MICE: THE INTERNATIONAL MUON IONIZATION COOLING EXPERIMENT: DIAGNOSTIC SYSTEMS*

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Abstract

The Muon Ionization Cooling Experiment will make detailed measurements of muon ionization cooling using a new constructed low-energy muon beam at the Rutherford Appleton Laboratory (RAL). The experiment is a single-particle experiment and utilizes many detector techniques from high energy physics experiments. To characterize and monitor the muon beamline, newly developed scinitillating fiber profile monitors and scintillator paddle rate monitors are employed. In order to monitor the purity of the beam and tag the arrival time of individual muons, a dual aerogel Cherenkov system is used, and a plastic scintillator time-of-flight system will be used. The phase-space vectors of the muons will be measured by two identical spectrometer systems (one before and one after the cooling apparatus) which employ a fiber tracker system, and electron and muon calorimeters are used to tag outgoing muons. We will discuss the design of the MICE diagnostic systems, the operation, and give the first results from beam measurements in the MICE experimental hall.

INTRODUCTION

A Neutrino Factory based on a muon storage ring is the ideal tool for neutrino oscillation studies and possibly for the discovery of leptonic CP violation. A Neutrino Factory could also be the first step toward a muon-antimuon collider. Ionization cooling, while not yet demonstrated, has been shown by simulations and design studies to be an important factor for the performance and cost of a Neutrino Factory. An international R&D program for the development of a Neutrino Factory and muon-antimuon collider has been established. An important step toward these facilities is a first experimental demonstration of muon ionization cooling. The main goals of the international Muon Ionization Cooling Experiment [1, 2] are to

- Design, engineer, and build a section of cooling channel with performance suitable for a Neutrino Factory
- Place the cooling channel in a muon beam, and measure its performance in various operation modes and beam conditions to test the limits and practicality of muon cooling.

EXPERIMENTAL LAYOUT

The MICE beamline will provide MICE with muon beams of various momenta and initial emittances. The main components of the beamline are shown in Fig 1.

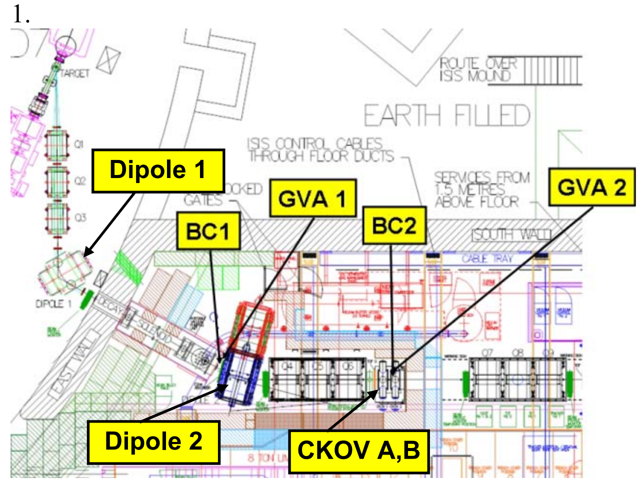

Figure 1: MICE beamline highlighting the particle rate and particle identification diagnostic systems.

ISIS at RAL accelerates protons to 800 MeV. A special MICE beamline has been made. A titanium paddle is dipped into the circulating beam once per second [3]. Proton-titanium collisions produce pions which are focused by a triplet of quadrupoles. Momentum selection of these pions is done by the first dipole magnet. Pion decay to muons will occur in a decay solenoid; to date, the decay solenoid has been installed in the beamline, but not powered. The muons are then detected by scintillating paddle rate monitors (GVA 1,2 in Fig. 1). Data from the scintillating fiber monitors (BC 1,2 in Fig. 1) has been collected, but not yet used in the beamline analyses. The paddle monitors record both the particle rate and arrival time. After passage through a second dipole magnet and another triplet of focusing quadrupole magnets, the muon beam passes through a dual aerogel Cherenkov system (CKOV A,B in Fig. 1) which identifies pions (and, ultimately, muons). Currently, the particle beam consists mainly of protons. The beam then passes through a third set of quadrupole magnets.

The main components of MICE are shown in Fig. 2. Cooling is provided by one cell from the 5.5 m cooling channel of "Study-II" [4]. Some components of the Study-II cooling channel have been modified to reduce costs and to comply with RAL safety requirements. The incoming muon beam first encounters a TOF counter. The TOF counters make precise time measurements which contribute to particle identification (PID). A lead diffuser [5] then generates a tunable input emittance. Then a spectrometer consisting of tracking detectors within a uniform solenoidal magnetic field measures the locations and momenta of each particle. After this initial

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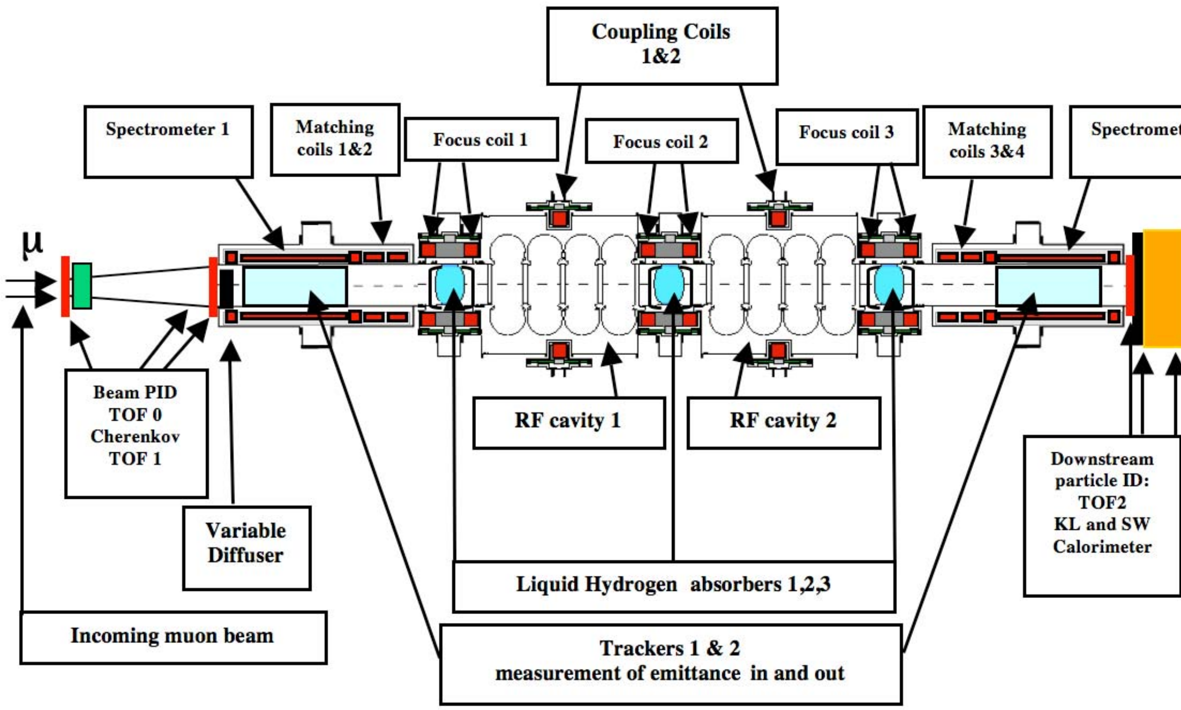

Figure 2: MICE layout.

momentum measurement is the cooling section consisting of liquid hydrogen absorbers, RF cavities, and superconducting coils. An additional absorber finishes the cooling section to protect the downstream tracker from dark currents emitted by the RF cavities. The track positions and momenta after the cooling section are measured by a second spectrometer identical to the first. After the second spectrometer, a third TOF counter and calorimeter provide further time and PID measurements and reject background electrons from muon decay.

MEASUREMENT TECHNIQUE

Precision measurements of the muon beam transmission and emittance require single particle tracking and detection using standard particle physics techniques instead of those typically used in beam instrumentation. Momentum measurements are made with magnetic spectrometers. Each spectrometer measures the x and y coordinates of an incident particle at given z positions. Momentum and angles are reconstructed by fitting a helix to the measured positions. The root mean square resolution of the position and transverse momentum measurements must be less than about 10% of the root mean square beam size and rms tranvserve momentum for the experimental resolution to remain small compared to the expected emittance change of about 10%. A precision measurement of the emittance also requires tracking that can determine if a particle left the MICE channel or completely traversed it, in order to separate the effects of collimation and cooling. The MICE PID system needs to keep the electron and pion contamination of the muon beam below 0.1% to achieve the desired emittance measurement precision. Measurements of accelerator and absorber parameters (RF phase and voltages, absorber thickness, etc.) are also needed for consistency checks and to ensure measurement reproducibility.

DETECTORS

The main design criteria for the MICE detector systems are precision, robustness in particular for the tracking detectors which must be able to handle potentially severe backgrounds near the RF cavities, and redundancy in PID to keep contamination below 0.1%. The two upstream TOF detectors consist of 6 cm wide layers of hodoscopes segmented in the x and y directions, and the downstream TOF detector consists of 4 cm wide layers of hodoscopes also segmented in the x and y directions. The timing resolution of the TOF detectors is about 60 ps as measured in a test beam. As well as PID the TOFs are essential for the determination of the phase of a muon with respect to the RF in the accelerating cavities. The upstream and downstream spectrometers each contain five sets of scintillating fiber planes deployed in three stereo views. Groups of seven fibers are read out using cryogenic VLPC photodetectors. The threshold Cherenkov system upstream of the cooling channel is two detectors containing aerogel radiators. The aerogel indices of refraction are 1.07 and 1.12. Each is read out with four photomultiplier tubes. The indices of refraction are such that over track momenta between 140 and 240 MeV/c, pions and muons going through the two detectors can be distinguished by the intensity of the Cherenkov light in each detector. The downstream PID system consists of the third TOF counter and the calorimeter. The calorimeter consists of two detector systems: a layer of lead with embedded scintillating fibers used to detect electrons (KL in Fig. 2), and forty layers of scintillator planes to detect (penetrating) muons (SW in Fig. 2). Careful diagnostic design and attention to system integration and calibration will enable emittance measurements with 0.1% precision.

STATUS AND IMMEDIATE PLANS

The MICE Collaboration is bringing together the MICE detector and cooling channel components at RAL. The full beam line is scheduled to be completed this summer, and initial emittance measurements are expected soon afterward with the addition of the first spectrometer. The sequential addition of the second tracker, absorbers, and RF cavities will culminate in extensive emittance and muon cooling measurements in varying run conditions.

Since February, MICE has been carrying out beam line commissioning measuring particle rates through the beam line and making particle identification of pions based on Cherenkov light and time of flight measurements [6]. Fig. 3 shows some results of the beam commissioning indicating particle transport and particle identification. MICE beam line commissioning also includes successful operation of the MICE target during ISIS running as well as successful operation of the MICE data acquisition system. Future beam line commissioning plans include turning on the decay solenoid and the last 3 of 9 focusing quadrupoles; both should increase particle rate and provide a measurable number of muons.

MICE will operate with a variety of settings allowing the cooling performance to be mapped out for a range of cooling-channel parameters and beam momenta. The cooling-channel performance will be compared with the predictions of detailed simulations. A demonstration by MICE that muon ionization technology is feasible and that its cost and performance are well understood will pave the way for the Neutrino Factory Conceptual Design Report and will provide direction to muon colliders in the longer term.

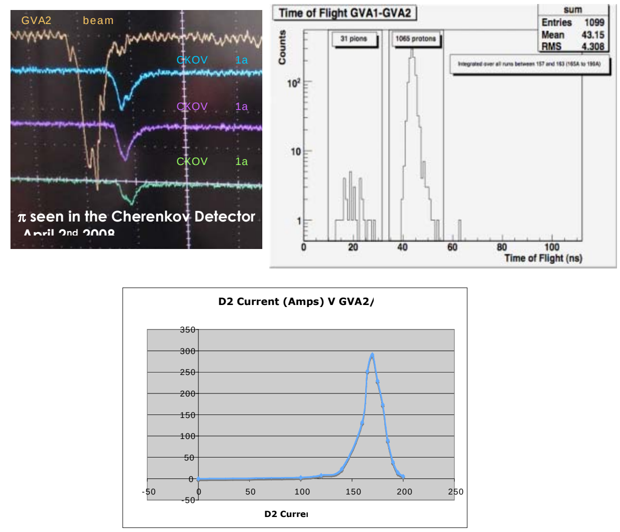

Figure 3: MICE beamline commissioning results. Top left: Cherenkov photomultiplier tube activity in coincidence with pulses from the second scintillating paddle (GVA 2) indicating the passage of pions. Top right: time differences between the two scintillating paddles (GVA 1,2) which differentiate faster pions from slower protons. Bottom: particle rate in GVA 2 as a function of the second dipole (Dipole 2) current. The peak at 170 A indicates transport of ~ 450 MeV/c particles through the MICE beamline.

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