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

Giuseppe Fasanella for the CMS Collaboration

Abstract

The CMS Electromagnetic Calorimeter utilizes scintillating 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 3pct/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.

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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: CMS; Electromagnetic Calorimeter; APD; High Voltage; Power Supply.
Contents

1. The CMS ECAL Barrel HV system
   1.1 HV stability requirements
2. Calibration of the HV system
   2.1 Performance
3. Conclusions

Introduction

The barrel part of the CMS Electromagnetic Calorimeter (ECAL) is made of 61200 lead tungstate (PbWO$_4$) 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 Fig. 1.

![Figure 1: A Crystal (PbWO$_4$) used in the CMS ECAL, shown together with capsules hosting two APDs.](image)

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]:

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

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 Fig.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: Half of the CMS ECAL Barrel HV system in the CMS underground service cavern (USC)](image)

<table>
<thead>
<tr>
<th>Parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Voltage Range</td>
<td>0-500 V</td>
</tr>
<tr>
<td>Programmable setting step</td>
<td>1 mV</td>
</tr>
<tr>
<td>DC Regulation at load</td>
<td>&lt; ± 20 mV</td>
</tr>
<tr>
<td>DC stability at load (30 days)</td>
<td>&lt; ± 60-65 mV</td>
</tr>
<tr>
<td>Low freq. noise at load (f &lt; 100 kHz)</td>
<td>&lt; ± 20 mV</td>
</tr>
<tr>
<td>High freq. noise at load (f &gt; 100 kHz)</td>
<td>&lt; ± 20 mV</td>
</tr>
<tr>
<td>Operating temperature at supply</td>
<td>15 ± 40 °C</td>
</tr>
<tr>
<td>Current Limit</td>
<td>15 mA</td>
</tr>
<tr>
<td>On and off maximum ramp rate</td>
<td>50V/sec.</td>
</tr>
<tr>
<td>External Calibration</td>
<td>&lt; ± 20 mV</td>
</tr>
</tbody>
</table>

Table 1: HV Channel Electrical Characteristics.
1.1 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 Fig. 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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Operating Voltage</td>
<td>500 V</td>
</tr>
<tr>
<td>Minimum Operating Voltage</td>
<td>200 V</td>
</tr>
<tr>
<td>Leakage Current (start of experiment)</td>
<td>&lt; 0.01 μA</td>
</tr>
<tr>
<td>Leakage Current (after 10 years)</td>
<td>&lt; 20 μA</td>
</tr>
<tr>
<td>dM/dV Gain Sensitivity (at gain M = 50)</td>
<td>3.1 %/V</td>
</tr>
<tr>
<td>APDs used in the ECAL barrel</td>
<td>122400</td>
</tr>
</tbody>
</table>

Table 2: APD Characteristics.

The APD gain variation as a function of the applied gain is shown in Fig. 4. Labeling the gain as $M$ and expressing the gain variation 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].

The ECAL calibration from physics channels can be updated typically every month. The HV system is placed in the CMS Service Cavern (USC) where there are no radiations and a small magnetic field. The HV cables are 120 meters long. Sense wires are used to compensate for the voltage drop along the cables.
2. 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, 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 consists of mechanical switches connecting the HV cables to the calibration system, guaranteeing that no additional noise is introduced. Usually the switches connect the HV to the APDs in CMS. During the calibration campaign the switches instead are 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 Fig. 5.

Figure 5: An open multibox used to commute from operation to calibration mode.
The multiplexers are Cytec boards JX/256-MF model, 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.

![Figure 6: A Cytec board hosting 16 switches.](image)

The calibration program cycles through all the channels allowing both to measuring the voltage and to recalibrating the channels one by one.

One complete calibration with the old system required about 3 weeks, while the new method, after the commissioning, will allow the calibration to be completed in about 1 week.

### 2.1 Performance

In order to commission the new calibration system, the ECAL Barrel HV system was calibrated both with the old and new calibration apparatus in early 2016. The plot in Fig. 6 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%.

![Figure 6: Relative difference of the APD response after HV calibration with the old and the new system.](image)
3. 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 one by one the HV boards. 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 singularly. 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.

Acknowledgements

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References


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