CMS Electromagnetic Calorimeter

Design and Upgrade for HLLHC

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January 3, 2020

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Table of contents

Introduction

The LHC

Figure 1: inserire didascalia

CMS

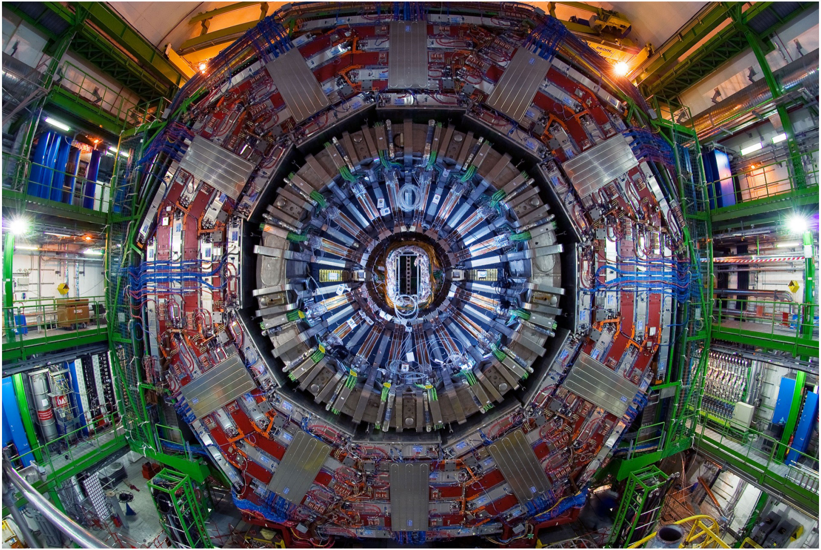


Figure 2: CMS experiment section view

CMS

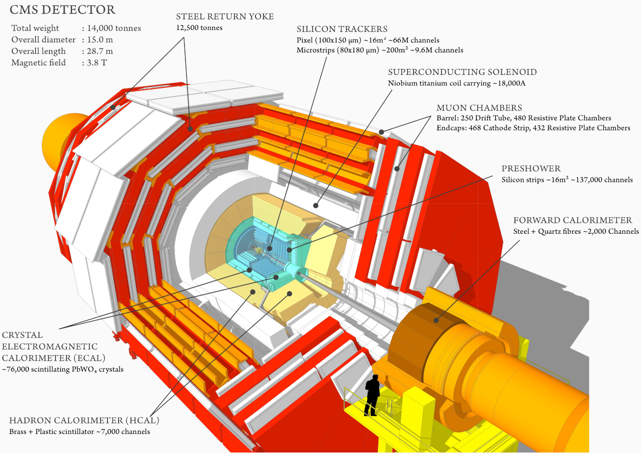


Figure 3: CMS experiment scheme

EM Calorimeter

EM Calorimeter

Barrel ECAL

- covering $|\eta| \leq 1.479$ range
- 61200 crystals organized in 5×5 modules and 36 supermodules
- 360-fold in ϕ (2×85)-fold in η
- crystal lenght: 230 mm corresponding to 25.8 X_0

Endcap ECAL

- $1.479 \leq |\eta| \leq 3.0$
- Each endcap divided in 2 "Dees", each with 3662 crystals organized in 5×5 supercrystals
- crystal lenght: 220 mm corresponding to 24.7 X_0

EM Calorimeter Design

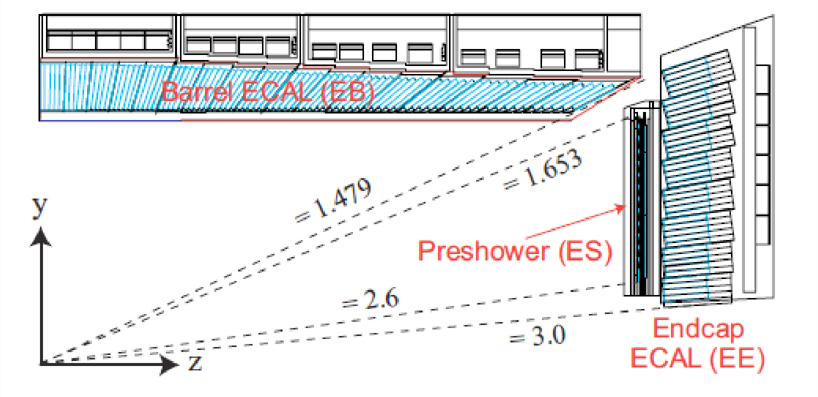


Figure 4: Emcal Scheme

Barrel EM Calorimeter

non mi piace molto questa foto, vedi se ne trovi una migliore...

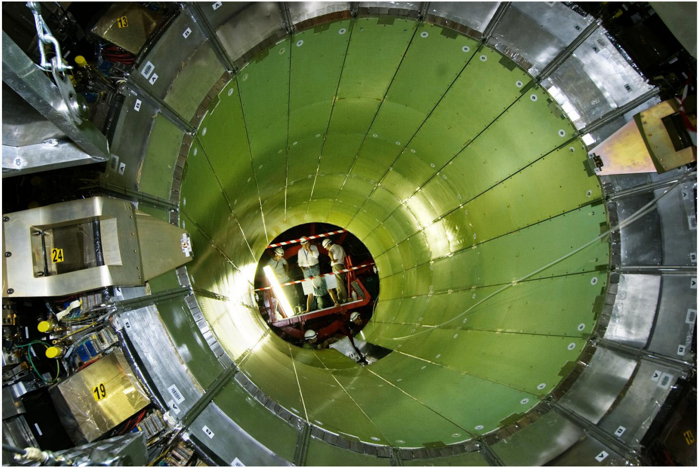


Figure 5: inserire didascalia

Endcap EM Calorimeter

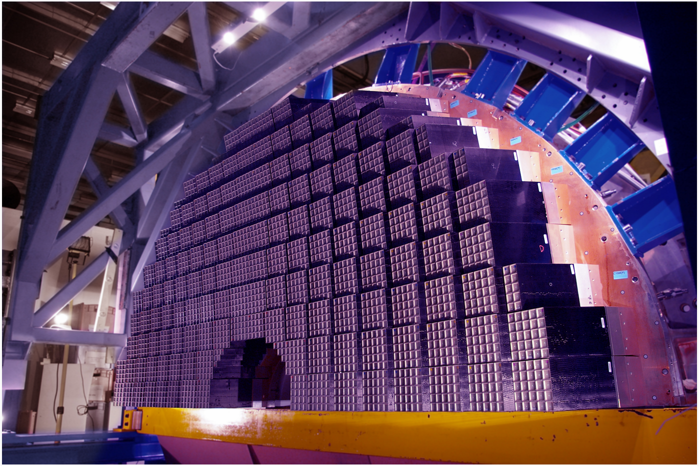
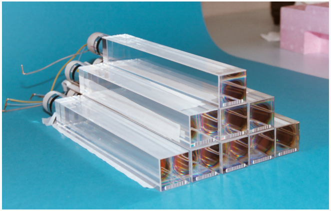


Figure 6: One of the four "Dees" of the endcap EmCal

Lead Tungstate ($PbWO_4$) Crystals



- $\rho = 8.3\,\mathrm{g/cm^3}$
- $X_0 = 0.89\,\mathrm{cm}$
- Moliere Radius $= 2.2\,\mathrm{cm}$
- Light Output: 4.5 ph/MeV
- Green-Blue light, max @ 420 nm
- Polished for internal reflection

High radiation levels throughout the duration of the experiment $\rightarrow$ wavelength dependent loss of light transmission without changes to the scintillation mechanism.

Radiation hardness properties are required: the induced light attenuation length must be always greater than $3\times$ crystal length.

Damage is tracked and corrected by a laser light monitoring system.

Photodetectors

Barrel EMCal

- Reverse structure avalanche photodiodes (APDs)
- Glued to the back of the crystals
- High quantum efficiency ($\sim 75\,\%$) with mean gain of 50

Endcap EMCal

- Vacuum Phototriodes
- Essentially photomultipliers, with a single gain stage
- Specially designed to withstand the $4\,\mathrm{T}$ magnetic field
- $22\,\%$ quantum efficiency with mean gain of 10.2 at $0\,\mathrm{T}$

Pre-shower Detector

Sampling calorimeter with two layers: lead radiators with silicon strip sensors placed in between. Located in the *forward region*, where the angle between couples of photons is more likely to be small, due to the boost of the π_0.

Main purposes:

- principal aim: the identification of neutral pions (from their decay products $\pi_0 \to \gamma\gamma$) within a fiducial region $1.653 < |\eta| < 2.6$
- improve position determination of e and γ due to its finer granularity (silicon strips $p \simeq 2\,\mathrm{mm}$).
- help electron identification against minimum ionizing particles.

Elettronica e Segnale

voglio dire qualcosa di elettronica ed elaborazione del segnale? è necessario?

Energy Resolution

Showers in EMCal are reconstructed by building *clusters* of crystals. Best performance is obtained using a simple 3x3 (or 5x5) sliding window centered in the crystal having the maximum energy deposition.

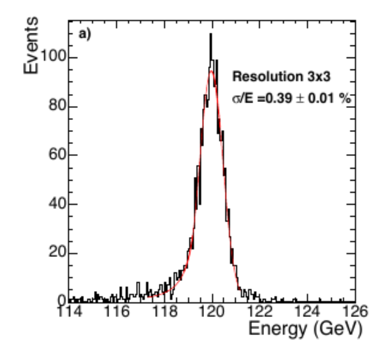


Figure 7: Energy Distribution reconstructed during the test beam (pointed to the centre of the supermodule).

Energy Resolution

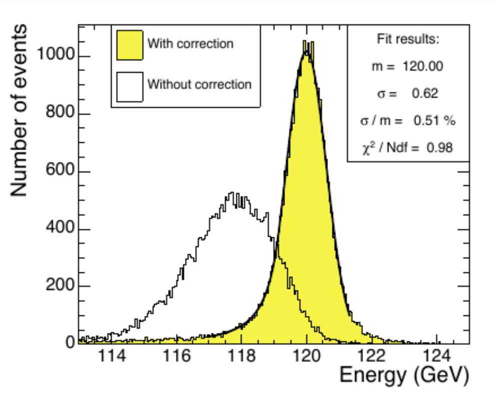


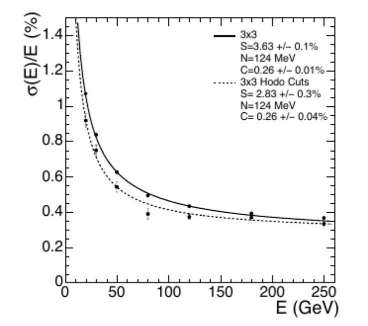
Figure 8: Energy distribution reconstructed during the test beam (pointed to a *corner* of the supermodule). A single correction function, parametrized from the data, was applied to all regions of the supermodule to take into account variations in shower containment.

Energy Resolution

Energy Resolution can be parametrized as a function of energy

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{S}{\sqrt{E}}\right)^2 + \left(\frac{N}{E}\right)^2 + C^2, \qquad (1)$$

- S is the **stochastic** term
- N is the **noise**
- C is a **constant** term



Calibration

It is a *severe technical challenge*. Naturally divided in two parts:

- **Absolute energy scale**
- **Inter-calibration** Needed since single crystals have different scintillation light yield ($\sim 8\%$ RMS)

The final energy measurement is given by

$$E_{e,\gamma} = G \times \mathcal{F} \times \sum_i c_i \times A_i \tag{2}$$

where

- G is a *global absolute scale*
- $\mathcal{F}$ is a *correction function* depending on particle type, position, η, momentum...
- c_i are the *inter-calibration coefficients*
- A_i are the *signal amplitudes* summed over the cluster of crystals

Calibration

Various methods are used to obtain values for the parameters in equation (**??**). These methods include:

- **Testbeam** precalibration.
- **Lab. Measurements** of the crystals light yield, giving a first estimate of the c_i coefficients.
- **Phi independence** Taking advantage of the ϕ symmetry of deposited energy to inter-calibrate crystal rings at constant η.
- **Single electrons** Exploiting single electrons p measurements from the *tracker* to inter-calibrate different crystals in a single module.
- **Z $\rightarrow$ ee** Reconstruction of the ee invariant mass and calibration exploiting the Z mass constraint, studying the distribution of

$$\epsilon^i = \frac{1}{2}\left[\left(\frac{M^i_{\mathrm{inv}}}{M_Z}\right)^2 - 1\right] \tag{3}$$

Phi Independence Method

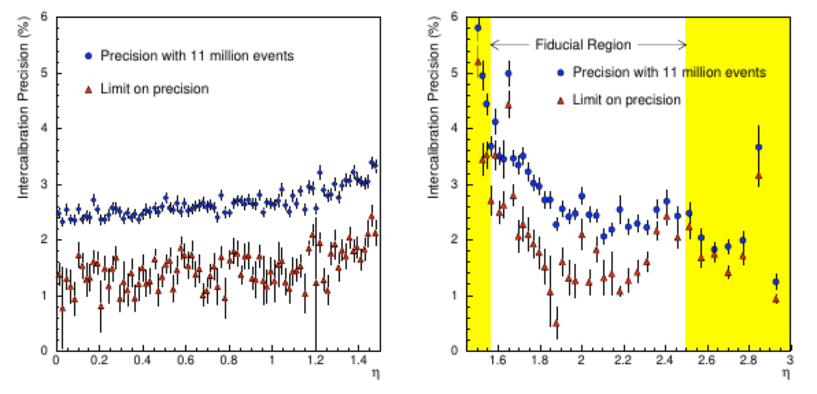
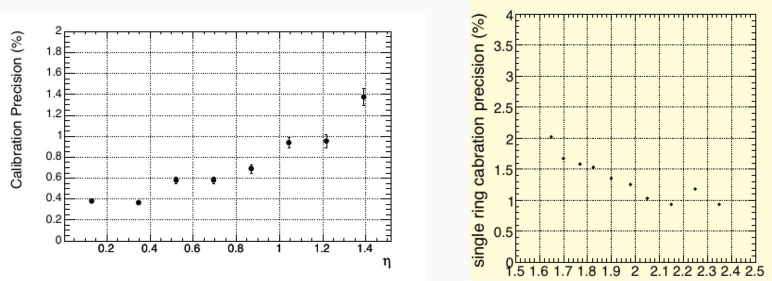


Figure 9: Intercalibration precision as function on η, for barrel and endcap, for the *phi-indipendence* method.

Single Electrons Method



(a) **(b)**

Figure 10: Calibration precision vs η obtained with the single electrons method. (a) barrel case (b) endcap case.

Z → ee Method

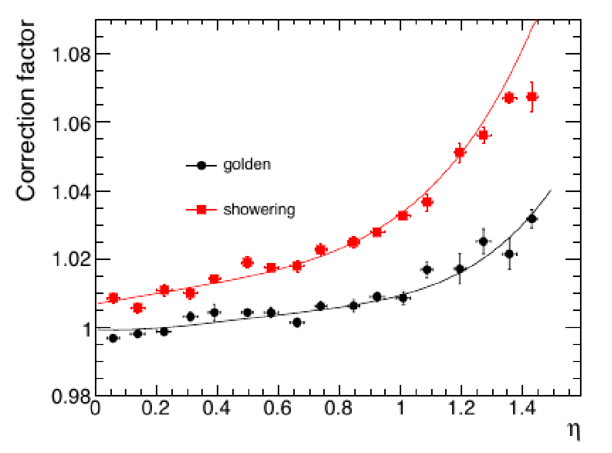
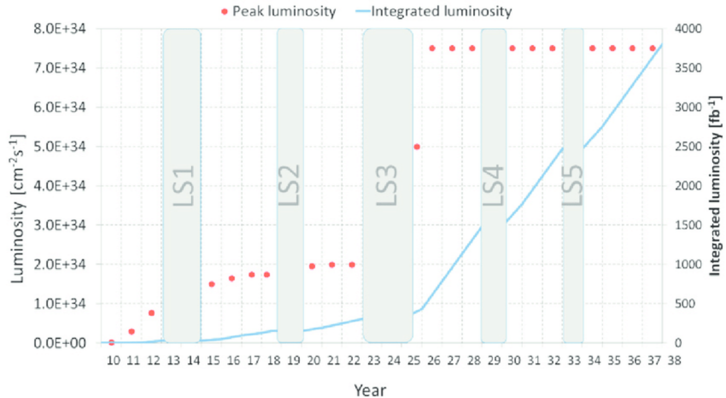


Figure 11: Correction factor $\mathcal{F}$ (**??**) in dependence of η, as extracted with the Zee method. *Golden* comes from a MC simulation, *showering* is obtained from $2\,\mathrm{fb}^{-1}$ of $Z \to ee$ with intercalibration precision at 2%.

HL-LHC Upgrade

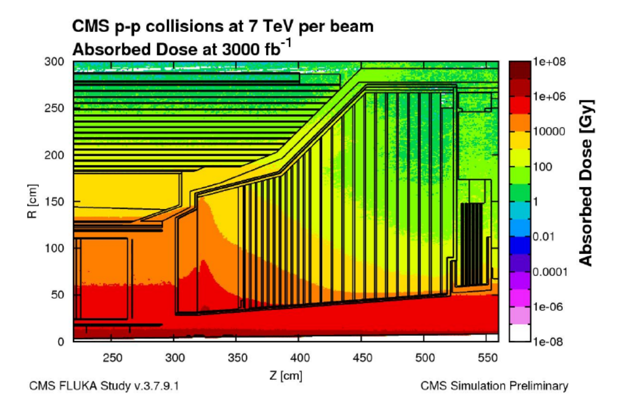
High Luminosity LHC Upgrade



Objective: integrated luminosity 3000 fb^{-1} ($10\times$ design value).

Significative challenges due to *high radiation* and higher *pileup* $\rightarrow$ detector upgrades needed.

Calorimeters Upgrade



Also calorimeters must be upgraded. The *endcap* calorimeters will be entirely replaced.

High Granularity Calorimeter

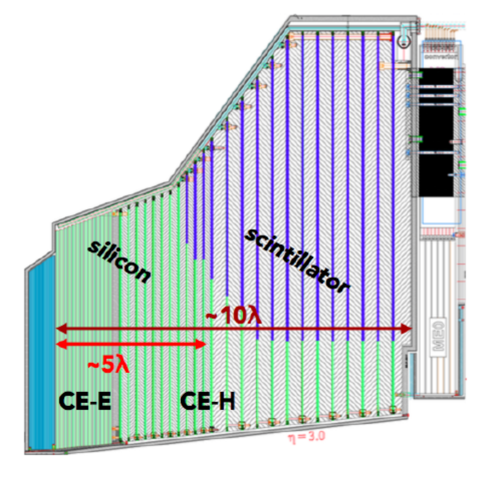


Figure 12: Schematic view of the High Granularity Calorimeter design.

High Granularity Calorimeter

It is a **sampling** calorimeter, consisting of an electromagnetic compartment (CE-E) followed by a hadronic compartment (CE-H).

The ECAL and a large fraction of HCAL will be based on hexagonal silicon sensors of $0.5 - 1\,\mathrm{cm}^2$ cell size, with the remainder of the HCAL based on highly-segmented scintillators with SiPM readout. Absorber layers are made by Cu (EMCal) and Stainless Steel (HCal).

- unprecedented transverse and longitudinal **segmentation** for both ECAL and HCAL compartments.
- **Fine structure** of showers can be measured $\rightarrow$ better pileup rejection and particle identification
- high-precision **timing** capabilities due to silicon sensors
- **5D imaging** calorimeter (x,y,z,t,E) through sophisticated algorithms

Conclusion?????

- one
- two