HELYCON: a status report

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Abstract—**The 'HEllenic LYceum Cosmic Observatories Network' - HELYCON collaboration is establishing a network of detector stations distributed over western Greece. The goal of HELYCON is to observe extensive air showers and to collect data corresponding to the flux, the direction and correlations between very energetic cosmic rays. In parallel this project aims to provide the educational platform to physics teachers, university and high school students to participate in a true scientific undertaking. In this report the design, the construction and the performance of a prototype array is presented.**

I. INTRODUCTION

THE Physics Laboratory of the Hellenic Open University (HOU) is constructing[1] an Extensive Air Shower (EAS) detector array. This array, HELYCON: HEllenic LYceum Cosmic Observatories Network, consists of detector stations distributed over western Greece. Each station is equipped with four large plastic scintillator counters (each 1 m^2 of effective area), Global Positioning System (GPS), trigger and digitization electronics and a PC based data acquisition system. The stations will be mounted on the roofs of high-schools and university buildings. In Figure 1, the locations of available buildings for the deployment of the detector stations, as well as the lateral size of air showers of various energies are shown. The time synchronization between detector stations is achieved through the timing signals from the GPS navigation satellites.

The primary aim of the project is to contribute to the research in astroparticle physics. A particular interesting prospect is the study of time and directional correlations between cosmic ray activity on station clusters separated by large distances (e.g. between towns). Such correlations would indicate that the cosmic ray particles have some common history. The creation mechanism of cosmic ray events arriving in time coincidence could be, for example, the photodisintegration of heavy nuclei by solar photons [1] or transient cosmic gamma-ray activity [2]. In parallel, HELYCON is providing the R&D workbench for the development of the calibration system of a deep sea neutrino telescope, as the Mediterranean KM3NeT [3],[4].

Furthermore, HELYCON will provide the platform for the development of novel educational programs which will give to educators, university and high-school students the possibility to gain insight and work on a modern research project.

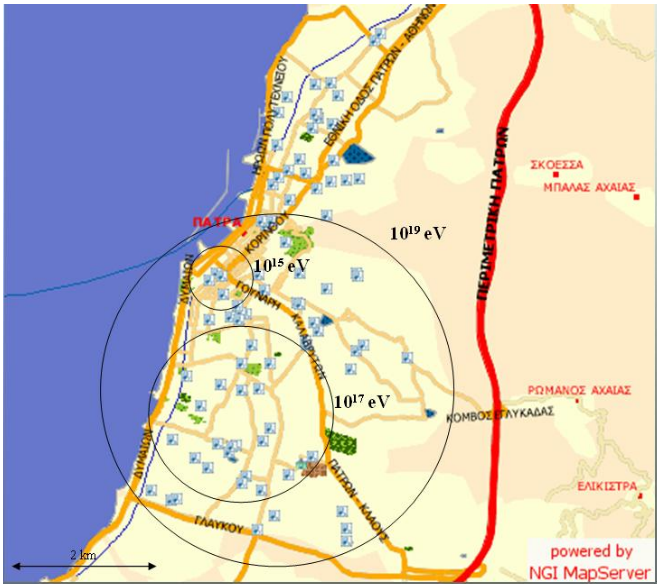

Figure 1: Geographical distribution of schools and HOU buildings (blue squares) in the city of Patras. The circles represent the lateral size of extensive air showers for various energies.

Presently, three detector stations are ready to be deployed at high schools of the Patras area. During 2007 the detector network will be expanded by at least four more stations in western Greece and three more stations in the island of Chios (~400km apart), including antennas and the adequate electronics for radio detection of Extensive Air Showers [5].

II. SYSTEM DESIGN

Figure 2 shows an overview of a HELYCON detector station. The station consists of four plastic scintillator counters with an effective area of 1 m^2 each and with photomultiplier read out. Three of the counters are arranged in a triangular formation, with a typical distance between them 20 meters. The fourth counter is placed either on top or next to one of the other three counters. Air showers initiated by a primary cosmic particle with energy above 10^{14} – 10^{15} eV are detectable by such a single station.

The scintillator counter is constructed from two layers of scintillating tiles (Protvino SC-301 [6]) supported by a wooden frame. Each layer consists of 80 tiles (12cm × 10cm × 0.5cm) wrapped in reflective paper (Dupont Tyvek 2460B [7]). The light is collected through wave shifting fibers

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[1] with the collaboration of the University of Patras, the University of Athens, the Aegean University, the University of Cyprus and the Secondary Education System of Western Greece.

(Bicron BCF91A [8]) embedded inside the grooves of the scintillating tiles and detected by a fast 19mm Photonis XP1912 photomultiplier tube (PMT) [9]. A programmable high voltage dc-dc converter (EMCO CA20N [10]), mounted on the detector wooden frame, is used to supply high voltage (HV) to the photomultiplier whilst an external power supply provides the power (12V, dc). The PMTs signal is transmitted to the digitization electronics through about 30m of RG58 cable. The control and monitor signals are transmitted through standard UTP cables: these include the HV controls and monitors as well as the readings of temperature sensors mounted near the PMTs. The PMT and HV supply are shielded from the ambient electromagnetic noise by means of a thick (0.3 mm) aluminum foil wrapped around the wooden frame. Finally, the whole detector is enclosed inside a water proof wooden box wrapped inside of a light reflecting and insulating Tyvek envelope. Figure 3 shows photographs of the detector in three stages of the construction procedure.

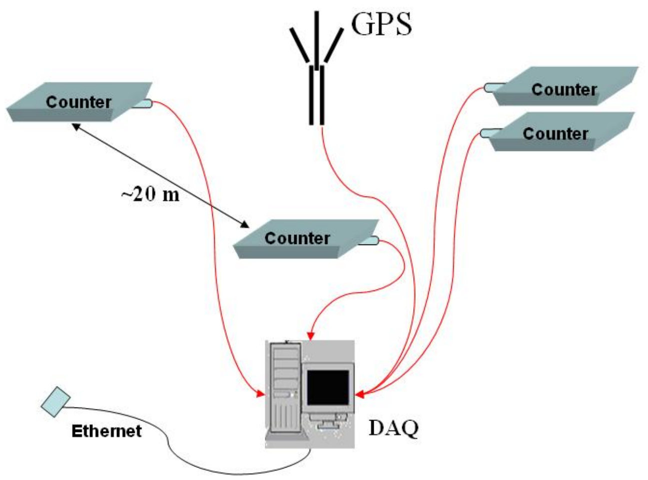


Figure 2: Overview of a HELYCON detector station

The read out system is based on a High Precision Time to Digital Converter (HPTDC) [11] chip designed in CERN whilst a 12-bit multifunction USB data acquisition card (National Instruments USB-6008 [12]) is used for the slow control. The synchronization between the stations of HELYCON is achieved through the digitization of the GPS (Motorola M12+ [13]) time-signal together with the PMTs waveform threshold crossings.

In Figure 4 the block diagram of the main acquisition card (developed in the I.N.P. of the NCSR ‘Demokritos’ [14]) is presented. This card has 5 analogue inputs one for each scintillation counter. The input signals are amplified and compared to three predefined voltage thresholds. The corresponding times of these waveform threshold crossings are digitized with an accuracy of 100ps by the HPTDC along with the 1 PPS output of the GPS receiver. The selection triggers are realized in the Field Programmable Gate Array (FPGA), requiring certain time relations between the input signals. The FPGA is also responsible for formatting the data and communicating with the host PC. The data are saved on the hard disk of the local computer and transmitted, through the Internet to the central server of the HELYCON telescope.

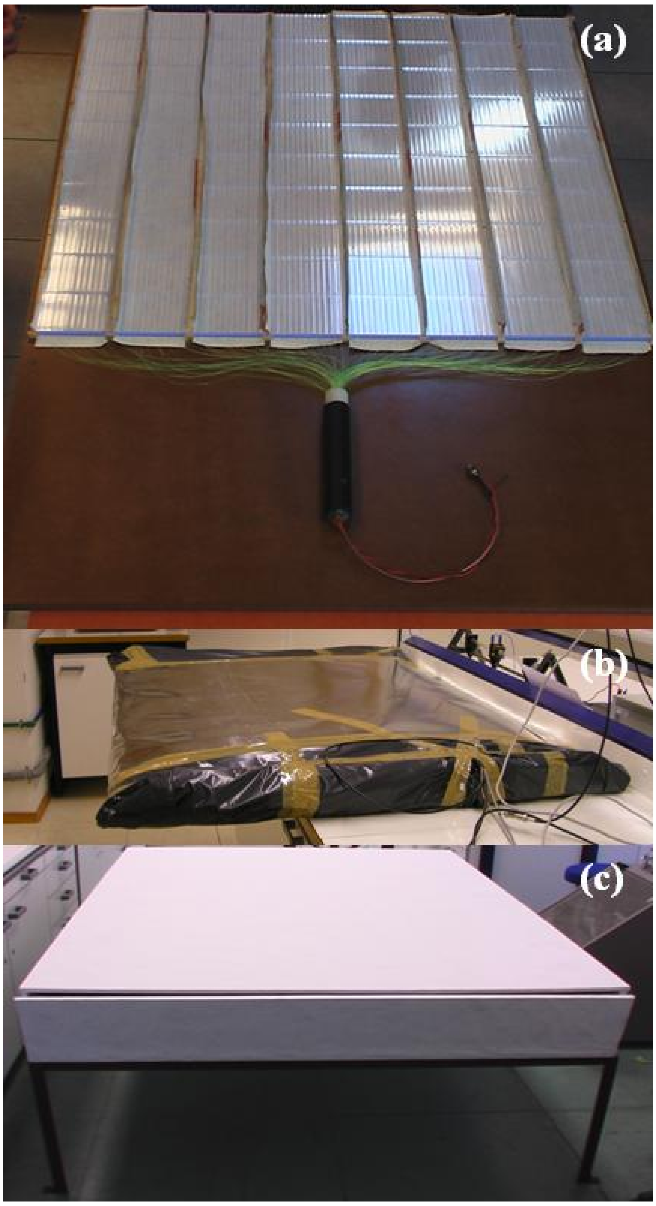


Figure 3: The detector in three stages of the construction procedure. In picture (a) the installation of the tiles, the fibers and the PMT has been completed. Picture (b) shows the detector wrapped inside the aluminium foil before it is enclosed inside the water proof wooden box (c).

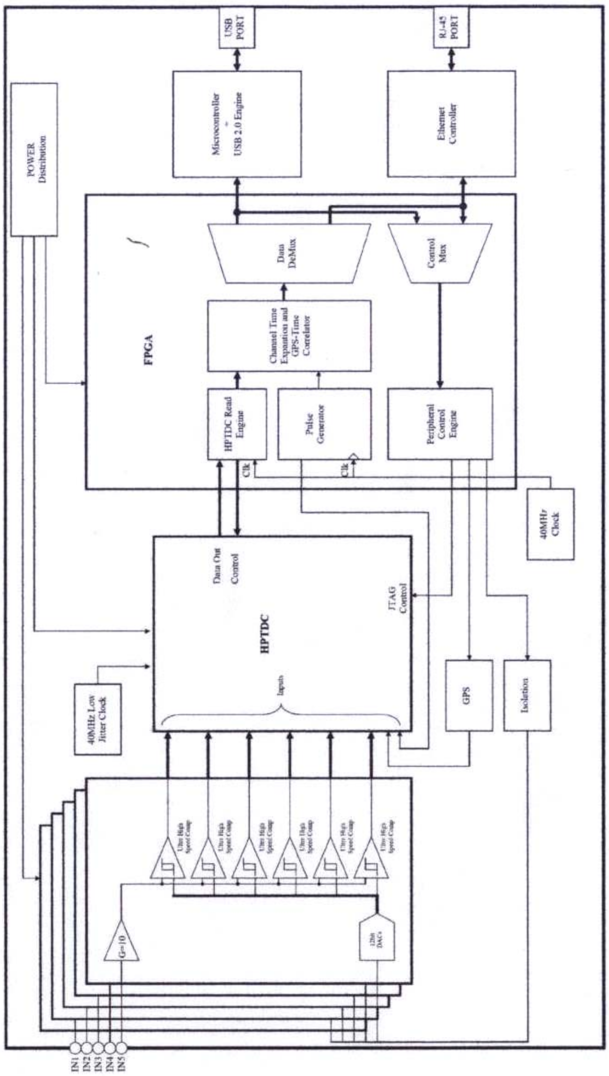


Figure 4: Block diagram of the main data acquisition card

III. Detector performance

The detectors, before their commission, undergo several evaluation tests and calibration procedures including the calibration of the photomultiplier tubes, measurements of the detectors response to a minimum ionizing particle (MIP), evaluation of the uniformity of the detectors response and synchronization of the detectors of a station. The photomultipliers are illuminated by LED light pulses (at 420nm wave length) in order to measure the gain variation as a function of the high voltage, as well as to evaluate the PMT response characteristics at a single photoelectron emission. The response to a MIP and the uniformity of the detector response are established by using a hodoscope (consisting of two small scintillators of 5cm × 10cm × 1cm and a lead absorber of 10cm thickness between the scintillators) in order to identify relativistic muons, as it is shown in Figure 5.

It was found that the typical response of the scintillation counters to a MIP corresponds to 21 photoelectrons (with a variation of 10%). In Figure 6, it is presented the response signal uniformity, of a typical detector, as a function of the coordinates of the muon hit.

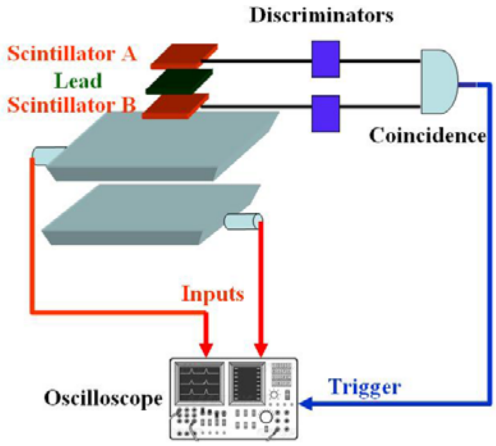


Figure 5: The experimental setup for the uniformity check. The two small scintillators A, B, discriminators and one coincidence unit provide the trigger to a fast oscilloscope which digitizes the waveforms of the large scintillator counters.

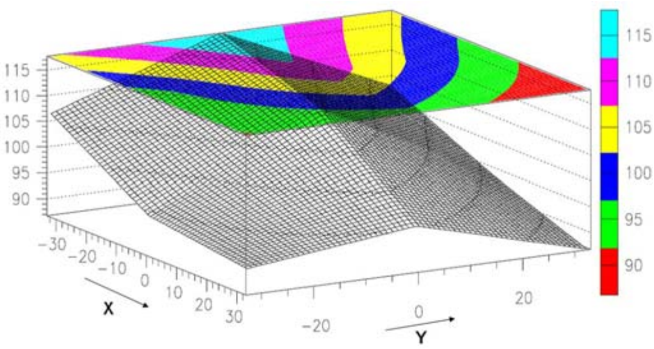


Figure 6: Response (in units of the mean charge deposited averaged over all the counter area) to a MIP of a typical scintillation counter as a function of the incidence position (in cm). The centre of the counter is at (X=0,Y=0).

The uniformity of the time response of the detectors as a function of the hit coordinates has also been studied. Using the experimental set up shown in Figure 5, it has been estimated that the resolution in measuring the arrival time of a single MIP is 2 ns, independently of the coordinates of the hit.

The calibration results have been compared with the predictions of a detailed Monte Carlo description of the HELYCON scintillation detectors, which has been developed utilizing the GEANT4 simulation framework [15]. Figure 7 presents the comparison of the measured response of a HELYCON detector to a MIP passing through the center of the counter with the Monte Carlo prediction. The excellent agreement between the Monte Carlo description with the experimental data verifies that the detector operation features are well understood.

In combination with the CORSIKA air shower simulation software [16], the Monte Carlo description of the counters is used for the evaluation of the performance of the HELYCON array (see Section V).

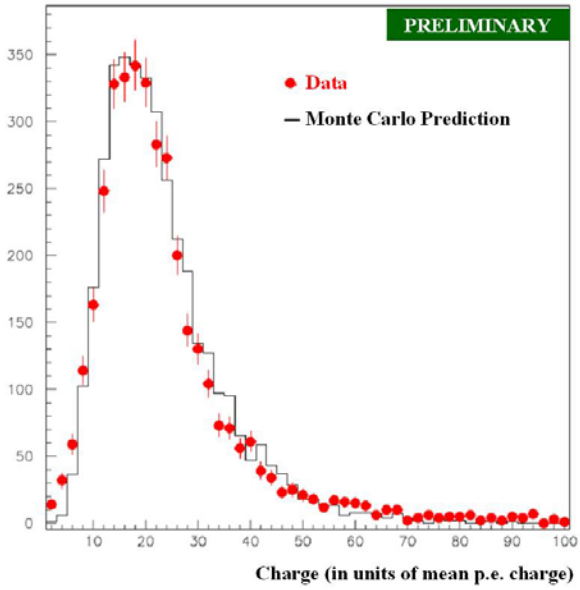


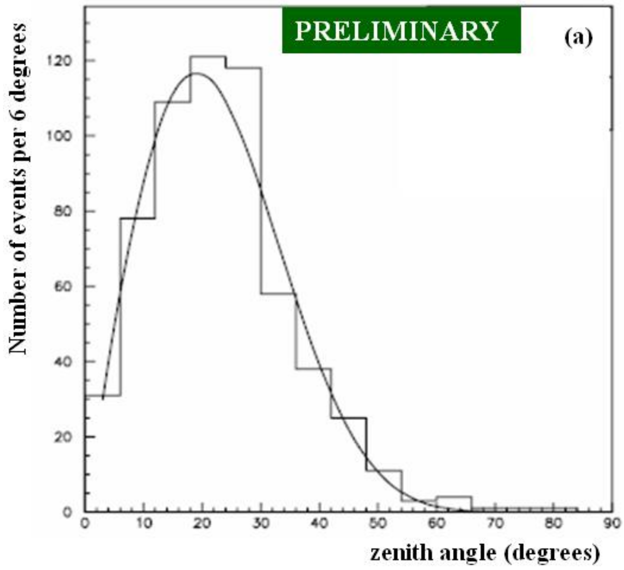
Figure 7: The distribution of the charge of a PMT signal corresponding to the response of a HELYCON detector to a MIP passing through the center of the counter. The red points represent calibration data collected in the Lab whilst the histogram describes the Monte Carlo prediction.

IV. First observations of air showers

The performance of a HELYCON station has been evaluated by operating a system of four detectors, in the laboratory, observing and reconstructing atmospheric showers. The counters were arranged in a triangular formation under a light wooden roof with brick tiles, with a distance between them about 12m, having placed two of them on top of each other to provide a selection trigger for the station. The trigger was formed by requiring the pulse heights of both the trigger detectors to exceed the mean pulse height of one MIP response. The waveforms of the other two detectors were digitized by a fast oscilloscope (Tektronix TDS5052B [17]). The relative arrival times of the detector signals were used in order to reconstruct the direction of the shower axis. For this reconstruction, a simple plane wave approximation analysis (triangulation) was applied. Further selection cuts on the pulse amplitudes were applied in order to improve the reconstruction resolution. The distribution of the reconstructed direction (zenith angle) of atmospheric showers collected during a continuous operation of about 24 hours is presented in Figure 8 for two different selection criteria. The distributions are fitted with a flux model:

$$\frac{dN}{d(\cos\theta)} \sim \left(\cos\theta\right)^{\alpha} \qquad (1)$$

The index α depends on the selection criteria and it is estimated as $\alpha = 8.5 \pm 0.4$ when we require at least 0.5MIP equivalent charge to be deposited on the each of the two counters, and $\alpha = 9.4 \pm 0.6$ when we require at least 1.5MIP. These results are in good agreement with the previously published results [18]: $\alpha = 9.4 \pm 0.2$.



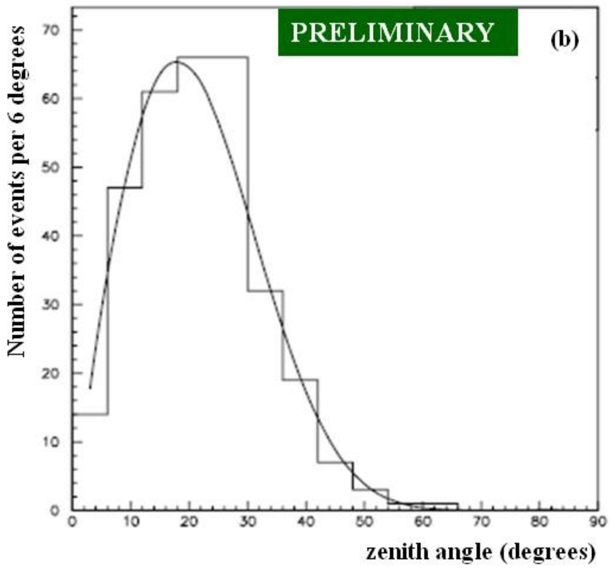


Figure 8: Zenith angle distributions of reconstructed air showers in the laboratory with one HELYCON detector station. In both distributions the threshold on the trigger counters was equivalent to 1 MIP. The threshold on the other two counters was 0.5MIP (a) and 1.5MIP (b). The distributions are fitted using the flux model (1) (see text).

V. Monte Carlo studies

Several Monte Carlo studies, based on the shower simulation model CORSIKA[2] and the Monte Carlo description of the HELYCON detectors, have been carried out in order to evaluate the HELYCON detector station performance. The results of these studies are also important for the estimation of the response functions [19] which are used during the reconstruction of the physical parameters of the primary cosmic particle. In Figure 9 the angular resolution of one detector station is presented for vertically incident showers with energies in the range of 10^6 – 10^7 GeV. In this

[2] In CORSIKA simulation the QGSJET II model was used for the high energy hadronic interactions and the GHEISHA model for the low energy hadronic interactions. EGS4 was used for the electromagnetic interactions.

simulation, the station consists of three detectors which are arranged on a equilateral triangle with edge 50m.

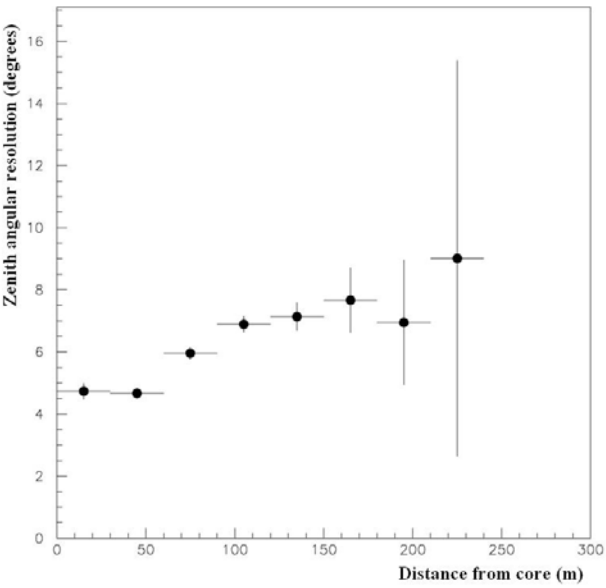


Figure 9: The angular resolution of reconstructing the shower axis as a function of the distance of the station centre from the shower core.

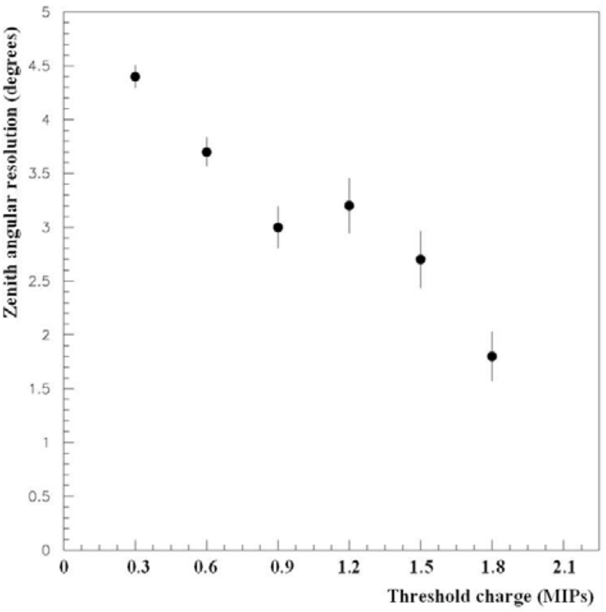


Figure 10: Zenith angular resolution of reconstructed showers for three HELYCON detector stations, as a function the selection criteria.

In Figure 10 the zenith angular resolution of reconstructed showers is presented for three detector stations and vertically incident showers in the energy range of 10^6 – 10^7 GeV. In this study the stations are arranged on a equilateral triangle with edge 170m. The zenith angular resolution depends strongly on the selection criteria applied. The angular resolution of the three stations is 4.5 degrees when the minimum produced light in the counters corresponds to 0.3 MIP, whilst the resolution improves to 1.5 degrees when the equivalent of 1.8 MIPs per detector is required.

VI. CONCLUSION

The HELYCON collaboration has constructed, tested and calibrated 15 detectors in order to facilitate and operate three of the telescope stations in Patras, by the end of 2006. Furthermore a detailed Monte Carlo description of the detectors has been developed and it has been found in an excellent agreement with the test and calibration results. In parallel with the pilot operation of the first HELYCON station more detector stations will be constructed and they will be deployed at the high schools and university buildings in the Patras area.

During 2007 more detector stations will be commissioned in nearby cities, as well as the island of Chios. The dispersion of the detector stations will make possible to study long range correlations between air showers.

Experimental techniques are also developed for radio detection of EAS and radio antennas will be included in the detector stations of the HELYCON array.

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