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Alignment Errors on Emittance Measurements for MICE

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Abstract

A first study on the effect of misaligning the downstream spectrometer of the Muon Ionisation Cooling Experiment (MICE) upon the measurement of fractional emittance change is presented. This preliminary study has limited statistical accuracy, but already shows that the MICE spectrometer trackers need to satisfy alignment constraints on both trackers of 3 mm in positional and 1 mrad in rotational accuracy to achieve the MICE stated experimental goals of $\sim 1\%$ error on the fractional emittance change due to the cooling channel.

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1 Introduction and MICE

The Muon Ionization Cooling Experiment (MICE) [1, 2] aims to experimentally demonstrate ionization cooling: the reduction in transverse (4 dimensional) emittance of a muon beam due to ionization through a low Z absorber (liquid hydrogen or lithium hydride) and subsequent re-acceleration via radio-frequency (RF) cavities. MICE aims to demonstrate a fractional emittance reduction of -10% with an error of 1% (absolute emittance precision of 0.1%) for a variety of muon beams between 2π mm rad and 10π mm rad emittance and with momenta between 140 and 240 MeV/c. The purpose of this study is to estimate the systematic error upon the measurement of the fractional emittance change, due to a misalignment of the MICE spectrometers.

MICE has already started running parasitically at the ISIS synchrotron at the Rutherford Appleton Laboratory (RAL). It will evolve in a stepwise fashion over time with incremental addition of detectors, radio-frequency (RF) cavities and absorbers (Figure 1). At either end of MICE there are two spectrometers, consisting of five scintillating fibre tracker planes each, embedded in two 4 Tesla superconducting solenoids for measuring the emittance before and after the cooling channel. Calorimeter, time of flight and Cherenkov detectors perform particle identification to exclude pions and electrons from the emittance measurement.

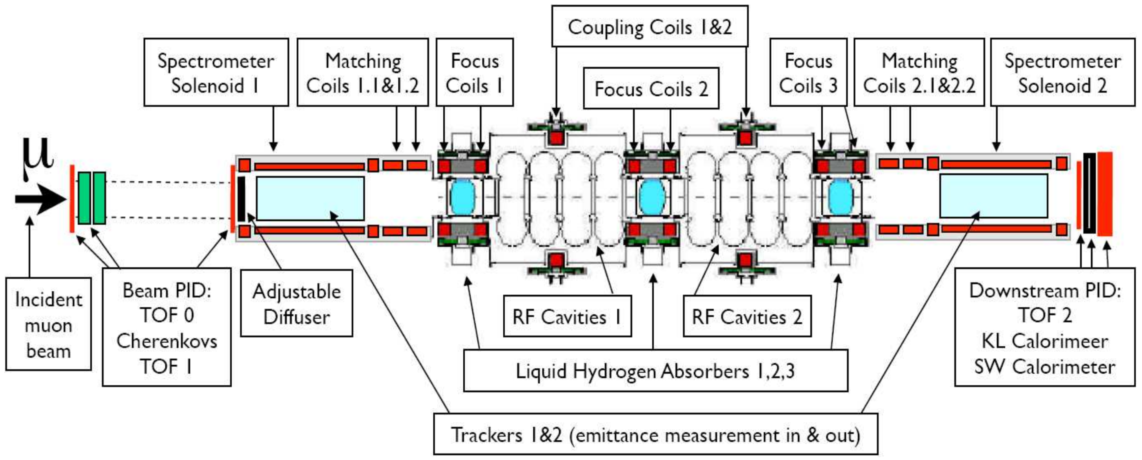

Figure 1: A schematic of the final stage of MICE. RF cavities and absorbers form the cooling channel, with particle identification and tracking detectors positioned at either end.

2 Spectrometer Misalignment

Since we are interested in measuring the emittance change before and after the cooling channel, it is the relative misalignment between the two trackers that is of interest, and so it is only necessary to misalign the downstream tracker to determine the relative effect on the emittance measurement. Twelve misalignment settings were studied: misalignment of ± 10 mm translation along the x and y axes, ± 3 mrad rotation on the $x - z$ and $y - z$ planes and a combination of the ± 10 mm translation and ± 3 mrad rotation. Monte Carlo simulations for each alignment setting and for beams with emittance between 1.5 and 10.0 π mm rad were made using the final configuration of MICE shown in Figure 1. Each independent simulation, with 10,000 muon tracks through MICE, was generated using the computing Grid [3] for the first time in the MICE collaboration. An example set of simulations in which the fractional change of emittance $\left(\frac{\Delta\epsilon}{\epsilon}\right)$ for a non-misaligned configuration compared to two with ± 10 mm misalignment in x for a range

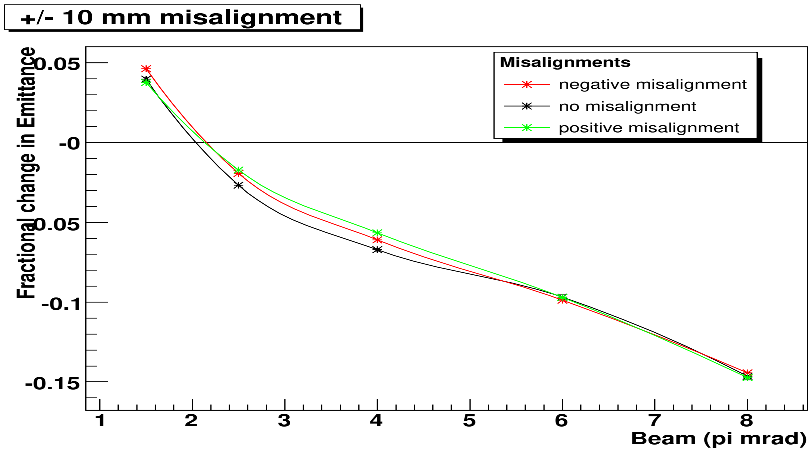

Figure 2: Fractional emittance change as a function of beam emittance. The aligned case is compared to that of the misaligned cases (±10 mm translation in x), with similar results.

of beam emittances is shown in Figure 2. Provisional results tabulated in Table 1 show the difference of fractional emittance change $\left(\frac{\Delta\epsilon}{\epsilon}\right)_{align} - \left(\frac{\Delta\epsilon}{\epsilon}\right)_{misalign}$ between a perfectly aligned and misaligned spectrometer for different emittance beams and for six misalignment configurations.

The goal of MICE is to measure the fractional emittance drop with an error of 1% or less. The largest change due to misalignment is 1.9% (Table 1), with statistical uncertainties of 0.5% to 1%. If these changes are linear in the size of misalignment, limiting these misalignments to 1/3 of those studied would meet the MICE specification, implying maximum acceptable misalignments of 3 mm (positional) and 1 mrad (rotational). Greater statistics are required in order to bolster these conclusions; however, this preliminary study suggests that with careful survey and alignment, the MICE specification can be met.

Emittance (mm rad)	1.5π	2.5π	4.0π	6.0π	8.0π	10.0π
x						
10 mm translation	0.66%	0.95%	1.06%	0.19%	0.22%	0.33%
3 mrad rotation	1.85%	1.56%	1.42%	0.55%	0.21%	0.81%
10 mm & 3mrad	1.39%	0.65%	0.68%	0.37%	0.44%	0.21%
y						
10 mm translation	1.02%	0.52%	0.26%	0.33%	0.29%	0.29%
3 mrad rotation	1.9%	1.37%	0.94%	0.34%	0.12%	0.25%
10 mm & 3mrad	0.91%	0.92%	0.91%	0.13%	0.23%	0.83%

Table 1: Preliminary results of fractional emittance change due to misalignment settings of 10 mm translation, 3 mrad rotation and a combination of both for six different emittance beams (1.5π to 10π mm rad).

References

[1] The MICE Collaboration, *An International Muon Ionization Cooling Experiment, Proposal to the Rutherford Appleton Laboratory (2003)*, http://mice.iit.edu/.

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[3] P.J.W. Faulkner et al., GridPP Collaboration, J. Phys. G32, N1-N20, 2006.