Direction Reconstruction of Atmospheric Neutrinos in JUNO with Machine Learning Methods

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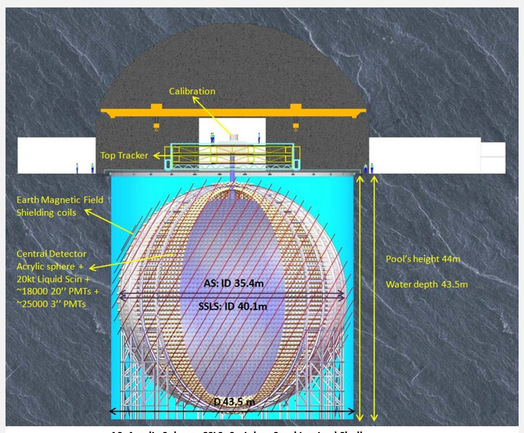
JUNO Experiment

- JUNO is a next-generation large liquid-scintillator neutrino detector
- The Central Detector is instrumented by 17’612 20-inch Large-PMTs (LPMTs) and 25’600 3-inch Small-PMTs (SPMTs)
- Its main goal is the determination of neutrino mass ordering



Motivation

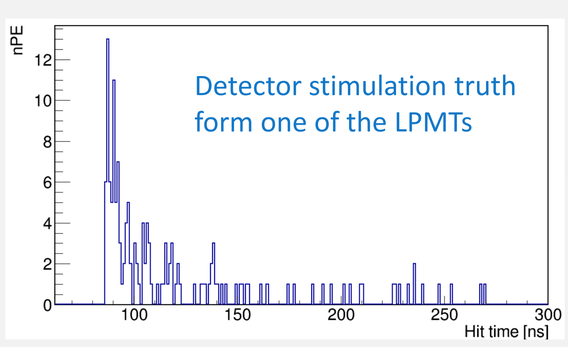
The sensitivity to the mass ordering comes from the measurement of

- reactor anti-neutrinos at low energies
- atmospheric neutrinos at high energies (GeV level)

See poster#848 by Jinnan Zhang

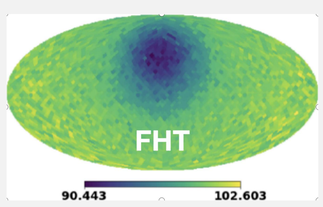
Feature Extraction

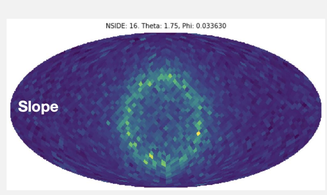
- The temporal evolution signals collected by PMTs, i.e. PMT waveforms, reflect the event topology in the JUNO Central Detector
- Features extracted from PMT waveforms not only reduce the input data volume, but also preserve the characteristic of each PMT signal



Feature extraction

- First Hit Time (distance between track and PMT, and angle information)
- Slope (angle between track and PMT)
- Total nPE (energy deposition topology)
- Peak Time (energy deposition topology)
- Four-moments, etc.





Model Inputs

Monte Carlo simulation sample:

- Detector simulation
- 135K atmospheric υ_μ events
- Charge-current neutrino events with energy above 1GeV

Input features:

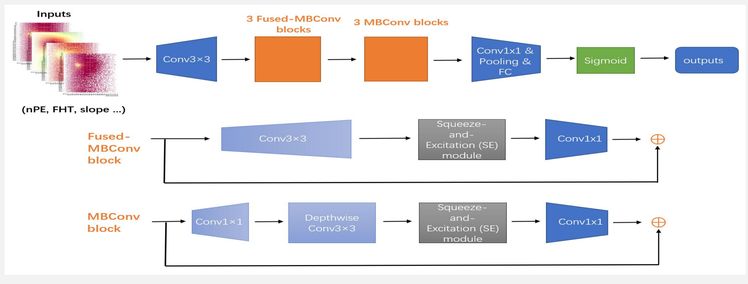
- LPMT features

Machine Learning Methods

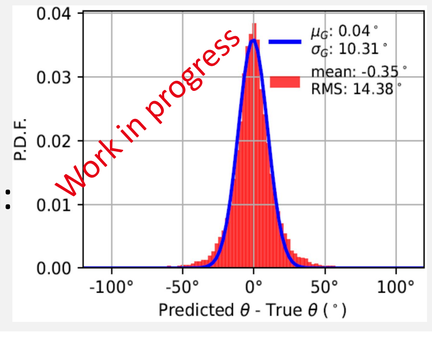
Two independent machine learning methods have been explored using two types of Machine learning models:

- Deep planar CNN model: EfficientNet[1]
  Input images are obtained by planar projection
- GNN model based on DeepSphere[2]
  Input images are directly built from the sphere to avoid distortions caused by projection

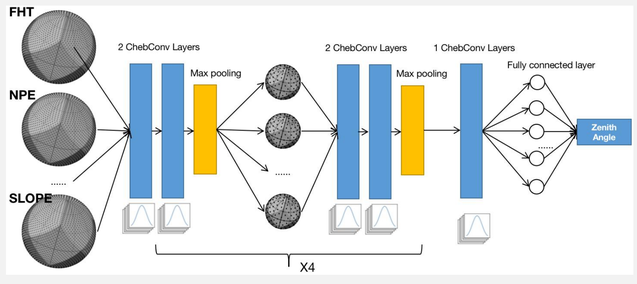
EfficientNet architecture [1]



Reconstruction performance in zenith(θ) direction:



DeepSphere architecture[2]



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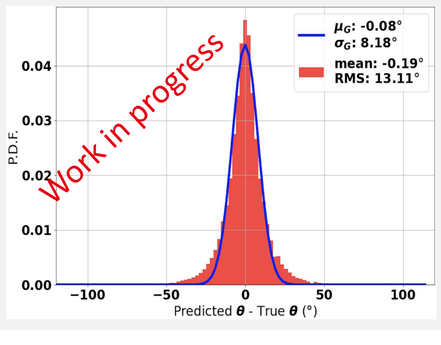
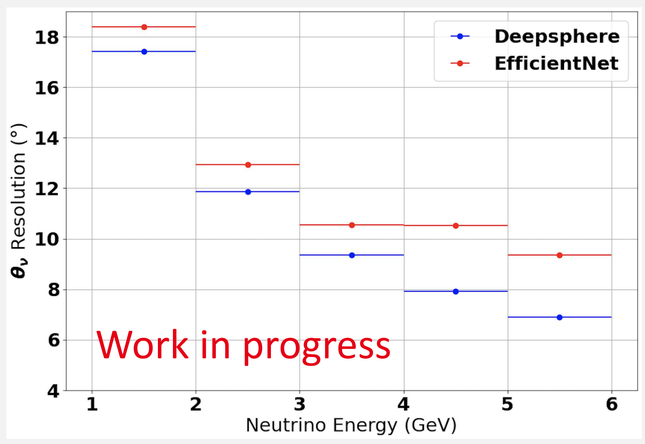


Conclusions

- Zenith angular resolution (gaussian sigma) improves with increasing energies
- Similar results are obtained from EfficientNetV2 and DeepSphere models



Summary and Outlook

- Similar direction reconstruction performance for atmospheric neutrinos in JUNO has been obtained using two independent machine learning methods.
- Preliminary results based on detector simulation show great potential for the high-precision reconstruction of the neutrino direction.
- ➢ Study based on full Monte Carlo simulation is ongoing, preliminary results show comparable performance to that obtained from detector simulation.

References

1. Tan M, Le Q. EfficientNet: Rethinking model scaling for convolutional neural networks. International conference on machine learning; 2019: PMLR.
2. Defferrard M, et. al. Deepsphere: a graph-based spherical cnn. arXiv:201215000. 2020.