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Cosmic ray mass composition through Cerenkov technique - a feasibility study

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Abstract: Detailed Monte Carlo simulations of atmospheric Cerenkov events, recorded by the 349 - pixel imaging camera of the TACTIC Imaging Cerenkov Telescope array at Mt. Abu , Rajasthan, have been carried out to study the possibility of using the Hillas image and orientation parameters for mass segregation of the primary air shower - initiating particles. Four primary species, namely, gamma rays, protons, Neon and Iron nuclei, with energies above 10 TeV have been considered for the simulations. Our preliminary results indicate that, except for Width, Azwidth and Length parameters, all other image parameters may not provide a significant segregation of the primary particles in terms of their mass.

Key Words : Atmospheric Cerenkov Technique, Cosmic Rays, Mass composition

1. Introduction

The 4 - element TACTIC Cerenkov telescope array at Mt. Abu comprises a central Imaging Element equipped with a 349-pixel Cerenkov imaging camera and three Vertex Elements, each of which is equipped with a special duplex detector array for recording the spectral, temporal and polarization characteristics of atmospheric Cerenkov events initiated by primary gamma ray and cosmic ray hadrons of energy > 1 TeV (Bhat, 1997).When operated in the large zenith angle mode (zenith angles > 50°), the TACTIC array provides a large collection area of $\geq 10^9$ cm^2 at a threshold energy of ~ 10 TeV, resulting in a statistically significant detection rate for cosmic ray hadron - initiated events , inspite of the rather steep cosmic ray power law energy spectrum (Bhat et al, 2001).This opens up the possibility of using the TACTIC array for cosmic ray mass composition studies if a suitable algorithm can be devised to segregate the recorded atmospheric Cerenkov events on the basis of the mass of the primary shower - initiating particle. In an earlier study (Bhat et al, 2001), it has been , on the basis of detailed simulations, parameters like the lateral distribution of Cerenkov photon density and the ultra violet to visible (U / V) light intensity ratio can segregate primary gamma-rays from protons and heavier hadrons, these parameters but on their own alone cannot lead to an effective mass segregation among the hadrons themselves. In the present study, we have extended this simulation - based study to include the conventional Hillas image parameters in order to identify possible parameter domains for effective segregation of the primary particles in terms of their mass.

2. Monte Carlo Simulations

We have used the CORSIKA (Version 5.61) program, based on Monte Carlo air shower simulation, with appropriate back-up software to generate Cerenkov images in the TACTIC camera in response to atmospheric Cerenkov events initiated by primary gamma-rays (850 showers:10TeV - 100 TeV), protons (720 showers; 20 TeV - 200 TeV), Neon nuclei (880 showers; 30 TeV - 300 TeV) and Iron nuclei (870 showers; 40 TeV - 400 TeV). The sampled at various representative core distance value, between 20m – 400m, resulting images, have been parameterised following the usual second moment analysis of the recorded photoelectron counts in the different image pixels (Bhat, 1997). As a result, the Length (L), Width (W), Azwidth (A), Distance (D), Miss (M), orientation (α) and size (S) determined for each simulated shower. The primary particles have been assumed to be incident isotropically from a 4^0 cone centered on the zenith direction of 50^0. We have compared the frequency distributions of these parameters for the events generated by these four primary species for core distances $\leq$ 200 m and $\geq$ 200 m to identify the parameter domains likely to provide the best segregation among the primaries.

3. Results

We present here the results obtained from the simulation of ~ 300 showers each of 30 TeV gamma rays, 60 TeV protons, 90 TeV Ne and 120 TeV Fe nuclei, the different energy values being chosen to provide nearly the same shower size in each case. Fig. 1 shows the frequency distributions of parameters L,W, A,D,M,S and α for showers initiated by the four primary species, averaged over core distances $\leq$ 200 m . It is seen that for R $\leq$ 200 m, the geometrical image parameters (L,W and A) show a clear segregation between gamma-initiated and hadron - initiated events, while the other parameters (D,M,S and α) do not show a clear segregation. On the other hand, for R $\geq$ 200 m, the only parameters which show a clear segregation among the various primary species are the Width parameter (W) and Azwidth (A) , while the distributions for other parameters are almost identical. We have identified the possible domains in the different parameter spaces which lead to an optimum segregation among the four primary species and summarize the results in Table I.Here we list 4 parameter domains for L, W and A which reject a majority of events initiated by three of the primary species while retaining a major fraction of the events initiated by the fourth primary species. For example, application of a cut to the data based on parameter domain 1 results in the retention of 91% gamma - initiated events (for R $\leq$ 200 m) while at the same time rejecting 89% protons, 99% Ne and 99.6% Fe - initiated events. Similarly, application of cuts based on parameter domains 2,3 and 4 preferentially retain a majority of proton, Ne and Fe - initiated events respectively. As seen from Table I, the differetiation between Ne and Fe events is not very clear for any parameter domain considered. Thus, data cuts based on optimised parameter domains of L , W and A can be used to segregate the recorded events in terms of gamma-initiated, proton - initiated and Heavy (Ne + Fe) - initiated, leading to a possible insight into the cosmic ray mass composition at these ultra high energies.

These results are of a preliminary nature and are likely to change when we take in to account the primary cosmic ray spectrum and the radial distribution of events triggering the system (~R dR dependence). Moreover, a multiparameter approach, using the distributions of all the image parameters and the recently - introduced fractal and wavelet parameters (Razdan et al, 1999) to segregate the recorded events in terms of primary mass, may lead to better inferences regarding the cosmic ray mass composition than the three parameter approach outlined above . We are presently looking into the possibility of using a properly trained Artificial Neural Network (ANN) to accomplish this multiparameter approach.

4. Conclusions

Detailed Monte Carlo simulations of atmospheric Cerenkov events, initiated by primary gamma-rays, protons, Ne and Fe nuclei with energies above 10 TeV, have been used to show that mass segregation of the primary shower - initiating particles may be possible to some extent through the use of image parameters L,W and A. Parameter domains which preferentially select one

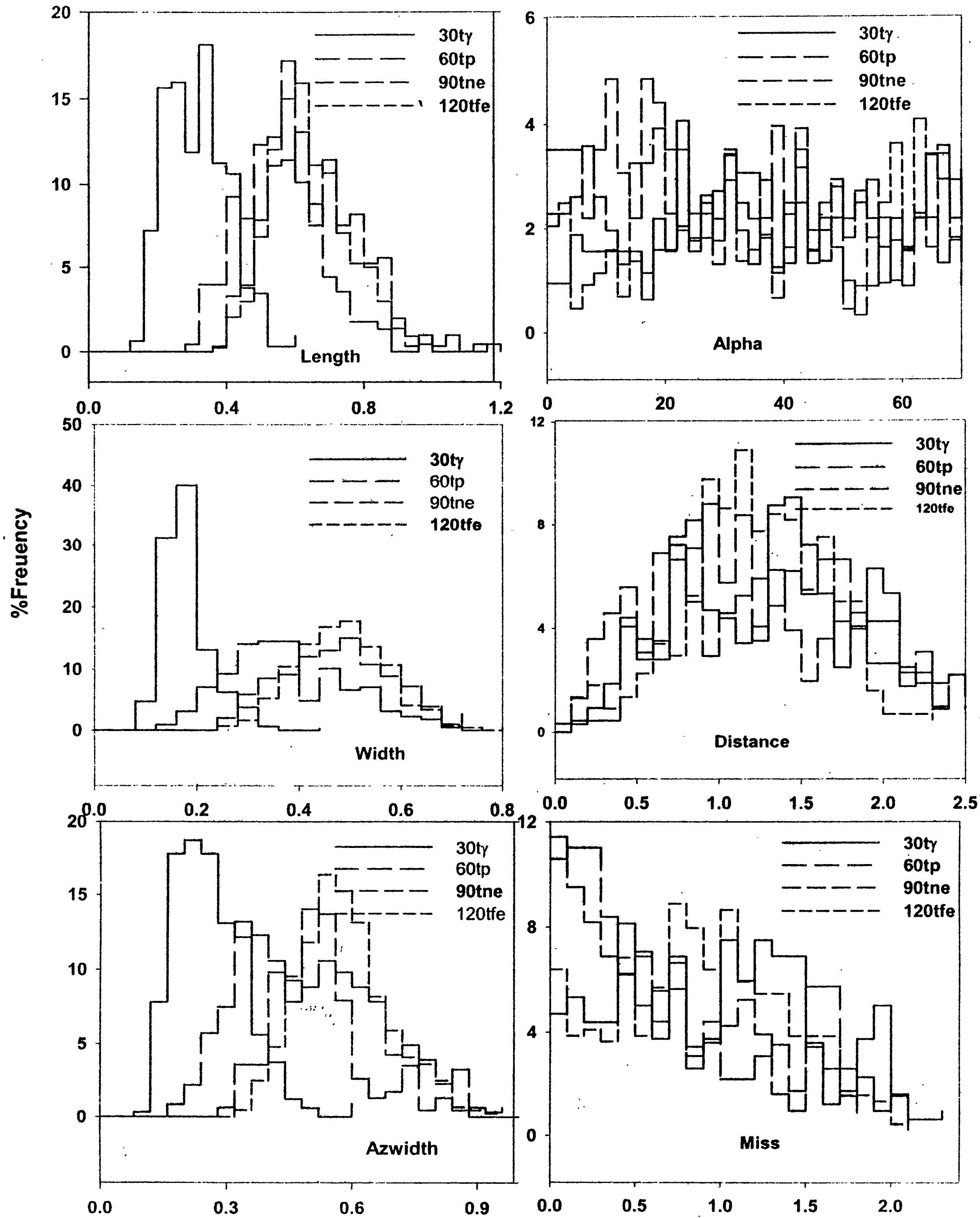

Fig1: Frequency distribution of image parameters Length(L), Width(W),Azwidth(A),Alpha(α),Distance(D),Miss(M) for showers initiated by the four primary species(γ,p,Ne,Fe). The distributions are averaged over core distances less or equal to 200mts.The primary energies considered are 30TeV(γ),60TeV(p),90TeV(Ne)and 120TeV(Fe)

Core Distance < 200 m					
S.No	Parameter Domain	% events retained after cuts			
		Gammas	Protons	Neon	Iron
1.	0.08 < L < 0.48 0.08 < W < 0.28 0.08 < A < 0.32	91.0	11.0	1.0	0.20
2.	0.32< L < 0.56 0.20 < W < 0.48 0.24 < A < 0.56	10.0	50.0	28.0	21.0
3.	0.44< L < 0.88 0.44< W < 0.60 0.44 < A < 0.76	0.20	22.0	43.0	51.0
4.	0.64 < L < 0.88 0.44 < W < 0.68 0.56 < A < 0.80	0.14	10.0	24.0	30.0
Core Distance > 200 m					
1.	0.18 < L < 0.56 0.08 < W < 0.24 0.16 < A < 0.48	74.0	25.0	6.0	2.0
2.	0.32 < L < 0.64 0.20 < W < 0.32 0.16 < A < 0.52	12.0	51.0	30.0	18.0
3.	0.52< L < 0.80 0.28 < W < 0.60 0.32 < A < 0.52	0.20	17.0	27.0	32.0
4.	0.52 < L < 0.88 0.36 < W < 0.64 0.52 < A < 0.78	0.05	4.0	14.0	23.0

Table I

primary species out of the four considered here, have been identified and evaluated for their efficiency.

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