Vol. 4 (2011) *Acta Physica Polonica B Proceedings Supplement* No 1

FAST TOF FOR MUON COOLING EXPERIMENTS*

Robert J. Abrams

Muons, Inc., Batavia, IL, USA

(Received January 31, 2011)

Fast timing detectors are used in muon cooling experiments to improve measurements of the muon momentum for determination of emittance reduction properties of muon cooling channels that are a necessary element of muon colliders and neutrino factories. Examples of their use are presented.

DOI:10.5506/APhysPolBSupp.4.79
PACS numbers: 29.40.Gx

1. Introduction

Multi-TeV lepton colliders are being planned to complement the LHC in the understanding of high energy physics phenomena and processes. Muon colliders require beams of low energy muons that are highly compacted in phase space so that they can be captured and accelerated to high energies. Due to the short lifetime of the muon, ionisation cooling is the only means to compact the phase space (emittance reduction). Ionisation cooling at low momenta (~ 200 MeV$/c$) causes energy loss, and for long cooling channels, it is necessary to restore the longitudinal component of the muon momentum by applying RF along the the cooling channel. Ionisation cooling experiments are underway and are being planned to determine the optimal designs of muon cooling channels. Fast timing detectors are useful in measurements of phase space and emittance in muon cooling experiments.

2. Fast timing detectors in the MICE experiment

The MICE ("Muon Ionization Cooling Experiment") [1], which is underway at RAL (Rutherford Appleton Laboratory) in England, is the first experiment to demonstrate muon cooling. Pions, produced in collisions of 800 MeV protons, decay in a solenoidal magnet to deliver a beam of ~ 250 MeV$/c$ muons to the cooling section and the associated detectors. The layout of the experimental apparatus is shown in Fig. 1. The cooling

* Presented at the Workshop on Timing Detectors, Kraków, Poland, November 29–December 1, 2010.

section consists of three 50 cm long liquid hydrogen absorbers, with RF accelerating cavities between them. The expected cooling effect (4-dimensional emittance reduction) is 10–15%. The muon momenta before and after the cooling section are measured with solenoidal spectrometers containing scintillating fiber planes. Additional detectors include Cherenkov counters to reject pions in the beam and a range detector to redundantly measure the final muon energy.

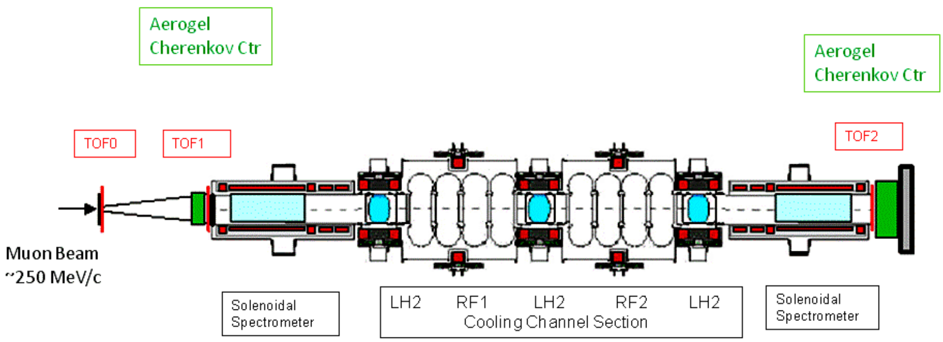

Fig. 1. Layout of MICE experiment.

There are three time-of-flight detectors (TOF0, TOF1, and TOF2). TOF0 is used to synchronize the muons with the RF timing. TOF1 and TOF2 are used to measure the total time of flight of the muon as it passes through the system. The TOF detectors are hodoscopes of fast scintillators and fast PMTs, with time resolutions if 50–60 ps and space resolutions of 2–3 cm. An illustration of how improvements in the time-of-flight measurement can improve the momentum resolution of the MICE spectrometers. Figure 2 (left) shows the expected resolution of P_z, the longitudinal component of the momentum as a function of P_z for the MICE spectrometers, and the expected P_z resolution for a pair of TOF counters with 10 ps and

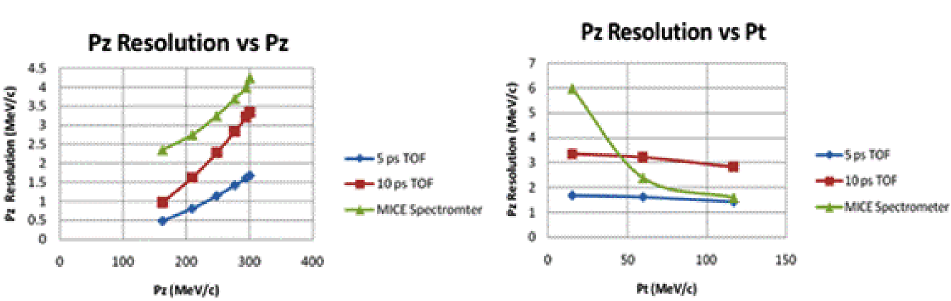

Fig. 2. Dependence of resolution on TOF.

5 ps time resolutions, respectively. Figure 2 (right) shows the P_z resolutions as a function of P_t the transverse component of the momentum. The P_z resolution of the MICE solenoidal spectrometers improves with increasing P_t, while the expected resolutions are rather independent of P_t.

3. Fast timing detectors in the proposed MANX experiment

The MANX ("Muon And Neutrino eXperiment") [2] has been proposed to be carried out either at Fermilab, or at RAL as an extension of the MICE experiment. The objective of the MANX experiment is to test the cooling of a unique type of cooling channel that is being developed by Muons, Inc. in collaboration with Fermilab and other institutions. The cooling channel is an HCC (Helical Cooling Channel). The layout of the MANX experiment as an extension of the MICE experiment is shown in Fig. 3. The MANX cooling channel is a 3.2 m long HCC filled with liquid hydrogen or liquid helium, without RF sections. The are "matching" magnets upstream and downstream of the HCC, which are used to provide a smooth transition of the muons into and out of the HCC. The matching magnets are not filled with absorber. There are five TOF detectors shown in the Fig. 3 of the type being developed by the LAPPD Collaboration [3], which are expected to have about 10 ps time resolution and about 0.5 mm position resolution. With fine resolutions such as these, it may be possible to eliminate the need for the solenoidal spectrometers, and use non-magnetic spectrometers based on the TOF detectors.

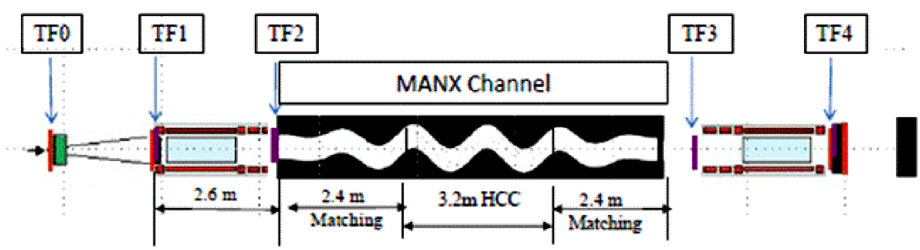

Fig. 3. Layout of MANX experiment.

4. The Helical Cooling Channel

In this section we provide a description of the HCC, as shown in Fig. 4. The magnetic field is produced by a helical solenoid, Fig. 4 (a), which consists of circular coils with their centres displaced along a helix [4]. The field has dipole, quadrupole, and sextupole fields so that the trajectories, as shown in Fig. 4 (b), follow a helical path about a reference trajectory.

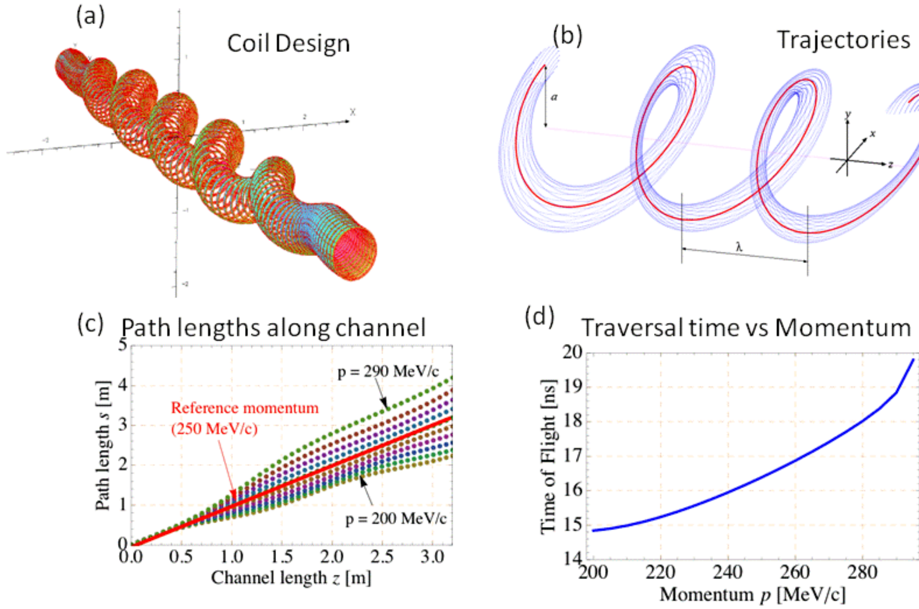

Fig. 4. HCC coils and trajectories.

The path lengths executed depend on the momenta, as shown in Fig. 4 (c), such that the path lengths of higher momentum particles travel through more material, and those of lower momentum travel through less material [2]. Thus at the end of the channel the range of the momenta is compressed, and the beam is cooled. In Fig. 4 (d) the relation between time of flight within the channel is plotted vs momentum. This also shows that better timing measurements are important in measuring the performance of the cooling channel.

The work has been supported in part by SBIR Grant DE-SC0005445 to Muons, Inc. and the University of Chicago.

REFERENCES

[1] MICE experiment web site, available at `http://mice.iit.edu/`

[2] R. Abrams *et al.*, MANX, A 6-D Muon Beam Cooling Experiment for RAL, Paper TH5RFP078K, Proceedings of PAC09, Vancouver, CA, May 2009.

[3] LAPPD web site, available at `http://psec.uchicago.edu/`

[4] V. Kashikhin *et al.*, Magnets for the MANX 6-D Muon Cooling Experiment, Paper MOPAS012, Proceedings of PAC07, Albuquerque, NM, June 2007.