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

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CMS barrel electromagnetic calorimeter (Barrel ECAL):

→ 61200 scintillating lead tungstate crystals.
→ Scintillating light is read by avalanche photodiodes (APDs)
→ APDs are silicon photon sensors with an internal gain
→ Typically operated at a gain of 50, achieved with a high voltage (HV) bias of 380 V
→ The gain stability implies a supply voltage stability better than 60 mV per month
→ The high voltage is provided to the detector through 120 meters cables. Sense lines are used to compensate for the voltage drop across the cables

The CMS ECAL Energy Resolution:

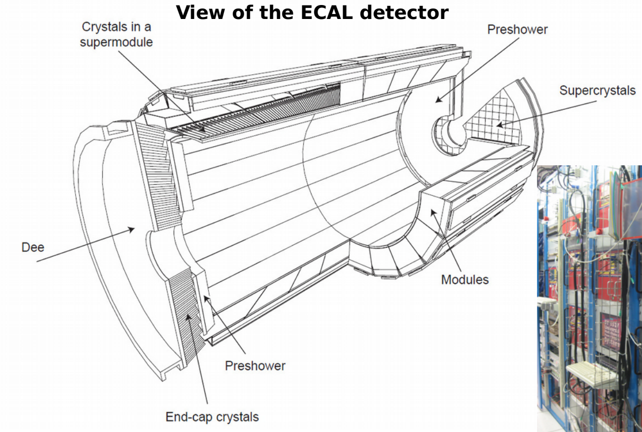
The APD contribute to all of the three terms:
a → Fano factor & quantum efficiency ~ 3%
b → Capacitance & Dark current ~ 200 MeV
c → HV & temperature stability ~ 0.5 %

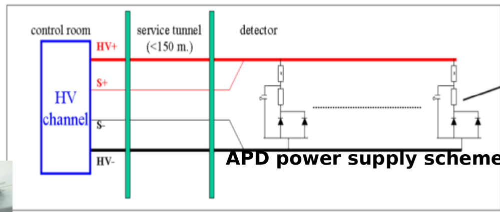
$$\frac{\sigma_E}{E}=\sqrt{\frac{a^2}{E}+\frac{b^2}{E^2}+c^2}$$

The HV system:

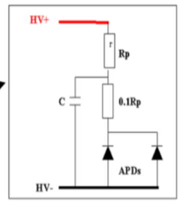
→ A dedicated power supply is used to bias the APDs
→ It was developed by **CAEN** in collaboration with **INFN-Roma**
→ It is installed in 6 racks in the CMS Service Cavern
→ It is composed of **18 CAEN SY4527 Mainframes**
→ Each mainframe hosts **8 CAEN A1520PE** 9-channels modules
→ Each channel is used to bias 100 APDs (50 crystals)

View of the ECAL detector



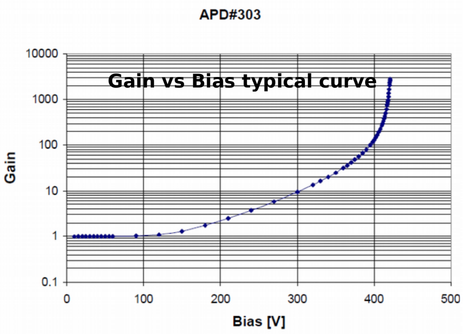


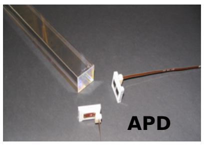
APD power supply scheme



Required stability:

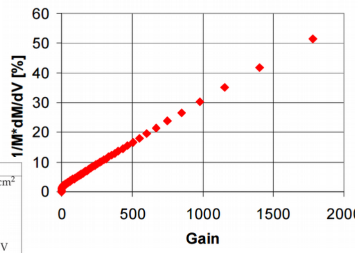
APD gain is sensitive to small fluctuations of the HV bias → **APD gain variation** is ~ **3.1%/V** at gain 50 → **direct effect on the energy Resolution.** The impact on the constant term is required to be less than 0.2% → **HV stability** at the level of **60 mV per month**
Variations on longer time scale can be corrected by the detector calibration using physics events





Characteristic	Value
Area	0.5×0.5 cm^2
Number of APDs per crystal	2
Capacitance	70 pF
Serial resistance	3 Ω
Quantum efficiency (at $\lambda = 420$ nm)	70%
Operating Voltage (at G=50)	350-420 V
Distance to breakdown (at G=50)	30-40 V
Temperature variation of the Gain	−2.3%/°C
Bias variation of the Gain (at G=50)	3.3%/V
Excess Noise Factor (at G=50)	2
Effective thickness	6-7 μm

APD gain variation



At gain (M) = 50:
(1/M)*dM/dV=3.1%/V

HV channel electrical characteristics

Parameters	
Output voltage range	0–500 V
Programmable setting step	20 mV
DC regulation at load	< ±20 mV
DC stability at load (over 90 days)	< ±20 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

Calibration of the HV system:

In order to avoid inducing noise on the calorimeter signal measurement, the HV system was not equipped with a continuos monitoring system. **Periodic** monitoring and **calibration campaigns are** hence **perfomed**.

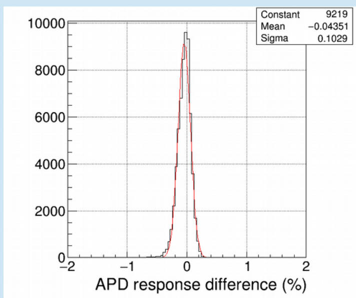
Old method:
Until 2015 the calibration was done **manually uncabling** the system in the CMS service cavern and calibrating one by one the HV boards with a precision multimeter. The calibration was done **once per year** during the LHC winter shutdown due to the **long time required.**

New method:
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. Calibration cables draw the bias to a precision multimeter through a set of multiplexers. 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 system required about 1 month, while the new method requires about 1 week.

Performance:

To commission the new calibration system in 2016 the ECAL Barrel HV system was calibrated **both** with the **old and new calibration** apparatus. The plot shows the **relative difference** of the laser monitoring signal when the HV was calibrated with the new and with the old calibration system.



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 30 mV level, which reflects in a 0.1% syst. error on the APD gain. There are **more than 99.4% channels within ±0.5%.** The few channels with large shift are understood to be due to calibrating without load on half of the channels (resistor not suitable for high load).