Institute of High Energy Physics

Chinese Academy of Sciences

Calibration and Performance of the CMS Electromagnetic Calorimeter in LHC Run2

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On behalf of the CMS collaboration

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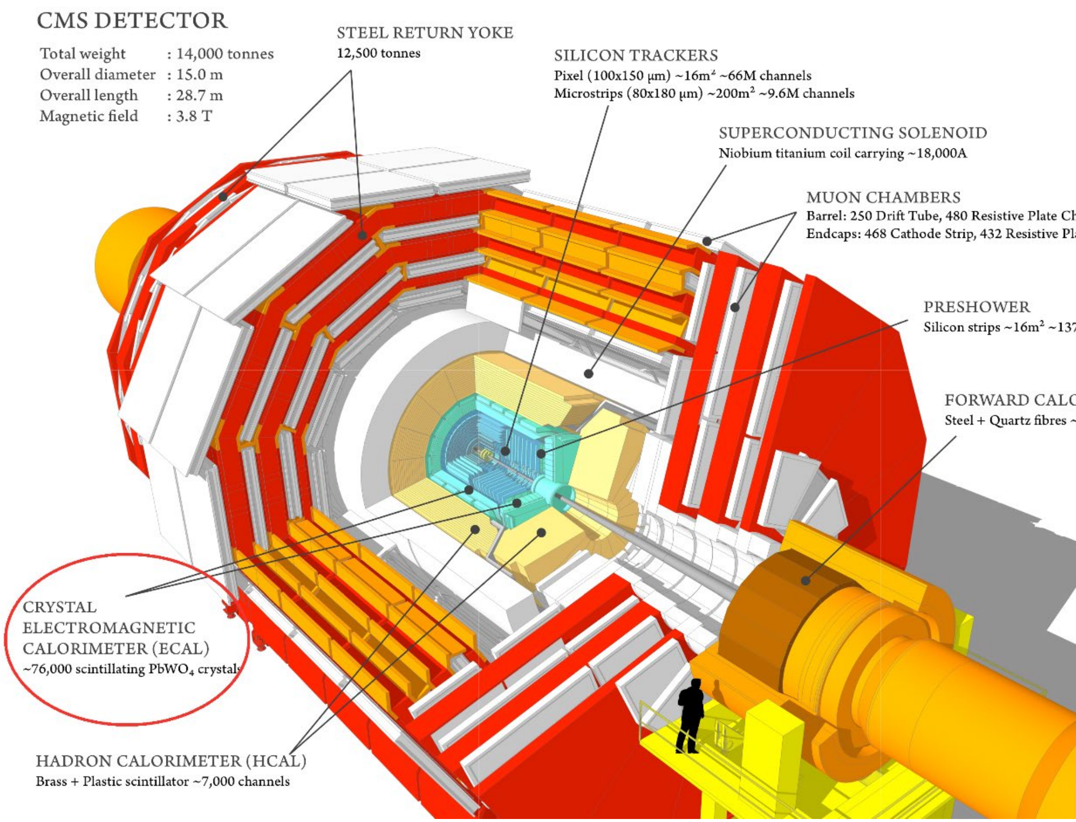
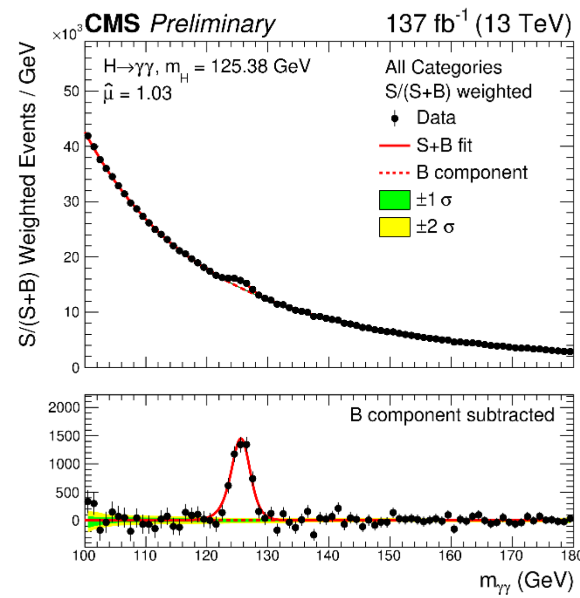
The CMS Detector

- CMS is a general-purpose detector designed to
  - test Standard Model (SM) predictions
  - search for new physics beyond the SM





CMS-PAS-HIG-19-015

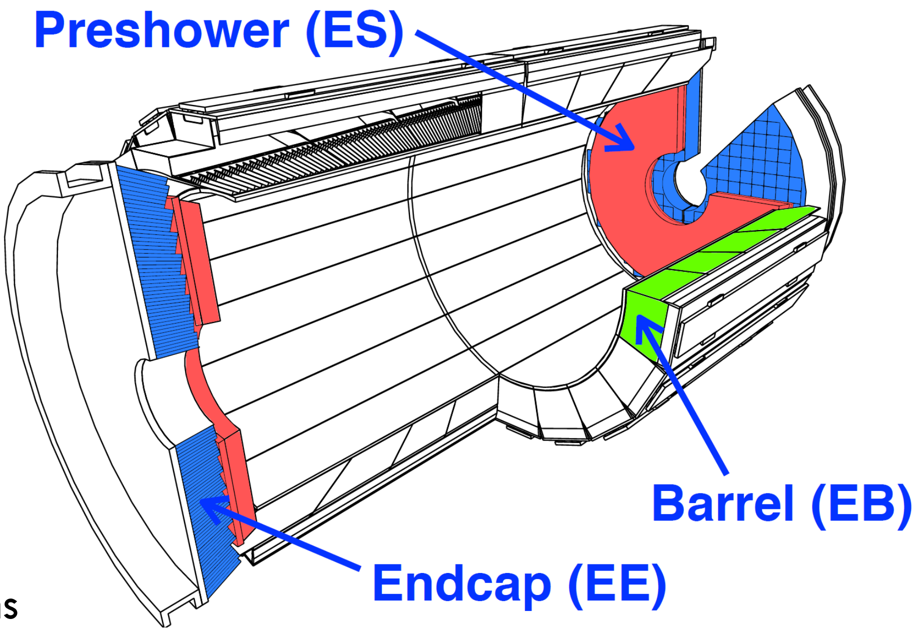
- **The electromagnetic calorimeter plays a crucial role in many CMS physics analysis that involve electrons or photons**

CMS Electromagnetic Calorimeter (ECAL)

- **ECAL: compact, homogeneous, hermetic and fine-grain crystal calorimeter**
  - designed to provide highly efficient and accurate reconstruction of photons and electrons

- 75848 PbWO4 crystals
- high density of 8.3 g/cm3
- short radiation length 0.89 cm
- small Moliere radius 2.2 cm
- fast light emission : ~80% in ~25 ns

Coverage:
Barrel (EB): $|\eta| < 1.48$
Endcap (EE): $1.48 < |\eta| < 3.0$
Preshower (ES): $1.65 < |\eta| < 2.6$
(ES: discriminate between prompt photons and photons from π_0 decay)



ECAL challenges in LHC Run 2:
- higher pileup and noise, increased exposition to radiations
- a larger variation of the calorimeter response that must be corrected for

ECAL Signal Reconstruction

- The electromagnetic particles deposit their energy over several ECAL crystals.
  - dynamic clustering algorithms used to collect the energy deposits in ECAL

- The reconstructed energy of electrons and photons is estimated by:

cluster correction obtained from a regression method

the reconstructed signal amplitude

preshower energy

$$E_{e,\gamma} = F_{e,\gamma} \times [G \times \sum_i (A_i \times LC_i \times IC_i) + E_{ES}]$$

global scale factor for the ADC-to-GeV conversion

laser correction: correct for crystal transparency loss

intercalibration: equalize the channel response at same η

Signal Amplitude Reconstruction

- 10 digitized ECAL pulse samples recorded for signal amplitude reconstruction
  - Run 1: Amplitude was a weighted sum of all 10 samples.
  - Run 2: ’multifit’ reconstruction method is explored to mitigate higher pileup.
    - Pulse shape is modeled as a sum of one in-time pulse and up to 9 out-of-time (OOT) pulses

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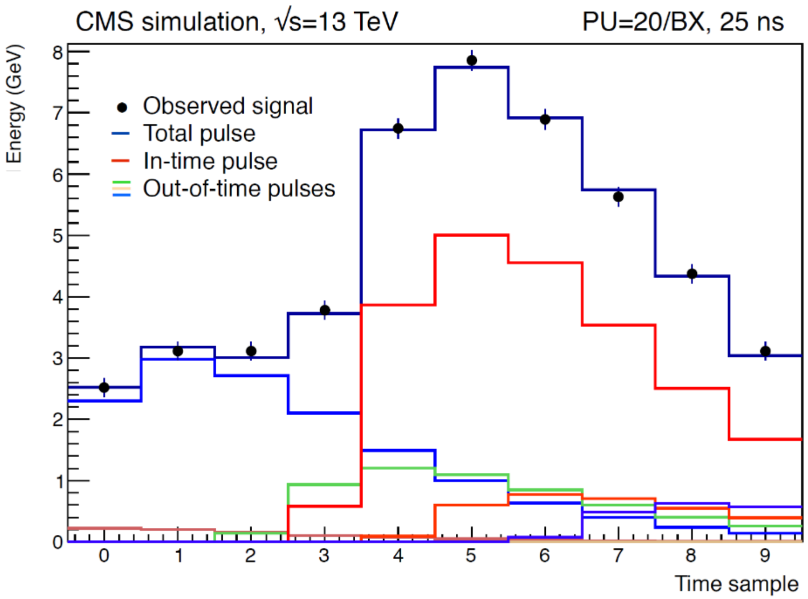
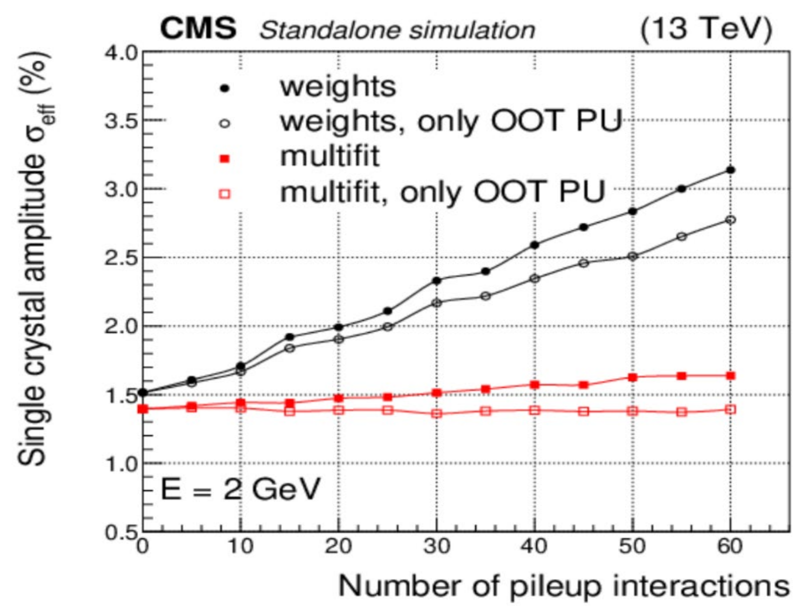
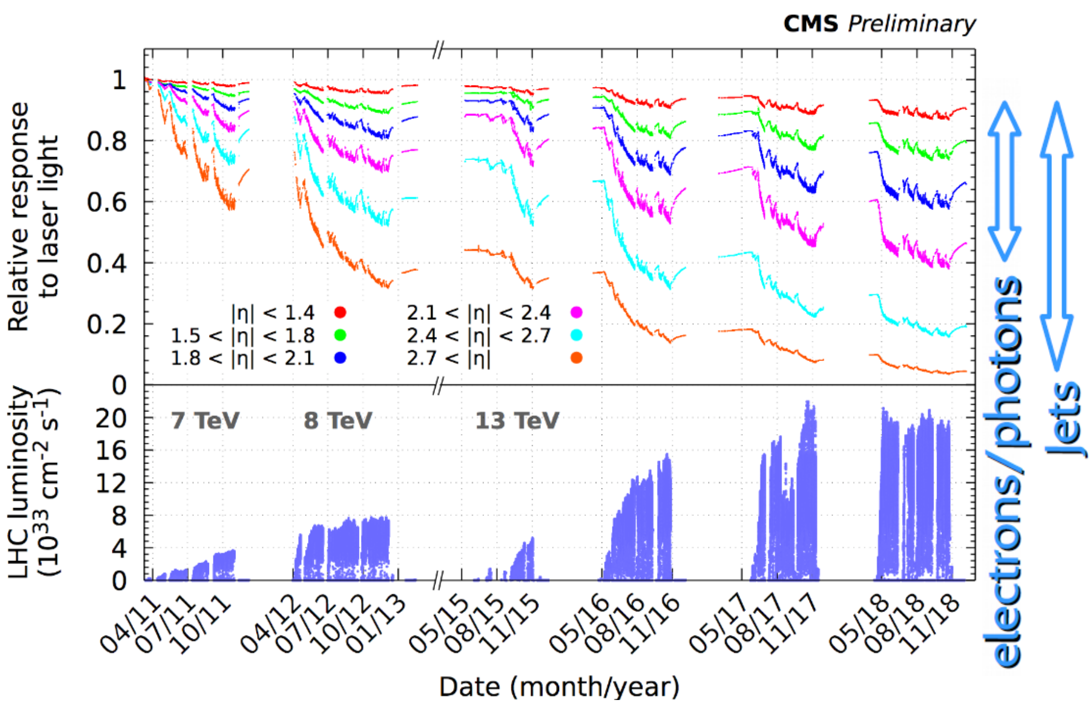




- The ’multifit’ reconstruction method is robust against pileup increase.

Laser Correction (LC)

- ECAL channel response varies with time due to radiation-induced effects
  - crystal transparency changes over time
  - photocathode aging with accumulated charge



Laser Correction (LC)

- A dedicated laser monitoring system is designed to provide corrections for this.
  - injects laser light with a wavelength of 447nm into each crystal
  - relates ECAL channel response variation to changes in the scintillation signal
  - measures the calibration point per crystal every 40 minutes
  - obtains and applies corrections within 48 hours for the prompt reconstruction

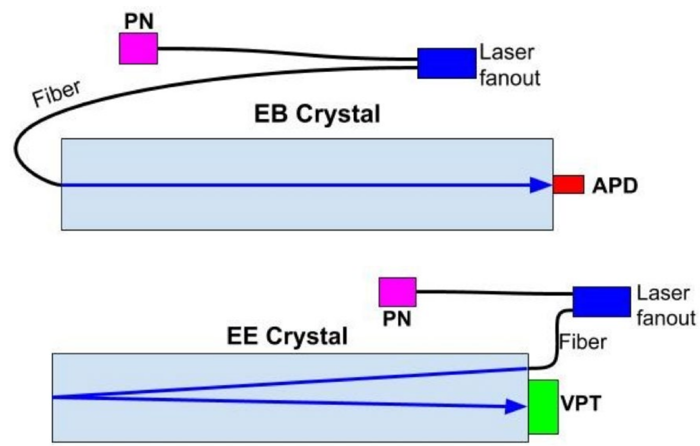
Correction for e/y scintillation

Response to injected laser

$$\frac{S(t)}{S_0} = \left(\frac{R(t)}{R_0}\right)^{\alpha}$$

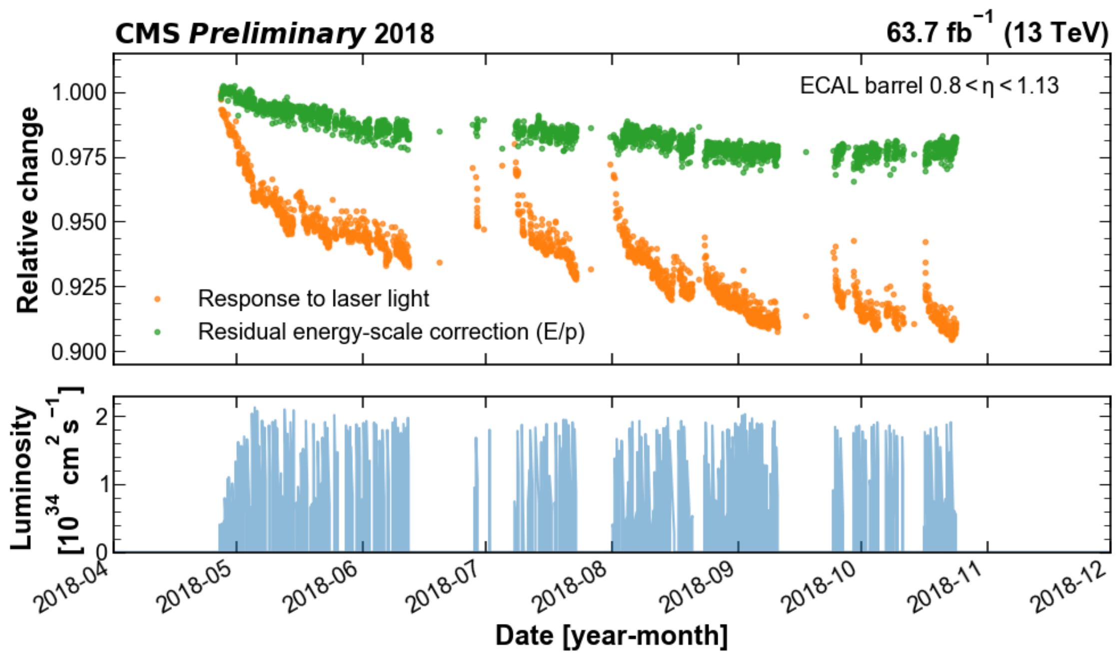
α parameter

Relative response = APD(VPT) / PN



- α parameter depends on η and evolves with integrated luminosity
  - periodically computed to ensure energy scale stability and high resolution

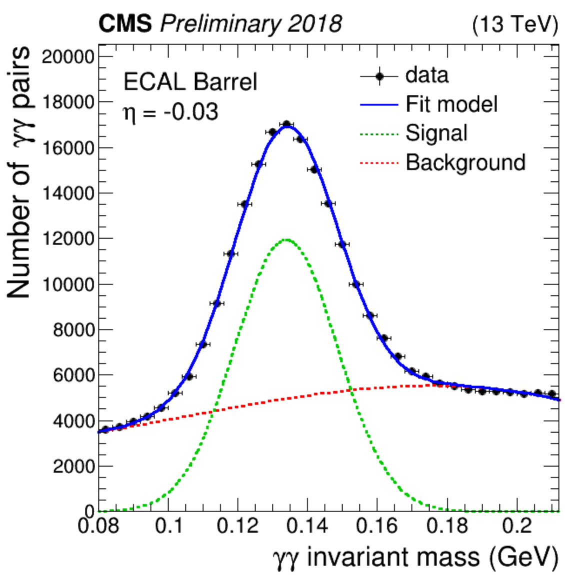
Laser Correction (LC)

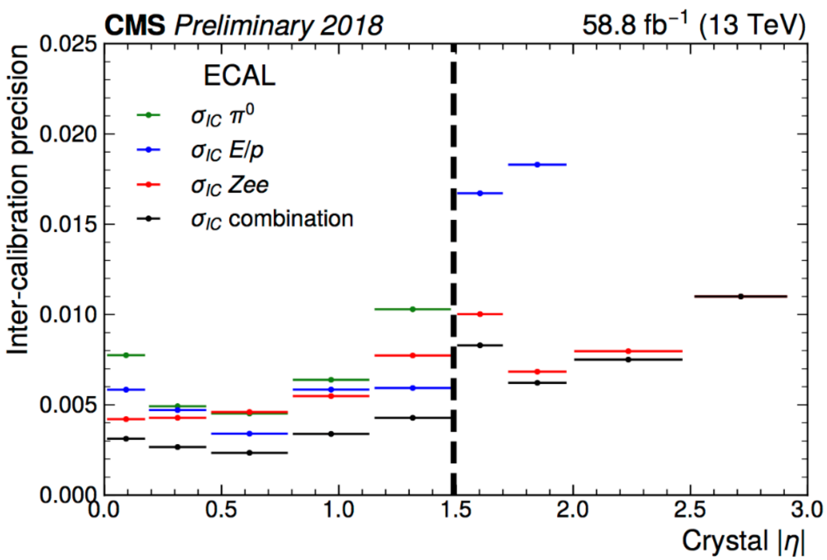


- Orange: relative response variations to laser light injected in the ECAL crystals
- Green: the residual energy-scale correction after the application of the laser corrections
  - correction needed due to a drift of the response of the PN diode used in the laser-based calibration system
  - correction determined by comparison with the tracker-measured momentum of electrons from W/Z bosons (E/p ratio)
  - a few percent variation during the year and independent on instantaneous luminosity

Intercalibration (IC)

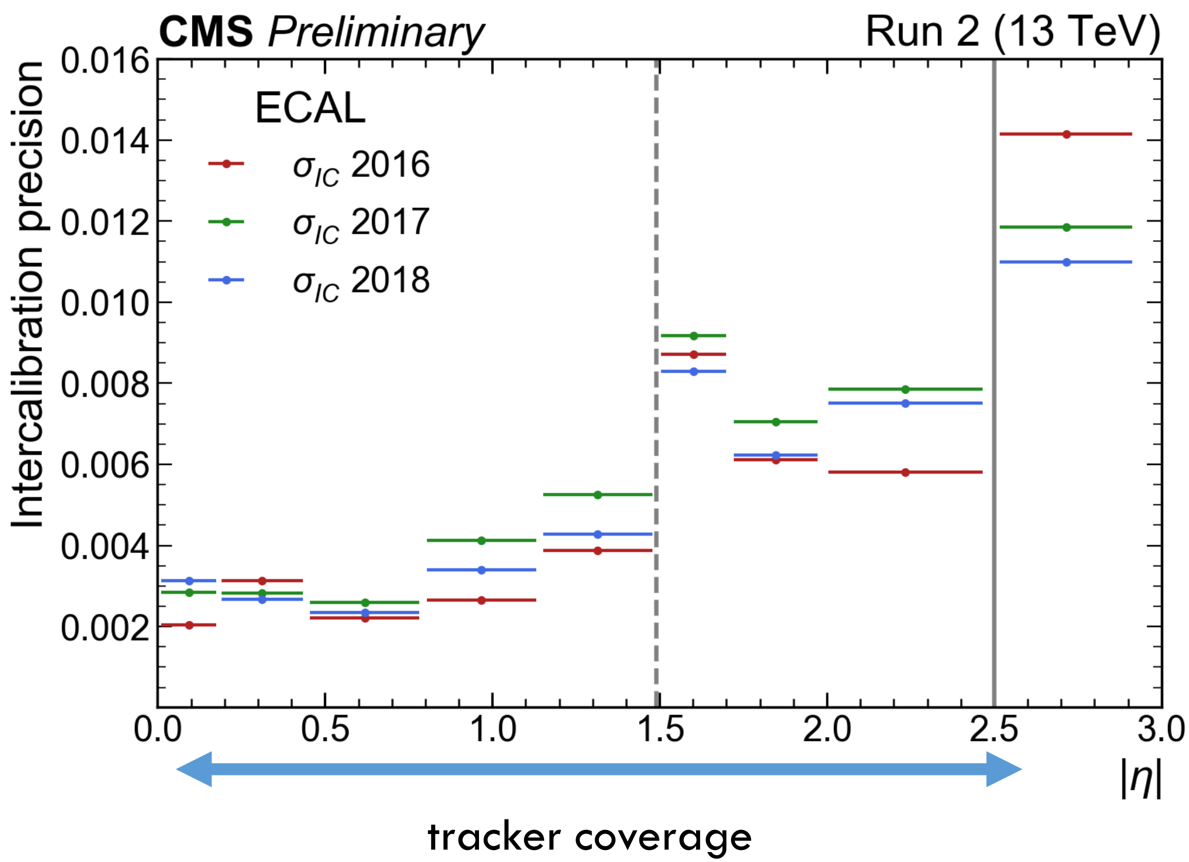
- IC: equalize the ECAL response for different crystals at the same η coordinate.
- A combination of several methods based different physics signals
  - π^0 mass: exploit reconstructed π^0 mass with its decay of photon pairs
  - E/p: comparison of the ECAL energy to the tracker momentum for isolated electrons from W/Z boson decay
  - Zee: exploit the invariant mass reconstructed with electron pairs from Z decays
  - ϕ-symmetry: correct non-uniformed energy flux around ϕ rings based azimuthal symmetry of minimum bias event, not used in combination due to bad precision





Intercalibration Precision

- Final intercalibration combines different methods by weighting their respective precision
  - precision evaluated with the relative energy resolution of Zee

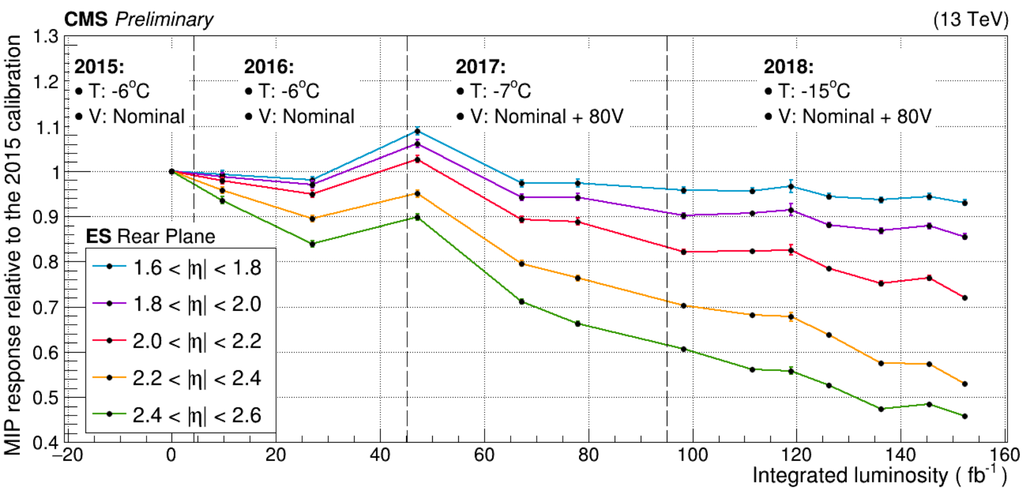


IC reaches very good precision

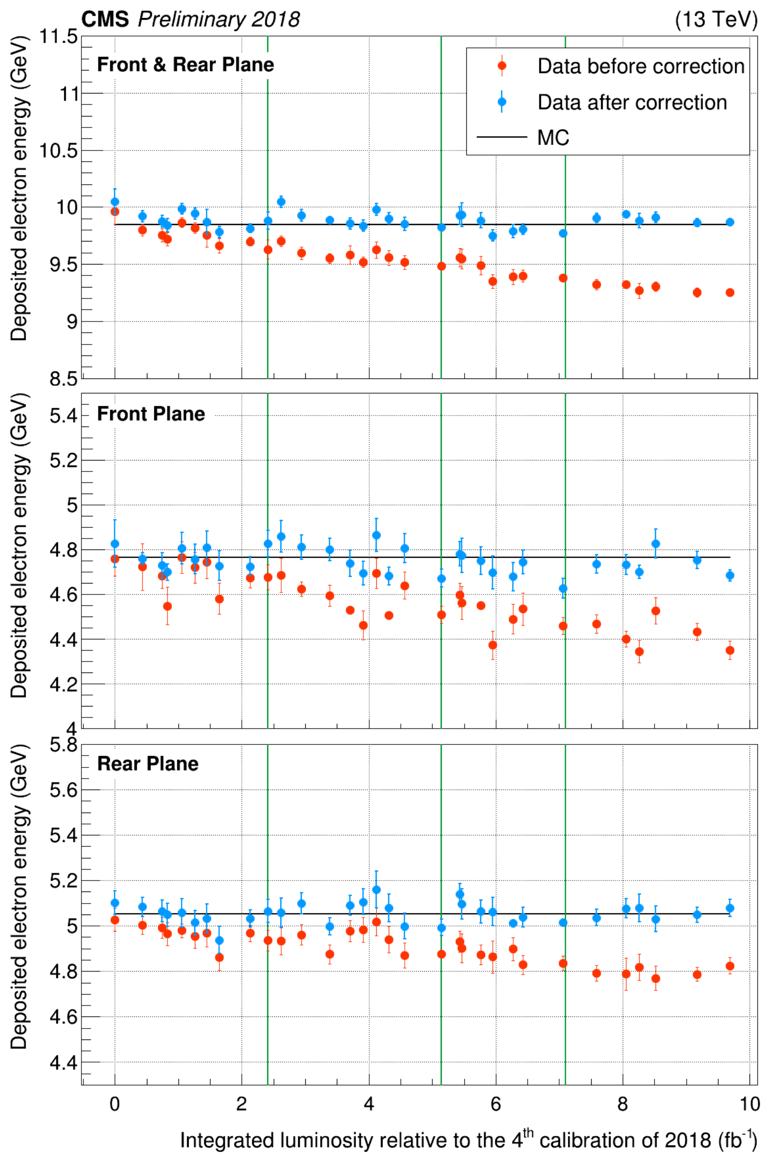
- <0.5% at barrel region
- <1% at endcap region
- dominant factor of the constant term in the final energy resolution

Preshower Calibration

- Preshower calibrated using minimum ionizing particles (MIPs)
  - channel by channel calibration
  - special runs taken for calibration every 10 fb^{-1}

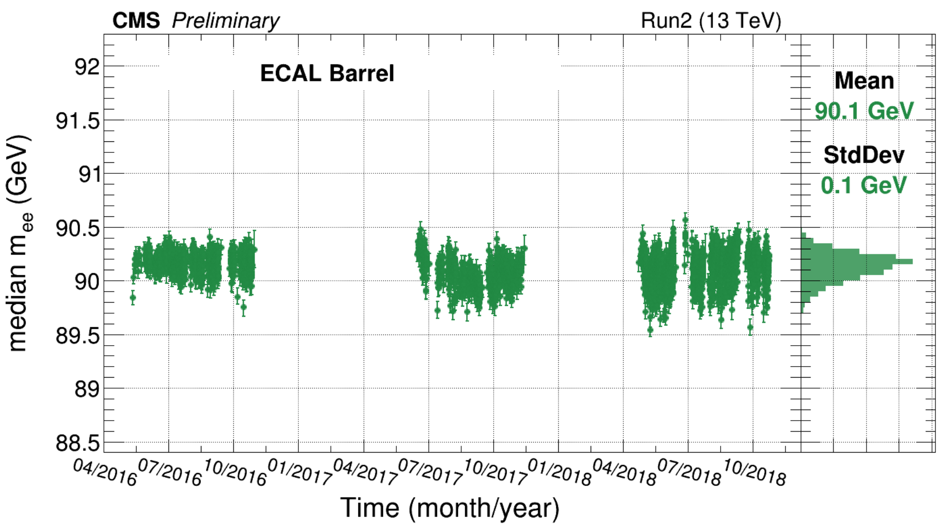


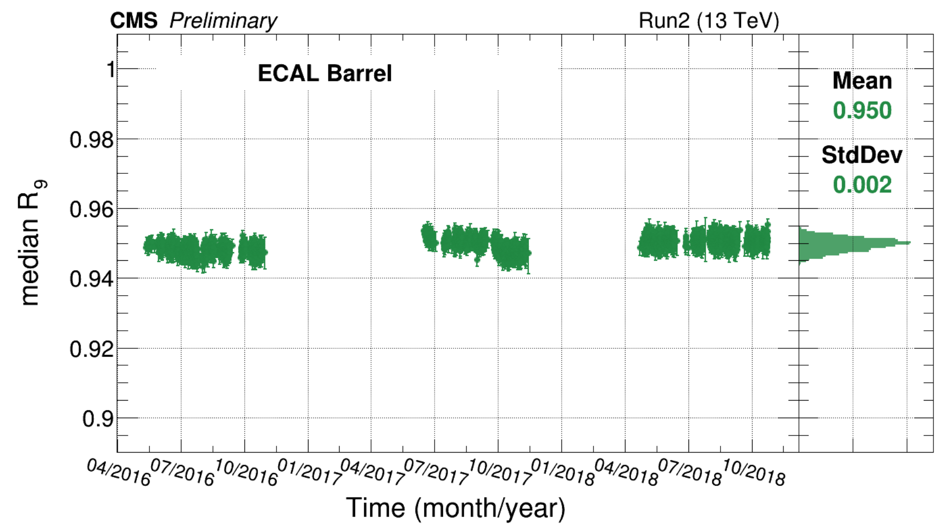
  - correction computed by minimizing the X² value between the energy distribution of data and MC using Z→ee events
  - Measured energy of ES cluster is stabilized by applying the correction.



ECAL Performance in Run 2

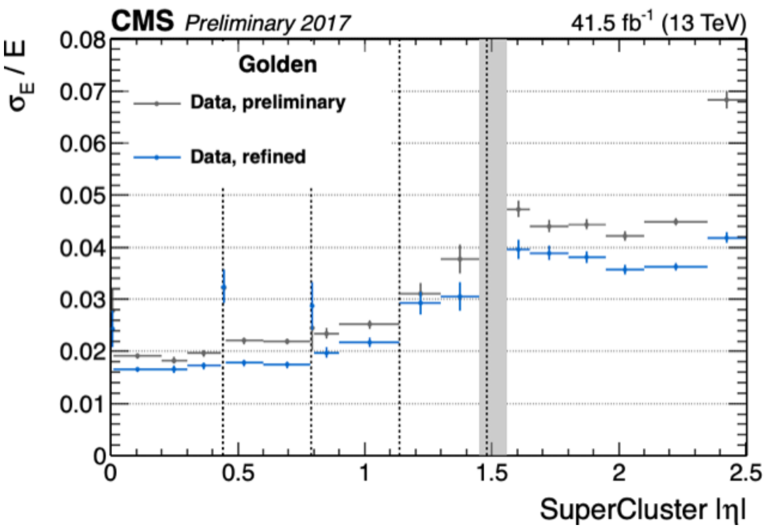
- **ECAL response is stable over time after corrections**
  - validated with $Z \rightarrow ee$ physics signals

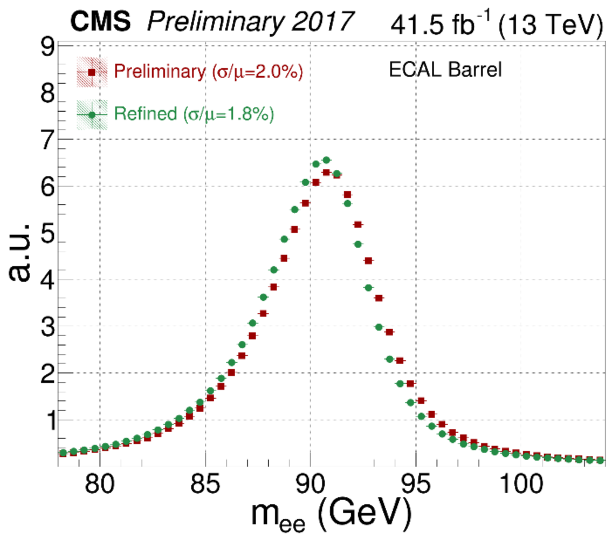




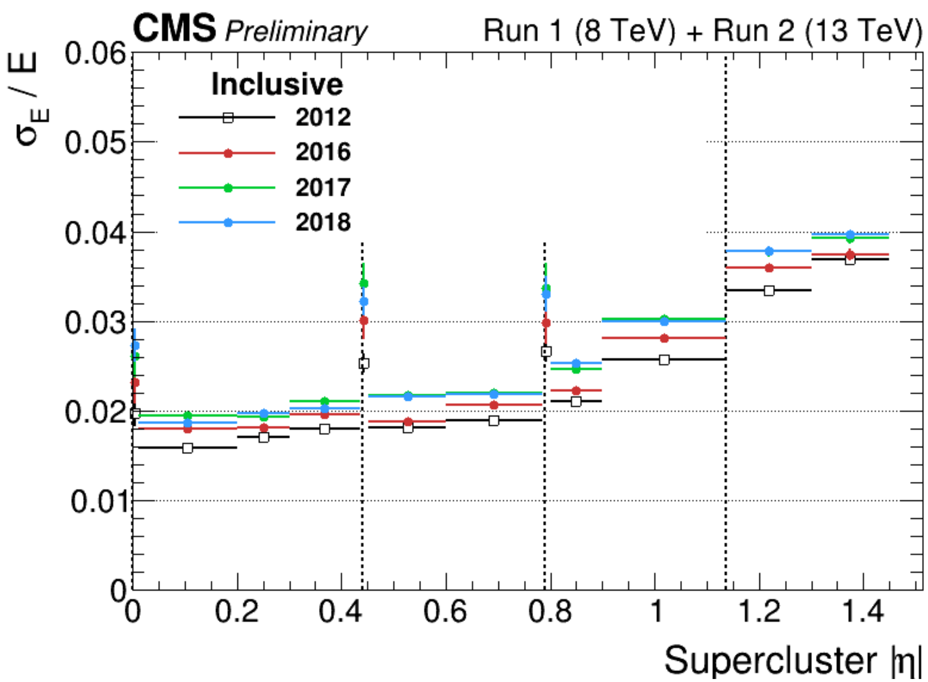
  - energy scale stable at ~1% level across 3 years
  - shower shape variable (R9) also stable over time with spread <<1%
    - important variable for the electron and photon identification

ECAL Performance in Run 2





- Energy and mass resolution with ECAL calibration



- clear improvements after refined calibration
- stable performance within Run 2
- similar performance in Run 2 and Run 1

Summary

- Challenging CMS ECAL calibration in Run 2 due to increased instantaneous luminosity and detector aging

- A range of recalibration and optimization has been exploited with full Run 2 data
  - new multifit method for amplitude reconstruction
  - laser correction to stable ECAL response over time
  - intercalibration to stable ECAL response in different crystals at same η
  - corrections to stable measured energy in preshower

- Excellent performance is achieved with ECAL calibration in Run 2
  - stable ECAL response over time with spread at ~1% level
  - resolution for electrons from Z-boson decays better than 2% in the central region of the ECAL and 4% elsewhere
  - similar ECAL performance achieved in Run 2 in comparison with Run 1 despite much harsher environment