Laser Calibration System - Analysis of the Local Monitors

Nandita Raha, *INFN Pisa*

Abstract: This document analyzes the local monitor data from a dataset of the first data–taking run (an accumulation of 60 hours of runs) and also performs some simulations to check the local monitor performance. It also tests if any long-term corrections related to temperature fluctuations, humidity etc. are essential or not for the local monitors at the desired level of precision of the experiment.

1. A reminder of the laser calibration system

The schematic of the calibration system is shown in Figure 1. We use six laser heads (LDH-P-C-405 M by PicoQuant) that provide up to 1 nJ of pulses 700 ps wide at a wavelength of 405 nm to calibrate all the calorimeters [1]. The light from each laser is divided in a ratio of 70:30 by a beam splitter. The 70% light is further divided into four equal parts and transported to the four calorimeters in the ring using 25 m-long quartz optical fibers via a diffuser (to convert the Gaussian distribution of light intensity into a more uniform and flat distribution) and a fiber bundle. This delivers light to each of the 54 PbF_2 crystals with the fiber bundle attached to a Delrin panel embedded with optical prisms located in front of the calorimeter. A Source Monitor (SM) is used to measure pulse-by-pulse the intensity of the remaining 30% of the laser light [2].

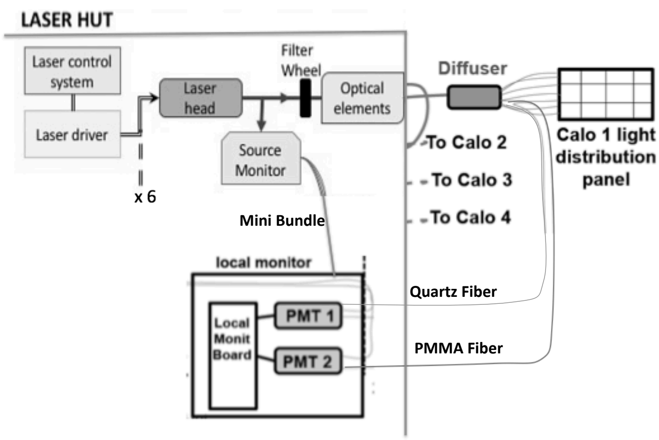

Figure 1. A schematic showing the laser calibration system.

The optical stability of this entire system is checked using a Local Monitor (LM). A mini-bundle fiber transmits light from the SM to the LM. Each LM consists of a PMT which collects this light from the SM and is used as a reference signal. This has an amplitude of A1 (amplitude is defined as the pedestal subtracted peak adc value of the waveform). The light from the optical elements, the diffuser, the 25 m quartz fiber (that transmits light to the calorimeter) is transmitted back to this PMT using by a quartz fiber. This has an amplitude of A2. However, certain calorimeters, namely 11, 12, 13, 18 and 20 used an additional old PMT. For these calorimeters, the light from the optical system to the PMT was transmitted using a PMMA fiber. This was done to investigate the properties of the fiber used for transmission of light and also for a comparison between the old and the new PMTs. The stability of this distribution system is quantified by comparing the ratio of light from the two sources i.e. A2:A1.

2. A study using old and new PMTs of the LM

The major goal is to check if the fluctuations in the LMs gain due to various external factors like temperature, humidity etc. will have an effect on the SiPMs gain calibration. Thus we begin by studying the stability of the LM for a long period of time. We considered a 60–hour data set of run 1 for consistency checks. Run numbers from 15920 to 15990 dated 22/4 (1:09 pm) to 25/4 (2:20 am) where precisely considered for our study.

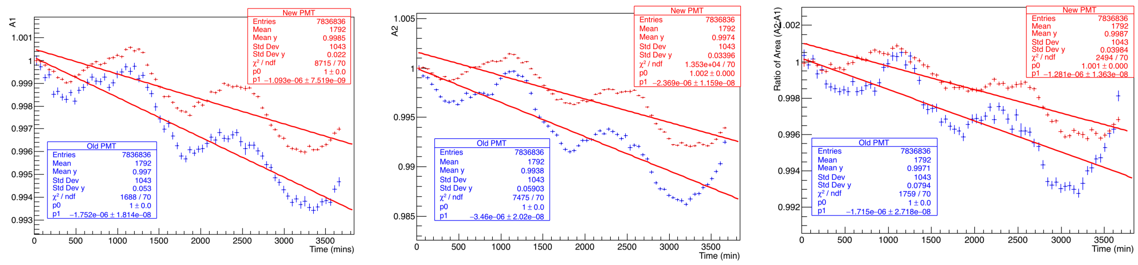

Figure 2. Comparing old (blue) and new (red) PMTs of the 60–hour dataset from run1. The left plot denotes variation of A1 with time. The middle plot denotes the same for A2 and the right plot denotes the fluctuation of A2:A1 with time.

Figure 2 compares the fluctuations of the old (in blue) and the new (in red) PMT channels respectively of the LM connected to calorimeter 20. The PMT of the LM is connected to SM with a very short fiber and so A1 practically denotes the gain of the PMT. On the hand, A2 includes various transmission fibers, diffuser and other optical elements and thus has a much larger drop (almost twice as that of A1, as is evident in the data - refer to figure 2). Since A2:A1 denotes the stability or fluctuation of the entire optical system along with the monitoring system, its drop (or fluctuation) is comparable or dominated by A2 as is evident in the right plot of figure 2.

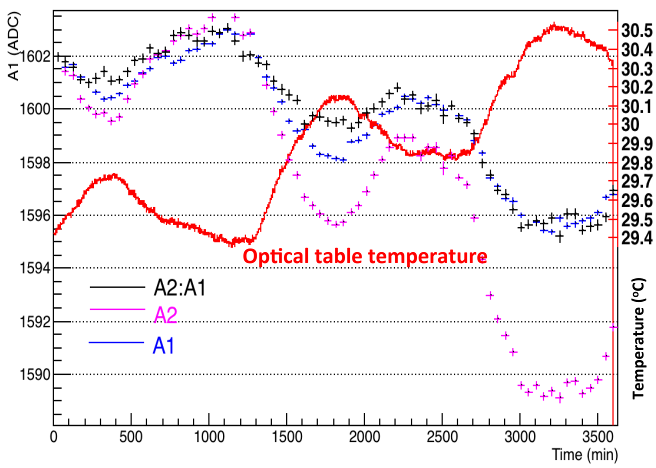

Figure 3. Effect of temperature on the LMs.

Note that we use linear fits in these plots which do not correctly represent the data but is reasonable to get a rough estimate of the drop in gain per minute for the 60 hours runtime. These plots also show that the old PMTs in all cases have a larger drop in gain (about 1.5 times more than the new ones). This could be due to aging or improper configuration of voltage settings or light intensities. The voltage settings of only the new PMTs were configured according to the light intensity from the filter wheel settings.

2.1. Effect of environmental factors on the performance of LMs

In the longer run (datasets of more than one day or so), it is important to check the effect of various environmental factors on the performance of the LMs. This mainly includes temperature and other minor factors like humidity, air pressure etc. The temperature with these minor corrections applied was read from the database for this dataset and exhibits a diurnal effect (peaks during the day and is low at night) as shown by the red plot in figure 3.

The temperature range for this 60–hour dataset is about 1.1 ^oC. The blue, pink and black plots show the variation of A1, A2 and A2:A1 respectively with time. A2 and A2:A1 are all normalized to the initial value of A1 and all the three plots are overlaid on the same plot to compare. This clearly shows a negative correlation of the gains with temperature (as the temperature increases these amplitudes decrease). To quantify this drop with temperature, we found the correlation of temperature with each of A1, A2 and A2:A1 as shown in figure 4 for the same channel.

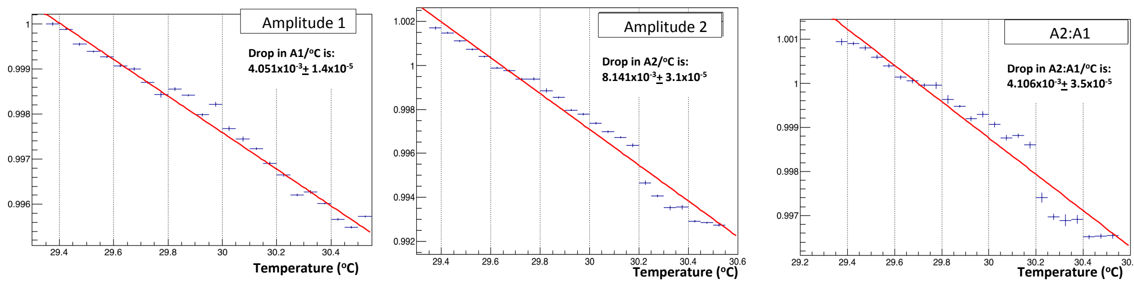

Figure 4. Variation of amplitude with temperature for a PMT channel of the 60–hour dataset.

To study the behaviour of the gain drops with temperature for all channels of the LM (from all 24 calorimeters), we find the correlation of A1, A2 and A2:A1 with temperature for each channel (a plot like figure 4) and perform a linear fit. The slope of this fit with its error estimates the drop in these quantities with temperature. The absolute value of these drops are plotted in the graphs of figure 5 for each channel.

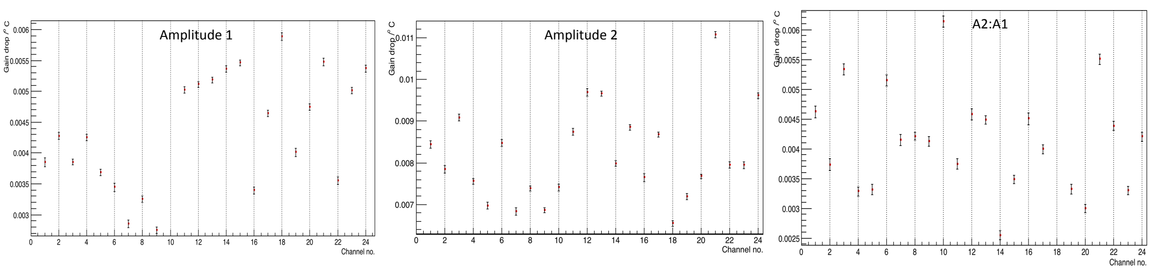

Figure 5. Drop of A1(left) A2(middle) and A2:A1(right) of all channels with temperature for the 60 hour dataset.

2.2. Effect of the connecting fiber on the performance of LMs

Irrespective of the temperature, the PMMAs have a much greater loss in gain compared to the silica fibers. To investigate this we recently took a special 24–hour long run. One of the channels was connected to the LM with PMMA while another was connected using a silica fiber from the calorimeters. Thus, A2 would show the effect of the type of fiber used, whereas A1 should be comparable for both channels. Both channels do show a negative correlation with temperature as expected but the drop in PMMA (left plot of figure 7) is more than 3 times larger compared to the drop in silica fiber (right plot of figure 7).

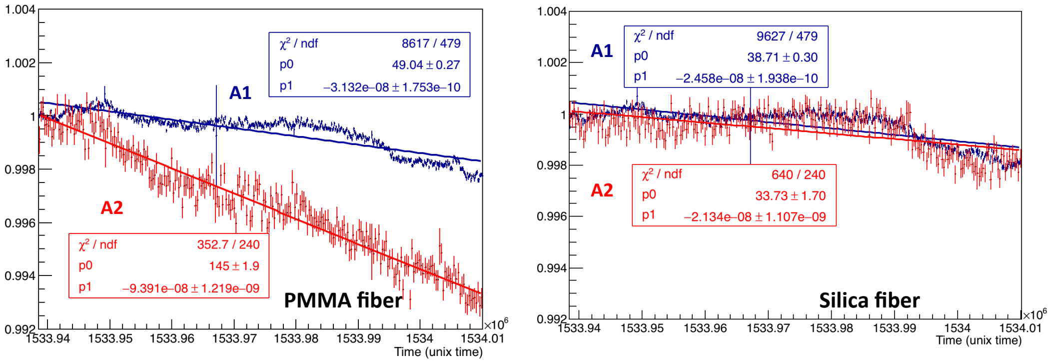

Figure 6. Difference between a silica fiber (right) and PMMA (left) one.

3. Effect of LM fluctuations on SiPM gain function - a simulation

To investigate the effect of these LM gain fluctuations on the SiPM gain functions used by the calorimeters we simulated this gain within a fill. A fill is a 700 μs muon beam time. The beam is structured as two bunches of eight such fills constituting a cycle (i.e. 16 fills in a cycle) [6]. The red plot in the right side of figure 7 represents the standard gain function within a fill given by,

$$G(t) = 0.992(1 - 0.04e^{\frac{-t}{30}}) \tag{1}$$

The asterisk (*) represent the points simulated by laser pulses. Three laser pulses are shot at 30 μs, 200 μs and 400 μs within a fill. After every 9 fills we move the laser pulse by an offset of 2.5 μs to obtain all simulated points within a fill as shown on the right side of figure 7. The data of the LM (A1) is plotted and fitted with a sinusoidal decreasing function (left side of figure 7). This resembles the diurnal temperature effect (with an anticorrelation) and fits the data better than a straight line. So we took this function for out-of-fill pulses for both the source and local monitors and took an average of the ratio of SiPM gain function (Q) with SM gain (S0) and LM gain (L0) over a sub run (i.e. about five cycles), given by,

$$\left\langle \frac{\left(\frac{Q}{S0\times L0}\right)_i}{\left\langle\frac{Q}{S0\times L0}\right\rangle_{OOF}} \right\rangle \tag{2}$$

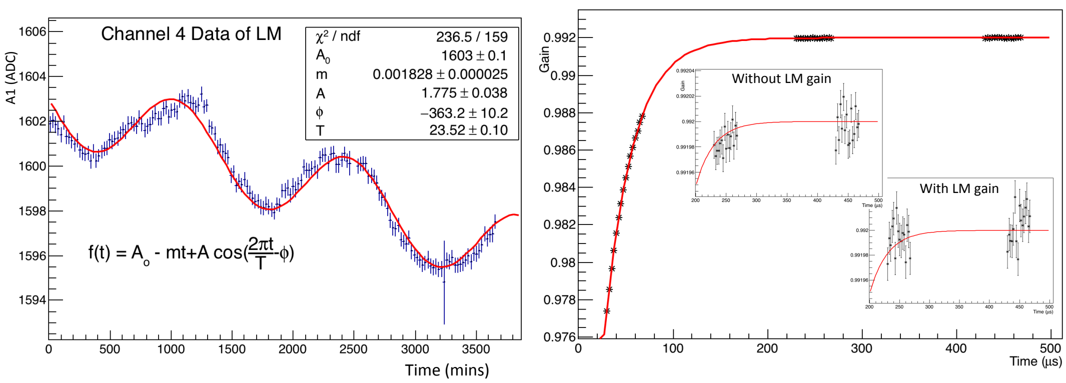

Figure 7. Left: A fit of the LM amplitude (gain). Right: A simulation - the effect of LMs in the SiPM gain. SiPM gain function without any effect of LM (top left) and including a LM gain function (bottom right).

where the subscript i denotes the i^{th} sub run. The effect is shown in the small bottom plot of the right panel of figure 7. The small top plot in the same panel does not include the effect of the LMs and the gain function is thus simulated using,

$$\left\langle \frac{(\frac{Q}{S0})_i}{\langle \frac{Q}{S0} \rangle_{OOF}} \right\rangle \tag{3}$$

It is evident that there is no noticeable effect of long–term LM fluctuations on the gain function. We tried using ten times larger gain drop of A1 with temperature and did not get any effect. Thus we do not need to correct for these fluctuations observed by the LM at our desired level of precision.

4. Conclusions

Finally, from this study we conclude the following: A1 primarily indicates the gain fluctuation of the PMT, as it is directly connected to the PMT from the SM using a silica fiber. As expected, all channels show a negative correlation with temperature with A1 (PMT gain). A2 can have additional effects in fluctuation due to forward and reverse fibers to and from the calorimeters respectively. For silica, no visible effects found on A2 (besides the Gain variation with temperature). For PMMA there is a significant drop in gain variation with temperature, thus making it unsuitable for use. The simulation shows that we do not need to correct for these fluctuations observed by the LM at our desired level of precision.

Acknowledgments

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