Optimising the performance of the CMS Electromagnetic Calorimeter in LHC Run2 for the measurement of Higgs boson properties

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on behalf of the CMS Collaboration
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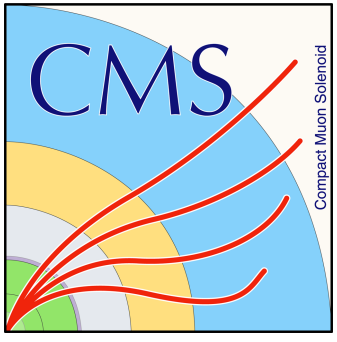

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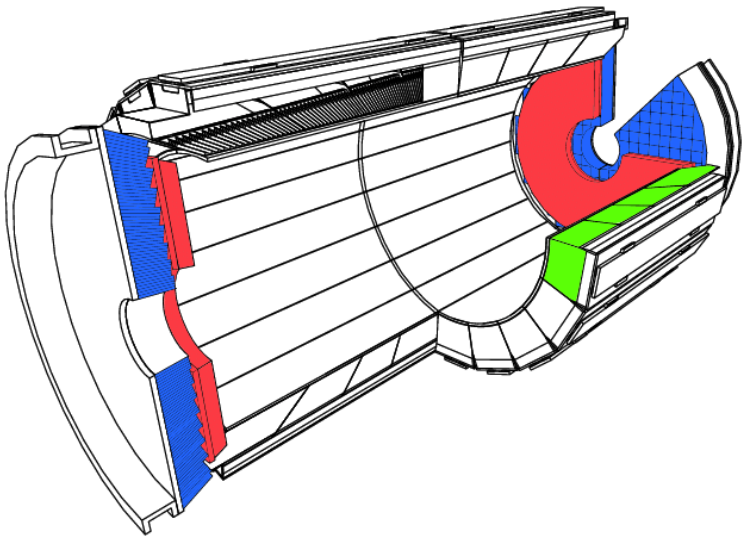
Higgs2021

October 20, 2021

The ECAL detector

Homogeneous, hermetic, high granularity $PbWO_4$ crystal calorimeter

- small Molière radius: $r_M = 2.19\ cm$
- high density: $\rho = 8.28\ g/\ cm^3$
- short radiation length $X_0 = 0.89\ cm$
- fast light emission: $\sim 80\%$ of light emitted within 25 ns



Barrel $(|\eta| < 1.48)$

61200 crystals read by Avalanche Photo-Diodes (APDs)

Endcaps $(1.48 < |\eta| < 3)$

14648 crystals read by Vacuum Photo-Triodes (VPTs)

Preshower $(1.65 < |\eta| < 2.6)$

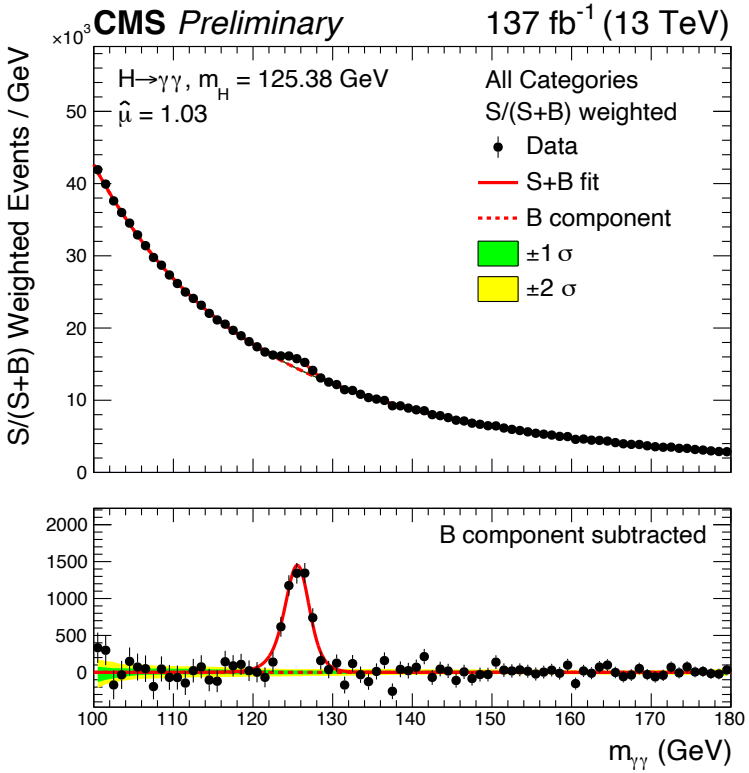
$3X_0$ of Pb/Si strips - to discriminate between prompt photons and photons from π^0 decay

The role of the ECAL performance in Higgs physics

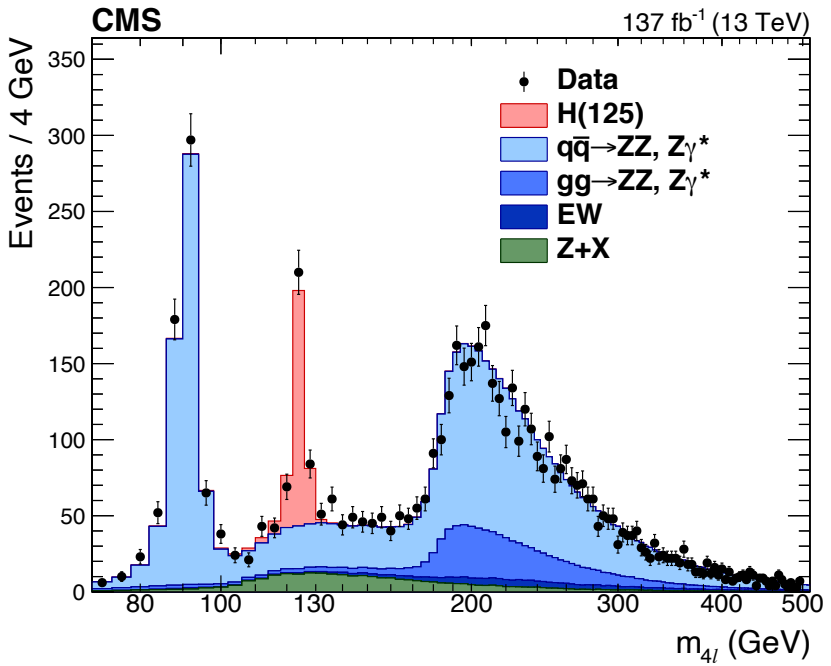
Design led by the H→ γγ search needs: target 1% energy resolution at low mass

- the excellent ECAL performance was crucial in the Higgs boson discovery

The energy resolution and electron/photon ID performance continue to be a key asset for the Higgs physics needs



JHEP 2021, 27 (2021)



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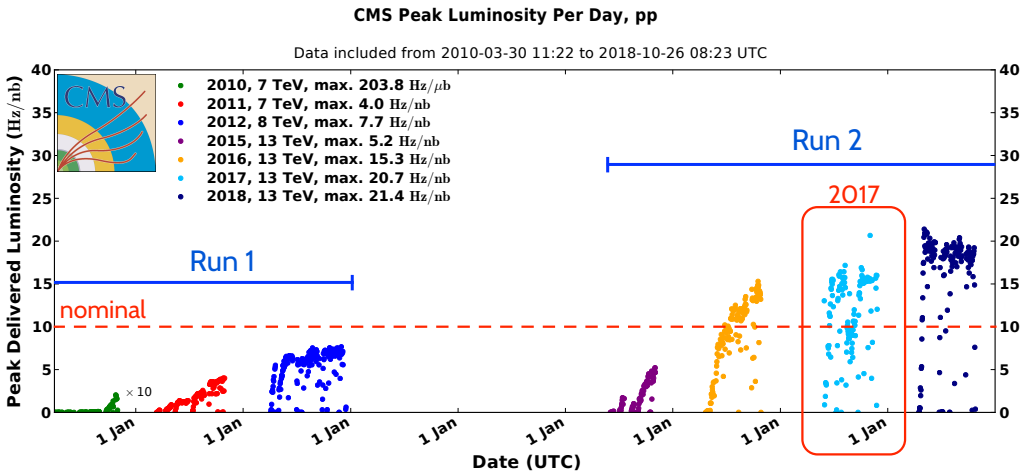
Data-taking challenges during Run 2

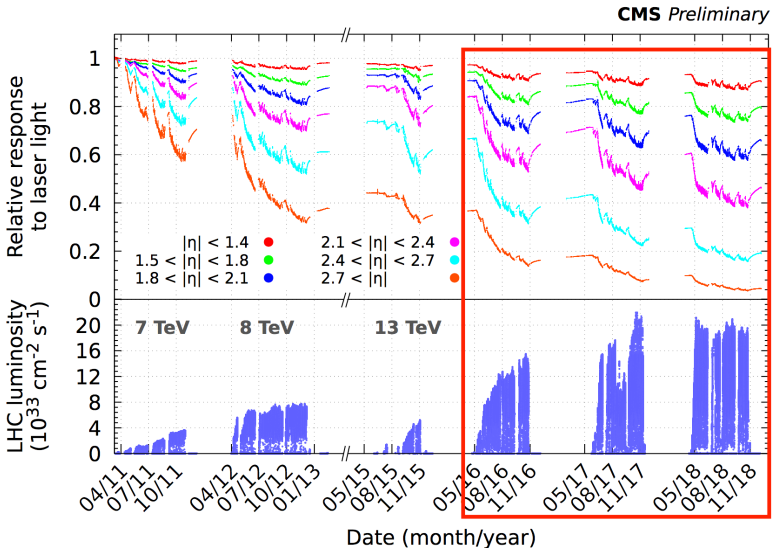
LumiPublicResults

Design LHC luminosity exceeded during Run2 (up to **about** ×2)

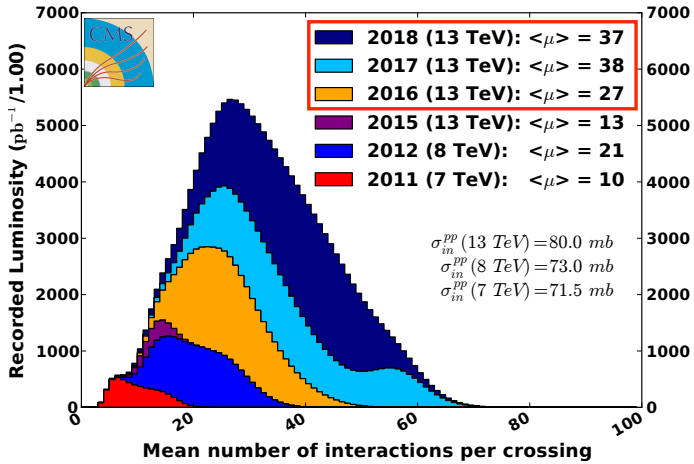


High luminosity implies:

Detector ageing: **reduced crystal transparency** and increased APD noise



Large pileup, **affecting the object reconstruction** in the calorimeters offline and at trigger level

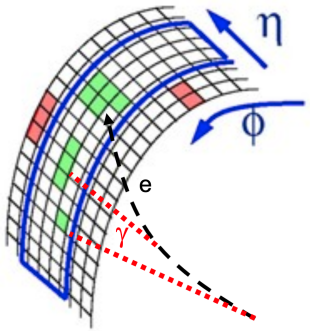


Run2: twice the pileup for which ECAL was designed

CMS-DP-2019-005

ECAL energy reconstruction

Electrons and photons deposit energy over several crystals



- $\sim 70\%$ of energy deposited in one crystal
- $\sim 97\%$ in a 3×3 array
- spread in the ϕ direction

Super-clustering algorithms to group together the physics objects

Cluster correction
from regression method

Signal amplitude
in ADC counts

Channels intercalibration
in η slices

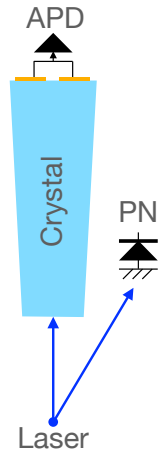
$$E_{e,\gamma} = F_{e,\gamma} \times [G \times \sum_i (A_i \times LC_i \times IC_i) + E_{ES}]$$

ADC-to-GeV conversion
global scale factor

Laser corrections
for crystal transparency loss

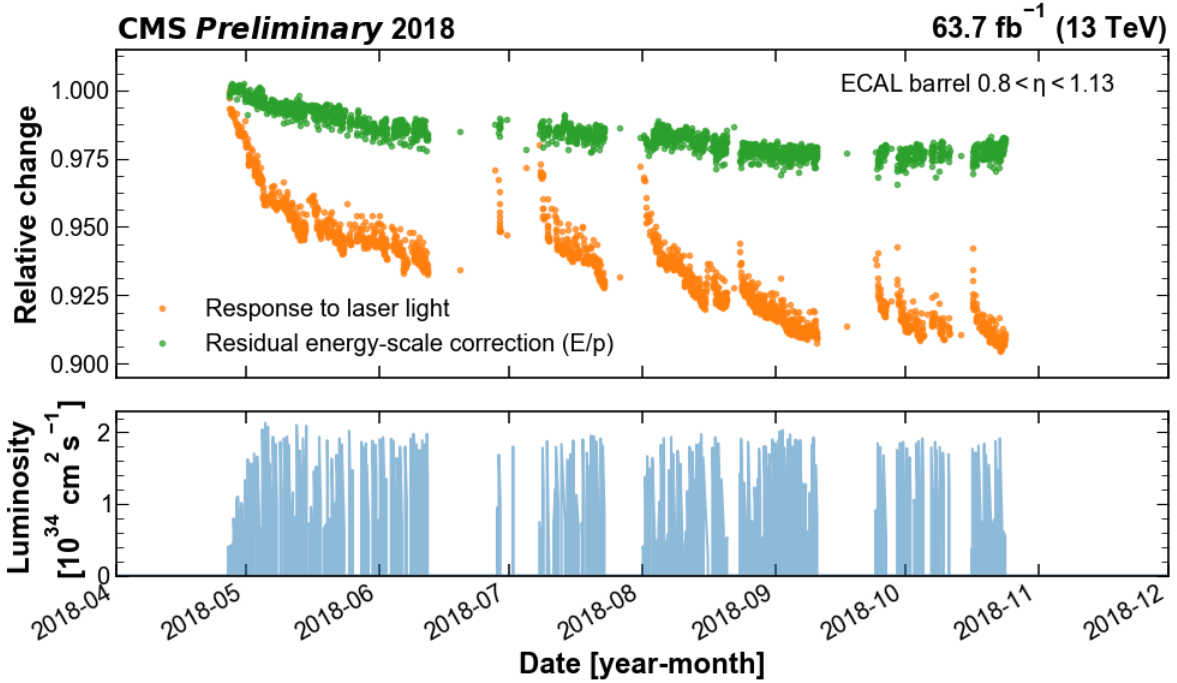
Preshower energy scale

Laser corrections



Dedicated monitoring system designed to provide corrections within 48h

- Laser light injected in every crystal every 40 mins
- Response to laser light used to monitor response to e/γ
  - the relation between response to laser light and e/γ is modelled with a power law



- Response measured through PN diodes
- Residual correction due to a drift of the response of the PN diodes

  computed from comparison with the tracker-measured momentum of electrons from W/Z bosons (E/p ratio)

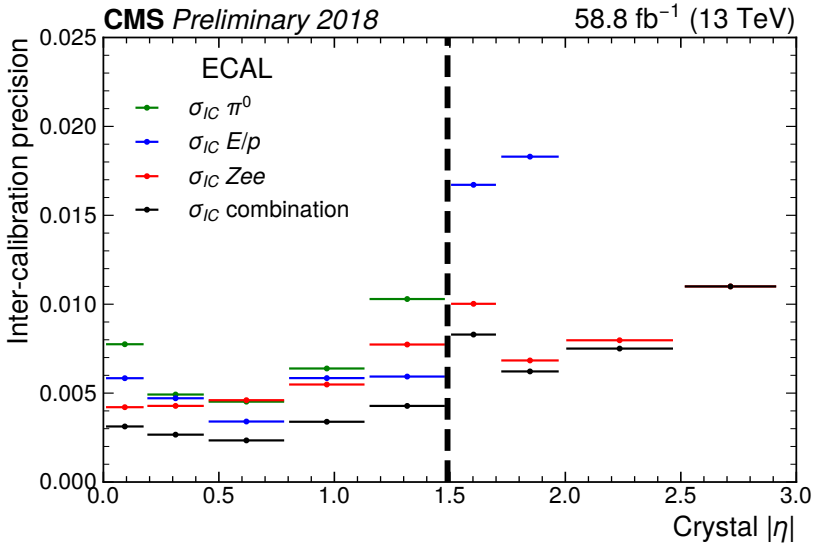
CMS-DP-2019-030

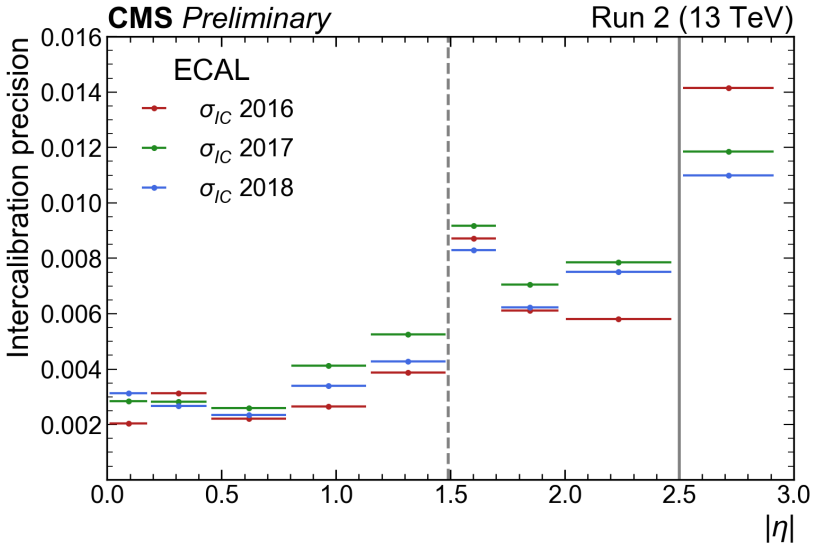
Channels intercalibration

CMS-DP-2020-021

Combination of several methods based on different physics signals to equalize response within η slices

slice-to-slice equalization derived from Z→ee mass reconstruction in data and MC





- π^0 mass though $\pi^0 \rightarrow \gamma\gamma$ reconstruction
- comparison with tracker-measured momentum of electrons from W/Z bosons (E/p ratio)
- Z mass though $Z \rightarrow$ee reconstruction

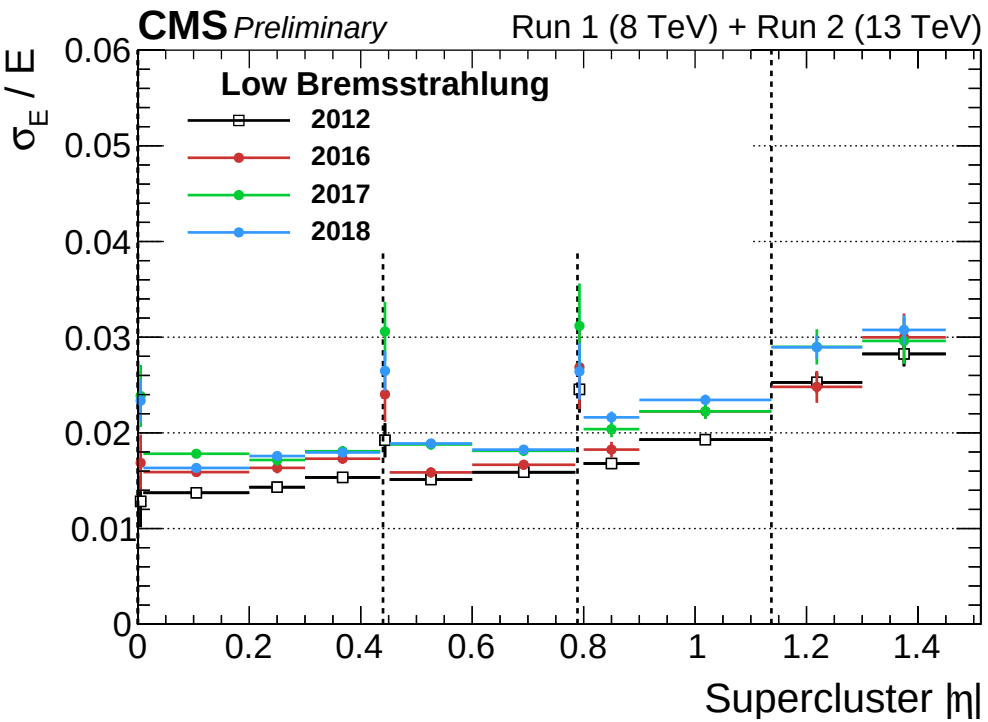
High precision achieved in all the regions

Barrel ($|\eta| < 1.5$):$< 0.5\%$
Endcaps ($|\eta| < 2.5$) $< 1\%$

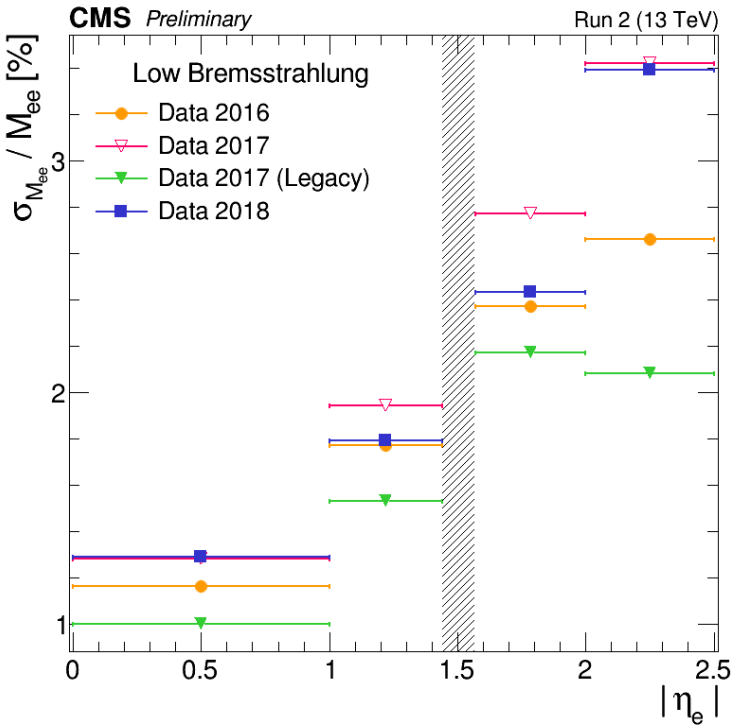
Run3 plans: rolling calibrations in automatic workflows

ECAL performance in Run2

- Resolution measured in Z→ee data events
- Pulse reconstruction and calibration methods evolved through Run2



CMS-DP-2020-021



CMS-DP-2020-037

Excellent energy resolution maintained along Run2
In spite of harsher data-talking conditions: pileup and detector ageing

ECAL timing resolution

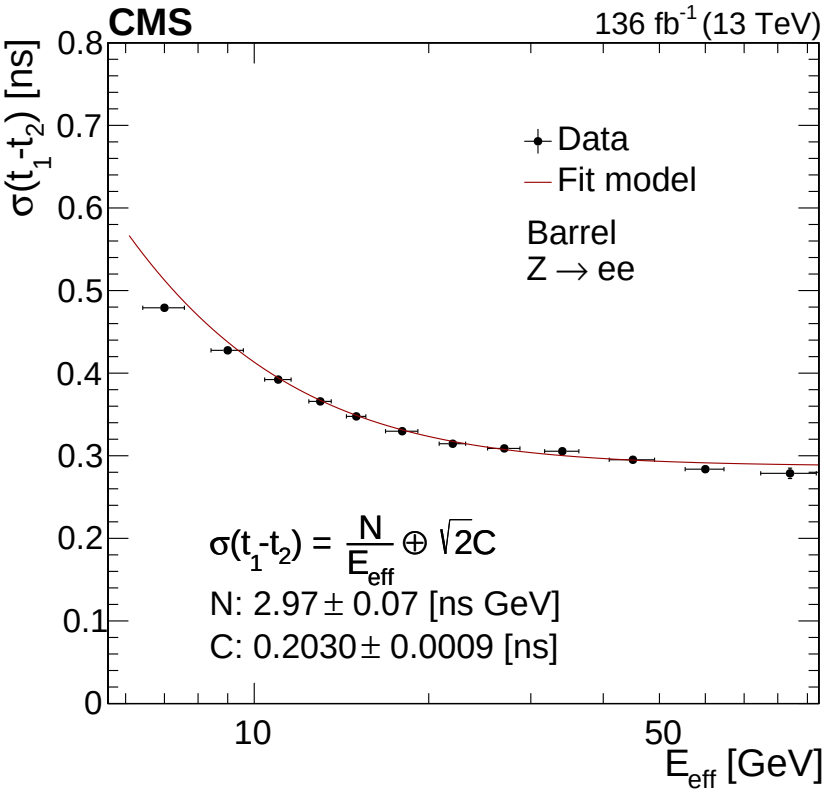
CMS-EGM-17-001

The timing performance is crucial

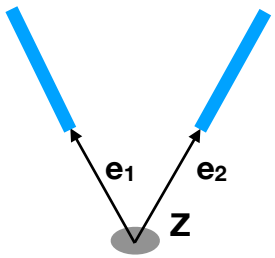
- for photon identification
- for in-time PU mitigation

$$\sigma(\Delta t) = N \oplus \sqrt{2}C$$

N = noise term
C = constant term



Resolution of about 200 ps for energies above 40 GeV

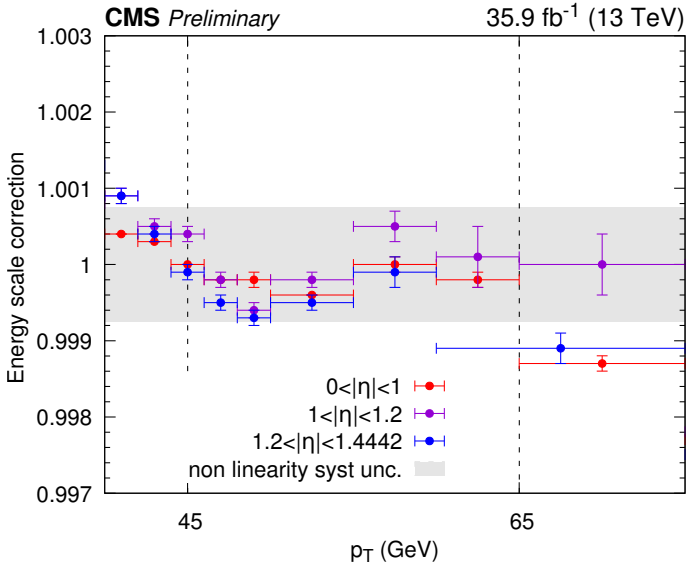


- Δt of time of arrival of two electrons
- Taking into account geometry, electronics...
- Measure of uniformity of the response (and the figure needed for physics)

Impact on H→ γγ photon reconstruction

PLB 805 (2020) 135425

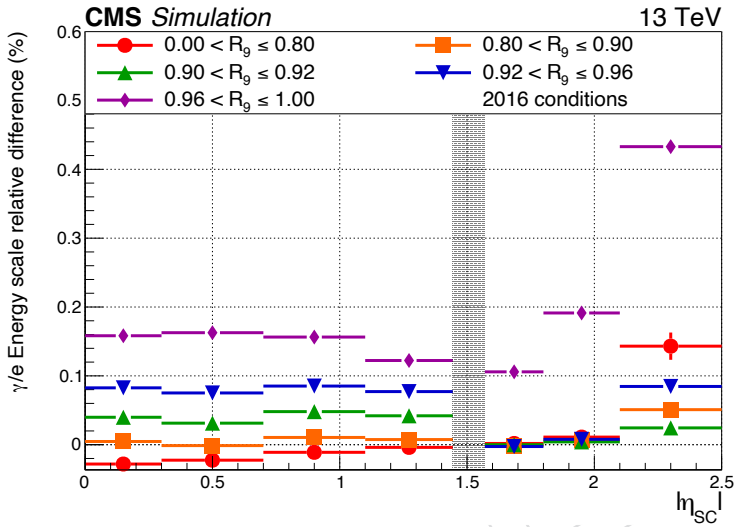
Z→ee
calibration
H→ γγ
physics



Energy scale corrections are small thanks to the meticulous calibration from Z→ee

- within 0.2% in wide photon p_T range

electrons
photons



γ/e energy scale difference due effects of radiation damage on non-uniformity of light collection

Barrel: $< 0.16\%$
Endcaps: $< 0.45\%$
Larger for high-R9 (unconverted photons)

H mass reconstruction

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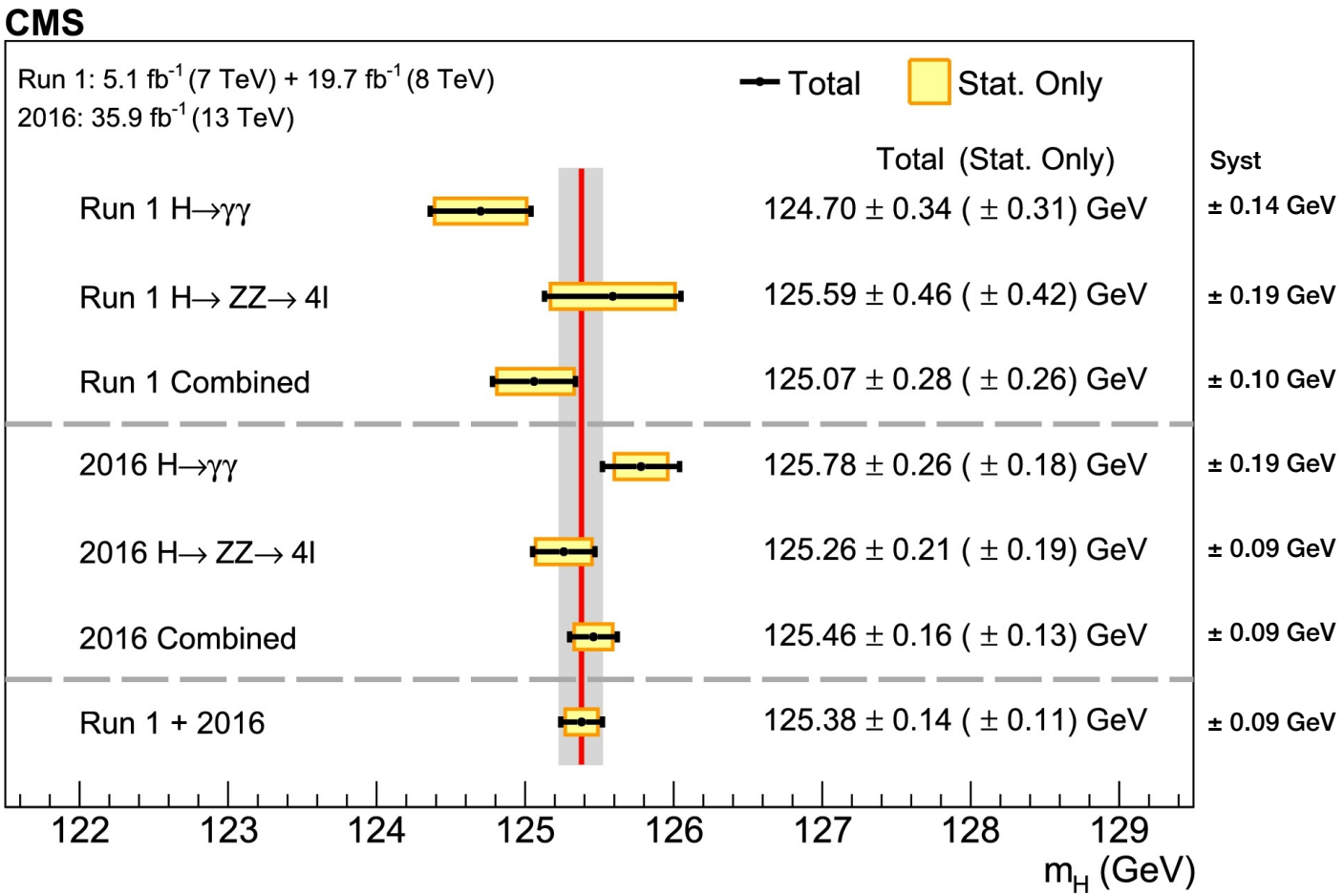
Largest sources of uncertainties:

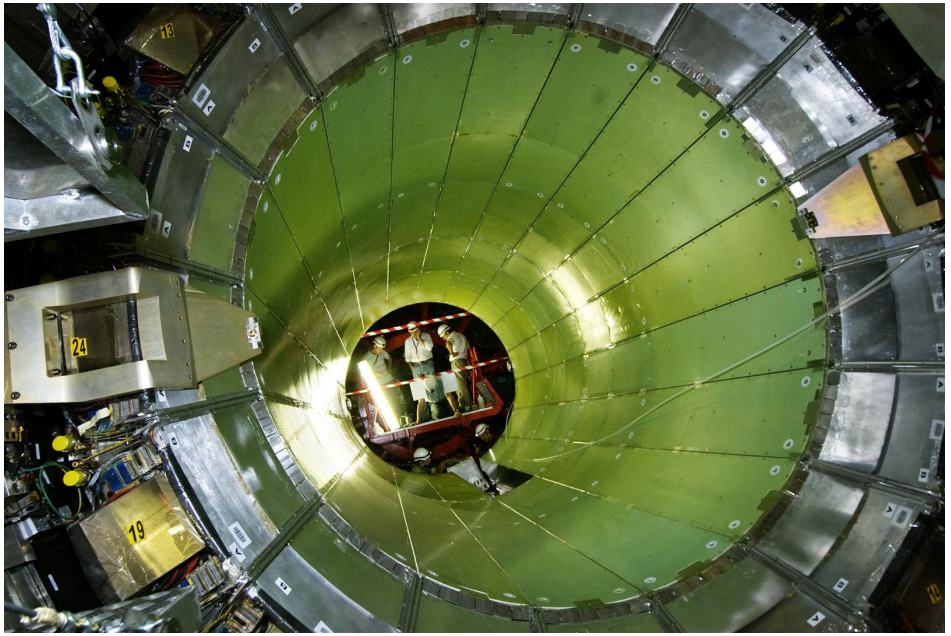
$H\to\gamma\gamma$	Electron energy scale and resolution corrections	0.10 GeV
	Residual p_T dependence of photon energy scale	0.11 GeV
	Nonuniformity of the light collection	0.11 GeV
$H\to ZZ\to 4\ell$	Uncertainty in the lepton energy scale	0.04% in 4e, 0.01% in 2e2μ



In spite of higher pileup and higher noise, the performance did not change significantly

Conclusion

Excellent ECAL energy resolution maintained during Run2



The ECAL calorimeter design has proven to be successful

- regular calibrations of channel response are crucial for the physics needs

The operations and calibrations in harsh data-taking conditions resulted in a **outstanding performance**

- the comprehensive understanding of the detector response will be fundamental in the upcoming LHC phases