Performance of the CMS electromagnetic calorimeter during the LHC Run II and its role in precision physics measurements

Marco Cipriani (on behalf of the CMS collaboration)
Sapienza Università di Roma – INFN Roma 1

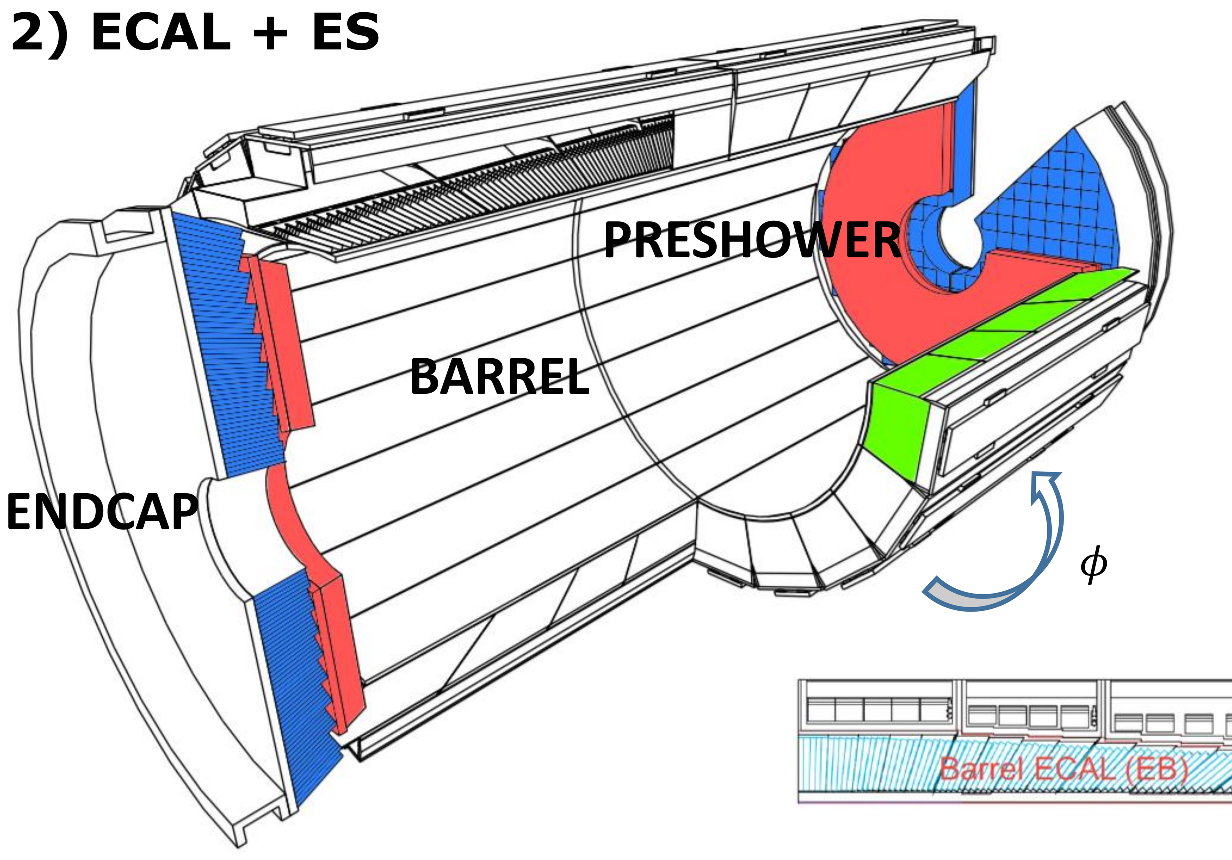
LHCP2018 Bologna, 4 – 9 June
email: marco.cipriani@cern.ch

1) Introduction

Many physics analyses using the Compact Muon Solenoid (CMS) detector at the LHC require **accurate, high resolution electron and photon energy measurements.** Particularly important are decays of the Higgs boson resulting in electromagnetic particles in the final state, as well as searches for high mass resonances decaying to energetic photons or electrons.
CMS features a **homogeneous electromagnetic calorimeter (ECAL)** comprising 61200 crystals of **lead tungstate ($PbWO_4$)** in the central Barrel (EB) closed by 7324 crystals in each of the two Endcaps (EE). A preshower detector (ES), based on lead absorbers equipped with silicon strip sensors, is placed in front of the Endcap crystals. $PbWO_4$ is characterized by the following properties:

- ✓ **fast decay scintillation light** (25 ns)
- ✓ **short radiation length** (X_0 = 0.89 cm, ECAL provides about 25 X_0 thickness)
- ✓ **small Moliere radius** (2.2 cm)

2) ECAL + ES

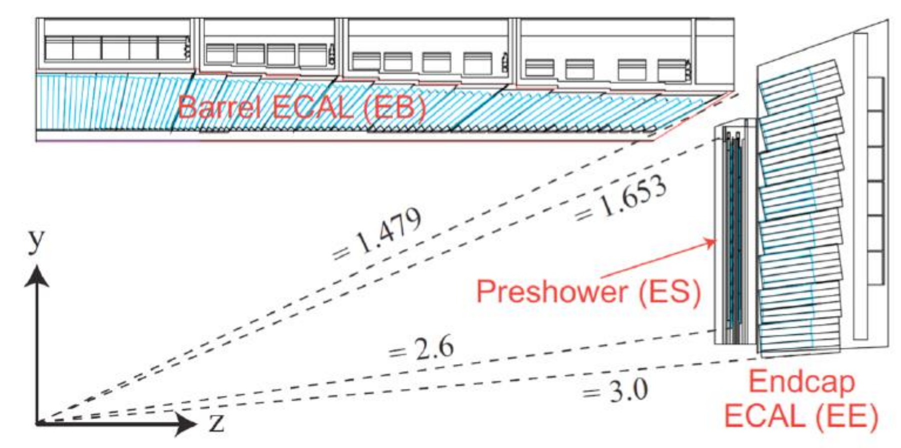


BARREL (EB):
36 supermodules (SM), 4 modules for each
$|\eta| < 1.48$

ENDCAP (EE):
4 half disk Dees, 2 for each Endcap
$1.48 < |\eta| < 3.0$

PRESHOWER (ES):
4 Dees, each made of 2 Lead/Si planes
$1.65 < |\eta| < 2.6$

EB and EE crystals are arranged pointing slightly off the interaction vertex (≈3°), to avoid gaps

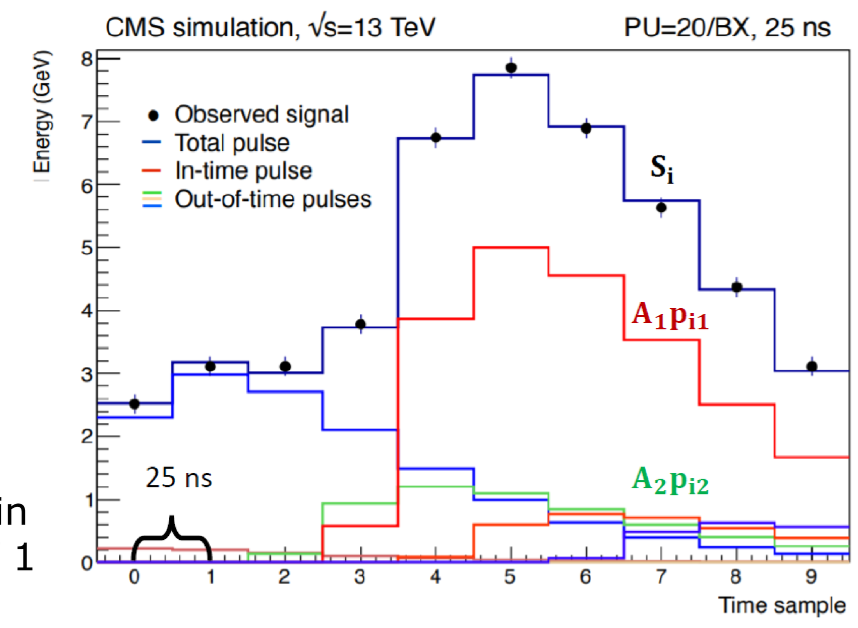


3) Electron and photon reconstruction

Electromagnetic particles are identified as **clusters of energy in ECAL crystals**. Basic clusters are **extended in ϕ to form superclusters** and recover additional energy deposits produced by electron bremsstrahlung or photon conversions.
The reconstructed e/γ **energy is the sum over all crystals in a supercluster**

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

- $F_{e,\gamma}$ → cluster corrections
- G → global scale
- $S_i(t)$ → laser monitoring
- C_i → intercalibration
- A_i → pulse amplitude

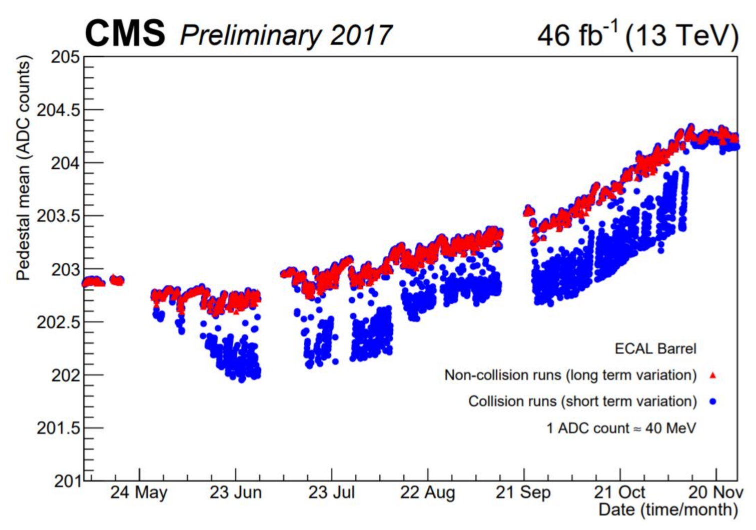


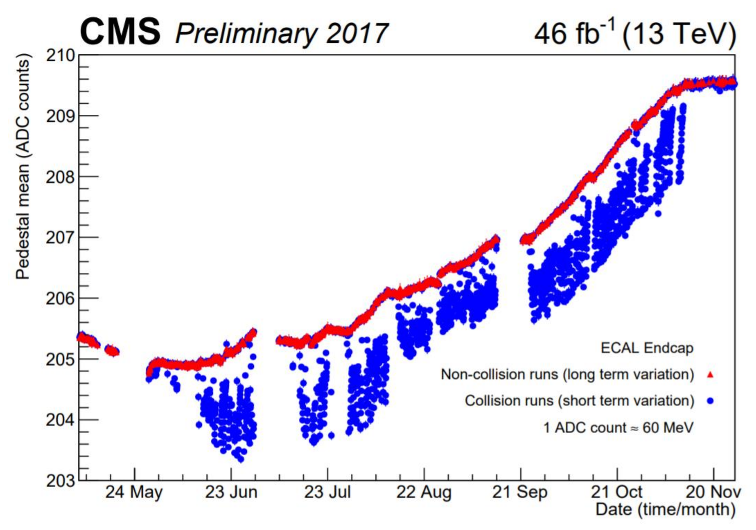
Each observed pulse shape is digitized in 10 samples and modeled as the sum of 1 in-time and up to 9 out-of-time pulse shapes A_j with the **Multi-fit algorithm**.

The Multi-fit extracts the in-time pulse by minimizing a χ^2. **Pulse templates p_j have same shape but 25 ns time shift.**
Baseline and noise covariance matrix σ_{S_i} is measured from dedicated pedestal runs

$$\chi^2 = \sum_{i=1}^{10} \frac{\left(\sum_{j=1}^{M} A_j \cdot p_{ij} - S_i\right)^2}{\sigma_{S_i}^2}$$

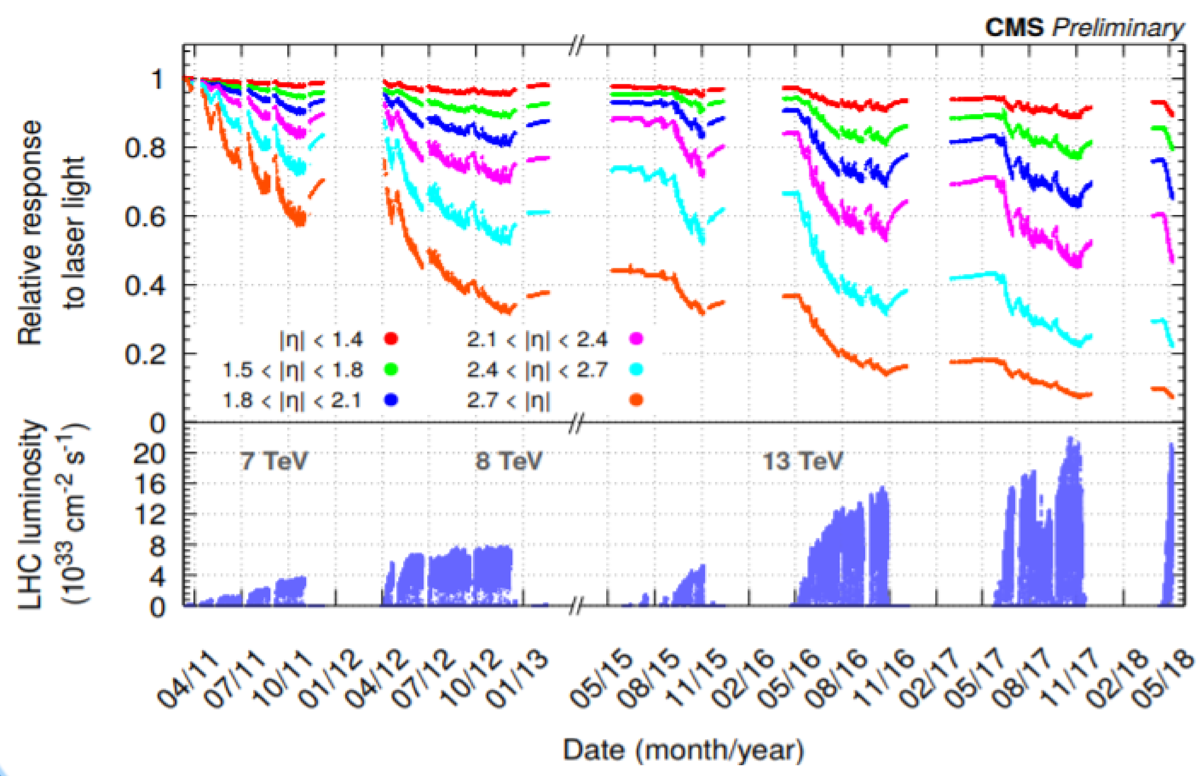
σ_{S_i}: noise covariance matrix

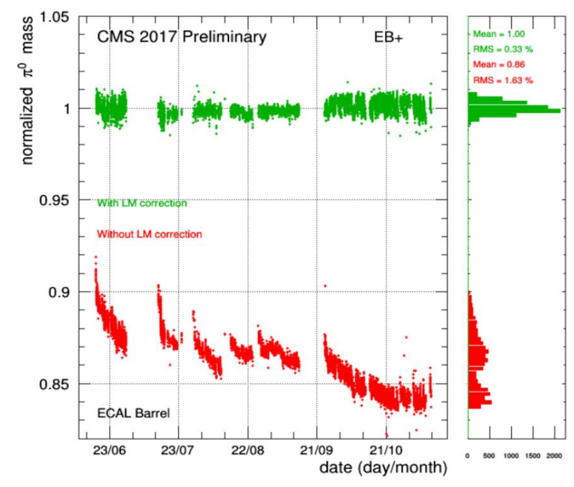




4) Crystals response monitoring and energy scale stability

ECAL crystals undergo a **change in transparency** due to radiation damage. This induces a change in the energy response, which is constantly **monitored and corrected** for by a dedicated laser system





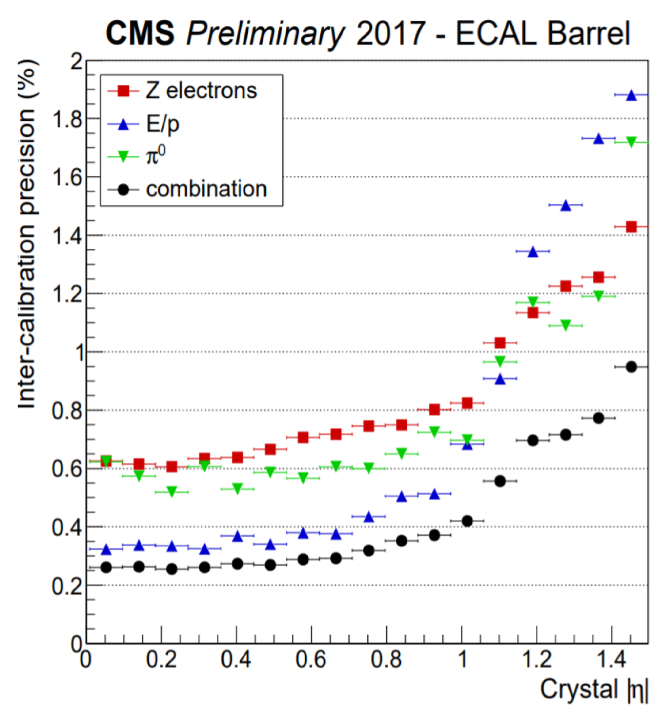
The **stability of the energy scale** is measured from the invariant mass distribution of $\pi^0 \to \gamma\gamma$. Each point is a fit to $\approx 5{\cdot}10^5$ $\gamma\gamma$ pairs collected by a dedicated data stream in ≈5 minutes

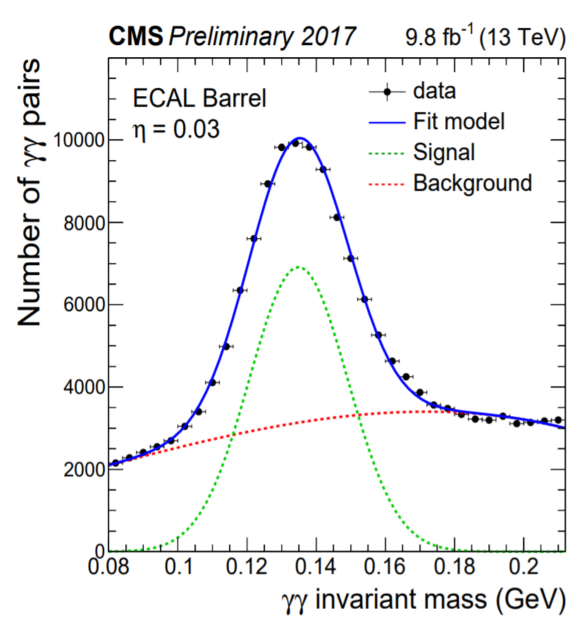
5) Crystals intercalibration and energy resolution

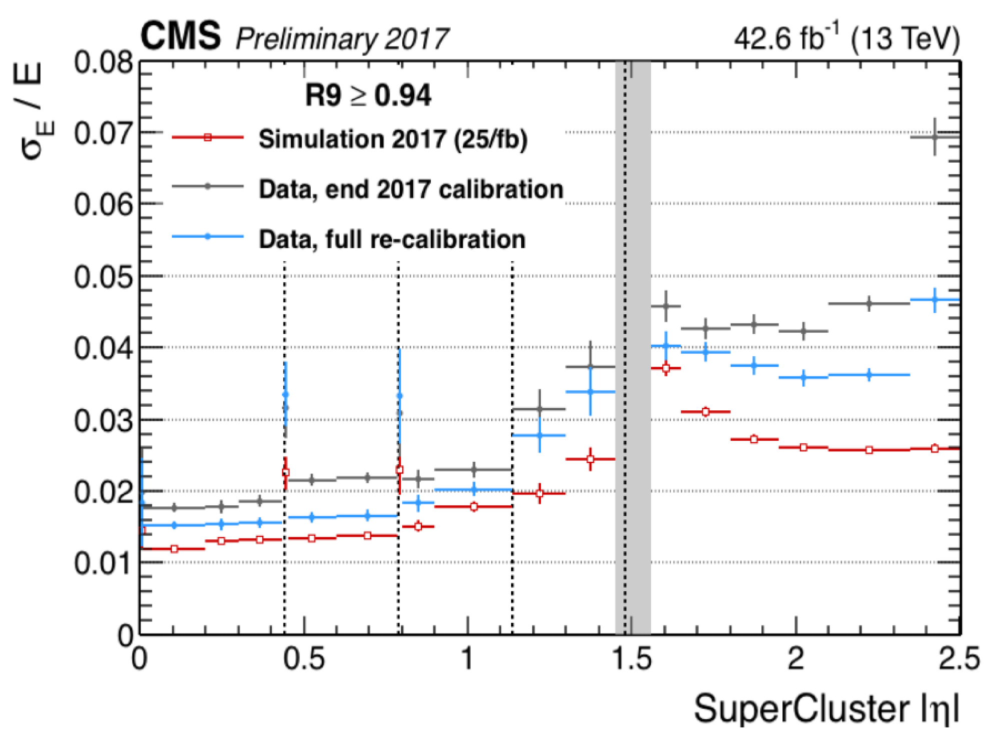
Intercalibration aims at **equalizing energy response variations** among different ECAL crystals, which **affects the constant term in the calorimeter resolution.**

Several methods based on physics processes are used:

- ❖ $\pi^0 \to \gamma\gamma$: peak of π^0 invariant mass distribution equalized
- ❖ **E/p:** comparison of prompt electrons energy E measured with ECAL and their momentum p measured with the tracker detector
- ❖ $Z \to ee$: as for $\pi^0 \to \gamma\gamma$, but based on the Z-boson invariant mass peak







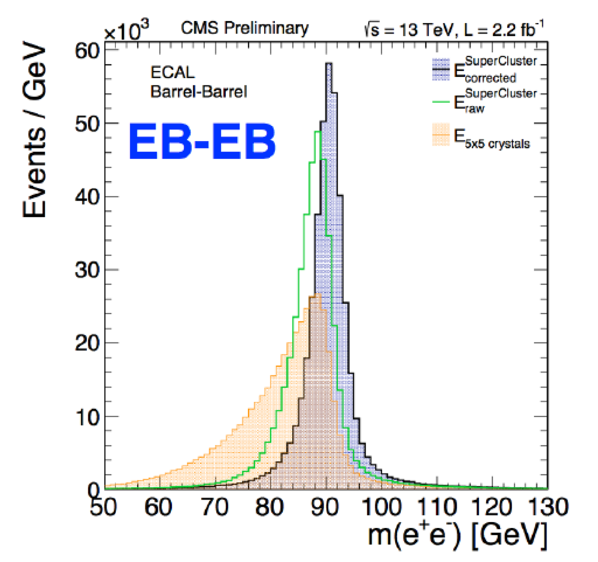
6) Supercluster energy correction and absolute energy scale

Reconstruction based on superclusters (SC) performs better than using simple matrices of 5x5 crystals to identify e/γ objects.

SC energy is corrected with an **MVA trained on MC**.

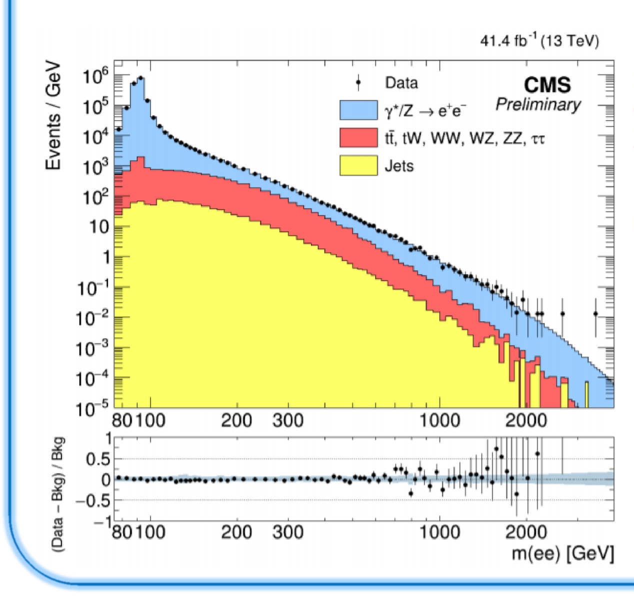
- ❖ crystal coordinates and shower shapes as input
- ❖ trained separately for e/γ to account for differences (conversions, bremsstrahlung)

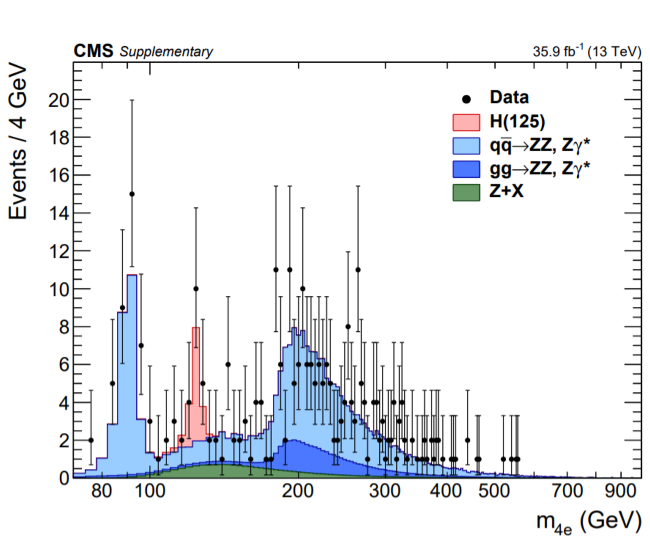
Finally, the absolute energy scale is set to match the Z mass of simulated events

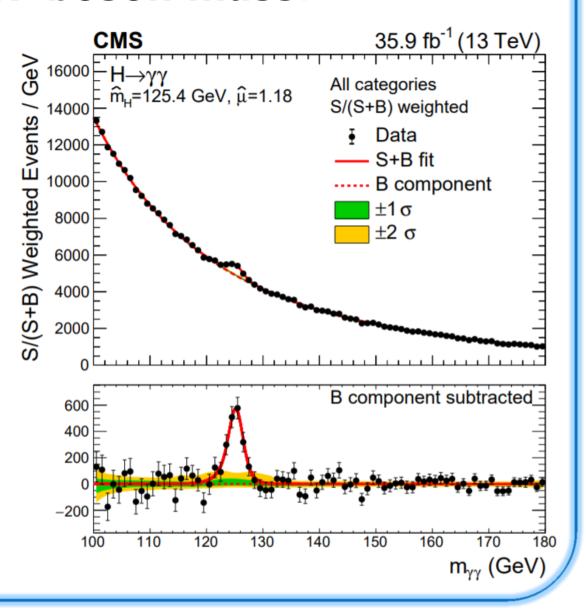


7) Impact on physics analyses

ECAL excellent resolution was paramount for the **Higgs boson discovery** during Run I. The same extraordinary performance is fundamental to study its properties and to probe the existence of **new heavy resonances** decaying into photons or electrons.
ECAL will also contribute to the precision measurement of the **W-boson mass**.







References:
[0] CMS Collaboration, "The CMS experiment at the CERN LHC", JINST 3, S08004 (2008)
[1] CMS Collaboration, "CMS: The electromagnetic calorimeter. Technical design report", CERN-LHCC-97-33, CMS-TDR-4
[2] CMS twiki: https://twiki.cern.ch/twiki/bin/view/CMSPublic/EcalDPGResults