Performance of the CMS Electromagnetic Calorimeter

And the Challenge of the Calibration

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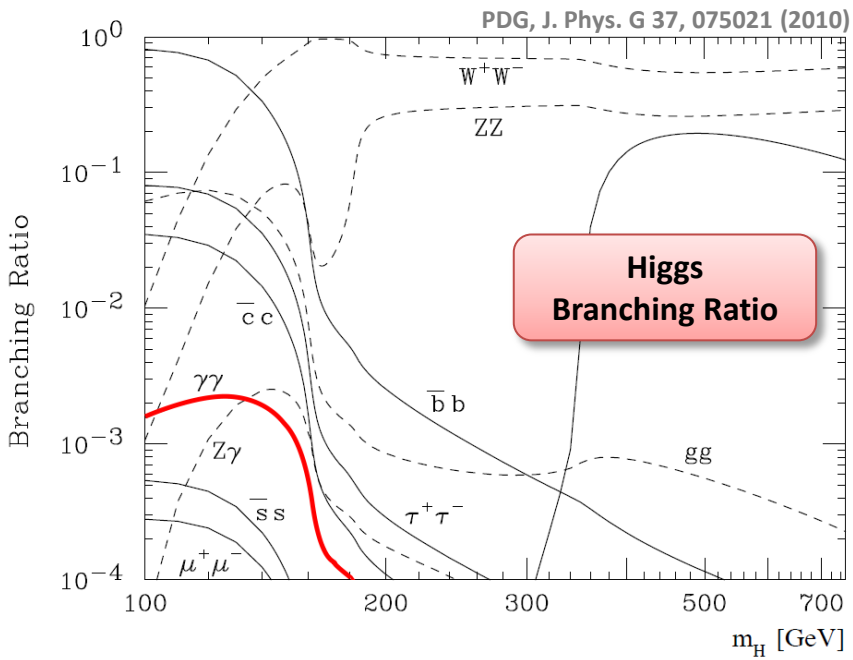
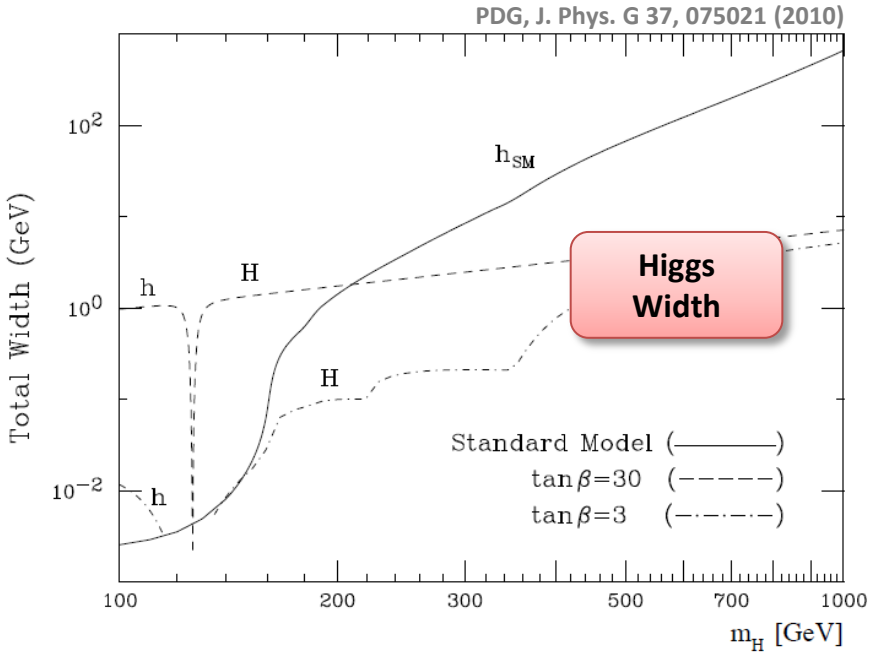
On behalf of the CMS ECAL Group

Physics with High Energy Photons





Low mass Higgs decays into b,τ,γ

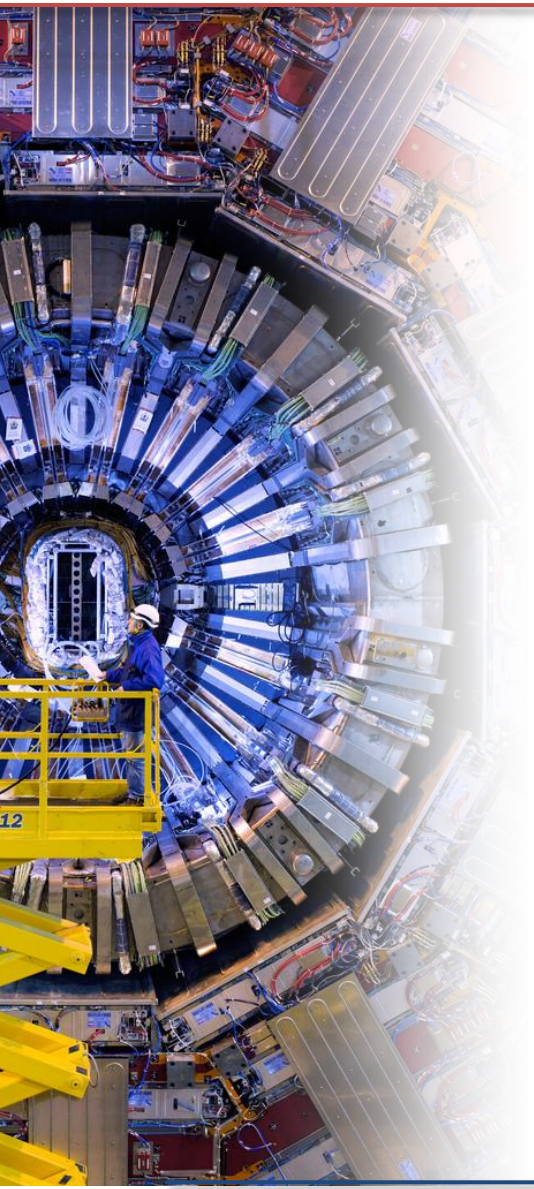
γ background well known

Relevant when looking for a small bump

SM Higgs: narrow resonance at low mass

Photon energy resolution drives discovery capability

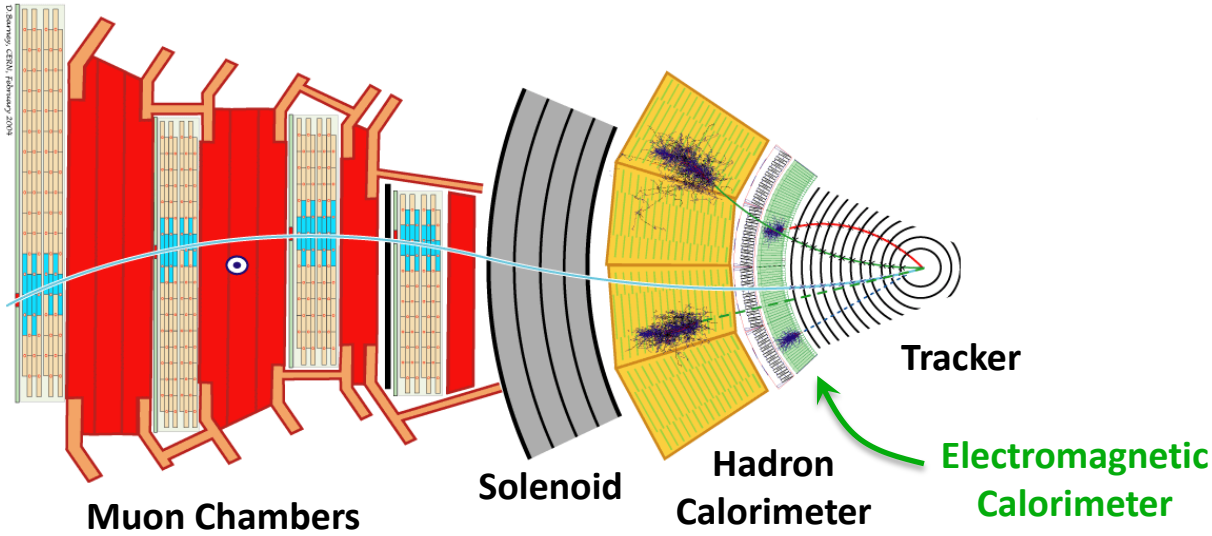
The Compact Muon Solenoid at the Large Hadron Collider



Large Hadron Collider (LHC)

- Proton-proton collisions at $\sqrt{s}$ =7 TeV
- Achieved Luminosity >$2 \cdot 10^{33}$ cm^{-2} s^{-1} (1380 bunches)
- More than 1 fb^{-1} data delivered

Compact Muon Solenoid (CMS) Experiment

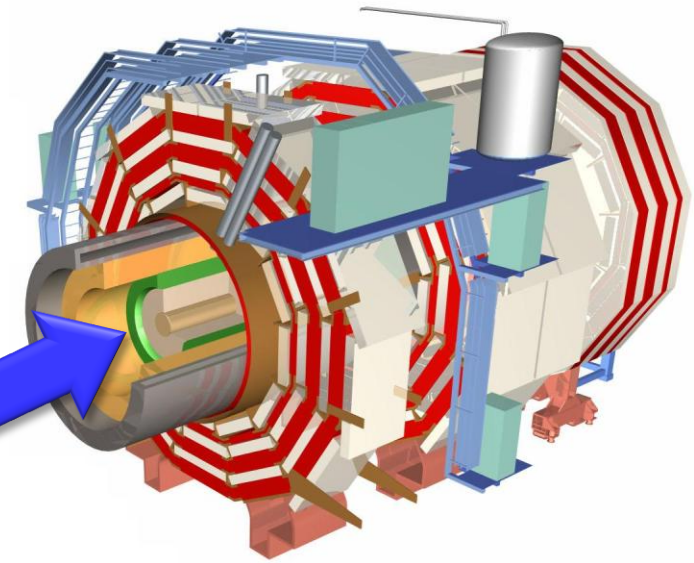


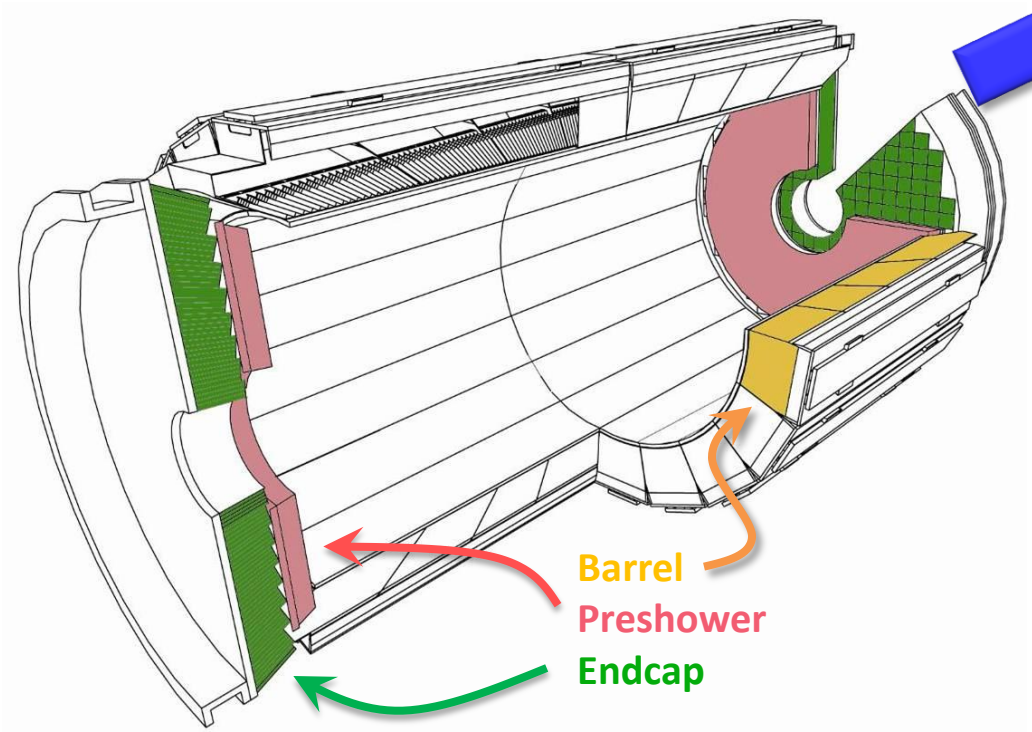
The Electromagnetic Calorimeter (ECAL)

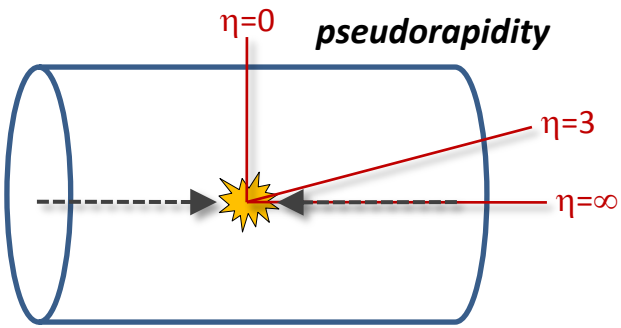
ECAL Features

- Homogeneous Calorimeter (>75000 $PbWO_4$ crystals)
- High density (8.3 g/cm^3),
- Short Radiation Length (0.89 cm)
- Small Moliere Radius (2.2 cm)

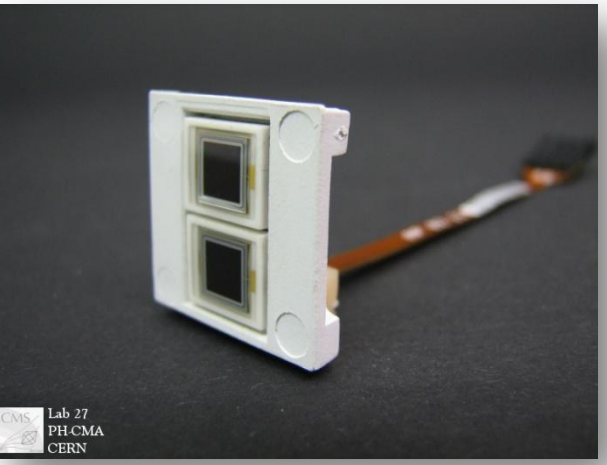
Compact
Fine Granularity





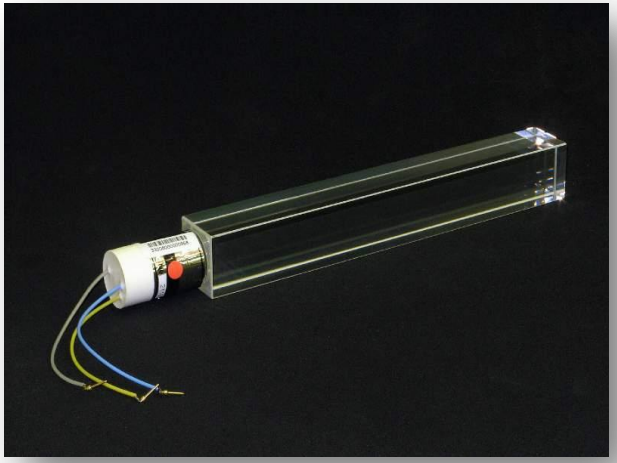


ECAL Photodetectors



Barrel:
Avalanche PhotoDiodes (APD)

- two 5x5 mm^2 sensors
- high QE: ~75%
- Temp. Sensitivity -2.4%/°C



Endcaps:
Vacuum PhotoTriodes (VPT)

- 280 mm^2 sensor
- QE: ~20%
- More radiation tolerant than APDs

~4.5 photoelectrons/MeV @ 18 °C both in APD and VPT

Energy Measurement of Electromagnetic Objects

$$E_{e,\gamma} = F_{e,\gamma}(\eta)\; G(GeV/ADC) \sum_i S_i(T,t) \times c_i \times A_i$$

5 4 3 2 1

1) A_i : Measured Amplitude in each channel (ADC counts)
2) C_i: Inter-Calibration Constants
3) $S_i(T,t)$: Corrections for Transparency Loss (T= crystal transparency, t = time)
4) G: ECAL Energy Scale: ADC to GeV Conversion Factor
5) F(η): Object Dependent Correction Factor → Factorises Geometry and Material Effects

Design Energy Resolution

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

stochastic noise constant

$$E_{e,\gamma} = F_{e,\gamma}(\eta)\; G(GeV/ADC) \sum_i S_i(T,t) \times c_i \times A_i$$

Inter-Calibration Methods

Calibration Strategies:

- **ϕ-symmetry** calibration: exploit the energy flow invariance around the beam axis
  - Fast method. Calibration precision limited to ~1.4%

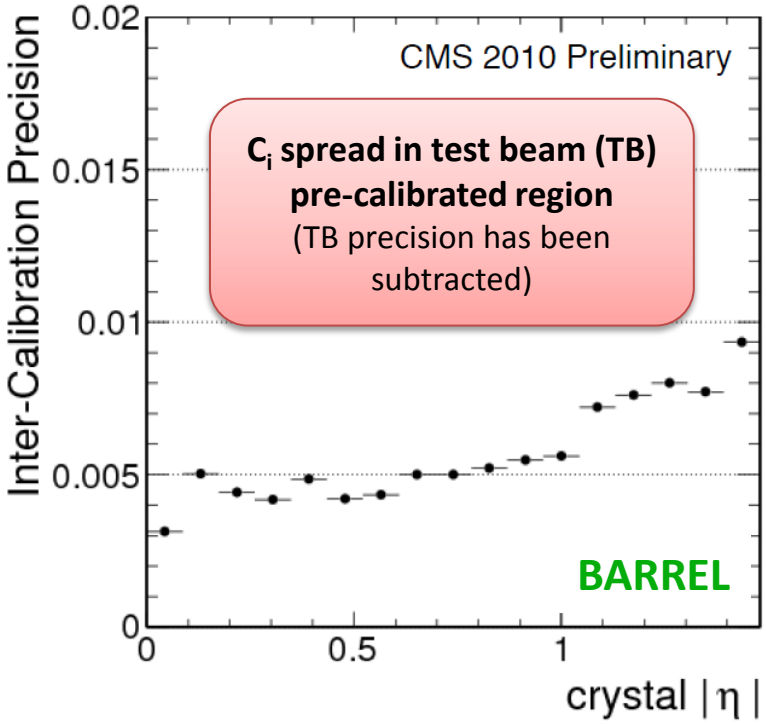
- **π^0 calibration**: photon pairs selected as $\pi^0 \rightarrow \gamma\gamma$ candidates
  - High statistics available (dedicated data stream in data acquisition flow)
  - Allows both crystal inter-calibration and absolute scale calibration

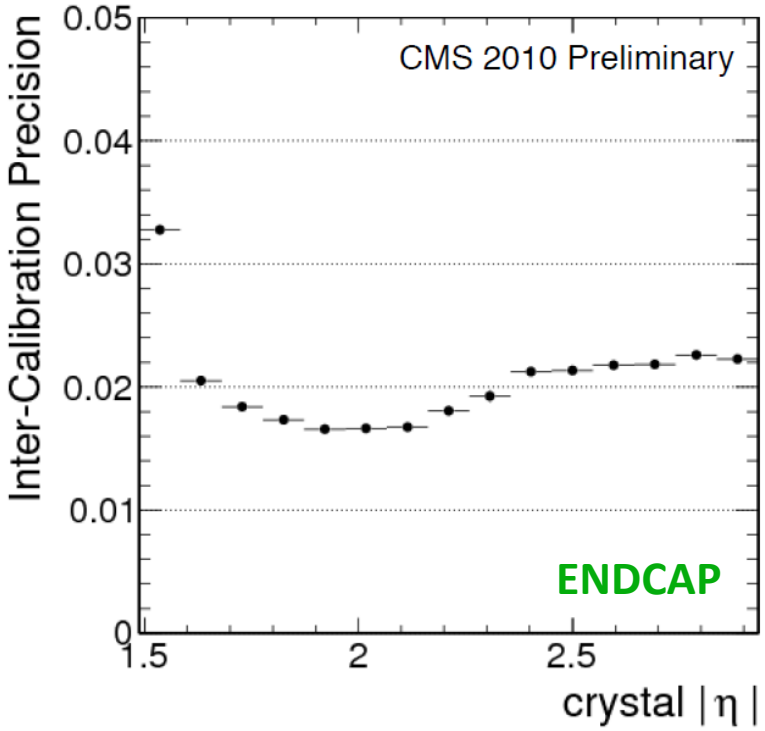
- **Isolated electrons** from $W \rightarrow e\nu$ and $Z \rightarrow e^+e^-$: compare the energy measured in ECAL to the track momentum
  - Several fb^{-1} needed to perform single crystal inter-calibration: integrated luminosity accumulated is not yet sufficient

- **Di-electron resonances** such as $J/\psi \rightarrow e^+e^-$ and $Z \rightarrow e^+e^-$: standard candles to define the ECAL energy scale.
  - Larger data sample is needed. So far Z used to compute only global scale

Inter-Calibration Results

- Inter-Calibration precision combining all the methods
- Barrel: $|\eta| \sim 1$ rapid increase of material budget in front of ECAL
- Endcap: $(|\eta| < 1.6) \cup (|\eta| > 2.5)$ No Preshower Coverage

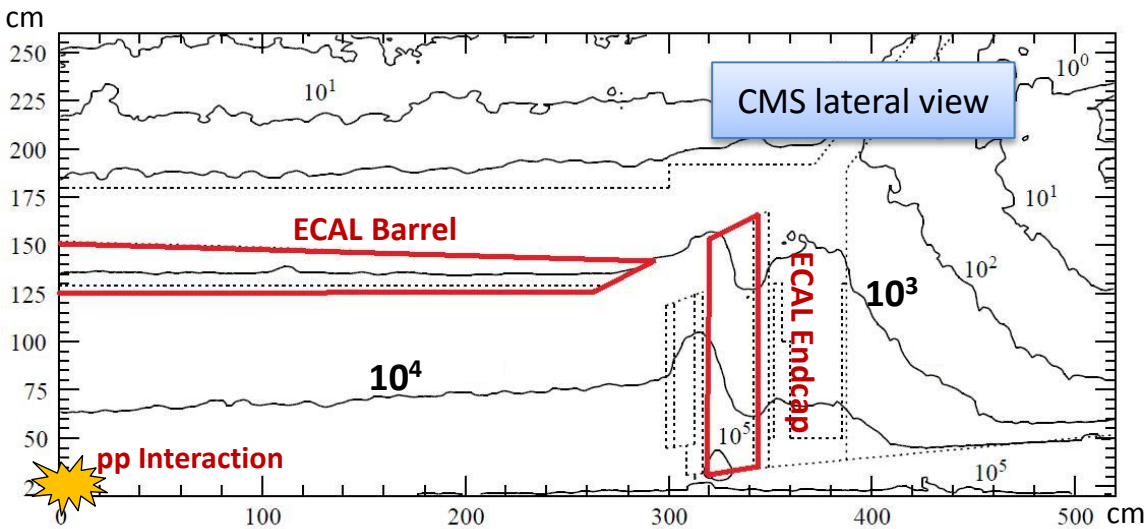




$$E_{e,\gamma} = F_{e,\gamma}(\eta)\; G(GeV/ADC) \sum_i S_i(T,t) \times c_i \times A_i$$

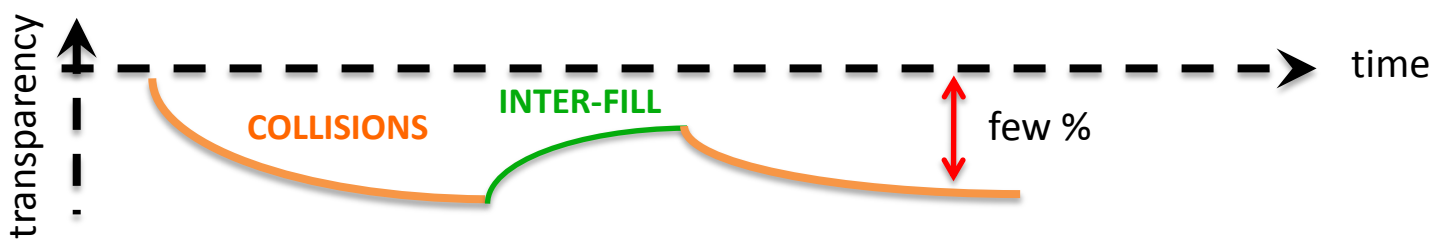
Crystal Radiation Damage

- ECAL crystals have to withstand huge radiation levels

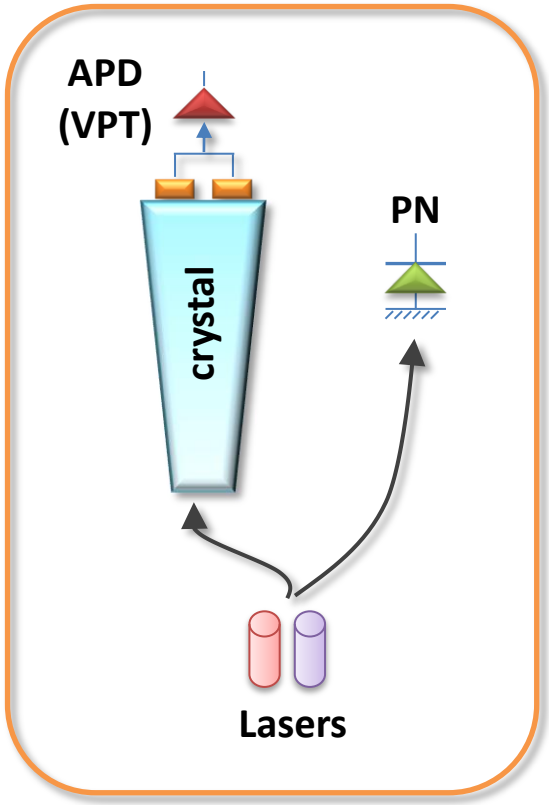


Radiation dose (in Gy) absorbed by ECAL. Corresponding integrated luminosity: 500 fb^{-1}

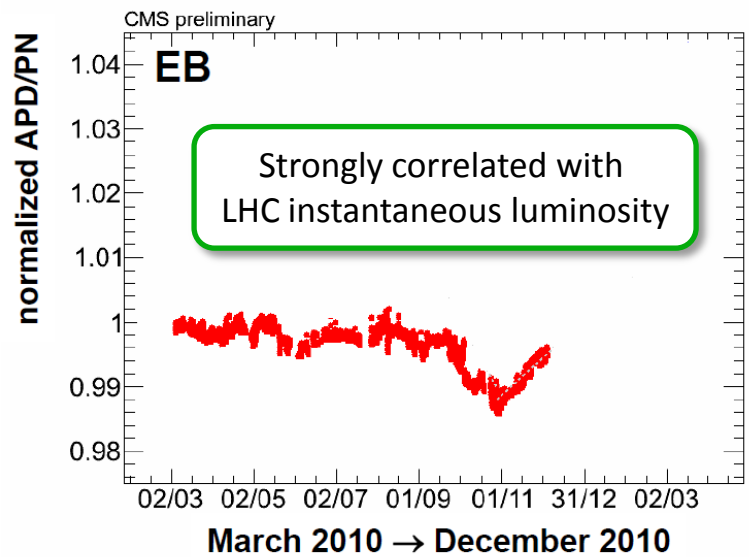
- Radiation ⇨ Wavelength-dependent loss of light transmission (w/o changes in scintillation)
- Crystal Transparency ***drops*** within a run by a few percent and ***recovers*** in the inter-fill periods



Correction for Crystal Transparency Loss: Method

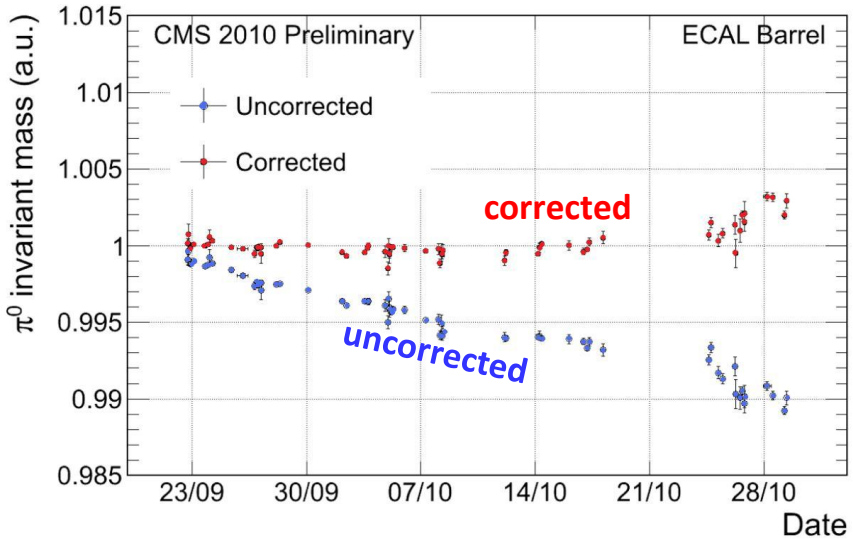


- Inject fixed amount of light (laser) to monitor transparency loss
- **Blue Laser**: check transparency at scintillation wavelength
- **I-Red Laser**: check response stability (blind to color centers)
- Transparency Loss of **~1% in EB** (**~3% in EE**) during 2010

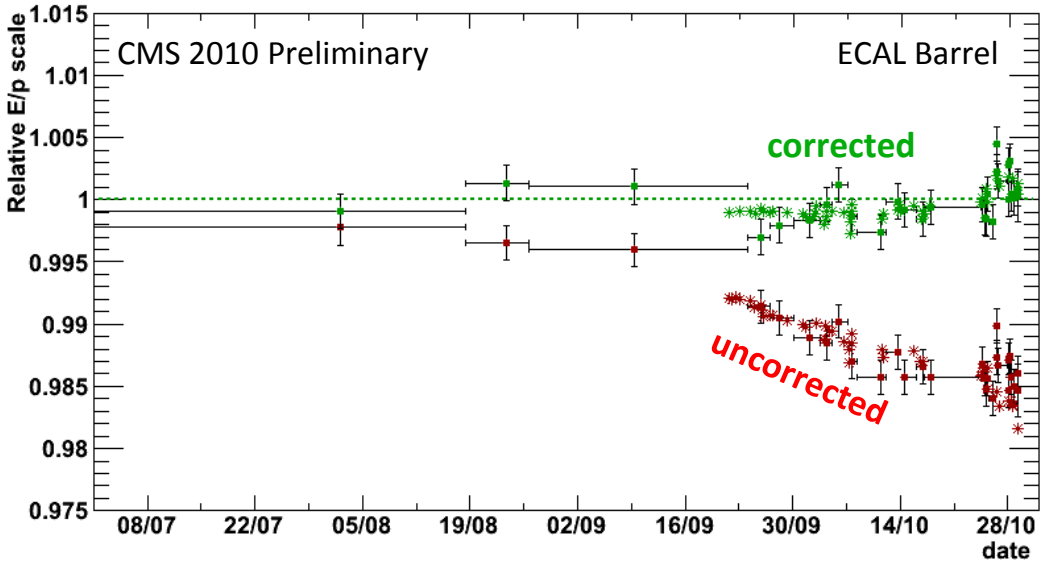


APD: Avalanche Photodiode (EB)
VPT: Vacuum Phototriode (EE)
PN: Reference diode

Correction for Crystal Transparency Loss: Results



- Normalized π^0 **invariant mass** history from di-photon events
- Data before/after laser energy corrections
- In Barrel 1% drop if not accounting for crystal transparency loss



- **Energy/Momentum Ratio** for high energy electrons
- Electrons selected from $W \rightarrow e\nu$ decays
- π^0 and e histories are not directly comparable (different rapidity reconstruction efficiency)

$$E_{e,\gamma} = F_{e,\gamma}(\eta)\ \underline{G(GeV/ADC)} \sum_i S_i(T,t) \times c_i \times A_i$$

Energy Scale Using $Z \longrightarrow e^+e^-$ Decay

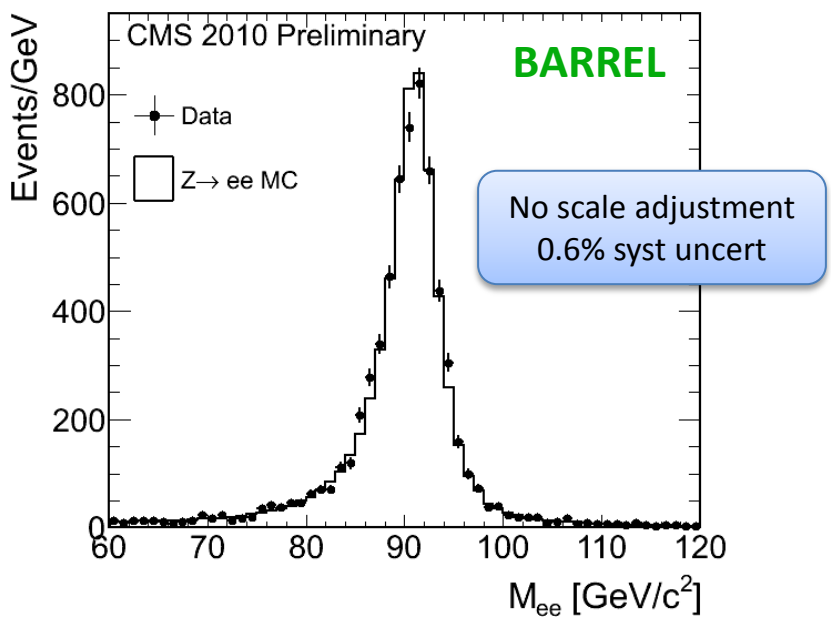
Energy scale measured at **test beam** for EB and EE separately

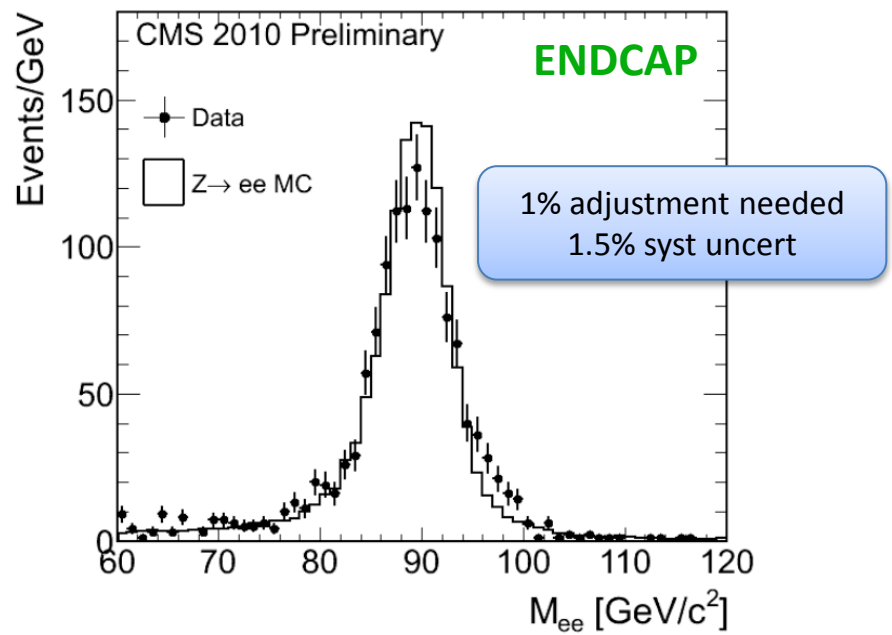
- Goal: equalizing energy sum of 5x5 crystal matrix to the electron beam energy

In-situ determination: reconstructing di-electron invariant mass of Z

- Requiring electrons emitting very low Bremsstrahlung

Method: matching reconstructed invariant mass peak position in data with MonteCarlo position (G-independent)

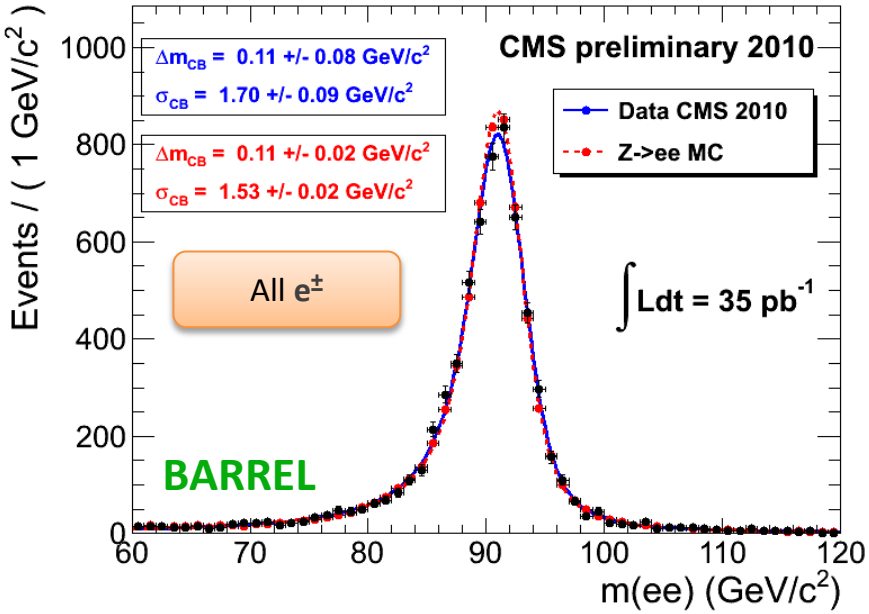


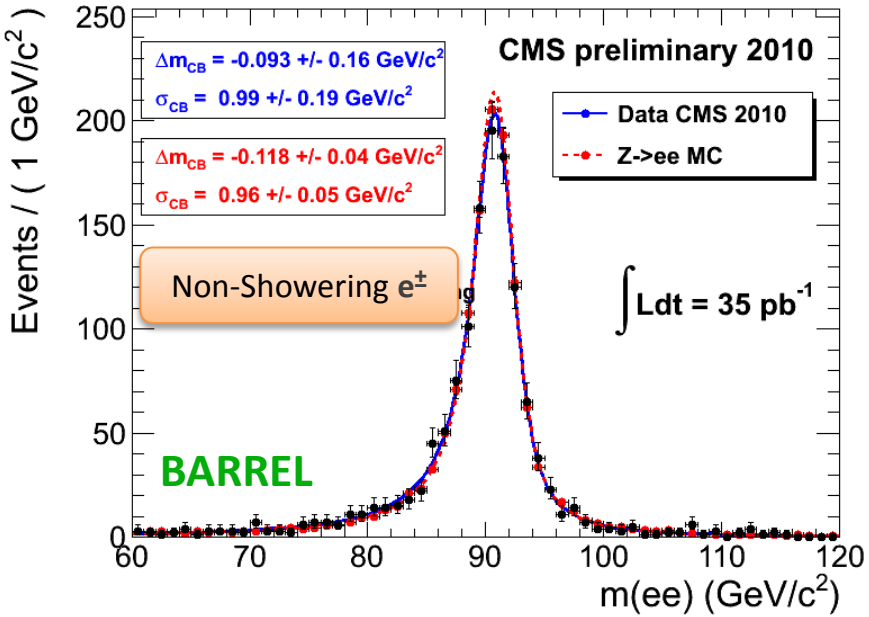


Energy Resolution Using Z Width

- Fit to the Z shape using convolution of Breit-Wigner and Crystal-Ball (CB)
- Δm_{CB}: difference between CB mean and true Z mass. σ_{CB}: width of CB function
- Energy scale of data distribution ***scaled*** to match the mean of the MC distribution

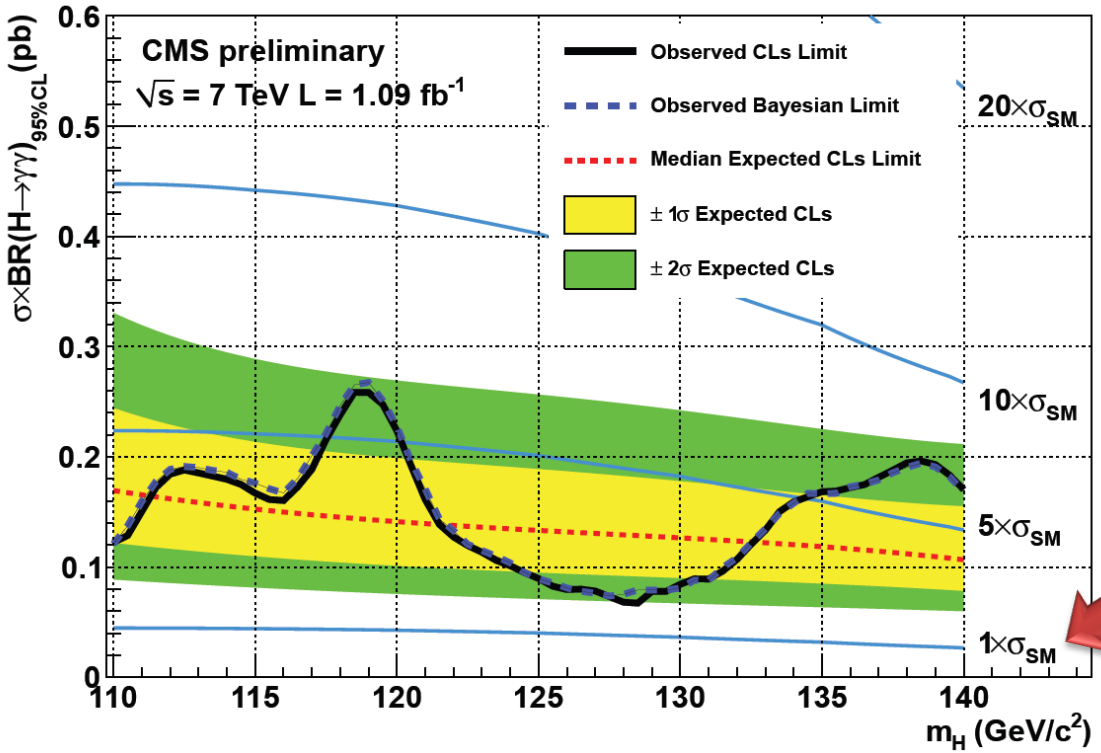
Resolution measured on data matches MC expectation (σ_{CB}~1GeV for non-showering $e^{\pm}$)





Outcome of ECAL Performance: H → γγ Results

- Search for H→γγ performed with 1.09 fb^{-1} *(CMS PAS HIG-11-010)*
- Excluded x2 ÷ x6 Standard Model Cross Section in 110 GeV < m(H) < 135 GeV
- Observed limit within 2σ from expected value



Almost there…

Conclusions

- ECAL is facing a big challenge to keep **energy resolution below 1%** at $E(\gamma)\sim100$ GeV with increasing machine luminosity
- Inter-calibration, laser corrections and absolute scale proved to be well tuned to **achieve design parameters** during 2010 (and begin of 2011) data taking
- $H\rightarrow\gamma\gamma$ is the main Physics channel profiting by ECAL performance, and it is now **reaching the sensitivity to discover/exclude** Standard Model Higgs
- Inter-calibration and laser corrections have to **keep improving** to fully exploit ECAL potential and increase Higgs discovery reach