Calibration and performance tests of the Very-Front-End electronics for the CMS electromagnetic calorimeter

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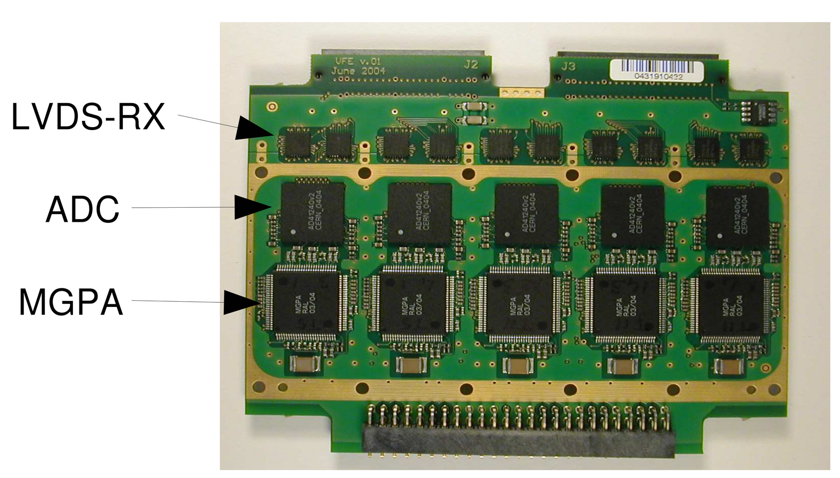
ABSTRACT

The Very-Front-End electronics processing signal from photodetectors of the CMS electromagnetic calorimeter have been put through extensive test program to guarantee functionality and reliability. The final characteristics of the VFE boards designed for the calorimeter barrel and endcaps are presented. The results, which have been also verified during test beam at CERN, confirm the high quality of the boards production and show that the CMS detector specifications are reached.

1 Introduction

1.1 Very-Front-Ends electronics

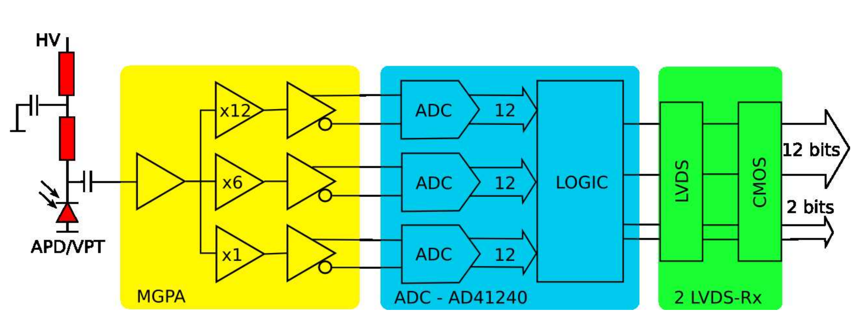
The VFE board was designed in two types: covering a dynamic range up to 50 pC corresponding to incident particle energy of $\sim$1.7 TeV for barrel and 16 pC for energy up to $\sim$3.5 TeV for the endcaps. Both types comprises five identical and independent read-out channels. Each channel, processing the signal from one crystal, consists of a Multi-Gain Pre-Amplifier (MGPA), a multi-channel analogue-to-digital convector (ADC) AD41240, and two level adapters LVDS-RX. The VFE ASICs are identical for both types of the board and various dynamic range is set by external electrical components.



Photography of the Very-front-end (VFE)

1.2 Architecture description

The MGPA chip [1] contains a pre-amplifier and three parallel gain stages with nominal gain 1, 6, and 12 that shape and amplify the photodetector signal. The three analogue output signals of the MGPA are then digitized in parallel by the sample 40 MHz 12-bit ADC (AD41240) [2]. An ADC internal logic determines whether a gain is saturated and then outputs the data from the highest non-saturated channel. The Low Voltage Differential Signal (LVDS) outputs of the ADC are adapted by two LVDS-RX to the single ended inputs of the front-end (FE) board.



Schematic representation of one channel of the VFE board.

The MGPA chip also includes a test pulse unit with an integrated digital-to-analog converter (DAC) programed via an I^{2}C interface which allows to check channel functionality by injecting a test charge directly into the input of the amplifier. In addition, the barrel VFE board also incorporates a Detector Control Unit (DCU) chip for measuring the APD leakage current and the crystal temperature.

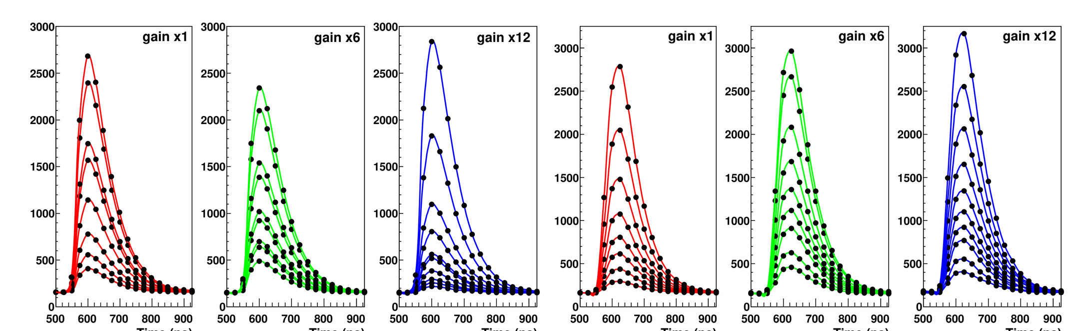
All the chips are implemented in 0.25 μm IBM CMOS radiation resistant technology.

2 Calibration and performance tests

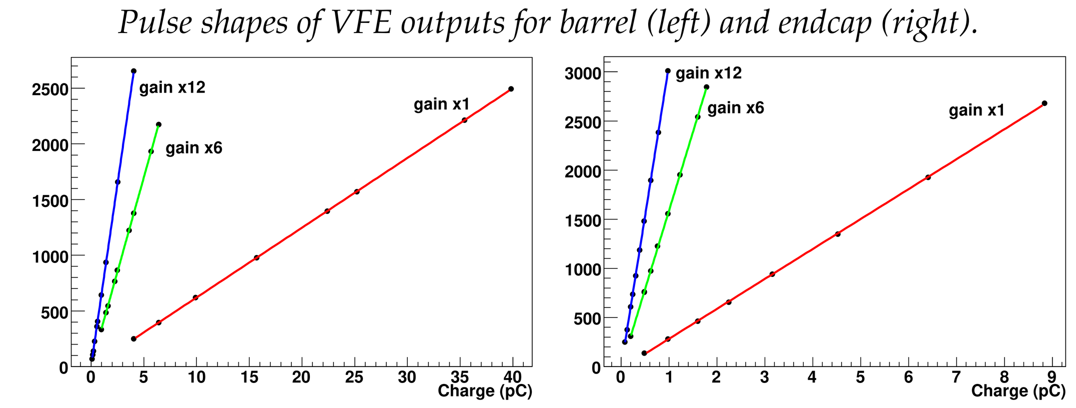
The main aim of the calibration and performance test of the VFE board is to fully characterize and verify all the operational parameters of the VFE board and build calibration database for each board which could serve for the first calibration of all the channels of the CMS ECAL.

2.1 Calibration

The calibration procedure includes an absolute calibration of each channel for the three gains in ADC counts versus injected charge in pC. Therefore a set of pulses of precise charges (generated through a 10 ± 0.01 pF capacitor) are injected into the VFE board and a digital output of the board is recorded over the full dynamic range for all three gains and five channels.



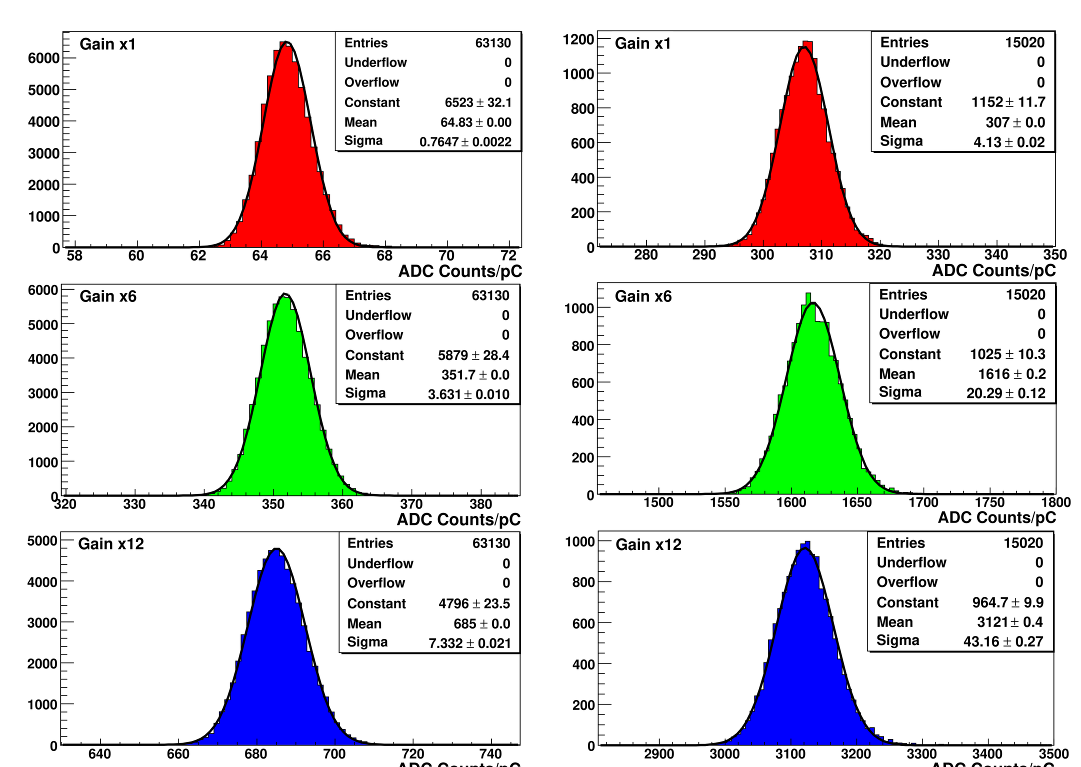
Pulse shapes of VFE outputs for barrel (left) and endcap (right).



VFE outputs in ADC counts versus injected charge in pC representing calibration curves for barrel (left) and endcap (right) VFE channel.

2.2 Slope of the calibration curve

Small value of dispersions (σ/mean around 1%) of the slopes shows very slight differences among measured channels that proves high quality and homogenity in VFE board production.



Slope distributions of the injected charges versus pulse height for barrel (left) and endcap VFE channels (right).

2.3 Linearity

Test of linearity were evaluated by help of the coefficient of determination r^2 delivered from the linear fit of the calibration curve. The coefficient for all measured channels is better than 99.99% for barrel and 99.98% for endcap VFE boards.

2.4 Gain ratio

Precision in knowledge of the gain ratio is required for high energies where switching to gain 6 or 1 occurs. Therefore several technique of the gain ratio determination were extensively studied.

Gain ratio on the calibration bench at IPNL

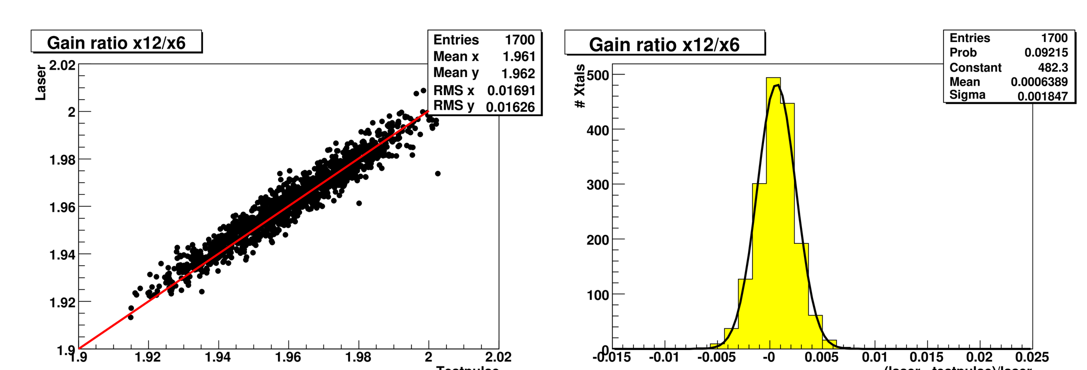
The gain ratio on the calibration bench can be determined as a ratio of slopes of the calibration curve between the gains or as a ratio of reconstructed amplitudes for chosen charge measured over the gains. The later can be performed by an external or internal injected charge (test pulse generated by the MGPA internal DAC).

	Barrel		Endcap	
Ratio	Mean	σ/mean (%)	Slope	σ/mean (%)
12/1	10.74	1.001	10.84	1.284
12/6	1.943	0.87	1.951	1.121
6/1	5.527	0.887	5.559	1.175

Mean value of the gain ratio computed as a ratio of slopes and corresponding dispersion for all the barrel and endcap VFE boards.

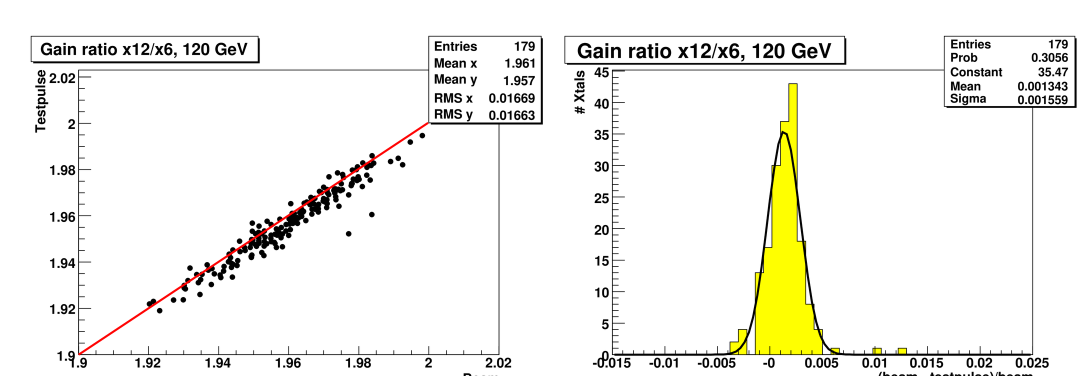
Gain ratio on the supermodule at CERN

The MGPA test pulse, measured by forcing the gains for a fixed charge of 4 pC, can be used as a in-situ technique (can be used in the CMS ECAL) for gain ratio determination. The gain ratio measured by test pulse and by monitoring laser system were compared and it was found that both methods give comparative results, well-correlated among channels.



Correlation (left) and difference (right) between gain ratio 12/6 measured by the MGPA test pulse and laser on a barrel supermodule.

In order to verify reliability of the gain ratio measurement with the MGPA test pulse, an electron beam of 120 GeV was used to determine gain ratio in data taking conditions.

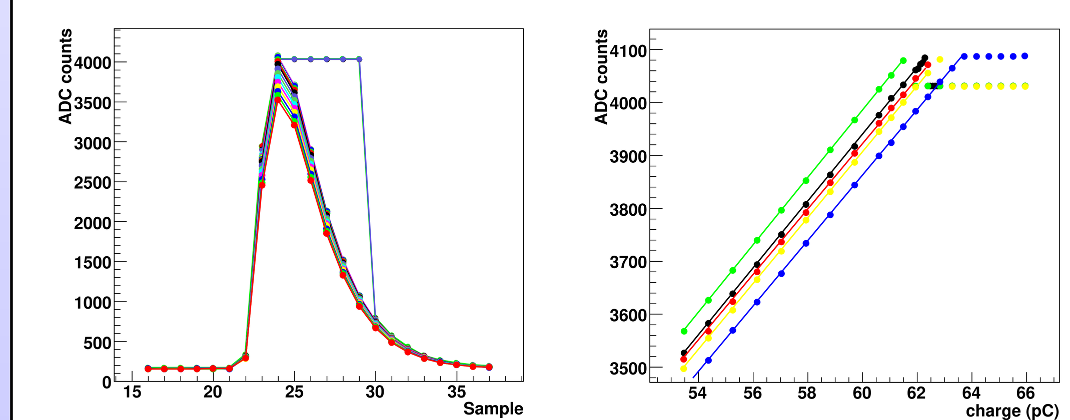


Correlation (left) and difference (right) between gain ratio 12/6 measured by the MGPA test pulse and with an electron beam of 120 GeV at CERN for 179 channels.

The results have confirmed that gain ratios obtained by the MGPA test pulses can be measured with sufficient precision and stability and thus could be used as a reliable method for gain ratio determination for the whole CMS ECAL.

2.5 Electronic saturation

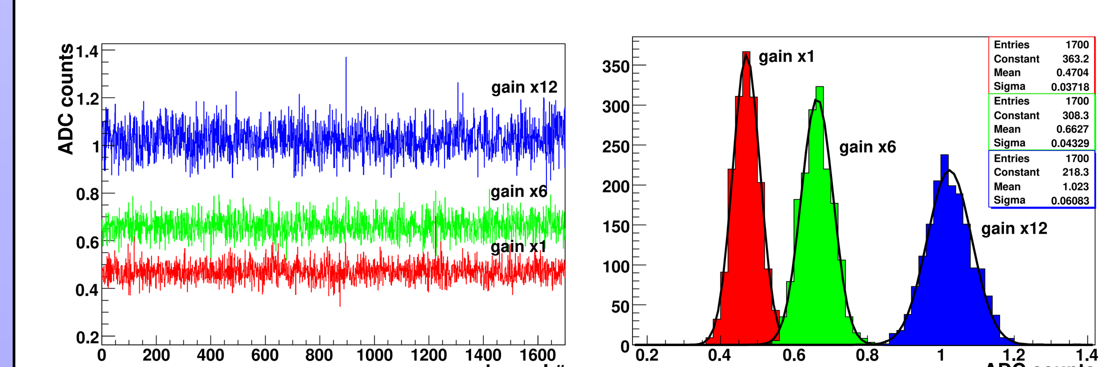
The saturation effect was studied on the barrel VFE board by applying injected charge up to 66 pC (above the specification and corresponding to > 2 TeV energy). It was found that ADC saturate before MGPA, which is linear up to saturation level that is larger than 3900 ADC counts. It was proved that saturation does not distort LHC bunch crossing identification.



ADC output for different injected charge in a single channel (left) and linearity plot for five channels of the barrel VFE board (right).

2.6 Electronic noise

An electronic noise was measured on fully assembled supermodules by applying amplitude reconstruction weight method on the pedestal runs. A typical mean value of the electronic noise for a single channel over entire barrel supermodule (1,700 channels) is around 1 ADC count ($\sim$37 MeV) for gain 12.



Electronic noise in ADC counts versus channel number (left) and its distribution (right) for a barrel supermodule.

3 Conclusions

The test program for all the 12,240 barrel and the $\sim$3,000 endcap VFE boards has been completed. The dispersion in the gains is found to be small ($\sim$1%). Noise, linearity and gain ratios are complying with the CMS detector specifications. Only around 2% of them failed the test criteria and have been rejected, the rest have been assembled into barrel supermodules and soon also into endcap supercrystals. Results are registered in a database and can be used for a first intercalibration of the ECAL. The results obtained during the Q&A program have been verified in summer 2006 and 2007, when several fully equipped supermodules and supercrystals were tested and calibrated with high energy electrons.

References

[1] M. Raymond et al., The MGPA Electromagnetic Calorimeter Readout Chip for CMS, IEEE Transactions on Nuclear Science, Vol. 52, 2005, 756–763

[2] G. Minderico et al., A CMOS Low Power, Quad Channel, 12 bit, 40MS/s Pipelined ADC for Applications in Particle Physics Calorimetry, 9th Workshop on Electronics for LHC Experiments, 2003, pp 88–91