Proceedings of ICRC 2001: 2407 © Copernicus Gesellschaft 2001

ICRC 2001

Observation of the Crab Nebula with the HEGRA system of IACTs using an advanced topological trigger

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Abstract. The HEGRA system of 5 imaging atmospheric Čerenkov telescopes (IACT) has an energy threshold of about 500 GeV in observations of γ-rays at zenith. We have made observations of the Crab Nebula for a total time of about 15 hrs using the *topological trigger* which allows to reduce noticeably the energy threshold of the system. The expected detection rates of cosmic rays and γ-rays, as well as the corresponding energy thresholds, were calculated using the Monte Carlo simulations. The test runs with the HEGRA IACT system have been done in order to establish the minimum threshold for the topological trigger. The final results of the data analysis will be presented at the conference.

1 Introduction

The system of 5 imaging atmospheric Čerenkov telescopes (IACTs) was built by the HEGRA (*High Energy Gamma-Ray Astronomy*) collaboration at La Palma, Canary Islands. Each of 5 telescopes has a reflector of 8.5 m^2 area and is equipped with the imaging camera, which consists of 271 pixels of an angular size of 0.25° each. The HEGRA IACT system was effectively used for the observations of the γ-rays from the galactic sources, i.e., Crab Nebula, Cas A, Tycho's SNR etc (for review see Völk et al. (1999)), as well as the extragalactic objects, in particular Mkn 421, Mkn 501 (e.g. see Kohnle et al., (2001)). The estimated energy threshold of the system is about 500 GeV. The effective dynamic energy range expands from 500 GeV up to 20 TeV, as it was shown in the long-term observations of the well established TeV γ-ray source - Crab Nebula (Aharonian et al. (2000)). Note that the HEGRA data allowed to measure the Crab Nebula spectrum with high accuracy over the entire dynamic energy range. The Inverse Compton (IC) modeling of the γ-ray spectrum from the Crab Nebula, taken along with the EGRET detection at GeV energies (de Jager et al., (1996); Atoyan, Aharonian (1996)) predicts the substantial flattering of its spectrum down to energies of 200-300 GeV, whereas above 1 TeV the spectrum has rather a power-law shape of a spectral index 2.6. The measurement of such change of the spectrum slope will constrain the IC models of γ-ray emission. Even though there were measurements of the γ-ray fluxes at 190 GeV with STACEE (Oser et al., (2000)) and at 250 GeV with CELESTE (Barrau et al. (1997)), these results inherited a certain systematic and statistical uncertainties which unable to make final joint fit of these data together with the measurements provided by the IACTs usually above 1 TeV. Here we propose a new approach to detect the low energy γ-rays with the system of HEGRA IACTs by use of a *topological system trigger* which allows to reduce the trigger threshold and correspondingly the energy threshold down to 300 GeV.

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2 Monte Carlo studies

Most of its operational time the HEGRA IACT system was running using the two-level trigger. The system telescopes trigger "locally" when the signals in at least two pixels (PMTs) exceed a given threshold of 7-8 ph.e., whereas for the second "global" trigger two telescopes are required to trigger in coincidence (see Bulian et al., (1998)). Any of two neighbouring pixels out of 271 could trigger the camera, and the trigger zone embraces entire camera field of view, which is of 4.3° in diameter. The detailed comparisons of the actual hardware event rate with the simulations for a different trigger configurations and threshold was given in Konopelko et al. (1999).

Here using the HEGRA Monte Carlo simulations we have estimated the detection rates of cosmic rays and γ-rays, as well as the energy threshold of the γ-rays for the HEGRA IACT array running with the *topological system trigger*. For the topological system trigger one has to use the restricted trigger zones within the camera field of view, which are adjusted to the regions of the most frequent appearance of the γ-ray images. For instance the restriction on the impact distance from the center of the IACT system at 50 m determines the specific distribution of the γ-ray events in the telescope's camera focal plane (see Fig. 1). One can see in Fig. 1 that the events are localized within the angular area corresponding to 19-37 camera pixels. The position of the trigger zone differs for each telescope and it is determined by the geometrical layout of the telescopes in the system.

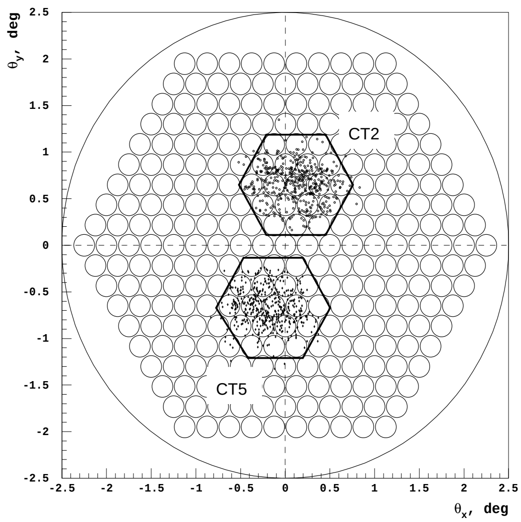

Fig. 1. Two-dimensional distribution of the centroid positions for the γ-ray showers, which triggered the HEGRA IACTs array and passed the selection of the impact distance from the center of the system by less than 50 m given for two of the telescopes of the system – CT2 and CT5. Simulations have been done for the showers at zenith.

2.1 Rates

We made calculations for two different trigger modes: (1) 4 telescopes out of 5 have to trigger by an event under the local trigger condition $2\mathrm{nn}/271 > \mathrm{q}_0$, where q_0 is a trigger threshold measured in photoelectrons; (2) 4 telescopes out of 5 have to trigger but under the local trigger condition $2\mathrm{nn}/19 > \mathrm{q}_0$, whereas 19 pixels have been selected for each telescope according to the established trigger zone. The detection rates of cosmic rays and γ-rays calculated for the different trigger thresholds (q_0) are shown in Fig. 2. Most of its observational time the HEGRA system of IACTs was running with the trigger threshold set at $\simeq 8$ ph.e. It corresponds to the detection rate of about 4 Hz for the 4-telescope coincidences. Note that the detection rates of the cosmic rays differ by a factor of about 10 for two trigger modes (see Fig. 2). It also roughly agrees with the simple estimate based on the number of the pixels in the trigger – $271/19 = 14$. In reality the effect of the camera edge introduce a certain reduction of the rate in standard trigger mode.

For the topological trigger (2) with the trigger threshold at 4 ph.e. the cosmic ray detection rate is about 1.15 Hz. That is somewhat higher than the measured rate. However, given a not perfect adjustment of the trigger window for the rate measurements (due to a certain pointing error) as well as slight difference between a Monte Carlo assumed trigger threshold and actual one (e.g., due to the reduced mirror reflectivity etc) one can conclude a rather good agreement in measured and calculated rates.

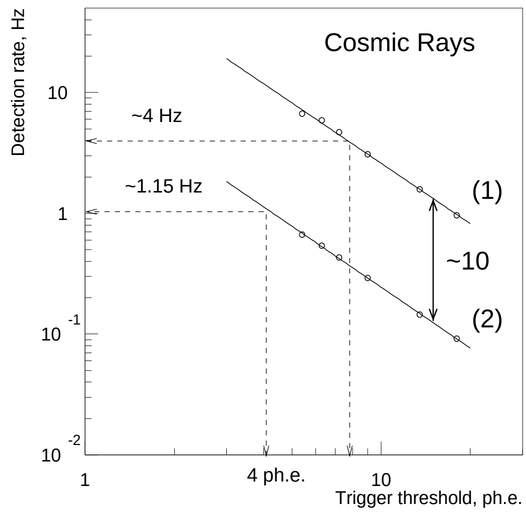

Fig. 2. Detection rates of the cosmic rays for two different trigger modes (1) – 4 telescopes out of 5, $2\mathrm{nn}/271 > \mathrm{q}_0$, and (2) – 4 telescopes out of 5, $2\mathrm{nn}/19 > \mathrm{q}_0$, where q_0 is a trigger threshold measured in photoelectrons.

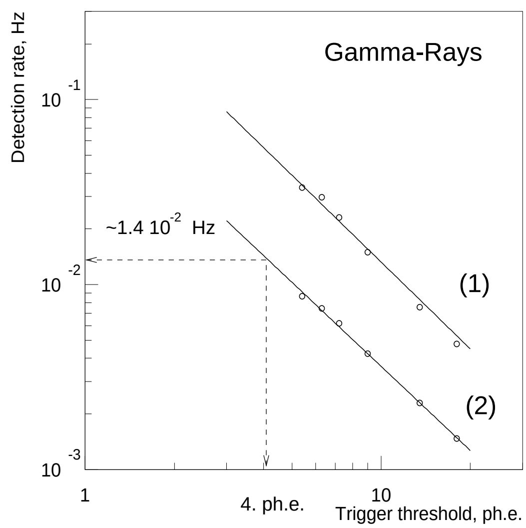

Fig. 3. Detection rates of the γ-rays for two different trigger modes (see caption for Fig. 2).

For the same topological trigger (2) the calculated γ-ray rate is of about $1.4 \cdot 10^{-2}$ Hz (53 γ's per hr) (see Fig. 3). Here we assume the Crab Nebula energy spectrum of the γ-rays. The peak of the differential detection rate corresponds to the effective energy threshold of the system for a particular trigger mode. Thus the dependence of the evaluated energy threshold on the trigger threshold might be well fitted as

$$log(E) = -1.0634 + 0.89 \cdot log(q_0). \quad (1)$$

Thus for the topological trigger mode and conventional trigger threshold (q_0 = 8 ph.e.) the energy threshold is about 500 GeV whereas for the reduced trigger threshold (q_0 = 4 ph.e.) the energy threshold is of $\simeq$ 300 GeV. This estimate of the trigger might have a systematic error due to the extrapolation to the lower threshold of about 50 GeV.

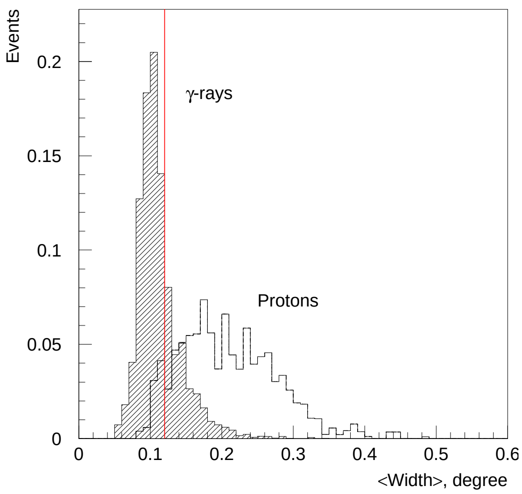

Fig. 4. Distributions of the parameter $< W >$ for the cosmic ray and γ-ray showers. The vertical solid line indicates the cut applied in the analysis, $< W > \leq 0.12°$.

2.2 Analysis

The triggered cosmic ray and γ-ray events can be plotted over *mean Width* $< W >$, weighted with the image size, for each individual event:

$$< W >= \sum_i^N A_i W_i / \sum_i^N A_i \quad (2)$$

where W_i and A_i are image Width and image size for each telescope out of N (N=4 or 5). The mean image size is given by

$$< A >= \frac{1}{N} \sum_i^N A_i \ . \quad (3)$$

Both distributions of cosmic ray and γ-ray events are shown in Fig. 4. One can see in Fig. 4 that the parameter $< W >$ enables rather good cosmic ray rejection. The corresponding quality (enhancement) factor is Q = 2.5. The after-cut γ-ray acceptance and cosmic ray contamination are $k_\gamma \simeq 0.72$, $k_{CR} \simeq 0.082$, respectively. In this analysis all γ-ray events were concentrated at small impact distances and additional scaling of the Width parameter over the impact distance does not make any difference in the results.

Table 1. Summary of the test runs taken with the HEGRA system of IACTs.

G/G_0	q_o [mV]	q_o phe	System rate [Hz]	Telescope rate [Hz]	Pixel rate [Hz]
1.0	8	6.7	0.41	1÷7	300
1.53	8	4.38	0.64	5÷92	2000
1.45	**7**	**4.04**	**0.89**	**8÷320**	**4000**
1.43	6	3.51	0.94	37÷1800	10000
2.07	8	3.24	0.19	220÷7700	15000
1.89	7	3.10	0.02	14000÷85000	30000
2.40	8	2.79	0.00	15÷3700	40000

The sensitivity of the HEGRA IACT system running with the topological trigger for the reduced trigger threshold can be estimated as

$$\mathrm{S/N} = \mathrm{R}_\gamma/(\mathrm{R}_{\mathrm{CR}})^{1/2}\mathrm{Q}\sqrt{\mathrm{t}} \ . \quad (4)$$

For 1 hr observation the signal-to-noise ratio is expected to be of about $\mathrm{S/N} \simeq 2.05\sigma$. The observations for 15 hrs will allow a detection of the Crab Nebula above $\simeq 300$ GeV at the confidence level of $\sim 8\sigma$. Searching for a pulsed γ-ray emission using additional phase analysis gives an improvement of a Q-factor in two times, which determines the sensitivity at the level of $\mathrm{S/N} \simeq 4.0\sigma$ per 1 hr.

3 Tests on trigger threshold

In September 2000, the configuration for the lowest possible threshold and the stability for ON-OFF viewing mode were tested for the HEGRA IACT system. The threshold was lowered both by decreasing the threshold of the discriminator as well as by increasing the high voltage (HV) of the PMTs. 19 pixels were included in the trigger for each camera, with the position of the 19 pixels calculated from the altitude and azimuth of the viewing angle and the position of the telescopes in the array. The system was running in the 4-telescope coincidence mode. The data runs were taken in normal data taking mode (wobble mode), with the altitude of about 80°. The Table 1 gives an overview of the configurations that were tested. Listed are the gain of the PMTs with respect to the nominal gain as calculated from the mean anode currents, the discriminator threshold in mV, the threshold in photoelectrons, and the system, telescope, and typical single pixel rates. The ratio G/G_0 shows the change of the gain after decreasing the threshold. G_0 is the nominal value of gain.

The lowest stable trigger threshold was 4.0 photoelectrons, with a PMT gain of ~1.5 times the nominal and a threshold of 7 mV (listed in bold type in the table). The system trigger rate was 0.9 Hz. The nominal threshold is 6.7 photoelectrons, with a threshold of 8 mV, and 1.2 mV/photoelectron.

The stability of this configuration was tested again later for three 10-minute runs being taken each at altitude of 80°. Within given statistics, the system trigger rate was the same for all three runs.

4 Conclusion

Using the Monte Carlo simulations and the test runs with the HEGRA system of 5 IACTs we have shown the possibility to perform the observations of the γ-rays with the energy threshold as low as 300 GeV. The Crab Nebula data were taken in fall of 2000 for a total of 15 hrs to check the performance of the system in such observational mode. The results of the analysis will be presented at the conference.

Acknowledgements. The support of the HEGRA experiment by the German Ministry for Research and Technology BMBF and by the Spanish Research Council CYCIT is acknowledged. We are grateful to the Instituto de Astrofisica de Canarias for the use of the site and for providing excellent working conditions.

References

Aharonian et al. (HEGRA collaboration), ApJ, 539:317-324 (2000)
Atoyan, A., Aharonian, F., MNRAS, 278, 525 (1996)
Barrau, A., et al. Towards A Major Atmosph. Čeren. Detector V, ed. O.C. de Jager (Potchefstroom, South Africa: Potchefstroom Uni.), 166 (1997)
Bulian et al., Astropart. Phys., Vol. 8, 4, 223 (1998)
de Jager, O.C., et al., ApJ, 457, 253 (1996)
Kohnle et al. (HEGRA collaboration), this proceedings (2001)
Konopelko et al. (HEGRA collaboration), Astropart. Phys., 4, 199 (1999)
Oser et at., ApJ, 547, 949 (2001)
Völk et al., GeV-TeV Gamma Ray Astrophysics Workshop, "Towards a Major Atmospheric Čerenkov Detector VI", Snowbird, Utah, Eds. B. Dingus, M. Salamon, D. Kieda, 197 (1999)