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Testing of MACRO PMT's

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Abstract

MACRO experiment at Gran Sasso Laboratory in Italy uses approximately 1600 8" PMT's. The experiment will be de-commissioned in January 2001, possibly making these PMT's available for use in the Auger project. We report the results of tests performed on four MACRO PMT's at UCLA.

1. Introduction

MACRO experiment at Gran Sasso Laboratory in Italy uses approximately 1600 8" PMT's. Majority of these PMT's are EMI 9350, but they also include approximately 200 Hamamatsu R1408 PMT's. The experiment will be decommissioned in January 2001, possibly making these PMT's available for the Auger project.

One major concern in using these PMT's in the Auger project is the afterpulsing. A fraction of these PMT's have Helium contamination originating from the streamer tubes used in the experiment. This contamination can result in large afterpulses with a characteristic delay of ~1 μs after the main pulse.

We obtained four MACRO PMT's from the CalTech MACRO group, and measured different characteristics including afterpulsing. Three of these PMT's are EMI and one of them is Hamamatsu. Two of these PMT's were known to have Helium contamination. The results of all the measurements are reported below.

2. Measurements

2.1 Quantum Efficiency

The method used for quantum efficiency (QE) measurement has already been described in a previous note [1].

The results of QE measurements on MACRO PMT's are shown in Figures 2.1.1 and 2.1.2.

Of the four MACRO PMT's tested, three are EMI tubes; two of which are type 9350KA (SN-8521 & SN-8527) and one is type D642KBFL (SN-7085). There are noticeable differences among these tubes. The EMI tube SN-7085 had a peak QE of 28.2% at 360 nm, while SN-8521 and SN-8527 peaked at 360 nm with QE of 22.0% and 23.6% respectively. The general shape of the graph is the same for all three PMT's, having a narrow peak of high QE. Tube 7085 has a very high peak QE, whereas tubes 8521 and 8527 have significantly lower peak QE with narrower peaks.

The MACRO Hamamatsu tube (SN-YA3753), showed a QE curve similar to the Auger Hamamatsu PMT's (Figure 2.1.2).

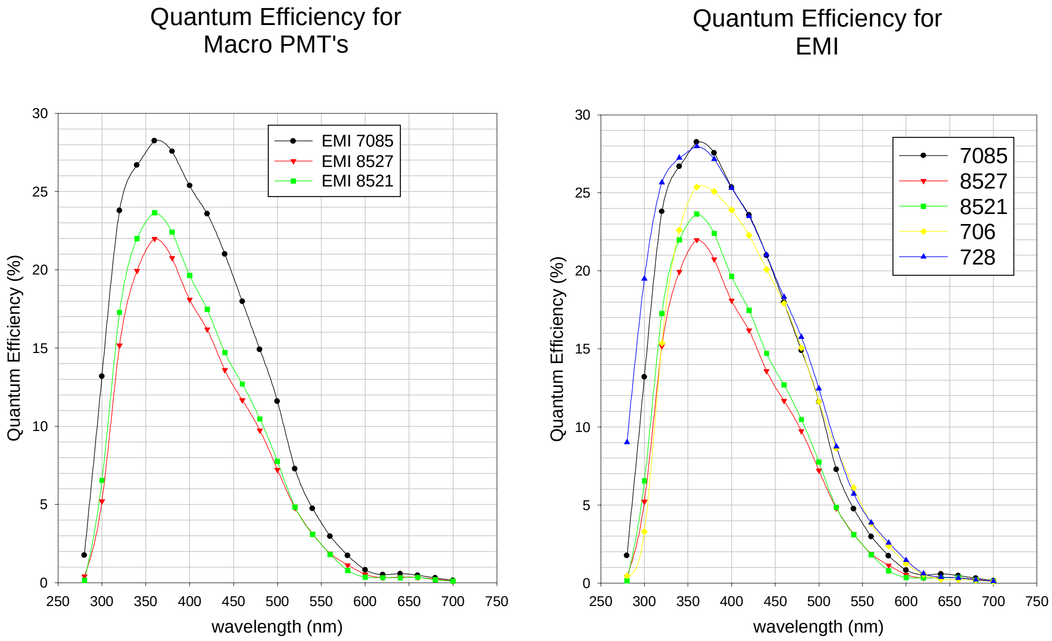


Figure 2.1.1 Quantum efficiency for MACRO EMI PMT's. The plot on the left is for MACRO PMT's alone, and the plot on the left includes the measurements from Auger EMI PMT's as well (706 and 728).

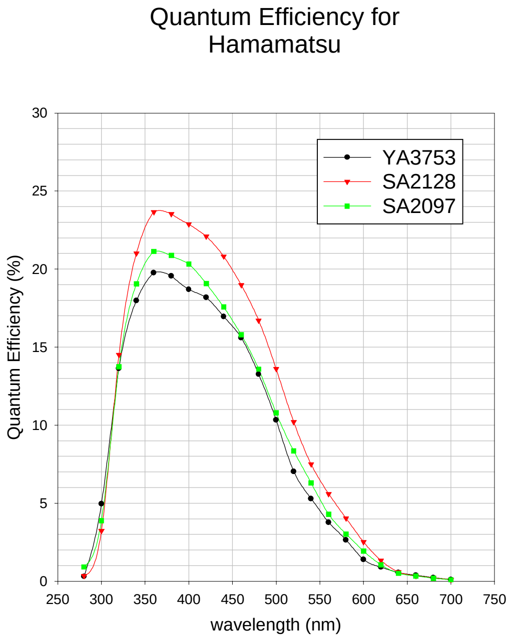


Figure 2.1.2 Quantum efficiency for MACRO Hamamatsu PMT (YA3753). For comparison, measurements done on Auger Hamamatsu PMT's are also shown (SA2128 and SA2097).

2.2 Single Photoelectron Spectra

We were able to obtain single photoelectron (PE) spectra only for two EMI PMT's (SN 7085 and 8527). The third EMI PMT was unstable. The measured single PE spectra are shown in Figure 2.2.1. These PMT's show clear single PE spectra, with good peak-to-valley ratio.

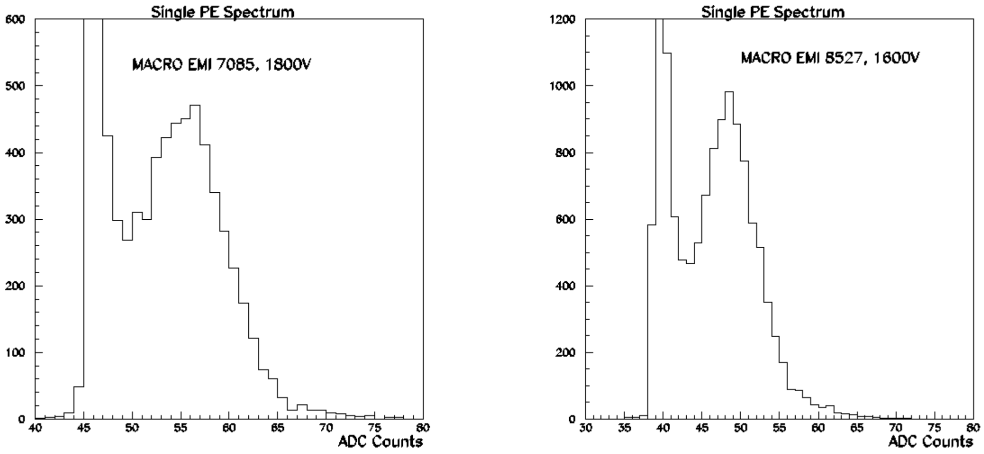


Figure 2.2.1 Single photoelectron spectra for MACRO EMI PMT's (7085 and 8527).

The Hamamatsu PMT did not yield a single PE peak well separated from the pedestal. Upon communication with MACRO group, we learned that the Hamamatsu PMT's in use by the collaboration are the ones that were produced before the PMT was optimized to yield a good single PE peak.

2.3 Gain and Dark Current

Again, the method used for measuring the gain and dark current is the same as in [1]. The results of these measurements are shown in Figure 2.3.1.

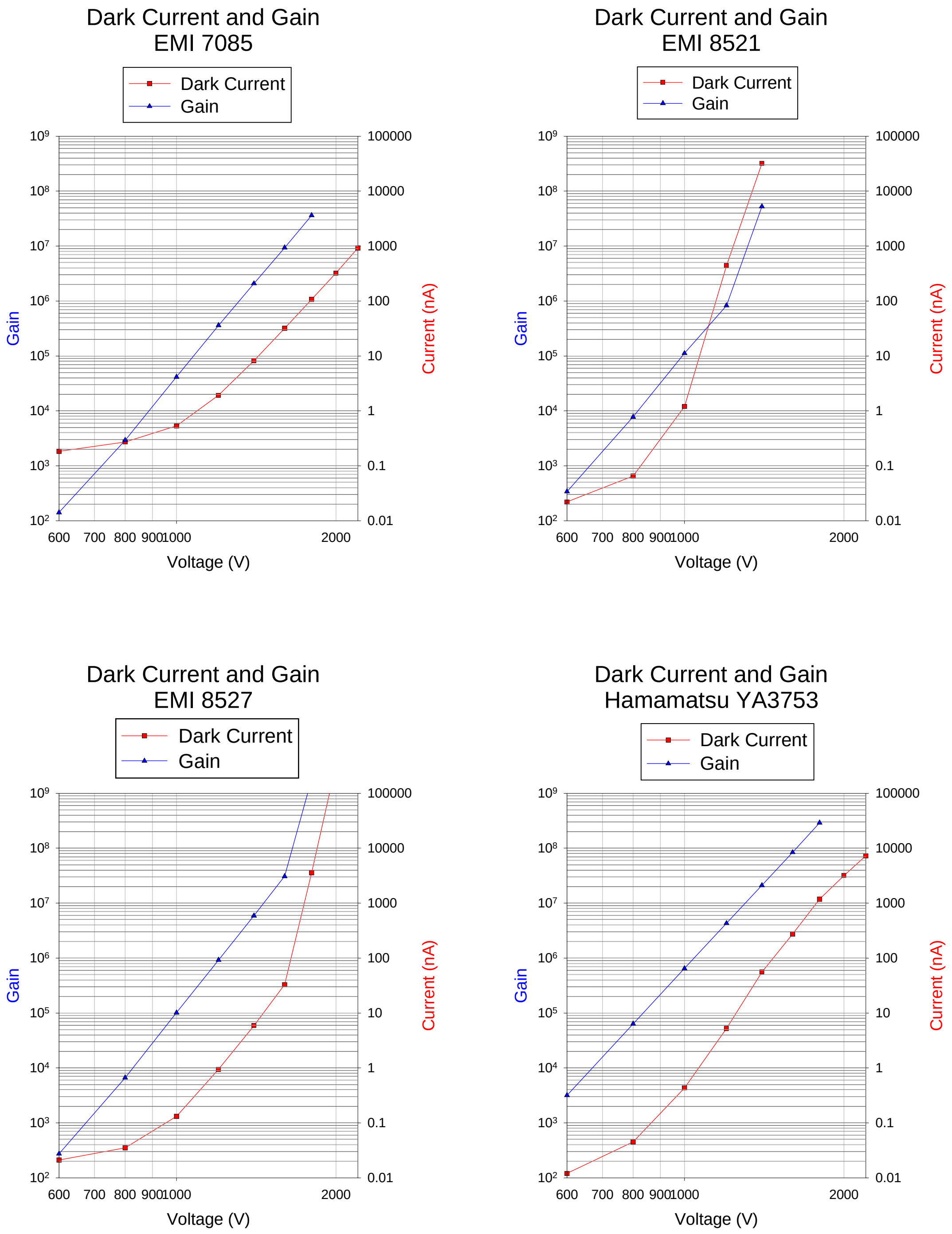


Figure 2.3.1 Gain and dark current as a function of high voltage for the four MACRO PMT’s.

Clearly, EMI 8521 and EMI 8527 exhibit unstable behavior, which is possibly a result of large He contamination. We will see later that these are also the PMT’s that are contaminated with He.

2.4 *Dark Pulse Rate*

In order to measure the dark pulse rate as a function of storage time in dark, we first expose the PMT's to ambient light in the lab. Then they are put back in the dark box. The applied HV is such that the single PE peak is at 10 ADC counts above the pedestal. Then the rate of dark pulses above 0.3 PE threshold is counted as a function of storage time in dark. The results of this measurement are shown in Figure 2.4.1.

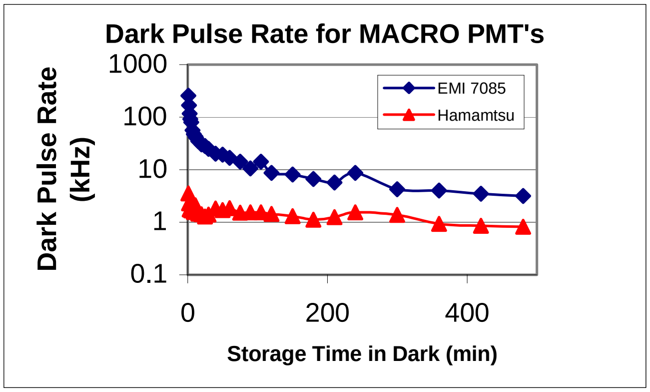


Figure 2.4.1 Dark pulse rate as a function of storage time in the dark for MACRO PMT's.

We were able to obtain the dark pulse rates for only one EMI PMT (7085), other two exhibited unstable behavior. This EMI PMT starts out extremely noisy, with dark pulse rates of about 300 KHz. However, after about 8 hrs in dark, it settles down to a dark pulse rate of less than 5 KHz.

Hamamatsu is much quieter, it starts out at less than 5 KHz, and settles down to less than 1 KHz after 8 hrs in dark.

2.5 Linearity

The linearity measurements were done on all four MACRO PMT's using the technique described in [1].

The results for EMI PMT's are shown in Figures 2.5.1-2.5.3. EMI7085 PMT shows very good linearity. It is linear up to peak anode current of 50 mA at a gain of 10^5. The other two EMI PMT's, EMI8521 and 8527 start to show nonlinearities bigger than 5% at a gain of 10^5 for peak anode currents exceeding 40 mA.

MACRO Hamamatsu PMT (Figure 2.5.4) shows very poor linearity even at an operating gain of 10^7, the reason probably being the large number of dynode stages – 14.

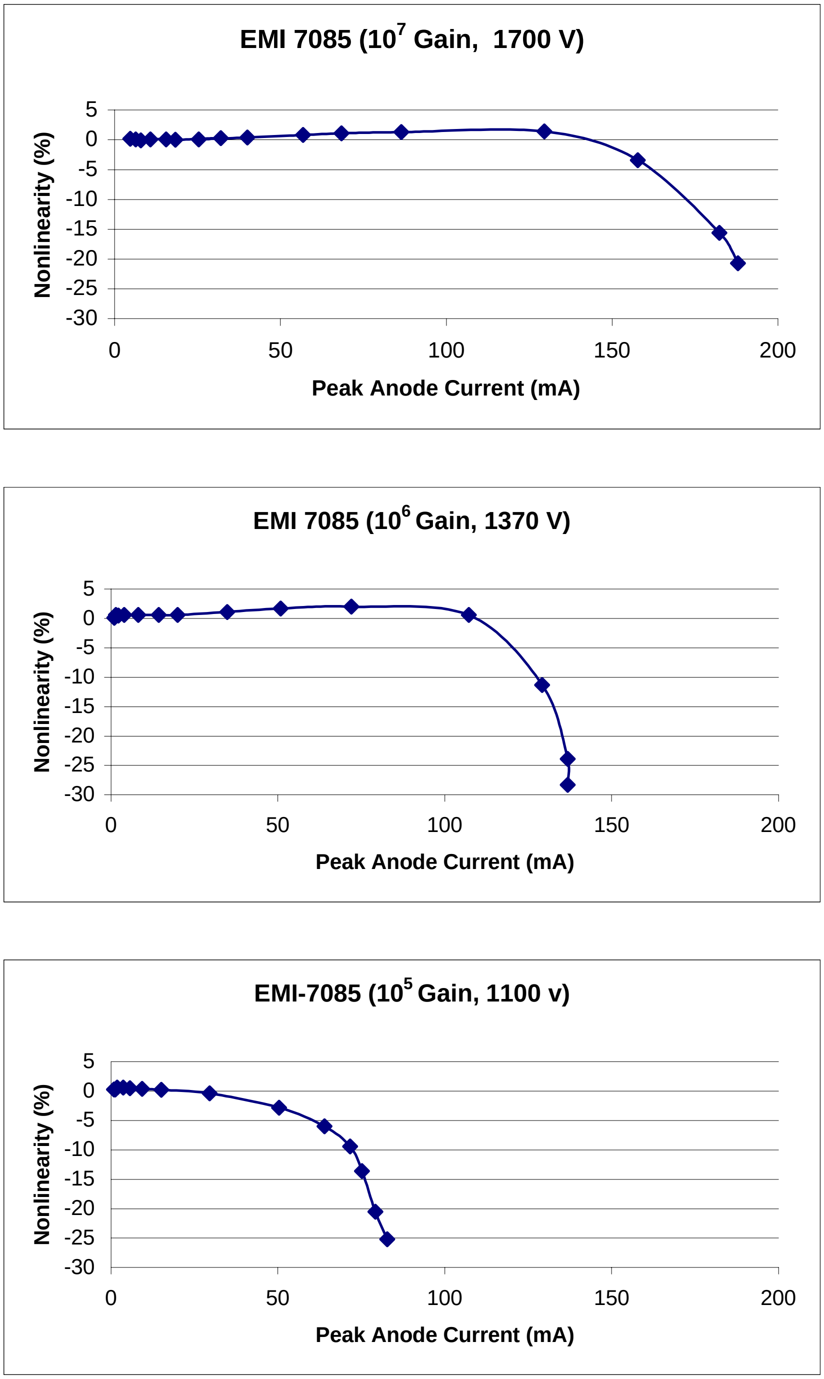


Figure 2.5.1 Nonlinearity as a function of peak anode current for MACRO EMI7085 PMT for different gains. This PMT is ***not*** contaminated by Helium.

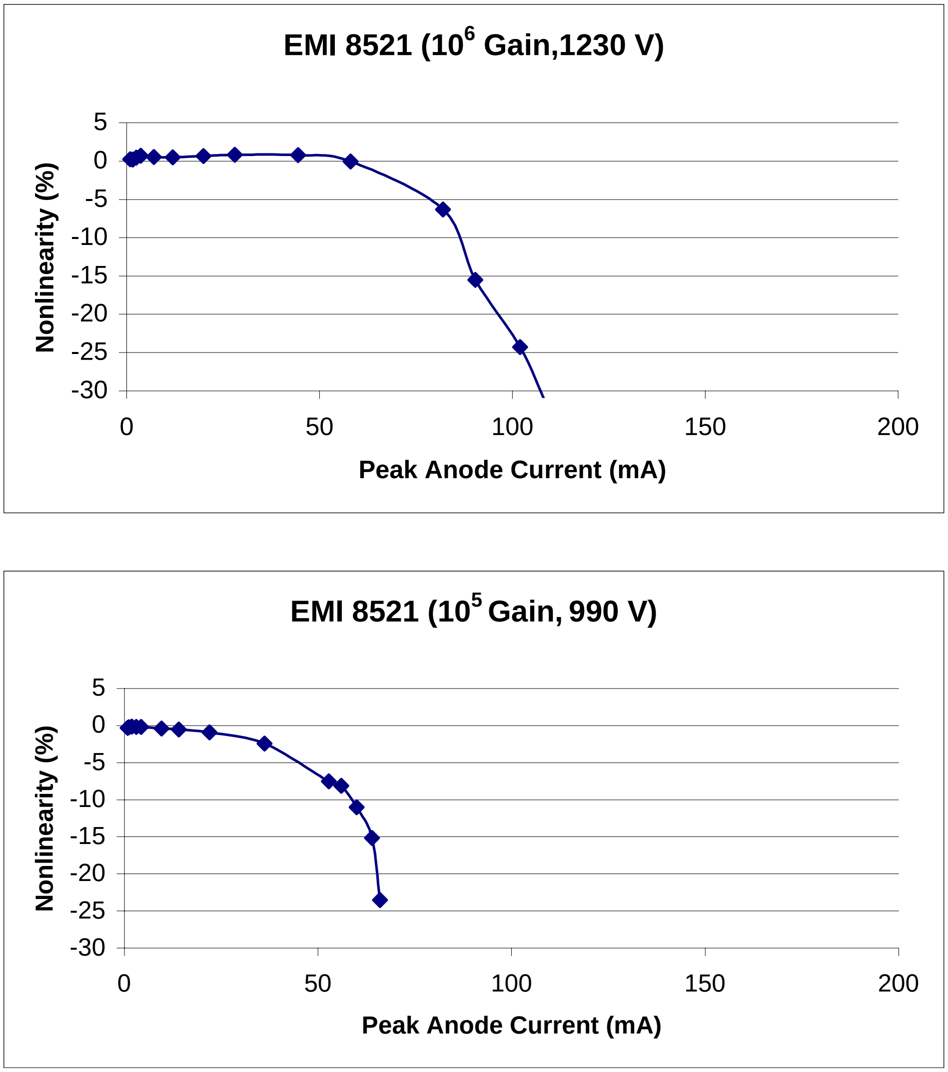


Figure 2.5.2 Nonlinearity as a function of peak anode current for MACRO EMI8521 PMT for different gains. This PMT has He contamination and becomes unstable before reaching the gain of 10^7.

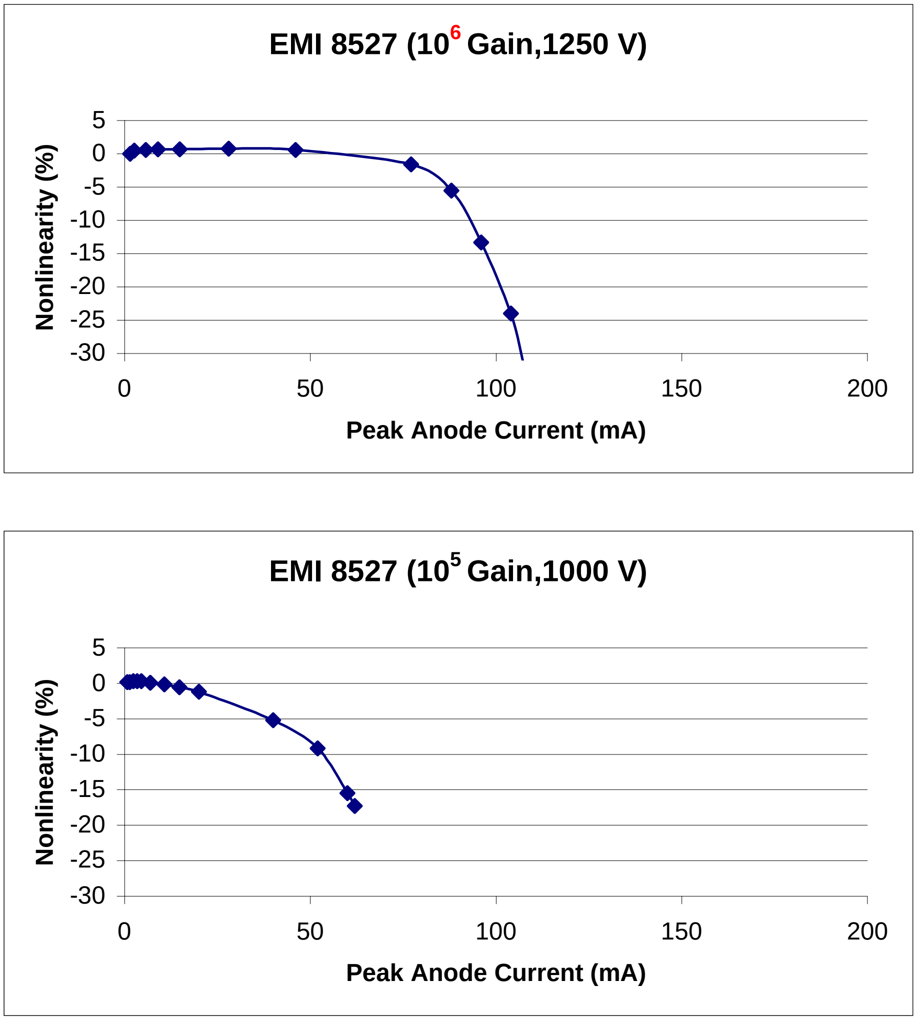
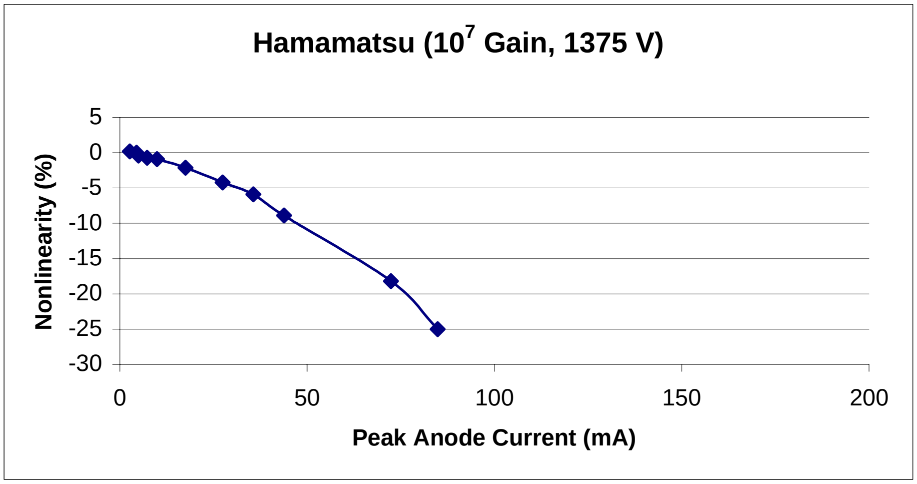
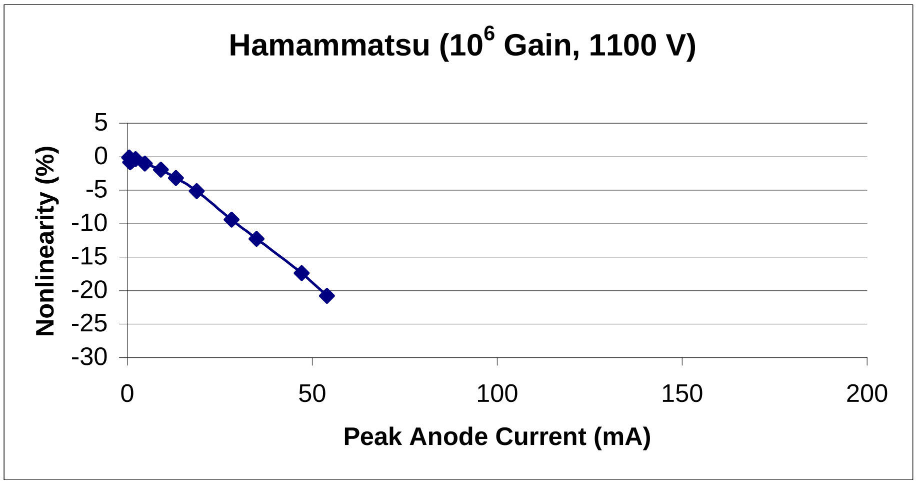


Figure 2.5.3 Nonlinearity as a function of peak anode current for MACRO EMI 8527 PMT at different gains. This PMT has Helium contamination and becomes unstable before reaching a gain of 10^7.





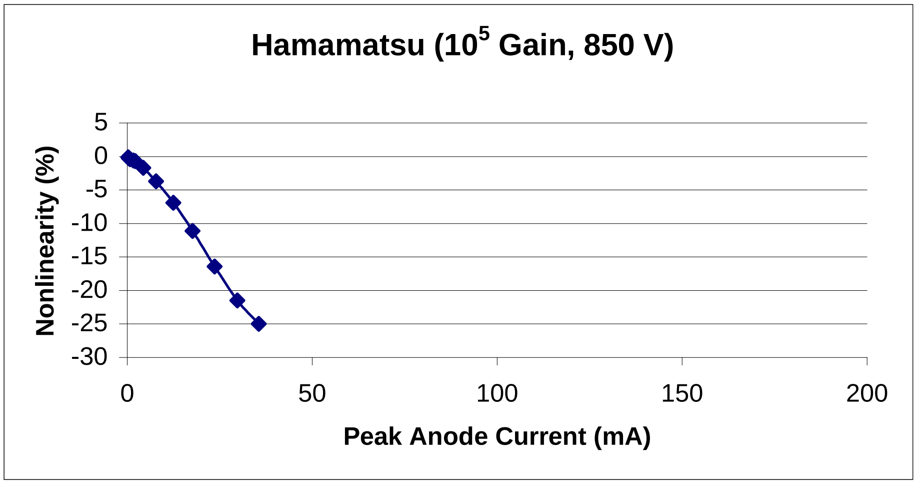


Figure 2.5.4 Nonlinearity as a function of peak anode current for MACRO Hamamatsu PMT for various operating gains.

2.6 Afterpulse Ratio

A major concern about using the MACRO PMT's in the Auger project is afterpulsing. A significant fraction of these PMT's are contaminated with He, and depending on the amount of contamination, they can give rise to large afterpulses with a charecteristic delay of ~1 μs after the main pulse.Two of the PMT's received at UCLA were He contaminated. The results of afterpulse ratio measurements on all four PMT's is listed in Table 1.

PMT	**Gain**	**No. of PE at Photocathode**	**Afterpulse Ratio (%) (200-5000 ns)**
EMI 8527	4 X 10^6	56	30.2 (He contaminated)
EMI 8521	3 X 10^6	57	15.1 (He contaminated)
EMI 7085	1.2 X 10^7	89	2.0
Hamamatsu	5 X 10^7	16	0.4

Table 1 Results of the afterpulse ratio measurements for the four MACRO PMT's.

Since He afterpulses arrive approximately 1 μs after the main pulse, one should be able to see a peak in the distribution of arrival time of afterpulses. We used a pico second laser to obtain this distribution. The laser provides a trigger that was used to start a LeCroy 2228 TDC, and the afterpulses from the PMT were used to stop it, after being discriminated by LeCroy 623B discriminator. The gain of the PMT was set such that single photoelectrons gave rise to pulses above 30 mv, the discriminator threshold.

The distribution of arrival times for one of the contaminated PMT's, EMI 8527, is shown in Figure 2.6.1. A dominant Helium peak can be clearly seen around 1 μs.

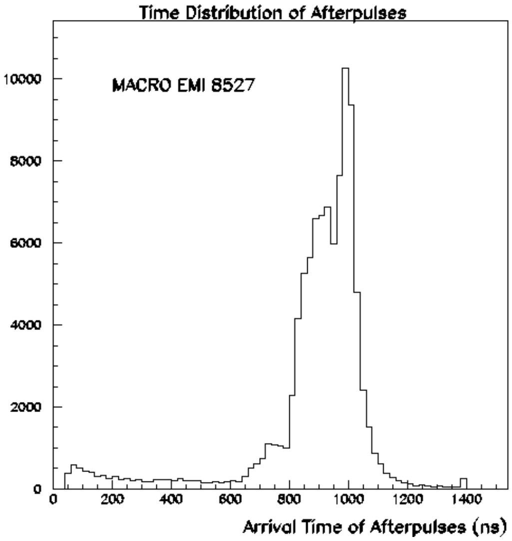


Figure 2.6.1 Distribution of arrival times of afterpulses for EMI 8527, on of the He contaminated MACRO PMT's.

2.7 What Fraction of MACRO PMT's are Contamined?

It is clear from the above measurements that MACRO PMT's are good PMT's, if they are not contaminated with He; as far as QE, dark current, single PE resolution, and dark pulse rate are concerned. The next question is, then, what fraction of these PMT's are contaminated with He?

MACRO collaboration monitors afterpulsing of all PMT's routinely, and stores the information in a database. We received the latest such database from Stephane Coutu. These measurements were taken in November 1998

The summary of this database is listed in Table 2. The fraction of PMT's that have afterpulse ratio less than 5% and those with afterpulse ratio less than 10% are listed. Based on these measurements, nearly half the PMT's have afterpulse ratio less than 5%. In absolute numbers, this corresponds to 682 PMT's. If we relax the afterpulse ratio requirement to less than 10%, then approximately 82% PMT's are useful, which translates into 1262 PMT's.

Layer	**Total Number of PMT's**	**PMT's w/ AP <=5%**	**PMT's w/ AP<=10%**
Top	408	58 (14.2%)	208 (51%)
Center	384	170 (44.3%)	348 (91%)
Bottom	384	172 (44.8%)	348 (91%)
East Face	168	126 (75%)	168 (100%)
West Face	168	128 (76%)	162 (96%)
North Face	14	14 (100%)	14 (100%)
South Face	14	14 (100%)	14 (100%)
Total	**1540**	**682 (44.3%)**	**1262 (81.9%)**

Table 2 Fraction of He contaminated MACRO PMT's with 5% and 10% levels of afterpulse ratios. These fractions are based on measurements made in Nov 1998 by MACRO collaboration.

3 Summary and Conclusion

We have measured several charachteristics of four MACRO PMT's at UCLA. From the point of view of QE, dark-current, dark pulse rate and single PE resolution, these are good PMT's, exhibiting a behavior comparable to Auger candidate PMT's currently being used.

The results of linearity measurement on these PMT's indicate that MACRO Hamamatsu PMT's show poor linearity, worse than R5912. EMI PMT's show linearity that is comparable to EMI9353, one of the candidate PMT's for Auger experiment. Typically, MACRO EMI PMT's are linear within 5% up to peak anode currents of 40 mA at a gain of 10^5.

We have also measured the afterpulse ratios for these PMT's. Two of the PMT's have very large afterpulse ratios, but they were hand-picked to be He contaminated for our tests. Uncontaminated PMT's can be usful for the Auger project.

We have investigated the latest MACRO database on afterpulsing to find out what fraction of these PMT's have low enough He contamination. About 44% (682) of MACRO PMT's have afterpulse ratio less than 5%, and 82% (1262) PMT's have afterpulse ratios less than 10%.

Since the effect of afterpulsing will cancel to a certain extent in energy calibration, up to 10% afterpulse ratio might be acceptable for Auger, although this needs to be studied.

To conclude, a large number of MACRO EMI PMT's without large Helium contamination might be useful for the Auger experiment, since their characteristics, including linearity, are comparable to those of EMI9353, currently being used in the Engineering Array. Study of a larger sample of such PMT's will be useful.

4 Acknowledgements

We would like to thank Erik Katsavounidis and Doug Michaels in MACRO collaboration for providing us with the PMT's and lots of information. We would also like to thank Prof. Stephane Coutu at Penn State University for giving us the latest MACRO database on afterpulsing.

5 References

1. Arun Tripathi, Chris DiPasquale, David Barnhill, Chris Jillings et al., *Study of 8"PMT's at UCLA for Pierre Auger Surface Detectors,* Auger Technical Note **GAP 2000-040** (2000).