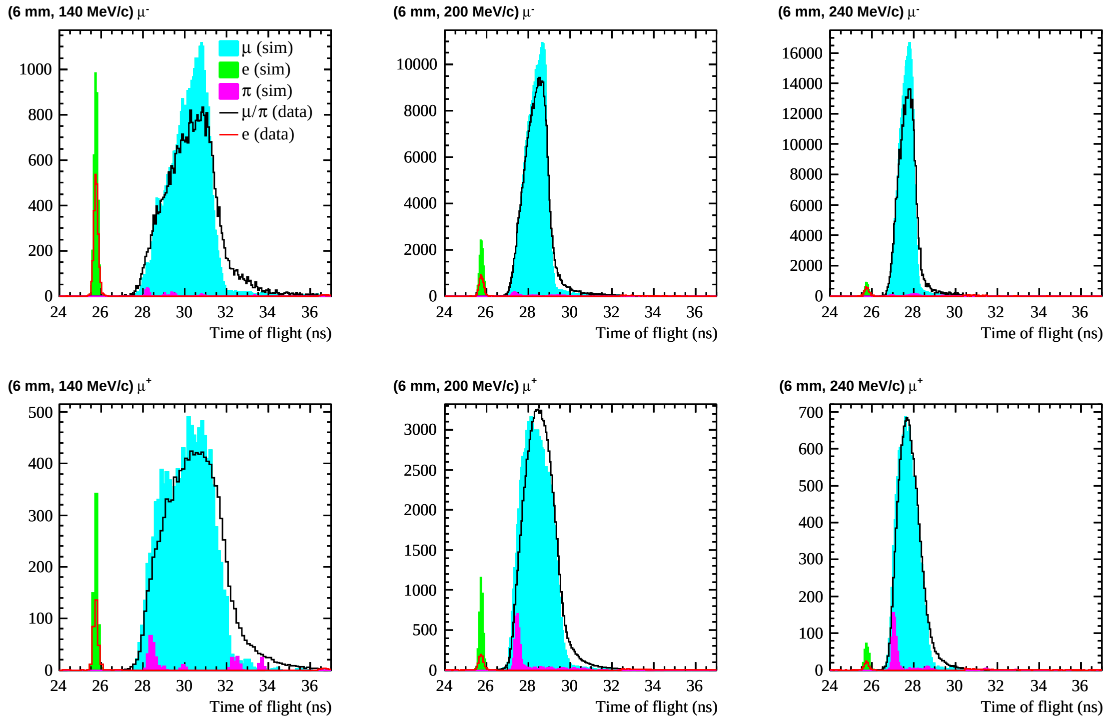

Figure 3: Time-of-flight between TOF0 and TOF1. Data vs Monte Carlo simulation for different 6 $mm\ rad$ beams, at different energies.

tectors. The particle content of the muon beam has been measured by using time-of-flight detectors (TOF0, TOF1, TOF2) [3].

The pion decays in flight provide muon beam which has a large momentum spread at the exit of the decay solenoid. This is illustrated in Fig. 2 (top). It shows how the momentum of the muons at the exit of the decay solenoid depends on the pion momentum selected by the first dipole. The kinematic limits for muons in the plot correspond to pion decays inside the solenoid and the maximum and minimum muon momenta are given by the decay muons flying forward and backward in the centre of mass system. Distinctly different distributions of particles can be produced by changing the nominal momentum, selected in the second dipole magnet.

Muon beam

The first possibility is to select particles having momentum close to the minimum muon momentum (Fig. 2, bottom). This will produce a muon beam with a small contamination from electrons and pions. Such a beamline configuration is usually called a muon beam and will be used for the demonstration of ionization cooling.

By looking at the particle time-of-fight between the TOF0 and TOF1 stations, particle identification was performed in order to separate muons from electrons/positrons and to determine the muon rate as a function of ISIS beam loss. The level of the residual pion contamination under the muon peak has been estimated by Monte Carlo simulation. Fig. 3 shows the simulated and measured time-of-fight spectra for various beam configurations and the estimated pion background.

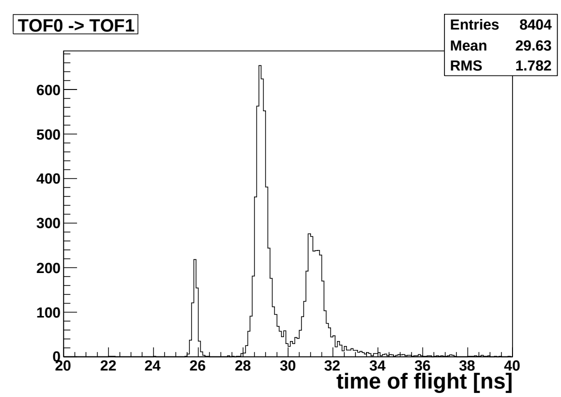

Figure 4: Time-of-flight between TOF0 and TOF1 for a detector calibration beam.

Beam for calibration of the detectors

Another possibility is to set the difference between the momenta selected in the first end the second dipole to be equal to the most probable energy losses of the particles in the materials between the dipoles. This type of beams is very useful for calibration of the detectors, electrons, muons and pions fall into three well defined peaks in the time-of-flight spectrum (Fig. 4).

MICE DIFFUSER

The diffuser (Fig. 5) is the final element of the MICE beamline and it is located just before the beginning of the cooling channel. It is use to provide inflation of the initial emittance and to match the beam into the cooling channel.

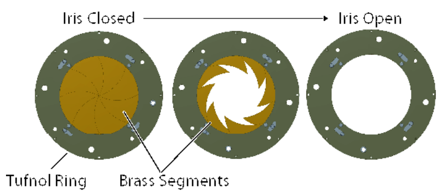

Figure 5: Design of the irises for the MICE diffuser.

The diffuser design consists of a stainless steel drum, which is inserted into the upstream section of the first spectrometer solenoid. The drum contains four irises, two of which are made out of brass (2.97 mm, $0.2X_0$, and 5.94 mm, $0.4X_0$, thick) and two made out of tungsten (2.80 mm, $0.8X_0$, and 5.60 mm, $1.6X_0$). By selecting different combinations of irises, one can achieve a total of $3X_0$ in steps of $0.2X_0$. The iris consists of two planes of four segments of material, surrounded by a Tufnol ring of radius 100 mm (Fig. 14). When closed, the iris inserts a solid piece of material into the beam and when it is open, the material withdrows into the Tufnol ring.

MEASUREMENT OF THE MUON RATES

Particle rates in the MICE beam line as a function of ISIS beam loss have been studied. The observed particle rates in the TOF0 and TOF1 detectors were recorded and the measured time-of-flight was used to select muon tracks [4]. The results are summarized in Table 1.

Table 1: Muon track rates for negative (top) and positive (bottom) polarities in the MICE beam line. Counts are normalized to the $V.ms$ units used to characterize the induced ISIS beam loss. Errors are mainly due to the time-of-flight cuts used to define a muon.

ε_N $(mm\,rad)$	μ^-rate P_Z 140 MeV/c	μ^-rate P_Z 200 MeV/c	μ^-rate P_Z 240 MeV/c
3	4.1 ± 0.2	6.3 ± 0.2	4.9 ± 0.2
6	4.1 ± 0.4	4.8 ± 0.2	4.5 ± 0.2
10	4.6 ± 0.2	5.4 ± 0.2	4.4 ± 0.2
ε_N $(mm\,rad)$	μ^+rate P_Z 140 MeV/c	μ^+rate P_Z 200 MeV/c	μ^+rate P_Z 240 MeV/c
3	16.8 ± 1.8	33.1 ± 3.2	33.0 ± 2.6
6	17.8 ± 1.8	31.0 ± 2.0	31.7 ± 2.0
10	21.6 ± 2.2	34.0 ± 2.5	26.1 ± 1.5

MEASUREMENT OF THE EMITTANCE

In order to prove the capability of the MICE beamline to provide the necessary muon beams with different momenta and optical parameters, a novel single-particle method for emittance measurement has been developed [5]. The beam emittance is constructed from a large sample of particles, and compared with simulation in order to prove the capability of the beamline to provide the muon beams needed for demonstration of the ionization cooling. The results are summarized in Fig. 6.

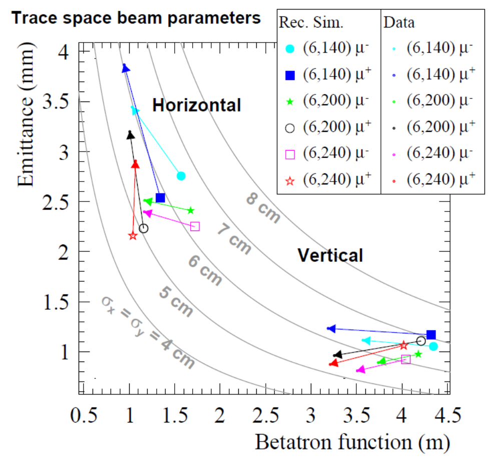

Figure 6: A comparison between beam parameters of the matched beams in simulation and data.

CONCLUSIONS

The MICE muon beam has been built and has already taken data during its first stage of commissioning. It has been demonstrated that the MICE beamline is able to deliver a high quality muon beams needed in order to carry out the MICE physics programme and demonstrate ionization cooling for the first time.

REFERENCES

[1] MICE web site *http://mice.iit.edu* contains detailed information about the experiment.

[2] The International Muon Ionization Cooling Experiment (MICE) proposal to the Rutherford Appleton Laboratory, 10 January 2003.

[3] R. Bertoni et al.,"The design and commissioning of the MICE upstream time-of-flight system", Nucl. Instr. Meth, A615 (2010) 14.

[4] A. Dobbs, K. Long, and A. Alekou,"The MICE muon beamline and induced host accelerator beam loss", Proceedings 2011 Particle Accelerator Conference (PAC'11), 28 March-1 April 2011, New York, 2011, MOP021.

[5] M. A. Rayner," The development of a novel technique for characterizing the MICE muon beam and demonstrating its suitability for a muon cooling measurement", PhD thesis, The University of Oxford, 2011.