The photomultiplier gain monitoring system of the Large Angle Electromagnetic Calorimeter for CLAS

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Abstract

The light pulser gain monitoring system based on YAP: Ce+^{241}Am, of the Large Angle Electromagnetic Calorimeter (LAC) for CLAS at TJNAF is described. The system is easy to install, reliable and allows a photomultipliers gain stability control with a precision $\leq$0.5%. Using this system we have controlled the stability of the gain of the 512 PMT of the LAC during one month of operation finding fluctuations around 0.5% during a short term observation (1 day) and of the order of 1-2 % after 27 days.

1 Introduction

The detection equipment used for application in the new generation accelerators involves a great number of channels of electromagnetic and hadronic calorimetry. So that one of the important issues concerning particle detectors using a large number of photomultipliers is to monitor their stability during a long period of time. In fact, since experiments take much time, the problem of stabilizing an energy scale for the detector becomes very important. In particular, the gain stability is extremely important for sampling calorimeters because it directly affects their energy resolution.

Since the expected energy resolution for the LAC is about $0.8/\sqrt{E[GeV]}$, at 6 GeV monitoring of the gains of PMT to a precision at the 2-3 % level is required.

There are many reasons why the gain of a PMT can vary. Among them, temperature changes, thermal and chemical reactions on the material. To control the PMT gain, a known amount of light is usually send to the PMT and the answer is read out. There are several different light sources available on the market. They are divided into 2 types:

- non triggerable devices, such as light pulsers (scintillating crystals coupled with a radioactive source) [1], [2]

Advantages	**Disadvantages**
1_Excellent stability of the pulse. 2_Unlimited number of pulses. 3_System very compact. 4_Absence of additional electronics.	1_Complicated trigger organization. 2_Low number of photoelectrons.

Table 1: Advantages/Disadvantages of the Light Pulser Based System.

- triggerable ones, such as Xe-flash tubes, light emitting diodes, laser beams [3], [4], [5], [6].

Some advantages and disadvantages of these two systems are given in Table 1 and Table 2.

One of the first calibration systems based on light pulsers was used for the experiments at KEK [1], [2]. At that time as a scintillating crystals were used NaI(Tl). One of the biggest problems encountered in the use of NaI(Tl) + ^{241}Am light pulser was the reliability in sealing NaI(Tl) crystals against moisture. Moreover, even if the NaI(Tl) has a high emission intensity , the crystal is hygroscopic and has a large decay time, roughly 0.25 μs. During the last years the new alternative scintillating crystals were developed, such as YAP (YALO3:Ce), LPO (LuPO4:Ce), PWO (Pb(WO4)2), LSO (Lu2(SiO4)O:Ce), YAG (Y3Al5O12:Ce). The physical properties of some important existing scintillating crystals are shown in Table 3.

The criteria we had in mind when designing the monitoring system were:

- the system should monitor the PMT gains as a function of time with an accuracy of 2-3 % in order not to degrade the energy resolution of the calorimeter.
- The light delivered to the PMT by the system should be in the range of that delivered during physics runs, so that the gain of the counters is measured in the normal range of operations of the counters and electronics.
- The system should be easy to use, fast and should be operated rapidly under computer control.

So to control the stability of the PMT of the Large Angle Electromagnetic Calorimeter, we choose radiactive light pulsers, YAP: Ce + ^{241}Am. The benefits of a system based on a scintillator connected to a radiactive source is the absence of additional electronics, essentially long term stability, a short-duration light flash and last but not least it does not require a complex optical set up. Moreover it is highly compact and produce light intensities large enough to generate, in our case, roughly 3 photoelectrons/MeV.

A general description of our gain monitoring system which satisfies the above criteria is given in section 2. Results of its performance during its operation in CLAS are given in section 3 and show that it maintained the expected performances.

Advantages	**Disadvantages**
1_Large number of the photoelectrons. 2_Possibility to have different reference points. 3_Short pulswidth.	1_Limited number of pulses. 2_Laser light instability. 3_Complicated light splitting & laser optics. 4_System sizes (use of long optic fibers). 5_Laser services (cooling, changing, etc.).

Table 2: Advantages/Disadvantages of the Laser Based System.

Physical properties	**YAP**	**NaI(Tl)**	**BGO**	**GSO**	**LSO**
Density (g / cm^3)	5.55	3.67	7.13	6.7	7.4
Effective atomic number	36	51	75	59	66
Radiation length (cm)	1.21	2.56	1.12	1.38	1.14
Refraction index	1.94	1.85	2.15	1.85	1.82
Relative emission intensity	40	100	15	25	75
Wavelength (nm)	350	410	480	440	420
Decay constant (ns)	27	230	300	56.6	40
Hygroscopic ?	NO	YES	NO	NO	NO
Rugged?	YES	NO	YES	NO	YES

Table 3: Physical properties of some important existing scintillating crystals.

2 The LAC gain monitoring system

The Large Angle Calorimeter (LAC) provided by the AIACE collaboration [7] of the Istituto Nazionale di Fisica Nucleare (INFN) is a sampling electromagnetic shower calorimeter, installed in the CLAS spectrometer at angles larger than 45 in the laboratory [8]. The two modules of the LAC, have a multi-layer structure consisting of 33 layers, each composed by a 2 mm thick lead plate and a 15 mm thick, roughly 10 cm wide plastic NE110A scintillators [9], [10]. Moreover, each module is longitudinally divided into an inner and an outer part to improve the electron-pion discrimination. Scintillators lying (for the inner and outer parts separately) one on top of the other with the same orientation form one stack. So for the inner and outer part separately there are 128 different stacks. The light generated in the scintillators is collected at both scintillator ends, and transmitted to the photomultipliers (EMI 9954A) [11]. The total number of the photomultipliers is 256 for each module so the total number of channels whose global (PMT+ADC effect) stability has to be controlled is 512.

To control the stability of the PMT we choose radiactive light pulsers, YAP: Ce+^{241}Am provided by SCIONIX (Holland) of 3.0 mm x 0.15 mm (outer diameter 4.0 mm x 1.0 mm thik) (Fig. 1), having a count rate of 20±4 c/s, hermetically sealed and chemically stable.

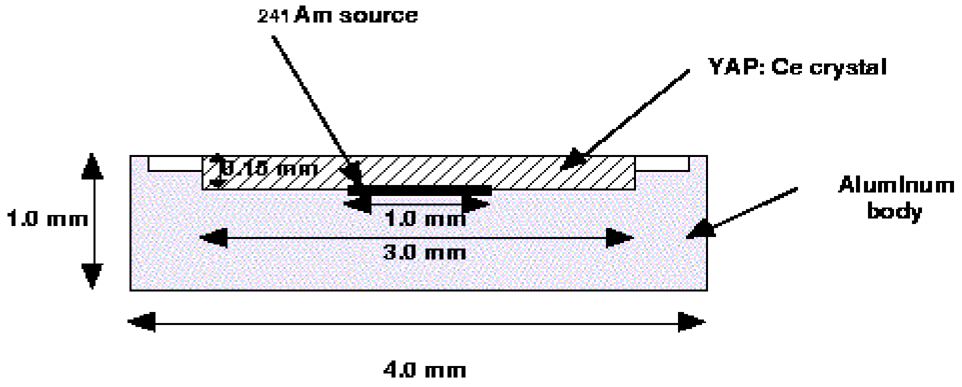


Figure 1: Drawing of the radiactive light pulsers, YAP: Ce + ^{241}Am used for the LAC gain monitoring system.

From Table 3 we see that the YAP crystal has a good emission intensity (40% to respect to NaI) , is not hygroscopic and has a short decay time (27 ns). Before installing them in the experimental apparatus, we measured at the Frascati laboratory, the resolution of the energy spectrum obtained with the light pulser mounted directly on the center of a 2" EMI 9954A PMT window. Among 512 light pulsers, the σ/peak ratio is distributed between 2% and 4% with the peak around 3% (see Fig. 2).

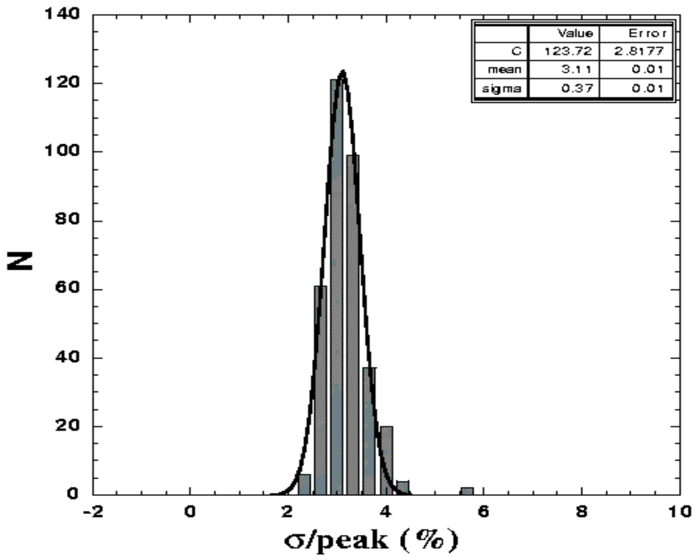


Figure 2: Distribution of the energy resolution for the 512 light pulsers as measured at the Frascati laboratory. The curve represents the gaussian fit of the distribution.

The basic idea of our gain monitoring system is very simple: the 5.49 MeV alpha particle from ^{241}Am causes scintillation in the YAP crystal and provides a continuous signal on the PMT (each phototube has is own light pulser) which will be recorded through the same electronic chain used during regular data taking.

The light pulsers are coupled in air to the photomultipliers. The 32x32 mm^2 central region of the 2” bialkali-cathode sensitive area of the PMT is covered by the group of 8 light guides [12] so we installed the pulsers out of this region choosing the position with the best quantum efficiency (Fig 3).

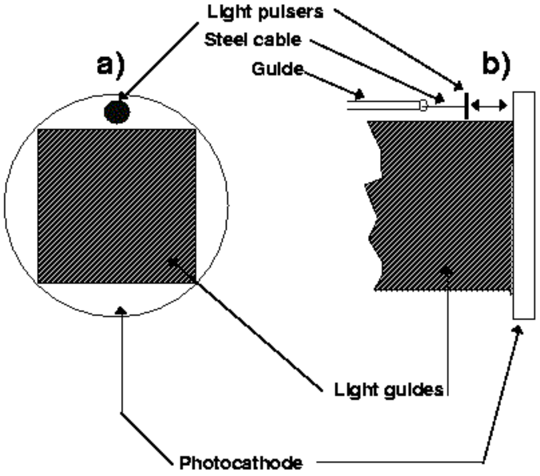


Figure 3: Conceptual design of the LAC gain monitoring system showing the position of the light pulser with respect to the PMT photocathode and to the light guide (a) and the mechanical system used to move it (b).

We did not glue the pulser to the photocathode in order to have the possibility to increase and decrease the amount of light on the tube sensitive surface just moving back and forth the pulser. The photomultipliers are positioned on the top surface of each module in a light-tight aluminium box. In order to be able to move the pulsers from the outside of the box, we mounted the light sources on the end of a steel cable which can slide inside a guide. We can move the other end of the cable through a cursor (which is installed outside the aluminium box) that, acting on the steel cable, allows to vary the distance between pulser and photomultiplier and therefore the amplitude of the light that reaches on the photocathode. The mechanical system used to this aim is shown in Fig.3.

2.1 Electronics

During the calibration runs, the light source information is recorded through the same electronic chain used to detect signals of the physicals runs with the only difference consisting in the trigger. The electronic scheme is reported in Fig.4.

The photomultiplier signal is first split just after the base output: a prompt signal goes to a summing amplifier module while the second, through a 470 ns low attenuation delay cable RG8, goes through a resistive splitter that provides two equal signals to the CAEN C207 CAMAC discriminators and LeCroy LC1881M FASTBUS ADC respectively. The discriminator outputs provide the stop signals to LeCroy LC1875A FASTBUS TDC. The summing module was designed by CAEN and INFN-Ge in order to have a linear

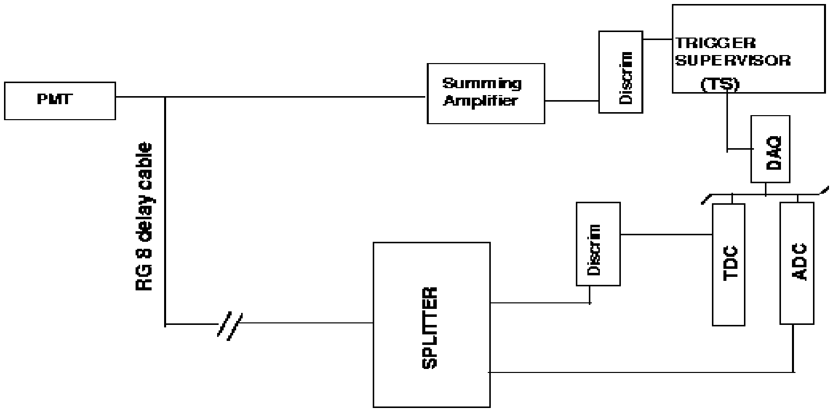


Figure 4: The electronic set-up.

response in the calorimeter for deposit energy up to 1 GeV, i.e. for energy of the incident electrons up to 3 GeV. It is used to form the trigger for the acquisition and it works in the following way : for each LAC module and for each part (inner and outer), the 40 PMT signals relatively to the short strips of the left side and the 40 PMT signals relatively to the short strips of the right side, are summed in groups of 10 (see Fig 5). In the same way the 24 PMT signals relatively to the long strips of the left side and the 24 PMT signals relatively to the long strips of the right side are summed in groups of 12. Each summing amplifier (having 24 inputs channels) provides six outputs: the linear sum of the 10 (12) signals of the left side module (ΣLx1), the linear sum of the 10 (12) signals of the right side module (ΣRx1), the linear sum of the 10 (12) signals of the left side module amplified by a factor 5 (ΣLx5), the linear sum of the 10 (12) signals of the right side module amplified by a factor 5 (ΣRx5). In addition to the linear sums, the module provides also the signal of the product [(left signal)x(right signal)] without amplification (Πx1) and with a factor 5 of amplification (Πx5). So the total number of the summing amplifiers used for each module is 12 (six for the inner part and six for the outer part). The trigger for the acquisition of the light pulsers signals is shown in Fig. 6 and it is formed using, for each LAC module, the total left sum signal and the total right sum signal amplified by a factor 5. These total left and right sums are obtained, summing the 12 partial left and right sums coming from each summing amplifiers, relatively to each module. Finally, the OR of a CAEN C207 CAMAC discriminator of these four (two from each module) signals provides the input for the TRIGGER SUPERVISOR of the CLAS experiment which generates the gate to the ADC.

3 Results

The results are based on 5 monitoring runs taken during a data acquisition period of 1 month. At each run 200000 light pulsers events were recorded and immediately followed by the acquisition of a pedestal run. To determine the precision with which the monitoring system measures the gains of the LAC phototubes two monitoring runs were done a few minutes apart and the light pulsers signals from the two runs were compared (let's call, throughout the paper, "reference run" the first one). The results are presented in Fig. 7, in which we see the distribution of the percentage difference between the peak positions of the light pulsers signals for the two consecutive monitoring runs for both modules of the LAC. The mean and sigma of this distribution are -0.1% and 0.5% respectively, indicating that the monitoring system measures the gains of the tubes with high precision. Using this system we have controlled the PMT gain stability in a short period (day) and during a long period (month). For that purpose we made 3 monitoring runs: one acquisition after 1 day and the other two after 16 days and 27 days to respect to the reference run. The results are shown in Fig. 8a, Fig.8b and Fig.8c in which the distributions of the percentage difference between the peak positions of the light pulsers signals for the reference run and those made subsequentely, for both modules of the LAC, are shown.

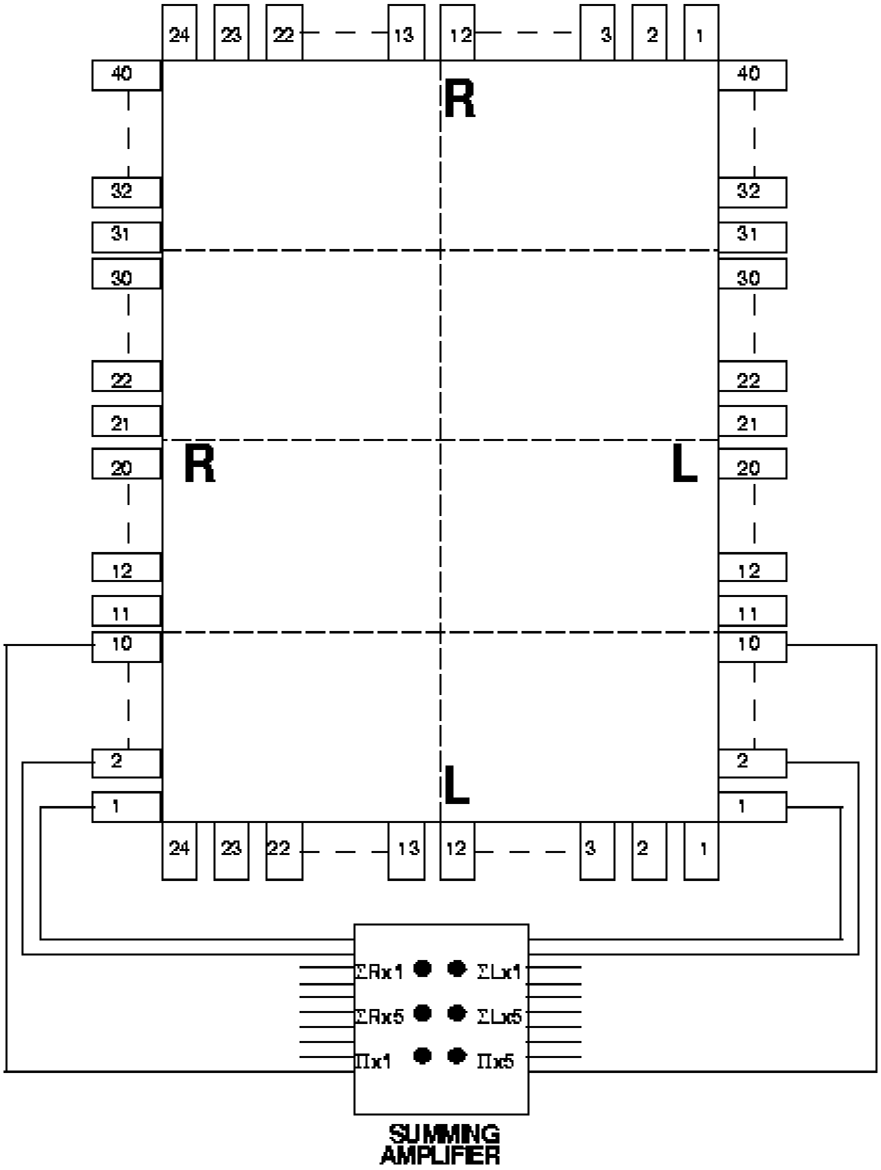


Figure 5: Conceptual design of the LAC PMT signals sums through the summing amplifier.

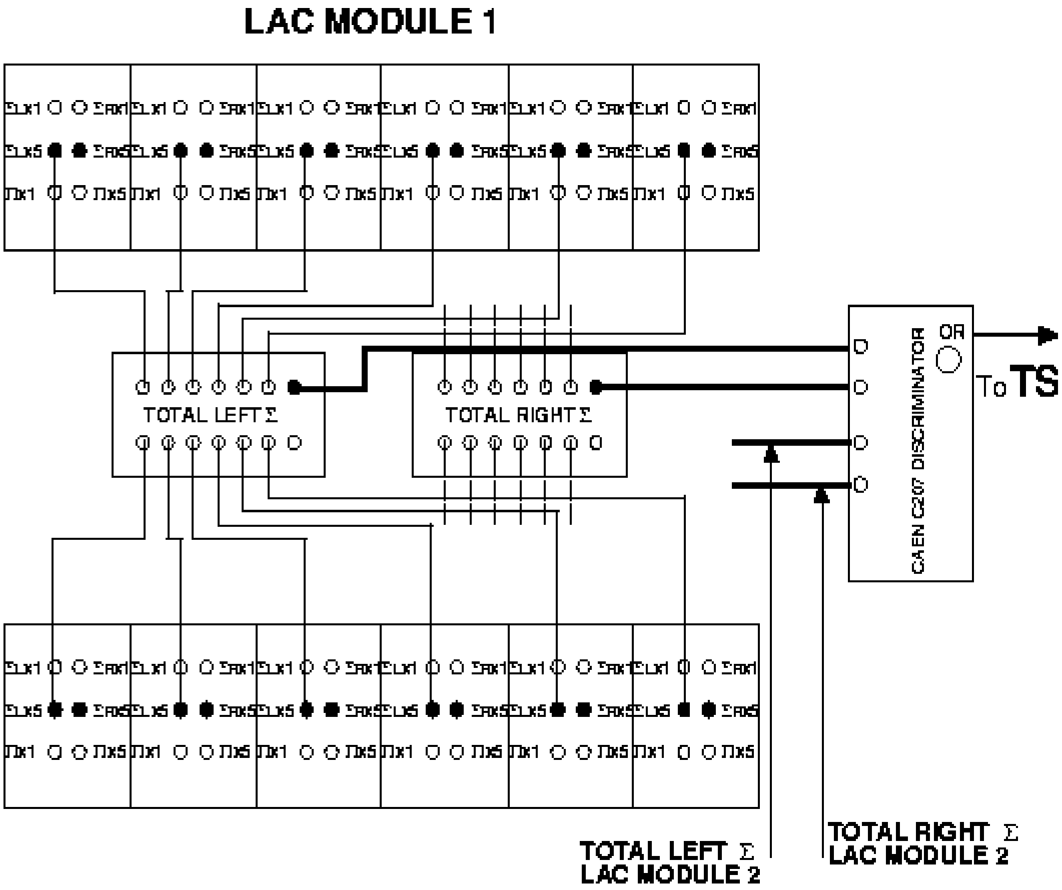


Figure 6: Conceptual design of the trigger used for the acquisition of the light pulsers signals.

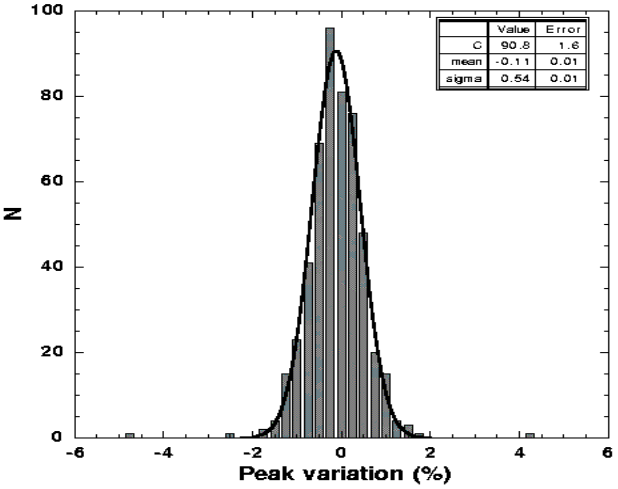
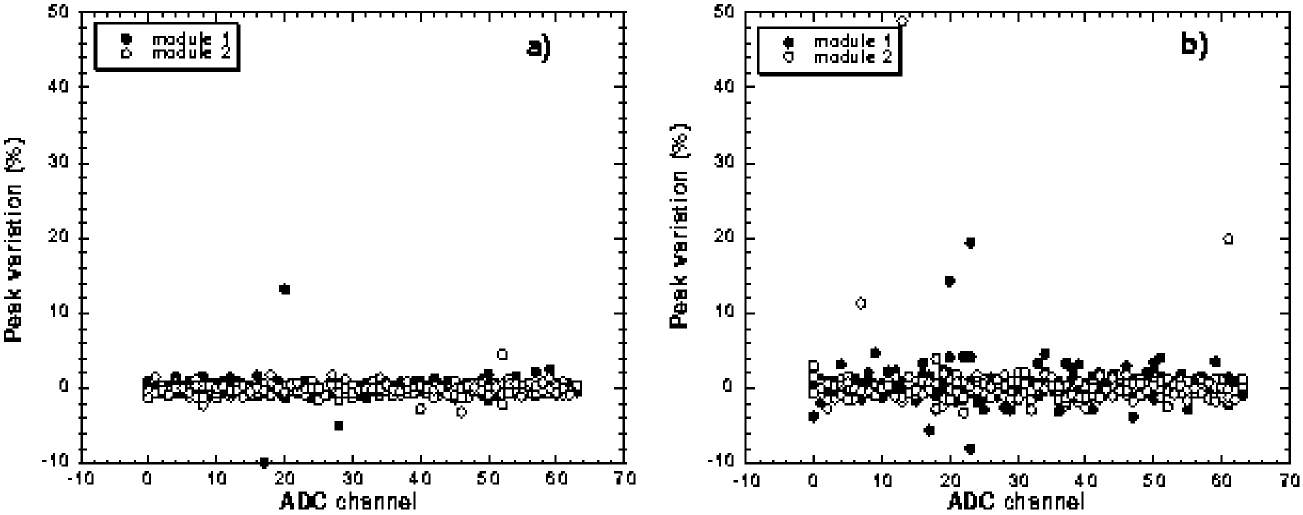


Figure 7: Distribution of the percentage difference between the peak position of the 512 light pulsers signals for the two consecutive monitoring runs used to measure the precision of the gain monitoring system. The curve represents the gaussian fit of the distribution.



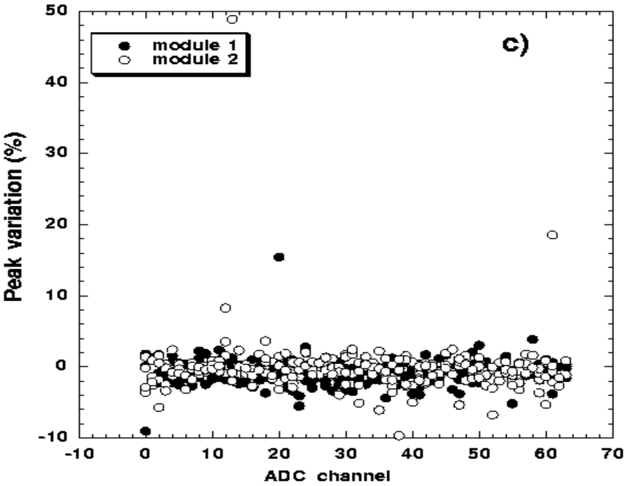


Figure 8: Distribution of the percentage difference between the peak position of the 512 light pulsers signals for the monitoring runs taken: a) after 1 day, b) after 16 days, c) after 27 days respect to the reference run.

The results are summarized in Table 4 where the mean values and sigmas of the gaussian curves to which we fitted the distributions are reported.

days	**mean value (%)** **MODULE 1**	**sigma (%)** **MODULE 1**	**mean value (%)** **MODULE 2**	**sigma (%)** **MODULE 2**
1	-0.32	0.52	-0.33	0.61
16	-0.53	1.00	-0.73	1.07
27	-1.35	1.36	-1.19	1.41

Table 4: Mean values and sigmas of the gaussian curves to which we fitted the distributions of the percentage difference between the peak positions of the light pulsers signals for the reference run and those made after 1day, 16 days and 27 days.

In Fig. 9, instead, the σ/peak ratio distribution for the 512 light pulsers signals of the two modules is shown. The difference in the mean value of this distribution (4.7%) compared to that shown in Fig.2 (3.1%) is due to the fact that to perform the test of the light pulsers in the Frascati Laboratory , as we mentioned above, we mounted the YAP: Ce+^{241}Am directly on the center of the PMT window while their position in the final experimental configuration is at a distance of 18.6 mm from the center of the photocathode. This means a reduction of the order of 20-25% in the number of photoelectrons (caused by the reduction of the quantum efficiency in the border of the photocathode) with the consequent worsening in the resolution.

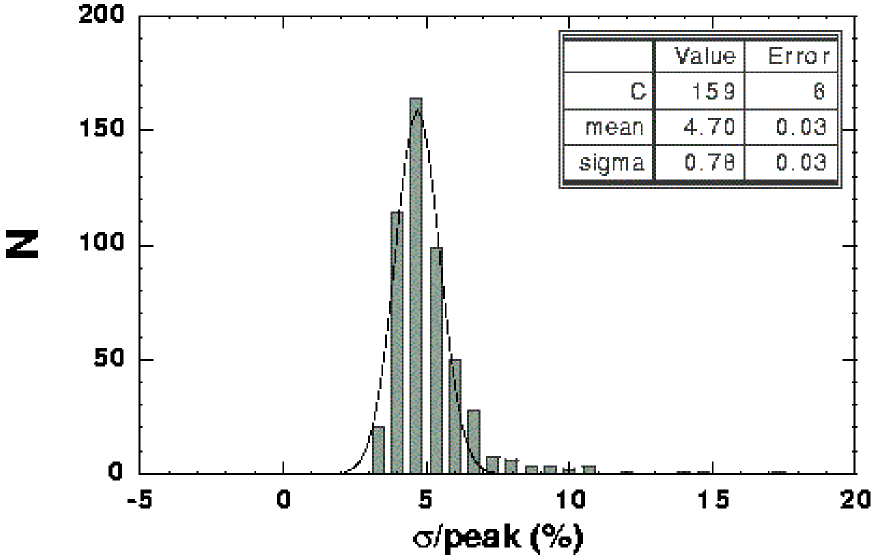


Figure 9: Distribution of the energy resolution for the 512 light pulsers installed in the 2 LAC modules. The curve represents the gaussian fit of the distribution.

Assuming the scintillation light of the crystal and the PMT quantum efficiency stable, the fluctuations in the peak position comes mainly from the following contributions:

- statistical fluctuation, $\sigma/\sqrt{N}$. In our case σ is of the order of 5%, as comes from results shown in Fig 9, and N is the total number of events under the peak. As the total number acquired in one run is 200000 and the total number of PMT is 512, N is of the order of 400 for each channel. So we can estimate the statistical fluctuation, $\sigma/\sqrt{N}$, of the order of 0.3%.
- Stability of the PMT. As reported in Ref [11], for the phototubes used, a fluctuation of 0.5% in the mean value is found during several (4-5) days of observation.
- Pedestal fluctuations. In 8 month of CLAS operations we measured a pedestal fluctuation of the order of 0.2% - 0.3%
- HV fluctuation. The CAEN SY527 and CAEN A734N boards, provide a power supply stability of 1/10000. As in our case, in first approximation, we can assume Δch/ch $\sim$ 10*ΔV/V, this contribution is around 0.1%

From Table 4 we see that after 1 day, the gaussian curve to which we fitted the distribution of the percentage difference of the light pulsers peak positions, for both modules, has a mean value of -0.3% and a sigma of the order of 0.5% which is the value we expect from the above considerations. After 16 days, the mean value and sigma of the gaussian curve fitting the same distribution increased more or less by a factor 2 (mean value -0.5 and -0.7 for module 1 and module 2 respectively and sigma of the order of 1%). Finally, repeating the monitoring run after 27 days, we found a stability of the gain photomultipliers of 1-2%.

As we said above concerning the criteria we had in mind when we designed the monitoring system, we required that the light delivered to the PMT by the system should be in the range of that delivered during physics runs so that the gains of the counters are measured in the normal range of operations of the counters and electronics. In Fig. 10a and 10b are reported the distributions of the peak position, in terms of ADC channels, of the light pulsers for the two LAC modules. As we can see the mean values of the gaussian curves fitting the distributions are 2700 and 3700 for module 1 and module 2 respectively with a corrisponding sigma of 800 channels and 1100 channels. This means that the light that hits the photocathode covers almost all the energy range of the physiacal events. In fact, we calibrated the 8192 channels of the ADC considering that the maximum energy deposited in one stack is 350 MeV. So that, an ADC range between channel 1000 and 6000 (2σ) means an energy range between 40 MeV and 250 MeV.

It is important to underline, moreover, that the light pulsers signals are totally uncorrelated and consequently they are easily eliminated from triggering on the physical events, which, on the contrary, give at the same time, a signal pulse at both end of the scintillators. Last but not least we want to outline the fact that to perform a calibration run it takes no more then 5 minutes of acquisition time and a semi-automatic program calculates in a short time as well the mean values and sigmas of the pulse height distributions of the light pulsers for all the 512 PMT. These values are, then, used in the

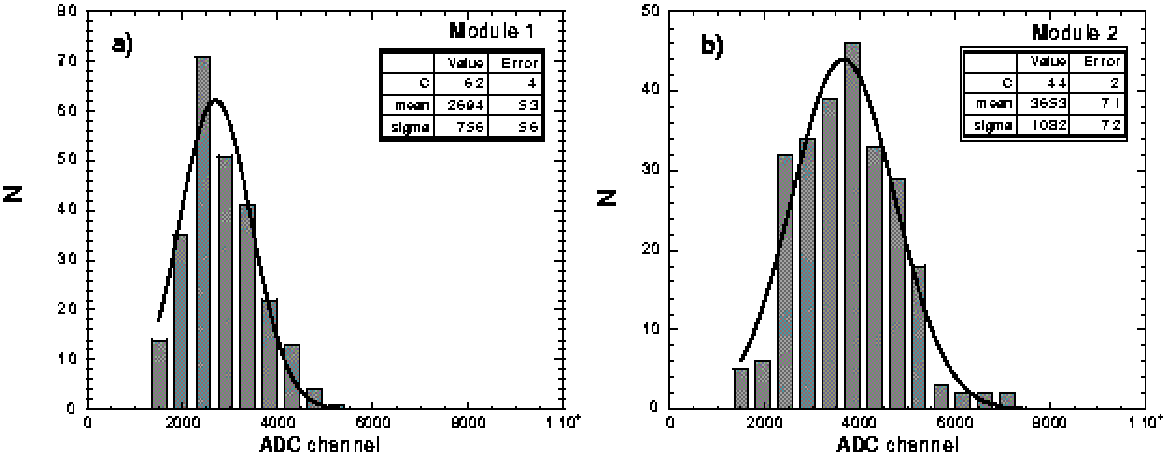


Figure 10: Distributions of the light pulsers peak position, in terms of ADC channels, for LAC module 1 a) and LAC module 2 b).

on-line and off-line analysis to correct the calibration constants that directly take part in the calculation of the deposited energy in the calorimeter.

3.1 Conclusions

We have described the monitoring system installed for the control of the gain stability of the 512 PMT of the two modules of the Large Angle Electromagnetic Calorimeter provided by the AIACE collaboration to the CLAS experiment. The system is based on YAP: Ce+^{241}Am light pulsers. The benefits of a system based on a scintillator connected to a radiactive source are shown. Mainly it is easy to install, reliable and it allows a photomultipliers gain stability control with a precision $\leq$0.5%. Moreover, using this system we have controlled the PMT gain stability in a short period (day) and during a long period (after 16 and 27 days). After 1 day, the light pulsers peak variation distribution for both modules has a mean value of $\sim$ -0.3% and a sigma of the order of 0.5%. We found more or less an increase of a factor 2 in the mean value and sigma of the distribution after 16 days (mean value $\sim$ -0.5 and -0.7 and sigma of the order of 1%) while after 27 days we found a stability of the gain photomultipliers of 1-2 %.

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