The MICE demonstration of ionization cooling

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Abstract

Muon beams of low emittance provide the basis for the intense, well-characterised neutrino beams necessary to elucidate the physics of flavour at the Neutrino Factory and to provide lepton-antilepton collisions at energies of up to several TeV at the Muon Collider [1]. 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 at such facilities. In an ionization-cooling channel, the muon beam passes through a material (the absorber) in which it loses energy. The energy lost is then replaced using RF cavities. The combined effect of energy loss and re-acceleration is to reduce the transverse emittance of the beam (transverse cooling). A major revision of the scope of the project was carried out over the summer of 2014. The revised project plan, which has received the formal endorsement of the international MICE Project Board and the international MICE Funding Agency Committee, will deliver a demonstration of ionization cooling by September 2017. In the revised configuration a central lithium-hydride absorber provides the cooling effect. The magnetic lattice is provided by the two superconducting focus coils and acceleration is provided by two 201 MHz single-cavity modules. The phase space of the muons entering and leaving the cooling cell will be measured by two solenoidal spectrometers. All the superconducting magnets for the ionization cooling demonstration are available at the Rutherford Appleton Laboratory and the first single-cavity prototype is under test in the MuCool Test Area at Fermilab. The design of the cooling demonstration experiment will be described together with a summary of the performance of each of its components. The cooling performance of the revised configuration will also be presented.

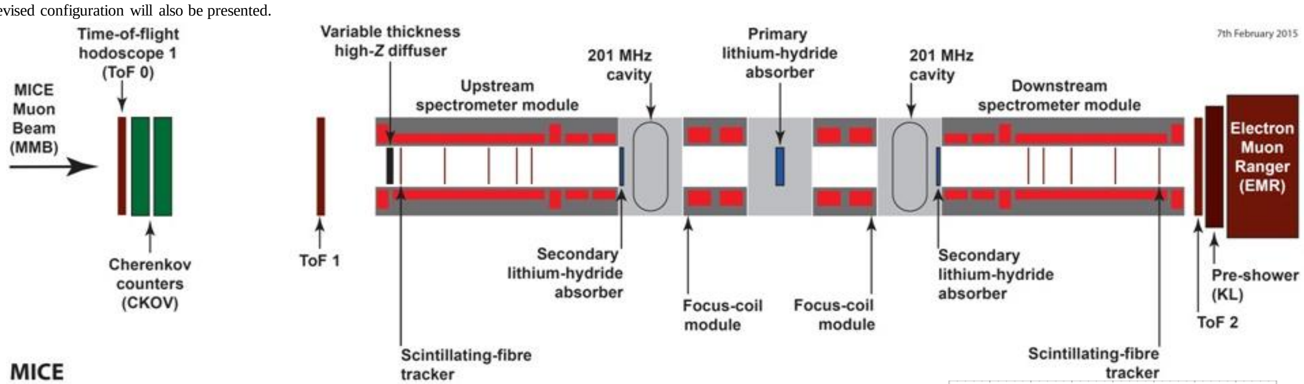

Figure 1: Layout of the novel lattice configuration for the MICE Cooling Demonstration.

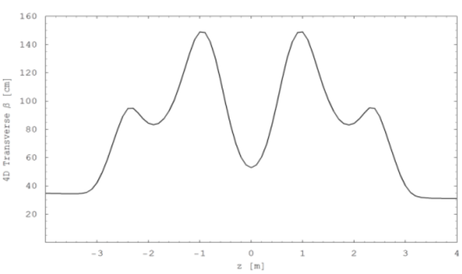

Figure 2: 4D betatron function evolution in the novel lattice designed for MICE Cooling Demonstration.

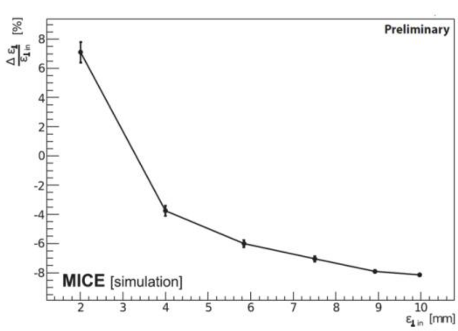

Figure 4: Change in muon beam normalised 4D emittance versus initial input emittance expected using the configuration adopted for the demonstration of ionization cooling.

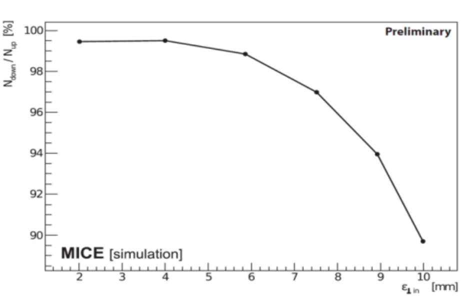

Figure 5: Transmission of the ionization-cooling demonstration lattice as function of the input beam emittance.

Lattice for Cooling Demonstration

- MICE aims to demonstrate sustainable ionization cooling of muons [2, 3] neccessary for future particle physics facilities such as the Neutrino Factory and a Muon Collider.
- Following P5 report [4] project was formally rebaselined to deliver the configuration presented in Fig. 1.
- The schedule shows that the initial demonstration of ionization cooling will be performed by the end of US fiscal year 2017, while preserving MICE measurements at Step IV [5] scheduled in 2015.
- A small betatron function (shown in Fig. 2) at the position of the primary absorber (LiH) can be achieved together with an acceptable beam size at the position of the 201 MHz cavities using magnetic configuration (see Fig. 3) based on only existing magnets.
- The baseline lattice performs very well in the Monte Carlo simulations (using MAUS software) yielding a measurable spectrum of cooling as shown in Fig. 4, while keeping the high transmission of muons through the cooling cell (see Fig. 5).
- The secondary LiH absorbers (SAs) will be introduced between the cavities and trackers in order to minimise the exposure of trackers to dark-current electrons to reduce correlated background to the muon tracks. Trackers [6] will be also protected by retractable, lead radiation shutters during RF conditioning. The SAs also increase the net transverse cooling effect.
- Radiation shutters and SAs will use independent but similar rail system (see Fig. 6) and will be located between SSs and the RF modules. The ability to remove the absorbers remotely will allow studies of the bare magnetic lattice.

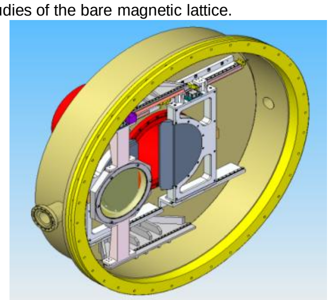

Figure 6: Design of the movable frame for the SA (front) and the lead radiation shutter (back). The half discs of lead shutter (grey) can be seen together with the rails inside the MICE vacuum chamber (yellow).

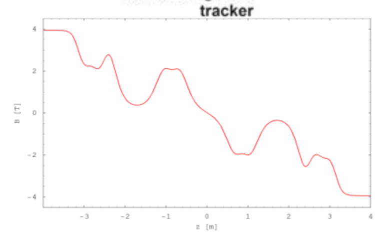

Figure 3: Solenoidal magnetic field on axis in the novel lattice designed for MICE Cooling Demonstration.

Conclusions and Future Plans

The MICE collaboration is now on track to deliver its demonstration of ionization cooling by 2017. The demonstration will be performed using lithium-hydride absorbers and with acceleration provided by two single, 201 MHz, cavity modules[7]. The equipment necessary to mount the experiment is either in hand (the superconducting magnets and instrumentation) or at an advanced stage of preparation (the single-cavity modules). The novel revised configuration has been shown to deliver the performance required for the detailed study of the ionization-cooling technique.

The demonstration of ionization cooling that MICE will provide is essential for the provision of the intense, well characterised muon beams required to elucidate the physics of flavour at the Neutrino Factory or to deliver multi-TeV lepton-antilepton collisions at the Muon Collider. The successful completion of the MICE programme will therefore herald the establishment of

Acknowledgemnts

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