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Lateral distribution studies for the PACT experiment

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Abstract. Monte Carlo calculations have been done to study the possibilities of using different spatial distributions, local fluctuations and the number of Cerenkov photons in gamma ray showers to increase the sensitivity of the PACT experiment. After matching the trigger rates in data with the predictions of simulations, the energy threshold of the array for gamma rays is found to be about 900 GeV. It is shown that a lateral distribution parameter β can increase the signal to noise ratio in the experiment. A typical season of 15 nights should be able to conclusively establish any source with Crab level fluxes. Two other possible parameters for increase of sensitivity are also discussed. Preliminary results on the application of the β parameter to the data from PACT experiment are discussed.

1 Introduction

It is well known that lateral distribution of gamma ray showers is significantly different from those of proton showers. Cerenkov photon densities in gamma ray showers are almost flat from the core upto 110 meters with a hump region between 110 meters and 130 meters whereas proton showers show a monotonically decreasing density with core distance. The Tata group has been advocating the use of lateral distribution as a discriminating factor between protons and gamma ray events [Rao (1988)] [Vishwanath (1993)]. It has been used for the pulsar data taken in 1992-1994 and it was shown that the events in the main pulse region for Crab and the preferred GeV emission phase region for Geminga display gamma ray like characteristics [Vishwanath (1997)]. Calculations have been done for the newly commissioned PACT [Bhat (2000)] which show that the use of lateral distribution(LD) parameter can increase the S/N ratio. The recent data taken with the PACT array on Crab is used to check some of the predictions of these calculations.

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2 Simulations for the array

Monte Carlo simulations for the new PACT array were done to understand the performance of the experiment and have been discussed in detail in other papers of the conference. 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 20 TeV. Chitnis and Bhat [Chitnis (1999)] have done extensive simulations in the recent years for atmospheric Cerenkov production from protons and gamma rays. The Lateral Distribution curves given by them for both protons and gammas were parametrized to cover the entire energy range. The number of Cerenkov photons at each mirror was obtained from this parametrization. These were converted to photoelectrons using a mean quantum efficiency and night sky background photoelectrons were added to these. Thus, the number of photoelectrons at each mirror of the PACT array was written out for about 0.2 million proton events and 0.1 million gamma ray events. The trigger requirement in the experiment was any four out of six telescope coincidence per sector. It was found that the experimental trigger rate for sector of about 4 Hz corresponds to about 55 photoelectrons for an individual telescope which translates to 900 GeV energy threshold for gamma rays and 2.2 TeV for protons.

3 Lateral distibutions

While several methods were used by us in the past to exploit the flatness concept, a single parameter β is used to exploit the full lateral distribution curve. β is defined as (max pulse height /mean pulse height of the rest -1). It is intuitively obvious that β should have a small value for gamma ray showers when the core distances are not far from the center of the array. At larger distances, β will have a larger value for gamma

ray showers because few detectors are hit either by the flat region or the hump whereas the other detectors will respond to the falling part of the LD curve. When median values of β were calculated, it was seen that median β increases from 0.05 (0.2) at < 50 meters to 0.45 (.15) at 200 meters from the core for gamma and proton showers respectively. Further, it was also seen that higher energy events have a larger median β for gamma ray showers.

Monte Carlo generated events which fulfilled threshold criteria were binned according to their β values and the number of gamma and proton showers triggering the array as a function of β were obtained. Fig 1(a) shows the fraction of events as s function of β. As expected, the fraction of gamma ray events is higher near and far core distances compared to the fraction of proton events. Fig 1(b) shows the signal strength for a crab flux of 2.5/minute with an exposure of 55 hours. It is seen that both low and high β regions can be exploited to increase the signal to noise ratio.

4 Comparison with Data

The data taken on Crab with the PACT array during the months of 2000 October and November totaling 2301 minutes were used to see whether the above mentioned LD parameter could be used to extract the signal from the source. ADC counts from mirrors were converted to pulse heights and normalized such that all mirrors have the same mean pulse height for both source and background. From the individual mirror responses, the total pulse height from each telescope was obtained and β parameter calculated and binned. Fig. 1(c) shows the normalized ratio of source to background events as a function of β. There is almost exact similarity between the two figures, the one obtained from Monte Carlo and the other from data. However, absolute values of the β in data are higher than in Monte Carlo. One can see that there is an excess of events at very low and very high β as predicted by the simulations. The excess from the source amounts to $3.63 \pm .38$ per minute. The arrival direction for each event was calculated as described in the papers of the PACT experiment in this conference. From the space angle differences, it was found that that on- axis showers show a higher fraction of source showers at low β, thus confirming the gamma ray nature of the events at low β. However, the events at large β did not show any preference for on-axis showers

5 Other Parameters

According to the simulations of Chitnis and Bhat[Chitnis (1999)], while density fluctuations for both types of showers are core distance dependent, the amount of fluctuation is much less in gamma ray showers: for example, at 100 meters the ratio of standard deviation to mean photon density is 2% and 20% for gamma ray and proton showers respectively. While this has been the input to the Monte Carlo for fluctuating the Cerenkov photons, it is of interest to see its effect

on the events which trigger the array. By using the photo-electron number at each mirror, the fractional error on the mean was computed for each telescope. By using the information from all telescopes, the overall mean of such a quantity (FEML) for the event and further for all Monte Carlo events was calculated. It was found that the fact that gamma ray events have a much smaller local fluctuation did translate to an overall mean FEML of 0.525 and 0.619 for gammas and protons respectively. The PACT array with information from as many as 175 mirrors is ideally suited to use this difference to increase the sensitivity. It should however be noted that the energy threshold for use of this parameter is significantly high, almost 1800 GeV for gamma rays since most showers will not have information from all mirrors. Another parameter of interest is the amount of Cerenkov light per telescope per event. It can be seen from the lateral distribution curves that the number of Cerenkov photons is roughly same for gamma showers of energy E and for photon showers of energy 2E. When a sample of events has both protons and gamma rays, the mean amount of light per event in that sample will depend on the amount of gamma ray admixture. For a Crab spectrum of slope -1.4 (as was used for these Monte Carlo calculations), the mean Cerenkov light for gamma rays triggering the telescope was higher than for proton events by 30%. If there are gamma rays from pulsars, then the pulsar data should provide a check of this difference between gamma and proton showers. This is exactly what was seen in the analysis of the data from the interim array (8 banks , each of area $2.5m^2$) runs at Pachmarhi during 1992-1994. The ADC information was used to get the Average Pulse Height per bank (APHB) per event as function of the pulsar phase. For the Crab pulsar data, the difference in APHB between that in the phase region 0-0.5 to the rest of the phase plot was 1.26 ± 0.26, a 5σ effect. Similar, but slightly less significant , effect was seen in the comparison for the Geminga data. It should be noted that the right place to look for such effects is in the data from pulsars (assuming there is pulsed emission at some phases) since all data would have been treated in the same manner ; it might be difficult to see such effects when the source region and background regions are entirely different.

6 Conclusions

It should be noted that the Q values (Quality factors) are not necessarily very high with the usage of the β parameter. Fluctuations degrade the Q values which should have been ideally much higher. Nevertheless, it is still an important sensitivity raising parameter for steady emitters like the Crab nebula. Fig 1(b) which shows the expectations for a 55 hour data sample is essentially for a typical 10-12 night run on a steady source with Crab like flux levels. Further, some of the deficiencies of the Monte Carlo simulations have to be noted. The photon densities were picked from fluctuations imposed on the LD curve for the particular energy. The densities for higher energy showers are picked from the extrapolations of
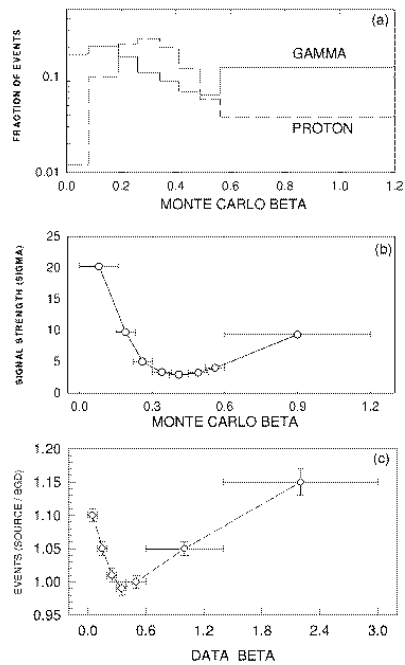
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Fig. 1. (a) Fraction of Triggered showers as a function of β
(b) Signal Strength v/s β for a Crab like source with exposure of
55 hours. (c) Ratio of Source to Background Events v/s β for Crab
data of 2000.

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 uncertainty in the attenuation factors, the reflectivity of the mirrors
etc would affect the quantities obtained from the Monte Carlo
calculations.

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