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Extreme High Energy Cosmic Ray Astronomy by the Pierre Auger Observatory

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Abstract. The Pierre Auger Observatory is the largest cosmic ray detector in the world. In its final configuration will cover 3000 km^2 in both hemispheres. In the period January 2004 - June 2005 it has achieved a total exposure of 1650 km^2 sr yr below 60° of zenith angle.

Key words. Cosmic rays: energy spectrum – Cosmic rays: chemical composition

1. Introduction

The investigation of high energy cosmic rays is currently the most active field of astroparticle research. Over a wide range of energies their origin, acceleration and propagation mechanisms are still unknown and this is particularly true for energies greater than 10^{19} eV. The interaction of the extremely high energy cosmic rays with the microwave background radiation is expected to result in a cut-off, known as GZK effect, in the energy spectrum above several times 10^{19} eV unless the sources are in our cosmological neighbourhood. Protons of these energies may point back to the source and open a new kind of astronomy with charged particles. Due to the very low flux (1 particle/km^2/sr/century) above the GZK cut-off, cosmic rays in this energy range have to be studied through the detection of Extensive Air Showers (EAS) by measuring at ground level the secondary particles produced by the interactions of the primaries with the atmosphere or by exploiting the atmospheric Cherenkov and fluorescence light.

The Pierre Auger Observatory (P.A.O.) is an hybrid experiment designed (Pierre Auger Collaboration 1997) to explore the given energy range with a full-sky coverage and aperture of 7350 km^2 sr in each hemisphere for zenith angles up to 60°. The Surface Detector consists of 1600 water tanks placed on a triangular grid with 1.5 km spacing to cover 3000 km^2. The Fluorescence Detector consists of twenty-four fluorescence detectors grouped in four locations at the perimeter of the ground array to oversee the entire surface array. The southern site of the P.A.O. is currently under construc-

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tion at Malargue (Mendoza, Argentina). On June 2005 the surface array has over 700 detectors and has been in stable operation since January 2004. At the same time three of four fluorescence sites have been completed and in operation. Two of them have been collecting data since January 2004.

2. The Surface Detector

The Surface Detector (SD) (Pierre Auger Collaboration 2004) of the Pierre Auger Observatory is designed to sample the particle density at ground level. It consists of water Cherenkov tanks having 3.6 m diameter, 1.2 m height and containing a Tyvek liner filled with 12 m^3 of purified water. Three large 9" photomultipliers (PMTs) XP1805 Photonis downward facing the water from the tank top are used to detect the Cherenkov light emitted by particles crossing the tank. The dynamic range of the photomultipliers extends from few photoelectrons to 10^5 photoelectrons. The electric power for the PMTs, the local electronics, GPS synchronization system and wireless LAN communication is provided by a solar panel and a buffer battery. The key parameter to measure for each detector is the average charge deposited by a vertical high energy muon traversing a tank (1 Vertical Equivalent Muon, VEM). This value is obtained by the distribution of charge deposited by muons crossing the detector in all directions: one VEM produces a signal of about 100 photoelectrons in one PMT. To monitor and to check the long term performances of the detectors and the accuracy of the online calibration, each local station sends every 6 minutes a block of monitoring data (various temperature, current and voltage measurements taken on each detector) to the Central Data Acquisition System (CDAS) (Pierre Auger Collaboration 2005). Every 4 hours, 1000 raw traces at low threshold (0.15 VEM) are taken and sent to CDAS without any processing, allowing checks of online calibration (Aglietta et al. 2005). A cosmic ray event is identified by a hierarchical trigger sequence: the lowest level is set on the local station, which is fired if the signals of all three PMTs are greater than 1.75 VEM, the highest level is reached when al least three stations are fired together out of chance coincidences (Lhery-Yvon et al. 2005). The arrival directions of the showers are measured from the relative arrival times of the signals in the fired stations, while the core position and the particle density at 1000 m from the core are determined from the water Cherenkov signals recorded by each selected station through a fit to a formula describing the EAS lateral distribution function.

3. The Fluorescence Detector

The Fluorescence Detector (FD) (Pierre Auger Collaboration 2004) measures the longitudinal profile of the high energy cosmic ray showers in atmosphere. The measurement is based on the detection of fluorescence light emitted by the atmosphere during the passage of the shower particles. The emission is mainly in the 300-400 nm interval and the intensity of the order of 4 photons per electron traversing 1 m of atmosphere. The FD consists of 24 wide-angle Schmidt telescopes grouped in four stations. Each telescope has a 30° field of view in azimuth and 28.6 in elevation.

The four stations at the perimeter of the surface array consist of six telescopes each for a 180° in azimuth field of view inward over the surface array. The uncertainty in the pointing direction of the telescopes due to the installation is 0.1 °, while the actual telescope pointing precision measured by the observation of stars crossing the field of view is 0.01 ° (Camin et al. 2005). Each telescope is formed by segments to obtain a total surface of 12 m^2 on a radius of curvature of 3.40 m. The aperture has a diameter of 2.2 m and is equipped with optical filters to match the fluorescence spectrum and a corrector lens. In the focal surface a camera of 440 hexagonal PMTs detects the light on 20 $\times$ 22 pixels of 1.5° $\times$ 1.5°. PMT signals are continuously digitised at 10 MHz sampling to filter out shower traces from the random background of 200 Hz per PMT. The absolute end to end calibration of a telescope is performed by mean of a large homogeneous diffuse light source of 375 nm placed on the front of the telescope. The ratio between the known light flux emitted by the source and the observed signal from each PMT gives the required calibration. Cross checks of the FD calibrations is made by observing and reconstructing the laser beam traces fired into the atmosphere from various locations of the Surface Detector. The observed difference between the reconstructed and the true laser energy is between 10-15% (Arqueros et al. 2005). Attention is given to a good knowledge of local atmospheric conditions as the Raleigh and aerosol scattering can reduce the light transmission between the shower axis and the detector, moreover the atmosphere must be monitored for the presence of clouds. The network for atmospheric monitoring therefore include LIDAR systems, cloud cameras and star monitor (Roberts et al. 2005) allowing a continuous check of the sky conditions.

4. Hybrid measurements

A hybrid event is an extensive air shower simultaneously detected by the surface and fluorescence detectors. The combination of particle detections at ground level and the observation of the atmospheric fluorescence light emitted by Extensive Air Showers provide a tool for an energy determination almost independent from simulations. The particle density at different distances from the shower core can be measured with the ground array while the shower longitudinal development, whose integral is proportional to the total energy release in atmosphere can be measured with the fluorescence detector. The hybrid events can be independently reconstructed and the results used for internal checks and to establish empirical rules for the energy conversion (Pierre Auger Collaboration 2005). For hybrid events the resolution in the core position is 50 m and in arrival direction of cosmic rays 0.6 °. These results for the hybrid accuracy are in good agreement with expectations (Sommers 1995) (Fick 2003). The hybrid operation of the Pierre Auger Observatory started in January 2004 and over 16000 hybrid have been reconstructed. Surface and Fluorescence Detectors have been running simultaneously 14% of time and the hybrid events represent 10% of the surface array data.

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