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A Scintillating Fibre Tracker for MICE

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The provision of intense stored muon beams would allow the properties of neutrinos to be measured precisely and provide a route to multi-TeV lepton-anti-lepton collisions. The short muon lifetime makes it impossible to employ traditional cooling techniques while maintaining the muon-beam intensity. Ionisation cooling, a process in which the muon beam is passed through a series of liquid hydrogen absorbers followed by accelerating RF-cavities, is the proposed cooling technique. The international Muon Ionisation Cooling Experiment (MICE) collaboration has been approved at the Rutherford Appleton Laboratory and proposes to perform an engineering demonstration of ionisation cooling. The MICE experiment will require the measurement of the momentum and position of muons entering and leaving a section of ionisation cooling channel with high precision and purity in the presence of a large background. The technology chosen to meet this challenge is scintillating fibres readout with Visible Light Photon Detectors. The design, construction and operation of a prototype detector is described, as well as a summary of ongoing research and development activities in preparation for supplying the trackers needed for the MICE experiment.

1. Introduction

Muon storage rings have been proposed for use as sources of intense high-energy neutrino beams and as the basis for multi-TeV lepton-antilepton colliding beam facilities. Optimisation of the performance of such facilities is likely to require the phase-space compression (cooling) of the muon beam prior to acceleration and storage. The short muon-lifetime makes it impossible to employ traditional techniques to cool the beam while maintaining the muon-beam intensity. Ionisation cooling, a process in which the muon beam is passed through a series of liquid hydrogen absorbers followed by accelerating RF-cavities, is the technique proposed to cool the muon beam. The international Muon Ionisation Cooling Experiment (MICE) collaboration has been formed to carry out a muon-cooling demonstration experiment and its proposal to Rutherford Appleton Laboratory has been approved [1].

MICE consists of a cooling section placed between two identical spectrometers to measure the beam into and out of the cooling section. The cooling section is composed of three liquid hydrogen vessels, two sets of four 201.25 MHz RF accelerating cavities and a series of superconducting solenoids to transport the muon beam through the channel.

The MICE specification requires that the relative change in emittance be measured with a precision of 0.1 %. The baseline solution for the spectrometer instrumentation in MICE uses five scintillating-fibre stations. Each station is composed of three planar layers of scintillating fibre laid out in a 'u, v, w' arrangement. To reduce multiple Coulomb scattering of muons to an acceptable level a fibre diameter of 350 μm is required. To reduce the cost of the readout electronics seven 350 μm fibres are read out through each clear-fibre light-guide.

2. The MICE Scintillating Fibre Tracker

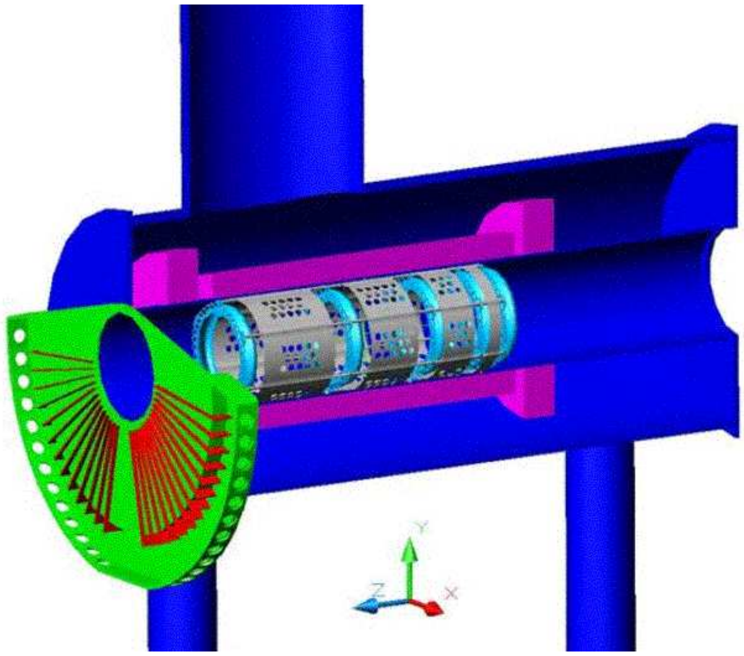

Fig. 1. Schematic layout of the MICE scintillating fibre tracker inside the spectrometer solenoid

A schematic drawing of the scintillating-fibre tracker proposed for MICE is shown in Figure 1. The super-conducting solenoid will produce an axial field of 4 T that is uniform at the 1% level over a 1.05 m region. The inner bore of the magnet will be 40 cm in diameter. The active area of the tracker is required to be 30 cm in diameter. The five stations that make up a tracker will be held in position by a carbon-fibre frame that will be supported at each end from the surface of the magnet cryostat. To reduce multiple Coulomb scattering, the inner bore of the solenoid will be evacuated. The stations will be constructed using carbon fibre to give a rigid structure onto which the three layers of 350 μm scintillating-fibre will be glued. Each station body will be constructed from a single carbon-fibre structure that allows for the mounting of optical connectors on a flat annulus separated by a conical section from a thin, flat ring onto which the scintillating-fibre planes can be bonded. The optical connectors on the station will mate seven 350 μm scintillating fibres to each 1.05 mm clear-fibre light guide. The light guides will transport the scintillation light from the stations to an optical patch panel that will be mounted on the end flange of the magnet cryostat. Since the tracker will be operated in a vacuum, the patch panel is required to form a vacuum seal to the cryostat end flange.

Three planes of scintillating fibre will be mounted on each station. Each plane will be composed of a doublet layer of scintillating fibre. In order that there be no dead spaces, the fibre layers will be offset as shown in Figure 2a. The three planes will be mounted on the carbon fibre support such that the angle between the fibres in one plane and those in another plane in the same station is 120° as shown in Figure 2b.

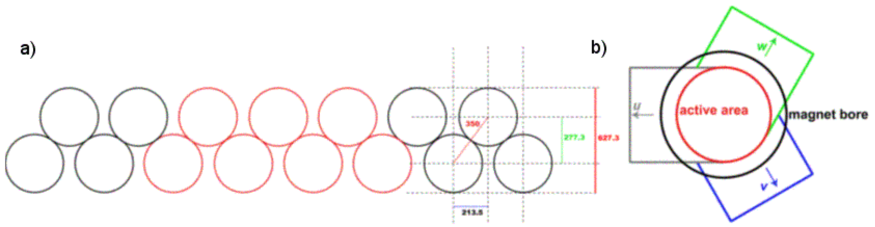

Fig. 2. Detail of arrangement of fibres in a station. (a) Cross-sectional view of fibre doublet. The dimensions of the fibre and fibre spacing are indicated in m. The fibres shown shaded indicate the seven fibres ganged for readout via a single clear fibre. (b) Layout of doublet layers in a station. The angle between the fibres in the doublet layers is 120°.

The scintillation light will be detected using Visible Light Photon Counters [2] (VLPCs). These devices are low band-gap silicon avalanche devices that are operated at approximately 9 K. The VLPCs have a high quantum efficiency (80%) and a high gain (50000). The light will be transported from the optical patch panel to the VLPCs using a further length of 1.05 mm clear fibre. The VLPCs will be read out using the Analogue Front End (AFE II) board developed by the D collaboration.

3. The first tracker prototype

In order to test the feasibility of the tracker design, a prototype was constructed in September 2003. Three stations were fabricated, supported on carbon-fibre rods and installed inside an aluminium light box. The central station (station B) was equipped with three fibre-doublet layers. Stations A and C were each equipped with two fibre-doublet layers. This allowed the properties of station B to be studied in an unbiased manner using reconstructed cosmic-ray tracks that passed through all 3 stations.

The scintillating fibres used in the prototype are 350 μm diameter Kuraray multi-clad doped polystyrene fibres. The primary dopant was p-terphenyl at a concentration of 1% (by weight). The secondary fluor used was 3-hydroxflavone (3HF). Fibre containing either 2500, 3500, or 5000 parts per million 3HF was used in the prototype.

4. Prototype Performance

The prototype detector was exposed to cosmic rays and the data used to determine the position resolution, light yield, single plane efficiency and dead channel rate.

The resolution of the tracker was determined to be $442 \pm 4(stat) \pm 27(syst)\mu m$, which agrees well with the expectation based on the fibre pitch and readout scheme.

Figure 3 shows the reconstructed light yield for the three different concentrations of 3HF.

The single plane efficiencies determined agreed well with the expectations from the light yield based on poisson statistics.

For the 2500 ppm 3HF fibre, which has the highest light yield, the single plane efficiency was determined to be $99.73 \pm 0.16\%$.

5. Future

The performance of the prototype tracker, along with a refined design for the full MICE tracker has been used to tune the MICE simulation and analysis software package G4MICE [3]. This software is currently being used to simulate the full MICE experiment and predict the performance of the scintillating fibre tracker in MICE.

A second prorotype detector is under construction. It will comprise the original three stations of the first prototype plus a new station built to the updated design, and using quality assurance techniques planned for the production trackers. It is envisaged that this tracker will be tested in mid 2005.

References

1. A full description of MICE can be found in the proposal submitted to the Rutherford Appleton Laboratory: (http://mice.iit.edu/mnp/MICE0021.pdf), and more details are avaialable on the MICE collaboration website: http://www.mice.iit.edu/.
2. D. Adams *et al.* [D0 Collaboration], arXiv:hep-ex/9410011.
3. Information about the G4MICE software package can be found at http://www.mice.iit.edu/software/software.html.

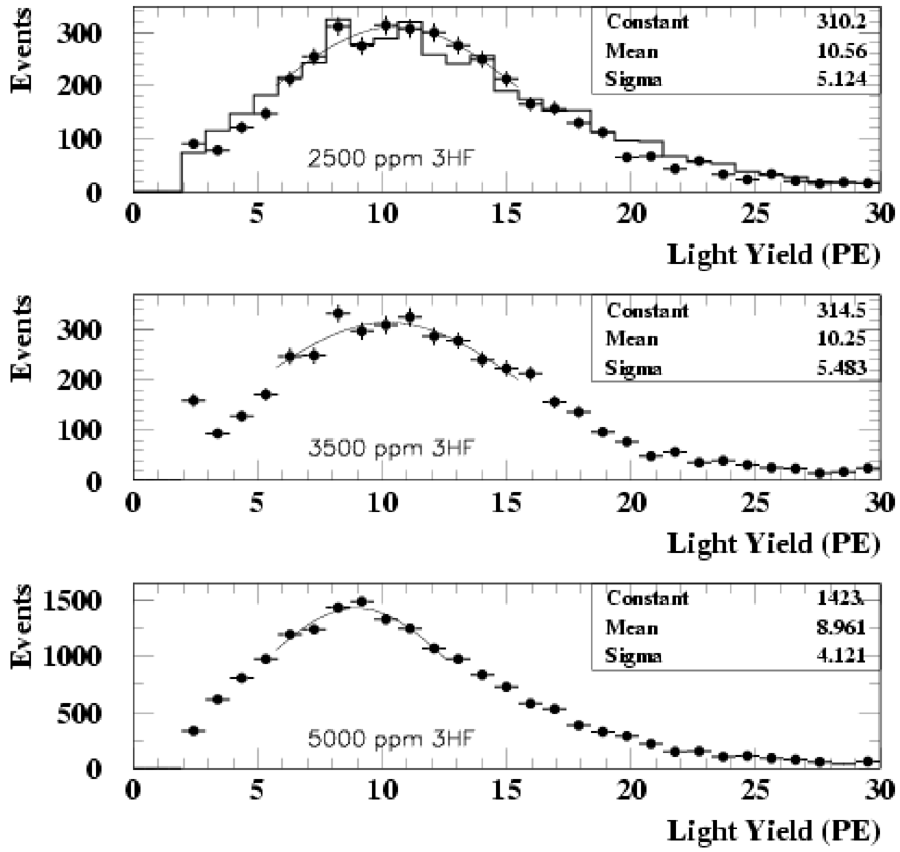

Fig. 3. Pulse height distributions: (top) 2500 ppm 3HF (middle) 3500 ppm 3HF (bottom) 5000 ppm 3HF. The data are shown as the points. The result of a Gaussian fit to the peak is shown as the solid line. The mean of the Gaussian distribution is noted. The shaded histogram is the result of the G4MICE simulation.