Report on Testing of PbGlass Supermodules at BNL, 1997

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1 Introduction

Since the operational stage of WA98 experiment at CERN is over now, 384 out of 420 supermodules of its LEDA spectrometer were transported to BNL to be used as a part of the electromagnetic calorimeter EMCal in PHENIX experiment. They were modified to comply with the PHENIX requirements. It is quite natural that the electronics of supermodules were thoroughly tested after that.

2 Supermodule structure

A supermodule consists of 24 (6x4) LeadGlass light-insulated modules, 40x40x400 mm^3 each, read out with FEU-84 photomultipliers (PMT). Each PMT is attached with optical grease to the back of the corresponding module. Behind the PMT its HV base is attached. Modules within a supermodule are wrapped with light-reflecting mylar film and epoxied together to form a single mechanical unit. PMTs and their electronics are shielded with thin steel plates glued to the modules.

All modules within a supermodule share a monitoring system which comprises 3 LED and a PIN photodiode with a connected preamplifier. The LEDs, the PIN diode and its preamp are in a plastic dome, which is screwed to the supermodule's front. Each dome has a light-reflecting inner surface. It helps to distribute LED light among the modules.

A more detailed description of the calorimeter structure can be found in [1].

3 Supermodule systems

Each supermodule has several separate systems:

- Readout system. A PbGlass module is read out with a FEU-84 PMT. Signals from six supermodules, or 144 modules, are sent to a single FEE motherboard [2]. These six supermodules may be referred to as a super-duper module.

- High voltage supply. High voltage for each PMT is generated with a Cockroft-Walton type multiplier base. Each of these bases is individually controlled with a custom VME based high voltage control system (HIVOC) [3]. One HIVOC VME control module can handle up to 2048 channels.

- Reference system. As PMT amplification factors slightly fluctuate with time, it's necessary to know gain correction factors that allow to compensate for this effect. The monitoring system [1] uses as a reference point amount of light emitted by 3 LEDs, which are viewed independently by the PMTs and the PIN diode. The response of the PIN diode is much more stable with time than the response of the PMT. LED signals observed in each module were calibrated in GeV equivalent using 10 GeV electron beam at CERN. The intention is to preserve the CERN calibration for use in PHENIX.

4 Supermodule mechanical modification at BNL

The EMCal PbGlass spectrometer is to be installed in the PHENIX East Arm. 192 supermodules (16 wide by 12 high) constitute a EMCal PbGlass sector. Each sector is divided into columns (2 supermodules wide by 12 high). All supermodules in one sector are held together with a common steel frame. As the design of the frame differs to one used at CERN, it was necessary to perform some mechanical modifications of the supermodules.

The process of PbGlass supermodule modification at BNL is presented schematically in fig.1. Rear steel plates were cut so that FEE motherboards can be placed inside columns as shown in fig.2. Fig.3 shows the final structure of the PbGlass column.

5 1997 test at BNL

5.1 Test setup

Block diagrams in fig.4 and fig.5 show the test setup and trigger. The pulse from the generator output launched the measurement cycle. The pulse, having been shaped by level and length with FAN IN/OUT and GATE GEN 1, initialized VME controller and CAMAC controller programs. The command from the CAMAC controller shaped the pulse of 600 μs length via OUT REG. This pulse blocked GATE GEN 1, and thus protected the system from repeated launches until the end of the measurement cycle. FAST AVALANCHE PULSER was initiated via GATE GEN 2 simultaneously with the VME controller. The PMT signal readout was performed with two LeCroy 2249W ADCs, PIN preamp readout with an ORTEC AD811 ADC. Codes generated by the ADCs[1] were transferred from the CAMAC controller to the VME controller via a CBD 8210 interface and then to an SGI machine where they were

[1]The signal from the pulser output was attenuated by a factor of 3.25 to avoid overflow in the reference ADC. Then the code from the PIN readout ADC, after pedestal subtraction, was multiplied by the same factor.

handled and stored. The input signal for the FAST AVALANCHE PULSER, having been shaped with DELAY DV8000 and OCT. DISCR., was used also as the gate for the 2249W ADCs. The same signal was used as the gate for the AD811 ADC after it was shaped with a programmable dual gate generator LeCroy 2323A.

5.2 Test software

The test software was based primarily on PDAC DAQ system and PSTUFF [4] online monitoring package, which were developed using the existing PHENIX C++ class libraries. The PSTUFF package allows to perform offline data analysis as well. Event files were stored on a hard disk and then handled using the routines from PSTUFF and various programs developed on top of it.

5.3 Test procedure

The test procedure was carried out in the 902 annex assembly area where all the supermodules were stacked. The supermodules were connected in turn to the same setup to be tested.

First, the HV bases were tested in several ways (block diagram in fig.6 presents the process).

- Bring all bases up to 1500 volts, then check readback from the HIVOC; this just tests if a base is bad.
- Starting at 1500V, raise all the bases up to 1900V in 50V steps, and check the readback to see how high each base will go.
- Reduce high voltage to 0, take a pedestal run using the CAMAC 2249W ADCs and Martin Purschke's PDAC data acquisition system. Analyze the peaks in the pedestal run, check to see if the pedestal peak is too wide or at too low a channel.
- Raise the HV to 1500V and take data with the avalanche yellow LED. Analyze the peaks; then iterate all the high voltages until their peaks are in ADC channel 1000. Check to see if peaks are too wide. These gain-balanced voltages are then recorded in an output file.

This procedure allowed to find bad HV bases and damaged PMTs.

Second, the PIN response and PMT response to LED light were tested using the CERN HV database for the PMTs. Signal from the avalanche pulser was fed to an avalanche yellow LED and data from PMTs and a PIN diode were taken. Thus it's possible to determine whether the CERN relative calibration can be applied in PHENIX by means of comparison to the similar data taken at CERN.[2]

And third, long-term stability of the PMTs was tested. To do this only one supermodule was chosen, namely 402. Response to the avalanche yellow LED was measured repeatedly in long time intervals (not less than a few hours) and the HV supply was left turned on between measurements. The PIN diode response was measured as well to provide reference data.

5.4 Test results and discussion

The first part of the test resulted in replacing of 51 damaged HV bases and 27 bad PMTs for the 1st sector, 41 bases and 40 PMTs for the 2nd sector. An example of the report file can be found in fig.7.

The PMT and PIN peaks derived from the data obtained during the second part of the test were compared to the similar data taken during operation at CERN in 1996. A typical report produced after data handling presented in fig.8. Pedestals were subtracted.

Fig.9 shows WA98/BNL PIN peak ratio distribution. The Gaussian function was fitted to this distribution within $\pm 3\sigma$ limits. The mean value of the Gaussian fit is $(8.98 \pm 0.02) \cdot 10^{-1}$. Let's see whether it is consistent with what we had at CERN.

The block diagram in fig.10 shows the design of the reference system used at CERN. The length of the cable between the avalanche pulser output and and the LED $l = 7.3$ m. The 12 bit ADC LeCroy 2281 has maximum input voltage of 4 V and pedestal $ped_C \approx 60$ counts. Hence the amplitude A_C of the pulse from the shaper output will be converted by the ADC to the digital code N_C according to the following formula:

$$N_C = \frac{(4096 - ped_C) \cdot A_C}{4}.$$

The measurement tract at BNL was different in that there was only one channel for all supermodules, the cable length was $l = 1.8$ m, and an ADC ORTEC AD811 was used instead of LeCroy 2281. The parameters of AD811 are the following: maximum input voltage 2 V, resolution 11 bits, pedestal $ped_B \approx 50$ counts.

It's important to mention that the amount of LED light depends on the length l of the cable from the avalanche pulser to the LED. These data are compiled in the table 1. It contains also results obtained for two PMT channels.

[2] To calculate the energy deposited in ith module the following formula was used for the data analysis at CERN:

$$E_i(t) = Gain_i(t_0) \cdot ADC_i(t) \cdot \frac{ADC_{PIN}^{AY}(t)/ADC_i^{AY}(t)}{ADC_{PIN}^{AY}(t_0)/ADC_i^{AY}(t_0)},$$

where:

$Gain_i(t_0)$ – gain factor;

$ADC_i(t)$ – PMT amplitude in the current beam event;

$ADC_{PIN}^{AY}(t)$ – PIN response to the AVALANCHE YELLOW LED light in the current run;

$ADC_i^{AY}(t)$ – PMT response to the AVALANCHE YELLOW LED light in the current run;

$ADC_{PIN}^{AY}(t_0)$ and $ADC_i^{AY}(t_0)$ – PIN and PMT responses to the AVALANCHE YELLOW LED light in the reference run respectively.

If all the PIN diode readout ADCs are replaced at some time t so that for signals of equal amplitudes $\left(ADC_{PIN}^{AY}\right)^{old} / \left(ADC_{PIN}^{AY}\right)^{new}$ is the same for all the supermodules, the relative calibration will remain.

l, m	$\frac{PIN(l)}{PIN(1.8)}$	$\frac{PMT_1(l)}{PMT_1(1.8)}$	$\frac{PMT_{13}(l)}{PMT_{13}(1.8)}$
1.8	1	1	1
7.3	0.895	0.893	0.897
16.6	0.735	0.734	0.728

Table 1: PIN and PMT signal dependence on the cable length

Digital code which is obtained with AD811:

$$N_B = \frac{(2048 - ped_B) \cdot A_B}{2},$$

where A_B is the amplitude of the shaper pulse.

Thus the ratio of the digital codes from the PIN diode

$$\frac{N_C}{N_B} = \frac{(4096 - ped_C) \cdot A_C \cdot 2}{(2048 - ped_B) \cdot A_B \cdot 4}.$$

According to the data from the above table

$$\frac{A_C}{A_B} = 0.895,$$

which gives us

$$\frac{N_C}{N_B} = 0.9.$$

This result corresponds well with the Gaussian fit mean mentioned above (fig.9).

The sigma of the Gaussian fit is about 4%. Where do these 4% come from?

Let's mark the BNL PIN peak position B, the WA98 PIN peak position W, the pulser signal amplitude α, conversion ratios of the LED, PIN diode, preamp, shaper and ADC β, γ, δ,ϵ and ζ respectively. For WA98 results we have (index i relates to ith supermodule):

$$W_i = \alpha_i \beta_i \gamma_i \delta_i \epsilon_i \zeta_i.$$

For the BNL test:

$$B_i = \alpha \beta_i \gamma_i \delta_i \epsilon \zeta.$$

The fact that α, ϵ and ζ don't have indices means that the same pulser, shaper and ADC were used for all measurements.

For the WA98/BNL ratio we have:

$$\frac{W_i}{B_i} = \frac{\alpha_i}{\alpha} \cdot \frac{\epsilon_i \zeta_i}{\epsilon \zeta}.$$

Let's designate the relative variances of $\frac{W_i}{B_i}$, $\frac{\alpha_i}{\alpha}$ and $\frac{\epsilon_i \zeta_i}{\epsilon \zeta}$ $\sigma_{W/B}$, σ_α and $\sigma_{\epsilon\zeta}$ respectively. After obvious transformations:

$$(\sigma_{W/B})^2 = (\sigma_\alpha)^2 + (\sigma_{\epsilon\zeta})^2.$$

2.6% RMS (difference of up to 10%) was observed in the signal amplitude between the 16 channels of the one particular pulser module, implying that most of the 4% variance in the PIN peak position ratios is due to the pulser signal variation between the modules used in WA98, and therefore the PIN measurement itself is very stable and reliable.

At CERN, the PMT output signal was measured with the SDM [2]. The design of the PMT readout is shown in the block diagram in fig.11.

The ADCs here have maximum input voltage of 4.5 V, and their range is $N_{max} = 975$ counts, pedestal subtracted. In oder to have consistent digital codes from the low gain and high gain ADCs, the low gain ADC's code was multiplied by a factor of 7.8.

The input charge Q_C will be converted by the active integrator into the voltage

$$V_{int} = \frac{R_{in} \cdot Q_C}{R \cdot C},$$

and this voltage will be converted by the low gain ADC into the code

$$N_C = 7.8 \cdot \frac{R_{in} \cdot Q_C \cdot N_{max}}{R \cdot C \cdot 4.5} = 8.44 \cdot 10^{12} Q_C.$$

At BNL, a LeCroy QDC 2249W was used to convert the PMT signal into code. Its parameters: maximum input charge $Q_{max} = 500$ pC, resolution 11 bits, pedestal $ped_B \approx 50$ counts.

Taking into account stability of the reference system, it's possible to evaluate the input QDC charge as $Q_B = Q_C/0.89$, and hence the output digital code is

$$N_B = \frac{(2049 - ped_B)}{Q_{max}} \cdot Q_B = 4.49 \cdot 10^{12} Q_C.$$

Thus the CERN code to BNL code ratio is

$$\frac{N_C}{N_B} = \frac{8.44 \cdot 10^{12} Q_C}{4.49 \cdot 10^{12} Q_C} = 1.88.$$

The distribution of this value measured in the test is presented in fig.12. The Gaussian function was fitted to it within $\pm 3\sigma$ limits. The mean is 1.86 ± 0.19, which corresponds well with the calculated value.

The sigma of the function is about 9%. Let's see what factors may contribute to this value.

The WA98/BNL PMT peak ratio may be presented like this:

$$\frac{W_{ij}}{B_{ij}} = \frac{\alpha_i}{\alpha} \cdot \frac{\beta_{ij}^{WA98}}{\beta_{ij}^{BNL}} \cdot \frac{\gamma_{ij}}{\gamma_j},$$

where α, β and γ designate the pulser signal amplitude, the light conversion quotient (including PbGlass itself, PMT optical coupling, PMT conversion efficiency etc.) and the ADC conversion ratio respectively. Index i relates to ith supermodule, index j to jth module within ith supermodule. α without an index means than there was only one pulser module in the BNL test, and γ_j means that only 24 ADC channels were used for all the supermodules tested.

The value of the sigma seems to be relatively large. Some of the possible reasons for this are:

1. It is due to the short warm-up time used during the BNL measurements;
2. The ADC tuning was different for each module;
3. It is due to fluctuation of the HV settings in the specified limits[3].

This 9% variance is of no great concern though, as there are strong indications that the monitoring system itself is stable and reliable (see above).

Fig.13 shows PMT peak positions divided by the corresponding PIN peak positions plotted vs time elapsed since the first measurement. After the warm-up period, which is about 50 hours, relative RMS of the peak position distribution for each channel does not exceed 4%. Peak position distribution for some of the PMTs and the PIN diode are presented in fig.14.

Calculations were performed to determine whether the reason 1 contributes significantly to the variance of the PMT peak ratio distribution. For the supermodule that underwent the long-term stability test, the WA98/BNL PMT peak ratio distribution sigma, which was obtained with the Gaussian fit, was evaluated for each run. The results can be seen in fig.15. No lessening of the sigma was found for this particular supermodule.

6 Acknowledgements

The authors would like to thank M. Purschke for developing PSTUFF package and PDAC DAQ system, which made it possible to carry out the tests.

Thanks to S. White for his support of this work, and without whose help and constant interest it wouldn't have been done.

Thanks to Yu. Drakin and V. Lebedev for their qualified assistance in supermodule modification.

References

[1] T. Peitzmann et al., A New Monitoring System for the Photon Spectrometer LEDA in the WA98 Experiment, Nucl. Instr. and Meth. A376 (1996) 368-374.

[3] The PMT base HV was considered to be set if the difference between its actual value and the specified one did not exceed 100 V.

[2] A. L. Wintenberg et al., Monolithic Circuits for Lead-Glass Calorimetry, Electronics for Future Colliders Conference, Montvale, New Jersey, May 11-13, 1997.

[3] S. Neumaier et al., A New VME-Based High Voltage Power Supply for Large Spectrometer Systems, Nucl. Instr. and Meth. A360 (1995) 593-597.

[4] M. Purschke, private communication.

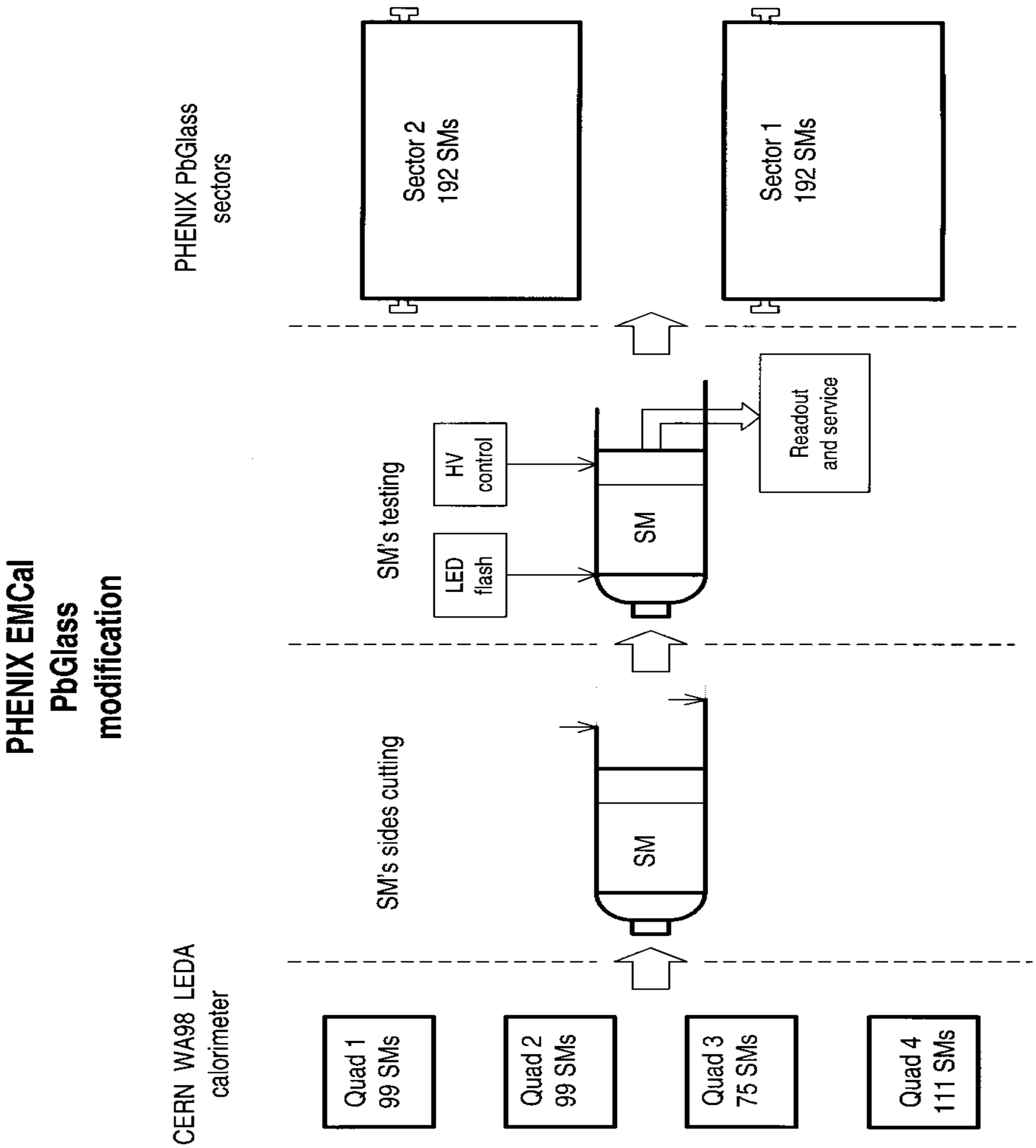

Figure 1: PbGlass supermodule modification at BNL.

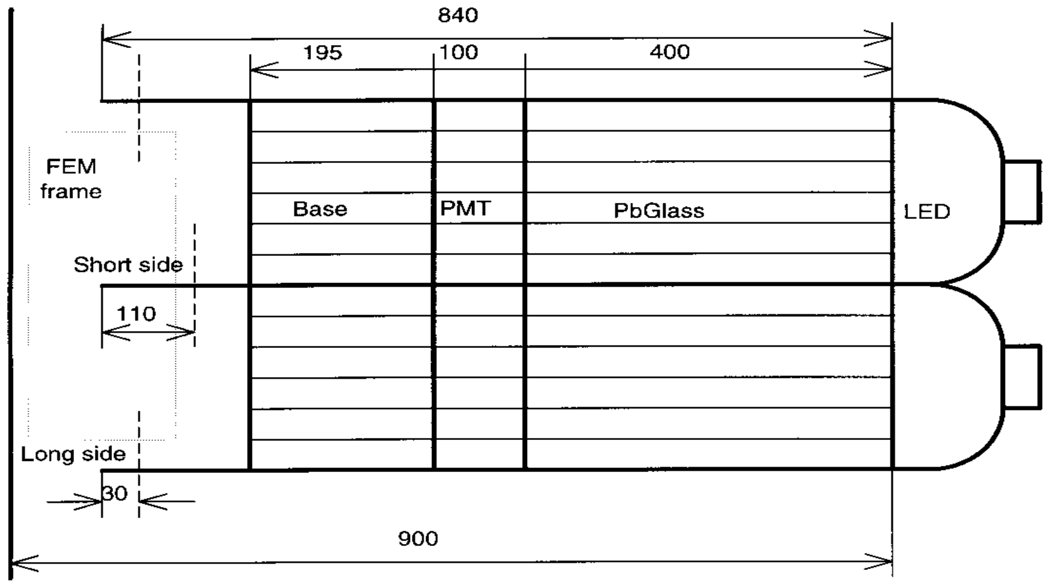

Figure 2: PbGlass supermodule cutting plan.

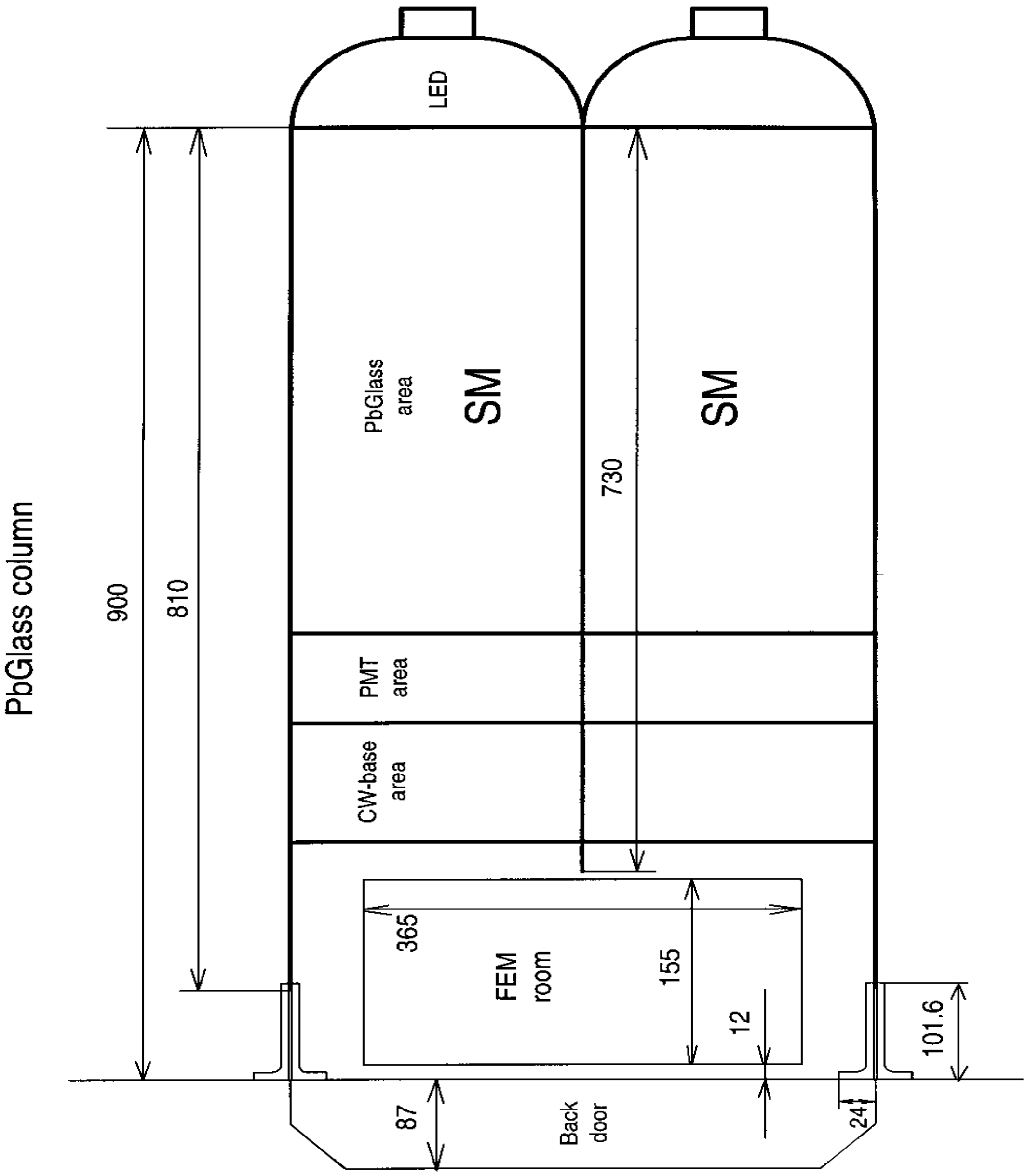

Figure 3: Structure of the PbGlass column.

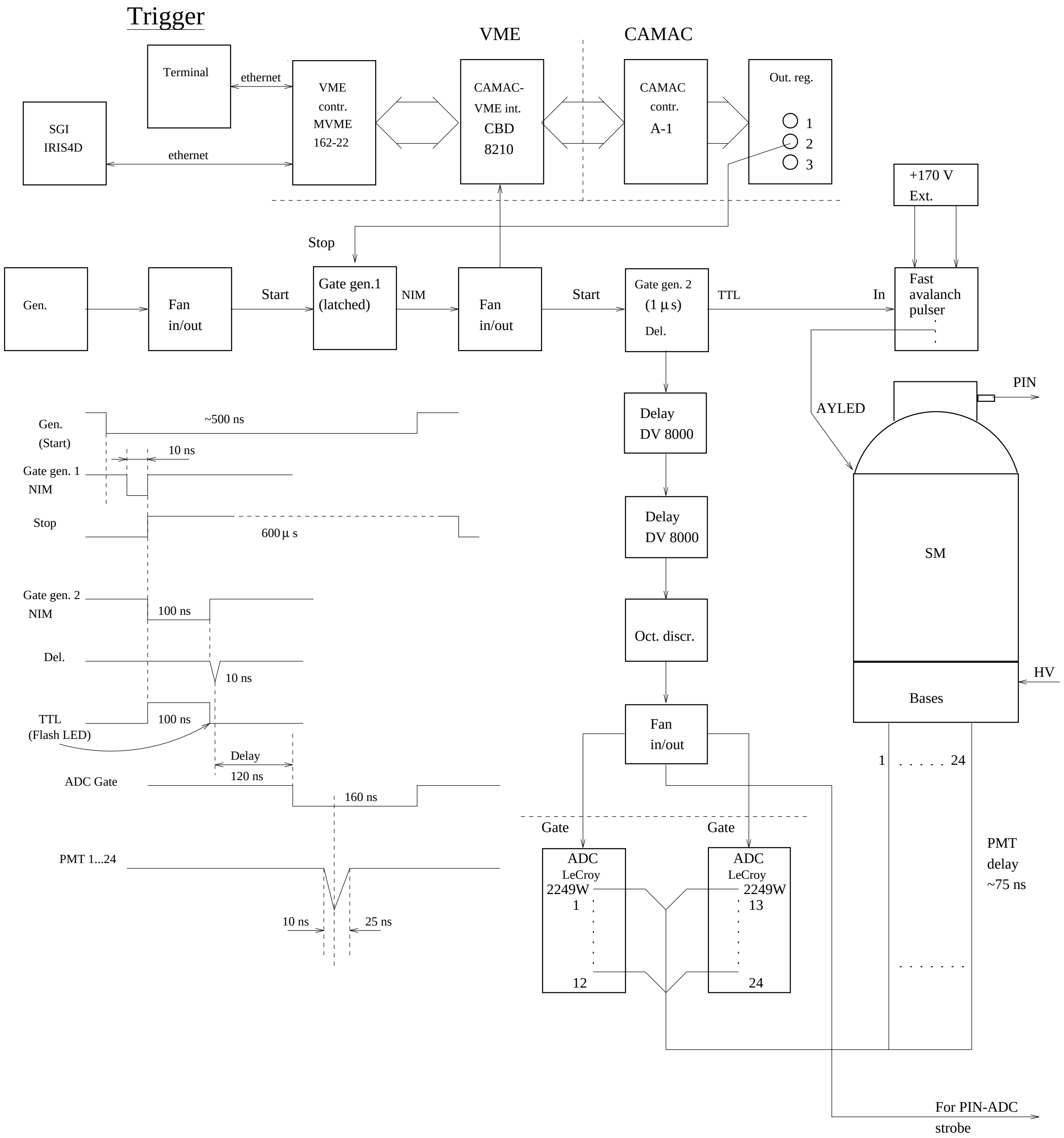

Figure 4: Test setup and trigger.

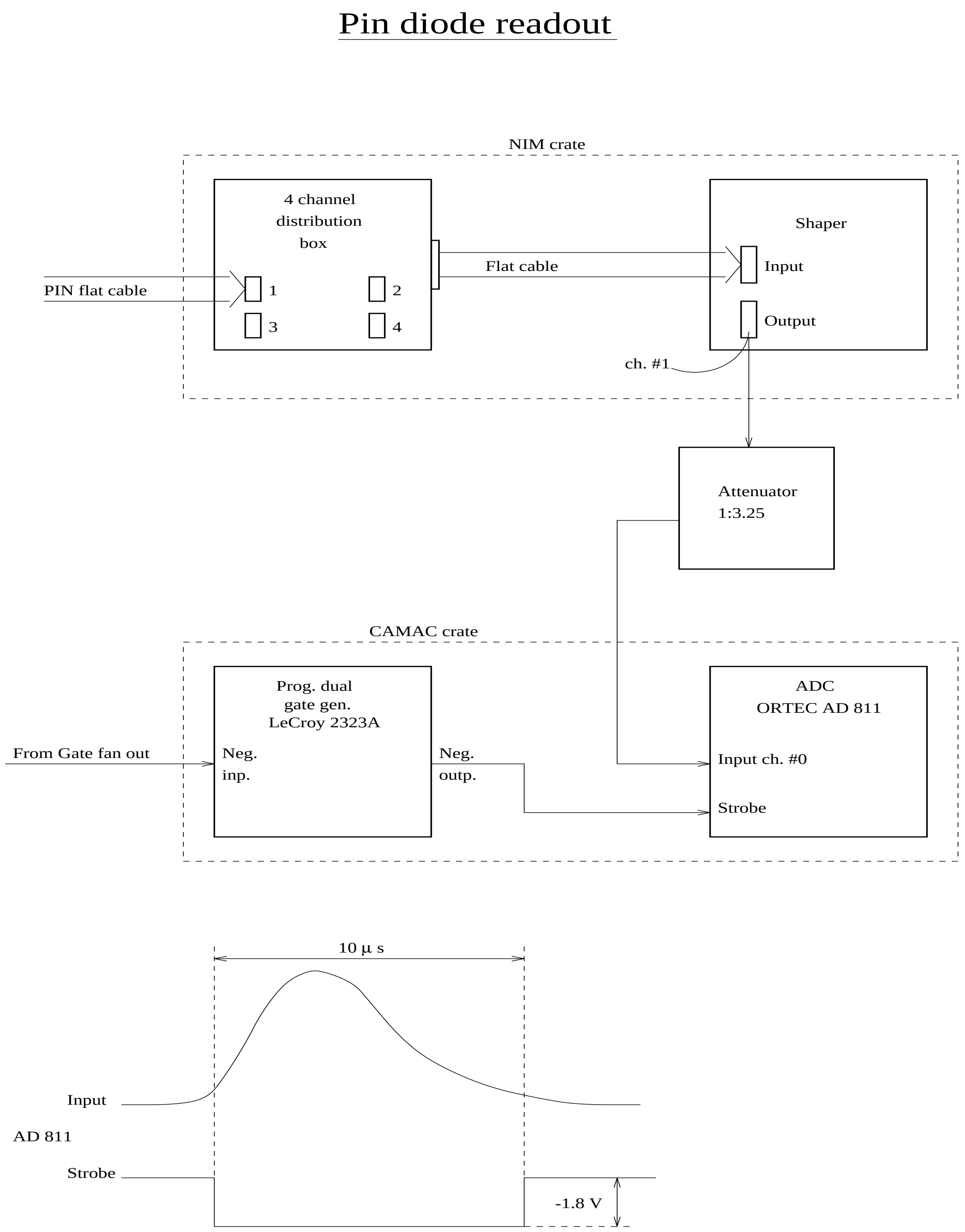

Figure 5: PIN diode readout system.

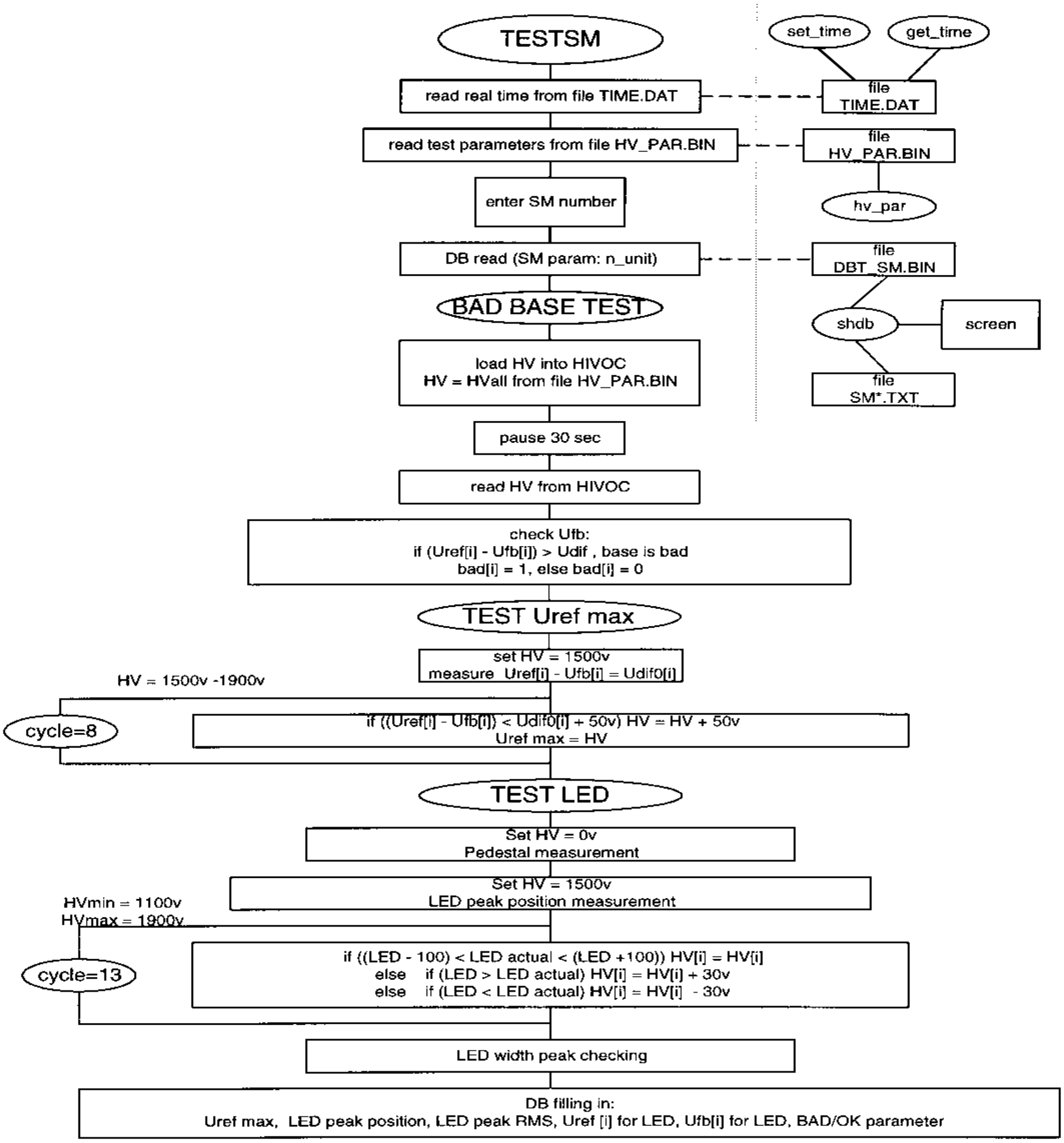

Figure 6: High voltage supply test.

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  Test stand report on PbGlass supermodule
  Time is Thu Oct 30 16:10:07 1997


  SM production number: 402 (subunit: 4)
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  Values of test stand parameters:
  Starting (nominal) high voltage: 1600V
  Max high voltage 1900V
  Number of events during HV adjustments: 200
  Number of events during peak/pedestal/WA98 analysis:500
  Tolerance for peak RMS/mean: 3.000000 percent
  Set-Readback tolerance for bad base check: 100V
  Set-Readback tolerance for max voltage check: 150V
  Target ADC channel for gain-balanced peak: 800(+/-160)
  Half-window tolerance for peak location: +/- 160 channels
```

Mod #	Max Set	Max Read	LEDpeak HV	LEDpeak position	LEDpeak RMS/mean	Bad base	Ped width	Peak width
1	1900	1786	1536	746	1.09	1	1	1
2	1900	1795	1472	703	0.96	1	1	1
3	1900	1780	1600	910	1.13	1	1	1
4	1900	1788	1472	659	0.99	1	1	1
5	1900	1801	1472	691	1.16	1	1	1
6	1900	1792	1472	856	1.07	1	1	1
7	1900	1791	1728	660	1.65	1	1	1
8	1900	1786	1600	654	1.29	1	1	1
9	1900	1779	1344	752	1.17	1	1	1
10	1900	1784	1536	837	1.05	1	1	1
11	1900	1785	1600	686	1.27	1	1	1
12	1900	1790	1664	819	1.38	1	1	1
13	1900	1805	1728	908	1.34	1	1	1
14	1900	1783	1600	772	1.45	1	1	1
15	1900	1782	1408	750	0.94	1	1	1
16	1900	1784	1664	814	1.22	1	1	1
17	1900	1791	1472	676	1.12	1	1	1
18	1900	1792	1728	646	1.63	1	1	1
19	1900	1796	1856	957	5.19	1	1	0
20	1900	1774	1728	846	1.24	1	1	1
21	1900	1816	1536	639	1.02	1	1	1
22	1900	1795	1472	653	0.82	1	1	1
23	1900	1788	1472	738	0.95	1	1	1
24	1900	1775	1536	794	1.14	1	1	1

```
  Base Mod# to be changed : ___________________________

  PMT  Mod# to be changed : ___________________________

     Operator :  vin
```

Figure 7: Typical report produced after the HV test.

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  WA98/BNL97 compare report on PbGlass SM

 SM production number: 402     WA98 number: 393
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        PINpeak PINpeak-ped    PIN ratio
         WA98      BNL97      WA98/BNL97

        2787.978 | 3164.626 |    0.881
-------------------------------------------------------


   Mod  LEDpeak  LEDpeak-ped    LED ratio
    #    WA98      BNL97      WA98/BNL97

    1 | 2314.399 | 1140.910 |    2.029 |
    2 | 1338.016 |  806.790 |    1.658 |
    3 | 1690.735 |  911.300 |    1.855 |
    4 | 2022.398 | 1116.330 |    1.812 |
    5 | 1301.251 |  700.240 |    1.858 |
    6 | 1258.693 |  678.590 |    1.855 |
    7 |  593.197 |  348.610 |    1.702 |
    8 | 1411.879 |  823.310 |    1.715 |
    9 | 1173.020 |  600.170 |    1.954 |
   10 | 1363.194 |  826.550 |    1.649 |
   11 | 2193.967 | 1220.210 |    1.798 |
   12 | 3162.774 | 1749.620 |    1.808 |
   13 | 1666.559 | 1160.160 |    1.436 |
   14 | 2049.247 |  972.720 |    2.107 |
   15 | 2293.566 | 1113.420 |    2.060 |
   16 | 2361.748 | 1224.470 |    1.929 |
   17 | 1066.736 |  601.060 |    1.775 |
   18 | 2058.494 | 1094.110 |    1.881 |
   19 | 1069.855 |  597.680 |    1.790 |
   20 | 1269.165 |  655.910 |    1.935 |
   21 | 2142.273 | 1236.550 |    1.732 |
   22 | 1842.696 | 1000.640 |    1.842 |
   23 |  972.707 |  577.670 |    1.684 |
   24 | 1358.849 |  736.900 |    1.844 |
```

Figure 8: Typical report produced after the LED response test.

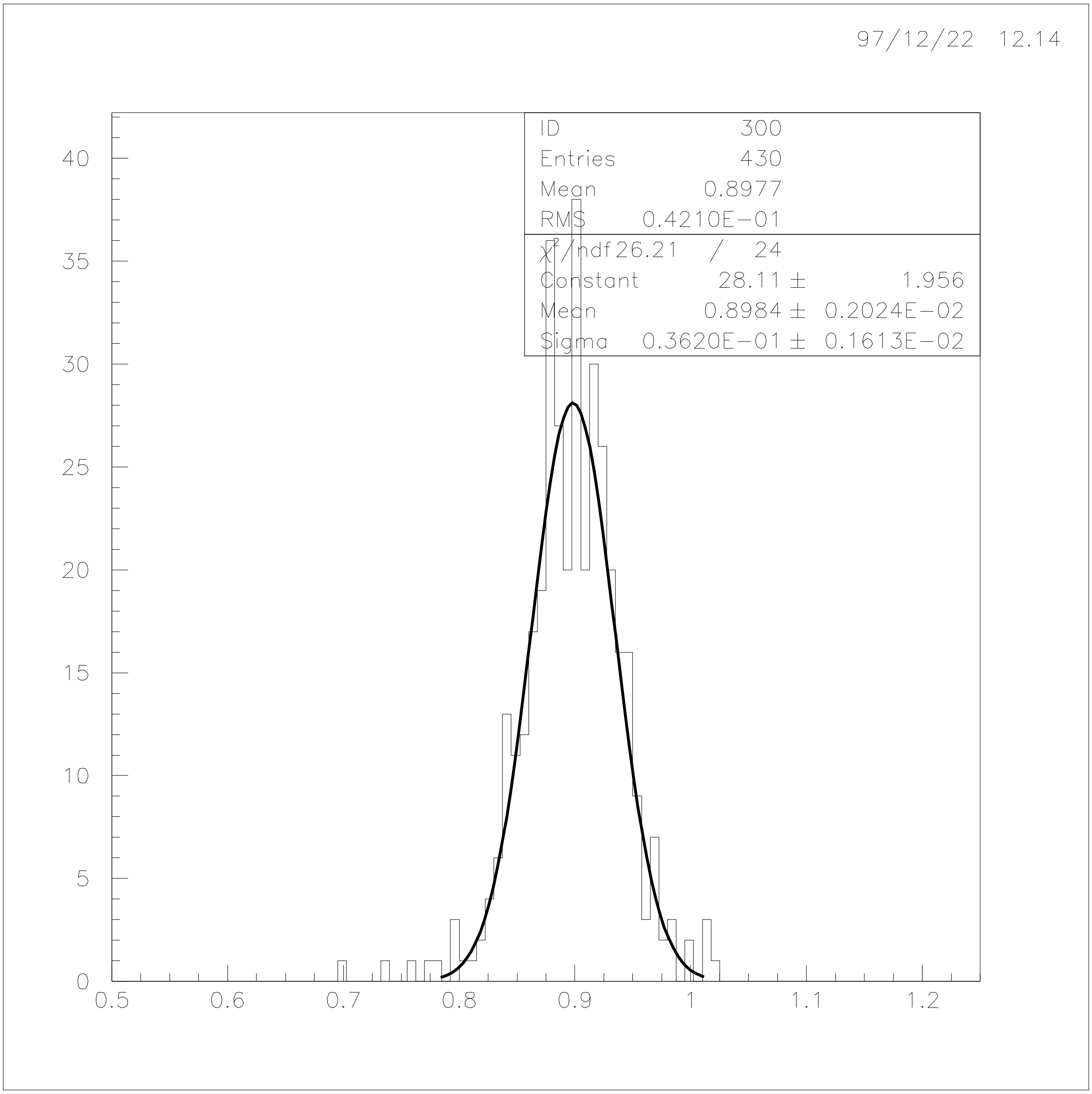

Figure 9: WA98/BNL PIN peak distribution.

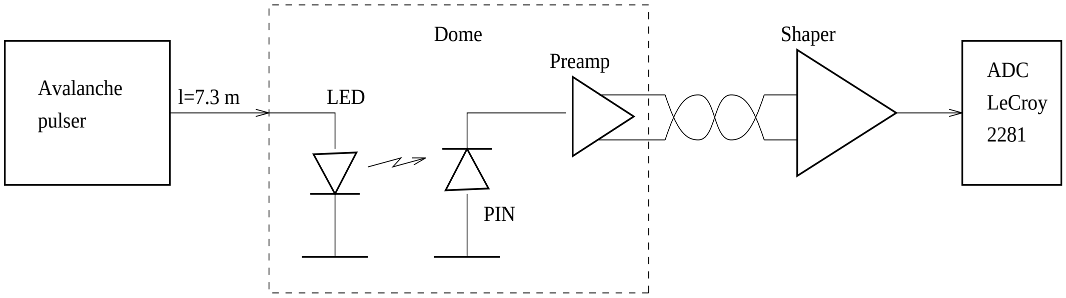

Figure 10: Reference system at CERN.

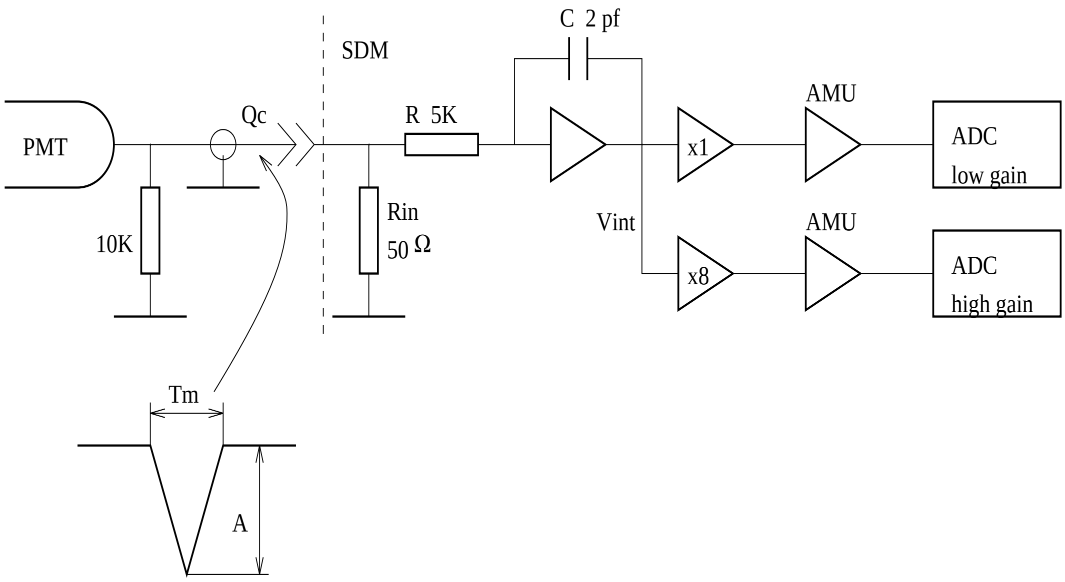

Figure 11: PMT readout at CERN.

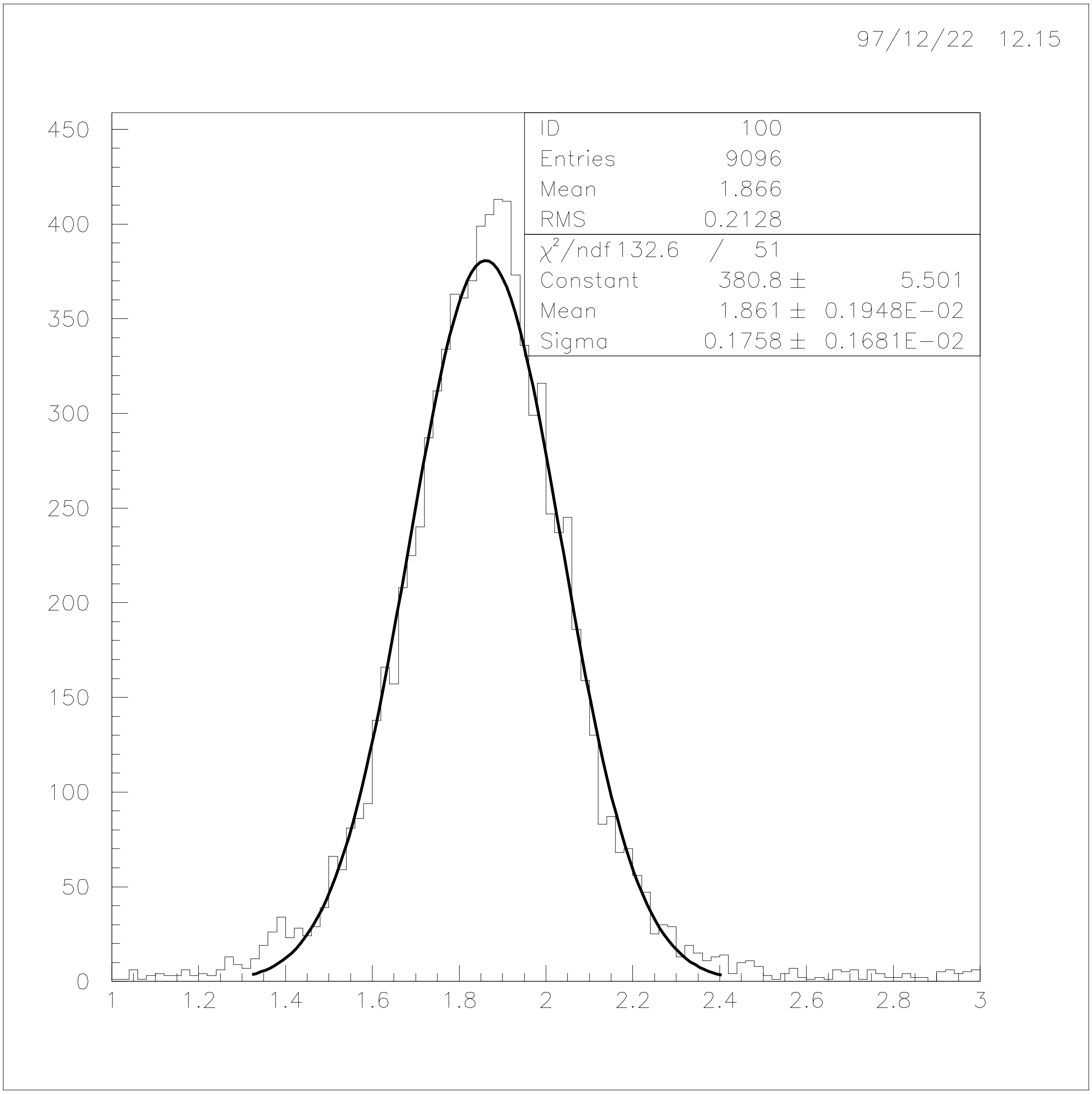

Figure 12: WA98/BNL PMT peak distribution.

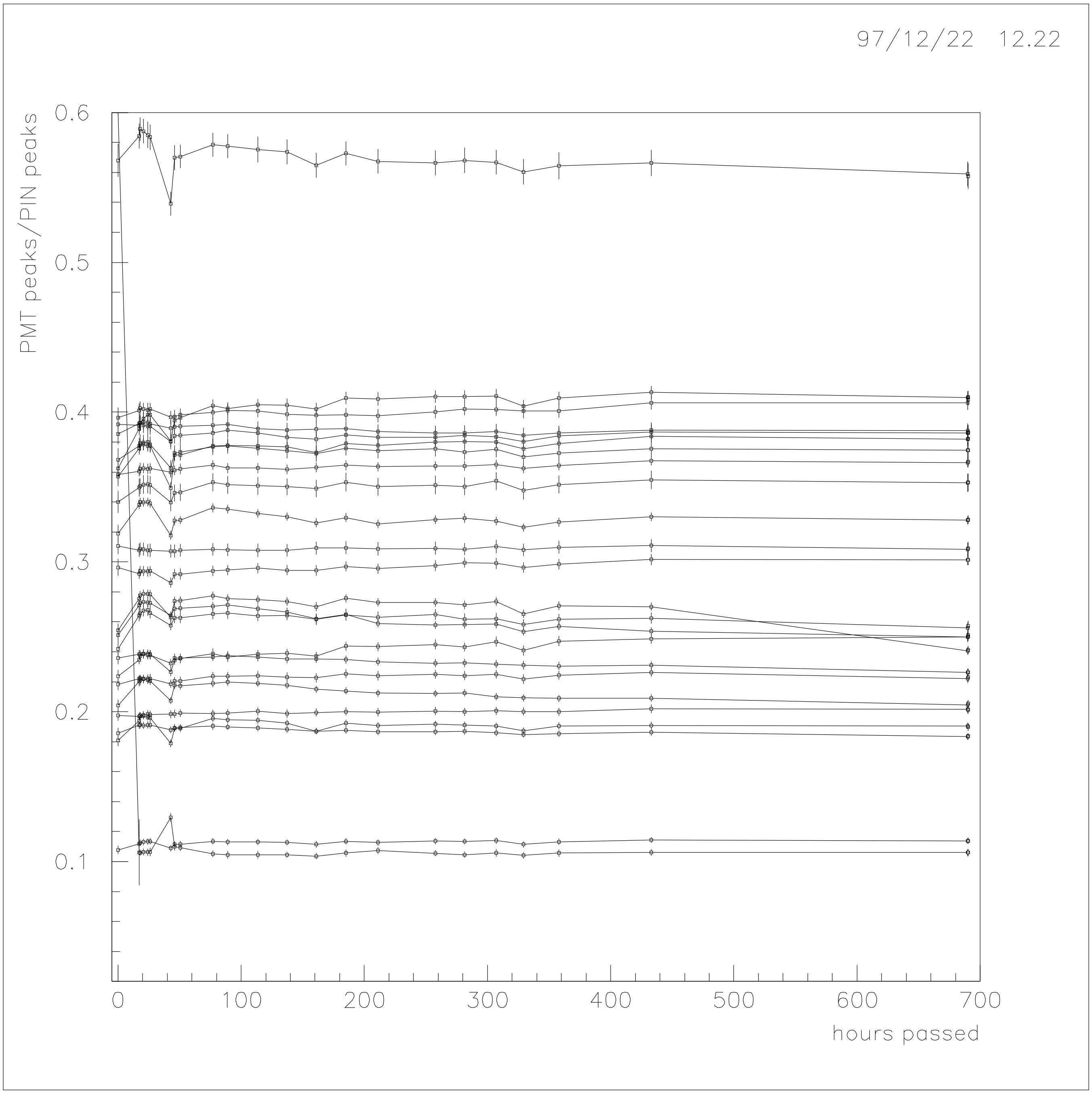

Figure 13: Long-term stability test.SM 402. PMT response to LED corrected by the PIN peak position.

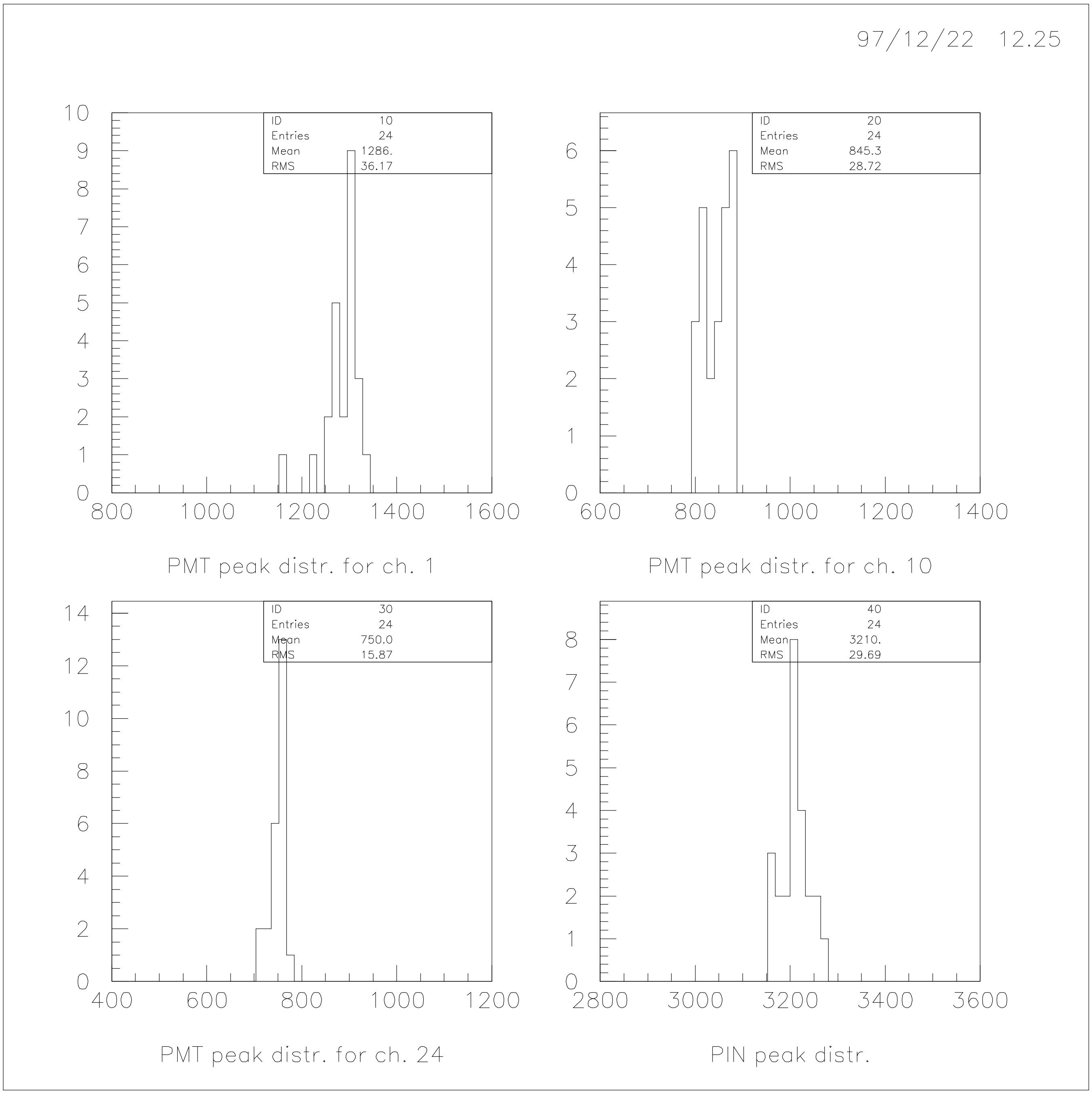

Figure 14: Long-term stability test. Peak position distributions.

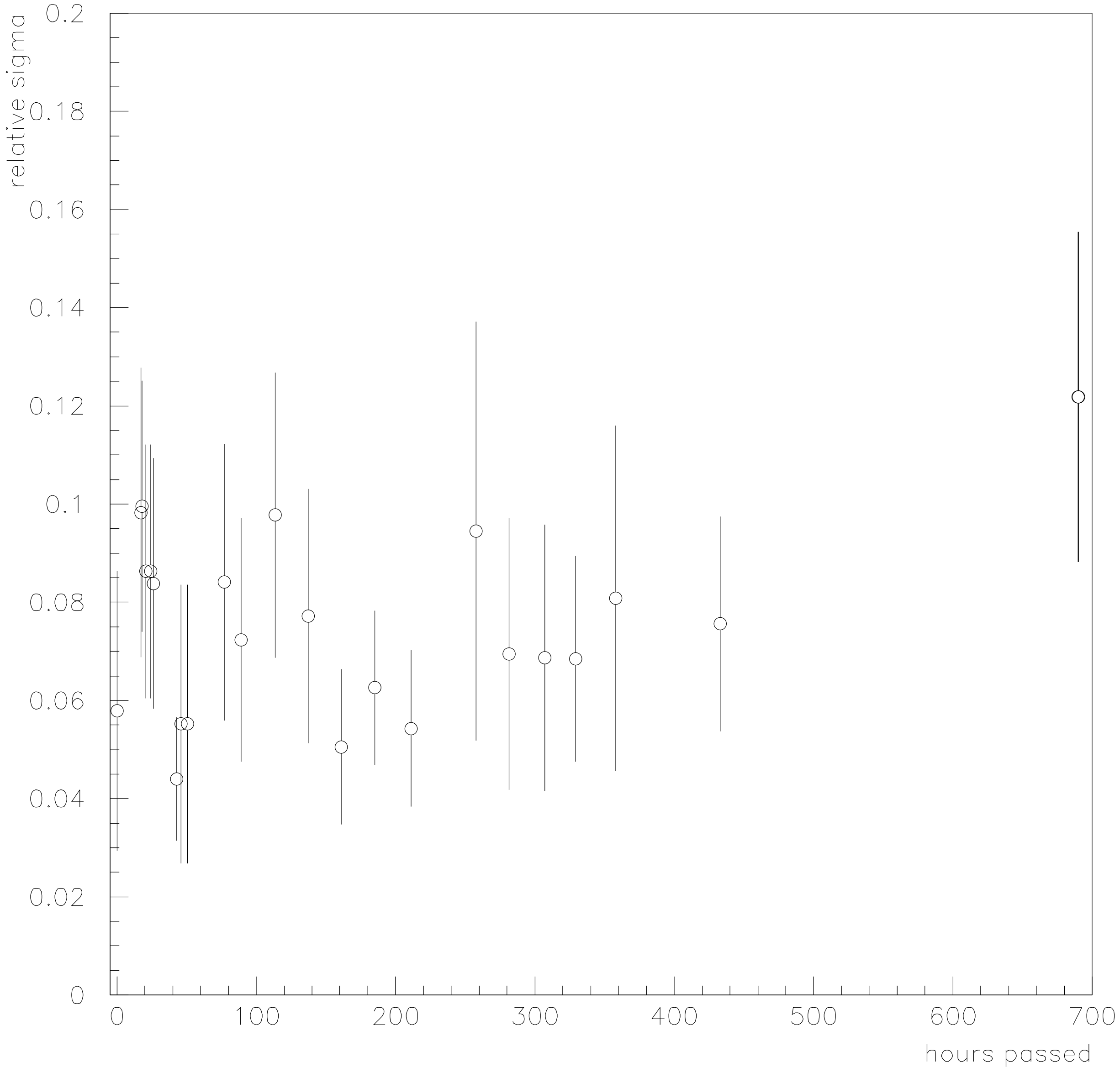

Figure 15: Sigma of WA98/BNL PMT peak distribution for SM 402.