STATUS AND RECENT RESULTS FROM THE PIERRE AUGER OBSERVATORY[*]

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We present the status and the recent measurements from the Pierre Auger Observatory. The energy spectrum will be described and its steepening discussed. The mass composition is addressed with the measurements of the variation of the depth of shower maximum with energy. We also report on upper limits in the primary photon fraction. And finally, searches for anisotropies of cosmic rays arrival directions are reported.

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1. The Pierre Auger Observatory

The Pierre Auger Observatory will be completed in early 2008 and will consist of 1600 $10\text{m}^2 \times 1.2\,\text{m}$ water-Čerenkov detectors deployed over 3000 km^2 on a 1500 m hexagonal grid overlooked by four fluorescence detectors (FD), each of them with 6 telescopes. The surface detector (SD) stations sample at the ground level the charged particles in the shower front that cross the stations. The fluorescence telescopes can record the ultraviolet light emitted as the shower crosses the atmosphere. By September 2007

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about 90% of the SD detector and all 24 FD telescopes were operational. The accumulated exposure[1] up to February 28, 2007 was 5165 km^2 sr yr, about the same as the monocular HiRes and three times larger then AGASA [1].

The Pierre Auger Observatory was designed as a hybrid detector, *i.e.*, to use both fluorescence and ground array techniques in an extensive way. About 10% of the events are detected simultaneously by both techniques. From them two variables can be measured: the ground parameter S_{38} and the energy as measured by the fluorescence detector. The correlation of the two variables is shown in Fig. 1, left. The dispersion is shown in the right.

With this calibration the energy of the showers that are detected by the SD only (tenfold more statistics) can be estimated in a empirical way [2].
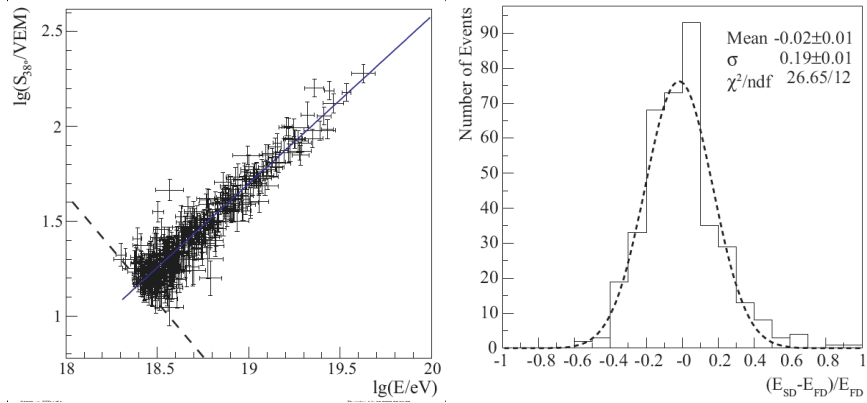

Fig. 1. Left: Correlation between the SD parameter S_{38} (see text) and the reconstructed FD energy of Auger hybrid showers. Right: Fractional dispersion of the SD/FD energy correlation.

2. Recent results

In Fig. 2 left, the energy spectrum multiplied by E^3 from SD data using showers at zenith angle above and below 60°, together with the spectrum obtained from the hybrid data set are shown. The three spectra obtained using different methods agree well and a combined fit is performed. Only statistical errors are quoted. A flattening of the slope of the energy spectrum from (-3.30 ± 0.06) to (-2.62 ± 0.03) is observed at $10^{18.6}$ eV and above $10^{19.6}$ eV the spectrum gets steeper, with slope (-4.14 ± 0.42). The number of events expected if the power-law observed at $10^{18.6}$ eV were extended above $10^{19.6}$ eV and 10^{20} eV are 132 ± 9 and 30 ± 2.5 whereas we observe

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[1] Unless otherwise noted, the data shown here was recorded from January 2004 to the end of February 2007 and was shown at the 30th International Cosmic Ray Conference, Mérida, Mexico, July 2007.

only 58 events and 2 events, respectively [3]. So a sharp suppression in the last decade of the UHECR spectrum is observed (as it was already shown by the HiRes experiment [4]). Whether this is due to the expected GZK cutoff or if it is due to other phenomena like a limit on the acceleration process, is an open question and needs further investigation. The "ankle" is determined to be at $E_{\mathrm{ankle}} = 10^{18.65 \pm 0.04}$ eV.
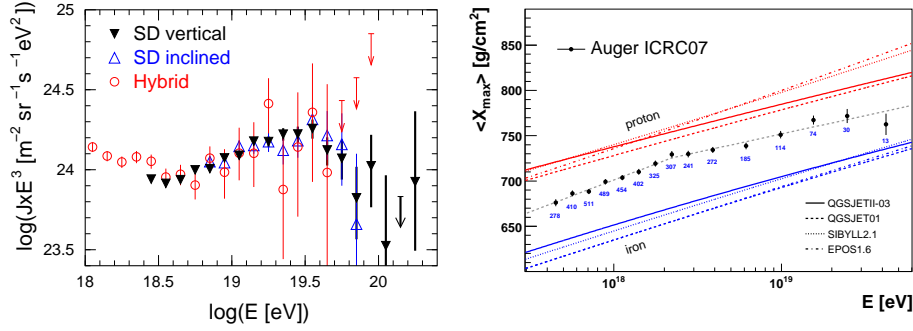

Fig. 2. Left: The energy spectrum multiplied by E^3 derived from SD using showers at zenith angles above (filled triangles) and below (opened triangles) $60°$, together with the spectrum derived from the hybrid data set (red circles) [3]. Right: The depth of maximum as a function of energy. The upper sets of lines are predictions of protons for several models, the lower set are under the assumption of Fe nuclei [5].

The depth of shower maximum depends on the primary mass and comparisons with Monte Carlo models can be made to extract information about the mass composition of the UHECR. Hybrid events allow the measurement of X_{max} and have the geometry of the shower well constrained by the SD information. The data is shown in Fig. 2, right. After appropriate quality and uniformity cuts, the X_{max} resolution is less than 40 g/cm^2. A single slope does not seem to fit the data and the rate of increase of X_{max} with energy is smaller for the region above 2×10^{18} eV than below. More data will be necessary to establish the tendency to heavier composition at high energies.

Primary photon showers are easier to distinguish from primary hadron showers, since they penetrate deeper in the atmosphere. This results in a larger rise time of the signal produced in the SD stations and in a smaller radius of curvature of the shower front. Those two variables can be measured precisely in the surface detector and are combined in one single variable through a principal component analysis. No event up to now was identified with a photon. The absence (or very small fraction) of photons in the incident primary cosmic ray flux allows stringent photon limits to be set up. For instance, at 10 EeV the upper limit [7] in the integral flux fraction

produced by primary photons is about 2%. This sets constraints to *top-down models*, where the UHECR are the decay products of heavy primordial particles or produced by topological defects.

One of the major aims for the experiment is the measurement of the anisotropy of the arrival direction of the UHECR. One expects that protons with energy of about 50 EeV or higher to deviate two or three degrees in the galactic magnetic field. In order to calculate the significance of the results in a unbiased way, an *a priori* specification of the details of the analysis to be done with *future* data is required. Any hint of a discovery found in a exploratory analysis will be subjected to a *prescription* that requires new data. Previous claims of anisotropy from the Galactic center and of clustering at high energies, as well as correlation with BL-Lacs were not confirmed by Auger [6].

3. Summary and perspectives

There are enhancements already approved and funded for the South Observatory. HEAT will reduce the energy threshold down to 0.1 EeV and AMIGA will detect showers down to 0.1 EeV and measure their muon content [8]. This will allow precise measurements of the shower composition in the "ankle" region and constrain hadronic models in this energy range. The North Observatory, planned to be built in Colorado, USA, possibly with a higher threshold in the detector energy, will provide full sky coverage with enhanced statistics at the end of the cosmic ray spectrum.

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