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Ground-based Very High Energy Gamma-Ray Astronomy at Pachmarhi

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1. Introduction

The field of Very High Energy (VHE) Gamma Ray Astronomy is the extension of traditional astronomies to high energies. A VHE photon impinging on the top of the atmosphere makes a shower of electrons which in turn give out Cerenkov radiation over a large area. Since the Cerenkov light is faint, the observations are done on moonless and cloudless nights with little or no ambient light. Pachmarhi in Madhya Pradesh provides one of the better sites in India for such observations. There are 15 groups world wide (including 2 in India) involved in these studies.

The signal has to be detected amidst much more numerous background events (noise) generated by cosmic ray particles. With first generation telescopes, several groups including ours have showed that some important sources are at least occasional TeV gamma ray emitters. The main effort in the second generation telescopes in this field at present is to devise methods to increase the sensitivity of the telescopes.

One of the methods to increase the *Signal/Noise* (*S/N*) ratio is to exploit the substantial differences in lateral distribution of Cerenkov photons between cosmic ray and gamma ray showers. These are ; (a) the lateral distribution of Cerenkov light from gamma showers has a hump (regions of increased density) at about 130 meters from the core (b) the lateral distribution of the density of Cerenkov photons in gamma showers is flat up to the hump region unlike proton initiated showers which have steeper density distributions and (c) because of limited fluctuations, gamma showers have a less bumpy lateral distribution of Cerenkov photons. The Monte Carlo calculations done by the group have shown that these differences can be highlighted by the use of certain parameters (Vishwanath *et al.* 1993a). These parameters are being used in the analysis of the data taken on the array in the past few years.

2. The experiment

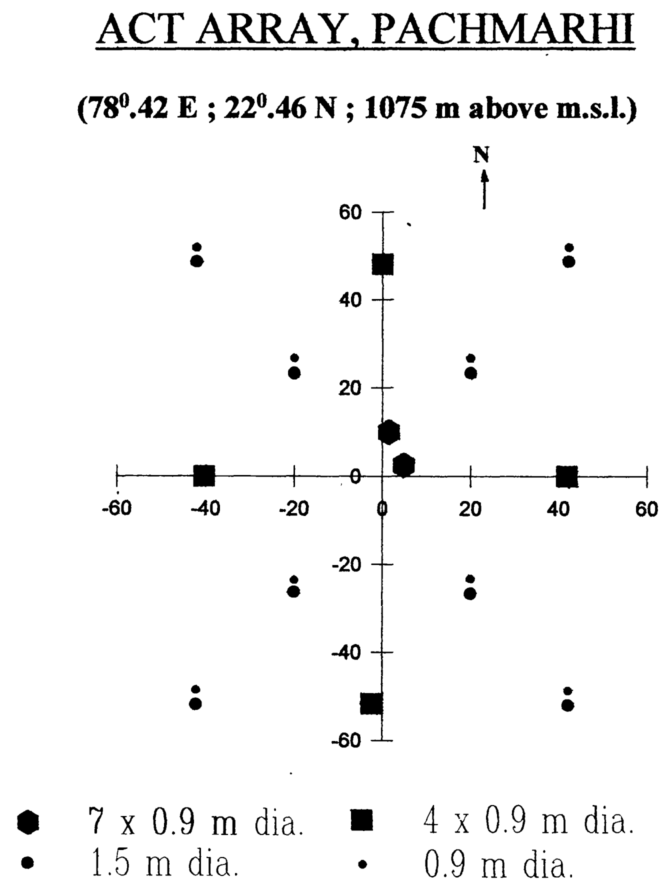
The expansion of the telescope array for exploiting the differences in lateral distribution of proton and gamma ray showers was started in 1993. The present array set up at Pachmarhi (altitude 1075m a.s.l) consists of 12 blanks of reflectors each of total area 2.5 m^2 and 2 banks of reflectors, each of total area 4.2 m^2. The array consists of (a) 8 1.5 diameter mirrors and 8 0.9 meter diameter mirrors on their own mounts (b) 4 mounts each with 4 mirrors of 0.9 meter diameter and (c) 2 mounts each with 7 mirrors of 0.9 diameter. The reflectors are spread over an area of 80 m x 100 m as shown in Fig. 1. Mirrors for the new array were made from glass sheets using parabolic stainless steel moulds in the Central Workshop of the Bhabha Atomic Research Centre (BARC).

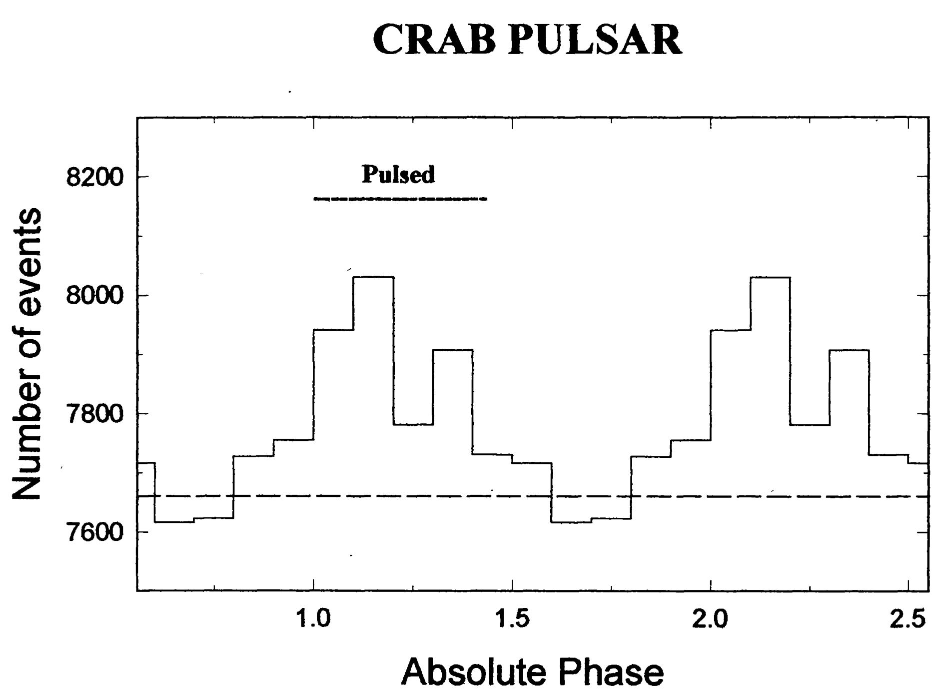
To achieve perfect tracking, clinometers (transducers who dc output is proportional to the angle from the vertical) were attached to the axes of both East–West and North-South rotations. These clinometers play the role of low cost absolute encoders. Considerable amount of R and D was done and now we have a system of 24 independent mounts which has been operating very reliably for the past two years. Thus, with the aid of these clinometers, apart from tracking the source for the run duration, we can automatically align the telescope to a given direction and correct the telescope for any tracking errors. At present, the pointing accuracy of the array is 0°.1.

Each of the 46 mirrors in the array has a RCA 8575 or equivalent Photo Multiplier Tube (PMT) at its focus. The high voltage to PMT's is fed from a computer controlled High Voltage system. The signals from these 46 PMT's (Channels) are grouped into 14 banks. Event triggers are obtained by a selective logic system which requires signals in at least 2 banks in both the inner and outer sections of the array. The triggering rate is about 3-5 Hz depending on the zenith angle of the source. The pulse amplitude and the time of arrival of the pulses are recorded using ADCs and TDCs. Data is acquired on-line using a PDP-11/23 based system. This system is being modified to a PC486 system. Event arrival time is derived from a GPS (Global Position Satellite) receiver having a time keeping accuracy of ± 100 ns. The online monitoring system involves check of all the individual mirror rates, bank rates, various sector rates, the total trigger rate and the chance rate. Any of these rates can be obtained as a function of time. Further ADC/TDC distributions of any channel can be looked into at any time during the run.

3. Monte Carlo Simultations

To understand the response of the detectors to showers of atmospheric Cerenkov radiation, simultations were done at first for a 8 bank array corresponding to the configuration of our interim array. Attempts were made to find suitable parameters for distinguishing between proton and gamma showers. One of the parameters that is quite powerful is a χ^2 like parameter based on observed pulse heights. This is termed α the Flatness Parameters and it was found that a good separation between gamma and proton showers can be made if we choose showers with low values of α. Another parameter β which is the ratio of the maximum pulse height to the mean pulse height of the rest of the detectors has been used to find events with possible hump. Low values of α or High values of β are possible signatures of gamma ray events.


ACT ARRAY, PACHMARHI
(78°.42 E ; 22°.46 N ; 1075 m above m.s.l.)
N
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60
7 x 0.9 m dia.
4 x 0.9 m dia.
1.5 m dia.
0.9 m dia.


CRAB PULSAR
Pulsed
8200
8000
7800
7600
Number of events
1.0
1.5
2.0
2.5
Absolute Phase

4. Preliminary Results

While development work was given priority, the existing mirrors were used in an interim array configuration. This had two aims : (a) the electronics could be set up and it would only need additions when the new mounts would be installed and (b) one could put to test some of the analysis techniques meant for the expanded array. During the last 2 years, data has been taken on the Crab, the Geminga Pulsar, PSR0355+54, Her X-1 and other sources. The ADC information is used to obtain parameters to differentiate between cosmic ray and gamma ray showers on the basis of lateral distribution. The TDC information is used to obtain the direction of the primary.

The preliminary analysis deals with data taken on 8 banks (each of area 2.54 m^2) in 1992 Oct - 1993 March. The observed event times were converted to the times at Solar system barycenter using the JPL ephemeris. The phase of each element is computed using contemporaneous pulsar ephemeris.

At GeV energies both the Crab and the Geminga pulsars show a main and an inter pulse; further there is emission in between the two pulses for the Crab (Thompson *et al.* 1994) and throughout for Geminga (Bertsch *et al.* 1992). Our analysis on archival data (1984-1985) taken on Germinga at Ooty to look for a pulsar had showed two peaks at exactly the same phases as in the recent GeV data (Vishwanath *et al.* 1993b).

Phasograms for the uncut data did not show any interesting features or the evidence for a continued emission of TeV photons from the pulsar, consistent with our earlier observations and by other groups (Sapru *et al.* 1996). To reduce the cosmic ray background, both α and β parameters were calculated for each event. As mentioned above, low value of α or high value of β are possible signatures of a gamma ray event. Events were classified according to these parameters and phasograms were generated for these classes of events.

The preliminary results from the Pachmarhi array on the Crab pulsar using only the differentiation based on differences in lateral distribution of Cerenkov photons (i.e. using cuts on α and β parameters) is shown in Fig 2. It can be seen that at these VHEs also the signature of the pulsar as seen in the GeV energy domain is visible. It is important to note that this is persistent emission and not just transient emission as detected by us and several groups from the Crab pulsar in the past (Acharya *et al.* 1992, and references therein).

Thus, it is encouraging to see that the method of increasing the S/N ratio using information on the lateral distribution of Cerenkov photons shows up the signature of the pulsar at these energies. While the signal levels are still low, it should be noted that there were only 8 banks of detectors for this set of data. Further, we have not yet used the TDC information which would give the arrival direction and this is expected to increase the signal strength. The analysis is being continued to look for other parameters which would further increase the S/N ratio. This approach of using lateral distribution for increase of sensitivity is expected to do much better when the array is completely built with 25 banks, each 7 mirrors of total area 4.2 m^2.

5. Acknowledgements

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