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on behalf of the CMS Collaboration

Performance of the CMS Electromagnetic Calorimeter in LHC Run 2

PIC 2019

18th September

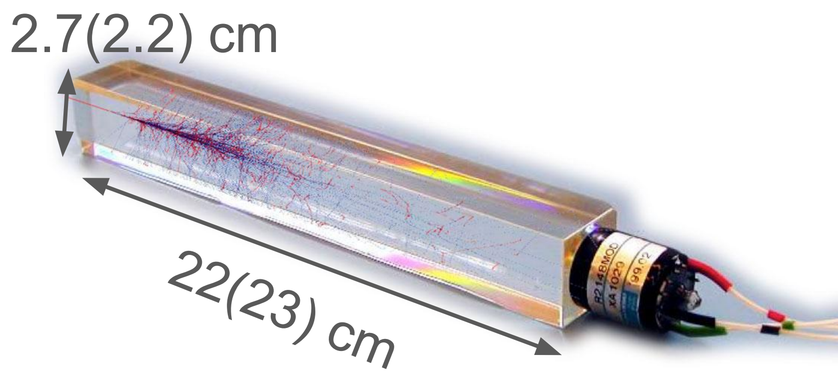
Outline

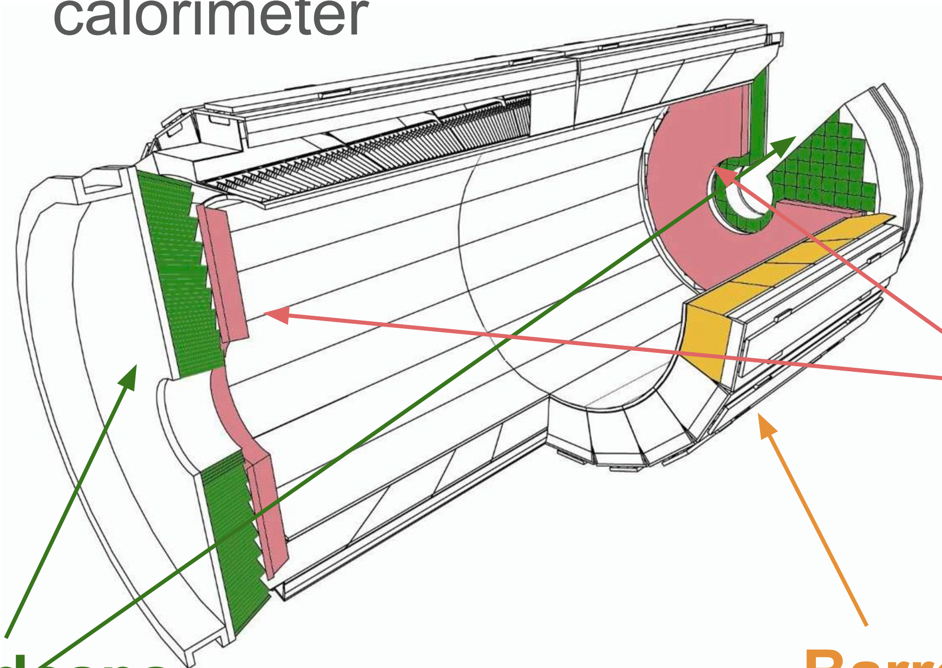
- The CMS Electromagnetic Calorimeter (ECAL) structure
- Importance of the ECAL
- Challenges faced during Run 2
- Achieved performance

The CMS ECAL

- Hermetic homogeneous calorimeter
- Between tracker and hadronic calorimeter

$PbWO_4$ scintillating crystal
- High density
- Fast light emission
- Crystal dim. ~ em. shower





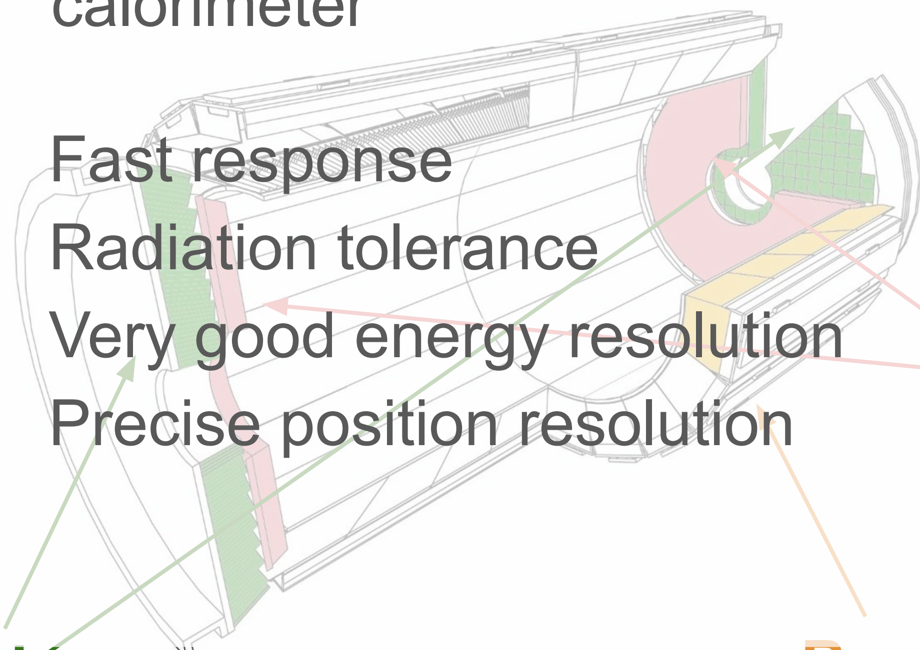
Preshower
- Two Pb/Si planes
- 1.65 < |η|< 2.6
- See L. Phuc talk

Endcaps
- 7324 crystals / endcap
- Vacuum Photo Triode readout
- 1.48 < |η|< 3.00

Barrel
- 61200 crystals
- Avalanche photodiodes (APD) readout
- |η| < 1.48

The CMS ECAL

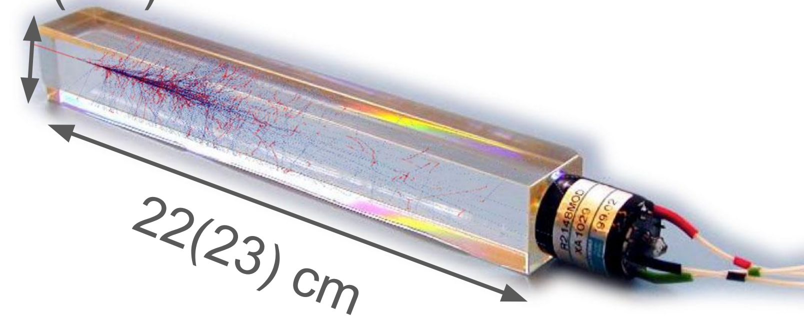
- Hermetic homogeneous calorimeter
- Between tracker and hadronic calorimeter



- ➢ Fast response
- ➢ Radiation tolerance
- ➢ Very good energy resolution
- ➢ Precise position resolution

$PbWO_4$ scintillating crystal

- High density
- Fast light emission
- Crystal dim. ~ em. shower



Preshower

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Importance of the ECAL for CMS analysis

- Fundamental role in CMS Run 2 (2015-2018)

Precision measurements of the Higgs boson in the channels:

- ➢ $H \rightarrow \gamma\gamma$
- ➢ $H \rightarrow ZZ \rightarrow ee\mu\mu$
- ➢ $H \rightarrow ZZ \rightarrow 4e$

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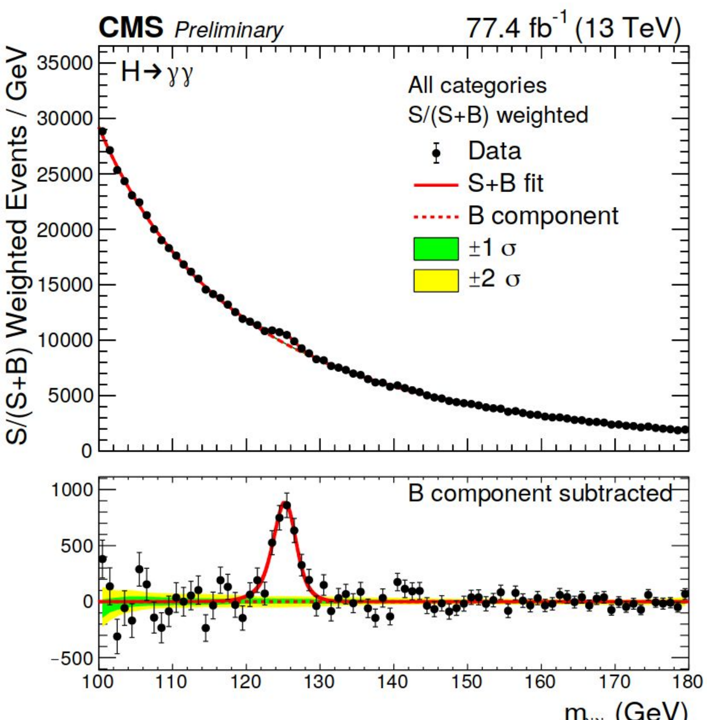
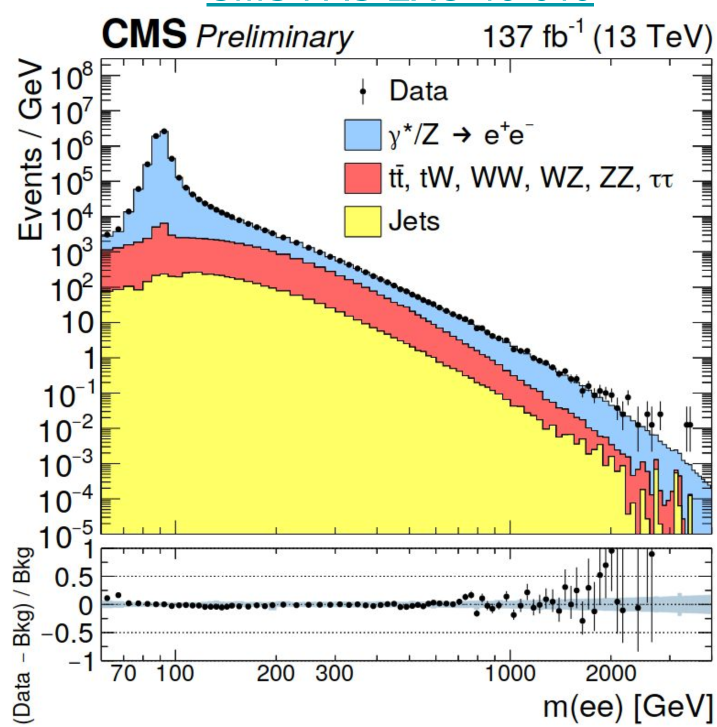


Searches for new phenomena:

- ➢ Any final state with e, or γ

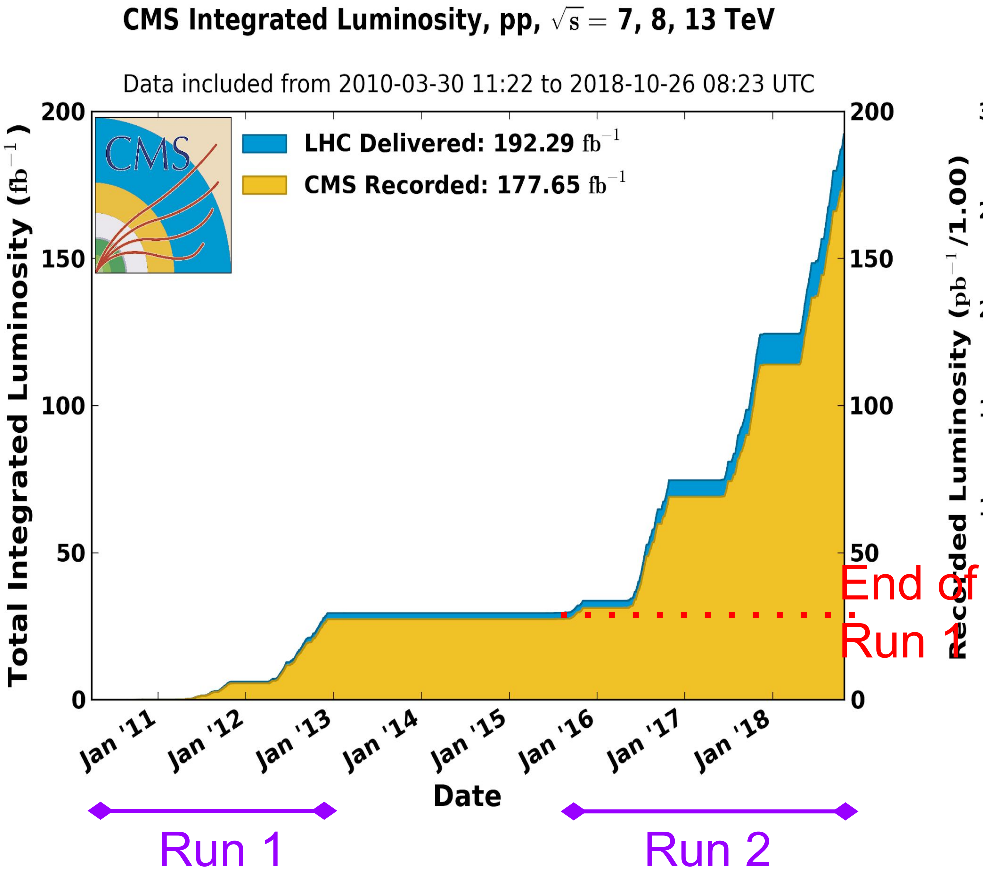
Search for high energy resonance decaying to di-electron

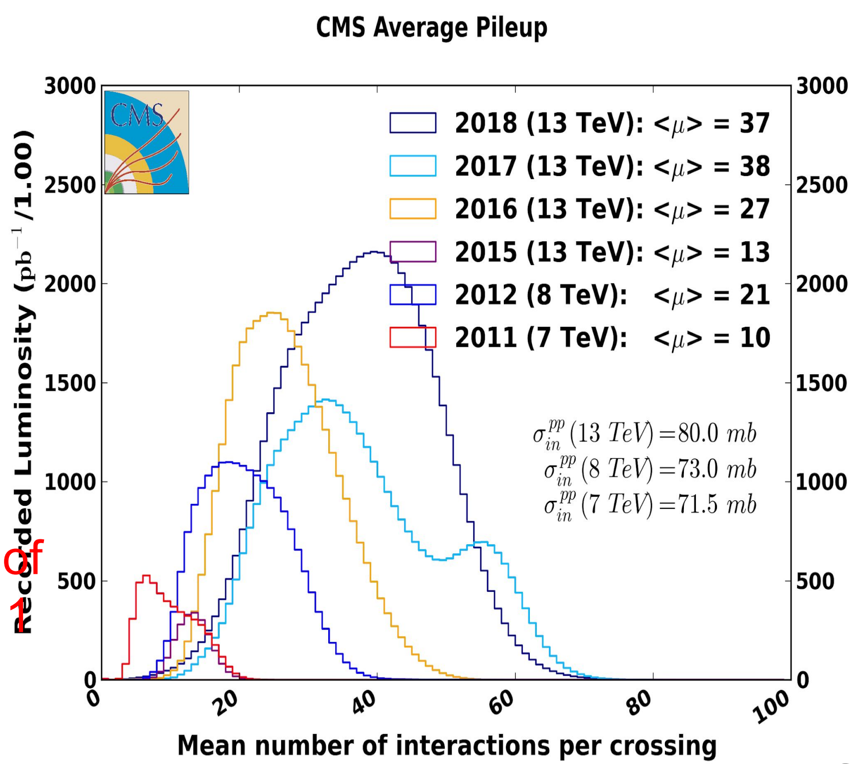
CMS-PAS-EXO-19-019



Challenges at LHC Run 2

- 2-4× increase of luminosity wrt Run 1
  - \+ Data equivalent to 140 fb^{-1} in 4 years of operation
  - \+ absorbed dose → radiation damage
  - \+ simultaneous interactions per bunch crossing (pileup)





Ingredients for energy reconstruction

Sum over crystals

Global scale

Cluster correction

$$E = \sum_i [A_i \cdot S_i(t) \cdot c_i] \cdot G(\eta) \cdot F_{e,\gamma}$$

Pulse amplitude

Correction for crystal transparency loss

Intercalibration constant
Equalizing the response of the channels

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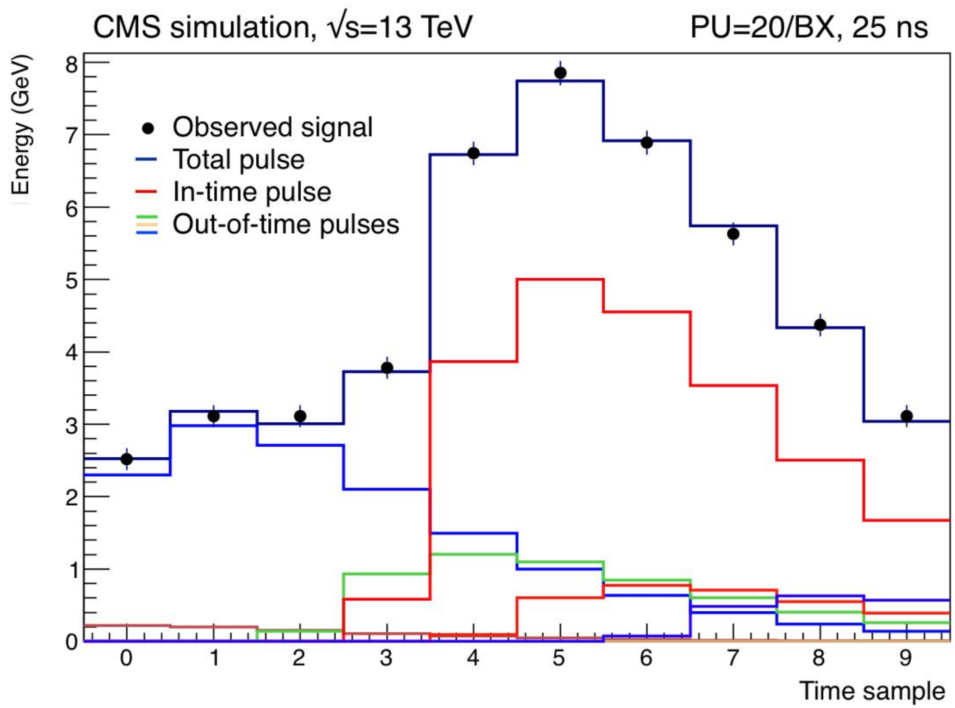
Equalizing the response of the channels

<u>New</u> pulse shape reconstruction

- “Multifit” = signal fit accounting for out-of-time (OOT) pulses
  - χ^2 minimization
  - Fit in-time pulse + up to 9 OOT pulses
  - Pulse shape extracted from data every ~week

➢ Mitigation of OOT pileup effect



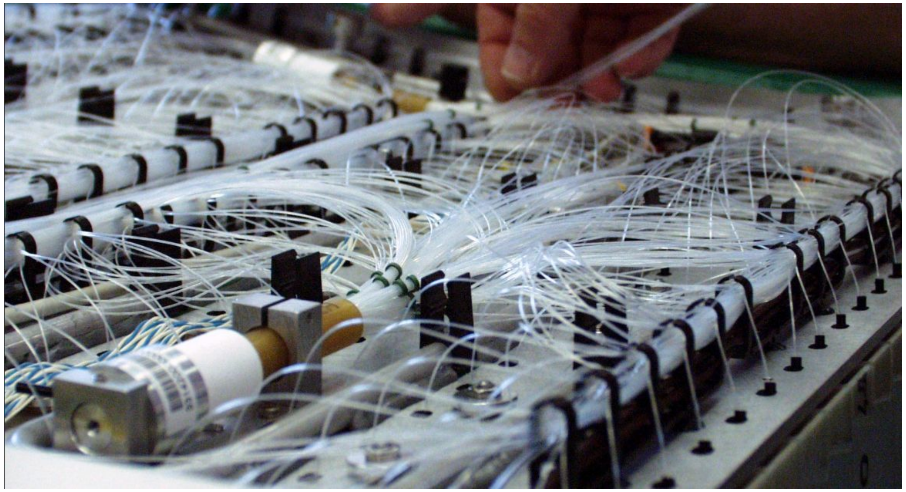
1 time sample = 1 bunch Xing
25 ns between two bunch Xing

Laser correction for transparency loss

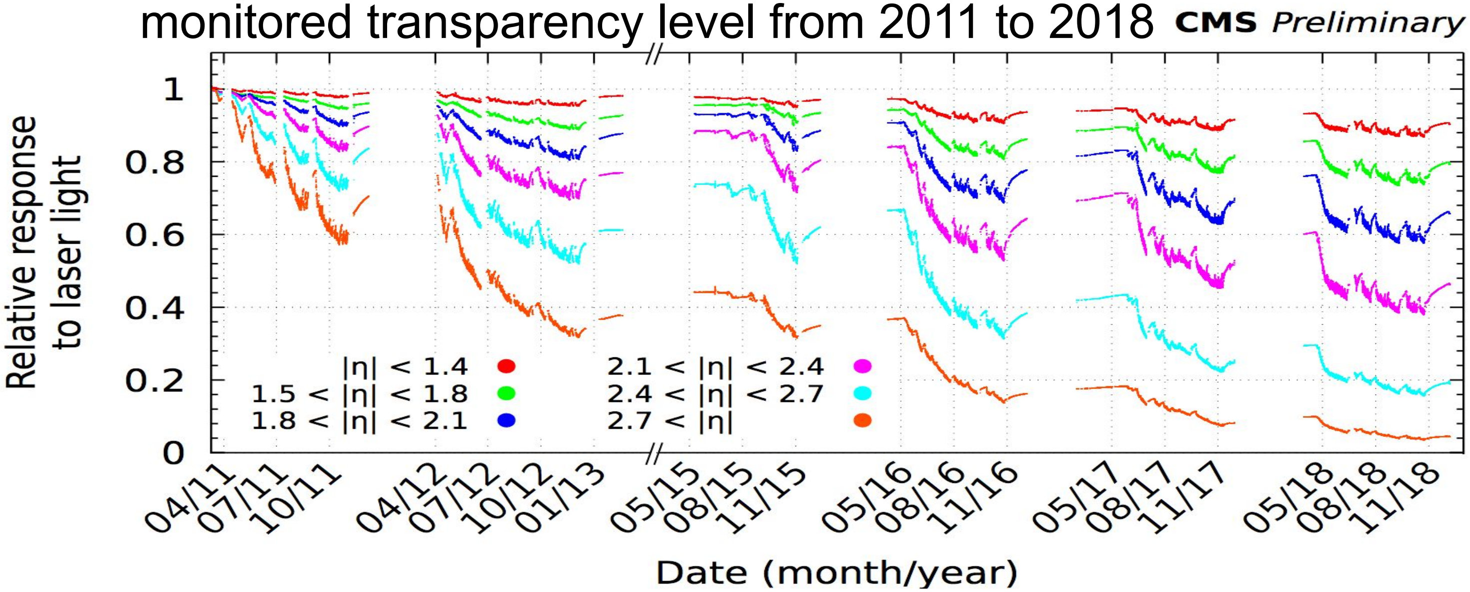
- Radiation damage to ECAL crystals → transparency loss

➢ Laser monitoring system to measure and correct for that
  - 1 measure every 45 min
  - crystal granularity

Laser pulse distributed to crystals through optical fibers



monitored transparency level from 2011 to 2018

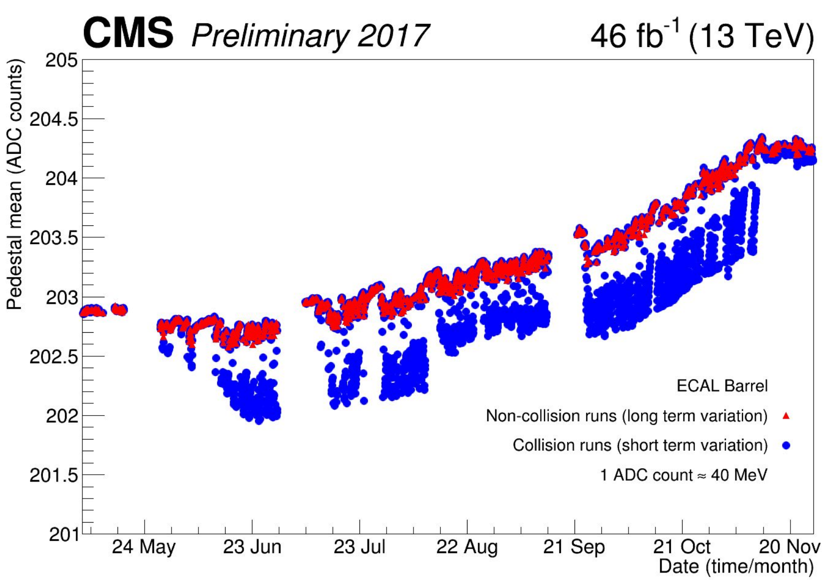


Dependence on luminosity, time, and η

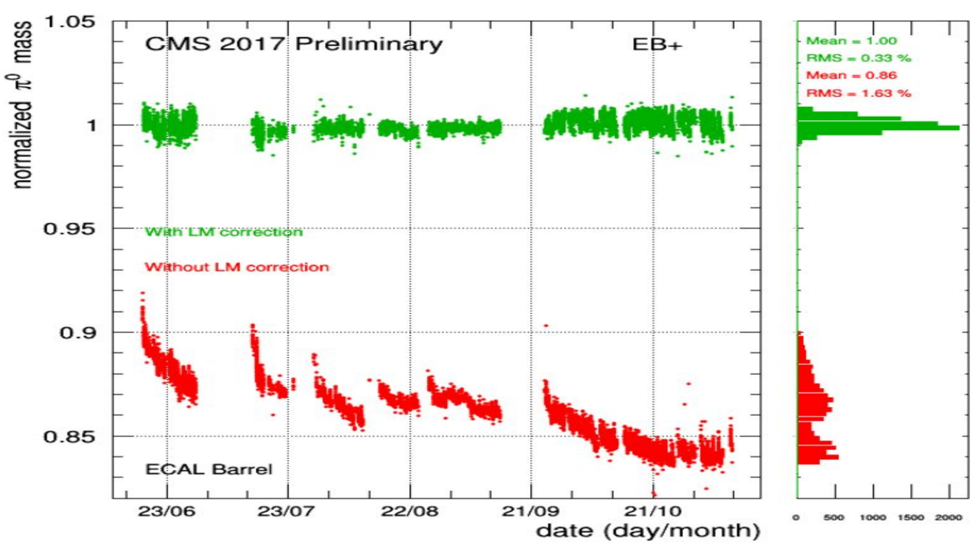
Pedestals evolution

- Pedestal drift throughout Run 2
  - Short term variation: variation of working condition (temperature)
  - Long term variation: radiation damage on APD→leakage current
- Significant effect on low energy signals, e.g. $\pi^0 \rightarrow \gamma\gamma$
  - Pedestal measured every ~40 min and promptly corrected

Pedestal evolution in 2017



$m_{\gamma\gamma}$ vs time before and after drift corrections for $\pi^0 \rightarrow \gamma\gamma$ in 2017

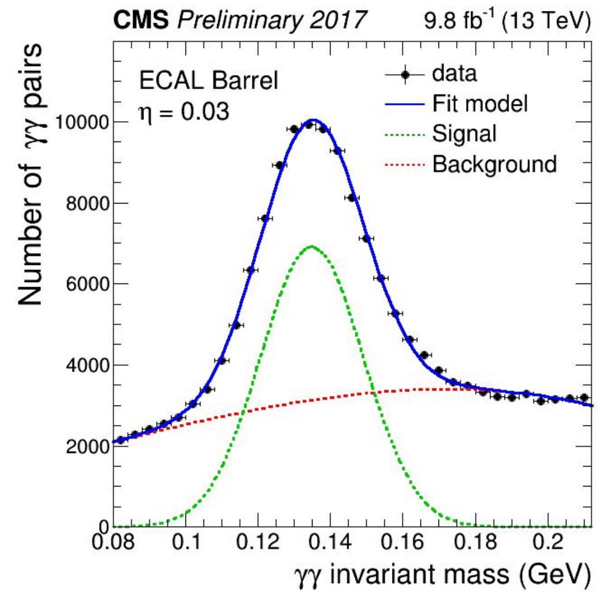


Inter-calibration

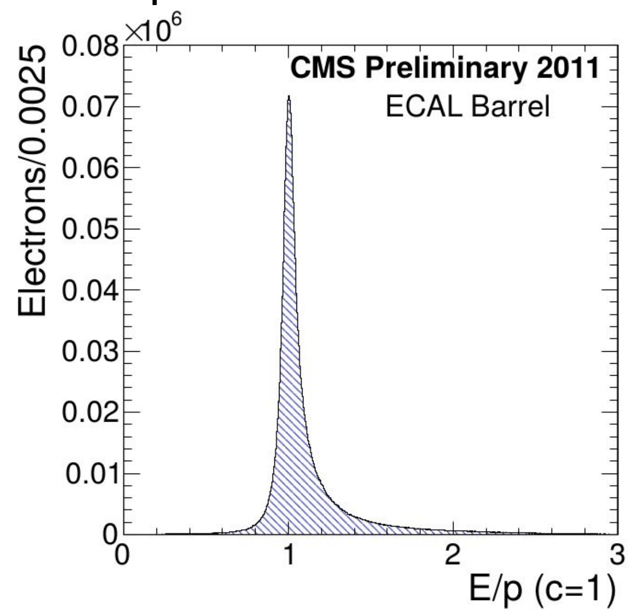
- Problem: channel-to-channel response spread
  - Variations of light yield, transparency, electronics gain

- Use reconstructed events to extract energy scale references
  1. Symmetry along ϕ of the average deposited energy from pp collisions
  2. Peak in m_{ee} for electrons from Z→ee decay (<u>new method</u>)
  3. Peak in $m_{\gamma\gamma}$ for photons from $\pi^0 \to \gamma\gamma$ decay
  4. *E/p* ratio for electrons from W→eν decays

Fit of $m_{\gamma\gamma}$ to extract π^0 peak



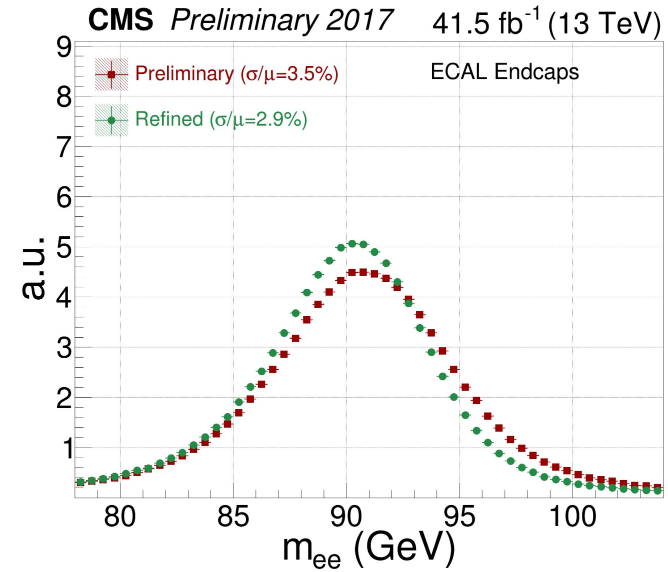
E/p distribution in barrel



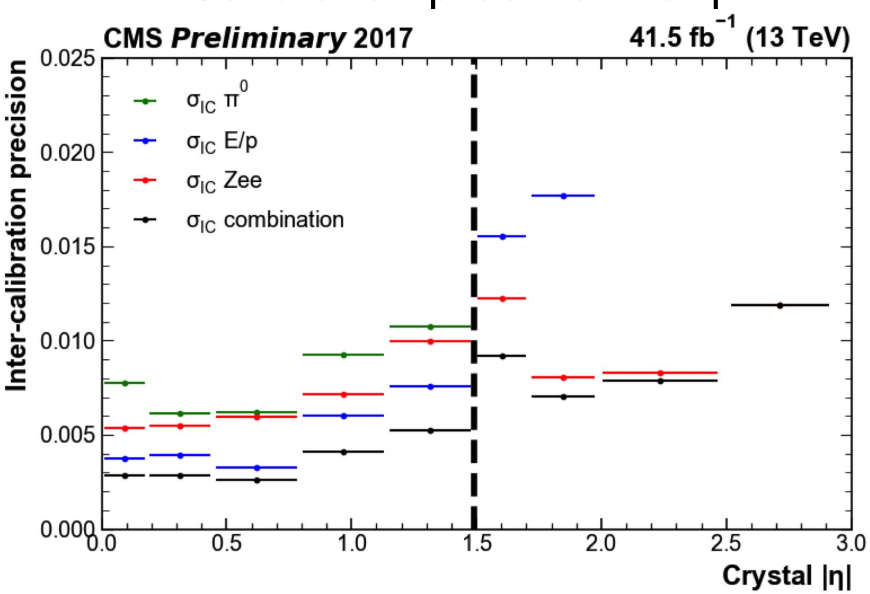
Inter-calibration results

- Ongoing re-calibration for optimized Run 2 data reconstruction
  - One inter-calibration per year to exploit full statistic
  - Residual mis-calibration < 0.5% in barrel and < 1% in endcaps

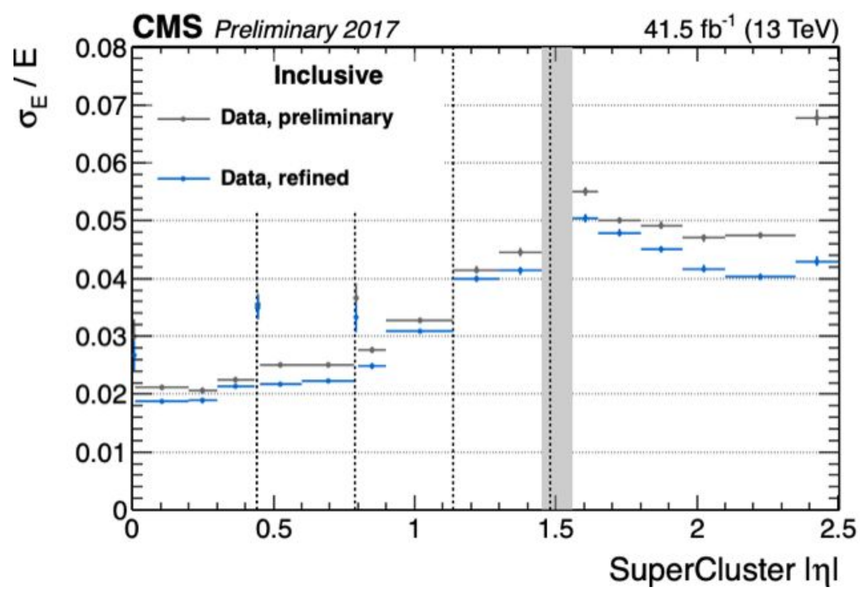
Impact of inter-calibration on Z→ee peak



Calibration precision vs η

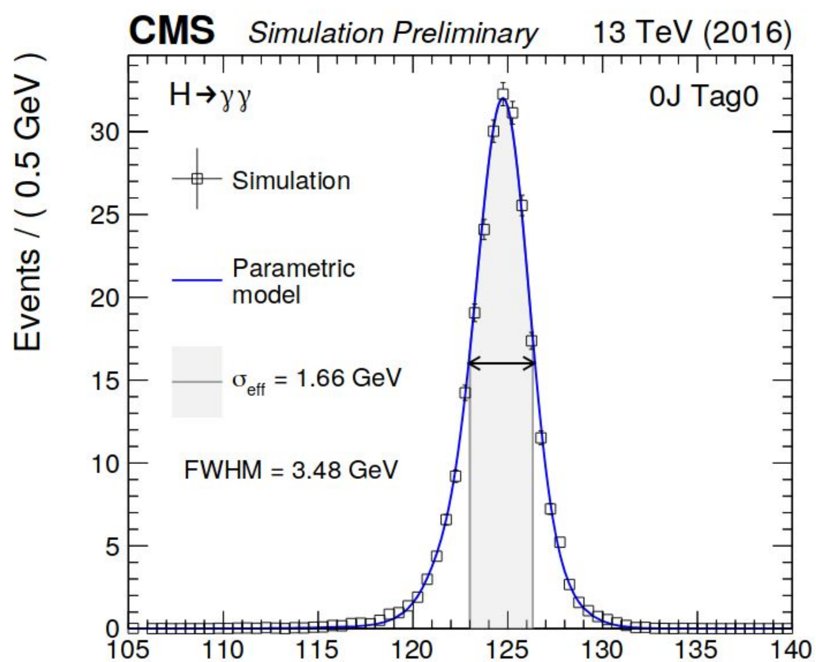


Energy resolution vs η



ECAL performance in Run 2

Very good energy resolution

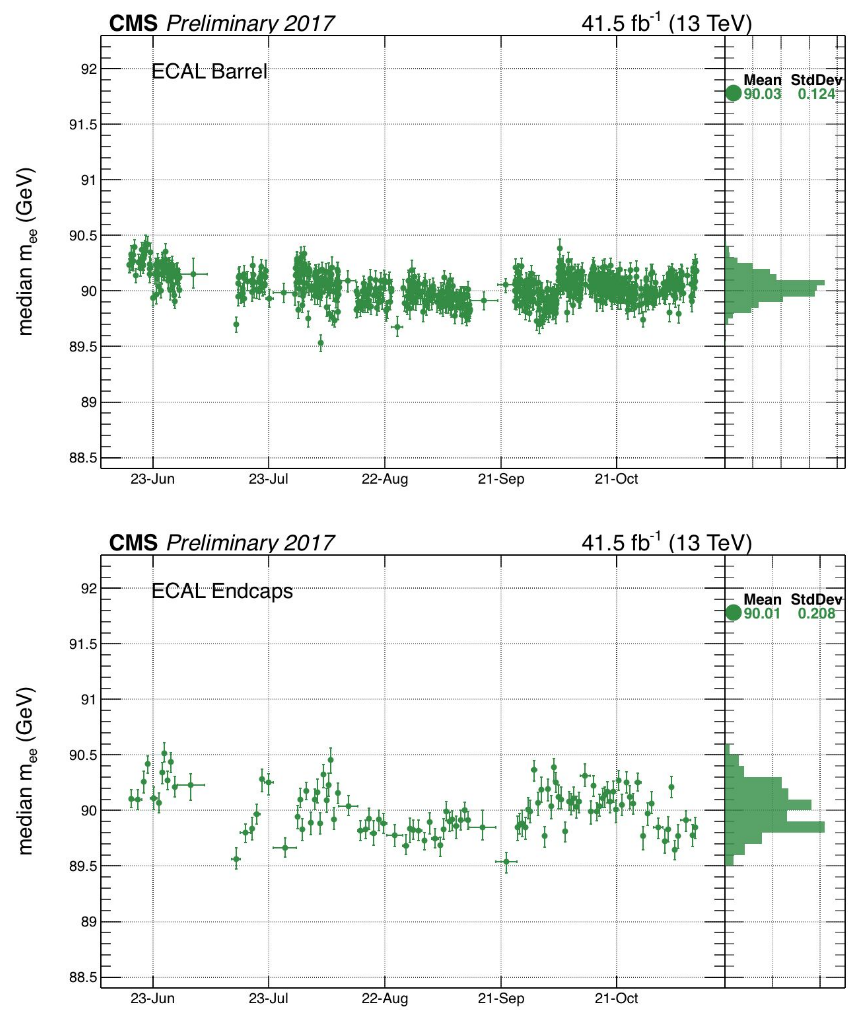


CMS-PAS-HIG-18-029

~1% resolution on $m_{\gamma\gamma}$ for H→γγ events

➢ Comparable to Run 1 performance despite larger PU and absorbed dose

Stable energy scale



Summary

- ECAL is a hermetic, homogeneous calorimeter able to provide very precise measurements of photons, and electrons energy

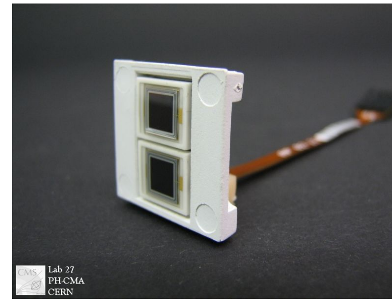
- In Run 2 increase of pileup and radiation damage required to optimize the strategies for reconstruction and calibration

- Stable performance throughout Run 2
  - Stable energy scale
  - Energy resolution of ~1.5-3% in barrel and of ~4% in endcaps
  - $H \rightarrow \gamma\gamma$ peak width comparable to Run 1

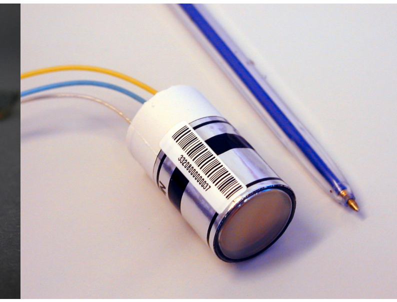
BACKUP

$PbWO_4$ crystal

APD

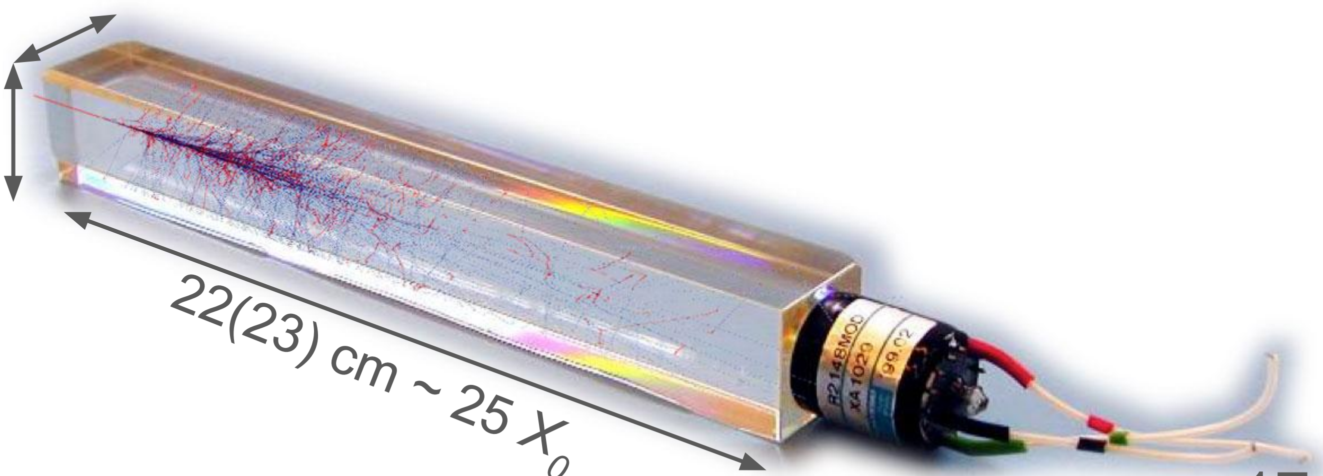


VPT



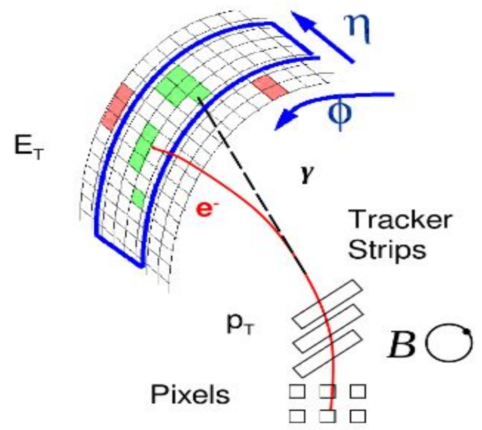
- High density 8.28 g/cm^3 ~ 2-4× glass
- Radiation length = 0.92 cm
- Moliére radius = 2.2 cm
- 80% light emission in 25 ns
- Light yield ~ 100 ph/MeV
- Readout:
  - APD in barrel: 2 APD of 5×5 mm^2 / crystal with gain ~50×
  - VPT in endcaps: 1 VPD of ~280 mm^2 / crystal with gain ~8-10×

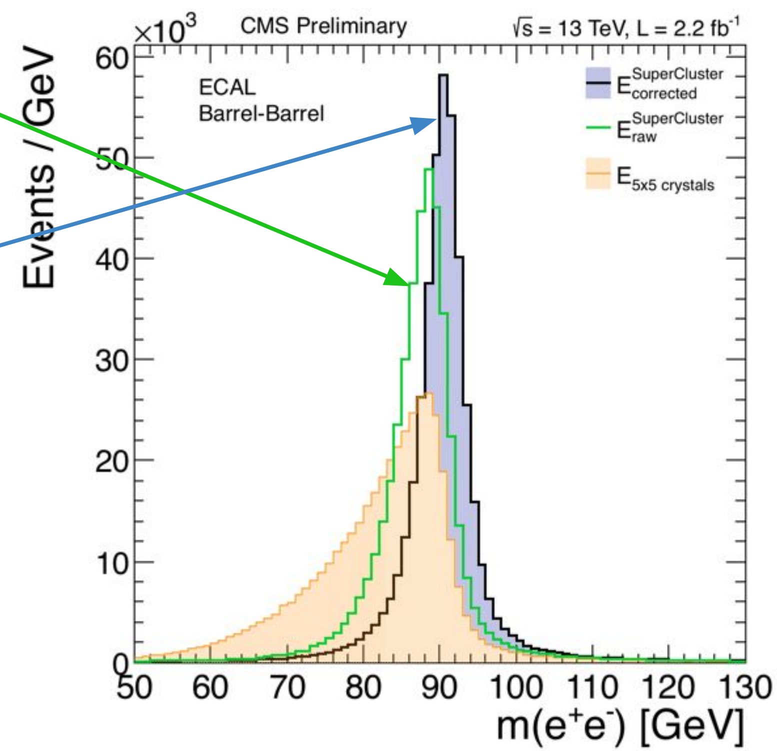
2.7×2.7 (2.2×2.2) cm^2
~ 1 Molière radius



Clustering reconstruction with ECAL

- Material in front of ECAL: tracker + supports
  - Electron bremsstrahlung
  - Photon conversion
- Clustering algorithms
  - "supercluster" of energy deposits compatible with a single e/ɣ shower
- Energy correction
  - for pileup, gaps between crystals, ...
  - <u>new</u> multivariate approach in Run 2





Pulse shape reconstruction details

Sum over 10 time samples

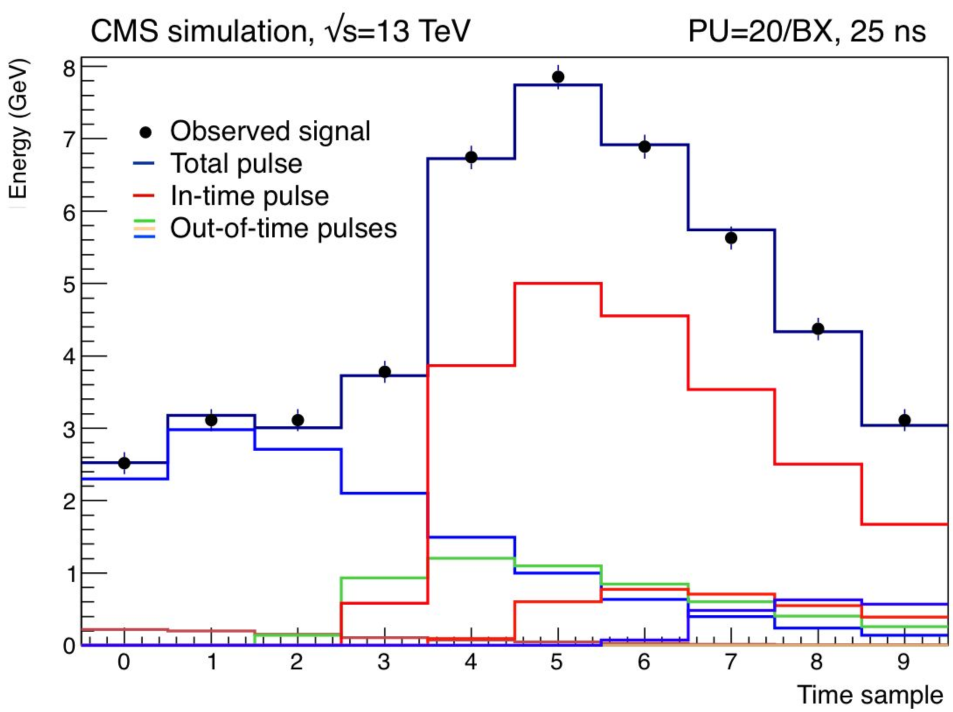
Sum over pulses

j-th pulse in i-th time sample

Observed signal

$$\chi^2 = \sum_{i=1}^{10} \frac{\left(\sum_{j=1}^{n} A_j \, p_{ij} - S_i\right)^2}{\sigma_{S_i}^2}$$

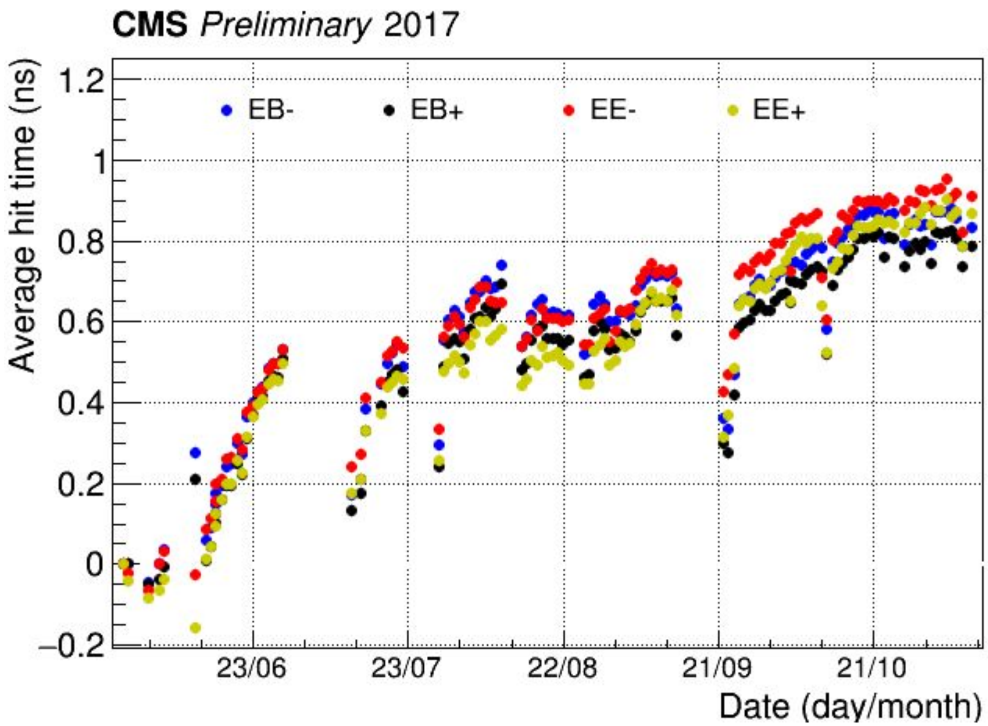
Noise ⊕ pulse shape uncertainty



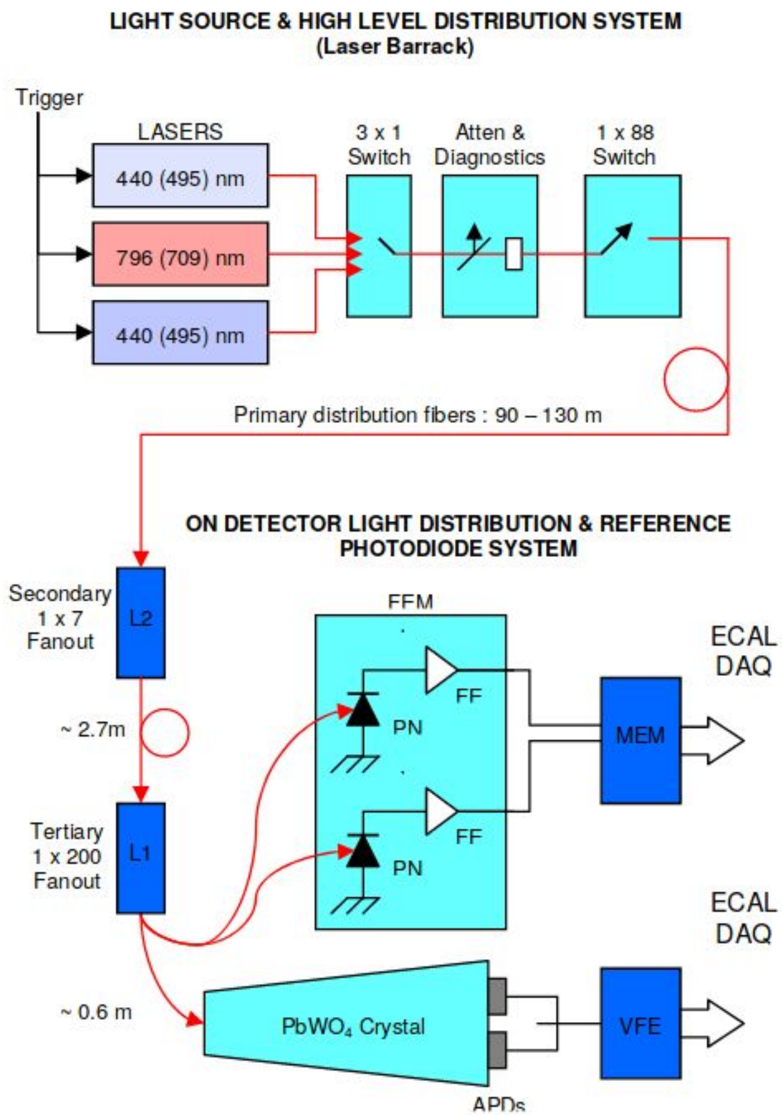
Timing drift

Drift of electronics and of the pulse shapes during the data taking

- ➢ Re-calibrate timing and pulse shapes when drift > 200 ps
- ➢ Typical timescale ~ week



Laser correction details



Pedestal vs noise evolution

- Long term pedestal evolution matches rather well to the noise increase related to the APD leakage current variation (radiation damage)
- No short term noise evolution are observed