Primary Trigger Update

Introduction

- There are ten cuts in use for the primary trigger. These are split into **single cluster cuts** and **cluster pair cuts**.
- Available cuts include:

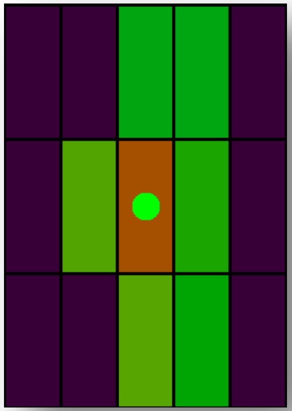
- **Cluster Single Cuts**
  - Seed Energy Lower Bound
  - Seed Energy Upper Bound
  - Cluster Total Energy Lower Bound
  - Cluster Total Energy Upper Bound
  - Cluster Hit Count

- **Cluster Pair Cuts**
  - Pair Energy Sum Lower Bound
  - Pair Energy Sum Upper Bound
  - Pair Energy Difference
  - Pair Energy Slope
  - Pair Coplanarity

Single Cluster Cuts

- **Cluster Seed Energy**
  - The cluster seed energy cut is a threshold applied to the highest-energy hit in a cluster.
  - The cut is mathematically defined as

$$E_{-} \leq E_{\text{seed}} \leq E_{+}$$



The above is a standard cluster after the FADC simulation readout with 7 hits. The central (red) hit is the seed.

- **Cluster Total Energy**
  - The cluster seed energy cut is a threshold applied to the energy of an entire cluster.
  - The cut is mathematically defined as

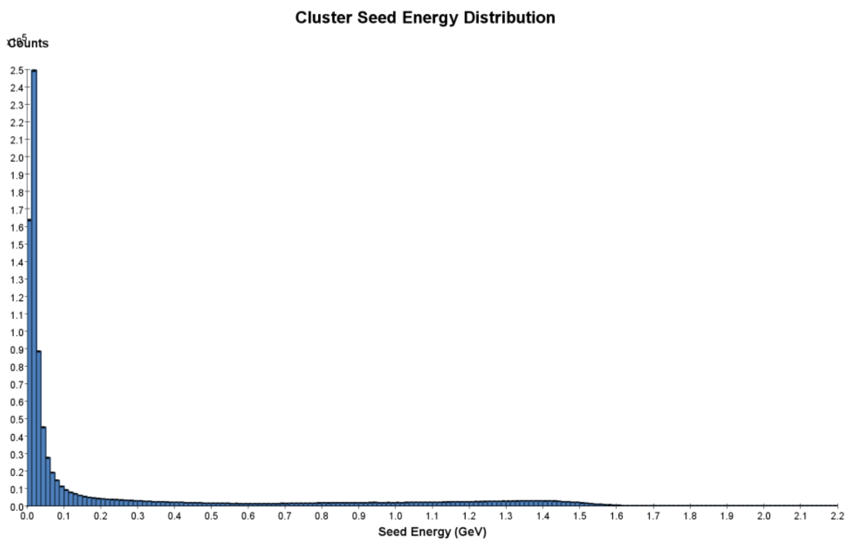
$$E_{-} \leq E_{\text{cluster}} \leq E_{+}$$

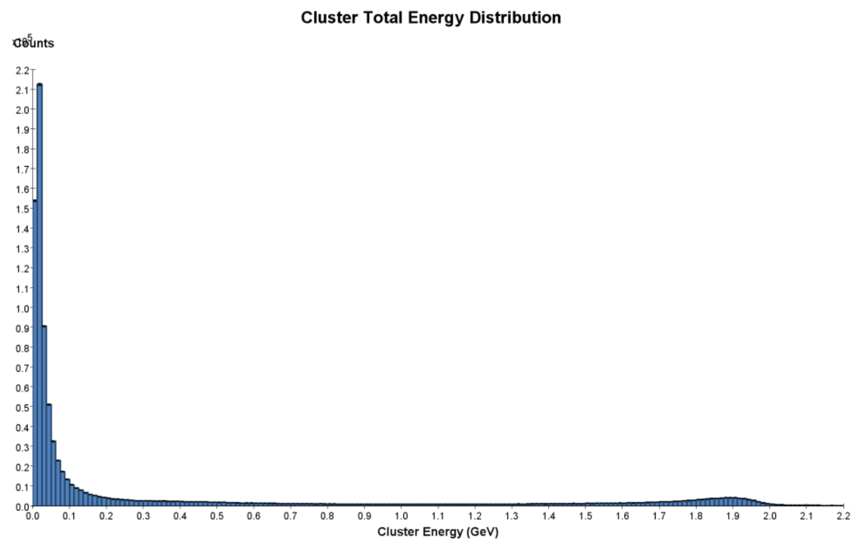
- **Cluster Hit Count**
  - The cluster hit count cut is a threshold on the minimum number of hits that must be included in a cluster for it to be considered by the trigger.
  - The cut is mathematically defined as

$$N_{\text{hits}} \geq N_{\text{min}}$$

Single Cluster Cuts

- The cluster seed and total energy cuts are valuable because most of the background tends to produce very-low-energy hits. This can be seen in the background distributions for these cuts:

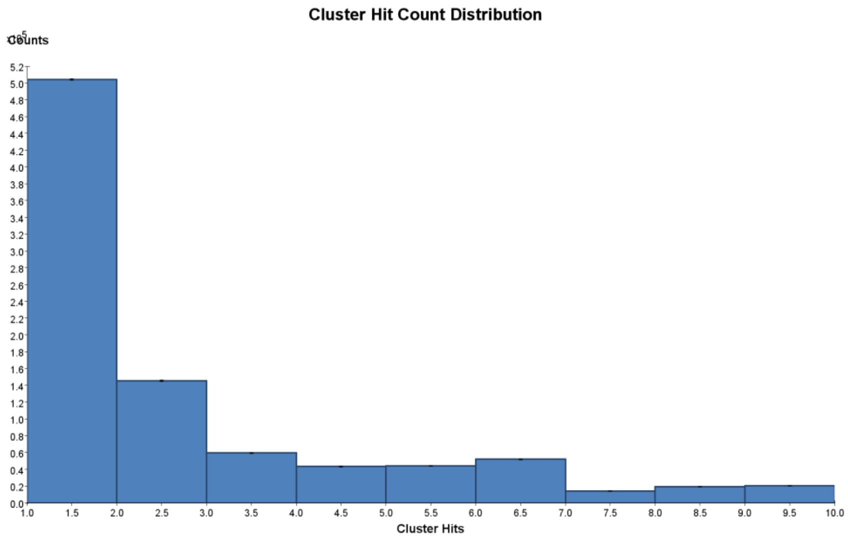


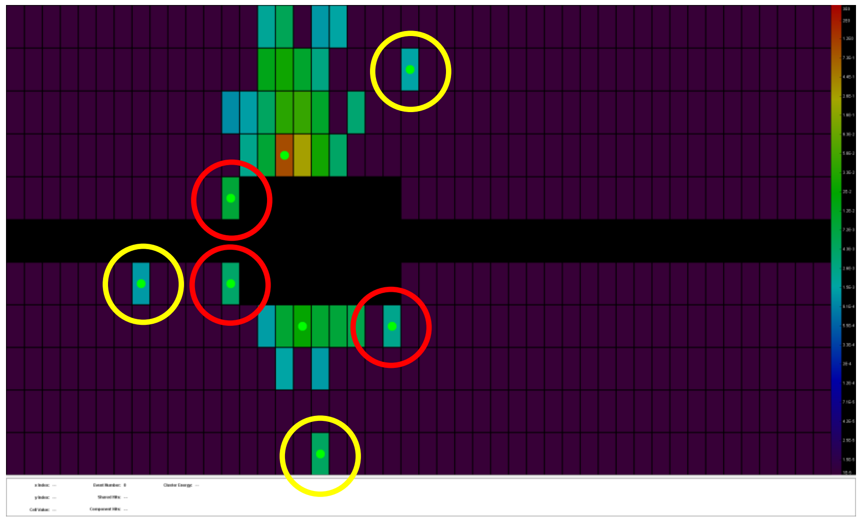


- By cutting these lower values, we eliminate massive swaths of background while the A’ events, which have comparably higher values for these cuts (as will be seen shortly) are relatively unaffected.

Single Cluster Cuts

- The cluster hit count cut serves two primary purposes.





- First, it eliminates much of the low-energy background much like the previous two cuts.

- Second, it eliminates "false clusters" that form as a result of spray crossing the beam gap (**red**) and also the common random single-hit clusters that form (likely from scattering or spray from the SVT) at various points around the calorimeter face (**yellow**). These very rarely have anything to do with the primary event cluster.

Cluster Pair Energy Cuts

- **Pair Energy Sum**
  - Pair energy sum cuts cluster pairs based on whether their combined energies fall between an upper and lower threshold.
  - The cut is mathematically defined as

$$E_{-} \leq E_1 + E_2 \leq E_{+}$$

- **Pair Energy Difference**
  - Pair energy difference cuts cluster pairs where the difference between the energies exceeds some threshold.
  - The cut is mathematically defined as

$$|E_1 - E_2| \leq E_{\mathrm{max}}$$

Cluster Pair Spatial Cuts

- **Pair Energy Slope**
  - Pair energy slope is a relation between the spatial location of the cluster pair and its energy. It cuts pairs with values where the calculated value falls below some threshold.
  - The cut is mathematically defined as

$$E_{\text{low}} + R_{\text{min}} \times F_{\text{energy}} \leq \xi$$

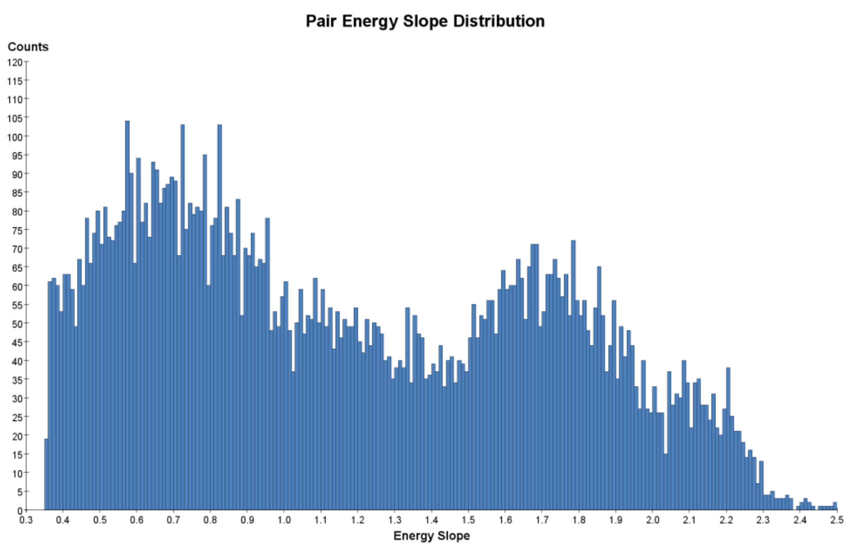
where $F_{\text{energy}} = 0.0055$ and $\xi = 1.1$. R_{min} is the distance between the center of the calorimeter and the cluster center (seed hit) of the lowest energy cluster.

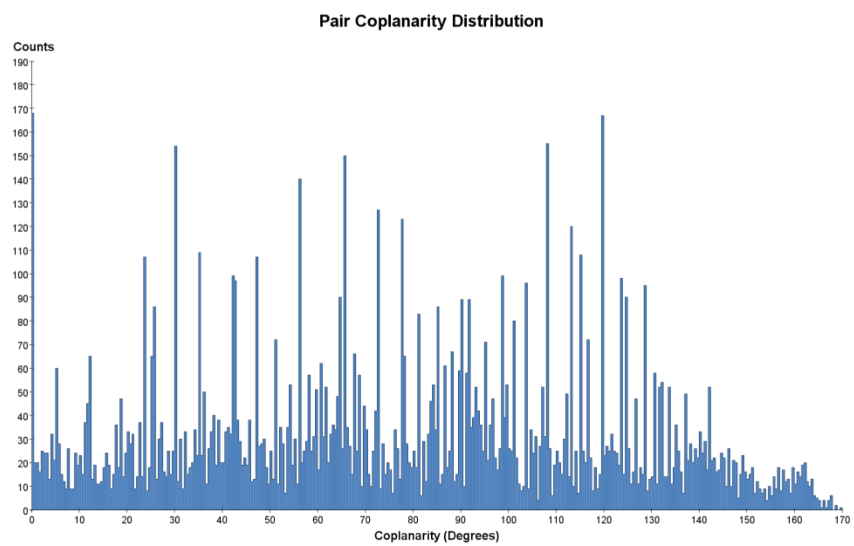
- **Pair Coplanarity**
  - Pair coplanarity is a relation between the physical positions of each cluster. It cuts pairs with a coplanarity that exceeds some threshold.
  - The cut is mathematically defined as

$$\left|\text{atan}\left(\frac{x_{\text{top}}}{y_{\text{top}}}\right) - \text{atan}\left(\frac{x_{\text{bot}}}{y_{\text{bot}}}\right)\right| \leq \theta$$

Cluster Pair Spatial Cuts

- The pair energy cuts, when combined, provide a useful means of constraining the energy of the cluster pair to a range that is feasible for an actual A' decay.
- Meanwhile, the pair spatial cuts provide a very useful means of background discrimination. Consider the distributions of these two cuts for the background:





- These cuts are essentially random for the background, but are peaked and concentrated in a much smaller region for A' events (as will be seen shortly). This allows for a significant degree of background elimination through these two cuts alone.

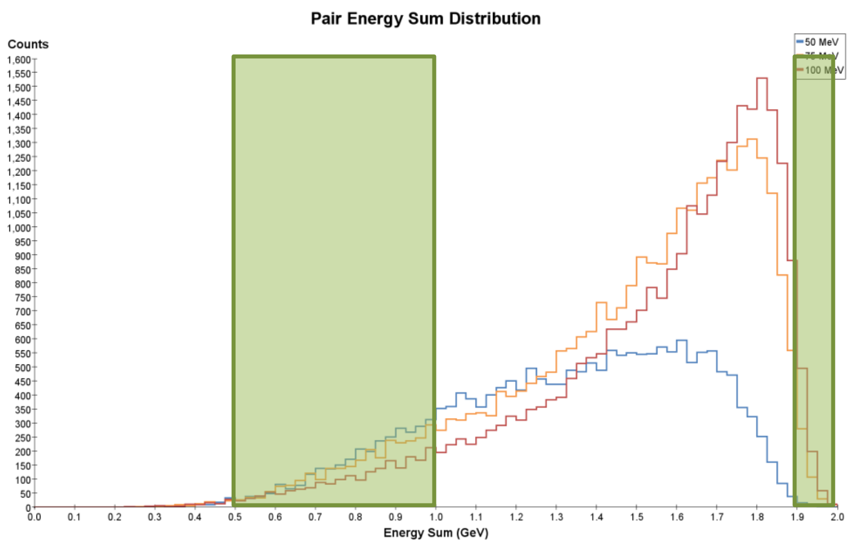
Selecting Cut Values

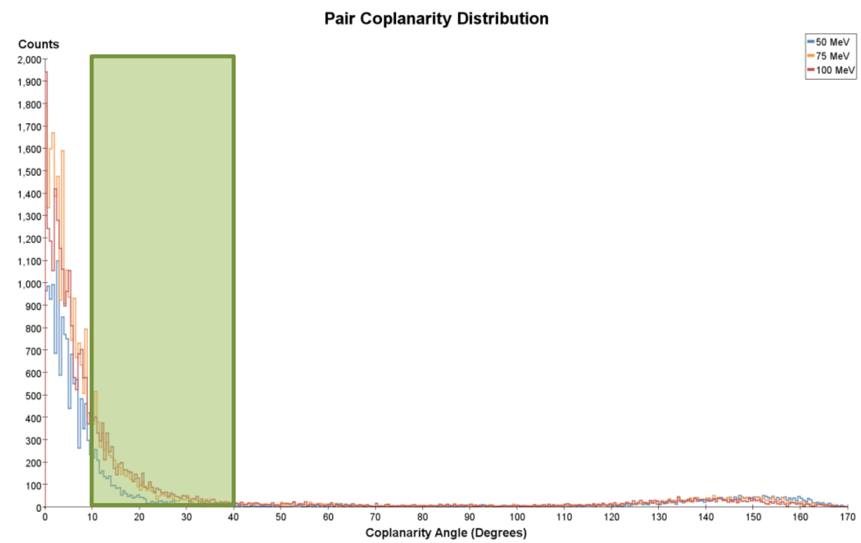
- Selecting cut values by hand is very difficult.
    - 10 different cut thresholds presents a lot of cuts to consider
    - Many cuts are strongly correlated and the large number of them makes mapping these correlations a challenge.
- Instead, an algorithm was used that simulated the trigger on every permutation of cuts over a predefined range of values for each one.

- The following steps were performed:
    - A range was selected for which to analyze each cut.
    - The range was broken down into steps.
    - Every permutation of possible steps over all cuts was simulated and the number of A’ triggers for both A’ events and background events were tabulated.
        - A’ masses of 50 MeV, 75 MeV, and 100 MeV were used to get a selection of events on all sides of the expected maximal acceptance curve for 2.2 GeV.
    - A second script selected the permutation that generated the highest average A’ acceptance with background below a set threshold.

Selecting Cut Values

- To select the ranges, the distributions for each cut were plotted so that the primary peak range could be selected.
- For example, consider the pair coplanarity and pair energy sum cuts.

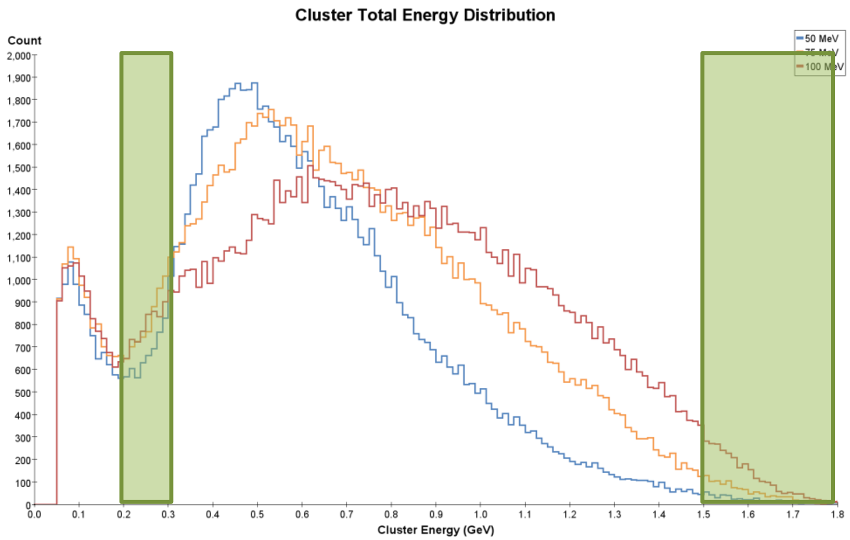


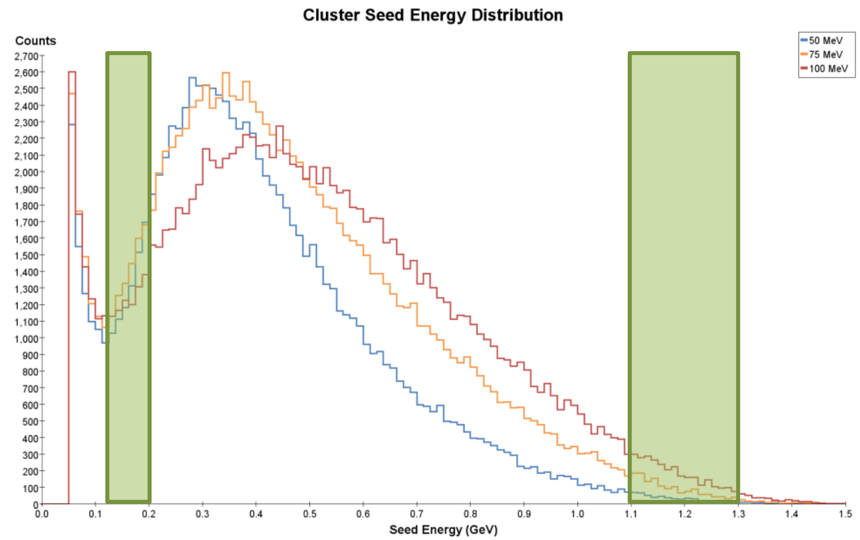


- From each distribution, a range was selected from a value that encompassed essentially all events (such as $40°$ for the coplanarity cut or 0.5 GeV for the energy sum lower bound) to a value that risked cutting a significant number of events (such as $10°$ for the coplanarity cut and 1.0 GeV for the energy sum lower bound).
- These ranges were then cut into reasonably sized chunks to serve as steps.

Selecting Cut Values

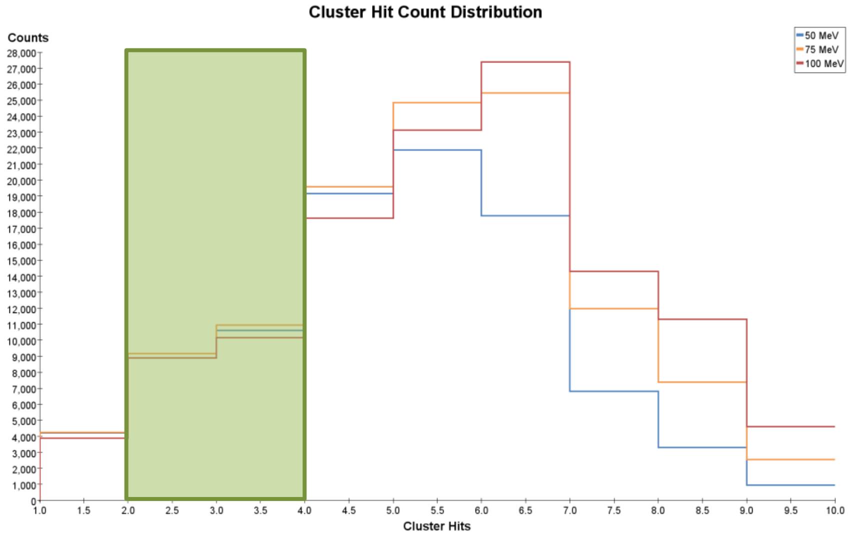
- The ranges for the other cut values are depicted similarly below.

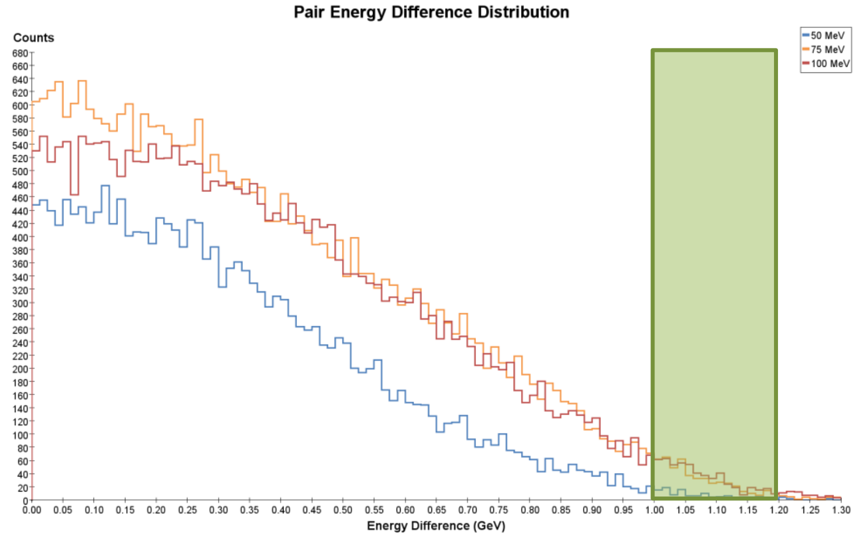


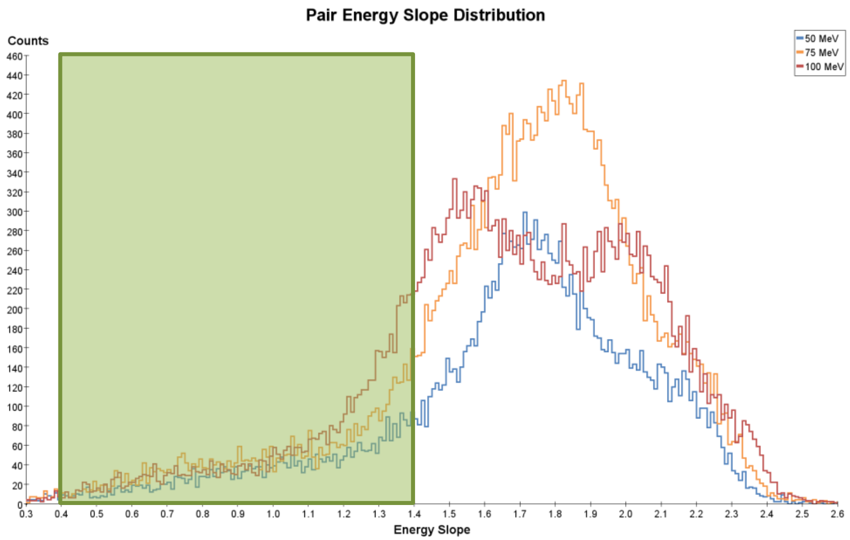


- The lower bounds for the cluster total and seed energy cuts were selected to avoid the low-energy peaks. These are mostly populated by clusters from spray and are not desirable in triggered data.

Selecting Cut Values







- Energy slope is given a very wide range because it has proven historically to be one of the algorithm's preferred methods for reducing background.

- Single-hit clusters are excluded because they are predominated by spray and other not-very-useful events.

Selecting Cut Values

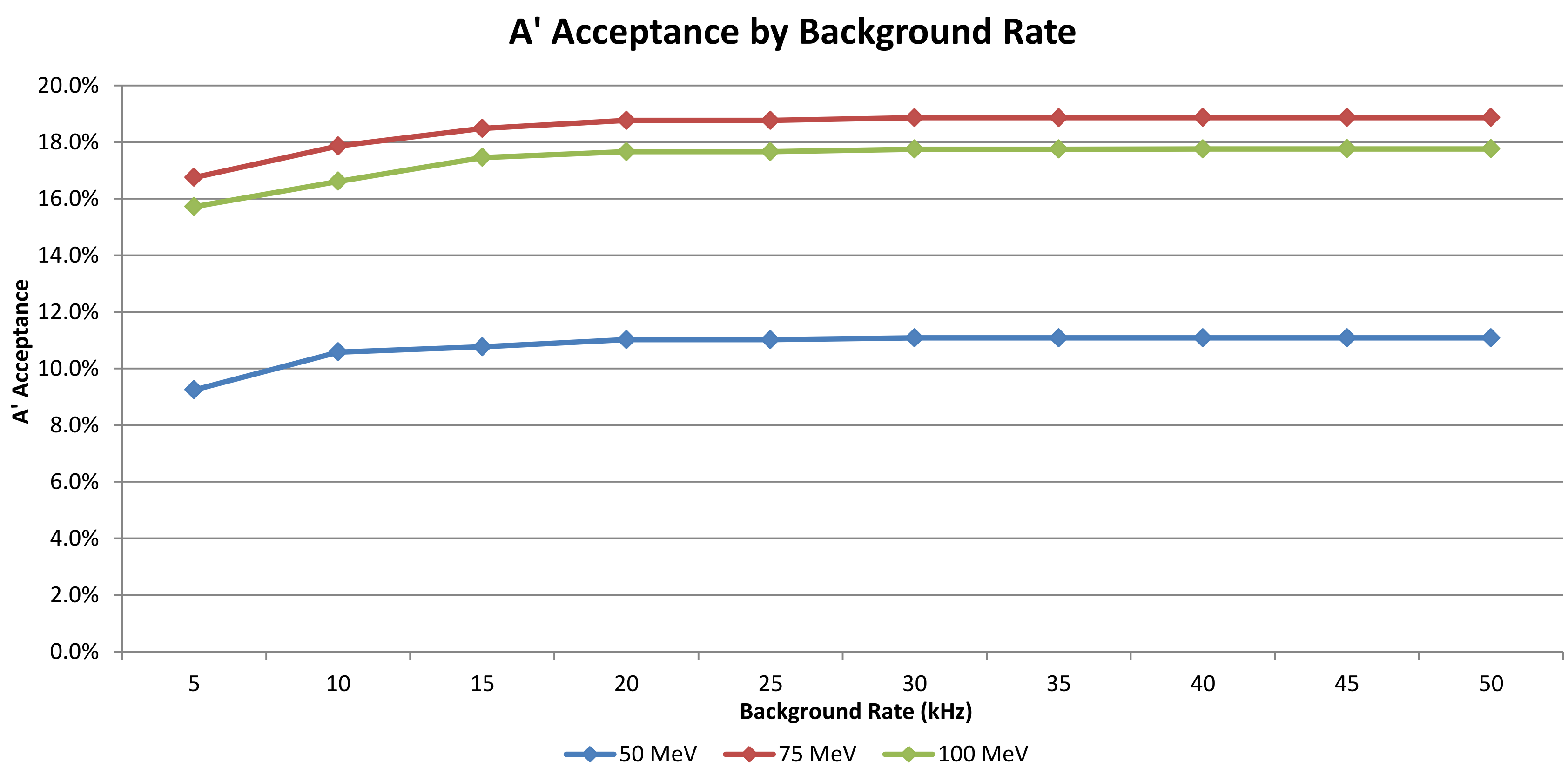
- The final selected cut values, listed in table form, are below.

Cut Name	Lower Value	Upper Value	Step Size
Cluster Seed Energy Low	0.125 GeV	0.200 GeV	0.025 GeV
Cluster Seed Energy High	1.100 GeV	1.300 GeV	0.100 GeV
Cluster Total Energy Low	0.200 GeV	0.300 GeV	0.050 GeV
Cluster Total Energy High	1.500 GeV	1.800 GeV	0.100 GeV
Cluster Hit Count	2 Hits	3 Hits	1 Hit
Pair Energy Sum Low	0.500 GeV	1.000 GeV	0.250 GeV
Pair Energy Sum High	1.900 GeV	2.000 GeV	0.100 GeV
Pair Energy Difference	1.100 GeV	1.200 GeV	0.100 GeV
Pair Energy Slope	0.4	1.4	0.1
Pair Coplanarity	$10°$	$40°$	$5°$

- Note that the lower and upper values each represent a step each, so the pair energy difference cut, for example, has three steps.

Selecting Cut Values

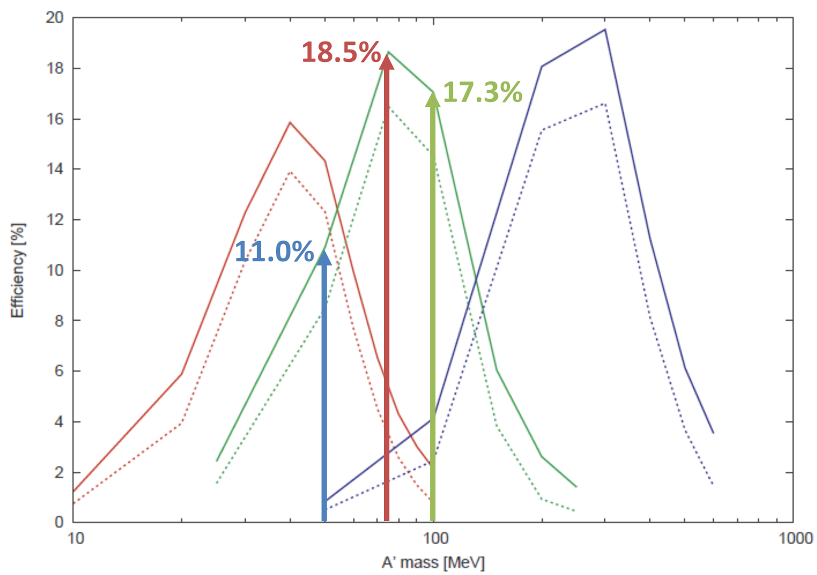
- All possible permutations of the above set of cuts were then simulated and the triggers for each of them tabulated and analyzed.
- The best acceptances for various background levels were selected and are as follows:

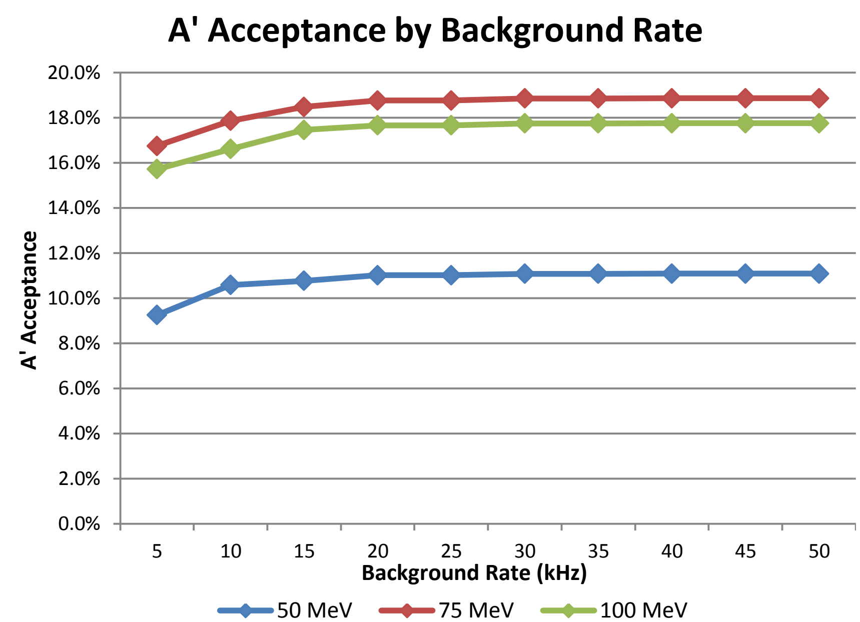


Selecting Cut Values

- This is about in line with the expected reach from the proposal.

Proposal Reach Plots (2.2 GeV in Green)





- By using the 15 kHz cut set, we obtain a hypothetical A’ acceptance of **10.8%**, **18.5%**, and **17.5%** for **50 MeV**, **75 MeV**, and **100 MeV** respectively. This is right on target!

Selecting Cut Values

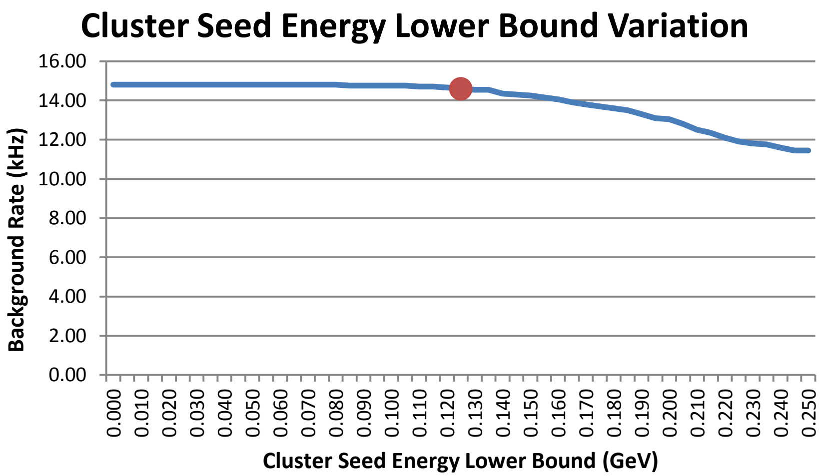
- The full table listing for the specific cut values at each background level and their respective acceptance is listed below.

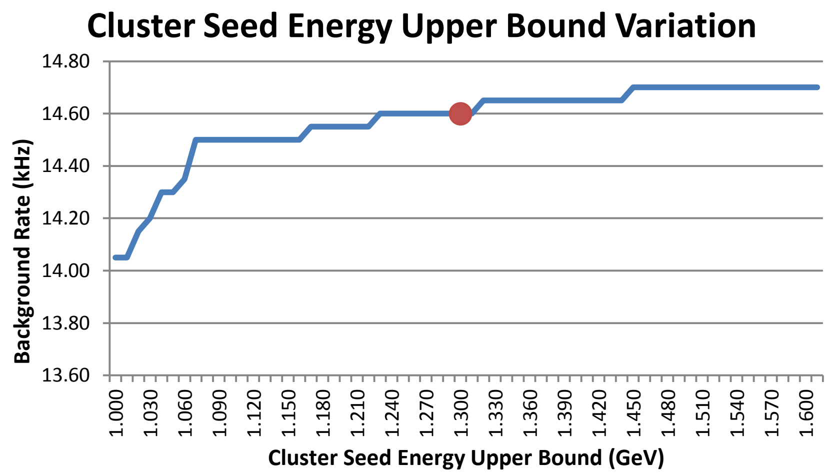
Background Level (kHz)	**Seed Low** (GeV)	**Seed High** (GeV)	**Cluster Low** (GeV)	**Cluster High** (GeV)	**Hit Count** (Hits)	**Sum Low** (GeV)	**Sum High** (GeV)	**Energy Difference** (GeV)	**Energy Slope**	**Coplanarity** (Degrees)	**50 MeV**	**75 MeV**	**100 MeV**
5	0.125	1.300	0.200	1.700	2	1.000	2.000	1.200	1.2	20	9.2%	16.8%	15.7%
10	0.125	1.300	0.200	1.700	2	0.500	2.000	1.200	1.0	20	10.6%	17.9%	16.6%
15	0.125	1.300	0.200	1.700	2	0.500	2.000	1.200	1.0	30	10.8%	18.5%	17.5%
20	0.125	1.300	0.200	1.700	2	0.500	2.000	1.200	0.8	30	11.0%	18.8%	17.7%
25	0.125	1.300	0.200	1.700	2	0.500	2.000	1.200	0.8	30	11.0%	18.8%	17.7%
30	0.125	1.300	0.200	1.700	2	0.500	2.000	1.200	0.6	30	11.1%	18.9%	17.8%
35	0.125	1.300	0.200	1.700	2	0.500	2.000	1.200	0.6	30	11.1%	18.9%	17.8%
40	0.125	1.300	0.200	1.500	2	0.500	2.000	1.200	0.4	30	11.1%	18.9%	17.8%
45	0.125	1.300	0.200	1.700	2	0.500	2.000	1.200	0.4	30	11.1%	18.9%	17.8%
50	0.125	1.300	0.200	1.700	2	0.500	2.000	1.200	0.4	30	11.1%	18.9%	17.8%

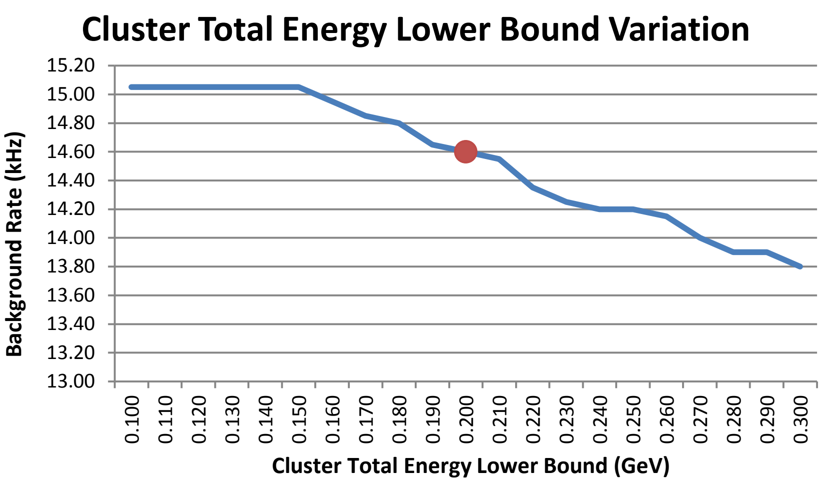
- In general, the algorithm favored keeping the energy cuts as loose as reasonable while using the spatial cuts (energy slope and coplanarity) to tune the background rates to the desired level.
- We also see that there is essentially no reason to exceed the 20 kHz cut set; we only see an increase of around one-tenth of a percent in acceptance past this point.

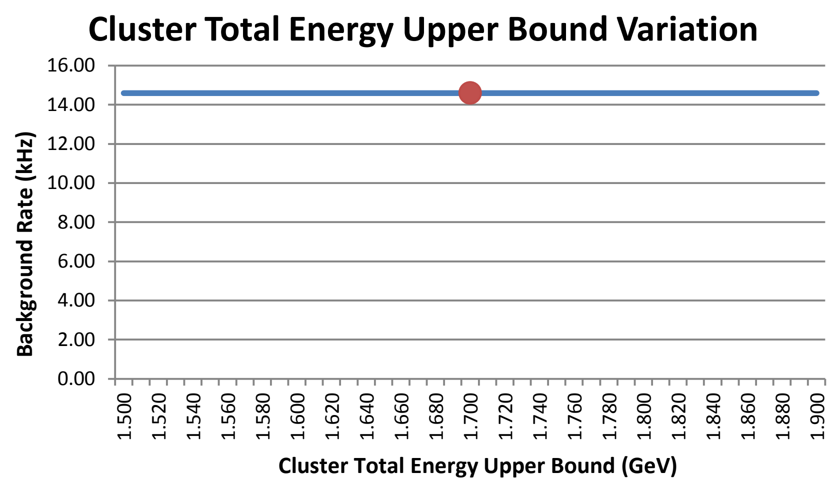
Selecting Cut Values

- All of the cuts for the 15 kHz cut set were further analyzed by varying only a single cut over a range to see what the effect would be on the overall trigger rate. The red dot is the real value.

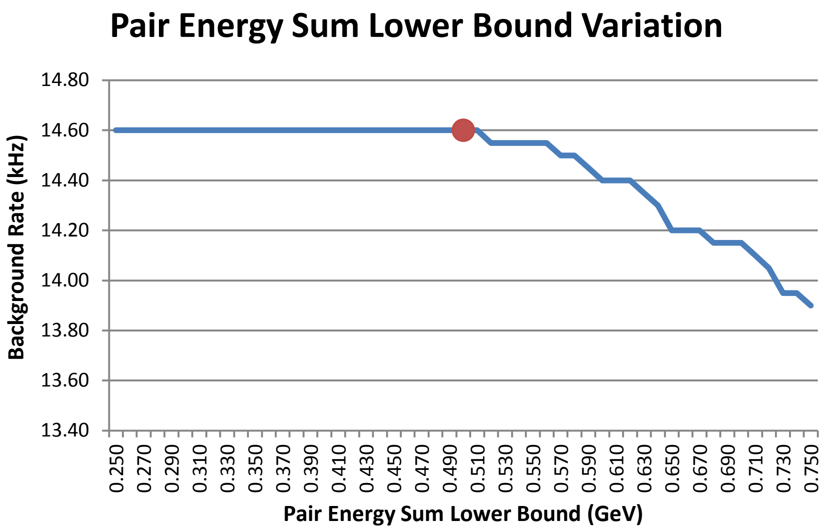


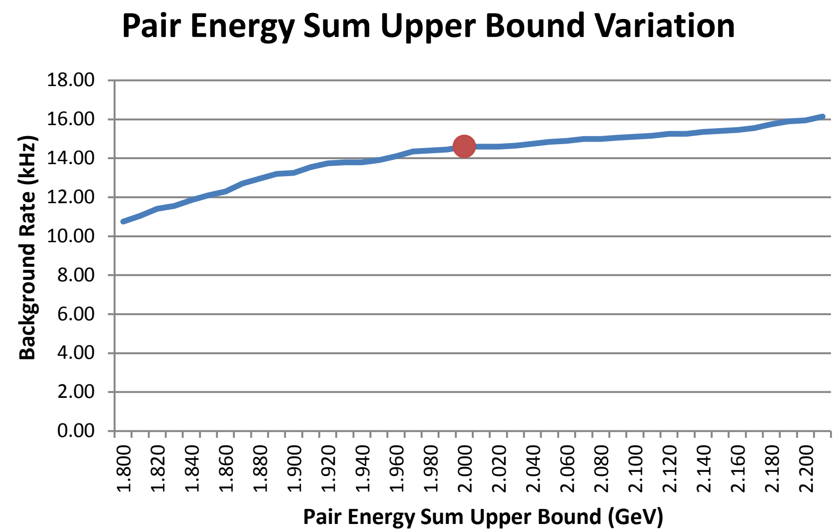


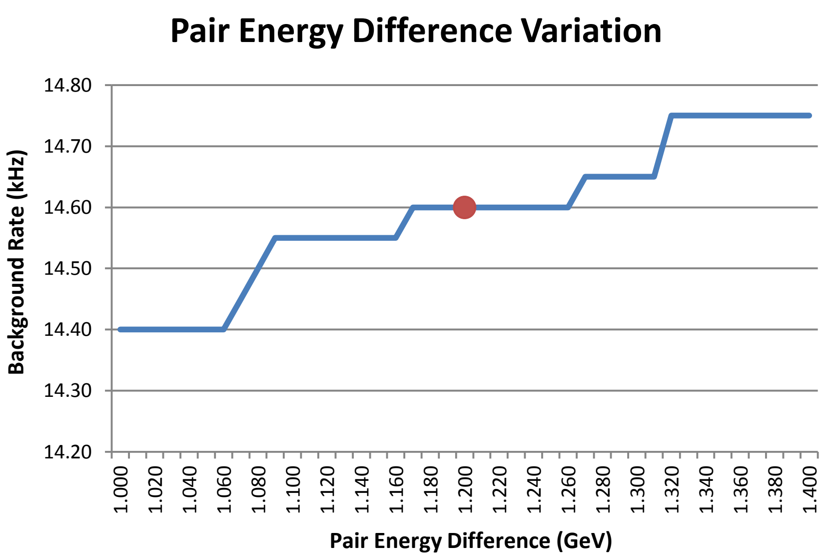


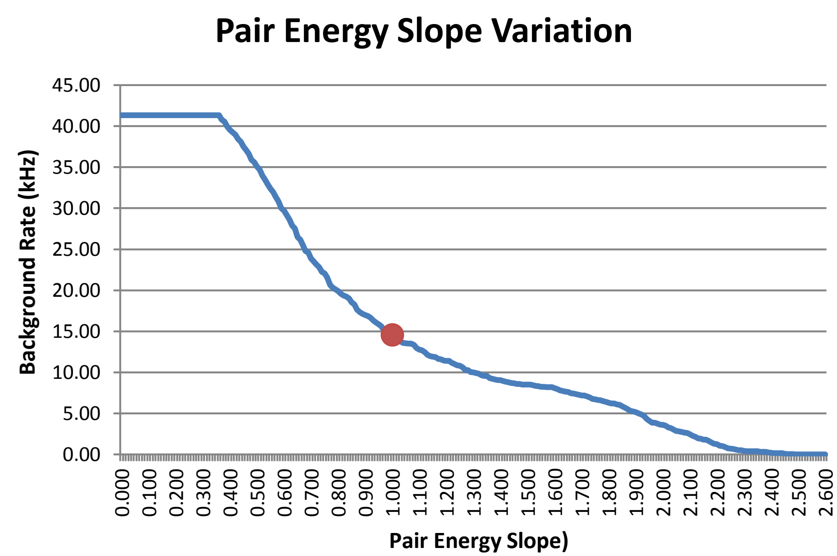


Selecting Cut Values

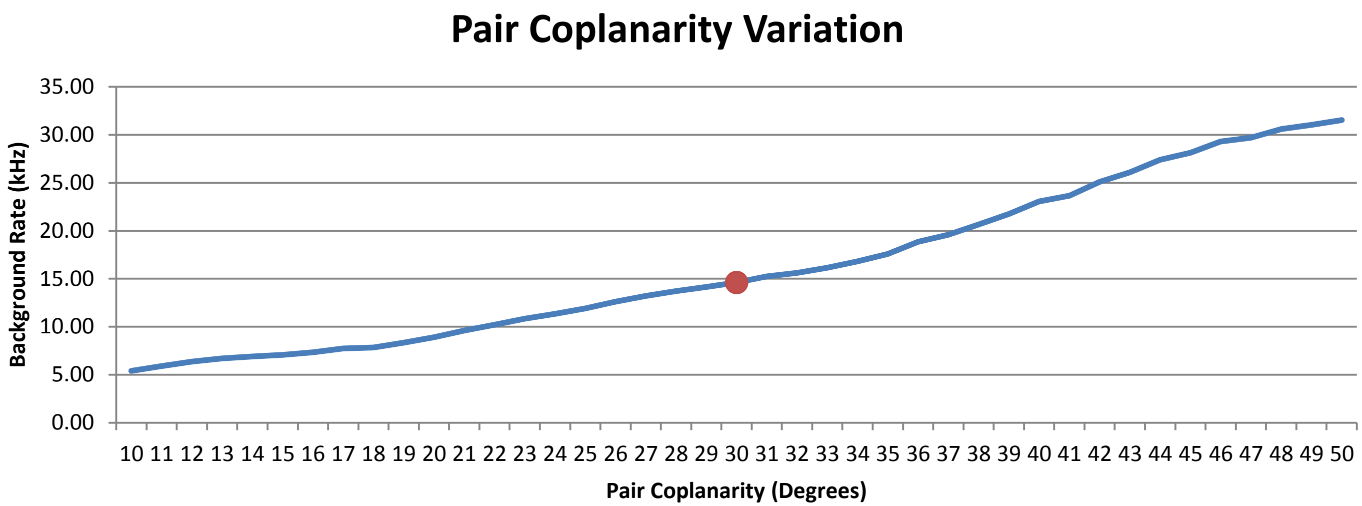


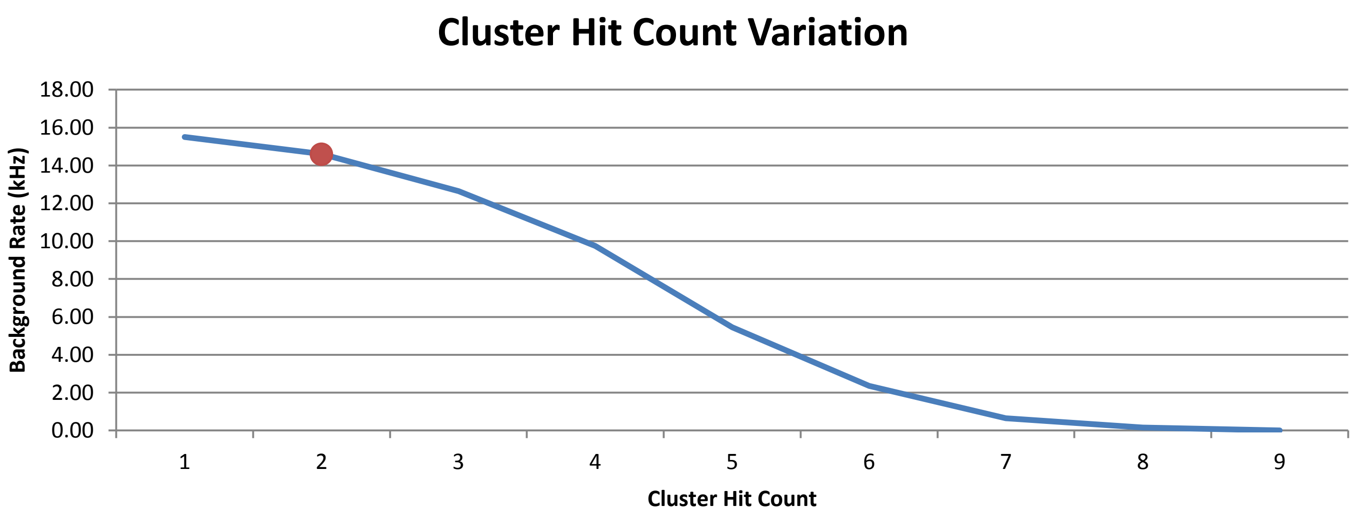






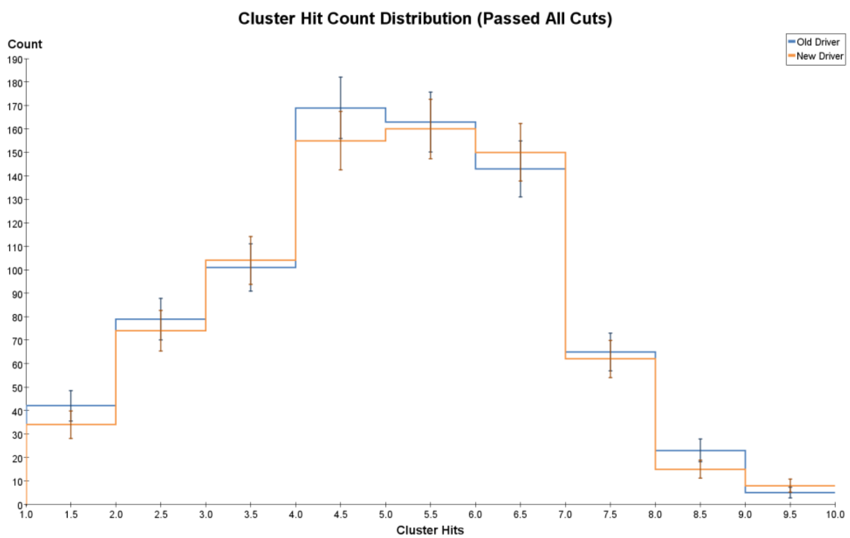
Selecting Cut Values

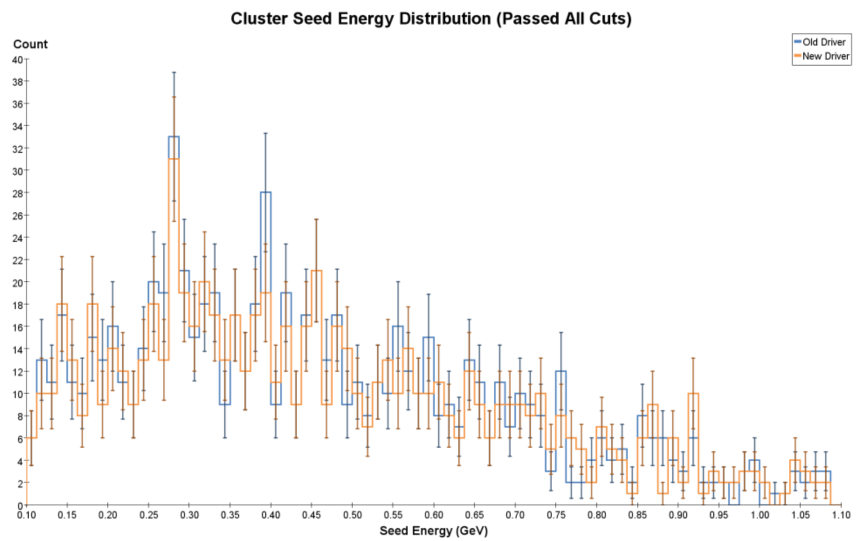




HPS Simulation Status

- The newest version of the trigger with all of the optimized cut values has been written into a driver and is part of the main HPS LCSim build.
- It is represented in the driver [**org.hps.readout.ecal.FADCPrimaryTriggerDriver**].
- The new driver was compared to the old driver by running over 10,000,000 background events and comparing the distribution plots produced by each. These matched to an extremely high degree of accuracy, suggesting that the new driver is properly simulating the trigger cuts.
- Two such comparison plots are included below.





Trigger Diagnostics

- There are six types of diagnostic plots available directly from the hardware.
- Three are produced for each crystal/channel.
    - **Pulses that cross the voltage threshold on FADC and discriminator**
        - A 32 bit value for each channel
    - **Pulse energy on the FADC distribution**
        - A 32 bit value for each of 1024 bins
        - Ranges from 0 MeV to 8192 MeV
    - **Number of crystal seed seen on SSP**
        - A 32 bit value for each crystal
- Three are produced for each half of the calorimeter (top and bottom).
    - **Cluster energy distribution**
        - A 32 bit value for each of 1024 bins
        - Ranges from 0 MeV to 8192 MeV
    - **Cluster hit count distribution**
        - A 32 bit value for each of 8 bins
        - Ranges from 0 hits to 7 hits (Last bin holds clusters with 7, 8, or 9 hits)
    - **Cluster latency**
        - Tracks the amount of time between when a cluster was seen to when a cluster was actually written out to the SSP.

Trigger Diagnostics

- These diagnostics alone are not very robust!

- The hardware additionally tags each event with trigger flags to indicate which triggers the event passed or failed. These are, from Ben Raydo at Jefferson Lab:

DATA:

This data field is specific to the TYPE field and indicates various pass/fail tests:

Cosmic trigger (type 0,1):

DATA(6..0) will be "0000000"

Cluster singles trigger (type 2-5):

DATA(0): 1/0 – pass/fail cluster "E MIN" cut.
DATA(1): 1/0 – pass/fail cluster "E MAX" cut.
DATA(2): 1/0 pass/fail cluster "N HITS MIN" cut.

Cluster pair trigger (6-7):

DATA(0): 1/0 – pass/fail pair "SUM" cut.
DATA(1): 1/0 – pass/fail pair "DIFFERENCE" cut.
DATA(2): 1/0 – pass/fail pair "ENERGY SLOPE" cut.
DATA(3): 1/0 – pass/fail pair "COPLANAR" cut.

Trigger Diagnostics

- With this information it is possible to produce many more plots.
  - By using triggered output, we may generate plots for triggered distributions for all cuts.
  - By using a random trigger, we may generate plots for the distributions which pass a given cut regardless of whether it passes all of the others.

- Additionally, trigger efficiency may be measured by using a random trigger and the trigger flags.
  - All random trigger readout events can have the same cuts performed on them via the software simulation.
  - The results from the software may then be compared to the SSP flags.
  - This information may then be used to either generate a ratio (number of events that should have passed a cut to number that did) or to plot the distributions of those clusters/cluster pairs that match or do not match.
  - From this, we may derive a great deal of insight as to whether the trigger is performing as expected.

Trigger Diagnostics

- Currently, the trigger-specific diagnostic plots are simulated in the FADCPrimaryTriggerDriver class mentioned earlier. Specifically, it simulates:
  - Number of crystal seed seen on SSP
  - Cluster energy distribution
  - Cluster hit count distribution

- The more advanced plots using the SSP trigger flag information has not been implemented into the simulation yet.
  - Support for the SSP trigger flags in the HPS LCIO data is not yet implemented! This needs to be done before the trigger efficiency analysis can be written.