

# Optimizing the Performance of the CMS ECAL Trigger for Runs 2 and 3 of the CERN LHC

2019 Meeting of the Division of Particles and Fields of the American Physical Society

Northeastern University

1 August 2019

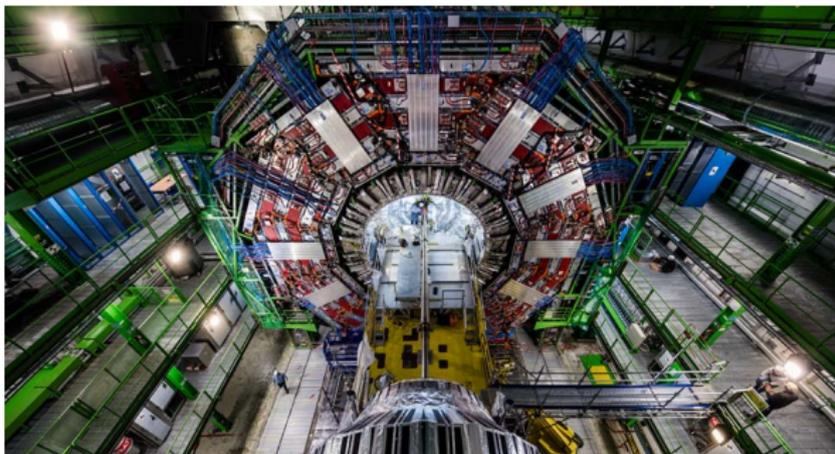
Abraham Tishelman-Charny  
On behalf of the CMS collaboration



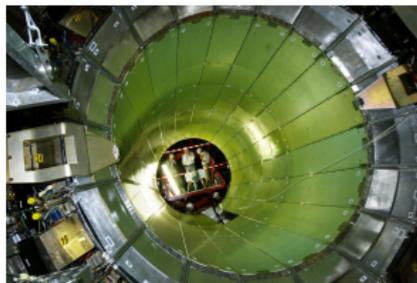
- 1 Introduction
  - ECAL Overview
  - ECAL Trigger
- 2 Trigger in Run 2
  - Calibration
  - Performance
- 3 Optimization for Run 3
  - Algorithm Improvements
  - Potential Gains
- 4 Conclusions

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  - ECAL Overview
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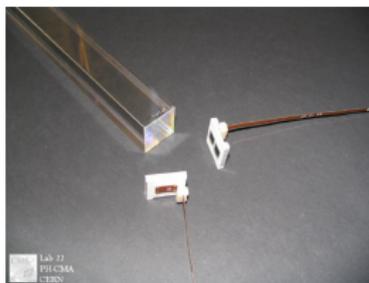
- The **Compact Muon Solenoid** is a general-purpose detector that studies many topics, including:
  - **Higgs Boson** properties
  - Searches for **Supersymmetry** and **Dark Matter**
- With dimensions:
  - Weight:  $\approx$  **14,000 Tonnes**
  - Length : **21.6m (70.9 ft)**
  - Diameter: **15m (49.2 ft)**



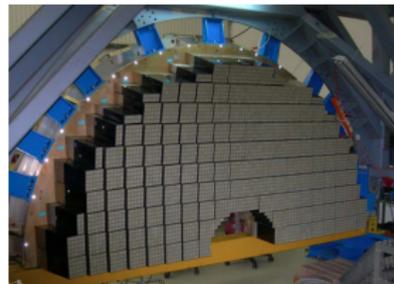
- The CMS ECAL is made up of the **EB** (ECAL Barrel) and **EE** (ECAL Endcaps), consisting of **75,848** PbWO<sub>4</sub> (Lead Tungstate) crystals.
- The barrel has **61,200** crystals, and the endcaps **14,648** (7,324 each)
- The purpose of ECAL is to measure the energies of **electrons and photons**, as well as the **EM fractions of jets**
- EM showers reach the back of the crystal and is detected by a **photodetector** (APDs [Avalanche Photo Diodes] in EB and VPTs [Vacuum Photo Triodes] in EE).



(a) ECAL Barrel

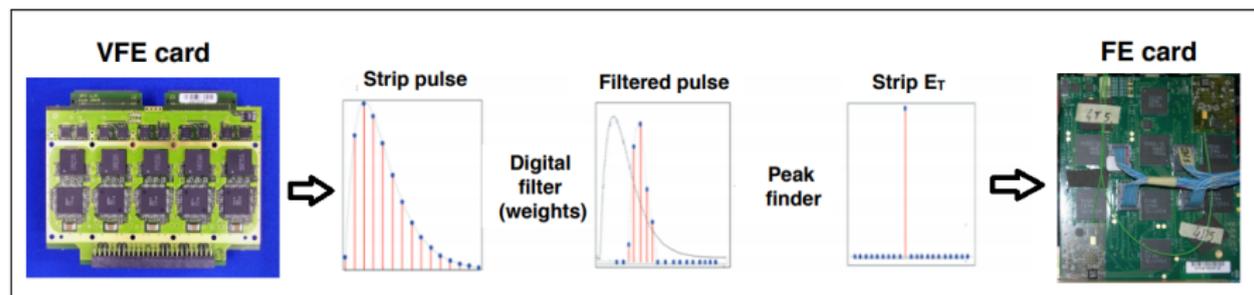


(b) Crystal and APD



(c) Half of an endcap

- L1 trigger uses fast algorithms in hardware to reduce LHC collisions rate of 40 MHz to 100 kHz of "interesting" events
- ECAL provides transverse energy sums from groups of crystals ("trigger primitives") to L1 to form e/photon and jet candidates
- Amplitude reco is performed on-detector using digital filter ("weights") on digitized pulse from front-end electronics connected to crystals and APD
- An ECAL L1 trigger primitive consists of an  $E_T$  (transverse energy) value, and a **sFGVB** (strip Fine-Grained Veto Bit) of 1 or 0



- Ideal weights can be derived for a given waveform
- This is done by a  $\chi^2$  minimization which takes in a waveform and noise correlation matrix

$$\chi^2 = (\mathbf{S} - \mathbf{G}(A, \delta t, P))^T \mathbf{C}^{-1} (\mathbf{S} - \mathbf{G}(A, \delta t, P))$$

Figure 3: Weights  $\chi^2$  [1]

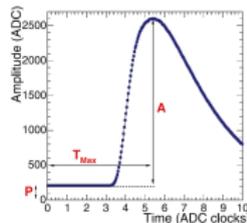


Figure 4: ECAL Waveform

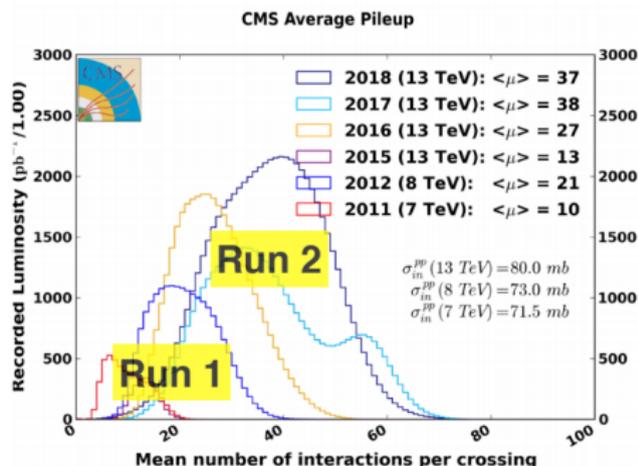
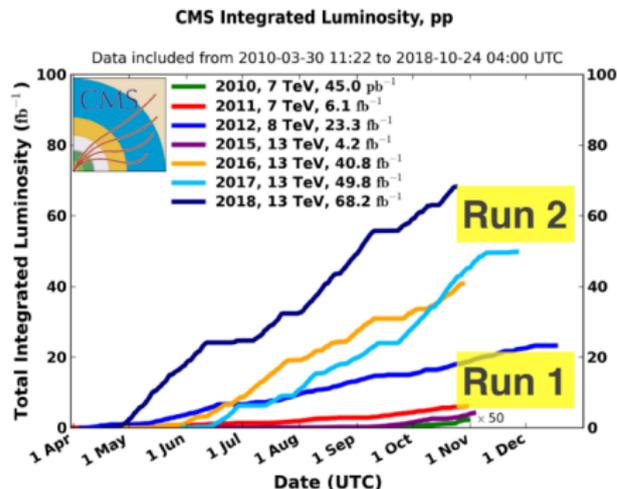
$$W_{A,i} = \frac{f_i - \frac{\sum_j^N f_j}{N}}{\sum_j^N f_j^2 - \frac{(\sum_j^N f_j)^2}{N}}$$

Figure 5: Equation for pedestal subtracting weights, assuming no noise correlation between samples

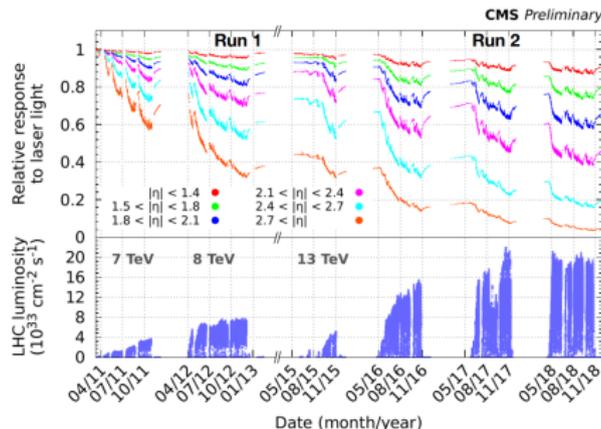
- $G = A \times f(t) + P$
- A: Amplitude
- $T_{Max}$ : Time of maximum amplitude
- P: Pedestal

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- During **Run 2** of the LHC (2015-2018),  $\approx 160\text{fb}^{-1}$  of data was collected, corresponding to  $\approx 6 \times 10^{16}$  proton-proton collisions
- With these massive amounts of data comes **challenging data taking conditions** for ECAL, with increased quantities compared to Run 1:
  - Ageing effects on crystals and on-detector readout
  - More challenging pulse reconstruction



- In EB and EE, crystal transparency **decreases** over time due to **radiation**
  - This decreases signal amplitude
- To correct for this, laser light with known amplitude is fired at all crystals **every 40 minutes**.
  - The **lower** the crystal amplitude, the **greater** the applied correction
  - Regular laser response corrections are applied to the trigger, to maintain stable e/gamma energy scale and resolution
  - Corrections applied twice per week during Run 2, compared to Run 1 which was once a week and only EE



- In EB, non-signal-like pulses called **spikes** are prevalent
  - Spikes are caused by direct ionization of APDs
  - Spikes are removed at L1 by the identification of isolated energy hits above a certain threshold
  - By providing a more accurate pedestal, isolated crystal energies will be more accurate and spike's can be more accurately identified
- By updating the **pedestals**, the L1 spike killer performance improves, but is still high at high  $E_T$ . We want to improve this for run 3

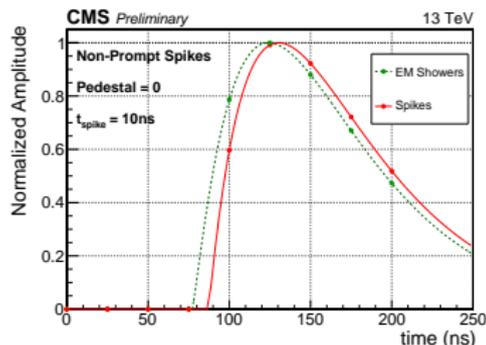


Figure 6: Non prompt spike and EM shower shapes

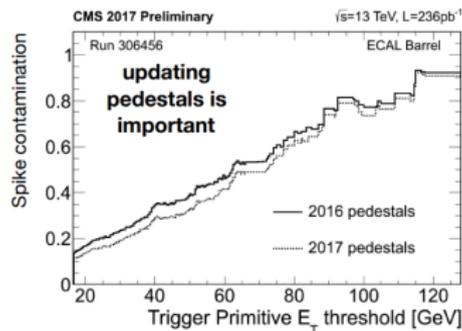


Figure 7: ECAL Waveform

- During Run 2, the operational efficiency of ECAL was better than 99%
- Thanks to stable ECAL and HCAL calibrations and detector performance, CMS maintained excellent e/g trigger efficiency in Run 2:

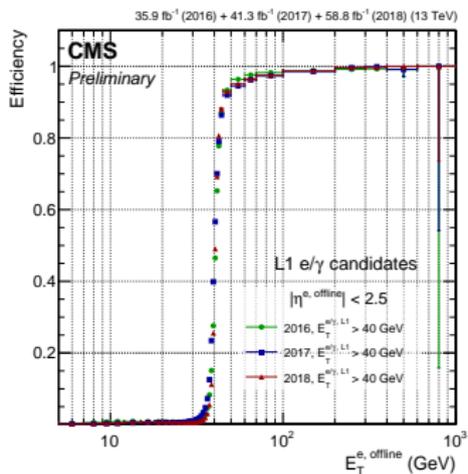
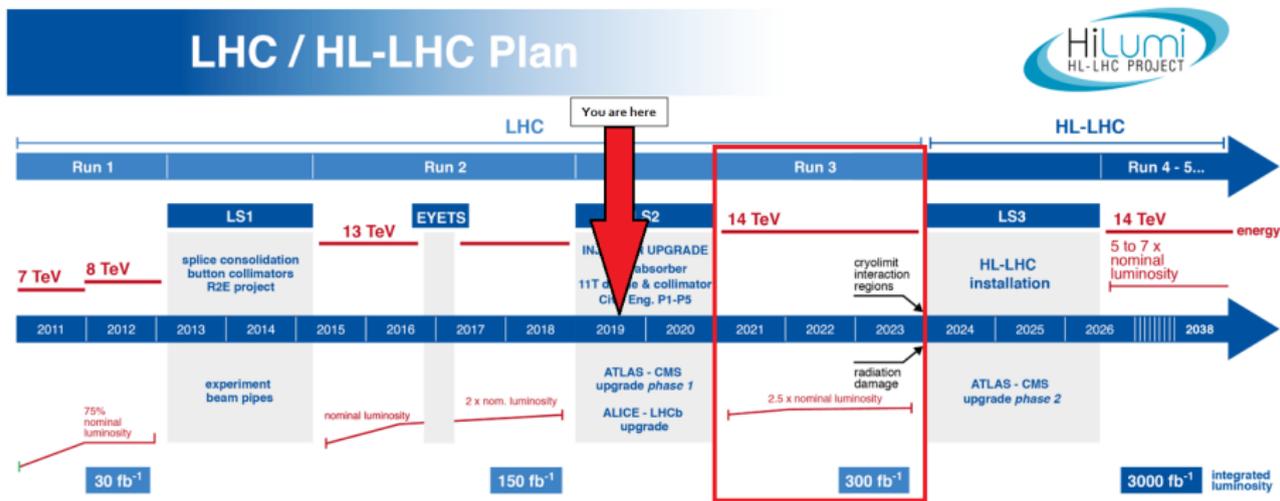


Figure 8: ECAL L1 Efficiency

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  - ECAL Overview
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- Run 3 of the LHC will go from 2021 - 2023
- About  $300 \text{ fb}^{-1}$  of integrated luminosity is expected (twice that of Run 2), and a PU of about 55-60 is expected.

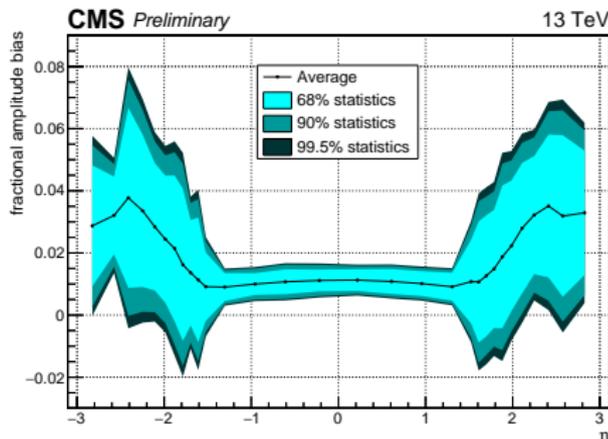




- The main ideas for algorithm improvements in ECAL for Run 3 are:
  - Updating the current **amplitude weights**
  - Using a **second set** of weights at L1
- By exploring these avenues of improvement, we can aim to:
  - Improve amplitude reconstruction to account for ageing effects and high PU.
  - Harness unused features in TP reconstruction to better reject spikes and PU

- The Run 2 weights used for amplitude calculation are **not ideal** for current detector conditions, especially in the **forward region**.
- This bias is caused by increasing radiation damage to crystals, particularly in the forward region, leading to a gradual distortion of the pulses

$$\text{bias} = (A_{\text{reco}}/A_{\text{true}}) - 1$$



**Figure 9:** Bias from Run 2 weights applied to September 2018 measured waveforms

- Updating the weights to reflect Run 2 detector conditions results in an improvement in the trigger primitive energy response and resolution:

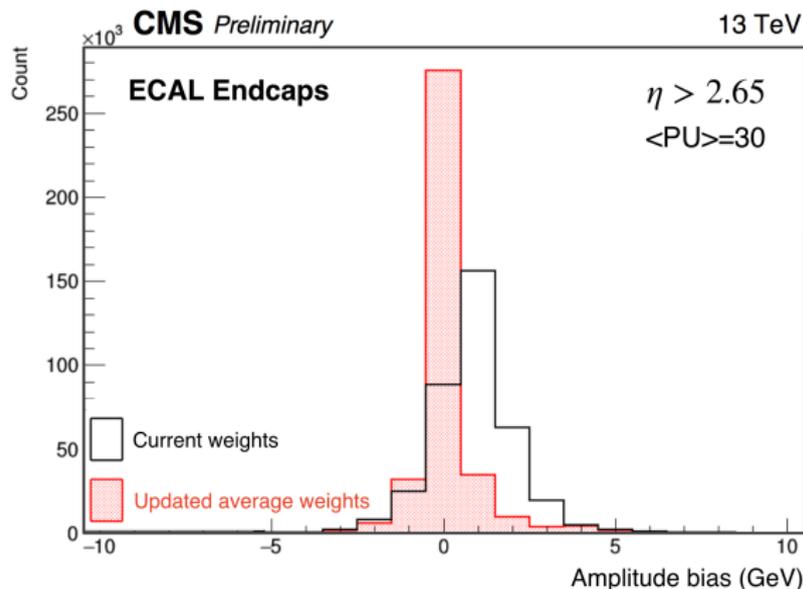
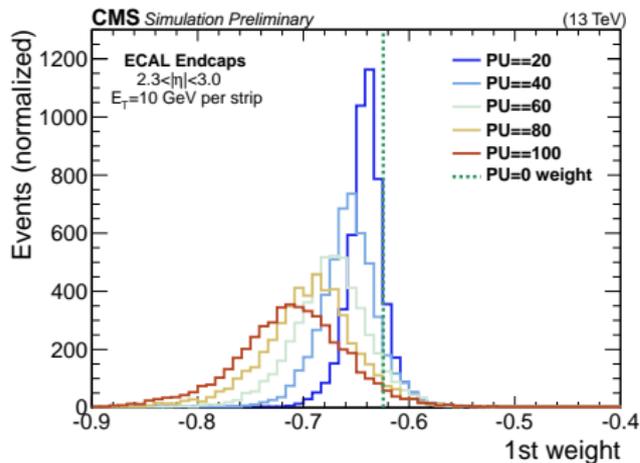
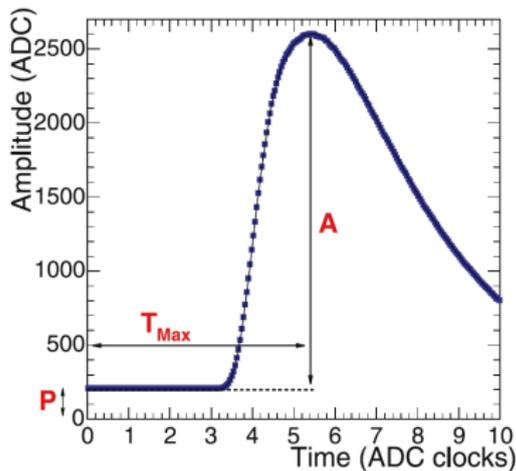


Figure 10: Bias counts for 2017 TPs with new average EE weights set used

- When weights are derived for signals with out of time PU, a change in weights is seen:



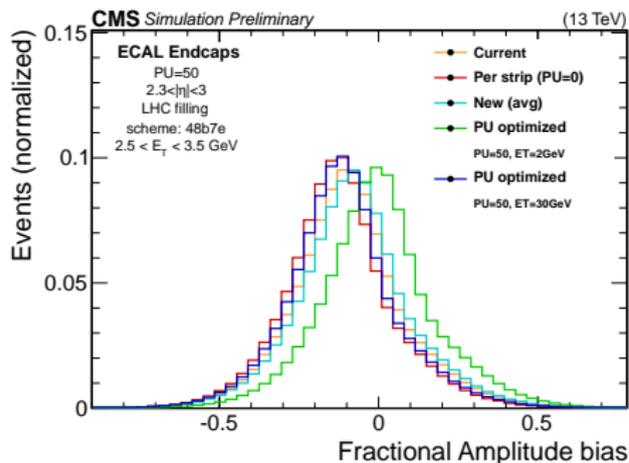
(a) 50 ns weight (2 ADC clocks)



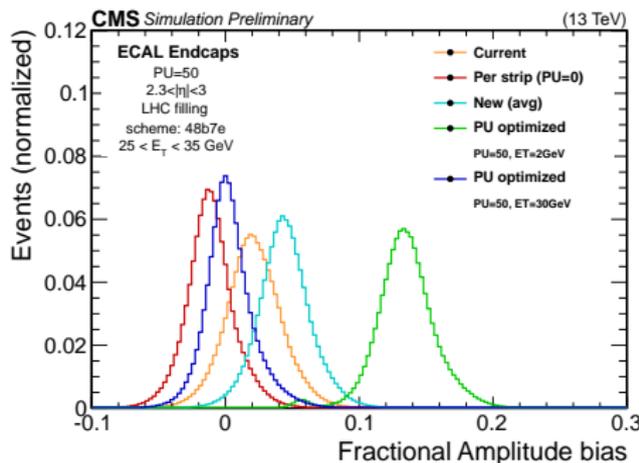
(b) ECAL Waveform

**Figure 11:** At higher PU, the pedestal weight becomes more negative to remove pileup

- When **new weights** are derived, and their resulting bias is compared to that of the current weights, a **reduction** in the average and spread is seen:



(a) Amp bias, for  $\approx 3 \text{ GeV}$  signals

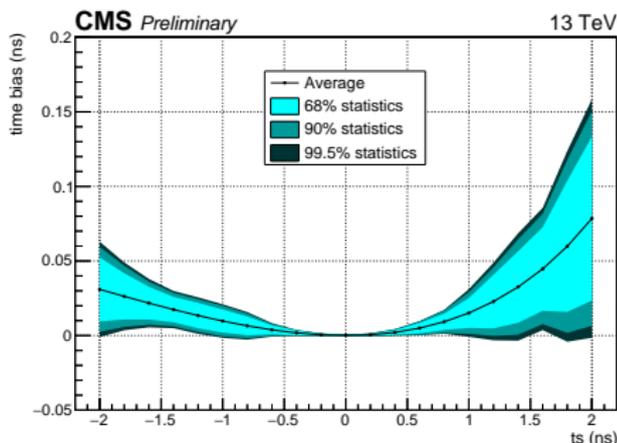


(b) Amp bias, for  $\approx 30 \text{ GeV}$  signals

- Will optimize for 50 PU, need to choose signal energy
- Developing performance metrics, exploring unused features: **6th weight, second set of weights**

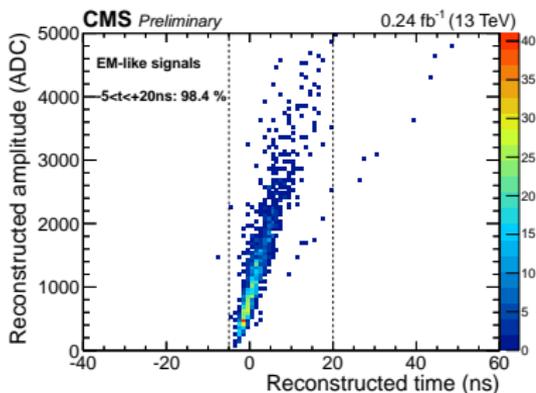
- There is a possibility of using a second, independent, set of weights in the ECAL TP computation.
- We are investigating the use of timing-sensitive weights, which can be derived using the formula shown on slide 6

$$\text{time bias} = ts_{reco} - ts_{true}$$

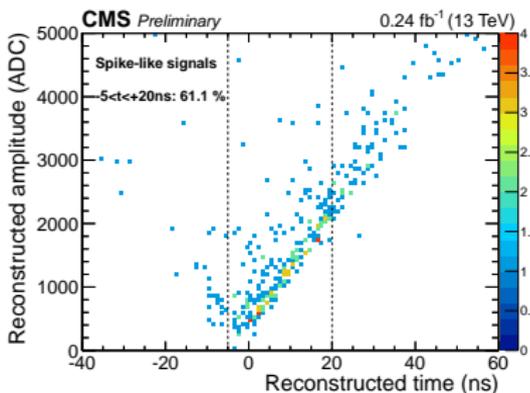


**Figure 13:** Time bias from ideal timing weights applied to September 2018 measured waveforms

- Difference in spike and EM shape seen on slide 10, figure 6
  - Indicates there is a chance of differentiating them using timing weights
- Timing-like weights are shown to differentiate EM shower and Spike signals
- In theory, applying a timing cut at L1 would reduce spike rate
  - **Note: A timing cut is not possible at L1, but this shows the ability of timing weights to differentiate EM showers from spikes**



(a) EM Showers



(b) Spikes

- If timing weights are used to eliminate spikes at L1, it may reduce the rate of spikes at L1:
- It has not yet been shown how a timing cut could be implemented at L1, and what its efficiency would be, but this shows the potential of the timing weights impact

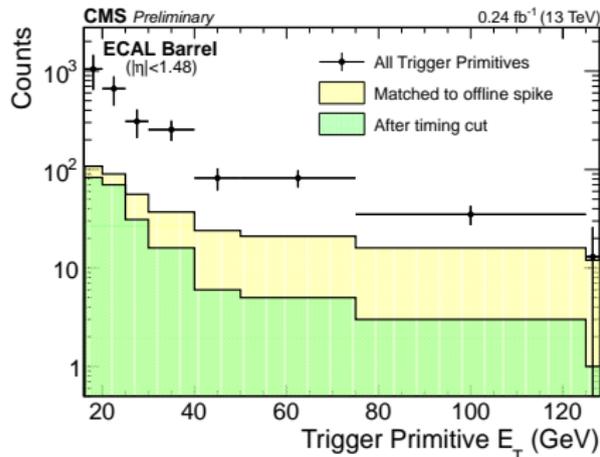


Figure 15: Non prompt spike and EM shower shapes

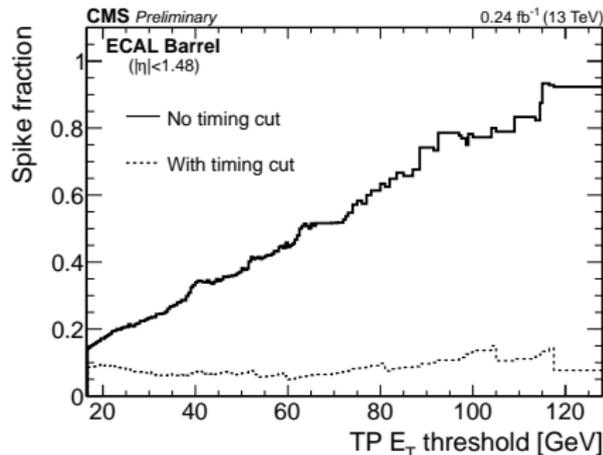


Figure 16: Spike contamination before and after timing cut

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- The **CMS ECAL** is a state-of-the-art electromagnetic calorimeter that operates on one of the largest particle detectors in the world, at the **largest machine** ever built
- During Run 2 of LHC, ECAL had **minimum downtime** and contributed to excellent  $e/\gamma$  Level-1 **trigger efficiency**
- For Run 3, there are possible **algorithm improvements** to be made
  - **Optimized** amplitude weights
  - Using **second set** of weights for spike and/or PU mitigation
- Studies show these may improve ECAL performance
  - These improvements will be tested in the coming months
    - These improvements will be tested in the coming months using a dedicated test setup at CERN
    - The improvements will be applied to Run 2 data and MC simulations to quantify the expected improvements on trigger performance for Run 3
    - Will work with L1 group to see effects on physics performance

Thank You!  
Any questions?



## 5 Backup



# Backup

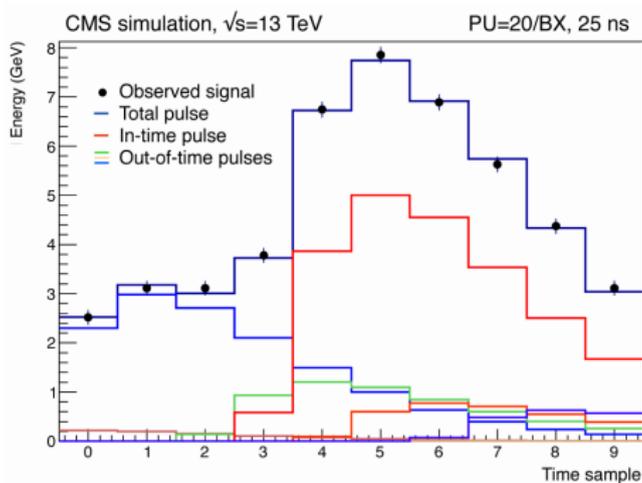
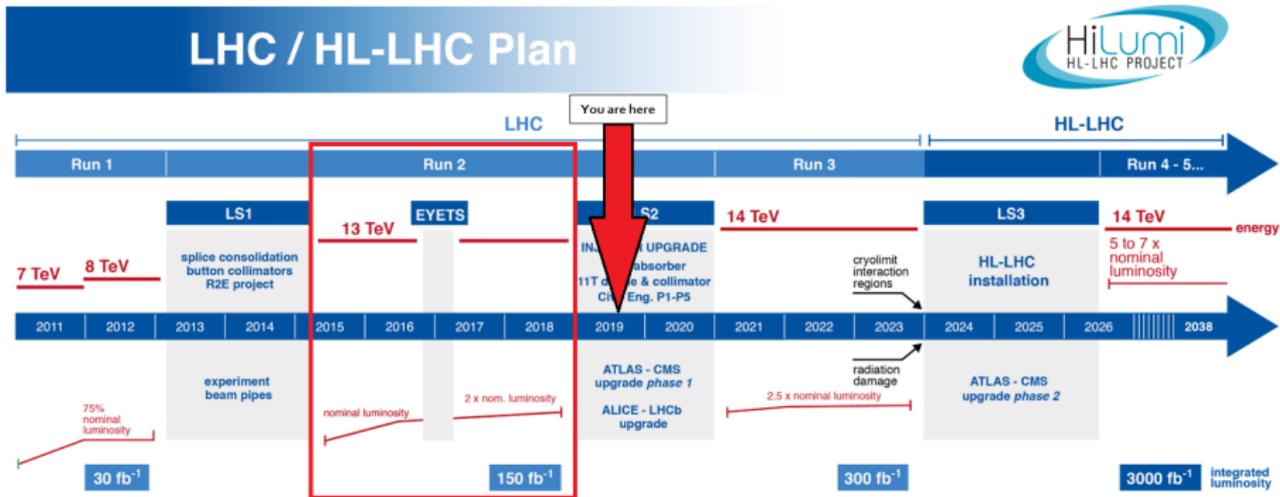
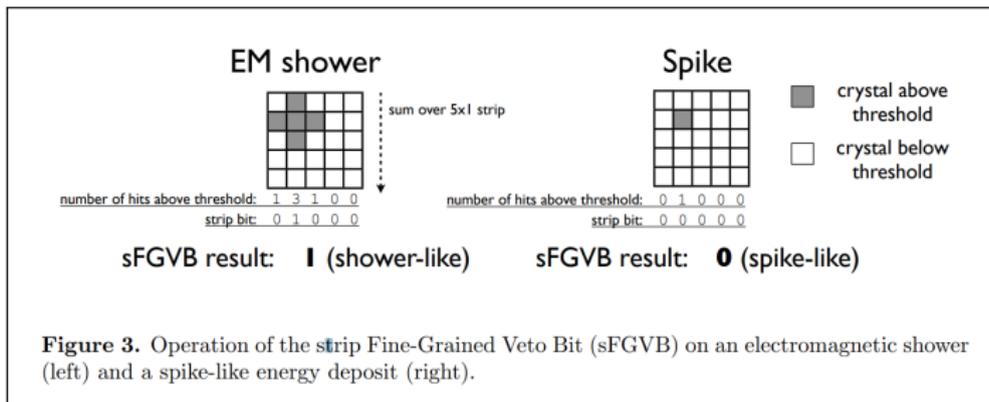


Figure 17: ECAL multifit algorithm used at HLT to identify out of time pulses

- The **Large Hadron Collider** is the **world's largest** particle collider:
  - Circumference: **27 km (17 miles)**
  - Maximum recorded center of mass energy: **13 TeV**
  - Maximum recorded instantaneous Luminosity:  **$2.06 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$**







(a) [D. Petyt, Figure 3]