Enabling A Deep Neural Networks based 3D Data Reconstruction Chain for Wire-Readout LArTPCs

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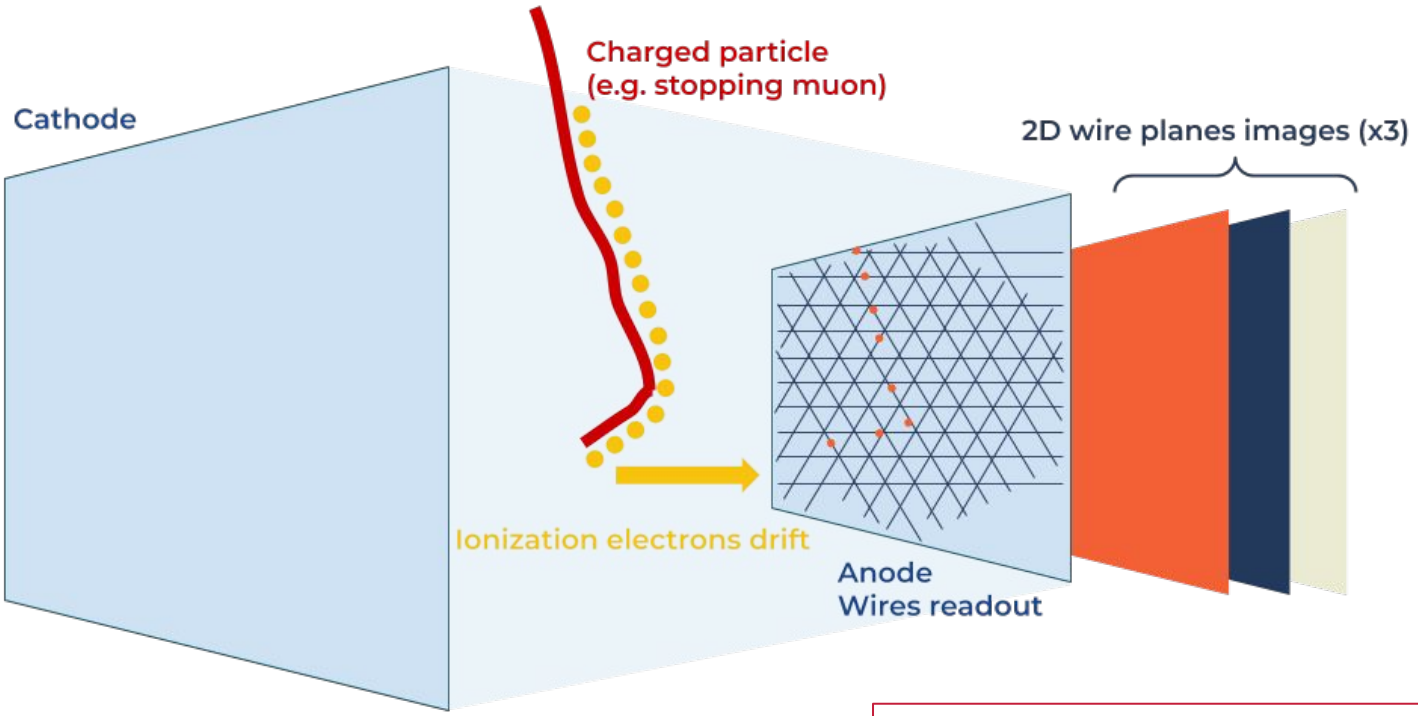
U.S. DEPARTMENT OF ENERGY

Stanford University

SLAC NATIONAL ACCELERATOR LABORATORY

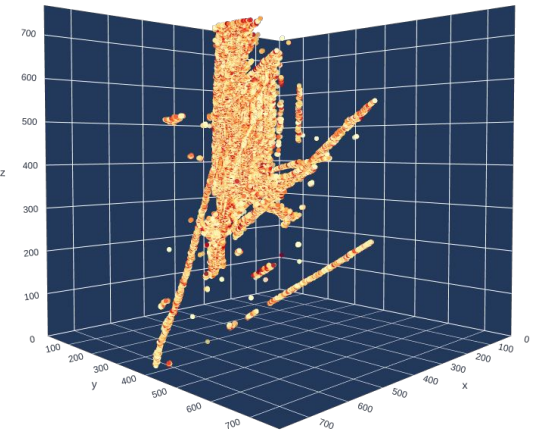
LArTPC with wire readouts



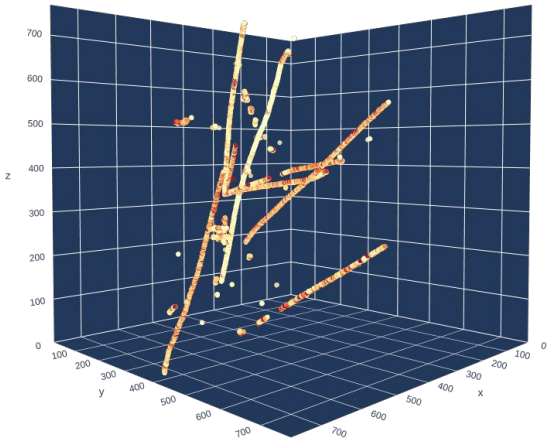
Goal: Application of *ML-based 3D reconstruction** to LArTPC.

Related Presentation
* ***F. Drielsma,*** "Scalable, End-to-End Deep Learning Based Data Reconstruction Chain for 3D Particle Imaging Detectors"

From 2D wire hits to 3D points

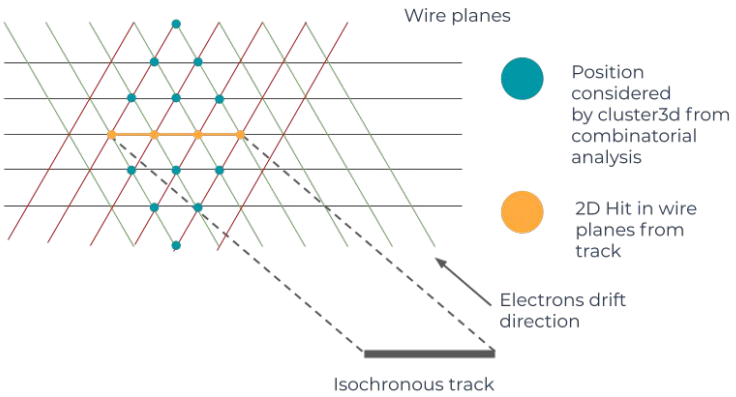


Reconstructed 3D points using *all* valid wire intersections from 2D views



True 3D trajectory image

How do ghost points arise?



An example of ghost points from false combinations of wire hits

Seeking a solution to produce high quality 3D points to enable 3D data reconstruction chain

Deghosting - Clean 3D Image for LArTPC

1. reconstruct 3D points w/ machine learning algorithm, or
2. improve existing 3D point reconstruction algorithms w/ ML techniques (*this talk*)

Unless specified, examples shown in this talk are from *ICARUS detector simulation* using *Cluster3D** point reconstruction.

Alternative 3D point reconstruction algorithms can be used.

Related Presentation
T. Wongjirad, "DL In MicroBooNE"

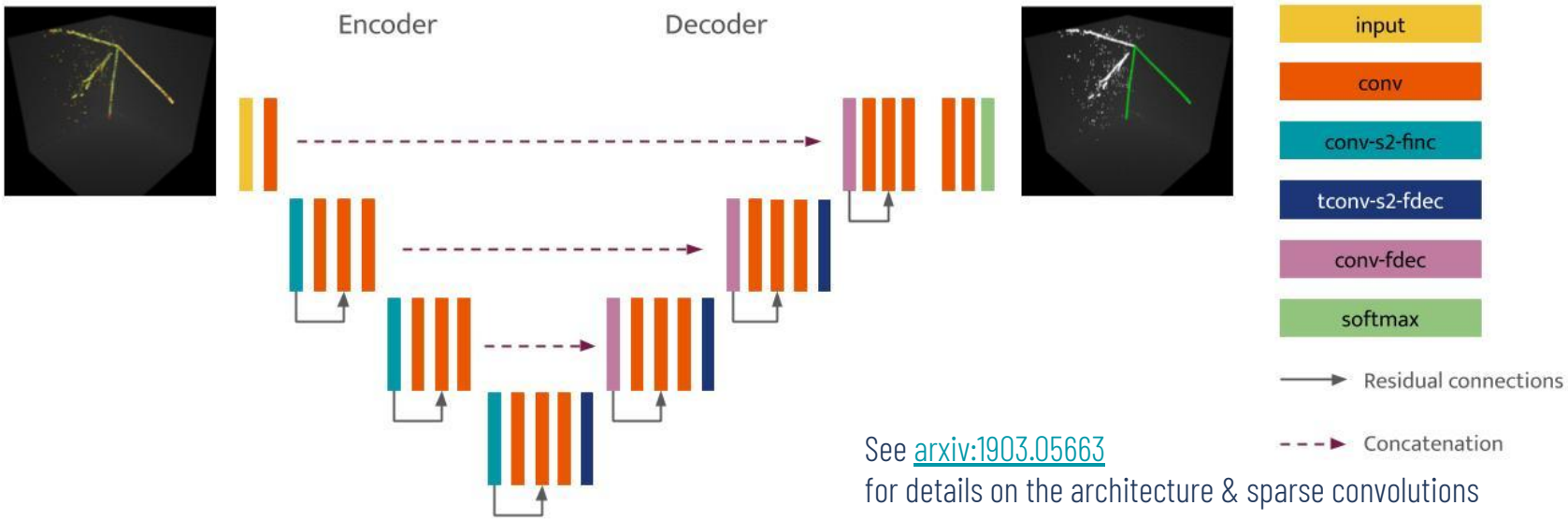
Cluster3D

- developed by Tracy Usher (SLAC)
- aims to reconstruct 3D points in high efficiency,
- with trade off of more ghost points

Deghosting w/ Sparse UResNet

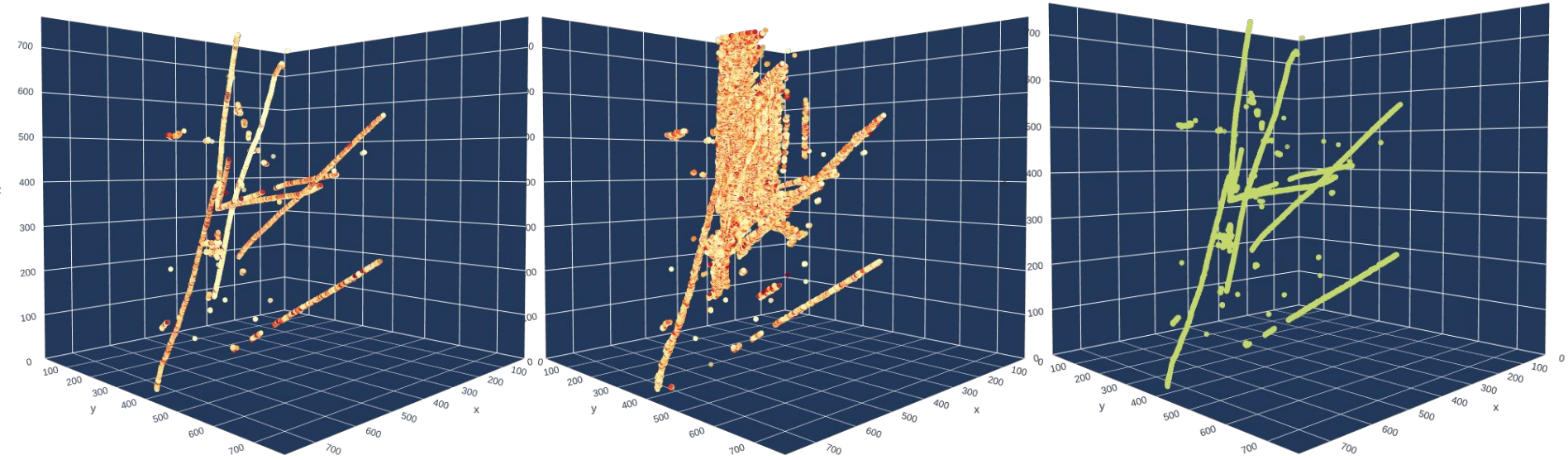
In addition to 5-type segmentation, add an extra classifier in **Sparse UResNet** to predicts binary semantic segmentation (ghost vs. non-ghost).

Related Presentations
L. Domine, "Scalable 3D Semantic Segmentation and Point Proposal Network for large-scale high resolution particle imaging detectors"
R. Itay, "Using Sparse Convolutional Neural Networks in MicroBooNE"



See arxiv:1903.05663
for details on the architecture & sparse convolutions

Deghosting Results



True 3D trajectory image

<u>Network Input</u>
Reconstructed 3D points
by *Cluster3D*

<u>Network Output</u>
After removal of predicted
ghost points

Deghosting Performance

92%

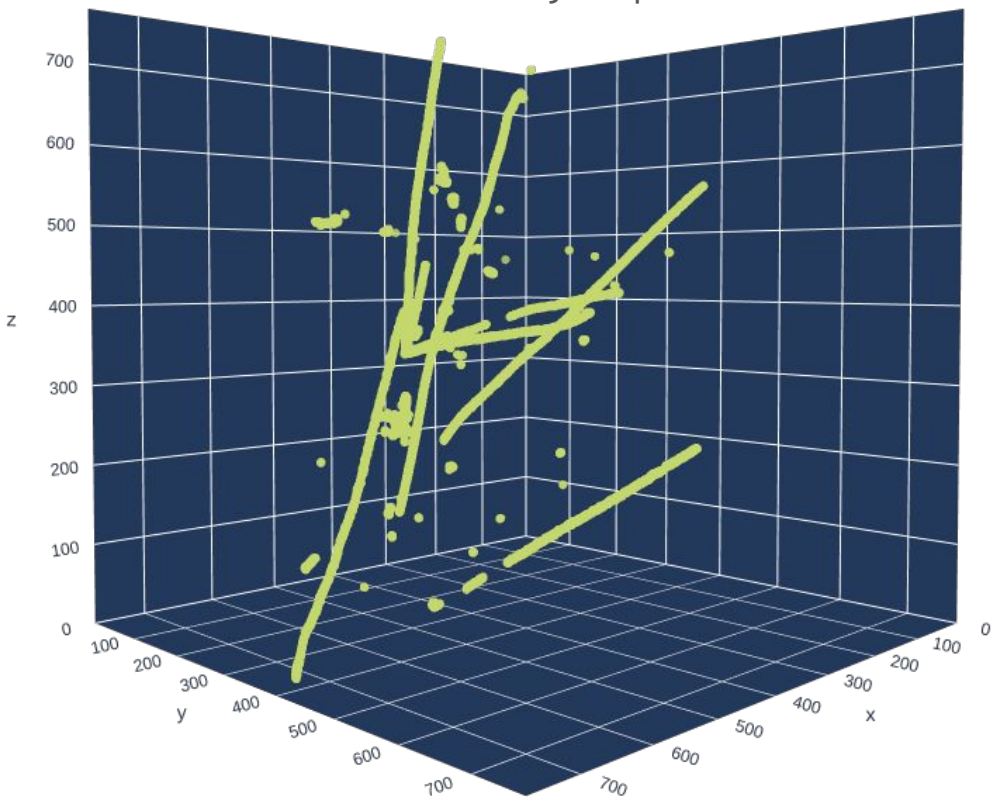
Fraction of ghost voxels correctly predicted

94%

Fraction of non-ghost voxels correctly predicted

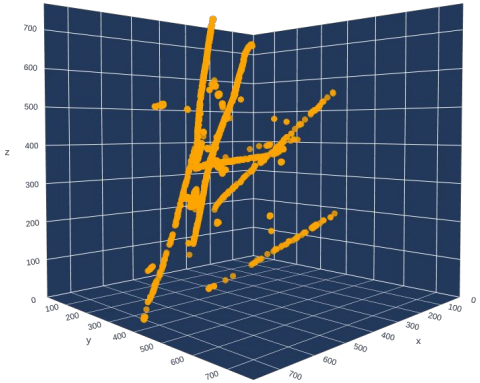
Remaining mistakes are "reasonable".

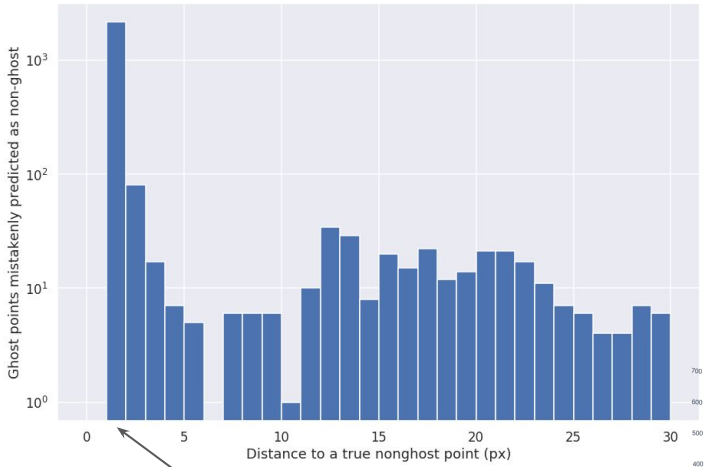
Predicted non-ghost points



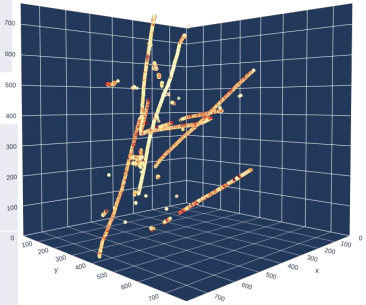
Deghosting Mistakes

True ghost voxels mistakenly predicted as non-ghost

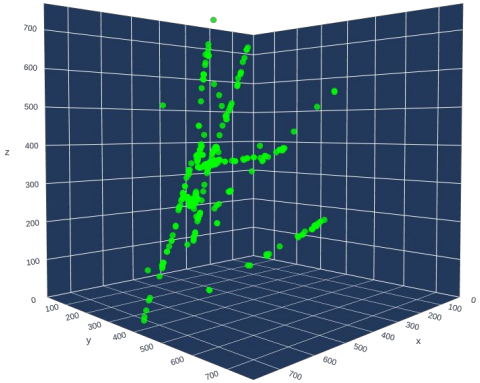


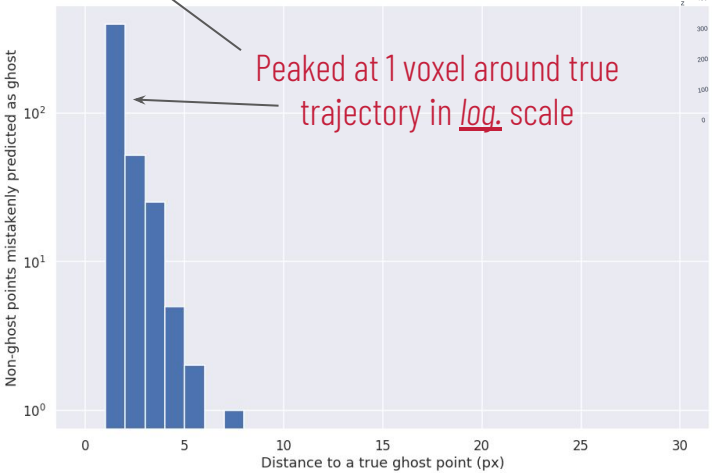


Ref: True 3D Image



True non-ghost voxels mistakenly predicted as ghost



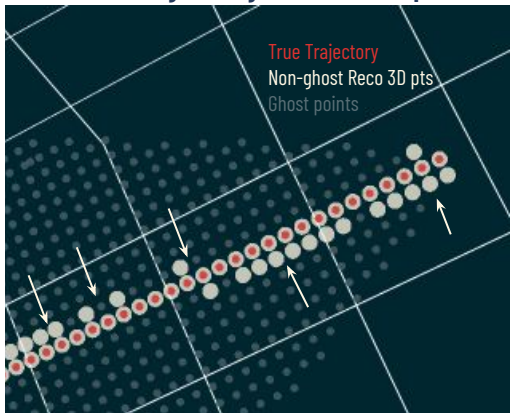


Peaked at 1 voxel around true trajectory in *log.* scale

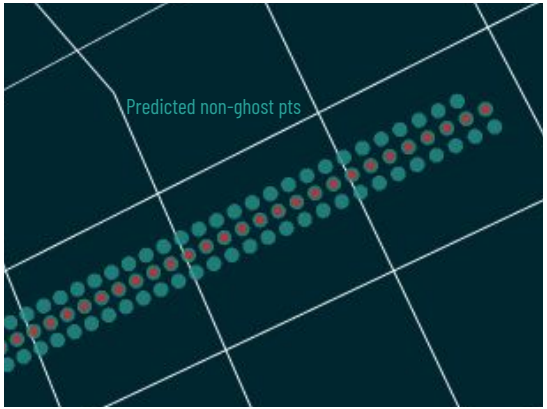
Deghosting Performance

Non-smooth local fluctuations in reco. 3D pts

True Trajectory + Reco. 3D pts



Network Predictions



Network predicts a smooth and slightly thicker segment.

<u>Remaining mistakes are "reasonable"</u>

- expected from the local fluctuations in reco. 3D pts
- misidentified ghost (or non-ghost) points are in the neighborhood of the true trajectory
- *overall event topology is preserved*

92%

Fraction of ghost voxels correctly predicted

94%

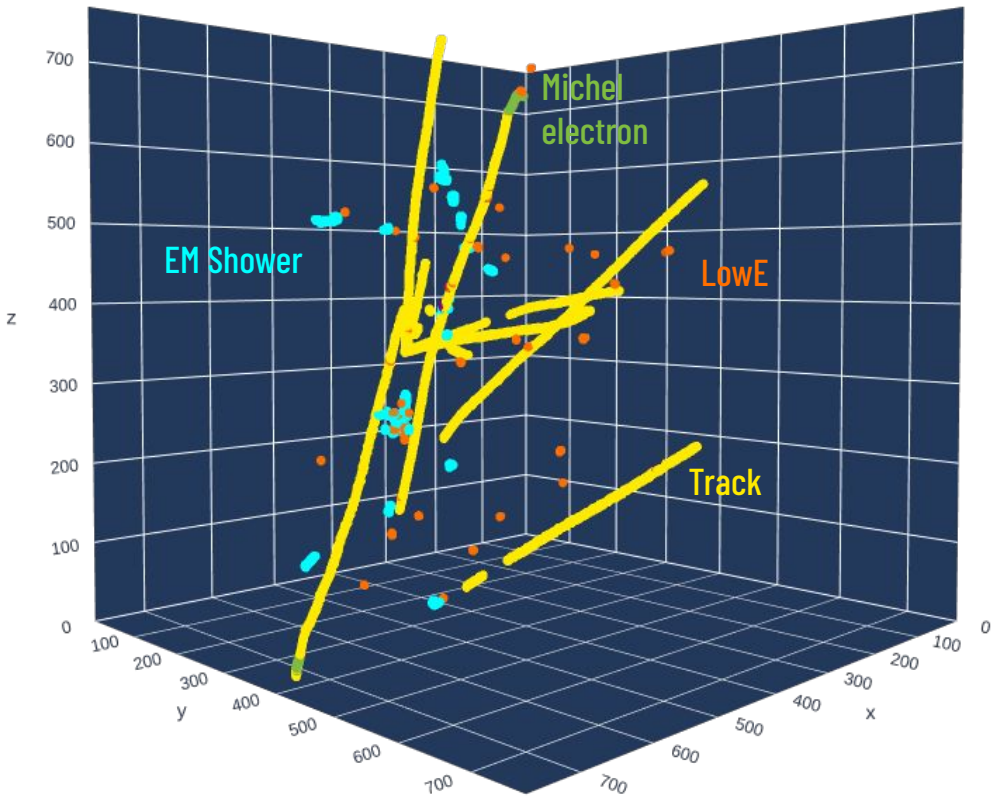
Fraction of non-ghost voxels correctly predicted

Deghosting Performance Breakdown

5-classes semantic segmentation on predicted non-ghost voxels

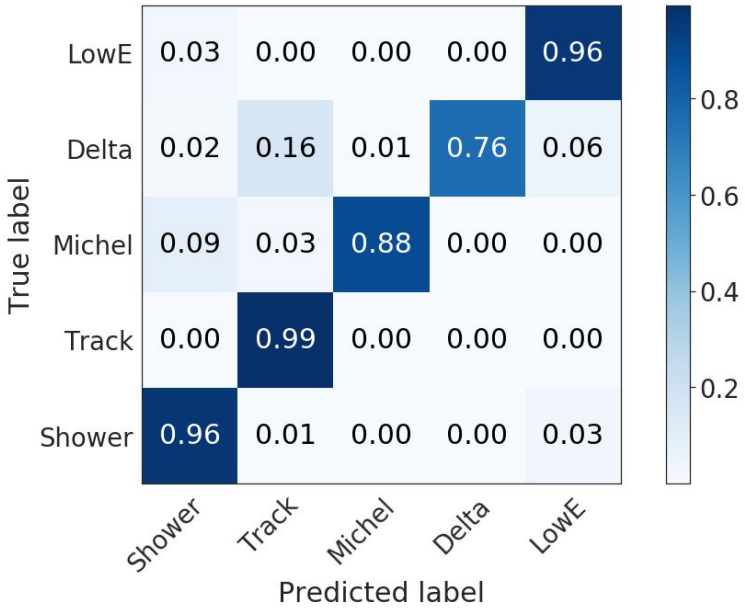
Class	Fraction of true nonghost correctly predicted
EM shower	92.6%
Track	97.5%
Michel	95.9%
Delta	90.5%
LowE	71%

Predicted particle type for each voxel

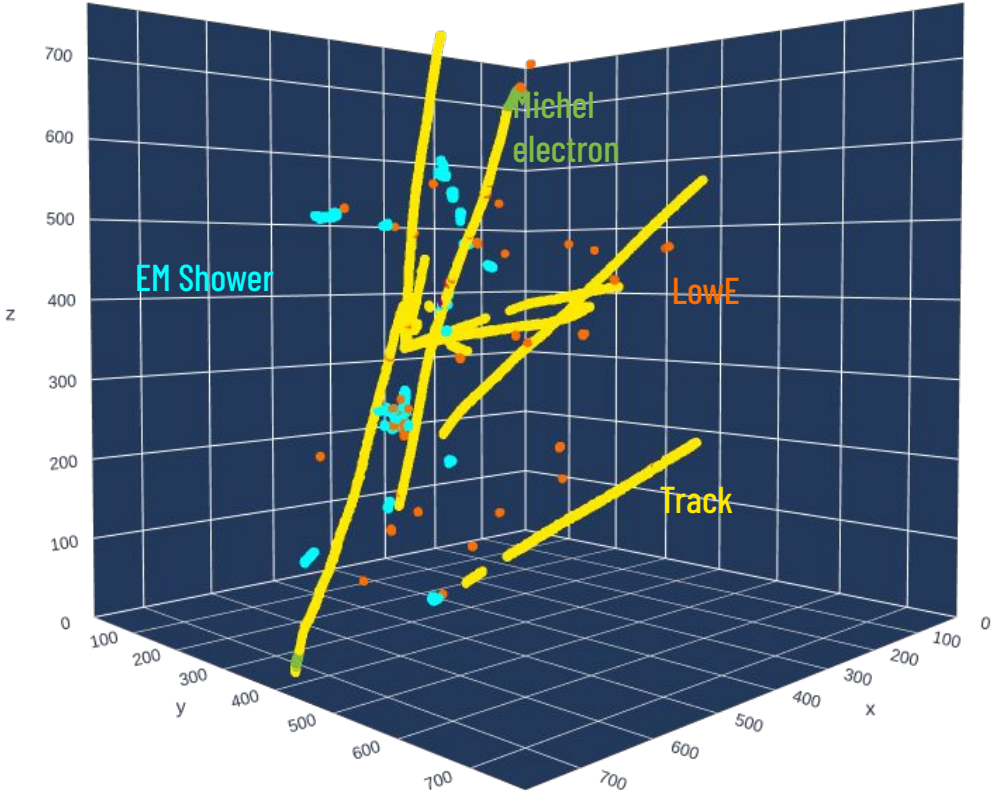


Semantic Segmentation After Deghosting

5-classes semantic segmentation on predicted non-ghost voxels

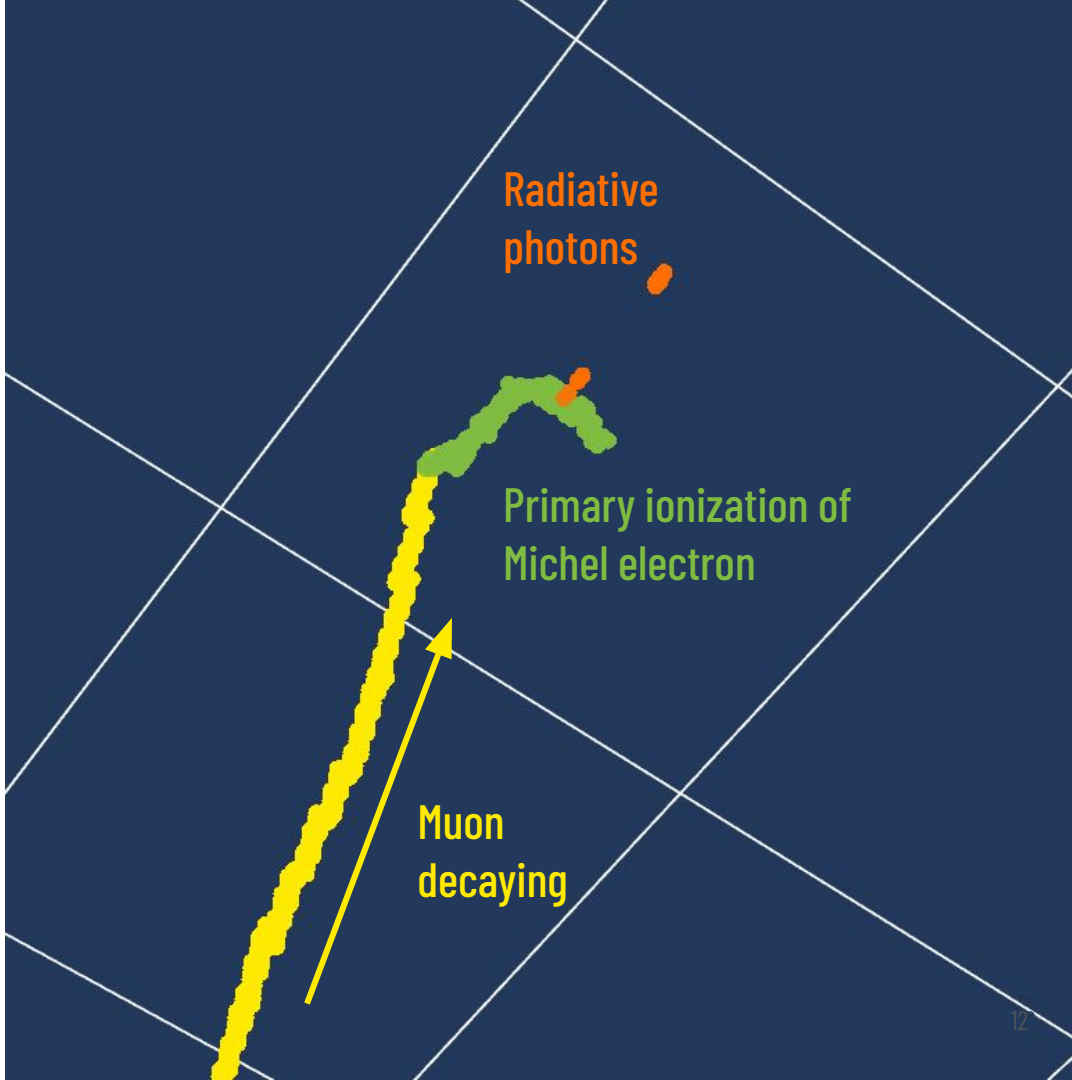


Confusion matrix (rows sum up to 1)



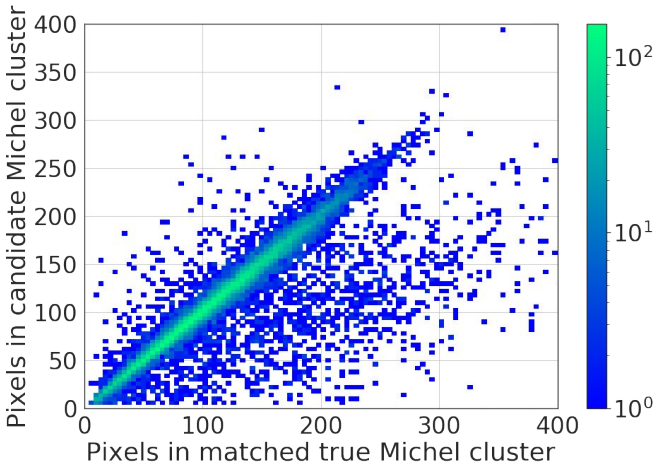
Predicted particle type for each voxel

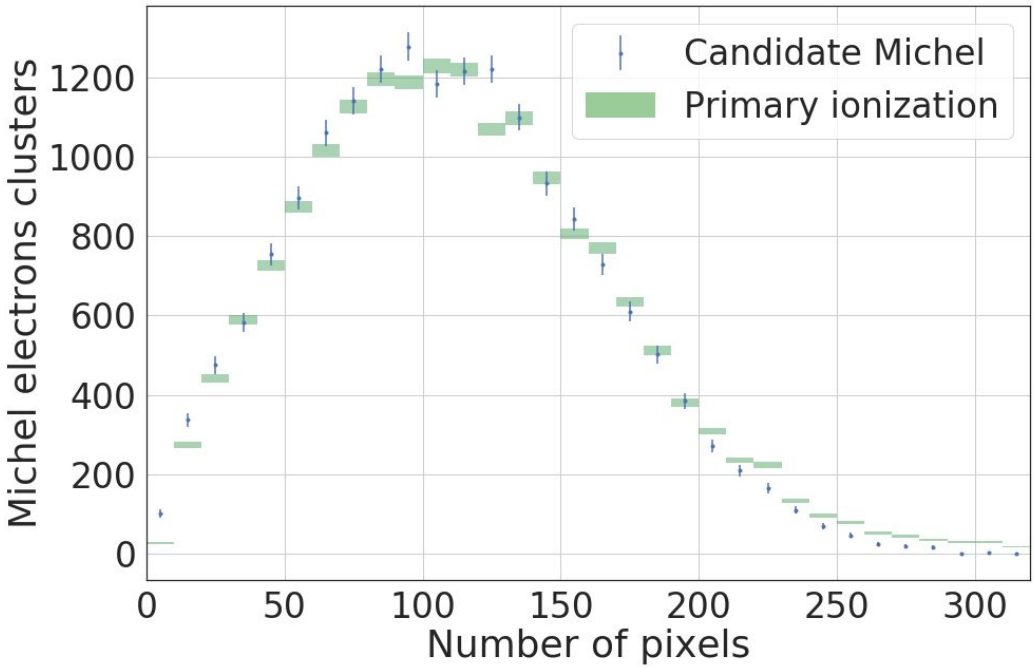
Enabling physics analysis: the example of Michel electrons



Michel electrons analysis

	Identification	Clustering
Purity	98%	91%
Efficiency	93%	88%



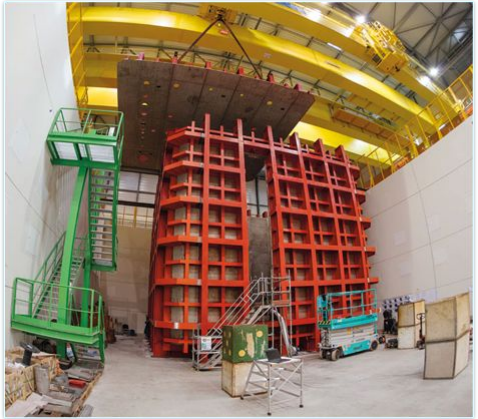


BONUS: Applying to other wire LArTPCs (ProtoDUNE-SP)

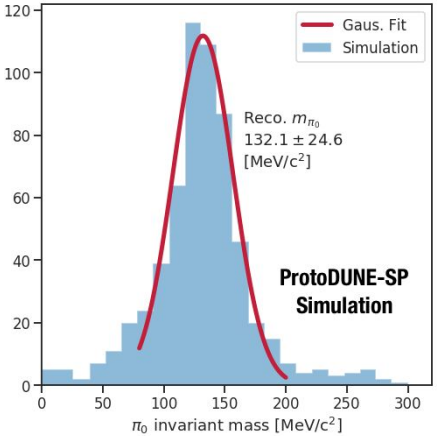
Related Presentation (Neutrino 2020 Poster #512)
K.V. Tsang, "Machine Learning Based Reconstruction of Neutral Pion in ProtoDUNE-SP"

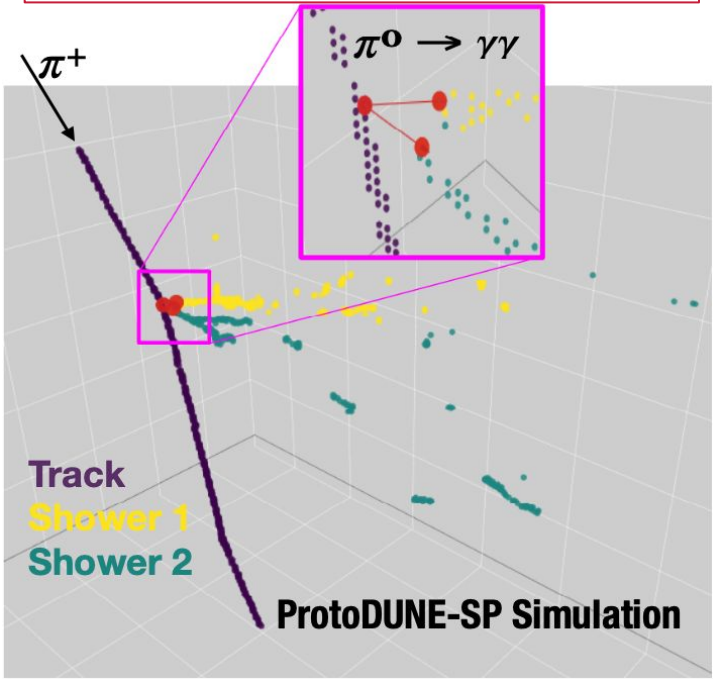
ProtoDUNE-SP

- a ~740-ton LArTPC prototype for DUNE
- similar to ICARUS detector with different geometry and wiring layouts



ProtoDUNE-SP





Example of a neutral pion decay

Summary

F. Drielsma, "Scalable, End-to-End Deep Learning Based Data Reconstruction Chain for 3D Particle Imaging Detectors"

- Combination of the `cluster3d` algorithm and deep neural network-based "deghosting" method enables our *3D reconstruction chain* for wire LArTPCs
  - Can be adopted to different experiments (SBN, ProtoDUNE-SP), and possibly DUNE-FD
  - Also applicable to different 3D point reconstruction algorithms (SpacePointSolver, WireCell ...)

- Preliminary results show that the reconstruction chain performance is retained.

- Next steps: finish integrating with the rest of the reconstruction chain:
  - EM shower clustering,
  - Interaction clustering,
  - Particle flow reconstruction,
  - Etc

D. Koh, "Proposal-free Deep Sparse Convolutional Neural Network for 3D Pixel Clustering"

Backup: Michel Electron Reco. w/ Open Dataset

L. Domine, "Scalable 3D Semantic Segmentation and Point Proposal Network for large-scale high resolution particle imaging detectors"

3D Semantic Segmentation

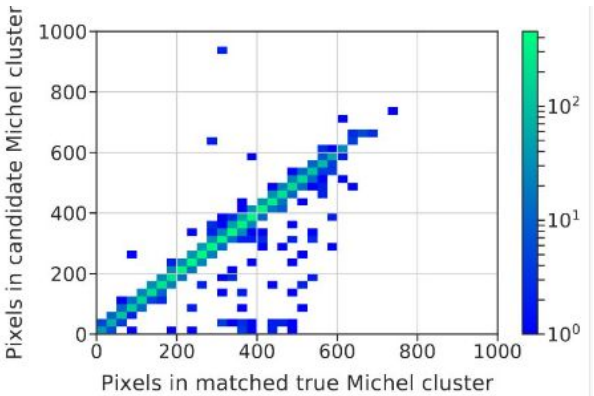
Example of application: finding Michel electron clusters

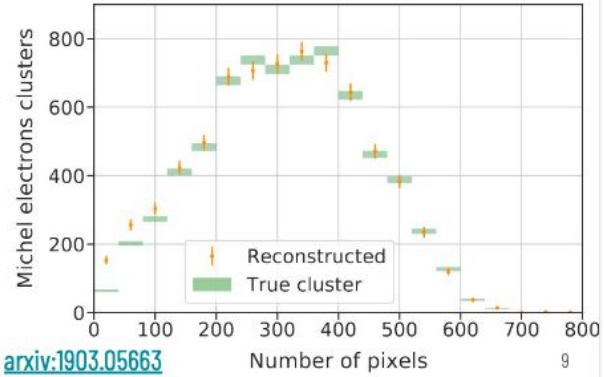
Straightforward algorithm based on UResNet semantic segmentation output:

1. Select MIP + Michel pixels
2. DBSCAN clustering algorithm
3. Simple cuts (Michel attached to the edge of a muon)

	Purity	Efficiency
Identification	97.3%	93.4%
Clustering	96%	96%

Including analysis cut of minimal 10px for Michel electron cluster size





See arxiv:1903.05663

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