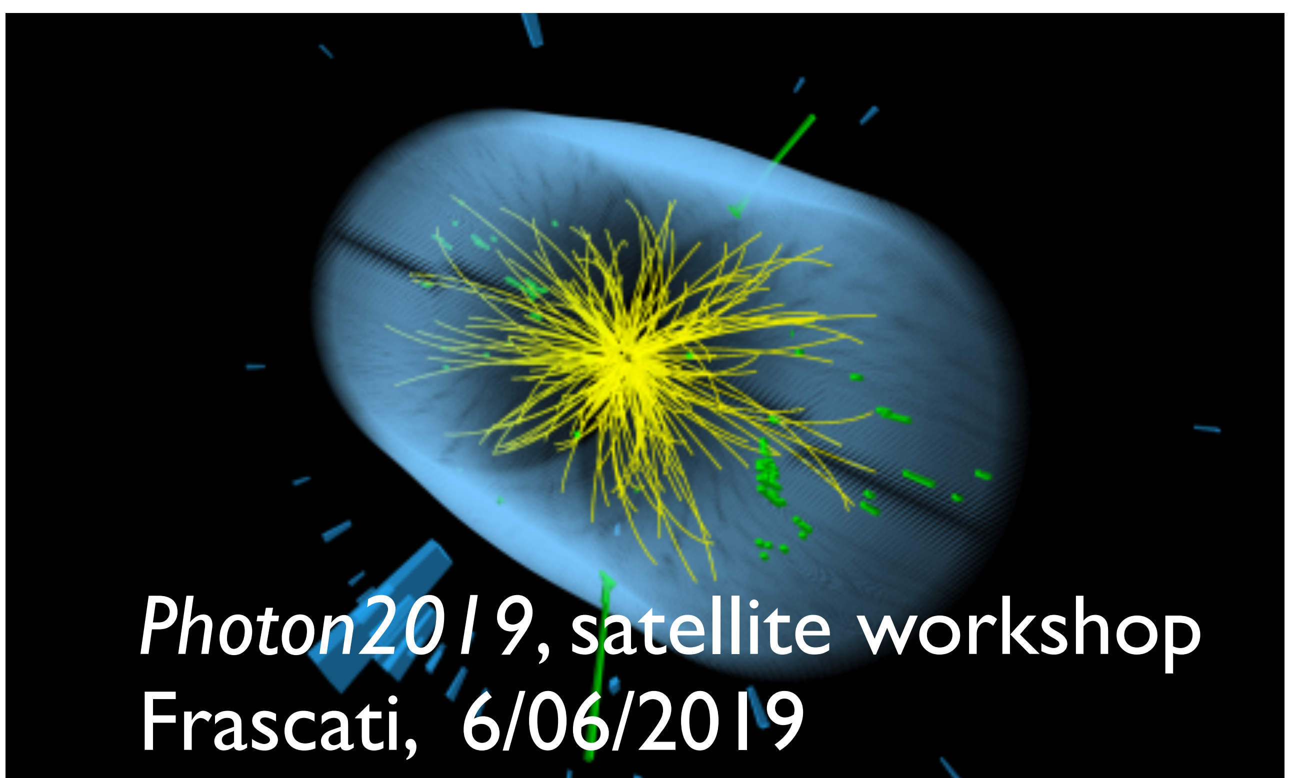
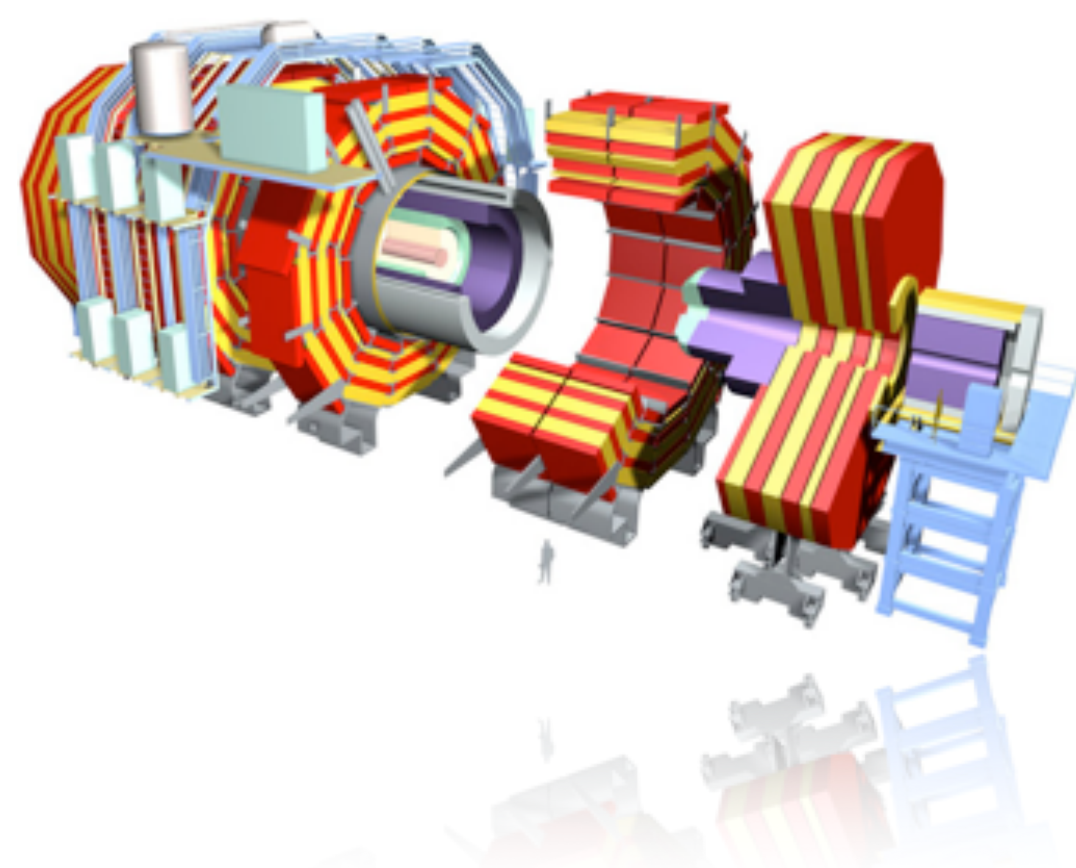
Detector and performance for photons in CMS

Fabrice Couderc,
on behalf of the *CMS collaboration*

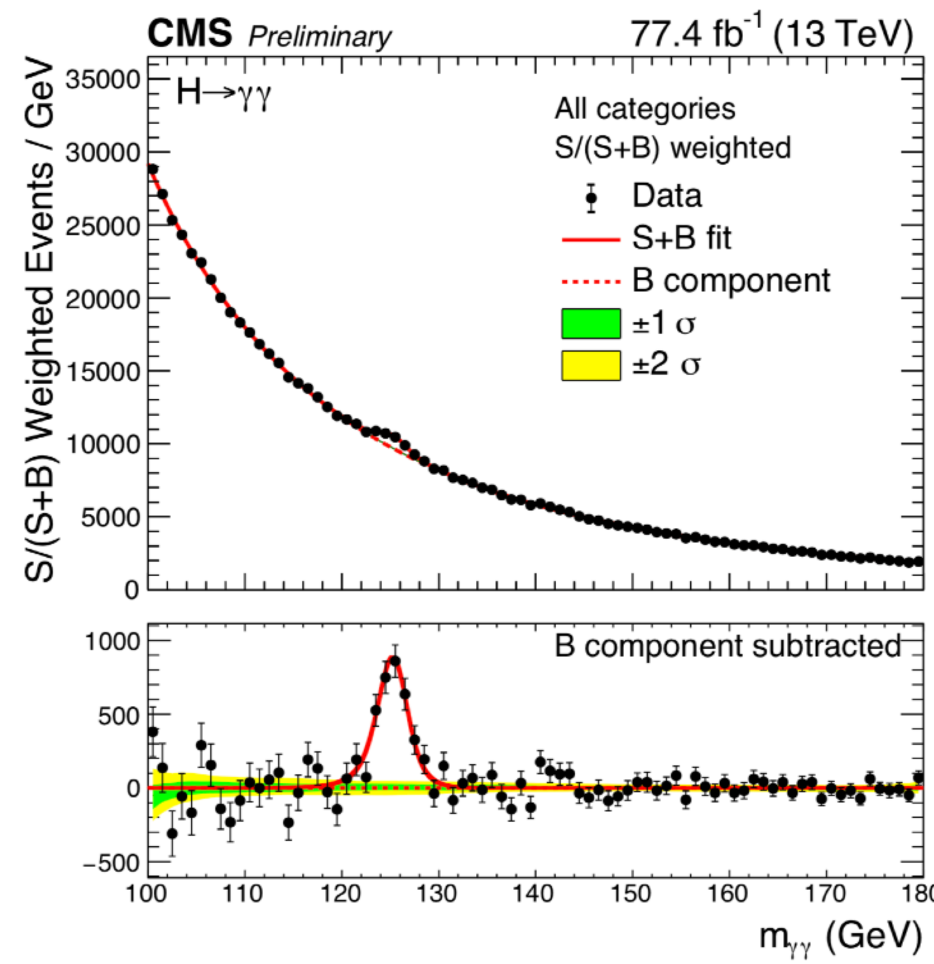


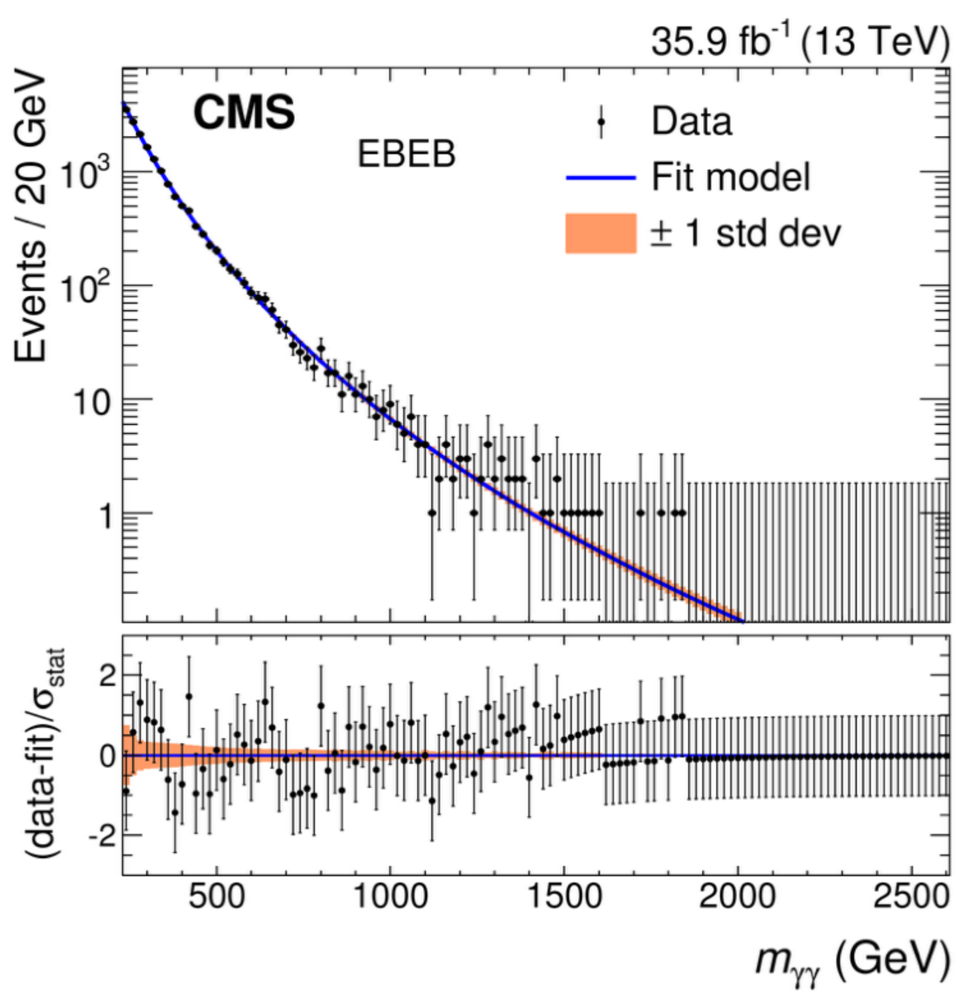


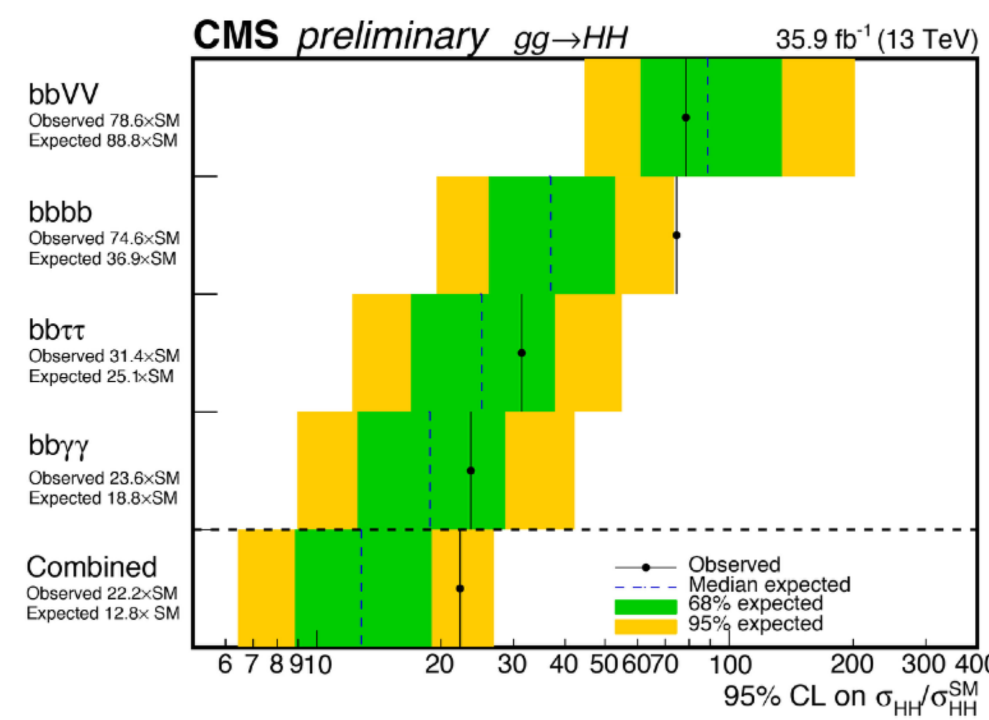
Overview

- Introduction
- CMS ECAL overview
  - ✓ ECAL detector
  - ✓ Energy measurement: the main ingredients
  - ✓ Channel-to-channel response equalisation
- Clustering for photons (and electrons)
- Photon identification
- Photon-energy measurement
- Conclusions

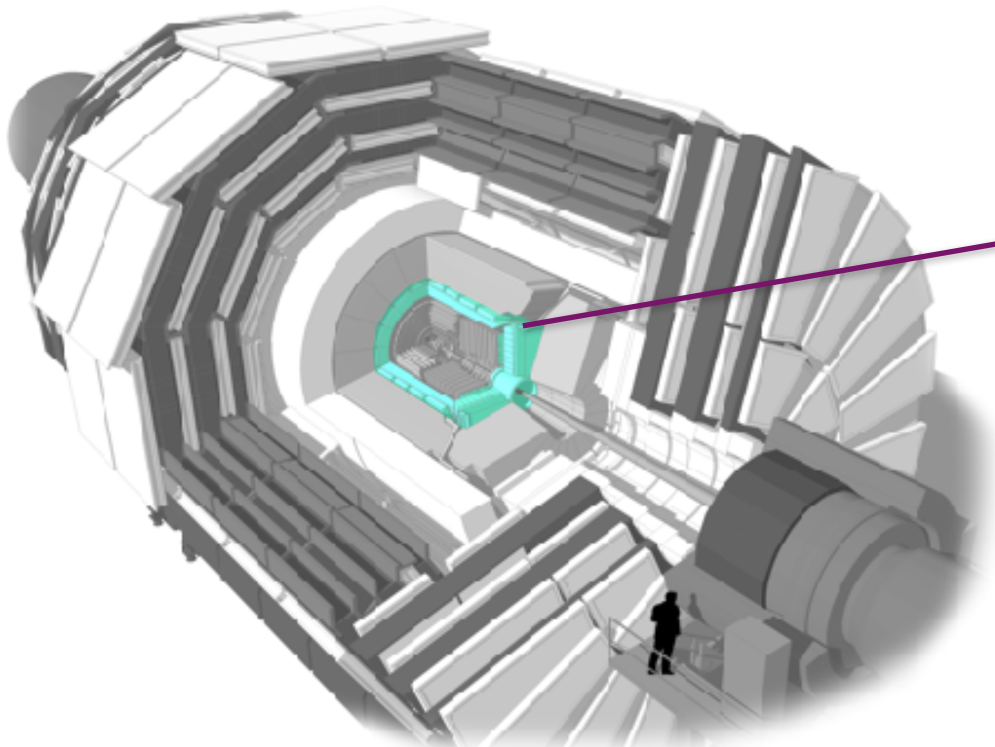
- Di-photon resonances are of paramount importance in the LHC physics program
- Search for new physics
- Higgs boson physics
  - ✓ H→γγ (Zγ)
  - ✓ One of the best channel for the study of ttH and HH productions

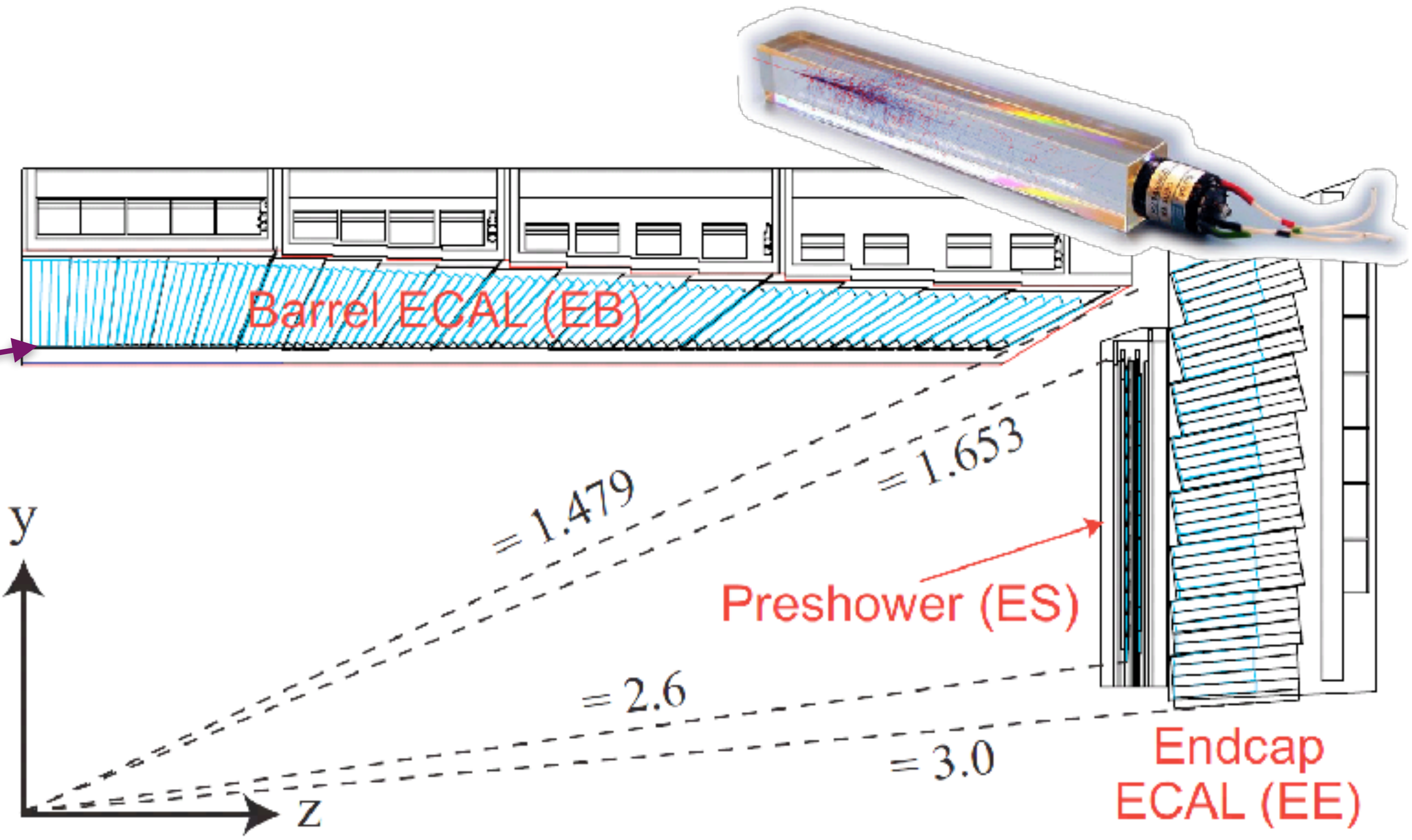


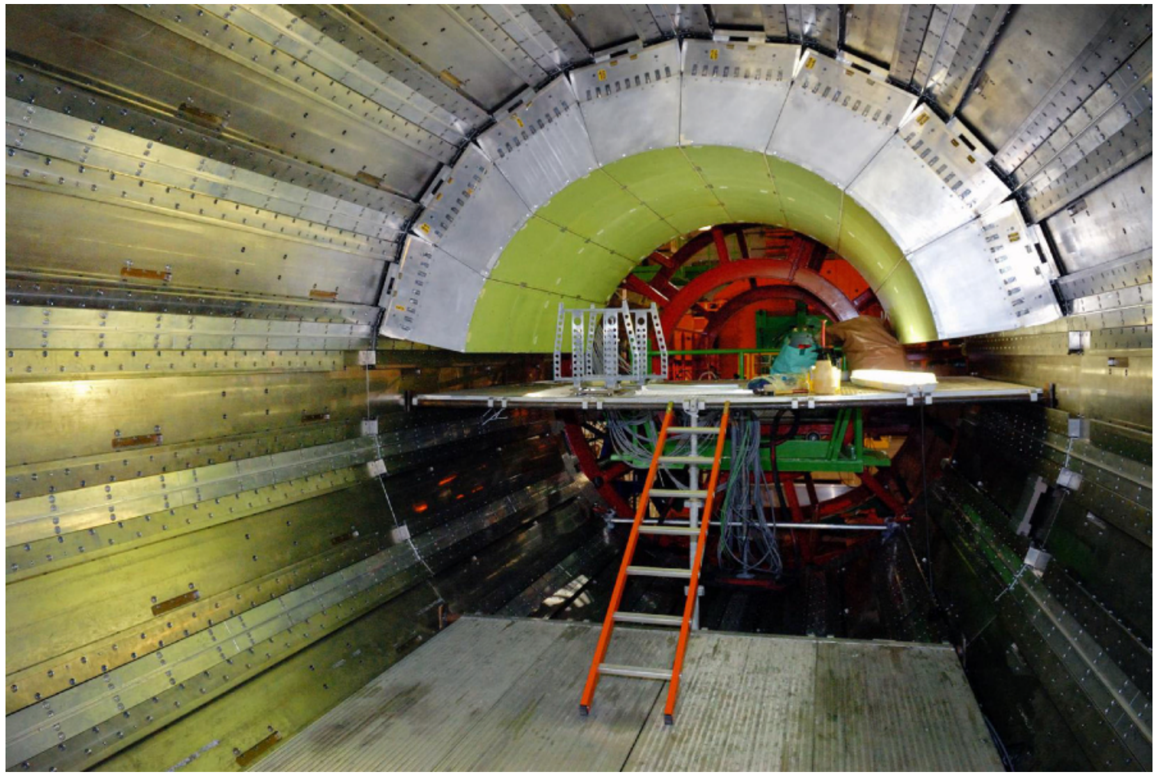




The main tool: CMS ECAL







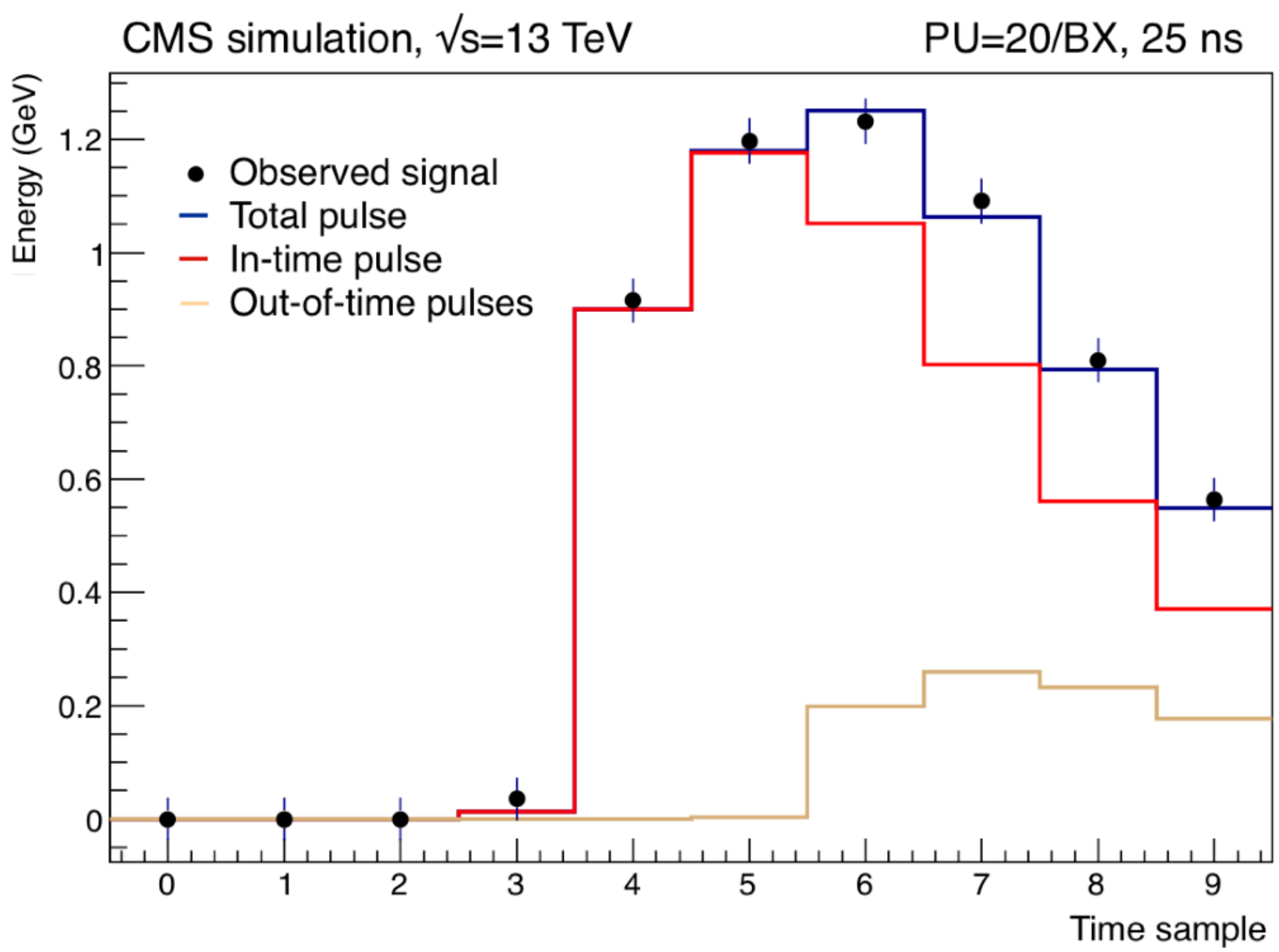
CMS Electronagnetic Calorimeter (ECAL): $PbWO_4$ crystals

- Barrel: |η| < 1.48, 61200 crystals $26X_0$
- Endcap: 1.48 < |η| < 3.0, 14648 crystals 25 X_0

Preshower: Lead (2 +1 X_0)/Si

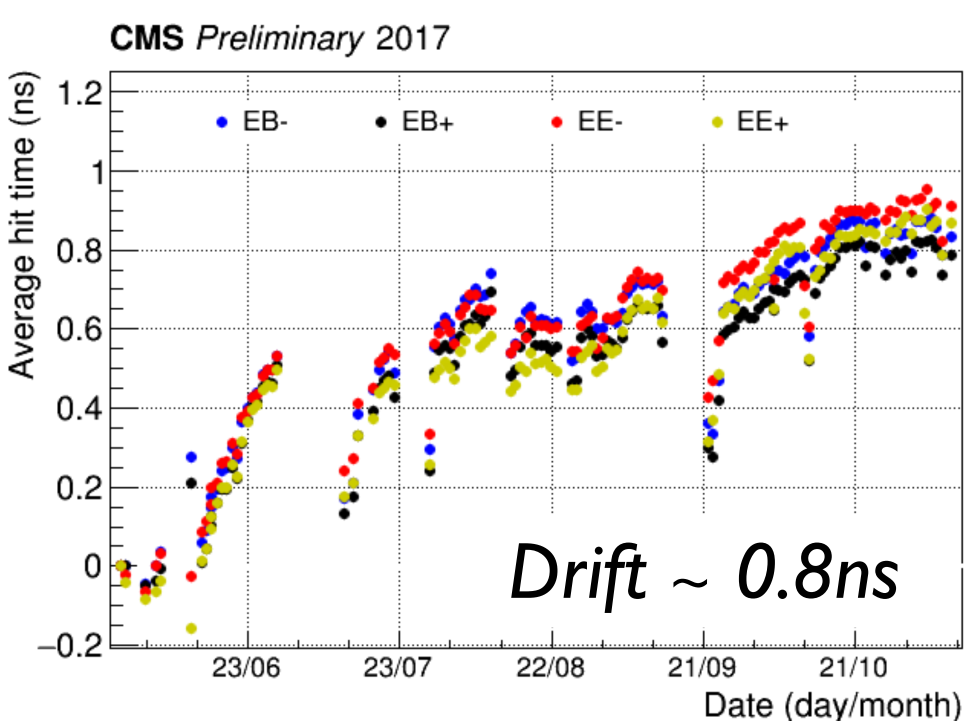
Ecal signal extraction

- Crystal energy extracted with the multifit method
  - ✓ ECAL signal digitisation done via 10 samples each 25 ns
  - ✓ Out-of-time pile-up (PU) rejection
- Time dependence of most of the ingredients entering signal extraction
  - ✓ Crystal transparence monitoring (laser monitoring system)
  - ✓ ECAL Pulse shape (from physics signal)
  - ✓ Pedestals monitoring (pedestal runs)

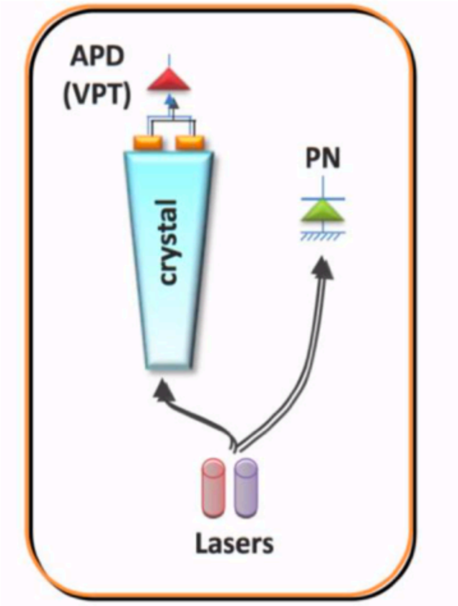


Example: Pulse shape

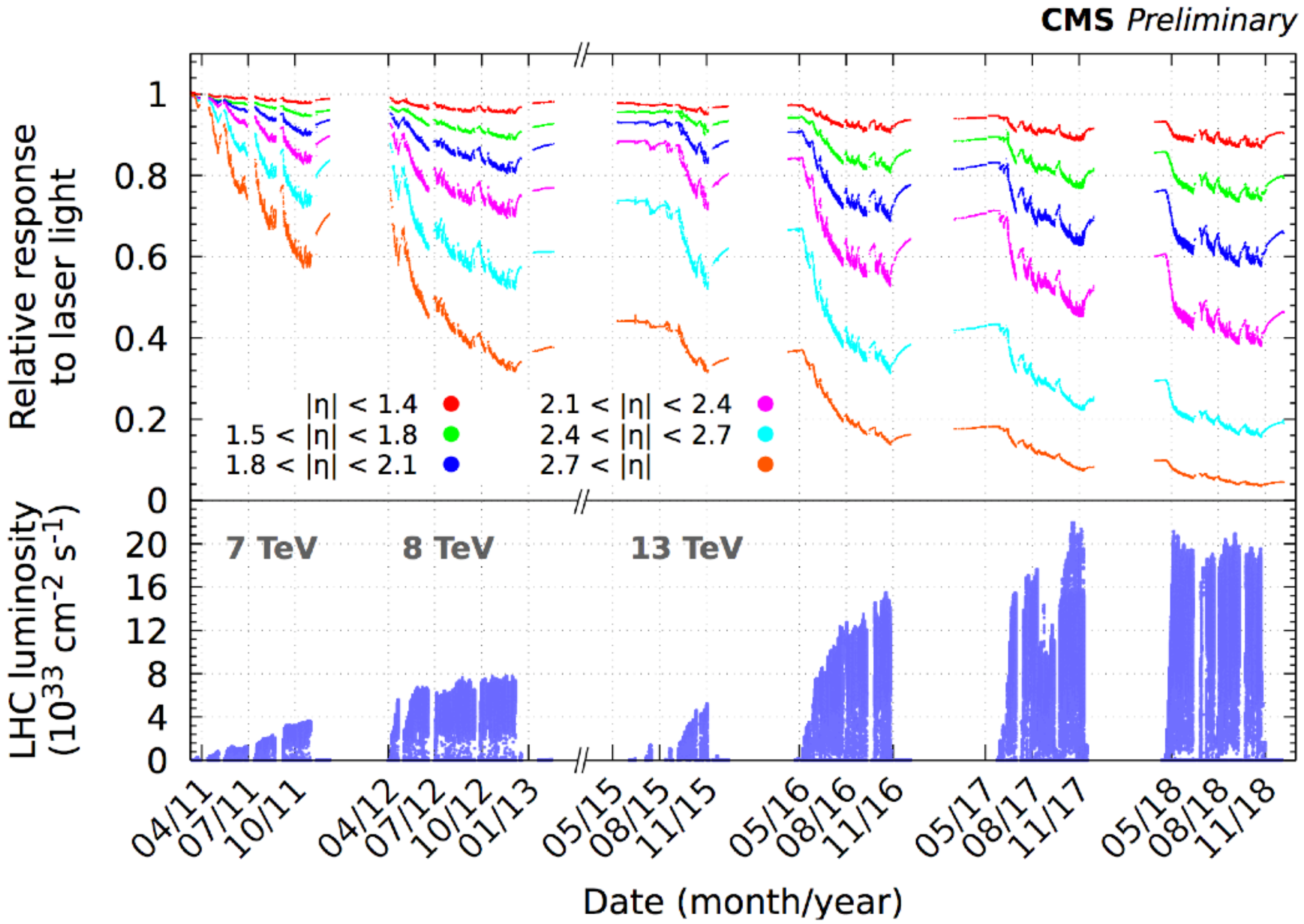
Average pulse-time evolution during 2017 data taking

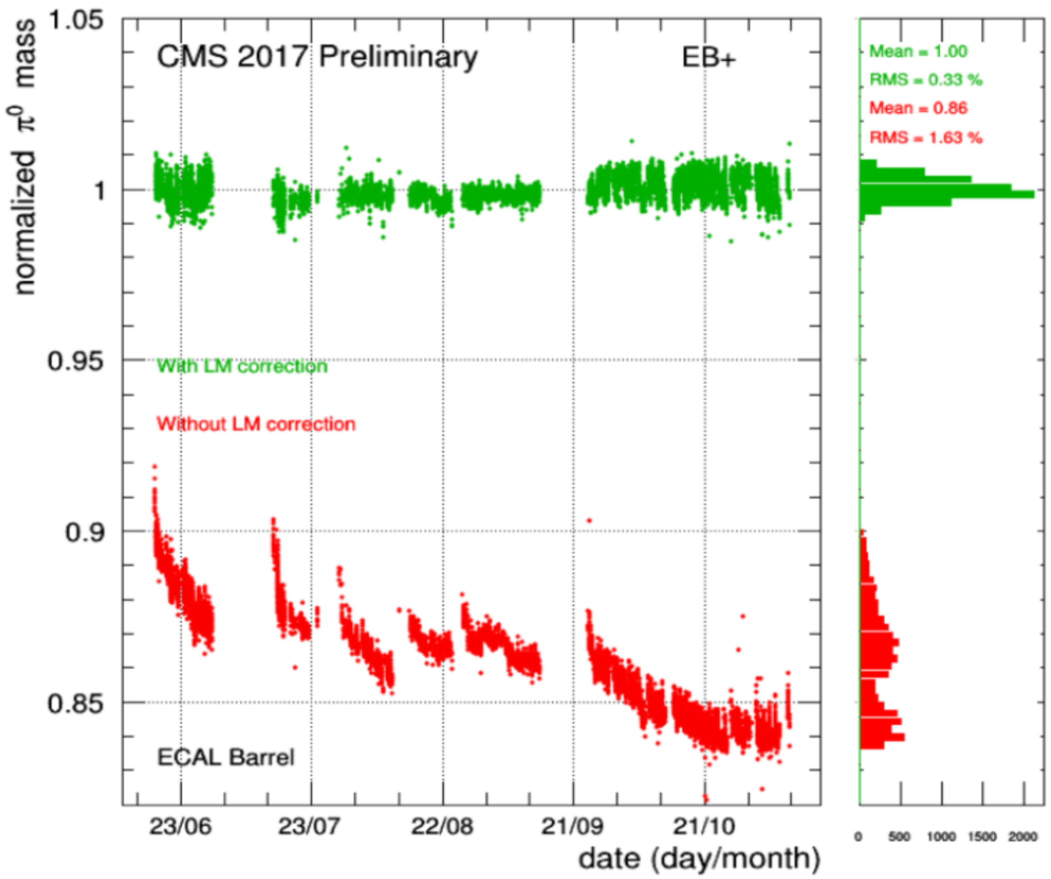


Crystal transparency monitoring



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





Measurement every 40'

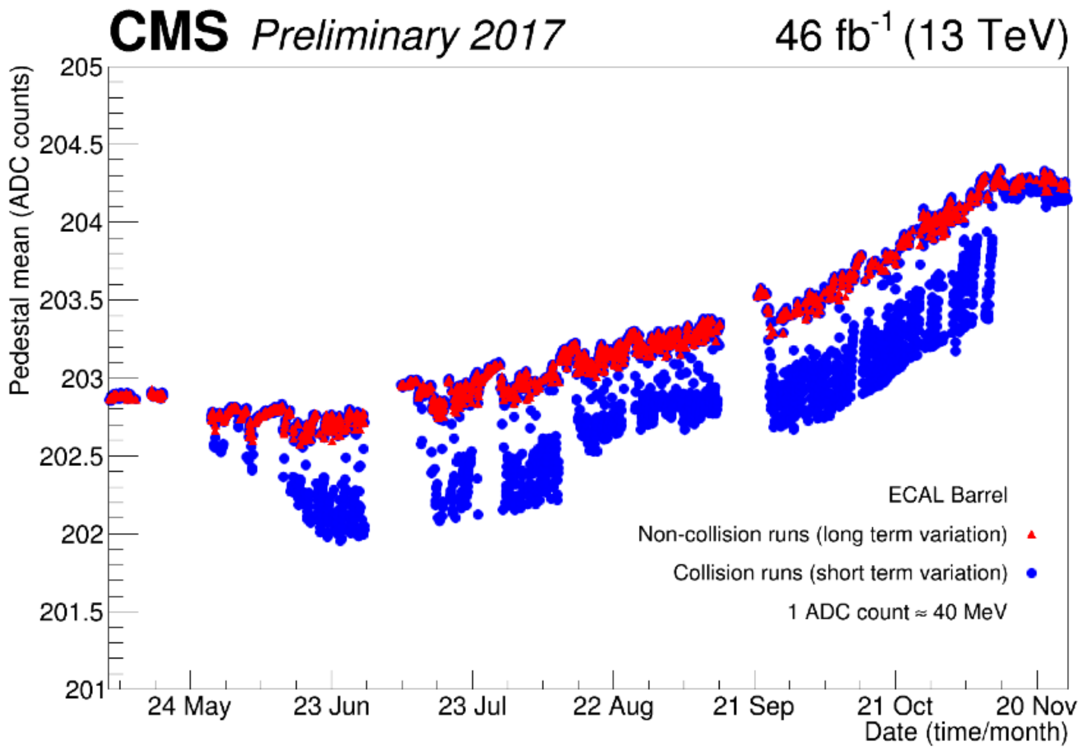
Irradiation induced damages in PbW04 crystals

Recoverable (EM) or not (Had)

Laser monitoring expected precision ≲ 0.2%

π^0 mass stability vs time during 2017

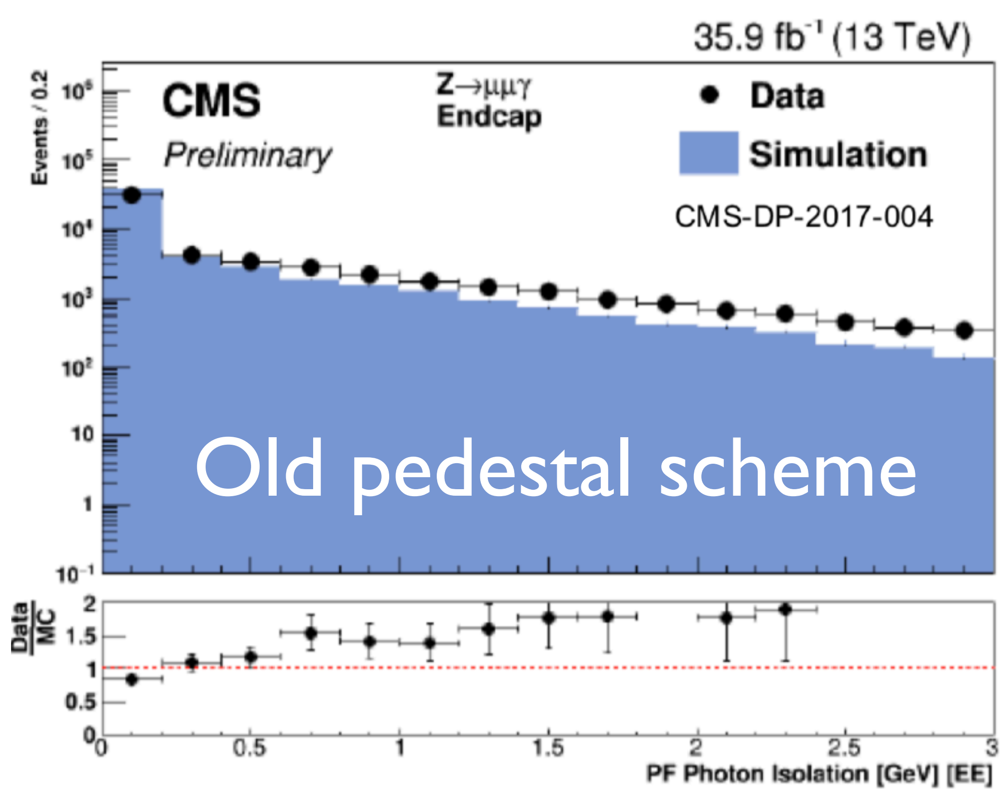
Peak RMS ≈ 0.3%

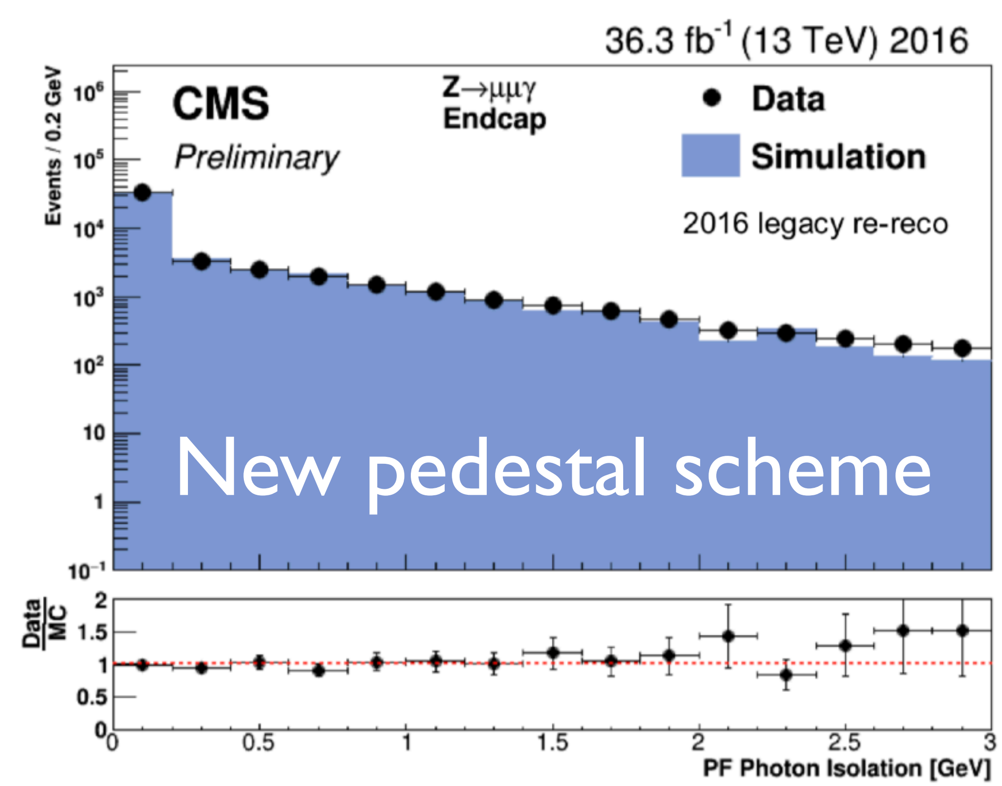


Pedestal measured during data-taking

- in/out fill effect
- Long term drift
- Short term drift

Same data as for laser monitoring

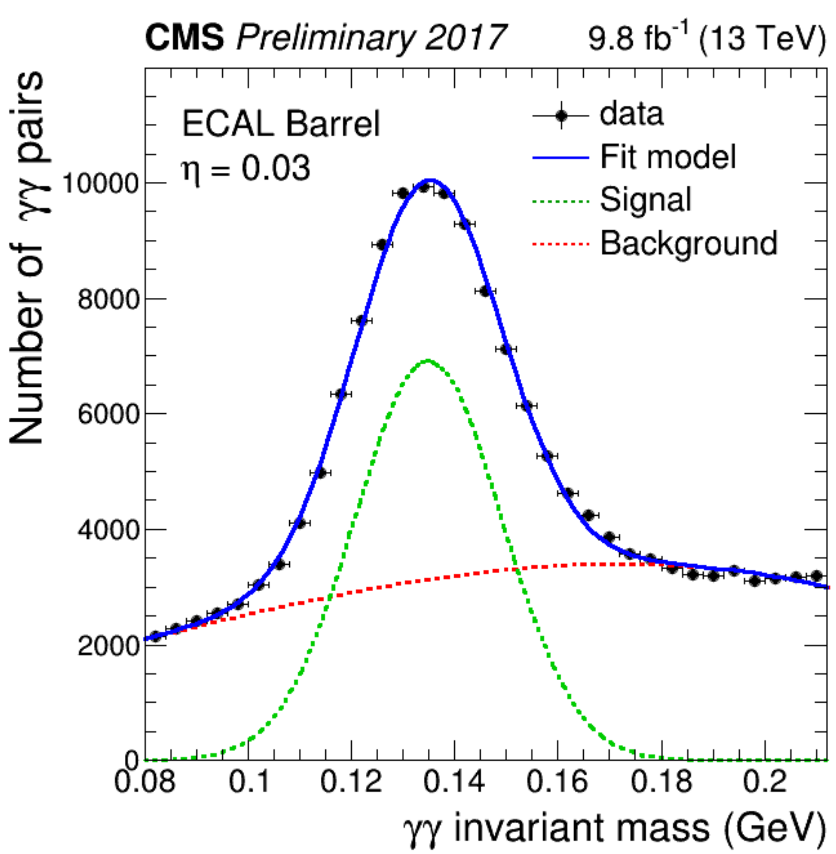


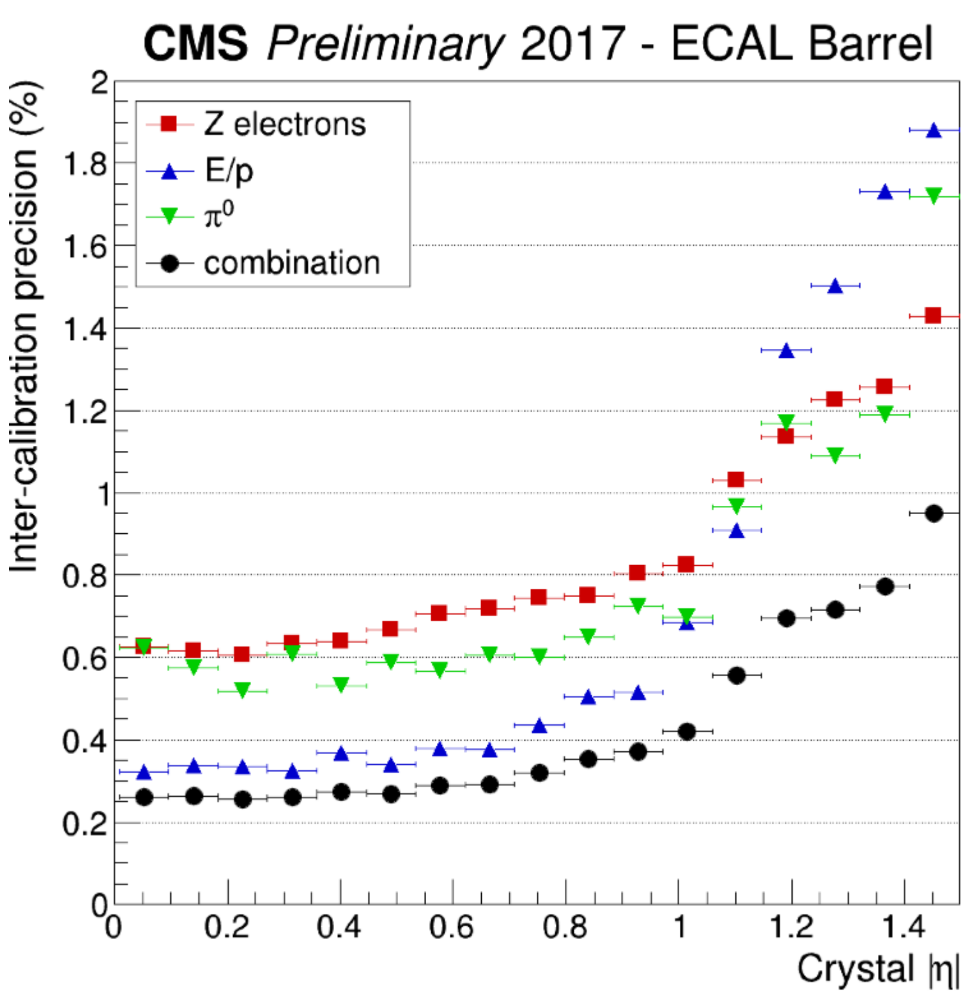


EM isolation used in physics object identification (2016 data vs MC)

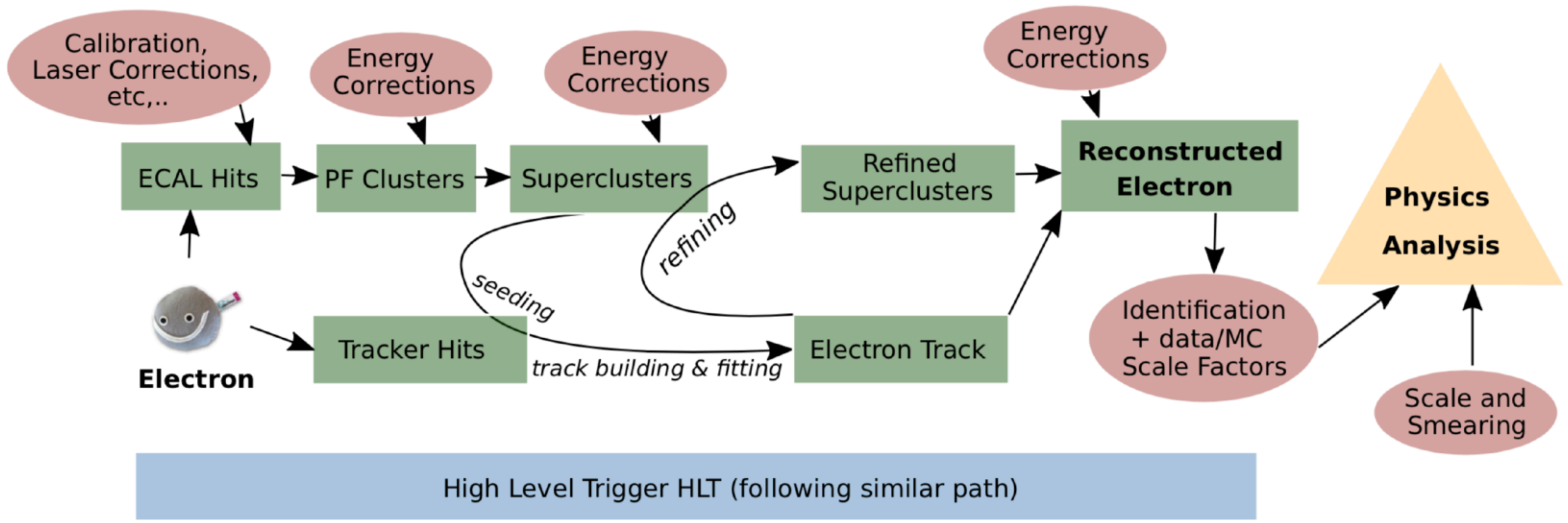
Channel inter-calibration

- Crystal to crystal response differences contribute to the constant term of the energy resolution (expected to be better than 0.5%)
- Several methods used to equalise the crystal response along φ
  - ✓ Min bias event energy flow vs φ
  - ✓ E/p : tracker energy scale propagated ECAL
  - ✓ π^0: known mass of the π^0
  - ✓ Z→ee : known mass of the Z (new in run2)
- In addition the absolute energy scale is derived from Z→ee and equalised along η to the energy scale in the simulation

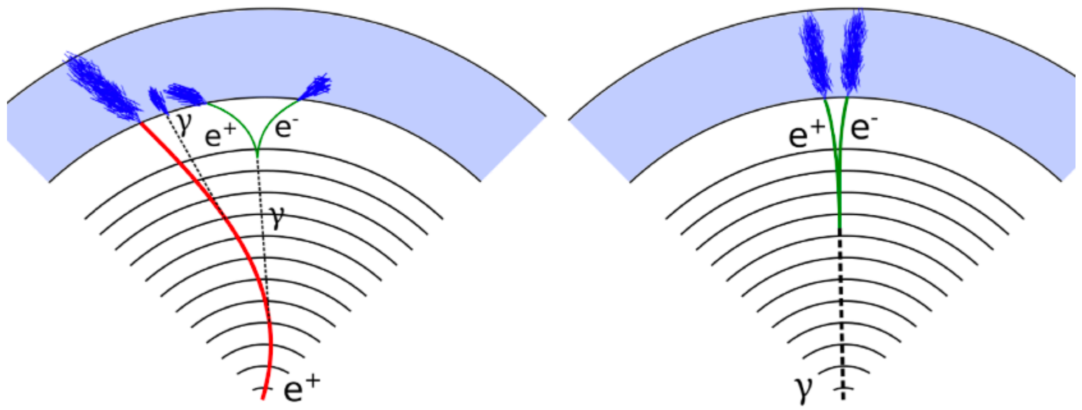




Photon and electron clustering



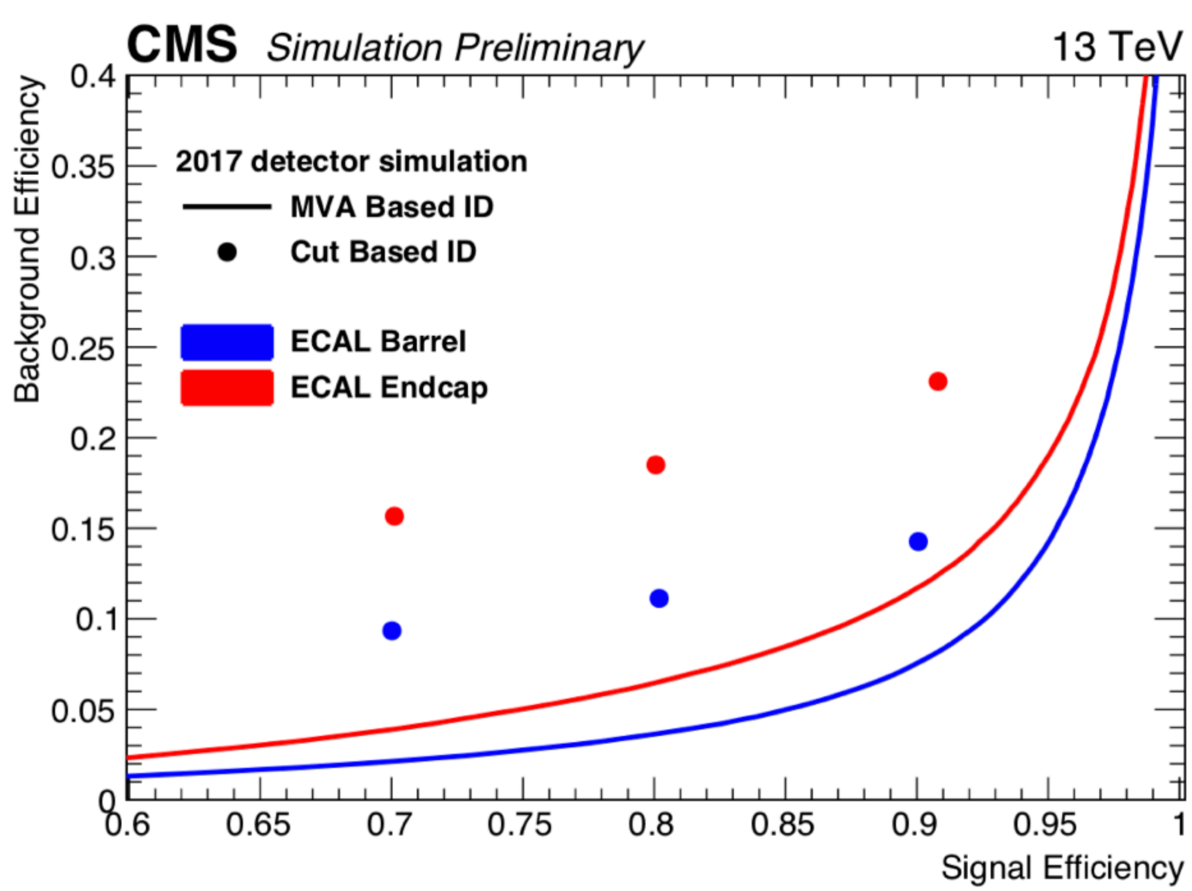
- γ/e same clustering algorithm
- Basic clusters merged in "supercluster" (SC):
  - ✓ Collects energy from brems and conversions
  - ✓ Accounts for electron B-field bending in φ and in η (relevant for low p_T clusters)
- Dedicated GSF tracking algorithm for electrons (used by conversion)
- SC refinement: clusters compatible with brems γ merged into the SC

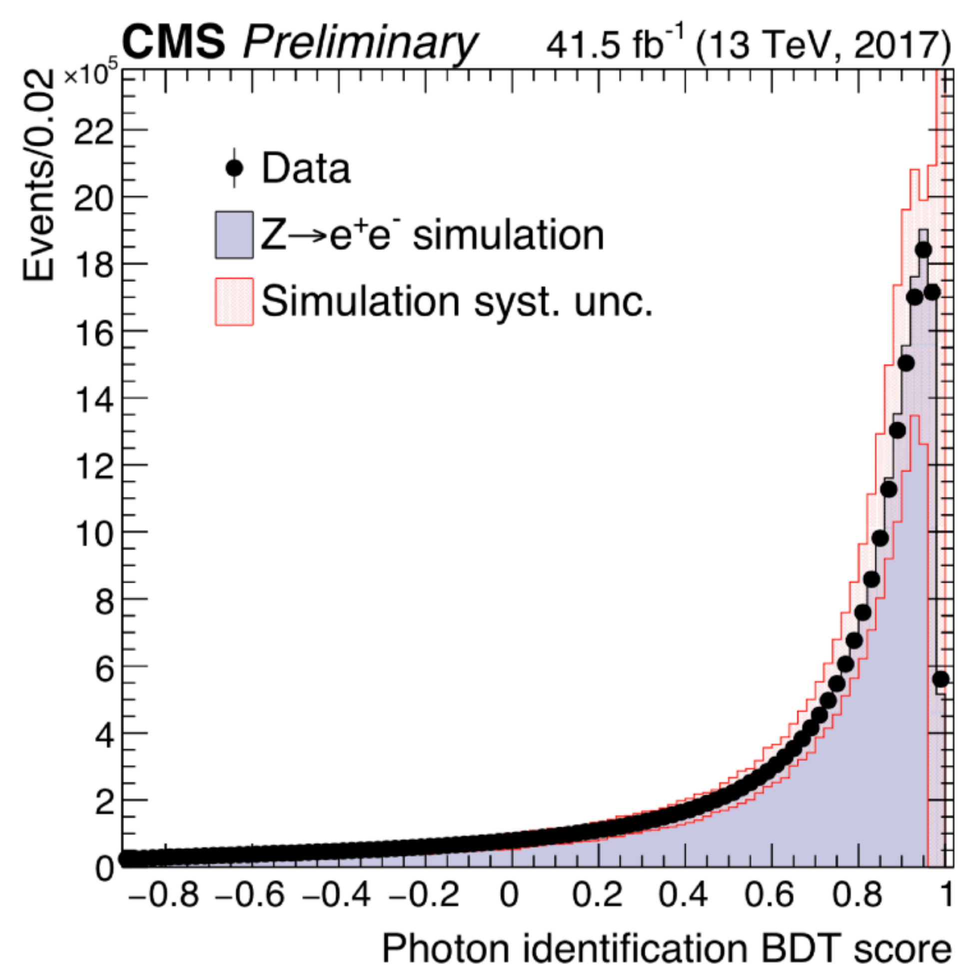


Photon identification (1)

- Two types of photon identification
  - ✓ Cut-based
  - ✓ Multivariate identification (e.g. H→γγ)
- Based on two kind of variables
  - ✓ Electromagnetic shower shape variables
  - ✓ Isolation variables (from tracker, Hadronic and EM calorimeters)
  - ✓ Accounts for PU

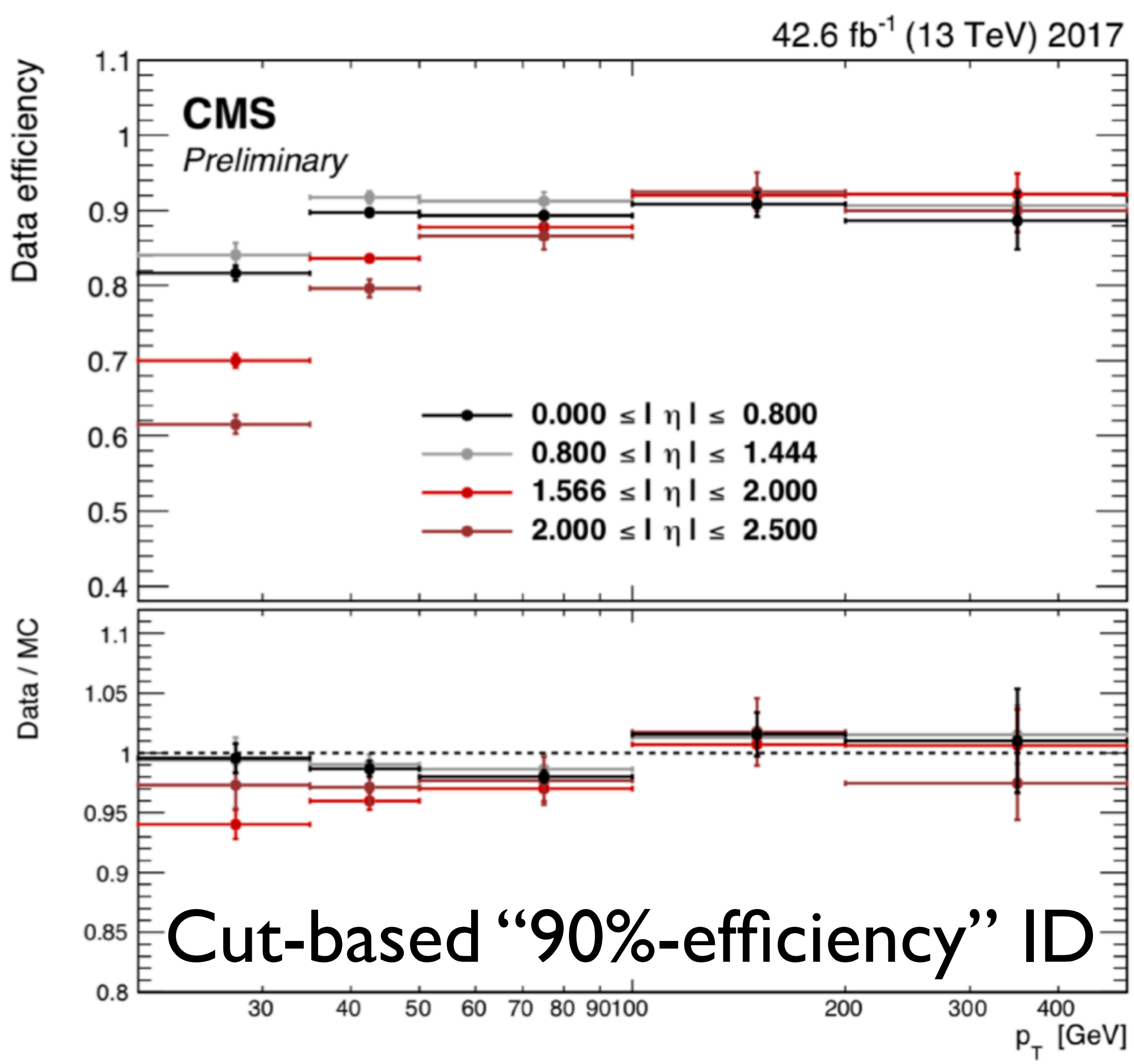
Data/MC agreement for the multivariate photon identification variable used by the H→γγ analysis (2017 data)

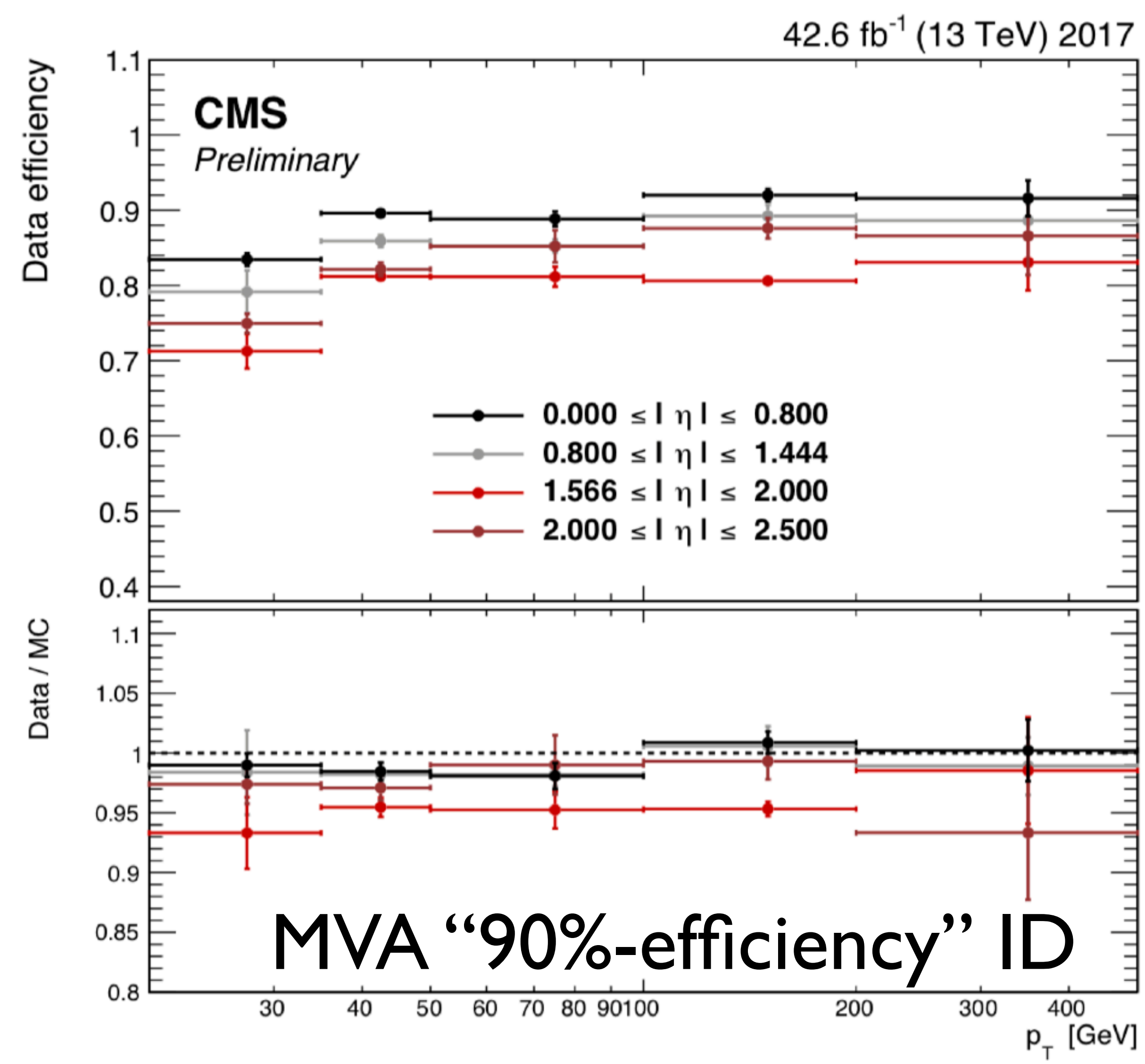




Photon identification (2)

- Photon identification efficiency measured with Z→ee events
  - ✓ Tag and probe method: one electron (used at the trigger level) tag the event, the other is used as probe to test the identification criteria efficiency
  - ✓ Measured in data and simulation: ratio used to correct the simulation efficiency

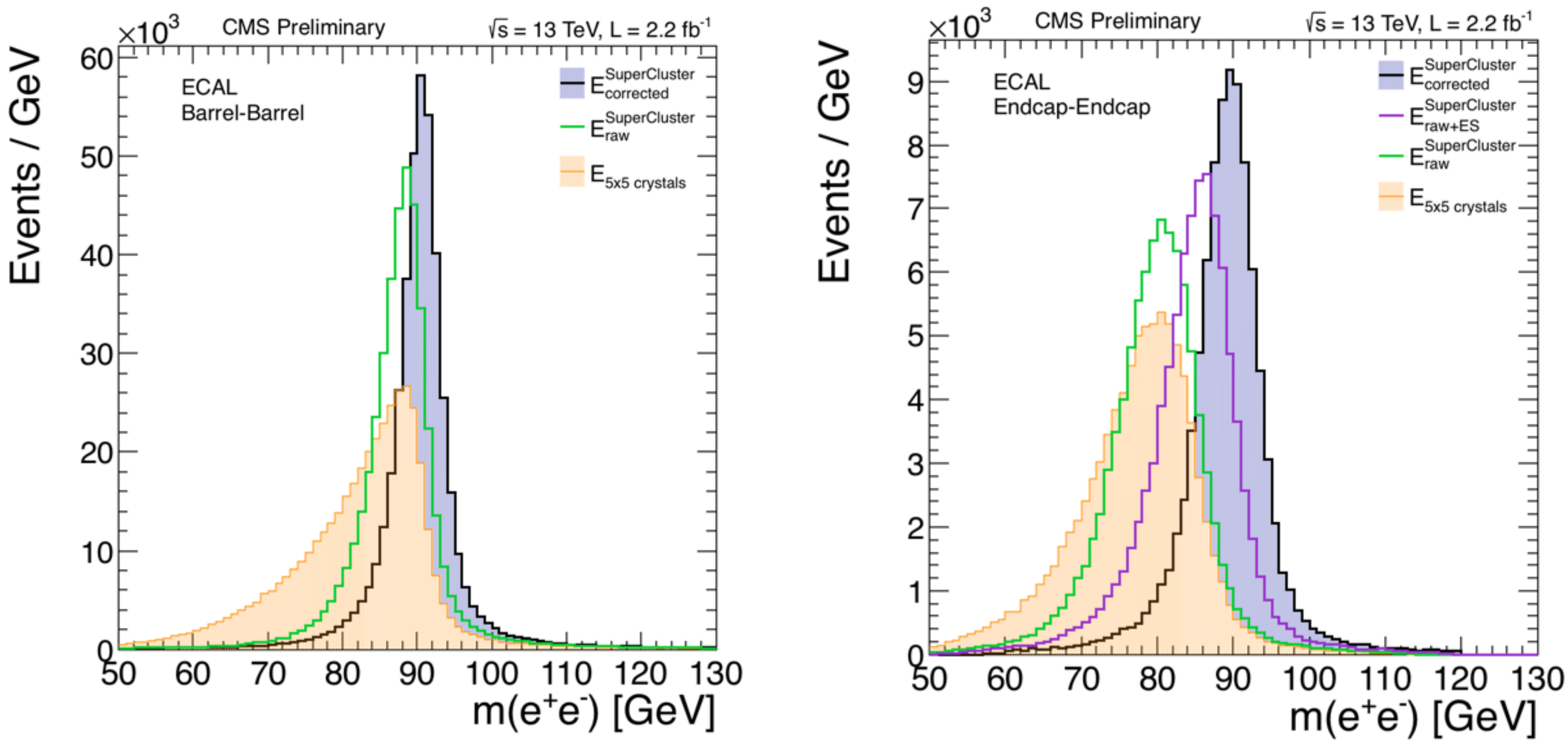




Photon energy measurement

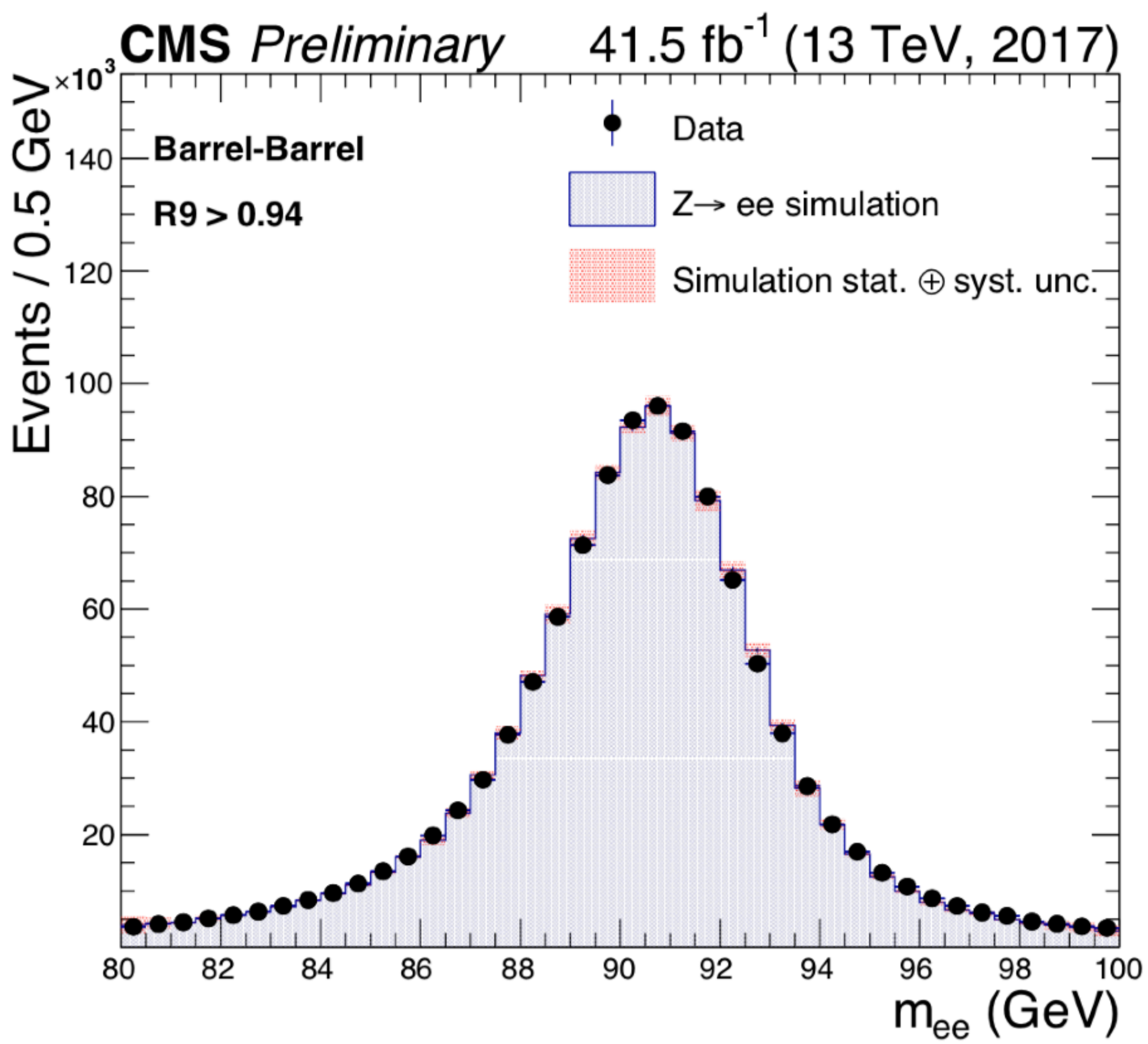
SC energy corrected for shower containment using a **multivariate regression trained on simulation**

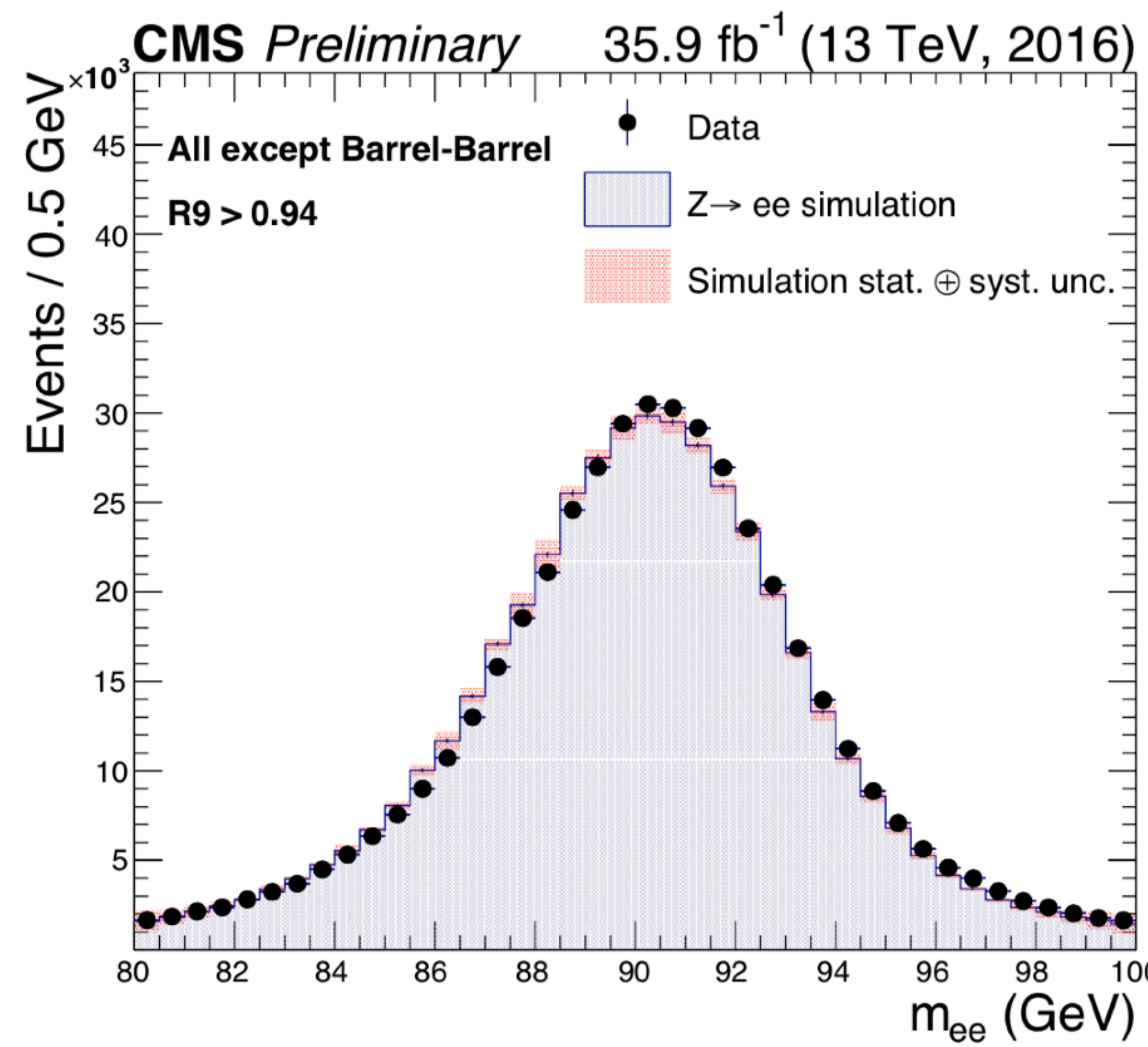
- E_{5x5}: energy in a 5x5 crystal matrix
- SC raw: SC-crystal energy sum
- SC corrected : includes energy corrections from regression



Absolute energy scale in data adjusted to the simulation (Z→ee)

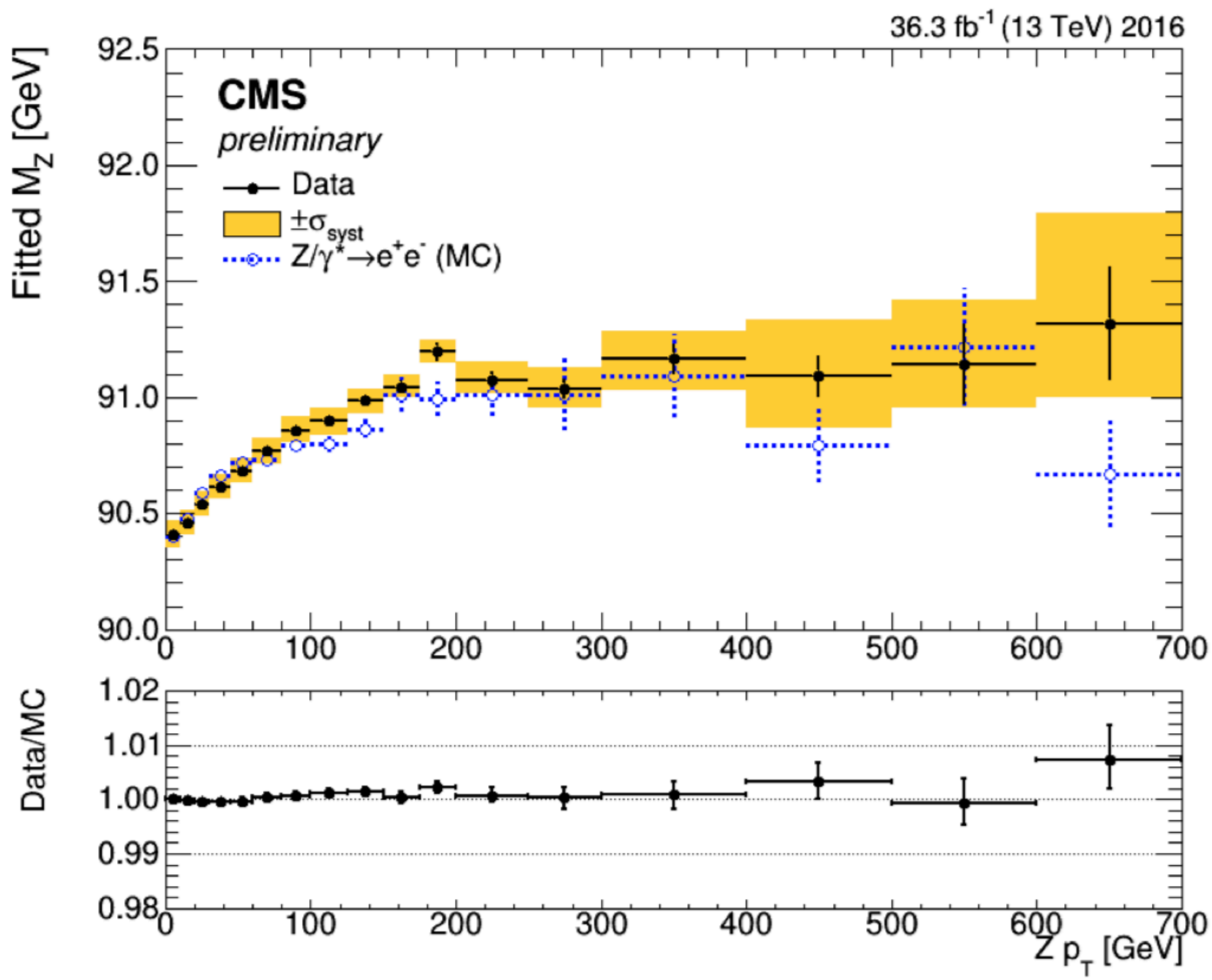
Residual simulation/data discrepancy in energy resolution is accounted for by over-smearing the simulation.





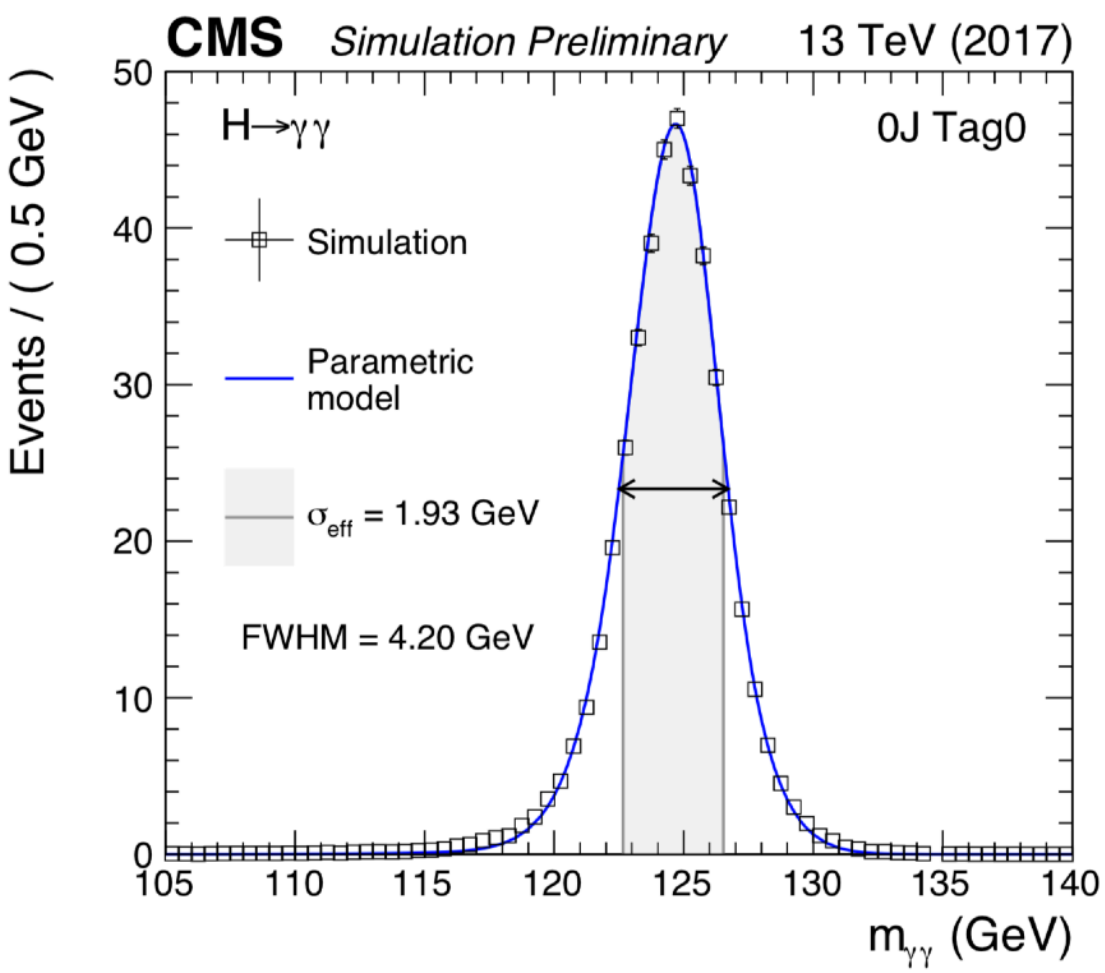
Energy linearity

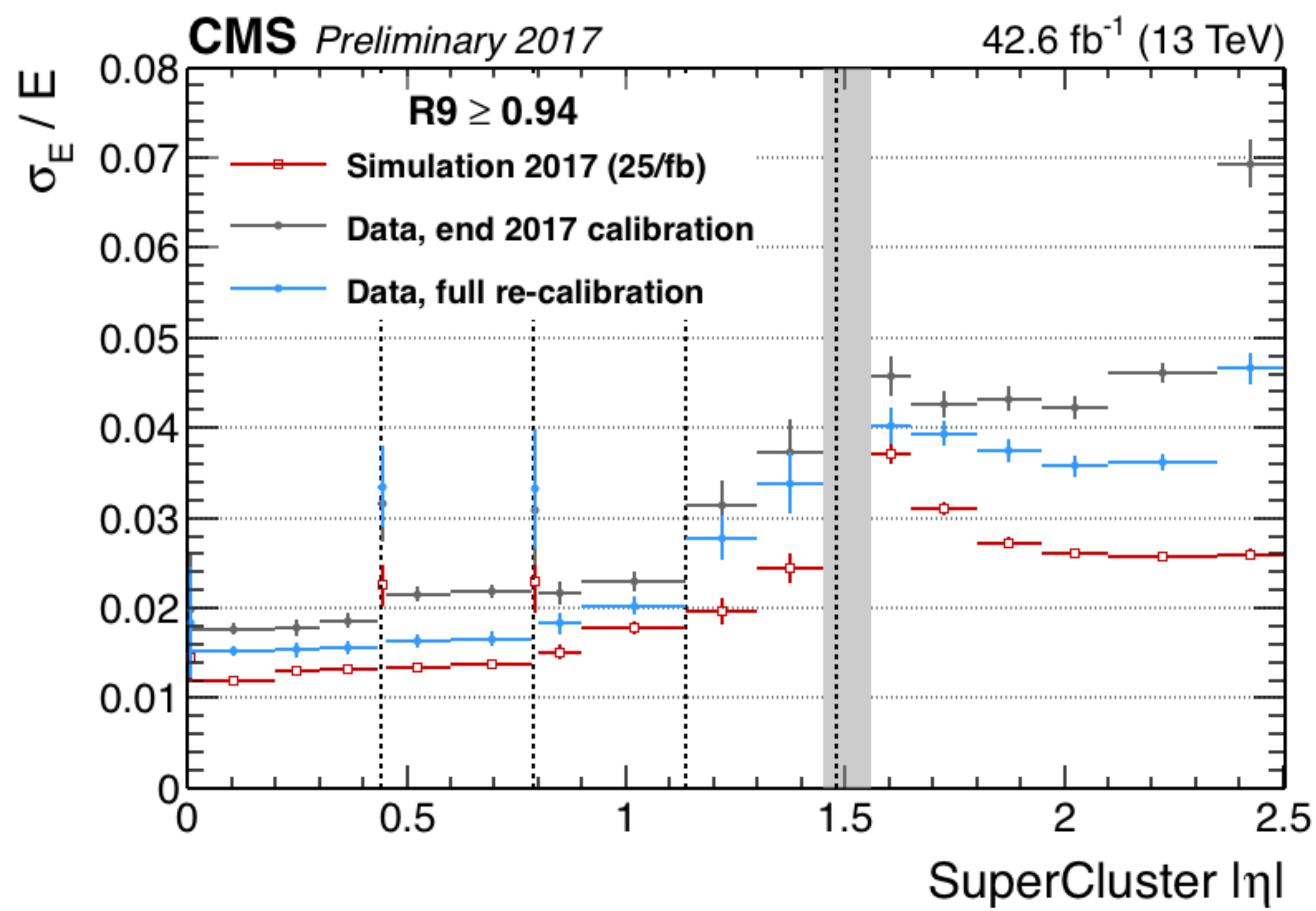
- Simulation properly reproducing the reconstructed Z mass dependence vs Z pT showing a proper calibration of the different gains.
  - ✓ High energy signals are readout by ADC with smaller gain and high dynamic range



Energy resolution performance

- All CMS Run2 data are being recalibrated
  - ✓ Preliminary results on 2017 data show a huge improvement in term of energy resolution and Data/MC agreement
  - ✓ Diphoton mass resolution should improved by more than 20%
  - ✓ Equivalent to improving the statistical precision on the H→γγ signal strength by 10%





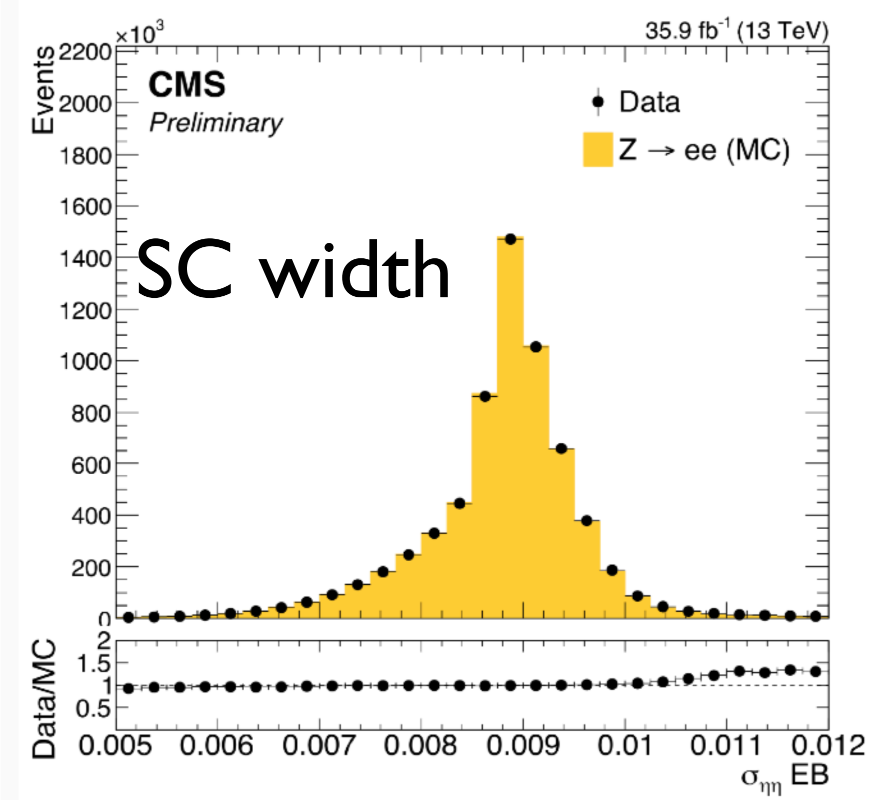
Conclusions

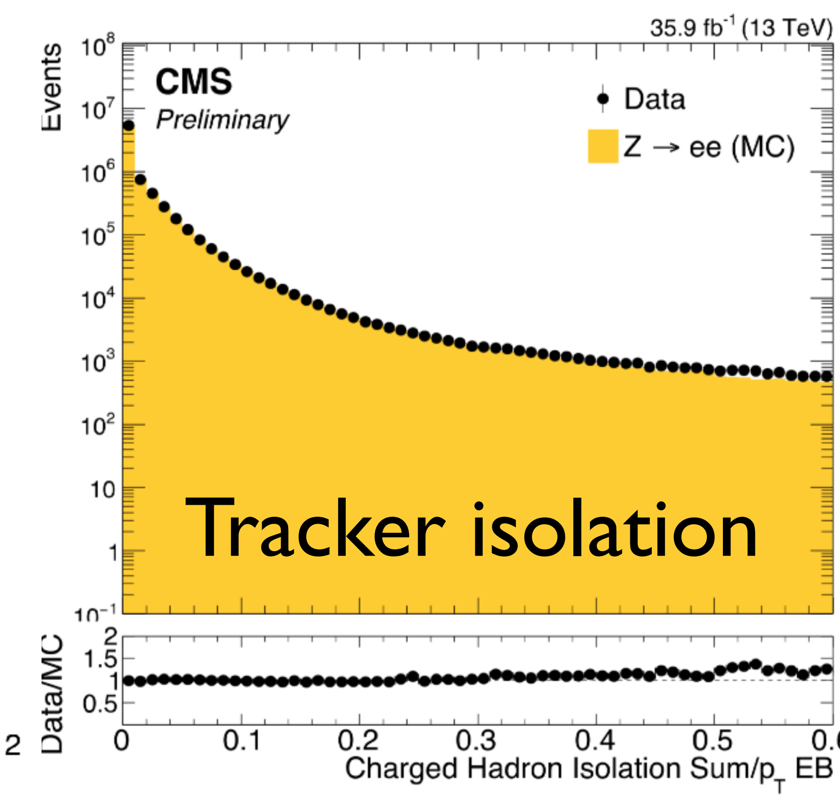
- CMS ECAL is the major tool for photon reconstruction and identification
- It has been very successful during LHC Run2
  - ✓ Dead channels $< 1\%$
  - ✓ Data loss due to ECAL issues ~ 0.5%
- LHC Run2 was also full of discovery and challenges for ECAL
  - ✓ Out-of-time PU mitigation with multifit strategy
    - ✦ adequate pulse shape extracted from data
    - ✦ proper estimation of pedestal
  - ✓ Time stability of the reference PNs
  - ✓ Updated calibration methods…
- Reprocessing of CMS Run2 data on-going
  - ✓ Improved calibration gain up to 20% in energy resolution
  - ✓ Improved noise treatment
  - ✓ Very promising for precise measurements in the diphoton channel…

Backup

Identification variables

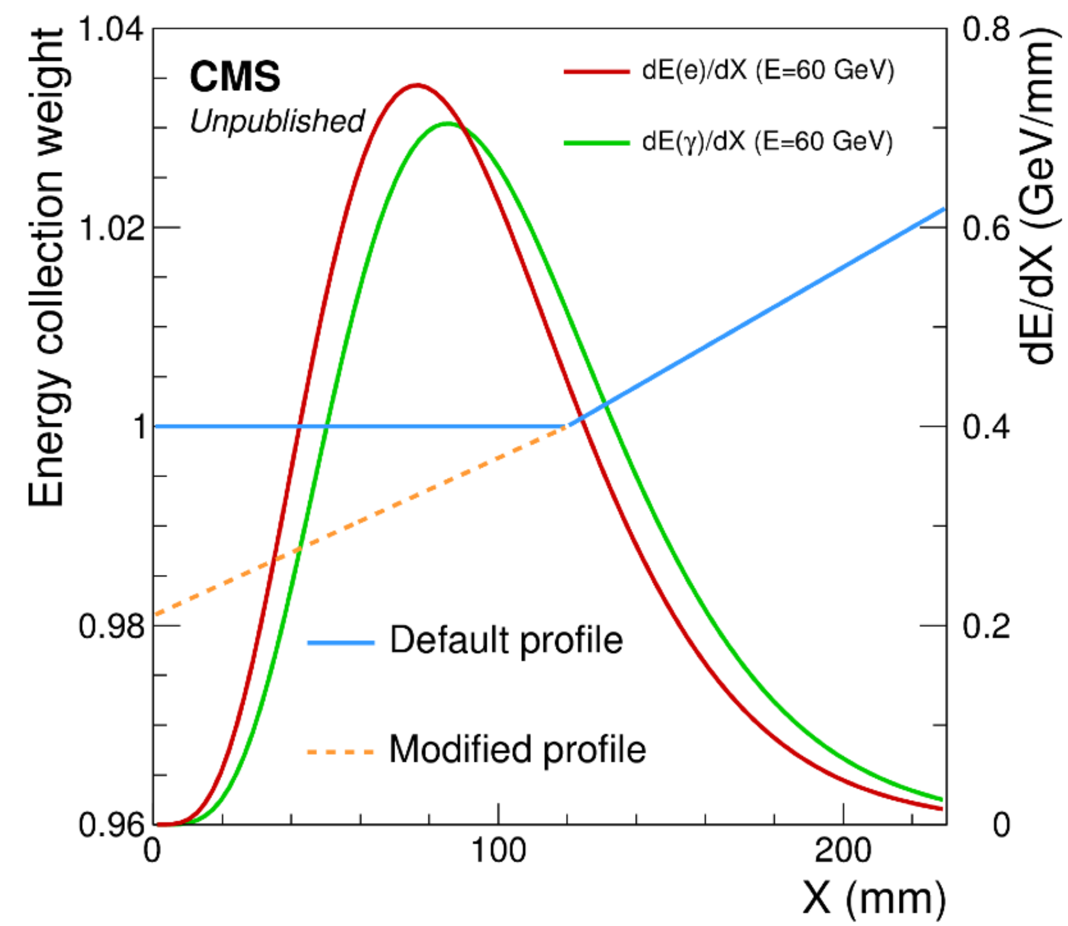
Example of
Data/MC agreement
(2016 data)



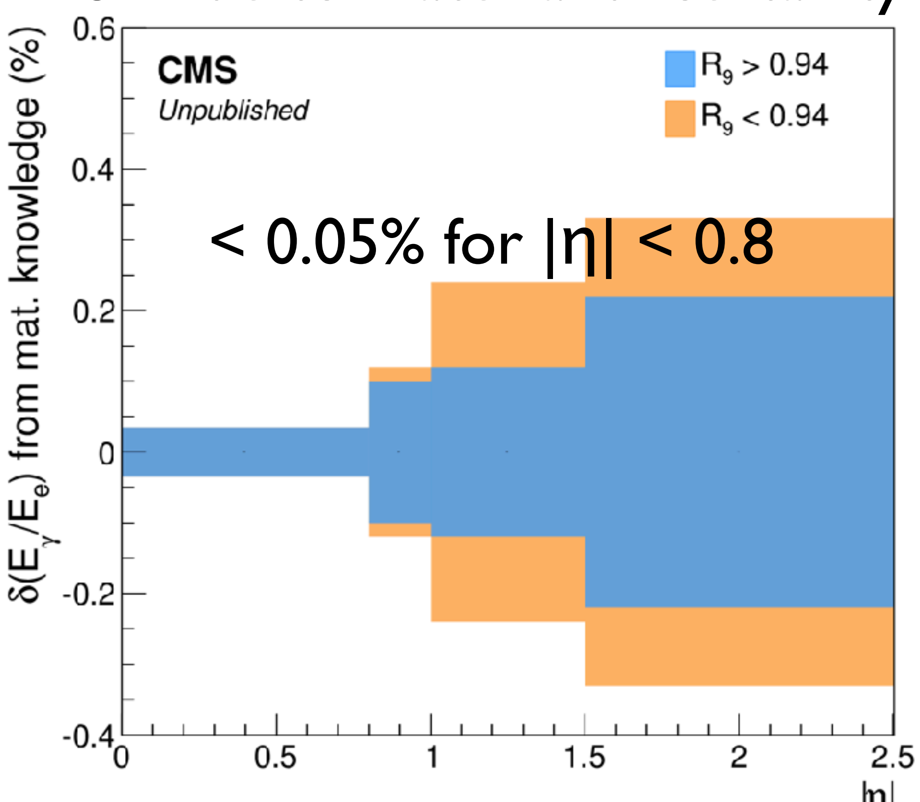


Run1 CMS $\mathcal{H}\rightarrow\gamma\gamma$

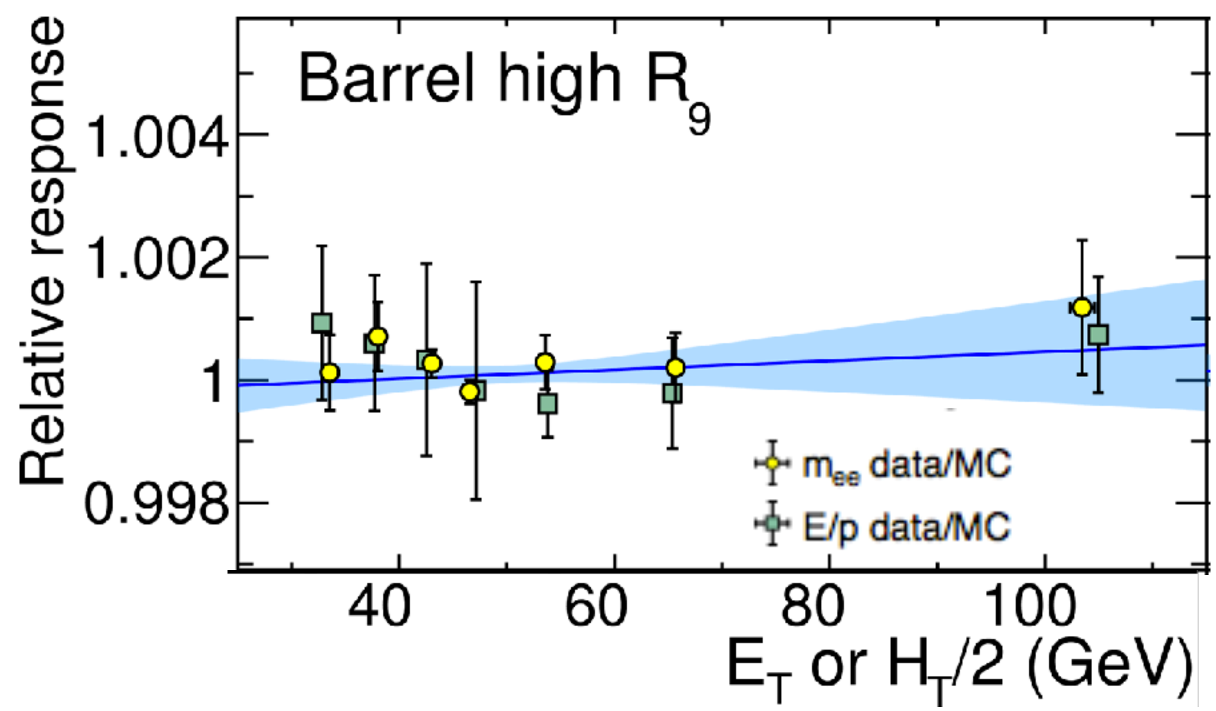
- 1D likelihood
  - ✓ $m_{\gamma\gamma}$ + event categorisation
- Experimental scale assessed from $Z \rightarrow ee$
  - ✓ also checked with E/p
- Inclusive mass resolution $\sigma_{\gamma\gamma}$ = 1.8 GeV



δE due to material uncertainty



E scale linearity

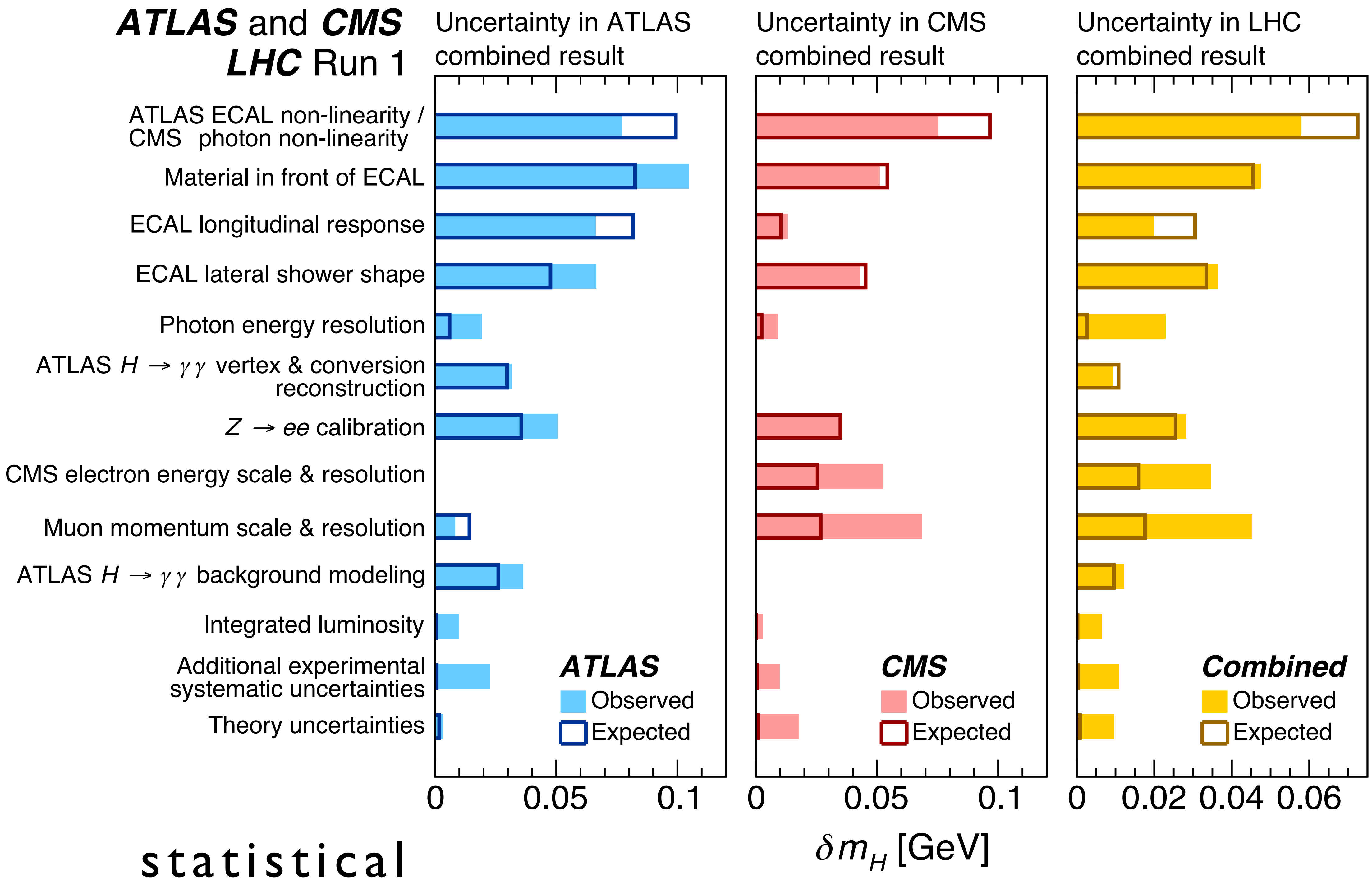


syst on m_H

material ≈ 70MeV

linearity ≈ 100MeV

Atlas + CMS combination



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statistical uncertainty

0.22