2019 Meeting of the Division of Particles & Fields of the American Physical Society

Calibration and Performance of the CMS Electromagnetic Calorimeter in LHC Run 2

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On behalf of the CMS collaboration

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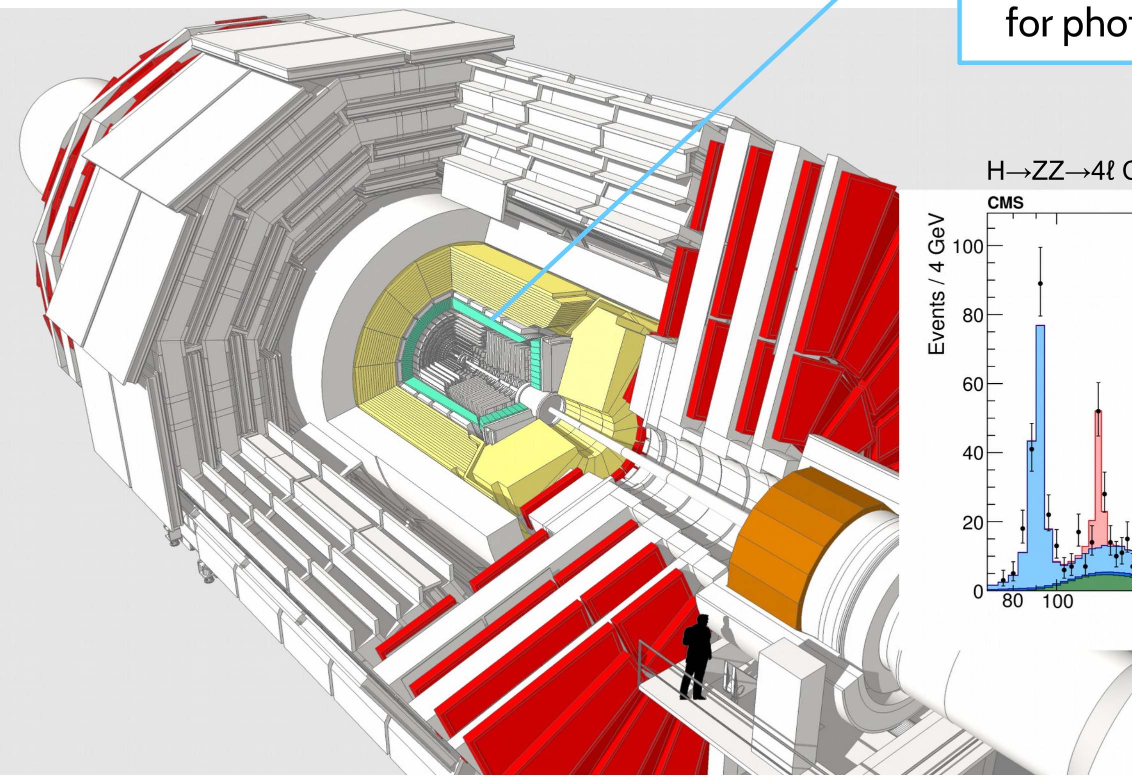
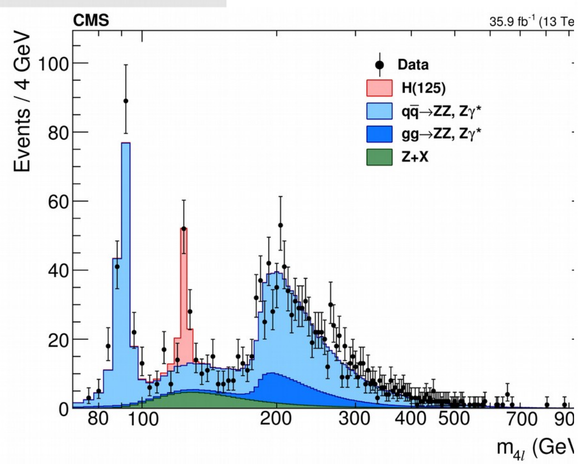
CMS Experiment

ECAL: Compact, homogeneous, hermetic and fine grain calorimeter

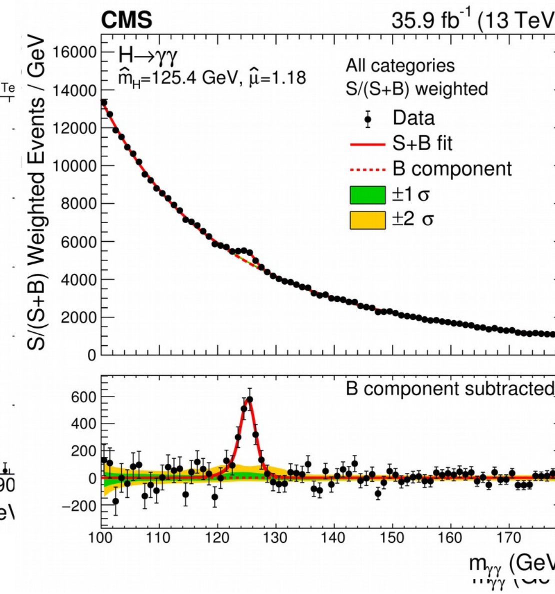
- Embedded in 4 T magnetic field
- 75848 lead-tungstate ($PbWO_4$) scintillating crystals
- Intrinsic light yield 100γ/MeV → 4p.e./MeV on the APDs
- Detector designed for excellent energy resolution for photons with 0.1 MeV-1.5 TeV



H→ZZ→4ℓ CERN-EP-2017-123

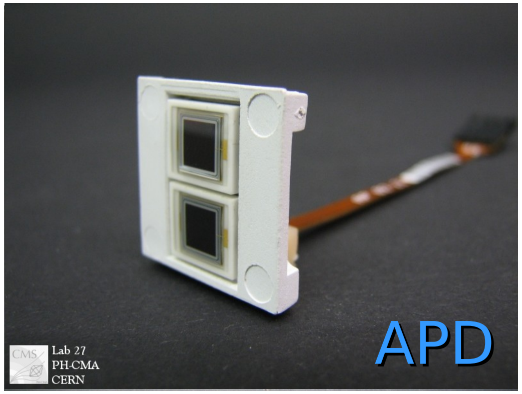


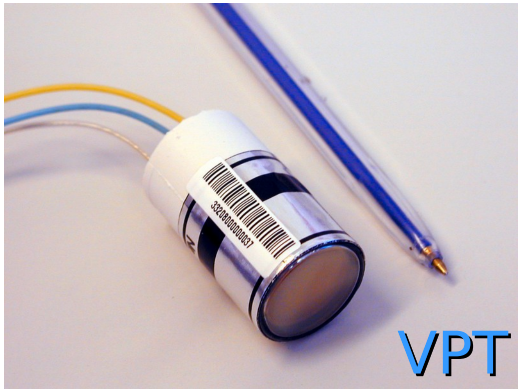
H→γγ CERN-EP-2018-060



Excellent resolution and electron/photon ID of the CMS ECAL crucial for discovery and characterization of the 125 GeV Higgs Boson

ECAL Detector

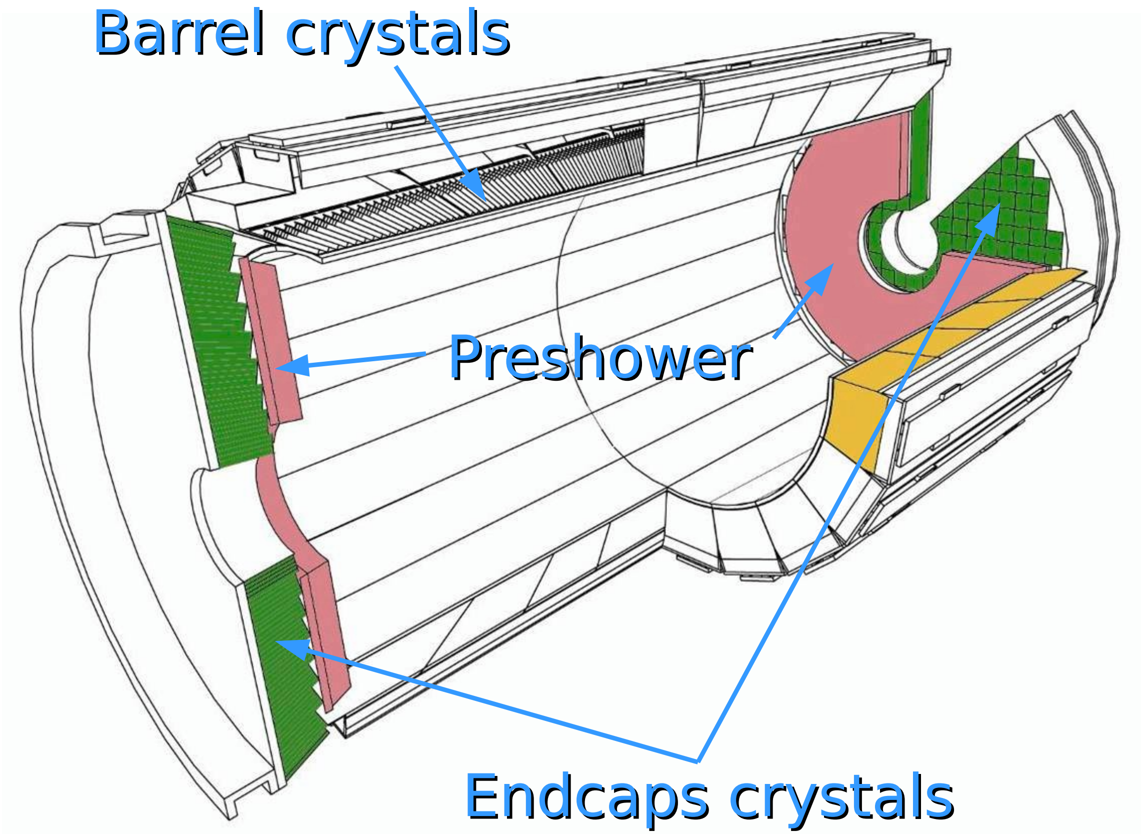




- **Barrel (EB):**
  - 36 supermodules (1700 channels)
  - Total of 61200 $PbWO_4$ crystals
  - Avalanche Photo-Diode readout (APD)
  - Coverage $|\eta| < 1.48$

- **Endcaps (EE):**
  - Four half-disk Dees (3662 channels)
  - Total of 14648 $PbWO_4$ crystals
  - Vacuum Photo Triode readout
  - Coverage: $1.48 < |\eta| < 3.0$

- **Preshower**
  - Two Lead/Si planes
  - 137,216 Si strips (1.8 × 61 mm 2)
  - Coverage: $1.65 < |\eta| < 2.6$



Energy Reconstruction

$$E_{e,\gamma} = F_{e,\gamma}\left[\boxed{G}\sum_{i}^{crystals}\left(\boxed{A_i}\times\boxed{S_i(t)}\times\boxed{C_i}\times\boxed{H_{i\eta}}\right)+\boxed{E_{ES}}\right]$$

Preshower energy

ADCtoGeV:
0.04 GeV in EB
0.06 GeV in EE

Energy regression

Amplitude: extracted from the multifit

Laser-Correction: correct for transparency loss

Intercalibration: equalizing crystals response

η-scale : equalizing ring response wrt MC

Energy Reconstruction

$$E_{e,\gamma} = F_{e,\gamma}\left[\boxed{G}\sum_{i}^{crystals}\left(\boxed{A_i}\times\boxed{S_i(t)}\times\boxed{C_i}\times\boxed{H_{i\eta}}\right)+\boxed{E_{ES}}\right]$$

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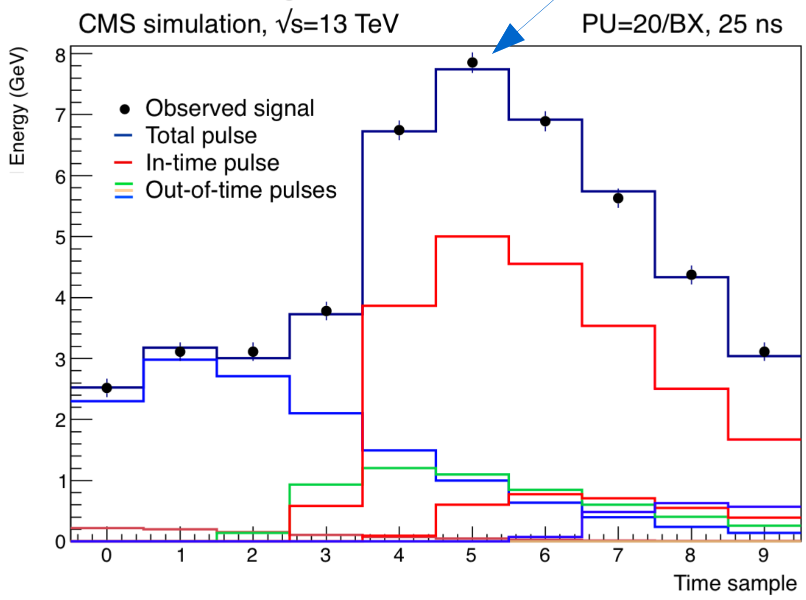

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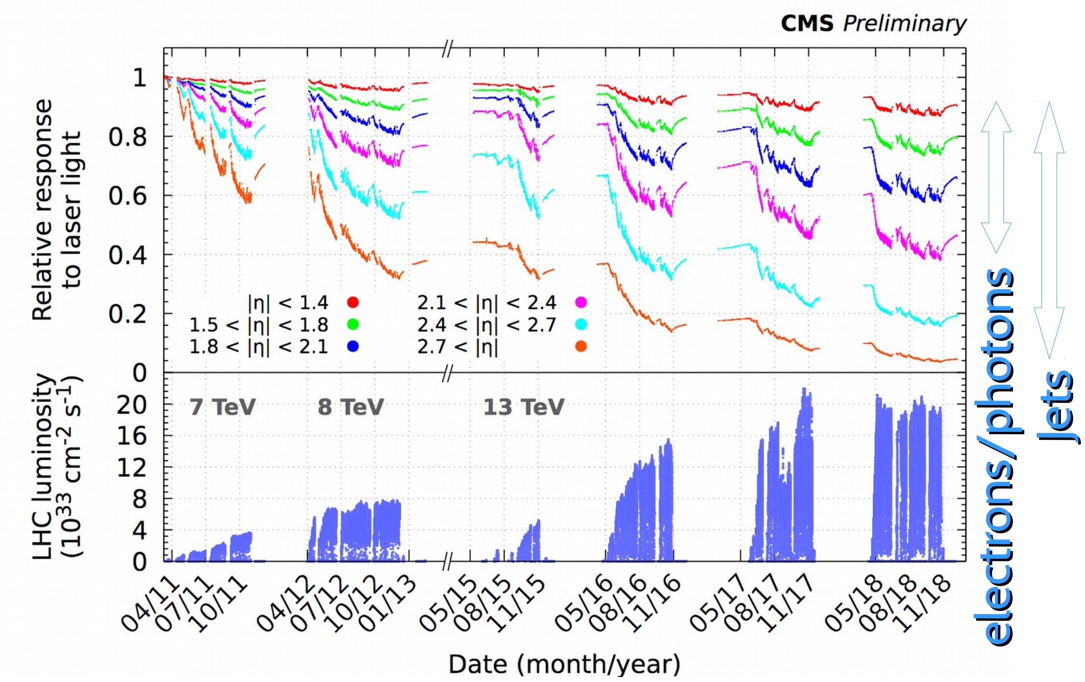
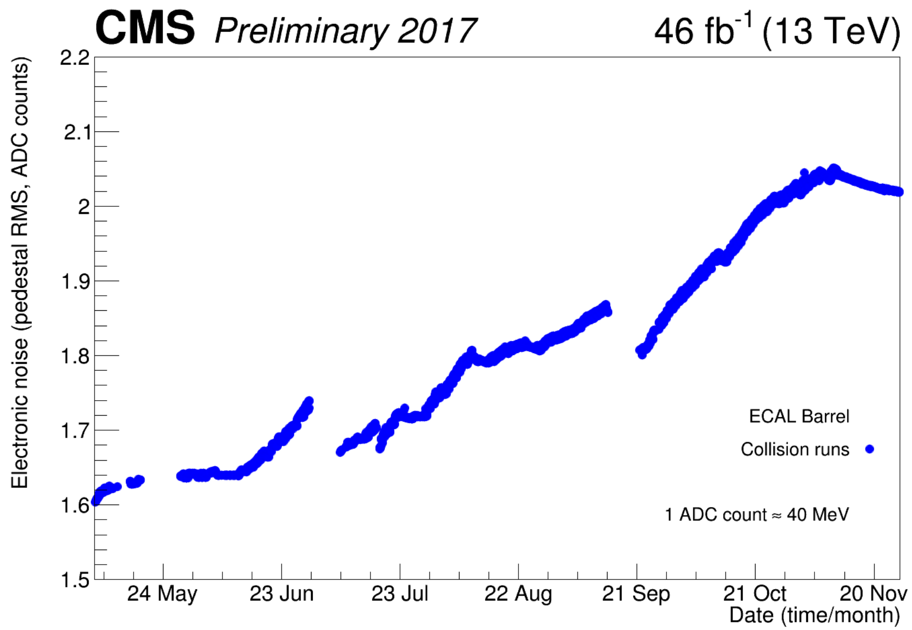
- $F_{e,\gamma}$: Energy regression
- G: ADCtoGeV: 0.04 GeV in EB, 0.06 GeV in EE
- A_i: Amplitude: extracted from the multifit
- $S_i(t)$: Laser-Correction: correct for transparency loss
- C_i: Intercalibration: equalizing crystals response
- $H_{i\eta}$: η-scale : equalizing ring response wrt MC
- E_{ES}: Preshower energy

Response variation in time due to the radiation:

→ Transparency loss of the crystals
→ Electronic noise increase (APDs only)
→ Pedestal increase (APDs only)
→ Pulse shape variations

Response Variation

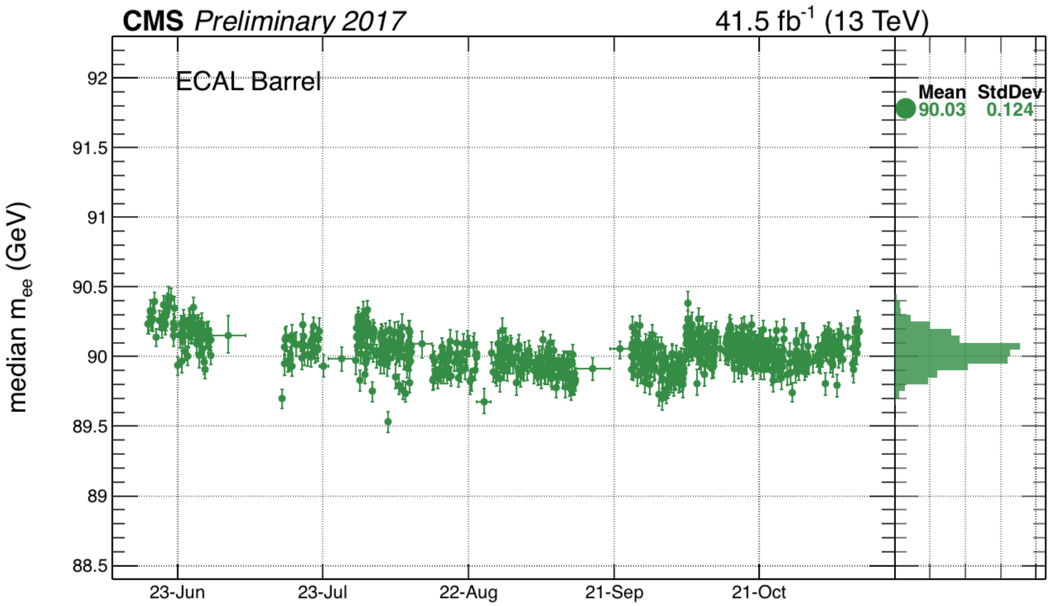


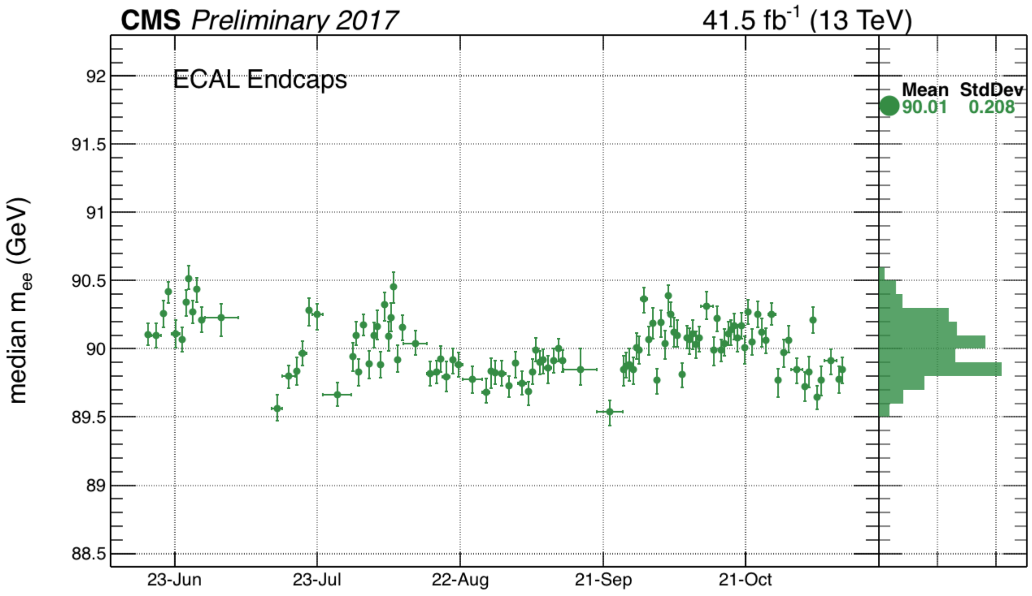


→ **During data calibration of ECAL:**
- **Make the response flat in time** (e.g. correct for the transparency loss)
- **Cope with the electronic noise increase**

→ **MC:**
- Conditions are taken from the data, in a moment representative of the average performance over the year

Response Stability





Take care of response variation → make response stable <<1%

Energy Reconstruction

$$E_{e,\gamma} = F_{e,\gamma}\left[\boxed{G}\sum_{i}^{crystals}\left(\boxed{A_i}\times\boxed{S_i(t)}\times\boxed{C_i}\times\boxed{H_{i\eta}}\right)+\boxed{E_{ES}}\right]$$

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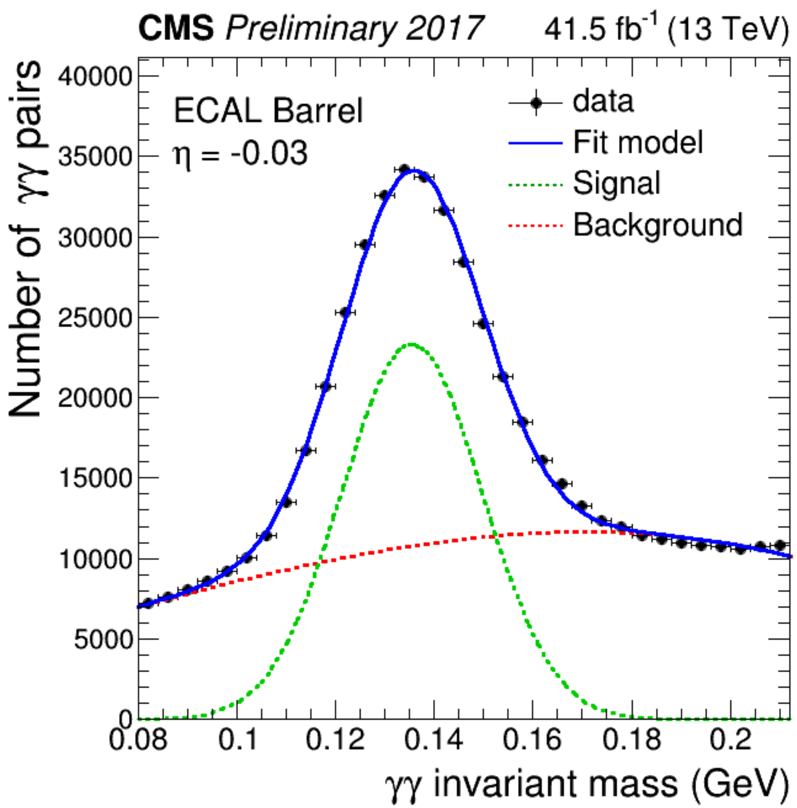
Intercalibrations

→ **Crystal by crystal equalization because different light-yield and photodetector response, through dedicated data streams (intercalibrations derived per ring):**

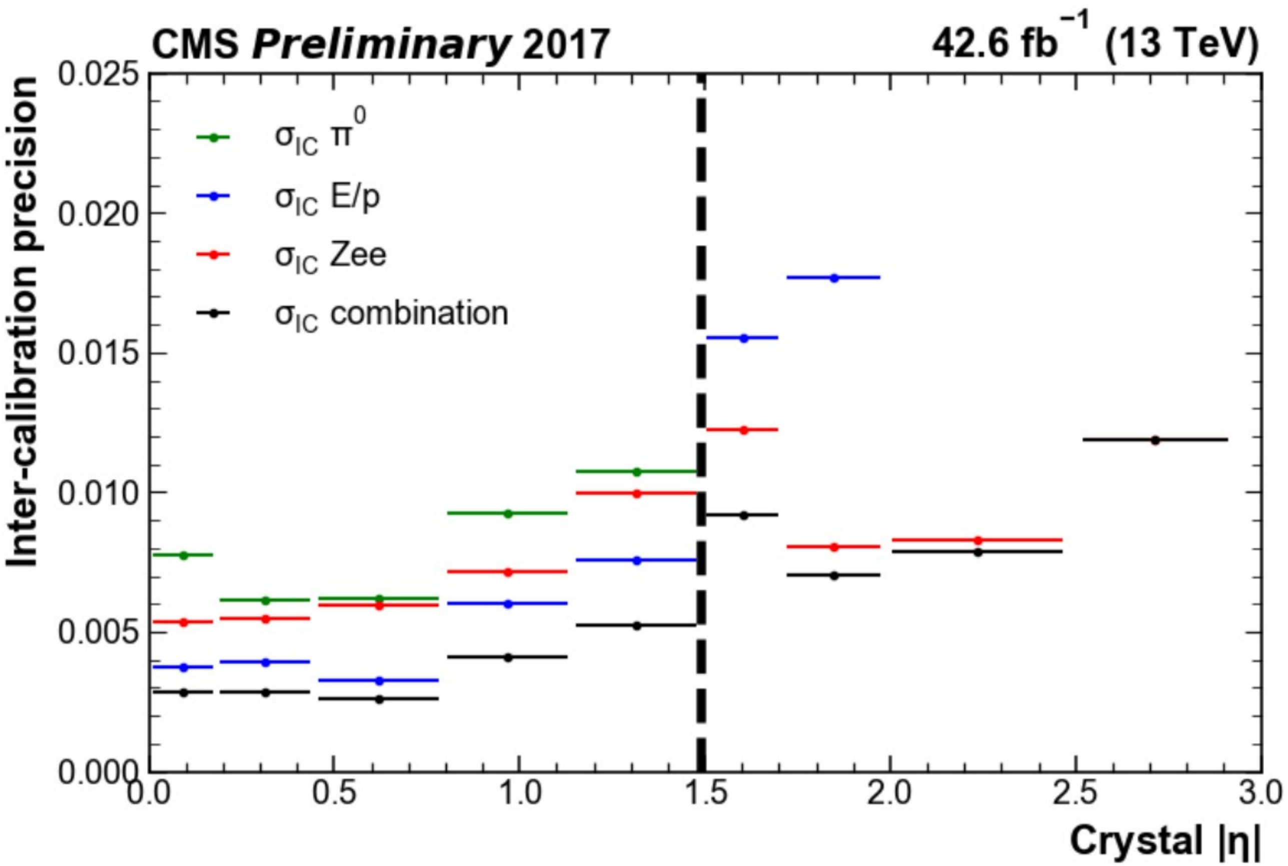
- **Φ-symmetry:** equalization of the average energy in channels located at a constant value of η
- **π^0mass:** iterative method exploiting the invariant mass reconstructed from unconverted photons arising from the decays of π^0
- **E/p:** iterative method, comparison of the ECAL energy to the tracker momentum for isolated electrons.
- **Zee:** exploit the invariant mass reconstructed from $Z \rightarrow e^+ e^-$

→ **Calibrations at |η|>2.5 (no tracking)**
- 1 electron with |η|<2.5
- 1 SC with |η|>2.5



Intercalibrations: Precision

- **Precision:** performance of the IC method on the relative energy resolution of Zee
- **Combination performed reweighting on the precision**



Energy Reconstruction

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Preshower energy

Energy regression

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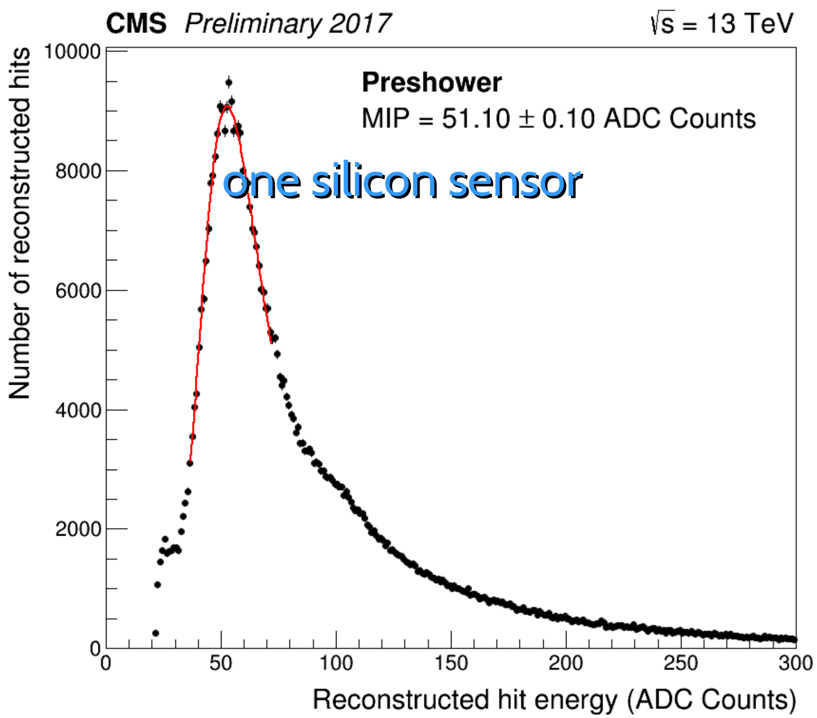
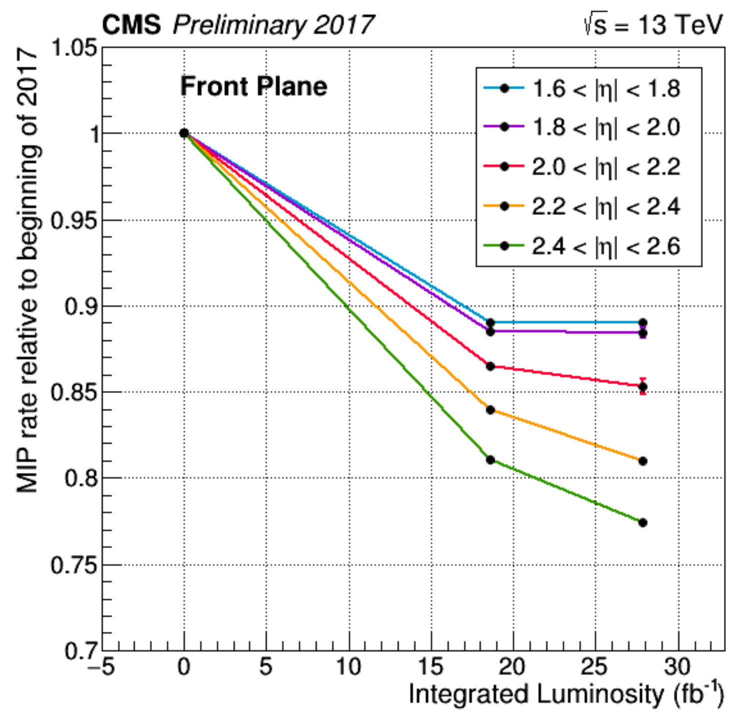
ES Calibration

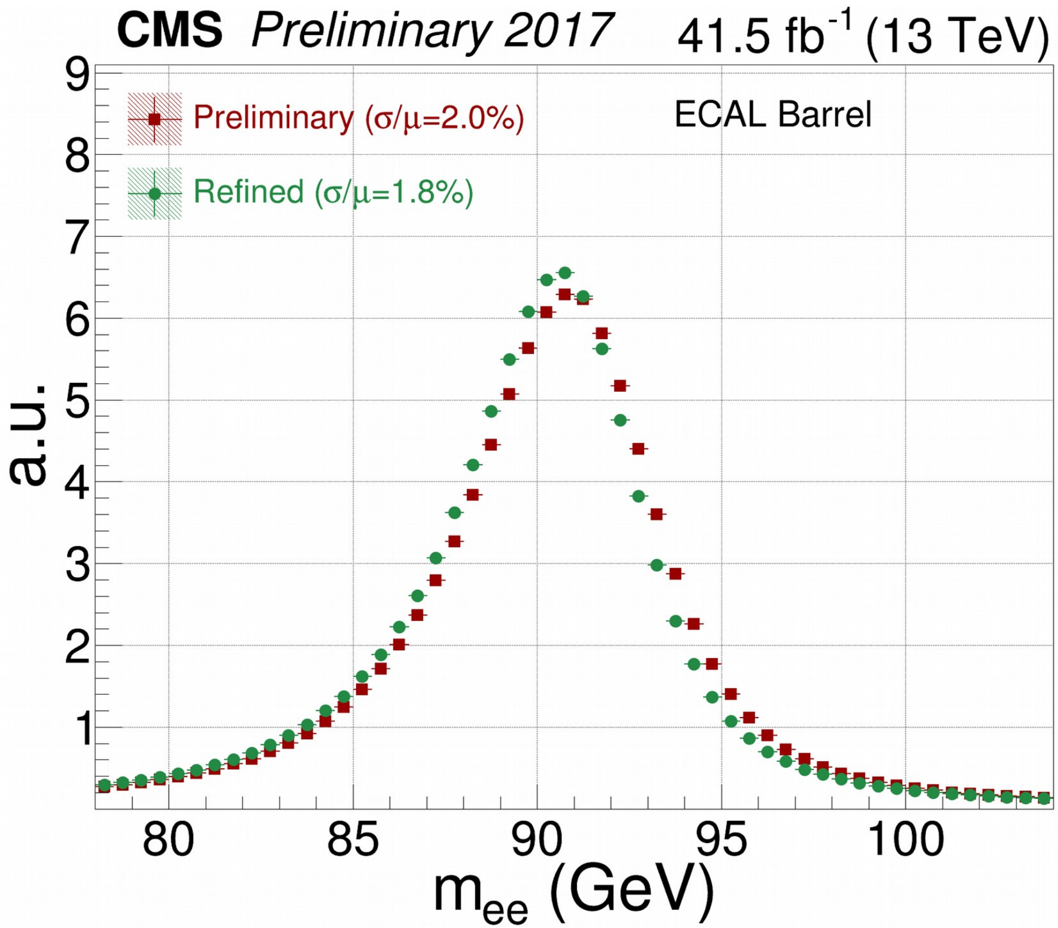
- Sensor by sensor calibration performed using the MIPs
- Every ~10/fb, special runs are taken for MIP calibration

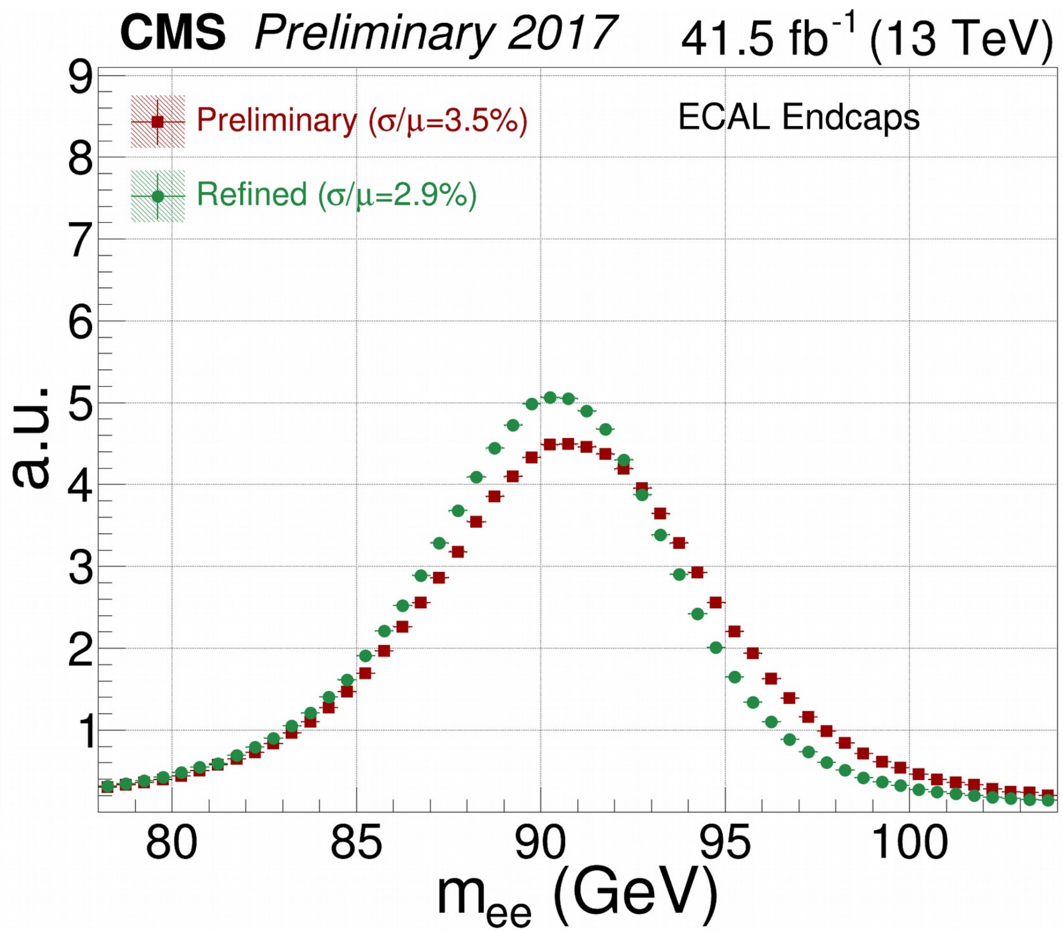




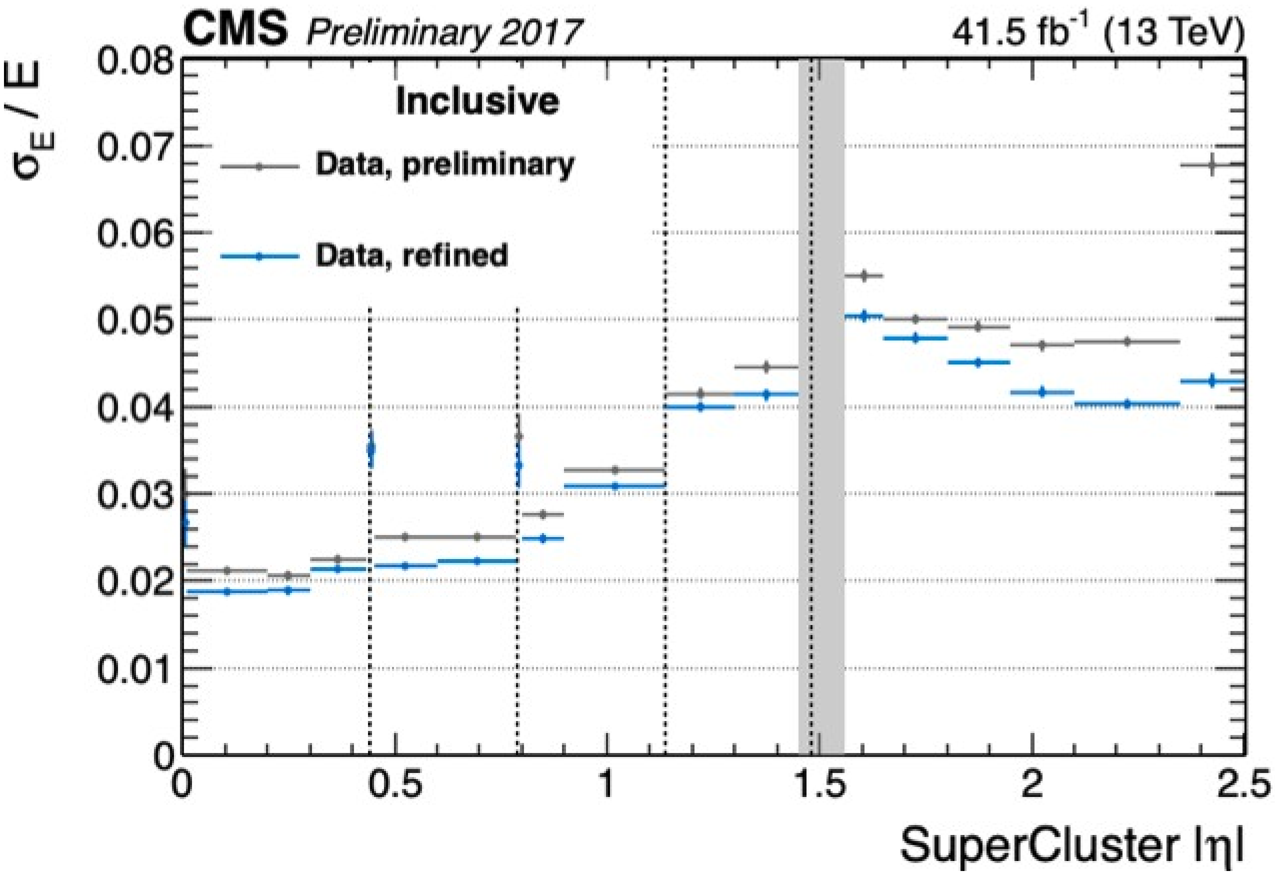
Integrated luminosity (/fb)

Performance





Performance



→ **EB resolution improvement at least 0.5%**

→ **EE resolution improvement of about few percent**

Summary

- **CMS ECAL detector designed for excellent energy resolution for photons with 0.1 MeV-1.5 TeV:**
  → 75848 lead-tungstate ($PbWO_4$) scintillating crystals
  → Signal read by APDs (in EB) and VPTs (in EE)

- **Final recalibration: best possible performance for legacy analyses**
  → Response uniformity in space and time
  → Optimal energy resolution

- **2017 data recalibration:**
  → Long procedure to reach the best performance
  → EB resolution improvement at least 0.5%
  → EE ($|\eta|<2.5$) resolution improvement of about few percent

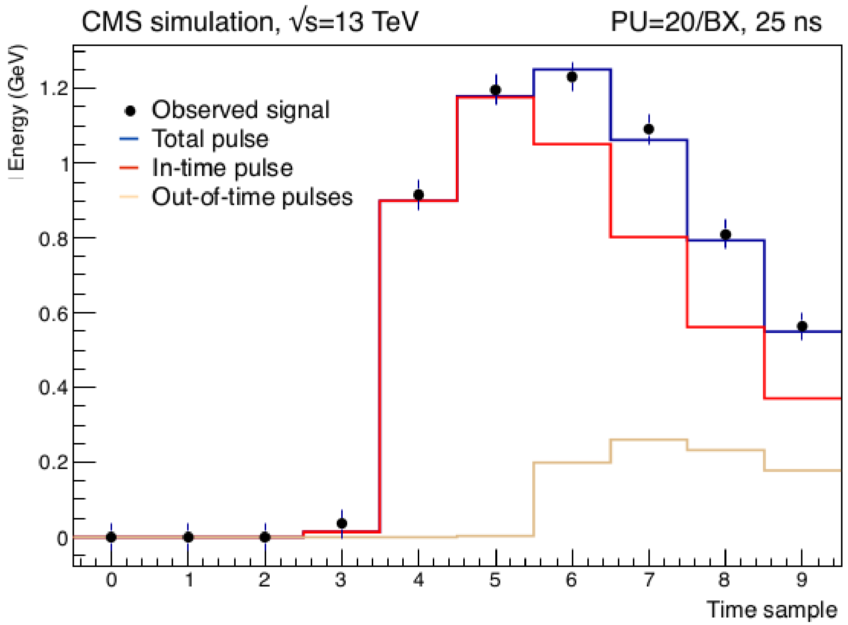
Back-up Slides

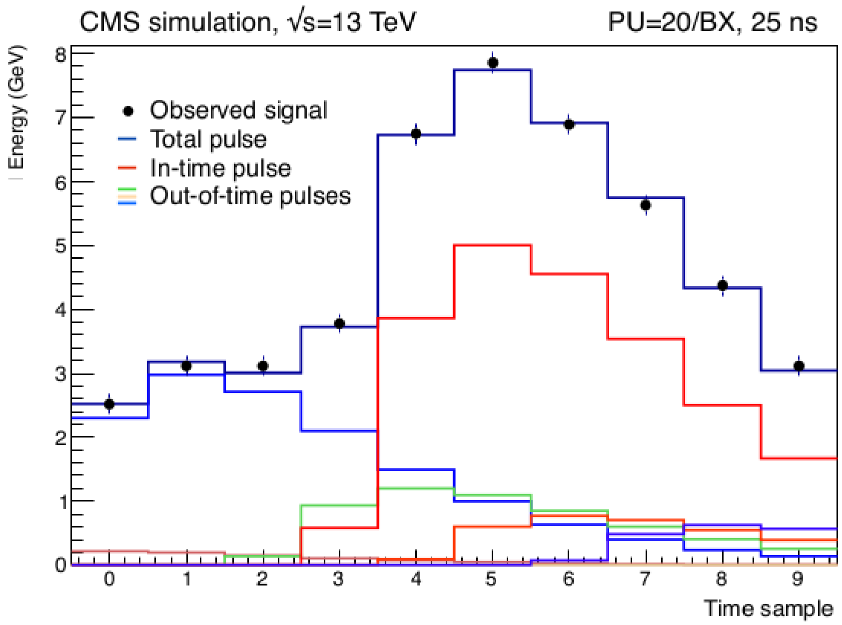
Amplitude Reconstruction: Multifit

- Estimation of in-time signal amplitude and up to 9 out of time amplitudes by minimization of the χ^2:

$$\chi^2 = \left(\sum_{j=1}^{N_{pulse}} A_j \vec{p}_j - \vec{S} \right)^T C^{-1} \left(\sum_{j=1}^{N_{pulse}} A_j \vec{p}_j - \vec{S} \right) \qquad C = C_{noise} \oplus \sum_{j=1}^{N_{pulse}} A_j^2 C_j^{pulse}$$

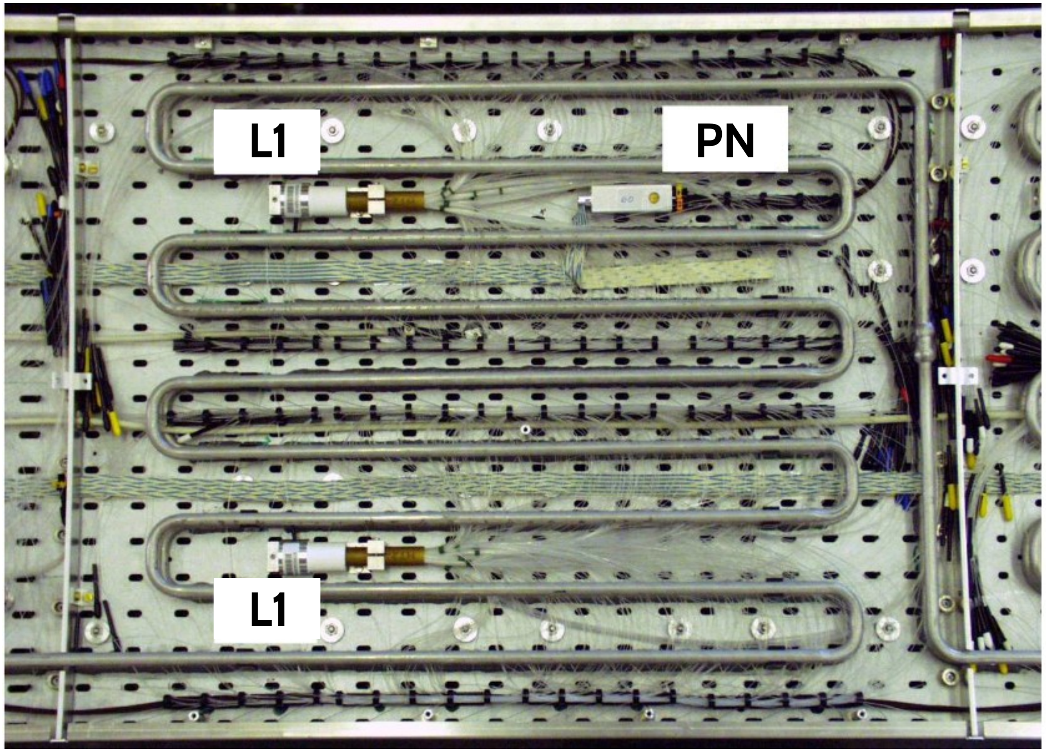
A_i = amplitude, **S** = 10 samples, $\mathbf{p}_i$ = template pulshapes, C = covariance matrix





Transparency corrections

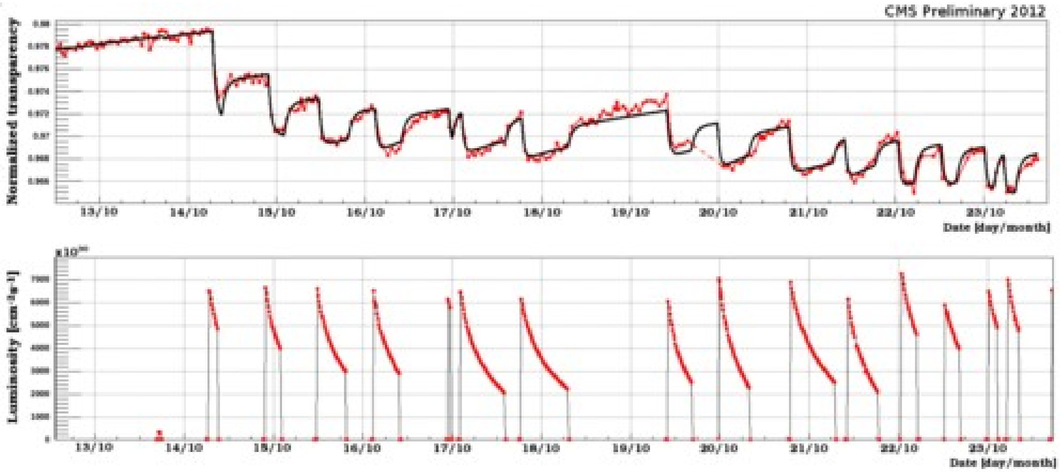
- **Crystal transparency changes are measured with a laser monitoring system, injecting laser light into the crystals continuously (at 100 Hz):**



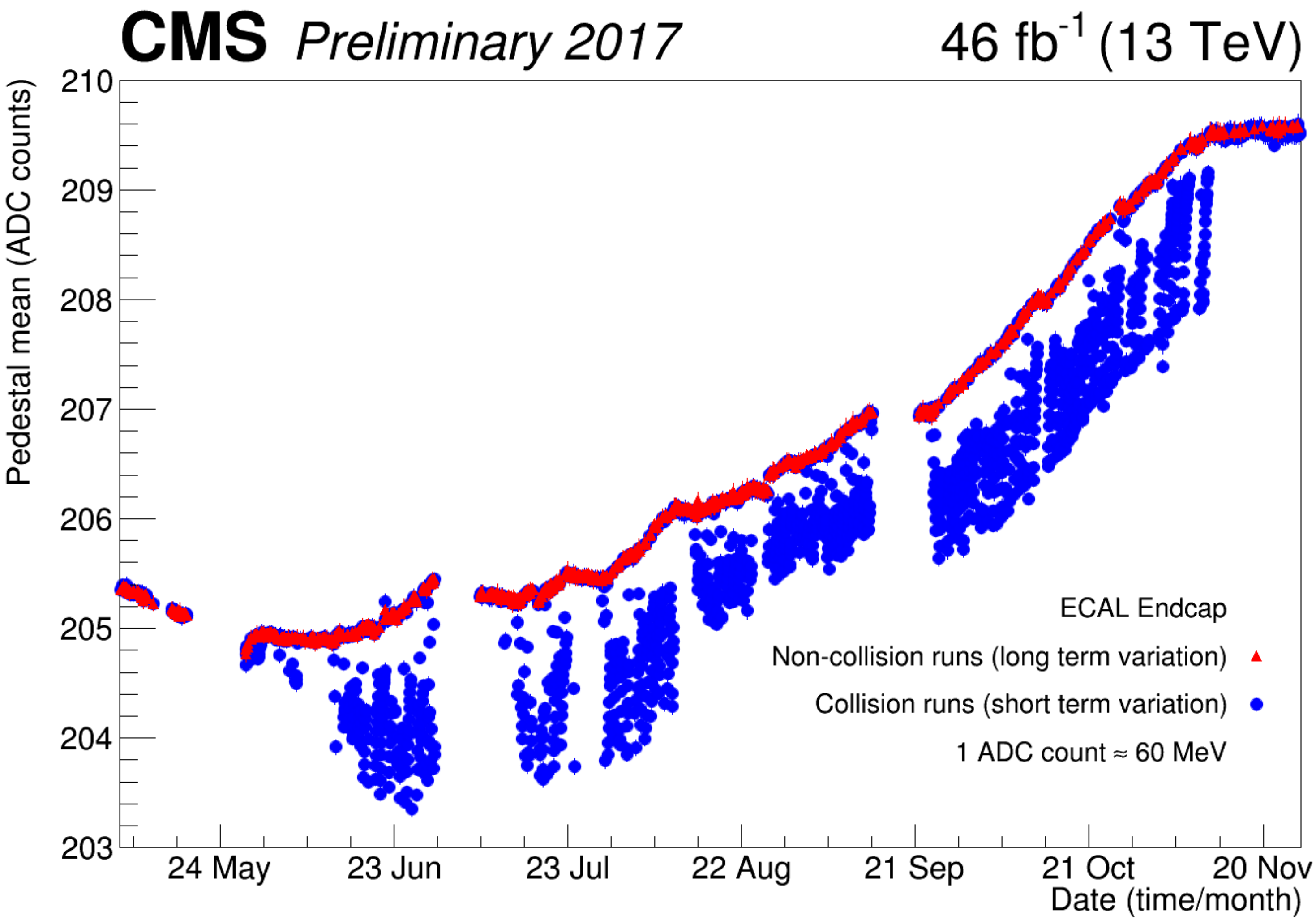
Laser-Correction = $(R/R_0)^{-\alpha}$, R = PhotoDetector/PN_{ref}

α = empirical parameter taking into account the differences between laser light and EM shower

PN_{ref} = reference PN photodiode, lit by the split laser light

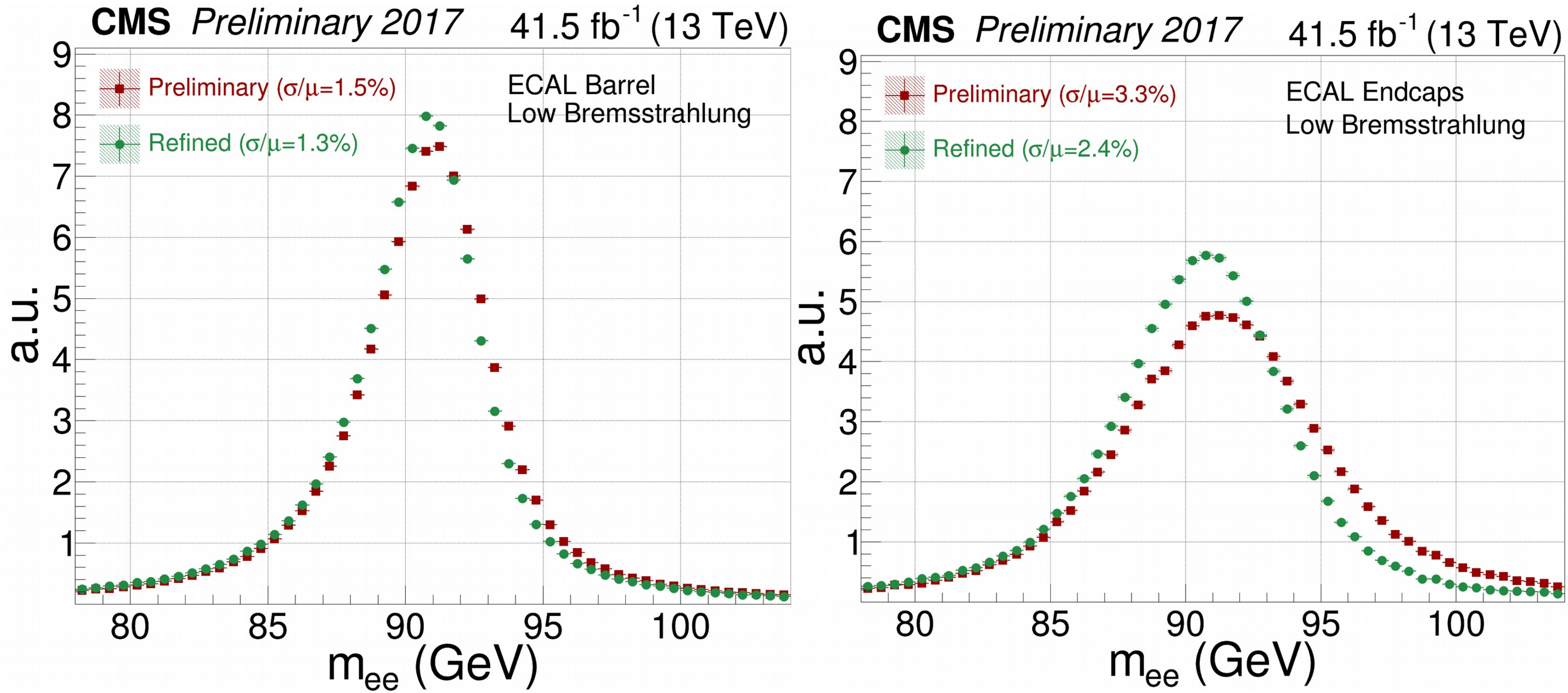


Pedestals



CMS Preliminary 2017
46 fb^{-1} (13 TeV)
Pedestal mean (ADC counts)
210
209
208
207
206
205
204
203
24 May
23 Jun
23 Jul
22 Aug
21 Sep
21 Oct
20 Nov
Date (time/month)
ECAL Endcap
Non-collision runs (long term variation)
Collision runs (short term variation)
1 ADC count ≈ 60 MeV

Performance: Low Bremsstrahlung



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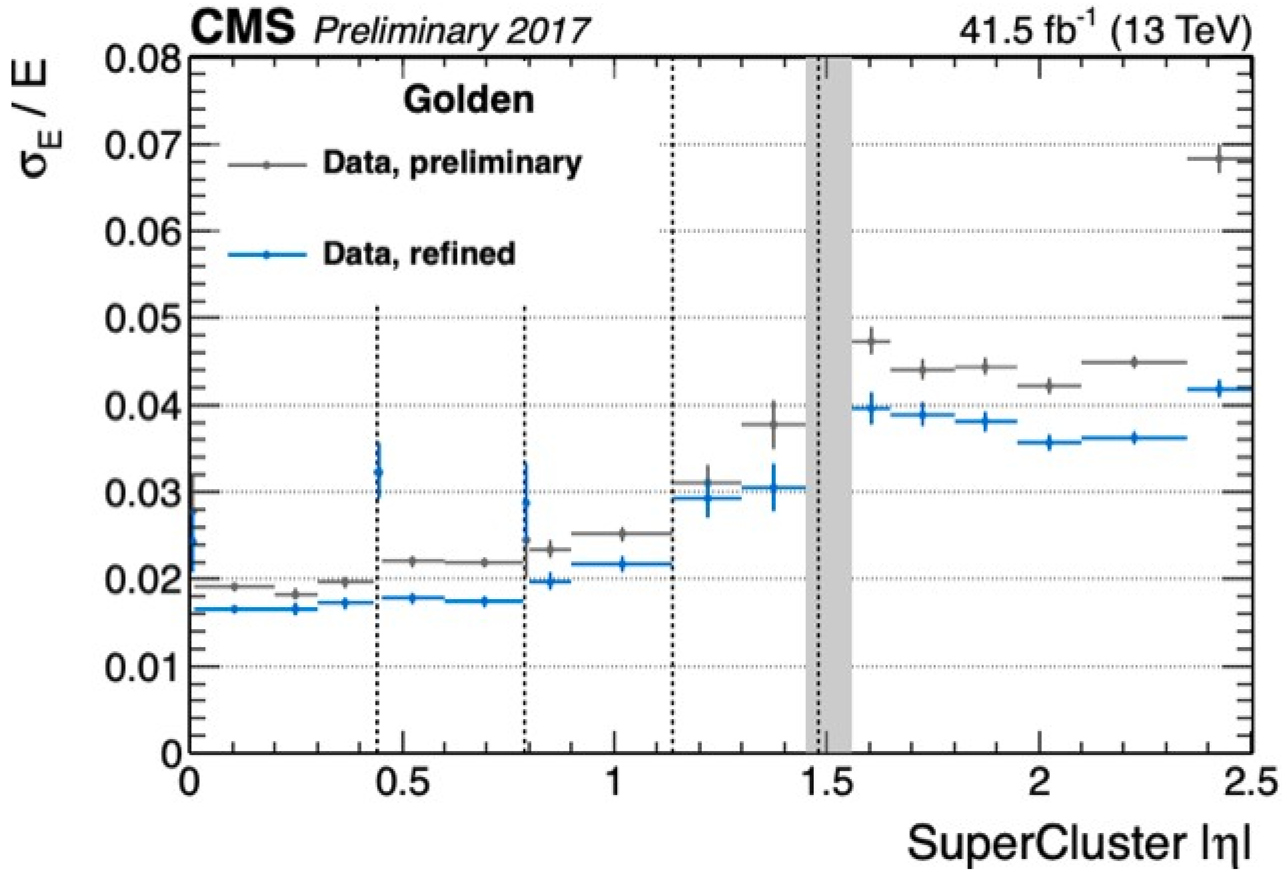

Performance: High Bremsstrahlung