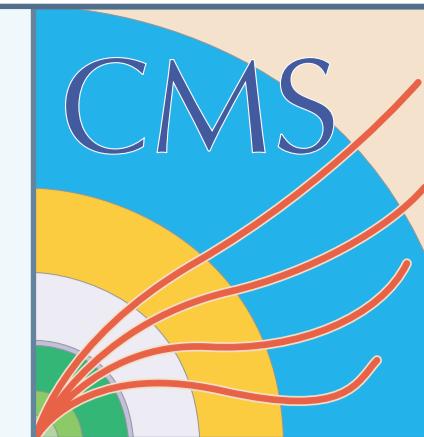


# Performance of the CMS Electromagnetic Calorimeter in LHC Run II



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on behalf of the CMS Collaboration



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5<sup>th</sup> – 10<sup>th</sup> August, Toronto (Canada)

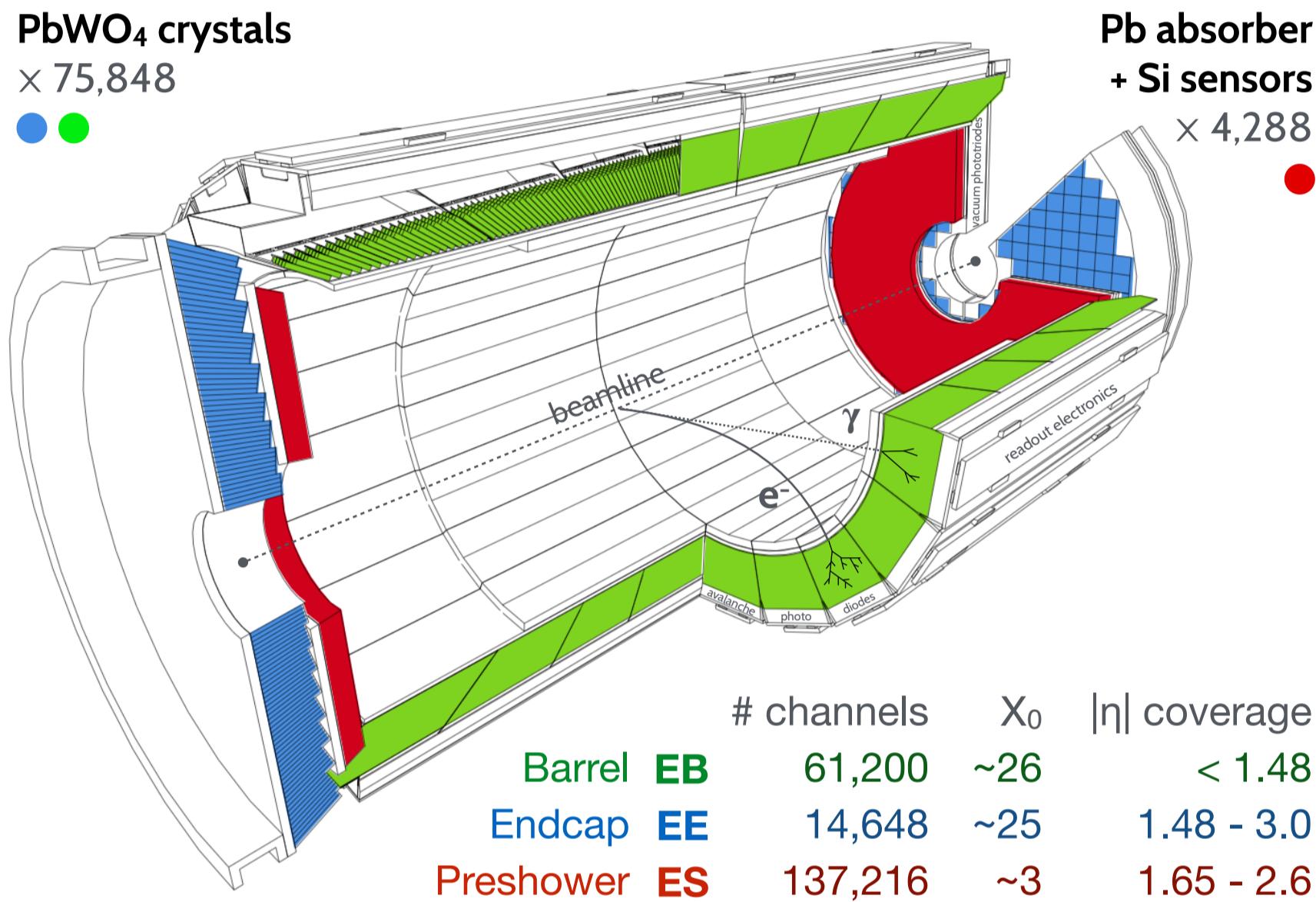
## 1. Key design considerations

Measures energy of electromagnetically interacting particles: scintillation  
particle → PbWO<sub>4</sub> crystal → light → APD/VPT → readout electronics

To perform well in the harsh LHC environment ECAL was designed to be:  

- homogeneous: high energy resolution, compact, mechanically simple;
- hermetic: minimum dead space, reliable measurement of missing  $E_T$ ;
- fine-grain: 22×22 mm<sup>2</sup> crystals; [360-fold in  $\phi$ , 2x85-fold in  $\eta$ ]
- responsive: 10 ns scintillation decay time in PbWO<sub>4</sub>.

## 2. Structure of the CMS ECAL



Crystal transparency degrades with absorbed radiation dose  
↳ each crystal continuously monitored with a laser system for calibrations

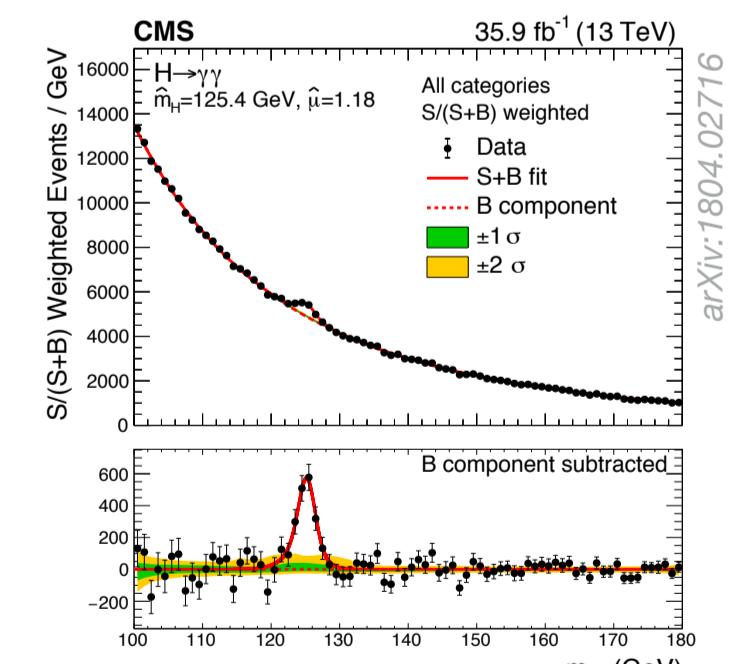
Scintillation yield of PbWO<sub>4</sub> and gains of APDs sensitive to temperature.  
↳ temperature maintained by water cooling with 0.02 °C precision

## 3. Role in CMS physics analyses

Energy measurements by ECAL are crucial for physics reach of CMS.

Precise  $m(H)$  measurement in  $H \rightarrow 4l$  channel: ( $l = e^\pm, \mu^\pm$ )  

- high  $e^\pm$  energy resolution;
- shower shape analysis thanks to the fine spatial granularity;



Measurement of  $\sigma(H)$  in the  $H \rightarrow \gamma\gamma$  final state:

- high photon-energy resolution ( $\geq 1\%$ );
- precise direction measurement;

## 4. Position reconstruction

Precise position reconstruction essential for matching signals with other detectors  
+ good  $m_{ee}/\gamma\gamma$  resolution

EB/EE/ES aligned wrt Silicon Tracker:  

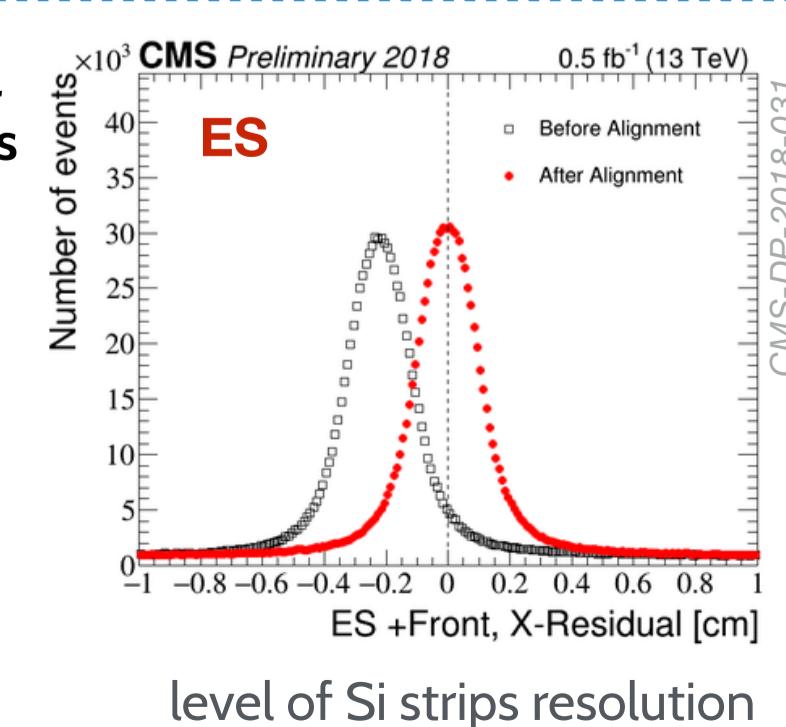
- minimising angular distance between extrapolated track and cluster position ( $\Delta\varphi, \Delta\eta$ )

$$\Delta\varphi$$

$$EB \quad 2.4 \times 10^{-3}$$

$$EE \quad 5.3 \times 10^{-3}$$

$$\Delta\eta$$



level of Si strips resolution

## 5. Energy reconstruction

Energy of a particle reconstructed from a cluster of multiple channels ( $i$ ) to account for spread by the magnetic field + interaction with Silicon Tracker and dead material:

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

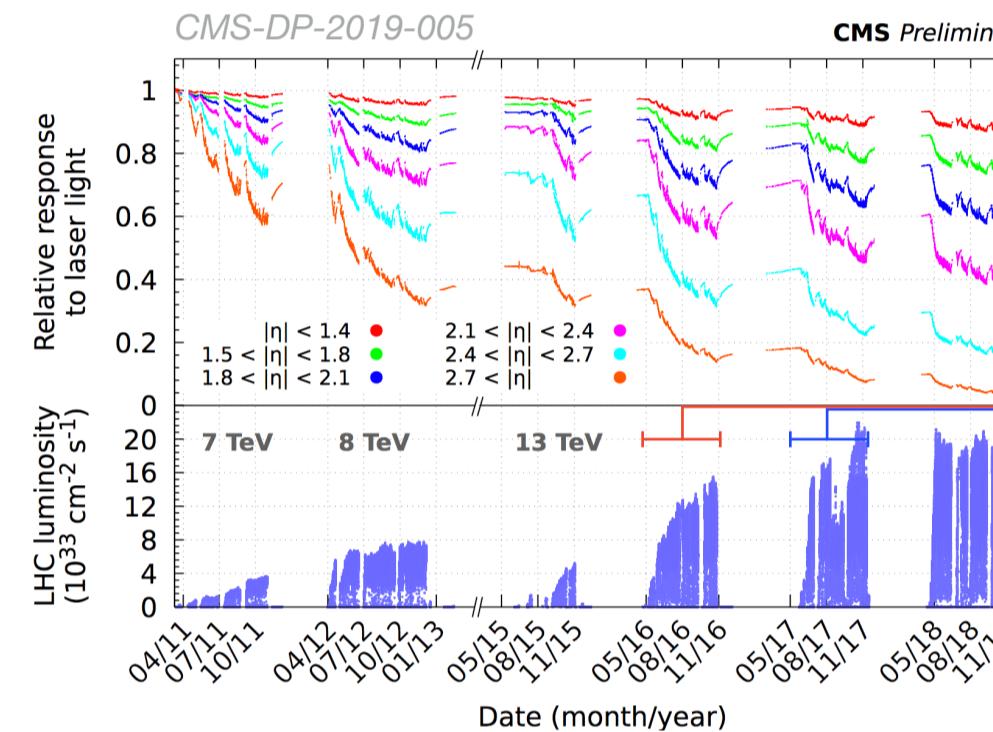
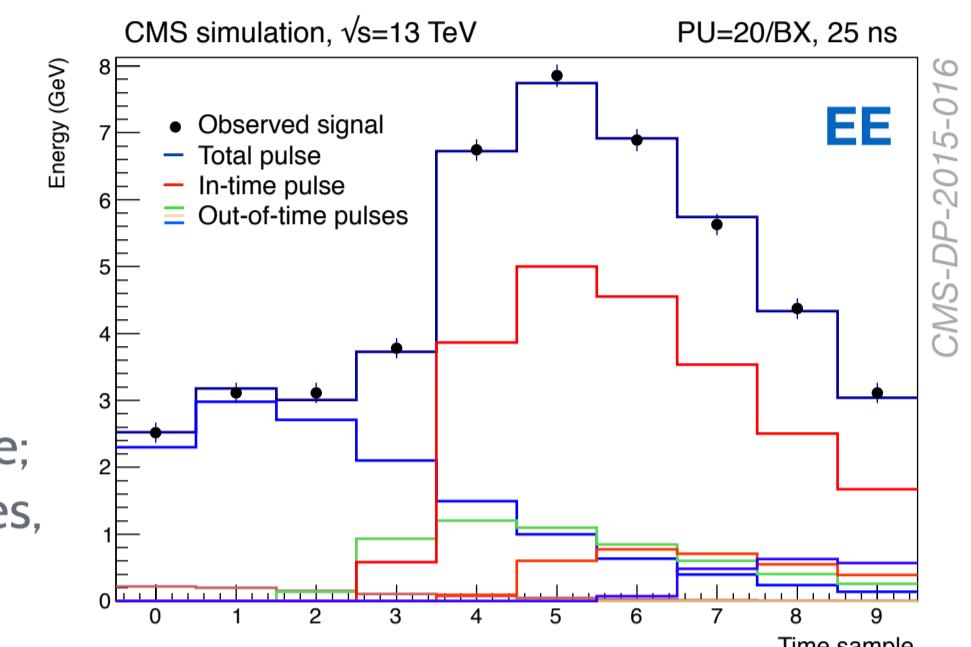
- $A_i$  – signal amplitude;  $C_i$  – intercalibration coefficient;
- $S_i$  – correction for response time variations;
- $G$  – ADC > GeV global scale;  $F_{e/\gamma}$  – cluster correction;

Signal amplitude affected by large pile-up (40+)  
↳ 10 consecutive samples used in reconstruction

Multi-fit performed to estimate 1 in-time and  $\leq 9$  out-of-time signal amplitudes ( $A_i$ )

$$\chi^2 = \sum_{i=1}^N \frac{(\sum_{j=1}^M A_j p_{ij} - S_i)^2}{\sigma_{S_i}^2}$$

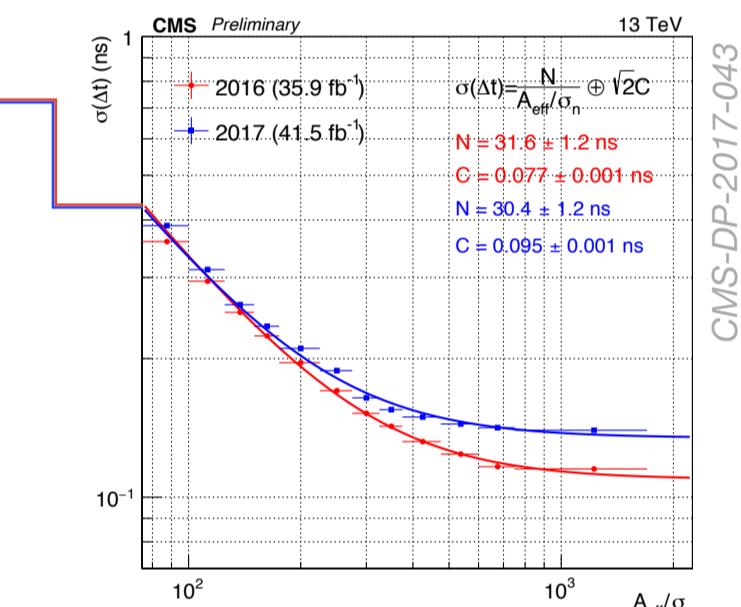
- $p_{ij}$  – pulse height;
- $S_i$  – electronic noise;
- sum over  $N$  samples,  $M$  bunch crossings.



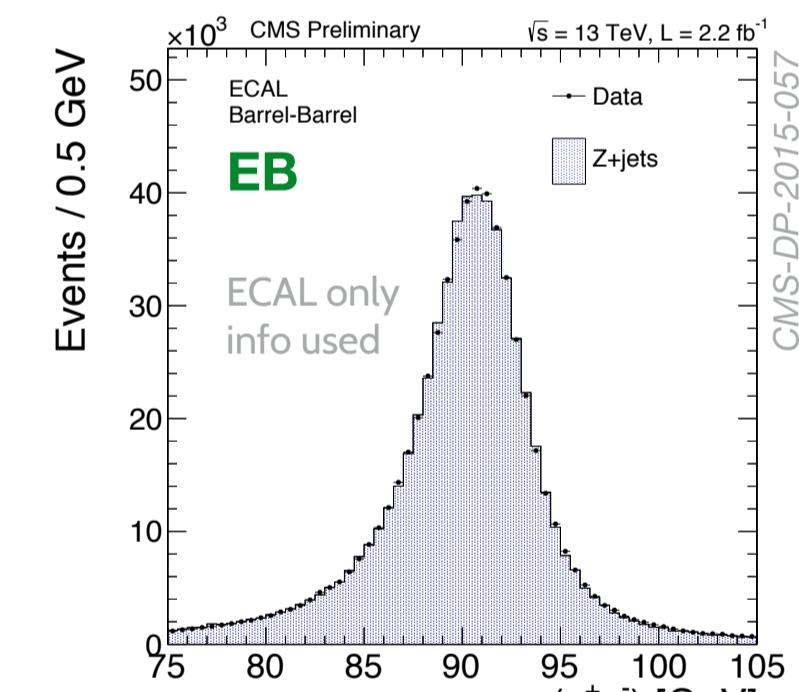
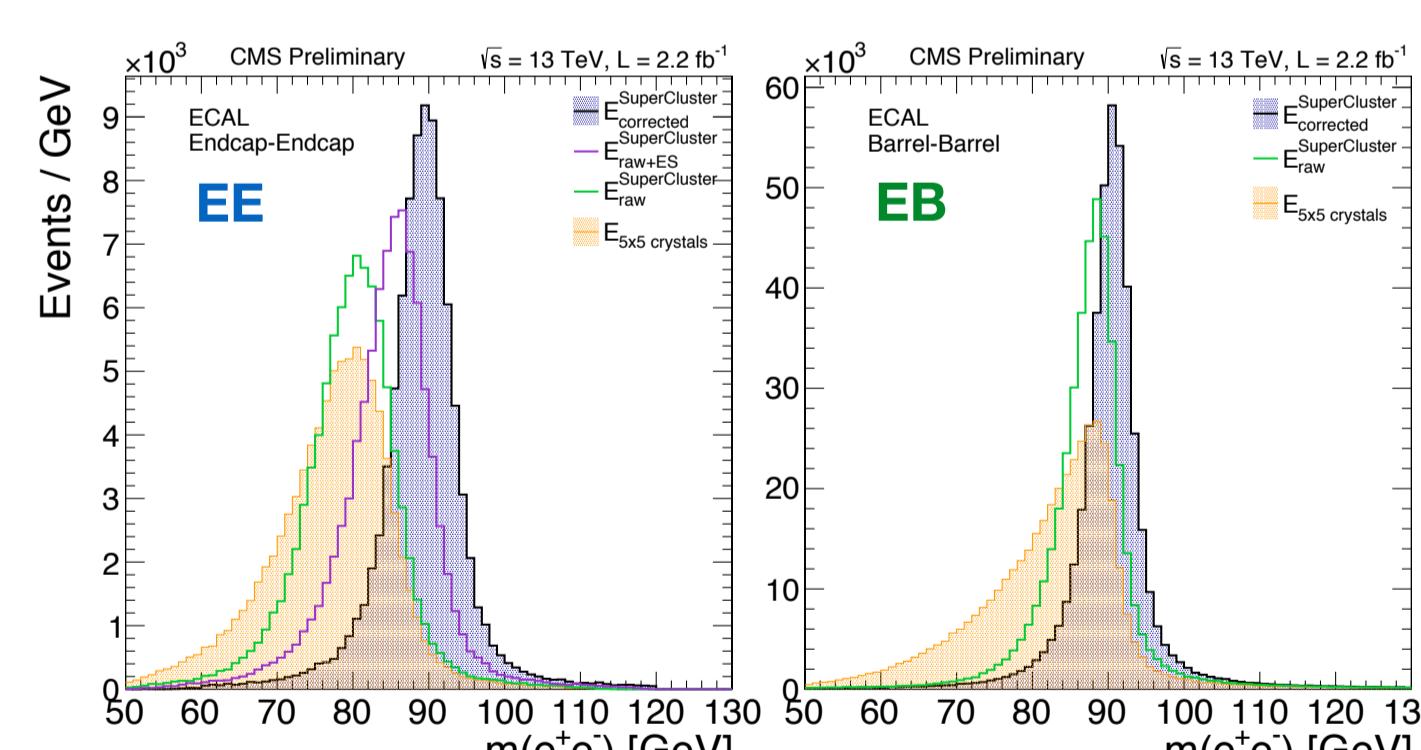
Timing conditions updated after each shift of 200ps → negligible impact on reconstruction

Timing stability of ~1ns required to maintain high energy resolution by rejecting noise, pile-up, etc.  

- degrades with absorbed radiation dose
- mildly recovers when not irradiated



Cluster corrections ( $F_{e/\gamma}$ ) determined using multivariate approach, tuned on MC simulations + Superclusters (SC) to recover bremsstrahlung radiation + Preshower energy (in forward region)



## 6. Energy resolution

Relative energy resolution of electrons from  $Z \rightarrow ee$  decays of two types:

- golden:  $E_{3x3} / E_{SC} \geq 0.94$
- bremsstrahlung:  $E_{3x3} / E_{SC} < 0.94$

Resolution significantly improved after the dedicated calibration using the full 2017 dataset

