Evolution studies of the CMS ECAL endcap response and upgrade design options for High-Luminosity LHC

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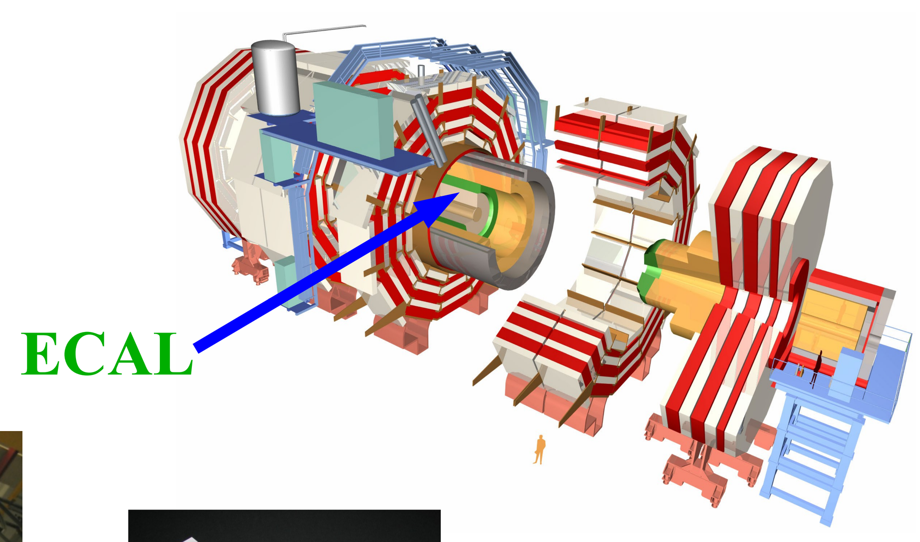
on behalf of the CMS collaboration

Physics motivations

Study of Higgs properties, maintain/improve resolution for H → γγ reconstruction, and electron/jet calibration even in the very forward region

An excellent energy resolution (0.5% constant term), essential for the Higgs boson search in the H → γγ channel



ECAL

Scintillating crystals:
- Radiation hardness → only transparency affected
- Fast scintillation → <100 ns

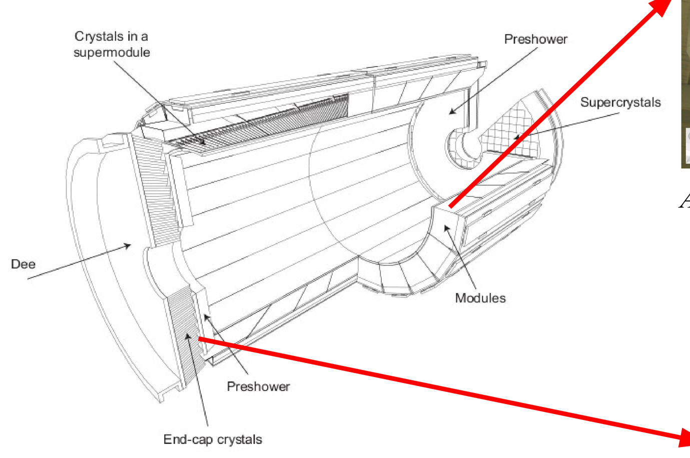
Structure and readout:
- Barrel (EB) → |η|<1.48 → Avalanche Photodiodes (APD)
- Endcap (EE) → 1.48 < |η|< 3.00 → Vacuum Phototriodes (VPT)

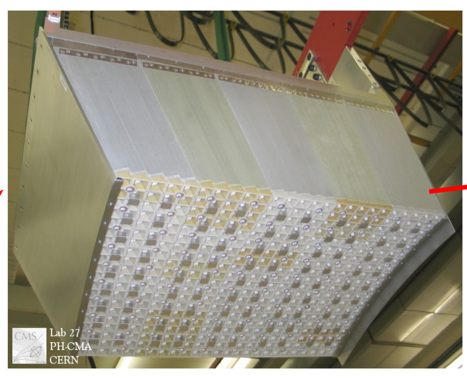
61200 $PbWO_4$ crystals 2.2 x 2.2 x 23 cm³ in EB

2 x 7324 $PbWO_4$ crystals 2.5 x 2.5 x 22 cm³ in EE

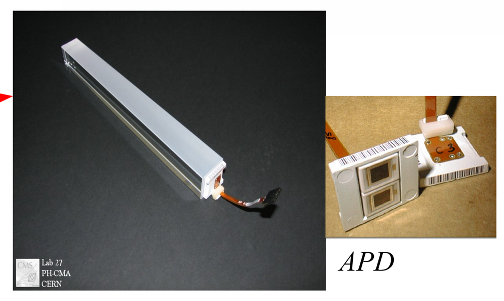
- Density: 8.28 g/cm³
- Radiation length: 0.89 cm
- Molière radius: 2.19 cm

High granularity



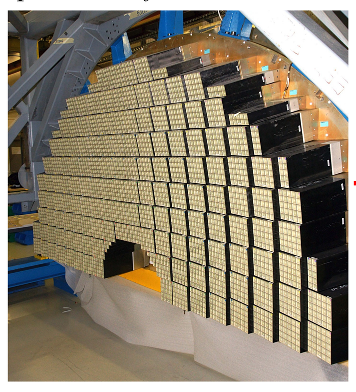


A supermodule from ECAL barrel

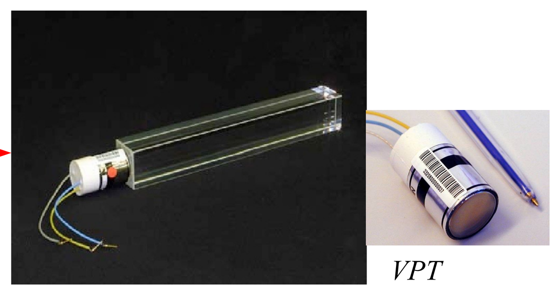


APD

A $PbWO_4$ barrel crystal



A Dee from ECAL endcap



VPT

A $PbWO_4$ endcap crystal

ECAL energy and calibration

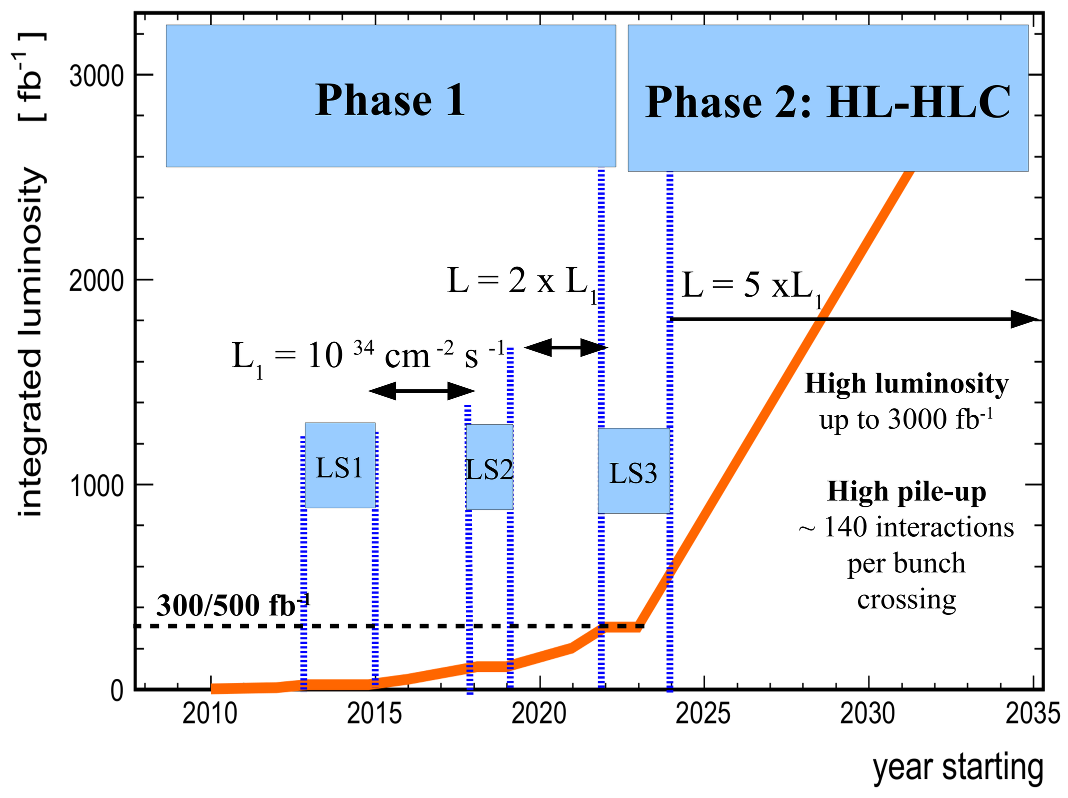
$$E_{ele/\gamma} = \mathcal{F}(xtals) \times \mathcal{F}(\eta) \times \mathcal{G}(GeV/ADC) \times \sum_{xtals} c_i \times A_i(ADC)$$

Clustering — Geometry — Absolute scale — Intercalibration

$$\left(\frac{\sigma_E}{E}\right) = \left(\frac{\sigma_{stat}}{\sqrt{E}}\right) \oplus \left(\frac{\sigma_{noise}}{E}\right) \oplus c$$

2.8 % — 120 MeV — 0.3 %

Future



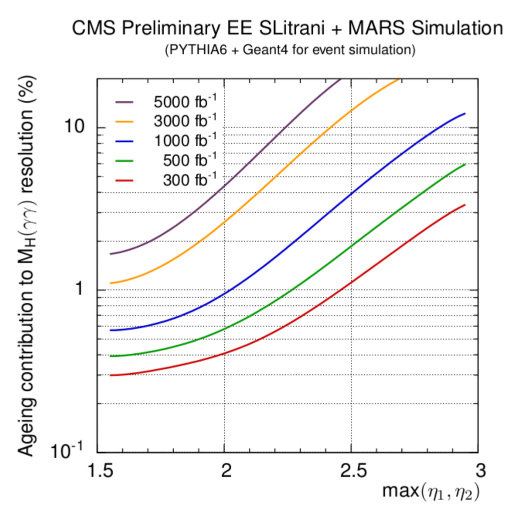
ECAL is designed to operate up to 500 fb⁻¹ at 10³⁴ cm⁻² s⁻¹ conditions (end of Phase1)

Phase II challenges

- Radiation 6 times more intense than LHC design
- With strong η dependence in EE

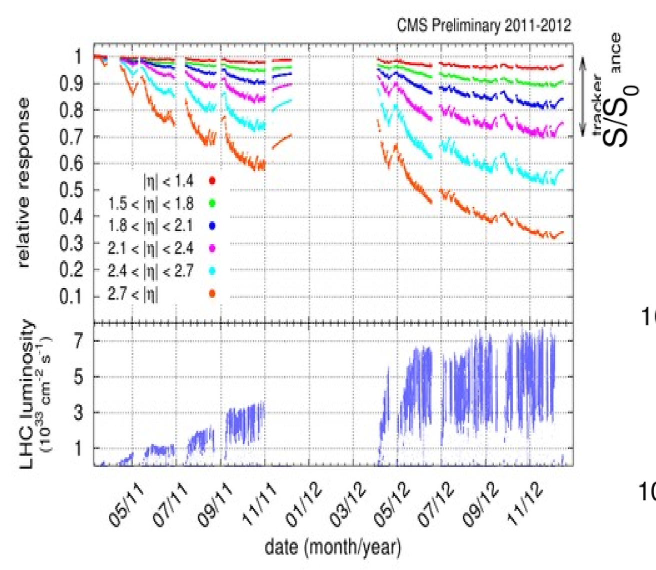
- Very high pile-up: 140 vertexes per bunch crossing
- Very high event rates

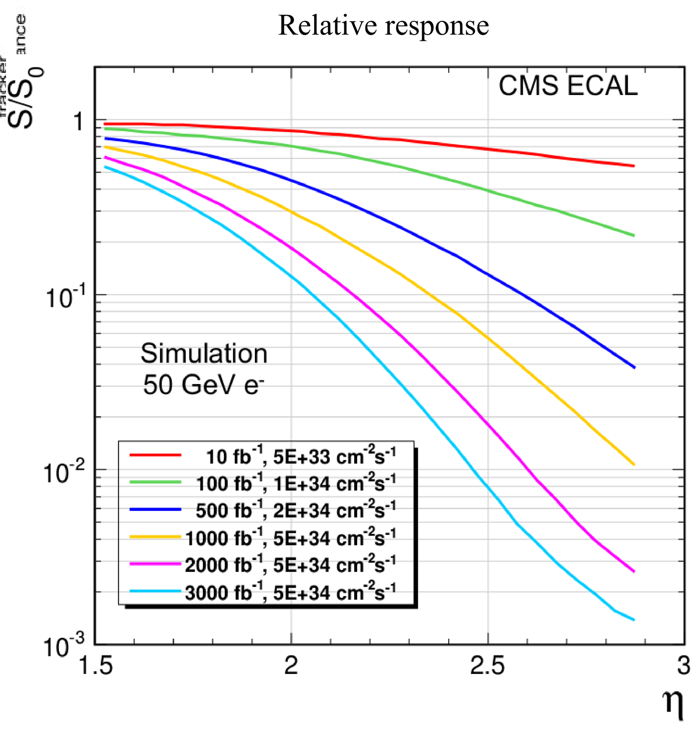
- EB performances still good
- EE: effects of ECAL performances on physics results: acceptable up to 500 fb⁻¹



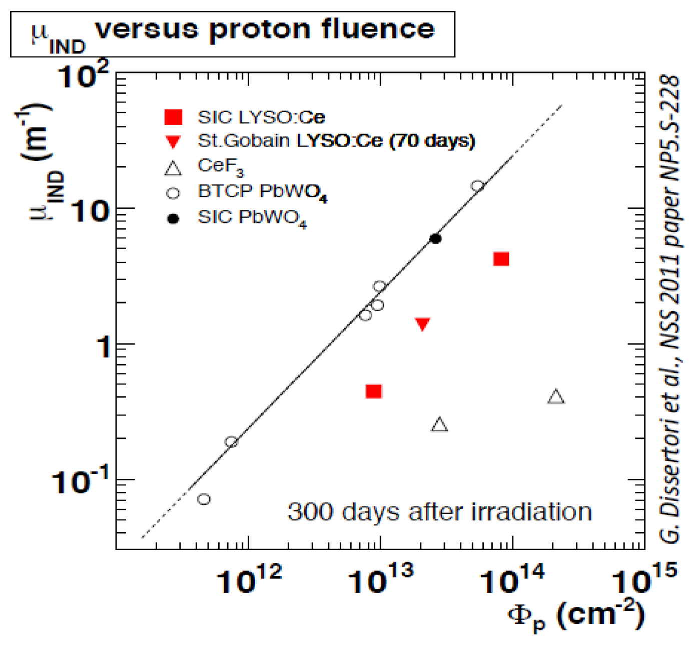
Evolution studies

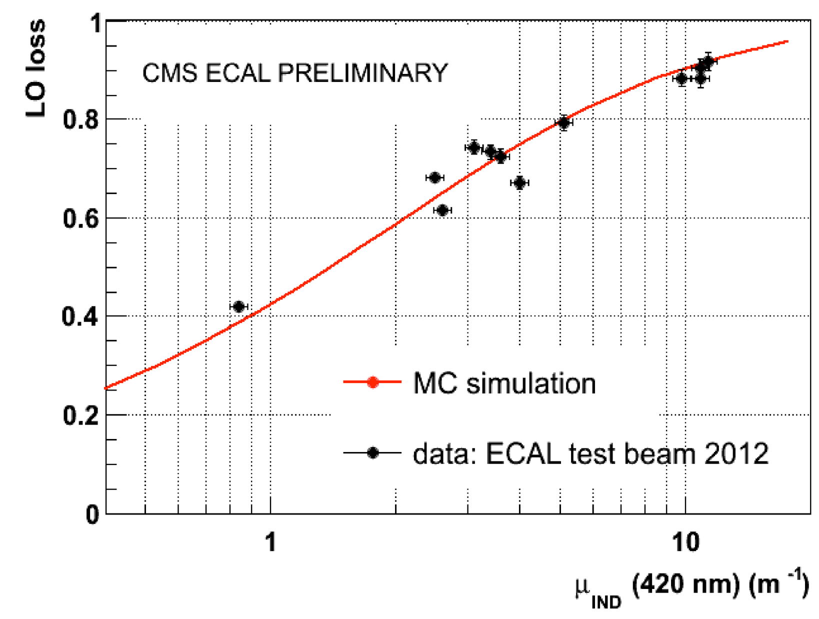
- **Noise**
  - the APD suffers from increasing dark current which grows linearly with proton fluence
- **Response loss**
  - Radiation damage creates clusters of defects which cause light transmission loss
  - Damages from γ radiation is recovered
  - Hadron damage is permanent and cumulative





- VPT ageing: response loss due to cumulative charge taken from photocathode
  - Simulation model validated with test-beam data
  - Exponential degradation up to a plateau at 90% (|η|~2.2) to 77% (high η) for L~ 3000 fb⁻¹





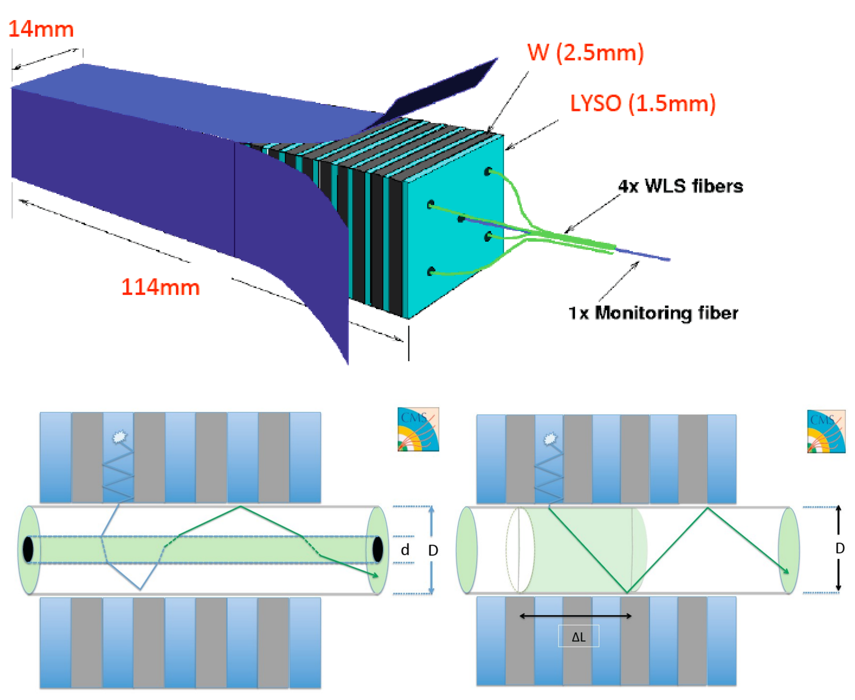
- μ_{ind} = 1/L ln ($T_{before\ irradiation}/T_{after\ irradiation}$) , L = crystal length, T = light transmission
- Light Output loss, LO_{loss}
  - Crystal transparency is reduced due to increase of μ_{ind}

Upgrade options

Shashlik

- W absorber layers and LYSO/CeF sampling layers read out with quartz capillaries with wave-shifter cores and GaInP photosensors
  - Thick quartz wall or quartz rod options as the wavelength shifting capillaries
  - Radiation hardness
  - High brightness
  - High density

	W/LYSO(Ce)	$PbWO_4$
Length (cm)	11.4	22.0
Transverse size (cm)	1.4	2.86
# modules for 2 EE	60800	14648
Average Moliere Radius (cm)	1.37	2.1
Average Radiation Length X_0 (cm)	0.51	0.89
Light Yield (relative to NaI)	85	0.3
Emission Wavelength (nm)	420	420
Decay time (ns)	40	25
Temperature Dependence (%/C)	-0.2	-2.2



High Granularity Calorimeter (HGC)

- High granularity calorimeter with detailed sampling in both hadronic and electromagnetic sections with pointing capability
- Sampling calorimeter with layers of silicon detectors
- Optimized to profit from particle flow reconstruction algorithms

- Electromagnetic Calorimeter (EE)
  - 30 samplings of lead/copper total of 25 X_0
- Front Hadronic Calorimeter (FH)
  - 12 layers of brass/silicon each 0.33 interaction lengths (4 X_0)

	EE	FH	Total
Area of silicon (m²)	420	250	670
Channels	3.7M	1.4M	5.1M
Detector Modules	19000	11000	30000
Weight One Endcap (tonnes)	16	63	79
Number of plates	30	12	42
Front end power (kW)	70-80	20-30	90-110