NuMI-L-928

UTKL-191

Some Facts and Comments on Long-term M16 Gain Stability

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May 2003

Abstract

We provide some data and comments on long-term stability of R5900-00-M16 photomultipliers from Hamamatsu Photonics used in the MINOS far detector.

1 Introduction

This is a brief note which brings together some facts on long-term gain stability of M16 PMTs [1] used in the MINOS far detector. Measurements of long term gain effects come from several sources:

1. Continuous measurements of 2 LED-monitoring PMTs and 2 reference PMTs in the 2 M16 test stands, one operated at UT in Austin, and the second used at UoA in Athens.
2. Comparison of gains "before" and "after" of a number of tubes which were used for about 1.5 years in CalDet.
3. Comparison of tubes tested on 2 M16 test stands;
4. Continuous measurements of PMTs installed in the far detector.

The purpose of this note is to summarize facts on the first three items in order to help to better understand the fourth one.

2 Setting the nominal gain

The nominal gain of M16s is set in three steps. First, a gain curve (a straight line in a log(gain)-log(HV) plane) is measured for every pixel. This is done by illuminating one fiber (out of eight) per pixel, specifically the fiber in position #4. Next, for every pixel a HV value is found for which that pixel reaches the gain of 1×10^6. Then, out of 16 HV values for 16 pixels, the lowest HV is selected [2],[3]. A sample of the HV "scan" is shown in Figure 1. Since the gain is calculated by using a Gaussian approximation which ignores the first dynode emission coefficient, the true gain is actually about 18% higher than the one obtained using the described technique, thus, a final correction is applied at the end on the basis of the gain-HV slopes. Figure 1 illustrates that approximately 1% of HV change corresponds to about 10% of the gain change.

3 Test stand monitoring and reference PMTs

Each M16 test station, one operated in Austin and another one in Athens, has one reference tube and one LED monitor PMT in addition to 10 tested PMTs. Testing of PMTs has been done in *batches* of 10 tubes. Each batch consists of 3 test *cycles* and takes about 3 days (i.e., about 24 hrs per cycle). All the tubes, including the reference and monitor, have their gains set to their nominal values for each cycle of the batch for every batch. Thus, if the gain of a tube changes its nominal HV changes. In Figures 2-5 the HV values for the reference and monitor tubes as a function of batch number are shown (each point corresponds to about a 3-day time period). It can be observed that HV values decrease with time, thus the gain of the tubes increases. This conclusion is perhaps

less obvious in Figures 4 and 5 where there is a significant discontinuity at about batch #20, after one of the test stands was transferred to Athens. Based on these measurements with tubes operated for about 2 years in the PMT test stands one can make an assessment that the HV for 10^6 gain decreases by about 15 V, and infer a gain change of about 20%.

4 "Texas" vs "Athens" test stand (both in Austin)

Both M16 test stands were designed, built, and initially operated in Austin. While both M16 test stands were characterizing PMTs in Austin we tested (over a short period of time) some number of PMTs in the two stands and compared all their characteristics. Figure 6 illustrates this process. Our general conclusion was that both test stands produced consistent results.

5 "Texas" vs "Athens" test stand

After a few months of operation in Austin the entire second test stand was transferred to Athens in the summer 2001. The only part which was not shipped and thus was different, was the LRS 1440 HV power supply. As the test stand was being recomissioned in Athens it was discovered that the HV settings for the same PMTs were different by about 7 volts correspodning to about 10% gain difference. Figure 7 illustrates this comparison. Attempts to exactly explain the effect took some time and it was ultimately concluded that both the LRS 1440 HV controller and HV card are partially to blame. In the end, it was decided to continue testing without any changes. Motivation for this was that by measuring the difference between the two power supplies and HV slopes we have enough information to apply corrections if necessary.

6 CalDet vs Texas

About 200 PMTs were first tested in Austin, then shipped to CERN. After using them for about 1-1.5 year a large fraction of the CalDet M16s was returned to Austin to be ultimately deployed in the far detector. Some of the PMTs were re-tested in the Austin PMT test stand, then shipped out to IU and Tufts for installation in the MUX boxes. A comparison of the nominal HV values before and after CalDet for 61 PMTs shows that on average the nominal HV decreased after about 1 year by about 13 V (corresponding to a 17.4% gain increase).

7 Improvements of Manufactured PMTs

Hamamatsu has been delivering M16 PMTs over a period of about 2.5 years. By now we have received about 1,800 PMTs. The nominal HV settings have been steadily dcreasing with time,

indicating improvements in gain of PMTs manufactured more recently.

8 Hamamatsu's Comments

Both, Hamamatsu's PMT manual and technical staff commented to us that gain change with time is expected due to two effects:

- There is a natural migration (or diffusion) of alkali metals (K-Cs-Sb) which activate the surfaces of the dynodes. Typically this leads to an excess of the Cs layer and lower work function. The gain may increase, but it depends on the actual use of the PMT and the amount of charge transferred through it.
- With longer time periods and larger integrated charge amplified through a PMT, the Cs layer becomes less electro-emissive and the gain decreases.

Thus, one may observe either increase on decrease of the gain, depending on the use of the PMT. It seems that the MINOS experience does not surprise the manufacturer.

9 Main Conclusions

Our main observations from the test stands characterizations show a slow gain increase of about 20 % over a 2-year period. This seems consistent with recent analysis using light injection data at the far detector. Over longer time the gain is expected to go down but not much since the amount of light which MINOS tubes see is dominated by the dark current.

References

[1] NuMI-L-526 (UTKL-143), *Manufacturer's Characteristics of 5900-00-M16 PMTs for MINOS*

[2] NuMI-L-527 (UTKL-144), *Evaluations of Hamamatsu R5900-00-M16 Phototubes Using a Fiber Scanning System*

[3] NuMI-L-529 (UTKL-146), *Studies of Linearity and Gains of Hamamatsu R5900-00-M16 Phototubes*

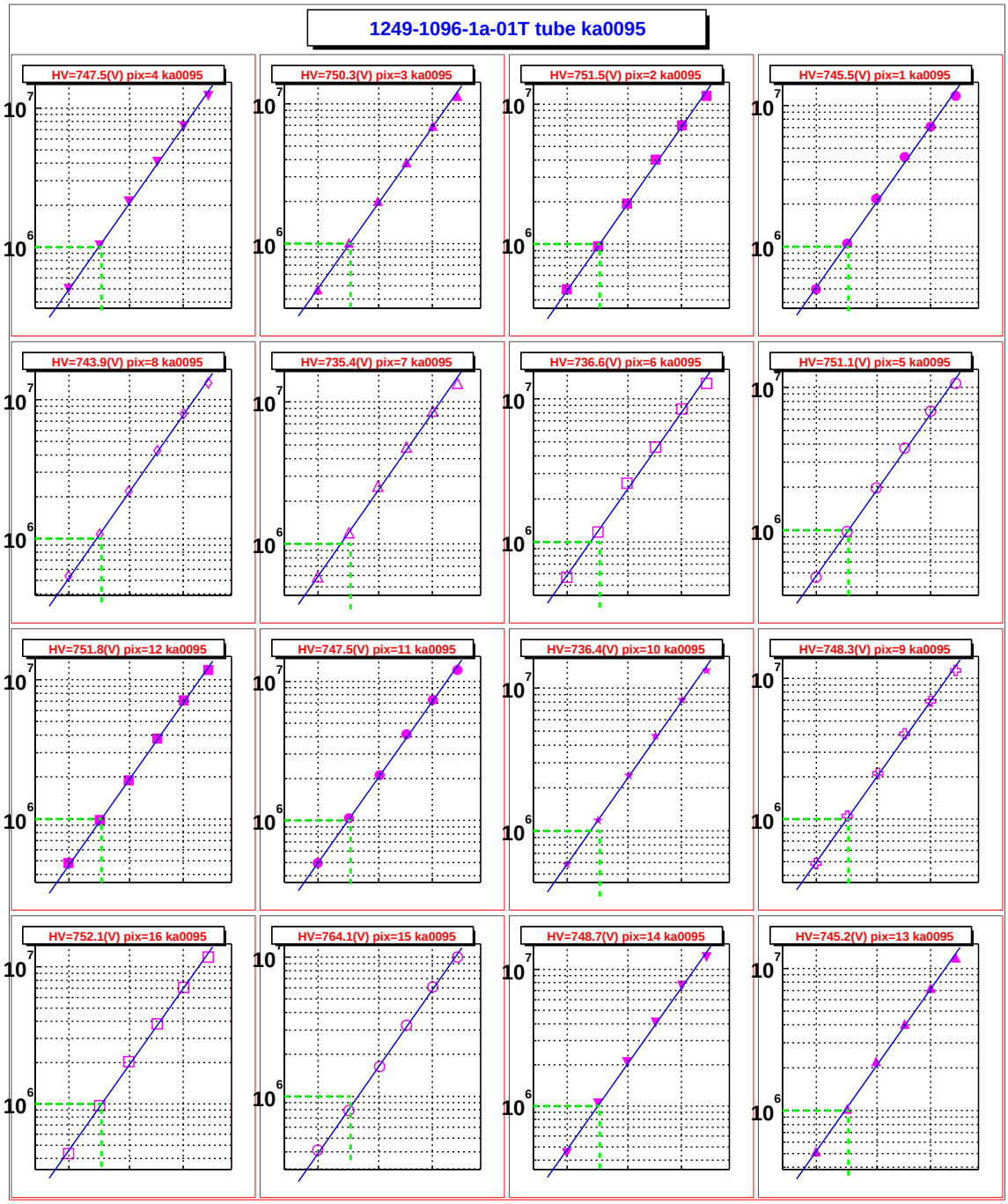

Figure 1: Gain curves (i.e., fits to gain-HV "scans") for 16 pixels of M16 (SN=KA0095) used in the "Texas" test stand as a reference PMT.

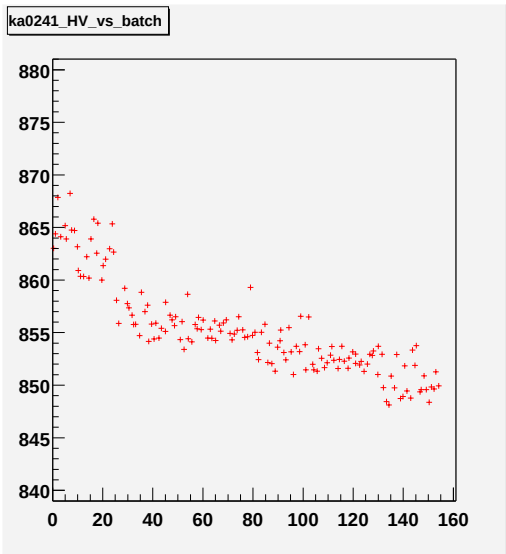

Figure 2: The nominal HV versus batch number as determined in each batch for the "Texas" monitor M16.

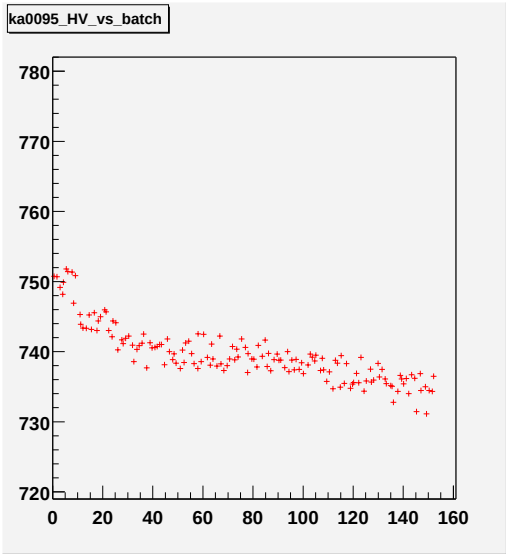

Figure 3: The nominal HV versus batch number as determined in each batch for the "Texas" reference M16.

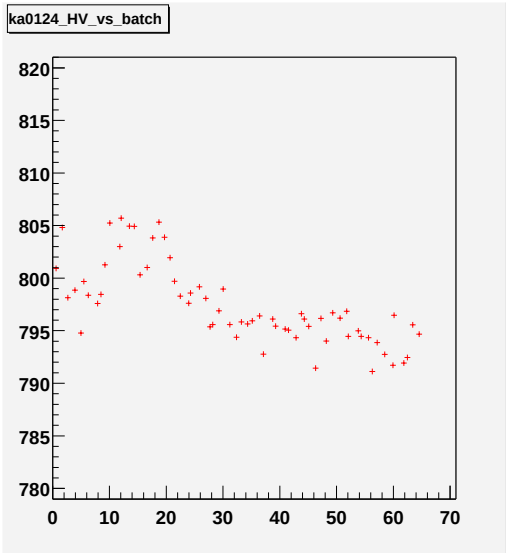

Figure 4: The nominal HV versus batch number as determined in each batch for the "Athens" monitor M16. The apparent discontinuity at batch #20 is due to the transfer of testing from Austin to Athens.

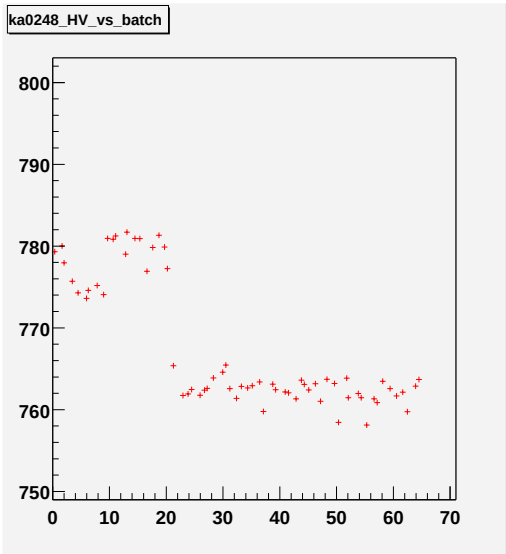

Figure 5: The nominal HV versus batch number as determined in each batch for the "Athens" reference M16. The apparent discontinuity at batch #20 is due to the transfer of testing from Austin to Athens.

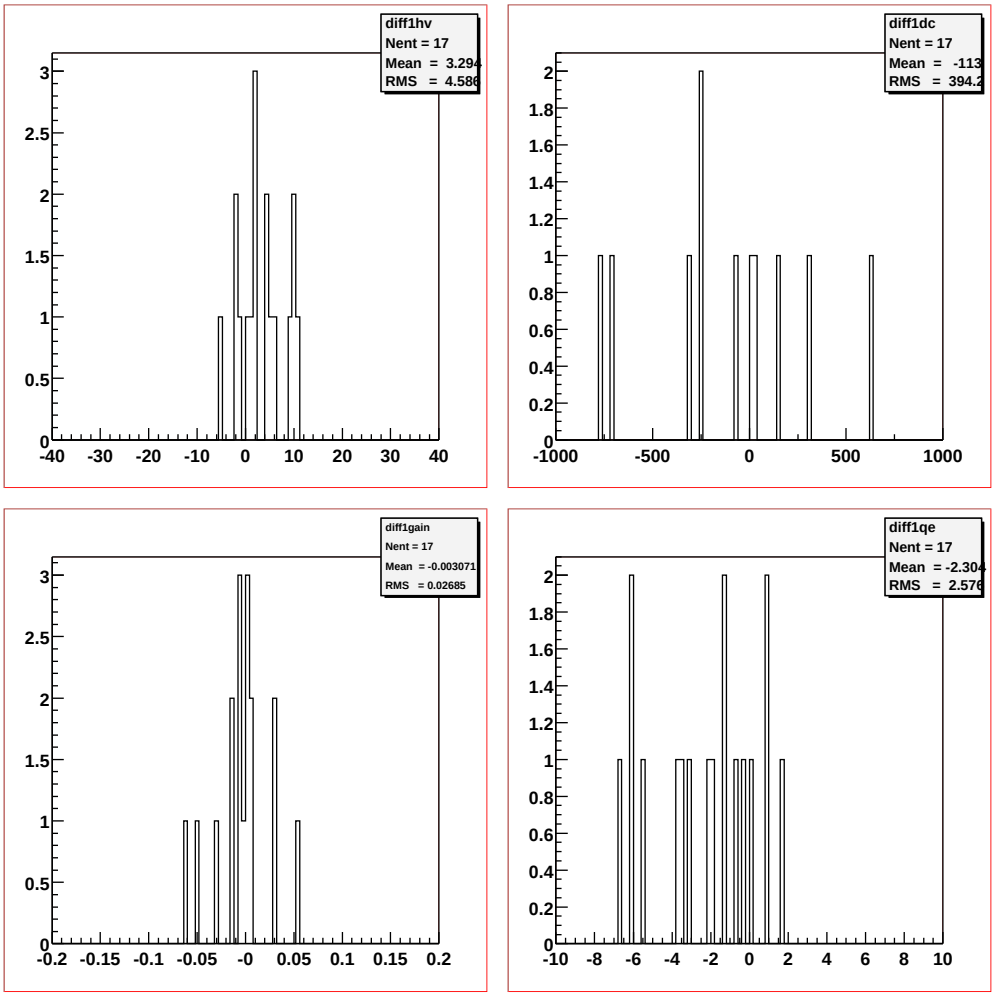

Figure 6: Left-top: HV difference $\mathrm{HV}_{\text{“Texas” Test Stand}} - \mathrm{HV}_{\text{“Athens” Test Stand}}$ for 17 PMTs when both stands operated in Austin. Bottom-left: Gain difference for the same measurements (in units of 10^6). Plots on the right should be ignored.

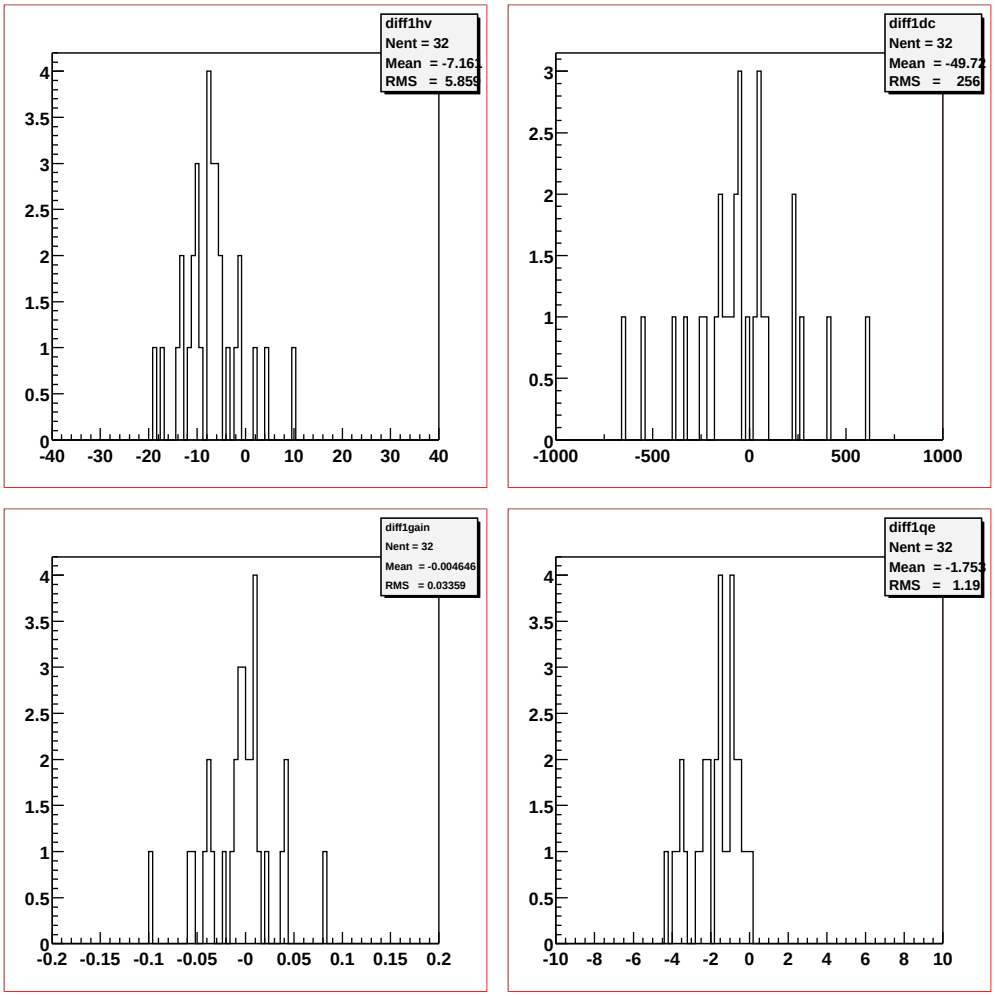

Figure 7: Left-top: HV difference $\mathrm{HV}_{\text{“Texas” Test Stand}} - \mathrm{HV}_{\text{“Athens” Test Stand}}$ for 32 PMTs compared between measurements in Austin and Athens. Bottom-left: Gain difference for the same measurements (in units of 10^6). Plots on the right should be ignored.

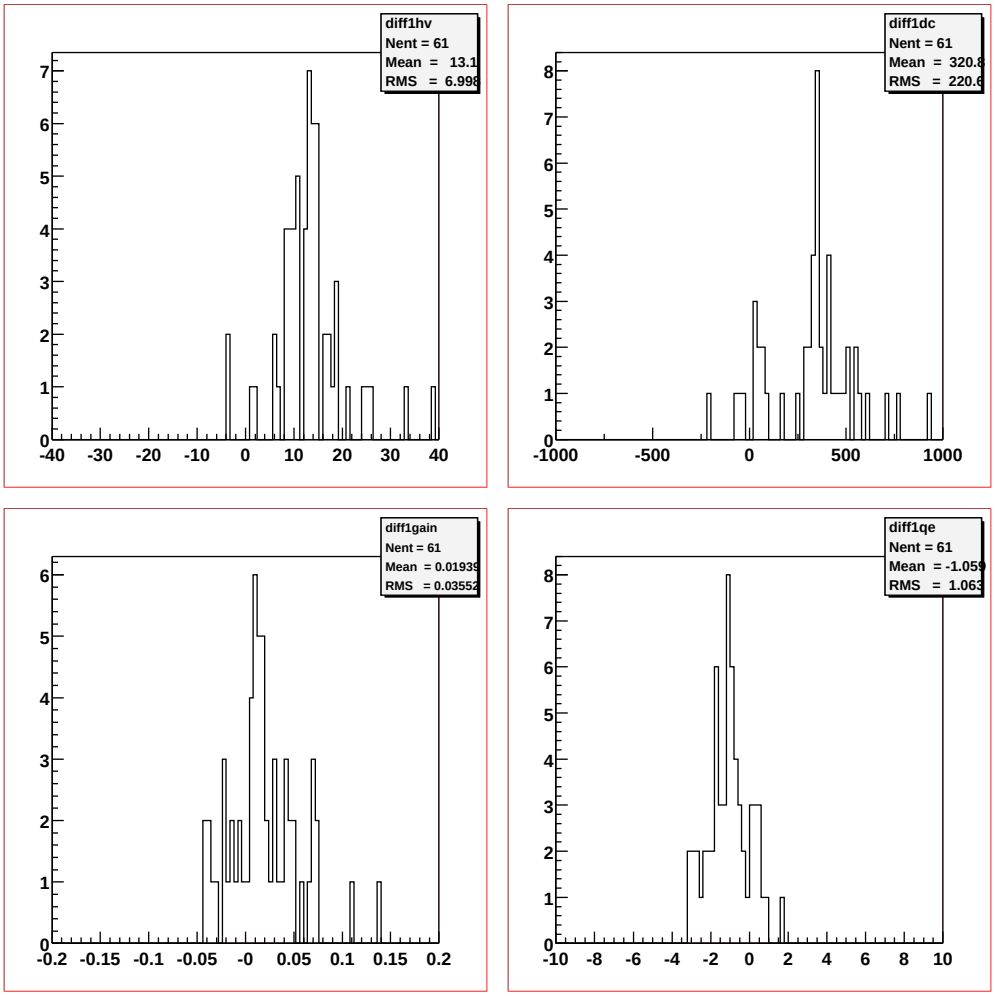

Figure 8: Left-top: HV difference $\mathrm{HV}_{\mathrm{Before\ Caldet}} - \mathrm{HV}_{\mathrm{After\ Caldet}}$ for 61 PMTs operated at CalDet for more than 1 year. Bottom-left: Gain difference for the same measurements (in units of 10^6). Plots on the right should be ignored.

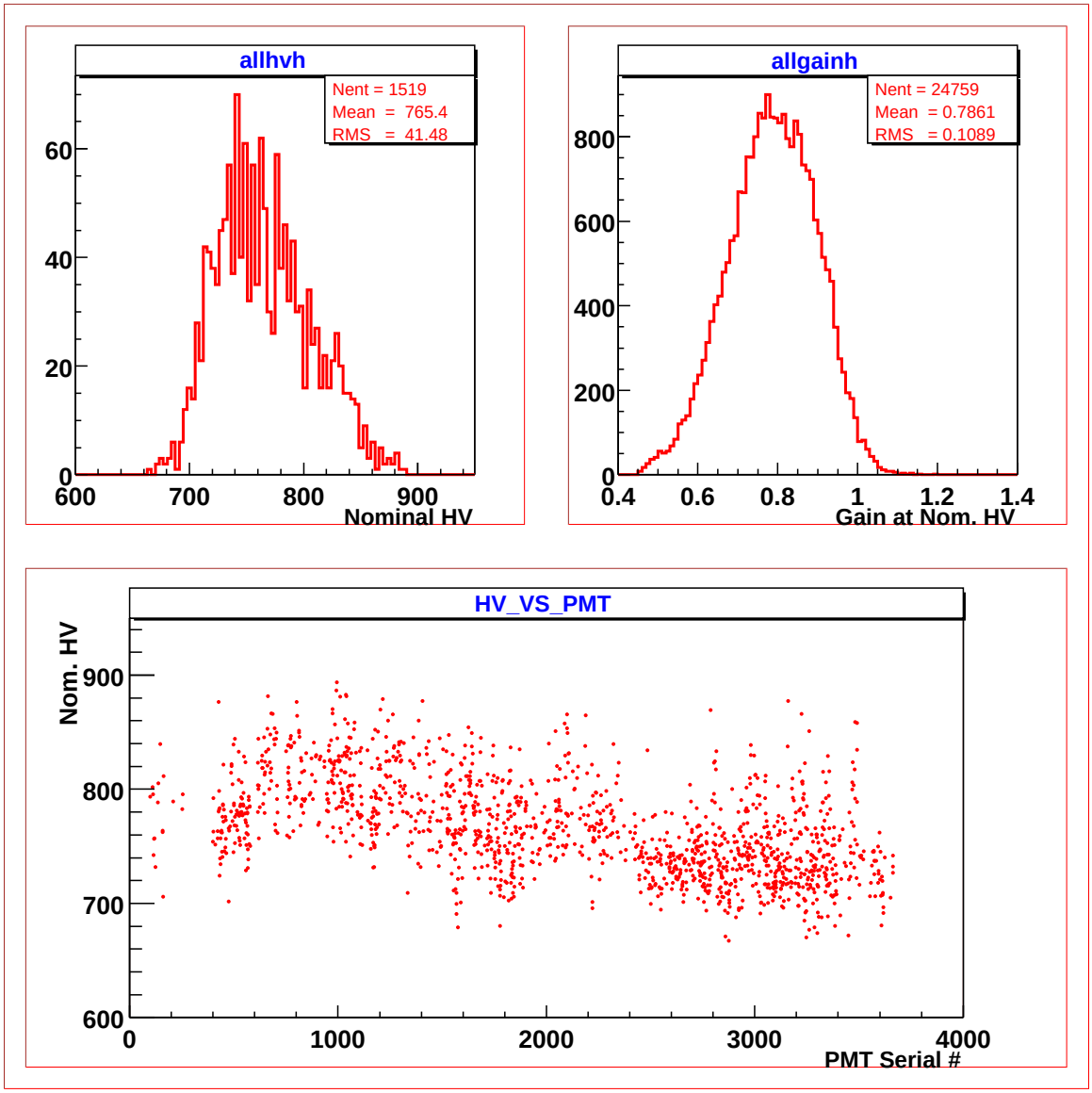

Figure 9: Nominal HV values (to reach a gain of 1×10^6 on the highest gain pixel) and gains of all the pixels for all the tested tubes.