# Calibration chain developed at LAPP for the ECAL of CMS

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**Abstract**

The experience of large calorimeters, in passed and actual experiments shows that the calibration is an extremely long and methodic task, implying several redundant methods in hardware and software as well. If, as expected nowadays, the Higgs has a mass under 150 GeV, its discovery in $\gamma\gamma$ decay by LHC experiments will rely heavily on the resolution of the ECAL. The precise measurement of these two gammas will depend in particular upon an accurate calibration (the constant term is expected < 0.5% in CMS) and upon a precise $\gamma$/e energy scale. The knowledge and the mastering of the calibration will play a major role. We describe here the electronic system, that has been developed at LAPP to update permanently the calibration of the electronic readout chain of CMS-ECAL, during data taking.

## 1-The CMS ECAL and its read out

The target characteristics of CMS ECAL make this project very challenging in terms of resolution, hadron rejection, particles isolation etc...Its characteristics are described in several publications [1,2,3] and I will only remember the principles of its read-out .

As this crystal calorimeter is fully immerged in the magnetic field of 4 Teslas, the choice was made to read out the crystals by APD photodetectors. A very aggressive R&D has been sent since 4 years and is being concluded by the production of 120 000 of these detectors. The first pre-production is actually under tests.

Each crystal will be equipped with 2 Hamamatsu APD's, in parallel, and the read out is made by sets of 2 read out cards, grouping 5 channels each.

On the read out card are implemented :

A/ 5 chips "FPPA", developed in Harris UHF1X process, which are multi-gain shaping amplifiers (gains = 1, 4, 8, 32) with a specific logic to indicate the first amplifier that does not saturates for the sampling (40 MHz) being made. The chosen amplifier is marked by 2 bits, added

B/ 5 commercial flash ADC 12 bits (Analog Device AD 9042, previously developed for USAF, in Bipolar XFCB Process), that digitize the amplitude every 25 ns.

C/ 5 serializers that convert the parallel 20 bits words (40 MHz) to a serial stream out (0.8GB.s) for the opto-coupler.

D/ One opto-coupler, developed in CHFET ASGA process, that transmits the digital information through a set of 3 fibers to the Read Out System ECAL (ROSE) card that, in the control room, links the front electronic to the general DAQ and to the trigger.

E/ One "Control Chip" (CTRL) developed in DMILL BICMOS process, that receives, from the ROSE card, through optical fibers, the adjustment parameters for the readout. It deserializes and dispatch them to individual chips.

Apart from the DAC, all the chips are full custom and have been developed at CERN by Princeton group. The final version of the whole system has been put in test beam for the first time in August and the analysis is under way.

## 2- The calibrations of ECAL

The task can be divided into 3 general topics [4]:

1. Before being mounted on the detector, all the super-modules will be pre-calibrated on a dedicated electron test beam to provide an initial precise set of calibration coefficients for each channel.
2. During data taking, the day to day, channel to channel calibration inside a same region will be updated during sterile cycles of the machine by light injection and charge injection. This calibration is made by alignment of the response of individual channels belonging to a same region. A region can be defined as a group of channels sharing the same bunch of fibers.
3. The medium and long range (in time) absolute calibration of the whole detector will rely on W and Z decay measurements.

The calibration of ECAL is then organized on several partially redundant methods:

1. Injections at the inner edge of the crystals of light pulses produced by two lasers and passing through a fiber distribution system: This system will follow the response of the ensemble crystal-readout chain to light pulses along the time. The first pulse, at the middle of the scintillation spectrum (420 nm) will follow the shifts of the overall system (in particular due to loss of transparency of crystals under irradiation)[5,6]. The second one, at 600nm is almost insensitive to transparency losses and will follow the APD gain and electronic shifts.
2. An independent system of charge injection at the input of the read-out chain will follow the shifts of the readout chain and cross-calibrate the different gains of the preamplifiers.
3. "In situ" calibration with physics events ; at low energy, the isolated electrons will be measured precisely by the tracker and their momentum compared with the response of the calorimeter. At medium energy (around 20 GeV), the W's and Z's will provide an absolute calibration for the whole

detector. According to luminosity, this "in situ" calibration will need between a few days and a month during which the local calibrations will have to be adjusted.

## 3-The calibration by Charge injection

The project consist of adding on the readout card *a)* one Test Pulse Logical System (TPLS), implemented inside the CTRL, *b)* one DAC, *c)* 5 injectors, producing on request a current pulse at the input of each FPPA. These pulses have a shape identical to the APD's one and their common amplitude is proportional to the order given to the DAC.

The system has been developed at LAPP (Annecy) in DMILL process, with following requirements :

1. no perturbation of the characteristics of the chain (in particular no add of correlated noise, no cross talk, nor any deterioration of characteristics).
2. at least as precise and reliable as the readout chain
3. robustness to eventual shifts due to irradiation damages
4. Use of existing supplies (0/5V) and very low power consumption

### 3.1 The Injector

The injector is the most critical part of this system. It has to cover the total dynamic of the APD's (pick current of 4mA, and a full-scale charge of 48 pC) with a linearity better than 0.5 % ; It has to be radhard up to $10^{14}$ n/cm$^2$ and 3 Mrads in $\gamma$ (10 years of LHC irradiation). The shape is a fast negative fall followed by an exponential rise ($\tau$=15ns), with a technical dispersion in amplitude and time lower than 10%. The PSRR (Power Supply Rejection Ratio) against the supply and the DAC line has to be as low as possible.

Since 1998, we have made 5 generations of prototypes ; a first one in AMS to test the principle, then two in CMOS, one in CMOS Bipolar and a last version integrating the 5 channels in one chip. In the final design, the injector is made of 3 components :

1. The trigger part, that adapt the PECL window signal (400ns width) received from the CTRL to levels compatible with the pulse generator stage. The edge of signals are also slightly reshaped to avoid the time jitter in the trigger of calibration pulses.
2. The amplifier that translates the voltage level produced by the DAC into a current level, transmitted to the pulse generator stage
3. The pulse generator is mainly a two branch bipolar circuit. The trigger splits the flowing current from one branch to the other one and the capacity $C_{out}$ (60pF), previously charged is rapidly discharged and then recharged through $R_{out}$ (250 $\Omega$) and the preamplifier (Zi ~7 $\Omega$). The decay time of the pulse is completely fixed by $R_{out}$ * $C_{out}$ . For precision and flexibility, the $C_{out}$ has been placed outside the chip.

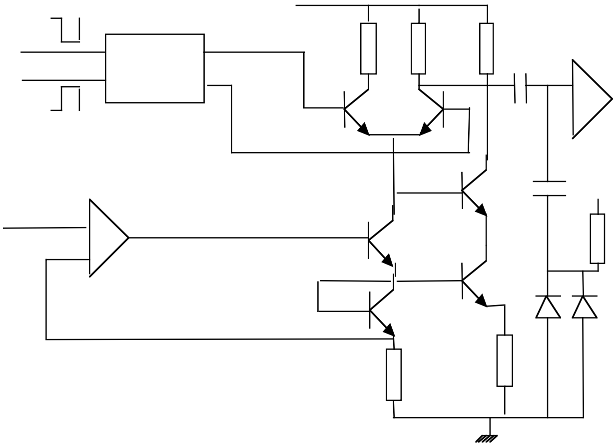


Figure 1 Principle of the Injector

### 3.2 The DAC

In a previous version, we have tested a commercial circuit, Analog Device AD 8582A in CB CMOS technology. This DAC is a parallel input, 12 bits, 0/4Volts, 5mA output, supplied on 0/5Volts, its dissipation is 5mW at rest. Its reference voltage level can be measured on an output pad. This chip has been extensively tested in lab and in irradiation beams. It fulfills the calibration requirements .

In a second step, a 10 bits DMILL version has been founded in view of assembling the whole project in one chip. This DMILL DAC is still under investigations due to process difficulties during foundry.

### 3.3 The control chip

The control chip first amplifies the amplitude of the 40MHz clock and of the data's received from the opto-coupler; then it recognizes, interprets and dispatches the orders to the different parts of the readout card.

## 4-The R&D

### 4.1 The tools

Figure 2 shows the chain that has been mounted at LAPP to measure the linearity, the dispersion and the stability of different components of the project. This chain is based on a PC linked to a VME and CAMAC crates for charge measurements. It is also linked to a Keithley Multimeter 2020 by GPIB link for levels measurements. An overall monitor Labview® program makes systematic rampings on the DAC with charge and levels measurements at each step. The linearity of the injector has been measured in tension (at the edges of $R_{out}$), which is the most precise and in total integrated charge, after $C_{out}$ In some runs, we have also verified by on a LECROY 9361 linked by GPIB that the shape was not affected.

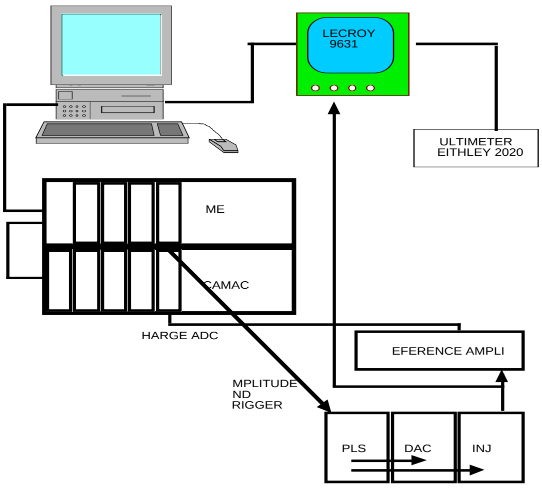
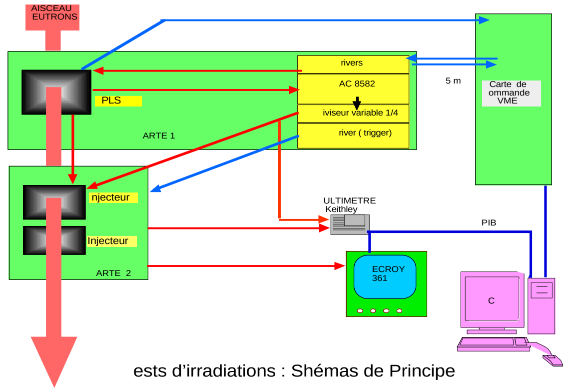



Figure 2  Principle of the Measurement chain

For irradiation tests, we moved an identical chain on the different available sites.




Figures 3 : set up used for  irradiation tests

After a preliminary test on the Nuclear plan Ulysses at Saclay (IR1), we have used the SARA installation at Grenoble (France) (IR 2) and after it's shut down, the CERI installations at Orleans (IR 3,4 and 5), where the irradiation facility had been moved. These beams [7,8] produce neutrons by stripping of deutons on a thick beryllium target. The average energy of these neutrons is ≈ 6 MeV and the FWHM is ≈ 6 MeV. Theses beam have a photon contamination that has been evaluated to 3.6 kGy for an integrated dose of $2*10^{14}$ n/cm$^2$ . The fluence depends on the distance to the target and can be adjusted up to $10^{13}$ n/cm$^2$/ hour. We have also used the 72 MeV proton beam of PSI (Villigen, Switzerland) (IR 6 and 7). The correction parameter for protons is ≈ 2 and the equivalent integrated dose for this irradiation was $4\ 10^{13}$ n/cm2. We have also used a photon Cobalt source facility at PSI to irradiate an injector up to 400 Krads (IR8).

## 4.2 The results

**Measurements in laboratory**

a/ On the digital electronics

Extensive tests have been made on TPLS in order to insure a default rate $<10^{-6}$ .

b/ On the DAC AD8582 A

The fig 5 shows the residues in Lsb units to a linear fit (1Lsb = 1mV). Despite the excellent results, a structure due to high bit steps is clearly seen and the overall dispersion is within ± .4 Lsb.

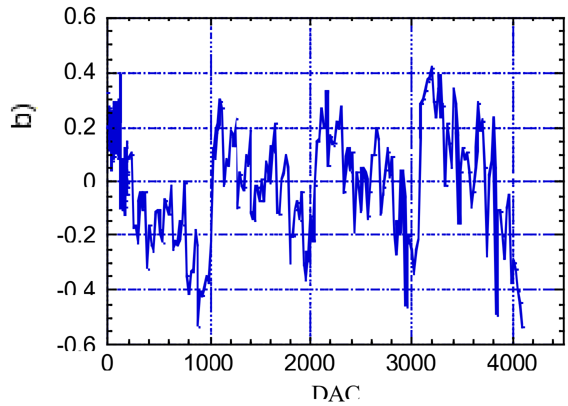



Figure 4  Residues to linearity of the AD 8582

c/ On the injector

The figure 5 shows the residues to a linear fit in voltage and charge, both in absolute value and %, for one of our CMOS  injectors.

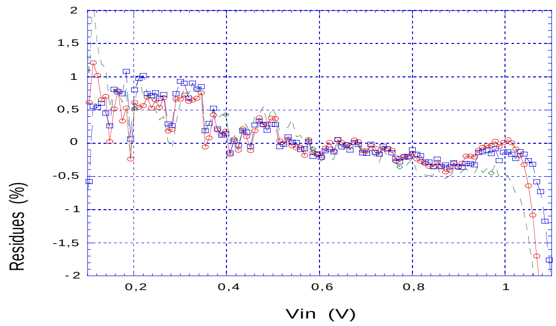



Figure 5 Residues to linearity for injector(Volts)

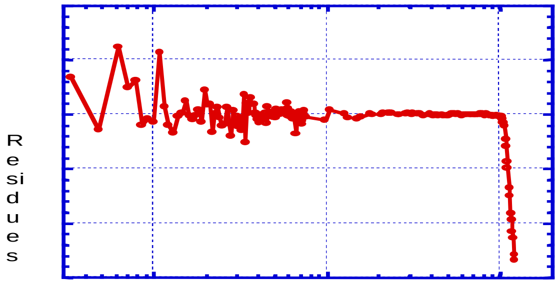



Figure 6 : Residues to linearity (%)

The noise and PSRR of the injector have been measured with a spectrum analyzer HP3589A, the noise has been found < 0.5 nV/√Hz for the injector at rest and < 2.5 nV/√Hz in active mode. The rejection (PSRR) on power supply and on DAC line (9).is always better than 60 dB up to 40 MHz (9).

**The irradiation tests**

A/ On TPLS

Extensive tests up to 5 $10^{13}$ n/cm$^2$ have been made on TPLS and we have found the default rate < $10^{-6}$.

B/ on DAC's

The DAC is mainly made of 3 parts : the band gap, the divider and the output buffer. The figure 7 shows the measurement of the shift of reference Voltage during the irradiation of 2 different DAC's, which measure the band gap hardness. The Vref shifts is < .2% for 10 LHC years.

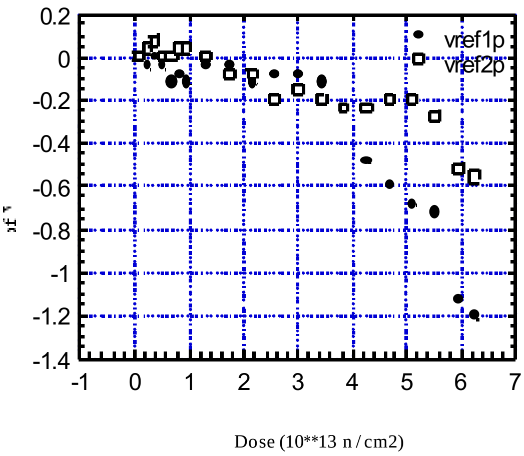



Figure 7 : Variation of Vref for DAC's

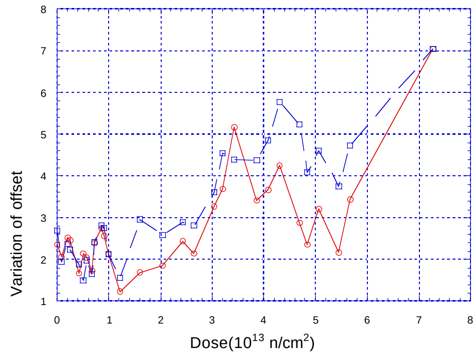



Figure 8 Variation of the offset for DAC's

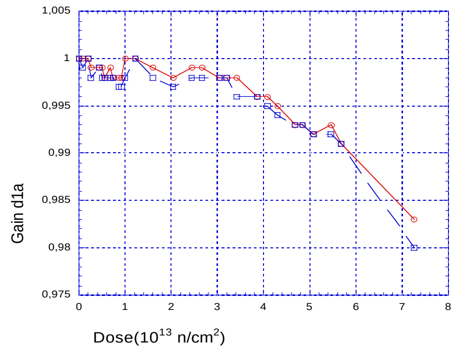



Figure 9 Variation of the slope for DAC's

C/ On Injectors

The figures 10 and 11 show the effect of the irradiation on the slope and on the offset of the injector.

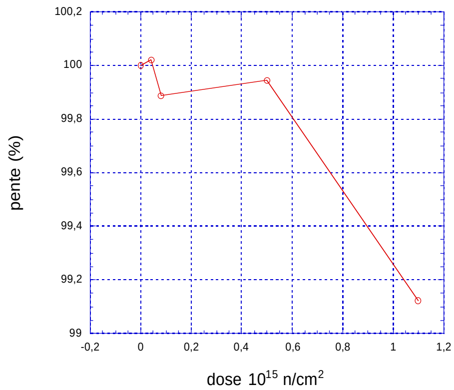



Figure 10 Variation of slope under irradiation

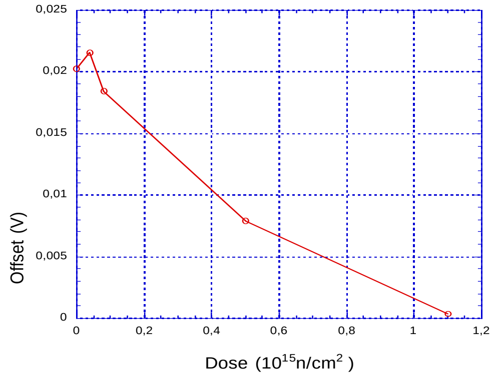



Figure 11 Variation of the offset

Up to $10^{14}$ n/cm$^2$ , the only effect is a shift in the offset. This effect, even if existing in real experiment, by forcing the trigger with DAC =0. After, (IR5), the dynamic range of the injector is reduced up to a factor 3 at $10^{15}$ n/cm$^2$ (1000 years of LHC !).

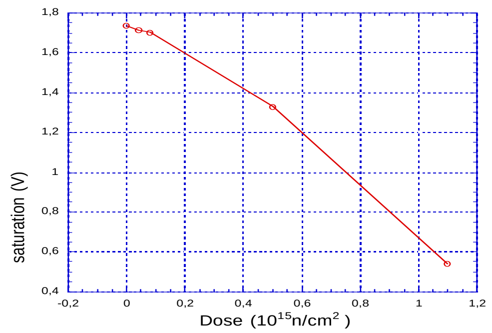



Figure 12 Variation of the saturation

## 5- Conclusions of this R&D

The technical conclusion of this R&D is that the DMILL process is extremely robust to irradiation, certainly more than we had expected. We have not been able to destroy the injector by irradiation, even at 400 Krads and several $10^{15}$ n/cm$^2$ .

The calibration system that we have developed for ECAL can be used on any read out chain working in an hostile environment of temperature, high radiation rate, inaccessibility, extreme reliability, low power consumption etc...

For a complex detector, it is a radical help to understand, debug, calibrate etc... It should be integrated from the start as a major component of the readout system.

This is typically the situation the space complex detectors and the actual conditions of foreseen experiments in astrophysics and high-energy physics are becoming identical. The electronic circuits need the same reliability and redundancy since in both cases they are inaccessible to human intervention.

## References

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