Calibration and Performance of the CMS Electromagnetic Calorimeter in LHC Run 3

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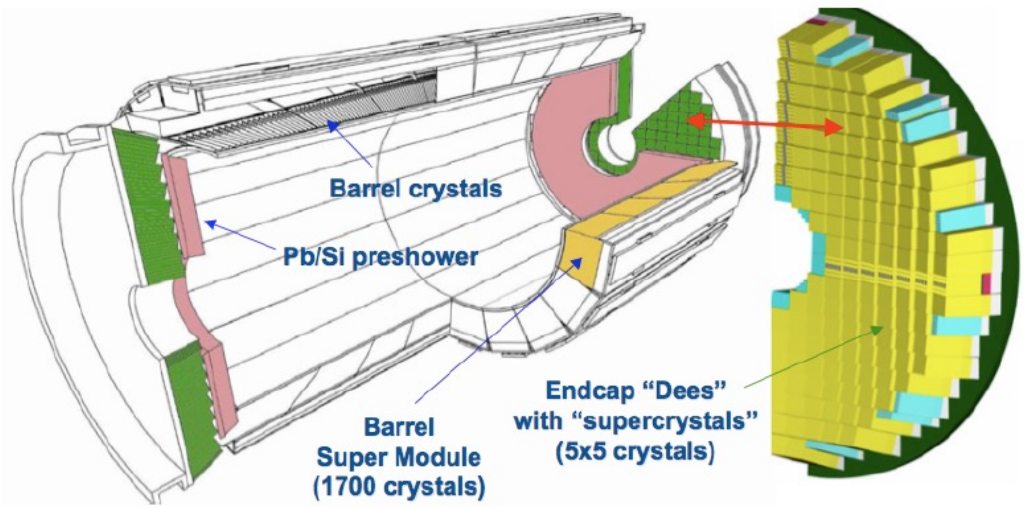
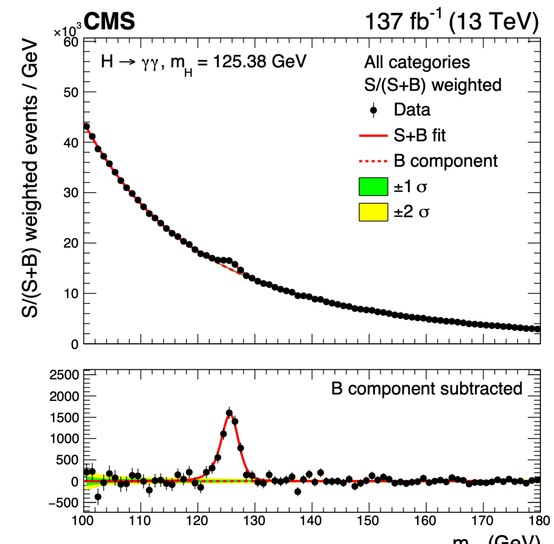
CMS Electromagnetic Calorimeter



- ❖ Homogeneous electromagnetic calorimeter (ECAL)
- ❖ Installed in the barrel (EB) and the endcap (EE) sections
- ❖ Constructed with 75848 lead-tungstate crystals
- ❖ Particles deposit energy in crystals producing a light pulse
- ❖ Light pulse is sampled and amplified by on crystal electronics
- ❖ Energy of interacting particle and time of interaction reconstructed

Essential in the CMS physics program

- ❖ Precise measurements of energy, position and time of arrival of photons and electrons
- ❖ Excellent energy resolution, fundamental in the observation of $H \rightarrow \gamma\gamma$ and $Z \rightarrow 4l$

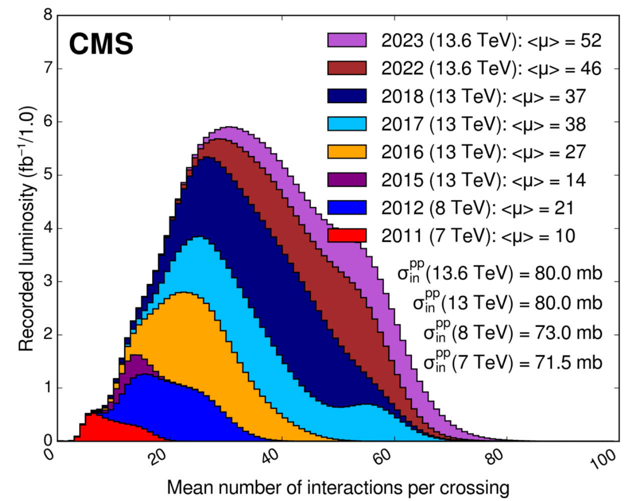


Plot from: CMS-HIG-19-015

CMS Electromagnetic Calorimeter

During Run 3, LHC experienced the largest luminosity so far

- ❖ Instantaneous luminosity increased
  - ❖ from 2×10^{34} cm^{-2} s^{-1} to 2.6×10^{34} cm^{-2} s^{-1}
- ❖ Increased number of simultaneous p-p collisions (PU)
  - ❖ Mean PU 52 in 2023
  - ❖ Mean PU 46 in 2022
  - ❖ Mean PU 32 in Run 2
- ❖ Luminosity levelling at PU 60-65 in 2024



Plot from: CMS Luminosity

Increased Luminosity results in more data and more challenges
Precise calibration of the detector is essential to achieve best possible resolutions

- ❖ Laser monitoring system provides online correction for crystal transparency changes
- ❖ Energy calibration using physics events
- ❖ New Time reconstruction and calibration

Laser Monitoring System

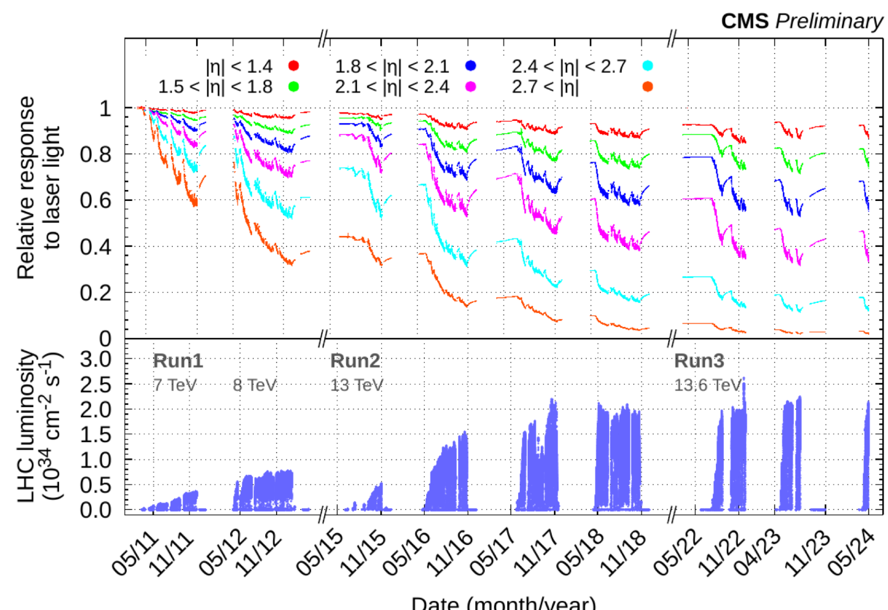
Monitors and corrects for changes in crystal transparency
Radiation damage ”darkens” crystals resulting in transparency loss

Loss is greater with increased Instantaneous luminosity

- ❖ Loss due to em particles recoverable
- ❖ Loss due to hadrons not recoverable
- ❖ Loss is greater at higher eta
- ❖ Some loss regained between runs

Run 3 corrections updated at trigger level for each beam fill

Increased from 2 per week in Run 2



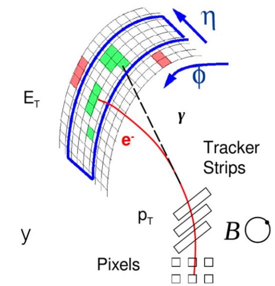
Plot from: CMS DP-2024/022

EM Objects Energy Measurement & Calibration

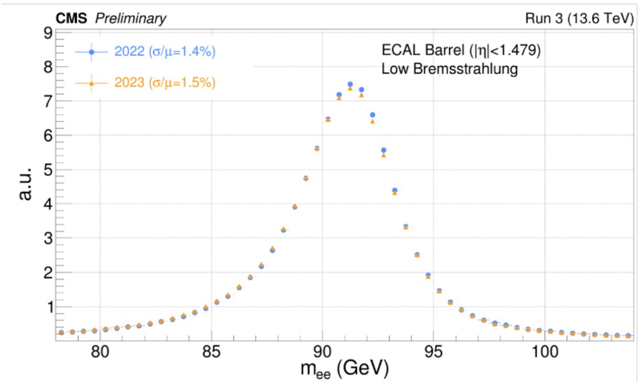
The energy of an electromagnetic particle ($E_{e,\gamma}$) is determined from the energy of the aggregation of crystal clusters in EB and EE

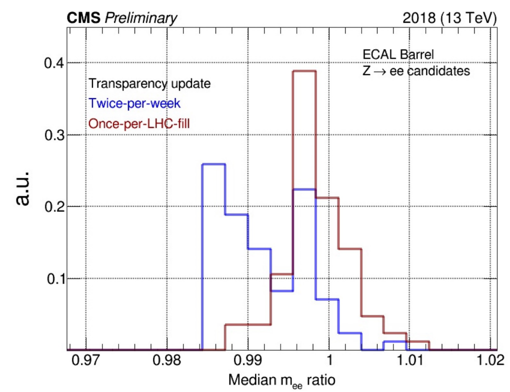
$$E_{e,\gamma} = G F_{e,\gamma} \sum_{crystal\ i} S_i(t) C_i A_i$$

- A_i pulse amplitude in ADC counts by crystal
- G absolute energy scale
- $S_i(t)$ response to scintillation light by crystal (Laser monitoring)
- C_i inter-calibration coefficient by crystal
- $F_{e,\gamma}$ energy correction for eta/phi, material, and particle effects



Inter-calibration coefficient measured with standard processes like Z → e$^+$e$^-$
Stable energy scale and resolution over the whole 2022-2023 period

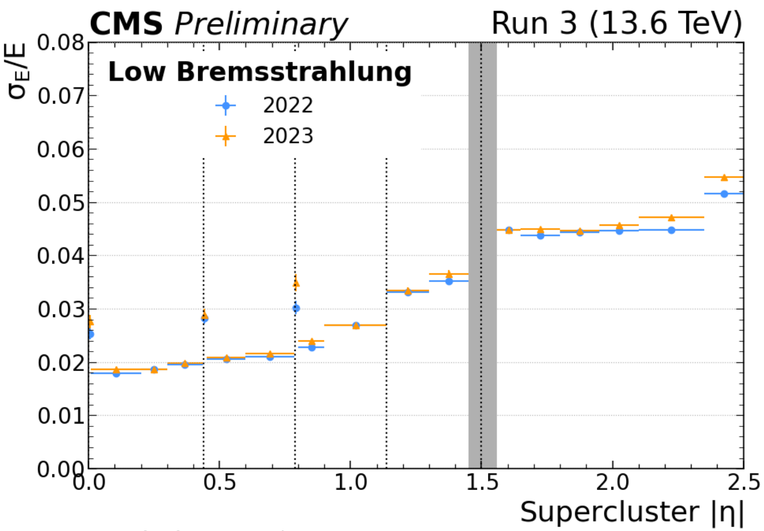


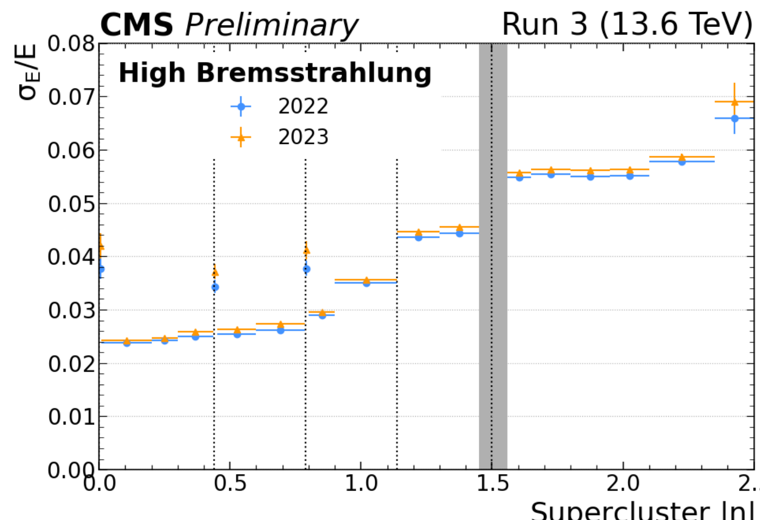


Plots from: CMS DP-2024/022

ECAL performance : Energy Resolution

Relative electron energy resolution computed with $Z \rightarrow e^+e^-$





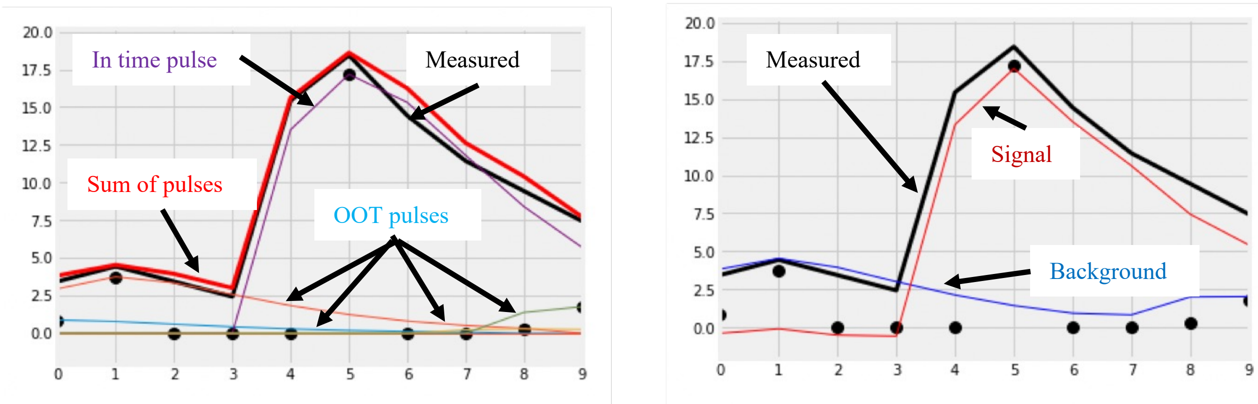
Plots from: CMS DP-2024/022

A stable ECAL energy resolution is observed in 2022 and 2023

Even with increased run condition challenges in R3 and detector aging able to achieve excellent energy resolution

Time Reconstruction

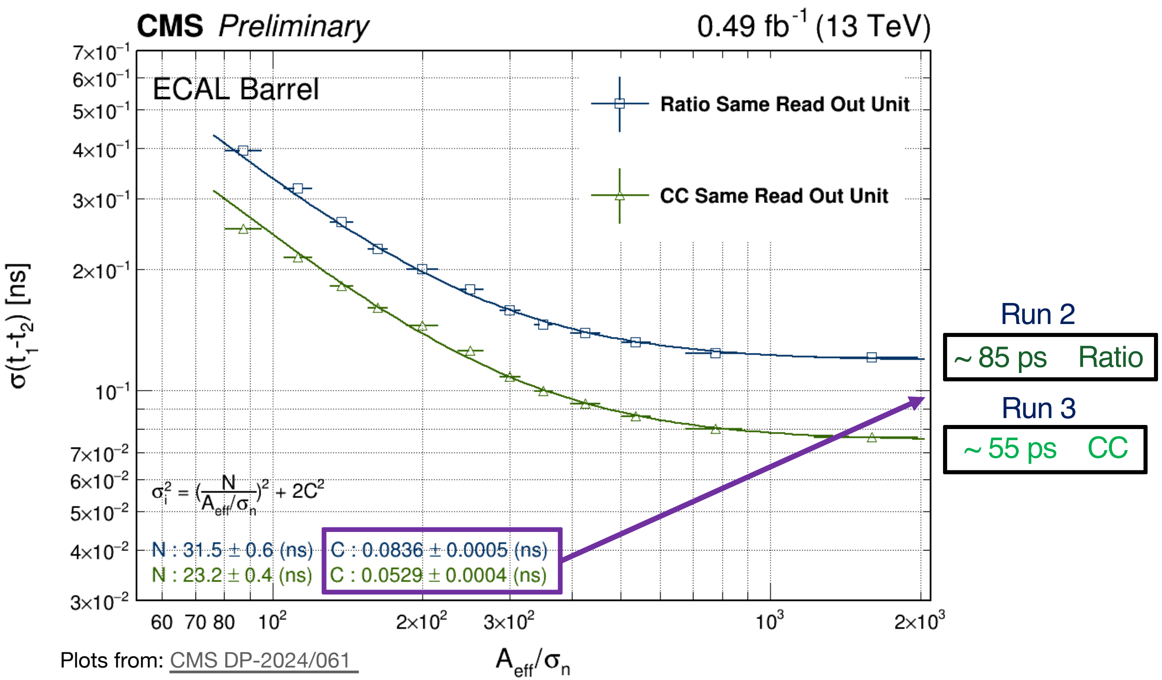
New time reconstruction algorithm (CC) deployed with heavy ion data taking in 2023
Mitigates the effect of increased number of back-to-back interactions
Essential with increased instantaneous luminosity



- ❖ With increased PU multiple overlapping pulses can occur simultaneously in a crystal
- ❖ Subtracts out overlapping (OOT) pulses origination from other particle interactions

Increases stability of time calibration across data taking periods
Improves analysis relevant time resolutions

ECAL performance : Time Resolution



Plots from: CMS DP-2024/061

Run 3 ECAL time reconstruction demonstrates improved performance over Run 2 approach

- Time reconstruction comparison with partial run 2 data
  - Run 3 (CC)
  - Run 2 (Ratio)
- Run 3 optimized resolution
  - ~ 55 ps single crystal (Same)
- Run 2 optimized resolution
  - ~ 85 ps single crystal
- Expected to achieved analysis relevant EM object Run 3 resolutions of **~ 100 - 200 ps**
- Typical Run 2 EM analysis relevant object resolutions observed at ~ 300 ps

Automatic Workflow Framework

New workflow framework in Run 3
Automates existing ECAL calibration and monitoring tasks
Allows for more frequent and consistent calibrations to be produced

ECAL workflows in production

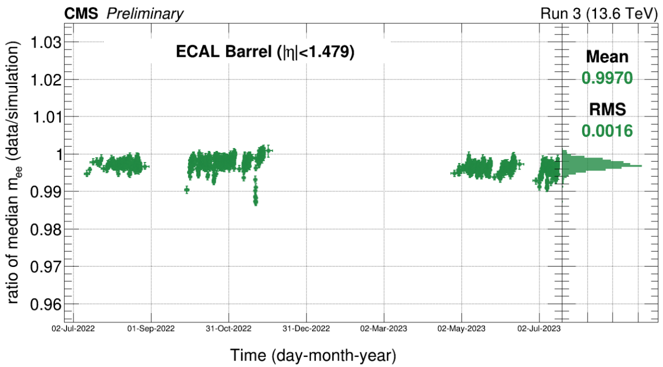
- alignment coefficients
- pulse shape Templates
- timing calibrations (for 2 algorithms)
- laser harness corrections
- Energy scales
- Φ - symmetry reconstruction
- π_0 and m_{ee} monitoring

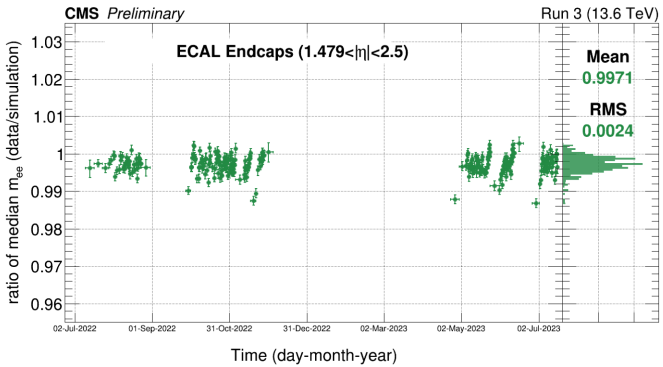
Project joined by

- Tracker
- Pixel
- Muons
- HCAL
- DT
- PPS

Example of physics validation from the automated framework

- Time stability of the di-electron invariant mass comparing data and simulation over 2022 and 2023 using $Z \rightarrow e^+e^-$
- The spread of the median ratio is at 0.1% level throughout 2022 and 2023



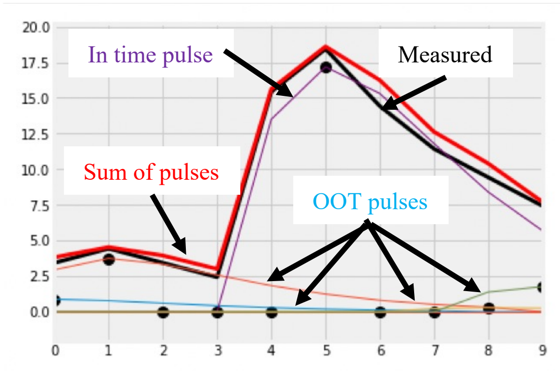


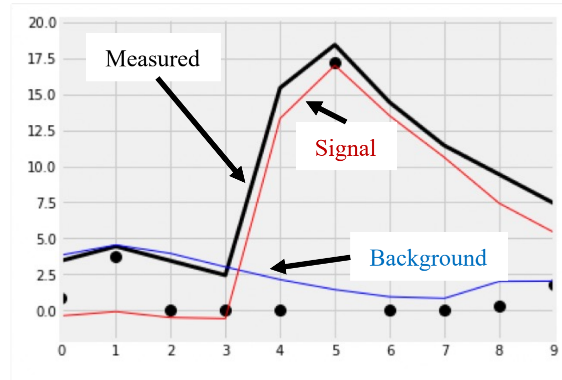
Plots from: CMS DP-2024/022

Conclusion

- The CMS Electromagnetic Calorimeter (ECAL) is essential in the CMS physics program thanks to its excellent measurements of energy, position and time of arrival of photons and electrons
- Precise calibrations of ECAL is essential to achieve optimal resolutions
- Energy calibrations and resolution are stable within expectations for Run 3
- New timing reconstruction and calibrations are in the process of being rolled out that will achieve analysis relevant time resolutions of ~ 100 – 200 ps
- New Automated workflow has been put in place to facilitate more frequent and consistent calibration and monitoring

BackUp





CC Algorithm Strategy :

- Take OOT Amplitudes from the multifit.
- Associate a templated pulse shape with each OOT Amplitude.
- Subtract these OOT pulses from the measured pulse to extract “in-time” pulse.
- Find the time that best matches the ”signal” pulse to the templated pulse shape with a cross correlation fit.

OOT Amplitude Correction

Cross Correlatio n Fit