Procedure for determination and setting of thresholds implemented in the LHCb Muon system.

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Abstract

The LHCb Muon system consists of 1368 Multi Wire Proportional Chambers of different size and readout for a total of ∼120k electronics channels. The choice of the correct threshold to be applied to each channel can be made on the basis of the detector simulation or, as we suggest in this note, by measuring the noise parameters for each channel and consequently setting the desired values. When dealing with individual channels of the Muon system, the variations of the specific properties of each CARIOCA channel should be properly taken into account in order to fine tune the thresholds. The discriminator stage of the CARIOCA is characterized by a voltage bias that needs to be properly measured and taken into account in the threshold calculations. The procedure used for such calculations for the physical channels of the Muon system is discussed in detail in this note.

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1 Introduction

The LHCb Muon Detector (1) consists of five stations (M1-M5) located along the beam axis and interspersed with iron filters. Each station is divided into four regions (R1-R4) of increasing distance from the beam. The detector is equipped mainly with Multi Wire Proportional Chambers (MWPCs) of different dimensions and read-out type/granularity (anode wires or (and) cathode pads with different segmentation).

The signals from the $\sim$120k detector channels are processed in the Front End (FE) electronics by means of an amplifier-shaper-discriminator (ASD) circuit, the CARIOCA chip (2), with individual programmable thresholds.

In this note we propose a method for a fine threshold tuning based on the analysis of the noise spectrum of each FE channel. The ASD characteristics, like the Equivalent Noise Charge (ENC) and offset, are measured and used to properly set the thresholds.

This procedure must cope with the huge number of readout channels and with the many different chamber types taking into account gain and offset variations (channel dependent) and capacitance variations (chamber dependent). The procedure should also account for the biases introduced by the differential threshold voltage (DTV) discriminator circuitry, implemented for each single channel of the CARIOCA chip (2).

A proper measurement of the offset and of the discriminator bias, together with the amplifier sensitivity, is crucial to convert a threshold measurement (in fC) into the corresponding DAC registers (rDAC) needed to program the channel by channel thresholds on the DIALOG chips (3) which are on-board the FE cards (in the following Front End Boards or FEB).

The measurement of CARIOCA induced *bias*, performed on positive and negative ASD channels, is presented in section 2, together with results of noise spectrum data analysis.

In section 3, we report in detail the technical aspects of this threshold calculation and tuning procedure, with numerical results and examples based on the analysis of all the MWPC chambers of the LHCb Muon Detector.

2 Noise spectrum analysis

In order to properly find and set individual thresholds for all the channels of the LHCb Muon system a noise measurement procedure, based on threshold scanning, has been performed using a dedicated software test suite (4). The results have been analyzed considering that the CARIOCA chip uses a differential discriminator with a bias that does not allow to measure the noise rate down to an ideal zero threshold level.

While not being directly accessible, this parameter can be measured assuming a gaussian noise distribution (5). The position of the 'zero threshold' and that of the maximum measured noise rate (the *offset*) are related and their distance (the *bias*) can be measured. A simulation of the gaussian noise as a function of rDAC, one rDAC register being equal to 2.35 mV, is shown in Fig. 1: the closed squares are showing the gaussian noise shape assuming no *offset* and no *bias*, the open squares are showing the effect of an *offset* (assuming zero *bias*), while the open triangles are showing the spectrum assuming an *offset* and a non zero *bias*.

The same figure, in the left plot, shows the logarithm of the noise rate as a function of the squared threshold: deviation from the linear distribution are seen when *bias* and *offset* are not properly taken into account.

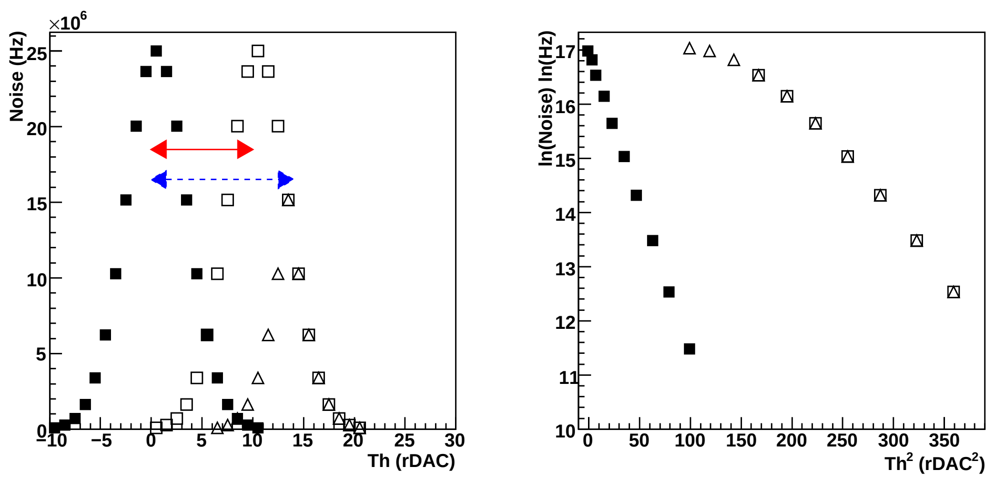

Figure 1 Left: gaussian noise simulation. The closed squares are showing the gaussian shape assuming no *offset* and no *bias*, the open squares are showing the effect of an *offset* (assuming zero *bias*), while the open triangles are showing the spectrum assuming an *offset* and a non zero *bias*. Right: Same as plot on the left but showing the logarithm of the noise rate as a function of the squared threshold: deviation from the linear distribution are expected if *bias* and *offset* are not properly taken into account.

In order to measure this *bias* using the threshold scan data (shown for example in Fig. 2) for the various types of chambers in the Muon system, two different strategies have been used: the first one relies on test performed directly on the FE cards on a test bench, while the second one exploits the data from FE cards mounted on the MWPCs.

The *bias* value can thus be extracted by assuming that its value is the same for all the channels of all the boards (being a characteristic of the circuit). This assumption is easily translated into the requirement of having a single value (e.g. 25 MHz in our case) for the noise rate at zero threshold.

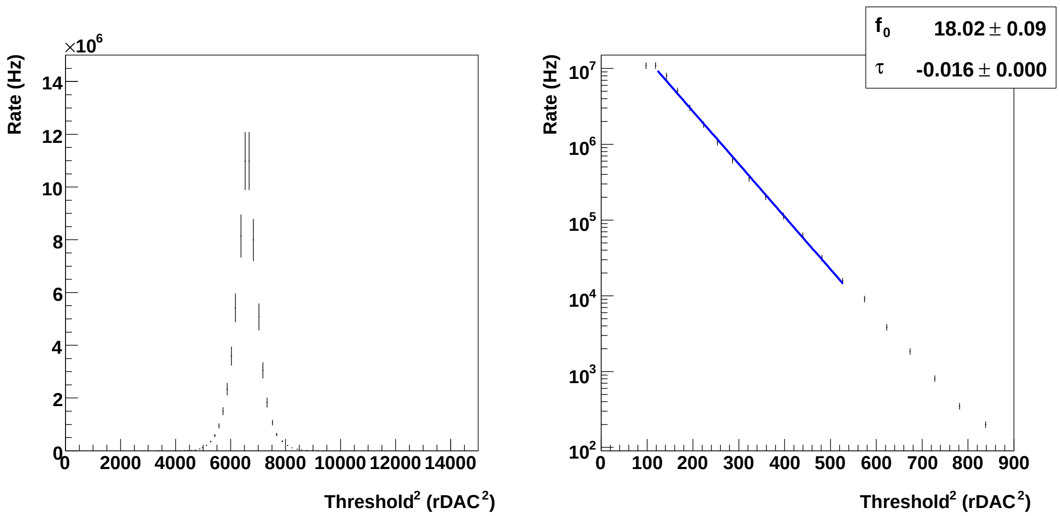

Figure 2 Sample plot from a channel of a FEB of an M5R4 chamber. On the left the noise rate spectrum is shown in linear scale. On the right the spectrum has been *offset* and *bias* corrected and is shown in log(10) scale. The function used in the fit (eq. 1) superimposed to the log(10) spectrum is presented in the text.

Once the *bias* and the *offset* are known, it is possible to measure the Equivalent Noise Charge (ENC) by directly fitting the threshold scan data. Each channel rate spectrum is fitted to the function:

$$f(MHz) = f_0 \cdot exp^{Th(rDAC)^2 \cdot \tau} \tag{1}$$

where f is the rate measured, $Th(rDAC)$ is the threshold in rDAC units and f_0 and τ are the exponential fit parameters. The value of ENC (in rDAC) can thus be extracted from the slope τ using the following relation:

$$ENC = \sqrt{1/(-2 * \tau)}. \tag{2}$$

The values obtained for ENC for each channel will be used to set the threshold as described in section 3. The rDAC values can be translated in mV and in fC using the 2.35 mV/rDAC factor and the sensitivity quoted in the second column of table 1.

2.1 Measurements with test bench

In order to measure the *bias* in a controlled environment, a test bench for the FE cards has been set up. The input of the FE cards has been connected to different capacitors and the corresponding threshold scans have been performed.

The various threshold scans obtained (several channels of different CARDIAC boards with different capacitance), after having subtracted the *offset*, have been linearized and fitted. The quality of the fit was ensured by retaining fits with $0.1 < \chi^2 /$ Ndof < 2.

The straight lines obtained from the fits for all the channels, shown in Fig. 3, are then analyzed in pairs: the x (Threshold^2) and y (Noise Rate) coordinates of the crossing point of each pair of straight lines are shown in Fig. 4. The distribution of the x coordinate is used to measure the *bias* following the procedure explained below.

The crossings of all the various threshold scan fits have been centered to zero with an iterative procedure that added, in steps of 0.2 rDAC, an increasing shift to the measured data. The resulting threshold scan distributions (when adding the shift that centers the x distribution in 0) are shown in Fig. 3: in this case the shift added to the threshold scan data is equal to (measure) the *bias*.

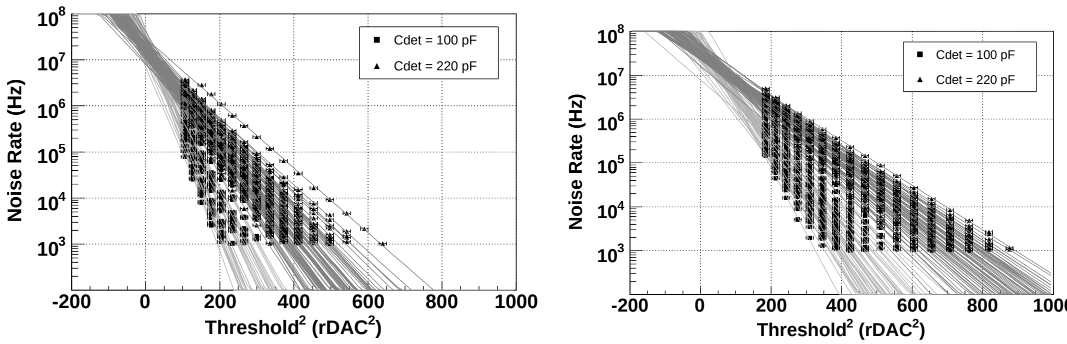

Figure 3 Noise Rate for negative(positive) CARDIAC boards is shown in the left(right) plot as a function of the threshold applied: the *offset* has been properly subtracted, and the *bias* added in order to center the crossings in zero.

The distributions for x (centered) and y are shown in Fig. 4 for negative (left) and positive (right) CARDIAC boards respectively. The values found for the *bias* (rDAC) and crossing frequency (MHz) are respectively: 8.3(11.3) rDAC and 19(34) MHz for negative(positive) CARDIAC boards.

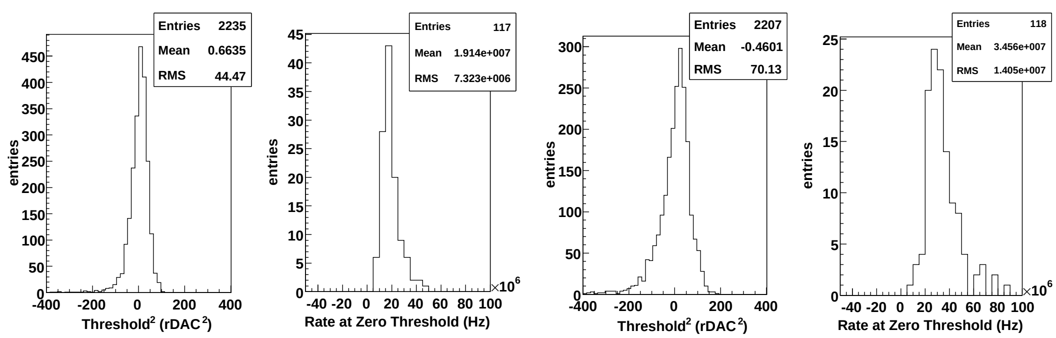

Figure 4 Histograms showing the distributions of the x and y coordinates of the various crossings after having subtracted the *offset* and added the *bias*. The two histograms on the left (right) are showing the results for CARDIAC negative (positive) boards.

2.2 Measurements on chambers

By analyzing the chambers data it is possible to minimize the measurement errors due to the number of channels available, and to have a more realistic picture of the physical channels noise characteristics. The procedure used to measure the *bias*, follows exactly the same steps outlined in paragraph 2.1.

First of all the threshold scan data of several channels (see Fig. 2, for example) of different CARDIAC boards are *offset* subtracted.

The spectra of all the channels are then fitted and the parameters from the linear fit are used to build the combination of the crossings of every line with all the others. The coordinates of the crossing points (x and y) are then used to build the histograms (see Fig. 5) used for the *bias* measurement.

Finally the *bias* value is measured requiring that the mean of the x crossings distribution is consistent with zero. The iterative procedure, that scans several *bias* values as already explained in the previous paragraph, is used, for example, as shown in Fig. 6(left) and 6(right) for M4R4 chambers.

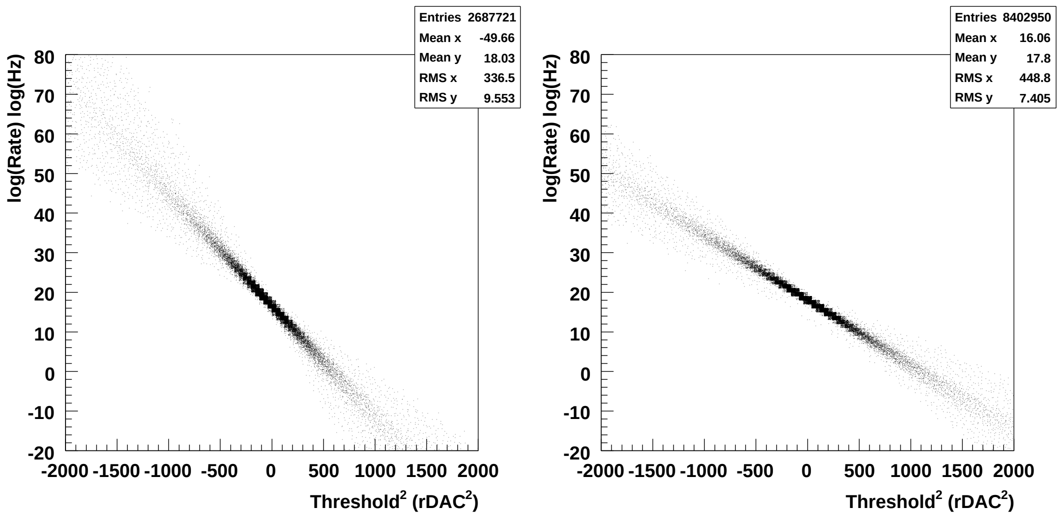

Figure 5 Scatter plot of the x and y crossing positions for M3R3 (left) and M5R4 (right) chambers. The projections along x are used in the iterative procedure to measure the *bias*.

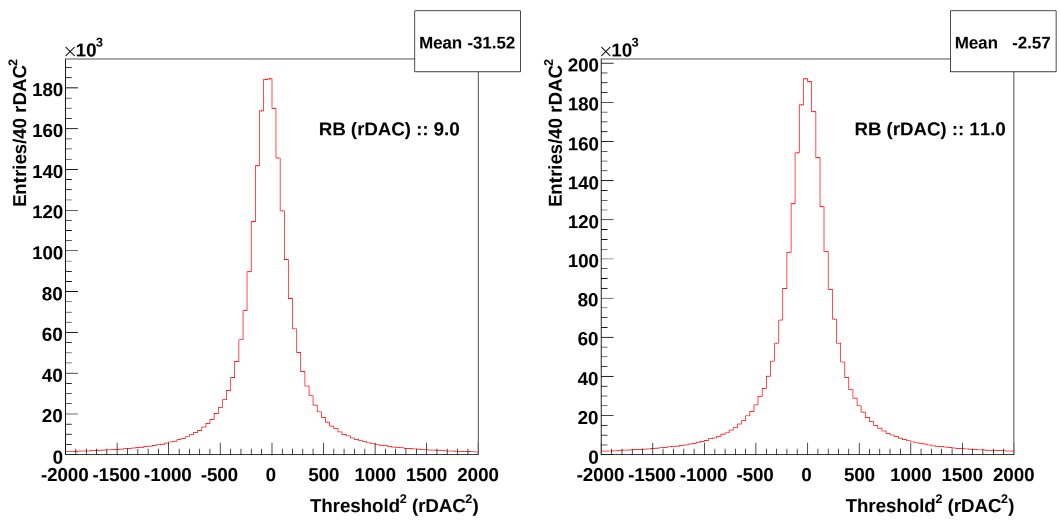

Figure 6 *bias* scan for M4R4 chambers. The value of the histogram mean, for each step, is used to measure the *bias*: starting from a negative mean value (*bias* = 9 rDAC) the distribution is centered at zero for *bias* = 11 rDAC.

As a consistency check, the *bias* measured from the iterative procedure, can be also obtained from the measured spectra of the centered channels, imposing a crossing in y (Noise Rate at zero threshold) at the measured frequency of 25 MHz (average of the y crossings in most of the chamber types). Fig. 7 shows this *bias* distribution (fC) obtained for all the channels of the M3R3 chambers with this alternative method. The distributions have been obtained for all the type of chambers and average *bias* values are in good agreement using the two methods.

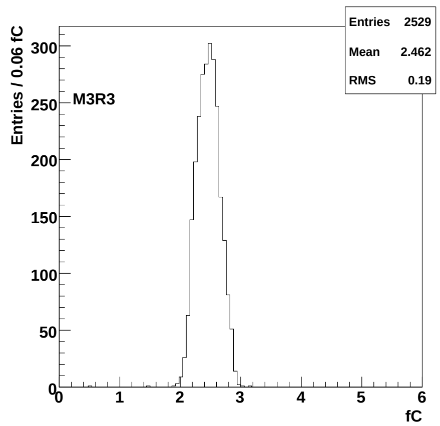

Figure 7 Histograms showing the *bias* distribution, in fC, for all the channels of the M3R3 chambers, obtained with the alternative fitting method described in the text. The *bias* and the *offset* have been properly taken into account.

2.3 Results

The results for the various types of chambers, obtained using the data with properly subtracted *offset* and added *bias*, are shown in table 1. The second column shows the sensitivity for each type of chamber that can be used to translate each threshold value in mV or fC according to the needs. The third column shows the measured detector capacitance (C_{det}), while the fourth column shows the measured values of the *bias*. The measured *bias* values, in rDAC units, are nearly independent of the type of chamber: we propose to use 11 rDAC (average of the measured values) for all the Muon MWPC chambers in the calculations needed to define the threshold values to be set in the DIALOG chips.

3 Threshold determination and setting

The measurements performed on all the chambers of the LHCb Muon system allowed to relate the (*offset*) position (measurable) and the threshold that one wants to set.

The procedure needed to set the desired threshold on each channel of the Muon system is the following:

- The max rate (*offset*) is found using the threshold scan data.
- The *bias* (in rDAC) is measured in table 1: we use the value of 11 rDAC for all the boards of the Muon system in the following.
- The threshold (in rDAC units) to be set for each channel can be obtained as

$$Th = \frac{Sens_{chmbtype}}{2.35} \cdot ENC \cdot S \qquad (3)$$

where the ENC (in fC) is measured from the slope of the linear fit to the threshold scan data and S is a safety factor (5 or 6) that measures the ratio noise to ENC. This parameter S can be chosen according to the user needs: for example S=6 can be chosen to completely suppress the noise.

Table 1 Results of threshold scan analysis of all the Muon MWPC chambers using properly *bias* and *offset* corrected data. The sensitivity is given in the second column. Column 3 shows the detector capacitance measurement, while column 4 shows the *bias* measurement in rDAC units (fC). The last column shows the ENC values (fC) obtained from the exponential fit.

Region	Sensitivity mV/fC	C_{det} pF	*bias* reg.(fC)	ENC fC
M1R2	16	50	-	0.33
M1R3	13.4		-	0.40
M1R4	10.8		11 (2.39)	0.82
M2R1W	15	70	-	0.53
M2R1C	10	120	12 (2.82)	1.09
M2R2W	14	80	-	0.48
M2R2C	11	100	11 (2.35)	0.97
M2R3	11.7	66	11 (2.21)	0.89
M2R4	10		11 (2.58)	1.13
M3R1W	14	80	-	0.47
M3R1C	10	130	11 (2.58)	1.14
M3R2W	14	90	-	0.57
M3R2C	11	110	11 (2.35)	1.02
M3R3	11.5	72	11 (2.25)	0.93
M3R4	10		10 (2.35)	1.15
M4R1	15	70	10 (1.56)	0.60
M4R2	10.2	110	12 (2.76)	1.11
M4R3	10.1	115	13 (3.02)	1.18
M4R4	8.3	192	11 (3.11)	1.47
M5R1	15	70	11 (1.72)	0.62
M5R2	10	121	10 (2.35)	1.17
M5R3	9.6	137	12 (2.94)	1.27
M5R4	7	228	11 (3.69)	1.86

- The threshold (in rDAC units) that needs to be written in the DIALOG chips (Th_{Wri}) for each channel can be obtained from the following relation:

$$Th_{Wri} = offset + Th - bias \tag{4}$$

  where $bias$ is 11 and the $offset$ is channel dependent

As an example we show in table 1 (last column), the mean values of ENC for the various types of chambers. The ENC distribution obtained for the M3R3 and M5R4 chambers on the properly corrected threshold scan data are shown in Fig. 8 (the plot for all the various chambers can be found in appendix (Fig. 9 and 10).

When setting the threshold for each channel those values are going to be replaced by the fit results that are channel dependent (as shown in Fig. 2).

The mean values shown in table 1 can be used if the quality of the fit is not satisfactory or the user wants to take into account only the chamber's types differences, neglecting the channel to channel differences.

Conclusions

The threshold scan data coming from all the MWPC chambers of the LHCb Muon system have been analyzed. The key ingredients needed to set an individual threshold on each channel of the Muon

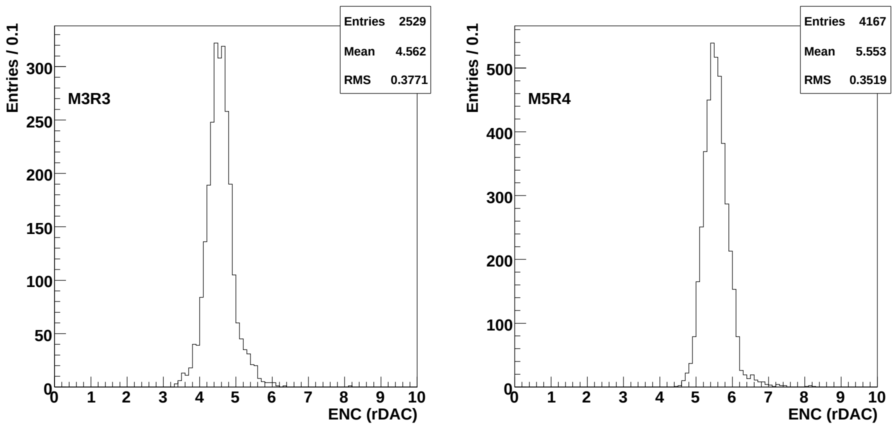

Figure 8 Histograms showing the ENC in rDAC units, obtained from measured slope of the exponential fit to all the channels of the FEBs of M5R4 and M5R3 chambers.

system have been measured and a procedure for threshold calculation and tuning has been defined. The results are consistent with the CARIOCA characteristics and have been crosschecked on front-end boards mounted on chambers and on a test bench.

Acknowledgments

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Appendix

Fig. 9 and 10 are showing the distributions of the ENC, in rDAC units, obtained from the slope of the exponential fit to all the channels of all the MWPC chambers of the Muon system, for data that has been *bias* and *offset* corrected .

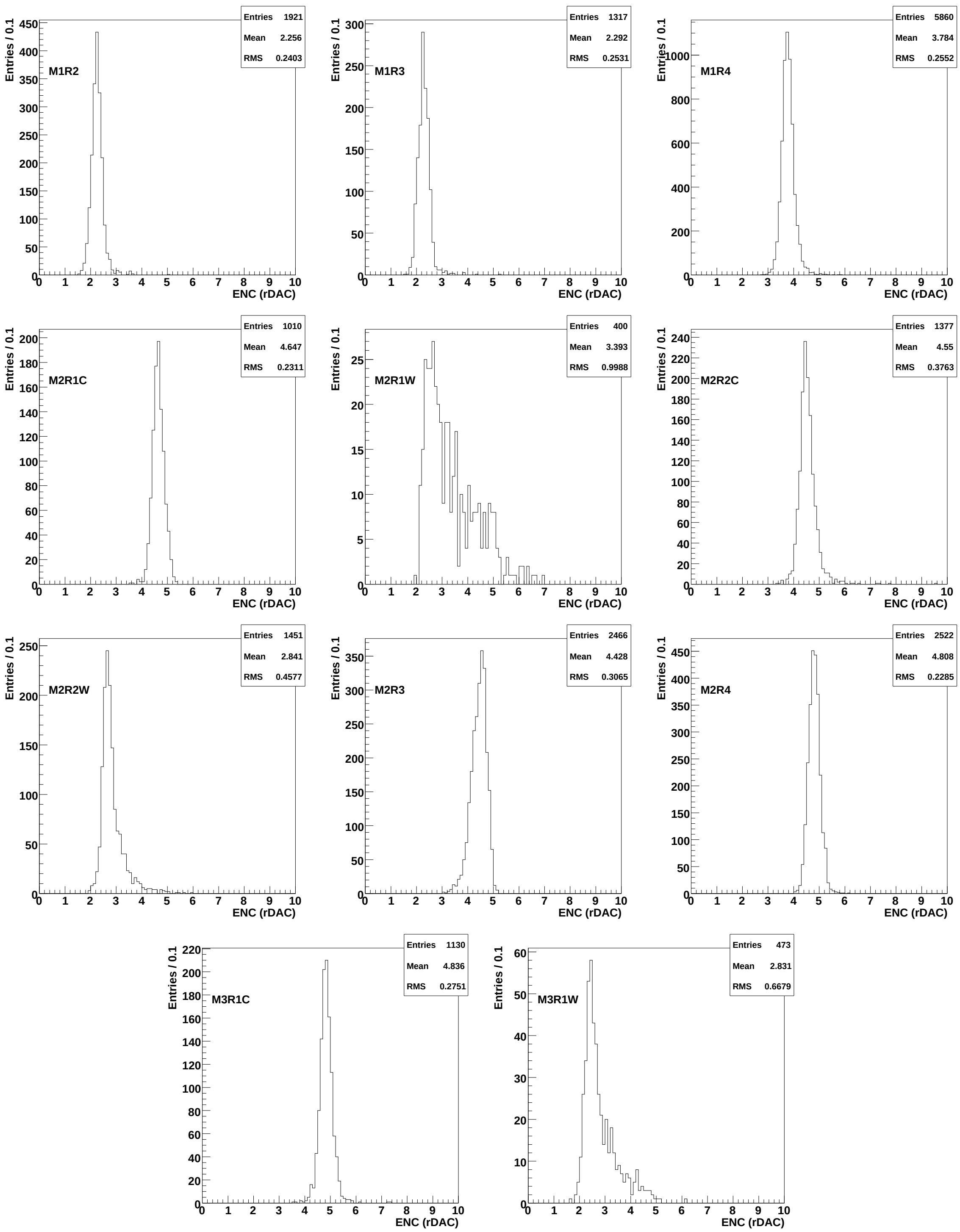

Figure 9 Histograms showing the ENC, in rDAC units, obtained from the slope measured for all the M1, the M2 and the M3R1 chambers.

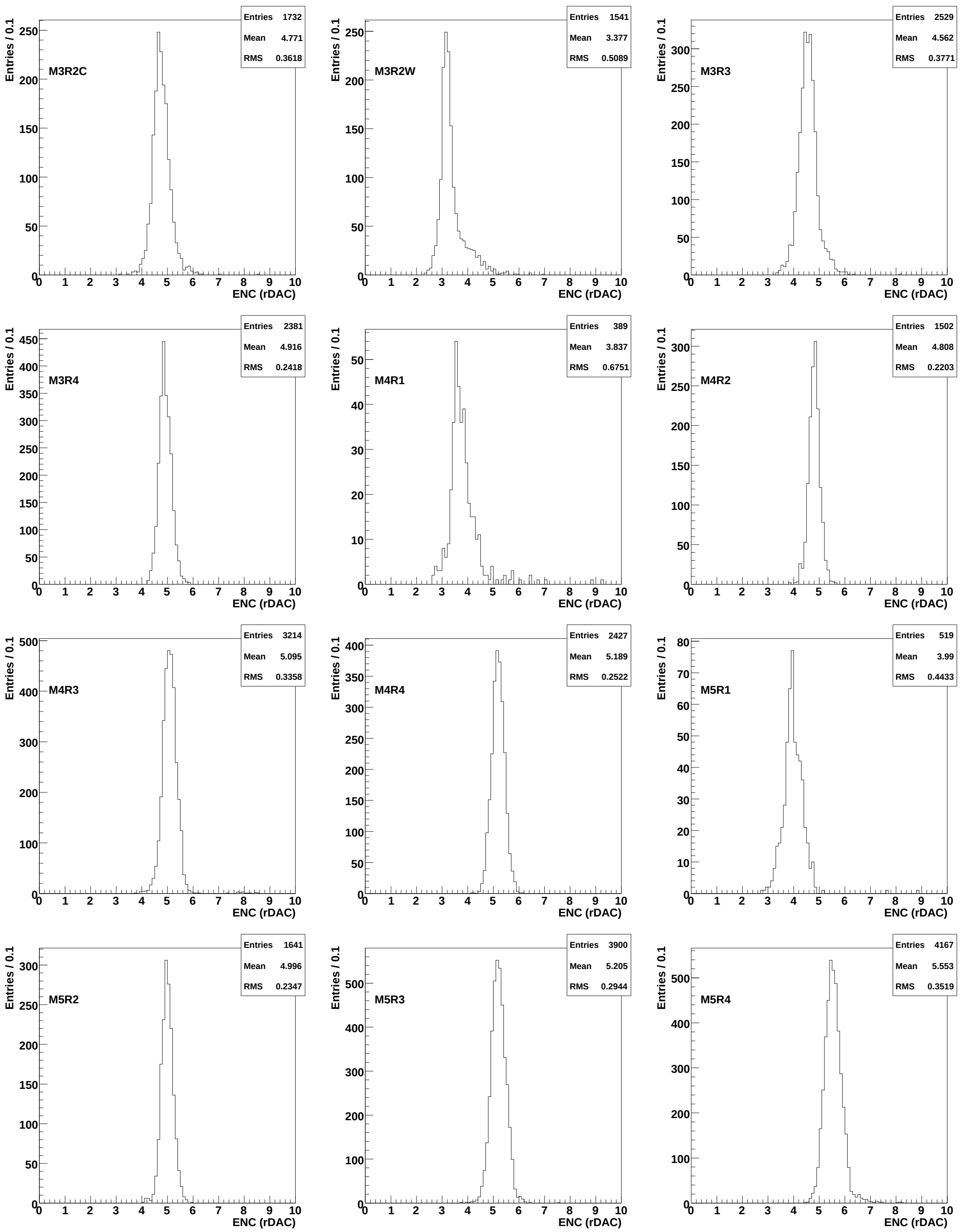

Figure 10 Histograms showing the ENC, in rDAC units, obtained from the slope measured for all the M4, the M5, the M3R2, the M3R3 and M3R4 chambers.