Spokesman's update

K. Long, 4 May, 2017

Spokesman's update

PAPERS

Design and expected performance of the MICE demonstration of ionization cooling

The MICE collaboration

Muon beams of low emittance provide the basis for the intense, well-characterised neutrino beams necessary to elucidate the physics of flavour at a neutrino factory and to provide lepton-antilepton collisions at energies of up to several TeV at a muon collider. The international Muon Ionization Cooling Experiment (MICE) aims to 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 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 experiment can deliver a demonstration of ionization cooling. The design of the cooling demonstration experiment will be described together with its predicted cooling performance.

1 Introduction

Stored muon beams have been proposed as the source of neutrinos at a neutrino factory [1, 2] and as the means to deliver multi-TeV lepton-antilepton collisions at a muon collider [3, 4]. In such facilities the muon beam is produced from the decay of pions generated by a high-power proton beam striking a target. The tertiary muon beam occupies a large volume in phase space. To optimise the muon yield while maintaining a suitably small aperture in the muon-acceleration system requires that the muon beam be "cooled" (i.e., its phase-space volume reduced) prior to acceleration. A muon is short-lived, decaying with a lifetime of 2.2 μs in its rest frame. Therefore, beam manipulation at low energy ($\lesssim 1$ GeV) must be carried out rapidly. Four cooling techniques are in use at particle accelerators: synchrotron-radiation cooling [5]; laser cooling [6, 7, 8]; stochastic cooling [9]; and electron cooling [10]. Synchrotron-radiation cooling is observed only in electron or positron beams, owing to the relatively low mass of the electron. Laser cooling is limited to certain ions and atomic beams. Stochastic cooling times are dependent on the bandwidth of the stochastic-cooling system relative to the frequency spread of the particle beam. The electron-cooling time is limited by the available electron density and the electron-beam energy and emittance. Typical cooling times are between seconds and hours, long compared with the muon lifetime. Ionization cooling proceeds by passing a muon beam through a material, the absorber, in which it loses energy through ionization, and subsequently restoring the lost energy in accelerating cavities. Transverse and longitudinal momentum are lost in equal proportions in the absorber, while the cavities restore only the momentum component parallel to the beam axis. The net effect of the energy-loss/re-acceleration process is to decrease the ratio of transverse to longitudinal momentum, thereby decreasing the transverse emittance of the beam. In an ionization-cooling channel the cooling time is short enough to allow the muon beam to be cooled efficiently with modest decay losses. Ionization cooling is therefore the technique by which it is proposed to cool muon beams [11, 12, 13]. This technique has never been demonstrated experimentally and such a demonstration is essential for the development of future high-brightness muon accelerators.

The international Muon Ionization Cooling Experiment (MICE) collaboration proposes a two-part process to perform a full demonstration of transverse ionization cooling. First, the "Step IV" configuration [14] will be

Accepted by PRAB

Papers

Papers in progress

Title	Contact	Comment
Step IV physics		
First measurement of emittance in Step IV	V. Blackmore	**Preliminary results made public.** Results being finalised so publication can be prepared.
Measurement of scattering distributions in MICE	R. Bayes	**Preliminary results made public.** Work continues following meeting with referees.
Ionization cooling demonstration		
Design and expected performance of the MICE demonstration of ionization cooling	J.B. Lagrange	**arXiv:1701.06403; Accepted by PRAB.**

Step IV field-on papers

Title	Contact	Comment
Step IV physics		
Field-on measurement of multiple Coulomb scattering	A. Young	Analysis underway
Measurement of energy-loss distributions	S. Wilbur	Analysis underway
Beam-based alignment	To be assigned	Analsis underway
Phase-space density/emittance reconstruction	To be assigned	Analsis underway
Phase-space density/emittance evolution; rapid communication	To be assigned	Analsis underway
Phase-space density/emittance evolution review paper	To be assigned	Analsis underway

- Completion of "milestsone papers" will require completion of a number of detailed analyses, e.g.:
  - Transfer matrix approach to magnetic alignment;
  - Study of effect of non-linear terms in the Hamiltonian (field) expansion;
- Each of these analysis may warrant a paper of its own.

Papers in progress

Title	Contact	Comment
Technical		
The MICE Analysis and User Software framework	D. Rajaram	**In preparation**
Muon Ionization Cooling Experiment	C. Whyte	**Work to start soon.**
The MICE RF system	K. Ronald	**Builds on conference publications.**
The MICE magnetic channel	A. Bross, J. Cobb	**Builds on conference publications**
The MICE liquid-hydrogen absorber	V. Bayliss, J. Boehm	**Builds on conference publications**

Spokesman's update

PREPARATION OF LH2 SYSTEM

Preparation of the LH2 system

- Installation going well
- Two substantive issues found:
  - Should LH2 freeze in pipes leading to vessel, possible for pressure to rise in vessel.
  - Burst pressure of H2 window is around 10bar. If window bursts, then get rapid pressure rise. Re-analysis of impact of pressure rise indicates that FC OVC may be compromised.
- Mitigation:
  - Relieve pressure in the H2 vessel – never generate high pressure
  - Removes risk of failure
  - Implementation underway
- HAZOP 16/17May17:
  - Now part of the “sign-off for operation”

LH2 team news

- Staffing:
  - V.Bayliss (lead):
    - Will go on maternity leave soon
    - J.Boehm in place to take over
  - Technical effort:
    - Strong contribution by a small team
      - Relies on V.Bayliss, M.Tucker, P.Warburton, J.Boehm, G.Govans
    - R.Preece, S.Balashov have been/are/will also contribute
- Now in critical phase:
  - Pump-down of system now started
  - Next step is “neon test”
    - Start cool down at the end of this week …

Spokesman's update

PLANS FOR CYCLE 2017/01

Operations in Cycle 2017/01

- Cycle started!
- Plan:
  - Wk 1 (this week): LH2 acivities
  - WKs 2&3: Staff 1 data-taking shift per day:
    - Alignment, calibration
  - Wk 4: 24/7 data taking:
    - LH2: field-off scattering

- NB:
  - No magnet operation this Cycle (straight-track programme)
  - No data taking with liquid neon:
    - Safety case requires minimum volume of LNe for viable test

Spokesman's update

COLLABORATION

Institute of High Energy Physics; Protvino

To: A. Zaitsev, State Research Centre of Russian Federation Institute for High Energy Physics (IHEP)
From: K. Long (MICE spokesman), C. Whyte (MICE Project Manager)

February 6, 2017

Brief specification of the MICE cooling demonstration

To deliver intense muon beams of high brightness requires that the muon-beam phase space is reduced (cooled) prior to acceleration and storage. Ionization cooling, in which the beam is caused to pass through a material (the absorber), in which it looses energy, and is subsequently accelerated, is the technique by which it is proposed to cool the beam. The international Muon Ionization Cooling Experiment (MICE) collaboration seeks to demonstrate the principle of ionization cooling by measuring the performance of a realistic ionization-cooling cell as a function of muon-beam energy, initial emittance and the optics of the lattice. The configuration that was proposed for the demonstration of ionization cooling is shown in figure 1 [1]. It contains a cooling cell sandwiched between two spectrometer-solenoid modules. The cooling cell is composed of two 201 MHz cavities, one primary (65 mm) and two secondary (32.5 mm) LiH absorbers and two superconducting "focus-coil" (FC) modules. Each FC has two separate windings that can be operated either with the same or in opposed polarity.

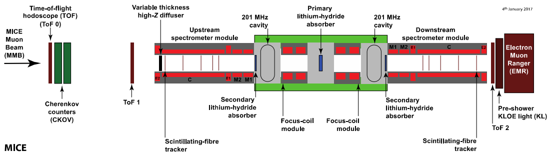

Figure 1: Layout of the lattice configuration for the cooling demonstration. The red rectangles represent the solenoids. The individual coils in the spectrometer solenoids are labelled E1, C, E2, M1 and M2. The ovals represent the RF cavities and the blue rectangles the absorbers. The various detectors (time-of-flight hodoscopes [2, 3], Cerenkov counters [4], scintillating-fibre trackers [5], KLOE Light (KL) calorimeter [6, 7], electron muon ranger [8]) used to characterise the beam are also represented. The green-shaded box indicates the cooling cell.

The MICE programme is executed in "Steps". The MICE collaboration is now executing "Step IV" of its programme. Step IV is optimised for the study of the factors that determine the size of the ionization-cooling effect and consists of the two spectrometer modules sandwiching a central lithium-hydride or liquid-hydrogen absorber (see figure 2). Each spectrometer solenoid is instrumented with a scintillating-fibre tracker [5]. The spectrometers have been designed such that the change in the properties of the beam as it passes through the absorber (for example $\epsilon_\perp^n$) can be measured with a relative precision at the per-cent level [5]. Upstream of the first spectrometer, time-of-flight (ToF) hodoscopes and Cherenkov (CKOV) counters are used to reject the small residual pion contamination in the beam [9]. The ToF system will also be used to trigger the experiment and, combined with the upstream spectrometer, measure the longitudinal phase-space of the incoming beam.

Downstream of the experiment, a ToF hodoscope, a lead-scintillator calorimeter (the KL) and a totally active scintillator calorimeter (the Electron Muon Ranger, EMR) will reject electrons (positrons) from muon decay and determine the longitudinal phase-space of the beam as it emerges from the absorber [10, 11]. Both LH_2 and LiH absorbers will be used at Step IV [12, 13].

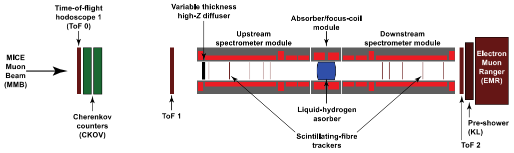

Figure 2: Schematic diagram of the Step IV configuration of MICE. The muon beam enters from the left of the figure. The beam-line instrumentation (the time-of-flight, ToF, hodoscopes, the Cherenkov (CKOV) counters, the pre-shower, KL, detector and the Electron Muon Ranger, EMR) are indicated. The spectrometer solenoids, and the scintillating-fibre trackers they contain are shown upstream and downstream of the central absorber/focus-coil (AFC) module.

Recently, one of the coils (labelled "M1" in figure 1) in the spectrometer solenoid placed downstream of the absorber module failed. Analysis of the failure indicates a possible weakness in the one remaining match coil (M2). As a result, the collaboration is preparing a proposal to upgrade the Step IV configuration to complete the ionization-cooling lattice cell and to reconfigure the instrumentation downstream of the cooling cell as shown in figure 3. Four scintillating-fibre stations from the unused downstream spectrometer will be used to measure the beam emerging from the cooling cell. The performance of the revised configuration is sufficient to prove the principle of ionization cooling and no longer relies on the damaged downstream solenoid.

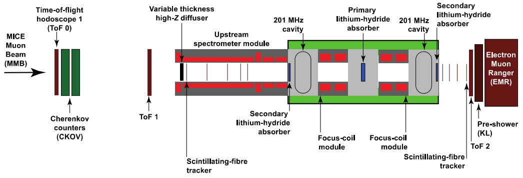

Figure 3: Schematic of the configuration prepared to deliver the demonstration of ionization cooling in the light of the issues related to the downstream solenoid.

The following paragraphs summarise the specification of the MICE Muon Beam on ISIS at the Rutherford Appleton Laboratory, the detector systems that are in use to measure each muon as it passes through the exper-

2

- Have opened discussion of:
  - MICE
  - MICE demo @ IHEP
  - 6D cooling experiment beyond MICE

Protvino

- Reply received Mar17

Phone call re involvement of Protvino

Phone call (Skype): 13Mar17; 14:00

Present: K. Long (MICE spokesman, Imperial/STFC);
C. Whyte (via mobile, Project Manager, Strathclyde/STFC);
V. Garkusha (Head of Beam Department);
A. Zaitsev (Deputy Director, responsible for experimental physics)

- Follow-up phone call 13Mar17:
  - Discussed possible implementation and issues
  - Agreed:

We discussed the next steps and agreed:

- To work towards a second phone call at the end of March or beginning of April to discuss outcomes of the above SoI process and progress in thinking on both sides;
- To include in the discussions longer term items such as a 6D-cooling experiment for which there is not yet a completed design.
- To work towards appropriate personnel from IHEP attending the MICE collaboration meeting in Belgrade, Serbia, 27-29 June 2017.
- KL will include AZ and VG in CC in emails relevant to the issues outlined above.

08/03/2017

Feasibility of the implementation of the MICE cooling demonstration at NRC KI IHEP

Here is a feasibility study of the MICE cooling demonstration at the 70-GeV machine at IHEP. In this analysis, the materials presented in Dr. K. Long's letter of 6 February 2017 and in the publications indicated in this letter are used. All findings are preliminary.

1. Layout

Experimental hall serving to place the installation, shown in Figure 1.

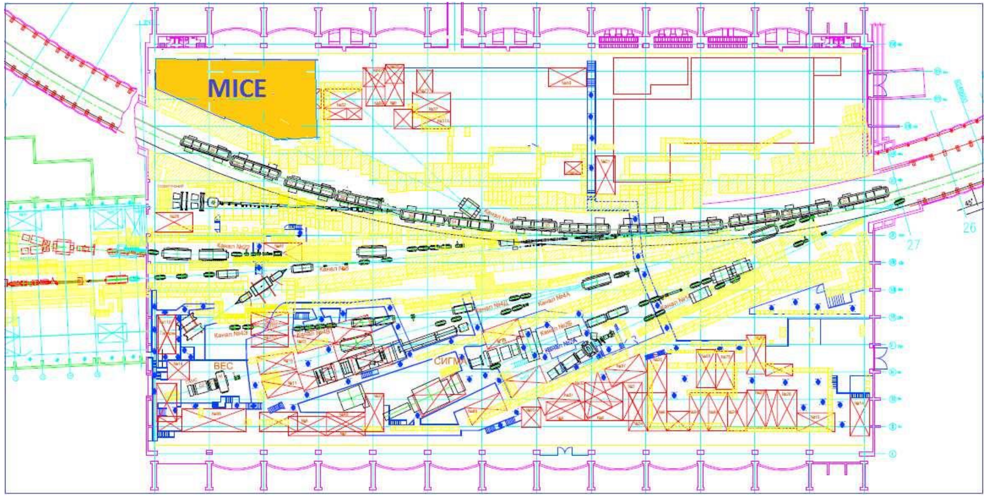

Fig. 1 Experimental hall

IHEP Protvino, stop press:

Zaitsev Alexandre 22 April 2017 at 20:05

MICE

To: Long Ken

Dear Ken,

I would like to inform you on our latest activities related to MICE project.

1. Next week, CERN will host a meeting of CERN management with Russian authorities, where one of the issues will be discussion of cooperation between Russia and CERN using Russian facilities. We proposed to include MICE in the list of projects where our side expresses readiness for implementation it at the U-70 accelerator. I understand that CERN is not a participant of the project and can not make decisions about it, but expressing interest and the advisability of development can be useful.

2. We have completed the preliminary calculations of the characteristics of the muon beam and confirm our conclusion about its suitability for the MICE project.

Best regards, Alexandre

- Follow-up call with A. Zaitsev to be organised for next week
  - Ideal way forward:
    - Bring IHEP into collaboration to help complete MICE
    - Develop joint activity for 6D cooling experiment to follow MICE

Spokesman's update

CONCLUSIONS

Conclusions

- Steady execution of Step IV programme:
  - LiH data for scattering and emittance evolution “in the can”
  - LH_2-absorber data now required to complete Step IV programme
    - Requires data taking in Cycle 2017/02: Sep/Oct 2017
      - Collaboration granted approval to operate in this Cycle
- This VC:
  - Presentation of results for IPAC:
    - Need to agree which data should be made public.