High Altitude Gamma Ray Observatory at Hanle

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Abstract

We have carried out Monte Carlo simulations to study the nature of Cherenkov light pool generated by γ-ray and proton primaries for the altitude of Hanle(4515m amsl) in the Himalayas, the site of proposed HAGAR experiment. The limited lateral spread of the Cherenkov light pool and near 90% atmospheric transmission at this high altitude make it possible to detect clestial γ-rays of few tens of GeV energy using ground based detectors. The chief advantage of this experiment is the low energy threshold which overlaps with the energy range of future satellite-based detectors like GLAST.

1. Introduction

Atmospheric Čerenkov technique is a well established ground-based technique for the study of VHE γ-ray emission from celestial sources. This technique has been successfully exploited by several experiments using imaging or wavefront sampling technique for the rejection of cosmic ray background [1]. The next generation of experiments using very large imaging telescopes (MAGIC and the like) or an array of imaging telescopes (HESS, CANGAROO-III and VERITAS) or large collection area arrays that use wave-front sampling technique (CELESTE, STACEE, etc.) are expected to achieve low energy thresholds of the order of few tens of GeV. Alternatively it is possible to lower the energy threshold by conducting experiments at very high observation altitude with a modest set-up. All the existing experiments are being carried out at altitudes of up to $2.5km$ above mean sea level (amsl). Here we describe Monte Carlo simulation studies for an experiment [2] to be carried out at Hanle (32° $46'$ $46''$ N, 78° $57'$ $51''$ E, 598 g/cm^2), at an altitude of $\sim 4.5km$ amsl. Our plan is to deploy 7 telescopes, similar to the ones used in PACT at Pachmarhi [3], in the form of a hexagonal mini-array and use the wave-front sampling technique for the rejection of cosmic ray background. The high altitude and low night sky brightness of this site offer certain advantages for the ground-based γ-ray astronomy.

pp. 2999–3002

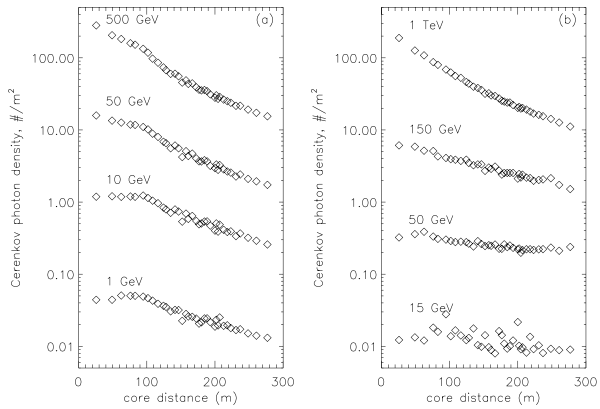

Fig. 1. Average Čerenkov photon density at Hanle as a function of core distance for showers initiated by (a) γ-rays of energies 1, 10, 50 and 500 GeV and (b) protons of energies 15, 50, 150 GeV and 1 TeV.

2. Monte Carlo simulation of Air Showers

We have carried out Monte Carlo simulation of extensive air showers, generated by γ-ray and proton primaries incident vertically at the top of the atmosphere, using CORSIKA package [4] and studied the nature of Čerenkov light pool at the altitude of Hanle. The Čerenkov radiation, produced by the secondary charged particles in the shower, within the bandwidth of 300-650 nm is propagated to the observation level. The atmospheric attenuation of Čerenkov photons at Hanle altitude is $\sim$ 14% as compared to $\sim$ 50% at sea-level. The simulated array consists of 7 telescopes, each with 7 mirrors , of total area 4.4 m^2. Six of the telescopes are deployed in a hexagonal pattern with each of them at distance of 50 meters from a telescope at the center of the array.

2.1. Lateral distribution of Čerenkov photons

The average Čerenkov photon density as a function of core distance for showers initiated by γ-rays and protons of various energies are shown in figure 1. The lateral distributions from γ-ray primaries indicate presence of a hump at a core distance of about 90 m, but somewhat less prominent compared to that seen at lower altitudes [5]. Dilution of the hump at higher primary energies as well as at higher altitudes is expected [6]. The Čerenkov photon density near the shower core at Hanle is higher by a factor of about 5-6 compared to that at sea-level in showers of given energy and primary particle. This higher photon density as well as the smaller distance to hump from shower axis arise due to the compactness of shower at this altitude. These features effectively reduce the energy threshold of the experiment.

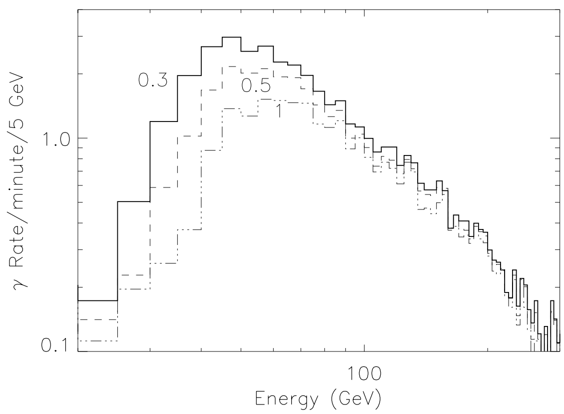

Fig. 2. Gamma-ray count rate differential spectrum for Hanle altitude using wavefront sampling technique.

2.2. The energy threshold of the proposed Hanle array

The γ-ray events were generated with a power law spectrum with a spetral index of -1.4 and the absolute values given by the extrapolation to lower energies of the Whipple spectrum at > 300 GeV. The proton events were generated with the cosmic ray spectrum. The lateral distribution curves of Fig. 1 were parametrized to obtain the number of Čerenkov photons for a given energy and distance from the core. A transmission coefficient of 0.91 and a reflectivity of 0.9 was used to obtain the number of Cerenkov photons at the PMT. Using a quantum efficiency of 0.16, the number of photoelectrons (pe) obtained was Poisson fluctutated to get the number of pe due to Čerenkov photons at each mirror. The mean night sky background (NSB) at Hanle is expected to generate 0.5 pe at the PMT. This was also Poisson fluctuated and added to those due to Čerenkov photons to get the total number of pe at each mirror. The output from each mirror was used to get the total output from the telescope. One of the trigger scenarios was where all the telescope outputs were added to get the so called Grand Sum. Thus a rate vs bias (in number of pe) was obtained for both γ-ray and proton events. Similar curves were obtained when only NSB was present. This would be responsible for accidental events. The pe bias for generating trigger events was selected as the bias at which the ratio of number of accidental events to the number of proton evens would be < 1 %. The Fig. 2 shows the differential energy distribution of γ-ray events per 5 GeV as a function of energy. The peak of this distribution is at 55 GeV. Similar calculations for a lower NSB (0.3 pe) gave the peak at 45 GeV and at a higher NSB (1 pe) at 65 GeV. The energy threshold, defined as the energy at which the distribution peaks, was found to be lower by 10 GeV for a spectum with a power law index of -2. The energy threshold was also found to be lower if the pe bias is decreased so as to allow the fraction of chance events to be < 5 %. Similar simulation for proton events for a mean NSB of 0.5 pe gives the energy distribution peaking at about 300 GeV. For a mean NSB of 0.5 pe and at a bias which would allow only < 1 % chance events, the rate of proton events is about 80 Hz, whereas the rate of γ-ray events is ~ 40 per minute. This would give a $> 9\sigma$ signal in about 4 hours of data taking. If one could reduce the background by arrival direction measurement and using 0.2 degree acceptance, then the isotropic proton background could be reduced by 96 %. Assuming that 50 % of γ-rays can be still retained, the Crab could be detected with a high statisitcal significance of $> 20\sigma$.

3. Conclusions

The prominence of hump in the lateral distribution of Čerenkov photons decreases with increasing altitude [6] since the position of shower maximum for a given primary energy becomes closer to the observation level. For the same reason the core distance at which the hump appears also decreases with increasing altitude of the observation level. Another feature of the lateral distribution of Čerenkov photons is that it becomes flatter with decreasing primary energy. The flattening is far more significant for proton primaries as compared to γ-ray primaries. As a result, at lower primary energies, the use of a focal point mask provides a simple discrimination against hadrons. Several parameters based on density and timing information of Čerenkov photons could be efficiently used to discriminate γ-rays from more abundant cosmic rays at tens of GeV energies [7]. Using several parameters in tandem it is possible to reject about 98% of proton showers retaining about 35% of $\gamma-$ray showers.

The ratio of Čerenkov yield for high energy γ-rays to that of protons of same energy increases exponentially with decreasing energy [1]. Combined with increased photon density due to reduced lateral spread of the pool makes a high altitude observatory like Hanle an ideal site for GeV γ-ray astronomy. The chief advantage of this experiment is the considerably lower energy threshold, almost overlapping with the energy range of future satellite-based detectors.

4. References

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