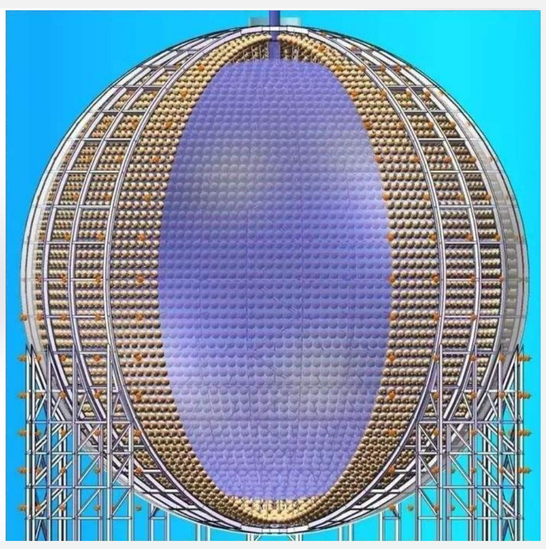
Cosmic-ray muon reconstruction with machine learning methods at JUNO

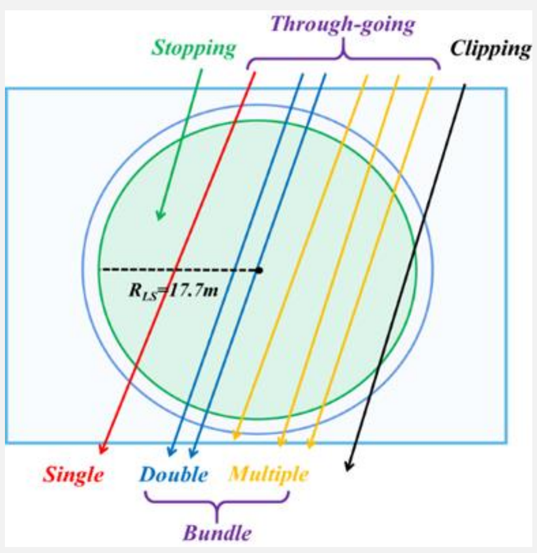
Jiaxi Liu[1], Zhen Liu[1]
[1] Institute of High Energy Physics, Beijing, China

Motivation

- JUNO is a next-generation large liquid-scintillator neutrino detector, designed to determine the neutrino mass ordering from its reactor neutrino measurement.
- Its Central Detector (CD) is a 20 kton liquid scintillator detector that uses 17,612 20-inch PMTs (LPMTs) and 25,600 3-inch PMTs (SPMTs) as photosensors.
- Cosmogenic backgrounds induced by muons should be rejected carefully by applying veto cuts to the CD, which requires accurate muon track and shower vertex reconstruction.



JUNO Central Detector design



CD muon event categories

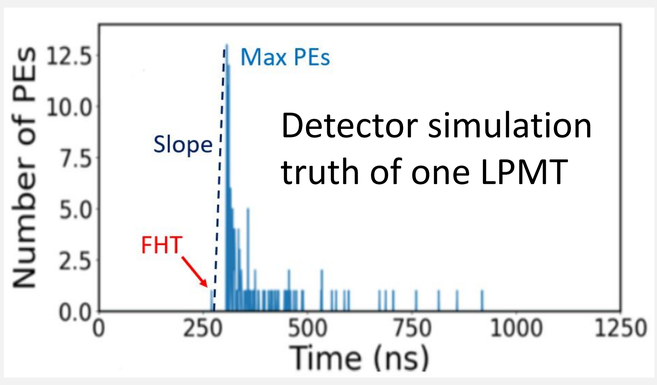
Data Sample

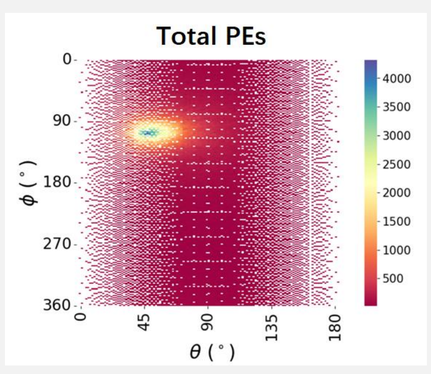
~100k events in total, divided into 8:2 train & test sets:

- Taken from Monte Carlo simulation without considering the electronic effect;
- All single through-going muon events;
- Deposited energy>0 in the Central Detector.

Features Extraction

- Features are extracted from each LPMT's PE distribution, which contains the topological information on muon event.
- All the LPMT positions on CD's spherical surface are projected to the 2-D (θ, φ) plane, as the input of machine learning model.



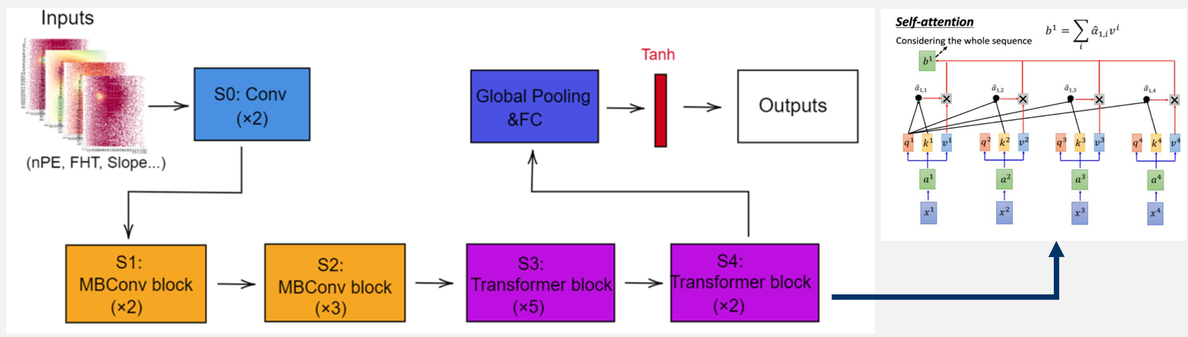


- 5 features are used for reconstruction: Total PEs, First hit time, Max PEs, Slope (Max PEs divided by peak time), PE ratio (PEs in the first 4ns divided by total PEs).

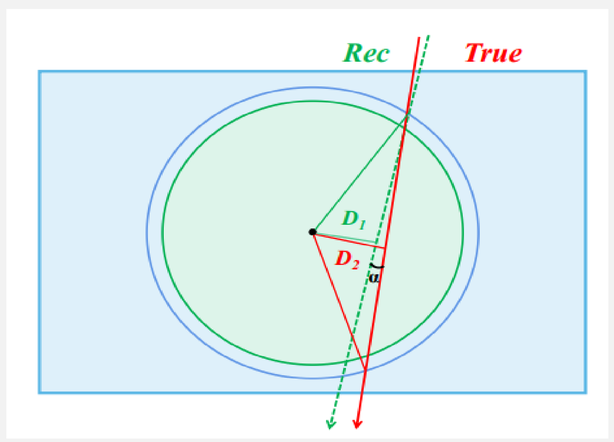
Machine Learning Model

CoAtNet: **CNN + Transformer hybrid networks**

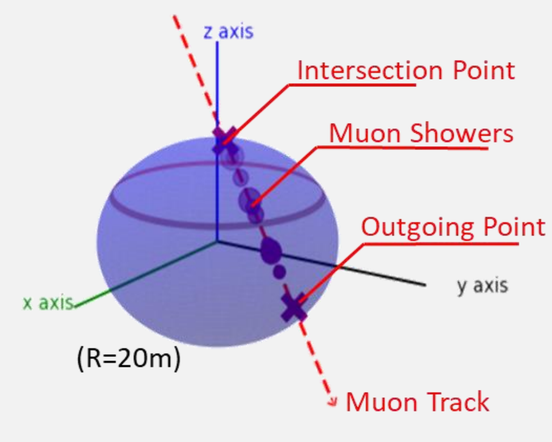
- Capture global information with Transformer blocks;
- Better performance with limited dataset than Transformer model;
- Good ability to learn from more and more data.



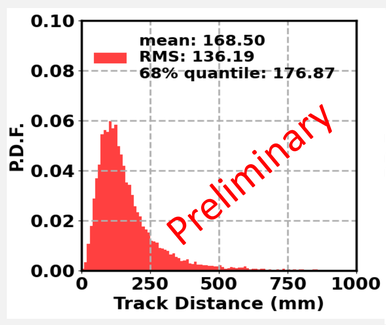
Reconstruction Performance

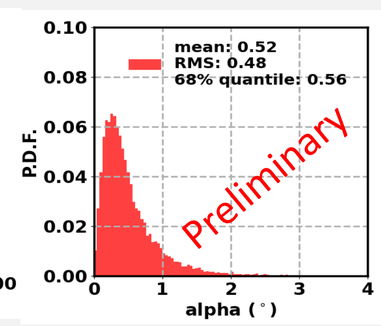


α: the angle between reconstructed and true track.
Track distance: The distance between midpoints of reconstructed and true track.

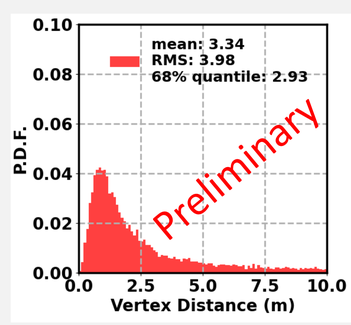


Shower definition: muon positions where muon energy loss (dE/dx) > 6 MeV/cm in the simulation.
Vertex distance: The distance between reconstructed and true shower vertex.





single muon track reconstruction performance



single muon shower vertex reconstruction performance

Summary and Outlook

- We presented a method of reconstructing cosmogenic single muon tracks and shower vertices with machine learning, and preliminary studies based on Monte Carlo simulation without considering electronic effect show unprecedented reconstruction performance.
- ➢ The method is planned to be further applied to new samples with full Monte Carlo simulation.

References

1. Yang, C. F., et al. (2022). Reconstruction of a muon bundle in the JUNO central detector. Nuclear Science and Techniques, 33(5), 59.
2. Dai, Z., et al. (2021). Coatnet: Marrying convolution and attention for all data sizes. Advances in Neural Information Processing Systems, 34, 3965-3977.