DUNE's Tau Neutrino Event Reconstruction and Selection Strategies Using Graph Neural Networks

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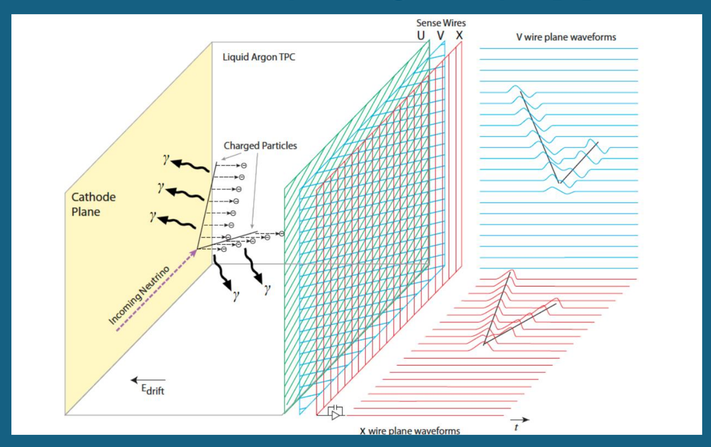
Tau Neutrinos and DUNE

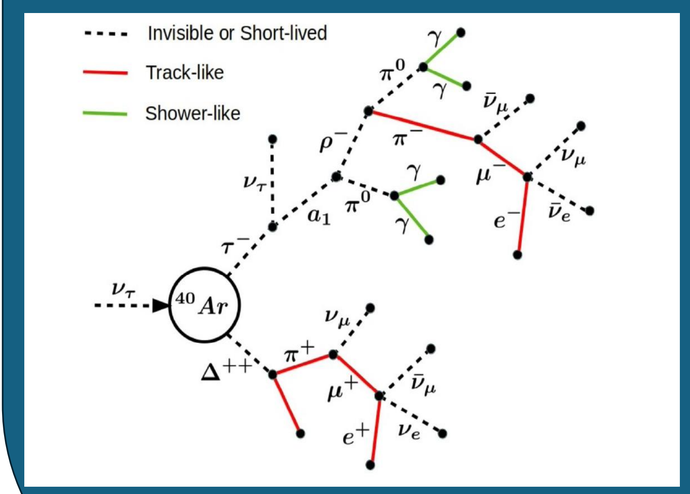
LArTPC Operating Principal [1]



Tau Lepton Decays[2]

Decay mode	Branching ratio
Leptonic	35.2%
$e^-\bar{\nu}_e\nu_\tau$	17.8%
$\mu^-\bar{\nu}_\mu\nu_\tau$	17.4%
Hadronic	64.8%
$\pi^-\pi^0\nu_\tau$	25.5%
$\pi^-\nu_\tau$	10.8%
$\pi^-\pi^0\pi^0\nu_\tau$	9.3%
$\pi^-\pi^-\pi^+\nu_\tau$	9.0%
$\pi^-\pi^-\pi^+\pi^0\nu_\tau$	4.5%
other	5.7%

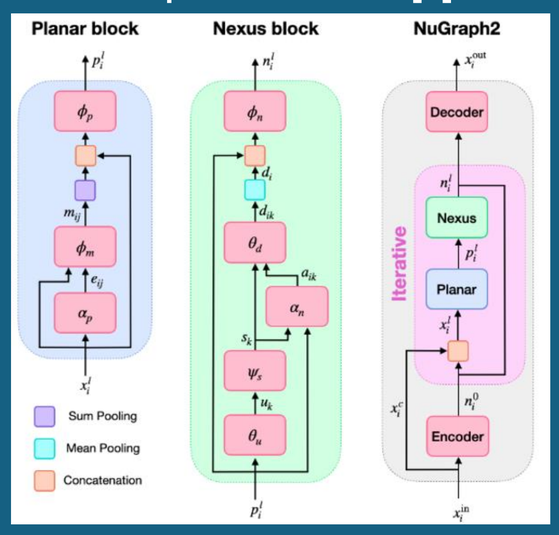
ν_τ-Argon Interaction Example[5]



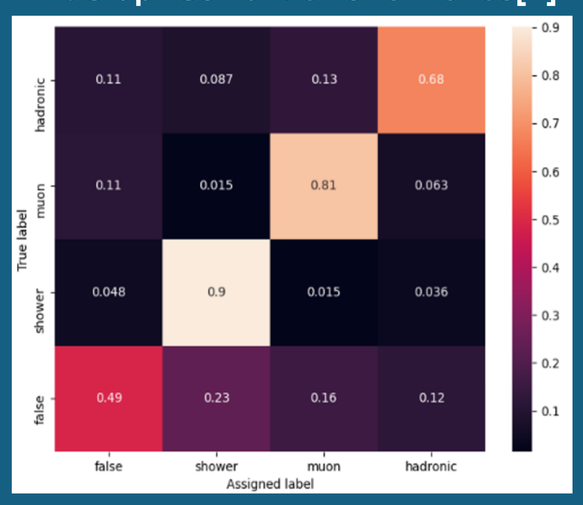
- We are interested in using NuGraph to do tau neutrino event selection which has many unique challenges that GNNs help solve.
- Specifically, the tau cannot be imaged in the TPC and signal and background is difficult
- DUNE will be able to collect a large sample of oscillated tau neutrino events.
- So far we have only studied the DUNE far detector in the reduced geometry.

NuGraph 1 and 2

NuGraph2 Architecture[3]



NuGraph Semantic Performance[4]



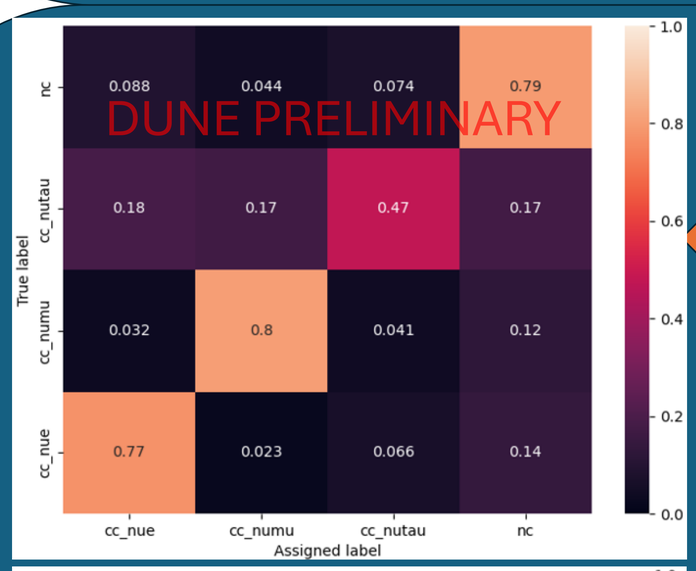
- NuGraph - originally tested with MicroBooNE data[6], showing efficiency and purity ~ 95% and consistency between wire planes ~98%
- The NuGraph2 architecture improved on the original NuGraph design by classifying hits according to particle type and using nexus connections between planes to utilize 3D context information
- We trained only the NuGraph2 model and have been gradually improving the classification of charged current tau neutrino events first by adding DUNE specific features and then by balancing our training data.
- The additional DUNE features gave only moderate improvements (still a WIP).
- Balancing the dataset across the classes by reducing the number of events in the other classes to the level of the tau charged current events had a much more significant improvement this is going to be the basis for a larger future training.

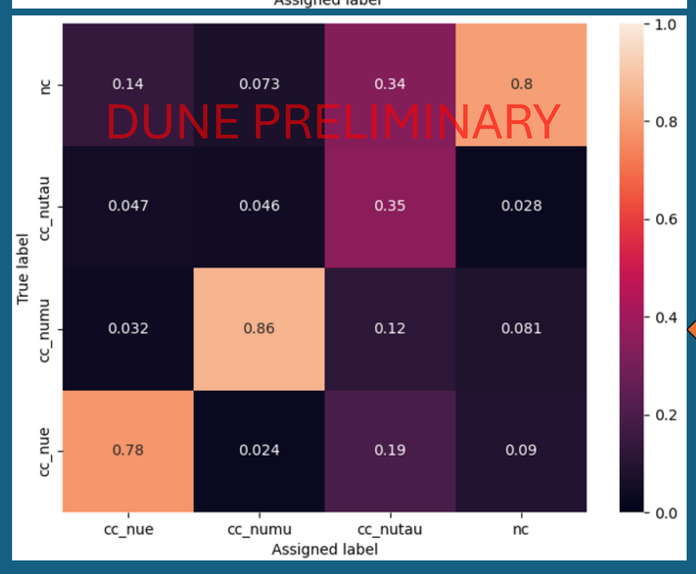
Results

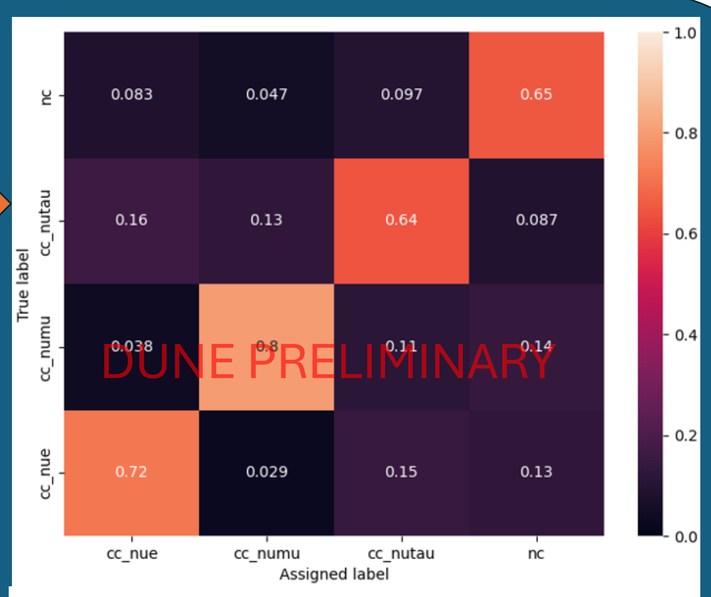
Recall/Efficiency Across Categories

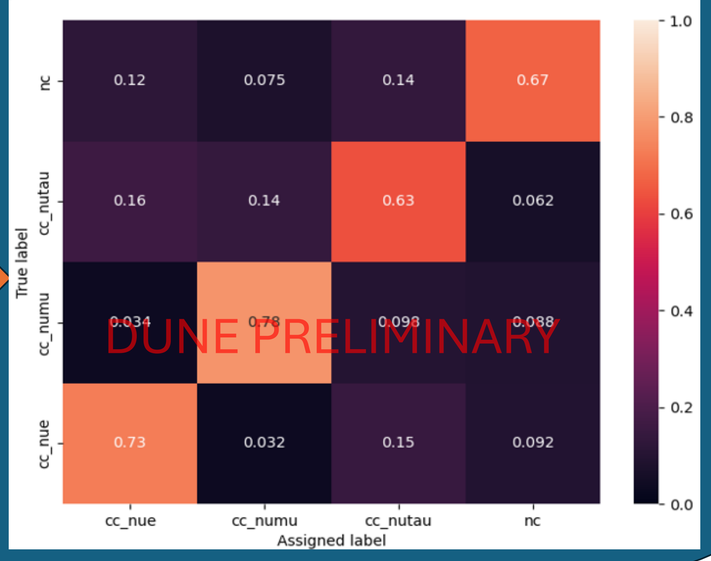
After Balancing Data

Precision/Purity Across Categories









The Network for these results was trained on a Monte Carlo sample with the standard DUNE beam fluxes using 09_77_00d00 of the DUNE software the only changes from the base code was to keep full Geant4 EM truth information

Conclusions and Future Studies

- We found a significant improvement on the ν_τ classification neural network with a balanced sample.
- Can expect potentially a substantial increase in the precision and recall across all categories by increasing the size of the dataset while keeping the number of events in each category roughly equal.
- Sensitivity studies using realistic FD events rates and future balanced-dataset trained NuGraph version are forthcoming.

For More On NuGraph/NuTaus see:
#150 - NuGraph3: Towards Full LArTPC Reconstruction using GNNS
#162 - NuGraph2: A Graph Neural Network for Neutrino Event Reconstruction
#130 - 3D-Reconstruction of Tau Neutrinos in LArTPC Detectors

References

[1] B. Abi et al. (2020). Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume II: DUNE Physics.
[2] Machado, P., Schulz, H., & Turner, J. (2020). Tau neutrinos at DUNE: New strategies, new opportunities. Physical Review D, 102(5).
[3] V Hewes, Adam Aurisano, Giuseppe Cerati, Jim Kowalkowski, Claire Lee, Wei-keng Liao, Daniel Grzenda, Kaushal Gumpula, & Xiaohe Zhang. (2024). NuGraph2: A Graph Neural Network for Neutrino Physics Event Reconstruction.
[4] Hewes, V., Aurisano, A., Cerati, G., Kowalkowski, J., Lee, C., Liao, W.k., Day, A., Agrawal, A., Spiropulu, M., Vlimant, J.R., Gray, L., Klijnsma, T., Calafiura, P., Conlon, S., Farrell, S., Ju, X., & Murnane, D. (2021). Graph Neural Network for Object Reconstruction in Liquid Argon Time Projection Chambers. EPJ Web of Conferences, 251, 03054.
[5] Roshan Mammen et al. (2022). Tau neutrinos in the next decade: from GeV to EeV.
[6] Journal of Physics G: Nuclear and Particle Physics, 49(11), 110501.
G. Cerati (MicroBooNE), MicroBooNE Public Data Sets: a Collaborative Tool for LArTPC Software Development, in 26th International Conference on Computing in High Energy & Nuclear Physics (2023) arXiv:2309.15362 [hep-ex].

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