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Ageing Measurements For The PS MultiAnode PhotoMultipliers Tubes

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1 Introduction

Multi-Anode PhotoMultiplier Tubes (MA-PMT) were found to be the best candidates for the read-out of the scintillator light of both the SPD and PS detectors. The basic characteristics of the MA-64 PMTs from the Hamamatsu company were considered as a baseline for the design of the VFE electronics for these two detectors.

In a recent period, the choice of the MA-PMT base, which defines the way the interdynode voltages are set, has been scrutinized. A key parameter for the correct behaviour of the MA-PMT is the average anode current [1]. This quantity has been estimated, in the framework of a first VFE electronics [2], from the energy deposits in the detector with simulated events for all the anodes of all the MA-PMT, symetrically for SPD and PS .

The results of these computations revealed two main issues : the first one is that the average anode currents for some MA-PMTs are beyond the specifications of the constructor, as far as the PS is concerned, requiring minimally the design of a dedicated base. The second one, far more critical, concerns the ageing of the photodetector. Dedicated studies showed that the gain of the MA-PMT when operated at large average anode current is rapidly decreasing, which prevents a correct operation of a large part of the photomultiplier channels.

The extrapolation of these ageing results to lower currents indicates that a decrease of the gain by a factor 10 would provide acceptable conditions for the operation of the photomultiplier. A dedicated experiment has been conducted to validate this choice and its results and major issues are discussed in this document. The choice of this new MA-PMT working point implied a full redesign of the first stage of the VFE electronics of the PS , ginving so far satisfactory performance. Furthermore, since the PMT gain for a typical channel is low (few 10^3), the 12-stages MA-PMT, considered as the baseline candidate until now, is not convenient anymore. The tests have been therefore conducted with a 8-stages MA-PMT.

The first section of the note exposes the framework of the ageing problem. The second section summarises the ageing results obtained with a test bench specially set up in Clermont-Ferrand. The third part of this document deals with specific studies of the short-term drifts of the MA-PMT in order to check different models of ageing. Eventually, the conclusion evokes the immediate actions which are underway and the short term perspectives in terms of the choice of the MA-PMT and the redesign of the electronics for the Preshower.

2 Position of the problem

Most of the estimates and results presented in this section are extracted from the reference [1]. The interested reader could find in it the detailed explanations of the computations or definitions of the various quantities used in the following.

The mean current on each anode of the MA-PMTs can be obtained through the following relation :

$$\bar{\mathbf{I}}_{\mathbf{(Ampere)}} \quad = \quad \bar{\mathbf{Q}}_{\mathbf{(Coulomb/MeV)}} \; * \; \bar{\mathbf{E}}_{\mathbf{(MeV/Event)}} \; * \; \bar{\mathcal{F}}_{\mathbf{e(Event/second)}}$$

where

- $\bar{\mathcal{F}}_{e(Event/second)}$ is the average event frequency.
- $\bar{E}_{(MeV/Event)}$ is the mean energy deposit in scintillator tile per event.
- $\bar{Q}_{(Coulomb/MeV)}$ is the total charge on the corresponding MA-PMT anode per unit of energy deposit.

All ingredients needed for the estimation of the mean anodic PS and SPD currents are summarized below :

- The event frequency $\bar{\mathcal{F}}_e = 14.75\ MHz$.
- The mean event deposit $\bar{E}_{(MeV/Event)}$ from an energy mapping computed with simulated events.
- The reference anodic charge $\bar{Q}^{\text{Ps}}_{ref} = 160 fC/mip$.
- The MA-PMT gain non-uniformities mapping convoluted with 15% light yield non-uniformity.
- The mip to MeV conversion factor : 1 MeV= 2.85 mip .

The resulting mean Ps currents for each channel of the MA-PMT are displayed in Fig. 1. The maximal current reaches 3.5 μA in the hottest channel and 0.3 μA on average over Ps .

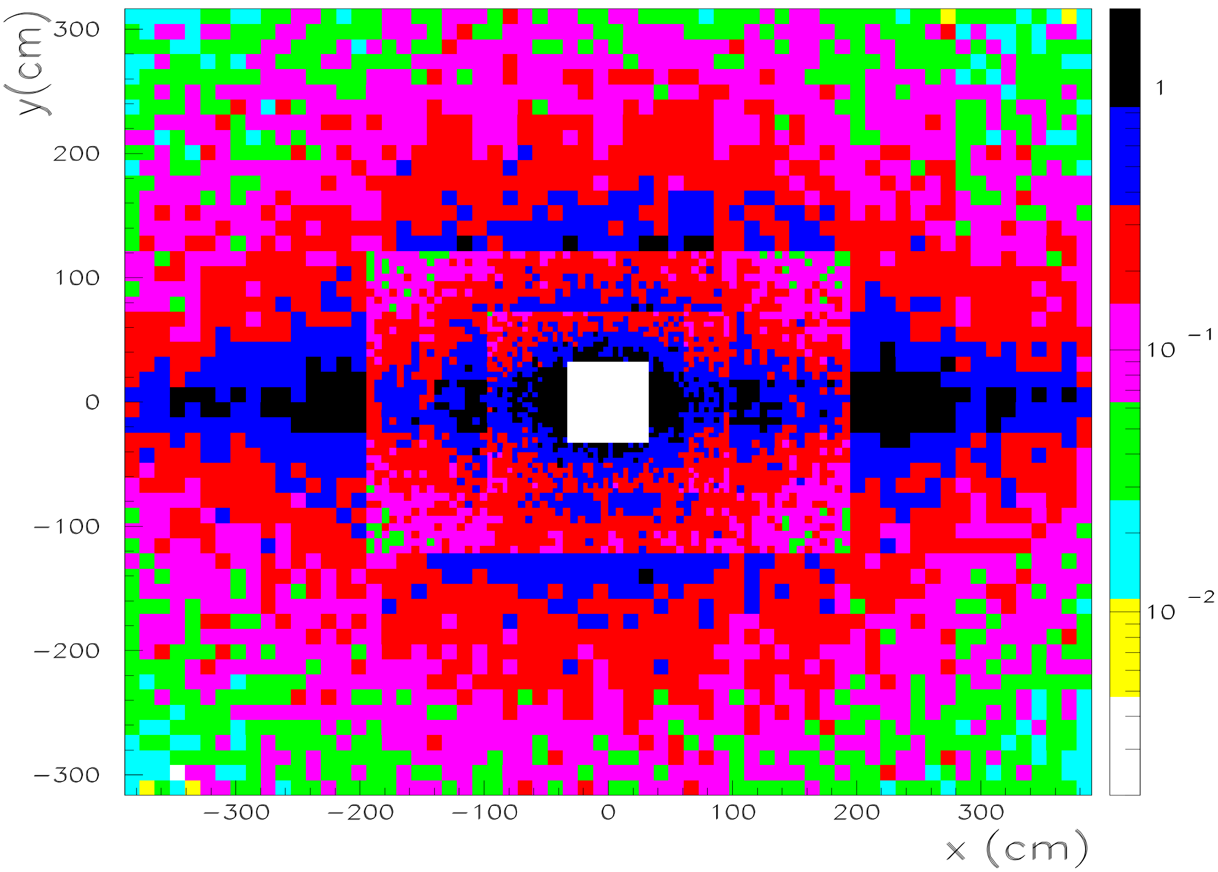

Figure 1: Mean current (μA) in each Ps channel.

2.1 Behaviour of the MA-PMT under high mean currents

The values displayed in Fig. 1 are far beyond the Hamamatsu base specifications, that could support a 18 μA maximal current and most of the MA-PMT in each calorimetric region exceed this limitation. Moreover, such large currents correspond to a mean charge of ~ 5 Coulomb per day for the hottest Ps MA-PMTs, that might lead to a fast depletion of the Cs layers of the last metal channel dynodes of the amplification chain.
A two-months duration test of the behaviour of MA-PMT under such currents has been completed at the end of summer 2002 and is described in [1]. Let recall here the main features. Figure 2

shows the current response of the MA-PMT channel continuously illuminated as a function of the time. A sharp exponential decrease was observed in the first part of the distribution. The physical explanation is related to the structure of the metal dynode channels : the Cs layer above the subtract is continuously depleted and then is less contributing to the secondary electrons emission. Once this layer is fully depleted, a less violent decrease of the gain (that can be considered linear along the duration of the test) is observed.

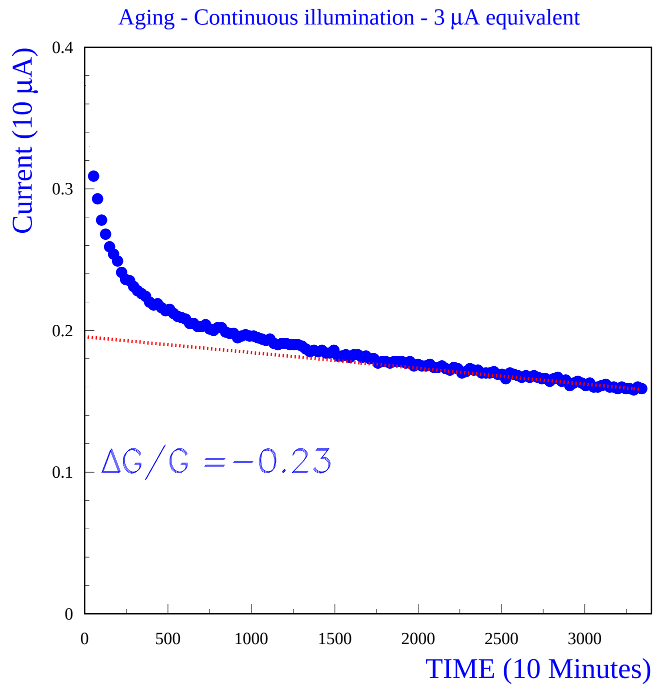

Figure 2: Distribution of the MA-PMT output as a function of the operation time for a continuous illumination.

The same qualitative behaviour has been observed for the other four channels under scrutiny, intermittently illuminated. The hypotheses of a gain recovery in absence of a light stress on one hand and after a period of rest on the other hand have been tested. No significant gain recovery is observed in absence of light stress, while some recovery was achieved after a period of rest (no HV) of one week.

When extrapolating to one LHCb year (taking into account a further time acceleration factor to deal with the ultimate non-uniformities [1]), it has been figured out that a significant fraction of the PMTs showed large gain non-uniformities in addition to the gain variations given in Fig. 2; both could not be controlled.

The same picture was drawn by considering ten times less current at the MA-PMT anodes. The overall picture became acceptable and should be considered as our definite working point. The currents assumed by now are those of the Fig. 1 divided by 10 and it is mandatory to check the behaviour of the PMT channels under those conditions. This is the purpose of the measurement campaign described in the next section.

[1] This time acceleration factor expresses the dependence of the ageing upon both the integrated charge and the current.

3 New campaign of ageing meaurements

The performance of the 8-stages MA-PMT were studied with the generic test bench [3] developped in Clermont prior to the ageing measurement. In particular, the linearity of the MA-PMT has been improved by optimizing the resistor values of an home-made active base [4]. The PMT supply voltage is 610 V for the new workimg point (G=5.10^3).
The main changes in the ageing test bench with respect to the previous campaign concern the light system. The other elements of the test bench are described in [1].

3.1 The experimental setup

The sketch of the test bench is shown Fig. 3. The monitoring of the light system and the data acquisition is performed with an electronics board controlling the input/output from the parallel port of a PC, through a Labview program.

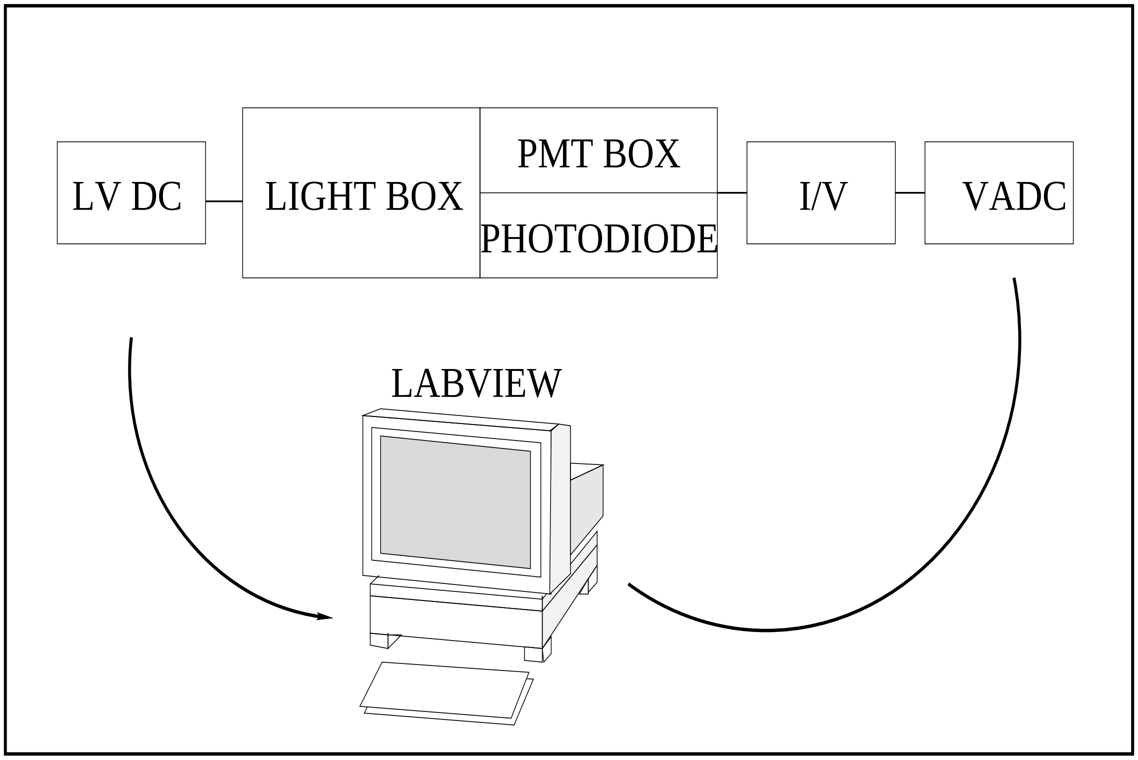

Figure 3: Sketch of the experimental setup for the ageing test bench.

The light system is composed of one blue LED, supplied at nominal values (6V, 30 mA). The light yield is on one hand filtered and sent to a seven-fibres(clear, 1 mm diameter) bundle, each fibre being sent to one channel of the MA-PMT. On the other hand, the unfiltered light is sent through another clear fibre to a photodiode, aimed at controlling the light changes. The Figure 4 shows the photodiode measurement of the light yield. Except the jump in the beginning of the test identically seen by all the photodetectors, the light variations are found to be small. Anyway, the variations seen by the photodiode are used to correct the PMT responses.
The illumination of the seven PMT channels is continuous, since no recovery was observed while intermittently illuminating. Nevertheless, it is likely that this non-recovery fact holds only in the case of the very high currents as it will be discussed in the next section.
The filter after the LED was set as to give a 300 nA signal at the hottest anode, as defined in Section 2. The current output ranges therefore from 120 nA to 300 nA for the seven instrumented

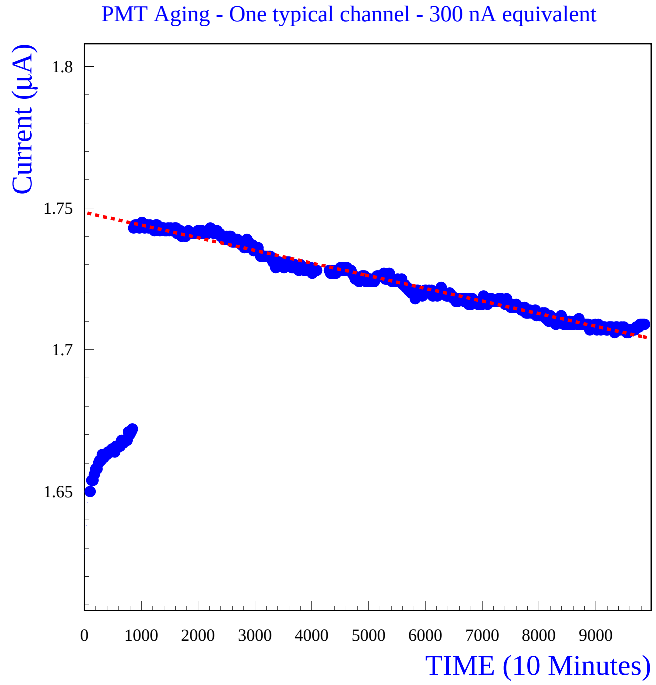

Figure 4: Variation of the light yield seen by the photodiode.

channels. In such conditions, contrarily to the previous test, the overall average anode current is well below the maximal value specified by the constructor.

The acquisition of the MA-PMT signals is performed by a 10 bits voltage ADC (included in the PPIO board and monitored with Labview) after a current/voltage conversion.

3.2 The results

Figure 5 shows the current response of the MA-PMT channel continuously illuminated at the level of 300 nA as a function of time. The duration of the test corresponds to one LHCb-year. The fit to the data by a straight line is performed for the last two months and a half. An up-drift is observed for all the seven channels and the overall amplitude is larger than 10%. Though, a stabilisation of the PMT response occurs after a month and a half and the fit to the data by a straight line is performed for the last two months and a half, when the PMT is stable.

The physical explanation is related to the structure of the metal dynode channels, as underlined in Fig. 6 : Cs atoms are implanted in the dynode to reduce the extraction energy of the electrons, giving a layered structure of the metal dynodes; the first Cs layer beyond the subtract (quasi monoatomic) has the effect of enhancing the secondary emission, while the Cs layer deposited in excess in the industrial process reduces it by recombination. Under important light stress as in the previous test, the monoatomic Cs layer is rapidly depleted yielding the sharp exponential decrease displayed Fig. 2. On the contrary, under light stresses as set in this experiment, the second Cs layer shall be depleted smoothly yielding an enhanced secondary emission and then a small up-drift.

The same qualitative behaviour has been observed, as shown Fig. 7, for the six other channels. For the seventh channel, a small decrease of the gain is observed, which could be interpreted as a complete depletion of the Cs layer in excess.

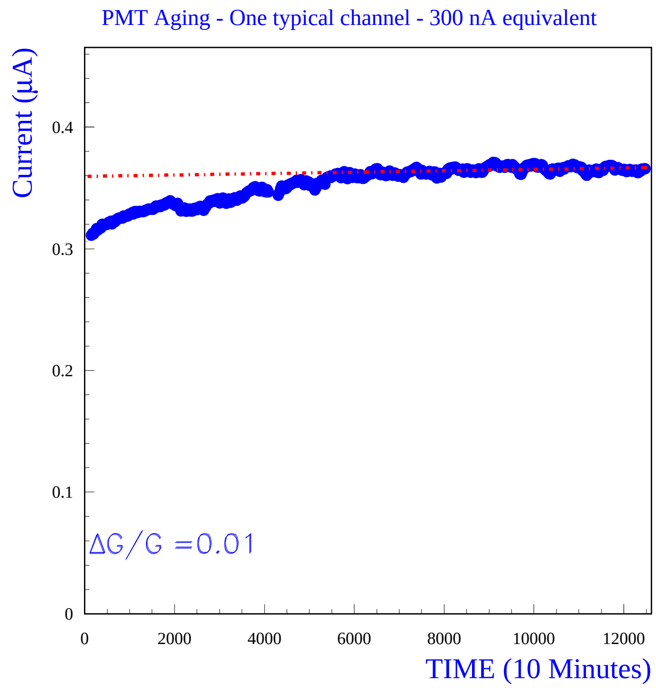

Figure 5: Distribution of the MA-PMT output as a function of the operation time (100 days).

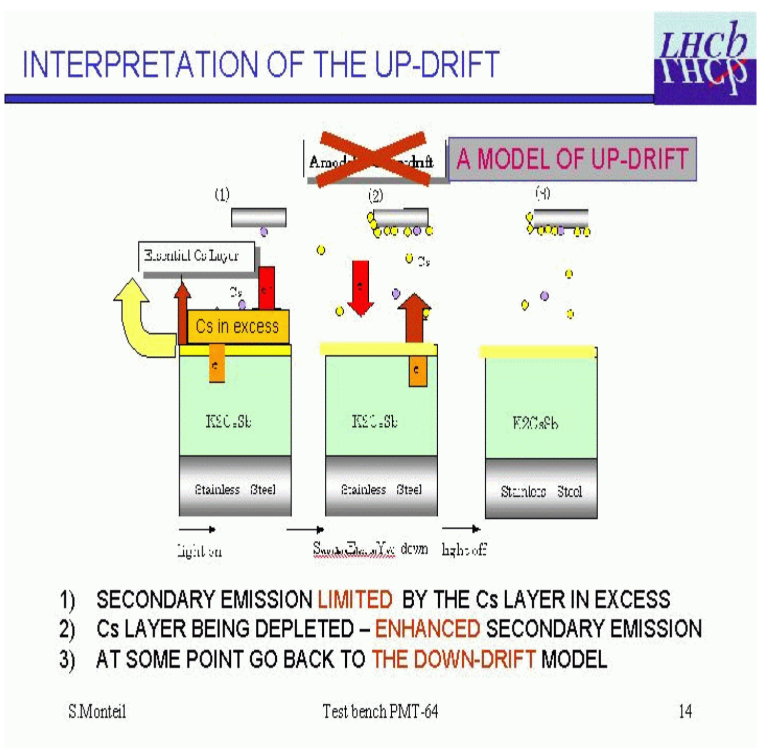

Figure 6: A model of up-drift.

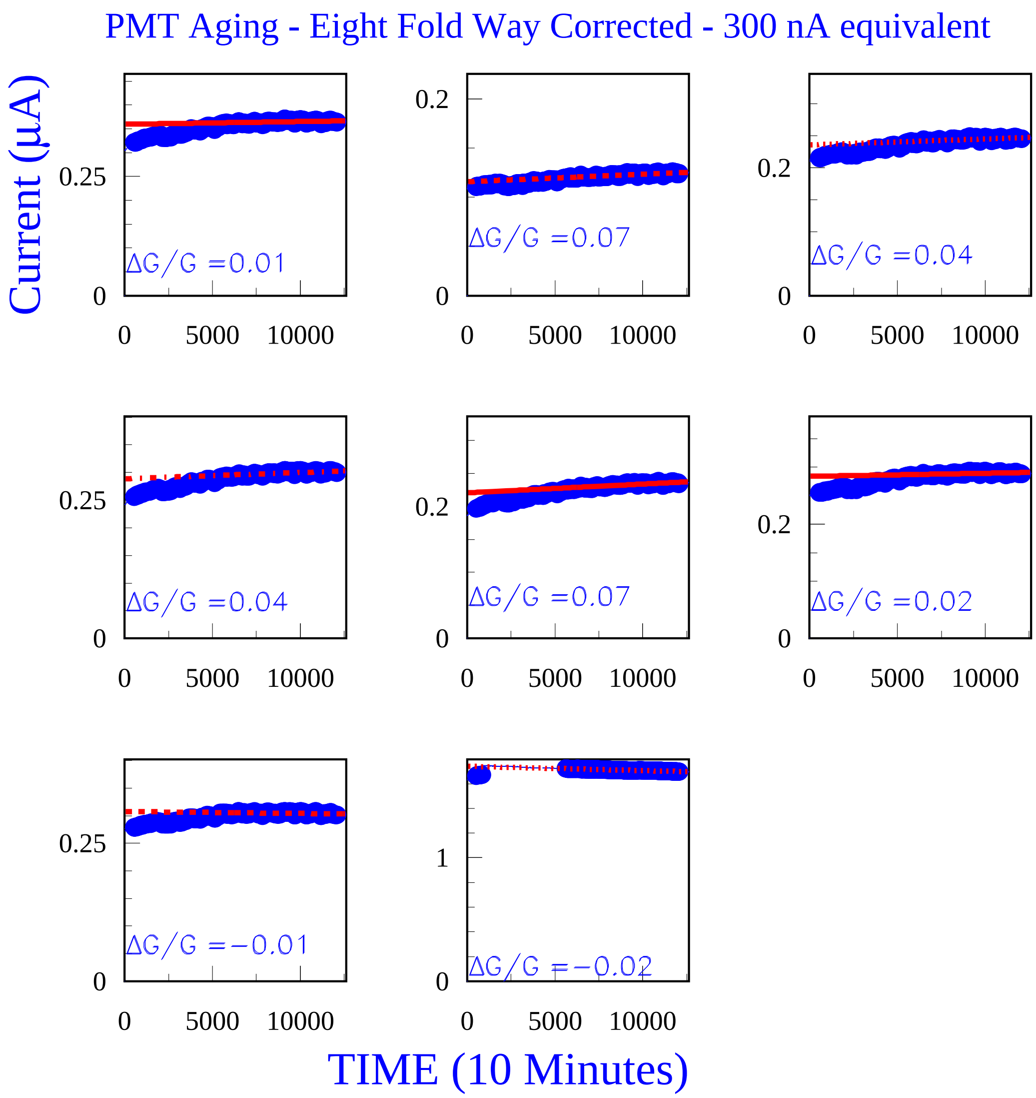

Figure 7: Distribution of the MA-PMT outputs for the seven channels as a function of the operation time (100 days). The last plot shows the photodiode output.

3.3 Main issues of this test results

It appears from the results presented above that the long-term instability of the photodetector, though still large, can be monitored. The present choice of the PMT HV working point is therefore validated. It remains that this photodetector is unstable by structure and will require a dedicated calibration procedure.
If our understanding of the PMT behaviour definitely progressed, most of the interpretations are still qualitative and supported by a reduced amount of data. As a consequence, they may not hold for all the PMT that will be bought and their validation tests should include to some extent long term behaviour of the PMTs.

4 Short term drift studies

The interpretation of the up-drift or down-drift relies on the depletion of the successive Cs layers of the dynodes. The quasi-monoatomic Cs layer is strongly linked to the subtract while the second Cs layer is much less. The presence of a second Cs layer implies that during the industrial process, Cs atoms are fixed on the dynodes and on the bulkhead of the tube. As a consequence, the Cs ions produced by depletion will be hardly fixed elsewhere and will recover the dynode when light is stopped. Therefore, contrarily to the previous ageing campaign for which almost no recovery was observed, it is expected that a significant recovery occurs when stopping the illumination. This is actually what has been observed as shows Fig. 8. The longer the stop is, the higher is the recovery. This observation supports the qualitative understanding of the drifts presented above. However the amplitude of the drift is a further concern in the operation of the MA-PMT. If the long-term drift (with an amplitude less than 1% for one day) should be easy to control, those short-term drifts of few percents are not since they occur over a 2-hour timescale. Actually the luminosity is not constant over a run but decreases exponentially($\tau \sim 10\ hours$) in the run duration ($\sim$ 7 hours). The drifts will consequently occur when most of the physics will be recorded. It is necessary to check that the amplitudes that has been recorded in this ageing experiment are related to the time of illumination.

5 Conclusions and perspectives

The choice of the MA-PMT base for both the SPD and PS has been scrutinized in regard to the average anode current, determined from the energy deposits in the detectors in the old design of the VFE electronics. The results of these studies revealed critical gain variations, far too large to operate correctly the PMT, as stated in [1].
The immediate actions that have been undertaken were to estimate, from the extrapolation of those results, an adequate working point for the MA-PMT, provided that the decrease of the gain would be compensated at the VFE electronics level. A satisfactory compromise was achieved by reducing the PMT gain by a factor 10 and accordingly increasing the VFE gain by the same factor, for which a redesign of the very first stage shall be done.
In such conditions, the 12-stages MA-PMT, considered so far as the baseline choice, is not suitable anymore. Yet, the 6- and 8-stages avatars of MA-PMT from the Hamamatsu company presents amplification characteristics consistent with the new working point. The ageing test bench has then be used to measure the long term behaviour of a 8-stages MA-PMT yielding an anodic current of about 300 nA. The duration of the experiment was one LHCb-year and the main conclusion is that the MA-PMT can be operated under such currents.

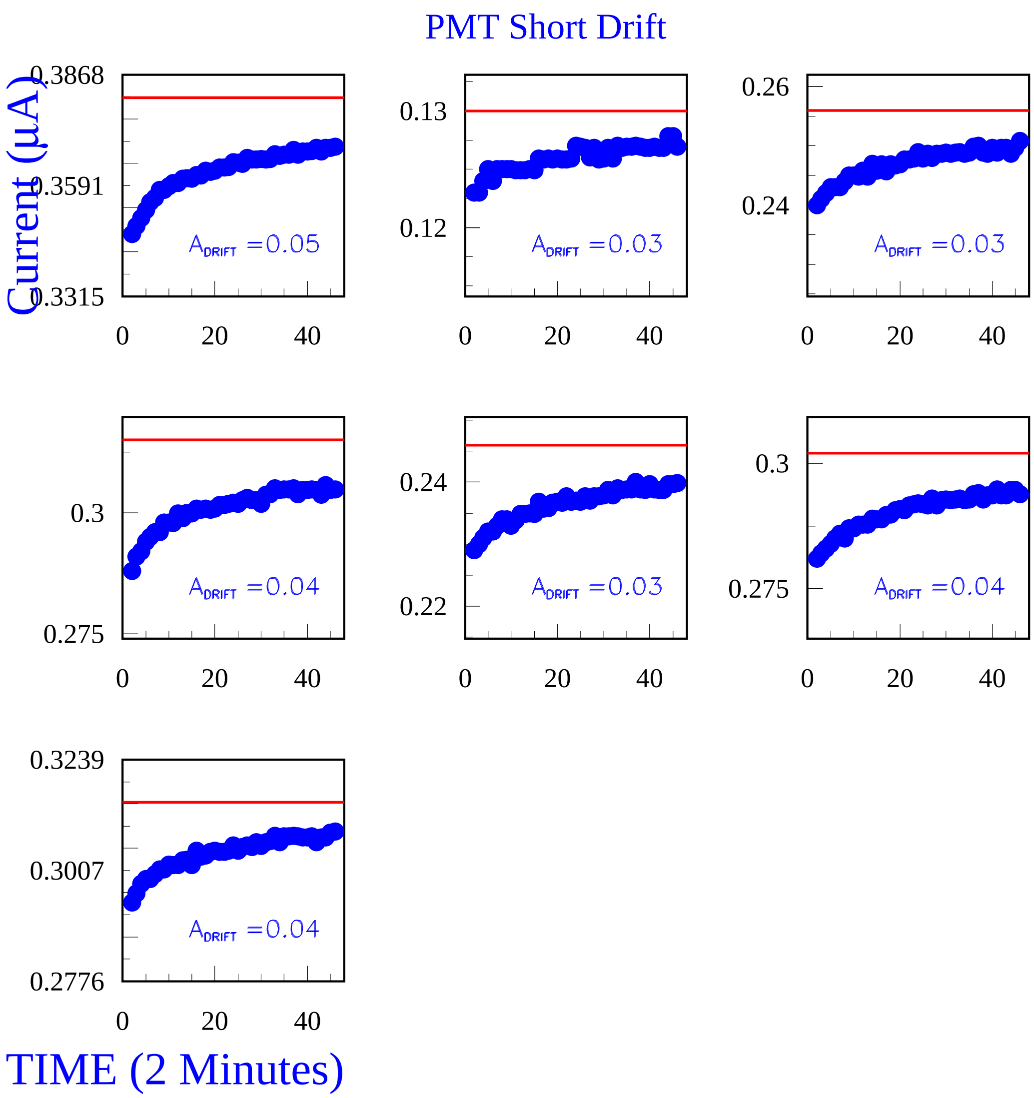

Figure 8: Variation of the output anode current after a lightstop of one day. The line shows the value of the output current at the light stop time.

References

[1] *Mean current in Ps/Spd MultiAnode PhotoMultipliers Tubes*, Bohner G. et al., ECAL-LHCb Note 2003-03.

[2] The mixed analog/digital shaper of the LHCb preshower, Lecoq J., 7th Workshop on Electronics for LHC experiments, Stockholm, Sweden (2001)

[3] *Proceedings of the* 3$^{\mathrm{rd}}$ *BEAUNE Conference* Z. Ajaltouni et al., June 17-21, (2002).

[4] *Study of the PS/SPD tubes*, S. Monteil, Calorimetry meeting, 25/02/2003.