Demonstration of Muon Ionisation Cooling, Experimental and Operational Plan

Summary of objectives

The key objective of the MICE Ionisation Cooling (IC) demonstration is to build on the studies undertaken at STEP IV on the interaction of muon beams with a range of absorber materials in different optical lattices, to demonstrate the emittance reduction and re-acceleration of the muon beam in a configuration that may be repeated in a realistic front end for a muon accelerator complex. The experimental plan is to study the emittance reduction as a function of the magnetic configuration of the system (characterised by the β_T achieved in the absorber), the input emittance and momentum of the muon beam for both muons (μ^-) and anti-muons (μ^+). This document provides a preliminary proposal for the experimental plan.

Outline of STEP IV analysis of muon rate

For details of the STEP IV analysis of the expected realistic data rate, please refer to the STEP IV data-plan[i] document, in summary however there are about 100 triggers per spill of which around 10% are expected to yield acceptable data for analysis. There are additional overheads associated with dead time in the trackers. In the present document it is assumed therefore that (for positive muons) one may achieve 100k particles in 8 hours of operation (for negative muons the rate is ~10k muons in 8 hours).

Initial assessment of equivalent muon rate for the Ionisation Cooling experiment

It is possible to project using the STEP IV analysis the likely data rate for the IC experiment. Depending on the nature of the experiment, this data rate will vary from being equivalent to the STEP IV rate (i.e. for experiments where the RF signal is irrelevant), reducing slightly (by about one third) where one must consider the overlap of the RF pulse duration (1ms) with the muon spill (2ms), assuming the RF pulse time may be tuned to match the most intense part of the muon spill. Where the RF phase is important, namely for experiments where the experiment is designed to analyse the impact of the re-acceleration on the beam emittance, the rate of comparable muons drops to 0.07 times the Muon rate at Step IV since only particles which arrive within a 10% window in AC wave period around the RF crest can be considered as receiving a similar voltage uplift on transiting the accelerating gap (note however that muons at other phases will also provide interesting data). This gives about 114 hours for 100k positive muons.

Assumptions regarding ISIS/MICE operations Autumn/Winter/Spring 2017-2018

It is planned that the IC experiment will be operational by Sept 2017. This gives a period of at least 7 months for recording of data ahead of the current project end date of end March 2018. It is assumed that during this time ISIS will be operational for ~3 months, giving some 90 days of data taking. It is assumed that 24/7 running may be achieved. It is conservatively assumed, in defining this initial experimental plan, that this timeframe will encompass the optics commissioning phase.

Experiments to be conducted

The decision has been taken to focus IC data taking predominantly on positive muons due to the significantly higher data rate (negative muons occur in MICE at a rate about one tenth of the positive particles). Experiments are proposed with neither RF nor absorbers to check the optics, with absorbers and without RF and with RF (at reduced power levels) and no absorbers as preliminary calibration and verification experiments. These will have data rates that differ only slightly from STEP IV. These experiments are defined in Table 1. Note the prefix # in the tables below indicates the number of data points to be recorded. The 'Baseline' configuration used as a default is μ^+, 200MeV/c with the upstream solenoid and focus coil in opposite polarity to the downstream solenoid and focus coil (++--). The baseline β_T and emittance will be determined by analysis currently in hand, but presently estimated at 500mm and 6 mm respectively.

Table 1: Estimated calibration run durations, total runtime projected to be 314 hrs.

Measurement	RF Status	Absorber Status	Momentum Settings	Emiitance Settings	β_T settings	# Muons	Est. Time (Hrs)
Magnet alignment	Off	Out	Baseline	Baseline	Baseline	$1x10^6$, μ^+	80
Verify Optics (1)	Off	Out	#10	Baseline	Baseline	$1x10^4$, μ^+	8
Verify Optics (2)	Off	Out	200MeV/c	Baseline	#10	$1x10^4$, μ^+	8
Verify Optics (3)	Off	Out	200MeV/c	#3	Baseline	$1x10^5$, μ^+	24
Verify RF acceleration	Reduced Power	Out	Baseline	Baseline	Baseline	$1x10^6$, μ^+	114
Verify Absorbers	Off	In	Baseline	Baseline	Baseline	$1x10^6$, μ^+	80

There are seven IC experiments planned, as defined in Table 2 below. The magnet configurations (++--) represent the polarities of the upstream spectrometer solenoid and focus coil then the downstream focus coil and spectrometer solenoid. The IC experiments will have the lower data rates as outlined above. The last experiment in Table 2 is intended to allow the central absorber to be changed, either in terms of its thickness or material. Absorbers materials will be plastic and LiH.

Table 2: Estimated experimental run durations, Total projected run time 1710 hrs.

Measurement	Magnet configuration	Momentum settings	Emittance Settings	β_T settings	Muons	Est. Time (hrs)
Test MC predictions	++--	200MeV/c	#3	Baseline	$1x10^5$, μ^+	342
Measure $\Delta\varepsilon$ vs β_T	++--	200MeV/c	Baseline	#10	$1x10^4$, μ^+	114
Measure $\Delta\varepsilon$ vs p	++--	#10	Baseline	Baseline	$1x10^4$, μ^+	114
Compare behaviour, μ^-	++--	200MeV/c	Baseline	Baseline	$1x10^4$, μ^-	114
Compare Solenoid optics	++++	200MeV/c	Baseline	Baseline	$1x10^5$, μ^+	342
Compare optics	+--+	200MeV/c	Baseline	Baseline	$1x10^5$, μ^+	342
Alternative Absorber	++--	200MeV/c	Baseline	Baseline	$1x10^5$, μ^+	342

The total estimated running time is therefore 2024 hours. This should be set against an estimated 3 month window where data may be taken, say some 90 days or 2160hrs. This leaves >5% contingency.

<u>Overall summary of experimental time required</u>

The experimental time required for this campaign, which will deliver the key results on ionisation cooling with re-acceleration, can be achieved within conservative assumptions of the runtime available from the commissioning of the apparatus. Certain risks will be impossible to completely understand prior to testing the experiment including the long term stability of the RF systems and possible saturation of the trackers due to dark currents reducing the data rates, however the tests currently underway at Daresbury and Fermi laboratories will inform this understanding and allow mitigation if required.

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[i] Boyd S and Blackmore V, 'Planning the MICE Step IV Data Campaign', Aug 2014, http://micewww.pp.rl.ac.uk/documents/106