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Performance Studies of the PACT Experiment

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Abstract. Monte Carlo calculations have been done to understand various characteristics like the energy threshold, collection area etc of the recently commissioned PACT. The energy threshold of the array for gamma rays is found to be about 900 GeV. A larger collection area than many other experiments is a reflection of the large extant of the array.

Key words: VHE-gamma ray astronomy, Monte Carlo methods, energy threshold, collection radius

1. PACT Experiment

A new atmospheric Cerenkov array to study cosmic sources of Very High Energy (VHE) Gamma rays has been set up in Pachmarhi in central India. While most of the atmospheric Cerenkov experiments in the recent years are based on the imaging techniaue, the aim of the new Pachmarhi Atmospheric Cerenkov Telescope (PACT) array has been to use the temporal and spatial distribution of Cerenkov photons in distinguishing between proton and gamma ray showers for increase of sensitivity. The array consists of 25 telescopes deployed in a field of 80m × 100 m area(Bhat et al, 2000)). Each telescope consists of 7 parabolic mirrors, each of diameter 0.9 m. Each mirror is looked at by a fast PMT behind a 3° circular mask. To keep the attenuation and distortions in the cable minimum the array is divided into 4 sectors, with each sector servicing a group of 6 nearby telescopes. The individual mirror rates were kept at about 5 KHz. The pulses from the 7 PMTs in a telescope were added linearly to form a Royal Sum pulse for each telescope. These Royal Sum pulses were discriminated to give a rate of about 30 KHz. A four fold coincidence of these Royal Sum pulses generated the event trigger. A single sector event rate was about 3 to 4 Hz for most atmospheric conditions. Both the timing and pulse height information for each mirror were recorded in the nearby sector electronics hut serving each sector. All royal sum pulses were brought into the control room and their arrival times were recorded along with the other housekeeping information. With all 4 sectors functioning, the overall event rate was about 9 Hz.

2. The generation of Monte Carlo events

Monte Carlo simulations for the new PACT array were done to understand the performance of the experiment. Events were generated with shower cores uniformly distributed inside a circle of 300 meters radius from the centre of the array. The energy for the event was picked from the energy spectrum of the cosmic rays ($\gamma-$ rays) with a slope of -1.66(-1.4) for protons($\gamma-$ rays). The energy range for these calculations was 500 GeV to 20 TeV. Chitnis and Bhat (Chitnis and Bhat, 1999) have done extensive simulations in the recent years for atmospheric Cerenkov production from protons and gamma rays. The Lateral Distibution (LD) curves given by them for both protons and gammas were parametrized to cover the entire energy range. After atmospheric attenuation of 0.5, the number of Cerenkov photons at each mirror was obtained from this parametrization. Bhat and Chitnis also showed that the extent of fluctuations was dependent on the core distance for both species of primaries and that intrinsic fluctuations were much less for gamma ray events. The data provided by them was used to fluctuate the number of Cerenkov photons at each mirror. A reflection coefficient of 0.6 was used to obtain the number of Cerenkov photons at the PMT surface. These photons were converted to photoelectrons assuming an average quantum efficiency of 0.2 and fluctuated using Poisson distribution. These were added to fluctuated night sky photoelectrons to get the total number of photoelectrons for each mirror. Suitable cable attenuation factors etc were also put in to reproduce the experimental conditions as much as possible. Thus, the number of photoelectrons from each mirror was calculated for all the mirrors in the array. This would be proportional to the ADC counts recorded in the experiment for each mirror. About 0.2 million proton events and 0.1 million gamma ray events were thus generated and the output written on to a tape.

3. The Energy Threshold

The individual mirror outputs are added to get the total telescope response which is equal to the so called Royal Sum pulse height. The trigger in the experiment demands a fourfold coincidence of these royal sum pulses above a certain discriminator threshold. Thus individual sector trigger rates were obtained for photoelectron number thresholds ranging from 35 to 100. This curve along with the trigger rate of one sector in the experiment is shown in Fig 1(a). It can be seen that the trigger rate corresponds to threshold of about 55 photoelectrons per telescope. Fig 1(a) also shows the conversion from Photoelectron threshold to absolute minimum energy threshold for both proton and gamma events. Thus the trigger rate corresponds to an absolute minimum of 700 GeV energy threshold. Fig 1(b) shows the experimental trigger rates when the number of sectors varied from 1 to 4. The overall trigger rate which varies essentially as the square root of the total mirror area changes from about 4 Hz with a single sector to 9 Hz when all the 4 sectors are used. The two lines in the figure refer to expectations from simulations for thresholds of 50 and 60 per telescope. Thus, both individual sector rates as well as the overall rates agree with threshold of 55 $\pm$ 5 photoelectrons per telescope. With 55 photoelectrons as threshold per each telescope, the Monte Carlo events generated were

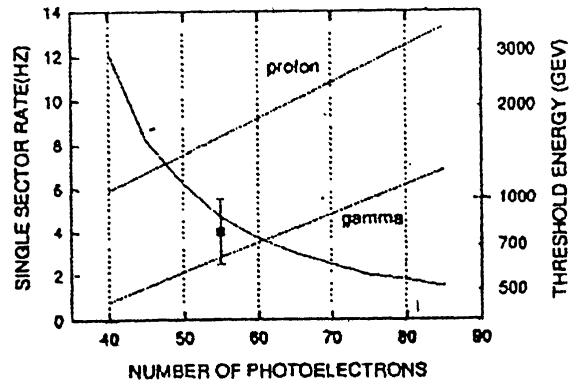

Fig - 1(a)

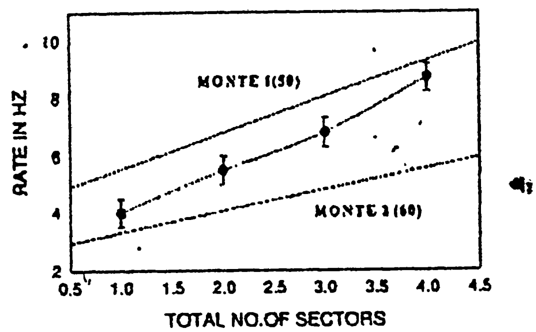

Fig - 1(b)

Figure 1. (a) On the left Monte Carlo single sector Trigger rate vs Threshold in number of photoelectrons per telescope. The data point is from the experiment; on the right is plotted threshold energy as a function of number of photoelectrons per telescope. (b) Variation of rate with number of sectors. The lines are Monte Carlo expectations for threshold of 50 and 60 photoelectrons respectively.

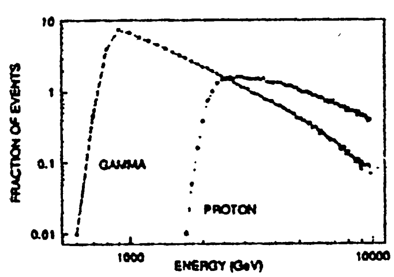

Fig - 2(a)

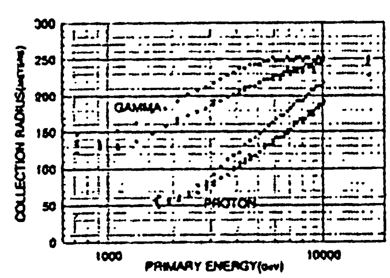

Fig - 2(b)

Figure 2. (a)Differential Energy Spectrum of triggered Monte Carlo events. The peak of the spectrum for $\gamma-$ rays correspond to about 900 GeV. (b) Collection Radius v/s Primary Energy. The two curves are for one and 4 sectors respectively.

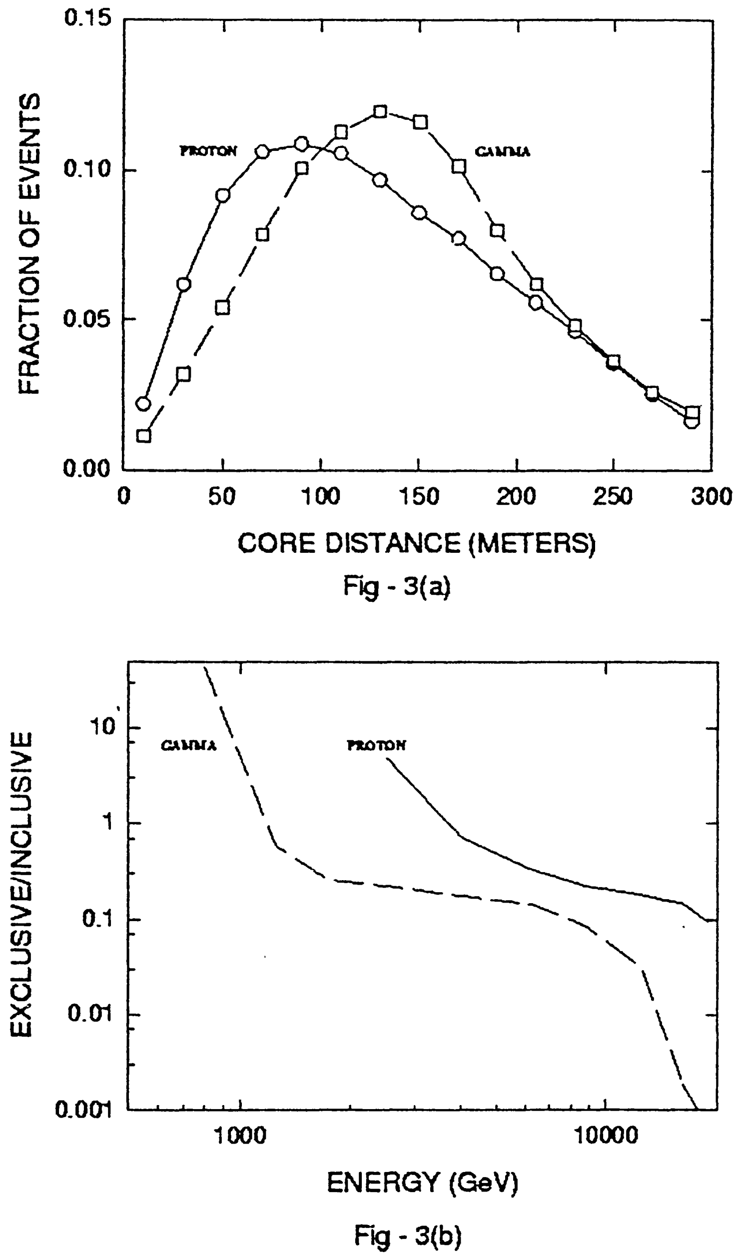

Figure 3. (a) The fraction of triggered events as a function of core distance. (b) Ratio of exclusive to inclusive events as a function of energy.

examined and the triggered events were classified according to their energy and distance from the core. Fig 2(a) shows the differential energy spectra for both gamma and proton events. The peak of these distributions give the energy threshold of the array : 900 GeV for gamma ray events and 2250 GeV for proton events. Further, the collection area for each event was calculated and binned accordingly. Fig 2(b) shows the collection radius for a single and all sectors as function of energy for both gamma and protons. It should be noted that the large collection radius (defined as the radius containing 67% of the events) of the PACT is essentially due to the large extant of the array. The saturation at large values of collection radius occurs because the events were generated only upto 300m radius.

It is interesting to find the percentage of events trigggered as a function of core distance. Fig 3(a) shows the fraction of triggered events as a function of core distance for both proton and gamma ray events. The fraction of gamma ray events increases from core to distances of 125 meters (hump region) after which it decreases. The peak of the distribution is about 75 meters for proton events. If we consider the fraction per unit area, the fraction is constant upto the hump region, the result of a flat LD at nearer distances. When only 2 sectors are present, the ratio of single sector events to double sector events is about 0.08%. Figure 3(b) shows the energy dependence of this ratio. As expected, the ratio is quite high at lower energies, tapering off at higher energies.

Some of the deficiencies of the Monte Carlo simulations have to be noted. While the number of showers generated to understand the performance of the array was quite large, each shower was not individually generated in the atmosphere. The photon densities were picked from fluctuations imposed on the average LD curve for the particular energy. The densities for higher energy showers were picked from the extrapolations of the published LD curves at rather low energies.. Thus, it is not apparent how well the real LD at the very high energies correspond to these extrapolated values. Further, the values of the attenuation factors, the reflectivity of the mirrors etc could be uncertain by small factors. All these uncertainties would affect the Energy Threshold, the collection area etc .

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