Identifying Neutron Captures in LAr TPCs with Machine Learning

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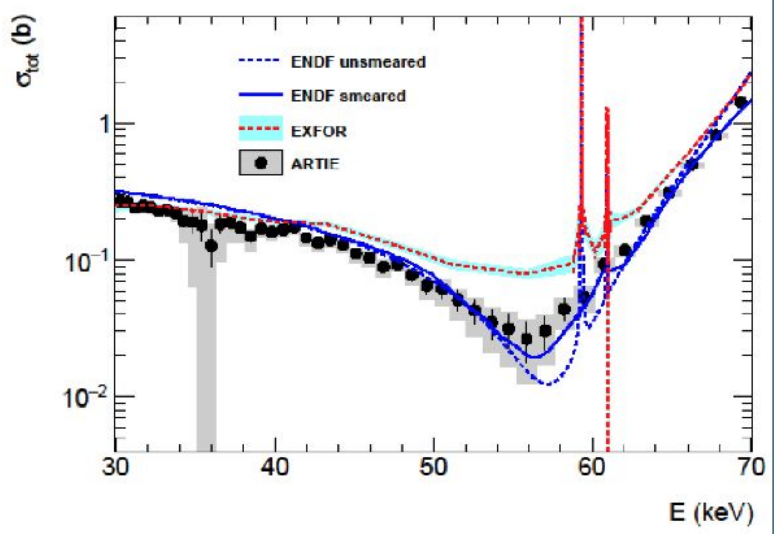
Neutron Calibration

One of the most important components of DUNE and other LAr TPC experiments is the calibration system. As part of it's calibration effort, DUNE will deploy a pulsed neutron source (PNS), which will inject low energy neutrons into the detector volume. These neutrons can be captured by Argon-40, which makes up the bulk of the natural Argon used in the detector. This approach has several benefits:

1. Neutron capture on Argon produces a ***standard candle*** of ~6.1 MeV gamma rays which then ionize the LAr and are subsequently detected.
2. There exists an ***anti-resonance*** in the capture ***cross section*** for neutrons on LAr at around 57 keV, which allows the neutrons to travel far into the detector volume before being captured, allowing for a scan of the bulk of the TPC volume.

A precision measurement of the 57 keV anti-resonance was performed by the group at UC Davis as part of the ARTIE experiment. Preliminary results are shown to the right.



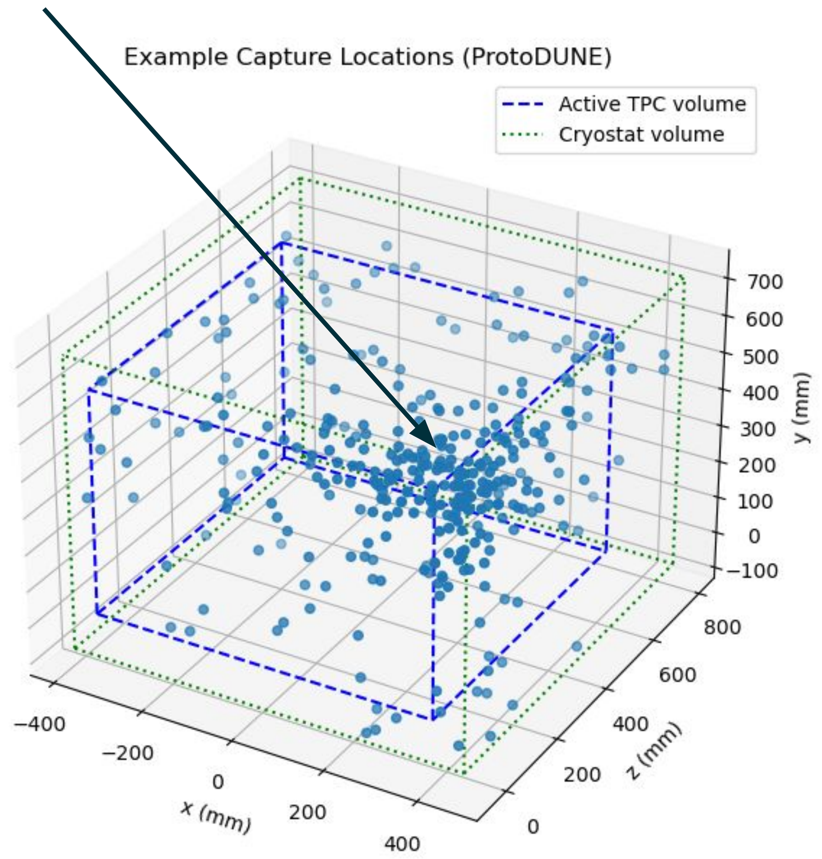
ProtoDUNE I and II

ProtoDUNE I allowed for some preliminary tests of the pulsed neutron source. Data from the PNS was taken during its run, which is currently being studied to build algorithms for:

1. reconstructing the ***capture energy spectrum*** as well as
2. detecting ***single neutron captures***.

Simulation is performed using LArSoft, a framework developed by Fermilab for its many LArTPC experiments.

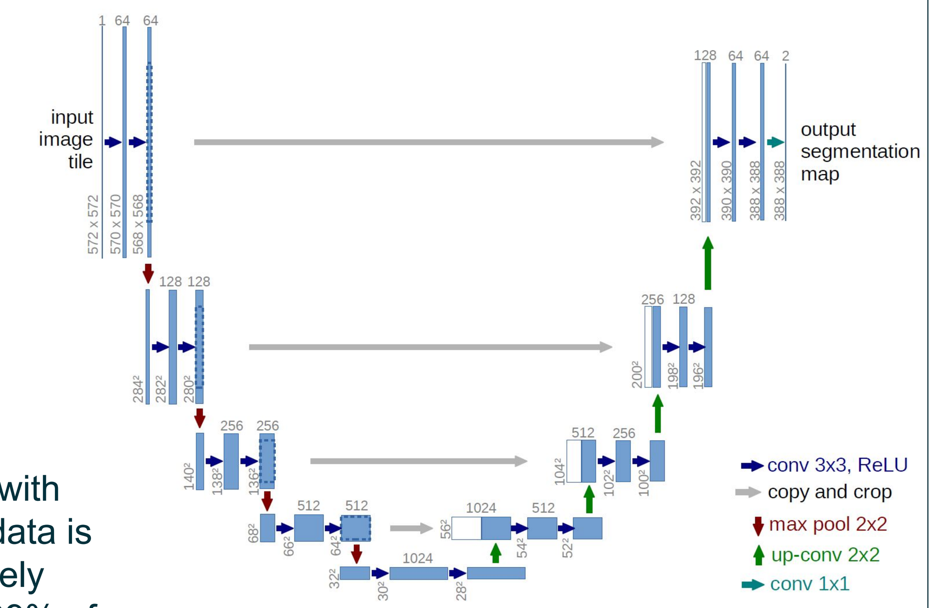
PNS Location in ProtoDUNE



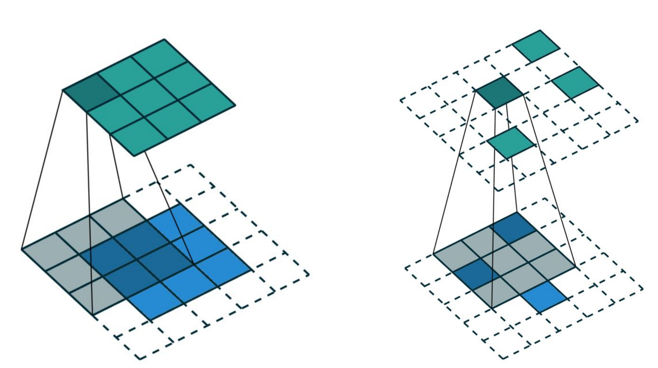
Semantic Segmentation

Due to ProtoDUNE being located above ground, there is a large background of cosmic ray muons. To remove cosmic muons from events, we use a machine learning (ML) approach called ***Semantic Segmentation***, which is a pixel-level classification scheme.

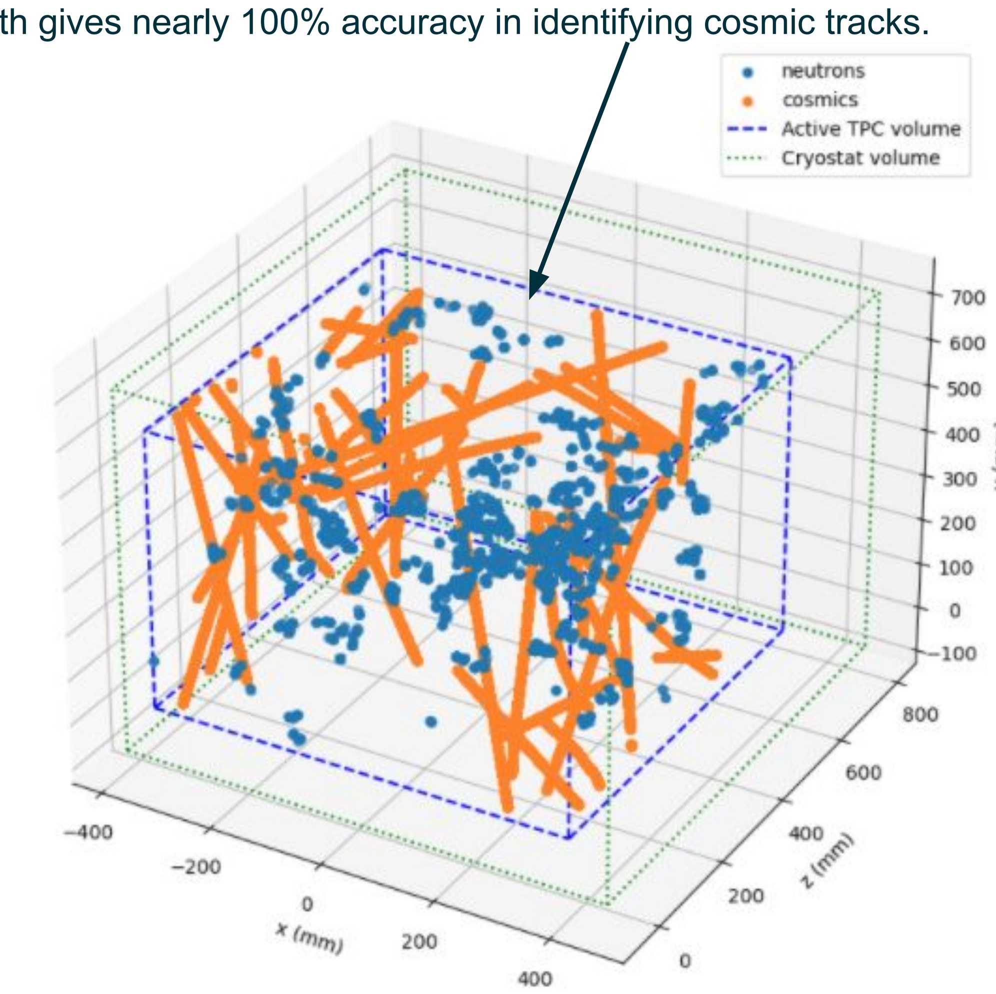
The model to the right is called U-Net, which is essentially a **fully-convolutional auto-encoder**.



One challenge with the protodune data is that it is extremely sparse (about 99% of voxelized event space is empty). To combat this redundancy, we use a **SparseTensor** implementation called MinkowskiEngine (ME), whose kernels behave like those on the right.



Results from running the trained **SparseUNet** model on unseen samples of MC truth gives nearly 100% accuracy in identifying cosmic tracks.



Future work involves

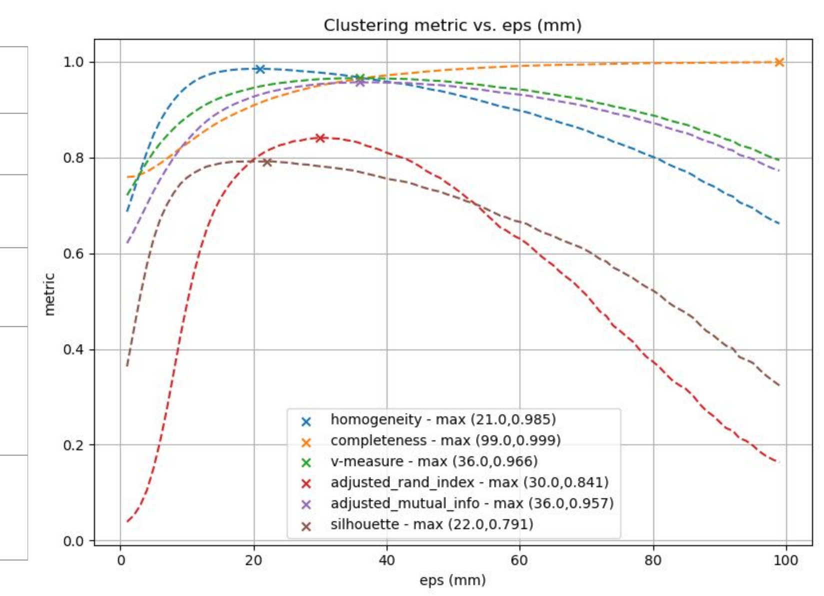
- including other backgrounds such as:
  - Secondary activity from the cosmic ray muons.
  - Point like activity from Argon-39 decay.
- extending the SparseUNet to
  - distinguish between muons and anti-muons.
  - identify delta rays, pions and Michel electrons.

Neutron Clustering

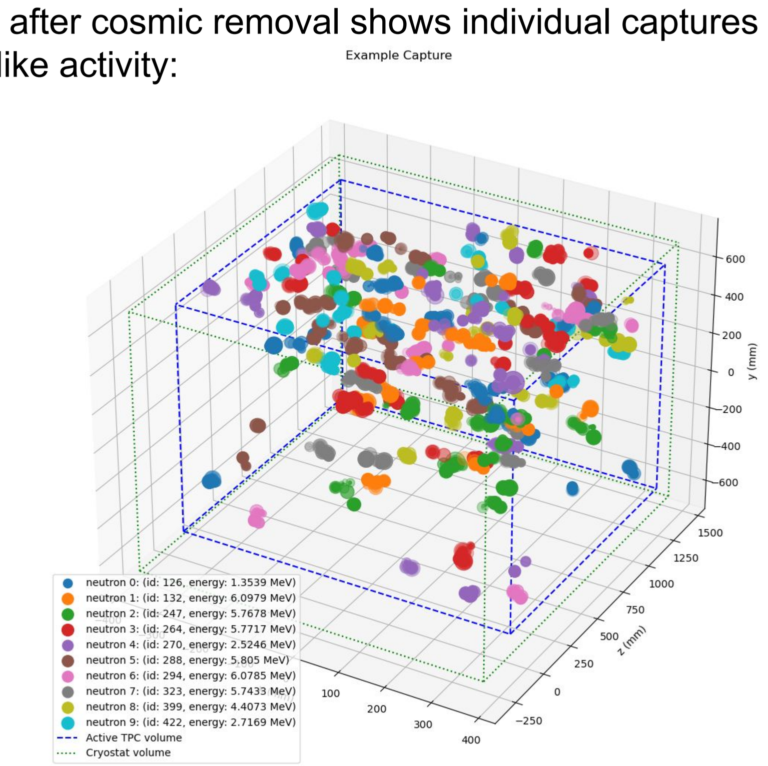
Once cosmics are removed, we perform a clustering using DBSCAN (*density-based spatial clustering of applications with noise*). The algorithm depends on a parameter ***eps***, which defines a local neighborhood distance.

We can gauge our clustering performance by using several metrics, such as ***adjusted rand score*** (ARI), which is best around **eps = 30.0**. Other metrics (AMI, v-measure) are also good in the **[30-40]** window.

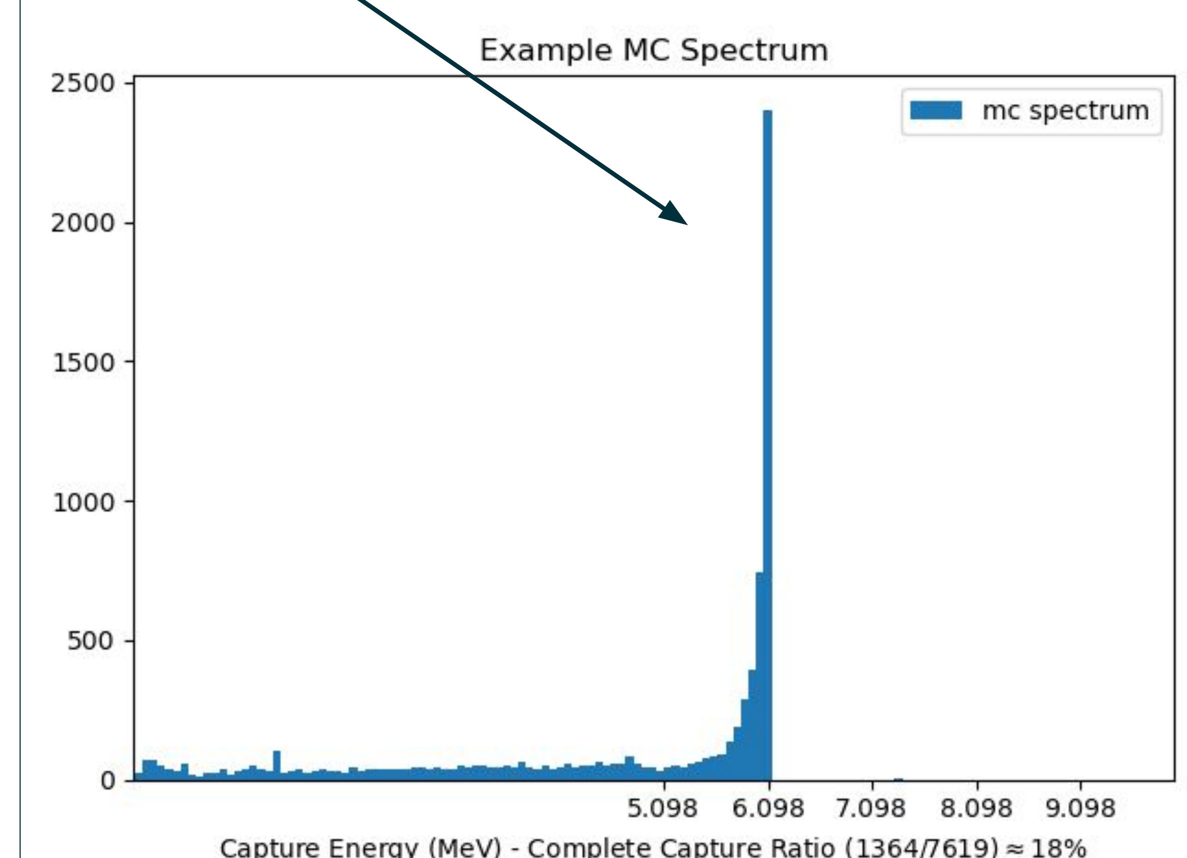
Metric	Score
Completeness	0.98
v-measure	0.95
Adjusted Rand Index	0.74
Adjusted Mutual Information	0.94
Silhouette Score	0.71



Results of clustering after cosmic removal shows individual captures as small blobs of point-like activity:



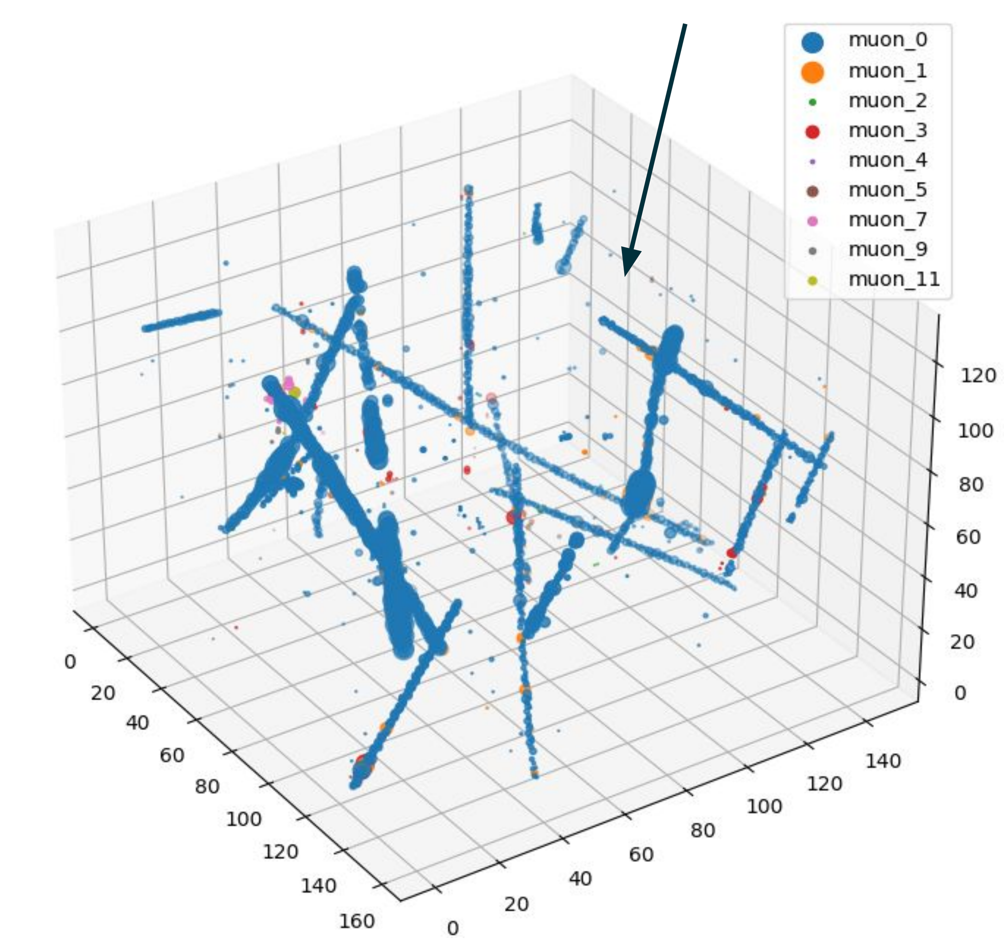
Plotting the spectrum of these blobs (using the true energy deposition values) shows a peak at the ***standard candle*** value of ~6.1 MeV



What about reconstruction?

We are currently tuning our algorithms on reconstructed events from ProtoDUNE, which introduces complications:

- ambiguities in reconstruction cause some tracks to look like ***point-like*** activity, making them difficult to remove.



Once these issues are sorted out, we will:

- train our algorithm on reconstruction and deploy it on the ProtoDUNE neutron capture data, which will allow us to
- prepare the algorithm for immediate deployment in ProtoDUNE run II which is slated to begin in summer 2022.

Software

All of the PNS related software can be found on github, which includes the following repositories:

- **NeutronCalibrationLArSoft** - a collection of gdml and fcl files for running simulations in LArSoft.
- **ProtoDUNENeutronCaptureTools** - machine learning and clustering tools including the SparseUNet for cosmic muon removal.

Acknowledgements

This material is based upon work supported by the Department of Energy National Nuclear Security Administration through the Nuclear Science and Security Consortium under Award Number(s) DE-NA0003996.

[1] O. Ronneberger et. al., *U-Net: Convolutional Networks for Biomedical Image Segmentation*, arXiv:1505.04597, 2015.
[2] C. Choy et. al., *4D Spatio-Temporal ConvNets: Minkowski Convolutional Neural Networks*, arXiv:1904.08755, 2019.
[3] M. Ester et. al., *A density-based algorithm for discovering clusters in large spatial databases with noise*, 1996.
[4] Eric Church, *LArSoft: A software package for liquid argon time projection drift chambers*, arXiv:1311.6774, 2013.
[5] DUNE Collaboration, *Status of single phase and dual phase DUNE prototype detectors at CERN*, XXXIX International Conference on High Energy Physics, 2018.

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