Trigger Performance

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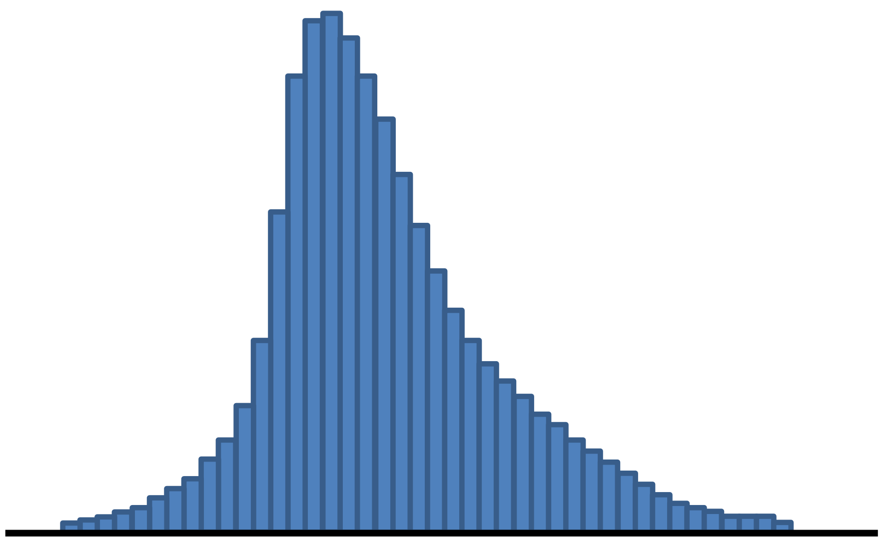
    - Raw pulses
        - Digitized pulses for each calorimeter hit recorded in the event.



Introduction

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- The hardware gives a few tools to assist with this process. Each readout event contains:
    - Raw pulses
    - Hardware clusters
        - Cluster energy
        - Time
        - Number of hits
        - x- and y-indices

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- The hardware gives a few tools to assist with this process. Each readout event contains:
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    - Hardware clusters
    - Hardware triggers
        - Trigger type (singles 0, singles 1, pair 0, pair 1)
        - Pass/fail status for trigger cuts
        - Trigger time

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- The trigger diagnostics provide a means of measuring how closely the hardware is performing to what is expected.
- The hardware gives a few tools to assist with this process. Each readout event contains:
  - Raw pulses
  - Hardware clusters
  - Hardware triggers
- By simulating the latter two objects from the former, we are able to check that the hardware is performing as we would expect it to.

Cluster Verification

- Cluster verification checks that clusters are being formed as expected.

Cluster Verification

- Step 1: Emulate hit formation
    - Clusters are formed from the pulses acquired from the hardware's output **Ev**ent **I**nput/**O**utput (EvIO) file.

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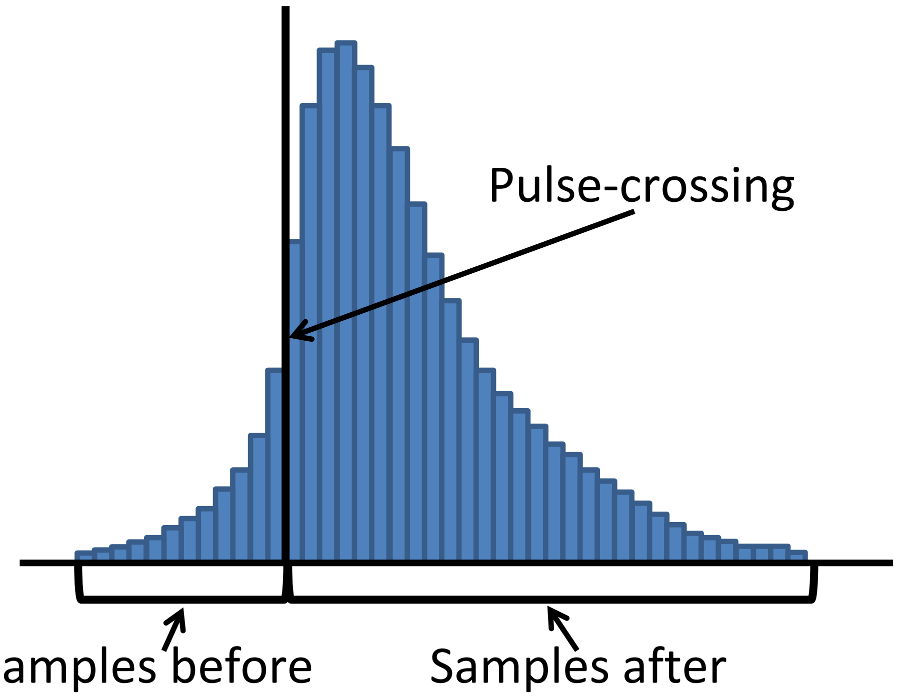
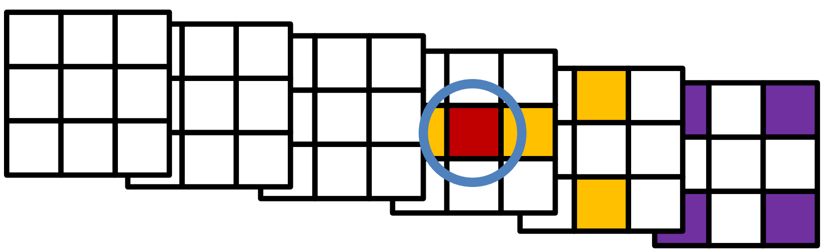
  - Pulses are checked to see if they cross a certain threshold. If so, they are integrated a certain number of samples before and after the crossing.
  - Gains, pedestals, and such are also applied. These values are acquired directly from the EvIO file.

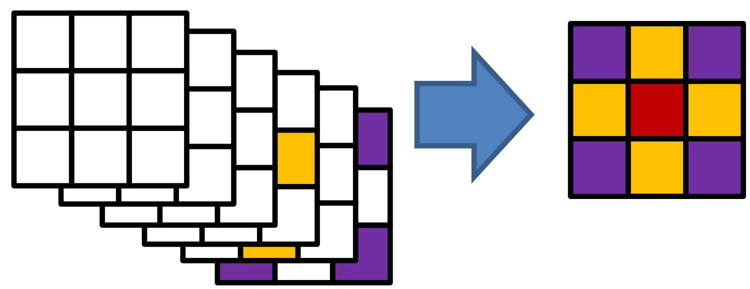


Cluster Verification

- Step 1: Emulate hit formation
- Step 2: Form clusters from emulated hits.
    - Clusters are formed from hits using the standard GTP algorithm.
        - Look for a “seed hit,” a hit that is a local maximum in energy with respect to the hits adjacent both at the same time and within a time window around that time.
        - Collect all hits in the 3×3 window across the time window and construct a cluster from them.



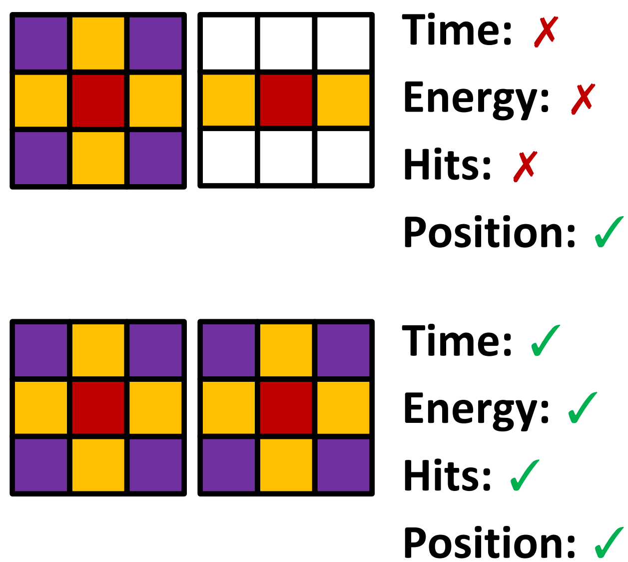
A seed hit is higher energy than all its neighbors in time and space.



All of the hits in the spatiotemporal window are used to create the final cluster.

Cluster Verification

- Step 1: Emulate hit formation
- Step 2: Form clusters from emulated hits.
- Step 3: Compare emulated clusters with hardware clusters.
    - Ideally, we should get the same results from emulated clustering as the hardware reports.
    - Each emulated cluster is compared to the hardware's clusters. To match, the following must be true:
        - $t_e = t_h$
        - $E_h - 9 \leq E_e \leq E_h + 9$
        - $\mathrm{ix}_e = \mathrm{ix}_h$
        - $\mathrm{iy}_e = \mathrm{iy}_h$
        - $N_e = N_h$



Cluster Verification

- Step 1: Emulate hit formation
- Step 2: Form clusters from emulated hits.
- Step 3: Compare emulated clusters with hardware clusters.
- Step 4: Calculate efficiency.
  - Efficiency is defined as the percentage of emulated clusters that could be uniquely matched to hardware clusters.

$$\text{Efficiency} = \frac{N_{\text{matched}}}{N_{\text{emulated}}}$$

Cluster Complications

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- Pulse-integration is not perfectly accurate.
    - Emulated pulse integrations are slightly inaccurate. Individual hits may vary in energy by around 3 MeV from the hardware.
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    - It may also cause some pulses to appear either under- or over-threshold to the emulation, but the opposite to the hardware.
- Pulse-clipping
    - Only the portion of a pulse that is within the readout window of an event is included.
    - Pulses near the beginning or end of the event may not contain the entire pulse.
    - Affected clusters are excluded from the verification test.

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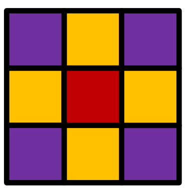
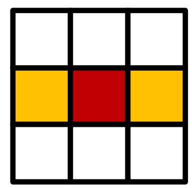


Cluster Energy: ✓
Hit Count: ✓
Triggered: ✓
Time: t_1 ns



Cluster Energy: ✗
Hit Count: ✓
Triggered: ✗
Time: t_2 ns

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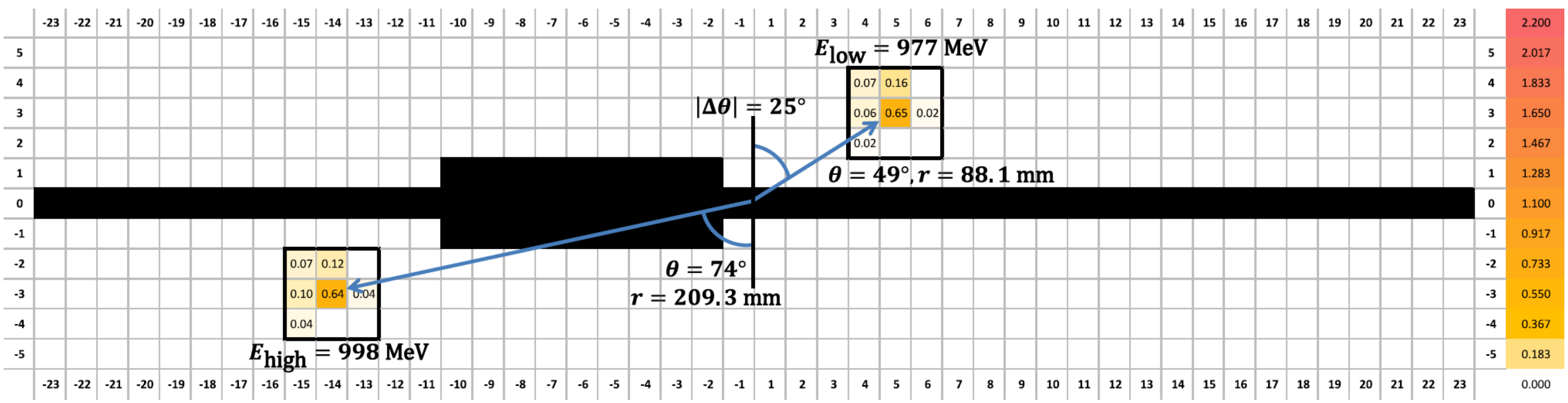
- The same is repeated for the pair triggers, except on all top/bottom pairs.



Cluster Energy: ✓ **Energy Diff:** ✓ **Triggered:** ✓

Hit Count: ✓ **Energy Slope:** ✓ **Time:** t ns

Energy Sum: ✓ **Coplanarity:** ✓

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- For the singles trigger, both triggers are applied to all clusters and trigger objects similar to the hardware are produced.
- The same is repeated for the pair triggers, except on all top/bottom pairs.
- These emulated trigger objects are then compared to the hardware's trigger objects. They are required to match in all fields.
- Efficiency is in the same manner as with clusters.

Verification Results

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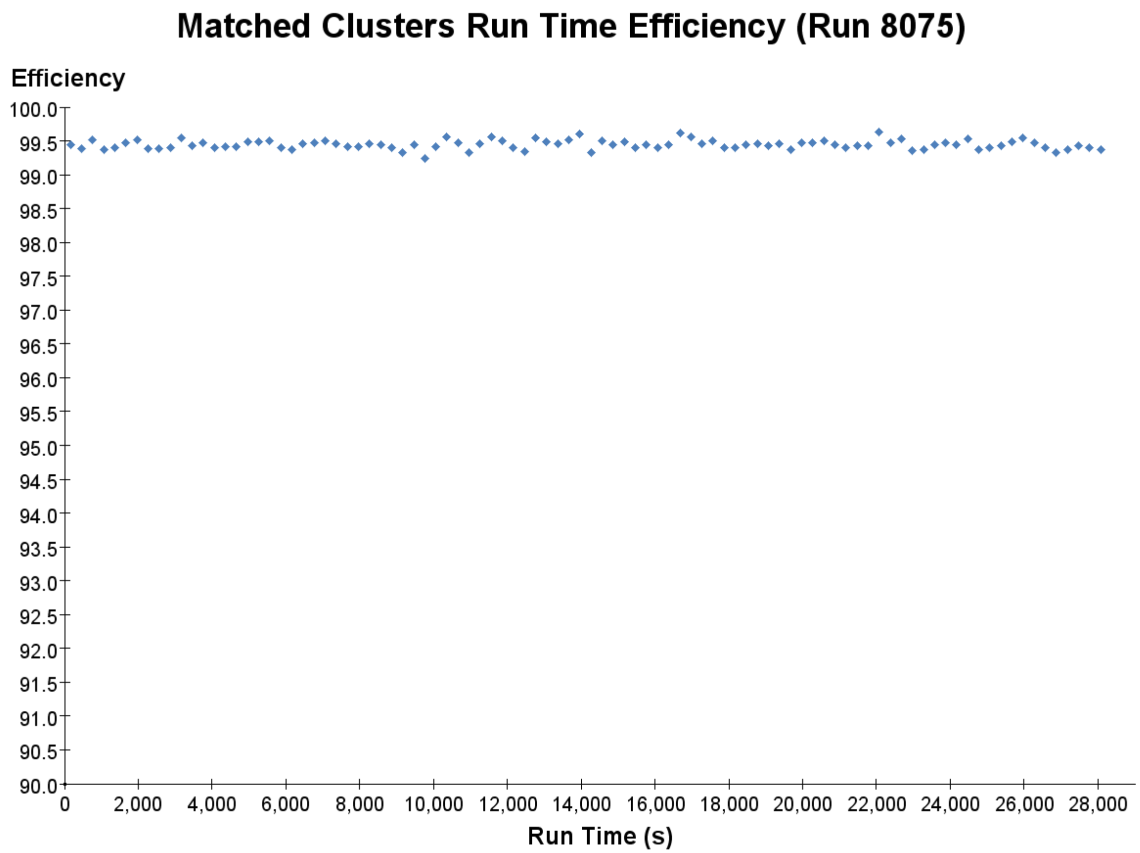
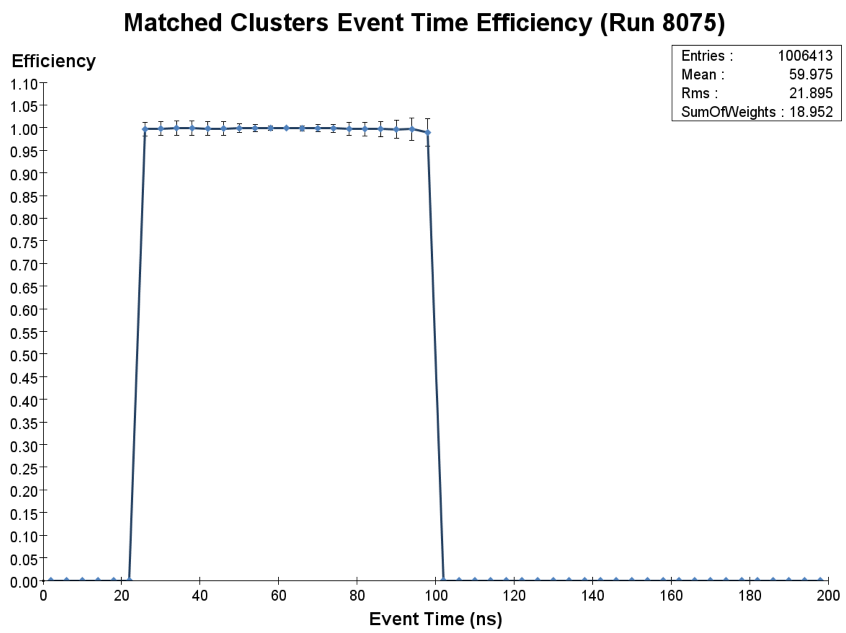
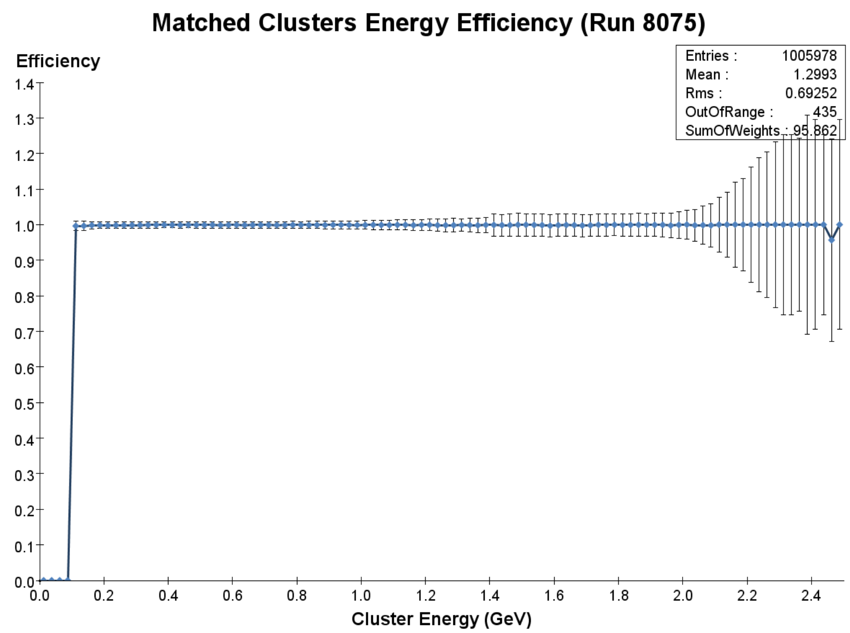


Verification Results

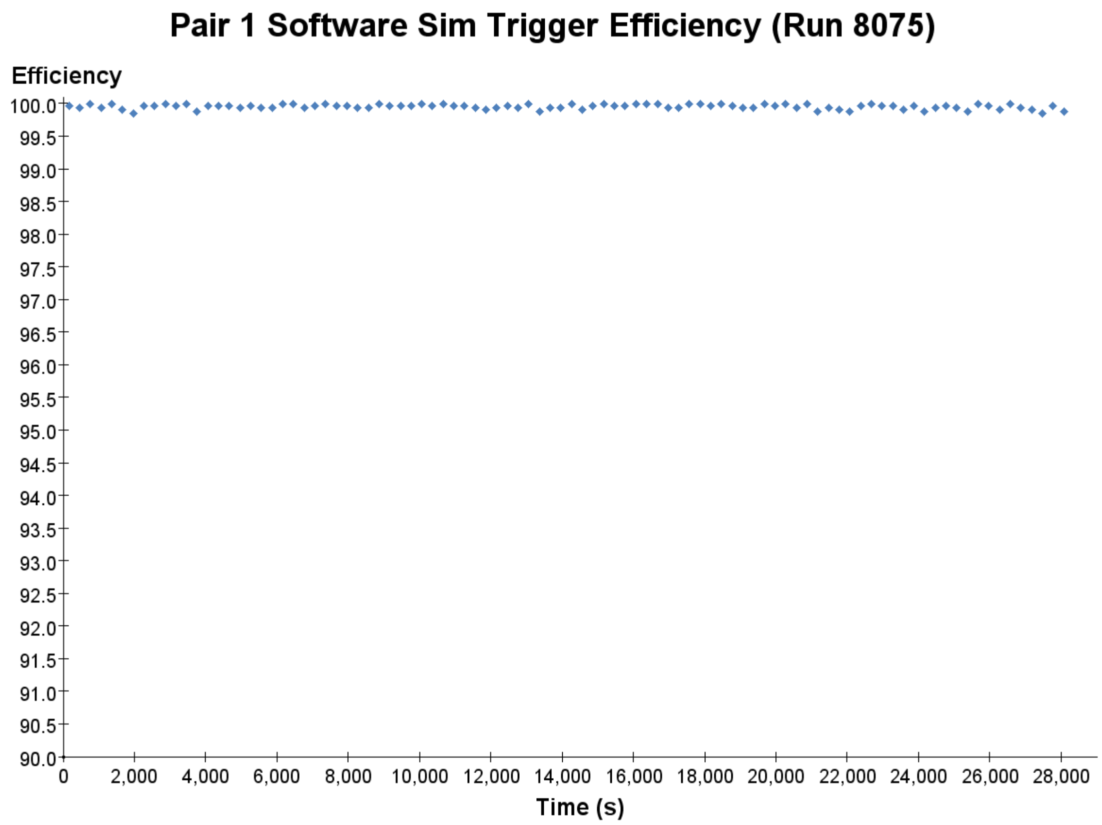
- Global clustering efficiency in 2016 is >99%.
    - Efficiency appears to be constant over time.
    - Efficiency depends neither on where a cluster falls within an event, nor on cluster energy.





Verification Results

- Global clustering efficiency in 2016 is >99%.
- Trigger efficiency for the production trigger in 2016 is also > 99%.
  - This is also consistent across time.



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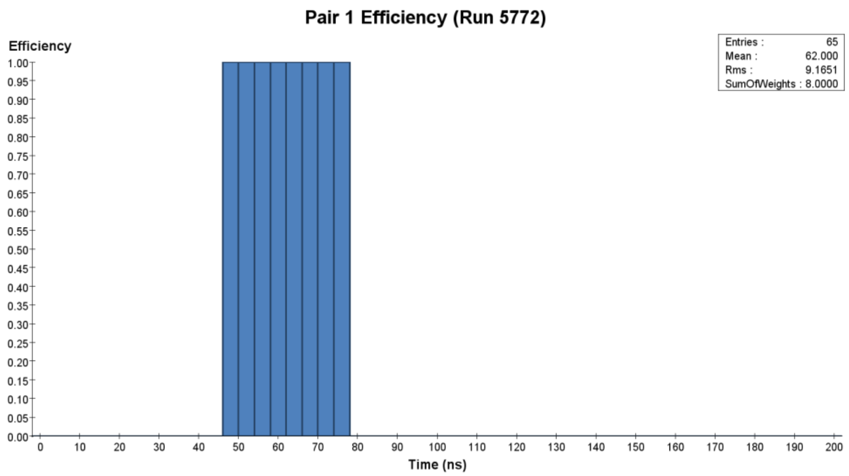
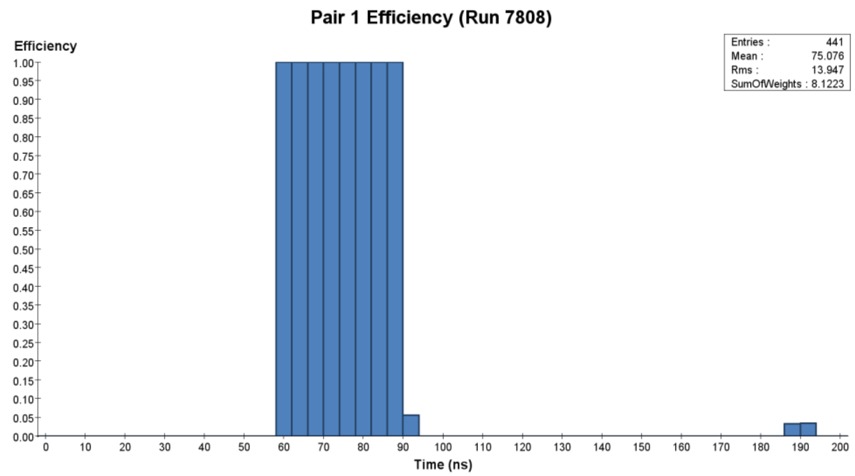
    - All possible triggers are simulated from FADC pulse data in the same manner as the trigger diagnostics.
    - For each time bin, we check to see if a simulated trigger occurred during the event. If so, we increment the denominator for that bin.
    - We then check to see if the TI-bit for that trigger type is set. If it is, we increment the numerator for that bin.
    - We then define the TI turn-on curve as the ratio.

TI Turn-On Curve

- We repeatedly find 100% efficiency for this test across checked runs.





- Note that we only expect to see values present within the "trigger window," the range of time during which the hardware is able to check for triggers and set the TI-bit.
    - This was $t_{\text{window}} = [48, 78]$ for the 2015 run and $t_{\text{window}} = [60, 88]$ for 2016.
- It is also possible to get some coincidental triggers at later time periods; we see this in the run 7808 data.

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  - Plots are binned by coplanarity (spatial dependence) and energy sum (energy dependence).

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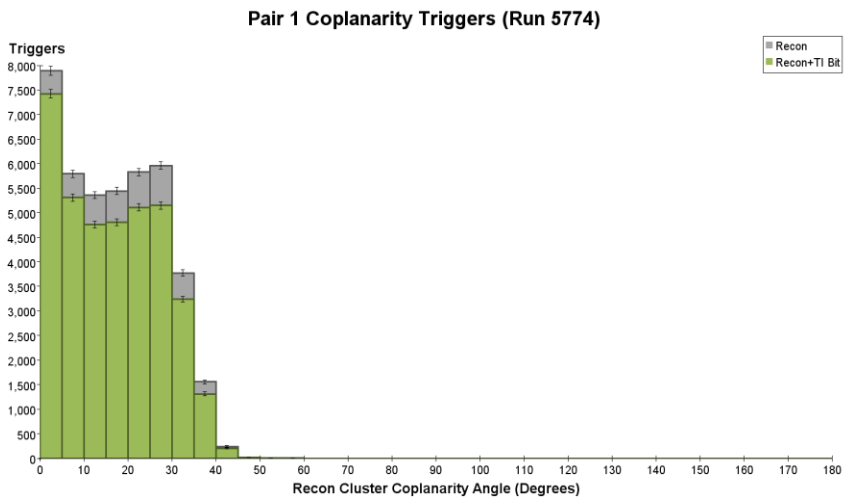
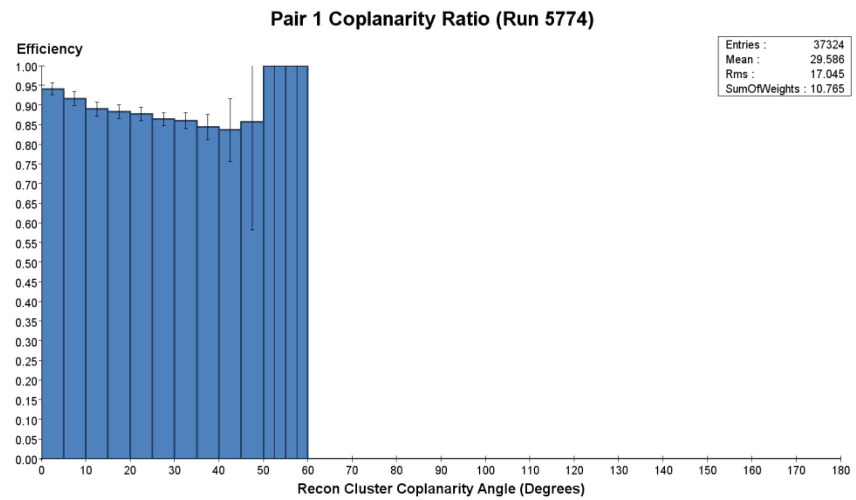
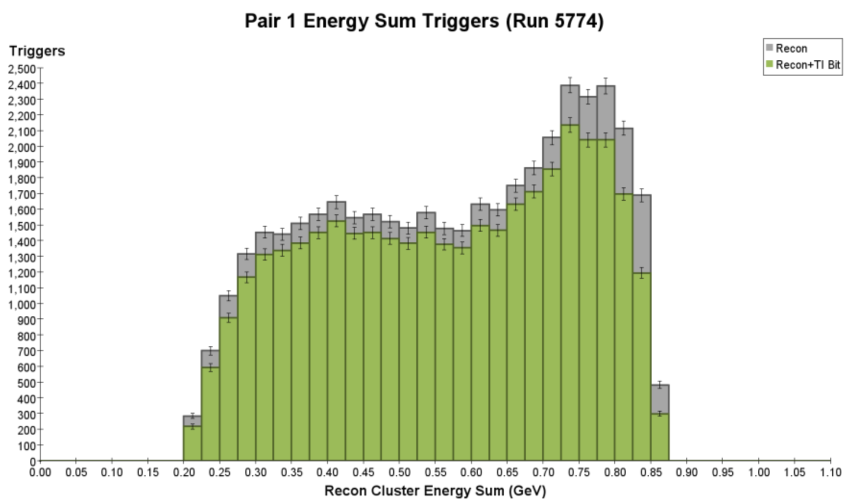
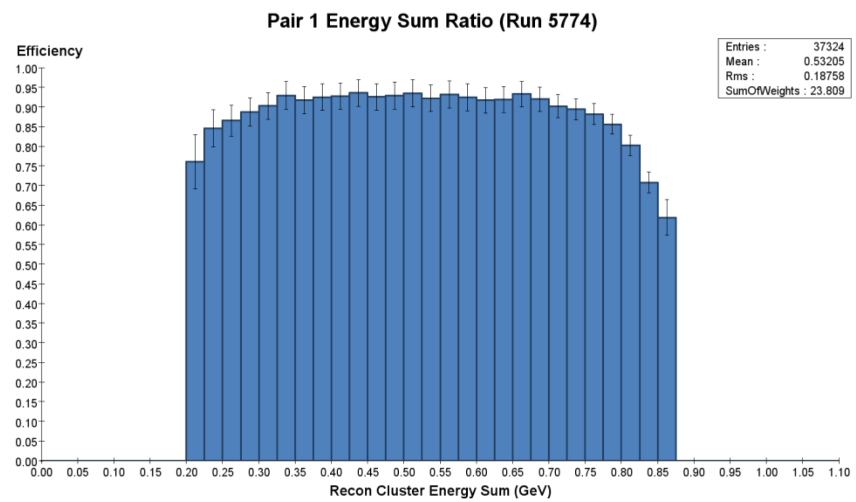
- This test is performed for both Monte Carlo pulser data and real pulser data from run 5774.

Results – Run 5774 Uncorrected

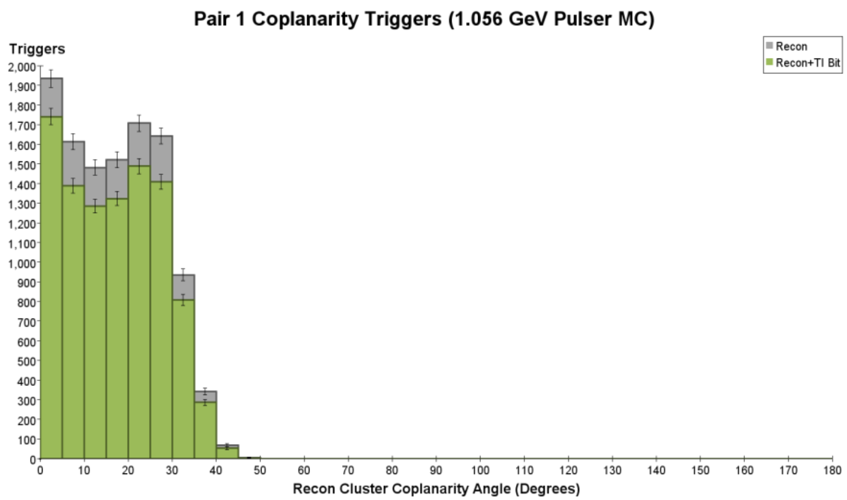


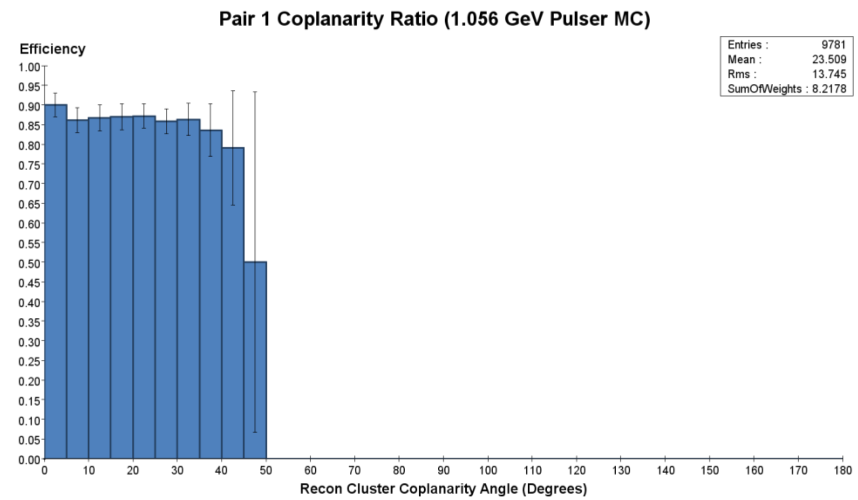


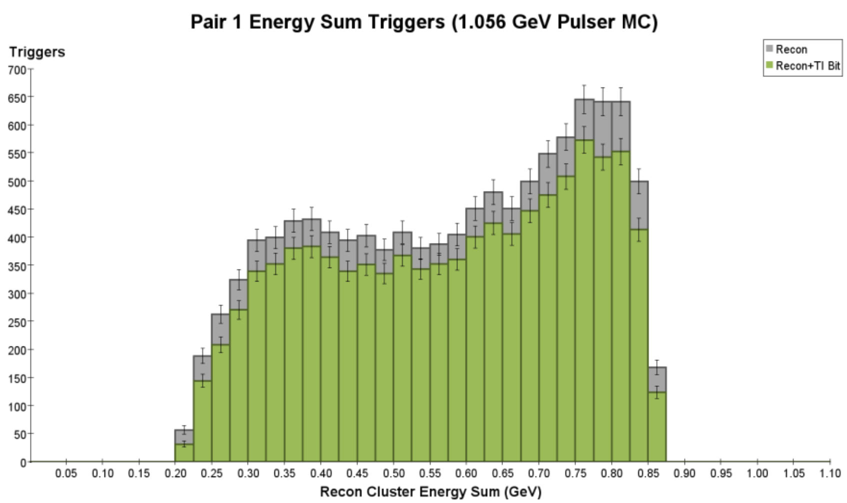


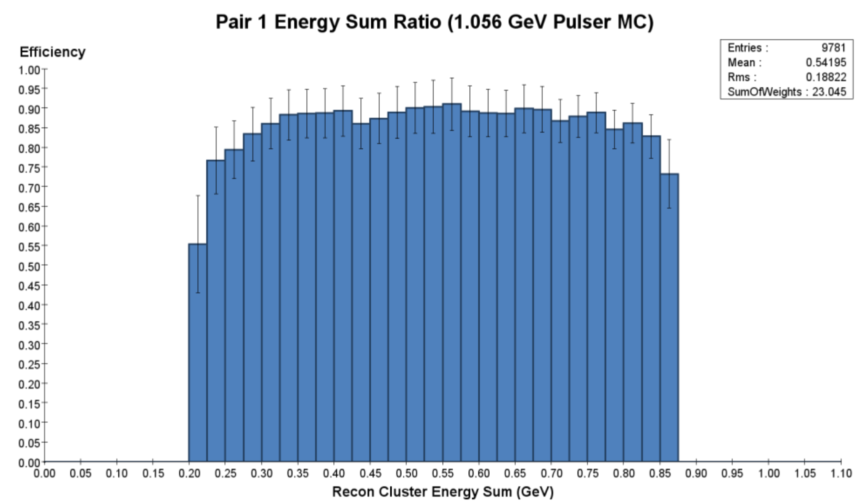


Results – Pulser MC Uncorrected

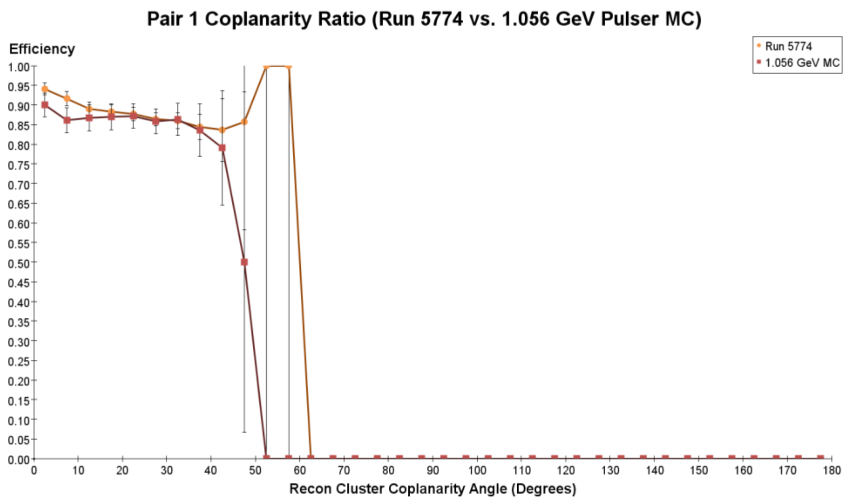


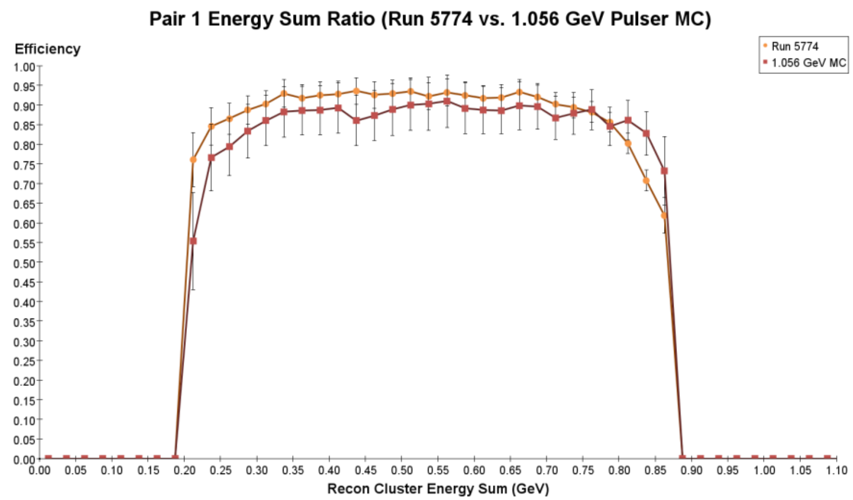






Results –Uncorrected Comparison





- When compared, we see that the Monte Carlo ratio is slightly lower than the data ratio in most places (though almost always well within uncertainty).
- There does not appear to be an energy or coplanarity dependent shift between the two ratios.

Other Trigger Performance Measures

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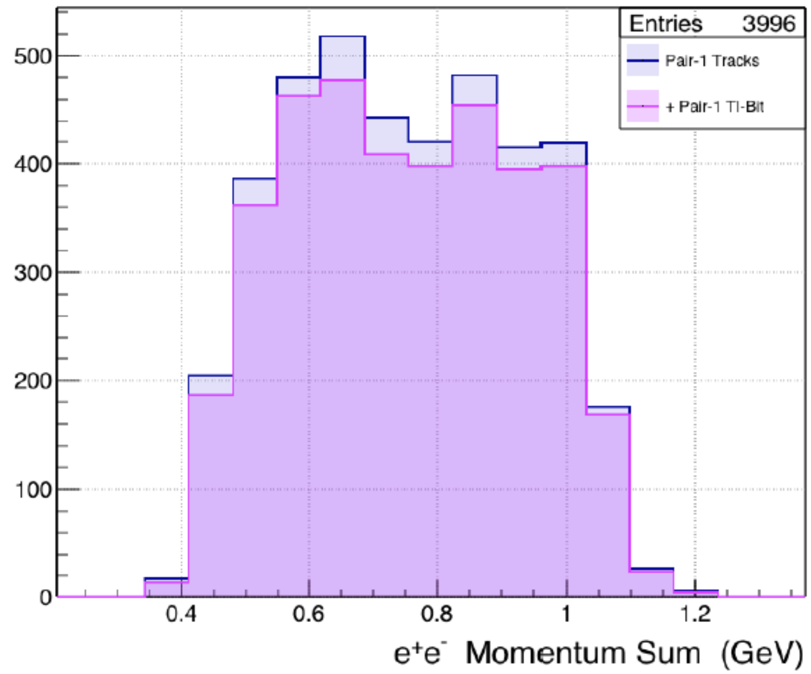
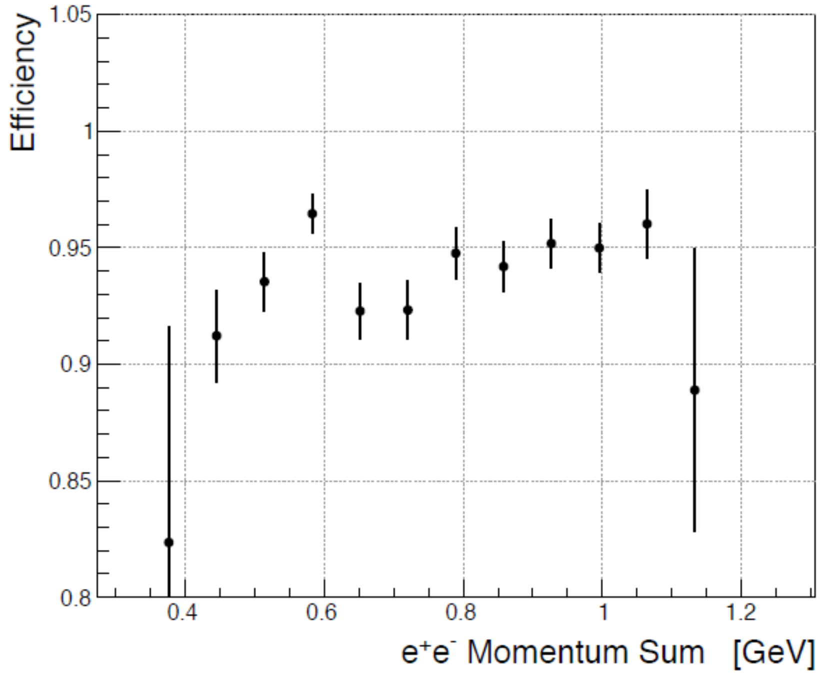
- Lastly, an estimate of total trigger efficiency was performed by using tracks to determine whether an event should have triggered and then checking the TI bit to see if it did.
- Events were selected if they met the following criteria:
  - Track pair $\chi^2 < 30$
  - Track projected position on calorimeter face within 1/10 of a crystal from the edge.
  - Track pair contains one top and one bottom track.
  - Track pair contains on negative and one positive track.
  - Track pair meets the energy difference and coplanarity cuts for the trigger.
  - Track pair meets the energy slope cut for the trigger, scaled by 130%.
  - Track pair meets the energy requirements $0.1\text{ GeV} \leq E_{\pm} \leq 0.8\text{GeV}$ and $0.4\text{ GeV} \leq E_{\text{sum}} \leq 1.2\text{GeV}$

Other Trigger Performance Measures

- The estimated efficiency was found to be roughly 95%.





Conclusions

- The trigger hardware appears to be working extremely well.
    - Hardware aligns with simulated expectations for 2016 at a rate of $> 99\%$ accuracy.
    - Events are marked with trigger bits as expected at $\approx 100\%$ accuracy.
- The trigger performance in data and Monte Carlo appears very similar.
    - A slight overall shift exists between the two, but there does not appear to be any significant systematic differences.
- Estimated trigger efficiency is roughly 95%.
    - There do not appear to be any losses in data due to the trigger.