2021 Trigger Analysis

Samantha K. McCarty

Introduction

- HPS is preparing for another experimental run at 3.7 GeV.
  - It is necessary to prepare new trigger settings.

- Several triggers are intended:
  - Positron Trigger (Production Trigger)
  - Full-Energy Electron Trigger (Calibration)
  - Møller Trigger (Calibration)

- The first two triggers are discussed herein.
  - Tongtong will discuss a pair trigger for A’ events and a Møller trigger.

FEE Trigger

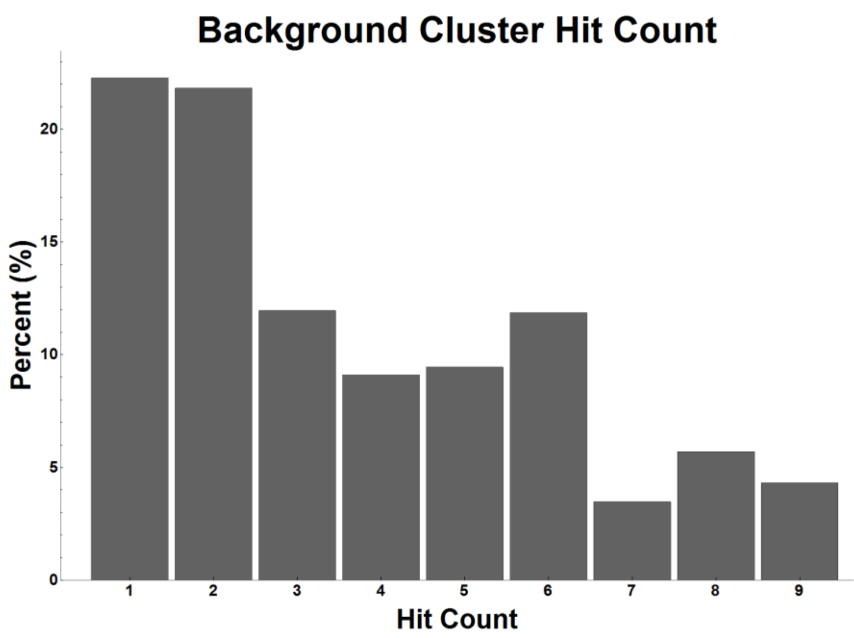
- Full-energy electrons are used for the energy calibration of the calorimeter so it is important to have a selection of full-energy electrons (FEEs) available.

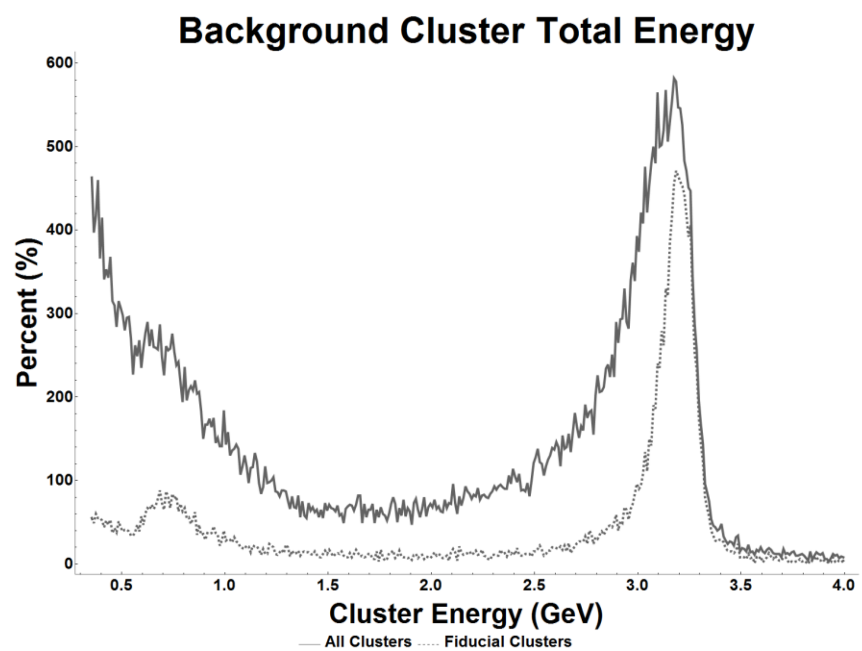
- This is accomplished through a specialized singles triggers. This trigger has:
  - A seed energy lower bound cut.
  - A cluster energy lower and upper bound cut.
  - A hit count cut.
  - A position-dependent prescale.

- To explore this trigger, beam background (tritrig-wab-beam) Monte Carlo is employed. Each beam background event represents a 2 ns beam bunch of standard electromagnetic processes, including FEEs.

FEE Trigger

- The seed energy cut is the same across all of the triggers and is set to 50 MeV.
- The other cuts are studied through the background Monte Carlo.
  - The energy and hit count of every cluster that is seen by the trigger during readout is plotted.





FEE Trigger

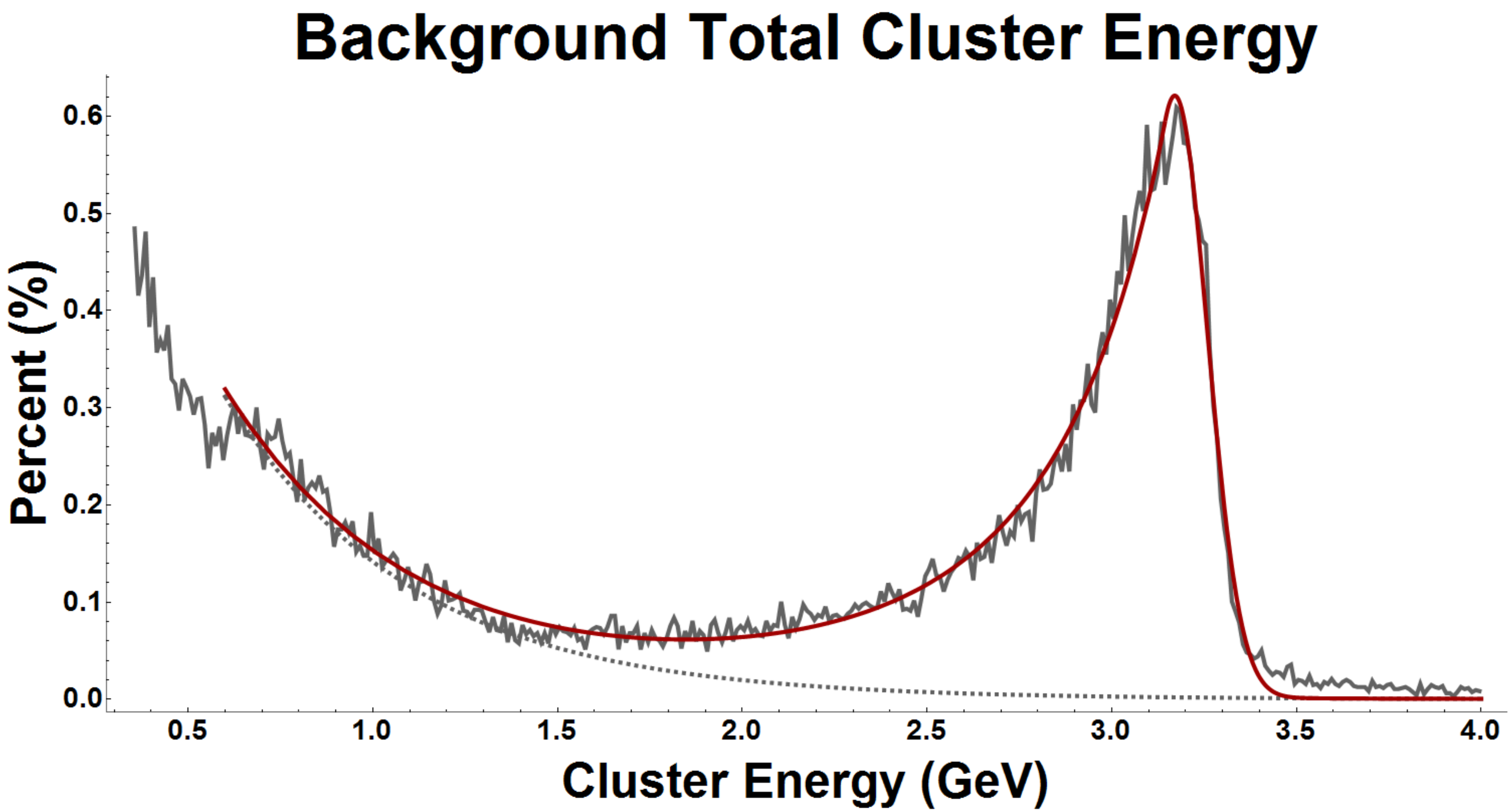
- The cluster energy cut is the easiest to measure. FEEs are expected to be near beam energy.
  - Note that they will be lower at the readout level, since readout clusters are only 3×3 and lack energy corrections.

- The FEE peak is clearly visible at around 3.1 GeV.

- The peak is fit with a function $\zeta(\alpha, n, \mu, \sigma, N;\ E) + A\, e^{-E/m}$
  - $\zeta(\alpha, n, \mu, \sigma, N;\ x)$ is a crystal ball function with E as energy and all other parameters decided by the fit. It represents the peak.
  - $A\, e^{-E/m}$ is a decaying exponential with E as energy and all other parameters decided by the fit. It represents the background.

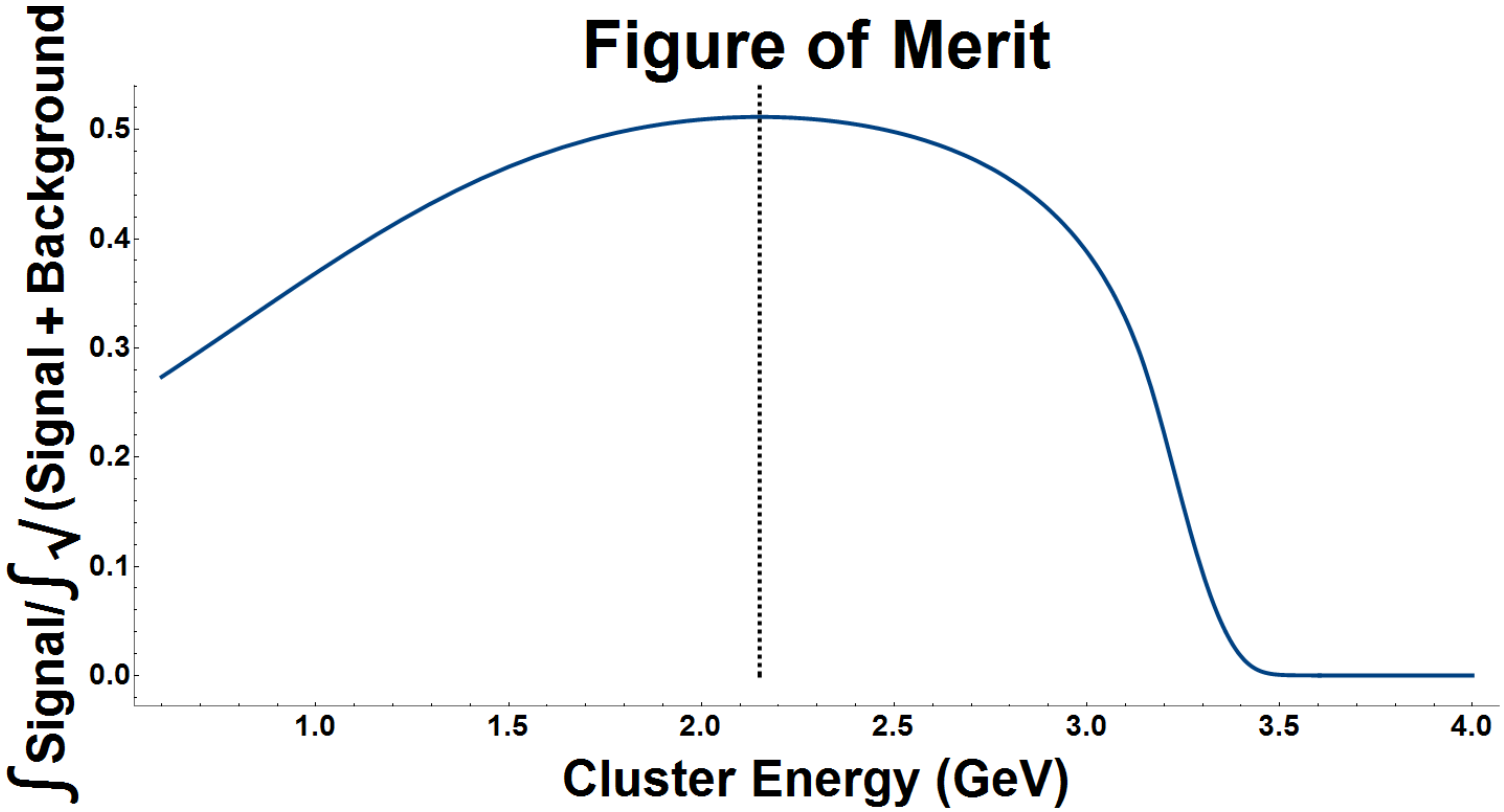
FEE Trigger

- The background-only (gray) and background + signal (red) fits are shown.



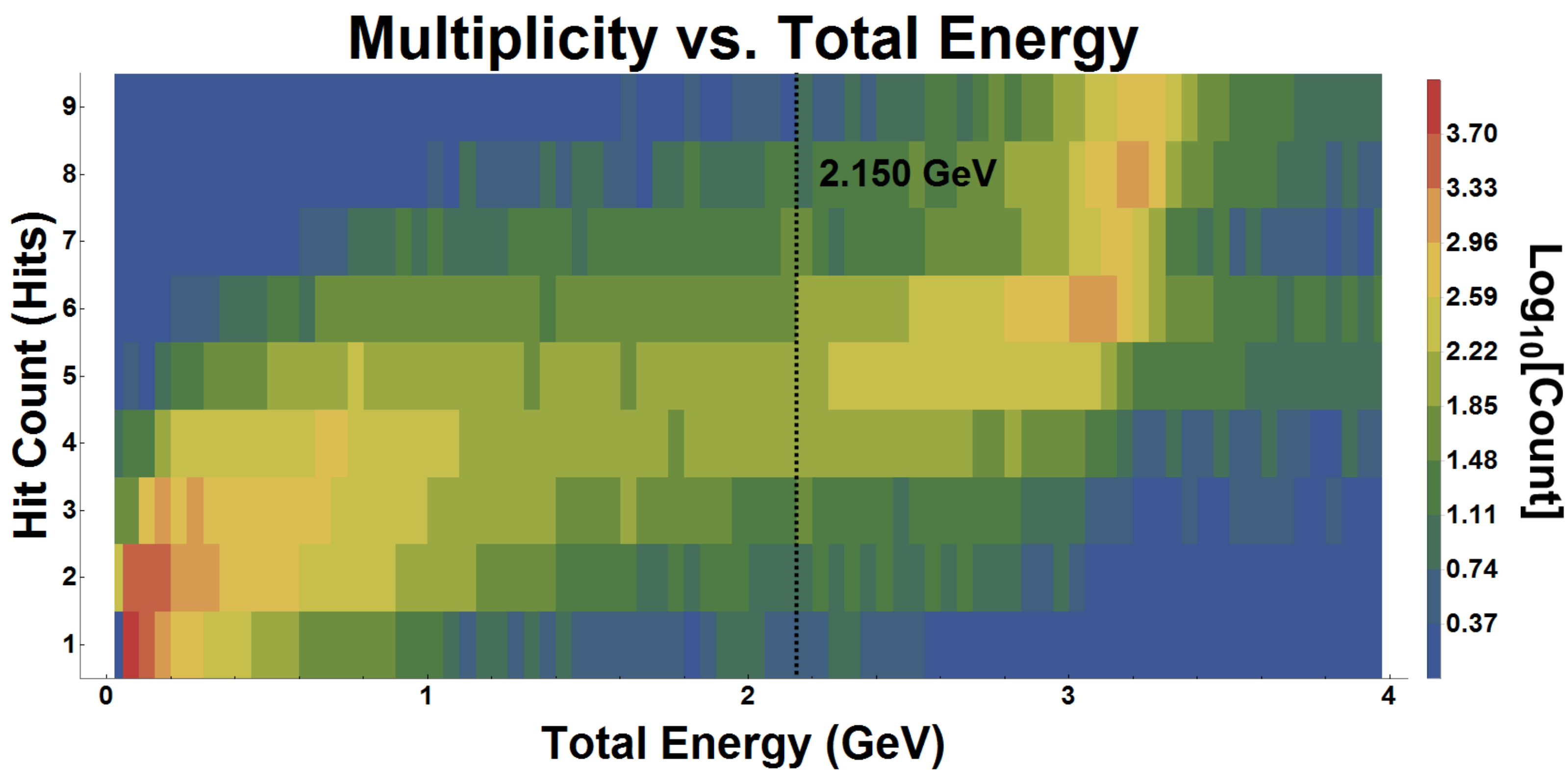
FEE Trigger

- A figure of merit is defined as $\int \mathrm{Signal} / \int \mathrm{Signal} + \mathrm{Background}$ to select the optimal energy cut, which is found to be 2.150 GeV.



FEE Trigger

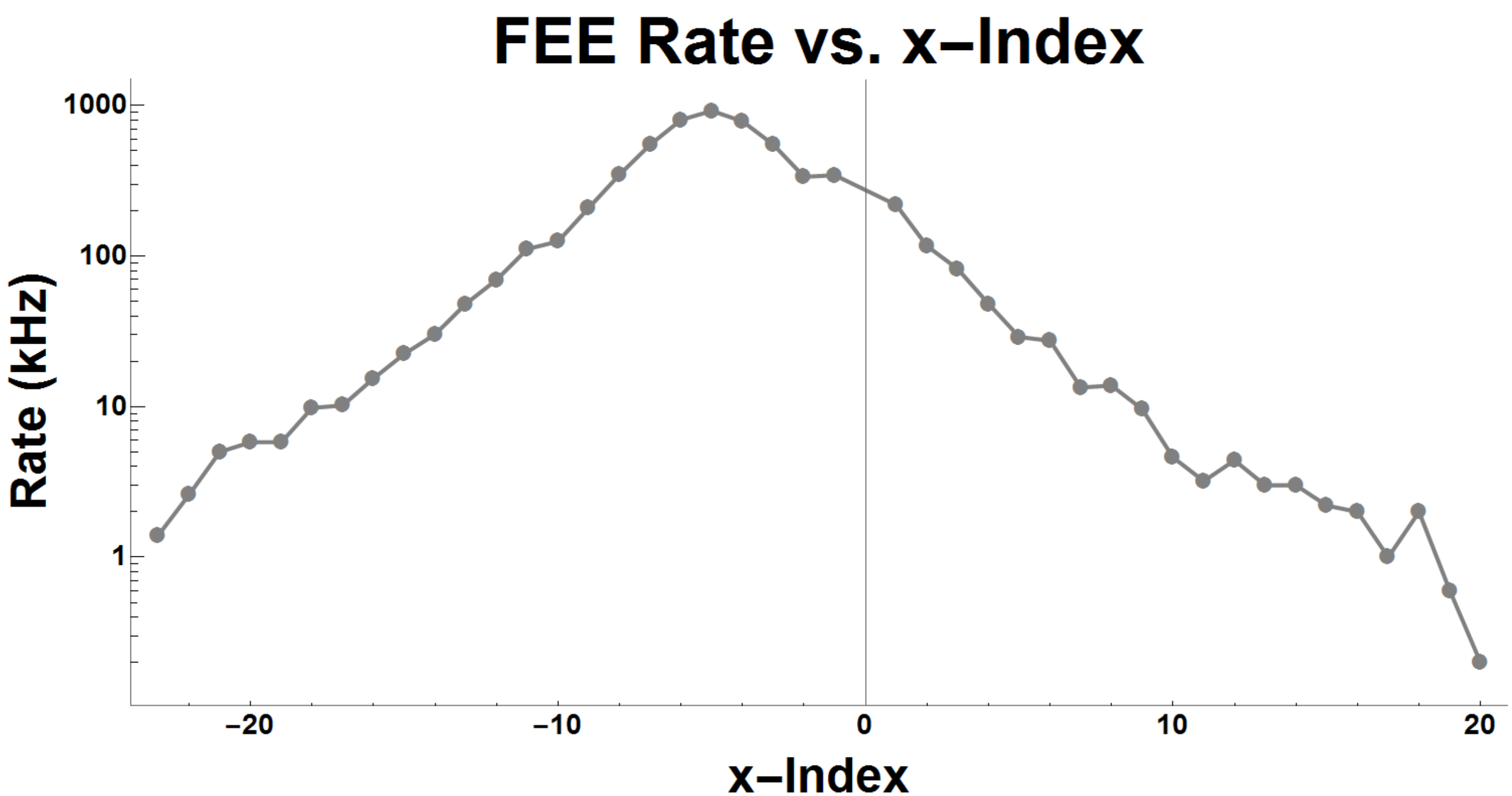
- The cluster hit count is highly correlated to the cluster energy, so it is useful to look at the cluster hit count as a function of energy.



- There is little below $N = 3$, making this a safe cut. This cut may also be lowered or ignored since the energy cut largely obviates the need for it.

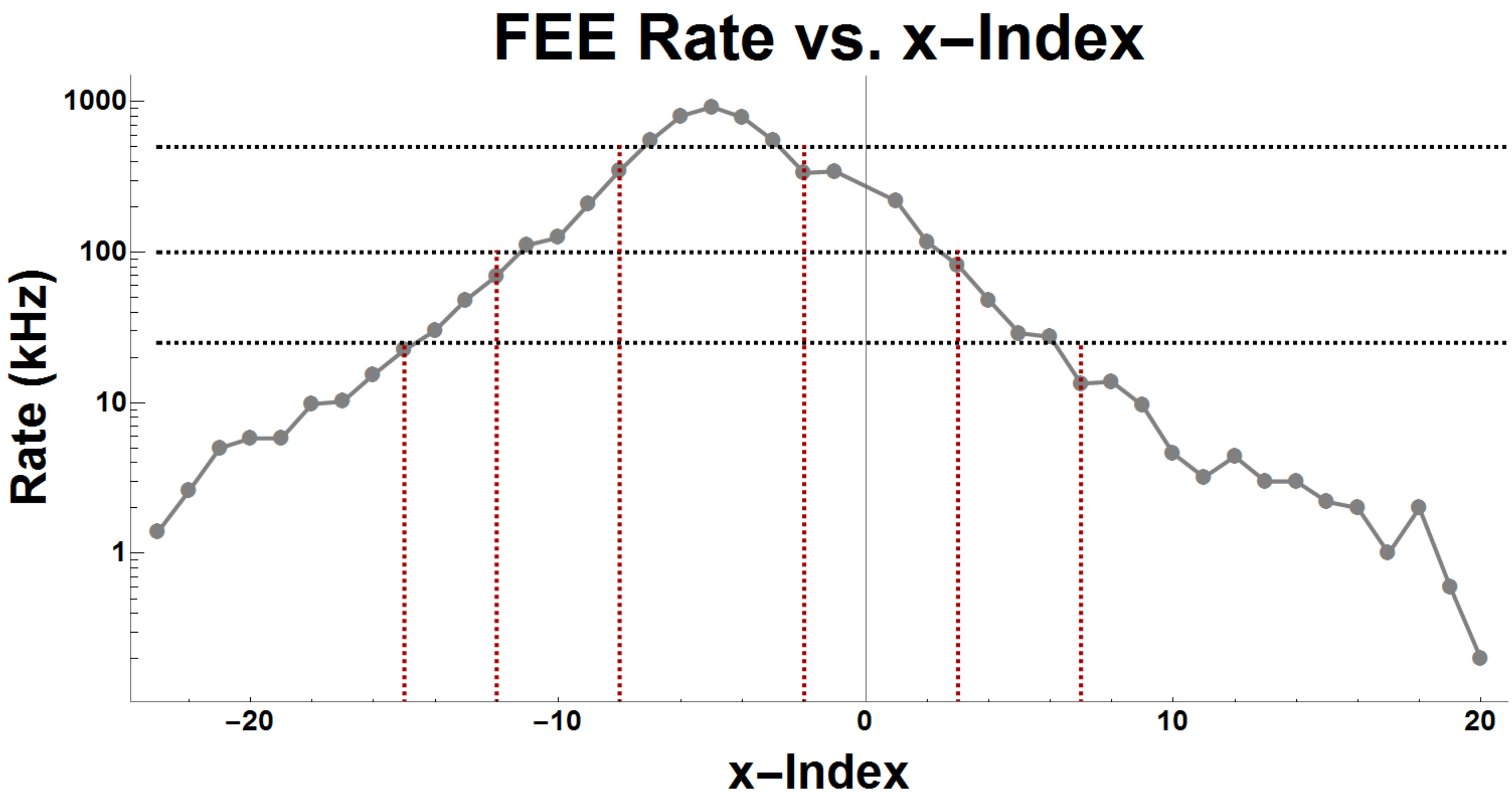
FEE Trigger

- The rate of FEEs at each calorimeter y-index may be approximated.
- This is not reliable as an exact value, but the general prescale regions may be selected.



FEE Trigger

- Regions are: [-23, -15], [-14, -12], [-11, -8], [-7, -1], [-2, 2], [3, 6], [7, 23]



FEE Trigger

- The FEE trigger is defined as follows:
  - $E \geq 2.150$ GeV
  - $N \geq 3$
  - Pre-scale regions [-23, -15], [-14, -12], [-11, -8], [-7, -1], [-2, 2], [3, 6], and [7, 23]

- NOTE: There are differences between the observed data values and the Monte Carlo values for readout cluster energy distributions.
  - Tongtong will discuss how to convert between the Monte Carlo results to more data-applicable values.

Positron Trigger

- The primary goal of HPS is to detect e^+e^- trident decays. Since 2019, this is done through the positron trigger.

- The positron trigger has several cuts:
    - Cluster seed energy lower bound.
    - Cluster energy lower and upper bounds.
    - Cluster hit count lower bound.
    - Position-dependent energy cut.
    - Hodoscope layer-to-layer correlation.
    - Hodoscope-to-calorimeter correlation.

- The positron trigger is tuned on pure A’ Monte Carlo of masses from 50 MeV to 190 MeV.

Positron Trigger

- In order to optimally tune the positron trigger, it is useful to select only those events which can actually be analyzed. These are referred to as "analyzable events" and are defined as follows:
    - Must have a positive and negative track.
    - Both tracks must have $\chi^2 < 20$.
    - The positive track must match to a cluster.

- The lattermost requirement is not strictly necessary for analyzability, but is needed for the trigger to actually register the event.

- Before any analysis may begin, the A' Monte Carlo must be prepared.

Positron Trigger

- Since tracks are needed for the planned analysis, it is necessary to run the A' Monte Carlo through both readout and reconstruction.
    - This induces a complication, however, as readout requires a trigger.

- Since it is important to induce no bias in the output data, a "dummy trigger" that accepts any event with a cluster of at least $E_{\text{cluster}} \geq 50\ \text{MeV}$. No clusters of lower energy would be viable, so the rejected events are irrelevant.

- Additionally, all A' events are spaced so that they are treated completely independently of one another by the readout simulation.

- Next, track/cluster-matching criteria are established.

Positron Trigger

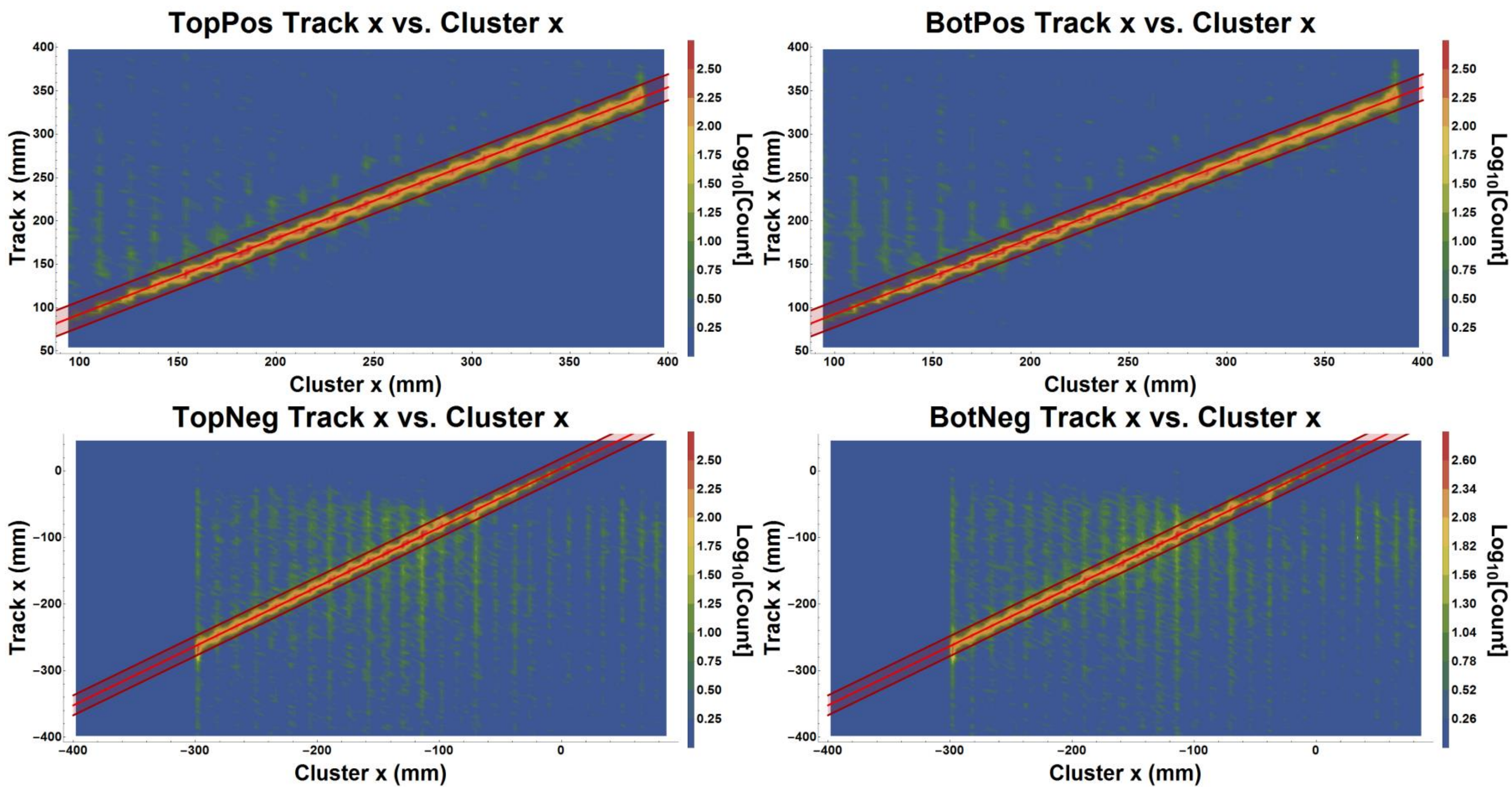
- To establish track/cluster-matching criteria, each A’ track’s x-position is plotted against the x-position of all possible clusters. The same is repeated for the y-position.
    - It is expected that actually correlated tracks and clusters will produce a peak in the distribution while random matches will be roughly equally distributed.

- This process is performed separately for all permutations of top/bottom and positive/negative tracks.

- Initial matching is performed for 80 MeV A’ data, but is checked against all other masses to ensure that it is still valid.

Positron Trigger

- Examples of correlation plots and matching criteria for x-position for A' data of 80 MeV.



Positron Trigger

- The following matching criteria are established:
  - For track/cluster x-position:
    - Positive Tracks: $(0.873x + 5) \pm 15$
    - Negative Tracks: $(0.890x + 4) \pm 15$
  - For track/cluster y-position:
    - Top Tracks: $(0.97y - 3) \pm 20$
    - Bottom Tracks: $(0.97y + 3) \pm 20$

- These correlations will be applied subsequently any time a track needs to be matched to a readout cluster for the positron trigger analysis.

- The fit line slope is less than 1 because the tracks are extrapolated to the calorimeter face, but hit positions are reported at the geometric center of the crystals. This creates a skew.

Positron Trigger

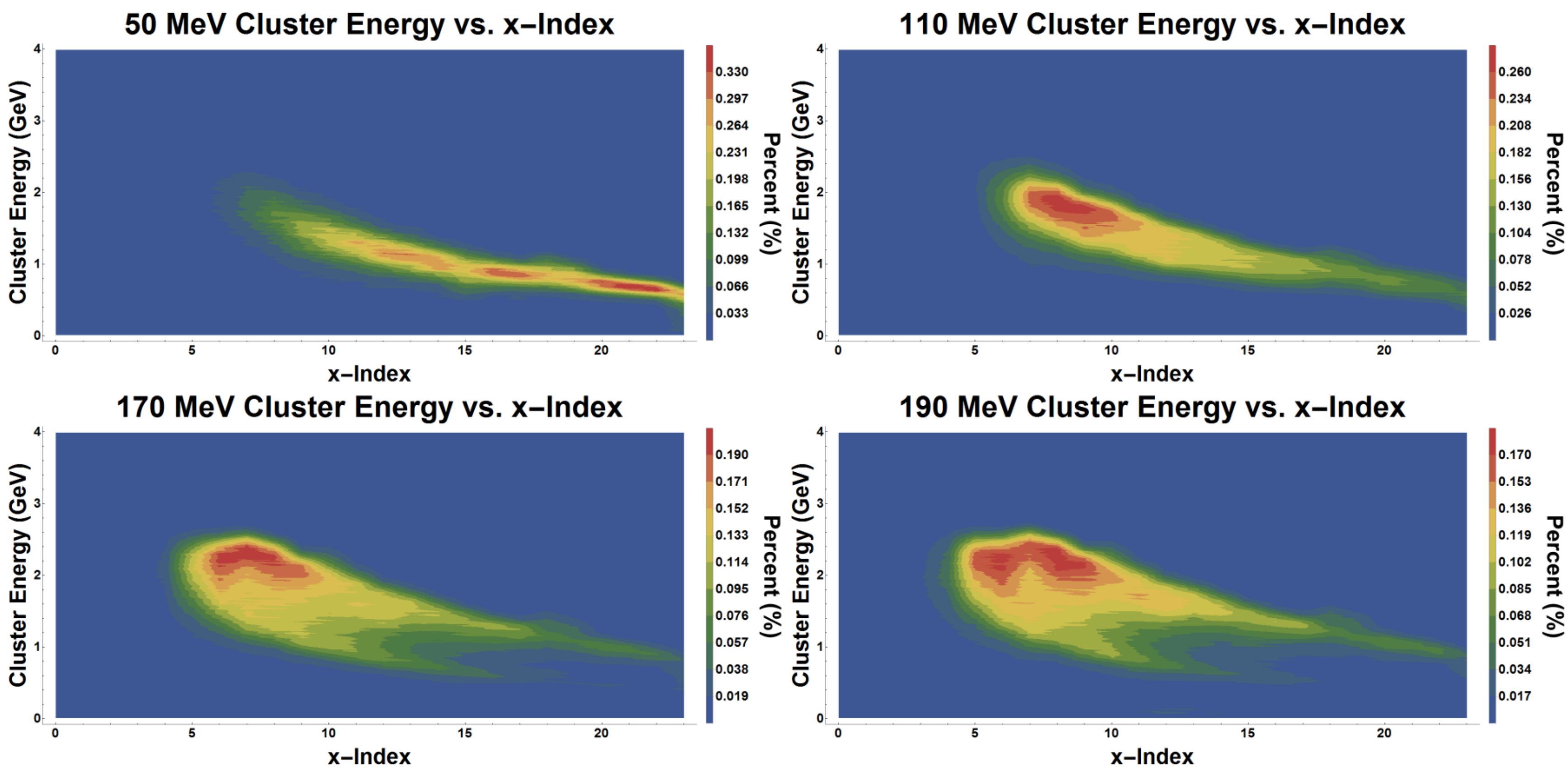
- With the Monte Carlo processed through reconstruction and track/cluster-matching defined, trigger analysis may begin.

- The first cut to be determined for the positron trigger is the position-dependent energy cut. This cut is composed of two parts.
    - A minimum crystal x-index.
    - A cluster energy lower bound that is a function of crystal x-index. This takes the form of an $\mathcal{O}(3)$ polynomial with coefficients $p_0 \ldots p_3$.

- To study this cut, an energy versus position plot is created for all positive tracks which are matched with a cluster for each A' mass.

Positron Trigger

- A sample of the energy vs. position distributions for four A' masses are depicted in the plots below.



Positron Trigger

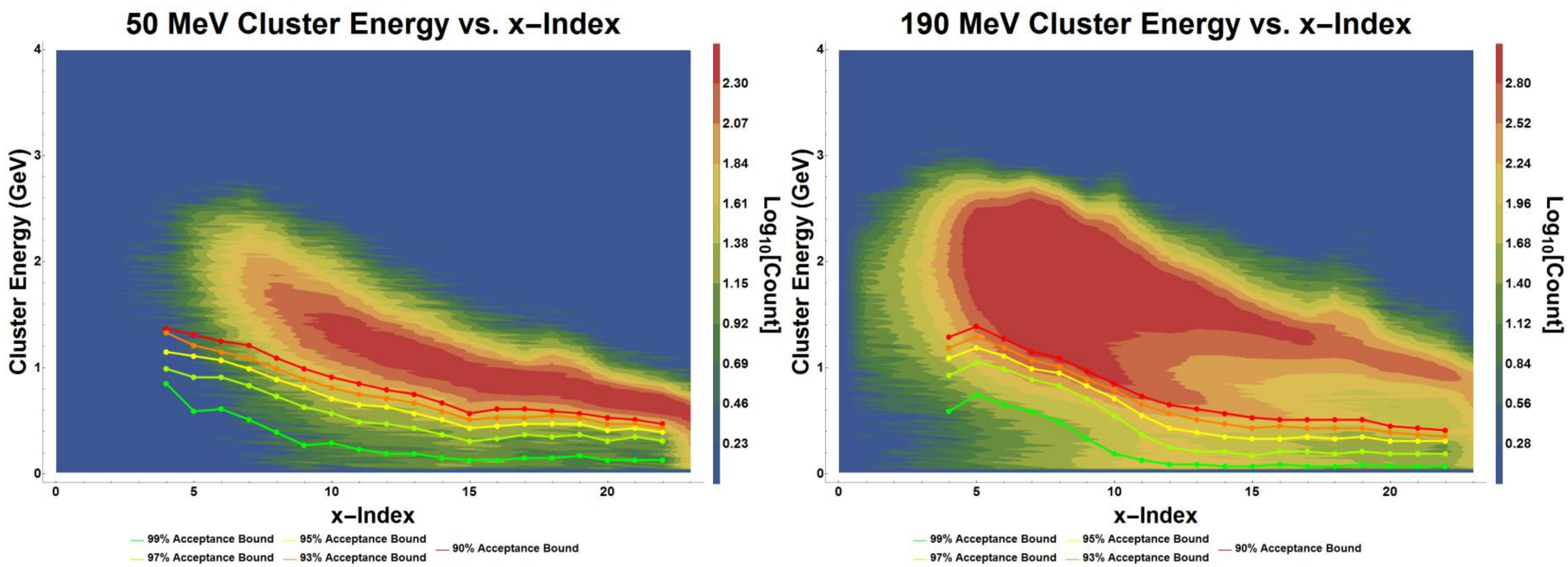
- With the energy vs. position distributions established and their irregularities characterized, it is necessary to select an $\mathcal{O}(3)$ polynomial for the position-dependent energy cut.

- Since the A' mass is unknown, it desirable to select a cut that retains events for both the low mass (50 MeV) and high mass (190 MeV) distributions.

- For each value of ix, the energy at which 90%, 93%, 95%, 97%, and 99% of events fall above said point is determined for both 50 MeV and 190 MeV.
  - This is safe – all masses in between are intermediate steps between these two distributions.

Positron Trigger

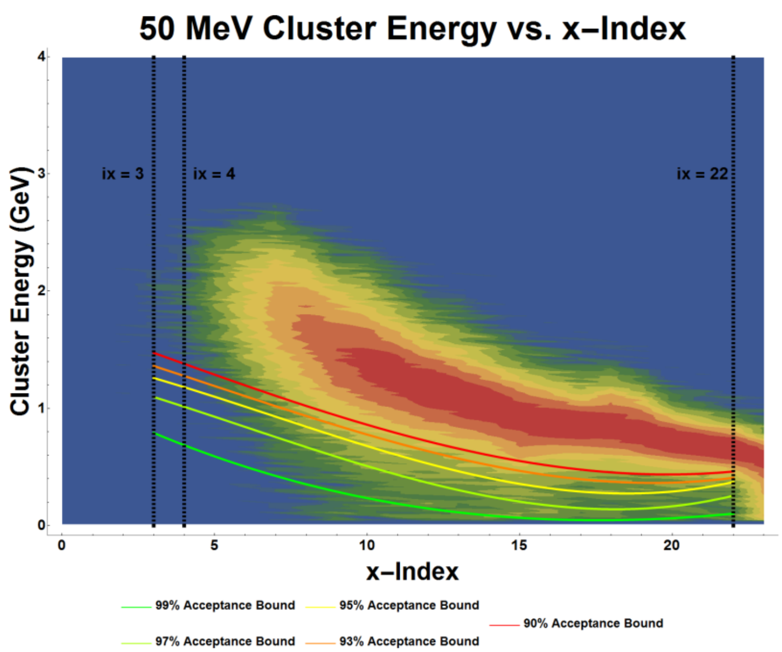
- The results are plotted against both the 50 MeV and 190 MeV energy vs. position distributions below.

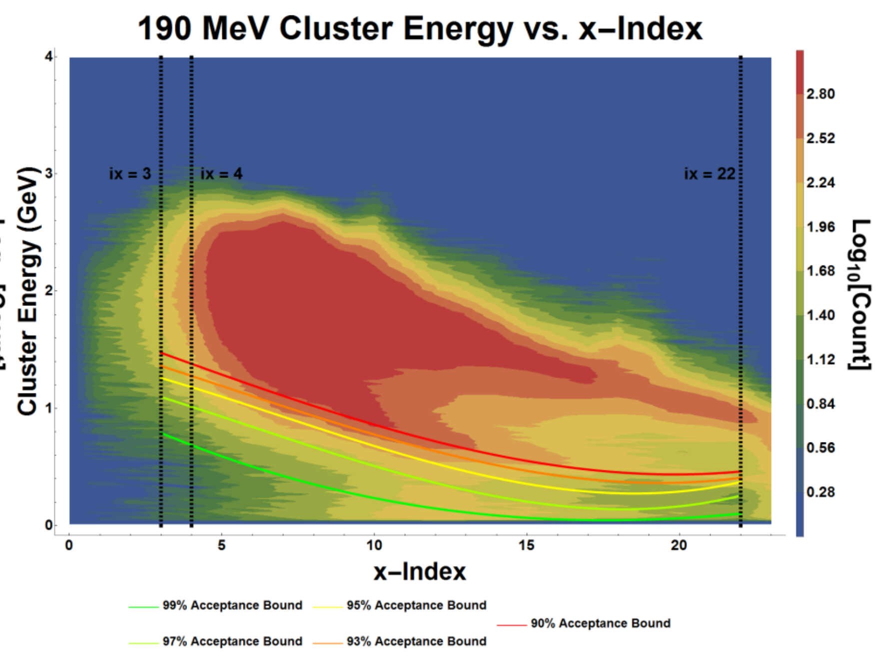


- Next, the smallest value for energy at each x-index is selected to ensure that the final result is inclusive of both extremes.
- This combined set of points is then fit with an $\mathcal{O}(3)$ polynomial.

Positron Trigger

- The fitted results are shown.





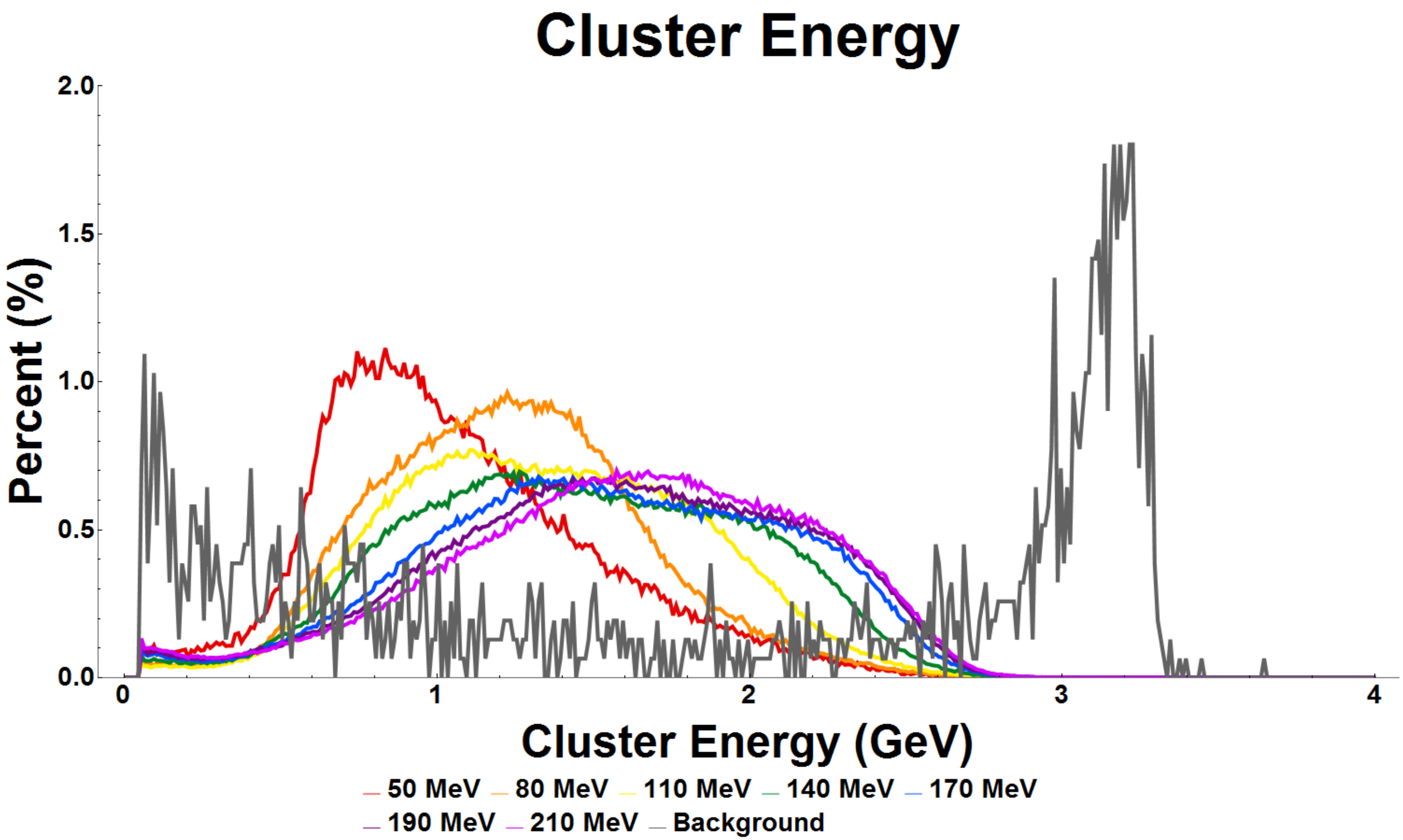
Parameter	90%	93%	95%	97%	99%
p_0	1.757145	1.604112	1.459266	1.322087	1.158917
p_1	-0.093213	-0.075760	-0.055345	-0.066244	-0.136559
p_2	-0.000654	-0.002093	-0.004392	-0.003456	0.004737
p_3	0.000101	0.000139	0.000212	0.000194	-0.000032

Positron Trigger

- The cluster energy and hit count cuts are set next.
- The background Monte Carlo used for the FEE trigger is used again.
- As with before, all clusters that are received by the trigger simulation are plotted, except this time they are filtered so that only those which pass the position-dependent energy cut are considered.

Positron Trigger

- The primary cluster energy background is at low and high energy.



Positron Trigger

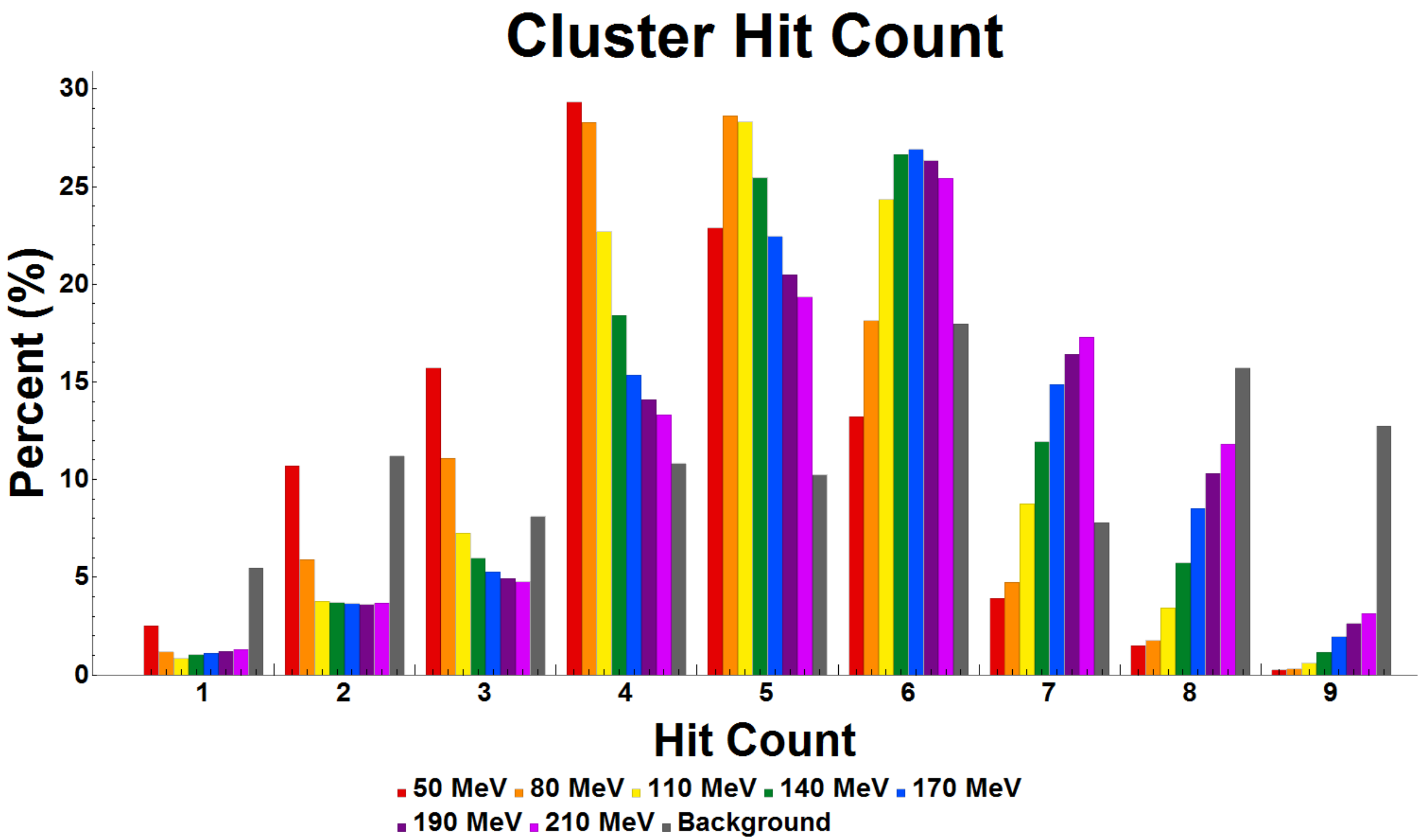
- FEEs can be largely eliminated by a cluster energy upper bound cut. $E_{\text{cluster}} \leq 2.700\ \text{GeV}$ retains almost all A' events but cuts most of the FEEs.

- Lower energy noise may be mostly eliminated with a cluster energy lower bound cut of $E_{\text{cluster}} \geq 0.400\ \text{GeV}$.

- Positron Trigger Cluster Energy Cut: $400\ \text{MeV} \leq E_{\text{cluster}} \leq 2{,}700\ \text{MeV}$

Positron Trigger

- Background dominates at low and high cluster hit count.



Positron Trigger

- Since there is only a hit count lower bound, the high hit count FEE background can not be treated with this cut.
    - This is okay – it is basically eliminated with the cluster energy cut.

- Background dominates notably at $N = 1$. It is also significant at $N = 2$, but so is A' data.
    - $N \geq 2$ does not significantly affect A' acceptance, and eliminates much background, so it is a safe cut.

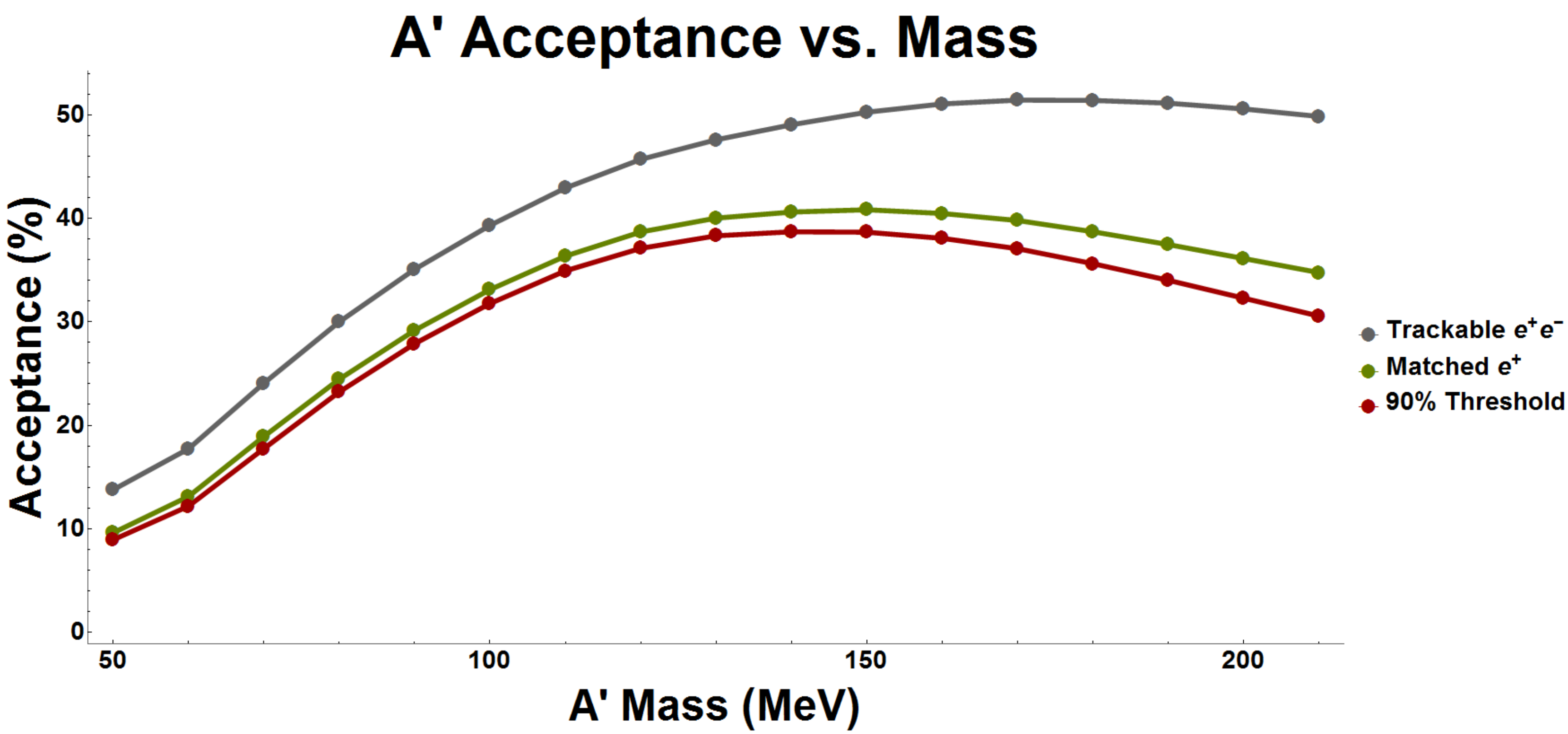
- Positron Trigger Hit Count Cut: $N_{\text{cluster}} \geq 2$

Positron Trigger

- With the calorimeter portion of the positron trigger settled, it is useful to consider the acceptance of trigger.
- First, the percentage of A’ Monte Carlo events that are retained by the trigger are considered.
- Here, “trackable events” (events with an positive and negative track), “matched events” (trackable events where the positive track is matched to a cluster), and triggered events (matched events which pass the “90% trigger”) are plotted.

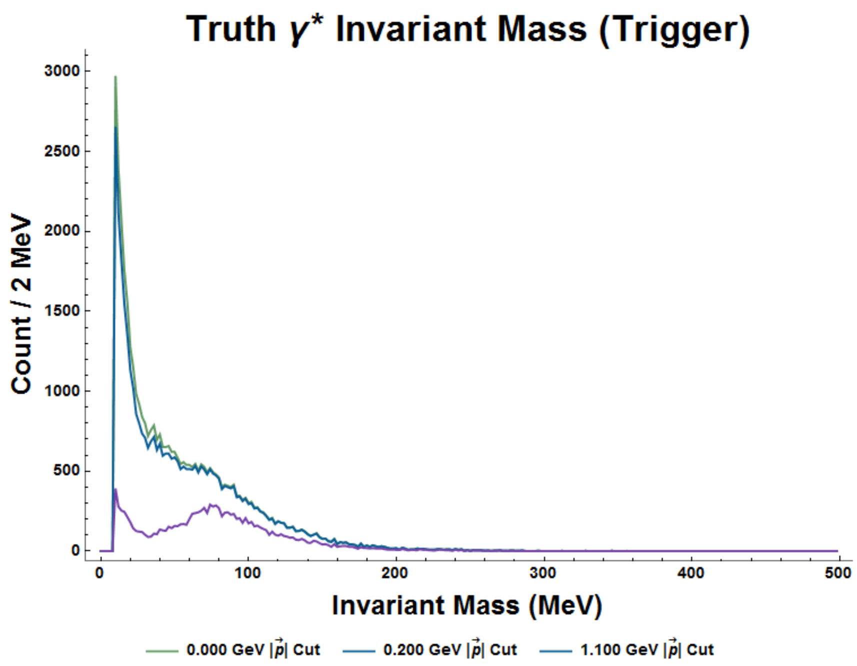
Positron Trigger

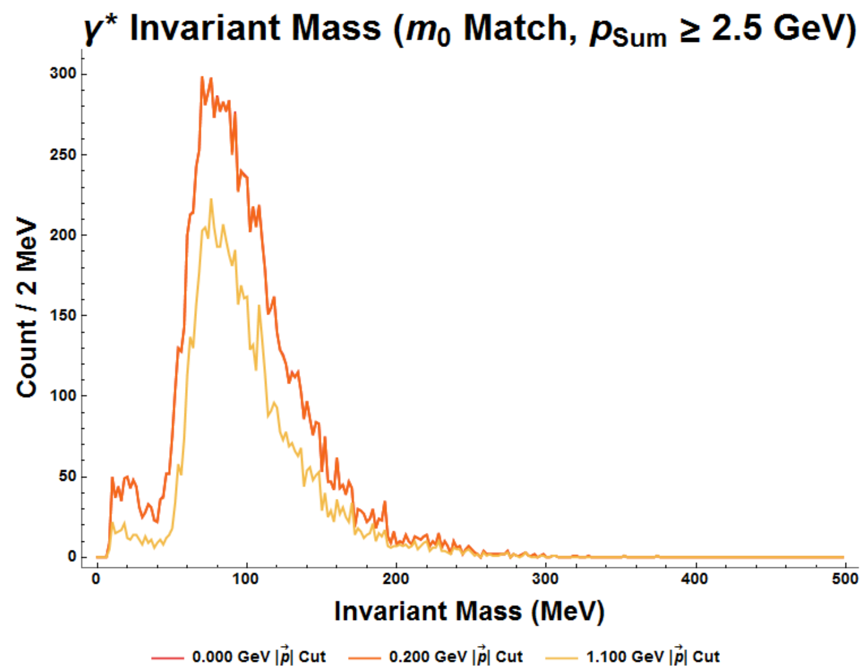
- A’ acceptance peaks at 170 MeV, but remains fairly solid event at higher masses. Acceptance at lower masses is fairly poor.



Positron Trigger

- However, while this measures the likelihood of capturing an A' event of a given mass if it occurs, it does not indicate the likelihood of such an event occurring in the first place.
- To study this, the acceptance of radiative tridents is plotted instead.





Summary

- The FEE trigger is defined as follows:
  - $E \geq 2.150$ GeV
  - $N \geq 3$
  - Pre-scale regions [-23, -15], [-14, -12], [-11, -8], [-7, -1], [-2, 2], [3, 6], and [7, 23]

- The positron trigger is defined as follows (with loosest trigger):
  - $E \geq 1.158917 - 0.136559x + 0.004737x^2 - 0.000032x^3$
  - $400 \text{ MeV} \leq E \leq 2{,}700 \text{ MeV}$
  - $N \geq 2$

- It is expected that y^* events at 90 MeV will be most common. Higher mass ($m_{y^*} \geq 190$ MeV) and lower mass ($m_{y^*} \leq 70$ MeV) will be rare.