

## Threshold energy estimate of the proposed MACE $\gamma$ -ray telescope at Hanle

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The fact that EGRET detected over 250 objects above 100 MeV while only a handful of sources have been detected above 100 GeV indicates that there is a good chance of detecting a significant number of these sources (particularly those which do not show a signature of steepening or cut off up to a few GeV), if the threshold energy of ground based telescopes is lowered to  $\sim 20$  GeV. In the present study, we report the threshold energy estimate of the MACE (Major Atmospheric Cerenkov Experiment) imaging telescope, proposed to be installed in the campus of Indian Astronomical Observatory at Hanle ( $32.8^\circ\text{N}$ ,  $78.9^\circ\text{E}$ , 4200m asl). The results of the Monte Carlo simulations carried out with CORSIKA code, suggest that using a pixel threshold of  $\geq 4\text{pe}$  and a nearest neighbour quadruplet trigger,  $\gamma$ -ray energy threshold of  $\sim 15\text{GeV}$  is achievable by the MACE telescope. Details of the simulation work for estimating the threshold energy along with results obtained are presented in this paper.

### 1. Introduction

The proximity of the energy domain below 100 GeV to the upper end of the energy range covered by the EGRET detector suggests that many objects (e.g. radio pulsars and distant AGNs), established as GeV sources, have a fairly good chance of being detected by the ground based Cerenkov imaging telescopes if their threshold energy is lowered to  $\sim 20\text{GeV}$ . While the next generation  $\gamma$ -ray satellite mission GLAST will extend the exploration of the  $\gamma$ -sky up to 100 GeV, with a sensitivity of  $\sim 100$  more than that of the EGRET instrument, the capability of GLAST beyond 10's of GeV energy range will be quite limited because of its limited detection area. This puts a serious limitation on the use of this instrument for performing detailed temporal and spectral studies of highly variable  $\gamma$ -ray sources like blazars and gamma-ray bursts, which have variability time scales of  $\sim 10$ 's of minutes and  $10^{-2}$  to  $10^3$  seconds, respectively. Exploring the  $\gamma$ -ray sky in the 10's of GeV energy range with low threshold ground based atmospheric Cerenkov imaging telescopes will thus lead to a potentially rich harvest of astrophysical discoveries, as has been already demonstrated by the HESS collaboration [1] at  $\gamma$ -ray energies  $\geq 100\text{GeV}$ . The aim of the next generation instruments like CANGAROO-III, HESS, MAGIC, VERITAS and MACE is thus to reach a sensitivity level which is mainly limited by the primary cosmic ray electron background.

The energy threshold of an atmospheric Cerenkov imaging telescope is primarily determined by the aperture of the light collector and the minimum discrimination threshold at which the system can be operated with an acceptable rate of chance coincidence triggers. Furthermore, the threshold energy of the telescope is also governed by the minimum number of photoelectrons in the image so that it can be parameterized with sufficient accuracy (the so called 'good-image' needs to have  $\sim 50$ -100 pe [2]). Since the Cerenkov photon density increases with observation height, the installation of a Cerenkov imaging telescope at very high altitudes ( $\geq 4000\text{m}$ ) is a straightforward method for reducing energy threshold [2,3]. The threshold energy of the system can be also reduced further by using multiple telescopes [2], intelligent trigger generation scheme for producing event trigger and an optimum combination of several other parameters like pixel size, coincidence gate width and trigger field of view.

## 2. Salient design features of the 21m diameter MACE telescope

The 21m-diameter MACE (Major Atmospheric Cerenkov Experiment) telescope, proposed to be set up at Hanle, India (32.8° N, 78.9°E, 4200m asl) is an atmospheric Cerenkov imaging telescope to explore the  $\gamma$ -ray energy domain  $\sim 20\text{GeV} - 10\text{TeV}$ . The light collector of the MACE telescope will use 356 panels of size  $\sim 984\text{mm} \times 984\text{mm}$  with each panel consisting of either 4 or 9 small spherical mirrors of size  $\sim 488\text{mm} \times 488\text{mm}$  and  $\sim 323\text{mm} \times 323\text{mm}$ , respectively. The overall light collector of the telescope, having a collection area of  $\sim 337\text{m}^2$ , will have a paraboloid shape with panels of graded focal lengths between 2091-2245 cm, so that apart from being isochronous the light collector design also yields a point spread function which is comparable to that of the Davies-Cotton design. The  $D_{95}$  (defined as a diameter of circle within which 95% of the reflected rays lie) of the paraboloid design with graded focal length mirror panels has been determined to be  $\sim 29.3\text{mm}$  ( $\equiv 0.08^\circ$ ) and  $\sim 84.7\text{mm}$  ( $\equiv 0.23^\circ$ ) at incidence angles of  $0^\circ$  and  $1^\circ$ , respectively.

The imaging camera of the telescope will comprise a cluster of 832 PMTs of two sizes, providing a field of view of  $4^\circ \times 4^\circ$ . While the innermost 576 pixels, covering a field of view of  $2.4^\circ \times 2.4^\circ$ , will have a pixel resolution of  $0.1^\circ$  for generating the event trigger, the remaining 256 pixels will have a resolution of  $0.2^\circ$ . While the optimal size of the pixel is primarily determined by the condition that a minimum of  $\sim 10$  pixels should contribute towards the formation of the Cerenkov image so that it can be parameterized with reasonable accuracy, using a smaller pixel size also allows to impose higher multiplicity trigger condition to suppress chance coincidence triggers. Since at  $E_\gamma \sim 20\text{GeV}$ , the characteristic size of the Cerenkov image is  $\sim 0.2\text{-}0.3$  square degree [2], using a pixel size of  $\sim 0.1^\circ$  in the trigger region apart from providing good image quality should also help us to suppress chance coincidence triggers by using the nearest neighbour quadruplet trigger. Since using a uniform pixel size of  $\sim 0.1^\circ$  for the camera field of view of  $4^\circ \times 4^\circ$  will need a total of  $\sim 1600$  channels, providing a guard ring of 256 pixels with a pixel size of  $\sim 0.2^\circ$  is probably the only cost effective alternative for recording the photon content of Cerenkov images beyond  $2.4^\circ \times 2.4^\circ$  field of view. While the MAGIC group is already following this concept, detailed simulation study for understanding the implications of following the hybrid camera design is, however, still under investigation.

## 3. Simulation methodology

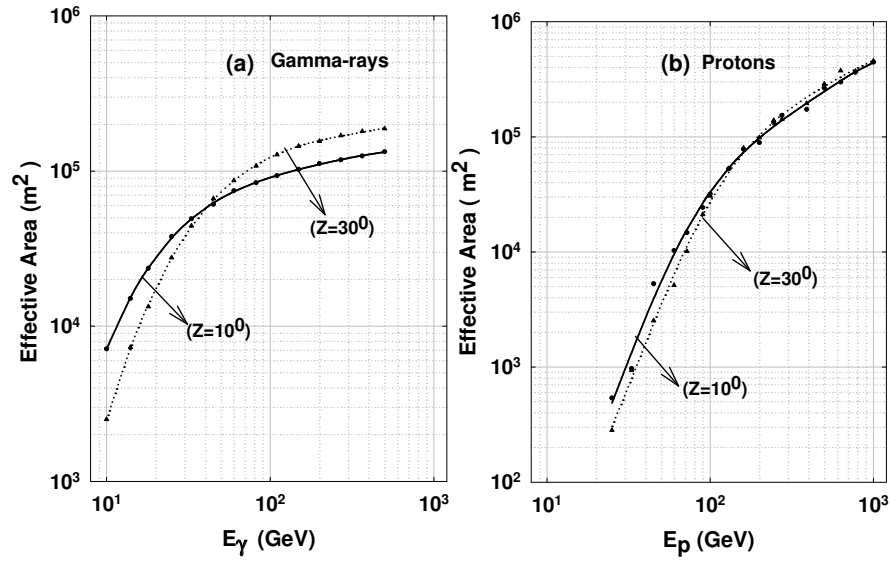
The results of the simulation studies presented in this paper are obtained for the Hanle altitude of  $\sim 4200\text{m}$  and are based on the CORSIKA air shower simulation code [4]. The simulation data-base uses about 300 000  $\gamma$ -ray (and 300 000 proton) initiated showers in the energy range of 10-500 GeV (25-1000 GeV) at zenith angles of  $10^\circ$  and  $30^\circ$  with an impact parameter of 0-300m. The field of view for the isotropic proton showers has been taken to be  $2.4^\circ \times 2.4^\circ$ . A supplementary backup code has been developed for performing ray tracing of the Cerenkov photons and to take into account wavelength dependent atmospheric absorption, the spectral response of the PMTs, reflection coefficient of mirror facets and light cones. The number of photoelectrons registered by each camera pixel is then determined so that the two-dimensional intensity distribution of the Cerenkov photons thus obtained can be used for further analysis.

A crucial input required for estimating the threshold energy of Cerenkov telescope is the variation of the single pixel rate as a function of the threshold level and this dependence was found by performing laboratory measurements on several gain calibrated PMTs. In these measurements, the light of night sky background (LONS) was simulated by using a LED with its intensity set in such a manner that the resulting anode current of the PMT is equal to what the PMT would have produced under actual conditions at Hanle. This obviously means that apart from using the measured value of the light of night sky background flux at Hanle ( $\sim 0.8 \times 10^{12} \text{photons m}^{-2} \text{s}^{-1} \text{sr}^{-1}$  corresponding to the measured UBV magnitudes of  $m_U=23.6$ ,  $m_B=22.9$  and  $m_V=21.5 \text{ mag arcsec}^{-2}$  [5]), one has to also account for the light collector area and pixel field of view while carrying out

these measurements. The measurement carried out by assuming a coincidence gate width of  $\sim 10$  ns and a trigger configuration of Nearest Neighbour Quadruplet (NNQ) trigger within a field of view of  $2.4^\circ \times 2.4^\circ$ , indicate that a single pixel threshold of  $\sim 4$  pe can be used for restricting the chance coincidence rate to  $\sim 0.1$  Hz. The corresponding single pixel rate of the PMTs has been found to be  $\sim 26$  kHz.

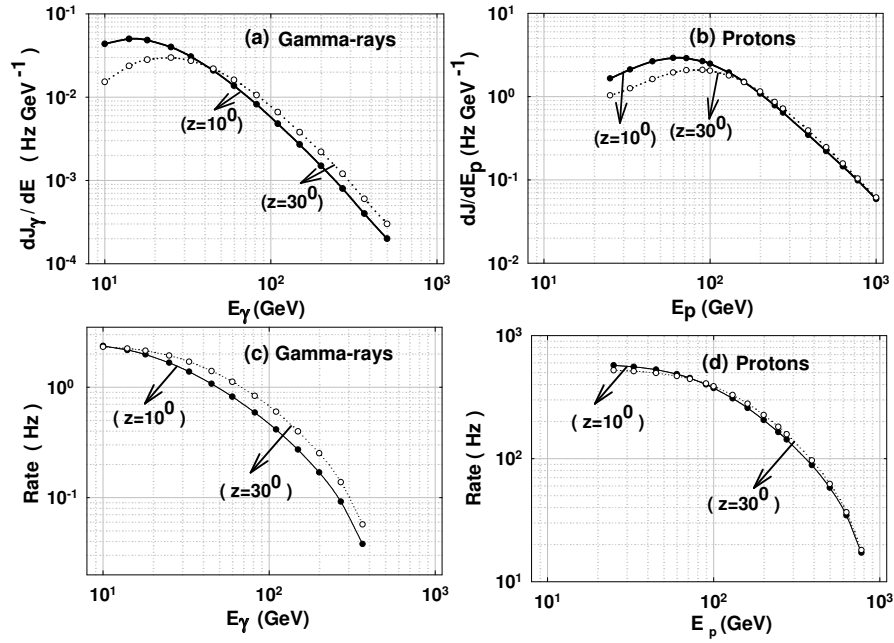
#### 4. Expected threshold energy of the MACE telescope

Using the data-bases generated as per details given in Section.3 and a NNQ trigger with a single pixel threshold of  $\geq 4$  pe, we have first obtained trigger efficiency for  $\gamma$ -ray and proton primaries at various energies as a function of the core distance. The trigger efficiencies are then used to evaluate the effective collection area of the MACE telescope corresponding to each primary energy and the results obtained are shown in Fig.1 The



**Figure 1.** (a) Variation of effective collection area as a function of primary energy for  $\gamma$ -ray (a) and proton (b) initiated showers at zenith angles of  $10^\circ$  and  $30^\circ$ .

corresponding differential and integral rates, shown in Fig.2, for  $\gamma$ - and proton primaries were then obtained by using the Crab Nebula and the cosmic ray proton energy spectra [6]. The results shown in Fig.2a suggest that by using a NNQ trigger with a single pixel threshold of  $\geq 4$  pe,  $\gamma$ -ray threshold energy of  $\sim 15$  GeV and  $\sim 25$  GeV at zenith angles of  $10^\circ$  and  $30^\circ$ , respectively is achievable by the MACE telescope. The corresponding threshold energy of the telescope for the proton primary at these two zenith angles is  $\sim 60$  GeV and  $\sim 90$  GeV. It is pertinent to point out that the expected  $\gamma$ -ray threshold energy of the MACE will be still lower for a source which has a pure power law type of energy spectrum with a differential spectral index of  $\sim -2.65$ .



**Figure 2.** Differential detection rates for  $\gamma$ -rays (a) and protons(b) as a function of the primary energy. The corresponding integral rates are shown in (c) and (d), respectively.

## 5. Conclusions

The results of the Monte Carlo simulations suggest that a  $\gamma$ -ray threshold energy of  $\sim 15$  GeV is achievable by the MACE telescope, which is proposed to be set at altitude of  $\sim 4200$  m. However, knowing that the stereoscopic approach allows a superior rejection of the hadronic showers and, more importantly suppression of local muon events, which are otherwise rather difficult to remove in the case of a single imaging telescope, the possibility of setting up a stereo-MACE using two telescopes is also being investigated. Necessary sensitivity calculations are also in progress to assess the potential of the MACE telescope for investigating various steady and episodic  $\gamma$ -ray emission phenomena in the sky.

## References

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