Search at CMS from the Bottom Up
(Calibration of the CMS Electromagnetic Calorimeter at the LHC)

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The Hunt for $H \rightarrow \gamma \gamma$

- Most sensitive channel at mass below ~130 GeV (as yet not excluded)

- Small branching ratio, but very clean signature: search for a narrow resonance of two high-$E_T$ photons over a non-resonant background of genuine or fake di-photons

- Discovery potential depends mainly on
  1) Invariant mass resolution: photon energy and position resolution are important
  2) Background rejection ($\pi^0/\gamma$ separation)
CMS ECAL: 75,848 PbWO$_4$ Crystals

Barrel: $|\eta| < 1.48$
- 61,200 crystals or $85 \times 2$ $\phi$-rings of 360 crystals each at the same $\eta$
- $(2.2 \times 2.2 \times 23 \text{ cm}^3) \sim 26X_0$

Endcaps: $1.48 < |\eta| < 3.0$
- 14,648 crystals total (39 $\times$ 2 effective $\phi$-rings)
- $(3.0 \times 3.0 \times 22 \text{ cm}^3) \sim 25X_0$

Preshower: $1.65 < |\eta| < 2.6$
- $3X_0$, 2 planes of Pb/Si strips
- $1.90 \times 61 \text{ mm}^2$ x-y view

Other CMS characteristics of note
Tracker coverage: $|\eta| < 2.5$
CMS Magnetic field: $B = 3.8 \text{ T}$
Barrel consists of 170 φ-rings of 360 crystals each: a crystal is uniquely characterized by η-index (-85 to 85) and φ-index (1-360). $H \rightarrow \gamma\gamma$ is the focus channel for the CMS ECAL: the central barrel is the best region for the Higgs search.
In CMS, the photon/electron energy is measured via

$$E_{e/\gamma} = G \cdot F_{e/\gamma} \cdot \sum_i (c_i \cdot s_i \cdot A_i)$$

- $A_i$: Single channel amplitude (ADC counts)
- $S_i$: Single channel time-dependent correction for response variations
  Obtained using a dedicated laser monitoring system
- $c_i$: Intercalibration constant: relative single channel response factor
- $F_{e/\gamma}$: Particle energy correction (detector geometry, clustering, etc…)
  Obtained using simulations and electrons from Z and W decays
- $G$: Global ECAL energy scale

This talk: how we measure the global energy scale and intercalibrate the 75,848 crystals of the CMS ECAL.
1) \( \pi^0/\eta \rightarrow \gamma \gamma \) method: equalizes measured \( \pi^0/\eta \) peaks for individual crystals.
2) \( \phi \)-symmetry: invariance around the beam axis of the energy flow in zero-bias events to intercalibrate crystal response in each of 248 \( \phi \)-rings.
3) single-electrons from W decays: use E/p ratio where p is measured in the tracker and E in the ECAL. In addition to single-crystal intercalibration, this method also intercalibrates the average response of 248 \( \phi \)-rings.
4) di-electrons from Z decays: use measured invariant mass to obtain the global scale corrections and study the ECAL resolution.

- Precalibration in 2000-2009 performed using test beams, cosmic rays, radiation source and “beam splashes” during the first LHC runs.
- \( \sim 30\% \) of the Barrel and 400 crystals in the endcaps were calibrated in the test beams to the design-goal single-crystal precision of 0.5%.
Dedicated Calibration Streams: $\pi^0/\eta \rightarrow \gamma\gamma$ and $\phi$-symmetry

- Each event passing L1 triggers contains a few $\pi^0$'s/event: no need to trigger on $\pi^0$'s
- Useful $\pi^0(\eta) \rightarrow \gamma\gamma$ decays selected online using only crystal-level information from localized regions of ECAL. Store only information about 20-30 crystals per event.
- Sustained rate in Summer-Fall 2011: ~7 kHz (including background).
- Similarly, for $\phi$-symmetry stream only crystals with energy depositions above a threshold are stored for events passing L1 ZeroBias triggers.
**π^0/η→γγ Selection and Calibration**

**Samples in the Barrel**

Based on local, ECAL variables — suitable for online filter farm.

- **Kinematics:** $P_T(\gamma) > 0.8$ GeV, $P_T($pair$) > 2$ GeV (> 3 GeV for $\eta$ decays).
- **Photon shower-shape cuts:** $S_4/S_9 > 0.83$, where the sums $S_i$ are defined with 2x2 and 3x3 crystal matrices.
- **Isolation cut** optimized to remove pairs with converted photons.

In 2011, collected about $10^{10}$ $\pi^0\rightarrow\gamma\gamma$ and $10^9$ $\eta\rightarrow\gamma\gamma$ decays in the barrel region. Peak resolution dominated by the error on the opening angle.
The single-crystal calibration precision in the barrel is dominated by systematics and was found to be 0.5% (1%) for $|\eta|<1$ ($|\eta|>1$).

Calibration updated each month in 2011 (every 2-3 months in the endcaps).
π⁰/η→γγ Calibration in the Endcaps

- 2011 calibration sample in the endcaps consists of $3 \times 10^8 \pi^0 \rightarrow \gamma \gamma$ and $3 \times 10^7 \eta \rightarrow \gamma \gamma$ decays. Similar calibration procedure used.
- The calibration precision estimated to be about 2-3%. Lower because of higher background, larger crystal size and increased material in front of ECAL; also dominated by systematics.
Select electron candidates from $W \rightarrow e \nu$ decays with $E_T > 30$ GeV. Further electron ID and isolation cuts: purity of the sample is 99%. ~120 electrons per crystal in the barrel for the entire 2011 dataset.

Calibration is performed using an iterative procedure by fitting $E_{ECAL}/p_{tracker}$ distributions for each crystal. Precision is up to 1% in the central barrel, limited by statistics.
The single-crystal calibration precision in the barrel is dominated by $\pi^0(\eta)$ precision while in the endcaps all three methods give similar precision.

Single-electron calibration became important in 2011 due to increased integrated luminosity and is still statistically limited (good news for 2012).
Overall calibration precision is about 0.5% for $|\eta|<1$ and 0.9% for $1<|\eta|<1.4$ in the barrel. In the endcaps, the precision is 2-3%.

This level of precision has been maintained starting from the second half of 2010 throughout the whole 2011.
The energy resolution for electrons was estimated using $Z \rightarrow ee$ decays and compared with simulations where the estimated calibration precision was taken into account.

The single-crystal calibration precision ($\sigma_{\text{calib}}$) is not the driving factor for the observed energy resolution: contribution to the constant term is about $0.75 \times \sigma_{\text{calib}}$ due to the shower spread over several crystals.
A single-crystal calibration precision of 0.5% (0.9%) in the central (outer) barrel has been achieved and maintained from mid-2010 to end of 2011, reaching the design goal of 0.5%. In the endcaps, the calibration precision is 2-3%.

In 2012, further improvements are expected not only from the increase in the calibration statistics but also from a further refinement of the calibration methods.
The Outlook? (Progress in understanding ECAL)

- **July 2011 (EPS):**
  - FWHM = 4.23 GeV/c²

- **March 2012 (Moriond):**
  - FWHM = 3.29 GeV/c²

- **July 2012 (ICHEP):**
  - FWHM = nan

- Improved single crystal and cluster corrections

- In progress…

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