CMS ECAL L1 Trigger: Rejection of 'Spike' Signals and Effects on e/γ Candidates

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14 December 2023

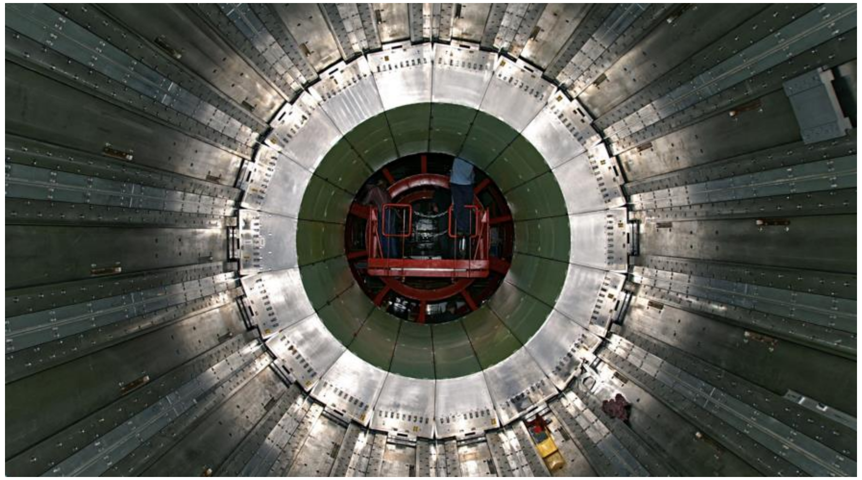
CMS Electromagnetic Calorimeter (ECAL):

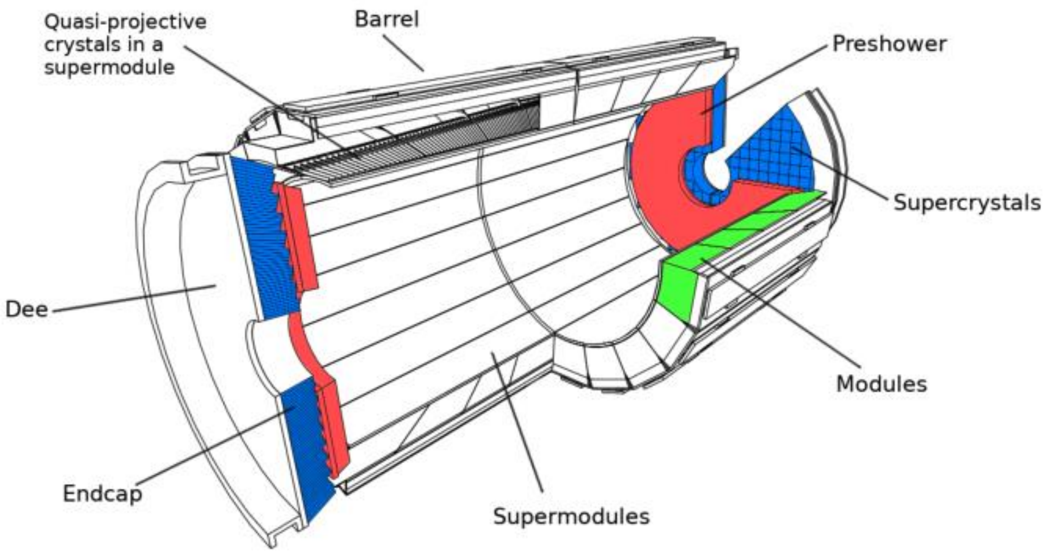
- electromagnetic calorimeter (CMS) is made up of the **EB** (ECAL Barrel) and the **EE** (ECAL Endcaps), consisting of 75,848 Lead Tungstate Crystals.

- The EB has 61,200 crystals and each EE has 7,324 crystals.

- Crystals are glued to either Avalanche Photodiodes (APDs) or Vacuum Phototriodes (VPDs) to convert the scintillation signal to an electric signal.

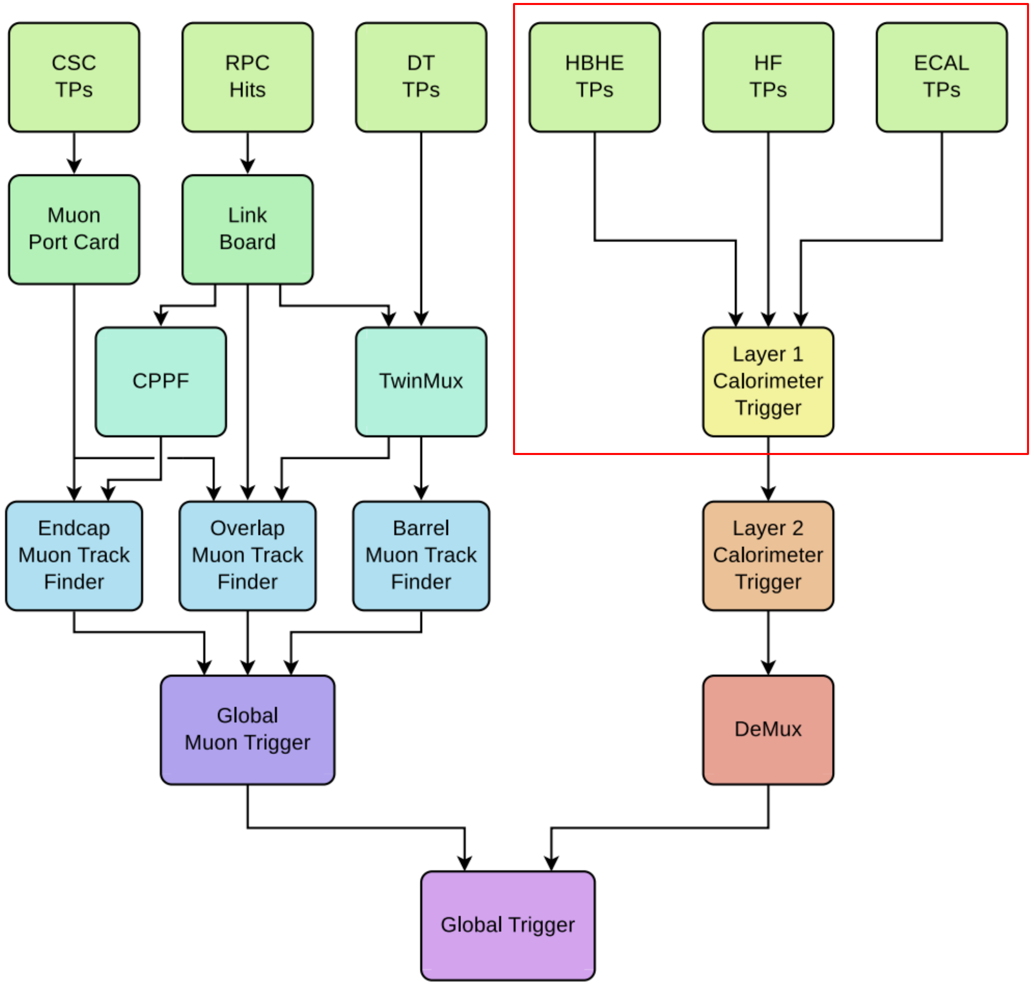
- CMS ECAL is used to measure precisely the energy sums of electrons, photons, taus, and jets.





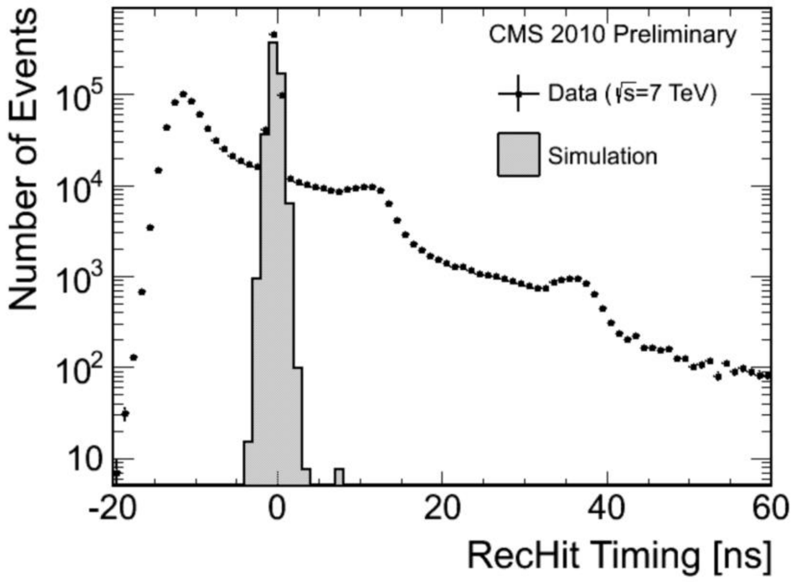
CMS ECAL: L1 Trigger

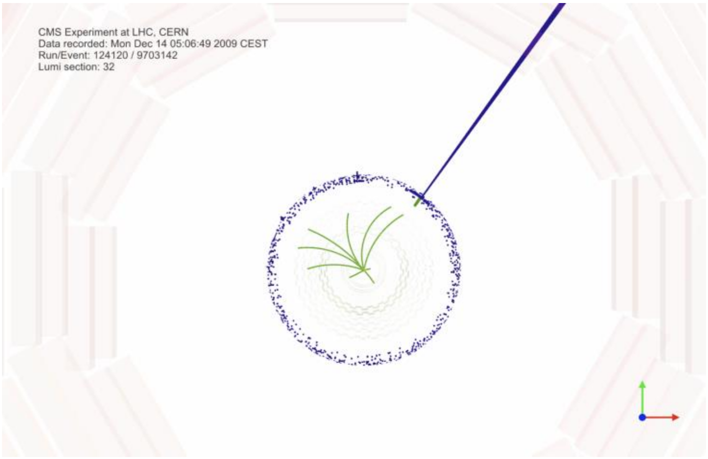
- The L1 Trigger is the first CMS **event selection system** and is hardware-based.
- The output rate of the L1 Trigger **110 kHz**.
- The ECAL trigger sends energy sums to the CMS L1 Trigger at a rate of **40 MHz**.
- Approximately 0.25% of events are saved for later analysis.
- The L1 Trigger output quantities are global and missing E_T sums for **electrons**, **photons**, taus, and jets.



Spikes

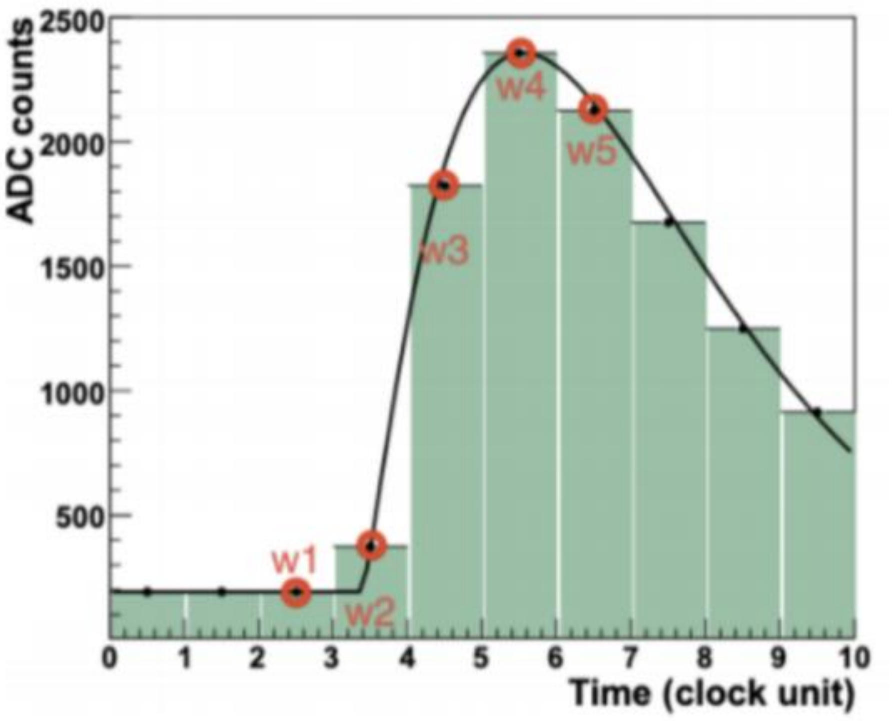
- **In-time** events occur when a particle collides with the crystal, causing light scintillation, which is converted to an electronic pulse by the APD.
- An ECAL **spike** occur when directly collides with APDs.
- Spikes are **large amplitude signals** which if untreated, saturate the bandwidth of the L1-Trigger of CMS.
- Spikes can pass trigger threshold and signal CMS readout, resulting in **uncalibrated energy sums**.
- Spikes mimic **isolated energy deposits** and are **out-of-time**. Both properties are used to reject spikes offline.
- Such out-of-time events will produce a pulse peaking **later** in the window with a **larger** summed E_T.





EVEN vs ODD Weights

- The ECAL signal amplitude is reconstructed using a set of weights (called the **EVEN** weights).
- A second set of **ODD** weights, along with the EVEN weights, can be used to optimize signal acceptance vs spike rejection.
- The figure is an illustration of an **ECAL pulse** with labeled weights. S_i are the incoming digitalized samples and w_i are a set of 5 weights.
- The EVEN weights are currently applied to all data taken with the CMS ECAL. The ODD weights have not been used.
- The current L1 spike killer uses only the **isolation**, we now want to exploit the **timing difference** to improve spike rejection at the L1 Trigger level.

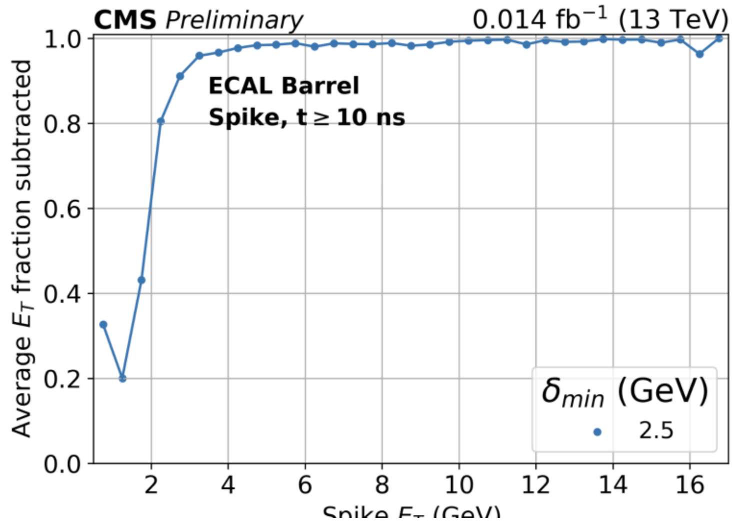


$$E_T = \sum_{i=1}^{5} S_i \times w_i$$

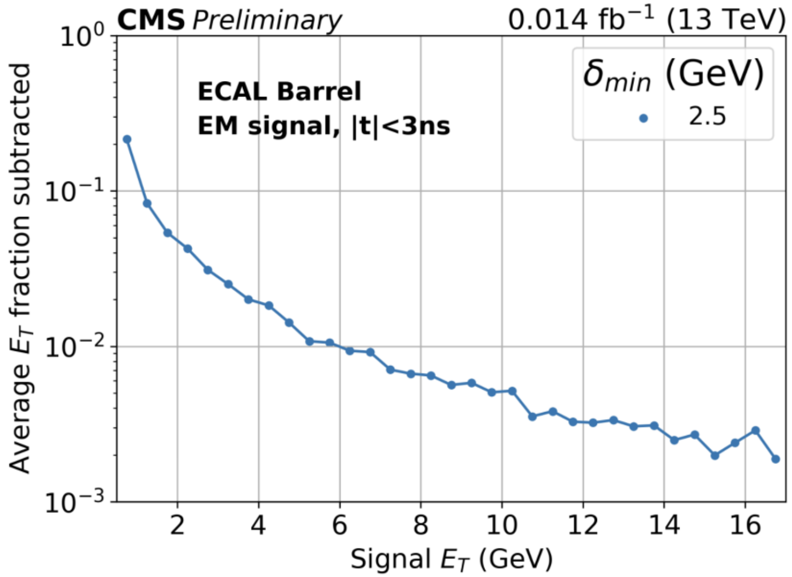
ODD Effect on TP Energies (for EM and Spike Signals)

- Plot A displays the fraction of spike energy removed by the ODD weights.
  - Spikes are selected by requiring pulses are **out-of-time** and that the energy spread between crystals is consistent with that of a **spike**.
- Plot B displays the fraction of EM signal energy removed by the ODD weights.
  - EM signals are selected by requiring that the pulses are **in-time** and that the energy spread between crystals is consistent with that of an **EM shower.**
- With certain E_T cuts, the ODD weights can become quite effective as a spike killer. (Below 1 GeV, noise and out-of-time pileup may make up a large fraction of the total energy)

(a)

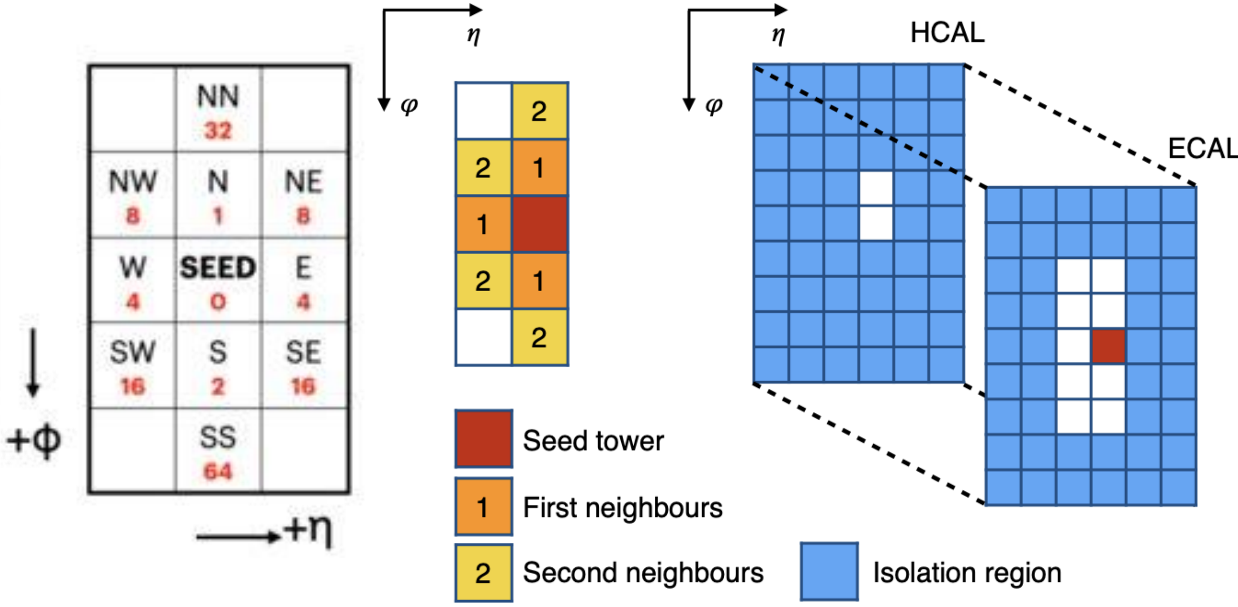


(b)



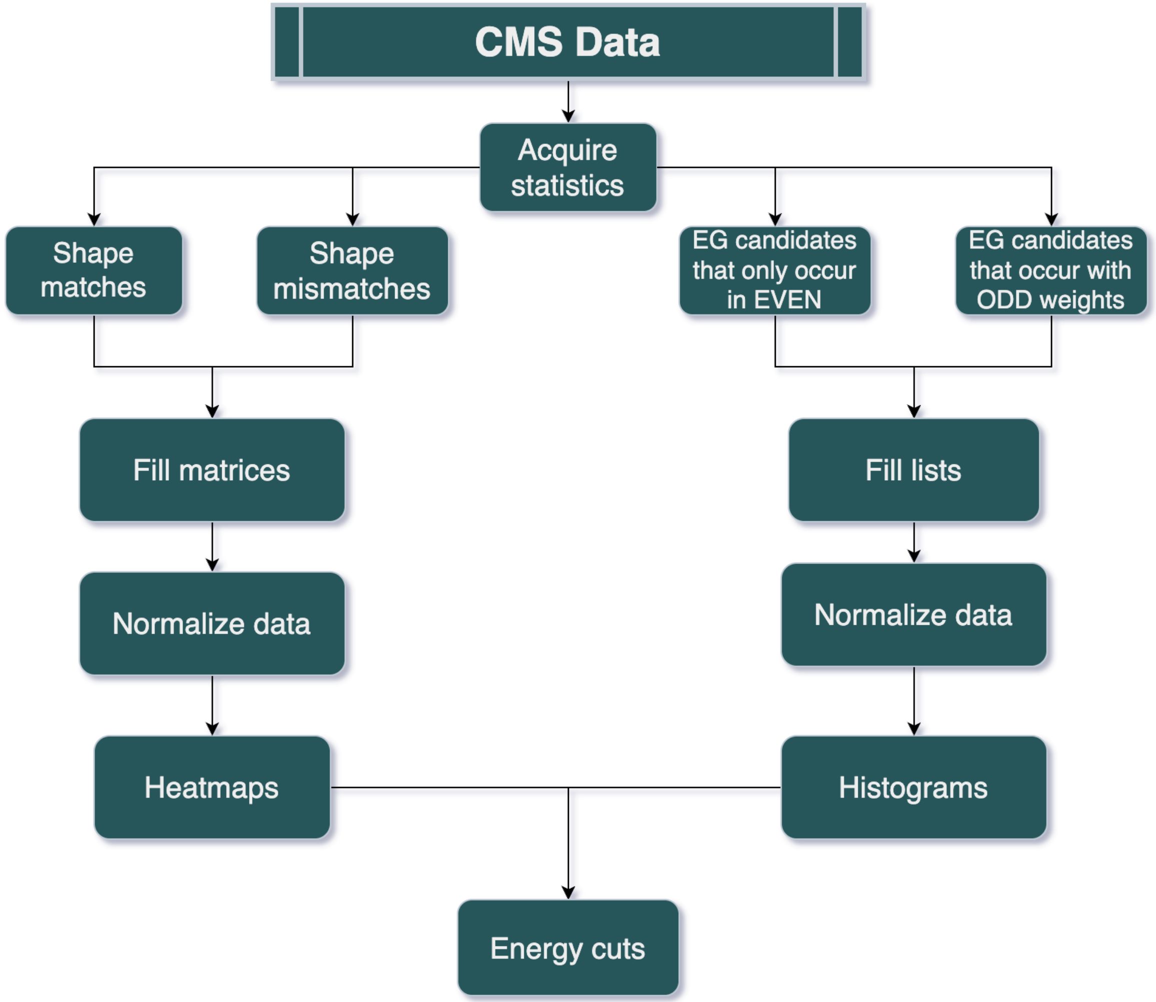
Impact on L1EG Candidates

- A L1 e/γ candidate is formed by **clustering neighboring towers** if they are linked to a seed tower. A candidate is considered to be **isolated** if the energy in the isolated (blue) region is smaller than a given value.
- Implementing the ODD weights can impact the reconstruction L1 object candidates (electrons/photons, taus, and jets).
- ODD weights can **suppress** the energy of low energy TPs.
- Parameters such as **shower shape** and **energy** can differ when emulating the L1 objects with the ODD weights either on or off.



Analysis Techniques

- We use real CMS data and are re-emulating the ECAL TPs and L1 objects with the ODD weights active.
- Use of dictionaries and parallel processing in-order-to efficiently analyze large data sets.
- Created and filled matrices with parameters of interest in order to acquire statistics migration between the EVEN and EVEN + ODD weights.
- Converts lists into sets and performing a set union to analyze the results from multiple ntuples.
- Normalized per parameter column to observe probability distribution per specific value.
- Create heat maps/histograms to observe the migration of specific parameters



Results (Thus far)

- There are four categories for L1 EG candidates:
  1. Match in energy.
  2. Do not match in energy.
  3. L1 EG object **disappears** when ODD weights are applied.
  4. L1 EG object **appears** when ODD weights are applied.

- A majority of the objects fall into the first category, but a significant enough amount occur in the others to warrant further investigation.

- L1 EG objects disappearing appears to be a **low energy** phenomenon, as expected.

- L1 EG objects appearing appears to be a **higher energy** phenomenon.

Further Investigations

- Loss of energy may impact energy scale potentially impacting trigger efficiency and energy resolution.

- Analysis on-going to understand impact on L1 EG objects when ODD weights are used to reject spikes.

- Loss of events may affect trigger efficiency.

- Investigating how the algorithms reconstruct objects.

- Investigating object migration with energy cuts.

Summary

- A numerical optimization returns weights optimized for realistic signal and spike energies/times.
- The ODD weights is an unused feature which can be used to improve spike rejection.
- EGs disappearing appears to be a low energy phenomena, as expected. EGs appearing appears to be a higher energy phenomenon.
- Continuing study as to how loss of energy/events affects trigger efficiency and trigger resolution.

Algorithms

- When applying the ODD weights, if $E_T^{even} > E_T^{odd}$ then we accept the pulse as an in-time event. If $E_T^{even} < E_T^{odd}$ then we reject the pulse and deem it out-of-time.

$$L_{SigEff} = \begin{cases} if((A_{w2,d1} - A_{w1,d1}) \geq \delta_{\min}): & (A_{w2,d1} - A_{w1,d1}) \\ if((A_{w2,d1} - A_{w1,d1}) < \delta_{\min}): & 0 \end{cases}$$

$$L_{SpikeRej} = \begin{cases} if((A_{w1,d2} - A_{w2,d2}) \geq \delta_{\min}): & (A_{w1,d2} - A_{w2,d2}) \\ if((A_{w1,d2} - A_{w2,d2}) < \delta_{\min}): & 0 \end{cases}$$