Measurement of large angle muon flux in GRAPES-3 experiment using triggerless DAQ system

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Abstract

The large area muon telescope of GRAPES-3 has been operating continuously for more than two decades with a DAQ which has several limitations. At present, this DAQ is in the process of being upgraded with a FPGA based system. The new DAQ system is designed to be triggerless and capable of recording every hit from the 3712 proportional counters along with a time-stamp (10 ns resolution) which has significantly expanded the physics horizon of the experiment. This triggerless feature allows the detection of muons beyond the nominal zenith range of the current system (θ<45°). The upgraded DAQ system has been deployed for 25% of the telescope. An offline software trigger has been developed for the reconstruction of muon tracks by using the timing and pulse height information of each hit in the raw data. For the first time the muons are reconstructed in the entire zenith angle range. The extensive air showers (EAS) at large angles can be studied through the muon component. We present measurements of the flux of the large angle muons and their correlation with EAS triggers.

The GRAPES-3 Muon Telescope

- At Ooty, India (11.4°N, 76.7°E, 2200 m amsl)
- Proportional counter (PRC) as basic element
- Mild steel tube, dimension 600 X 10 X 10 cm^3, thickness 2.3 mm
- Total 3712 PRCs, arranged in 16 muon telescopes
- Each muon telescope with 4 layers of PRCs, alternate layers arranged orthogonally
- Total area covered 560 m^2, sky coverage 2.3 sr

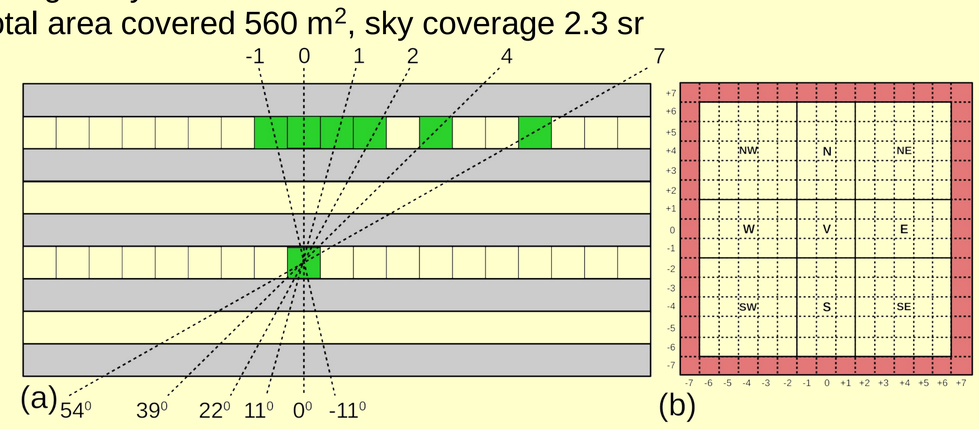

Figure 1: (a) Reconstruction of muon direction in one projection (b) 13×13=169 directions

- 2.4 m thick concrete blocks as absorber (~550 g cm^{-2})
- Energy threshold sec(θ) GeV
- Reconstruction 13x13=169 directions, average accuracy 4°
- Records 4X10^9 muons daily, statistical error ~0.001%
- Successfully corrected for detector efficiency variation

Triggerless Muon DAQ System

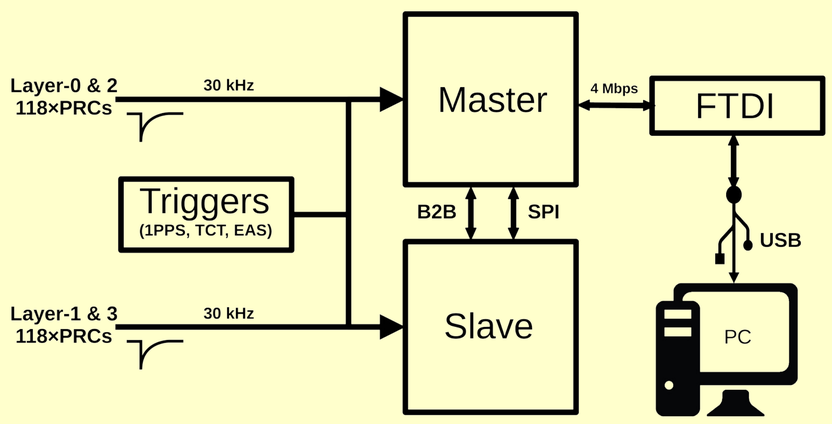

Figure 2: Block diagram of the new triggerless DAQ system

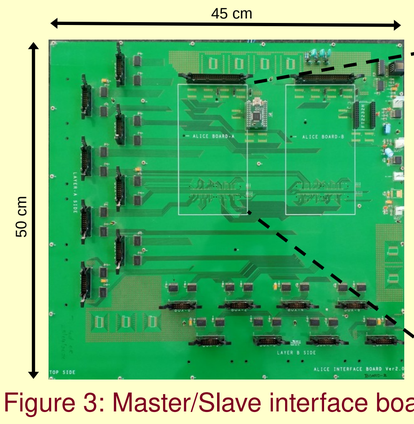

Figure 3: Master/Slave interface board

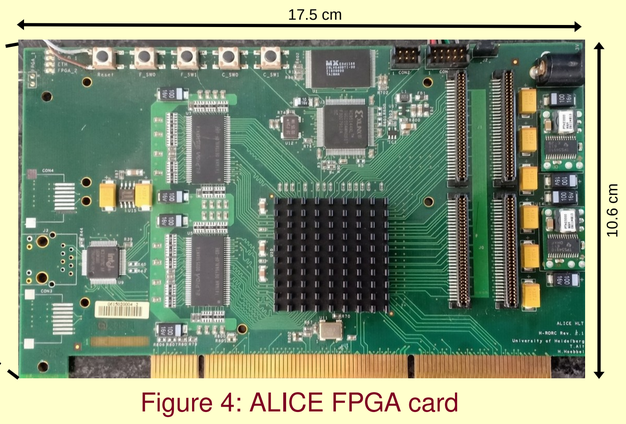

Figure 4: ALICE FPGA card

- ALICE FPGA card
- Onboard 100 MHz and 50 MHz clock
- Time resolution of 10 ns
- Pulse width and time measurement at 10 ns
- Count rate monitoring of all PRCs
- Various layer coincidence trigger logic
- Input signal rate at ~60 kHz
- Output data rate at ~4 Mbps
- Dead time ~0.001% (compared to ~12% in old DAQ)

Reconstruction of muon tracks

Preparation

- Formation of normalised time using 100 MHz clock count
- Sorting the PRC hits based on normalised time

Identification of clusters

- Successive hits (N) delay < 1.1 μs
- Minimum N = 2
- Trigger time: T = last hit time if N <= 6
  T = middle hit time if N > 6

Direction (θ, ϕ) determination by fitting of hit PRC coordinates

- Identification of blocks in each layer
- Blocks' coordinates are plotted and fitted for each projection (i.e. Even: L0 & L2, Odd: L1 & L3)
- From the slopes (S) of least square fitting

$$\theta_{e,o} = \arctan(S_{e,o}) \qquad \theta = \arctan\left(\sqrt{S_e^2 + S_o^2}\right) \qquad \phi = \arctan(S_o / S_e)$$

Large Angle Muon Tracks

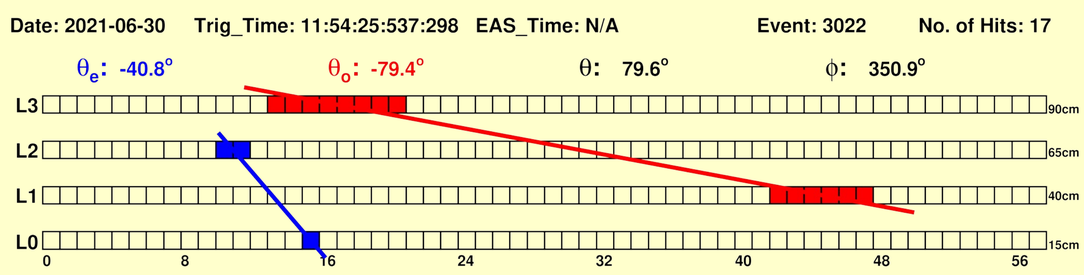

Figure 5: An example of large angle muon passing through all four layers

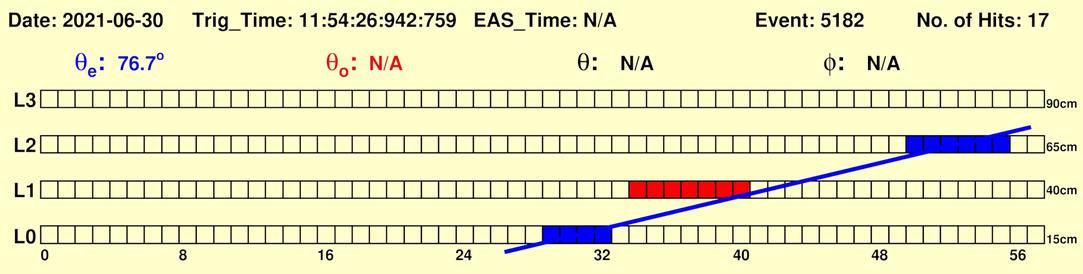

Figure 6: An example of large angle muon passing sidewise through bottom three layers

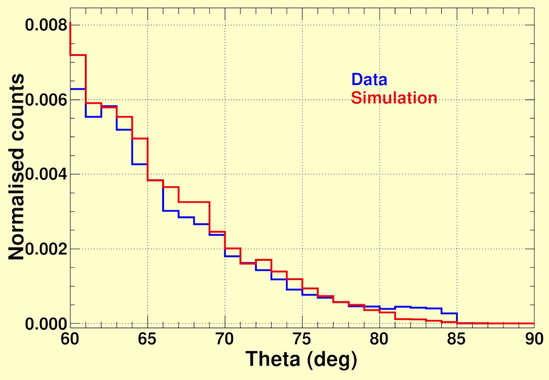

Figure 7: For zenith below 60° comparison shows a reasonably good agreement between data and Monte Carlo simulations. The data is collated for large angle muons that pass through all four layers of the module. The distributions are normalised for display. Below 60° the reconstructed muon directions have larger error due to limited resolution at the smaller angle (Ref. Figure 1a).

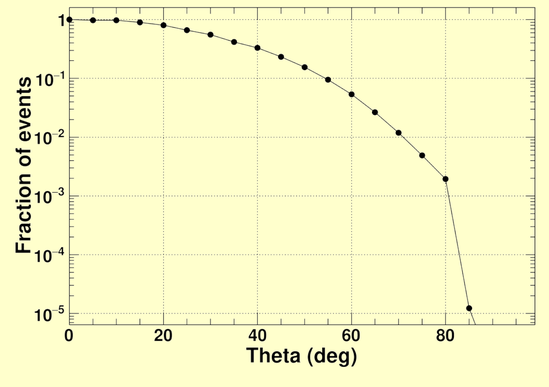

Figure 8: Profile shows integral distribution of fraction of muons as a function of zenith angle for the muons passing through all four layers.

Conclusions: It can be seen from these figures that the GRAPES-3 muon telescope can record a considerable fraction of large angle muons with good angular resolution with the help of the new triggerless DAQ system.