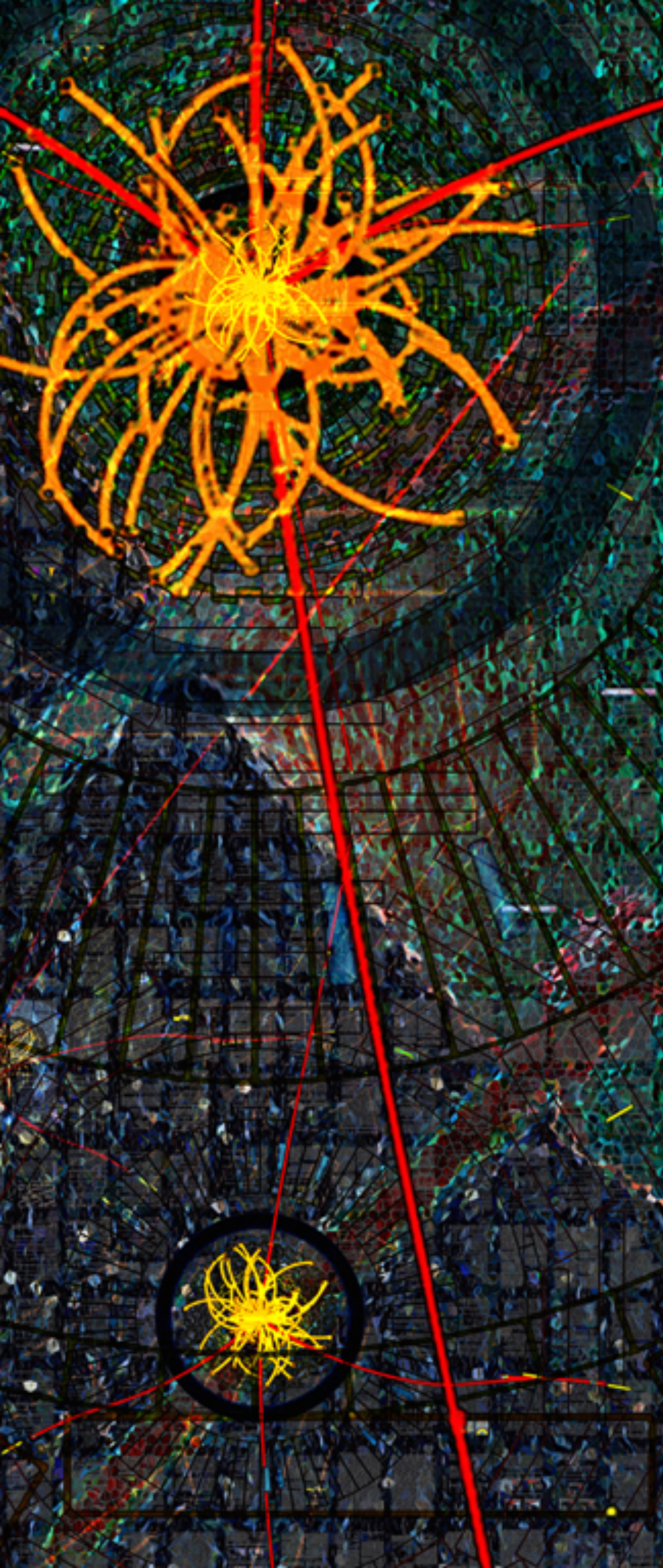


Northeastern University

Energy Reconstruction and Electron & Photon Performances with the CMS ECAL in Run II

Rafael Teixeira de Lima,

on behalf of the CMS Collaboration

CALOR 2016

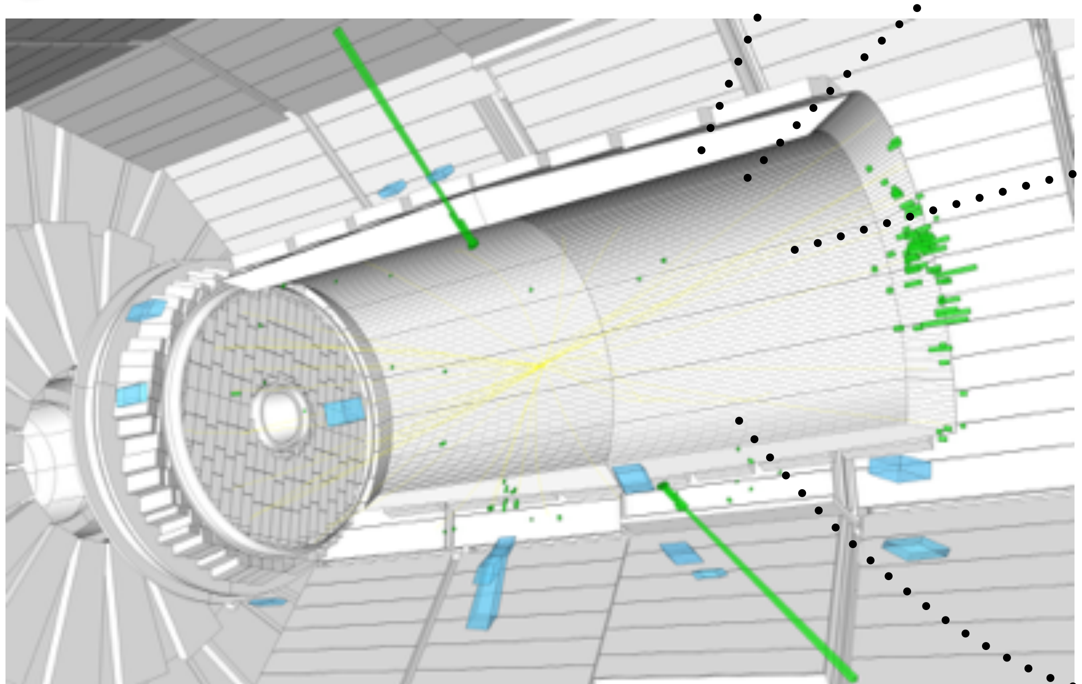
XVII[th] International Conference on Calorimetry in Particle Physics

May 15 - 20, 2016, Daegu, Korea (South)

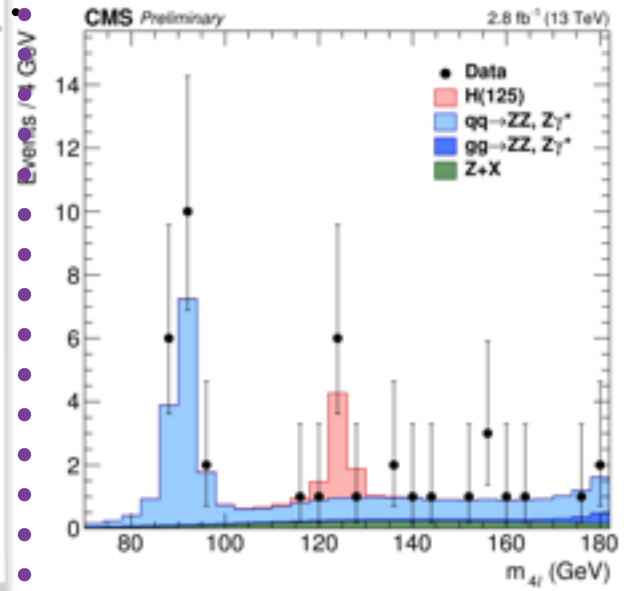
ELECTROMAGNETIC CALORIMETRY AT THE LHC

ECAL is crucial!

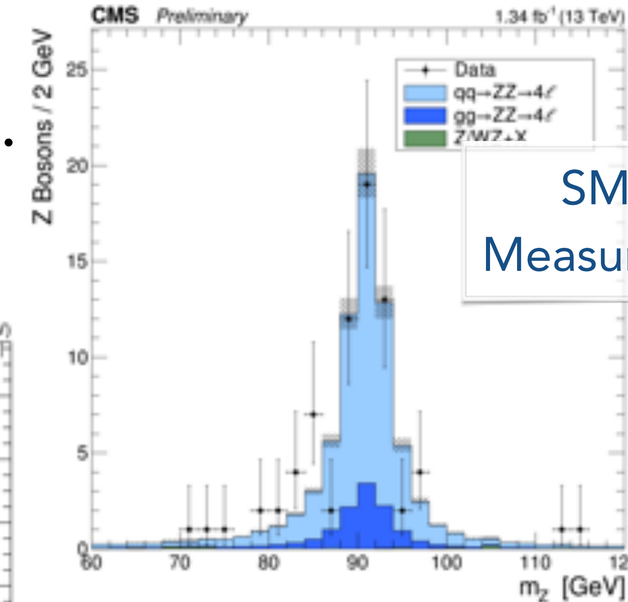
- High performance electromagnetic calorimetry needed for many analyses during the LHC Run II
- A requirement for both new physics searches (see Paolo's talk) and Standard Model measurements



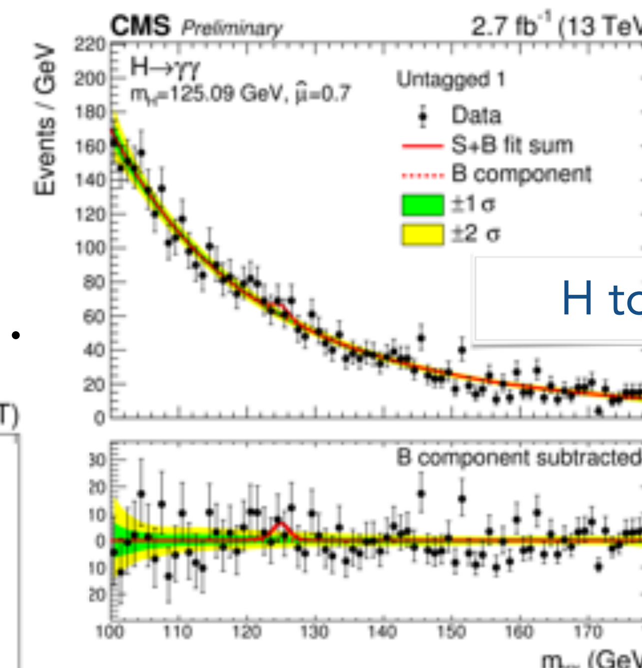
H to 4l



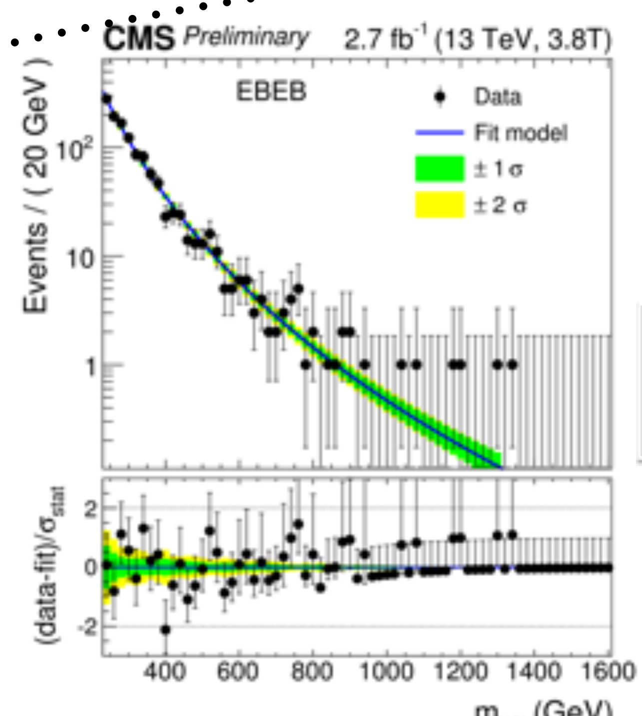
SM ZZ Measurement



H to γγ



X to γγ, high mass



CMS 13 TeV public results
http://cern.ch/go/JJr6

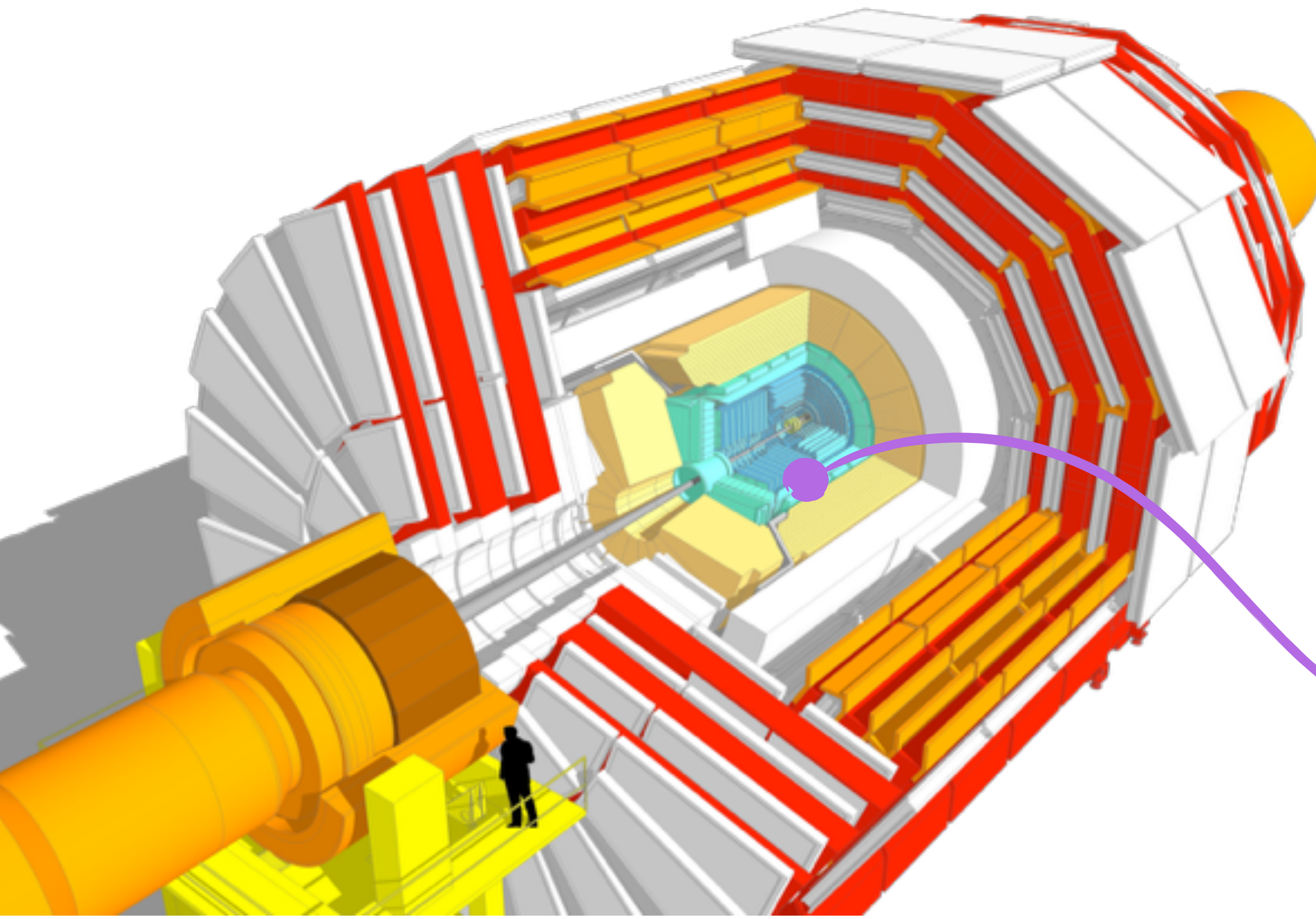
Outline

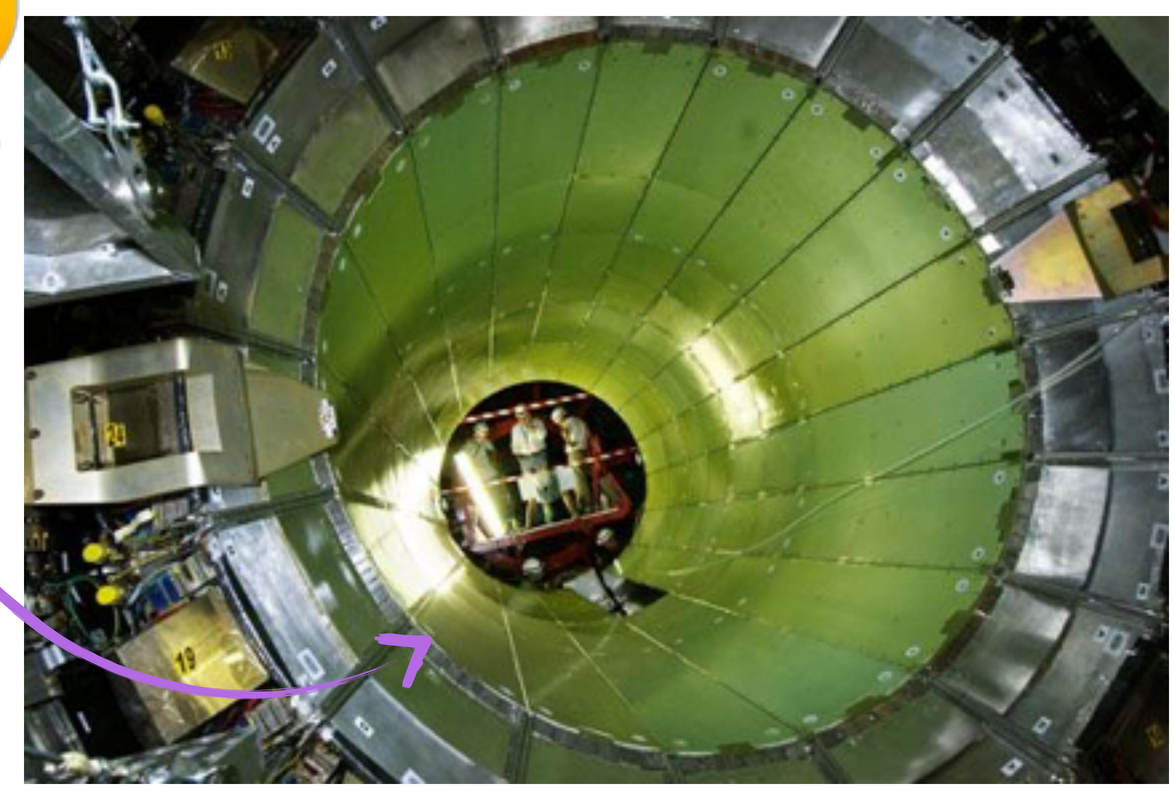
CMS Electromagnetic Calorimeter

LHC, CMS and ECAL@Run II

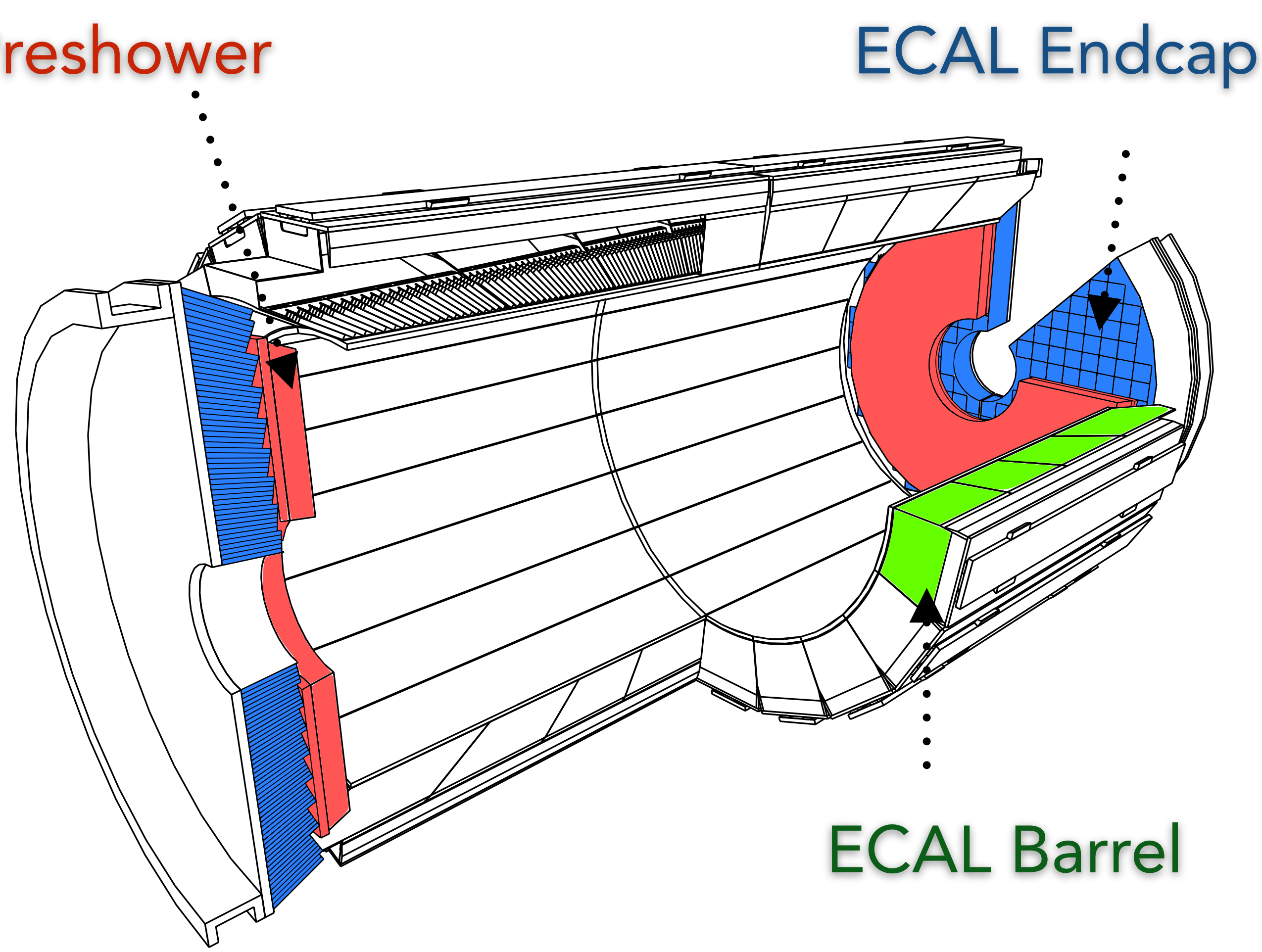
ECAL Monitoring, Calibration and Energy Reconstruction

ECAL Performance and Summary





CMS Electromagnetic Calorimeter (ECAL)

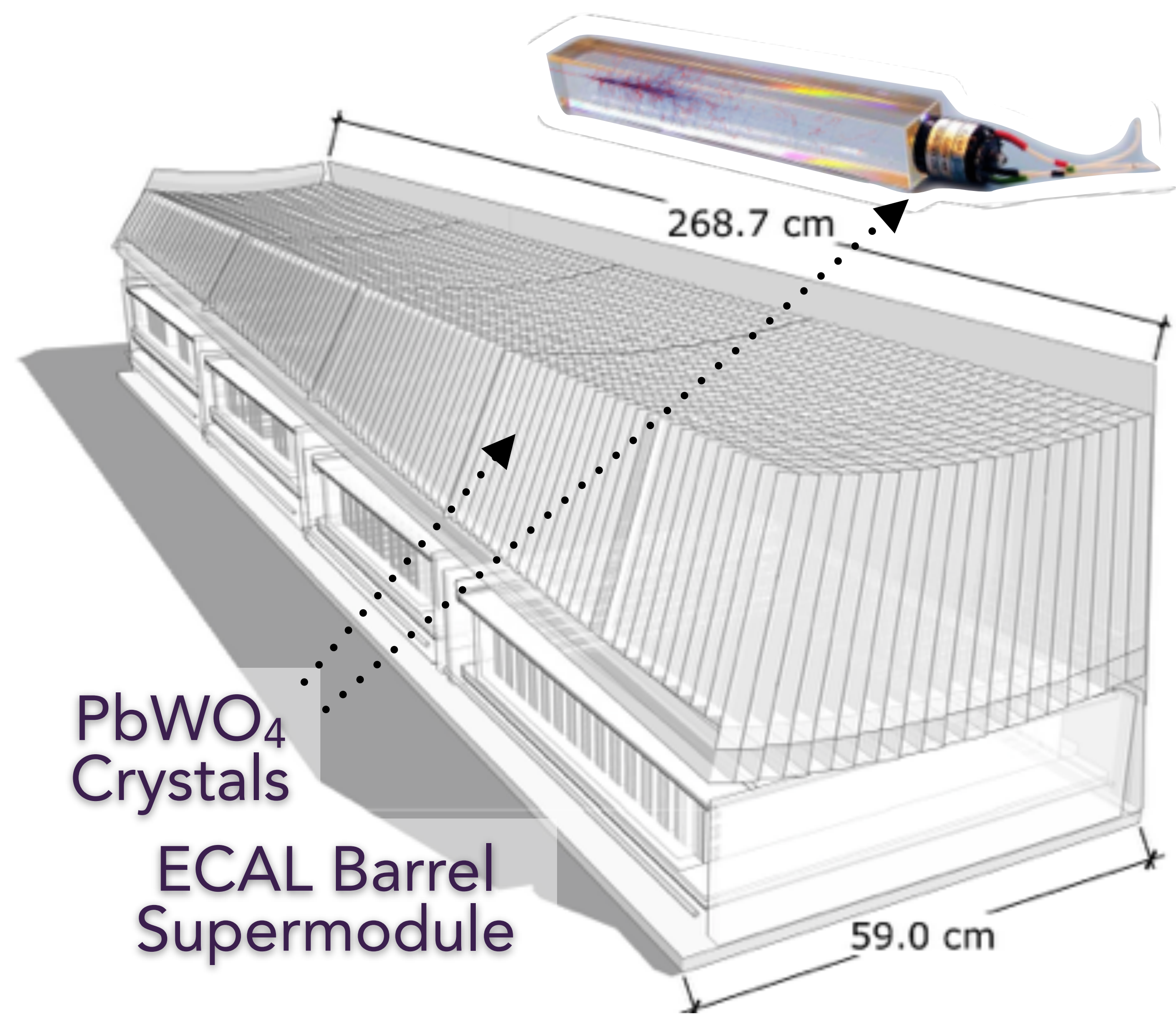


CMS ECAL Must Provide:

- Precise energy reconstruction resolution
- Precise position resolution for reconstructed deposits
- Fast and efficient readout for online selection (DAQ & Trigger)

ECAL Characteristics

Barrel (EB)	$\lvert\eta\rvert < 1.48$	61200 $PbWO_4$ Crystals	$\sim 26X_0$
Endcap (EE)	$1.48 < \lvert\eta\rvert < 3.0$	14648 $PbWO_4$ Crystals	$\sim 25X_0$
Preshower	$1.65 < \lvert\eta\rvert < 2.6$	137200 Pb/Si strips	$\sim 3X_0$

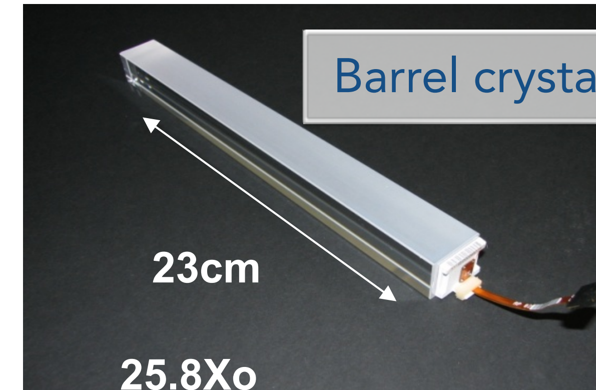


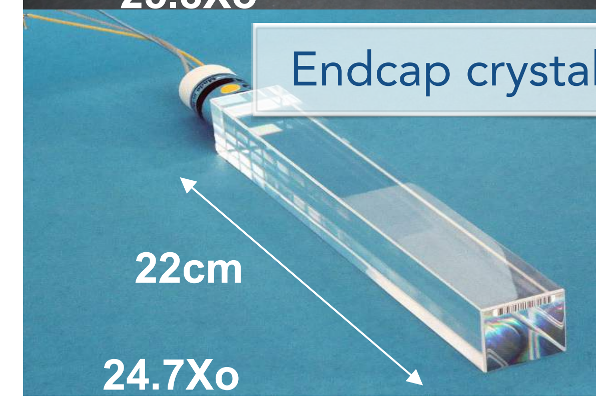
ECAL Crystals and Readout

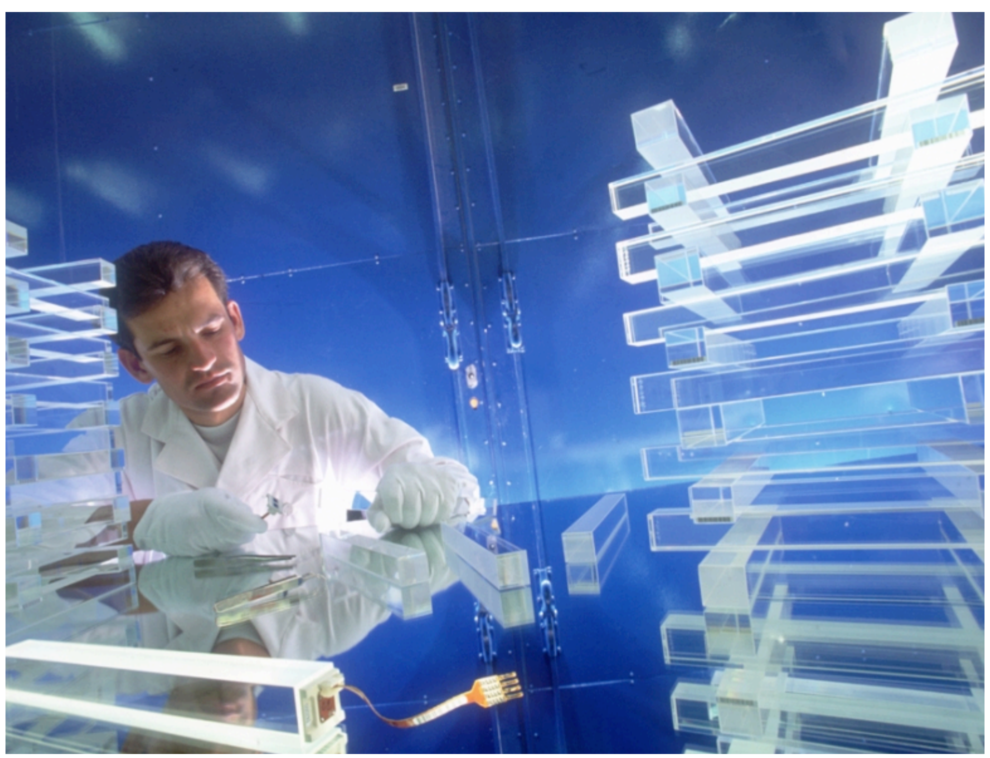
PbWO$_4$ crystal grown in ingot

ECAL $PbWO_4$ Crystals

- Homogeneous medium
- Fast light emission → ~80% in 25ns
- Short radiation length → X_0 = 0.89 cm
- Small Molière radius → R_M = 2.10 cm
- Emission peak → 425 nm
- Reasonable radiation resistance







$PbWO_4$ Crystals have **low light output** and must work **under a 3.8T field**: challenge for readout

Barrel:

Avalanche photodiodes (APD)

- Two 5x5 mm^2 APDs/crystal
- Gain: 50
- Temperature dependence: -2.4%/^{O}C (precise temperature control: < 0.03/0.08 $^{\circ}$C in EB/EE)

Endcap:

Vacuum phototriodes (VPT)

- Active area ~ 280 mm^2/crystal
- Gain 8 - 10 at 4T
- More radiation resistant than Si diodes (with UV glass window)

LHC, CMS and ECAL@Run II

LHC

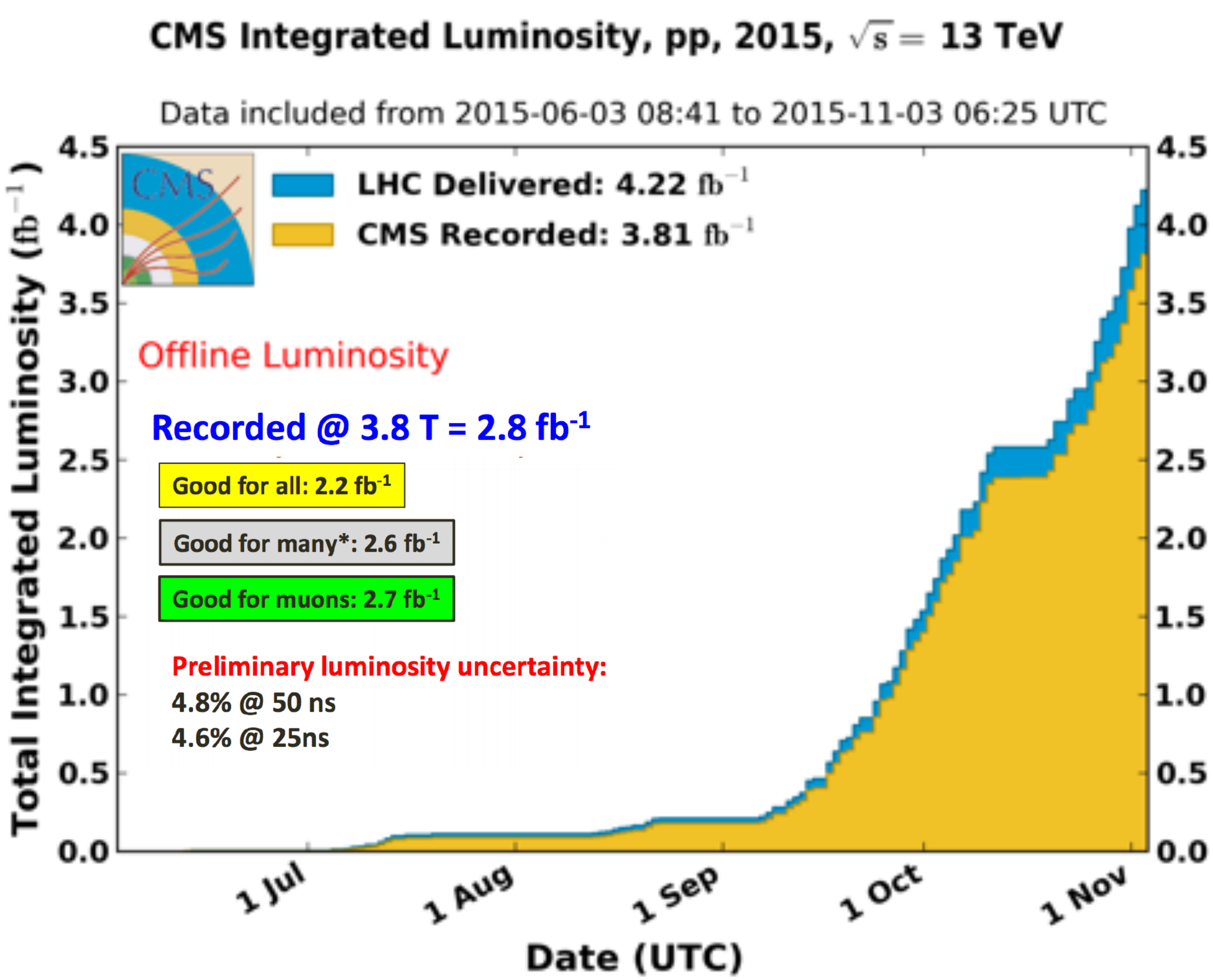
- 6.5 TeV/beam
- 25ns bunch spacing
- 2015: ~10 interactions per bunch crossing
- 2016: projected ~40 int. per bunch crossing

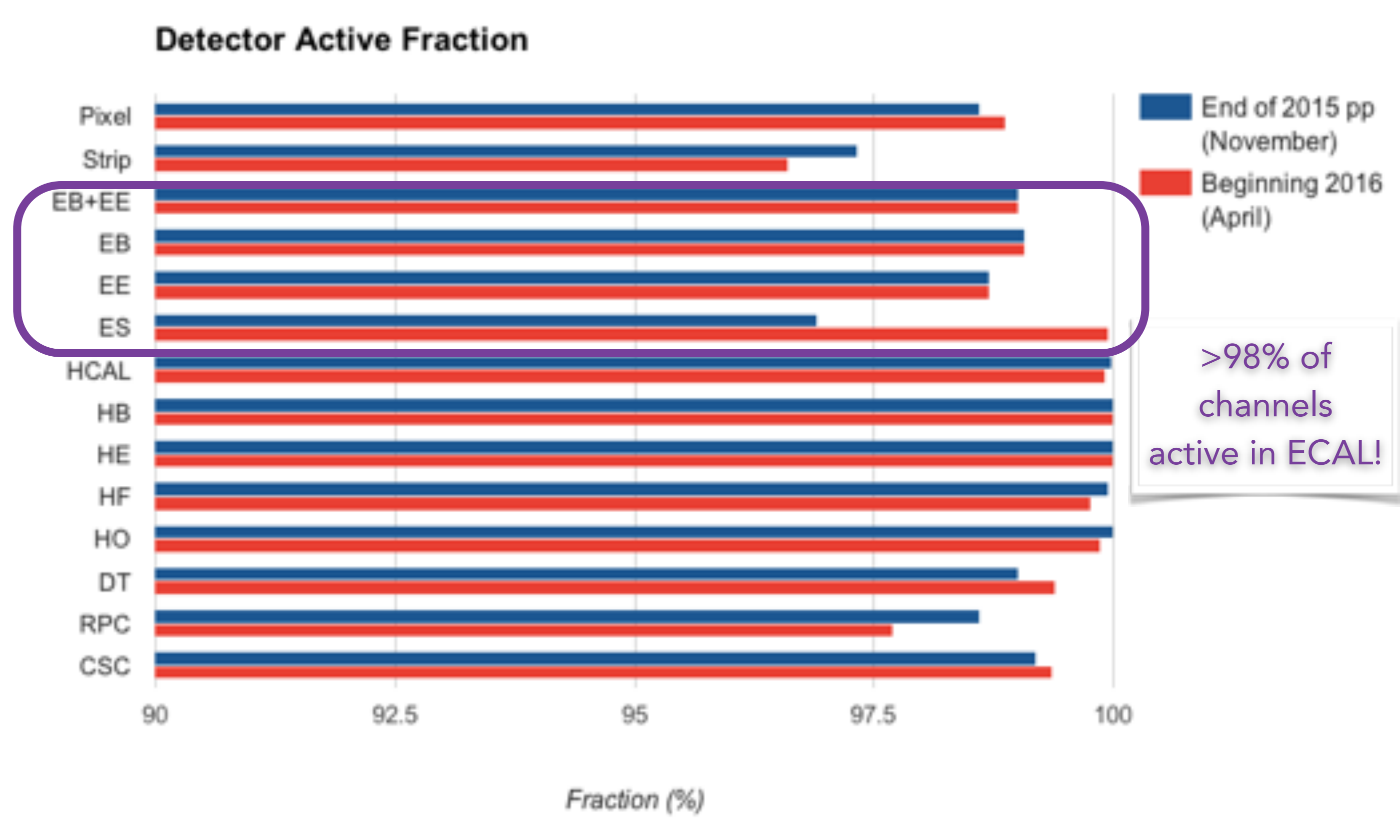
CMS

- New luminosity detectors
- Upgraded L1 calorimeter trigger
- Upgraded data acquisition (DAQ) HW
- Among others…

ECAL

- Link between ECAL DAQ and calorimeter trigger upgraded (optical)
- DAQ/Trigger Software upgrades
- New online pulse shape reconstruction





Reconstructing Energy With ECAL

Laser Monitoring | Intercalibration | Global Scale | Cluster Corrections

Energy reconstruction for photons and electrons

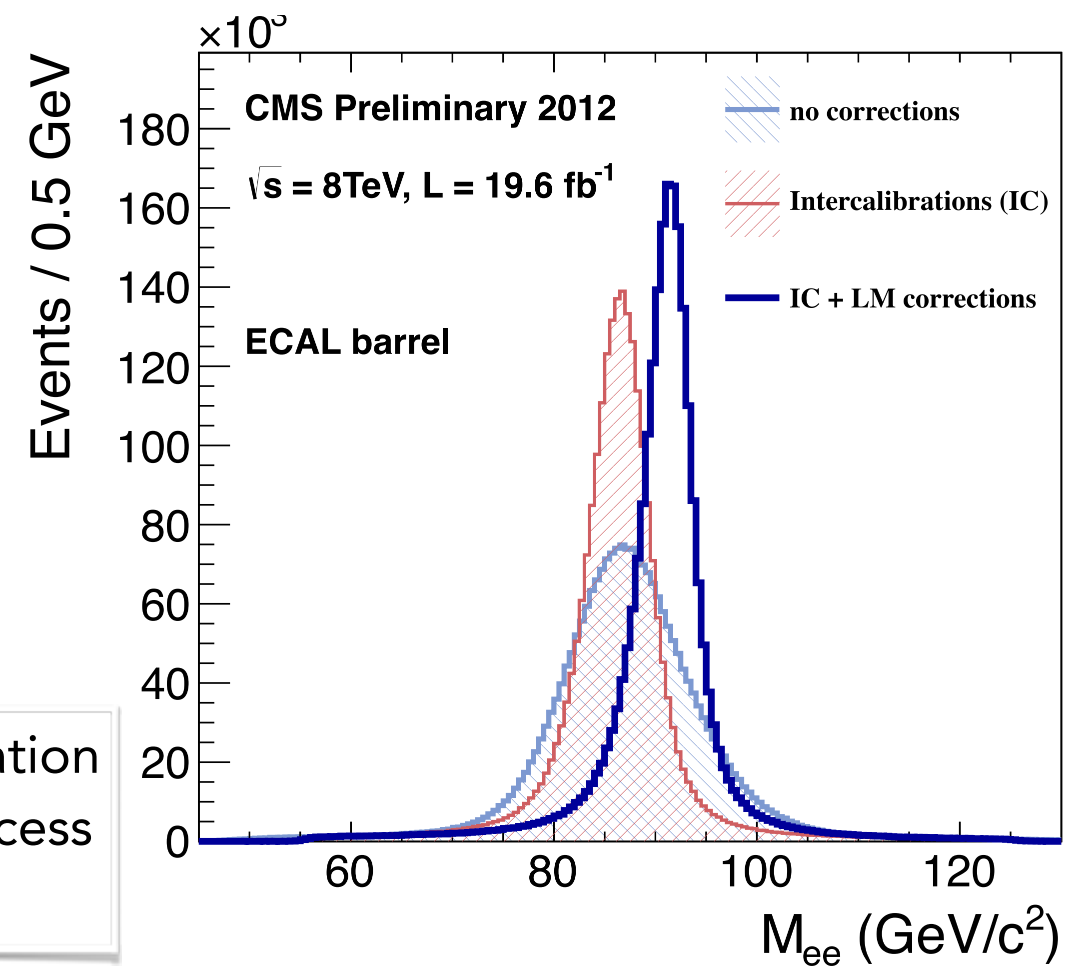
$$E_{e,\gamma} = \sum_i [S_i(t) \times c_i \times A_i] \times G(\eta) \times F_{e,\gamma}$$

Pulse Amplitude

CMS ECAL Energy Resolution

- **Uniformity and stability resolution** (intercalibration and monitoring) required < 0.5%
- For barrel photons, **1% energy inclusive resolution achieved in 2012** for unconverted/ late-converting photons (from H→γγ)

Effect of laser monitoring (LM) and intercalibration (IC) corrections on the width of the Z→ee process with 2012 data and calibration procedure



Online Pulse Shape Reconstruction

New in Run II!

Multifit Reconstruction

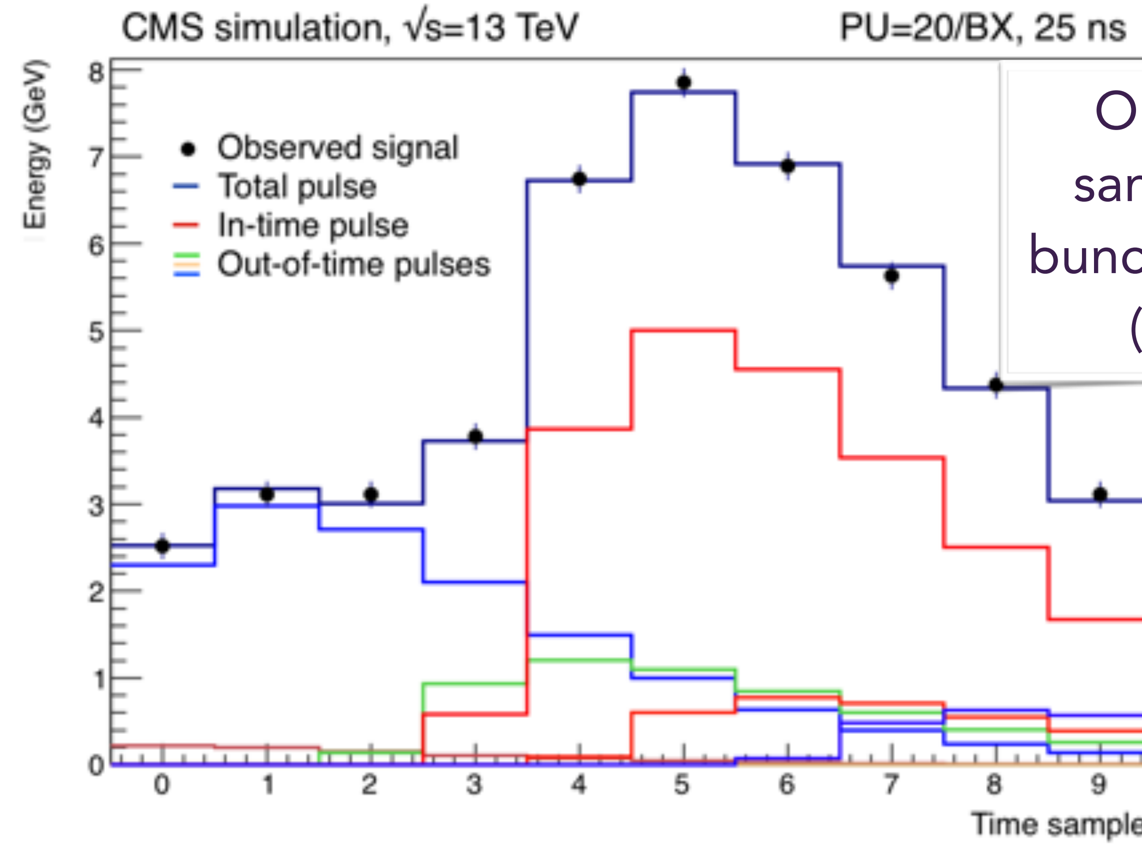
- Online pulse reconstruction method must be **resistant to out-of-time (OOT) pile up**
- **Solution**: pulse shape is a sum of one in-time pulse plus OOT pulses

Time samples

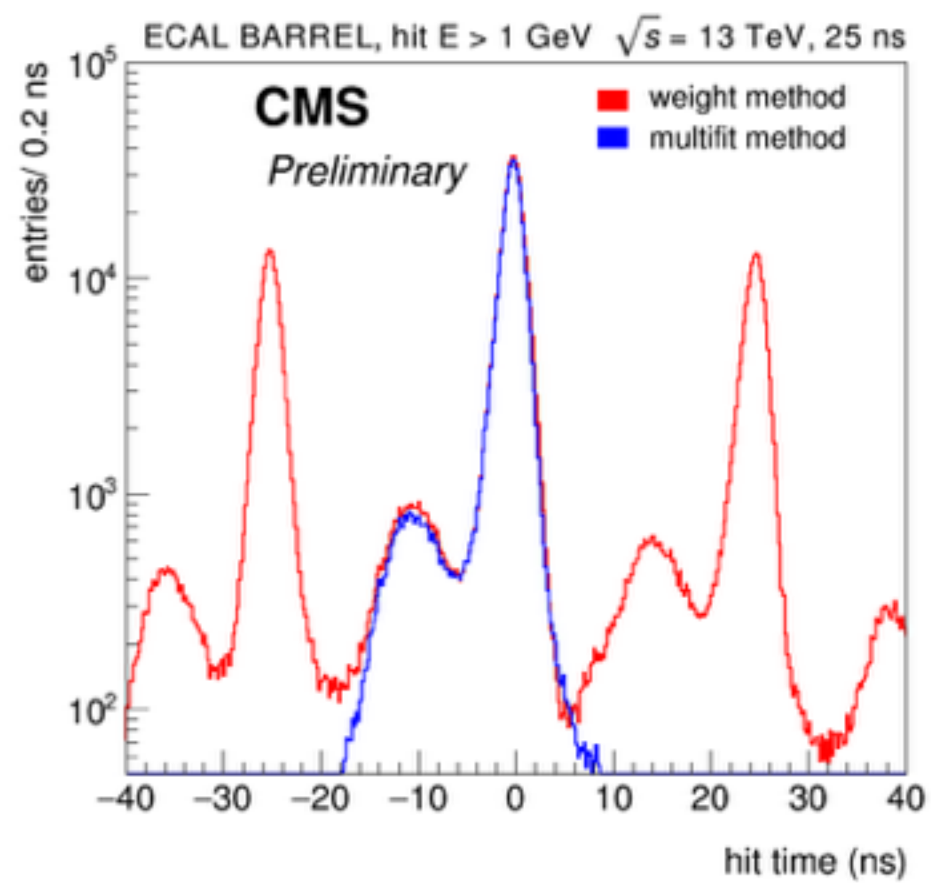
Different pulses contributions

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

- Up to 9 OOT pulses (one per time sample)
- Minimize χ^2 distribution for best description of the in-time shape
- Pulse **shapes extracted from LHC isolated bunches** in 2015 (no out-of-time pile up)



One time sample per bunch crossing (25 ns)

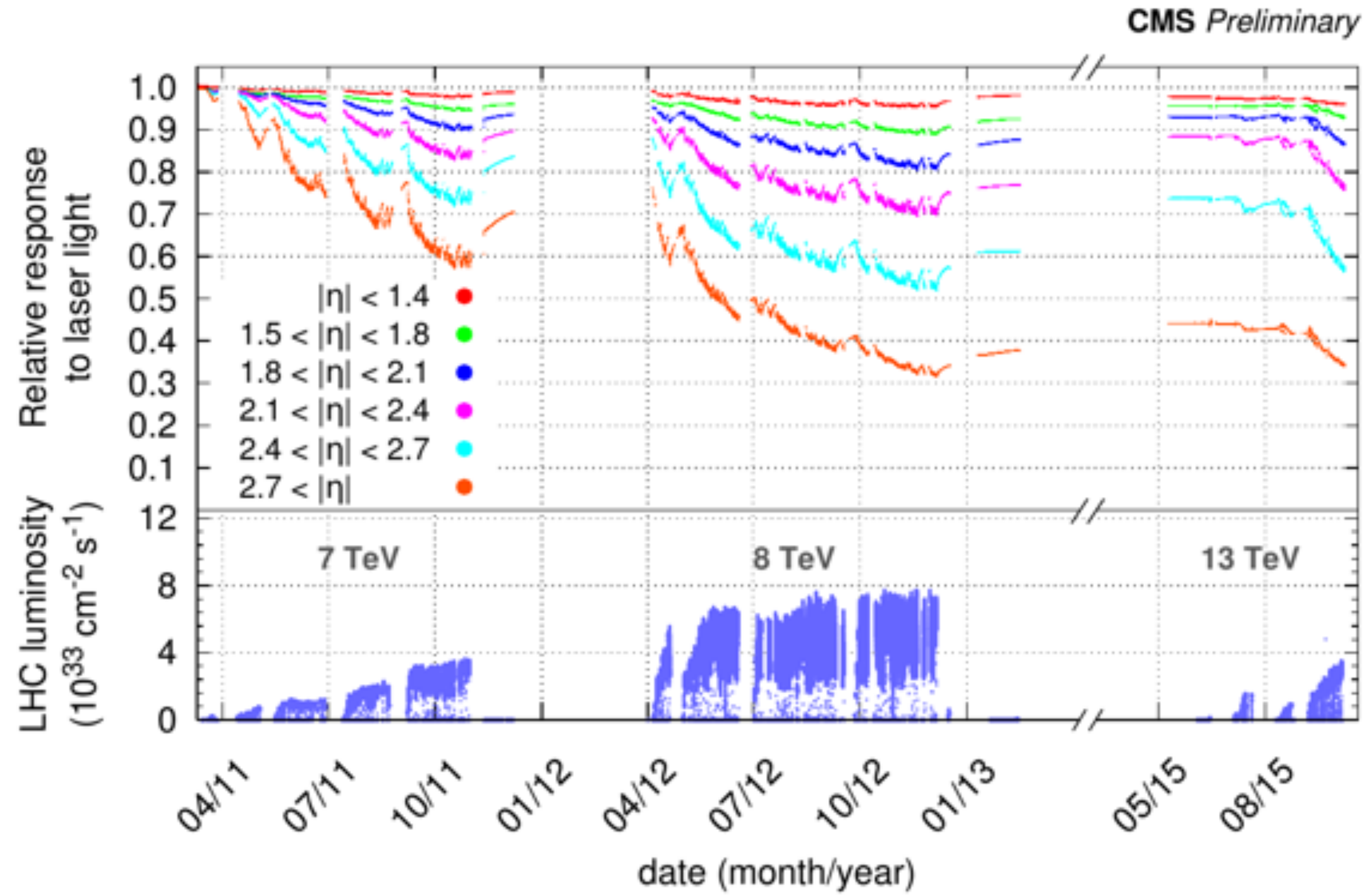


Run I Pulse reconstruction also reconstructs out-of-time pulses

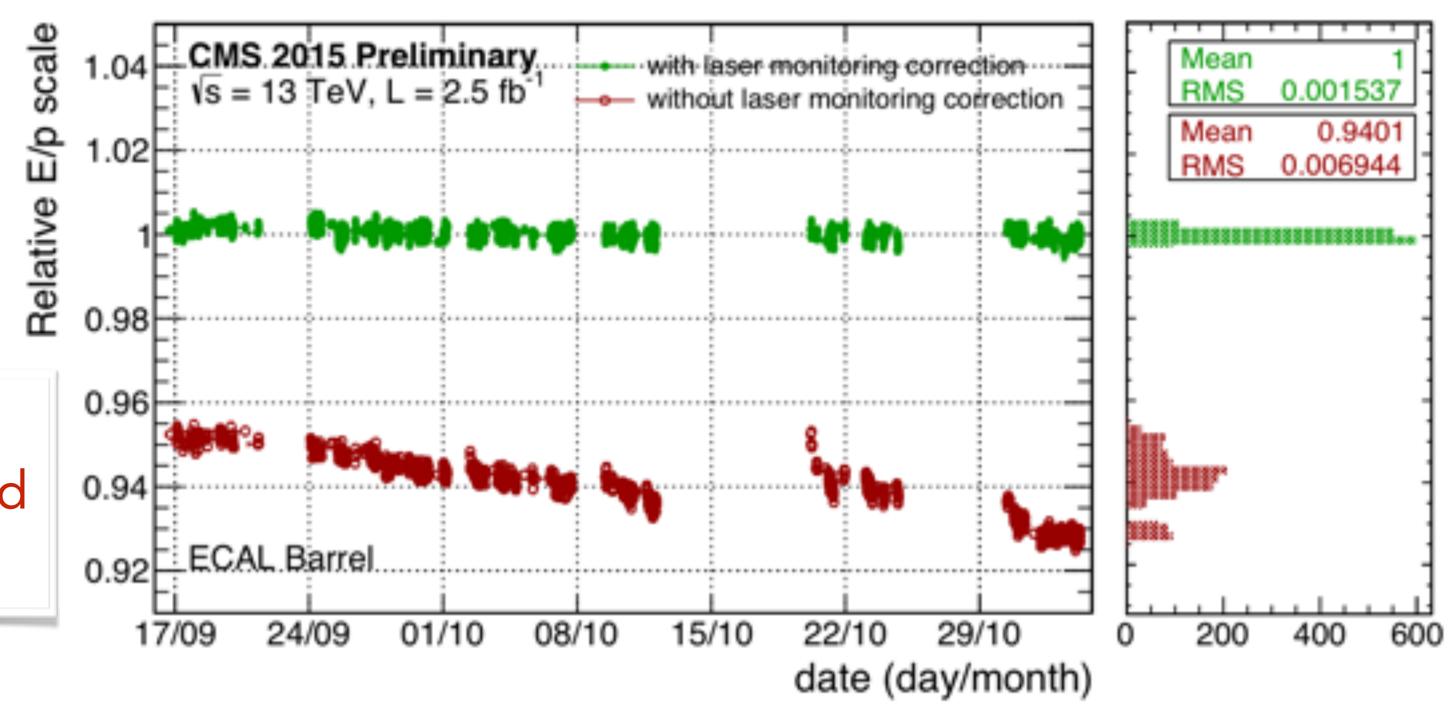
ECAL Crystal Response Monitoring

Laser Monitoring

- **ECAL crystals change response** due to radiation exposure (time dependent): change in crystal transparency and VPT response in endcaps
- Response is **monitored with a laser system** injecting light in every ECAL crystal
- $PbWO_4$ **crystals partially recover** during periods with no exposure
- Monitoring **corrections obtained/ applied promptly** (~48h)
- **Stability:** interpolate 2nd of 3 consecutive readings **<< required 0.2%**



Effect of monitoring corrections by comparing energy of electron reconstructed by ECAL (E) and tracker (p)

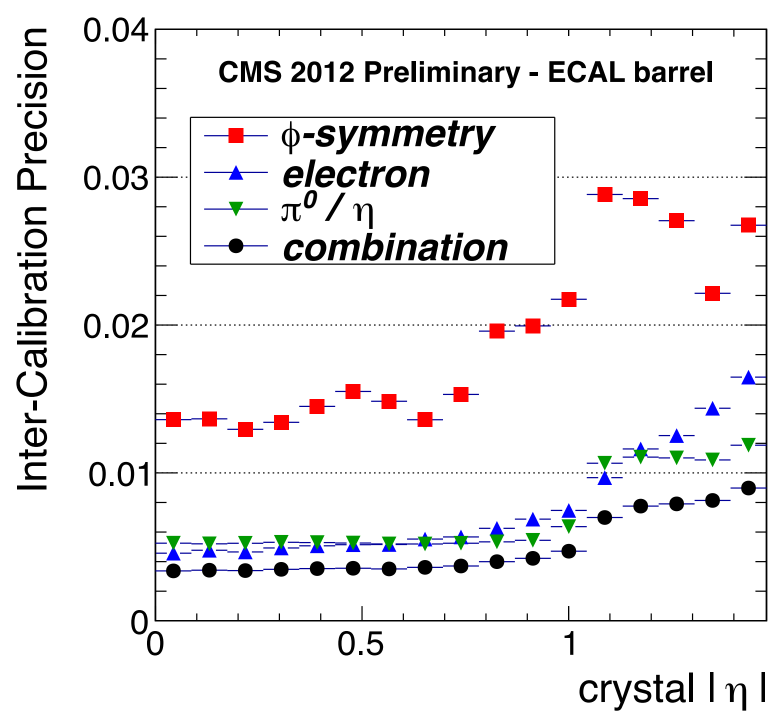


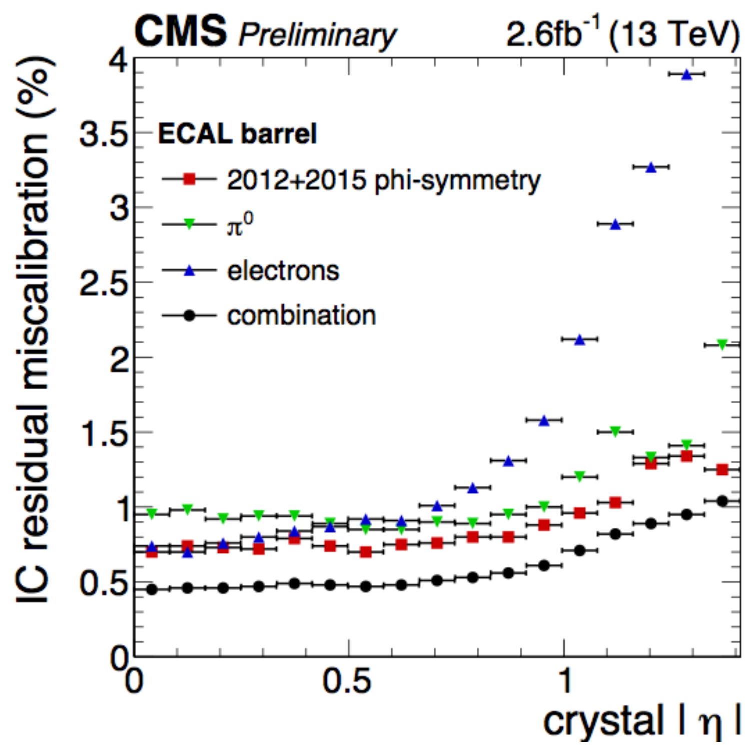
RELATIVE CALIBRATION OF SINGLE CHANNEL RESPONSE

Intercalibration (IC)

- **Equalizes the response of each single crystal** to the deposited energy
  - Constants are normalized not to interfere with absolute scale

Intercalibration strategy same as in Run I



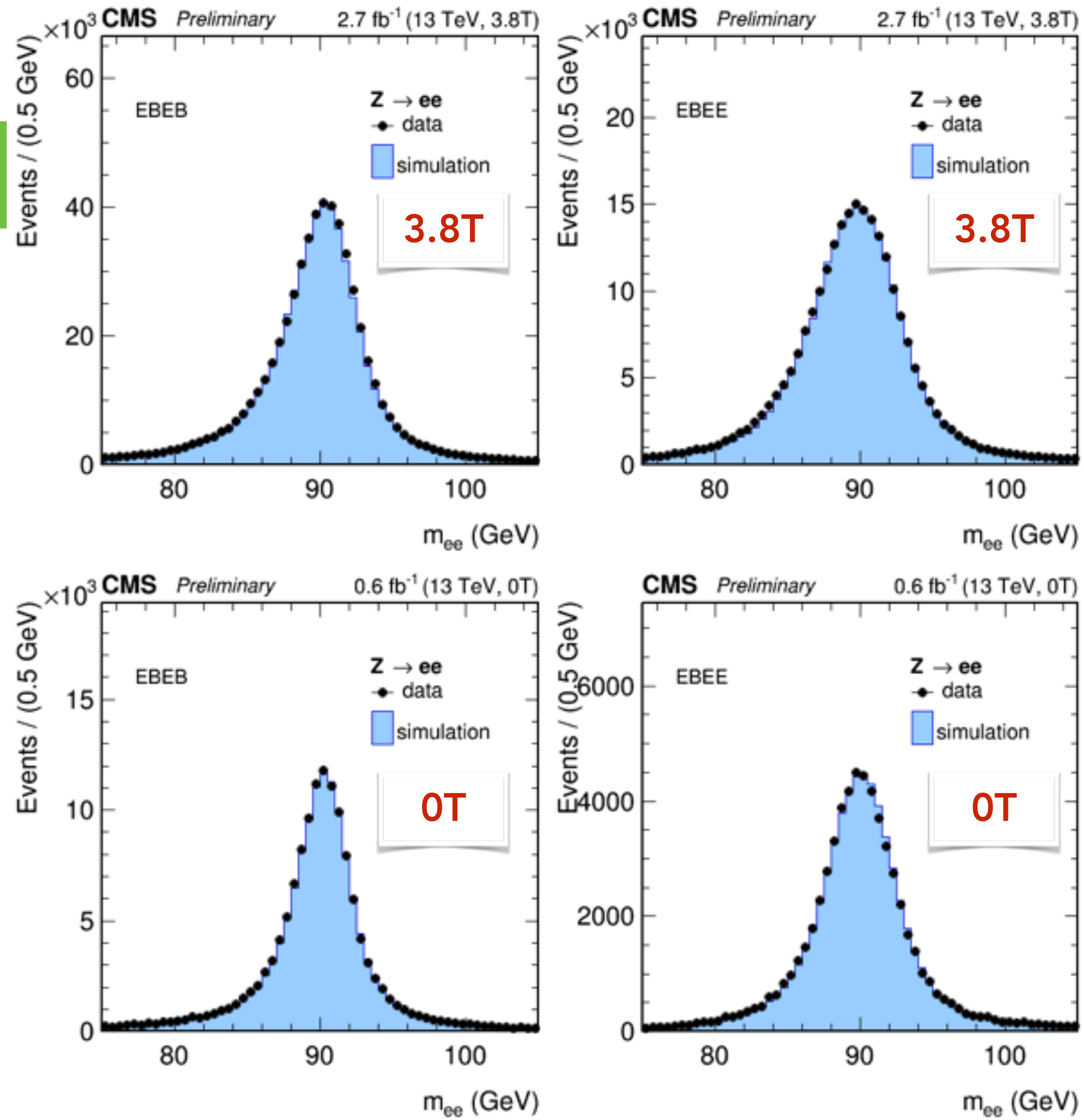


Method	Description	Timescale	Run I Precision (20 fb^{-1})
ϕ-symmetry	Energy flux around ϕ rings (constant η) should be uniform - IC corrects for non-uniformity	~days	Barrel: <3% Endcap: < 10%
$\pi^0/\eta \to \gamma\gamma$	In a ϕ ring, use IC to improve M(γγ) resolution for π^0 and η resonances	~months	Barrel: <1.5% Endcap: < 10%
E/p	Compare isolated electron energy from ECAL and Tracker, calculate IC to correct discrepancies	statistically limited	Barrel: <2% Endcap: < 10%

ABSOLUTE CALIBRATION AND η SCALE

Calibration with Z→ee

- **Electrons from Z→ee** events are used to calibrate the **η dependence** of the energy reconstruction and its **absolute scale**
- The **Z peak is used to fix the overall absolute calibration (ADC to GeV)**, matching data to a detailed simulation of the detector
- Z peaks reconstructed with **electrons in a single ϕ ring** are used to **correct the relative scale** between different η regions

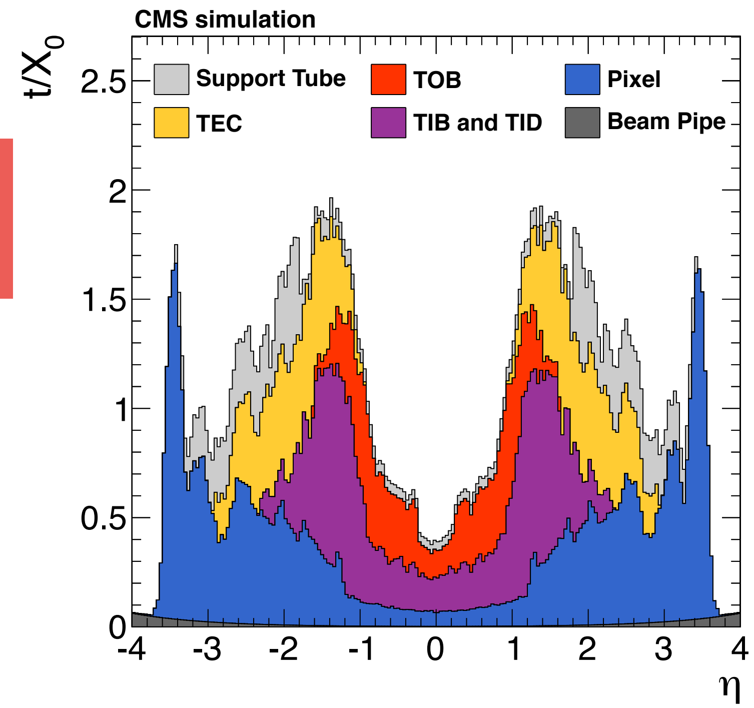


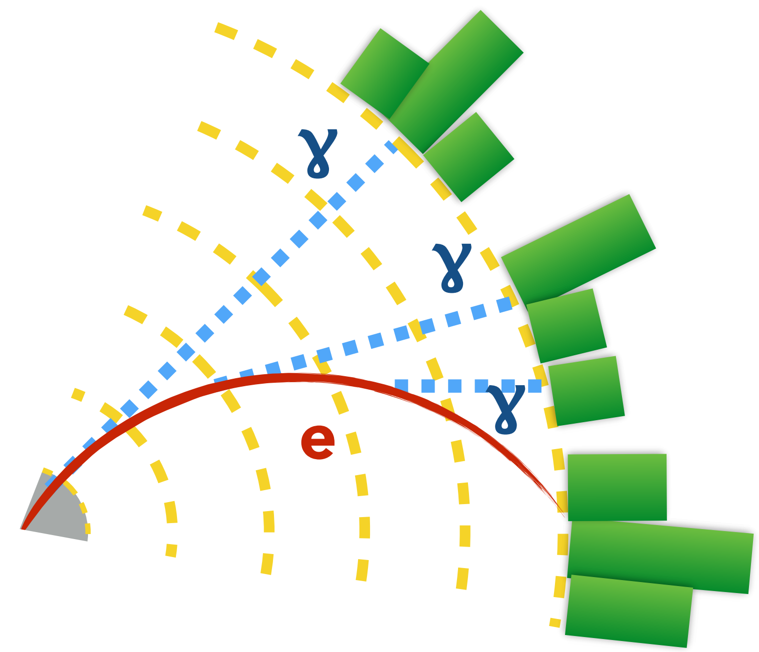
0T: no energy loss in reconstruction due to bremsstrahlung → better resolution

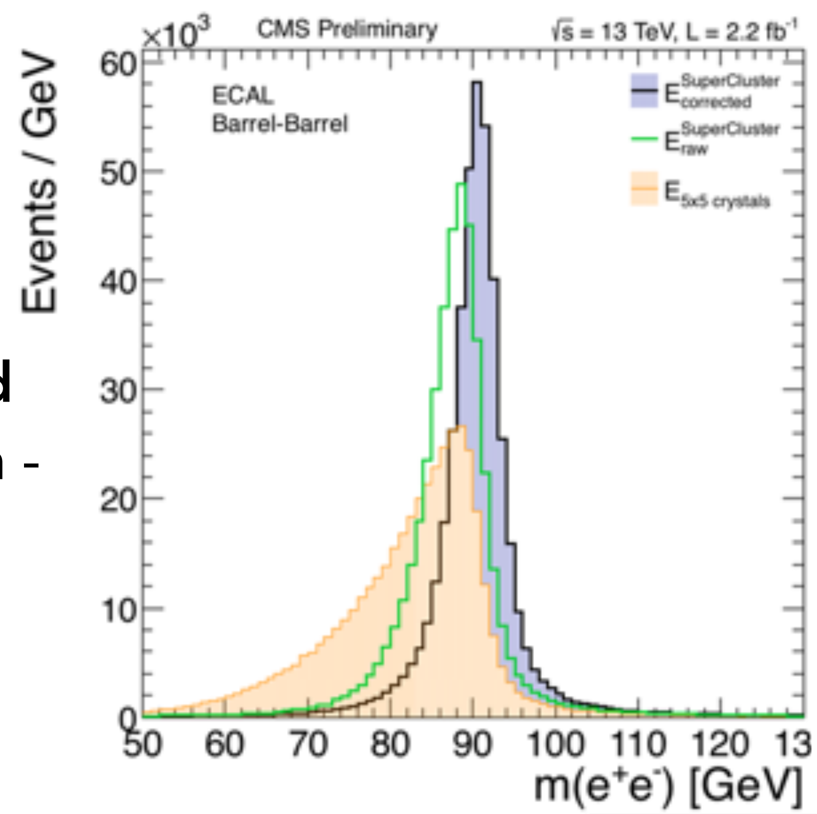
Clustering Reconstruction and Corrections

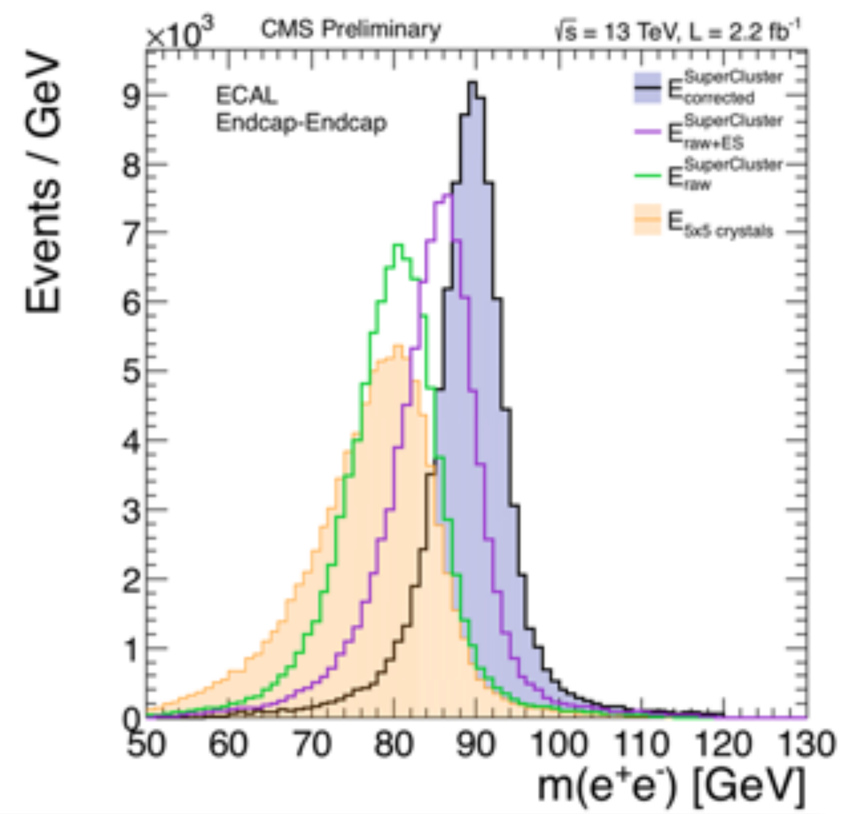
Cluster Corrections

- Large amount of **material before ECAL** - high **probability of bremsstrahlung** emission for electrons **and conversion** for photons
- **Clustering algorithm gathers clusters** of energy deposit **into superclusters** to recover that information
- **Supercluster's energy is corrected following a multivariate approach** - **see J. Bendavid's talk**







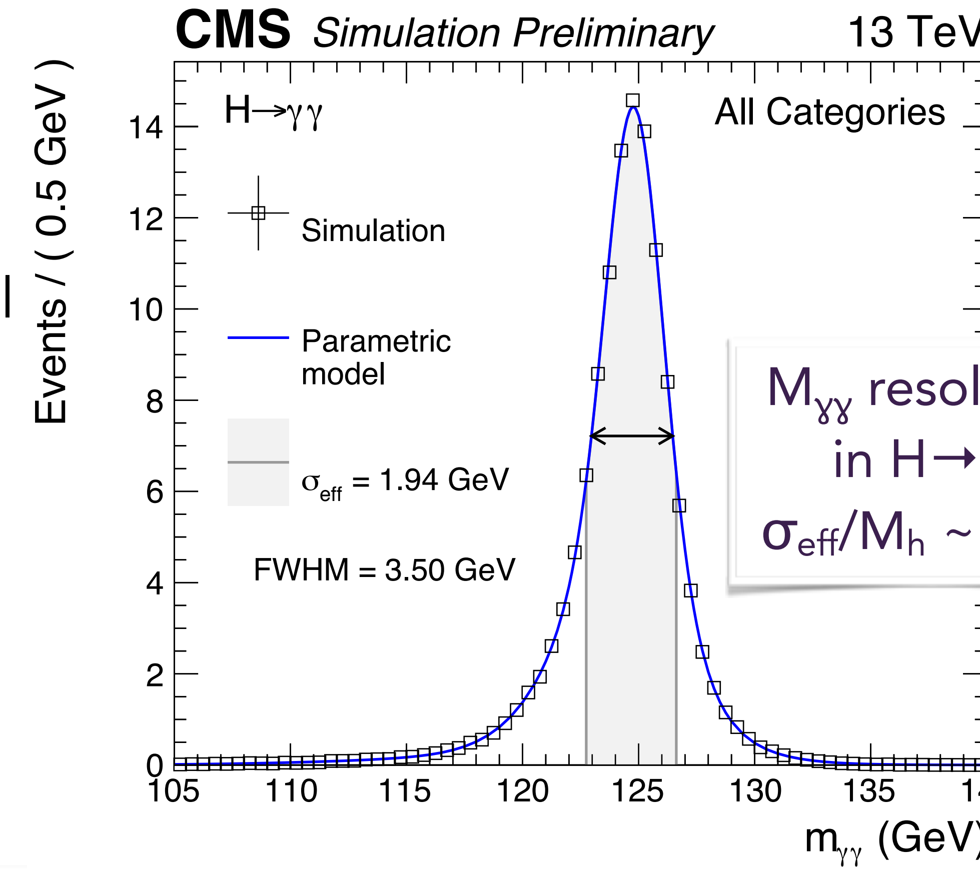


For endcap e/γ, energy deposited in the preshower is added to the supercluster

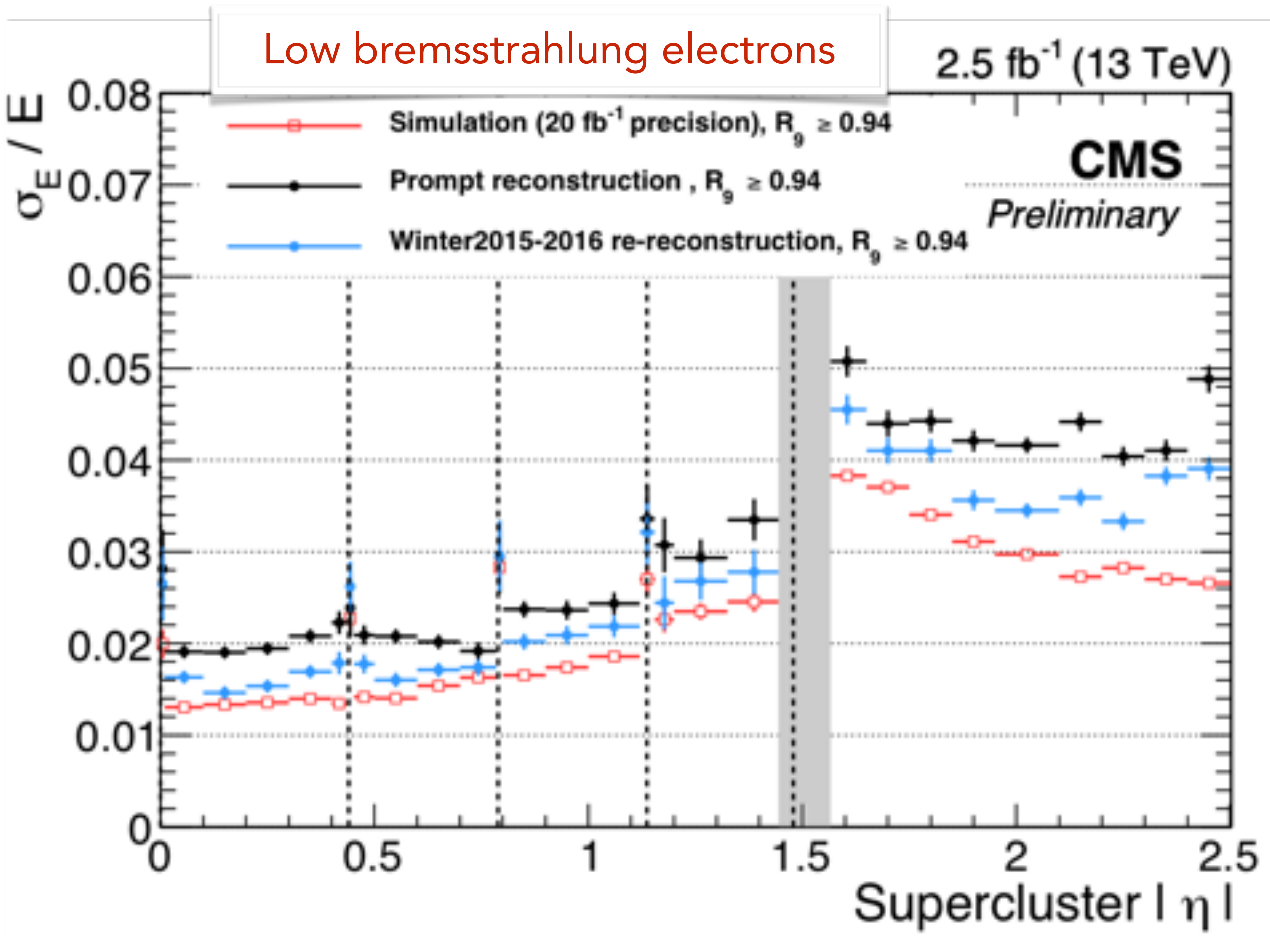
ECAL Energy Resolution with 2015 Data@3.8T

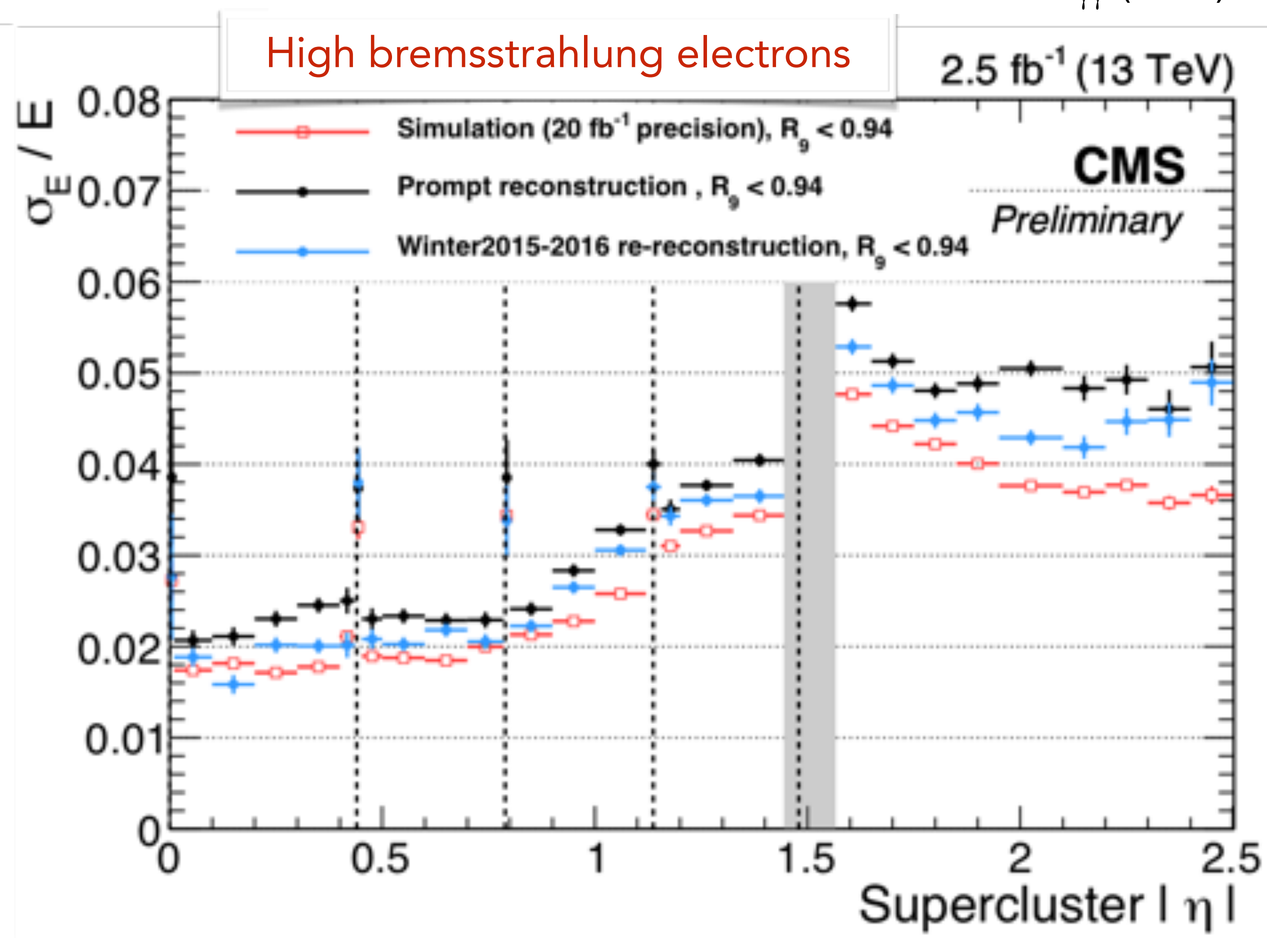
- The relative **resolution is extracted from an unbinned likelihood fit to Z→ee events**, using a Breit-Wigner function convoluted with a Gaussian as the signal model
- Large **improvement by recalculating calibration with 2015 data** (winter re-reconstruction) with respect to initial calibration (prompt) with Run I values for intercalibration/calibration constants

Current resolution is close to what is expected after calibration with 20 fb^{-1} of data



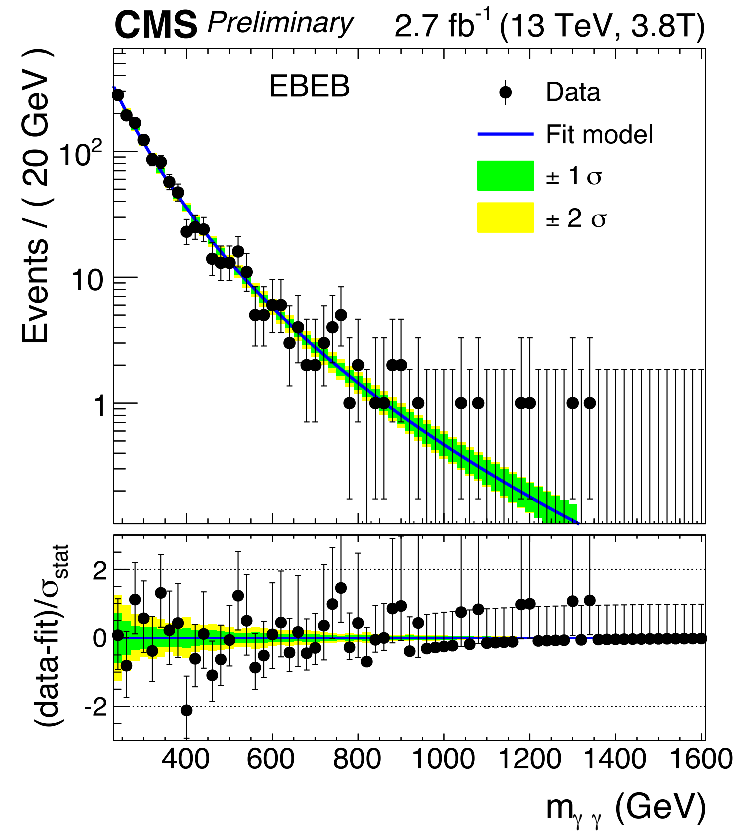
$M_{\gamma\gamma}$ resolution in H→γγ
σ_{eff}/M_h ~ 1.5%

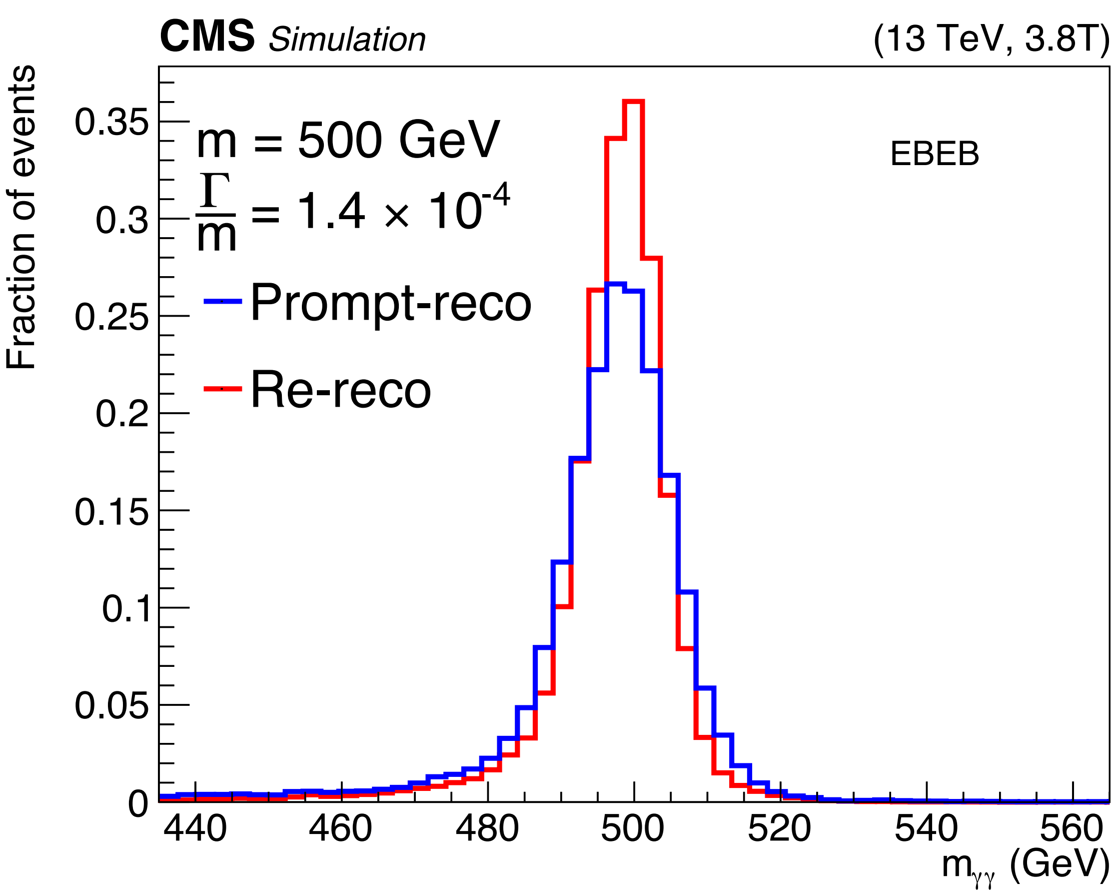


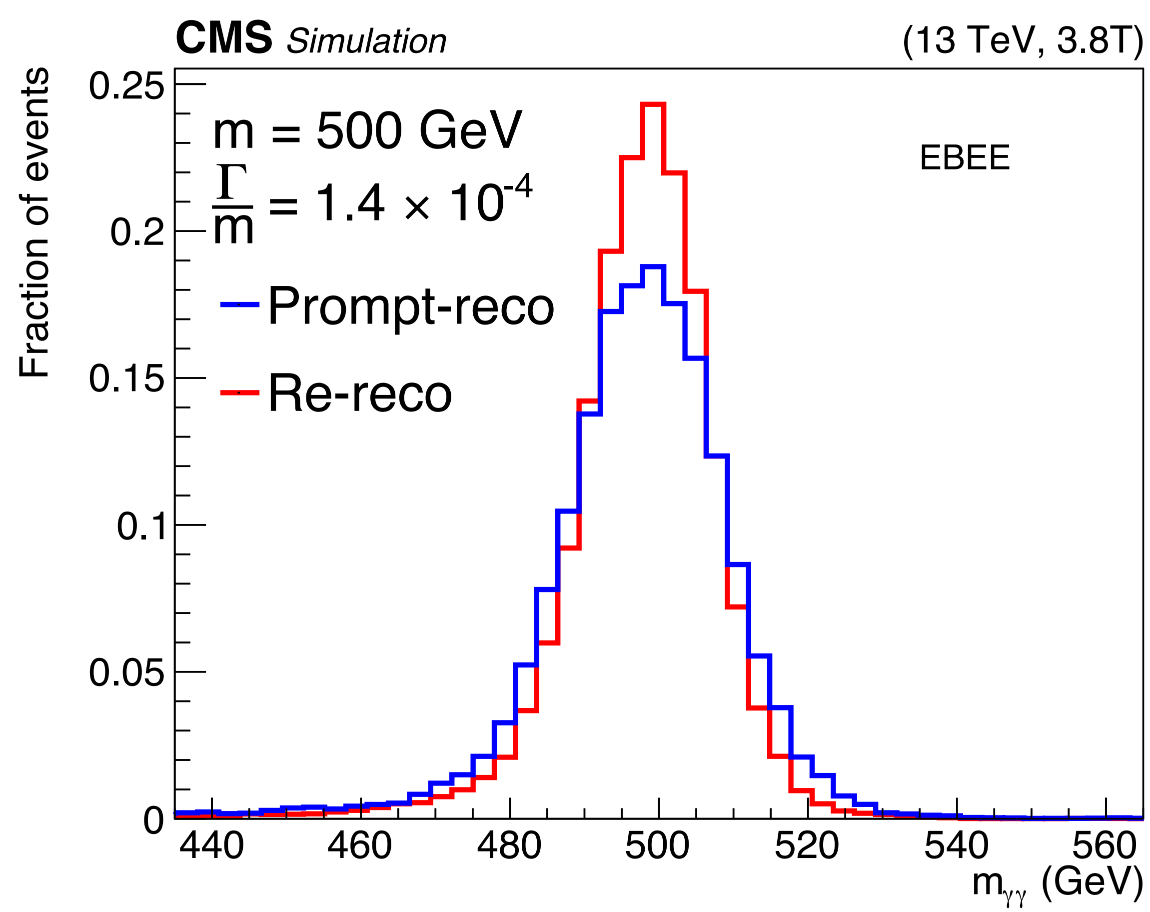


Energy Resolution for High Energy Photons

- Impact of recalibration also important for high energy photons
- Possible **saturation effects corrected with multivariate approach**:
  - Saturation **impact on energy scale < 2%**
- Data/MC **energy corrections stable to 0.5% (0.7%)** for photons up to 150 GeV in barrel



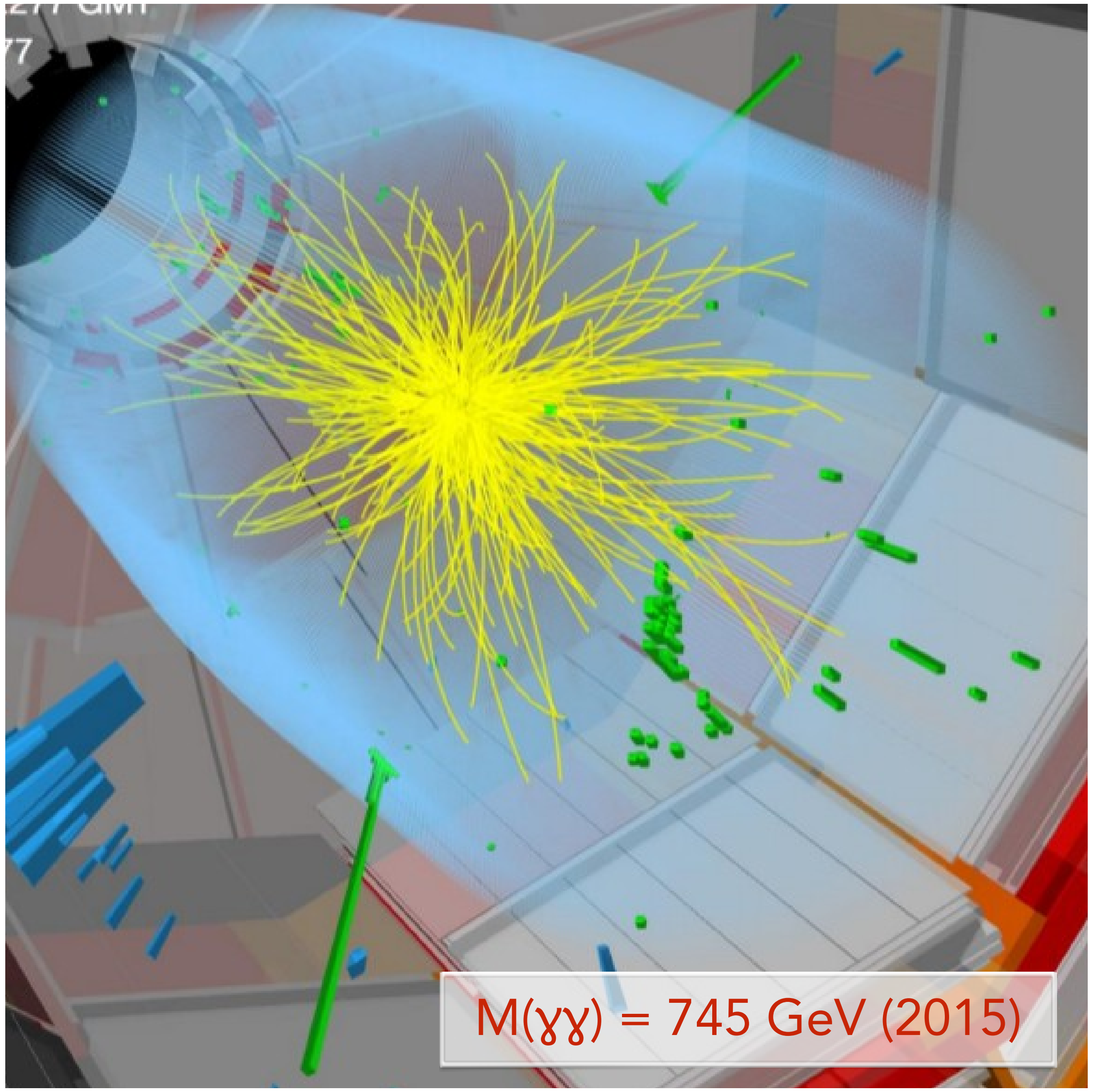




SUMMARY

- The CMS Electromagnetic Calorimeter has performed well with 2015 data of the LHC Run II
- New online reconstruction algorithm in place to mitigate the expected ~40 PU scenario in 2016
- Energy resolution, calibrated with 2.5 fb^{-1} of 2015 data, is close to expected value with 20 fb^{-1}
  - **σ_E/E < 2% (barrel central region)**

ECAL (and preshower) is currently fully operational and taking 2016 data!



THANKS!