Pachmarhi Array of Čerenkov Telescopes

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Abstract

Pachmarhi Array of Čerenkov Telescopes (PACT) has been commissioned to study celestial $\gamma-$rays using ground based atmospheric Čerenkov technique. Here we present some preliminary estimates of the parameters indicating the expected performance of PACT. Based on the measured night sky background at Pachmarhi and the expected trigger rate, the energy threshold of PACT is estimated to be $\sim 750\,GeV$. The expected trigger rate of $\sim 3-5\ Hz$ is generated by a majority logic demanding at least 4 of the 6 telescopes of a sector. The telescope signal is generated by the analog sum of 7 individual mirror signals. The detection sensitivity of PACT, which indicates the minimum $\gamma-$ray flux from a point source, that could be detected at a significance level of 5σ, is estimated to be $3.8 \times 10^{-12}\ ph\ cm^{-2}\ s^{-1}$, for an on source exposure of 50 hours. This is a conservative estimate and translates into the detection of Crab nebula at a significance level of 6σ in 20 hours of observation.

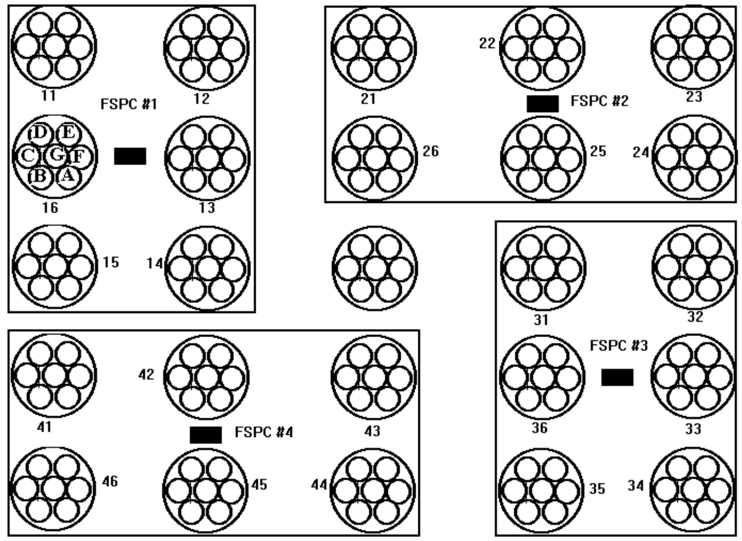
1 Introduction:

Atmospheric Čerenkov Technique is a well known method for the astronomical investigation of TeV $\gamma-$rays. It is mainly based on the effective detection and study of Čerenkov light emitted by the secondary particles produced in the extensive air showers initiated by the primary $\gamma-$rays or more abundant cosmic rays. Second generation telescopes have achieved a significant improvement in sensitivities by being able to reduce the background due to cosmic ray primaries (Vacanti *et al.*, 1991, Baillon *et al.* 1994, Goret *et al.*, 1993). Čerenkov imaging technique has been successfully demonstrated to be an efficient method of rejecting more than 99.9% of the hadronic background (see Fegan, 1997 for a review). Angular imaging and spatial multiple sampling are two complementary ways to examine the same bundle of Čerenkov photons. Simulation studies have shown that wavefront sampling technique could well identify parameters to distinguish between electromagnetic and hadronic cascades similar to that carried out in imaging technique (Chitnis & Bhat, 1998; Chitnis & Bhat, 1999). Hence we decided to adapt the wavelength sampling technique in order to improve the signal to noise ratio by rejecting hadronic background.

2 The Array

Pachmarhi Array of Čerenkov Telescopes consists of an array of 25 Čerenkov telescopes deployed in an area of about $80\ m \times 100\ m$ at the High Energy Gamma Ray Observatory (HEGRO) Pachmarhi ($latitude = 22°\ 28'\ N\ and\ longitude = 78°28'\ E\ and\ altitude = 1075\ m$). The separation between neighboring telescopes in the N-S direction is 25 m while it is 20 m in the E-W direction. Each telescope consists of 7 parabolic mirrors ($f/d \sim 1$) of diameter 0.9 m mounted symmetrically on a single equatorial mount. The total reflector area of the array is more than 133 m^2. The reflectors are fabricated locally and their image size is $<\ 1°$ FWHM. A fast phototube (EMI 9807B) is mounted at the focus of each mirror defining a field of view of $\sim 3°$ FWHM.

The movement of the Čerenkov telescopes is remotely governed by a low-cost control system called Automatic Computerized Telescope Orientation System (ACTOS). The hardware consists of a semi-intelligent closed loop stepper motor control system which senses the angular position using a gravity based transducer called clinometer with an accuracy of $1'$. The two clinometers, one in the N-S and the other in the E-W direction are accurately calibrated using the stars. The system can orient to



Pachmarhi Array of Cerenkov Telescopes

Figure 1: The deployment of the 25 7-mirror telescopes in a 80 $m \times 100$ m field. The telescopes are divided into 4 groups of 6 telescopes for minimizing the signal losses during transmission. The signal processing & data acquisition is accomplished by a networked data acquisition system.

the putative source with an accuracy of $\sim$ $(0.003 \pm 0.2)^{\circ}$. The source pointing is monitored with an accuracy of $\sim$ 0.05° and corrected in real time.

The performance of PACT is evaluated and compared with other similar experiments. Čerenkov photons from air showers generated by cosmic rays or $\gamma-$ rays are to be detected in the presence of a night sky background which is about 10^4 times the former and it decides the energy threshold of the experiment. Cosmic rays form another source of background while detecting $\gamma-$ rays from astronomical sources (Fegan, 1997). Cosmic ray flux is roughly 10^3 times the $\gamma-$ ray flux from typical astronomical object. Sensitivity of the experiment is defined as the lowest flux of $\gamma-$ rays that can be detected by the experiment. Using typical instrument characteristics of PACT, these parameters are estimated here and compared with those of other experiments.

3 Energy Threshold:

The Night Sky Background (NSB) measured at Pachmarhi is $\sim 3.3 \times 10^8$ $ph\ cm^{-2}s^{-1}sr^{-1}$.

Energy threshold of the experiment $E_{th} \propto \frac{N}{S}$, where $N = noise\ from\ NSB\ and\ S =$ Čerenkov signal, given by :

$N = \sqrt{NSB \times Aq\beta\Omega\tau}$ and $S = F_{\check{C}} Aq\beta$

q : quantum efficiency of the PMT at the focus.

β : reflectivity of the parabolic mirror

Ω : solid angle defined by the telescope opening angle.

τ : integration time of the PMT

$F_{\check{C}}$: Čerenkov photon flux

In order to derive the optimum event trigger, analog sum (called royal sum) of the signals from the individual PMTs is used. The royal sum counting rates were recorded at various discriminator thresholds, while the telescope was tracking a dark region of the sky.

Trigger is selected such that $\leq 10\%$ of the counts are due to night sky noise. It is $\sim 3-5\ Hz$ per telescope. Using this the Čerenkov photon threshold of PACT is estimated to be $\sim\ 20\ ph\ m^{-2}$. The corresponding energy threshold is $E_{th}\ \sim\ 750\ GeV$ for $\gamma-$ rays.

Energy threshold of the experiment could be decreased by using the grand sum for generating a trigger. The grand sum is the sum of royal sums from all the six telescopes in a sector. However the direction & density information may not be available for such low energy threshold events.

4 Angular Resolution of PACT

4.1 Mirror & Telescope Alignments The alignment of individual mirrors of the telescope is done using the drift scan method of a bright star across the telescope field of view. All the optic axes of the 7 mirrors are then adjusted, using this method, to be parallel to each other within an error of $0.2°$ to ensure that all mirrors view the same part of the sky.

4.2 Angular Resolution of the System In order to estimate the angular resolution of the array one has to measure the relative arrival time of the Čerenkov shower front at different telescopes. This has been done using fast time to digital converters (TDC's). From these measurements carried out recently for a quarter of the array, the accuracy in time measurement has been estimated to be 1.3 ns. This implies that angular accuracy by which the arrival direction of a Čerenkov front can be estimated is $0.18°$ near vertical direction for a quarter of the array. Based on these measurements, the expected angular accuracy of the entire array is estimated to be $\sim 0.075°$.

In order to estimate the angular resolution of the Čerenkov telescope, one has to estimate the accuracy of time measurement. A series of TDC distributions were taken with all the telescopes in vertical direction. Using the TDC difference distribution, the timing resolution is estimated to be δt = 1.3 ns. Using a typical inter telescope distance of 50m for a sector the angular resolution is given by:

$$\delta\theta = (c\delta t)/(Dcos\theta)$$

$= 0.18°$ in the vertical direction.

Corresponding $\delta\theta$ for the entire array is $0.08°$.

5 Expected Sensitivity of PACT

The signal to noise ratio, with $\gamma-$ rays forming signal and cosmic rays as background, is given by:

$$N_{sig} = \frac{K_g E_g^{-G} A_g(E_g) T}{\sqrt{K_b E_b^{-1.6} A_b(E_b)\Omega T}}$$

$$\propto \sqrt{\frac{A_p T}{\Omega}} E^{0.85-G}$$

where G : $\gamma-$ ray spectral index

A_p : effective collection area

T : duration of observation

Ω : solid angle ot the telescope

A 5σ sensitivity for an observation duration of 50 hours for three different background rejection capabilities are:

Without background rejection is $\sim 5.5 \times 10^{-11}\ ph\ cm^{-2}s^{-1}$.

The angular resolution of the array is estimated to be $\leq 0.2°$. This would enable the rejection of 98% off-axis background counts using arrival angle information resulting in an improved sensitivity of $\sim 7.7 \times 10^{-12}\ ph\ cm^{-2}s^{-1}$.

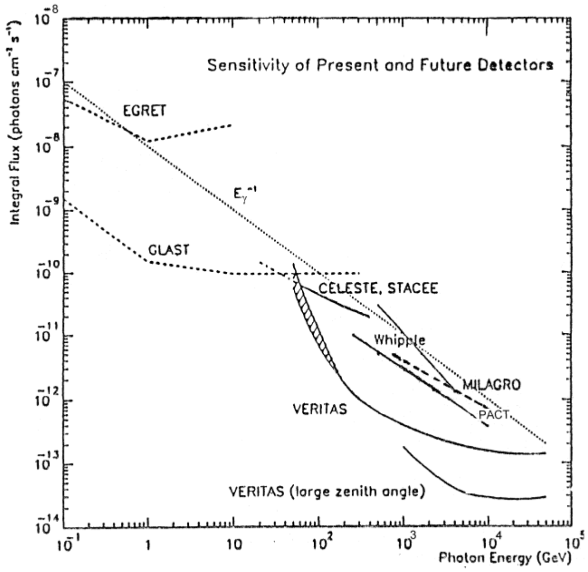


Figure 2: Sensitivity of PACT in the range 0.75-10 TeV is shown for a 99.5% background rejection criteria.

With an additional rejection of $\sim$ 75% on-axis proton showers based on temporal and spatial distributions of Čerenkov photons - from simulation studies, (amounting to total background rejection of 99.5%) is $\sim 3.8 \times 10^{-12}$ $ph\ cm^{-2}s^{-1}$.

Based on these conservative estimates, minimum duration of observation required to detect Crab nebula at a significance level of 6σ is $\approx$ 20 hours.

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