THE MICE PID DETECTOR SYSTEM

M. Rayner, Department of Physics, Oxford University, UK *
M. Bonesini, Sezione INFN Milano Bicocca, Milano
(on behalf of the MICE Collaboration)

Abstract

The international Muon Ionization Cooling Experiment (MICE) will perform a systematic investigation of ionization cooling of a muon beam. The demonstration comprises one cell of the neutrino factory cooling channel. As the emittance measurement will be done on a particle-by-particle basis, sophisticated beam instrumentation is needed to measure particle coordinates and timing vs RF. A PID system, in order to keep beam contamination (e, π) well below 1%, based on time-of-flight stations, two Aerogel Cerenkov detectors and a KLOE-like calorimeter has been constructed and installed at RAL. First performances in beam at RAL are reported.

INTRODUCTION

The MICE experiment [1] at RAL aims at a systematic study of a section of the cooling channel of the proposed US Study 2 [2], attaining a 10% effect for a 6π·mm rad beam. The 5.5 m long cooling section consists of three liquid Hydrogen absorbers and eight 201 MHz RF cavities encircled by lattice solenoids. As conventional emittance measurement techniques reach barely a $\sim 10\%$ precision, a novel method based on single particle measurements has been envisaged. Particles are measured before and after the cooling section by two magnetic spectrometers complemented by TOF detectors. For each particle x,y,t,p_x,p_y, E coordinates are measured. In this way, for an ensemble of N particles, the input and output emittances may be determined with a precision up to 0.1%, that allows a sensible extrapolation of the results to the full cooling channel.

THE MICE DETECTOR SYSTEM

The secondary muon beam from ISIS (140-240 MeV/c central momentum, tunable between $1 - 10\pi\cdot$ mm rad input emittance) enters the MICE cooling section after a Pb diffuser of adjustable thickness (see figure 1 for details). Muons originate from π decay inside a 5 m long SC solenoid upstream of the first PID detectors.

The driving design criteria for MICE detectors are robustness, in particular of the trackers, to sustain the severe background conditions in the vicinity of RF cavities and redundancy in PID in order to keep beam contaminations (e, π) well below 1% and reduce systematics on the emittance measurements.

* presenter

The PID detector system

PID is obtained upstream of the first tracking solenoid by two TOF stations (TOF0/TOF1) and two threshold Cerenkov counters (CKOVa/CKOVb), that will provide π/μ separation up to 300 MeV/c. A picture of the upstream PID detectors, inside the closed DSA area [1], is shown in figure 2.

Figure 2: Image of TOF0 and the two Aerogel Cerenkov counters in final position inside the closed DSA area at RAL. Beam impinges from the left.

Downstream the PID is obtained via a further TOF station (TOF2) and calorimeters (EMCAL), to separate muons from decay electrons. All TOF detectors are used to determine the time coordinate (t) in the measurement of the emittance.

To determine the timing with respect to the RF phase to a precision of 5^0 a detector resolution ~ 50 ps is needed for TOF0. To allow a better than 99% rejection of pions in the incoming muon beam, a resolution ~ 100 ps for the TOF measurement between TOF0 and TOF1 is needed. All these requirements imply a conservative request of $\sim 50 - 60$ ps for single TOF station resolution.

It is not possible to select a single Cerenkov radiator that is sensitive to muons and blind to pions over the entire momentum range. The chosen solution [3] is two different aerogel counters with refractive indices 1.07 and 1.12, each equipped respectively with four 8" low background EMI9356KA PMTs from the earlier Chooz experiment. Purities better than 99.7% are thus obtained in the momentum range 210 to 365 MeV/c. Thus high purities are obtained: from 99.7% with both counters on to 99.98% with both counters off in the momentum range between 210 and

[1] Decay Solenoid Area - closed area nearby the extraction point of the pion secondary beam from ISIS that contains a 5 m long, 5 T decay solenoid for muon collection and the first PID detectors

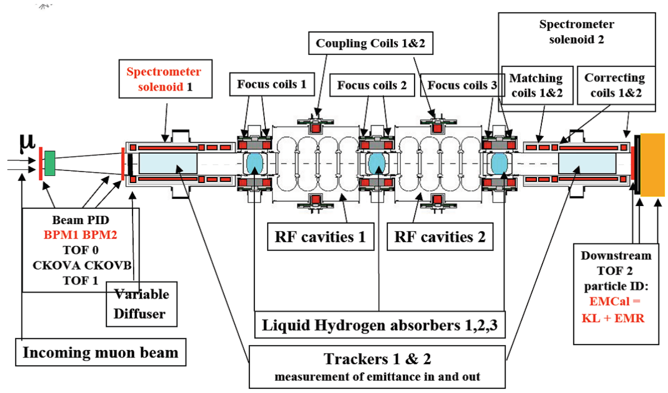

Figure 1: 2-D layout of the MICE experiment at RAL. The muon beam from ISIS enters from the left. The cooling section is put between two magnetic spectrometers and two TOF stations (TOF1 and TOF2) to measure particle parameters. The position of the various detectors of the MICE instrumentation is shown.

365 MeV/c. At lower momenta, the π/μ separation is obtained by a tof measurement, both Cerenkov detectors being blind to both particle types.

All the TOF stations share a common design based on fast 1" scintillator counters along the X/Y directions (to increase measurement redundancy) read at both edges by conventional R4998 Hamamatsu photomultipliers [2]. While TOF0 planes cover a 40×40 cm^2 active area, TOF1 and TOF2 cover respectively a 42×42 cm^2 and 60×60 cm^2 active area. The counter width is 4 cm in TOF0 and 6 cm in the following ones. All downstream detectors and the TOF1 station must be shielded against stray magnetic fields (up to 1300 Gauss with a ≤ 400 Gauss longitudinal component). Two options for the local TOF1/TOF2 shielding have been chosen: in one (for TOF1) a double-sided shielding cage will fully contain the detector, aside a hole for the beam, while in the other (for TOF2) massive soft iron boxes for shielding the PMTs are used. While the first solution is more elegant and reduces the detector weight, it gives complications for detector access and maintenance.

The TOF stations must sustain a high instantaneous incoming particle rate (up to 1.5 MHz for TOF0). R4998 PMT rate capabilities were tested in the laboratory with a dedicated setup based on a fast laser [3]. The rate capability was increased by the use of an active base.

The PMT signals, after a splitter, are sent to a fast CAEN V1290 TDC, following a Lecroy 4415 leading edge discriminator, for time measurements and are digitized by a CAEN V1724 FADC [4] to give the pulse height for the time-walk correction.

The downstream calorimeters (EMCAL) consist of a Pb-scintillating fiber calorimeter (KL), of the KLOE type [5], with 1-mm diameter blue scintillating fibers glued between 0.3 mm thick grooved lead plates [5] followed by an electron-muon ranger (EMR), made of a 1 m^3 fully sensitive segmented scintillator block. This "spaghetti" design for KL offers the possibility of fine sampling and optimal lateral uniformity. The expected resolution $\sigma_E \simeq 5\%/E$ is fully dominated by sampling fluctuations and is linear for electrons or photons in the range 70-300 MeV. EMR will be made with extruded scintillator bars with WLS fibers readout. In the EMCAL while KL will measure electrons, the EMR will measure precisely the muon range.

The TOF0/TOF1/TOF2 and KL detectors have been installed in steps in the MICE Hall at RAL in 2008 and 2009, as shown in figure 3.

They have performances compatible with requirements. After time-walk corrections and the calibration procedure with impinging beam particles (see reference [4] for details), the TOF detector timing resolution can be measured by using the time difference Δt_{XY} between the vertical and horizontal slabs in the same station (see figure 4). The obtained resolution on the difference is $\sigma_{XY} \sim 100\ ps$ for TOF0 and TOF2, $\sigma_{XY} \sim 120\ ps$ for TOF2 [6]. Resolutions are compatible in the TOF0 detector (4 cm wide slabs) and the TOF2 detector (6 cm wide slabs), showing that path lenghts fluctuations effects are negligible.

Figure 5 shows, as an example, the distribution of the time-of-flight between TOF0 and TOF1 for the 300 MeV/c pion beam and a positron beam [7]. The first peak which

[2] 1" linear focussed PMTs, typical gain $G \sim 5.7 \times 10^6$ at B=0 Gauss, risetime 0.7 ns, TTS $\sim$ 160ps

[3] An home-made system based on a Nichia NDHV310APC violet laser diode and an AvetchPulse fast pulser (model AVO-9A-C laser diode driver) was used. This system gave laser pulses at $\sim$ 409 nm, with a FWHM between $\sim$ 120 ps and $\sim$ 3 ns and a max repetition rate of 1 MHz

[4] the same ADC is used also for the KL calorimeter readout

[5] since the particle energy is lower than in KLOE, the ratio of fiber to lead has been adjusted by making the lead foils thinner, hence the name Kloe Light or KL in shorter

[6] This translates into $\sim 50(60)ps$ resolution for the full TOF0/TOF2 (TOF1) detector with crossed horizontal and vertical slabs. The worse resolution of TOF1 is probably due to the poorer quality of the PMTs used.

[7] this beam is set by starting from the settings for pion beam at 300 MeV/c and reducing down all the currents in the upstream magnets to a nominal 100 MeV/c momentum. At this momentum only positrons reach TOF stations

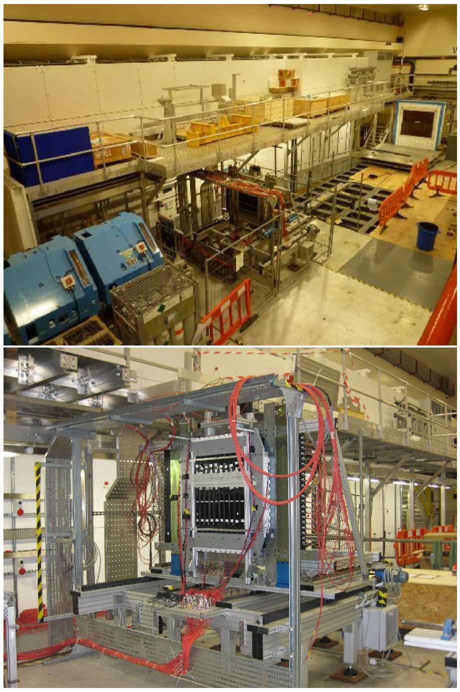

Figure 3: *Top panel: presently installed beamline in the MICE Hall at RAL. TOF1 is on the temporary trolley and TOF2 on the final downstream RM3 platform in front of KL. Bottom panel: enlargement of TOF2 and KL.*

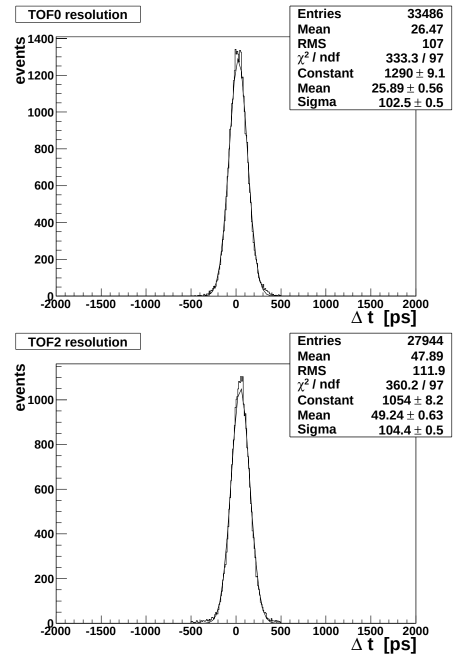

Figure 4: *Time difference Δt_{XY} between vertical and horizontal slabs in TOF0 (top panel) and TOF2 (bottom panel). Trigger is on TOF1.*

is present in both distributions (pion and positron beam) is considered as the $time\ of\ flight$ of the positrons and is used to determine the absolute value of the time in TOF1. A natural interpretation of the other two peaks is that they are due to forward flying muons from pion decay and pions themselves.

CONCLUSIONS

The fist step of MICE, corresponding to characterize the incoming muon beam, has been mainly accomplished, by the construction of the muon beamline and the PID detectors. Obtained detector performances are compatible with requirements.

REFERENCES

[1] A. Blondel et al., MICE proposal, RAL, 2004.

[2] S.Ozaki *et al.*, BNL-52623, June 2001 ; M.M. Alsharo'a et al., Phys. ReV. ST. Accel. Beams 6,081001 (2003).

[3] L. Cremaldi *et al.*, IEEE Trans. on Nucl. Science 56 (2009) 1475.

[4] R. Bertoni *et al.*, Nucl. Instr. and Meth. A615 (2010)14.

[5] A. Aloisio et al., KLOE coll., Nucl. Inst. and Meth. A 494 (2002), 326.

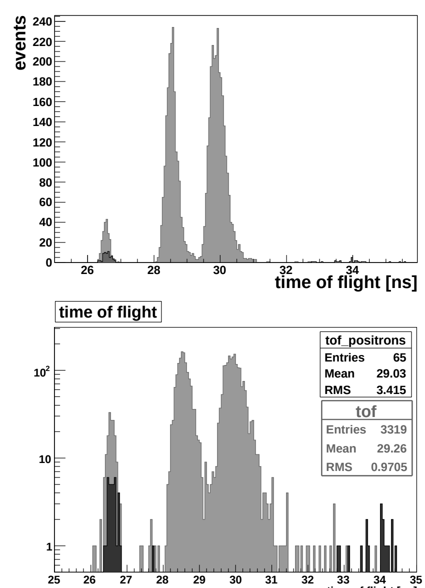

Figure 5: Time of flight between TOF0 and TOF1 for the $positron$ (black) and $pion$ (grey) beams in normal (top) and logarithmic (bottom) scale.