EMITTANCE MEASUREMENT DEVICES IN THE MUON IONIZATION COOLING EXPERIMENT

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Abstract

The Muon Ionisation Cooling Experiment (MICE) at the ISIS[1] accelerator located at the Rutherford Appleton Laboratory will be the first experiment to study muon cooling with high precision. The proposed operation of the experiment is described, and performance measurements on the crucial detector components are presented.

THE MICE EXPERIMENT

Introduction

The MICE experiment is designed to measure the performance of a cooling channel based on the design from Study II for a Neutrino Factory[2].

In this design the muon beam is passed through a series of absorbers of low atomic number to reduce the muon energy, each absorber followed by a set of RF cavities working at 201.25 MHz which accelerate the beam to the original energy. In MICE a small part of this cooling channel will be tested by measuring precisely the momentum and position of each muon as it enters and leaves the channel. From these measurements an input beam of given emittance can be synthesised[3] and the emittance of the resulting output beam measured. The results will allow a reliable prediction of the performance of the full channel. A set of plates of variing thickness (diffuser) placed just before the first emittance measurement is used to vary the incoming beam characteristics and allow a wider range of input beams to be synthesised.

The experiment runs parasitically in ISIS, by dipping a titanium target into the beam. The structure of the ISIS beam imposes constraints on the operation of the MICE target and beamline. ISIS runs at 50Hz and during each cycle a few$\times 10^{13}$ protons are injected into the ring and accelerated over the following 10ms to 800 Mev. If the titanium target enters the beam too early very few pions are produced and the beam is severely disrupted by energy loss and multiple scattering; thus the target can only intersect the beam during the last one to two milliseconds. The target is only dipped once per second, to minimise the disruption to other ISIS users. The required event rate of 600 muons per second then requires a readout and detector system capable of operating at MHz. We must be able to determine the phase of the RF in the cavities as the muons pass through the cavities, which requires sub nanosecond timing.

Overview

A schematic of the MICE beam and cooling channel is shown in Figure 1. The interactions of the protons with the target produce a spray of pions. The pions at 25° are focussed by a triplet and then bent to enter a superconducting solenoid which projects through the wall of the machine hall. Muons produced by pion decay in the solenoid are captured by the field and enter the MICE hall, where they are bent, focussed by two additional triplets and then enter the MICE cooling channel. Two Cerenkov counters, used for particle identification, are placed before the channel; a scintillator based timing system is placed before and after the channel and used as part of the particle identification system and for the timing with respect to the RF phase. Finally a ranger is used to confirm the identity of particles which traverse the full channel.

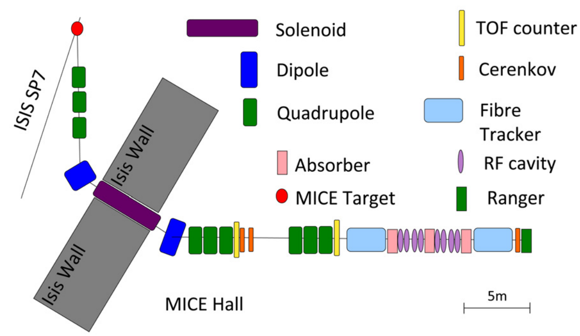

Figure 1: Schematic of MICE beam and cooling channel.

Muon Production

Once per second the MICE target is dipped into the beam. It was a titanium blade of length 35 mm which presents a target 1 mm wide and 10 mm deep. Simulations[4] show that 1.4×10^{12} protons must intercept the target in order to generate a flux of 600 *good* muons per target dip. (*Good* muons refer to those which are captured by the MICE beam line and traverse the whole cooling channel). Studies in 2006 allowed us to measure the external diameter of the beam and show that the target was capable of intercepting the beam during the last two milliseconds of the cycle and still clear the beam envelope before the next pulse. The number of muons produced can be varied by adjusting either the timing of the start signal or the depth of travel.[5]

Pions produced and captured by the upstream magnets are bent through a hole in the ISIS vault where they enter an eight metre superconducting solenoid with a field of five Tesla. The pions decay into muons which are captured by the field and emerge to be bent and foccused into the MICE experiment.

Superconducting Spectrometer

The measurement of beam cooling, relies on the accurate determination of particle position and momentum both before and after the cooling channel. To make this measurement MICE have built a pair of identical spectrometers. To make an accurate measurement of both position and momentum without disturbing the trajectory of the muons, MICE needs a system with low mass, high efficiency and good resolution. This is provided by scintillating fibre detectors sitting, radius 30 cm, in a four Tesla superconducting magnet whose field is uniform to the level of 3 parts per mil. The tracker is read out by visible light photon counters (VLPCs)[6, 7] held at 9K, using the D0 central fibre tracker read-out and electronics system[8]. The tracker consists of five stations, each one consists of three doublet layers at 120° to each other to provide a space point (Figure 2a). They are held in a carbon fibre space frame with an overall length of 110cm. In order to measure position without disturbing the muon trajectory thin fibres must be used (350 microns in diameter). Such fibres produce very little light and so visible light photon counters are used. The VLPC combination of very high efficiency with low background allow good track measurement even with these slender fibres. The fibres are laid up in doublet layers Figure 2b to ensure complete coverage. The position resolution achievable in such a setup is actually better than that required for the measurements and since the most expensive part of the the system is the readout system, the individual fibres are bundled together in groups of seven (as shown in the Figure 2b and each bundle feeds one channel. Increasing the size of the fibres would ease the construction of the detectors, but the resulting fibre thickness leads to unacceptable multiple scattering.

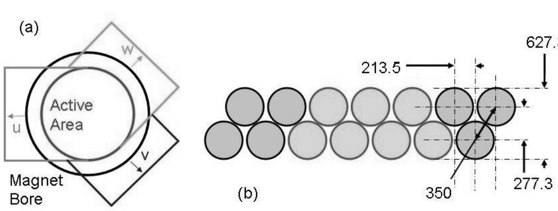

Figure 2: a) Three views per station. (b) Doublet layer shaded fibres bundled to form one channel (all distances in microns).

Five modules were then mounted onto a carbon fibre frame and their positions accurately measured using a coordinate measuring machine to produce a tracker. The tracker was then placed inside a black carbon fibre cylinder and supported on an aluminium space frame with the beam axis pointing vertically upward. A cosmic ray telescope was created using a trigger scintillator just above the tracker and a four inch layer of lead blocks followed by a second trigger scintillator. The lead ensured that the system only triggered on muons of momentum 130 MeV/c or greater. Data was taken using this arrangement between July 2008 and November 2008. The second tracker has since been completed and testing has just restarted on both trackers.

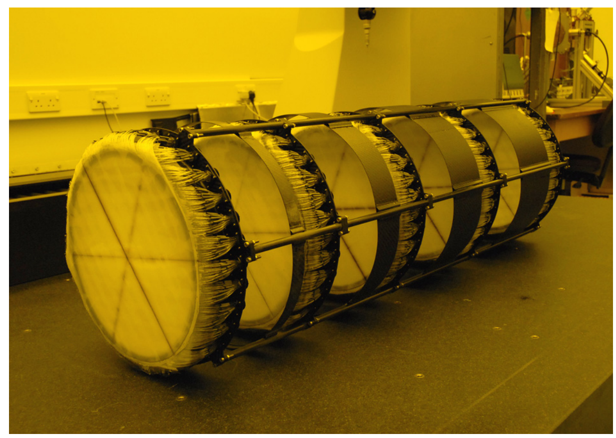

Figure 3: Completed tracker.

Results from the first tracker were analysed by: creating clusters from one or two neighbouring channels in each view and clusters with greater than two photo-electrons are kept. Space points are defined as a cluster in each view from a given station, where the distance between two pairwise intersections is small enough. Any remaining clusters are used to create space points. Sets of three space points from distinct stations are tested for collinearity; the tracks of those that pass are extrapolated to the other two stations and the closest space point to the extrapolated track is taken as part of that track as long as it lies inside a small road around the extrapolation. Finally each set of 3, 4 or 5 points is passed to the Kalman filter track fit [10] and the combination with the smallest χ^2 per degree of freedom is kept. The points thus used are removed from consideration and the process repeated until all the space points have been removed or no more tracks are found. From these tracks the light yield and the resolution of the tracker can be determined. Figure 4 shows the mean light yield is eleven photo-electrons. The yield of individual layers varies from 8.6 to 11.2 p.e. Figure 5 shows the diffference between the extrapolated track and the hit position in x, y is similar. The values of 583 microns in X and 597 microns in Y and consistent with the design goal of 470 microns, once the extrapolation errors are taken into account.

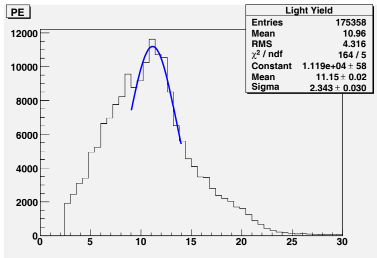

Figure 4: Light yield Histogram : all channels tracker 1.

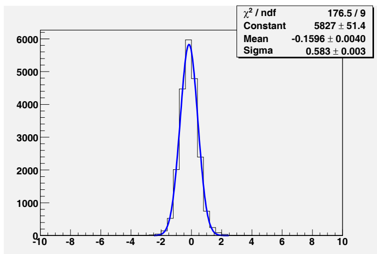

Figure 5: Residuals.

TOF Counters

A TOF detector is made of two layers of scintillator slabs. The first layer has vertical slabs and the second has horizontal slabs. Each slab is equipped with two PMTs, one at each end and each feeding a TDC to measure the absolute time of the hits. The system has a very fast and precise response time but corrections still need to be applied to obtain our design resolutions. First light propagation down the scintillator: this can be estimated both by the time difference between the two PMTs which define a single hit; and by the position measured in the orthogonal view in events with only a single hit in each view. Next because a leading edge discriminator is used the time at which the discriminator registers a hit is dependent on the size of the pulse *(time walk)*. Finally the propagation time down the readout cables has a dispersion which must be removed by measurement. During running in December 2009[11] a small amount of data was taken, concentrated in the area in the centre of the counters and which allowed the calibration of 9 *pixels* in TOF0 and 2 *pixels* in TOF1. The corrected time of flight distributions (Figure 6) shows a clean separation between pions and muons and approaches the design resolution.

Future Work

The second tracker is currently being measured using cosmic rays. Runs later in 2009, with the decay solenoid powered will allow a complete calibration of the TOF system and the measurements on the emittance of the input beam will commence towards the end of the year.

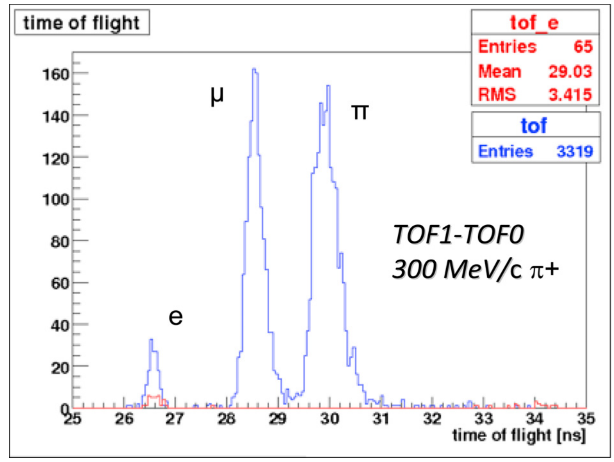

Figure 6: Time of Flight between the TOF counters for a *positron* (red) and *pion* (blue) beam.

REFERENCES

[1] Findlay, DJS, ISIS: Pulsed neutron and muon source, Prepared for Particle Accelerator Conference (PAC 07), Albuquerque, New Mexico, 25-29 Jun 2007 http://www.isis.rl.ac.uk

[2] Feasibility Study-II of a Muon-Based Neutrino Source, eds. S. Ozaki, R. Palmer, M. Zisman, and J. Gallardo, BNL-52623 (2001) www.cap.bnl.gov/mumu/studyii/FS2-report.html

[3] Statistical weighting of the MICE Beam. C.T. Rogers EPAC'08, 11th European Particle Accelerator Conference, 23-27 June 2008, Genoa, Italy

[4] T. Roberts. MICE beamline analysis TRD Sept 2004. Presented to MICE Collaboration Meeting, 10th Feb 2005. www.mice.iit.edu/cm/cm11/cm11_roberts_g4beamline.ppt

[5] Paul Smith. The Development of the Target Mechanism for the Muon Ionisation Cooling Experiment (MICE) Thesis Sheffield University 2008

[6] M. Petroff and M. Stapelbroek, Photon-Counting Solid-State Photomultiplier, IEEE TRANSACTIONS ON NUCLEAR SCIENCE 36 (FEB, 1989) 158162.

[7] M. Petroff and M. Atac, High-Energy Particle Tracking using Scintillation Fibers and Solid-State Photomultipliers, IEEE TRANSACTIONS ON NUCLEAR SCIENCE 36 (FEB, 1989) 163164.

[8] D0 Collaboration, V. M. Abazov et al., The Upgraded D0 Detector, Nucl. Instrum. Meth. A565 (2006) 463537, physics/0507191.

[9] MICE technical reference document, 2004. http://www.isis.rl.ac.uk/accelerator/MICE/TR/MICE_Tech_ref.html

[10] A. Cervera-Villanueva, J. J. Gomez-Cadenas, and J. A. Hernando, RecPack a reconstruction toolkit, Nucl. Instrum. Meth. A534 (2004) 180183.

[11] Karadzhov Y., Bonesini M., Graulich J.S., Tsenov, R. TOF Detectors Time Calibration http://mice.iit.edu/mnp/MICE0251.pdf