High Altitude γ-ray Observatory at Hanle (HAGAR)

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Abstract

We have proposed to set up an experiment to detect celestial γ-rays of energy ≥ 20 GeV using the atmospheric Čerenkov Technique at Hanle, a high altitude location in the Himalayas. The limited lateral spread of the Čerenkov light pool, near 90% atmospheric transmission of Čerenkov light and low sky brightness makes this high altitude site an ideal place to set up a ground-based γ-ray observatory. In this experiment, we plan to deploy 7 telescopes, similar to the ones used in PACT at Pachmarhi, in the form of a hexagonal mini-array and use the wave-front sampling technique for rejection of cosmic ray background. The chief advantage of this experiment is the low energy threshold which is comparable to that of MAGIC and also 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 wave-front sampling technique for the rejection of cosmic ray background [Ong 1998]. 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 threshold 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. All the existing experiments are being carried out at altitudes of up to 2.5 km above mean sea level (amsl). Here we describe an experiment [Cowsik 2001] based on wavefront sampling technique

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to be carried out at a location called Hanle at an altitude of about 4.5 km amsl. The Indian Astronomical Observatory has already been set up recently at Hanle (32° $46'$ $46''$ N, 78° $57'$ $51''$ E, 4515m amsl, 598 g/cm^2), situated in the high altitude cold desert in the Himalayas. The observatory has 2-m aperture optical-infrared telescope, installed by the Indian Institute of Astrophysics, Bangalore, India. The high altitude and low night sky brightness of this site offer certain advantages for the ground-based γ-ray astronomy. The limited lateral spread of the Čerenkov light pool, and near 90% atmospheric transmission at this location makes it an ideal site for a γ-ray observatory. These could result in a very low gamma ray energy threshold ~ 20 GeV for a modest set-up at this altitude.

2. Lateral distribution of Čerenkov photons

We have carried out Monte Carlo simulation studies using CORSIKA package [Heck et al. 1998] for this observation altitude to study the nature of Čerenkov light pool generated by γ-ray and proton primaries incident vertically at the top of the atmosphere. Air showers generated by γ-rays and protons of various primary energies were simulated. 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 wavelength dependent atmospheric attenuation of Čerenkov photons is not taken into consideration in this calculation). Location and altitude appropriate for Hanle are used in the simulations. For low energy primaries (γ-rays of energy 1 and 10 GeV, and protons of energy 15 and 50 GeV) 500 showers were simulated while 100 showers were simulated for higher energy γ-ray (50 and 500 GeV) and proton (150 GeV and 1 TeV) primaries. The energies of γ-ray and proton primaries are chosen such that their showers have comparable Čerenkov photon yields at the observation level. 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, due to effective focusing of Čerenkov photons from a range of altitudes. However, this hump is somewhat less prominent compared to that seen at lower altitudes [Chitnis and Bhat 1998]. Also, the density distribution within hump is not as flat as in the case of lower observation altitudes. Dilution of the hump at higher primary energies as well as at higher altitudes is expected [Rao and Sinha 1988]. A comparison of lateral distributions due to a primary of given energy reveal that 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. This higher photon density as well as the smaller distance to hump from shower

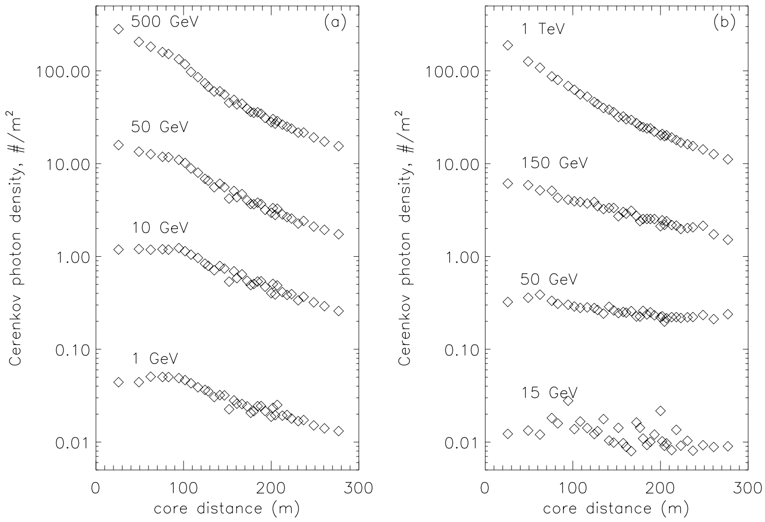

Fig. 1. Average Čerenkov photon density at Hanle as a function of core distance for showers initiated by (a) γ-rays of energies 1, 10, 50 and 500 GeV and (b) protons of energies 15, 50, 150 GeV and 1 TeV.

axis arise due to the compactness of shower at this altitude. This will effectively reduce the energy threshold of the experiment appreciably compared to operating the same array at lower altitudes.

3. Gamma-hadron separation

All atmospheric Čerenkov experiments have to deal with substantial background from air showers generated by cosmic rays. Therefore, effective rejection of this background is necessary for improving the signal to noise ratio. In experiments based on wavefront sampling technique, such as the present one, parameters based on arrival time of Čerenkov shower front and Čerenkov photon density at various locations within the Čerenkov pool could be used for discrimination. The usefulness of these techniques at lower observation altitudes was demonstrated by Chitnis and Bhat [Chitnis and Bhat 2000,2002]. We have studied the effectiveness of these parameters at Hanle altitude. A fictitious array of 6 telescopes, each consisting of seven mirrors with a total reflector area of 4.45 m^2 per telescope, spread over an area of 20 m $\times$ 50 m was considered.

We have examined the applicability of six parameters, 3 each based on Čerenkov photon arrival times at the telescopes (the curvature of shower front, Shape of Čerenkov pulse and Relative arrival time jitter) and Čerenkov photon density (local density fluctuations (LDF), medium range density fluctuations

Table 1. Gamma-hadron separation for showers initiated by 500 GeV γ-rays and 1 TeV protons at Hanle

Parameter	Threshold value	Quality factor Q_f	Fraction of accepted γ	Fraction of accepted p
Curvature	5.2 km	1.39 ± 0.21	0.577	0.173
Pulse Decay time	4.54 ns	1.40 ± 0.12	0.682	0.236
Timing jitter	0.084	2.63 ± 0.02	0.487	0.034
Decay time and jitter	4.54 ns, 0.084	2.25 ± 0.05	0.349	0.024
LDF	0.127	1.53 ± 0.03	0.803	0.276
MDF	0.164	1.24 ± 0.09	0.386	0.097
LDF and MDF	0.127, 0.164	1.60 ± 0.15	0.338	0.045

(MDF)and flatness of lateral distribution of photon density). The timing jitter parameter is defined as the ratio of RMS of average arrival times of Čerenkov photons at seven mirrors of the telescope to the mean of seven averages. The LDF and MDF are defined as the ratio of RMS of Čerenkov photon densities at 7 mirrors of a telescope to the mean density and the ratio of RMS of photon densities recorded at six telescopes to the mean density respectively.

We use quality factor, Q_f, as a figure of merit to distinguish between γ-ray and proton initiated showers. It is defined as

$$Q_f = \frac{N_a^\gamma}{N_T^\gamma}\left(\frac{N_a^{pr}}{N_T^{pr}}\right)^{-\frac{1}{2}} \tag{1}$$

where N_a^γ is the number of γ-ray events accepted, N_T^γ is the total number of γ-ray events, N_a^{pr} is the number of proton events accepted and N_T^{pr} is the total number of proton events in the data sample. The optimum quality factors, derived using various parameters are given in Table 1.

4. Conclusions

It is generally said that the lateral distributions of Čerenkov radiation from γ-ray and proton generated showers are distinctly different in the sense that in the former case it is flat up to about $\sim 140\ m$ at sea level and characterized by a hump at that distance while in the latter case it is steeper and smoother with practically no hump [Rao and Sinha 1988]. However the situation changes as the

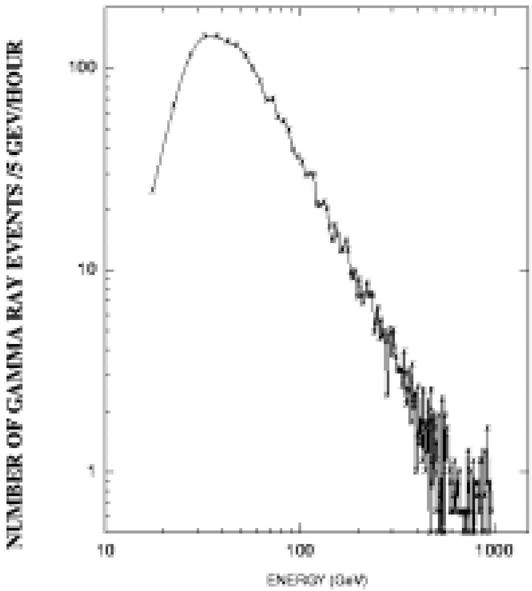

Fig. 2. Gamma-ray count rate differential spectrum for Hanle altitude using wavefront sampling technique.

observation altitude increases, since the position of shower maximum for a given primary energy becomes closer to the observation level. Thus the prominence of hump decreases with increasing altitude. 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. The light pool size increases with lowering primary energy which is a consequence of significantly larger number of photons arriving at larger angles. When the lateral distribution curves are generated with a finite focal point mask, the density as well as the total number of photons detected reduces significantly for proton primaries. For example, the fractions of photons detected when a 5° mask is in use are 64.3% and 33.2% respectively for 50 GeV & 15 GeV protons. Similar fractions for γ-ray primaries are 90.1% and 96.4% respectively for 10 & 1 GeV energy. 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, including local and medium range photon density fluctuations as well as photon arrival time jitter could be efficiently used to discriminate γ-rays from more abundant cosmic rays at tens of GeV energies. Because of the proximity of the shower maximum at higher observation altitudes, the parameters like radius of curvature is more sensitive to primary species as compared to lower observation levels. As can be seen from table 1, using these parameters in tandem it is possible to reject about 98% of proton showers retaining about 35% of $\gamma-$ray showers.

In addition, the atmospheric attenuation of Čerenkov photons at Hanle altitude is $\sim 14\%$ as compared to $\sim 50\%$ at sea-level. The ratio of Čerenkov yield for high energy γ-rays to that of protons of same energy increases exponentially with decreasing energy [Ong 1998]. 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.

Based on the Monte Carlo studies we plan to set up an experiment at Hanle to detect celestial γ-rays of energy $> 20\ GeV$ using the atmospheric Čerenkov Technique. In this experiment, we plan to deploy 7 telescopes, similar to the ones used in PACT at Pachmarhi [Bhat et al. 2000], in the form of a hexagonal mini-array. The figure 2 shows a preliminary estimate of the expected differential γ-ray count rate spectrum from Crab nebula for such an array at Hanle altitude. The peak of the distribution is around 35 GeV.

The chief advantage of this experiment is the considerably lower energy threshold, almost overlapping with the energy range of future satellite based detectors, that may be achieved. The high slew speeds ($\sim 30°/min.$) of these telescopes would be ideal to orient quickly to a possible Gamma Ray Burst (GRB) location for searching any GeV γ-ray counter parts of GRB after-glows.

5. References

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