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Pierre Auger Observatory

Surface Detector Electronics Upgrade Critical Design Review

Small PMT
Technical Design Document

Purpose

This document supports the SDEU CDR for the evaluation of the Small PMT readiness

Scope

This document describes requirements, goals, design implementation and status of the Small PMT project

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Acronyms

CDR = Critical Design Review
CR = Configuration Requirement
EA = Engineering Array
FR = Functional Requirement
GPS = Global Positioning System
LED = Light Emitting Diode
PAO = Pierre Auger Observatory
PMT = Photo Multiplier Tube
PPS = Pulse Per Second
SD= Surface Detector
SDE = Surface Detector Electronics
UB = Unified Board
UUB = Upgraded Unified Board
WCD = Water Cerenkov Detector

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System requirements and design concept

The Auger Surface Detector Upgrade requires an extension of the tank dynamic range up to 21 bits ([3, 4]).
This will be achieved by adding a small photomultiplier (SPMT) to the WCD, with an active cathode area of at least 60 times lower wrt to the existing large PMTs of the tanks, which can easily record signals that saturate in the standard PMTs up to the desired dynamic range and can be housed in the spare LED window already present in the liner, without requiring significant modifications to the WCD. Integration of a 4th PMT in the upgraded electronics, Data Acquisition system and reconstruction should be straightforward and should not require ad-hoc developments of electronics or mechanics.

The choice of the specific SPMT model is driven by the following technical considerations [1],[2] and subject to qualification tests in the field:

1 - Diameter: mechanical compatibility with the existing 30 mm spare LED window
2 - Photocathode active area: a simple down-scaling of the SPMT light collecting area with respect to the XP1805 PMTs directly results in an extension of the tank dynamic range (if $G_{spmt} \approx G_{xp1805}$)
3 - Linearity: maximum non linearity of -5 % for $I_{anode} \approx 50$ mA as for XP1805

Design implementation

The SPMT will be installed in the spare LED window located 60 cm off center of the liner.
The side window is easily accessible through the PMT1 hatch cover for installation and maintenance.
The tubes will be powered by means of resistive dividers with progressive voltage ratio on the last stages (*tapered dividers)* prototyped in the Torino INFN Electronic Lab.
The dc-dc converter will be installed in a small box separated by the main UUB body providing the necessary connections to the slow control ([1],[2]). HV and signal cables will connect the SPMT to the HVPS and to the front end on the UUB.
The current prototype mechanics for holding the SPMT will be validated in the Engineering Array field test.

Prototype qualification tests

Three tubes were considered and tested as SPMT candidates: Hamamatsu R6094 (28 mm diameter) and R8619 (25 mm diameter), ET Enterprise 9107B (28 mm diameter). The related ratio between the sensitive areas being:

$$A_{xp1805}/A_{R6094,9107B} \approx 75 \qquad A_{xp1805}/A_{R8619} \approx 100$$

The results of the linearity tests performed in the Torino INFN Electronic Lab. are shown in Table 1. All the tubes are linear (less than -5 % deviation from linearity) up to Ianode ~ 60 mA.

Engineering Array Test Plan

The Engineering Array field test will qualify all the selected models for the final production: two tanks will be equipped with the Hamamatsu R6094, two with the ET9107B and three with Hamamatsu R8619.
The Engineering Array SPMT dividers have been finalized in IPN-Orsay [2].
To assure a steady contact between the transparent membrane of the window and the water a large diameter PVC flange (~ 40 cm) will be inserted around the window for flattening the liner, increasing the pressure on the water and to better hold the SPMT in vertical position. The SPMT

will be secured to the liner with a plastic bolt screwed on the rim of the port as currently done for the LED flashers plastic case
Figure 1 shows the prototype of the SPMT holder for the EA test. The design is compatible with all the SPMT models considered for the upgrade. Seven of these prototypes are ready for the Engineering Array.
The SPMT will be powered by Sens Tech PS2010/12 dc-dc converter as for large PMTs. The new dc-dc converter CAEN A7501 has been tested in Torino and the performances will also be checked in the Engineering Array.

Test report

Preliminary measurements and stability tests have been performed on DIDI tank using as SPMT the Hamamatsu photomultipliers R6095 (longer version of R6094) and R8619.
Fig. 2 shows the obtained charge spectra of the DIDI tank.

For both SPMT candidates Figure 2 clearly shows the overlapping linear region of the PMTs, the XP1805 saturation and the extension of the dynamic range of the WCD obtained by the SPMT. The lower part of the XP1805 charge spectrum is not visible because of the applied cuts to underline the SPMT performances [1], [2].
As discussed in [1], the stability of the calibration was monitored every few hours with the ratio between the SPMT and the standard PMTs responses to real events. Figure 3 shows the latest result for Hamamatsu R8619: the inter calibration is stable, with an uncertainty of 4%, in agreement with previous results.

Design Status

The design of the SPMT mechanics, high voltage and readout electronics is defined and the first prototypes are ready.
All performance specifications are met, and the extension of the Surface Detector dynamic range with the Small PMT is expected to be at least of a factor of 32, promising insight into the physics of Cosmic Ray showers close to the core.

Figures and tables

Hamamatsu	S/N	Glass Diameter [mm]	Photocathode diameter [mm]	Heigth [mm]	I_{anode} [mA] N.L. ≤ -5% G ≈ 6 ÷ 8 10^5 HV ≈ 1000 V
R8619	RU7647	25	22	79	58
R8619	RS6915	25	22	79	60
R8619	RW5738	25	22	79	60
R8619	RW5585	25	22	79	58
R6094	RJ1578	28	25	92	88
R6094	RJ1577	28	25	92	60
R6094	RJ1412	28	25	92	70
ET Enterprise					
9107B	63312	28	25	87	65
9107B	73310	28	25	87	78
9107B	73289	28	25	87	115

Table 1: linearity tests of prototype SPMT

Figure 1: SPMT holder for the Engineering Array

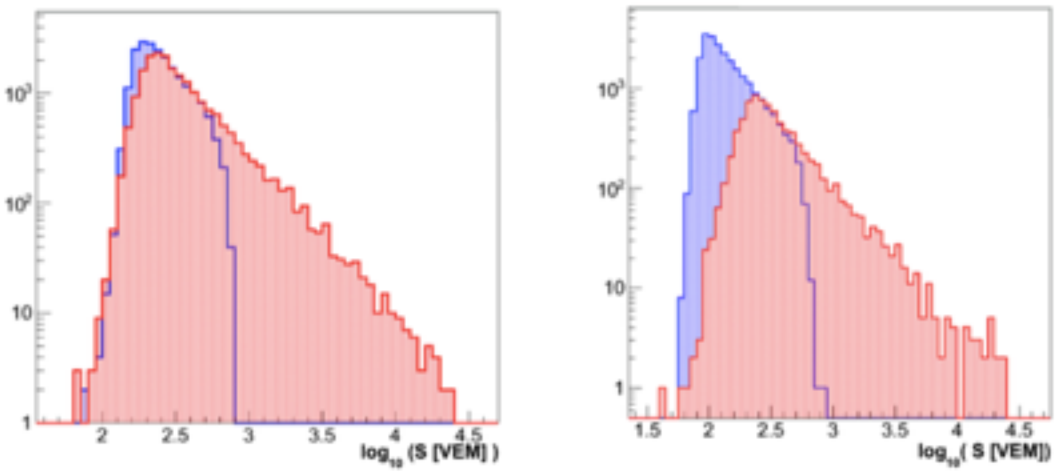

Figure 2: charge spectra (in VEM unit) of the DIDI tank. Left panel: R6095 SPMT; Right panel: R8619 SPMT. The blue and red histograms show the spectrum measured by the large and Small PMT respectively

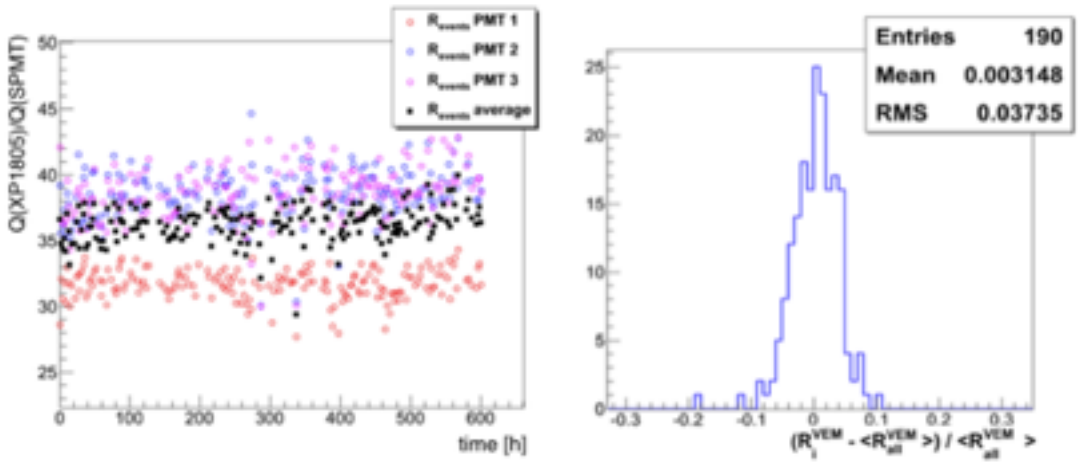

Figure 3: Left panel: average charge ratio between the large and small PMTs for vertical muons (4 hours time bins). Right panel: relative distribution of the PMT charge ratios (($R_i^{VEM} = Q_i^{XP1805} / Q_{SPMT}$).

References

1. M.Aglietta et al, “Small PMT – Status Report”, GAP 2014-17
2. M.Aglietta et al, “Small PMT Upgrade Project: status report for the Engineering Array”, GAP 2014-75
3. H. Asorey, X. Bertou, “ Determining the Dynamic Range needed for new Surface Detectors”, GAP 2008-117
4. M. Roth, “Shower universality: comments on anisotropy and saturation”, Auger Analysis Meeting Lisbon 2013