PROCEEDINGS OF SCIENCE

With AugerPrime to the Phase II of the Pierre Auger Observatory

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AugerPrime, the upgrade of the Pierre Auger Observatory, is nearing completion and the Observatory is now prepared to collect physics data after the commissioning of the new components. The Pierre Auger Observatory has demonstrated, based on the data collected thus far, the existence of the cutoff in the spectrum with high accuracy. However, the origin of this cutoff remains incompletely understood. The upgraded Observatory is designed to address the unresolved questions regarding the nature of the cosmic ray flux cutoff thanks to its capability to disentangle the muon and electromagnetic components of extensive air showers. Furthermore, the measurement of the muon component at ground level can verify the accuracy of hadronic interaction models currently used. This presentation will provide an overview of the status of the Observatory and the accurate commissioning done before the start of the physics run. Furthermore, we will present the initial data from Phase II data mainly dedicated to proving the continuity of operation of the Observatory from Phase I to Phase II.

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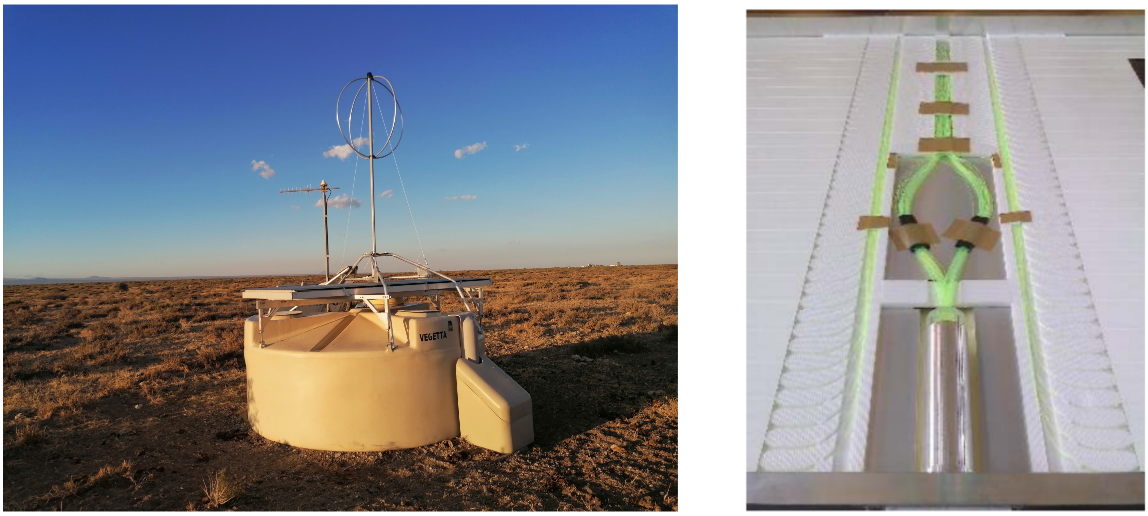

Figure 1: (Left) Photography of one of the Local Stations of the surface detector of the Pierre Auger Observatory, after its upgrade. (Right) Wavelength-shifting optical fibers routed inside the grooves and fixed at the housing of the PMT.

1. Introduction

The Pierre Auger Observatory is located in the region of Mendoza, Argentina, near the city of Malargue. The observatory's surface detector array (SD) consists of 1600 Water-Cherenkov Detectors (WCD) on a 1500 m triangular grid of covering 3000 km^2. Another 60 WCDs form the infilling area. The array is monitored by four fluorescence detectors (FD). Each detector contains six telescopes, covering a field of view of 180° azimuth and 30° elevation[1]. At one of the sites are located three telescopes tilted 30 degrees higher to maximize the observation of lower-energy showers and overview a filled surface field 30 km long and 750 m apart. Atmospheric showers (EAS) caused by ultra-high energy cosmic rays (UHECR) are sampled near the ground by SD. FD measures the evolution of EAS by detecting nitrogen UV light produced as shower particles move through the atmosphere. Additional research and development equipment for muon and radio-based detection is also located on-site.

To make further progress and better leverage the power of statistics, the Auger Collaboration decided to improve the configuration sensitivity of SD. Therefore, the observatory is undergoing a major upgrade to its experimental capabilities called AugerPrime[2]. This makes it possible to disentangle the muon and electromagnetic (EM) components of large air showers, thereby reducing his UHECR composition, composition-related anisotropy, and hadronic interaction effects at the highest energies.

2. The Upgrade Design

The components of AugerPrime are a radio detector (RD)[3] and a scintillator-based detector (SSD)[4] placed atop each WCD. The WCDs also have a Small PMT (SPMT)[5] added to improve them dynamic range. In addition the local station electronics has been fully upgrade to permit the connection of the new detectors and improve its performance[6] (Fig.1). While the SSD and

RD are primarily sensitive to the EM component, the WCD exhibits good sensitivity mainly to the muonic component. The composition sensitivity is, therefore, increased by taking advantage of these various responses. Additionally, the solid angle coverage of the SSD and RD complement each other, with the SSD optimized for more vertical showers and the RD for showers with higher zenith angles. Additionally included is the Underground Muon Detector (UMD), which measures the shower muon content and its time structure directly through buried muon counters. The UMD array spans 23 km^2 and is situated in the infill area. AugerPrime is presently being deployed, and the performances are being monitored. The SSD are already installed, as are installed the SPMT and the new electronics. Up until 2024, the RD detector will continue to be deployed. The Auger Collaboration intends to collect data using AugerPrime between 2024 and 2034. This would result in showers with zenith angles less than 60 degrees having an exposure of 40000 $km^2\ sr\ yr$. The sample of data that will be collected in this ten-year period is tagged Phase II. For comparison the phase I data sample that is currently available has an exposure of about 80000 $km^2\ sr\ yr$.

The calibration of the large WCD PMTs and of the SSD PMTs is performed by using background muons. The Vertical Equivalent Muon (VEM) signal is the reference unit for the WCD while the Minimum Ionizing Particle (MIP) is the unit used for the calibration of the SSD. An example of the VEM and MIP calibration histograms is shown in Fig.2 left.

The same figure (right) illustrates the very high correlation between the calibrated SSD and WCD signals. 20,000 VEM/MIP can be achieved with both WCD and SSD detectors. Based on simulations, this corresponds to a distance of about 250 m from the shower core. This results in a more precise estimation of the shower core position and of the lateral distribution function (LDF) than is possible with the current SD array.

3. Status and performance

Currently, all the SSD detectors have been installed atop WCDs with the new electronics and the SPMT. Since the begin of 2021, data collection for commissioning has been ongoing. The monitoring program, the data analysis pipeline, and the central data acquisition (CDAS) program are all being updated concurrently for AugerPrime. To acquire different resolutions and evaluate the consistency of detector stations and their long-term performance, AugerPrime data are constantly tracked and examined. The air shower's ground footprint is captured by the SD. Once the event selection criteria are met, the intrinsic properties of the primary cosmic ray are estimated using standard shower reconstruction techniques. In the SD event reconstruction, the information about signal start times is used to reconstruct the arrival direction of the primary using a spherical model of the shower front. After the estimation of the arrival direction, the LDF of signals at the ground is fitted. This distribution results from the convolution of the detector response with the energy spectrum and the direction of theshower particles. All the reconstruction and analysis algorithms are under modification to optimize them performances taking into account the new configuration of the array and the upgraded performance of the electronics.

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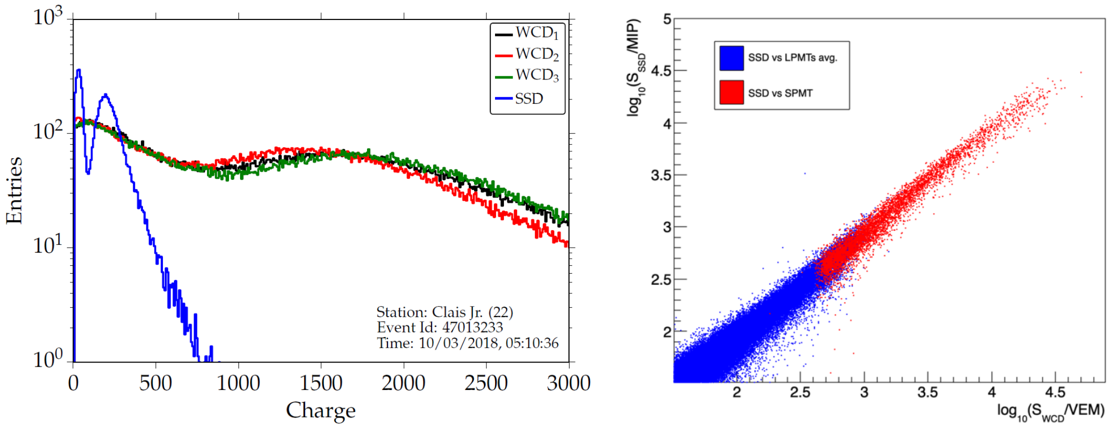

Figure 2: (Left) Calibration histograms for SSD and the three large PMTs of WCD. (Right) Correlation between SSD and WCD calibrated signals. Figure

4. Conclusions

The Pierre Auger Observatory is the apparatus with the largest exposure for UHECR in the world and its data collected up to now have led to many breakthroughs in the field of ultra-high energy cosmic rays. The Observatory with its upgrade that will enhance the sensitivity to primary cosmic rays composition above $4 \times 10^{19}\, eV$ will play a fundamental role in the field for the next decades. The new configuration of the Observatory will allow a multi-hybrid measurement of extensive air showers with a nearly 100% duty cycle. With this technique it will be possible to measure the muonic and electromagnetic components of the showers on an event-by-event basis and, therefore, identify the mass of primary cosmic rays. This will help us to understand the origin of the suppression in the cosmic ray spectrum and to identify the regions of the near universe where the UHECRs are accelerated.

References

[1] The Pierre Auger Collaboration, Nucl. Instrum. Meth. **A 798**, 172 (2015)

[2] The Pierre Auger Collaboration, *The AugerPrime Design Report*, *arXiv:1604.03637*.

[3] F. Schluter [Pierre Auger coll.], *Expected performance of the AugerPrime Radio Detector*, PoS(ICRC2021) 262.

[4] G. Cataldi [Pierre Auger coll.], *The upgrade of the Pierre Auger Observatory with the Scintillator Surface Detector*, PoS(ICRC2021) 251.

[5] A. Castellina [Pierre Auger coll.], *The dynamic range of the AugerPrime Surface Detector: technical solution and physics reach*, PoS(ICRC2017) 397.

[6] The Pierre Auger Collaboration, JINST **18**, P10016 (2023)