A compact cosmic muon veto detector and possible use with the Iron Calorimeter detector for neutrinos

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Introduction

The motivation for a cosmic muon veto (CMV) detector is to explore the possibility of locating the proposed large Iron Calorimeter (ICAL) detector at the India based Neutrino Observatory (INO) at a shallow depth of ∼100 m. ICAL is a 51 kiloton device consisting of 3 modules to study atmospheric neutrinos and will be set up in the underground INO laboratory at Pottipuram, Tamil Nadu in India [1]. The rock overburden is greater than 1 km in all directions and will reduce the cosmic ray background, mainly due to muons, by about a factor of $\sim 10^6$. It would therefore seem counter intuitive to build this detector at a shallow depth of about 100 m below the surface as the muon event rate in the detector of the size of ICAL would be eight orders of magnitude larger than that due to neutrinos. For such a Shallow depth ICAL (SICAL), it is clear that events due to cosmic muons need to be identified very efficiently and discarded.

A small sized cosmic muon veto detector

An assembly of small cosmic muon veto shield was build at Tata Institute of Fundamental Research using 14 plastic scintillator (PS) paddles of size 320 mm (width) 960 mm (length) and 10 mm (thickness). These paddles were arranged in the form of an inner and outer cosmic veto "hut" with 4 paddles standing on the side forming a square of inner dimension about 920 mm. The "ceiling" of the CMV hut consisted of 3 paddles placed on top of the 4 side "walls". The top of the outer hut had paddles placed in a direction perpendicular to the ones in the inner hut "ceiling". Two configurations of μ-trigger, as shown in Fig.1, having a set of 4 PS of transverse dimensions 440 mm × 440 mm and 10 mm thick (MuL) and 150 mm × 200 mm and 10 mm thick (MuS) were studied. Two sets of 2 PS, each placed on top of one another, were separated by about ∼30 mm of lead i.e., shield I to reduce γ-γ coincidences. A logic AND was generated to form the 4-fold muon trigger with rate ∼15Hz (∼2Hz) for MuL(MuS). The total OR of 14 HUT scintillators was then ANDed with the muon trigger to form a 5-fold which was used for efficiency calculations. The time resolution was measured to be ∼1 ns for trigger scintillators of MuS configuration and ∼2 ns for top hut scintillators. The photon transport within the scintillator results in a spread in timing data.

Results and discussion

The efficiency for the rejection of cosmic muons from the ratio of the 5-fold to 4-fold coincidences was calculated after analyzing the event-by-event TDC data in a CAMAC based data acquisition system. The time window for the prompt gate was kept to be 100 ns. The results are summarized in Table I.

In order to study the inefficiency of the CMV detector, with the MuS trigger detector, a third layer was added on top of the upper two layers. Three side paddles from the outer hut were used for this purpose. The paddles in the third layer on top was placed parallel

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FIG. 1: Photographs of the MuL (top) and MuS (bottom) trigger detectors inside the CMV detector with the top layers removed.

TABLE I: CMV efficiencies at V_{Th} = -20mV for both configuration with shield I.

Veto configuration	Veto efficiency (%)(MuL)	Veto efficiency (%)(MuS)
Inner hut	99.420 ± 0.015	99.680 ± 0.007
Outer hut	99.354 ± 0.016	99.652 ± 0.007
Total	99.880 ± 0.007	99.847 ± 0.005

to, and with an offset of 20 mm, from the 2nd layer of paddles so as to cover the gaps between the adjoining scintillators. In this set of experiments the thresholds (V_{Th}) of the MuS trigger paddles were varied from -20 mV to -150 mV to emphasize muons and reduce the gamma ray shower contribution. An increased threshold results in increase in veto efficiency from (99.823 ± 0.012)% to (99.922 ± 0.010)%. The effect of removing or placing lead between successive layers of the PS constituting the muon trigger MuS on the CMV detector efficiency was also studied. With no lead in MuS the veto efficiency dropped to (99.16 ± 0.01)%. This is significantly smaller than the efficiency with one layer of lead, strongly suggesting that γ-ray induced events are being misidentified as muons leading to a lower CMV efficiency. To test this hypothesis three layers of lead i.e., shield II, were placed in successive plastic scintillators of MuS. The results are summarized in the Table II.

TABLE II: Veto efficiencies for different layers of a 3 layer CMV-MuS at V_{Th} = -100mV.

Description	Veto efficiency (%)(100ns gate)	Veto efficiency (%)(from fit)
Top Layer	99.749 ± 0.006	99.52 ± 0.010
Middle layer	99.951 ± 0.002	99.920 ± 0.005
Bottom Layer	99.933 ± 0.003	99.908 ± 0.006
Any one Layer	99.981 ± 0.002	99.978 ± 0.003

Another source of inefficiency could be PS paddle's zone wise inefficiencies. To study this all the paddles used in constructing the CMV huts were placed in the 12 layer RPC (1m × 1m) stack detecting cosmic muons [2] to measure the local inefficiency for muon detection as a function of X-Y position. The efficiency for a 320 mm × 320 mm pixel was measured.

Conclusion

Since the CMV detector was assembled from plastic scintillators, PMTs and WLS, that were available in our laboratory, the measured 99.98% veto efficiency is very encouraging. A proof-of-principle CMV is being planned for the 80 ton mini-ICAL (4 m × 4 m × 10 layers with a centrally located 2 m × 2 m Resistive Plate Chamber in each layer) that is being built at IICHEP, Madurai.

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References

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