Gamma Rays and the H.E.S.S Project

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Abstract

The H.E.S.S experiment (for High Energy Stereoscopic System) consists of four imaging Cherenkov telescopes situated in the Namibia Khomas Highland desert (1800 m asl). Its main characteristics are the low energy threshold (100GeV) and substantial flux sensitivity (1% Crab units). The combination of the four telescope data analysis provide good background rejection and angular resolution. Recent results on the performance and operation are reported here.

1 Gamma Rays and Ground Based Detection

Gamma Ray Astronomy focuses on violent phenomena of the universe. The observation of high energy gamma rays, beam of extreme energy, allows to deepen the understanding of extreme objects and processes that produce these rays. The celestial objects that attract our attention can be found in our galaxy, and even beyond. These are e.g residues of the explosion of a star (remnants of supernova) whose shock wave of the initial explosion may accelerate particles at speeds sufficient to produce gamma rays.

They might also originate by distant galaxies which accommodates in their center a supermassif black hole. This hole takes its energy by the surrounding gravitating matter. This matter liberate its energy as it falls inside the black hole, which produces extremely energetic jets of particles with speeds close to the speed of light. These particles, in their turn, can produce gamma rays which we detect if they are oriented toward our galaxy.

Even more exotic these gamma rays can be produced within regions rich in dark matter. This mysterious matter which its existence is predicted by a lot of theories but still undetectable up to now, can also produce gamma rays due to annihilation process.

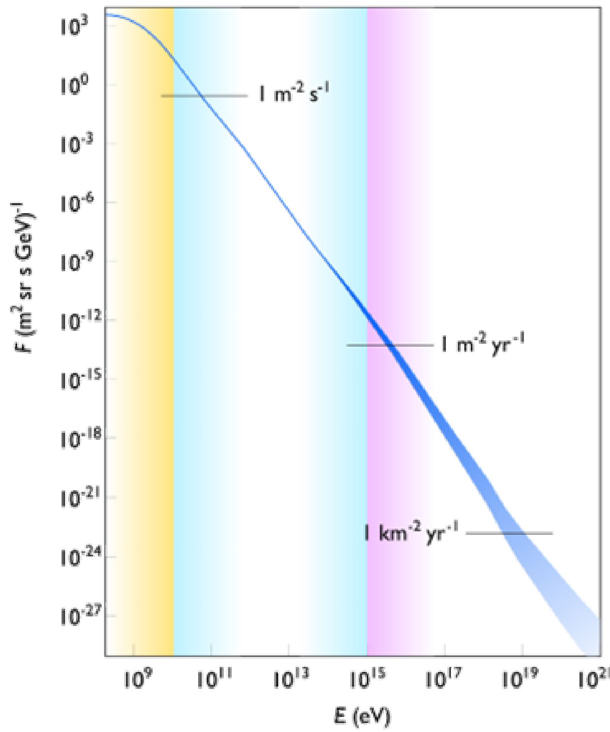


Fig. 1. Cosmic Rays Spectrum.

These gamma rays are detected by telescopes using the "Atmospheric Cherenkov effect." Indeed, a gamma ray, interacting with the atmosphere, gives birth to a cascade of particles, which in their turn they also have a very high energy. By Cherenkov effect, analogous to the effect of sonic boom Concorde, these particles emit a brief flash, a few billionths of a second blue light, which is reflected by large mirrors to very specialized cameras having very high temporal resolution. A major challenge is to distinguish these cascades of those, created by cosmic rays as protons or electrons that bombard the earth continuously, and who, unlike gamma rays, have lost all memory of their original direction.

2 Experimental Design

H.E.S.S is an array of four 13m diameter identical telescopes, Fig 1, arranged in a square of 120m sides. They use an alt-az mount, which rotates on a 15m diameter rail. A 100^o/min positioning speed is provided with a 10" digital resolution. The reflectors are assembled by 380 quartz-coated round facets (60cm diameter), arranged with Davies-Cotton optics. The facets are made of ground glass, aluminized and quartz coated, with reflectivity in the

80-90% range. Each mirrors is equipped with two motors to allow remote alignment.

Fig. 2. Panoramic view of all four H.E.S.S telescopes actually operated at the site.

At the nominal 15m focal length, a fine modular pixel camera is mounted, consisting of 960 photomultipliers (Photonis XP2960). This gives a pixel size of 0.16^o for a total field of view of 5^o. The PM's are grouped in modules of 60 called "drawers". They are operated at a gain of $2x10^5$. For best linearity, the four last dynodes are actively stabilized. Each drawer consist of 16 PMs and is made up of a mechanical structure, two analogue memories cards and a mother-board with slow-control and regulated DC-DC power supply. Each analogue memory card contains four analogue memory chip called ARS[1].Each ARS has 4 channels of 128 cells which are continuously written at 1 GHz.

Fig. 3. Camera and related front-end electronics mounted at the focal plane of the telescope. Only three interconnect cables are needed to communicate with the DAQ System of H.E.S.S.

As the key element of the H.E.S.S DAQ, the principle of read-out of these chips is the following : Upon the arrival of the trigger pulse at the ARS chip, the data sampling continues for 128-Nd cells, where Nd is the trigger formation time. Then it stops and a pointer is positioned at the beginning of the read-window. A user defined number of samples can then be readout at a lower rate of 100MHz. Two read-out mode are available: sample mode and charge mode where on the later a summation is performed of all samples and only

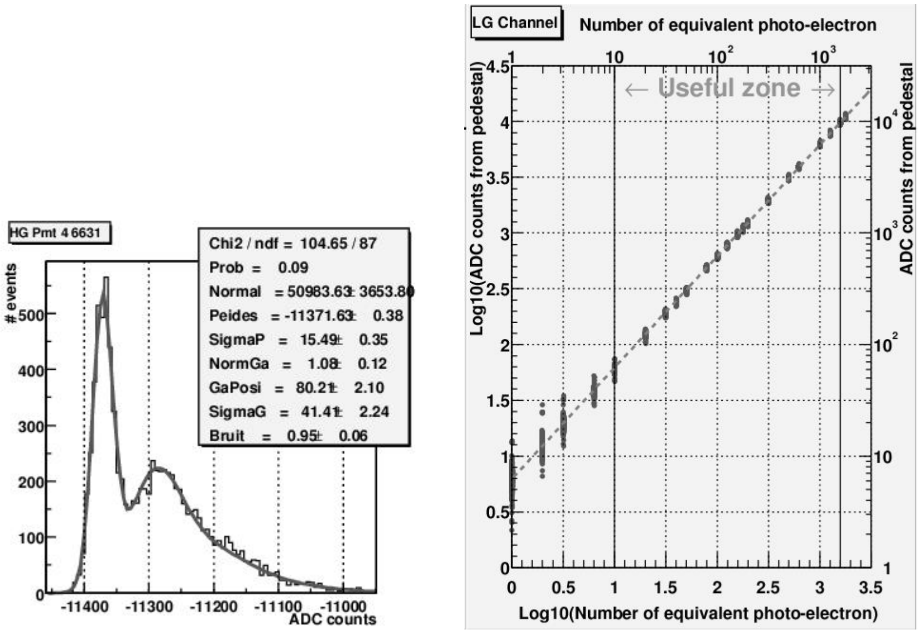


Fig. 4. Single Photon Spectra using a pulsed laser source (Left) and Linearity tests of the ARS Readout chip (Right)

the total is transfered for processing.
To provide a large dynamic photon yield, it is necessary to use two channels per PM in order to cover up to 1600 photoelectrons. The first channel covers the range 1 to 100 photoelectron with an amplification of 50; the second covers the range 16 to 1600 photoelectrons with an amplification of 3.

The camera trigger is formed by a coincidence of a number of PMs hits (typically 3-5), within a 8x8 matrix when they exceed an adjustable threshold. The later usually within the range of 3 to 5 photoelectrons. The decision time for the trigger formation is within 2ns range. A central trigger processor receive all four incoming trigger signals and creates, after correcting for electronic delays, the global trigger.

Finally a number of auxiliary systems serve to monitor the telescope performance (pulsed laser and LED calibration sequencer) and atmospheric quality (ceiliometer and infrared radiometers).

3 System Performance

Extensive tests of the complete DAQ chain were performed, using laser pulsed source. The single photon response of the PMs was measured (Fig.4a) as well as the linearity of the ARS read-out chain (Fig.4b).

First data were taken with a single telescope in June 2002, while the complete experiment, all four telescopes, has been taking date from beginning 2004. The telescope pointing accuracy was verified using images of stars on the camera lid. Images with no corrections were centered on the camera lid with an rms error of 28". A more elaborate method, using a 12-parameter model, to correct for misalignments, brings this figure to 8". For even better performance, a guide telescope attached to the dish could bring it to 2.5" rms. Figure 3 shows the optical spread function for the H.E.S.S telescopes.More informations on the optical performances of H.E.S.S can be found in [2] and [3].

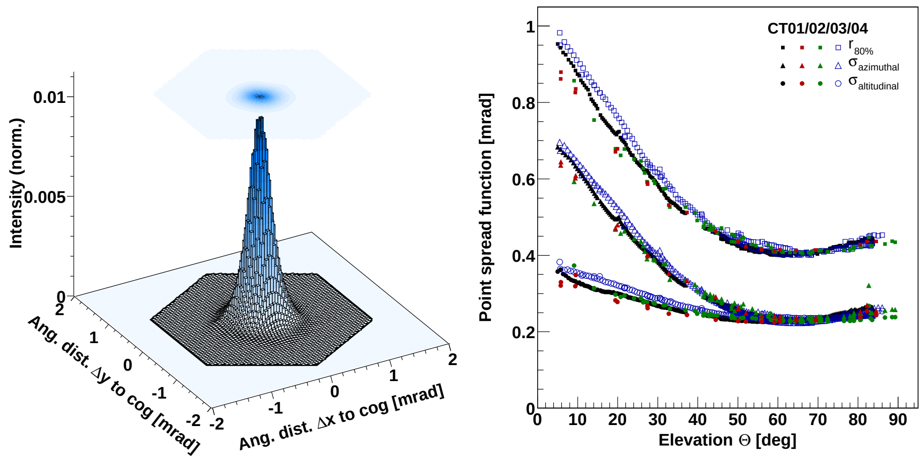


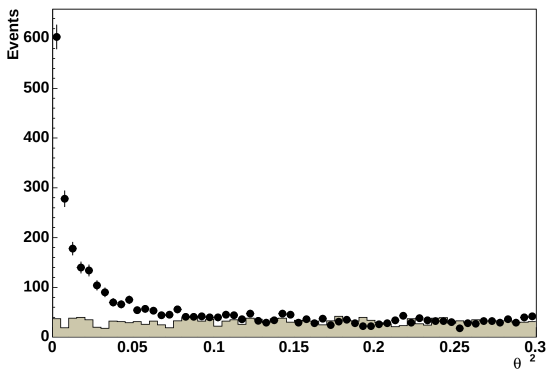
Fig. 5. Left:On-axis point spread function (PSF) of an image of a star compared with the pixel size (represented by the hexagonal),Right:Azimuth of the dependence of the PSF.

Data trigger levels are quite stable at the expected 150Hz with no significant variations due to night sky background. This could be obtained using a low threshold of 4 photoelectrons. Otherwise the observed background on dark regions is close to 100MHz, as expected. Variations of the PMs gain show a 10% value within a nine months period.
Finally using muon data, we could deduce the efficiency of our system with response to true Cherenkov light. Using single-ring muon images, that occur in our data at 1Hz and averaging over many runs, the through-put of the telescopes seems to be 10% less than predicted by the simulations - within the systematic errors in the calculation.

4 Gamma-Ray Observations

First Gamma-Ray observations data were taken using the Crab nebula as a target. This source, been a well studied VHE gamma-ray one, serves usually as a reference for evaluation and system checks. Data shown here, were taken within the period of October to November 2003. A total of 4.7 hours on-source data were acquired, with an equivalent time spend on off-source. A preliminary analysis, using a typical *Hillas* Parameter fit, was used to reconstruct the showers detected. A steady rate of 3.6γ 's/min is observed with a significance of 20.1σ. Figure 5 shows the distribution of the α-parameter for these data, using an energy threshold cut of 800GeV. On the left a sky plot of the same data are shown. Combined with MC simulations (CORSIKA and telescope ones) we calculate a preliminary flux of $(2.64 \pm 0.20) \times 10^{-7} m^{-2} s^{-1}$.

The potential of using four telescopes in stereo mode, gave soon very



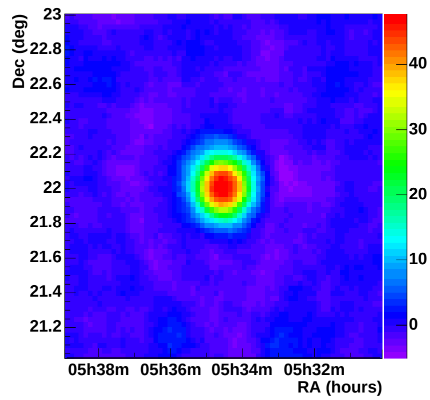


Fig. 6. Left: Pointing angle α for a single telescope Crab observations. The solid line represent the off-source data Right: Reconstructed sky-plot of gamma-ray excess in the Crab region

promising results, especially on the rejection of the muon induced background. The implementation of the hardware stereo trigger, while maintaining the dead-time to acceptable levels (20%), contributed to a significant reduction of the camera trigger threshold.

One of the most interested HESS result is the detection of gamma rays coming from SNR (supernova remnant) RX J1713.7-3946 object already observed by CANGAROO[6]. The TeV gamma emission originating clearly from the supernova shell, demonstrates that the shock wave is capable of accelerating particles to multi-TeV energies, generating photons due to interaction with the surrounding gas or by Inverse Compton scattering depending if we deal with protons or electrons. A strong correlation with the X-ray emission is also evident. The energy spectrum, extending to 30 TeV, is of the power law type with a spectral index between 2.1 and 2.3. This measurement coincides with predictions of shock-wave acceleration models, the high energy photon energies detected demonstrating that the energy of the primary particles was up to 10^14eV and beyond. Detailed analysis of the data presented elsewhere [5], demonstrate the preference for a hadronic origin of the high energy gamma rays, however conclusive evidence is still ahead.

Another interesting region observed with HESS, was the Galactic center [4].

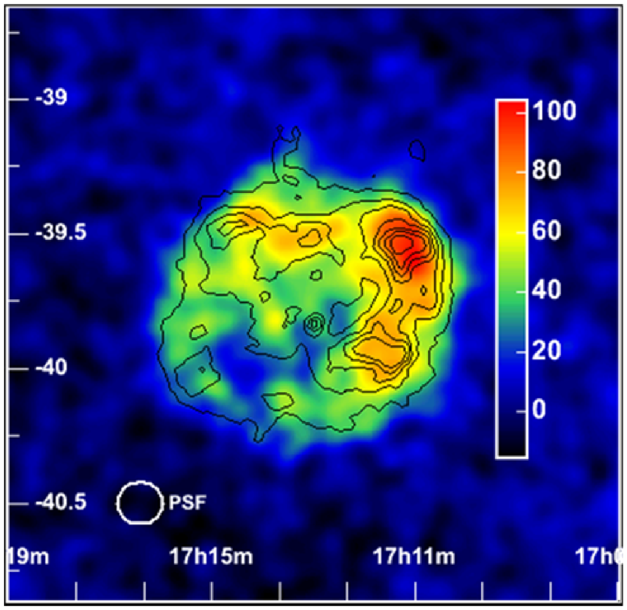


Fig. 7. SNR RX J1713.7-3946. Color indicates gamma ray count rates, while contour lines is the X-ray emission by ASCA[7].

The origin of a gamma ray signal coming fro this region could be explained by a lot of scenarios from the most usual (SNR,PWN, Black Hole processes) to more exotic such as Dark Matter and neutralino annihilation. Some of the sources detected with HESS can be identified as having SNR or PWN counterparts (SNR G0.9+0.1 or a PWN) while the signal close to the center SNR Sgr A favors more the scenario of processes du the presence of a black hole. Dark Matter signature as an explanation from this same region is non compatible with the observed smooth energy spectrum extending beyond 10 TeV. Classical SUSY scenarios gives strongly curved energy spectra and lower energy cutoff.

5 Conclusions

All four H.E.S.S telescopes have been installed and are operational since January 2004. The first results confirmed the experimental solutions chosen, and the performance of the apparatus is consistent with the MC expectations. Gamma-ray observations of the Crab nebula results in a sensitivity in the 10mCrabe range while the energy threshold is at the level of 100 GeV. The application of the stereo analysis technique gives very promising results, especially eliminating the muon background considerably.

A lot of interested results have been published up to now and continuing so, demonstrating the capabilities of the Cherenkov technique for Astrophysical measurements. Cosmic Gamma ray data in this energy domain provides addi-

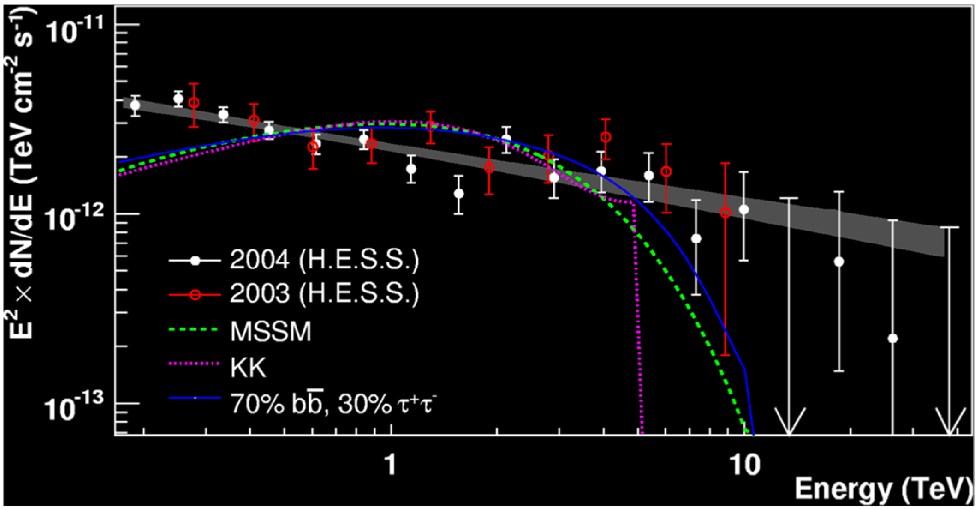


Fig. 8. Energy spectrum observed by HESS superimposed to possible scenarios for Dark-Matter interpretations.

tional and valuable information for understanding the complex structure and processes of the our Galactic and Extragalactic universe.

6 Acknowledgment

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