STATUS AND PERFORMANCES OF THE PIERRE AUGER OBSERVATORY

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The Pierre Auger Observatory is a project to study cosmic radiation at the highest energies ($E_0 > 10^{18}$ eV). The first of the two sites, in the Southern hemisphere (Argentina) is halfway to completion. The experiment combines two complementary techniques, surface observation of atmospheric air showers and atmospheric fluorescence detection. Present status and performances of the detector array are described.

1 Introduction

The detection of cosmic rays of extreme energy has to rely on huge sensitive areas: the steep spectral index of c.r. flux being such that at about $10^{20}$ eV the event rate is about $1/(100 \text{ km}^2 \text{y})$. Therefore no direct experiment carried by satellite or balloons will ever have the chance to observe anything. The only possibility is to detect secondaries produced by the interaction of the primary particle and giving origin to the so called Extensive Air Showers, detectable on the ground by arrays of detectors (Cherenkov radiators or scintillators) and/or observing the wake of atmospheric N$_2$ fluorescence. Results obtained with these different techniques (7), by the AGASA ground array and the HiRes fluorescence detector, exhibit a difference which becomes important above $10^{20}$ eV, where against 11 events observed by AGASA, the HiRes spectrum seems abruptly broken. That energy region is extremely relevant since it is where the primary nuclei lose energy interacting with the universal blackbody radiation (the so called GZK cutoff). The primary spectrum is affected by such energy losses if the cosmic rays path (i.e. the distance of the sources) exceeds about 100 Mpc. Therefore, if no cutoff is observed, as in the case of the AGASA spectrum, we should conclude that the sources are located at distances $d < 100$ Mpc. Although our knowledge of the extragalactic magnetic fields is limited, we expect minimal angular deviations (few degrees) of a proton of $10^{20}$ eV, for a total path-length of 100 Mpc. Therefore it should be possible to identify possible sources. To improve
our understanding of the experimental scenario we need: a) improved energy determination. b) simultaneous "surface" and "fluorescence" observations of the same events with the two main complementary techniques (ground and fluorescence) in order to resolve any systematics in the energy scale. c) improved statistics above the GZK energy d) study of the composition and evolution of the composition vs. primary energy.

2 The Auger Project

The Auger Project was planned to meet such experimental requirements, by combining surface and fluorescence detectors operating in coincidence over extremely wide collecting areas. Two observatories, one for each geographic emisphere, will be realized, to obtain a full sky coverage. The Southern site, now under construction, is located near the town of Malargue (province of Mendoza, Argentina), in a flat region called Pampa Amarilla at 1400 m above sea level, atmospheric depth 875 g/cm$^2$, latitude -35.5°.

2.1 The Surface Detector (SD)

The Surface Detector array (see Fig.1) is made of about 1600 water tank detectors (10 m$^2$ base, 1.2 m height, see Fig.2), an equilateral triangular grid with 1.5 km spacing, and covering an area of approximately 3000 km$^2$. Power is supplied by batteries charged by solar panels; communications are realized through a radio network; the timing of the events is obtained by GPS with measured accuracy of about 8 ns. The Cherenkov light produced by ultrarelativistic particles (and diffused by a tyvek liner inside the tank) is detected by three 9” diameter photomultipliers. The anode and dynode signals (amplified $\times$ 32) of the PMTs are sampled at a rate of 40 MHz, producing continuous records (two 10 bit FADCs). The overall dynamic range is 15 bits. A hierarchical trigger sequence selects events from the local station (in "threshold" and "time over threshold" modes, the latter mainly efficient for selecting events at large core distances), which are then passed to the central DAQ system. Presently, with about 750 operating SD detectors, the event rate is typically about 600 events per day. For hadronic events, 100% efficiency is reached at the primary energy of about $3\cdot10^{18}$ eV. Continuous calibrations and monitoring are done using the uncorrelated atmospheric muon flux by the muon flux (about 3 kHz/tank).
2.2 The Fluorescence Detector (FD)

The FD is made by four eyes (see Figs. 3, 4, 5, 6) with six mirrors each covering a 30° (azimuth) x 28.6° (elevation) angular field of view per mirror, located at about 50 km from each other. The optical aperture is 3.8 m² (Schmidt optics, using a corrector ring to compensate for the spherical aberrations), and is closed by an optical filter, selecting the wavelength range 300 < λ < 400 nm, i.e. the Nitrogen fluorescence region. Each mirror (A=11 m² is viewed by a matrix of 440 PMTs at focal distance of 1.7 m); the angular aperture of each PMT is given by its 1.5 degree opening angle. The absolute pointing of each pixel is measured exploiting the signals of the stars in its field of view: the average orientations of the Los Leones mirrors (which have the longest live time) are thus determined with precision at the level of 0.1°. The PMT outputs are read with 10 MHz sample (12 bits ADC, 15 bits dynamic range). The hierarchical trigger is based on adjustable thresholds on the individual channels, up to the selection of triggering patterns compatible with air shower traces. The energy threshold for nearby events is $E_{FD}^i \approx 10^{17}$ eV. The end-to-end calibration of the chain is obtained by means of monthly measurements performed with a "drum" with internal teflon surfaces illuminated by an UV-LED (the LED being monitored by a PMT, absolutely calibrated by a NIST photodiode: the resulting calibration constant is about 4.0 photons/ADC count, established and monitored at better than 10%). The relative calibrations are continuously followed by means of UV lamps, while a continuous monitoring is provided by the study of the fluctuations of the night-sky background. The atmospheric transparency is a main factor for the FD (light for distant events can travel more than 30 km in horizontal direction); it is therefore continuously monitored through complementary techniques operating at the same time, such as cloud monitors, steerable lidar systems, a laser beam facility. Regular balloon flights provide continuous pressure and temperature profiles of the atmosphere. The PMT matrix acts in some way as a Time Projection Chamber: the EAS core being seen as a track in the PMT matrix, giving its direction on the optical plane of the chamber. A second projection is given by the times of flight between the different PMTs. Direction in 3-D space is thus completely determined. While the SD is active for 100% of the time, and therefore is the main tool for reaching the required statistics, the FD detectors can operate only in dark, clear New Moon nights, and therefore with a duty cycle of the order of 10%.

3 The data

One of the major advantages of the Observatory is the possibility of "hybrid" detection, that is simultaneous observations of an EAS by the SD array and by one or more of the FD eyes. For such events, adding knowledge of the "impact point" from the SD array to the FD information provides the complete definition of the geometry. Hybrid events provide also the possibility of
crossed inter-calibrations on energy and absolute pointing. They represent the "golden sample" of Auger data especially when they are "stereo", i.e. more than one eye is involved. Of course the hybrid statistics is limited by the FD duty cycle. An hybrid-stereo event (i.e. an event observed both by the surface and the fluorescence detectors, from two of its eyes) is shown in Fig. ?? concerning the SD, together with the reconstructed lateral distribution. As best estimator of the primary energy, the signal at 1000 m from the core is used. The core location as obtained from the fit to the SD densities is compared in Fig. ?? to the one obtained from the FD data (i.e. the crossing of the two observation planes from the two eyes). The event as seen by one of the FD eyes is shown in fig. ??.

The statistical uncertainties in the reconstruction of hybrid events of $10^{19}$ eV are $\delta \theta \approx 0.3^o$ for the arrival direction, $\delta r \approx 20$ m for the core location, $\delta E_0/E_0 \approx 7\%$ for energy determination, $\delta X_{max} \approx 25$ g·cm$^{-2}$ for the depth of shower maximum (the observable which is strictly related to the mass of the primary). In the event under consideration the SD and FD independent energy determinations are quite consistent, about $(7-8)\times10^{19}$ eV.

4 Conclusions

At present (May 1, 2005) 750 tanks of the SD are in operation, together with 2 full fluorescence eyes (Los Leones and Coihuecho, for a third one the infrastructure is completed and the installation is on the way). 120,000 SD events are available for analysis; 16,500 have tank multiplicity $m \geq 4$ and primary energy $E_0 \geq 10^{18}$ eV. The number of hybrid events, that we consider the "foundations" of the energy measurements, is 1750, of which 350 "golden" i.e. with both detectors fulfilling both triggering conditions (much less information is sufficient for the hybrid reconstruction technique). The data show the quality of the information. The completion of the South site array is foreseen in 2006.

References