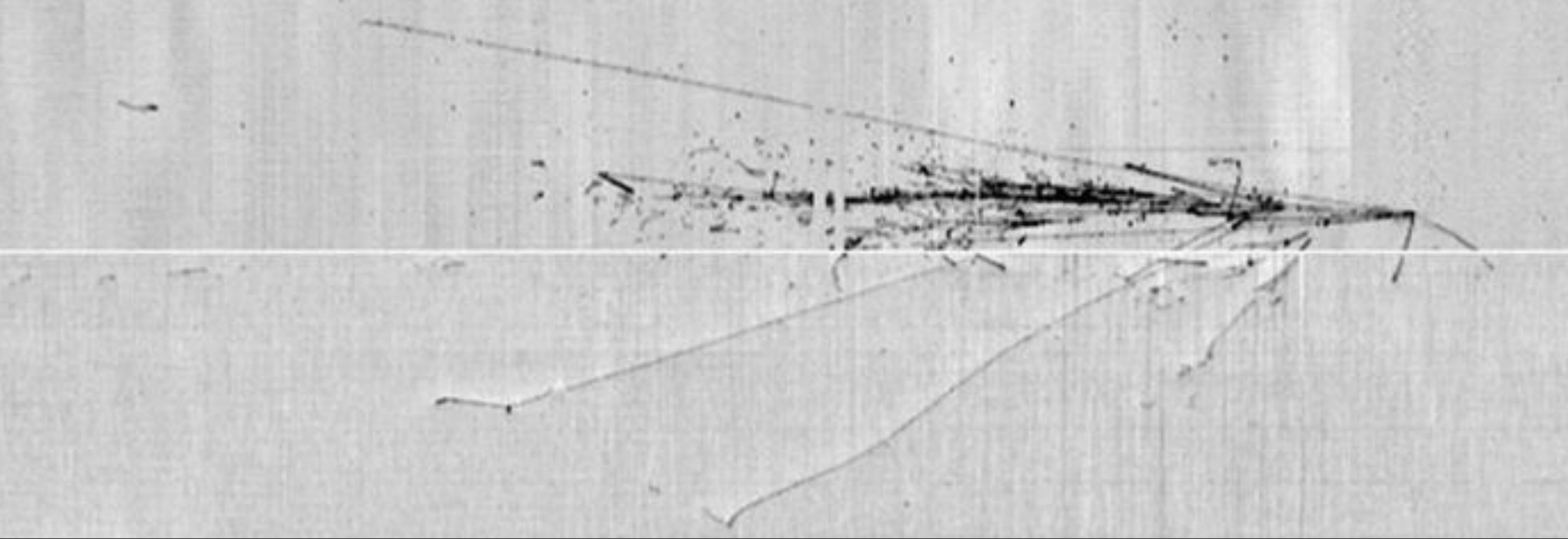


Computer Vision and Machine Learning for ICARUS Physics Reconstruction

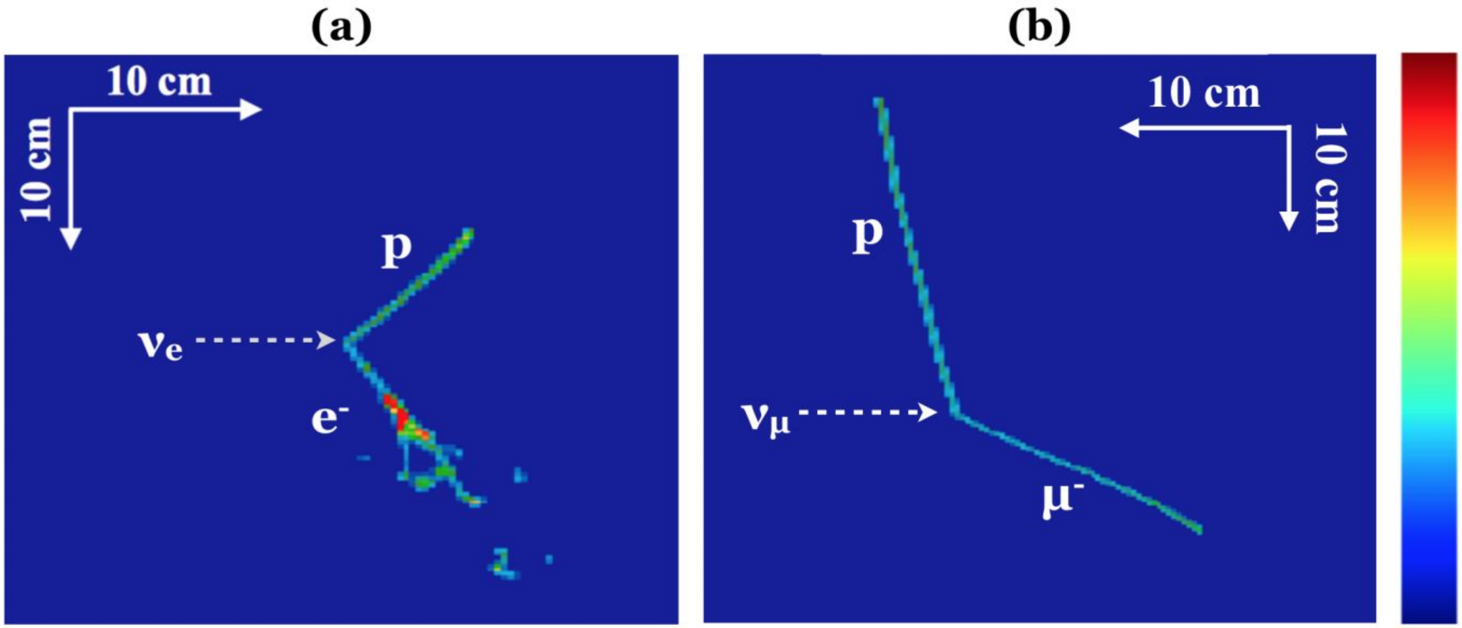
Francois Drielsma, *Kazuhiro Terao, Laura Domine*
SLAC National Accelerator Lab.
ICARUS Collaboration Meeting @ FNAL
September 12th 2019

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Development Workflow without Machine Learning

1. Write an algorithm based on physics principles

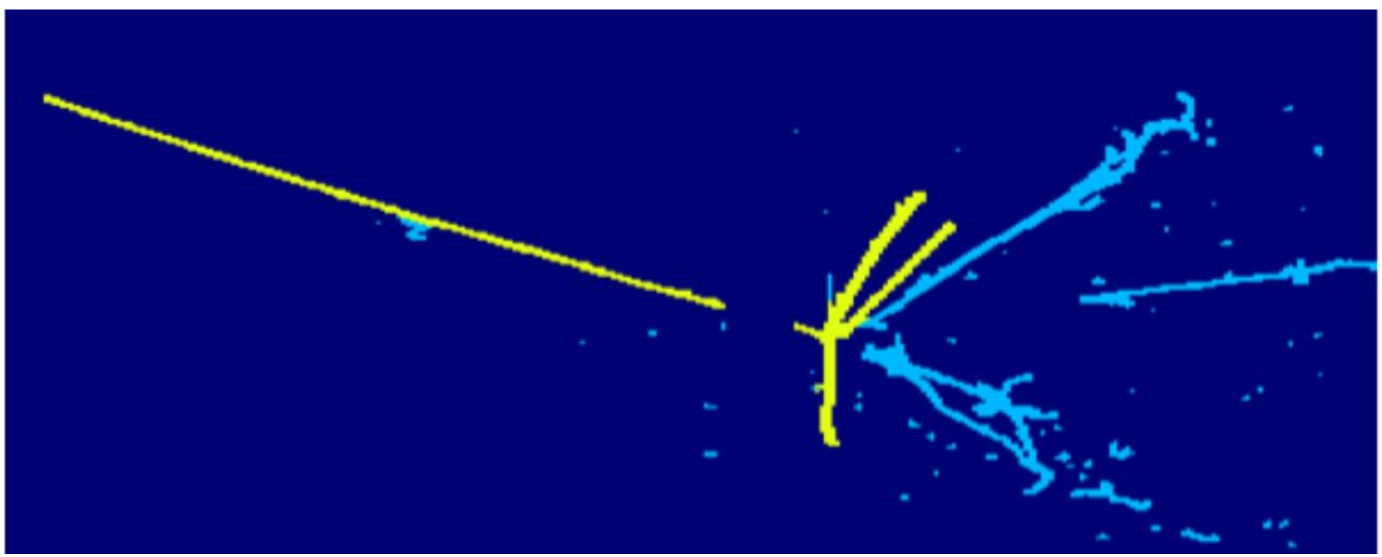


Neutrino interaction = collection of certain shapes

Computer Vision and LArTPC Image Data Analysis

Development Workflow without Machine Learning

1. Write an algorithm based on physics principles
2. Run on simulation and data samples
3. Observe failure cases, implement fixes/heuristics
4. Iterate over 2 & 3 till a satisfactory level is achieved
5. Chain multiple algorithms as one algorithm, repeat 2, 3, and 4.



https://arxiv.org/pdf/1808.07269.pdf

Computer Vision and LArTPC Image Data Analysis

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Development Workflow without Machine Learning

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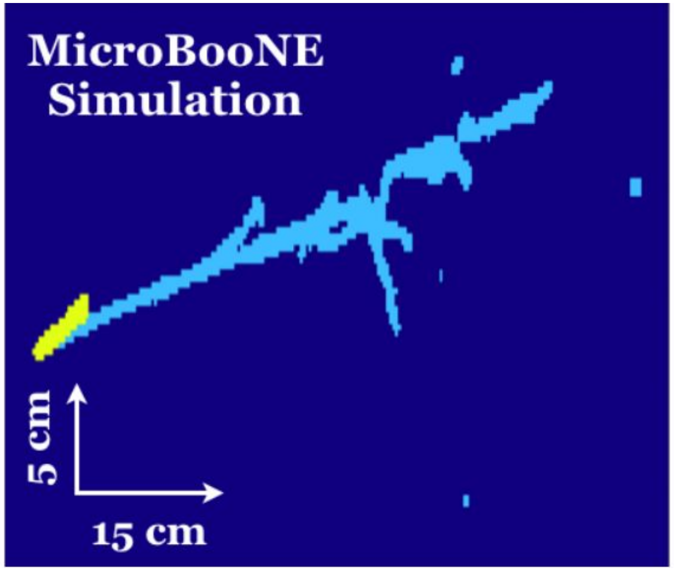
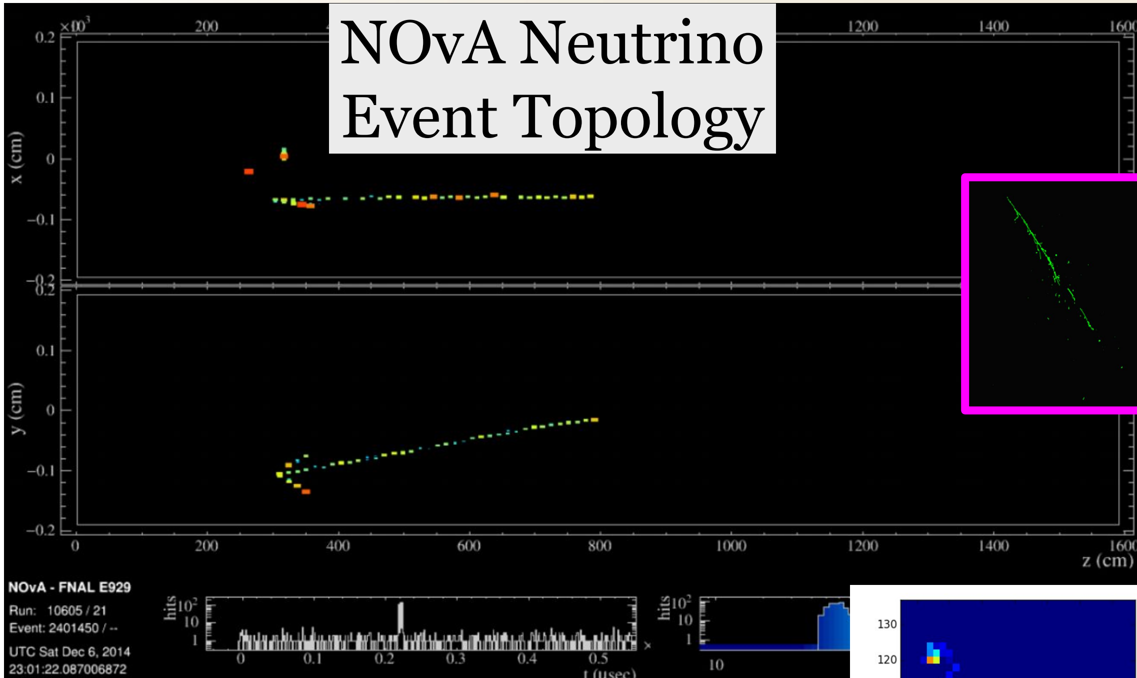
Machine Learning

- **"Learn patterns from data"**
  - automation of steps 2, 3, and 4"
- **"Chain algorithms & optimize"**
  - step 5 addressed by design
- **"Deep Neural Network"**
  - de-facto standard in computer vision

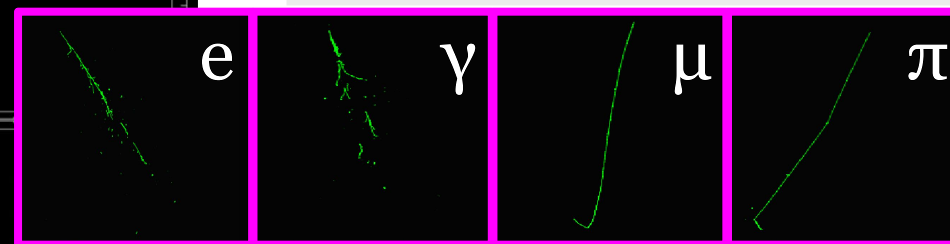


Computer Vision + Machine Learning in
Particle Imaging Neutrino Detectors

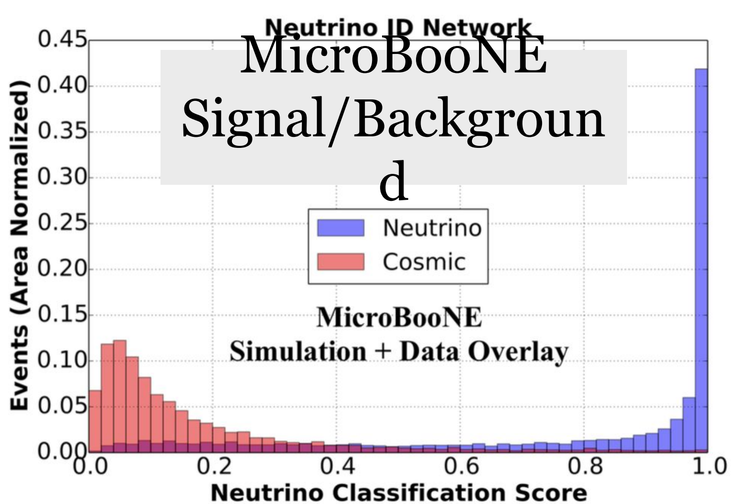
SLAC

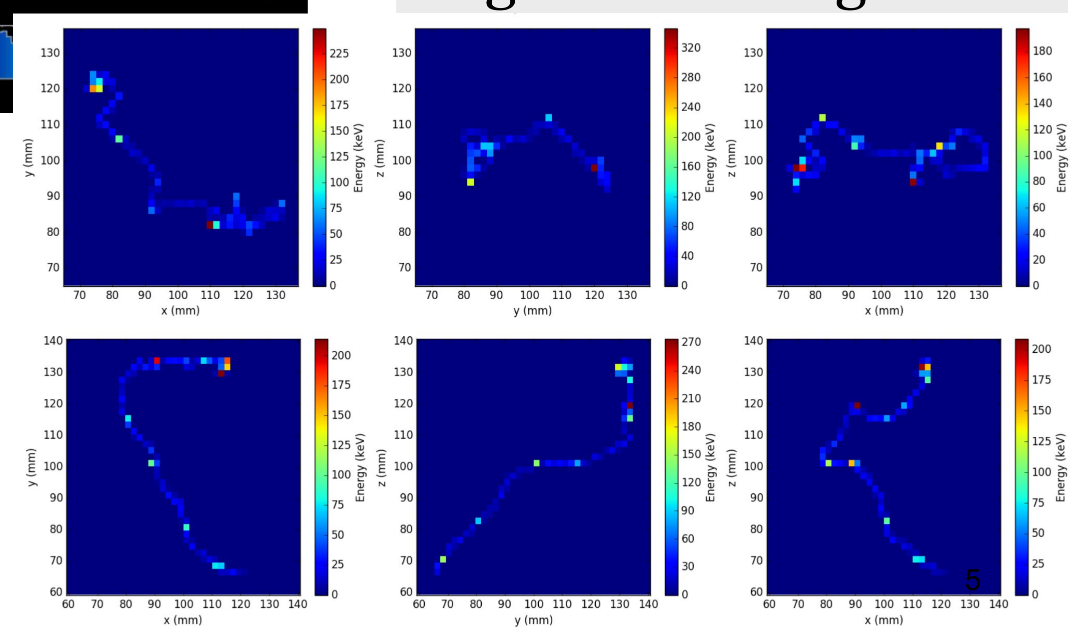


LArTPC particle ID



NEXT
Signal vs. Background





Computer Vision + Machine Learning in Particle Imaging Neutrino Detectors

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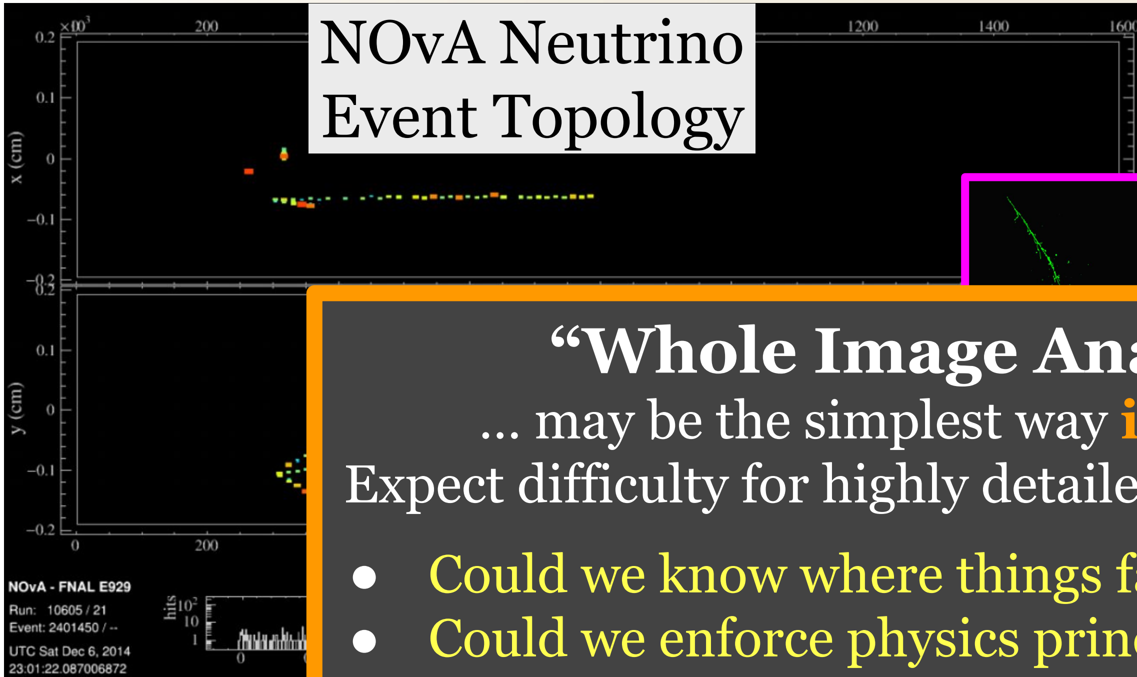
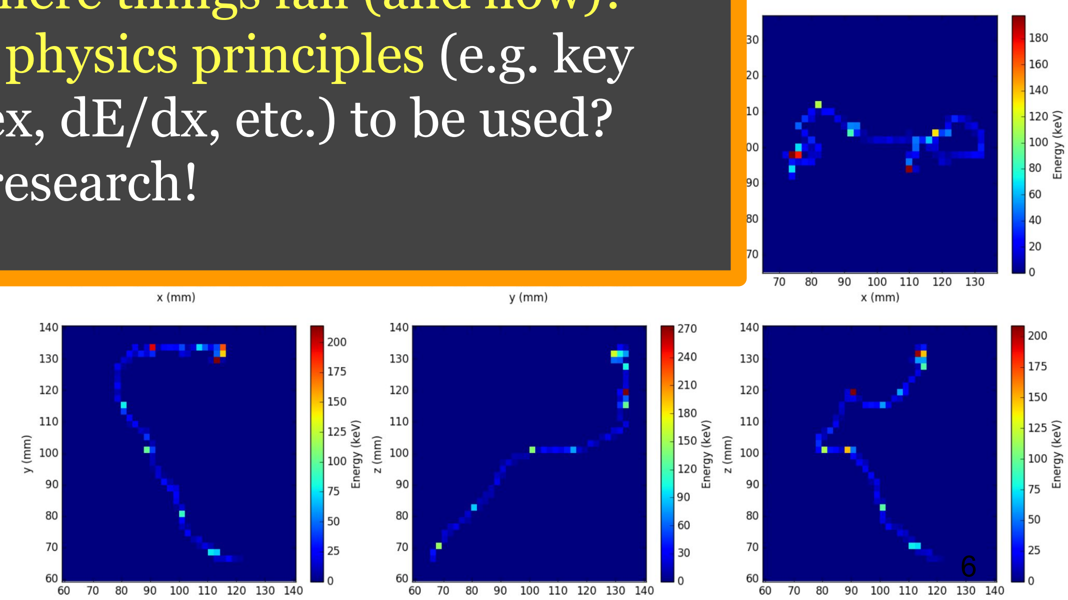
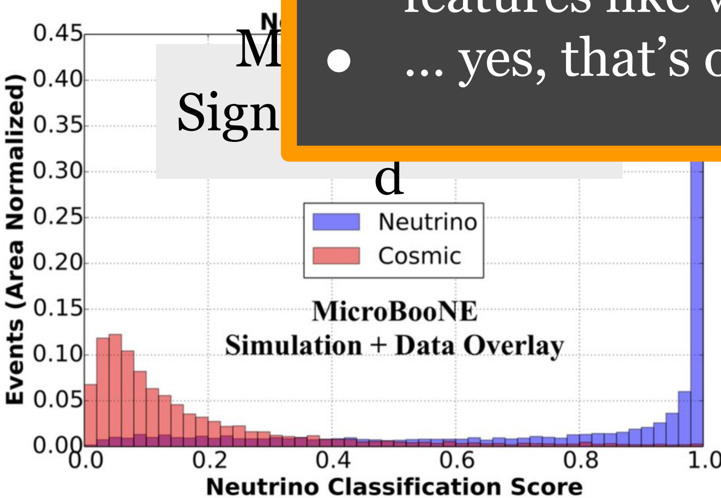


LArTPC particle ID

XT
ackground





"Whole Image Analysis"

... may be the simplest way **if it works!**

Expect difficulty for highly detailed LArTPC images

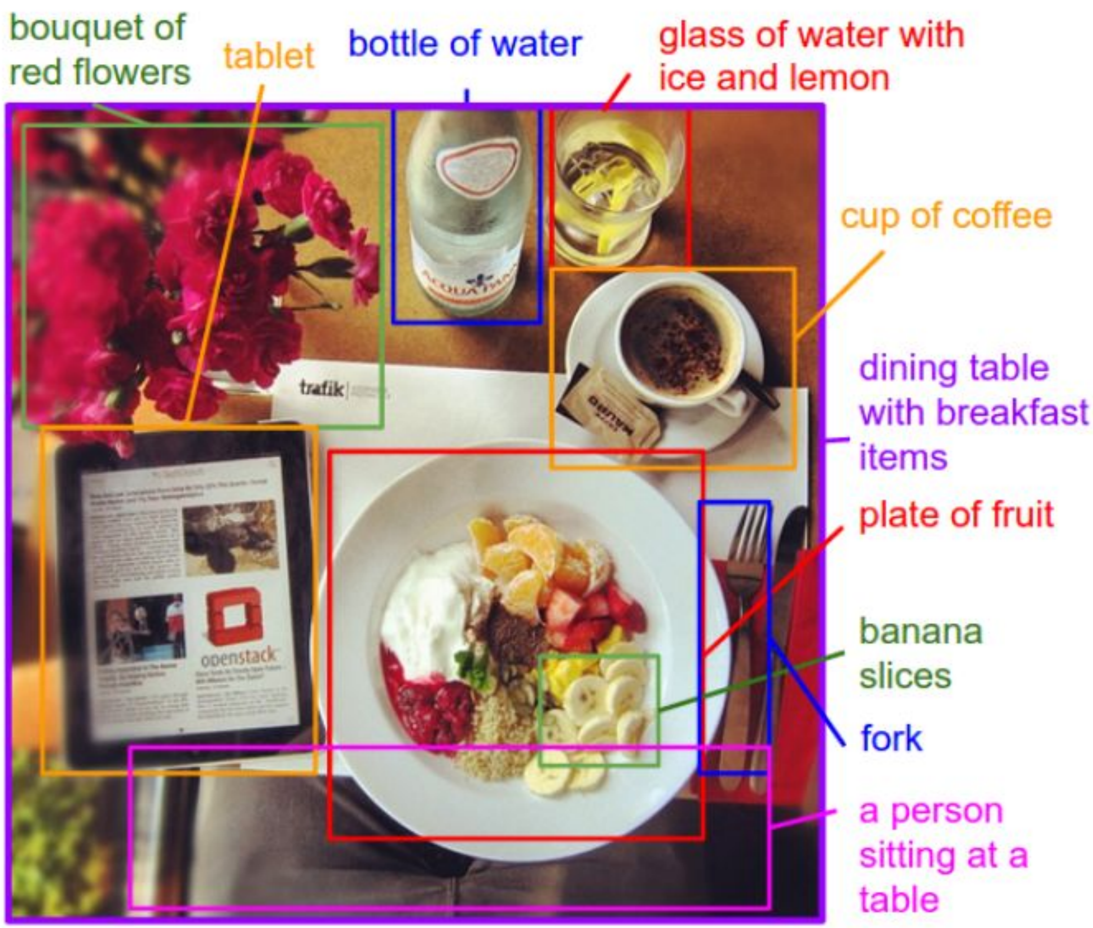
- Could we know where things fail (and how)?
- Could we enforce physics principles (e.g. key features like vertex, dE/dx, etc.) to be used?
- ... yes, that's our research!

Computer Vision + Machine Learning for Image “Feature” Extraction

Image Context Detection

- Identify object location (where)
- Identify object class (what)

Interpret image context correlations

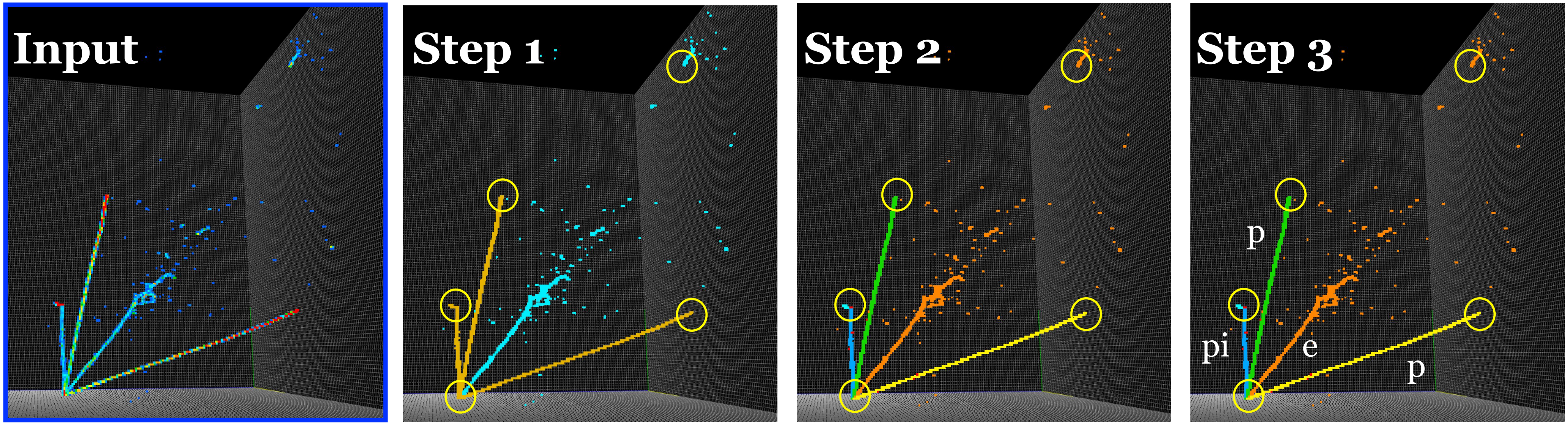


https://cs.stanford.edu/people/karpathy/cvpr2015.pdf

ML-based Full Data Reconstruction Chain

A hierarchical chain of task-specific algorithms

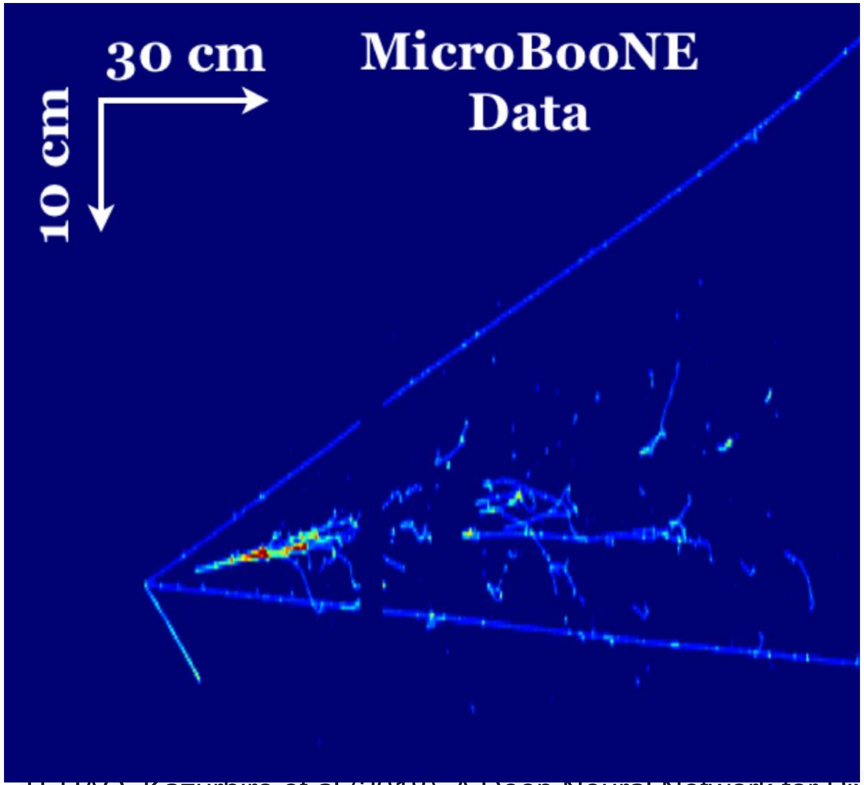
1. Key points (particle start/end) + pixel feature extraction
2. Vertex finding + particle clustering
3. Particle type + energy/momentum
4. Interaction ("particle flow") reconstruction
5. PMT-TPC signal "matching"



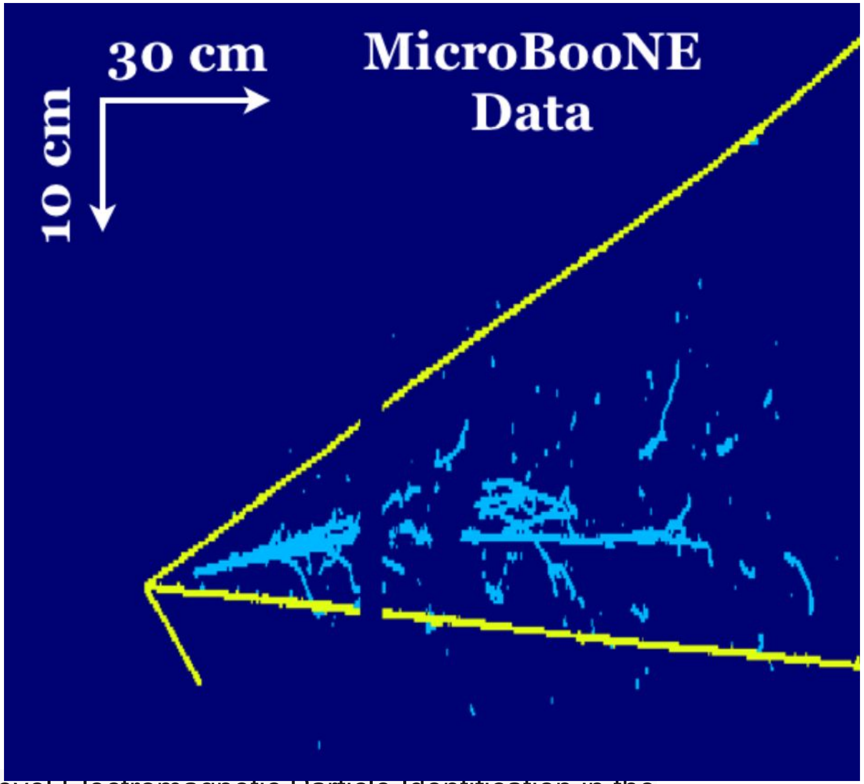
Computer Vision + Machine Learning for LArTPC Image Data Analysis

Example: pixel classification algorithm used in MicroBooNE to identify shower pixels, useful for nue interaction

Input: data (MicroBooNE)



Output: shower/track separation



TERAO, Kazurhiro et al (2018). A Deep Neural Network for Pixel-Level Electromagnetic Particle Identification in the MicroBooNE Liquid Argon Time Projection Chamber, https://arxiv.org/pdf/1808.07269.pdf

Computer Vision + Machine Learning for LArTPC Image Data Analysis

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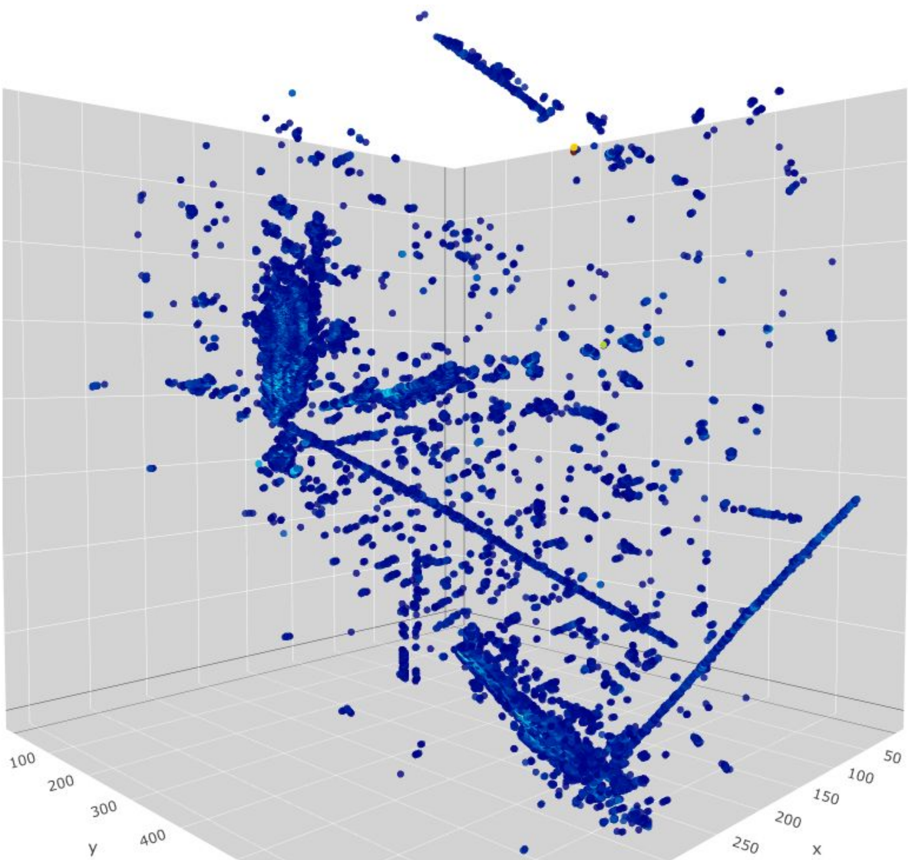
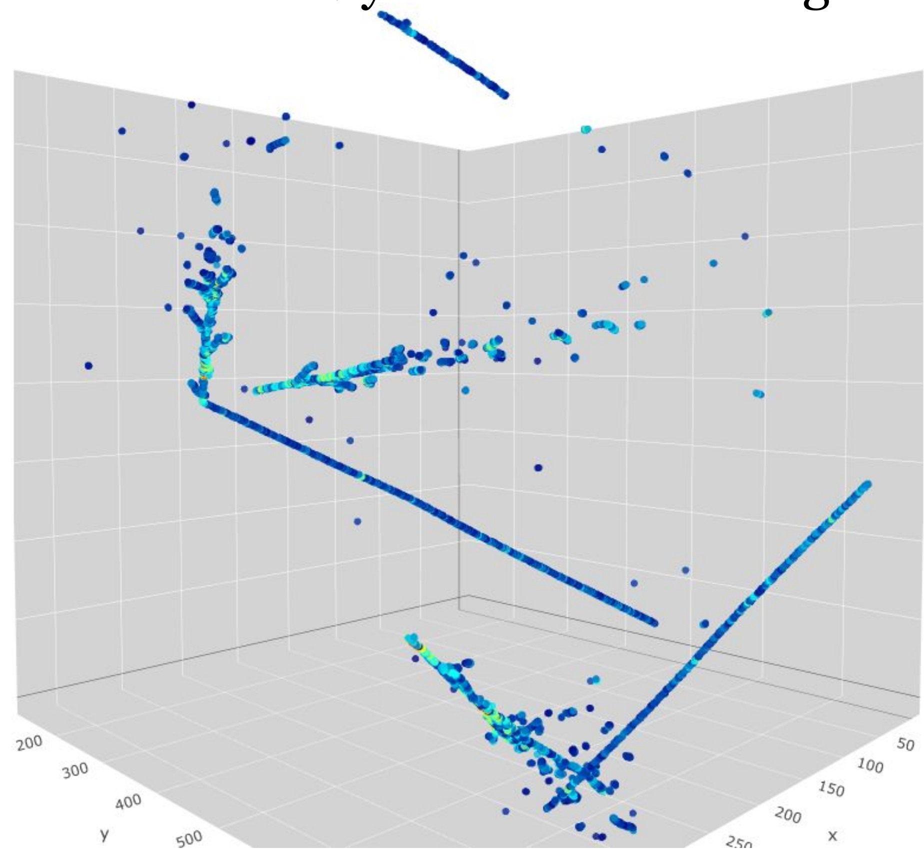
Example: removal of mis-reconstructed 3D points

Input: reconstructed 3D points



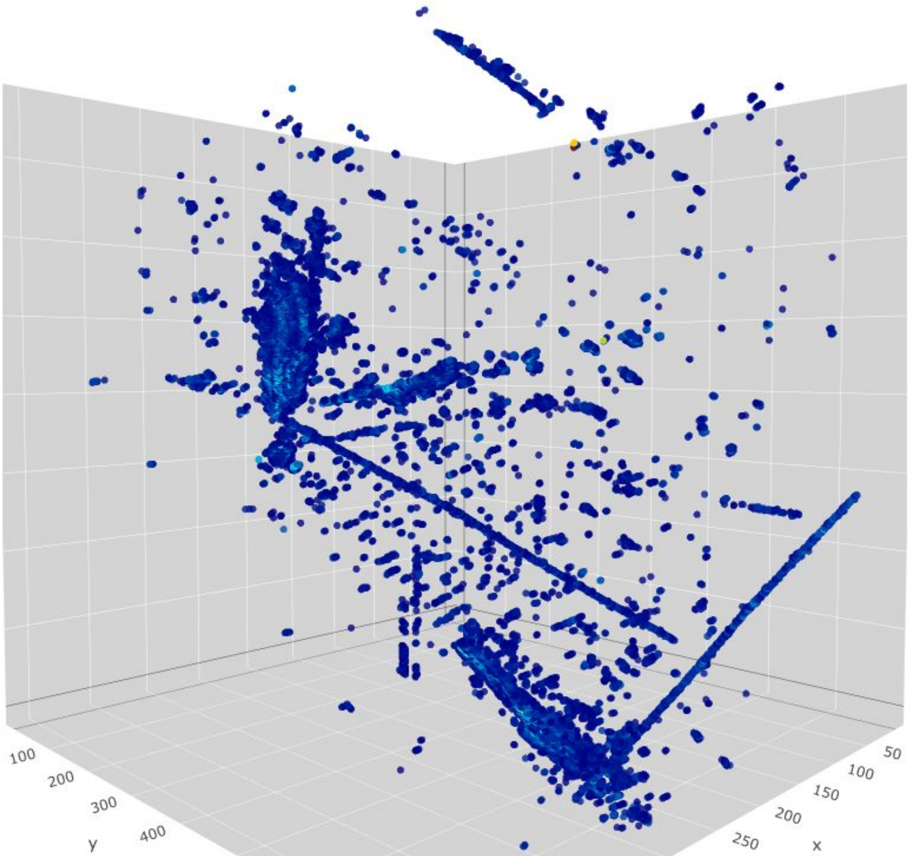
Output: mis-reconstructed points removed by Machine Learning



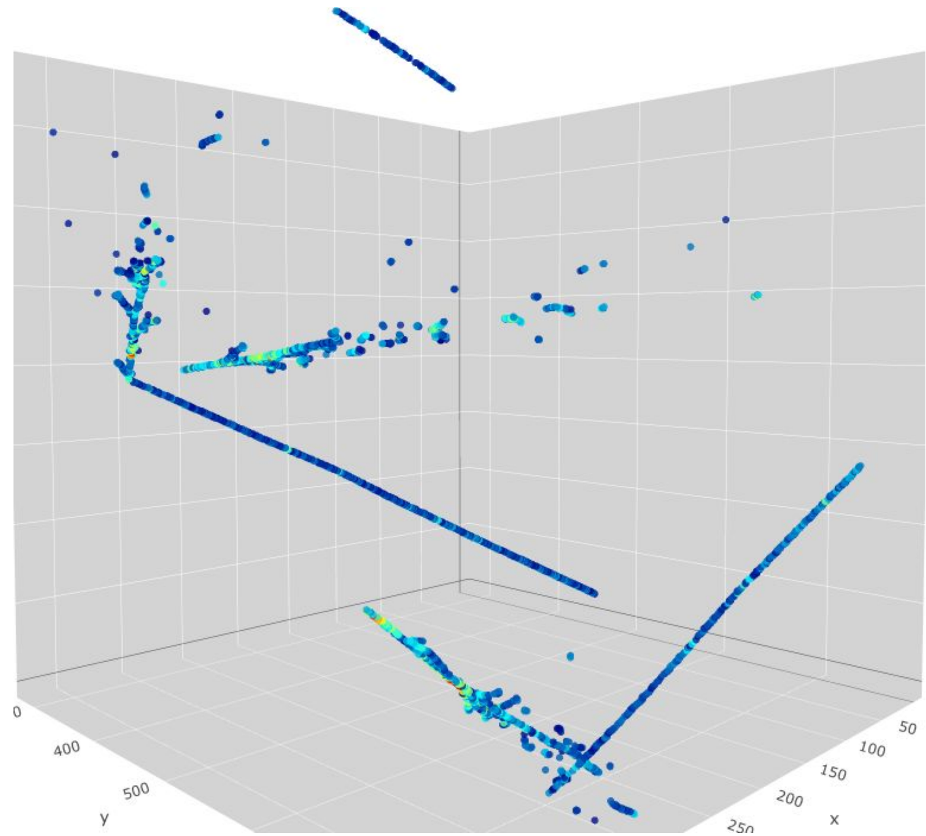
Computer Vision + Machine Learning for LArTPC Image Data Analysis

Example: removal of mis-reconstructed 3D points

Input: reconstructed 3D points



Reference: mis-reconstructed points removed by truth info



Computer Vision + Machine Learning for LArTPC Image Data Analysis

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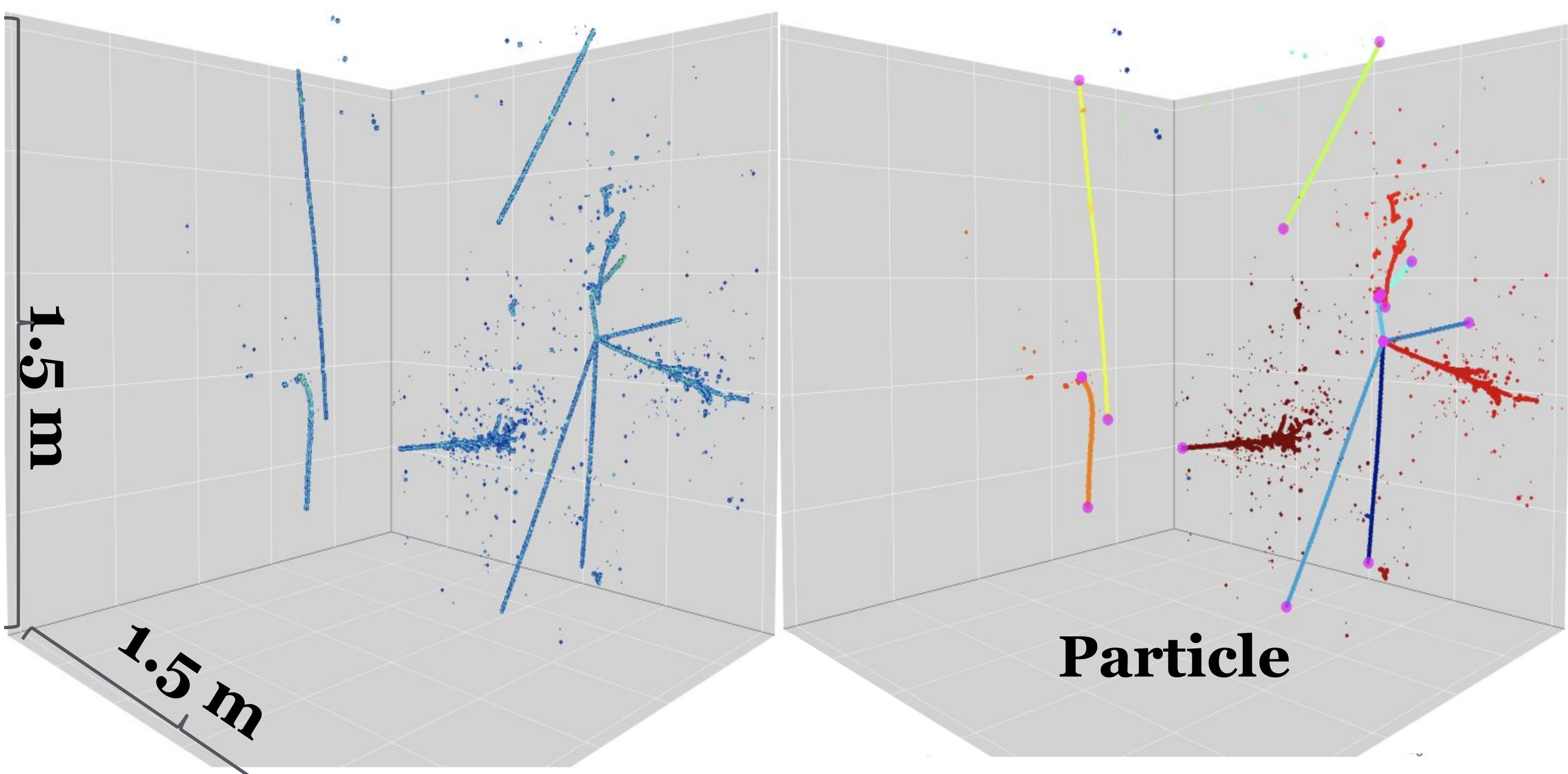
Next Goal: **point prediction + particle clustering** on ICARUS sample (**warning**: below is for DUNE-ND)



Computer Vision + Machine Learning in ICARUS

Plan Overview

Goal: maximize physics extraction from ICARUS data

Plan: develop a reconstruction chain for physics feature extraction using machine learning algorithms

- So far primarily 3D pattern recognition (3D points input)
  - Can use other algorithms (WireCell, Pandora, etc.)
- Starting on 2D image analysis (identical algorithms)
  - Michel reconstruction (next talk) + data vs. simulation discrepancy study/mitigation during commissioning

Team: **anyone is welcome**, SLAC team consists of 6-8 people supported by three DOE grants dedicated for machine learning for LArTPC experiments (SBN/DUNE) + CSU faculty and graduate students (3-5)

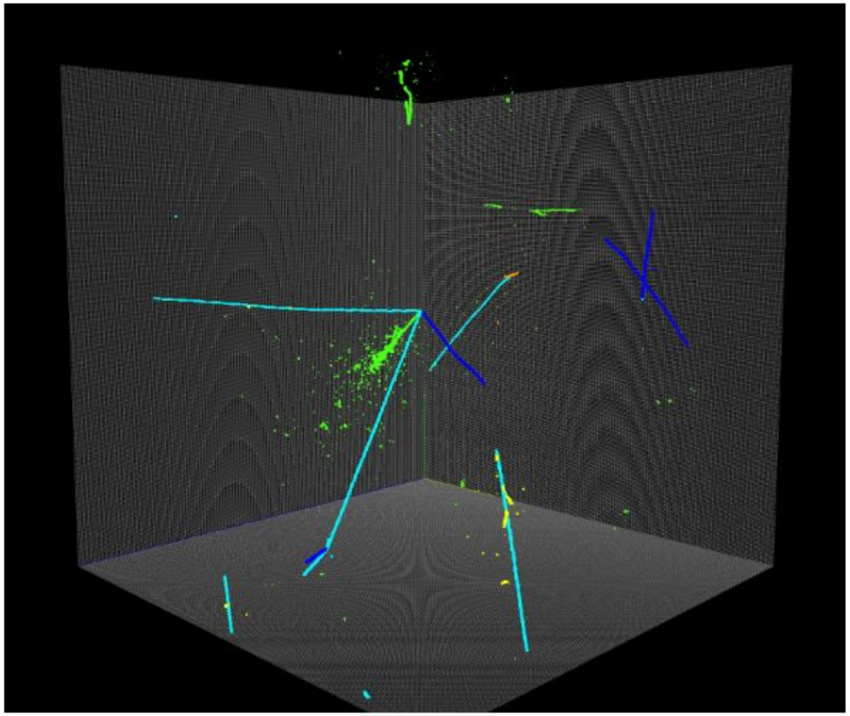
- Further collaborations (ATLAS/LSST/outside HEP) for uncertainty estimates/optimization + distributed computing on High Performance Computing facilities

Backup slides

Computer Vision + Machine Learning for Pixel-wise identification

Segmentation segmentation: pixel-wise identification performance in simulations

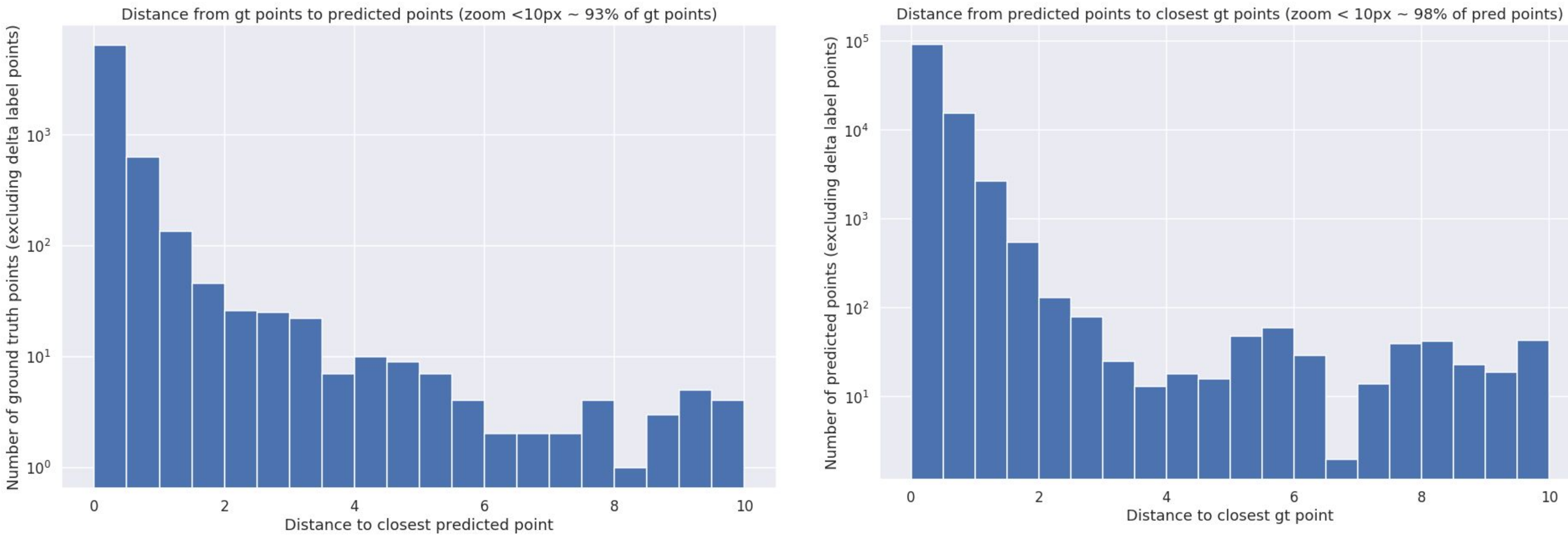
Particle Type	Pixel-wise accuracy
Heavy ionizing particle	99.3%
MIP	98.1%
Shower	99.2%
Delta rays	97.2%
Michel electrons	95.7%
Total	**99.1%**



DOMINE, Laura, & TERAO, Kazuhiro. (2019). Scalable Deep Neural Networks for Sparse, Locally Dense Liquid Argon Time Projection Chamber Data, https://arxiv.org/abs/1903.05663

Computer Vision + Machine Learning for Point proposal

Point proposal: performance of identifying end points of tracks and start points of showers in simulations



DOMINE, Laura, & TERAO, Kazuhiro. (2018). Applying Deep Neural Network Techniques for LArTPC Data Reconstruction. Zenodo. http://doi.org/10.5281/zenodo.1300713