The CMS Electromagnetic Calorimeter workflow

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on behalf of the CMS Collaboration

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The CMS Electromagnetic Calorimeter

Homogeneous, high granularity, hermetic PbWO$_4$ crystals calorimeter + Lead/Si Preshower

<table>
<thead>
<tr>
<th></th>
<th>coverage</th>
<th>channels</th>
<th>readout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrel (EB)</td>
<td>$</td>
<td>\eta</td>
<td>&lt;1.48$</td>
</tr>
<tr>
<td>Endcaps (EE)</td>
<td>$1.48&lt;</td>
<td>\eta</td>
<td>&lt;3$</td>
</tr>
<tr>
<td>Preshower</td>
<td>$1.65&lt;</td>
<td>\eta</td>
<td>&lt;2.6$</td>
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Largest crystal calorimeter ever built for a high energy physics experiment

ECAL plays a crucial role for the CMS physics program

Goal: precise (%-level) e/γ energy measurement

$\rightarrow$ stability and uniformity in situ must be $<<1\%$
Challenges

ECAL goal is in-situ stability <<1%, but response variation is >>1%

Crystal calorimeters require constant monitoring to correct for environment effects and radiation induced light output change, and periodic channel-to-channel calibration

⇒ Dedicated streams
⇒ Dedicated monitoring workflow

To have frequent and high granularity corrections
Limited number of data reprocessings/year

Dedicated workflows to ensure good data quality since the beginning
CMS Calibration workflow

Trigger selecting good events (L1 hardware + HLT software)

3 data streams

Express
- Prescaled
- Prompt feedback and calibrations

Alignment and calibration streams produced at HLT:
- Low CPU usage
- Reduced event content

Prompt reconstruction:
- Delayed 48h to get updated calibrations from a Prompt Calibration Loop (PCL)
CMS Calibration workflow

Calibrations computed quasi online, in PCL and offline

Uploaded to Conditions Database

Used in prompt reco
ECAL calibration streams @HLT

Online streams to accumulate millions of events for calibration even if the relevant triggers are normally heavily prescaled
• Smaller size -> reduced event content -> higher rate allowed

φ-symmetry stream
*For calibration and local reconstruction tuning*
• HLT output: filtered ECAL digis above noise
• Rate fixed by L1 prescale

π⁰ and η -> γγ stream
*For calibration and response stability monitoring*
• Unpack only ECAL regions around L1 relevant seeds
• HLT output: filtered ECAL digis, in regions with a π/η candidates

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate</th>
<th>Event Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>φ-symmetry</td>
<td>~3 kHz</td>
<td>Few kBs</td>
</tr>
<tr>
<td>π⁰, η</td>
<td>~7 kHz</td>
<td>~2kB</td>
</tr>
</tbody>
</table>

More frequent, more granular updates
Monitoring ECAL response

Scintillation mechanism in ECAL crystals radiation hard, but crystal transparency affected

Crystals response monitored event by event with a laser system

Laser light injected in each crystal during LHC abort gap @100Hz
• Blue (447 nm) and green (527 nm)
• 1 point / crystal every 40 min (entire detector)

Data processing @laser monitoring farm

Offline corrections computed in PCL
• Run unattended just after data taking
• Uploaded to the condition database in time for prompt-reconstruction

Online conditions (L1/HLT) updated 2/week
• Stabilize energy scale, resolution, efficiency
Monitoring pedestals

Electronic pedestals drift with time

Input to local reconstruction, needs monitoring
- Data processing @Tier-0
- Laser stream data used

Offline corrections computed in PCL
- 1 point / crystal per run
- Uploaded to the condition database in time for prompt-reconstruction

Online conditions (L1/HLT) updated 2/week
- Stabilize rate
- Reduce impact of spikes (direct APD ionization) at L1

Pedestal mean (EB)
Other conditions

Other conditions computed offline and updated manually after validation

**Timing-related quantities**
- From $\varphi$-symmetry stream
- Updated when amplitude bias $\sim 1\%$ ($\sim 1$ ns drift)

**Energy scale**
- From $Z\rightarrow ee$ events in prompt-reco data
- Updated when relevant scale drift ($\sim 1$-2%)  

**Alignment**
- Updated at data-taking startup (tracker movements during shutdown)
- No further updates during year
- From $Z\rightarrow ee$ (ECAL) and charged tracks (preshower)
Computing intercalibrations

Crystals intercalibration precision directly affects ECAL energy resolution

Complementary techniques, gain from combination

<table>
<thead>
<tr>
<th>Method</th>
<th>Frequency / year</th>
<th>HLT stream</th>
<th>Data-format</th>
</tr>
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<tbody>
<tr>
<td>( \phi )-symmetry</td>
<td>several</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>( \pi^0/\eta \rightarrow \gamma\gamma )</td>
<td>1</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Electron E/p</td>
<td>1</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Z\rightarrow ee mass</td>
<td>1</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>

Manual
- Minor updates, if any, during data-taking
- Recalibration performed at the end of the year and used the year after

Reduced format: regional and electrons infos.
ECAL-only 1y data processings take 3-4 days on LSF or HT condor.

See F.Cavallari’s poster in T2
Data reprocessing

During Run2 CMS re-processed data at the end-of-the year to provide improved conditions for analysis. Further full re-processing of Run2 data ongoing to achieve optimal performance.

ECAL: offline re-derivation of ALL conditions exploiting full statistics and with better granularity
- e.g. several pedestals IOVs / run (1 IOV/run in prompt-reconstruction)

About 2 months / year for recalibration
Summary

Keeping high performance for a crystal calorimeter at hadron colliders is a real challenge and requires novel techniques.

The CMS ECAL exploits a complex workflow for monitoring and calibration.

During LHC Run1 and Run2 it proved to be well designed:
• Capability of providing results timely to ensure high quality of prompt reconstruction within 48h.

Plans for increasing automation of described workflows in Run3, minimizing manual intervention.

Goal is to have the full calibration chain up and running at the beginning of Run3 to contribute to high quality CMS publications.
Backup
Energy reconstruction

Electrons and photons deposit their energy in several crystals (~70% in 3x3 array) collected by a clustering algorithm.

\[ E_{e,\gamma} = \sum_i \left[ A_i \times S_i(t) \times C_i \right] \times G(\eta) \times F_{e,\gamma} \]

- Pulse amplitude
- Time dependent response correction
- Global scale
- Cluster corrections (multivariate)

Energy resolution from test-beam (no irradiation, no material in front, no magnetic field)

\[ \sigma(E) = \frac{2.8\%}{\sqrt{E(\text{GeV})}} \oplus \frac{41.5\text{MeV}}{E(\text{GeV})} \oplus 0.3\% \]

Stability and uniformity in situ required \(<1\%\)

All terms to be carefully monitored and updated

Complex and dedicated workflows in place
ECAL conditions @trigger

Spikes: caused by direct ionization of APDs and removed at L1 identifying isolated hits above threshold.
ECAL data validation

ECAL workflows complexity requires robust validation

Several stages of Data Quality Monitoring (DQM):

*Online DQM*: monitor detector performance during data-taking
- Dedicated event stream (sampling)

*Offline DQM*: monitor performance
- Run on full statistics available for analysis

*CMS centrally-coordinated effort*

Several semi-automatic checks:
- Prompt and reliable derivation of conditions in PCL
- Energy scale stability in prompt reco
- Any other issue

*ECAL-specific effort, involving experts and shifters*

Two efforts combination => ECAL data-certification, to provide a list of good runs/events for physics