EPJ Web of Conferences **209**, 01008 (2019) https://doi.org/10.1051/epjconf/201920901008
RICAP-18

Status of the AugerPrime upgrade of the Pierre Auger Observatory

Niraj Dhital[1,a] for the Pierre Auger Collaboration[b,c]

[1] *Institute of Nuclear Physics PAN, Krakow, Poland*

Abstract. The Pierre Auger Observatory has been very successful in determining many aspects of the highest-energy cosmic rays including, among others, the flux suppression at energies above 4×10^{19} eV, stringent upper limits on photon and neutrino fluxes at ultra-high energies and an unexpected evolution of the mass composition with energy. We expect an extension of the frontiers of our knowledge on these aspects from a major upgrade of the Observatory. The upgrade, known as AugerPrime, will include an addition of a 4 m^2 Surface Scintillator Detector atop each water-Cherenkov station of the Surface array. The new detectors will provide us with an unprecedented opportunity to perform a complementary measurement of the shower particles and thus determine the primary mass composition with good accuracy on an event-by-event basis. AugerPrime will also include an upgrade of electronics, installation of the AMIGA Underground Muon Detector and a change of observation mode of the Fluorescence Detector, which will increase its current duty cycle by about 50%. Current status of the upgrade with the main focus on the Surface Scintillator Detectors will be presented, following a brief description of the physics motivation for the upgrade.

1 Introduction

Measurements of the highest energy cosmic rays made by the Pierre Auger Observatory[1] over the past decade have helped us understand many aspects of ultra-high energy cosmic rays (UHE-CRs). Nonetheless, a number of important questions on UHECRs remain to be addressed, which require additional measurements from the Observatory after a major upgrade. The upgrade called AugerPrime[2] will allow the operation of the Observatory until the end of 2024 with new types of detectors as well as an enhancement of already existing ones. The new measurements from the upgraded Observatory will provide additional information on extensive air showers (EASs) which are of crucial importance to resolve these important concerns. The main objective of the upgrade is to elucidate the mass composition and the origin of the flux suppression at the highest energies. The upgrade will also allow us to search for a flux contribution of protons up to the highest energies, which in turn will open up the prospects for more accurate particle astronomy. Also, fundamental particle physics at energies beyond those accessible at man-made accelerators, especially EASs and hadronic interactions will be better understood. This improved physics understanding will help to resolve the discrepancy between the number of muons observed in data and that obtained from simulations.

[a] e-mail: niraj.dhital@ifj.edu.pl
[b] Av. San Martín Norte 304 (5613) Malargüe, Prov. de Mendoza, Argentina
[c] Full author list and acknowledgments at: http://auger.org/archive/authors_2018_09.html

AugerPrime comprises four main improvements: 1) addition of the Surface Scintillator Detector (SSD) atop each water-Cherenkov station of the Surface Detector (SD) array, 2) Surface Detector Electronics Upgrade, 3) extension of the operation of the Fluorescence Detector (FD) and 4) installation of Underground Muon Detector.

2 The Surface Scintillator Detector

An SSD unit consists of 48 bars of 160 cm $\times$ 5 cm $\times$ 1 cm plastic scintillators grouped into two modules, enclosed in an aluminium casing [3]. Each bar has two extruded holes for insertion of wavelength shifting (WLS) fibre. The WLS fibres, which collect the scintillation light produced by the shower particles passing through the bars, are grouped into a bundle before being glued to a photomultiplier tube (PMT). The assembled SSD is installed on the top of a WCD. A layout of an

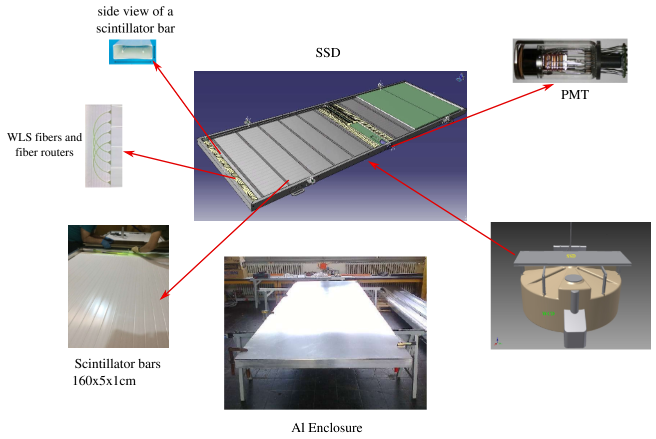

Figure 1: Layout of an SSD unit.

SSD unit and its placement above a WCD detector is shown in Fig. 1.

The installation of SSDs atop each water-Cherenkov detector (WCD) in the SD array will enable an additional measurement of particles in the EASs independent of the measurement from WCDs. An additional detector type (SSD) is a sensible approach for a better investigation of EASs since using scintillators is not only a robust and well-understood technique of particle detection but also provides measurements of shower particles which are complementary to the measurements performed using the water-Cherenkov technique and allows a good measurement of muons. Thanks to the different

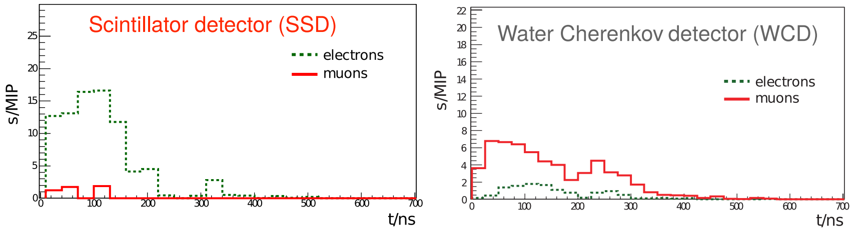

Figure 2: Detector response of electrons and muons for SSD (left panel) and WCD (right panel).

responses of SSDs and WCDs to the electrons and the muons in EASs, as can be seen in Fig. 2, the upgraded observatory will have much better sensitivity to the UHECR primary mass composition, even on an event-by-event basis.

3 SD Electronics Upgrade and additional small PMT

The upgraded electronics will process both the WCD and the SSD signals. It will increase the data quality by providing a faster sampling of ADC traces at a rate of 120 MHz compared to the current rate of 40 MHz. The faster sampling rate is better suited for counting muons. Also, a better absolute timing accuracy will be obtained from new GPS receivers. In addition, more powerful local station processor and FPGA will enhance the local trigger and processing capabilities. The new electronics will provide a facility for interfacing not only the SSD but also any other additional detector in future. Backwards compatibility with the current data-set will be maintained and the deployment have minimal impact on the continuous data taking of the SD.

Each WCD will have an additional 4th small PMT with an active area of 1% of the currently used standard PMT. This will greatly improve the dynamic range of WCDs. Consequently, there will be less than 2% saturated events at the highest energies and the determination of particle densities down to $\sim$ 300 m from the shower core will be possible.

4 The Underground Muon Detector

The Underground Muon Detector (UMD) will consist of 61 AMIGA muon detectors[4], each with an effective area of 30 m^2, on a 750 m grid in the infill array over a total area of 23.5 km^2. The UMD will provide direct muon measurement of a sub-sample of showers detected by the SSDs and WCDs and serves for fine-tuning of different hadronic models and verification of the methods used to extract shower muon content using the SSDs and WCDs.

5 Extension of Duty Cycle of the FD Observations

The FD provides excellent information about EASs (model-independent energy reconstruction and direct measurement of the longitudinal development profiles). However, it is limited mainly by its duty cycle which is around 15%. The main goal of the extension is to increase the exposure for cosmic ray events above 10^{19}eV by extending the FD measurement into hours with a larger illuminated fraction of the moon when the night sky background is high. This extension will increase the duty cycle to $\sim$ 23%. The extension is achievable by reducing the PMT gain lowering the supplied high-voltage to avoid an excessively high anode current. This procedure has been successfully tested in one telescope for a few nights.

6 Status of the Upgrade

The first twelve AugerPrime detectors were deployed at the Engineering Array (EA) site and are operational since October 2016 [5]. Nine of the EA stations are located in the standard SD array (1500 m spacing between the adjacent SD stations), while the remaining three are located in the infill region. The upgraded stations with WCDs and SSDs operate with good stability and signals from EA stations are as expected. SSDs in the EA are currently triggered by the corresponding WCDs in each station. The co-located SSD and WCD pairs sample the EASs essentially at the same positions. The correlation between the signals measured by the SSD and the corresponding WCD for same showers is shown in Fig. 3. Also, in Fig. 4, an example event triggering both the upgraded stations in the EA and WCDs in the regular 1500 m SD array is shown. The lateral distribution function (LDF) for the event is obtained by performing a fit using the regular array, while the signals measured by the upgraded stations are shown alongside. Signals measured by the WCDs of the upgraded stations are in a good agreement with the fitted LDF.

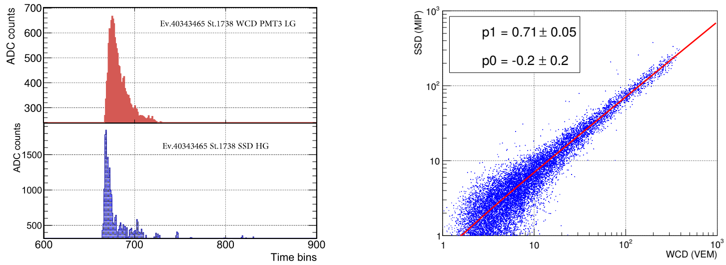

Figure 3: Left panel: WCD and SSD signals in the same station for an event. Right panel: Correlation between sizes of the SSD and WCD signals.

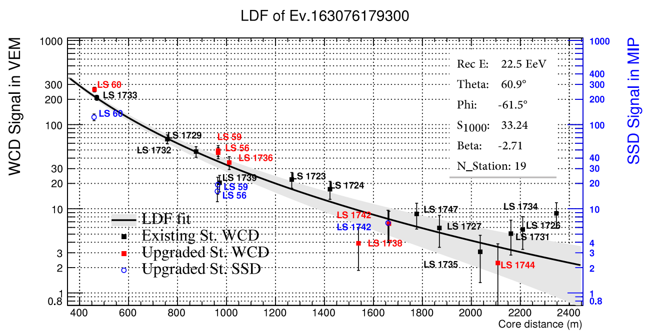

Figure 4: Signals in upgraded stations from an event compared with its LDF reconstructed with regular 1500 m array.

7 Summary

Definitive answers to some of the pressing questions on UHECRs are expected with the data from the upgraded Observatory. Its operation until 2024 will provide us not only better event statistics but also additional information on air showers. Measurement of air showers with the upgraded Observatory will provide high-quality data helpful to extend the current frontiers of our knowledge on UHECRs. The improved knowledge on UHECRs will allow reanalysis of the current data for more accurate energy evaluation and mass-composition studies. The AugerPrime EA has been operational since October 2016. The upgraded stations with WCDs and SSDs operate with good stability and signals from EA stations are as expected. SSDs are being assembled and tested at several sites, and the deployment has just begun.

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