Calibration of the CMS Electromagnetic Calorimeter with first LHC data

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On behalf of the CMS Collaboration
OUTLINE

- The CMS Electromagnetic Calorimeter (ECAL)
- Pre-calibration: crystal intercalibration before the LHC startup
- In situ calibration: crystal intercalibration with collision data
- Results with very first collisions
- Calibration data streams
- 2010 plans
ECAL

- Hermetic homogeneous calorimeter made of PbWO$_4$ Crystals

- Barrel (EB) $[|\eta|<1.48]$ 
  36 Supermodules (SM) with 1700 crystals each 
  Photodetectors: Avalanche Photodiodes (APDs)

- Endcaps (EE) $[1.48<|\eta|<3.0]$ 
  2 Dees each side, 14648 crystals in total 
  Photodetectors: 
    Vacuum Phototriodes (VPTs)

- Preshower (ES) $[1.65<|\eta|<2.6]$ 
  Sampling calorimeter (lead, silicon strips)
ECAL ENERGY RESOLUTION

Excellent energy (and position) resolution for photons and electrons crucial for studying interesting physics channels ($H \rightarrow \gamma\gamma$, $H \rightarrow ZZ \rightarrow 4e$, …)

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

Constant term depends on:
- channel intercalibration accuracy
- non uniformity of the longitudinal light collection
- rear leakage
Target value: 0.5 % (benchmark: $H \rightarrow \gamma\gamma$ channel)

High precision in the channel to channel intercalibration crucial.

$Z \rightarrow ee$ width
(both electrons in EE)

$H \rightarrow \gamma\gamma$ width

effective sigma

Gaussian fit

from isolated electrons after 5 fb$^{-1}$ of data

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PRE-CALIBRATION

Extensive 10 years long pre-calibration program carried out before ECAL installation in CMS.

[ Intercalibration of the barrel electromagnetic calorimeter of the CMS experiment at start-up - 2008 JINST 3 P10007 ]

<table>
<thead>
<tr>
<th>Test Beam at CERN</th>
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<td>90-120 GeV electrons</td>
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<tr>
<td>(2004-2007)</td>
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From repeated measurements:

intercalibration precision ~0.3%

dominated by statistical uncertainty, determined comparing two independent data samples (A and B) collected in the same conditions.
**PRE-CALIBRATION**

<table>
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<th>Light yield (LY) measurements with $^{60}\text{Co}$ ($\sim 1\text{MeV }\gamma$) during crystal qualification (2000-2006)</th>
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- **EB**: LY Measurements  
  Intercalibration precision $\sim 4.5-6.0\%$

- **EE**: LY + VPT gain Measurements  
  Intercalibration precision $\sim 8\%$
**PRE-CALIBRATION**

- **EB**: LY Measurements
  - Intercalibration precision ~4.5-6.0%
- **EE**: LY + VPT gain Measurements
  - Intercalibration precision ~8%

- **36 EB SMs** operated on a cosmic ray stand for a period of ~1 week/SM
  - Deposited energy per crystal ~ 300 MeV

Channel intercalibration with cosmic muons (2006-2007)

Mean intercalibration precision ~1.5%

- Light yield (LY) measurements with $^{60}$Co (~1MeV $\gamma$) during crystal qualification (2000-2006)

- Cosmic muons

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**PRE-CALIBRATION**

**Beam splashes:** in September 2008 and November 2009 beam was circulated in LHC, stopped in collimators 150 m away from CMS.

Combination of LY and beam splashes gives ~5% intercalibration precision over the entire EE.

**All Endcap crystals**

Intercalibration precision ~6%
PRE-CALIBRATION CONSTANTS

**EB**
- LY, cosmics, test beam.
  - Combination strategy:
    - Select best calibration available
    - Combine when comparable precision from two sources

**EE**
- Test beam (460 crystals)
- Combination of LY and beam splashes

Intercalibration precision achieved with these constants: 0.3-2.2%

Intercalibration precision achieved with these constants: 5%

Entries 61200
Mean 1
RMS 0.1116

Entries 14648
Mean 1
RMS 0.272
ENERGY SCALE: ADC counts to GeV

ECAL energy scale fixed by Test Beam data in Barrel and Endcap separately

- ~63 MeV/ADC in EE
- ~39 MeV/ADC for EB

- Confirmed later in dE/dx analysis with cosmics(*) and with $\pi^0$ and $\eta$ mass peak in collisions.

- Waiting for higher mass resonances to check the scale in situ at high energy.

(*) presented by F. De Guio
IN-SITU CALIBRATION

Several methods to calibrate in-situ:

- **$\phi$-symmetry method**: intercalibration for crystals at the same pseudorapidity.
  
  Based on invariance around the beam axis of the energy flow in minimum bias events.
  
  Calibration performed comparing the total energy deposited in each crystal with the mean of the distribution of the total energies for all crystals in a ring at a given pseudorapidity.
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- **π⁰ and η method**: single crystal intercalibration
  
  Constants derived using unconverted γ’s from π⁰ and η decay reconstructed in 3x3 matrices
  
  The reconstructed mass is used to determine the photon energy
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- **High energy electrons from W→eν and Z→ee decays (J/ψ under study)**
  Higher integrated luminosity required. Helpful at the startup only for energy scale.
SUPERMODULE RELATIVE SCALE

First calibration with collisions of the barrel.

- First results in 2009 with \( \sim 0.01 \text{ nb}^{-1} \) collected at \( \sqrt{s} = 900 \text{GeV} \)
- Scale derived in 2010 with \( \sim 0.4 \text{ nb}^{-1} \) collected at \( \sqrt{s} = 7 \text{TeV} \)
  - Systematic error: 0.5% (see next slide)
  - Statistical error negligible w.r.t. systematic one

Tested with beam

CMS Preliminary \( \sqrt{s} = 7 \text{TeV} \)

\( \phi \)-symmetry data
\( \pi^0 \) data

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SUPERMODULE RELATIVE SCALE

In-situ SM relative scale defined as the weighted average of $\pi^0$ and $\phi$-symmetry results.

Distribution of the relative scale of 10 SMs calibrated with test beam electrons.

The RMS of 0.5%±0.1% estimates the current precision of the combined in-situ SM relative scale calibration.

Distribution of the relative scale of 26 SMs calibrated only with cosmic rays.

The RMS is 1.2%±0.2% is consistent with the expected precision of cosmic ray scale.

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RECONSTRUCTED $\pi^0 \rightarrow \gamma \gamma$ PEAK

- L = 0.43 nb$^{-1}$
- $P_T(\gamma) > 0.4$ GeV, $P_T(\gamma\gamma_{pair}) > 1.0$ GeV (pure ECAL selection)
- Good agreement between data and MC.
- Number of $\pi^0$ from the fit: $1.46 \times 10^6$

The fitted mass agrees with the expectation to within 1%
(first in situ validation of absolute energy scale)
RECONSTRUCTED $\eta \rightarrow \gamma \gamma$ PEAK

- $L = 0.43$ nb$^{-1}$
- $P_T(\gamma) > 0.5$ GeV, $P_T(\gamma\gamma_{pair}) > 2.5$ GeV (pure ECAL selection)
- Good agreement between data and MC
- Number of $\eta$ from the fit: $2.55 \times 10^4$

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**CMS Preliminary Data $\sqrt{s}=7$ TeV**

- $M = 537.37 \pm 0.53$ MeV
- $\sigma = 6.1 \pm 0.1$ %
- $S/B_{\pm 2\sigma} = 0.34$

**CMS Preliminary MC $\sqrt{s}=7$ TeV**

- $M = 543.70 \pm 1.10$ MeV
- $\sigma = 6.4 \pm 0.2$ %
- $S/B_{\pm 2\sigma} = 0.23$

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CALIBRATION DATA STREAM

In CMS dedicated paths of data acquisition (streams) are implemented for calibration.

In $\pi^0$ and $\phi$-symmetry streams, only few tens of “useful” crystal hits are stored for each accepted event (output limited to 1kHz per stream).

Calibration stream commissioned with collision data.

$\pi^0$ peak from dedicated calibration stream (better S/B because of higher transverse energy cuts in calibration stream)
PLANS FOR 2010

In the Barrel
- improve crystal calibration down to 1% in the whole EB with a few pb$^{-1}$.
- reach the goal of 0.5% precision in EB with $\sim$10pb$^{-1}$, expected by the end of the year.

Fluctuation due to material in front of ECAL

- Improve Endcap crystal calibration from 5% to 1-2%.
- Set the absolute scale to few permille.

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**SUMMARY**

- ECAL crystal intercalibration in very good shape.

<table>
<thead>
<tr>
<th>Method</th>
<th>Calibrated crystals</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab. measurement</td>
<td>All</td>
<td>~ 5% in EB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>~ 8% in EE</td>
</tr>
<tr>
<td>Cosmic</td>
<td>All EB</td>
<td>~1.5% in average</td>
</tr>
<tr>
<td>Test Beam</td>
<td>10 SMs in EB</td>
<td>~0.3%</td>
</tr>
<tr>
<td></td>
<td>~400 xtal in EE</td>
<td></td>
</tr>
<tr>
<td>Beam splash</td>
<td>All EE</td>
<td>~6%</td>
</tr>
</tbody>
</table>

Z width already almost insensitive to residual miscalibration.

- **First calibration result with collision data:** SM relative scale in EB. \( \pi^0 \) and \( \phi \)-symmetry in agreement.

- Calibration streams commissioned.

- With the collected statistics (~17 nb\(^{-1}\) at May 26\(^{th}\)) single crystal intercalibration started.

- 2010 goals: 0.5% intercalibration precision in EB
  1-2% intercalibration precision in EE
Laser monitoring

- Radiation dose-rate dependent changes in crystal transparency
  - Due to creation of color centers which absorb transmitted light
  - Recovery in absence of irradiation
  - Must monitor and correct for changes in light output in order to maintain high energy resolution
- Dedicated laser system to monitor crystal transparency changes
  - Provide transparency corrections with precision of 0.2%
  - Also useful for monitoring stability of channel response
Intercalibration with cosmic muons
Beam splashes

Map of the energy deposited by splashes in the two ECAL endcaps with beam from EE- side
Energy Pre-Calibration

- All sensors went through cosmic-ray pre-calibration which also serves as burn-in and thermal cycles.
- Pre-calibration using MIPs with correction applied on sensor thickness, temperature, and crossing angle.
- Accuracy at 2.5% with 24 hours of data taking.
In-situ Energy Calibration

- In-situ calibration looks at the energy deposit from charged hadrons passing through Preshower.
- Results from first in-situ calibration obtain 3.3% precision w.r.t pre-calibration.