The ultimate CMS ECAL calibration and performance for the legacy reprocessing of LHC Run 2 data

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On behalf of the CMS collaboration

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From scintillation light to the Higgs boson

Endcaps
PbWO$_4$+VPT

Barrel
PbWO$_4$+APD

Preshower
lead+silicon sensors

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S. Pigazzini | CALOR-2022
$E_{e,\gamma} = \sum_i [L_i(t) \cdot C_i(t) \cdot A_i(t)] \cdot G(\eta) \cdot F_{e,\gamma}$
Signal amplitude reconstruction

\[ E_{e,\gamma} = \sum_i [L_i(t) \cdot C_i(t) \cdot A_i(t)] \cdot G(\eta) \cdot F_{e,\gamma} \]
Signal amplitude reconstruction

- The **signal pedestal and phase are inputs** to the amplitude reconstruction algorithm.
- Pedestal measured from laser events every 40 minutes.
- Time shift corrected every year, **drift during datataking absorbed in the templates** used by the algorithm (1 per channel).
Transparency loss correction

\[ E_{e,\gamma} = \sum_i [L_i(t) \cdot C_i(t) \cdot A_i(t)] \cdot G(\eta) \cdot F_{e,\gamma} \]
Transparency loss correction

- Continuous operation of the laser monitoring system has allowed a constant monitoring: **all crystals measured every 40 minutes**.

- **Run2 challenge**: sizable radiation damage in laser transmission fibers and reference diode.

  → **corrected using electrons from W/Z boson decays** and relative measurement w.r.t tracker.
Channel intercalibration and energy scale

\[ E_{e,\gamma} = \sum_i [L_i(t) \cdot C_i(t) \cdot A_i(t)] \cdot G(\eta) \cdot F_{e,\gamma} \]
→ Equalize response of channels at same $\eta$ combining different methods: $Z \rightarrow e^+ e^-$, $E/p$ and $\pi^0 \rightarrow \gamma \gamma$ (in practice: *reduce peak width*).

→ Energy scale vs $\eta$ corrected in data to match MC using $Z \rightarrow e^+ e^-$ mass peak (in practice: *adjust peak position*).

→ Negligible impact on the energy resolution from intercalibration precision.
Clustering and object level correction

\[ E_{e, \gamma} = \sum_i [L_i(t) \cdot C_i(t) \cdot A_i(t)] \cdot G(\eta) \cdot F_{e, \gamma} \]
Clustering and object level correction

- **Energy thresholds** for hits clustering re-tuned to mitigate pile-up and noise contamination. Preshower operation adjusted to cope with irradiation.
- Energy measurement in the **preshower** crucial for particle ID (photon/neutral hadron separation) and EM-shower energy measurement (in the endcaps):
  - Regular response corrections derived using short, **dedicated runs with gain adjusted for m.i.p sensitivity**.

- Object energy corrected for leakage, material effects using a **semiparametric BDT** to provide the ultimate performance for physics analysis.
ECAL performance in Run2

- Excellent energy scale stability crucial in different aspect of the CMS reconstruction:
  - Photon/electron energy resolution and identification (shower description)
  - Jet EM-component measurement.
Run3 outlook
Inclusion of **precise time of flight** ($\sim 20 – 30\text{ps}$) information in the event reconstruction is a goal for the CMS HL-LHC upgrade (Charlotte's talk).

- **ECAL time information will play a crucial role in HL-LHC but not only:**
  - An excellent time resolution already achieved in Run1+Run2, **exploited** in LLP searches.
  - **Run3, Level-1 trigger:** reduction of anomalous signals (APD direct ionization, a.k.a. “spikes”) rate exploiting redundancy feature of existing trigger ASIC.
Encouraging tests of L1 developments

- Topological spike tagger re-optimized using a set of Run2 data with PU conditions close to the Run3 expected ones.

Time-based spike tagging working in CMS, tested using LHC beam splashes.
Calibration of prompt reconstruction in Run3

- The main focus in Run3 will be to improve the mitigation of noise and pile-up related effects → ML-based algorithm (more in Polina’s talk).

- But there’s a catch…
Calibration of prompt reconstruction in Run3

- The main focus in Run3 will be to improve the mitigation of noise and pile-up related effects → ML-based algorithm (more in Polina’s talk).

- But there’s a catch...

- Ultimate performance ~ 40% (= 1 year of work) better than the one with “prompt” calibration.

- Run3 goal: automatize the calibration procedures that rely on collision data to provide the highest quality calibration possible within few days from data-taking.
• Implement each calibration workflow as a **finite state machine**.
• Execute jobs regularly updating conditions when predefined conditions are met.
• Exploit tools from industry deployed by CERN IT: **Openshift, influxdb, Jenkins, HTCondor**.

A new run is injected into the system

Jobs for each workflow are submitted

Jobs run on CAF queues

All jobs completed, the task is marked as done

A new calibration is produced

If requirements are matched (e.g. enough data) the next task is started.

Jobs logged as failed in the DB are resubmitted
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\[ \rightarrow \] The system is being commissioned with data from cosmics runs.

\[ \rightarrow \] Execution monitoring through webpages and dedicated **Mattermost alerts and slash commands**.
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Moving forward with Run3:

- More challenges coming from increasing noise and pile-up levels, new ML techniques being explored to cope with them.
- The ECAL community is constantly working to squeeze any bit of performance out of the detector: new developments being tested to improve the L1 trigger.
- A crucial objective for Run3 will be to deploy all calibrations promptly during the data-taking.