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AugerPrime: The upgrade of the Pierre Auger Observatory

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Summary. — The Pierre Auger Observatory is the largest observatory in the world for the detection of ultrahigh-energy cosmic rays. The Auger Collaboration started collecting data in 2004, and, so far, results have led to many significant discoveries in this field but also to puzzling observations. To answer all the key questions that are still open it was decided to extend the operation of the Observatory up to 2024 and to enhance its capability in identifying the mass of the primary cosmic rays. Motivations for the upgrade will be described together with some hardware characteristics of the project.

1. – Introduction

The Pierre Auger Observatory is the largest cosmic-ray observatory in the world. It was designed to study ultrahigh-energy cosmic rays (UHECRs), from a fraction of an EeV (10^{18} eV) to the highest energies ever observed (hundreds of EeV). The Observatory is located near Malargüe, in the Province of Mendoza, Argentina, and with it the Auger Collaboration started collecting data in January 2004. The Observatory is composed of a Surface Detector (SD) of 1660 water-Cherenkov detectors (WCDs) covering an area of $3000\,\text{km}^2$ [1] and of a Fluorescence Detector (FD) consisting in 24 telescopes placed at four sites at the borders of the WCD array [2]. In the past years the original design of the Observatory was refined by the addition of other detectors: the *Infill* array, a subarray of 61 water-Cherenkov detectors on a denser grid covering about $30\,\text{km}^2$ and three High Elevation Auger Telescopes (HEAT) dedicated to the observation of fluorescence light coming from lower-energy showers.

The essential feature of the Pierre Auger Observatory is its hybrid design: extensive air showers are detected simultaneously by the SD that samples the particles at ground

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level with a duty cycle of 100%, and by the FD used to reconstruct the longitudinal development of the shower in the atmosphere through the detection of the UV fluorescence light that is emitted isotropically by atmospheric N_2 molecules. Data from the FD can only be collected during moonless nights in good weather conditions, achieving a duty cycle of about $\sim 15\%$ at the present time.

Since fluorescence-light production is proportional to the collisional energy deposit by the shower in the atmosphere, the technique provides a near-calorimetric method for determining the primary cosmic-ray energy. Moreover, the depth at which a shower reaches maximum size, X_{max}, is the most direct indicator of the mass composition of the primary particle that generated the shower [3].

2. – Physics motivations for the upgrade

Measurements made with the Pierre Auger Observatory have led to a number of discoveries in the field of UHECRs: the all-particle energy spectrum demonstrates a suppression of the cosmic-ray flux at energies above $4{\cdot}10^{19}$ eV [4] and limits on photon and neutrino fluxes disfavour top-down processes as sources of the observed particle flux [5]. Moreover Auger data have allowed us to perform studies of purely high-energy particle physics such as a measurement of the proton-air and corresponding proton-proton cross sections at 57 TeV in the center of mass system [6]. Despite these and other discoveries, the astrophysical scenario resulting from Auger measurements is very complex and cannot at present be understood in terms of a unique interpretation for the sources, propagation and composition of the UHECRs. For example, the interpretation of the measured depth of the shower maximum with LHC-tuned hadronic-interaction models suggests a particular evolution of the mass composition in the energy range of the ankle (the area of the spectrum, at $4.8 \cdot 10^{18}$ eV, where it flattens) and above: a large fraction of protons is present at 10^{18} eV, changing to a heavier composition at $10^{19.5}$ eV [7]. An improved understanding of the mass composition of the primary particles at the highest energies can shed light on the origin of the cut-off in the spectrum, can clarify the potentiality of a future proton-astronomy and can help the study of extensive air showers and multiparticle production at energies beyond the reach of the LHC. These goals can be met with an improvement of the capability of the SD in the identification of the mass of the primaries on an event-by-event basis; indeed due its low duty cycle, the data from the FD on the depth of shower maximum extend only up to $4{\cdot}10^{19}$ eV, the mere onset of the suppression region.

3. – Characteristics of the upgrade

The best way to obtain mass-composition information is an improved discrimination between the electromagnetic and muonic components of the air shower. The upgrade of the Observatory, dubbed AugerPrime, consists in an upgrade of each existing WCD and in the installation of a new additional detector made of plastic scintillator (Scintillator Surface Detector - SSD) above it [8].

Each WCD will be provided with new electronics that includes improvements in sampling speed, dynamic range, triggering, and calibration. Furthermore, an additional small $1''$ photomultiplier tube will be inserted in each WCD to enhance the dynamic range by a factor of 32, to decrease the number of shower events at energy above 10^{19} eV that cause saturation in the existing $9''$ PMTs, especially in the WCDs nearest the core of the showers.

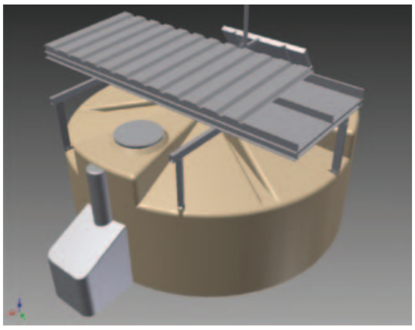

Fig. 1. – 3D layout of a SSD station installed on a WCD.

An SSD unit consists of a box of dimensions $3.8\,\mathrm{m} \times 1.3\,\mathrm{m}$, housing two scintillator modules. Each module consists of several bars of 1 cm thick scintillators: the light produced by charged particles crossing the bars is read by wavelength-shifting fibers that guide it to a photomultiplier tube (a single one for both modules). The layout of the SSD atop a WCD is shown in fig. 1.

Since WCDs and SSDs have different responses to muons and electromagnetic particles, the combined analysis of their signals allows the reconstruction of the different shower components. The Auger Collaboration is working to develop different reconstruction techniques using information related to detector signals at different lateral distances from the shower core, and also to the arrival time of the shower front and temporal structure of the signal measured in the detectors.

4. – Conclusion

The Pierre Auger Observatory upgraded to AugerPrime will continue taking data until 2024. The extension will allow doubling the number of events detected to date, with the crucial advantage of obtaining mass-composition information from every shower event. In the second part of 2016 an engineering array of 10 detectors, consisting of upgraded WCDs and SSDs, will start data taking, to be followed by the deployment of the new detectors over the whole array starting in 2017.

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