PACT Results on Very High Energy γ-ray Emission from CRAB Pulsar

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Abstract

The data taken on the Crab pulsar by the recently commissioned array of Čerenkov Telescopes at Pachmarhi using the wave front sampling technique have been analyzed. The phasograms show significant excess of events at the Radio Main Pulse phase. This excess corresponds to a 5.7σ signal and is confined to a narrow angular region around the source. It is present in most runs indicating constancy of emission. The energy estimate of the events indicate that the signal is due to higher energy events. This excess could correspond to the possible second component of Outer Gap models.

1. Introduction

The early experiments on VHE γ-ray emission from Crab pulsar had shown the steepening of the energy spectrum at $> \ 100 \ GeV$. The new experiments in the 90's have also not detected any signals around 1 TeV from pulsars like Crab [1,2]. However, of the two competing models (the Polar Cap and the Outer Gap) for γ-ray emission from pulsars, the Outer Gap model has an inverse Compton component due to gap accelerated particles at $> \ 1 \ TeV$ [3]. A new atmospheric Čerenkov telescope array to study cosmic sources of VHE $\gamma-$rays has been set up in Pachmarhi in central India. The aim of the new Pachmarhi Array Cerenkov Telescopes (PACT) has been to use the temporal and spatial distribution of Cerenkov photons to distinguish between proton and γ-ray showers for increase of sensitivity in the detection of VHE γ-rays. We describe here the preliminary results from the analysis of the Crab pulsar data.

2. The PACT experiment

The PACT consists of 25 telescopes deployed in a field of 80 $m \times 100$ m area [4,5,6]. Each telescope is mounted with 7 parabolic reflectors with a fast photomultiplier tube (PMT) at the focus. To minimize the attenuation and distortions of signals in the cables, the array is divided into 4 sectors, with each

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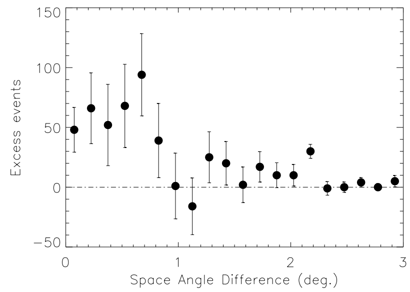

Fig. 1. Number of excess events in the MP phase bin as a function of space angle

sector servicing a group of 6 nearby telescopes. The 7 pulses from the PMT's of a telescope are lineraly added to generate a telescope pulse (Royal sum pulse). The relative arrival time (TDC) and charge (ADC) informations of all pulses (individual PMT and Royal sum) were recorded. A coincidence of any 4 out of 6 Royal sum pulses of a sector formed the event trigger. Only two sectors were ready at the time of data taking in 1999-2000. Data were recorded independently in both sectors and collated using the arrival times of the events. The mean rate for the event trigger, mostly due to cosmic rays, is $\sim 3-4\ Hz$ for a sector. The corresponding threshold energy for γ-ray primary is obtained from Monte Carlo simulations as 850 GeV. Data on background regions were acquired either before or after the Crab run but over the same zenith angle range.

3. Data Analysis

The data on Crab with absolute time keeping information amounted to 1355 minutes in 12 runs. About 50-60 % of the events were common to both the sectors. Further analysis was restricted to these common events. The phase analysis of the data was carried out using the pulsar elements applicable to the epoch of our observations. The arrival direction of shower was estimated using the TDC information from the Royal Sum pulses. Space angle (α) is defined as the angle between two directions, the shower and Crab directions.

The phasogram showed a significant peak at the radio Main Pulse (MP) phase with an excess of 424 ± 101 events compared to the mean expected from all the phase bins. Phasogram is constructed for each space angle bin and the distribution of number of excess events in the MP phase bin is shown as a function of space angle in Fig. 1. Most of the excess is confined to $\alpha < 0.9$ degrees. The phasogram of all events within $\alpha < 0.9$ degree showed an excess of 328 ± 72 events which translates to a rate of 0.24 ± 0.05 events per minute. No phasograms for the background data (total of 13 runs) with or without the space angle cut showed any significant deviation from mean in any phase bin. Fig. 2 shows the rate of

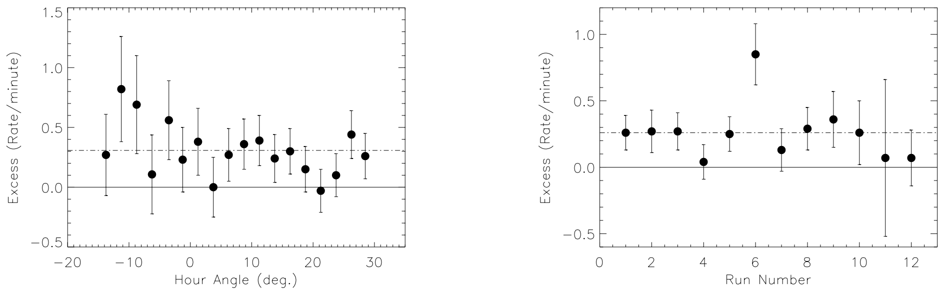

Fig. 2. Rate of excess events in MP phase bin (for $\alpha < 0^\circ.9$) as a function of hour angle (left panel) and Run Number (Right panel) for ON source events.

excess events in the MP phase bin for ON source events and within $\alpha < 0.9$ degree as a function of hour angle of Crab and Run number. It can be seen that the excess is present in almost all Runs and in all hour angle intervals.

The ADC information is used to estimate the energy of the shower. The energy estimation was limited to hour angle $< 15^\circ$ and is based on the method arrived at by the semi Monte Carlo simulations of the detector response [7]. The energy resolution is about 0.2 at low energies, increasing to 0.5 at 5 TeV. It should be noted that the energy estimation thus obtained has an uncertainty due to energy threshold, energy resolution and simulation method. It was found that the excess was almost nil in the lower energy region from 900 GeV to 1600 GeV. But at $> 1600\ GeV$, the excess rate is 0.27 per min. Using this, we get the preliminary value for integral flux as 6.5 ± 2.2 in units of 10^{12} $photons\ cm^{-2}\ s^{-1}$. At $> 1600GeV$, the nebular flux according to Hillas et al. [8] is about a factor of 2 higher. Data were sub-divided into 1 minute intervals and grouped according to the trigger rate. No excess at MP was seen from data during high trigger rate ($>\ 100/m$) intervals while an excess of 301 ± 54 (a 5.7σ signal) was seen in those periods of data with lower trigger rates ($< 100/m$). This corroborats the earlier observation that the excess is seen in higher energy events.

4. Discussion

The Durham group [9], working at the Dugway site in USA, detected a 4.3σ signal at the main pulse phase position from 103 hours of observation at an energy threshold of 1 TeV. The flux was found to be 5×10^{-12} $photons\ cm^{-2}\ s^{-1}$. With arrival direction estimation, they had shown that the signal falls off away from the pulsar direction. All the earlier observations gave only upper limits [10,11]. The recent upper limits with imaging telescopes come from the Whipple [12] and HEGRA experiments [13]. The non imaging experiments, the CELESTE [14] and

STACEE [15], also have no evidence for pulsed emission from Crab.

The present PACT result is the only recent experiment showing significant signal for pulsed VHE γ-ray emission. However one has to consider this positive result against results of imaging experiments which do not see any emission. It had been pointed out by Bhat et al.[16] that the analysis procedures in the imaging technique could have biases for sources with a flatter spectrum than that of the crab nebula. Further, it was seen that the collection area falls with energy for the supercut procedures used in imaging technique [17]. This possible discrepancy needs further studies. The recent Outer Gap models predict an inverse Compton component due to gap accelerated particles at higher energies. This result from the PACT experiment on steady emission of VHE gamma rays from Crab pulsar at higher energies could be due to such a second component.

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