Status, Performance and Perspectives of the Pierre Auger Observatory

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Abstract

The Pierre Auger Observatory will be the largest cosmic ray detector ever built, covering 3000 square kilometres in both hemispheres in its full configuration. The first runs have demonstrated a very good performance of the apparatus.

1. Introduction

Cosmic ray research is at the energy forefront of astroparticle physics. Of particular interest are cosmic ray particles with energy $> 10^{20}$ eV. At these energies the protons, nuclei, or photons interact with various background radiation fields and should be strongly attenuated except if the sources are in our cosmological neighborhood (< 100 Mpc). Also protons of these energies may point back to the source and open a new kind of astronomy with charged particles.

2. The Pierre Auger Observatory

The Auger Observatory is designed for full-sky coverage with an aperture of 7350 $\mathrm{km}^2\mathrm{sr}$ in each hemisphere above 10^{19} eV for zenith angles up to 60°. In the final configuration 1600 water tanks will be placed on a triangular grid with 1.5 km spacing to cover 3000 km^2. Twenty-four fluorescence detectors in total will be grouped in four locations at the perimeter of the ground array to oversee the entire surface detector. This hybrid detection technique combines the statistical power of a ground array with calorimetric energy measurement and detailed longitudinal reconstruction for a 10% subset of showers recorded during clear, dark nights. Detailed information may be obtained from the Pierre Auger Project internet portal [http://www.auger.org].

Construction of the Southern site started in 1999 in the Province of Mendoza, Argentina. The observatory campus is located in the city Malargue at the South-east border of the detector field, see Figure 1.

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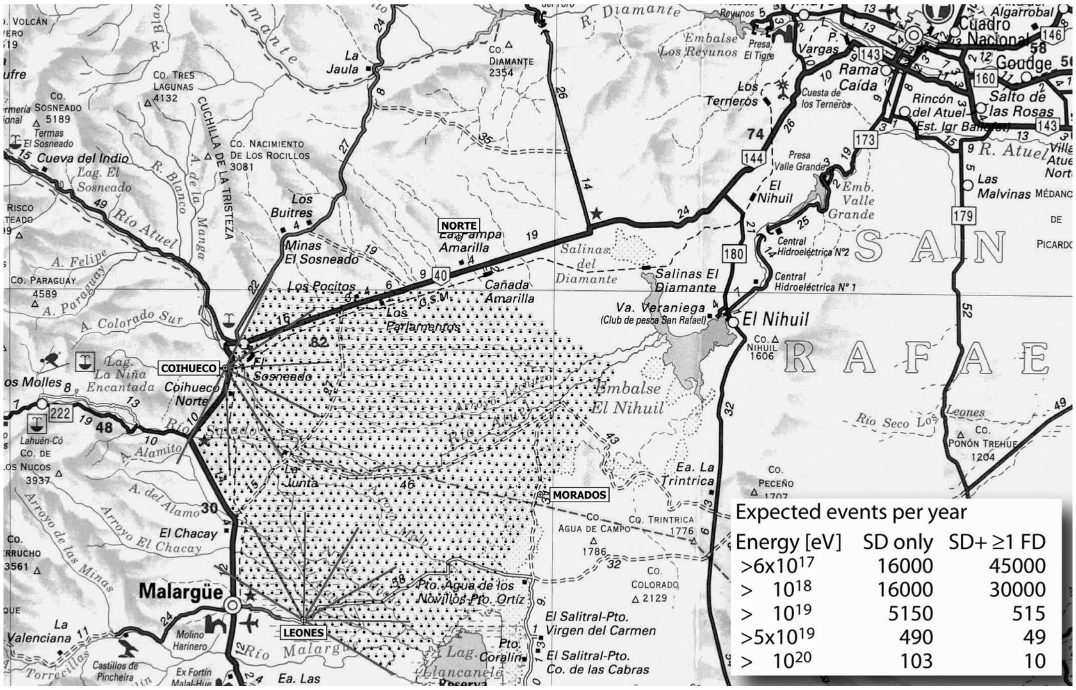

Expected events per year

Energy [eV]	SD only	SD+ ≥1 FD
$>6\times10^{17}$	16000	45000
$> 10^{18}$	16000	30000
$> 10^{19}$	5150	515
$>5\times10^{19}$	490	49
$> 10^{20}$	103	10

Fig. 1. Location and layout of the Southern Pierre Auger Observatory in Mendoza, Argentina. Each dot represents one water Cherenkov detector. The four telescope stations are placed on small elevations called LEONES, COIHUECO, MORADOS and NORTE. The fields of view for some telescopes are indicated. The inset gives the expected number of events per year for the full configuration assuming the AGASA energy spectrum.

The Surface Detector (SD) is made of water Cherenkov tanks. The tanks have 3.6 m diameter and 1.2 m height to contain 12 m^3 of clean water viewed by three 9" photomultiplier tubes (PMT). A solar panel and a buffer battery provide electric power for the local intelligent electronics, GPS synchronization system and wireless LAN communication. The abundant cosmic ray muons produce an essential calibration signal of about 80 photoelectrons in one PMT. The signals are continuously digitised with 16 bit dynamic range at 40 MHz sampling rate and temporarily stored in local memory. The time structure of PMT pulses carries rich information related to the mass of the primary particle. The trigger conditions will require four or five stations with a significant energy deposit. Detection efficiency will begin around 10^{18} eV and reach 100% at 10^{19} eV.

The Fluorescence Detector (FD) consists of 24 wide-angle Schmidt telescopes grouped in four stations, see Figure 1. Each telescope has a 30° field of view in azimuth and vertical angle. The four stations at the perimeter of the surface array consist of six telescopes each for a 180° field of view inward over the array. 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 and a corrector lens. In the focal surface a photomultiplier camera detects the light on 20×22 pixels. Each pixel covers $1.5^\circ \times 1.5^\circ$ and the total number of photomultipliers in the FD system is 13,200. PMT signals are continuously digitised at 10 MHz sampling rate with 15 bit dynamic range. The FPGA-based trigger system is designed to filter out shower traces from the random background of 200 Hz per PMT.

Attention is given to atmospheric monitoring, making use of laser beams, LIDAR, calibrated light sources and continuous recording of weather conditions. Special efforts are being made to determine the air fluorescence efficiency and its dependence on relevant conditions.

The track reconstruction in a stereo configuration or in a hybrid configuration together with a ground array is greatly improved compared to a monocular reconstruction. The detector is sensitive to the primary particle type exploiting the atmospheric depth in which the shower maximum occurs, the ratio of muons to electrons in the shower, and the time structure of the shower disk. Neutrinos may be identified as nearly horizontal electromagnetic showers just above the surface array. The background for neutrinos is produced by baryonic primaries, and the showers will mainly consist of energetic muons.

3. Results from the Engineering Array

An Engineering Array (EA) consisting of 40 water tanks and 2 prototype telescopes was built to demonstrate the hybrid concept and to validate the techni-

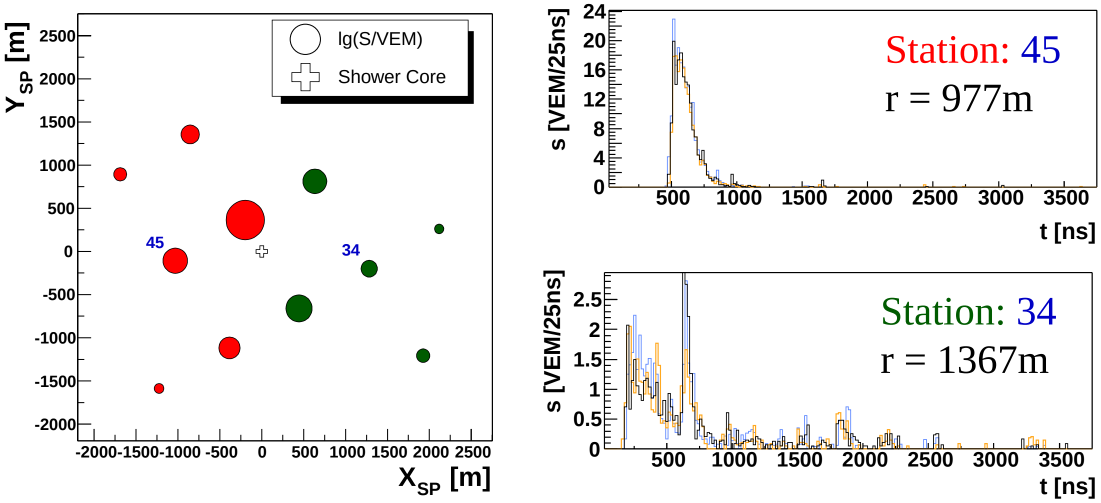

Fig. 2. Examples of events detected with the engineering array. Left panel: Particle densities projected into the plane perpendicular to the shower axis. The energy of this 11-tank shower is $(2-3)\cdot 10^{19}$ eV, the zenith angle is about 54°. Right panels: Close to the core substantial pulseheights are recorded; farther out, individual pulses from electrons (lower, wide-spread signals) and muons (sharp peaks) can be seen.

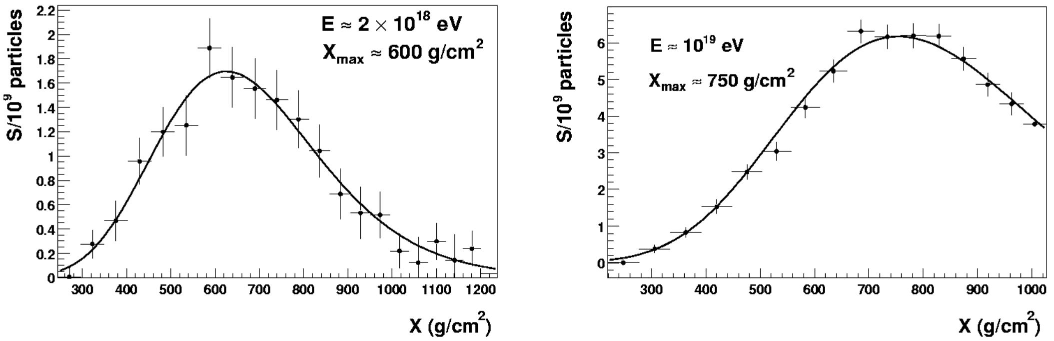

Fig. 3. Two events seen by the fluorescence detector. The reconstructed number of particles is shown as a function of atmospheric depth together with a Gaisser-Hillas curve fit.

cal designs before mass production. The ground array and fluorescence detectors were commissioned with the distributed, asynchronous data acquisition system from December 2001 onwards. During four months, the EA was operated continuously. It recorded several thousand events in either subsystem and about 70 hybrid events. In Figures 2 and 3 we show examples for some events. The SD time synchronization using GPS works well within 50 ns and the angular resolution is the order of 1° or better. The fluorescence detectors were preliminary calibrated and atmospheric corrections were evaluated based on laser beams, LIDAR and calibrated light sources at various distances from the telescope. The sensitivity was estimated to be 10 EeV at 26 km distance. The two telescopes were operated during dark periods at 11% duty cycle as expected and recorded about one event every 20 minutes.

The prototype apparatus has met or exceeded all our specifications; numerous detailed reports are given in these proceedings. We are thus confident to proceed with the construction of the full-scale observatory.

4. Perspectives and Conclusion

At the time of writing about 130 tanks in total have been positioned. Two buildings for fluorescence telescopes at LEONES and COIHUECO, indicated in Figure 1, are ready for installation of the final telescopes. We expect to operate the surface array together with stereoscopic optical detection starting late 2003. The full configuration of the Southern site will be reached by 2005. Thereafter, it is planned to commence construction of the Northern Auger Observatory. The selected site is in the USA in Millard County, Utah, located at 39° N, 113° W.

The Pierre Auger Observatory, starting up in a few years, will improve significantly our understanding of ultra-high energy cosmic rays.