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PIERRE AUGER OBSERVATORY

How does the Pierre Auger Observatory measure the energy of ultra-high-energy cosmic rays (UHECRs)?

The Pierre Auger Observatory reconstructs the energy of UHECRs from the detection of extensive air showers (EASs). EASs are huge cascades of secondary particles produced by millions of interactions, that deposit the energy of the primary cosmic ray in the atmosphere. The Observatory employs two techniques to measure EASs.

Most of the cosmic ray (CR) energy is dissipated into charged particles that excite molecules of air, producing fluorescence light. This light is measured by 27 telescopes, located at 4 different sites, called the Fluorescence Detector (FD). Hence, the FD provides a high-precision measurement of the energy of the primary CR.

The faint fluorescence emission can only be measured on clear moonless nights, that is, about 15 % of the time. For all other events, the primary energy must be indirectly estimated using the surface detector array (SD). The 1660 stations of the SD, spaced by 1.5 km, measure the signal produced by shower particles reaching the ground level (Fig. 1, upper left). The intensity of the measured signal is a proxy for the primary energy. In particular, the signal as a function of the distance to the shower axis is fitted to the lateral distribution function, to find the signal at 1000 m from the shower axis called S(1000), as shown in Fig. 1 lower left. The values of S(1000) are corrected for the zenith-dependent attenuation of the particle content of the EAS and then cross-calibrated with the CR energy measured by the FD using showers measured simultaneously by both detectors.

Credit: Auger Early Career Collaborators Assembly

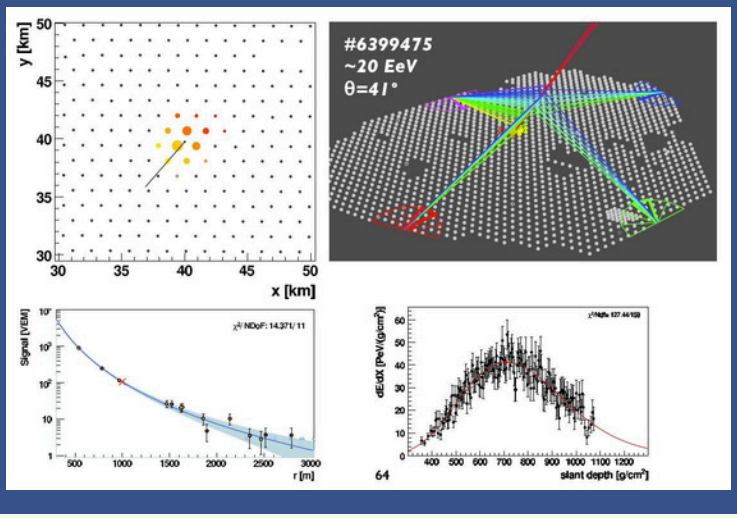

Figure 1. Upper left: Footprint of the air shower measured by the SD. Colors indicate the arrival time, while the sizes of the dots illustrate the amount of total signal measured in each station. The black line is the shower axis projected on the ground. Upper right: 3D view of a stereo golden hybrid. The air shower (red line) is first detected by the FD telescopes (red, green, blue and purple segmented half-circles). The colored lines indicate the observation time of each point of the shower. Lower left: Fitted SD signal as a function of the distance to the shower axis. The value of S(1000) is indicated by the red cross, enabling an estimation of the primary energy from an SD-only measurement. Lower right: Fitted energy deposit of the air shower in the atmosphere estimated from the fluorescence light measured by the FD.

Air showers detected by one FD telescope and at least one SD station are called hybrid events. If more than three SD stations are involved, allowing for an independent SD reconstruction, then the event is a golden hybrid. If more than one FD station observes the event, then it is called a stereo event. Thus, the event in the upper right panel of Fig. 1 is a stereo golden hybrid event.

The most energetic events

The 100 most energetic events recorded between 1 January 2004 and 31 December 2020 have energies between 78 and 166×10^{18} eV [A. Abdul Halim et al 2023, ApJS 264, 50]. The highest-energy event of (166±13)×10^{18} eV was measured on 10 November 2019 with 34 SD stations. This energy corresponds to 26.6 J, or a tennis ball flying at 110 km/h.

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