Linearity Measurements for sPMT R6095

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In this note we describe the linearity tests performed on a small size PMT [1] candidate to be employed in the upgrade for the Pierre Auger Observatory (PAO) experiment.
The proposed upgrade focuses on the physics goal of the primary beam composition determination by improving the muon/electron separation of the surface detector (SD). Enhancing the dynamic range of the SD detector meets with the tank saturation problem that affect about 40% of ultra high energy events. A solution to extend the SD dynamic range is to introduce in the tank a fourth dedicated photomultiplier with a smaller sensitive area [2] in order to reduce drastically the number of events with saturated signals.
The choice of the candidate PMT has been driven by several constraints. Reducing the collecting area respect to the three others PMT (PHOTONIS XP1805) translates into an increase of the dynamic range when the small PMT operates at the same gain and linearity of the others. Moreover, in order not to change the mechanical structure of the tanks, the PMT photocathode must have a size compatible with a small 30 mm window already existing in the liner that was designed to accommodate LED calibration. Finally the anode pulse rise time must be compatible with the upgrade program for the FADC sampling rate, i.e. < 6 nsec. The evaluated PMT can also used for the light collection of the ASCII modules [3].
We tested two small size PMT (1 and 2) from HAMAMATSU (R6095), other test reults can be found in [4]. In Tab. the requested characteristic are shown. Fig.1 shows the scheme of the possible divider for PMT R6095. We used a purely resistive divider with the progressive voltage ratio on the last stages as shown in Fig.1. This voltage distribution allows to obtain anode pulse with high current and good linearity. The linearity measuremets are performed using three dividers: one is a tapered divider finalized in the Lecce electronic laboratory, the other two dividers are one tapered and one standard form Hamamatsu.

Table 1
Hamamatsu PMT6059 characteristics.

	Glass ⌀ $[mm]$	Useful photocathode ⌀ $[mm]$	Height $[mm]$	QE $[\sim 400nm]$	Dynode Number	Imax $[mA]$ N.L. <5%
Product						
R6059	28	25	112	27%	11	40-80

Electrodes	K	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9	Dy10	Dy11	P
Standard ratio	1	1	1	1	1	1	1	1	1	1	1	1	
Tapered ratio	2	1	1	1	1	1	1	1	2	3	4	3	

K : Photocathode, Dy : Dynode, P : Anode

Figure 1. Standard and tapered ratio for R6095 PMT divider.

In the Astroparticle Lecce Laboratory we have already the facility [5] used to test PMTs for the upgrade programs and for the standard deployment of the detector. The light source for the test consists of a LED pulser controlled through a National Instruments USB-6353 Board connected to the data acquisition computer. Two blue LEDs (470 nm, 45 deg viewing angle) are used and in order to have a fast turn-on turn-off response an appropriate LED driver has been designed (see [5]). The two LEDs are positioned in the center of a small box housing the driver. The LED-system can be mechanically moved to different points respect to the PMT. The signal from the anode is sent to a digital oscilloscope of 4 GSa/s sampling and 1 GHz bandwidth (AGILENT MSO6104A) connected to the computer through USB.
As we mentioned before, one of the most serious concern is the necessity of having PMTs which have a linear response over a large dynamic range. The requirement is to have linearity within $\pm 5\%$ up to an anode current of 50 mA at the nominal gain. In order to measure the linearity of the tested PMT we used the double LED method. This idea is simple: the system pulses two blue LEDs (LED_1 and LED_2) independently and in succession, followed by simultaneous pulsing of the two LEDs together (LED_{12}). Varying the light intensity of the two LEDs and plotting the

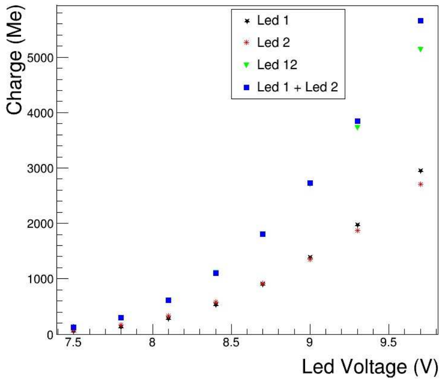

Figure 2. Charge as a function of the LEDs bias voltage from the double LED linearity setup for the sPMT1.

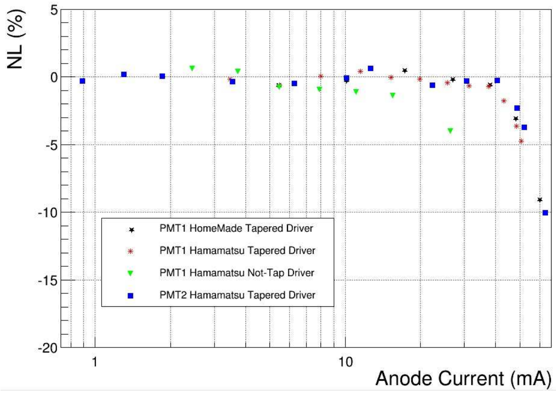

Figure 3. Non Linearity ratio vs Anode Current for the two PMTs. The measuremets are performed at 1000 V PMT applied voltage.

following difference:

$$Non - Linearity = \frac{(LED_{12} - (LED_1 + LED_2))}{(LED_1 + LED_2)} \quad (1)$$

we get a measurement of the non-linearity of the PMT as a function of the anode signal. Measurements on the peak amplitude data and integrated charge were performed. In Fig.2 anode integrated charge as a function of the flashing LEDs bias voltage is shown. Good linearity is shown when LED_{12} data points coincides with the LED_1 + LED_2 points.

Fig.3 shows the result for the two PMTs. As expected, for the standard ratio divider the linearity degrades pretty soon ($\sim$ 30 mA). For the tapered ratio divider instead, the test evidences an acceptable linearity up to 50 mA that is identical for the two dividers (homemade and Hamamatsu).

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