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Energy resolution of the TACTIC imaging element

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Abstract. We explore here the possibility of using artificial neural network (ANN) for characterization of atmospheric Cerenkov events (progenitor type and energy) detected by the imaging γ-ray telescope array, TACTIC.

1. Introduction

The TACTIC γ-ray telescope array (Bhat et al. 1994), recently commissioned at Mt. Abu, Rajasthan (26.6° N, 72.7° E, 1400 m asl), consists of 4 atmospheric Cerenkov telescopes, each ~ 9.5 m (Hillas 1985) in the light-collector area. This compact array has a triangular configuration with 3 members, called the Vertex Elements (VE), disposed at the vertices of a triangle of side 20m and the fourth member, referred to as the Imaging Element (IE), placed at the centroid of the triangle. The IE, with which we shall be dealing in the present work, deploys a 349-pixel photomultiplier tube (PMT)-based imaging camera as its focal-plane instrumentation. The camera covers a large field of view (FoV) of ~ 6° x 6° with a pixel-resolution of ~ 0.31°. Using what may be called the 'serial-filter approach', various image shape (length, L, width, W and distance, D) and orientation (azwidth, A or alpha, α) parameters[2] (Fig. 1) have been utilized effectively in the past to classify the progenitor type (γ-ray/cosmic ray nucleus. As for the primary-particle energy, in principle, it can be estimated using the image size(S), provided the progenitor type and its impact parameter (or core-distance) and zenith angle are known. This has been done so far largely through guidance drawn from extensive simulation studies. In the present study, we appeal to the intrinsic cognitive and fault-tolerant capabilities of properly trained artificial neutral networks (ANN) in seeking classification of events likely to be detected by a TACTIC-like Imaging Cerenkov telescope. Assuming that the ANN approach works satisfactorily, the advantage would be that primary energy estimation would be direct, without any explicit functional dependence on size.

2. Database-generation

Folding in the TACTIC array configuration into the CORSIKA (Heck et al. 1998) air-shower simulation code, we have generated Cerenkov images produced by γ-ray primaries of energies 0.5, 0.63, 0.8 and 1 TeV incident on the top of the atmosphere at a typical zenith angle 20° and having impact parameters linearly increasing with distance D from the IE. To represent the corresponding cosmic-ray background events, images produced by 1.0, 1.26, 1.6 and 2 TeV

FIG 1: IMAGE PARAMETERS

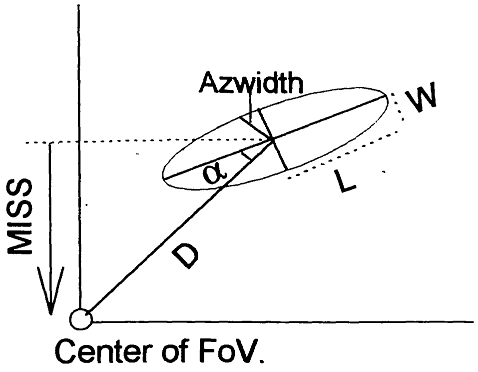


FIG 2: γ/p PREDICTION BY ANN

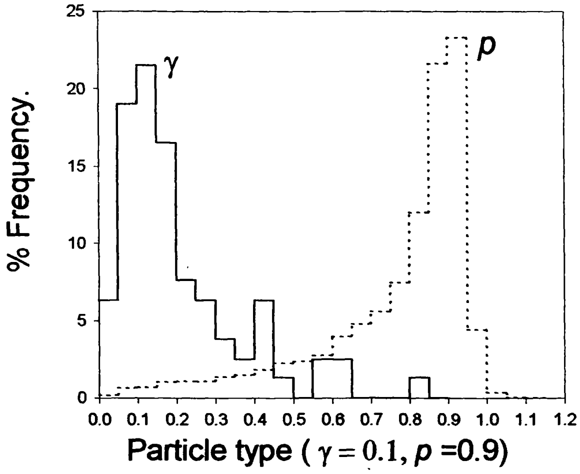


FIG 3 : GAMMA PROGENITOR ENERGY ESTIMATION BY ANN

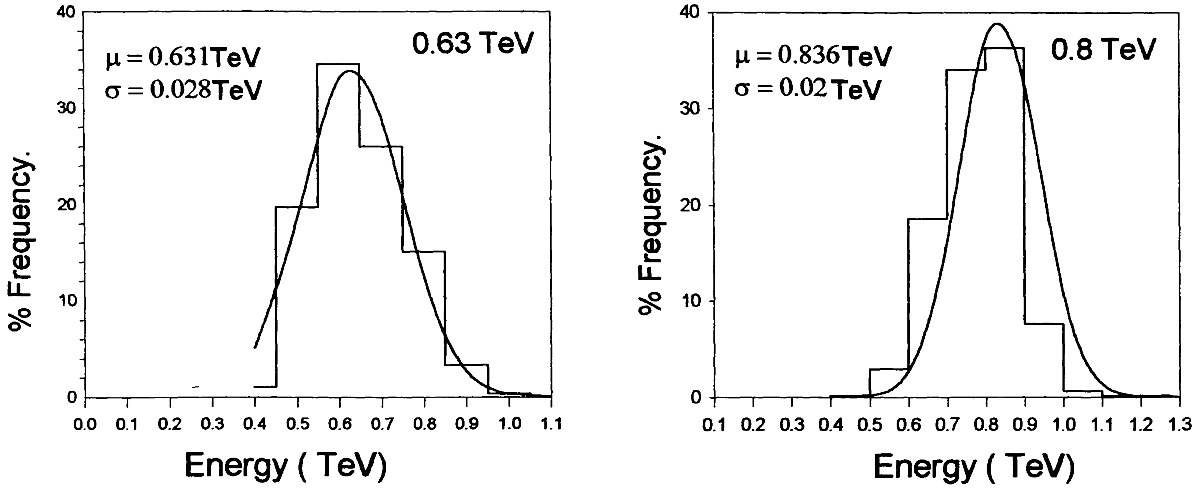
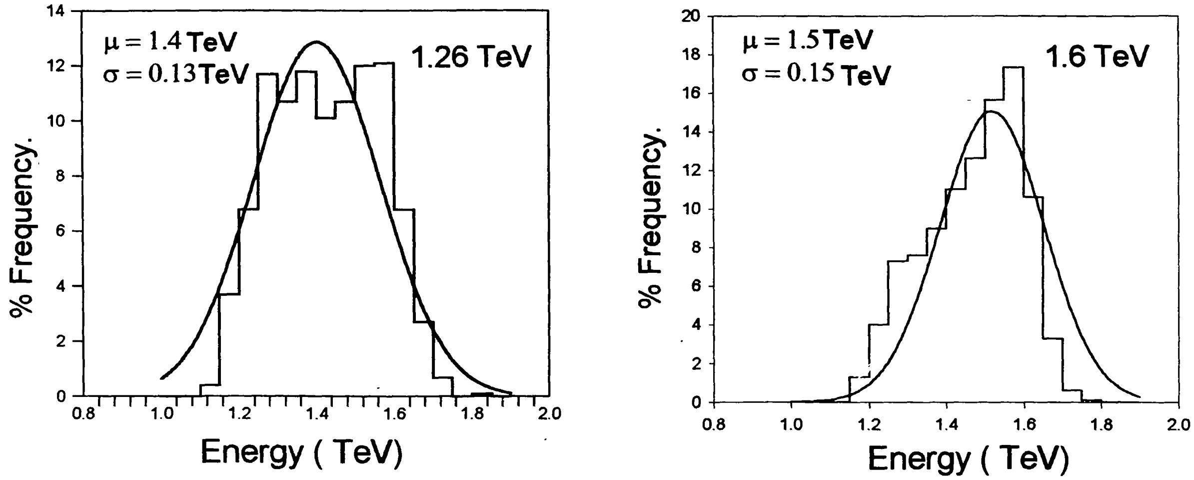


FIG 4 : PROTON PROGENITOR ENERGY ESTIMATION BY ANN



protons, distributed uniformly within the FoV of the IE (axis zenith angle = 20°) have also been generated following ~ R dR scaling law, where R is the shower core distance from the IE. This law ensures that the no. of events used are linearly proportional to the area of concentric annuli around the core centre. Various image parameters, including its size S, orientation parameter α and shape-parameters length L, width W and distance D have been calculated.

3. ANN (training and testing) Results

Two exercises were carried out using the ANN-based on standard Back Propagation Algorthim[4] (Rumelhart 1986), viz (i) progenitor type (γ-ray (0.1) or proton (0.9)) prediction and (ii) primary energy estimation. For particle type prediction exercise, 5:250:1 ANN configuration with 5 image parameters viz, L, W, D, S, α as input, one hidden layer of 250 neurons and 1 output node (particle type (γ/p)) was used for training. A sample size of 40000 events with equal contributions of γ-rays and protons were considered and the ANN was trained upto an rms residual error of 0.011. A sample size of 80 γ-ray and 8000 proton events (1:100 ratio) was considered for testing and the results are as shown in Fig. 2. It is seen that 63% γ-rays are returned at the expected net output value between 0-0.15 as against 2.5% protons, leading to a quality factor Q ~ 4 for γ-ray sensitivity. For the energy estimation exercise, a 5:350:1 ANN configuration was used for training with image parameters like L, W, D, S, α as input as in the first exercise but with primary energy value as output. Training sample size of 20000 each and testing sample size of 10000 for both γ-ray and proton events in the above mentioned energy ranges were done separately. The results are presented in Figs. 3 and 4 for the two progenitor types along with the corresponding Gaussian fits. It is noted that the expected progenitor energy values are returned within a range of 0.2-5% of the actual value for γ-rays (6-11% for protons) with a random error of ~ 2.5-4.5% for γ-rays and ~ 10% for protons belonging to the middle energy values considered here. The corresponding uncertainty in prediction for the boundary energy values are found to be much higher e.g., in the range of ~ 7-20% for γ-rays and ~ 25-40% for protons.

Conclusions

Our study on particle type prediction yielded a Q value of ~ 4 when a realistic (γ/p) sample in the ratio of 1:100 was considered. In the case of energy estimation, for both γ-ray and proton events, the middle energies could be predicted within reasonable uncertainties of 10% while the ANN is not found as effective in estimating boundary energy values.

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