# Deep-learning applications for BNB electron neutrino reconstruction in the ICARUS experiment

Dae Heun Koh[1,2] on behalf of the ICARUS Collaboration

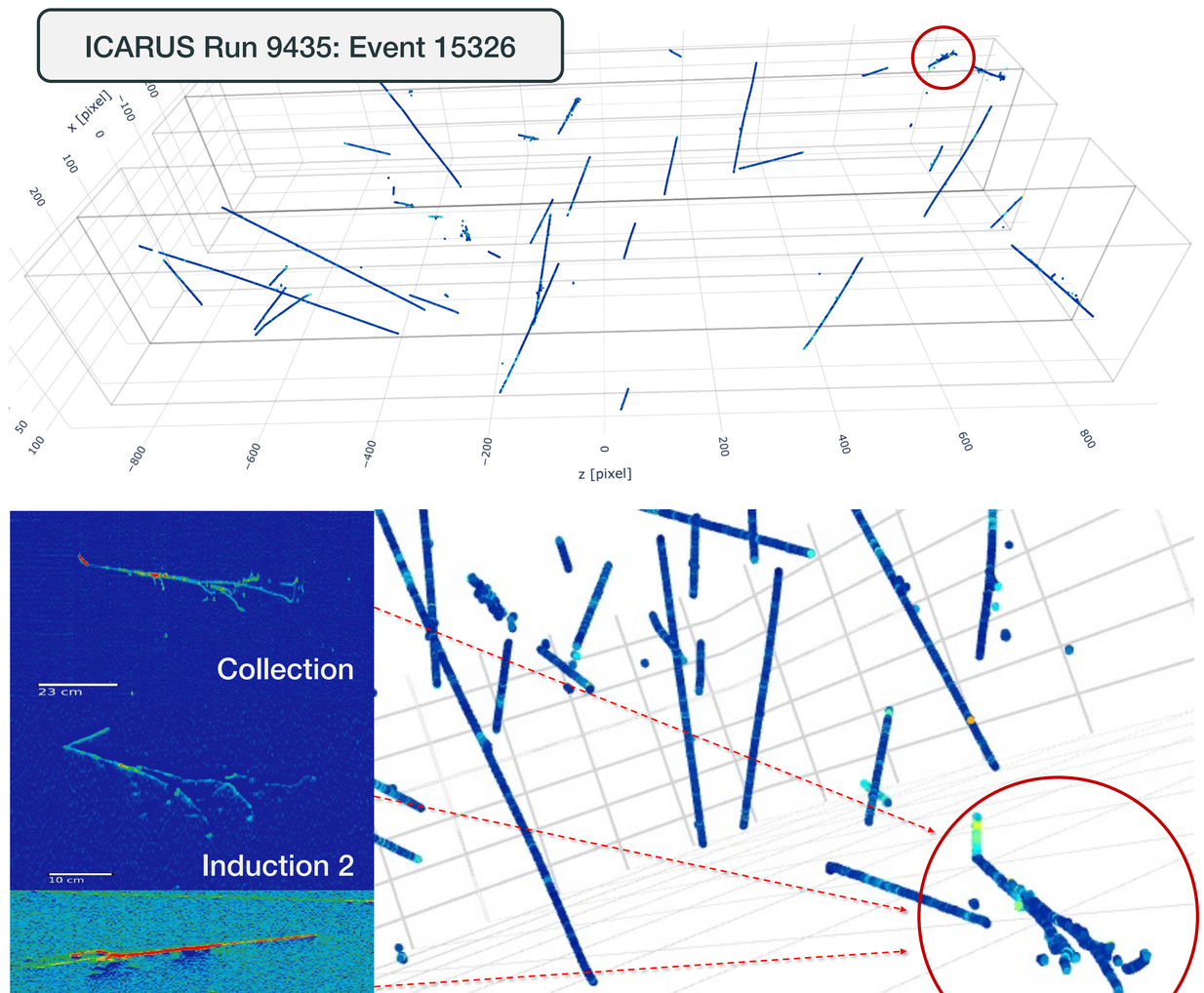
SLAC National Accelerator Laboratory[1], Stanford University[2], koh0207@slac.stanford.edu

## I. Introduction

- Develop and demonstrate the first application of a fully-automated deep-learning based reconstruction to Booster Neutrino Beam (BNB) $\nu_e$ searches in the ICARUS Experiment.
- Primary Goal: reconstructed neutrino energy spectrum with benchmarked purity and efficiency estimates.

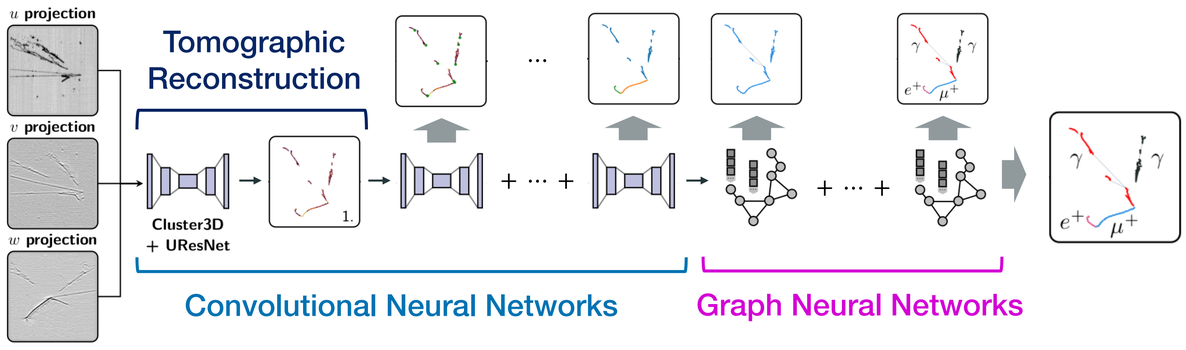
## II. ICARUS Detector and Neutrino Event Reconstruction in 3D

- The three plane views are combined to form a 3D view of the detector event.
- Challenges for $\nu_e$ reconstruction for the BNB Beam in ICARUS:
  - ~14 $\mu$ (cosmic ray) per 1ms TPC drift readout
  - BNB Beam Content: 99.5% $\nu_\mu/\bar{\nu}_\mu$ with 0.5% intrinsic $\nu_e/\bar{\nu}_e$ contamination.

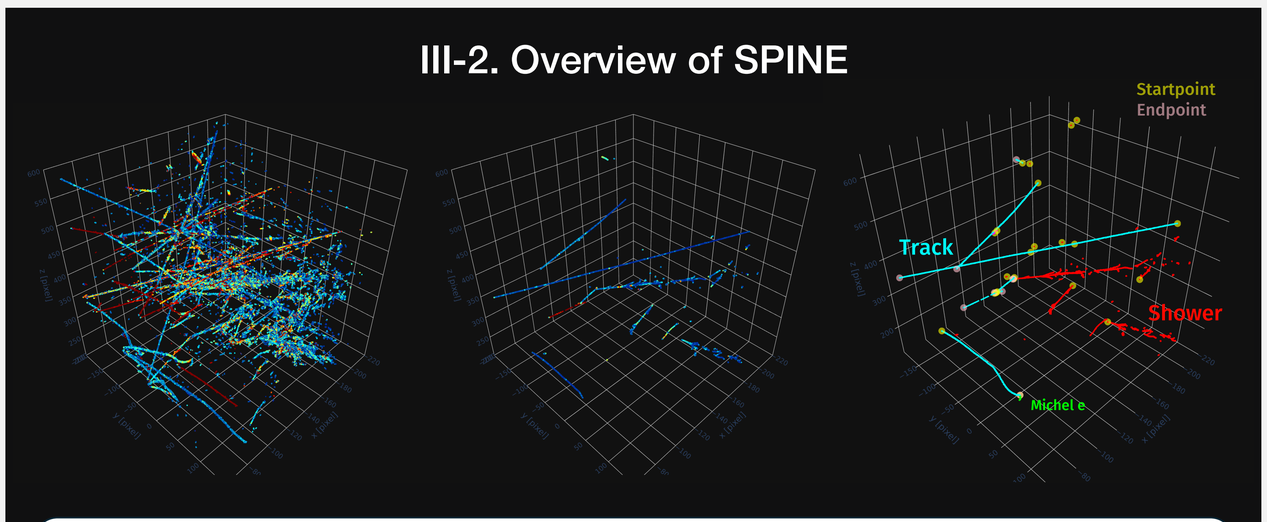



## III-1. SPINE: Scalable Particle Imaging with Neural Embeddings

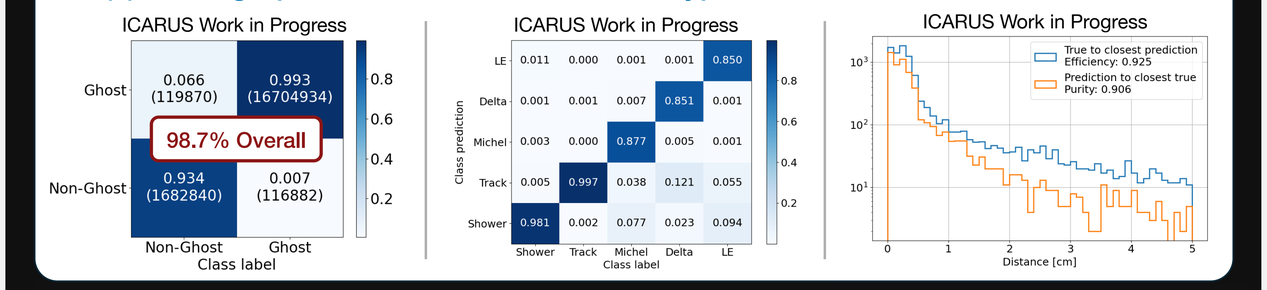
- Goals for AI/ML assisted event reconstruction:
- **Interpretable**:
  - Chain of neural networks specializing in various sub-tasks
  - Allows detailed and informative error analysis, if certain parts of the chain fails
- **Automatic optimization**:
  - Entire chain is trainable simultaneously using gradient-based optimization
- See #108, #156, #252 for other applications of SPINE [1,2]

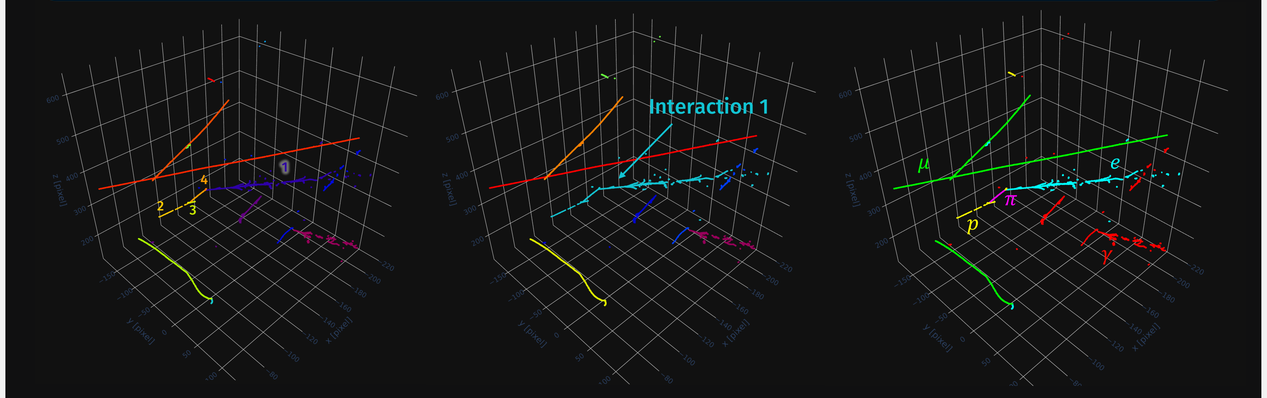



## III-2. Overview of SPINE

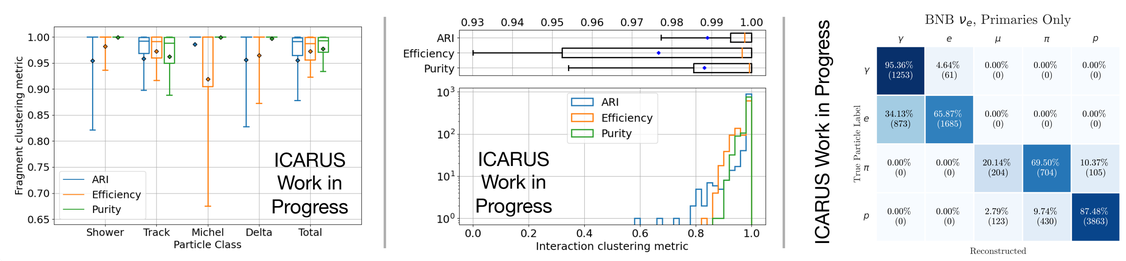



### III (a). Tomographic Reconstruction + Pixel Type Classification + Point Detection



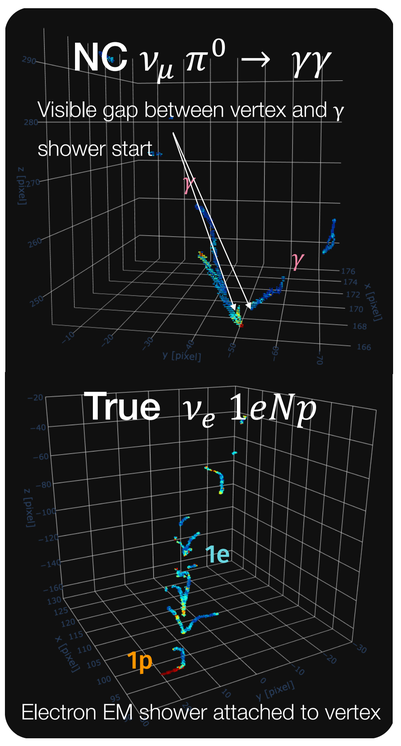




### III (b). Particle Clustering + Interaction Clustering + Particle Type Prediction

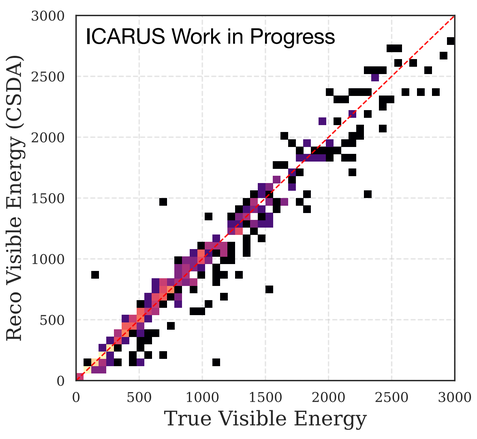



## IV. BNB Electron Neutrino Selection for ICARUS

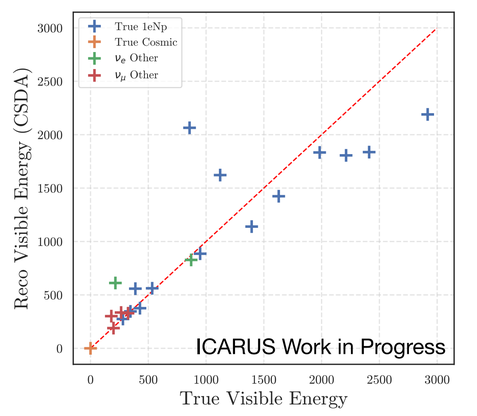
- **Signal Definition: 1eNp with BNB beam window consistent PMT signal.**
  1. $1eNp$: **one primary electron and at least one primary proton.**
  2. **Visibility Cut**: 25 MeV on all particles; 30 MeV cut for protons.
  3. **Fiducial Cut**: reconstructed vertex must be within
  4. $0\gamma 0\pi^{\pm}$: Require no primary photons and charged pions.
  5. **Shower Conversion Distance Cut**: electron must be within 0.8cm from vertex.




**BNB $\nu_e$ only (3.5k MC)**




**BNB $\nu_\mu + \nu_e$ (13k MC)**




## MC BNB $\nu_e$ Selection Results

- BNB $\nu_\mu(99.5\%) + \nu_e(0.5\%)$ **(13k MC):**
  - 51% Efficiency, 67% Purity
- **Rejects all (100%) 291k Intime Cosmics**
- **BNB $\nu_e$ only (3.5k $\nu_e$): ~ 20% FWHM** of fractional error in $\nu_e$ initial energy estimation.
- High statistics study planned in future with larger BNB $\nu_e$ only (~450k) and $\nu_\mu + \nu_e$ (~350k) samples and new training weights.

## Acknowledgments

This work was supported by the Department of Energy, Contract DE-AC02-765F00515. It will be part of the Stanford thesis: *Electron Neutrino Reconstruction for the ICARUS experiment.*

## References

1. SPINE Github Repository: https://github.com/DeepLearnPhysics/spine
2. Drielsma, F., Terao, K., Domine, L., & Koh, D. (2021). *Scalable, End-to-End, Deep-Learning-Based Data Reconstruction Chain for Particle Imaging Detectors.* In 34th Conference on Neural Information Processing Systems.