Overview of Machine Learning in DUNE

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For the DUNE Collaboration

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CSU

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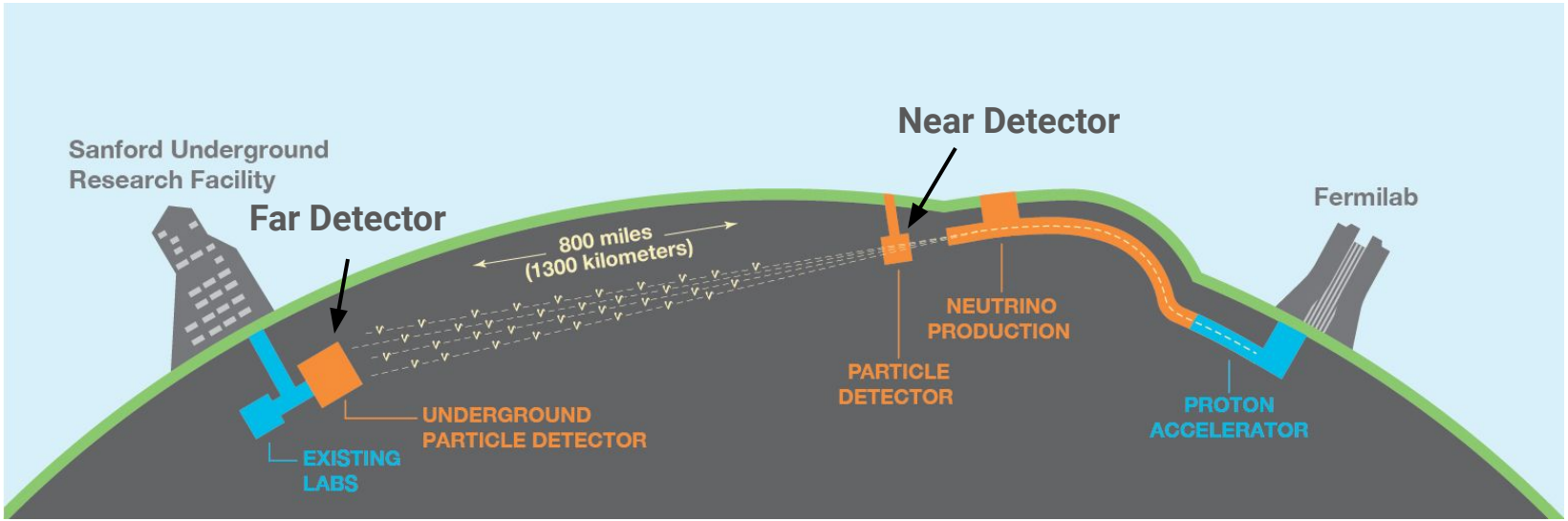
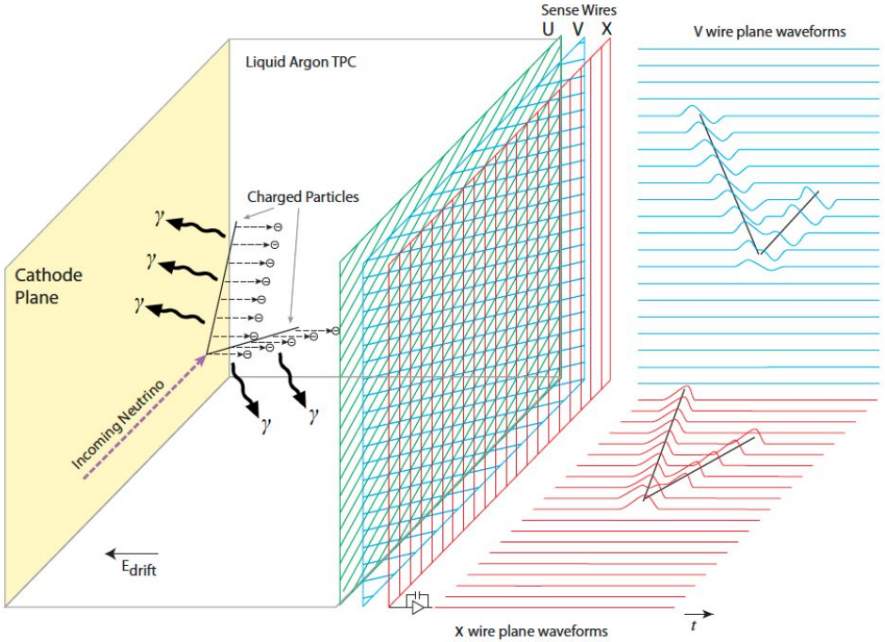
DUNE

- Deep Underground Neutrino Experiment (see Mike Mooney's plenary talk)
- Long-baseline neutrino oscillation experiment with near detector (ND) at Fermilab and far detector (FD) at SURF; ProtoDUNE-SP at CERN
- Neutrino mass ordering, value of δ_{CP}, etc.



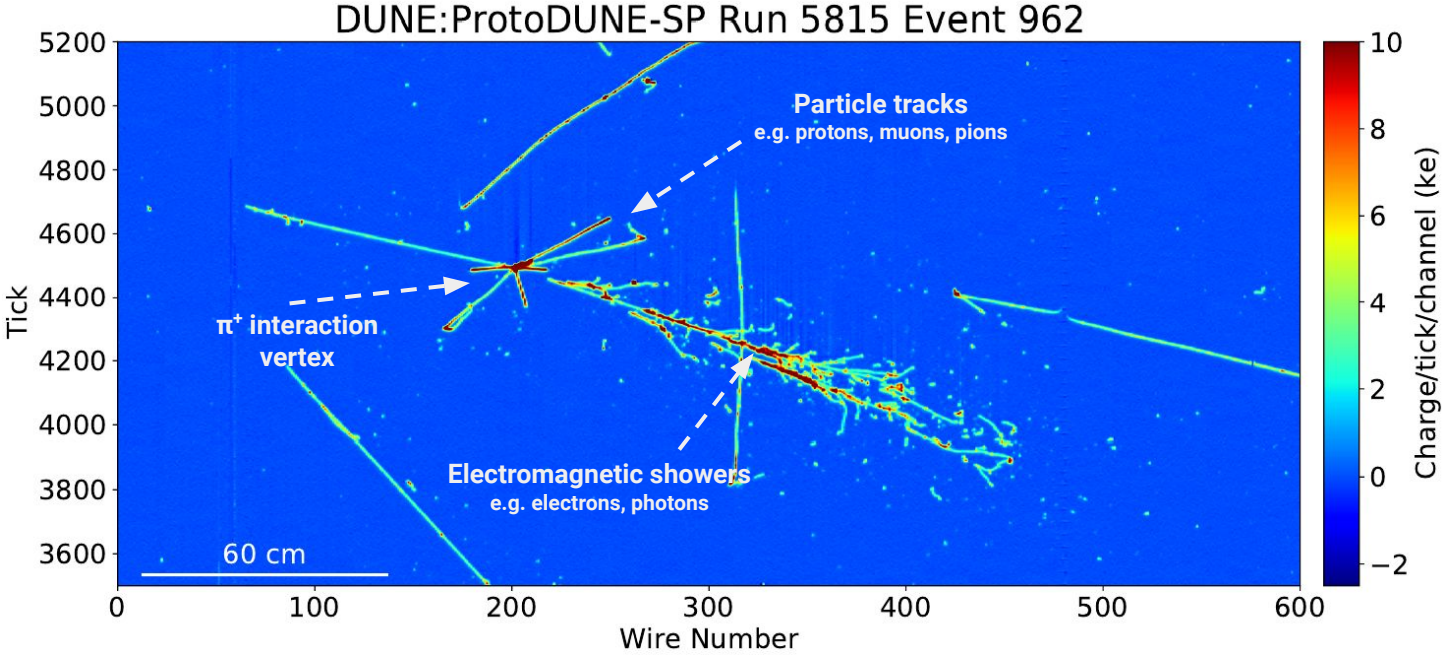
Liquid Argon Time Projection Chambers

- Liberated ionization electrons travel toward readout planes under the influence of an applied electric field; scintillation photons give timing information



Reconstruction in LArTPCs

- Interaction objects generally classified as either tracks or showers
- Event topology and calorimetry allow for classification



Why Machine Learning?

- Deep learning techniques for image recognition have been actively developed for the past few decades
- Convolutional neural networks (CNNs) are particularly good at image classification
- Extract high-level image features by scanning with filters (i.e., *convolution*)
- Adding multiple convolutional layers allows for better feature extraction
- We can use this to identify particle objects in detector images

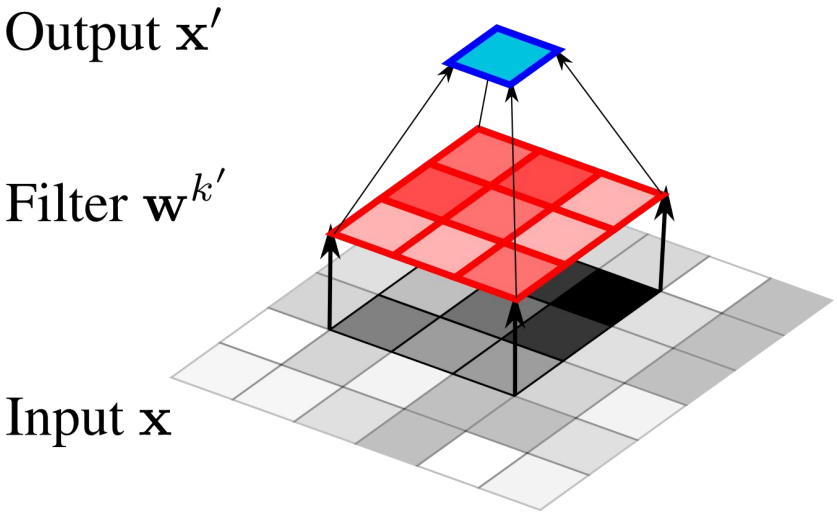
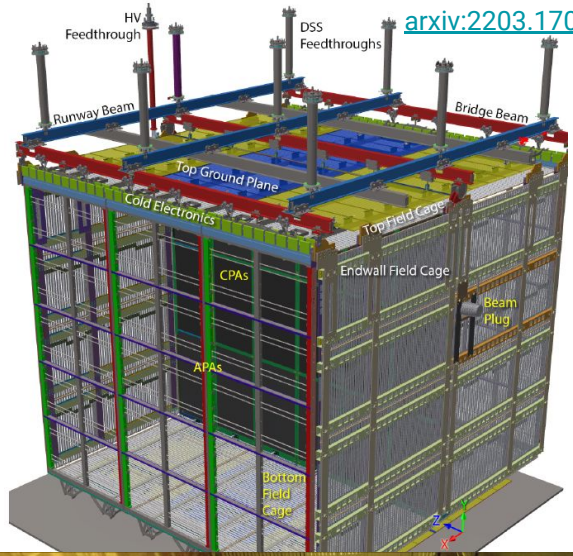


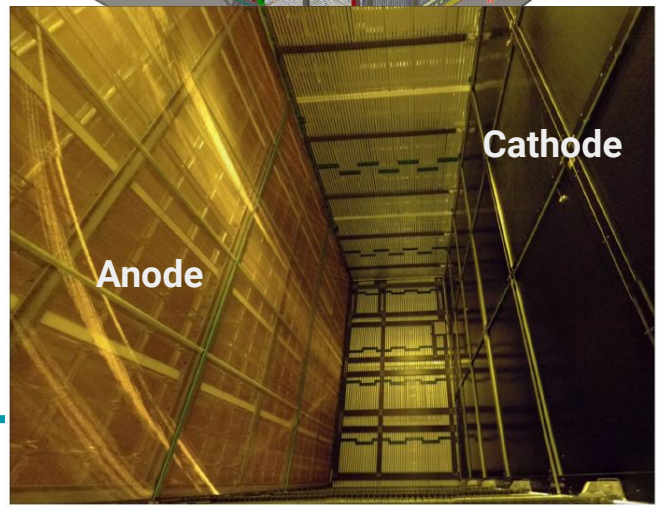
Image source

ProtoDUNE-SP

- Single-phase liquid argon time projection chamber (LArTPC) located at CERN
- Two active volumes (6.1 x 7.0 x 3.6) m
- Central cathode with two anode planes
- Anodes have a shielding plane, two induction planes, and a collection plane
- Beam of charged pions, muons, protons, and positrons
- ProtoDUNE beam selects particle species
  - Muons and pions separated based on end position along beam direction
  - Muons stop further in the detector than pions
- Phase I data collection 2018-2020; Phase II planned to start Fall 2022



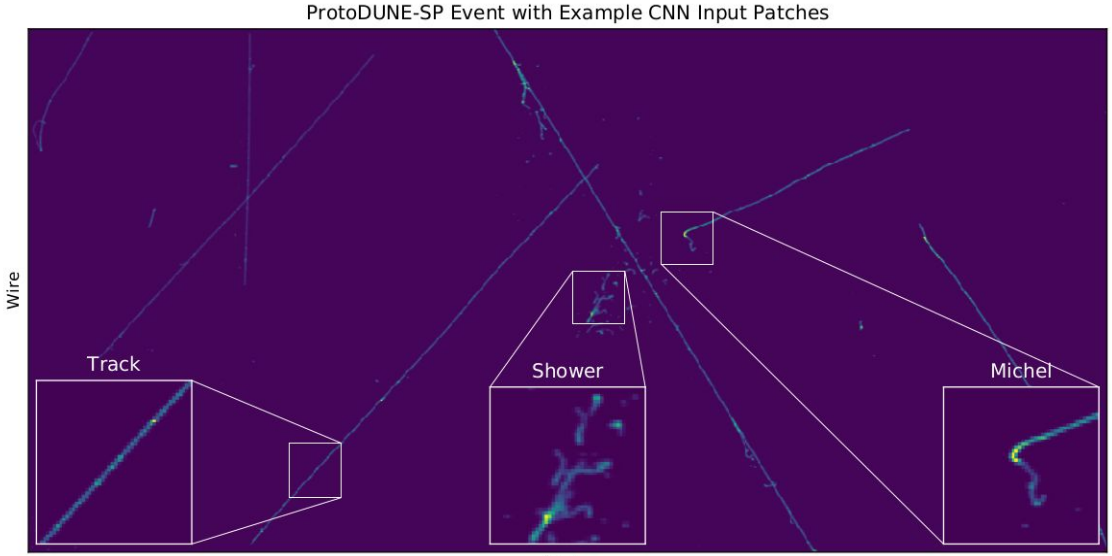
arxiv:2203.17053

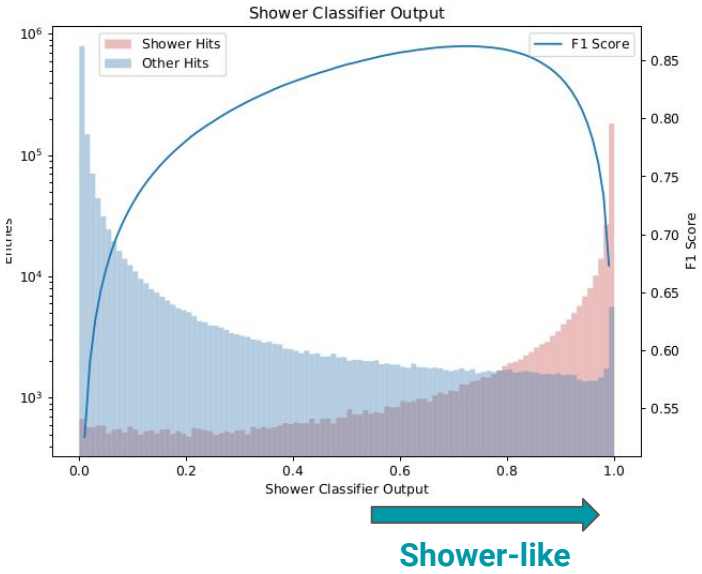


ProtoDUNE Convolutional Neural Network

- CNN architecture designed to select track, showers, and Michel electrons
  - Michels considered separately from tracks and showers due to overlap with shower classification

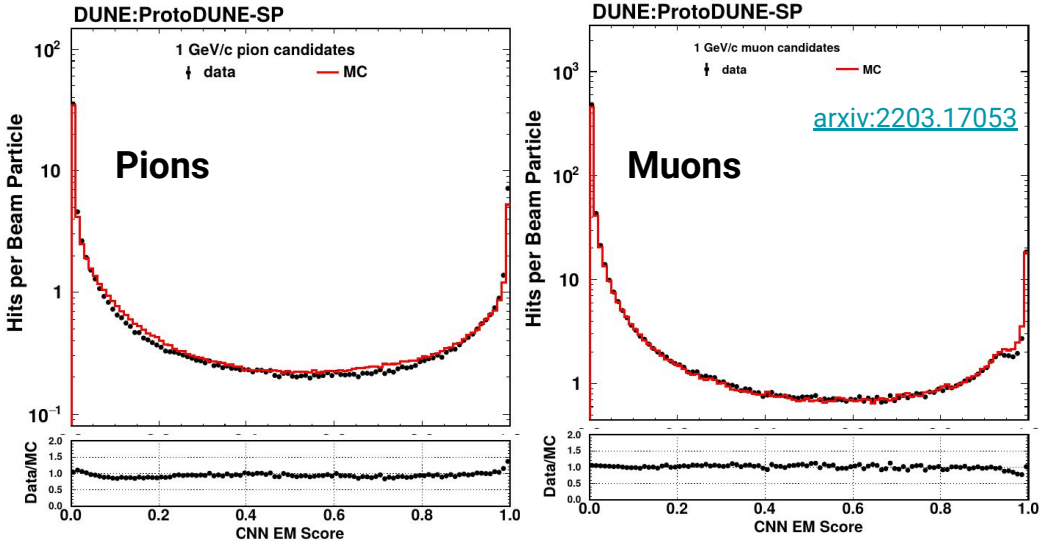
arxiv:2203.17053

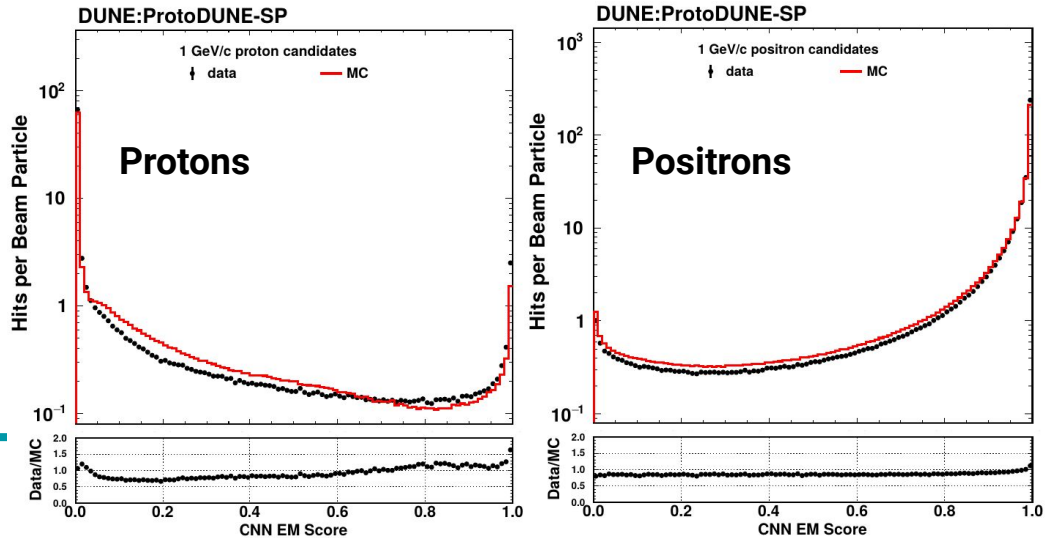




Hit-Level Validation using Data

- Overall good agreement in hit-level identification
- Some differences may be attributed to local E-field distortions
- Positron and proton data appear more shower-like than simulation





DUNE Far Detector

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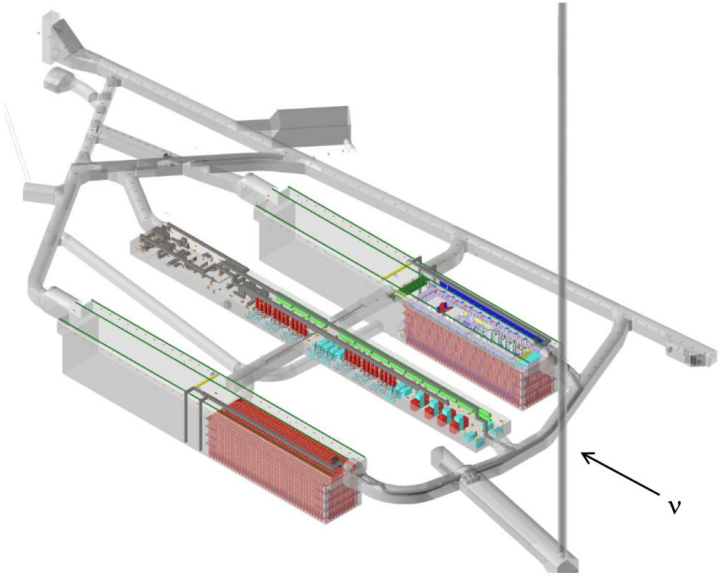
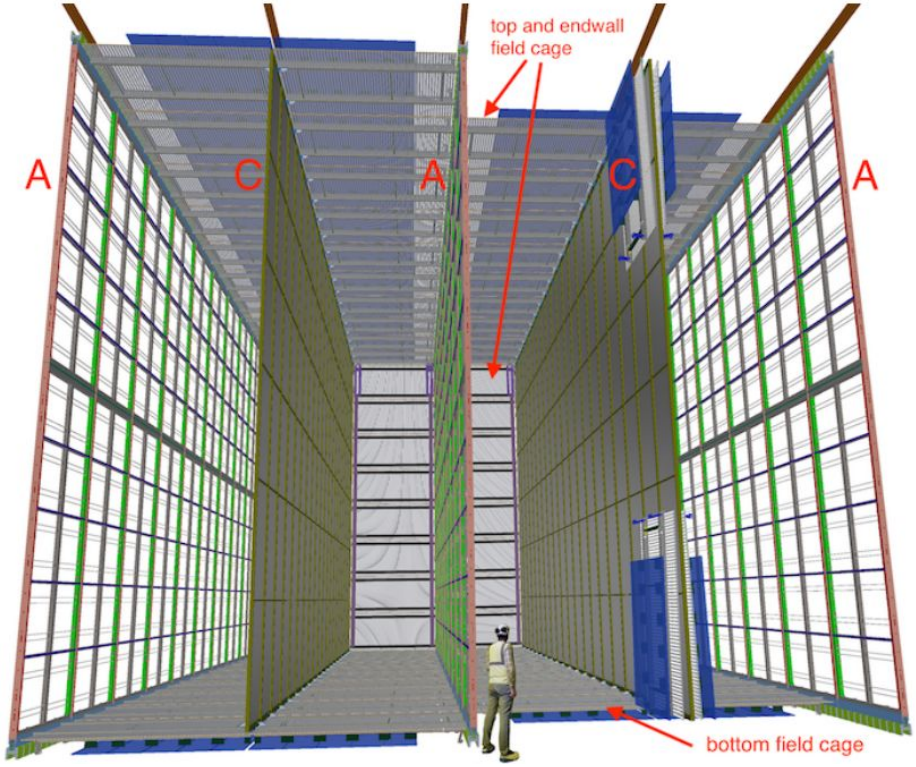
- Pictured: one 17 kt single-phase horizontal drift module
- Full FD will consist of four modules

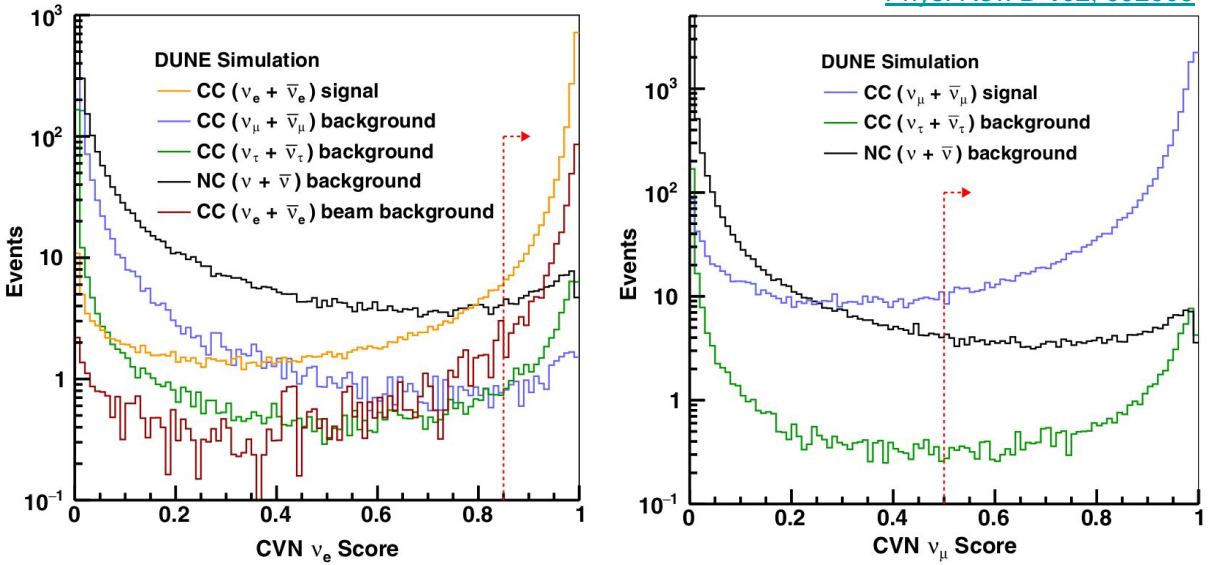




DUNE FD CNN

- Uses SE-ResNet architecture
  - SE-ResNet: residual network with squeeze-and-excitation blocks
- Classify neutrino events CC ν_e, CC ν_μ, CC ν_τ, or NC

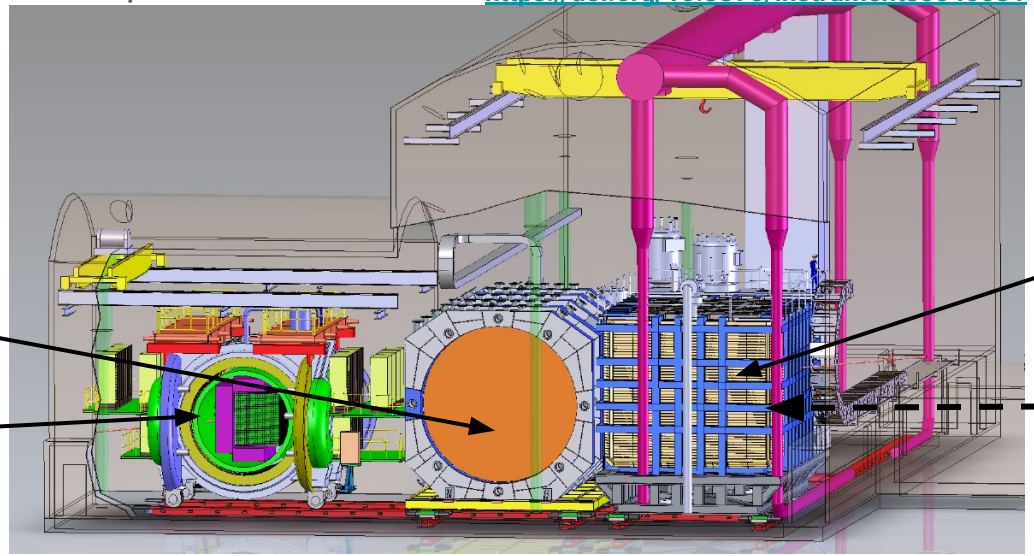
Phys. Rev. D **102**, 092003



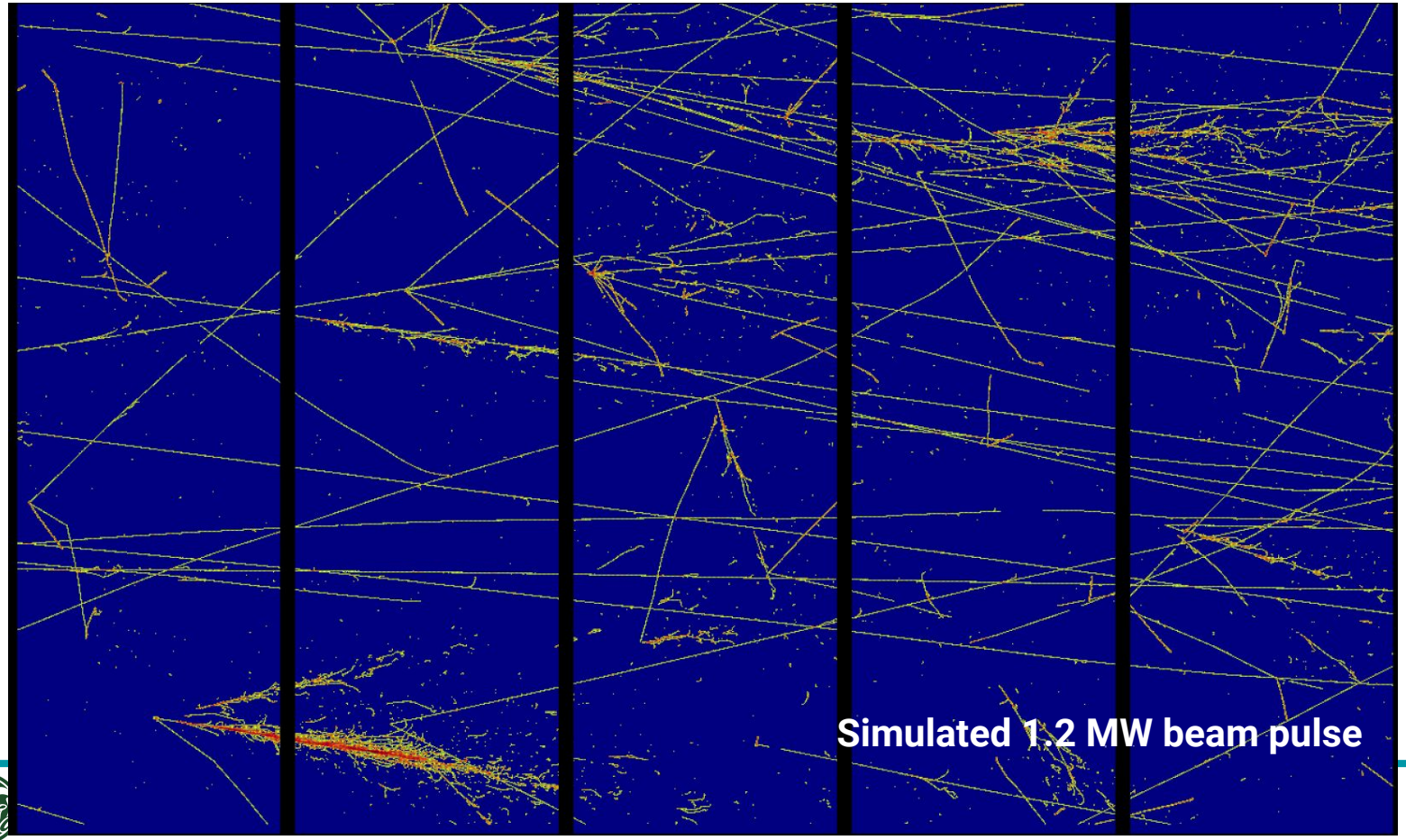
ND-LAr

- Liquid argon detector in the near detector complex
- Uses pixel readout instead of wire readout
- Modular design to mitigate neutrino pileup
  - 7 x 5 array of independent modules

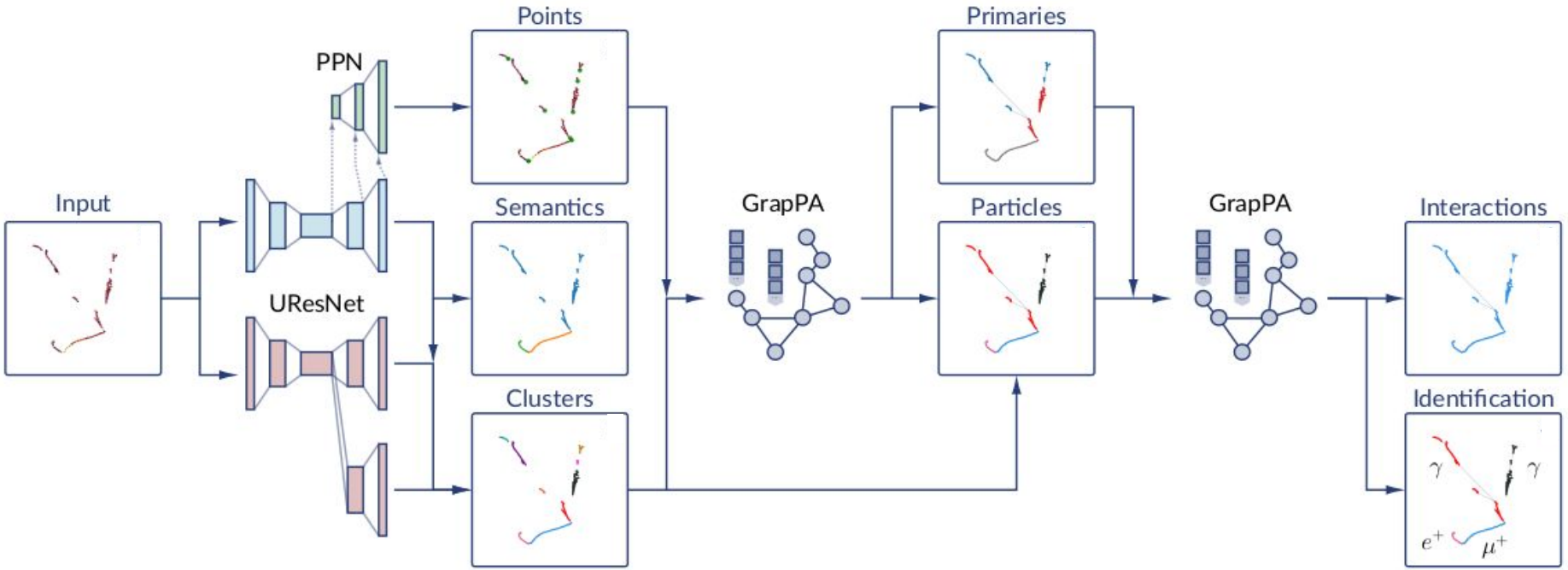
https://doi.org/10.3390/instruments5040031



Typical Event Display in ND-LAr



ND-LAr ML Reco Architecture



https://arxiv.org/abs/2102.01033

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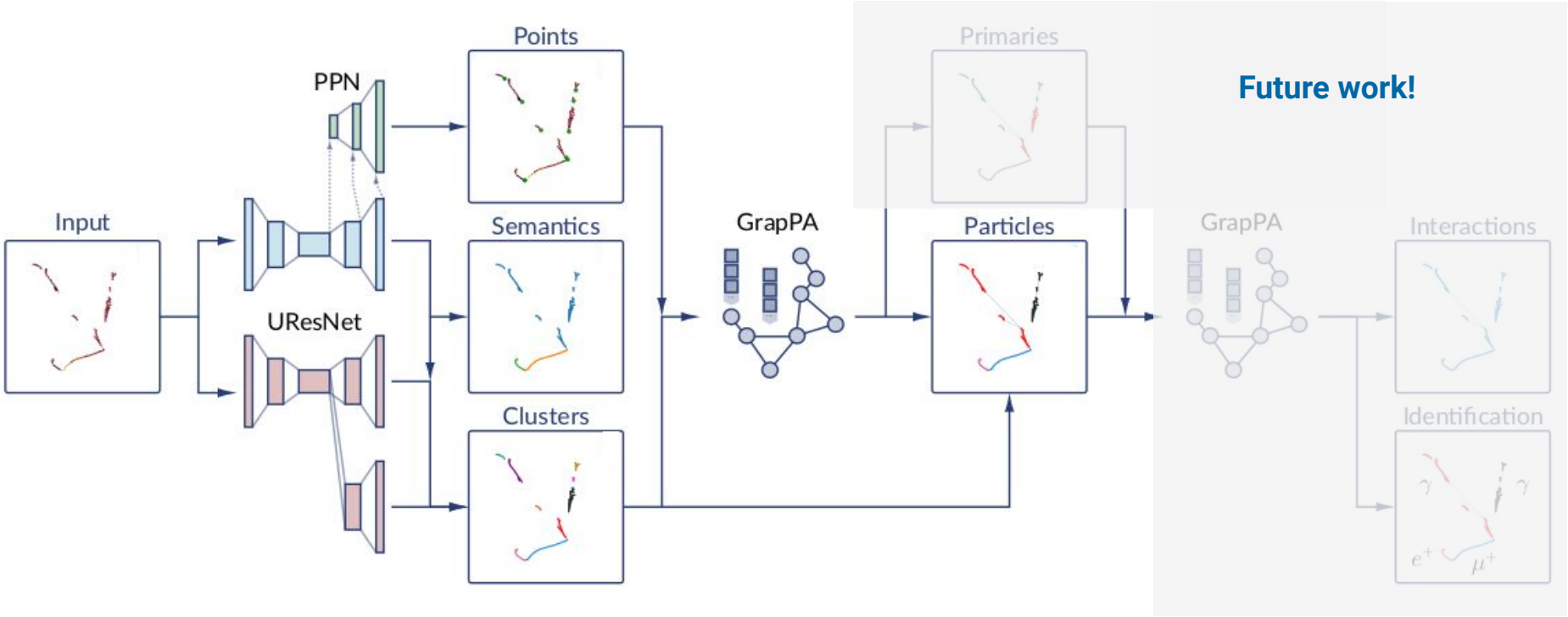

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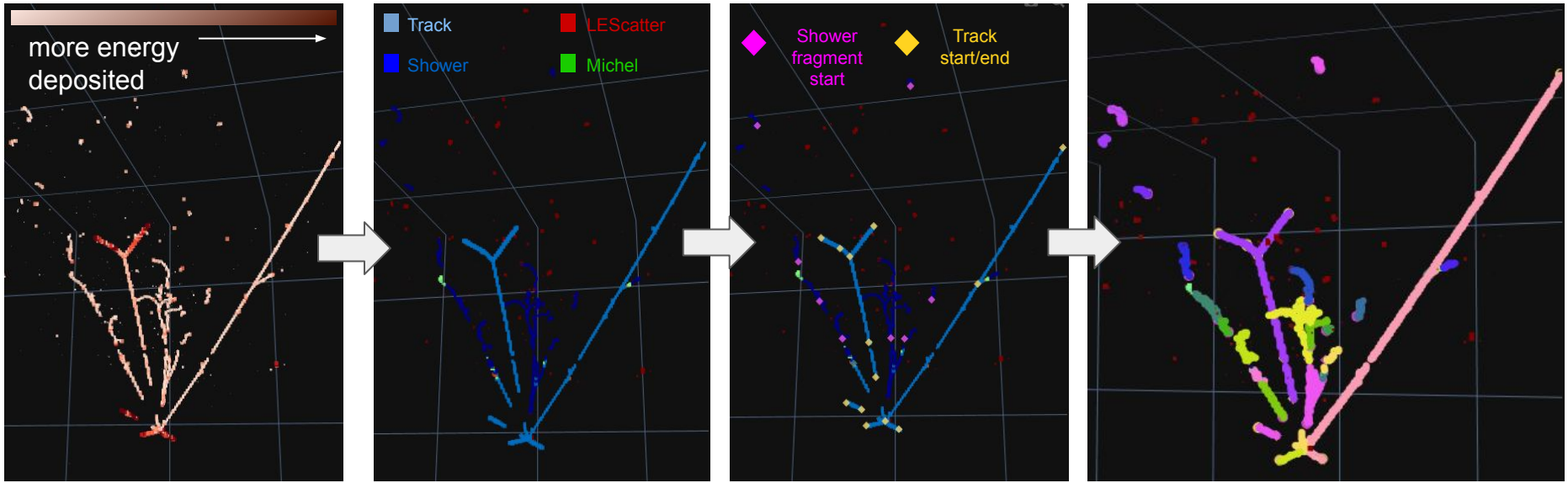
Example of Reconstruction Flow



"Voxelized" energy depositions

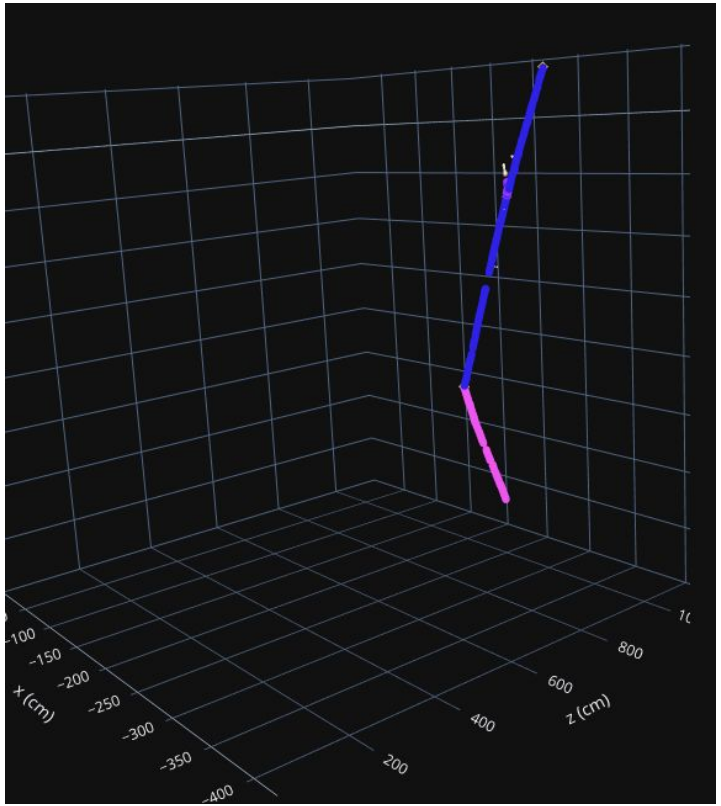
Classification

Points of interest

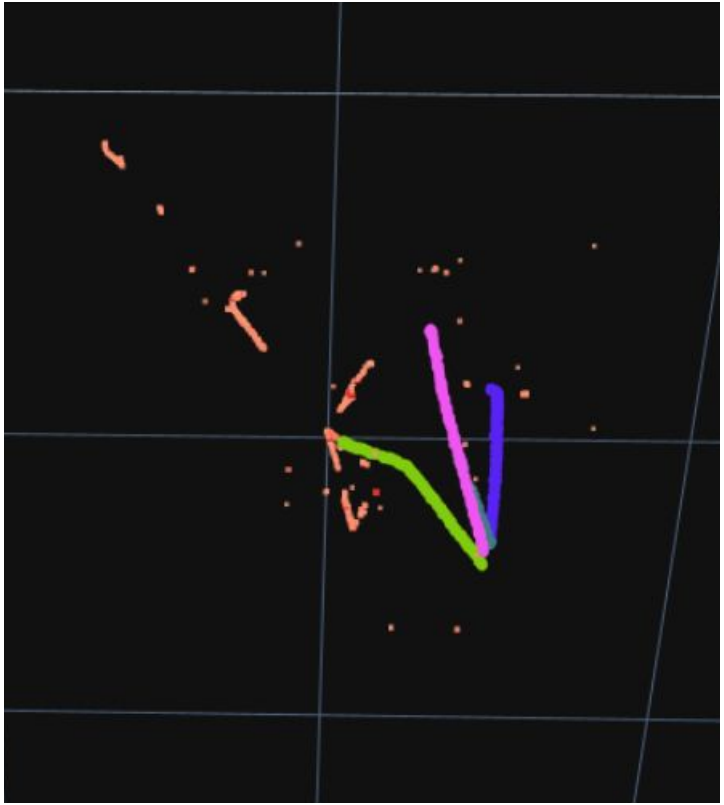
Clusters

ND-LAr Machine Learning Reconstruction

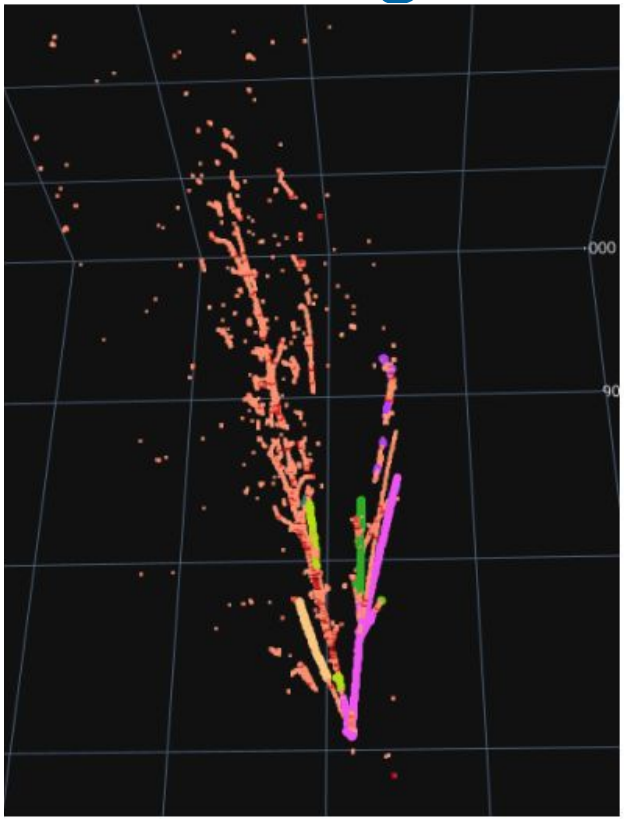
- Currently developing full end-to-end simulation and reconstruction
- Pictured: **first fully simulated and reconstructed event in ND-LAr**
- Colors show particle semantics
  - Correctly identifies two distinct tracks
- To-do: add true particle labels, update training model, apply to more complex interactions



ND-LAr Machine Learning Reconstruction



ND-LAr Machine Learning Reconstruction



Summary

- The DUNE experiment seeks to answer important open questions in neutrino physics, including the neutrino mass ordering and value of δ_{CP}
- Several machine learning architectures developed between ProtoDUNE, DUNE FD, and ND-LAr
  - ProtoDUNE CNN classifies hits with reasonable accuracy in data
  - DUNE FD CVN shows strong separation power between signal and background
  - ND-LAr ML reconstruction under active development; showed first end-to-end simulated and reconstructed events