



LOUISIANA STATE UNIVERSITY



Generic Neutrino Selection and Cluster-Evaluation Performance

SBND Wirecell Meeting

Prabhjot Singh, 30 July 2026

Overview

- Current status of Neutrino Selections: Based on reconstructed information
- Status of Charge-Light-Matching Evaluation: Based on True and Reco Cluster Comparisons

Part 1: Current status of Generic Neutrino Selections

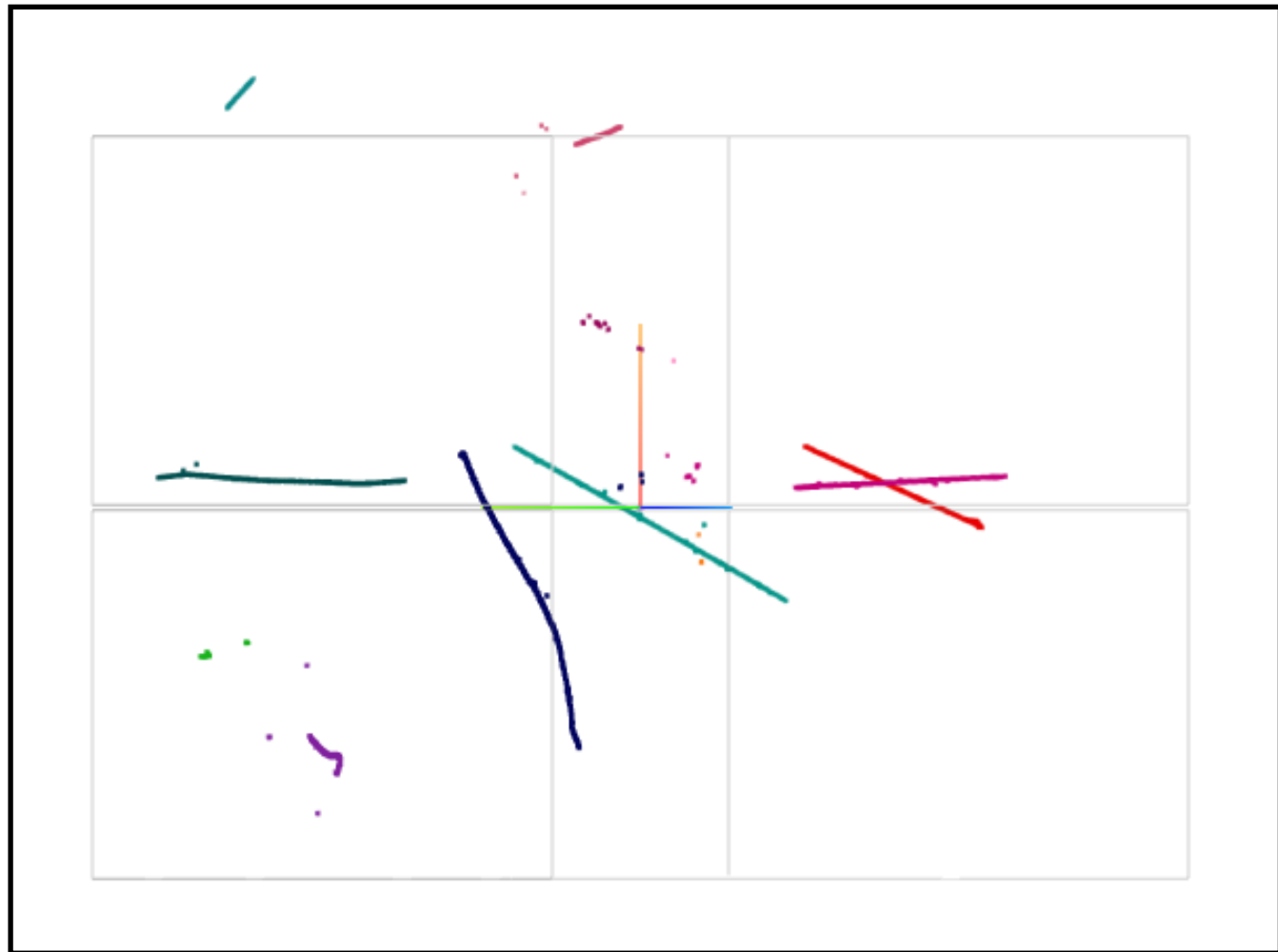
Charge-Light Matching: New Wirecell Files

- **op.json**: contains information about the optical flash time and information of clusters that has a op flash time
- **img-global.json**: contains information about imaging: clusters **before** SCE, **before** charge-light matching, and **before** clustering
- **clustering-global.json**: contains information about clustering: clusters **after** SCE, **after** charge-light matching
- **sed-sce_drift_smear_readout.json**: true clusters **before** charge-light-matching
- **sed-smear_readout.json**: true clusters **after** charge-light-matching
- **mc.json**: contains true information about the particle flow, for instance: neutrino or non-neutrino, true energy deposited, total energy, parent and children particles, their start and end true positions

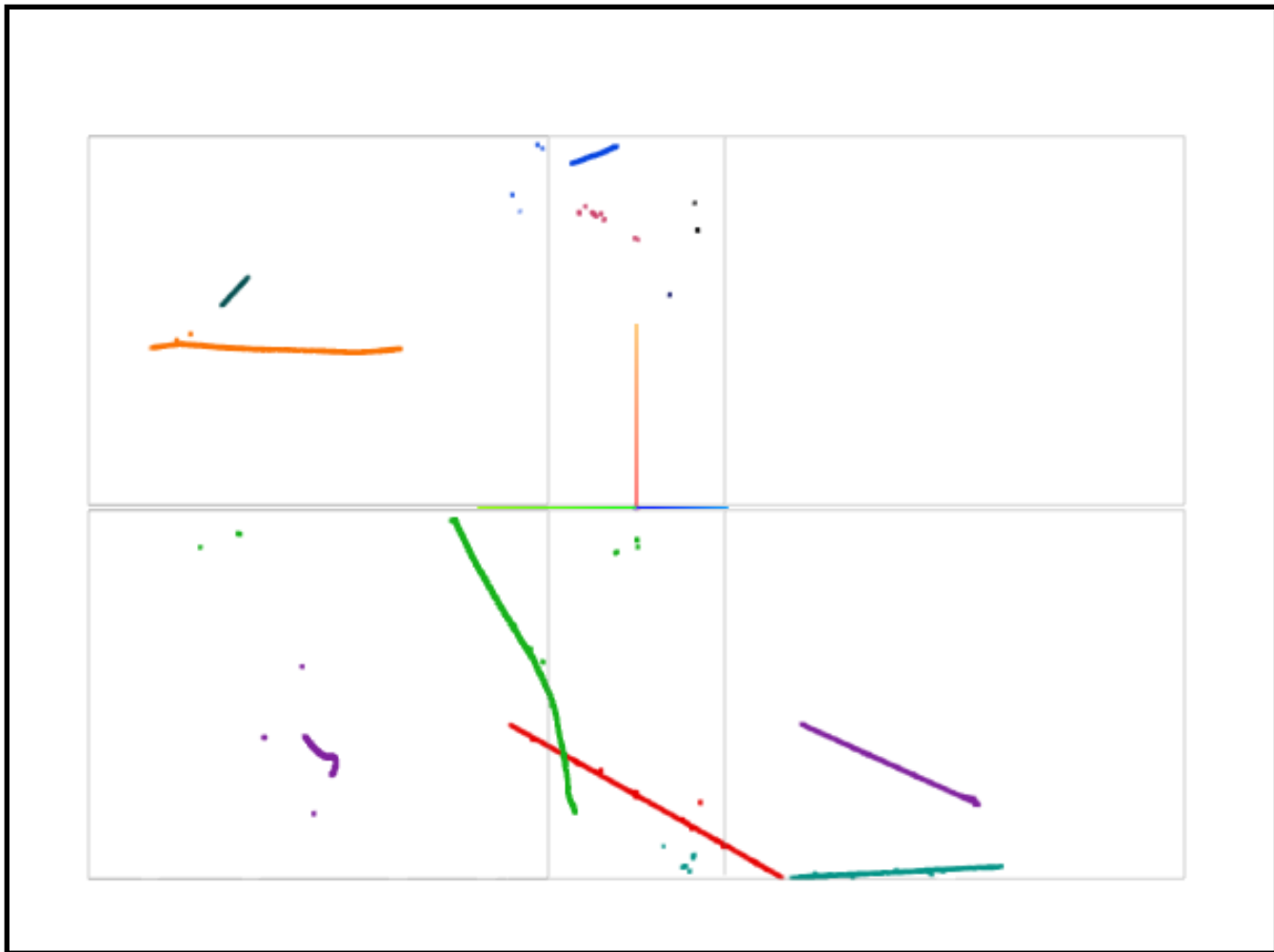
Charge-Light Matching: New Wirecell Files

[Bee-link](#)

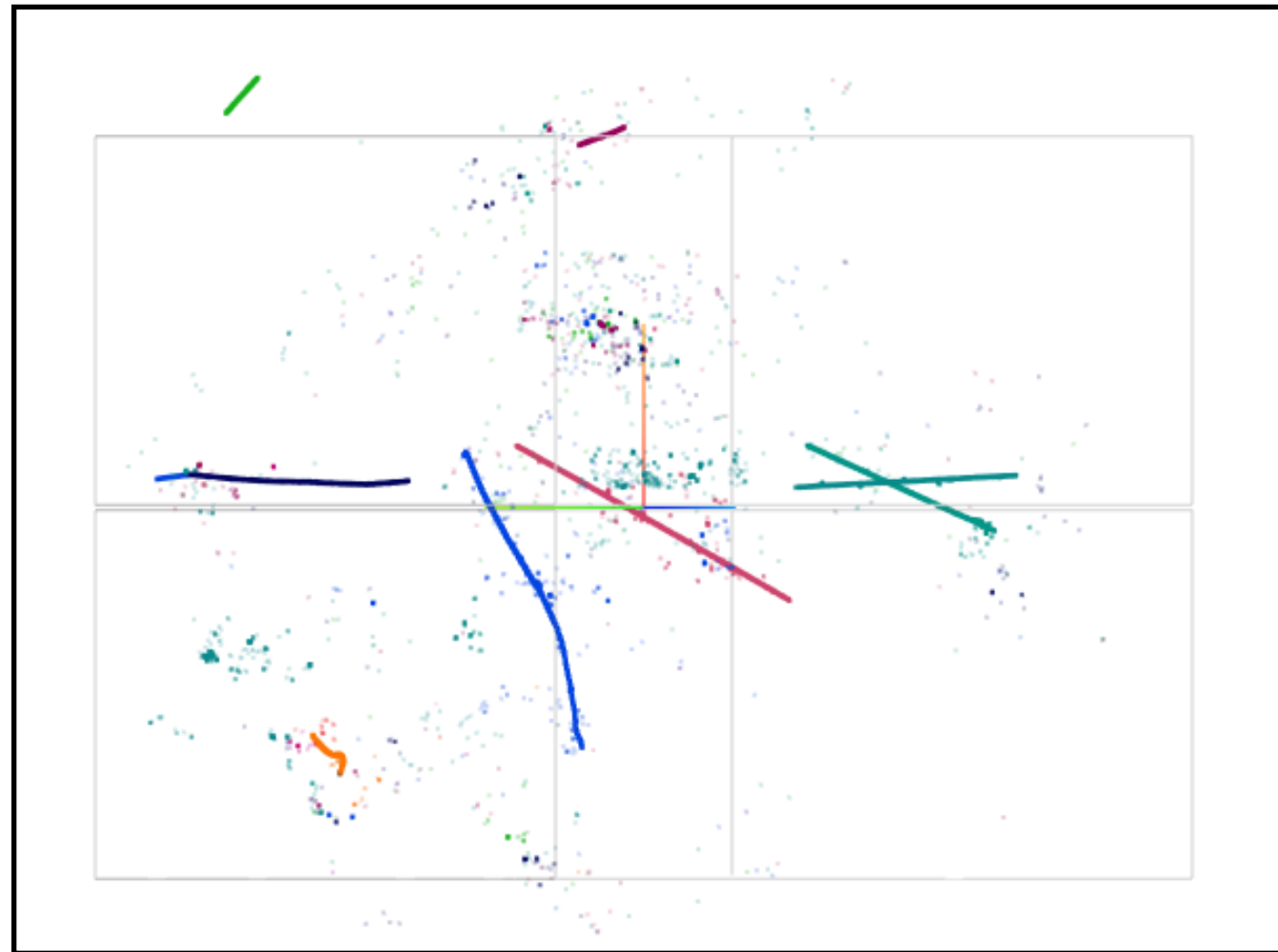
img-global.json



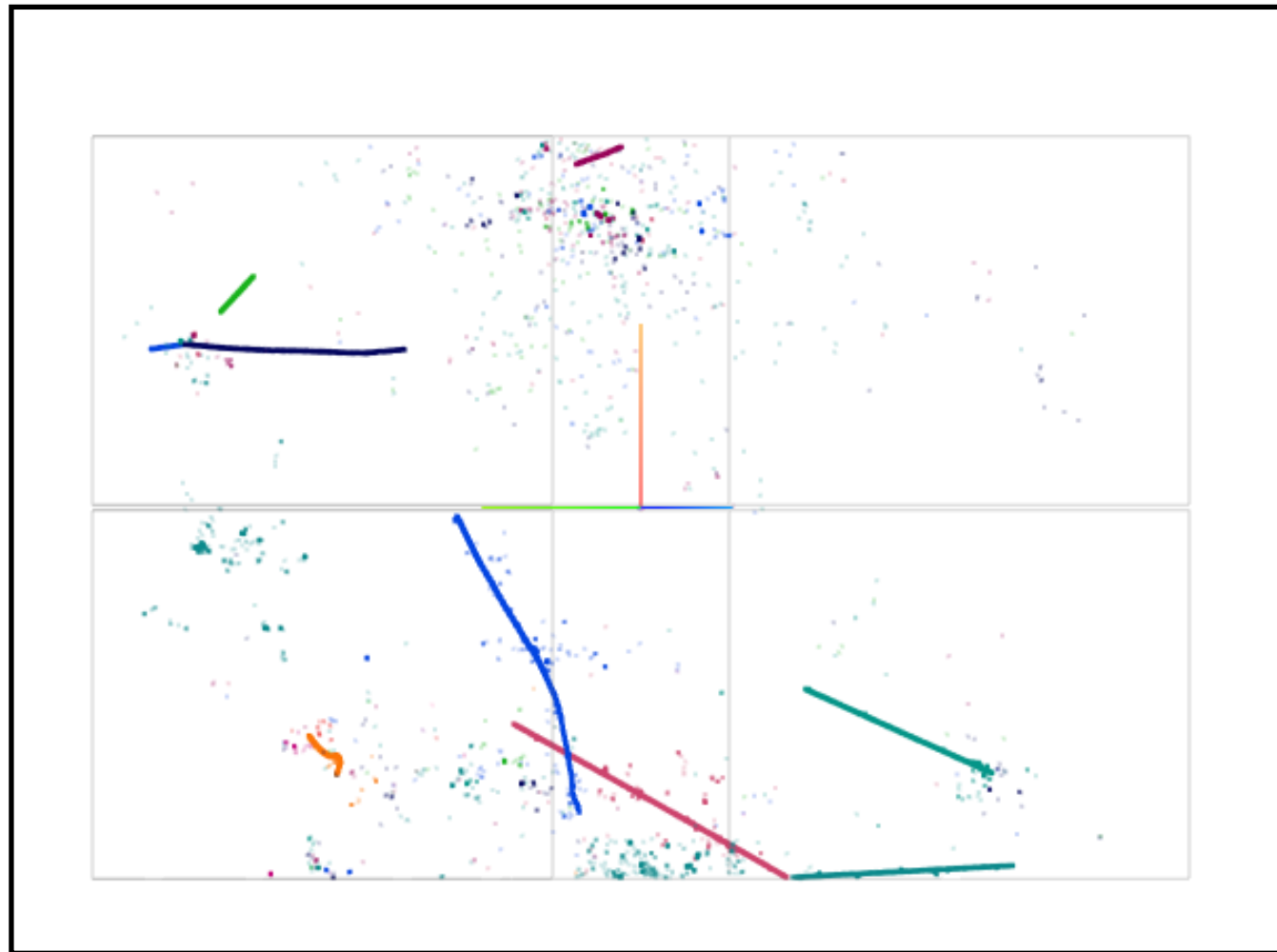
clustering-global.json



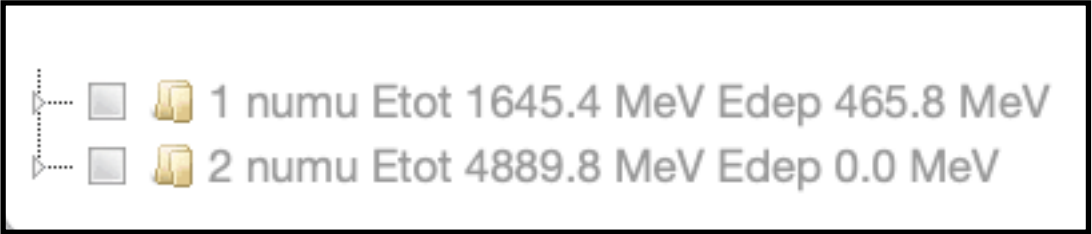
sed-sce_drift_smear_readout.json



sed-smear_readout.json



mc.json



Information Flow

op.json → img-global.json

Associate op flash time
to clusters

Information Flow

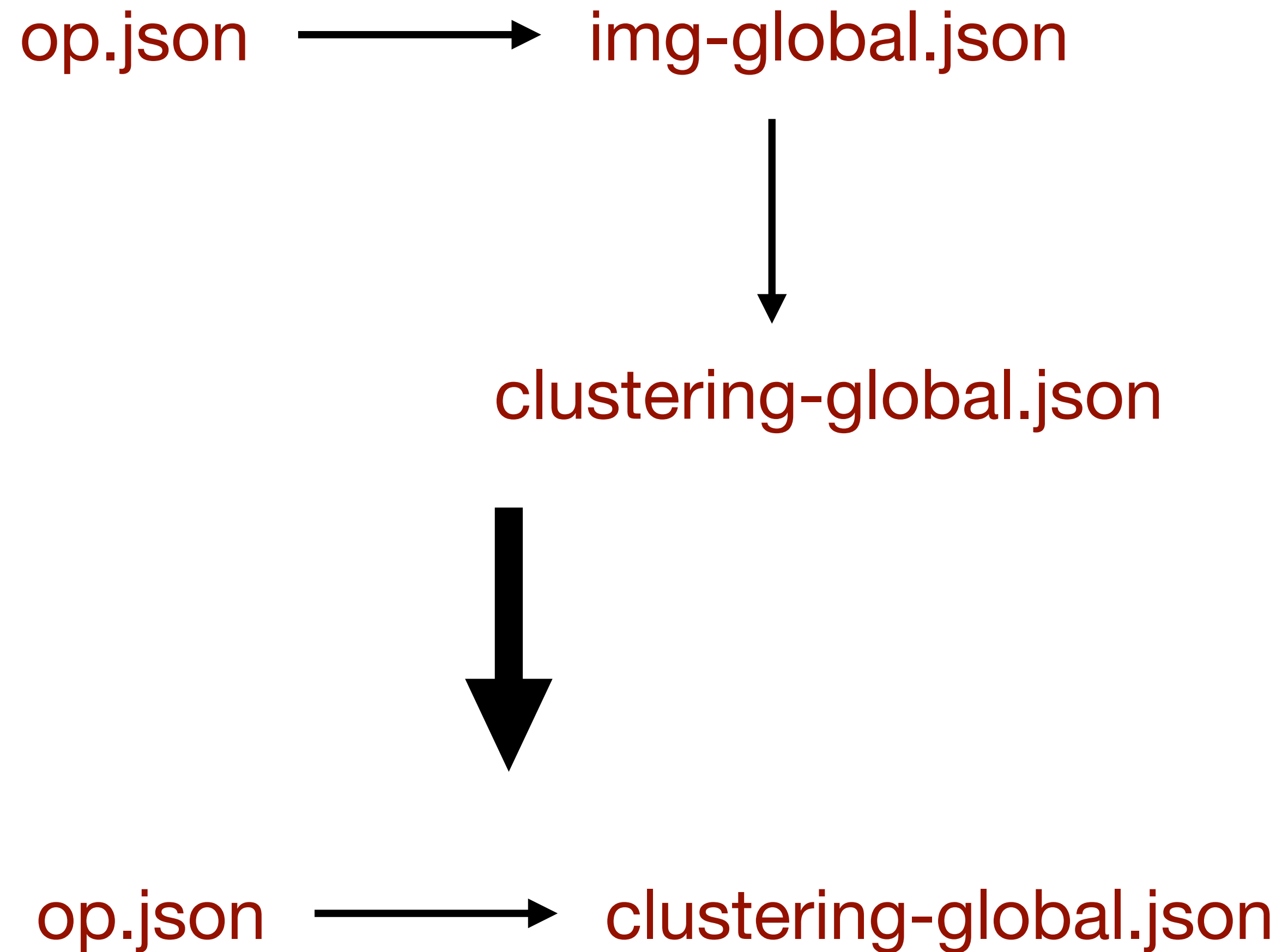
op.json → img-global.json



clustering-global.json

Associate cluster information
from before to after
charge-light matching

Information Flow



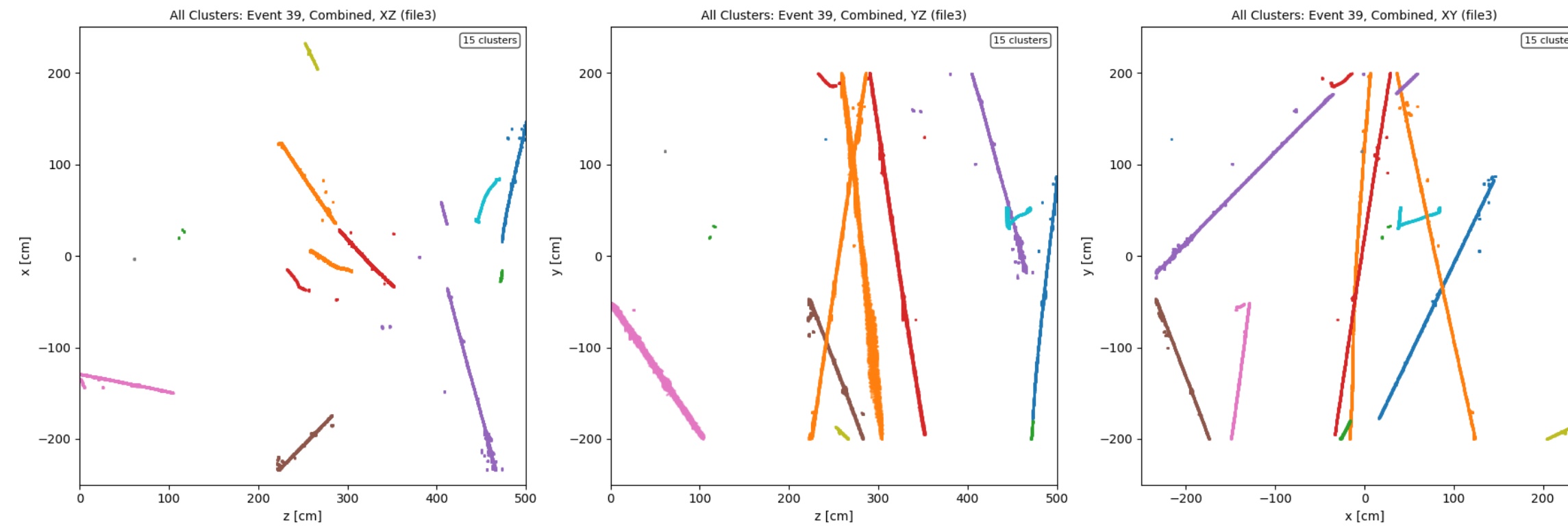
Through img-global we can know op flash time of clusters

This is all we need to apply time-window cut to only select activity within beam-window

Flash-Time Performance on Imaging

[Bee-link](#)

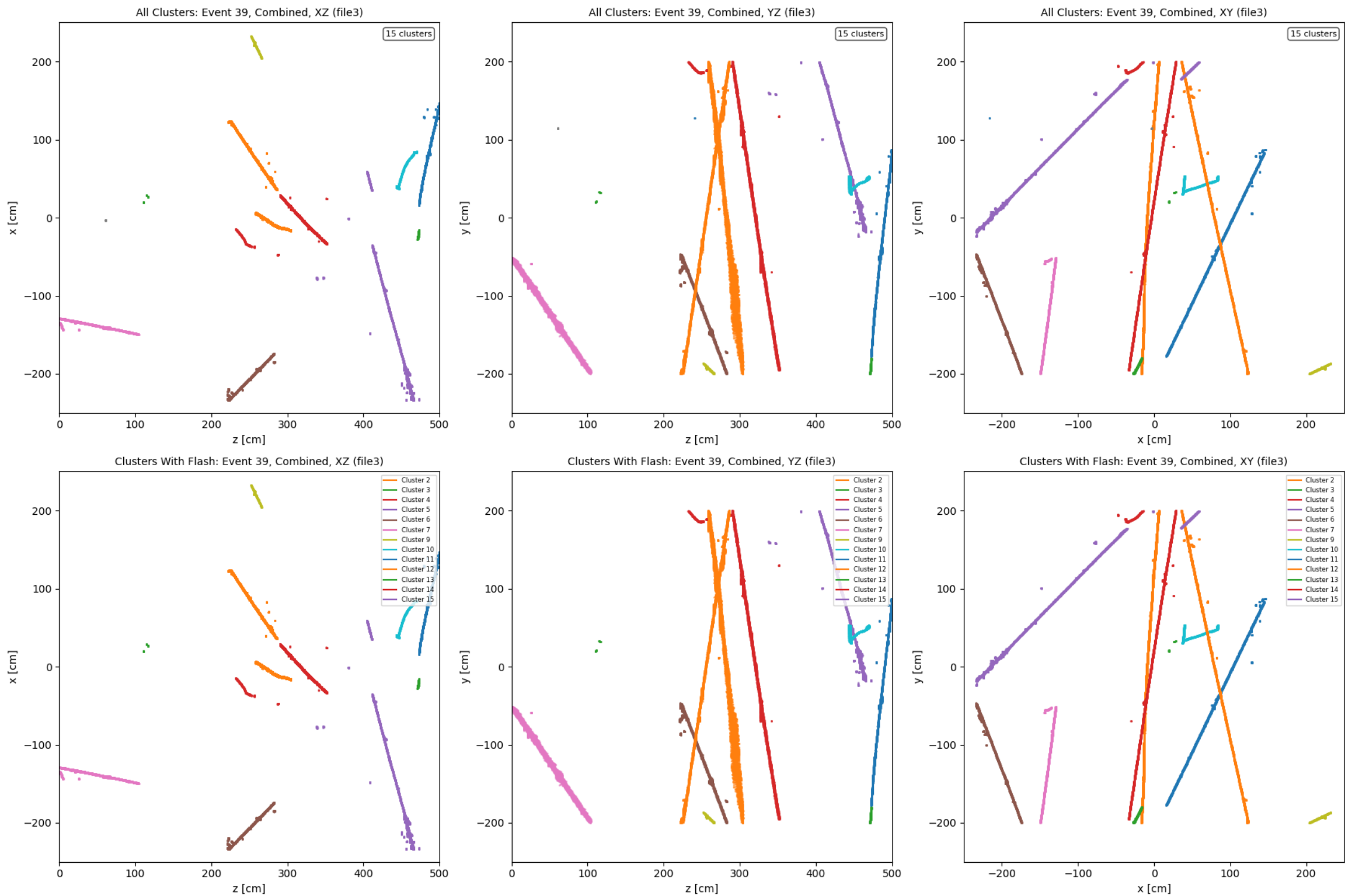
img-global.json



All clusters before charge-light matching

Flash-Time Performance on Imaging

img-global.json



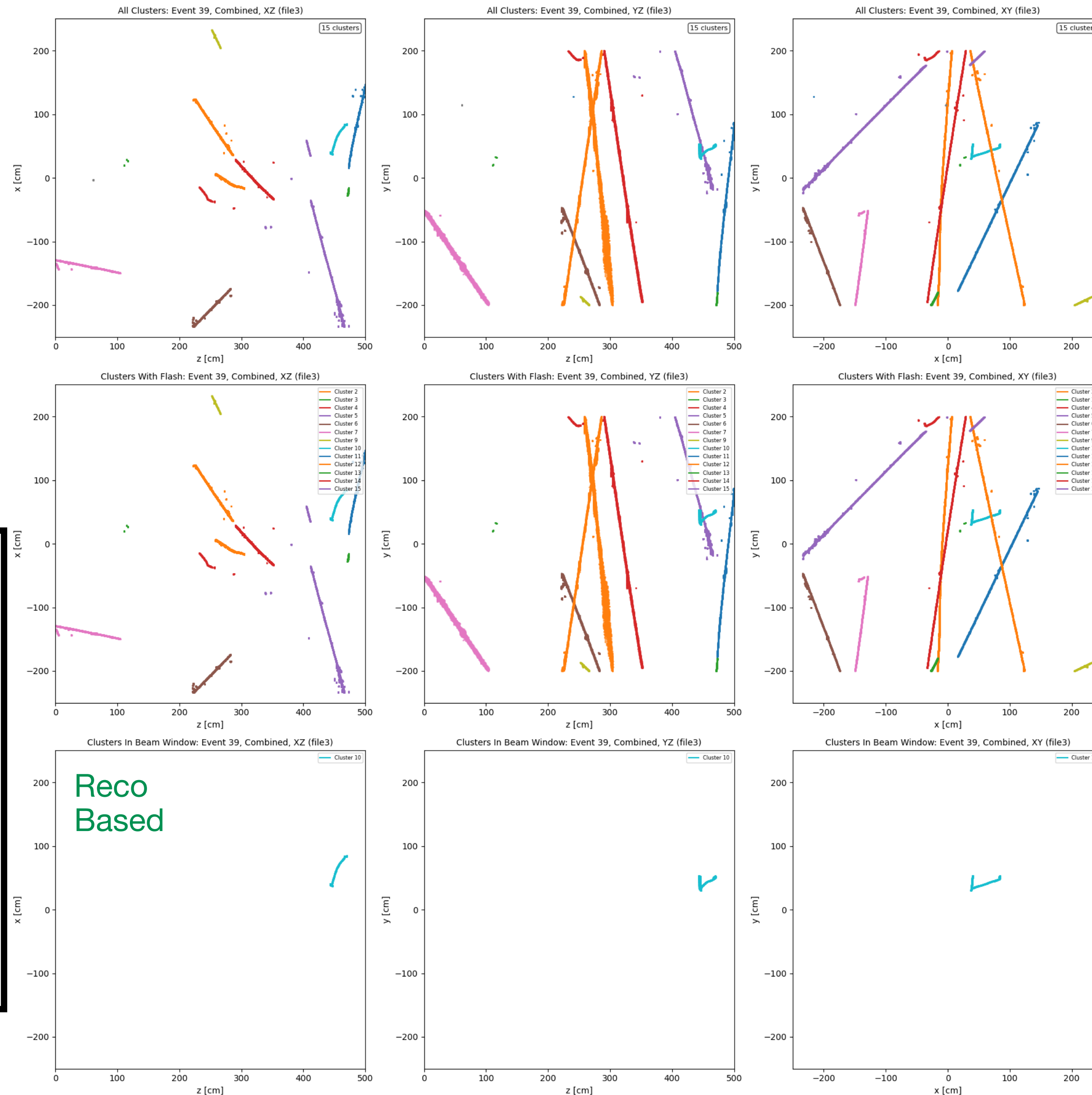
All clusters before charge-light matching

We find how many of clusters have op flash information

Flash-Time Performance on Imaging

[Bee-link](#)

img-global.json



All clusters before charge-light matching

We find how many clusters have op flash information

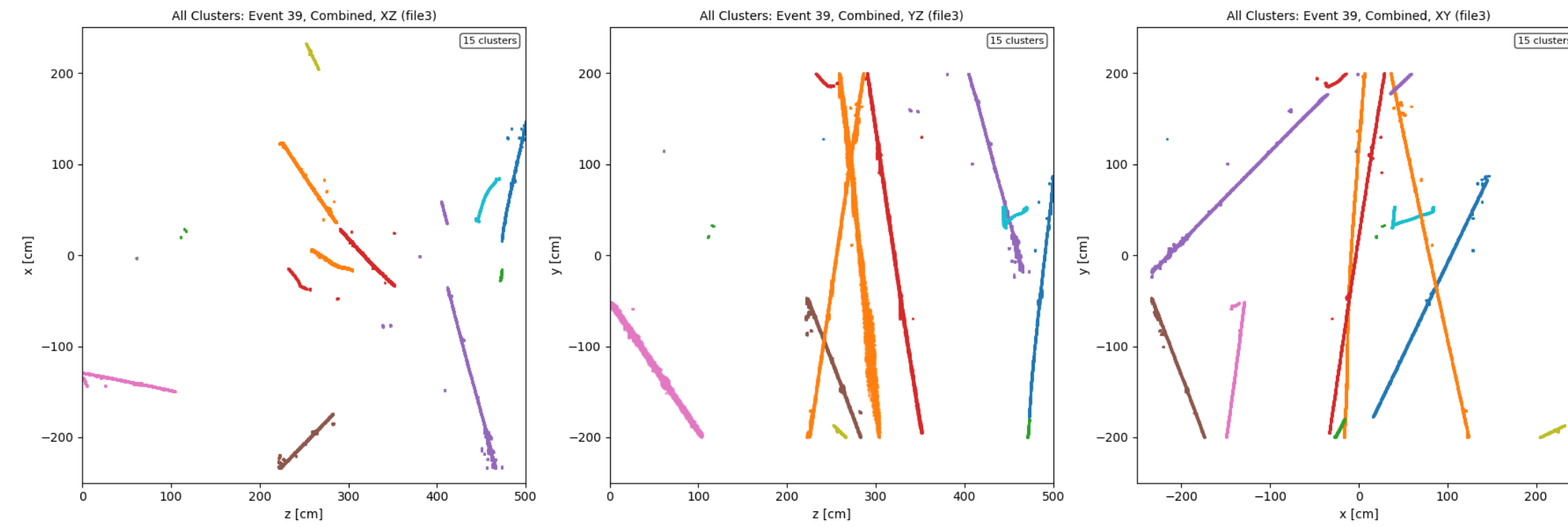
We apply beam time-window cut (0.33-1.93 μ s) to only keep in-beam activity

This example shows that the op flash time info was correctly assigned to images

Flash-Time Performance on Clusters

[Bee-link](#)

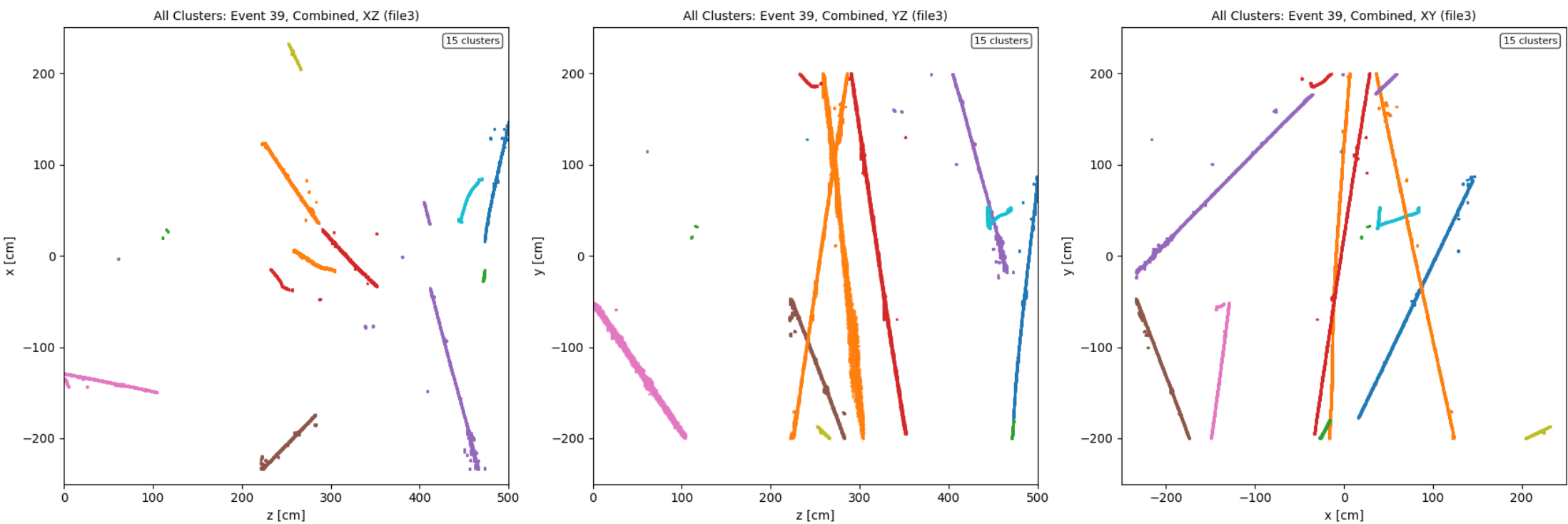
img-global



All clusters before charge-light matching

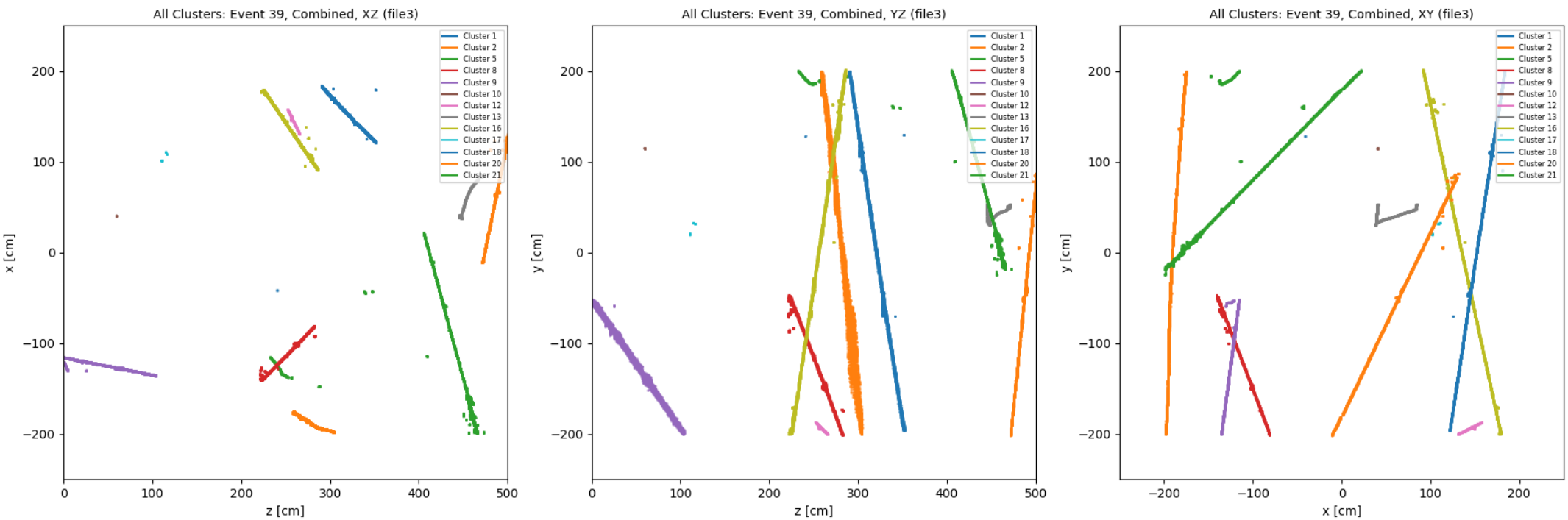
Flash-Time Performance on Clusters

img-global



All clusters before charge-light matching

clustering-global

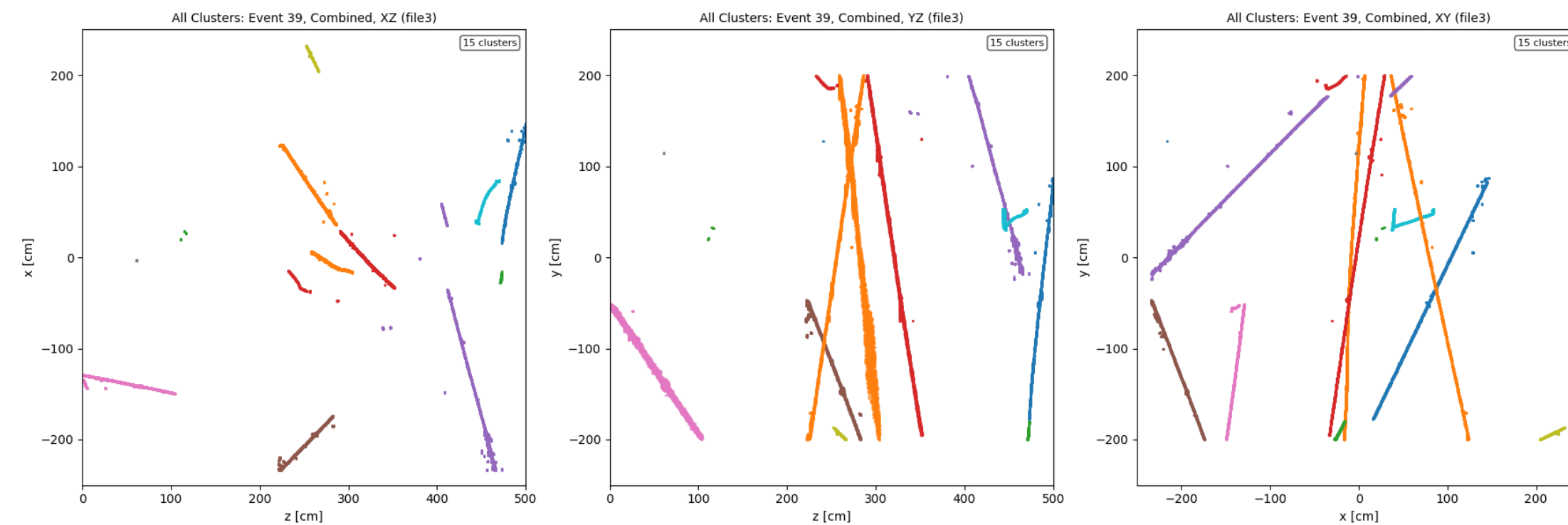


All clusters after charge-light matching

Flash-Time Performance on Clusters

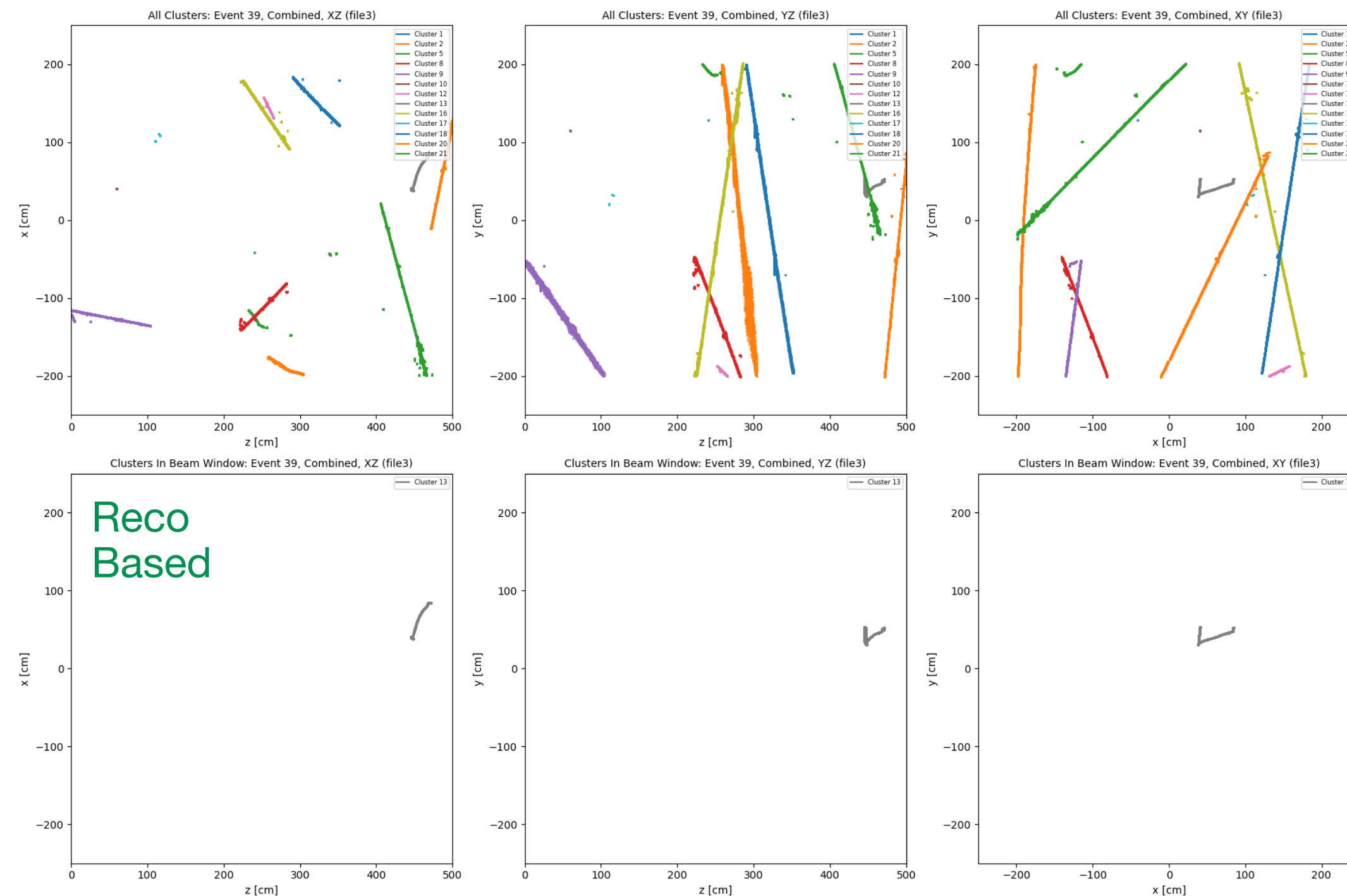
[Bee-link](#)

img-global



All clusters before charge-light matching

clustering-global



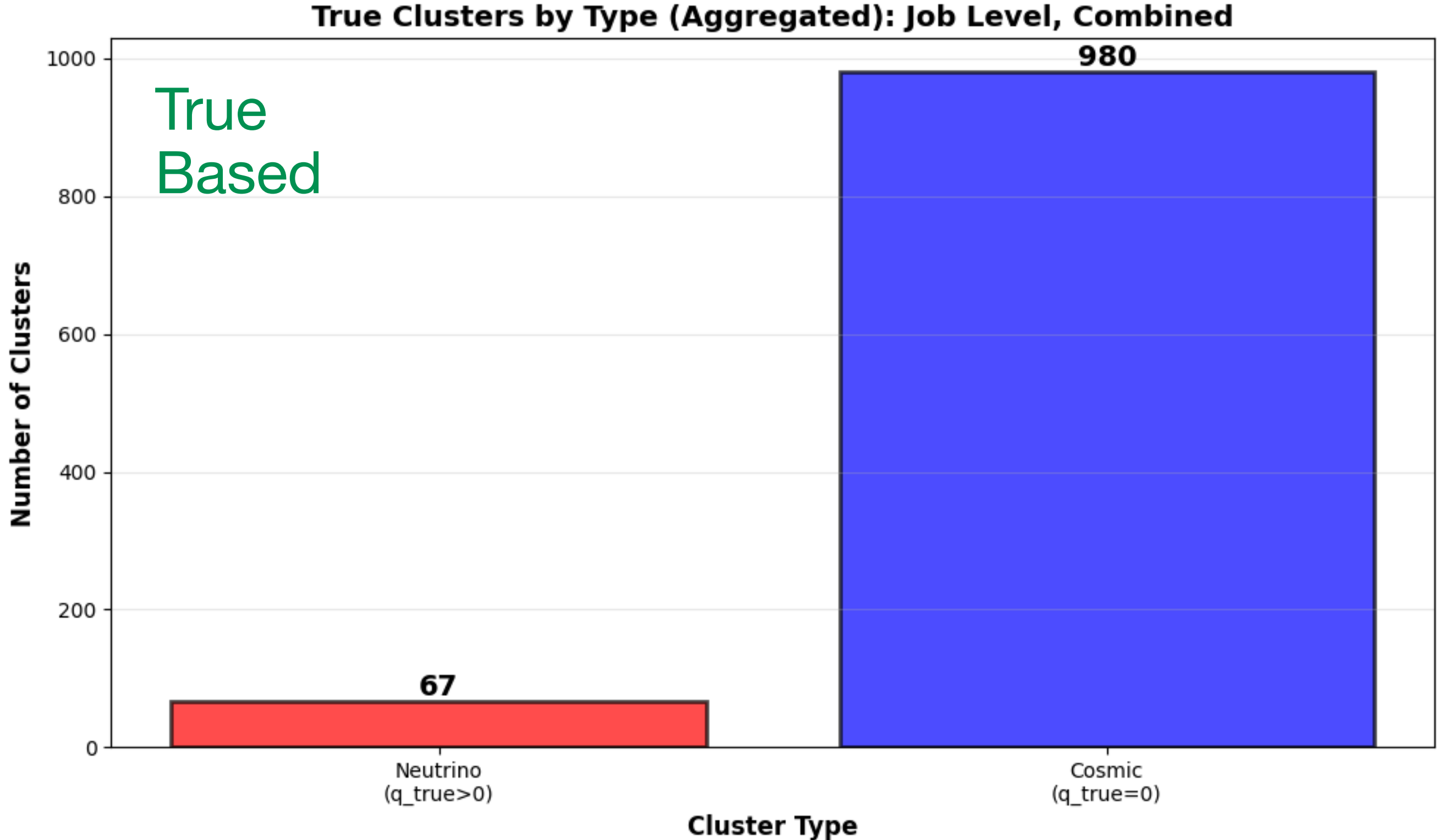
All clusters after charge-light matching

This example shows that information flow from img-global to cluster global to select in-beam activity worked successfully

We apply beam time-window cut (0.33-1.93 μ s) to only keep in-beam activity

High-Statistics: Both APAs combined

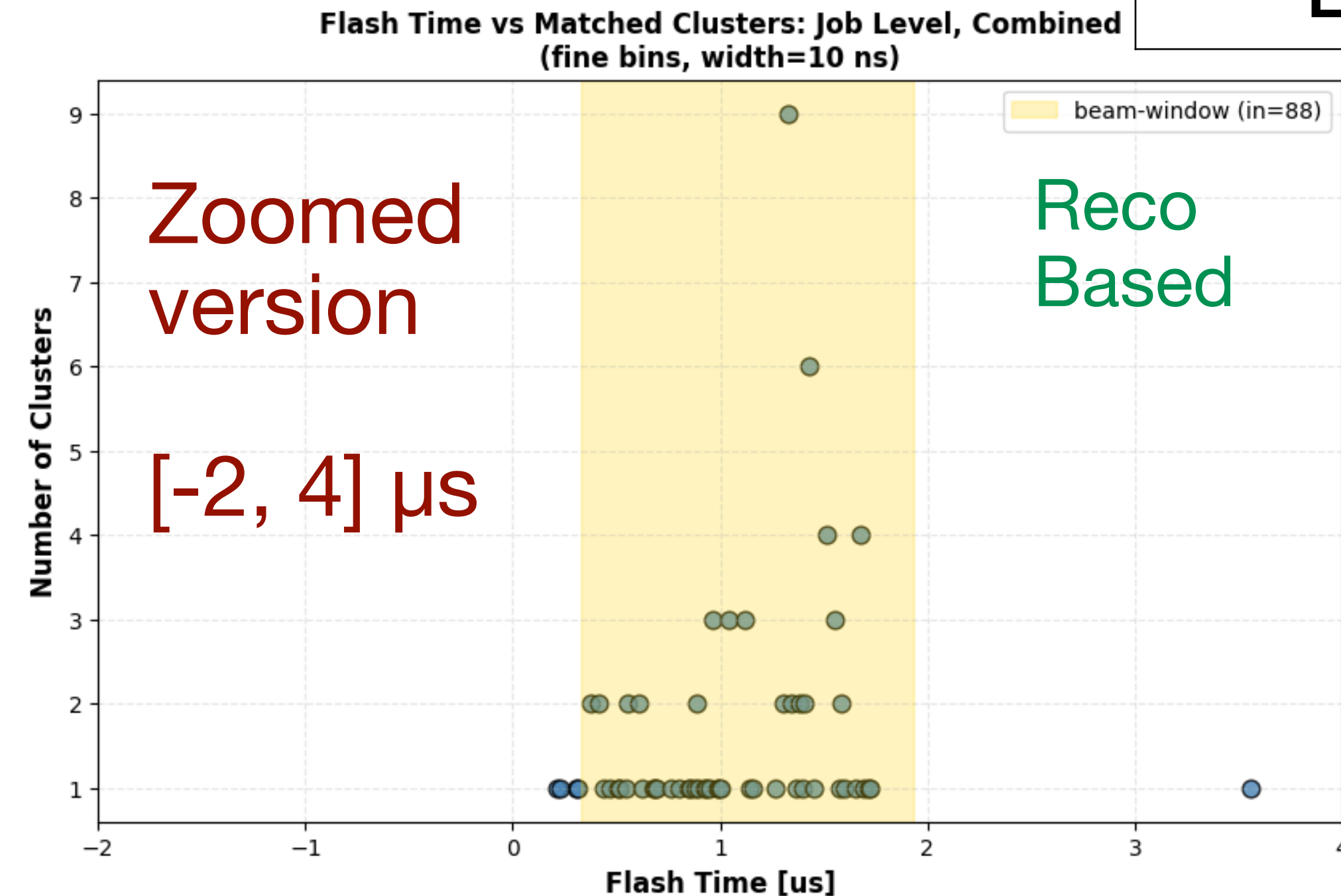
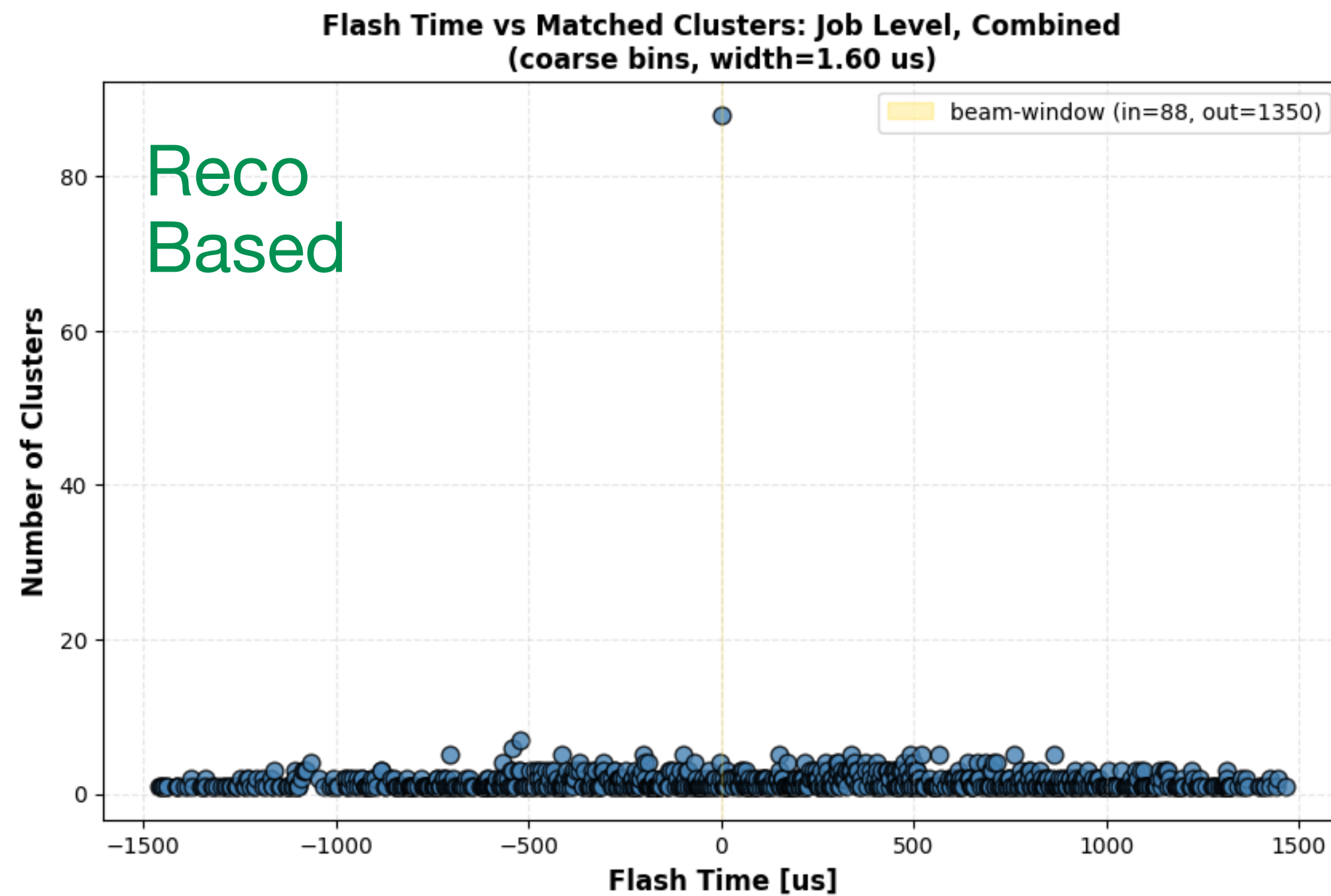
Number of Files	10
Events	118



- Though small but relatively good sample of neutrino and cosmic clusters for reconstruction efficiency and purity evaluations

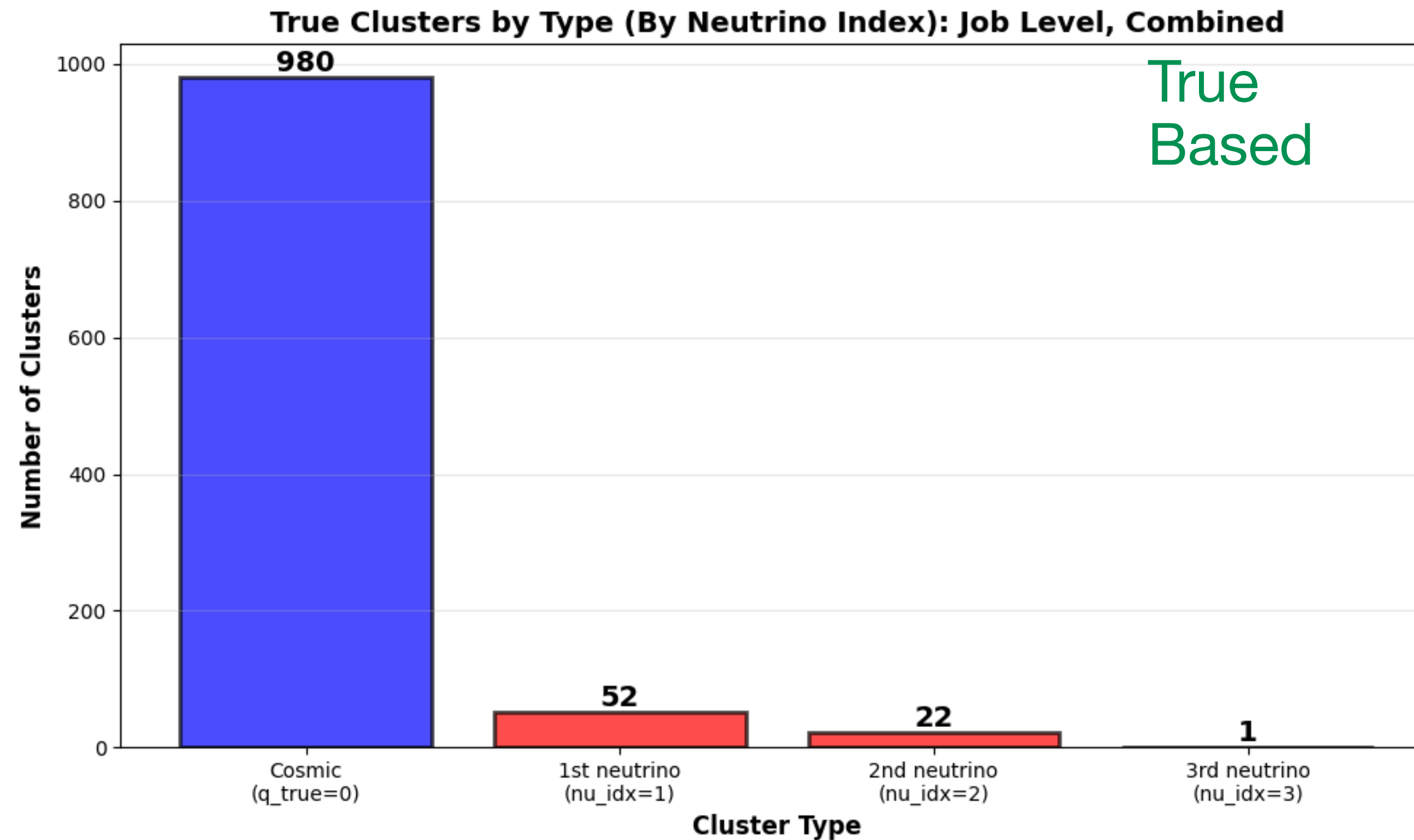
Flash Time

Number of Files	10
Events	118



- There is a large in-beam activity: clear evidence of finding neutrinos in beam-window
- There could also be coinciding cosmic activity within beam-window
- Next step in selections would be to have a cosmic-tagger to tag cosmic activity within beam window so that we can isolate it from neutrinos

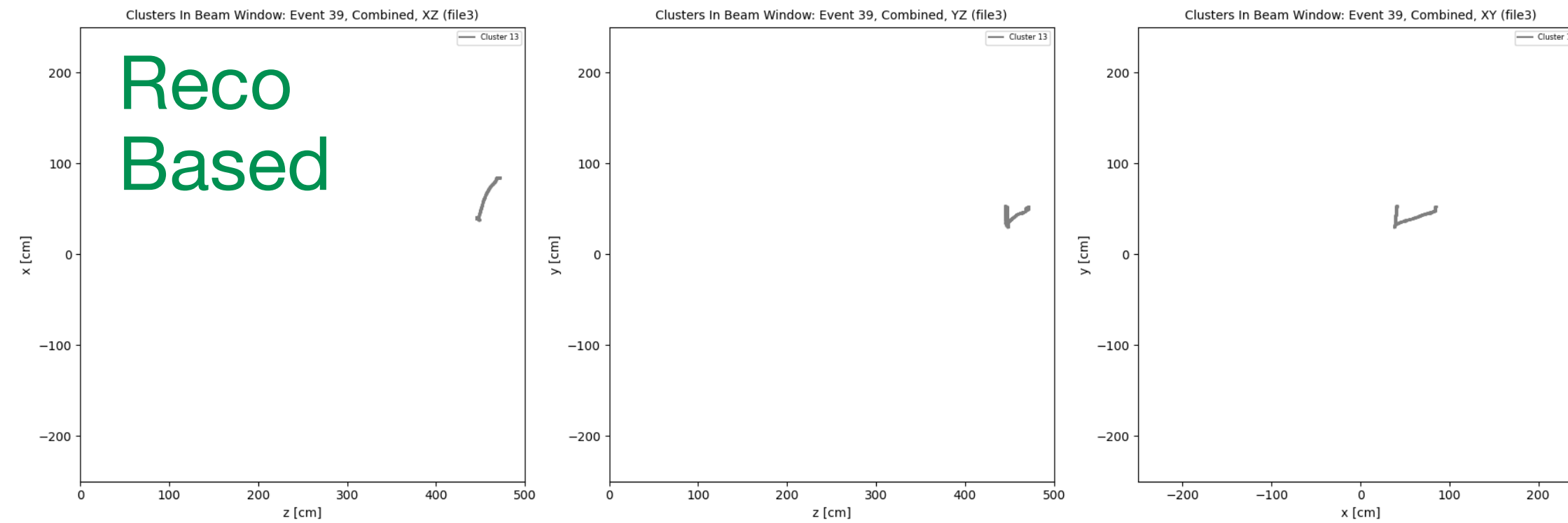
Multi-Neutrino Cases



- Using truth-information, we find that there are several cases of seeing one than one neutrinos in beam-window

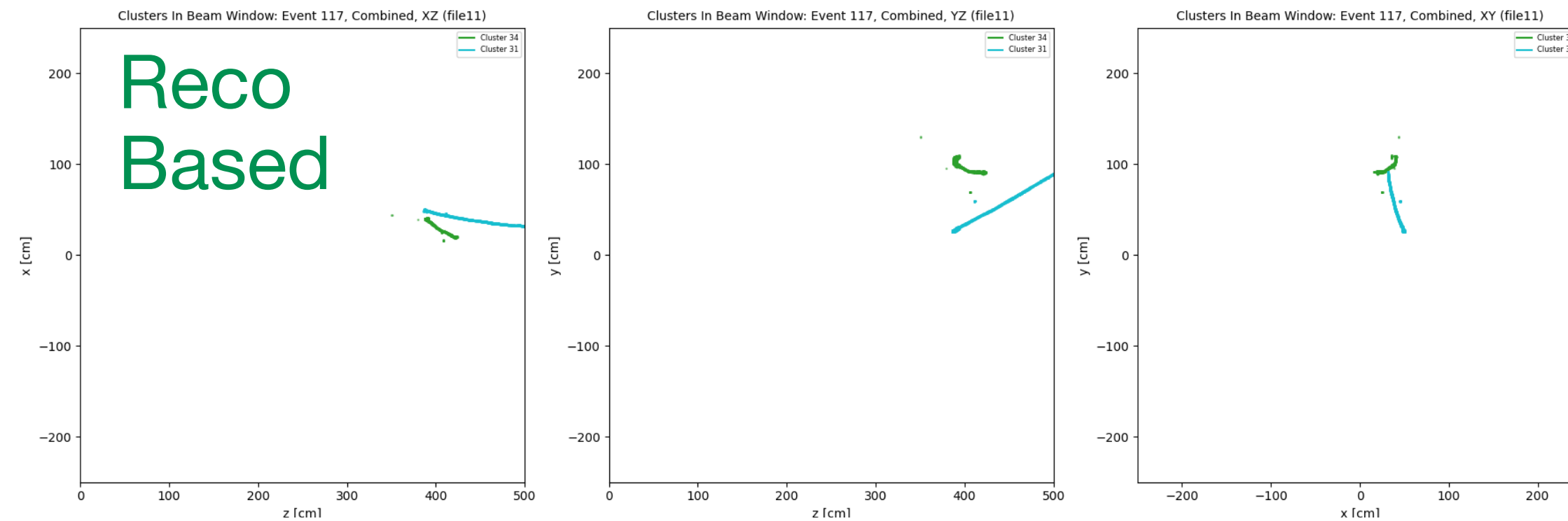
Multi-Neutrino In-Beam Activity

Single-
Neutrino



[Bee-link:39](#)

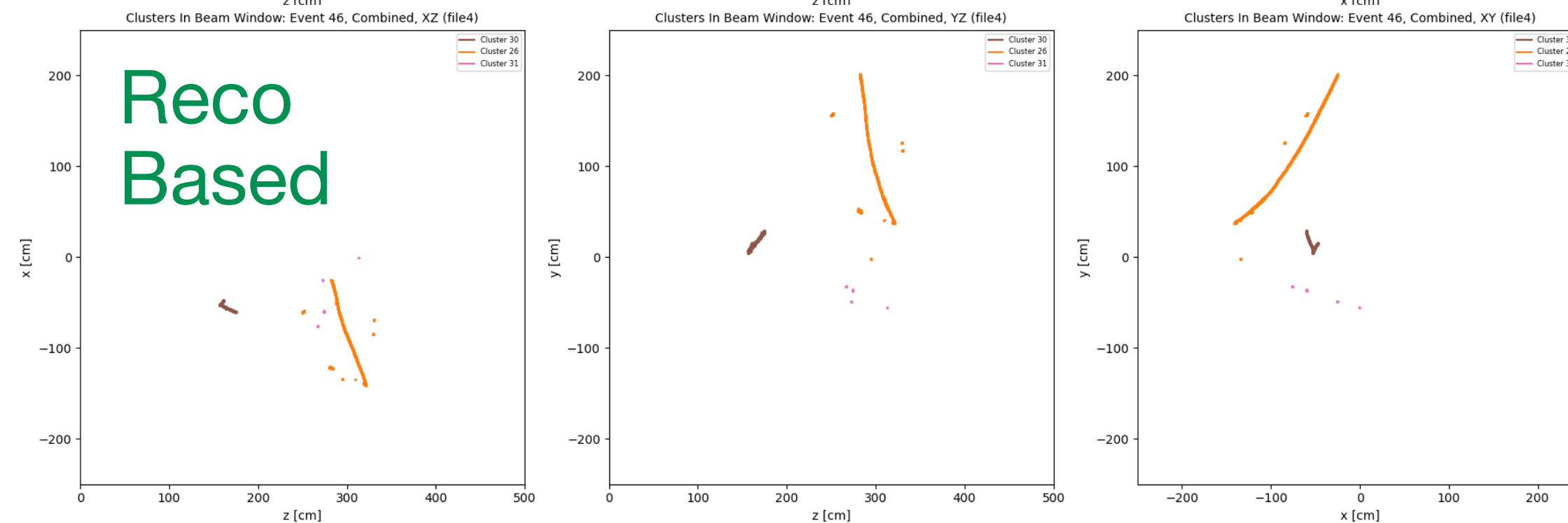
Two-
Neutrino?



[Bee-link:117](#)

Need to find
some for
examples

Neutrino
and
Cosmic?

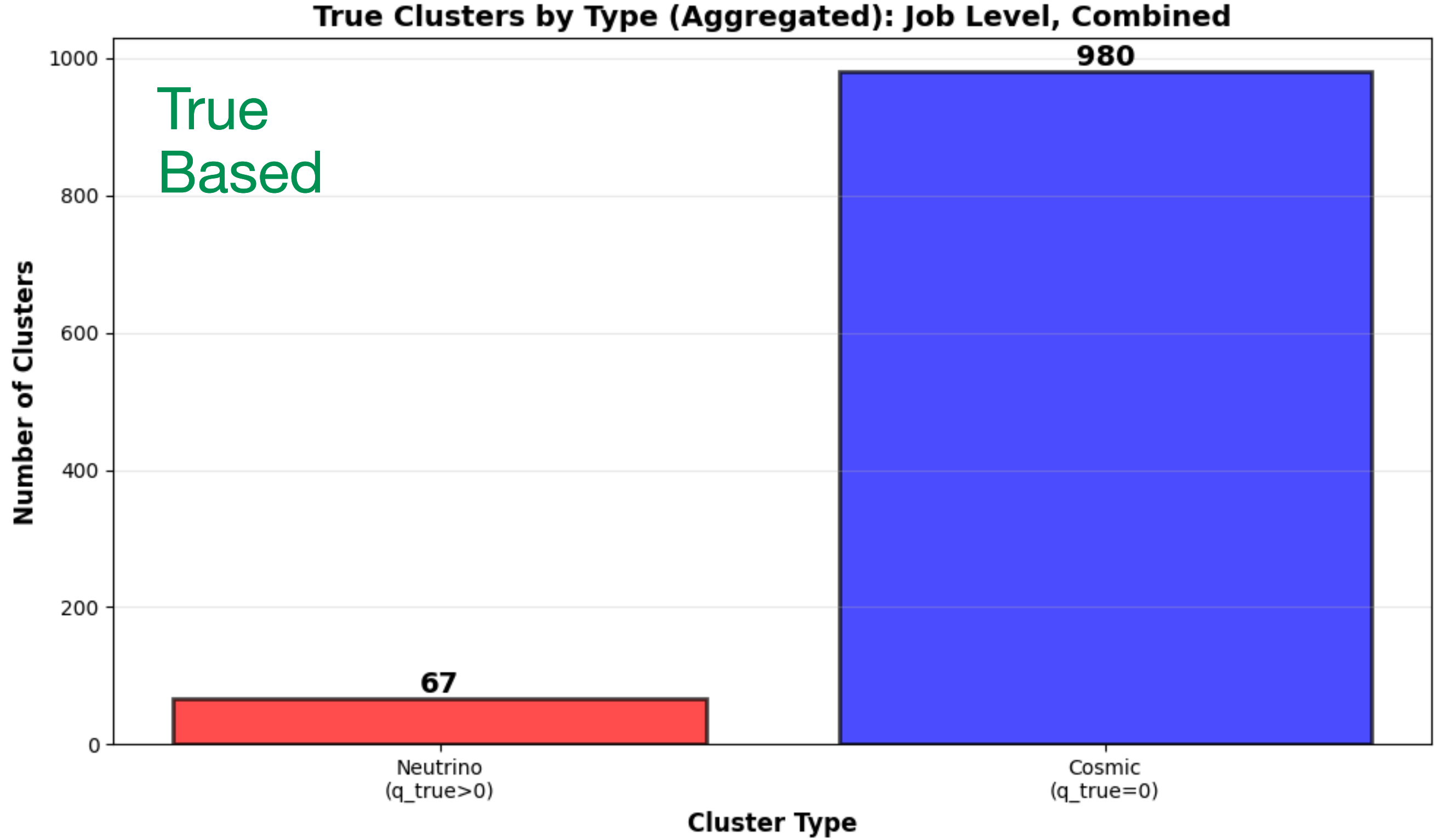


[Bee-link:46](#)

Need to find
some for
examples

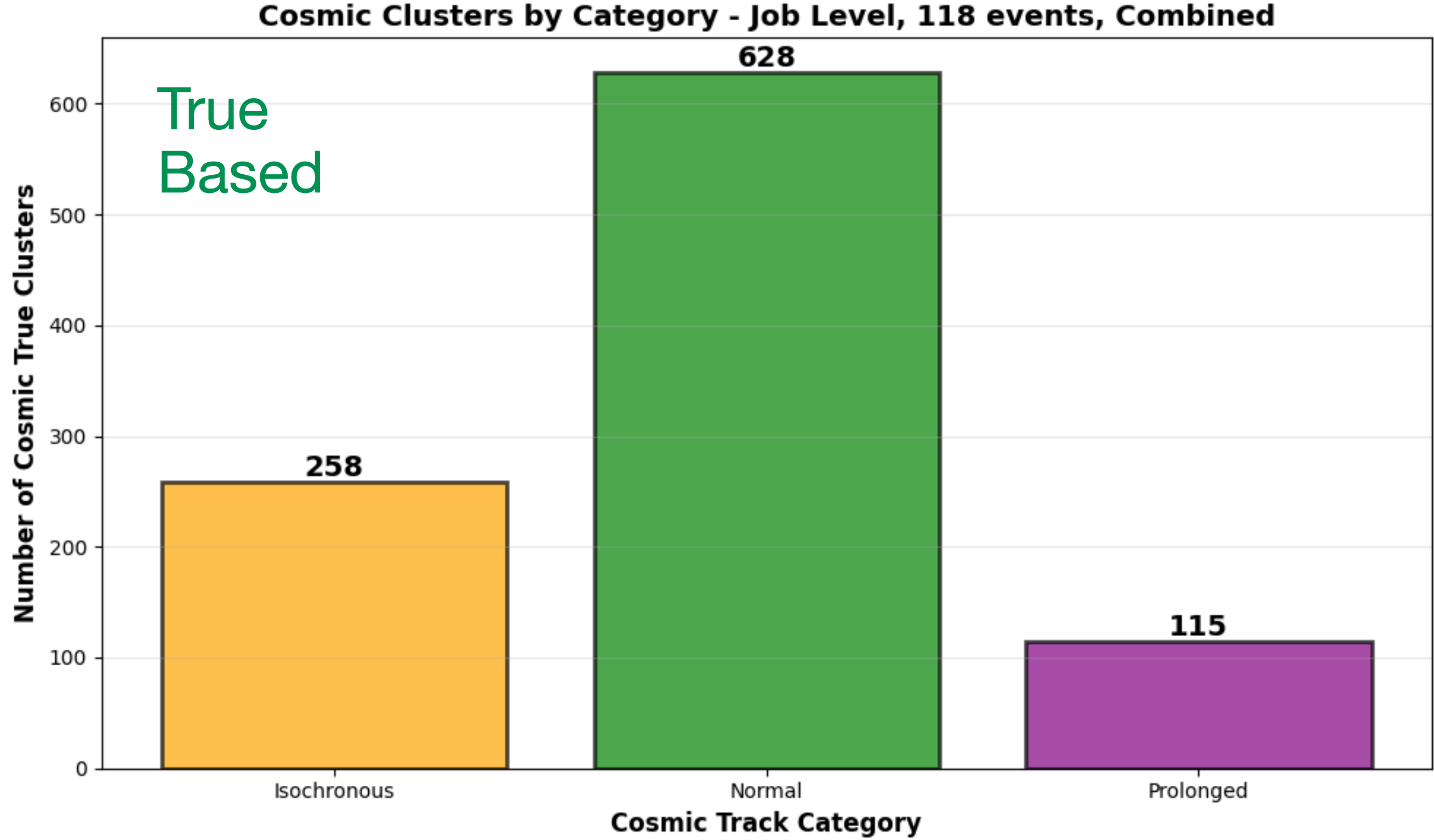
Part 2: Cluster Performance

Sample



Number of Files	10
Events	118

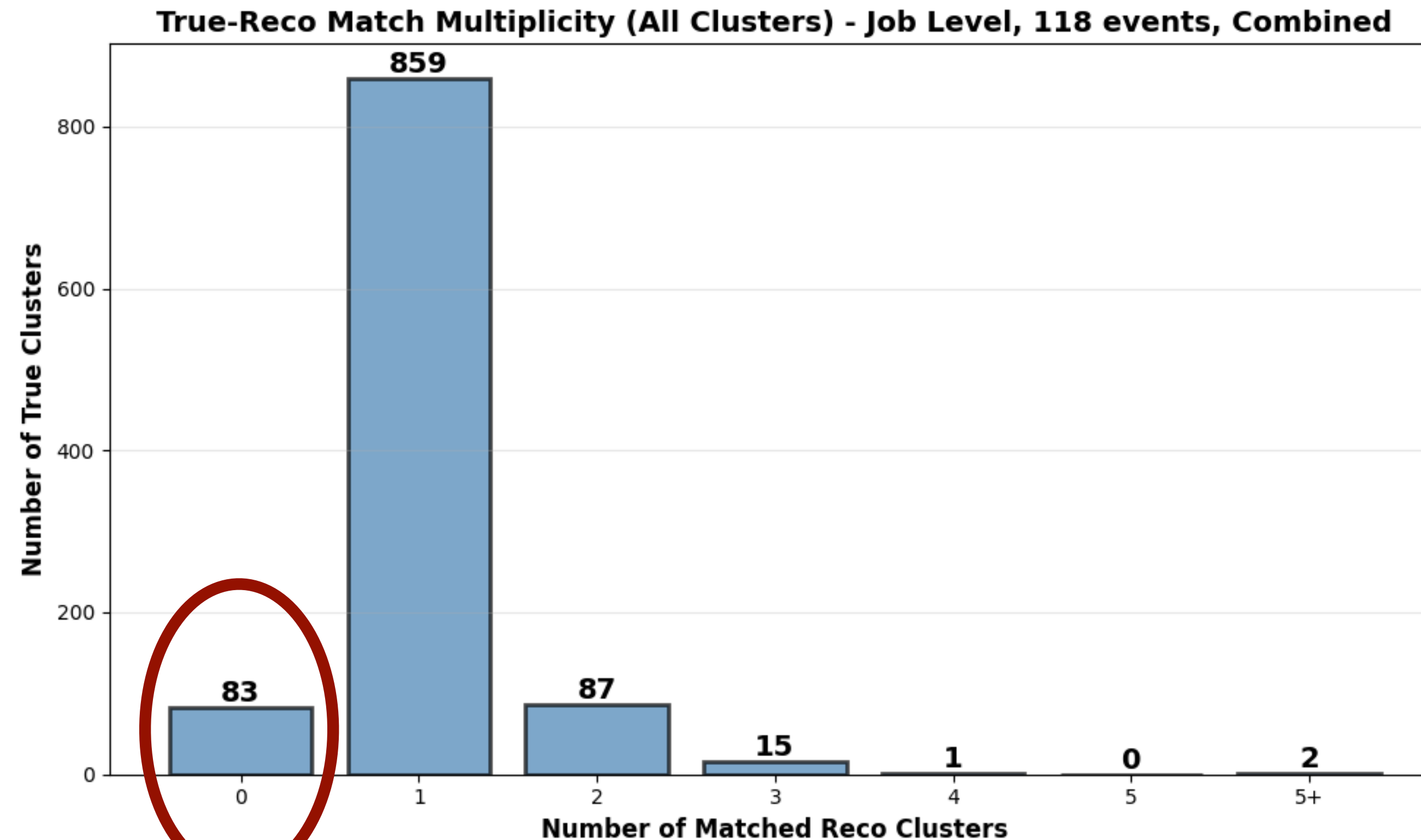
Sample



Number of Files	10
Events	118

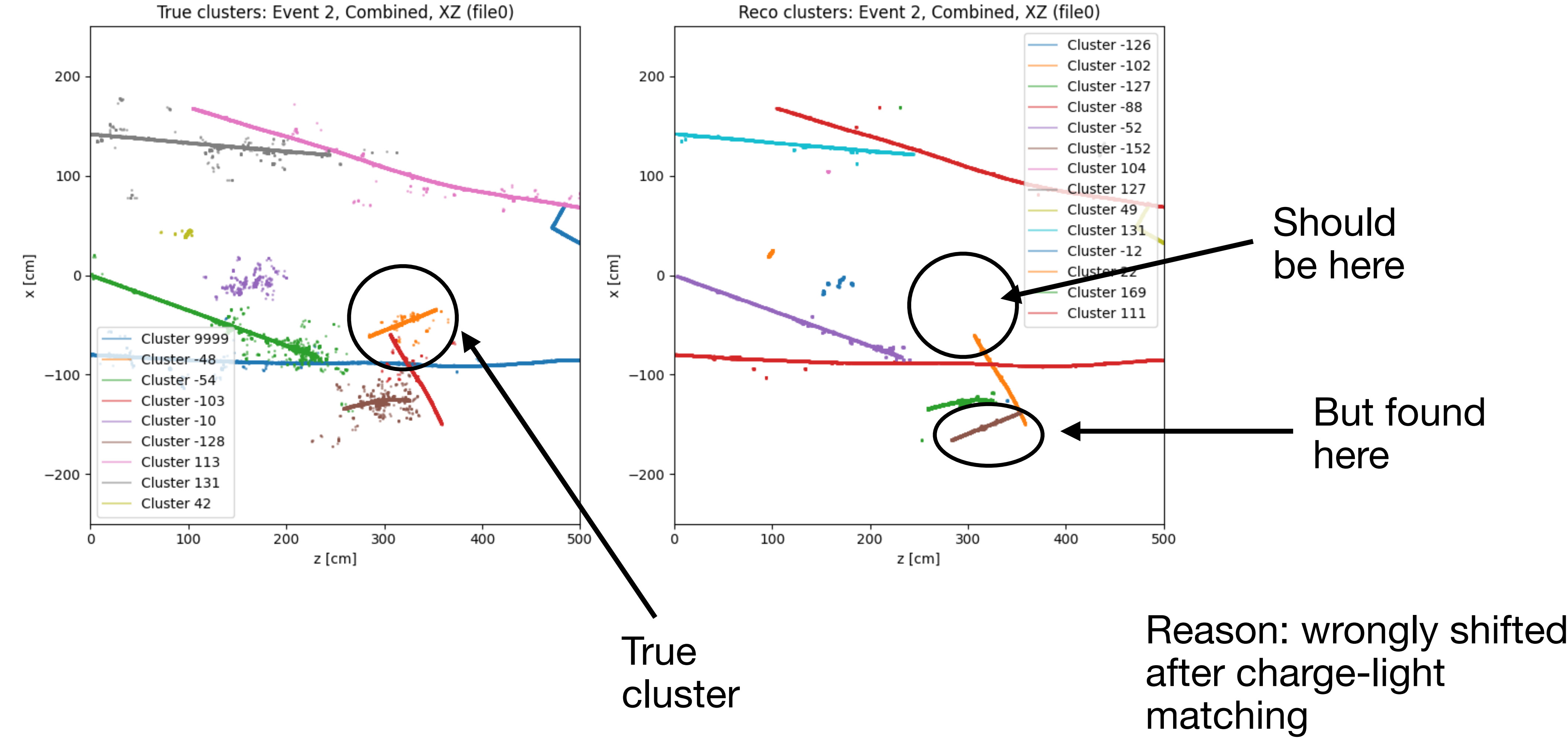
- Isochronous cosmic clusters: $\theta_{xz} < 20^0$
(need to reduce to 15^0)
- Prolonged cosmic clusters: $\theta_{xz} > 70^0$
(need to increase to 70^0)
- Normal cosmic clusters: $\theta_{xz} : 20^0 - 70^0$
(need to change to $\theta_{xz} : 15^0 - 75^0$)

Matching-Multiplicity

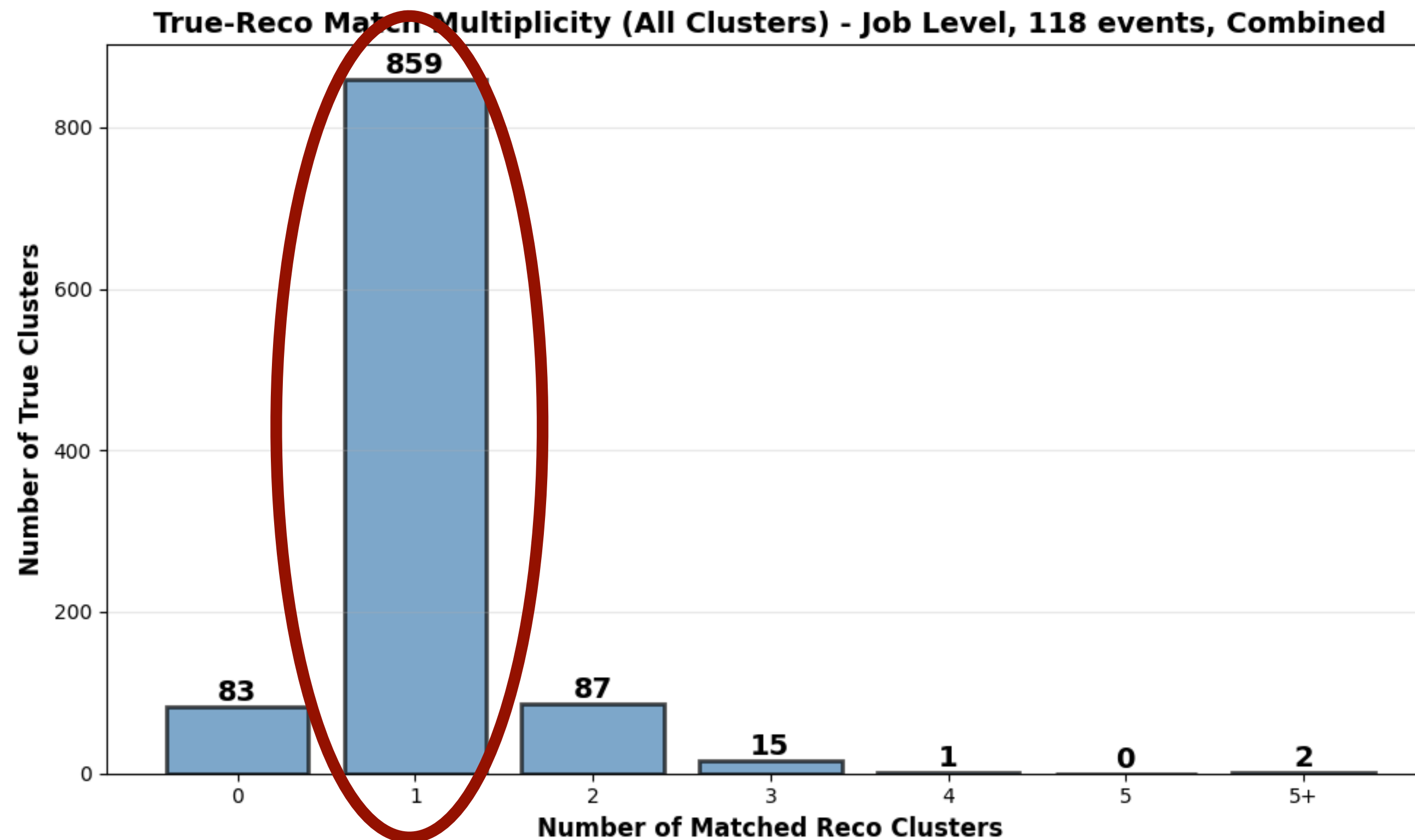


Several cases where true clusters did not find any reco

No Reco Matched to True

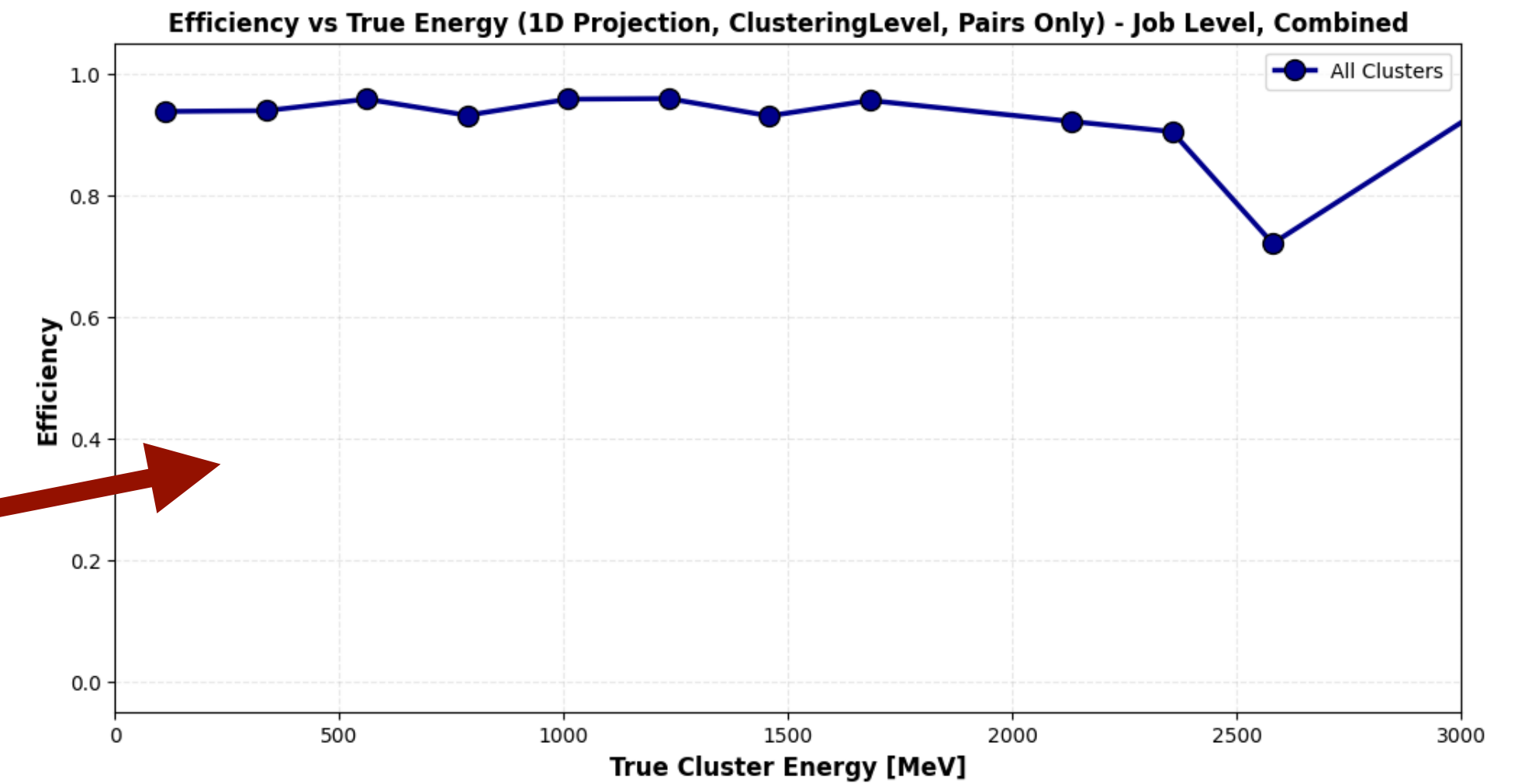
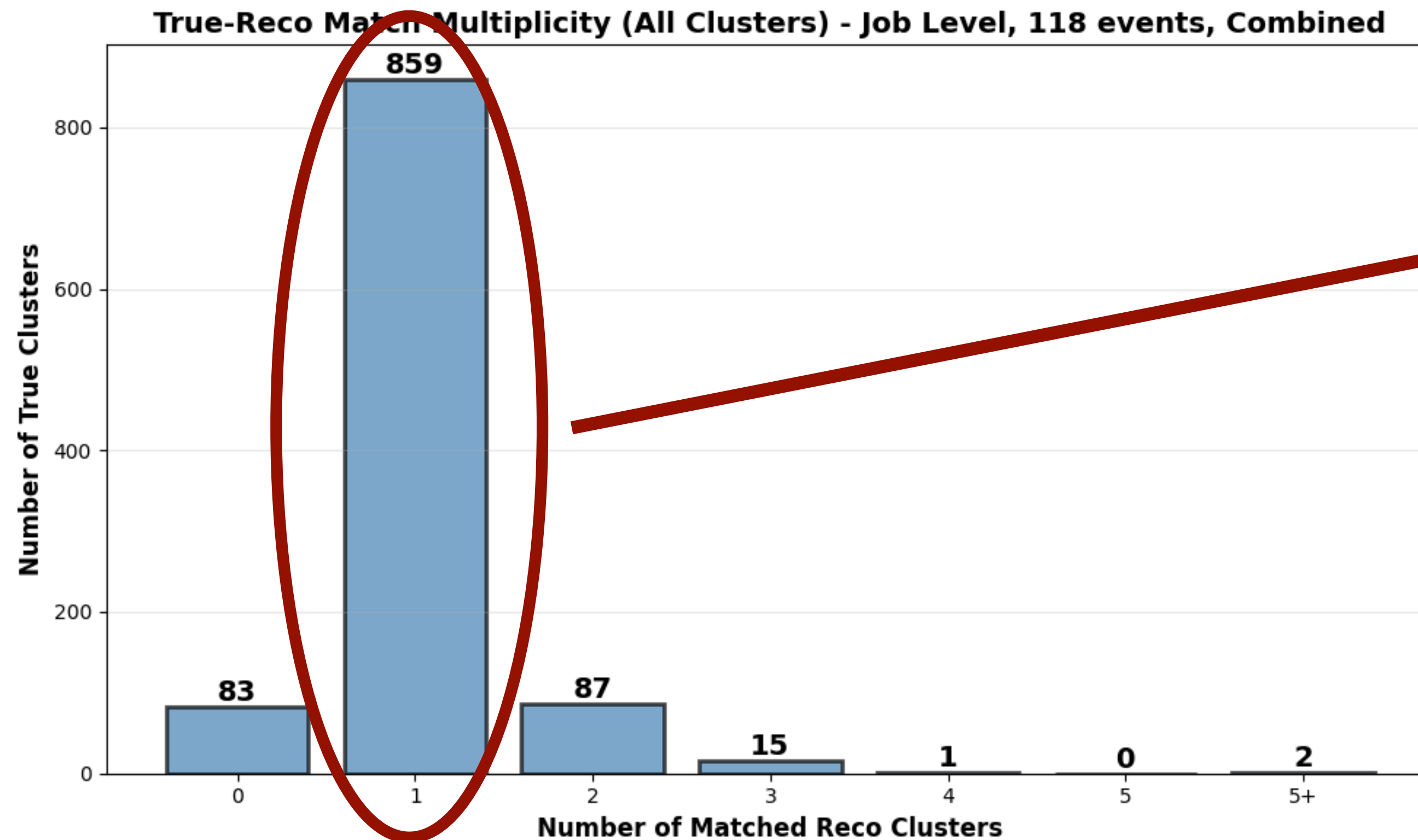


Matching-Multiplicity



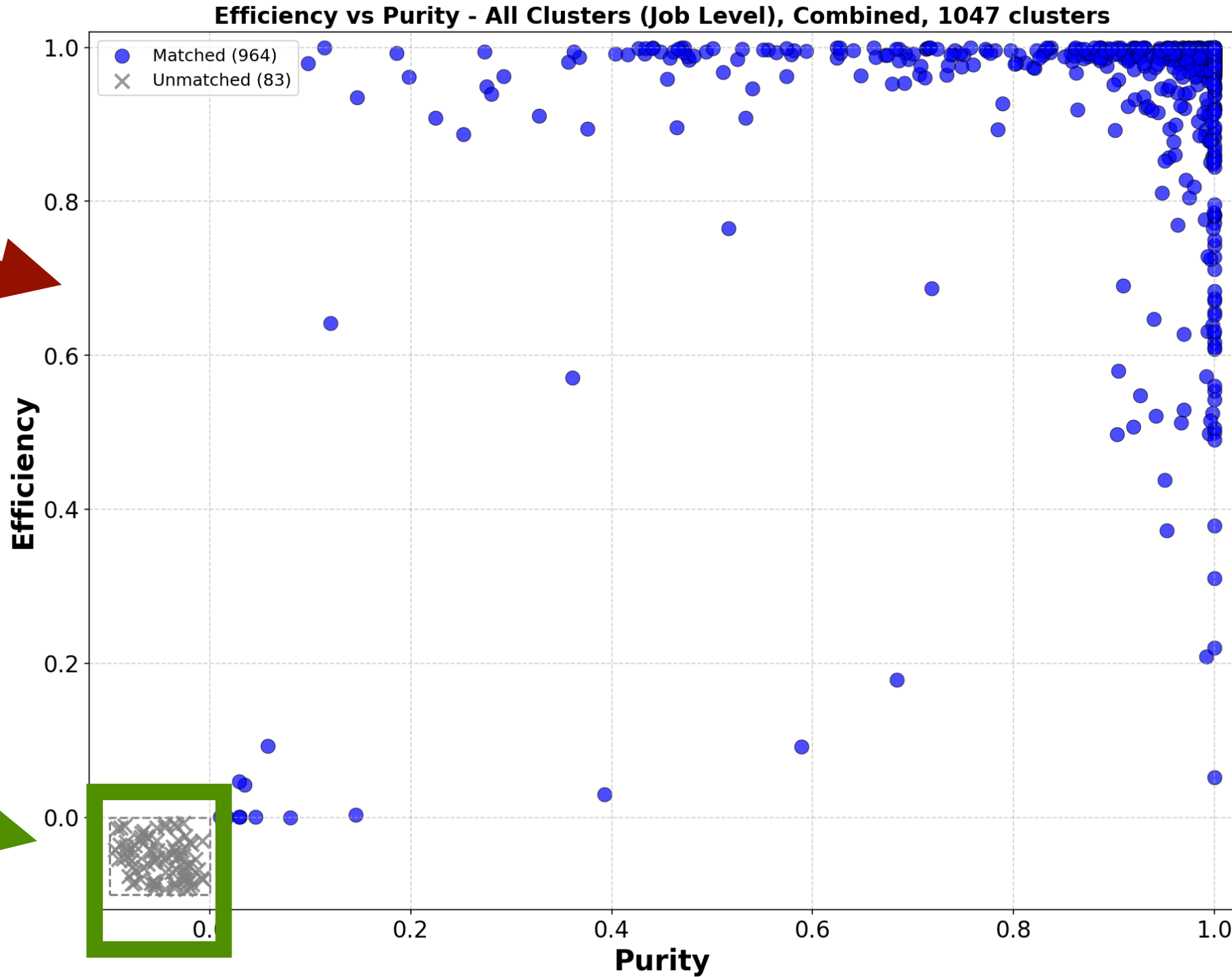
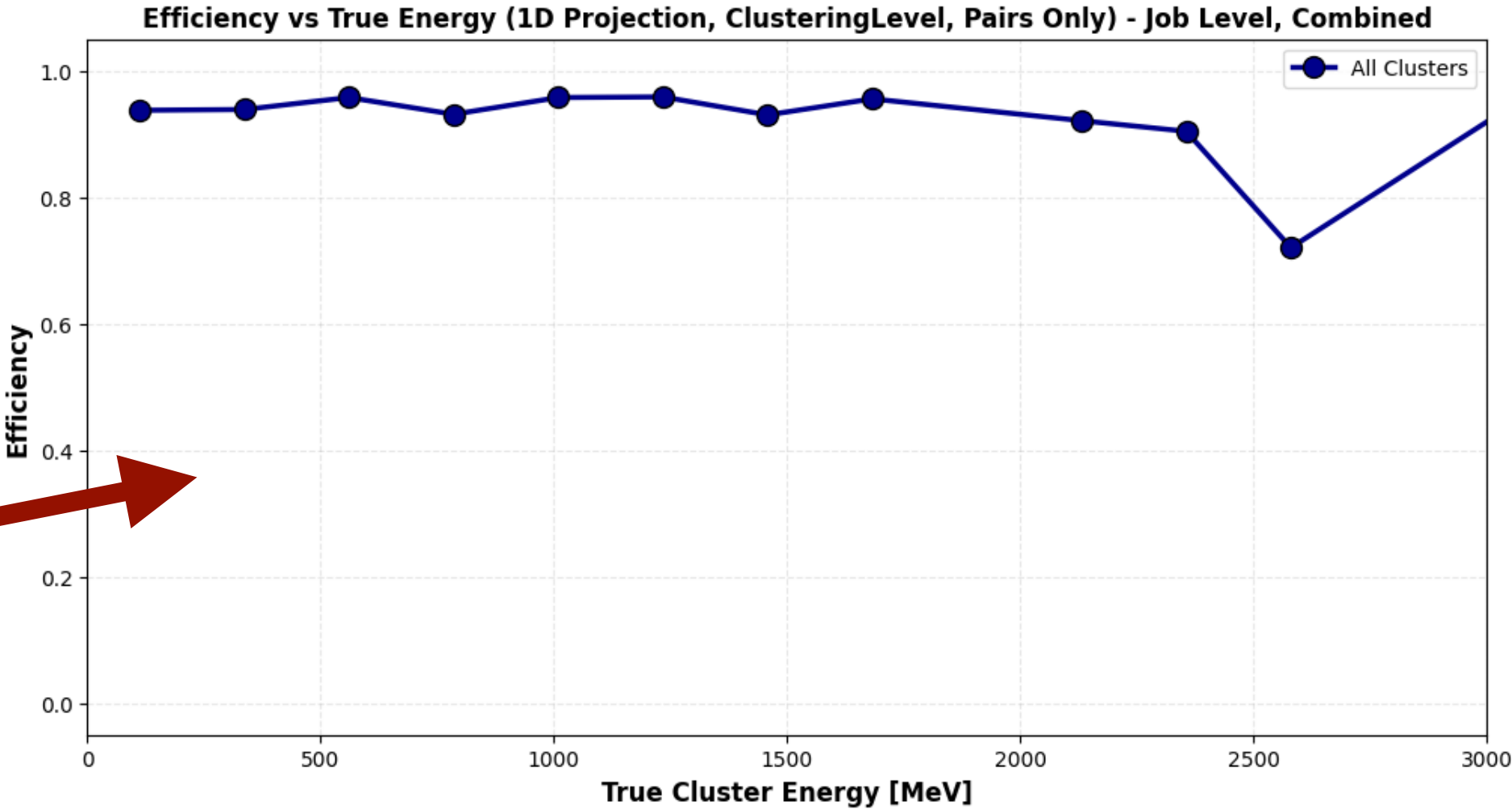
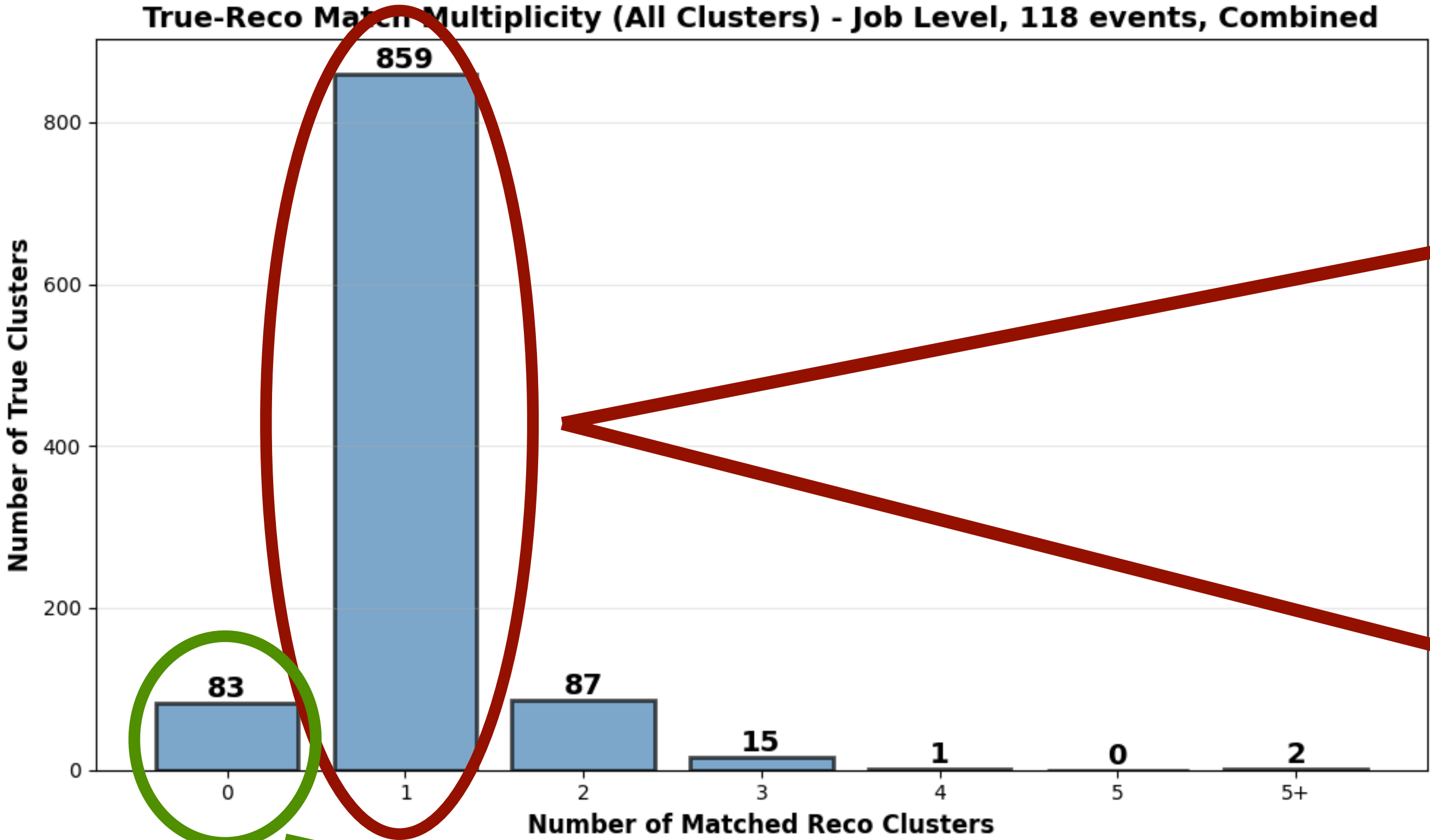
Use this to evaluate reconstruction performance

Matching-Multiplicity



Use this to evaluate reconstruction performance

Matching-Multiplicity



More Evaluation

- I have done more evaluation but still going through some plots
- I will more observation next time

Conclusion

- Optical time flush successful selected in-beam activity
- There are some corner cases that needs more investigation
 - Multi neutrino cases,
 - Neutrino and cosmic in beam-window
 - Few mis-match cases in true-reco clusters after charge light-matching
- Need to go through more evaluation plots: especially to look for reconstruction efficiency and purity

Backup

Revision: Current Selections for Cluster Evaluation

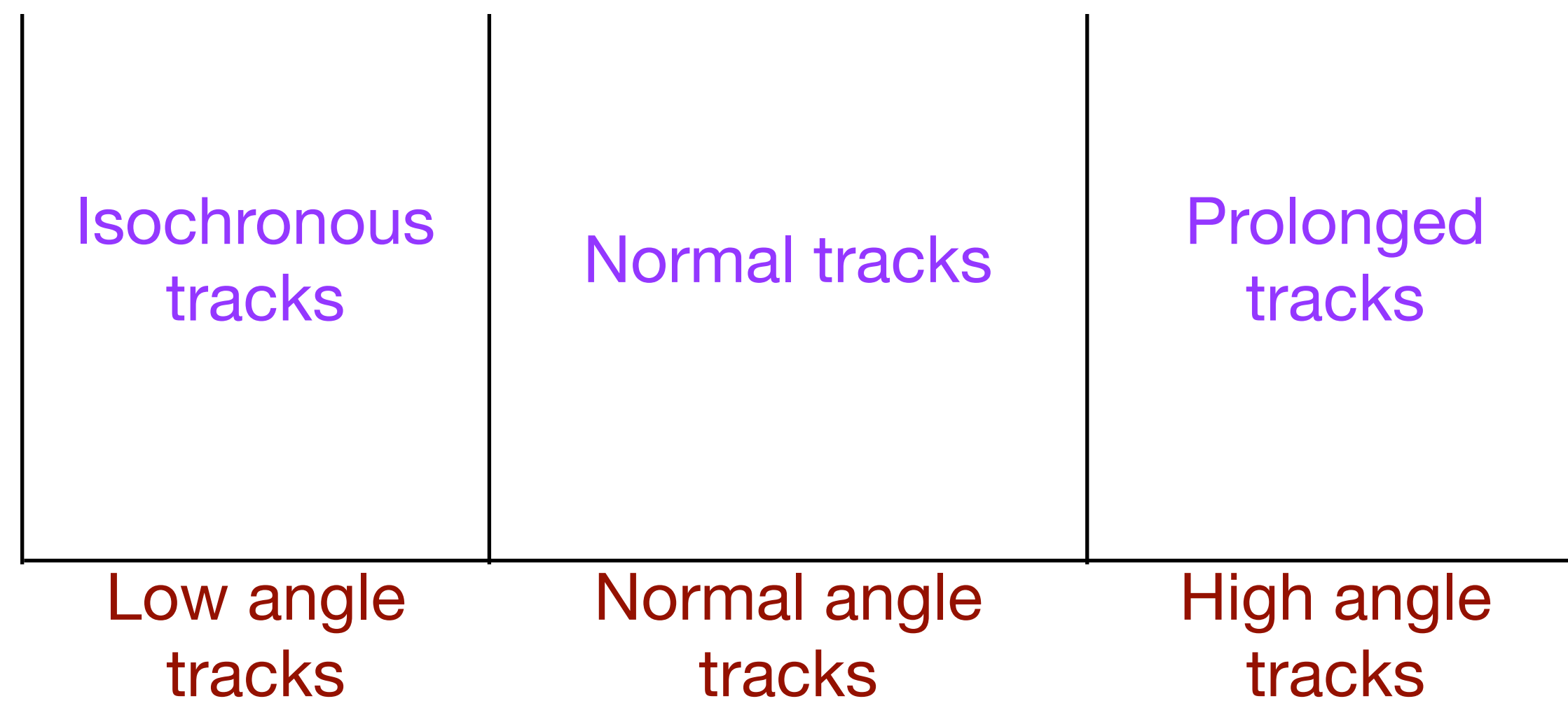
Selections	Accepted Values	Description	Applied? Yes or No
Energy Cut	$E > 10 \text{ MeV}$	True clusters below 10 MeV are removed from evaluation	
Min true point cut	$N > 200$	Removes true and reco clusters with fewer than 200 points	
Wire readout sensitive yz plane cut	$-200 \text{ cm} < y < 200 \text{ cm}$ $0.15 \text{ cm} < y < 500.85 \text{ cm}$	Removes true and reco points output wirecell sensitive regions in y and z	
Time window cut	$-205 \mu\text{s} < t < 1508.5 \mu\text{s}$	Removes true points outside time window cut. Applied at CellTree level Reco points are already within time window cuts so we apply this to true clusters	
Dead Area cut		Reco points are NOT reconstructed within dead wire areas so we also need to remove true points from dead areas for correct reco-true comparisons	

Revision: Current Selections for Cluster Evaluation

Selections	Accepted Values	Description	Applied? Yes or No
Energy Cut	$E > 10 \text{ MeV}$	True clusters below 10 MeV are removed from evaluation	All Applied
Min true point cut	$N > 200$	Removes true and reco clusters with fewer than 200 points	
Wire readout sensitive yz plane cut	$-200 \text{ cm} < y < 200 \text{ cm}$ $0.15 \text{ cm} < y < 500.85 \text{ cm}$	Removes true and reco points output wirecell sensitive regions in y and z	
Time window cut	$-205 \mu\text{s} < t < 1509 \mu\text{s}$	Removes true points outside time window cut. Applied at CellTree level Reco points are already within time window cuts so we apply this to true clusters	
Dead Area cut		Reco points are NOT reconstructed within dead wire areas so we also need to remove true points from dead areas for correct reco-true comparisons	

Revision: Plans for Isochronous and Prolonged Tracks

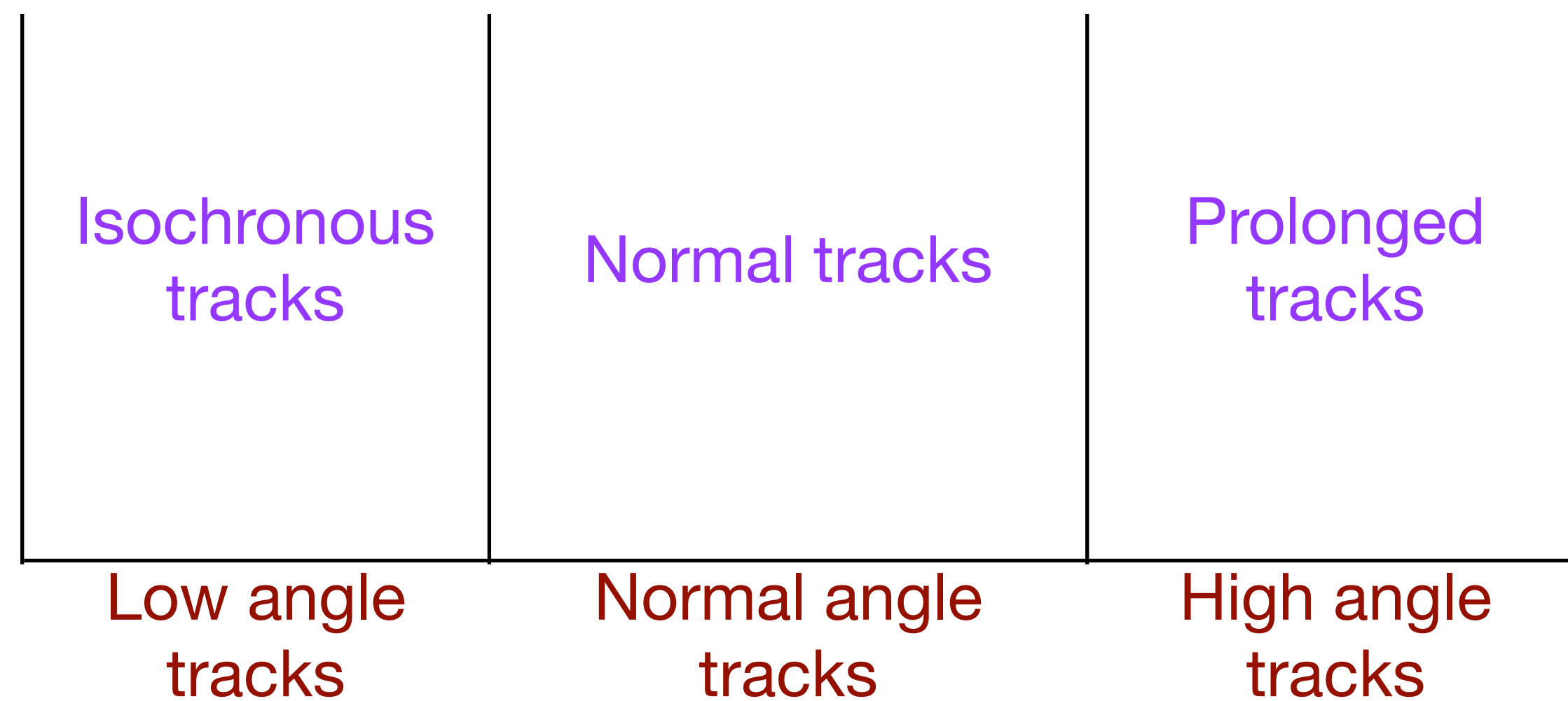
- Both isochronous and prolonged tracks affect the evaluation
- Isochronous tracks affect the purity due to their spread
- Prolonged tracks affect efficiency because sometime they show gaps irrespective of dead area
- For evaluation purposes, we need to separate isochronous, and prolonged tracks from rest of the tracks



The idea is to divide tracks into low, high and normal angle bins and then do evaluation

Revision: Plans for Isochronous and Prolonged Tracks

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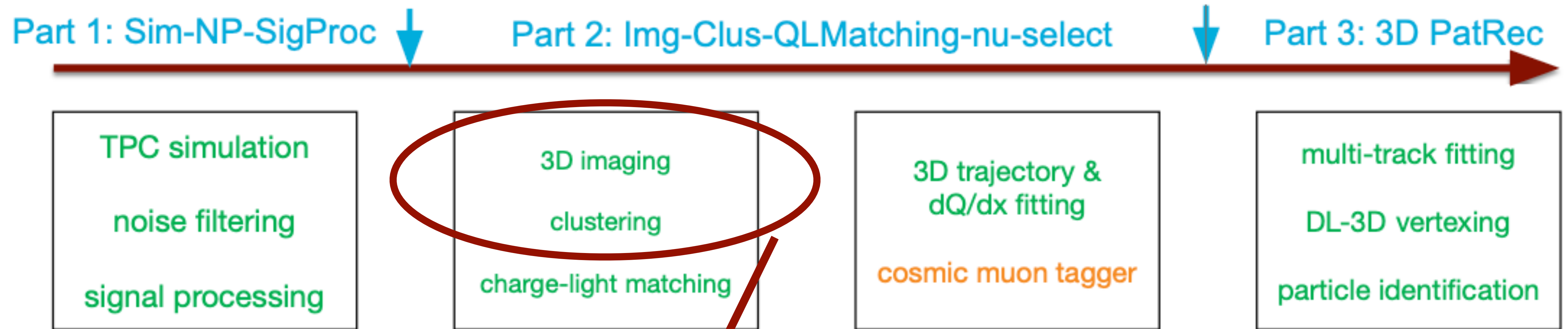
The idea is to divide tracks into low, high and normal angle bins and then do evaluation

All Applied

Efficiencies

- There are still some clusters that have low efficiencies so we will go through them to understand the reasons

Structure of Overall Progress



Haiwang's CM Talk

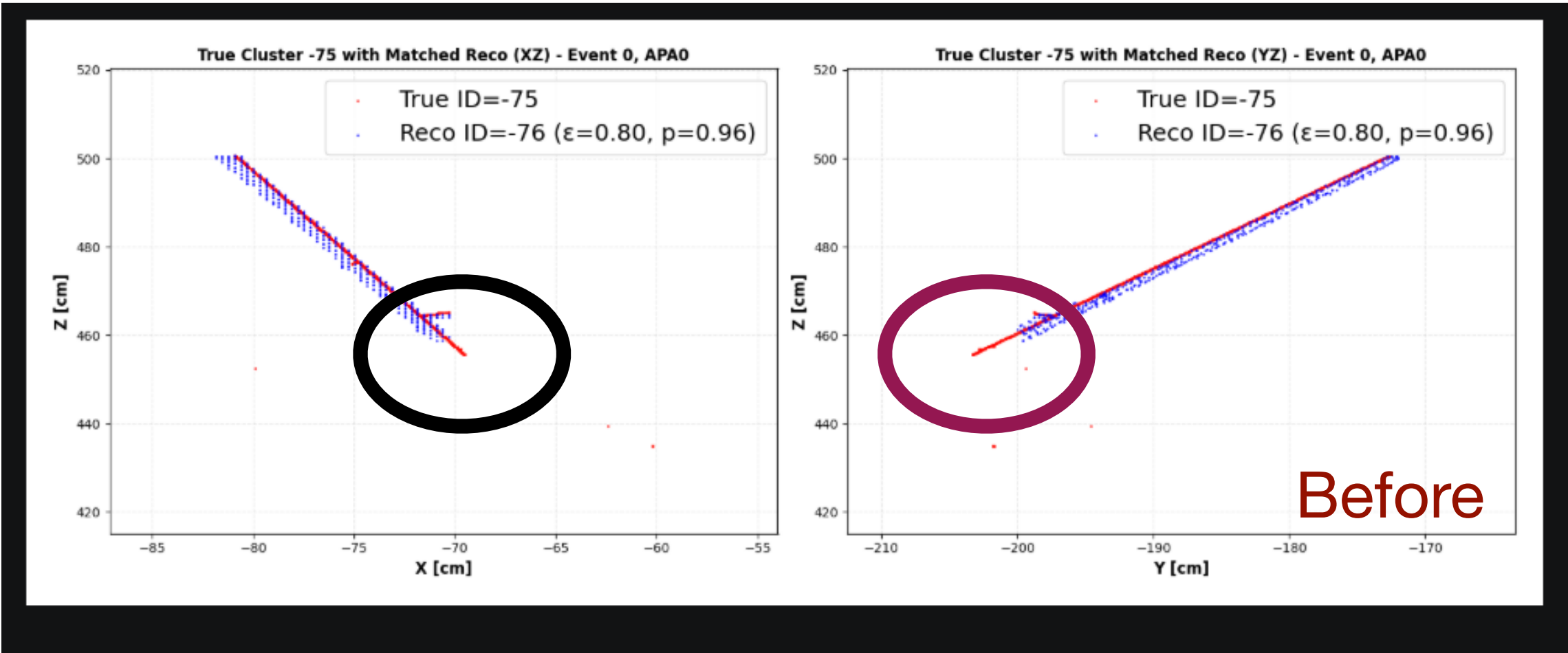
- Currently focussed on the imaging+clustering evaluation (scanning and numerical evaluation)
- Evaluation of charge-light matching after this

Revision: Current Selections for Cluster Evaluation

Selections	Accepted Values	Description	Applied? Yes or No
Energy Cut	$E > 10 \text{ MeV}$	True clusters below 10 MeV are removed from evaluation	Yes
Min true point cut	$N > 200$	Removes true and reco clusters with fewer than 200 points	Yes
Wire readout sensitive yz plane cut	$-200 \text{ cm} < y < 200 \text{ cm}$ $0.15 \text{ cm} < y < 500.85 \text{ cm}$	Removes true and reco points output wirecell sensitive regions in y and z	Yes
Time window cut	$-205 \mu\text{s} < t < 1509 \mu\text{s}$	Removes true points outside time window cut. Applied at CellTree level Reco points are already within time window cuts so we apply this to true clusters	Yes
Dead Area cut		Reco points are NOT reconstructed within dead wire areas so we also need to remove true points from dead areas for reco-true comparisons	Yes

Wire readout sensitive yz plane cut

Ymin: -200 cm, Ymax: 200 cm, Zmin: 0.15 cm, Zmax: 500.85 cm (a bit smaller than detector active volume Y-Z)

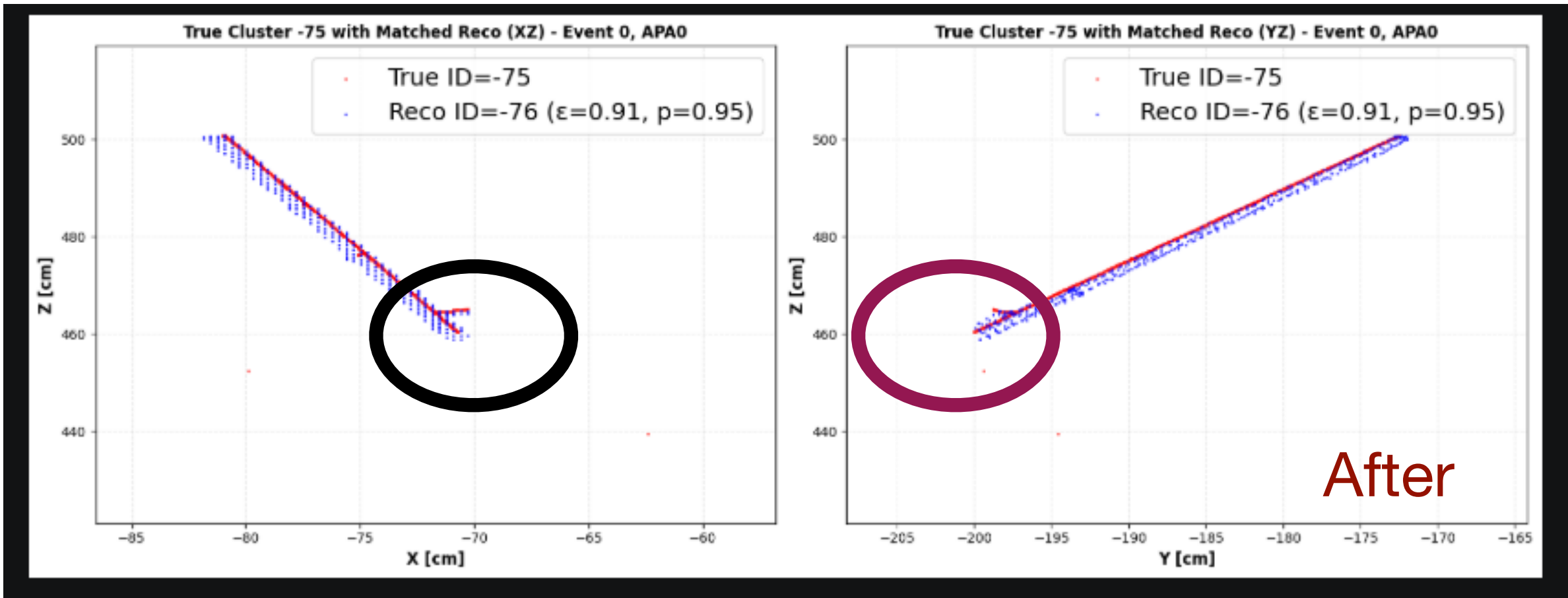


	Efficiency	Purity
Before	80%	96%
After	91%	95%

Conclusion: efficiency increased by ~10%

Caveat: This selection is only applied at evaluation level not at CellTree (True jobs) not at img-clustering (Reco jobs)

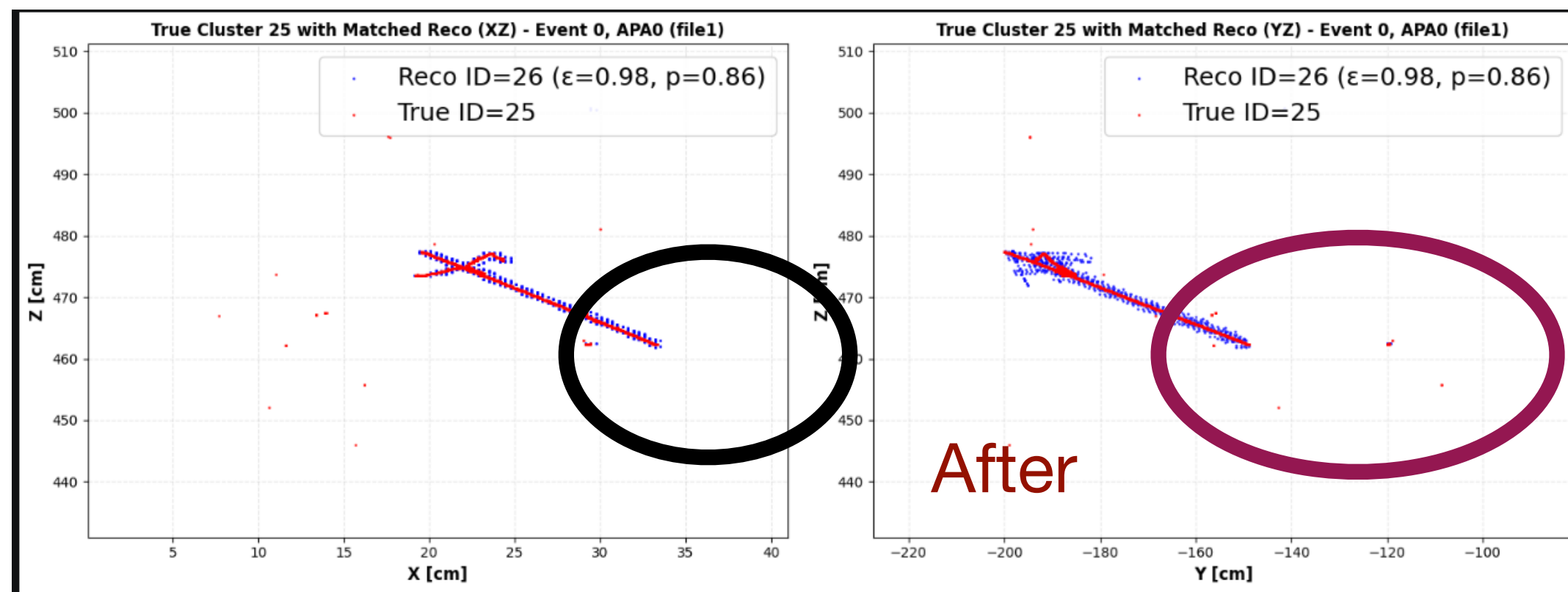
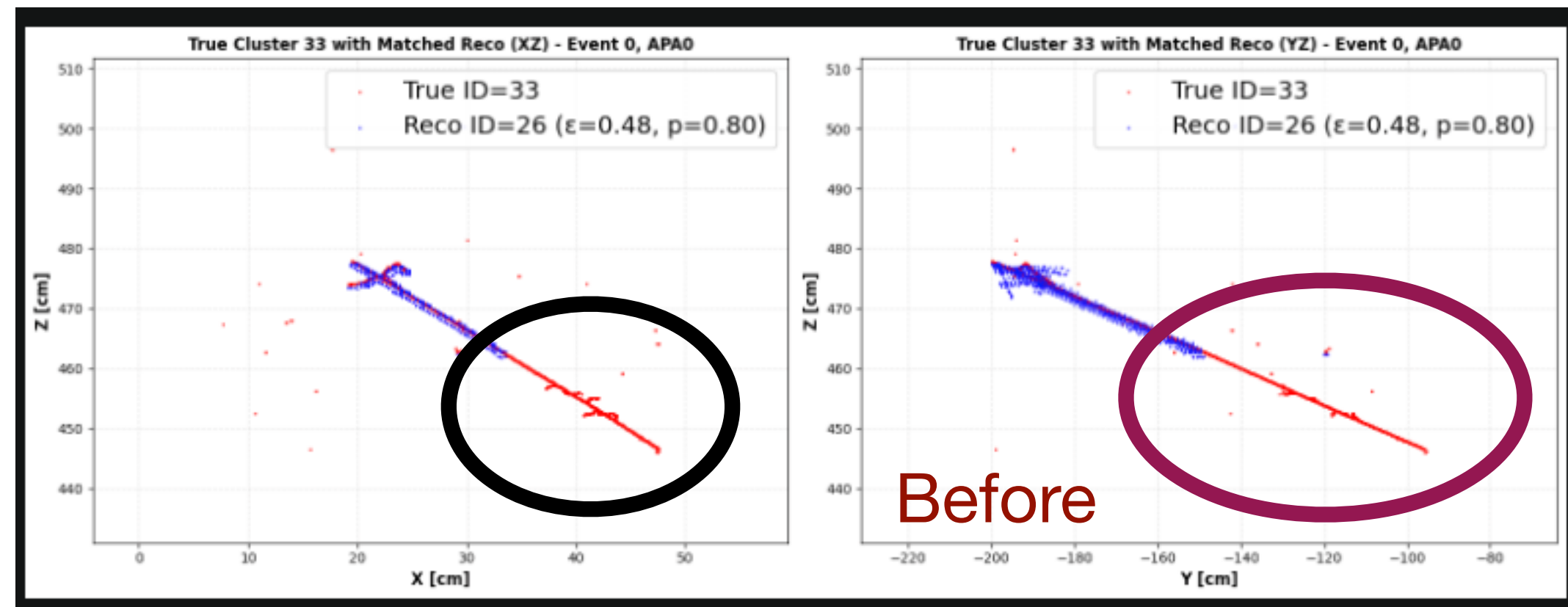
*More info in google-sheet for [yz-plane cut](#)



Time Window Cut

Removes true points outside time window cut

Reco points are already within time window cuts so we apply this to true clusters



	Efficiency	Purity
Before	48%	80%
After	98%	86%

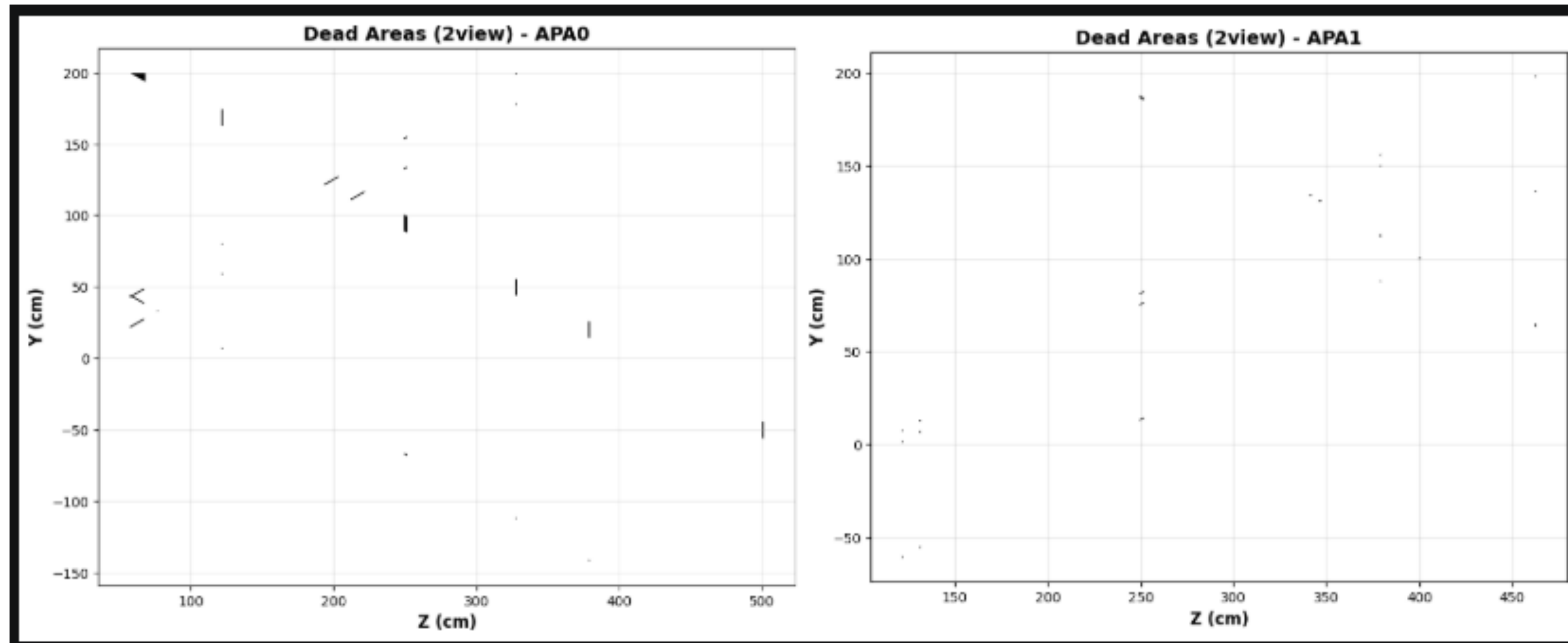
Conclusion: efficiency highly improved. Improvement depends on how much true was outside time window cut

Caveat: Fhicl level change for CellTree (true) job

*More info in google-sheet for [time window cut](#)

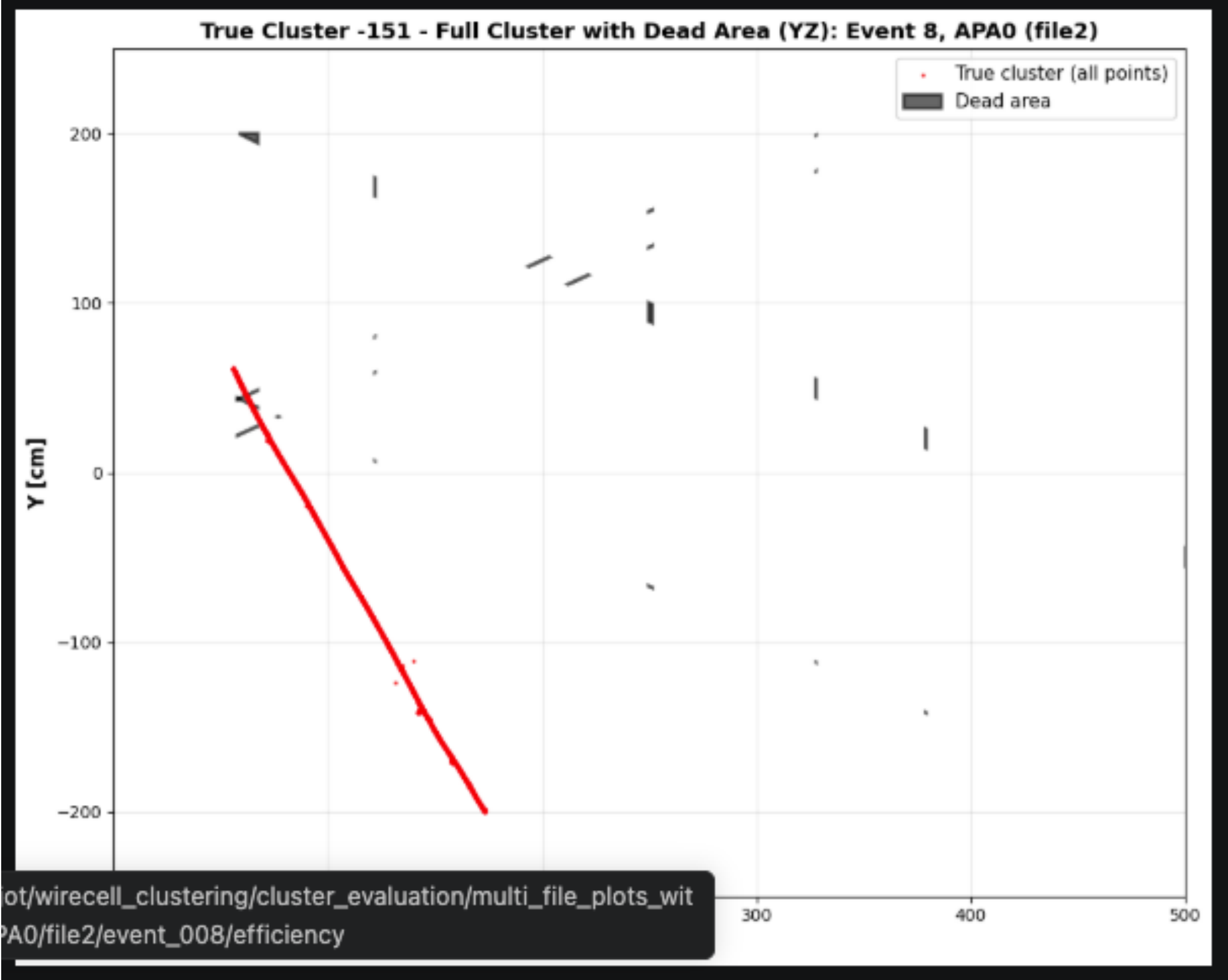
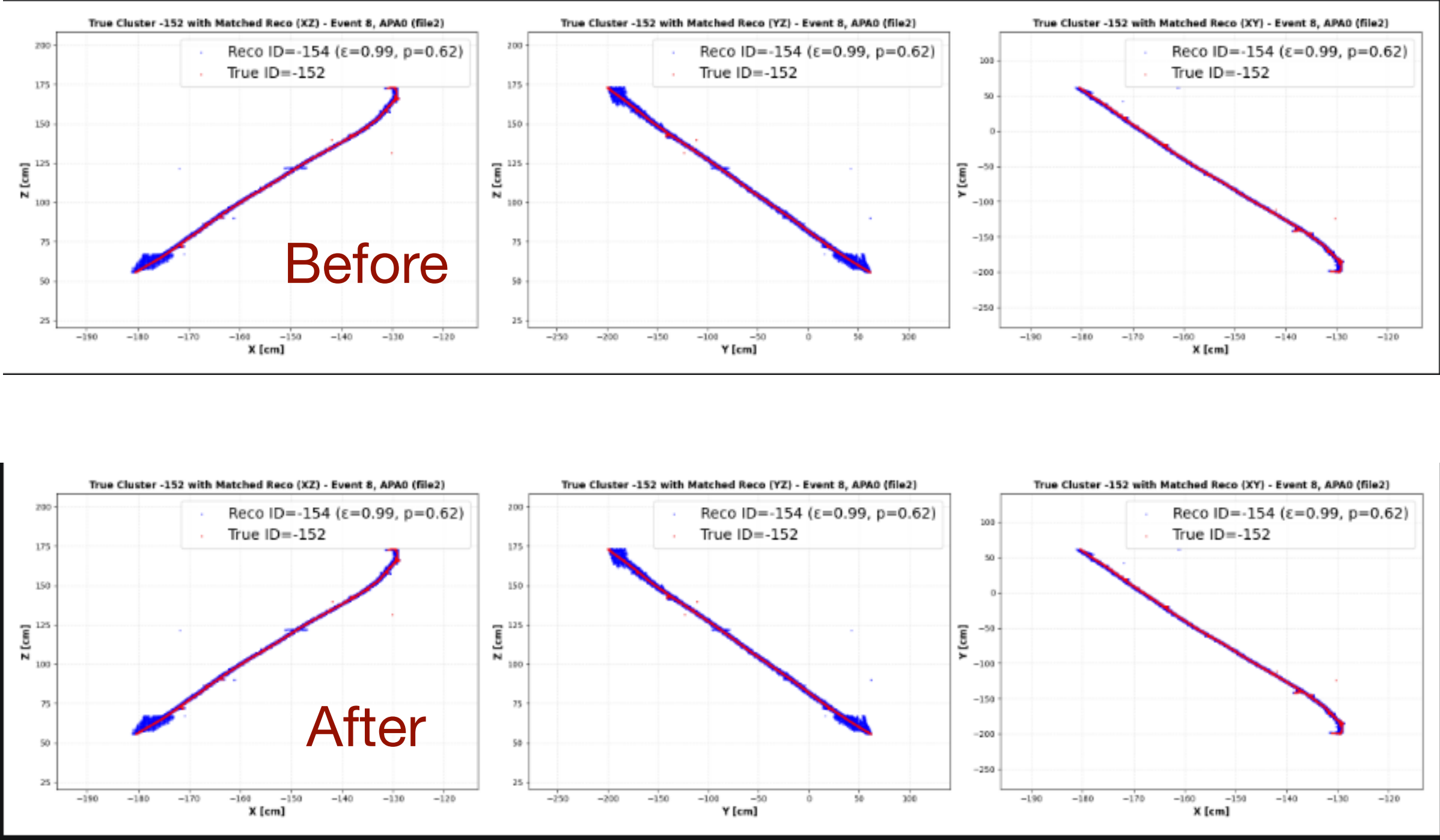
Dead Area Cut

Reco points are NOT reconstructed within dead wire areas so we also need to remove true points from dead areas for reco-true comparisons



For 2view active, the dead area regions are very small, so the improvement on efficiency would be small but it is important to exclude true points in dead area for evaluation purpose

Dead Area Cut



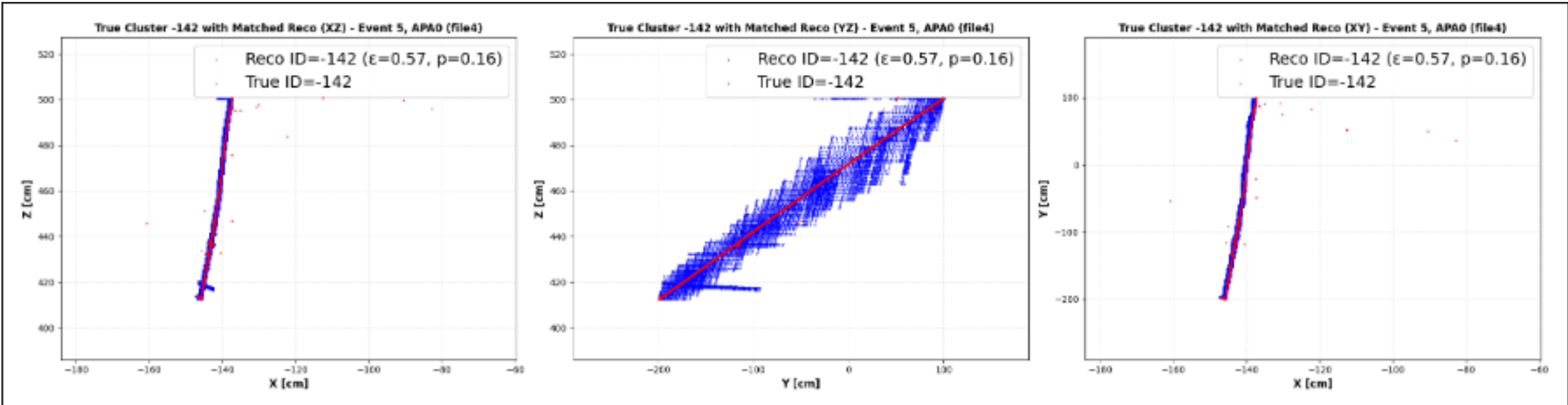
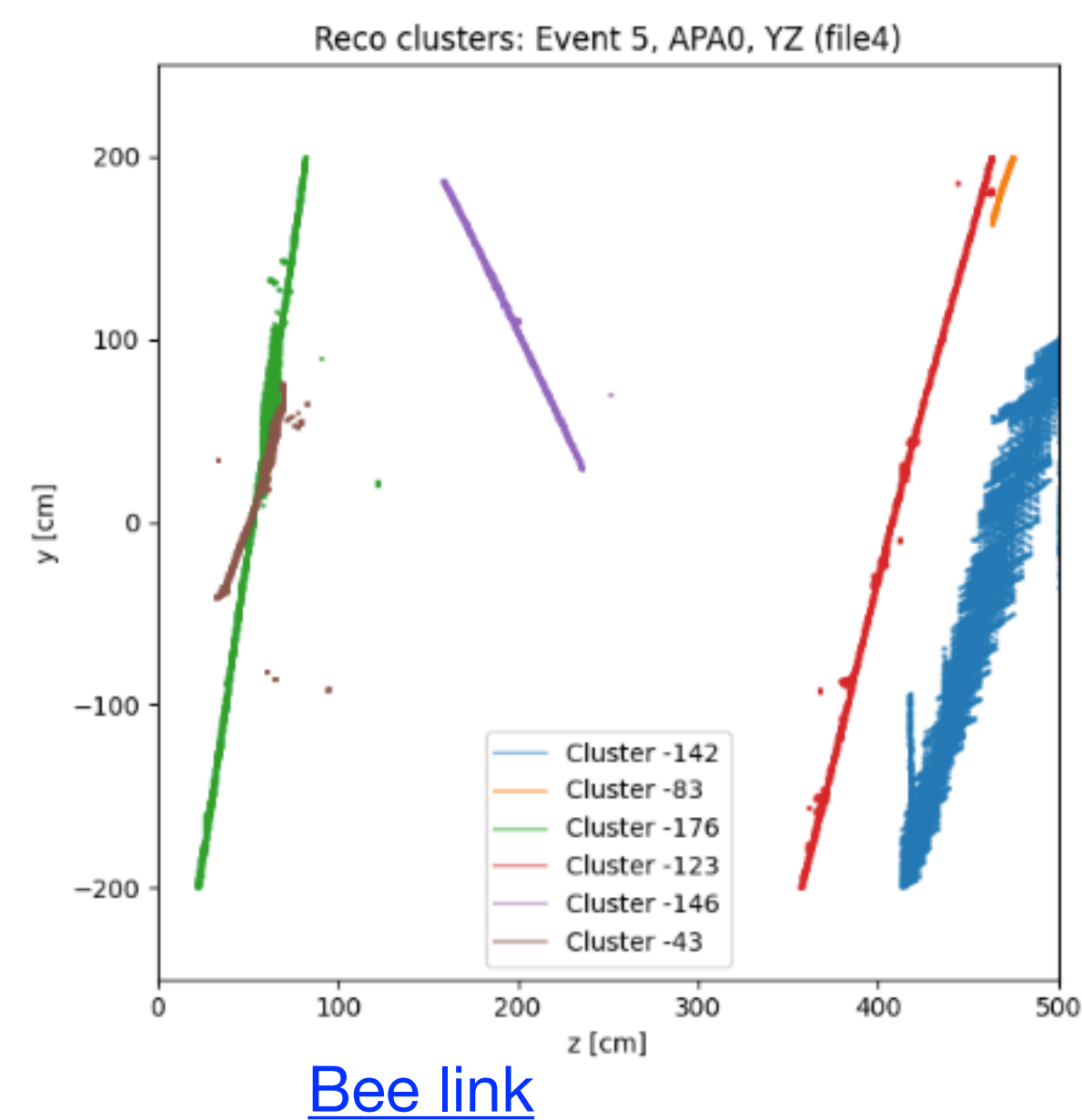
Conclusion: as expected not much effect on efficiency

Caveat: Dead area cut doe not affect 2view active cases but would be very effective for old 3 view cases

	Efficiency	Purity
Before	99%	62%
After	99%	62%

Plans for Isochronous and Prolonged Tracks

- Both isochronous and prolonged tracks affect the evaluation
- Isochronous tracks affect the purity due to their spread



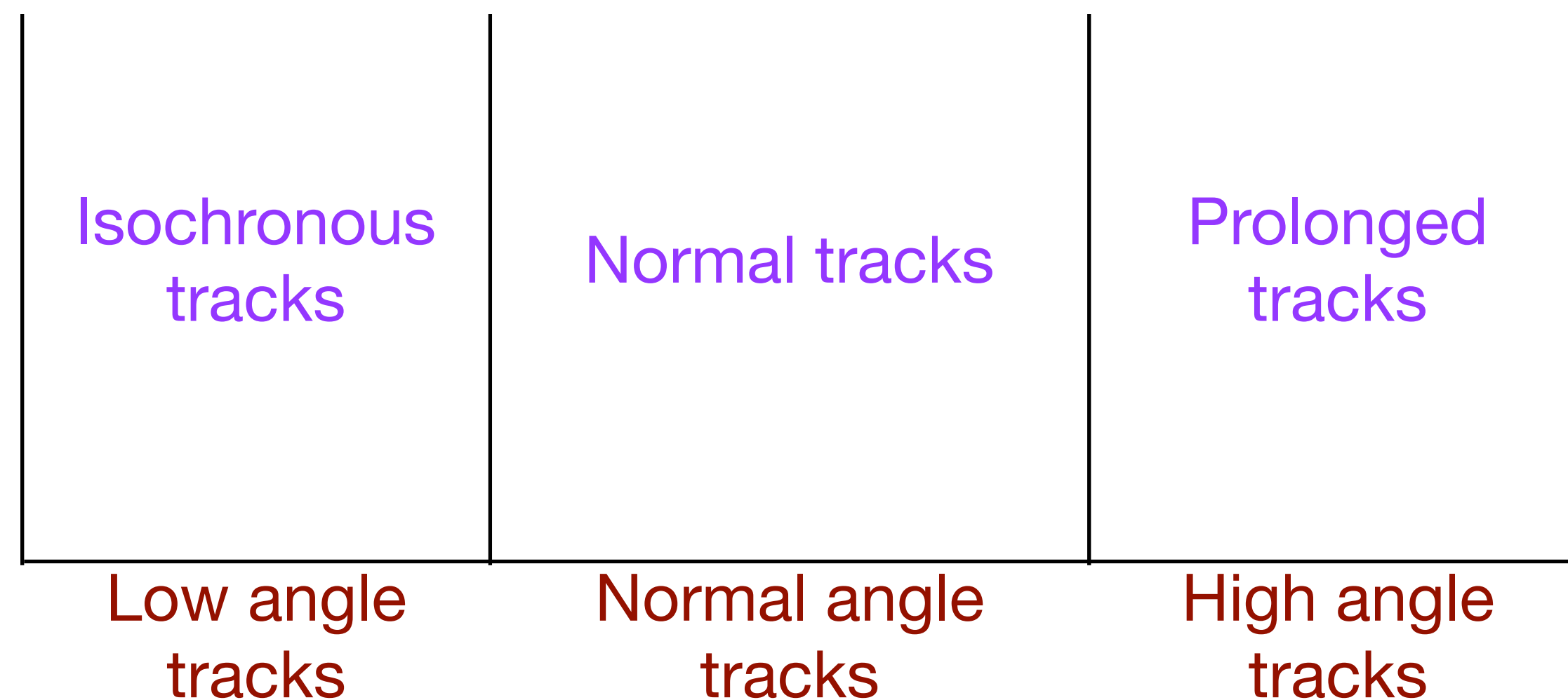
Track Type	Efficiency	Purity
Isochronous	57%	16%

Plans for Isochronous and Prolonged Tracks

- Both isochronous and prolonged tracks affect the evaluation
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Plans for Isochronous and Prolonged Tracks

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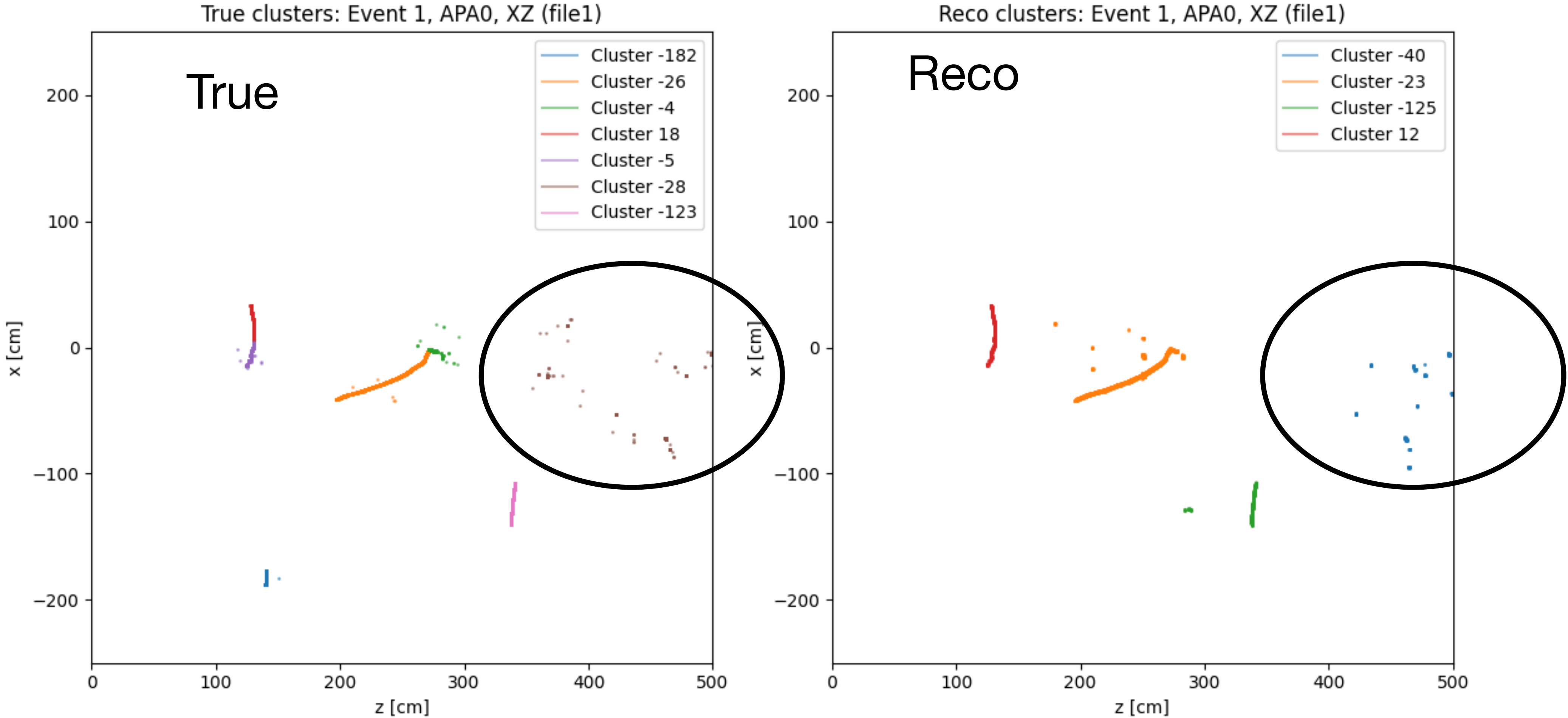
The idea is to divide tracks into low, high and normal angle bins and then do evaluation

Initial Plans for Generic Neutrino Selections

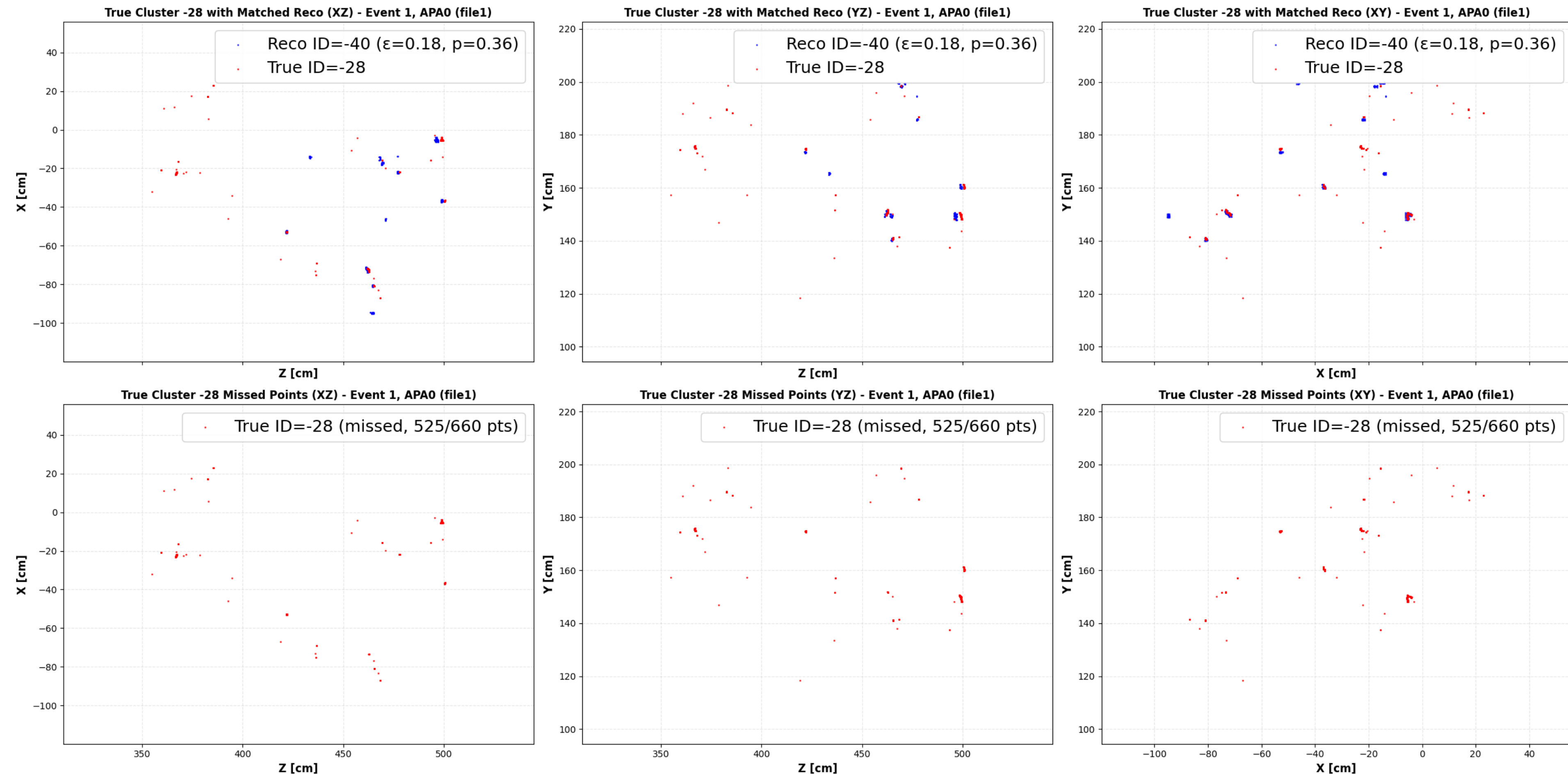
- Currently reading uBoone's Wirecell based neutrino selection paper at <https://arxiv.org/pdf/2011.01375>
- There are several ideas some of them is to check the Data and MC Distributions of
 - Reco clusters X, Y, Z
 - Time distributions to check clusters are within the time window
 - POT correction
 - Distributions as a function of reco charge information
- In next few meetings, I will show/discuss more on this topic

Some cases of low efficiency: 1

$\epsilon = 20\%$



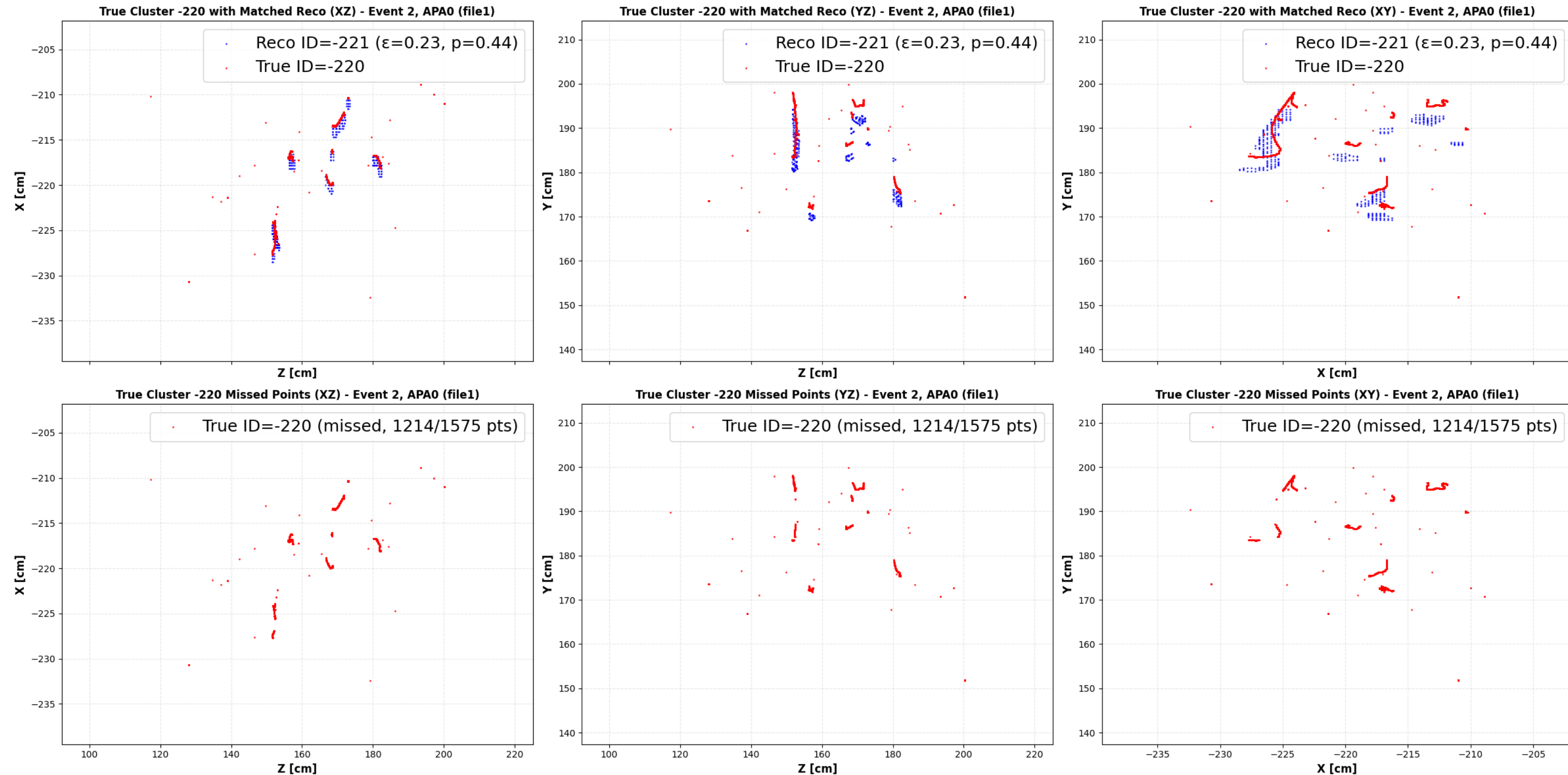
Some cases of low efficiency: 1



$\epsilon = 20\%$

Reason for low efficiency: Very few and scattered true points

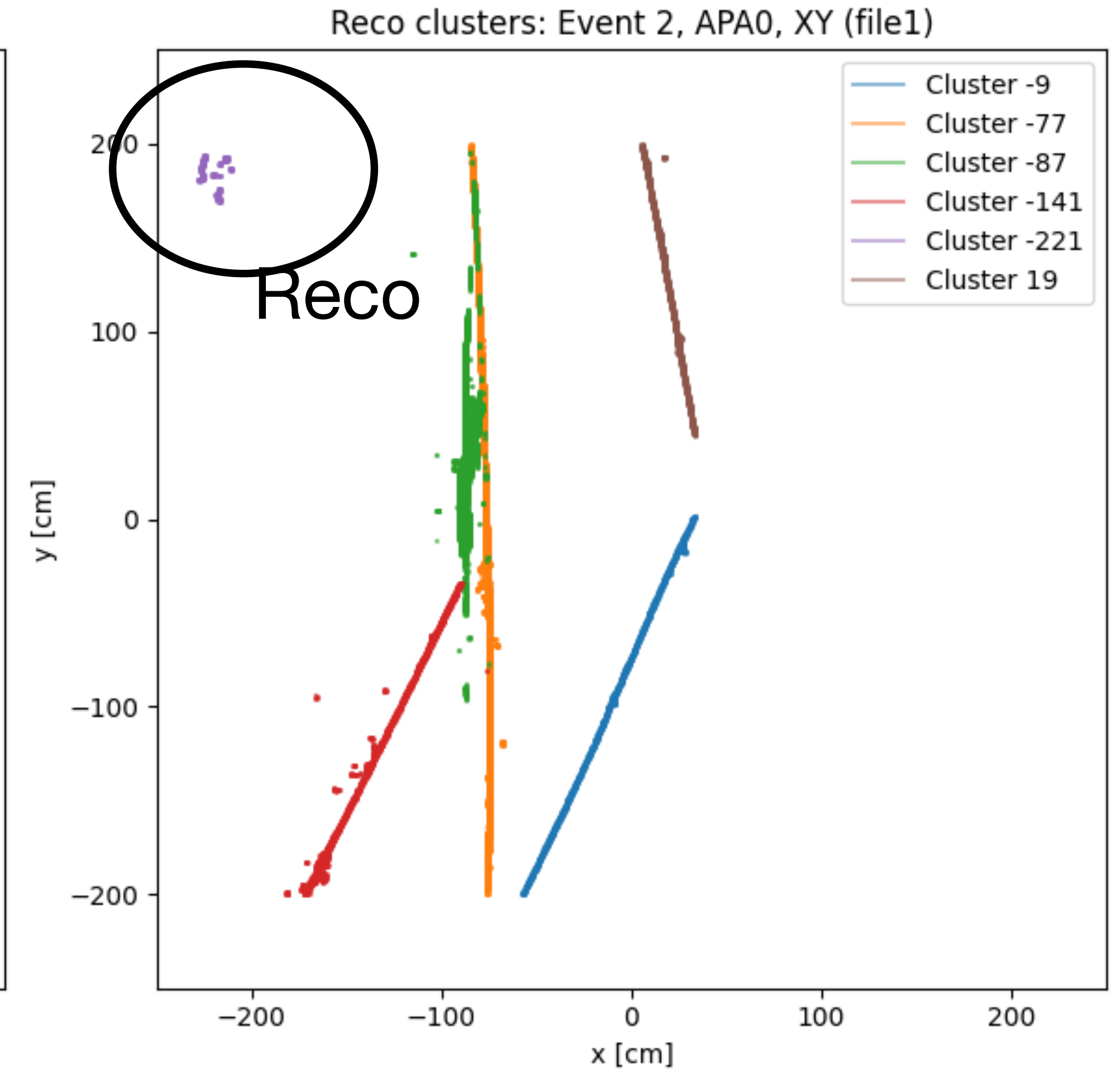
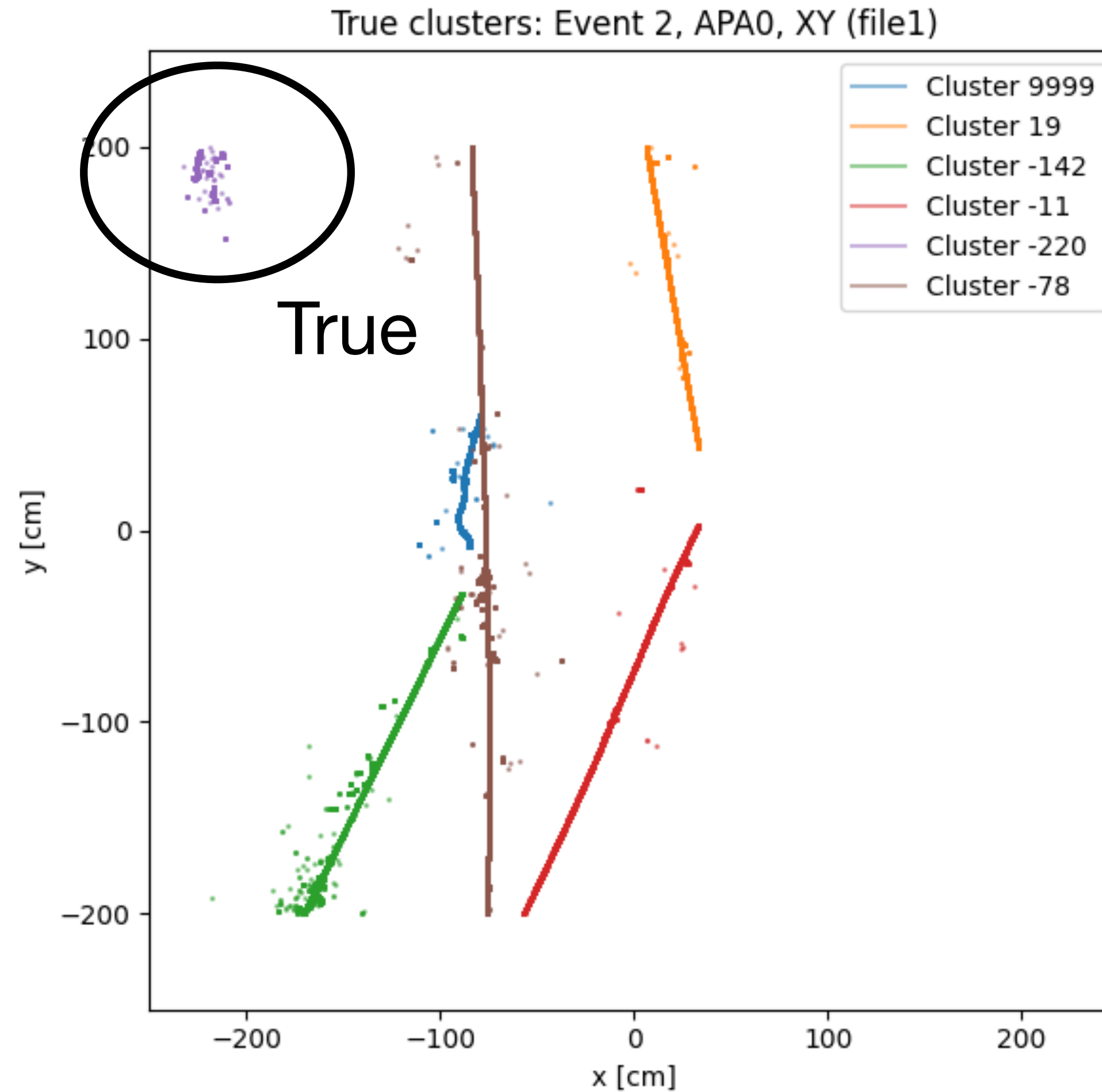
Some cases of low efficiency: 2



$$\epsilon = 23\%$$

Reason for low efficiency: Very few and scattered true points

Some cases of low efficiency: 2



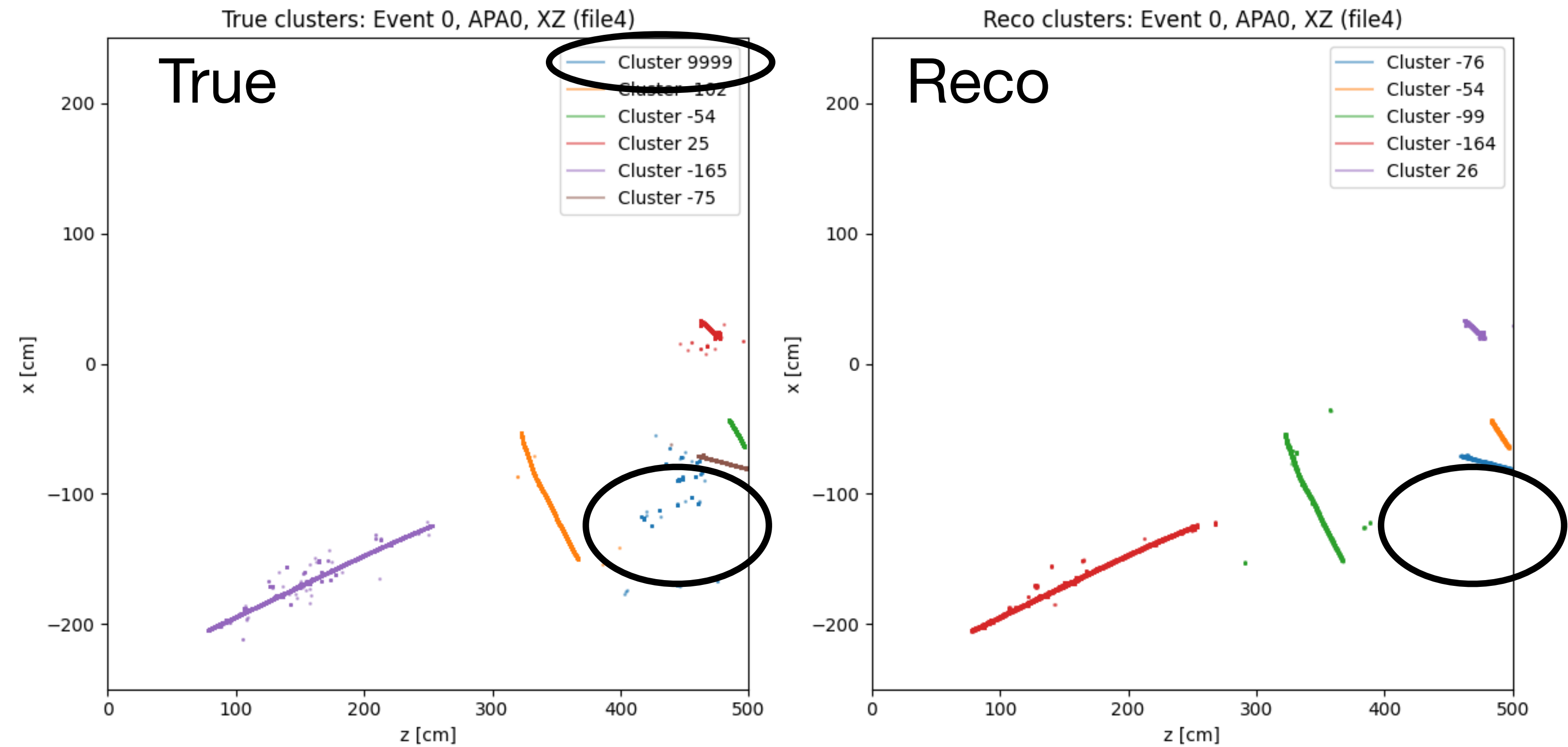
$$\varepsilon = 23\%$$

Example of True Neutrinos not finding any reco clusters

File 4: Event 0

2cm efficiency radius

APA 0

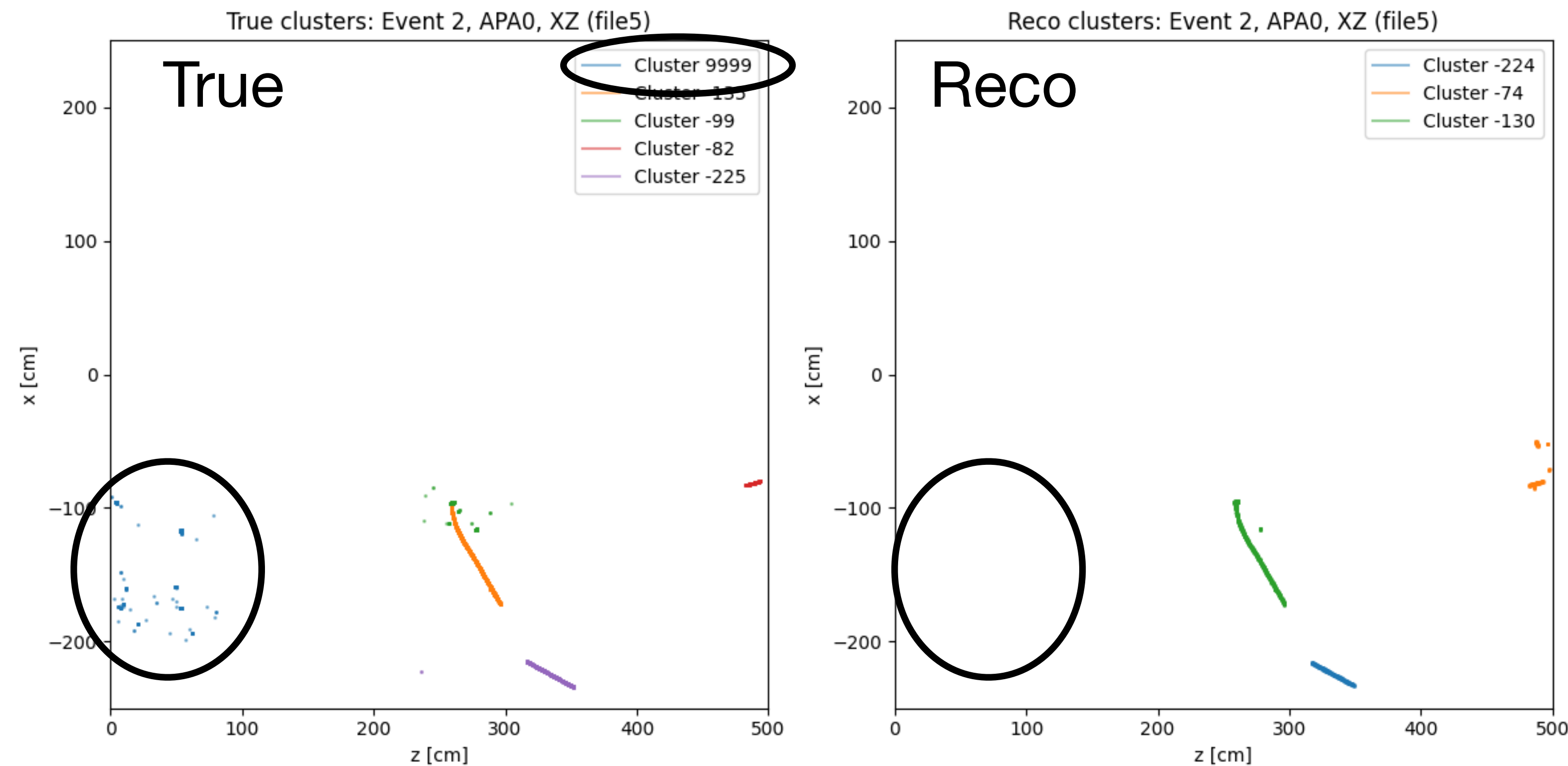


[Bee Link](#)

Example of True Neutrinos not finding any reco clusters

File 5: Event 2

2cm efficiency radius
APA 0

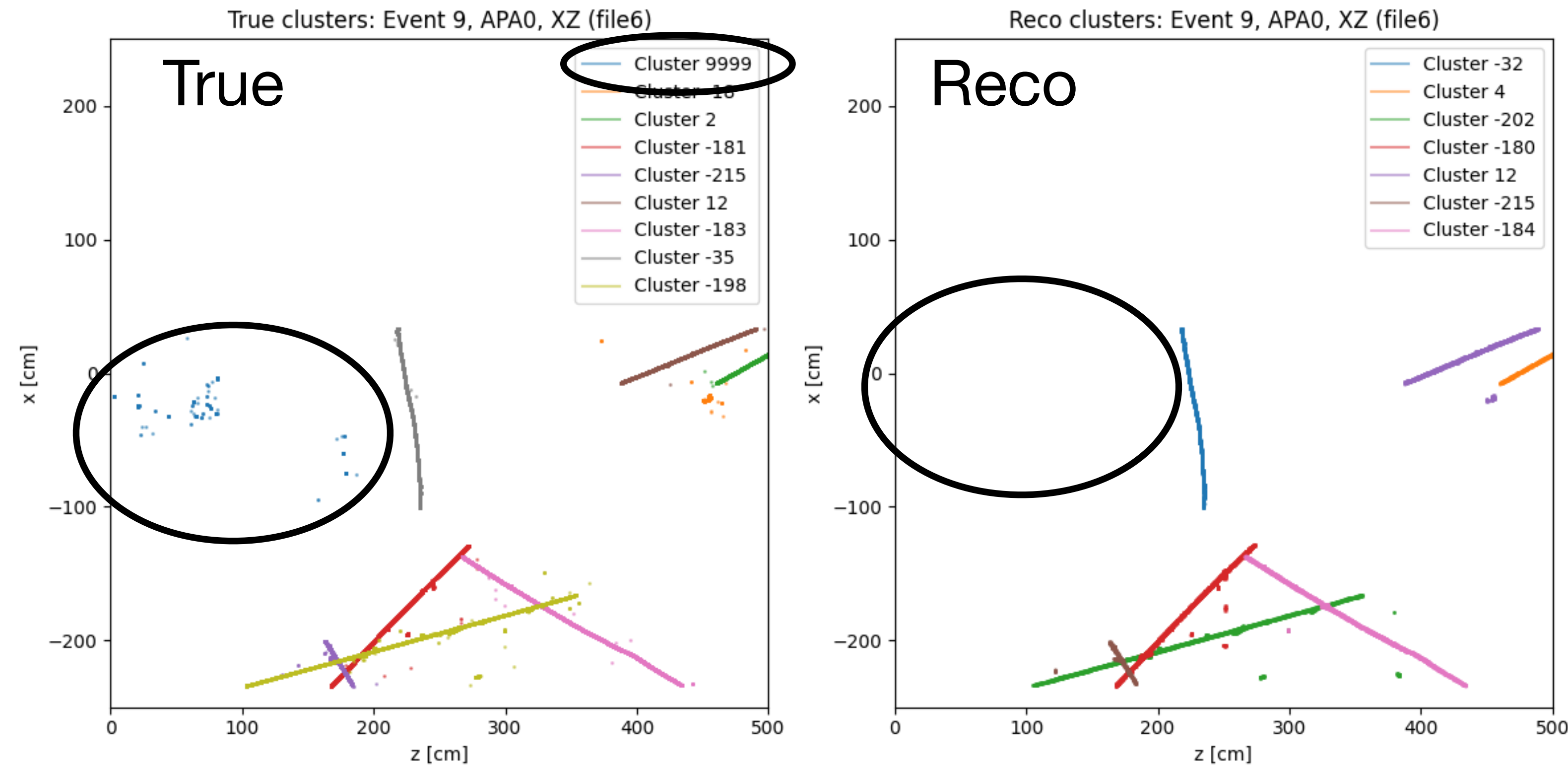


Bee
Link

Example of True Neutrinos not finding any reco clusters

File 6: Event 9

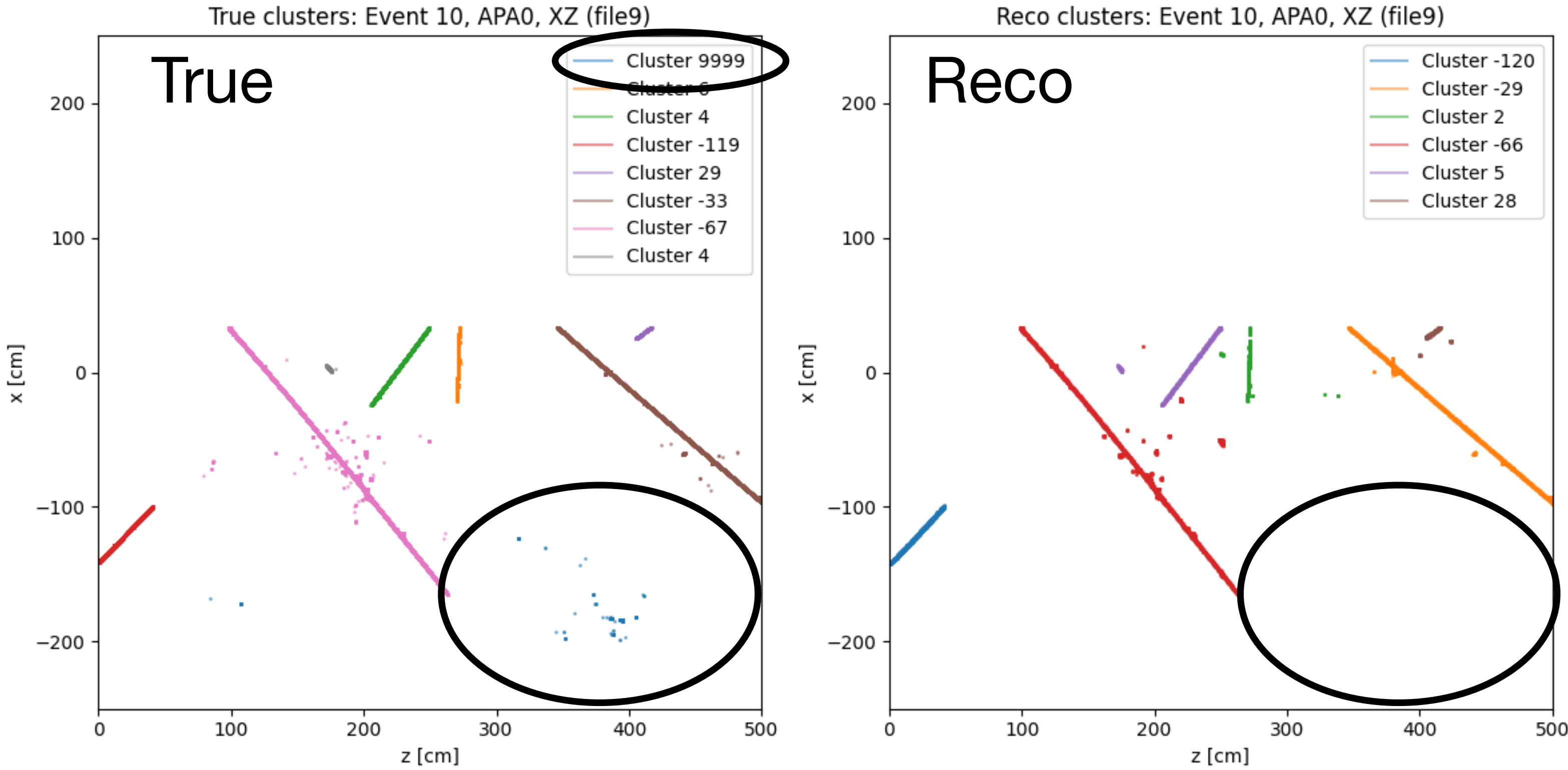
2cm efficiency radius
APA 0



Bee
Link

Example of True Neutrinos not finding any reco clusters

2cm efficiency radius
APA 0

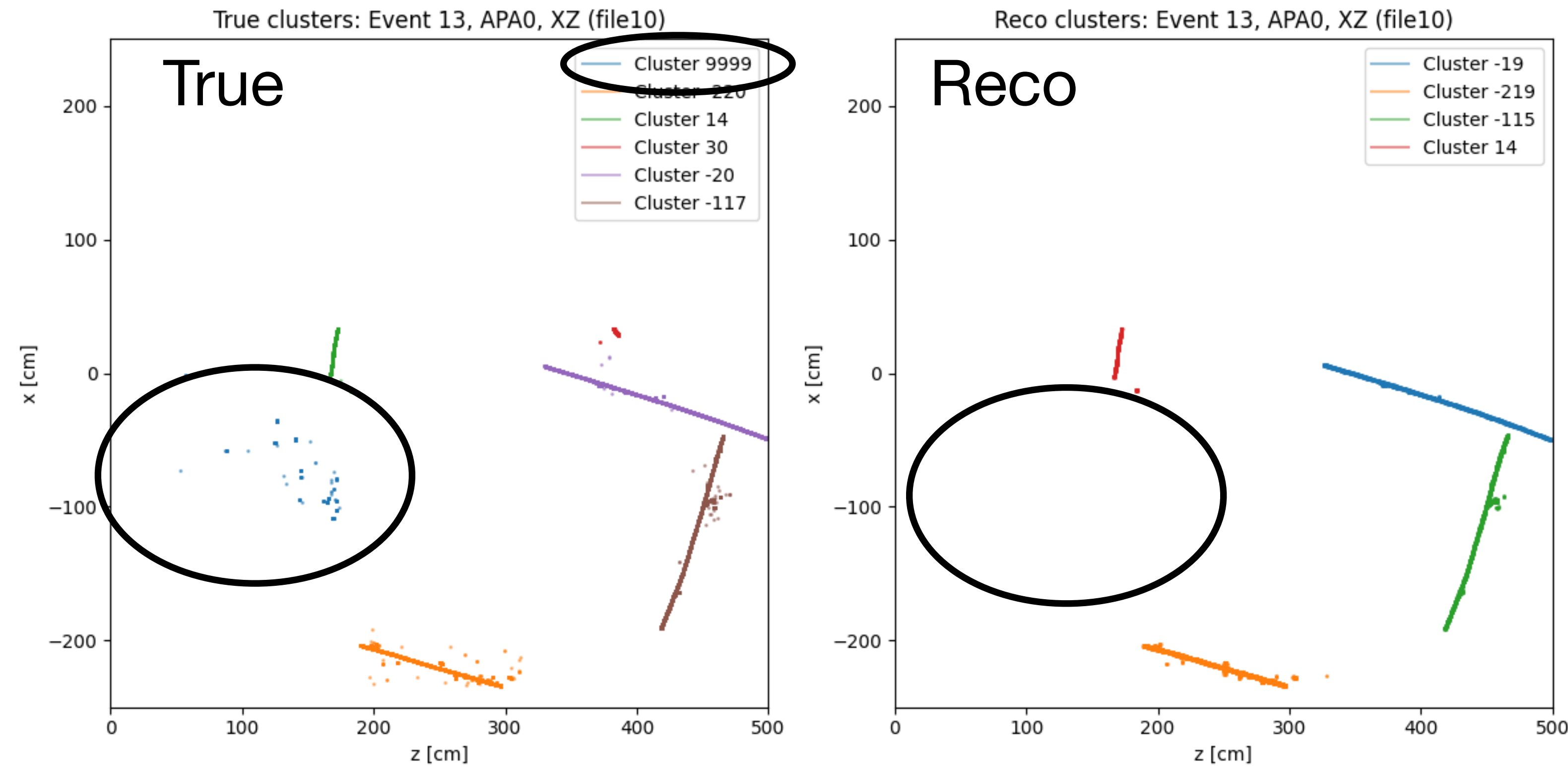


Example of True Neutrinos not finding any reco clusters

File 10: Event 13

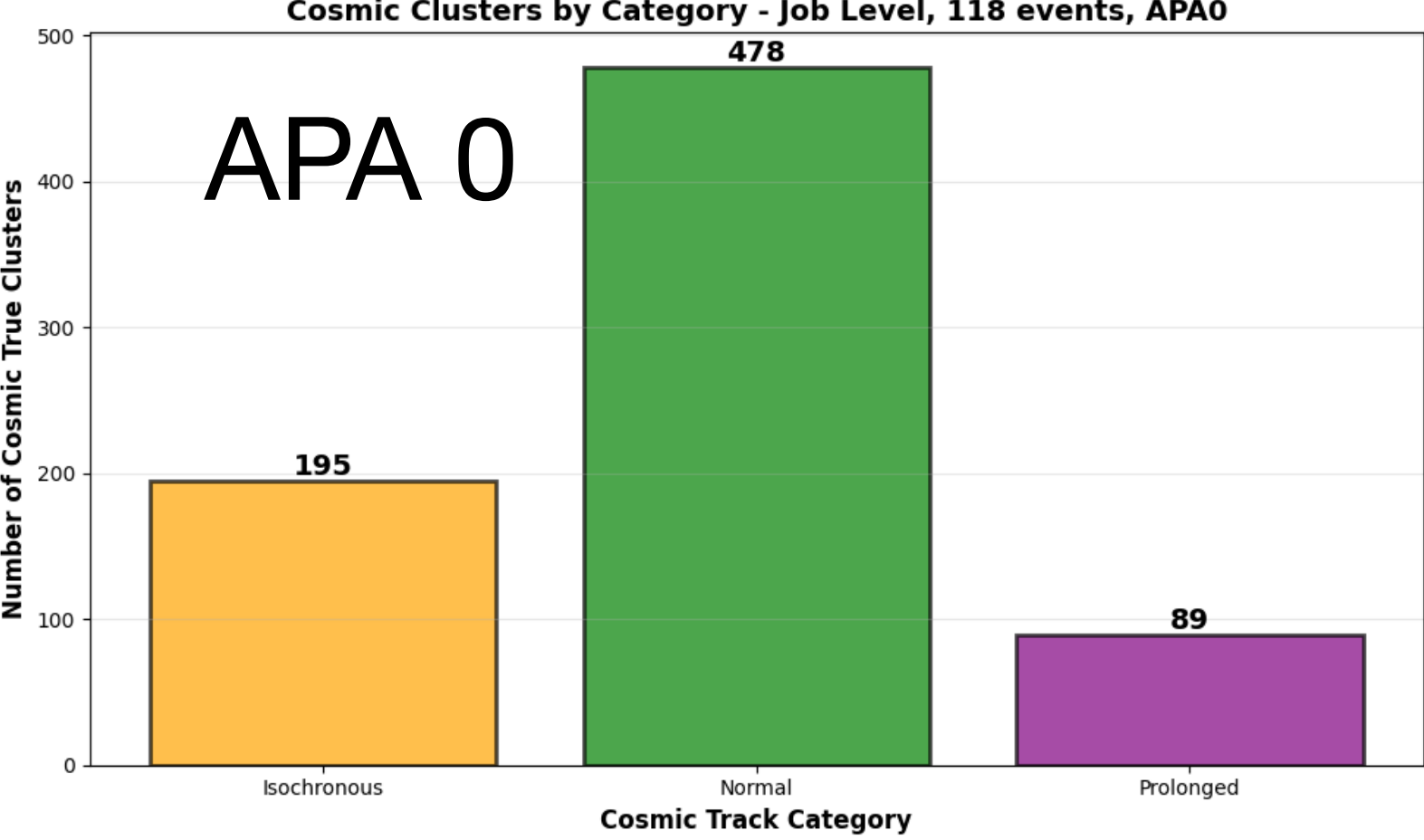
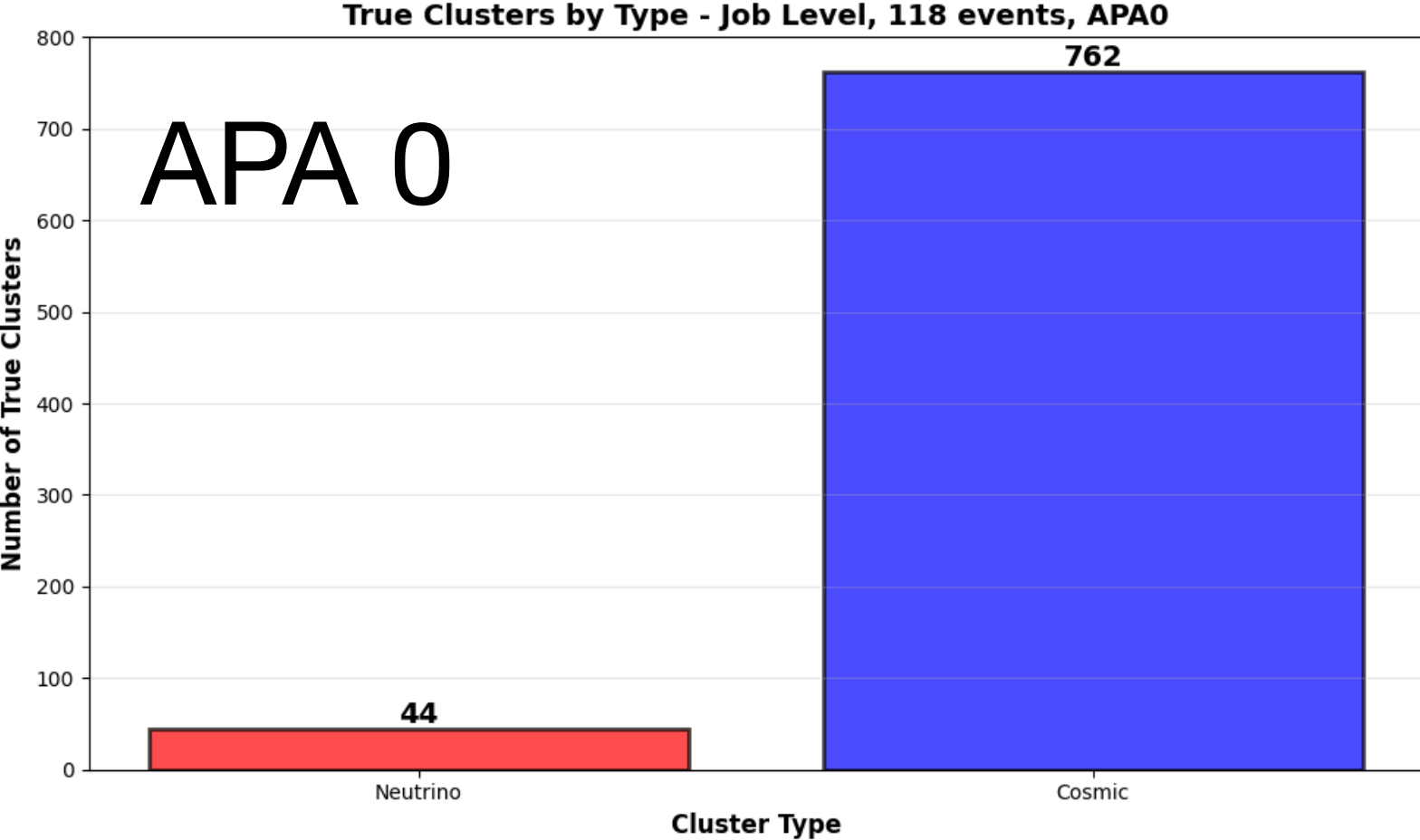
2cm efficiency radius

APA 0



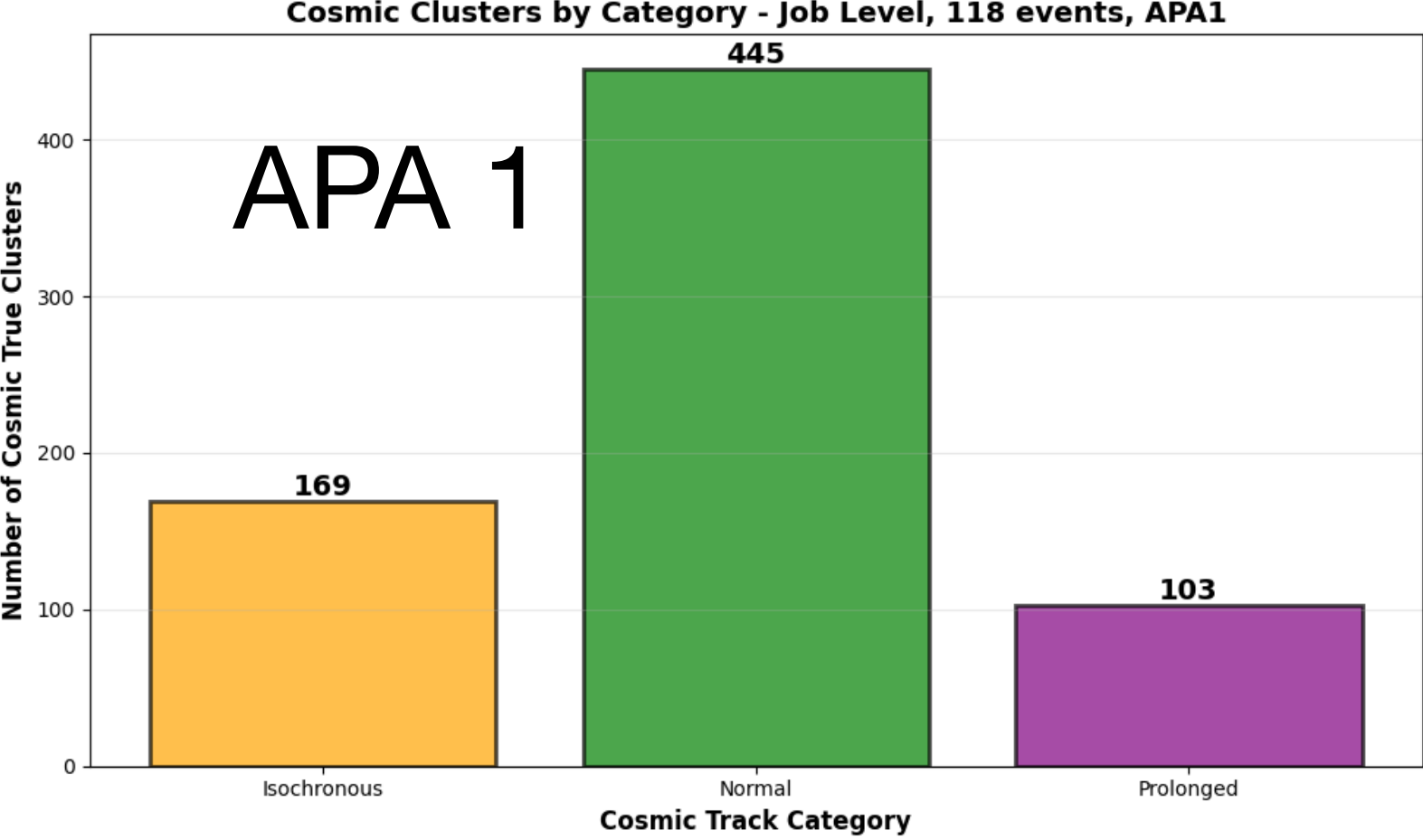
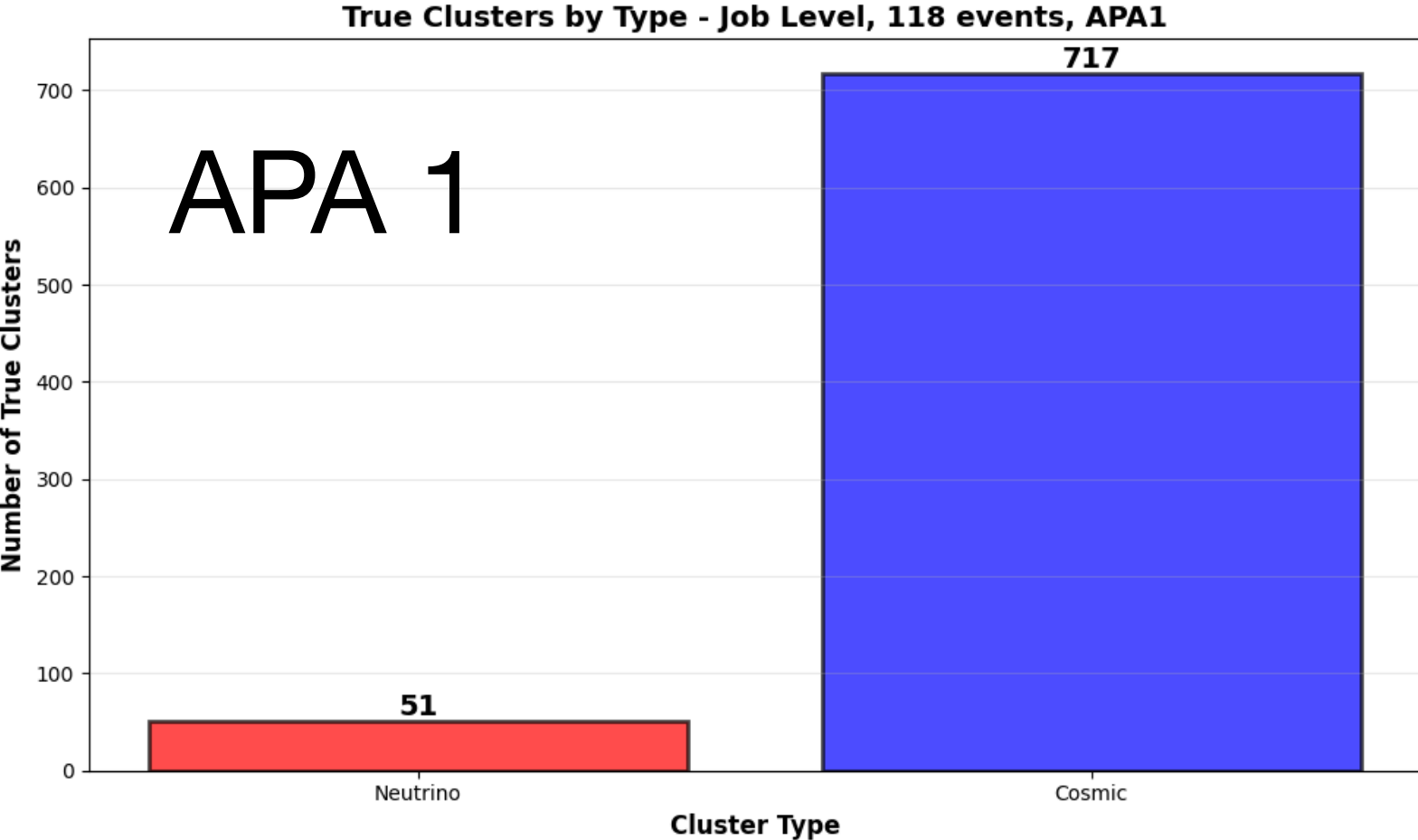
Bee
Link

Sample for Evaluation



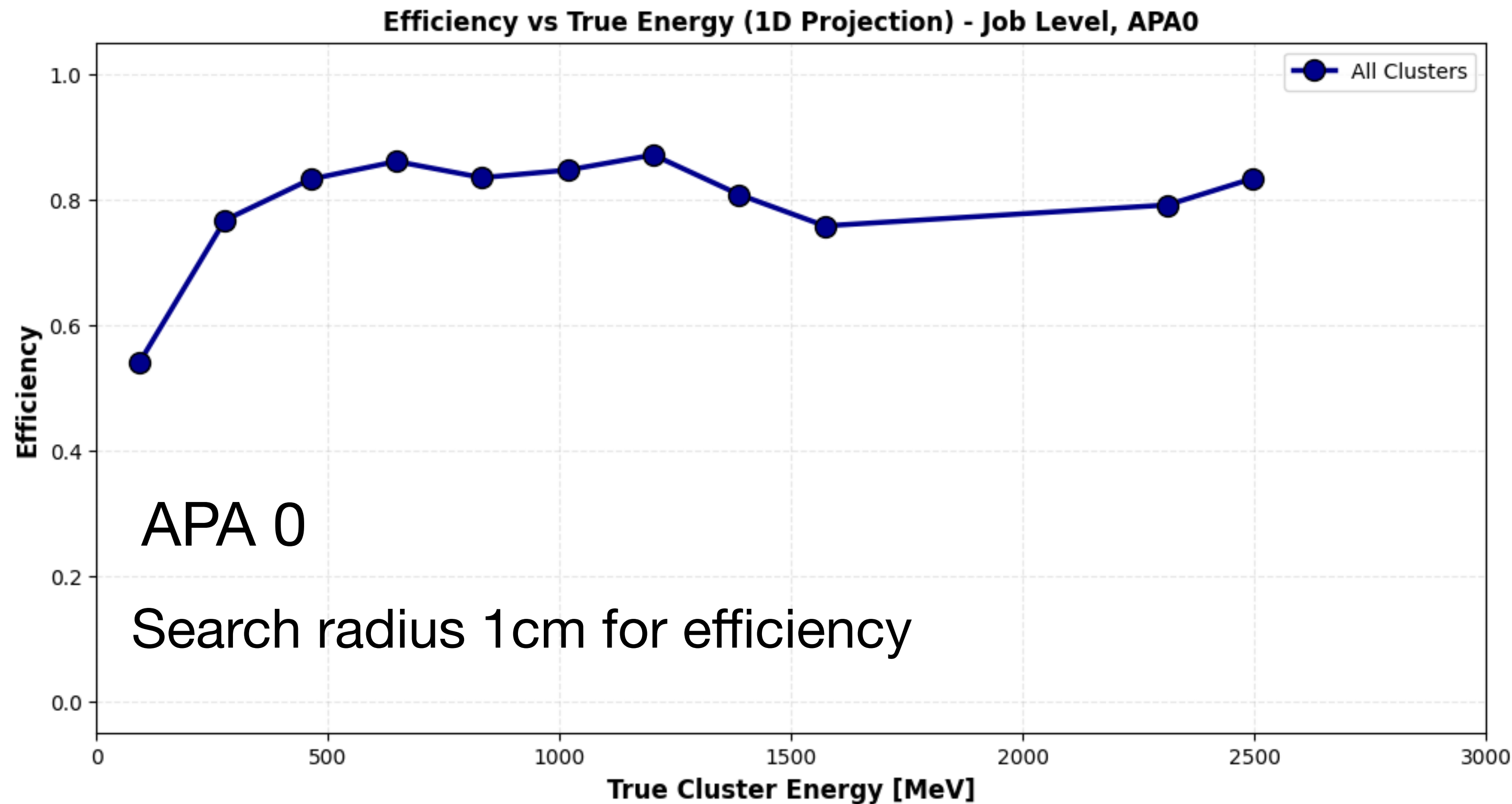
Number of Files	10
Events	118

- Though small but relatively good sample of neutrino and cosmic clusters for reconstruction efficiency and purity evaluations



- Isochronous cosmic clusters: $\theta_{xz} < 20^0$ (need to reduce to 15^0)
- Prolonged cosmic clusters: $\theta_{xz} > 70^0$ (need to increase to 70^0)
- Normal cosmic clusters: $\theta_{xz} : 20^0 - 70^0$ (need to change to $\theta_{xz} : 15^0 - 75^0$)

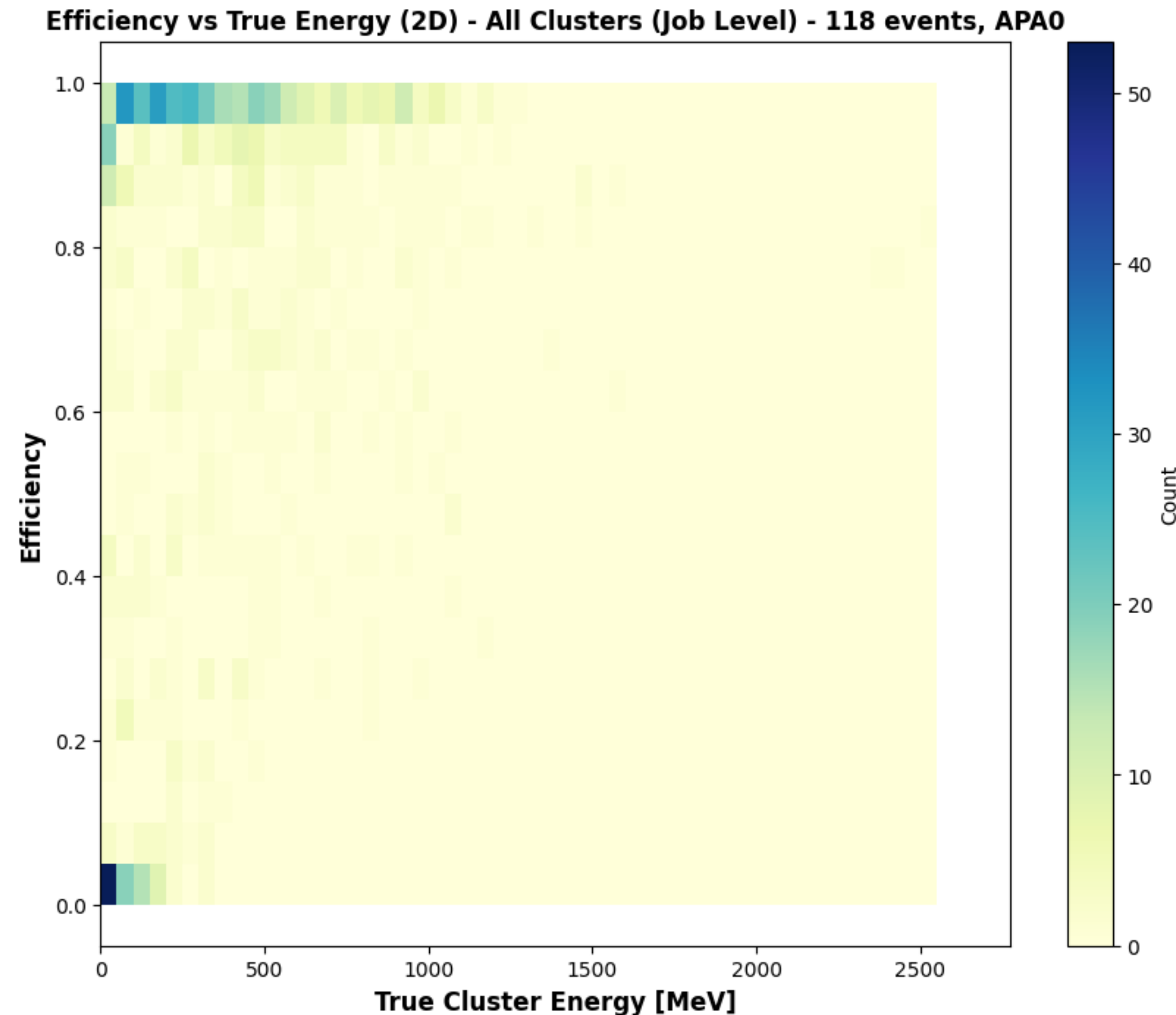
Efficiency as a function of True Cluster Energy



- This efficiency is estimated for all neutrinos and all cosmics
- As expected efficiency is flat and stable as a function of true energies of clusters
- Each point is an average efficiency in a given true energy bin
- Though the efficiency curve is flat and stable but it is not as high as we would have expected

Efficiency definition: fraction of true clusters matched to reco clusters

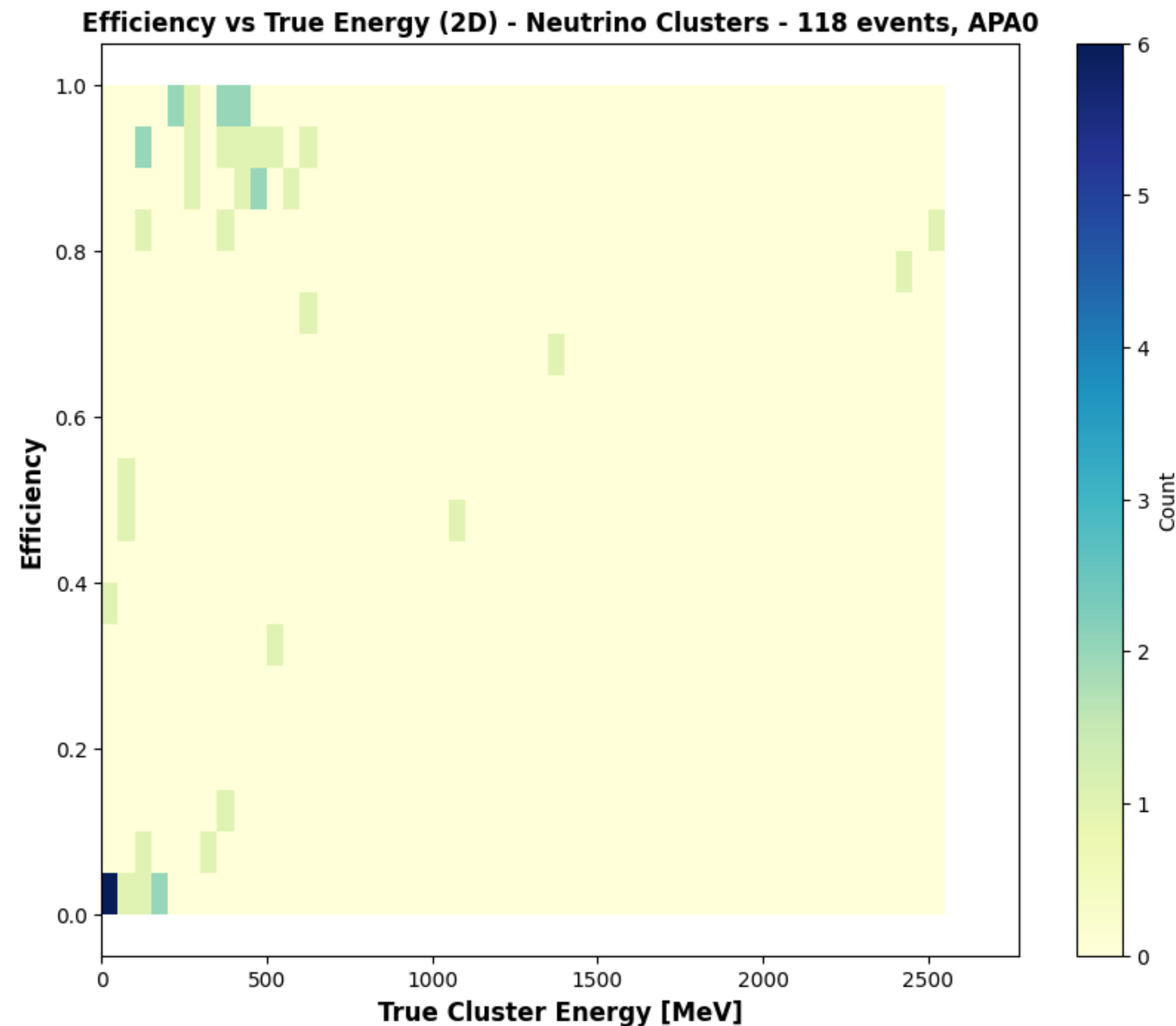
Efficiency as a function of True Cluster Energy



- 1d efficiency plot is estimated from this 2d plot
- In each true energy bin we take the average efficiency
- As you can see a large fraction of true clusters are closer to 100% efficiency which we would expect
- There is also a large fraction of true clusters close to zero efficiency which we do not expect and it needs further investigation

Efficiency definition: fraction of true clusters matched to reco clusters

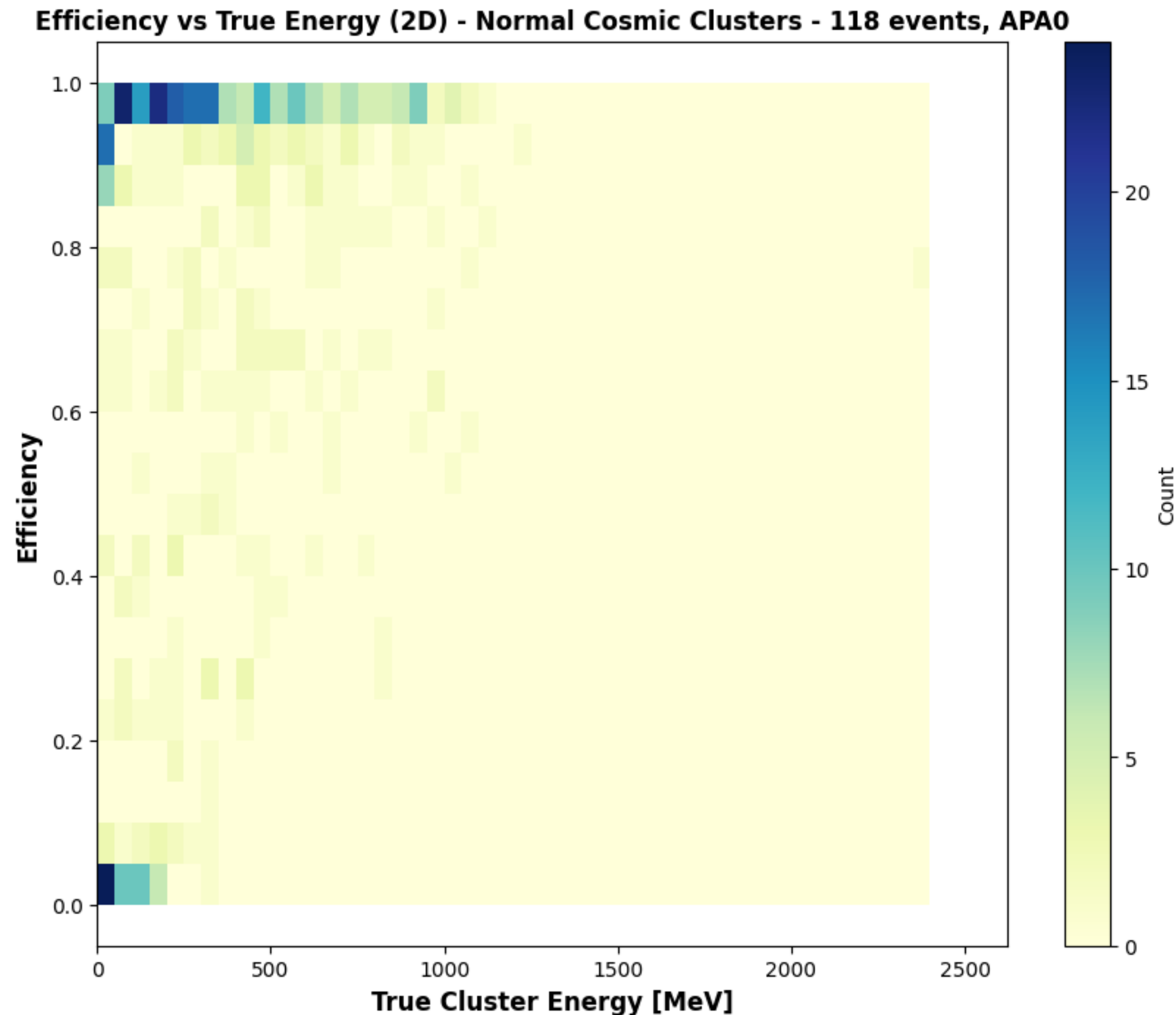
Efficiency as a function of True Cluster Energy



- Several neutrino clusters are at high efficiency regions but there are also some at very low efficiencies

Efficiency definition: fraction of true clusters matched to reco clusters

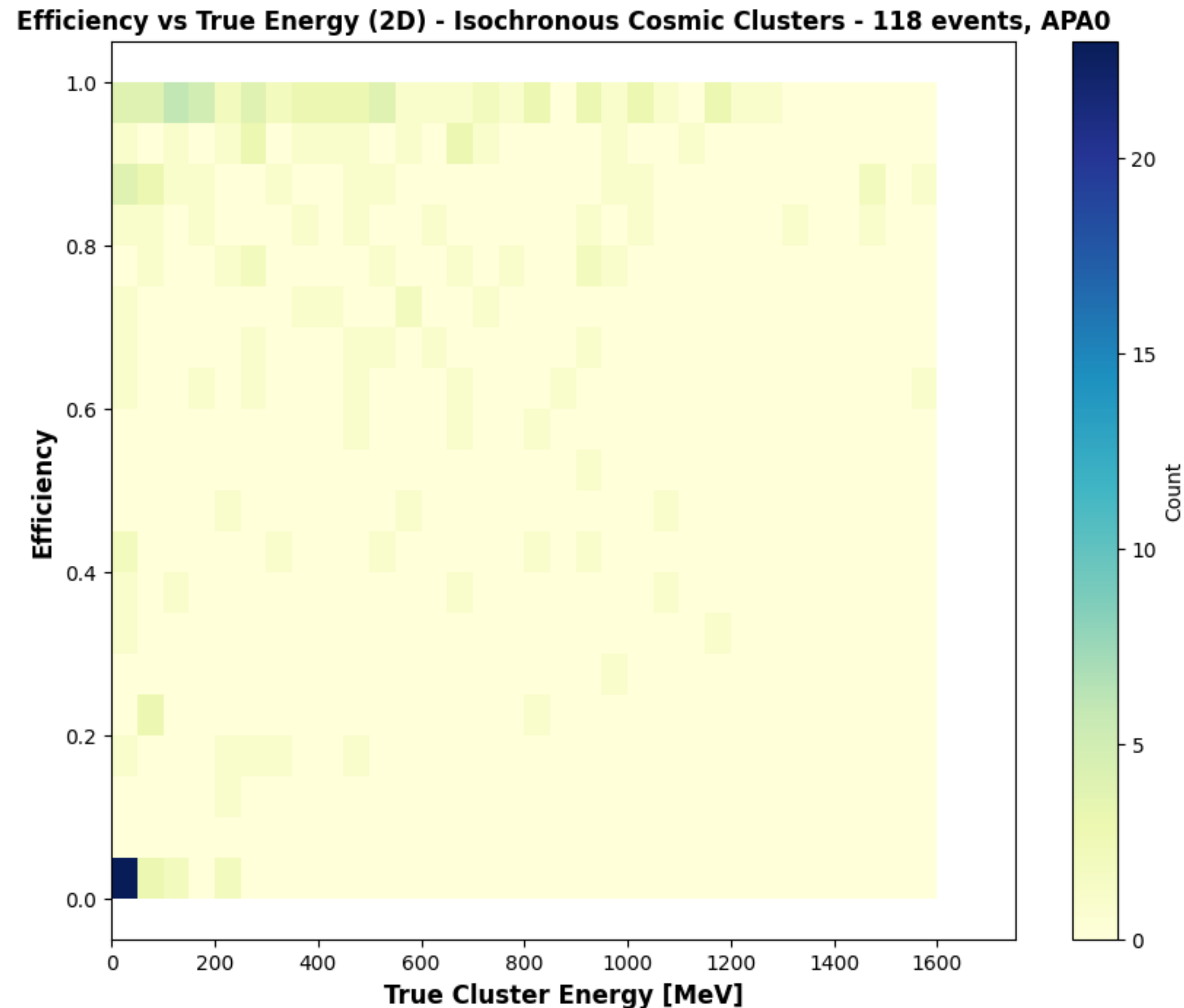
Efficiency as a function of True Cluster Energy



- Normal cosmic: non-isochronous and non-prolonged closures
- This plot shows some fraction of normal cosmic true clusters also are close to zero efficiency

Efficiency definition: fraction of true clusters matched to reco clusters

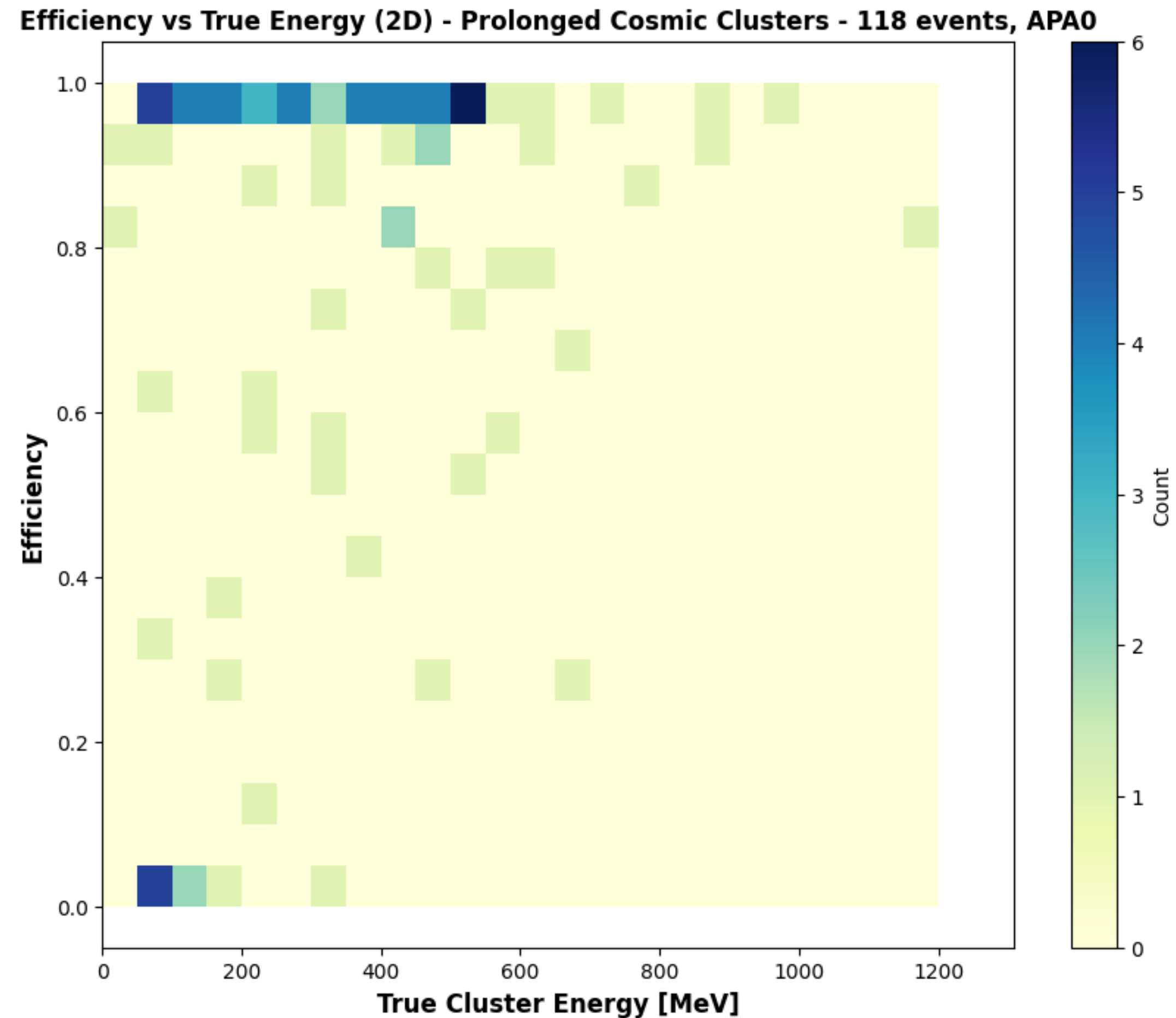
Efficiency as a function of True Cluster Energy



- Some isochronous true clusters are also at zero efficiency regions

Efficiency definition: fraction of true clusters matched to reco clusters

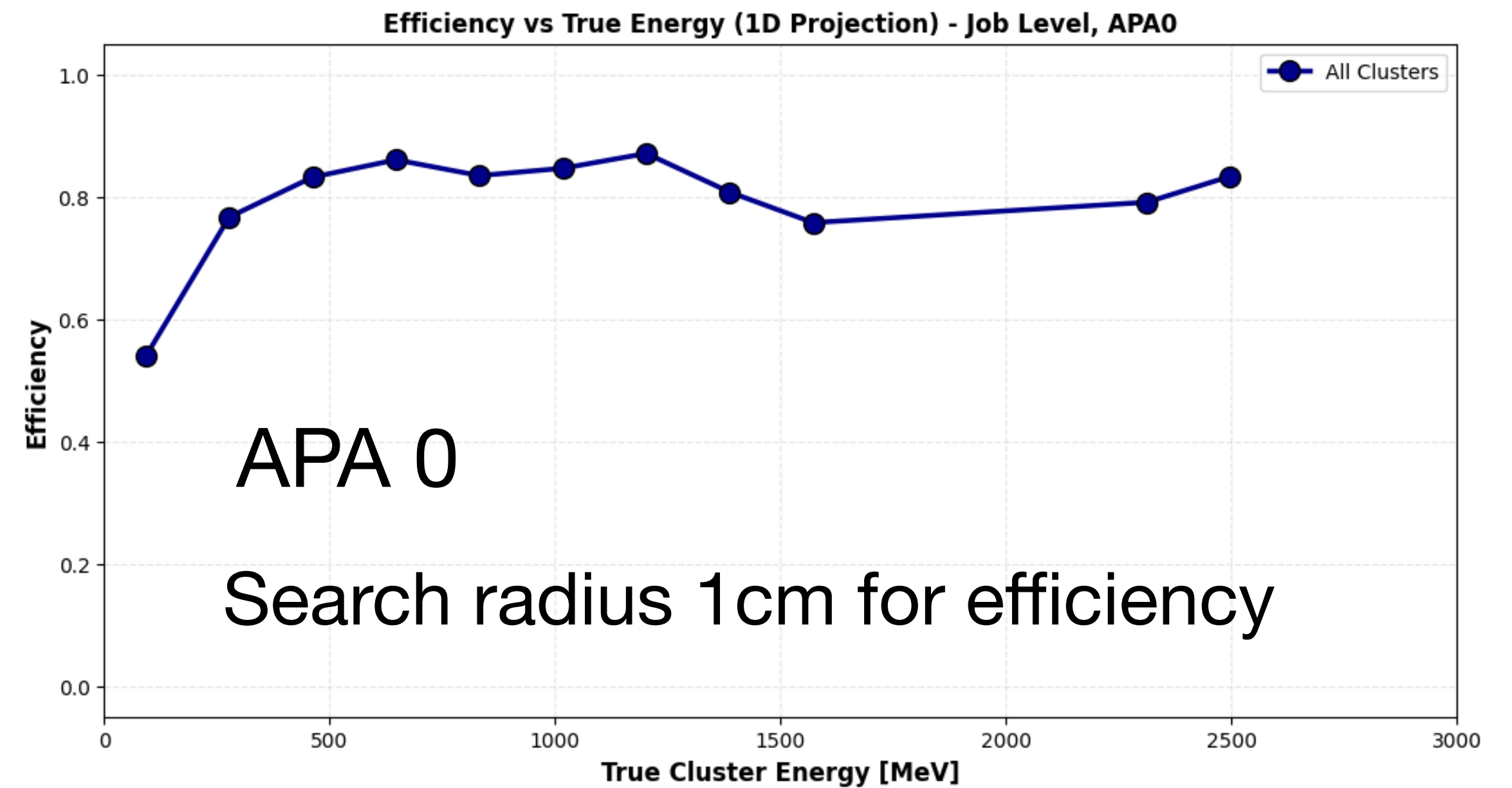
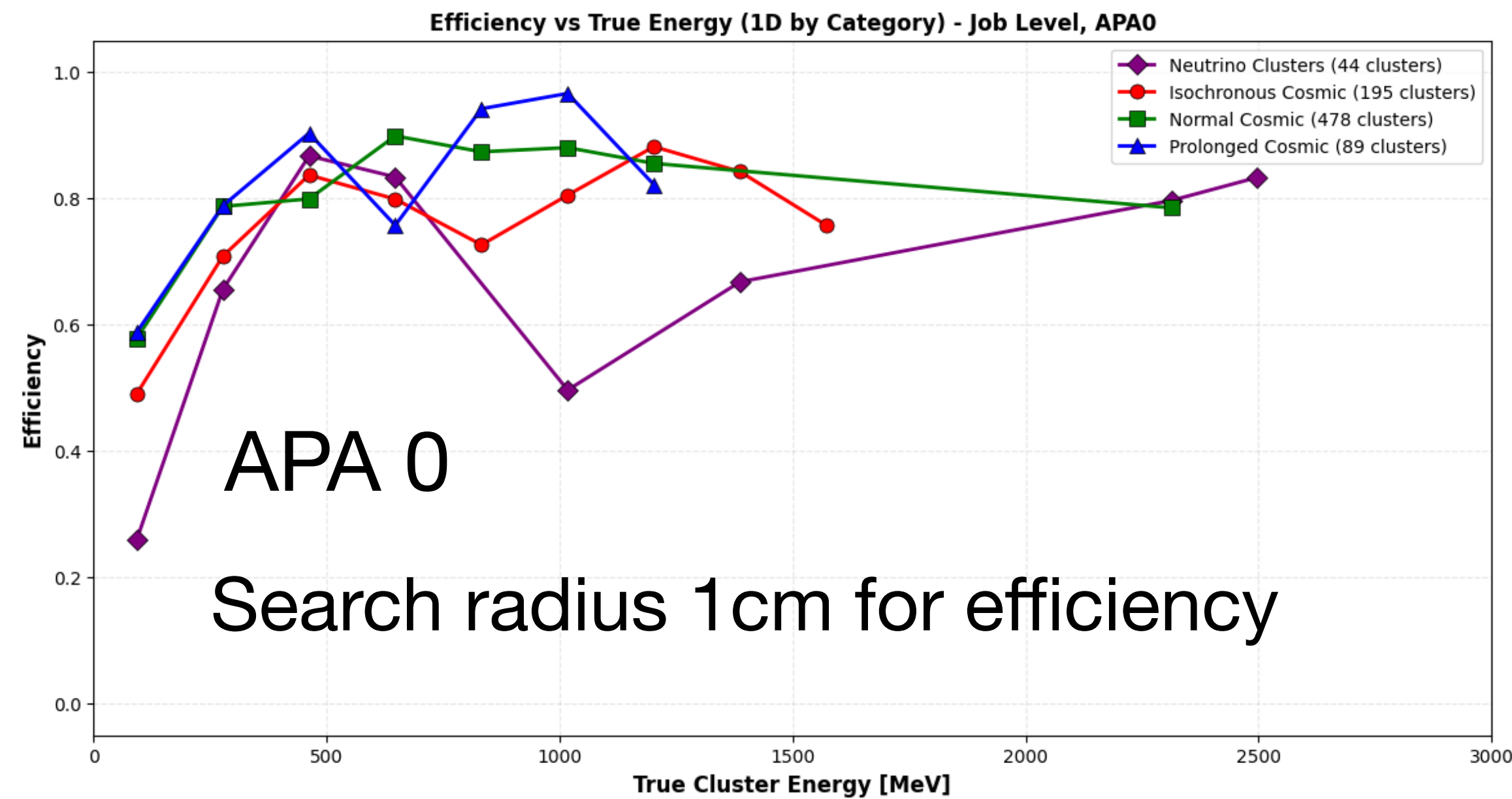
Efficiency as a function of True Cluster Energy



- A lot of prolonged cosmic clusters are at high efficiency regions and few are at low regions

Efficiency definition: fraction of true clusters matched to reco clusters

Efficiency as a function of True Cluster Energy



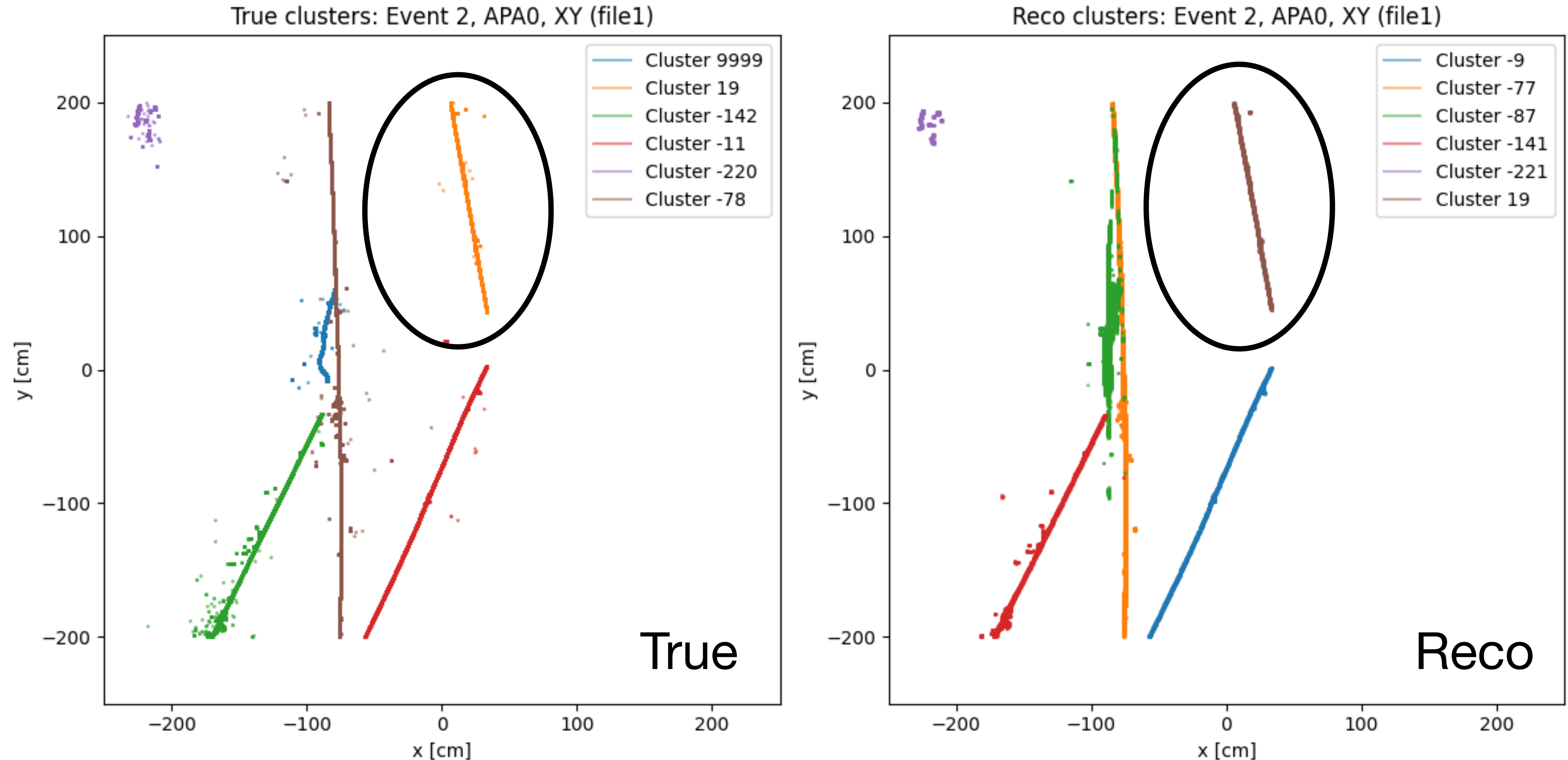
- These are summarized 1d efficiency plots for all categories: Neutrinos and Cosmics
- All of these need some further investigation to understand the low efficiency cases

Reasons of low efficiencies

- A large fraction of low efficiency clusters is caused due to uncorrected space-charge effects
- Space-charge effects can cause reco clusters to be reconstructed slightly away from true clusters
- For efficiency estimates we include reco points within 1 cm radius from true clusters but if reco points are more than 1 cm away from true points then they are excluded from efficiency evaluation leading to low efficiencies
- There are also some cases where true clusters did not find any reco clusters which caused zero efficiency cases
- Some more investigation is needed to find may be other reasons for non-matching between true and reco points

Some cases of low efficiency: Event 2

[Bee Link](#)

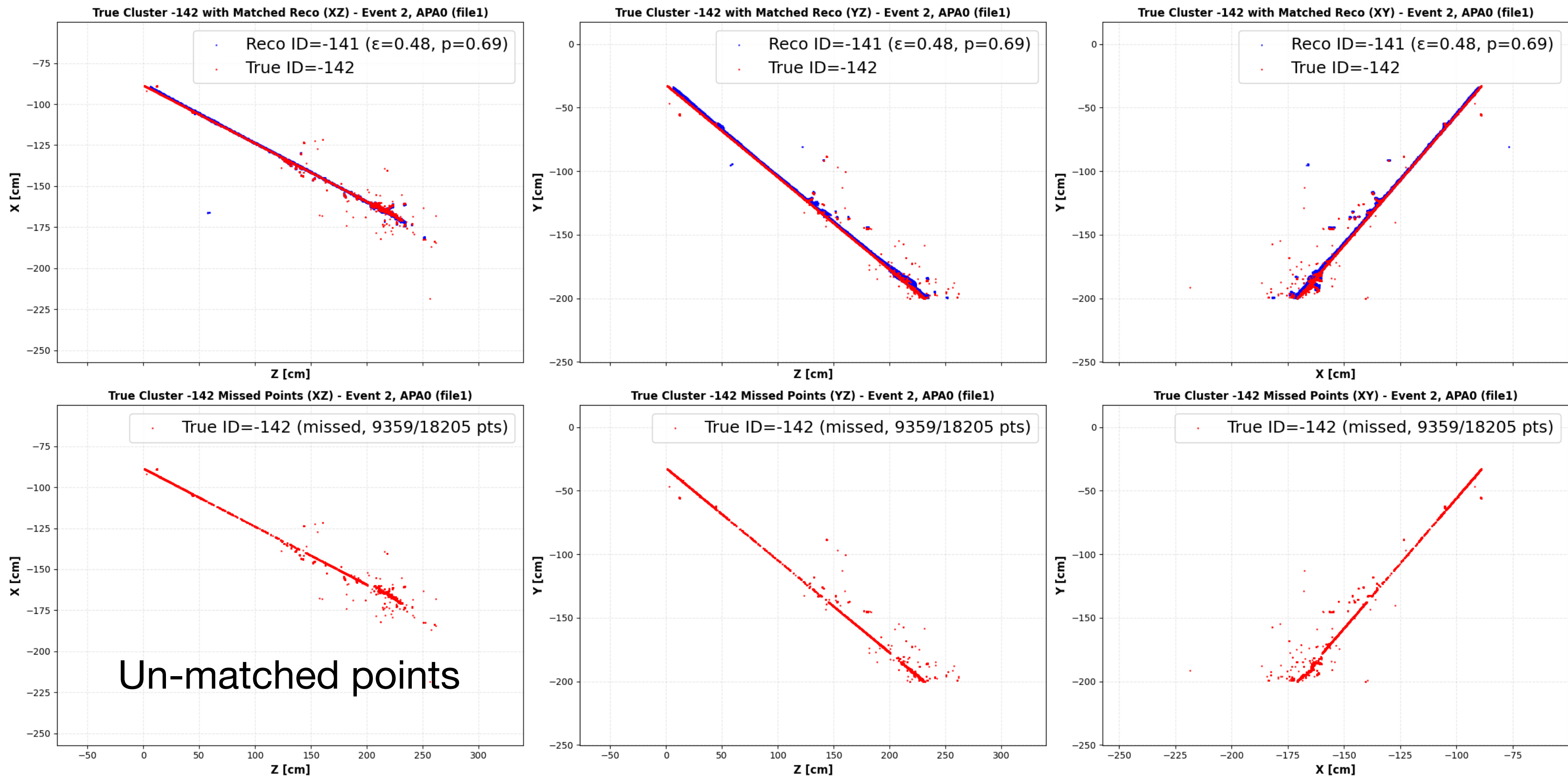


$\varepsilon = 48\%$

Reason for low efficiency: Space-charge effect

Some cases of low efficiency: Event 2

[Bee Link](#)

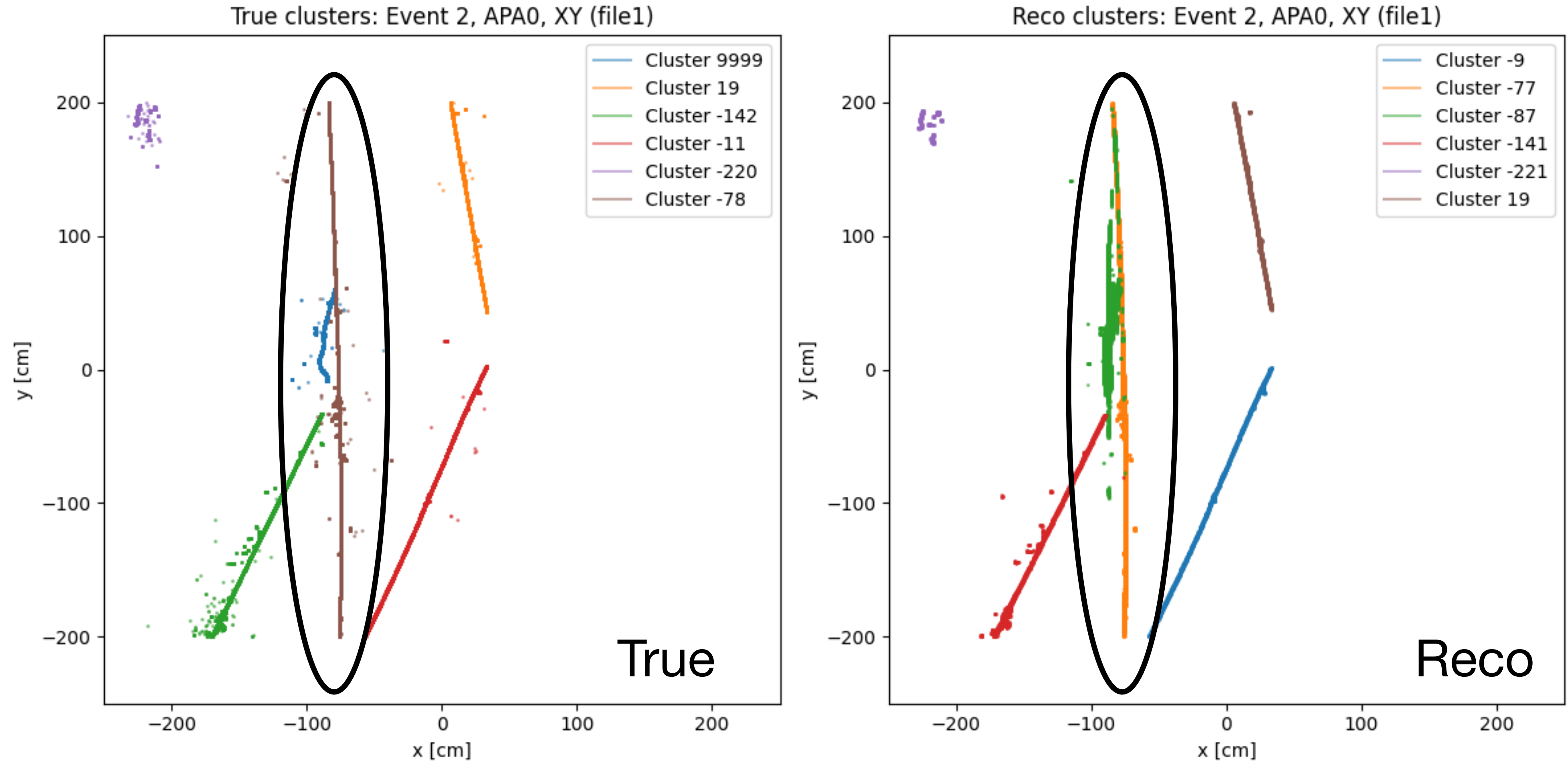


$\epsilon = 48\%$

Reason for low efficiency: Space-charge effect

Some cases of low efficiency: Event 2

[Bee Link](#)

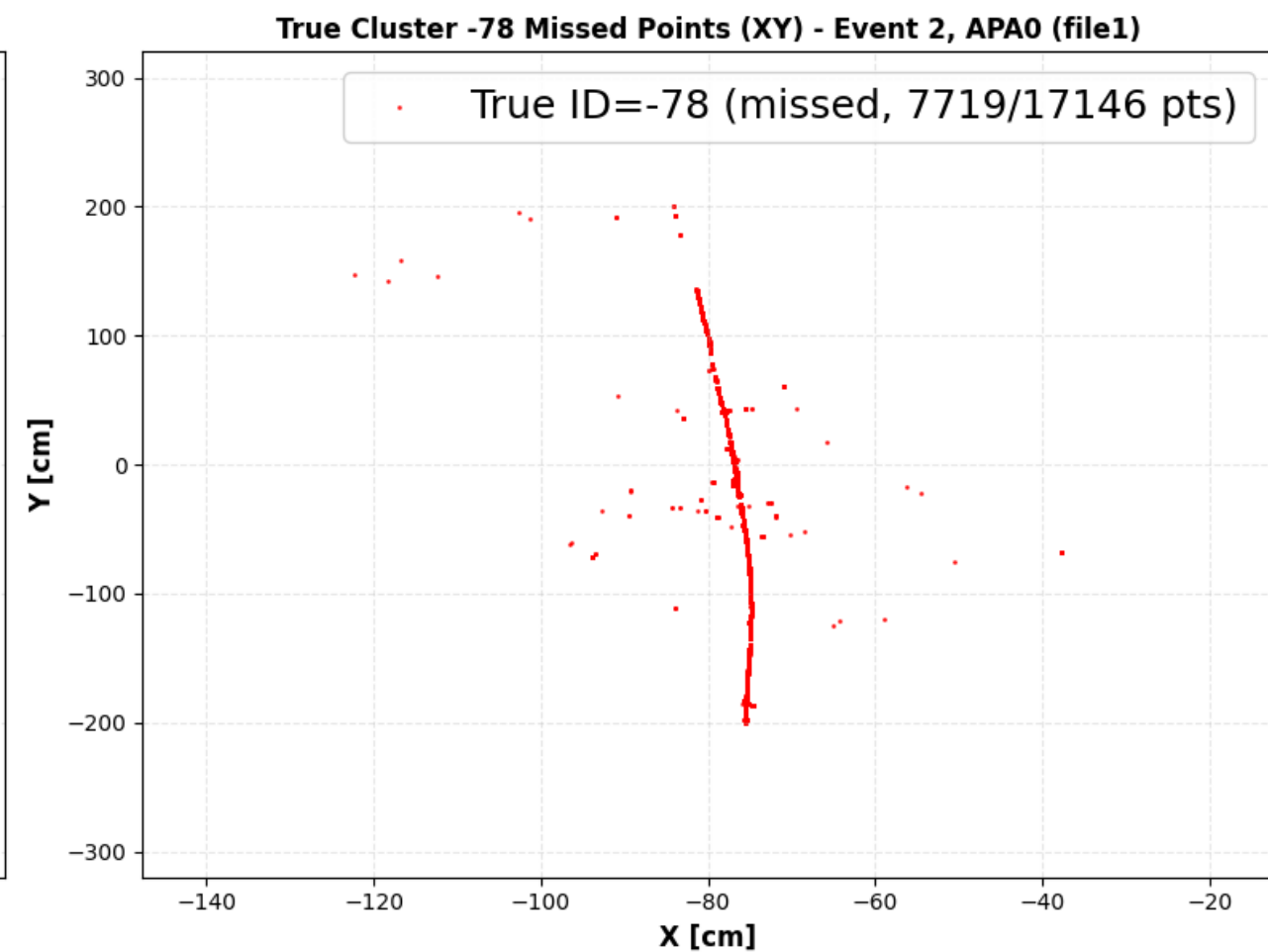
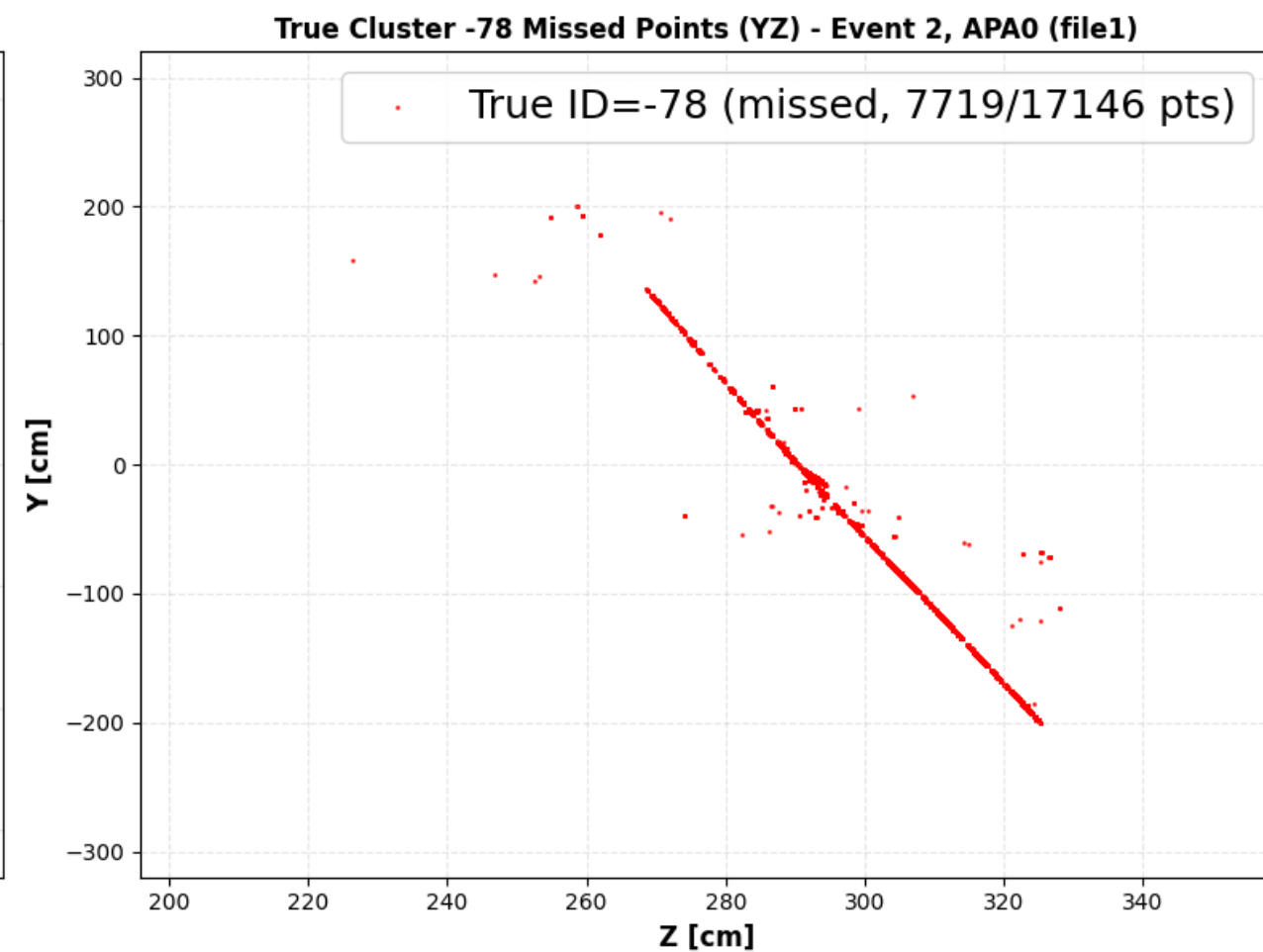
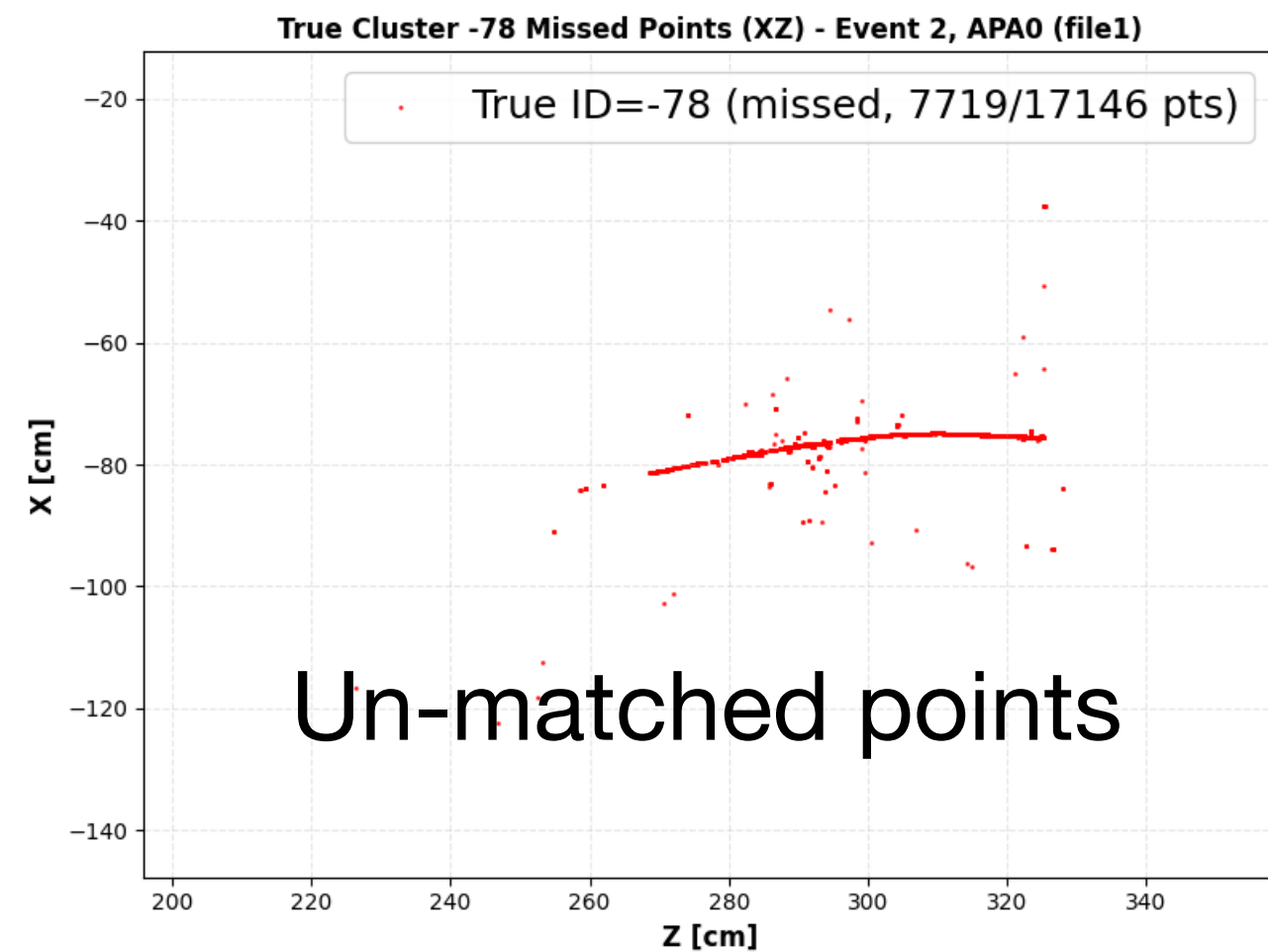
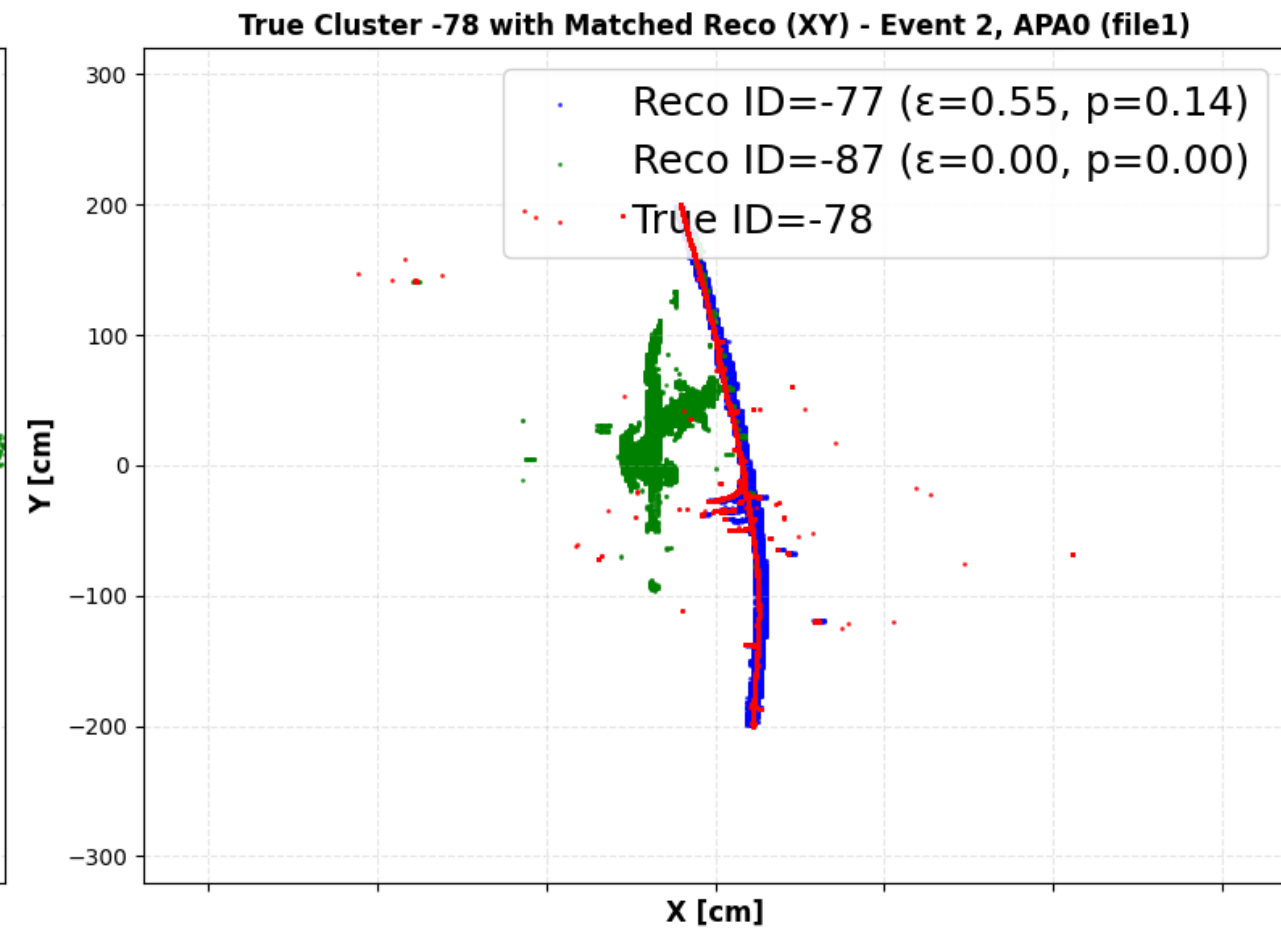
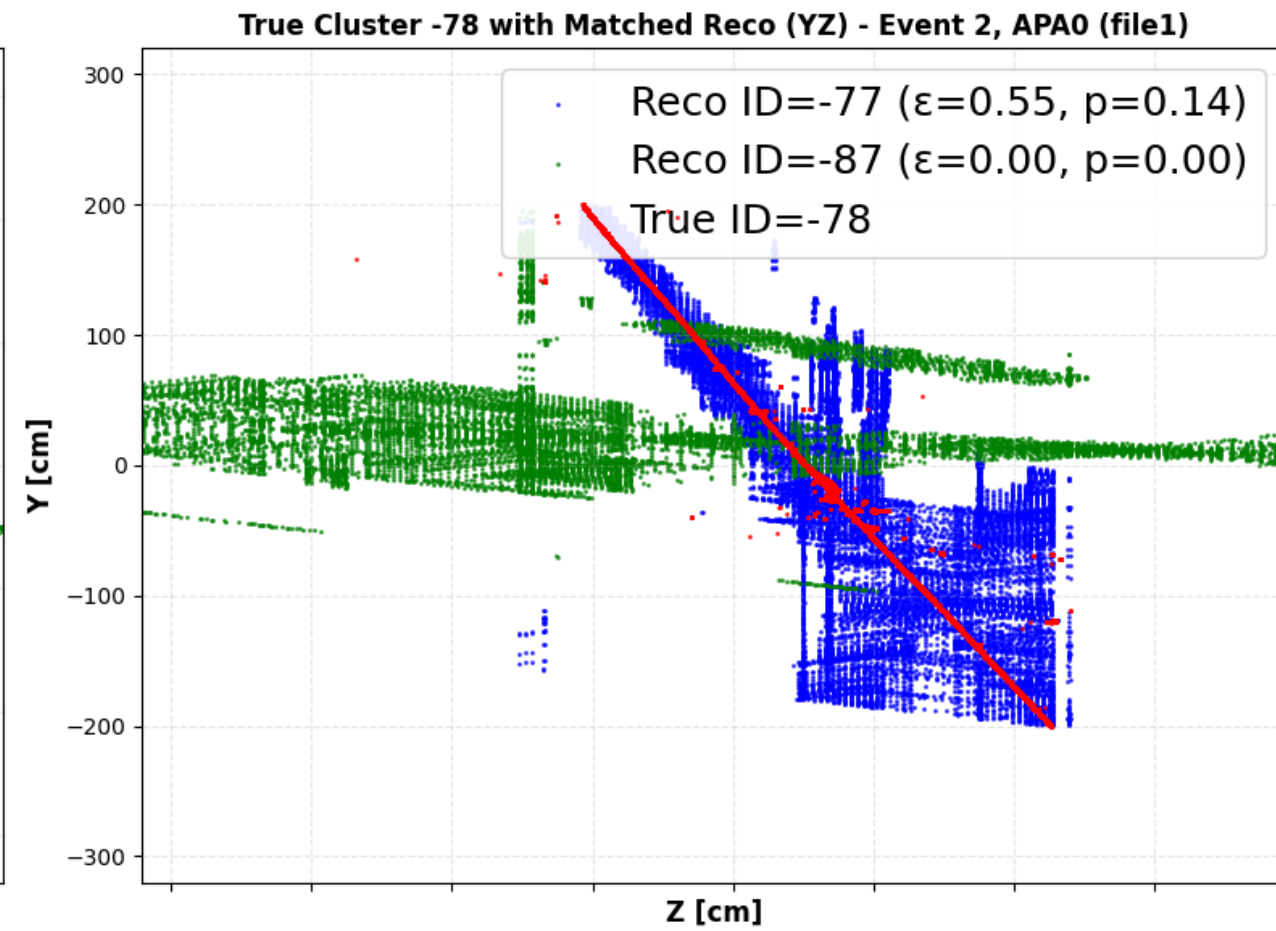
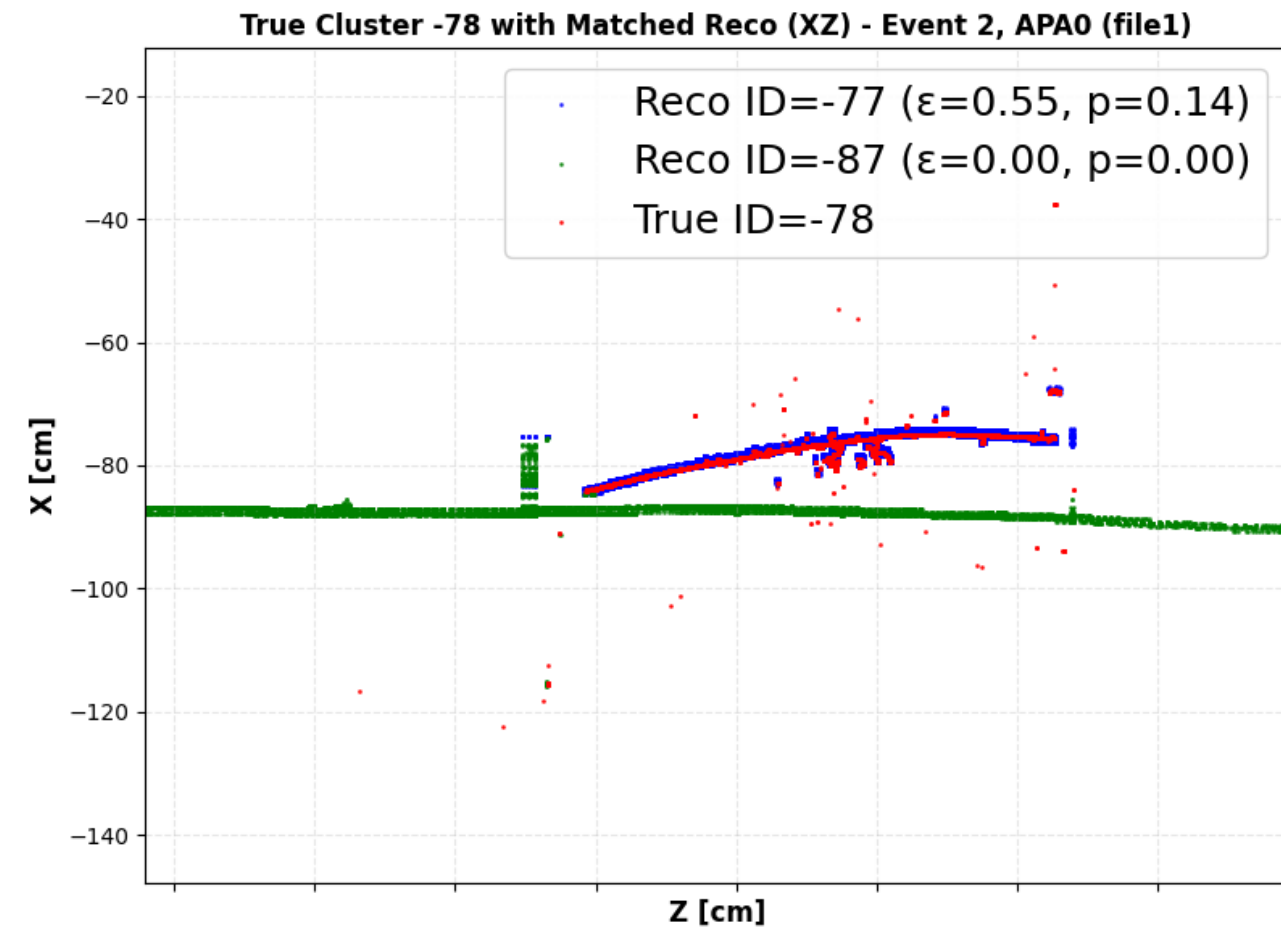


$\varepsilon = 55\%$

Reason for low efficiency: Space-charge effect

Some cases of low efficiency: Event 2

[Bee Link](#)



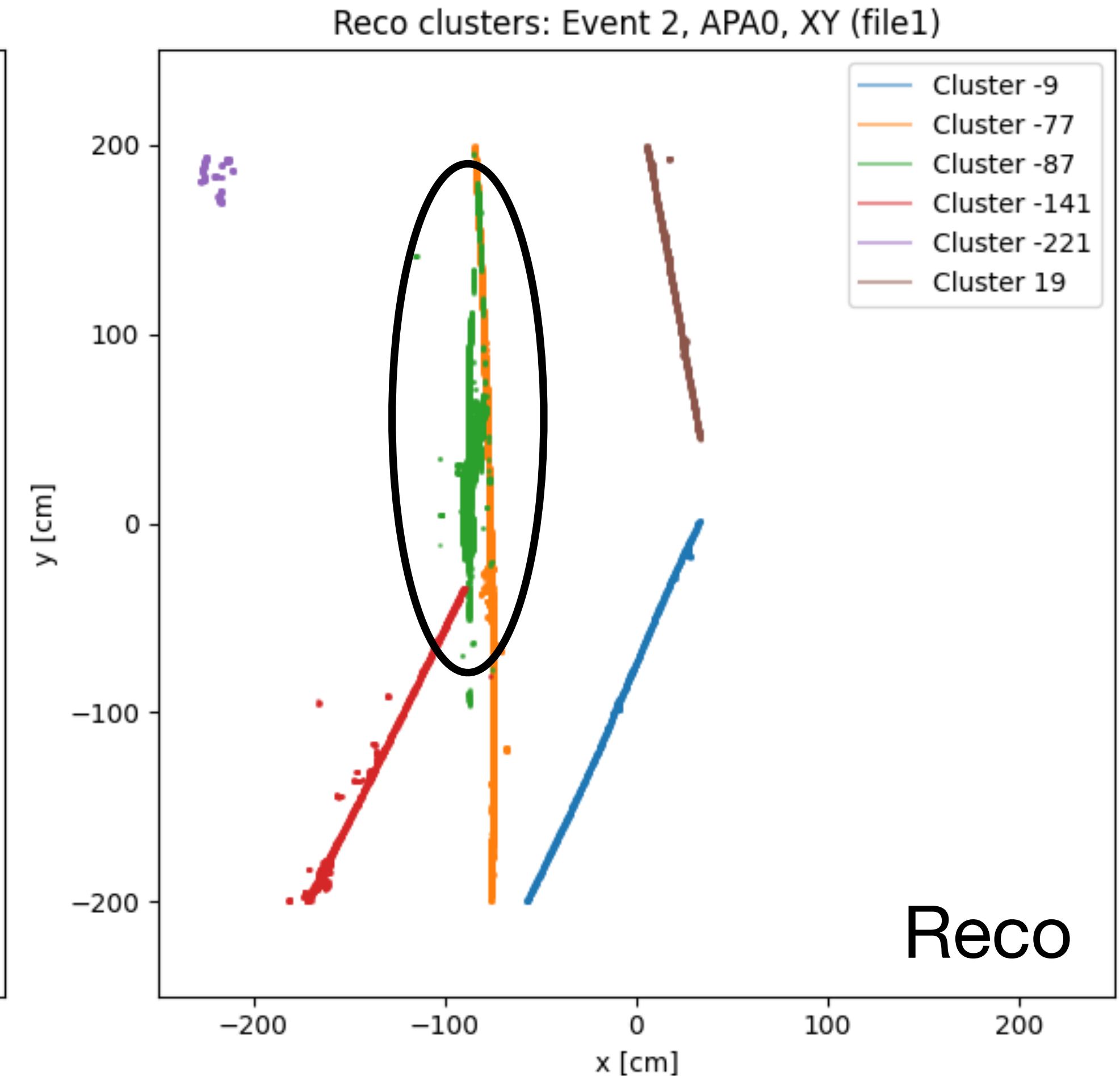
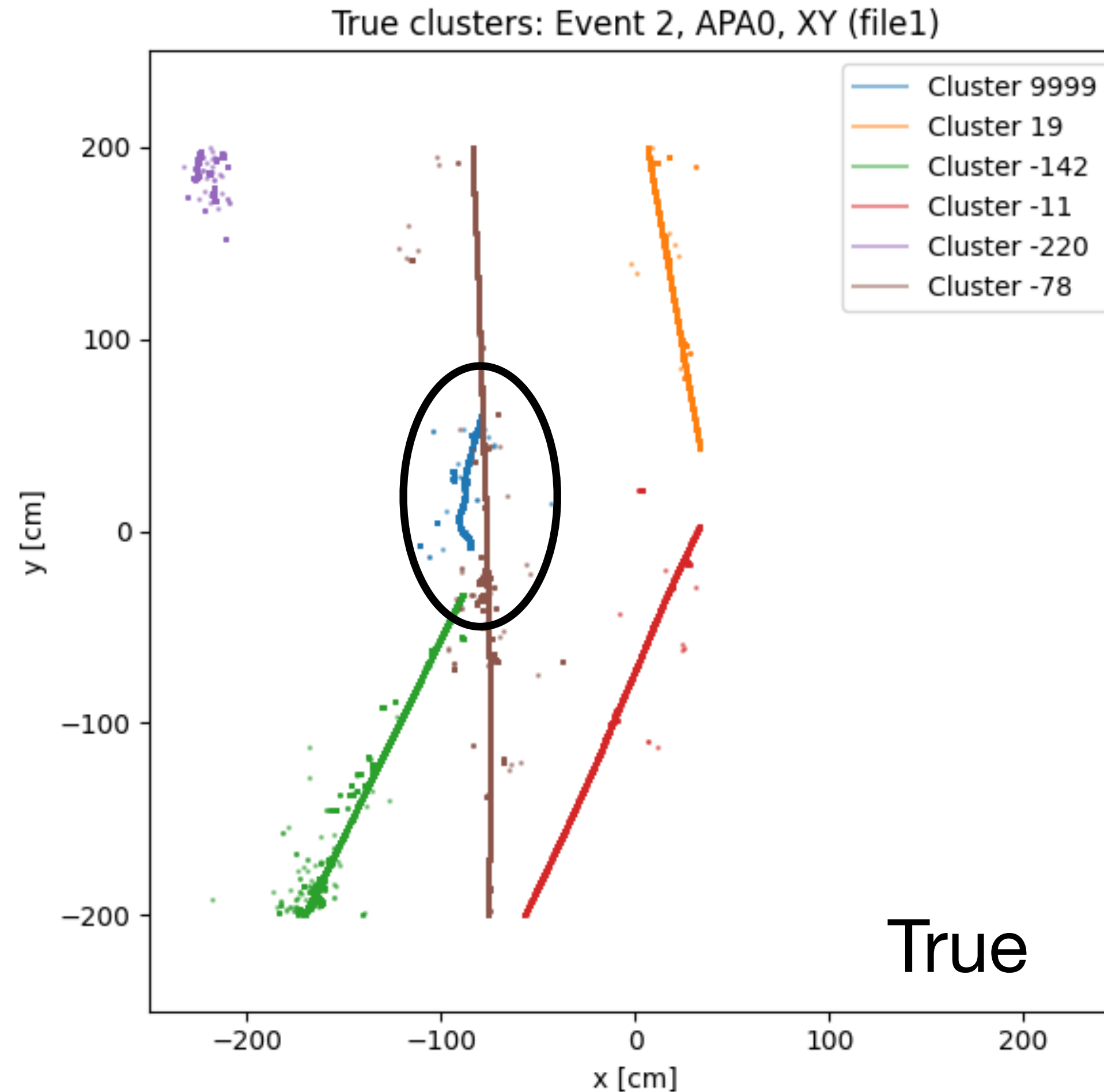
$\epsilon = 55\%$

Reason for low efficiency: Space-charge effect

Some cases of low efficiency: Event 2

[Bee Link](#)

Neutrino
Interaction



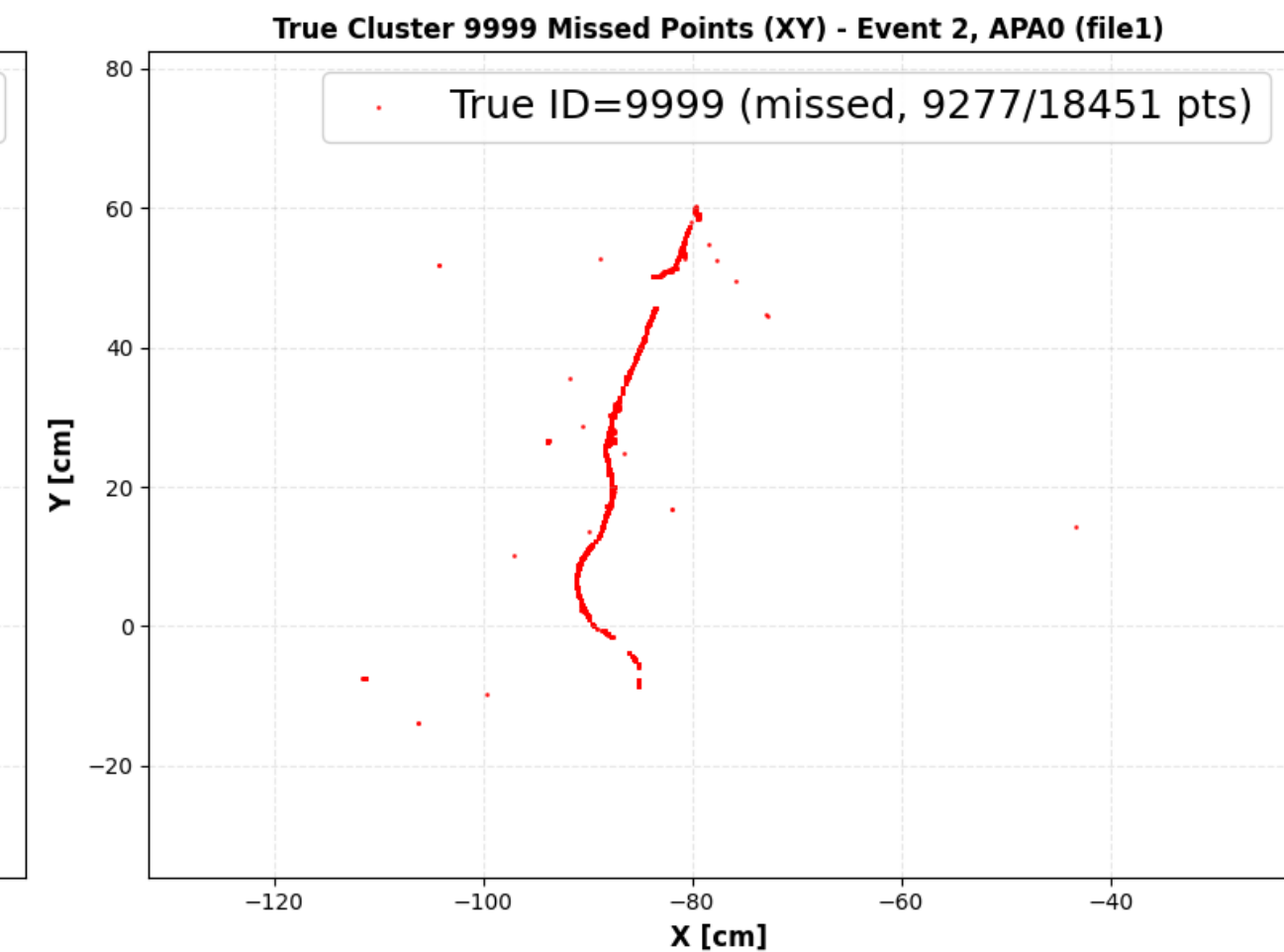
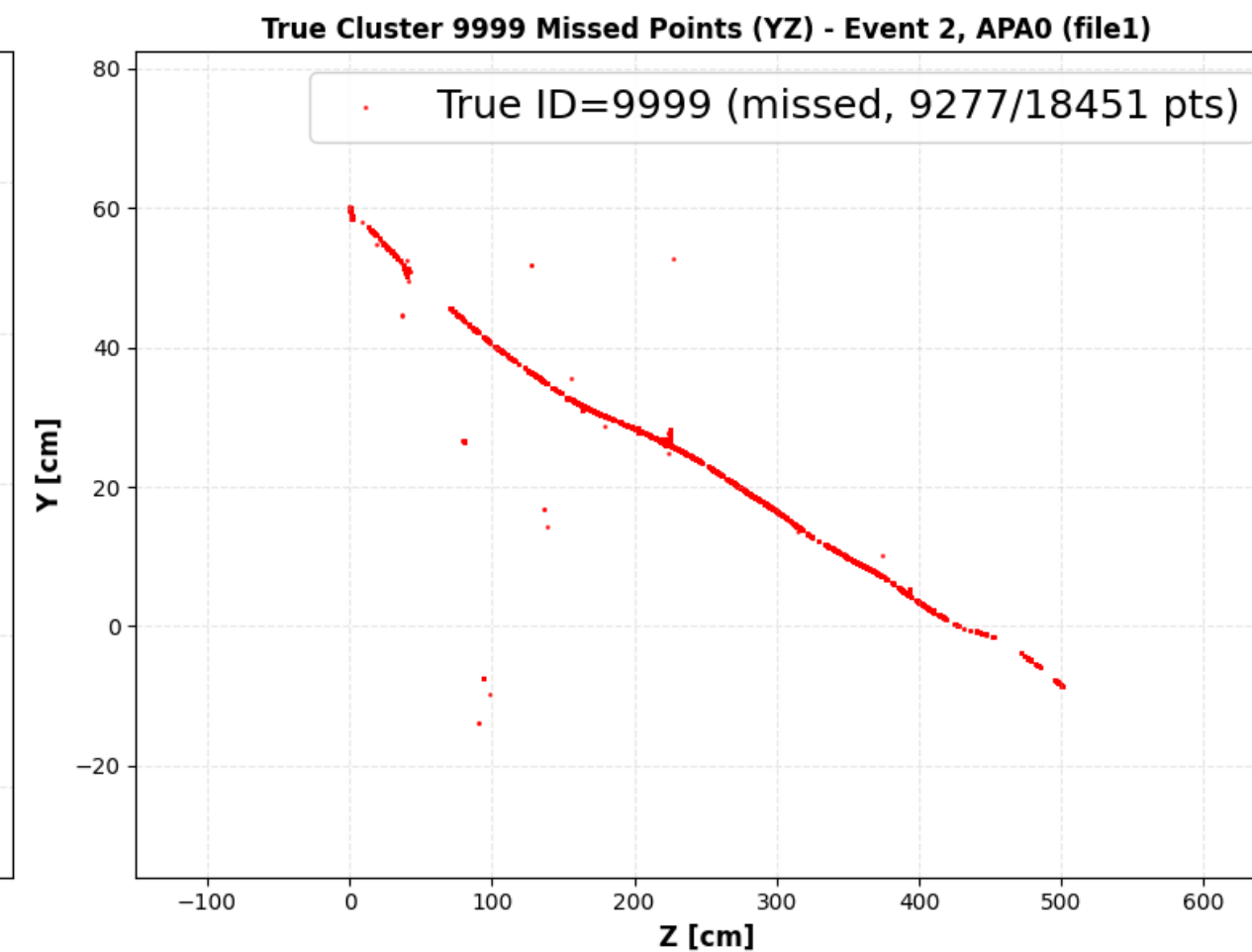
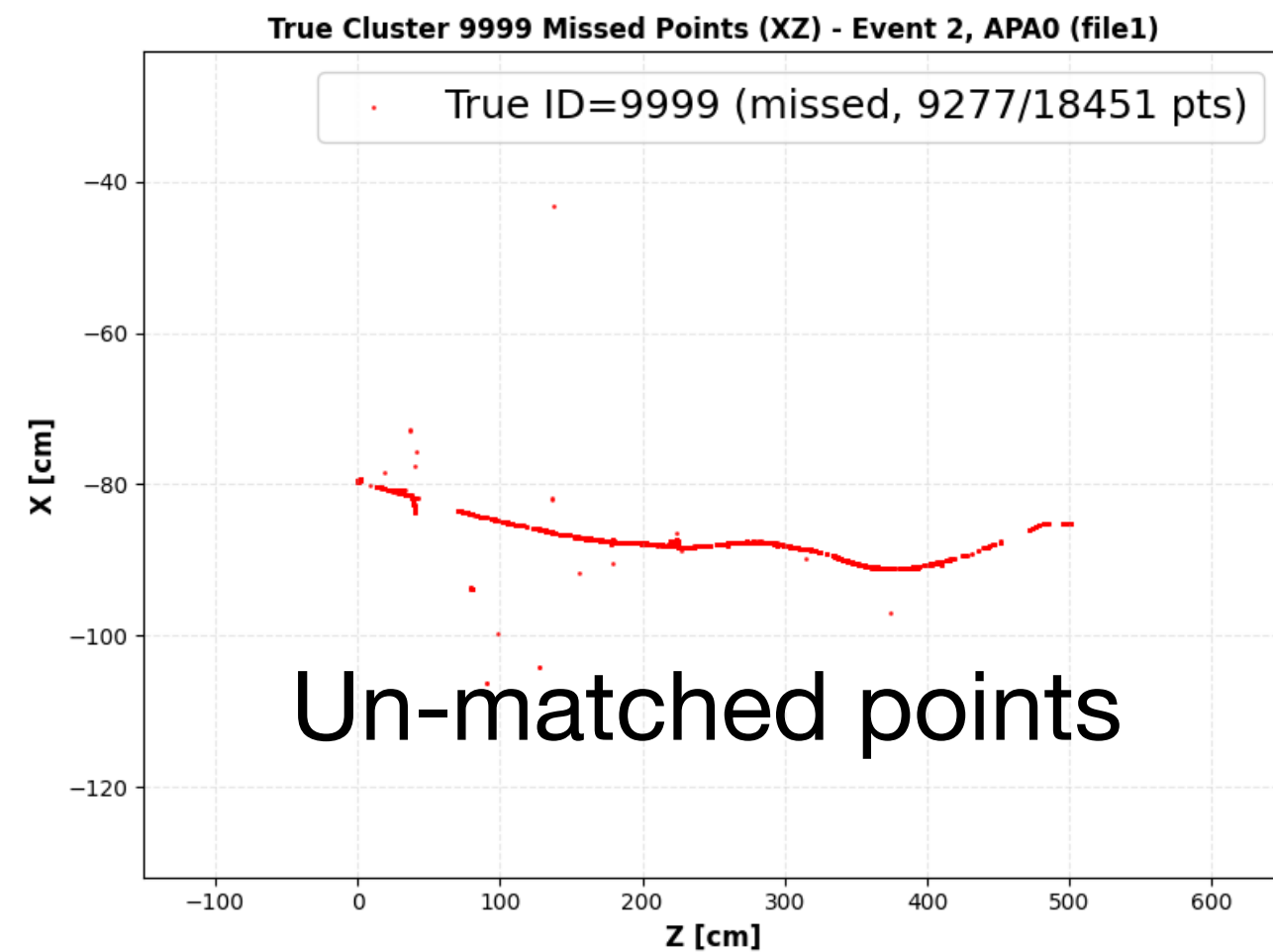
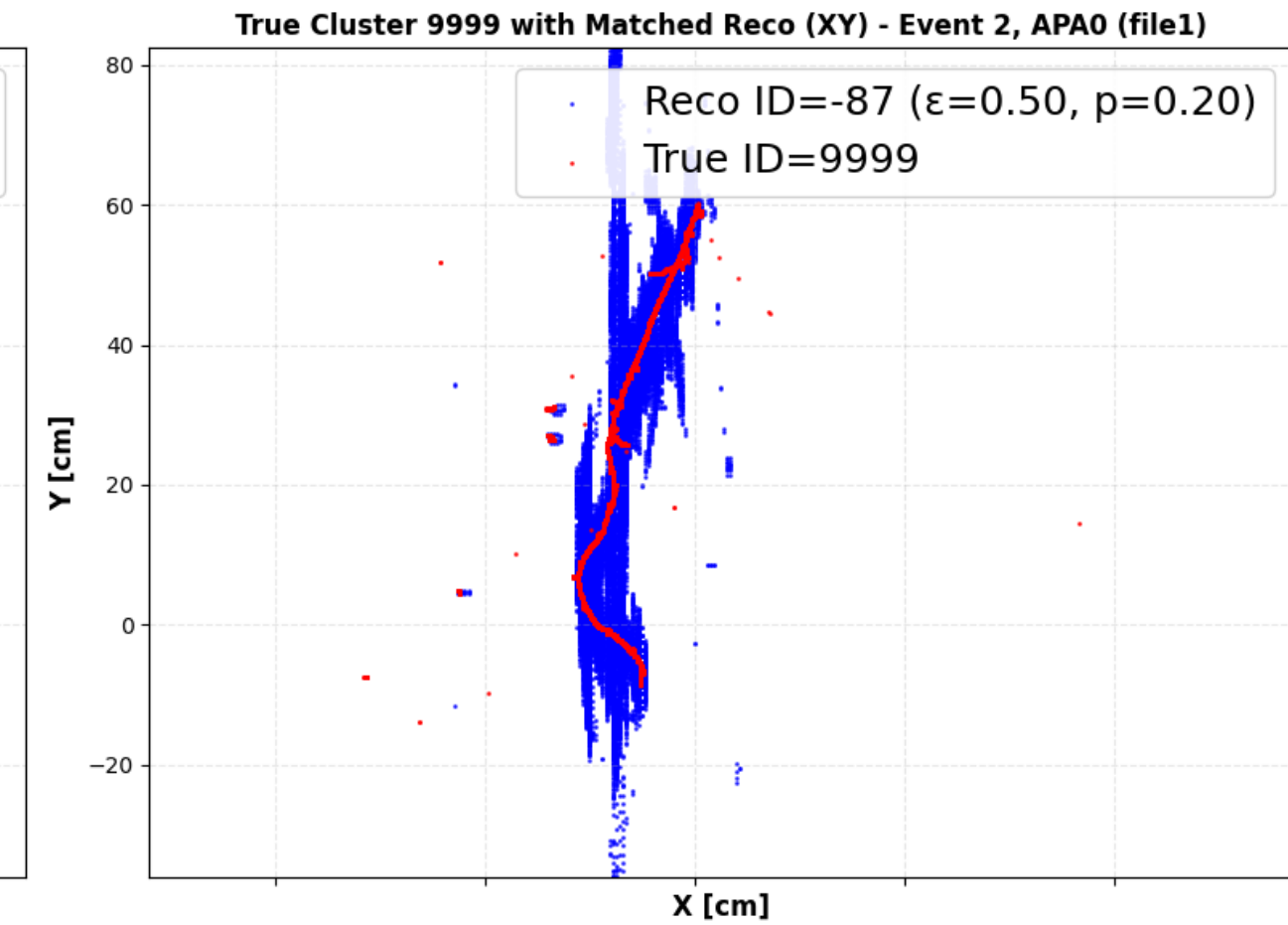
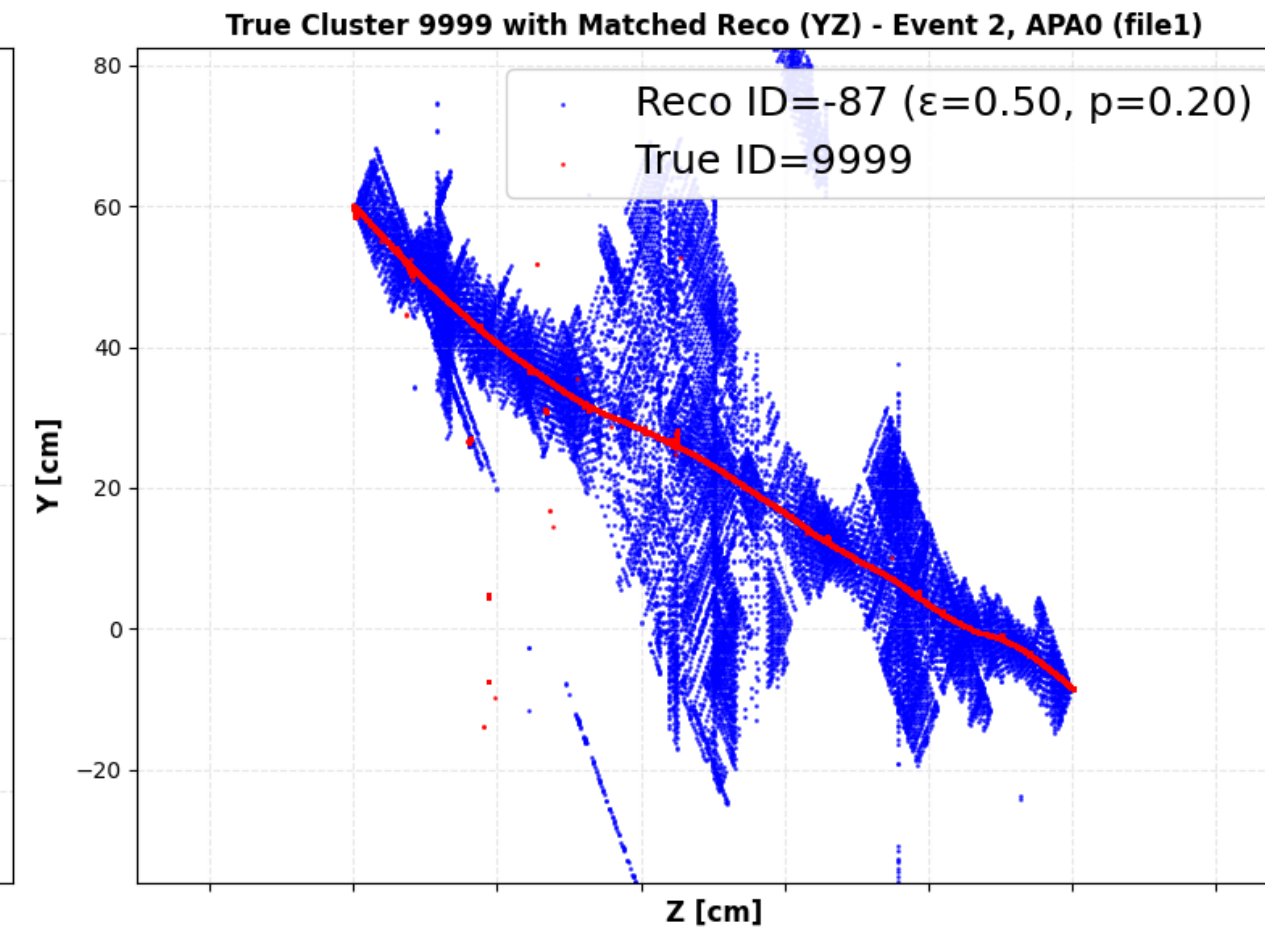
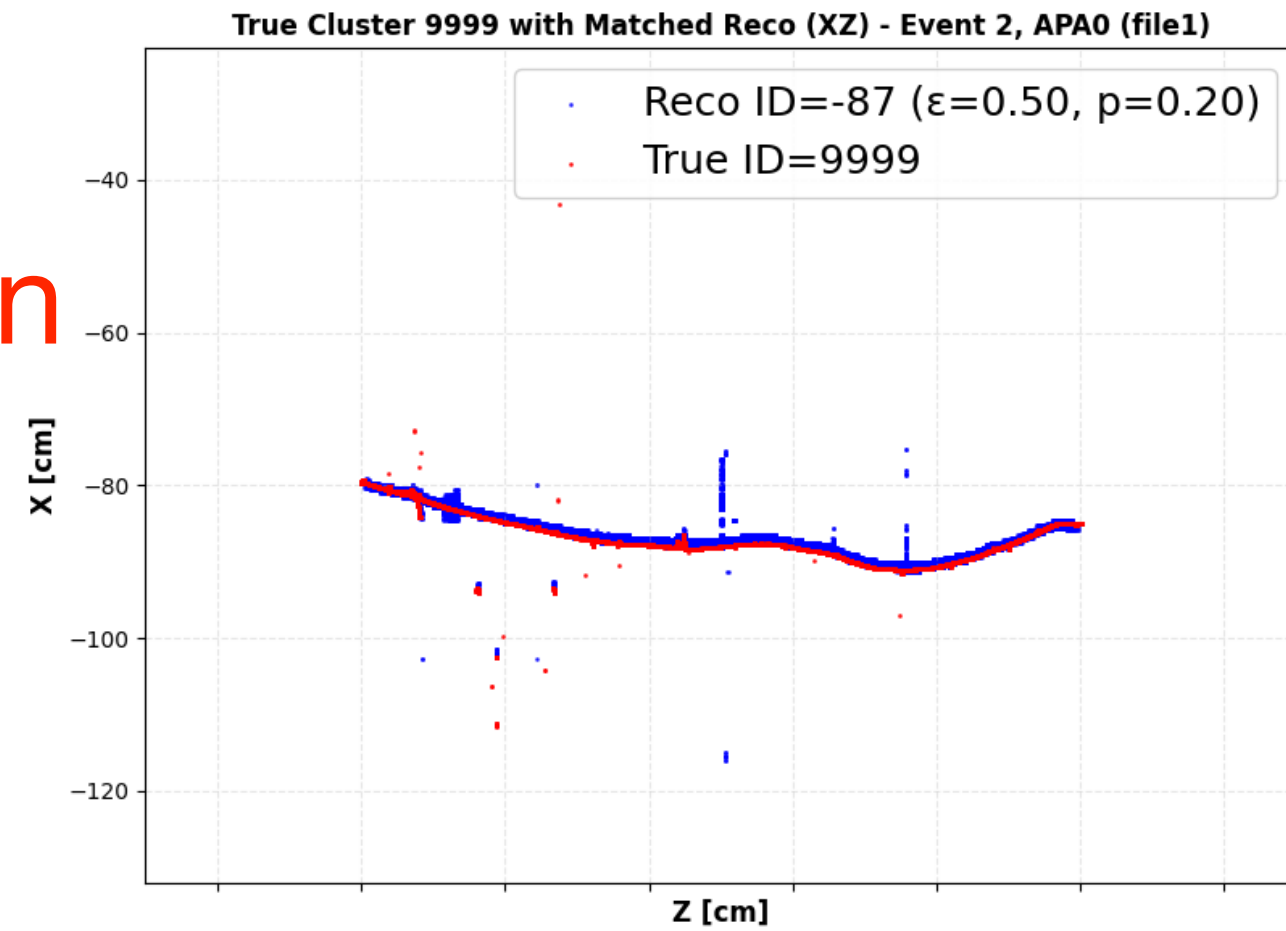
$\varepsilon = 50\%$

Reason for low efficiency: Space-charge effect

Some cases of low efficiency: Event 2

[Bee Link](#)

Neutrino
Interaction



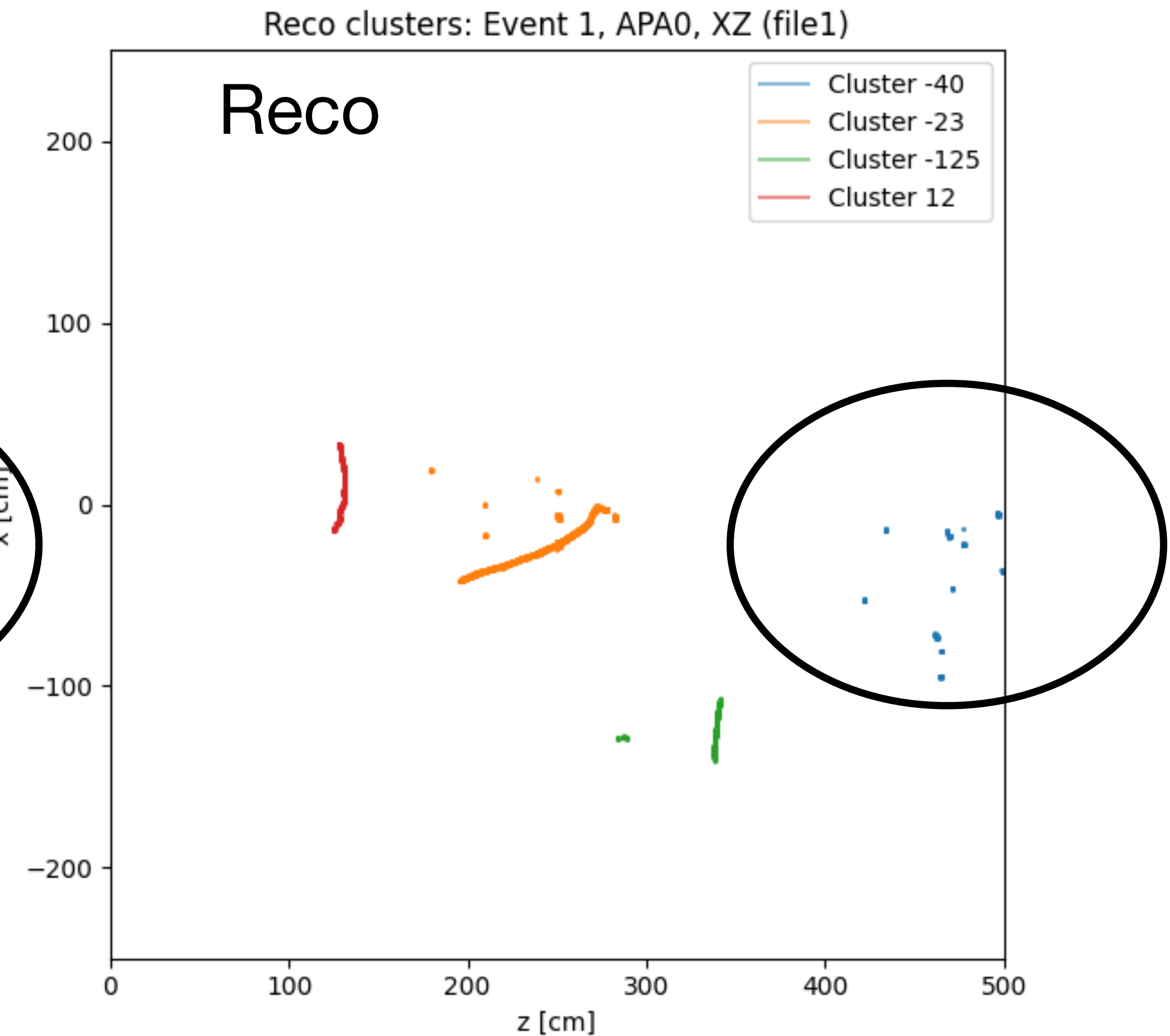
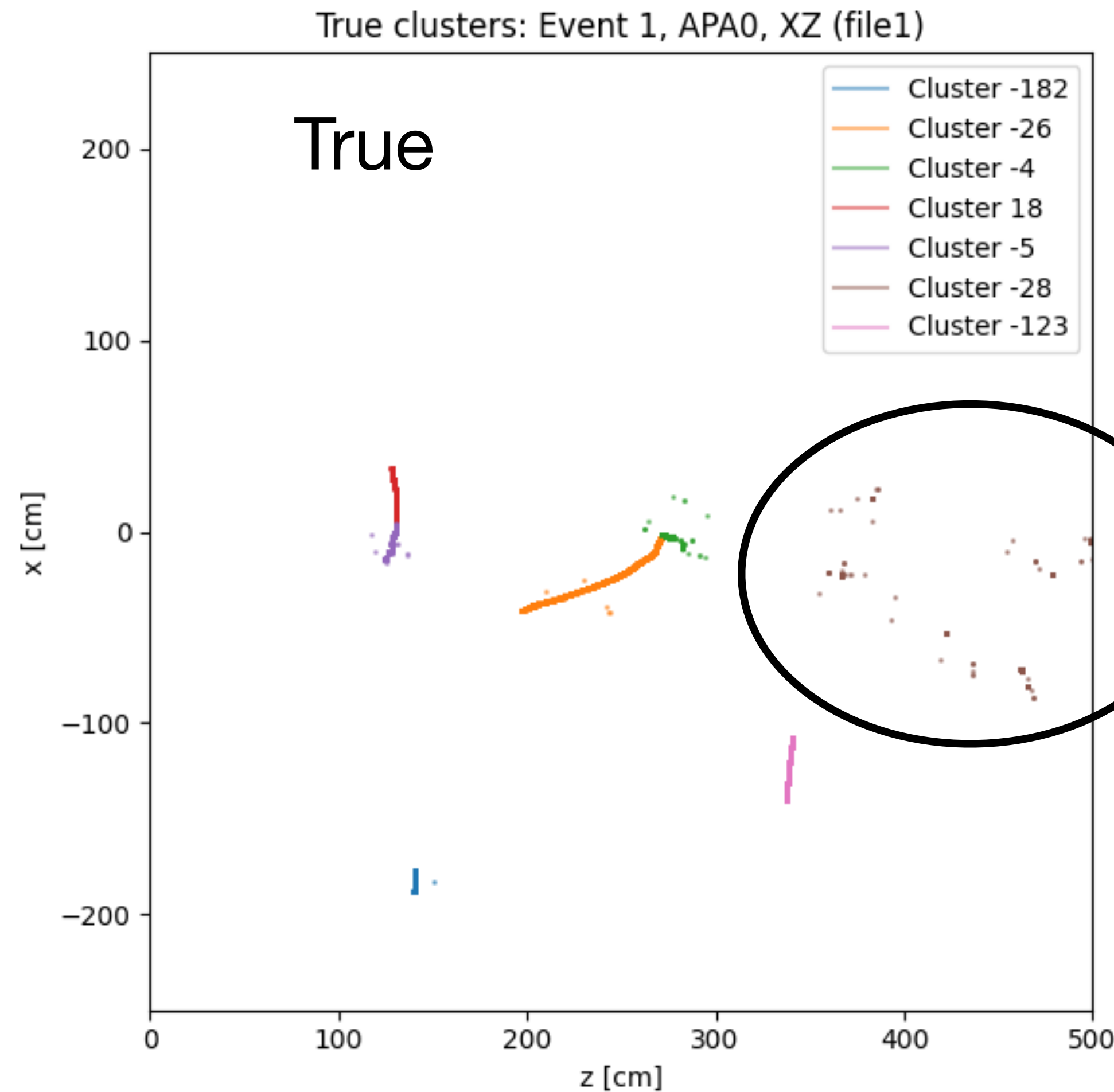
$\epsilon = 50\%$

Reason for low efficiency: Space-charge effect

Some cases of low efficiency: Event 1

[Bee Link](#)

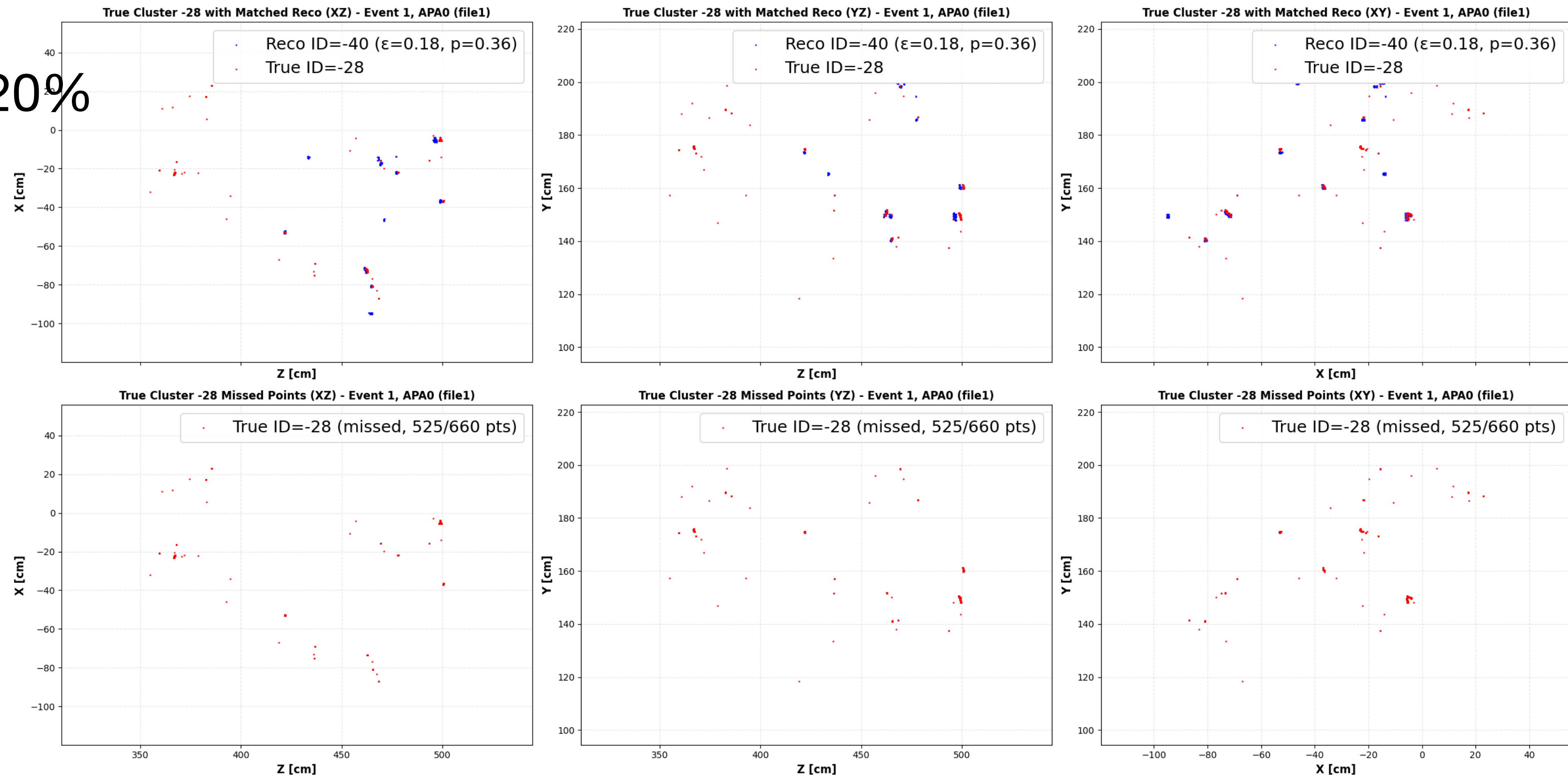
$\varepsilon = 20\%$



Reason for low efficiency: Very few and scattered true points

Some cases of low efficiency: 1

$\varepsilon = 20\%$



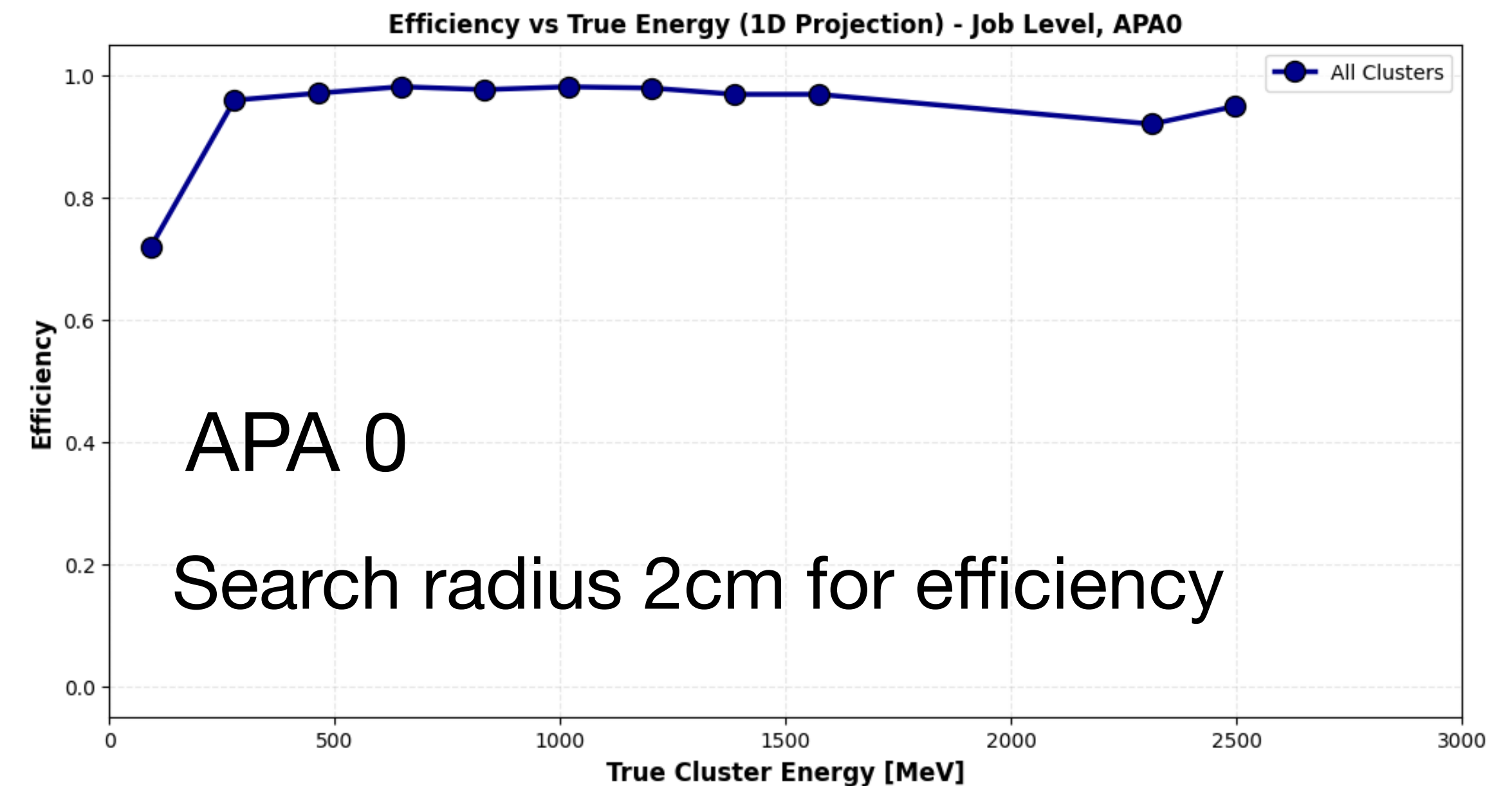
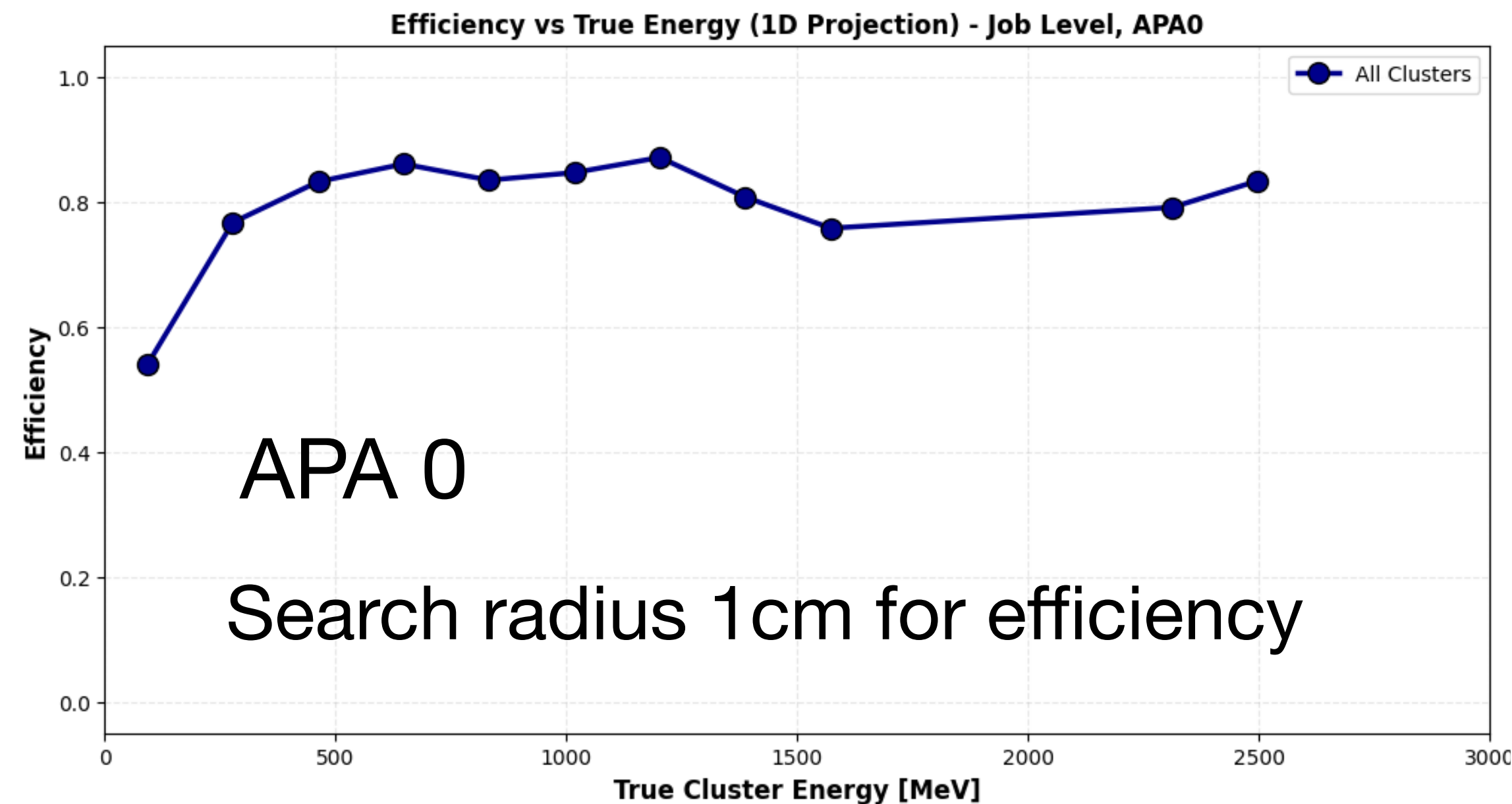
Reason for low efficiency: Very few and scattered true points

We need selections to identify and remove these kind of clusters

Space-Charge Effects

- I saw several examples of space-charge effects which cause drop in efficiency
- We know space charge effects are maximally within 1cm
- So, if we loosen our 1cm efficiency radius to 2cm then it would cover the space-charge effects which is a good test of our assumption that space-charge effects are causing a big drop in efficiency
- Once we apply space-charge corrections in wirecell reconstruction then we should revert back our efficiency-radius to 1cm

Efficiency as a function of True Cluster Energy



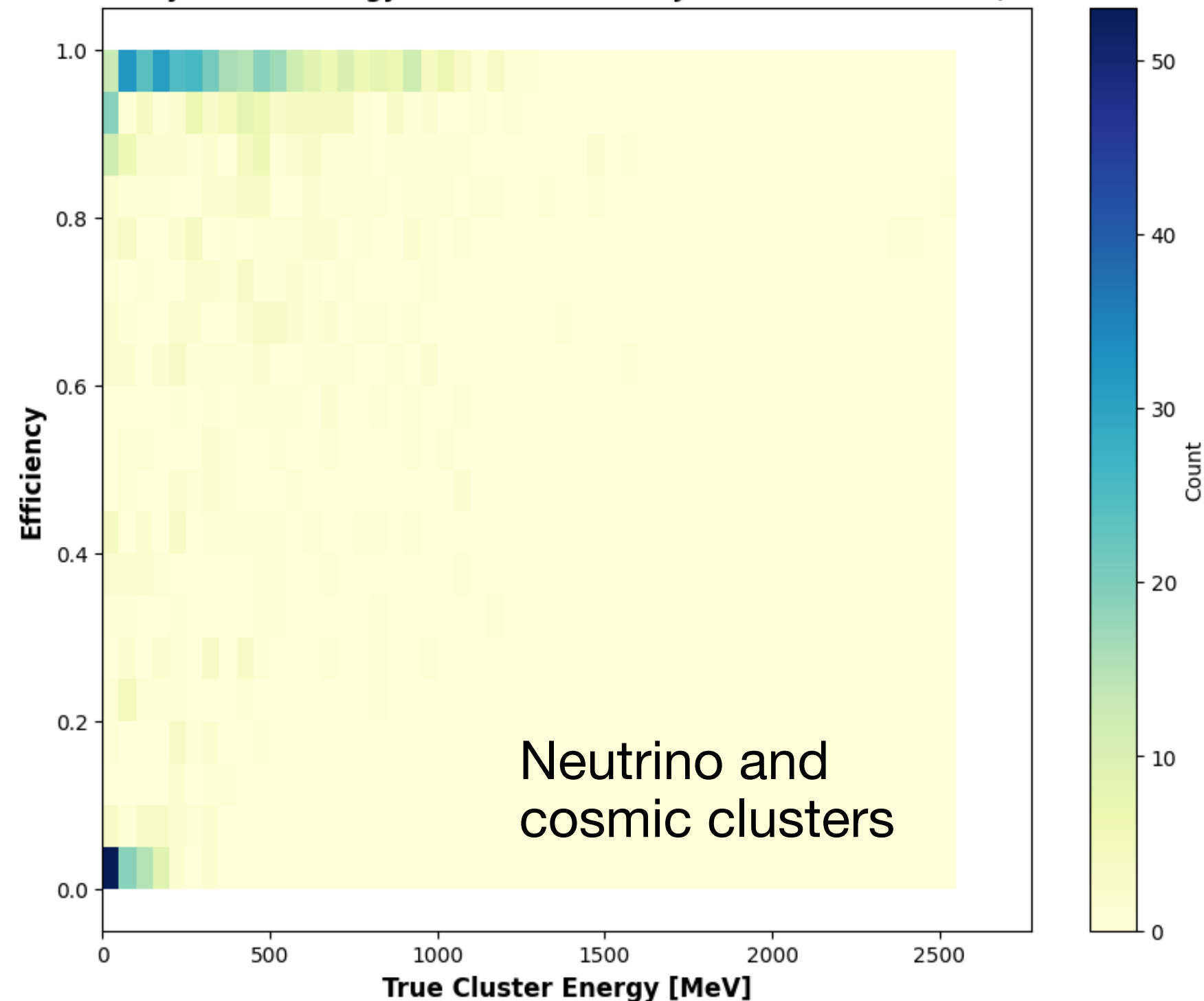
- As expected loosening efficiency-radius to 2cm from 1cm significantly improved efficiency
- This proves that the large drop in efficiency was due to space-charge effects

2D Efficiency as a function of True Cluster Energy

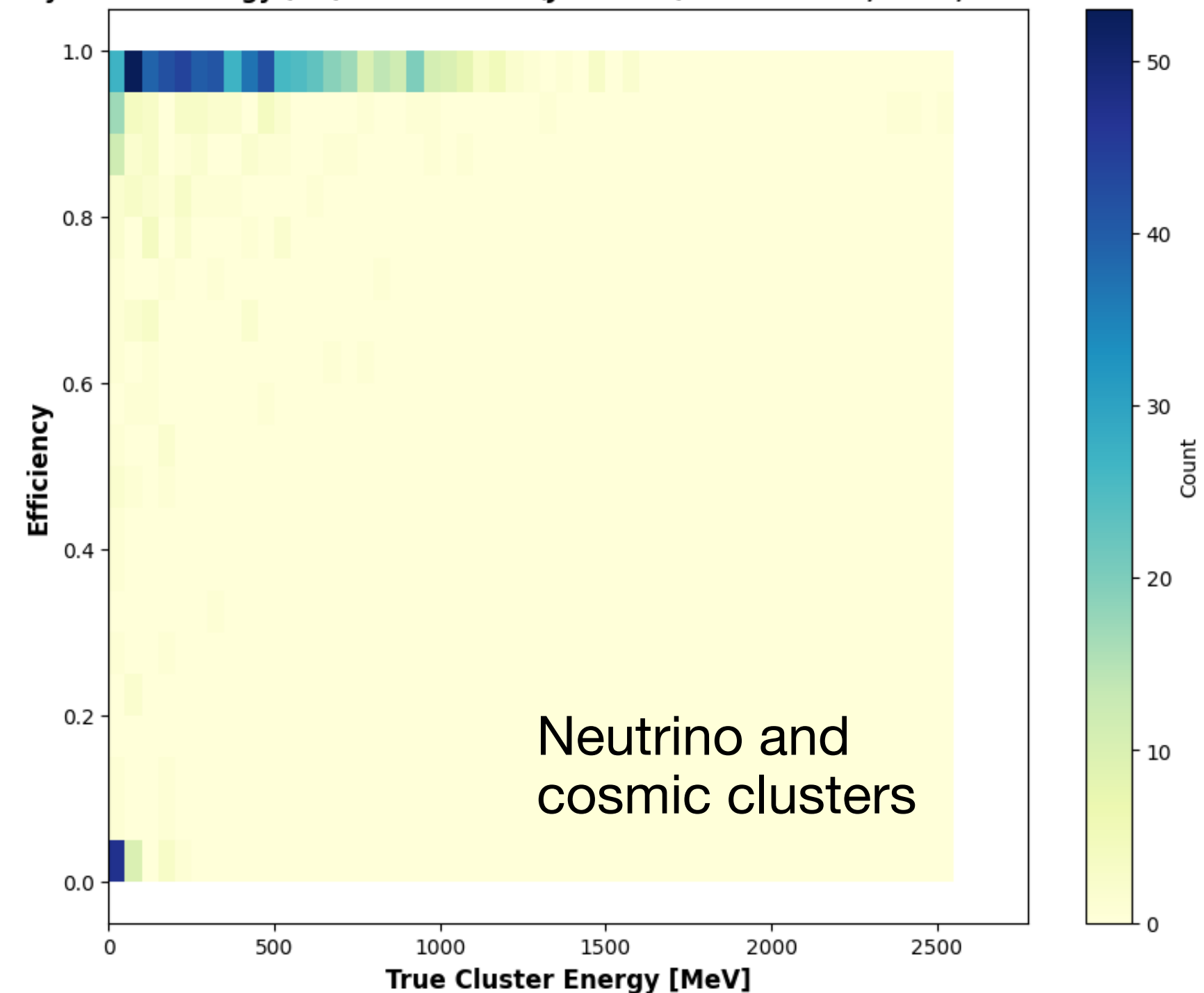
APA 0 Search radius
1cm for efficiency

APA 0 Search radius
1cm for efficiency

Efficiency vs True Energy (2D) - All Clusters (Job Level) - 118 events, APA0

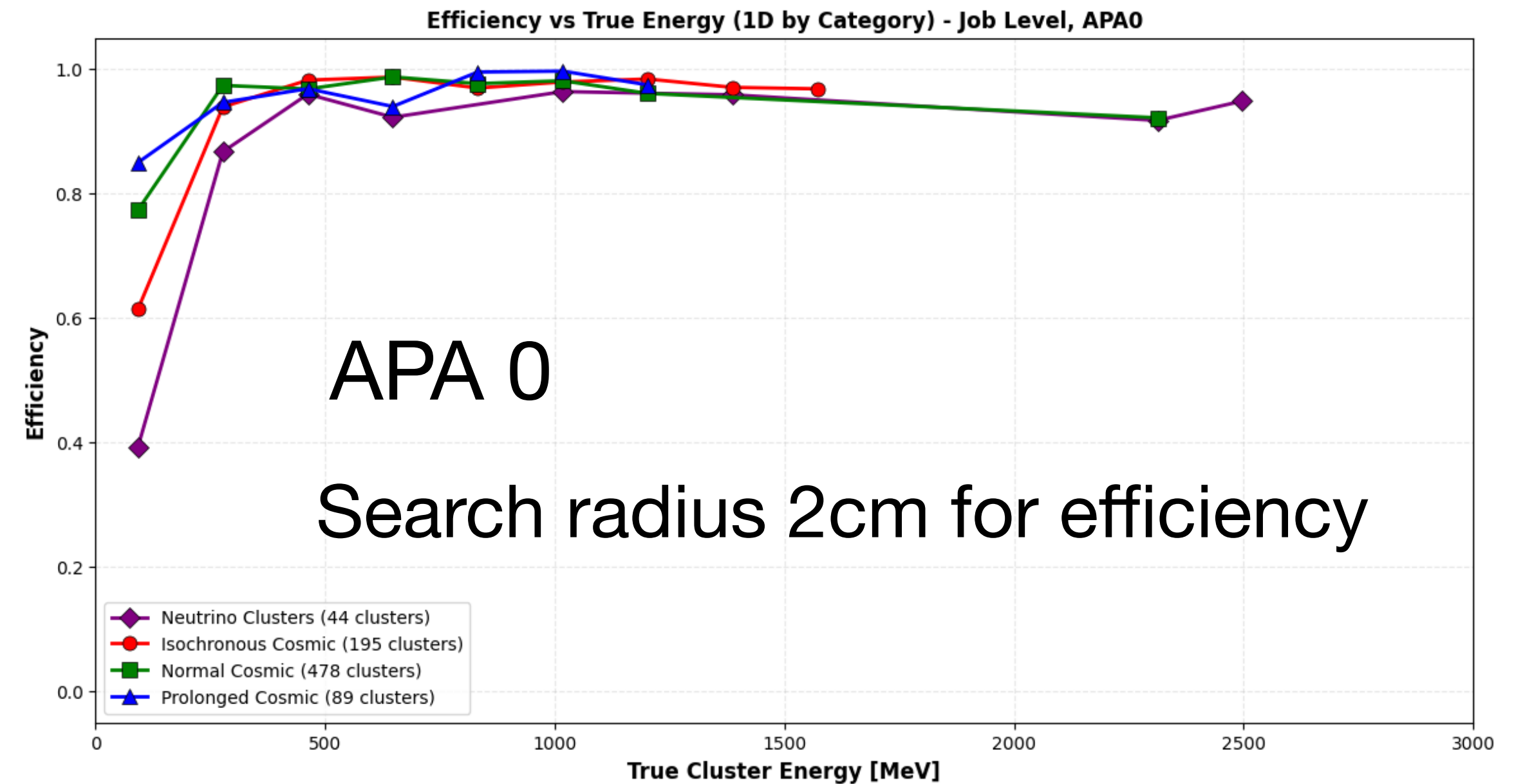
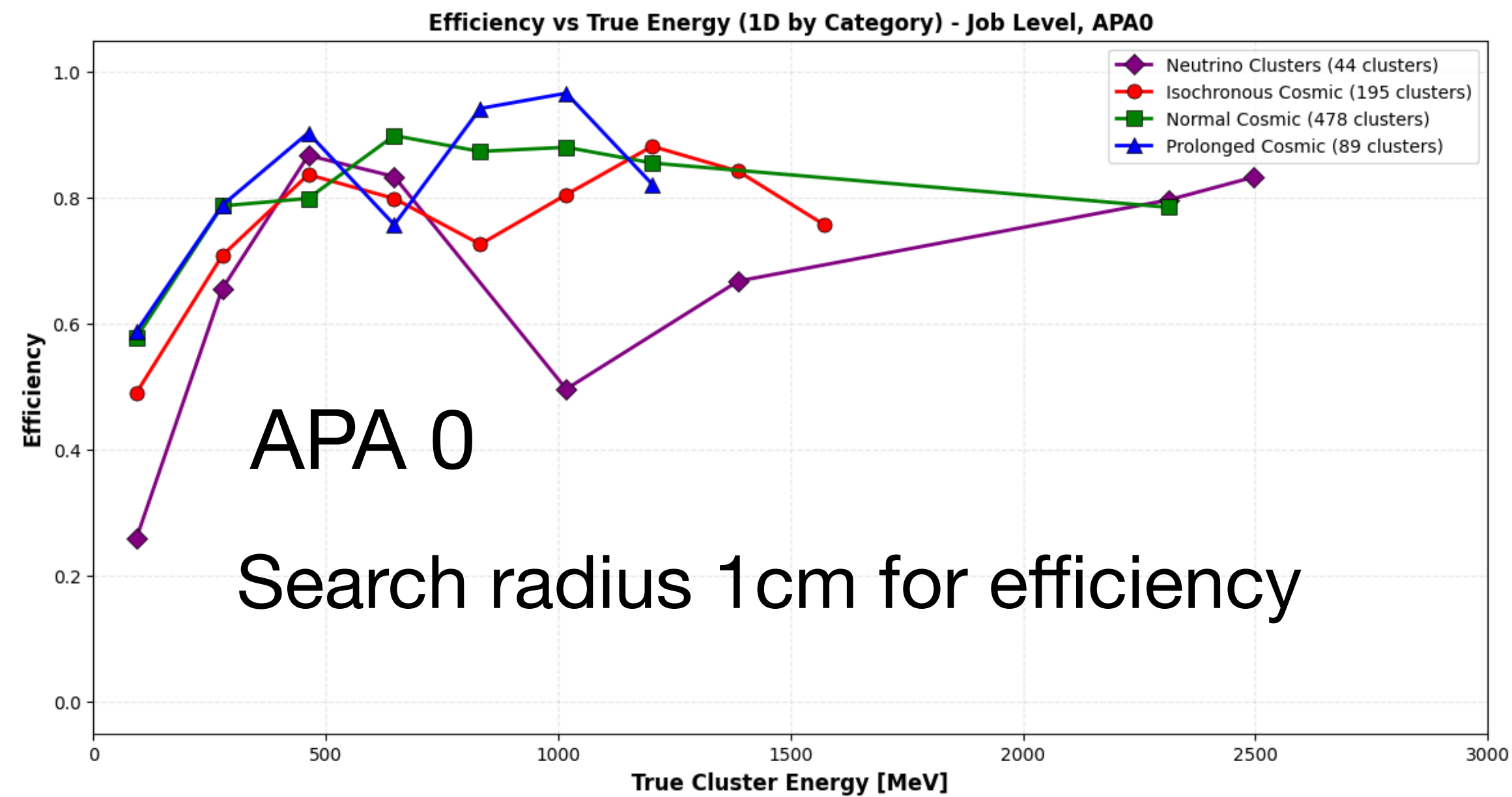


Efficiency vs True Energy (2D) - All Clusters (Job Level) - 118 events, APA0, 806 true clusters



- Significant improvement in efficiency
- More clusters closer to 100% efficiency which we would expect
- There are still some close to zero or very low efficiency

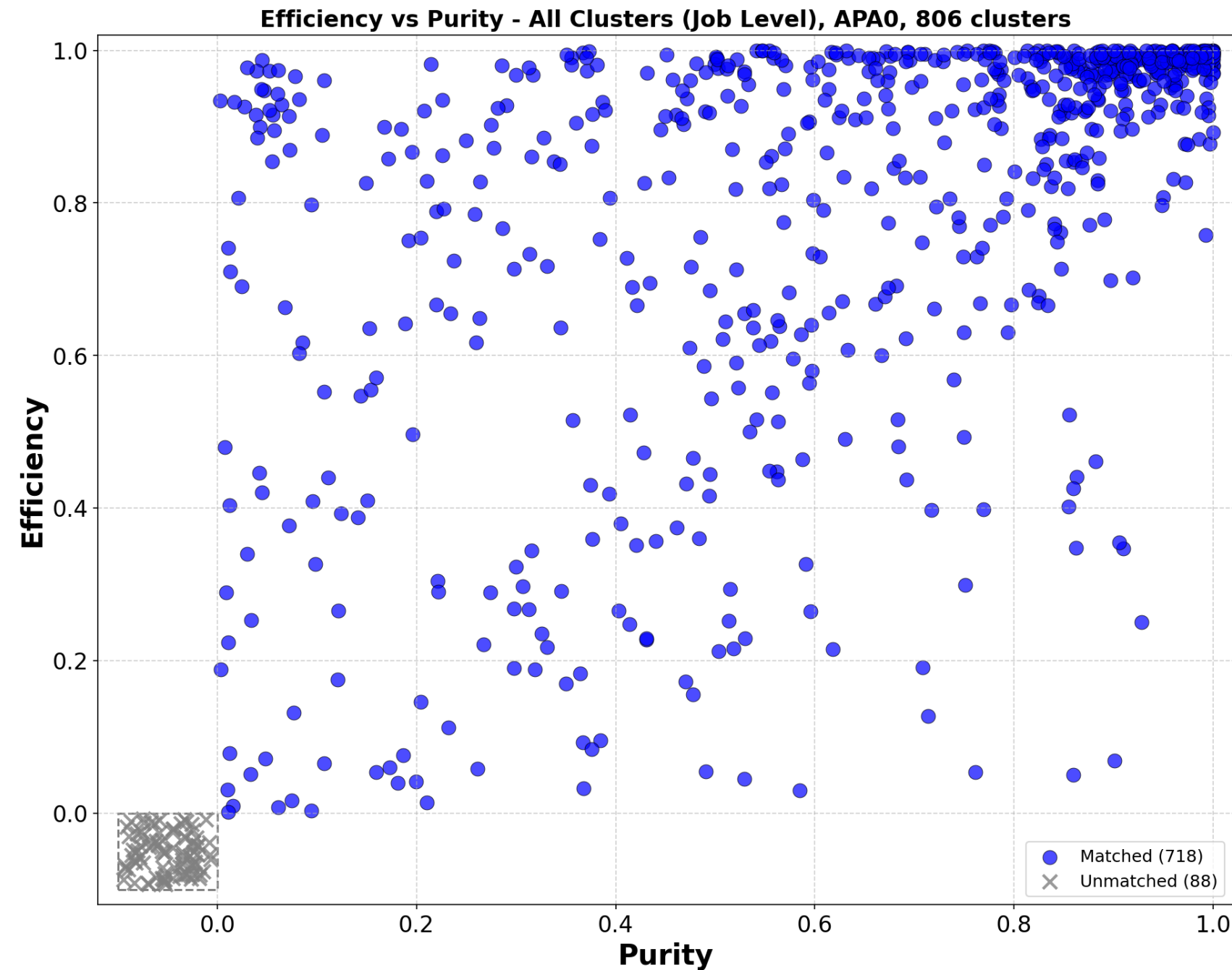
Efficiency as a function of True Cluster Energy



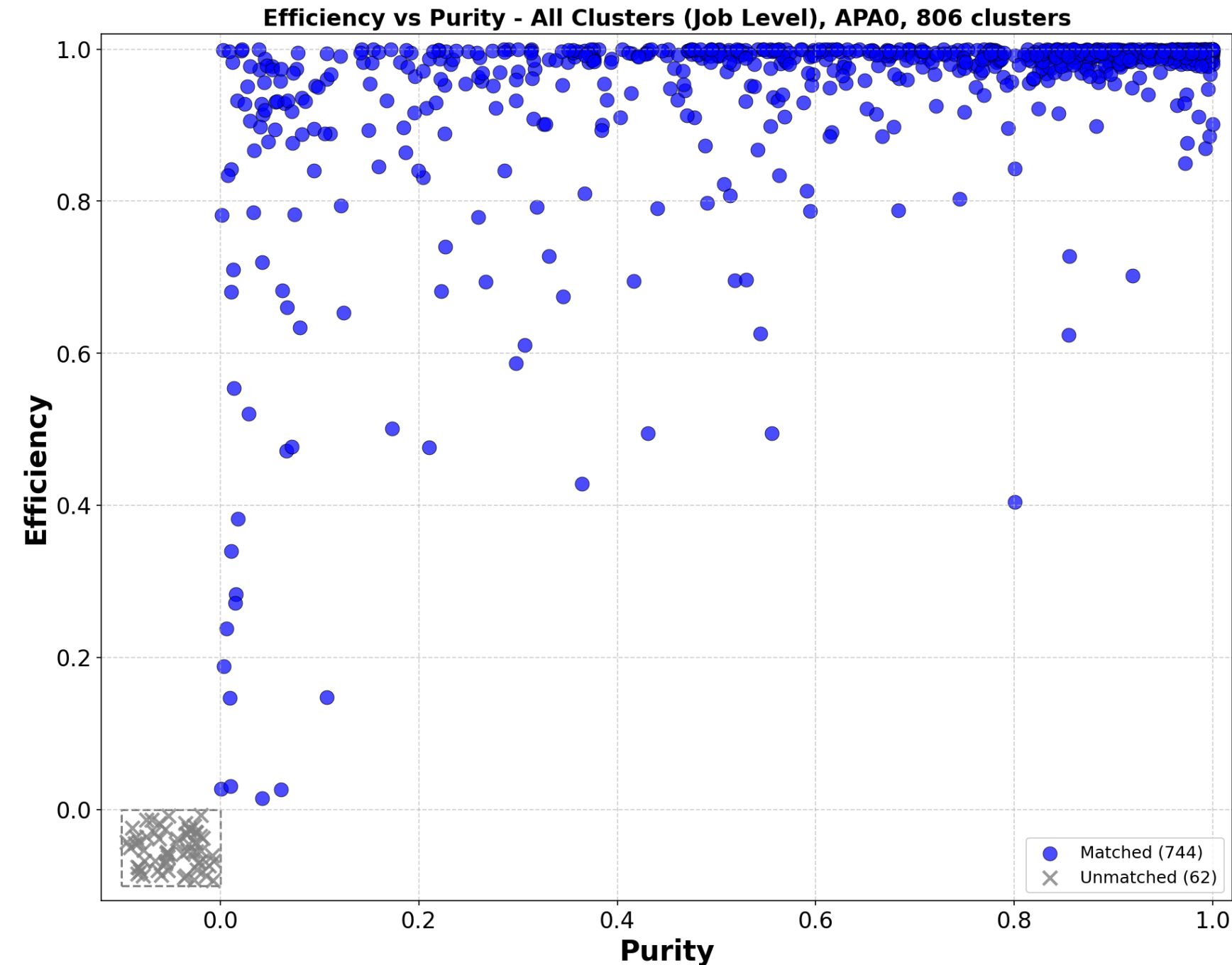
- Performance/efficiency of neutrinos, and all cosmic clusters also improve

Efficiency at Clustering

APA 0 1cm efficiency radius



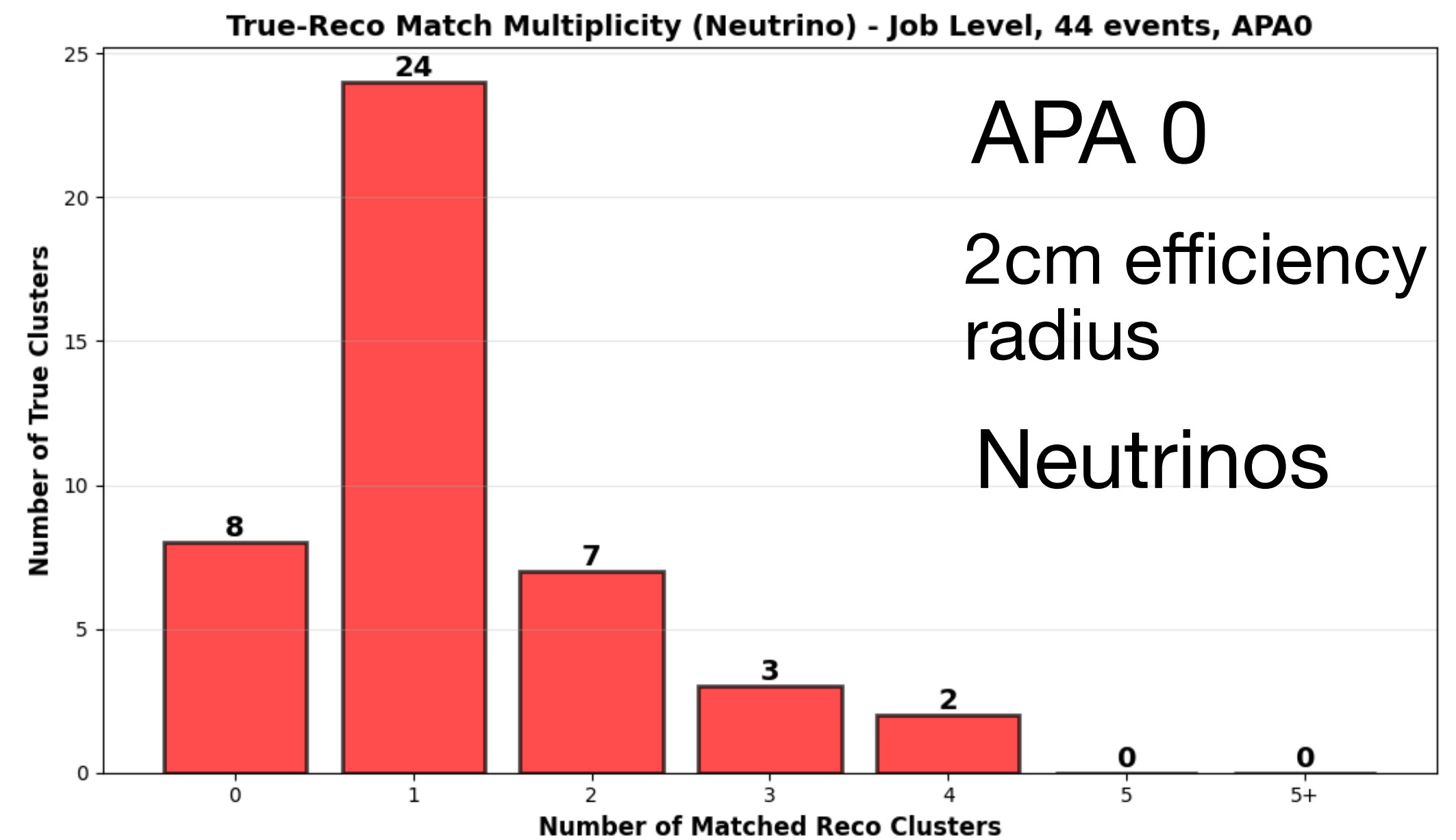
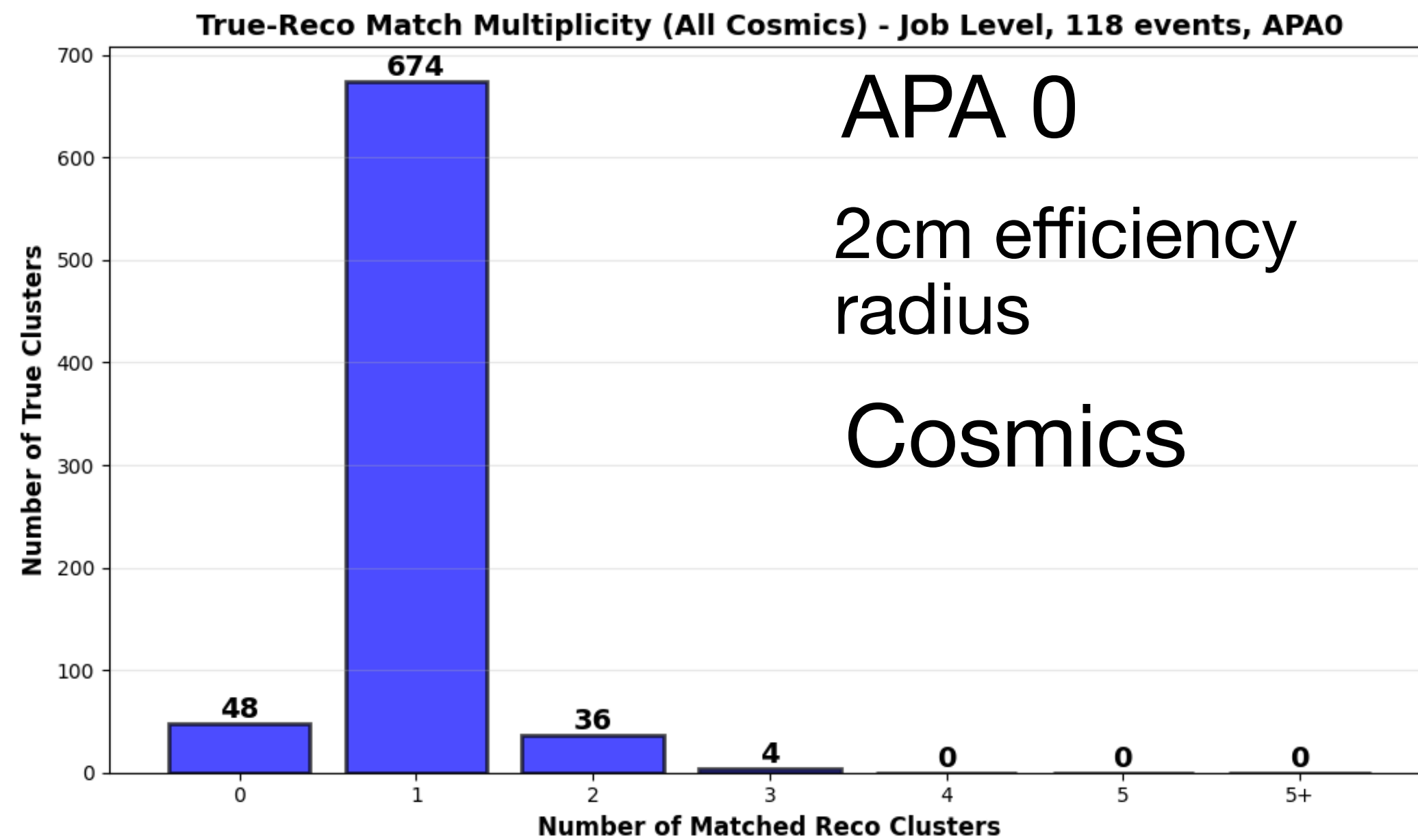
APA 0 2cm efficiency radius



- To know the efficiency performance at clustering level, we pair one true cluster to one reco cluster
- If one true cluster matches with one reco cluster then all good but there could be cases that one true cluster matches with more than one true clusters
- In that case, we make true-reco pair by selecting the highest efficiency

- Each point in this plot is one true-reco pair
- As expected, after loosing search-radius to 2cm, to cover SCE, most of the pairs are concentrated at high efficiencies
- There is a fraction of true clusters unmatched to any reco cluster shown in bottom-left box. This needs investigation
- There are also clusters with low purity. This needs investigation also needs further investigation though many of those also come from isochronous clusters

True-Reco Matching



- These plots show how many true clusters did not find any or more than one reco clusters
- One-to-one match from true to reco is the best case scenario but we need to understand why some true clusters did not find any reco clusters
- Next I will show some examples, for neutrino interactions

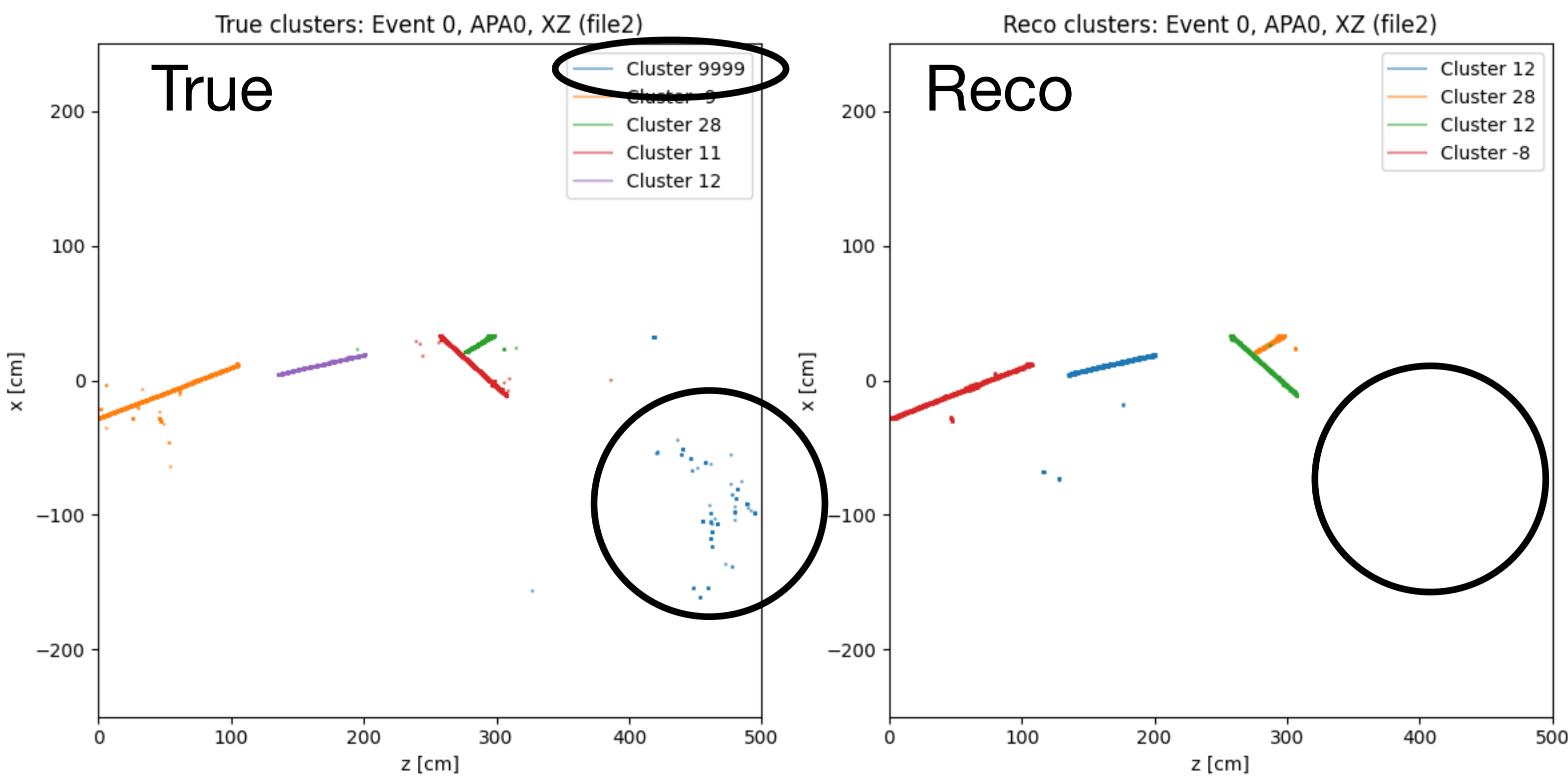
Examples of True Neutrinos not finding any reco clusters

8 examples

Example of True Neutrinos not finding any reco clusters

File 2: Event 0

2cm efficiency radius
APA 0

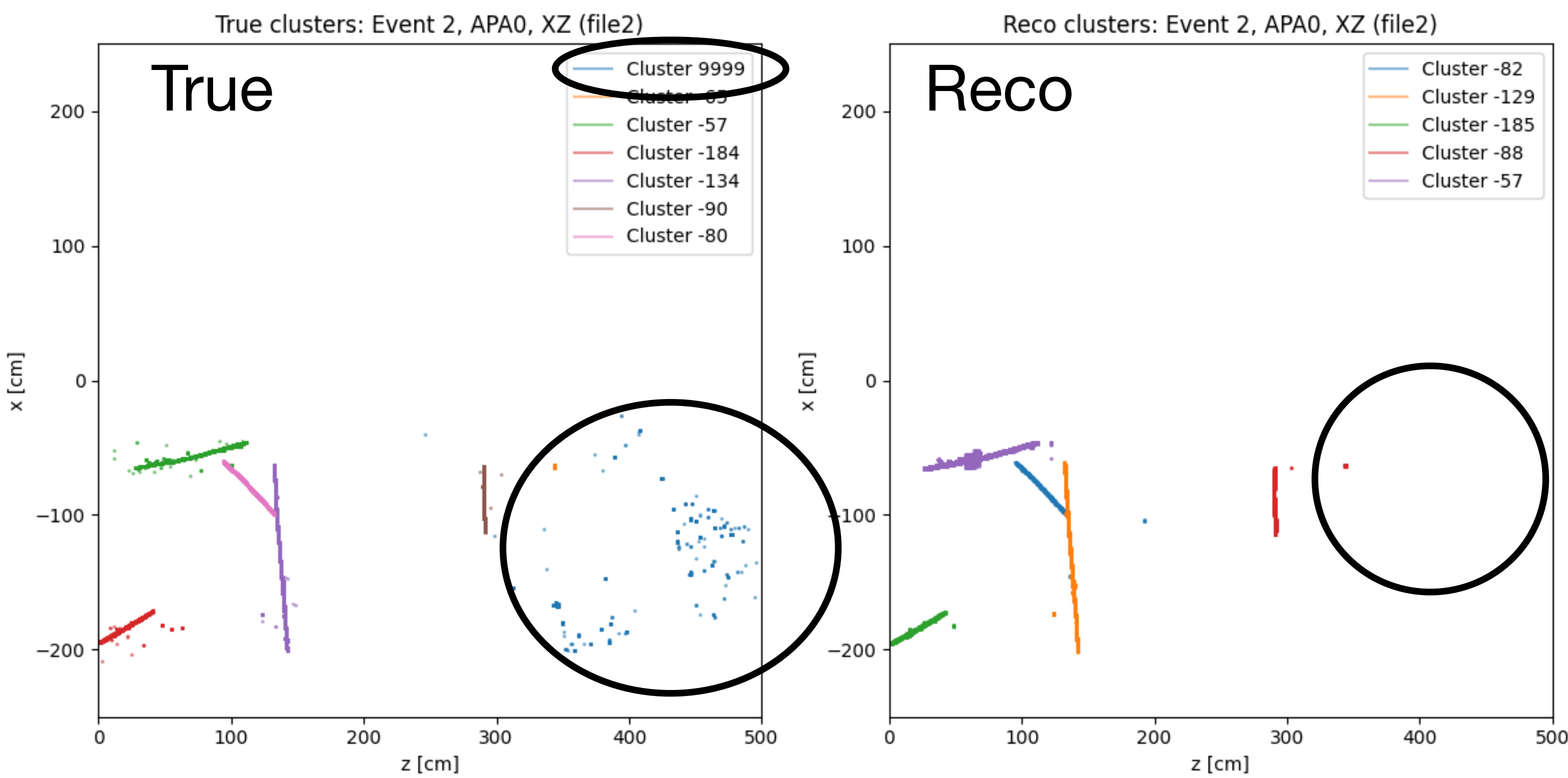


Bee
Link

Example of True Neutrinos not finding any reco clusters

File 2: Event 2

2cm efficiency radius
APA 0

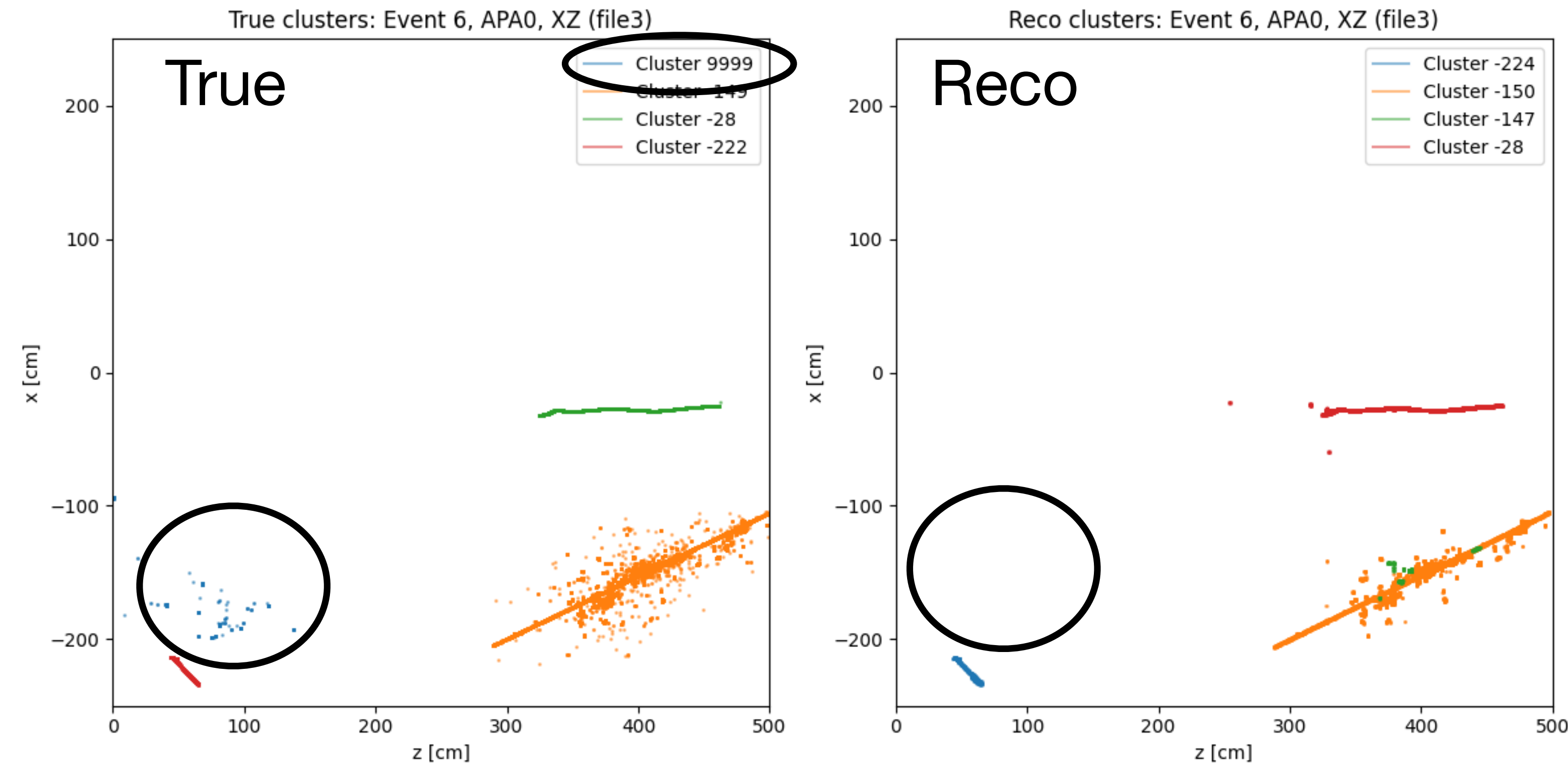


[Bee Link](#)

Example of True Neutrinos not finding any reco clusters

File 3: Event 6

2cm efficiency radius
APA 0



Bee
Link

Other neutrino cases are also similar ones. I have them in backup slides

We need selections to identify and remove these kind of clusters

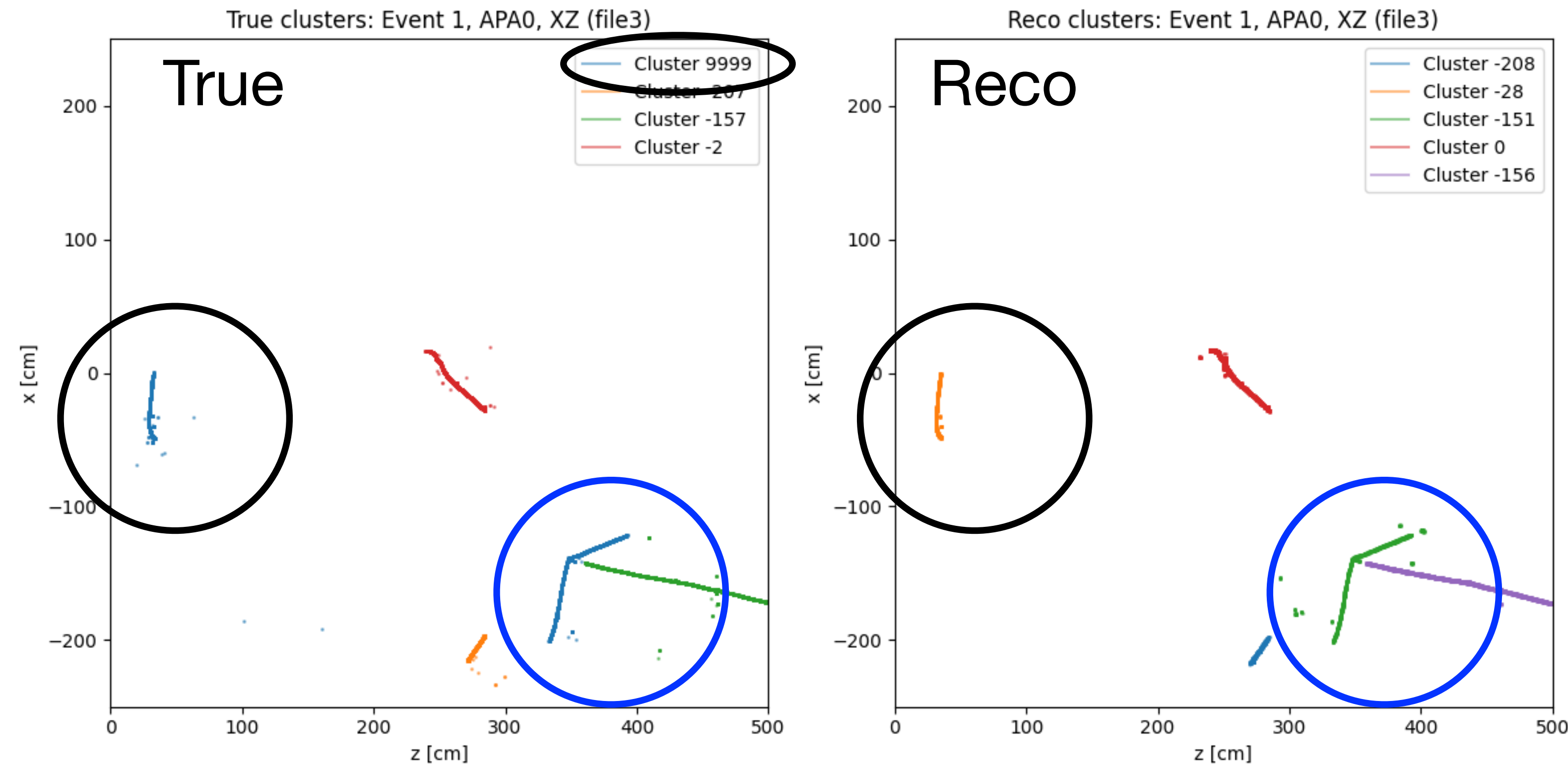
Examples of True Neutrinos finding 2 reco clusters

7 examples

Examples of True Neutrinos finding 2 reco clusters

File 3: Event 1

2cm efficiency radius
APA 0



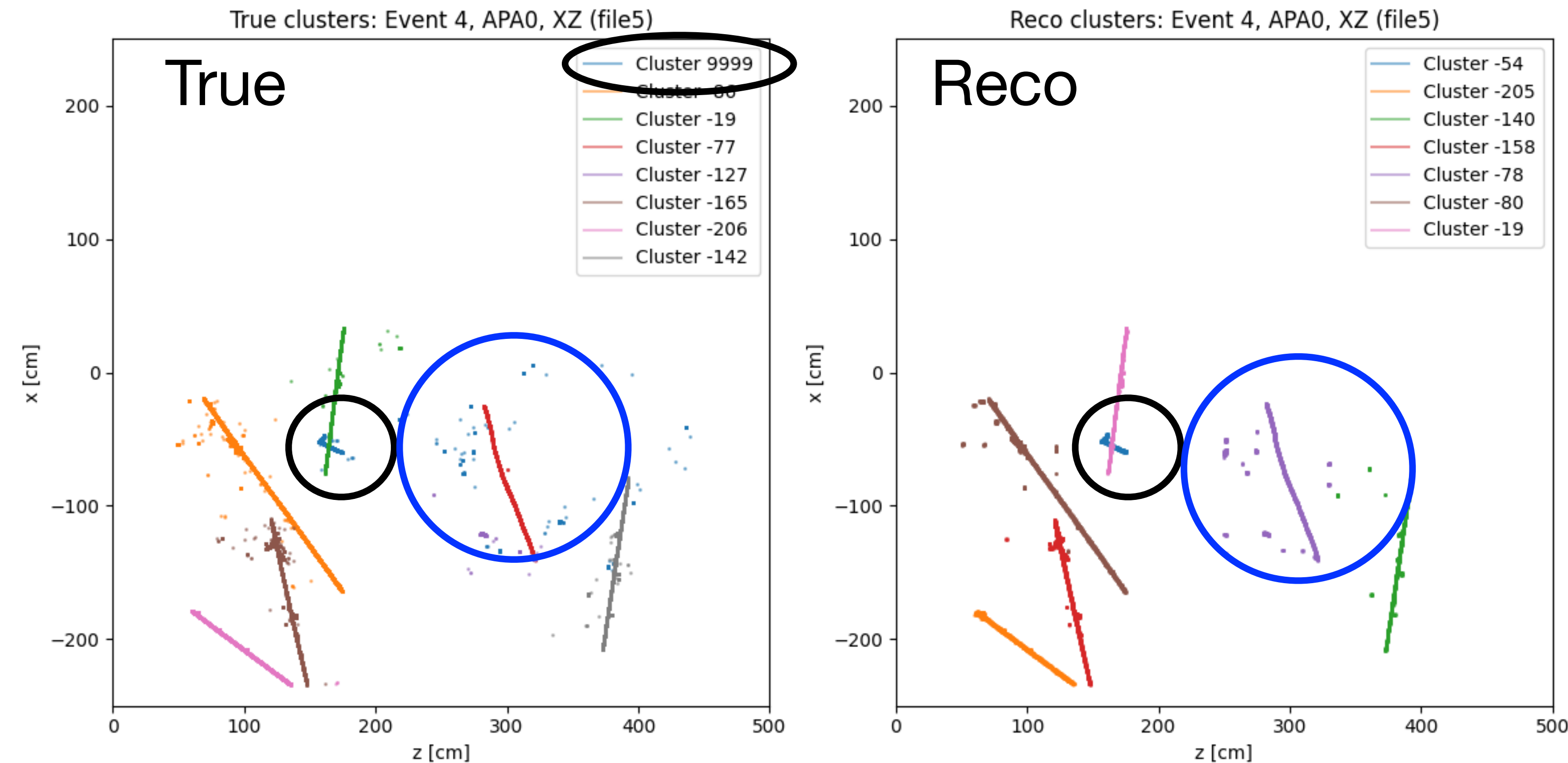
Bee
Link

- Are there two neutrinos?
- Or is it one neutrino but separated by a distance?

Examples of True Neutrinos finding 2 reco clusters

File 5: Event 4

2cm efficiency radius
APA 0



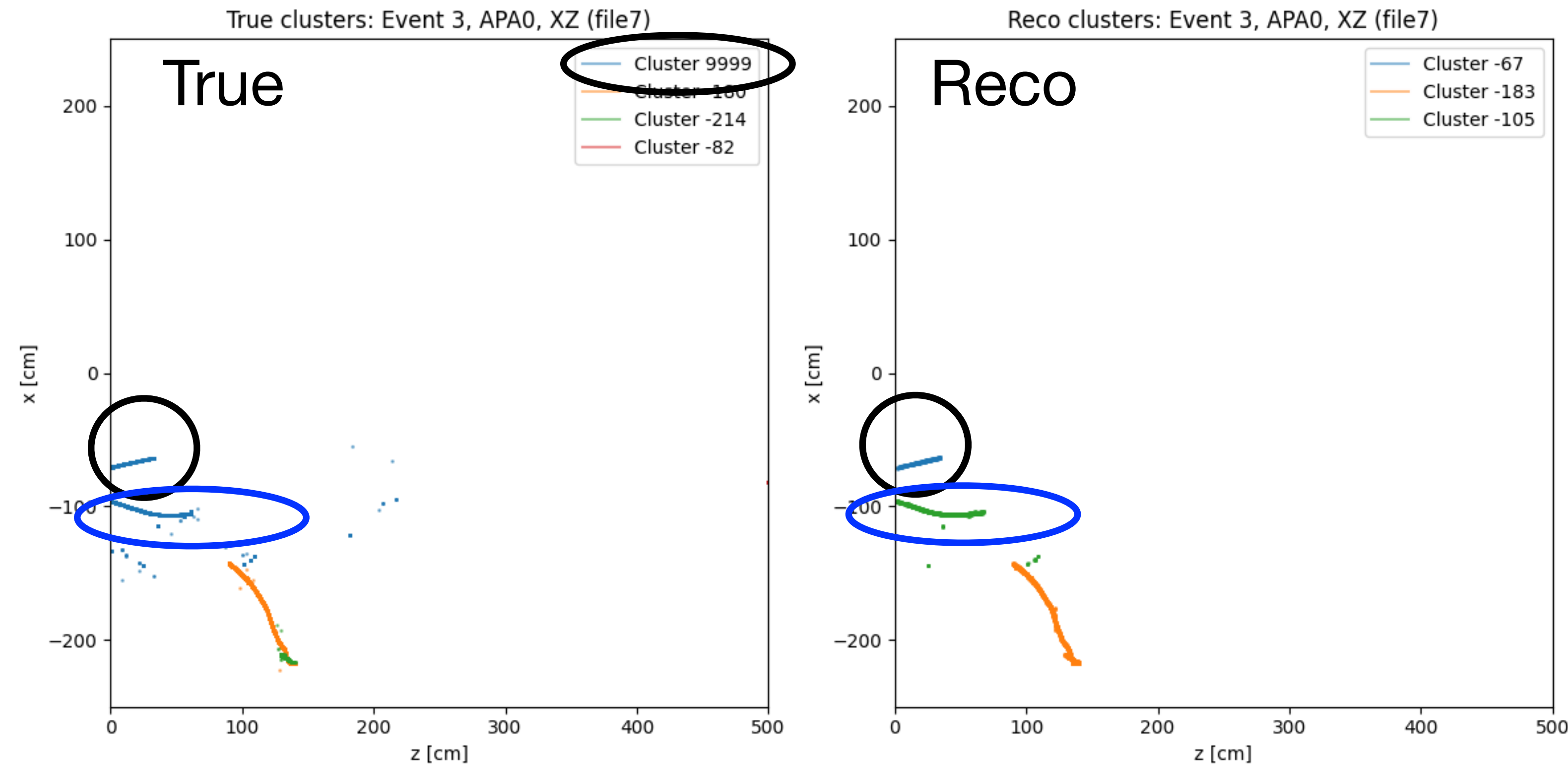
Bee
Link

- Are there two neutrinos?
- Or is it one neutrino but separated by a distance?
- If two neutrinos, one is scattered

Examples of True Neutrinos finding 2 reco clusters

File 7: Event 3

2cm efficiency radius
APA 0



Bee
Link

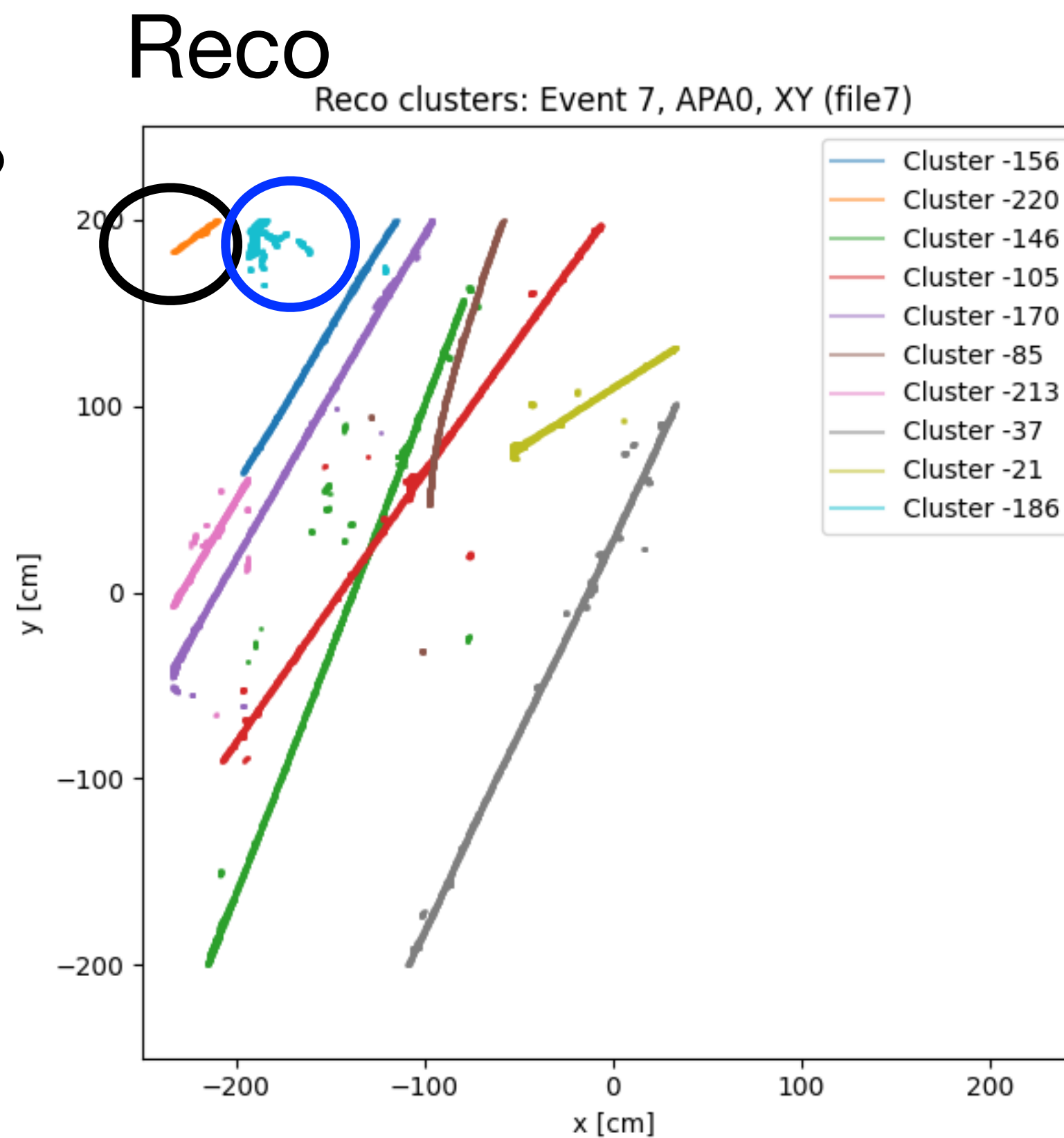
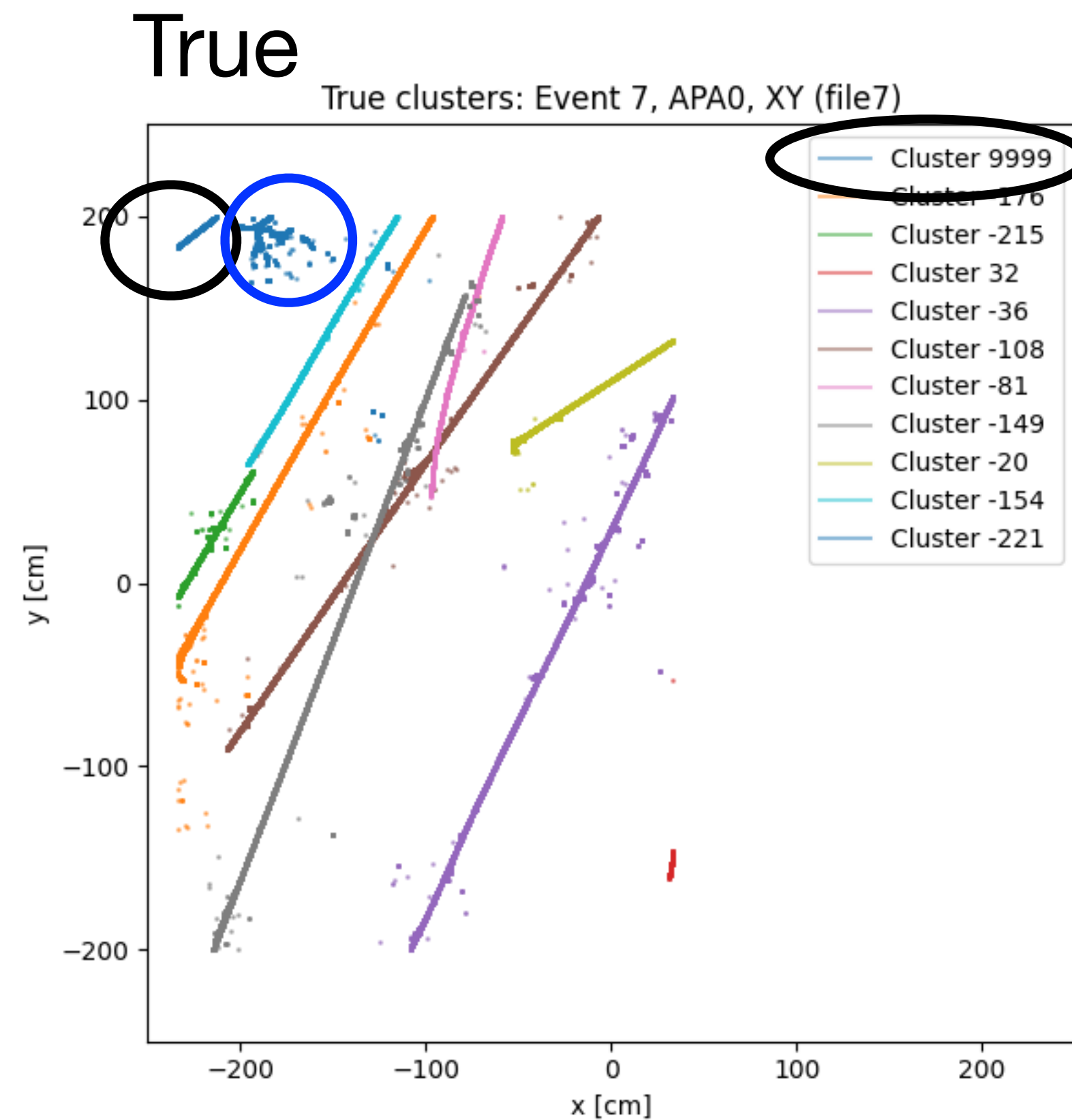
- Same: Are there two neutrinos?
- Or is it one neutrino but separated by a distance?

Examples of True Neutrinos finding 2 reco clusters

File 7: Event 7

2cm efficiency radius
APA 0

Bee
Link



- Same: Are there two neutrinos?
- Or is it one neutrino but separated by a distance?

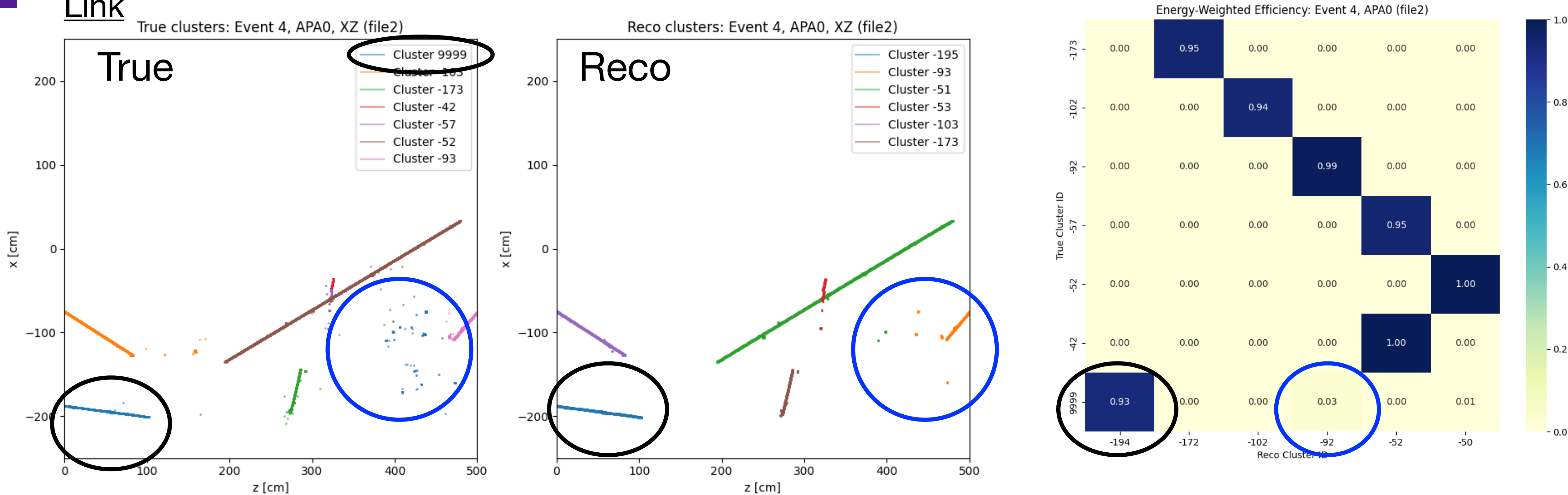
Examples of True Neutrinos finding 3 reco clusters

3 examples

Examples of True Neutrinos finding 3 reco clusters

File 2: Event 4

Bee
Link



2 neutrinos and one of them overlapped
tiny bit with another reco clusters

Conclusions

- Overall seems we are in a very good state
- There are some corner cases that need attention
- We are planning to present an update in the Simulation/Reconstruction meeting soon to follow up our reconstruction work after the collaboration meeting

