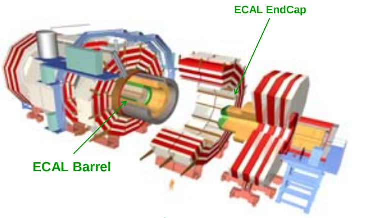
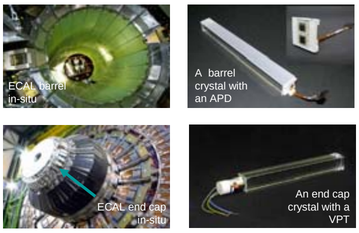
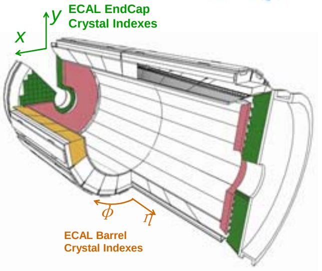
Commissioning, Performance and Calibration of Crystals of the CMS Electromagnetic Calorimeter

CMS ECAL Overview

- Includes 75848 high resolution, high granularity Lead-tungstate ($PbWO_4$) scintillating crystals.
- Molière radius, R_M = 2.2 cm.
- Radiation length, X_0 = 0.89 cm
- Fast response, radiation hard
- Barrel(EB) readout by *Avalanche Photodiodes* (APD), Endcap (EE) readout by *Vacuum Phototriodes* (VPT)







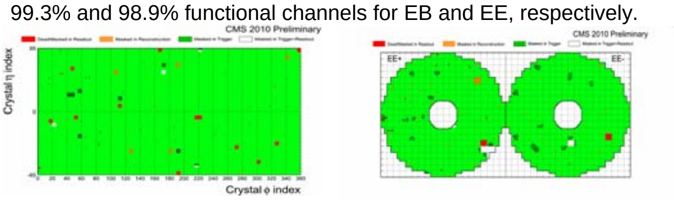
The design energy resolution has a constant term of less than 0.5%, which dominates the energy resolution for unconverted high energy photons.
The energy resolution has been measured in test beams to be

$$\frac{\sigma(E)}{E} = \frac{2.8\%}{\sqrt{E(GeV)}} \oplus \frac{12\%}{E(GeV)} \oplus 0.3\%$$

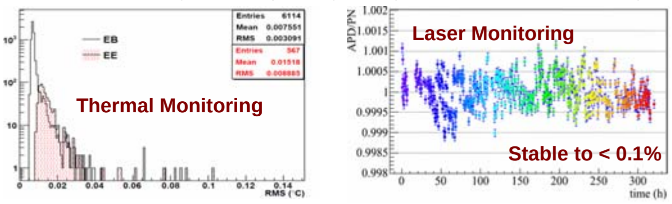
Precise in-situ calibration and monitoring is needed, to meet the design goals.

ECAL Operations during LHC collisions

99.3% and 98.9% functional channels for EB and EE, respectively.



To achieve the required 0.5% constant term of energy resolution, it is crucial to ensure a stable thermal environment (specification EB <0.05 ^{0}C and EE <0.1 ^{0}C) and to monitor the crystal transparency changes due to irradiation damage.



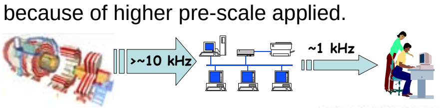
Left, RMS of the measurements of each thermistor over two months. Right, ratio of signals from the APD and PN diode when illuminated by the laser over two weeks.

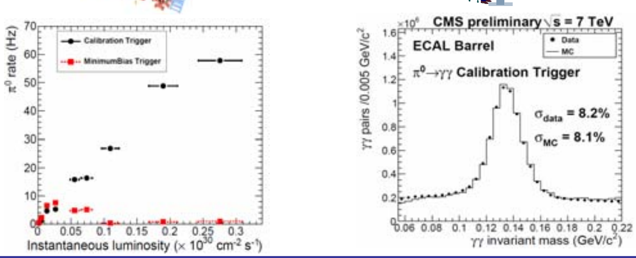
Inter-calibration Methods of ECAL Crystals

CMS's strategies for in-situ inter-calibration at start-up include:

- ϕ-symmetry method. ϕ-invariance around the beam axis of energy flow in minimum bias events. Inter-calibration in ϕ is performed by comparing the total transverse energy (ΣE_T) deposited in one crystal with the mean total ΣE_T collected by crystals at the same absolute value of η.
- π^0 (η) → γγ calibration. Uniformity of the π^0 (η) peak positions obtained for individual crystals. Inter-calibration is performed on an iterative procedure where the inter-calibration constants are updated after each iteration step.

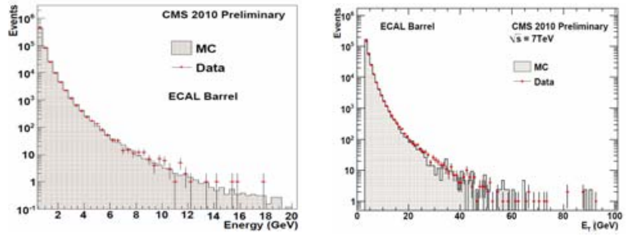
Dedicated calibration streams for both methods run on the CMS online filter farm. MinimumBias trigger becomes less useful at higher instantaneous luminosity because of higher pre-scale applied.



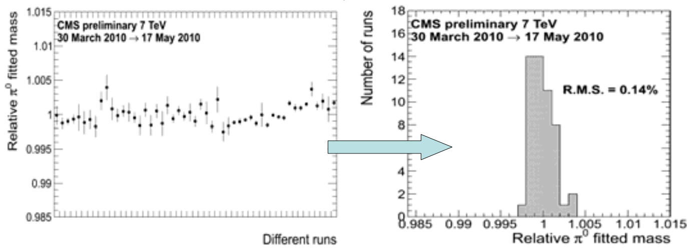


ECAL Performance

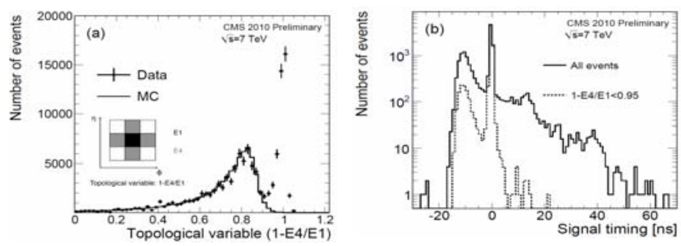
Good agreement between data and MC simulation for the energy spectra of individual channels and transverse energy of super clusters is observed.



ECAL stability with time obtained by measuring invariant mass peak of $\pi^0 \rightarrow \gamma\gamma$ from the first 7 weeks of ECAL operation at 7 TeV.

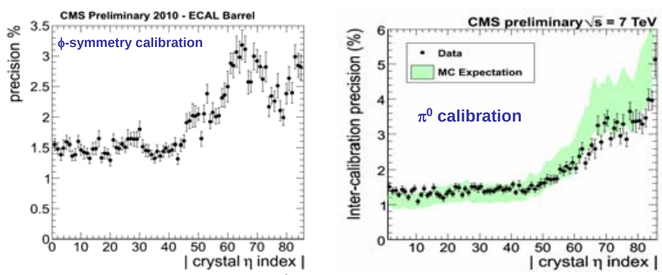


Anomalous signal (spikes) induced by heavily ionizing particles depositing energy in the APD are rejected by topological and timing cuts.

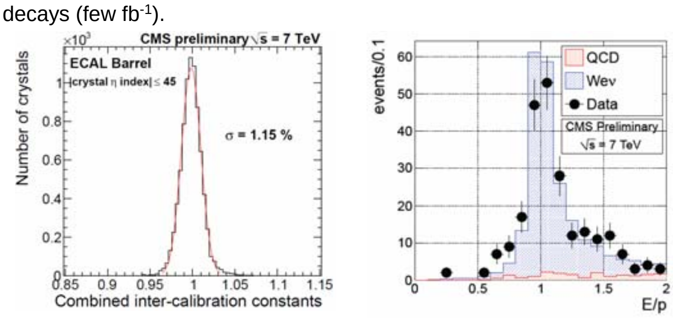


Calibration Results and Outlook

Calibration with the ϕ-symmetry method gives a precision of about 1.5% for the central part (|η| <0.8|) of the barrel, reaching the systematic limit of the method. The precision is estimated from the Gaussian width of the obtained inter-calibration constants on the test-beam calibrated crystals with precision about 0.5%.
Calibration with π^0s gives a precision of about 1.4% for the central part of the barrel. The precision is statistically limited (L=123 nb^{-1}). We expect to achieve a 0.5% precision for most of the barrel crystals with 5-10 pb^{-1}.



Combining ϕ-symmetry and π^0 calibration improves the calibration precision to 1.15%.
In addition to ϕ-symmetry and π^0s, in future calibration will be performed with photons from η decays (50-100 pb^{-1}) as well as isolated electrons from W,Z decays (few fb^{-1}).



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