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Status of the High Energy Stereoscopic System (H.E.S.S.) Project

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Abstract. The paper summarizes the status of the H.E.S.S. project as one of the next-generation instruments for very-high-energy (VHE) gamma-ray astronomy. In its first phase, a system of four large Cherenkov telescopes, each with about 100 m^2 mirror area, will be installed in the Khomas Highland of Namibia. A later expansion of the system is foreseen.

The following status report will briefly touch on the physics goals of the H.E.S.S. instrument - which have been covered, for example, in previous proceedings (Kohnle 1999) - and will then concentrate on the description of the instrument, the status of its construction, and its anticipated performance.

1 Physics goals of H.E.S.S.

The basic physics goal of H.E.S.S. is to provide a comprehensive study of energetic non-thermal phenomena in the universe, using VHE gamma-ray emission as a diagnostic tool, with emphasis on the precise spectral and spatial mapping of sources. VHE gamma rays are (almost) always secondary products; one is primarily interested in the parent populations, including in particular galactic and extragalactic nonthermal electron populations, and the nucleonic component of the nonthermal universe. In addition, issues in observational cosmology and astroparticle physics can be addressed, and sky surveys will provide an unbiased view of the VHE gamma-ray sky.

Gamma rays from nonthermal electron populations are characterized by their double-humped spectra governed by synchrotron radiation at low (often keV) energies, and by the Inverse Compton (IC) component at high energies. From the analysis of multiwavelength spectra, the electron spectrum and the local B fields can be determined. Interesting galactic sources include pulsar nebulae; a source of the strength of the Crab Nebula can be detected by H.E.S.S. almost anywhere in the Galaxy. Among extragalactic sources, AGNs are of special interest. HESS will be able to detect a source like Mrk 501 out to $z \approx 0.3$, limited mainly by the $1/r^2$ decrease in flux rather than by absorption of gamma rays in interactions with the IR/O background.

A central part of the HESS program will be the search for the elusive sources of the nucleonic cosmic rays (CR). Here, gamma rays are used to probe the product of the local CR density times the local gas density. Targets include SNR as CR sources, but also Giant Molecular Clouds which allow to probe the distribution and spectrum of CR throughout the Galaxy. Probing the CR flux in external galaxies is also of great interest; here, starburst galaxies and clusters of galaxies are expected to generate a detectable gamma-ray flux.

Observational cosmology and astroparticle physics with HESS includes the measurement of the IR/O background density with its implications concerning the history of galaxy formation, the search for pair halos around AGNs, which allow to measure absolute distances, and the search for WIMP annihilation lines from the Galactic center.

2 Design considerations

H.E.S.S. will follow the proven concept of a stereoscopic system of imaging atmospheric Cherenkov telescopes, equipped with fast fine-grained cameras. The basic design considerations are covered in the Letter of Intent (Aharonian 1997) and, for example, by Hofmann (1999). The energy range - 100 GeV and above - emphasizes high-energy phenomena, but also provides large event statistics and enhanced extragalactic range. This energy range implies a mirror area of about 100 m^2 per telescope. Since many of the target objects represent extended sources, the H.E.S.S. cameras provide a large field of view of $5°$; good imaging over this field of view implies a relatively large focal length of the telescopes of 15 m, resulting in $f/d \approx 1.2$. The camera pixel size of $0.16°$ (3 mrd) is well matched to typical image sizes. IACT stereoscopy for improved angular recon-

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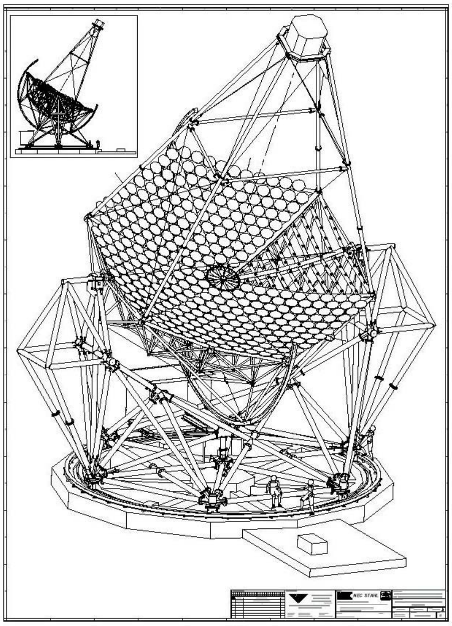

Fig. 1. One of the H.E.S.S. telescopes; on one section of the dish, mirrors are removed to show the support structure.

Fig. 2. The last step in the assembly of the structure of the first telescope is the mounting of the camera support.

struction, energy reconstruction and background suppression requires at least two telescopes; the experience with HEGRA shows that more views are desirable. In the first stage of H.E.S.S., therefore, a cluster of four telescopes will be implemented, arranged to form a square with 120 m sides. The spacing represents a compromise between optimum performance at low energies - where a somewhat smaller spacing is preferred - and detection area and angular resolution at high energies and larger zenith angles. Operating at a remote site, the construction of the telescopes emphasizes reliability.

3 The H.E.S.S. telescopes

Site. H.E.S.S. is situated in the Khomas Highland of Namibia, at about 100 km distance from the capital of Namibia, Windhoek. The exact location is $23°16'18''$ S, $16°30'00''$ E, at 1800 m asl. The area is renowned for its excellent observation conditions and was once discussed as a potential site for the ESO telescopes. At 1.5 h driving distance from Windhoek with its international airport, the site is easily accessible. With a flat area of well over a km^2, it provides ample space for the planned expansion in Phase II of H.E.S.S.. The climate is mild, with temperatures between $0°$C and $35°$C, low winds, little rain and no snow, and allows operation of the telescopes without protective enclosures. The location in the southern hemisphere provides optimal viewing conditions for sources in the central part of the Galaxy.

Site infrastructure will include a control building with offices and workshops, a residence building and a power station with two 150 kW Diesel generators. A microwave link will provide network connectivity to Windhoek and from there to the H.E.S.S. institutes. The infrastructure should be operational by late summer 2001.

Telescope structure. The 382 individual mirror segments of a H.E.S.S. telescope (Fig. 1) are mounted in Davies-Cotton fashion on a hexagonal dish with a flat-to-flat width of 12 m. The camera at $f = 15$ m is supported by four masts emerging from four corners of the dish. The dish is supported in an alt-az mount. Since weight was not of primary concern and since alternative technologies do not offer advantages in terms of cost or stability, the mount and dish are constructed of steel; the structure was designed by SBP in Germany and is manufactured by NEC/Namibia. The mirror support points are specified to be stable within 0.15 mrd rms over the full altitude range, in order to maintain a constant point spread function. The mount rotates on a 13.6 m diameter circular rail. Friction drives systems acting on rails at about 7 m radius from the axes control the movements in azimuth and elevation. The 4 kW drive motors accelerate the telescope in less than 1 s to its peak slewing speed of $100°$/min. Pointing is controlled by encoders with 10" digital resolution and an additional analog track providing a vernier with a few arcseconds resolution. In May 2001 the structure of the first telescope was assembled on site (Fig. 2); the remaining three telescopes will be assembled until early 2002.

Mirrors. The mirror of each H.E.S.S. telescope is composed of 382 round segments of 60 cm diameter. The segments are made of ground glass, aluminized and quartz-coated. Production is shared between COMPAS in the Czech Republic and GALAKTICA in Armenia. The point spread function and reflectivity is measured for each segment individually. The 1131 mirrors measured so far have a typical spot size of 0.45 mrd (diameter for 80% light containment); the specification was 1 mrd. Reflectivities average to 77% at 300 nm, 85% at 400 nm and 470 nm and 81% at 600 nm. About 23% of the mirrors delivered suffered from poor reflectivity or other problems and had to be returned. Long-term tests of mirrors in Namibia showed no significant degradation over a period of one year.

The mirrors are attached to the mirror support tubes of the dish using support systems which hold the mirror in three points, using pads glued to the back of the mirror. Two support points are adjustable by remote-control motorized actuators and serve to align the mirrors. In tests, the typical alignment precision was below 0.1 mrd.

For the full mirror of a telescope, with its 105 m^2 area, a point spread function of 0.5 mrd (rms) is anticipated on axis, and 1 mrd (rms) for rays 2° off axis.

Fig. 3. Camera body, with some the “drawers” inserted.

Camera and readout. The H.E.S.S. cameras provide a $5°$ field of view, and are comprised of 960 PMT pixels of $0.16°$ (3 mrd) size. The complete electronics for triggering and readout is integrated into the camera body, reducing the connections to only the electrical power, and a few digital optical fibres. A camera (Fig. 3) features a modular construction; 60 drawers each containing 16 PMTs and the associated electronics are inserted into the camera body, plugging into connectors on the backplane. A common “funnel plate” with Winston cone light concentrators is installed in front of the drawers, and serves both to focus the light from the 40 mm entrance of a pixel onto the 21 mm active area of the PMT, to limit the viewing angle and to exclude albedo. Two movable racks in the back of the camera contain the power supplies, the last stages of the trigger processing, a CPU as well as interfaces for readout and slow control. The octagonal camera with a diameter of 1.5 m weighs 820 kg.

Apart from the 16 PMTs (30 mm Photonis XP2960), a drawer (Fig. 4) contains individual HV supplies for each PMT (with active regulation for the last four dynodes), the analog and digital signal processing and the trigger circuitry. Signals from the PMTs are captured at 1 GHz sampling rate by analog memories with 128 ns depth (the Analog Ring Sampler (ARS) ASIC). After a camera trigger, the relevant memory locations are addressed, digitized and and optionally a certain range of samples is summed up by a programmable logic device (PLD). The ARS provides a dynamic range of about 10 bits; separate high and low gain branches are used to extend the dynamic range to 14 bits, or 2000 photoelectrons maximum signal. The drawer provides via the readout bus additional monitoring information, such as PMT currents and trigger rates as well as temperatures etc. For each drawer, the trigger circuitry sums the output signals from comparators; the summed signal represents the number of PMTs with signals above a certain threshold. In the back of the camera, these signals are summed over 64-PMT “sectors” and discriminated. A typical camera trigger condition requires 4 pixels above 4 photoelectrons in one sector. The effective pixel coincidence window is very short, about 1.5 ns, suppressing random coincidences. After a camera trigger, the sampling of analog signals is stopped; if the trigger is confirmed within a few μs as a system trigger (two or more telescopes in coincidence), the signals are read out, otherwise the sampling is restarted. The system trigger decision is taken by logic in the control building, communicating with the telescopes by optical fibers.

Monitoring and control. Various auxiliary systems serve to monitor the performance of the instrument as well as the atmospheric properties. Integrated into the lid of the camera is a light pulser system using blue LEDs, which allows to flash each PMT with an individually adjustable light pulse, to test response and trigger characteristics. A laser-driven light pulser in the center of the dish serves to flat-field the camera, and provides adjustable intensity and wavelength. A CCD camera with a $f = 80$ cm lens attached to the dish observes

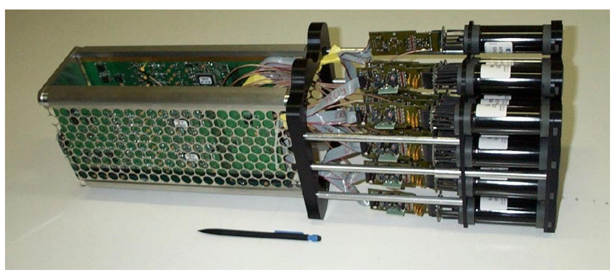

Fig. 4. A “drawer” contains 16 PMTs, their individual HV supplies, as well as the analog and digital electronics and the trigger circuitry.

guide stars and helps to refine the telescope tracking. A second CCD in the center of the dish monitors the position of the PMT camera via LEDs on the camera body, and guides the automatic alignment of mirrors using stars imaged onto the closed camera lid. A reflectometer will monitor mirror reflectivities in-situ.

Instruments to monitor the atmosphere will include IR radiometers attached to each telescope and a cloud scanner. Using robotic optical telescopes on the H.E.S.S. site, atmospheric transparency will be measured. Atmospheric density and temperature profiles are available from radiosonde measurements near Windhoek.

Data acquisition and data processing. In each camera, data are transfered from the drawers via a custom bus and a PCI interface into a CPU under Linux, where data are formatted, buffered and, via Ethernet and a commercial fast switch, sent to a processor farm. Data from all telescopes (for a given event) are routed to one processor, where the event is assembled, processed, and stored locally. The processor address and an event number are distributed by the central trigger system, encoded into the trigger signal. The processor farm is comprised of 16 dual-Pentium units and additional servers, which during daytime collect preprocessed events from disks of the individual processors and assemble a single chronological event stream. The data acquisition software (DASH - Data Acquisition System for HESS) and the analysis framework (SASH - Storage and Analysis Structure at H.E.S.S.) are fully object-oriented and written in C++. CORBA is used for interprocess communication, and the ROOT framework for event analysis. DASH provides simple yet effective tools for process control and for the transfer and assembly of event data and monitoring information. There is a seamless integration between online and off-line software; SASH analysis tools can either operate online on the farm CPUs or off-line during reprocessing or DST analysis. The code is operational on the farm, and continues to be refined.

4 Simulations and performance studies

Over the last two years, considerable effort went into refinements of the simulation tools, and into the discussion of systematic effects which limit the precision with which absolute energy scales can be defined. For example, the influence of atmospheric density profiles and of Earth magnetic fields turned out larger than previously anticipated. Approximations used in air shower simulation codes resulted in differences between different codes in the 10% to 20% range. Precise modeling of PMT pulse shapes and trigger comparator response turned out to be critical. The simulations use different air shower codes (ALTAI, CORSIKA, KASKADE, MOCCA) and three different instrument simulations, and the comparison of the results - now virtually identical for gamma-rays - has contributed much to the understanding of critical areas and assumptions.

According to these simulations, the H.E.S.S. instrument will provide a threshold - defined by the peak differential detection rate for a Crab-like source - below 100 GeV. The direction of individual photons will be determined to $0.1°$, their energy to 20% or better. The goal is, furthermore, to attain sufficiently precise pointing of the telescopes such that strong sources can be located with a precision of a few arc-seconds. Concerning the sensitivity for point sources (Fig. 5), the estimates shown in (Hofmann 1999) have not yet been updated; H.E.S.S. should be able to detect within 50 h a source at the level of 10 mCrab or slightly below. The goal of the H.E.S.S. Phase II expansion is to reach the mCrab regime. For extended sources, the sensitivity deteriorates due to the increased backgrounds and reaches 0.1 Crab for a $1°$ (rms) source; at this size, systematic uncertainties in the background estimates also start to become an important factor.

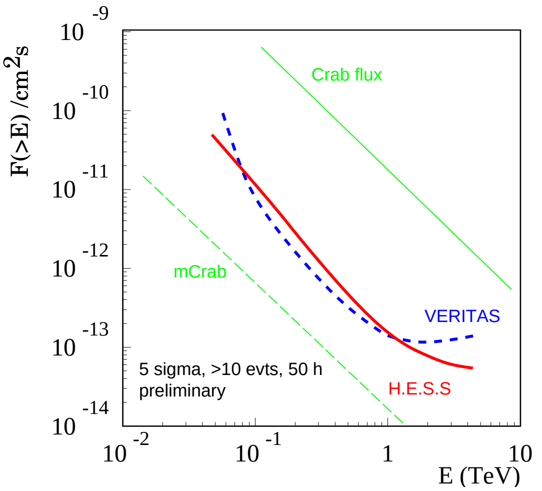

Fig. 5. Minimal detectable flux as a function of energy threshold, for 50 h of observation time. Also shown is the sensitivity quoted in the VERITAS proposal, and for comparison the Crab flux levels.

5 Outlook

The R&D for the first four H.E.S.S. telescopes is completed and construction is progressing well. The first telescope is expected to go into operation in late 2001, the remaining three will be completed in 2003. The expansion of the system for Phase II is under investigation, with the primary aim to further improve the sensitivity in the 100 GeV energy range.

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