Observations of the Crab Nebula with the Second HEGRA Cherenkov Telescope

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Abstract

The HEGRA collaboration is constructing a system of 5 imaging Cherenkov telescopes which will be part of the HEGRA cosmic–ray detector complex on the island of La Palma (2200 m asl.). Since the completion of the second telescope at the end of 1993 two air Cherenkov telescopes are used to search for discrete VHE γ sources. One identified source is the Crab Nebula. VHE γ–emission has been detected from this object with a significance of more than 7 σ based on 100 hours on–source observation time. Calculations for the absolute flux will be presented.

1 Introduction

The Crab Nebula was the first VHE γ source identified at a high level of statistical significance. This observation was made by the Whipple collaboration [1] using a 10 m air Cherenkov telescope and the image analysis technique proposed by Hillas [2]. Other reports including the study done by the HEGRA collaboration with their first telescope [3] established this object as an emitter of photons in the TeV range. In order to use the Crab Nebula as a so-called standard candle for cosmic–ray detectors it is necessary to carry out very detailed studies especially with regard to the calculation of the flux and the spectral index. Based on this motivations the HEGRA collaboration performed further observations using their second Cherenkov telescope with a 8.5 m^2 reflector. Here we report on results of the analysis of data recorded with this telescope during the observation periods in 1994 and 1995.

2 The second HEGRA telescope

Telescope 2 was installed in 1993 and the first data were taken in December 1993. It has an alt–azimuth mount and is equipped with 30 spherical mirrors of circular shape and a diameter of 60 cm. The total mirror area corresponds to 8.5 m^2. A 2500 Å thick coating of SiO_2 on the aluminium front surface guarantees a long term weather protection.

The camera in the focal plane consists of 61 12–stage photomultipliers. In order to enhance the light collection efficiency each photomultiplier (PM) is

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optically coupled to a plexiglas light guide which has the shape of a truncated cone with a hexagonal front face and a round face on the PM side. These light guides are transparent to UV light above 300 nm. The resulting shape of the camera is a hexagon with an angular size of 3.9°. The angular size of each pixel is 0.43°.

Each PM is connected to a constant fraction discriminator and — via a suitable delay — to a charge integrating ADC. The discriminator thresholds are set to a level corresponding to 20 photoelectrons. The logic outputs of the discriminators are summed up in a majority logic unit, where triggers are generated if at least two pixels fulfil the trigger condition, i.e. a coincidence of two signals with more than 20 photoelectrons per pixel. The trigger signal opens the ADC gates and latches the universal time information from a Rubidium clock of 200 ns least count. Finally the event information is written to a hard disk of an Apple Macintosh II. This Macintosh controls also the tracking and the data acquisition. The on–line readout is done via a CAMAC system.

For the following analysis it is important to take into account the small differences between the electronic channels of the camera due to non-identical characteristics of their components. Therefore a calibration system is necessary to check periodically the PM gains during the measurements. For the hardware calibration of the camera a nitrogen laser is used which illuminates an organic scintillator (type NE 102A) acting as a wavelength shifter. This scintillator is positioned in the centre of the reflector to ensure homogeneous illumination of all photomultipliers in the camera.

Many of the parameters of this telescope are equal to those of the first telescope which has been described previously [4].

3 Analysis and results

The observations of the Crab Nebula used for the analysis were performed between September 1994 and March 1995 using the on/off tracking technique. The zenith angle ranged from 7° to 45°. Each on- and off–source run lasted 20 minutes. During the on–source runs the bright star ζ Tauri was present in the field of view moving across different pixels because the reflector is on an alt–azimuth mount. Hence it was not possible to remove single channels from the trigger logic during the observations. This has to be taken into account for the analysis. Due to this effect the rate was higher than expected without a star in the field of view and many spurious events were recorded. Several methods have been developed to treat such a case. They will be discussed in section *(2)*.

The following passages describe the consecutive procedures applied to the runs to extract the important data.

(1) Run selection. In the first step on/off run pairs were excluded if the data acquisition was disturbed by changing weather conditions or irregularities in the trigger rate, e.g. caused by background light of the moon. Those runs, which included only a short term disturbance (e.g. light from passing cars), were accepted, but for the period of the disturbance the events were rejected. In addition the same period was exluded for the corresponding run partner.

(2) Treatment of ζ Tauri. To eliminate the influence of the star ζ Tauri we have tested three different methods after the run selection:

(a) The raw data were submitted to a software trigger to reconstruct the hardware trigger. This software trigger accepts all events which have at least 2 pixels fulfilling the trigger condition $2/37 > q_0$ (q_0 is the trigger threshold) except those pixels with ζ Tauri in it. Hence for each on–source run all pixels with ζ Tauri inside were determined. These pixels were also excluded from the software trigger for the complementary off–source run to avoid systematic changes between on- and off–source data. Next in each on/off run pair the ADC values were set to zero for the affected pixels.

(b) The 'software padding lamps' approach [5] was used. For each pair of on/off–source runs the 'padding sigmas' $\sigma_{pad} = \sqrt{\sigma_{on}^2 - \sigma_{off}^2}$ were calculated. Then an additional background was implemented in the off–source runs choosing random numbers from the Gaussian distribution with $\sigma = \sigma_{pad}$. Finally the software trigger $2/19 > q_0$ or $2/37 > q_0$ ($q_0 = 20$ photoelectrons) was applied to the data. Pixels having additional light due to the star were excluded from the trigger.

(c) The events were filtered by the software trigger and were cleaned by the image preparation procedures described in *(3)*. Then all events, which have its shower centre inside the pixels influenced by the star ζ Tauri and inside a defined range around these pixels, were rejected.

The determination of those pixels with ζ Tauri inside required for the methods *(a)* – *(c)* was done using the broadening of the ADC spectra due to the star.

(3) Image preparation. In the third step the pedestal value for each pixel was subtracted and the gain differences determined by the laser calibration data were corrected. This procedure was also performed before applying the software trigger if the star ζ Tauri was treated by the methods described in *(2b)* and *(2c)*. Next all ADC values lower than c_1=5 photoelectrons were set to zero (static tail–cut). Pixels with more than 5 photoelectrons but no neighbouring pixel with at least c_2=15 photoelectrons were treated equally.

In a second and third analysis method a dynamical tail–cut has been applied to the data. Here the parameters c_1 and c_2 were determined by the RMS pedestal deviation σ for each pixel. In order to check the stability of our results against reasonable changes of c_1 and c_2 we used two sets of parameters: c_1=3.5, c_2=5.5 and c_1=2.25, c_2=4.25. Finally the Hillas parameters were calculated for each event.

(4) Event filtering. The events were filtered by several cuts. These cuts exclude events caused by cosmic ray muons, events near the margin of the field of view or events with only two pixels fulfilling the trigger condition. In detail the cuts applied to the data to accept an event were: a) total number of ADC channels $\geq Q_0$ (where Q_0 is typically 150 ADC channels), b) concentration < 1.0, c) $0.4° \leq$ distance $\leq 1.4°$, d) 2 < numbers of pixels including the image < 25 and e) the centre of the image is not in the outer ring of pixels.

In order to select the data with regard to an enrichment of photon induced showers a cut on the azwidth parameter was applied to the data. This cut leads to an excess corresponding to a statistical significance of more than 7 σ based on 100 hours on–source observation time. The signal could be enhanced to a significance above 10 σ by applying supercuts. The calculation of the absolute flux of γ–rays was done on the base of Monte Carlo simulations [6]. Detailed results will be presented at the conference.

4 Conclusions

During the period September 1994 – March 1995 the HEGRA collaboration searched for VHE γ–emission from the direction of the Crab Nebula. The analysis of 100 hours on–source observation time carried out with a 8.5 m^2 telescope reveals an excess corresponding to a statistical significance of more than 7 σ. After applying supercuts the absolute flux could be calculated.

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