Studies of pixel vs wire detectors using machine learning

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Motivation

- Pixel detectors should offer higher performances than wire-based detectors (provide more direct information)

- No solid demonstration has been performed to prove that this is the case (for the physics)

- In order to proceed further with hardware development, strong physics studies are required

- Not trivial task to do in short amount of time

Strategy for the studies

- Ideally, one would develop a full pixel-based detector simulation (built in LArSoft for efficient comparison and support within DUNE), but this is several months of dedicated work (no resources with required expertise available at this time).

- Simplified simulations could be done with existing framework and traditional reconstruction algorithms could be used, but this is tricky because 2D algorithms and 3D algorithms perform very differently (for example wireCell (see Xin's talk)). In addition, one doesn't want to assess the performance of 2D vs 3D algorithms…

Strategy for the studies: Our choice…

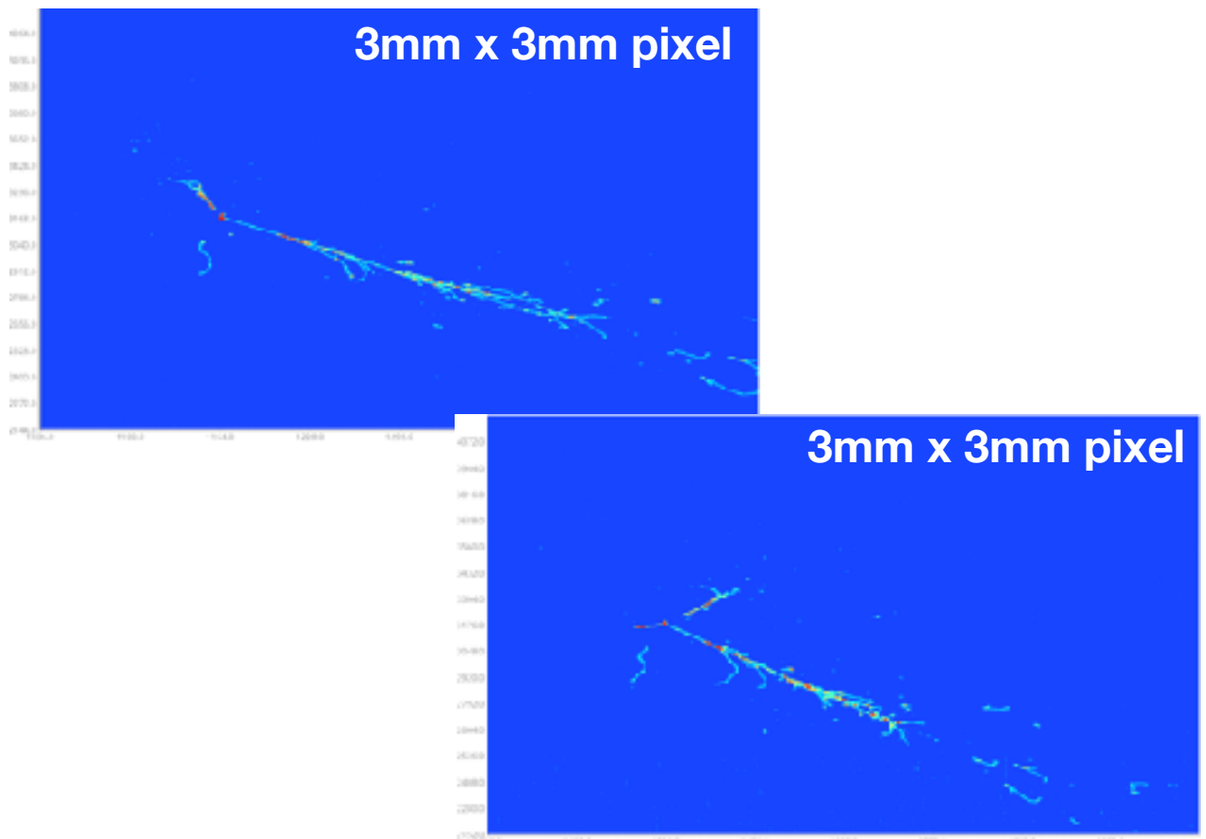
- Machine Learning studies seem a good “user-independent” way to compare wire and pixel detectors (not 100% true, but best “apple-to-apple” comparison available).

- These studies are meant to be fast and first order (nothing at the level of colleagues developing proper reconstruction techniques with Machine Learning (see Kazu’s effort)

- Many caveats (that will be addressed) remain present in the current studies and future work is definitely needed

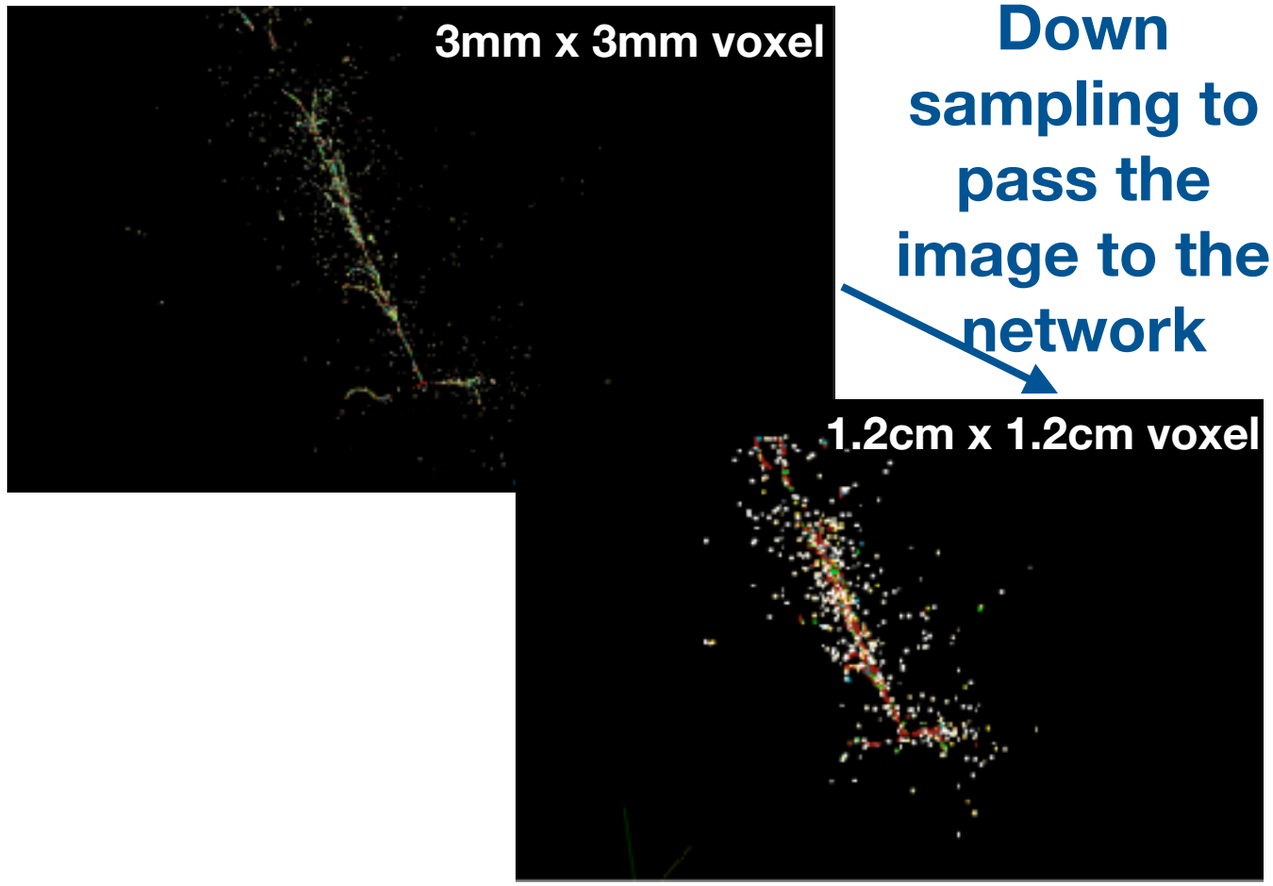
Method

- We represent the perfect **wire** detector with a suite of **three 2D images**



- Use 2D classification networks

- We represent the perfect **pixel** detector with **one 3D image**



- Use 3D classification networks

Caveat: The image resolution for 2D and 3D images is very different!

2D: 3mm x 3mm

3D: 1.2cm x 1.2 cm

Event generation and classification

- We generate 3 categories of events: ν_μ **CC,** ν_e **CC, NC**
- **Caveat:** We currently use BNB energy spectrum (peak at 800MeV), this is lower than DUNE
- We do not simulate any signal digitization for the pixel (the wires use SBND signal processing and deconvolution)
- No noise is included
- Networks provide 4 simultaneous classifications (neutrino ID, # of protons, # of pi0 and # of charged pions)

(Very) Preliminary results

- We compute the accuracy (efficiency) of each network at correctly identifying the right neutrino interaction (ν_μ CC, ν_e CC, NC)

2D	*nueCC:*	0.9492
	numuCC:	0.9320
	NC:	0.8586
3D	*nueCC:*	0.9504
	numuCC:	0.9119
	NC:	0.9149

Preliminary

(Very) Preliminary results

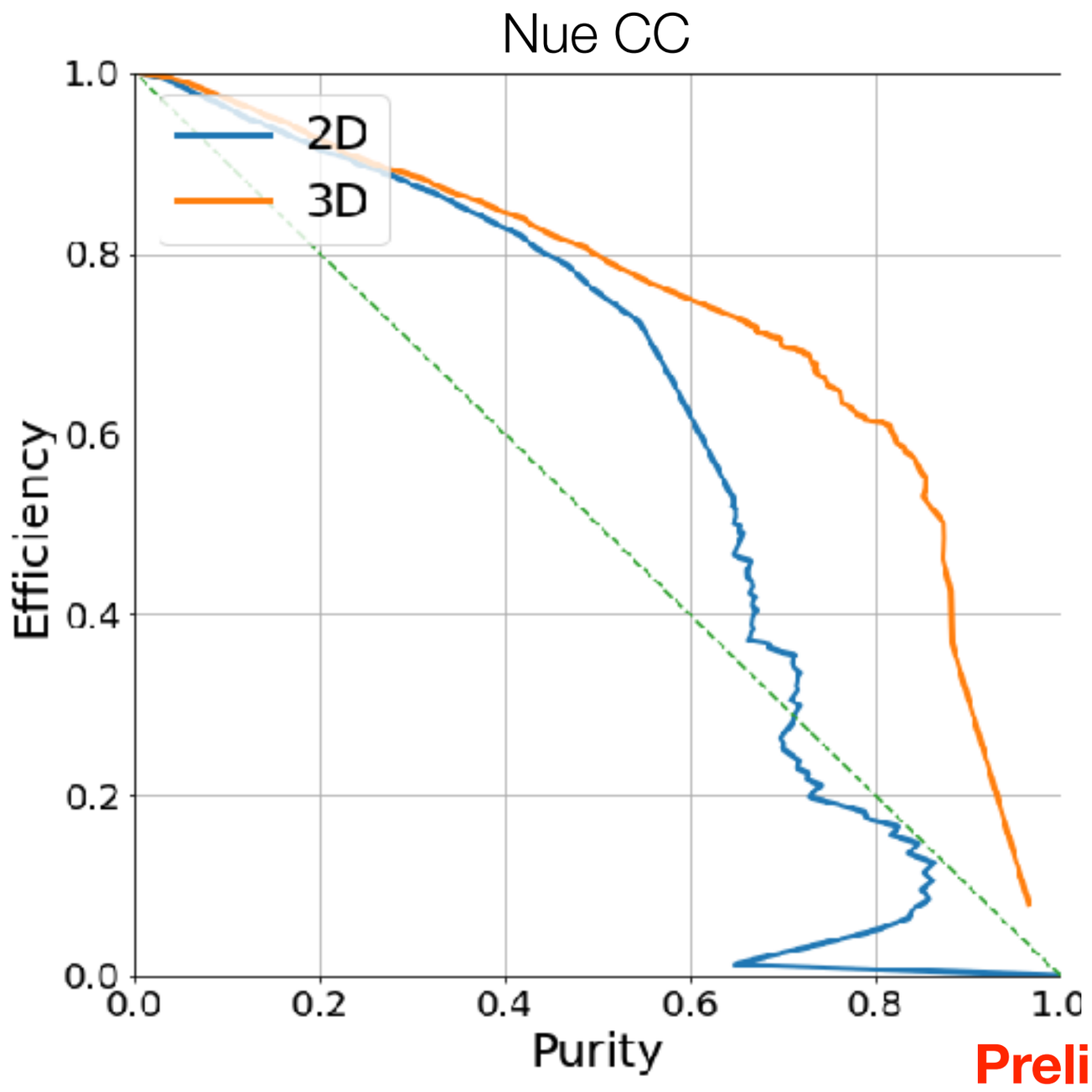
- Classifying events by topologies (important to understand backgrounds)

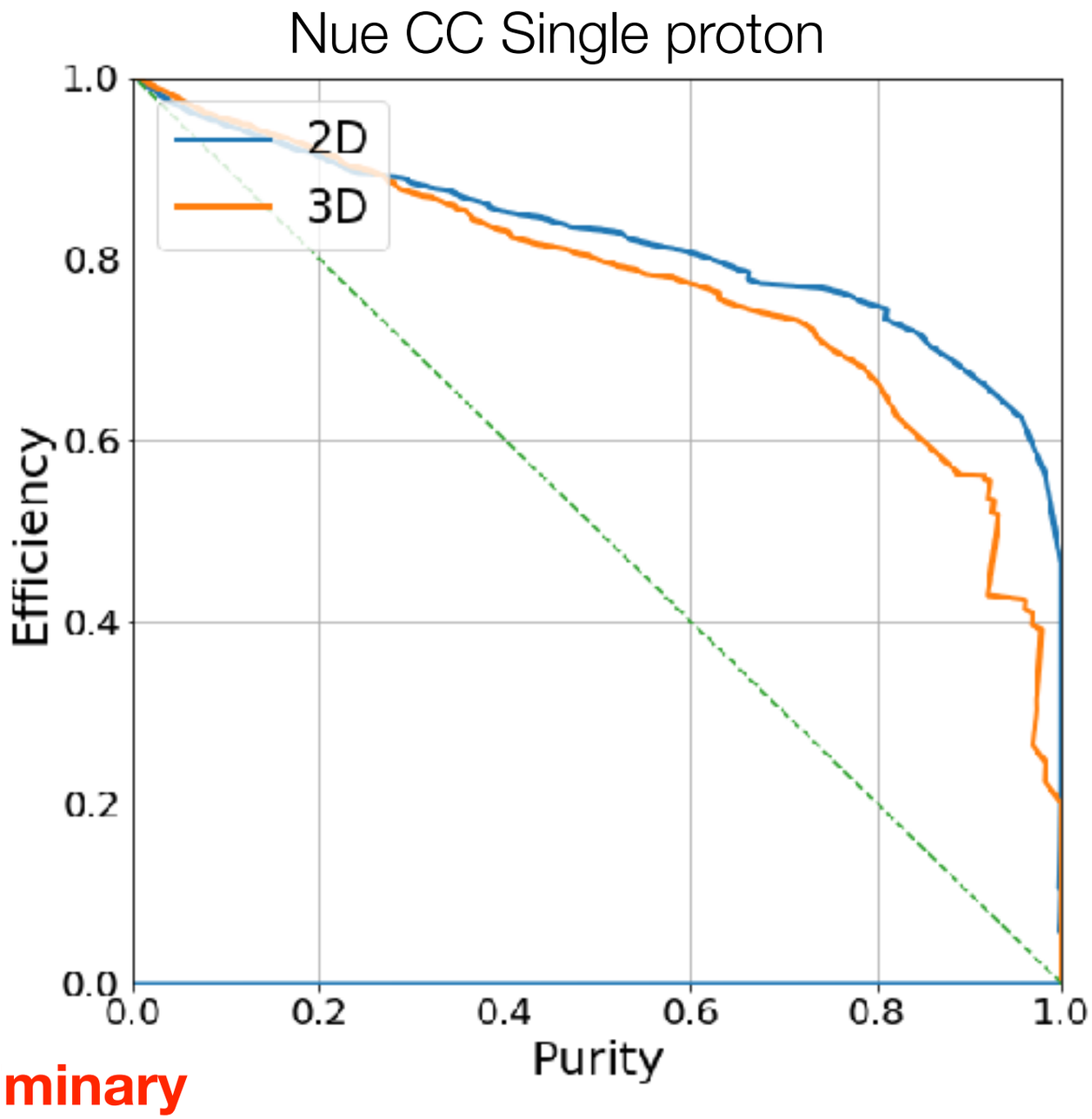
2D	*0 pi0:*	0.9885		*0 proton:*	0.9329
	1+pi0:	0.8160		*1 proton:*	0.9044
				2+ proton:	0.8839
3D	*0 pi0:*	0.98082		*0 proton:*	0.9151
	1+pi0:	0.8841		*1 proton:*	0.8826
				2+ proton:	0.8751

Protons are badly reconstructed in 3D due to the large voxel size (1.2cm x1.2cm)

Preliminary

Efficiency vs purity for each sets



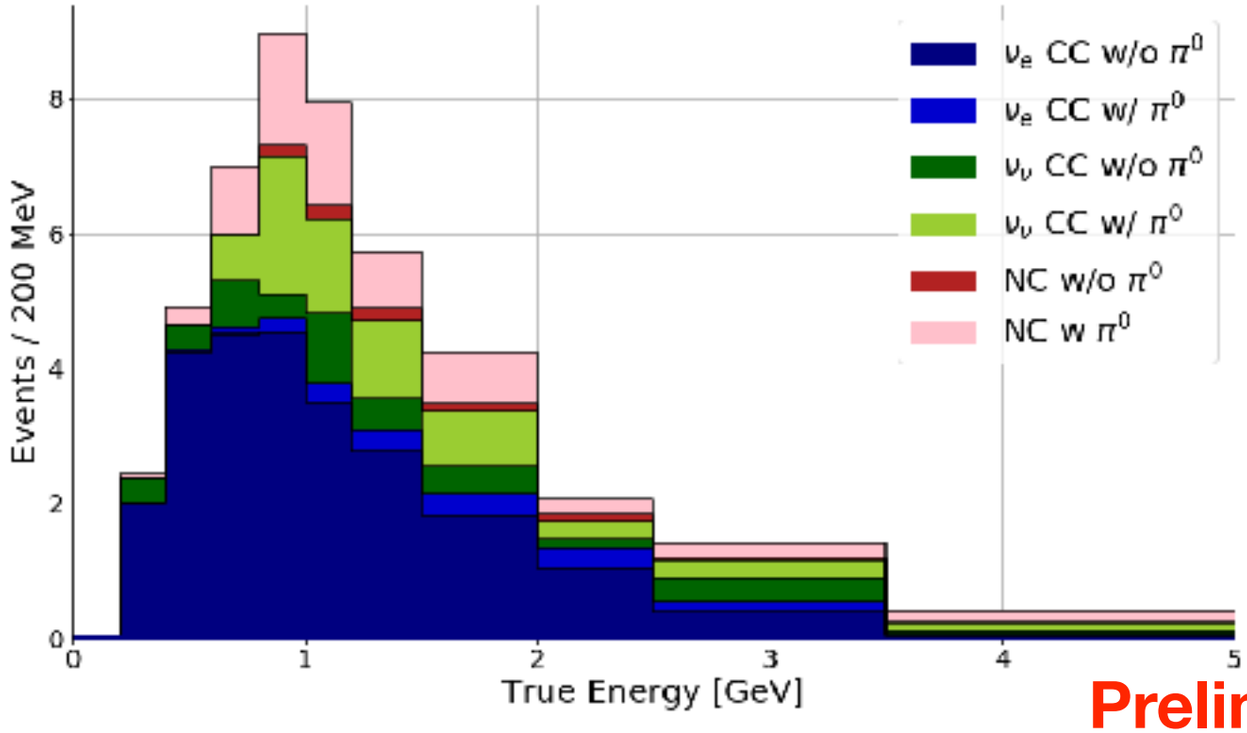


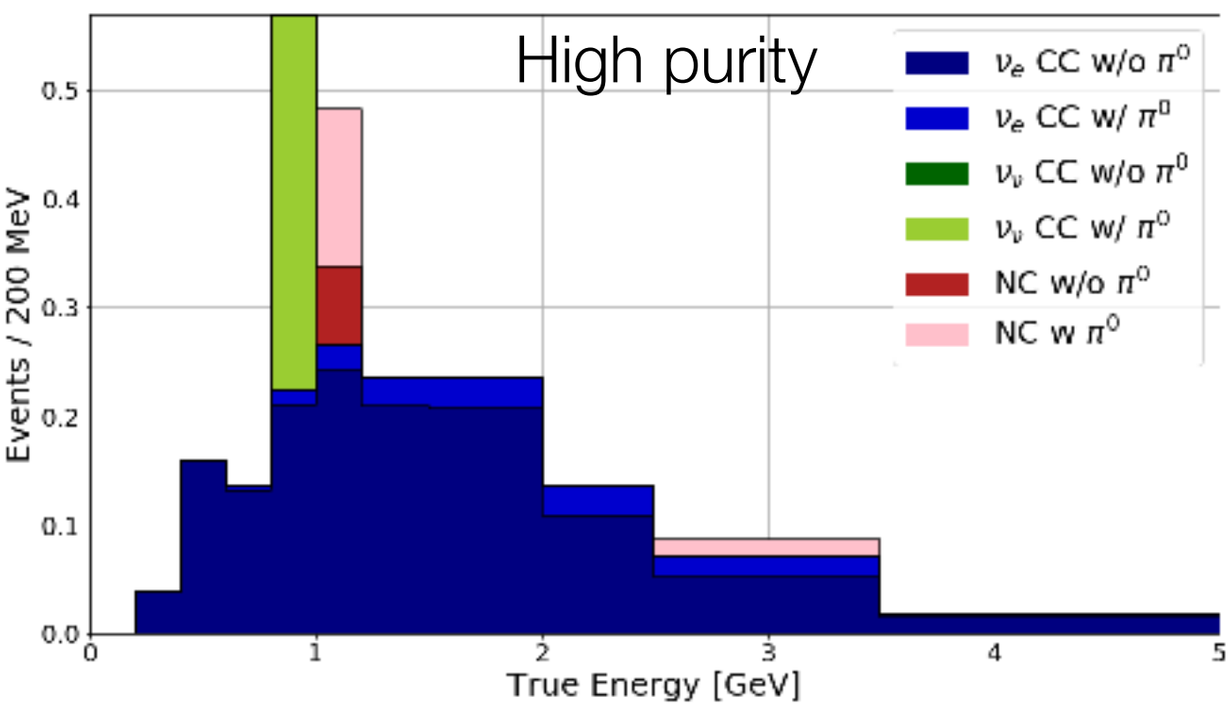
Preliminary

Protons are badly reconstructed in 3D due to the large voxel size

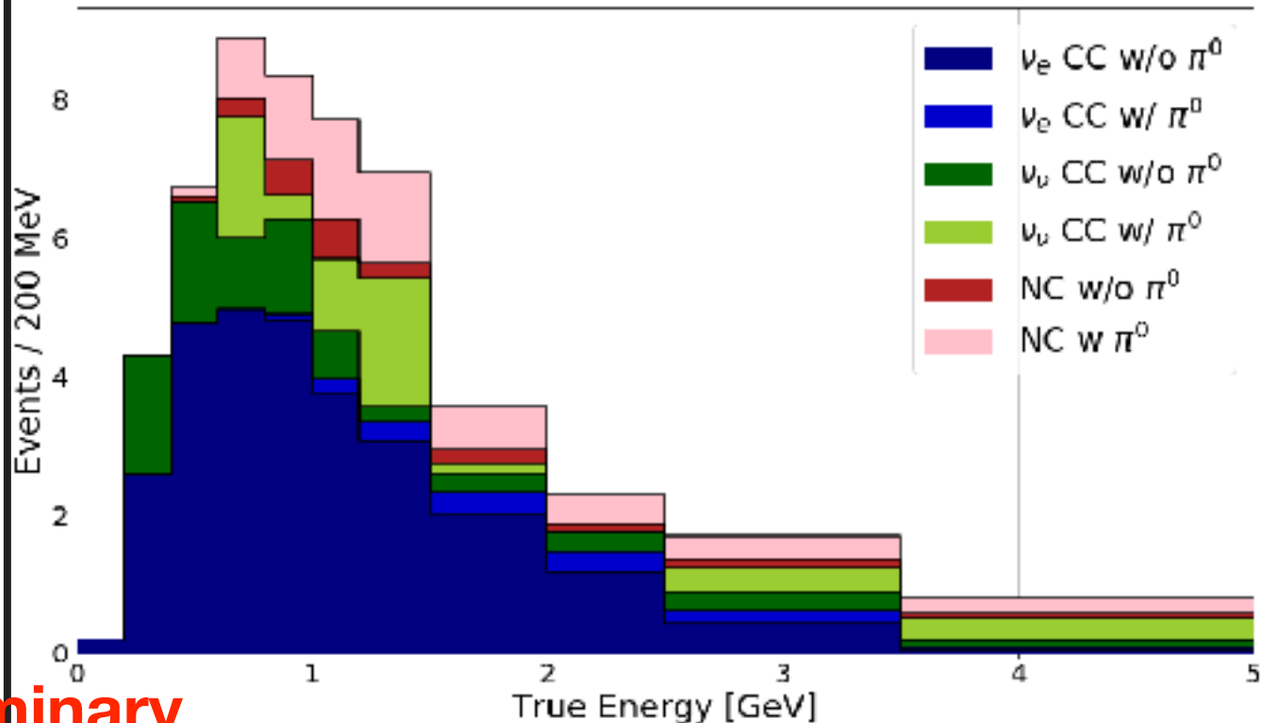
Example of ν_e contamination

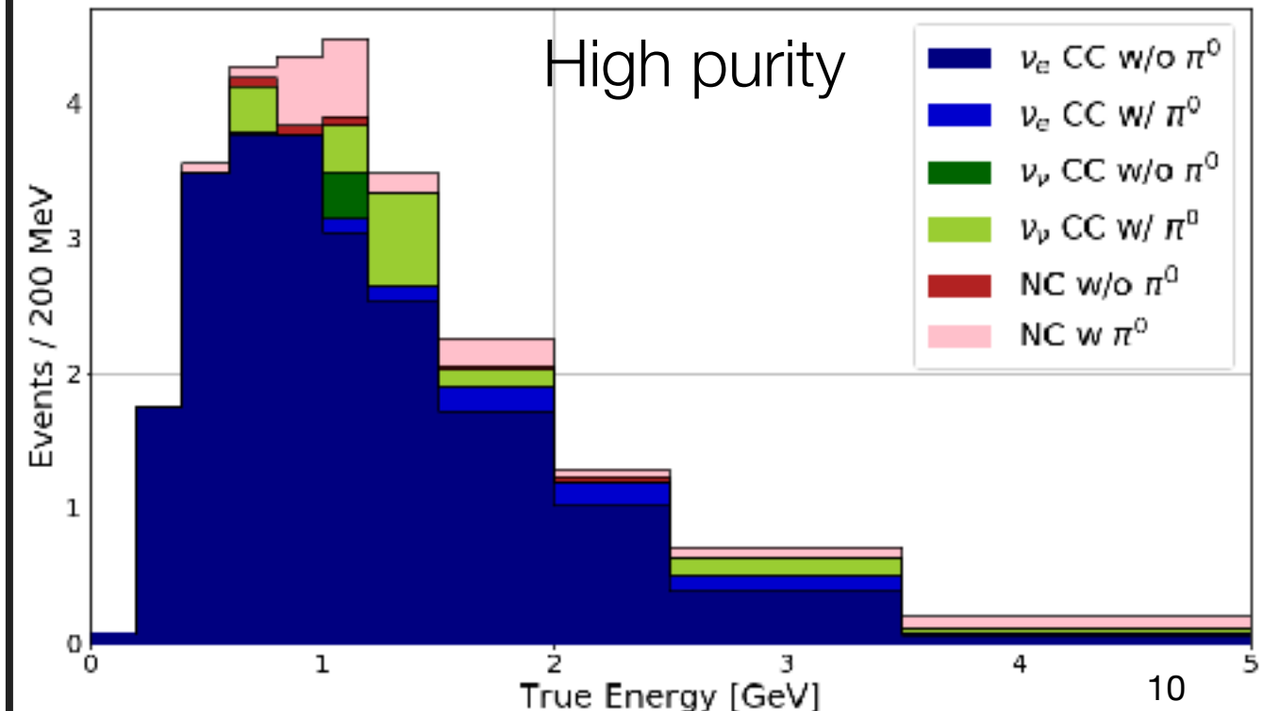
Wires (2D)





Pixels (3D)

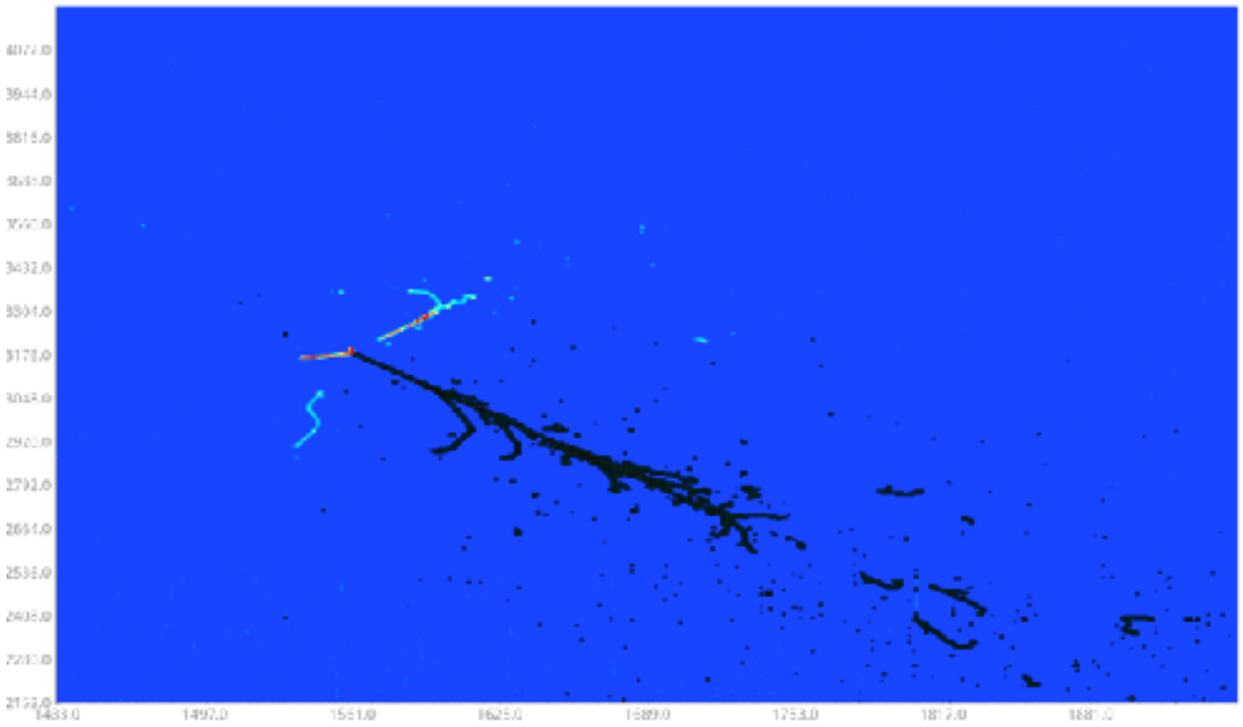




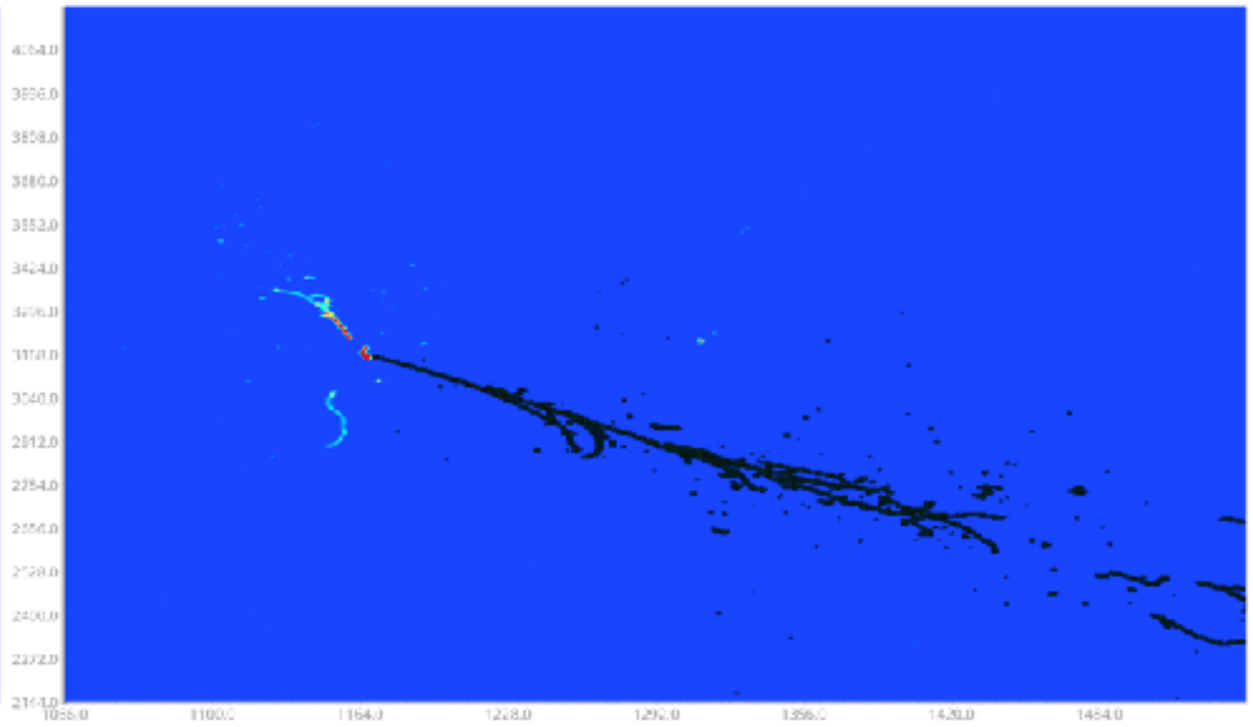
Preliminary

Lepton identification

- Using lepton semantic segmentation for the study



Black points:
Network outputs for leptons hits



Colored points:
Network outputs for non-lepton hits

- This could lead to studying neutrino energy for nue CC events, as the lepton and protons are identified or to reconstruct a pi0 mass peak

Near term future work

- Increase the pixel (3D) image granularity to 3mm x 3mm voxel for more relevant comparison (now)

- Use DUNE energy spectrum (near future) and use DUNE CDR assumptions for studies

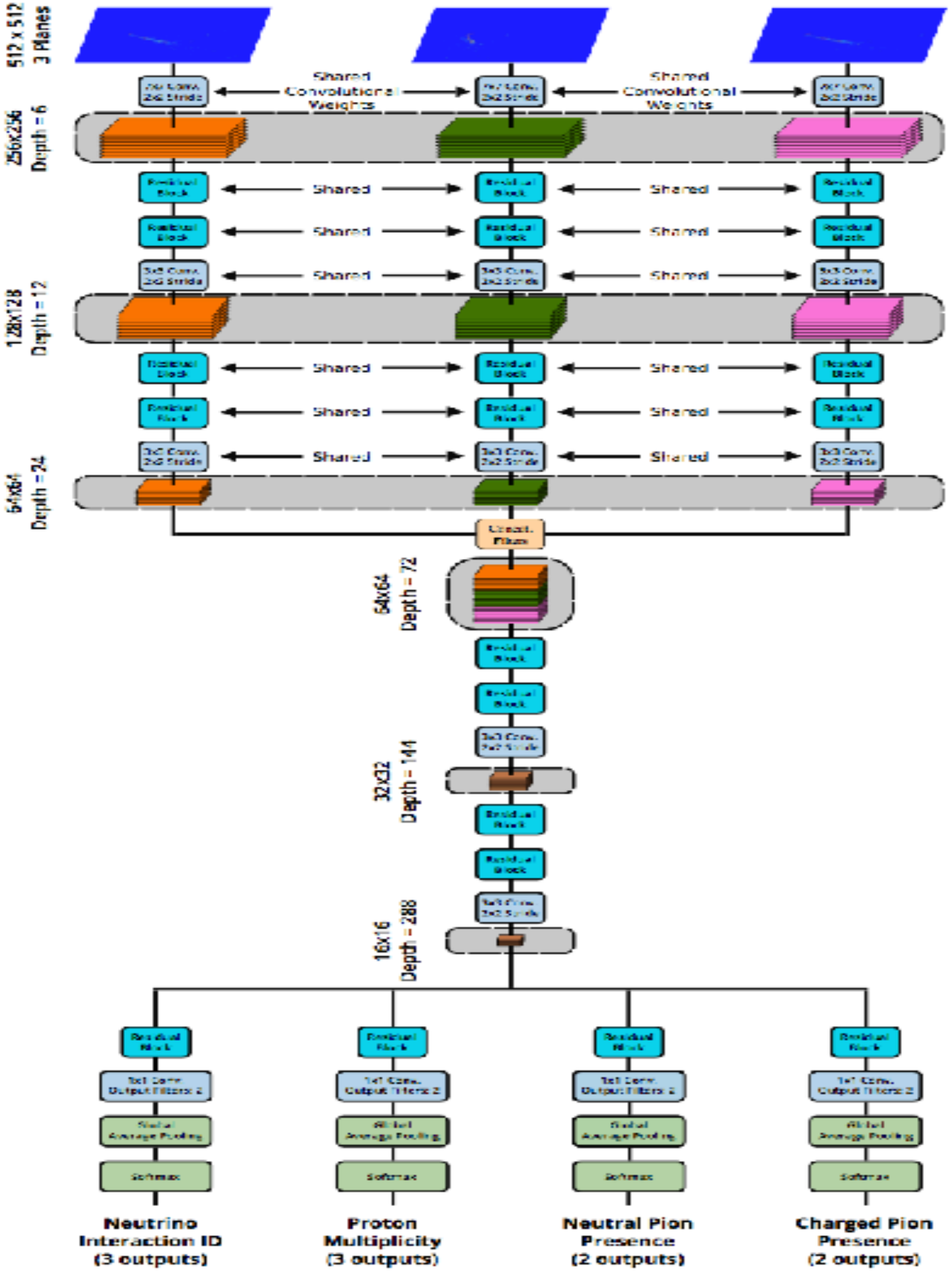
- Final efficiencies for nueCC selection, background contamination (especially from NC pi0 events) and reconstruct pi0 mass peak

- Add noise and defects to both types of images (random broken wires/pixels and correlated bunch of broken wires/pixels) (near future)

- Add some pixel signal digitization to make it more realistic (this is already available in 2D) (longer term)

Long term future plans

- Implement pixel readout in LArSoft
- Coordinate efficiently with the ArgonCube team who are doing work on related things
- Perform detailed MC studies, using LArSoft (the reconstruction issues remains, but several potential tools being developed (Xin's effort on WireCell at BNL or Kazu's DL reconstruction effort at SLAC)
- Resources are limited to perform more involved work and strong plan should be established


512 x 512
3 Planes
Shared
Convolutional
Weights
Shared
Convolutional
Weights
256x256
Depth = 6
Shared
Shared
Shared
Shared
Shared
Shared
128x128
Depth = 12
Shared
Shared
Shared
Shared
Shared
Shared
64x64
Depth = 24
64x64
Depth = 72
32x32
Depth = 141
16x16
Depth = 288
Neutrino
Interaction ID
(3 outputs)
Proton
Multiplicity
(3 outputs)
Neutral Pion
Presence
(2 outputs)
Charged Pion
Presence
(2 outputs)

Lepton segmentation