CMS Calorimeters Run 2 Experience and Phase 1

LCWS 2018

Todd Adams

Florida State University

on behalf of the CMS Collaboration

THE FLORIDA STATE UNIVERSITY

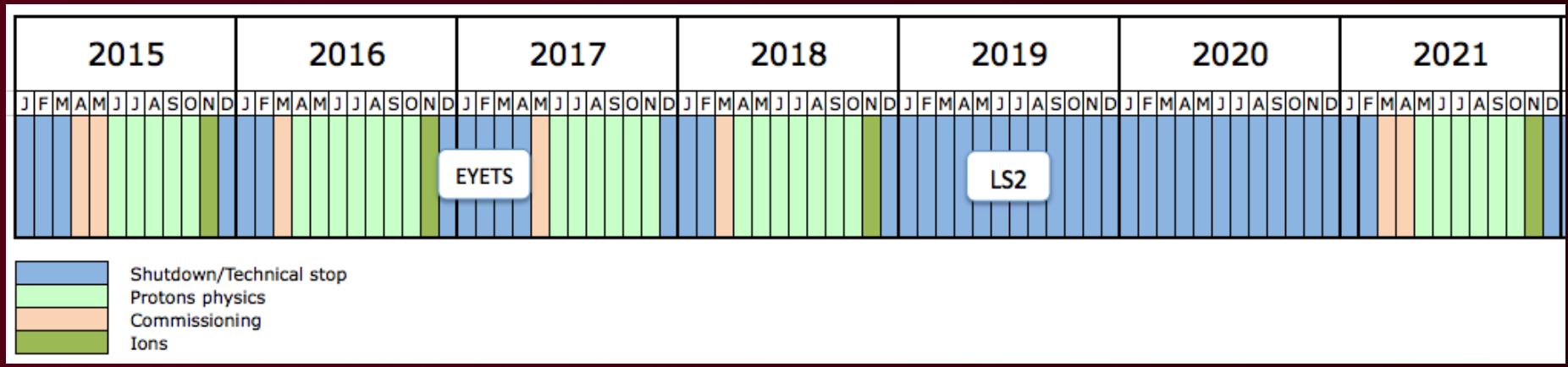
Run 2 and Phase 1

Run 2

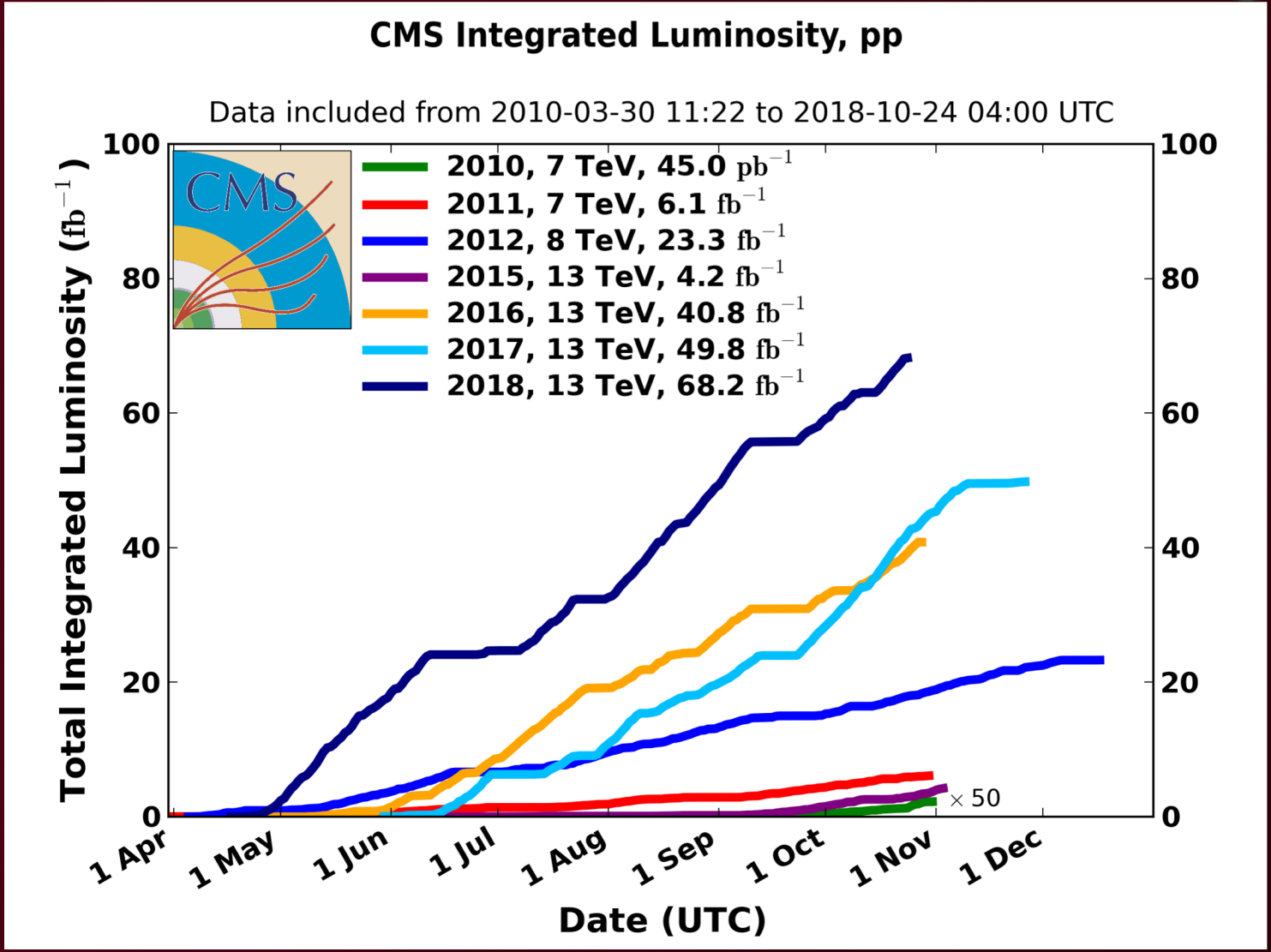
- 2015-2018 operations
- √s = 13 TeV

Phase 1 upgrades

- Long Shutdown 2 (LS2)
- 2018-2021 (~2.25 years)
- Many parts started during Run 2

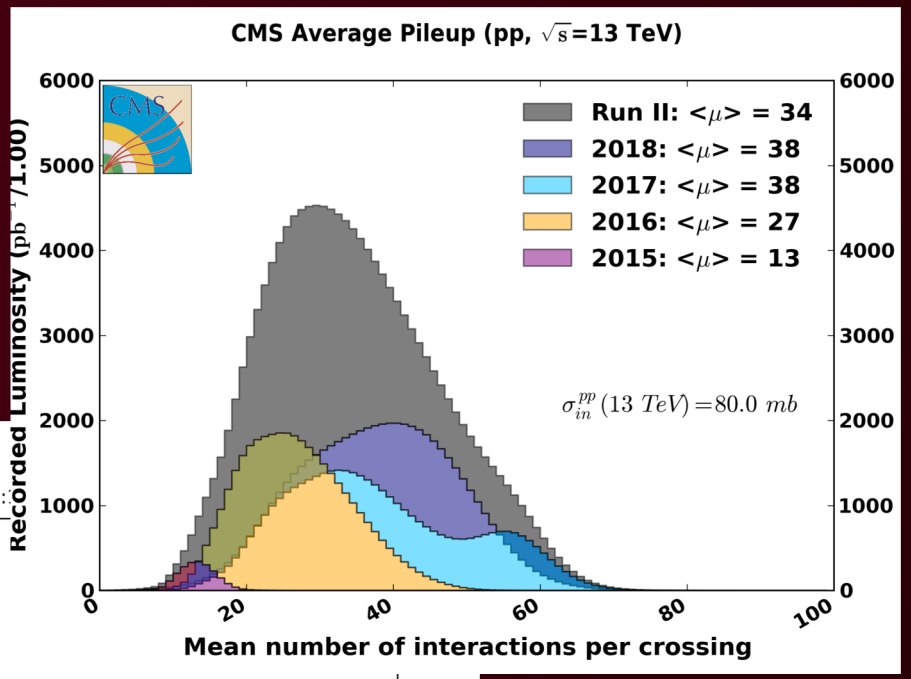


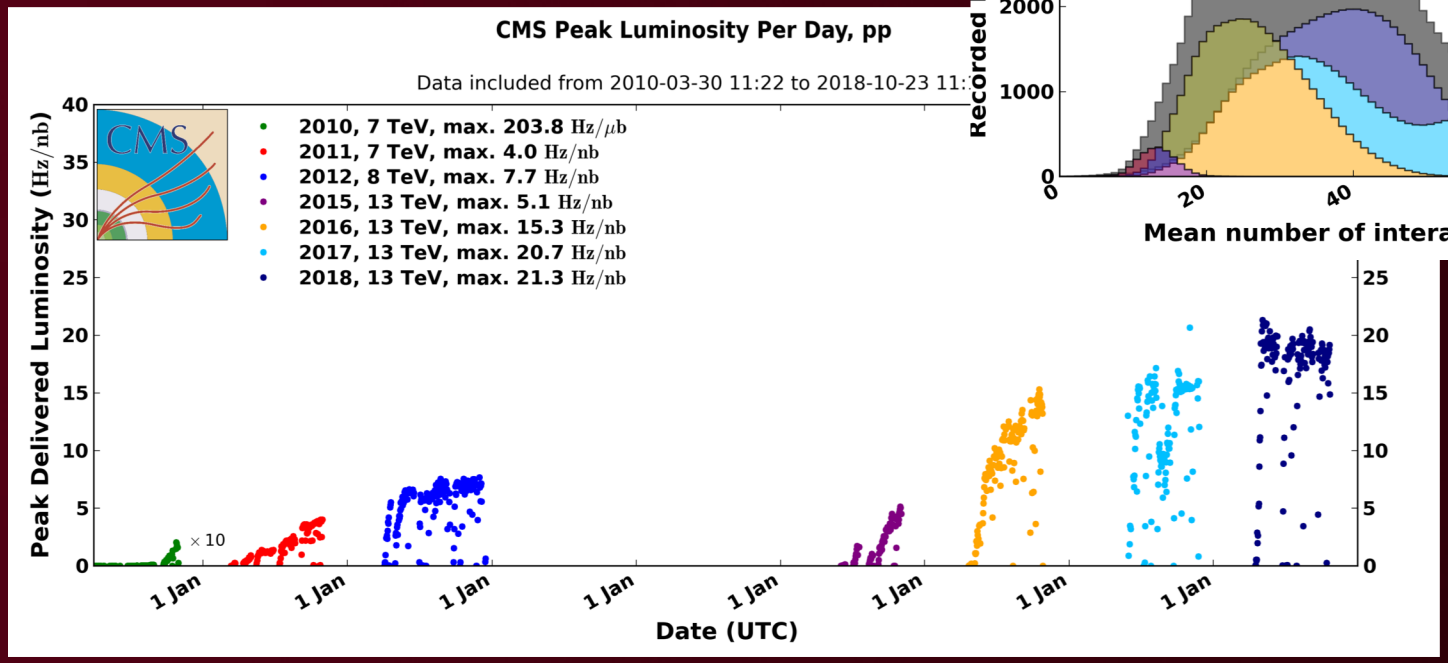
CMS Integrated Luminosity



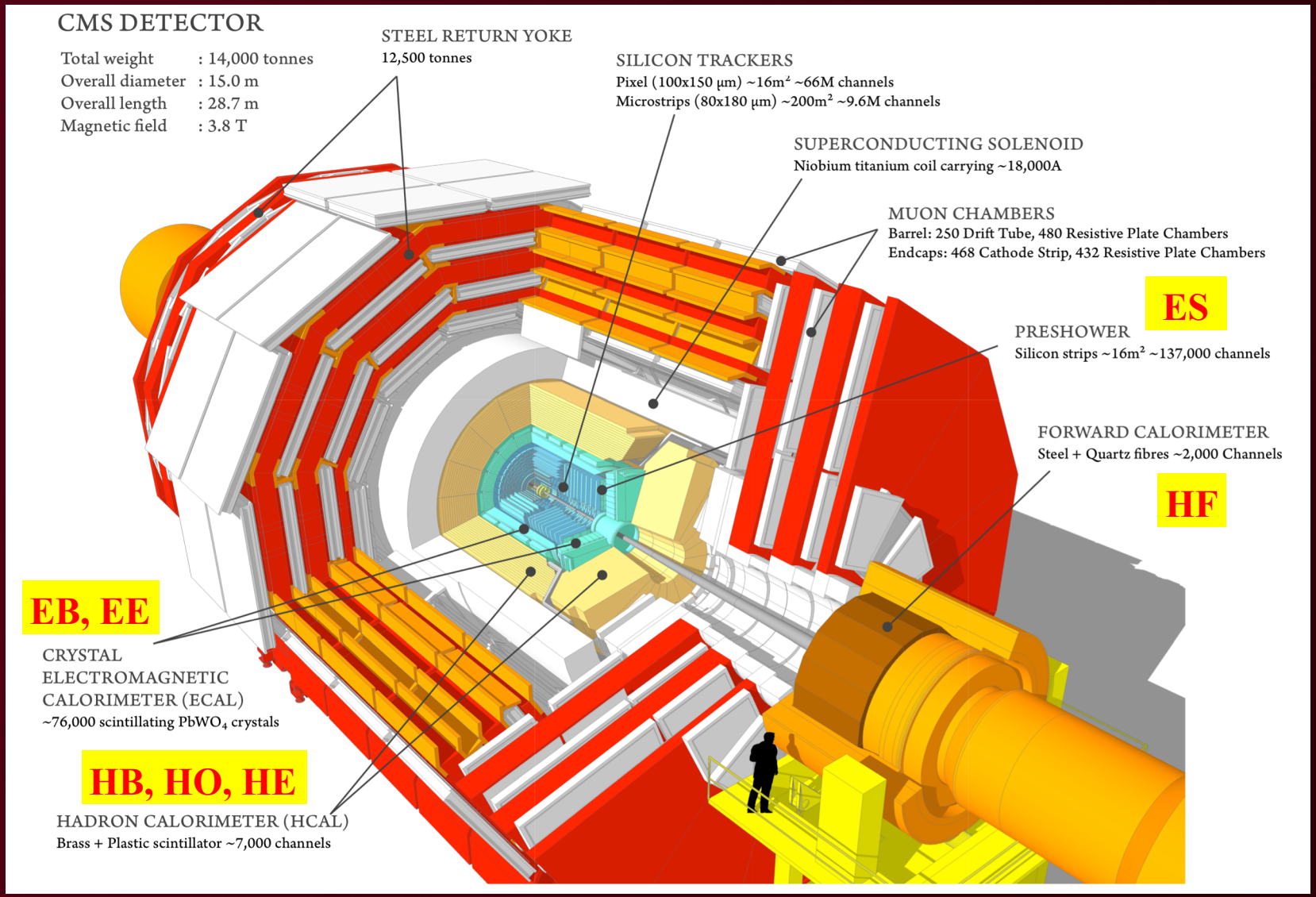
Instantaneous Luminosity

- Instantaneous luminosity increasing with time
  - along with # of interactions per bunch crossing



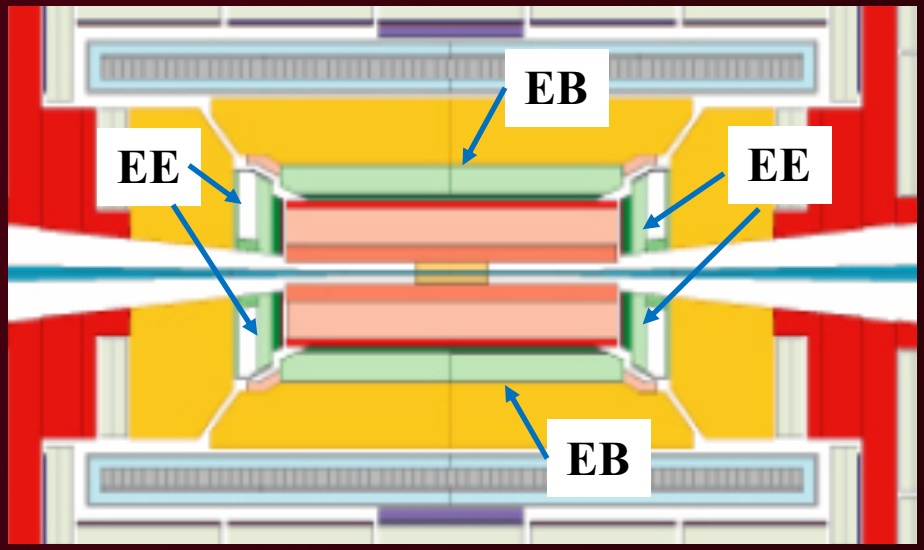


Seven Calorimeters



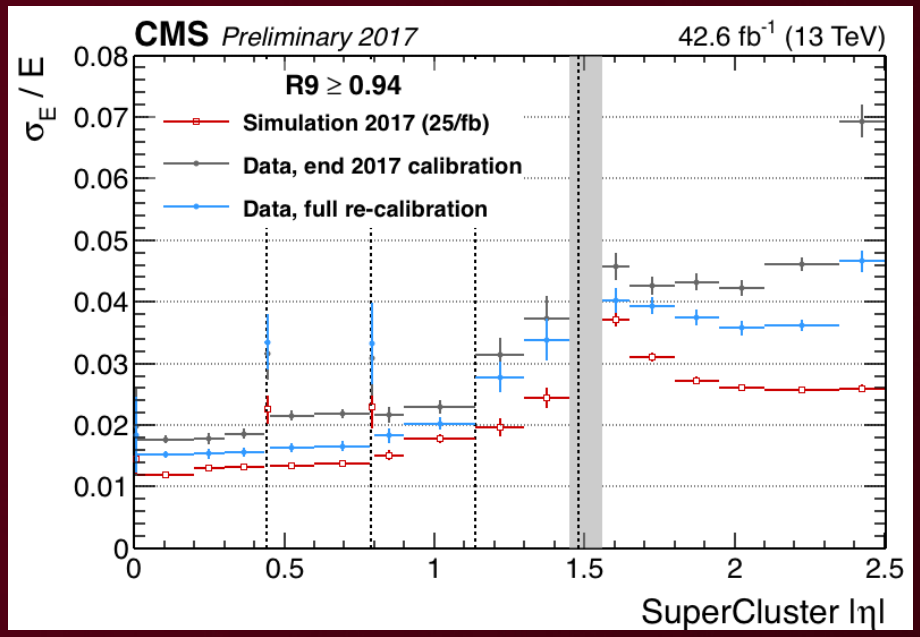
Electromagnetic Calorimeter

- ECAL Barrel (EB)
- ECAL Endcaps (EE)
  - includes preshower detector
- Lead tungstate ($PbWO_4$) crystals
  - 61,200 crystals in barrel
  - 14,648 crystals in endcaps
- Photodetectors
  - Barrel: Avalanche Photodiodes (APDs)
  - Endcaps: Vacuum Phototriodes (VPTs)
- Preshower
  - silicon layers between absorbers to allow improved photon/π^0 discrimination
- Laser monitoring system

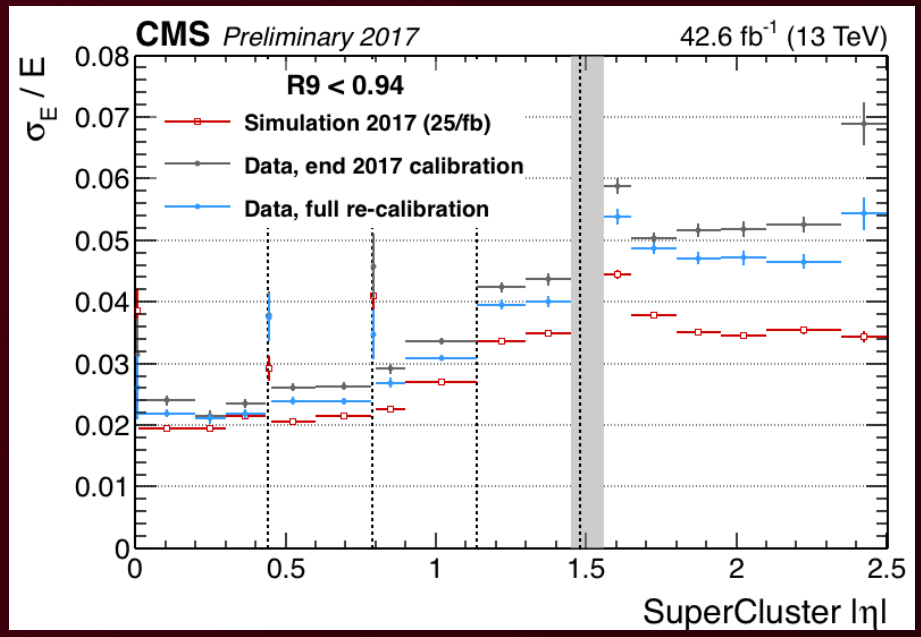


ECAL Resolution in Run 2

- Use electrons from Z→ee
- Resolution improved after full re-calibration



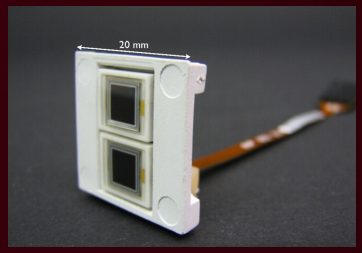
golden



Bremstrahlung

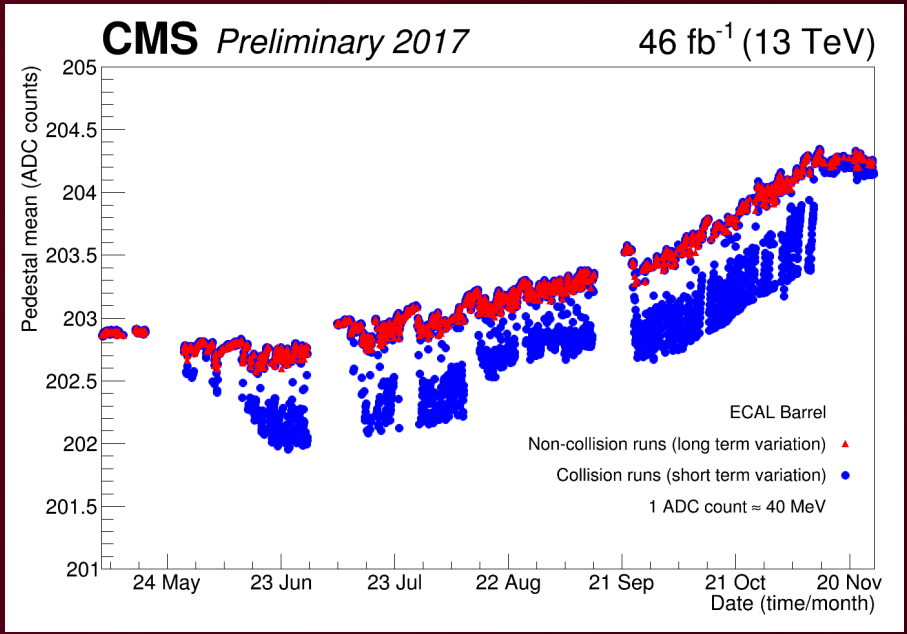
ECAL Operations Challenges

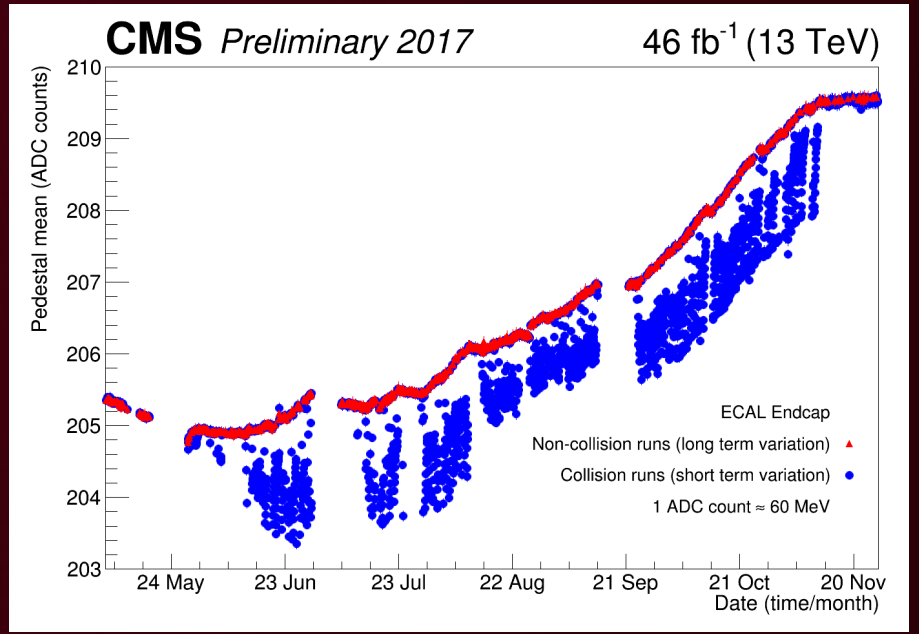
- Transparency loss in crystals
- Direct interactions with APDs
- Alignment
- Calibration



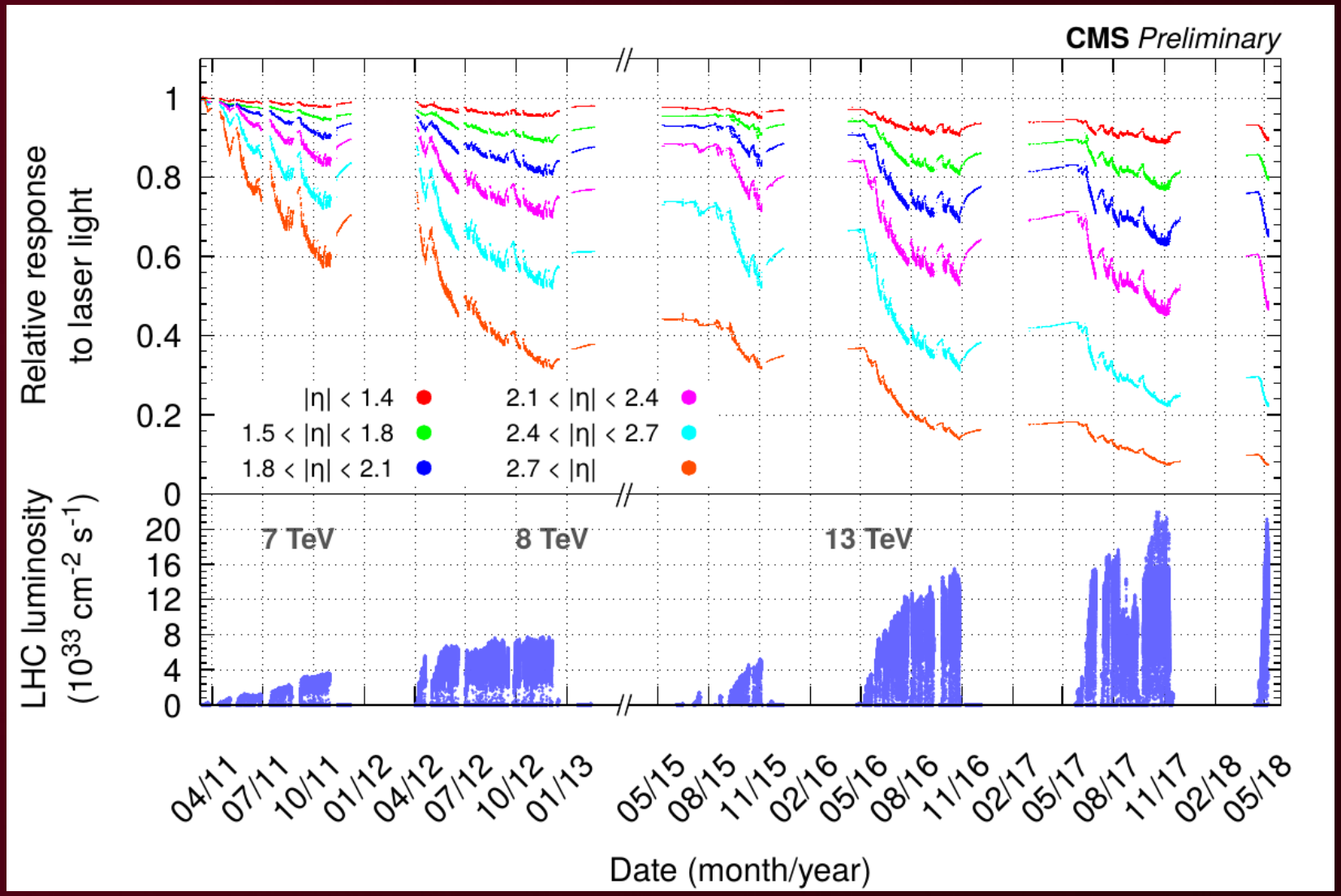
ECAL Pedestal Drift

- Over time the pedestals drift
- Red is long-term changes
- Blue is short-term, luminosity dependent changes



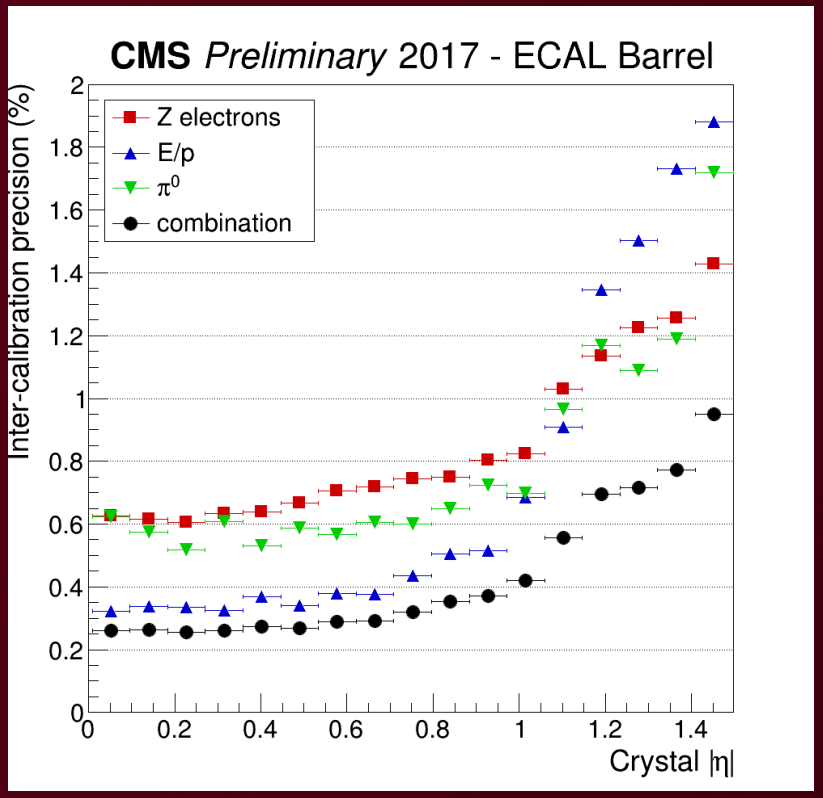


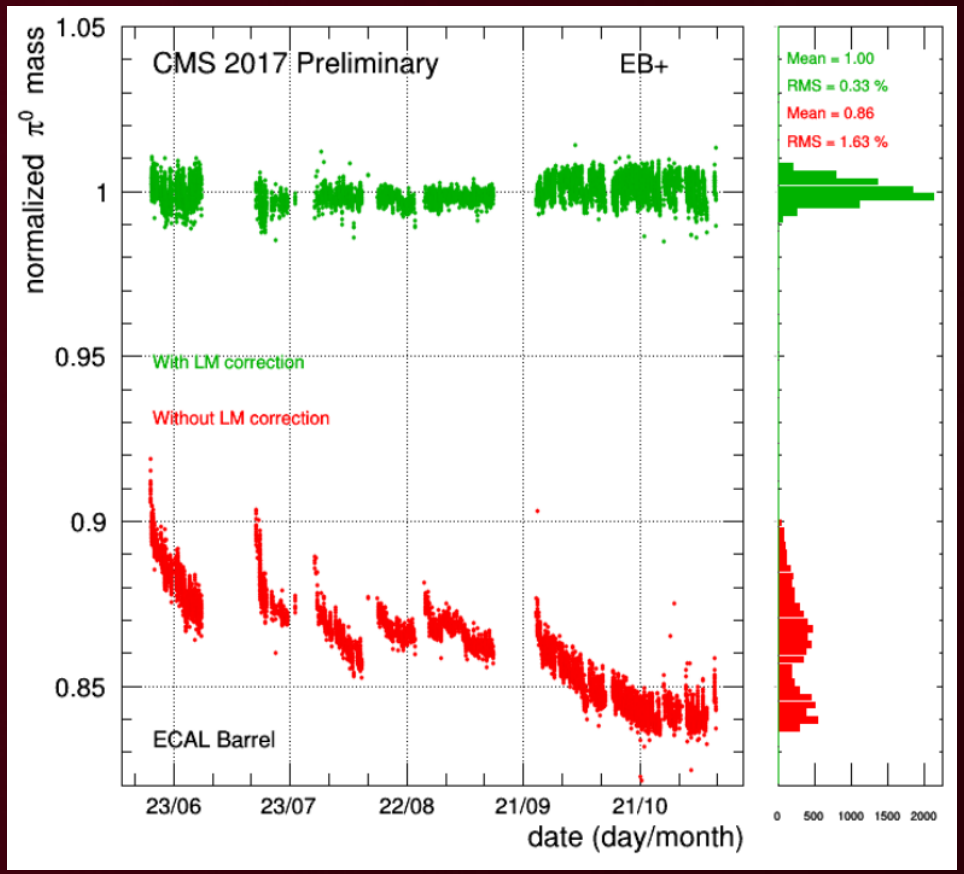
ECAL Transparency



Calibration

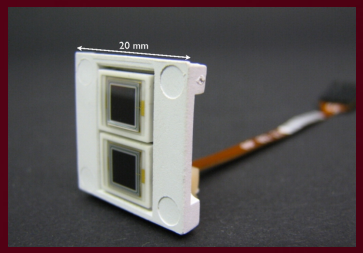
- Crystal intercalibration
  - Z → ee
  - calorimeter E/tracker p
  - π^0



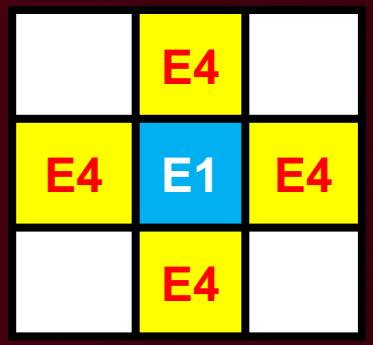


first Run 2 intercalibration

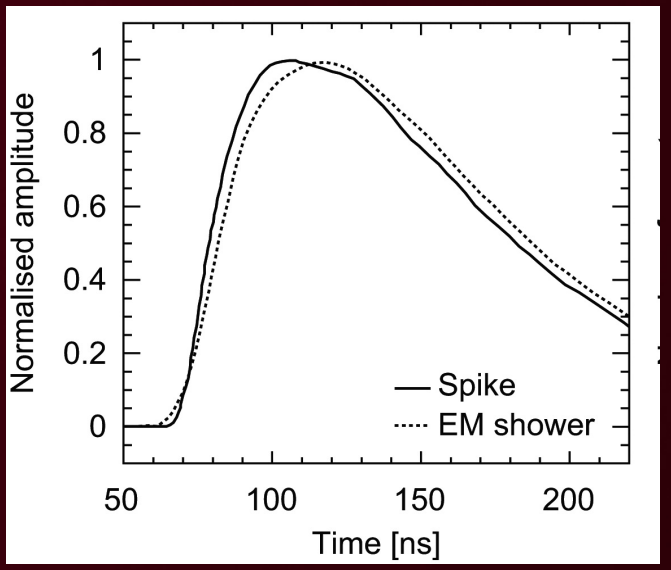
ECAL Spikes

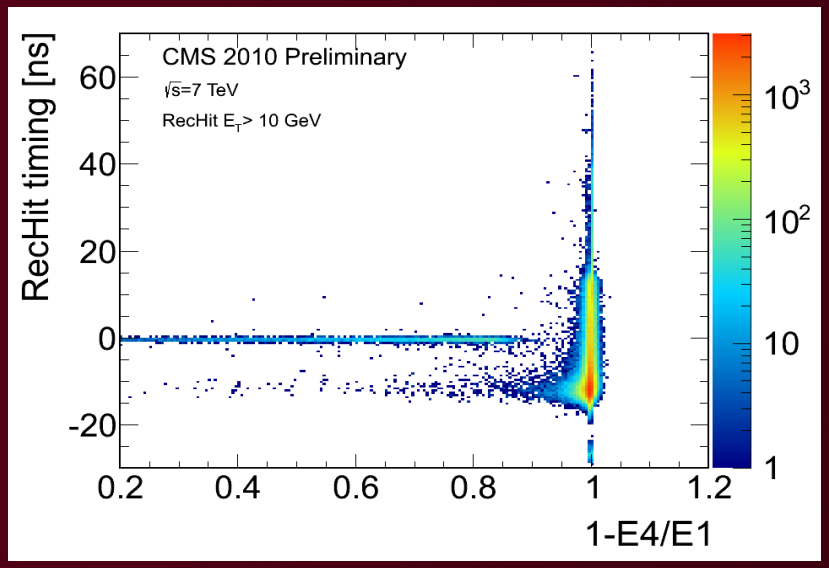


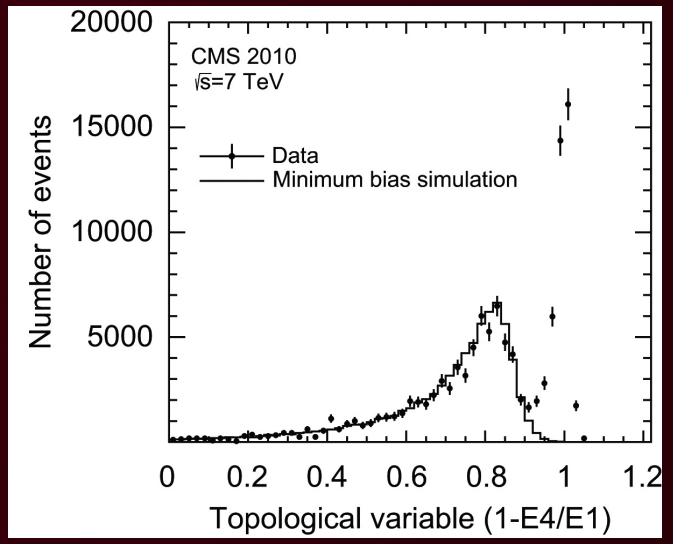
- Direct interactions with photodetectors
  - particularly in barrel APDs
- Different timing/energy distributions
- Use to reject offline



$$1 - \frac{E4}{E1}$$



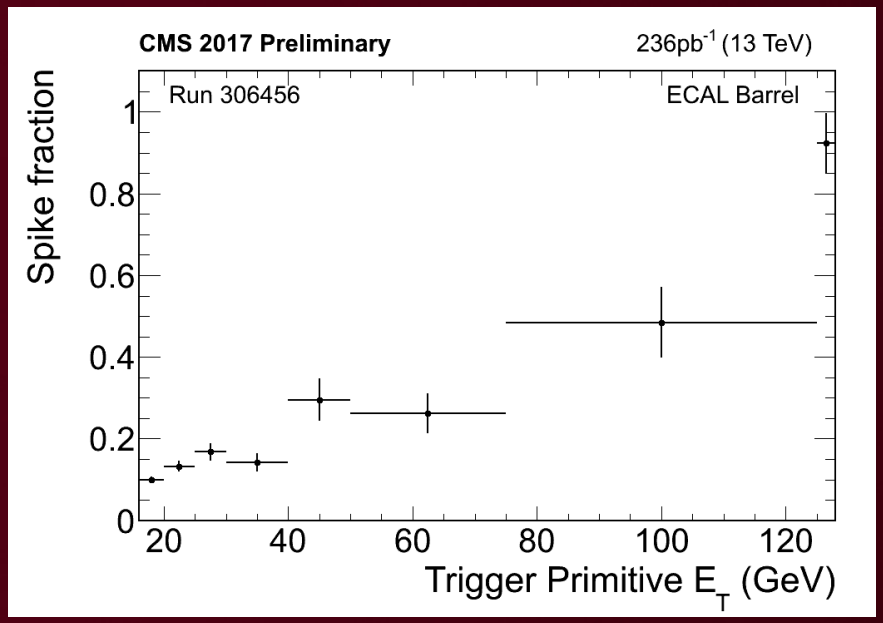


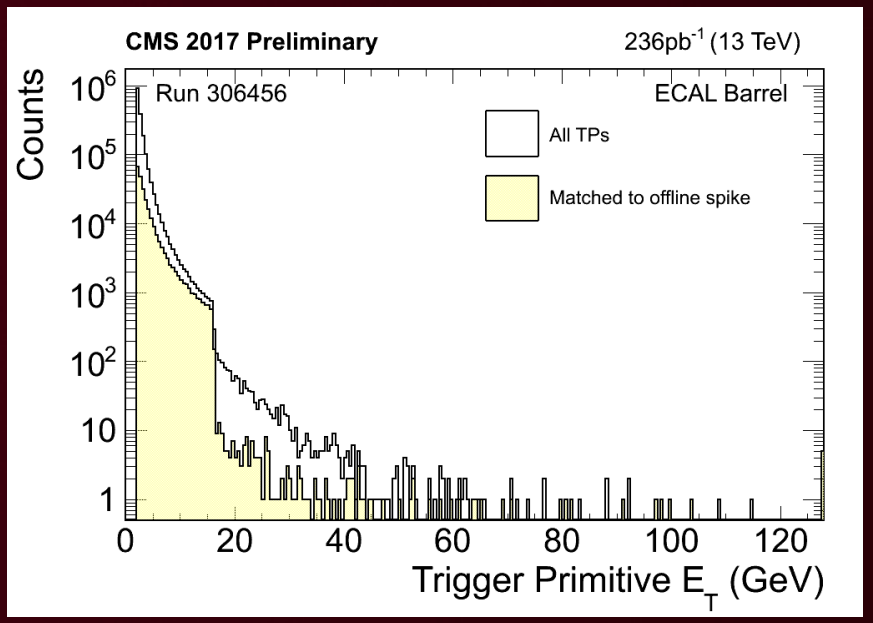


Spikes and Trigger

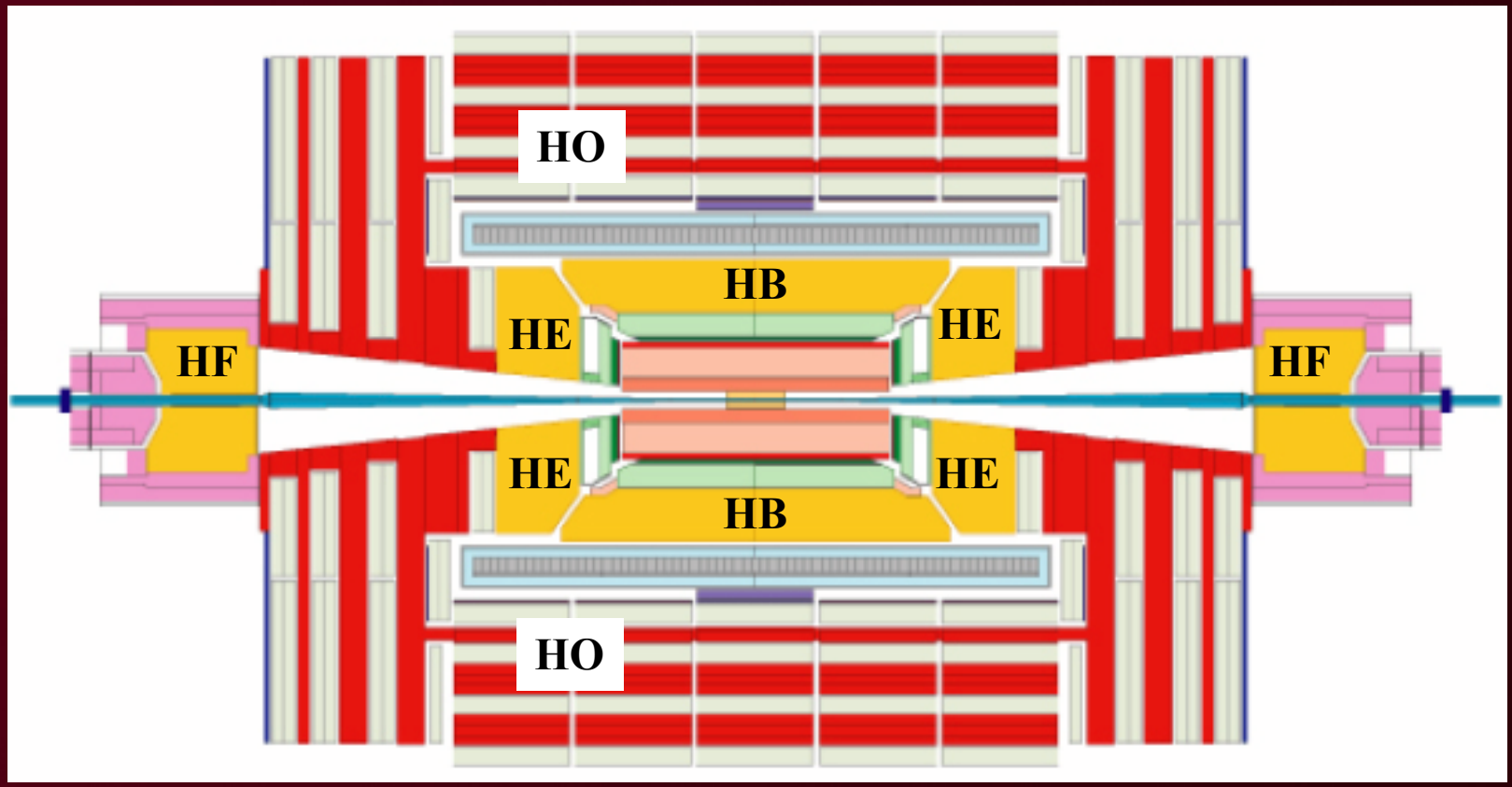
- Challenge to reject spikes at trigger level
  - can't implement offline rejection in CMS L1 trigger
  - developed rejection for L1 trigger FPGA

E_T threshold	Spike fraction
20 GeV	17%
30 GeV	24%
40 GeV	35%
50 GeV	39%





Hadronic Calorimeter



- Hadron Barrel (HB)
  - $|\eta| < 1.3$
- Hadron Outer (HO)
  - $|\eta| < 1.3$
- Hadron Endcap (HE)
  - $1.3 < |\eta| < 3$
- Hadron Forward (HF)
  - $3 < |\eta| < 5.2$

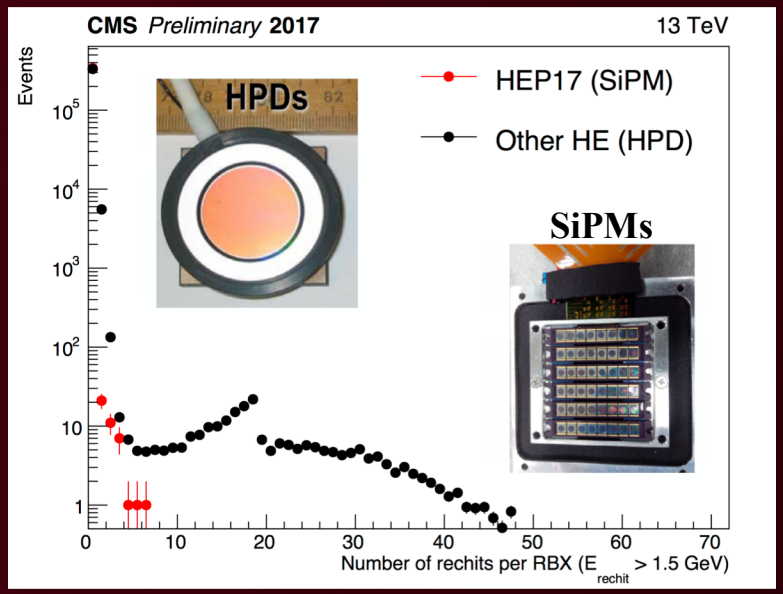
Hadronic Calorimeters

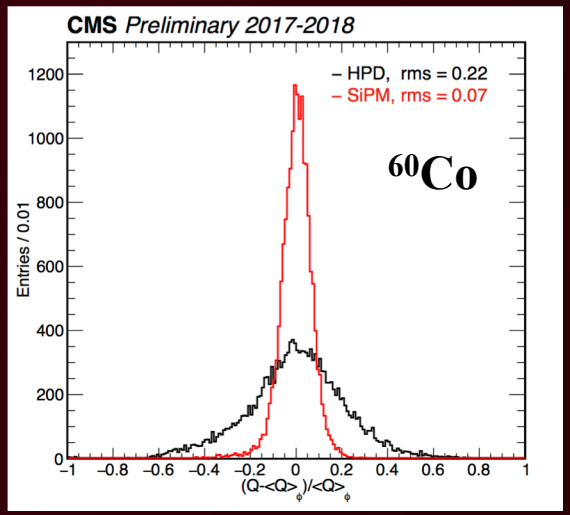
- Barrel HCAL (HB)
  - brass absorber
  - scintillator plates
  - waveshifting fiber
  - hybrid photodiodes (HPDs)
- Endcap HCAL (HE)
  - brass absorber
  - scintillator plates
  - waveshifting fiber
  - HPDs and silicon photomultipliers (SiPMs) – see next slide
- Outer HCAL (HO)
  - iron absorber (and magnet+cryostat)
  - scintillator plates
  - waveshifting fiber
  - SiPMs
- Forward HCAL (HF)
  - iron absorber
  - quartz fibers (Cerenkov light)
  - air core light guides
  - photomultiplier tubes (PMTs)

- Signals combined into towers for readout and triggering
- Limited longitudnal segmentation

Upgraded HCAL Endcap

- Endcap hadronic calorimeter partially upgraded during Run 2
- Photodetectors: HPDs → SiPMs
  - x2.5 higher PDE
  - x400 higher response
  - reduced noise
  - note: HO was upgraded to SiPMs before Run 2
- Frontend Electronics: QIE8 → QIE11
  - 8-bit ADC with built in TDC
- Backend Electronics: switch to μTCA
  - allows higher data volume and new trigger primitives
- Yields better longitudinal segmentation



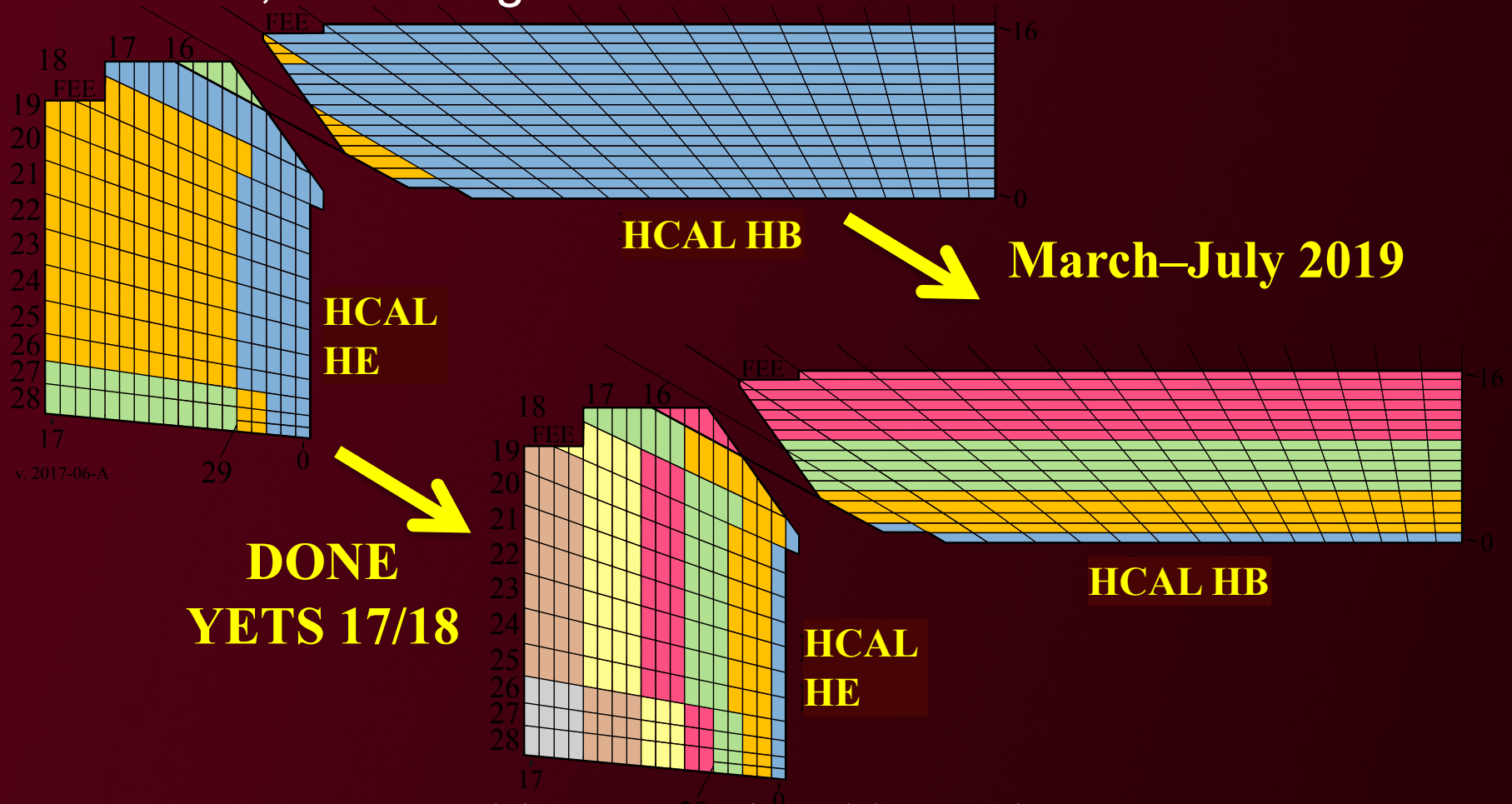


2017 HE Upgrade

- For the 2017 run, one wedge of HE was upgraded
  - 20^{o} in phi
  - only one end
- Testbed for:
  - SiPMs, FE electronics, backend electronics
  - Ability to maintain operating temperature
  - Improved reconstruction
- For triggering and primary reconstruction, combine signals to match rest of HE segmentation

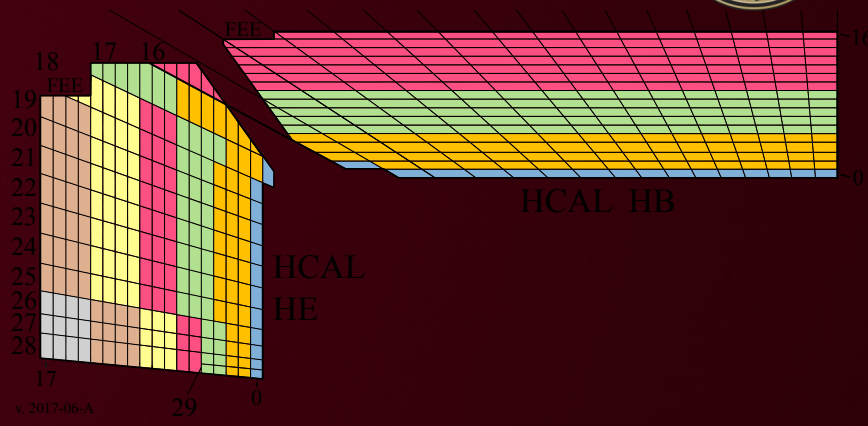
Improved Longitudinal Segmentation

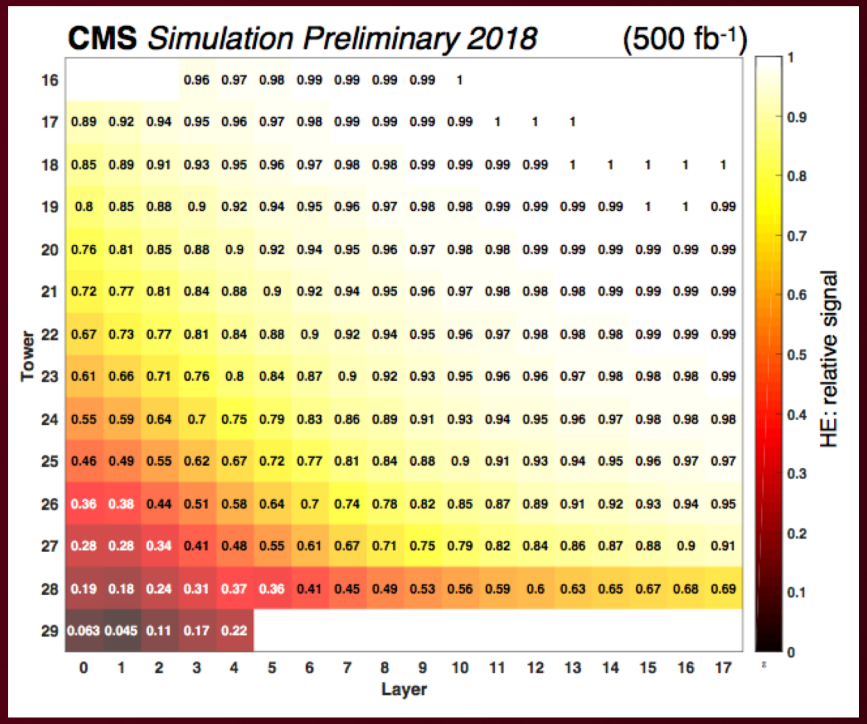
- 1-3 longitudinal layers → 3-7 longitudinal/radial layers
- HE done, HB during LS2

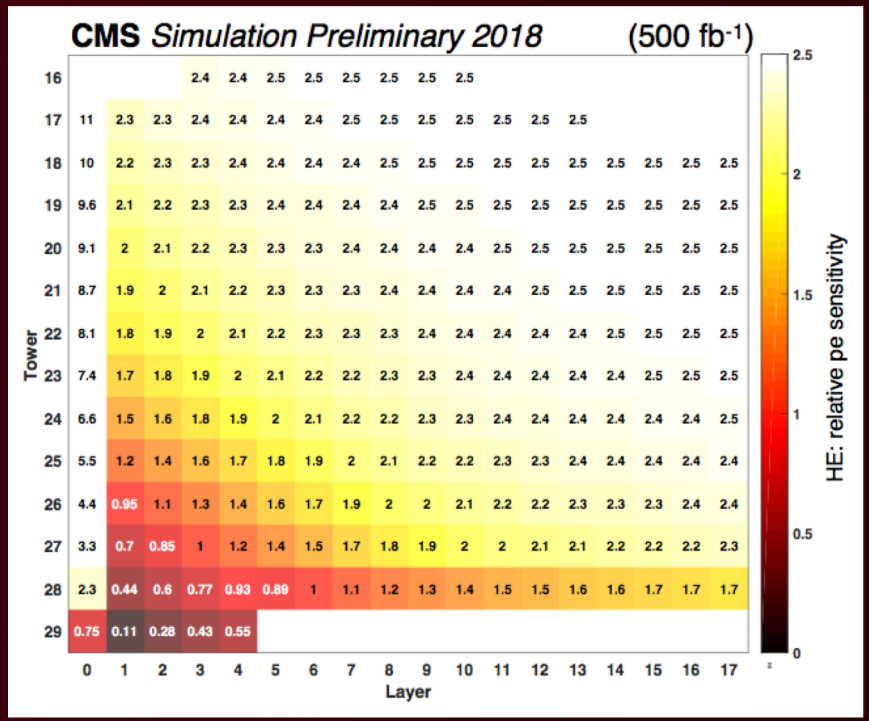


Improved Longitudinal Segmentation

- Improved algorithms being developed
- Improved calibration as detector ages
  - allows for different calibration constants for different radiation damage conditions

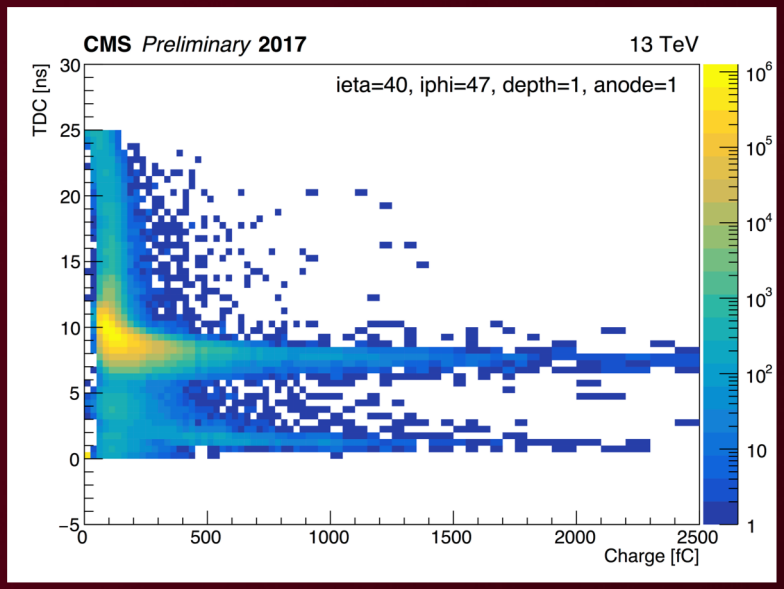


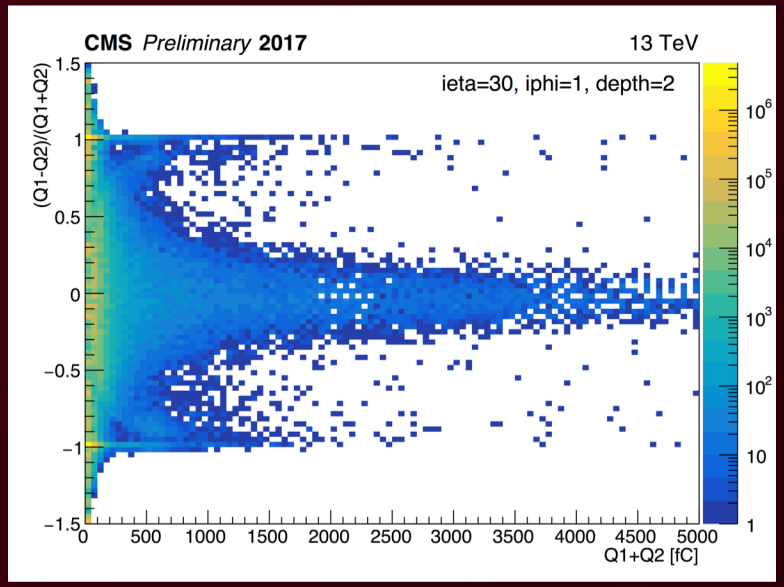




HF Upgrade
Completed during Run 2

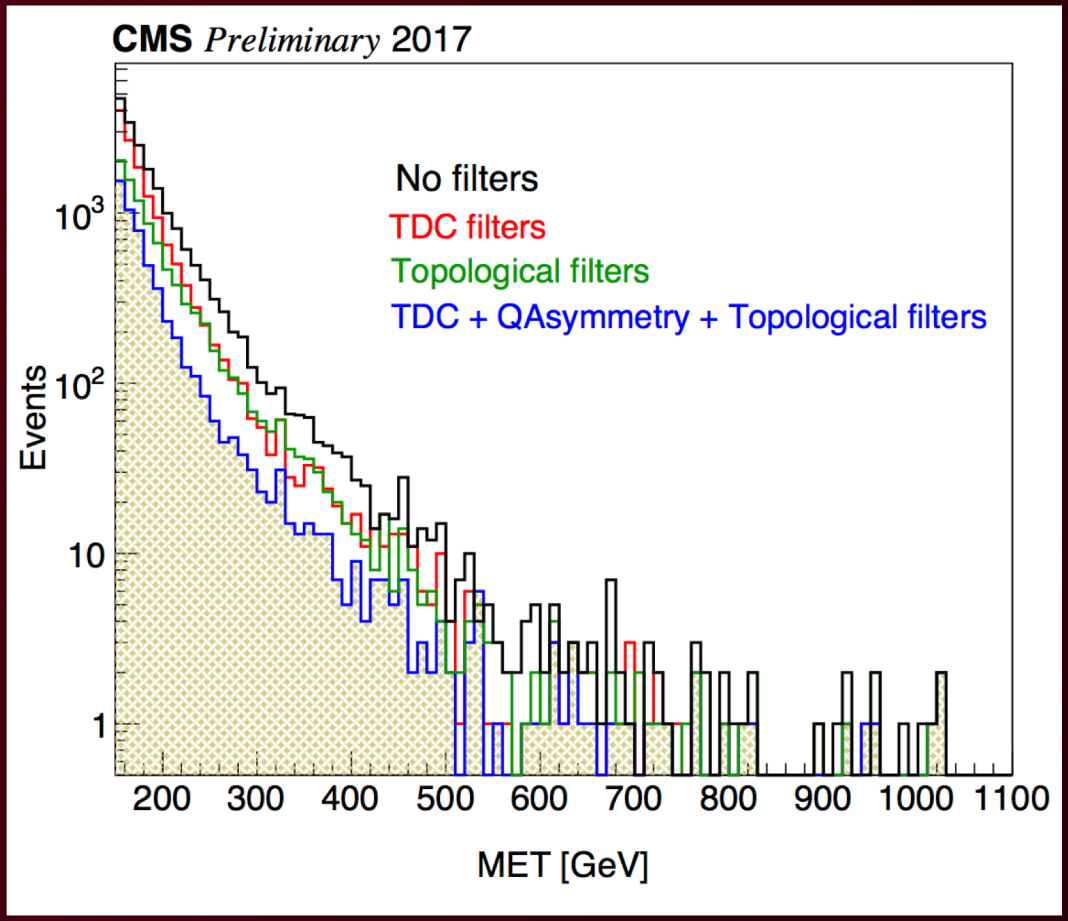
- Replace old PMTs (R7525) with 4-anode PMTs (R7600U-200-M4)
- Upgrade readout electronics
  - readout two channels per PMT
- Direct hits
  - early timing
  - signal in only one channel





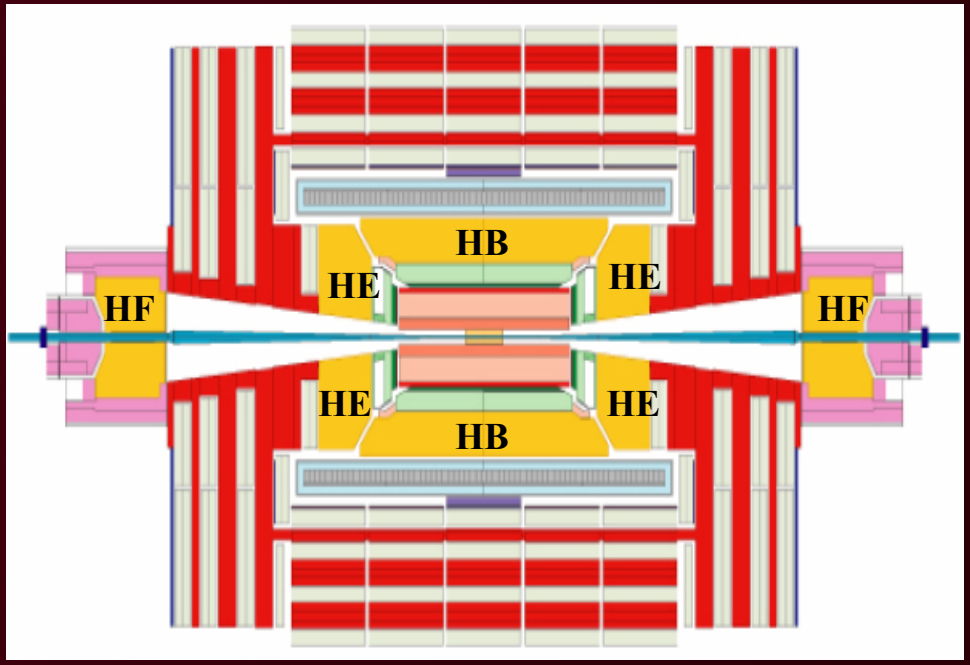
Improved HF Performance

- Filters based on timing and two channel readout improve MET performance



HCAL Phase 1 Upgrade
During LS2

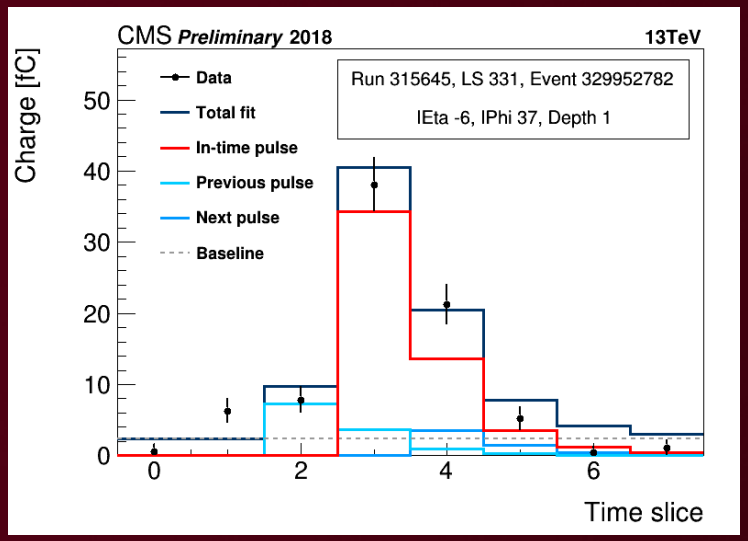
- Much of the upgrade has already been completed
  - HO: HPDs → SiPMs before Run 2
  - HE: HPDs → SiPMs, electronics during Run 2
  - HF: New PMTs, new electronics during Run 2
- Plans for LS2
  - HB
    - HPDs → SiPMs
    - frontend electronics
    - backend electronics
  - HE
    - fix DC-DC converter failure
      - lost one segment of HE during 2018 operations

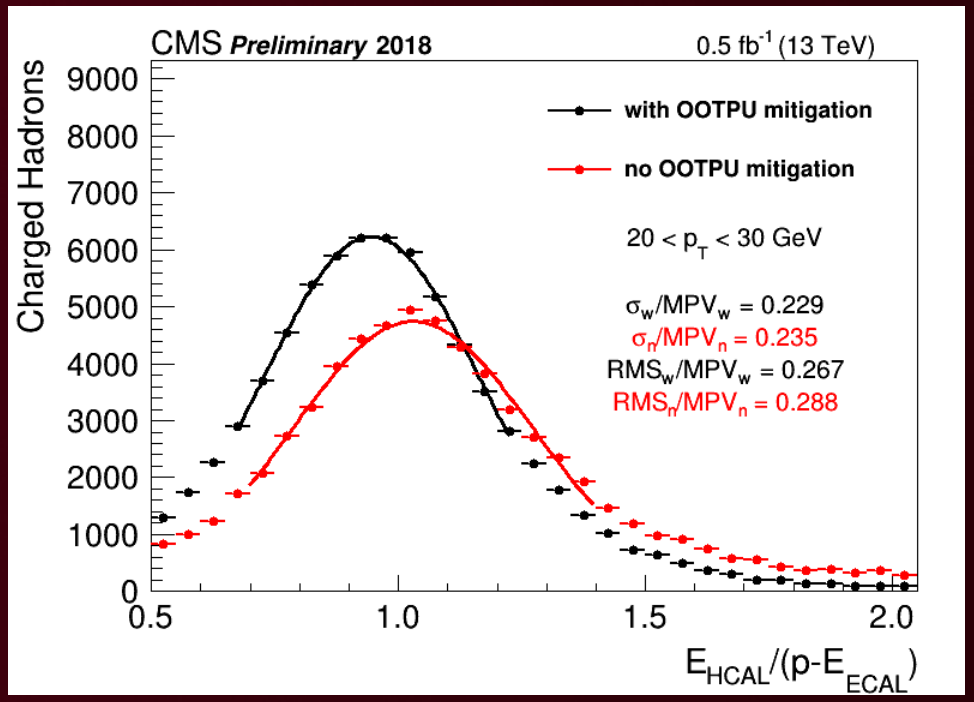


Out of Time Pileup Mitigation

Improved Run 2 Algorithms

- Use differences in timing of signals to separate
  - previous bunch crossing
  - in-time bunch crossing
  - next bunch crossing
- Fit timing distribution



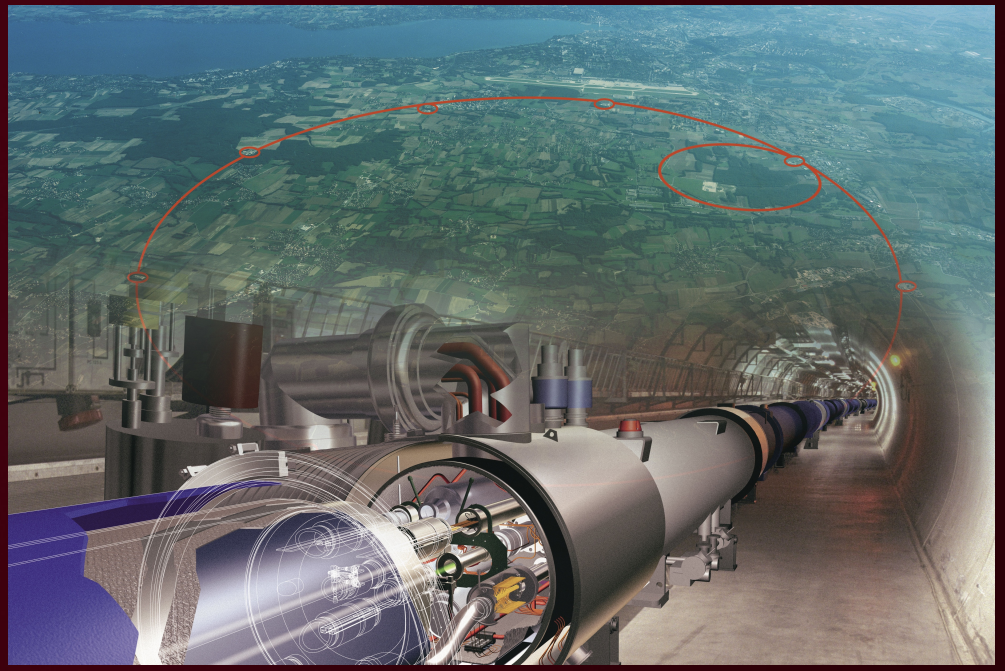


CMS Calorimeters
Summary

- CMS is completing Run 2 with successful operations
- Overcame some challenges
- Completed some of the upgrades
- Will finish HCAL Phase 1 upgrades during LS2

Future upgrades:

- ECAL Phase 2 electronics
- Endcap calorimeters replaced
  - see Felix Sefkow's talk



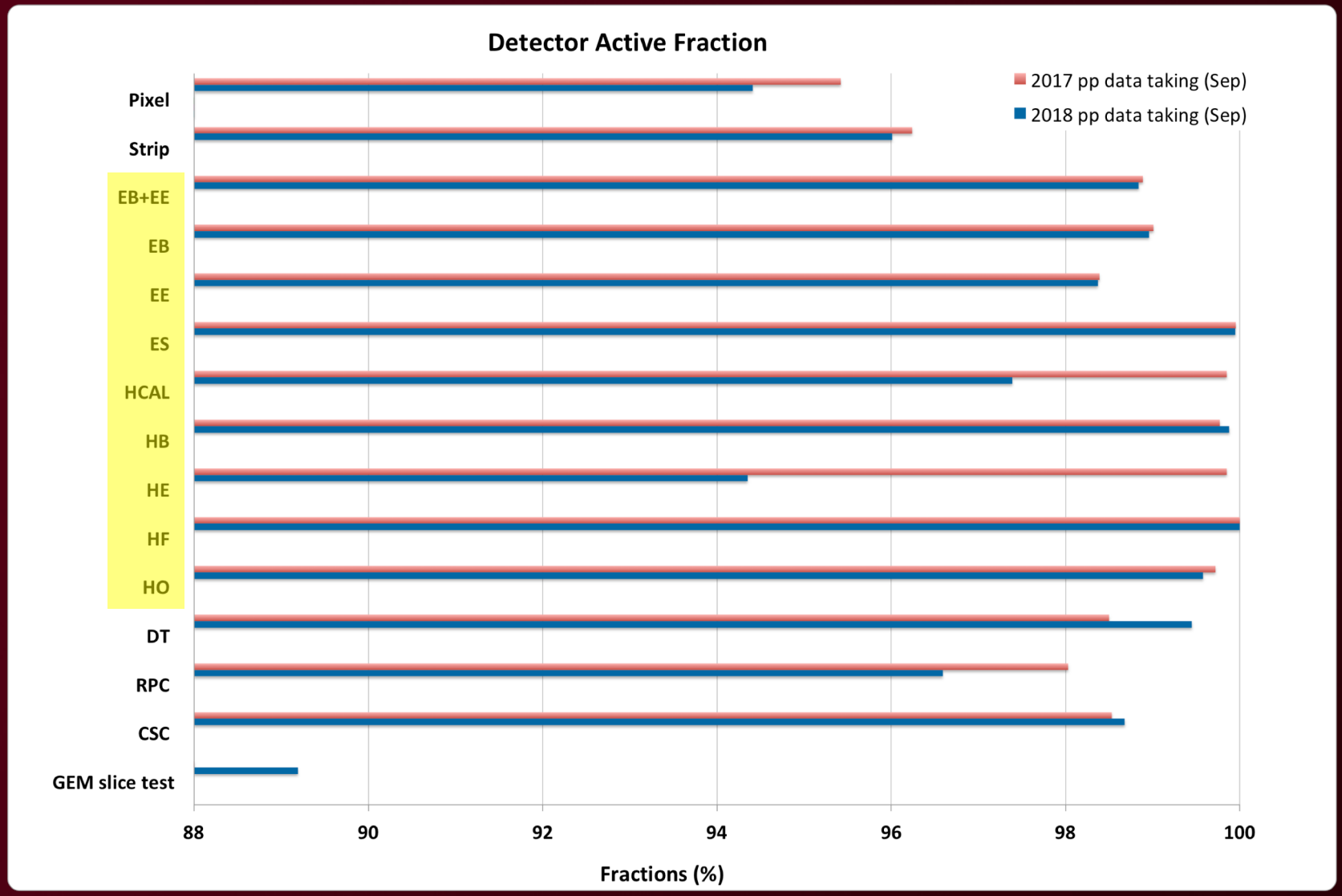
Other LHC Detector Talks

in case you want more info

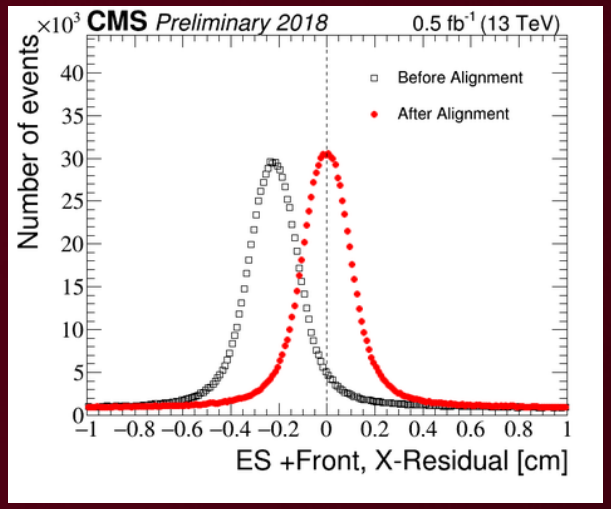
- "ATLAS Calorimeter system: Run 2 performance, Phase-1 and Phase-2 upgrades"
  - Haleh Hadavand, Tues. Oct. 23, 8:30am
- "High granularity Phase II upgrade of the CMS endcap calorimeter"
  - Felix Sefkow, Tues. Oct. 23, 9am
- "CMS Muon Detectors: Run 2 experience"
  - Adrian Thompson, Thurs. Oct. 25,
- "The CMS Muon Detectors: Phase 1 and Phase 2 upgrade"
  - Alexei Safonov, Tues. Oct 23, 10am
- "The CMS Tracker: Run 2 experience and upgrades"
  - Matthew Kilpatrick, Tues. Oct. 23, 2:30pm
- additional talks on LHC physics results

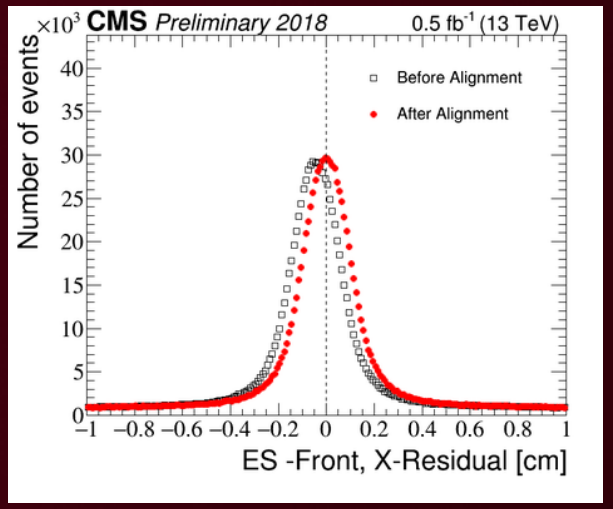
Backup

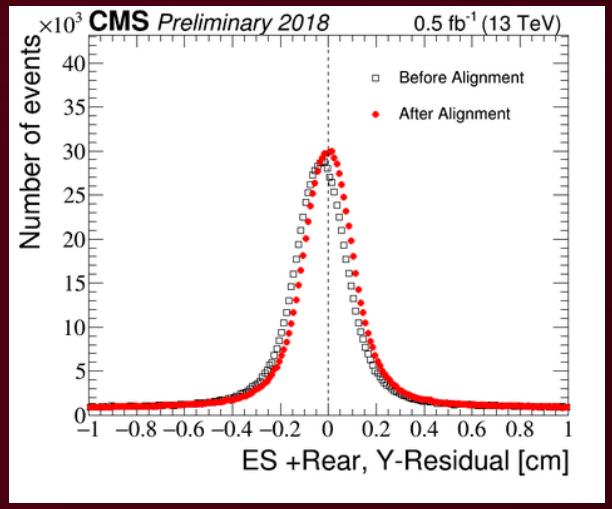
Detector Operations

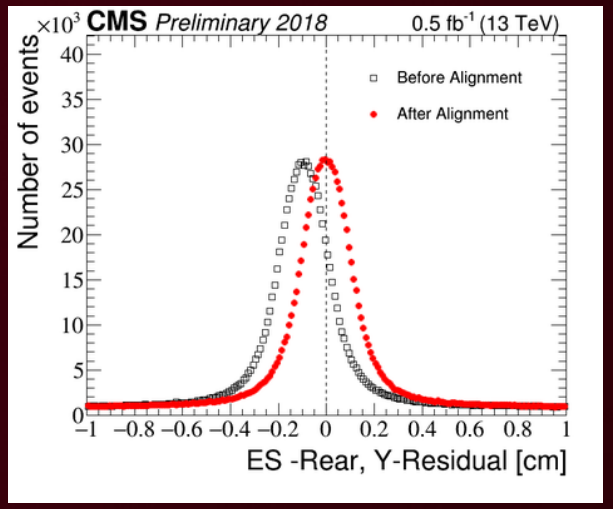


Preshower Alignment



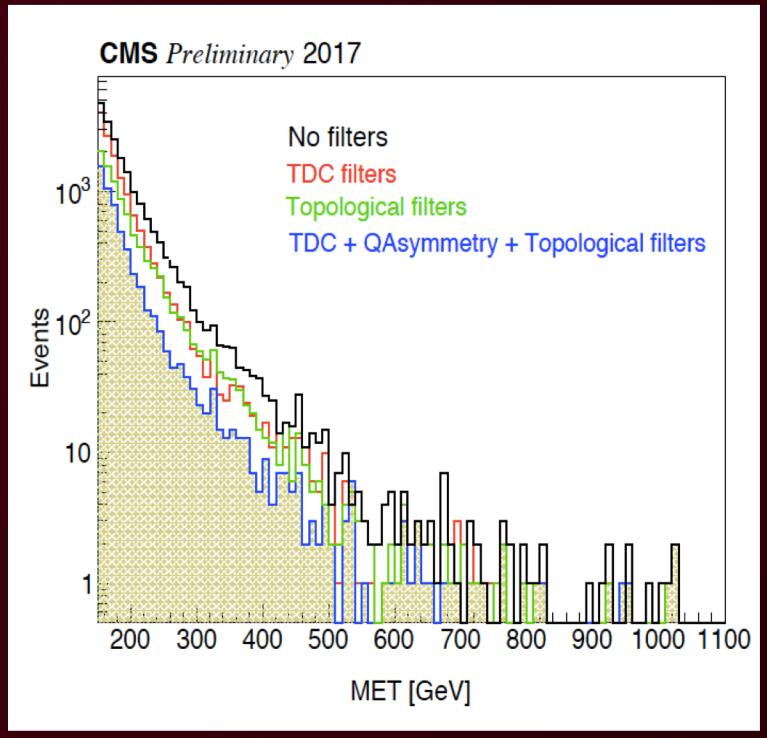






HF Topological Filters

- New PMT in HF with dual readout and timing capability to suppress anomalous noise.
  - see also CMS-DP-2017/034
  - http://cds.cern.ch/record/2281147
- Topological filters based on:
  - ratio of energy in the long vs short fibers
  - ratio of the energy surrounding 3x3 cells to the central
  - signal to noise threshold defined for each ieta
  - see also 2012 J. Phys.: Conf. Ser. 404 012044
- These topological filters were employed in the previous year data reconstruction.



Particle Flow Reconstruction

Improve resolution using best measurement

- Particle flow uses best measurement for reconstruction
- Combine information from different subsystems
  - Ex.: electron is a charged track and ECAL deposit
  - Ex.: hadron is a charged track and ECAL+HCAL deposit
- Form jets from sum of particles
- Missing transverse energy improved by using best information
- Allows for improved separation between primary interaction and secondary interactions

Segmentation