Enhancements to the Southern Pierre Auger Observatory

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Enhancements to the Southern Pierre Auger Observatory

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Abstract. The southern Pierre Auger Observatory has been detecting cosmic rays above 10^{18}eV since 2004, exploiting a hybrid air shower detection technique, with 1660 water Cherenkov detectors together with 24 air fluorescence telescopes on a 3000 km^2 site. As low energy enhancements to the observatory, 3 additional telescopes with elevated fields of view were built (HEAT). The detector density was increased in the HEAT fields of view by a factor of four in an area of about 25 km^2. This setup enables unbiased hybrid data taking above 10^{17}eV. The infilled area is also being equipped with large underground scintillator muon detectors (AMIGA). Finally, a prototype array of radio antenna stations (AERA), working from 30 to 80 MHz, has been installed in a part of the infill. Properties and status of AMIGA, HEAT, and AERA are presented.

1. Introduction

The primary goal of the Pierre Auger Observatory is the measurement in both hemispheres of ultra high energy cosmic rays (UHECRs) with energies above 10^{18}eV. This is achieved through the detection of extensive air showers (EAS) induced by these particles in the earth atmosphere with unmatched accuracy and exposure. The Southern Observatory was installed on the "Pampa Amarilla" near the city of Malargüe in the province of Mendoza, Argentina at 1400m above sea level on a 3000 km^2 site. The baseline design consists of (a) 1600 water Cherenkov detectors (10 m^2 each) on a 1500 m triangular grid for the secondary particles in the extensive air showers, the Surface Detector SD [1], and (b) of 24 wide angle fluorescence telescopes located in four stations at the periphery of the detector array, the Fluorescence Detector FD [2]. This setup enables high quality air shower measurements above $3x10^{18}$ eV. Hybrid measurements by the fluorescence telescopes probe below 10^{18} eV. This is only possible in clear moonless nights (i.e. with up to 15 % uptime). The SD data are used to determine the flux of UHECRs and their energy spectrum as well as the distribution of arrival directions. Hybrid events, including the FD information, are used for absolute energy calibration and for the study of the mass of the primary particle by investigating the longitudinal shower development. Data taking commenced early in 2004 and is planned to continue until 2020.

Since 2006 several proposals have been developed inside the Pierre Auger collaboration to add enhancements to the original design. One objective was to extend the measurements in a part of the array down to ~10^{17} eV to cover the assumed transition range from Galactic to Extragalactic cosmic rays and the highest energy UHECRs in one experiment. Another goal was to determine the muon content of air showers at energies around 10^{18} eV by independent measurements, also for testing and improving UHE interaction models. In addition, studies of novel EAS detection techniques like measurements of MHz or GHz emission from extensive air showers were proposed and begun.

2. The AMIGA Enhancement

The AMIGA (Auger Muons and Infill for the Ground Array) [3] enhancement consists of a detector infill area of about 25 km^2 with 61 water Cherenkov detectors on a 750 m grid. This produces a ten times lower threshold compared to the 1500 m array (see figure 1). Underground scintillator detectors with large area (30 m^2) are buried near these detectors for counting muons in air showers, which land in or close to the infill array.

The installation of detector tanks in the infill area was done in steps as resources became available. The deployment is complete now. Data taking with a part of the infill array began in 2008. More than 200.000 high quality events were collected and analyzed by mid 2011. The UHECR spectrum determined from this first data set covers the energy range from 3x10^{17} eV to nearly 10^{19} eV and is in very good agreement with the published results of the baseline Auger experiment above 10^{18} eV. The high event rate of the full infill array will enable detailed studies of the lateral distributions of air shower particles and a precise determination of the UHECR spectrum up to 10^{19} eV.

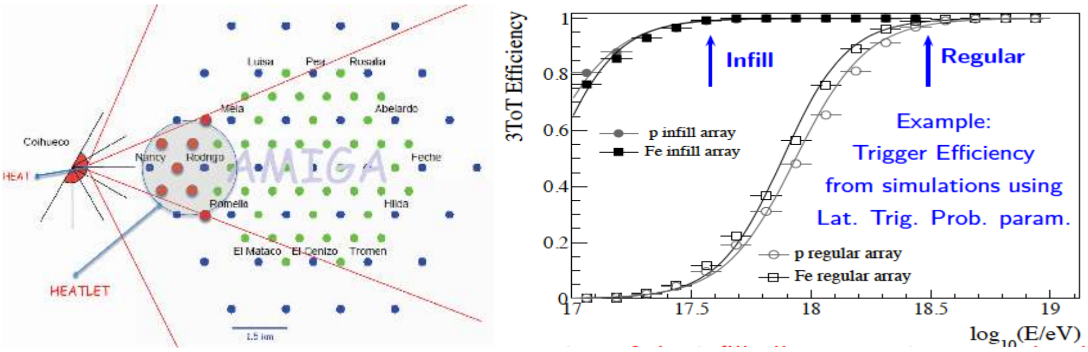

Figure 1. The AMIGA Infill Array near the Coihueco FD building and the infill detection efficiency vs. primary energy compared to the regular 1500 m array [3]

The muon detectors of AMIGA are polystyrene scintillator stripes with wavelength shifter fiber readout buried close to the 61 infill tanks under 2.3 m of soil. Each station consists of two scintillator modules of 10 m^2 and two smaller modules of 5 m^2. Their muon energy threshold is about 1 GeV. Several prototype counter modules were deployed in 2010 and extensively tested in the field.

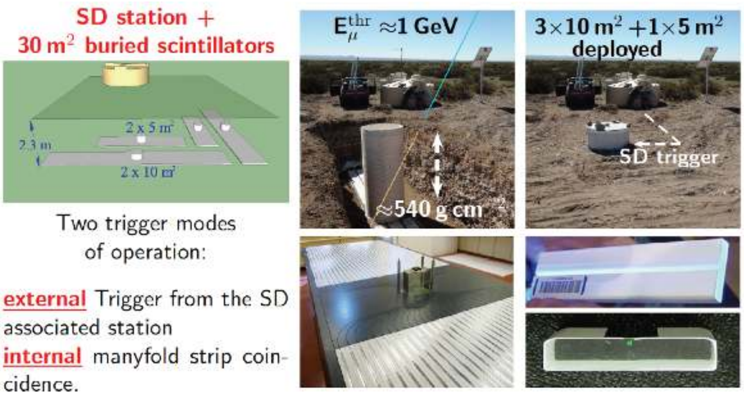

Figure 2. The AMIGA muon counter layout and photos of the prototype production and deployment

As a first step towards the full muon detector array the installation of a hexagon of seven stations of 30 m^2 is foreseen for early 2012. This "unitary cell" of AMIGA will be used to study in detail the concept of muon detection under soil shielding and to optimize the full detector production.

The original layout of the infill array has been changed recently. Additional water tanks on the west side of the array close to the FD building further increase the effective infill array area for low energy shower measurements. These HEATLET (HEAT Low Energy Trigger) tanks are of special value for hybrid data taking at very low energies with the Coihueco and HEAT telescopes (see next section).

3. The HEAT Fluorescence Telescopes

The mass composition of cosmic rays as function of energy is an important clue for the understanding of the sources and propagation of UHECRs and for tests of different theoretical models. The determination of this information at UHE energies is indirect and depends on interaction models. However, all these models agree that two observables are strongly correlated with the mass of the primary: the number of muons at ground will be larger, and the longitudinal shower development will be faster for heavy nuclei than for light nuclei and photons. The Auger fluorescence telescopes are designed to measure the details of the longitudinal air shower development with high accuracy. The atmospheric depth X_{max} (g/cm^2), where the number of secondary particles in the shower reaches its maximum N_{max}, depends on both primary mass and energy. The latter can be estimated by N_{max} or better by integrating over the longitudinal distribution of the energy deposit dE/dX in the atmosphere. In addition, the width of the fluctuations of X_{max} at a given energy depends on the primary mass. It follows from simple arguments that for heavier primaries the fluctuations should be smaller.

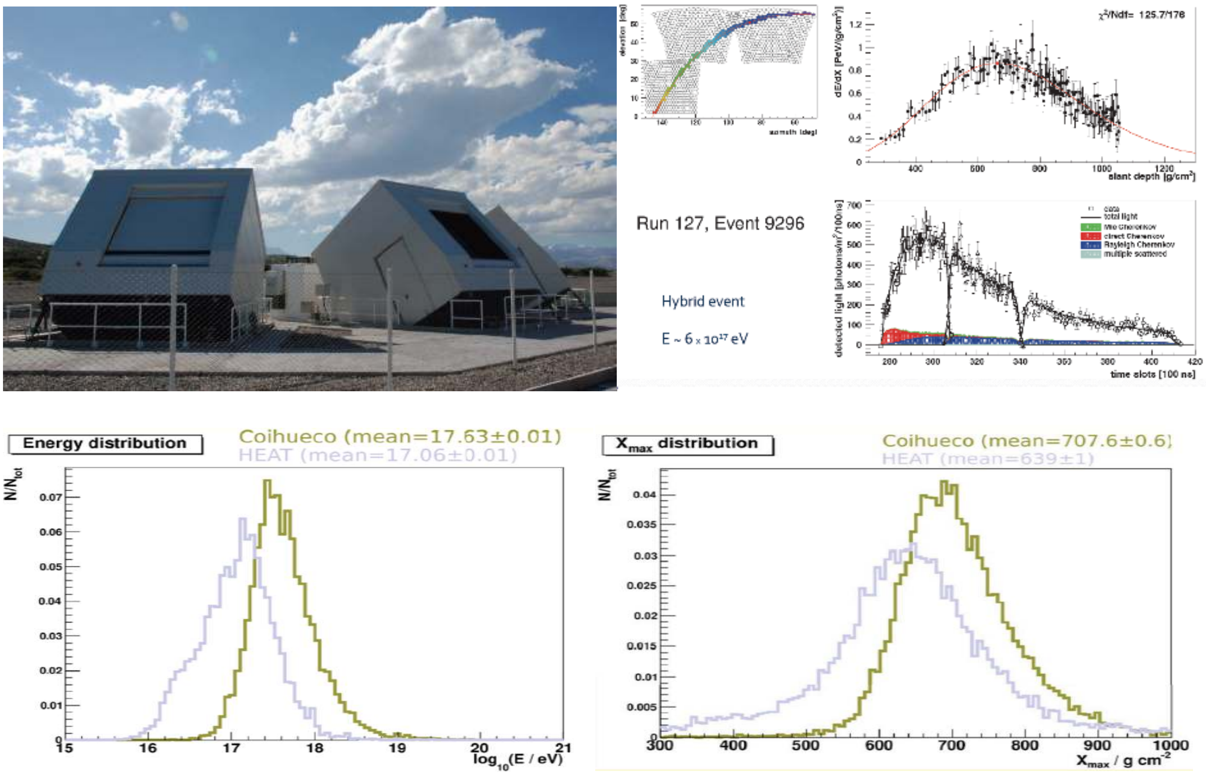

Figure 3. a) HEAT telescopes in tilted position, b) an event detected by one Coihueco and two HEAT telescopes, and c) impact of first HEAT data on the energy threshold and the X_{max} measurement range.

For an unbiased determination of the primary mass, X_{max} of the shower development must be clearly identified within the field of view of the fluorescence telescopes. The telescopes of the Auger baseline design have a vertical field of view from about 1 to 30 degrees above the horizon. Showers landing very close to the telescopes will quite often reach their maximum above the field of view and thus miss the quality cuts for reconstruction. However, at very low energies most showers can only be detected at close distance due to their dim light output. The detection efficiency is then low and measurements of the X_{max} values are biased by field of view cuts. To avoid this bias, three additional fluorescence telescopes with an elevated field of view were installed as shown in Figure 3.

These HEAT (High Elevation Auger Telescopes) telescopes [4] are located near the FD Coihueco building overlooking HEATLET and the AMIGA Infill Array area. They are very similar to the FD telescopes but are housed in three individual buildings, which can be tilted hydraulically by 30 degrees to cover the range from 30 to 60 degrees above horizon. When used together with the Coihueco telescopes, unbiased measurements of shower profiles and X_{max} are thus possible for energies around 10^{17} eV. The inclusion of timing information from at least one triggered infill tank enables showers at very low energies to be reconstructed with good accuracy. The single tank trigger probability needed for such hybrid measurements depends on the detector spacing, as well as on the energy, zenith angle, and mass of the primary particle. Simulations show that a detector spacing of 750 m as used for HEATLET and the Infill Array removes both the trigger bias from the primary mass and UHE interaction models down to an energy of 10^{17} eV for zenith angles up to 45 degrees.

4. AERA and GHz detection tests

An array of 21 antenna stations working in the frequency range from 27 to 84 MHz was installed on a 150 m grid in the infill area. This Auger Engineering Radio Array [5] has studied radio emission from UHE air showers in great detail since early in 2011. Several coincidences of self-triggered events with data measured by the surface detector tanks and fluorescence detectors have been recorded already. The main goals of AERA are the calibration of the radio signals from EAS with the information from the infill array and the fluorescence detectors plus detailed studies of the emission properties of MHz radiation. The lateral distribution of EAS radio signals will be determined by this engineering array and used for the design of a larger area antenna field suitable for the autonomous detection of higher energy UHECRs. In 2012, the next stage of AERA will use a larger spacing of 250 m for about 75 radio detection stations. Detailed studies will be needed to clarify the possible use of radio detection for energy and mass determination of UHECRs on an even larger scale.

Several ongoing investigations [6] of the use of antennas in the GHz range for the detection of UHECR air showers are in a preliminary state. They will be continued at the Auger observatory site in Argentina as a necessary and very promising R&D study for a next generation giant UHECR experiment.

References

[1] Allekotte I *et al.* 2008 *Nucl. Instr. Meth.* A **586** 409
[2] Pierre Auger Collaboration 2010 *Nucl. Instr. Meth.* A **620** 227
[3] Sanchez F *et al.* 2011 Proc. 32nd ICRC (Beijing, China); arXiv: 1107.4807
[4] Mathes T H-J *et al.* 2011 Proc. 32nd ICRC (Beijing, China); arXiv: 1107.4807
[5] Kelley J *et al.* 2011 Proc. 32nd ICRC (Beijing, China); arXiv: 1107.4807
[6] Allison P *et al.* 2011 Proc. 32nd ICRC (Beijing, China); arXiv: 1107.4807