STABILITY OF THE MICE MUON BEAM LINE*

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Abstract

The international Muon Ionization and Cooling Experiment (MICE) aims to demonstrate transverse beam emittance reduction for a muon beam [1]. During the summer of 2010, data was taken using different configurations of the upstream beam line magnets to measure the optical parameters of the muon beam and study the functionality of the beam line itself. Throughout this period of data taking, reference runs were taken with a fixed target configuration, and magnet settings which provide a muon beam with 200 MeV/c momentum and 6π 4D transverse emittance. Time of flight (TOF) detectors were used to measure many of the beam properties including emittance, particle identification, and profile. Analysis of these reference runs was carried out in order to determine the stability and reproducibility of the beam line data. This overall data quality check is essential to ensure the validity of measurements made so that further analysis can be carried out and that the muon beam is suitable for the MICE cooling channel.

INTRODUCTION

The MICE experiment, located at Rutherford Appleton Laboratory (RAL) in the United Kingdom, aims to demonstrate transverse emittance reduction for a muon beam. Such a technique is an essential component in the design of a neutrino factory or muon collider. Ionization cooling consists of first passing the muon through liquid-hydrogen absorbers to reduce momentum, and then re-accelerating it along the direction of the beam line with radio frequency (RF) cavities [1]. In order to properly correlate the timing of the RF cavity, high precision TOF detectors are used [2].

REFERENCE RUNS

During the spring and summer of 2010 MICE successfully completed Step I, in which these TOF detectors were used for particle identification and characterization of the beam line. Scans of current in upstream beam line components such as the decay solenoid and quadrupole magnets were performed, and measurements of beam parameters were made. In this way, the upstream beam line was studied and optimized to select for the desired particle momentum downstream [3]. In order to ensure the quality of measurements made with the TOF detectors, data was taken with a specific target configuration and magnet current settings that corresponded to “reference runs“. The values for all magnet currents can be found in [8]. These currents correspond to a beam with 200 MeV/c momentum and 6π 4D transverse emittance. The typical beam loss in the ISIS proton beam source was approximately 900 mV, corresponding to a target pulse depth of 32 mm. If running with a positive beam polarity, protons from the target interaction with the ISIS proton beam can contaminate the muon beam, which would saturate TOF0. Thus, the polyethylene proton absorber was installed with a thickness of 83mm [4]. The trigger was set to TOF1.

TOF DETECTORS

There are 3 TOF detectors in the MICE beam line: TOF0, TOF1 and TOF2. Each detector has two planes (x and y) made up of fast, 1 inch scintillator counting slabs outfitted with R4998 Hamamatsu photomultipliers (PMT) at each end. Each plane of TOF0 has 10 slabs, each of which is 4 cm wide, and has an active area of 40x40 cm. TOF1 planes have 7 slabs, 6 cm wide, and active areas of 42x42 cm. TOF2 has 10 slab, each 6 cm wide, and an active area of 60x60 cm [2]. Time to digital converter (TDC) and analog to digital converter (ADC) signals are read out at both ends of each slab in detectors. Each slab records a ”hit” when there is a coincidence between the PMTs at each end, which are referred to as PMT0 and PMT1 in this study. For a TOF to record an event, coincidence between two PMTs for a slab in the x plane *and* two PMTs for a slab in the y plane are necessary. This corresponds to a space point in the detector, which can be resolved to 1.15 cm for TOF0 and 1.73 cm for TOF1 [5]. The average timing resolutions are 52.2 ± 0.9 ps, 59.2 ± 0.7 ps, and 52.7 ± 1.1 ps for TOF0, TOF1, and TOF2 respectively[6].

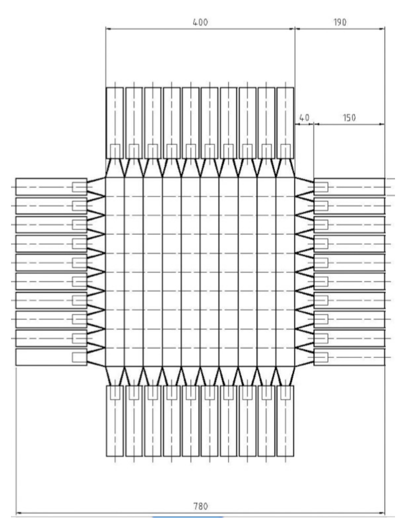

Figure 1: Schematic of TOF0. PMTs shown at either end of each strip. Coincidence between 4 PMTs (2 from each plane) is necessary for a space point[7].

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ANALYSIS

This analysis uses the G4MICE application *DataQualityCheck* to analyze TDC data from reference runs for a muon beam [1] [9]. The average x an y positions were measured, as well as the fraction of hits in each TOF slab and the correlation between signals in PMT0 and PMT1 for each slab. The data were plotted as a function of run number so as to emphasize the stability of the beam over the entire data taking period. Linear fits were applied to all graphs, and the slopes and $\chi^2/n.d.f.$ values were recorded.

Average x and y Positions

The average x and y positions of the beam were measured as a function of run number. There is a clear separation between the average x positions when running with a positive versus a negative beam line as seen in Figure 2. As a result, the two populations were fit separately. The discrepancy between positive and negative runs is much more pronounced in the x plane than in the y plane. Furthermore, moving downstream the difference between average x positions for positive and negative beams decreases, being approximately 1.5 cm, 1.0 cm , and 0.2 cm for TOF0, TOF1, and TOF2 respectively. The slopes were all found to be approximately 10^{-4} cm/run or less, with a $\chi^2/n.d.f. \approx 1$, indicating good fits.

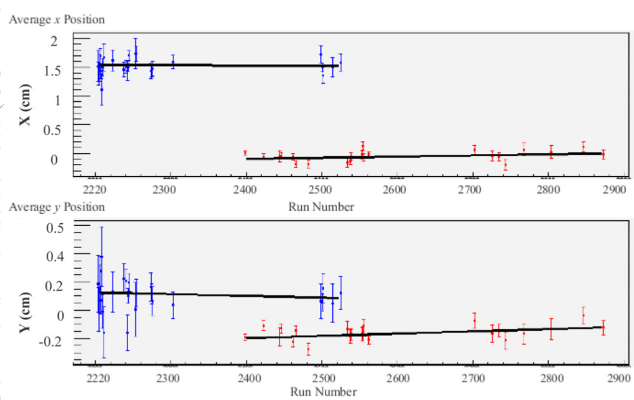

Figure 2: Average x (top) and y (bottom) beam position for TOF0. Blue indicates negative polarity beam line and red indicates positive polarity.

Fractional Hits in TOF Slabs

The percentage of hits in each slab for each plane of all TOFs were all graphed as a function of run number. It is expected that the highest percentage of hits is found in the center-most slabs, and that is indeed what is observed. The discrepancy between positive and negative polarity beam line settings is again present, and thus the fits were done separately for positive and negative populations. The plot for a particular slab in TOF 0 is shown in Figure 3. The slopes for all such fits were all approximately 0, with a $\chi^2/n.d.f. \approx 1$.

[1]The proton absorber removes proton impurities in the beam, and the timing resolutions of the TOFs are good enough to seperate electrons from the study. There may be some pions in the data analyzed, but relatively few compared to muons

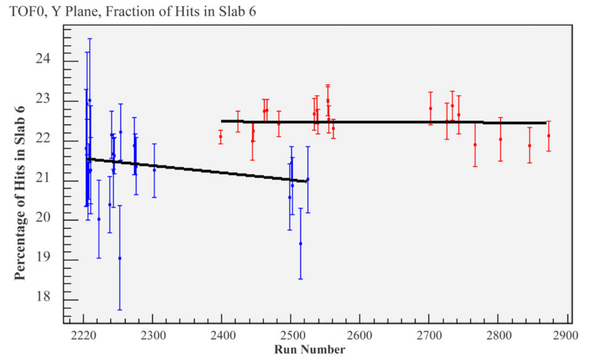

Figure 3: The percentage of all the hits in the TOF0 y plane that is recorded in slab 6. Blue corresponds to negative polarity runs; red corresponds to positive polarity.

PMT Signal Coincidence

Each PMT is read out with both a TDC and flash analog to digital converter (FADC) signal. It is expected that there should always be a FADC signal read whenever there is a TDC signal. It is confirmed that this is seen for all of the PMT's for all three TOF stations. Furthermore, there should be approximately the same number of TDC readings from PMT0 as PMT1. Slight differences are tolerable however, as long as they are consistent over the period of data taking. A histogram of the hits in the x plane of TOF0 is shown in figure 4. The green indicates a slab hit, and therefore coincidence between PMT0 and PMT1. The red line corresponds to the number of TDC signals from PMT0, while the blue corresponds to the number of TDC signals from PMT1. Note that for slab 6 in this figure, there are more signals in PMT0 than in PMT1. Figure 5 shows

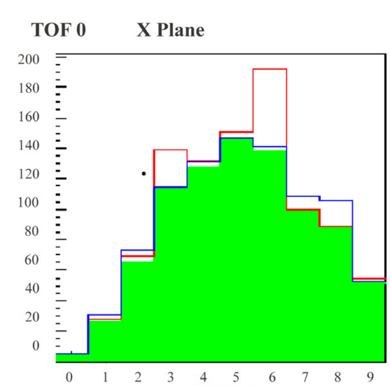

Figure 4: Histogram showing the slab hits due to PMT coincidence (green), as well as the TDC signals for PMT0 (red) and PMT1 (blue) for all slabs in the x plane of TOF0.

the percentage of TDC signals from PMT0 and PMT1 as a function of run number for slab 6. The fits were again done separately for positive and negative polarity beams. From the slopes of the fits for each PMT it was determined that the difference remained consistent over the course of the running period. Note also that slab 1 seems to have approximately the same number of signals in PMT0 as PMT1, as shown in figure 6, which is also consistent for all reference runs. The slopes of all fits were $\approx$ 0.0, and the $\chi^2/n.d.f.$ $\approx$1.

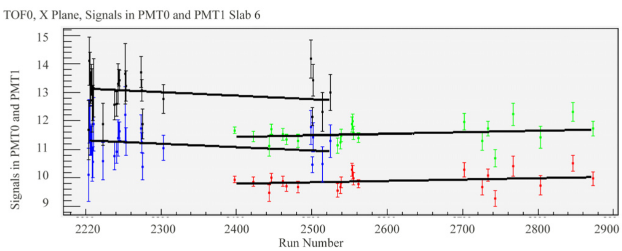

Figure 5: The percentage of signals in PMT0 and PMT1 for slab 6 in the x plane of TOF0. Green and black correspond to PMT0 signals for positive and negative runs respectively. Red and blue correspond to PMT1 signals for positive and negative runs respectively. There is a greater difference between the number of signals in each PMT for this slab than for most others.

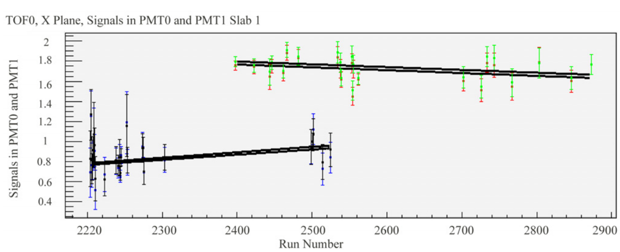

Figure 6: The percentage of signals in PMT0 and PMT1 for slab 1 in the x plane of TOF0. There is little difference between the number of signals in each PMT for this slab. Green, black, red and blue have the same meaning as in Figure 5.

CONCLUSION

Overall, the beam is stable for positive and negative runs analyzed separately. The beam is centered well with an average *x* position of -0.067 cm for positive runs and 1.526 cm for negative runs, and an average *y* position of -0.171 cm for positive runs and 0.105 cm for negative runs in TOF0, where 0.0 is taken to be the center of the plane. Furthermore, the slopes of all linear fits are essentially 0.0, which indicates that there is little fluctuation, and the $\chi^2/n.d.f.$ values are all $\approx$1, indicating a good fit. There were only few runs that were found to be outliers in the data set. The results of this study indicate that the data taken during Step I of MICE are of good quality and fit for higher levels of analysis.

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