29th International Cosmic Ray Conference Pune (2005) **6**, 25–28

Energy dependence of Cerenkov pulse parameters and γ-hadron segregation at multi-TeV energies

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The CORSIKA air shower code along with appropriate backup software has been used to estimate the temporal characteristics of atmospheric Cerenkov pulses recorded in a large wide-angle Cerenkov detector array with γ-ray threshold detection energy of 10 TeV. We present preliminary results on the energy dependence of pulse parameters for γ-ray and cosmic ray proton initiated events and investigate the efficiency of the temporal parameters for γ-hadron segregation at primary energies $\geq$ 10TeV.

1. Introduction

The Cerenkov imaging technique in both mono and the stereoscopic mode of operation has been used extensively and reasonable successfully for cosmic γ-ray investigations in the energy range above a few hundred GeV [1] and $\sim$15 sources of VHE γ-rays ($E_\gamma \geq$ 100GeV) identified within the galaxy and beyond [2]. Keeping in mind the astrophysical importance and the observational challenges in making the source detections in the multi-TeV regime, several experiments (AIROBICC, Tibet ASA, Milagro...) have been set up and used for a survey of the northern hemisphere sky with limited success [1].The MYSTIQUE wide-angle Cerenkov detector array, proposed by our group [3], for a sky survey at $\geq$ 10TeV energy will comprise 256 wide-angle Cerenkov detectors spread over an area of 600m $\times$ 600m with inter-detector separation of 40m. In addition to an excellent angular resolution of $\sim$0.2 °, enhancement in γ-ray flux sensitivity is expected to be achieved from the differences in the lateral distribution of the photon density and time-structure of the Cerenkov pulses initiated by the signal photons and the background cosmic ray hadrons. The efficiency of Cerenkov pulse parameters in discriminating between γ-ray initiated and cosmic ray proton-initiated atmospheric Cerenkov events in the VHE ($\sim$1TeV) range has earlier been studied by Patterson and Hillas [4],Roberts et.al. [5] and Chitnis and Bhat[6]. Here we report the results from our preliminary simulation based study of the temporal characteristics of γ-and-proton initiated events which shows that the differences in the derived temporal parameters of the two event types are too marginal to provide any hope of effective segregation at multi-TeV energies. We compare our results at energy E_γ= 5TeV with almost similar work reported by Chitnis and Bhat [7] at $E_\gamma \leq$1TeV who find pulse decay time and photon arrival time jitter as the two parameters which provide efficient discrimination between γ-ray events and the background events

2. Simulation methodology

Simulations for the MYSTIQUE were carried out using the air shower simulation code CORSIKA [8] (version 5.6240) in the wavelength range 300nm $\leq \lambda \leq$ 650nm at Mount Abu (24.6^{o}N, 72.7^{o}E, 1300m asl). In order to reduce the CPU time for simulations, a total of 529 detectors in a grid of 23 $\times$ 23 were spread over an area of 440m $\times$ 440m and the inter-detector separation was reduced to 20m for better sampling of photons.The shower core positions were centered at the centre of detector array. Each generated Cerenkov photon (i.e. bunch size =1) was tracked individually and shower propagation time of each photon hitting the detector on ground was recorded.No detector response function was included and wavelength dependent absorption of Cerenkov photons in the atmosphere was also not taken into account. For the present study,we analyzed only vertical showers. The temporal profile of Cerenkov photons was fitted by the Lognormal probability distribution function of the form

$$f(t) = \frac{1}{t\sigma\sqrt{2\pi}} \exp(\frac{-1}{2\sigma^2}(\log(t) - \mu)^2) \quad (1)$$

at various core distances using Levenberg-Marquart method. Mean and variance of arrival times of Cerenkov photons at each detector position were calculated.Lognormal function parameters were derived by using the above described mean and variance.

3. Results and Discussion

Figure 1. shows the energy dependence of mean pulse decay time and mean FWHM for gamma and proton-initiated showers. The proton energies have been taken as twice the corresponding γ-ray energies to ensure the same Cerenkov photon yield from the two shower types.

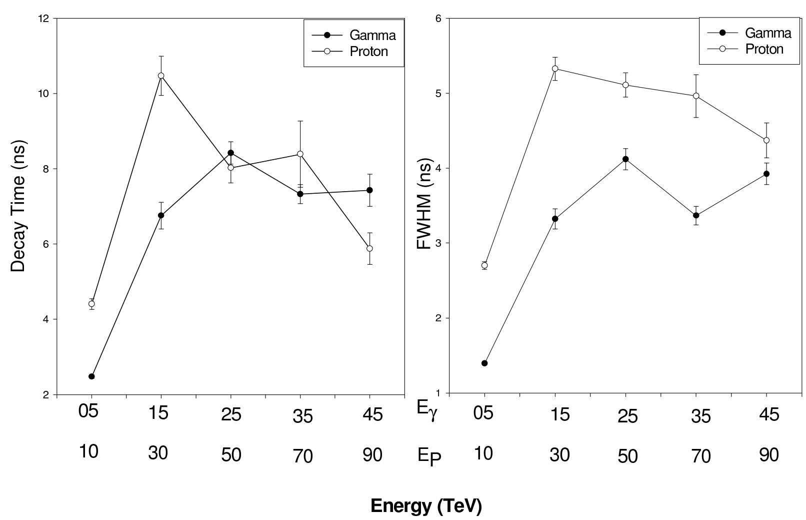

Figure 1. Energy dependence of mean pulse decay time and FWHM for gamma and proton-initiated showers.

It is found that both the pulse decay time and FWHM increases systematically with energy till $E_{\gamma} \sim$ 15TeV ($E_{proton} \sim$ 30TeV) and saturates thereafter. Moreover,while in the case of decay time, the value for proton-initiated events is larger than the value for gamma-initiated events (by almost a factor of 2) only till $E_{\gamma} \sim$ 15TeV, the value of FWHM for proton events is always larger than that for gamma initiated events.This suggests that while the pulse decay time can be used as a possible discriminating parameter at energies $E_{\gamma} <$ 15TeV, the other parameter (FWHM) can be used over the entire energy range.

Figure 2. shows the frequency distribution of Cerenkov pulse decay time at a core distance of 140 meter for

500 Cerenkov events initiated by 5TeV gamma rays and an equal number of proton initiated events of 10 TeV energy. The most likely values for the decay time, 2ns for gamma initiated events and 3ns for proton events,

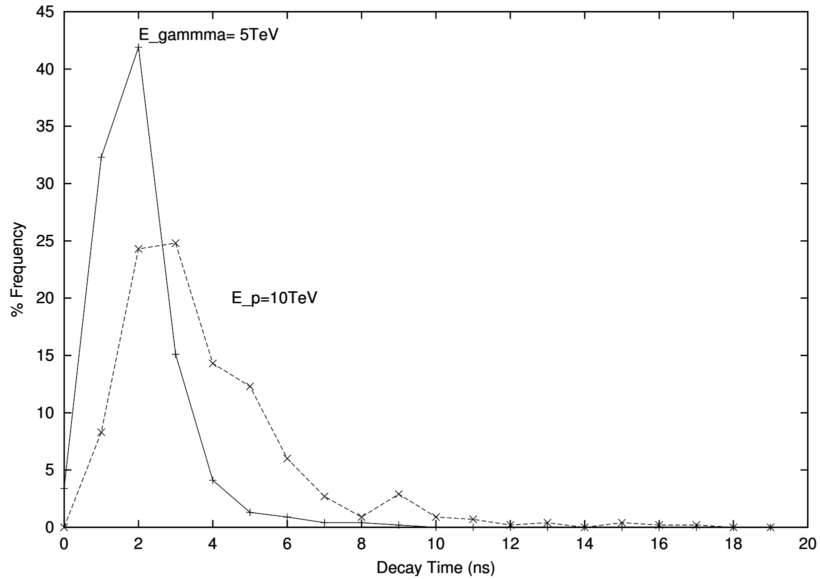

Figure 2. Frequency distribution of Cerenkov pulse decay time for E_γ= 5 TeV and E_p= 10 TeV.

are lower than the corresponding values of $\sim$3.5ns and 5.5 ns for 1TeV gamma initiated events and 2 TeV proton events found by Chitnis and Bhat [6].The lower values at the higher energies are a possible reflection of the fact that the first interaction in the atmosphere occurs at a lower altitude as the primary energy increases. Contrary to the results obtained at $\sim$1TeV energy, both the distributions in Figure.1 are found to be sharply peaked with a long tail only in the case of proton initiated events, although there is a considerable overlap at lower decay time values. Applying a cut at a value of τ_d =2.7 ns, we find that while 67% of the gamma events are retained, only 77 % of the proton events ($\tau_d > 2.7$ ns) are rejected,leading to a gamma proton segregation quality factor of Q=1.39 as compared to a value of 2.41 reported by Chitnis and Bhat [6] for 1 TeV gamma and 2 TeV proton initiated events. Thus, unlike at energies $\sim$1TeV where the Cerenkov pulse decay time seems to be the most sensitive parameter for gamma-hadron segregation, at energies around 10 TeV the efficiency of this parameter almost disappears . The same conclusion can be drawn for higher energies(upto $E_\gamma = 45$TeV) No further dependence of the quality factor Q on shower core distance is found in the simulated data.

Figure 3. shows the frequency distribution of the mean FWHM of the Cerenkov pulse recorded at a core distance of 140m for 5 TeV gamma-initiated events and 10 TeV proton-initiated events. As in the case of decay time, significant overlap is observed between the two distributions indicating poor gamma-proton segregation capability. With a cut off at $\tau_{\ FWHM} \sim$ 1.7 ns, the quality factor is found to be Q=1.29, apparently in agreement with the result at 1 TeV energy where Chitnis and Bhat [6] find FWHM to be a poor parameter for gamma-hadron segregation. No improvement in Q as a function of shower core distance or primary energy is found from our simulations.We, therefore find that inspite of inferred differences in the pulse decay time and FWHM between gamma-initiated and proton -initiated events (atleast upto energies $E_\gamma \sim$15TeV), the two parameters turn out to be rather inefficient in segregating the two event types at energies above 5 TeV. More

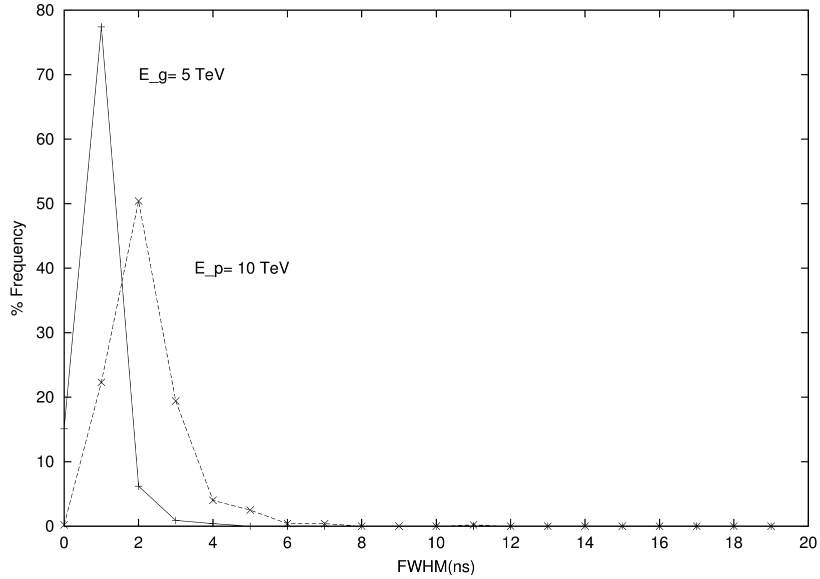

Figure 3. Frequency distribution of Cerenkov pulse FWHM for E_γ= 5 TeV and E_p= 10 TeV.

detailed simulations are being conducted to consolidate these results and to assess the suitability of other pulse parameters for gamma-hadron segregation at multi-TeV energies.

4. Acknowledgements

We thank Shri S.Bhattacharyya and S.Sahayanathan for the useful discussions on non linear fitting.We also thank Dr. Varsha Chitnis, Dr. R.C.Rannot, Dr. A.K.Tickoo and Sh. Ramesh Koul for their useful inputs during the course of this work.

References

[1] R. Ong. Phys. Rep. 305 93 (1998)
[2] D. Horen, T.C.Weekes, New Astrn. Rev. 48 527 (2004)
[3] R.Koul et.al., Proc. "27th ICRC",Hamburg (2001)
[4] J.R.Patterson, A.M.Hillas, Nucl. Instrum & Methods A 278 553 (1989)
[5] M.D. Roberts et al., J. Phys. G 24 255 (1998) .
[6] V.R. Chitnis and P.N. Bhat. Astropart. Phys. 15 29 (2001)
[7] V.R. Chitnis and P.N. Bhat. Astropart. Phys. 12 45 (1999)
[8] Heck D.et al.,1998, **FZKA 6019** Forschungszentrum Karlsruhe