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Threshold energy estimates of TACTIC array elements

M.L.Sapru*, N.Satyabhama,M.K.Koul, A.K.Tickoo and C.L.Bhat
Bhabha Atomic Research Centre, Nuclear Research Laboratory,
Mumbai-400085, India

Abstract. Using the CORSIKA-code based simulation studies,we present here results on the γ-ray and the cosmic-ray proton trigger-thresholds for the Imaging-Element and the 3 Vertex-Elements of the TACTIC atmospheric Cerenkov telescope array. The thresholds have been derived for several, potentially useful trigger-configurations.

Keywords : Atmospheric Cerenkov Technique, EAS Simulations, TACTIC, Energy-Threshold

1. Introduction

The TACTIC array, which has been set up at Mt.Abu, Rajasthan in Western India (24.65^o N, 72.7^o E, 1300 m asl), consists of 4, alt-azimuth- mounted, atmospheric Cerenkov telescope elements, (Figure 1a) deployed at the centriod and the vertices of an equilateral triangle of 20 m side (Bhat 1997a, Bhat 1997b). Each telescope element is steered with a computer-controlled 2-axes drive-system (Tickoo 1999). Its tessellated light collector consists of 34 front aluminized, spherical mirror facets (reflectivity $\sim$ 80-90%) (Udupa 1993). These mirror facets are mounted suitably so as to generate an overall light collector surface which approximates a Davis-Cotton optical configuration with an effective surface area of 9.5 m^2, focal length of $\sim$ 4 m and an on-axis spot-size of 0.3^o dia (Koul 1997).The Imaging Element (IE), located at the centroid of the triangle, has been operational since January 2000, with its full, 349-pixel PMT-based camera,which covers a field of view (FoV) of $\sim$ 6^o× 6^o with a uniform pixel- resolution of $\sim$ 0.31^o (Figure 1b).

*e-mail:mlsapru@apsara.barc.ernet.in

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For the three Vertex Elements (VE), located at the Vertices of the TACTIC triangle (Fig 1a), an unconventional focal plane instrumentation,covering a common FoV of $\sim 3.5^o \times 3.5^o$, is being explored. In both the IE and VE cameras dead-space between the pixels is minimised by the use of mettalic Compound -Paraboloid Collimator (CPC) light guides with overall collection efficiency of about 60 % . In the VE's a study of spectral content, time profile and/or polarization-state of the Cerenkov event will be conducted to augument the event characterization of the IE. As shown in Fig 1c the instrumentation can be R(Reflection) and T (Transmission)-mode Duplex-Detector-Array (DDA), where in the corresponding pixels of R and T arrays are facing each other across a panel of (i) Dichroic-Filter (DF) or (ii) a Beam-Splitter (BS), positioned midway between R and T arrays perpendicular to the telescope axis. While the DF have $\sim$ 90 % efficiency, (for the reflected photons in the wavelength range 300 - 450 nm(B-band) and the transmitted photons in the wavelength range 450 -600 nm (G-band)), the BS have $\sim$ 32.5% reflection and transmission efficiencies in the photon wavelength range 300 - 600 nm. The third type of the focal-plane instrumentation being explored is by using only the top camera of the DDA and replacing the smaller pixels, sesitive in the wavelength range 300-600 nm, by Ultraviolet-pixels sensitive in the wavelength region 250-310 nm. The motivation to use the DDA with DF is to study the B/G ratio for event characterization. However using BS along with sheet polarizers, it is possible to measure both the degree and angle of linear polarization of the Cerenkov event and thus have two additional, potentially promising parameters for the primary particle characterization,viz., core shower-location and primary type (Gokhale 2000). In the third type i.e a multipixel mono-camera, the relative fluxes detected by the U and V-pixels yielding U/V flux-ratio, which , as suggested previously (Stepenian 1983), is proposed to be used as a supplementary classifier, for γ -ray and hadron-produced Atmospheric Cerenkov Events (ACE), along with the time profile of these events.We estimate here the trigger thresholds achievable for various trigger-generation schemes for Imaging Element and the Vertex Element array.

2. TACTIC Simulations

The simulation studies have been carried out, using the CORSIKA air-shower code, version 5.6211, (Heck 1998) with the Cerenkov option (Martinez 1995), for Mt. Abu observatory altitude. Appropriate values have been considered for the horizontal and the vertical components of the terrestrial magnetic field. Primary γ-rays (protons) are sampled over the energy range $\sim$ 320 GeV to 5 TeV ($\sim$630 GeV to 10 TeV) with a total sample size of 4000 events for γ-rays and 12000 events for protons. The principal axis of a TACTIC element is assumed to be directed towards the zenith angle θ=20^0 and the primary γ-ray is assumed to be incident along the axis. Cosmic-ray proton directions, on the other hand, are selected randomly from within the telescope FoV of $\sim$ 6^{0}x6^0), centered on θ =20^0.

The reflection, of each photon bunch, from the TACTIC reflectors to the focal-planes of IE and VE, is taken care of by a supplementary BACUP-code, after considering the

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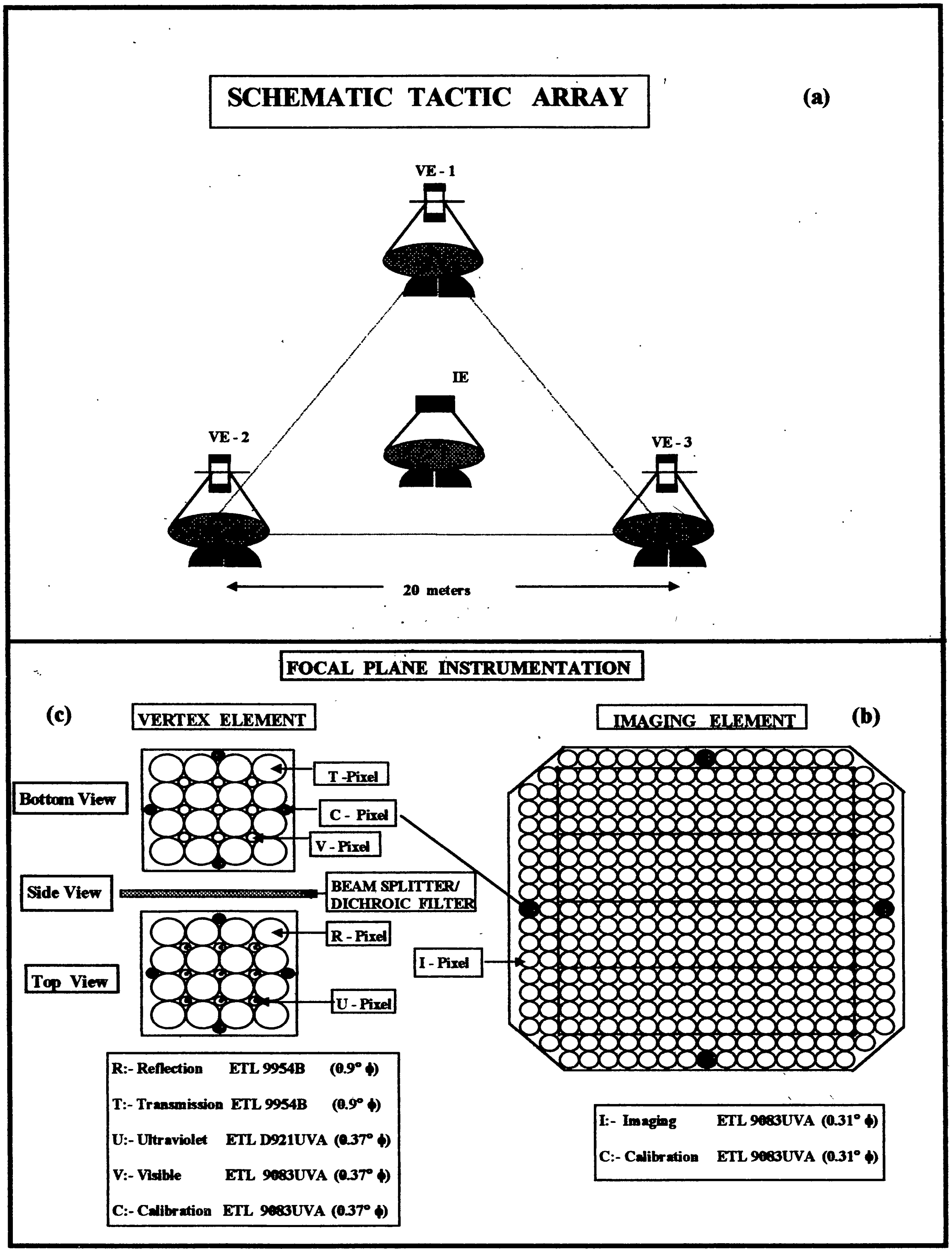

Fig 1: A schematic diagram of the 4-element TACTIC Array (a); Camera configurations used for Imaging Element (b) And Vertex Elements (c) .

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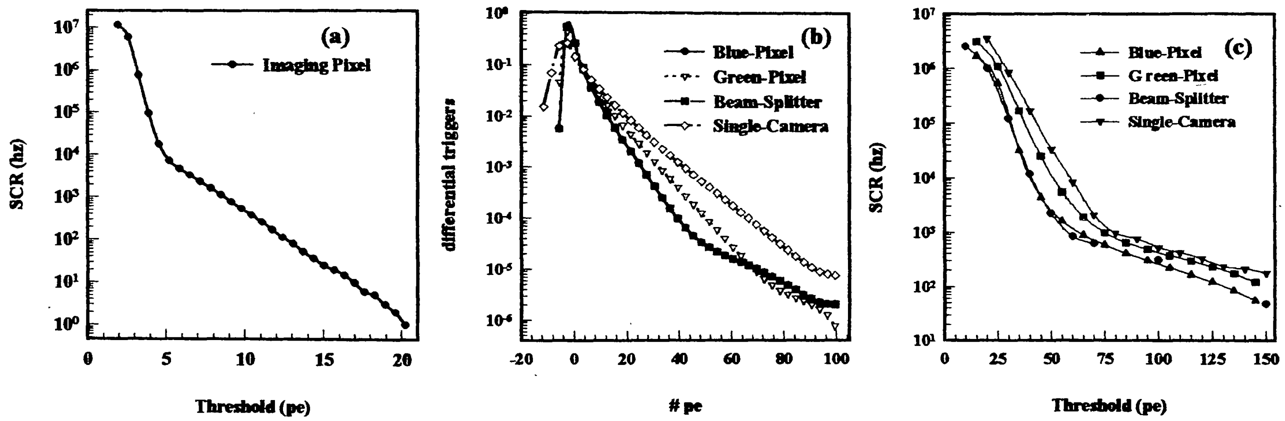

Fig 2: a) Variation of single-channel rate as a function of threshold for IE PMT ; b) Differential distribution of shot-noise pulses for VE PMT and c) Variation of single-channel rate as a function of threshold for the VE PMT

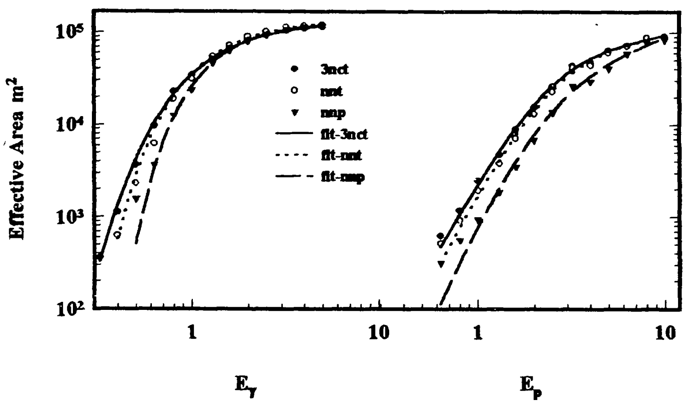

Fig 3: Effective Area for various trigger schemes in case of Imaging Element

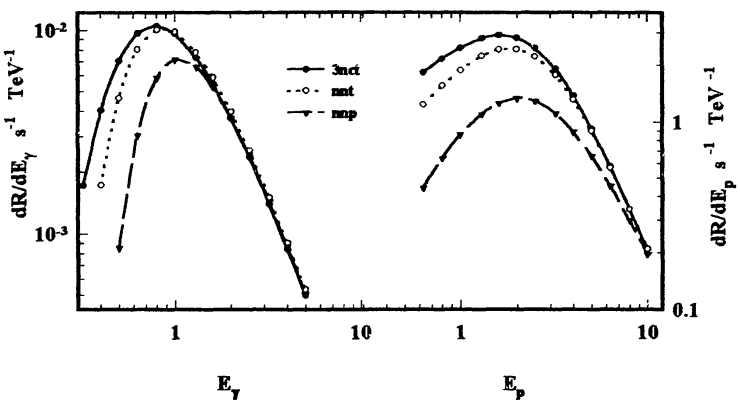

Fig 4: Estimated differential rates for gamma-ray and proton events as seen by the Imaging Element for different trigger schemes

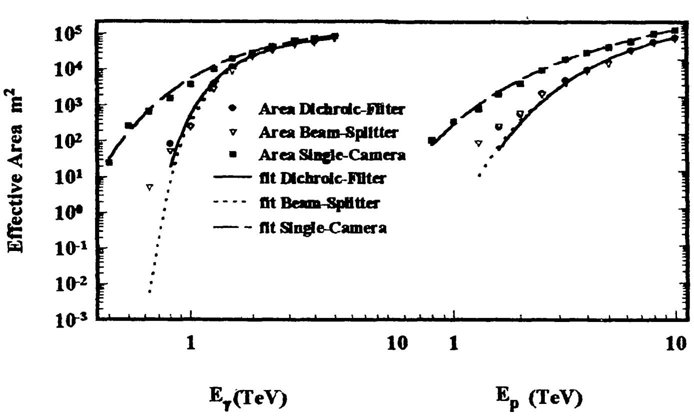

Fig 5: Effective Area for various trigger schemes in case of Vertex Element Array

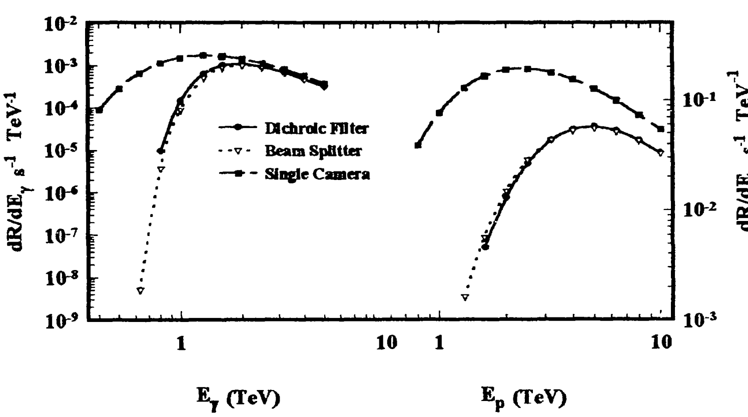

Fig 6: Estimated differential rates for gamma-ray and proton events as seen by the Vertex Element Array for different trigger schemes

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λ -dependent atmospheric absorption. This code also takes account of beam-splitter/ dichroic-filter efficiency (in case of VE only), the obscuration due to the mechanical structure, CPC efficiency and the quantum efficiency of the corresponding photocathodes, to determine the number of photoelectrons (pe) registered by the corresponding pixels of the IE and VE.

The resulting data -bases, consisting of pe distributions in the IE and VE at various core distances are used to estimate,independently, the effective threshold energies for IE and the VE array. For this purpose, in case of VE, light of night sky (LONS)induced shot-noise, based on the mean number and the standard deviation values of background pe, likely to be seen by each pixel is superposed on the pixels with non-zero numbers of pe produced by a γ -ray or proton primary. To account for the effect of PMT afterpulsing (Mirzoyan and Lorenz 1995), the LONS induced shot-noise distribution is obtained from the experimentaly observed noise profile (Figure 2a, b, and c). However, in case of the IE, the LONS generated shot-noise is not injected and only noise-free images are used.

In the case IE, triggers are derived from the innermost 240 pixels (16x15 matrix) for the following 3 topological configurations: Nearst-Neighbour Non-Collinear Triplets (3NCT),Nearest-Neighbour Triplets (NNT) and Nearest Neighbour Pairs (NNP). For the VE, the triggers are generated for the following different situations: (i) DF- generated flux ratio cuts, where, in accordance with the spectral character of Cerenkov light,the ratio of the Cerenkov light flux, received by a R-pixel in the B-band to that by a T-pixel in G-band is $\sim 2(1)$ in absence (presence) of the sky noise fluctuations. (ii) BS - generated, prompt 2-fold coincidence cut, where the total Cerenkov light, is shared in a 1:1 ratio (λ-independent) between a R-pixel and the corresponding T pixel. In both (i) and (ii) cases here, the master trigger consists of an appropriately lined-up 3-fold coincidence between the trigger outputs of the individual VE. For comparison, we have also studied the corresponding situation for the conventional single multi-pixel camera (MP) where a differentially delayed 3- fold coincidence is demanded among the 3 VE after obtaining a coincidence in the Nearest Neighbour pair of the individual VE, for trigger generation purposes. The PMT discrimination levels used (or equivalent single-channel rates) are chosen so that the expected chance-coincidence rate at the final trigger-level is within manageable limits of the anticipated cosmic-ray trigger rate for the IE, considered in a stand-alone mode, and for the 3VEs,taken together in a prompt coincidence mode.

3. Results and Discussion

Figures 3 and 5 show the effective collection area , as a function of the progenitor particle -energy for all the trigger-generation modes in the IE and VE referred to above. The effective collection area, at various energies, along with the representative Crab Nebula spectrum for the γ -rays and the background cosmic ray spectrum for protons have been used to estimate the differential event rate profiles for the two species. The resulting

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profiles, (Figures 4 and 6) have been utilised to predict the trigger-threshold energies, for various trigger modes for IE and VE telescopes.

4. Conclusion

The present study leads to the conclusion that all the 3 topological trigger generation schemes considered here, viz, 3NCT, NNT and NNP lead to γ-ray threshold energies,($\sim$ 0.8 TeV-1.0 TeV)for the IE . On the other hand, for VE array, the trigger-threshold energies turns out to be $\sim$ 2.0 TeV($\sim$ 5.0 TeV) for γ-rays(protons), in DF/BS cases and $\sim$ 1.3 TeV ($\sim$ 2.5 TeV) for MP case. We plan to use the 3NCT trigger mode for the IE (expected to be less sensitive to single-muon Cerenkov events). The focal-plane instrumentation for the VE's will be finalized only after carrying out detailed tests based on above results. The other alternative mode, utilising the event trigger from IE and using VE's in the slave mode for recording the spectral and temporal information of the recorded event is also being investigated.

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