



The HEAT Telescopes of the Pierre Auger Observatory Status and First Data

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Abstract: The southern Pierre Auger Observatory was designed to detect ultrahigh energy cosmic rays above 10^{18} eV with high accuracy exploiting a hybrid detection technique. A surface array of 1660 water Cherenkov detectors on a 1500 m triangular grid covers an area of 3000 km². The atmosphere above the array is viewed by 24 wide angle telescopes. These telescopes observe the faint fluorescence light of the extensive air showers at dark moonless nights, i.e. with a duty cycle of about 15 %. As an enhancement to this baseline design of the Auger Observatory three additional telescopes with elevated field of view were built and now constitute HEAT, the high-elevation Auger telescopes. These telescopes are similar to the 24 other fluorescence telescopes (FD) but can be tilted by 29 degrees upward. They cover an elevation range from 30 to 58 degrees above horizon to enable the unbiased detection of nearby low energy air showers. Especially in combination with the detector information from an infill array of water tanks on a 750 m grid close to the HEAT site the energy range of high quality hybrid air shower measurements is extended down to below 10^{17} eV. HEAT is fully commissioned and is taking data continuously since September 2009. The status and prospects of HEAT are discussed and first (preliminary) data are presented.

Keywords: Pierre Auger Observatory, cosmic rays, HEAT, high-elevation fluorescence telescope

1 Introduction

The Pierre Auger Observatory was designed to measure the energy, arrival direction and composition of cosmic rays from about 10^{18} eV to the highest energies with high precision and statistical significance. The construction of the southern site near Malargüe, Province of Mendoza, Argentina has been completed since mid 2008 and the analysis of the recorded data has already provided important results with respect to, for example, the energy spectrum of cosmic rays [1], their distribution of arrival directions [2], their composition [3], and upper limits on the gamma ray and neutrino flux [4, 5]. The measured cosmic ray observables at the highest energies are suitable to tackle open questions like flux suppression due to the GZK effect, to discriminate between bottom-up and top-down models and to locate possible extragalactic point sources.

However, for the best discrimination between astrophysical models, the knowledge of the evolution of the cosmic ray composition in the expected transition region from galactic to extragalactic cosmic rays in the range 10^{17} eV to 10^{19} eV is required. Tests of models for the acceleration and transport of galactic and extragalactic cosmic rays are sensitive to the composition and its energy dependence in

the transition region where the observatory with the original design had a low detection efficiency.

The fluorescence technique is best suited to determine the cosmic ray composition by a measurement of the depth of shower maximum. As the fluorescence light signal is roughly proportional to the primary particle energy, low energy showers can be detected only at short distances from the telescopes. In addition, as these showers develop earlier in the atmosphere, their shower maximum lies higher in the atmosphere and thus is not accessible to the standard Auger telescopes due to their limited field of view in elevation (30°). Furthermore, the geometric orientation of the shower axis with respect to the telescope imposes a bias on the shower selection [6]. This was the motivation to build HEAT, the high-elevation Auger telescopes. The three HEAT telescopes are similar to the 24 standard ones and can be tilted, providing the extension of the field of view to larger elevation angles. From the data collected with the Pierre Auger Observatory we know that the quality of the reconstruction is improved considerably if the showers are recorded by a hybrid trigger. Hybrid events provide information about the shower profile from the data of the fluorescence detector (FD) and of at least one surface detector (SD). The time and location of the shower impact point on ground set further constraints which improves

the reconstruction of the shower energy significantly [7, 8]. The Pierre Auger Collaboration has built an additional in-fill surface detector array located at an optimal distance in the field of view of HEAT [9].

2 Design and properties of HEAT

In 2006, the Auger Collaboration decided to extend the original fluorescence detector, a system consisting of 24 telescopes located at four sites at the periphery of the surface detector array, by three High Elevation Auger Telescopes (HEAT). These telescopes have now been constructed, and they are located 180 m north-east of the Coihueco FD building. At the same time, the collaboration deployed extra surface detector stations as an in-fill array of 24 km² close to and in the field of view of HEAT. The layout of HEAT and the in-fill array is shown in Fig. 1.

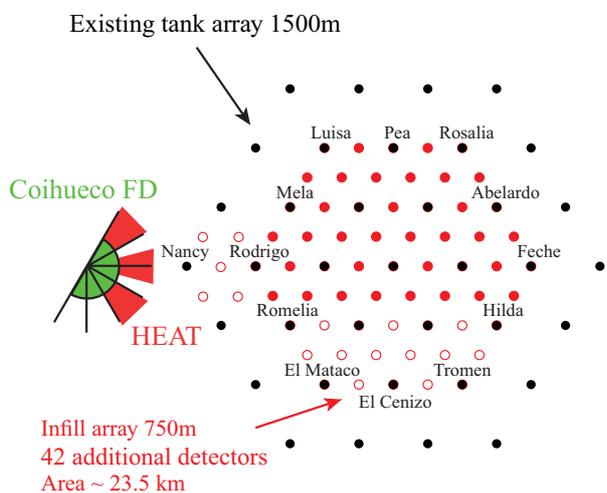


Figure 1: Layout of the in-fill array and the Coihueco and HEAT fluorescence telescopes. The additional in-fill stations are marked red (solid: already integrated in data taking).

The design of HEAT is very similar to the original FD system [10], except for the ability to tilt the telescopes upwards by 29°. In both cases a large field of view of about 30° × 30° is obtained using Schmidt optics (approx. 30° × 40° when tilted). Fluorescence light entering the aperture is focused by a spherical mirror onto a camera containing 440 hexagonal PMTs. A UV transmitting filter mounted at the entrance window reduces background light from stars effectively. An annular corrector ring assures a spot size of about 0.6° despite the large effective aperture of about 3 m². The high sensitivity of the Auger FD telescopes enables the detection of high energy showers up to 40 km distance. A slow control system for remote operation from Malargüe allows safe handling.

Differences between the conventional FD telescopes and HEAT are caused by the tilting mechanism. While the original 24 FD telescopes are housed in four solid concrete buildings, the three HEAT telescopes are installed in indi-

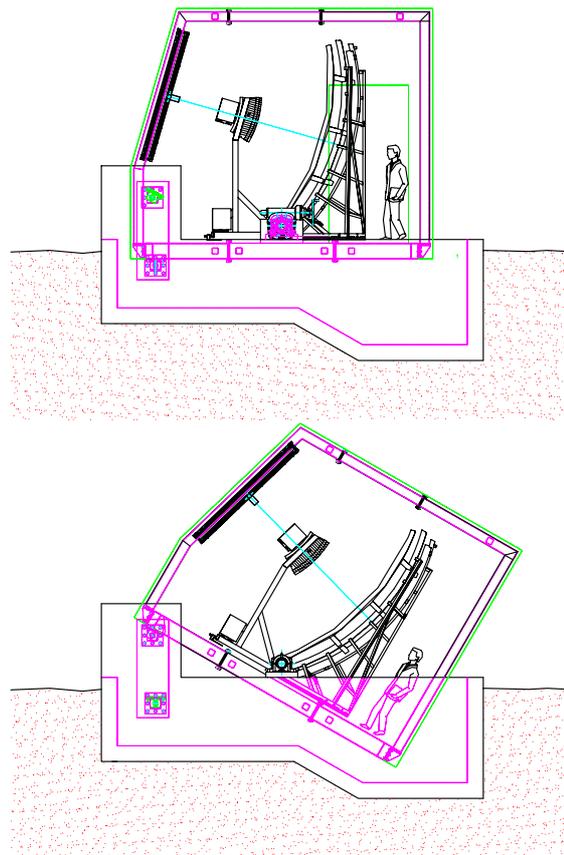


Figure 2: Schematic view of the cross-section of one of the HEAT telescopes. Top: Horizontal mode for service and cross-calibration, bottom: data-taking mode in tilted orientation.

vidual, pivot-mounted enclosures. Each telescope shelter is made out of lightweight insulated walls coupled to a steel structure. It rests on a strong steel frame filled with concrete. An electrically driven hydraulic system can tilt this heavy platform by 29° within two minutes. The whole design is very rigid and can stand large wind and snow loads as required by legal regulations. All optical components are connected to the heavy and stiff ground plate to avoid wind induced vibrations and to keep the geometry fixed. Mirror and camera were initially adjusted in the horizontal position (service position). To ensure sufficient mechanical stability of camera body and mirror support system, additional steel rods and overall improved support structures are employed. The mechanical stability is monitored by means of distance and inclination sensors. The principle of tilting is illustrated for one bay in Fig. 2.

Another design change for HEAT is the use of an improved data acquisition electronics (DAQ) whose concept and partitioning is, in principle, the same as with the previous version. The new design of the electronic is modernized and updated with larger and faster FPGAs. Along with that, the sampling rate of the digitizing system was increased from 10 MHz to 20 MHz and the overall readout speed can be



Figure 3: Photograph of HEAT in tilted mode with closed shutters.

potentially increased. From the point of view of the data taking and operation, HEAT acts as an independent fifth telescope site.

The aforementioned distance monitoring system has been used to prove that the tilting of the telescope enclosures does not modify the optical parameters of the telescopes significantly. In addition, reference calibration measurements at different tilting angles have shown that the influence of the Earth's magnetic field on the performance of the PMTs is only marginal and can thus be neglected.

A photograph of HEAT in tilted mode is shown in Fig. 3.

3 Measurements

Data taking with the new telescopes of HEAT is possible in horizontal ('down') position as well as in the tilted ('up') position. The horizontal position of the HEAT telescopes, which is used for installation, commissioning and maintenance of the hardware, is also the position in which the absolute calibration of the telescopes takes place. In this position the field of view of the HEAT telescopes overlaps with those of the Coihueco telescopes. This offers the possibility of doing special analyses of events recorded simultaneously at both sites. In addition, these events can be used to check the alignment of the new telescopes and provide a cross-check of their calibration constants.

With the HEAT enclosures in the tilted position, the combined HEAT-Coihueco telescopes cover an elevation range from the horizon to 58° . This extended field of view enables the reconstruction of low energy showers for close-by shower events and resolve ambiguities in the X_{\max} determination. The improved resolution in energy and X_{\max} determination is especially visible in the low energy regime.

The first measurements with a single HEAT telescope started in January 2009 whereas measurements using the new DAQ electronics with all three telescopes commenced in September 2009. An example of one of the first low-energy showers recorded with HEAT and the Coihueco station is shown in Fig. 4.

The initial data taking period served as commissioning and learning period. Since June 2010, the data taking and data quality reached a satisfactory performance level and all results presented here are based on the latter data taking period. During this period, an absolute calibration campaign with a uniformly lit drum [11] and a roving laser for these new telescopes has been performed successfully.

The alignment of the regular fluorescence telescopes is obtained from star tracking. In addition to this method, a new method was introduced to determine the alignment of the HEAT telescopes. Given a reference geometry from any number of sources (SD, hybrid, reconstruction from other sites, laser shots) and the observation of the corresponding light traces in a HEAT telescope, the developed algorithm determines the optimal pointing direction for the telescope. The accuracy of the method increases when applied to many events. This method results in a statistical accuracy of 0.3° or better for elevation and azimuth. For the HEAT telescope 1, which has the Central Laser Facility (CLF) [12] in its field of view, accuracies of better than 0.1° can be achieved.

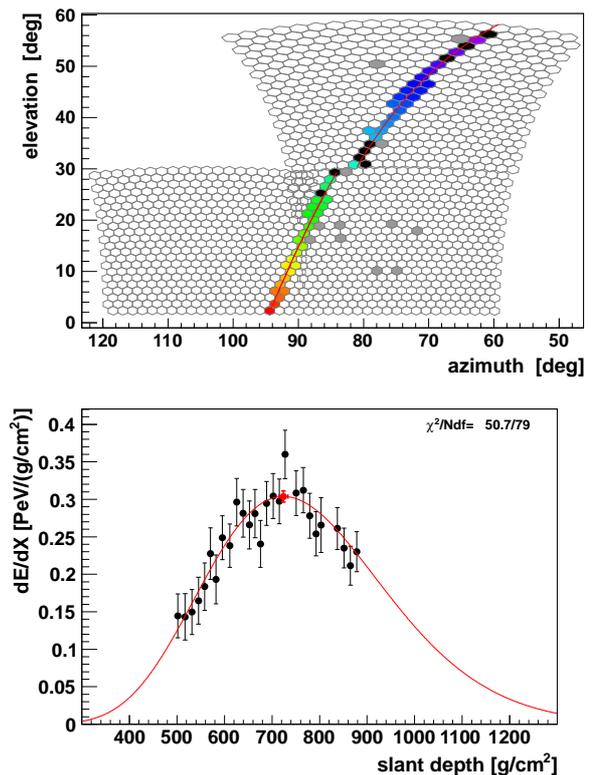


Figure 4: Example of a low-energy event recorded in coincidence with HEAT and two Coihueco telescopes. Top: Camera image of the recorded signal. The arrival time of the light is color-coded (blue early, late red). Bottom: Reconstructed energy deposit profile. This nearly vertical event with a zenith angle of 19° has a reconstructed energy of about 1.7×10^{17} eV.

The different FD sites and the SD are operated independently. Their data are merged offline using the GPS pulse-per-second timestamps. It is thus vital for the reconstruction based on event times to measure and control the time-offsets between the components. Instead of minimizing the angular difference, a similar approach is also used to minimize the time difference between SD and HEAT. A correctly determined SD-HEAT time offset is also characterized by the fact, that in the combined SD-HEAT (time) geometry fit, the least number of pixels is rejected in the event reconstruction.

4 Data analysis

For the shower reconstruction it is desired to combine the data from HEAT and Coihueco. However, in the standard shower reconstruction chain the data from each building is used separately. Thus, the analysis software package *Offline* [13] has been generalized from a building-based to a telescope-based reconstruction. The different telescopes can then be combined in any desired form to build a virtual site.

In the same manner, the module for the hybrid geometry finding was extended in a way that shower detector plane (SDP) times and the time determined by the analysis of the SD data are combined in a kind of global fit procedure. In each fitting step the parameters describing the SDP and the shower core are calculated together.

Initially, when the HEAT telescopes went into operation, no absolute calibration for the HEAT telescopes was available, the gain of the camera was only flat-fielded. Using showers measured in coincidence with HEAT (downward mode) and Coihueco which fulfill certain quality criteria, a set of preliminary calibration constants could be achieved. The cross-check with the updated calibration constants (after an absolute calibration was performed) resulted in differences of 2 % or less (depending on the telescope). With this method also the energy resolution of the telescopes could be determined to be of the order of 10 %, see Fig. 5.

5 Conclusions

The telescopes of the HEAT site have operated since September 2009 and are producing high quality data in a stable manner. The first data from this site were used to produce rough calibration and alignment constants for this newly built part of the observatory.

Even from a short period of data taking so far it is clear that these new telescopes improve the quality of data for energy and mass composition analyses significantly at low energies. Their extended field of view allows for an unbiased measurement of $\langle X_{\max} \rangle$ down to much lower energies than has been possible with the standard Auger fluorescence detectors.

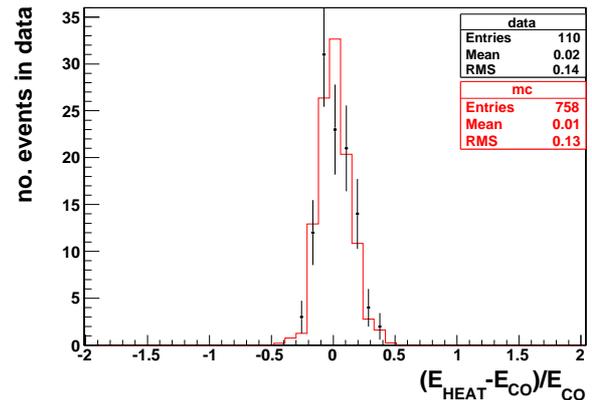


Figure 5: Determination of the energy resolution of the HEAT and Coihueco telescopes. Shown is the difference between the energy reconstructed with HEAT in downward mode with respect to that of Coihueco. Assuming that all telescopes have the same energy resolution one has to divide the RMS by $\sqrt{2}$ to obtain the resolution of one telescope. The histogram also shows simulated showers reconstructed the same way as data.

The improvements to the combined field of view of old and new detectors required major changes to the *Offline* analysis framework and the development of new reconstruction components. This is currently still work in progress.

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