$H \rightarrow \gamma\gamma$ Search at CMS from the Bottom Up

(Calibration of the CMS Electromagnetic Calorimeter at the LHC)

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on behalf of the CMS Collaboration

New Perspectives 2012

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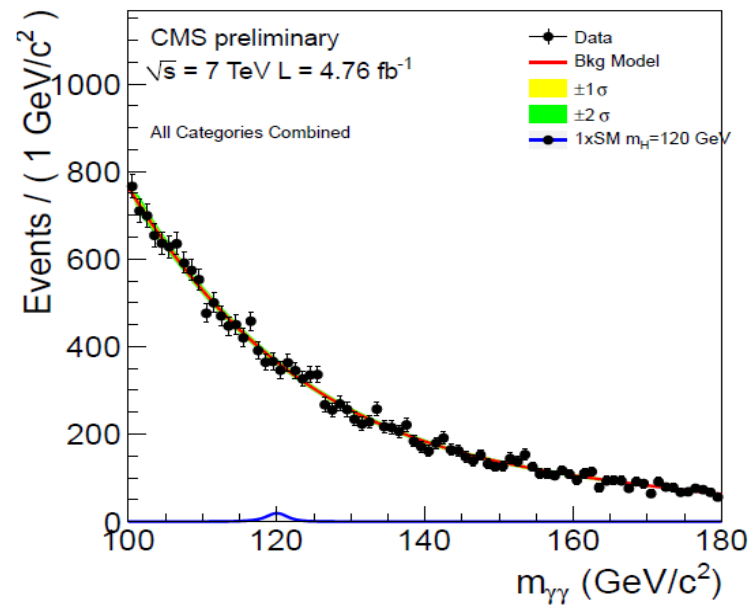
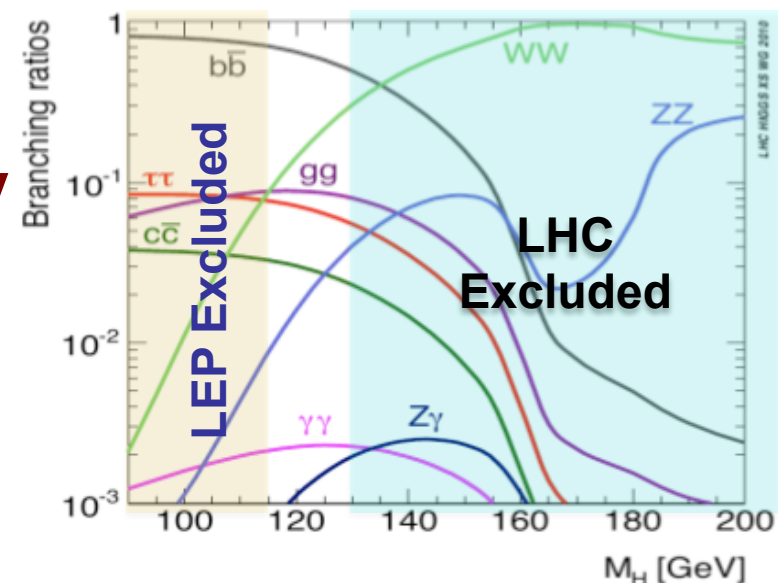
The Hunt for H→γγ

- Most sensitive channel at mass below ~130 GeV (as yet not excluded)

- Small branching ratio, but very clean signature: search for a narrow resonance of two high-E_T photons over a non-resonant background of genuine or fake di-photons

- Discovery potential depends mainly on
  1) Invariant mass resolution: photon energy and position resolution are important
  2) Background rejection (π^0/γ separation)





CMS ECAL: 75,848 $PbWO_4$ Crystals

Barrel: $|\eta| < 1.48$

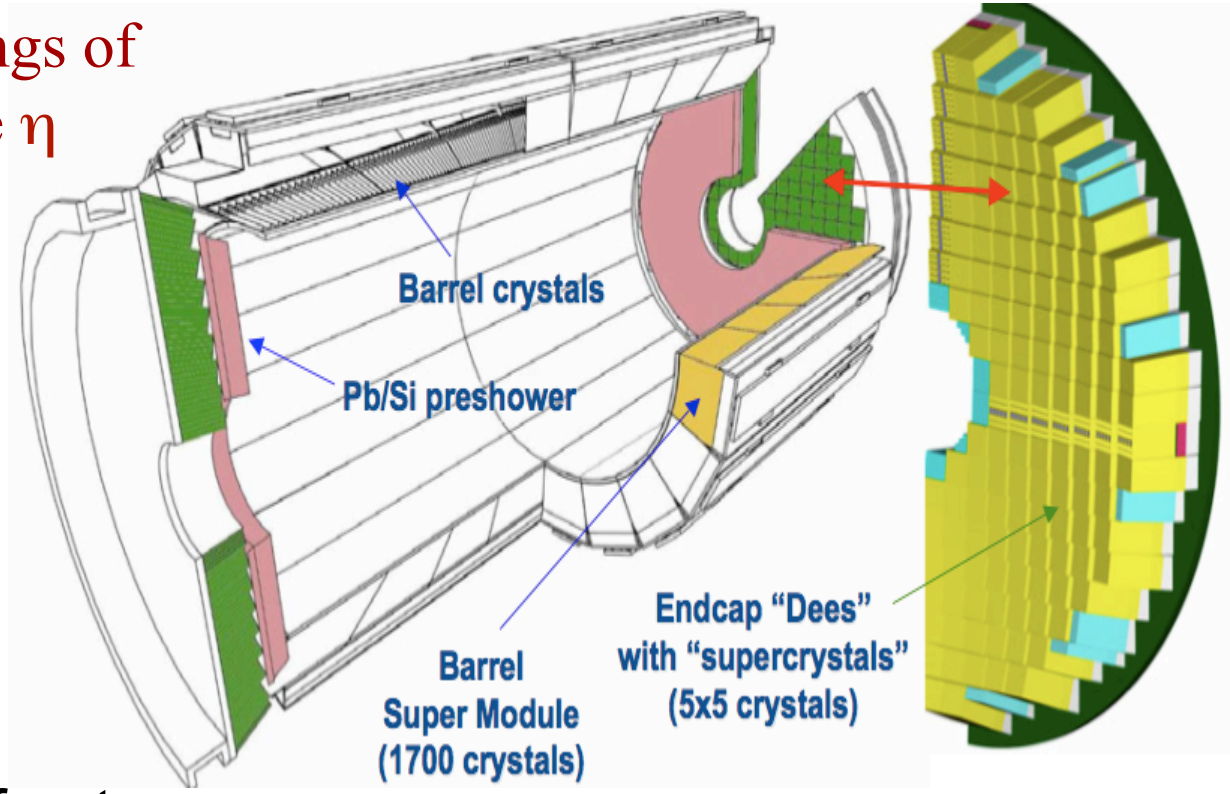
- 61,200 crystals or 85×2 φ-rings of 360 crystals each at the same η
- $(2.2\times2.2\times23\ cm^3) \sim 26X_0$

Endcaps: $1.48 < |\eta| < 3.0$

- 14,648 crystals total (39×2 effective φ-rings)
- $(3.0x3.0\times22\ cm^3) \sim 25X_0$

Preshower: $1.65 < |\eta| < 2.6$

- $3X_0$, 2 planes of Pb/Si strips
- $1.90 \times 61\ mm^2$ x-y view

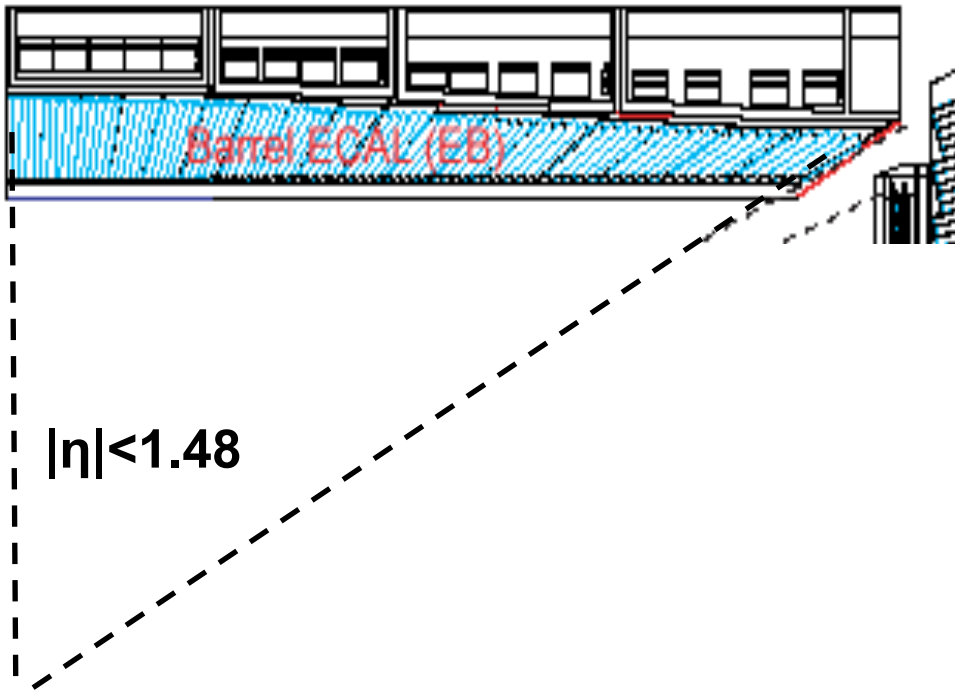


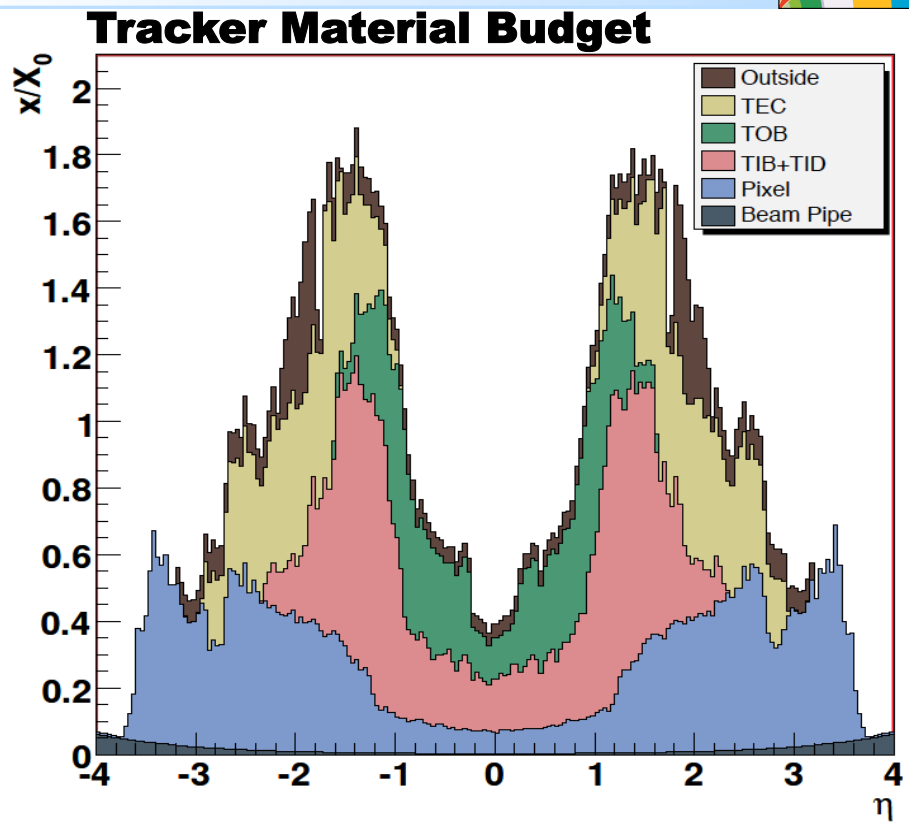
Other CMS characteristics of note

Tracker coverage: $|\eta| < 2.5$

CMS Magnetic field: B = 3.8 T

CMS ECAL: Material and Geometry





Barrel consists of 170 φ-rings of 360 crystals each: a crystal is uniquely characterized by η-index (-85 to 85) and φ-index (1-360).

H→γγ is the focus channel for the CMS ECAL: the central barrel is the best region for the Higgs search.

Electron-Photon Energy Measurement

In CMS, the photon/electron energy is measured via

$$E_{e/\gamma} = G \bullet F_{e/\gamma} \bullet \Sigma_i \, (c_i \, s_i \, A_i)$$

A_i **Single channel amplitude (ADC counts)**

s_i **Single channel time-dependent correction for response variations**
Obtained using a dedicated laser monitoring system

c_i **Intercalibration constant: relative single channel response factor**

$F_{e/\gamma}$ **Particle energy correction (detector geometry, clustering, etc…)**
Obtained using simulations and electrons from Z and W decays

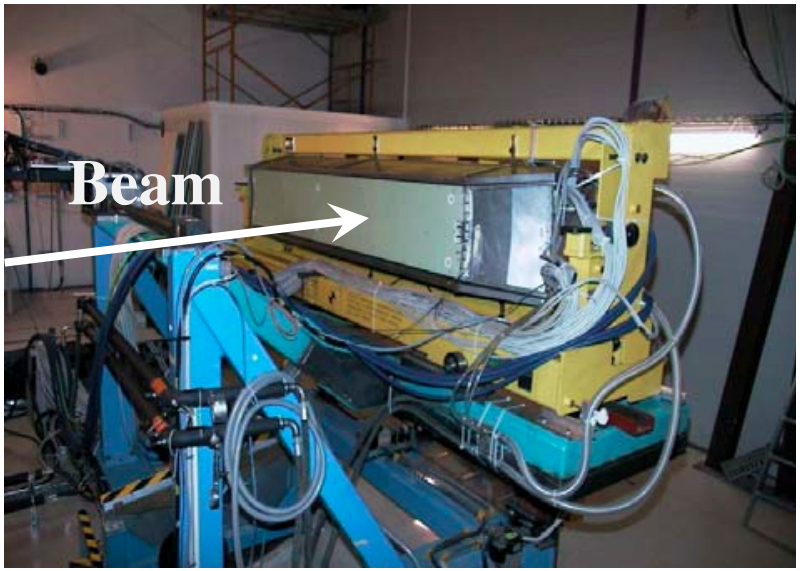
G **Global ECAL energy scale**

This talk: how we measure the global energy scale and intercalibrate the 75,848 crystals of the CMS ECAL.

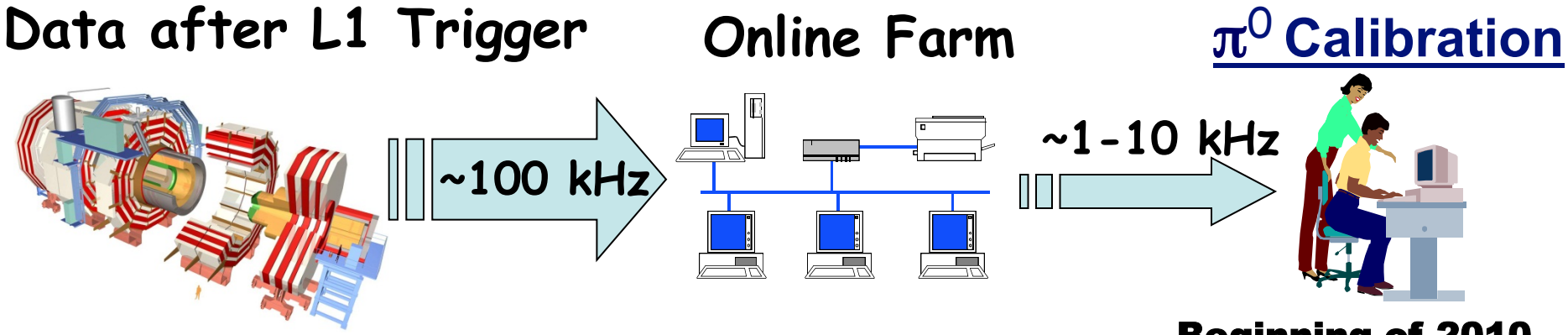
ECAL In Situ Calibration Strategy

1) $\pi^0/\eta \rightarrow \gamma\gamma$ method: equalizes measured π^0/η peaks for individual crystals.
2) φ-symmetry: invariance around the beam axis of the energy flow in zero-bias events to intercalibrate crystal response in each of 248 φ-rings.
3) single-electrons from W decays: use E/p ratio where p is measured in the tracker and E in the ECAL. In addition to single-crystal intercalibration, this method also intercalibrates the average response of 248 φ-rings.
4) di-electrons from Z decays: use measured invariant mass to obtain the global scale corrections and study the ECAL resolution.

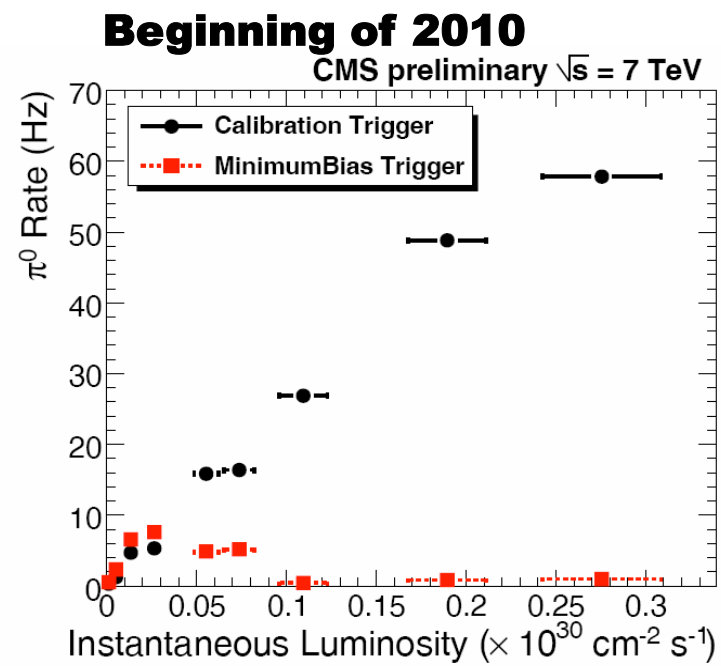
- Precalibration in 2000-2009 performed using test beams, cosmic rays, radiation source and "beam splashes" during the first LHC runs.
- ~30% of the Barrel and 400 crystals in the endcaps were calibrated in the test beams to the design-goal single-crystal precision of 0.5%.



Dedicated Calibration Streams: $\pi^0/\eta \to \gamma\gamma$ and φ-symmetry



- Each event passing L1 triggers contains a few π^0's/event: no need to trigger on π^0's
- Useful $\pi^0(\eta) \to \gamma\gamma$ decays selected online using only crystal-level information from localized regions of ECAL. Store only information about 20-30 crystals per event.
- Sustained rate in Summer-Fall 2011: ~7 kHz (including background).

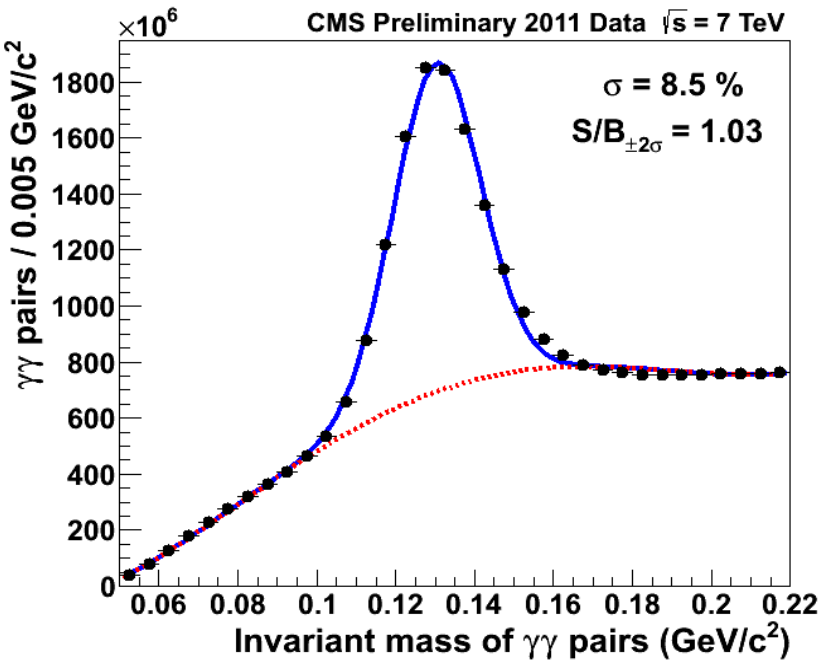


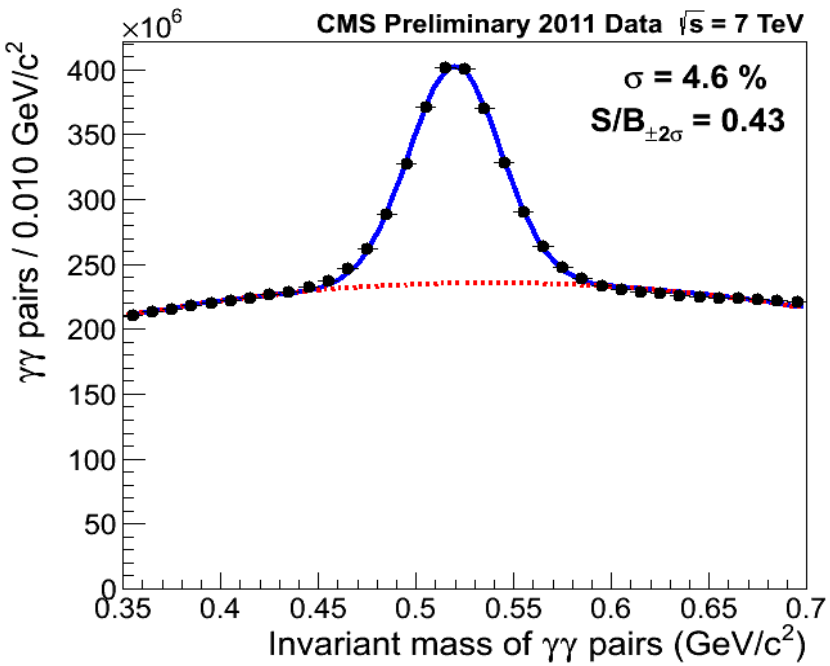
- Similarly, for φ-symmetry stream only crystals with energy depositions above a threshold are stored for events passing L1 ZeroBias triggers.

$\pi^0/\eta \to \gamma\gamma$ Selection and Calibration Samples in the Barrel

Based on local, ECAL variables — suitable for online filter farm.

- **Kinematics: $P_T(\gamma)$ >0.8 GeV, P_T(pair) > 2 GeV (> 3 GeV for η decays).**
- **Photon shower-shape cuts: S_4/S_9 > 0.83, where the sums S_i are defined with 2x2 and 3x3 crystal matrices.**
- **Isolation cut optimized to remove pairs with converted photons.**

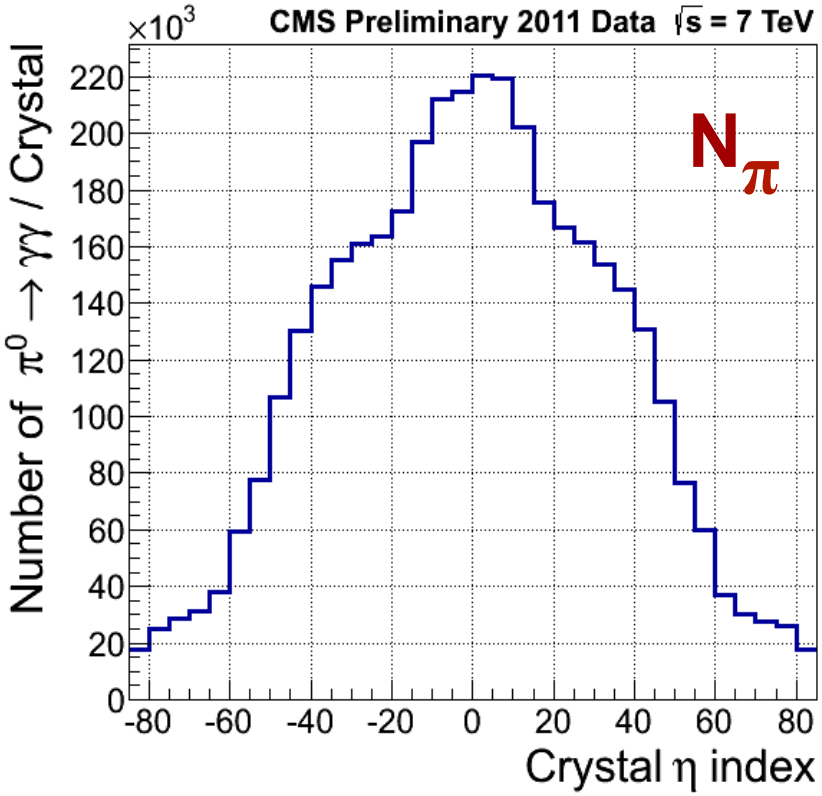


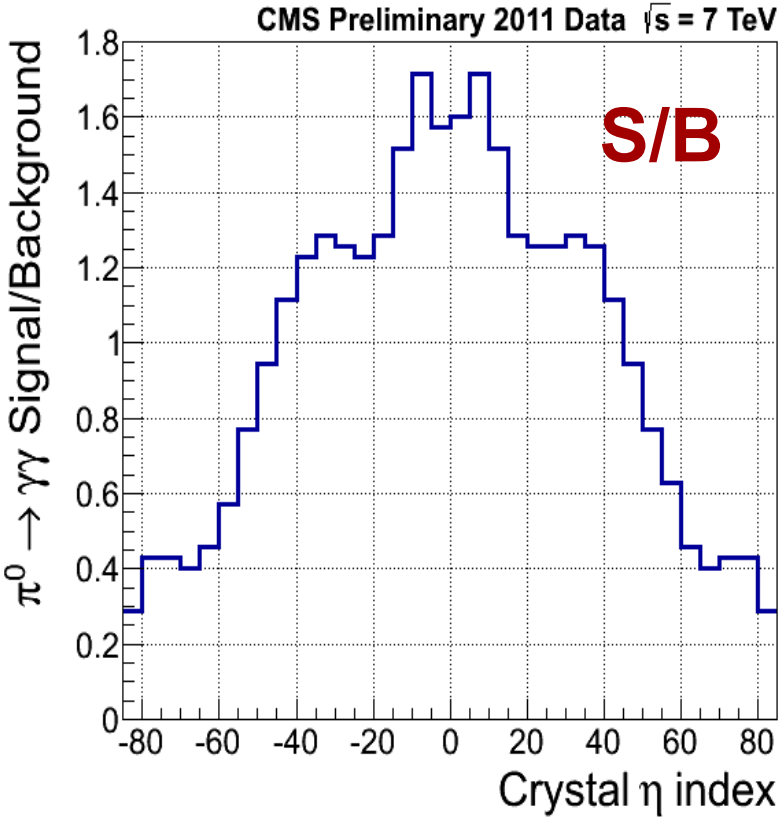


In 2011, collected about 10^{10} $\pi^0 \to \gamma\gamma$ and 10^9 $\eta \to \gamma\gamma$ decays in the barrel region. Peak resolution dominated by the error on the opening angle.

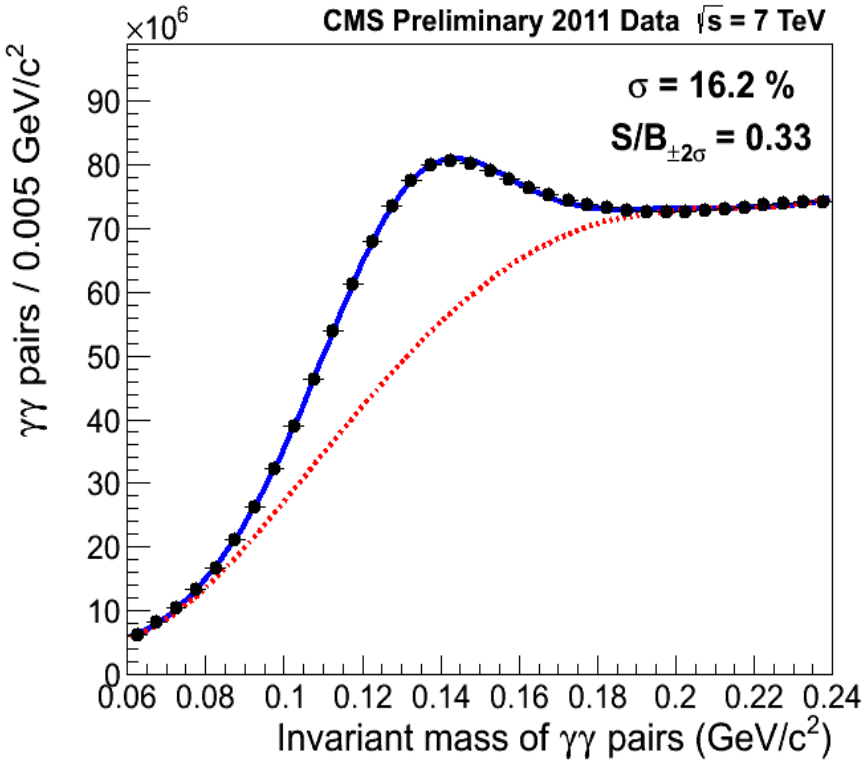
π^0/η Calibration Performance

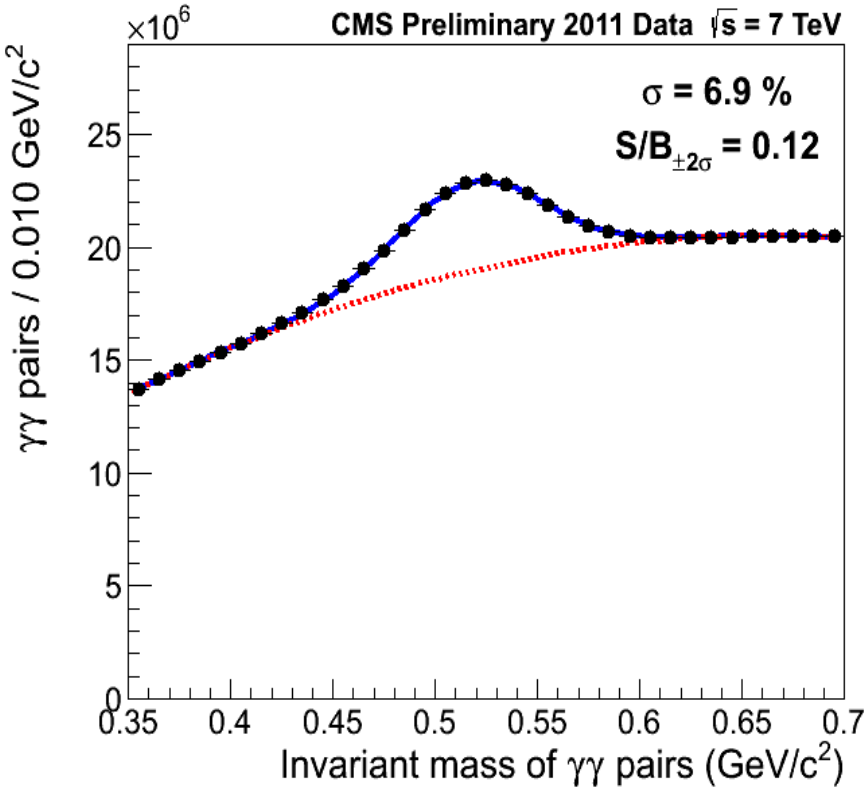
- The single-crystal calibration precision in the barrel is dominated by systematics and was found to be 0.5% (1%) for $|\eta|<1$ ($|\eta|>1$).
- Calibration updated each month in 2011 (every 2-3 months in the endcaps).





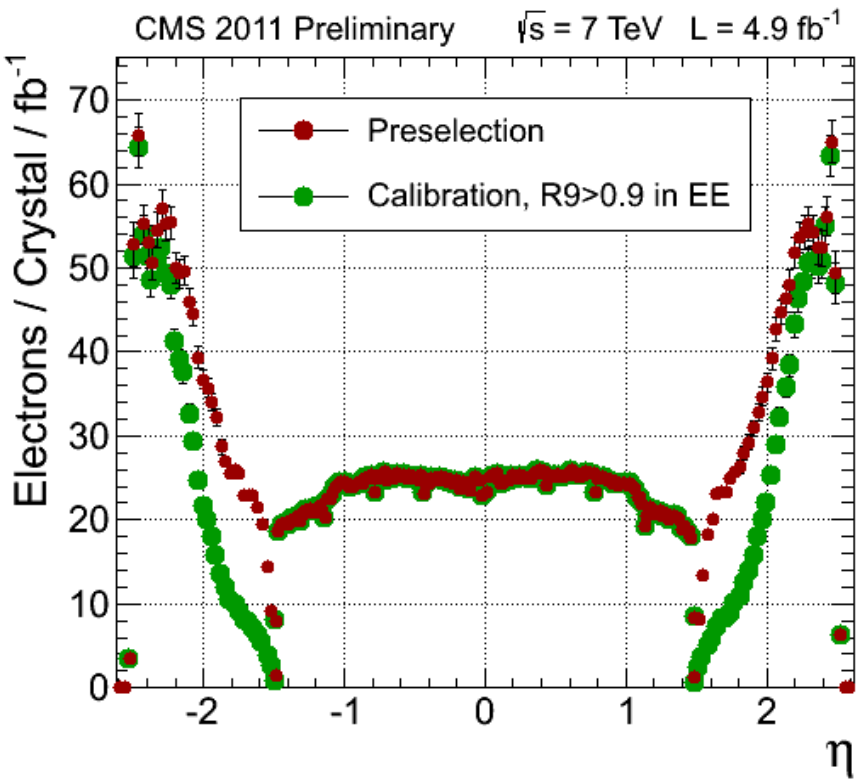
$\pi^0/\eta \rightarrow \gamma\gamma$ Calibration in the Endcaps

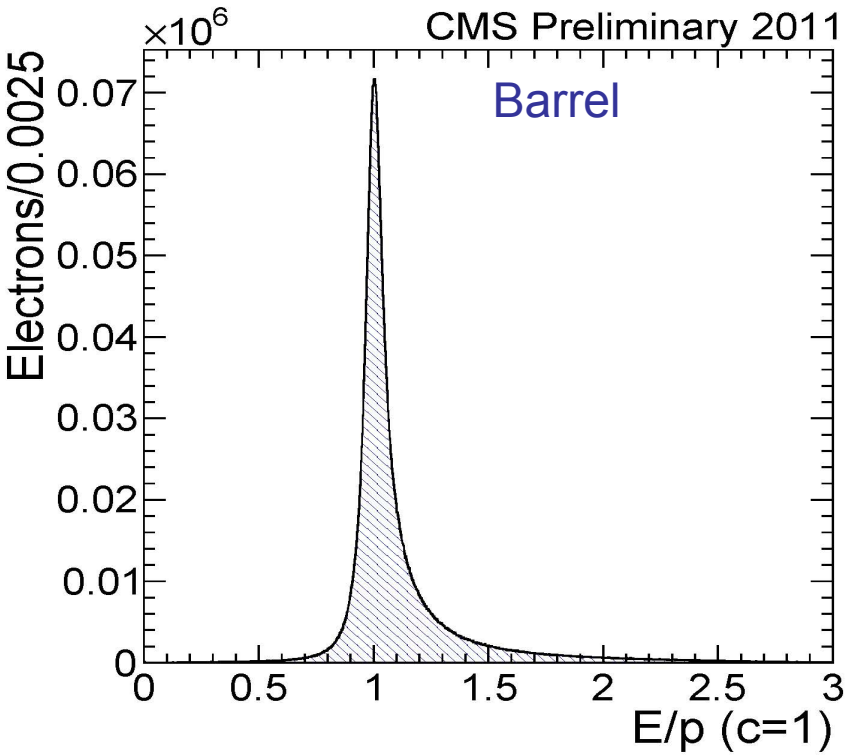




- **2011 calibration sample in the endcaps consists of 3×10^8 $\pi^0\rightarrow\gamma\gamma$ and 3×10^7 $\eta\rightarrow\gamma\gamma$ decays. Similar calibration procedure used.**
- **The calibration precision estimated to be about 2-3%. Lower because of higher background, larger crystal size and increased material in front of ECAL; also dominated by systematics.**

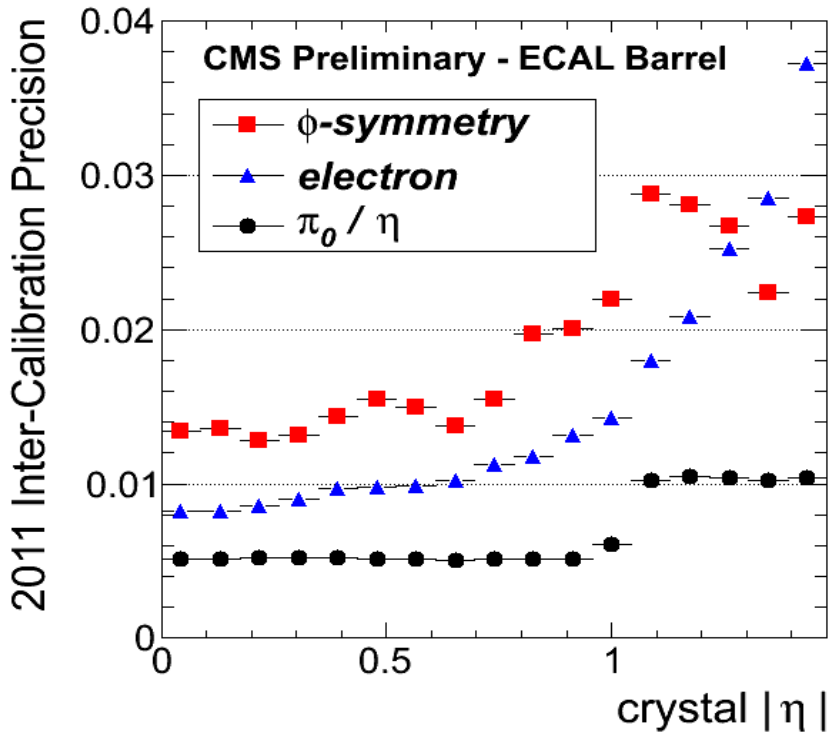
Single-Electron Calibration

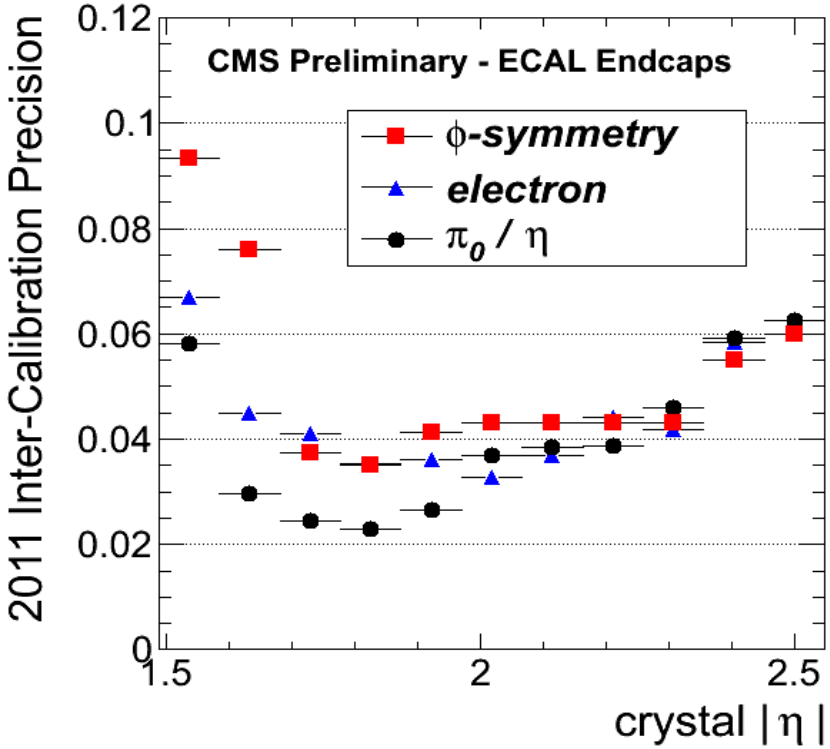




- Select electron candidates from $W \rightarrow e\nu$ decays with E_T>30 GeV. Further electron ID and isolation cuts: purity of the sample is 99%. ~120 electrons per crystal in the barrel for the entire 2011 dataset.
- Calibration is performed using an iterative procedure by fitting E(ECAL)/p(tracker) distributions for each crystal. Precision is up to 1% in the central barrel, limited by statistics.

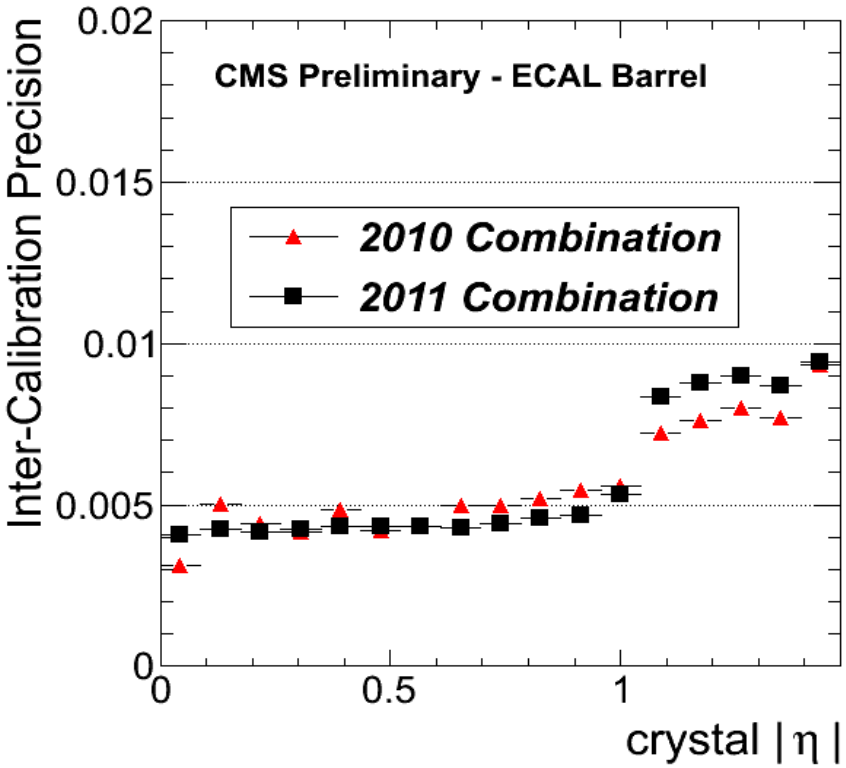
Each Method Plays an Important Role

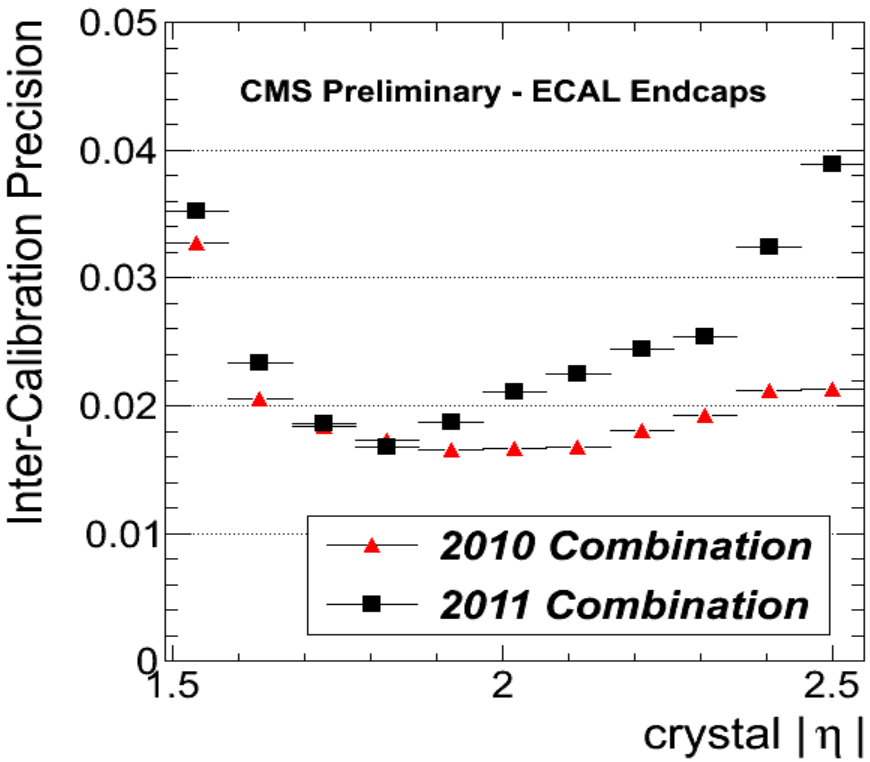




- The single-crystal calibration precision in the barrel is dominated by $\pi^0(\eta)$ precision while in the endcaps all three methods give similar precision.
- Single-electron calibration became important in 2011 due to increased integrated luminosity and is still statistically limited (good news for 2012).

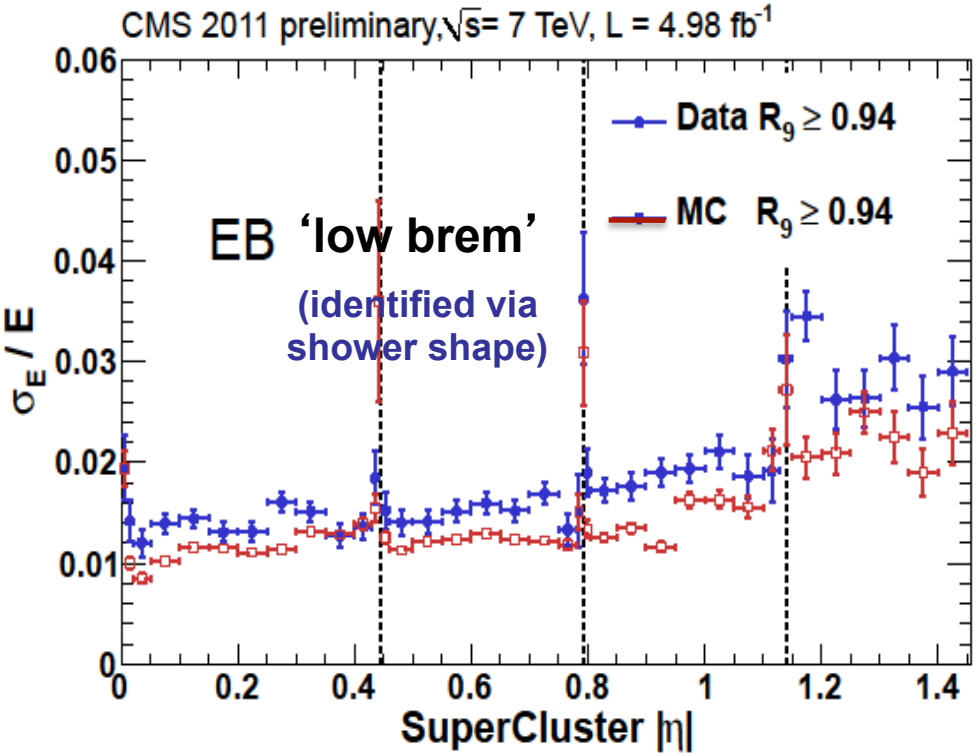
Overall Calibration Precision

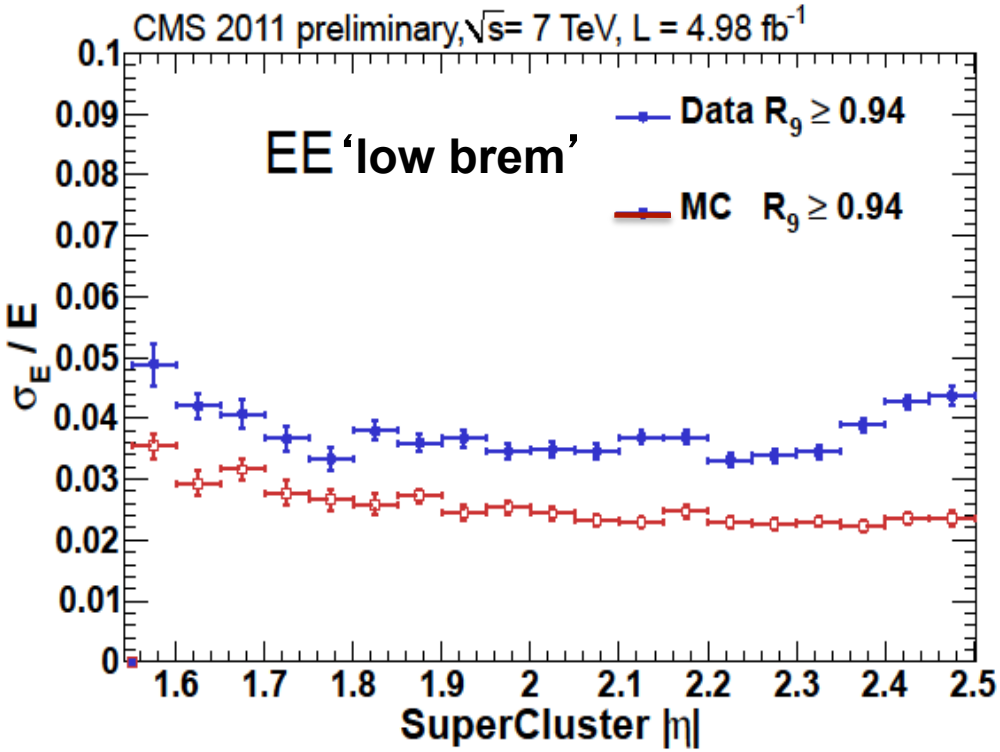




- Overall calibration precision is about 0.5% for $|\eta|<1$ and 0.9% for $1<|\eta|<1.4$ in the barrel. In the endcaps, the precision is 2-3%.
- This level of precision has been maintained starting from the second half of 2010 throughout the whole 2011.

Impact on the Energy Resolution

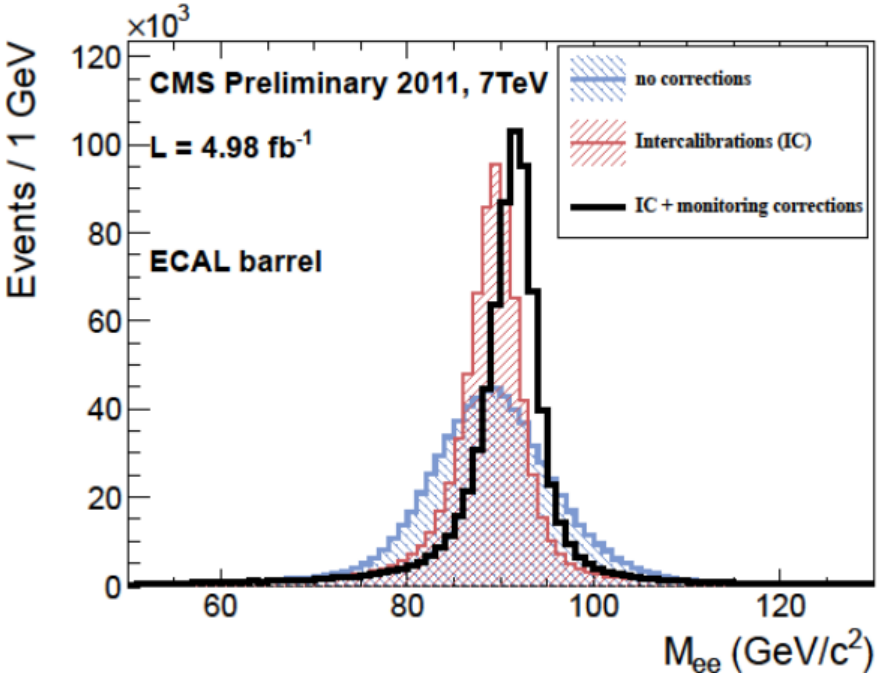


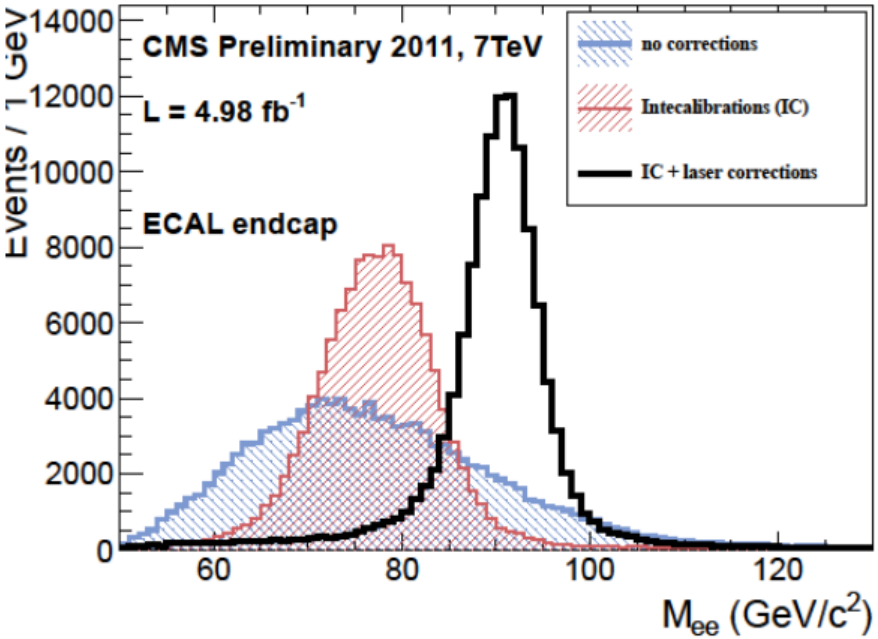


- The energy resolution for electrons was estimated using Z→ee decays and compared with simulations where the estimated calibration precision was taken into account.
- The single-crystal calibration precision (σ_{calib}) is not the driving factor for the observed energy resolution: contribution to the constant term is about $0.75\times\sigma_{calib}$ due to the shower spread over several crystals.

Summary

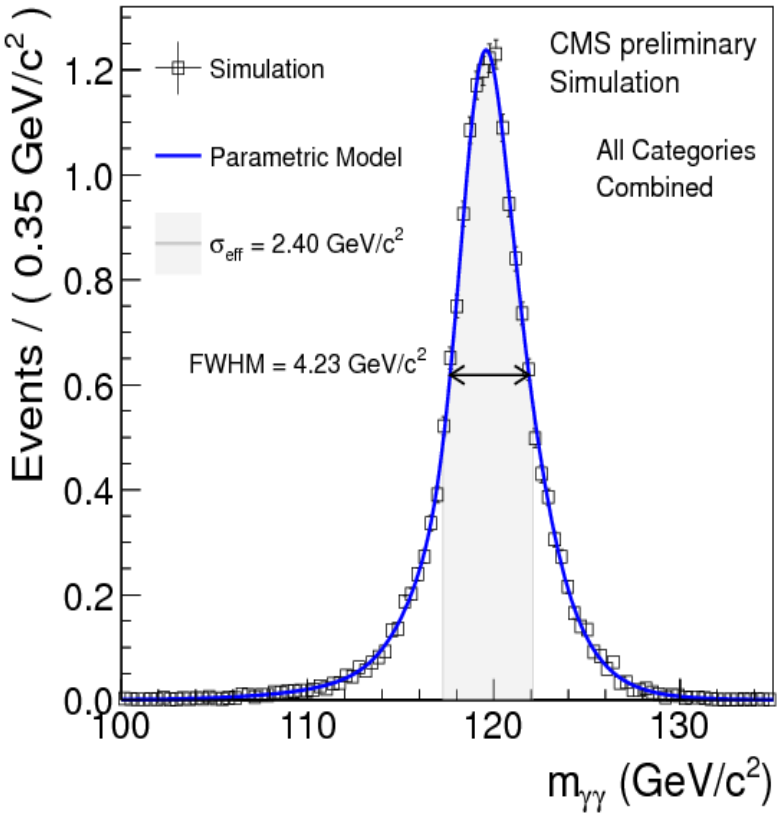
- A single-crystal calibration precision of 0.5% (0.9%) in the central (outer) barrel has been achieved and maintained from mid-2010 to end of 2011, reaching the design goal of 0.5%. In the endcaps, the calibration precision is 2-3%.
- In 2012, further improvements are expected not only from the increase in the calibration statistics but also from a further refinement of the calibration methods.



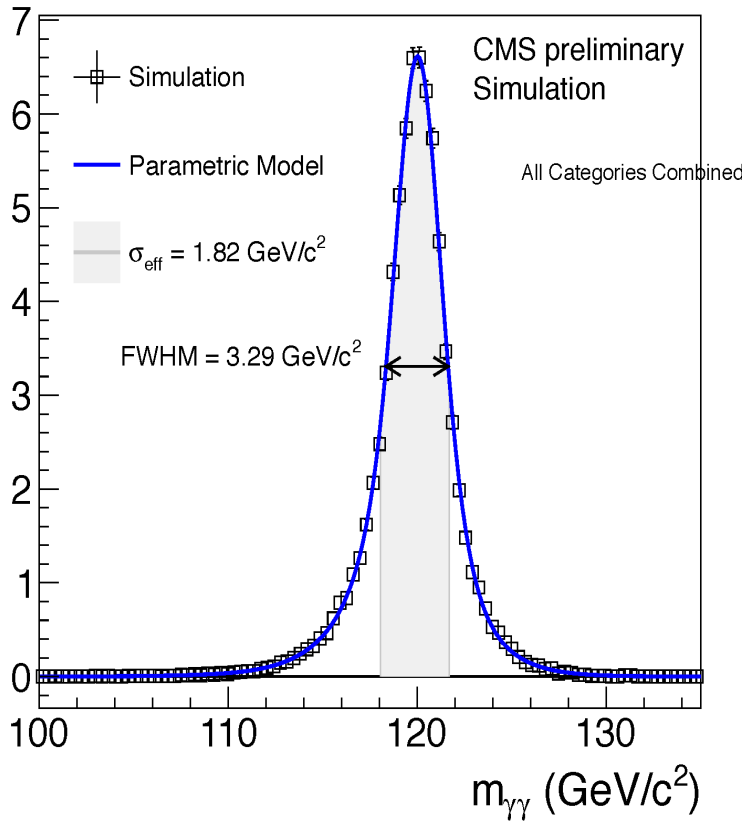


The Outlook ? (Progress in understanding ECAL)

- **July 2011 (EPS):**
  - FWHM = 4.23 GeV/c^2



- **March 2012 (Moriond)**
  - FWHM = 3.29 GeV/c^2



- **Improved single crystal and cluster corrections**

- **July 2012 (ICHEP)**
  - FWHM = **nan**

- **In progress…**