Study of the Performance of a Single Stand-Alone H.E.S.S. Telescope: Monte Carlo Simulations and Data

A. Konopelko,[1] W. Benbow,[1] K. Bernlöhr,[1,6] V. Chitnis,[2,*] A. Djannati-Ataï,[3], J. Guy,[2] W. Hofmann,[1] I. Jung,[1] N. Leroy,[4] S. Nolan,[5,**] J. Osborne,[5] M. Punch,[3] S. Schlenker,[6] for the H.E.S.S. collaboration
(1) Max-Planck-Institut für Kernphysik, Heidelberg, Germany
(2) LPNHE, Universités Paris VI - VII, France
(3) PCC Collège de France, Paris, France
(4) Laboratoire Leprince-Ringuet (LLR), Ecole polytechnique, Palaiseau, France
(5) Durham University, U.K.
(6) Humboldt Universität Berlin, Germany
* now at Tata Institute of Fundamental Research, India
** now at Purdue University, U.S.A.

1. Introduction

The High Energy Stereoscopic System (H.E.S.S.), a system of four 12 m imaging Cherenkov telescopes is currently under construction in the Khomas Highland of Namibia [1]. The first telescope has been taking data since June 2002. An extended sample of cosmic ray images recorded in observations at different elevations, as well as a representative sample of γ-ray showers detected from the Crab Nebula after a few hours of observations at about 45° in elevation, along with simulated data, give an opportunity to study the telescope performance in detail.

2. Telescope

The telescope mount holds 380 mirrors of 60 cm each, which results in a 107 m^2 reflecting area. The mirrors are arranged in the Davies-Cotton design for $f/d \simeq 1.2$. The point spread function is such that the radius containing 80% of the light is about 0.4 mrad on-axis and 1.8 mrad for 2.5° off-axis. The point spread function is well-reproduced by simulations [2]. The mirror reflectivity varies between 78% to 85% in the wavelength range from 300 to 600 nm. The telescope reflector focus the light onto a high resolution imaging camera. About 11% of the incident or reflected light is obscured by the camera support structure. Winston cones are placed in front of the camera in order to optimize the light collection efficiency. Efficiency of Winston cones averaged over wavelength range is about 73%. The imaging camera consists of 960 PMs (Photonis XP2960) of 0.16° each, and has a 5° field of view. A typical quantum efficiency of PMs exceeds 20% over the

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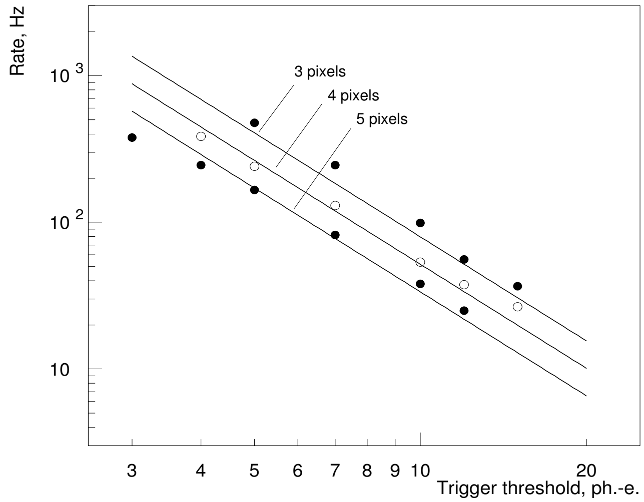

Fig. 1. Comparison between the measured (circles) and computed trigger rates (solid lines) for different trigger settings.

wavelength range from 300 to 500 nm and has a maximum efficiency of 26% around 400 nm. The overall detection efficiency, averaged in a range from 200 nm to 700 nm, is about 0.06.

The H.E.S.S. site has a mild climate with well-documented optical quality. It is at 1800 m above the sea level and is relatively far away (about 100 km) from the nearest city of Windhoek, a potential source of light pollution. The illumination of camera PMs by the night sky background corresponds on average to a photo-electron rate of 80-200 MHz. The estimated contamination of the aerosols above the site is rather low. After taking into account the atmospheric absorption the overall detection efficiency is about 0.036.

3. Simulations

An extended library of air showers induced by primary γ-rays, protons, and nuclei was generated using a number of Monte Carlo codes available to the H.E.S.S. collaboration, ALTAI, CORSIKA, KASCADE, and MOCCA. Possible systematic uncertainties in parameters of the Cherenkov emission caused by a specific shower generator were studied in detail. Air showers were simulated within the energy range from 10 GeV to 30 TeV, and for a number of elevations in a range from 30° up to the Zenith. The angle of incidence of cosmic ray showers was randomized over the solid angle around the telescope optical axis with a half opening angle of 5° in order to simulate the isotropic distribution of arrival directions. Position of shower axis was uniformly randomized around the telescope over the area limited typically by a radius of 1000 m.

A procedure of simulating the camera response accounts for all efficiencies of the

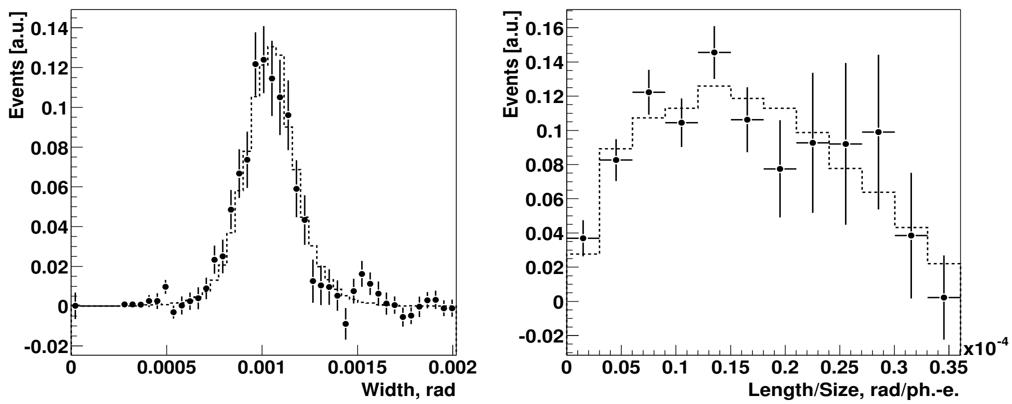

Fig. 2. Distributions of image parameters $Width$ and $Length/Size$ for the γ-rays detected from the Crab Nebula (dots with the error bars) as well as for the simulated γ-ray images (histogram).

Cherenkov light transmission on the way from the telescope reflector to the single camera pixel. A single photo-electron response function, measured for a number of PMs, was implemented to model the PM output. Simulations trace the propagation time for each individual photon in a shower, as well as all delays related to the design of the optical reflector, PM time jitter etc. An individual photo-electron pulse shape was introduced according to the detailed time profile measured for the current electronics setup. The signal recording procedure conforms to the actual hardware design based on 1 GHz ARS ASIC with the signal integration time of 16 ns. The comparator-type trigger scheme demands a coincidence of 4 pixels in one of 38 overlapping groups of 64 pixels each but fewer near the edges of the camera. The currently used PMs trigger threshold is 140 mV, which roughly corresponds to 5 photoelectrons. The effective time window for the pixel coincidence was set to 2 ns.

4. Event Rate

The telescope trigger rate was measured for a number of pixel coincidences varying from 2 to 7, as well as for the different values of adjustable pixel trigger threshold within a range from 3 to 15 photoelectrons. A ten-minute technical run was taken for each trigger setup at an elevation about 70°. The simulated trigger rates reproduce the measured rates for all trigger setups with an accuracy of typically 25% (see Figure 1). For the default trigger setup (4-fold pixel coincidence with a pixel signal above 5 ph.-e.) a dead-time unfolded telescope event counting rate is about 255 Hz at an elevation of 80°. Given the read-out time of 1.5 ms during these early measurements it corresponds to a dead time of 40%. The Monte Carlo predicted rate is 253±18(stat)±53(syst) Hz. Air showers from cosmic ray nuclei provide about 27% of the total event rate. The muon rate represents a substantial fraction of the telescope rate. Despite the fact that muon images mimic very effectively the images from the γ-ray air showers, they offer a powerful tool for the telescope calibration using muon rings [3]. The measured and computed event rate at an elevation of 45° are $\simeq$ 200 Hz and 208 Hz, respectively.

5. Image Analysis

Recorded images have been cleaned using a standard two-level tail cut procedure [4]. The tail cut values were chosen as 5 and 10 ph.-e. For each image a set of second-moment parameters was calculated. Distributions of the image parameters for cosmic ray showers and for γ-ray showers extracted from the Crab Nebula data are in a good agreement with the simulations of these populations (see Figure 2). A set of optimum analysis cuts for elevation of 45° is : $Alpha < 9°$; $Distance < 17$ mrad; 0.05 mrad $< Width < 1.3$ mrad; $Length < 4.8$ mrad; $Length/Size < 1.6 \times 10^{-2}$ mrad/ph.-e.; $Size < 10^5$ ph.-e. This set of cuts results in an acceptance for γ-ray showers at the level of 30% and cosmic ray rejection of 0.02%. It corresponds to the quality factor of about 20.

6. Performance

Applying the analysis cuts listed above to the Crab Nebula data taken mostly at an elevation of 43° one can get a γ-ray rate of about 3.57 ± 0.18 min^{-1}. This rate is consistent within 30% with the γ-ray rate of 2.9 ± 0.18(stat) ± 0.9(syst) min^{-1} derived from the simulations, assuming the Crab Nebula energy spectrum as measured by HEGRA [5]. The background data rate after applying the analysis cuts is 2.5±0.1 min^{-1}. It is also consistent with the expectation based on the simulations, which is 2.3±0.1(stat)±0.6(syst) min^{-1}. The single H.E.S.S. telescope can see the signal from the Crab Nebula at the level of 9σ after one hour of observations. A Crab-like source can be detectable at an elevation of 70° after one hour of observations at the 11σ level. The energy threshold for detected γ-rays is about 180 GeV at an elevation of 70° and rises to 550 GeV at an elevation of 45°.

References

1. Hofmann W. 2003, these proceedings
2. Cornils R., et al. 2003, The optical system of the H.E.S.S. IACTs, Part II, accepted for publication in *Astroparticle Physics*
3. Leroy N., et al. 2003, these proceedings
4. Punch M. 1994, Proc. Workshop "Towards a Major Atmospheric Detector III", Tokyo, Ed. T. Kifune, p. 163
5. Aharonian F., et al. 2000, ApJ, 539:317-324.