Performance of the CMS Electromagnetic Calorimeter in the LHC Run II

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on behalf of the **CMS Collaboration**

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1. Key design considerations

Measures energy of electromagnetically interacting particles: scintillation

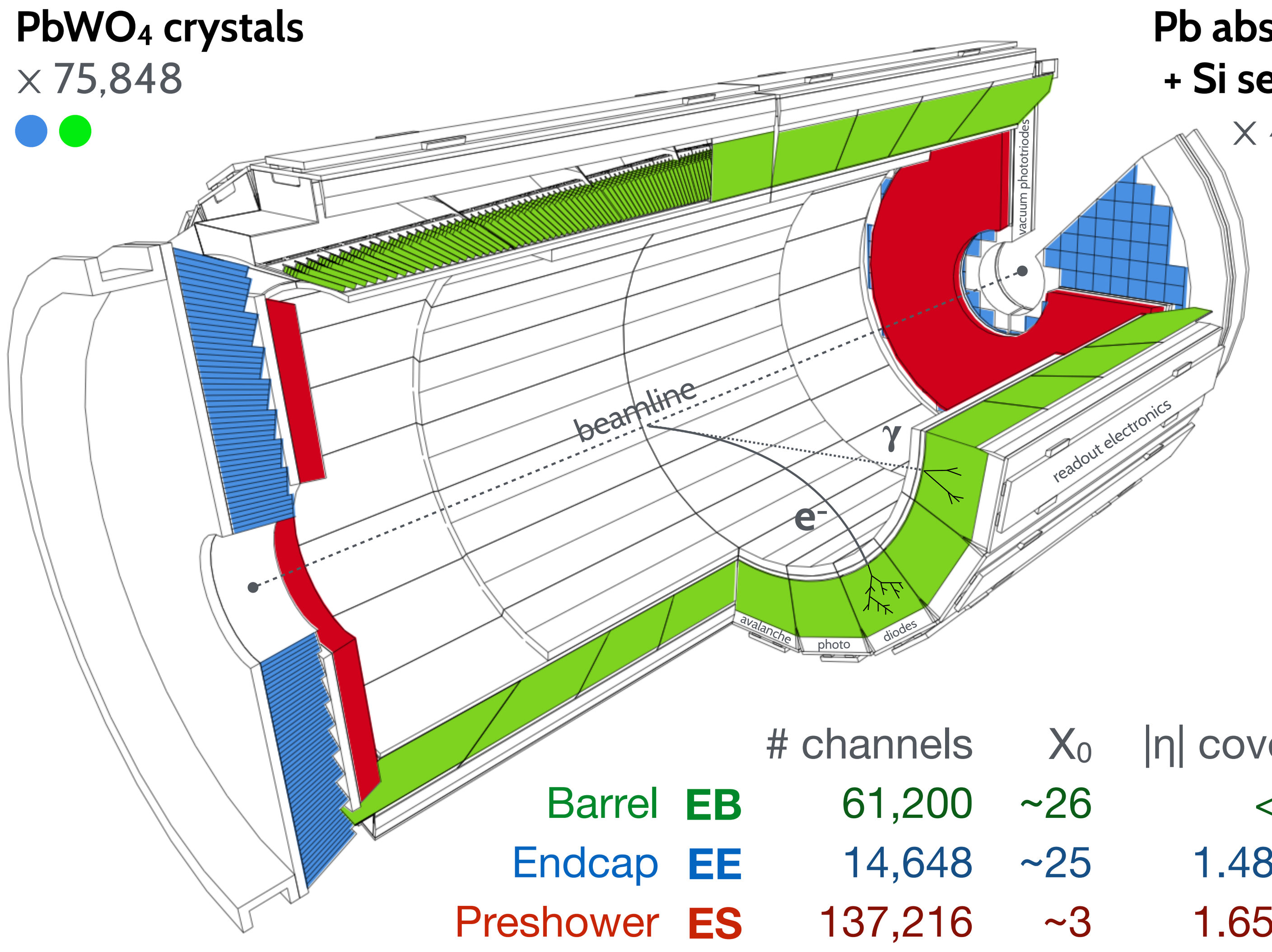
particle → $PbWO_4$ crystal ⇢ (light) APD/VPT → readout electronics

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 mm² crystals; [360-fold in ϕ, 2x85-fold in η]
- **responsive:** 10 ns scintillation decay time in $PbWO_4$.

2. Structure of the CMS ECAL

$PbWO_4$ crystals × 75,848

Pb absorber + Si sensors × 4,288



		# channels	X_0	|η| coverage
Barrel	**EB**	61,200	~26	< 1.48
Endcap	**EE**	14,648	~25	1.48 - 3.0
Preshower	**ES**	137,216	~3	1.65 - 2.6

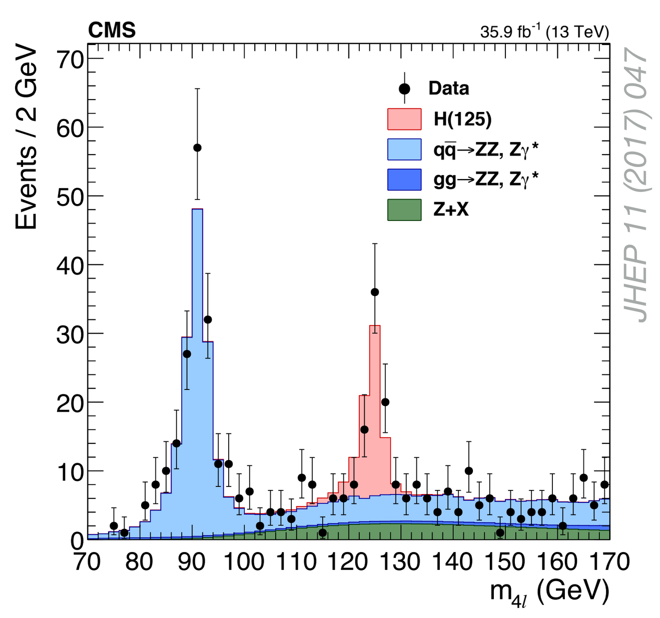
Crystal transparency degrades with absorbed radiation dose
↳ each crystal continuously monitored with a laser system for calibrations

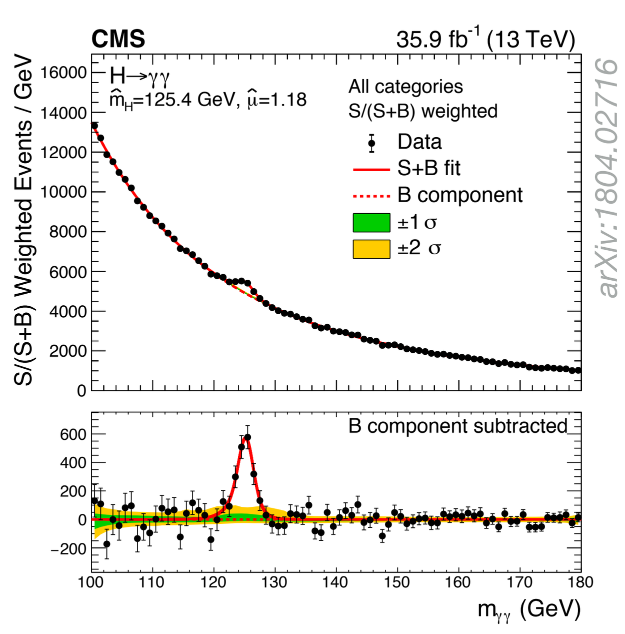
Scintillation yield of $PbWO_4$ and gains of APDs sensitive to temperature.
↳ temperature maintained by water cooling with 0.02 °C precision

3. Role in CMS physics analyses

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

Precise m(*H*) measurement in $H\to 4l$ channel: ($l = e^\pm, \mu^\pm$)
- high $e^\pm$ energy resolution;
- shower shape analysis thanks to the fine spatial granularity;





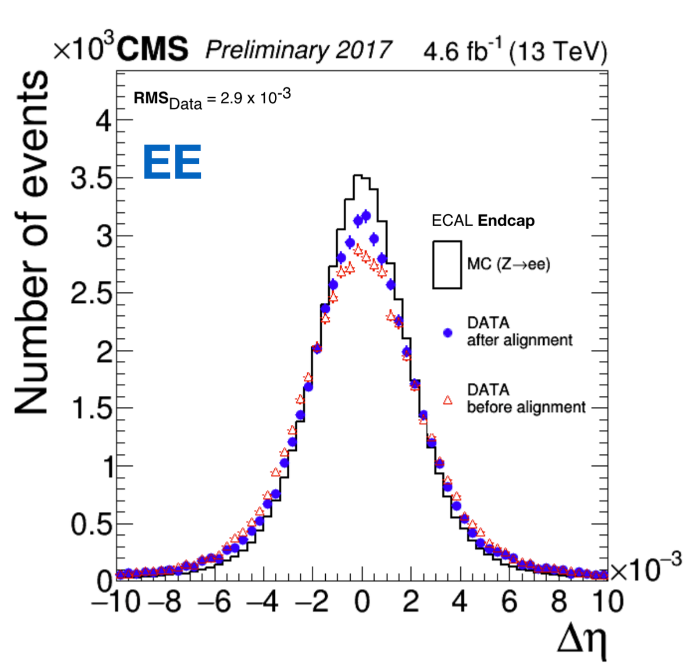
Measurement of σ(*H*) in the $H\to\gamma\gamma$ final state:
- high photon-energy resolution (≥1%);
- precise direction measurement;

4. Position reconstruction

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

Crystals aligned wrt Silicon Tracker:
- minimising angular distance between extrapolated track and cluster position ($\Delta\varphi, \Delta\eta$)

	$\Delta\varphi$	$\Delta\eta$
EB	2.4 × 10^{-3}	1.1 × 10^{-3}
EE	5.3 × 10^{-3}	2.3 × 10^{-3}



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:

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

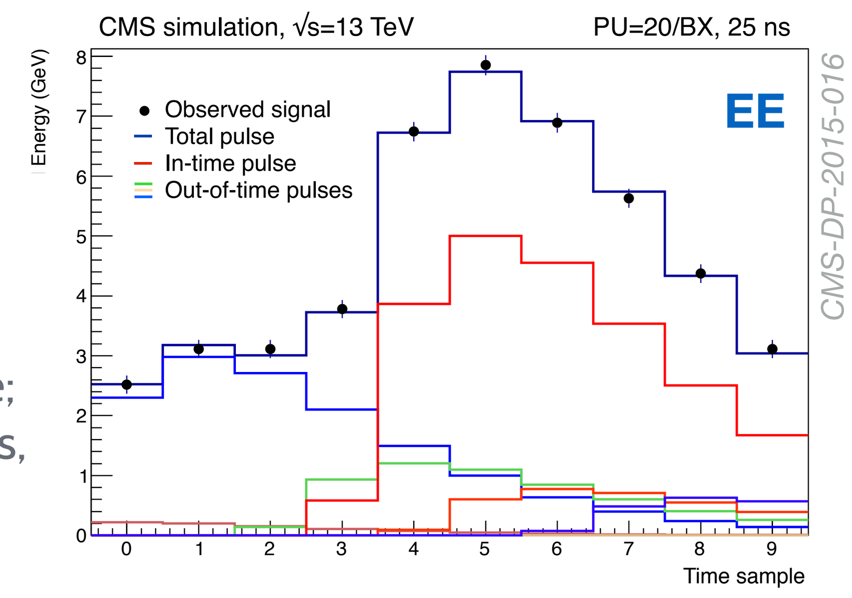
- A_i – signal amplitude; C_i – intercalibration coefficient;
- S_i – correction for response time variations;
- G – ADC > GeV global scale; $F_{e/\gamma}$ – cluster correction;

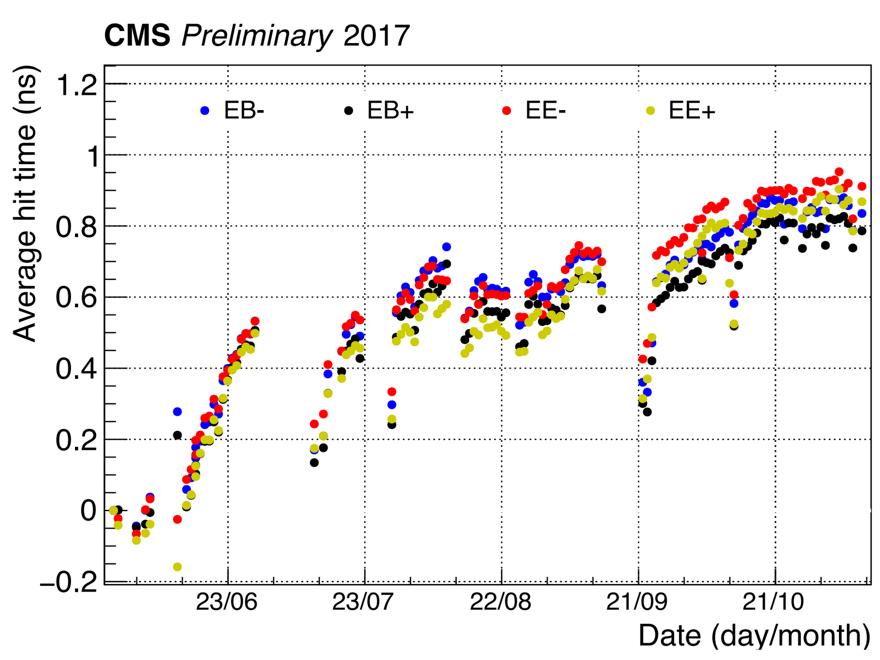
Signal amplitude affected by large pile-up (40+)
↳ **10 consecutive samples used in reconstruction**

Multi-fit performed to estimate 1 in-time and ≤9 out-of-time signal amplitudes (A_j)

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

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

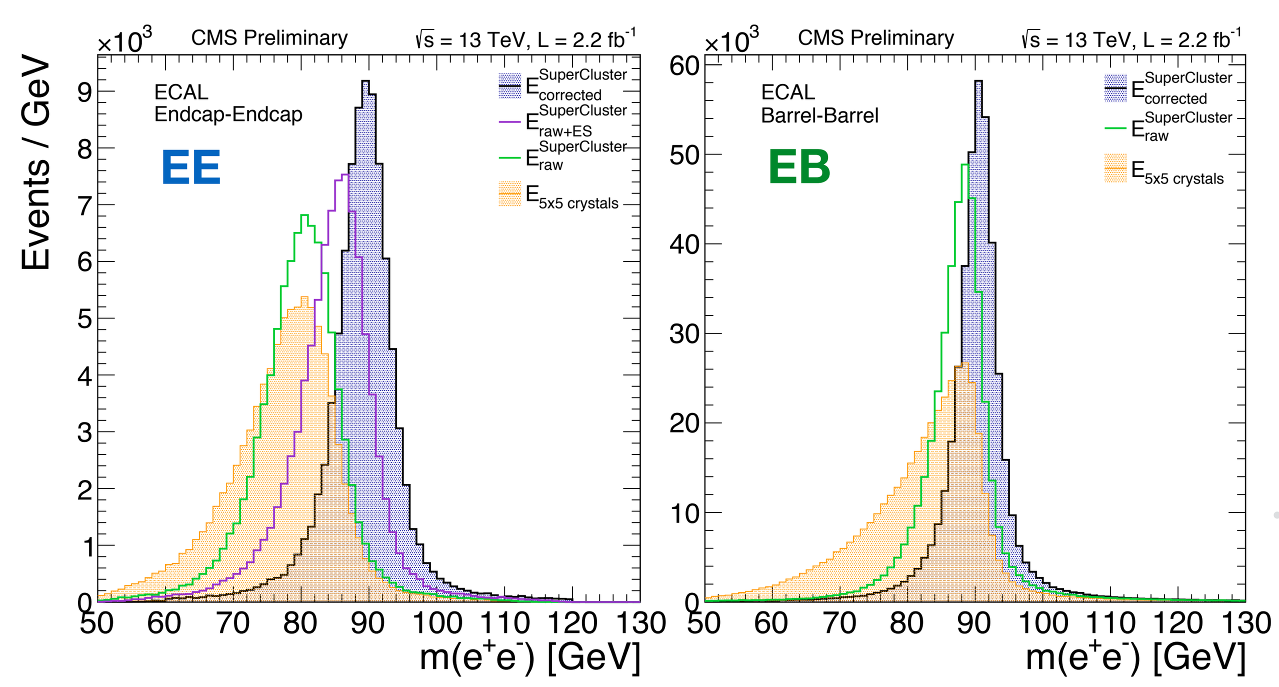


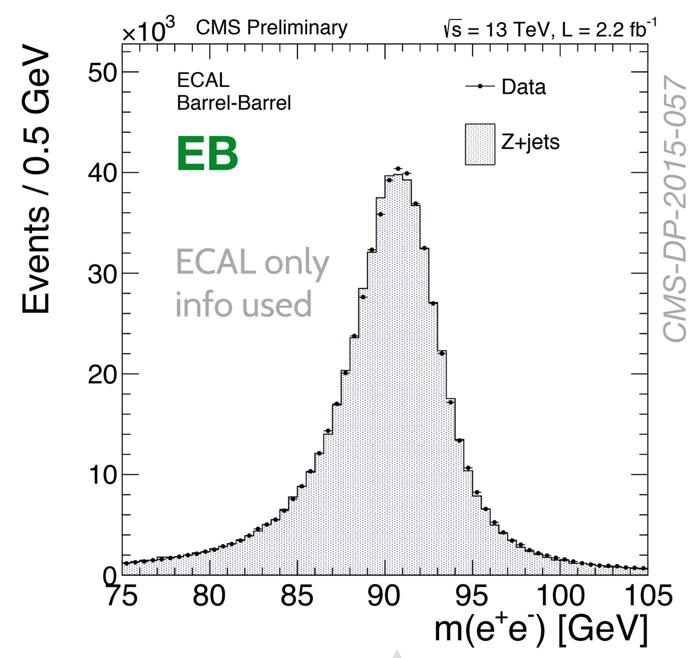


Timing stability of ~1ns required to maintain high energy resolution by rejecting noise, pile-up, etc.
- degrades with absorbed radiation dose
- mildly recovers when not irradiated

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

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





Data
MC
✓

See more in the poster by Tanvi Wamorkar

6. Energy resolution

Relative energy resolution of electrons from $Z\to ee$ decays of two types:
- golden: E_{3x3} / E_{SC} ≥ 0.94
- bremsstrahlung: E_{3x3} / E_{SC} < 0.94

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