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INVESTIGATION OF THE TEMPERATURE DEPENDENCE OF AVALANCHE PHOTO DIODES FOR THE ALICE ELECTROMAGNETIC CALORIMETER

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Abstract

This report briefly describes the temperature dependence of the avalanche photo diodes installed in the ALICE electromagnetic calorimeter. Such aspect is important, since these devices will work at ambient temperature inside the L3 magnet, thus suffering considerable temperature changes during the data-taking. Additional tests carried out on the APDs before their final installation showed the possibility to accurately study the temperature dependence and find a suitable parameterization to foresee the APD behaviour for different conditions of temperature and gain.

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1 INTRODUCTION

The addition of a large acceptance electromagnetic calorimeter (EMCal) in the ALICE experiment at LHC [1-3] will greatly enhance its capabilities for the reconstruction of jets and high momentum photons and electrons, thus enabling an extensive study of jet quenching phenomena at LHC energies.

The design of the EMCal is based on a layered Pb-scintillator sampling calorimeter with longitudinal wavelength shifting fibre light collection. The detector is segmented into 12288 towers, approximately projective in ϕ and η to the interaction vertex. The smallest block in the calorimeter design is the individual module, which contains 2 x 2 = 4 towers, built by 77 alternating layers of Pb (1.44 mm) and polystyrene (1.76 mm), with a front face dimensions of 6 x 6 cm^2.

The scintillation light produced in each tower is collected by an array of 36 wavelength shifting fibres (WLS), which run longitudinally through the Pb/scintillator stack. Each fibre terminates in an aluminized mirror at the front face of the module and it is integrated into a group of 36 fibres joining the photo sensor at the back of the module. The readout of the modules makes use of large area (5 x 5 mm^2) Hamamatsu Avalanche Photo Diodes (APD S8148), which will be operated at room temperature and moderate gain with a low noise and high gain stability.

To ensure an optimal resolution for high energy electromagnetic showers, it is important to have a tower-to-tower relative energy calibration better than 1% in the offline analysis. This will be achieved by cosmic rays and on beam events. However, even during the data taking, in order to provide a reliable EMCal trigger, the APD gains need to be adjusted to match a relative energy calibration better than 5 %. This has required a careful measurement of the individual gains as a function of the APD bias voltage, with a calibrated LED pulser system. Since the APD gain drifts with the operating temperature, measurements of the APD gains at different temperatures are in order, to check their temperature coefficient. The use of a LED calibration system will finally ensure a proper monitoring of the system during data taking. A detailed description of the EMCal project is reported in Refs.[2,3].

This report briefly describes additional measurements undertaken with the aim of studying the temperature dependence of the avalanche photo diodes already installed in the first super-modules of the EMCal.

2 TEST SETUP

To carry out a series of measurements of the APD gain at different temperatures, the setup includes a system for the control and monitoring of the APD temperature. This makes use of a liquid from a chiller, flowing through a pipe inside a copper plate; the APDs are placed in direct contact with this plate and their temperature is continuously monitored by a thermocouple placed on the APD surface. Once the nominal temperature is set through the board controller of the chiller, the APD temperature reaches the desired value after a few minutes. The use of such system allows a control temperature with precision of 0.1 °C.

To collect and analyze the data, the acquisition system makes use of the same hardware and software configuration which is being used during in-beam ALICE data taking. Signals from each APD, through its preamplifier, are sent to a T-card which couples the devices to the Front-End (FE) card, where the signals are shaped and sampled by two 10-bit ADCs. The digitized data are transferred, via an optical link, to a computer running the ALICE DAQ (DATE).

A detailed description of the experimental setup used for the characterization of a large number of individual APD devices is reported in Ref.[4].

3 VARIATION OF THE APD GAIN VERSUS TEMPERATURE

It is well known that the gain of the avalanche photodiodes is strongly dependent on the temperature: since the avalanche multiplication depends on the mean free path of electrons between ionizing collisions, which is temperature dependent, the APD gain decreases with temperature. Examples of gain curves, for the same APD, obtained at different temperatures in the range from 19 °C to 29 °C, are shown in Fig. 1.

The gain undergoes strong variations when the temperature changes and this effect is more evident for higher values of the bias voltage. The relation between gain and temperature is approximately linear at a fixed value of bias voltage (Fig. 2). The parameter from the linear fit allows to calculate for each APD the temperature coefficient $1/M \times dM/dT$, which is the percentage change in gain per one degree change in temperature. Figure 3 shows, for a typical APD, the temperature coefficient as a function of the APD gain. At $M=30$ the temperature coefficient is -1.7%/°C. Measurements repeated on a small batch of 21 APDs with similar dark current showed that the temperature coefficient at $M=30$ is quite similar for all APDs. The RMS of the temperature coefficient distribution is less than 0.1%/°C (Fig. 4).

The situation considerably changes if we compare APDs with different values of the dark current: at a fixed gain, the value of the temperature coefficient depends on the APD dark current. Since the avalanche photo diodes installed in the EMCal exhibit dark currents ranging from 1 nA up to 70 nA, a detailed analysis was requested to evaluate the concurrent effects of temperature and dark current on the APD gain.

4 EFFECT OF DARK CURRENT ON THE TEMPERATURE COEFFICIENT

In order to study the dependence of the APD gain on the temperature and the dark current, we performed additional measurements on a considerable number of APDs, in total 147. These APDs were divided into 4 different batches, depending on their characteristics.

- BATCH 0: APDs with low dark current, produced from a 4 inch wafer (21 APDs)
- BATCH 1: APDs with higher dark current, produced from a 6 inch wafer (42 APDs)
- BATCH 2 and 3: APDs with higher dark current produced, from a 4 inch wafer (42 + 42 APDs)

All these APDs were tested at different temperatures, from 21 °C to 29 °C, with 1 degree step. Since the nominal gain at which the APDs will work in the EMCal is M=30, we firstly evaluated the temperature coefficient at this gain. As already mentioned, we did not get the ideal value 1/M×dM/dT = -1.7%/°C anymore, due to the spread in dark current. However, the temperature coefficient seems to be linearly correlated to the dark current, as shown in Fig. 5. In the light of what obtained, we tried to look for some approximate universal relation between the temperature coefficient and the dark current. Moreover, since the applied voltage values will typically not be the same as V_{30} (i.e. the bias voltage at which the gain is 30) due to the modules calibration with cosmic rays, such analysis has been extended to a reasonable region of gain around M=30, from 25 to 35.

5 PARAMETERIZATION OF THE TEMPERATURE COEFFICIENT

The aim of this analysis is to find a parameterization of the temperature coefficient TC = TC(M, I_{dark}) as a function of the gain and dark current. In this way, if an APD with a dark current I0 works at a gain M0 (different from 30), it will be possible to evaluate its temperature coefficient even in such conditions. Firstly, we tried to find a relation between the temperature coefficient and the gain. In the limited gain range explored (25 < M < 35), this relation is quite linear, as shown in Fig. 6, where a simple poly-line between every points is drawn. Of course, the spreading of such curves reflects the spread in dark current of these APDs. The fit with a linear function (TC = p0 + p1×M) gives reasonable results. Moreover, the fit parameters p0 and p1 are quite correlated to dark current, as shown in Fig. 7. For the data in Fig. 6 we also tried to use a second order polynomial (TC = p0 + p1×M+ p2×M2) as fitting function. The χ^2 distribution indicates that the fit is more accurate with a second order polynomial than a linear fit, but apparently there is no correlation between the fit parameters and the dark current (Fig. 8). Probably the addition of new parameters leads to the loss of correlation with the dark current. These results suggest using a linear fit to parameterize the temperature coefficient dependence on the gain.

The last step was to find the relation between the fit parameters p0 and p1 and the dark current. The data in Fig. 7 can be well fitted with a linear function. The result is:

$$p0 = -0.903 - 1.381 \cdot 10^7 \times I_{dark}$$

$$p1 = -0.023 - 496589 \times I_{dark}$$

Thus, we found the desired parameterization:

$$TC(M, I_{dark}) = p0 + p1 \times M = (-0.903 - 1.381 \cdot 10^7 \times I_{dark}) + (-0.023 - 496589 \times I_{dark}) \times M$$

6 QUALITY CHECK OF THE PARAMETERIZATION

In order to check the capability to retrieve a correct value of the temperature coefficient using the parameterization found, we evaluated for all APDs the temperature coefficient at different gain values (more precisely, the same 11 values used for Fig. 6), using such parameterization. The result was compared with the temperature coefficient extracted from the experimental data. The distribution of their differences is plotted in Fig. 9 for all APDs, and in Fig. 10 for each individual batch. At first sight the distribution is quite narrow and the RMS is about 0.1%/°C. However the histograms show the presence of some anomalous peaks, whose presence may require further investigation.

7 CONCLUSIONS

While testing all the APD devices to be used in the electromagnetic calorimeter, in order to match their individual gain for a reasonable ready-to-start calibration, an additional set of measurements were undertaken in the INFN test laboratory in Catania, to further investigate their behavior at different ambient temperatures. Even though a LED calibration system has been designed in order to monitor the temperature variations during ALICE data taking and introduce a proper off-line correction of the data, the results obtained in the course of this investigation showed that it is possible in principle to have an accurate description of the temperature coefficient and find a suitable parameterization of such coefficients as a function of the gain and dark current.

8 REFERENCES

[1] The ALICE Collaboration, Journal of Instrumentation, 2008_JINST_3_S08002 (2008)
[2] The ALICE Collaboration, The Electromagnetic Calorimeter, Addendum to the Technical Design Report, CERN-LHCC-2006-014
[3] The ALICE Collaboration, The Electromagnetic Calorimeter, Technical Design Report CERN-LHCC-2008/014.
[4] A.Badalà et al., INFN Report TC-08-7 (2008)

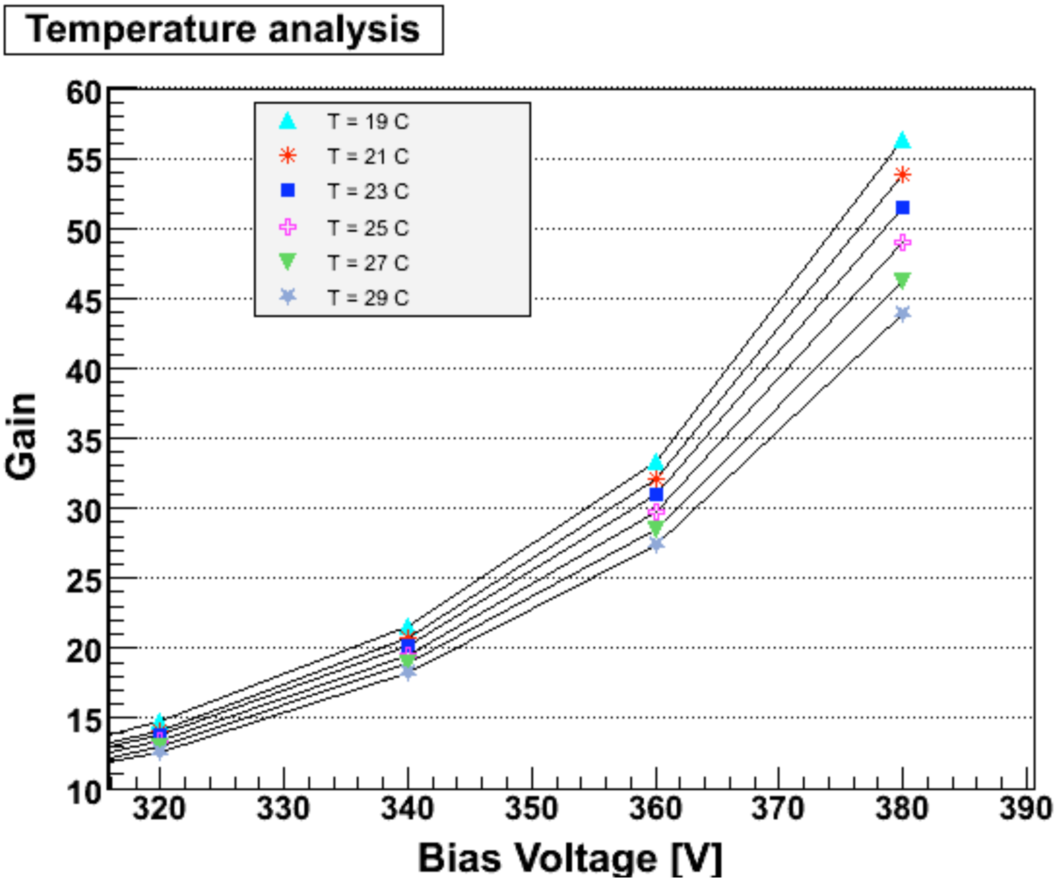

Fig. 1: Gain curves measured at different APD temperatures.

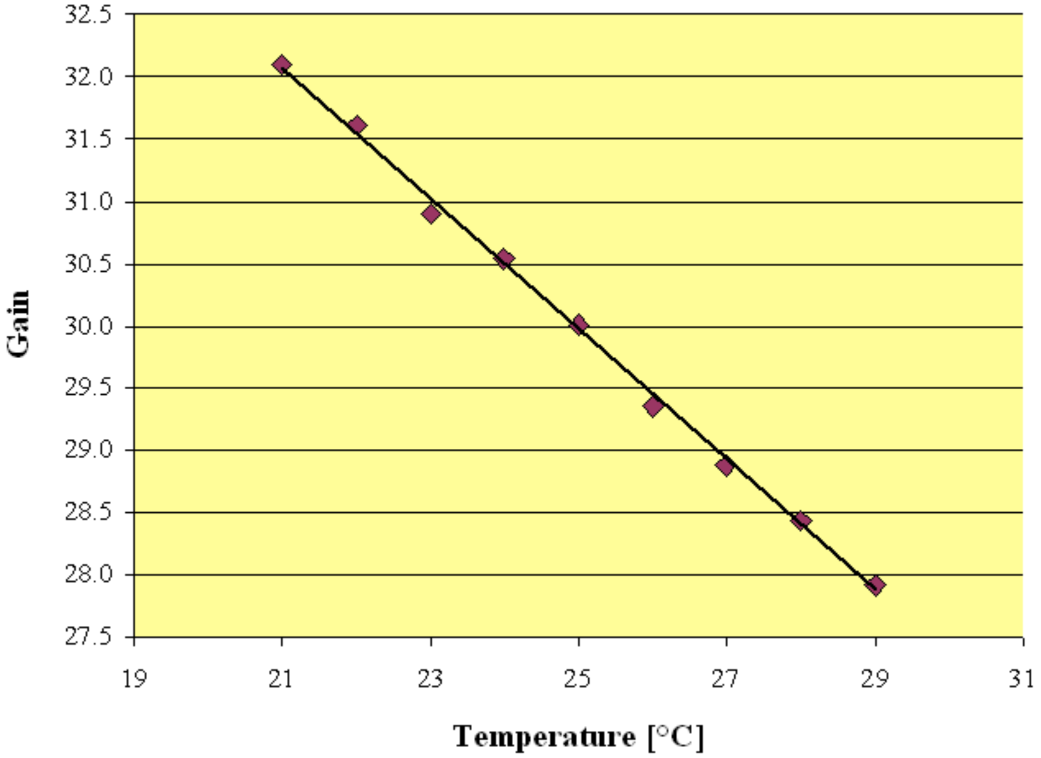

Fig. 2: APD gain dependence versus temperature.

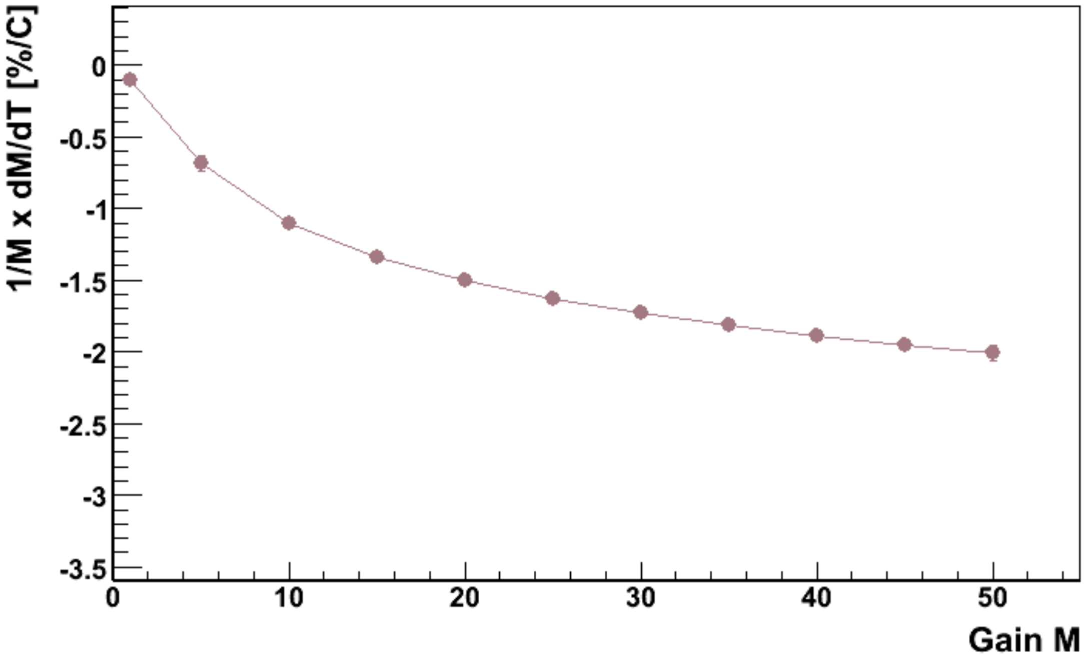

Fig. 3: Temperature coefficient as a function of the APD gain.

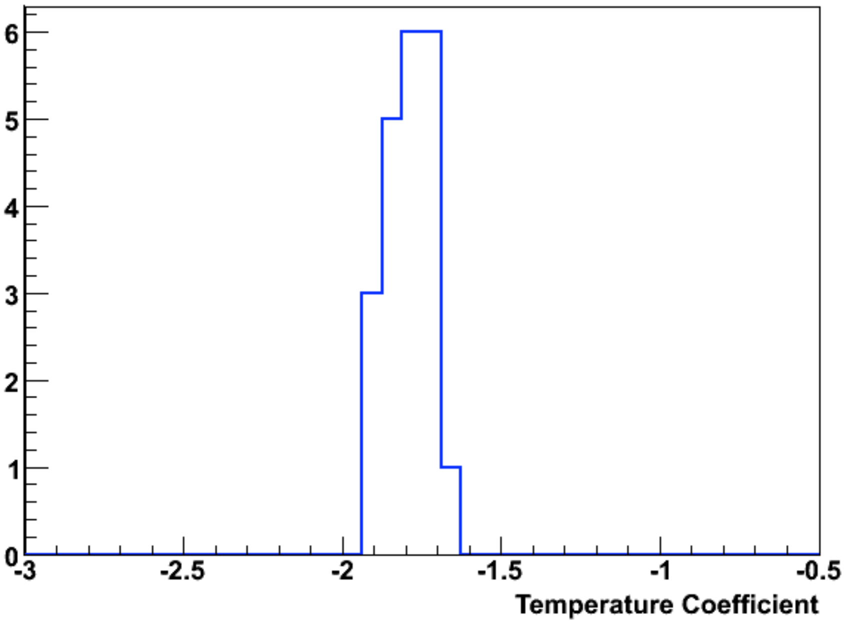

Fig. 4: APD temperature coefficient at M=30, for a set of 21 devices (Batch 0).

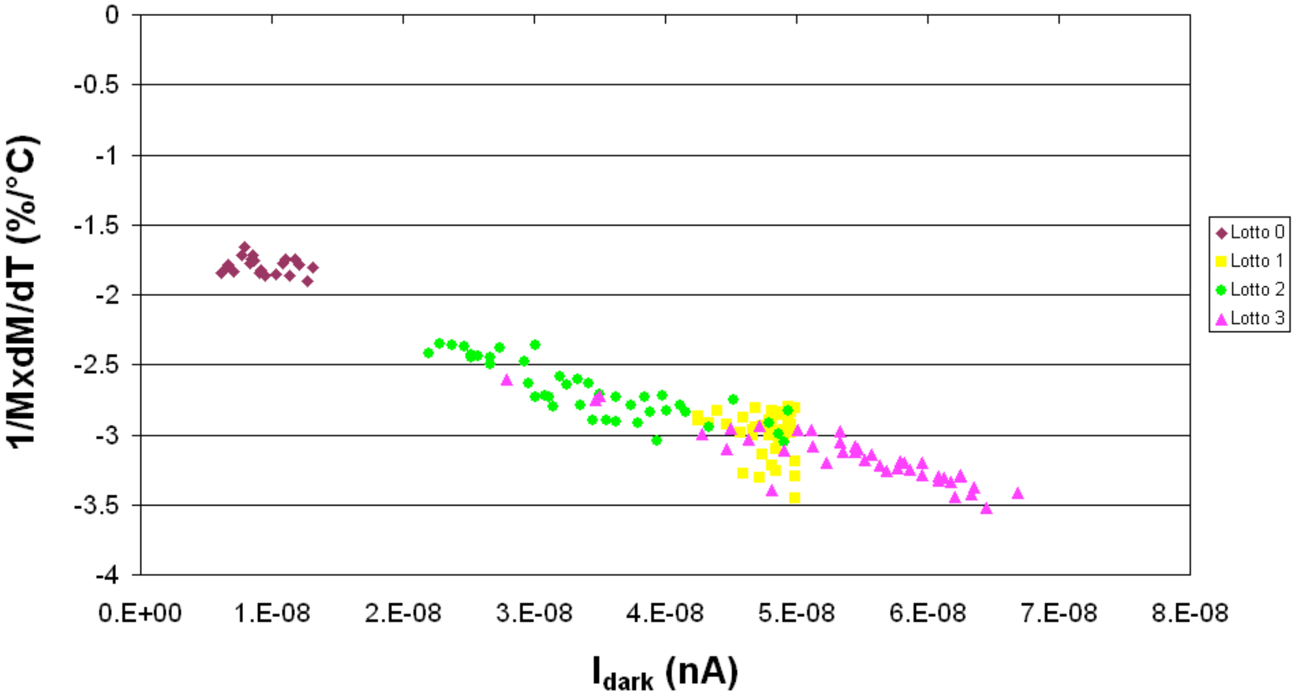

Fig. 5: APD temperature coefficient at M=30, as a function of the dark current.

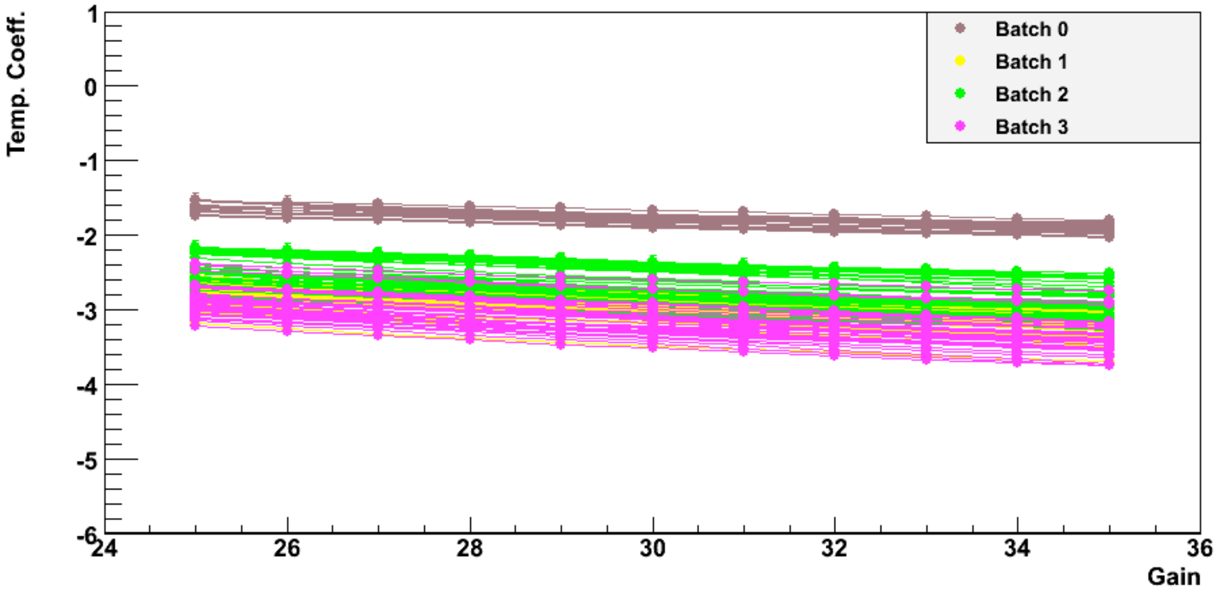

Fig. 6: Temperature coefficient as a function of the gain, for the 4 different APD batches under test.

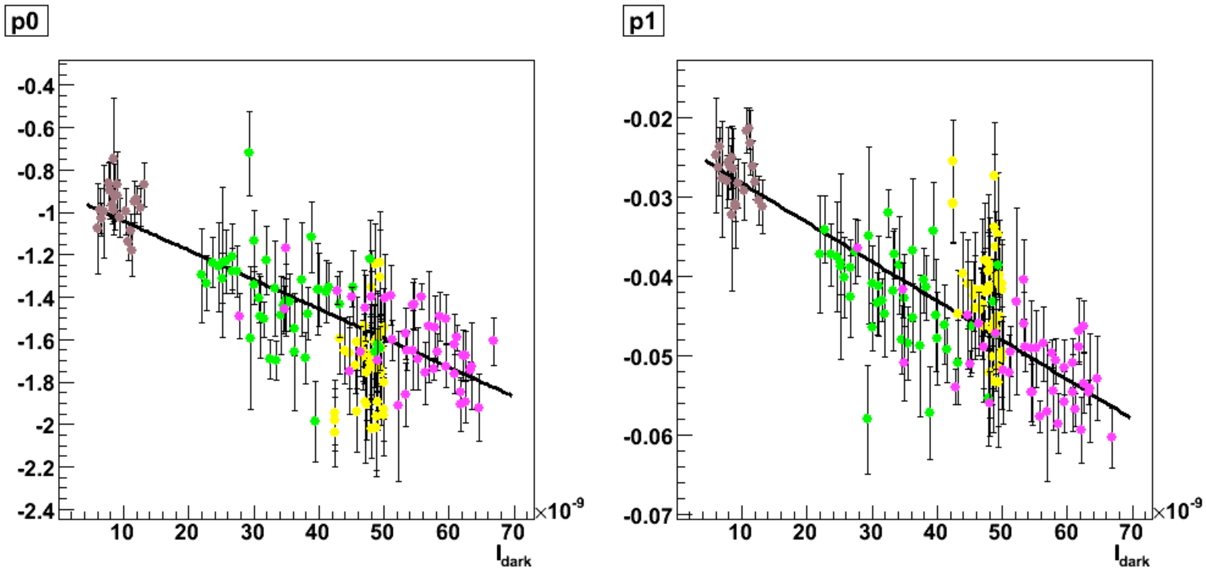

Fig. 7: Correlation between the parameters p0, p1 (extracted from the linear fit) and the APD dark current.

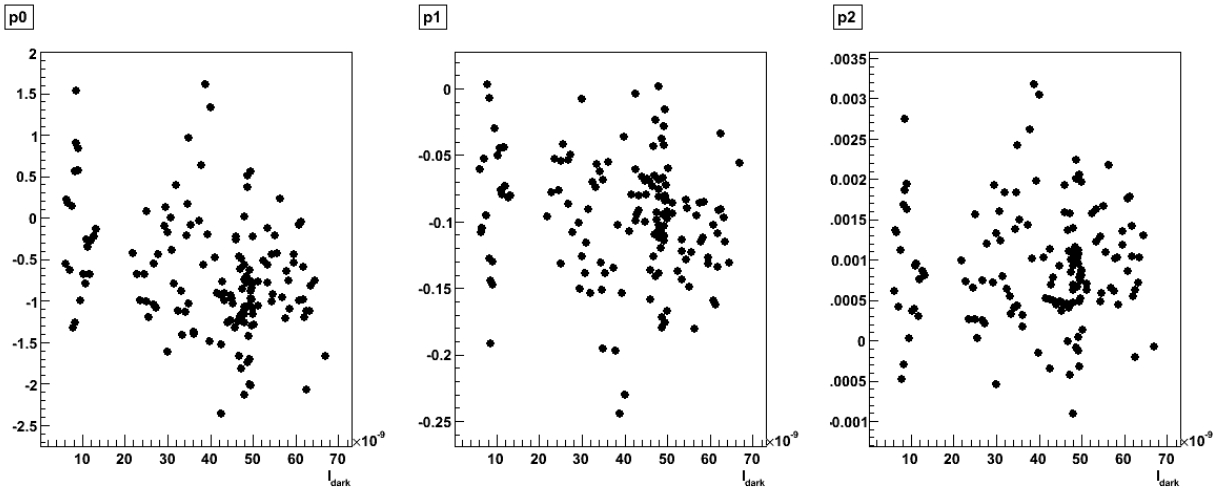

Fig. 8: Correlation between the parameters p0,p1 and p2 (extracted from a fit with a second order polynomial) and the APD dark current.

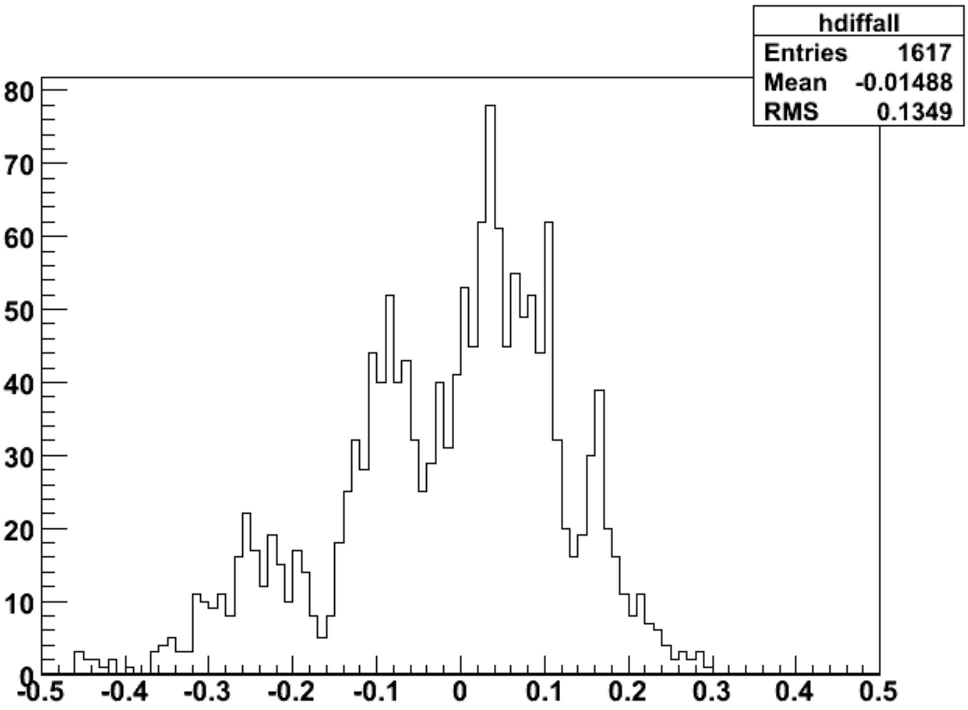

Fig. 9: Distribution of the differences between the temperature coefficient extracted from the experimental data and that obtained by the parameterization discussed in the text, for all 147 APD devices.

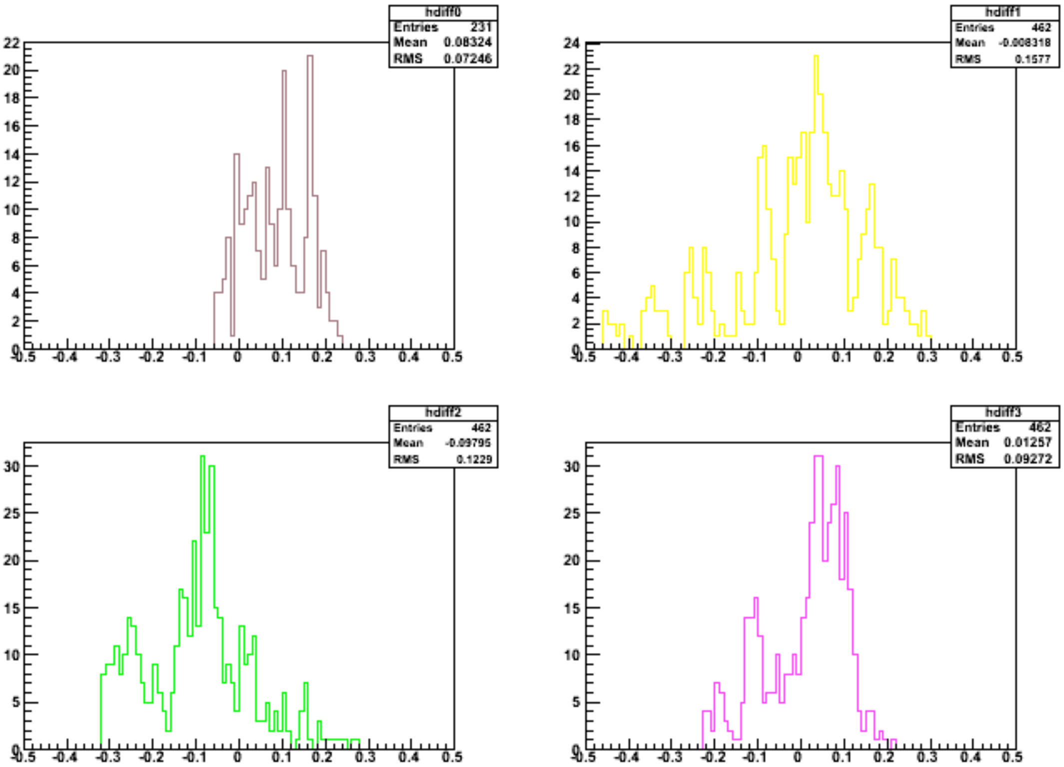

Fig. 10: As for previous figure, for the 4 different APD batches.