Low-Energy Charge Light Matching in ProtoDUNE-HD

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DRA PDS Meeting
November 11th, 2024

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Overview

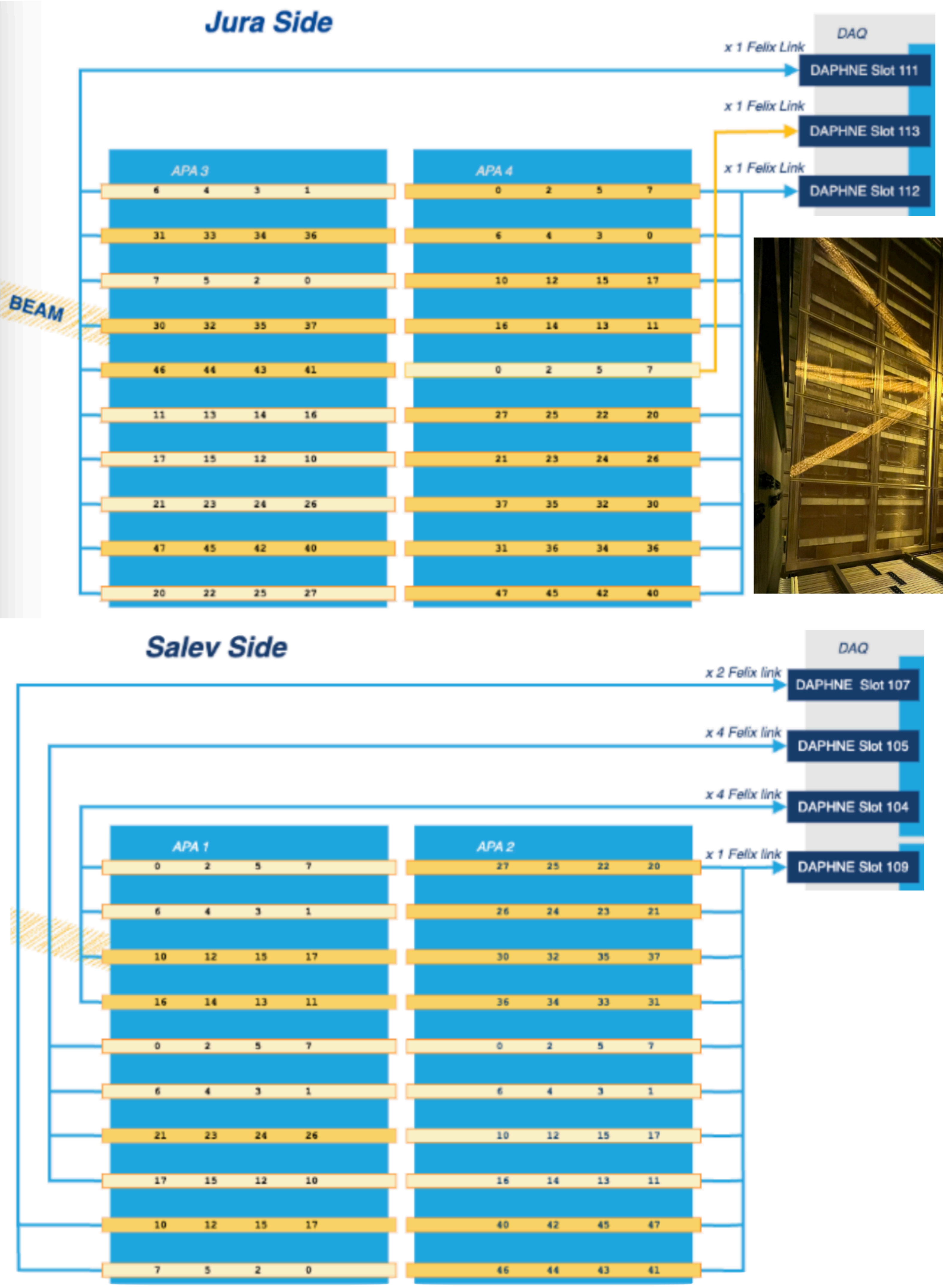
- Goal: Investigate charge-light matching for ambient radiological activity in PDHD
- Followup to a study I have done in the ND-LAr prototypes, which showed promising results
  - A study in PDHD/PDVD will be very different, but worth pursuing
- The idea is to use ambient radiological activity for detector calibrations.
  - Using light information may open up more opportunities for calibration than with charge alone
  - Relevant for understanding to what extent we can tag low energy activity of various kinds

Summary

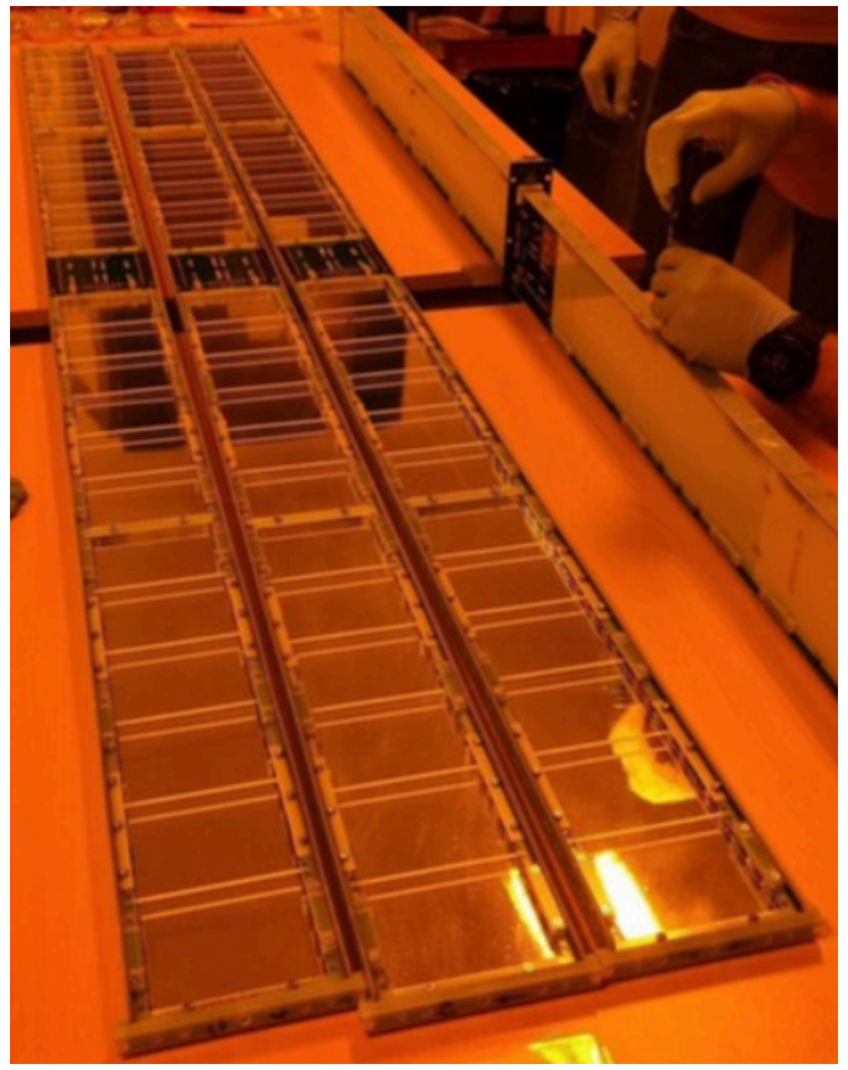
- Description of analysis procedure
  - Gallery-based C++ macro
- Initial results in a PDHD data taking run
- Conclusions and next steps

PDS Readout

- PDHD uses the X-Arapuca
  - Four channels per module
  - 10 modules per APA
- APAs 2-4 uses **self-triggered readout**, so each channel triggers independently depending on the amount of light collected
  - APA 1 uses streaming (like charge readout), but given the collection plane bias issue, I am focusing my study on APAs 2-4

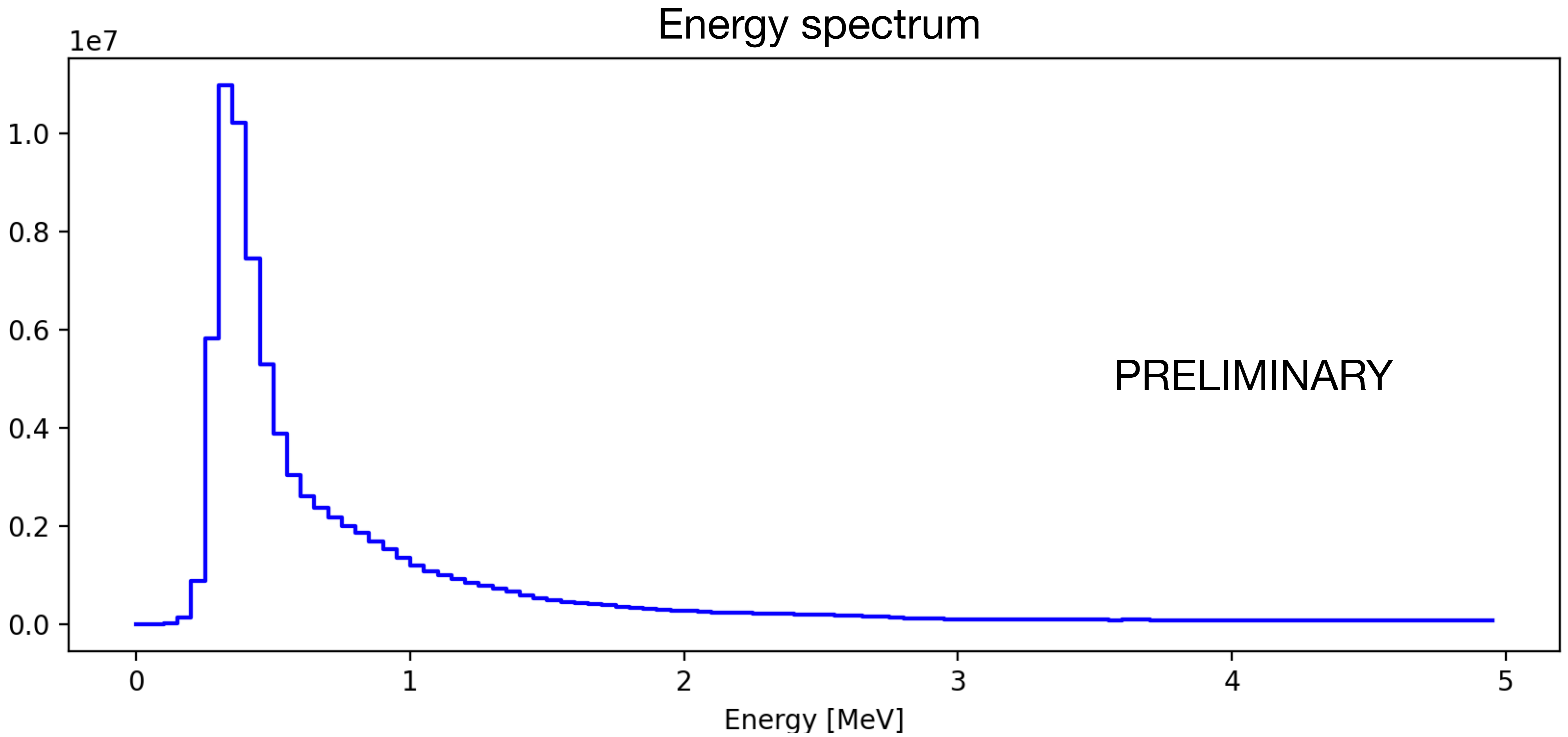


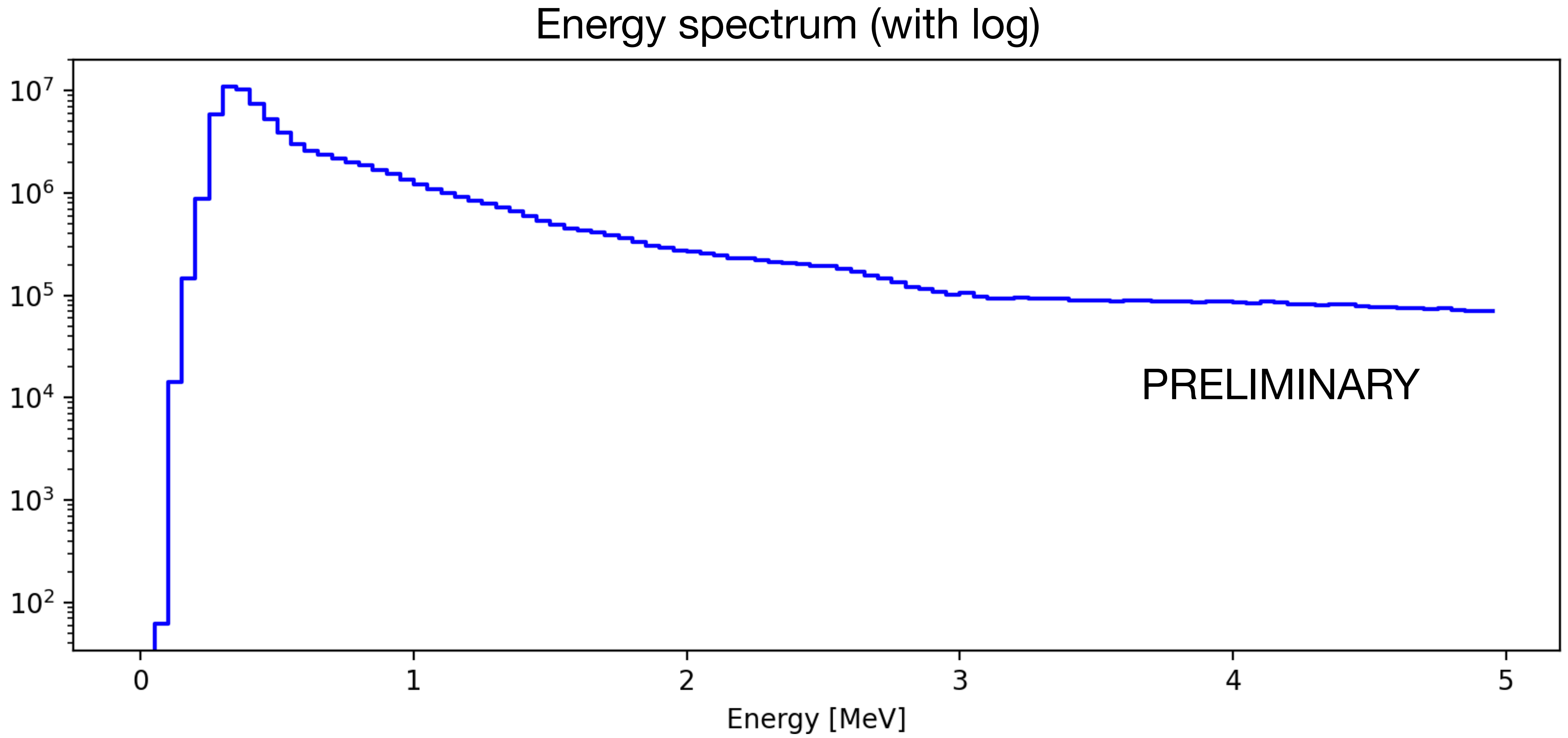
PDHD PDS Modules
Before Installation



Charge Reconstruction

- For charge reconstruction I am using Emile’s LArSoft analysis module to find low energy clusters
  - Finds isolated and localized charge clusters with low energy
  - Last meeting Emile showed results in PDHD using charge in data and MC https://indico.fnal.gov/event/66638/#1-bismuth-source-studies-in-pd





Reconstruction Steps

1. Load self-triggered waveforms from **OpDetWaveforms**

    - Find single isolated hits in time and space with symmetric window centered around time/location of hits

2. Open ROOT ntuple with isolated low energy charge clusters made using the singlehit analysis module

3. Match each isolated PDS hit to charge clusters using:

    - Time window around PDS timestamp

    - Space window around the hit's optical channel

4. Save results to ROOT ntuple

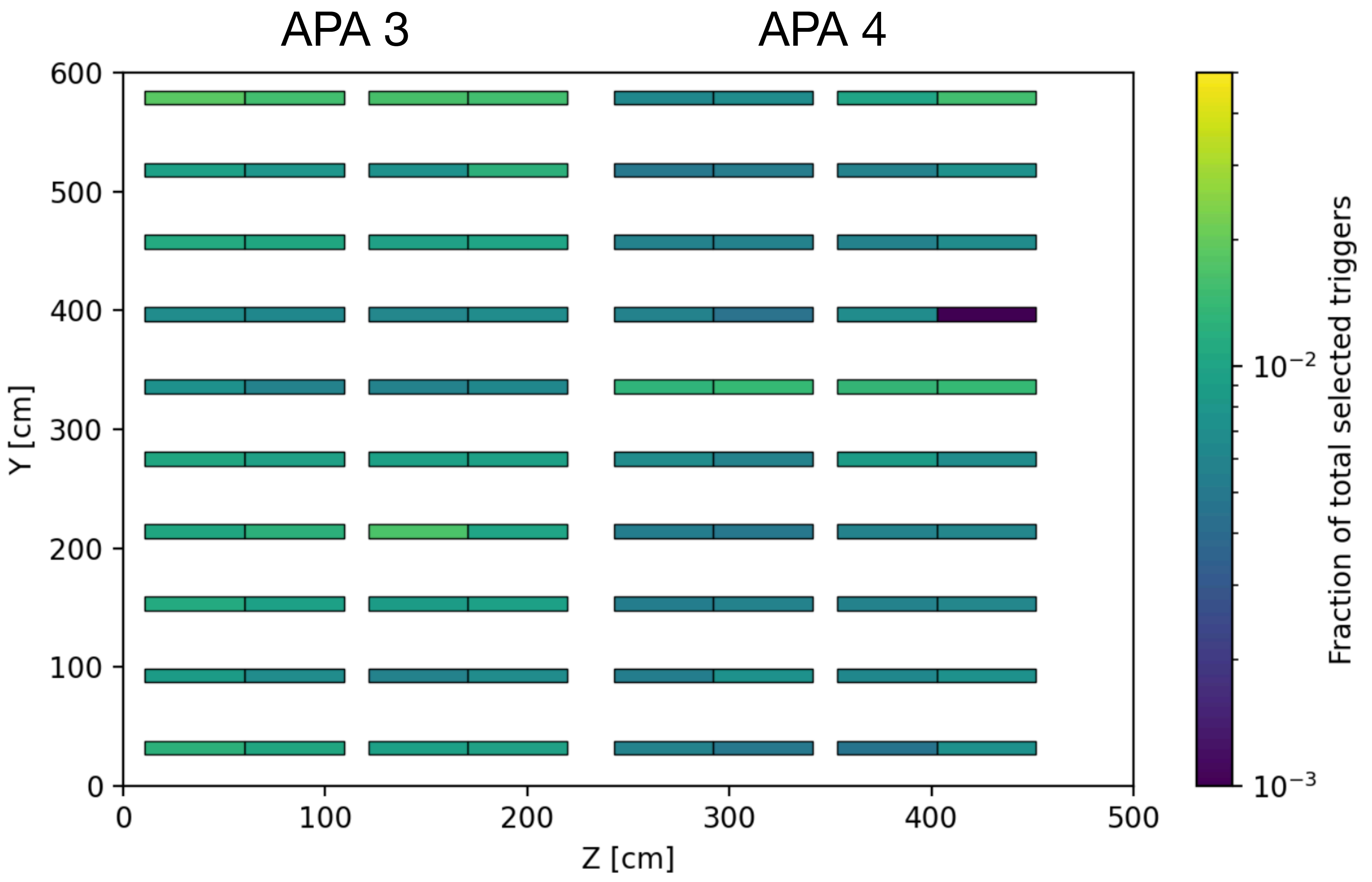
PDS Hit Clustering Methodology

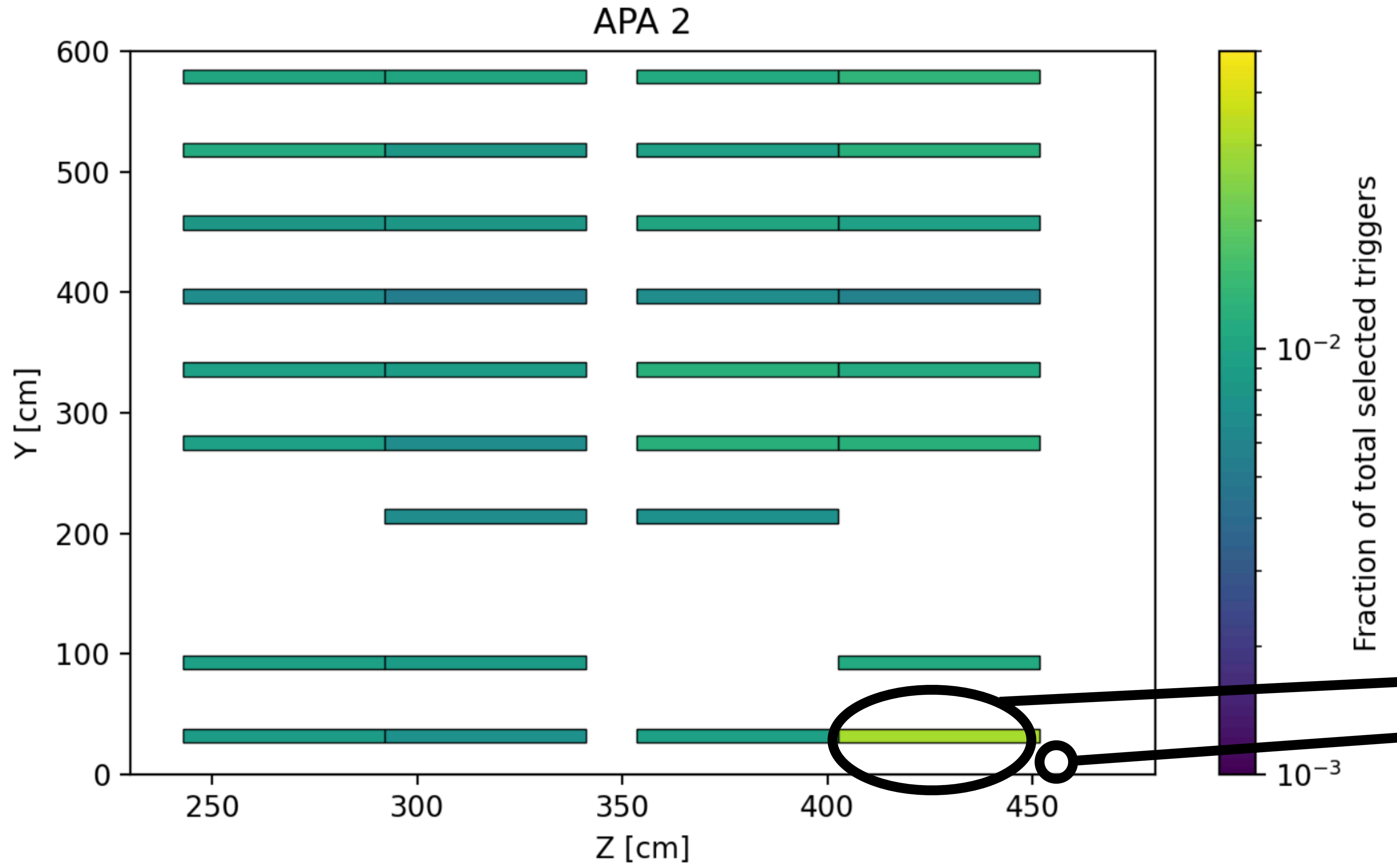
First group hits in time using **0.1 usec window** (i.e. +/- 0.05 usec) around each hit.

PDS Hit Clustering Methodology

First group hits in time using **0.1 usec window** (i.e. +/- 0.05 usec) around each hit.
Then use simple Z and Y window to find single isolated PDS hits within *each group*

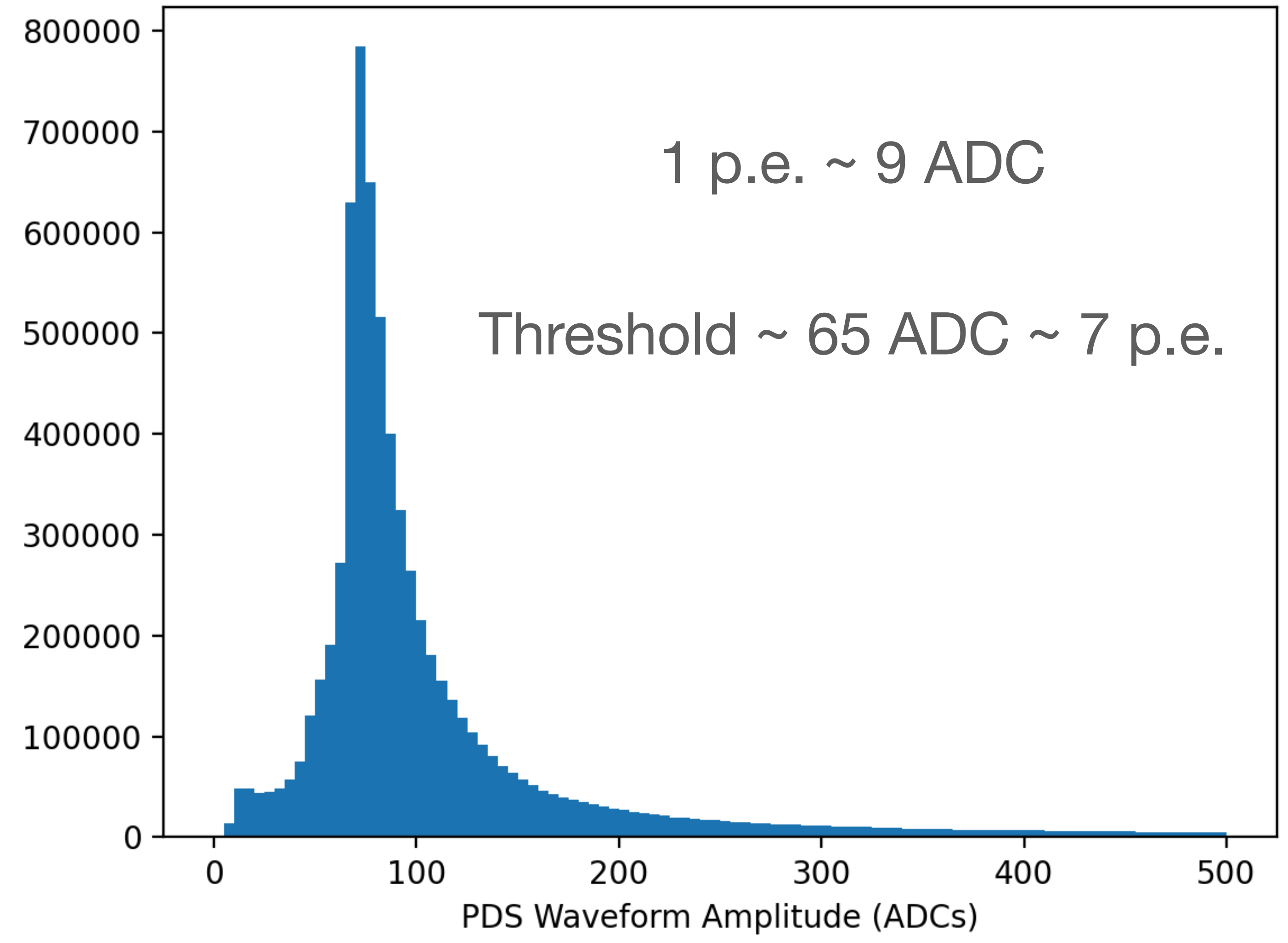
Isolated PDS Hits

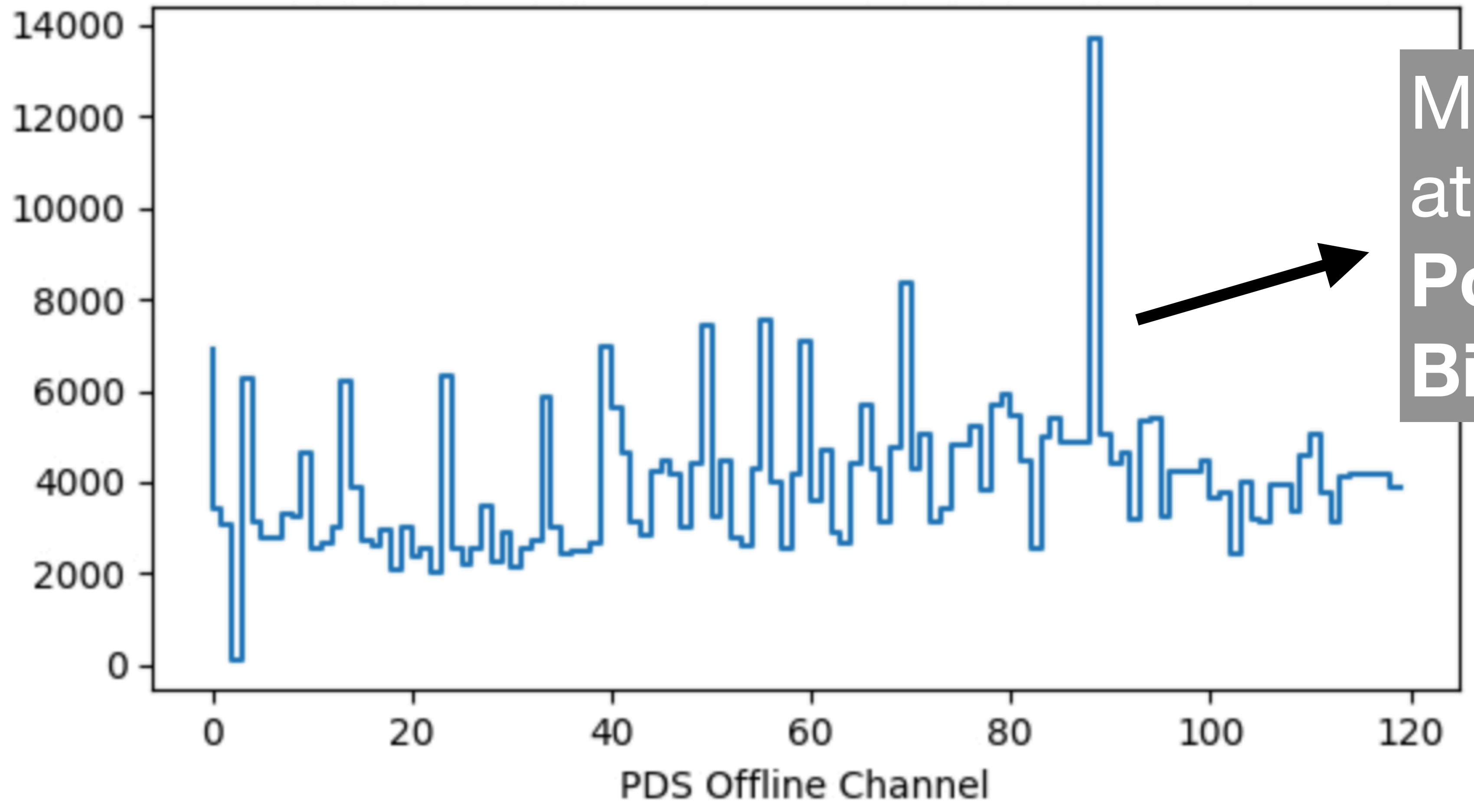




Channel 89

207Bi Location, near APA





Maximum # of PDS triggers at channel 89

Possibly due to Bismuth source

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Charge Light Matching Procedure

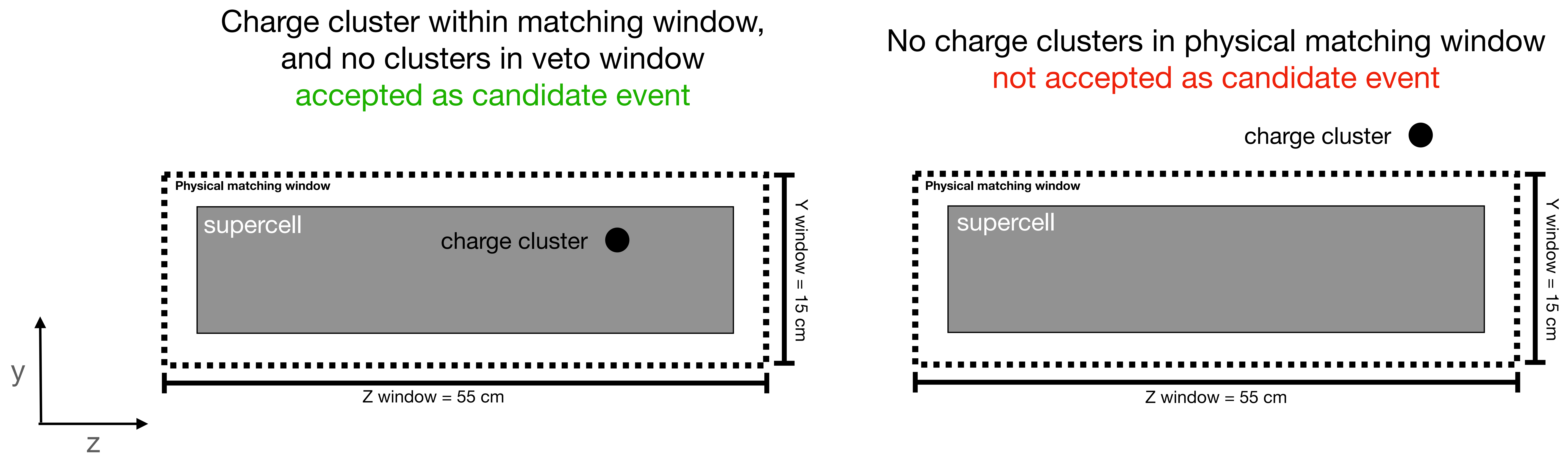
- To find absolute charge timestamp:
  t_charge = *RDTimeStamp*0.016us/tick + PeakTime*0.512us/tick*

- To find absolute PDS timestamp, **t_pds**, I use the timestamp from **OpDetWaveforms** (all that is needed for the self-triggered PDS data)

- Match PDS triggers and charge clusters that satisfy the condition:
  (t_charge > t_pds) & (t_charge < t_pds + 600 us)
  - *But this is not sufficient (next slide)*

Charge Light Matching Procedure

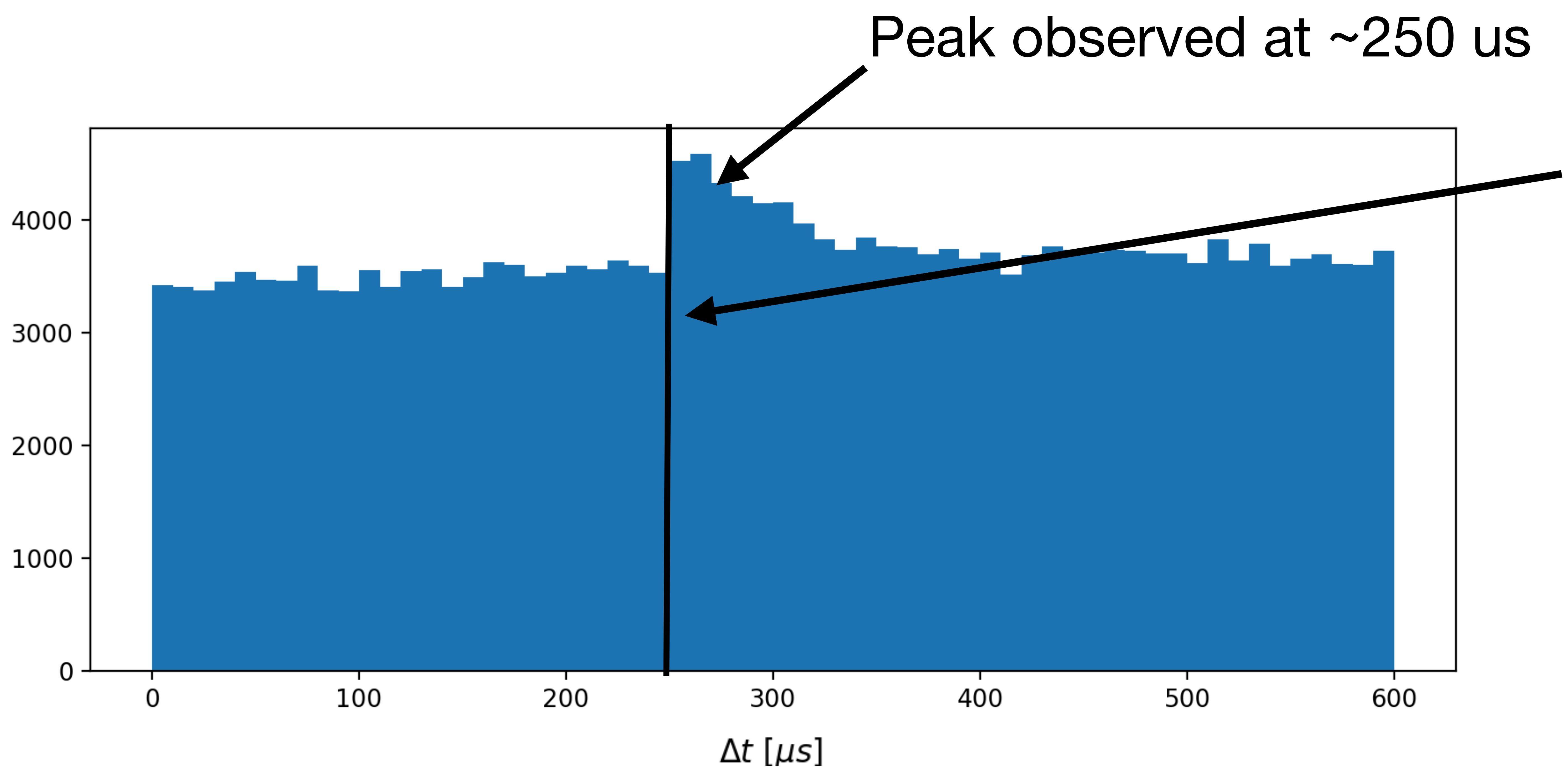
- But a simple timestamp matching is *not sufficient* since PDHD is so large… you will get a lot unrelated charge matching to the same PDS trigger
- Most likely, many of radiologicals that induce triggers in PDS will be near a optical channel
  - So if a PDS trigger matches to charge using the timestamp matching, I require the charge to be close to the corresponding PDS channel in Z and Y



Results

- I have started by analyzing run 28850
  - Cosmics run, no beam
  - Only ~45 min long
  - 680 files
- I plan to look at more runs soon

Results



Why is peak offset from 0?

A change was made in LArSoft in September that changed the definition of RDTimeStamp.

This change made RDTimeStamp correspond to the beginning of each raw::RawDigit (i.e. *before* the TPC pre-trigger window of 500 tick or 256 us).

But before September, the LArSoft decoder was set up to make RDTimestamp located after the pre-trigger window. I am using keepup processing files made in August for this run, so the change has not been corrected.

I will include the correction going forward.

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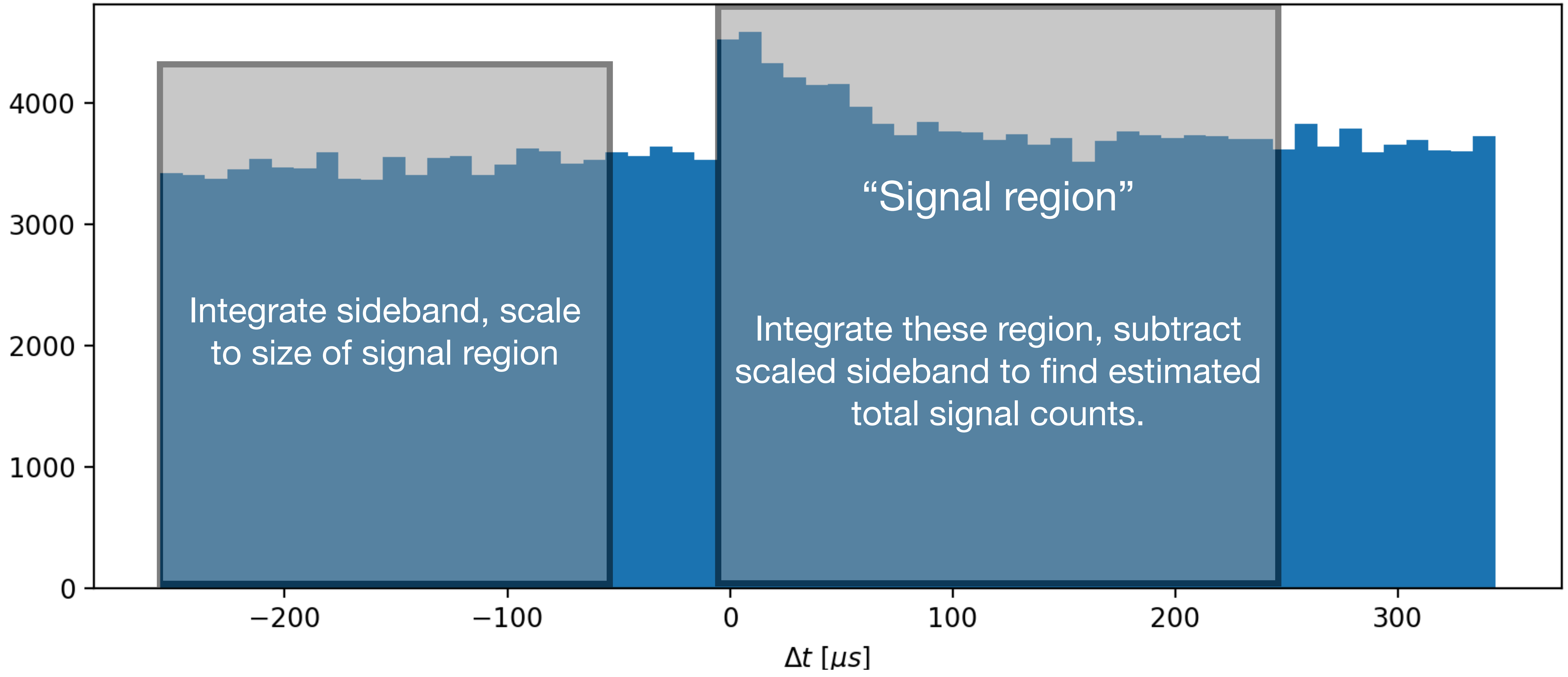
Results

The following includes clusters with at least 2-views
Selection purity is obviously quite poor with this selection.
Purity can be improve with selection cuts.



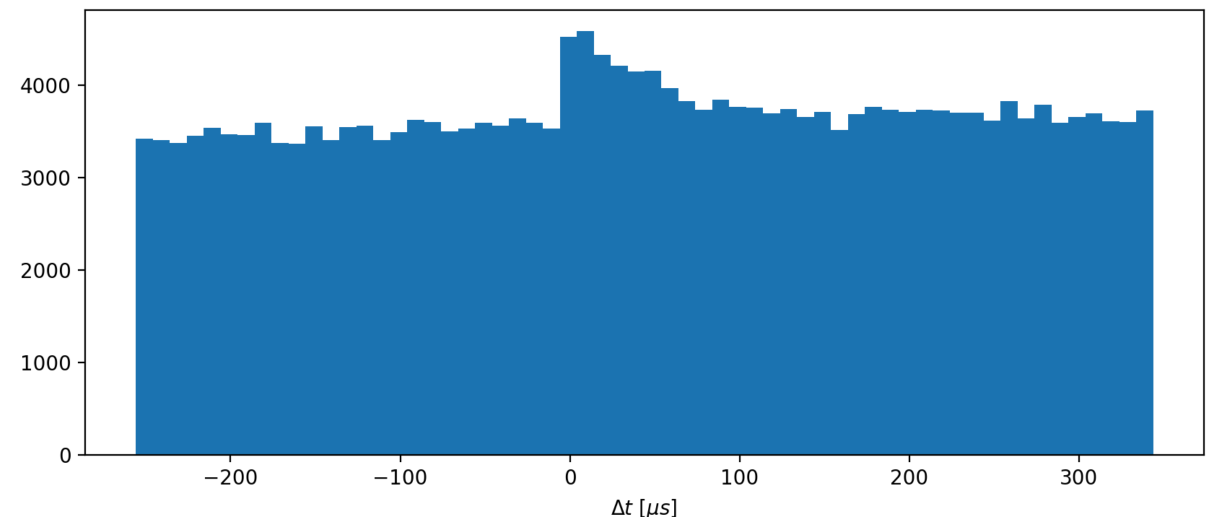
Total counts in signal region = ~97020

Estimated background counts = ~87070

Estimated signal counts = ~9950

Estimated purity = ~10.3%

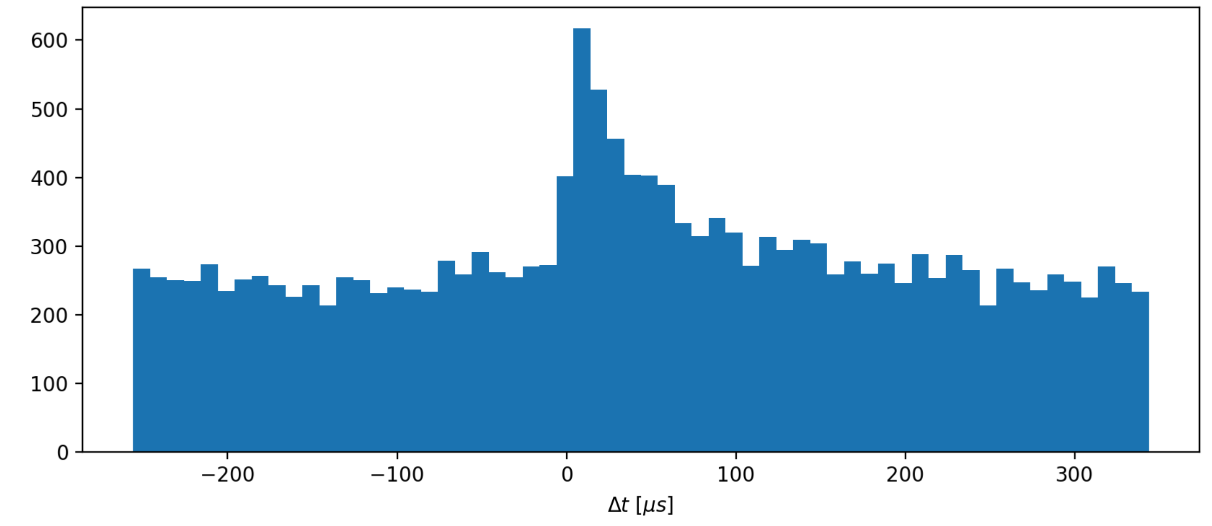
Results



Includes 2 and 3-views charge clusters

Estimated signal counts = ~9950

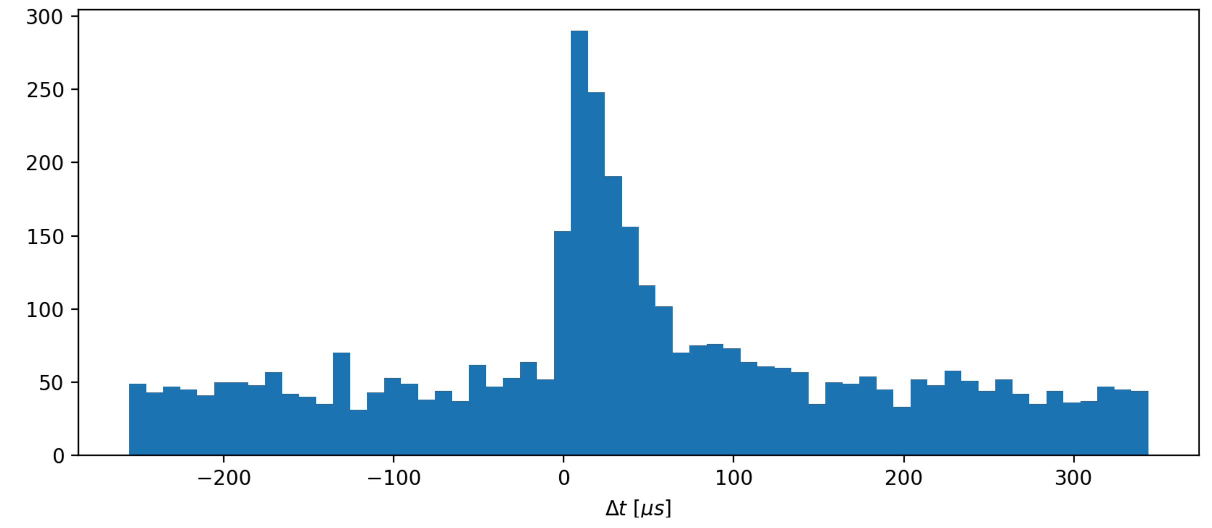
Estimated purity = ~10%



Includes **only** 3-views charge clusters

Estimated signal counts = ~2240

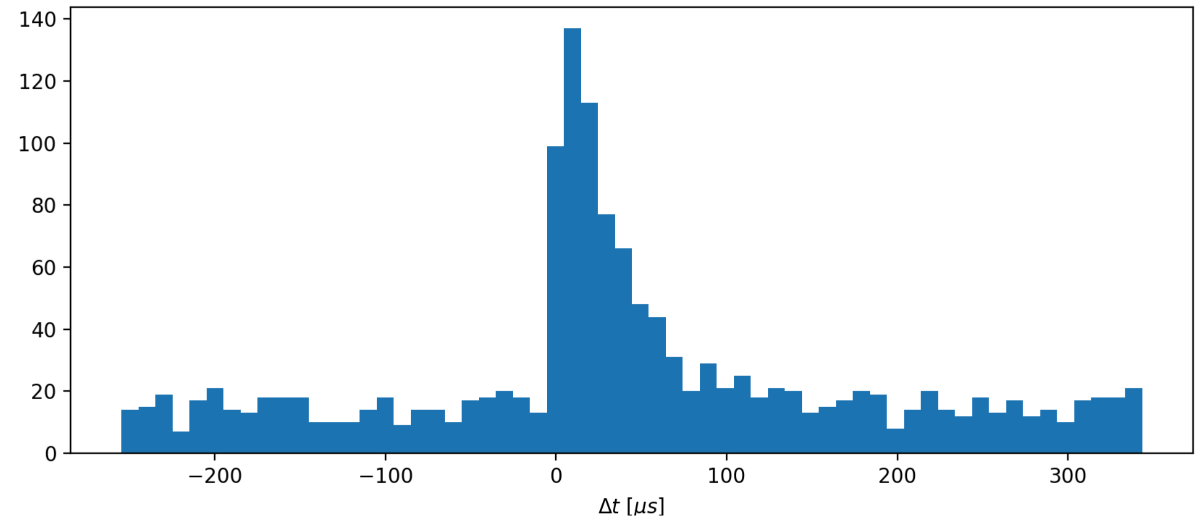
Estimated purity = ~27%



Includes **only** 3-views charge clusters
+ cut PDS amplitude < 120

Estimated signal counts = ~1540

Estimated purity = ~47%

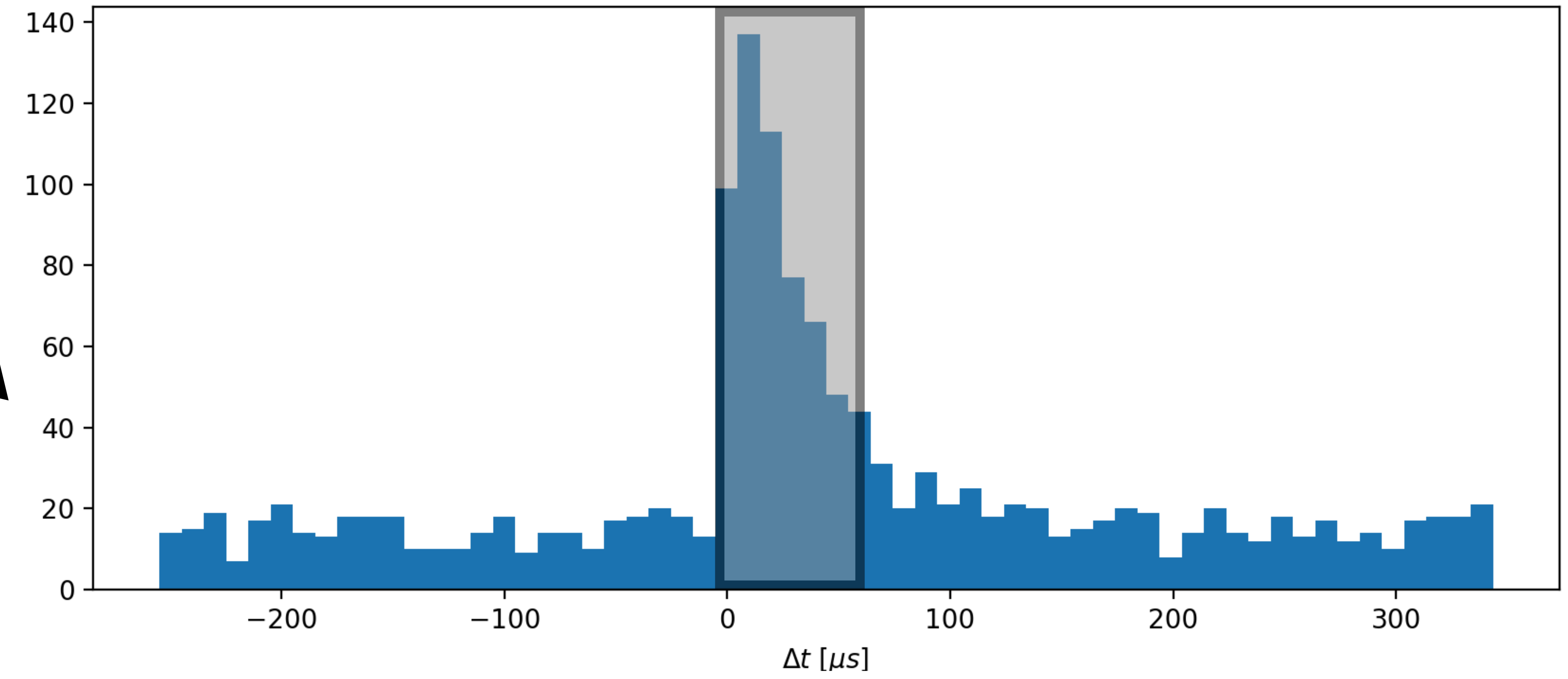


Includes **only** 3-views charge clusters
+ cut PDS amplitude < 120
+ cut charge energy < 15 ADC*tick

Estimated signal counts = ~770

Estimated purity = ~59%

Minimizing signal region can improve purity even further



<u>Selecting only 0 us to 60 us:</u>

Estimated signal counts = ~525

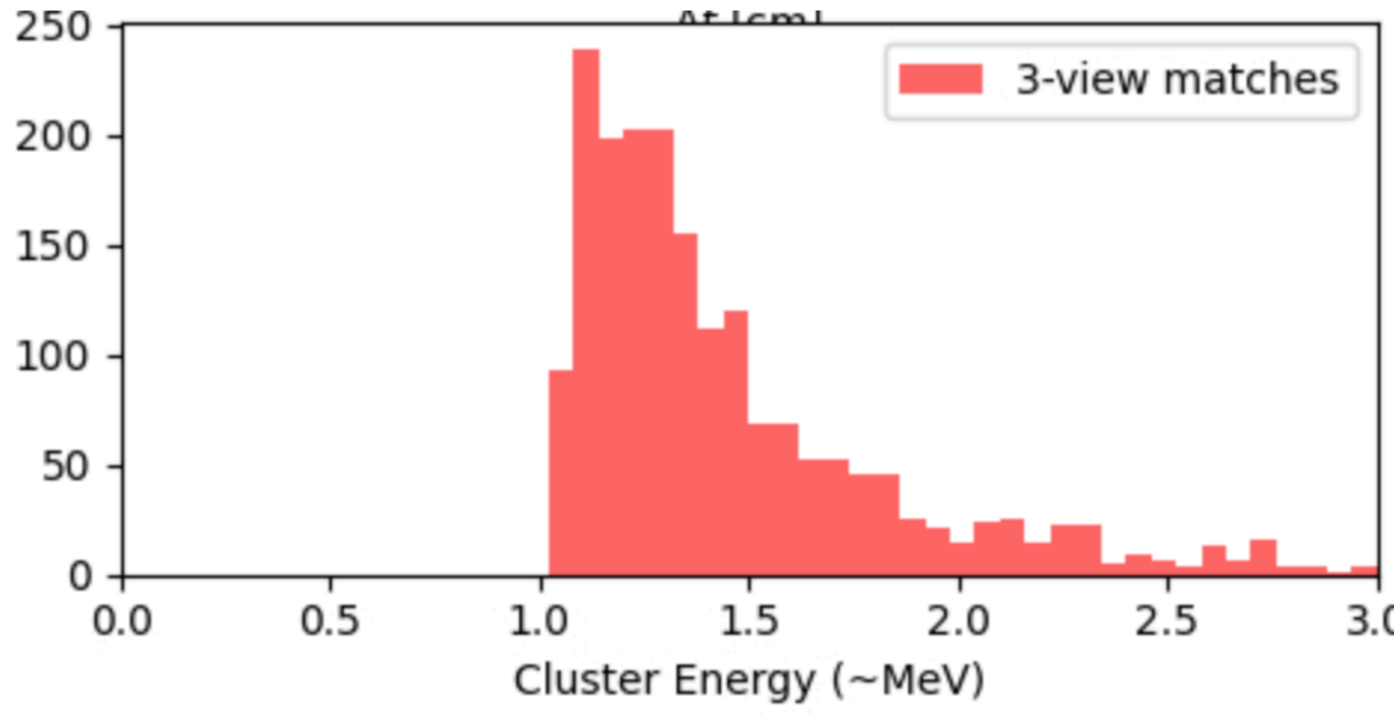
Estimated purity = ~80%

<u>Selecting only 0 us to 30 us:</u>

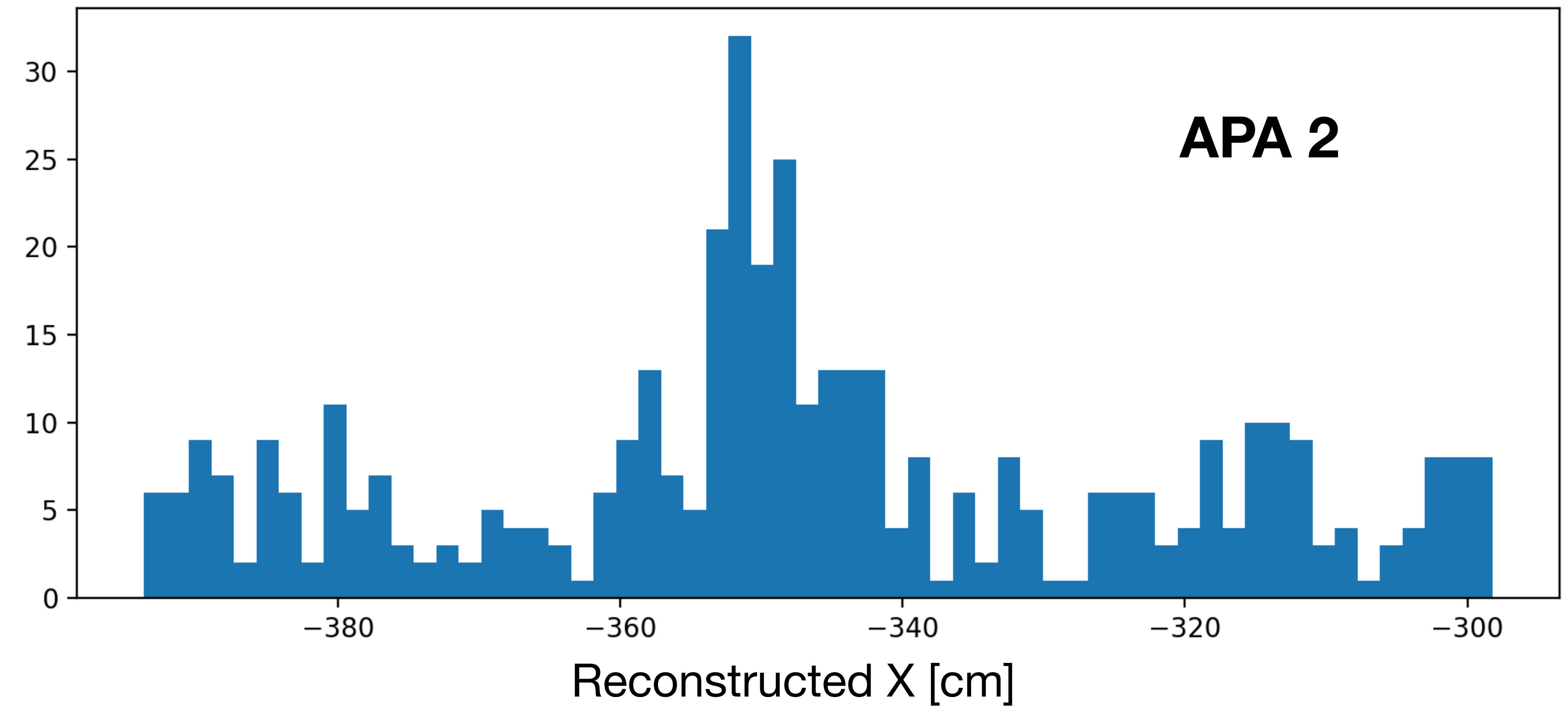
Estimated signal counts = ~340

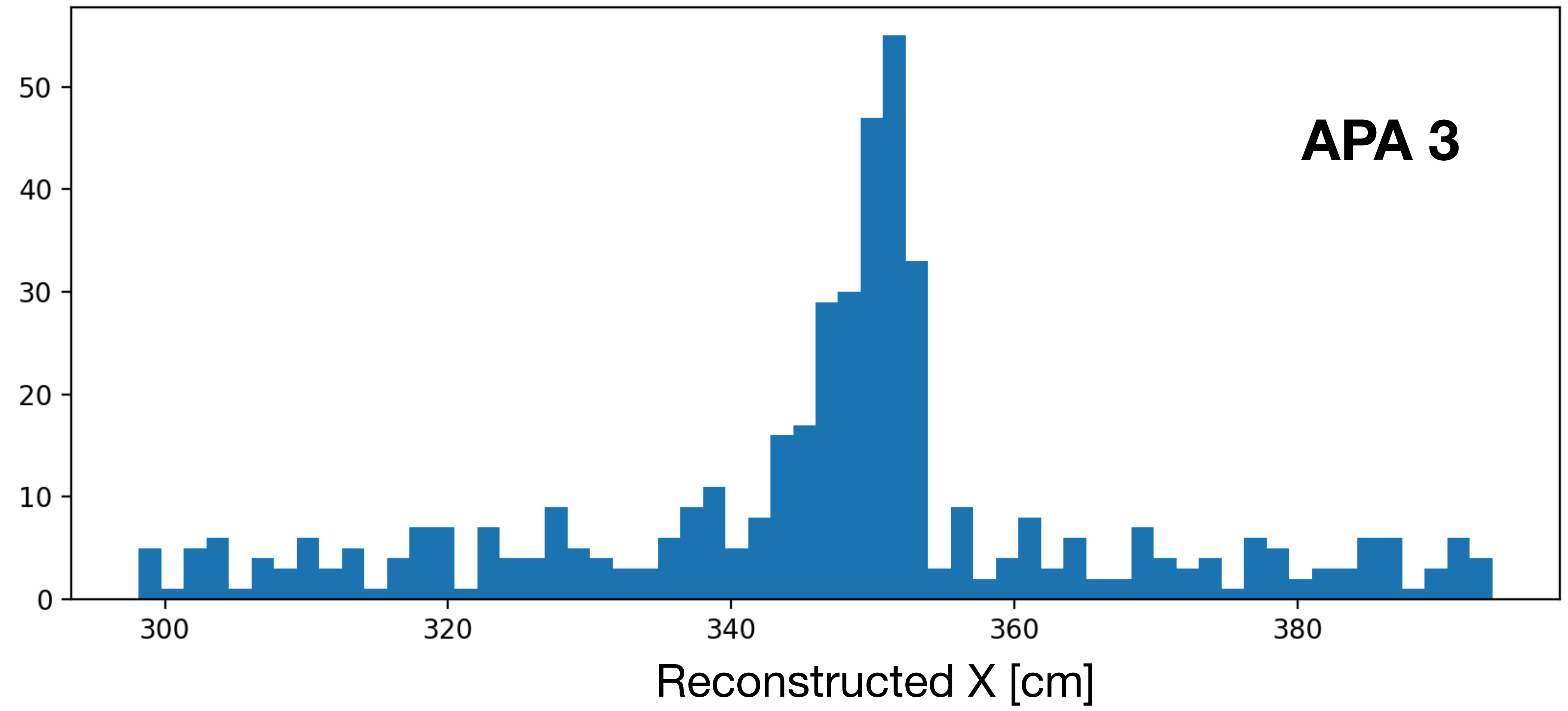
Estimated purity = ~84%

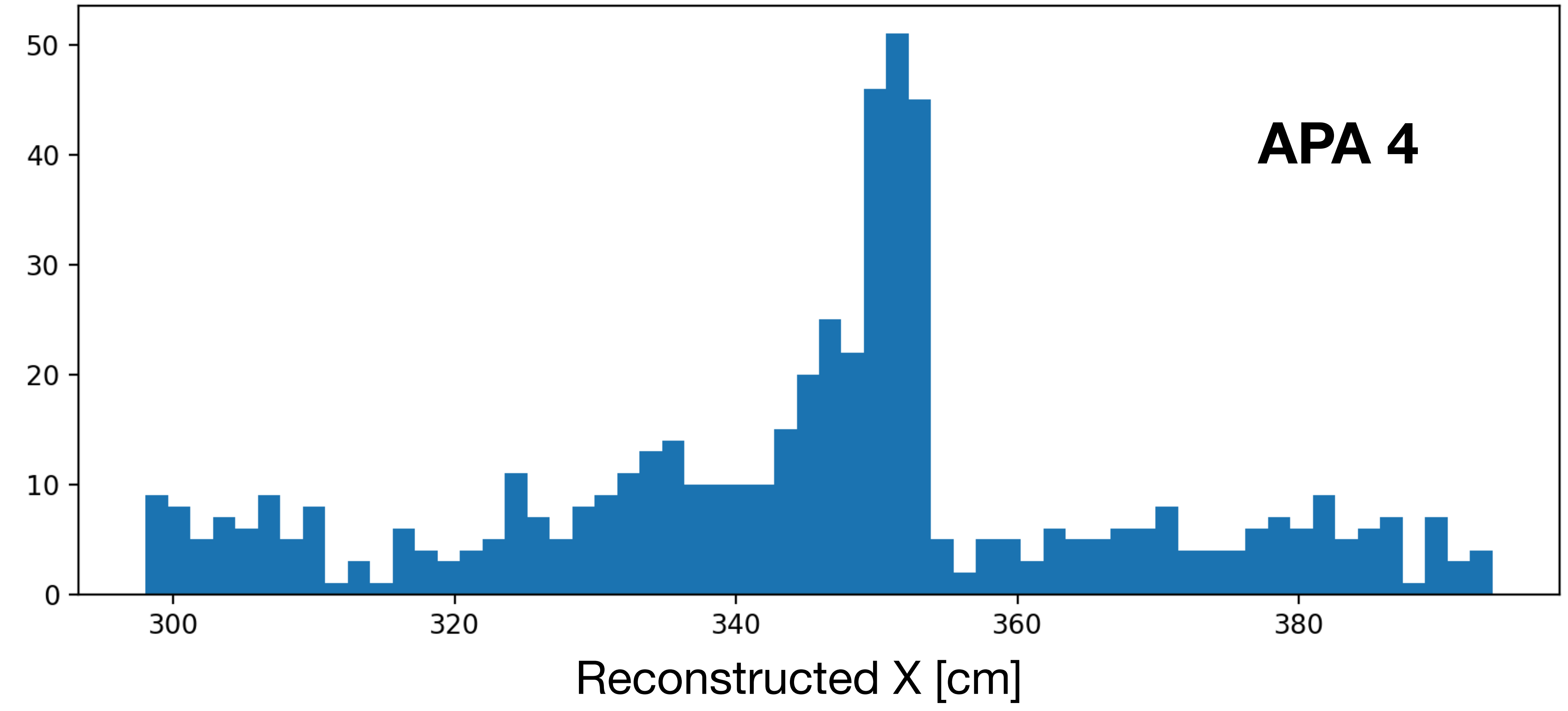
(Can achieve close to 87% with fine tuning
of energy and amplitude cut.)

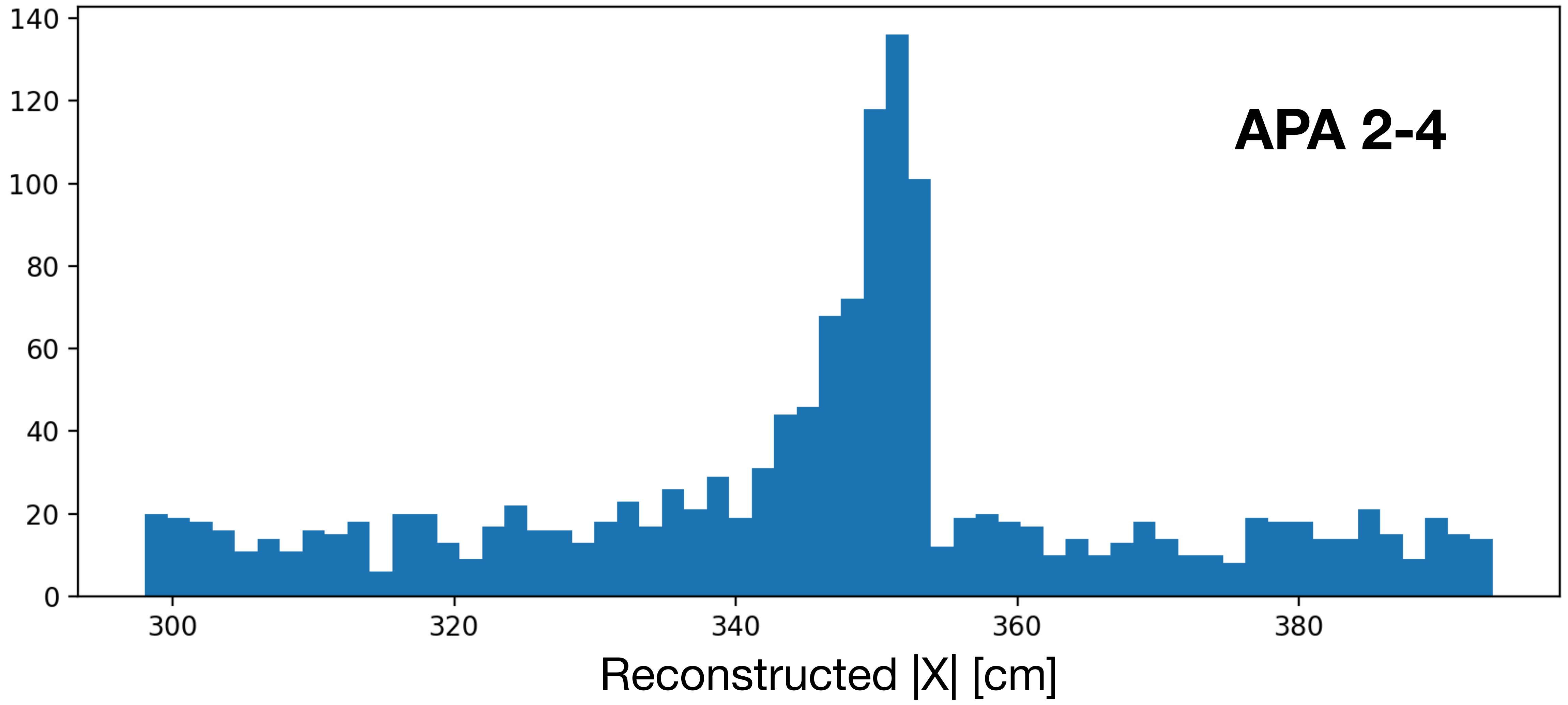


Reconstructed X Coordinate

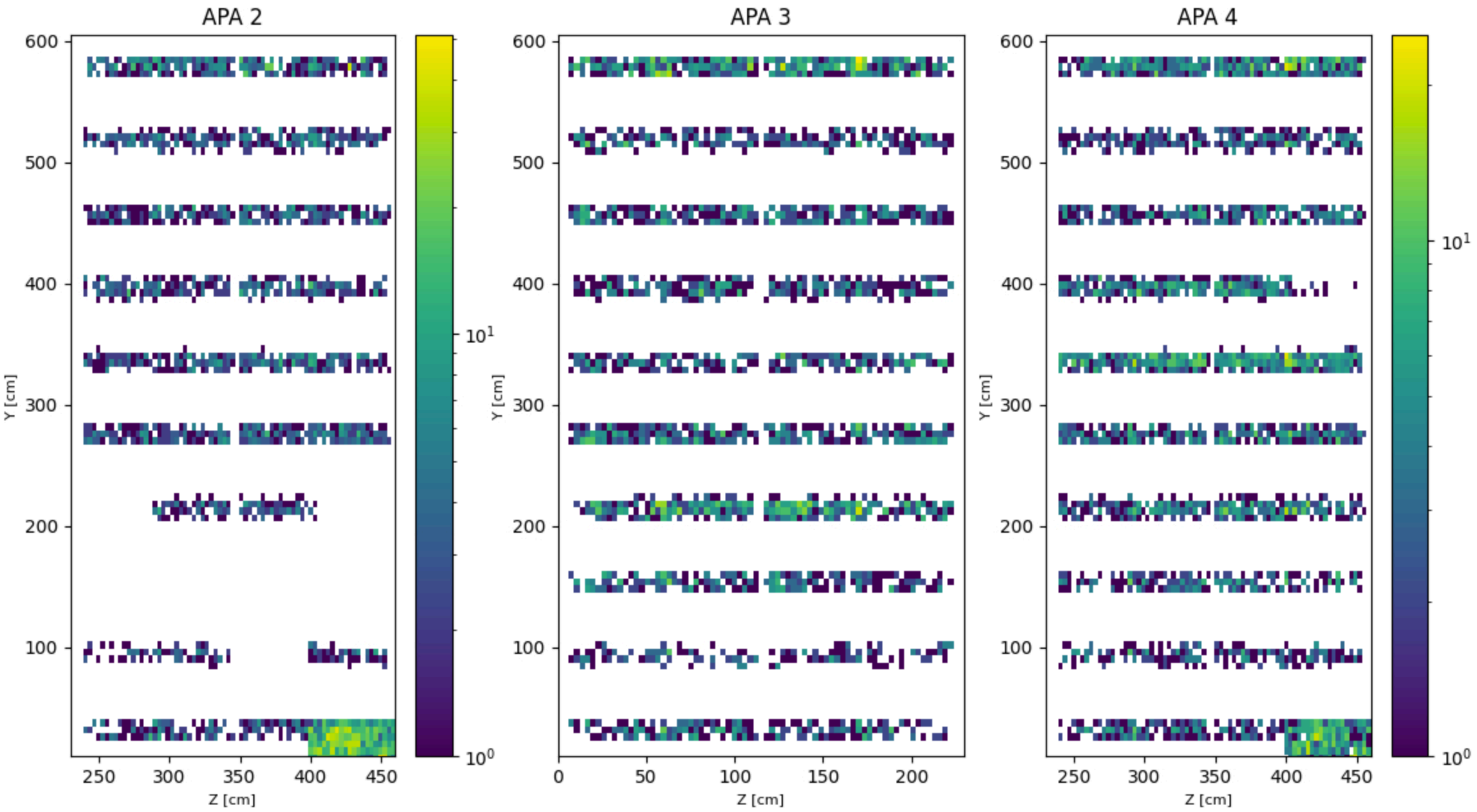








2D Distribution



Conclusion

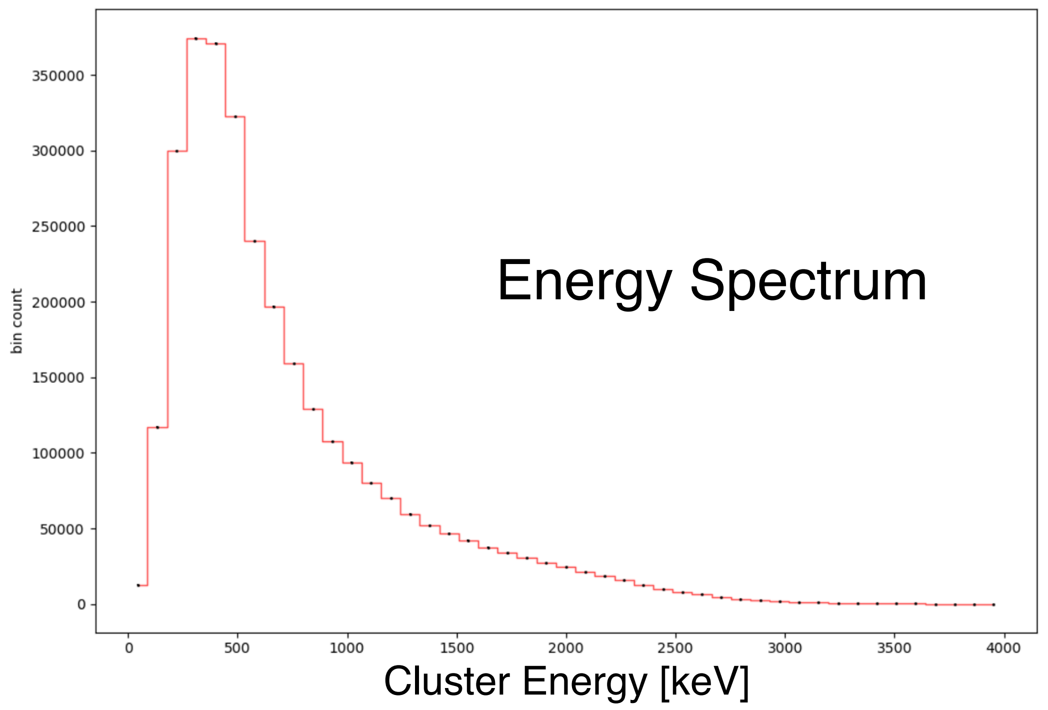
- Initial results show a peak in the reconstructed X coordinate near each APA
  - Likely caused by low energy radiologicals near the photon detectors — but should validate this using PDHD MC
- Some progress on improving selection purity with data cuts
  - More investigation needed to improve purity further without further impacting efficiency

Next Steps

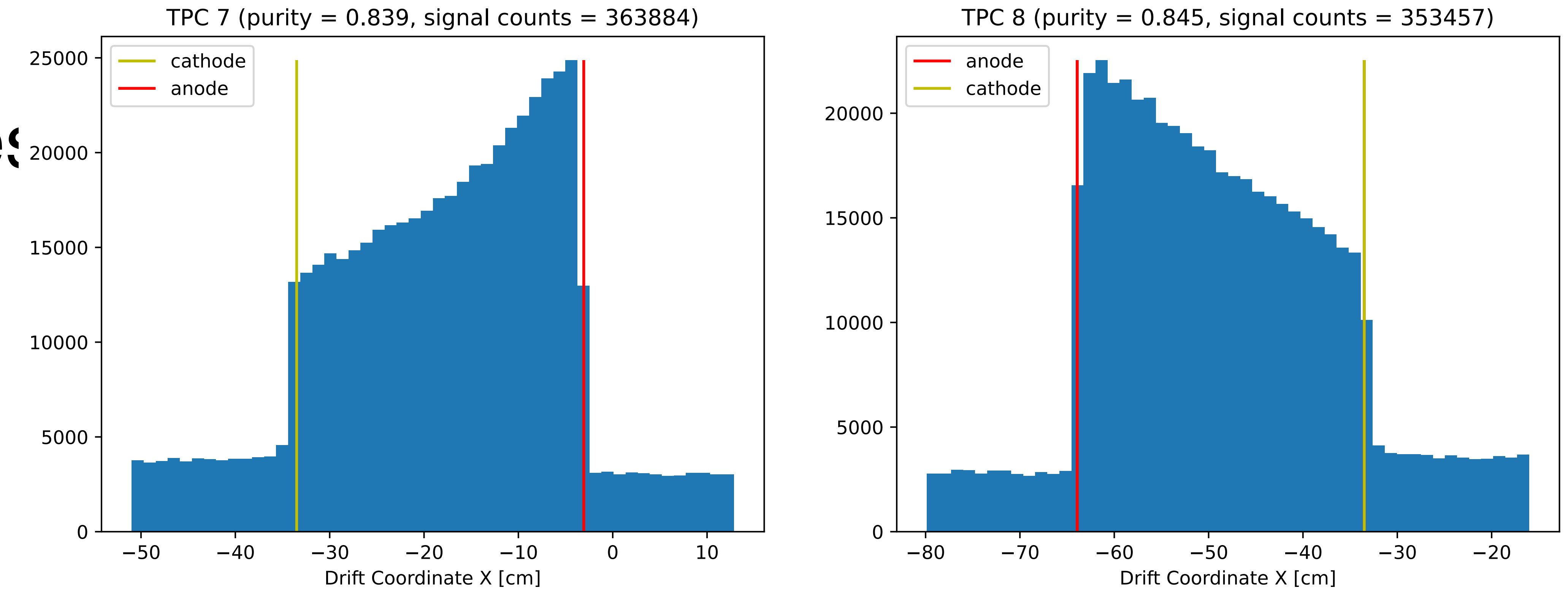
- Look at more runs from PDHD
  - Look closer at Bismuth source
- Further improve selection purity/efficiency
- Apply analysis to PDHD MC
- Investigate applications of the selection in calibrations

Backup

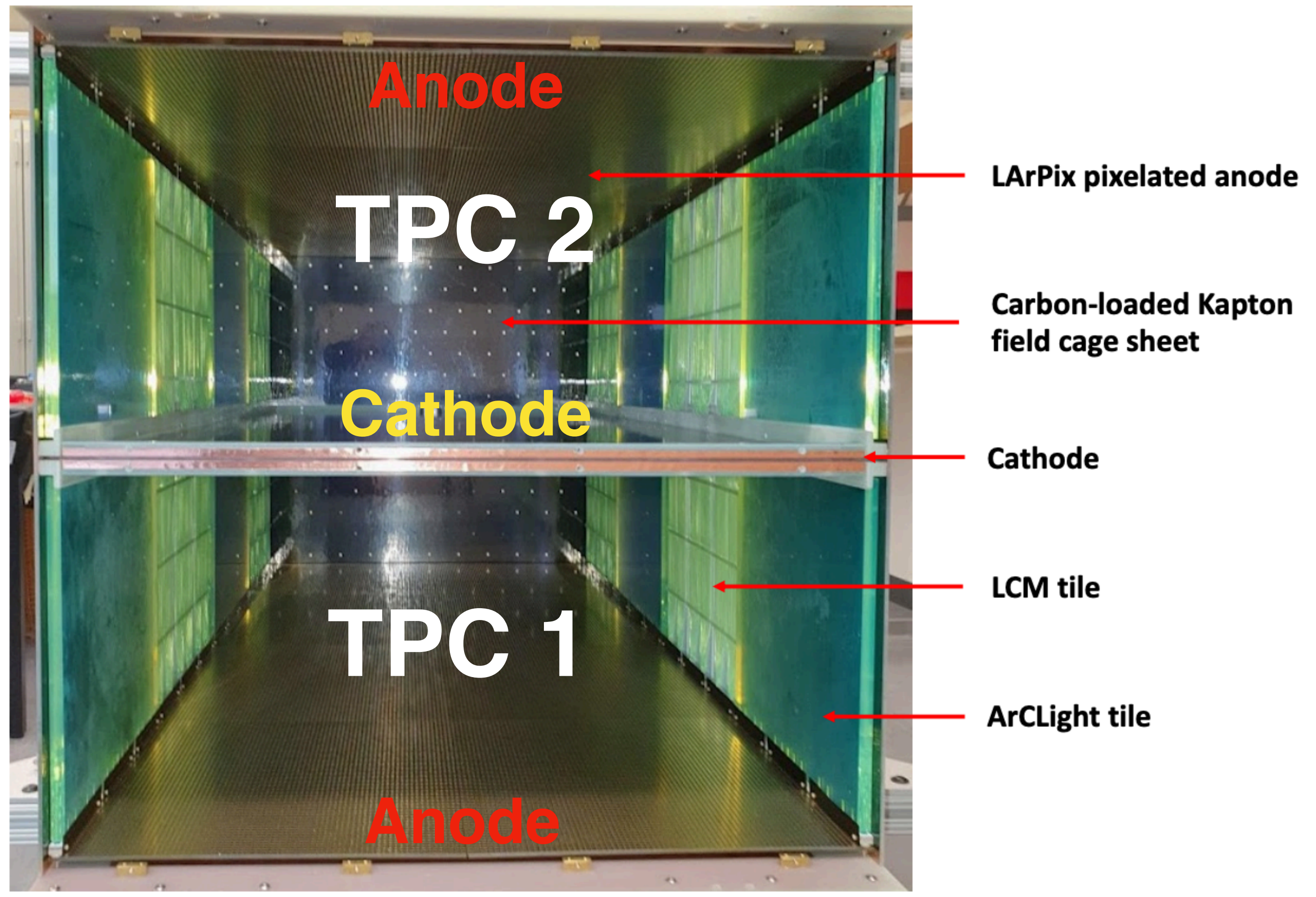
Overview of ND-LAr Study

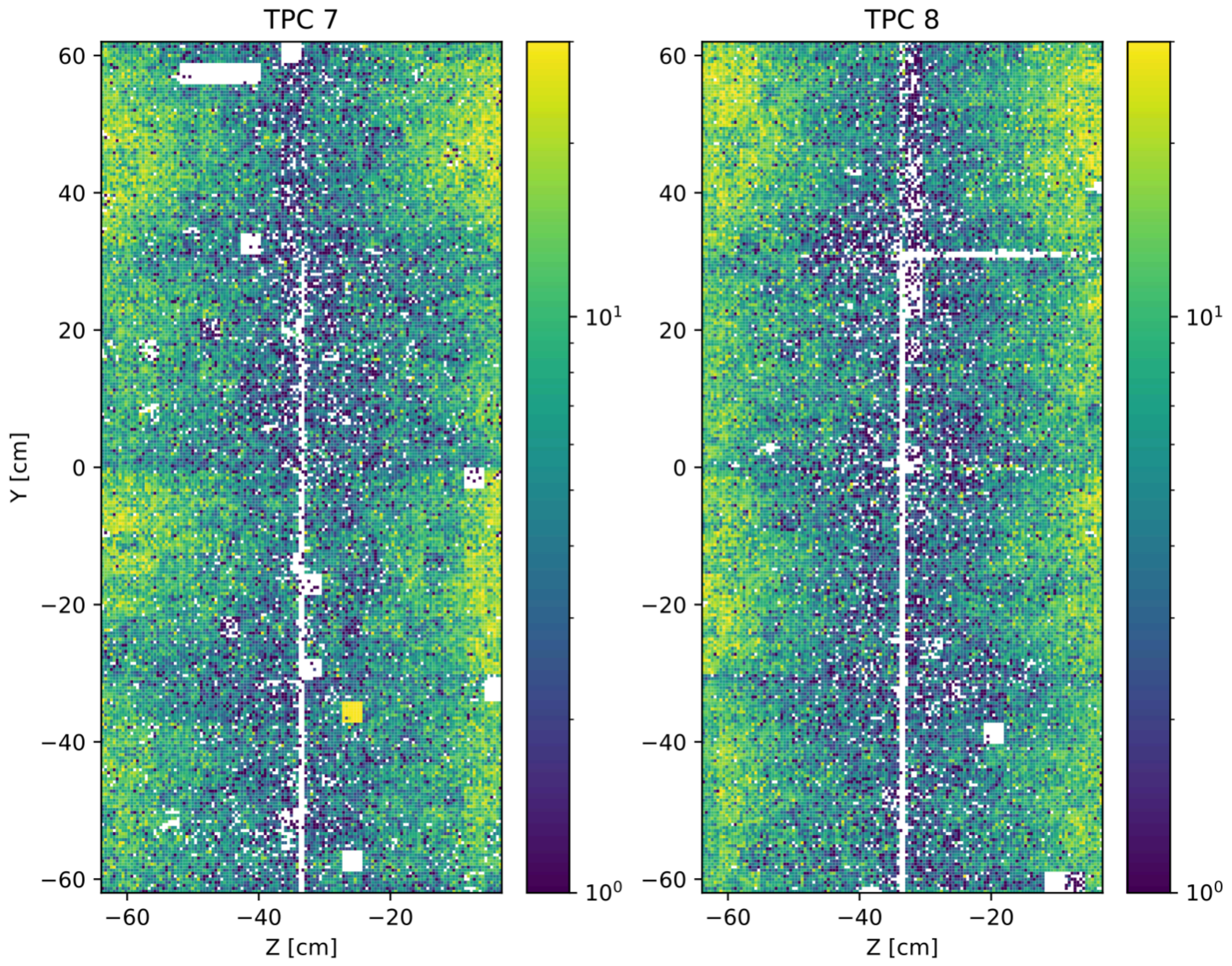


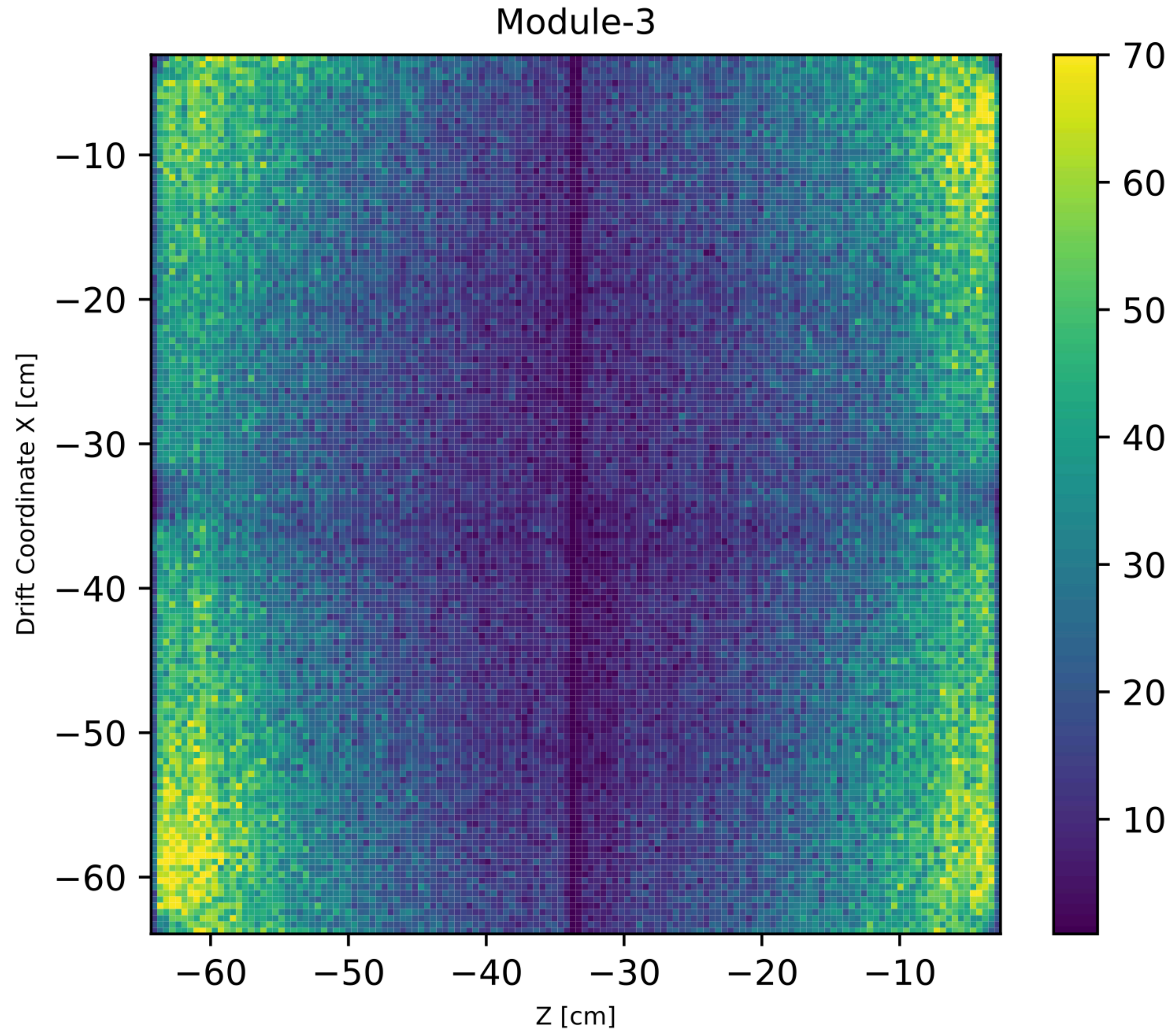
- I have pursued a study of matching charge and light for radiologicals in the DUNE ND-LAr prototypes
  - ND-LAr is quite suited for this given the “small” TPC volumes and large photon detector coverage of active LAr
  - A similar study in HD/VD will be quite different (next slide)



Inside a 2x2 Module







PDHD Study

- There are some obvious differences compared to ND:
  - Much larger active volume (~55x larger than the 2x2)
  - Longer drift distances (350cm in HD, 30cm in 2x2, ~50cm ND-LAr)
  - Smaller photon detector coverage (relative to active LAr)
  - We do not (currently at least) trigger on these events in HD, but do in ND-LAr
  - Higher photon detection efficiency (~2-3% HD compared to 0.2-0.6% ND)