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Large-Area Wide Angle (LAWA) Cerenkov detector for MYSTIQUE array.

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Abstract. An ultra-sensitive, multidetector wide angle atmospheric Cerenkov telescope array is being set up at Mt.Abu for cosmic γ-ray studies in tens of TeV energy region. The design features of the Cerenkov light detector, along with its efficiency, based on simulation and prototype testing studies, are presented in this paper.

Key words: Gamma-ray , MYSTIQUE telescope, LAWA detector.

1. Introduction

The MYSTIQUE (Multi-element ultrasensitive telescope for quanta of ultra high energies) experiment is proposed to consist of a distributed array of Large Area Wide Angle (LAWA) based atmospheric Cerenkov detectors for studying γ-ray sources in ultra high energy ($\geq$ 10 TeV) domain. The array is designed to combine all the important features of atmospheric Cerenkov technique (high angular resolution and large effective area) so that it can be deployed as a high-sensitivity 'survey' instrument for detecting γ-ray sources in the ultra high energy region (Bhat et al, 1997). In addition, it can also be used to study cosmic-ray mass composition at ultra-high energies.

2. Experimental Setup

The MYSTIQUE telescope is planned to be an array of 320 (LAWA) Cerenkov detectors, each 1 m^2 in size and spread over an area of $\sim$ 0.36 km^2 with an average inter-detector separation of 40m (Bhat et al 1997). The array has a modular structure and is divided into 16 independently operating stations comprising 20 LAWA detectors each. A significant portion of $\sim$ 10 - 20 % of the Cerenkov light (λ=300-400 nm) incident on each LAWA element, is finally ducted for detection by a PMT detector with the help of a suitable arrangement of adiabatic light guides. Following generation of a station trigger, based on semi-autonomous trigger scheme (any three neighbours of a given station), the arrival times of Cerenkov wavefront at various station elements are recorded with an accuracy of $\leq$ 2ns. These timing data are logged along with the absolute epoch of the event as well as the time profile of the overall Cerenkov pulse recorded by each

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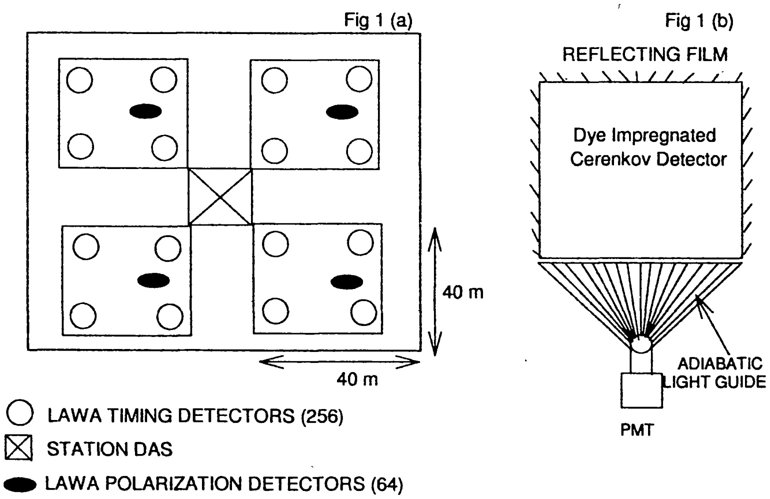
detector element. The array would enable the determination of event arrival direction with an accuracy of $\leq 0.25°$, assuming that the event arrival can be timed with a relative accuracy of 1-2 ns, in atleast 20 timing detectors (Dhar et al, 2000). The array threshold energy is estimated to be 5 TeV for a γ -ray primary corresponding to the threshold photon density of $\sim$ 400 photons m^{-2}. Additional improvement in gamma-ray (signal) to cosmic-ray (noise) ratio is sought through various offline cuts based on Cerenkov wavefront sampling and measurements of the polarization state of the detected events. The combination of these factors is expected to yield much higher sensitivity for MYSTIQUE (Koul et al, 2001) as compared to AIROBICC (Lorentz 1996, Karle et al, 1995), the only other distributed array of Cerenkov detectors operating at present.



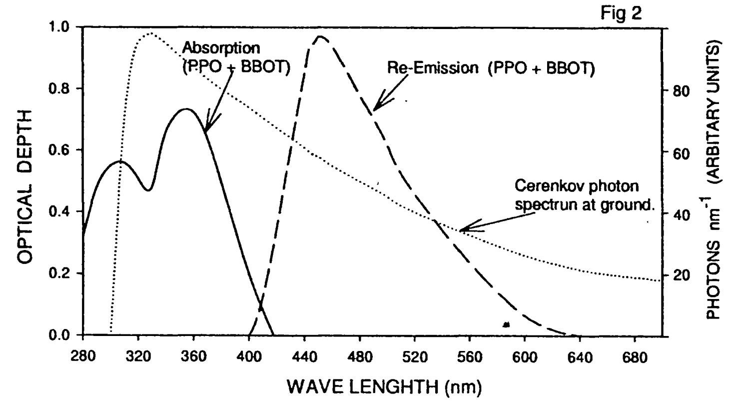


Figure 1. Schematic layout of one station of the proposed MYSTIQUE (1a) and LAWA Detector (1b).

Figure 2. Emission and absorption spectra of dye combination (PPO + BBOT) along with Cerenkov photon spectrum at ground level.

3. Detector Characteristics

Fig 1(a) and Fig 1(b) show the schematic diagram of one station of the proposed MYSTIQUE array and the LAWA detector respectively. The LAWA detector consists of four juxtaposed acrylic sheets, each of 50cm x 50cm x 1 cm in size. The sheet is body impregnated with a mixture of PPO (phenyl -phenyl-oxazyl) and BBOT (butyl- benzoxazyl thiopene) in toulene, whose composition has been adjusted to provide an absorption spectrum which significantly overlaps with a large part of atmospheric Cerenkov spectrum over the wavelenth band of 300-400nm. A large fraction of flourescent photons emitted isotropically by the dye impregnated sheets over the wavelength band 420-660 nm,(Fig 2), suffer total internal reflection within the acrylic sheet and emerge at its edges. The three sides of each sheet are polished and the fourth side is optically coupled to adiabatic light guides made up of transparent acrylic sheets, which duct these photons to a fast PMT.

4. Simulation results

First order simulation studies have been carried out to assess the suitability of the detector system in terms of its overall collection efficiency (η) and the time jitter in the PMT output. Efficiency was determined for two possible configurations. First, a monolithic detector assembly, wherein detector sheet and light guide form one single unit and second, a separate assembly for detector sheet and light guide. For the sake of simplicity, we assumed 100% absorption of the Cerenkov photons by the flourescent dye impregnated sheets. The propagation of each re-emitted fluorescent photon is followed inside the acrylic sheet and the number of photons emerging from the four edges of the sheet and their relative arrival time distribution determined. Same procedure was adopted for the passage of photons within the light guides with different bending and twisting angles of the adiabatic light guide. The simulated photon collection efficiency at the PMT is given in Fig. (3a) and (3b) as a function of the bending angle. The overall efficiency for the LAWA and the adiabatic light guide combination is found to be $\sim$ 20% for monolithic set-up and $\sim$ 12% for separate detector sheet and light guide.

5. Prototype testing

The prototype detectors have been tested, using pulsed nitrogen laser (λ peak $\sim$ 337 nm) for excitation of scintillation light in the LAWA sheets. In the monolithic set-up the two LAWA sheets of sizes of 19 cm x 17.5 cm x 1cm (sheet I) and 50 cm x 50 cm x 1 cm (sheet II) have been used. The adiabatic light guides choosen are four strips of 30cm x 3.6cm x 1cm for sheet I and seven strips for 70 cm x 6.8 cm x 1cm for sheet II. For separate detector and light guide set-up the sheet size choosen is 23cm x 40 cm x 1 cm. The PMT output corresponding to the input laser pulse of a known average amplitude is recorded using CAMAC based fast electronics. About 500 triggers have been used to calculate the average collection efficiency. The results obtained so far indicate an overall light collection efficiency of $\sim$ 10.6% for sheet I and only 2.5% for the sheet II, in the monolithic set-up. Corresponding light collection efficiency for separate sheet and light guide is $\sim$ 2.3%. Lower efficiency values are believed to be primarily due to the scattering of light at the LAWA surfaces, a factor difficult to control in actual practice.

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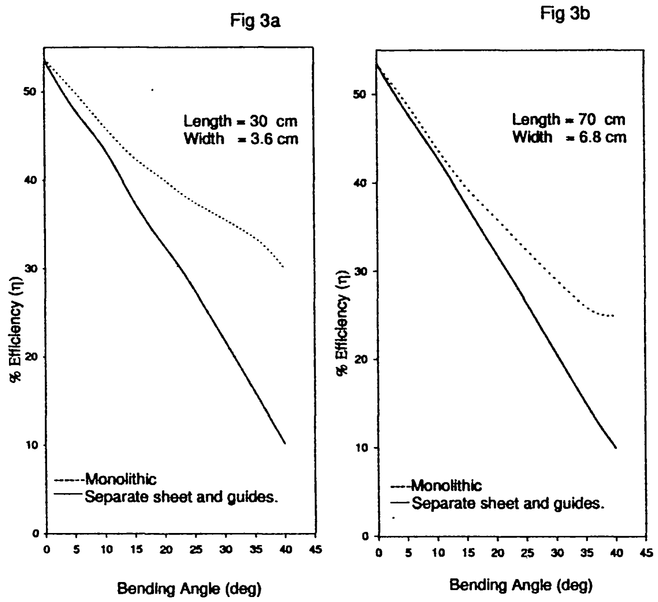

Figure 3. Efficiency of dye impregnated LAWA sheets of lengths 30cm x 3.6cm x 1cm (3a) and 70cm x 6.8cm x 1cm (3b) as a function of the bending angle.

6. Conclusion

Preliminary laboratory testing of the proposed LAWA detector for the MYSTIQUE array has indicated that there is significant room for further improvement in the photon collection efficiency of these detectors. Attempts are being made to cut down on the losses so that collection efficiency can be improved significantly. Other alternative designs employing large diameter PMT without any LAWA detector, are also being studied so that it can be used if we are unable to obtain the desired light collection efficiency of ~ 20 % for the LAWA detector.

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