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Energy Sensitive Search for Pulsed Photons from Crab Pulsar using the TACTIC Imaging Element

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Abstract. The Imaging Element (IE) of the 4-element TACTIC array of atmospheric Cherenkov telescopes is in operation at Mt. Abu Rajasthan, in Western India. We have successfully detected a steady signal from the Crab Nebula at a sensitivity level of ~ 6.3 σ in 40 hours at $E_\gamma \geq 1$ TeV, during the period Jan.- March 2001. This database has been used to carry out a search for the presence of pulsed photons at two higher threshold energies ($E_\gamma \geq 2$ TeV and $E_\gamma \geq 3$ TeV) by applying energy- sensitive size cuts. We do not find any evidence for the presence of an energy- dependent pulsed photon signal from the Crab pulsar direction. However, we place the upper limits of 1.08×10^{-12} and 8.88×10^{-13} photons cm^{-2} sec^{-1} for the 2TeV and 3TeV light curves respectively. Results presented here, are however preliminary and we are collecting more data on the source so as to be able to arrive at a more definitive conclusion about the TeV γ -ray pulsed emission from the Crab pulsar.

Keywords : VHE, TeV γ-rays, Crab Nebula, Pulsar

1. Introduction

The Crab Nebula is the first source to be convincingly detected as a standard source of steady TeV γ-rays (Naurois et al 2002 and references therein), but it has not been detected as a pulsed TeV γ-ray source (Lessard et al, 2000). Several generation-I atmospheric Cherenkov telescopes had detected episodic pulsed activity (Gibson et al 1982; Bhat et al 1986: Acharya et al 1992) from the Crab Nebula/pulsar region in the eighties. Although the EGRET experiment onboard the CGRO has detected a pulsed signal from the Crab up to 10 GeV (Ramanamurty et al 1995),

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but the current Cherenkov telescopes operating in the energy range 60 GeV - 50 TeV, have not detected any pulsed emission component from the source (Hillas et al 1998; Tanimori et al 1998; Lessard et al 2000; Oser et al 2000 and de Naurois et al. 2002). However, preliminary results from the non-imaging PACT array at Pachmari, indicate the detection of a pulsed main peak at ≥1.5 TeV from the pulsar (Vishwanath et al. 2001). At PeV energies also, the CASA-MIA experiment has not found any statistically significant evidence for pulsed gamma -ray emission at the Crab pulsar radio period (Borione et al. 1997). Earlier, we have used the TACTIC database of 28 hours, recorded during the period Jan.- March 2001, to search for pulsed signal at $E_\gamma \geq 1$ TeV, but no evidence was found for the presence of a statistically significant pulsed γ -rays (Rannot et. al. 2002). We have reanalysed the database and present here, the IE results on the pulsar at higher threshold energies ($E_\gamma \geq 2$ TeV and ≥ 3 TeV).

2. Experimental setup

The γ-ray telescope TACTIC is located at Mt. Abu (24.6° N, 72.7° E, 1400 m asl), Rajasthan, in Western India. Its Imaging Element (IE) uses a tessellated light-collector of 9.5 m^2 area, which is configured as a Davis-Cotton surface, with a spot-size of 0.3° for on-axis parallel rays. The PC-controlled 2h -axes drive system gives a pointing accuracy of better than 5 arc-mins. The pixel resolution of its imaging camera is $\sim 0.31°$ throughout the camera field and a field of view (FoV) of $\sim 6° \times 6°$. The innermost 240 pixels (15× 16 matrix) are used for event-trigger generation, based on the 3NCT (Nearest Neighbour Non-Collinear Triplets) topological logic, demanding ≥ 7 pe's for the 3 pixels which participate in the trigger-generation (Kaul et al, 2003). Whenever the single's rate of one or more pixels goes outside the preset operational band (3 - 7 kHz), it is automatically restored to within the prescribed range by appropriately adjusting the pixel(s) high voltage(s). The resulting change in the pixel(s) gain is monitored by repeatedly flashing a bright LED lamp, improvised to produce a homogeneous light field over the entire camera surface (Bhatt et. al, 2001). From the logged digital counts (dc), the relative gains of all the pixels are derived with respect to 4 'calibration' pixels for which the high voltage is always kept fixed. In addition, these pixels, which are located on the 4 edges of the camera, are provided with Am^{241}-embedded scintillator pulsers for on-line absolute calibration. The absolute occurrence time of each individual event is recorded with a resolution of 1μs and an absolute accuracy of about ±20 μs, using GPS provided reference time-markers for synchronization of the local clock.

3. Data Analysis and Results

Each Cherenkov image is characterized by using a moment analysis (Hillas 1985). The roughly elliptical shape of the image is described by the length and width parameters and its location and orientation within the field of view are given by the distance and α parameters, respectively. The amount of light in the image is estimated by the parameter called the size. Various dynamical cuts, used in the analysis to extract gamma-ray signal from the large background of hadronic showers are shown in the Table 1. The variable Npix, used in the Table is the minimum number of pixels required to qualify an event in the γ domain.

Table 1. Dynamical-cuts used in the analysis

$0.08° \leq$ Width $\leq (0.025+0.025*\ln(\text{size}))°$
$0.11° \leq$ Length $\leq (0.23+0.025*\ln(\text{size}))°$
$0.5° \leq$ Distance $\leq 1.2°$
Npix ≥ 4
Size ≥ 300 and ≥ 450 dc

For the energy sensitive pulsed signal search in the above mentioned database, two size cuts ($\geq$300 and $\geq$450) corresponding to threshold energies of 2 and 3 TeV have been used. The obtained α plots are shown in the Figure 1 (top) . Here, it may be noted that for the TACTIC IE gamma-ray domain in the α plot is $\alpha \leq 15$ ° (Koul et al. 2002) and this value has been used for selecting events for pulsed gamma-ray signal search.

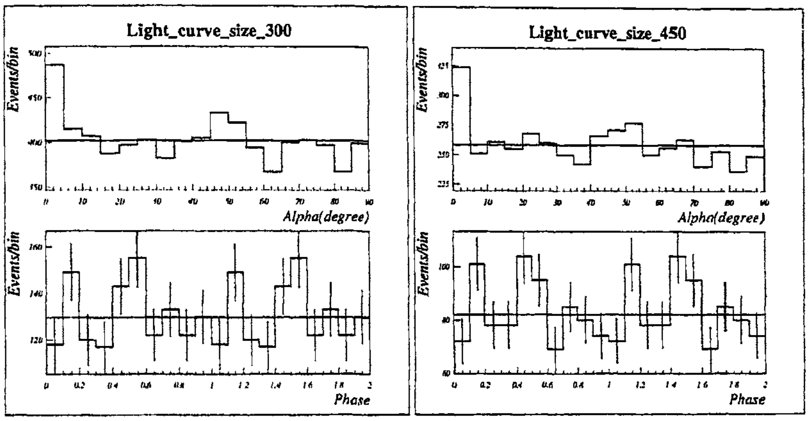

Figure 1. (Top), Alpha distributions of events recorded from the Crab direction after standard cuts (size $\geq$ 300 (2 TeV) and $\geq$ 450 (3 TeV) digital counts) and (bottom) ten bin light curves for events with alpha $\leq$ 15 deg. for corresponding size cuts

Accordingly, corrected arrival times of all selected events were barycentered by using JPL DE 200 ephemeris and contemporary values of pulsar frequency and its derivative were used from Jodrell Bank database to calculate the absolute phase of each event. The resulting 10 bin phasograms, for two threshold energies, mentioned above, have been shown in Figure 1 and are characterized by χ^2 values of 12.96 and 16.2 respectively. The chance origin probabilities for obtaining these χ^2 values, turn out to be 0.1 and 0.02 for the 2TeV and 3TeV phasograms respectively, which indicate consistency with the uniform distributions and favour acceptance of the null hypothesis. Therefore, we do not find any evidence for the presence of any statistically significant pulsed signal in any of the phasograms shown at the bottom of Figure 1. We place the upper limits of 1.08×10^{-12} and 8.88×10^{-13} photons cm^{-2} sec^{-1} for the 2TeV and 3TeV phasograms respectively. These upper limits are in close agreement with the results of the Whipple observatory (Lessard, et al, 2000) and the preliminary results of the TATA group (Vishwanath et al, 2001) on the same pulsar.

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