H.E.S.S. — the High Energy Stereoscopic System

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H.E.S.S., the High Energy Stereoscopic System, is a new imaging atmospheric Cherenkov telescope project being built up in Namibia. In its first phase, the system will consist of four telescopes with a 13 m mirror diameter and 15 m focal length. Each camera has 960 PMTs and the complete electronics with trigger and readout system included. A processor farm will provide online data processing. The first telescope should be operational before the end of 2001 and the full four-telescope system by the end of 2002.

1 Introduction

After the Whipple [1] collaboration pioneered the imaging atmospheric Cherenkov telescope (IACT) technique in high-energy (HE) γ-ray astronomy, further projects have extended the IACT technique considerably. In particular, the HEGRA [2] telescope system demonstrated the advantages of the stereoscopic method while CAT [3] substantiated the gains of a high-resolution camera. The H.E.S.S. [4,5] project not only combines the expertise gained from HEGRA and CAT but also from other IACT projects.

The importance of spectroscopy for HE γ-ray astrophysics, for example in the case of the Mkn 421 and Mkn 501 objects, was shown with existing IACT projects – but over a rather limited energy range. One of the main aims of H.E.S.S. is to extend spectroscopy over a wider energy range, about 100 GeV to 10 TeV, while further improving gamma-hadron discrimination and angular resolution as compared to current experiments and, thus, the sensitivity. The stereoscopic method is a key ingredient to these goals by providing the accurate shower geometry and several independent views of each shower. Using the full information on shower direction, core position, and height of shower maximum obtained from stereoscopy, an energy resolution approaching 10% is feasible. To take full advantage of that resolution, considerable effort is put into detector calibration and the monitoring of telescopes and atmosphere. The wide energy range to be covered also requires improvements in dynamical range and linearity over existing detectors.

Another important aspect in the design of the H.E.S.S. telescopes has been to map extended sources, from marginally extended sources – requiring high angular resolution and accurate pointing – to really extended sources – requiring a large, homogeneous field of view. To reduce optical aberrations to a level well below the pixel size, H.E.S.S. telescopes have a rather large f/D (focal length / diameter) ratio.

2 H.E.S.S. telescopes

The H.E.S.S. telescopes (see fig. 1) will be instrumented with 380 (nominally: 382) circular mirror tiles of 60 cm diameter in Davies-Cotton design, adding up to a total mirror surface of 107 m^2. The almost hexagonal outline of the mirror dish corresponds to some 13 m diameter, extending to 14.1 m across the corners, while the mirror area corresponds to an 11.7 m circular reflector (without gaps). The mirrors are supported by a rather stiff space-frame made of steel and carried by an Alt-Az mount which shares the load between the central bearing and a set of six wheels on a circular rail.

The focal length is 15 m. The r.m.s. of the point spread function expected for this mirror configuration ranges from 0.03° on-axis to 0.06° at the edge of the field of view. To actually achieve such small spot sizes, each mirror mounting has two motors with actuators for an automatic alignment of the mirror tiles. This procedure will be carried out with closed camera lid, e.g. during moon time, with bright stars projected onto the lid and viewed by a CCD camera. No mirror realignments during normal operation should be needed.

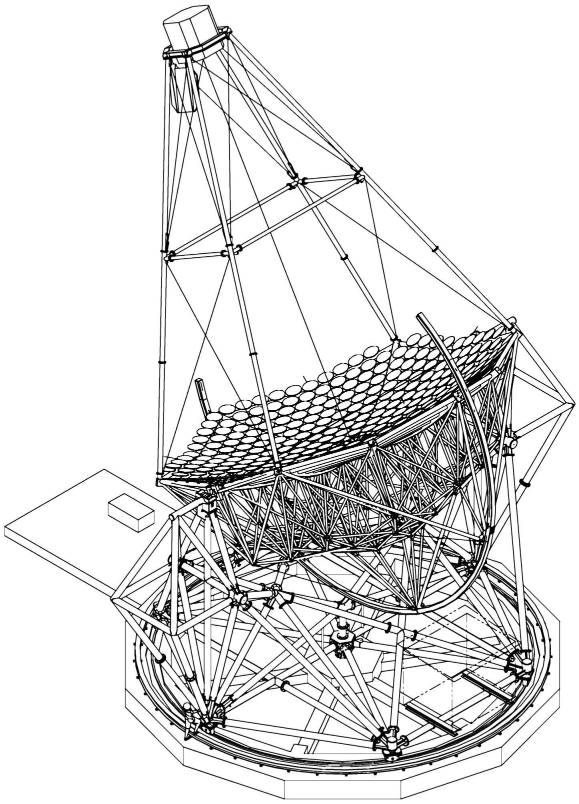

Figure 1: Drawing of a H.E.S.S. telescope.

3 H.E.S.S. cameras

Each H.E.S.S. camera has a total of 960 photomultiplier tubes (PMTs) organised in 60 *drawer* modules. The field of view has 5° diameter. The 42 mm pixel diameter corresponds to 0.16° – as determined by the hexagonal Winston cones in front of the 29 mm PMTs. Each PMT has its own high voltage supply board with active control of the last four dynodes for improved linearity. Each drawer (see fig. 2) holds 16 PMTs but also the analogue and digital electronics needed for them, from preamplifiers, comparators, and a 1 GHz analogue pipeline chip (*ARS*: analogue ring sampler) to multiplexed 12-bit ADCs controlled by programmable gate arrays and a custom bus system for data transfer to the camera host CPU. The telescope trigger electronics and the host interface of the custom bus as well as the CPU itself are contained in two racks in the back of the camera. External connections can, thus, be essentially limited to power supply, system trigger, and communication fibers.

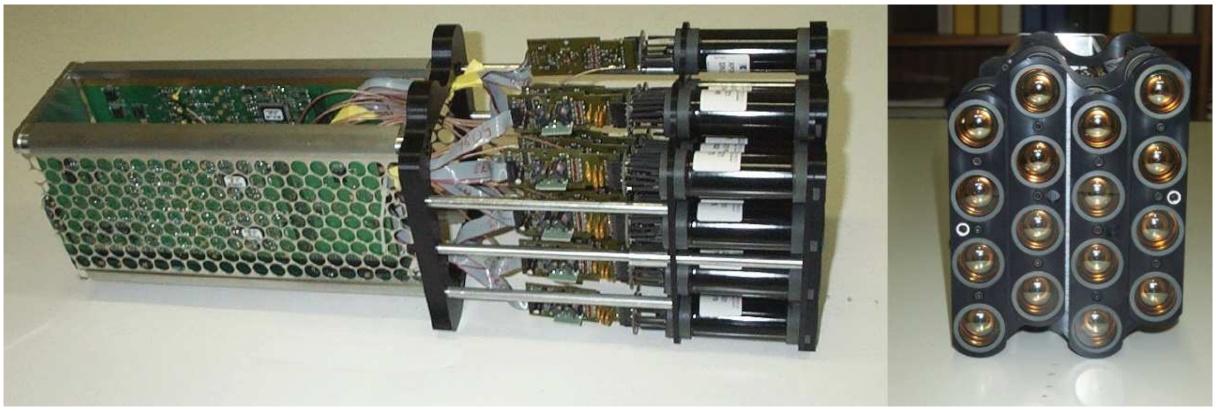

Figure 2: One drawer of a H.E.S.S. camera (left: side view, right: front view; without Winston cones).

To increase the dynamic range, each PMT has two readout channels with different gains. High- and low-gain signals are stored in separate ARS chips to minimise cross-talk. The ARS chips store signals up to 128 ns at 1 GHz, more than adequate for telescope trigger decisions but too short for the system trigger decision which should come 3 μs later. Therefore, the ARS pipeline clock is stopped after a telescope trigger and digitisation of the relevant 10–20 ns of the signal starts. The digitisation is only completed if a corresponding system trigger is received. Otherwise it is cancelled and the ARS clock is restarted. To minimise the amount of data, the gate array normally adds up the 10–20 digitised values for each channel before transferring any data to the CPU.

4 Data acquisition and processing

The H.E.S.S. data acquisition includes a processor farm for online data (pre-) processing. The CPUs of all H.E.S.S. cameras – which deliver the main bulk of data – and the system trigger CPU will send raw data to one farm node for an interval (time slice) of a few seconds, after which they switch over to the next one. Data from other nodes, like those controlling and monitoring telescope tracking, which comes in at a much lower rate, can be distributed to all farm processors. After a farm processor has received all relevant data for a time slice, raw event data is merged and stored on local disks for later reprocessing. Preliminary data processing and shower reconstruction is carried out immediately. Results are collected and further analysed for γ-ray signals at one place. The system also allows to operate sub-systems independent of each other even when they share the central trigger system. During daytime, a second processing with updated calibration constants may follow before raw data blocks from the farm nodes are collected on a single machine and stored on tape.

5 The site and H.E.S.S. status

The H.E.S.S. site is in Namibia, near the Gamsberg mountain, at an altitude of 1800 m a.s.l. In contrast to the plateau on top of Gamsberg (2400 m a.s.l.), the final site offers easy access for heavy vehicles. Compared to other candidate sites considered, the site in Namibia offers suitable climatic conditions to dispense with shelters for the telescopes, provides very clear skies, in particular during the longer winter nights, and optimum observing conditions for the inner part of the Galaxy.

Phase I of H.E.S.S. will see four telescopes, in a square configuration of 120 m. A control building also housing the system trigger will be located just outside the square. Steel and

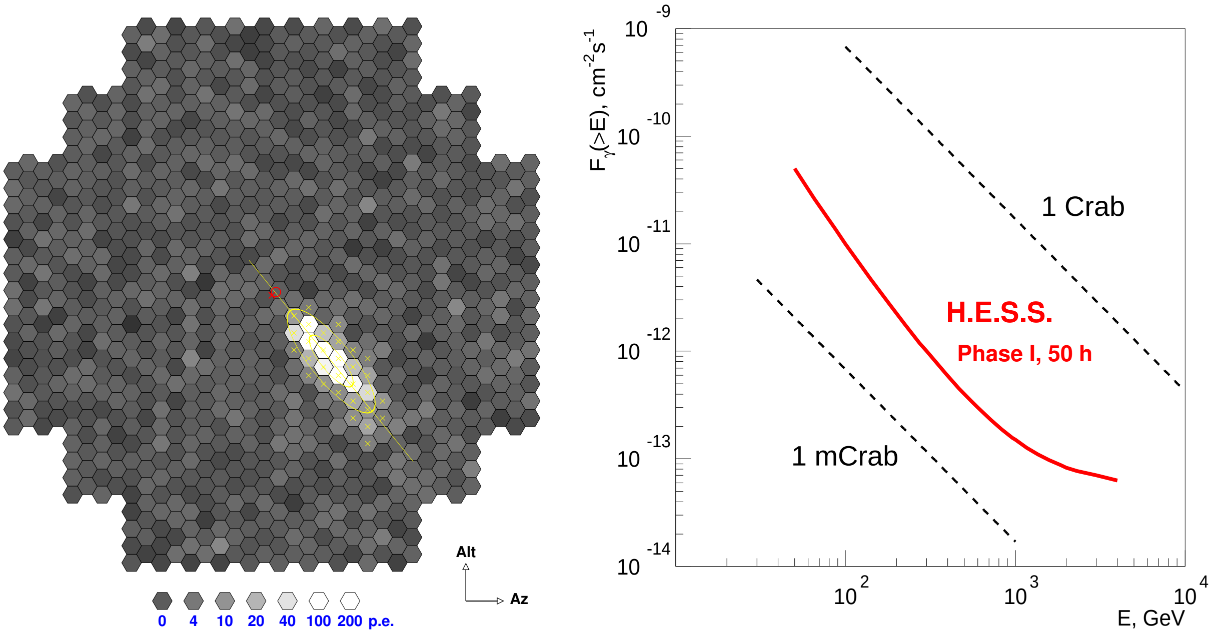

Figure 3: Left: Simulated shower image of a 1 TeV γ-shower. Right: Expected sensitivity in terms of a detectable photon flux of a four-telescope H.E.S.S. system. Dashed lines indicate Crab and milli-Crab flux levels.

construction work is under contract with local Namibian companies. Foundations are ready since the end of 2000. Buildings should be ready by this summer, as well as the on-site assembly of the first telescope which started in February 2001. While the first one is expected to be fully operational well before the end of 2001, commissioning of the other three telescopes will extend up to the end of 2002. After that point, phase II will see a further extension of H.E.S.S.

6 Performance

The expected performance of the H.E.S.S. system has been evaluated by a variety of (still on-going) Monte Carlo simulations. While the γ-ray energy threshold for triggering the 4-telescope system is expected to be well below 100 GeV under normal operating conditions, recorded images should be useful for spectroscopy and accurate shower reconstruction. A γ-ray flux sensitivity of about 10^{-11} cm^{-2} s^{-1} above 100 GeV is expected within 50 hours of observation time. At a few 100 GeV, the sensitivity should reach a level as low as some 7 mCrab for a point source (see fig. 3).

Acknowledgments

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