Achieving the optimal performance of the CMS ECAL in Run II

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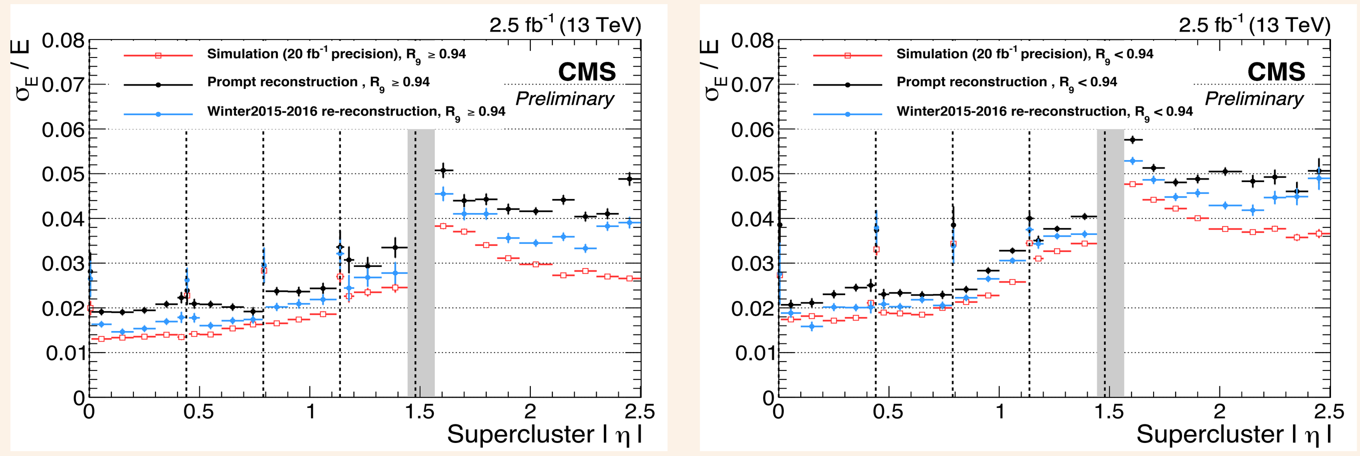
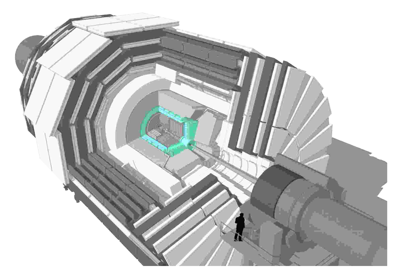
ECAL Run II Performance

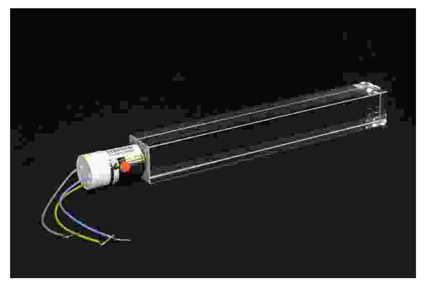
The performance of CMS electromagnetic calorimeter (ECAL) was crucial for the discovery of the Higgs boson and continues to play an important role in searches for new physics and Standard Model measurements.

The ECAL has been taking data with excellent performance at $\sqrt{s} = 13$ TeV in Run II:

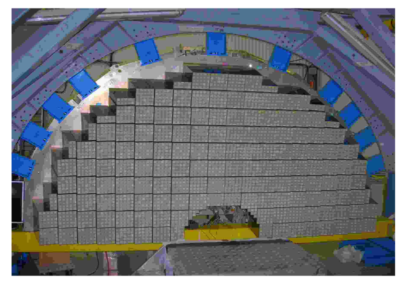
- An energy resolution between 1.4% and 3% for unconverted photons is achieved in the barrel section of the ECAL. The resolution in the endcap is between 3% and 4%.
- The ECAL alignment has obtained a precision of $2 \cdot 10^{-3}$ rad in ϕ and $2 \cdot 10^{-3}$ units in η in the barrel.



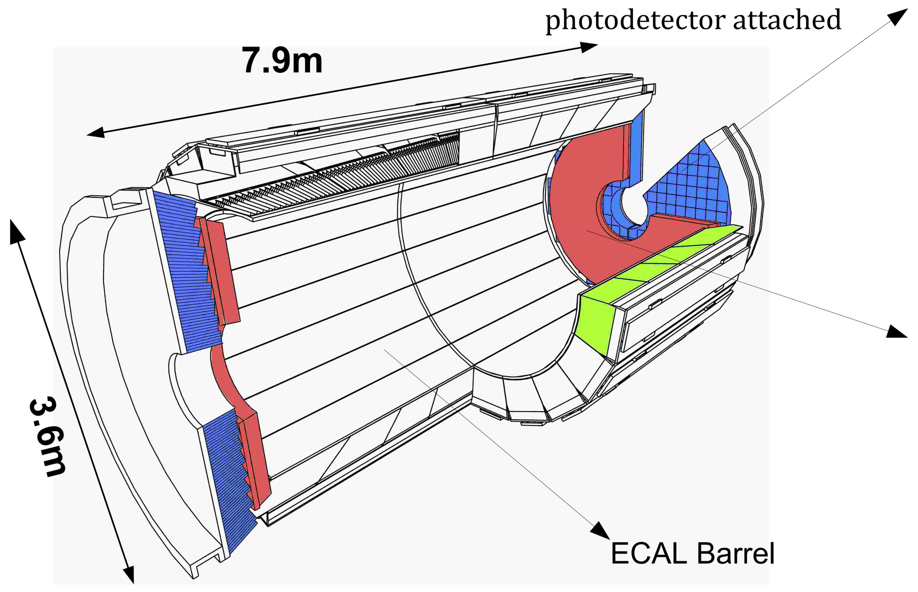


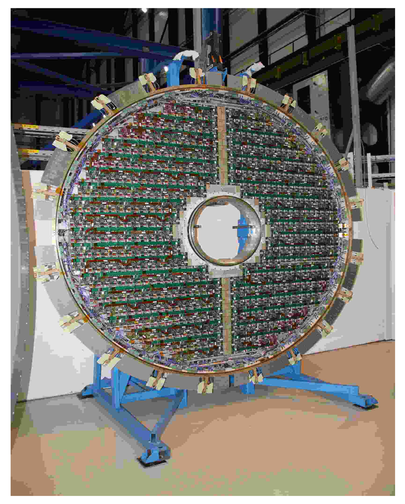


A $PbWO_4$ crystal with photodetector attached



Endcap Dee with supercrystals





ECAL Preshower

CMS ECAL

The CMS electromagnetic calorimeter

75848 lead tungstate crystals:

Short radiation length $X_0 = 0.89$ cm

Small Molière radius $R_M = 2.10$ cm

ECAL layout:

	Active material	Readout electronics	η coverage
Barrel	$PbWO_4$ crystals 2.2×2.2×23 cm ($\sim 25.8\ X_0$)	avalanche photodiodes (APD)	$\lvert\eta\rvert < 1.48$
Endcap	$PbWO_4$ crystals 3×3×22 cm ($\sim 24.7\ X_0$)	vacuum phototriodes (VPT)	$1.48 < \lvert\eta\rvert < 3.0$
Preshower	2 layers of Pb/Si ($\sim 3\ X_0$)	137200 read-out channels	$1.65 < \lvert\eta\rvert < 2.6$

ECAL Energy Reconstruction

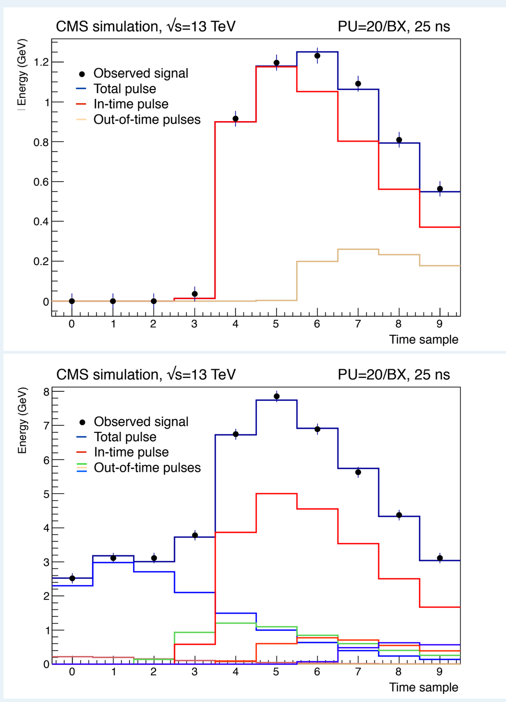
$$E_{e,\gamma} = F_{e,\gamma} \cdot [G \cdot \sum_i S_i(t) \cdot C_i \cdot A_i + E_{ES}]$$

A_i: pulse amplitude
C_i: inter-calibration coefficient
S_i: time-dependent correction for channel response change

G : global ADC to GeV scale factor
E_{ES}: preshower energy
$F_{e,\gamma}$: cluster energy correction

Amplitude Reconstruction

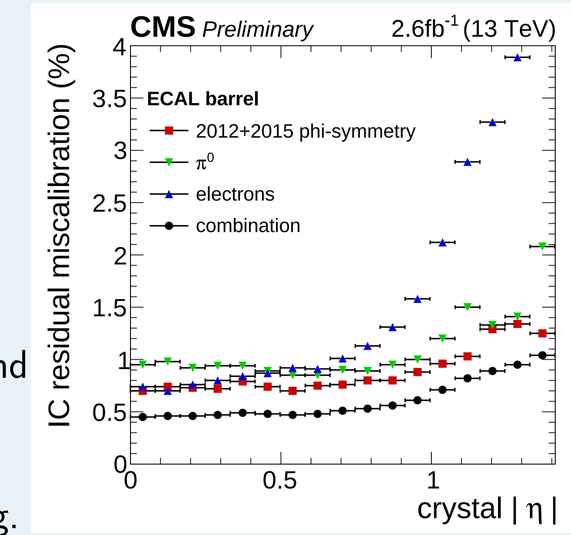
- **Run I**
  Pulse amplitude was given by a weighted linear combination of 10 time samples:
  $$A = \sum_{i=1}^{10} w_i \times S_i$$
- **Run II : multi-fit method**
  A new reconstruction algorithm has been implemented to mitigate the effect of out-of-time pileup and improve the performance of ECAL under the high luminosity conditions of Run II.
  $$\chi^2 = \sum_{i=1}^{10} \frac{(\sum_{j=1}^{M} A_j p_{ij} - S_i)^2}{\sigma^2_{S_i}}$$
  (A_i = amplitude, p_{ij} = pulse height, σ_{S_i} = noise covariance matrix)
  Estimates the in-time signal amplitude and up to 9 out-of-time amplitudes by minimizing χ^2



Single channel inter-calibration

Inter-calibration is used to equalize the variations in channel responses due to different light-yield and photodetector responses.

- **Azimuthal symmetry**: crystals in the same pseudo-rapidity ring should have same average energy deposition.
- **π^0/η mass**: invariant mass of photon pairs from $\pi^0(\eta^0) \to \gamma\gamma$ are exploited for calibration.
- **E/p of isolated electrons**: comparison of ECAL energy E to tracker momentum p of isolated electrons from W and Z decays.
- **Z → ee (Run II)**: exploiting the Z mass peak to get the scale constant of channels in the same pesudo-rapidity ring.



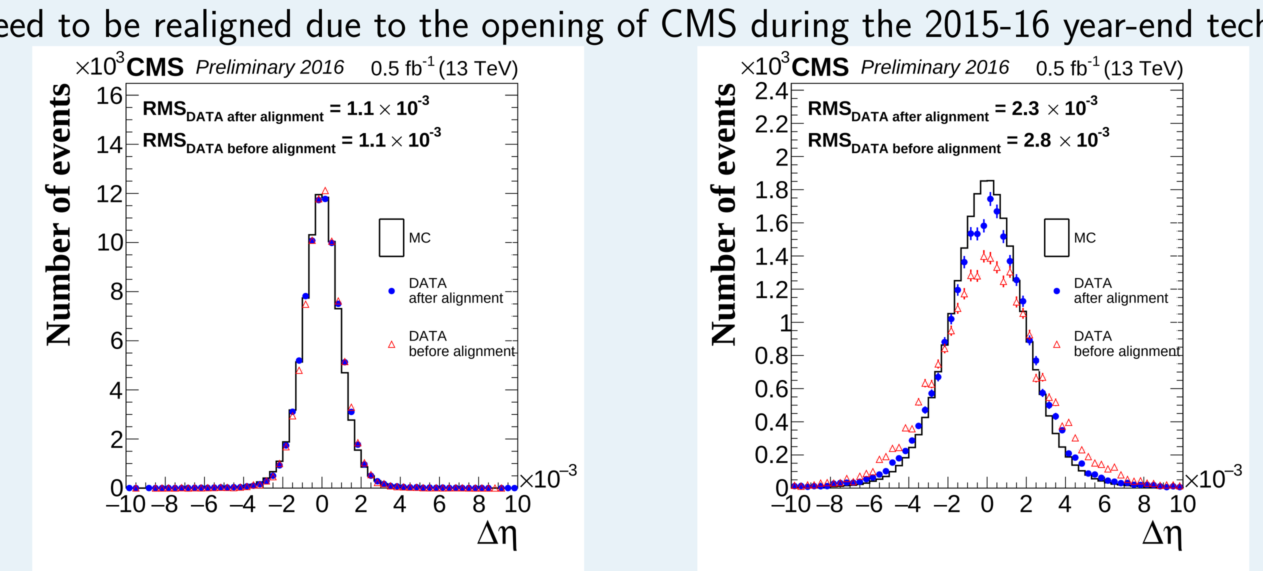
The combined inter-calibration factor is the mean value of individual corrections weighted by their respective precisions.

Alignment

Alignment of ECAL with respect to tracking system:

- The strategy is to compare for each electron the ECAL supercluster position to the tracker based position.
- Based on the assumption that with ideal detector conditions MC and data should agree in $\Delta\phi$ and $\Delta\eta$ values, the alignment is achieved by minimizing the χ^2 function:
  $$\chi^2 = \chi^2_+ + \chi^2_-$$
  $\chi^2_\pm$ depends on the charge of leptons:
  $$\chi^2_\pm = \sum_{lepton} \frac{(\Delta\phi - \langle\Delta\phi^{MC}_\pm\rangle)^2}{\varepsilon^2_\phi} + \frac{(\Delta\eta - \langle\Delta\eta^{MC}\rangle)^2}{\varepsilon^2_\eta}$$

A precision of 2×10^{-3} rad in ϕ and 2×10^{-3} units in η has been achieved in the barrel, while endcaps and preshower need to be realigned due to the opening of CMS during the 2015-16 year-end technical stop.

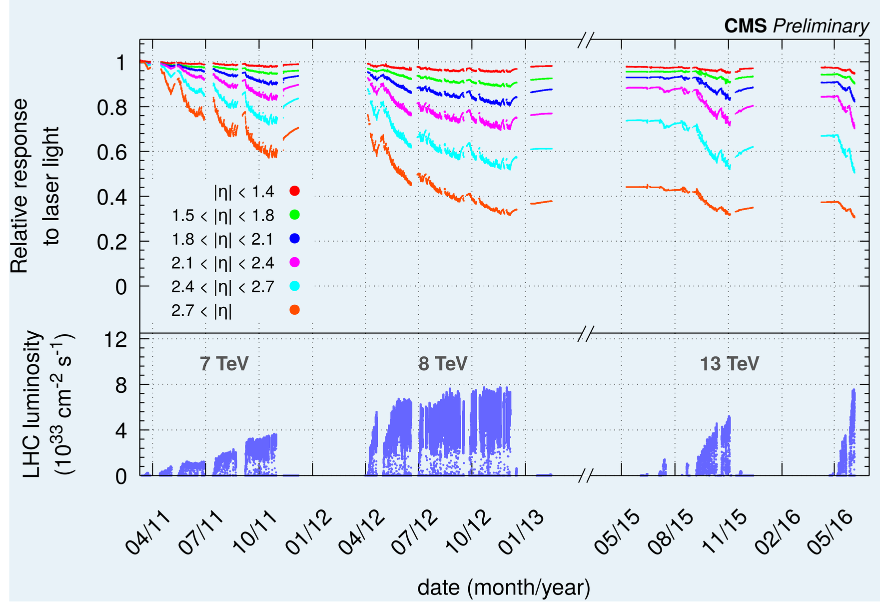


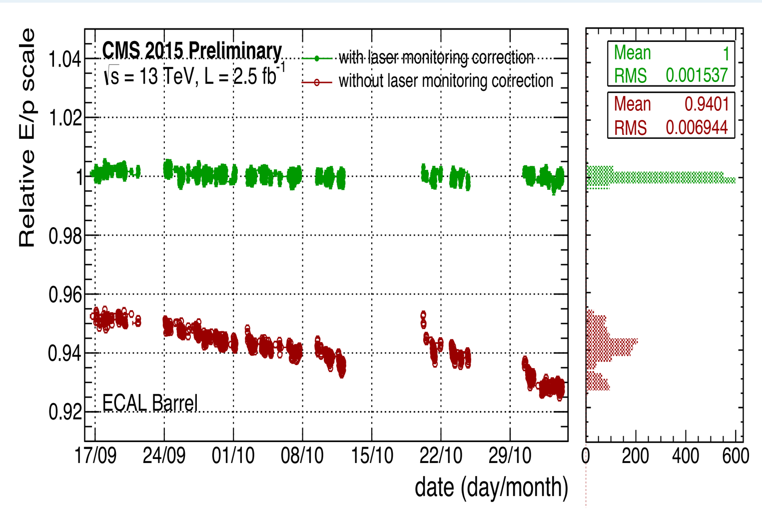
Barrel

Endcaps

Response Correction

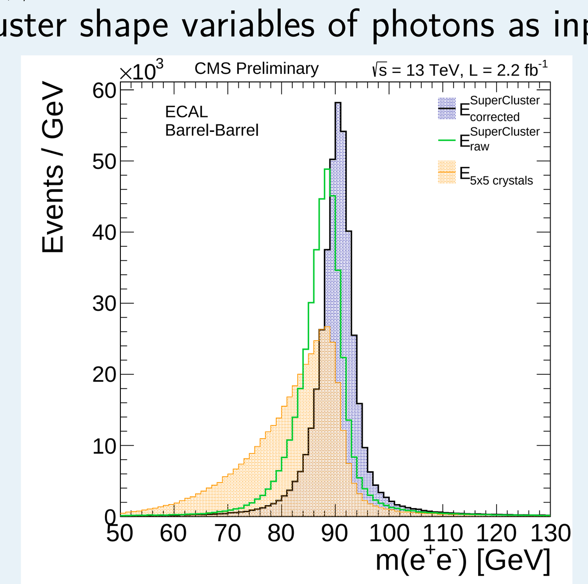
- Radiation causes a degradation in crystal transparency and VPT response. The transparency loss will partially recover in absence of irradiation. A laser based light monitoring system is used to determine corrections for the variation of the ECAL response.
- Relative response to scintillation light is given by: $\frac{S(t)}{S_0} = (\frac{R(t)}{R_0})^\alpha$
- The response correction is validated using the E/p of single electrons.

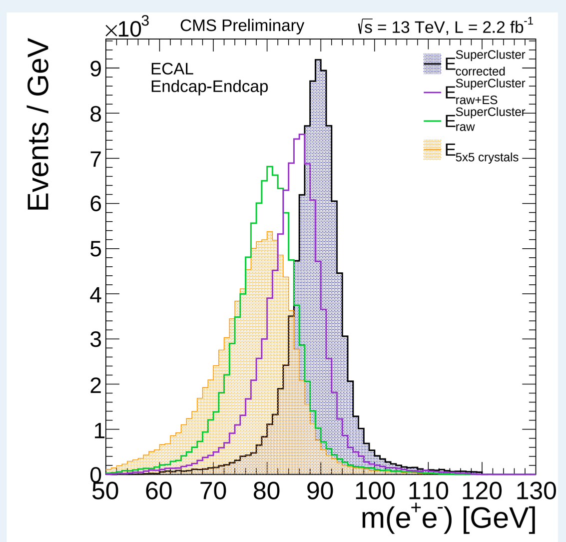




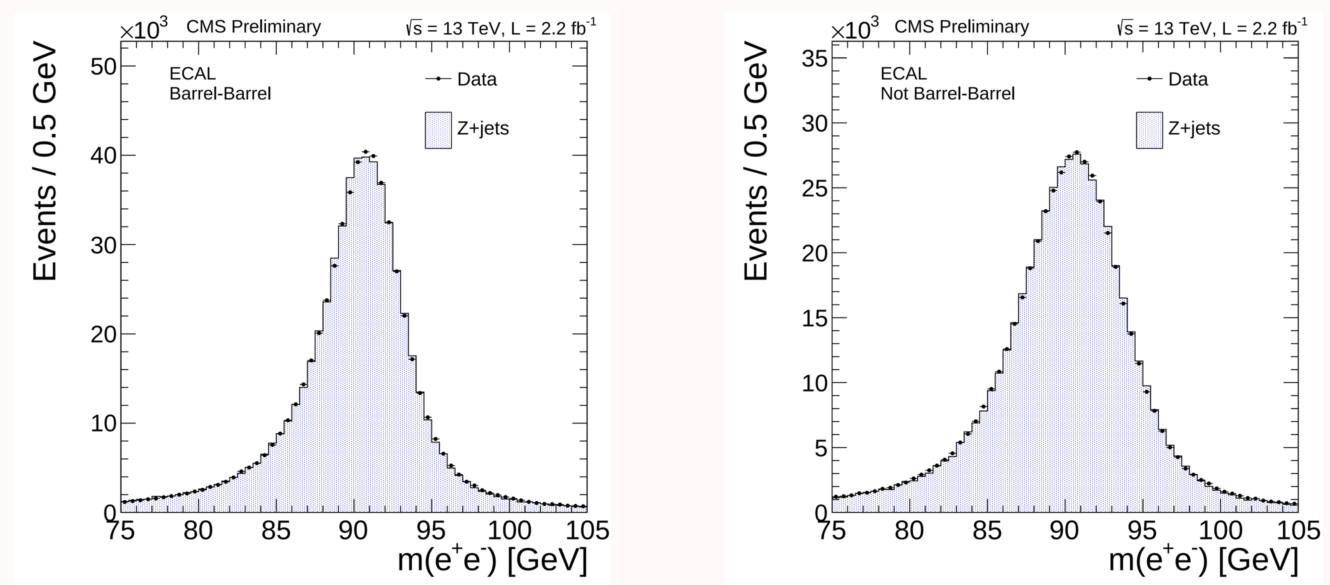
Energy Calibration

- **Global scale G**:
  ADC to GeV scale factor is determined separately for ECAL barrel and endcap with $Z \to ee$ events, such that the reconstructed mass in data matches that in MC simulation.
- **Cluster energy correction $F_{e,\gamma}$**:
  Cluster energy correction is applied to correct energy containment effect.
  $F_{e,\gamma}$ is computed using a multivariate regression algorithm with the pseudo-rapidity, ϕ and cluster shape variables of photons as input.





13 TeV Data



Invariant mass distribution of $Z \to e^+e^-$ events from 13 TeV collision data shows good agreement with MC simulation. The electron energy is estimated using ECAL-only information. Dedicated supercluster corrections are applied.

References

[1] "Performance of electron reconstruction and selection with the CMS detector in proton-proton collisions at $\sqrt{s} = 8$ TeV", JINST 10 (2015) P06005, CMS-EGM-13-001, CERN-PH-EP-2015-004

[2] "Energy calibration and resolution of the CMS electromagnetic calorimeter in pp collisions at $\sqrt{s} = 7$ TeV", JINST 8 (2013) P09009, CMS-EGM-11-001, CERN-PH-EP-2013-097

[3] "Pulse amplitude reconstruction in the CMS ECAL using the weights method" - P. Paganini, I. Van Vulpen CMS-NOTE-2004-025