Calibration and Performance of the CMS Electromagnetic Calorimeter

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CMS-DP-2024-022

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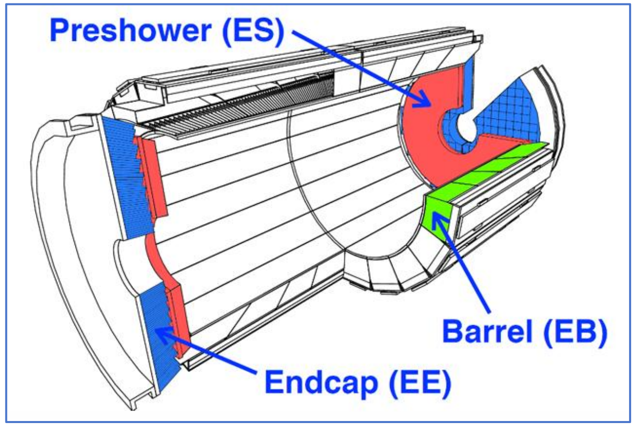
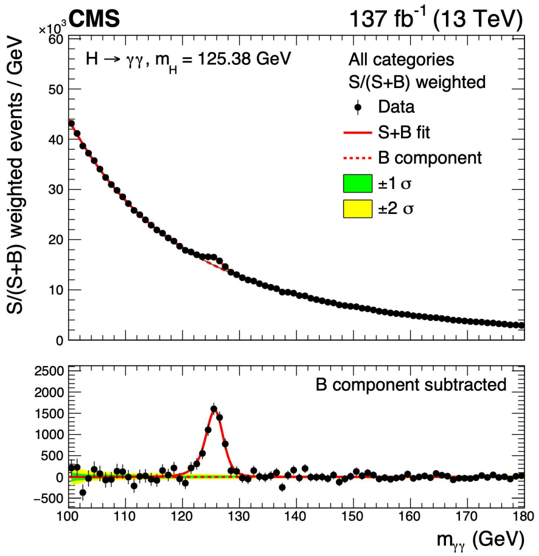
CMS Electromagnetic Calorimeter (ECAL)



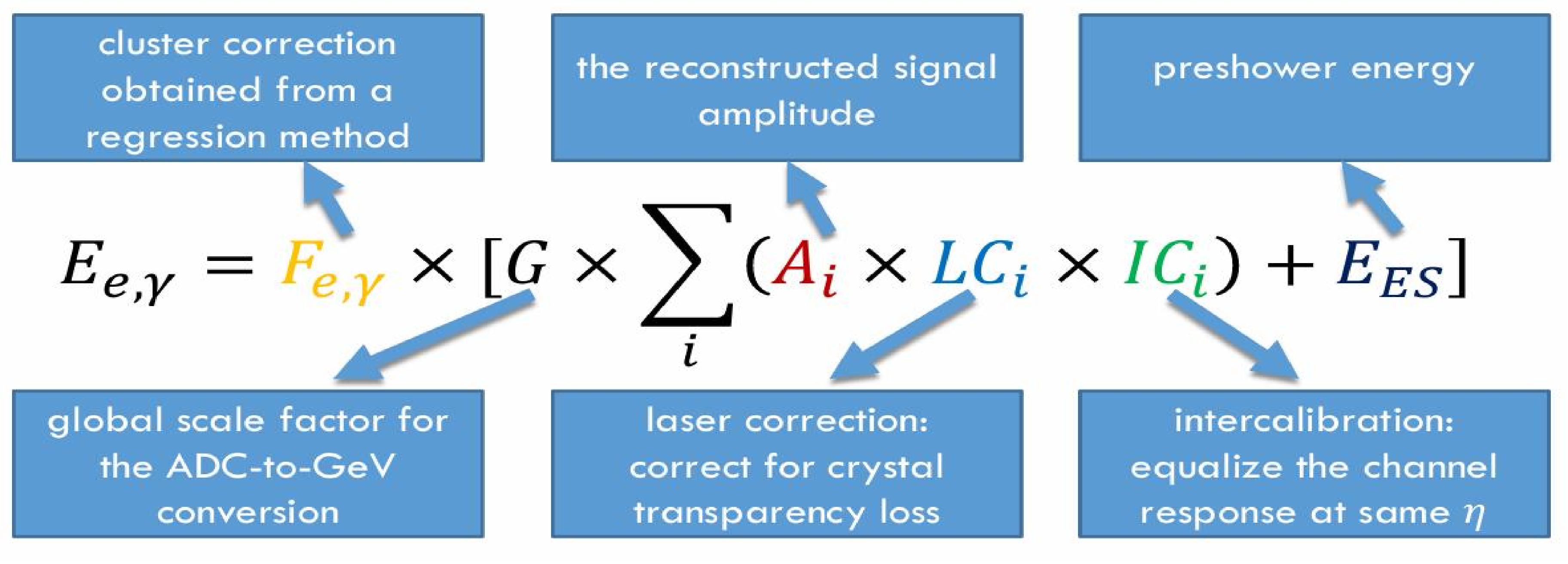
- ECAL: a homogeneous and hermetic scintillating lead tungstate crystal ($PbWO_4$) calorimeter.
  - ✓ 75848 lead tungstate crystals $PbWO_4$
  - ✓ Coverage:
    - **Barrel(EB)**: $|\eta| < 1.479$
    - **Endcaps(EE)**: $1.479 < |\eta| < 3.0$
    - **Preshower (ES)**: $1.65 < |\eta| < 2.6$



- **A highly efficient and accurate reconstruction of photons and electrons over a wide range of energies**
  - Low-energy electrons(5GeV) typical of multilepton events
  - Electroweak-scale energies(Higgs and W/Z bosons)
  - Up to the TeV scale typical of high-mass resonance searches

ECAL signal reconstrction

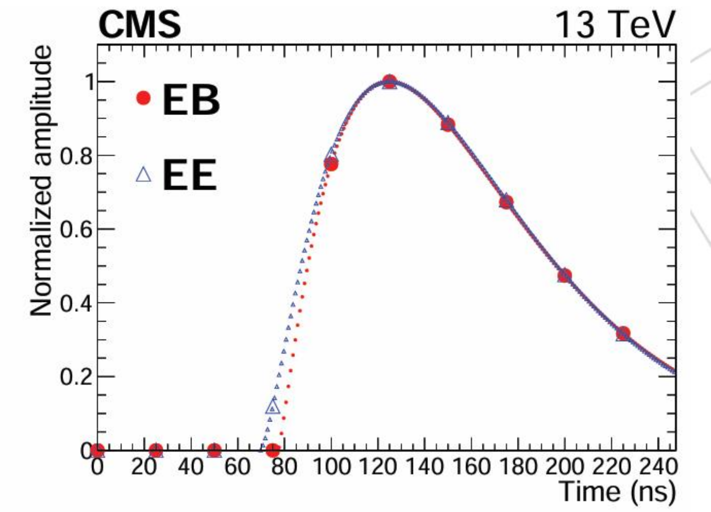
- The energy **E** of an electromagnetic shower in the CMS ECAL is represented as the energy of a **SuperCluster**.
- The reconstructed energy of electrons and photons is estimated by:

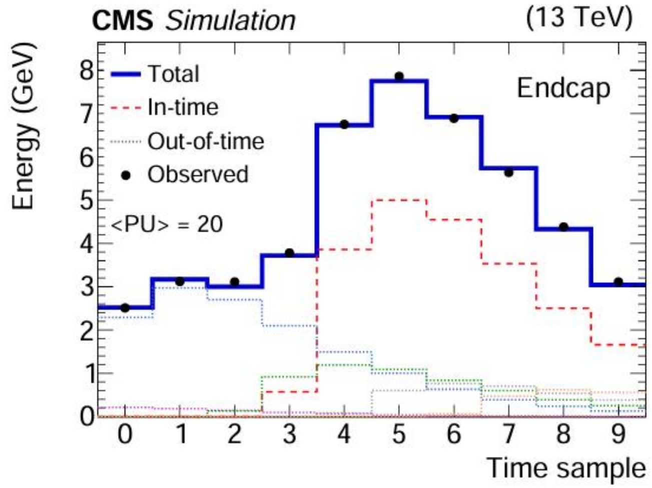


The index, i, represents individual crystals within the supercluster

Signal amplitude reconstruction(A_i)

- **The amplitude A is reconstructed from the ten digitized pulse samples.**
  - First three samples in a pulse are used for pedestals.
- **To mitigate the effect of the increased pileup, “multifit” method was developed.**
  - One in-time pulse and up to 9 out-of-time (OOT) pulses
  - The signal shape for in-time signals was derived using collisions of isolated proton bunches.
  - The signal shapes for the out-of-time signals were obtained from the in-time signal by shifting the time in steps of 25 ns.

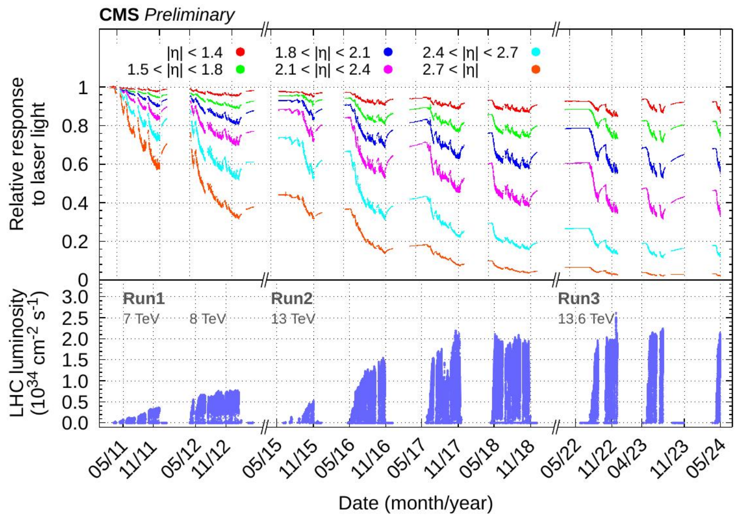




Reference

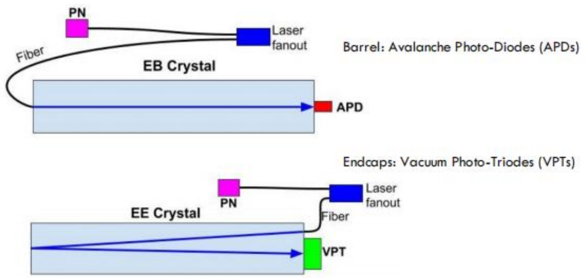
Laser correction (LC_i) for transparency loss

- The energy response of the ECAL changes continuously with time due to the ageing of the crystals and high radiation.
- **Transparency loss corrections** are crucial to maintain the stability of the reconstructed energy scale and resolution.
- A dedicated **light-monitoring system** is used to measure the transparency of each crystal and the photodetector response



- **The relative response is obtained by measuring the ratio of the light measured by the photodetectors and by the reference PN.**

APD(VPT)/PN



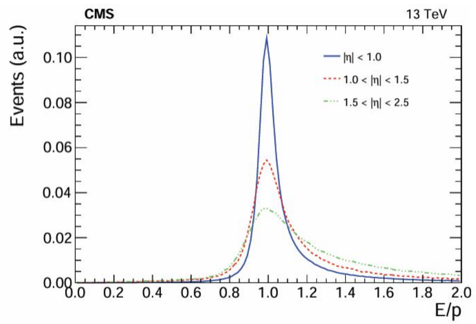
Parameter depends on η and evolves with integrated luminosity

$$LC_i(t) = \left[\frac{R_i(0)}{R_i(t)}\right]^{\alpha}$$

Response to injected laser

Intercalibration (IC_i)

- **Per-crystal intercalibration** constants, **IC_i**, are computed to equalise the crystal response.
- A **combination** of several methods based on different physics signals:



π^0 method：

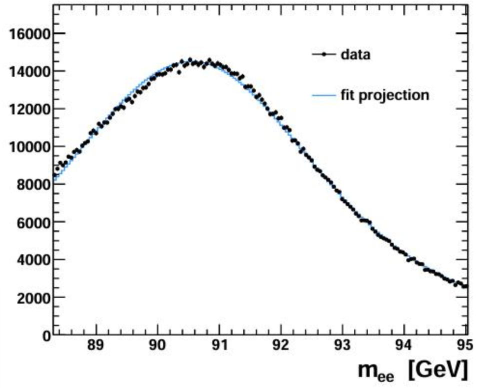
- Exploit reconstructed π^0 mass with its decay of photon pairs
- The IC is derived from a fit to the m distribution measured in each channel.

E/P method:

- Comparison of the ECAL energy to the tracker momentum for isolated electrons

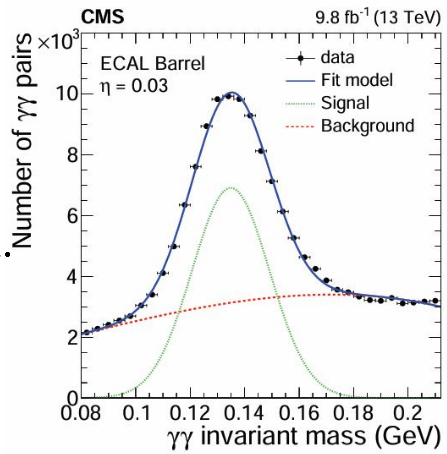
from W/Z boson decay.

- The IC is used to constrain the average E/p ratio to 1.



Zee method:

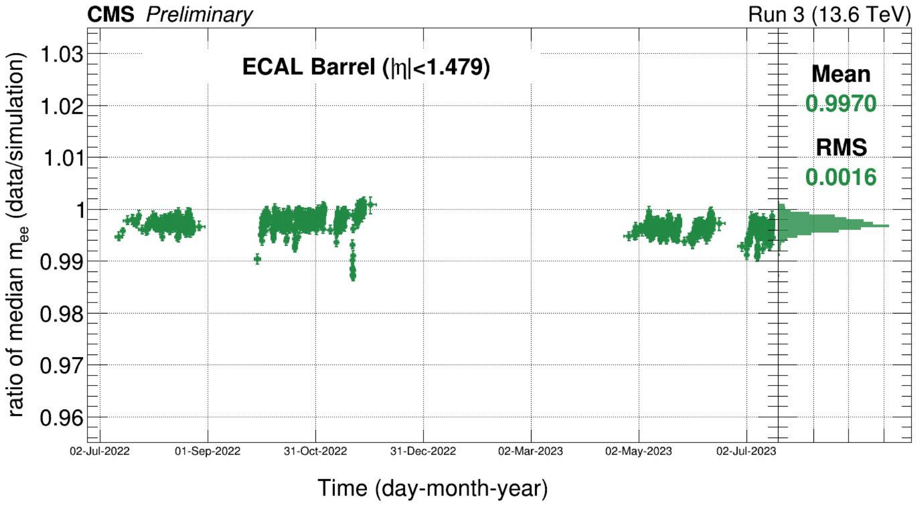
- Exploit the invariant mass reconstructed with electron pairs from Z decays
- The IC is derived from a fit to the m distribution measured in each channel.

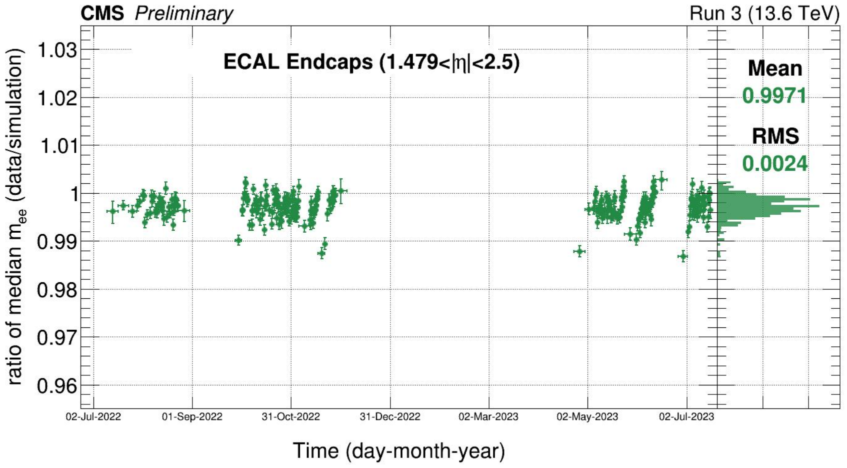


Reference

ECAL performance in Run3

- ✓ **ECAL response is stable over time after corrections**
- ✓ **The spread of the median ratio is at per mil level throughout 2022 and 2023**

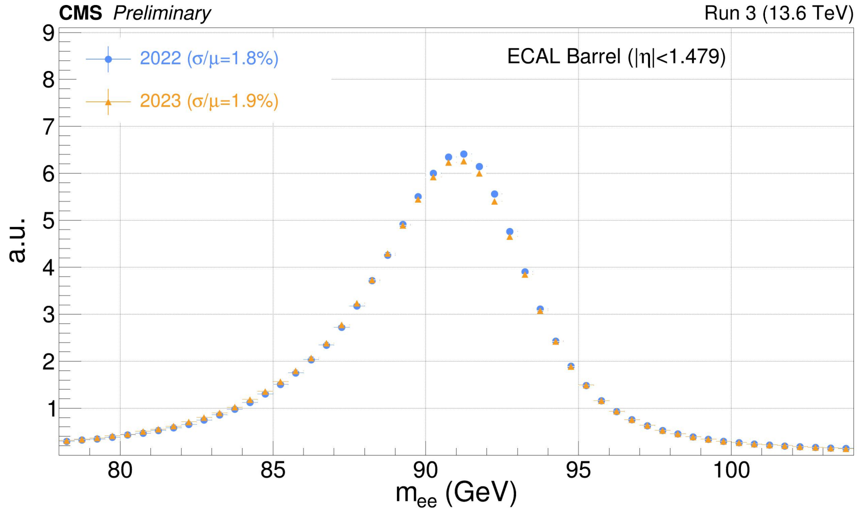


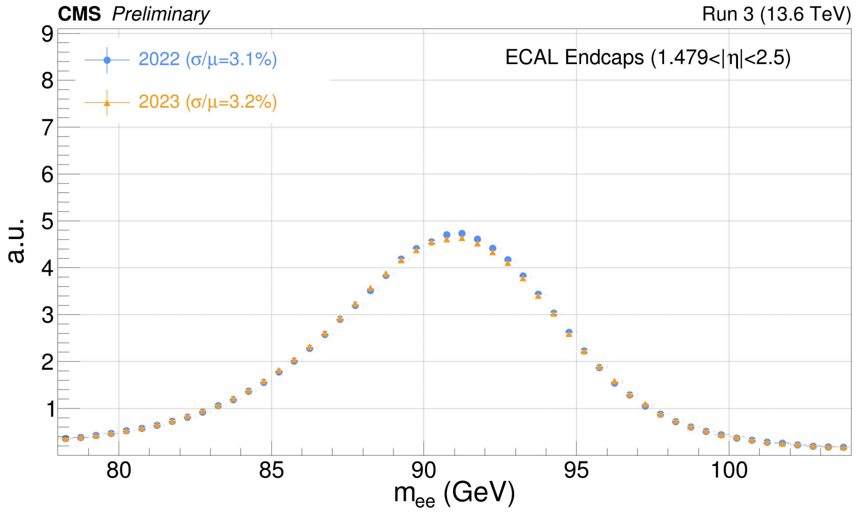


- Time stability of the di-electron invariant mass comparing between data and Monte Carlo (MC) simulation for the 2022 and 2023 data-taking period using Z→ee
- Time-dependent effects produce asymmetric distributions causing a slightly lower median in data wrt Monte Carlo
- Lower mass value appear in correspondence of low statistic runs occurring after an LHC stop but before a new update of the pulse shape templates used in amplitude reconstruction

ECAL performance in Run3

- ✓ **Stability over the whole 2022-2023 period despite luminosity increase and detector ageing**
- ✓ **The inclusive resolutions of electrons are less than 2% in the barrel for both 2022 and 2023, and around 3.2% in the endcap in 2022 and 2023.**

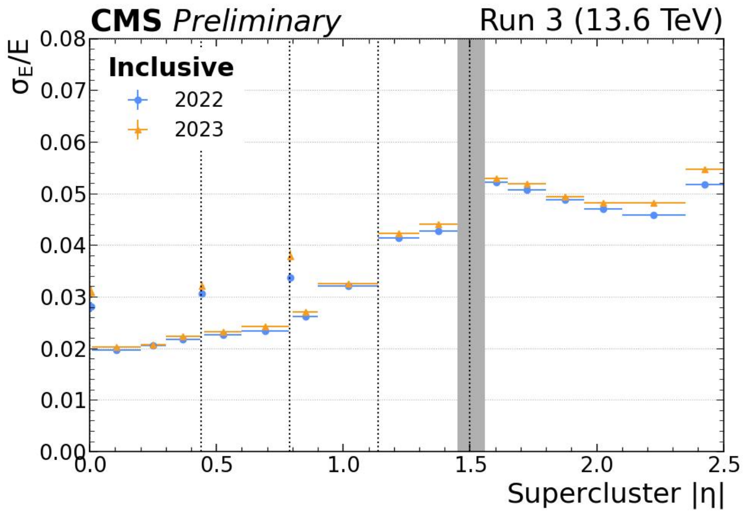


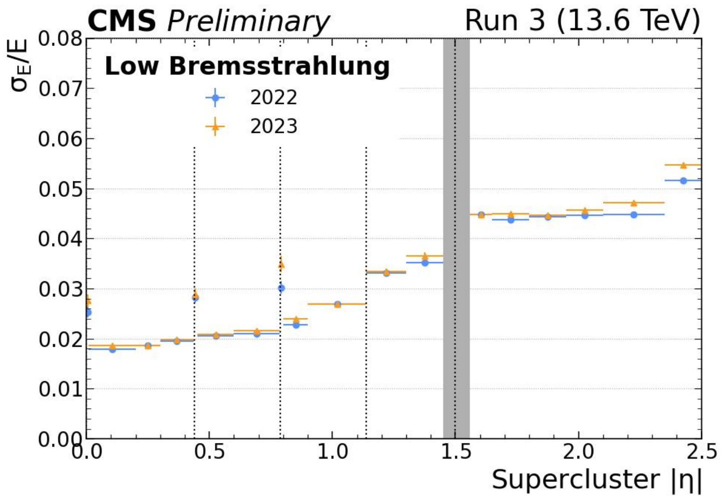


The plots show the invariant mass distribution comparing 2022 and 2023 data-taking period using inclusive $Z \to ee$ events with a refined re-calibration.

ECAL performance in Run3

- ✓ **Stability over the whole 2022-2023 period despite luminosity increase and detector ageing**
- ✓ **The resolution of electrons ranges from 1.8% to 5% depending on η for Z → ee low bremsstrahlung electrons.**





Relative electron (ECAL) energy resolution unfolded in bins of pseudorapidity η. Electrons from Z→ee decays are used. The vertical bars on the points represent the statistical uncertainty.

Summary

- **Calibration and optimization has been exploited in CMS ECAL.**
- **Outstanding performance of the CMS ECAL with calibration**
  - **Stable ECAL response over time with spread at ~1% level**
  - **Resolution of electrons between 1.8% and 5%**
  - **ECAL performance stable over time despite much harsher environment and detector aging**
- **More work ongoing within ECAL to improve the performance**
  - **Automation framework for calibration and monitoring, machine learning in clustering and DQM etc..**

Thank you!