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# Development of a large-area, wide-angle Cerenkov radiation detector for the MYSTIQUE gamma-ray telescope

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**Abstract.** An ultra-sensitive, multi-detector gamma-ray telescope array is being setup at Mt. Abu for cosmic gamma-ray studies in the tens of TeV energy region. Here, we present the essential design features of the Cerenkov radiation detector, proposed to be used in the system, and describe the results of some preliminary simulation studies and prototype testing.

## 1. Introduction

The MYSTIQUE (Multi-element, Ultra-sensitive Telescope for Quanta of Ultra-high Energies) experiment is essentially a distributed array of Large-area, Wide-Angle (LAWA) atmospheric Cerenkov detectors for cosmic gamma-ray investigations in the ultra-high energy (> 5 TeV) domain. The system is designed to combine the desirable features of, both, atmospheric Cerenkov telescopes (high angular resolution, high gamma to hadron separation) and the extensive air-shower arrays (large-area, wide field-of-view) and will enable a search for steady, episodic or sporadic emission from potential gamma-ray sources within its 45° (half-angle) field-of-view (Bhat, 1997). In addition, it will also permit the study of TeV gamma-ray emission from extended sources like nearby supernova remnants and the primary cosmic ray composition at energies above ~ 50 TeV.

## 2. Experimental system

The MYSTIQUE telescope comprises an array of 225 LAWA Cerenkov detectors, each $4m^2$ in size, and spread over an area of ~ 0.36 $km^2$ with an average inter-detector separation of ~ 40km. The array has a modular structure and is divided into 9 independently-operating stations comprising 25 detectors each. Following a station trigger, based on a 'semi-autonomous' trigger generation scheme (any 3 nearest neighbours of a given station), the arrival times of the Cerenkov wavefront at various station elements are recorded with an accuracy of ~ 2ns. These timing data are logged along with the event absolute epoch as well as the time profile and the overall Cerenkov photon content sampled by each detector element. The special design of the detector is expected to enable ~ 20% of the incident Cerenkov photons, produced following the initiation of an extensive air-shower by a gamma-ray primary, to be collected by an array of fast, small-size photomultiplier tubes with an overall time-jitter of ≤ 3ns. This enables the determination of the event arrival direction with an accuracy of ~ 0.25°, assuming that the event arrival can be timed with a relative accuracy of 5ns in at least 20 detectors. The system threshold energy is estimated to be 5 TeV for a $\gamma$-ray primary, corresponding to a threshold Cerenkov photon density of ~ 2000 photons $m^{-2}$. The combination of a large effective area, lower operating threshold energy, better angular resolution and extrinsic noise suppression based on lateral distribution and time-profile analysis, is expected to yield an order of magnitude higher sensitivity for MYSTIQUE as compared to that of AIROBICC (Lorentz, 1996), the only other distributed array of Cerenkov detectors operating at present.

## 3. Detector characteristics

Fig. 1 shows a schematic diagram of the proposed LAWA detector. It consists of 4 juxtaposed borosilicate glass plates, each $1m \times 1m \times 0.5cm$ in size. The top surface of each sheet is coated with a scintillating dye mixture of PPO (Phenyl-Phenyl-Oxazoyl) and BBOT (Butyl-Bene-Oxazoyl-Thiophene) in toluene (alongwith a small quantity of optical grade perspex to act as the binder for getting a smooth film), whose composition has been adjusted through experimentation to provide an absorption spectrum which significantly overlaps a large part of the atmospheric Cerenkov radiation spectrum over the wavelength band 320-400nm. A large fraction of the fluorescent photons, emitted isotropically by the dye film over the wavelength band 420-660nm (peak emission at 450nm), suffers total internal reflection within the glass sheet and emerges at its four edges. Ribbons of 1mm-dia. green scintillating fibres (Bicron-make, BCF-91A) are optically cemented to the four edges to allow optimal absorption

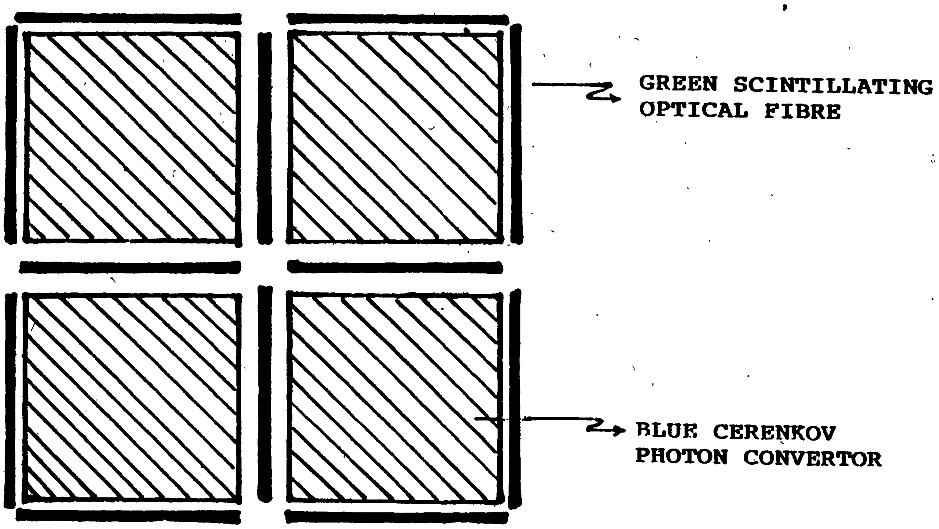

**Figure 1.** Proposed LAWA detector configuration.

of the emerging photons by the fibres. The fluorescent fibres shift the absorbed photon wavelength to the range 440-600nm (peak emission at 490nm) and carry the re-emitted photons to 4 fast photomultipliers placed at the corners of the detector assembly with minimal losses. Fig. 2 shows the absorption and emission spectra of the scintillating dye mixture and the fluorescent fibres used in this preliminary study.

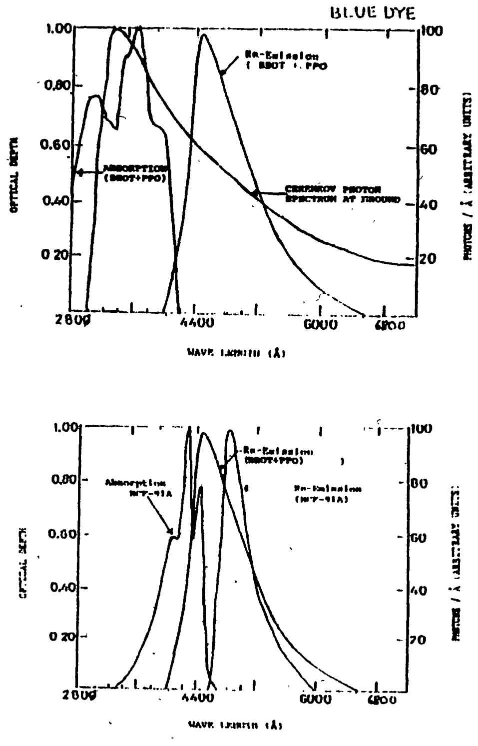

**Figure 2.** Emission and absorption spectrum of (a) (PPO+BBOT) fluorescent dye combination and (b) scintillating fibres.

## 4. Simulation results

First order simulation studies have been carried out to assess the suitability of the proposed detector configuration in terms of the overall collection efficiency and the time jitter in the PMT output. For the sake of simplicity, we have assumed 100% absorption of the incident Cerenkov photons by the fluorescent dye coating. The propagation of each re-emitted fluorescent photon is followed inside the glass sheet and the number of photons emerging out at the four edges and the total path length traversed by each photon within the glass sheet is estimated for a given input Cerenkov pulse of spectrum and duration consistent with that expected to result from an extensive air-shower. The same procedure is repeated to follow the propagation of the secondary photons in the fluorescent fibre ribbons, following the absorption of photons emerging from the four edges in the fibres and their re-emission and propagation within the fibres. These first simulations have indicated an effective photon collection efficiency at the

PMT of ~ 20% with a propagation time-jitter of ≤ 2ns. More exact simulations are being carried out to take into account the actual absorption and emission spectra of the fluorescent dye combination and the optical fibres as well as propagation losses within the glass sheets and the fibres.

## 5. Prototype testing

A pulsed nitrogen laser ($\lambda_{peak} = 337nm$) has been employed to excite the prototype detector which consists of a 40cm × 25cm × 1cm borosilicate glass sheet with a top surface coating of PPO+BBOT fluorescent dye mixture described above. Fluorescent light emerging out of one of the edges of the sheet is ducted onto a fast photomultiplier (2″-dia) through the fluorescent optical fibre ribbon fixed on the edge so as to cover almost its entire area. The CDC counts corresponding to an input pulse of known amplitude, are recorded at the PMT output using CAMAC-based fast electronics. The average of 500 similar measurements has been used to calculate the average collection efficiency. Preliminary results obtained so far indicate an overall collection efficiency of ~ 2%. The large difference between the measured value and the value indicated by the simulations is believed to be due to several factors, including the inadequate coupling between the glass sheet and the optical fibre ribbon and the significant mismatch between the emission spectrum of the dye combination and the absorption spectrum of the fluorescent fibres. In the first order simulations referred to above, 100% absorption has been assumed both at the first stage (Cerenkov spectrum and absorption spectrum of the dye combination) and the last stage (emission spectrum of dye combination and absorption spectrum of the fibres). A significant improvement in the collection efficiency is expected when a better matching between these spectra is realised by using the appropriate dye combination — an exercise presently underway.

## 6. Conclusions

Preliminary laboratory testing of the proposed LAWA detectors for the MYSTIQUE array has indicated that there is a significant room for further improvement in the photon collection efficiency of these detectors. Attempts are being made to affect these improvements by cutting down on losses and by searching for fluorescent dye combination with absorption spectra more closely matched to the atmospheric Cerenkov radiation spectrum. An alternative scheme is also being tried where the photons emerging out of the four edges of the LAWA sheet are directly coupled to the PMT's through transparent optical fibres attached to the edge over its entire area. Further tests with the prototype detector using the two types of light guides, are expected to help in optimizing the detector and light guide design.

## References

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