HESS - The High Energy Stereoscopic System

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Abstract

The HESS collaboration is planning to build a large Imaging Atmospheric Cherenkov Telescope (IACT) array in the Southern Hemisphere in the Khomas Highland of Namibia. In its final stage, the HESS experiment will have up to 16 telescopes each with a 80 m^2 reflector and a high resolution camera. The schedule foresees to start with scientific operation of the first 4-telescope subsystem in 2002 (Phase 1).

HESS will have a detection threshold of about 40 GeV and an angular resolution of less than a few arcminutes. The flux sensitivity above 100 GeV of 10^{-12} ph/(cm^{2}s) is more than one order of magnitude better than currently achieved in IACT experiments. This should allow the observation of a significant number of objects and new source populations at GeV-TeV energies.

This paper focuses on the performance and the technical realization of the HESS experiment.

1 Introduction

The discovery of TeV gamma-rays from a number of different source classes, the detection of strong variability in blazars correlated with the variability at other wavelengths and other results have shown the great potential of the IACT technique for observations at TeV energies. Nonetheless, the total number of detected sources is still small. In addition, there has up to now been no unambiguous evidence for hadron acceleration in the sources, with most of the observations being compatible with electron acceleration. Finding the hadron accelerators is however decisive for the open question of the origin of cosmic rays.

An increase in sensitivity should dramatically increase the number of sources known to emit VHE gamma-rays, and possibly also lead to the discovery of new source classes. A lower energy threshold leads to increased photon statistics for the already known steady sources, and allows one to detect new sources at larger cosmological distances. Measuring detailed energy spectra gives clues about the nonthermal particle acceleration mechanisms and allows one to study cutoffs due to intrinsic source absorption or absorption by the Diffuse Extragalactic Background Radiation (DEBRA) fields. Many of the predicted gamma-ray emitters (young Supernova Remnants, Galactic Microquasars, giant Molecular Clouds, Galaxy Clusters, Pair Haloes around UHE sources) are extended. A large, homogeneous field of view is a prerequisite for the observation of these types of sources.

2 The HESS experiment

The HESS experiment is a large array of IACTs for the stereoscopic observation of air showers from cosmic gamma rays. The aim of HESS is high sensitivity, low energy threshold, high-resolution spectroscopy, good angular resolution, and a large field of view for the observation of extended sources. Details of the HESS experiment are given in Aharonian et al., 1997a and in Hofmann, 1997. HESS will consist of a total of 16 telescopes in the Khomas Highland in Namibia in the Southern Hemisphere. Each telescope has a segmented 80 m^2 reflector with 15 m focal length. A high-resolution camera with a $\sim$4.3 degree field of view extendable to 5 degrees and a pixel size of 0.16 degrees is at the focal plane. In addition, an optical telescope on the site for multiwavelength observations of variable sources is planned.

3 HESS performance

HESS uses the stereoscopic technique, i.e., the simultaneous viewing of air showers with two or more Cherenkov telescopes under widely varying viewing angles. The stereoscopic technique allows an unambiguous reconstruction of the shower axis, providing a good angular resolution. The determination of the shower core and the multiple images allow a good energy resolution and an effective gamma/hadron separation. Requiring a multi-telescope trigger leads to reduced background due to local muons or night sky noise, making a lower energy threshold possible. Finally, the redundant shower information allows one to control and reduce systematic errors of the determination of energy spectra. The stereoscopic technique has been pioneered by the HEGRA experiment, an array of five identical IACTs on the Canary Island of La Palma (Daum et al., 1997, Aharonian et al., 1999). HESS is a natural successor to HEGRA, with a lower energy threshold and with greatly improved sensitivity.

In order to optimize the HESS design, detailed Monte Carlo studies of low-energy showers have been carried out to determine the energy resolution, angular resolution, and the optimum spacing of the telescopes for different trigger conditions and different pixel sizes (Aharonian et al, 1997b and Konopelko, 1999).

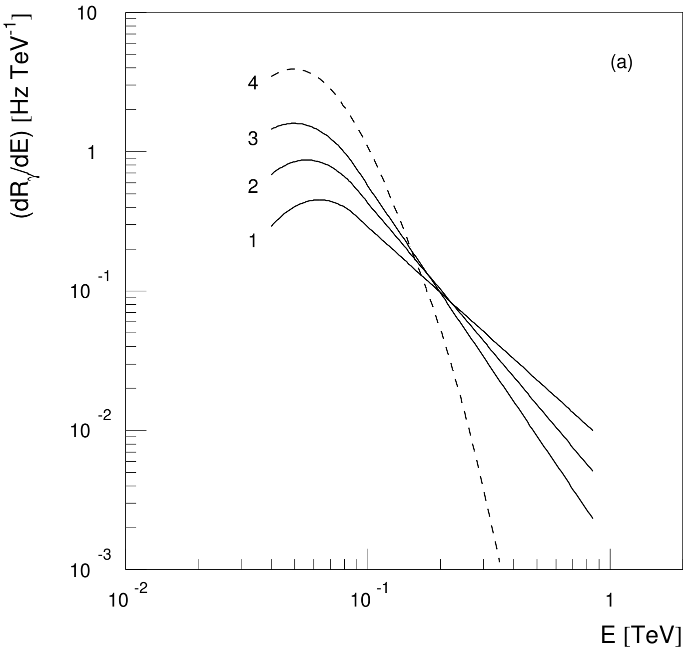

Figure 1: *The detection rates for a flux of* $dN/dE(>100GeV) = 10^{-11}$ *ph/(cm^2 s) and differential spectral indices of 2.0 (curve 1), 2.5 (curve 2), and 3.0 (curve 3) as well as for an exponential cutoff at 50 GeV (curve 4).*

As an example, the detection rate for different source spectra is shown in Fig. 1. The detection rate is shown for a flux $dN/dE(>100GeV) = 10^{-11}$ ph/(cm^2 s) and a power law differential flux with spectral indices of 2.0 (curve 1), 2.5 (curve 2), and 3.0 (curve 3) as well as for an exponential cutoff at 50 GeV (curve 4). The curves are for a zenith angle of 20 degrees, a telescope spacing of 100 m, and a local trigger of 2 pixels above 13 photoelectrons. Defining the energy threshold as the energy of the maximal detection rate gives a threshold of 40 - 60 GeV. The performance of HESS is summarized in Table I. Compared to HEGRA, HESS is one order of magnitude more sensitive.

4 Realization of HESS

4.1 Site Requirements for the site are a documented optical quality, mild weather conditions (no ice or snow), a mountain altitude, and easy access. Furthermore, a site in the Southern Hemisphere is preferred, for complementarity to the Northern Hemisphere experiments, and for favourable viewing conditions of the Galactic Centre region. The HESS experiment will be built in the Khomas Highland in Namibia (Lat. 23° 20' S, Long. 15° 50' E). The site is about 100 km from the next town, the capital Windhoek, and is situated on a farm. The altitude is $\sim$1800 m a.s.l.

energy threshold	40 GeV (detection) 100 GeV (spectroscopy)
angular resolution per primary photon	0.1°
energy resolution per primary photon	20 %
integral flux sensitivity F(E>100 GeV) for 100 h	10^{-12} ph/ (cm^2 s)
minimal energy flux at 1 TeV (100 h)	10^{-13} ergs/ (cm^2 s)

Table 1: *The performance of the HESS experiment.*

4.2 Telescope Structure The foundation, mount, mirror dish, and the alt-az drive will be built by industry. A design study with finite element calculations for the telescope structure has been carried out by Schlaich Bergermann and Partner (Fig. 2). The design foresees a welded steel space frame for stiffness. An alt-az wheel friction drive allows a positioning anywhere on the sky with a precision of 0.01 degrees and a maximal speed of 100 deg. /minute.

4.3 Mirrors and mirror alignment The mirror area is composed of $\sim$300 mirror tiles arranged in a Davies Cotton fashion. The individual mirrors are aluminized, 60-cm diameter glass mirrors with a protective quartz coating. Two companies, COMPAS in the Czech Republic, and GALAKTICA in Armenia, are currently producing the mirrors. Specifications include a tolerance on the focal length of 15 ± 0.25 m, a focal spot containing at least 80% of the light within 1 mrad, and an absolute reflectivity > 80 % over the range of 300 to 600 nm. The mirrors are individually motorized using motors for power windows from car industry. Each mirror is supported by two actuators and a joint. The actuators have a Hall sensor output with 4 μm resolution. The required accuracy is 40 μm, corresponding to 0.1 mrad.

An automatic mirror alignment will use a CCD camera to observe images of stars on the camera lid. The alignment procedure works as follows: each mirror is moved away from the main image, the position is recorded with the CCD camera, and then the mirror is moved to the nominal position. The estimated time for the alignment of all mirrors is $\sim$ 2 h.

4.4 Camera Requirements on the camera are a large field of view and a homogeneous pixel size to have a flat acceptance for gamma showers over the field of view, important for the observation of extended sources.

The camera development is based on the experience gained from the CAT and the HEGRA experiments (Barrau, 1998, Bulian, 1998). The camera consists of $\sim$700 pixels arranged in a roughly circular fashion with each pixel viewing 0.16 degree of the sky, giving a total field of view of 4.3 degrees. Additional rings of pixels can be added to increase the field of view to 5 degrees. The maximal active camera diameter is 1.4 m. Conventional fast photomultipliers (PMTs) with bialkali photocathodes will be used for the first four telescopes, with the possibility to use alternative detectors in the second generation. The high voltage for the PMTs is produced by HV cards containing a DC-DC converter in back of each PMT. A large part of the trigger electronics, analog signal storage, and control and monitoring electronics will be contained in the camera. This provides short paths for the fast analog signals in order to allow short gate times, thereby minimizing the night sky background noise and uncertainties due to timing jitter.

The trigger electronics consist of a first level single pixel trigger and a second level topological trigger in the camera. Depending on the exact trigger condition, the single pixel threshold is 3 to 5 photoelectrons. The third level global trigger fires if a minimal number of telescopes have triggered within a short coincidence window.

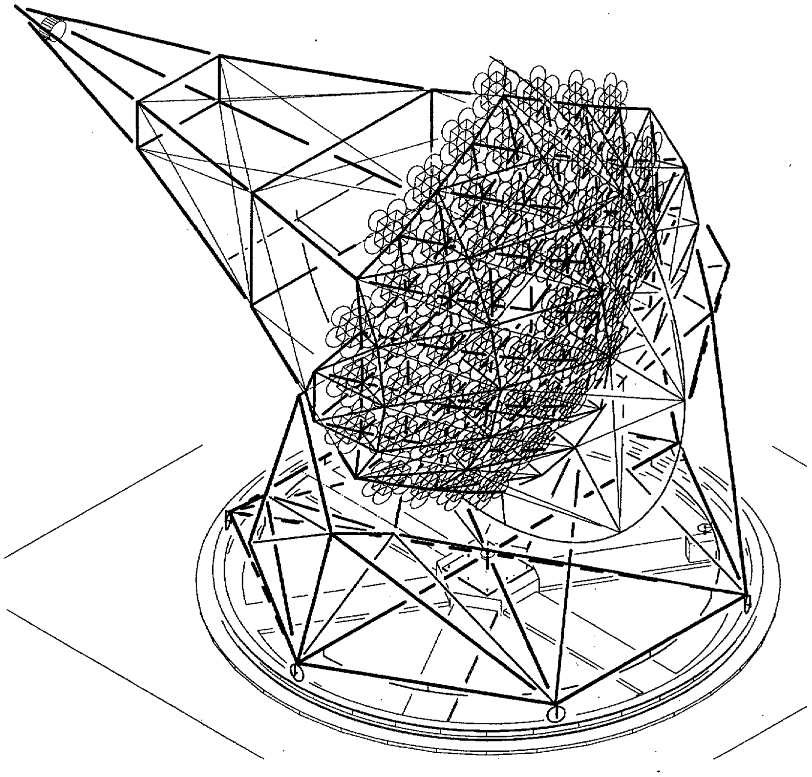

Figure 2: *The telescope structure (design study).*

5 Status and Outlook

All details of the technical implementation of HESS have been under intense study, and most of the major design parameters are now fixed. Prototypes of the mirror actuators and the camera are being tested. The building of the infrastructure on the site in Namibia is foreseen for the beginning of 2000, and the mount of the first telescope should be installed in mid-2000. The start of scientific operation of the first four-telescope subsystem is planned for 2002.

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