The CMS Electromagnetic Calorimeter: Construction, Commissioning and Calibration

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CMS ECAL Requirements

- Compact
- Hermetic
- Large Energy Range
- Fast
- Stable
- Radiation Resistant
- Excellent Energy Resolution
- Benchmark channel: Discovery of low mass Higgs in $H \rightarrow \gamma\gamma$ channel
- Target energy resolution 0.5% at high energy
Homogenous Lead Tungstate (PbWO$_4$) Crystal Calorimeter + Pb-Si Preshower

**Barrel (EB):**
- 61200 crystals
- 36 Supermodules (SM), each 1700 crystals
- $|\eta| < 1.48$

**Endcap (EE):**
- 14648 crystals
- 4 Dees, SuperCrystals of 5x5 xtals
- $1.48 < |\eta| < 3.0$

**Preshower (ES):**
- Pb-Si
- 4 Dees
- 4300 Si strips
- $1.65 < |\eta| < 2.6$
ECAL Construction

EB Module: 400/500 crystals

EB SM with electronics

EB @ P5

EE Dee

SuperCrystal

EE Dee 1 & 2 @ P5

Dec2 Dec1
Highlights from the CMS ECAL Timeline

2006-2007: Commissioning & calibration of each SM with cosmics on surface

2006: H4 Test Beam: 9 SM calibrated; H2 Combined Test Beam: ECAL+HCAL

2006: 2 SM tested with B-field on surface (MTCC)

2008: Endcap Installation. Commissioning with cosmics and first beam in-situ

2009: Installation of preshower and commissioning of Endcap trigger

2007: H4 EE Test Beam; Individual signoff of each SM during installation
Beam Splash Events: Single beam shots of $2 \times 10^9$ protons onto closed collimators 150m upstream of CMS

A “wave” or “splash” of secondary particles passed through CMS, depositing a huge amount of energy.
Beam Splash: ECAL Energy

- More than 99% of ECAL channels fired
- Enormous amount of energy deposited in calorimeters!
- ~200 TeV energy deposited in EB+EE
- Estimated hundreds of thousands of muons passing through CMS per event
- White areas: channels masked from readout
Beam splash events provide a source of synchronous hits throughout detector, allowing to internally synchronize ECAL

\[
\Delta t = \Delta t_{\text{Readout}} + \Delta t_{\text{PlaneWave}} = (\sqrt{x^2 + y^2 + z^2} - R \pm z)/c
\]

- **Hardware** allows steps of 1ns steps
- Further synchronization applied in offline reconstruction, **better than 1 ns**
- Synchronization prior was done with laser light; Latency then adjusted w/ splashes
- Synchronization from beam splashes will be start-up condition; better precision w/ LHC data
Commissioning ECAL with Cosmics

CRAFT: Cosmic Run At Full Tesla
- > 300 M cosmic events collected
- 3.8T field operated for ~1 month
- All CMS subsystems participated

ECAL Timing
- Average timing of cosmic signal
- Top-bottom difference (t.o.f.)

\[ t_{top} - t_{bottom} = c \cdot t_{flight} \]
Stopping Power $dE/dx$ with Cosmics

dE/$\rho$dx of cosmic muons traversing ECAL vs muon momentum

- Events for $dE/dx$ selected to be loosely pointing: $d0<1m$, $|dz|<1m$
- $dE$: energy from ECAL clusters
- $dx$: length traversed in ECAL crystals
- Momentum measured by silicon tracker

Results indicate the correctness of the tracker momentum scale and ECAL energy scale.
ECAL Calibration & Monitoring

Calibration of ECAL crucial to maintain high energy resolution

- Without inter-calibration, same signal would produce different outputs in different crystals.
- Also need overall energy scale

Mathematical equation:

\[ E_{e,\gamma} = G \times \mathcal{F} \times \sum_{i} c_i \times A_i \]

- uncertainties:
  - absolute energy scale
  - inter-calibration constants
  - algorithmic corrections

Uncalibrated Supermodule:
6%-10% spread in response among channels

Lab Pre-Calibration:
- 4% EB, 9% EE (all crystals)

Cosmic Pre-Calibration:
- 1.5-2.5% (all EB)

TestBeam Pre-Calibration:
- <1% (1/4 of EB & 400 EE xtals)

In-Situ Physics Calibration:
- 0.5% resolution

ECAL Monitoring (Monitor Stability and Measure Radiation Effects):

ECAL Stability (< 0.5%):
- Monitored with Laser System

Transparency Change Correction:
- Signal Change under Irradiation,
- Measured with Laser Monitoring System
ECAL In-Situ Calibration

Goal: improve startup calibration as quickly as possible in-situ

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Time</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi$ symmetry: use invariance of mean energy deposited by jets at fixed $\eta$</td>
<td>Few hours</td>
<td>$\sim 2-3%$</td>
</tr>
<tr>
<td>$\pi^0 \rightarrow \gamma \gamma$: mass peak @ low luminosity</td>
<td>Few weeks</td>
<td>$\leq 1%$</td>
</tr>
<tr>
<td>$Z \rightarrow e^+ e^-$: absolute energy calibration</td>
<td>100 pb$^{-1}$</td>
<td>$&lt; 1%$</td>
</tr>
<tr>
<td>$W \rightarrow e\nu$: E/p measurement</td>
<td>5-10 fb$^{-1}$</td>
<td>0.5%</td>
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</tbody>
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![Graph of $\pi^0 \rightarrow \gamma \gamma$](image1)

![Graph of integrated luminosity](image2)
Conclusions

• **Crystal ECAL has been integrated and commissioned in situ, and has been collecting data since 2008**
  - Performance has been proven with first LHC circulating beams
  - In addition, more than 300M cosmic ray events collected during CRAFT

• **Preshower detector installed in Feb-March 09**
  - Being commissioned and has joined CMS global data taking

• **CMS ECAL on track for first LHC collision data**
  - Ready to improve pre-calibration with in-situ physics calibration
  - Expect results not just with cosmics or single beam, but with collisions soon!