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A mini ACT experiment at low and high altitudes

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A simple experimental apparatus was used to measure rate of cosmic ray events due to Atmospheric Cerenkov Radiation at two mountain altitude sites with the height difference of 3.5 km. The event rates at Hanle (altitude $\sim$4.5 km AMSL) was found to be a factor $\sim$ 2 higher than those at Pachmarhi (altitude $\sim$ 1 km AMSL). Consideration of the ratio of mean distance of the Cerenkov photon from the axis of the shower for the two altitudes shows a decrease in energy threshold of cosmic rays by a factor of 3.5$\pm$0.7 at the higher altitude. A semi Monte Carlo calculation using the lateral distribution curves and the detector response also shows a similar decrease in the energy threshold. However, for a bigger array like the one at Pachmarhi the energy threshold is expected to decrease by a larger factor ($\sim$ 6$\pm$2) since cosmic rays become inefficient in production of Cerenkov light at lower energies.

1. Introduction

It has been recently realized that many celestial sources have a dramatic change of behaviour in the 10-200 GeV energy range. The EGRET experiment [1], which has given a wealth of data below 10 GeV, has detected about 270 sources. On the other hand, the atmospheric Cerenkov experiments [2] which start becoming viable at $>$ 200 GeV have detected much fewer sources. Most of the EGRET detections have been of AGNs. Most of these AGNs with large red shift have not been detected by the atmospheric Cerenkov experiments. This could be due to either a cutoff in the emission at the source itself or due to attenuation by the intervening IR background. Further, the Energy spectrum of most of the pulsars seem to steepen in the energy band 10-100 GeV. This is also a viable energy region to study GRBs. Thus, it is imperative to conduct experiments in this energy range for a full understanding of the processes in these interesting celestial sources.

While the next generation satellite experiment GLAST [3] is expected to address some of these issues, the atmospheric Cerenkov experiments with improved angular resolution and a larger duty cycle are ideally suited for these studies. The low Cerenkov photon density which is a problem at these energies can be overcome by using a large single detector like the MAGIC [4]. However, it has also been realized that the same objective is achieved by conducting experiments at very high mountain altitudes. An array of imaging telescopes at such heights has been suggested by Aharonian et al [5]. By extensive simulations, Cowsik et al [6] and Acharya et al [7] have suggested that even experiments on a modest scale could achieve similar objectives.

Thus it is interesting to explore experimentally the order of energy threshold reduction that is possible by comparing the response of a simple experiment at low and high altitudes. We report here the results of a mini experiment with 2 small mirrors at Pachmarhi (altitude of 1 km AMSL) and Hanle (altitude of 4.5 km AMSL). The Cosmic ray rate differences at these two altitudes have been used to speculate about the possible energy reduction for gamma ray events.

2. The Experiment

At Pachmarhi, the experiment consisted of taking coincidence between 2 small parabolic mirrors (diameter 0.9 meters) which had already been mounted on a telescope which was the basic unit of the PACT [8]. The separation between the two mirrors was 3 meters. The telescope was kept vertical. At Hanle, the experiment consisted of two such small parabolic mirrors, but on independent mounts, and separated by 5 meters. In both observations, the mirrors were kept vertical.

At both sites, the electronics was similar. A fast photomultiplier was placed at the focus of each mirror. High voltage given to the PMTs ranged from -1.8 kV to -2 kV. A simple coincidence set up was used where the widths of the input pulses were 20 ns. Three different settings of HTs were used which gave individual mirror rates 1, 2 and 5 kHz respectively. The data were taken for about 15 minutes at each setting. Table 1 shows the trigger rates for both altitudes as well as the ratio of rates at Hanle and Pachmarhi. The ratios for the three settings are similar within errors.

Table 1. Event rates at Pachmarhi and Hanle

Indiv. PMT rate (kHz)	Pachmarhi (Hz)	Hanle (Hz)	Ratio
1.0	0.32 ± 0.03	0.80 ± 0.10	2.50 ± 0.39
2.0	0.42 ± 0.05	0.95 ± 0.11	2.26 ± 0.37
5.0	0.63 ± 0.10	1.38 ± 0.15	2.19 ± 0.08

3. The Analysis

The ratio of the Cosmic ray rates at the two sites is given by

$$X = \frac{T_1 F_1(> E_1) A_1}{T_2 F_2(> E_2) A_2} \tag{1}$$

Where F(>E) refers to the flux of Cosmic rays above energy E, A is the collection area. The subscript 1 and 2 refer to Hanle and Pachmarhi respectively. The transmission factors T_1 and T_2 are 0.9 and 0.65 [9].

When a Cerenkov photon is released at angle theta at the production height H, it intercepts the ground at Hanle (altitude h_1 amsl) at distance R_1 and at Pachmarhi (altitude h_2 amsl) at distance R_2. The height of the shower maximum for proton showers changes from ~8.3 km for 1 TeV to ~7 km for 10 TeV [9]. For values of H equal to 7 and 8.3 km, the corresponding ratio of the intercepts is 2.4 and 1.9 respectively. Since the ratio of areas would be proportional to the square of the ratio of intercepts, we obtain a value of 4.7 ± 1.1 for the overall ratio of collection areas. Also, the mean experimental value of X from the table is 2.32 ± 0.54. Thus the ratio of fluxes F_1/F_2 is obtained to be 7.9 ± 2.6 which translates to a factor of 3.5 ± 0.7 in reduction of energy threshold for the Cosmic ray spectrum with slope of -1.65. Thus, according to this intuitive picture, the energy threshold reduction can vary from a factor of 2.8 to 4.2.

A semi Monte Carlo calculation was also done to find the energy thresholds at the two sites. The method used was similar to the one for the Pachmarhi experiment. The lateral distribution curves were obtained for various energies. The events were generated with the energy given by the cosmic ray spectrum. The core was allowed to fall uniformly on an area centred on the two mirrors. Events were generated upto 300 meters from the center. The Cerenkov photon densities at the mirrors were calculated using a parametrization to the lateral distribution curves. The final number of photons was obtained by adding those due to night sky background. Proper reflection coefficients and quantum conversion efficiencies were used to get the number of photoelectrons at the output of the PMT. A two fold coincidence was demanded and the rate of trigger events vs discriminator bias(in photoelectrons) was obtained. From these, the energy thresholds corresponding to the observed rates were obtained: (1) 1.9 TeV for 1.48 Hz trigger rate at Hanle and ∼8 TeV for 0.73 Hz trigger rate at Pachmarhi (2) ∼ 3 TeV for 0.77 Hz at Hanle and ∼ 10 TeV for 0.44 Hz at Pachmarhi. These correspond to reduction in energy threshold of ∼4.2 and ∼3.5 respectively.

4. Conclusions

If we assume the same factor of energy threshold reduction for a bigger array like the one operating at Pachmarhi [8], the Cosmic ray energy threshold of 1700 GeV will go down to (using the two extreme values) ∼486± 97 GeV at Hanle. If we use the conventional factor of ∼2 for the ratio of Proton energy threshold to gamma ray threshold, the gamma ray threshold of ∼800 GeV at Pachmarhi should come down to ∼243 ± 45 GeV at Hanle. However, protons become more and more inefficient in production of Cerenkov radiation at lower energies [2]. Using a simple fit to the data of Proton energy threshold vs Gamma ray energy threshold for the same amount of Cerenkov light given by Aharonian et al [5], we get a gamma ray threshold of ∼125 ± 35 GeV. Thus the gamma ray energy threshold is expected to go down by a factor of ∼6 ± 2 when an ACT experiment is shifted from altitude of 1 km to an altitude of 4.5 km. A realistic Monte Carlo calculation using the relevant night sky background for a circular array of radius 50 meters and with 7 telescopes each with 7 mirrors of 0.6 m^2 and with an aperture of 1° radius at Hanle gives an energy threshold of about 300 GeV and 65 GeV for protons and gamma rays respectively [10].

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