Inter-Calibration of the CMS Electromagnetic Calorimeter with $\pi^0(\eta) \rightarrow \gamma\gamma$

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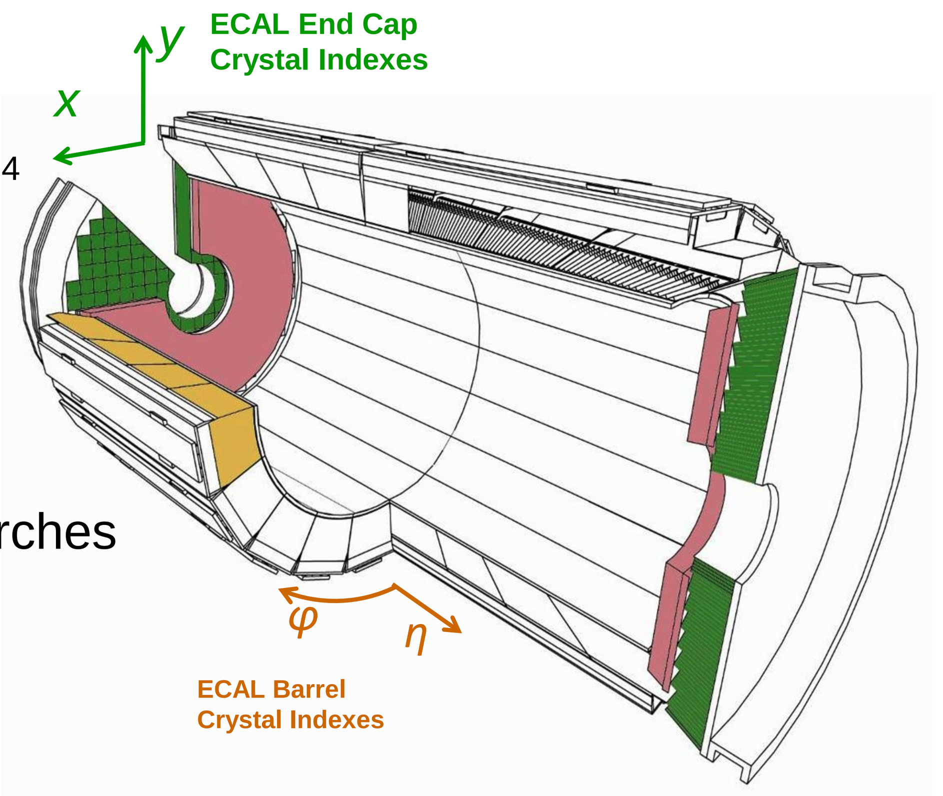
CMS ECAL Calibration Overview

- ECAL consists of 75,848 crystals (61,200 in the Barrel) of high resolution, high granularity scintillating $PbWO_4$
- Inter-calibration precision is expected to be one of the key contributions to the constant term of the energy resolution:

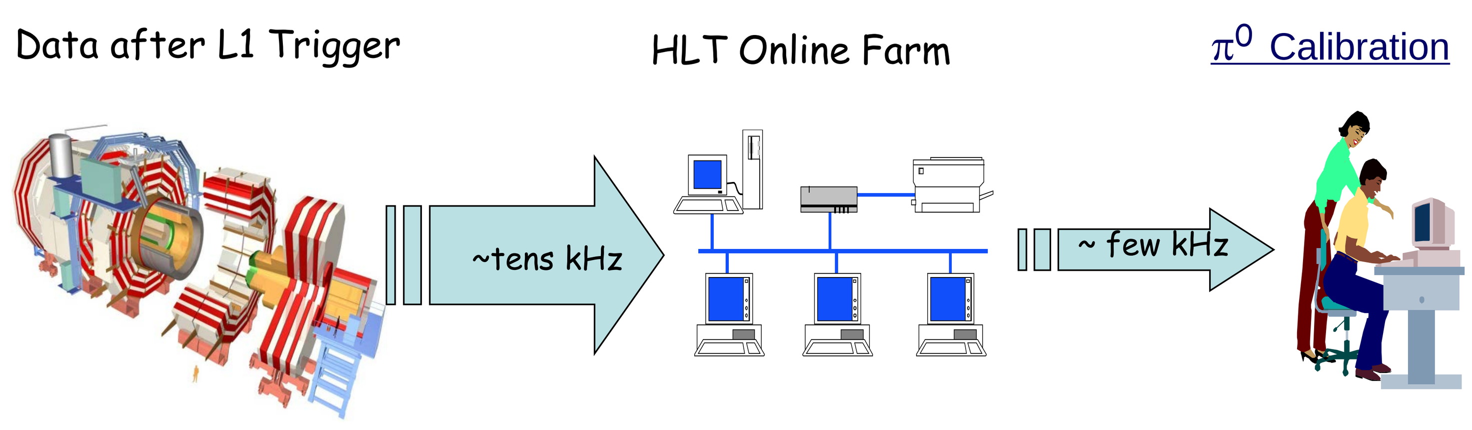
$$\frac{\sigma(E)}{E} = \frac{2.8\%}{\sqrt{E(\mathrm{GeV})}} \oplus \frac{12\%}{E(\mathrm{GeV})} \oplus 0.3\%$$

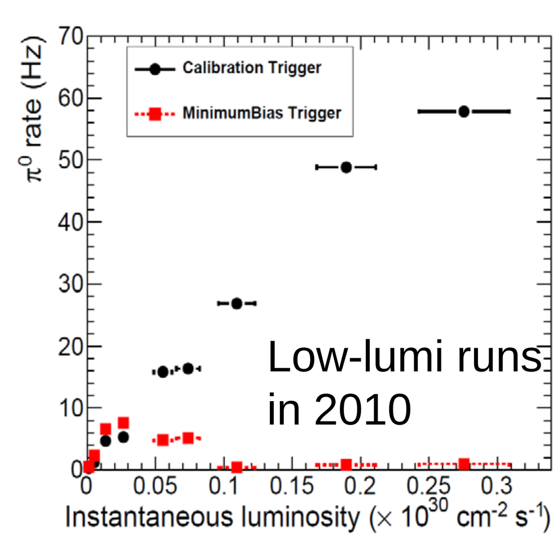
- Achieving the design-goal inter-calibration precision of 0.5% is particularly important for the Higgs boson searches in the decay channel $H \rightarrow \gamma\gamma$.
- Several strategies have been explored for in-situ crystal-by-crystal inter-calibration:
  - ϕ-symmetry calibration, exploiting invariance around the beam axis of energy flow in minimum bias events.
  - $\pi^0(\eta) \rightarrow \gamma\gamma$ calibration, exploiting the reconstructed $\boldsymbol{\pi^0(\eta) \rightarrow \gamma\gamma}$ peak position for individual crystals.
  - single-electron calibration, exploiting the E/p from ECAL and tracker measurements.

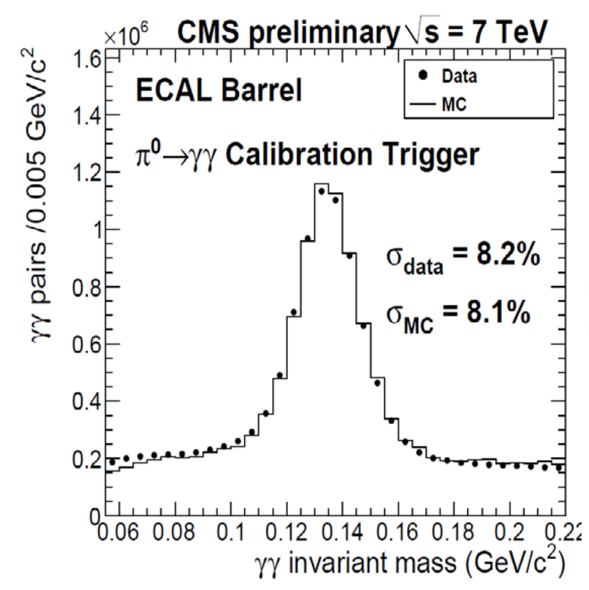


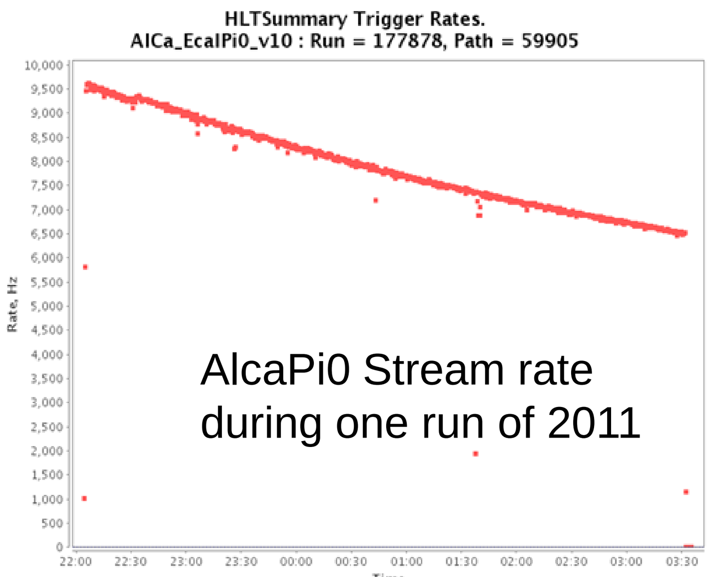
The $\pi^0(\eta)$ Calibration Trigger

- ~3000 π^0 / crystal are needed to reach a statistical precision of calibration of 0.5%; Therefore, it is not sufficient to use the physics High Level Trigger, which is limited to a rate of O(100) Hz, to obtain a fast inter-calibration on a time scale of a few weeks.
- A special calibration trigger has been developed and is running at the HLT, with features listed below:
  - **Level-1 seeds.** Electromagnetic triggers and jet triggers are used to enhance the rate.
  - **Regional unpacking**. Only ECAL raw data around Level-1 EG trigger objects above a 2GeV E_T threshold are used. This step not only enhances the selection efficiency but also reduces the CPU time consumption at the HLT filter farm.
  - **Special clustering algorithm and simplified selection**. Fast 3x3 clustering algorithm is used to make photon candidates. Simplified selection criteria on photon E_T, shower shape and isolation, all based on ECAL crystal variables, are used to select $\pi^0(\eta)$ candidates for calibration.
  - **Light event content.** Only EcalRechits which are useful for offline calibration are saved on tape (~50 Rechits per event).







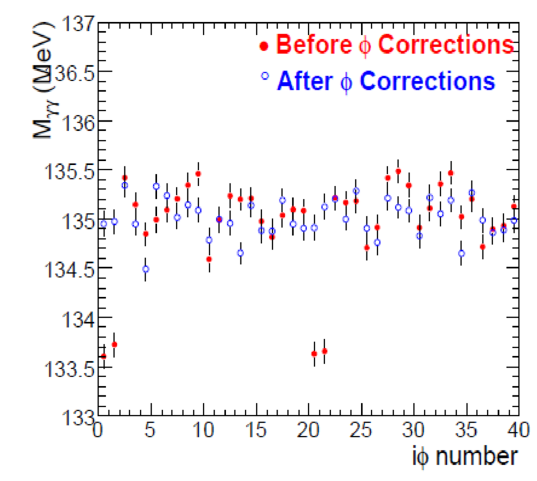


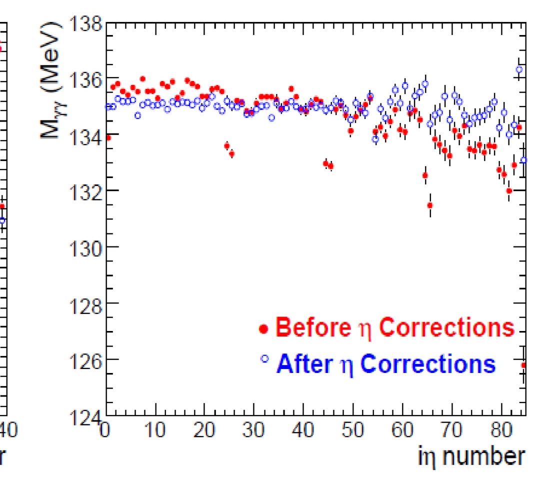
$\pi^0(\eta)$ Calibration Method

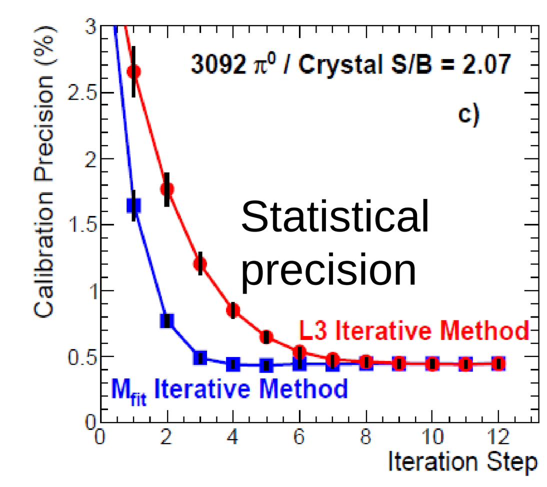
- The energy of each photon candidate is calculated as the sum of all crystals' energies, taking into account the Laser Correction value (LC) and Inter-Calibration constant (IC).

$$E = \sum_j ADC_j \times GeV/ADC \times LC_j \times IC_j \qquad M_{inv} = \sqrt{2E_1E_2(1-\cos\theta_{12})}$$

- Inter-calibration with the physics resonances $\pi^0(\eta) \rightarrow \gamma\gamma$ derives the IC for each crystal using the resonance peak position reconstructed with $\pi^0(\eta)$ candidates selected by requiring one of the two photons to be centered on that crystal.
- Uniformizing the peak positions obtained for individual crystals gives the IC for each crystal. However, several other effects were found to bias the measurement of the photon energy:
  - Variations of the shower containment with energy and pseudorapidity;
  - Energy losses for photons near module cracks and gaps;
  - Energy losses for photons near dead or masked trigger towers or crystals;
  - Imperfections of the laser corrections.
- Special corrections have been derived from the calibration data to minimize the bias in the IC due to the above effects, except the laser corrections which are derived from a separate laser monitoring data.
- Two inter-calibration iterative algorithms were found to be consistent:
  - The L3 method, first developed for the calibration of the ECAL crystals at the L3 experiment.
  - The Fit method, fitting the invariant mass distribution obtained for each individual crystal.

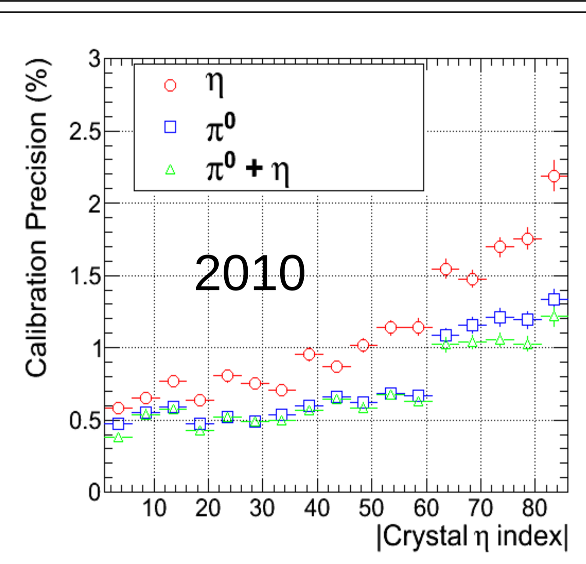


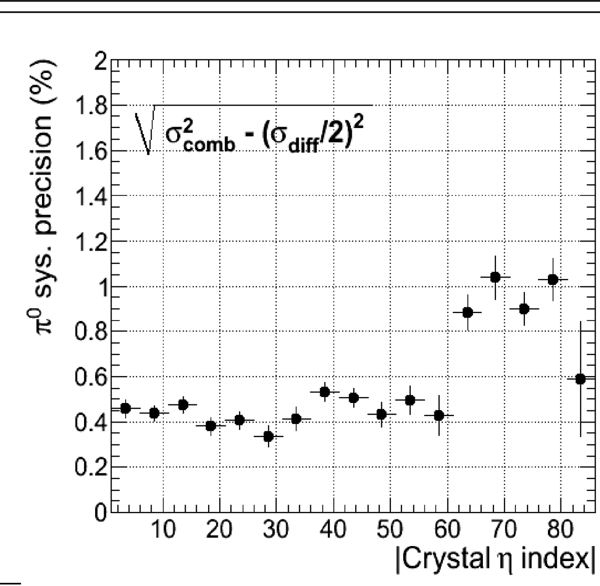


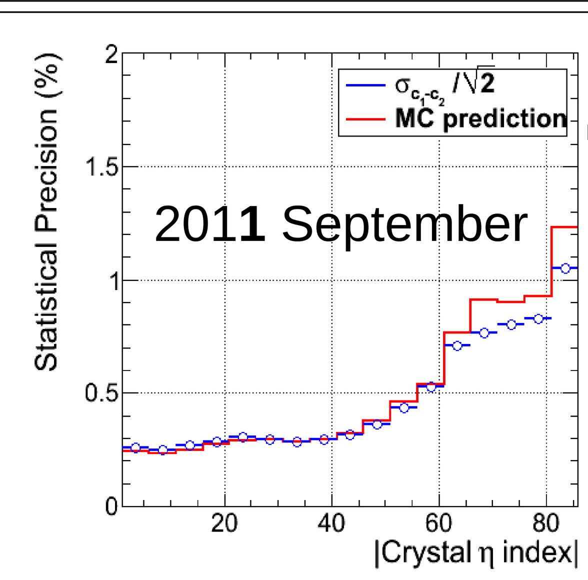


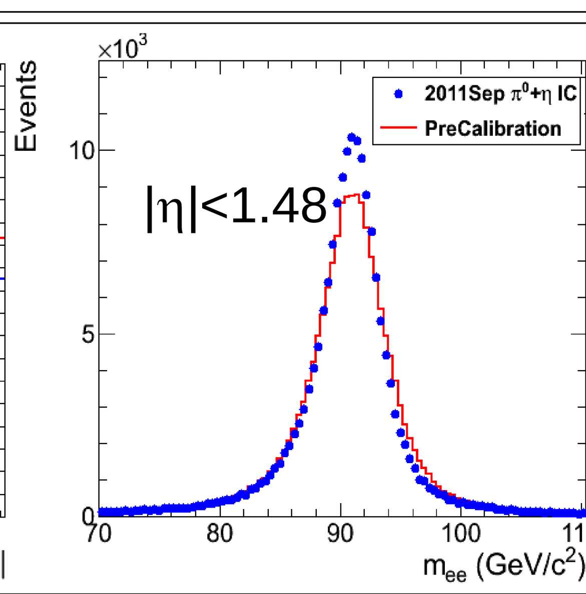
Inter-calibration Performance

- With 2010 data, inter-calibration with $\pi^0(\eta) \rightarrow \gamma\gamma$ reached the precision of 0.5-0.6% for $|\eta|<1$ in Barrel. Systematic precision found to be 0.4-0.5%.
- Similar calibration precision was achieved throughout 2011, despite a higher level of crystal transparency change.









Summary and Outlook

- Dedicated $\pi^0(\eta) \rightarrow \gamma\gamma$ calibration stream proved to be capable of sustaining the high output rate of about 10 kHz.
- In 2010 and 2011, the $\pi^0(\eta) \rightarrow \gamma\gamma$ has been the most important inter-calibration method for CMS ECAL. The design-goal inter-calibration precision of 0.5% has been reached for the majority of the barrel ($|\eta|<1$).
- Precise sub-percent inter-calibration of a crystal calorimeter at a hadron collider performed for the first time.
- The $\pi^0(\eta)$ calibration continues to play an important role for precision physics with photons and electrons at CMS.

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