Cosmic Muon Veto for the mini-ICAL detector at IICHEP, Madurai

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Abstract. A 51-kiloton magnetised Iron Calorimeter (ICAL) detector, using Resistive Plate Chambers (RPCs) as active detector elements, aims to study atmospheric neutrinos. A prototype - 1/600 of the weight of ICAL, called mini-ICAL was installed in the INO transit campus at Madurai. A modest proof-of-principle cosmic muon veto detector of about $1 \text{ m} \times 1 \text{ m} \times 0.3 \text{ m}$ dimensions was setup a few years ago, using scintillator paddles. The measured cosmic muon veto efficiency of 99.98% and simulation studies of muon induced background events in the ICAL detector surrounded by an efficient veto detector were promising. This led to the idea of constructing a bigger cosmic muon veto around the mini-ICAL detector. Details of the design and construction of the detector including the electronics, trigger and DAQ systems planned will be briefly presented.

1. Introduction
A 51-kiloton magnetised Iron Calorimeter (ICAL) detector, using Resistive Plate Chambers (RPCs) as active detector elements, aims to study atmospheric neutrinos. It will be the flagship experiment at the India-based Neutrino Observatory (INO), which will be housed in a cavern at the end of a 2 km tunnel in a mountain near Pottipuram (Tamil Nadu) \cite{1}. A prototype - 1/600 of the weight of ICAL, called mini-ICAL was installed in the INO transit campus at Madurai, to gain experience in the construction of a large-scale electromagnet, to study the detector performance and to test the ICAL electronics in the presence of a fringe magnetic field. This $4 \text{ m} \times 4 \text{ m} \times 1.1 \text{ m}$ detector, with 11 iron layers and 20 RPCs in the central region, has been in operation for over 2 years and has been collecting cosmic muon data. A modest proof-of-principle cosmic muon veto detector of about $1 \text{ m} \times 1 \text{ m} \times 0.3 \text{ m}$ dimensions was setup a few years ago, using scintillator paddles \cite{2}. The measured cosmic muon veto efficiency of 99.98% and simulation studies of muon induced background events in the ICAL detector surrounded...
by an efficient veto detector [3] were promising. This led to the idea of constructing a bigger cosmic muon veto around the mini-ICAL detector.

2. Design of veto detector

The veto walls around three out of four sides (fourth side is not covered due to operational reasons) and top of the mini-ICAL will be built using three staggered (by 15 mm) layers of extruded scintillator strips (donated by Fermilab) [4]. Strips of 4400-4700 mm in length, 50 mm wide and 10 or 20 mm thick will be used to construct the veto shield that aims at 99.99% efficiency to tag cosmic muons. Double-clad WLS fibres of 1.4 mm in diameter (from Kuraray) are inserted into two extruded fibre holes along the length of the strip and separated by 25 mm to collect the light signal. Hamamatsu SiPM’s of 2 mm \( \times \) 2 mm active area collect the light on both sides of the fibres. About 750 strips, about 7 km of fibre and 3000 SiPM’s are going to be deployed. All the five veto walls/stations are designed to be movable from their designed positions, providing service access to the mini-ICAL inside (see Fig. 1).

![Figure 1](image1.png)

**Figure 1.** A collage of schematic drawings showing the overall structure of the cosmic muon detector around the mini-ICAL, staggering of scintillator layers, a view of the support structure for the side veto walls and the di-counter readout.

3. Veto detector requirements

The main requirements of the veto detector are measurement of charge, position, relative arrival time of the SiPM signals on trigger from mini-ICAL trigger. The mini-ICAL trigger signal is used to correlate the veto detector event data, which is acquired on the veto detector’s local trigger, with that of the mini-ICAL data. For the charge measurement, a dynamic range of 100 pC with a resolution (the required signal detection threshold) of 20 fC and single photo-electron charge of about 100 fc are specified. A resolution of 100 ps is sufficient for the time measurement. Closed loop gain/biasing control for every SiPM or Di-Counter as well as in-situ calibration using LED pulser or noise signals are essential for stable and reliable detector operation.

Extensive characterisation and calibration studies were carried out on the main elements of the cosmic muon detector – namely the extruded scintillator strips, fibre and SiPMs. The studies were carried out using LED an pulse, a \(^{22}\text{Na}\) radioactive source, as well as cosmic ray muons. Using these studies, we obtained a single PE avalanche charge: 0.242 pC. The typical PE yields
obtained for 10/20 mm thick scintillators are 34/57, while the typical signals for cosmic ray muons are 8.33 pC (10 mm) and 13.82 pC (20 mm). Using time-of-flight measurement across the length of the scintillator strip, a position resolution of $9.18 \pm 2.27$ cm was obtained across scintillator strip.

4. Detector readout

The veto walls are assembled using pre-fabricated di-counters, which are essentially two extruded scintillators strips glued sideways. One end of the four fibres from each of the di-counter are readout by one SiPM assembly as shown in Fig. 2.

![Diagram of detector readout](image)

**Figure 2.** An exploded view of various components of the di-counter detector readout. Two such readout modules are used for readout of either ends of a di-counter.

The fibres are passed through the fibre guide block which is mounted on the di-counter face using sleeves and sleeve pins. A neoprene gasket cushions the fibres to terminate properly on the active windows of the SiPMs which are placed in the SiPM mounting block. The SiPMs are actually individually mounted on tiny SiPM carrier boards “mouse-bite” boards, which themselves are locked in fixed slots in the SiPM mounting block. Finally, the counter mother board that houses the SiPM bias voltage services, the ambient parameter sensors, calibration LED source and other services is mated to the SiPM mounting block using plastic screws. The SiPM signals, power supplies, the LED drive voltage etc., are carried between the detector readout assembly and backend electronics via an HDMI connector mounted on the counter mother board.

Initially coincidence of ORed signals from two out of three layers from either side of a station will be used to generate a trigger signal from that station. Trigger signals from five stations are combined to form the final cosmic ray muon veto trigger signal. On veto trigger, the DAQ system will gather the charge produced by, arrival time and position of muon tracks in the scintillator strips. But the data collected is transferred to the backend only if the main trigger from the mini-ICAL detector is also received in time, or else the data is discarded. Extensive
configuration, control and calibration of the detector elements are also planned. An overall scheme of the electronics and DAQ system is shown in Fig. 3.

**Figure 3.** Schematic of the electronics and data acquisition system for the cosmic muon detector. Two identical segments are designed to read data from either side of the veto walls. A central system takes care of final trigger generation and data transfer to the backend.

**References**


