

MEASURING EMITTANCE WITH THE MICE SCINTILLATING FIBRE TRACKERS

D. Adey, The University of Warwick, UK
On behalf of the MICE Collaboration

Abstract

The Muon Ionization Cooling Experiment (MICE) aims to measure a 10% reduction in a muon beam emittance to within 1%. To achieve this two scintillating fibre trackers will be placed within a 4T solenoidal field. The trackers utilise fibres with a diameter of $350\mu\text{m}$ to provide a position resolution of less than 0.5mm. Details of the tracker hardware, electronics and its calibration and reconstruction methods are presented, along with the measured performance under cosmic ray tests and the simulated performance in MICE.

INTRODUCTION

Reduction of the initial muon beam emittance is a key requirement of a future Neutrino Factory or Muon Collider. Due to the short muon lifetime, this emittance reduction (cooling) must be done quickly and ionization cooling is the method of choice.

In muon ionization cooling, the total momentum of the muon is reduced by passing the muon beam through an absorber material and then the muons are re-accelerated with RF cavities restoring only the longitudinal momentum.

The Muon Ionisation Cooling Experiment (MICE) [1], based at the Rutherford Appleton Laboratory in the UK, aims to measure emittance reduction in a muon beam with an absolute measurement on the emittance to within 0.1%. In order to accomplish this two scintillating fibre trackers have been constructed and will operate within 4T solenoids. The $350\mu\text{m}$ fibres allow for an accurate position measurement to be used in track fitting and a calculation of the beam emittance. The trackers require a transverse momentum of resolution of less than 10% of the beam RMS [2].

TRACKER GEOMETRY

The MICE trackers consist of five stations with spacings of between 20 - 35cm, each made of three planes of scintillating fibres placed at 120° to each other and covering an active region with a diameter of 30cm, corresponding to approximately 212 channels per plane. The arrangement of the stations within the tracker body can be seen in Figure 2. Seven $350\mu\text{m}$ fibres are ganged together into a single

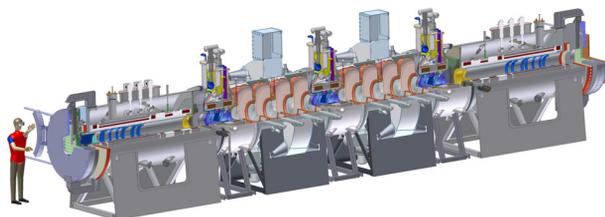


Figure 1: The Muon Ionisation Cooling Experiment.

channel. The resulting approximately 1.6 mm wide cell provides sufficient tracking resolution and enables a 7X reduction in the channel count.

Photons are detected using Visible Light Photon Counters (VLPCs), identical to those used in the DØ Central Fibre Tracker [3], which provide a high gain, high quantum efficiency single photon detection system. The light yield per cluster has been measured to have a mean of greater than 10 photo-electrons [4].

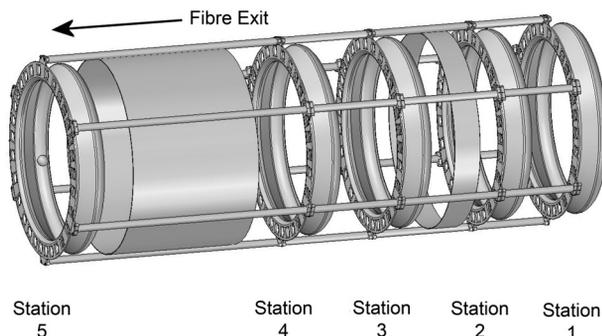


Figure 2: Tracker Stations.

SPACE POINT QUALITY

In a cosmic ray test the quality of the space point reconstruction was tested. Given the readout plane construction and channel ordering within each station, for a triplet space

point (a space point made from channels in all three views) the sum of the constituent channel numbers should peak at the sum of the central channel numbers. A delta function at the sum of the central channel numbers in each plane indicates a perfect overlapping of the channels to form the active region for a space point.

Any deviation from this shows internal misalignment in the individual stations. As the stations have an even number of channels the central values appear at a non-integer, and so the expected peaks will have two values - at the integers either side of the true sum.

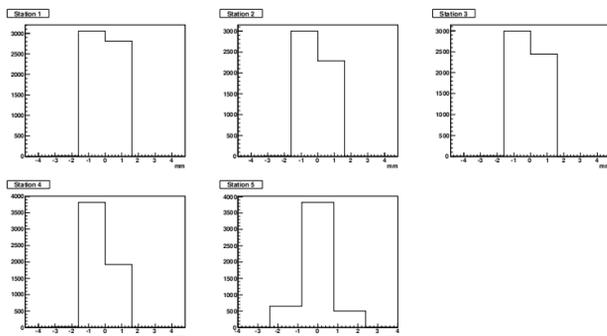


Figure 3: Tracker 1 Triplet Internal Residuals for triplets made from single channel clusters.

Figure 3 shows the channel number sum produced by cosmic rays (station 5 has a known difference in construction, producing a different expected channel sum). The dominance of the central bins shows there is no major misalignment within the planes themselves. The skew within these bins shows the minor internal misalignments within each station; this has been calculated (as shown in Table 1) and can be included in the final track fit.

Table 1: Summary of tracker parameters

Tracker	Station	Offset (mm)
1	1	0.032
1	2	0.114
1	3	0.085
1	4	0.28
1	5	0.047

Each station has a measured space point producing efficiency of more than 99.7%.

PATTERN RECOGNITION

The Tracker Analogue Front End (AFE) readout electronics utilises the TriP-t chip, which adds a time measurement to that of the geometry based position measurement.

From an initial calibration procedure, the time resolution of the tracker electronics is expected to be less than 2ns, as shown in Figure 4. Taking this time resolution of an individual channel, and the expected approximate time of flight of a muon through the tracker body, a slice in time can be defined inside which any hits can be grouped together into a candidate track. In this study, a time slice with a variance of 5ns was defined, and any groups of space points from unique stations lying within this range were passed to a track fitting algorithm.

The purity of this method alone (which does not include additional path length considerations based on the helical motion of the particles) is shown in Figure 5 at more than 90%.

Using this pattern a seed state is calculated from the centre and radius of the helix matching the candidate points and the tracker magnetic field. This state is then passed to a Kalman filter to predict and smooth the track state at the remaining space points. Utilising the type-dependent space point position resolutions, in combination with the measured station internal misalignments, a simulation of the tracker performance within the design magnetic field can be obtained.

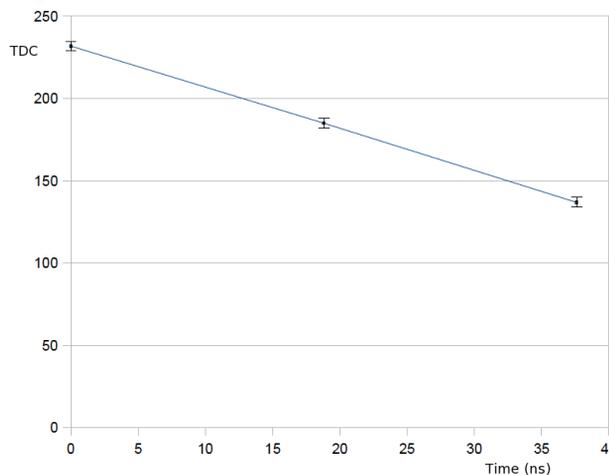


Figure 4: Tracker TDC Resolution .

TRACK FITTING

A fast Kalman filter was developed to operate with a simple model of both the material effects and the spectrometer magnetic field. The field was assumed to be a uniform 4T, and the material in the station a thin slice equivalent to 0.45% radiation lengths. No finite stepping is required and the state prediction takes the form of a single calculation

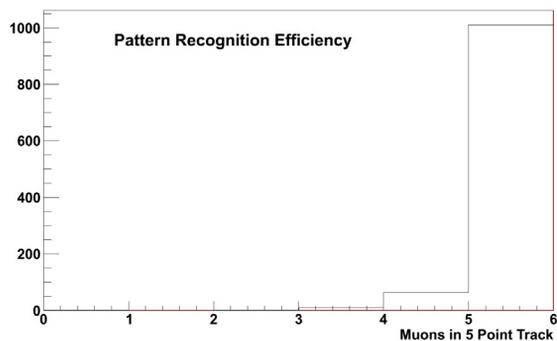
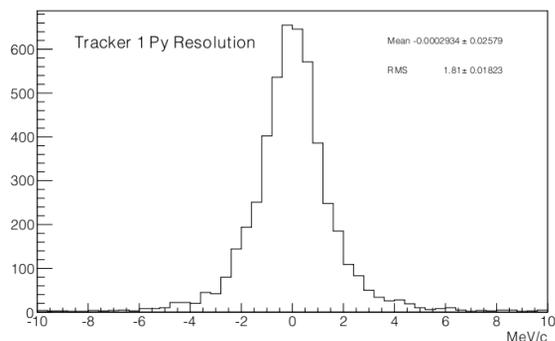
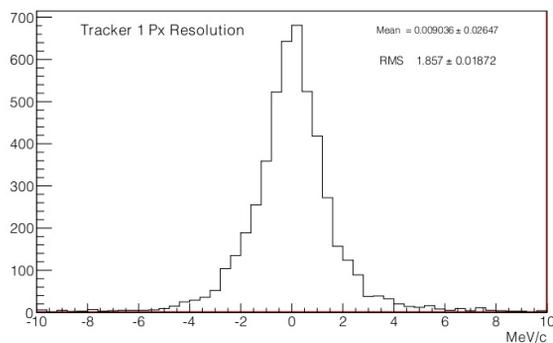


Figure 5: Track Purity from time slice.

Figure 7: Tracker P_y Residual.

propagating the state from one station to the next.

The momentum residual based on a simulation of a 6mm transverse emittance, 200MeV/c momentum muon beam (the central MICE operating mode) can be seen in Figures 6 and 7 for x and y respectively. The RMS is shown on the figures.

Figure 6: Tracker P_x Residual.

CONCLUSION

The details of the MICE tracker construction, and how this contributes towards position resolution, is understood. Attempts to utilise the time resolution of the readout electronics have shown that timing can contribute towards improved pattern recognition. A Kalman filter has been implemented and has shown the transverse momentum resolutions to be consistent with the design specifications.

As the experiment moves forward tracking of real particles will expand to include a thorough treatment of the true magnetic field and the as-built resolution contributors

of the station planes. The MICE Trackers are therefore expected to provide the necessary resolutions to meet the requirements of MICE for a precision measurement of the emittance of a muon beam.

REFERENCES

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