MICE Particle Identification System

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Abstract
The Muon Ionization Cooling Experiment, MICE, at the ISIS accelerator located at the Rutherford Appleton Laboratory, UK, will be the first experiment to study muon cooling at high precision. Demonstration of muon ionization cooling is an essential step towards the construction of a neutrino factory or a muon collider. Muons are produced by pion decay in a superconducting solenoid and reach MICE with a range of emittances and momenta. The purity of the muon beam is ensured by a system of particle detectors we will briefly describe here.

1 Introduction

The Muon Ionization Cooling Experiment, MICE [1] at the Rutherford Appleton Laboratory aims to test ionization cooling technique for muons at minimum ionising energy (approximate momentum range from 140 to 240 MeV/c). The muons first lose energy both in transversal and longitudinal direction by passing through a liquid absorber LH_2. Then they undergo an energy restoration in RF cavities but only in their longitudinal component, thus the cooling is transversal only. The emittance is precisely measured before and after the cooling channel by tracking each muon individually. The muon is identified by a set of particle detectors: three time-of-flight stations, two Cherenkov counters and a low energy electron-muon calorimeter. In Fig. 1 is shown MICE spectrometer cooling channel and particle detectors.

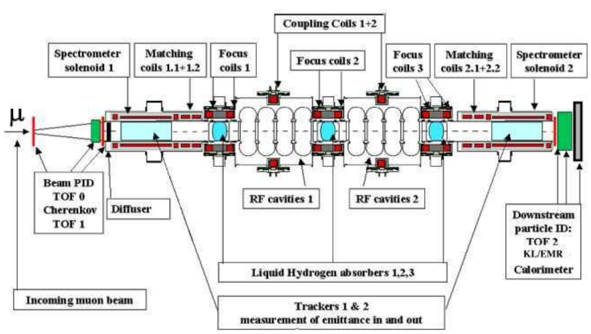

Fig. 1: Layout of MICE experiment.

2 Time-of-flight system

The aim of the TOF system [2] is twofold: first, is to synchronize precisely the muon time with the phase of radio-frequency and second, to distinguish muons from background particles (π, e) at level below 1%. For such a purpose a time resolution of about 70 ps is needed. MICE TOF system consists of three stations named TOF0, TOF1 and TOF2[1]. TOF0 and TOF1 are situated upstream of the first solenoid ensuring PID in the incoming beam and TOF2 is located downstream of the second solenoid as a part of downstream PID system.

[1]Currently TOF0 and TOF 1 are operational, TOF2 is about to be installed and commissioned by the end of 2009.

All TOF stations are based on a common design - 1” thick scintillator counter. TOF0 has 10 slabs each 4 cm wide, TOF1 has 7 slabs each 6 cm wide, and TOF2 has 10 slabs each 6 cm wide. The covered area for TOF0, TOF1 and TOF2 is 40 $\times$ 40 cm^2, 42 $\times$ 42 cm^2 and 60 $\times$ 60 cm^2 respectively. The readout is solved as dual R4998 PMT. Photomultipliers in TOF1 and TOF2 are shielded against high magnetic field (up to 1000 - 1500 Gauss) in metal boxes.

The intrinsic time resolution of TOF0 and TOF1 obtained by real data is shown to be between 55 and 65 ps, which is very close to the requirements. In Fig. 2 is shown particle separation by time-of flight between TOF0 and TOF1 for a 300 MeV/c pion beam momentum.

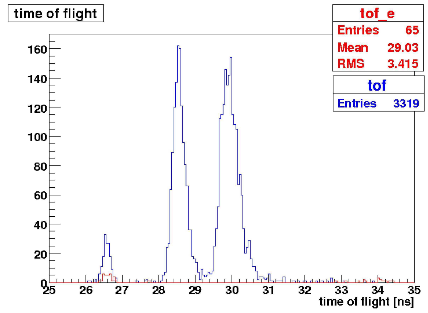

Fig. 2: Particle identification by TOF. The e, μ and π peaks are clearly separated.

3 Cherenkov counters

At higher momenta range (220-360 MeV/c) the difference of time-of-flight for μ and π decreases from 2.4 ns to 1 ns over 10 m distance (approximate distance between TOF0 and TOF1). This will create difficulties in μ/π separation by TOF technique. As a complimentary device in the upstream part of the beam line two aerogel Cherenkov counters [3] are located. The selected aerogels have indexes of refraction n = 1.07(p_μ^{th} = 280 MeV/c, p_π^{th} = 360 MeV/c) and n = 1.12(p_μ^{th} = 220 MeV/c, p_π^{th} = 280 MeV/c). Both Cherenkovs have eight photomultipliers in total.

The calibration of Cherenkov detectors is done by studying their response to 200 MeV/c positrons. In Fig. 3 is shown a typical energy spectrum. The collected yield is 5-6 photoelectrons per PMT or 20-24 per detector, which is sufficient for muon tagging efficiency at 98% at low pion misidentification.

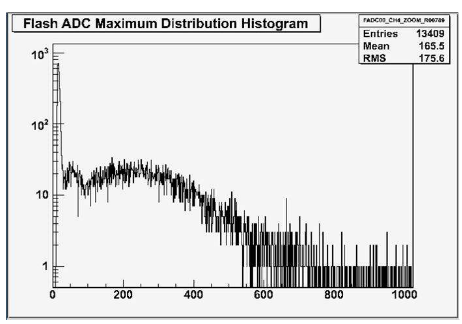

Fig. 3: Typical energy spectrum from one Cherenkov PMT in response to 200 MeV/c positrons.

4 Calorimeter

The MICE calorimeter is the most downstream part of the MICE spectrometer. It is not intended to be used for energy measurement, its main goal is to provide separation between muons and decay positrons.

In addition it should be able to separate muons from pions and electrons. The electromagnetic calorimeter consists of two parts: KL (Kloe Light, based on Kloe calorimeter design [4]) which is installed and fully operated at MICE site and EMR (Electron-Muon Ranger [5]) which is in a prototype phase.

KL is a sampling calorimeter, composed by extruded Pb foils in which scintillating fibers are placed in a volume ratio $\sim$ 1:2. The KL has 2.5 X_0 depth which corresponds to 4 cm thick active depth. It has an energy resolution of $\Delta E/E \sim 7\%/\sqrt{E}$ for electrons and a time resolution of $\Delta t = 70ps/\sqrt{E}$.

KL has 21 cells, 42 readout channels (one for each side of the cell). The light is collected by 42 phototubes Hamamatsu R1355. In Fig. 4 is shown KL response to positrons and muons in a nominal 300 MeV/c positron beam.

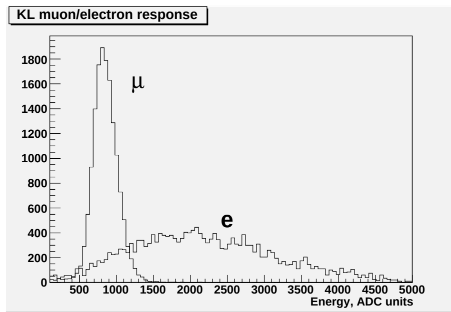

Fig. 4: KL energy spectrum for positrons and muons in response to nominal 300 MeV/c positron beam.

The particles which pass through KL enter further into Electron–Muon Ranger. It represents 50 layers of active scintillator bars organized in x–y plane. The total thickness of EMR is about 85 cm. Each plane consists of 59 triangular shape 1.1 m long bars (see Fig. 5). Light is carried out by a single 1.2 mm diameter WLS(Bicron BCF-92) fiber inserted and glued in the bar hole. The fiber on one side is connected to a single channel photomultiplier (XP2972, Philips) and on the other side to a 64 channel multianode photomultiplier (H7546B, Hamamatsu). The EMR is designed to have a longitudinal momentum resolution of about 4 MeV/c.

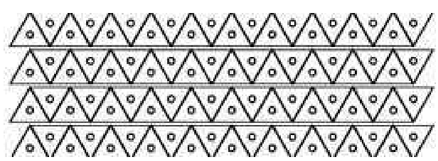

Fig. 5: Layout of the EMR structure.

References

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