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Sensitivity and energy resolution estimates of the TACTIC gamma-ray telescope — Inputs from simulation studies (II)

M. K. Koul, R. C. Rannot, M. L. Sapru, N. Sathyabama, C. L. Bhat, A. K. Tickoo, A. K. Razdan and V. N. Gandhi

Bhabha Atomic Research Centre, Nuclear Research Laboratory, Mumbai 400085, India

Abstract. The response of the recently-commissioned TACTIC imaging Cerenkov telescope to atmospheric Cerenkov pulses produced by cosmic gamma-ray and hadron-initiated extensive air-showers has been studied through Monte Carlo simulations, using the CORSIKA code (Capdeville et al., 1992). Preliminary results are presented on the likely performance of 3 different imaging camera sizes : 2.8° × 2.8°, 4.7° × 4.7° and 5.9° × 5.9°, with regard to event calorimetry and characterization.

1. Introduction

The TACTIC (**TeV** **A**tmospheric **C**erenkov **T**elescope with **I**maging **C**amera), India's first imaging Cerenkov telescope system, is being set up by the Bhabha Atomic Research Centre at Mt.. Abu, Rajasthan, with the primary aim of carrying out high-sensitivity temporal and spectral investigations of cosmic gamma-ray sources above 0.2 TeV energy. The essential technical details of the TACTIC array have been described earlier (Bhat, 1997). Recently, the central Imaging Element (IE) of the array has been made operational with a prototype 81-pixel camera, to be finally replaced by the full-scale 349-pixel camera having a pixel resolution of ~ 0.31°. The camera produces a two-dimensional distribution of the Cerenkov photons intercepted by the telescope mirror (area ~ $9.5m^2$), following the initiation of an extensive air-shower by a primary γ-ray or cosmic-ray particle. The shape and orientation parameters of the resulting Cerenkov image can be used to reject > 99% of the proton-initiated background events and, when considered alongwith the event size parameter, to estimate reliably the energy of the γ-ray primary. The capability of the system to distinguish between the two event types is quantified in terms of Q, the Quality Factor, defined as $Q = f_\gamma / \sqrt{f_p}$, where f_γ and f_p represent the fractions of γ- and proton-initiated events retained in a data-set after applying various image shape and orientation cuts. We have employed the CORSIKA air-shower simulation code to estimate the calorimetric capability (energy resolution) and the quality factor (Q) of the TACTIC imaging camera. We present our preliminary results here.

2. Simulation methodology

The methodology followed for TACTIC simulations using the CORSIKA code has been described in detail in the accompanying paper by Sathyabama et al. (1998). The basic database generated from the simulations consists of the photoelectron content registered by each PMT pixel of the imaging camera in response to the incidence at the top of the atmosphere of a primary γ-ray of energy between 250 GeV - 5 TeV from the zenith angle direction, $\theta = 20°$, or that of a primary cosmic-ray proton of energy 500 GeV - 10 TeV, incident from any random direction within the detector field-of-view centered on $\theta = 20°$. The resulting, two-dimensional Cerenkov light images are used to determine the image parameters : Length (L), Width (W), Distance (D), Alpha (α) and Size (S) for the gamma- and proton-initiated Atmospheric Cerenkov events (γ-and p-ACE respectively here onwards), as would be recorded by imaging cameras of three sizes : 9 × 9 (present), 15 × 15 (interim) and 19 × 19 (final) pixels, covering fields of view of 2.8° × 2.8°, 4.7° × 4.7° and 5.9° × 5.9° respectively.

3. Results and discussion

Fig. 1 explores the calorimetric potential of the average event-size parameter, $< S >$, in the case of γ- and p-ACE in the TeV energy range. While the case for the camera size of 19 ×

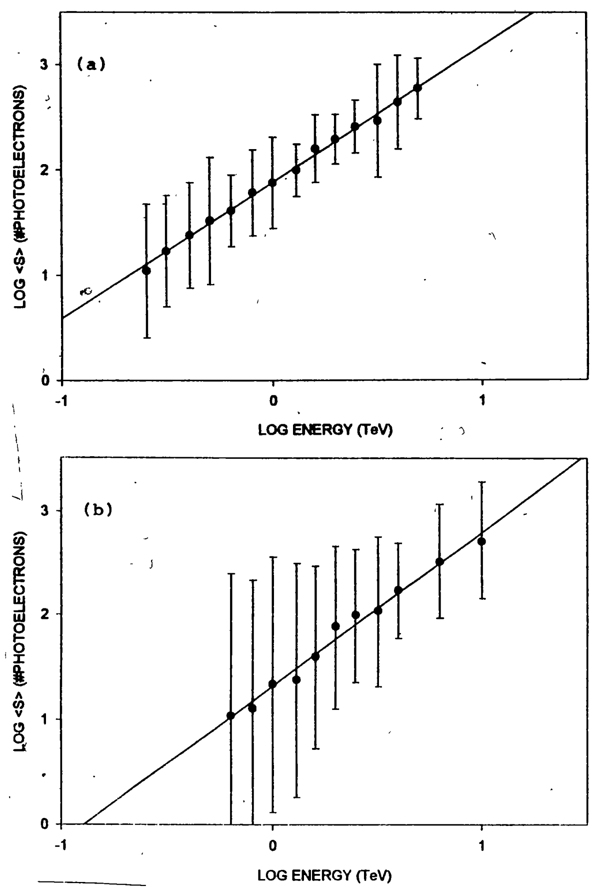

Figure 1. Energy dependence of the average size of Cerenkov images produced by γ-ray (a) and proton primaries (b) for the 19 × 19 pixel TACTIC imaging camera. Error-flags shown represent ± 1 σ standard deviation values.

19 pixels is illustrated for a representative shower-core distance of 85m, the situation for the other two camera-sizes of 15 × 15 pixels and 9 × 9 pixels is found to be essentially similar. The best-fit lines, shown in Fig. 1, have a slope ~ (1.29 ± 0.29) for the γ-ACE and ~ (1.43 ± 0.69) for the p-ACE. The magnitude of departure noted in the values of the slope from unity, the value expected for a good energy-estimating parameter, as also the amplitude of the associated ±1σ statistical error (found to be larger for p-ACE) is due to the effect of inter-shower fluctuations, leading to an event size (*S*) distribution which is skewed. The degree of asymmetry is found to be a function of the primary energy (E) and particle type (γ/p), as can be inferred from Fig. 1. Though not shown here, the slope of the < S > v/s E line is also known to be dependent on the shower-core distance, being skewed for all core-distances in the case of p-ACE and upto the hump region (≤ 130m) in the Cerenkov photon density profile in the case of γ-ACE. Beyond the hump region, the *S*- distribution for the γ-ACE is known to become more symmetrical.

Fig. 2 gives the distributions of the image-parameters *L*, *W*, *D* and α for the γ- and p-ACE (Hillas, 1985; Punch et al., 1992) for a primary energy of 1 TeV (γ-ACE) and 2 TeV (p-ACE) for the TACTIC 19 × 19 pixel camera. A total of 4000 events of each type have been sampled

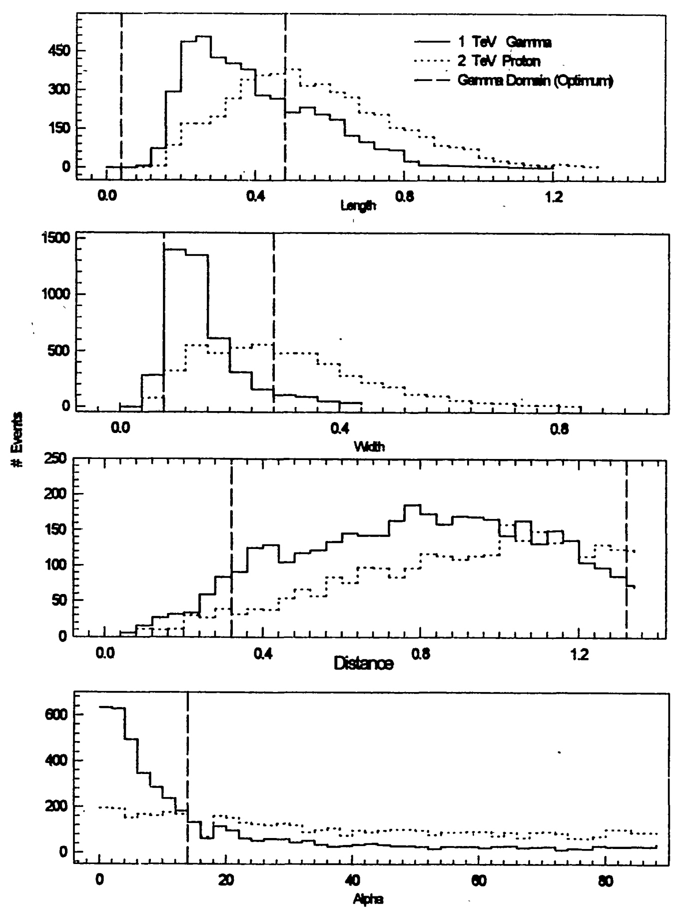

Figure 2. Distribution of Length (*L*), Width (*W*), Distance (*D*) and Alpha (α, orientation) image parameters predicted for the TACTIC 19 × 19 pixel imaging camera for γ-ray and proton primaries. All the parameters are plotted in degrees.

from 168 detector locations, arranged in a grid-structure with an inter-element spacing of 10m × 6m. Using these distributions, the highest Q values are obtained for the following optimum ranges of the image parameters : $0.04° \leq L \leq 0.48°$, $0.08° \leq W \leq 0.28°$ and $0.32° \leq D \leq 1.32°$. For the 9 × 9 pixel camera, the corresponding ranges turns out to be : $0.04° \leq L \leq 0.4°$, $0.08° \leq W \leq 0.20°$ and $0.32° \leq D \leq 1.12°$. For the TACTIC in its present configuration, the quality factor is found to maximize for $\alpha = 15°$. Using all these image shape and orientation filters in a sequential manner, the present work indicates that it would be possible to reject ~ 99.7% p-ACE while retrieving ~ 50% of the γ-ACE, leading to an overall Q ~ 10. This sensitivity level was actually achieved during recent observations of the active galaxy Markarian 501 by the IE of the TACTIC (81-pixel camera) : a 13.3σ confidence level signal was detected from this source (average flux : ~ 4 Crab units) during 47.8h of on-source observations (Bhat et al., 1997; Protheroe et al., 1997).

4. Conclusions

Monte Carlo simulations, using the CORSIKA air-shower code, have been used to determine the calorimetric and even characterization capabilities of the TACTIC γ-ray telescope for 3 representative camera sizes. Over the restricted primary energy range (~ 0.25 - 10 TeV) considered in this first study, comparable results have been obtained for the 3 cameras. Further, the average event size $< S >$, estimated for a shower-core distance of 85m, is found to be not linearly related to the primary energy E, thereby underlining an important limitation of this parameter for use as such as an energy-estimator. The image-parameter space, leading to an optimum signal-to-noise ratio for the TACTIC has been delineated for primary energies of 1 TeV (γ-ACE) and 2 TeV (p-ACE) and is found to be reassuringly congruent with that prescribed in literature for the supercuts image-selection procedure (Punch et al., 1992).

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