THE ROLE OF FLUCTUATIONS IN ATMOSPHERIC ČERENKOV TECHNIQUE

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ABSTRACT
In the absence of a standard source of gamma rays or hadrons of known energy one has to study the details of production of Čerenkov light at the observation level only through detailed simulation studies. Recently such studies have become all the more important in view of the various techniques resulting from such studies, to distinguish between gamma ray initiated events from those generated by much more abundant hadronic component of cosmic rays. We have carried out a detailed simulation studies using the CORSIKA package in order to study the Čerenkov photon density fluctuations at various core distances both for photon and proton primaries incident vertically at the top of the atmosphere. It is found that the density fluctuations are significantly non-statistical. Such fluctuations are much more pronounced in the case of proton primaries as compared to photon primaries at all energies. Several statistical parameters have been computed some which might lead to a technique in distinguishing photon primaries.

INTRODUCTION
Ground based atmospheric Čerenkov technique is the only way by which TeV \( \gamma \)-rays could be detected from point sources such as \( \gamma \)-ray pulsars, short period X-ray binaries or BL-Lac objects. Recent detection of TeV emission from a few of these objects (Vacanti et al., 1991; Punch, et al., 1992) has created much interest in the field of TeV \( \gamma \)-ray astronomy. The \( \gamma \)-ray signals found typically are \( \sim 1\% \) of the abundant background events of cosmic ray nuclei, particularly protons. In order to detect faint Very High Energy (VHE) \( \gamma \)-ray sources, one has to enrich the data with the signal by rejecting a bulk of the hadronic background. In order to do so it is imperative to study the detailed characteristics of Čerenkov light production by photon initiated and proton initiated cascades in the atmosphere.

We have, therefore planned to carry out detailed simulation studies using the CORSIKA (Knapp and Heck, 1996) package for various photon and proton energies incident on the top of the atmosphere. The input parameters used in the package correspond to that of Pachmarhi Array of Čerenkov Telescopes (PACT, Bhat et al., 1995). Eventually, these studies are expected to lead to the derivation of an event parameter which would enable us to distinguish between the two types of primaries. In this paper we present preliminary results from such studies.
studies involving the Čerenkov photon density fluctuations at different primary energies as a function of core distance.

THE ARRAY

PACT, described elsewhere (Bhat et al., 1995; Bhat, 1996) consists of 25 Čerenkov telescopes deployed in the form of a $5 \times 5$ array over an area of 80 m x 100 m located at Pachmarhi (latitude: 22°28′N longitude: 78°26′E). Each Čerenkov telescope consists of 7 parabolic reflectors making up a total area of $4.45 \, m^2$. Individual phototubes are placed at the focus allowing us to carry out multiple sampling of photons at a telescope. The expected energy threshold of an event triggering the computerised data acquisition system is expected to be around 350 GeV. We plan to distinguish between the photon initiated showers from those of the proton initiated showers by the measurement of photon densities received at each telescope. In addition, the fine timing measurements will enable us to measure the shower direction correct to $\sim 0.2^\circ$ because of which we can reject the off-axis showers which are presumably initiated by hadrons.

THE SIMULATIONS

About 100 showers have been generated for vertically incident $\gamma$-ray photons and protons at the top of the atmosphere. The number of Čerenkov photons in the wavelength range 300-450 nm incident at each telescope is written out on the data file. Several such simulation studies have been carried out in the past (Hillas and Patterson, 1990; Rao and Sinha, 1988; Hillas, 1982). Initially it was decided to study the role of density fluctuations at various core distances. The question one is trying to answer is how do the fluctuations depend on the nature of the primary and how does it depend on the core distance. For this purpose the frequency distributions were derived at each detector and fitted to a known probability distribution function. The statistical parameters like various moments were used as a measure of the nature of these fluctuations.

RESULTS

Figure 1 shows the average (100 showers) lateral distributions derived for proton and photon primaries with comparable Čerenkov yields. As expected the photon showers are characterized by the increased density at a core distance of $\sim 120m$, which is commonly known as the ‘hump’ region, at all the three primary photon energies viz. 250, 500 and 700 GeV. Figure 2 shows the variation of the various statistical parameters as a function core distance at a fixed energy of 250 GeV for $\gamma$-ray primaries and 500 GeV for protons. On the top left corner the variation of the ratio of the variance to the mean is shown which shows a clear
Figure 1: Average lateral distribution of Čerenkov photon densities generated by γ-rays (at 3 different energies 250, 500 & 700 GeV) and protons (at 3 different energies 500 GeV, 1000 GeV & 1300 GeV with comparable Čerenkov yields) incident vertically at the top of the atmosphere.

separation for γ-ray and proton primaries. It may be noted that this parameter is rather large even for γ-ray primaries while it is expected to be unity for a Poisson distribution, thus showing that the density fluctuations are significantly non-statistical consistent with previous studies (Sinha, 1995). The plot on the top right shows normalized $\chi^2$ values for a Gaussian fit to the density distribution. While distribution for a γ-ray primary fits well with a Gaussian (when the RMS is used as the standard deviation) it does so poorly for proton primaries. The other two plots show similar variations for third and fourth moments.

CONCLUSIONS

From our present simulation studies it is found that the Čerenkov photon density fluctuations, measured as a ratios of the variance to the mean, are highly non-statistical at all core distances. These ratios are much larger in the case of proton primaries than for γ-ray primaries at all core distances even though the difference seems to reduce at higher primary energies. For a given primary, this ratio seems to be proportional to the mean density itself. The density distribution at a given core distance for a γ-ray primary seems to fit with a Gaussian if one uses the RMS as the standard deviation while that for proton primary does not fit well even though the fit improves at higher primary energies. The third and fourth moments show that the density distributions for proton primaries are more
Figure 2: Variation of 4 statistical parameters derived from Čerenkov photon density distributions as a function of the core distance, for 250 GeV γ-ray and 500 GeV proton primaries.

asymmetric and more uneven compared to that of γ-ray primaries while these differences reduce with increasing primary energies.

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