The Status of MICE

A. J. Dobbs on behalf of the MICE collaboration
Imperial College London, Blackett Laboratory, Prince Consort Road, London, SW7 2AZ, U.K
E-mail: adobbs@imperial.ac.uk

Abstract. Muon beams of low emittance provide the basis for the intense, well characterised neutrino beams for a Neutrino Factory and for lepton-antilepton collisions at energies of up to several TeV at a Muon Collider. The international Muon Ionization Cooling Experiment (MICE) will demonstrate ionization cooling, the technique by which it is proposed to reduce the phase-space volume occupied by the muon beam. MICE is being constructed in a series of Steps. The configuration currently in operation at the Rutherford Appleton Laboratory is optimised for the study of the properties of liquid hydrogen and lithium hydride that affect cooling. The plans for data taking in the present configuration will be described together with some preliminary results. A description of the next experimental configuration, used for the final cooling demonstration, is also presented.

1. Ionization Cooling
Future facilities based on muon acceleration offer the potential to probe new physics at both the intensity and energy frontiers. A Neutrino Factory is a proposed high intensity neutrino source based on the decay of muons in a storage ring and offers the greatest reach for measuring the CP violating parameter $\delta$ [1]. A Muon Collider offers a potential route to multi-TeV lepton - anti-lepton collisions in order to perform precision Higgs studies and discovery searches [2]. Both facilities are based on muon acceleration, a key component of which is ionization cooling.

Muons are produced as tertiary particles in both the Neutrino Factory and Muon Collider (proton - nucleon interaction leading to pions, pions decaying to muons). This results in a large initial beam phase space volume (that is, the 6 dimensional space comprising both position and momentum), a quantity known as the beam emittance. Beam cooling is therefore necessary in either facility in order to ensure good transmission of the muon beam through the beam line. Traditional beam cooling techniques however cannot be used due to the short muon lifetime.

Muon ionization cooling is a fast technique for reducing the emittance of a muon beam. Beam momentum is reduce uniformly in all directions via ionization energy loss by passing the muon beam through a suitable absorber. Low atomic number materials are chosen in order to minimise the opposing effect of multiple scattering. Following the absorber, the beam is passed through a radio frequency (RF) electric field which restores momentum in the longitudinal direction only. This procedure is then repeated until a sufficient reduction in the beam emittance is achieved.

2. The Muon Ionization Cooling Experiment
Muon ionization cooling has yet to be demonstrated at the energies of interest for a Neutrino Factory or Muon Collider. The Muon Ionization Cooling Experiment (MICE) is designed to demonstrate ionization cooling for application in these facilities. The experiment is based at the...
MICE

Figure 1. The final configuration of the MICE cooling channel (highlighted in green), magnetic lattice, spectrometer modules and particle identification detectors. $M$ refers to matching coils, $E$ to end coils and $C$ to the coils used to generate the solenoidal fields for tracking.

Science and Technology Facilities Council Rutherford Appleton Laboratory, U.K., employing the ISIS synchrotron as a proton driver.

The experiment consists of a fully instrumented beam line; a cooling cell; and upstream and downstream spectrometers. The muon beam is generated by dipping a titanium target into the circulating ISIS synchrotron beam with the subsequent pion shower being captured by a quadrupole triplet. The pions decay providing the required muons. The beam line is fully instrumented using two threshold Cherenkov detectors; three time-of-flight (TOF) stations; and a downstream calorimeter. Beam emittance is measured immediately prior to and after the cooling channel by means of the two spectrometers, each of which consists of a high precision scintillating-fibre tracker in a solenoidal field. Lastly, the cooling channel itself consists of three absorber modules (which allowing testing of various low atomic number media) and two RF cavities. A diagram of the final cooling channel is shown in figure 1.

MICE is a staged experiment, built and run in discrete steps. The initial stage, the implementation and characterisation of the muon beam line, is complete [3, 4, 5, 6]. The present stage, known for historical reasons as Step IV, introduces the two spectrometers and the first absorber module. The next and final stage, known simply as the demonstrate of ionization cooling (DEMO), introduces the RF cavities and additional absorber modules. The physics goals of each step are described in table 1.

Table 1. MICE physics programme. $\epsilon_\|$ denotes the normalised transverse emittance, $\epsilon_\perp$ the transverse emittance and $\epsilon_\parallel$ the longitudinal emittance.

| Step IV:                                      |
|-----------------------------------------------|
| Material properties of LiH and LH$_2$ that determine the ionization cooling performance |
| Observation of $\epsilon_\perp$ reduction     |

| DEMO:                                         |
|-----------------------------------------------|
| Observation of $\epsilon_\perp$ reduction with re-acceleration |
| Observation of $\epsilon_\perp$ reduction and $\epsilon_\parallel$ evolution |
| Observation of $\epsilon_\perp$ reduction and $\epsilon_\parallel$ and angular momentum evolution |
3. Step IV Status

The Step IV programme calls for the measurement of multiple scattering, energy loss and transverse emittance reduction in various absorber media (principally LiH and \( \text{LH}_2 \)) for a range of input beam settings. The Step IV cooling cell matches that shown figure 1 but with only one absorber module present in a focus coil, and no RF cavities.

Step IV is fully approved, construction is complete and data are now being collected. Due to the failure of one of the downstream spectrometer match coils, various alternative optics programmes are presently being studied [7]. Once complete the final Step IV operating parameters may be defined.

Initial Step IV data have been taken throughout 2016, including for empty absorber, Xe and LiH absorbers. Running is due to continue throughout 2017, including using a LH\(_2\) absorber, when the first transverse emittance reduction observations are expected to be measured. Some preliminary data showing the measured beam emittance and transverse phase space for the empty absorber configuration are shown in figure 2.

![Figure 2. MICE muon beam properties measured in Step IV running. Left: Transverse normalised emittance versus \(P_z\). Right: Distribution of \(x\) against \(P_x\).](image)

A description of the proposed DEMO stage is given in [8].

4. Conclusion

MICE has completed the initial step of its programme having produced and fully characterised the muon beam line. The present step is currently taking data in order to characterise the cooling performance of various media.

References

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