A deep-learning based waveform region-of-interest finder for the liquid argon time projection chamber

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Introduction

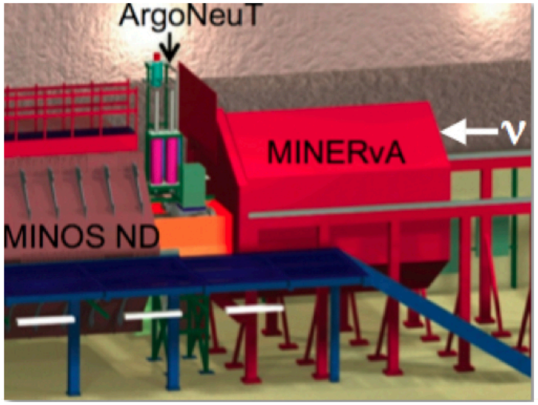
- LArTPC offers excellent spatial and energy resolution for low energy physics.
- Understanding and optimizing the signal and noise discrimination capabilities of LArTPCs is especially critical for low-energy physics, such as supernova/solar neutrino interactions and some new physics scenarios [2002.02967, 1810.7513, 1911.07996]

waveform in LArTPC:

Is there a signal? Where is the signal?

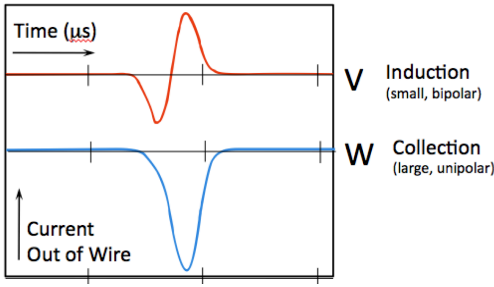
- An application of a 1D-CNN to the task of finding the region-of-interest (ROI) in LArTPC raw waveforms is considered and tested on the ArgoNeuT experiment.

- **ArgoNeuT LArTPC**
  - First LArTPC in a neutrino beam (NuMI) in the US
  - Located between MINOS near detector (ND) and MINERvA, using MINOS ND as muon spectrometer
  - $40\times47\times90$ cm^3 [vertical, drift, horizontal (beam)]
  - Two readout wire planes (60° to each other)
    - 240 induction wires and 240 collection wires
    - 2048 samples with 198 ns sampling time.
  - Data taking in $\nu/\ \bar{\nu}$ mode in 2009-2010.



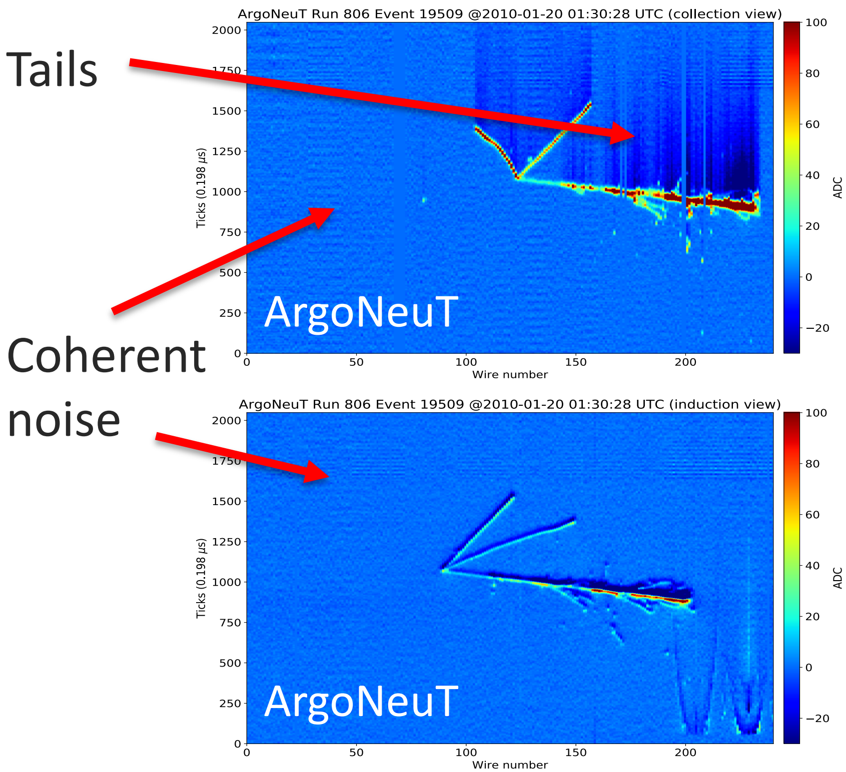
Signal and Noise

[1205.6747]

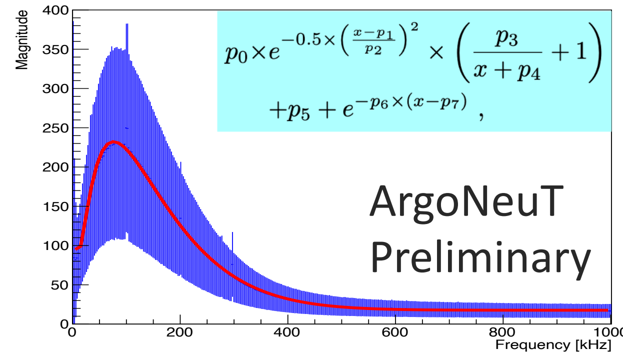


- In LArTPC detectors, the shape of the raw signal waveform is determined by how the charge signal is formed.
- The negative tail and coherent noise components can cause problems for charge reconstruction and need to be removed before further signal and noise discrimination.

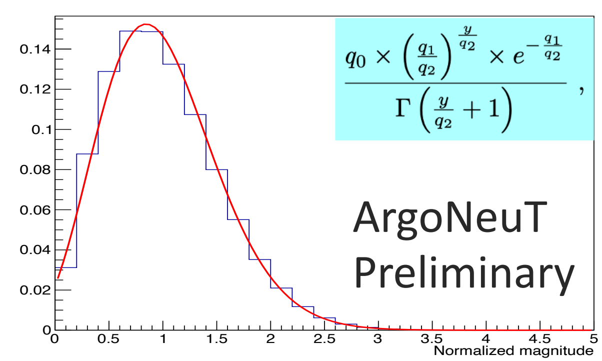
Raw waveforms



Data-driven noise model



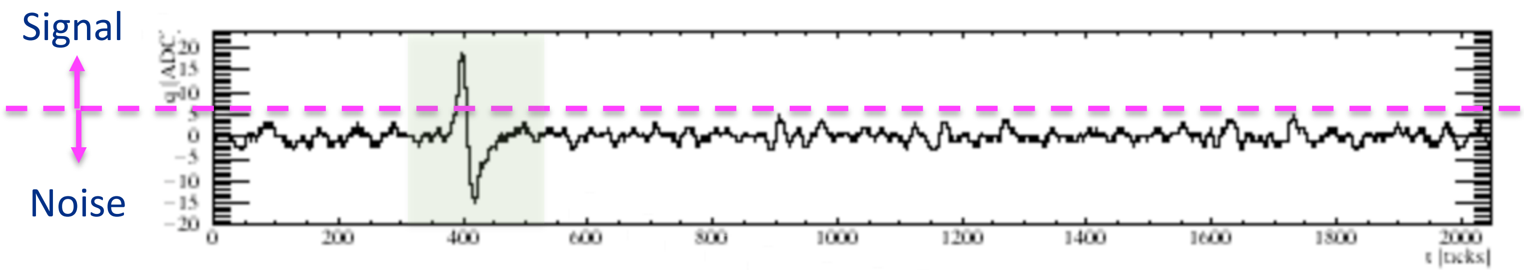
Noise frequency (error bar: RMS)



Noise fluctuation at each frequency bin

Waveform Region-of-Interest (ROI) Finder

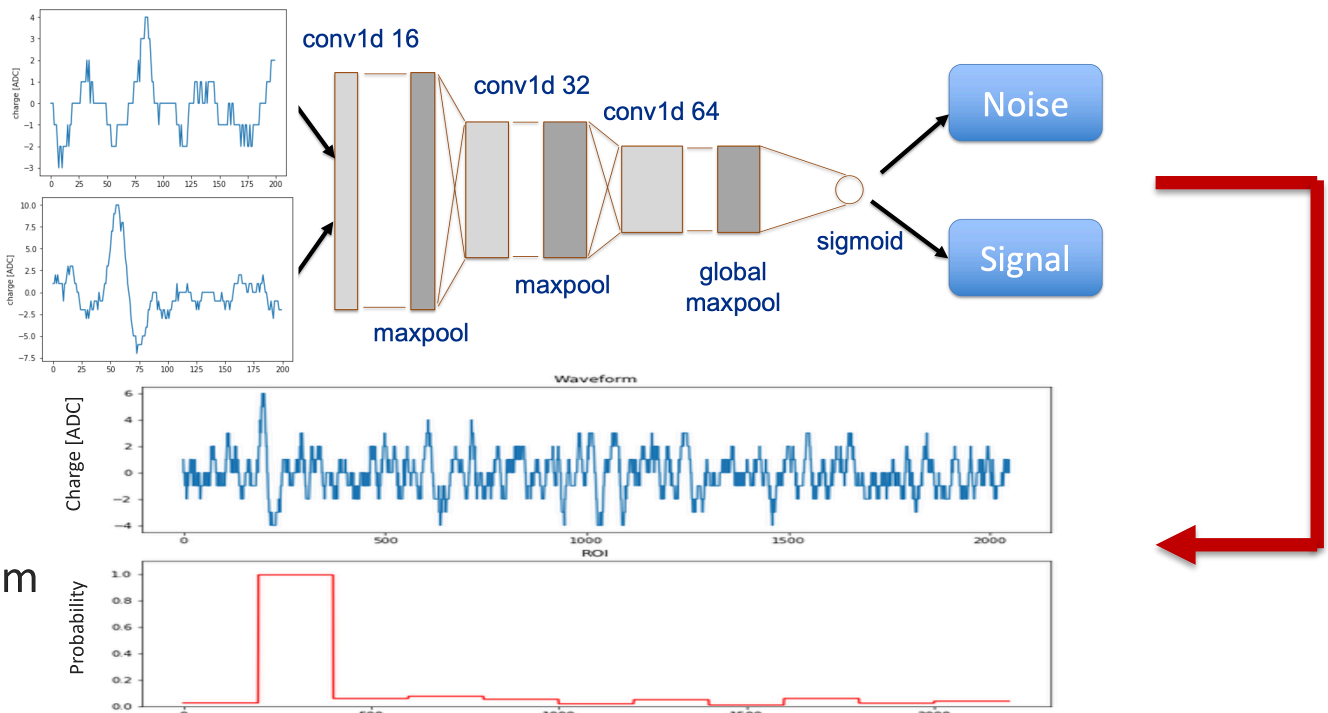
- Waveform ROIs: regions that contain charge/energy deposition
- Traditionally, waveform ROI finder is based on an **over-threshold algorithm**, i.e.,



- 1D- Convolutional Neutral Network (1D-CNN) waveform ROI finder

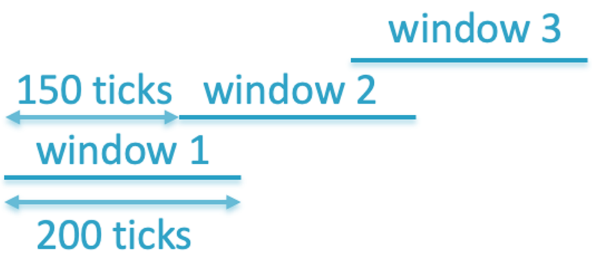
Inputs:
200-tick
waveforms

output:
probability that
200-tick waveform
contains a signal



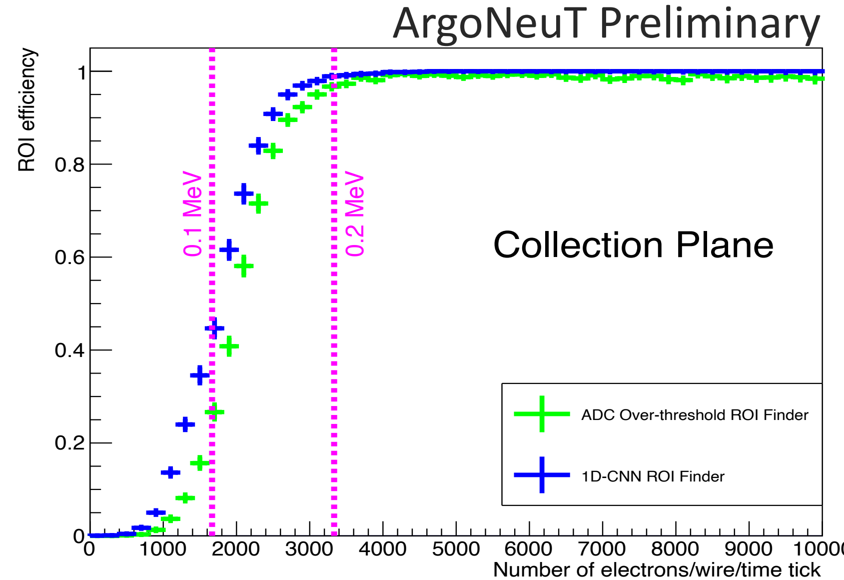
Results for ArgoNeuT

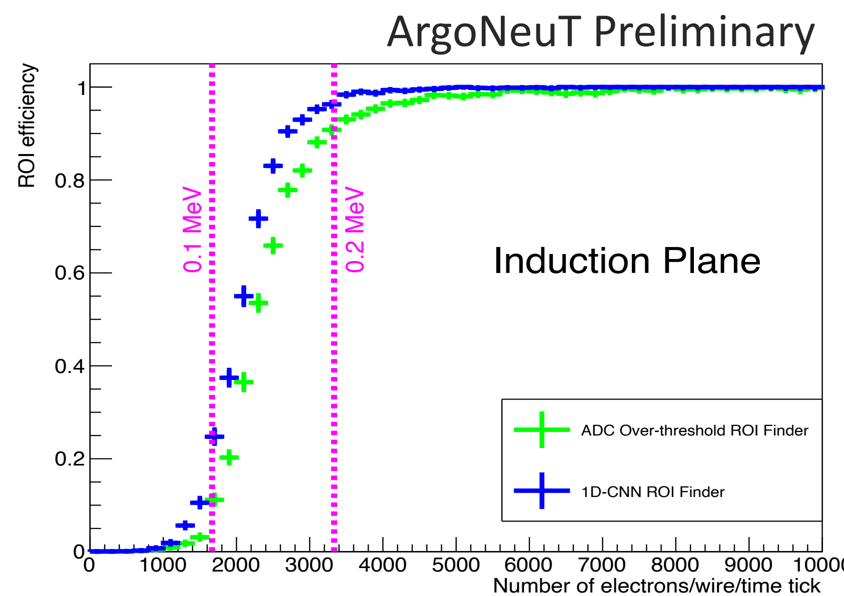
Schematic of applying ROI finder:



Maximum number of electron at a time tick in a ROI is used to represent the signal size of that ROI.

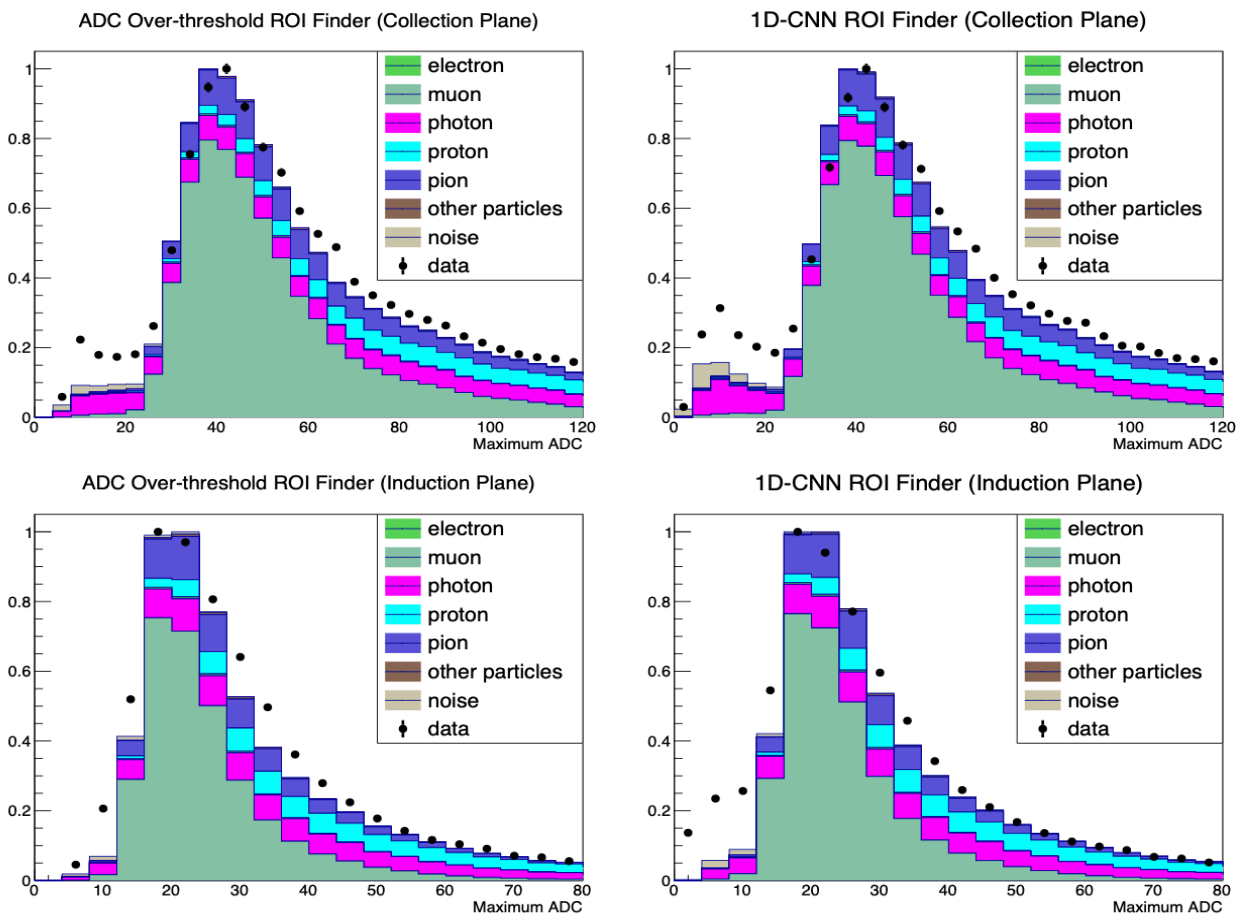
$$\text{ROI efficiency} = \frac{\text{number of signals in ROI}}{\text{number of signals}}$$





Results for ArgoNeuT

- Maximum ADC at a time tick in a ROI is used to represent the signal size of that ROI.
- Data vs MC: charged-current muon neutrino events are selected (with electron lifetime and gain corrections)



ArgoNeuT Preliminary

Disagreement between data and MC at low-energy region is understood:

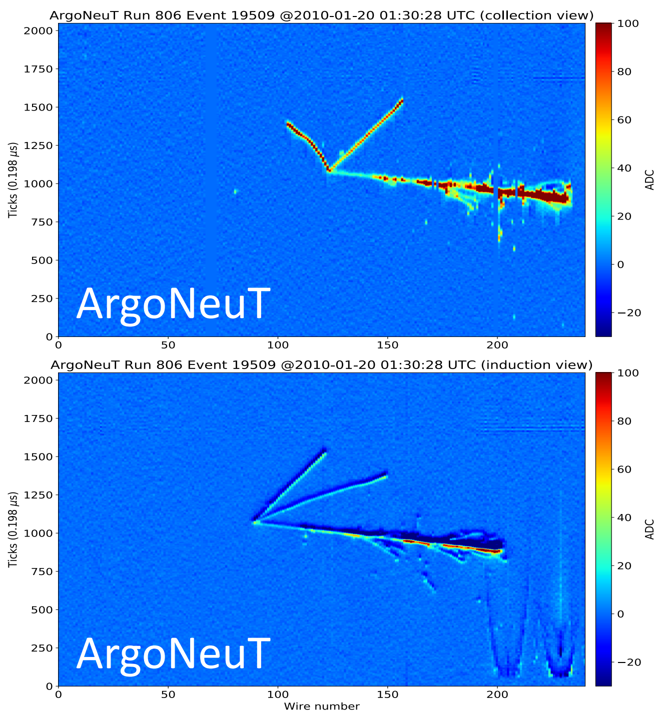
- Photons from de-excitation of argon nucleus are not simulated.

1D-CNN ROI finder shows great capability for small signals on both data and MC.

Conclusions

- Encouraging results in the application of 1D-CNN to the task of finding ROI in LArTPC waveforms using ArgoNeuT data are shown. The efficiency of it is roughly twice that of a traditional ADC over-threshold algorithm in the very low energy region (~0.03-0.1 MeV).
- The 1D-CNN shows a promising ability to extract small signals and offers great potential for low-energy physics. It can be applied to other LArTPCs for achieving their specific physics goals, such as the solar and supernova neutrinos in DUNE.
- A publication on this is in preparation.

After noise removal



After applying 1D-CNN ROI finder