Trigger Tuning for Moller and A' Pair of 3.7 GeV Beam

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HPS Collaboration Meeting

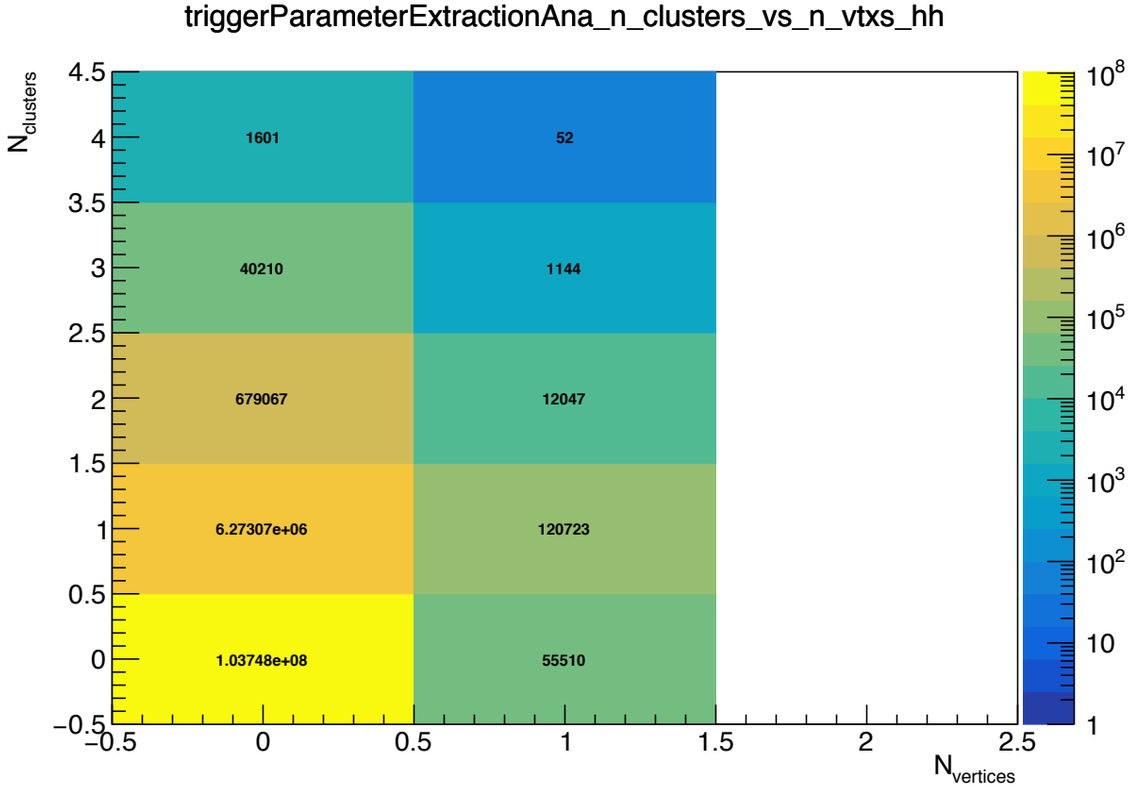
June 23-25, 2021

Outline

- Trigger tuning for Moller
- Trigger tuning for A’ pair
- Comparison of GTP cluster energy between hardware and readout
- Correction of trigger cut conditions based on ratios of GTP cluster energy between hardware and readout
- Summary

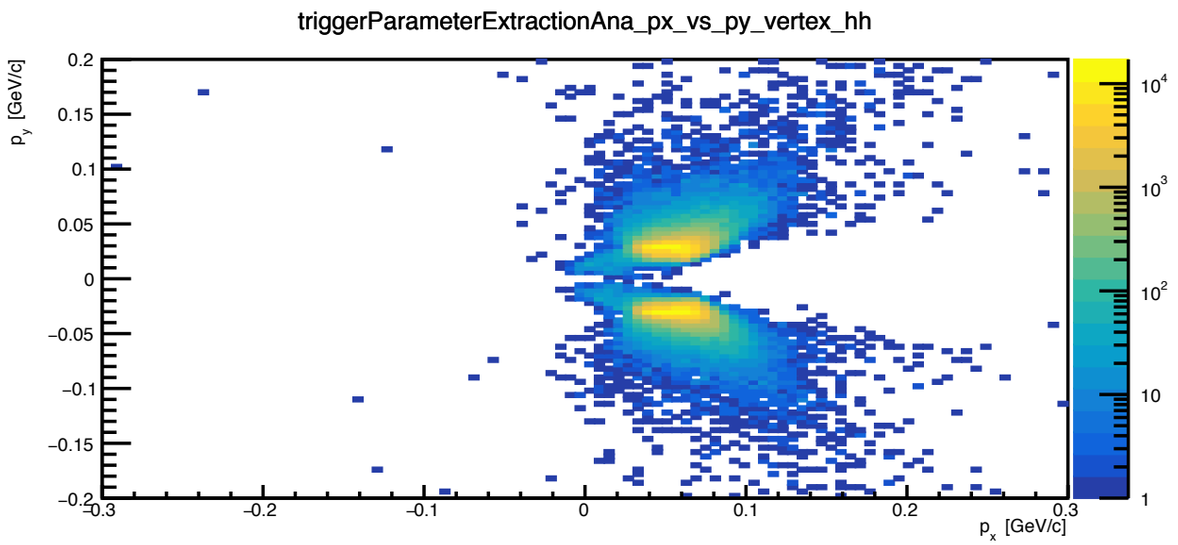
Pure Moller

Discussion for Acceptance

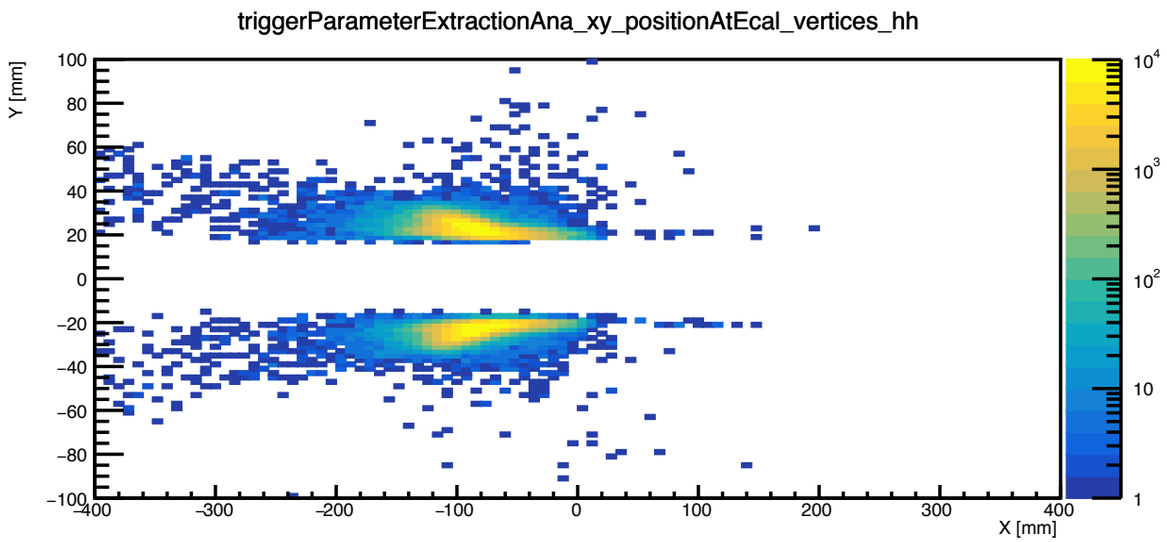


- For events with reconstructed vertex, most include one cluster, some have no cluster, and only small part include two clusters.
- For most of Moller events, one/two tracks within SVT acceptance pass through Ecal hole/gap.
- Therefore, pairs trigger is not suggested for Moller.
- Trigger with single cluster is tuned for Moller.

px vs. py for tracks from vertex



Extrapolation at Ecal face for tracks from vertex

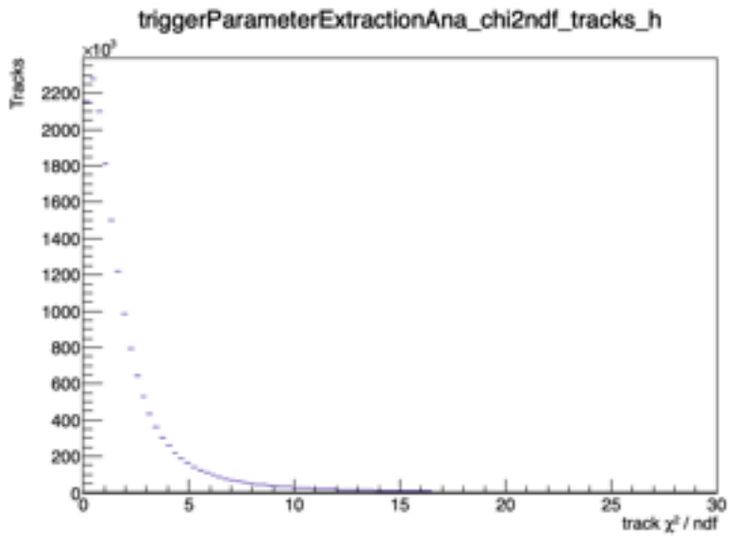


Basically, tracks with negative initial px are not detected. py is small, so that Ecal clusters are mostly distributed near gap.

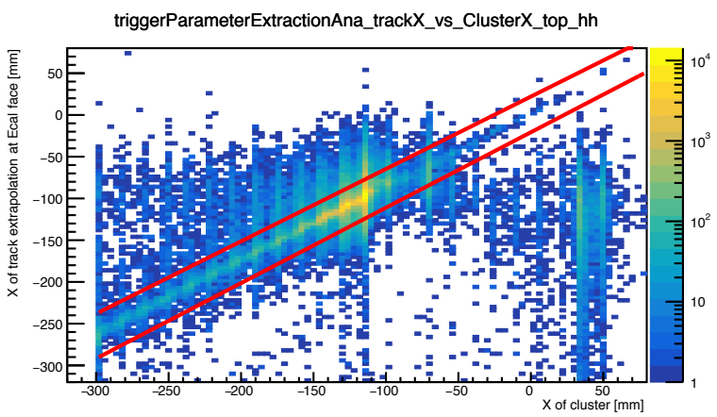
Pure Moller

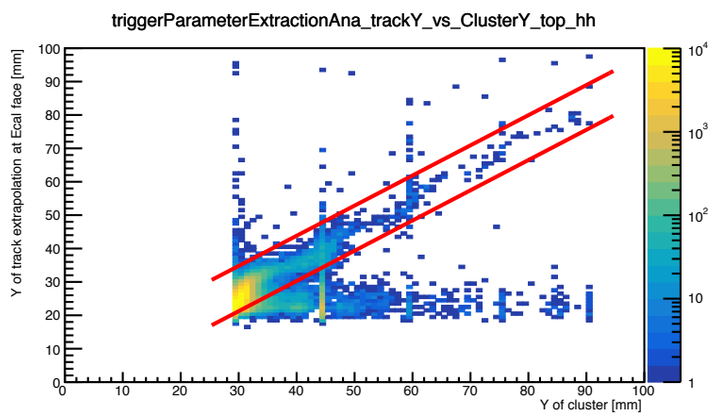
Analyzable events for Moller Trigger Tuning

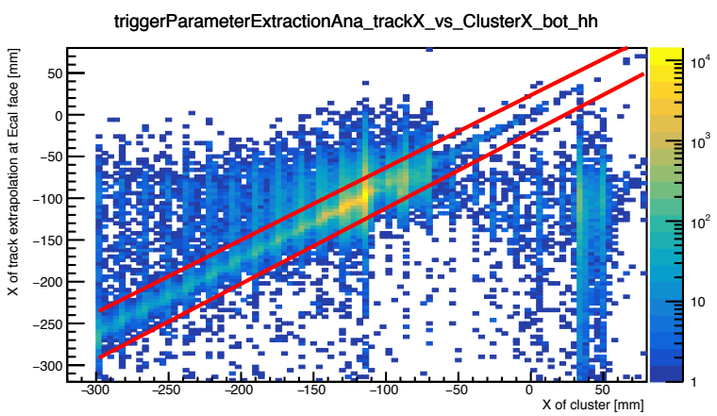
- Analyzable events include at least one top and one bot tracks with Chi2/NDF less than 20 and negative charge.
- Clusters are selected by track-cluster matching.
- Selected clusters include at least one cluster with energy larger than 100 MeV.

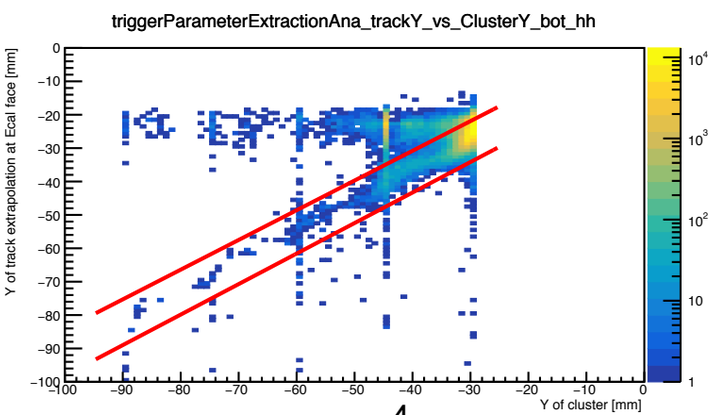


track-cluster matching



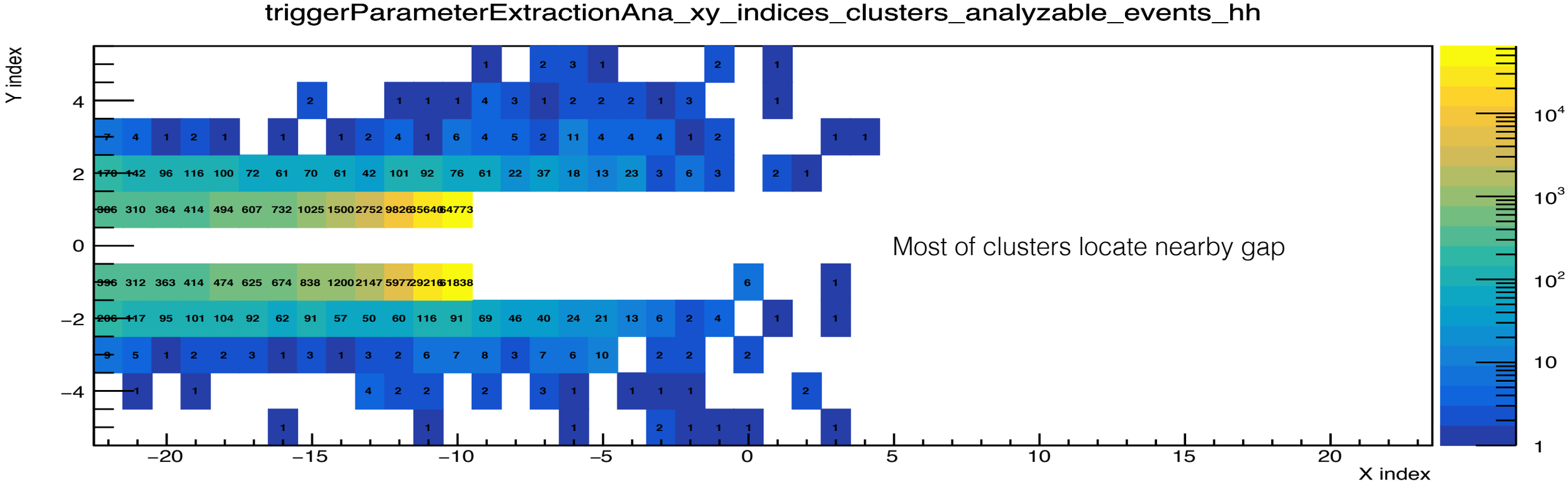


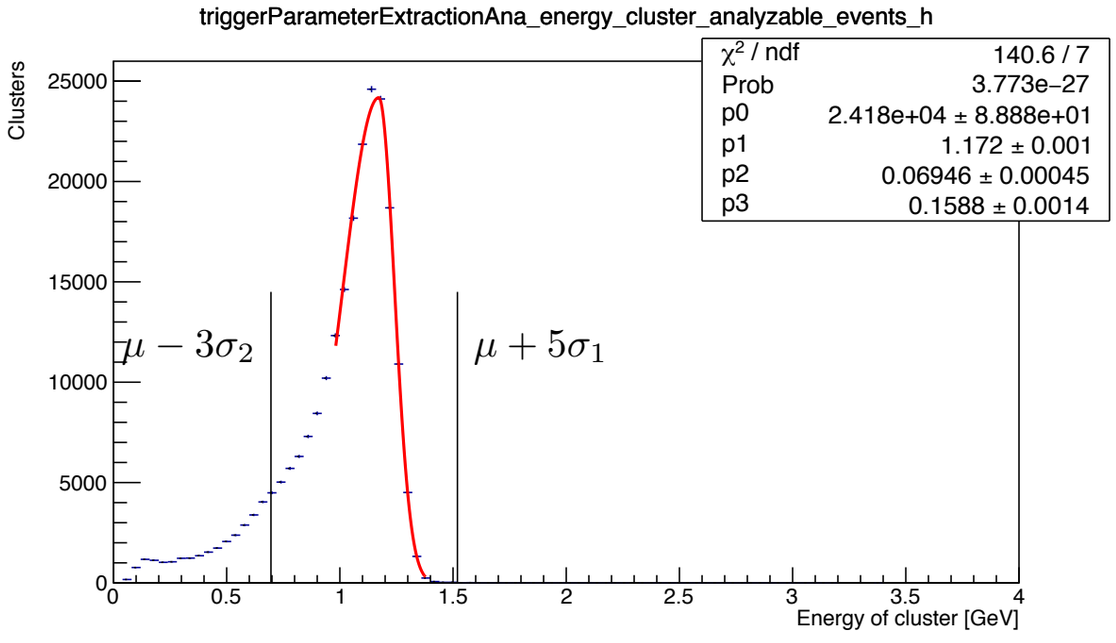




Pure Moller

X vs. Y and Energy Range





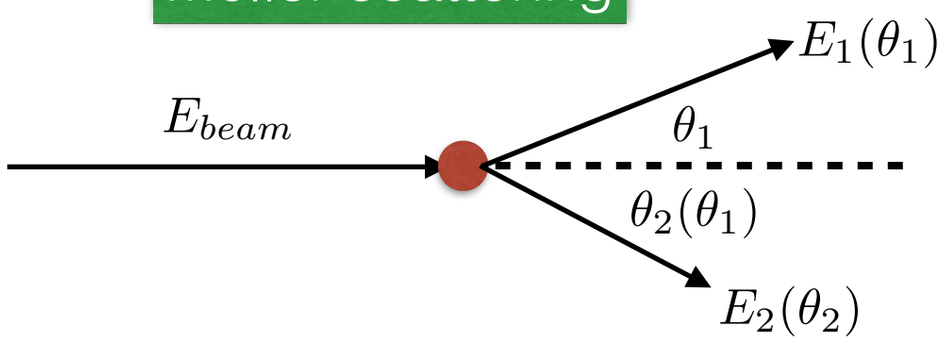
Fit function: Double Half Gaussians Adjoint

$$f(x) = \begin{cases} Ae^{-\frac{(x-\mu)^2}{2\sigma_1^2}} & (x >= \mu) \\ Ae^{-\frac{(x-\mu)^2}{2\sigma_2^2}} & (x < \mu) \end{cases}$$

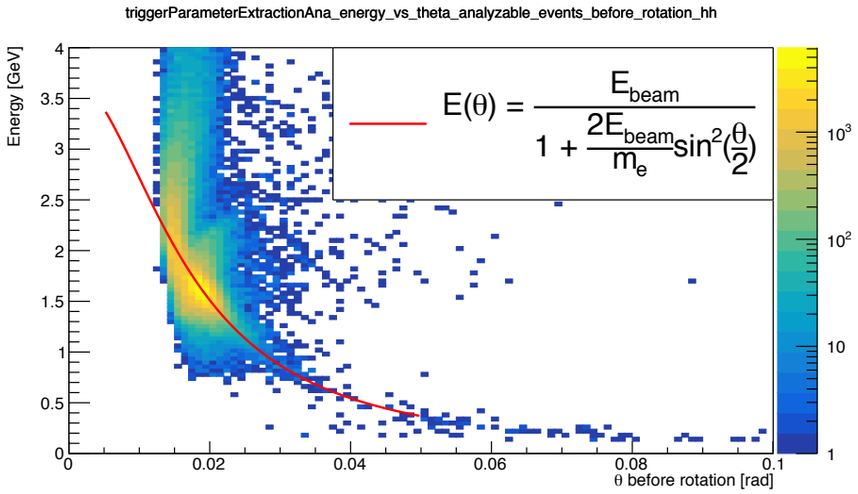
Pure Moller

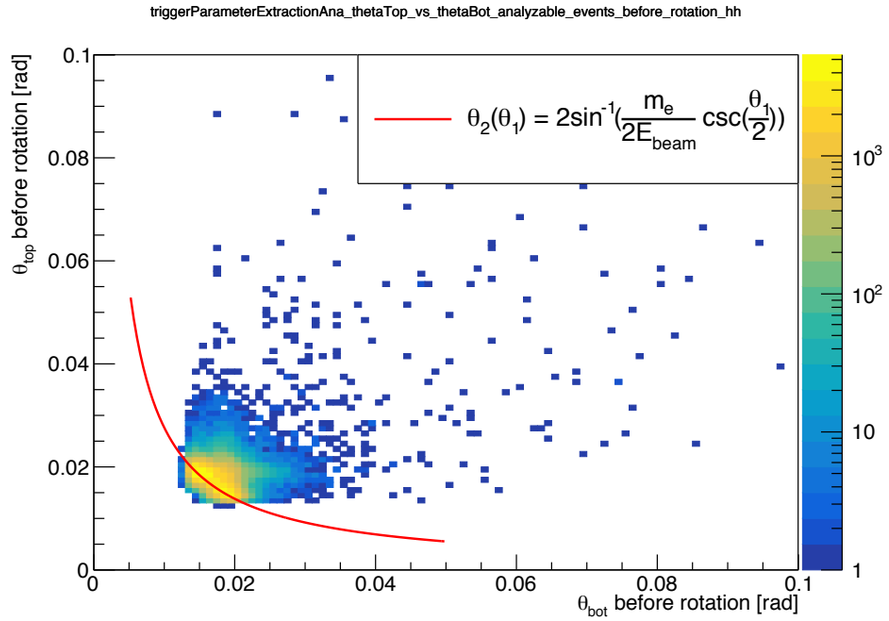
Kinematic Cuts

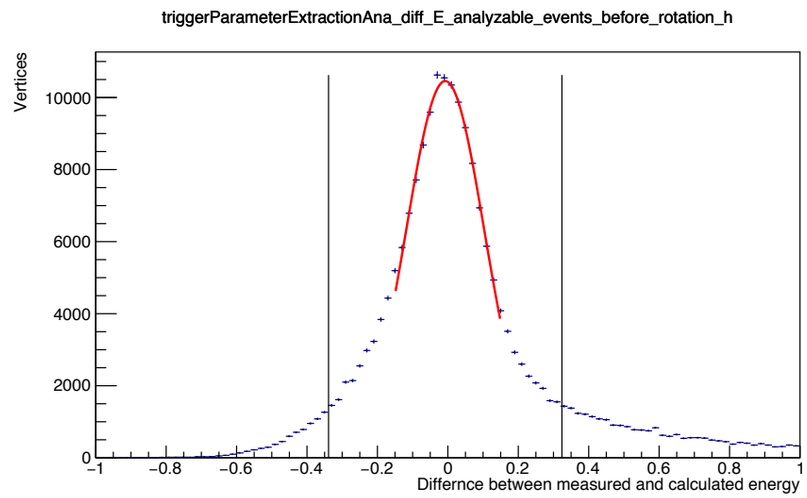
Moller scattering

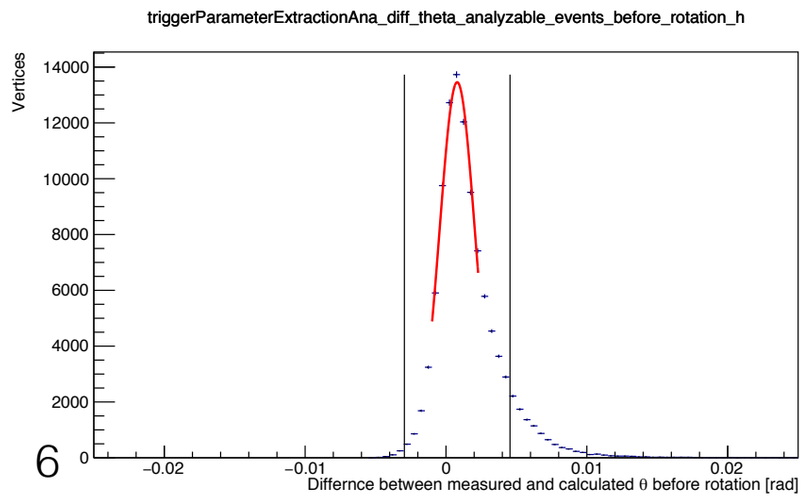


- Particles' momentum from recon is transformed into origin before rotation (30.5 mrad around y).
- As a two-body system, kinematics of two outgoing particles from Moller scattering can be fully expressed as functions of a kinematic variable with beam energy as parameter.
- Cuts for difference between measured and calculated energy/theta can be applied.





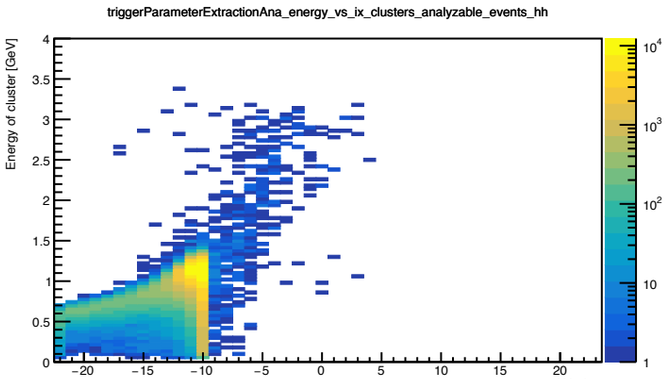


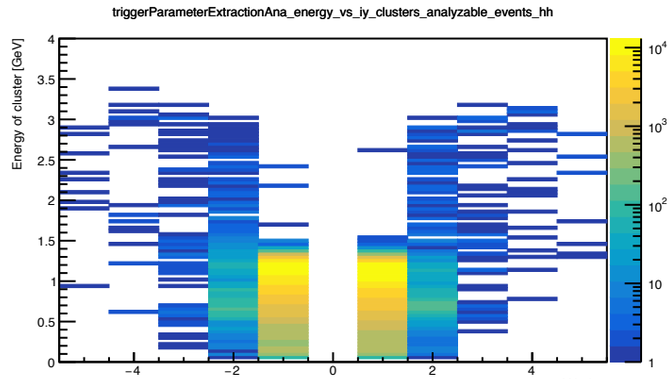


Pure Moller

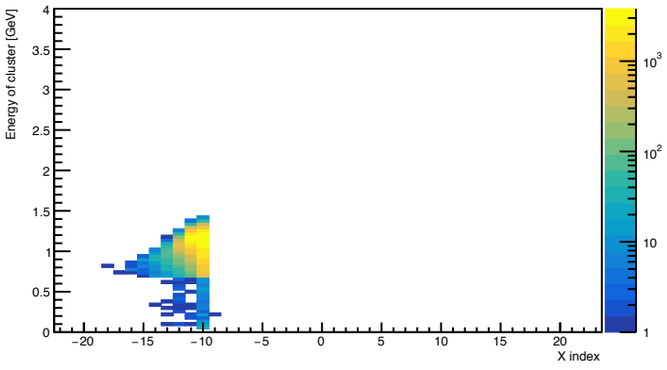
Crystal Index Limits and Energy Upper Limit by PDE

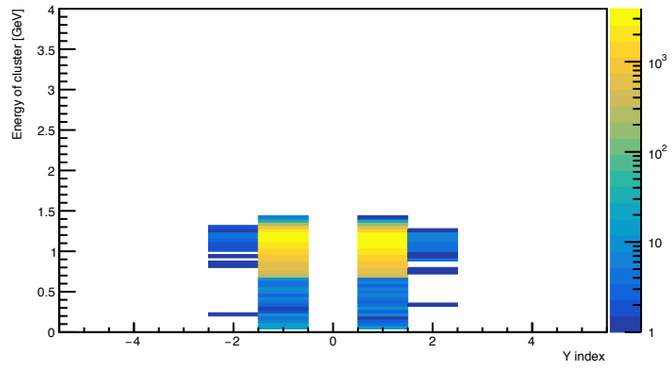
Analyzable events

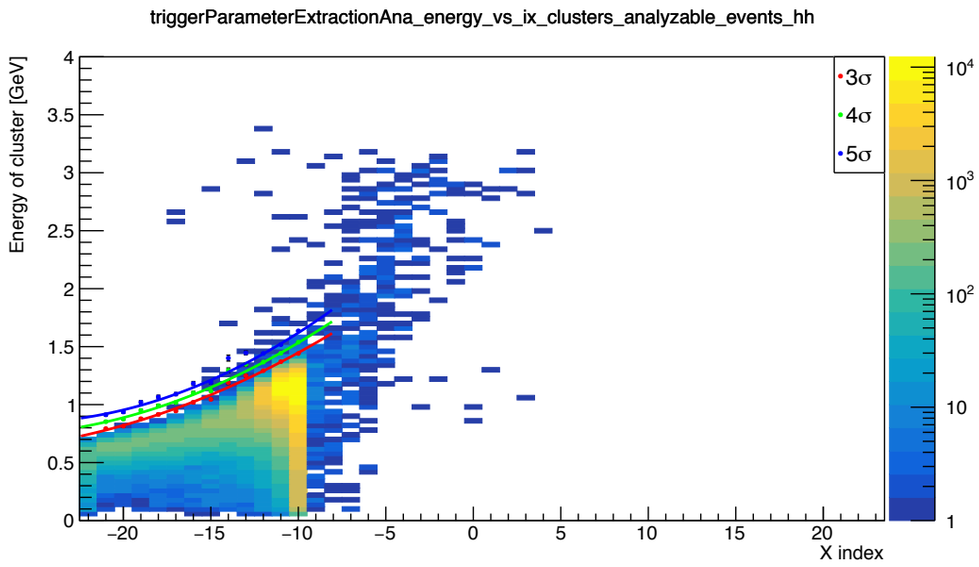




Triggered analyzable events with kinematic cuts







For each sub-range, points at 3 or 4 or 5 sigmas are extracted to be fitted by pol2.

Suggested cuts:

- XMax: -10
- Y: [-2, 2]
- Energy upper limit as function of X

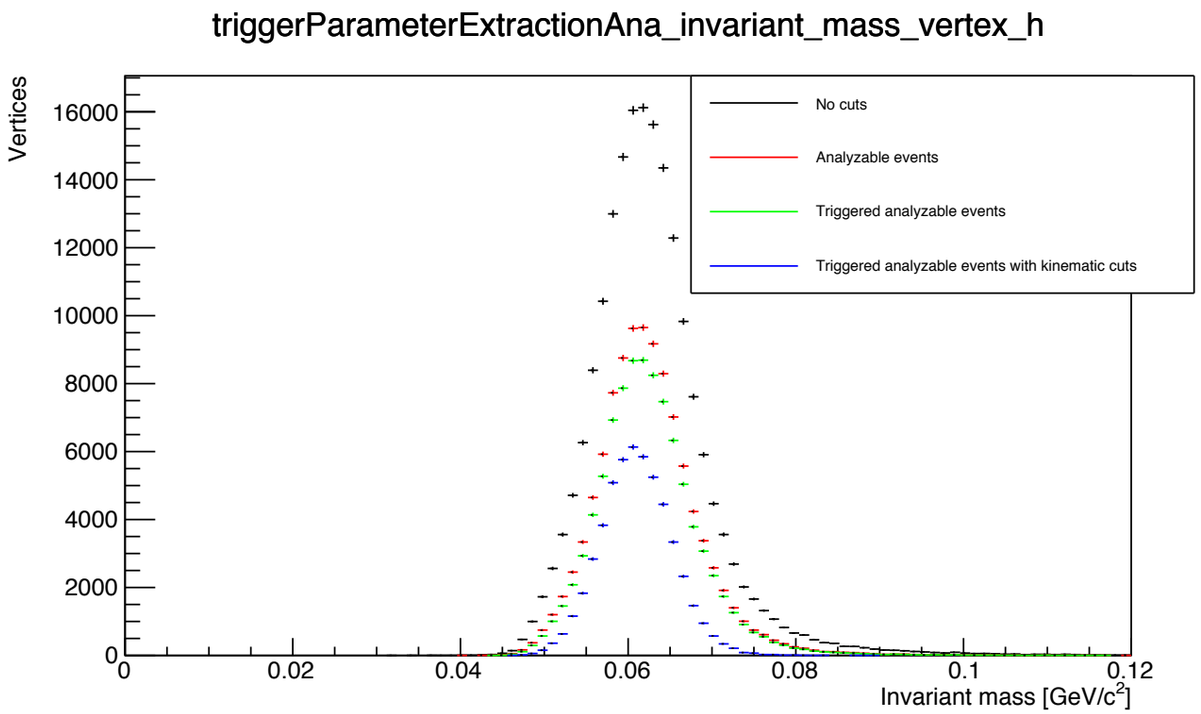
Suggested Cuts for Moller

- Cluster energy: [0.70, 1.52] GeV
- NHits: >= 1 (no limit)
- X index: <= -10
- Y index: [-2, 2]
- Energy upper limit as a function of X index

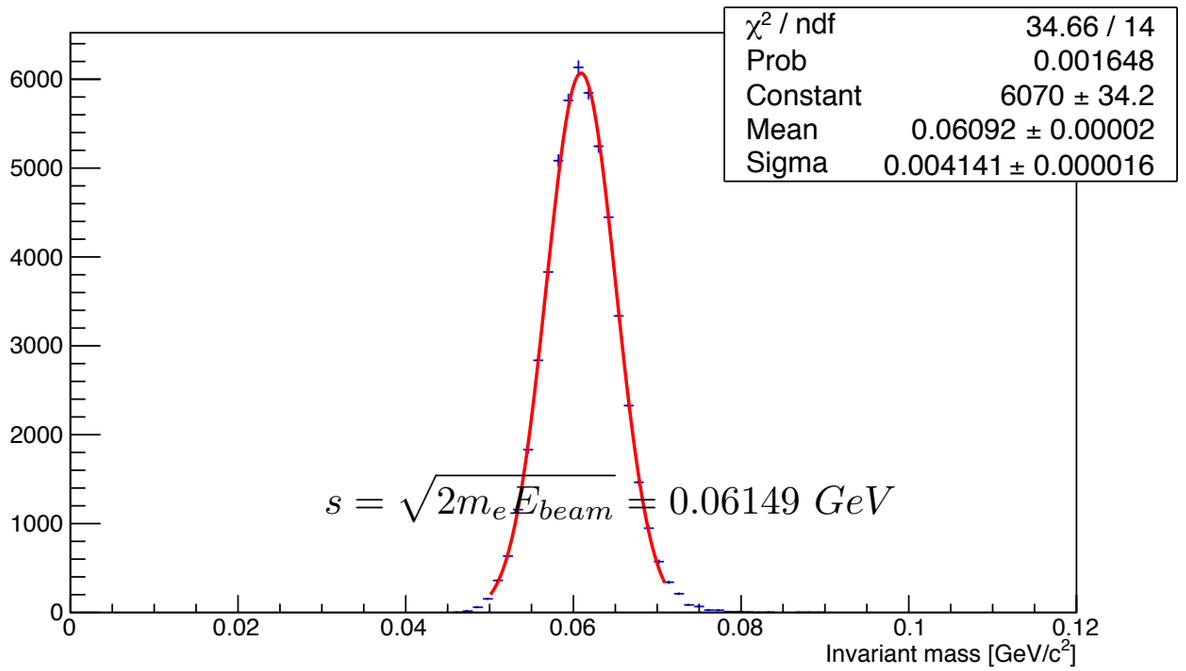
2rd pol.	p0 [GeV]	p1 [GeV]	p2 [GeV]
3σ	2.49249	0.125182	0.00208005
4σ	2.69614	0.141927	0.00257436
5σ	2.8977	0.158384	0.0030593

Pure Moller

Invariant Mass Distribution



Trigger analyzable events with kinematic cuts

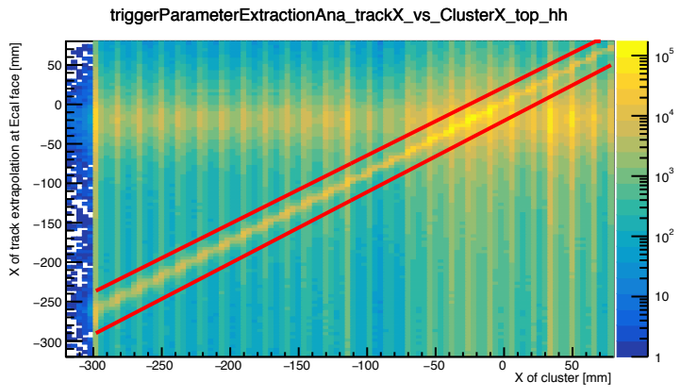


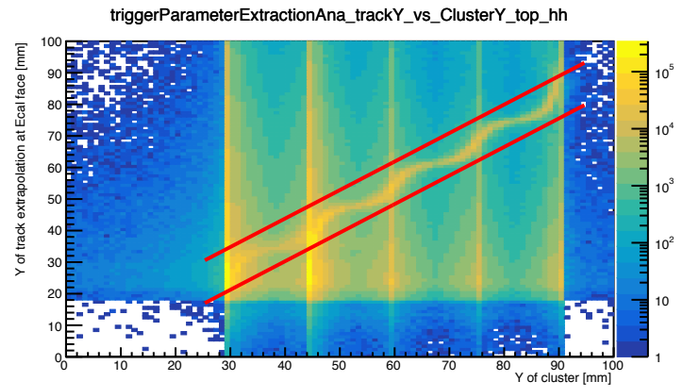
Resolution will be further improved with application of MOUSE, PSum and Δt cuts.

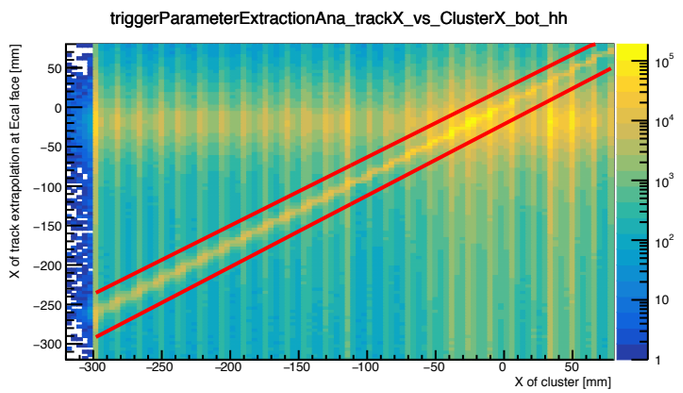
Analyzable events

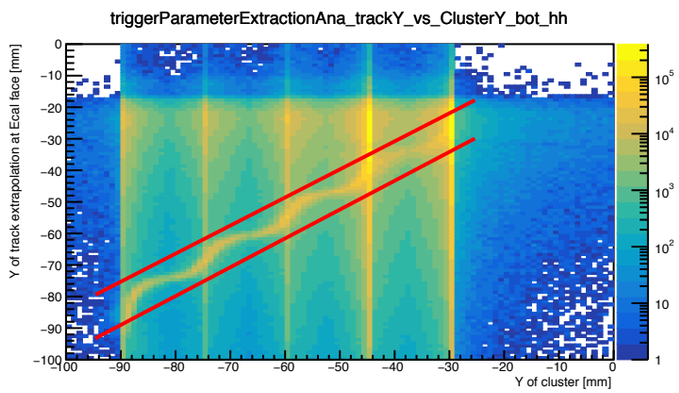
- Analyzable events include at least one top and one bot tracks with Chi2/NDF less than 20 and negative charge.
- Clusters are selected by track-cluster matching.
- Selected clusters include at least one cluster with energy larger than 100 MeV.

track-cluster matching

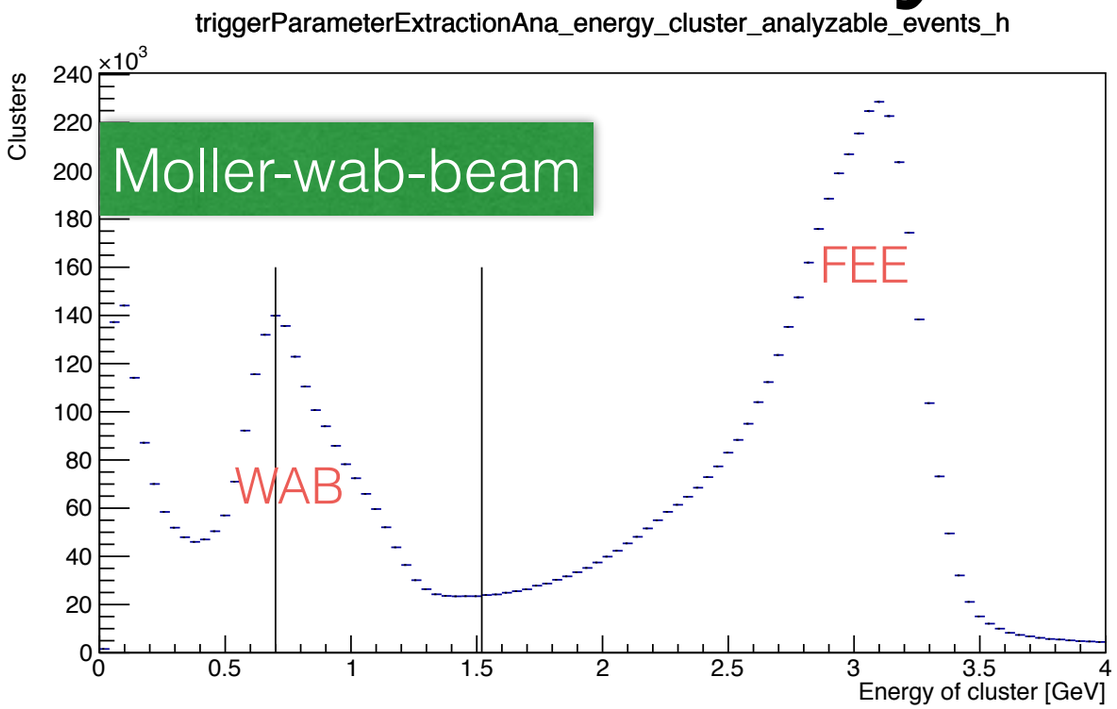


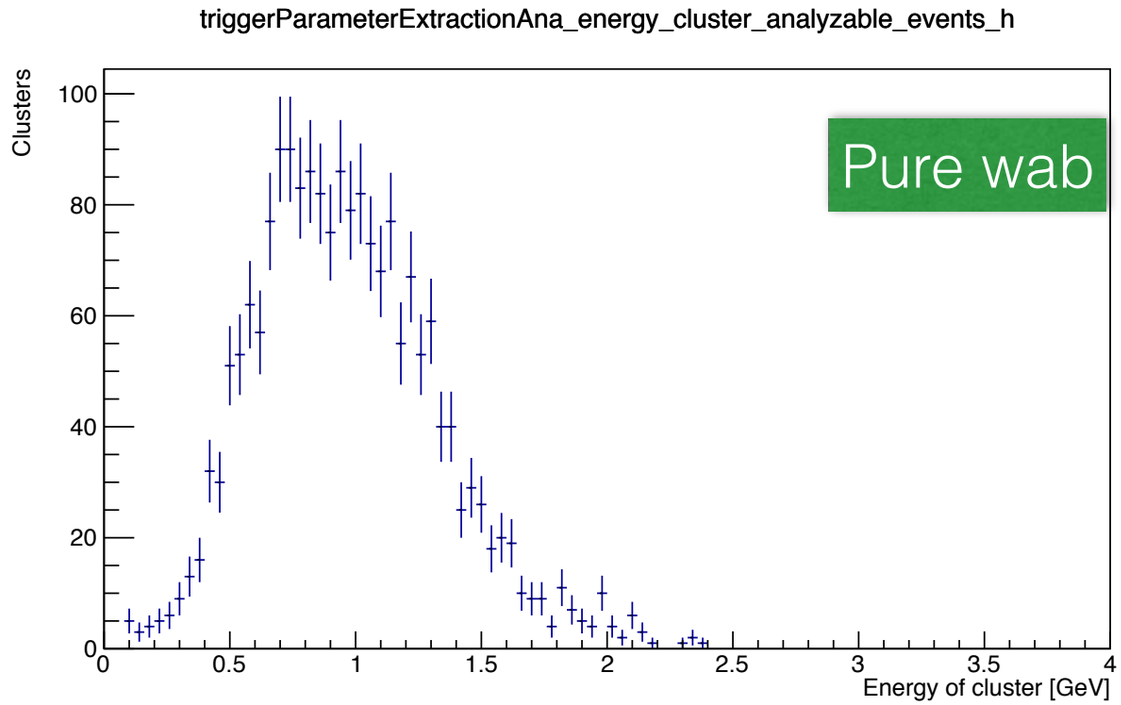


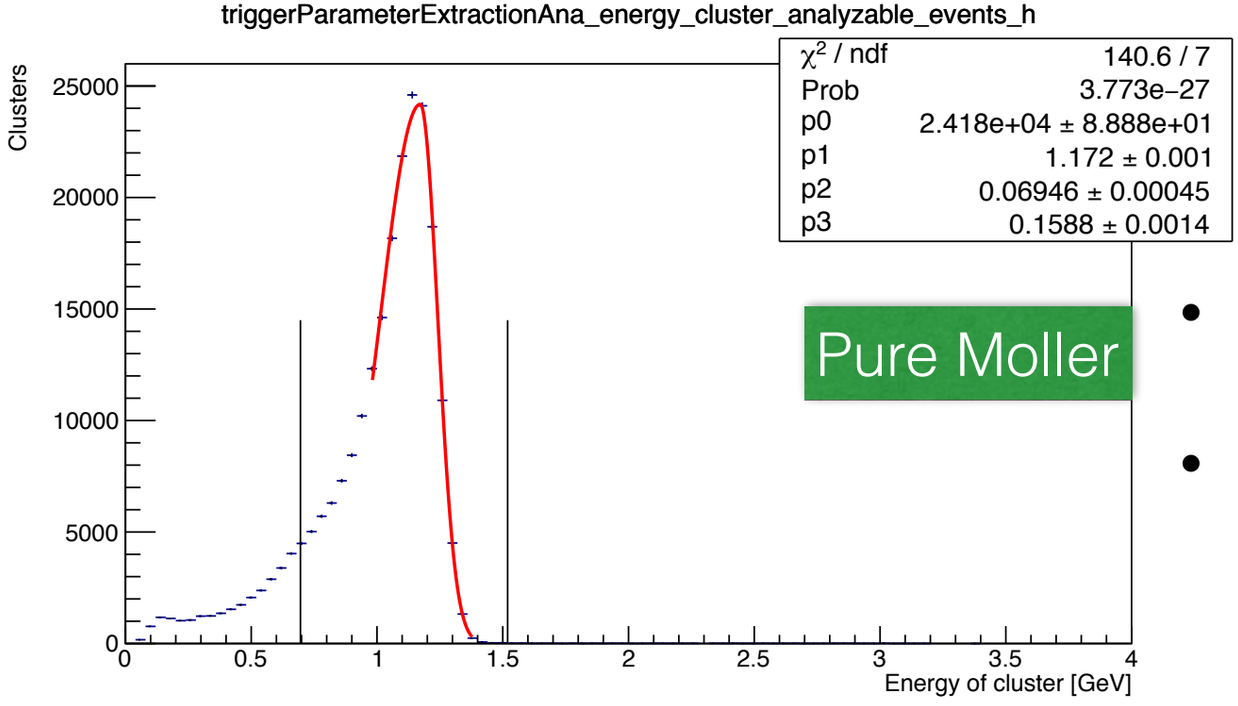




GTP Cluster Energy for Analyzable Events



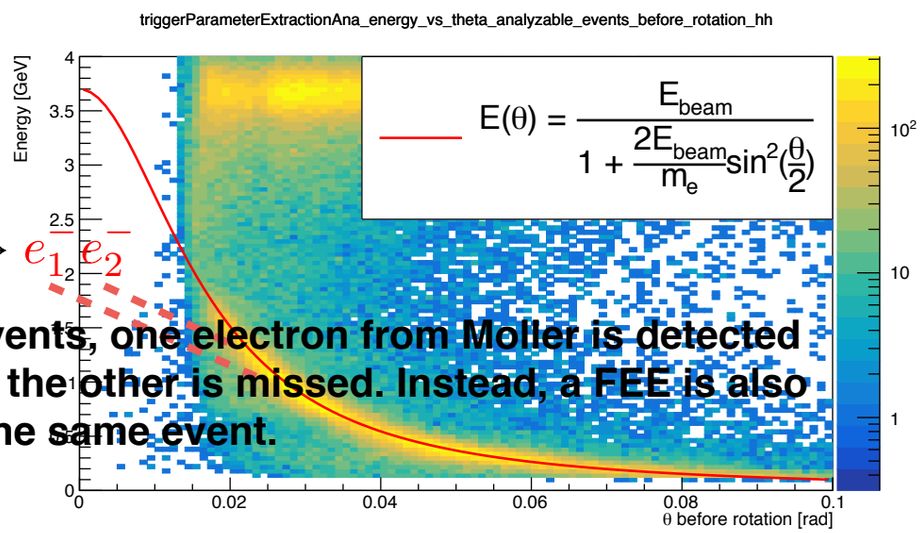


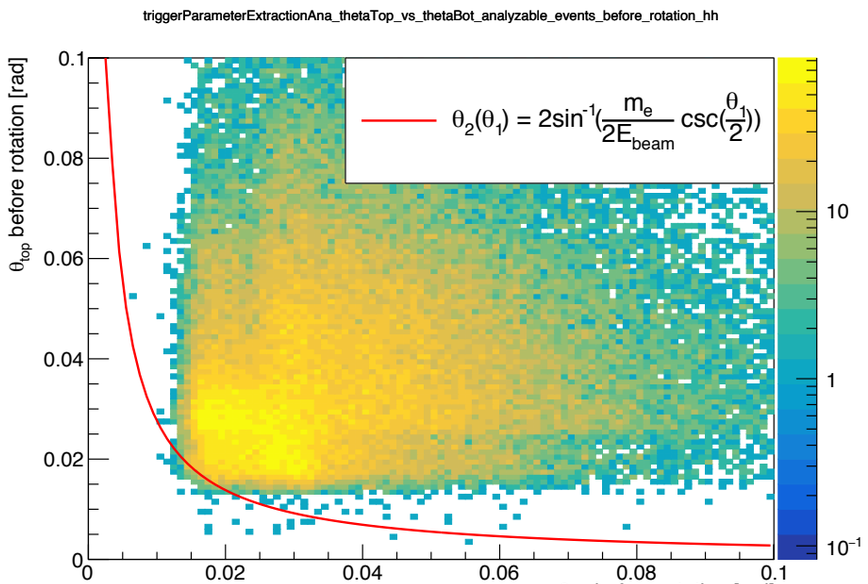


- No Moller peak appears in the cut range of the distribution for Moller-wab-beam.
- It figures out that wab events dominates in the cut range.

Moller-wab-beam

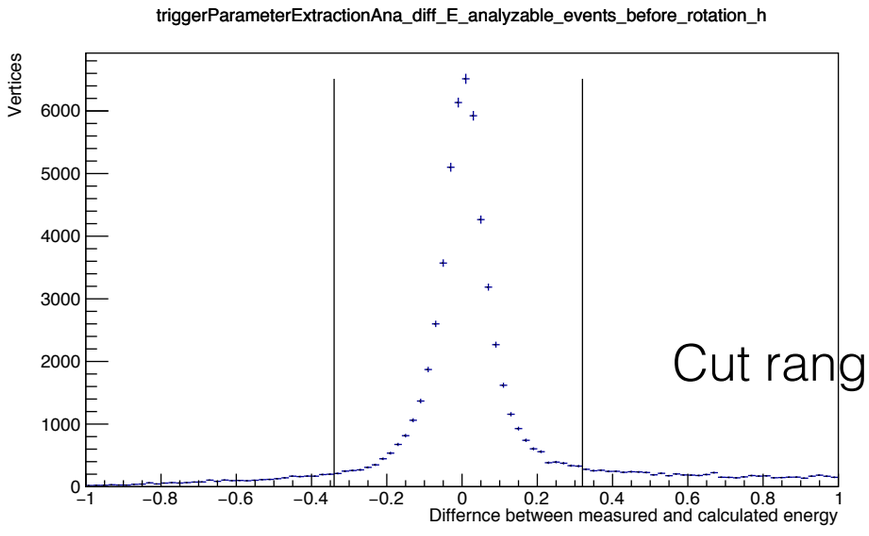
Kinematic Cuts

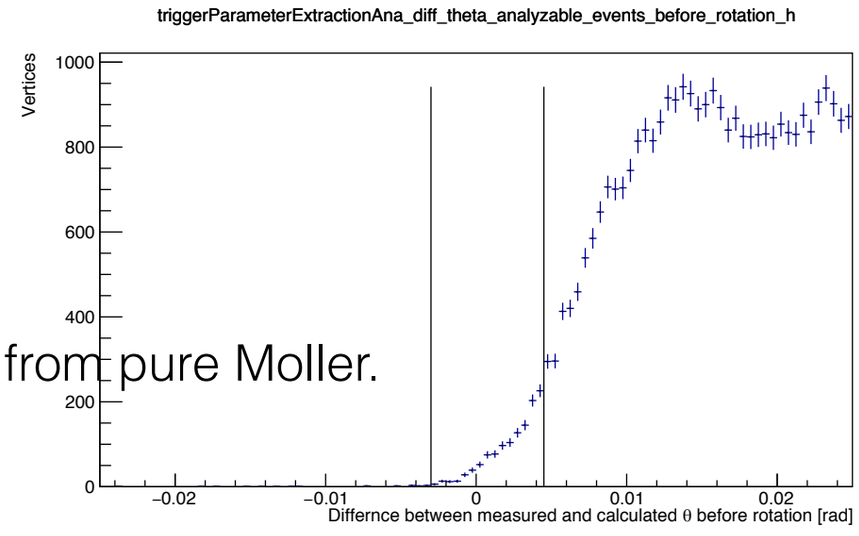




Moller: $e^- \rightarrow e_1^- e_2^-$

For a lot of events, one electron from Moller is detected by SVT, while the other is missed. Instead, a FEE is also detected by the same event.





Cut ranges are from pure Moller.

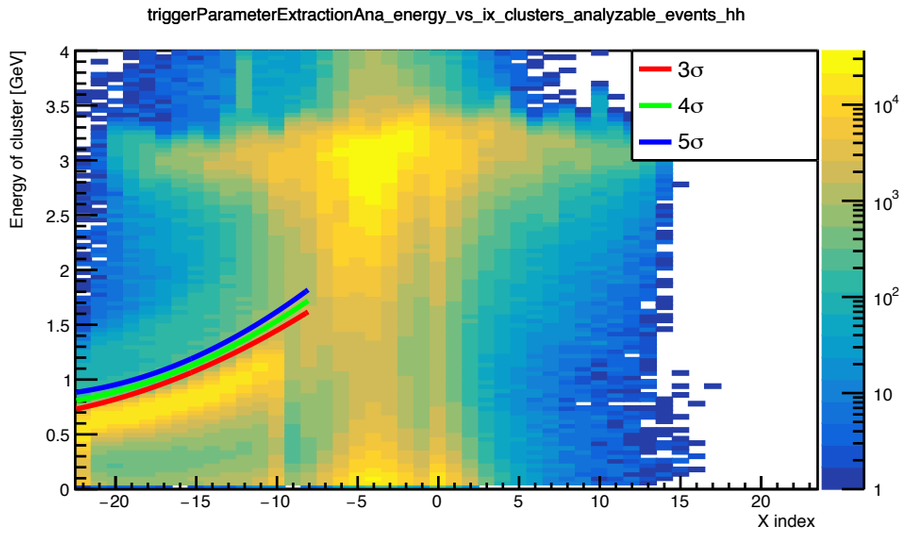
It can significantly eliminate backgrounds to require:

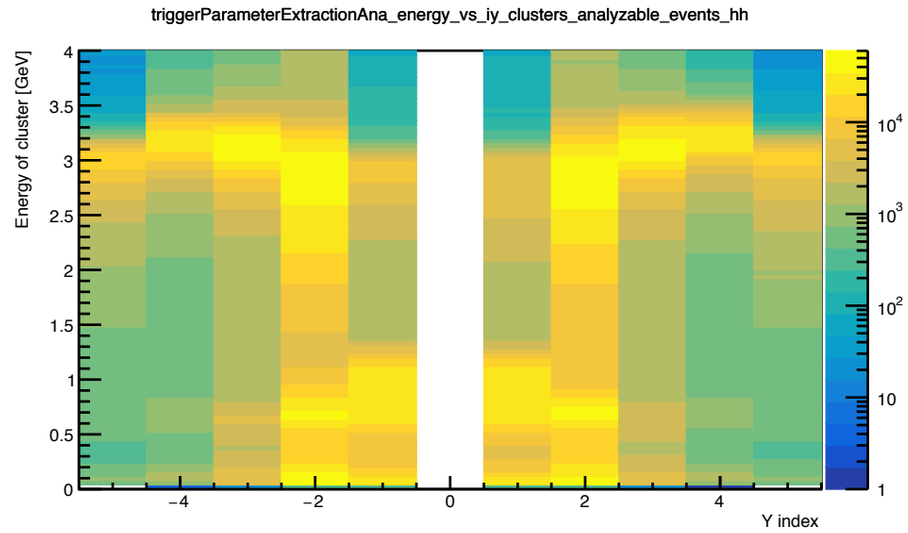
- Satisfying cut for difference between measured and calculated energy for both of tracks with negative charge.
- Satisfying cut for difference between measure and calculated scattering angle, where scattering angle of one track is calculated by scattering angle of another track.

Moller-wab-beam

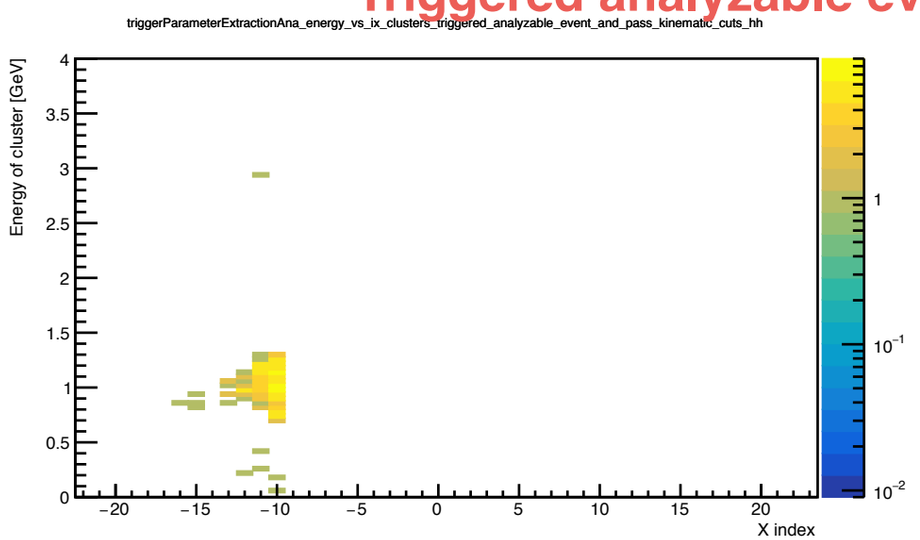
Crystal Index Limits and Energy Upper Limit by PDE

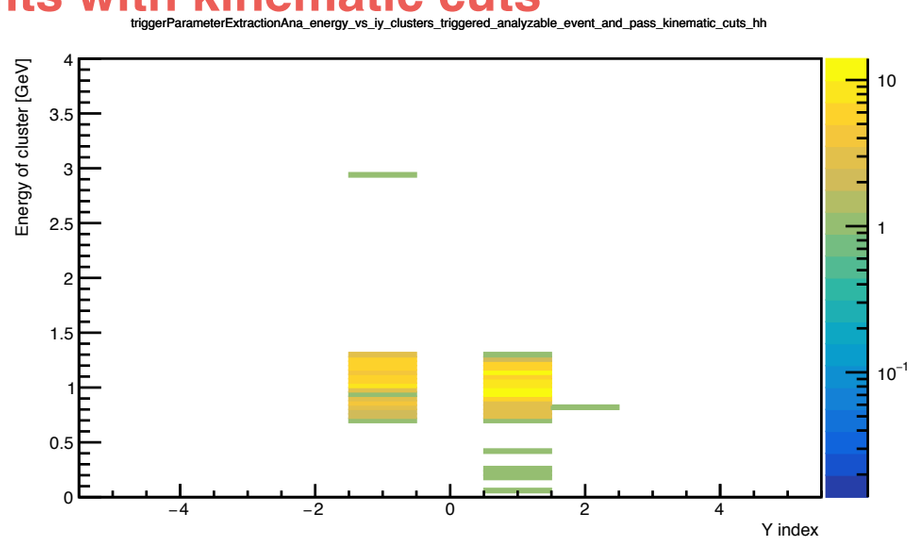
Analyzable events





Triggered analyzable events with kinematic cuts



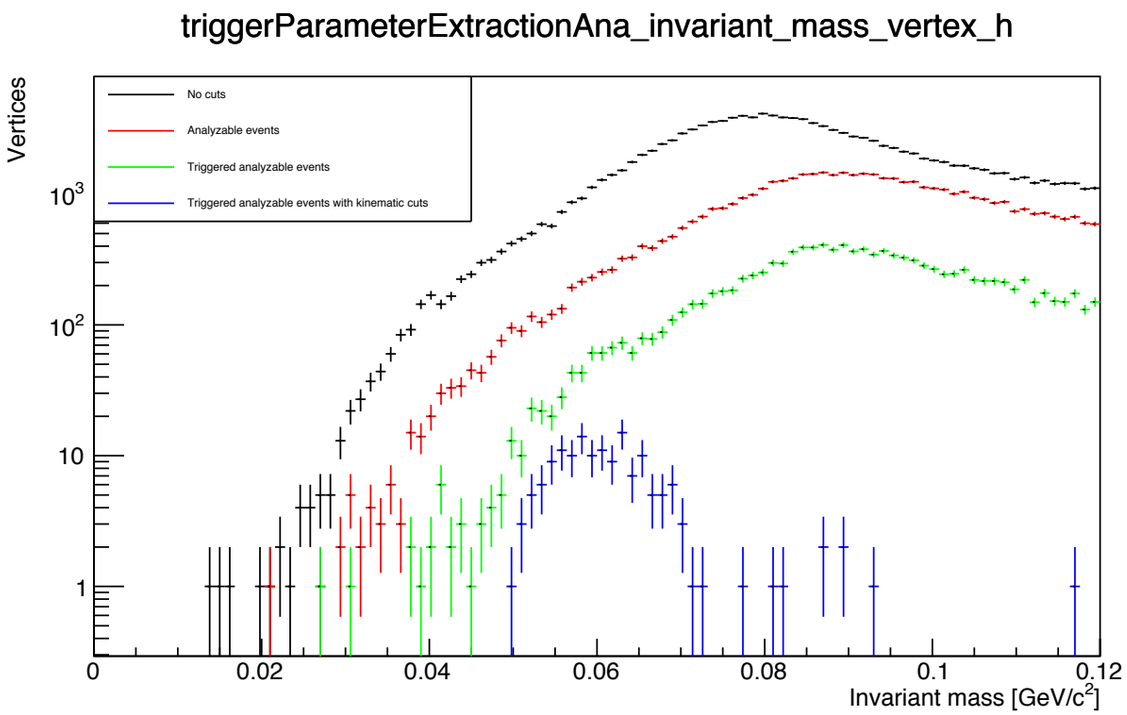


Suggested cuts:

- XMax: -10
- Y: [-2, 2]
- Energy upper limit as function of X

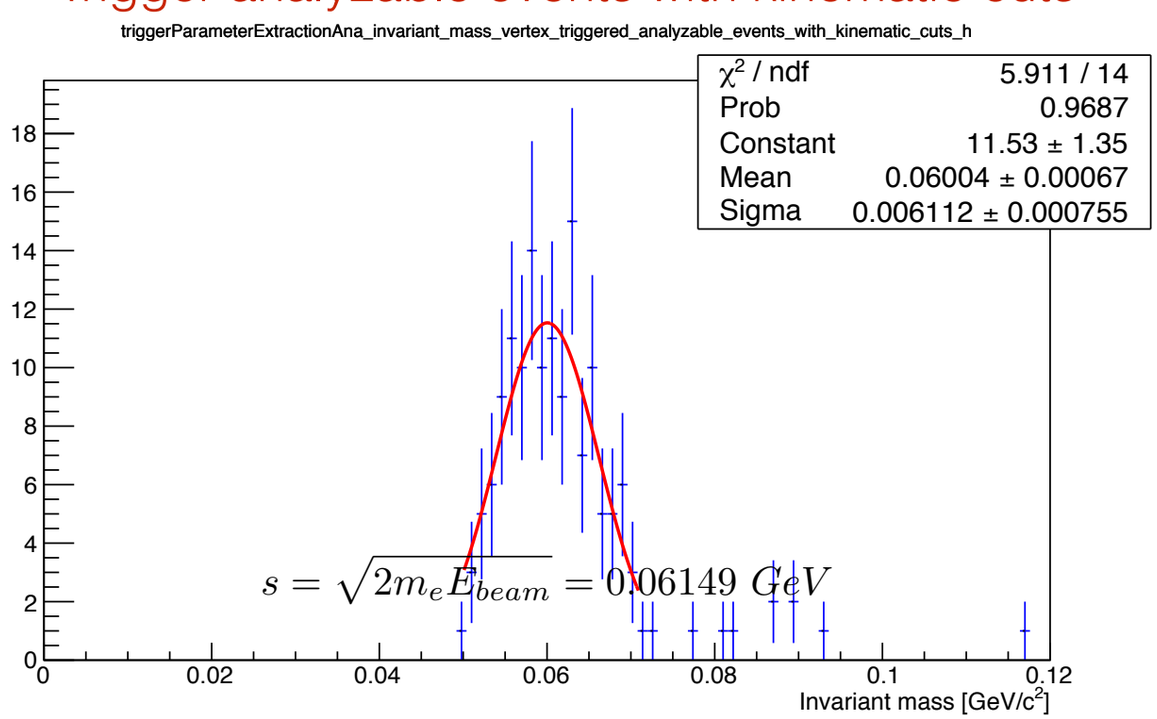
Moller-wab-beam

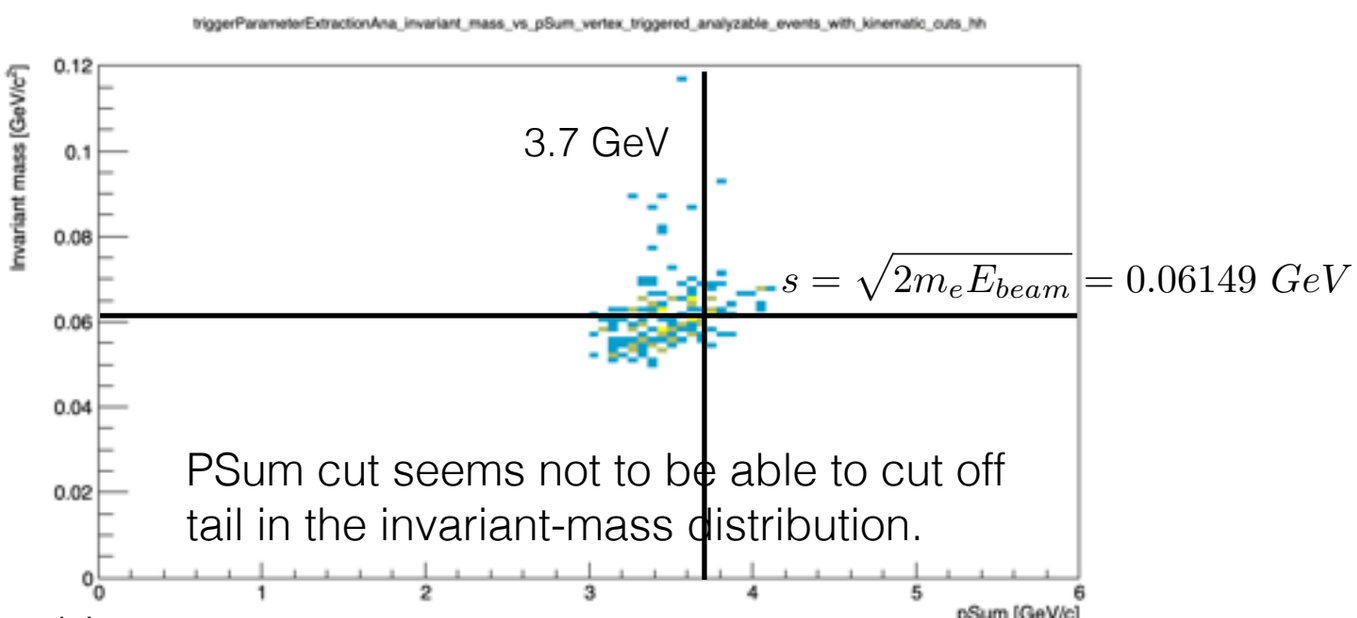
Invariant Mass Distribution



Kinematic cuts based on difference between measured and calculated can significantly eliminate backgrounds, especially wab.

Trigger analyzable events with kinematic cuts





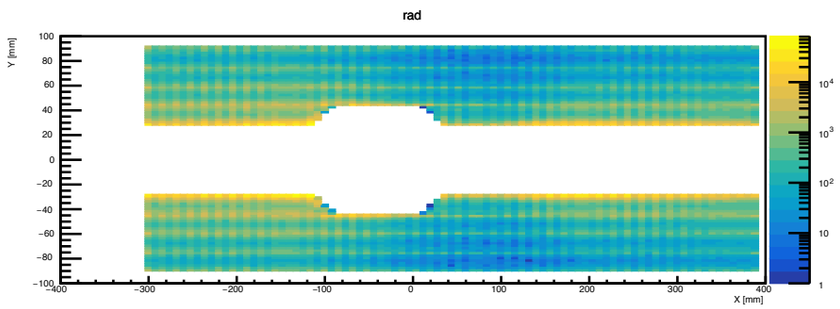
Event Rate

- Beam: 120 nA; Target: 20 um
- 4s pure Moller; 16ms Moller-wab-beam

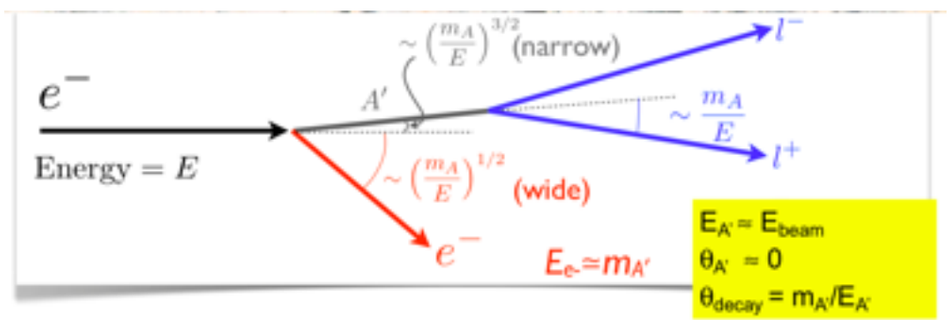
Event rate (Hz)	Pure Moller	Moller-wab-beam
Analyzable events	26456	4861875
Triggered analyzable	23602	1074625
Triggered analyzable with kinematic cuts	13330	9500
Triggered events	619165	1.285E+08

Pure rad and ap

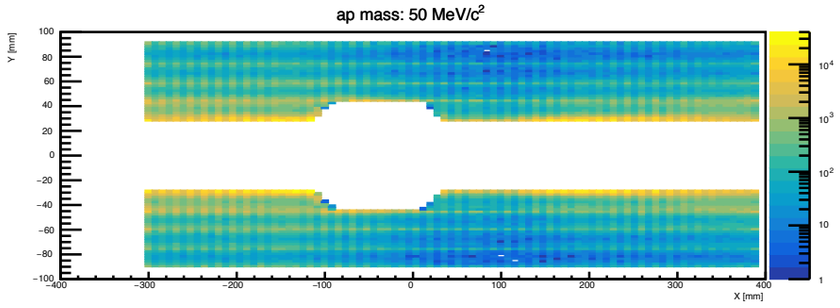
X vs. Y of GTP clusters

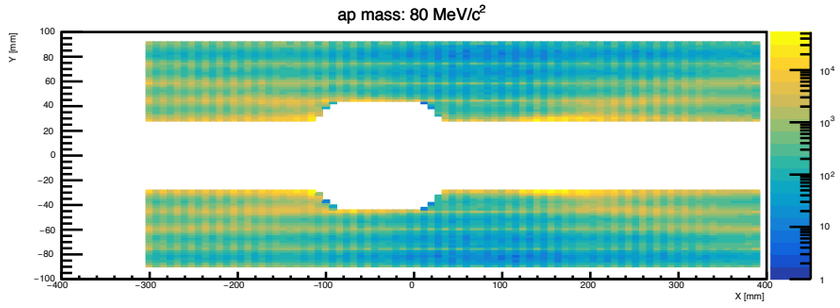


ap mass: 50 MeV/c^2

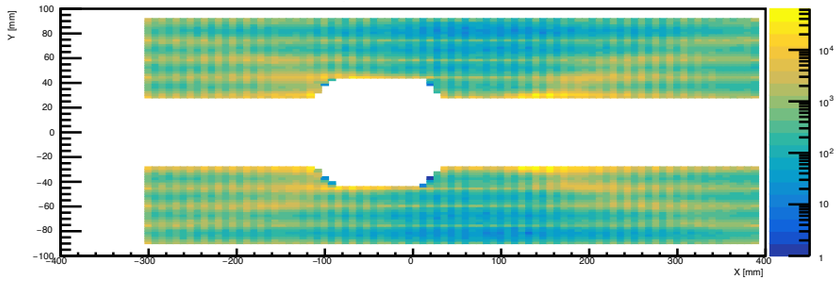


ap mass: 80 MeV/c^2

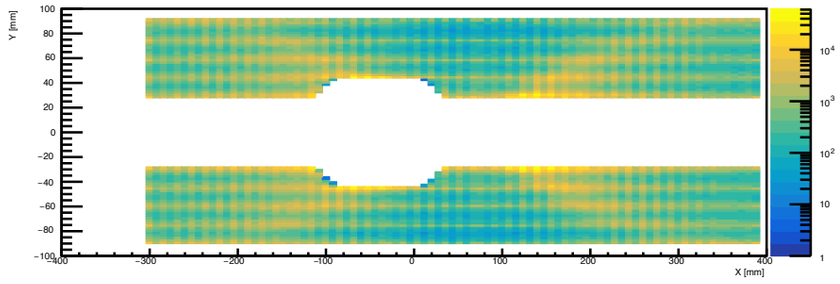




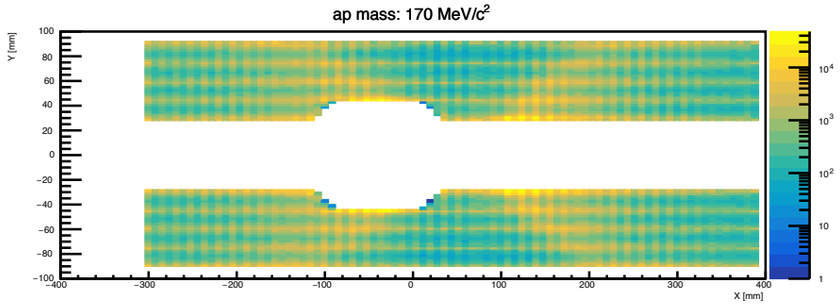
ap mass: 100 MeV/c^2



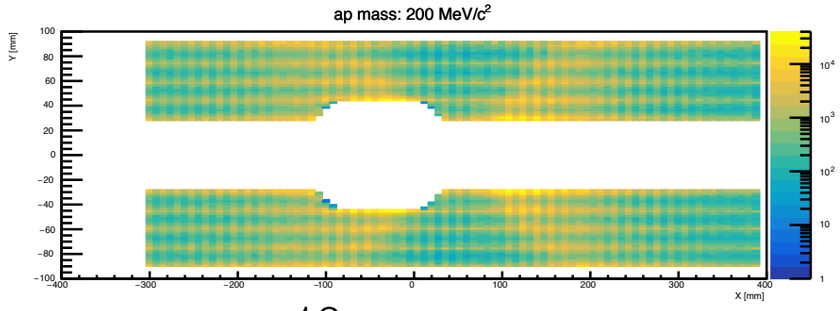
ap mass: 130 MeV/c^2



ap mass: 170 MeV/c^2



ap mass: 200 MeV/c^2



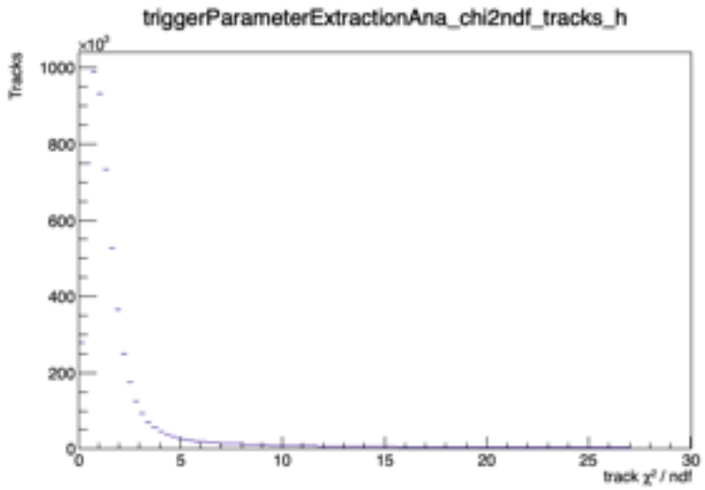
As ap mass increases, scattering angle of A' and decay angles of e+e- pair increases. It could cause several consequences:

1. More e+/e- track from ap is out of SVT acceptance
2. More clusters are out of Ecal acceptance or appear at edge of Ecal, and such clusters might lose energy

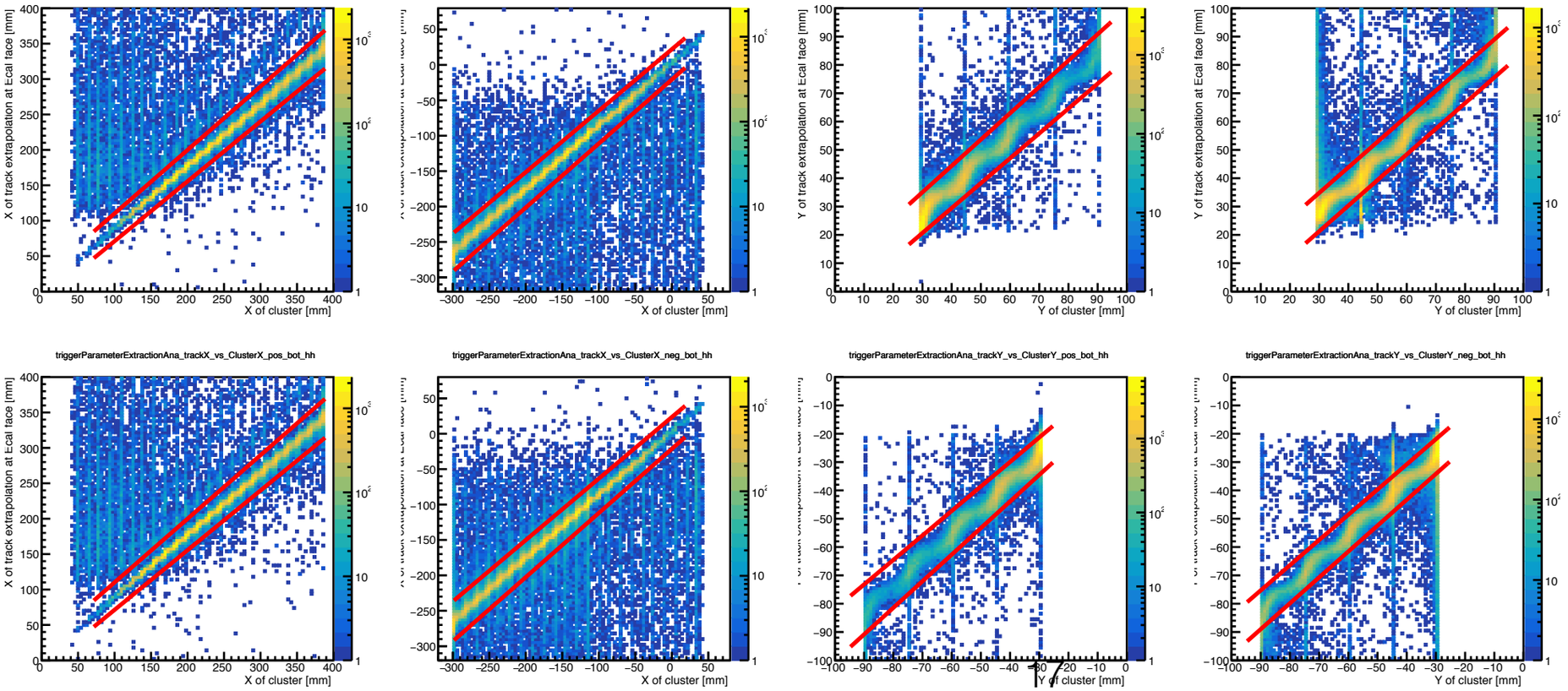
Pure ap

Analyzable events for ap Pair Trigger Tuning

- Analyzable events include at least one pair of pos_top + neg_bot or pos_bot + neg_top tracks, whose Chi2/NDF are less than 20.
- Clusters are selected by track-cluster matching
- Selected clusters include at least one top and one bot clusters with energy larger than 100 MeV.



track-cluster matching

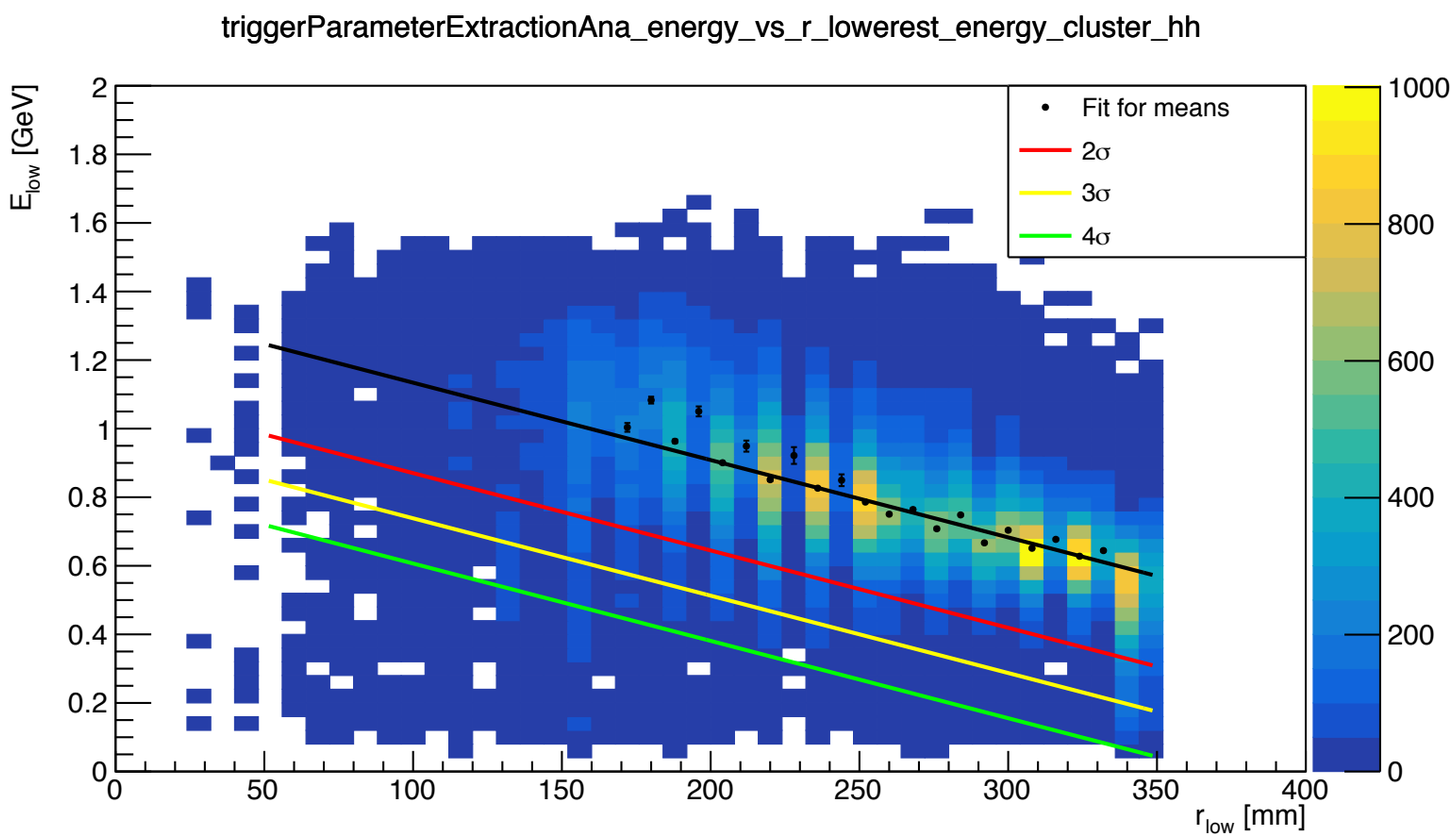


Pure ap

Pairs Trigger Tuning: Energy Slope

- The pair energy slope cut places a lower bound on a value calculated from a combination of cluster energy and cluster position.
- The energy slope cut is calculated using the energy of whichever cluster in the pair has the least energy.
- It is defined as $E_{low} + r_{low}F >= E_{threshold}$

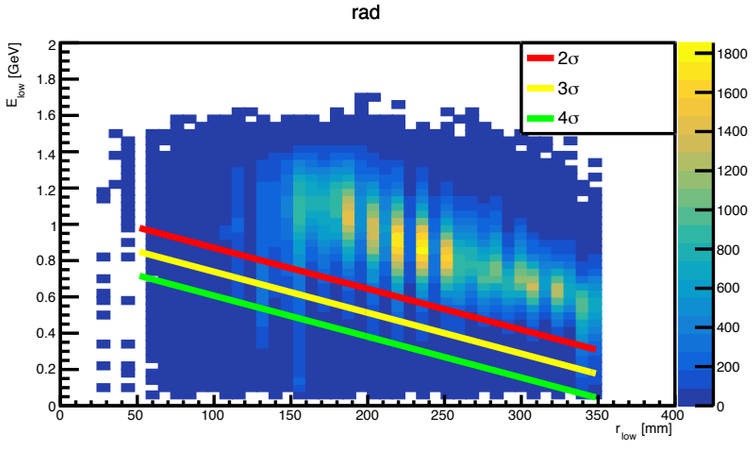
ap: 50



For each sub-range, a point at mean is extracted. Then, points at means are fitted by pol1. The function from fitting shifts 2 or 3 or 4 sigmas as a cut function, where the sigma value is average of sigmas of all sub-ranges.

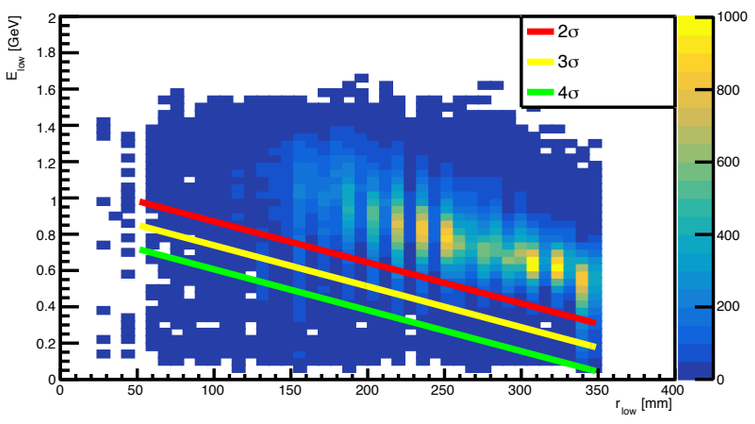
Pure ap

Energy Slope for rad and various ap points

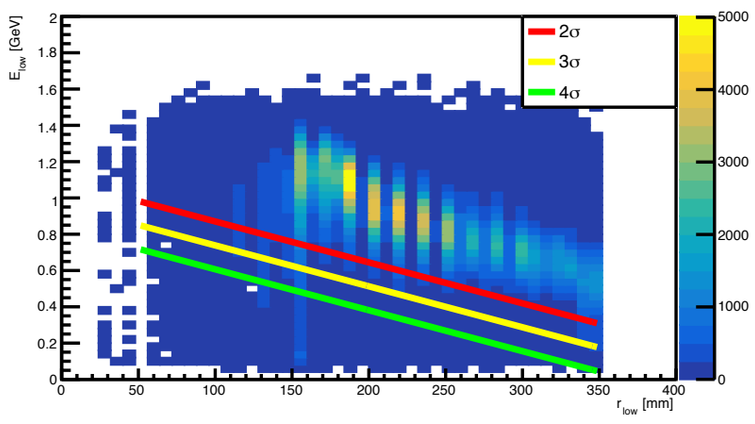


- As ap mass increases, energy at low r_{low} is not stable. From distributions of x vs. y for GTP clusters, we can observe that more and more clusters at low r_{low} are close to edge and might lose energy, as ap mass increases.
- It seems fine that all ap masses apply cut functions from 50 ap mass.

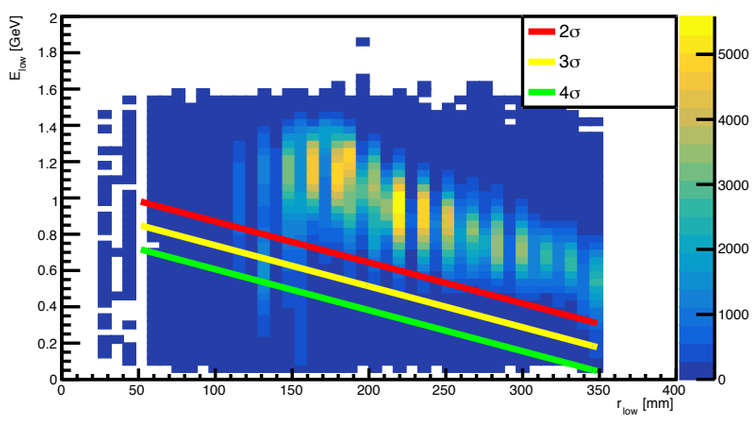
ap: 50



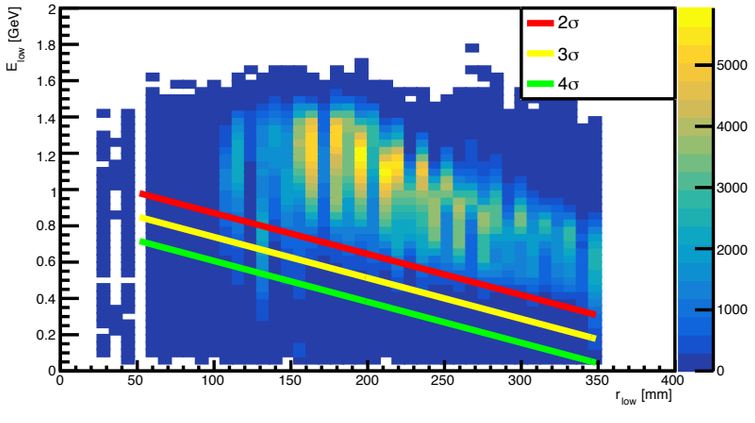
ap: 80



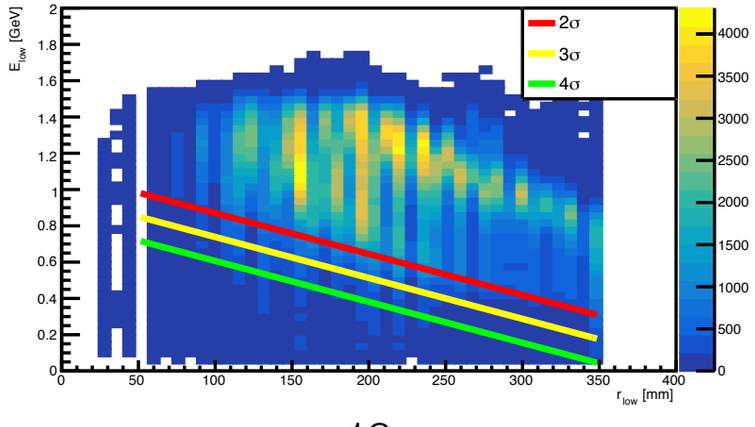
ap: 100



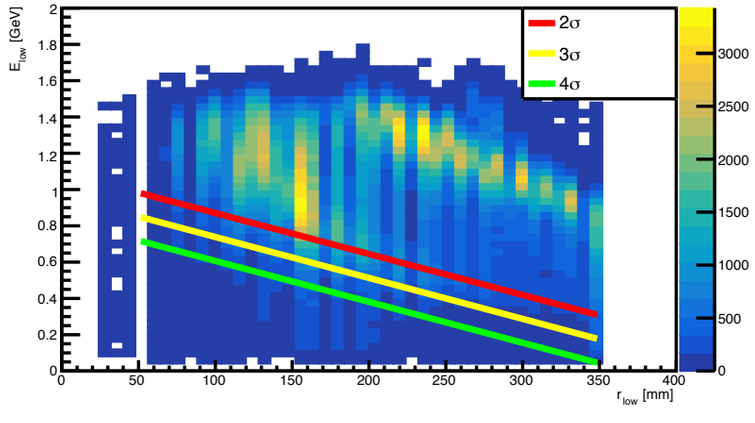
ap: 130



ap: 170

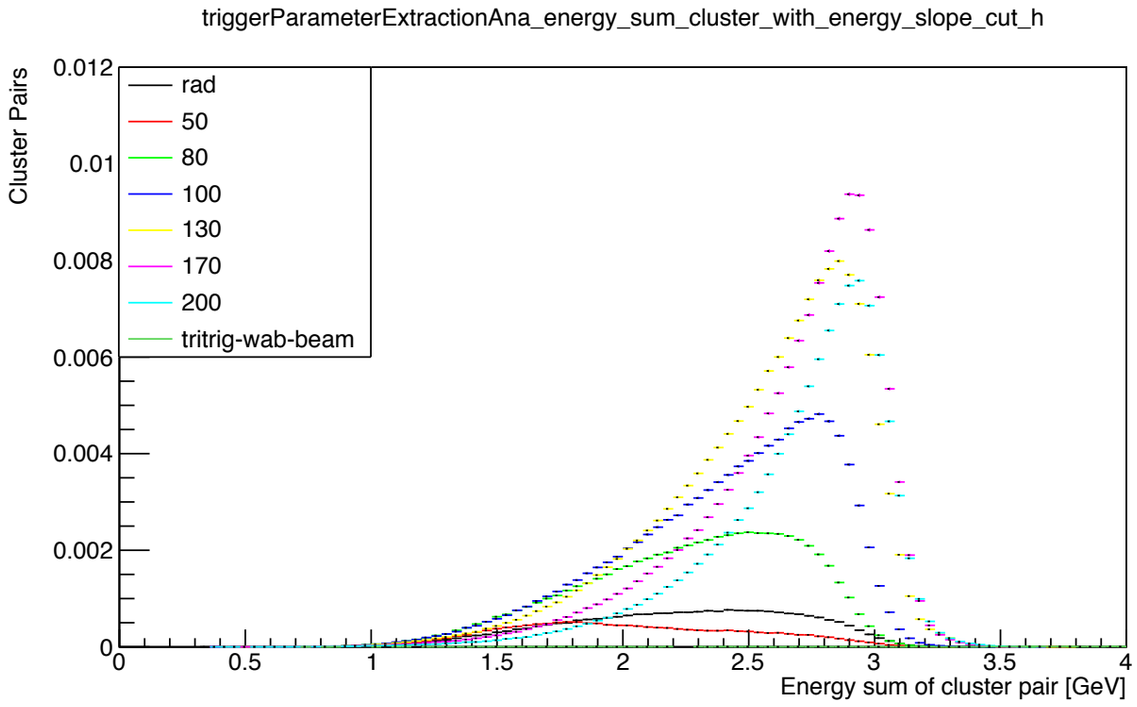


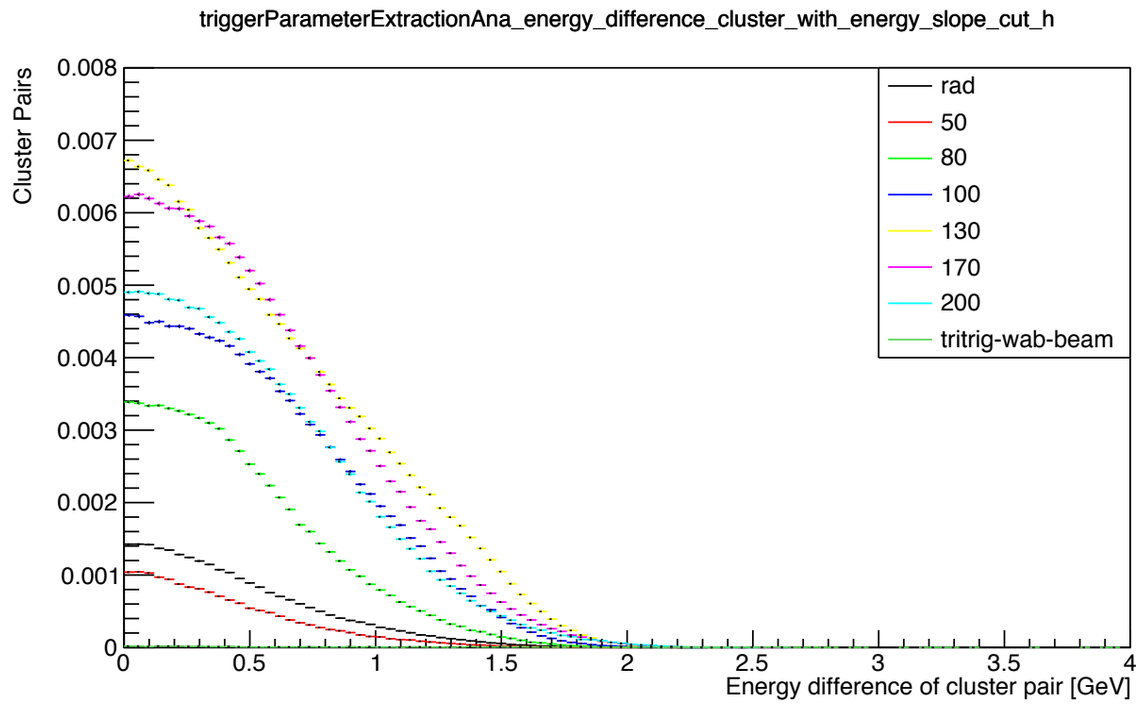
ap: 200

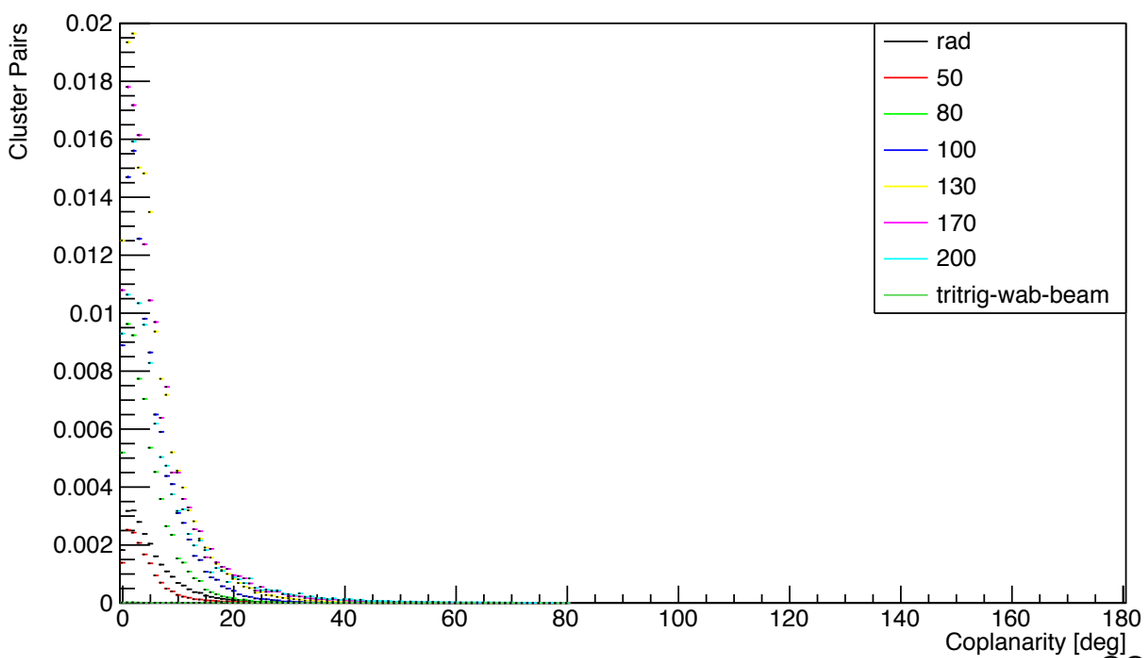


Pure ap

Pair Trigger Tuning







- **Histograms are normalized by total number of generated events.**
- **Energy slope cut at 3σ is applied.**

Suggested Cuts for ap Pair Trigger

- Cluster energy: [0.3, 2.8] GeV
- NHits: >= 2
- Energy sum: [1, 3.3] GeV
- Energy difference: [0, 2.2] GeV
- Coplanarity: [0, 40] deg
- Energy slope from ap of 50 MeV/c^2

1st pol.	F [GeV/mm]	$E_{threshold}$ [GeV]
2σ	0.00225597	1.09592
3σ	0.00225597	0.964074
4σ	0.00225597	0.83223

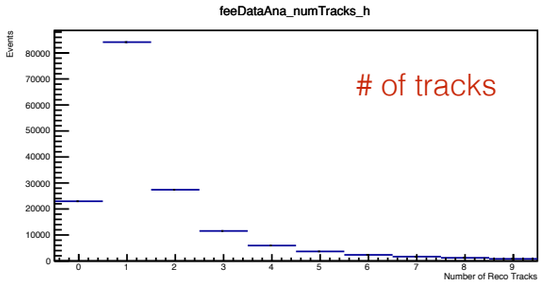
Comparison of GTP Cluster Energy between Hardware and Readout

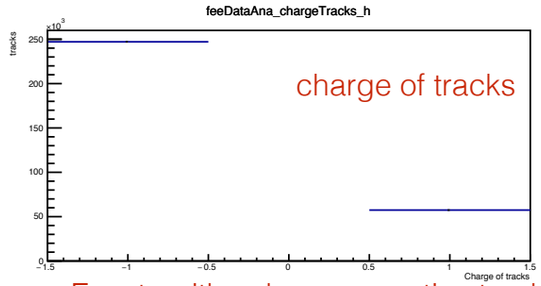
- GTP cluster energy is the most important feature for setup of trigger conditions.
- In the analysis, we use 2019 FEE data and MC to extract ratios of mean and resolution for GTP cluster energy between hardware and readout, so that trigger cut conditions relative to energy can be corrected based on the ratios.

2019 FEE Run 10103

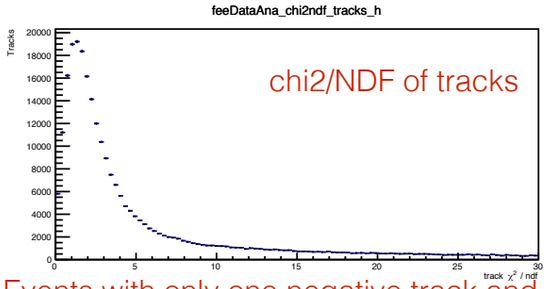
Extract FEE Peak of GTP Clusters from Hardware

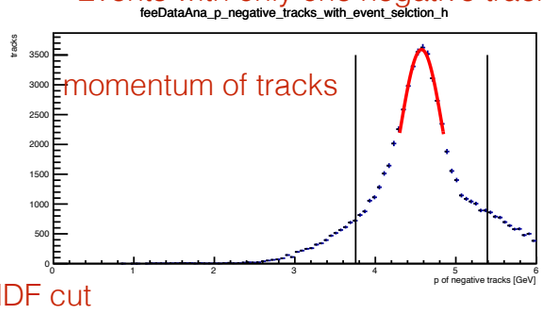
Event selection



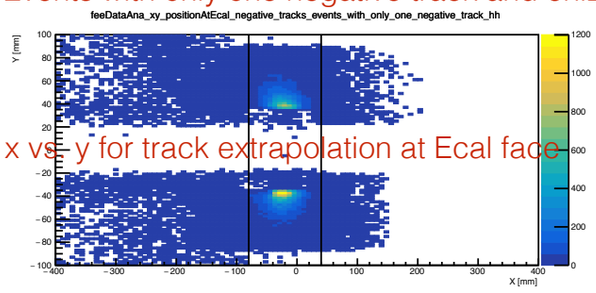


Events with only one negative track



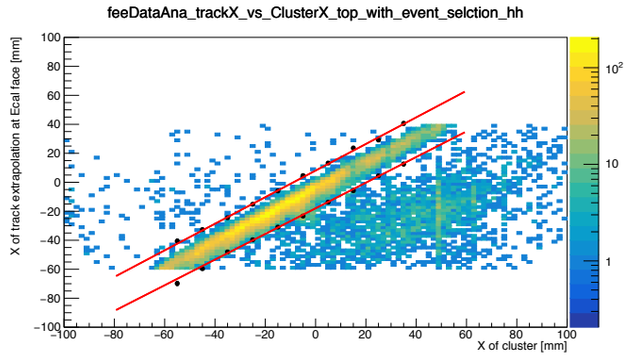


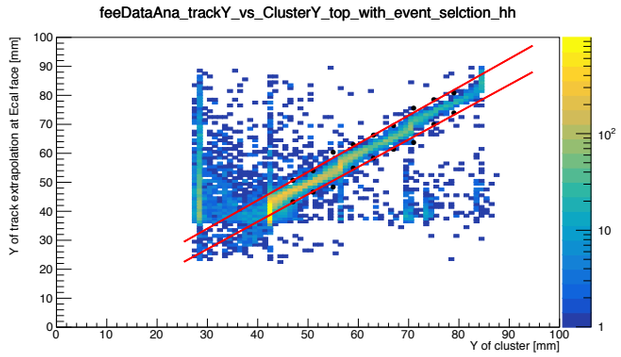
Events with only one negative track and chi2/NDF cut

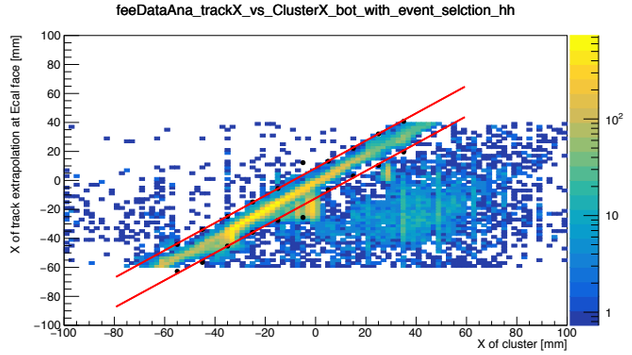


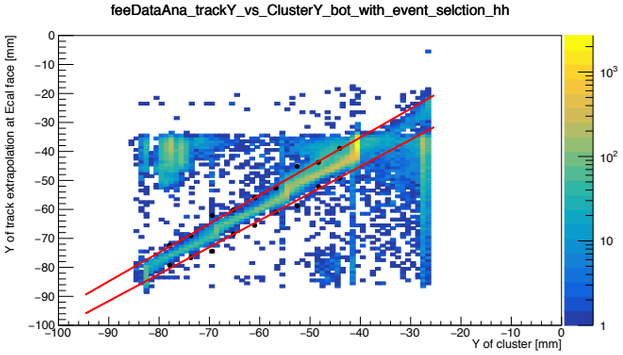
x vs. y for track extrapolation at Ecal face

Track-cluster matching

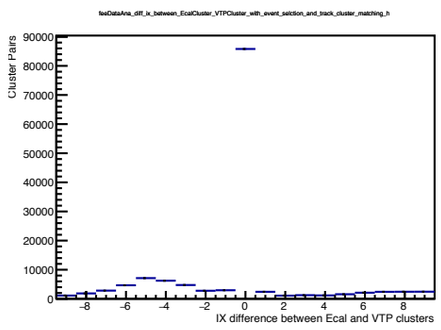


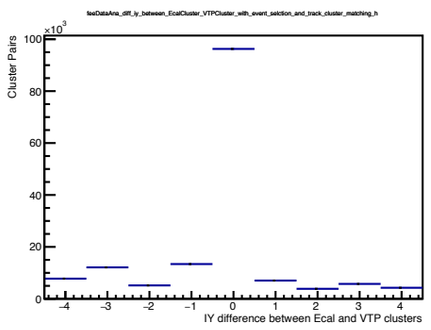


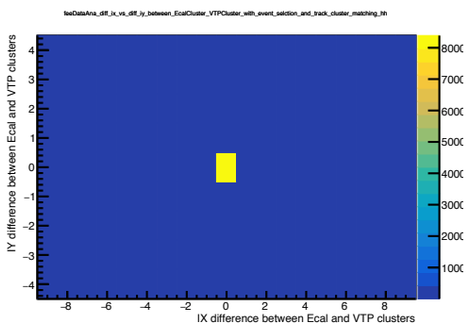




Ecal-GTP-cluster matching





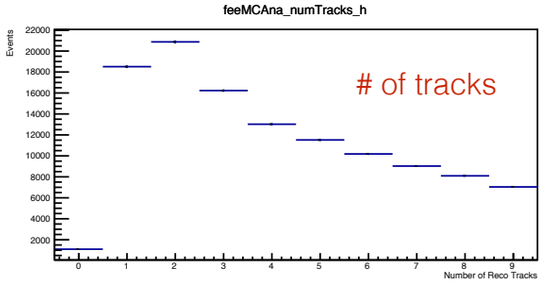


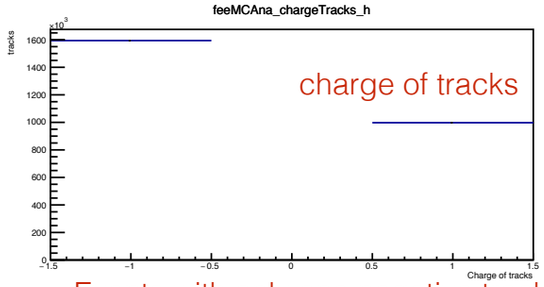
- Event selection through track collection:
  - Events only includes one track with negative charge, while no track with positive charge
  - The track satisfy tight cuts for chi2/NDF, moment range and x range for track extrapolation at Ecal face
- Select reconstructed Ecal clusters by track-cluster matching
- Find GTP clusters by Ecal-GTP-cluster matching with requirement that XY indices are consistent of each other

tritrig-wab-beam

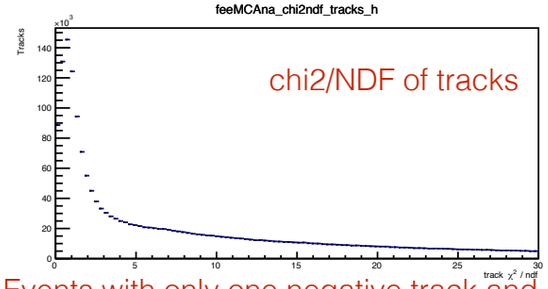
Extract FEE Peak of GTP Clusters from Readout

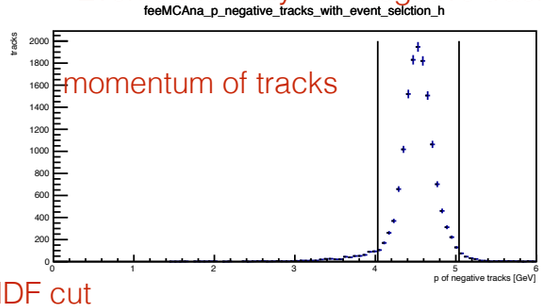
Event selection



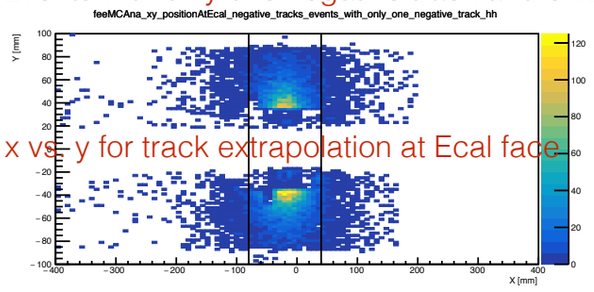


Events with only one negative track

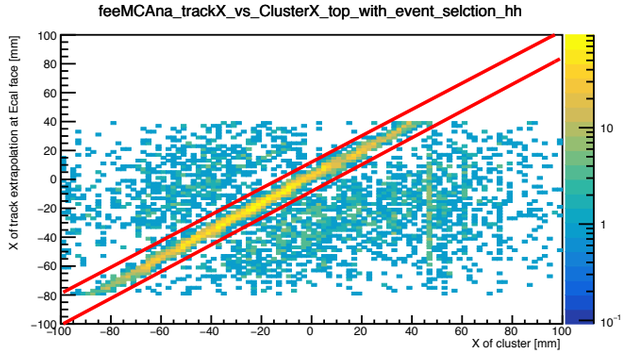


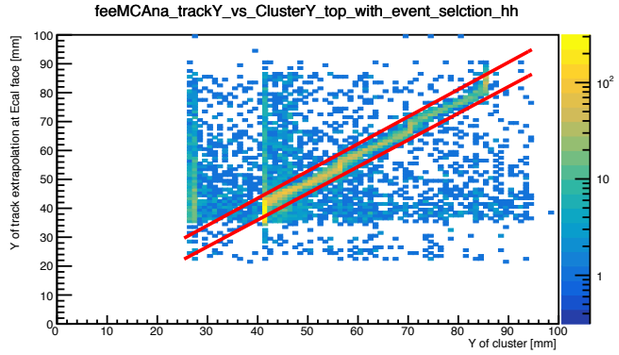


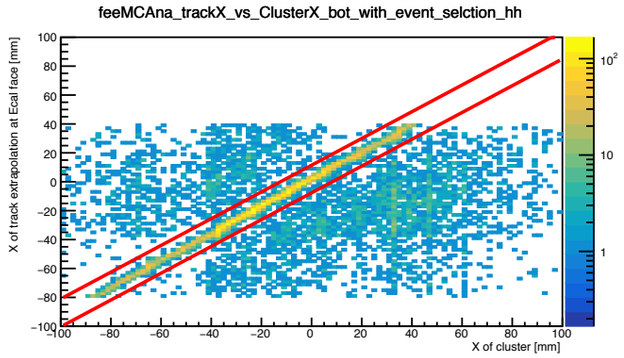
Events with only one negative track and chi2/NDF cut

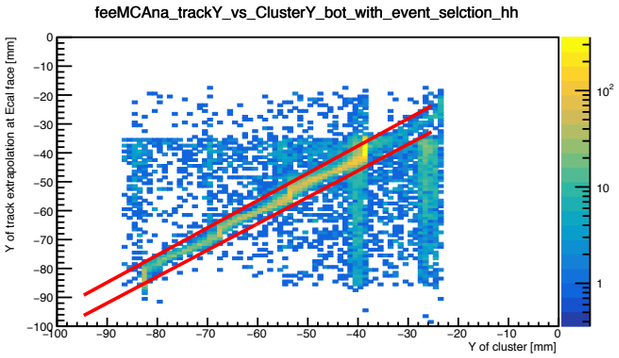


Track-cluster matching



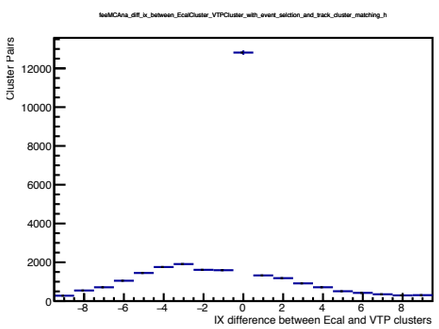


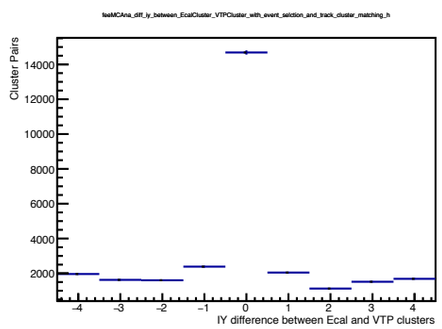


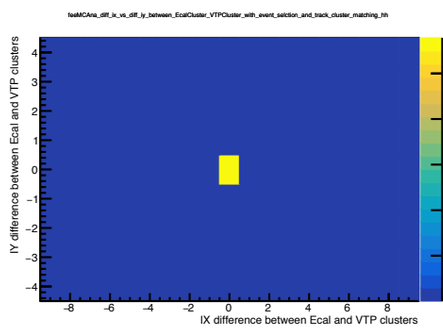


- Event selection through track collection:
  - Events only includes one track with negative charge, while no track with positive charge
  - The track satisfy tight cuts for chi2/NDF, moment range and x range for track extrapolation at Ecal face
- Select reconstructed Ecal clusters by track-cluster matching
- Find GTP clusters by Ecal-GTP-cluster matching with requirement that XY indices are consistent of each other

Ecal-GTP-cluster matching





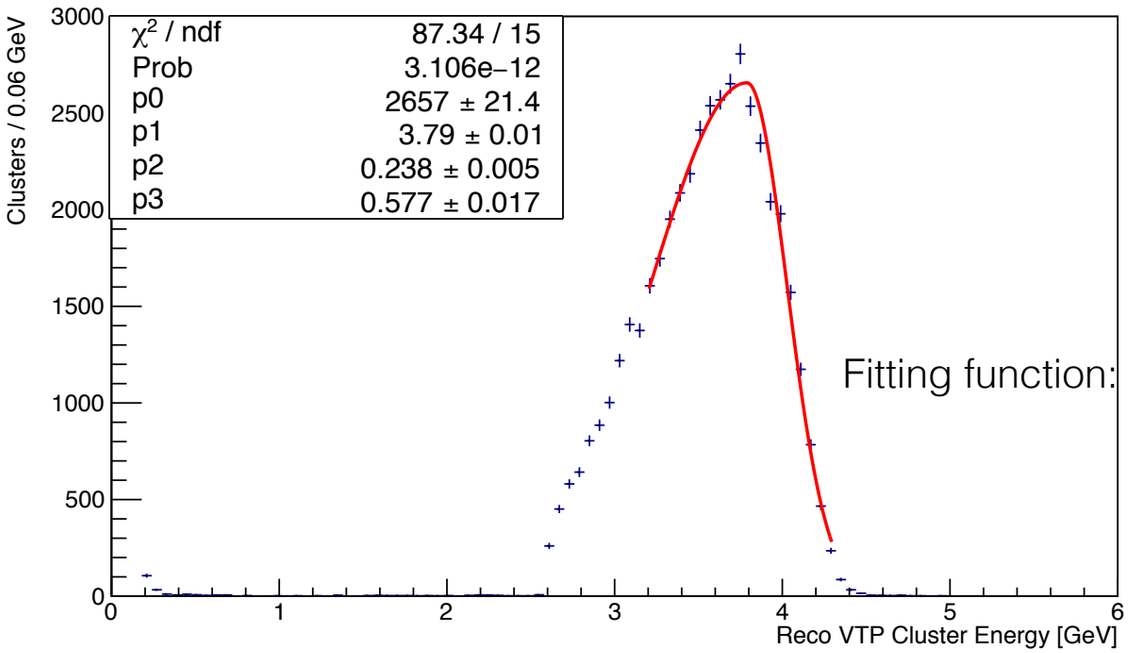


Comparison of FEE for GTP Clusters from Readout and Hardware

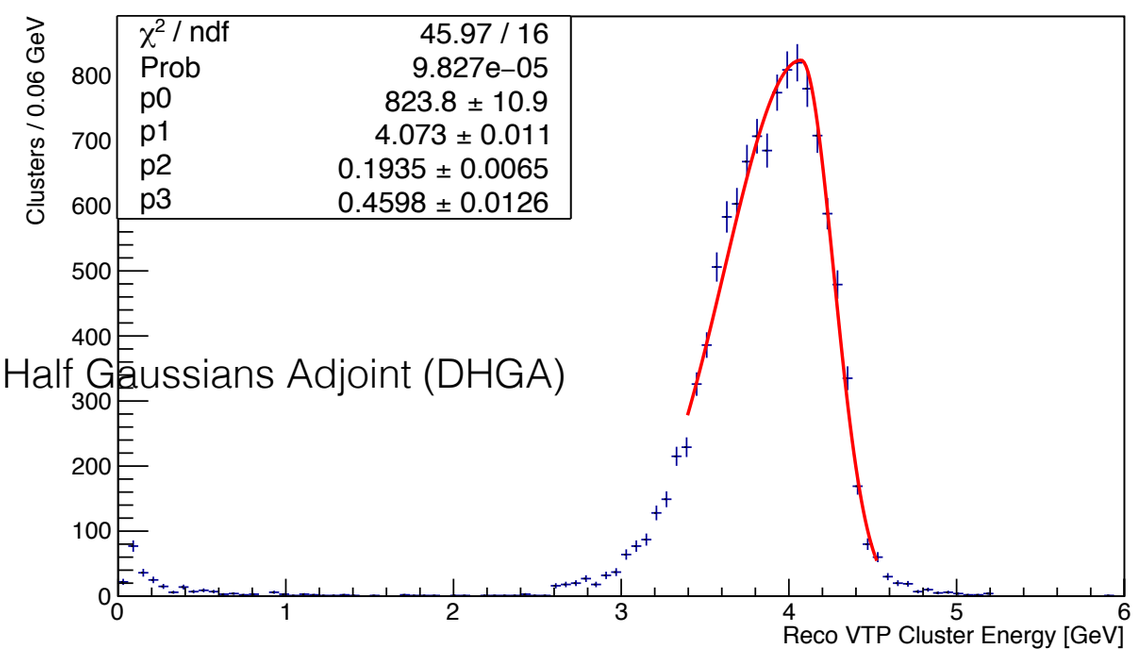
2019 FEE Run 10103

tritrig-wab-beam

hardware



readout



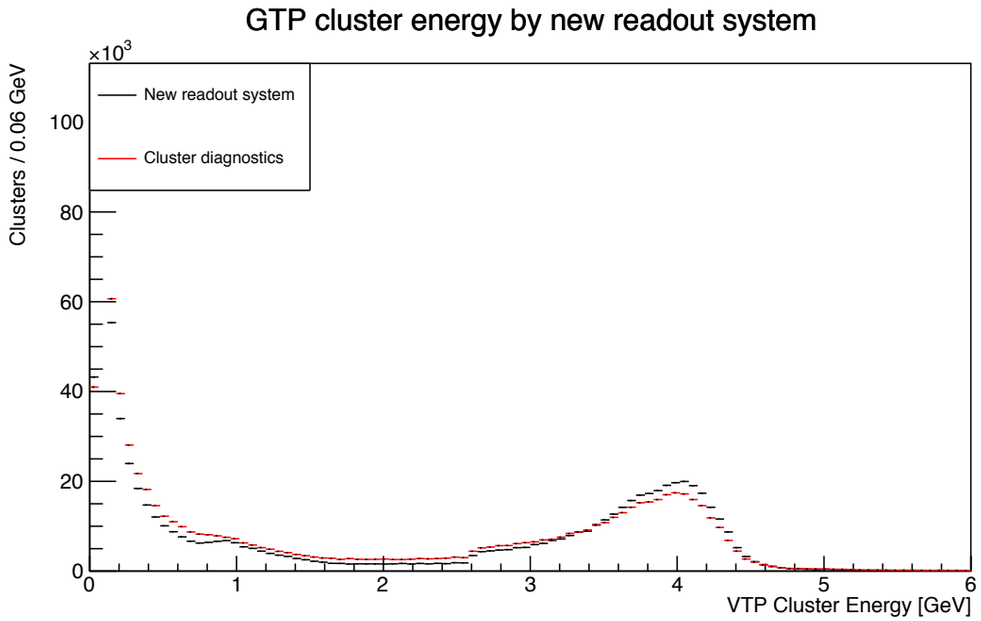
Fitting function: Double Half Gaussians Adjoint (DHGA)

Ratios of hardware to readout:

$$R_{mean} = 0.93,\ R_{\sigma_1} = 1.23,\ R_{\sigma_2} = 1.25$$

$$or \quad R_{mean} = 0.93,\ R_{\sigma} = 1.24$$

What Cause Difference?



Check if algorithms of pulse integration and GTP clustering in hardware and readout are consistent with each other:

- The 2019 cluster/trigger diagnostics system perfectly emulates algorithms in hardware. We input ADC samples from readout into the diagnostics system to reconstructed GTP clusters, which are compared to GTP clusters by the trigger system in readout.
- Energy difference of GTP clusters constructed by hardware and readout trigger systems with the same input of ADC samples is slight. It figures out that algorithms of pulse integration and GTP clustering in hardware and readout are basically consistent with each other. The slight difference is caused by simplification of algorithms in readout.

- Difference could be likely caused by three aspects:
    - Difference between Ecal clusters from experiment and simulated clusters by SLIC.
    - Difference between realistic pedestals and gains in hardware and pedestals and gains in database determined by data.
    - The three-pole model is applied for digitization in readout, while realistic pulse situations in experiment are much more complicated.
- We probably can figure out contributions of the three aspects and improve the readout system or the detector simulation package for Ecal. But it needs a lot of efforts.

Correction of Trigger Cut Conditions

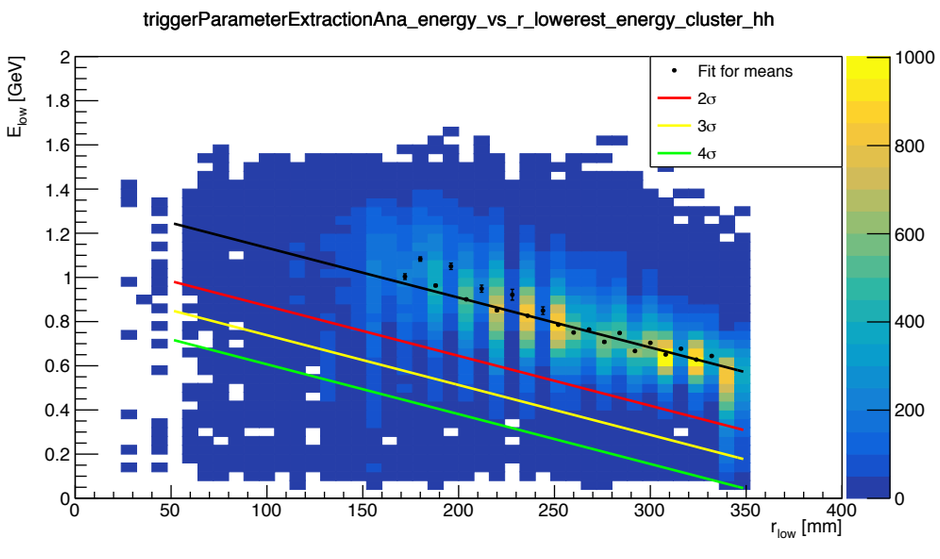
Trigger cut conditions relative to GTP cluster energy include:

- Range of energy for ap singles/pair
- PDE for ap singles
- Range of energy sum and difference for ap pair
- Energy slope for ap pair
- Range of energy for FEE
- Range of energy for Moller
- PDE for Moller

Pure ap

Energy Slope for ap pair

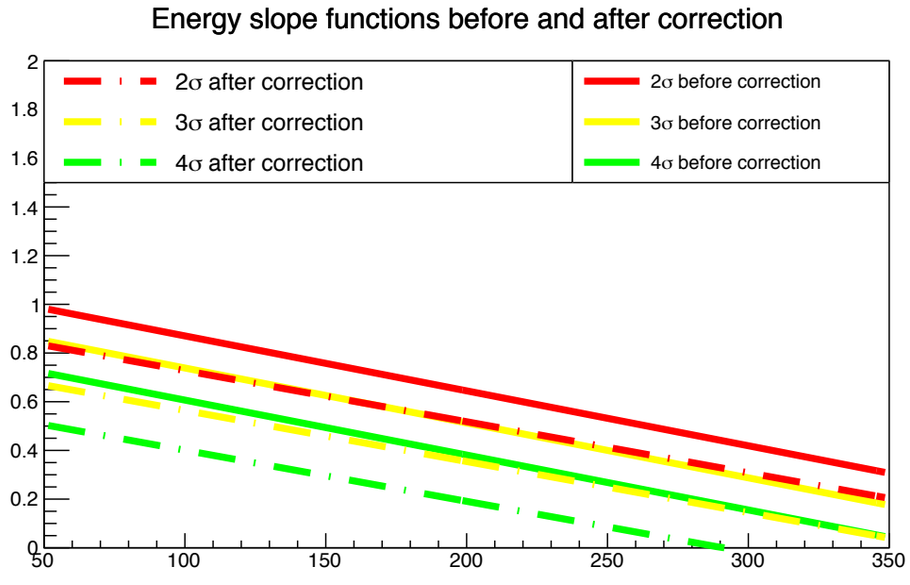
ap: 50



Before correction:

1st pol.	F [GeV/mm]	$E_{threshold}$ [GeV]
2σ	0.00225597	1.09592
3σ	0.00225597	0.964074
4σ	0.00225597	0.83223

- To extract energy slope function, a point at mean is extracted for each sub-range. Then, points at means are fitted by pol1. The function from fitting shifts 2 or 3 or 4 sigmas as a cut function, where the sigma value is average of sigmas of all applied sub-ranges.
- For correction, the function from fitting is scaled by ratio of mean, and shifts are scaled by ratio of resolution.



After correction:

1st pol.	F [GeV/mm]	$E_{threshold}$ [GeV]
2σ	0.00209805	1.00075
3σ	0.00209805	0.868901
4σ	0.00209805	0.737058

Suggested Cuts for Moller with Correction

- Cluster energy: [0.50, 1.52] GeV
- NHits: >= 1 (no limit)
- X index: <= -10
- Y index: [-2, 2]
- Energy upper limit as a function of X index

2rd pol.	p0 [GeV]	p1 [GeV]	p2 [GeV]
3σ	2.50741	0.131992	0.00239416
4σ	2.75714	0.152371	0.00299458
5σ	3.00577	0.1726	0.00359016

Suggested Cuts for ap Pair Trigger with Correction

- Cluster energy: [0.3, 3.0] GeV
- NHits: >= 2
- Energy sum: [0.7, 3.2] GeV
- Energy difference: [0, 2.7] GeV
- Coplanarity: [0, 40] deg
- Energy slope from ap of 50 MeV/c^2

1st pol.	F [GeV/mm]	$E_{threshold}$ [GeV]
2σ	0.00209805	1.00075
3σ	0.00209805	0.868901
4σ	0.00209805	0.737058

Summary

- Trigger conditions for Moller and ap pair are determined by trigger tuning analysis and corrected based on ratios of GTP cluster energy between hardware and readout.

- Main codes of trigger tuning analysis for ap singles/pair triggers, FEE trigger and Moller trigger of 3.7 GeV beam have been developed in hpstr.

- The same codes will be applied into trigger tuning for 1.92 GeV beam.

- Basically, trigger tuning for 3.7 GeV has been done. Trigger tuning for 1.92 GeV will be priority in my to-do list, as the 2021 experiment is close.