High precision, low disturbance calibration system for the CMS Barrel Electromagnetic Calorimeter High Voltage apparatus

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Abstract: The CMS Electromagnetic Calorimeter utilizes scintillation lead tungstate crystals, with avalanche photodiodes (APD) as photo-detectors in the barrel part. 1224 HV channels bias groups of 50 APD pairs, each at a voltage of about 380 V. The APD gain dependence on the voltage is 3%/V. A stability of better than 60 mV is needed to have negligible impact on the calorimeter energy resolution. Until 2015 manual calibrations were performed yearly. A new calibration system was deployed recently, which satisfies the requirement of low disturbance and high precision. The system is discussed in detail and first operational experience is presented.

Keywords: Calorimeters; Hardware and accelerator control systems
Introduction. The barrel part of the CMS [1] Electromagnetic Calorimeter (ECAL) is made of 61200 lead tungstate (PbWO₄) crystals whose scintillation light is detected using Avalanche Photodiodes (APDs) produced by Hamamatsu Photonics [2, 3]. Two APDs are glued on each crystal as shown in figure 1.

**Figure 1.** A crystal (PbWO₄) used in the CMS ECAL, shown together with capsules hosting two APDs.

The ECAL energy resolution is very important for several physics analyses at CMS, as for example for the study of the diphoton decay of the Higgs boson [4]. The energy resolution of the calorimeter is parametrized, as a function of the incident electron/photon energy, as the sum in quadrature of three terms expressed by the following formula [5]:

\[
\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} + \frac{b}{E} + c \quad (0.1)
\]

where the first term (a) is the stochastic term, the second one (b) is related to the electronics noise and the third one (c) is the constant term, which includes contributions from response uniformity and stability. The APDs contribute to all of the three terms. In particular, the operational APD gain is achieved with an appropriate High Voltage (HV) system. The operating voltage of the APDs, which directly affects the gain, must be kept stable to minimise the contribution to the constant term.
1 The CMS ECAL Barrel HV system

The light produced by the scintillating crystals of ECAL is read out by the APD (for the Barrel section of the calorimeter). The APDs need to be appropriately biased to provide a gain of 50 by applying a voltage of about 380 V with high stability. A dedicated HV power supply system [6], developed by INFN-Roma in collaboration with CAEN, is used to bias the APDs. The system is installed in 6 racks (see figure 2) in the CMS Service Cavern (USC) where no damage to the electronics circuits due to radiation is foreseen. It is composed of 18 CAEN SY4527 Mainframes, each hosting 8 CAEN A1520PE boards. Each board carries 9 HV channels. Each channel is used to bias 100 APDs, i.e. 50 crystals. Sense wires are used to compensate for cable voltage drops along the supply lines. Each capsule receives its bias voltage through a passive filter network and a protection resistor (of 136 kOhm) to avoid damaging the APDs sharing the same HV channel, in case of a short circuit between one APD cathode and the HV ground. The HV channel characteristics are summarized in table 1.

![Figure 2](image-url)  
**Figure 2.** Half of the CMS ECAL Barrel HV system in the CMS underground service cavern (USC).

| Parameters                          | Values              |
|-------------------------------------|---------------------|
| Output Voltage Range                | 0–500 V             |
| Programmable setting step           | 1 mV                |
| DC regulation at load               | < ± 20 mV           |
| DC stability at load (30 days)      | < ± 60–65 mV        |
| Low freq. noise at load (f<100 kHz) | < ± 20 mV           |
| High freq. noise at load (f>100 kHz)| < ± 20 mV           |
| Operating temperature at supply     | 15–40°C             |
| Current limit                       | 15 mA               |
| On and off maximum ramp rate        | 50 V/sec.           |
| External Calibration                | < ± 20 mV           |
2 HV stability requirements

The main characteristics of the APDs employed in the ECAL Barrel are summarized in Table 2 while the typical curve of the APD gain as a function of the HV bias voltage is shown in Figure 3. The APDs are operated at gain 50, requiring a bias voltage in the proximity of the breakdown region (350–450 Volts). During the construction phase the APDs were sorted in order to have 50 pairs with similar characteristics in each HV channel.

| Parameters                                  | Values       |
|---------------------------------------------|--------------|
| Maximum operating voltage                   | 500 V        |
| Minimum operating voltage                   | 200 V        |
| Leakage current (start of experiment)       | < 0.01 µA    |
| Leakage current (after 10 years)            | < 20 µA      |
| Gain sensitivity (at gain = 50)             | 3.1%/V       |
| APDs used in the ECAL barrel                | 122400       |

The APD gain variation as a function of the applied gain is shown in Figure 4. Labeling the gain as M and expressing the gain sensitivity as $\beta = (1/M)\delta M/\delta V$, it is found (at gain 50) that $\beta=3.1%/\text{Volt}$.

Since the contribution of the gain variation to the ECAL energy resolution constant term is required to be less than 0.2% this implies that the high voltage stability has to be better than 60–65 mV per month. Every HV channel was tested and qualified according to this requirement before installation [6]. Variations on a time scale longer than a month can be corrected for by the detector calibration with physics events, while the calibration method described in this contribution can be performed during the technical stops (3–4 times in a year at most).

The target of the voltage calibration is to tune all the HV channels within 20 mV in the voltage range required by the APDs. The specific voltage of the each group of APDs, so of each channel,
is different and ranges between 350 and 420 V. Three voltage values are taken as calibration points: 380, 420, 480 V. The voltage measured on each channel after the calibration must be within 20 mV from the desired voltage value for all three calibration points, thus ensuring both that each HV channel is well calibrated and showing a linear response in the APD voltage range.

![Graph](image)

**Figure 4.** Gain variation vs. applied gain.

### 3 Calibration of the HV system

In order to avoid inducing noise on the calorimeter signal measurement, the HV system was not equipped with a continuous monitoring system. Periodic monitoring and calibration campaigns are therefore required during beam-off periods. Until 2015 the calibration was performed manually uncabling the system in the CMS service cavern and calibrating one by one the HV boards with a precision multimeter. Due to the long time required and in order to reduce mechanical stress on cables and connectors, the calibration was performed once per year during the LHC winter shutdowns. A new calibration system was deployed at the end of 2015. It includes mechanical switches connecting the HV cables to the calibration system, guaranteeing that no additional noise is introduced. During operation the switches connect the HV to the APDs in CMS. During the calibration campaign the switches are instead manually turned to connect the HV towards the calibration system. In this case, calibration cables direct the bias voltages to a precision multimeter through a set of multiplexers. A picture of an open multibox used to commute from operation to calibration mode is shown in figure 5.

The multiplexers are Cytec boards JX/256-MF model [7], which contain 4 ways HV relais rated up to 500 V. Two HV boards with 8 channels are connected to one Cytec board hosting 16 switches, while the HV boards with 9 channels are connected on Cytec boards hosting 9 switches. A Cytec board with 16 switches is shown in figure 6. The calibration program cycles through all the channels allowing both to measure the voltage and to recalibrate the channels one by one. One complete calibration with the old procedure required about 3 weeks, while the new hardware, after the commissioning, will allow the calibration to be completed in about 1 week.
4 Performance

In order to commission the new calibration system, the ECAL Barrel HV system was calibrated both with the old and new calibration procedure in early 2016. The plot in figure 7 shows the relative difference between the laser monitoring signals in the ECAL Barrel crystals when the HV was calibrated with the new and with the old calibration system. The distribution is fitted with a gaussian function. The sigma is 0.1%, well within the requirements. The mean is slightly shifted from zero, due to the use of two different multimeters in the two HV calibration systems, whose calibration is compatible at the level of 30 mV. This result reflects in a 0.1% systematic error on the APD gain. There are more than 99.4% channels within ± 0.5%.

5 Conclusions

A new calibration method of the CMS ECAL Barrel HV system has been presented. The old method required manual intervention to uncable the system in the CMS service cavern and calibrate the HV boards one by one. This results in a lengthy procedure that can only be performed during year-end technical stops, and causes increased mechanical stress on the HV cables. The new calibration system presented here introduces mechanical switches to connect the HV cables to the calibration system and a specific software program cycling through all the channels allowing both to measure the voltage and to recalibrate all the channels individually. The new method is less time consuming than the previous one (1 week vs. 3 weeks) and does not require to uncable and recable the whole system, reducing the mechanical stress on the connectors. The use of mechanical switches allows to commute between the operation and the calibration mode when needed, and no disturbance is
induced on the calorimeter signal. The new system was tested at the beginning of 2016 and both methods provide compatible results.

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