The CMS ECAL Barrel HV system

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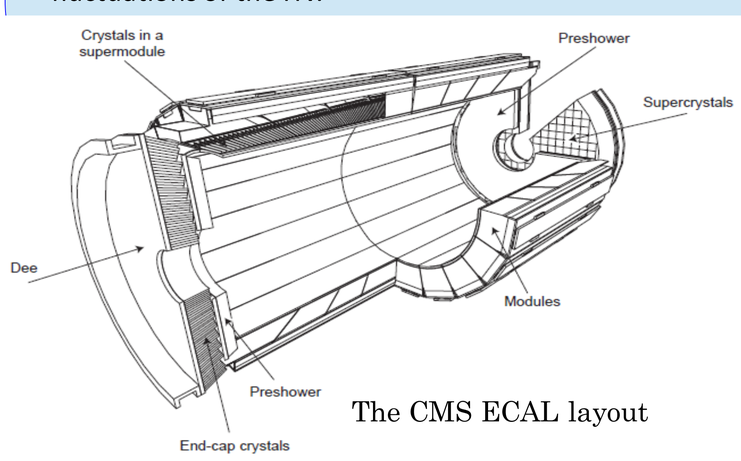
ABSTRACT
The CMS electromagnetic calorimeter (ECAL) comprises 75848 scintillating lead tungstate crystals. 61200 crystals are contained in the ECAL Barrel section and are read out by avalanche photodiodes (APD) with internal gain of about 50. This gain is achieved with a high voltage (HV) of around 400 V. The gain stability requirement implies a supply voltage stable to within 0.01%.
We describe our experience with the installed Barrel HV power supply system, which has been used for data taking since 2008.

The CMS ECAL

The CMS electromagnetic calorimeter (ECAL) is used to detect and measure the energy of photons and electrons produced in collisions at the LHC.
The barrel part comprises 61200 lead tungstate ($PbWO_4$) crystals whose scintillation light is detected using Avalanche Photodiodes (APD) produced by Hamamatsu Photonics. Two APDs are used for each crystal. A dedicated high voltage (HV) power supply system is used to bias the APDs. The stability of the HV System has a direct influence on the constant term of the barrel ECAL energy resolution since the gain of the APDs, and hence the calibration of the system, is sensitive to small fluctuations of the HV.



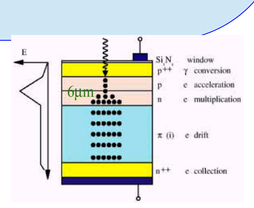
The CMS ECAL layout

The electromagnetic energy resolution parametrised as a function of the incident electron/photon energy → $\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$

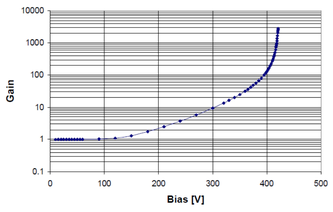
Required HV and Stability

The APDs in CMS are operated at a gain 50, requiring a high (bias) voltage in the proximity of the breakdown region (350-450 Volts). The APD gain variation is about 3.1%/V at gain 50 and the contribution of this gain variation to the ECAL energy resolution constant term is required to be less or equal to 0.2%. This implies that the high voltage stability has to be of the order of 60–65 mV. This requirement places constraints on the combination of electrical system characteristics including:
noise, ripple, voltage regulation and absolute precision, for short- and long-term periods.

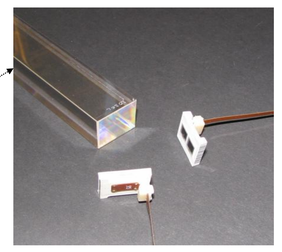
APD characteristics	
Max Operating Voltage	500 Volts
Min Operating Voltage	200 Volts
Leakage Current (start of experiment)	< 0.01 microA
Leakage Current (after 10 Years)	< 20 microA
Gain Sensitivity (Gain = 50)	3.1 %/V
APDs used in the ECAL Barrel	122400



APD structure



Typical APD Gain vs Bias Curve

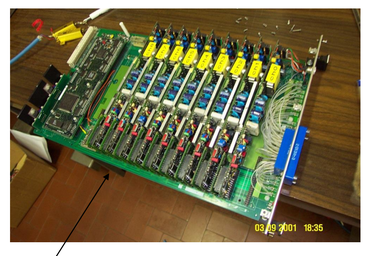


Assemblies of 2 APDs connected in parallel are used for each crystal

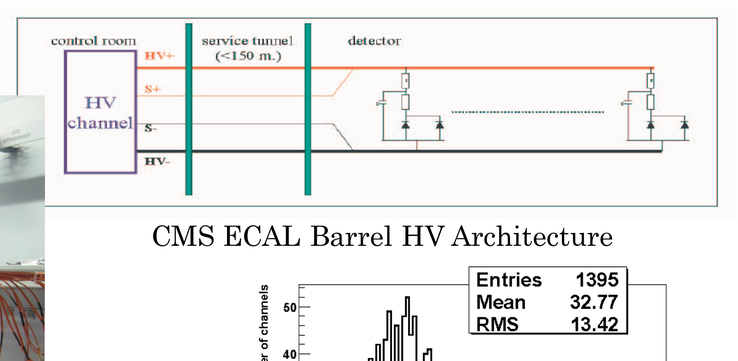
The HV system

The CMS ECAL HV power supply system was developed starting from 1999 by INFN Roma in collaboration with CAEN. The system was installed in 2008 in 6 racks in the CMS Underground Service Cavern (USC).
It is composed of 18 CAEN SY1527 mainframes, hosting 144 A1520E modules for a total of 1224 HV channels . Since APDs are sorted to have similar Vbias each channel is used to bias 100 APDs (50 crystals) and sense wires are used to recover cable voltage drop. It is possible to set the output voltage in the range 0V-500V with a maximum output current of 15mA per channel.
Each channel was tested before installation in CMS. Channels not compliant with the required 65 mV stability over 30 days were not used.

HV channel parameters	
Output Voltage Range	0-500 V
Programmable Setting Step	10 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)	< ±2 mV
Operating temperature at supply	15÷40 °C
Current Limit	15 mA
On and Off max ramp rate	50 V/sec
External Calibration	< ±20 mV



144 A1520E module are used in the HV system



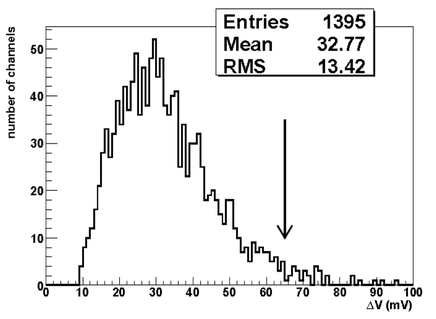
CMS ECAL Barrel HV Architecture

Controlling the ECAL HV System

Remote monitoring and control of all individual channel parameters (status, output voltage, current limit, etc.) is performed by the ECAL Detector Control System (DCS) over Ethernet. The DCS continuously checks critical parameters, generating warnings and alarms to the CMS control room and to the ECAL experts if necessary.

ECAL HV DCS Screen

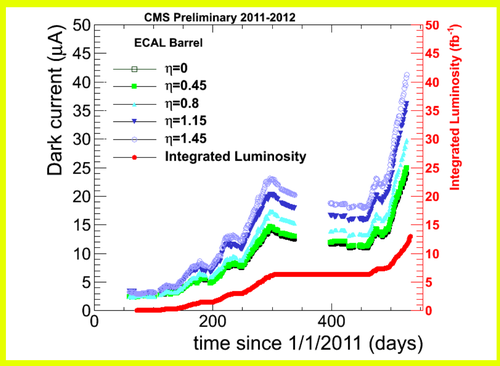
Half of the CMS ECAL Barrel HV System in the USC



|Vout-Vset| Distribution of HV channels
Channels with dV > 65 mV were not used

The ECAL Barrel HV System performance during the first 3 years of operation in CMS

During the past three years the HV system has been periodically calibrated using a dedicated external system to guarantee absolute voltage precision with an accuracy of ±20mV.
Measurements of HV channel voltage stability (performed before each calibration) show excellent performance, corresponding to an APD gain stability of better than 0.2% for >97% of channels.
The DCS monitors the APD dark current evolution due to the radiation damage. Values measured are consistent with the forecast done during the system design phase corresponding to a maximum current per HV channel <2 mA after 500 fb^{-1} integrated luminosity.



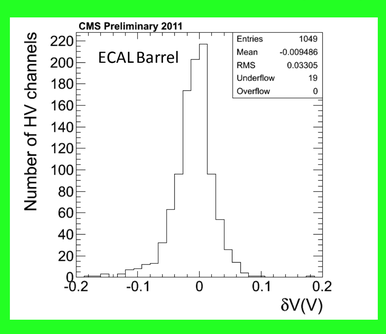
Dark current (for 1 HV Channel = 100 APDs) increase during the 2011 & 2012 Runs and corresponding Integrated luminosity (red points). The different blue/green colors represent the different channels in one ECAL Supermodule (1700 crystals).

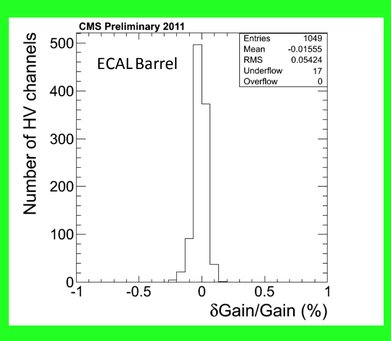
Voltage stability during 2011 run:

Top Plot, High Voltage stability: RMS 33mV

Bottom plot |δG|/G :

97% HV channels with |δG|/G≤0.2%

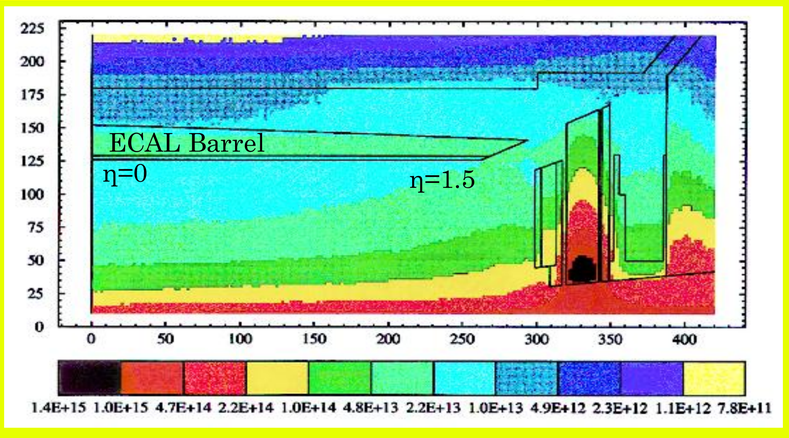




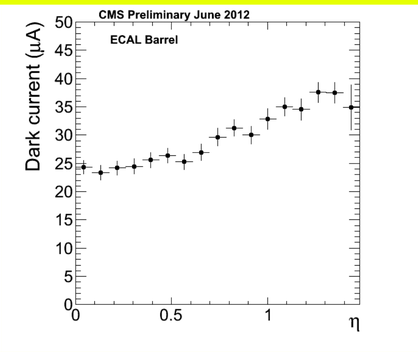
The APD gain depends on the bias voltage at

δGain/Gain = β δV β=3.1%/Volt (at Gain 50)

The HV system is calibrated once or twice a year with dedicated electronics.
During this calibration the voltage is set at 380 V and the voltage output is measured.
One calibration took place at the end of 2010, and one in january 2012.
The plot shows the gain deviation for all HV channels measured after one year of data taking (2011).
These gain instabilities due to the APD HV are at the 0.1% level and they are partially corrected via the laser system as shown in the left bottom plot (RMS: 0.05%).



CMS expected neutron fluence after 500 fb^{-1}



APD Dark Current vs η after 13 fb^{-1} of integrated luminosity