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Highlights from the Pierre Auger Observatory

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The Pierre Auger Observatory has been detecting ultra-high energy cosmic rays (UHECRs) for more than ten years. It presents the first "hybrid"observatory on the world's largest scale, comprising a 3000 km2 surface detector (SD) of 1600 water Cherenkov stations spaced 1500 m apart and four fluorescence detectors (FD) overlooking the array. It also now includes three high elevation fluorescence telescopes (HEAT) which overlook a 23.5 km2 denser SD sub-array partly equipped with the AMIGA muon detectors, and a 17 km2 array of 153 radio antennas (AERA), all of them aimed at extending the cosmic ray energy range down to 10ˆ17 eV. The analyses of data taken by these instruments (and their combination) have led to a multitude of results on UHECRs that will be highlighted. The updated high-precision measurement of the energy spectrum over more than three decades in energy is a good example of the power of using the combination of different detectors. The large accumulated exposure of more than 50000 km2 sr yr and the large field of view have also allowed us to measure the flux in different regions of the sky for the first time. We have also measured the depth of the shower maximum down to 10ˆ17 eV for the first time, allowing us to extend by one decade in energy the mass composition sensitivity based on LHC-tuned shower models. The measured evolution of the flux and of the mass composition as a function of energy has permitted a detailed comparison of our data with a set of simple astrophysical models. While the depth of shower maximum as observed by the FD is the premier observable to infer the nature of the primaries, we have exploited observables with the SD as well. On the one hand, this has enabled us to search for UHE photons and neutrinos with unprecedented sensitivity. On the other hand, the study of observables such as the muon production depth, or the number of muons, or the asymmetry of the rise-time of the signals, has yielded a powerful probe of current air shower models at center-of-mass energies as high as 140 TeV, thus providing insights into hadronic interactions at these otherwise inaccessible energies. The new measurement of the proton-air cross-section, extended down to 10ˆ17.8 eV, is another example of the particle-physics capability of the Observatory. To complement the spectrum and mass measurements, we have studied the distribution of the arrival directions of the detected cosmic rays at different angular scales. By including in these studies for the first time cosmic rays with zenith angles up to 80°, the field of view has been extended to cover the declination range from -90° to +45°. At the highest energies, above 40 EeV, we have looked for small- to intermediate-scale anisotropies, both intrinsic ones and in correlation with potential astrophysical sources. We have also implemented different analyses to search for dipolar and quadrupolar large-scale anisotropies over four orders of magnitude in energy, above about 10ˆ16 eV.
The rich harvest of the first 10 years of operation has guided the Collaboration towards a plan for an upgrade of the Observatory. The rationale for this it and its status will also be presented.

Collaboration

Pierre Auger

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