TILECAL-No-xx
24 August 1996

Results of test linearity of 10-stages and 8-stages R5900 PMTS

G. Montarou, M. Crouau, E. Garnier
LPC Clermont-Ferrand
Université BLAISE PASCAL, IN2P3/CNRS
63177 AUBIERE CEDEX

Abstract

This note summarizes the results of linearity tests done on the R5900 HAMAMATSU photomultipliers for the TILE calorimeter. Previous tests lead to optimize the voltage repartition corresponding to the dynamic specification for ATLAS. These results are qualitatively confirmed by tests performed by Hamamatsu, using a different method. These results are also in agrrement with tests of a set of 15 PMTs that should used in Module 0. Finally, we request to Hamamatsu Photonics to investigate a 8-stages R5900. First results on linearity performance of such PMTs are reported, and first optimisation of voltage repartition for ATLAS specifications are done.

1. Linearity tests of 10-stages R5900 PMTs with different voltage divider configurations

Linearity tests had been performed previously on a specific R5900 (5D10D1), using an YLF laser as a light source, in order to optimize the voltage divider configuration. Different configurations had been then tested [1]:

1:1:1:1:1:1:1:1:1:1:1
1.2:1.5:1.8:1:1:1:1:1:1:1.5:1.5
2.5:1:1:1:1:1:1:1:1:1:2.5
2.5:2.5:1:1:1:1:1:1:1:2.5:2.5
1:1:1:1:1:0.5:1:1:1:1:1

It is obvious that many more configurations could be tested but the idea was at that time to have an indication on how improve the linearity.

Figure (1) reminds what was the experimental set-up [2]. The core of this system is a frequency doubled YLF solid-state laser, both externally triggerable and modulated, fully computer controlled. The produced light pulses have characteristics similar to the light delivered by particles in the calorimeter; especially the pulse width that was of the order of 20 ns.

During a period, the laser is driven to produce trains of 16 adjusted light pulses of increasing intensity, spanning the PMT dynamic range. The intensity of each pulse is measured by photodiodes used as laser monitors. For a given adjusted laser amplitude, there are pulse-to-pulse laser fluctuations. These fluctuations contribute to enlarge the 16 light pulses. Nevertheless, measuring event by event the light pulses, all the events are individually used to compare the PMT and the light as recorded by the photodiodes.

As PMT gain was known, its anode charge had been expressed directly as a function of the number of photoelectrons before amplification. Results of these tests indicate that a good linearity could be achieved on the whole dynamic range when operating the PMT with an amplification of 10^5 and using a symmetric repartition 2.5:2.5:1—2.5:2.5 of the high voltage. This is shown on Figure (2) which represents the ratios PM/D1 as a function of the number of photoelectrons ($N_{p.e.}$) before amplification. The left part of that figure corresponds to an amplification of 10^5, and the right part to an amplification of 10^6. At 10^5 the data indicate that the linearity is achieved almost up to $N_{p.e.}$ equal to 30K photoelectrons. At 10^6, a deviation from linearity appears clearly for a lower value of the photoelectron number. Using $N_{p.e.}$ equal to $70K$ as a benchmark, the results on that PMT for the different divider configurations are reported in Table (1)

This 2.5:2.5:1-1:2.5:2.5 repartition has the advantage to improve the light collection efficiency on the first stage, and also by increasing the electric field to overcome non linearity effects induced by space charge in the final stages.

[1] Results reported at Chicago Meeting 4 Feb 96
[2] see ATLAS Internal Note TILECAL-NO-039

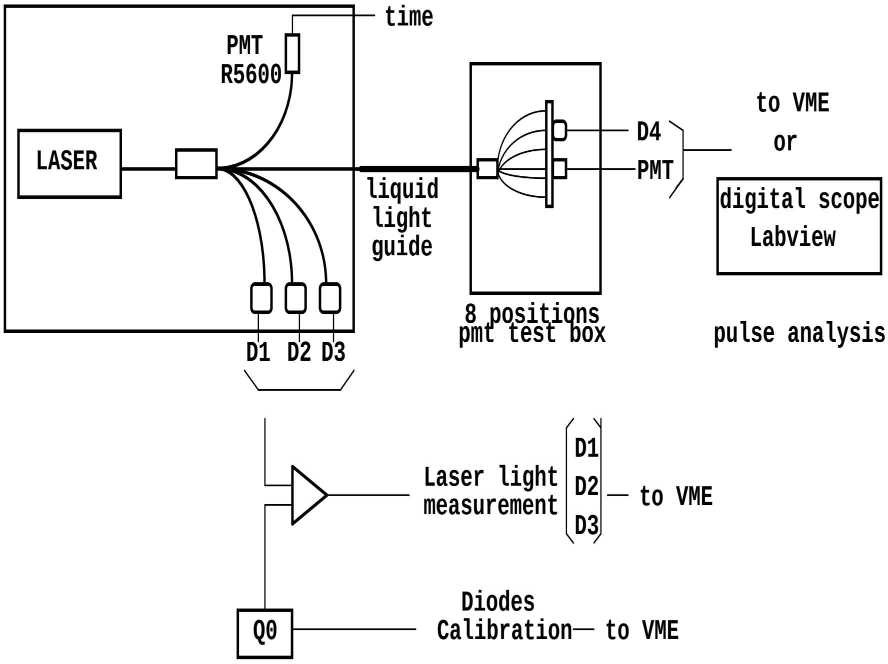


Figure 1 : Block diagram of the Laser system used as a modulated and adjustable light source for the PMT linearity measurements.

Operating the PMT at such a low amplification (10^5) had been suggested from the specifications that should fullfiled the PMT in the final ATLAS configuration. These specifications are the following.

Energy deposited in a cell of the calorimeter goes from 2 TeV (high energy jet) down to 350 MeV for muon response. Calorimeter detection efficiency as measured on prototypes is now at the level of 25 photoelectrons/GeV/PMT. So the dynamical range of photoelectron before amplification goes from $N_{p.e.}$ equal to 50K down to a few photoelectrons. Such a dynamic avoids to operate the PMT with a too large amplification, since a PMT gain of 10^6 should induce an anode charge from 1 pC to 8 10^4 pC; i.e. an anode current [3] up to 530 mA. On the other hand, a PMT operating with an amplification of 10^5 induces an anode charge up to 800 pC; i.e. an anode current up to only 53 mA.

Afterthat it was decided that Module 0 PMT voltage divider will be designed with a 2.5:2.5:1–1:2.5:2.5 repartition. But in order to have a confirmation of such results, it was requested to HAMAMATSU Photonics to test an equivalent voltage repartition.

[3] calculated with a pulse width of 15 ns

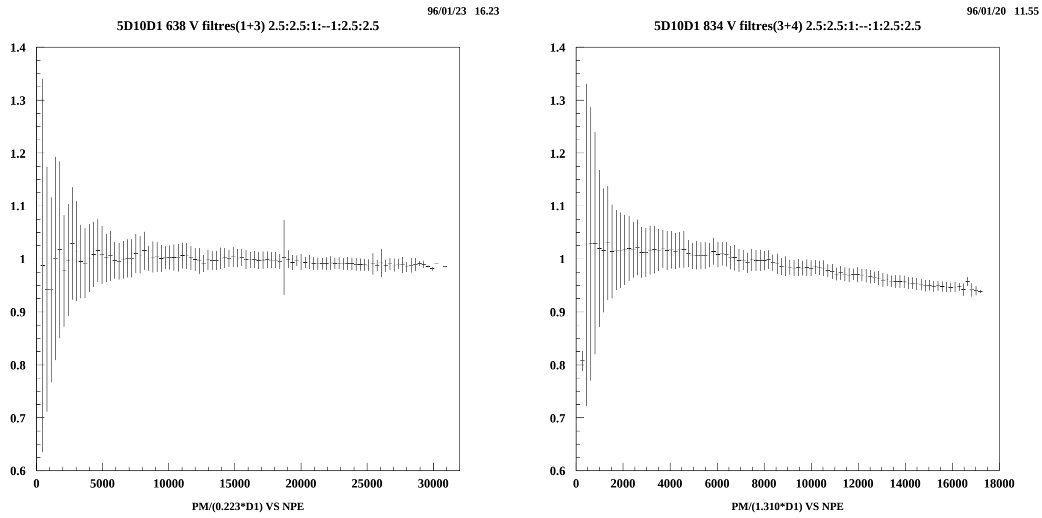


Figure 2 : Differential linearity curve with the 2.5:2.5:1–1:2.5:2.5 repartition. Left part of the figure corresponds to an amplification of 10^5*, right part corresponds to an amplification of* 10^6*.*

Figure (3) represents the linearity deviation (in percent) as a function of the anode current of a set of 5 R5900 PMTs operated with an amplification of 10^5 and a 2:2:2:-1:2:3:2 voltage repartition. The complete data are reported in Table (1). For these tests the pulse width was 50 ns.

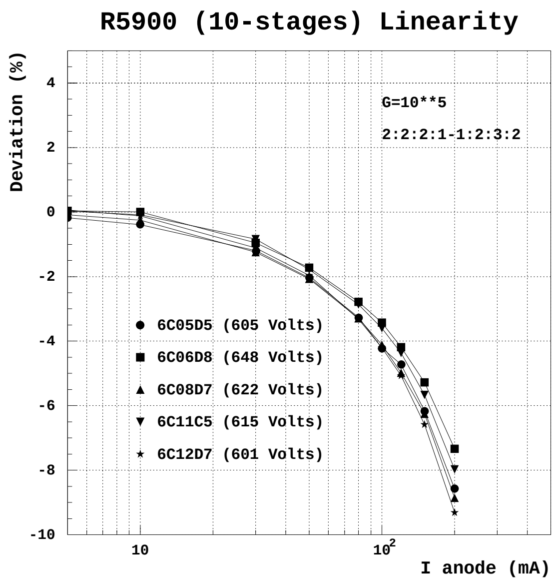


Figure 3 : Linearity test results for 10-stages R5900 operated at 10^5 *with the 2:2:2:1-1:2:3:2 configuration. Pulse width was* $50ns$*.*

In Table (2) the second column indicates, for each value of the anode current, the equivalent number of photoelectrons before amplification. Below an anode current of 30 mA, the linearity deviation is less that 2%. This 30 mA limit corresponds, with an amplification of 10^5, to $N_{p.e}$ equal to 9.4K, and so stays far from the dynamic limit of 50K photoelectrons deduced from the ATLAS specifications.

Figure (4) represents the linearity test results for a specific PMT (6C11C5) operating with the 2:2:2:1-1:2:3:2 voltage repartition but with different HVs and so different amplifications. Table (3-a) summarize the corresponding data and Table (3-b) indicates the correspondance between the anode current and the number of photoelectrons for the different amplifications.

With a high voltage of 500 Volts (amplification $\sim 10^4$) a 2% limit is achieved below 30 mA with no constraint on the photoelectron number.

Increasing the high voltage to 800 Volts (amplification $\sim 10^6$) pushes away the 2% deviation limit. For a 50 mA anode current, the linearity deviation is less than 1%, but now the available photoelectron number range is equal to 16K and so prohibits such a high gain.

700 Volts (amplification $\sim 3 \times 10^5$) seems to be a good compromise between the two constraints, i.e. for an anode current of 50 mA (corresponding to $N_{p.e.}$ equal to 52K), the deviation linearity is of the order of 1%.

Finally these measurements confirm at least qualitatively the choice made for the voltage repartition. Nevertheless one should keep in mind that the pulse width for HAMAMATSU tests is twice the calorimeter pulse width. That is why we operate linearity tests on the set of R5900 shipped to Clermont for the Module 0 preparation.

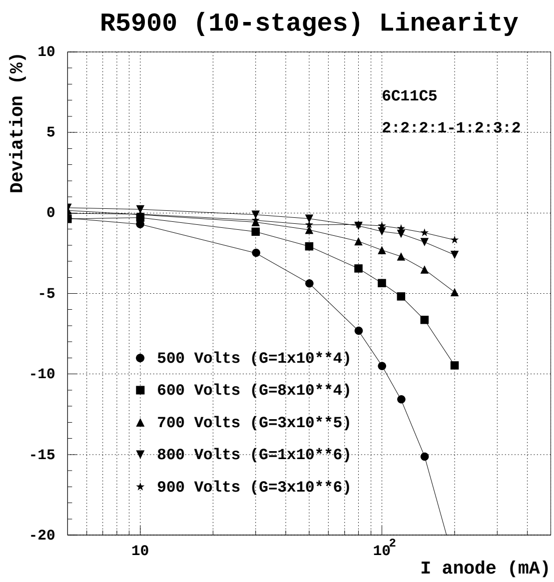


Figure 4 : Linearity test results for 6C11C5 (10-stages) operated at different values of the HV and with the 2:2:2:1-1:2:3:2 configuration.

2. Linearity tests of 15 R5900 PMTs dedicated to Module 0

The 15 R5900 PMTs dedicated to Mmodule 0 had been tested at Clermont with the light sources of a pre-prototype of the final PMT test bench, using fast blue LED. For the linearity tests, the pulsed part of the light source was coupled to a 9-positions neutral filter wheel in order to modulate the light intensity. Now the pulse width was of the order of 20 ns.

After the attenuation filter, the light is focused in a large acceptance liquid fibre that transports the light to the PMT test box. In that PMT box the light is then splitted to 6 channels: 5 PMT dedicated channels and one monitoring channel where the light is read-out by a photodiode.

The photomultiplier tube outputs in response to the light pulses are the charge Q_{PM}, and the photodiode output in response to the same light pulses are the charge Q_{PhD}.

The highest attenuation filter position is used to have a reference assuming that for that position, there is no linearity deviation. So let us call Q_{PM0} and Q_{PhD0} the charges corresponding to that position, i.e. the lowest luminous flux. The deviation from linearity of the PMT at anode current I_a is estimed by the following formula,

$$D(\%) = 100 \times \frac{(Q_{PM}/Q_{Phd}) - (Q_{PM0}/Q_{Phd0})}{(Q_{PM0}/Q_{Phd0})}$$

Results are presented in Figures (5). In Table (4) are reported the corresponding data for a typical PMT (5M26DA), the best linear one (5M27C2), and the worse linear one (5M26CA). The PMT's were operated with an amplification of 10^5 and the 2.5:2.5:1-1:2.5:2.5 voltage repartition

For the typical PMT, $N_{p.e.}$ equal to 50K corresponds to an anode current of 40 mA and so, reading on Figure (5), to a 4% linearity deviation. The test achieved on PMT 5D10D1 (Table (1)) had reported a 5% deviation for $N_{p.e.}$ equal to 70K, i.e. an anode current of 60mA. Figure (5) confirm that value.

For the best linear PMT (5M27C2), the 40 mA anode current corresponds to a 2% linearity deviation. On the other hand the 5M26D8 presents a 10% deviation for 40 mA anode current. It is obvious that these results are very dependant on the reference measurements where errors could be relatively important. But since a set of 5 samples are measured at the same time, it allows a cross-check on the reference measurement of each set of PMTs.

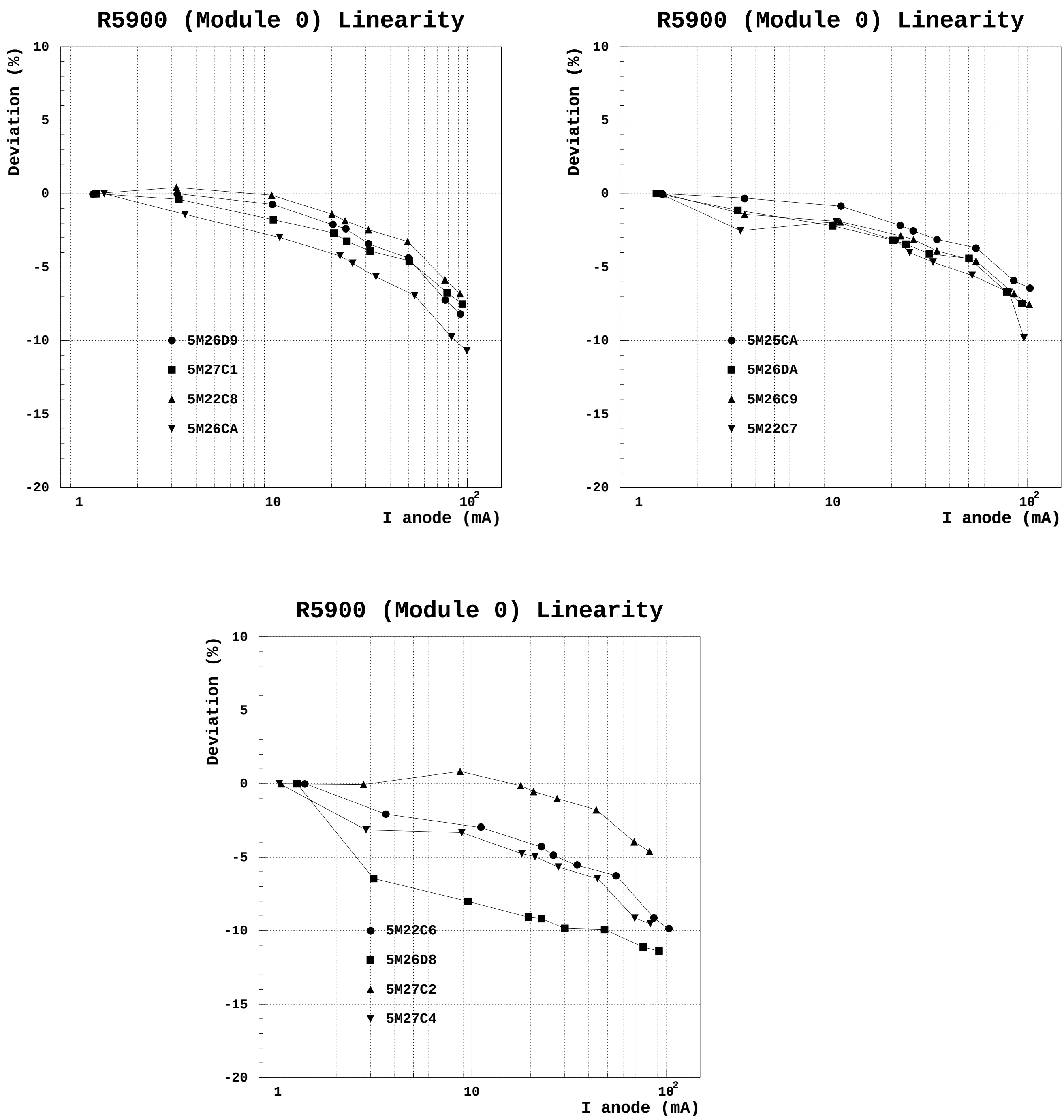


Figure 5 : Linearity test results for Module 0 PMT operated at 10^5 *with the 2.5:2.5:1-1:2.5:2.5 configuration. Pulse width was* $20ns$.

3. Linearity tests of 8-stages R5900 PMTs

Considering the low amplification used to achieve a good linearity, it was of common sense to investigate a 8-stages PMT. So it was requested to HAMAMATSU Photonics to study such a device. Results of linearity test of a set of 8-stages R5900 PMTs are shown in Figures (6) to (10), and the corresponding data are reported in Tables (5) to (9). For all these tests the pulse width was 50 ns.

Figure (6) presents the results for a set of 8-stages PMTs operated at 10^5 with the 2:2:2:1-1:2:3:2 configuration. The associated data are reported in Table (5). Pulse width was 50 ns, and these results could be directly compared to those of Figure (3) corresponding to 10-stages PMTs operated with the same conditions. It appears clearly that for a given value of the anode current (and so a given value of $N_{p.e.}$), the linearity deviation of 8-stages PMTs are lower: for 30 mA the averaged value of the linearity deviation is equal to 1.066% for the 10-stages PMTs instead of 0.45% for the 8-stages PMTs. This could be explained by the voltage repartition: for 10-stages PMTs with an amplification of 10^5 the averaged value of the HT is equal to 618 Volts instead of 727 Volts for 8-stages PMTs. So the interdynode voltage are much higher for the 8-stage configuration, and so could in a easier way overcome the charge space effect.

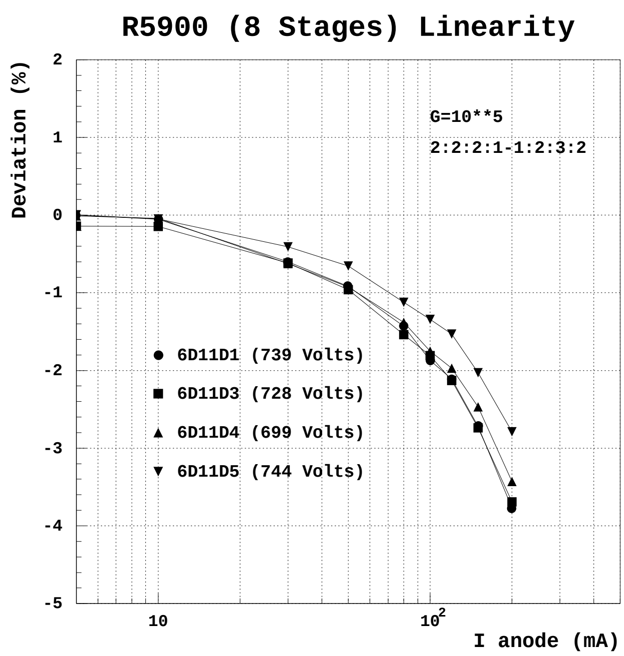


Figure 6 : Linearity test results for 8-stages R5900 operated with an amplification of 10^5 *and a 2:2:2:1-1:2:3:2 configuration. Pulse width was* $50ns$*.*

Figure (7) represents the linearity deviation for a specific 8-stages PMT (6C11C9) operated with different values of the HV (and so with different amplifications). Associated data are reported in Tables (6a) and (6b). It should be directly compared to the Figure (4). Whatever the voltage may be, the 8-stages linearity deviations are lower than those of the 10-stages ones. Moreover it seems that 8-stages PMT allows to operate the PMT at a much lower amplification without a so high linearity deviation: with a high voltage of 600 Volts (corresponding to an amplifcation of $\sim 10^3$) the linearity deviation is less than 1% instead of 2.48 % for a 10-stages PMT with an amplification of 10^4.

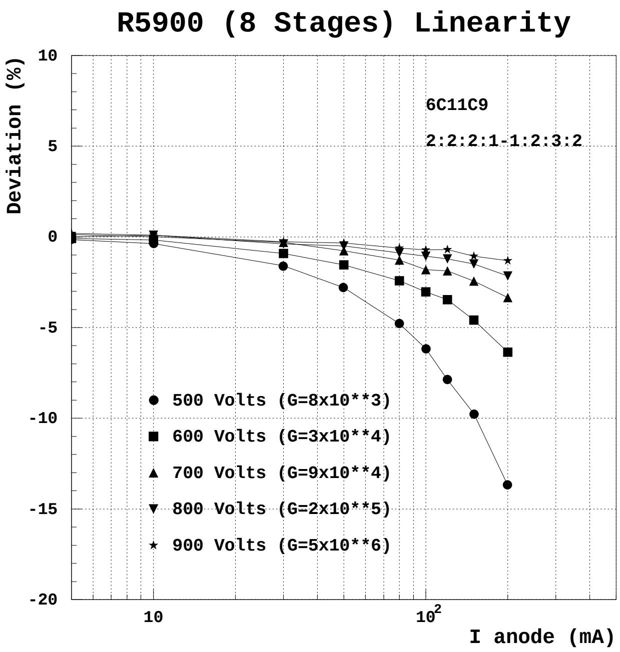
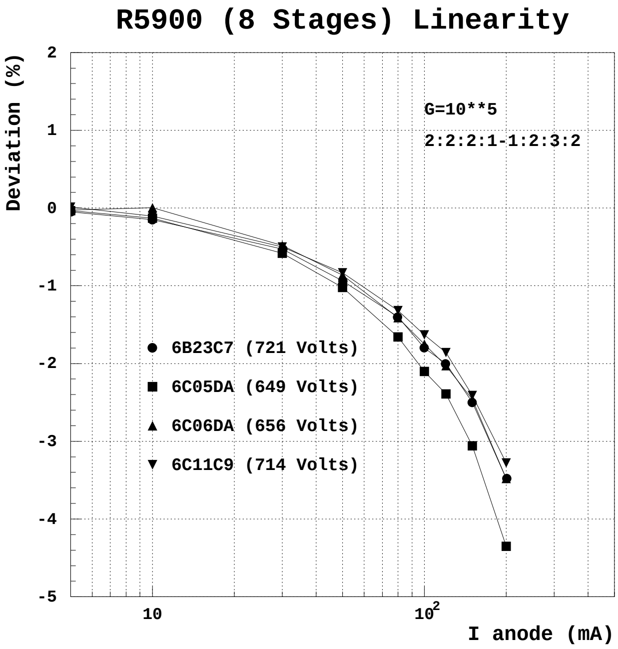


Figure 7 : Linearity test results for 6C11C9 (8-stages) operated with different values of the HV and the 2:2:2:1-1:2:3:2 configuration. For each value of the HV the PMT amplification is indicated.

Figure (8) represents the linearity deviation for a set of 8-stages PMT operated with the same amplification (10^5) but with two different voltage repartitions: a 3:3:3:1-1:2:3:2 and a 2:2:2:1-1:2:3:2 configuration. Associated data are reported in Tables (7a) and (7b). Clearly in the first one, increasing the interdynode voltage on the first stages has the consequence to decrease the electric field in the final stages. The overall result is that for 30mA anode current the averaged value of the linearity deviation is equal to 0.827% for the 3:3:3:1-1:2:3:2 repartition instead of 0.503% for the 2:2:2:1-1:2:3:2 repartition.



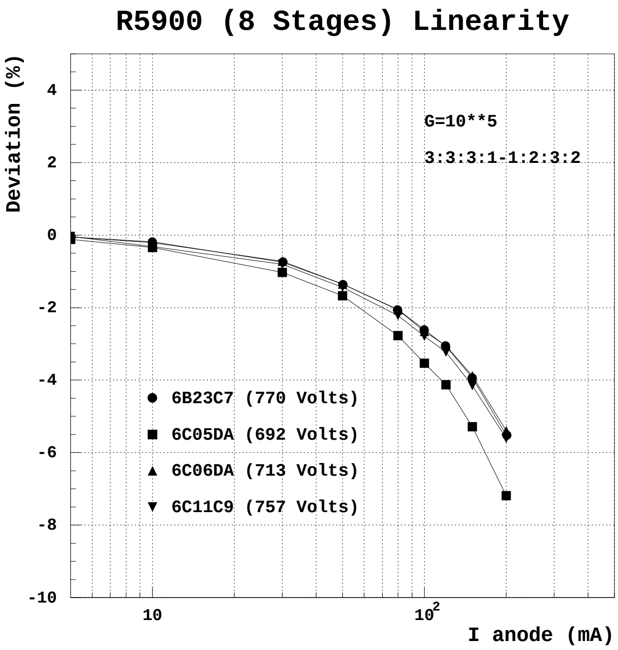


Figure 8 : Comparison of linearity test results for 8-stages R5900 operated with an amplification of 10^5*, the 3:3:3:1-1:2:3:2 (top) and 2:2:2:1-1:2:3:2 (bottom) configuration. Pulse width was* $50ns$*.*

Figure (9) represents the linearity deviation for a specific 8-stages PMT (6C11C9) operated with different values of the HV (and so with different amplification). Associated data are reported in Tables (8a) and (8b). It should be directly compared to the Figure (7) and the Tables (6a) and (6b). For a high voltage of 800 Volts, the resulting amplification is quite the same $\sim 2 \times 10^5$, and there again the 2:2:2:1-1:2:3:2 repartition corresponds to a lower linearity deviation. But now with the 3:3:3:1-1:2:3:2 one could go down to an amplification of 6×10^3 with a 4% linearity deviation. On the other side, assuming a maximum voltage of 900 Volts, the maximum amplification goes down only to 3×10^5. That means that one has with that 3:3:3:1-1:2:3:2 repartition a safety factor of only 3 to compensate a long term aging.

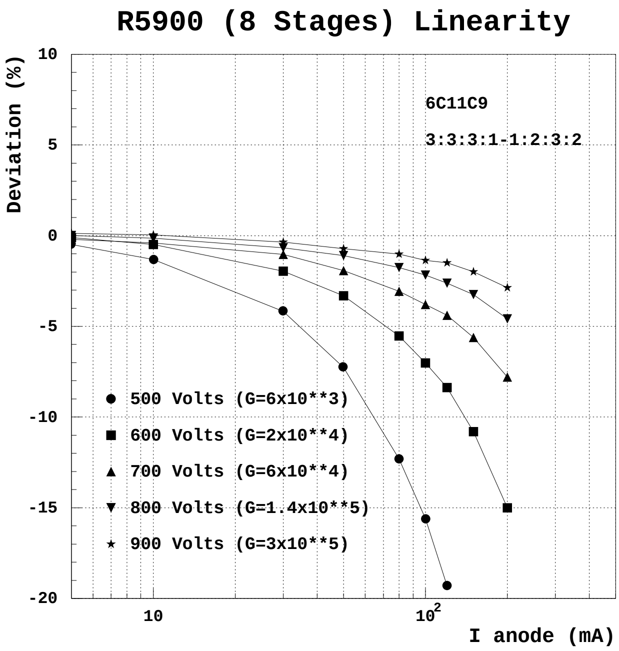


Figure 9 : Linearity test results for 6C11C9 (8-stages) operated with different values of the HV and with the 3:3:3:1-1:2:3:2 configuration.

Variations in the voltage repartition are shown on Figure (10) for a specific 8-stages PMT (6C05DA) operated with an amplification of 10^5.Associated data are reported in Table (9). The tested repartition and corresponding voltage were:

A: 1.5:1.5:1.5:1:1:1:1:1:0.5 $\longrightarrow$ 560 Volts

B: 1:1:1:1:1:1:1:1:1 $\longrightarrow$ 574 Volts

C: 2:2:1:1:1:1:1:1:2 $\longrightarrow$ 684 Volts

D: 2:2:1:1:1:1:1:2:3 $\longrightarrow$ 730 Volts

E: 2:2:1:1:1:1:2:3:3 $\longrightarrow$ 717 Volts

F: 2:2:1:1:1:1:2:3:2 ⟶ 675 Volts

G: 2:2:1:1:1:1:2:2:2 ⟶ 659 Volts

For an anode current of 30mA, the lowest linearity deviation is achieved for the repartition F (2:2:1:1:1:1:2:3:2), with a voltage of 675 Volts. It could be compared to the isorepartition B (1:1:1:1:1:1:1:1:1) for which the deviation is of the order of 1%. The worse configuration is A (1.5:1.5:1.5:1:1:1:1:1:0.5) that correspond to 2% deviation but only 560 Volts (and so the possibility to have a large amplification range when increasing the voltage up to 900 Volts).

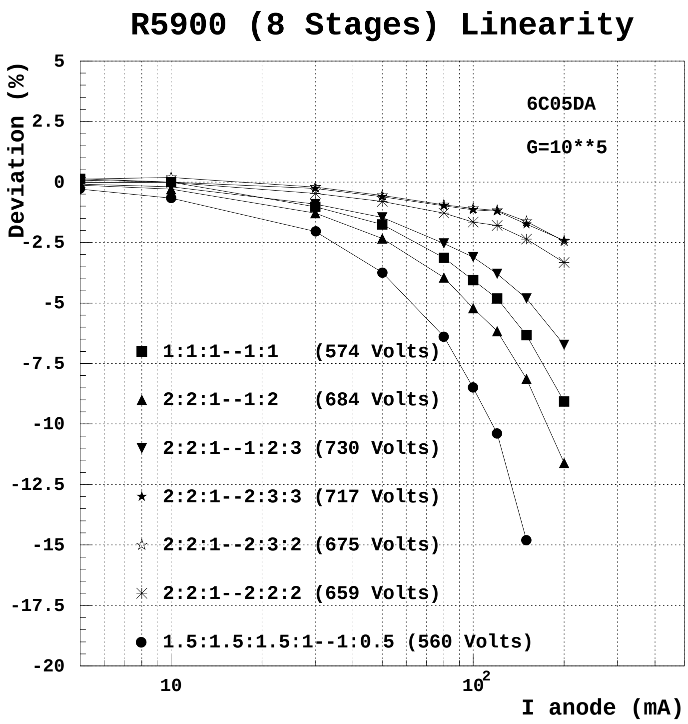


Figure 10 : Linearity test results for a 8-stages R5900 (6C05DA) operated with an amplification of 10^5 *and with different voltage configurations.*

4. Conclusions

Linerarity performances are directly related to the voltage repartition. The first optimisation of that repartition lead to a symmetric 2.5:2.5:1:1:1:1:1:1:1:2.5:2.5 configuration. This repartition had been at least qualitatively confirmed in an independant way by HAMAMATSU results, even though their tests had been performed with a pulse width more than two times larger than calorimeter pulse one.

Moreover the previous results had been also confirmed by the linearity tests performed on a set of 15 PMTs dedicated to Module 0. In addition the Module 0 PMTs test indicate, that even on such a low number of samples, there is a dispersion in the linearity performance, since one PMT presents a prohibitive linearity performance. This demonstrates that the linearity should be tested for each PMT with the final test bench.

From some times, it was obvious that the nominal design of the R5900 (10 stages with a nominal amplification of 10^5 at 800 Volts) is not the optimum design for the ATLAS configuration. The low amplification specification brings to consider very seriously a 8-stages configuration. That is why it was requested to HAMAMATSU Photonics to investigate a 8-stage R5900 configuration. The preliminary results confirm that this solution gives a better linearity in comparison with the 10-stages configuration for the ATLAS dynamical specifications.

Clearly this configuration should be tested more carefully before a definitive conclusion. For example, the linearity tests should be performed again with a correct pulse width, of the order of 20 ns. Moreover further tests should be done on the dynamic stability of the 8-stages R5900 PMTs with a DC background like in the final ATLAS configuration.

Nevertheless the 8-stages R5900 PMTs could be a significant improvement for the TILECAL light read-out system.

5. Data

Voltage Divider Config.	Dev. (%) G=10^5	Dev. (%) G=10^6
1:1:1—-1:1	-10.	-14.3
1.2:1.5:1.8—-1.5:1.5	-4.9	-7.3
2.5:1:1—-1:2.5	-9.5	-14.3
2.5:2.5:1—-2.5:2.5	-4.5	-7.1
1:1:1–0.5–1:1	-7.8	-9.3

Table 1 : Results of linearity tests performed on 5D10D1 PMT for different voltage divider configurations and two amplification: 10^5 *and* 10^6*. Linearity deviation had been measured using the YLF laser with the experimental set-up shown in Figure (1). Linearity deviation measured at* 10^5 *(*10^6*) corresponds to* $N_{p.e.}$ *equal to 70K (15K) respectively.*

		6C05D5 (605V)	**6C06D8** (648V)	**6C08D7** (622V)	**6C11C5** (615V)	**6C12D7** (601V)
I_p (mA)	N_{pe} (K)	Dev. (%)	Dev. (%)	Dev. (%)	Dev. (%)	Dev. (%)
1	3.12	0.	0.	0.	0.	0.
5	15.6	-.177	.037	-.085	.029	.065
10	31.25	-.391	.002	-.252	-.090	-.122
30	93.75	-1.19	-.956	-1.24	-.835	-1.11
50	156.25	-2.04	-1.72	-2.07	-1.78	-1.96
80	250.0	-3.26	-2.78	-3.29	-2.86	-3.32
100	312.5	-4.21	-3.43	-4.11	-3.60	-4.20
120	375.0	-4.72	-4.19	-4.98	-4.37	-5.07
150	468.75	-6.16	-5.28	-6.25	-5.67	-6.58
200	625.	-8.58	-7.34	-8.68	-7.97	-9.31

Table 2 : Linearity test results for 10-stages R5900 PMTsoperated with an amplification of 10^5 *and the 2:2:2:1-1:2:3:2 configuration. Pulse width was* $50ns$ *and the second column gives the corresponding photoelectron number for each value of the anode current.*

	500V (1×10^4)	**600V** (8×10^4)	**700V** (3×10^5)	**800V** (1×10^6)	**900V** (3×10^6)
I_p (mA)	Dev. (%)	Dev. (%)	Dev. (%)	Dev. (%)	Dev. (%)
1	0.	0.	0.	0.	0.
5	-.326	-.037	.151	.328	-.03
10	-.699	-.285	-.108	.232	-.068
30	-2.48	-1.17	-.571	-.108	-.456
50	-4.37	-2.08	-1.05	-.346	-.741
80	-7.32	-3.45	-1.76	-.792	-.711
100	-9.48	-4.36	-2.31	-1.15	-.807
120	-11.6	-5.19	-2.70	-1.29	-.960
150	-15.1	-6.63	-3.51	-1.81	-1.23
200	-21.8	-9.46	-4.92	-2.61	-1.68

Table 3-a : Linearity test results for 6C11C5 (10-stages) operated with different values of the HV and the 2:2:2:1-1:2:3:2 configuration. For each value of the HV the PMT amplification is indicated.

	500V (1×10^4)	**600V** (8×10^4)	**700V** (3×10^5)	**800V** (1×10^6)	**900V** (3×10^6)
I_p (mA)	N_{pe} (K)	N_{pe} (K)	N_{pe} (K)	N_{pe} (K)	N_{pe} (K)
5	156.2	19.5	5.2	1.56	.5
10	312.4	39.	10.4	3.12	1.
30	937.2	117.	31.2	9.36	3.
50	1562	195	52	15.6	5.2

Table 3-b : Correspondance between the anode current (mA) and the photelectron number (10^3) for each value of the HV, and so of the PMT amplification. The configuration was 2:2:2:1-1:2:3:2.

5M27C2 (683V)			5M26DA (669V)			5M26CA (605V)		
I_p (mA)	N_{pe} (K)	Dev. (%)	I_p (mA)	N_{pe} (K)	Dev. (%)	I_p (mA)	N_{pe} (K)	Dev. (%)
1.04	1.3	0.	1.23	1.54	0.	1.34	1.67	0.
2.76	3.4	-.05	3.23	4.03	-1.13	3.52	4.4	-1.14
8.70	10.9	.84	9.95	12.44	-2.2	10.79	13.5	-2.97
17.83	22.3	-.13	20.4	25.5	-3.17	22.06	27.6	-4.23
20.80	26.	-.55	23.82	29.8	-3.45	25.69	32.1	-4.74
27.49	34.36	-1.03	31.43	39.3	-4.1	33.80	42.3	-5.65
43.77	54.71	-1.78	50.25	62.81	-4.48	53.48	66.9	-6.93
68.57	85.71	-3.6	78. 6	98.25	-6.68	83.09	104.	-9.77
82.36	103.	-4.6	94.24	117.8	-7.48	99.46	124.	-10.7

Table 4: Linearity test results for Module 0 PMT operated with an amplification of 10^5 *and the 2.5:2.5:1-1:2.5:2.5 configuration. 5M26DA data corresponds to a typical behaviour in the set of 15 R5900 tested. 5M27C2 and 5M26CA data correspond to extremum. Pulse width was* $20ns$ *and the second column gives the corresponding photo-electron number for each value of the anode current.*

		6D11D1 (739V)	6D11D3 (728V)	6D11D4 (699V)	6D11D5 (744V)
I_p (mA)	N_{pe} (K)	Dev. (%)	Dev. (%)	Dev. (%)	Dev. (%)
1	3.12	0.	0.	0.	0.
5	15.6	.001	-.143	-.011	.004
10	31.25	-.052	-.146	-.043	-.05
30	93.75	-.601	-.617	-.623	-.409
50	156.25	-.918	-.960	-.927	-.654
80	250.0	-1.43	-1.54	-1.38	-1.12
100	312.5	-1.87	-1.81	-1.75	-1.34
120	375.0	-2.11	-2.13	-1.97	-1.53
150	468.75	-2.72	-2.74	-2.47	-2.03
200	625.	-3.77	-3.69	-3.43	-2.79

Table 5 : Linearity test results for 8-stages R5900 operated with an amplification of 10^5 *and the 2:2:2:1-1:2:3:2 configuration. Pulse width was* $50ns$ *and the second column gives the corresponding photoelectron number for each value of the anode current.*

	500V (8×10^3)	**600V** (3×10^4)	**700V** (9×10^4)	**800V** (2×10^5)	**900V** (5×10^5)
I_p (mA)	Dev. (%)	Dev. (%)	Dev. (%)	Dev. (%)	Dev. (%)
1	0.	0.	0.	0.	0.
5	-.149	-.096	124	-.011	.187
10	-.375	-.172	.016	.098	.085
30	-1.60	-.916	-.311	-.381	-.276
50	-2.80	-1.55	-.767	-.509	-.334
80	-4.76	-2.42	-1.28	-.876	-.622
100	-6.16	-3.03	-1.61	-1.07	-.718
120	-7.68	-3.47	-1.67	-1.21	-.699
150	-9.75	-4.56	-2.43	-1.50	-1.06
200	-13.7	-6.36	-3.34	-2.15	-1.31

Table 6a : Linearity test results for 6C11C9 (8-stages) operated with different values of the HV and the 2:2:2:1-1:2:3:2 configuration. For each value of the HV the PMT amplification is indicated.

	500V (8×10^3)	**600V** (3×10^4)	**700V** (9×10^4)	**800V** (2×10^5)	**900V** (5×10^5)
I_p (mA)	N_{pe} (K)	N_{pe} (K)	N_{pe} (K)	N_{pe} (K)	N_{pe} (K)
5	195.3	52.1	17.4	7.8	3.
10	390.6	104.2	34.7	15.6	6.
30	1172.	313	104	46.8	18.

Table 6b : Correspondance between the anode current (mA) and photelectron number (10^3) for each value of the HV, and so of the PMT amplification. The configuration was 2:2:2:1-1:2:3:2.

		6B23C7 (721V)	**6C05DA** (649V)	**6C06DA** (656V)	**6C11C9** (714V)
I_p (mA)	N_{pe} (K)	Dev. (%)	Dev. (%)	Dev. (%)	Dev. (%)
1	3.12	0.	0.	0.	0.
5	15.6	-.051	-.034	-.028	.011
10	31.25	-.149	-.129	.004	-.105
30	93.75	-.528	-.583	-.482	-.499
50	156.25	-.936	-1.02	-.863	-.833
80	250.0	-1.40	-1.66	-1.41	-1.32
100	312.5	-1.80	-2.10	-1.75	-1.63
120	375.0	-2.00	-2.39	-2.03	-1.86
150	468.75	-2.50	-3.06	-2.46	-2.41
200	625.	-3.48	-4.35	-3.48	-3.28

Table 7a : Linearity test results for 8-stages R5900 operated with an amplification of 10^5 *and the 2:2:2:1-1:2:3:2 configuration. Pulse width was* $50ns$ *and the second column gives the corresponding photoelectron number for each value of the anode current.*

		6B23C7 (770V)	**6C05DA** (692V)	**6C06DA** (713V)	**6C11C9** (757V)
I_p (mA)	N_{pe} (K)	Dev. (%)	Dev. (%)	Dev. (%)	Dev. (%)
1	3.12	0.	0.	0.	0.
5	15.6	-.056	-.121	-.005	-.033
10	31.25	-.182	-.341	-.212	-.315
30	93.75	-.749	-1.03	-.722	-.808
50	156.25	-1.35	-1.67	-1.35	-1.44
80	250.0	-2.05	-2.77	-2.06	-2.22
100	312.5	-2.61	-3.53	-2.66	-2.79
120	375.0	-3.07	-4.13	-3.05	-3.23
150	468.75	-3.93	-5.29	-3.88	-4.15
200	625.	-5.52	-7.19	-5.39	-5.61

Table 7b : Linearity test results for 8-stages R5900 operated with an amplification of 10^5 *and the 3:3:3:1-1:2:3:2 configuration. Pulse width was* $50ns$ *and the second column gives the corresponding photoelectron number for each value of the anode current.*

	500V (6×10^3)	**600V** (2×10^4)	**700V** (6×10^4)	**800V** (1.4×10^5)	**900V** (3×10^5)
I_p (mA)	Dev. (%)	Dev. (%)	Dev. (%)	Dev. (%)	Dev. (%)
1	0.	0.	0.	0.	0.
5	-.478	-.114	-.201	.014	.124
10	-1.31	-.482	-.398	-.145	.047
30	-4.17	-1.95	-1.03	-.669	-.348
50	-7.27	-3.32	-1.92	-1.09	-.712
80	-12.3	-5.53	-3.06	-1.76	-1.01
100	-15.6	-7.01	-3.80	-2.18	-1.37
120	-19.3	-8.38	-4.38	-2.62	-1.50
150		-10.8	-5.62	-3.24	-1.99
200		-15.0	-7.80	-4.58	-2.86

Table 8a : Linearity test results for 6C11C9 (8-stages) operated with different values of the HV and the 3:3:3:1-1:2:3:2 configuration. For each value of the HV the PMT amplification is indicated.

	500V (6×10^3)	**600V** ($2 \times 10^{4)}$	**700V** (6×10^4)	**800V** (1.4×10^5)	**900V** (3×10^5)
I_p (mA)	N_{pe} (K)	N_{pe} (K)	N_{pe} (K)	N_{pe} (K)	N_{pe} (K)
5	260	75.3	26	11.	5.2
10	521	156.	52.	22.3	10.4
30	1563.	468.	156.	67.	31.

Table 8b : Correspondance between the anode current (mA) and photelectron number (10^3) for each value of the HV, and so of the PMT amplification. The configuration was 3:3:3:1-1:2:3:2.

		A (560V)	**B** (574V)	**C** (684V)	**D** (730V)	**E** (717V)	**F** (675V)	**G** (659V)
I_p (mA)	N_{pe} (K)	Dev. (%)	Dev. (%)	Dev. (%)	Dev. (%)	Dev. (%)	Dev. (%)	Dev. (%)
1	3.12	0.	0.	0.	0.	0.	0.	0.
5	15.6	-.291	.128	-.124	-.093	.084	.116	-.016
10	31.25	-.659	-.008	-.299	-.193	-.01	.189	-.018
30	93.75	-2.05	-1.02	-1.29	-.913	-.264	-.217	-.475
50	156.25	-3.74	-1.75	-2.33	-1.46	-.608	-.559	-.807
80	250.0	-6.39	-3.13	-3.95	-2.54	-.986	-.944	-1.28
100	312.5	-8.5	-4.05	-5.21	-3.11	-1.15	-1.09	-1.66
120	375.0	-10.4	-4.81	-6.16	-3.79	-1.21	-1.18	-1.79
150	468.75	-14.8	-6.33	-8.13	-4.82	-1.74	-1.63	-2.36
200	625.		-9.07	-11.6	-6.73	-2.42	-2.45	-3.33

Table 9 : Linearity test results for a 8-stages R5900 (6C05DA) operated with an amplification of 10^5 *and different configurations. Pulse width was* $50ns$ *and the second column gives the corresponding photoelectron number for each value of the anode current.*