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AugerPrime Upgraded Electronics

G. Marsella[a,b,*] on behalf of the Pierre Auger[c] Collaboration

[a]Università degli Studi di Palermo, Dipartimento di Fisica e Chimica "E. Segrè" Via delle Scienze ed. 17, 90128 Palermo, Italy
[b]INFN Sezione Catania, Via S. Sofia, 64, 95125 Catania, Italy
[c]Observatorio Pierre Auger, A. San Martin Norte 304, 5613 Malarg ue, Argentina
E-mail: spokespersons@auger.org

PIERRE AUGER OBSERVATORY

Introduction

The principal motivation for the upgrade of the Pierre Auger Observatory, AugerPrime[2], is to provide additional measurements to address the following questions:

- The origin of the flux suppression at the highest energies and the measurement of the mass composition beyond the reach of the Fluorescence Detector (FD).
- Search for a proton contribution in the flux suppression region ($E > 5 \times 10^{19}$eV), aiming at reaching a sensitivity to a proton contribution as small as 10% in this region, search of point sources and estimation of the physics potential of existing and future cosmic ray, neutrino, and gamma-ray experiments.
- Fundamental particle physics at energies beyond man-made accelerators and studies of ex- tensive air showers and hadronic multiparticle production.

The proposed upgrade consist of: (i) the addition of a plastic scintillator plane (SSD[3]) above the existing Water-Cherenkov Detectors (WCD); (ii) the installation in the Surface Detector (SD) stations of new electronics that will process the signals from all AugerPrime detectors; (iii) the installation of an additional small PMT (sPMT[4]) in the WCD to increase the dynamic range, (iv) the installation of an underground muon detector (UMD[5]) in the existing SD Infill area; (v) Radio Detector (RD[6]) added on top of each water Cherenkov detector.

2. The Upgraded Unified Boards

The new electronics[7] processes the signals of SSD, SPMT, interfaces UMD and RD and provides a faster sampling of ADC traces for the WCD PMTs. The new electronics implements faster ADCs (120 MHz instead of 40 MHz) with larger dynamic range (12 bits each instead of 10 bits) and a significantly more powerful FPGA. Specifically, it employs a Xilinx Zync-7020 Programmable SoC (Artix-7 FPGA and associated Cortex A9 Dual 333 MHz ARM co-processor). Xilinx PetaLinux, a light LINUX operative system, runs on the embedded ARM processor. The UUB integrates various functions (analog signal processing, triggering, calibration, GPS time tagging, and data acquisition) on a single board. The FPGA is connected to a 4 Gbit LP- DDR2 memory and 2 Gbit flash memory.

3. Production and Test

The UUB are produced and assembled in Italy by SITAEL SpA[1]. All the UUBs have a record in the KIT database (containing the UUB production number and the internal serial number). The boards, before reaching the field, undergo 2 test phases[8]: 1) Manufacturer test directly in the company where the boards are realised; 2) Environmental Stress Screening (ESS) tests realized in Prague by the local Auger group.

3.1 Manufacturer Test

The manufacturer test, setup in the producer SITAEL company, aims at verifying that all functional blocks of the UUBs are correctly assembled and in operation. The UUB is connected on a stable socket of 160 cm × 80 cm size. (Fig.1 (Left)). As a first step of the testing procedure, all UUBs should pass an initial optical inspection. The inspection allows us to detect problems related to the soldering process (such as excessive or insufficient solder paste) and issues related to component assembly (such as missing components, wrong orientation or distortion of integrated circuits, wrong component polarity). After that stage a semi-authomatic full functionality test is executed. Analysed data are formatted and saved in a database to Karlsruhe Institute of Technology (KIT).

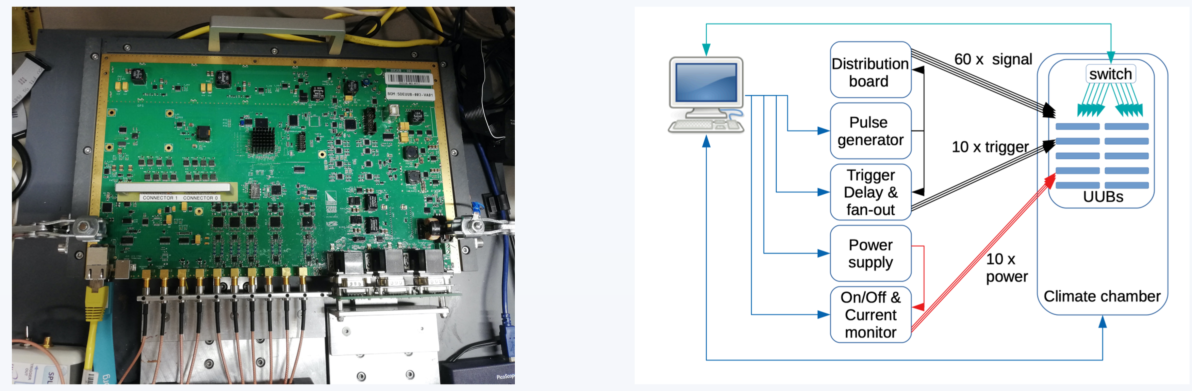


Figure 1: Left: UUB in Manufacturer Test system. Right: ESS Test system description.

3.2 Environmental Stress Screening test

The UUBs are sent to the Institute of Physics, Prague after the manufacturing test. The ESS testing is done in three steps: First, preliminary tests are executed to evaluate the noise and general status of each board. Next, 10 UUBs at a time are placed inside the climate chamber Binder MKFT115 for the burn-in procedure. Finally, the Environmental Stress Screening is done in 10 cycles, going down to -20◦C and up to +70◦C (temperature change of 3◦C/min). Thus, the measurement points are: 20◦C, 0◦C, -20◦C, 0◦C, 20◦C, 45◦C, 70◦C. At extreme temperatures the stabilisation and readout time take 15 minutes. During the two last cycles the power ON/OFF test is performed (over/under voltage protection). Further details on the tests performed can be found in [8]. The scheme of the ESS test bench is shown in Fig.1(Right).

4. Deployment and Performances

Actually 81 boards are installed in the field (as shown in Fig.2), 79 in a pre-production engineering array and 2 in the AugerPrime stations Clais and Trak. Since the end of 2020, all installed boards are acquired with standard array. Currently the UUB trigger signals are filtered at 40MHz to emulate UB, in order to not perturbate the standard DAQ. The new devices such as SSD and sPMT are then continuously studied by the collaboration. For each board, the ten ADC channels are verified to have stable baselines both in mean values and RMS. Also the calibration of all detectors are performed and monitored as shown in the following sections.

4.1 WCD and SSD

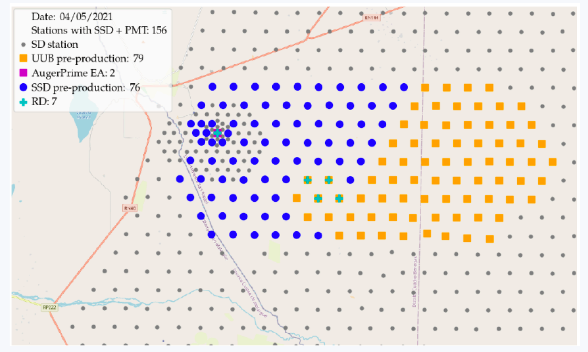


Figure 2: UUB pre-production

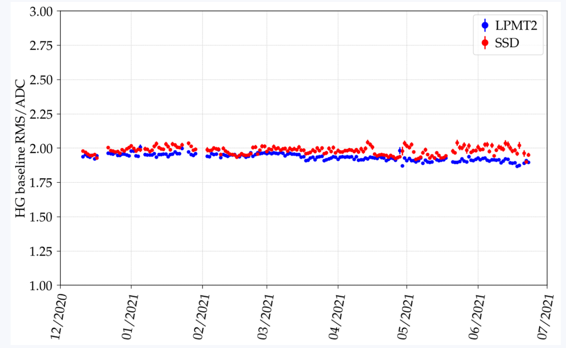


Figure 3: Distribution of the daily mean value of the baseline RMS.

In Fig.3 the HG RMS of the baseline distribution in function of time is shown for station 22 with UUB implemented. A WCD LPMT and an SSD signals are shown. In all stations the HG channel RMS are less than 2 ADC counts while in LG channels are less than 0.5 ADC counts. The data shown have been taken between January the 1st 2021 and May the 31st 2021. Each point is the daily mean value of the baseline RMS distribution and the error bar is the RMS of such daily distribution.

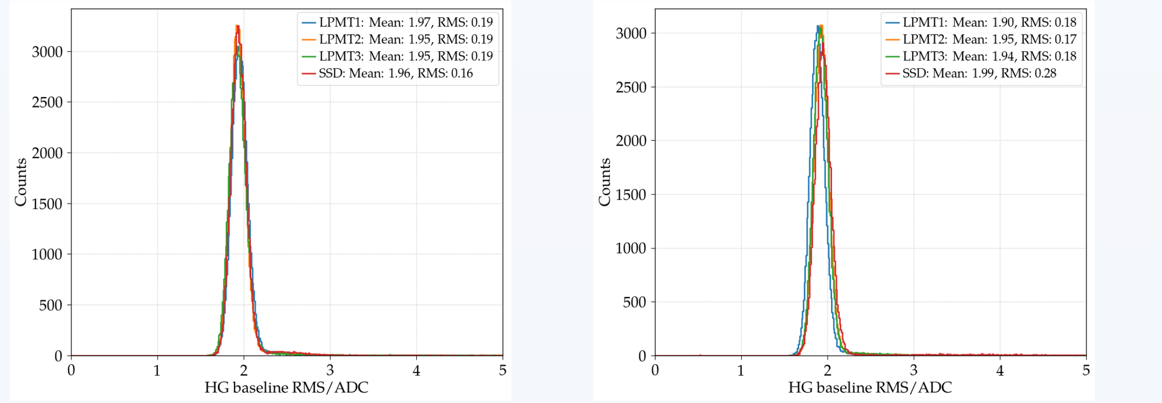
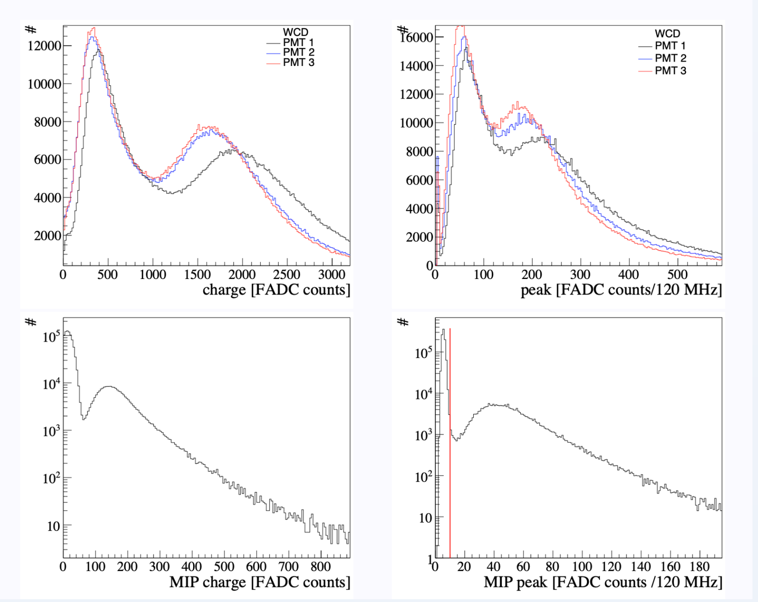


Figure 4: Distribution of the daily mean value of the baseline RMS for the stations 20 (Left) and 22 (Right)

In Fig.4 the distribution of the daily mean value of the baseline RMS for the stations 20 and 22 are shown (Left station 20 and Right station 22 signals). Also the baseline values are monitored and are very stable (within ± 1 ADC count).

For the Calibration of the WCD PMTs the muon signals are acquired by dedicated triggers and the Vertical Equivalent Muon (VEM) is evaluated using HG channel. The Low Gain channel is calibrated in the range of superposition of signals with HG. The SSD calibration is based on the signal of a minimum-ionizing particle (MIP) going through the detector. About 40% of the calibration triggers of the WCD produce a MIP in the SSD. An example of the VEM and MIP calibration histograms is shown in Fig.5.

Figure 5: Calibration Histograms: Top - histograms show the muon charge (left) and peak (right) for the three WCD PMTs; Bottom - The muon charge (left) and peak (right) in the SSD. The red line in the last plot, indicates the cut to apply on SSD ADC peak to enhance the hump to valley ratio for VEM evaluation in WCD PMTs calibration



The time resolution has been studied with the prototype UUBs in two tanks. The result shows that, in measuring the fixed delay between these two stations with a mutual trigger, the time resolution is ∼5.0 nanoseconds.

4.2 The small PMT

For the purpose of extending the dynamic range of the signal acquisition, the WCD is equipped with an additional small photomultiplier tube (sPMT). The sPMT has an active area ∼100 times smaller than LPMTS. Adjusting the sPMT gain, it allows the measurement of signals up to the required target of 20,000 VEM without saturation. A dedicated selection of small local shower is set up to calibrate it. The signals in a region of superposition are then exploited to cross-calibrate the sPMT using the VEM-calibrated signals of the WCD PMTs.
The cross-calibration factor is also employed to estimate the maximum signal that can be measured by each sPMT without saturating the acquisition electronics. Its average value is shown in Fig.6 (Left) for a set of stations. The dispersion among the daily estimations results to be of the order of few %. Using the small showers events and the cross-calibration result, the relation between the signals in the WCD and in the scintillator can be examined even on a timescale of few weeks, as shown in Fig.6 (Right). The SSD signals are expressed in MIP while the WCD ones in VEM. The signals show a larger dispersion with respect to standard ultra-high energy air showers.

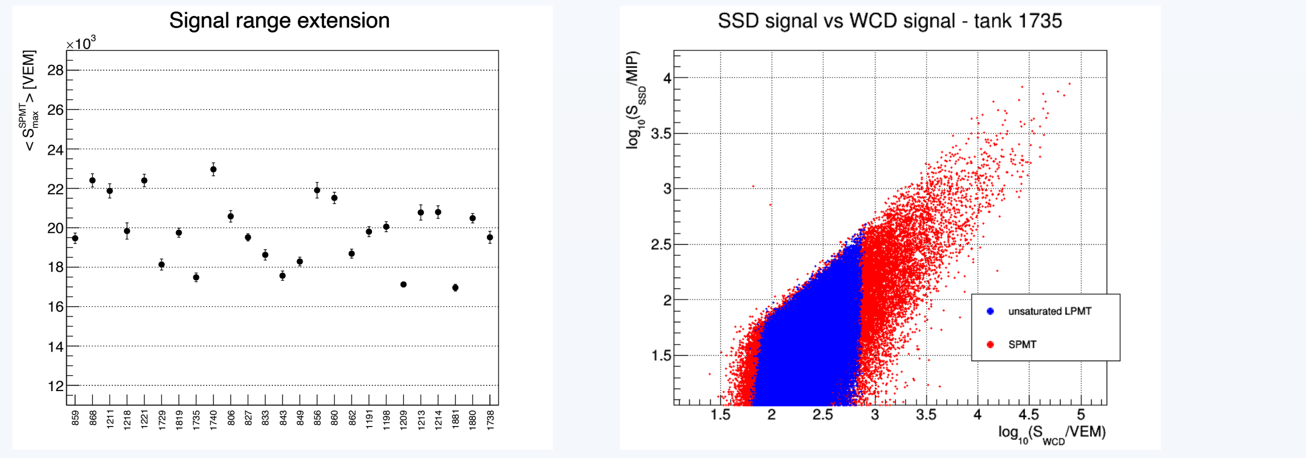


Figure 6: Left: Expected maximum sPMT signal without saturation for a subset of stations, estimated using 1 month of small showers data. The error bars in each value represent the dispersion among the daily SPMT estimations of $Smax$. Right: Correlation between the WCD and the scintillator signals for one upgraded AugerPrime station, using the small showers selected for the cross-calibration procedure.

Conclusions

AugerPrime is in its commissioning phase and all detectors are being installed in the field. The UUBs are in production. All the phases have been intensively verified and tested and the process is now in its full active phase. Already 81 boards are in Argentina and at the end of July 2021 84 more will be sent and 400 more are planned at the end of August 2021. Since December 2020, all UUBs in the field are included in the standard DAQ and monitored offline. The performances of the boards are stable and well within the design requirements. The process is going on as expected and we foreseen the completion of the UUB deployment by the end of 2022. Special thanks are due to the local staff involved in the operations.

References

[1] A.Aabetal.[PierreAugerColl.],*ThePierreAugerCosmicRayObservatory*,*Nucl.Instrum.Meth.***A798**, 172-213 (2015) [1502.01323].
[2] A.Aabetal.[forthePierreAugerColl.],*ThePierreAugerObservatoryUpgrade*,[1604.03637].
[3] G.Cataldi[forthePierreAugerColl.],*TheupgradeofthePierreAugerObservatorywiththeScintillatorSurface Detector*, *These Proceedings, PoS(ICRC 2021) 1017*.
[4] A.Castellina[forthePierreAugerColl.],*AugerPrime:thePierreAugerObservatoryUpgrade*,*EPJWeb Conf.* ***210*** *(2019) 06002*, [1905.04472].
[5] A.Botti[forthePierreAugerColl.],*StatusandperformanceoftheundergroundmuondetectorofthePierre Auger Observatory*, *These Proceedings, PoS(ICRC 2021) 778*.
[6] F.Schlüter,[forthePierreAugerColl.],*ExpectedperformanceoftheAugerPrimeRadioDetector*,*Inthis Proceedings, PoS(ICRC 2021) 1210*.
[7] D.F.Nitz[forthePierreAugerColl.],*NewElectronicsfortheSurfaceDetectorsofthePierreAugerObservatory*, *Proc. of the 36th Int. Cosmic Ray Conf., PoS(ICRC 2019) 370*.
[8] M.Bohacova[forthePierreAugerColl.],*TestbenchesfortheupgradeofthePierreAugerObservatory electronics*, *Proc. of the 36th Int. Cosmic Ray Conf., PoS(ICRC 2019) 199*.

[1]https//www.sitael.com