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Energy evolution of cosmic-ray mass and intensity measured by the Pierre Auger Observatory

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The Pierre Auger Observatory has conducted measurements of the energy spectrum and mass composition of cosmic rays using different methods. Utilizing both surface and fluorescence detectors (FD and SD), the Observatory provides unprecedented precision in understanding these particles. While primarily designed to measure ultra-high-energy cosmic rays, the FD's high-elevation telescopes and the dense arrays of SD stations enable observations even down to 6 PeV and 60 PeV, respectively. To determine the depth of shower maximum, a critical parameter for identifying primary particle types, both direct longitudinal profile measurements from the FD and indirect signal analyses from the SD are employed. An energy evolution of the mass of primary particles, as well as of the spectral index of the flux intensity, are observed and characterized by features described in presented work. The measurements benefit from the joint operation of the FD and SD, delivering a systematic uncertainty of 14% in energy determination and an accumulated exposure reaching 80 000 km² sr yr at the highest energies.

Primary author: NOVOTNY, Vladimir (IPNP, Charles University)

Presenter: NOVOTNY, Vladimir (IPNP, Charles University)

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