LOW ENERGY NEUTRINO CALIBRATION / RECONSTRUCTION

Sergio Manthey Corchado

Motivation

Charge Calibration for LowE Events:

- Find appropriate **calibration factor** for charge to particle energy.
- Current hits follow **wirecell's standard** workflow which is **not optimized for low energy** interactions (discussion with wirecell team ongoing).
- With current settings: ~0.5 MeV threshold (1.2 MeV for > 90% eff.) and ~10% energy resolution > 5 MeV

Neutrino CC Signal Reconstruction:

- Try to recover info. from deex. gamma blips.
- Background limits reconstruction algorithms both in terms of clustering and resolution.

Productions

Using dune10kt_1x2x6 standard workflow + SolarNuAna.

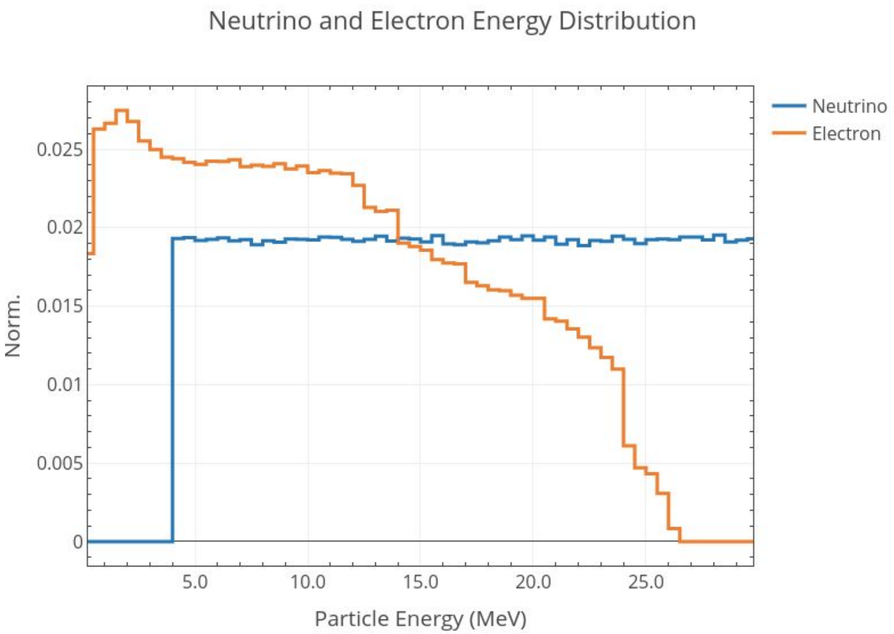
- **Productions**:

  1. Flat NuE CC 4-30 MeV fcl. homogeneous across detector producing a main electron track & deex. gammas (+ others).

  2. Flat NuE CC 4-30 MeV + full centralAPA background production.

  3. Cavern Neutron Production only (high statistics).

True Particle Spectrum



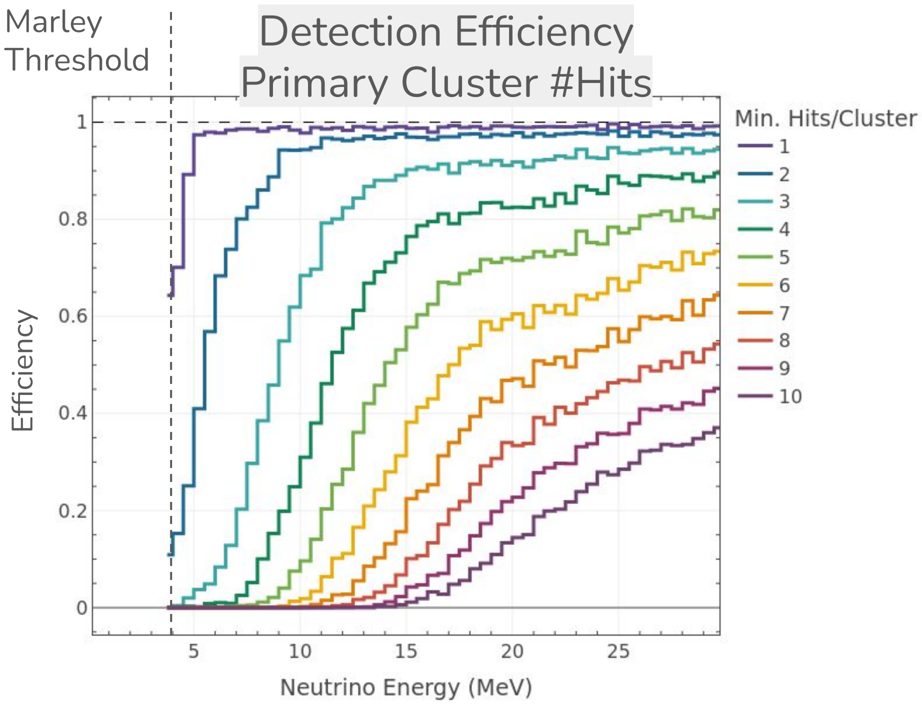
- Due to the process of charged current, the flat neutrino spectrum leads to an **uneven electron distribution** in energy.
- Distribution **favours lower energy statistics**.
- All **values are calculated per bin** avoiding spectral bias.

Calibration

Electron Clustering and Calibration Factor Definition.

Low Energy Clustering

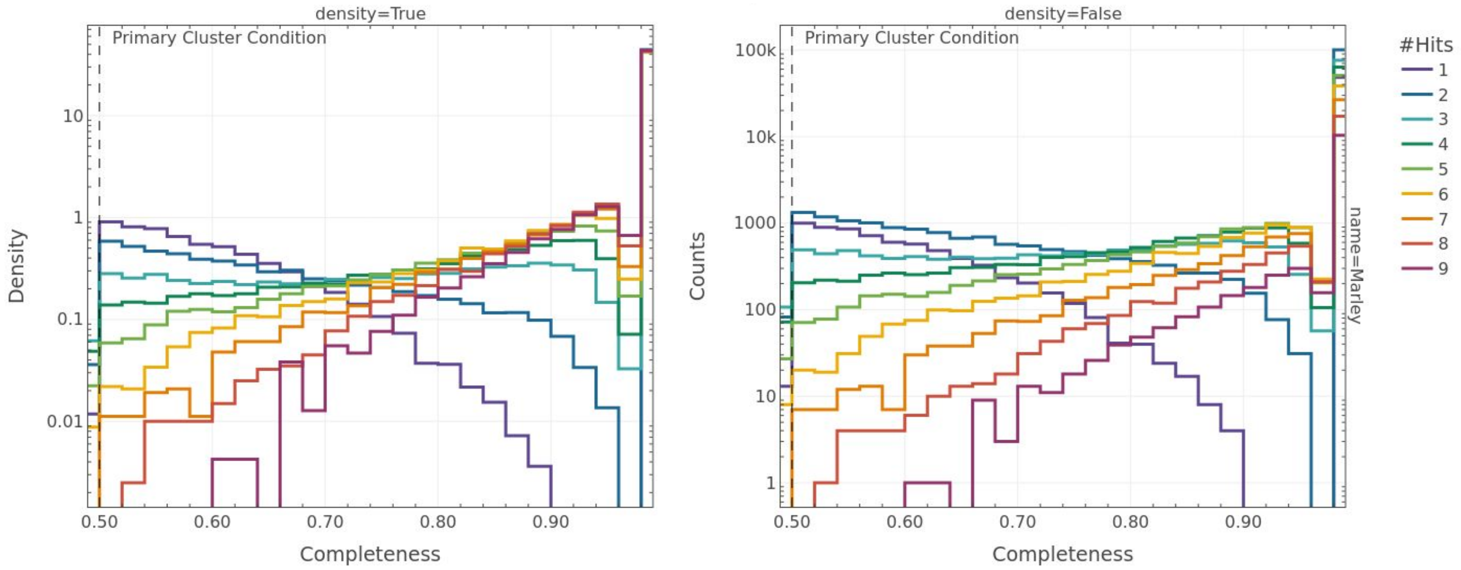
- Reconstructed **wirecell hits**: col. plane + ind. plane matching (at least 1).
- Matched col hits grouped into clusters according to time & wire proximity (25 tick & 3 channels) **ensuring cluster purity**.
- Clusters divided into **“Primary”**and **“Adjacent”** (R adj cl. < 1m & charge adj. < charge primary).



- **Detection Efficiency**: Probability of finding **at least 1 primary cluster per event**.
- Important to look for low hit multiplicity in the context of low energy interactions.

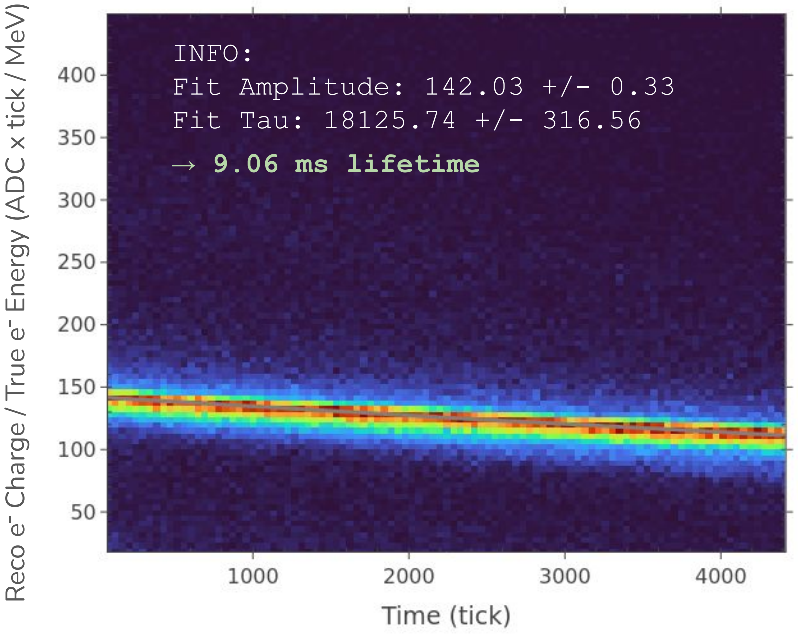
Primary Cluster Completeness

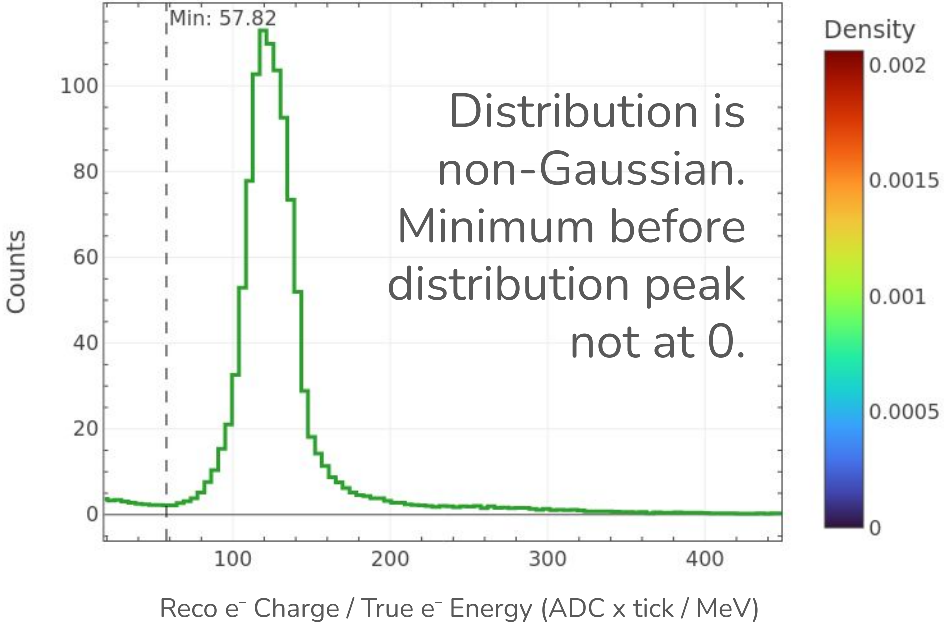
- **Electron Charge Completeness** (fraction charge in primary / charge in total cl.).
- **2 OM separation** between samples with max. completeness and incomplete distributions.



Electron Charge Drift Correction

- Select primary clusters for events < 20 MeV (w/o nuclei emission).
- Distribution is non-Gaussian. **Need to understand tail populations**.

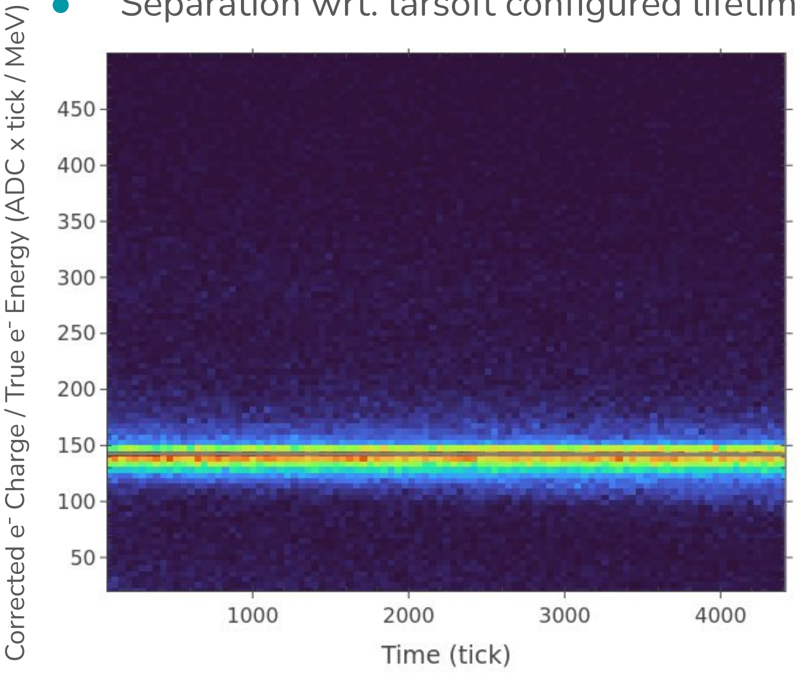


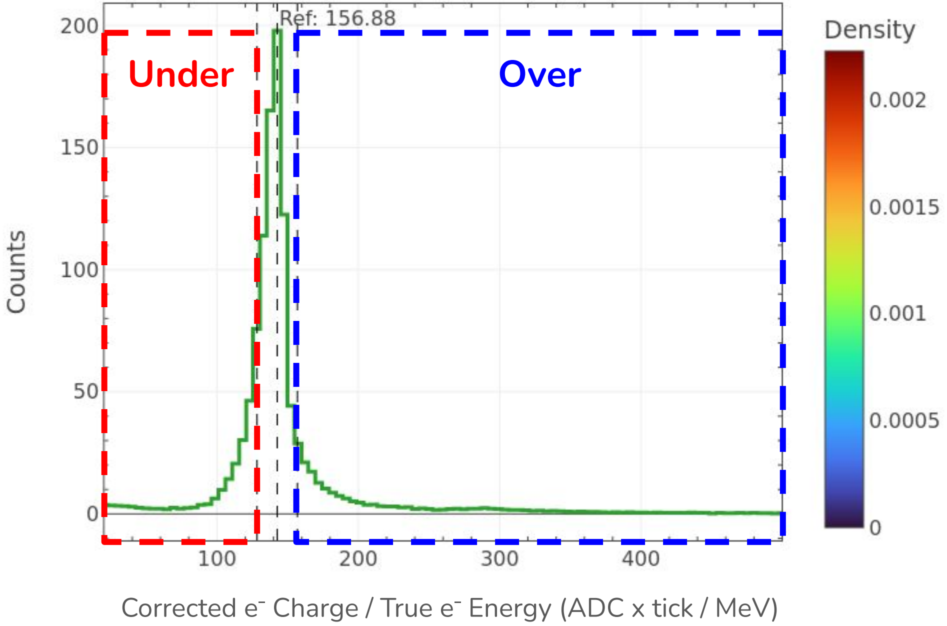


Distribution is non-Gaussian. Minimum before distribution peak not at 0.

Electron Charge Drift Corrected

- Correcting for lifetime (9.06 ms) returns “Corrected Charge” variable.
- Separation wrt. larsoft configured lifetime of 10 ms attributed to border effects.

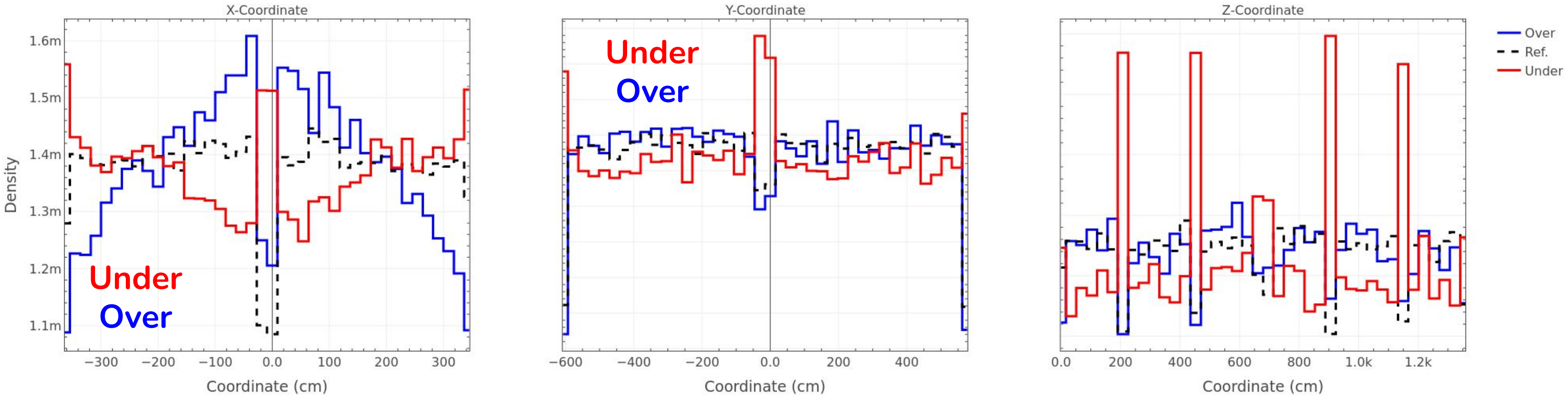




Over/Under Corrected Clusters

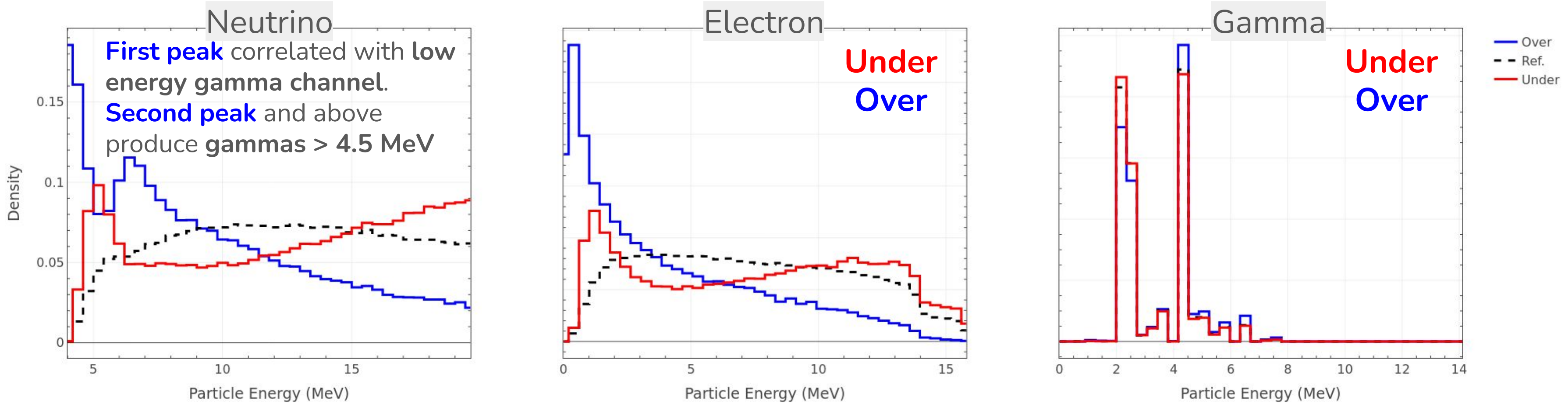
- Underestimated charge reconstruction clearly matched to APA borders.
- Overestimated charge reconstruction less intuitive (see next slide).

Drift X = 0 cm　　Y = 0 cm　　Z = *232, 463, 695, 926 cm

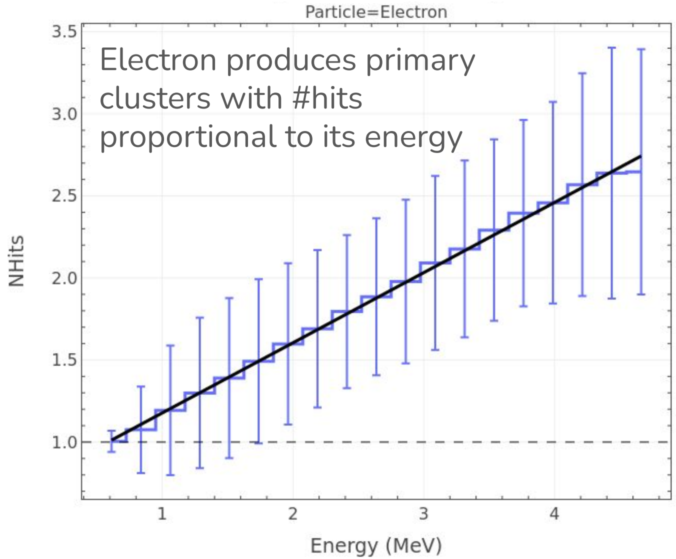


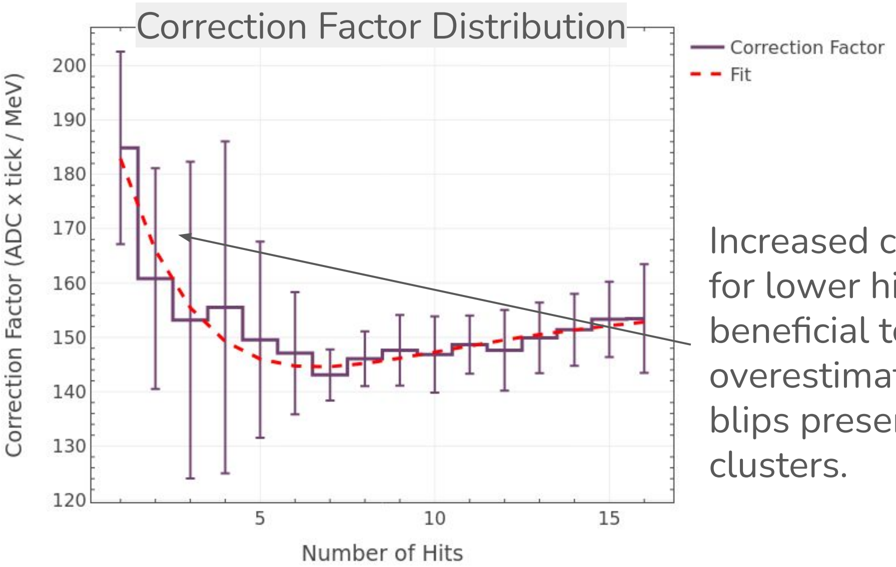
Over/Under Corrected Clusters

- Lower energy neutrinos more likely to overestimate charge. Possible threshold effects? Less secondary production, increasing visible energy?
- Conversion of **electron/gamma deposited charge not identical**.



Correction Factor vs NHits



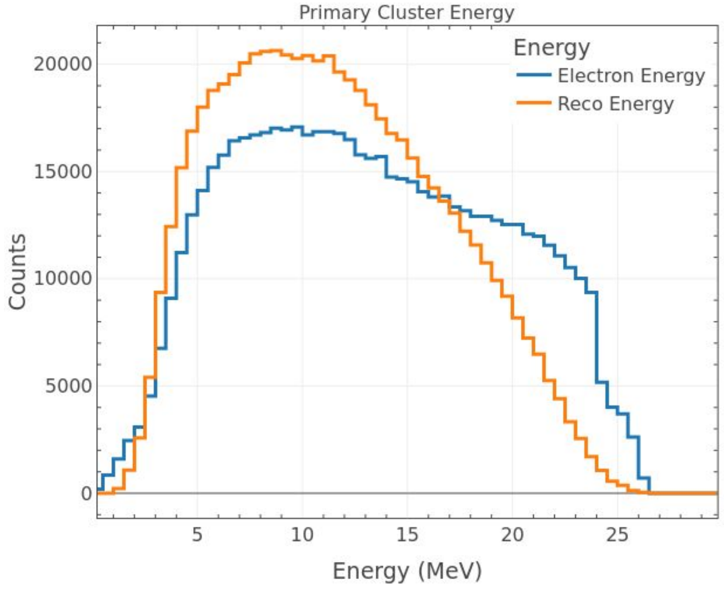


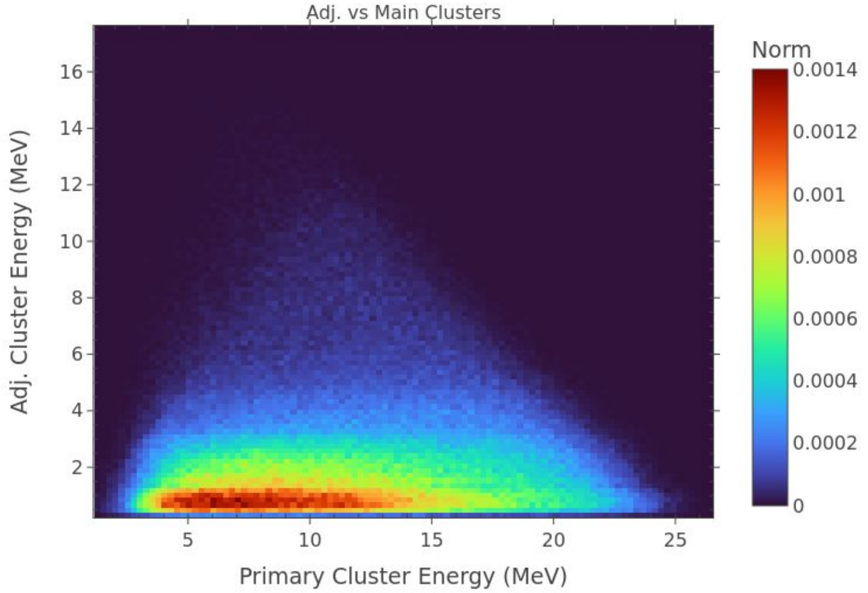
Increased correction factor for lower hit count is beneficial to avoid overestimation of bkg blips present as adj. clusters.

- Number of hits is quite low. For 1 MeV electron only ~1Hit on average
- Use **effective correction factor** from electron charge and calibrate clustered data at a later stage.

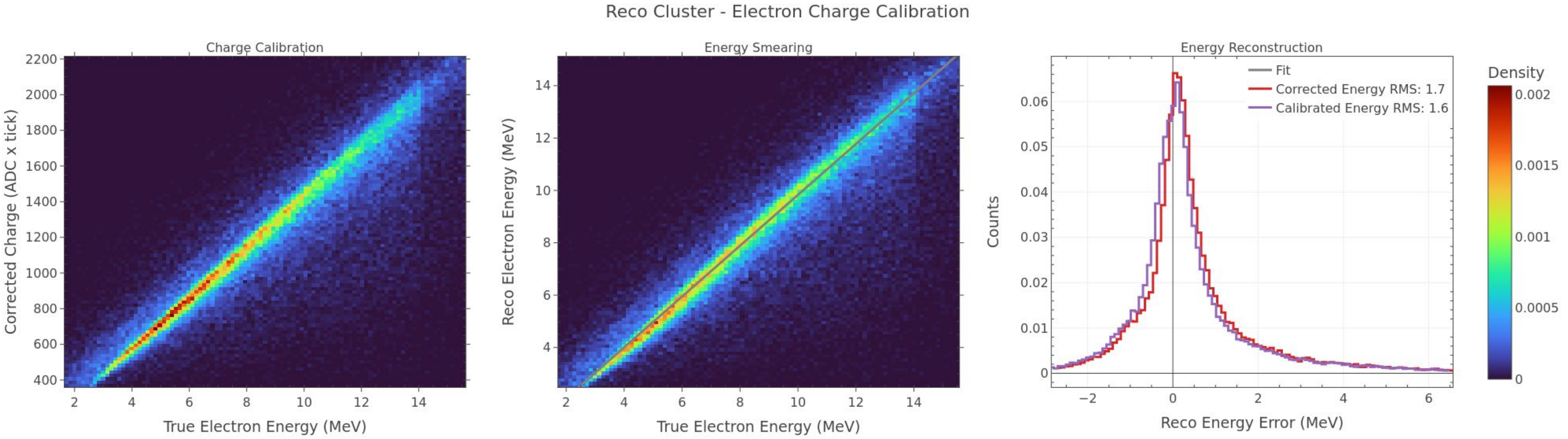
Electron Energy Reconstruction

- Reconstruction of electron sample. Reconstruction method slightly biased towards lower energy due to secondary interactions at higher values.





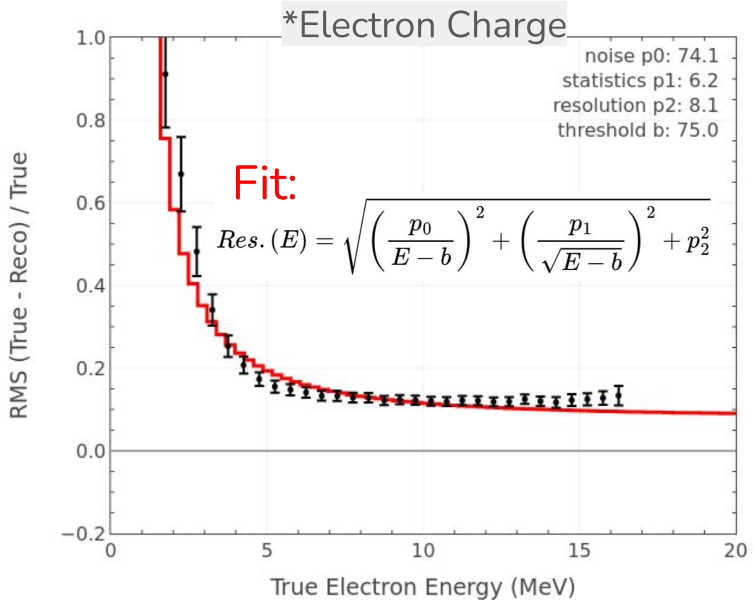
Electron Cluster Reconstruction

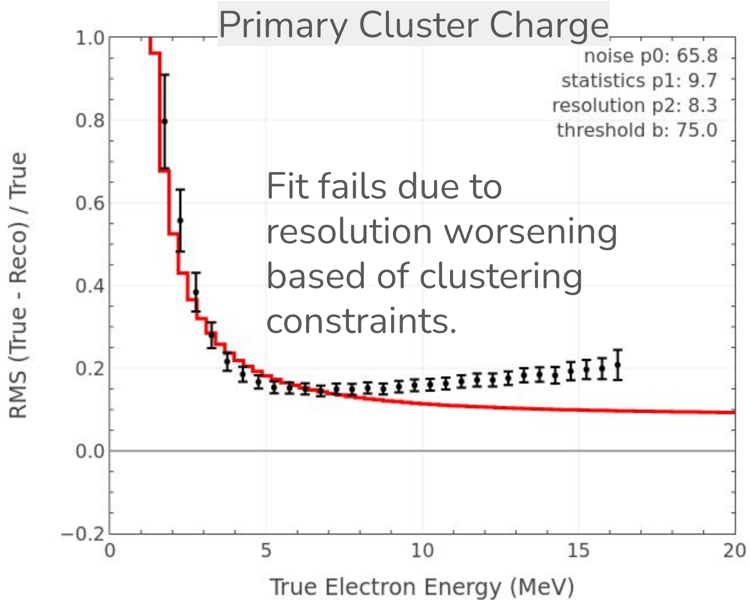


- Calibrate cluster energy to compensate use of **correction factor** from electron charge.
- Need to think about sample weighting. Probably better to weight original spectrum to solar CS.

Electron Energy Reconstruction

- Compute RMS to estimate low energy electron resolution.





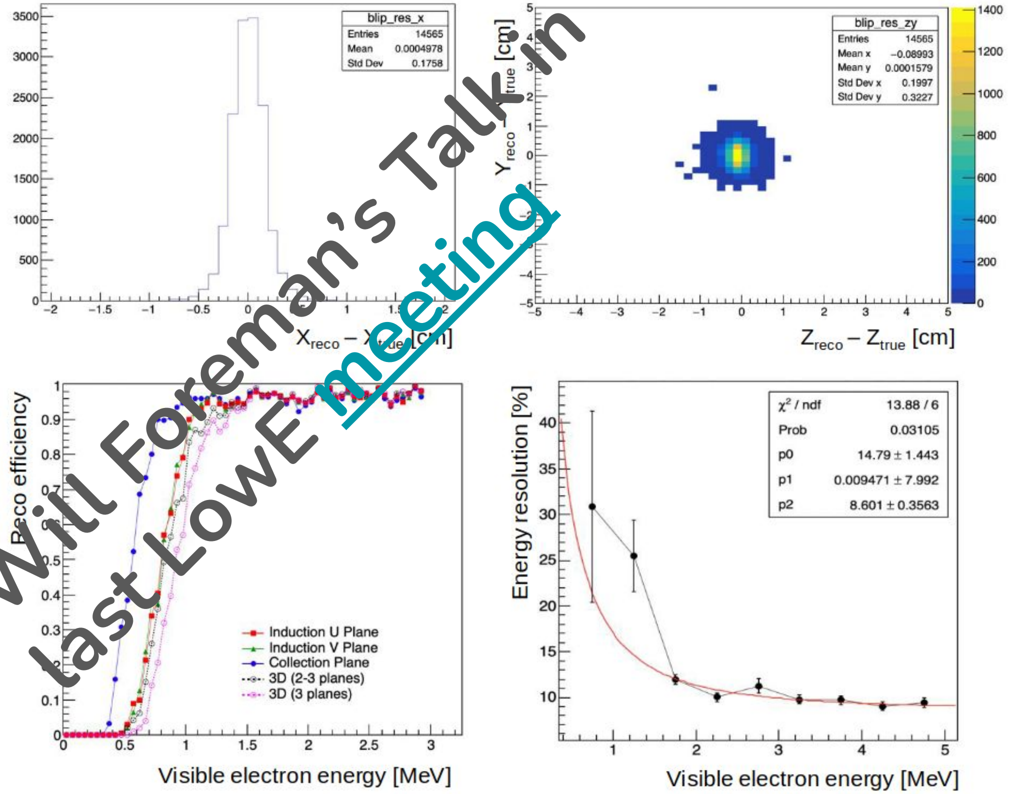
*Electron Charge is collected from all electron clusters (primary + adj.) using truth information.

Energy Reconstruction: Microboone Comparison

Position resolution
$\sigma_x \sim 0.18$ cm
$\sigma_y \sim 0.32$ cm
$\sigma_z \sim 0.20$ cm

Energy resolution
$\sigma_E \sim 10\%$ for > 1.8 MeV
$\sigma_E \sim 20\text{-}30\%$ at 1MeV
(need more stats)

Energy threshold
> 95% above 1.3 MeV
>50% above 0.8 MeV
(0.6 MeV for 2D hits on collection plane)

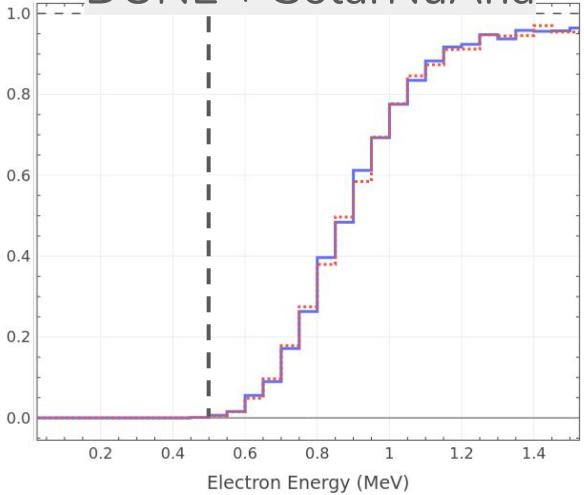


See Will Foreman's Talk in last LowE meeting

Energy Reconstruction: Microboone Comparison

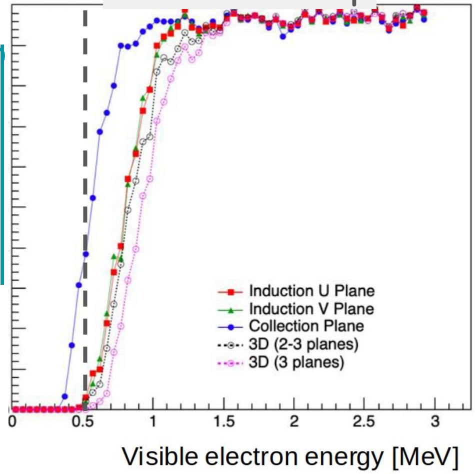
DUNE + SolarNuAna

LowE Event Selection



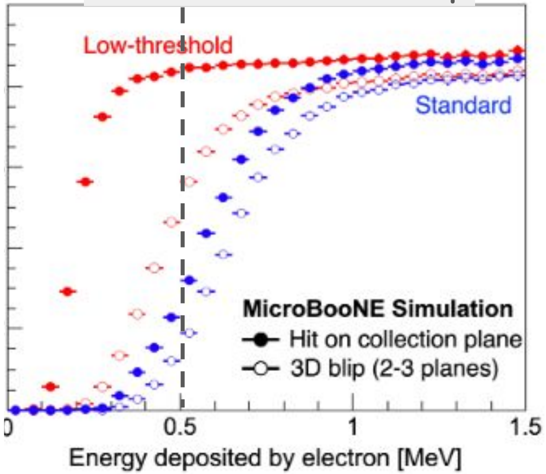
DUNE + Blip

Prev. LowE Meeting



Microboone + Blip

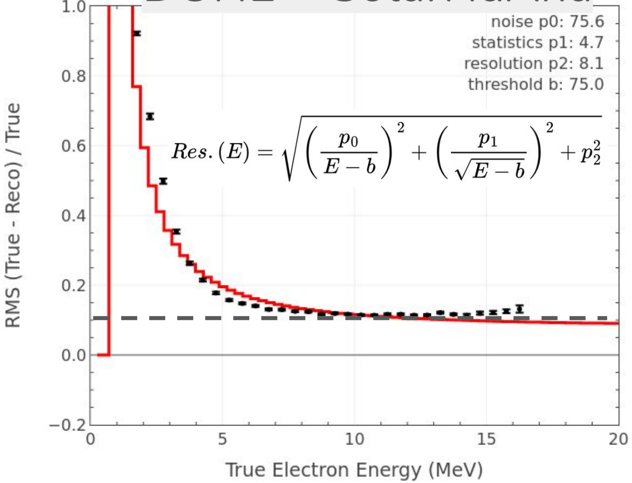
MicroBooNE Ambient Radon



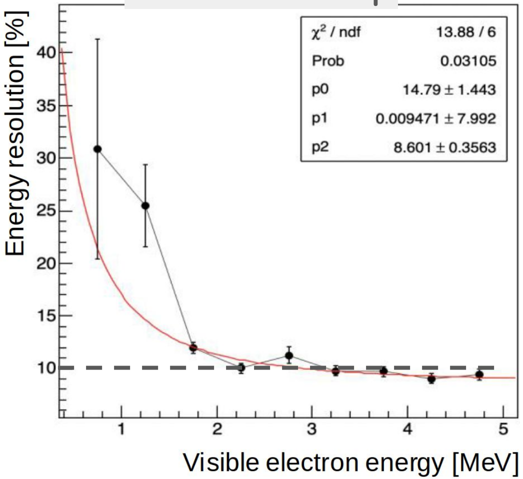
- Blip reconstruction delivers better results in microboone simulation.
- MicrobooNE has shorter wires and narrower pitch (3 mm).

Energy Reconstruction: Microboone Comparison

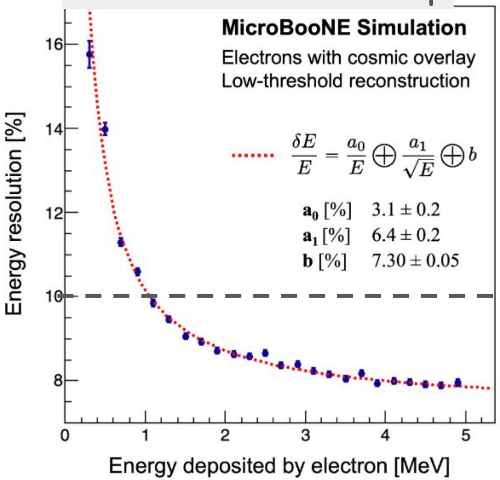
DUNE + SolarNuAna



DUNE + Blip



Microboone + Blip

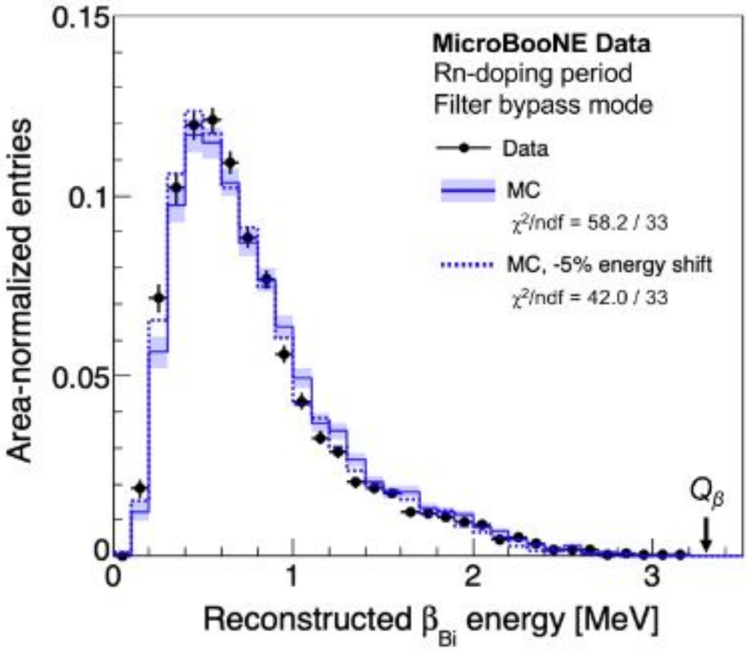


MicroBooNE Ambient Radon

- MicrobooNE implemented lowe changes in wirecell allowing better energy resolution and threshold.

MicrobooNE Comparison

MicroBooNE Ambient Radon



- Showing nice low energy result from MicrobooNE. **Is this possible in DUNE?**

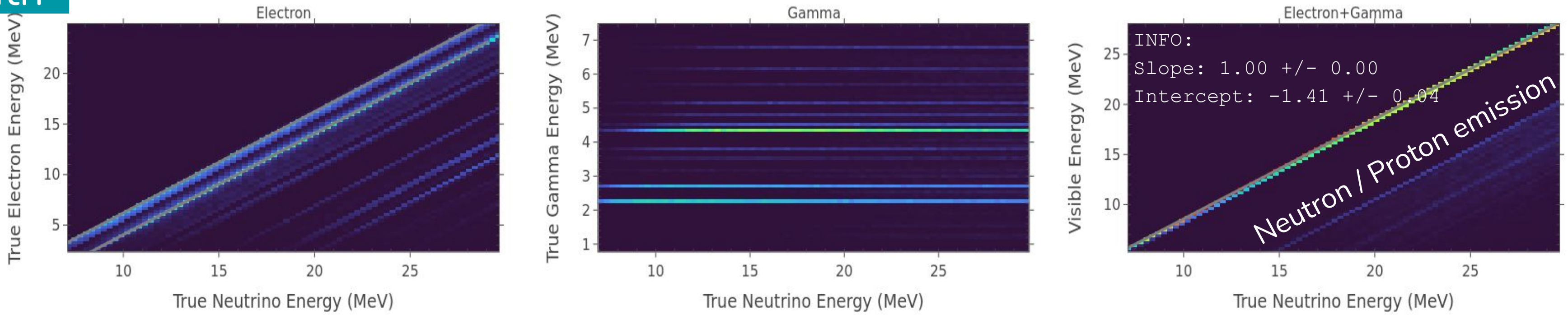
	MicrobooNE Low-Thld	MicrobooNE Standard	DUNE
Detection Threshold	0.2 MeV	0.3 MeV	0.5 MeV
Threshold 80% eff.	0.8 MeV	1 MeV	1 MeV
Energy Resolution	8%	—	10%

Reconstruction

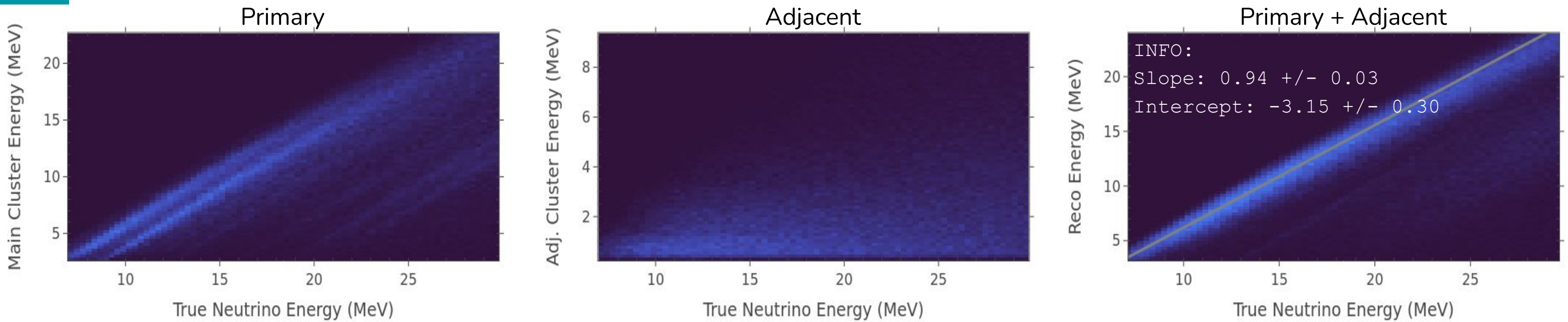
Neutrino Signal and Background Comparison.

Neutrino Energy Reconstruction

Truth



Reco

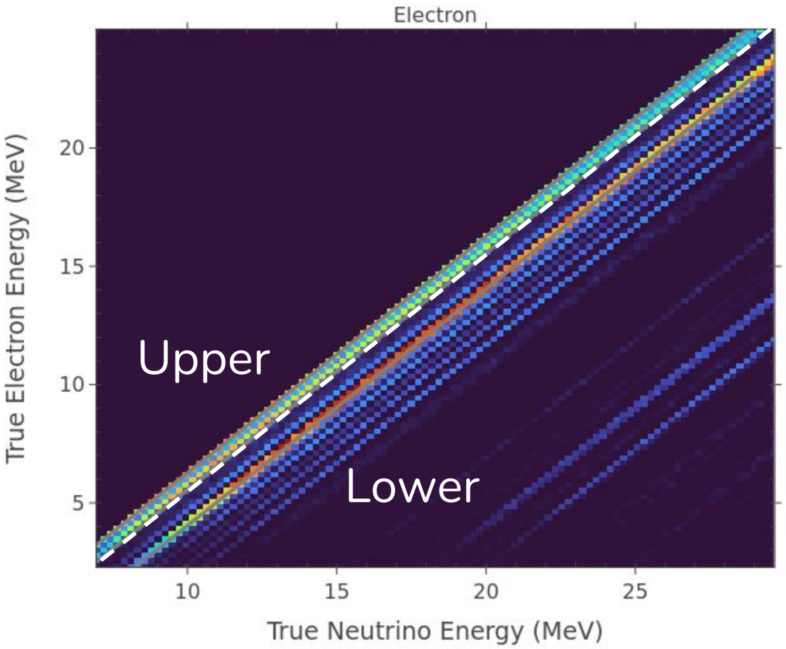


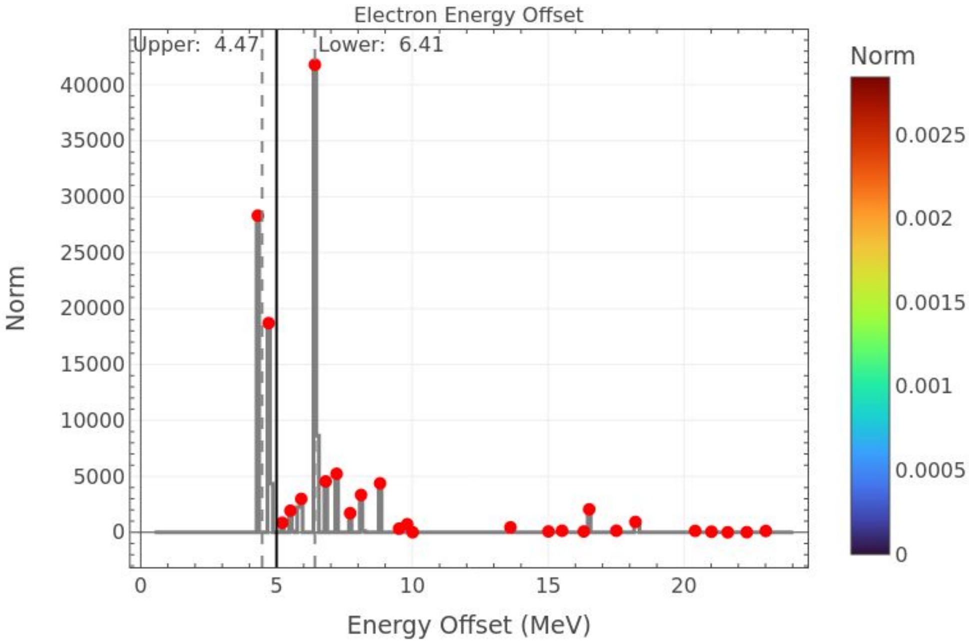
Energy Reconstruction Algorithms

- Developing and comparing 3 methods for neutrino energy reconstruction:
  - TotalEnergy: Add to the energy of the main cluster (electron candidate), the energy of the adj. clusters (gamma candidates) within 1m radius.
  - SelectedEnergy: Same as prev. but select a subset of adj. clusters based on cuts wrt background cluster distributions (here considering clusters closer >20cm, but other cuts could be applied see slide).
  - **SolarEnergy**: Reduce the problem of adj. clusters to an effective offset of 4.47 or 6.41 MeV of energy, compensating for Q value (1.5 MeV), the electron mass (0.5 MeV), prominent gamma lines (see slide) and effective average losses of CC process (see slide).
- Additionally, in all cases, I apply a final linear correction that I extract from the plot on slide.

Neutrino Signal: SolarReco Strategy

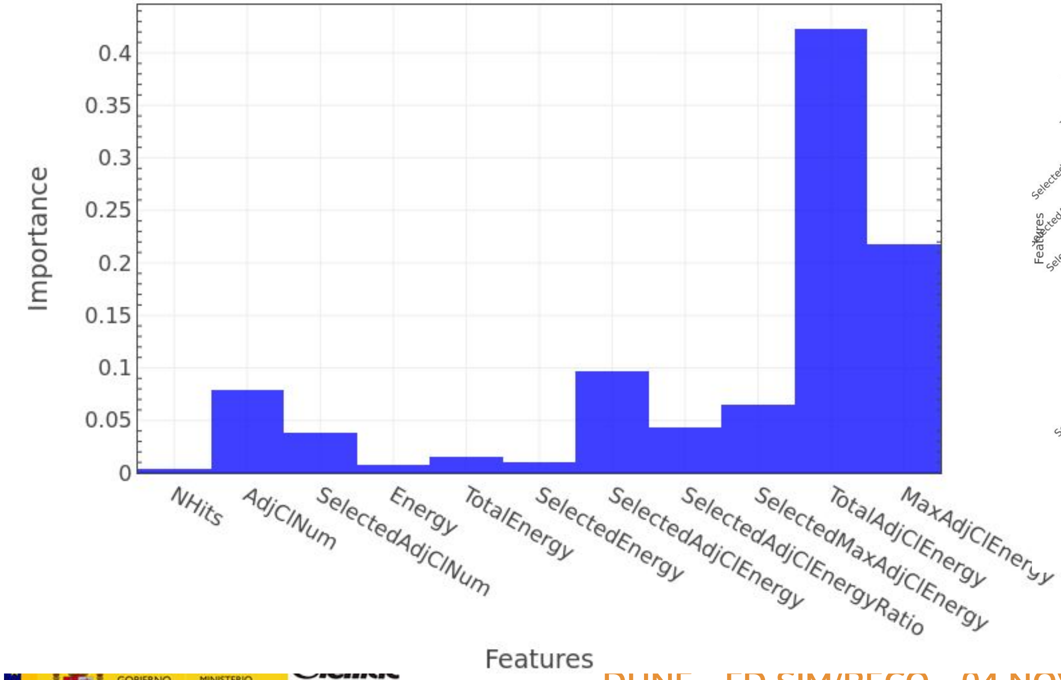
- Use ML (BDT) model to discriminate between **Upper** and **Lower** electron populations in energy offset and compute effective neutrino energy.

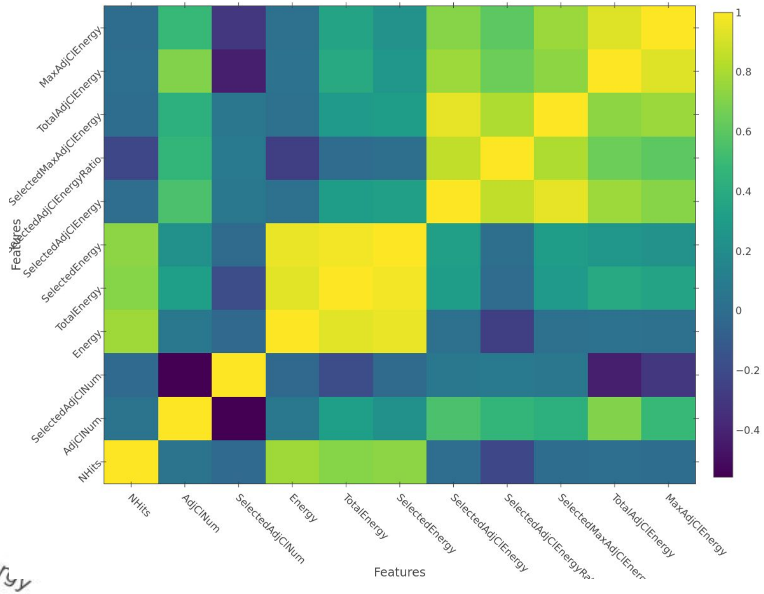




SolarReco: ML Feature Importance

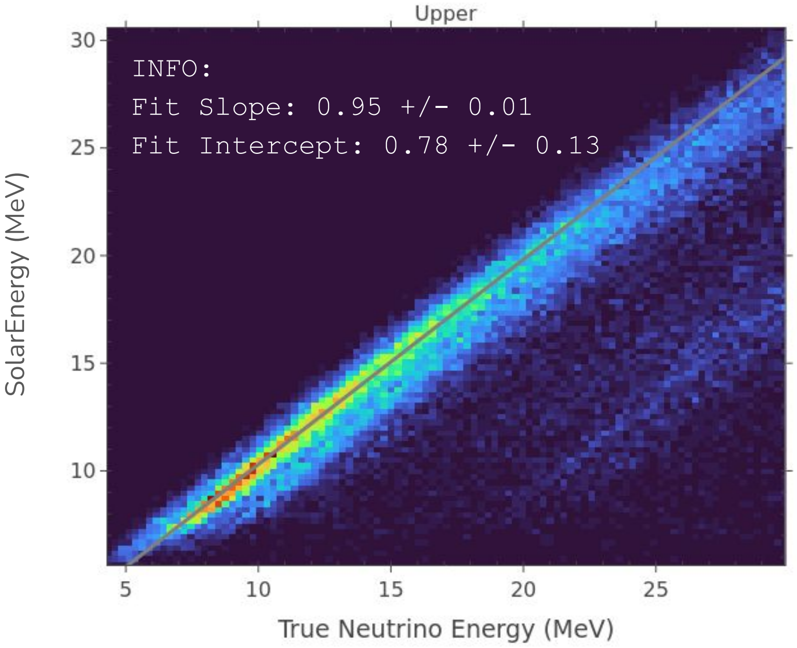
- ML model takes as an input primary cluster and adj. cluster main variables.
- Most important are total adj. cluster and max. adj. cluster energies.

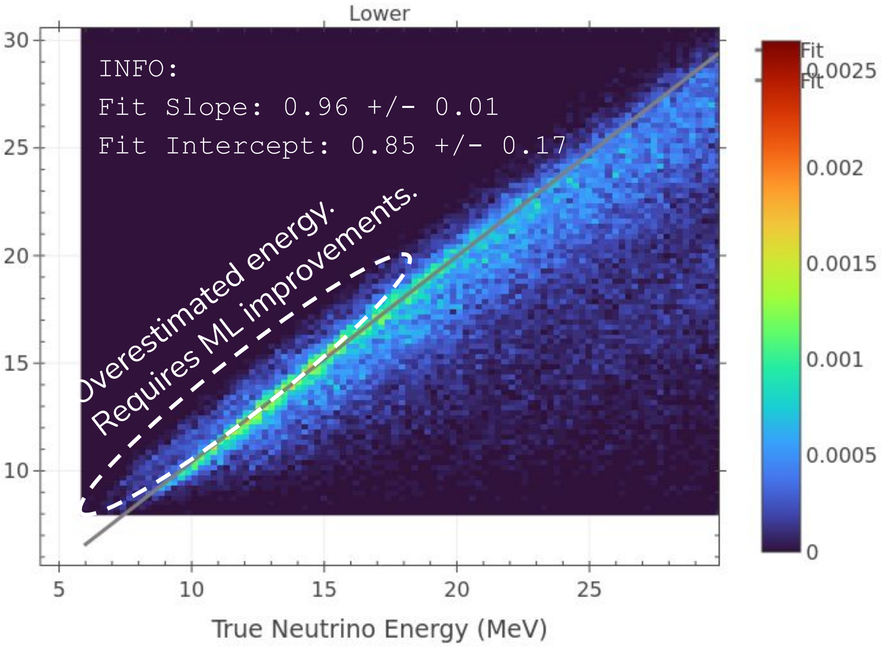




Smearing Matrices for ML Samples

- Check energy reconstruction of both samples.

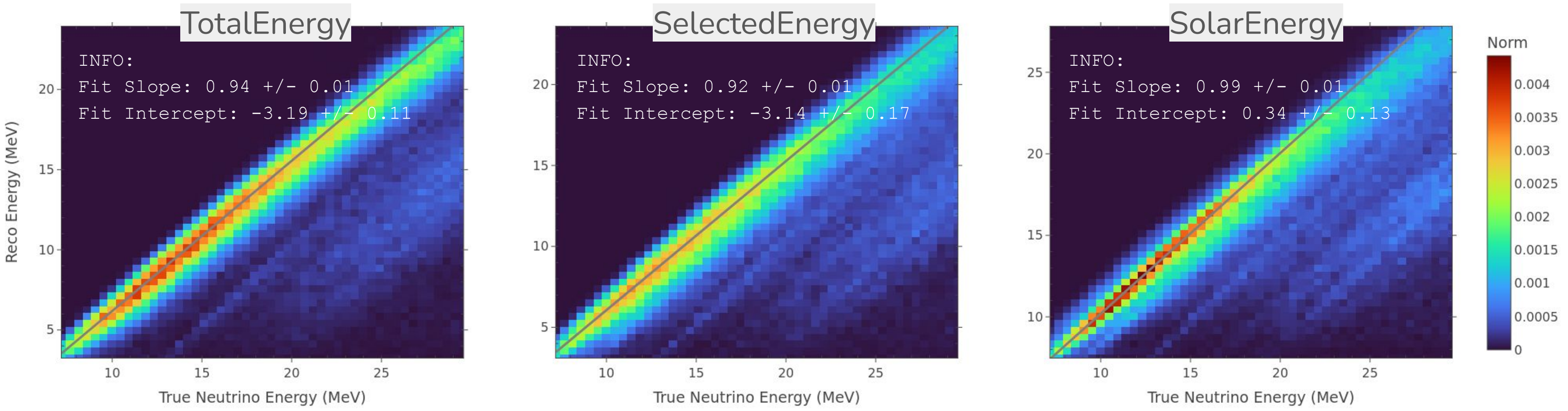




Neutrino Energy: Smearing

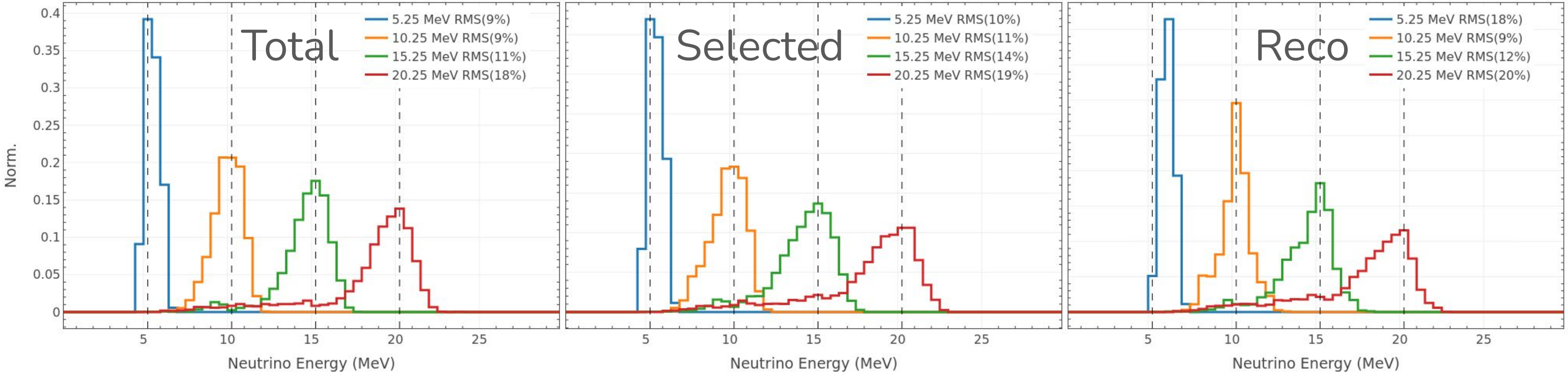
Additional Neutrino Energy Calibration Computed from Smearing:

- Match neutrino energies by correction for slope and intercept of the distributions.
- Compensate for Q-value (1.5 MeV), electron mass (0.5 MeV) and additional effects.



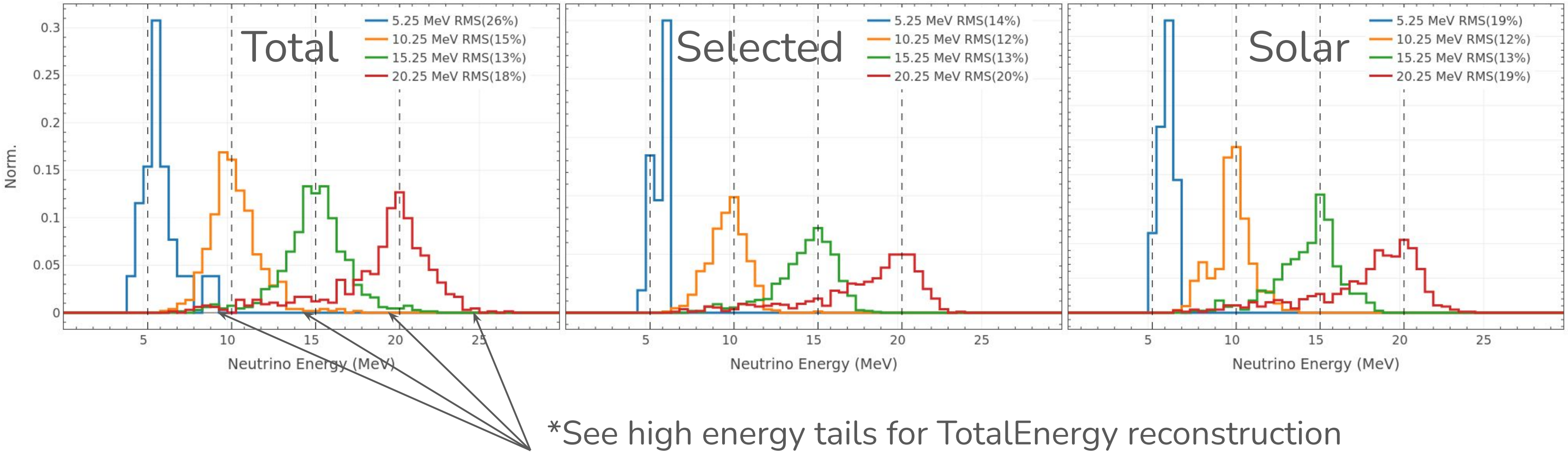
Neutrino Energy Reconstruction

- Showing signal Energy Reconstruction.
- As expected we identify worsening of resolution for higher energies due to secondary productions and nuclei emission.



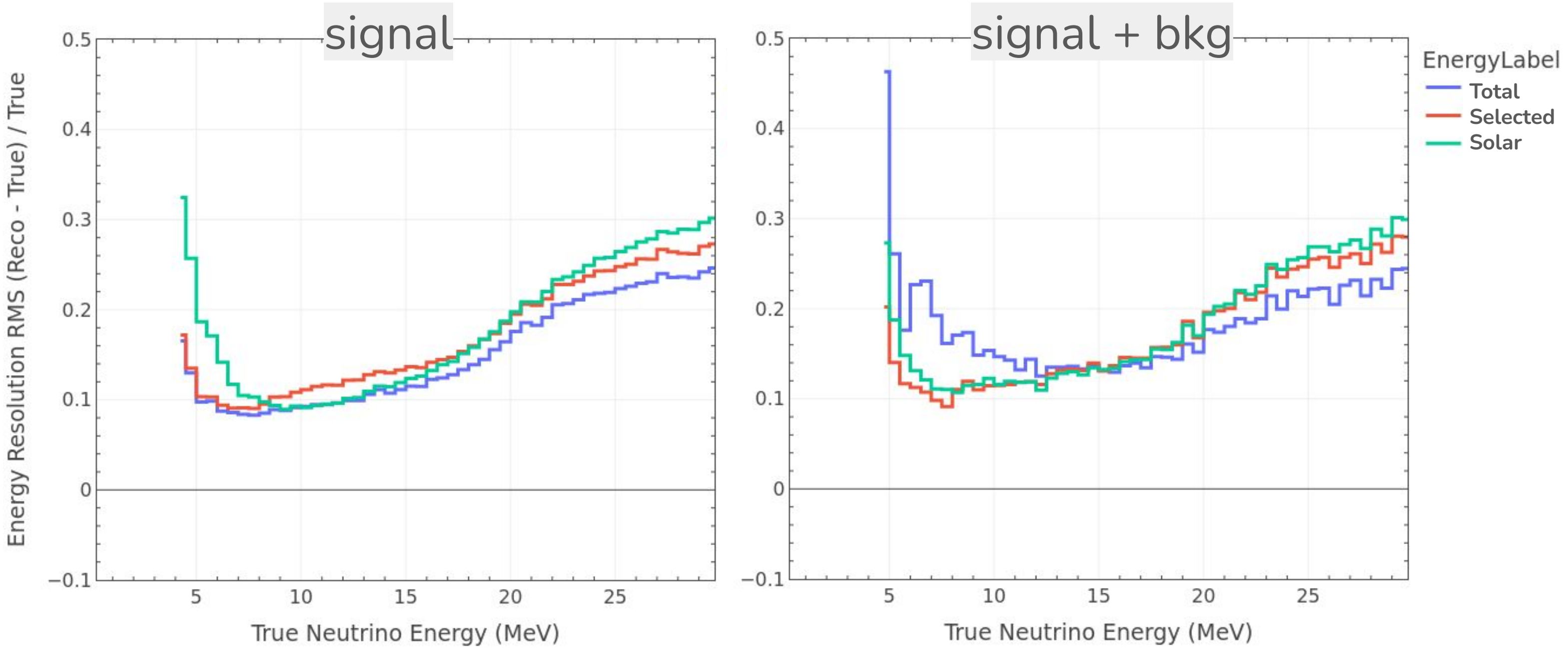
Neutrino Energy Reconstruction Examples

- Signal + Bkg Energy Reconstruction.
- Background influence on signal reconstruction is noticeable*.



*See high energy tails for TotalEnergy reconstruction up to 10 MeV overestimation in low stats production.

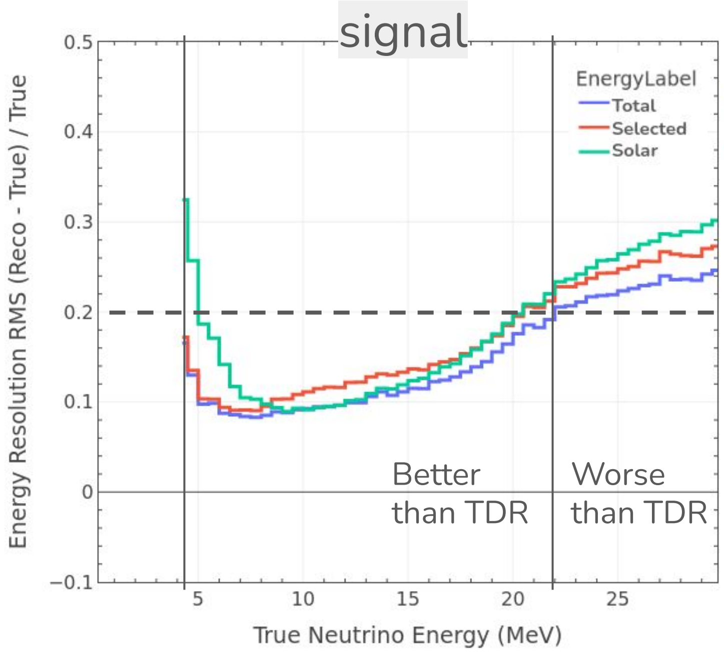
Neutrino Energy Resolution (RMS)

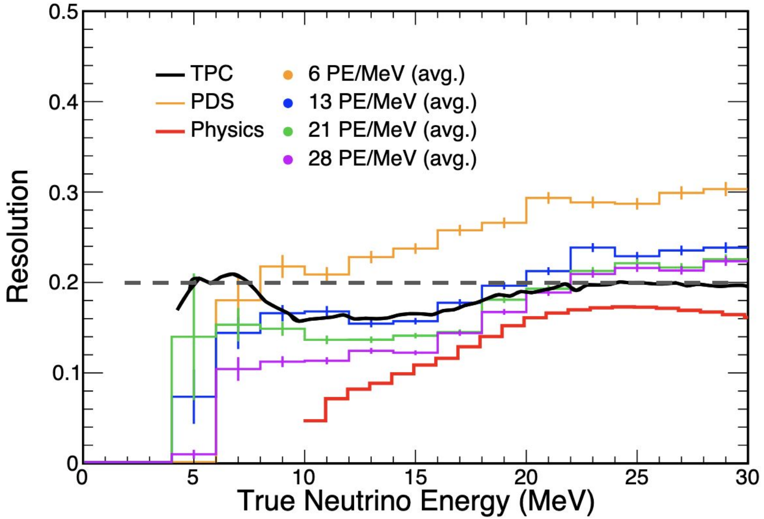


- Different calibration methods result in similar energy resolution for signal samples.
- In the case of signal + background, the "TotalReco" algo. clearly worsens low energy resolution.

Resolution Comparison

- Low energy reconstruction (**this work**) leads to better results. Need to understand losses compared to TDR samples at higher energy.



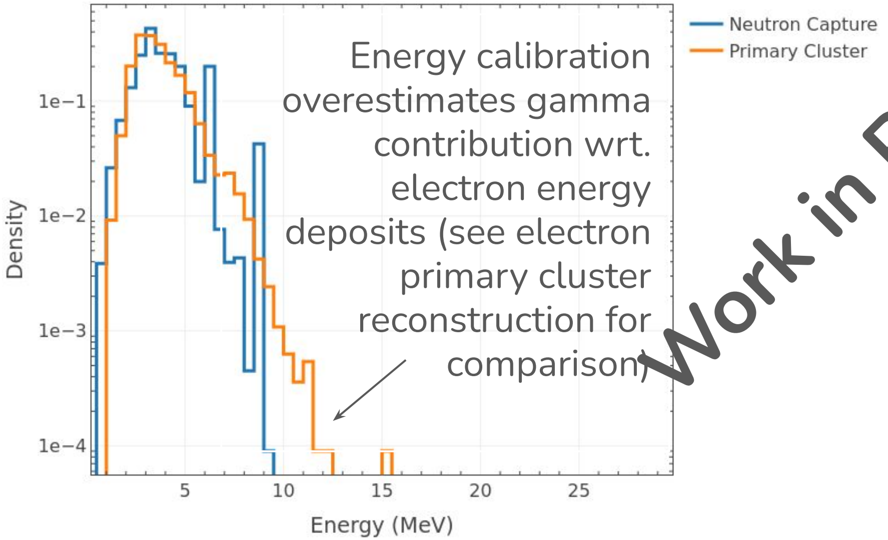


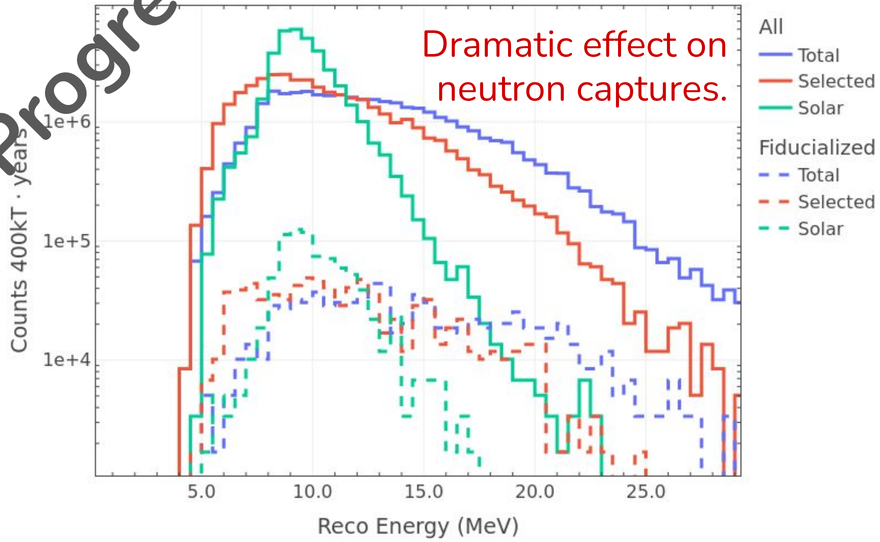
*TDR Uses pmtrack reconstruction with ideal electron charge clustering

Reconstructed Neutron Capture Energy

- Blindly applying reconstruction to neutron capture sample.
- Both primary cl. energy and reconstructed energy lead to **high values**.
- **SolarReco is the best algorithm** to mitigate impact of high reconstructed energies.

Work in Progress!





Summary

- Implemented low energy calibration for CC neutrino events.
- Showed updated results for energy resolution and detection threshold.
- Developed different strategies for neutrino energy reconstruction:
    - **SolarReco** being a ML approach to add a specific maximum energy to the primary cluster given adjacent topological information.
    - Proven to be the most reliable in the context of full background and specifically for Neutron Captures (most challenging for the solar neutrino analysis).
- Presented work in progress of PDS matching effects on energy reconstruction and fiducialization for the example of neutron captures.

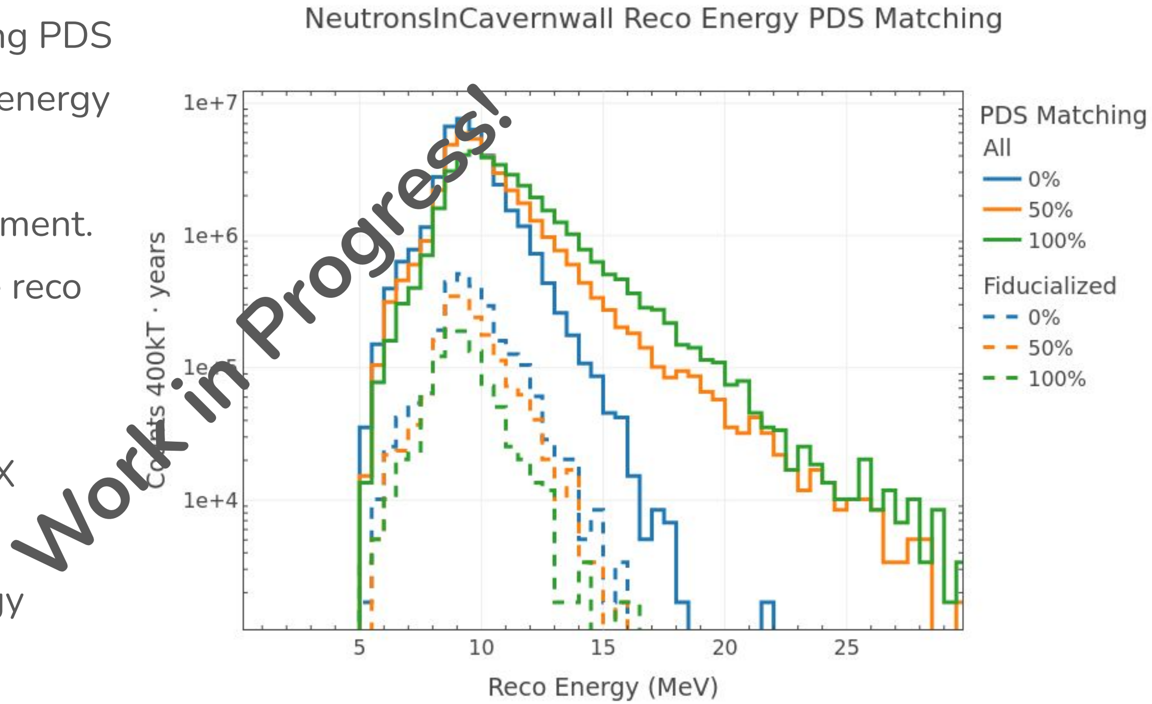
Next Steps

- Evaluate charge calibration based on **pure electron sample** and understand impact of sample weighting (use flat spectrum or solar?).
- **Updated ML SolarReco** algorithm **from BDT to CNN** returning a continuous adj. cluster energy estimator.
- Further investigate neutron signal. Current simulation/calibration seems to overestimate contribution. Does **gammas energy need separate calibration**?
- Evaluate official production.
- **Writing technote** about solar neutrino analysis in DUNE.

Backup

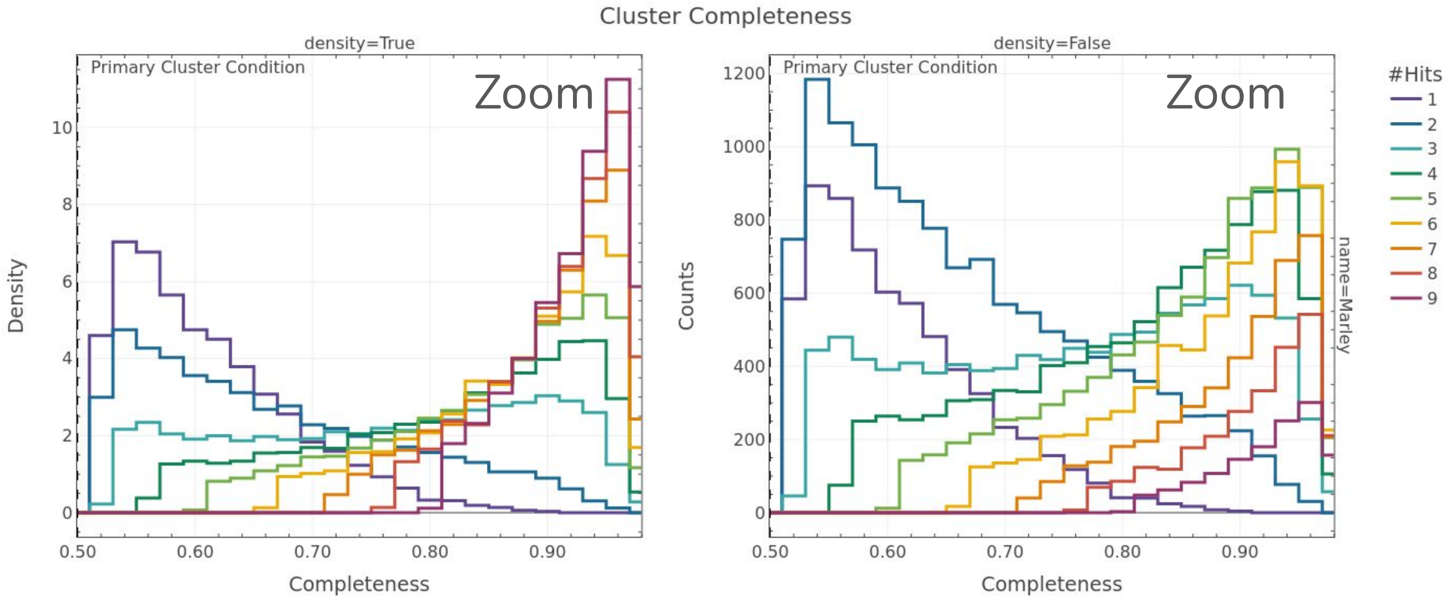
Bonus Slide: PDS Matching & Fiducialization

- Currently working on evaluating PDS matching scenarios while low energy flash is being optimized:
  - **0%** full random X assignment.
  - **50%** assignas half of the reco clusters random a X reconstruction.
  - **100%** assumes optimal X reconstruction.
- Assumptions affect both energy resolution and fiducialization.

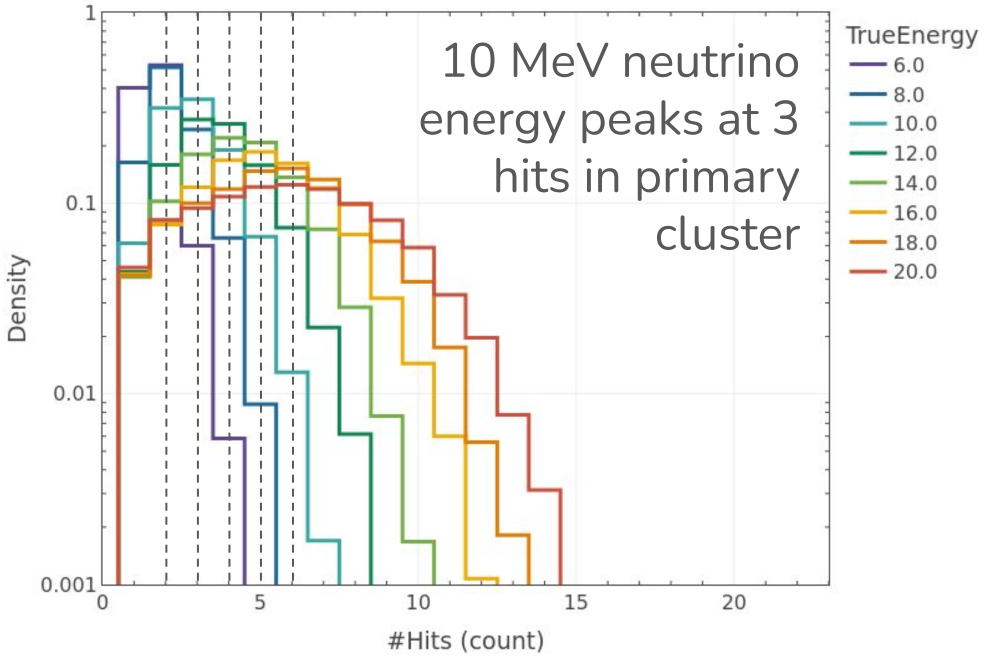


Primary Cluster Completeness

- **Electron Charge Completeness** (fraction charge in primary / charge in total cl.).
- **Increases with #hits**, best to consider +3Hit clusters for physics analysis.



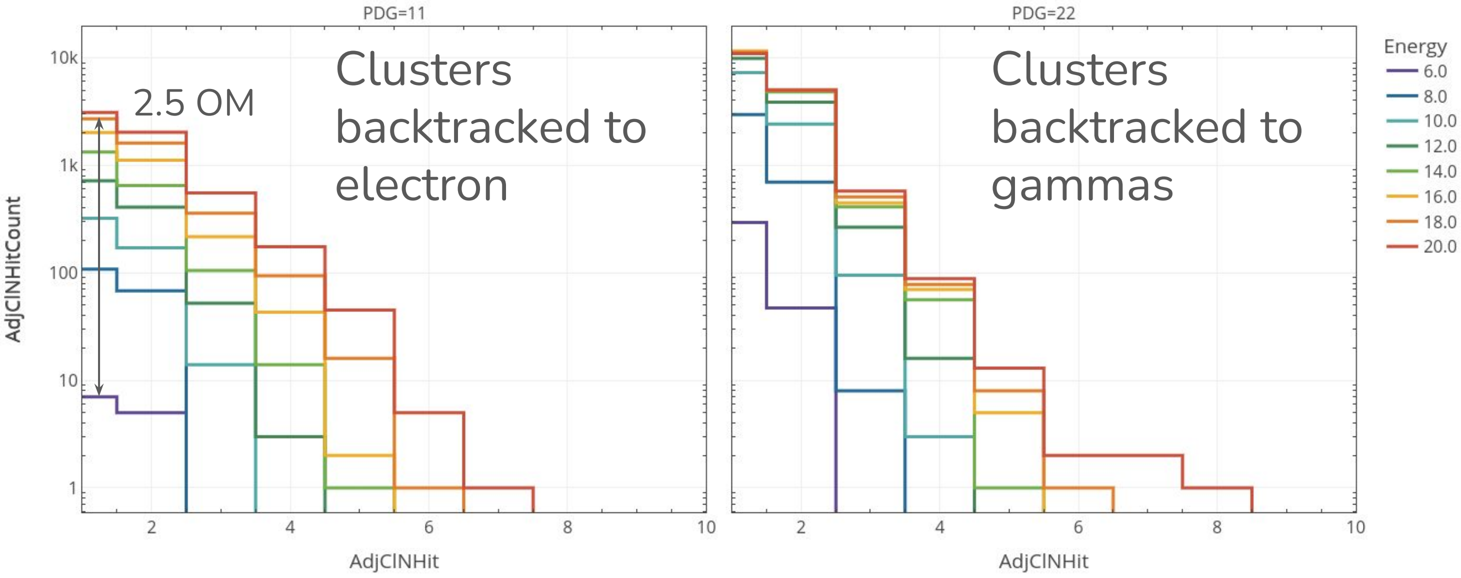
Primary Cluster #Hits



- For reference, #hits of primary cluster for different true neutrino energies.
- From 6 to 20 MeV the peak of #hits increases from 2 to 6 continuously.

Adjacent Clusters #Hits

- #AdjClusters increases with neutrino energy but all of them are typically 1 hit.
- Probability of electron generating adj. clusters grows 2.5 OM from 6 to 20 MeV.



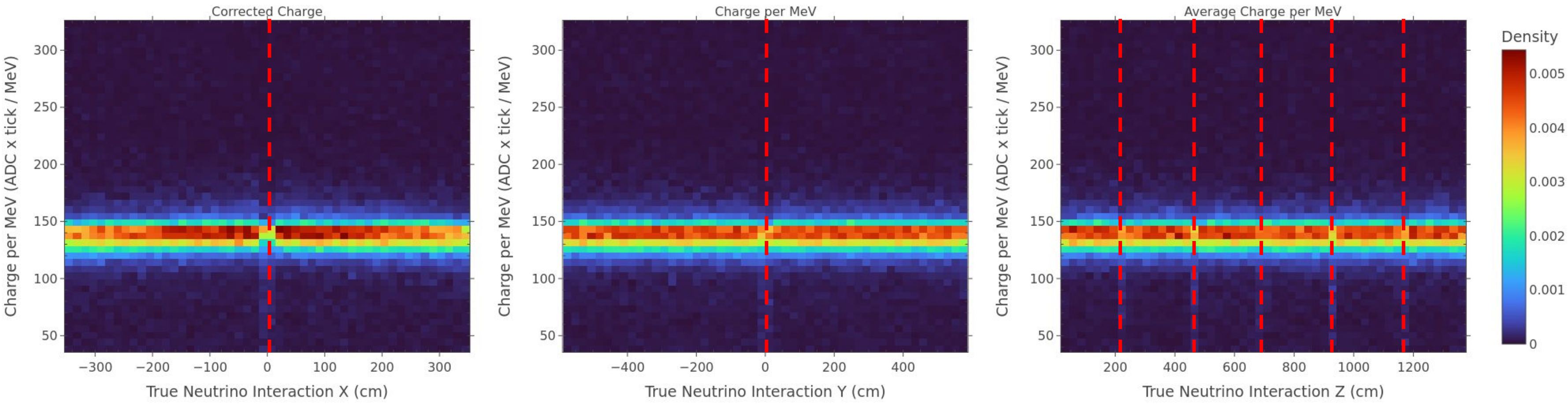
Electron Cluster Reconstruction

- See collected charge per electron energy vs detector coordinates.
- Ideal calibration factor affected by events occurring between APA borders.

X = 0 cm

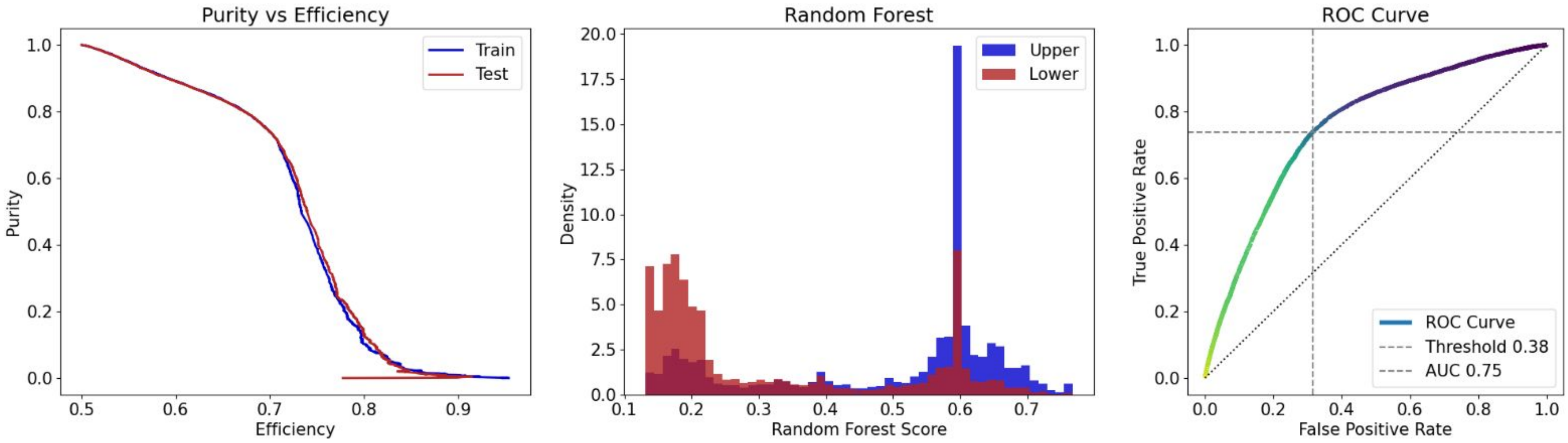
Y = 0 cm

Z = *232, 463, 695, 926 cm



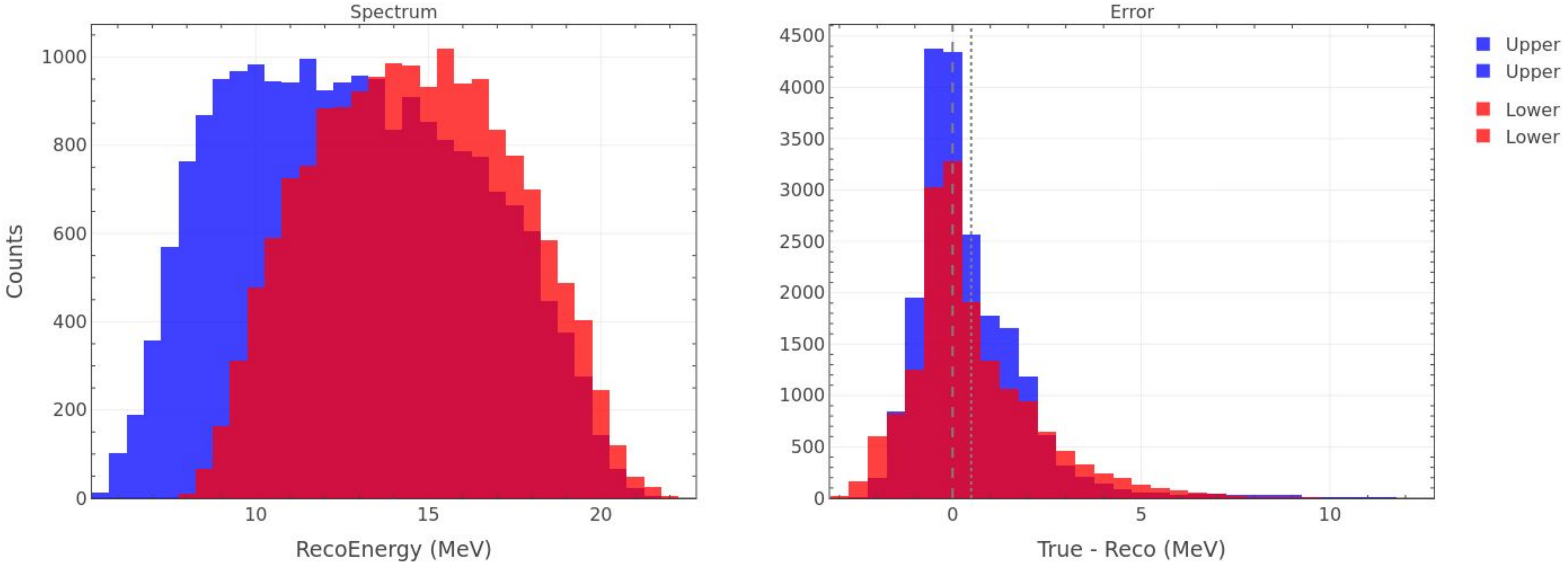
*APA width 2.316 m & hight 6.324 m

ML Selection Algorithm

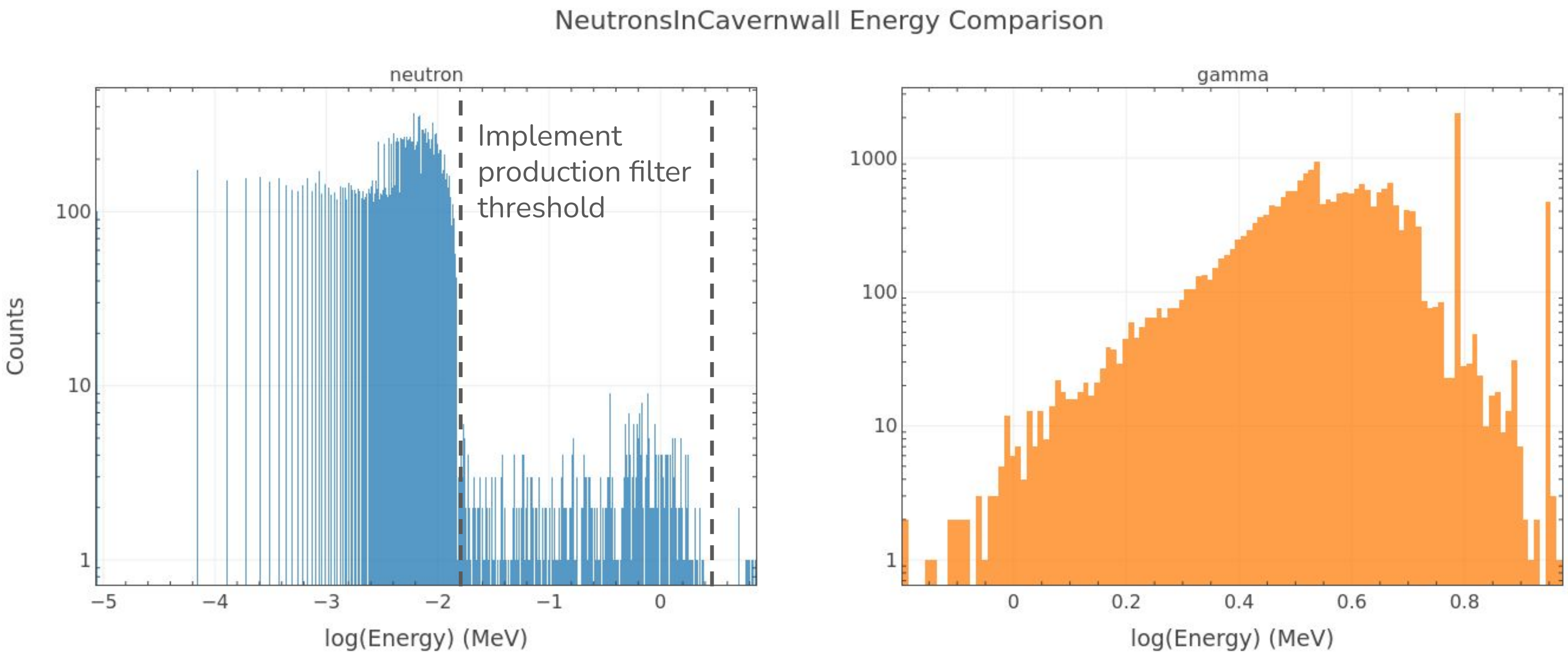


Neutrino Energy Reconstruction

- Resulting signal event distributions can be plotted to check consistency.

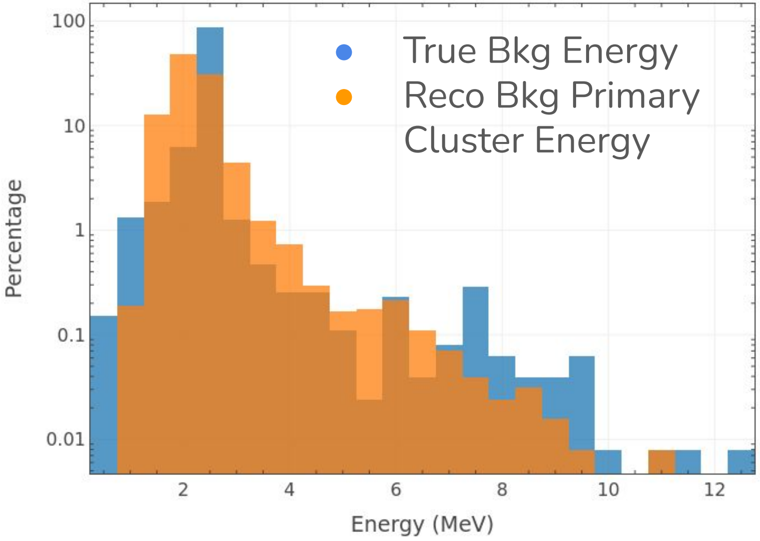


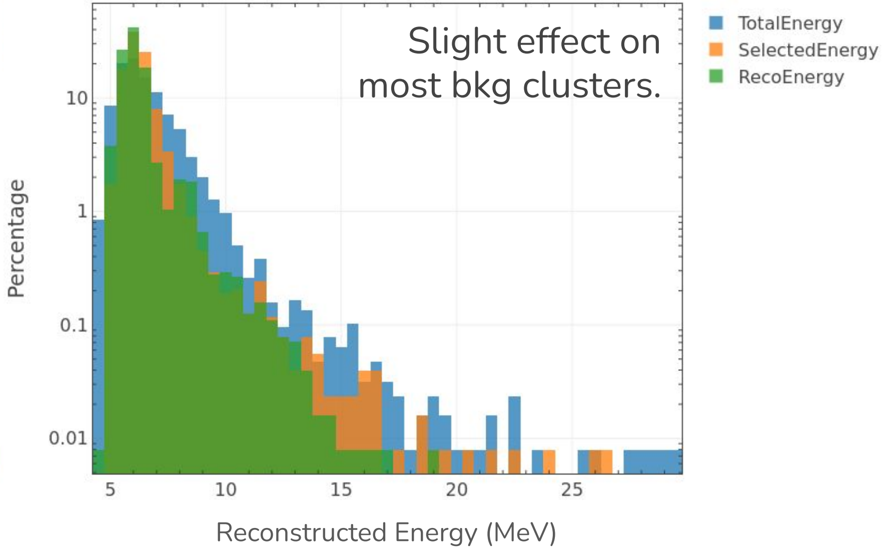
True Neutron Spectrum



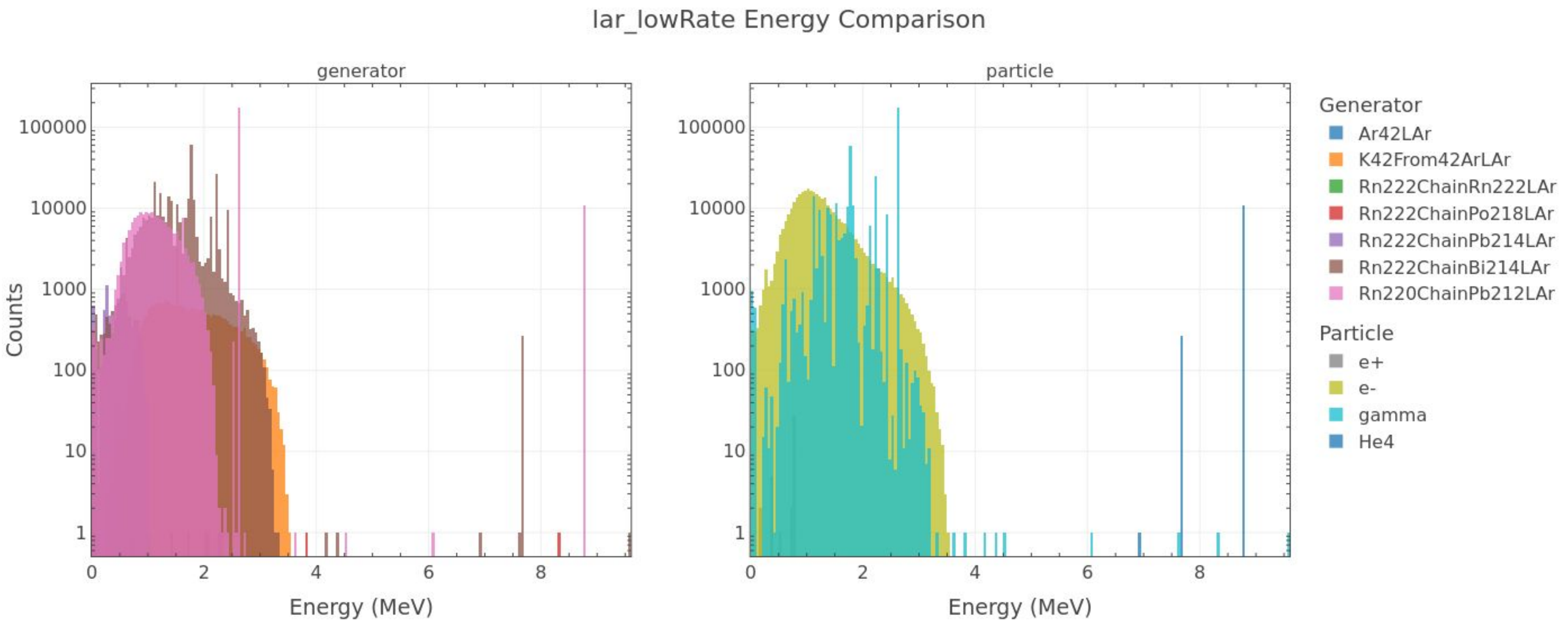
Reconstructed Background Energy

- Comparing backtracked cluster energy and reco energy.

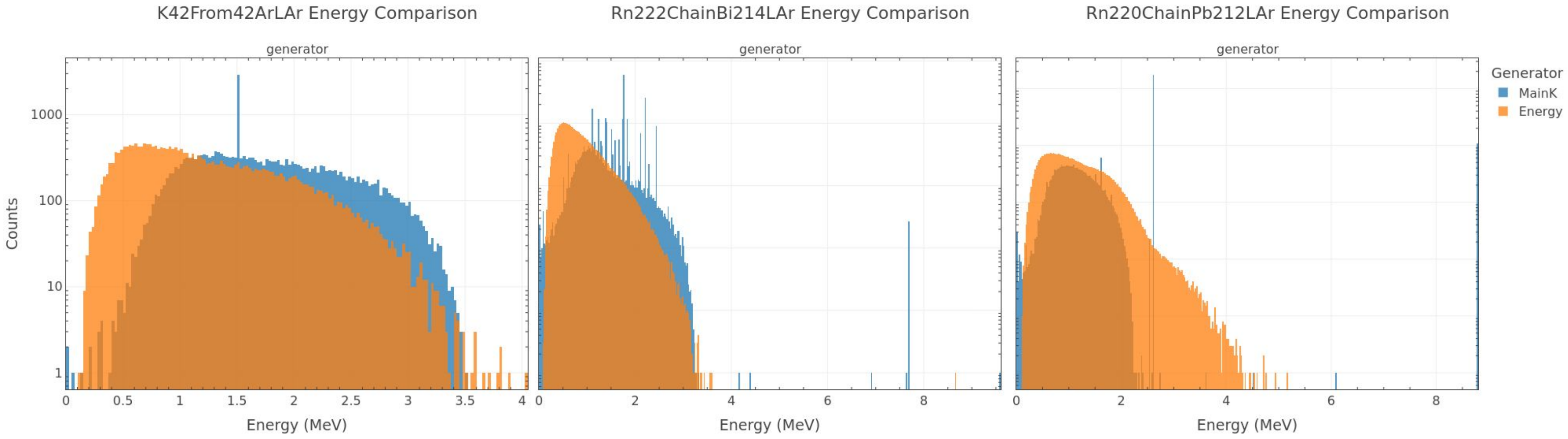




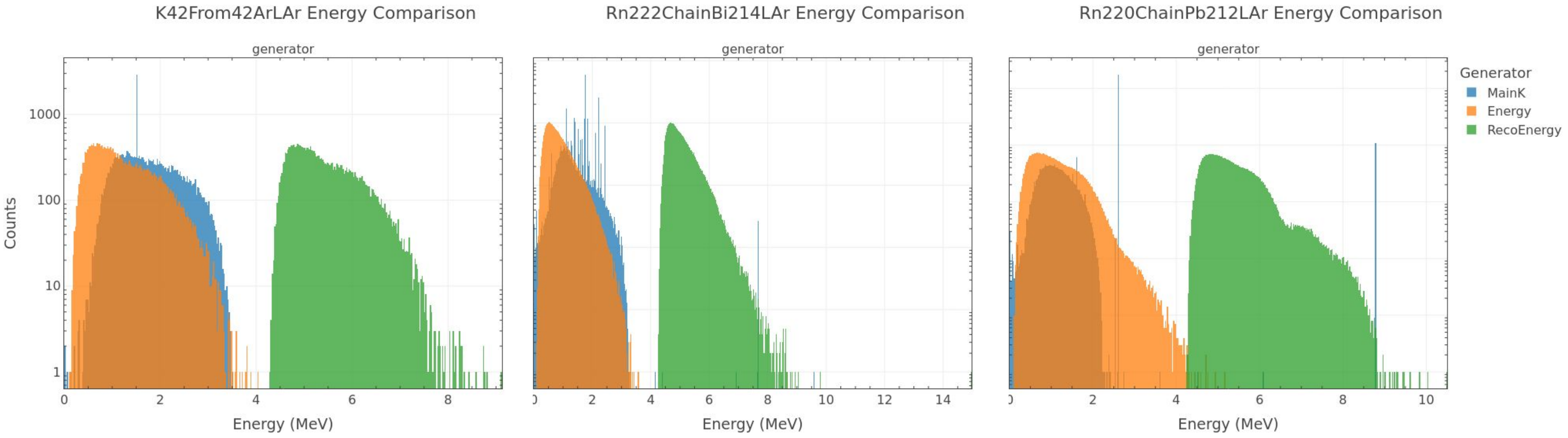
Intrinsic LAr LowRate Backgrounds



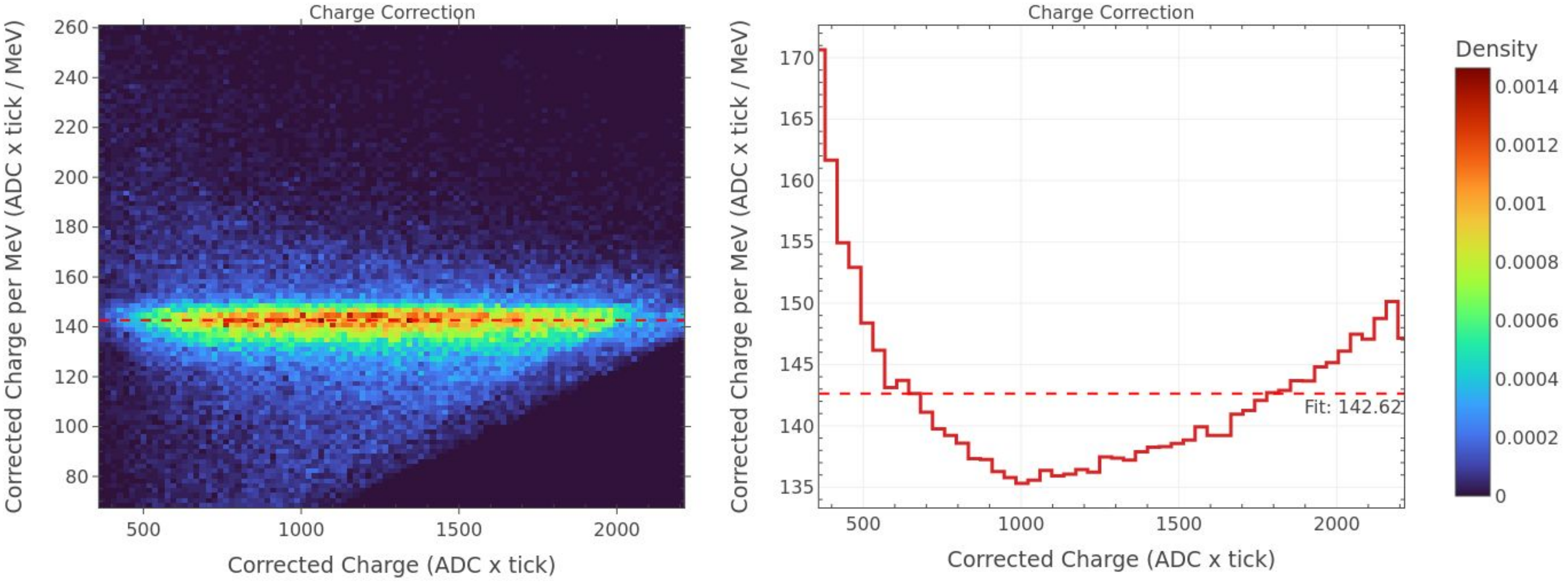
Reconstructed Background Energies



Reconstructed Background Energies

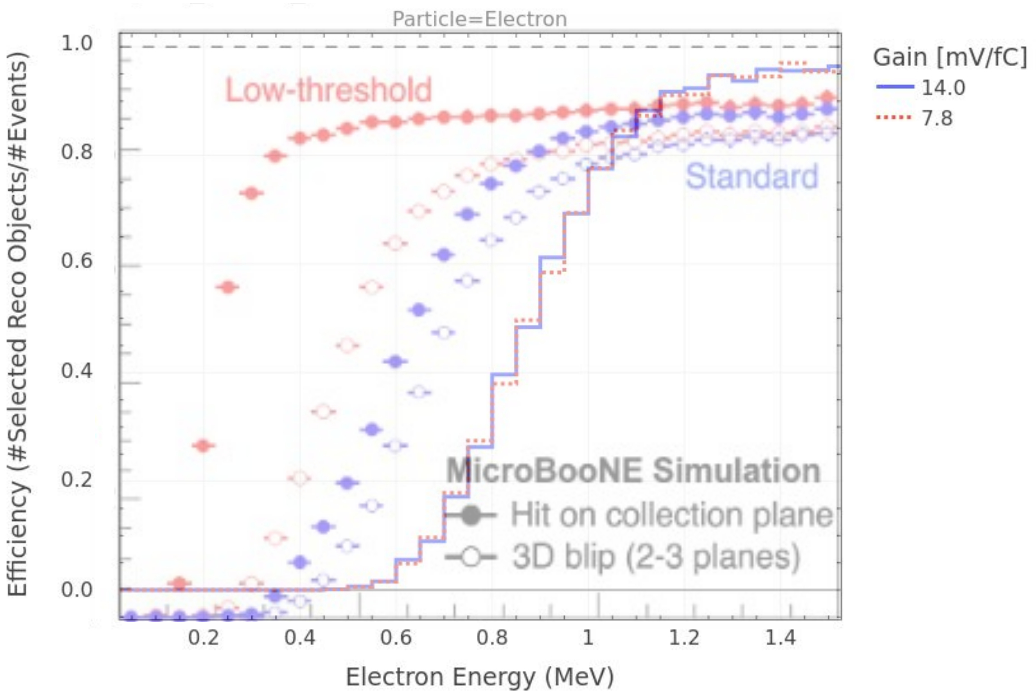


Electron Cluster Correction Check

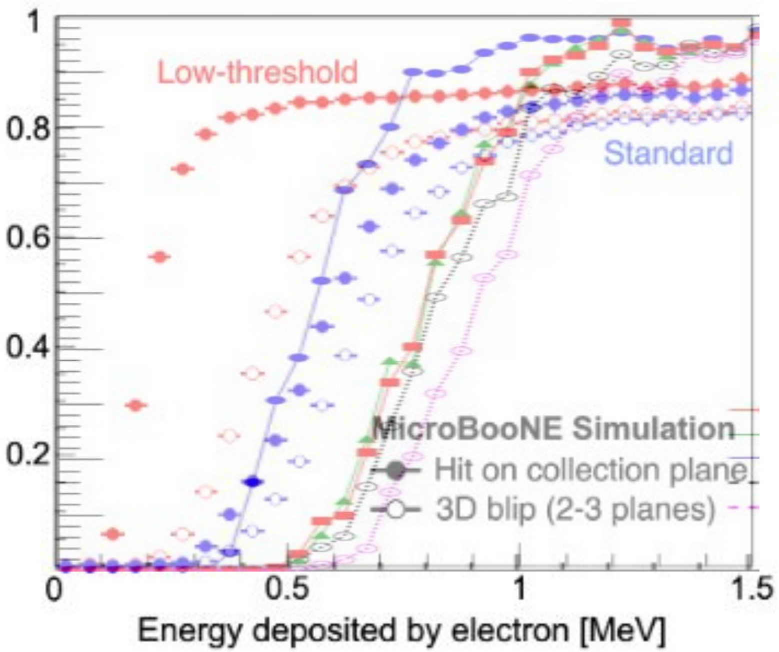


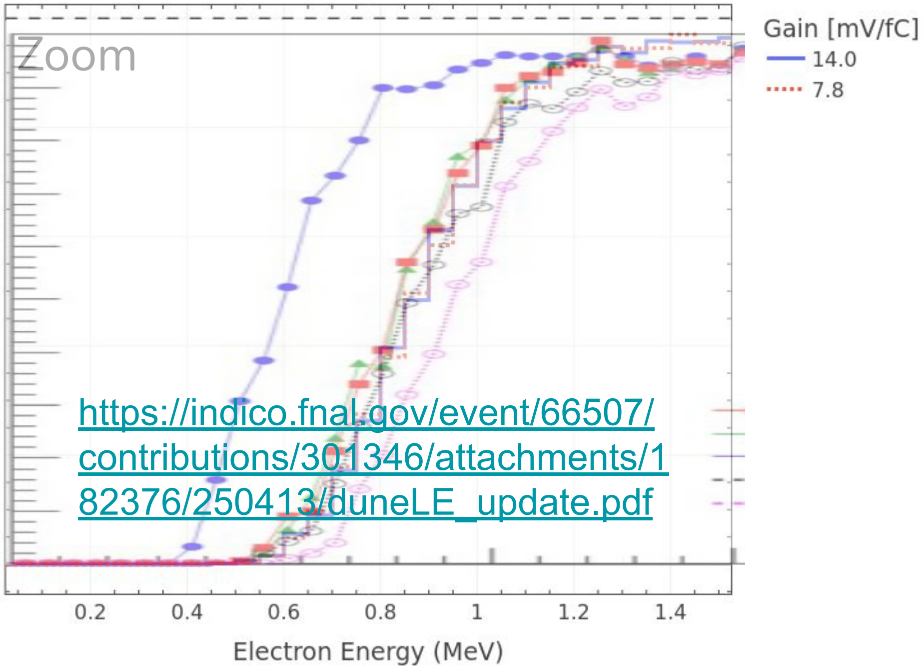
- Applying **truth correction factor** to primary clusters results in average correction factor shift.

Electron Threshold: Experiment Comparison



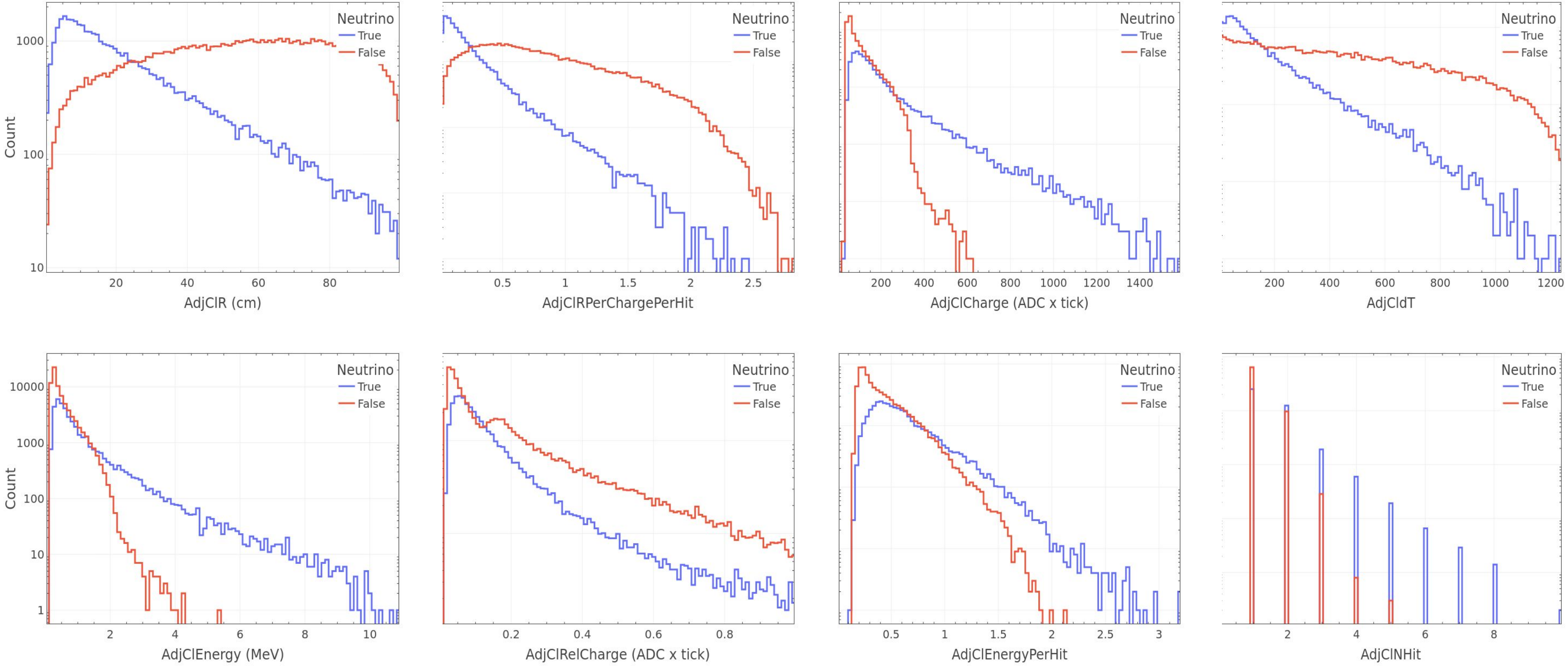
Electron Threshold: Experiment Comparison



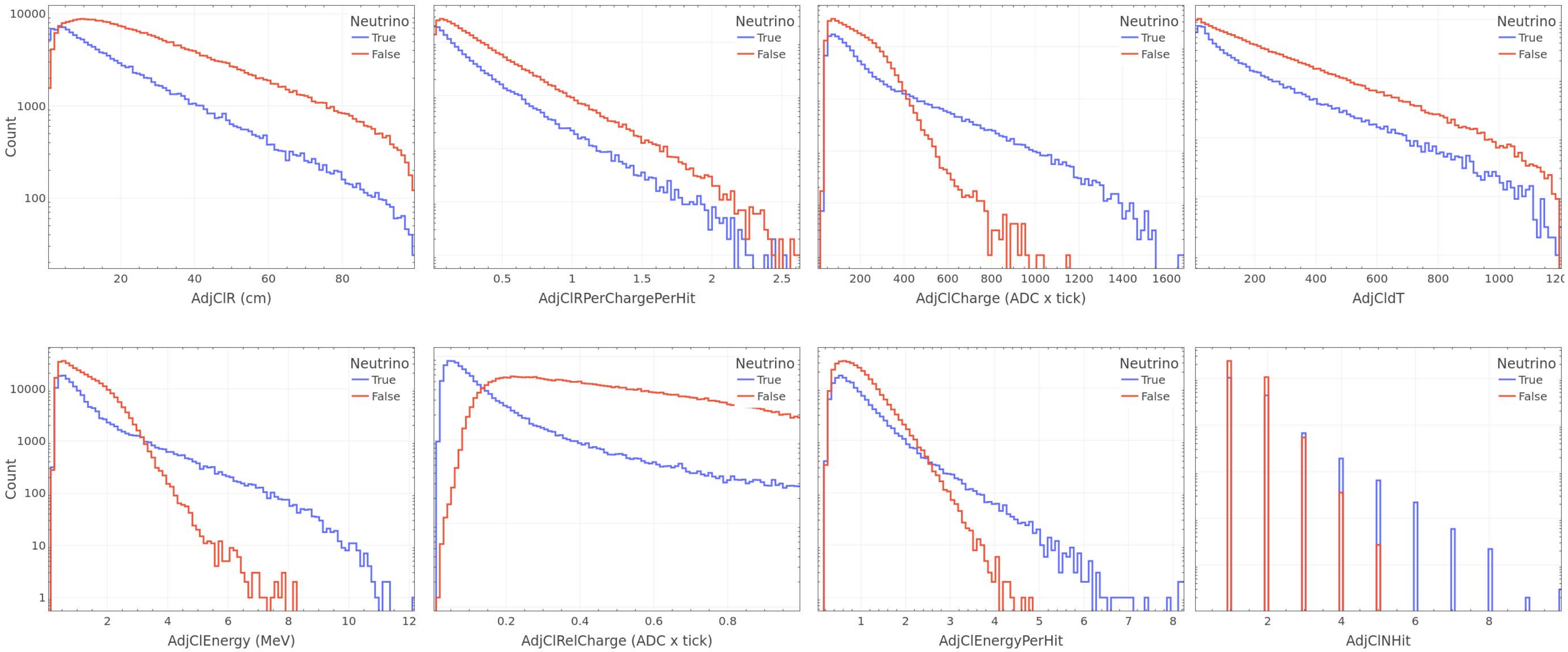


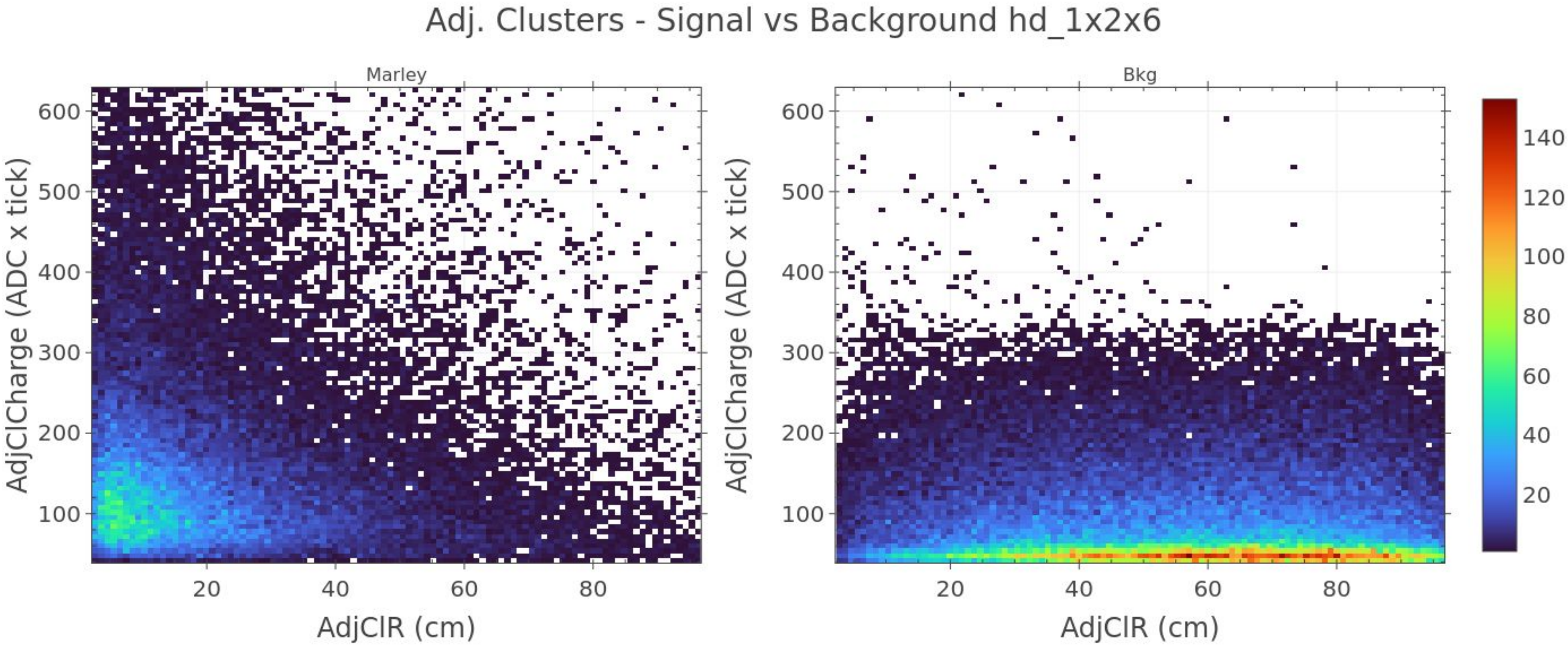
https://indico.fnal.gov/event/66507/contributions/301346/attachments/182376/250413/duneLE_update.pdf

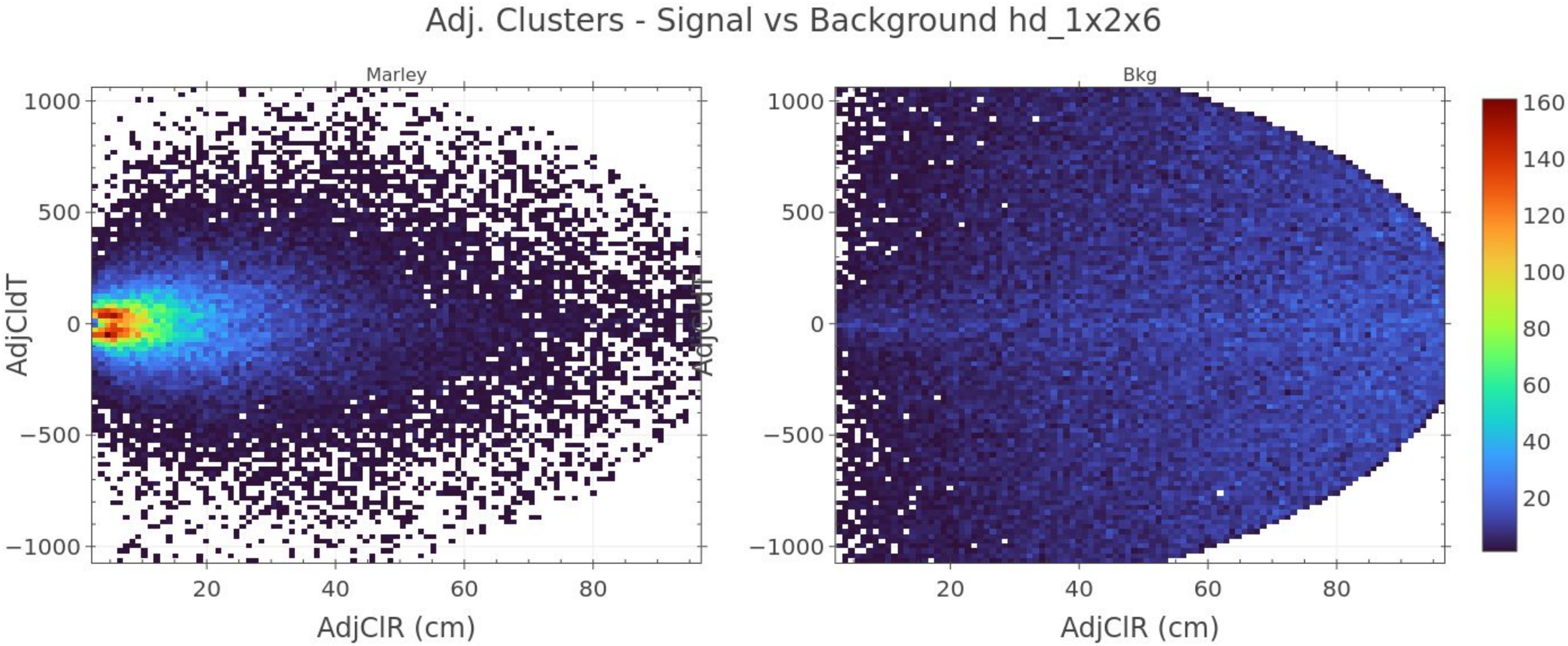
Background Adj. Cl Distributions

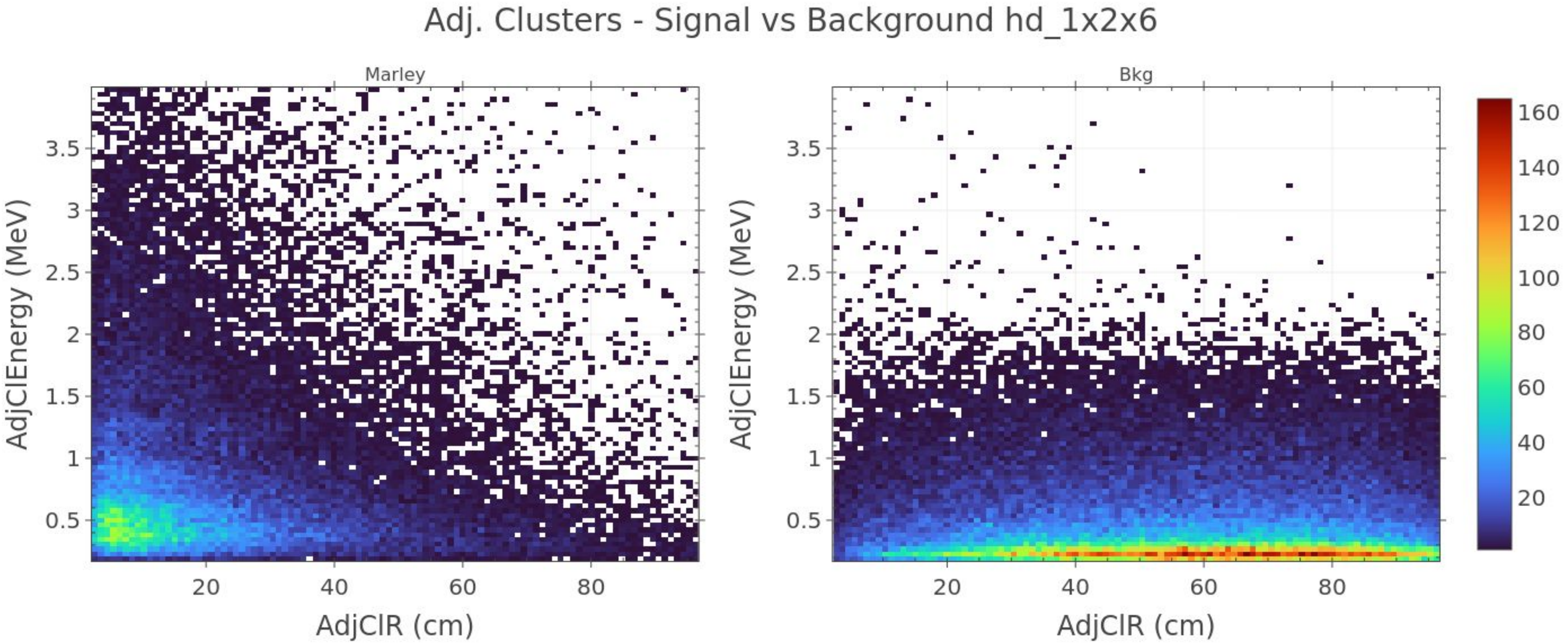


Background Adj. Cl. Distributions: Neutrons




Adj. Clusters - Signal vs Background hd_1x2x6
Marley
Bkg
AdjClCharge (ADC x tick)
AdjClR (cm)
100
200
300
400
500
600
20
40
60
80
140
120
100
80
60
40
20


Adj. Clusters - Signal vs Background hd_1x2x6
Marley
Bkg
1000
500
0
−500
−1000
AdjCldT
20
40
60
80
AdjClR (cm)
160
140
120
100
80
60
40
20


Adj. Clusters - Signal vs Background hd_1x2x6
Marley
Bkg
AdjClEnergy (MeV)
AdjClR (cm)
3.5
3
2.5
2
1.5
1
0.5
20
40
60
80
160
140
120
100
80
60
40
20

TDR RESOLUTION STUDIES