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HEAT – Enhancement Telescopes for the Pierre Auger Southern Observatory

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Abstract: The southern part of the Pierre Auger Observatory (PAO) is nearing completion in the province of Mendoza, Argentina. Since 2004 the instrument is used to take air shower data at the highest energies [1]. The energy threshold of the 3000 km² surface array of 1600 particle detectors for high quality air shower reconstruction is about $3 \cdot 10^{18}$ eV. The 24 Auger fluorescence telescopes (FD), located in four "eye" stations at the edge of the detector array, enable precise air shower measurements even at primary energies below 10^{18} eV. The Auger Collaboration has decided to further expand its energy range down to 10^{17} eV after completion of the southern observatory around the end of 2007 by three additional fluorescence telescopes with an elevated field of view from 30^o to 60^o above the horizon. It is foreseen to use these High Elevation Auger Telescopes (HEAT) in combination with the existing telescopes at one of the four existing FD sites (Coihueco) as well as in hybrid mode using the shower particle data from a new infill detector area of about 25 km² with fourfold sampling density – close to HEAT and in the field of view of the new telescopes. This SD infill array (AMIGA) will also be equipped with large area muon detectors [2]. In addition, it will be a perfectly suited test area for the development of novel detection techniques for air showers at ultrahigh energies [3].

Introduction

Cosmic rays with energies in the range between 10^{17} eV and $5 \cdot 10^{18}$ eV are of special interest for the determination of the details of the transition from galactic to extragalactic cosmic rays. The precise shape of the energy spectrum and the possible changes in primary composition must be well known to enable stringent tests of models for the acceleration and transport of both, galactic and extragalactic, cosmic rays. More elaborated arguments can be found in a separate contribution to this conference [4].

The fluorescence technique for the detection of air showers encounters difficulties at energies below 10^{18} eV. The signal strength in fluorescence photons per unit path length is (at air shower maximum) roughly proportional to the primary energy. Therefore, the effective distance range of air shower detection gets smaller at lower energies. Only relatively close-by showers will trigger the DAQ. At these small distances the height of observation by the FD telescopes is limited. In addition, lower energy air showers reach their maximum of development at higher altitudes. This height cutoff effect naturally gets even worse for air showers incident at larger zenith angles.

The maximum of shower development will thus quite often fall outside the field of view of the existing FD telescopes of the Auger Observatory, which is limited to about 30^o above the horizon. For an unambiguous reconstruction of the shower profiles this leads to severe cuts in the triggered data, which may be dependent on primary mass. The telescope detection efficiency for showers, which hit the ground at a certain distance from the "eye", also depends on the shower-detector geometry. Showers approaching the telescopes will have a higher trigger probability due to the angular dependence of the scattered Cherenkov light. Also, the efficiency for successful reconstruction of the shower profile and X_{max} will be increased as is illustrated in figure 1. Therefore, it is clear that for lower energies the fluorescence telescopes benefit from a larger elevation range.

The Auger Collaboration will combine several of their existing telescopes with three additional telescopes tilted by about 30^o, therefore covering elevation angles up to 60^o above horizon, but else these will be very similar to the existing systems.

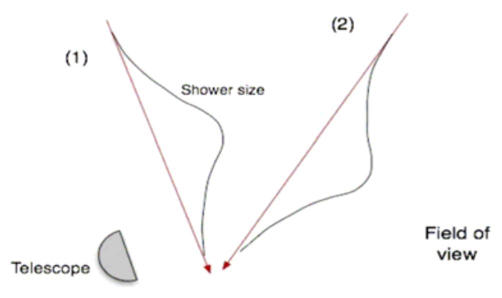

Figure 1: Severe effects of a limited field of view of fluorescence telescopes. Showers approaching the “eye” have higher reconstruction efficiency.

Auger FD and the HEAT Telescopes

The Auger Collaboration has installed 24 fluorescence telescopes at the southern observatory site in Argentina. The telescopes are taking data in four FD buildings (45 km apart from each other at the edges of the array) overlooking the 3000 km² array of 1600 particle detector tanks.
Each telescope has a field of view of 30^o x 30^o. The Schmidt optics of the telescopes has an effective aperture of about 3 m². The signal/noise ratio is improved by the use of UV transmitting filter glass (M-UG6) for the entrance windows. The high sensitivity of the Auger telescopes enables the detection of showers with $E > 10^{19}$ eV up to distances of more than 40 km. Therefore, most of the highest energy events are detected in stereo mode by at least two telescopes simultaneously.
The strength of the Auger experiment is the operation in Hybrid mode. More than 10% of all events are detected by the surface detector system (SD) and at least one (FD) telescope. These events are especially valuable in two different ways. The FD information allows the independent energy calibration of well measured SD events at higher energies. On the other hand, the FD traces for low energy events can be reconstructed much better, if at least one of the SD detector tanks has triggered and its timing information can be used for the event reconstruction. In this “brass hybrid mode” the energy threshold of reconstruction is much lower than for the surface detector alone, where at least five tanks must trigger for good reconstruction quality of all shower parameters.
Therefore, the energy range below $10^{18.5}$ eV is the domain of the Auger FD telescopes. The three new HEAT telescopes will show their full strength also in the hybrid mode.
An SD infill area of 25 km² with fourfold surface detector density close to the HEAT telescopes will raise the hybrid trigger rate considerably and lower the combined threshold for high quality data. The additional large area muon detectors in this area (AMIGA) will further enhance the high capabilities of the PAO South experiment for the determination of the mass distribution of the primary cosmic ray particles.
The installation and commissioning of these two enhancement systems will fit perfectly in the time span between the end of detector commissioning in Argentina and the start of installations for the PAO North experiment in Colorado.

Properties of the HEAT Telescopes

In the context of design studies for the Auger North experiment planned for a Colorado site it became obvious to the FD study group that the quality of the fluorescence telescopes operating in Argentina is very satisfying. Apparently there is no need for major design changes. Therefore, it was decided to keep the main design parameters like the structure of the PMT cameras and the layout for the telescope optics unchanged.
These decisions lead to new requirements for the mechanics of the HEAT telescopes. The existing 24 telescopes are operated in four solid concrete FD buildings. The new systems will be installed in moveable individual enclosures. As several obsolete electronic circuits will have to be replaced anyhow, new designed readout electronics will be used for HEAT, also as baseline design and prototypes for the PAO North FD telescopes.
The three telescope shelters are made from steel structures with lightweight insulating walls. They are design to withstand large wind and snow loads according to the local conditions and legal regulations. Each shelter is built on a heavy platform, a strong steel frame filled with concrete. These platforms can be tilted by 30^o using commercial hydraulic drives and heavy duty bearings. The large weight of the ground plates is necessary to reduce wind induced vibrations of the shelters. All critical installations are connected to these solid ground plates only, not to the shelter walls.

Additional fixing bolts and improvements of the mechanical support structures are foreseen in order to ensure the stability of the alignment of the optical system, which is critical both for the telescope pointing and for the optical resolution.

HEAT “Downward” Operation

In the horizontal (“down”) position, installation, commissioning, and maintenance of the hardware are performed. These operations for HEAT are very similar as for the existing telescopes. Also the absolute calibration of the telescopes will be performed only in the horizontal position of the shelters. Possible changes in telescope properties due to the tilting of the whole system will be monitored by a high accuracy relative calibration system based on pulsed LEDs with measurements in both orientations and careful tracing of any gain variations due to e.g. the change of the orientation of the PMTs in the earths magnetic field. Data taking on cosmic ray air showers or laser shots will be possible both in the “up” and in the “down” position. In the “down” orientation the telescopes will cover the same field of view as some of the existing telescopes at the Coihueco building, which is located at a distance of less than 200 m from the HEAT area. A comparison of the reconstruction results for air shower data (or laser scattering events) taken simultaneously by the old and the new telescopes enables a direct determination of the Auger telescope resolution e.g. in energy and X_{max} as is demonstrated by a set of simulated events in figure 2.

HEAT Tilting Operation

The whole system of ground plate, enclosure and telescope will be tilted by 30^o using a hydraulic drive and two heavy bearings. The stability of the mechanics and optics during the tilting will be monitored precisely by multiple sensors for the tilt angle of some of the elements like mirrors, PMT cameras, corrector ring lenses, etc. as well as by vibration sensors to detect wind induced effects and by several other measuring devices for the control of distances between mirrors and the PMT camera, or the corrector ring, respectively.
All mechanical monitoring data will be readout and stored by the Slow Control System of HEAT, which else is similar to the system operating in the already existing four FD buildings.

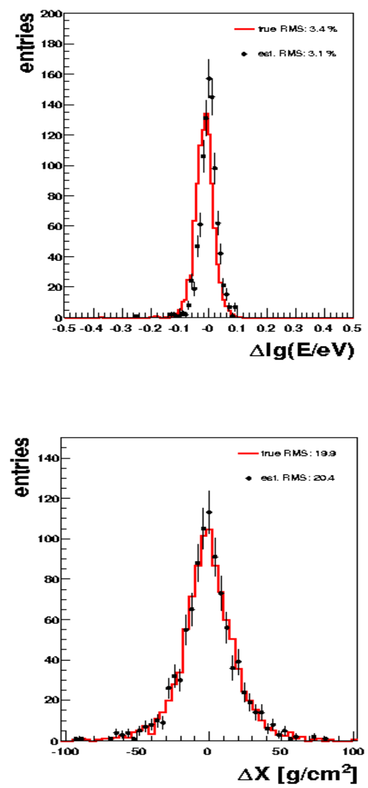

Figure 2: Telescope resolution study simulating a “double-downward” measurement campaign for the energy range above 10^{18} eV.

HEAT “Standard” Operation

With the HEAT enclosures in the “up” position, the combined telescopes cover an elevation range from the horizon to about 60^o. As can be seen in the example of a simulated close-by shower event in figure 3 the extended field of view will enable the reconstruction of low energy showers and resolve ambiguities in the X_{max} determination.
HEAT will act as an independent fifth “eye” of the PAO South experiment. The combined shower data of the FD and the HEAT telescopes will lead to better resolutions for the determination of air shower energy and X_{max}. This effect is present at all energies, but especially in the energy range below 10^{18} eV. The results of the corresponding Monte Carlo simulations are shown in figure 4.

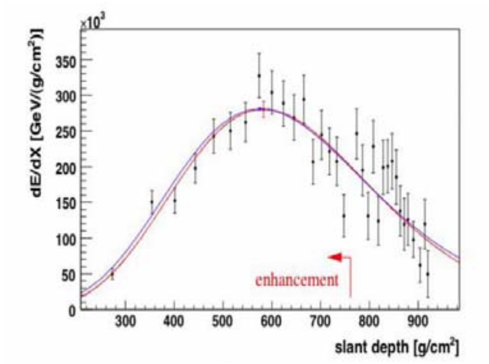

Figure 3: "Data" and reconstruction for a simulated shower with E = $10^{17.25}$ eV at R = 1.2 km. The data measured by the HEAT telescopes (left of the red arrow) would enable the reconstruction.

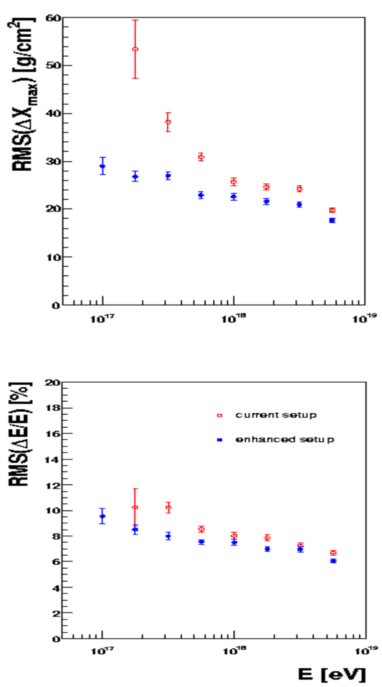

Figure 4: Enhanced reconstruction quality of the Auger FD system by the HEAT telescopes (MC).

By using the additional information of the "brass hybrid triggers", the combination of the HEAT telescopes with the denser infill array of AMIGA will enable "bias-free" measurements of the air shower elongation rate down to about 10^{17} eV.

The fourfold SD detector density will effectively remove the dependence of the single tank trigger efficiency on the primary CR mass at this energy. The improved quality at low energies can also be seen in the increased trigger and reconstruction efficiencies for nearby showers.

The hybrid count rates of the combined HEAT and infill SD array will be sufficient to measure the important parameters for the cosmic ray spectrum and composition above 10^{17} eV with good statistical quality within three years of operation.

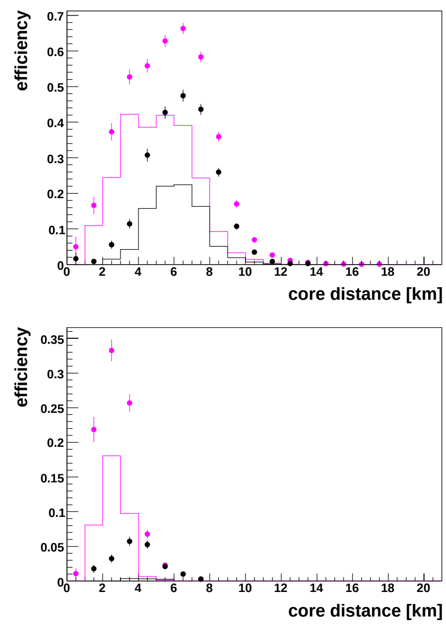

Figure 5: FD trigger probability (dots) and reconstruction efficiency (solid lines) for near showers.

Top: at $10^{17.5}$ eV and bottom: at $10^{17.0}$ eV. Black: old FD telescopes, pink: FD + HEAT telescopes.

References

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