Performance of the CMS electromagnetic calorimeter at the LHC and role in the hunt for the Higgs boson

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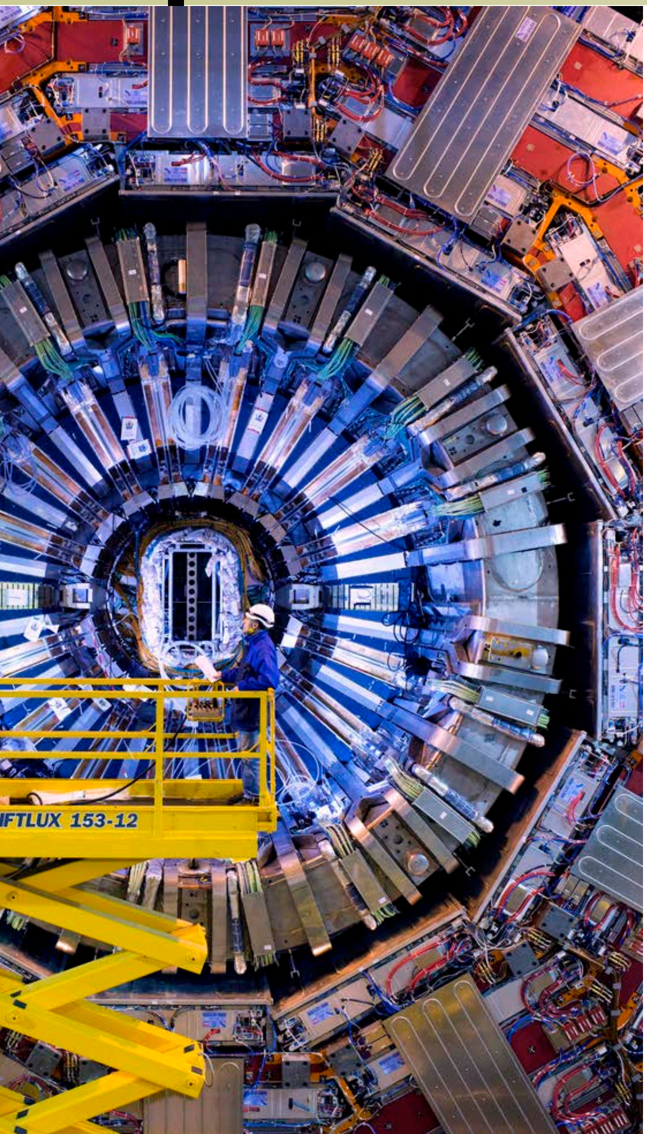
on behalf of
CMS Collaboration

ICHEP 2012

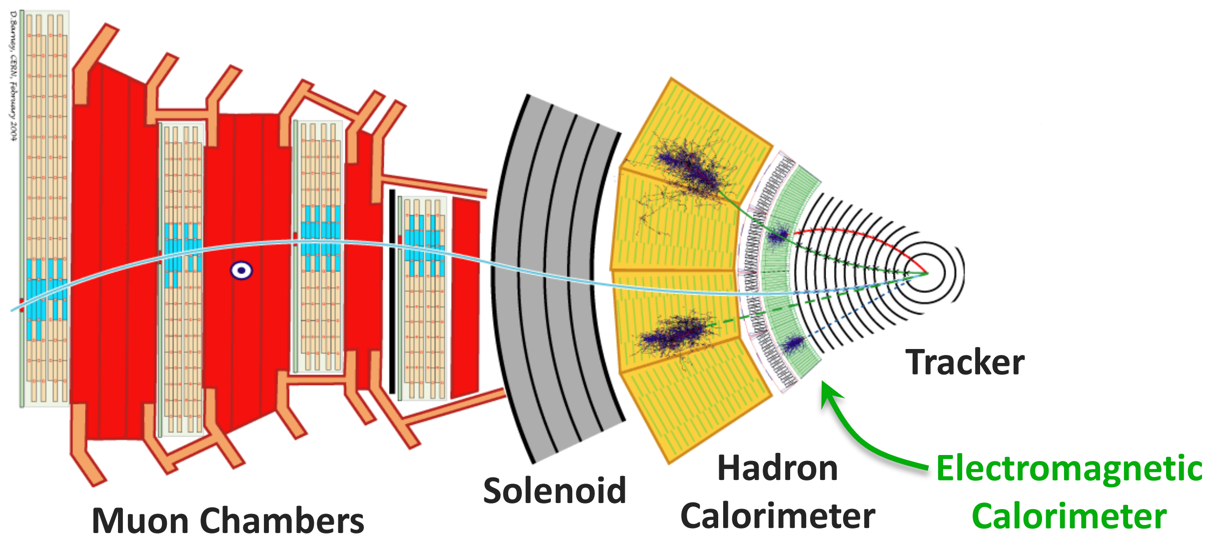
Melbourne – 6th July

Compact Muon Solenoid



Multipurpose experiment at the Large Hadron Collider.

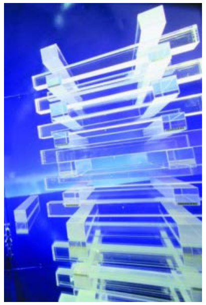
~5+5 fb^{-1} of p-p data collected at 7 TeV (2011) and 8 TeV (2012) centre of mass energy with a peak lumi of $7 \cdot 10^{33}$ cm^{-2} s^{-1}



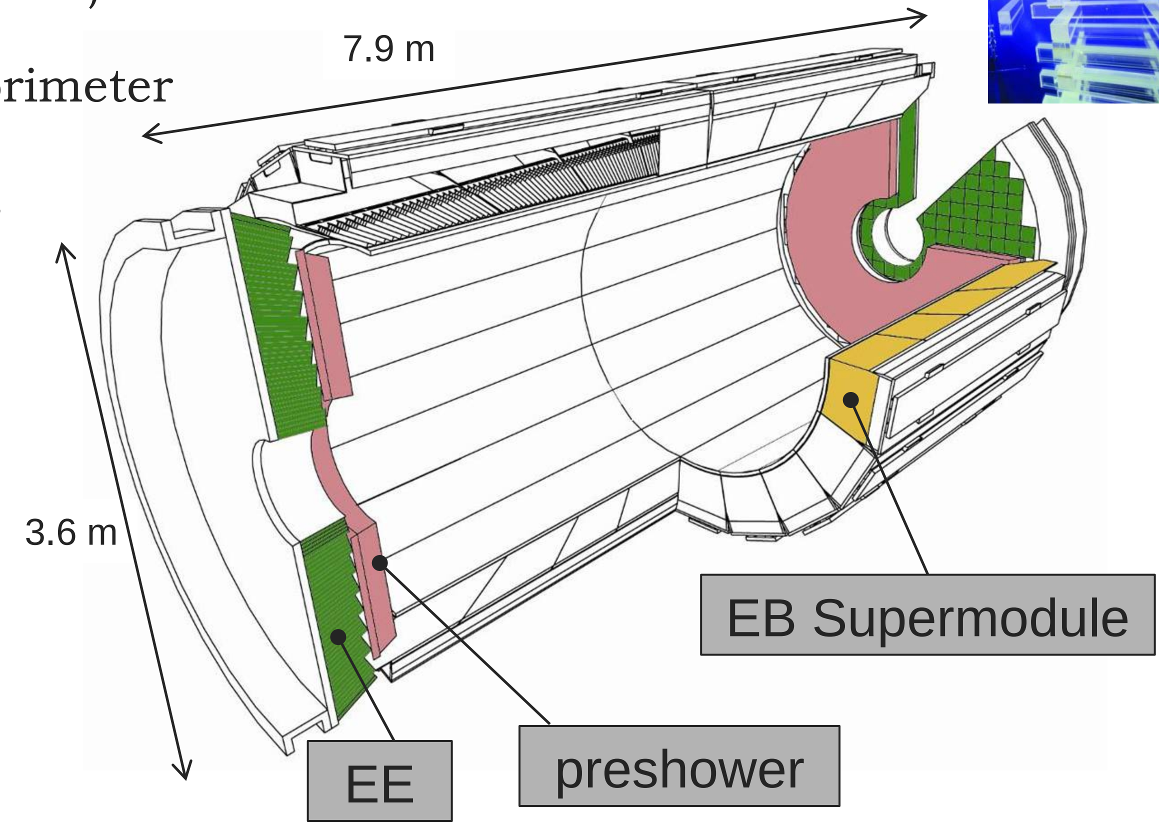
Outline:

- The Electromagnetic Calorimeter
- ECAL calibration
- e/γ energy resolution

CMS Electromagnetic Calorimeter



- Excellent energy (and position) resolution for photons and electrons ($H\to\gamma\gamma$, $H\to ZZ\to 4e$)
- Lead Tungstate ($PbWO_4$) homogenous crystal calorimeter
- Barrel (EB):
  - 36 Supermodules (SM), each 1700 crystals
  - $|\eta|<1.48$
  - APD photodetectors
- Endcaps (EE):
  - 2 Endcap sides, each 7324 crystals
  - $1.48<|\eta|<3.0$
  - VPT photodetectors
- Preshower (ES):
  - sampling calorimeter (lead, silicon strips)
  - $1.65<|\eta|<2.6$

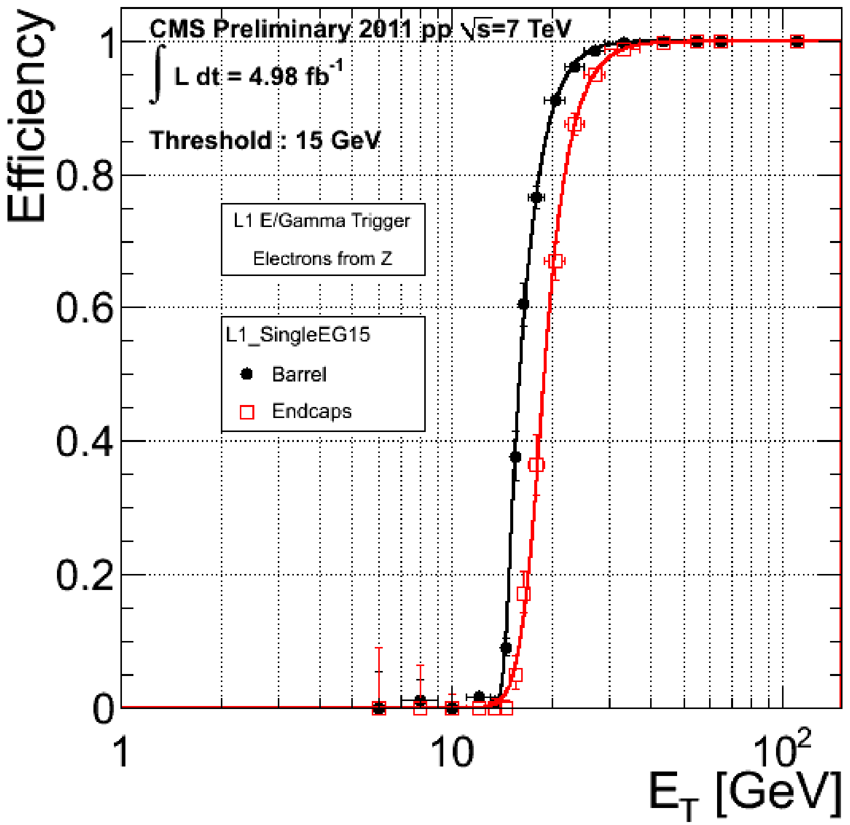


- Fraction of working channels stable in the last three years: EB 99.2%, EE 98.5%, ES 96.9%

Electromagnetic trigger

- Electron and photon selection in CMS starts with the online selection.
- The plot shows the Level-1 e/γ trigger efficiency (nominal 15 GeV threshold) for electrons from Z decay estimated with Tag & probe method.
- Transparency corrections not applied at trigger level in 2011 data-taking (applied since the beginning of 2012).

EG15	EB	EE
50%	$16.06^{+0.01}_{-0.01}$ GeV	$19.05^{+0.05}_{-0.06}$ GeV
95%	$22.46^{+0.04}_{-0.05}$ GeV	$27.06^{+0.58}_{-0.43}$ GeV
99%	$28.04^{+0.07}_{-0.10}$ GeV	$34.57^{+1.48}_{-1.10}$ GeV
100 GeV	$99.95^{+0.01}_{-0.88}$ %	$99.84^{+0.10}_{-0.28}$ %

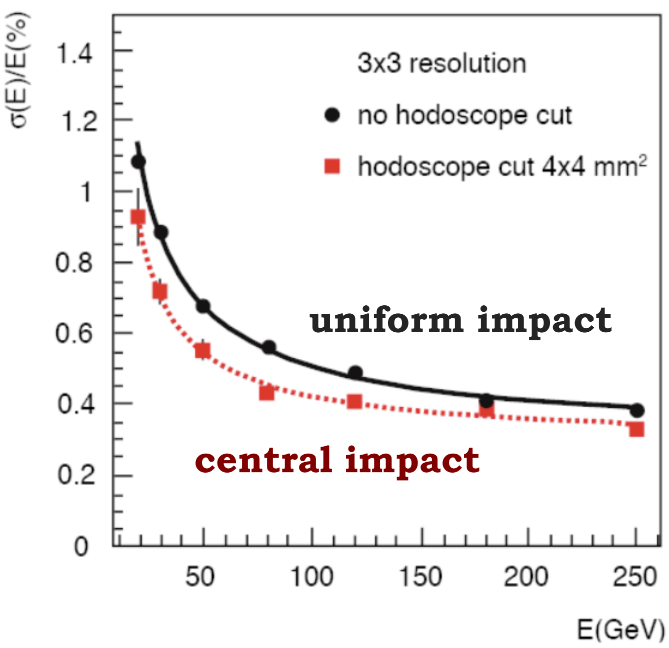


Energy resolution challenge

- ECAL «standalone» energy resolution measured at the test beam: (3x3 arrays of barrel crystals in the absence of magnetic field, with no material in front of the calorimeter and negligible inter-calibration contribution in the constant term)

$$\frac{\sigma(E)}{E} = \frac{2.8\%}{\sqrt{E(GeV)}} \oplus \frac{0.128}{E(GeV)} \oplus 0.3\%$$

- Results used to tune MC simulation.
- In-situ, for unconverted photons with energies in the range of interest for physics analyses, ~100 GeV, the in-situ constant term dominates.
- Constant term in-situ strongly depends on the quality of the stability, calibration and monitoring.
- Asymptotically to be kept at ~0.5%

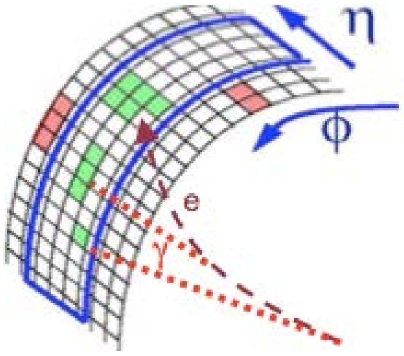


e/γ energy with ECAL

Measurement of electron/photon energy:

$$E_{e,\gamma} = F_{e,\gamma} \cdot \sum_{xtal} (G \cdot C_{xtal} \cdot L_{xtal}(t) \cdot A_{xtal})$$

- A_{xtal} [ADC counts] → signal channel amplitude
- L_{xtal} → laser monitoring correction (time dependent)
- C_{xtal} → crystal inter-calibration ($\langle C_{xtal} \rangle = 1$)
- G [GeV/ADC] → ECAL energy scale
- Σ →e.m. shower, energy deposited over several crystals clustered with dynamic algorithms
- F → cluster energy corrections
  - particle dependent
  - compensate shower leakage and bremsstrahlung losses for electrons)

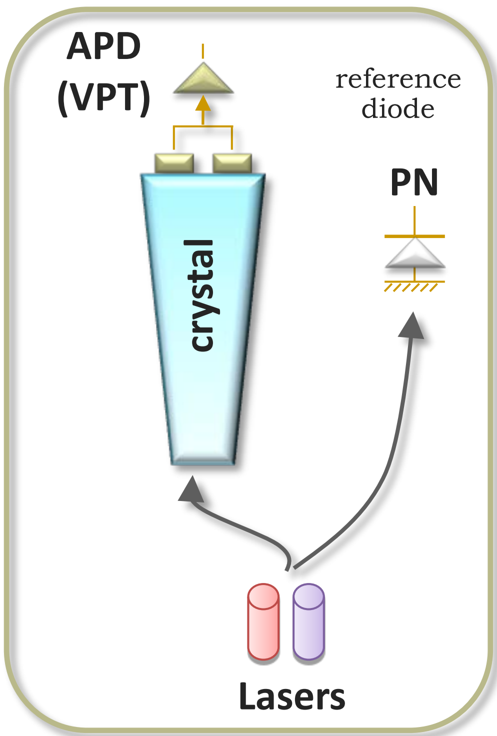


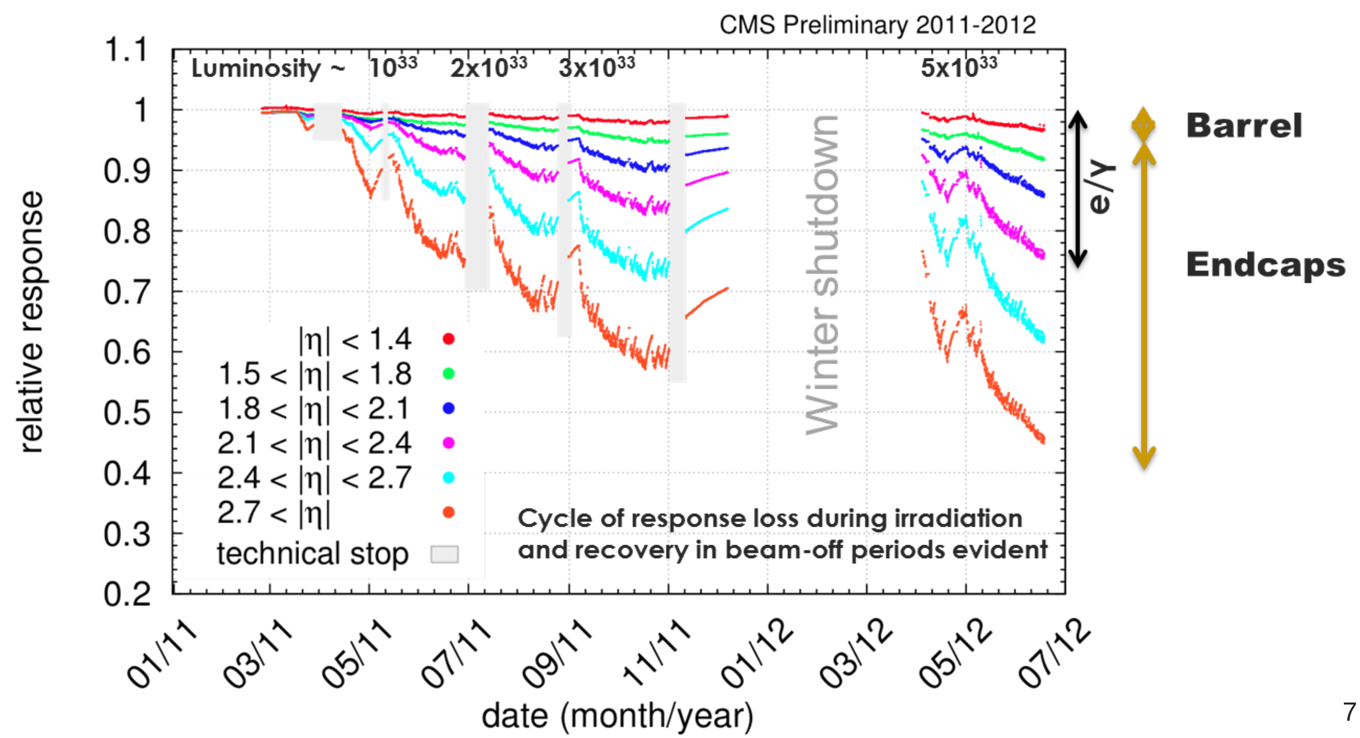
ECAL response monitoring

Radiation ⇨ Wavelength-dependent loss of light transmission (w/o changes in scintillation)

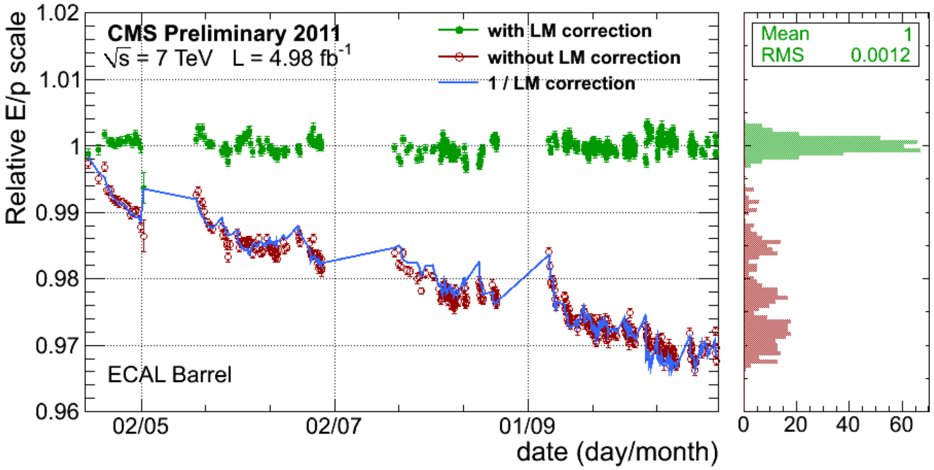
Crystal Transparency ***drops*** within a run by a few percent but ***recovers*** in the inter-fill periods

- Inject fixed amount of light to monitor transparency loss
- Response loss up to 5% in EB and 30%-50% in EE (20% in the electron acceptance region |η| < 2.5)





ECAL response stability

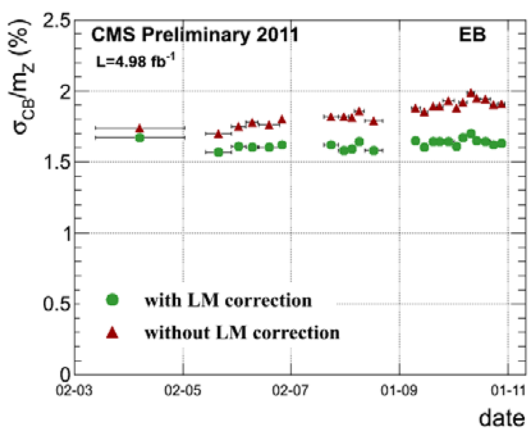


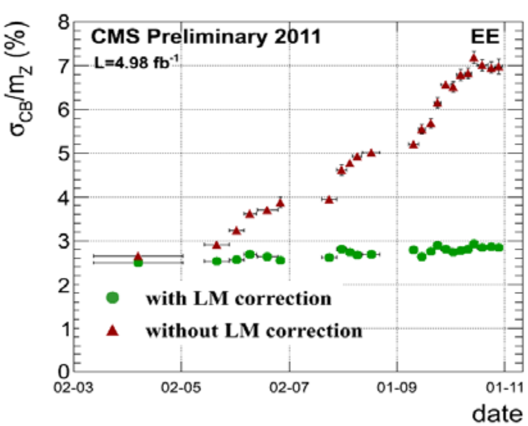
Stability of the energy scale after monitoring corrections with W$e\nu$ events.

- Barrel: average signal loss ~2.5%
  RMS stability ~0.12%
- Endcaps: average signal loss ~10%
  RMS stability ~0.45%
- 2012 prompt reco:
  Barrel RMS stability ~0.19%

Stability of the ECAL resolution from Zee invariant mass peak.

- Barrel: resolution stable within errors.
- Endcaps: worsening of ~1.5% in quad. (residual PU effect)

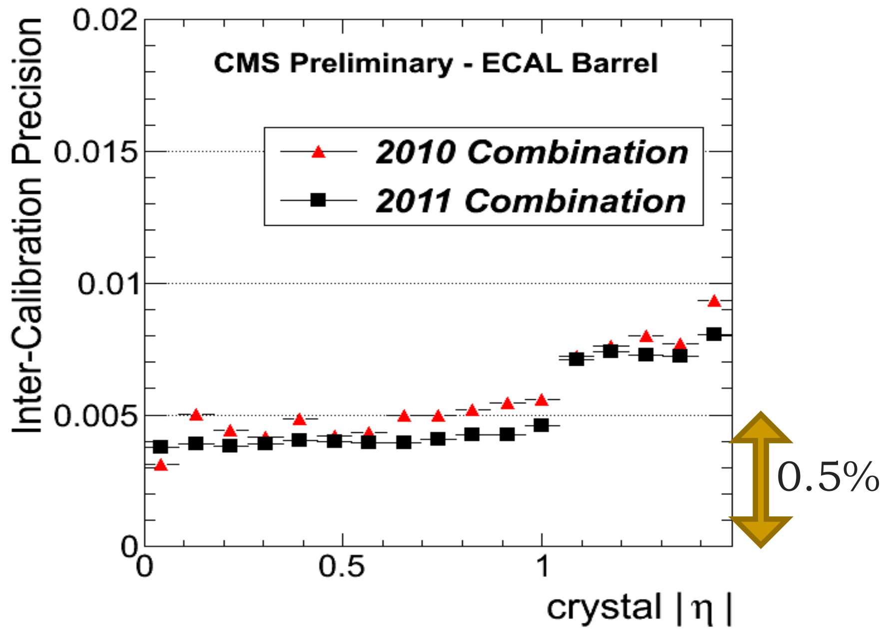


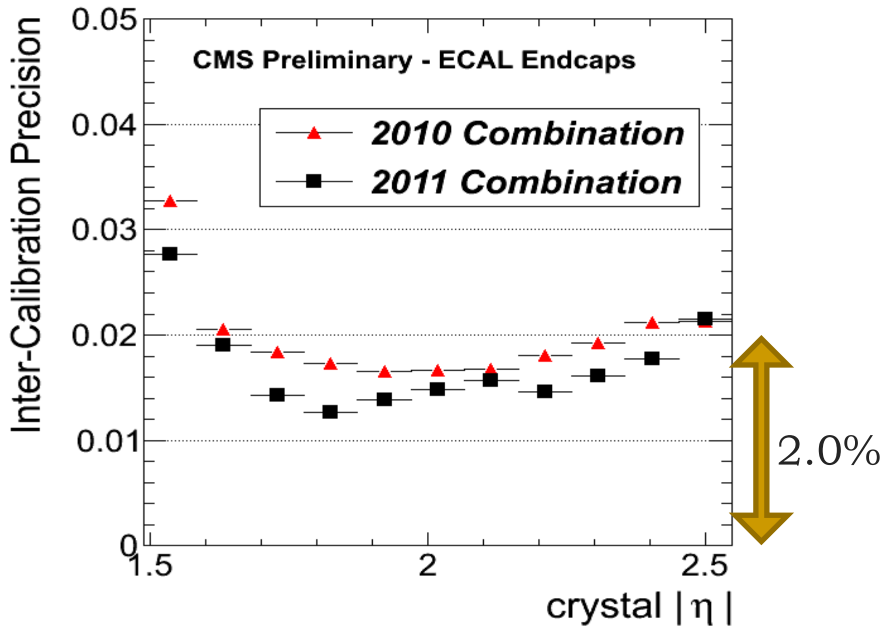


Crystal Inter-calibration

- Several methods to calibrate (and follow-up) in-situ:
  - **φ-symmetry calibration**: invariance around the beam axis of energy flow in minimum bias events. Intercalibrate crystals at the same pseudorapidity.
  - **π^0 and η calibration**: mass constraint on photon energy, use unconverted γ's reconstructed in 3x3 matrices of crystals.
  - **High energy electron** from W and Z decays (E/p with single electrons and invariant mass with double electrons).

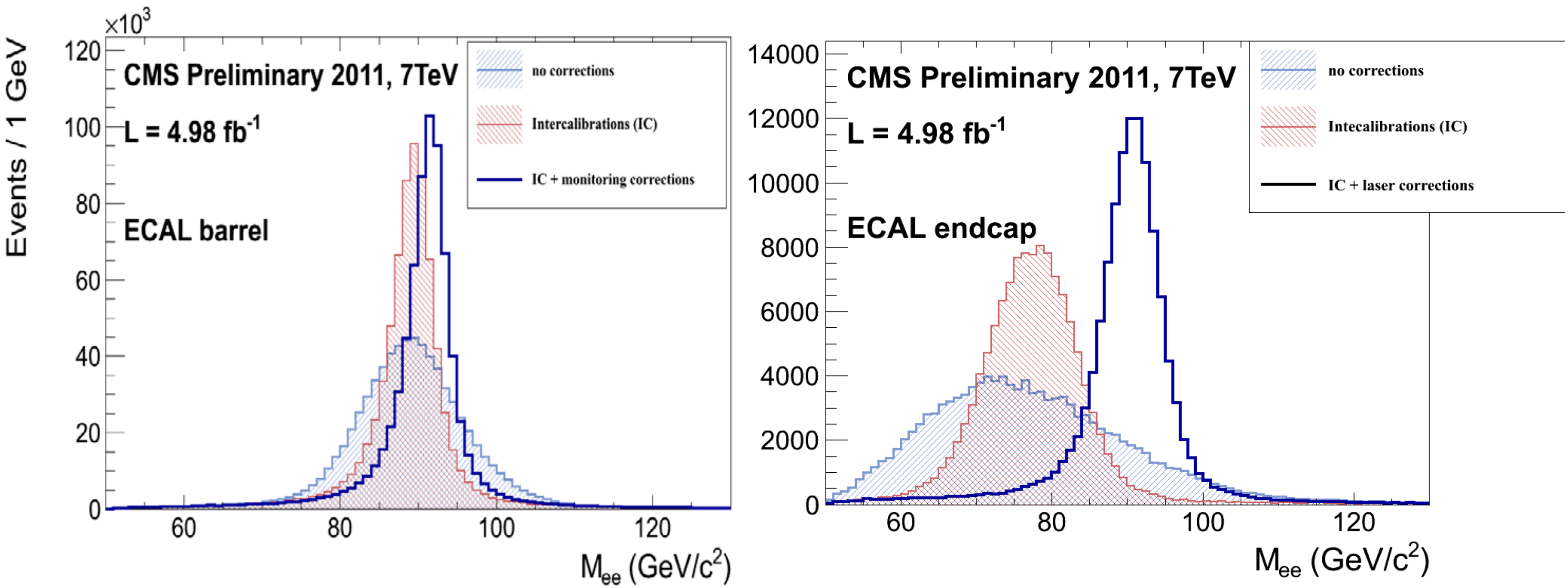
The precision (not yet asymptotic at |η|>1) is strongly related to the material in front of ECAL





ECAL Calibration

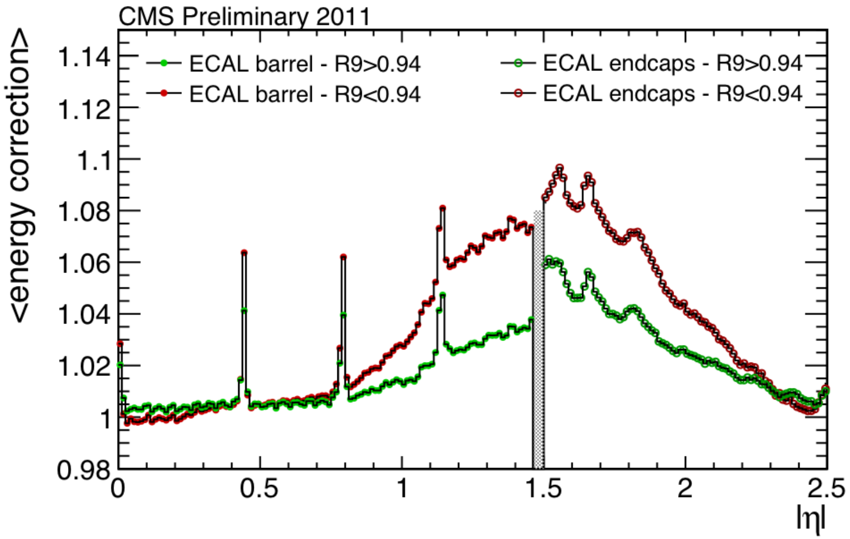
- Zee invariant mass distribution applying :
  - channel Inter-Calibration
  - IC and Laser Monitoring corrections

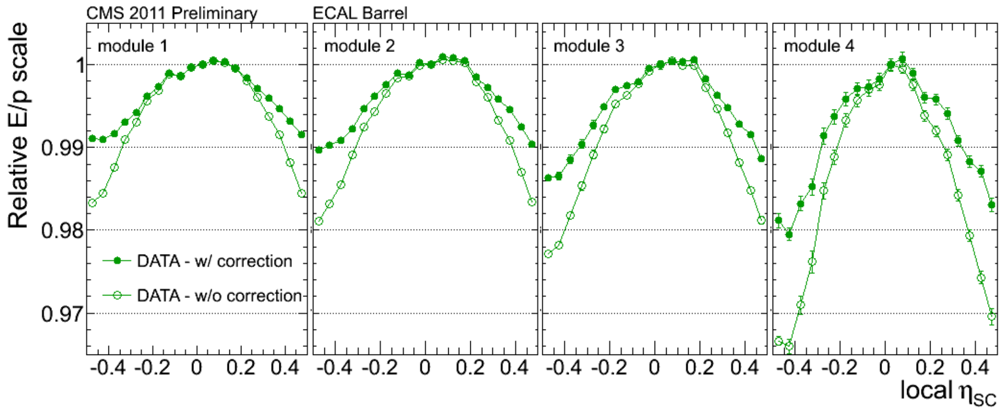


Cluster Energy Corrections

Cluster Energy corrections vs pseudo-rapidity for non-showering and showering electrons.

- compensate for unclustered energy and energy not reaching the calorimeter: strongly related to the amount of material in front of ECAL.
- energy lost inside gaps: intermodule boundary visible in the Barrel



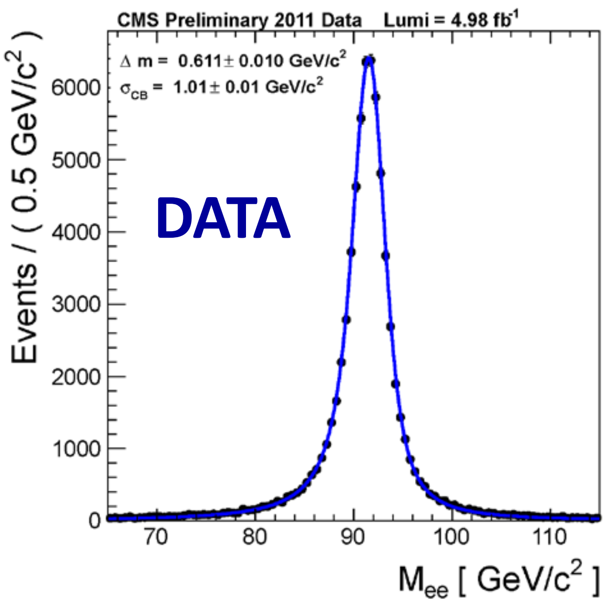


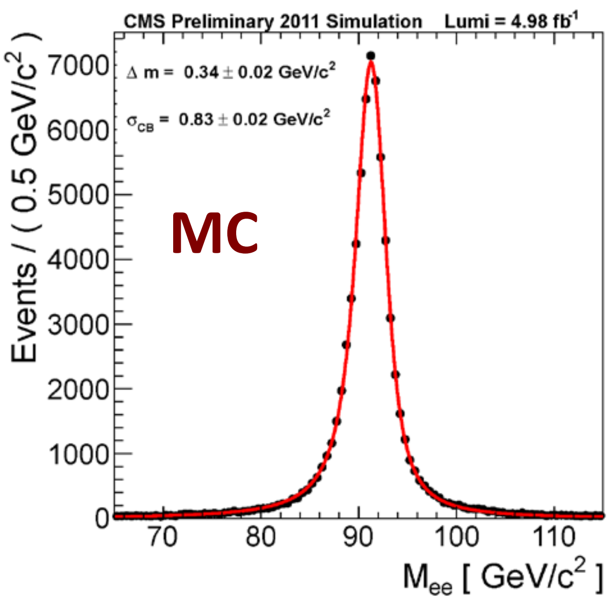
Reconstructed energy as a function of the local position of the most energetic crystal in the cluster, with E/p method.

- MC driven corrections not sufficient to correct the data
- crystal staggering variation along η (bigger in module 4)

Energy scale and resolution with Z→ee events

- Fit of the Z invariant mass shape with convolution of Breit-Wigner (fixed PDG mass and width) and Crystal Ball (CB).
- Energy scale and resolution estimated with CB parameters.
- Cross-check of energy scale with radiative Zμμ events.
- An extra energy smearing is applied to the MC to match the observed resolution of the Z→ee peak in data (additional contribution in the constant term).



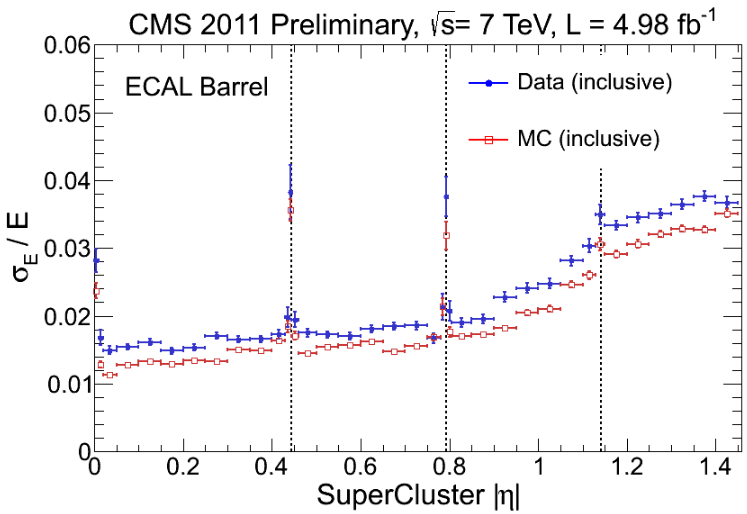


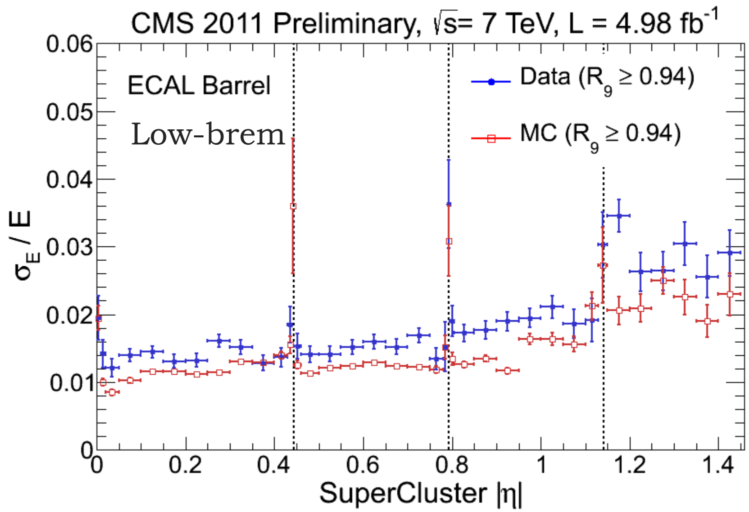
Golden category (both electrons in EB and low-brem): σ_{CB} = 1.01 GeV

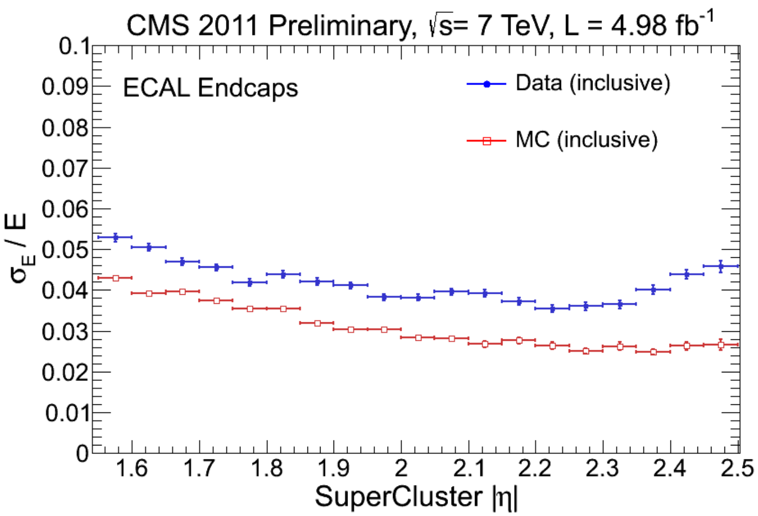
Both electrons in EB: σ_{CB} = 1.56 GeV

Both electrons in EE: σ_{CB} = 2.57 GeV

Z electrons energy resolution







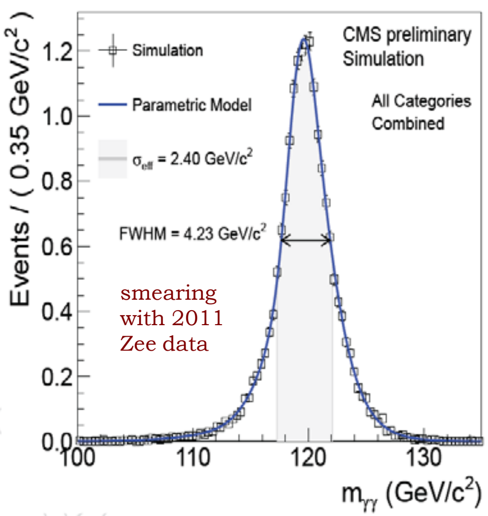
Double effort continuously ongoing to:

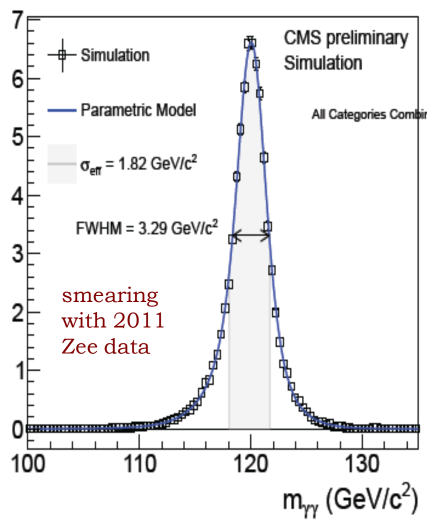
1. Improve the energy resolution both in Data and MC: inter-calibration precision, optimization of cluster corrections.
2. Reduce/nullify the difference between data and MC due to contributions possibly not fully simulated (improvement observed in laser correction stability, tuning of the material simulation, etc).

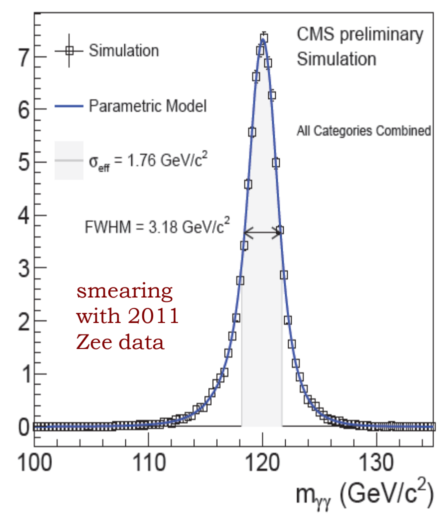
Evolution of CMS H→γγ invariant mass resolution

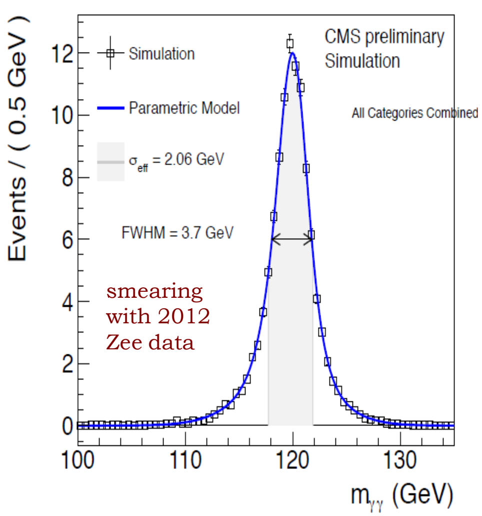
- Inclusive Hgg invariant mass distribution after the MC energy smearing

July 2011 EPS	March 2012 Moriond	July 2012 ICHEP	July 2012 ICHEP
2011 Zee data (re-reconstructed with improving conditions)			2012 data (prompt reco)
FWHM/2.35 = 1.80 GeV (1.50%)	FWHM/2.35 = 1.40 GeV (1.17%)	FWHM/2.35 = 1.35 GeV (1.13%)	FWHM/2.35 = 1.57 GeV (1.31%)



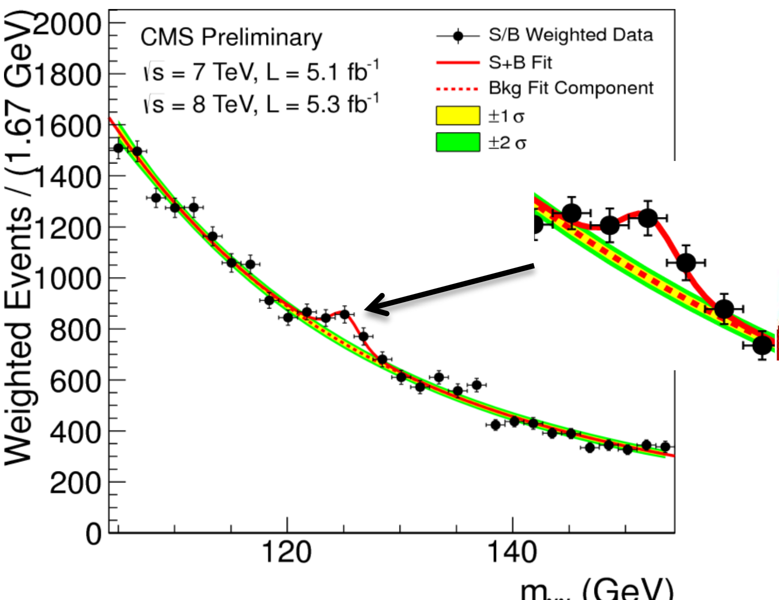


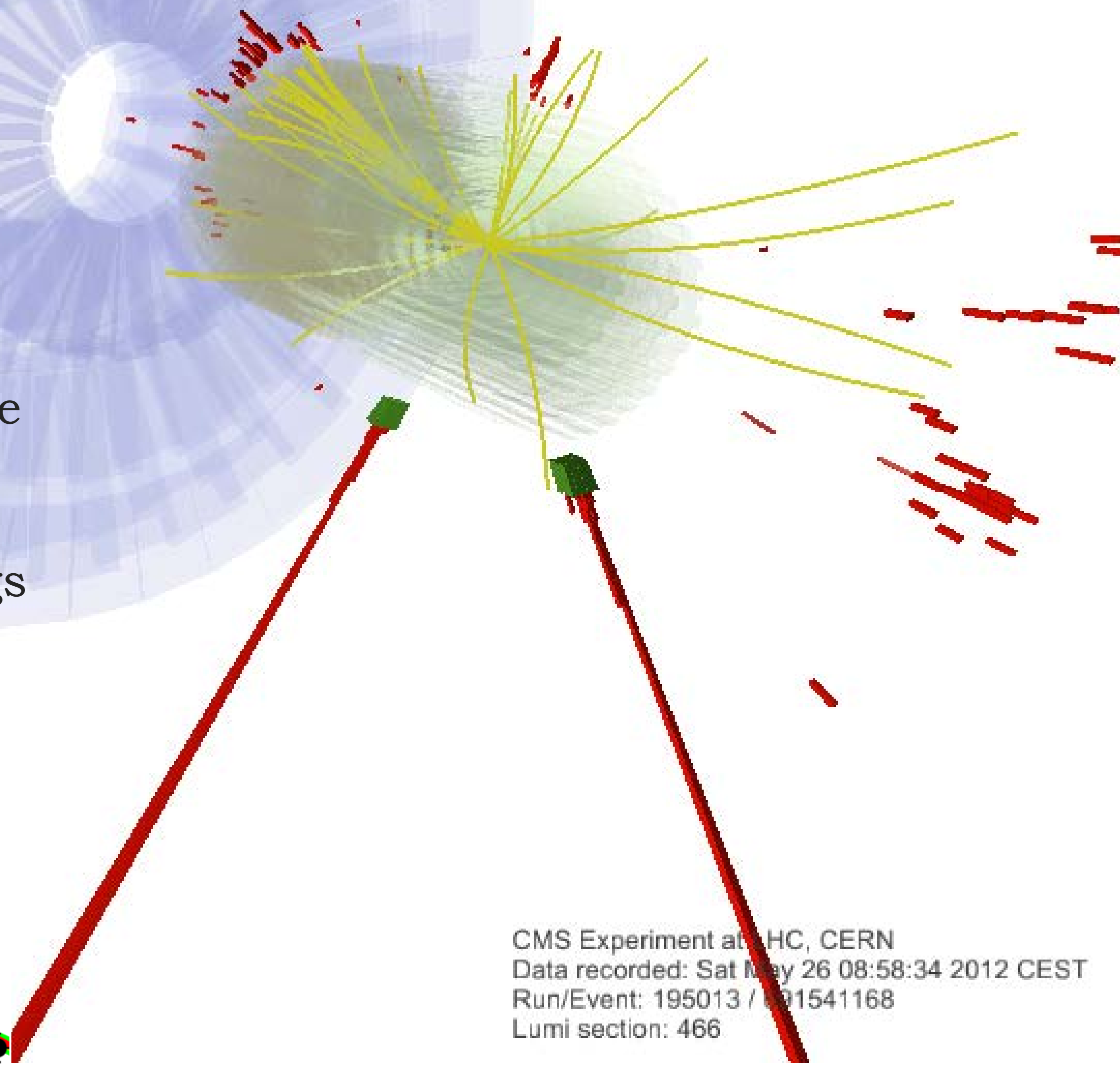




Golden category (both photons in EB and unconverted) FWHM/2.35= 1.04 GeV (0.87%)

The excellent ECAL performance of the last two years is visibly demonstrated by this historic plot from the CMS 4th July Higgs search presentation





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- M. Anfreville et al., *Laser monitoring system for the CMS lead tungstate crystal calorimeter*, NIM A594 (2008) 292-320
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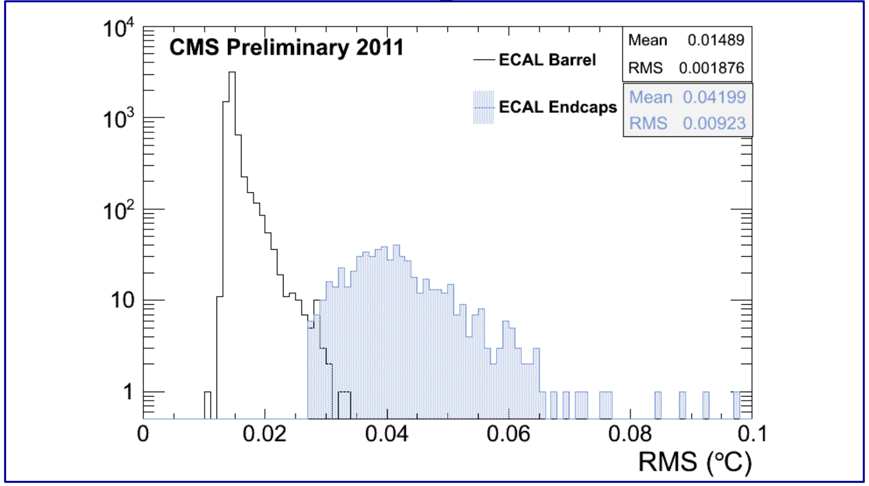
No time for…

ECAL stability

- Fraction of working channels stable in the last three years: EB 99.2%, EE 98.5%, ES 96.9%

- Temperature stability:
  - crystal light yield and APD gain are temperature dependent.
  - negligible contribution to the energy resolution constant term if temperature of the Barrel/Endcap stable within 0.05 °C/0.1 °C (VPT are stable in temperature).

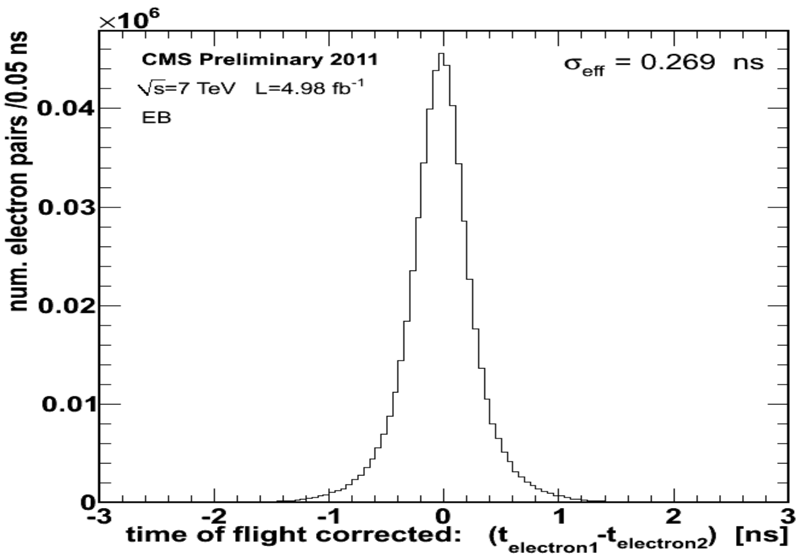
Temperature stability of the ECAL Barrel and Endcap detectors.

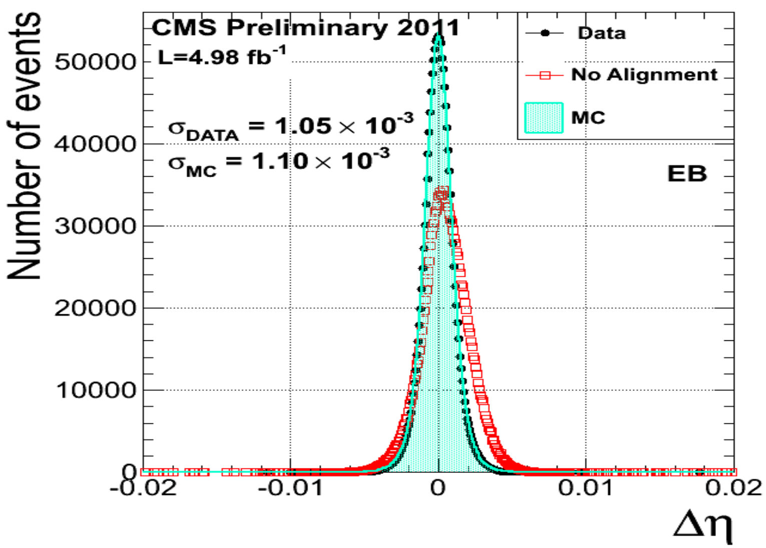


- High Voltage stability (EB):
  - APD gain very sensitive to the bias voltage: 3%/Volt
  - Stability < 60 mV is required to provide a negligible contribution to the constant term of the energy resolution.
  - High Voltage stability well within allowed limits

Alignment (in time and space)

- Timing fundamental in exotic long lived particle searches and in anomalous signal rejection.
- Time difference between the seed crystals for the two Z electrons.
- The time resolution for a single ECAL crystal, for the energy range of electrons from Z decays, is 0.19/0.28 ns in EB/EE.
- No longitudinal segmentation of ECAL → Photon direction from shower position and identification of the interaction vertex
- Relative alignment of the ECAL crystals and the CMS tracker measured using electrons from $Z \to ee$ and $W \to e\nu$ events.
- Position resolution ≤ 1 mm



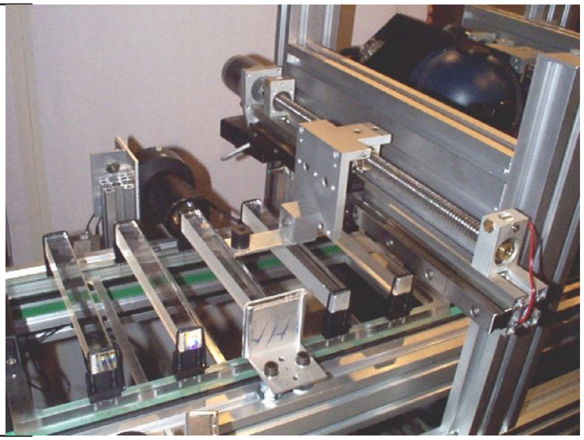


Pre-calibration Campaign

A very intense 10 years long pre-calibration campaign. Several orders of magnitude in energy: from 1 MeV of Co^{60} source to 120 GeV electron beam.

Laboratory measurements during crystal qualification phase.

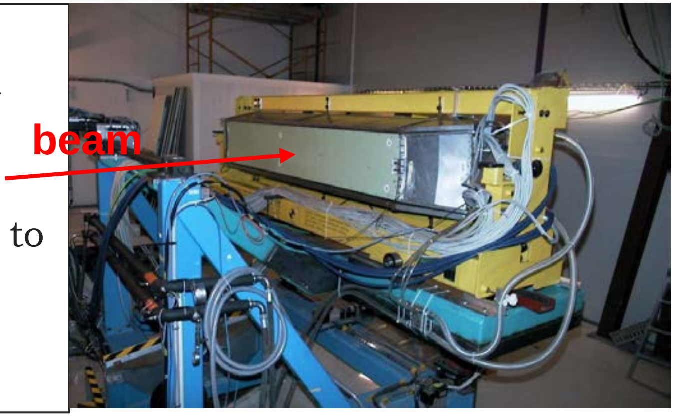
(2000-2006)



Test Beam: Cern electron beams.

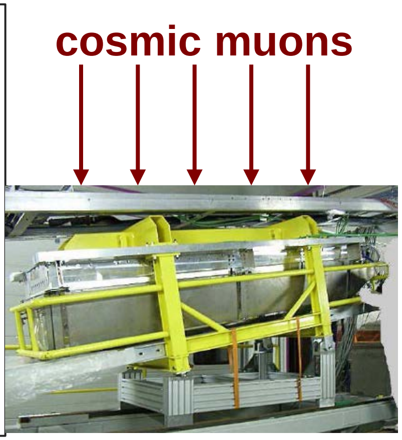
From 15 GeV to 250 GeV.

(2004-2007)

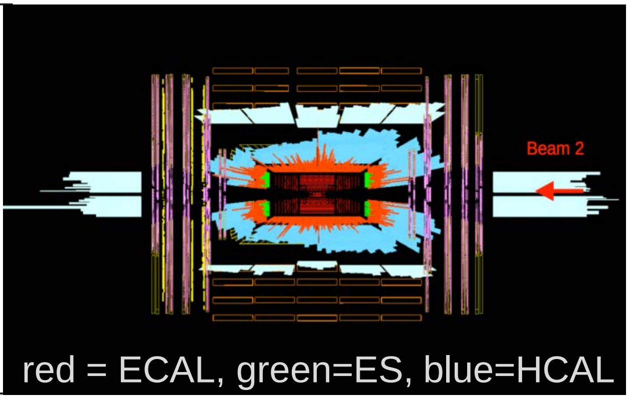


Channel intercalibration with cosmic muons (only Barrel SMs)

(2006-2007)

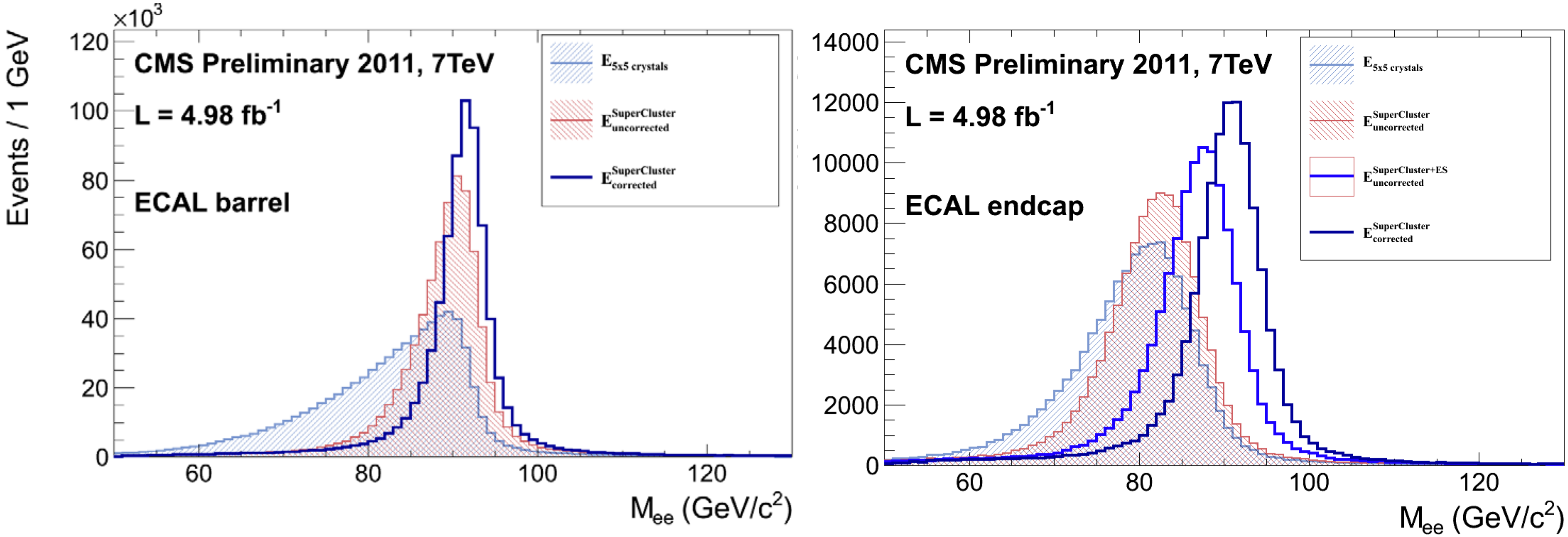


Beam Splash:
In September 2008 and November 2009, beam was circulated in LHC, stopped in collimators 150m away from CMS



Optimal clustering

- Zee invariant mass distribution with optimal ECAL clustering



2012 ECAL performance

Single electron energy scale (E/p) stability in the ECAL barrel measured using Weν events in prompt Reco.

- **RMS stability after Laser Monitoring corrections: 0.19%**
  - was 0.12% in the final rereco of 2011 data (0.45% in EE).