Machine Learning Applications for Atmospheric Neutrinos in JUNO

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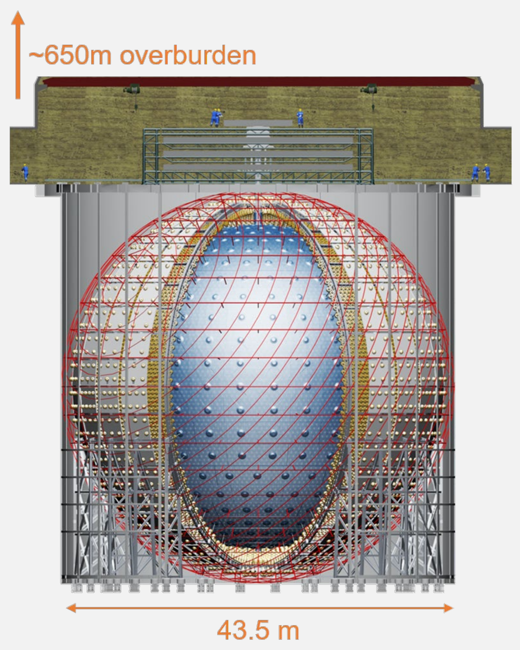
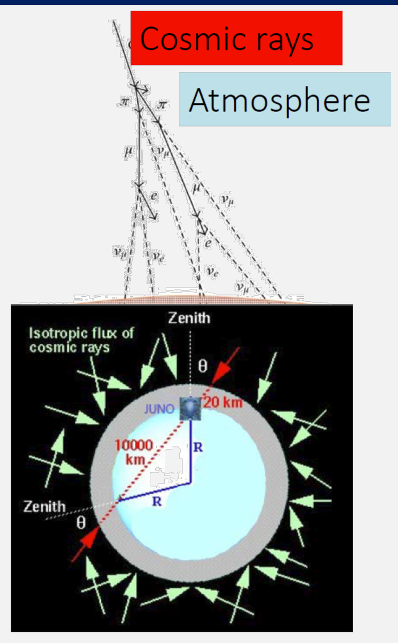
JUNO Experiment



- JUNO is a next-generation 20 kton liquid-scintillator neutrino detector.
- The Central Detector is instrumented by 17'612 20-inch Large-PMTs and 25'600 3-inch Small-PMTs.
- JUNO's main physics goal is the determination of neutrino mass ordering (NMO).

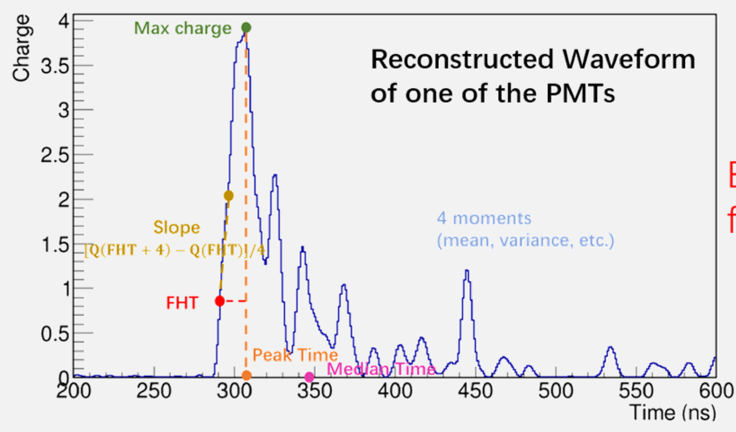
Motivation



- JUNO's sensitivity to NMO can be enhanced by combining the measurements of reactor neutrinos and atmospheric neutrinos.
- Event reconstruction and flavor identification are challenging but crucial for the study of atmospheric neutrino oscillations.

Waveform Feature Extraction

Features extracted from each PMT's waveform reflect the event's topological structure and carry information about the event's direction, energy, etc.



The first readout Waveform signal from one of the PMTs (with waveform reconstruction: deconvolution and noise removing)

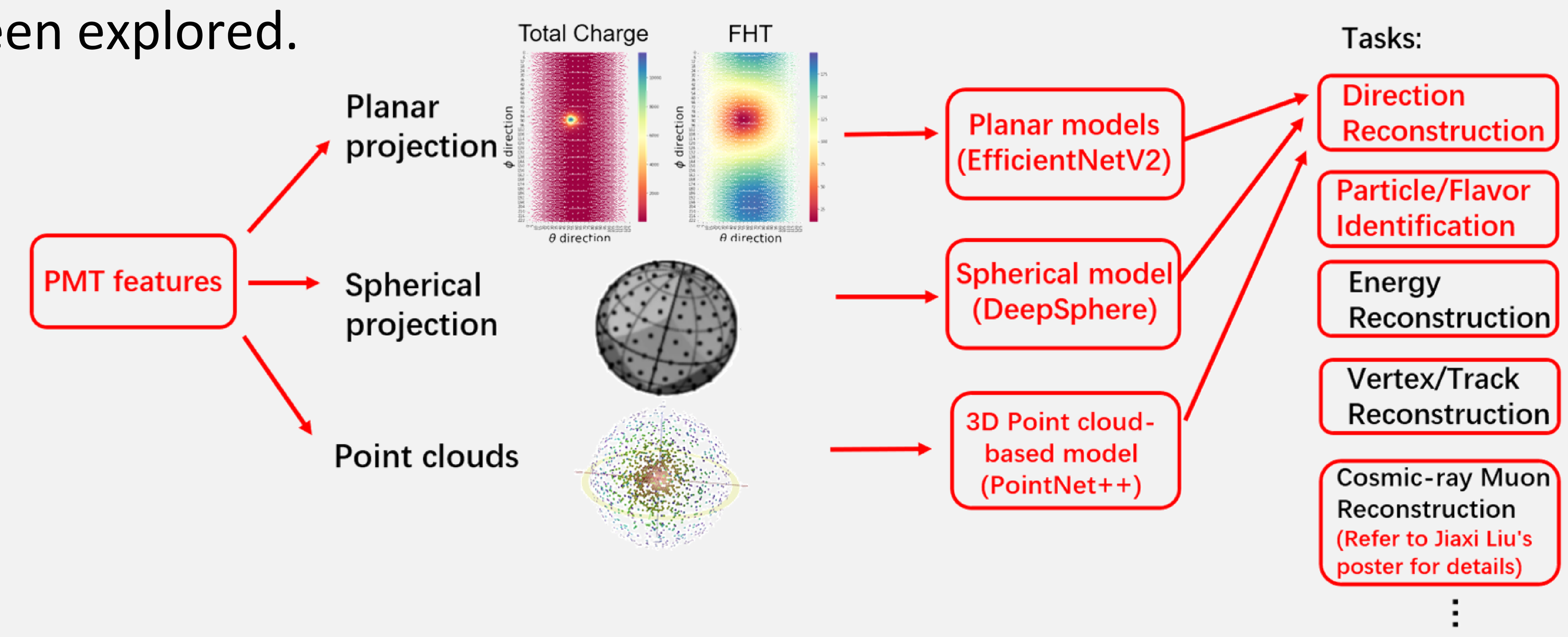
Extracted feature

- FHT: first hit time.
- Total charge: the total charge in the first readout time window.
- Slope: max charge divided by peak time.
- Charge ratio: charge in the first 4ns divided by the total.
- Max charge, Peak Time

Features after importance check

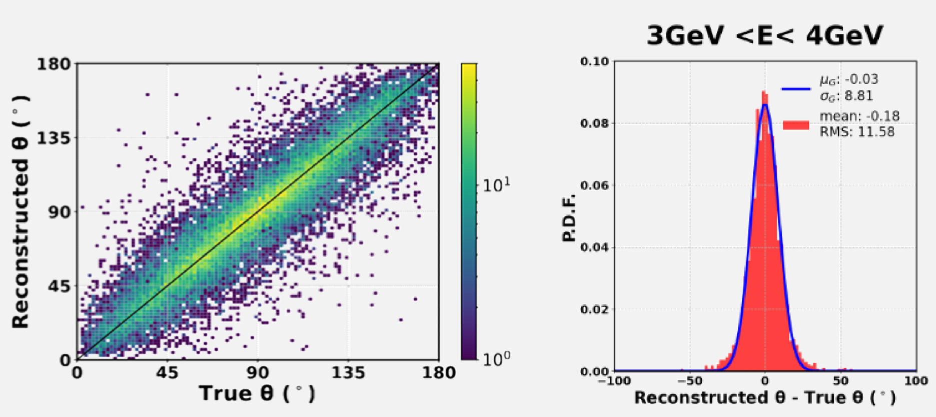
A Multi-purpose Machine Learning Approach

Combining the waveform features of all PMTs forms a spherical point cloud signal, upon which different types of neural network models have been explored.

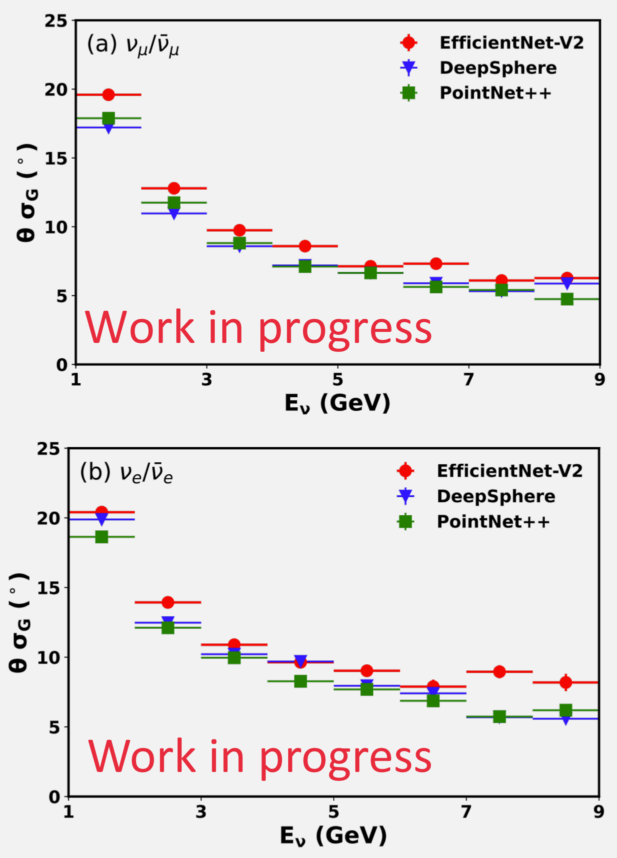


Direction Reconstruction Performance

Zenith angle (θ) reconstruction performance presented as an example.



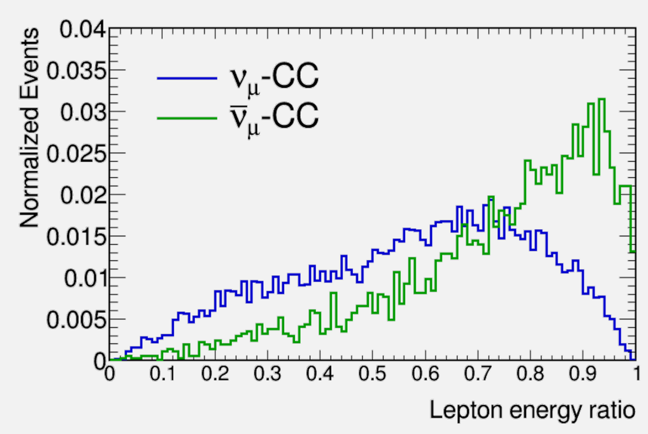
2D distribution of Reconstructed θ VS True θ in all energies, and 1D distribution of Reconstructed θ - True θ in [3,4]GeV ($\nu_\mu/\bar{\nu}_\mu$ full MC simulation events, PointNet++ result as example)



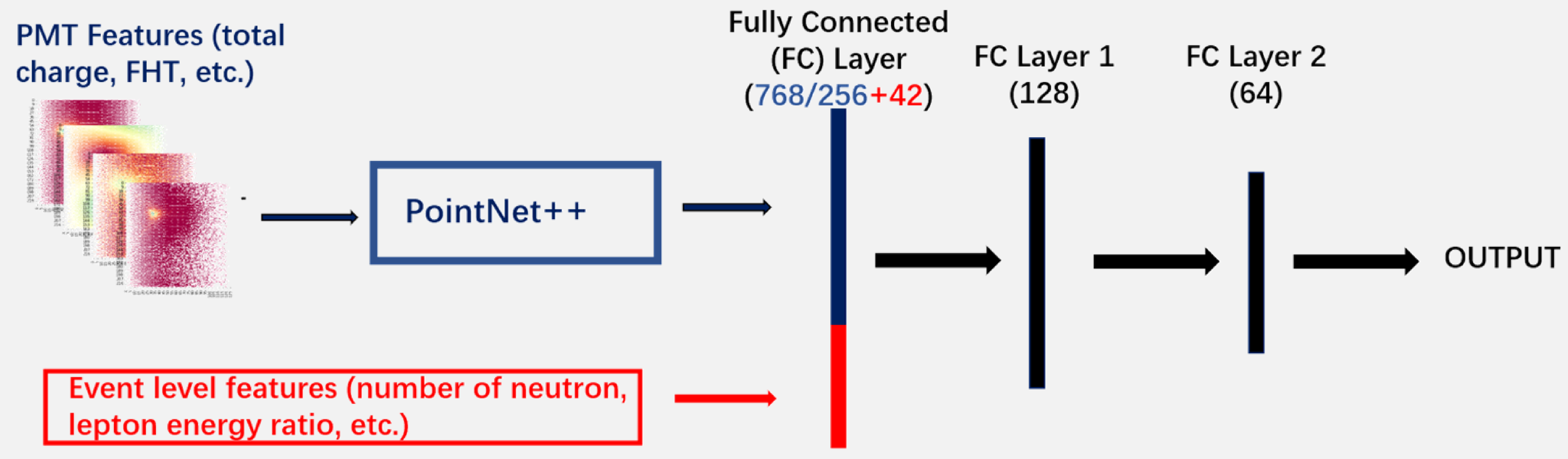
θ resolution for $\nu_\mu/\bar{\nu}_\mu$ and $\nu_e/\bar{\nu}_e$ events

Model Optimization for Flavor Identification

Besides waveform features, event-level features (such as lepton energy ratio, neutron multiplicity, etc.) can also help to distinguish between $\boldsymbol{\nu}$ and $\bar{\boldsymbol{\nu}}$.

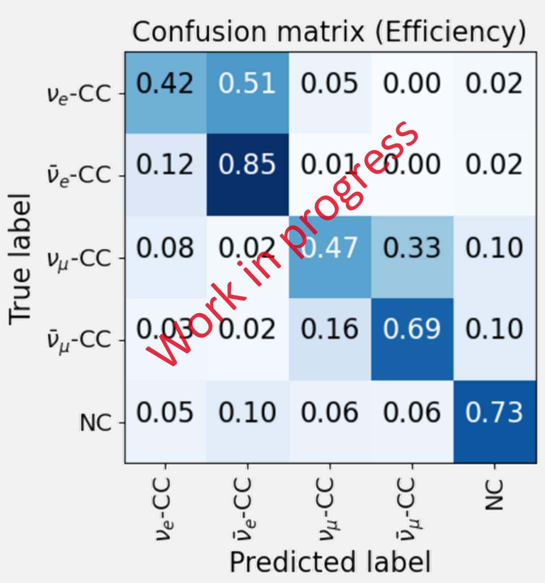


Optimized flavor identification model by using both waveform and event-level features:



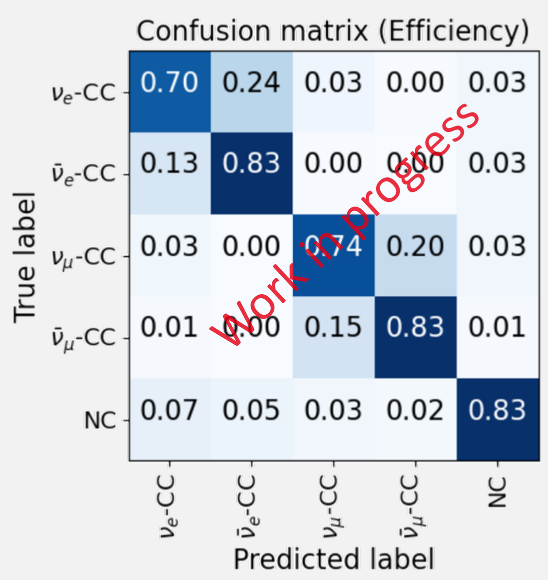
Flavor Identification Performance

Flavor identification result* without using event-level features



True label \ Predicted label	ν_e-CC	$\bar{\nu}_e$-CC	ν_μ-CC	$\bar{\nu}_\mu$-CC	NC
ν_e-CC	0.42	0.51	0.05	0.00	0.02
$\bar{\nu}_e$-CC	0.12	0.85	0.01	0.00	0.02
ν_μ-CC	0.08	0.02	0.47	0.33	0.10
$\bar{\nu}_\mu$-CC	0.04	0.02	0.16	0.69	0.10
NC	0.05	0.10	0.06	0.06	0.73

Flavor identification result* using both waveform and event-level features



True label \ Predicted label	ν_e-CC	$\bar{\nu}_e$-CC	ν_μ-CC	$\bar{\nu}_\mu$-CC	NC
ν_e-CC	0.70	0.24	0.03	0.00	0.03
$\bar{\nu}_e$-CC	0.13	0.83	0.00	0.00	0.03
ν_μ-CC	0.03	0.00	0.74	0.20	0.03
$\bar{\nu}_\mu$-CC	0.01	0.00	0.15	0.83	0.01
NC	0.07	0.05	0.03	0.02	0.83

*Result obtained without considering the electronic effect of the detector. A more realistic study using reconstructed event level information based on full MC is on-going.

Summary

- A multi-purpose machine learning approach has been proposed for the event reconstruction (including directionality, energy, interaction vertex, etc.) and particle/flavor identification for high energy (GeV) events.
- Preliminary results based on simulations show great potential in measuring atmospheric neutrinos, with good resolution for reconstructing GeV events and high efficiency for neutrino flavor separation.

References

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3. Qi, C. R., et al. (2017). Pointnet++: Deep hierarchical feature learning on point sets in a metric space. Advances in Neural Information Processing Systems.