ECAL Trigger performance in Run 2 and improvements for Run 3

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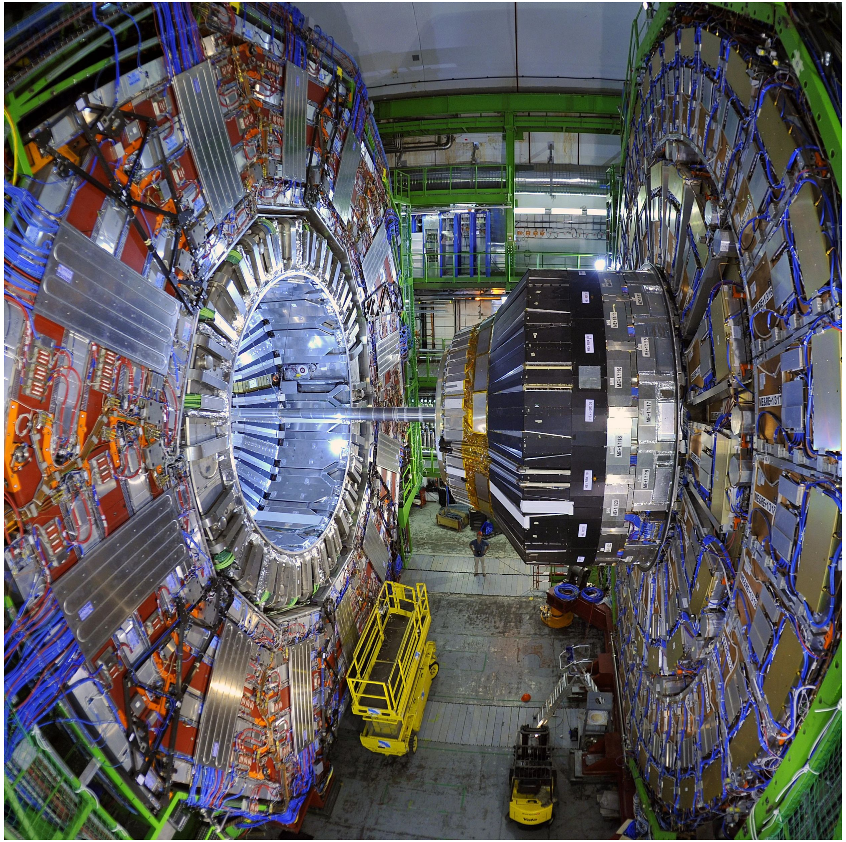
Outline

1. **Introduction**
2. **ECAL trigger in Run 2**:
    - Detector evolution and trigger calibration
    - Anomalous signals suppression
    - Overall performance
3. **Improvements for Run 3:**
    - Amplitude estimation re-optimisation
    - Performance on data and MC
    - Further developments
4. **Conclusions**

CMS detector at LHC and L1 trigger

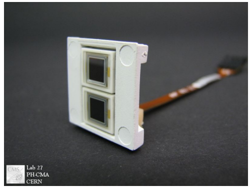
- The **C**ompact **M**uon **S**olenoid is a general purpose detector at **L**arge **H**adron **C**ollider (CERN)
  - Tracking detectors, muon chambers, **electromagnetic** and hadronic **calorimeters** with a 3.8 T magnetic field
- The LHC collides trains of **bunches of protons** at **40 MHZ** in the center of the detector at 13 TeV of center of mass energy.
- The **CMS L1 trigger** uses fast algorithms in custom electronics to select 100 kHz of *interesting* events out of 40 MHz of LHC collisions with a latency of 3.8 μs



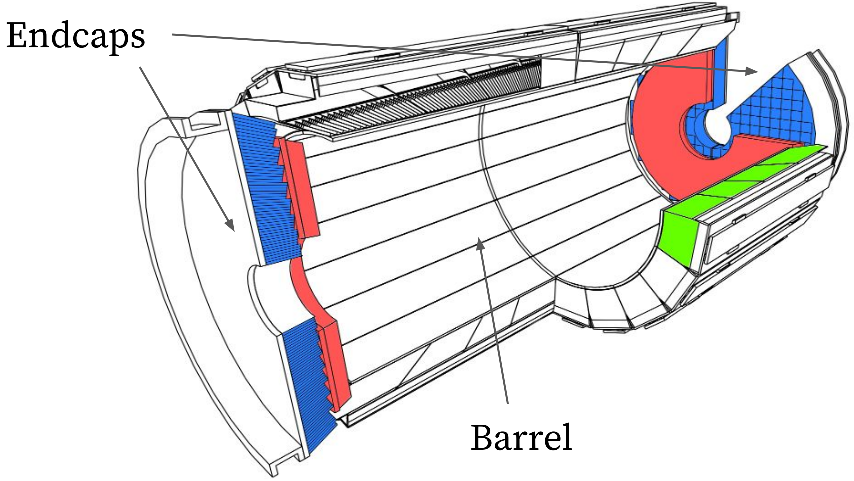
ECAL detector

- The **CMS ECAL** is an homogenous and hermetic calorimeter made of **75,848** scintillating lead tungstate ($PbWO_4$) **crystals**, located inside the CMS solenoid.
- It is divided in **ECAL Barrel EB** (61,200 crystals) up to $|\eta| < 1.48$, and **ECAL Endcaps EE** (7,324 crystals each) reaching $|\eta| < 3$, read out by Avalanche Photo Diodes (APDs) in the EB and Vacuum Photo Triodes (VPTs) in EE.
- ECAL purpose is to measure precisely the energies of the **electrons and photons**, as well as the **EM fraction of jets**

Endcap crystal with VPT

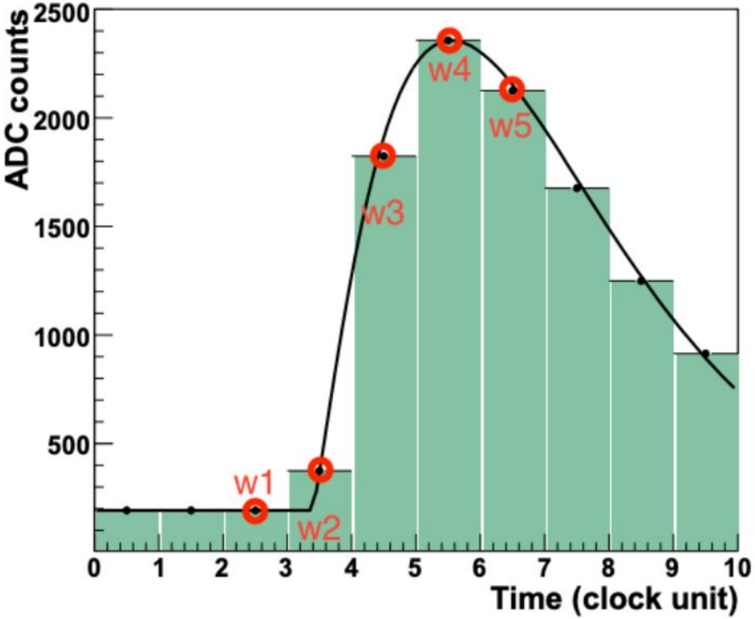


APDs



ECAL Trigger Primitives Generation (TPG)

- ECAL provides **transverse energy sums** (*trigger primitives* or *TPs*) of groups of crystals (25 in EB, 5-15 in EE) to L1 trigger to form **e/ɣ and jet candidates** at **each bunch crossing** (BX)
- **Amplitude reconstruction** and **BX energy assignment** performed on-detector by ASIC chips by applying a **digital filter** (configurable **weights**) on the digitized pulse **for each strip** (5 crystals line)
- The ECAL pulse extends over several 25ns samples: **readout window 10 BX**, **TP weights on 5 samples** both before and after the peak
- A **Strip Fine-Grained Veto Bit** (sFGVB) is computed to flag **anomalous signals** (*spikes*) registered by the electronics.

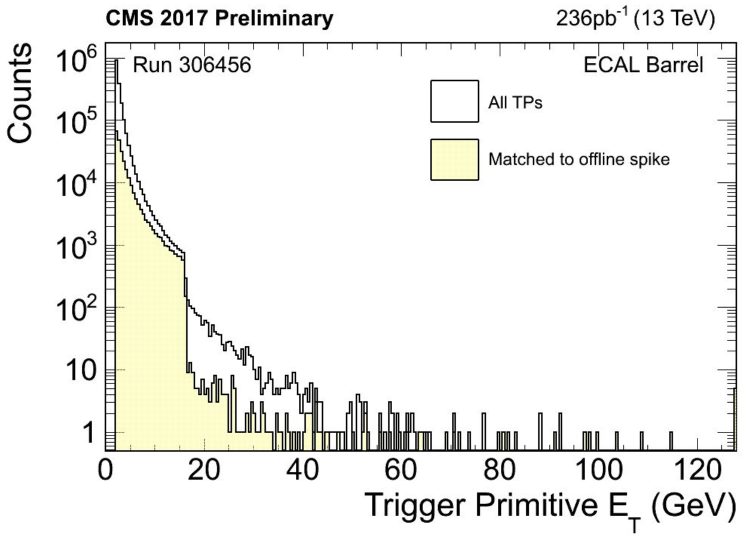


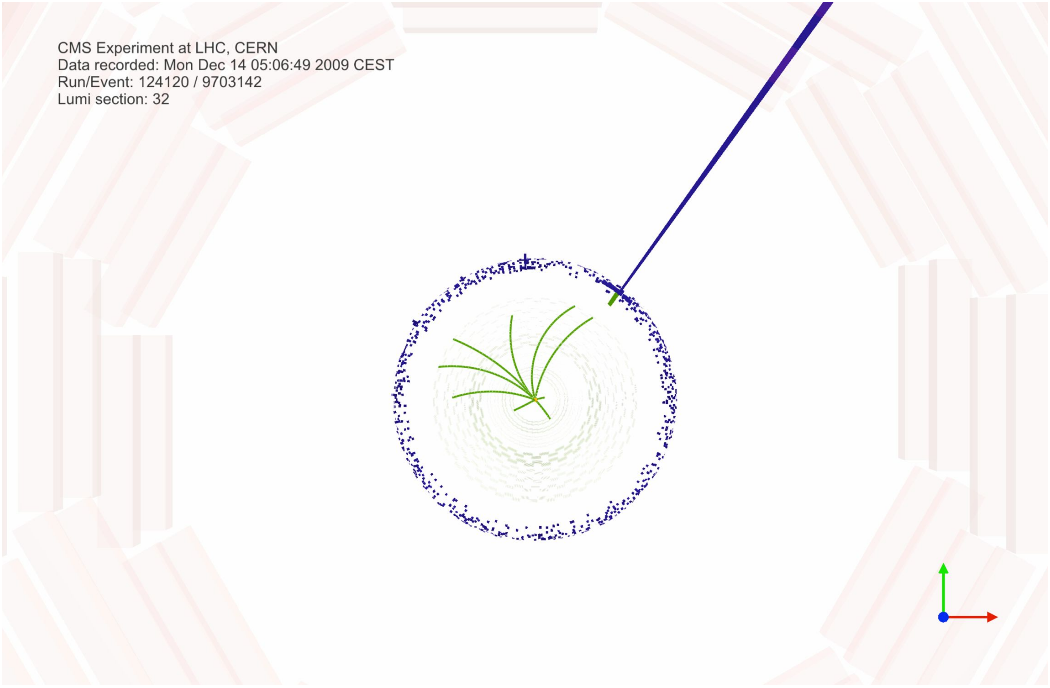
	w1	w2	w3	w4	w5
EE	-0.656250	-0.515625	0.250000	0.515625	0.406250
EB	-0.562500	-0.546875	0.250000	0.484375	0.375000

Current sets of weights for EB and EE

APD anomalous signals (spikes)

- Large signal in a **single crystal** coming from **direct ionization** by hadrons of APD in the barrel.
- They would **saturate the L1 rate** at high ET if not identified and **removed**

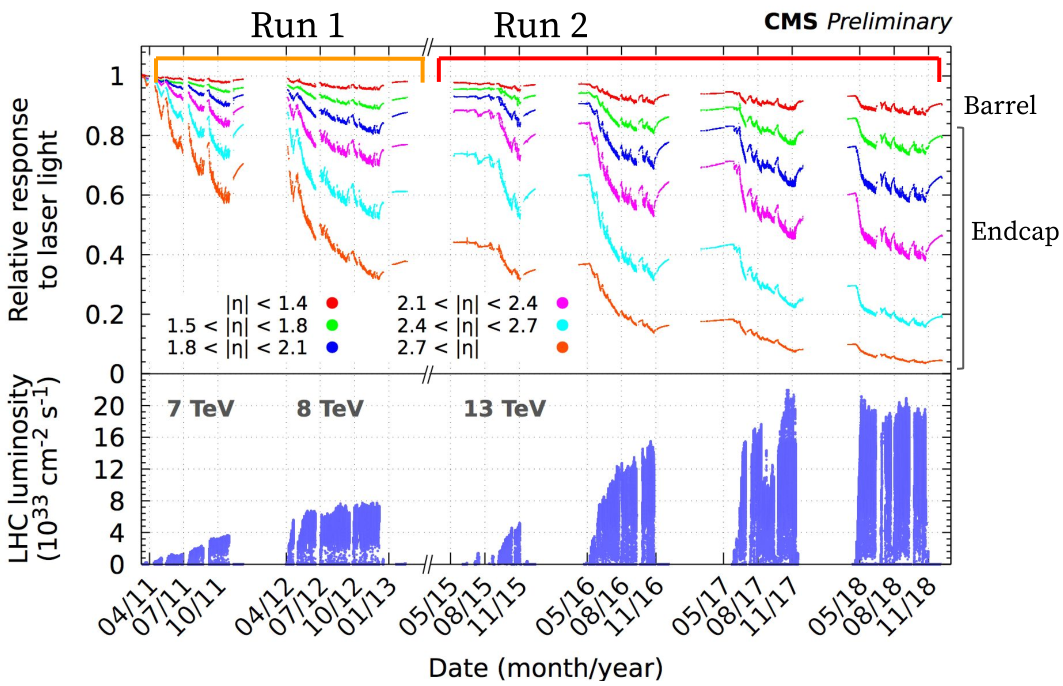




Event display with ECAL *spike*

LHC Run 2

- During **Run 2** of LHC (2015-2018), ~ 160 fb^{-1} of collisions has been collected.
- The **instantaneous luminosity** has increased steadily during Run 2, as well as the mean number of **pileup interactions** (PU) up to < PU > ~ 50 in 2018.
- These have been **challenging data taking conditions** for ECAL:
  - **Larger crystal transparency** loss compared to Run 1
  - **Increase of noise** due to ageing of APD photodetectors
  - More challenging **pulse reconstruction** with increasing out-of-time PU (OOT-PU)



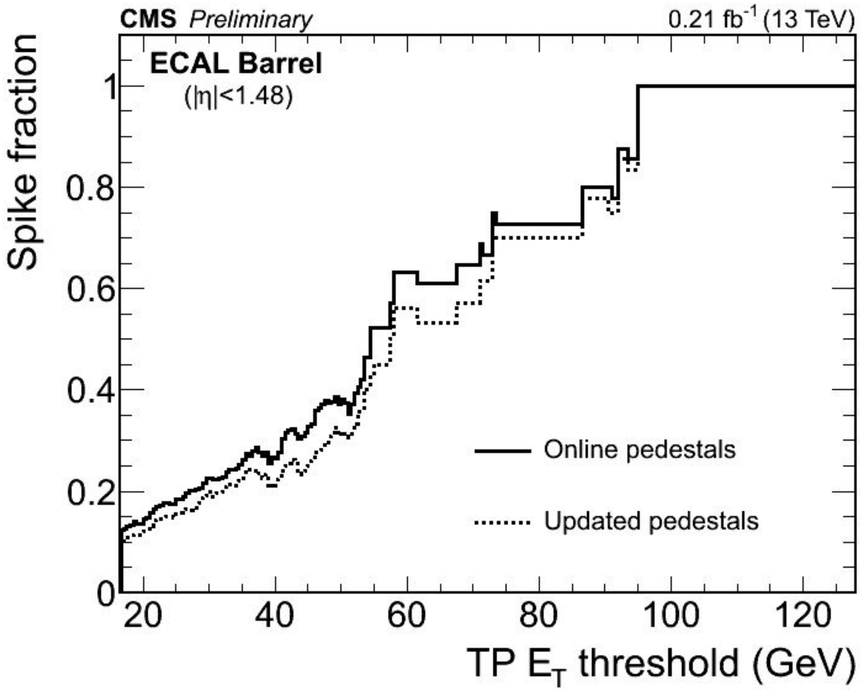
Twice-weekly crystal response corrections needed to maintain stable trigger efficiency over time

ECAL Trigger calibrations

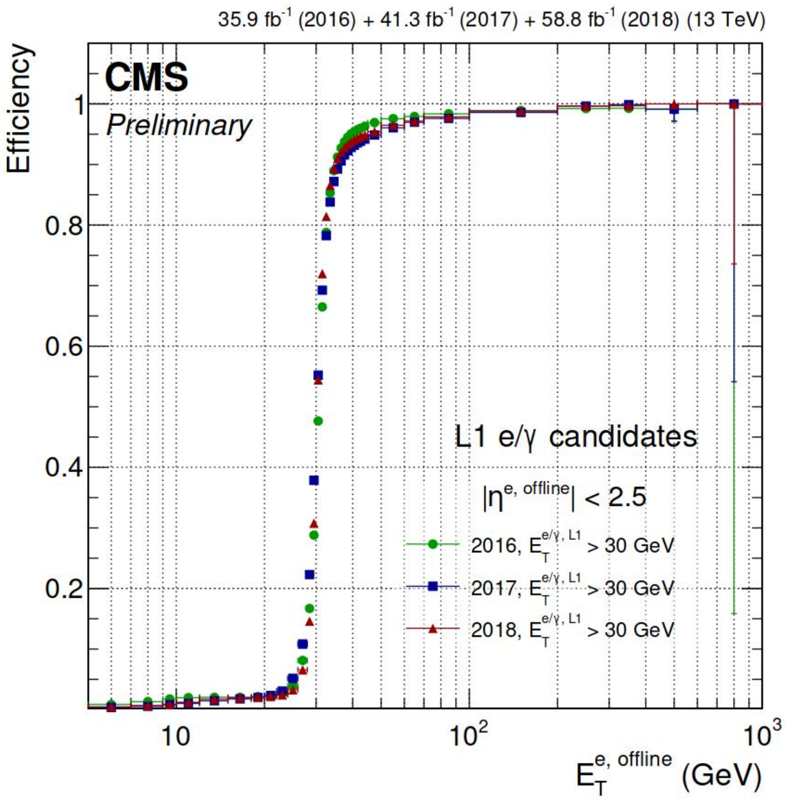
Regular **updates** to trigger primitive **conditions and calibrations** needed to maintain performance during Run 2.

- Spikes are removed at L1 trigger looking for **isolated energy** hits above a certain **threshold**
- Frequent **pedestal updates** needed to reduce as much as possible the fake rate at L1.

E_T threshold	Online pedestals	Updated pedestals
20 GeV	13%	**11%**
30 GeV	22%	**19%**
40 GeV	27%	**21%**
50 GeV	38%	**32%**



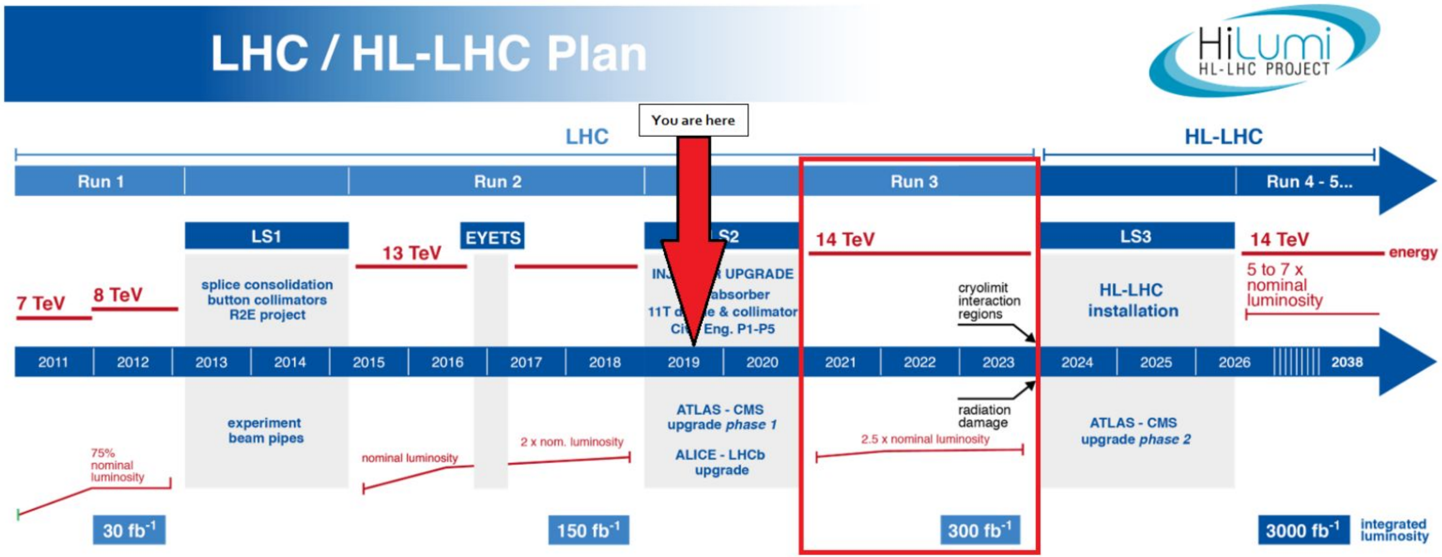
Run 2 performance



- During Run 2, the operational efficiency of ECAL has been better than 99 %.
- Thanks to stable ECAL and HCAL calibrations and detector performance, **CMS maintained excellent e/ɣ trigger efficiency at L1** during Run 2.

LHC Run 3

- Run 3 of the LHC from 2021 to 2023
- An integrated luminosity of **300 fb^{-1}** is expected → **Larger loss of transparency** at high η
- **< PU > ~ 55-60** is expected → Larger **out-of-time PU** pulse contamination



ECAL Trigger generation optimisation for Run 3

- Current ECAL **TPG weights** (**1 set** for EB, **1 set** for EE) computed from test beam (2003) data using **undamaged crystals**
- **No more optimal** especially at high η because of radiation-induced changes to pulse shapes:
  - **Large bias in energy estimate**
- The re-optimisation of weights is proceeding by steps:
  - Recompute weights using **pulse shapes measured from data** during 2018
  - Increase weights **granularity**: optimised for **each strip** separately instead of **whole EB/EE**

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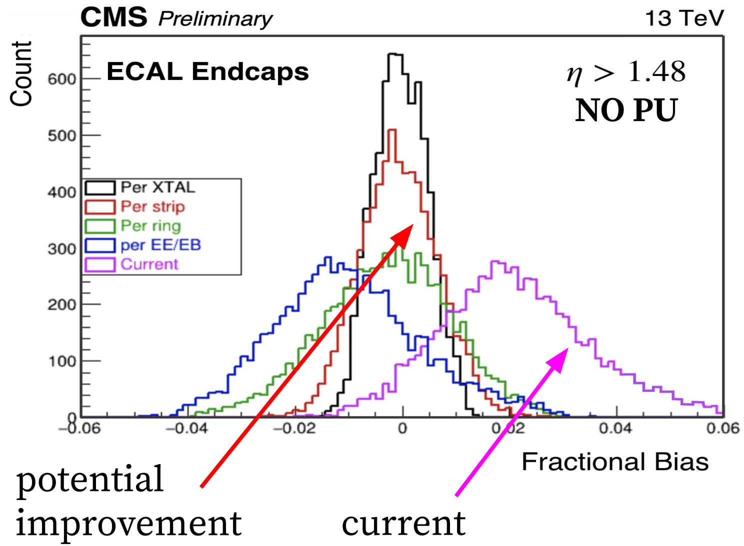
TPs bias spread and average improves a lot

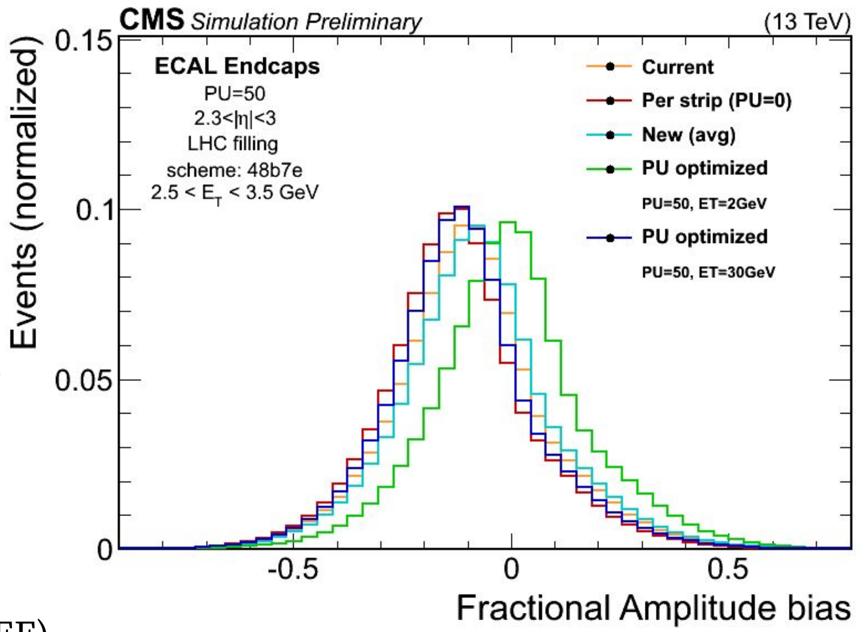


Fractional **bias** $= < E_{tp}/E_{true} > -1$

Fractional **spread** (TP resolution) $= \dfrac{\mathrm{RMS}\left(E_{tp}/E_{true}\right)}{< E_{tp}/E_{true} >}$

Weights optimisation for out-of-time PU

- OOT PU from LHC collisions trains **distort** the ECAL pulse
- Developed **standalone MC** to simulate **OOT PU effects:**
  - **simulate** PU pulses → **optimize** weights for distorted pulse → **extract best** weights using many events
- The optimisation depends on the relative magnitude of signal amplitude and PU level
- **PU optimised weights can further reduce TP energy bias and spread**

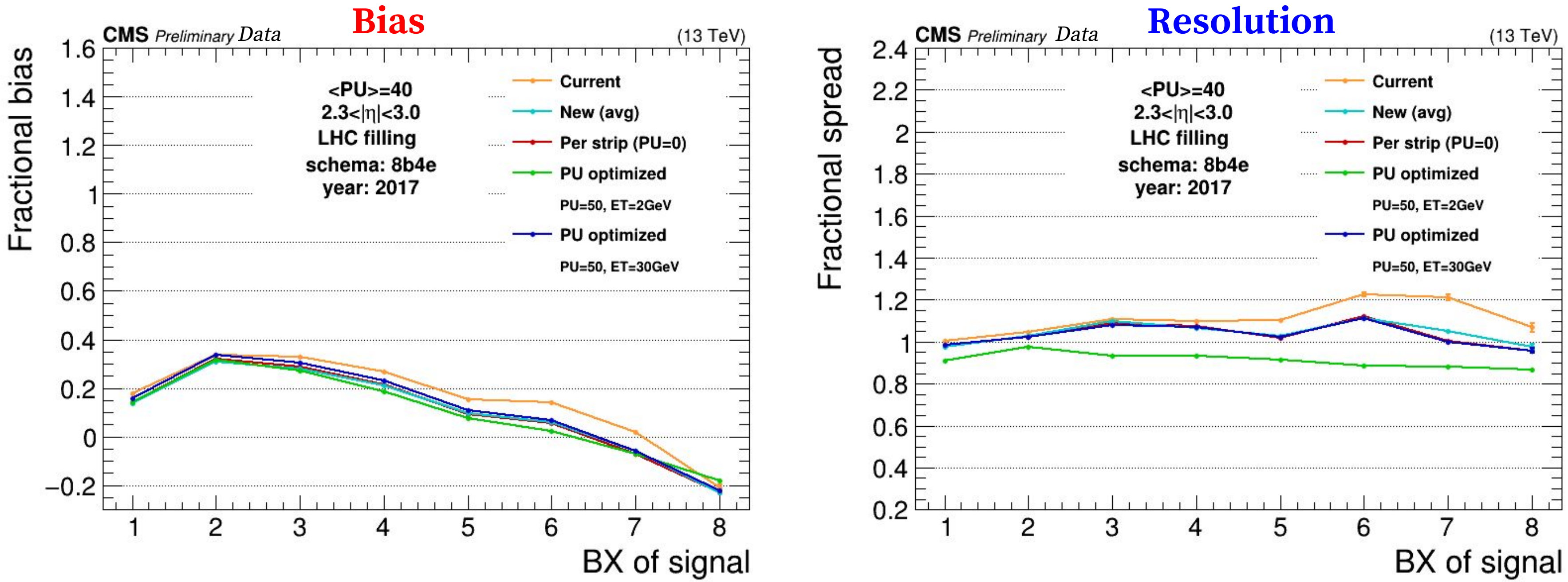


- Several **sets of weights** have been compared:
  - **Current**: existing weights (1 set EB, 1 EE)
  - **PU0 new avg**: updated average weights (1 set EB, 1 EE)
  - **PU0**: updated per-strip weights: using only signal pulse shape
  - **PU50 S2**: updated per-strip weights - optimised for PU=50 and E_T=2 GeV signals
  - **PU50 S30**: updated per-strip weights - optimised for PU=50 and E_T=30 GeV signals

New weights performance evaluation

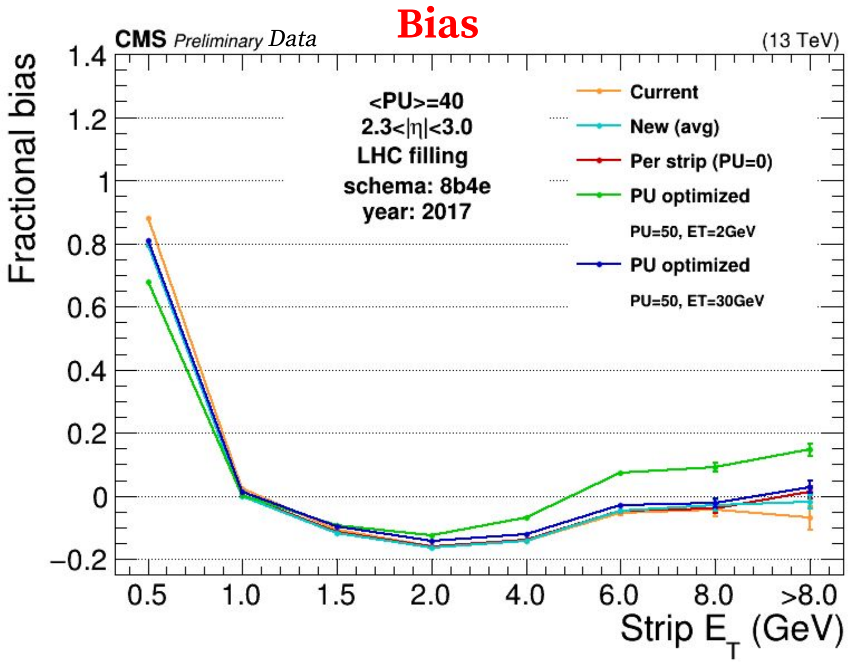
- The performance of the new sets of weights is evaluated in terms of **bias and resolution of the TPs**
- Studied bias and resolution of TPs by **BX position** along the train and by **signal E_T bins**
- Used events from **2017 and 2018 CMS Data** with different LHC filling schemes:
    - The pulse distortion depends on the **position of the signal** within the LHC bunch train
    - Different LHC schema have **different effects on TPs**
    - **8b4e scheme**, with continuously varying OOT PU, is most challenging for ECAL TPs
- Improving the weights by optimising for PU will improve the **average behaviour**, but cannot account for **pulse-to-pulse** and **BX-to-BX** distortion

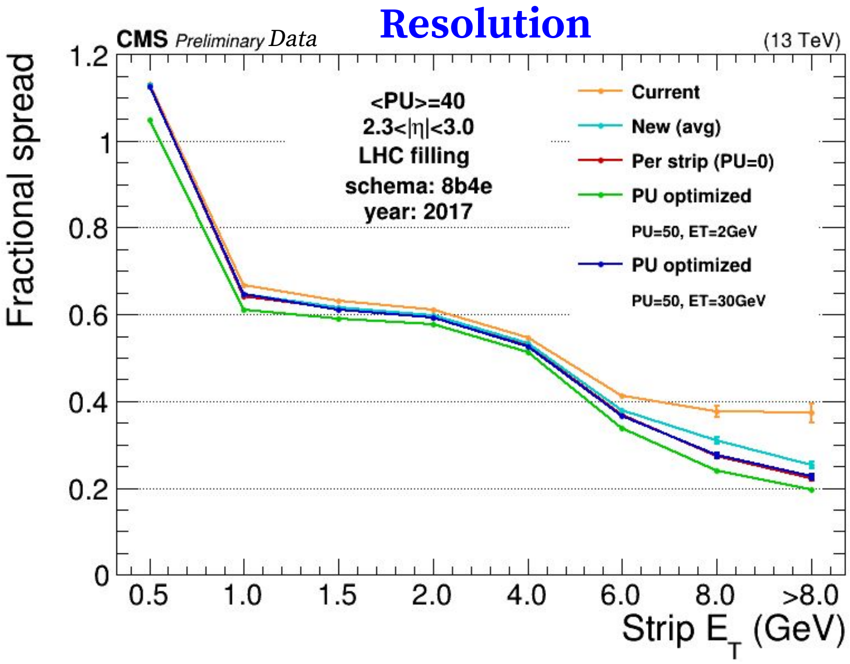
TPs performance by BX position



- There is a **strong bunch position dependence** to the amplitude bias intrinsic to the method
- Using **PU optimised weights** improves the **TP resolution** and **reduces variations** along the LHC train

TPs performance by strip E_T

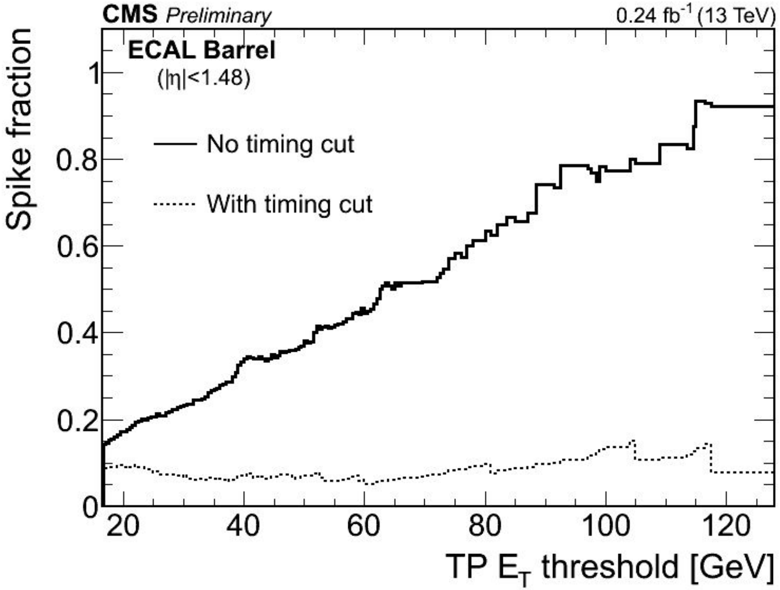




- There is a **strong E_T dependence** to the amplitude bias and resolution, especially at low energy TPs.
- There are **measurable resolution improvements** observed when using **PU optimised weights**

Further developments

- Not all the FENIX features have been used:
  - **6 weights** available: 5 used until now
  - **2 parallel filter + peak finder** blocks available: 1 used until now
- Potential improvements are **under study**
  - **Pulse timing** estimation:
    - potential to improve **spike rejection at L1** with a simple timing cut
    - **not yet understood** if possible with current electronics
  - The **interplay of the 2 sets** of filters is being explored to understand what is possible in hardware
- We are testing new features directly on the **test bench ECAL DAQ** electronics in 904 Lab @CERN



Offline simulation of best case scenario

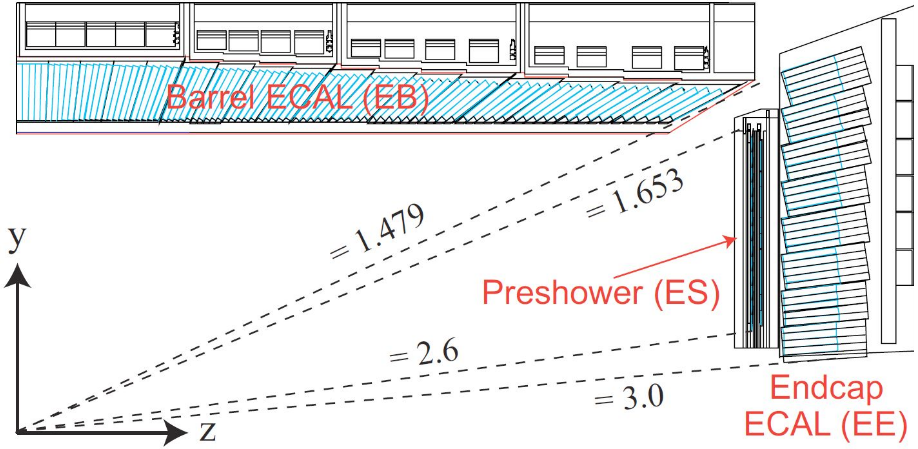
Conclusions

- **ECAL Trigger Run 2 performance:**
  - **Challenging** data taking conditions: high luminosity and PU
  - Followed **detector evolution** to maintain stable trigger efficiencies and rates
  - Minimum downtime and **excellent e/ɣ Level-1 trigger efficiency**
- **Improvements for Run 3:**
  - Plan to **deploy optimised amplitude weights** to account for larger radiation damage and higher PU
  - **Testing new features** to improve **OOT PU discrimination** and **spike rejection**:
    - Tests ongoing on ECAL electronics
    - The potential improvements will be quantified using data and MC before deciding on final implementation

Thanks for your attention

Backup

ECAL Geometry in CMS detector



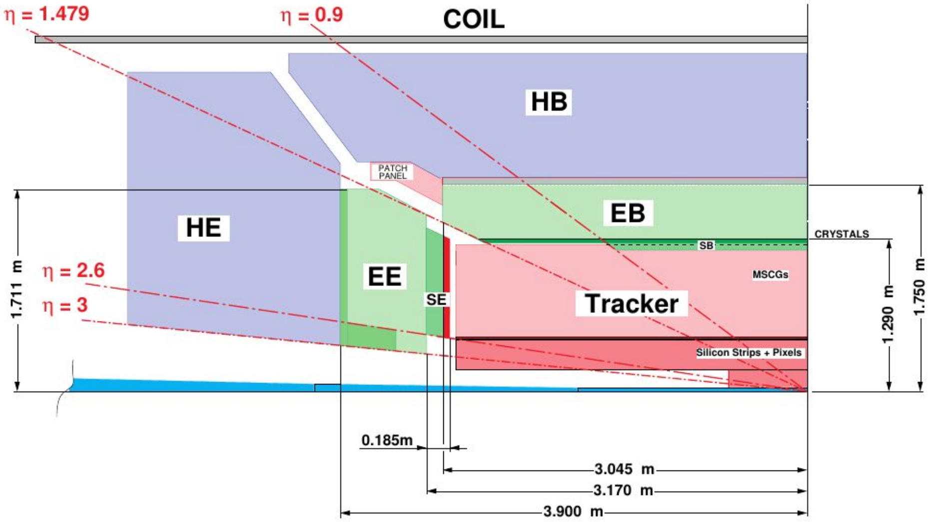
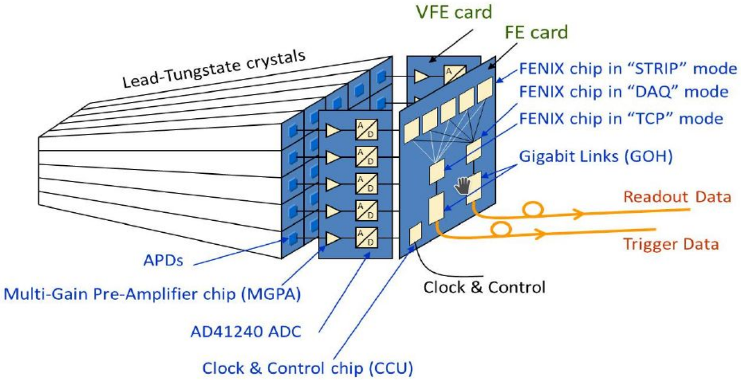
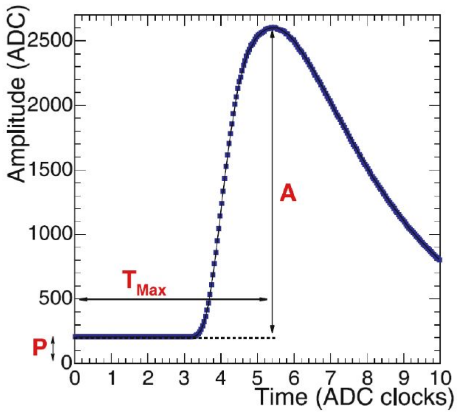


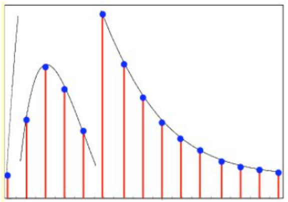
Fig. 1.2: Schematic view of one quadrant of the calorimetry and tracking system.

ECAL on-detector electronics



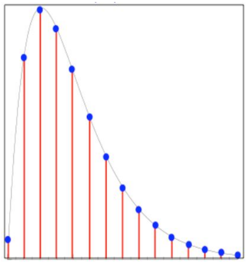


Strip waw samples



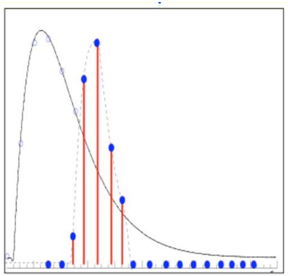
Linealiser, calibration, compute $\mathbf{E_T}$

Strip pulse



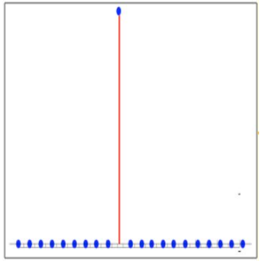
Digital filter (**weights**)

Filtered pulse



Peak finder, assign **BX**

Strip E_T



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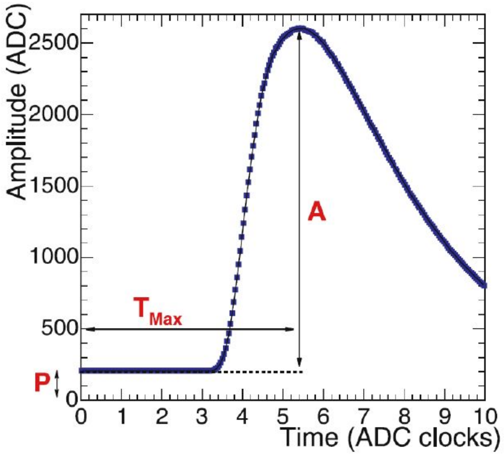
Amplitude weights derivation

- Amplitude weights can be derived for a given waveform
- This is sone by a χ^2 minimization which takes in a waveform and noise correlation matrix. [CMSNOTE2006/037]



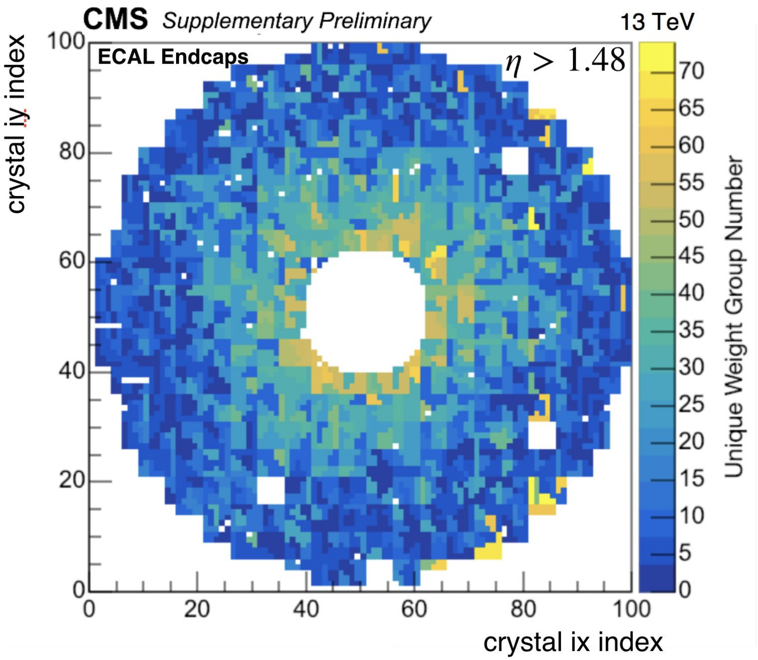
Equation for pedestal subtracting weights, assuming no noise correlation between samples

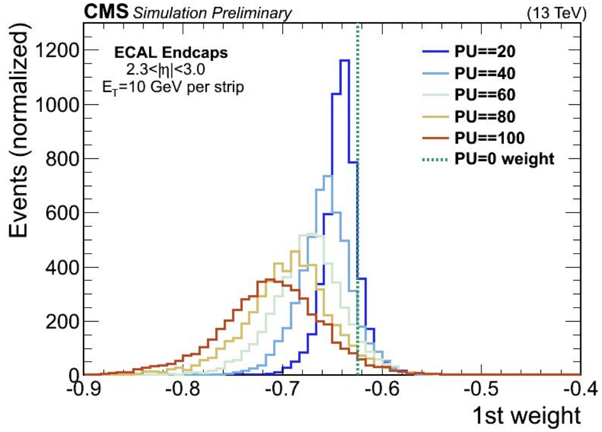
$$W_{A,i} = \frac{f_i - \frac{\sum_j^N f_j}{N}}{\sum_j^N f_j^2 - \frac{(\sum_j^N)^2}{N}}$$

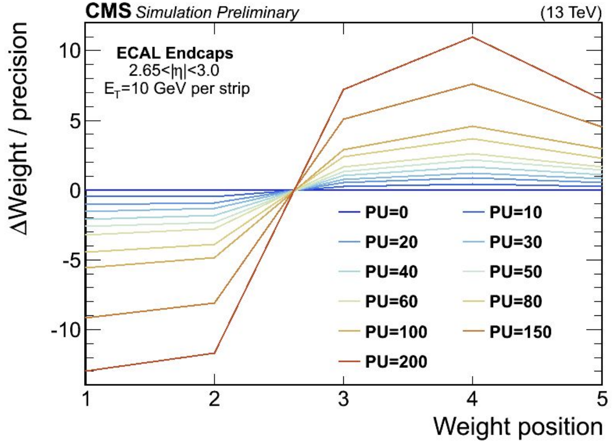
	w1	w2	w3	w4	w5
EE	-0.656250	-0.515625	0.250000	0.515625	0.406250
EB	-0.562500	-0.546875	0.250000	0.484375	0.375000

Current weights

PU optimised weights

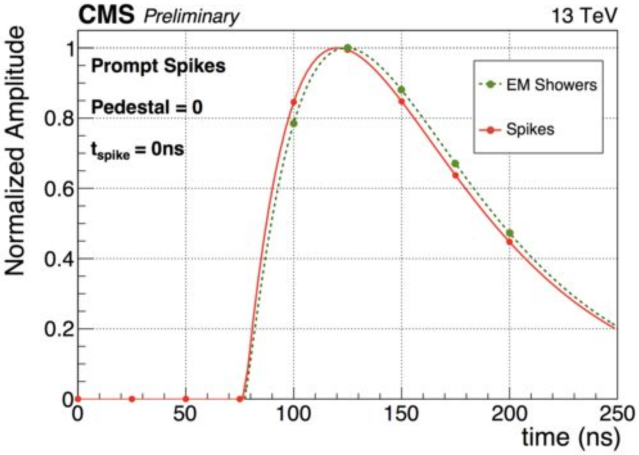


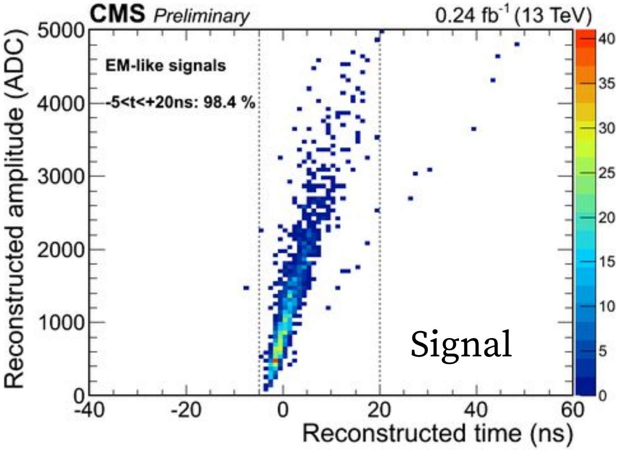


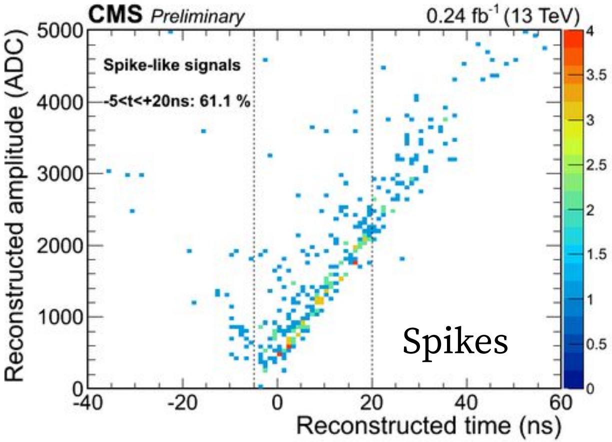


Timing weights for spikes discrimination

- FENIX weights can be optimized to **estimate timing** of the pulses
- **Spikes** and EM shower pulses have small **timing difference**
- Apply a timing cut would have a great impact on **spike discrimination**
- **Not yet understood if possible** to implement this strategy in FENIX

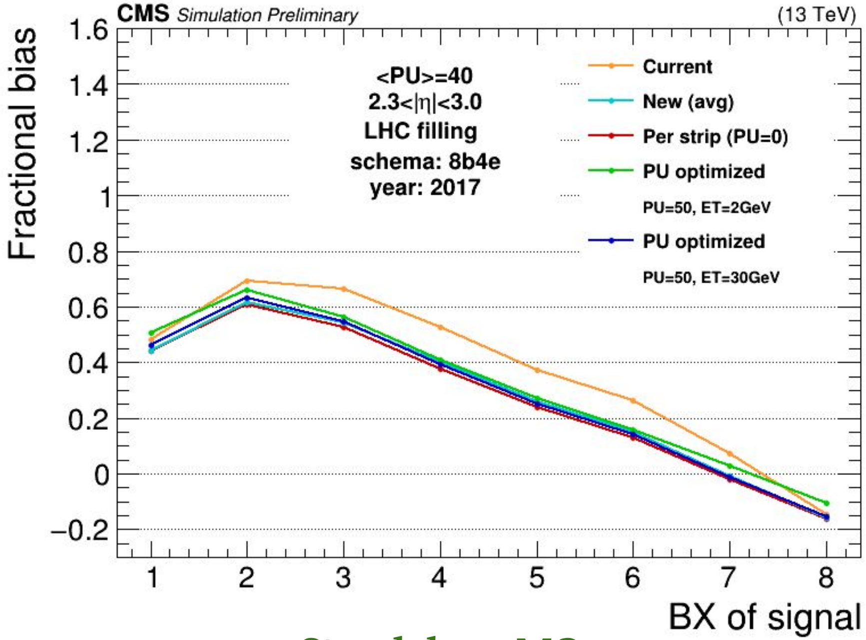




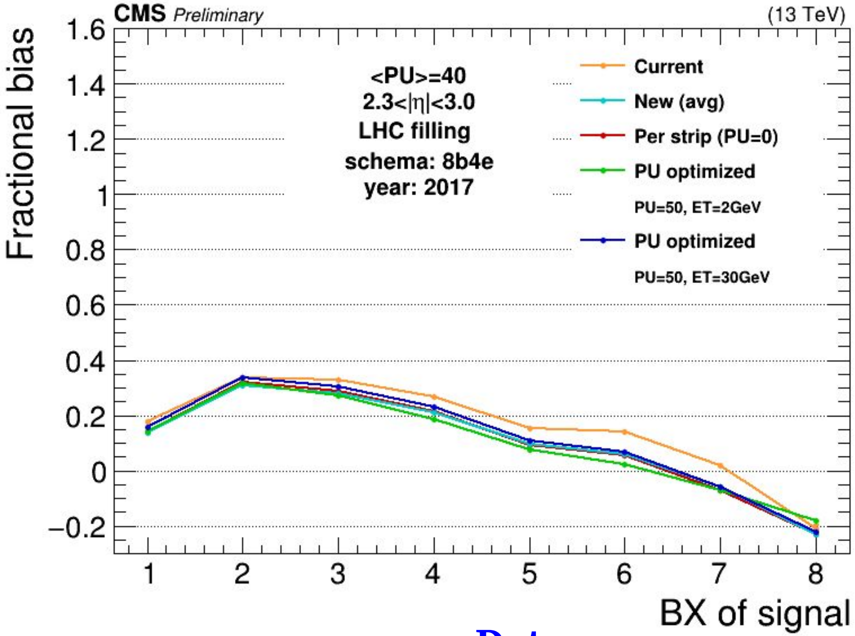


Data / MC comparison, bias by BX

Comparison of the performance of new weights on **TP bias** along the train, in standalone MC and data



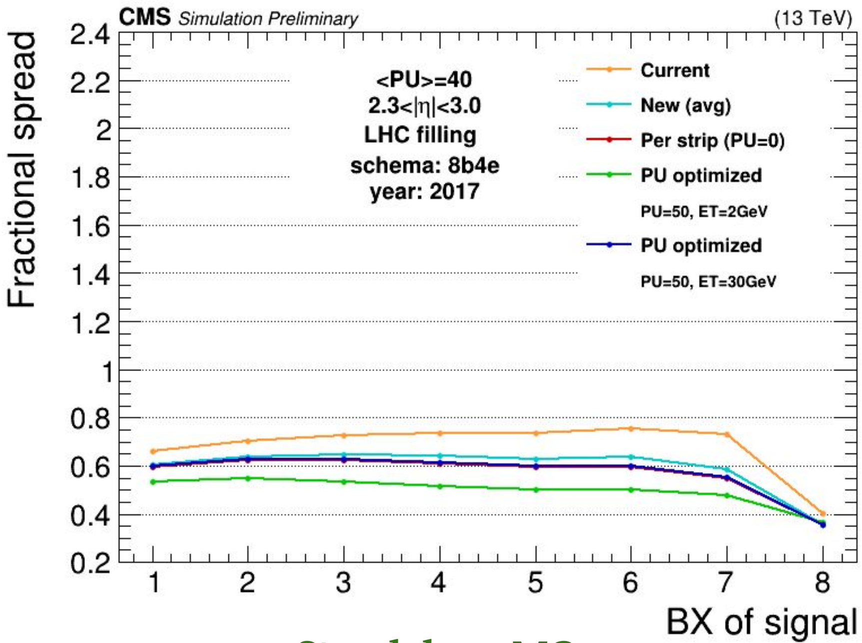
Standalone MC



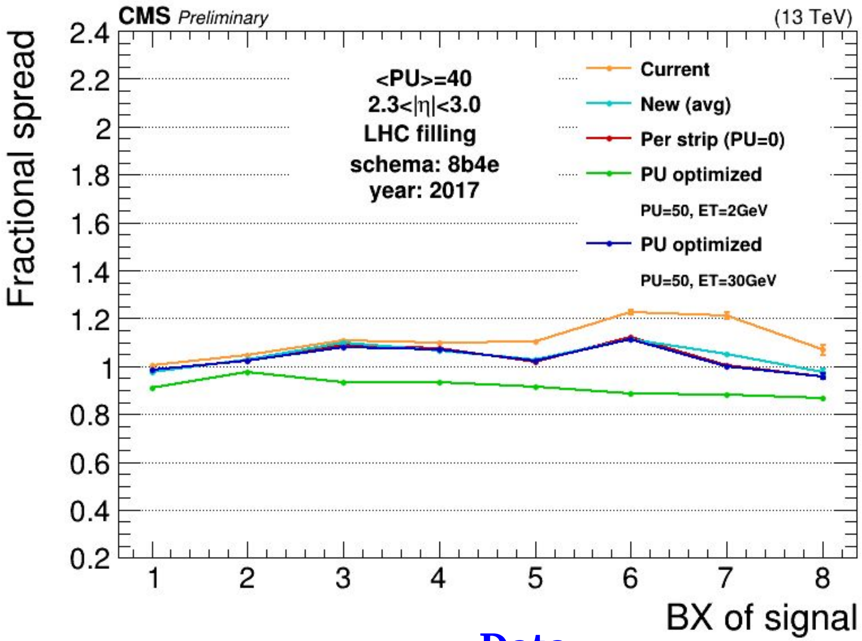
Data

Data / MC comparison, spread by BX

Comparison of the performance of new weights on **TP resolution** along the train in standalone MC and data



Standalone MC



Data