Cosmic Muon Veto for the INO's mini-ICAL detector

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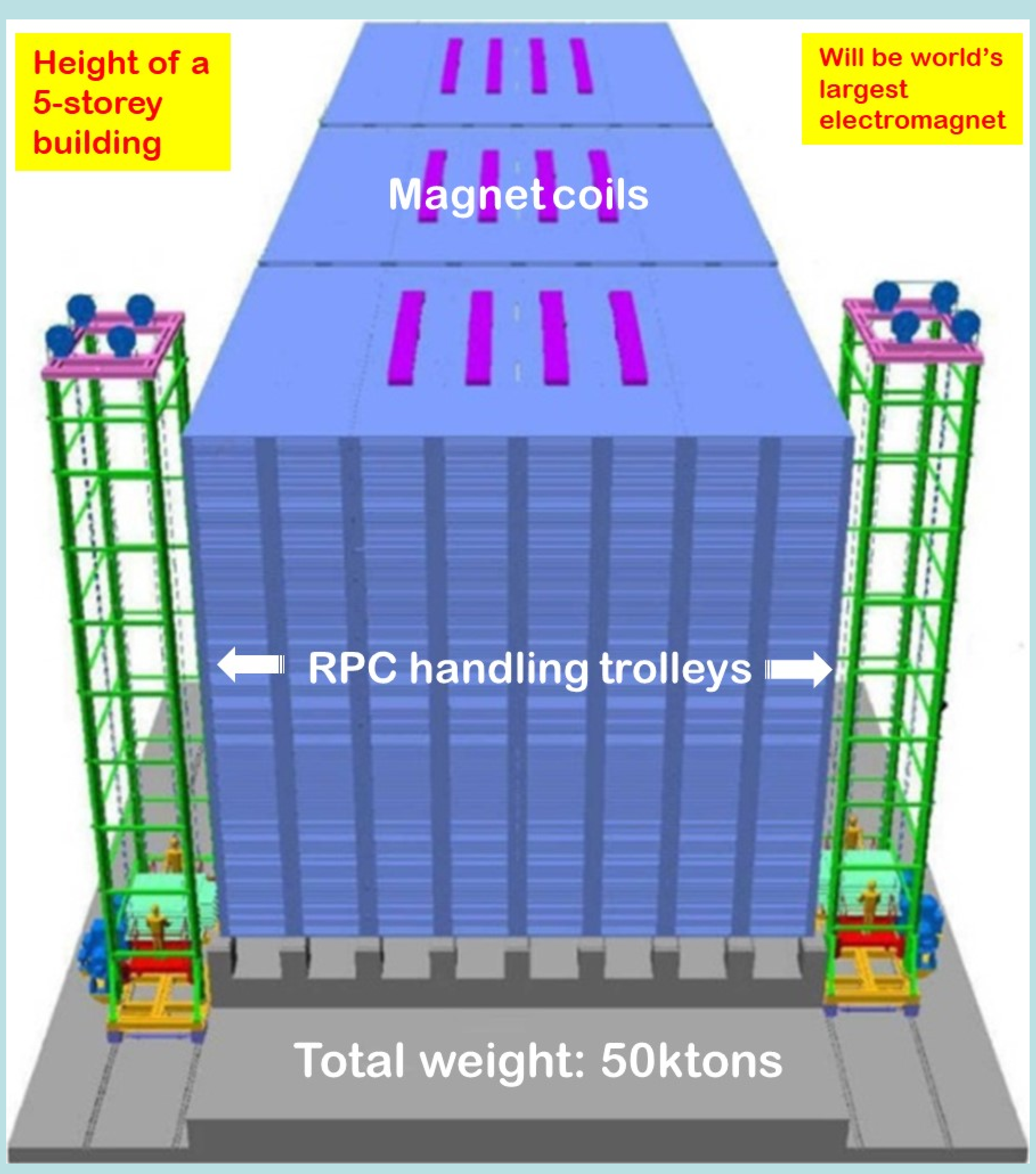
Abstract

A 51-kt magnetised Iron Calorimeter (ICAL), using Resistive Plate Chambers, is the flagship experiment at the India based Neutrino Observatory (INO). A prototype - 1/600 of the weight of ICAL, called mini-ICAL was installed in the INO transit campus at Madurai. A cosmic muon veto around the mini-ICAL is now being planned. The veto walls will be built using three staggered layers of extruded scintillator strips. WLS fibres of 1.4mm in dia are inserted into two extruded holes along the length of the strip to collect the light signal. Hamamatsu SiPM's of 2mm×2mm active area collect the light on both ends of the fibres. On veto trigger, the DAQ system will gather the charge, arrival time and position of muon tracks in the scintillator strips. But the data collected is transferred to the backend only if the trigger from mini-ICAL is also received in time. Details of the design and construction of the detector including the electronics, trigger and DAQ systems planned will be presented.

What INO and ICAL detector can do?

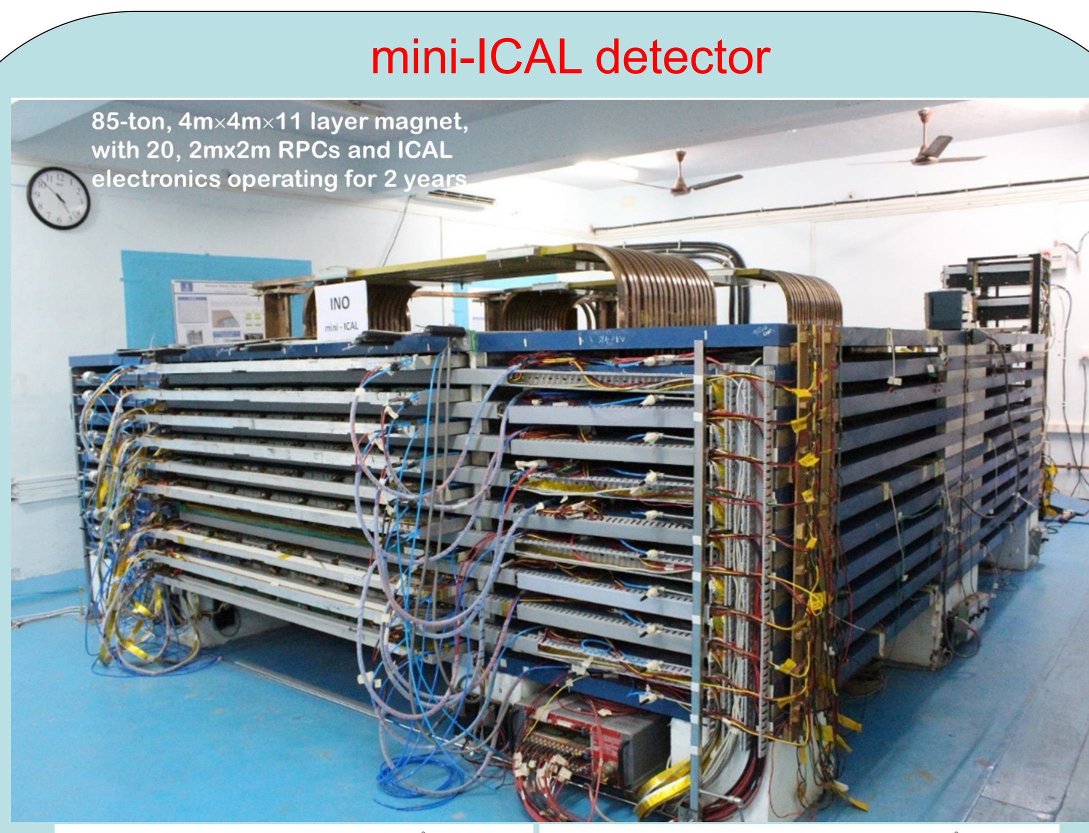
- Measure atmospheric muon neutrinos and antineutrinos, separately.
- Will target the open problem of ordering of the three tiny neutrino masses - Mass Hierarchy.
- Will help address CP violation in the neutrino sector, which could help in our understanding of why there is a preponderance of matter over anti-matter in the universe.

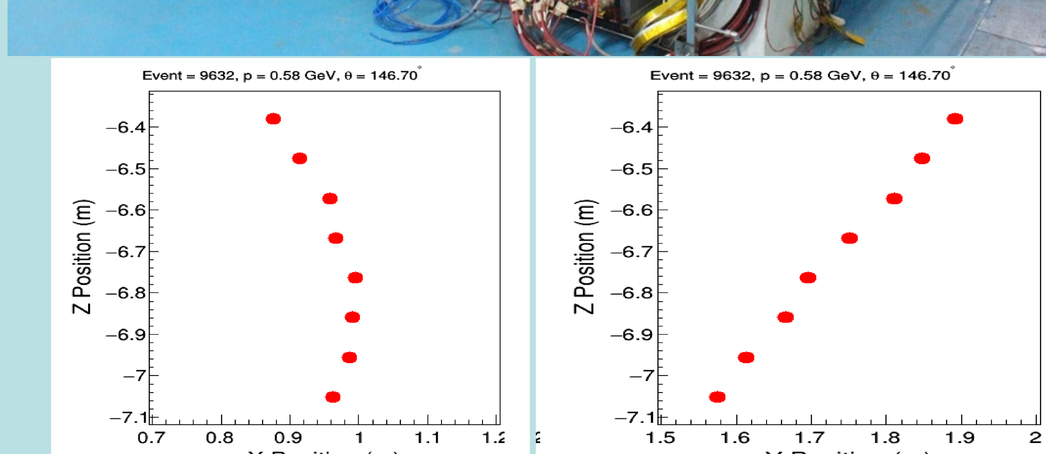


Facts and Figures of ICAL detectors

Parameter	ICAL	e-ICAL	m-ICAL
No. of modules	3	1	1
Module dimensions	16.2m×16m×14.5m	8m×8mx2m (90:1)	4m×4mx1m (720:1)
Detector dimensions	49m×16m×14.5m	8m×8mx2m	4m×4mx1m
No. of layers	150	20	10
Iron plate thickness	56mm	56mm	56mm
Gap for RPC trays	40mm	40mm	45mm
Magnetic field	1.3Tesla	1.3Tesla	1.3Tesla
RPC dimensions	1,950mm×1,910mm×24mm	1,950mm×1,910mm×24mm	1,950mm×1,910mm×24mm
Readout strip pitch	30mm	30mm	30mm
No. of RPCs/Road/Layer	8	4	2
No. of Roads/Layer/Module	8	4	1
No. of RPC units/Layer	192	16	2
No. of RPC units	28,800 (107,266m^2)	320 (1,192m^2) (90:1)	20 (74.5m^2) (1440:1)
No. of readout strips	3,686,400	40,960 (90:1)	2,560 (1440:1)

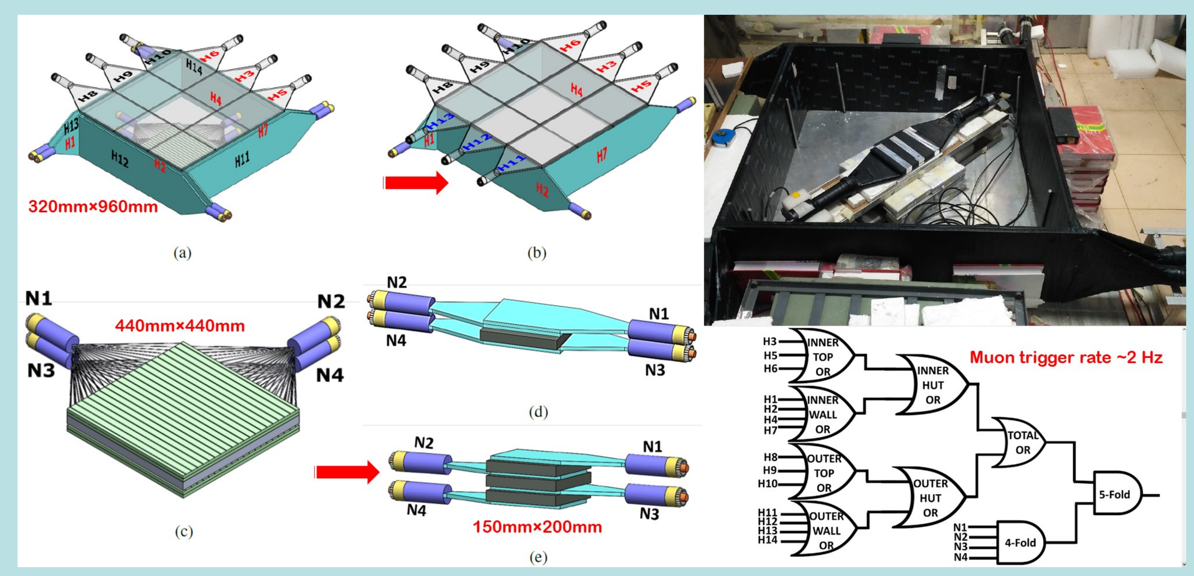
mini-ICAL detector



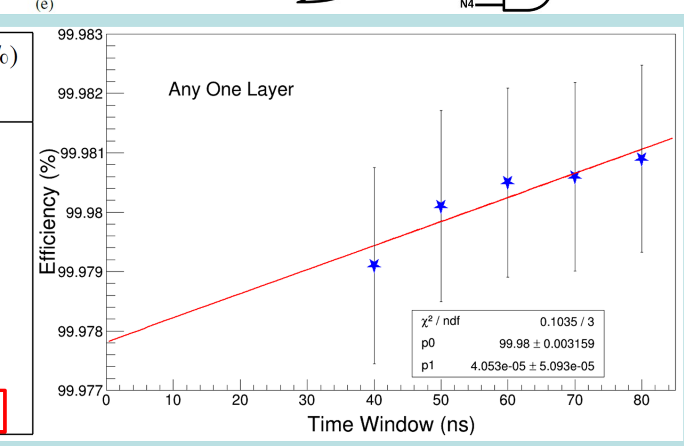


Motivation for veto detector

- The advantages of locating a large detector such as ICAL at a shallow depth of 100 m, are obvious.
- Muon background at such a depth at ICAL of about 3×10^8 /day and the small atmospheric neutrino event rate of about 3 per day in the same detector.
- If one were to build a cosmic muon veto detector which could detect muons with > 99.99% efficiency, the fraction that would escape detection would be of the same order or similar to that which survives after traversing a rock cover of about 1 km.



Description	Veto efficiency(%) (from fit)
Top Layer	99.52 ± 0.010
Middle layer	99.920 ± 0.005
Bottom Layer	99.908 ± 0.006
Top or middle Layers	99.964 ± 0.004
Top or bottom Layer	99.969 ± 0.004
Middle or bottom Layer	99.975 ± 0.003
Any one Layer	99.978 ± 0.003



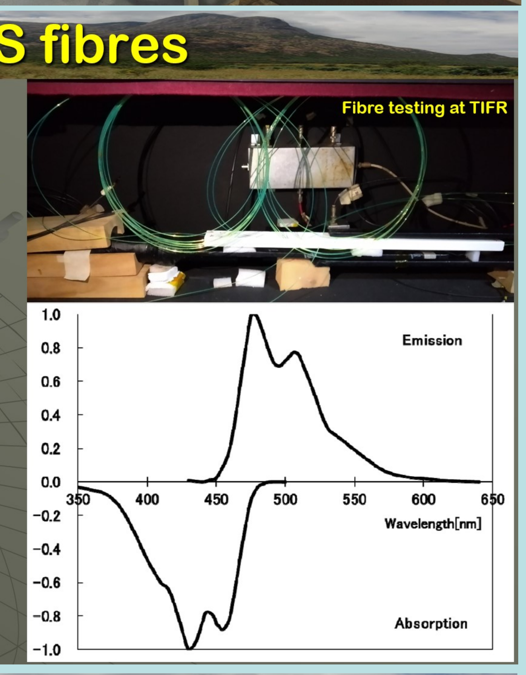
Veto detector design and components

Structure of veto detector around mini-ICAL

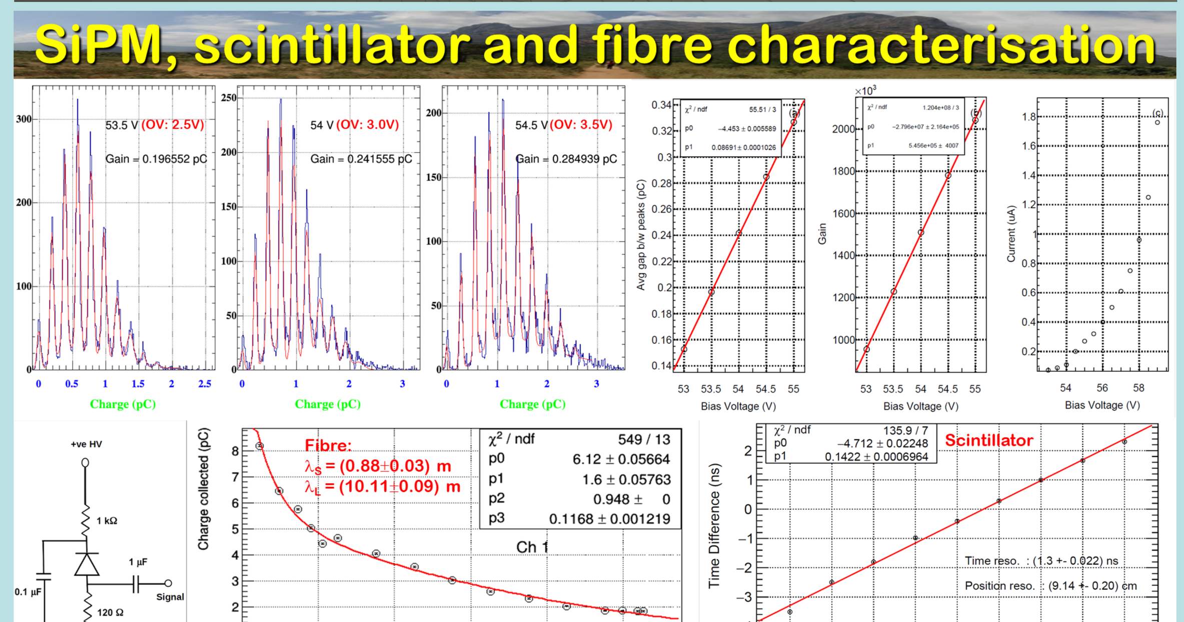
Extruded plastic scintillators by Fermilab

Kuraray WLS fibres

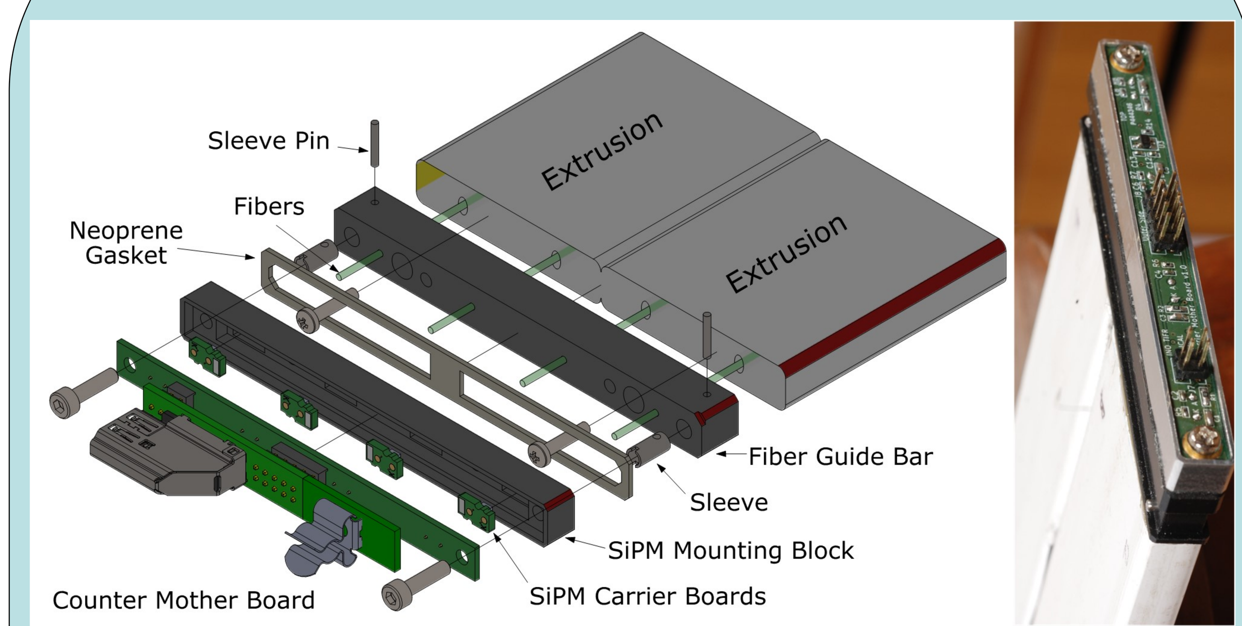
- Fiber type: Y-11 (175) MJ.
- K-27 dye in core material that controls light yield optimization is at 175 ppm concentration.
- M is for multi(double)-cladding fiber.
- J is a long term stable type for attenuation length.
- non-S type: good attenuation length, but mechanically weak.
- Core: Polystyrene (n_d=1.59).
- Inner cladding: Polymethylmethacrylate (PMMA, n_d=1.49).
- Outer cladding: Fluorinated PMMA (n_d=1.42).
- Thickness of claddings each is 2% of the fiber diameter.
- Attenuation length: >3.6m.
- Diameter: 1.400±0.006mm, RMS≤0.037mm.

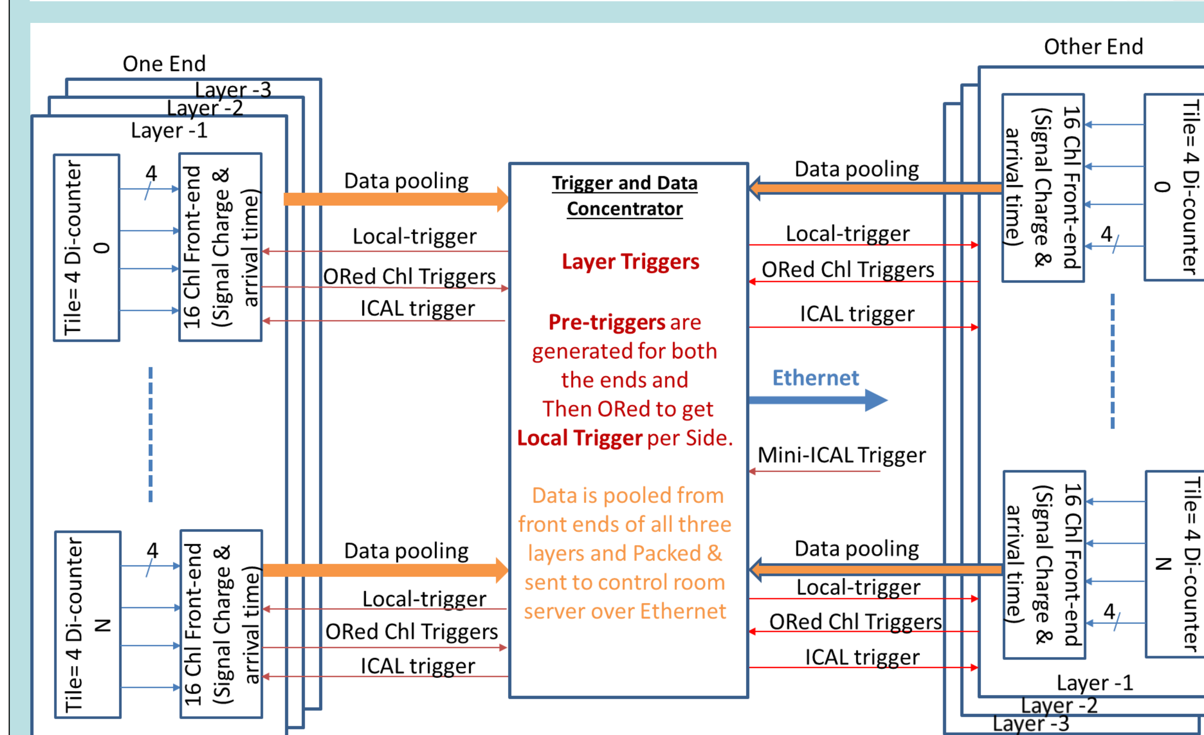


SiPM, scintillator and fibre characterisation



Readout and data acquisition scheme





❖Trip-T
- 32 channel charge amplifier, Charge and time of arrival per channel
- 48 deep analog pipeline, 16 digital outputs crossing set threshold

❖VMM-3
- 64 channel bi-polar inputs, Fast digital output signal per channel
- The peak charge and peak to reference clock TAC values stored in analog memory.
- The digital data read out on two lines @200Mbps.

Veto detector requirements

- Design Requirements
  - Charge, position, relative arrival time for SiPM signal on mini-ICAL trigger
  - Event Marker used to collate the CMVD event data with the mini-ICAL data
  - Charge: Dynamic range of 100pC, least count of 20fC, single Photo-Electron (PE) charge ~100fC
  - Relative arrival time: Least Count of 100ps
  - Closed loop gain/biasing control for every SiPM or Di-Counter.
  - In-situ calibration
- Supporting results from test studies
  - Single PE avalanche charge: 0.242pC
  - Typical PE yields for 10/20mm scintillators: 34/57
  - Typical muon yield: 8.33pC (10mm) and 13.82pC (20mm)
  - Position resolution (on scintillator strip): 9.18±2.27cm

Project status and plans

- Extruded plastic scintillators, fibre and SiPMs procured.
- QC/QA and characterisation of the same are done.
- Scintillator+Fibre+SiPM assembly parts designed and prototyped.
- Search and studies for a suitable FE chip are going on.
- Design of electronics and DAQ to start soon.
- Ordering of materials and fabrication of infra in progress.
- Many jigs, tools, assembly tables etc. designed.
- Detector gluing table with exhaust designed.
- Design of the detector and support structures completed.
- Production of detectors and mounting structures will begin.
- Dead line for project commissioning is end of 2021.

References

1. A Kumar et al. In: Pramana 88.5 (2017), p. 79.
2. N Panchal et al. In: JINST 12 (2017), T11002.
3. N Panchal et al. In: JINST 14 (2019), P02032.
4. L Bartoszek et al. In: arXiv:1501.05241 (2015)

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